Joint R & D Centers

Fostering Partnerships
The Indo-US Science and Technology Forum (IUSSTF) established under an agreement between the Governments of India and the United States of America in March 2000, is an autonomous, not-for-profit-society that promotes science, technology, engineering and biomedical research through substantive interaction among government, media and industry.
Joint R & D Centers

Fostering Partnerships

Indo-US Science and Technology Forum
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From the Executive Director’s Desk

To enable Indian and American scientists, researchers and students from academia, laboratories (both public and non-governmental) and industry to carry out joint research activities by leveraging already existing infrastructure and funding available with the partners at both sides, the Indo-US Science and Technology Forum supports linkages established through virtual networked joint centers.

The Indo-US Knowledge R & D Networked Centers and Public-Private Networked Centers aim to encourage joint project implementation on focal areas of thematic and applied research based on synergy of activities and harnessing complementary strengths of performing groups from the two countries. Knowledge R & D Networked Centers also provide opportunities for integrating research with education, through both student and faculty exchanges. Public-Private Networked Centers, on the other hand, enable to foster academia-industry partnerships by promoting pre-commercial R & D activities having potential towards applied research and product development. These Centers are aimed to capitalize on the scientific and technological innovation and entrepreneurship in translating ideas from the bench to the market place. More information on the Networked Centers can be accessed at www.iusstf.org.

We at IUSSTF are pleased to provide a flavour of work done by all such Networked Centers supported by IUSSTF over the years in the past across various thematic areas. This compendium has been brought out on the occasion of the IUSSTF completing 15 years, and highlights the collaborative work carried out by such Joint Networked Centers supported by IUSSTF. The success of these Networked Centers have been amply demonstrated by the collaborative research outcomes, the value additions, joint publications, patents, reciprocal student and faculty exchanges, and most significantly in the ability of some of the partnering groups to garner national funding in their respective countries by leveraging the strength and value of such networked partnerships. We hope that the information provided in this compendium would also help interested stakeholders to identify researchers working in their areas of interest and forge new linkages in India and the US.

Rajiv Sharma
Executive Director, IUSSTF
Chemical Sciences
Indo-US Joint Center on
Integrated Study of Correlated Electrons in Organic and Inorganic Materials

About the Center
The central goal of this project has been:

- To develop a theory to understand the common features between correlated electron oxides and other compounds of transition metals and organic charge-transfer solids (CTS).

Superconducting CTS have nominally quarter-filled bands and aside from the common band fillings these inorganic systems share two other common features with the organic CTS:

- strong electron-electron interactions; and
- lattice frustration.

Thus superconducting CTS in all cases have lattice structures that are anisotropic triangular. The inorganic systems that we identified, such as LiTi$_2$O$_4$, MgTi$_2$O$_4$, CuIr$_2$S$_4$ and CuRh$_2$S$_4$ are spinels and the present research activity of this joint center had been focused on spinels.

Work Plan/Methodology
In order to incorporate orbital degeneracy, frustration, and the possibility of Peierls order in multiple directions the following Hamiltonian had been considered for a checkerboard lattice with doubly degenerate metal orbitals at each lattice site. (see Fig. 1).

The Hamiltonian consists of (i) $H_{	ext{spin}}$ that contains the kinetic energy and the inter-ion electron-phonon (e-p) coupling, (ii) an orbital-ordering (OO) term $H_{	ext{oo}}$ and (iii) electron-electron interaction $H_{ee}$ that includes short-range e-e interactions within each site.

Treating OO and e-p interactions using a standard self-consistent approach derived from the equations:

The self-consistency equations were used iteratively given an initial starting distortion. In the infinite system the OO or the bond distortion would occur for infinitesimally small coupling constants $g$ and $a$. In finite-size clusters, however, due to the finite-size gaps between successive energy levels, non zero coupling constants are required before the symmetry-broken state appears. We, therefore, consider $g$ and $a$ to a close to the minimum values needed for the broken-symmetry state to occur. We performed calculations for lattices up to 16 x 16 (256 atoms with 512 orbitals).

We found a stable, orbitally-induced Peierls bond-dimerized state for carrier concentration of one electron per atom. The Peierls bond distortion pattern continues to be period 2 bond-dimerization even when the charge density in the orbitals forming the one-dimensional band is significantly smaller than 1. In contrast, for carrier density of half an electron per atom the Peierls instability is absent within one-electron theory as well as mean-field theory of electron-electron interactions, even for nearly complete orbital ordering.
Publications


MnV2O4 from First-Principles Calculations.

\[ H = H_{SSH} + H_{OO} + H_{ee} \]
\[ H_{SSH} = \sum_{\alpha \beta \gamma \delta} t_{\alpha \beta \gamma \delta}^{\alpha \beta} (1 + \alpha \beta \gamma \delta) \delta_{\alpha \beta \gamma \delta} \delta_{\alpha \beta \gamma \delta}^{\alpha \beta} \]
\[ H_{OO} = \frac{g}{2} \sum_{\alpha \beta \gamma \delta} Q_{\alpha \beta \gamma \delta} (n_{\alpha \beta \gamma \delta} - n_{\alpha \beta \gamma \delta}) + \frac{1}{2} K_{\alpha \beta \gamma \delta} \sum_{\alpha \beta \gamma \delta} \delta_{\alpha \beta \gamma \delta} \]
\[ H_{ee} = U \sum_{\alpha \beta \gamma \delta} \delta_{\alpha \beta \gamma \delta} \delta_{\alpha \beta \gamma \delta} + \frac{U'}{2} \sum_{\alpha \beta \gamma \delta} \delta_{\alpha \beta \gamma \delta} \delta_{\alpha \beta \gamma \delta} \]

\[ \frac{\partial \langle H \rangle}{\partial Q} = 0 \quad \frac{\partial \langle H \rangle}{\partial \Delta_{\alpha \beta \gamma \delta}^{\alpha \beta \gamma \delta}} = 0. \]

Software Generated

Software had been generated to solve the model Hamiltonian incorporating orbital degeneracy, frustration, and the possibility of Peierls order in multiple directions.

Partnering Institutions

**INDIA**
- S. N. Bose National Centre for Basic Sciences, Kolkata
- Indian Association for the Cultivation of Sciences, Kolkata

**US**
- University of Arizona, Tucson
- Mississippi State University, Mississippi State

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Gender ≠ Species

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Fig. 1

Software had been generated to solve the model Hamiltonian incorporating orbital degeneracy, frustration, and the possibility of Peierls order in multiple directions.
## Exchange Visits

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name and Affiliation</th>
<th>Institution(s) Visited</th>
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<tr>
<td>1</td>
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<td>S.N.Bose Centre</td>
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<td>S.N. Bose Centre, Cultivation of Sciences</td>
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<td>R. Torsten Clay</td>
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<td>4</td>
<td>Tanusri Saha-Dasgupta</td>
<td>University of Arizona</td>
<td>University of Arizona</td>
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<td>Soumyajit Sarkar</td>
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<td>T. Saha-Dasgupta</td>
<td>University of Arizona</td>
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</table>
Indo-US Joint Center on
Development of Metal-Ceramic Composites through Microwave Processing

Principal Investigators

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Kanpur, India
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Jiann Yang
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About the Center
The major research thrust at the center is towards gaining a fundamental understanding of the microwave-metal interaction and consolidation of a range of ferrous and non-ferrous particulate materials using microwaves. In specific center focuses to:

- Promote exchange of researchers between the participating institutes for conducting experiments and technological/scientific discussions.
- Establish a proof-of-concept of microwave processing of various materials specifically metal powders and metal-ceramic composites.
- Understand phenomenology of particulate consolidation through the microwave heating.
- Investigate and develop unique microstructural formulations exploiting unique advantages of microwave heating.
- Characterize the properties (microstructural; mechanical; tribological) of microwave sintered composites vis-à-vis their conventionally sintered counterparts.
- Further enhance the properties of microwave sintered composites through alloy design and tailoring the compositions.
- Provide education and training to students affiliated with the participating institutes in the area of microwave processing of materials.
- Render assistance to the interested and relevant industry and research institutes in microwave sintering and operational details of equipment design and set-up.

Work Plan/Methodology:
- Fabrication of fine micro structured various metal-ceramic composites through microwave sintering and powder metallurgy.
- Investigation and development of unique microstructural formulations exploiting unique advantages of microwave heating.
- Characterization of the properties (microstructural; mechanical; tribological) of microwave sintered composites vis-à-vis their conventionally sintered counterparts.
- Further enhancement of the properties of microwave sintered composites through alloy design and tailoring the compositions.
- Education and training of students affiliated with the participating Institutes.
- Executing exchange of researchers between the participating institutes for conducting experiments and technological/scientific discussions.
Summary Activities at IIT Kanpur:
- Liquid Phase Sintering of 2712, 6711 and 7775 Aluminum Alloys and their Properties (IIT/K + PSU)
- Microwave Heating of Stainless Steels (IIT/K + PSU)
- Modeling of Microwave Heating of Particulate Metals and Its Application in Sintering of Tungsten-Based Alloys (IIT/K + PSU)
- Microwave Sintering of Bronze (IIT/K + PSU)
- Microwave Sintering of W-Ni-Fe Alloy (IIT/K+PSU)

Activities at Industrial Microwave Research Center, Mumbai:
- Kick-off meeting of the Center: Held on 18 July, 2008 and the primary objective was to apprise to and interact with Indian industries and other R&D centers about the objectives of the IMRC and educate them about the microwave materials processing.
- Sintering of Stainless Steel: Held in collaboration with IIT Kanpur and MPEC, USA.
- Workshop on Microwave Steel making: Held on February 27, 2009.
- Microwave Steel making (IMRC + MTU)
- Bulk Metal Heating & Heat Treatments (IMRC)
- Visits to MPEC and Michigan Tech. University: By Dr. Shivanand Borkar from 20th October to 17th November 2008.

Achievements
The research focus has been towards investigating the sintering aspects of ferrous and non-ferrous materials and major findings are summarized as follows:
- Microwave Heating of Stainless Steels
- Microwave Sintering of Bronze
- Microwave Sintering of W-Ni-Fe Alloy

Both ferrous and non-ferrous alloys can be successfully processed through microwave sintering. As compared to conventional heating, microwave sintering results in significant reduction in the processing time ranging from 70-90%. Therefore microwave sintering offers a potentially viable means to consolidate particulate metals, alloys and composites for high performance applications.

Conclusion
- Microwave heating can effectively produce cracks in the silicate matrix of the high grade metal sulphide ore.
- Heating to temperatures of 400 °C in air/argon reported no mass loss of the sample, important for processing conditions, if microwave pretreatment
of the ore was employed to produce cracks, as the mass loss results in gas production mainly in the form of SOx.

- By heating to temperatures in excess of 800 °C in air/argon mass loss is reported from the formation of voids in the metallic bearing phases of the ore.
- Localized melting occurs within the silicate matrix forming a flux containing all elements found in that region of the sample. As metallic phases heat to high temperatures, the heat is transferred to the neighboring silicate causing it to melt engulfing the metallic bearing within it. This is not good from a mineral processing standpoint as the thermal runaway occurring within the ore causes the economically valuable minerals to be further trapped by the silicate matrix.

Publications


### Exchange Visits

<table>
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<th>Duration/Time Period</th>
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<tr>
<td>Prof. Dinesh Agrawal (PI)</td>
<td>IMRC, Mumbai</td>
<td>15-30 July 2008</td>
</tr>
<tr>
<td>Mr. Matthew Andriese (Student)</td>
<td>IMRC, Mumbai, IIT, Kanpur</td>
<td>8-18 May 2009, 18 May - 8 July 2009</td>
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<th>Exchange visits to US</th>
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<tr>
<td>Dr. Shivanand A. Borkar (Co-PI)</td>
<td>Penn State, Michigan Tech</td>
<td>15 Oct. - 10 Nov. 2008, 10-14 Nov. 2008</td>
</tr>
<tr>
<td>Dr. Anish Upadhyaya (PI)</td>
<td>Penn State, Michigan Tech</td>
<td>30 May - 3 July 2009, 8-12 June 2009</td>
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Under Review
Indo-US Joint Center on
Theoretical Physics of Ultra-Cold
Atoms in Optical Lattices

About the Center
The Joint Center “Theoretical Physics of Ultra-Cold Atoms in Optical Lattices” was set up in April 2010. H R Krishnamurthy and Vijay B Shenoy from the Indian Institute of Science (IISc.), Bangalore, and Krishnendu Sengupta from the Indian Association for the Cultivation of Science in Kolkata were involved from the Indian side. The U. S. side included James K Freericks and Marcos Rigol from Georgetown University (Washington DC), and Nandini Trivedi from the Ohio State University. The objectives of the Joint Center were to promote collaborative theoretical research in the emerging area of ultra-cold atoms in optical lattices.

Achievements
A total of thirteen exchange visits took place as part of the activities of this centre, involving students, post docs and faculty. Six of these were visits from India to the US, by H R Krishnamurthy, Krishnendu Sengupta, Vijay Shenoy and Manjari Gupta, a doctoral student at IISc. The other seven were visits from US to India, by J K Freericks, Marcos Rigol and four post-doctoral fellows from Georgetown University, Karlis Mikelsons, Juan Carraquilla, Christopher Varney and Herbert Fotos. Some of the collaborative research that was facilitated by these visits is described briefly below.

Manjari Gupta is working with H R Krishnamurthy (HRK) and James K Freericks (JKF) to extend the strong coupling expansion developed by them in an earlier collaboration to systems of ultra-cold bosonic atoms in a deep optical lattice as described by the Bose-Hubbard model with a trap potential, for parameter regimes when superfluid regions are present. Many equilibrium quantities that are directly experimentally measured such as the inhomogeneous density profile, the entropy, etc. are being calculated. Some sample results are shown in Fig. 1. The expansion works well in much of the experimentally relevant regimes, provided the temperatures are chosen to be slightly smaller than the experimentally assigned temperatures. (Fig. 2). A paper describing this work has been published in Physical Review. Additionally, research is currently underway to extend this work to mixtures of bosons, and calculate the efficiency for dipolar molecule formation in Rb-Cs mixtures on an optical lattice for use in an experiment from the Innsbruck team, as well as to bosons in rotating in an annular trap superposed on an optical lattice.

Another technique for handling strongly correlated inhomogeneous systems such as ultra-cold atoms in a trap is that of inhomogeneous dynamical mean-field theory (DMFT). This is computationally very challenging. A tremendous simplification results by using the local density approximation (LDA) where the inhomogeneous system is mapped to a set of
homogeneous systems at the local chemical potentials, whence the results from a homogeneous DMFT can be used. But this approximation does not work very well for deep trap potentials. Karlis Mikelsons (KM) worked in collaboration with HRK and JFK to develop a generalized gradient approximation to improve upon the LDA while retaining the advantage of being able to use homogeneous DMFT results. This work has been published in the (refereed) proceedings of a HPCMC user group conference. [Ref. 1 in the list of publications]

A key aspect of cold atom systems is that they provide a unique test bed for the study of non-equilibrium dynamics of its constituent atoms in the strongly correlated regime. For, experimentalists routinely manipulate the cold atoms and molecules either to prepare the system in a given state, or to perform measurements. While the preparation of the system is often approximately adiabatic, the measurements often destroy thermal equilibrium. Some of the experiments that involve non-equilibrium dynamics of the cold atoms and molecules in an essential way are:

- Free expansion of an originally trapped gas of atoms,
- Dipole oscillations,
- Modulation spectroscopy,
- Preformed molecule formation via a mixing of atomic species,
- Bloch oscillations.

James K Freericks (JKF), Karlis Mikelsons (KM) and H R Krishnamurthy (HRK) initiated the development of an entirely new line of theoretical techniques to study such non-equilibrium dynamics of cold atoms.
in optical lattices. These are obtained by extending to the non-equilibrium case the strong coupling expansion techniques developed by JKF and HRK in an earlier collaboration for bosons in an optical lattice in thermal equilibrium. They also make use of methods developed by JKF for treating non-equilibrium problems numerically by discretizing paths in a complex time plane, where the portions of the paths on the real time axis describe non-equilibrium time evolution of the quantum system, whereas the portion of the path on the imaginary time axis describes the initial equilibrium state of the system.

As a first application of these new methods, they explored a system of 40K atoms trapped in an optical lattice and subjected to a “synthetic electric field”. (Cold atoms are electrically neutral. However, experimentalists have devised ingenious ways of creating “synthetic fields” that act on the neutral atoms in the same way that real electric field act on charged particles such as electrons.) At the simplest level, they modelled the system as a Fermi Hubbard model on a simple cubic lattice of (128) 3 sites, with an inter-site nearest neighbor hopping of J, and on onsite Hubbard repulsion energy of U. The electric field is abruptly turned on at time t = 0 along a specified direction, eg., (111). The damping of the ensuing Bloch oscillations was found to depend on the direction of the field and for a broad range of field strengths a long-lived transient prethermalized state was found to emerge. This long-lived transient regime implies that thermal equilibrium may be out of reach of the time scales accessible in present cold atom experiments. However it was found that an interesting new quasi-universal transient state exists in nonequilibrium governed by a thermalized kinetic energy but not a thermalized potential energy. In addition, when the field strength is equal in magnitude to the interaction between atoms, the system was found to undergo a rapid thermalization, characterized by a different quasi-universal behavior of the current and spectral function for different values of the hopping (figure 3). This work has been published in Physical Review Letters.

Following this work, Andreas Dirks, working in collaboration with KM, JKF and HRK, extended the above work to come up with a comprehensive theory for modulation spectroscopy of ultra-cold Fermionic atoms in a trap. The theoretical predictions compare well to the experimental time traces of doublon production. For experimentally feasible conditions, this work provides a quantitative prediction for the presence of nonlinear “two-photon” excitations at strong modulation amplitudes. The work has been published in Phys. Rev. B (Rapid Communications).

Both of the above constitute substantive contributions to the field, largely fulfilling the aims of the joint centre, and what we had proposed to do.

There was also progress on a few other problems that were not directly connected to actual cold-atom systems, but address closely related non-equilibrium pump-probe studies of correlated condensed matter systems. The last one is especially significant in that it points to the possibility of a novel non-equilibrium closing of the gap in the photoemission spectra of...
pumped charge density wave systems such as TaS2 and TbTe3 while the charge density remains modulated, with the gap reforming after the pump pulse has passed. This non-equilibrium scenario qualitatively describes the common short-time experimental features in such systems.

A system of ultra-cold bosons in an optical lattice provides opportunities for the study of the superfluid-insulator (SI) quantum phase transition of the bosons, and in particular, the non-equilibrium dynamics of the bosons near the SI transition by quenching the parameters of the system from one regime to another. Krishnendu Sengupta (KS), a co-PI in the project has developed a technique of addressing quench dynamics in cold atoms beyond the standard mean-field theory. Also, Marcos Rigol (MR) has been looking into the physics of thermalization leading to the formation of steady states in isolated quantum systems during their evolution subsequent to a quench. Thanks to the IUSSTF Joint Centre, KS and MR initiated a collaboration to understand the steady state formation and thermalization of the Bose-Hubbard model near its quantum critical point using the technique developed earlier by KS. Such a study, which has never been carried out for the Bose-Hubbard model, has the promise of being directly relevant to realistic experimental systems such as 87Rb atoms in an optical lattice.

Collaborative and collaborative work of the sort described above would have been impossible to generate and sustain had it not been for the generous support for exchange visits provided by the IUSSTF Joint Centre. The visits also provide a wonderful cultural experience, especially for the young students and post-docs from both sides.

**Scientific Value Addition**

We completed the following projects, which we believe are significant contributions.

- We developed a strong coupling expansion for quantities that are directly experimentally measured in systems of ultra-cold bosonic atoms in a deep optical lattice as described by the Bose-Hubbard model with a trap potential, for parameter regimes when superfluid regions are present. The expansion works well in much of the experimentally relevant regimes.
- We developed a generalized gradient approximation to go beyond the local density approximation in handling strongly correlated inhomogeneous systems such as ultra-cold atoms in a trap.
- We succeeded in achieving a key goal we had set forth in our proposal, namely that of the development of an extension of our strong-coupling approach to non-equilibrium ultracold atomic problems in an optical lattice with a trap, and in particular to modulation spectroscopy.
- We also made progress a few other problems that were not directly connected to actual cold-atom systems, but address closely related non-equilibrium pump-probe studies of correlated condensed matter systems.

We have a number of other projects we started working on in the context of the IUSSTF proposal, where we have made progress, but these are not yet completed enough to be publishable yet. When they do eventually get published, as we are sure they will, the IUSSTF support will still be acknowledged, although the tenure of the project is now completed.

- Calculating the efficiency for dipolar molecule formation in Rb-Cs mixtures on an optical lattice for use in an experiment from the Innsbruck team.
- Studies of strongly correlated Bose-Hubbard systems in annular traps, under conditions of super-flow.
- Further elaboration and implementation of the generalized gradient approximation as a way to go beyond the local density approximation in a variety of contexts.

**Publications**

- J. K. Freericks, K. Mikelsons, and H. R. Krishnamurthy. (2011) *The generalized gradient approximation applied to the three dimensional*...
### Exchange Visits

<table>
<thead>
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<td>1</td>
<td>Jim Freericks (PI)</td>
<td>IISc</td>
<td>1 week (Feb. 2011)</td>
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<td>1 Month (April-May 2011)</td>
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<td>Georgetown</td>
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<td>1 month (Jan. - Feb. 2013)</td>
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Indo-US Joint Center on
Thin-Films and Nanostructured Emerging Coating Technologies

Principal Investigators

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About the Center
The main objectives of the Joint Center are:

- Develop non-metallic alternatives to metal coatings for steel with particular emphasis on emerging nanomaterial and nanocomposite based multifunctional coatings.
- Develop thin-film nanostructure coatings with tailored functionalities such as corrosion resistance, exceptional formability, weldability, conformability, electrical conductivity and mechanical resilience.
- Replace metallic coating like (Zn, Cr) with thin film nanostructured coatings.
- Develop multifunctional thin film nan-structured coatings for value addition to steel substrate.
- Develop a comprehensive understanding of structure-function correlations for nanostructured coatings.
- Develop sustainable coatings with minimal environmental impact.

Achievements
- Development of sustainable and “green” nanocomposite coatings for replacement of carcinogenic hexavalent chromium and expensive zinc metallurgical coatings for corrosion protection of low alloy steels.
- Dispersion of nanostructured ZrO2 and MgO within water-soluble acrylic matrices.
- Development of atom-efficient coating methodologies that emphasize reduction of volatile organic content, CO2 emissions, and toxic curing agents.
- Functional coatings incorporating 8-hydroxy quinololine for UV protection.

The Indo-US Joint Networked Center (henceforth denoted by its acronym PROTECT) has sought to develop sustainable coating alternatives based on the development of polymer nanocomposites. Considerable progress has been achieved between 2012 and 2014 by combining the complementary expertise of the academic and industrial participants. Specific achievements of the project team include a novel method for incorporating graphene oxide and oxidized multiwalled carbon nanotubes within epoxy and isocyanate resins wherein the carbon nanomaterial fillers are used as the curing agents. The prepared coatings allow for incorporation of unprecedented weight fractions of the carbon nanomaterials within the polymeric matrices without phase segregation. The epoxy nanocomposites have been found to endow remarkable corrosion inhibition to low alloy steel substrates when applied as coatings. In a similar vein, a novel nanostructured magnesium/polyetherimide nanocomposite system has been developed that combines the barrier properties of the host polyetherimide matrix with sacrificial cathodic...
protection afforded by incorporated magnesium nanoparticles. These coatings serve as excellent lightweight alternatives to galvanized zinc and far outperform state-of-the-art metallurgical and composite coatings. Finally, the incorporation of 8-hydroxyquinoline within multilayered architectures constituted from alternate layers of poly(ethyleneimine) and poly(methyl styrene) has been pursued to obtain self-healing and UV protective functionalities. PROTECT has emphasized sustainable coating technologies that minimize the use of toxic curing agents, organic solvents, and heavy metals.

**Milestones**
- To replace metallic coatings like “Zn” and “Cr” by thin film nano-structured coatings.
- To develop sustainable coatings to minimize environmental impact.

Both milestones have been accomplished in their entirety. An article published in the ACS journal Industrial & Engineering Chemistry (dx.doi.org/10.1021/ie500897n) reports the development of novel nanocomposites based on the incorporation of Mg nanoparticles within polyetherimide matrices for replacement of hexavalent chromium and zinc coatings for the corrosion protection of steel. Another coating formulation based on dispersion of graphene oxide and carbon nanotubes within epoxy resins has been submitted for publication to RSC Advances (Manuscript ID: RA-ART-09-2014-009693).

**Scientific Value Addition**
- Corrosion is recognized as one of the most serious problems in modern society and the resulting losses each year are in the billions and trillions of dollars. PROTECT has developed multiple versatile coating platforms wherein carbon nanomaterials, inorganic nanostructures, and molecules are dispersed within polymeric matrices.
- An active-passive strategy for designing corrosion-resistant coatings has been developed. Our approach wherein the barrier properties of a polymeric matrix are combined with the electroactive properties of nanoparticle fillers is versatile, sustainable, and amenable to large-scale production. This strategy has attracted significant attention from industrial partners such as Tata Steel. The project team has also had fruitful discussions with private industry including in Thane (India) and in Ohio and New York State in the United States.
- We have developed and introduced nanostructured, eco-friendly and sustainable solutions to replace the chromate based environmentally unfriendly surface treatments. Nanostructured graphene oxide and functionalized multiwalled carbon nanotubes have been used as curing agents to induce cross-linking of an epoxy resin. This approach allows for incorporation of to 50 wt.% of carbon nanomaterials and represent an attractive alternative to the hazardous high-temperature fluorination and amine curing reactions that are usually required to formulate epoxy composite systems.
- The composites developed here provide an attractive sustainable alternative to carcinogenic coating materials such as hexavalent chromates and to toxic resin curing processes requiring fluorination and diamines.
• The functionalization of graphene oxide and MWCNTs and the additional driving force for mixing provided by π—π interactions allows for enhanced compatibility between the two disparate types of materials (carbon nanomaterials and polymeric matrix). The composite formulations allow for incorporation of up to 50 wt.% nano-fillers into the polymer matrix without phase segregation.

Furthermore, we emphasized the inclusion of additives to impart UV-resistant properties. Specifically, we have utilized the organic material, 8-hydroxyquinoline, to obtain self-curing and UV protection properties. Green and sustainable coating methods have been developed by emphasizing water-soluble acrylic based polymers with incorporated nanostructured materials within the coating formulations (in order to completely eliminate volatile organic components and CO2 emission).

Way Forward
The accomplishments of PROTECT in developing versatile coating platforms that endow corrosion protection and can further be tuned to incorporate additional functionality leaves us interestingly poised for targeting different coating applications. The interfacial chemistries developed as part of this initiative further hold promise for development of bulk polymer composites. The University at Buffalo/ICT teams are in discussions with the industrial partners to seek additional funding to sustain the collaboration. The UB/ICT teams are further seeking to apply for funding under a joint US-UK-India program administered by the Institute for International Education in collaboration with Bangor University.

Publications


Publications planned :
• Robert V. Dennis, Vikas Patil, Jeffrey P. Aldinger, G. D. Yadav,* and Sarbajit Banerjee* (joint first authors; * joint corresponding authors), Hybrid Nanostructured Coatings for Corrosion Protection: A Sustainability Perspective, 2014, manuscript under preparation for submission to Materials Research Express (invited review article)

• Vikas Patil, Robert V. Dennis, Tapan K. Rout, Sarbajit Banerjee, Ganapati D. Yadav*, Graphene Oxide and Functionalized Multi Walled Carbon Nanotubes: An interesting facet for classical isocyanate curing (manuscript under preparation)
About the Center
An IUSSTF Joint Center entitled “Dynamics of Dislocations in Solid Helium and its Role in Supersolid Behavior” was set up in July 2011. Chandan Dasgupta from the Indian Institute of Science, Bangalore, and Surajit Sengupta from the Indian Association for the Cultivation of Science in Kolkata (currently at the TIFR Centre for Interdisciplinary Sciences in Hyderabad) were the scientists involved from the Indian side; the US counterparts were Oriol T Valls from the University of Minnesota in Minneapolis, and John Toner from the University of Oregon in Eugene. The objective of the Joint Center was to promote and enhance collaborative theoretical research in the area of “supersolid” phenomena in solid 4He. The tenure of the Joint Center ended in December, 2013.

Achievements
Several studies on various aspects of the theme of the Joint Center have been completed. One of these is a calculation of the hydrodynamics of compressible superfluids in confined geometries. The calculation begins with the development of a perturbation procedure to study the hydrodynamics of compressible superfluids (previous work included only the incompressible case). It is then shown that the relevant systems under consideration can be treated within the perturbation approach. To illustrate the workings of the method, two examples are worked out in detail and the flows calculated. Some results are illustrated in Fig.1 that shows a plot of the radial component of the velocity field for an obstructed cylinder at several angular values.

Another important part of the proposal that has been completed pertains to analytic and numerical calculations of the equilibrium properties of a spin model on a random network with quenched or annealed disorder. The main objective here is to understand the effects of the motion of the segments of a network (representing the network of dislocation lines in the supersolid problem) on the ordering of spins along the network. In the model we consider, the network is represented as a collection of four-fold coordinated Ising spins, coupled via Ising chains containing a variable number of spins. This number is determined from a Gaussian probability distribution. If the disorder is treated as being annealed, then this is the analog of allowing the dislocation lines to move (dynamic dislocations), while if the disorder is assumed to be quenched, one is dealing with fixed dislocation lines. So one can then gauge the importance of dislocation dynamics by comparing the results for the annealed and quenched systems. We have studied the specific heat in this system, concentrating on the difference between quenched and annealed results. This is illustrated in Fig.2 that shows the contribution of two-dimensional critical fluctuations to the specific heat for both quenched...
and annealed disorder. The temperature at which the specific heat peaks represents the transition temperature. These results show that the phase transition occurs at a higher temperature if the disorder is quenched. In the context of superfluidity along dislocation lines, these results imply that the motion of dislocation lines reduces the temperature of the superfluid transition.

We have also carried out one of the proposed studies in which the dynamics of a large number of dislocations is described using a formulation of continuum plasticity theory and the effects of the stress field of the dislocations on the occurrence of supersolid behaviour are determined from a coupling of the stress field to a complex scalar field that describes superfluid order, as in the Dorsey-Goldbart-Toner (DGT) model. It is known that an initial smooth distribution of dislocations spontaneously coarsens into defect-free regions interspersed with shock-like structures of high dislocation density or “cell walls”. Internal stresses at such cell walls, which may be large initially, eventually anneal out producing stress free-grain at late times. If the superfluid field couples only to volumetric stress, as in the DGT model, transient superfluidity may exist at cell walls with large stress if dislocation climb is allowed. Once cell walls evolve into symmetric grain boundaries, this superfluidity vanishes. This behaviour is illustrated in Fig.3 that shows the time evolution of both the stress field and the superfluid order parameter. If climb is arrested, the plastic current is volume preserving and the superfluid field, if initially absent, cannot form. Similarly, annealing of an initially non-zero superfluid field is severely constrained without dislocation climb. This suggests the following scenario for the occurrence of supersolid behaviour. At high temperatures, dislocation climb, ensured through mass transport through dislocation cores, results in the formation of symmetric grain boundaries and vanishing of the supersolid fraction at long times. As the temperature is reduced and/or pinning of dislocations by impurities becomes effective, climb is suppressed and the resulting long-lived residual superfluidity at cell walls contributes to supersolid behaviour.

**Scientific Value Addition**

Eight exchange visits have taken place as part of the activities of this Center, involving both students and faculty. Four of these have been visits by graduate students: one visit each by Soumya Kanti Ganguly, a student working with Professor Dasgupta and Debabrata Sinha, a student working with Prof.
Fig. 3. Space (z)– time(t) plots for the stress (a) and the superfluid fraction (b). The superfluid fraction becomes large at one of the cell walls where the initial stress is also large. It subsequently decays to zero as the stress relaxes.

Sengupta, and two visits by A.N. Malmi-Kakkada, a student working with Professor Valls. These visits have contributed significantly to the training of these students and their development as theoretical physicists.

Some of the results obtained from work carried out under the Joint Center have been reported in invited talks given by Professor Dasgupta at the following Conferences.


Way Forward
Several studies started under the Joint Center are currently in progress. One of these involves the evaluation of the dislocation mobility in a supersolid. This calculation, being performed by Mr. Malmi-Kakkada with inputs from Professors Valls and Dasgupta is nearly completed. It uses previously developed hydrodynamic equations and a procedure, originally employed in the study of quasicrystals, to extract the dislocation mobility from these equations. The results suggest that the experimentally observed increase in the shear modulus of solid 4He at low temperatures may be caused by the onset of superfluidity.

An important component of the research proposed under the Joint Center is the development of a Monte Carlo code for simulating the equilibrium properties of a collection of interacting dislocation lines in solid 4He. Soumya Kanti Ganguly, a PhD student working with Prof. Dasgupta, has made considerable progress...
in this problem. He has developed a Monte Carlo code for a simpler network model that describes interacting vortex lines in a superfluid and used this code to obtain interesting results for the phase transition in this system. He is now working on the modification of the code for treating dislocation lines.

Considerable progress has been made in a calculation of the elastic properties of a solid in which a large number of dislocations, described using a formulation of continuum plasticity theory, are coupled to a complex scalar field that describes superfluid order. This calculation shows that when both climb and glide of dislocations are allowed, there is an enhancement of strain rate sensitivity (effective elastic constant) due to coupling with the superfluid field. This enhancement increases when temperature decreases and vanishes above a particular temperature at which superfluidity disappears. The effective elastic constant increases with decreasing strain rate. These results exhibit many similarities with experimental results for elastic properties of solid 4He at very low temperatures.

Two papers on these results are in preparation. We expect that these studies will lead to at least two more publications. These calculations, when completed, will lead to a significant improvement in the present understanding of the properties of the putative supersolid phase of 4He.

Publications

Indo-US Joint Center on
Rational Control of Functional Oxides

Principal Investigators

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About the Center
The broad aim of the Centre is to put together a strong team that is capable of tackling this challenging problem of obtaining a microscopic understanding of properties of transition metal oxide systems close to various instabilities through a combination of state of the art experimental and theoretical. Our specific objectives are the innovative synthesis of designer materials, detailed investigation of their physical properties as well as spectroscopic investigations to obtain microscopic information on their electronic and magnetic properties, and theoretical modeling at several levels. The teams on both sides have been hand-picked keeping in mind the requirements of this demanding program.

Work Plan/Methodology
Ultra-thin films of the nickelate materials will be synthesized in the laboratory of Jak Tchakhalian at University of Arkansas. Electrical and magnetic characterizations of these samples will also be completed there. Synthesis work will begin immediately upon funding of the Center, and as part of the synthesis effort students from India will come to Arkansas to be involved in the growth and characterization. Characterized samples will be available within 6 months, at which time they will be subjected to detailed spectroscopic investigations employing a wide array of techniques. These techniques can be roughly divided in to two groups, namely those which need an access to synchrotron centre and those which can be carried out in a laboratory with suitable facilities. Most of the synchrotron-based work will be carried out at Advanced Photon Source by the group of John Freeland. This will cover techniques such as x-ray absorption spectroscopy, x-ray magnetic circular and linear dichroism, x-and ray scattering. High-energy spectroscopic characterizations using x-ray and UV photoelectron spectroscopy, Auger electron spectroscopy, Bremsstrahlung Isochromat spectroscopy, and electron energy loss spectroscopy will be carried out in the group of D. D. Sarma at Indian Institute of Science. A US student will join the group of D. D. Sarma to participate in part of this work.

The other part of the project concerns the negative charge transfer cuprate materials, which will be studied in parallel with the nickelates. Whereas the nickelate materials can already be grown in ultra-thin-film form, the negative charge transfer materials have not yet been successfully grown in this way. The work here will involve both bulk synthesis carried out in the group of D. D. Sarma (first 6 months) and thin film synthesis in the lab of Chakhalian (this is exploratory—it is not yet known how to grow these as films) (second 6 months).

The Sarma group has synthesized these materials in the past and they will make the bulk samples attain and carry out detailed local structure measurements using EXAFS. A visitor from the Sarma group to the US will provide needed expertise in the materials chemistry of
these systems and will assist with the film synthesis. The growth will be followed by experimental study at Bangalore and at Argonne (second 6 months and year 2). Within the purview of this project we would like to investigate two aspects. The first is to examine the evolution of the character of the doped holes in Na doped Ca2CuO3 and Sr2CuO3. Earlier work has established that Na doping still leaves the system insulating. The origin of the insulating state despite doping with a monovalent atom for the divalent Ca/Sr atom has been associated with the formation of polarons. Detailed structural analysis will be carried out to understand the changes in the crystal structure as a function of hole doping.

Once thin films are grown, photoemission studies will be carried out by the group of D.D. Sarma (second year, first 6 months) X-ray absorption studies as well as various dichroism measurements will be carried out by the group of John Freeland. This will be done in the second year of the project.

In parallel with the experimental efforts, theoretical studies will be carried out in the groups of Priya Mahadevan and Andrew Millis. Ab-initio calculations (first year, Mahadevan) will provide insight into the local structure, nature and character of the doped holes. The theoretical results will also be used to help plan the X-ray linear dichroism experiments at Argonne (Freeland, second year) to probe the orbital character of the doped holes. As the detailed spectroscopic results become available they will be fed into the many body calculations which will provide theoretical modeling for the photoemission experiments (second year, Millis group).

Theoretical analysis of spectroscopic data both on

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**Exchange Visits**

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<td>9.</td>
<td>Andrew J. Millis</td>
<td>Indian Institute of Science</td>
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<td>Columbia University</td>
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the nickelate and the cuprate materials using various model Hamiltonian approaches will be carried out by P. Mahadevan at S. N. Bose National Centre for Basic Sciences and D. D. Sarma of Indian Institute of Science. P. Mahadevan will also investigate electronic and magnetic structures of these materials with an effective single-particle approach based on various density functional theories which is also expected to give rise to an understanding of the microscopic origin of magnetism in each of these samples. Using these as inputs, the group of Andrew Millis at Columbia University will set up the most appropriate model many-body Hamiltonian and probe its properties using modern techniques of cluster dynamical mean field theory. During the second 6 month period of the grant a student of Millis will visit the Mahadevan group to gain experience in the first principles calculations and during the beginning of the second year a theoretical student from India will spend a lengthy period at Columbia, bringing first-principles expertise to the Millis group and becoming familiar with the many-body methods.

Achievements

A microscopic understanding of the charge ordering in NdNiO$_3$

Charge ordering in the nickelates has been seen across the series of rare-earth(RE) nickelates with the exception of metallic LaNiO$_3$. Various features about the charge ordering pattern have emerged which indicate a checkerboard pattern of notionally Ni$^{2+}$ and Ni$^{4+}$ sites forming. The charge ordering is accompanied by a breathing mode lattice distortion, with the NiO$_6$ octahedra being uniformly expanded about the Ni atom which is associated with a 2+ valency and that about the Ni atom which is associated with 4+ valency being uniformly contracted. There is however no real charge difference between the two sites. Starting from a microscopic Hamiltonian which considers the lattice distortions and the magnetic structure, one is able to arrive at an insulating state. However, the charge ordering is built into such an approach and so comes a consequence of the lattice distortions that are imposed. While these aspects have been discussed in the literature, it is not clear what is the microscopic considerations that drive the charge ordering in the nickelates. In order to probe this aspect, we considered the transition metal atom which adjoins the Ni atom, i.e Co. Examining NdCoO$_3$ one finds that we do find a charge ordered solution. However, this has a higher energy compared to ground state solution for NdCoO$_3$. This has given us a clue that an analysis of the microscopic interactions for NdNiO$_3$ and NdCoO$_3$ should provide us with the clues for the interaction strength which determines the presence/absence of charge ordering. In order to analyse this aspect we have mapped the ab-initio band structure for both NdNiO$_3$ and NdCoO$_3$ onto a tight binding model which includes TM d states as well as O p states in the basis. The parameters entering the tight-binding model have been determined by a least-square error minimization process and provide us with some clues of the microscopic interactions responsible for charge ordering in the nickelates. In order to probe this aspect further, we are carrying out state of the art ab-initio electronic structure calculations which allow us to vary the responsible microscopic interaction strengths in a controlled manner. The primary aim of this approach is to analyse various contributions to the energetics while relaxing the structure simultaneously to estimate the extent of charge ordering.

Additional microscopic analysis is being carried out within the framework of a multiband Hubbard model in which the tight binding part of the Hamiltonian has been determined by fitting the ab-initio band structure.

Magnetic structure of NdNiO$_3$

The perovskite oxides with the formula ABO$_3$, where
A is a rare-earth atom and B is a transition metal atom are usually found to favour an antiferromagnetic ground state with either A,C or G-type magnetic ordering. Some members of this series are also nonmagnetic or ferromagnetic. The antiferromagnetic structures favoured are simple with each transition metal atom having 2, 4 or 6 nearest neighbour atoms coupled antiferromagnetically. In contrast the magnetic structures that have been proposed for the nickelates are very complex. One of the candidate structures proposed is the E-type structure with the spins arranged to the pattern up-up-down-down along all three crystal axes. This seems a surprising structure for the system to adopt as its ground state structure as the nearest neighbour interactions are largest among the perovskite oxides. Such a structure would have no contributions to the total energy coming from nearest neighbour interactions. An alternate structure that has been proposed has nearest neighbour spins rotated by 90 degrees with respect to each other. The usual model that seems appropriate for describing the magnetic structures of transition metal oxides has been the Heisenberg model. However, with nearest neighbour spins oriented at 90 degrees with respect to each other, there is no contribution to the total energy from nearest neighbour spins assuming a Heisenberg model. Such a magnetic structure could be favoured by Dzyaloshinskii Moriya (DM) interactions, resulting from spin-orbit effects. However the large magnetic ordering temperatures (150-200 K) observed in experiments cannot be explained by DM interactions alone. In view of these considerations we have explored various candidate magnetic structures for NdNiO3 and have arrived at a new model for the magnetic structure. In order to examine which interactions contribute to stabilize the magnetic structure, we have calculated the spin wave spectra along various symmetry directions. These have then been analysed in terms of an extended Heisenberg model and the exchange interaction strengths have been extracted. Now we are trying to understand the microscopic considerations that lead to the values of the exchange interaction strengths.

**Ultrathin films of NdNiO3**

Experiments from the group of Prof. Chakhalian on thin films of NdNiO3 find an insulating state in the absence of charge ordering. We have been trying to understand the origin of the insulating state using ab-initio electronic structure calculations. Ni in NdNiO3 has a formal d7 configuration. We first considered the bulk unit cell of NdNiO3 with the substrate merely introducing a strain and examine if Jahn Teller effects can drive the system insulating. Jahn-Teller effects are found to be small in NdNiO3, resulting in bondlength variations of 0.01 Å. Hence they cannot drive the system insulating. We have then gone on to simulate the thin film by considering 12 monolayers of the substrate NdGaO3 as well as the NdNiO3 overlayers and the results are being analysed.
Indo-US Joint Center on
3-D Engineered Electrodes for
Electrochemical Energy Storage

About the Center
The objective of the center is to carry out cutting edge collaborative research on innovative ideas to design and build 3-D architectures using various nanostructures (including graphene, carbon nanotubes, polymers, metal oxide nanowires/clusters etc.) in order to incorporate them as active electrode components in electrochemical energy storage devices. Specific research goals to be met by the center are:

- Development of conformal and space filling methods for fabricating 3-D engineered architectures for thin film batteries and supercapacitors.
- Characterization of resulting devices in terms of their microstructures with particular reference to their electrode-electrolyte interfaces.
- Investigation of electrochemical performance of these devices, analysis and understanding the underlying physical phenomena of the hybrid configuration of the devices.
- Model/simulate optimized hybrid nanostructures for improved electrochemical energy storage.
- Explore new configurations/designs for these devices to obtain vastly improved performances.
- Obtain easily integrated designs to build hybrid devices between storage formats based on battery and supercapacitors.

Achievements

Fluorinated graphene based high performance electrodes for primary lithium battery: Although rechargeable Li ion batteries have become the dominant power source for portable electronics applications, primary batteries are still used in applications like military and defense tools, and medical implants. We have demonstrated a single-step strategy capable of improving specific capacity, power density and faradic yield of a Li/CFx battery system using fluorinated graphene. The excellent electrochemical performance achieved using fluorinated graphene with a very low fluorine content (x = 0.22) could lead to the development of highly efficient primary battery systems perhaps with low cost and minimum environmental impact.

Synthesis of vertical arrays of TiO2/CoFe2O4 hybrid nanowire electrodes for 3-D microbatteries: We have synthesized vertical arrays of TiO2/CoFe2O4 hybrid nanowires using a combination of electrochemical anodization and hydrothermal techniques. These hybrid nanowires are being tested for their electrochemical performance as efficient anodes for 3-dimensional microbattery applications.

Electrical transport studies on disordered reduced graphene oxide: A collaborative research between Central Electro Chemical Research Institute (CECRI)
Partnering Institutions

**INDIA**
- CSIR-Central Electrochemical Research Institute, Karaikudi
- Indian Institute of Science Education & Research, Thiruvananthapuram
- Indian Institute of Science, Bangalore

**US**
- University of Houston, Houston
- Southern Illinois University Carbondale

and Southern Illinois University Carbondale (SIUC) has been conducted on the development of stable conductive inks of reduced graphene oxide and their electrical transport properties. This was primarily a fundamental study with an aim for the use of these inks in electrochemical devices after patterning them over substrates. This work has been reported in the journal 2D Materials.

**Way Forward**
Research activities in the area of 3D nanoarchitectures are being carried out for their application as efficient electrodes in energy storage devices such as electrochemical supercapacitors and rechargeable batteries. Some of the on-going and future works are summarized below:

- Development of 3-D scaffolds of graphene based nanostructures for supercapacitor applications.
- Various morphologies of 2-dimensional layered nanocrystals (MoS2, WS2 and their hybrids) are being synthesized using different approaches (Chemical vapor deposition, liquid phase exfoliation) and it will be interesting to study the lithium diffusion in these nanostructured materials.
- 3-dimensional nanoarchitectures using different...
Low and High resolution SEM images of TiO2/CoFe2O4 hybrid nanowires.

metal oxide/polymer will be fabricated using template approach and their electrochemical performance will be studied using cyclic voltammetry, Galvanostatic charge-discharge and electrochemical impedance spectroscopy.

• In addition to the electrochemical measurements, temperature dependent electrical transport studies will be carried out in detail for these materials.
• Theoretical modeling of different materials and electrode designs are being performed with a focus on the electrode/electrolyte interface.

• Planned to organize an international workshop on ‘Advanced Electrode Materials for Electrochemical Energy Storage’ under the auspices of our joint R&D virtual center, in 2015.

Under the auspices of Indo-US joint R&D Network Center on ‘3D Engineered Electrodes for Electrochemical Energy Storage’, an Indo-US workshop on “Engineered Electrodes for Electrochemical Energy Storage” has been organized during April 3-4, 2014,

Exchange Visits
The Indo-US center has undertaken exchange visits of graduate students and PIs across the Partnering Institutions in the last one year, as detailed below. The short stay undertaken by the students in different institutes has been very fruitful in terms of newer ideas and exposure.

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<td>P. M. Ajayan (US-PI)</td>
<td>Rice University, Houston, USA - CECRI, Karaikudi - IISER Thiruvananthapuram</td>
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<td>SIUC, USA - IISER Thiruvananthapuram</td>
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<td>M. M. Shaijumon (Indian-PI)</td>
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<td>Abhishek K. Singh (Indian-PI)</td>
<td>IISc Bangalore - Rice University, USA</td>
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<td>5.</td>
<td>Sujoy Ghosh (US-student)</td>
<td>SIUC, USA - CECRI, Karaikudi - IISER Thiruvananthapuram</td>
<td>1 month</td>
</tr>
<tr>
<td>6.</td>
<td>Mohamed Kabbani (US-student)</td>
<td>Rice University, Houston, USA - IISER Thiruvananthapuram</td>
<td>1 month</td>
</tr>
<tr>
<td>7.</td>
<td>Soumya Vinod (US-student)</td>
<td>Rice University, Houston, USA - IISER Thiruvananthapuram</td>
<td>1.5 months</td>
</tr>
<tr>
<td>8.</td>
<td>Dijo Damien (Indian-student)</td>
<td>IISER Thiruvananthapuram - Rice University, USA - SIUC, USA</td>
<td>1.5 months</td>
</tr>
<tr>
<td>9.</td>
<td>Deya Das (Indian-student)</td>
<td>IISc Bangalore - Rice University, USA</td>
<td>1.5 months</td>
</tr>
<tr>
<td>10.</td>
<td>Sumana Kundu (Indian-student)</td>
<td>CECRI, Karaikudi - Rice University, USA - SIUC, USA</td>
<td>1.5 months</td>
</tr>
</tbody>
</table>
at Chennai. The workshop was aimed at bringing the experts in electrochemical energy storage devices, from both the countries, particularly those who work in the novel aspects of electrode materials, to a common platform and to discuss their views in novel designs and materials for electrochemical energy storage applications.

In addition to the invited talks from experts, there were oral and poster presentations by young scientists as well as Ph.D. students related to a variety of energy related issues. There were 15 invited talks by experts from India and USA, 6 short talks by Ph.D students and about 30 poster presentations. The workshop was well balanced with discussions on both experimental and theoretical aspects of the topic. Three best poster prizes and one best oral presentation prize have been awarded to the students during the concluding session. From various feedbacks expressed by the participants, the workshop is believed to be well received and very successful. All the participants, especially the students and young researchers have been benefitted and were well exposed to several new directions in the materials science and electrochemistry of 3D engineered electrodes for energy storage.

**Publications**

Indo-US Joint Center on
Elastohydrodynamic Lubrication Studies

About the Center
Elastohydrodynamic lubrication (EHL) is a common phenomena occurring within the non-conformal contacts of bearings, gears, cam-follower, valves etc. These tribological components are very critical and are of significant importance in the functioning of the elite mechanical systems. However, even after appropriate maintenance practices, these components fail unwarrantedly leading to severe loses. Hence, the IUSSTF funded Joint Centre on Elastohydrodynamic Lubrication envisages understanding the untouched domains of EHL and developing perspective methodology to understand the failure phenomenon in the elastohydrodynamic lubricated contacts.

The Joint centre established in 2013 in collaboration/participation between IIT – Roorkee, CSIR – IIP Dehradun, Northwestern University and University of Akron has grown one year old. During the one year span significant achievements has been attained by the centre in terms of gaining new knowledge pertaining to EHL and also strengthening and augmenting the strengths of the partnering institutions.

Achievements
- A generalized mathematical model for one-dimensional EHL line contacts has been developed using the Finite Difference and Discontinuous Galerkin techniques. The generalized EHL line contact model represents the contact geometry in roller bearings, gears, cam-followers etc.
- The initial smooth surface EHL line contact model was upgraded to the rough surface EHL line contact lubricated with non-Newtonian lubricants. The surface roughness in the model has been incorporated using stochastic and deterministic approaches (Figure 1). The non-Newtonian rheology of the lubricants is represented by Power-law lubricants.
- The model provides the film thickness distribution and the contact pressures within the contact under different operating conditions. The generalized operating parameters viz. Load, Speed and Material property forms the input to the model. Figure 2 shows the film thickness and pressure distribution within the contact for a shear thinning fluid.
- The study undertaken has revealed that the speed, material parameter and the power law index have significant influence on the performance of the EHL contact as these parameters significantly influences the fluid film thickness (Figure 3).
- A CFX based model has been developed for a bump shaped asperity in an EHL contact. The contact pressure and the deformations have been investigated. The non-Newtonian rheology of lubricant has been
Partnering Institutions

**INDIA**
- CSIR - Indian Institute of Petroleum, Dehradun

**US**
- University of Akron, Akron

employed using the Power Law concept. Figure 4 shows the results on the pressure distribution and velocity profile of the contact under investigation.

**Scientific Value Addition**
The outcome of the Joint centre in the first year has resulted into development of theoretical model of EHL which has been upgraded to investigate more realistic contact conditions. The CFX approach followed is for the first time in the EHL studies. These studies will be of immense help in design and development of tribo-components and also to understand the failure phenomena associated with these components.

**Way Forward**
The Joint centre is determined to bring into more realistic approaches of mechanical systems with the help of theoretical models and experimental validation. As a way forward the activities pertaining to the development of failure models and the incorporation of real surface roughness into the investigation are planned for the second year. Further a joint collaborative workshop in order to disseminate the findings of the centre is planned in the second year.

**Publications**
Figure 4: Pressure & Velocity distribution for Power law index n=0.8

Exchange Visits

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Name and Affiliation</th>
<th>Institution(s) Visited</th>
<th>Duration/Time Period</th>
</tr>
</thead>
</table>
| 1.     | Satish C. Sharma  
Prof., IIT- Roorkee   | Northwestern University and University of Akron | 15 days              |
| 2.     | S. P. Harsha  
Associate Prof., IIT- Roorkee           | Northwestern University and University of Akron | 15 days              |
| 3.     | G. D. Thakre  
Research Scholar, IIT- Roorkee            | Northwestern University and University of Akron | 45 days              |

Prof. Satish C. Sharma, Sh. G. D. Thakre & Dr. S. P. Harsha at the School of Engineering, Northwestern University.

Indian team with Prof. Q. Jane Wang at the Northwestern University.

Prof. Satish C. Sharma, Prof. M. J. Braun & Sh. G. D. Thakre at the test facility developed from the financial support of NASA at University of Akron.

Prof. Braun and his team with Prof. Sharma & Sh. G. D. Thakre at the Tribology laboratory, Univ. of Akron.
Indo-US Joint Center on

From Fundamentals to Applications of Nanoparticle Assemblies

About the Center
The Center is focusing on specific activities which are integrated to go from particle synthesis to applications. The center would complement Synthesis of Nanoparticles where experiments with molecular theory and population balance models will address the open questions. Deliverables here include an experimentally validated, predictive theory for digestive ripening, and therefore NPs with any desired size and surface passivation.

In another aspect of the proposal the center seeks to learn from the small molecule surfactant literature and assemble the polymer grafted NPs into novel structures such as spheres, micelles and rods (relevant to drug delivery, self-healing materials), and periodic in both the NPs and the polymers (relevant to batteries, solar cells), and even more complicated structures. The studies will use advanced characterization tools, such as optical, confocal and electron microscopies, combined with X-ray diffraction and small angle X-ray and neutron scattering, and spectroscopy to elucidate structure and properties of the individual nanoparticles and their assemblies.

Deliverables here are a much bigger tool kit from which we can select a desired NP superstructure, and understanding how these structures can be formed either under quiescent or driven conditions. The deliverables also include a theoretical rationalization linking the mechanical response of nanoparticle/small organic molecule hybrids to the assembly technique.

Achievements
The Center has established several connections between US and Indian Partners. Specifically, (i) between IITB, CSIR-NCL and Columbia University in the area of size-controlled synthesis of nanoparticles; (ii) between CSIR-NCL and Columbia University in the area of elastic macroporous scaffolds from particle assemblies; (iii) between IIT-Delhi and Columbia University in theory and modeling of nanoparticle interactions; (iv) between IIT-Patna/ IIT-Kharagpur and University of Houston in the area of polymer nanocomposites.

Several Joint publications between US and India partners have been generated.

NOTE: Center’s publication on elastic macroporous assemblies was highlighted in Chemical and Engineering News, a prestigious American Chemical Society news magazine.

Scientific Value Addition
Between IIT-Patna/IIT-Kharagpur and University of Houston
Chemical modification of graphene to introduce functional groups in a site specific manner was carried...
out (IIT-Kharagpur/IIT Patna). These were then coupled with silane monomers and novel nanocomposites were prepared (Univ. Houston). Such polymer nanocomposite exhibited instant conducting adhesive behavior (Fig. 1). Furthermore, by introducing bulky pendant groups at the edge sites that exert stress on the basal plane of graphene, its band gap of the could be engineered (Fig. 2). The modified material demonstrated a semi-conducting behavior over the semi-metallic behavior of the pristine material IIT-Patna/IIT-Kharagpur & University of Houston).

An acrylamide based monomer using 2-aminotriptycene was prepared (IIT-Patna). A polymerization of this monomer using the wellknown ATRP polymerization protocol is being planned (University of Houston). The objective is to derive novel triptycene based polymers and study their properties.

**Between NCL-Pune/IIT-Bombay and Columbia University**

The NCL-Pune/IIT-Bombay and Columbia University partnership is focusing on (i) of size-controlled synthesis of nanoparticles and (ii) preparation of elastic macroporous scaffolds from particle assemblies. In the area of nanoparticle synthesis, the partners are trying to evolve a mechanistic understanding of the wellknown digestive ripening process. A series of model experiments have been planned and being executed at CSIR-NCL/IIT-Bombay. The results are being shared with Prof. Sanat Kumar’s group at Columbia University who are trying to model the digestive ripening process. Other plans of this partnership include understanding the effect of polydispersity in grafting density of polymer chains on nanoparticle surface that influences the shape of nanoparticle-aggregates (IIT-Bombay) and preparation of macroporous monoliths (CSIR-NCL), comprised primarily of colloidal particles, that are elastic (Fig. 3). The latter work benefited extensively from the discussions the CSIR-NCL partners had with Prof. Sanat Kumar (Columbia University). The discussions with other scientists at Columbia, during the visit of Dr. Kumaraswamy (facilitated by the Joint Center) with Dr. Jacques Jestin and Prof. Jeffrey Kysar, resulted in further collaborations and different experiments on
the elastic particle assemblies are currently underway in Prof. Kysar’s group of Columbia University.

**Between IIT-Delhi and Columbia University**

The IIT-Delhi/Columbia University partnership is focused on probing the fluctuation driven anisotropy in effective pair interactions between gold nanocrystals that are densely passivated with short ligands. The results clearly suggest that for dense grafting regime, inclusion of anisotropic effects as well as many-body interactions is necessary to adequately describe the thermodynamics and assembly behavior of nanoparticles.

**Way Forward**

- The Indian and US partners successfully bid for a Faraday Discussions on the topic of Nanoparticle Assemblies that will be held in Mumbai (at the IITB) in January 2016 (towards the end of the Joint Center tenure).
- The team has planned a unique workshop at the culmination of the Joint Center to bring together academics and industry, to understand the opportunities offered by nanoparticle assemblies (January 4-6, 2016). Several prominent researchers (including Prof. Daan Frenkel from Cambridge University, Prof. Vinothan Moharan from Harvard University and Prof. Oleg Gang from Brookhaven National Laboratory, Prof. Laxminarayanan from the Raman Research Institute), in addition to members of the Joint Center have agreed to conduct this workshop.

**Exchange Visits**

As part of the visitations associated with the Joint Center, one scientist from the US visited their Indian counterparts and three Indian scientists and one student visited their US partnering Institutions.

**Publications**

Four publications (listed below) have already appeared in print. Several other are in pipe line.


![Figure 3: Ultralight elastic porous 3-dimensional scaffolds from colloidal self-assemblies.](image)
Indo-US Joint Center on
Crystallization at Interfaces

About the Center
The broad aim of the Centre is to put together a strong team that is capable of tackling this challenging problem of obtaining a microscopic understanding of properties of transition metal oxide systems close to various instabilities through a combination of state of the art experimental and theoretical. Our specific objectives are the innovative synthesis of designer materials, detailed investigation of their physical properties as well as spectroscopic investigations to obtain microscopic information on their electronic and magnetic properties, and theoretical modeling at several levels. The teams on both sides have been hand-picked keeping in mind the requirements of this demanding program.

The Center aims to carry out fundamental research to understand self-organized mechanism in formation of Crystals at solid and liquid Interfaces. Under this broad theme our specific interests will be to understand the a) growth of crystals of atoms/molecules with symmetries that are generally absent in bulk, and b) growth of crystals of mono-dispersed nano-particles. It shall primarily use synchrotron scattering, high resolution microscopy and spectroscopy techniques in this collaborative project. A general interest in the above studies lays in development of materials for highly efficient energy conversion/storage and for ultra-low-power dissipation nano-devices.

Under the aegis of the Joint Center, special attention will be given to:

- Interfacial growth of crystals of atoms and molecules which cannot either be grown at all

Principal Investigators

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Michael J. Bedzyk
Northwestern University
Evanston, USA
bedzyk@northwestern.edu

Partnering Institutions

INDIA
- Indian Association for the Cultivation of Science, Jadavpur
- Saha Institute of Nuclear Physics, Kolkata

US
- Argonne National Laboratory, Lemont
- Northwestern University, Evanston
or grow with a different symmetry in the bulk crystals.

- Growth of lattices, of three or lower dimensions, of nanoparticles of different shapes and sizes but with high size and shape monodispersity. Some of the areas under focus of the proposed Indo-US Joint Centre will be in-situ studies of MBE growth of oxide materials, ex-situ studies of MBE growth of Si-Ge quantum structures.
- *In-situ* studies of crystallization of nanomaterials at the liquid-liquid and air-liquid interfaces.
- *Ex-situ* studies of organized nanostructures on silicon/quartz substrates, using x-ray scattering, microscopy and spectroscopy. While ex-situ studies will be carried out in the respective laboratories in India and US, in-situ studies will be performed at Advanced Photon Source, Argonne National Laboratory, USA and at the India-Japan Beamline (developed by Saha Institute of Nuclear Physics) in Photon Factory, KEK, Tsukuba, Japan.
Indo-US Joint Center on
Theoretical Studies of the Correlated Electronic Structure of Graphene

About the Center
The broad aim of the Joint Centre is to put together a team capable of obtaining a microscopic understanding of properties of transition metal oxide systems close to various instabilities through a combination of state of the art experimental and theoretical.

The principal research objective is to arrive at accurate correlated-electron description of graphene and wide quasi-2D graphene nanoribbons. In the context of graphene nanoribbons our motivation is to determine how true two-dimensionality is reached as the width of the nanoribbons is increased in a controlled manner. The Joint Center’s educational mission is to expose graduate students and postdoctoral fellows to modern techniques of computational and theoretical materials chemistry and physics.

The US and Indian researchers bring complementary techniques such as quantum chemistry with high order configuration interaction, the Density Matrix Renormalization Group and the Path Integral Renormalization Group into the effort. In all cases the motivation is to work in a highly collaborative environment in order to achieve the objectives. In addition, the researchers have established collaboration with the synthetic chemistry group of Professor Klaus Muellen of MPI, Mainz, who will provide samples of large PAH molecules and the attosecond spectroscopy group of Professor Arvinder Sandhu, who will perform one-and two-photon absorption measurements on the molecules supplied by the Muellen group.

Achievements
The Joint Center has performed theoretical research on the PAH molecules coronene, hexa-peri-hexabenzocoronene (HBC), circumcoronene and ovalene (Fig. 1) below. In all cases we performed sophisticated multiple reference singles and double configuration interaction (MRSDCI) calculations, whose precision was as good as quadruple-CI (QCI). Besides, we have also employed a DMRG approach to calculate electronic structure of nanoribbons and of nanodiscs. These are the largest CI calculations performed on 2D PAH molecules to date.

Within one-electron and Hartree-Fock theories, the lowest two-photon state in all cases is predicted to be significantly above the lowest one-photon optically allowed state. In contrast the calculated two-photon states are below the lowest one-photon state or nearly degenerate. This is strictly a correlation effect. Experiments on coronene and HBC confirmed the theoretical prediction (Fig. 2).

The team has discovered a peculiar role of geometry. The first three molecules in Figure 1 all have $D_6h$ symmetry. Although correlation effects are significant, it is found that these effects were weaker than that in linear...
In polyenes, the lowest two-photon state is at or nearly at the same energy as twice the energy of the lowest spin-triplet state, indicating that both the lowest triplet and the lowest two-photon state are covalent in the valence bond language. In the D_{6h} PAH molecules, the lowest two-photon states are significantly below twice the lowest triplet energy, indicating the significant ionic contributions to both the triplet and the two-photon state. This is not entirely unexpected, as with three nearest neighbors per carbon atom (except the peripheral ones) the one-electron bandwidth in the 2D PAH molecules is much larger than that in the polyenes. What is surprising is that the lowest two-photon state is at twice the energy of the lowest triplet in D_{5h} ovalene (Figure 1(d)), which has the same bandwidth as the D_{5h} molecules. (Table I)

As part of visitations associated with the Joint Center, two scientists from US visited their Indian counterparts and three Indian scientists visited their US partnering institutions.

**Publications**

**Publication Planned**
- Theory of singlet fission in carotenoids, acenes and covalently linked acenes,” K. Aryanpour, A. Shukla and S. Mazumdar.

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### Partnering Institutions

**INDIA**
- Indian Institute of Science, Bangalore
- Indian Institute of Technology, Bombay

**US**
- University of Arizona, Tucson
- Mississippi State University

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### Exchange Visits

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
<th>Institution(s) Visited</th>
<th>Duration/Time Period</th>
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<tr>
<td>1.</td>
<td>Sumit Mazumdar University of Arizona</td>
<td>Indian Institute of Science, Bangalore</td>
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<td>2.</td>
<td>R. Torsten Clay Mississippi State University</td>
<td>Indian Institute of Science, Bangalore</td>
<td>12 days</td>
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<td>3.</td>
<td>S. Ramasesha Indian Institute of Science, Bangalore</td>
<td>University of Arizona</td>
<td>14 days</td>
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<td>4.</td>
<td>Alok Shukla Indian Institute of Technology, Bombay</td>
<td>University of Arizona</td>
<td>16 days</td>
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<tr>
<td>5.</td>
<td>Suryoday Prodhan Indian Institute of Science, Bangalore</td>
<td>University of Arizona</td>
<td>45 days</td>
</tr>
</tbody>
</table>

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Figure 1: (a) Coronene (C24H12), (b) HBC (C42H18), (c) circumcoronene (C54H18), and (d) ovalene. The PPP-MRSDCI calculations were done for the full MO-space of coronene, and ovalene; for HBC and circumcoronene the outermost 5 and 6 pairs of MOs, respectively, were ignored in our calculation.
Figure 2: (a) Experimental (red) and calculated (black) optical absorption spectra of coronene; calculations are within the PPP model. The weak absorption at ~3.5 eV, missed in the calculation, is to a state that is optically dark within the purely electronic PPP Hamiltonian with nearest-neighbor electron hopping. (b) Same as in (a) for HBC. The lowest energy weak absorption is again to a dark state. (c) Experimental linear (red) and two-photon absorption (TPA) (blue) spectra of coronene. The gray curve gives the TPA due to the solvent. Notice the significant TPA of coronene below the linear absorption edge. (d) Same as (c) for HBC. (e) Calculated linear absorption (red) and average TPA (blue) for coronene. Two-photon resonances are to both 1Ag and 1B1g states (arrows) which are nondegenerate within the PPP model. (f) Same as in (e), for HBC.

<table>
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<tr>
<th>Molecule</th>
<th>One-photon states</th>
<th>2^1A_u</th>
<th>T1</th>
<th>T2</th>
<th>1A_u states (~2 × T1)</th>
<th>1A_u states (~2 × T2)</th>
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</thead>
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<tr>
<td>Decapentaene</td>
<td>4.12 (1^1B_2g)</td>
<td>3.66</td>
<td>1.52 (1^1B_2u)</td>
<td>2.45 (1^1A_2g)</td>
<td>3.66 (2^1A_2g)</td>
<td>4.81 (3^1A_2g)</td>
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<td>Oxaene</td>
<td>2.91 (1^1B_2g)</td>
<td>3.03</td>
<td>1.57 (1^1B_2u)</td>
<td>2.65 (1^1B_2u)</td>
<td>3.03 (2^1A_2g)</td>
<td>5.27 (3^1A_2g)</td>
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<td></td>
<td>3.56 (1^1B_2u)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>4.18 (2^1B_2u)</td>
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<td>Coronene</td>
<td>4.11 (1^1B_2g, 1^1B_2u)</td>
<td>3.96</td>
<td>2.38 (1^1B_2u)</td>
<td>3.04 (1^1B_2u, 2^1B_2u)</td>
<td>4.77 (5^1A_2g)</td>
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<td>HBC</td>
<td>3.37 (1^1B_2g, 1^1B_2u)</td>
<td>3.30</td>
<td>2.07 (1^1B_2u)</td>
<td>2.72 (1^1B_2u, 2^1B_2u)</td>
<td>4.12 (5^1A_2g)</td>
<td>5.35 (16^1A_2g)</td>
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<td>Circumcoronene</td>
<td>2.66 (1^1B_2g, 1^1B_2u)</td>
<td>2.75</td>
<td>1.20 (1^1B_2u)</td>
<td>1.97 (1^1B_2u, 2^1B_2u)</td>
<td>2.94 (3^1A_2g)</td>
<td>3.68 (8^1A_2g)</td>
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Table I: PPP-MRSDCI excited state energies for decapentaene and the PAH molecules of Figures 1(a)-(d) (in eV). The 1A_u states in the last two columns have energies that are nearly twice those of the lowest triplets T1 and T2.

Engineering Sciences
Indo-US Joint Center on
Highway and Airport Pavement Engineering

About the Center
Highway and Airport Pavement Engineering is a critical area for any country seeking to upgrade its infrastructure to meet emerging and existing needs of its economy. The Joint Center seeks to develop practical guidelines for road and airport pavement construction.

Work Plan
The Joint Center has two main research themes, namely modified binders and mechanistic empirical design.

The specific steps of research on modified binders are:

- Identify two typical modified asphalts (IIT-KGP, IIT-M) based on their availability and demonstrated potential including one crumb rubber modified binder.
- Conduct tests for characterization of these asphalts (IIT-KGP, IIT-M).
- Prepare samples and test samples with different amounts and types of asphalts, including one unmodified (control) asphalt (IIT-KGP, IIT-M) needed for mix designs to determine the optimum asphalt content.
- Conduct additional testing (IIT-KGP, IIT-M WPI, UTEP) needed to validate the performance of the designed mixes.
- Using test data to simulate pavements with pavement design software to predict cracking and rutting (WPI, UTEP).

Steps for research on mechanistic empirical pavement design (MEPDG) are:

- Prepare samples using aggregates and asphalts (UTEP, WPI).
- Conduct state of the art testing (such as dynamic modulus, creep compliance and indirect tensile strength of three commonly used dense graded mixes and accelerated testing on mixes to relate test parameters with performance) (WPI, UTEP).
- Generate master curves for mixes (UTEP, WPI).
- Analysis of data and usage in flexible pavement design procedures to simulate appropriate conditions (IIT-M, IIT-KGP).
- Evaluation of the effect of mix properties on thickness (IIT-M, IIT-KGP).
- Recommend appropriate thickness and design procedures (Develop models relating rutting, fatigue and thermal cracking test parameters to the corresponding performances) (IIT-M, IIT-KGP, UTEP, WPI).

Achievements
On Binders

- Recommend appropriate amount and type of modified asphalt (IIT-KGP, IIT-M WPI, UTEP)

Steps for research on mechanistic empirical pavement design (MEPDG) are:

- Prepare samples using aggregates and asphalts (UTEP, WPI).
- Conduct state of the art testing (such as dynamic modulus, creep compliance and indirect tensile strength of three commonly used dense graded mixes and accelerated testing on mixes to relate test parameters with performance) (WPI, UTEP).
- Generate master curves for mixes (UTEP, WPI).
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- Evaluation of the effect of mix properties on thickness (IIT-M, IIT-KGP).
- Recommend appropriate thickness and design procedures (Develop models relating rutting, fatigue and thermal cracking test parameters to the corresponding performances) (IIT-M, IIT-KGP, UTEP, WPI).

Achievements
On Binders

- Enhanced pavement service life (resistance to rutting) twice when compared to unmodified asphalt binder by use of polymer modified asphalt binder.
- Higher viscosity values of unaged (Styrene butadiene
styrene-Polymer Modified Bitumen) PMB-40, PMB-70 and (crumb rubber modified bitumen) CRMB-55.

- Higher bitumen content is needed in case modified binders compared to unmodified binder.
- Varied Rheological characteristics of bitumen binders collected from different sources.
- Alternative method to simulate short term and long term aging by RTFO and PAV of some modified binders was developed with normal oven
- Evaluation of the impact of polymer modified binder on the structural performance of asphalt pavements.
- The MEPDG has been utilized to determine the effect of polymer modified binders on the life of asphalt pavements.
- Evaluation of life cycle cost of mixes with and without modified binders.

On Bituminous Mixes

- Significantly higher Rutting resistance of asphalt concrete mixes with unmodified asphalt binder.
- Approx. 4.8 times resistance of Styrene butadiene styrene polymer modified asphalt binder mix of that offered by an unmodified binder mix during laboratory rutting studies.
- Utilization of waste plastic and other modified asphalt reduced the life cycle cost of pavement when compared to unmodified asphalt binder. However pavement with SBS polymer modified asphalt binder resulted in lowest life cycle cost among the alternatives considered in this study.
- Reduction in air voids below (3%) resulted in higher rutting compared to higher air voids (more than 7%) irrespective of type of binder used in the bituminous mix. However modified binders have shown higher resistance to rutting compared to normal binders.
- Comparable performance characteristics of VG-40 binder mix.
- Higher fatigue life of the dense bituminous mixes with small increment in binder content above optimum binder content.
- Evaluation of Dynamic Modulus ($E^*$) for BC (Bituminous Concrete) which increases with increase in frequency and vice-versa.

Research Outcomes


**Book**: A 500-page book writing proposal by the participants of the IUSSTF project has been accepted for consideration for publication by Springer.

**Title**: Road Design, Construction and Management: Challenges and Solution

This book presents the most critical problems that are faced by the pavement engineers, especially in developing countries, and suggests optimal solutions to those problems. Even though the principles of pavement engineering are well established, quite often the adoption of even the best principles result in roads that are prematurely in poor condition because of widely differing soil and environmental conditions and unpredictable traffic conditions. This can be due to many reasons, with the most important ones being a disconnect between design and construction, lack of indigenous data on important parameters, and the unavailability of proper equipment. The problems can be more complicated especially when sustainability and green engineering have to be taken into account. On the other hand, developing countries can significantly take advantage of factors such as the availability of cheap labor. How can one use the existing conditions to the best of their potential and design, construct and manage pavements? This book looks at answering this question with state of the art, innovative and practical solutions. Practicing engineers and advanced degree students will find this book very useful in understanding the challenges in pavement engineering and meeting those challenges. It presents in-depth analysis of design, construction and management practices, with a focus on practicality.

**Publications**

- Sasidhar Rao and Amaranatha Reddy M. *Rheological Parameters of Crumb Rubber*
### Exchange Visits

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
<th>Institution(s) Visited</th>
<th>Duration/ Time Period</th>
</tr>
</thead>
</table>
| 1     | M. Amaranatha Reddy  
IIT Kharagpur          | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 15 days               |
| 2     | Prof. B.B. Pandey  
IIT Kharagpur           | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 15 days               |
| 3     | Mr. Ajit Krishna Singh  
M.Tech Student, IIT Kharagpur | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 15 days               |
| 4     | Prof. A. Veeraragavan  
IIT Madras             | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 15 days               |
| 5     | S. Anjan Kumar  
Ph D Student, IIT Madras | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 15 days               |
| 6     | Dr Rajib Mallick  
Worcester Poly Institute (WPI) | IIT Madras, Chennai  
IIT Kharagpur, Kharagpur | 04 days               |
| 7     | Carelli Jonathan James  
MS Student (WPI) | IIT Madras, Chennai  
IIT Kharagpur, Kharagpur | 04 days               |
| 8     | O’ Sullivan Karen Anne  
MS Student (WPI) | IIT Madras, Chennai  
IIT Kharagpur, Kharagpur | 04 days               |
| 9     | Dr Vivek Tandon  
University of Texas ElPaso | IIT Madras, Chennai  
IIT Kharagpur, Kharagpur | 04 days               |
| 10    | Prof. S. Nazarian  
University of Texas ElPaso | IIT Madras, Chennai | 09 days               |
| 11    | Vamsi Krishna  
MS Student, University of Texas ElPaso | IIT Madras, Chennai | 10 days               |
| 12    | Dr M. Amaranatha Reddy  
IIT Kharagpur          | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 20 days               |
| 13    | Prof. B.B. Pandey  
IIT Kharagpur           | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 20 days               |
| 14    | Mr. K. Kranthi Kumar  
M.Tech Student, IIT Kharagpur | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 20 days               |
| 15    | Prof. K. Sudhakar Reddy  
IIT Kharagpur          | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 20 days               |
| 16    | Bharath Kumar*  
IIT Kharagpur           | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 20 days               |
| 17    | Prof. A. Veeraragavan  
IIT Madras             | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 20 days               |
| 18    | Neethu Roy  
Ph D Student, IIT Madras | Worcester Polytechnic Institute, MA, USA  
The University of Texas ElPaso | 20 days               |
| 19    | Dr Rajib Mallick  
Worcester Poly Institute (WPI) | IIT Madras, Chennai  
IIT Kharagpur, Kharagpur | 10 days               |
| 20    | Dr Vivek Tandon  
University of Texas ElPaso | IIT Madras, Chennai  
IIT Kharagpur, Kharagpur | 10 days               |
| 21    | Prof. S. Nazarian  
University of Texas ElPaso | IIT Kharagpur | 10 days               |
| 22    | Prof. Ferregut Carlos, M  
University of Texas ElPaso | IIT Kharagpur | 10 days               |
| 23    | Vamsi K. Pinnamaneni  
MS Student, University of Texas ElPaso | IIT Madras, Chennai  
IIT Kharagpur, Kharagpur | 20 days               |

*Additional student – for consideration*

• Siddagangaiah, Anjan Kumar (PhD student), Veeraragavan, A (IIT-Madras), Laboratory Investigations on Rutting Resistance of Bituminous Concrete Mixes with Modified Binders, World Conference on Recent Trends in Flexible Pavements, New Delhi, 05 February 2010.

• Siddagangaiah, Anjan Kumar (PhD student), Veeraragavan, A (IIT-Madras), Saravanan, U and Murali Krishnan, J, Rheological Characterisation of Modified Binders at Mixing and Compaction Temperatures, World Conference on Recent Trends in Flexible Pavements, New Delhi, 05 February 2010.

• Siddagangaiah, Anjan Kumar (PhD student), Veeraragavan, A (IIT-Madras), Saravanan, U and Murali Krishnan, J, Permanent Deformation Behaviour of Modified Asphalt Mixes – Use Of Polymer And Recycled Waste Materials In India., 11th International Conference on Asphalt Pavements, organized by the International Society of Asphalt Pavements in Nagoya, Japan, August 2010:

• Anjan Kumar S., (PhD student, IIT-Madras), Hazera Tahseen (M-tech student IIT-Madras), Mallick, Rajib B (WPI) and Veeraragavan, A (IIT-Madras). Life Cycle Cost Analysis of Flexible Pavements with Modified Asphalt Mixes – Indian Experience., 11th International Conference on Asphalt Pavements, organized by the International Society of Asphalt Pavements in Nagoya, Japan, August 2010:


• Vijay Kakade, Amaranatha Reddy M. Effect of Binder quality and quantity on Rutting Characteristics of Bituminous Mixes, Communicated to Journal of IRC

• Ajit Krishna Singh, Amaranatha Reddy M. Sudhakar Reddy K. An Alternate to Superpave Aging Methodology for Bitumen Binders Communicated to Journal on IRC.

Indo-US Joint Center on
Intelligent Transportation Systems Technologies

About the Center
The overarching theme of the Joint Center is related to ITS data, including monitoring, collection and archiving, and the ways in which this data can be used to solve transportation problems. The JC will leverage the existing ITS test sites (concentrating on urban arterials) and ITS modeling capabilities at the participating universities. The research areas the Joint Center focus on are:

• Evaluation of automated traffic data collection techniques (sensors, loops, video, cell phones, etc.)
• Data monitoring and archiving techniques; and
• Modeling of transportation system with ITS data

The main objectives of the Joint Center are:
• Public and private partnership to develop sustainable programs in research and education
• Evaluation of automated traffic data collection techniques (sensors, loops, video, cell phones, etc.) that will work for traffic conditions with heterogeneity and lack of lane discipline, data monitoring and archiving and traffic modeling using these data for various ITS applications.
• Development of state-of-the-art ITS based traffic monitoring centers at each of these institutions.
• Increase the number of students and faculty involved in the undergraduate, graduate, and professional programs of the IUJC-ITST consortium members.
• Increase the quality and quantity of the transportation workforce by providing international educational opportunities.
• Disseminate JC research results to Indian/ US transportation agencies.

Achievements
IITM–UNL: A test bed has been set up in the Rajiv Gandhi Salai in Chennai, India, with various traffic detectors that are sending data in real time to the ITS laboratory. Real time data monitoring has been established using wireless and GPRS communication and data archiving is under development. The following off the shelf products are being evaluated and calibrated for Indian conditions: Radar Detector – Smartsensor, Infrared Detector - TIRTL, Video Sensor – Collect-R, and Image processing –Tazer. The following new sensors are being developed: (a) an inductive loop detector (ILD) specifically suited for the less lane disciplined and heterogeneous traffic conditions, (b) a Bluetooth sensor unit and video image processing solutions.

Using these data, traffic models are being developed. The models will be used in the development of methods and technologies to regulate the movement of road vehicles.

IITB–Purdue: An area of common interest was
explored and finalized with Prof. Srinivas Peeta at Purdue University. Mr. Caleb Ronald Munigety, Research Scholar at IIT Bombay has shown interest in the above study. The broad objective of the study would be to bring out a robust simulation model catering to the needs of mixed traffic conditions which can be thought to be vehicle type dependant. Specifically, the focus would be on the critical analysis of the lateral movements by vehicle type and to bring out the influential variables. Later, the lateral movement decision and execution models would be developed which will form a critical component in the development of the simulation model.

**IIITM–Purdue:** Dynamic origin-destination estimation aims at estimating the time-dependent O-D trips such that the deviations between observed and estimated traffic flow parameters such as link flows or link densities are minimized. In the case of a general urban network, the challenge is to identify the route choices and departure time based on the time at which the vehicles have been observed at the counting stations. In the case of such large and complicated urban networks, the trip-based information for at least a sample of the vehicle population obtained from license plate studies or Bluetooth surveys could aid in increasing the observability of O-D pair flows. A proper methodology to integrate the different data sources to be developed to increase the reliability of estimation.

**Way Forward**
Outcomes are mainly the learning and support in test bed and laboratory development, manpower development, and research publications. The follow up plans are as follows:
- A joint course on ITS to be offered by the participating institutions.
- Development, and field implementation of more Bluetooth sensors and further data analysis.
- Data archive generation using data collected at collaborating institutions for R&D purposes
- Continue collaboration on theoretical work
- Research publications
- A repository of data, findings and lessons learned from these projects to be generated for sharing
- A common discussion forum to be generated for posting issues to get support from the pool of expertise
- Find avenues to support student exchange funding
- Write next level proposal for collaborative research funding

**Publications**
<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
<th>Institution(s) Visited</th>
<th>Duration/Time Period</th>
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<tbody>
<tr>
<td>1</td>
<td>Lelitha Devi Vanajakshi, Associate Professor, Dept. of Civil Engg., IIT Madras</td>
<td>University of Nebraska Lincoln</td>
<td>10 days</td>
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<td>2</td>
<td>Gitakrishnan Ramadurai, Assistant Professor, Dept. of Civil Engg., IIT Madras</td>
<td>Purdue University</td>
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<td>3</td>
<td>Ranju Mohan, Research Scholar, Dept. of Civil Engg., IIT Madras</td>
<td>Purdue University</td>
<td>3 months</td>
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<td>4</td>
<td>Tom Mathew, Professor, Dept. of Civil Engg., IIT Bombay, Mumbai</td>
<td>Purdue University</td>
<td>1 week</td>
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<tr>
<td>5</td>
<td>Caleb Ronald Munigutty, Doctoral Student, Dept. of Civil Engg., IIT Bombay, Mumbai</td>
<td>Purdue University</td>
<td>12 weeks</td>
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<tr>
<td>6</td>
<td>Anuj Sharma, Assistant Professor, Dept of Civil Engg., University of Nebraska Lincoln</td>
<td>IIT Madras and IIT Mumbai</td>
<td>1 week</td>
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<tr>
<td>7</td>
<td>Boby George, Assistant Professor, Dept. of Electrical Engg., IIT Madras</td>
<td>University of Nebraska Lincoln</td>
<td>1 week</td>
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<td>8</td>
<td>Shankar Ram C S, Associate Professor, Dept. of Engg. Design, IIT Madras</td>
<td>University of Nebraska Lincoln</td>
<td>2 weeks</td>
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<tr>
<td>9</td>
<td>Anusha Nair, Research Scholar, Dept. of Civil Engg., IIT Madras</td>
<td>University of Nebraska Lincoln</td>
<td>2 months</td>
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<td>10</td>
<td>Vincy Varghese, Research Scholar, Dept. of Civil Engg., IIT Madras</td>
<td>University of Nebraska Lincoln</td>
<td>2 months</td>
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<tr>
<td>11</td>
<td>Helen Thomas, Masters Student, Dept. of Civil Engg., IIT Madras</td>
<td>University of Nebraska Lincoln</td>
<td>2 months</td>
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<tr>
<td>12</td>
<td>Jijo Mathew, Masters Student, Dept. of Civil Engg., IIT Madras</td>
<td>University of Nebraska Lincoln</td>
<td>2 months</td>
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<tr>
<td>13</td>
<td>Alex Hainen, Research Scholar, Dept. of Civil Engg., Purdue University</td>
<td>IIT Madras</td>
<td>10 days</td>
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<td>14</td>
<td>Steve Remias, Research Scholar, Dept. of Civil Engg., Purdue University</td>
<td>IIT Madras</td>
<td>10 days</td>
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<tr>
<td>15</td>
<td>Sheik Mohammed Ali, Research Scholar, Dept. of Electrical Engg., IIT Madras</td>
<td>University of Nebraska, Lincoln</td>
<td>14 days</td>
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<td>16</td>
<td>Laurence Rilett, Professor, Dept of Civil Engg., University of Nebraska Lincoln</td>
<td>IIT Madras</td>
<td>5 days</td>
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<tr>
<td>17</td>
<td>Elizabeth John, Associate Professor, Dept of Civil Engg., University of Nebraska Lincoln</td>
<td>IIT Madras</td>
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<tr>
<td>18</td>
<td>Darcy Bullock, Professor, Department of Civil Engg., Purdue University</td>
<td>IIT Madras</td>
<td>5 days</td>
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<tr>
<td>19</td>
<td>Sreenivas Peeta, Professor, Department of Civil Engg., Purdue University</td>
<td>IIT Madras</td>
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</tr>
<tr>
<td>20</td>
<td>Anuj Sharma, Assistant Professor, Dept of Civil Engg., University of Nebraska Lincoln</td>
<td>IIT Madras</td>
<td>4 days</td>
</tr>
</tbody>
</table>
• Performance Comparison of a Radar Based Traffic Sensor - Smart Sensor HD for Indian and American Traffic Condition, 5th Urban Mobility Conference, December 2012, Delhi, India.
• Queue length and delay estimation at signalized intersections using detector data, Urban Mobility Conference, 2013, December 4-5, Delhi, India.
• A simple methodology for queue length estimation, International Conference on Energy and Environment, ICEE 2013, December 12-14, RIT Kottayam, Kerala, India
• Studying Platoon Dispersion Characteristics under Heterogeneous Traffic in India, 2nd Conference of Transportation Research Group of India, 2013, Agra

• Driver Behavioral Modeling in Mixed traffic Conditions: A Spring-mass Dynamical System Analogy”, Under preparation
• Development of a model based traffic control, Under Review, Journal of the Transportation Research Record.
• Model Based Analysis of Signalized Intersections, Under Review, Journal of the Transportation Research Record.

**Other Activities**

• A workshop on Systems and Control Theory towards Traffic Analysis was offered at UNL by Dr. Shankar Ram in July, 2013. 20 hours of lecture on areas related to control systems and state space analysis was given.
• A symposium for disseminating the findings from the collaborative projects carried out as part of the centre was organised at IIT Madras on December 9 and 10, 2013.
About the Center

The thrust of the Joint Networked Center for Intelligent Structural Health Monitoring is on developing Quantitative Nondestructive Evaluation (QNDE) tools and ISHM systems and methodologies with pragmatic adaptation. The Joint Center has adopted a multi-pronged approach towards developing and implementing state of the art QNDE tools such as laser-induced ultrasonics, fiber optics sensing, and piezo-electric wafer active sensor-based guided wave ultrasonics.

The technical goals of the Joint Centre are:

- Development of fiber optic sensors and piezo wafer active sensors that can be attached/ embedded on a structure and used as sensors;
- Generation and propagation of guided waves in composite structures using ultrasonics;
- Understanding the behaviour of guided waves in structures such as ones used in aerospace and development of models that permit the simulation of the experiment and creation of optimal experimental protocols;
- Development of high bandwidth demodulation apparatus that can convert the changes in the light traveling inside fiber optics into conditioned electrical signals that can be digitized and stored in a computer or a microprocessor based computing chip; and
- Development of data fusion and data processing algorithms to improve the quality of signals and provide an interpretable signal to the end user on the status of the structure/component.

Achievements

The project led to the development of a virtual center of excellence in the field of “Intelligent Structural Health Monitoring” (ISHM) that has the potential to change the way industry manages critical assets such as aircrafts, bridges, industrial pipes, etc. Intelligent Structural Health Management is an emerging concept that provides an efficient methodology to minimize the possibility of catastrophic failure of safety-critical structures. Structural Health Monitoring (SHM) is born from the awareness that damage prognosis systems in civil, mechanical and aerospace structures are necessary for apprising the user of the structure’s health, informing the user of the incipient damage in real time and assessing the remaining useful life of the structure. As a technology, ISHM has an enormous potential for cutting cost and time as the maintenance procedure with such systems could change from being schedule-driven to condition-based. The ISHM concept includes initial assessment of a structure, followed by continual non-intrusive assessment as the structure...
is in service, and intrusive inspections and repairs as necessary when structures are close to failure. ISHM comprises diagnostic and prognostic modules (Fig. 1). This was accomplished using research efforts towards bringing the knowledge and the sensing techniques established in the field of Quantitative Nondestructive evaluation (QNDE) of the four participating groups. The groups complemented each other and through this collaboration, 2 new proposals were submitted and funded by NSF (a) the PIRE project which allows for the collaboration between IITM and NWU and (b) the IRES project which supported the collaboration between IITM and MSU. These additional funds allowed for increased leverage for increased exchange of personnel between the collaborating organisations, well beyond the initially proposed numbers in the IUSSTF proposal. The total number of exchanges during this period, between IITM, MSU, NWU and CGCRI, was THIRTY comprising of undergraduate, post-graduate, post-doctoral fellows, scientists and faculty. Additionally, due to these interactions collaborative MoUs have been signed between IITM and NWU and IITM and MSU through this IUSSTF project. These further promote long term collaboration in the area of ISHM and other fields of common interest. In addition, the visits also encourage cultural experiences that included visits to Indian Weddings, visit to archeological and other venues of heritage, shopping, etc.

The project resulted in several key activities that have resulted in the following technologies:

- Wireless trans-receiver for SHM sensors that were jointly developed between IITM and MSU.
- Crack propagation models and experiments to understand the failure behavior of aerospace metallic structures.
- Improved Non-linear ultrasound methods for early detection of damage in metals.
- Several Conference papers and journal papers have been submitted or are currently under submission process between the four groups.
- IITM received additional grants from Aeronautical Development Agency for work in the area of guided ultrasonic waves under the NPMASS project as a followup to this collaboration.

**Scientific Value Addition**

Quantitative Nondestructive evaluation (QNDE) of integrity and quality of materials and structures is a widely accepted and efficient tool for engineering critical assessment, structural health monitoring and process monitoring in process, automotive, civil, manufacturing and aerospace industries. From large structural members of bridges and buildings to medium sized automotive components down to micrometric and nanosized advanced materials and structures, such as, thin films, coatings, functionally gradient materials (FGM), micro-electro-mechanical systems (MEMS) etc., QNDE covers a wide gamut of applications across various industrial and laboratory scale operations. In recent years, QNDE has assumed a great deal of importance due to a paradigm shift towards intelligent structural health management (ISHM) – a methodology that aims to minimize the possibility of catastrophic failure of safety critical structures which is of great concern to the international community due to unacceptable loss of life and disruption of economic and societal activities. ISHM comprises both off-line and on-line monitoring of materials, components and structures and provides diagnostic and prognostic tools for fail-safe management of structures. ISHM

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**Partnering Institutions**

**INDIA**
- Central Glass and Ceramic Research Institute, Kolkata

**US**
- Michigan State University, East Lansing

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Joint R & D Centers

encompasses a broad horizon of emerging and mature fields of science and engineering, namely, smart materials, structural health monitoring, damage and failure mechanics, structural and reliability analysis and nondestructive evaluation. In the US there are several agencies, such as the National Science Foundation, AFOSR, Army Research Office, ONR, DARPA, DOE, and the Department of Homeland Security that are interested in sensors and sensing systems, QNDE and SHM and their applications to engineering critical structures. Similar interests exist among different Indian agencies, such as DST, Indian Railways, Department of Defense, Aeronautical Labs, Department of Atomic Energy, etc. However, currently there is no formal mechanism set up for conducting active collaborative research between the two countries. The underlying premise of the proposed program is that the types of issues and problems related to structural integrity of civil, mechanical and aerospace materials and systems both in the US and India are similar enough that a cross-disciplinary, multi-institutional approach will be most productive. The research and education thrust of this international partnership is therefore focused on developing QNDE tools and ISHM systems and methodologies for safety-critical civil, aerospace, and mechanical structures using the common paradigm indicated above, but with pragmatic adaptation to suit the specifics of the structural types and material systems used in these structures.

This ISHM approach would involve the following research objectives to be satisfied: (a) Development of Fiber Optic Sensors and Piezo Wafer Active Sensors (PWAS) that can be attached/embedded on a structure, and used as sensors, (b) Generation and propagation of guided waves in structures using ultrasonics, (c) Understanding the behaviour of guided waves in structures such as ones used in aerospace and develop models that permit the simulation of the experiment and obtain optimal experimental protocol, (d) The development of high bandwidth demodulation apparatus that can convert the changes in the light traveling inside the fiber optics into conditioned electrical signals that can be digitized and stored into a computer or a microprocessor based computing chip, (e) The development of data fusion and data processing algorithms that will improve the quality of the signals and provide an interpretable signal to the end user on the status of the structure/component. The following 4 topics below were the focus of the work conducted jointly as described later:

ISHM through Wireless Sensor Network for Lamb Wave based technologies: One of the relatively new areas is Wireless Sensor Networks for structural health monitoring and damage detection. In summer of 2010 and 2011, graduate students visited in IIT-M which included Professors Lalitha Udpa and Nizar Lajnef from the civil engineering department at MSU. They worked on on wireless NDE sensors for SHM applications. Significant progress was made on the wireless sensor project – resulting in two conference publications. For continuous monitoring of power-plant components, the use of in-situ sensors (i.e., sensors that are permanently mounted on the structure) is necessary. In-situ wired sensors require an unrealistic amount of cabling for power and data transfer, which can drive up costs of installation and maintenance. In addition, the use of cabling in hostile environments (high temperature/pressure environments) is not a viable option. The
### Exchange Visits

<table>
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<tr>
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<tr>
<td>1</td>
<td>Lalitha UDPA Prof., Michigan State University (MSU)</td>
<td>IIT Madras</td>
<td>2009</td>
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<tr>
<td>2</td>
<td>Aurora Zinck PhD Student, Northwestern University (NWU)</td>
<td>IIT Madras</td>
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<td>3</td>
<td>Nizer Lajnef Assistant Prof., MSU</td>
<td>IIT Madras</td>
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<td>4</td>
<td>Charles Erik B Ardel PhD Student, MSU</td>
<td>IIT Madras</td>
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<td>5</td>
<td>Lassaad Mhamdi PhD Student, MSU</td>
<td>IIT Madras</td>
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<td>Gerges Hanna Dib PhD Student, MSU</td>
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<td>K. Balasubramaniam Prof., IIT Madras</td>
<td>Northwestern University</td>
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<td>8</td>
<td>Brad Regez Post Doc. Fellow, NWU</td>
<td>IIT Madras</td>
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<td>Jesse Lee B. Tech Student, NWU</td>
<td>IIT Madras</td>
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<td>Emma Dutton B. Tech Student, NWU</td>
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<td>S. Krishnaswamy Prof., NWU</td>
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<td>13</td>
<td>Abilasha Ramdas PhD Student, IIT Madras</td>
<td>Northwestern University</td>
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<td>Ketan Nayak MTech Student, IIT Madras</td>
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<td>Janardhan Padiyar PhD Student, IIT Madras</td>
<td>Northwestern University and Michigan State University</td>
<td>2010</td>
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<td>16</td>
<td>Eric Trakleson B. Tech Student, MSU</td>
<td>IIT Madras</td>
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<td>17</td>
<td>Nicholas Wilson B. Tech Student, MSU</td>
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<td>Cori Lynn Roth B. Tech Student, MSU</td>
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<td>Jake Formanczyk MS Student, MSU</td>
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<td>Nigli Yang PhD Student, NWU</td>
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<tr>
<td>23</td>
<td>S. Krishnaswamy Prof., NWU</td>
<td>CGCRI and IIT Madras</td>
<td>2011</td>
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group from MSU worked with the group at IITM (Prof. Krishnan Balasubramaniam and research scholar Janardhan Padiyar) towards the integration of the low profile ultrasonic pulser-receiver with the wireless mote developed at MSU. This resulted in a new product that could provide integrated wireless ISHM for composite aircraft structures.

ISHM through porous media models for ultrasonic wave based technologies: The objective was to experimentally correlate acoustic nonlinearity to dislocation structures in mechanically deformed metal samples; for development of acoustic nonlinearity as a nondestructive evaluation tool. The Nonlinear Ultrasonic measurements are taken using a contact transducer method, with a Ritec SNAP system. Tests are run on samples in a static setup as well as in an MTS for in-situ testing. Transmission Electron Microscopy is used for observing dislocation structures. Samples for TEM are prepared as self-supporting disks and observed under bright field, dark field, and weak beam conditions. Vickers micro-hardness and optical microscopy are used to collect additional microstructural information. Here, the NWU team and the IITM team worked very closely towards new insight into the physics of ultrasonic wave propagation in porous media.

ISHM through Materials Characterisation understanding using Acoustic Non-linearity phenomena. Here, the NWU team and the IITM team worked very closely towards developing new understanding of the nonlinear behaviour in materials. Preliminary results were used to develop Nonlinear Ultrasonic techniques and initial observations of a connection between acoustic nonlinearity and dislocation structures. Current experiments focus on in-situ testing of polycrystalline copper samples under tension, observing the nonlinearity while a specimen undergoes a loading and unloading cycle. The results of in-situ experimentation have been compared to static experiments, showing that acoustic nonlinearity is sensitive to the structural changes throughout loading cycles, as would be observed in fatigued metals.

ISHM through ultrasonic Scattering models and Experiments from defects for Lamb mode based technologies: The objective was to study the ultrasonic Lamb wave scattering from a defect in a plate and provide the time domain data for developing the algorithm of Lamb wave imaging, a Finite Element Analysis (FEA) model was constructed to simulate ultrasonic Lamb wave scattering of a defect in a 2 mm thick Aluminum plate.
Way Forward
The Indo-US Knowledge R&D Networked Joint Center aims to further develop this umbrella organization in the area of quantitative non-destructive evaluation and intelligent health monitoring of smart materials and engineering critical structures consolidating and complementing the domain expertise of established Indian and US institutes. The group is working on several project proposals that can expand the group to other institutions in both countries and also exploring funding opportunities for continued support for bilateral collaborative scientific activities.

Publications
Indo-US Joint Center on
Design of Sustainable Products, Services and Manufacturing Systems

About the Center
In the current networked and complex manufacturing environment, an integrated systems approach for sustainability requires the development of robust and cost-effective life cycle analysis and synthesis methodologies, standards, and tools so that designers and engineers can track and aggregate the overall sustainability of a product throughout its life and across the networked and distributed production system. Such data generation and aggregation is beyond the capability and missions of many of the manufacturing companies today, as it involves their entire global supply chain and significant gains can be achieved through India-US research and industry collaborations. To support development of sustainable manufacturing systems, the following are needed:

- Measures with which to assess sustainability of these systems.
- Suitable guidelines, methods and tools with which to generate such systems.
- Suitable standards, guidelines, methods and tools for evaluating/selecting such systems.
- Suitable training materials for training people in designing sustainable systems.

The main objective of the Joint Center is to leverage the Indo-US research efforts in creating synergy between the needs of the emerging and advanced economies.

Achievements
The project started in June 2014. So far, the following has been achieved:

- A preliminary document has been created on existing definitions, measures, Indicators, design methods and tools, curricular methods and tools, and case studies related to education and practice of development of sustainable products, services and manufacturing systems. This document will be used as the starting point for the research to be carried out by the Center during the next two years.
- A meeting took place among the principal investigators and some of the co-investigators to finalise the specific details of the visits to take place and the specific means of carrying out collaborative work. A shared Google calendar has been created for dynamic and collaborative finalisation of the various visit plans.
- A website of the Center, and is expected to develop a running website in the next few months.

Principal Investigators

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Scientific Value Addition
While it is too early to comment on scientific value addition, the Center intends to carry out a comprehensive study of appropriate definitions, measures, indicators, design methods, educational approaches, and case studies for supporting education and practice of design of sustainable products, services, and manufacturing systems. Some of the methods will be tested on Indian and US problems, so that the experience of their use can be shared through case studies and lessons learnt.

The centre will add scientific value in answering the following questions:

- What is meant by sustainability in the context of development of products, services and manufacturing systems?
- How can a product, service or manufacturing system be assessed for how sustainable it is, and to what extent it is more or less sustainable than another product, service or manufacturing system?
- What methods and tools are currently available for generating or evaluating a product, service or manufacturing system for sustainability, and in what context are these to be used?
- What methods and tools are currently available for education of developing a product, service or manufacturing system for sustainability, and in what context are these to be used?
- What case studies are available to demonstrate the use of these methods and tools?
- What is the detailed experience in using some of these methods and tools, and how good have they been in these cases?

Way Forward
- The partners are expected to meet once in each country every year during the project for carrying out joint research, organise joint workshops, and solving problems in each country jointly using some of the methods and tools for supporting development of sustainable systems.
- A website is being developed where information about all the knowledge created, assimilated, or collated, as well as a list of educators, researchers, practitioners, and administrators in this area will be made available online.
- A workshop with both academia and industry is also planned towards the end of the project to disseminate the knowledge among major stakeholders, i.e. students, teachers, researchers, administrators and practitioners in the areas of design, engineering and manufacturing.

Publications
It is expected that during the course of the project, several peer-reviewed publications that reports new knowledge in this area will be published. It is also expected that a book will be published to share the outcomes of the project.
About the Center
Michigan State University in collaboration with University of Texas at Austin, CSIR-Central Building Research Institute, Roorkee and Indian Institute of Technology – Delhi, established an “US-India Virtual Fire Center” for enhancing fire safety in built infrastructure. The research teams at these institutions are developing methodologies, design tools and guidelines for performance based structural fire safety design. Under the virtual fire research center, the team will focus on exchanging and sharing research expertise, experimental facilities and test data for improving fire safety in two countries. Specifically, the team will develop engineering guidelines and solutions for overcoming fire problems in reinforced concrete beams. In addition the proposed center will help in knowledge dissemination among the academia, design professionals and construction industry through seminars and workshops.

The main aim of the “Indo-US Virtual Fire Center” is to establish collaboration among the Partnering Institutions in US and India for exchange and dissemination of information in fire safety field with respect to fire research, education, training and technology transfer activities in India to improve overall fire safety in built environment. The center will facilitate exchange of students, scientists as faculty amongst partner Institutions.

In order to exchange and disseminate the information in the field of fire safety and the experience gathered during last one year of this project, a short term workshop has been planned during 09 – 10 March 2015 at CSIR-CBRI Roorkee, India. The tentative topic of the workshop decided is “Fire Safety in Buildings: Structural and Passive Fire Protection Issues & Challenges”. It has also been planned that about four to five faculty experts from either side (both India and USA) will take part actively as speakers. The researchers from different Institutes of India who are working in the area of Fire Engineering will be invited to participate in the workshop. Also arrangements will be made to invite the experts from Industries who are involved in the fire safety issues for effective interactions amongst the researchers and the professionals.

“PROTECT 2015- Fifth International Workshop on Performance, Protection and Strengthening of Structures under Extreme Loading” is planned for June - July, 2015 at Michigan State University, USA. Researchers from Indian Institute of Technology (IIT) Delhi and Central Building Research Institute (CBRI) Roorkee will attend this workshop and will deliver presentations. It is expected that researchers from across the world will take part in this workshop through contributory research participation.

Work is in progress for the development of a dedicated fire resource website. The basic purpose of the website...
is to provide information to the users working for the promotion of fire safety in built environment. Accordingly a site-map of the website has been finalised and it will include:

- Details of codes/ standards/ perspectives (adhering to copyright laws and regulations);
- Technical awareness on: analysis/ design procedures and software simulations;
- Test data sharing for possible benchmarking;
- Publications (details, direct links of textbooks, journals, SIF proceedings etc.);
- Up-coming events in the area of structural fire engineering; and
- Suggestions and comments by the visitors.

For the fire performance assessment of structural elements modeling studies will be carried out. For the validation of models required test data is to be generated. Experimental studies have been carried out and the test data has been generated on the fire performance of beams under loading conditions.

To study the fire performance of reinforced concrete (RC) beams under loading conditions, experiments were carried out through a well-designed experimental set-up. The experimental set-up consists of a floor furnace to produce temperature and a reaction frame for applying loads, to which a structural member might be exposed during a fire in practice.

The tests include a series of eight experiments on normal and high strength concrete beams. To study the flexural behaviour of RC beams, two reference specimens of two different grades namely M30 and M60 were tested under two point loadings. The observations were made for the first cracking load, ultimate load and load at permissible deflection.

Reinforced Concrete (RC) beam specimen, enclosure fire and test set-up for testing the beam at Fire Research Laboratory of CSIR-CBRI, Roorkee, India
Tested Bean Specimens

M 30 beam after failure

Close view of M 30 beam after failure

M 60 beam after failure

Close view of M 60 beam after failure
Reinforced Concrete (RC) beam specimen, enclosure fire and test set-up for testing the beam at Fire Research Laboratory of CSIR-CBRI, Roorkee, India

Further to determine the fire resistance rating, the experiments were carried out by exposing the reinforced concrete beam specimens to standard ISO 834 fire. The beams were preloaded with two point loads to a fixed percentage of ultimate strength at room temperature. After applying the loads on the beams, the beams were exposed to standard heating conditions. During the entire period of fire exposure the predefined load was maintained. The temperature of the furnace as well as that in concrete and rebars and deflection of beams were recorded during fire exposure.

On comparison of the results of normal and high strength concrete beams it was found that the temperature at all locations in high strength concrete beam was higher as compared to normal strength concrete beam during the entire period of fire exposure.

Similarly for the same loading of 15kN during fire exposure, the fire resistance rating of normal strength concrete beam was higher as compared to high strength concrete beam.

To develop high temperature properties of concrete the material property tests are planned. The material properties that may have significant influence on fire resistance and spalling are high temperature thermal and mechanical properties. The specimen of cubes and cylinders are under preparation at CBRI and will be shipped to IIT-D for undertaking property tests.

Exchange Visits

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<tr>
<td></td>
<td>Research Student, IIT-Delhi</td>
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<td></td>
<td>IIT Delhi</td>
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<td></td>
<td>Director, CSIR-CBRI, Roorkee</td>
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<td></td>
<td>Senior Principal Scientist, CSIR-CBRI, Roorkee</td>
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<td></td>
<td>Michigan State University</td>
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Environment and Energy
About the Center

The Indo-US Joint Center on Eco-Informatics Centre is envisioned as a web-enabled, publicly accessible resource for integrated and value-added information on ecology and the environment that actively promotes collaboration in applied research and capacity building in the area of ecoinformatics. The idea behind starting the Eco-informatics Centre was to create a place of international excellence in eco-informatics that would serve as a guiding post to lead, drive and sustain ecological informatics and biodiversity conservation initiatives in the Indian subcontinent. It is conceived as a facility for enhancing cooperation and exchange of information within the scientific community towards the creation and sharing of scientific information for biodiversity conservation and planning. The Centre also imparts training on various aspects relating to the application of ecological informatics at the national and international levels. The specific objectives of the Centre are to:

- Assemble, organise and disseminate biodiversity data in the public domain for use by researchers, students, teachers, policy makers and wide range of other professionals interested in biological research, conservation and management of natural resources.

- Promote applied research through the organization and dissemination of databases by involving modelling and development of tools and software.

- Train environmental professionals in handling large databases, modelling and spatial analysis of information.

Achievements

Within a short period of over 2 years, the Centre has moved from being an idea in mind to becoming a place of international recognition in the Eco-informatics domain. The Center focused on research, training and collaboration and has made steady progress in all three directions.

- Many of the Center’s projects have the distinction of being the first and only projects of their kind in India. An example of such a project is the creation of a comprehensive Eco-informatics Repository that successfully integrates biophysical features with socio-economic data. This is important because no biodiversity conservation initiative can succeed without a clear understanding and participation from the community involved.

- A plant biodiversity map of Western Ghats has been created that profiles over 1300 genera. Currently, the team at the center is working to include a plant biodiversity map for the whole of India. Other
projects that are in different stages of completion include databases on ants, grasshoppers and honey bees of India. Hopefully, by taking the idea to the next level, the Center will be able to successfully map the entire plant, animal and insect biodiversity of the Indian subcontinent. The team has also archived 169 raster layers of datasets covering a range of climatic, terrain and land cover parameters at spatial resolution varying between 1km to 10km grids, for the whole country.

- The Center has developed efficient modeling tools and more than 30 multi-utility software applications in eco-informatics, customized to match the needs of researchers working in the Indian subcontinent.
- Creation of the state of art Niche Modeling Algorithms using the Open Modeler Interface on the Indian Datasets. This species distribution modeling tool is of great significance to users as it can help them to explore and test their hypotheses more effectively.
- Eco-Informatics Center’s website is becoming India’s only eco-informatics knowledge portal that serves many different user groups. Currently, a user manual is provided to help navigating on the web GIS portal. Besides researchers, planners and policy advocates, Center is also attempting to create specific applications and content tailored to match the requirements of a much more varied group of professionals, students, concerned citizens and children.
- It is hoped that in future, the portal will also evolve to offer a number of community based GIS initiatives that can provide a forum for eco-friendly product manufacturers and suppliers, eco-friendly architects, builders, farmers and high school teachers too.

**Scientific Value Addition**

The Center have successfully collaborated with several both Indian and international institutions of eminence. Center has signed an MOU with NCBI-NCL and is collaborating with the IUCN Invasive Species Specialist Group to launch the Invasive Species Information System.

The Centre is working on 18 different projects in collaboration with institutes like the Indian Institute of Remote Sensing, the Forest Department of Maharashtra, Bombay Natural History Society, Bandipur Tiger Reserve, Bannerghatta National Park, National Remote Sensing Agency, Hyderabad, The French Institute, Pondicherry, Madras Crocodile Bank, Periyar Tiger Reserve and ATREE’s own Centre for Conservation Governance and Policy.

The capacity building initiatives of the Center include conducting training programmes, developing training modules, providing facilities for post-graduate research,
training in eco-informatics and creating dissemination & outreach materials. The Centre is a preferred destination for research and training in landscape ecology and the use of GIS and RS based applications. Center regularly conduct a joint training programme on applications of GIS & RS in Landscape Ecology in collaboration with the Wildlife Conservation Society (WCS) and Centre for Wildlife Studies (CWS) at the National Centre for Biological Sciences (NCBS) Bangalore. The Center organized a workshop on Modeling Land-Use / Land-Cover Change and Species Distribution (Jan. 2005), International Certificate Course in GIS/RS Applications for Landscape Ecology (Aug. 2004), the 3rd GBIF Ecological Niche modeling workshop, (Nov. 2006). The team at center has published articles in peer reviewed journals, presented research findings in international conferences, and participated in study tours and faculty exchange programmes.

Way Forward

Efforts are on to implement truly distributed building of a taxonomic database using internationally recognized data exchange and quality protocols. The research publication database is under continuous updation and extension of the capabilities of the WebGIS application is underway even as a large body of ecological, social and biophysical data is already available. Center is planning to generate this data on a finer scale and with added information for use of the wider community.

The portal will shortly incorporate interfaces for a wide domain of spatial modelling methodologies and raw and processed data on various biophysical and ecological parameters will be available for free download.

Publications

- Giriraj A, Irfan-Ullah M., Roy A., Murthy M. S. R.,

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<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
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<tr>
<td>1.</td>
<td>Mohammed Irfan-Ullah Fellow (Scientist) and Convener Ecoinformatics Centre, Ashoka Trust for Research in Ecology and the Environment (ATREE), India</td>
<td>University of Kansas, Kansas; Grand Valley State University, Michigan and The Clark University, Massachusetts, USA</td>
<td>June – Sep. 2005</td>
</tr>
<tr>
<td>2.</td>
<td>Kamal S. Bawa University of Massachusetts, USA</td>
<td>ATREE, India</td>
<td>December 2004 – Jan. 2005</td>
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- Irfan-Ullah M., Chaitra M. S. and Shankar K. (Under Prep). Modelling the distribution of Nasikabatrachus sahyadrensis – to enhance conservation prioritisation in the Western Ghats, South India.

- Irfan-Ullah M., Charles B. and Dharmarajan P. (Under Prep). Conservation prioritisation for the elephant dung beetle (Heliocopris dominus) within Western Ghats.


About the Center
A large number of nitro compounds are manufactured for application in diverse fields like agriculture, defense, automobile, textile, etc. Their residues are subsequently released into the environment, however only a few of these are studied for their environmental toxicity. The health hazards of some of these nitro-compounds are now well identified with evidences of cancer and paralysis. To remediate sites contaminated with such toxic chemo pollutants, use of biological entities is assuming importance. Bioremediation technology makes use of versatile microorganisms that degrade the toxic compounds to non-toxic products. Phytoremediation is a biotechnological approach, which uses green plants and their associated microorganisms to remove or degrade hazardous, persistent organic compounds from contaminated sites.

The goal of the Joint Center is to develop a combined bioremediation-phytoremediation strategy for treating HMX-wastewater, and to obtain insights into the biological mechanisms involved. The major objectives of the project were:

- To perform bench-scale studies on bioremediation and combined electrochemical-reduction of nitrate from HMX-wastewater
- Development of horizontal packed-bed biofilm reactor (HPBBR) and sequencing batch reactor (SBR)
- To screen plant species for phytoremediation of untreated and microbially-treated HMX-wastewater
- Development of a wetland-microcosm for testing effectiveness of the selected aquatic species(s) in remediating the contaminants in a flow-through setup
- Development of a strategy using an integrated process involving electrochemical treatment, bioremediation and phytoremediation strategy for future field applications

Achievements
The research was carried out on the following research work elements –

- Electrochemical reduction of nitrate containing wastewater
- Bioremediation of HMX wastewater
- Phytoremediation of HMX wastewater
- Development of an integrated process for remediation of HMX wastewater

Two soil isolates of yeast (Williopsis sp. and Pichia sp.) were able to tolerate high concentration of nitrate & acetate, and were used for bioremediation of HMX waste water using Horizontal Packed Bed Bioreactor (HPBBR) and Sequential Batch Reactor (SBR). Williopsis sp. reduced nitrate and acetate to the extent
of 73 and 82 % respectively within 8 days at ambient temperature in batch type HPBBR. *Pichia* sp. showed 49% and 72% reduction in nitrate and acetate content of the waste water in HPBBR run in both batch and continuous mode. *Pichia* sp. was able to remove 68% acetate and 76% nitrate from the HMX wastewater within 96 hr of incubation in SBR having alternate aerobic and anaerobic cycles of 24 hr duration at 27°C. The phytoremediation studies in Hydroponics experiments showed *Hydrilla* sp. to be more efficient in removing nitrate from the suitably diluted HMX waste water having concentration of nitrate as 8000 mg/L, followed by *Ceratophyllum demersum*, *Salvinea molesta*, and *Vallisneria* sp. All the four plants showed around 50% removal and uptake of nitrate from the HMX waste water. All the plants exhibited nitrate reductase activity (maximum is found in *Hydrilla verticillata*). *Hydrilla* plants used in constructed wetland system, showed around 61% removal of nitrate content from the waste water with 63% uptake of nitrate by the leaves.

Attempts have been made to develop an integrated process using bioremediation and phytoremediation techniques for removal of nitrate from HMX waste water using Silver oak plants and untreated / microbially treated HMX waste water in hydroponics experiments. The results showed good nitrate removal and uptake of nitrate from both the microbially treated as well as untreated waste water at 7000 mg/L concentration of nitrate. The plants showed ~ 95 % removal of nitrate from waste water with ~75% uptake of nitrate by leaves.

The studies carried out at Colorado State University (CSU), US by an Indian researcher include electrochemical reduction of simulated waste water containing 2 g % sodium acetate (20000 mg/L) and 4 g % ammonium nitrate (40000 mg/L) using coupled cell and divided cell assemblies. The results indicated the feasibility of an electrochemical reduction process.
and divided cell assembly with Nefion semi permeable membrane as more suitable than coupled cell assembly with graphite felt as cathode material for the purpose. The phytoremediation studies using *Brassica juncea* showed ability to accumulate nitrate ions in the leaf tissue and thus removed nitrate from the simulated waste water to which the plants were exposed.

HEMRL, Pune provided HMX waste water samples and all the necessary related information.

**Scientific Value Addition**

The collaborative work of the Joint Centre resulted in development of a remediation process involving bioremediation, phytoremediation and electrochemical reduction for high nitrate containing waste water like the waste water generated during production of High Melting Explosive. The work is concluded with fulfillment of the objectives of the Joint Centre. While one paper is published, other data are being communicated for publication.

**Publications**


**Presentations at Conferences / Symposia / Seminars**


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<tbody>
<tr>
<td>1.</td>
<td>Ninad Gujarathi Co-PI (ARI, Pune)</td>
<td>Colorado State University</td>
<td>6-12 November 2006</td>
</tr>
<tr>
<td>2.</td>
<td>Prafulla Shede Research Associate (ARI, Pune)</td>
<td>Colorado State University</td>
<td>6 November 2006 to 6 January 2007</td>
</tr>
<tr>
<td>3.</td>
<td>P.P. Kanekar Indian Project Coordinator (ARI, Pune)</td>
<td>Colorado State University</td>
<td>22-29 August 2007</td>
</tr>
<tr>
<td>4.</td>
<td>T Soman Co-Investigator (HEMRL, Pune)</td>
<td>Colorado State University</td>
<td>22-29 August 2007</td>
</tr>
<tr>
<td>5.</td>
<td>Prafulla Shede Research Associate (ARI, Pune)</td>
<td>Colorado State University</td>
<td>21 July to 21 September 2007</td>
</tr>
<tr>
<td>8.</td>
<td>Kenneth Reardon Prof. and Head, Dept. of Chemical and Biological Engineering, Colorado State Univ.</td>
<td>Agharkar Research Institute Pune</td>
<td>18-22 Nov. 2007</td>
</tr>
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containing waste water” The 4th BRSI Convention and the International Conference on ‘New Horizons of Biotechnology’ Trivandrum, November 26-29, 2007


Indo-US Joint Center on
Climate Change and its Impact on
the Ecosystem of the Arabian Sea

About the Center
The main objectives of the Joint Center are:

- Strengthen and enhance INDO-US collaboration and cooperation in oceanographic research and long-term monitoring.
- Encourage and promote interdisciplinary research and excellence in oceanographic and climate change sciences of the Arabian Sea through optimal use of expertise, resources and technology.
- Create an environment that encourages scientific curiosity about the oceans and foster cross-cultural exchange of ideas especially among students and young scientists.
- Inspire and nurture a new generation of researchers to investigate climate change issues of relevance to the Indian Ocean and human populations that interface with it.

Work Plan/Methodology
Training of students/exchanges

- One student has gone under training in USA on isolation of harmful algae and its bio-optical characteristics.
- Two students were trained in grazing and ocean color remote sensing to apply Noctiluca detection from space.

Pre-Cruise Meetings:
Year I
- Two US scientists took part in pre-cruise meeting of planning of the Noctiluca studies in the field.

Year II
- Two Indian scientists took part in the pre-cruise planning and processing of the data in USA.
- Three US Scientists took part in the pre-cruise meetings in India.

Science plan during cruise: The plan included study of reference area and bloom area. Bloom area is marked by ocean color images and reference studies are occupied in the bloom free area. The main transects were fixed in the bloom area covering this entire bloom area. Data on wind speed, wind direction, air pressure and air temperature for all stations were recorded on board Sagar Sampada and Sagar Kanya.

Temperature and salinity was recorded by CTD (Seabird Electronics Inc., USA) system.

Chemical parameters
Nutrients: Water samples from depths based on water column characteristics were collected from different stations using CTD for the estimation of dissolved oxygen, pH and nutrients (Nitrate, Nitrite, Phosphate and Silicate). The other parameters used were Yellow substance (C-DOM), Bio-optical Studies, Bio-optical
Partnering Institutions

INDIA
• National Institute of Oceanography
  Goa

US
• Bigelow Laboratory for Ocean Sciences
  Maine, USA

Profiling (IOP Characterization), Biological studies (Phytoplankton Taxonomy, Pigments by HPLC method, Primary Productivity, Microbial studies; Nutrient cycling, new and regenerated production, Photosynthesis versus light measurements, Remote Sensing (Satellite data processing, Chl a Retrieval from IRS P4 OCM) and Sediment trap and new production.

Achievements

• Shipboard and satellite data shows that *Noctiluca miliaris* blooms are becoming an increasingly important component of phytoplankton communities of the Arabian Sea.

• Phytoplankton cell density, chlorophyll a (chl a) concentration and pigment data collected during a series of five cruises in the northern Arabian Sea in the Northeast Monsoon (NEM, Nov–Jan) and the Spring Intermonsoon (SIM, Mar–May) since 2003 contradicted the established notion that winter blooms mainly consist of diatom communities.

• Recent data show that following the NEM and well into the SIM, phytoplankton populations are dominated by the dinoflagellate *Noctiluca miliaris* Suriray (synonym *Noctiluca scintillans* Macartney). In the SIM they were often in association with the well-known blooms of the diazotroph *Trichodesmium* sp. Large blooms of *N. miliaris* have also begun making their appearance annually in the Gulf of Oman and off the coast of Oman.

• The study uses NASA’s recently developed product of merged SeaWiFS and Aqua-MODIS chl a data to investigate the temporal evolution and spatial extent of these taxonomically validated blooms.

• *N. miliaris* blooms are becoming an annual and widespread feature in the Arabian Sea proceeded by diatoms-dinoflagellates communities and followed by extensive blooms of *Trichodesmium* (Paper accepted by *Chinese Journal of Oceanology and Limnology*, 2010).

• Primary production is only C source in any open ocean and production rates vary from BLOOM to NON BLOOM areas indicates seasonal fast changing conditions in the NE Arabian Sea as the bloom ages and declines.

• *Noctiluca miliaris*, a conspicuously large heterotrophic dinoflagellate containing green symbionts of the prasinophyte *Pedimonas noctilucae*, has only been observed in the northern Arabian Sea. Since that time expansive blooms have been observed during the winter monsoons. Community composition predicted by the model compares well with coincident microscopic observations (Paper communicated to Geophysical Research Letter, 2010).

Other Activities

Dr. S. G. Prabhu Matondkar and Dr. J. I. Goes attended workshop at IIT Kanpur during 7 to 9 December 2008 and made a presentation on Joint Centre activities and its scientific programme.

Arranged workshop for training on bio-optics in NIO, Goa during 15-19 December 2008 inaugurated by Dr. A. Mitra, Executive Director, INDO-US Science and Technology Forum, New Delhi which was attended by other participating institutions.

Planned and executed cruise on Sagar Kanya (SK-256) as the first phase of the active bloom (26 Feb - 13 Feb. 2009).

Planned and arranged Sagar Sampada cruise (SS-263) as the second phase of the bloom study which was attended by participating organizations (26 Feb. - 13 Mar., 2009).

Arranged post cruise meeting at Space Application Centre, Ahmedabad for discussions of results in between US and Indian collaborators.

Planned and arranged third bloom phase cruise SK-258 (18-30 April 2009) where all the Indian collaborators has participated.
Planned/ arranged cruise on Sagar Sampada (SS-273) during 5-13 March 2010 for study of fourth phase of bloom.

One day workshop at Ahmedabad on 20th January 2010 for discussions and presentations by participating organizations.

Publications


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<tbody>
<tr>
<td>1</td>
<td><strong>J. I. Goes</strong> Senior Scientist, PI US Side, Bigelow Laboratory for Ocean Science, USA</td>
<td>National Institute of Oceanography, Goa; Space Application Centre, Ahmedabad, India</td>
<td>December 2008 - January 2009 (2 months)</td>
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<tr>
<td>2</td>
<td><strong>H. R. do Rosario Gomes</strong> Scientist, Bigelow Laboratory for Ocean Science, USA</td>
<td>National Institute of Oceanography, Goa; Space Application Centre, Ahmedabad, India</td>
<td>December 2008 - January 2009 (2 months)</td>
</tr>
<tr>
<td>3</td>
<td><strong>Collin Roesler</strong> Bigelow Laboratory for Ocean Sciences and University of Maine</td>
<td>National Institute of Oceanography, Goa; Space Application Centre, Ahmedabad, India</td>
<td>December 2008</td>
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<tr>
<td>4</td>
<td><strong>Suraksha Pednekar</strong> Ph.D. Student, NIO, Goa, India</td>
<td>Bigelow Laboratory for Ocean Sciences, Marine Institute &amp; Port Aransas Texas, University of Maine</td>
<td>June-July 2009 (1 month)</td>
</tr>
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<td>5</td>
<td><strong>Sushma G. Parab</strong> Post-Doc Fellow, NIO, Goa, India</td>
<td>Bigelow Laboratory for Ocean Sciences, Horn Point Laboratory, Bowdoin University, USA</td>
<td>September - October 2009 (1 month)</td>
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<tr>
<td>6</td>
<td><strong>S. G. Prabhu Matondkar</strong> Scientist F, PI Joint Centre, NIO, Goa, India</td>
<td>Bigelow Laboratory for Ocean Sciences, University of Southern California, USA</td>
<td>December 2009</td>
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<tr>
<td>7</td>
<td><strong>R. M. Dwivedi</strong> Scientist, Co-PI, SAC, Ahmedabad</td>
<td>Bigelow Laboratory for Ocean Sciences, University of Southern California, USA</td>
<td>December 2009</td>
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<tr>
<td>8</td>
<td><strong>Collin Roesler</strong> **** Bigelow Laboratory for Ocean Sciences and University of Maine</td>
<td>National Institute of Oceanography, Goa; Space Application Centre, Ahmedabad, India</td>
<td>January - March 2009</td>
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<td>9</td>
<td><strong>J. I. Goes</strong> Senior Scientist, PI US Side, Bigelow Laboratory for Ocean Science, USA</td>
<td>National Institute of Oceanography, Goa; Space Application Centre, Ahmedabad, India</td>
<td>January - March 2009</td>
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<tr>
<td>10</td>
<td><strong>H. R. do Rosario Gomes</strong> Scientist, Bigelow Laboratory for Ocean Science, USA</td>
<td>National Institute of Oceanography, Goa; Space Application Centre, Ahmedabad, India</td>
<td>January - March 2009</td>
</tr>
<tr>
<td>11</td>
<td><strong>Jeremy Werdel</strong> Ph.D. Student, NASA, USA</td>
<td>National Institute of Oceanography, Goa; Space Application Centre, Ahmedabad, India</td>
<td>16-20 January 2010</td>
</tr>
<tr>
<td>12</td>
<td><strong>Jena Campbell</strong> Ph.D. Student, Texas University</td>
<td>National Institute of Oceanography, Goa.</td>
<td>10 Feb. - 10 March 2010</td>
</tr>
<tr>
<td>13</td>
<td><strong>Pat Glibert</strong> Scientist, Horn Point Laboratory, Cambridge, USA</td>
<td>National Institute of Oceanography, Goa.</td>
<td>10-12 February 2010</td>
</tr>
</tbody>
</table>

* Traveled on other projects


Indo-US Joint Center on
Climate Change and Health Adaptation

Principal Investigators

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About the Center
In response to excess mortality due to heat wave in May 2010, the Public Health Foundation of India (PHFI), Indian Institute of Public Health Gandhinagar (IIPHG) and the Natural Resources Defence Council (NRDC) have been working to develop a network of scientists, researchers and policymakers to plan, develop and implement an actionable heat health early warning system for the municipal corporation of Ahmedabad. The objective of the Joint Center is to reconvene scientific experts working on health adaptation research in India and the U.S. This scientific advisory group will continue to guide the assessment and strategizing process. Because scientific research on climate adaptation is still nascent, this bilateral exchange will advance climate science by getting health researchers, modelling experts, academics and policymakers in this field to discuss the state of existing scientific research and identify next steps required to be taken for development of a heat health early warning system in India. The Center will also serve as a mechanism to articulate principles for health adaptation in India and generate a list of climate health issues for consideration and prioritization. The activities of the Joint Center include vulnerability assessment surveys, focus group discussions, factsheets, posters and training and sensitization workshops.

Achievements
In Ahmedabad, Gujarat, strong local government leadership, which partnered with Indian Institute of Public Health-Gandhinagar lead consortium of Indian and US institutions, enabled the development and effective implementation of a pilot Heat Action Plan – the first of its kind in South Asia! Launched in March 2013 and continuing into 2014, the Plan was based on robust scientific research and understanding of similar plans in the west. It built prediction of heat waves, creates public awareness of the risks of extreme heat, trains medical and community workers to prevent & respond to heat-related illnesses, and coordinates an interagency emergency response to heat waves. Sharing international experiences and best practices helped change the perception among project stakeholders in Ahmedabad that heat was not a significant health threat. However, further awareness-raising is still necessary to convince the general public as well as administrators and medical practitioners.

The Ahmedabad Heat and Climate Study Group is a team of academicians and researchers from India and USA that consist of (in alphabetical order): Dileep Andhare (IIPH-G), Gulrez Shah Azhar (IIPH-G), Meredith Connolly (NRDC), Bhaskar Deol (NRDC), Priya Shekhar Dutta (IIPH-G), Partha Sarthi Ganguly (IIPH-G), Jeremy Hess (Emory University), Anjali
Jaiswal (NRDC), Nehmat Kaur (NRDC), Kim Knowlton (NRDC and Mailman SPH, Columbia University), Dileep Mavalankar (IIPH-G), Ajit Rajiva (IIPH-G), Perry Sheffield (Icahn SOM at Mount Sinai) and Abhiyant Tiwari (IIPH-G). This group emerged from an international workshop supported by the Indo-US Science and Technology Forum in 2011. This initial support catalysed a small grant from NRDC that allowed the project team to leverage support from the Climate Development and Knowledge Network for international scientific collaboration which finally led to the development of Heat Action Plan for the Ahmedabad Municipal Corporation. Key activities of the Ahmedabad Heat Action Plan are:

- Research activities on effects of heat on slum communities and outdoor workers.
- Development of 7 days temperature forecasting for summer in Ahmedabad with help of CFAN Centre at Georgia Tech.
- Development of an early warning system for extreme heat for Meteorological Department and international forecasting models working with Ahmedabad Municipal Corporation.
- Sensitisation and training of hospital superintendents, physicians and ‘108 Emergency Response Services’ to heat-health risks.
- Enhancing health facility preparedness for dealing with heat stroke to reduce mortality: supplying ice packs at Ahmedabad Municipal Corporation hospitals and health centres and building capacity for heat-illness surveillance.
- Media engagement including workshops and meetings to raise awareness on extreme heat through television, radio and print outlets: pamphlets distributed to school children and other vulnerable populations; large hoardings at a dozen locations around Ahmedabad; banners attached to rickshaws; digital visual displays (containing the temperature, information of heat; illness symptoms and precautions).
- Dissemination of regular heat alerts and information to local agencies and stakeholders.
- Continuous monitoring of daily incidence of heat related illness cases and deaths by Ahmedabad Municipal Corporation during peak summer.
- Continuous monitoring of emergency calls for heat illnesses by GVK-EMRI.
- Analysis of completed activities and data collected during inaugural phases.
- Reorientation of all medical and paramedical staff of Ahmedabad Municipal Corporation and project team.

**Scientific Value Addition**

As a research-focused initiative, the Ahmedabad heat health project delivered new cutting-edge scientific research on climate adaptation, with particular focus on public health for the most vulnerable populations in India. This includes:

- Increasing knowledge of the events of 2010 Ahmedabad heatwave.
- Analysis of the effects of extreme heat on vulnerable groups in Gujarat.
- Translating knowledge to policy on heat waves and its effects.
Developing a heat wave early warning system for Ahmedabad.

The rigorous scientific research effort created a strong platform for international support and local action leading to credibility. This research focused on identifying vulnerable populations and formulating strategies to protect them. Such research is certainly not happening anywhere else in South Asia (and probably anywhere else in the developing world), and hence is of great interest to the international scientific community. Access to data and the quality of existing data has been a challenge. The team has observed strong association of heat wave and all-cause mortality, but have not yet been able to show association with heat wave related causes of mortality. This points to the need for further research on heat health impacts.

The team plans to expand scientific collaboration by way of. Also research exchange visits of municipal officers, scientist and physicians from India and USA. Plans are also afoot to broaden this Center’s engagement with scientists in other Indian states and cities.

Way Forward

The Ahmedabad Heat Health Project has been recognized nationally and internationally for its scientific and policy success in bringing heat health issues to the fore. There is new interest in scientific research and climate-induced extreme heat preparedness and also demands to scale up this project. Based on learnings from the project’s first phase, and interest expressed by other state and municipal governments in India, the next phase shall build upon this momentum and expand scientific research and action on extreme heat.

Publications


• Report Series: Rising Temperatures, Deadly Threat (March 2013): Slum Community; Outdoor Worker; Medical Professionals; Local Government http://www.nrdc.org/international/india/extreme-heat-preparedness/
• Report: Climate Change and Health Preparedness in India http://www.nrdc.org/international/india/india-health-report.asp
• Fact Sheet: Fighting Climate Effects: Protecting People from Extreme Heat in One of India’s Fastest Growing Cities http://www.nrdc.org/international/12012701.asp
About the Center

The Joint Center addresses the problem of improved forecasts of severe weather events over tropical regions within the Framework for India-U.S. Cooperation on Weather and Climate Forecasting and Agriculture. The aim of the center is to advance the Hurricane Weather Research and Forecasting System to a Regional Tropical Prediction System over India for improved forecasts of high impact weather events.

During the past few years, significant progress has been accomplished in the tropical cyclone (TC) track, intensity and structure forecasts under the auspices of and support from the United States (US) National Oceanic and Atmospheric Administration (NOAA)’s Hurricane Forecast Improvement Project (HFIP, Gall et al. 2013). In particular, for the first time, a very high-resolution (3 km) deterministic numerical weather prediction (NWP) model, known as the Hurricane Weather Research and Forecast (HWRF) modeling system, developed as a joint project by the Environmental Modeling Center (EMC) and the Hurricane Research Division (HRD) of NOAA’s Atlantic Oceanographic and Meteorological Laboratory (AOML) and implemented at the National Centers for Environmental Prediction (NCEP), has shown comparable and at times superior TC intensity forecast skills compared to the best performing statistical models.

The HWRF model is now paving the way for removing the roadblocks to improvements in the operational TC intensity forecasts, which have had virtually stagnant skill for the last two decades (http://www.emc.ncep.noaa.gov / HWRF / IWTC_VIII / IWTC.html). This modeling system was implemented in operations at the India Meteorological Department under the implementation agreement (IA) between MOES and NOAA. In order to share NOAA’s advanced understanding and forecasting techniques acquired in the last few years, an Indo-US workshop on Advanced modeling and data assimilation for tropical cyclone predictions with special reference to the hurricane weather research and forecasting (HWRF) system was organized by U.C. Mohanty (IIT, Bhubaneswar) and Sundararaman Gopalakrishnan (NOAA). The Indo-US forum for science and technology provided support to hold a joint workshop in Bhubaneswar, July 09-14, 2014. This workshop seeded the research effort for advancing HWRF developments in India. In the meanwhile the scientists at HRD have developed a more advanced version of the HWRF. This version, dubbed as the basin scale HWRF, has the potential to be used for forecast applications beyond tropical cyclones. In Indian context, this system will be extended to severe weather forecast applications with a very high potential for research to operations (R2O). Since the IMD is using one version of the HWRF system, it is envisioned the R2O process may be a seamless one.

Indo-US Joint Center on

Advanced Modeling of Tropical Land-Atmosphere-Ocean System for Simulation of Extreme Weather Events

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Achievements

Based on the 2013 version of operational HWRF system, the Hurricane Research Division (HRD) of the Atlantic Oceanographic and Meteorological Laboratory (AOML) with its partners at Environmental Modeling Center (EMC), National Centers for Environmental predictions (NCEP) have developed a basin scale HWRF system that can operate with multiple moving nests spanning at resolution down to 3 km over the Atlantic Ocean. We have configured the same system for North Indian Ocean (outer domain covers Westpac, north Indian Ocean) with the help of US counter partners.

Initial testing and experimental runs have been conducted with the recent very severe cyclonic storms (VSCS), Phailin (Oct’ 2013), Lehar (Nov’ 2013) and Madi (Dec’ 2013) over Bay of Bengal. This model clearly showed overall superiority at longer range forecast (4-5 days) in terms of track, intensity, size and structure. In all the cases, HWRF showed significant improvements in the evolution of intensity (Figure 1). Figure 2a provides wind swath of Phailin demonstrating that the system made landfall with very severe cyclonic storm intensity in advance of 3 days. The rainfall amount and structure is improved significantly, in case of Phailin showing peak rainfalls activity over Northern parts of Odisha as observed (Figure 2b). In case of Lehar, model indicated the dry air incursion into TC environment when the TC started interacting with the land which causes weakening of Lehar over the Bay of Bengal itself before making landfall. The rarest track and intensity evolution (maximum intensification to VSCS and dissimilation over the Bay of Bengal without landfall) of Madi was also predicted more accurately.

Scientific Value Addition

The basin scale HWRF system has scientific capabilities

- To study multi-scale interactions such as large scale – storm scale and storm scale – storm scale.
- As quality of initial conditions (storm intensity, position and structure) are important, this system has state-of-the-art vortex initialization and relocation technique to correct initial intensity, position and structure based on observations.
- Assimilation of environmental and storm scale observations can be done within this system using advanced Hybrid EnKF data assimilation system which provides background error flow.
- Provides guidance much in advance whether the West Pacific/China Sea typhoons are emerging into Bay of Bengal and its movement and intensity.
- Provides sufficient large scale environment at high resolution.

Way Forward

Initial testing is underway to study the sensitivity of updating SST (6hrly) during model integration on model performance.

Hybrid data assimilation

- Development of customized land surface data assimilation system for Indian region to represent and characteristics (soil moisture and temperature profiles with depth) when a cyclone start interacting with the land for better structure of wind and rainfall during landfall.
- Coupling of ocean model with atmospheric HWRF model for North Indian region

Exchange Visits

Thanks to travel support from Indian Institute of technology, New Delhi and NASA's jet propulsion lab, two visits, both related to the above effort were completed by Indian scientists in the past 6 months paving a way for future exchange visits under the Indo-US network proposal and accelerated advancement of this project. Prof. U.C. Mohanty visited HRD for 4 days in July, 2014 to discuss strategy related to the future directions for the project and Dr. Krishna Kishore visited HRD for about 2 months to learn the Basin Scale HWRF system. Dr. Kishore has been instrumental in implementing an Indian configuration of the Basin Scale HWRF system.
Publications
Apart from advanced man power generation from the Bhubaneswar workshop, another significant outcome of that workshop was the compilation of lectures that has led to the text book entitled “Advanced Modeling and Data Assimilation Techniques for Tropical Cyclone Predictions over Indian Seas (Editors: Prof. U. C. Mohanty and Sundararaman Gopalakrishnan)” has been reviewed and is expected to go to press by December, 2014. The contributions from the IUSSTF is kindly acknowledged for the workshop as well as this ongoing follow up efforts.
A couple of manuscripts are under preparation on (i) Impact of advanced vortex initialization and relocation over Bay of Bengal using High resolution HWRF modeling system (ii) Improvements in model predictions with cold and cyclic vortex initialization.
Life Sciences
**Indo-US Joint Center on**

**Silk Protein Matrix for Cell Based Tissue Engineering**

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**About the Center**

Silk protein biomaterials offer enormous prospects in the fast ever-expanding field of tissue regeneration, cell therapy, and regenerative medicine. *In-vitro* and *in-vivo* experiments show that silk materials exhibit a wide spectrum of properties that can be modulated to enhance tissue formation.

- Measurements of mechanical properties of different types of engineered pure silk and blended for tissue engineering applications constructs.
- Biomechanical, biochemical, immunohistochemical, and structural analysis of the cartilaginous tissue/contact formed *in vitro* upon culture of chondrocytes in the fibroin/chitosan 3D scaffolds.
- Optimization of bovine joint chondrocyte cell seeding density on cell viability, morphology and biochemical properties of 3-D engineered cartilage constructs.
- Osteogenic and adipogenic differentiation of rat bone marrow cells on nonmulberry and mulberry silk gland fibroin 3D scaffolds.
- Self-assembled nanostructures of the silk protein sericin obtained from two silkworms, the domesticated mulberry silkworm *Bombyx mori* and wild non-mulberry *Antheraea mylitta*.
- Design of novel hybrid protein by combining specific domains of mulberry fibroin and sericin to be used as new biomaterial.

**Work Plan/Methodology**

**Silkworm’s Collection**

The 5th instar larvae of Indian tropical tasar silkworm *Antheraea mylitta* were collected from local tasar silk farms and *Bombyx mori* silkworm cocoons from Debra Sericulture farm, West Midnapore, West Bengal, India. The posterior silk glands of fully-grown 5th instar larvae were dissected for extraction of silk protein fibroin using established methods and kept at –20°C.

**Preparation of silk protein fibroin aqueous solution:**

- From non-mulberry silkworm *A. mylitta* silk glands
- From mulberry silkworm *B. mori* silk cocoons
- Scaffolds preparation and treatment
- Tissue Culture
- Digestion of scaffolds
- Biochemical assays
- Live dead assay
- Collagen assay by hydroxyproline assay
- Histology (Alcian blue staining)
- Immunohistochemical staining
- Biomechanical testing

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**Principal Investigators**

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**Achievements**

**In-vitro** tissue engineering of cartilage had been studied using chondrocytes and 3D porous scaffolds. Cartilaginous constructs were formed from SF scaffolds seeded with varying initial cell densities. The biochemical content of native cartilage matrix molecules increased with cell density and concomitantly, biomechanical properties of the engineered tissue also demonstrated enhanced load-bearing properties for the seeded constructs compared to non-seeded scaffolds. The results indicate the importance of cell seeding density in the development of cartilaginous tissue.

SF protein and chitosan-blended polyelectrolyte complex porous scaffolds are also being studied for cartilage tissue engineering **In-vitro**. The scaffolds seeded with chondrocytes were incubated and analyzed for biochemical, biomechanical, and histological properties. Blended scaffolds modulated production and deposition of extracellular matrix molecules, sulfated glycosaminoglycan and type II collagen, and also enhanced compressive properties. These results suggest a possible benefit of tissue engineering with material blends.

Formation of new biomaterials from novel hybrid proteins combining specific domains of mulberry fibroin and sericin has produced recombinant silk-sericin like proteins. Silk sericin gene design and cloning, protein expression in bacteria, recombinant protein purification and macrophage response studies have been conducted to examine the direct activation of the innate immune response by such materials.

Rat bone marrow stem cells cultured on 3D scaffolds made up of non-mulberry and mulberry silk gland fibroin for 28 days under static conditions in osteogenic and adipogenic media respectively led to induction of differentiation. Proliferation and spreading of fibroblasts and bone marrow cells on silk scaffolds were observed to be dependent on scaffold porosity as revealed through confocal microscopic observations. Histological analysis shows osteogenic differentiation within silk scaffolds resulting in extensive mineralization in the form of deposited nodules as observed through intense Alizarin Red S staining. Similarly, adipogenesis was marked by the presence of lipid droplets within scaffolds on staining with Oil Red O. Real-time PCR studies reveal higher transcript levels for osteopontin (Spp1), osteocalcin (Bglap2) and osteonectin (Sparc) genes under osteogenic conditions. Similarly, upregulated adipogenic gene expression was observed within A. mylitta and B. mori scaffolds under adipogenic conditions for Peroxisome proliferator activated receptor gamma (PPARY), lipoprotein lipase (LPL) and adipocyte binding protein (aP2) genes. The results suggest suitability of silk fibroin protein 3D scaffolds as natural biopolymer for potential bone and adipose tissue engineering applications. The scaffolds are mechanically robust and show homogenous pore distribution with high porosity and interconnected pore walls. Low immunogenicity of fabricated silk scaffolds as estimated through TNF α release indicates its potential as future biopolymeric graft material.

The biomechanical properties of scaffolds are also a regulatory factor for indwelling cells. Hence, the static and dynamic mechanical properties of porous scaffolds fabricated from mulberry and non-mulberry SF proteins have been compared.

Human Embryonic stem cells (ESCs) can generate **in-vitro** a variety of cells including those of neural crest. A suitable culture condition for these stem cells to proliferate and differentiate in non-mulberry SF scaffolds is being developed. Constructs are being examined for morphology, expression of specific proteins, and biomechanical properties. The results will help to define the 3-D microenvironment of scaffolds based on SF appropriate for differentiation of ESCs into specific cell types.

**Publications**

- Mandal BB, Kundu SC. (2009). Osteogenic and
## Exchange Visits

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
<th>Institution(s) Visited</th>
<th>Duration/Time Period</th>
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<tr>
<td>1</td>
<td>S. C. Kundu</td>
<td>IIT Kharagpur, UCSD and Tufts University</td>
<td>May to July, 2008</td>
</tr>
<tr>
<td>2</td>
<td>Robert L. Sah</td>
<td>University of California, San Diego (UCSD)</td>
<td>November, 2008</td>
</tr>
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<td>3</td>
<td>S. C. Kundu</td>
<td>IIT Kharagpur, UCSD and Tufts University</td>
<td>May to July, 2009</td>
</tr>
<tr>
<td>4</td>
<td>Nandana Bhardwaj</td>
<td>IIT Kharagpur, UCSD and Tufts University</td>
<td>June to September, 2008</td>
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<td>5</td>
<td>Sarmistha Talukdar</td>
<td>IIT Kharagpur, UCSD and Tufts University</td>
<td>June to September, 2008</td>
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<td>6</td>
<td>Sunita Nayak</td>
<td>IIT Kharagpur, UCSD and Tufts University</td>
<td>June to September, 2008</td>
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<td>7</td>
<td>Jacqueline Green</td>
<td>UCSD, IIT Kharagpur</td>
<td>December, 2009</td>
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<td>8</td>
<td>Q.T. Nguyen</td>
<td>UCSD, IIT Kharagpur</td>
<td>December, 2009</td>
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<td>9</td>
<td>Robert L. Sah</td>
<td>UCSD, IIT Kharagpur</td>
<td>March, 2010</td>
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<td>10</td>
<td>S. C. Kundu</td>
<td>UCSD and Tufts University</td>
<td>May to July, 2010</td>
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<td>11</td>
<td>Banani Kundu</td>
<td>UCSD and Tufts University</td>
<td>September to December, 2010</td>
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<td>12</td>
<td>David L. Kaplan</td>
<td>Tufts University, IIT Kharagpur</td>
<td>February, 2011</td>
</tr>
</tbody>
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**Images:**

- S. C. Kundu and his IIT Kharagpur students having discussion with Alexey Terskikh with S.C. Kundu
- Robert L. Sah of UCSD having discussions
- IIT Kharagpur students having discussion with David Kaplan
- David Kaplan with S. C. Kundu and his group at IIT Kharagpur


- Talukdar S, Nguyen QT, Chen AC, Sah RL, Kundu SC. Effect of initial cell seeding density on 3D-engineered silk fibroin scaffolds for articular cartilage tissue engineering. Biomaterials. 2011; 32: 8927-37. IF-7.88
Indo-US Joint Center on

Stem Cell and Tissue Engineering

Principal Investigators

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About the Center

The objectives of the Joint Center are:-

• Develop methodology for differentiation of human embryonic stem cells and mesenchymal stem cells into cardiomyocytes, endothelial cells and smooth muscle cells on 3D-constructs.
• Develop a methodology to isolate, characterize and purify differentiated lineages.
• Identify factors that influence the development and differentiation of stem cells to cardiomyocytes, endothelial cells and smooth muscle cells.
• Study how extracellular matrix component proteins affect the process of development or differentiation of stem cells to cardiomyocytes, endothelial cells and smooth muscle cells.
• Study of specific molecules/mechanisms that aid in the maintenance of specific cell phenotypes on 3D constructs.
• Develop novel biodegradable polymers with elastomeric character synthetically or modify existing polymers by blending and grafting of natural polymers.
• Fabricate 2D and 3D interconnected open porous matrices suitable for seeding cardiomyocytes, endothelial cells and smooth muscle cells.
• Characterise developed scaffold structures for their physicochemical properties.
• Develop biomimetic properties on the scaffolds by surface and bulk modification of the novel polymers, which are then capable of eliciting specific cellular response and redirecting new tissue formation.
• Assess the biocompatibility, and angiogenic potential of the developed materials.
• Develop the tissue engineered cardiac patch and blood vessel by a combination of the scaffolds and cells in the stimulated conditions of bioreactors.
• Develop in-vivo model of myocardial infarction and transplant the cardiac patch.

Work Plan/Methodology

To fulfill various objectives a multi-level work plan had been set-up separately including:

• differentiation of human embryonic stem cells into cardiomyocytes.
• 3D-constructs with appropriate protocols for standardization of in vitro differentiation and their characterization by RT-PCR and immunocytochemistry.
• identification of factors influencing development and differentiation of stem cells to cardiomyocytes.
### Partnering Institutions

**INDIA**
- Sree Chitra Tirunal Institute for Medical Sciences & Technology, Trivandrum
- Stem Cell Research Centre, Manipal Academy for Higher Education

**US**
- Georgia Institute of Technology, GA
- University of Washington Centre for Engineered Biomaterials, Seattle, WA

- Micro array study for embryonic stem cells to differentiation to show the affect of development and differentiation process on extracellular matrix proteins. Study of specific molecules/mechanisms that aid in the maintenance of tissue assembly on 3D constructs.
- Stem cell isolation from various sources including bone marrow and umbilical cord for the standardization and assessment for differentiation potential into ECs.
- Ultra structure studies by scanning and transmission electron microscopy. Purification of the differentiated cells by using FACS sorter with cell surface markers and magnetic-labeled antibodies, evaluation of suitable factors for proliferation and differentiation of stem cells into ECs.
- Synthesis of elastomeric biodegradable polymers such as polyurethanes and polyesters, and fabrication of 2D and 3D interconnected open porous scaffolds by processes such as: solvent casting and salt leaching, freeze drying, emulsion freeze drying, Aphron process or solvent based or thermal induced phase separation techniques.
- Surface and bulk modification of biomaterials via chemical or physical methods with bioactive molecules and physicochemical characterization of the novel polymers.
- The influence of pulsatile forces, pressure, flow rate, compression, expansion, shear stress, frequency, and stroke rate and stroke volume on the growth of cells and tissues on scaffolds will be studied.

### Achievements

- During the first year several biocompatible and biodegradable biomaterials were synthesized and characterized at SCTIMST India and supplied to MAHE for growing different cell types on these materials and for a feedback of the suitable materials for growing specific cell types. SCTIMST also tried to isolate mesenchymal stem cells from umbilical cords and assess their suitability to assess the cytotoxicity of the biomaterials with the adult cells and MSCs. The group at MAHE focused on characterizing the main adult cells such as smooth muscle, endothelial and cardiomyocyte cells as well as stem cell differentiation from mesenchymal and embryonic origins to the adult cells of interest.
- The visit to Georgia Institute of Technology aimed at addressing various issues of culturing the cells on scaffolds and in Bioreactors. The compatibility of gelatin Based scaffold and hyaluronic acid based scaffold to support the growth of both smooth muscle cells and mesenchymal stem cells were analyzed. Different histological techniques like paraffin embedding, plastic embedding and cryo embedding were practiced with the scaffolds and mesenchymal stem cell derived spheres.
- Flow cytometry study of mesenchymal stem cells was performed to detect the percentage of Smooth Muscle Actin (SMA) and CD-31 (PECAM) positive cells. Magnetic cell sorting CD31 positive endothelial cells were observed.
- Mesenchymal cells grown on parallel plate bioreactor with a definite flow rate of media were observed to analyze the effect of shear stress on cells.
- Operation of Disc Plate Bioreactor with mesenchymal stem cells grown to analyze the effect of mechanical stress on cells was studied and learned the construction of collagen tube constructs with endothelial cells as to study the effect of shear stress and mechanical stress on cells and thus to come close to the in vivo conditions which cells in the heart are exposed to.
- Operation of the dynamic bioreactor and a collagen and smooth muscle cell seeded blood vessel model with the bioreactor was also studied.
- The porosity, permeability of scaffolds and the viability of cells grown on GEV and HaH scaffolds were analyzed using Confocal Microscopy (Zeiss LSM 510 Confocal Microscope) and Live Dead assay.
• The possibilities of surface modifications of scaffolds with amino acids and peptides were studied with the help of Electron spectroscopy for microscopic analysis (ESCA).

• Gelatin based scaffolds were identified as a better candidate to grow Mesenchymal stem cells and seeding the cells on scaffolds through slow centrifugation yielded better results.

In the second year, the main work was to seed smooth muscle cells on biomaterial scaffolds and to study the growth of blood vessels in the dynamic conditions of the bioreactor at GTEC.

In the period of March 1-30, 2008 Dr. Prabha D. Nair, Project Coordinator of the program from SCTIMST India visited the US partner sites of Georgia Tech and University of Washington. Dr. Nair interacted with Prof Robert M. Nerem at Georgia Tech and Prof. Buddy D. Ratner at UWEB, on the objectives of the program and also ascertained the visits of the US partners to India in the second year of the program. Her PhD student and main contributor to the work at SCTIMST, Ms Lynda V. Thomas also visited the US partner sites of Georgia Tech and
University of Washington for a period of two months. From MAHE, India, Dr. Vibha Choudhary, Principal Scientist; MIRM to visit the two partner sites at US. Mr Shinsmon Jose SRF from MIRM visited Prof Nerem’s lab at GTEC.

Apart from visiting and interacting with Prof Ratner’s lab at UWEB, and Prof Nerem’s lab at GTEC, Dr. Nair and Dr. Choudhary also visited the labs of Dr. Charles Murry and Dr. Mike Laflamme lab and opened up avenues for future collaboration on tissue engineering of cardiac patch. Dr. Prabha Nair and Ms Lynda Thomas got acquainted with the recent technologies used to study scaffolds and their properties. Dr. Choudhary and Mr Shinsmon Jose worked with some scaffolds (made in Dr. Prabha’s lab at India) and identified a gelatin based scaffold to be good for MSC growth. Characterisation of the materials using the tools of ESCA and other techniques from UWEB were extended to the Indian student Ms Lynda Thomas, who visited from SCTIMST. She was also exposed to biomaterials surface modifications by plasma polymerization, some novel methods of forming porous structures standardized and commercialised by UWEB as well as techniques of electrospinning. She was also given an opportunity to attend some lecture classes of Prof Ratner and other faculty of the Biomedical engineering program of UWEB. Ms Thomas was also taught to work with a collagen blood vessel model and one of the bioreactors standardized at Georgia Tech.

Dr. Nair and Dr. Choudhary also had an opportunity to attend the Annual Hilton Head Conference on “Regenerative Medicine, Advancing to Next Generation Therapies, March 12-16, 2008” organized by Georgia Tech. They had opportunities to interact with many different groups at this meeting as well as during their stay at Georgia Tech, and in overall get an idea of advances made in the field of tissue engineering.

This exposure is expected to help in designing of new scaffolds which would be tailor made for a specific cell types. While at GTEC, Dr. Nair and Dr. Choudhary gave presentations on the work carried out at the Indian labs SCTIMST, Trivandrum and MIRM, Bangalore.

The second year visit from MAHE was planned at UWEB to Dr. Laflamme lab in Oct 2008 while the visits from SCTIMST were planned for GTEC also in October 2008 and January 2008. The short periods of one or two months at one instance were considered as not enough to generate fruitful results on the use of dynamic bioreactors for a systematic study on the seeding of relevant cell types on new biomaterials and formation of a biological substitute like blood vessel or cardiac patch in vitro. The Cardiovascular research

(A) Interconnected pore structure of electrospun gelatin based scaffold
(B) Smooth muscle cells cultured on these scaffolds, Green colour indicates live cells
Joint R & D Centers

Group headed by Prof Nerem has a long history of working with and designing specific bioreactors for a variety of work with cells. A collagen blood vessel model was first developed by this Group and several landmark publications on fluid flow and cell growth have emerged from this Group at GTEC. The knowledge of almost all such bioreactors was freely shared with Dr. Nair and the team that visited in the first year of the program. The detailed drawings for starting the Indian lab with one bioreactor for dynamic culture of a blood vessel was exchanged with the Indian group.

In the second year of the program, four visits have taken place from the Indian side to the US partner sites. Project Coordinator, Dr. Prabha D. Nair visited the Georgia Institute of Technology, for a period of one month from August 17, 2008 to Sept 16, 2008. Though the bioreactor drawings and designs were shared by GTEC, it was not feasible to make the similar one in India in the shorter time span due to unavailability of some components and hence work could not be carried out in these lines at SCTIMST. Dr. Nair hence worked with the US team to have a bioreactor fabricated at the GTEC lab and kept ready for the exclusive use of the students who were scheduled to visit GTEC in October 2008. She also ascertained the reciprocal visits of members of the US team to India.

Ms Lynda Thomas from SCTIMST and Ms Neethu Mohan from SCTIMST visited GTEC for the period of one month from October 15, 2008 to Nov 15 2008. Smooth muscle cells that were isolated and characterized by Prof Nerem’s lab at Georgia Tech (RASM) were used by them to seed biomaterial tubes taken from Dr. Nair’s lab at India. These cells were cultured in the control collagen seeded constructs of Nerem lab in static and dynamic culture in bioreactors and also in the test cells on biomaterial tubes. The fabrication and characterization of the new biomaterials from SCTIMST used for the study were in turn shared with the US labs.

Mr Shinsmon Jose from MAHE is underwent training for a period of 2 months from Sept 2008 to Nov 2008 at Dr. Mike Laflamme’s lab as earlier planned on the effects of subjection of cardiomyocytes to strain and electrical stimulation and stem cell to adult cell transitions on application of electrical an magnetic fields at UWEB.
Cancer Nanotechnology is an evolving interdisciplinary area of research cutting across the fields of biology, chemistry, engineering, and medicine with significant implications in cancer detection, diagnosis and treatment at the molecular level. The need to expand and accelerate research in biomedical and nanosystems engineering is imperative to foster continued growth.

The objective of the Indo-US Joint Networked Center for Nanomedical and Cellular Engineering is to advance the functional understanding of cell biology using nanoscience and nanotechnology.

The center is a partnership between Purdue University and the Center for Cellular and Molecular Biology collaborating with the University of Illinois at Urbana-Campaign (UIUC), University of Notre Dame (UND), the National Institute of Interdisciplinary Science and Technology (NIIST) and the Indian Institute of Chemical Technology (IICT). It brings together a team of engineers, physicists, chemists, cell and molecular biologists with an unusual but complementary set of skills to address fundamental issues in the field of nanomedicine and cellular engineering. The team will create, design, and evaluate nanomaterials, biomaterials, imaging tools, nano and micro devices for diagnosis and therapy of diseases with a specific focus on cancer, in conjunction with the Purdue Cancer Center one of the seven National Cancer Institute designated basic research cancer centers in the United States.

The goals of NCE were addressed through a coordinated set of experiments that build upon ongoing efforts at Purdue and CCMB and their collaborating partners to:

- Develop multifunctional nanoprobes and photonic structures for sensing.
- Develop targeted and trackable nanomaterial based carriers of therapeutic nucleic acids.
- Develop in-vitro and in-vivo cellular targeting and therapy administration methodologies for disease treatment and prevention.
- Incorporate into these studies multimodal imaging tools comprising of Raman, fluorescence, hyperspectral, and magnetic resonance imaging with a long-term potential for in vivo imaging.
- Fabricate nano-devices and biosensors to diagnose rare disease events that have a high potential for commercialization in the long term.

The Joint Center provides a shared platform for a core group of faculty and students with a common interest in nanotools, imaging tools, and nanodevices to develop long-term collaborations in high impact programs for early detection and treatment of cancer. There are presently two Ph.D. students associated under the Joint Center - one each from CCMB and Purdue University.
Partnering Institutions

**INDIA**
- National Institute for Interdisciplinary Science & Technology, Trivandrum
- Indian Institute of Chemical Technology, Hyderabad

**US**
- University of Illinois, Urbana-Champaign
- University of Notre Dame, Notre Dame
- Arizona State University, Tempe

**Achievements**

The lead PI’s from CCMB and Purdue have received internal grants from respective institutions as an aftermath to the establishment of the bilateral IUSSTF supported Center.

Using complementary highly sensitive probes, detection platforms, and devices enabled by nanotechnology with clinical translation potential will help track the evolutionary state of the disease relevant to protein expression, signaling pathway activity, and molecular profiles enabling early cancer detection. To improve therapeutic outcomes, especially with emerging therapies, it is essential to target multiple pathways and devise multi-diagnostic strategies for *in vitro* and *in vivo* characterization of tumors. Such nanoscale detailing combined with time-resolved characterization will help to better understand cancer progression/regression for more effective administration of therapy for individualized treatment. Besides cancer, the NCE’s effort will also impact other angiogenesis-related diseases.

Some of the work accomplished by the Joint Center thus far are:
- Complete synthesis and characterization of iron oxide nanoparticles at CCMB.
- Synthesis of gold nanoclusters and silver nanoparticles for drug delivery, and development of tools to quantify compartmentalization of drugs in different cellular compartments in single cells at Purdue University.
- Examination of chemical structure on nanoparticles is under progress and will assist in revealing protein structures.
About the Center
The prevalence of cardiovascular diseases in general and heart failure in particular is rising worldwide with the increasing aging population. Available heart failure therapy is directed towards neurohormonal intervention (beta blockers, angiotensin receptor blockers and angiotensin converting enzyme inhibitors). In spite of these therapies, heart failure remains a progressive disease with high rate of mortality and morbidity, demanding new therapeutic strategies.

During the past decade, large number of Indian population, especially urban, has been identified as at risk of diabetes, cardiovascular and cerebrovascular disorders. According to a recent study in the United Kingdom, mortality from stroke is higher among South Asians compared to their European counterparts. Taken together, extensive research on cardiovascular diseases is a prerequisite for facing these challenges.

Recent decade has seen a paradigm shift in our understanding of how mammalian cells behave in an organismal milieu. It now appears that each cell type has a repertoire of regulatory module that is highly dynamic in interaction. Also, certain molecules like reactive oxygen and nitrogen species that were once regarded as only deleterious are now accepted as key modulator of cellular function under both pathological and physiological contexts.

The objectives of the Joint Centre are:
A) Adrenergic receptor dynamics and heart failure
   • To determine how PI3K regulates βAR resensitization.
   • To determine the molecular mechanism of regulation of PP2A by PI3K-ROS/RNS axis
   • Shyamal K. Goswami, Jawaharlal Nehru University and S Prasad, Lerner Research Institute, Cleveland

B) Efficacy of nitrite in therapeutic angiogenesis
   • Studying the implications of nitrite reductase in ischemic endothelium and angiogenesis.
   • Effect of sodium nitrite in compensating ROS/RNS imbalance under ischemia to restore blood flow.
   • Alan Schechter, NIDDK, USA and Suvro Chatterjee, Anna University.

Work Plan/Methodology
1. To integrate upstream adrenergic receptor (AR) dynamics with downstream redox signaling in the context of heart failure. Immediate experimental objectives in this context are:
   • To determine how PI3K regulates βAR resensitization.
   • To determine the molecular mechanism of...
regulation of PP2A by PI3K-ROS/RNS axis.

2. Efficacy of nitrite in therapeutic angiogenesis: Nitric oxide donors have long been explored for inducing angiogenesis in ischemic tissues. Recent studies have shown nitrites are better alternative as it releases nitric oxide through nitrite reductase. The proposed objective was to study nitrite driven nitric oxide production in ischemic endothelium.

**Achievements**

**Group 1 [S K Goswami and S Nagaprasad; Biology of heart failure]**

PI3Kinase plays a nodal role in β-adrenergic receptor phosphorylation, a key determinant of its desensitization heart failure. The US Co-PI (S. Nagaprasad) has made a seminal contribution in this area by demonstrating that PI3Kγ inhibits protein phosphatase 2A (PP2A) at the receptor complex, resulting in increased receptor phosphorylation and desensitization (Vasudevan et al., Mol Cell. 2011; 41(6):636-48). Since cellular redox plays a key role heart failure/cardiac dysfunction, we had hypothesized that reactive oxygen species might also influence the PI3Kinease-PP2A interaction and receptor cycling.

**Group 2 [Alan N. Schechter and S Chatterjee]**

Recent evidences show that dietary nitrate and nitrite has beneficial cardiovascular effect. Vegetables contribute ~85% of the dietary nitrate. Recent report from Dr. S Chatterjee’s laboratory has shown that nitrite in fennel seed has promotes angiogenesis, cell migration and vaso-relaxation. As suggested by Dr. Alan Schechter, US-PI, his student Ms. Krishna Priya worked as a special volunteer in NIH performing experiments measuring reduction of nitrite to nitrate to NO in some commonly used Indian spices.

**Other Activities accomplished under the Joint Centre**

Dr. S Chatterjee organized an International Conference on Angiogenesis in (Chennai, March 2012). Dr. David Roberts, Dr. Yunling Gao from NIH and Dr. Satyamangala Prasad (US Co-PI) attended the conference.

**Scientific Value Addition**

The travel grant from IUSSTF has laid the foundation for a long lasting collaboration between Sathyamangala V. Naga Prasad (US Co-PI) and Prof. S K Goswami (Indian PI) in the cutting edge area of cardiovascular receptor biology. It has long been known that redox state of the cell modulates physiological outcomes of GPCR signaling but underlying mechanisms are yet to be discovered. In this context, the collaborative work initiated by the grant has allowed the center to make significant headway into the problem of how redox state predisposes cardiac output and heart function.
During the reciprocal visits both teams have obtained interesting leads on the project both in cellular systems and in experimental mouse. A segment of this data has been included in the report demonstrating the clear role ROS play in cardiac function. Since this is a cutting edge area, the team continues to work in this project as collaborators with respective resources. More specifically center has pursued the in-vivo role of NADPH Oxidase/cellular redox in modulating cardiac function at steady state and under stress.

To summarise, studies have found that redox state of the cell predisposes beta-adrenergic receptor responses in the heart and this pre-disposition may have significant implications in cardiac function. Since this is a seminal observation, center plans to pursue this line in the long term with available resources. As underlying mechanisms get discovered more publications are expected from the ongoing work. Taken together, funding from IUSSTF has helped the center to develop a seamless integration of GPCR biology and cardiac redox state which is a major contributing factor for cardiac dysfunction.

**Publications**

Indo-US Joint Center on
Biological Timing

About the Center

Biological clocks have evolved to interact with daily changes in our environment and time appropriate physiology, metabolism, and behavior to right time of the day or to the right season. Optimum timing events underlie increased biomass production by plant species, optimum growth, cell division, reproductive success, healthy lifespan and improved prognosis in animals and in humans. In contrast, disruption of the biological timing system as in genetic mutations affecting the internal clock or changes in environmental factors impairs fitness and predisposes to chronic diseases and early aging.

Biological timing is a rapidly emerging field and it has profound implications in multiple fronts common to the national interests of both the USA and India. These areas include food security, energy security, public health, and ecosystem restoration. While biological timing researchers in the USA have been at the forefront of understanding the molecular basis of biological clocks in model organisms, Indian researchers have pioneered the understanding of physiology and behavior in complex organisms that are under daily and seasonal regulation.

The Indo-US Center for Biological Timing will be the hub for research, training and education by involving two important Universities of India (University of Delhi and the University of Lucknow) and two important centers of research and education of the USA (University of California and Salk Institute for Biological Studies). The basic science collaborations will center on ongoing funded research with direct relevance to public health and ecosystem restoration. Research collaborations will form the platform for cross-training of researchers and students during short-term visits. These visits and online tools will be leveraged to generate and disseminate education materials on biological timing. Success of the research program will solidify collaboration between two countries while training and education efforts will expand bilateral collaboration.

Activities planned under this center are organized into three aims:

- Light modulation of activity, sleep, reproduction, regeneration, and migration.
- Circadian rhythm, eating pattern, and regulation of metabolic homeostasis.
- Scientific meetings, symposiums, and training schools.

The strength of the collaboration between partners of the joint center lies in the non-overlapping species and techniques followed in each center institute.

Principal Investigators

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A dedicated website will highlight the executive summary of the center and will also provide information on research activities of participating principal investigators, list of meetings and symposiums in the subject area, link to other chronobiology centers, laboratories and relevant databases.

For public outreach, the web site will also include aims and objectives of materials for educating the general public on chronobiology. Center members will use skype and other online communication tools for periodic web-based discussion and consultation.

The collaboration between the partnering institutions through this center will expand in future and the outcome in terms of research and knowledge from the project is envisaged to contribute to the information on public health and conservation of biodiversity in both countries.

**Partnering Institutions**

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Indo-US Joint Center on 
Research Excellence in Science and Engineering (CRESE) on Nanobiotechnology

About the Center
Two emerging areas that will dramatically impact medical sciences in the future are stem cell biology and nanotechnology. Although, these two areas are already intersecting, the interface between these areas offers an untapped niche for scientific exploration and inventions that will revolutionize translational medicine. This Joint Center brings together the strengths of National Center for Biological Sciences, JNCASR and CCMB in stem cell biology and the core expertise of Harvard-MIT Division of Health Sciences and Technology in material sciences and nanotechnology to develop an Indo-US Joint Center for Nanobiotechnology.

The overall objectives of the Joint Centre are in three main areas:

Research on the ‘Regulation of Stem Cell Biology during Neo-vascularization by Nanostructures’.

Specifically, the research aims are:

Elucidate the mechanisms underlying the differentiation of stem cells into vascular structures. Use of embryonic stem cells or iPS cells to direct the differentiation into vascular lineages.

1.1. Standardize in vitro systems for monitoring stem cell to vascular differentiation using immunohistoctyochemistry, RT-PCR, and Western blots.

1.2. Study the mechanisms underlying stem cell to vascular differentiation using a systems biology-based approach.

1.3. Validate the mechanisms using a RNAi-based strategy, where the focus will be to develop novel nanostructures-based delivery of RNAi.

Engineer novel nanostructures of defined morphology and physicochemical properties and test their contribution to the differentiation of stem cells into vasculature. A nanostructure can potentially facilitate stem cell-induced vascularization through two steps, 1. by recruitment of stem cells or progenitor cells to the desired site of neovascularization, or 2. by promoting differentiation of the stem cells. To test this hypothesis we will:

2.1. Engineer and characterize novel nanostructures.

2.2. Study the effect of these nanostructures on differentiation of stem cells

2.3. Elucidate the mechanisms underlying the role of novel nanostructures on stem cell-induced neovascularization

Translate the in vitro results in an in vivo model of ischaemic pathology.

We will use a mouse central artery occlusion model as a surrogate for peripheral artery disease (PAD) to
test the effect of nanostructures in inducing collateral circulation. Specifically, we will develop a model of PAD by occluding the central artery of the ear of a Swiss albino mouse. Collateral vasculature formation will be measured through gross pathological analysis following light photography and by immunohistocytochemistry following temporal necropsy. We will evaluate the potential of the nanostructures to facilitate the differentiation of stem cells into neo-vasculature in this model.

**Development of Novel nanostructures for delivery of molecules**

[Dr. Shiladitya Sengupta, Harvard-BWH; Dr. R.A. Mashelkar, NCL Pune; Dr. Sudipta Basu, IISER Pune, Dr. Shankar Ghosh, TIFR Bombay]. This project had a two pronged approach, 1. Develop novel nanostructures that can specifically target cancer cells, preferably cancer stem cells, and 2. Elucidate the mechanical properties of these cells at the nanoscale.

**B.** The Joint Center also focuses on the training of the next generation of scientists.

Specifically the Training Aims are: Exchange of postdoctoral fellows between partner laboratories for extended periods such that personnel involved in the research projects learn the vocabulary of both nanotechnology and basic biology. Abhijit Majumdar, Sudhir Ranganath, Sashikath Parcha are already in Boston or scheduled to spend time in Boston labs in 2012-13.

To host three short-term training programs in NCBS, where graduate students, research fellows and junior faculty will be given hands-on training in nanotechnology and stem cell biology techniques, in addition to lectures on the cutting edge topics in these fields. Separate funding will be requested from the Indo-US forum for these events. A 10 day hands-on training course in nanotechnology and stem cell techniques is planned at NCBS/InStem.

**C. Meetings - Dissemination of Results and Building Translational Collaborations**

At end of Year 1 and 4, we will host Translational meetings that will bring together the research team with potential industry partners. The first meeting will help engage the industry in the research projects and the final meeting will facilitate the translation of the developed technologies to the industry. Our first meeting led to the formation of BERI, which will have strong translational focus.

We anticipate that this grant from the Indo-US forum will facilitate the creation of an ecosystem that will evolve into a long-term collaboration between the two nations, fostering additional grant funding from multiple sources in the future, training of manpower/sharing of expertise, generating of IPR, and most importantly emerge as a leader in scientific research in this exciting and biologically relevant area.

**Achievements**

**Training of young scientists and exchanges**

A critical component of this joint center was to develop a new cadre of scientists who can bridge biology and engineering. It was naturally anticipated that the transition of physical scientists/engineers to biology would take some time but that the infusion of new ideas would make significant contributions moving forward. In fact, this is exactly the type of cross-disciplinary move encouraged by the creation of these joint centers and is in keeping with their philosophy. We are delighted to highlight the following successes:

Dr. Sudipta Basu, a chemical biologist working on this project in Sengupta Lab at Harvard has joined as a faculty at IISER Pune, and is setting up a nanobiotechnology laboratory funded by a Ramalingaswamy fellowship.

We recruited two very talented postdocs with outstanding publication records (Sudhir Ranganath and Abhijit Majumdar) -who are experts in the physical sciences- and are working on stem cell projects in the Karp lab at Harvard-MIT after a stint at NCBS and JNCASR. Abhijit has been working for about 2 years and Sudhir about 1.5 years, and both have made substantial progress in developing their biological
Joint R & D Centers

Joint R & D Centers

(stem cell) systems, as well as creating the environment for nanotechnology experiments in a biolab setting. Integration of bio-with the nano/engineering aspects is ongoing. Abhijit has been awarded a Wellcome Trust DBT Fellowship that he activated early in 2013 at InStem, on his return from MIT and will be a stepping stone towards his independent career. Indeed, he has already received offers for positions in academia which he is considering.

Dr. Shashikant Parcha, a physicist recruited on this grant from the University of Melbourne, worked initially with Dr. Shankar Ghosh of TIFR and then with Pramod Pullerkat at RRI, and is currently in Sengupta Lab, researching the mechanobiology of cancer stem cells using Atomic Force Microscopy, and their contribution to metastasis.

The postdocs are making excellent progress on their projects. However, given the time required for them to learn a new field and to focus on high impact work, it was decided to move them to the US later than we first anticipated. The flexibility of this program for its successful completion is a key distinction.

In addition to the above key personnel, Students / Postdocs from Sengupta lab visited JNCASR and TIFR for 6 weeks in 2010 and 2011. Several professors and postdocs from Boston visited NCBS for a 2-day meeting in 2010 to discuss potential collaborative opportunities. This was the prelude to the setting up of the Bioengineering Research Initiative (BERI) at the NCBS.

Impact on research environment

Nucleation of Bioengineering at NCBS. Our grant and meetings funded by it was instrumental to nucleate the formation of the NCBS-InStem BioEngineering Research Initiative (BERI) and is listed on the BERI website: http://beri.ncbs.res.in/home. This is a partnership that includes IIT Madras, and has already resulted in the hiring of Dr. Praveen Vemula from Karp Lab as a new faculty at InStem. Dr Vemula has initiated an exciting new program in nanotechnology and stem cells.

New collaborations have been nucleated as a result of this grant and include engagement with Prof. Pramod Pullerkat a physicist at the Raman Research Institute, Prof. V. Kumaran a chemical engineer at the Indian Inst. of Science, both in Bangalore, and with Prof. R.A. Mashelkar of NCL Pune, Dr. Sudipta Basu of IISER Pune, and Dr. Shankar Ghosh of TIFR Mumbai.

We have emphasized on quality over quantity. Multiple high impact papers (outlined under Publications) have been published including in Cell Stem Cell, PNAS, etc.

Three patent applications have evolved from work carried out under this project, that have been filed globally. The patents were critical in starting up two companies, Vyome Biosciences and Invictus Oncology, which have successfully raised a total of Rs. 34 Crores in the last 2 years, and has attracted top scientific talents to India to further develop these products.

Three active research projects initiated by the binational team are:

Project 1: Mechano-biology of the niche and induction of quiescence in hMSC [Abhijit Majumder, INSTEM-NCBS, Jyotsna Dhawan, INSTEM-NCBS and Jeffrey M. Karp, Harvard-MIT]

Background: Bio-chemical and mechanical properties of the tissue micro-environment or “niche” have strong influence in determining cell fate and behavior. The mechanical and geometric signals/cues include material stiffness, topology, structure, fluid shear, mechanical strain and ligand distribution. In short, mechano-signal encompasses any force interaction between cell and its micro-environment. The diverse array of mechano-signals may have short-term (minutes to hours) to long-term (days) effect on cell fate, the mechanism of which is yet to be elucidated. It has been demonstrated that cytoskeletal arrangement and acto-myosin contractility are the important players. Specifically, the RhoA signaling regulator and its downstream effector, ROCK, strongly influence the cellular response to a given mechano-signal. It is expected that understanding
mechano-signaling will help us in controlling the cell behavior and tissue regeneration.

In this project, we specifically focused on cell cycle progression and cell cycle arrest of mesenchymal stem cells (MSCs) in response to various mechano-signals. It has been reported that while loss of adhesion leads to apoptosis for capillary endothelial cells, the same pushes myoblasts and fibroblasts towards a reversible undifferentiated cell cycle arrested state called quiescent or G0 state. Earlier studies in Dhawan lab established that abolition of focal adhesions or inhibition of cytoskeletal contractility leads to reversible cell cycle arrest and suppression of differentiation. In this project, we aimed to engineer a population of quiescent mesenchymal stem cells and study their activity on different substrates. Given that quiescent cells have lower oxygen requirements, transplantation of an exogenous source of quiescent stem cells may enhance tissue regeneration within an avascular defect where the diffusion of nutrients and oxygen is minimal until sufficient angiogenesis emerges. Remaining ‘dormant’ until sufficient angiogenesis arrives to support higher levels of metabolic activity may enhance the potential for these cells to contribute to the healing response.

**Scientific Results and Conclusions**

As per the project plan, the work was performed in close collaboration between Dhawan Lab and Karp lab. In Dhawan’s lab at InStem-NCBS, Bangalore, focus of the work was to establish quiescence in MSCs in response to a set of mechano-signals and to characterize the molecular behavior. In May 2012, Abhijit Majumder, Post-Doctoral fellow working in this project, moved to Karp Lab, Boston, where he engineered scaffolds for cell implantation and designed a novel microfluidic chip to study MSC migration in response to a soluble gradient, e.g. inflammatory signals.

In this project, we have:

- standardized methods for proliferation, quiescence and differentiation of human and mouse MSC
- standardized methods for generating substrates of varied stiffness
- established methods for maintaining cells in a viable quiescent state on substrates of different stiffness
- optimized assays for querying molecular events (DNA synthesis, gene expression, protein localization, imaging) in cells maintained on substrates of varying stiffness
- identified the threshold substrate stiffness to induce quiescence in MSCs.
- standardized assays for measuring physico-chemical substrate parameters
- have performed experiments for generating micro-patterned substrates and maintaining cells on these surfaces
- have created a micro-fabricated multi-well cell implant device
- have created a shear free, stable microfluidic chamber to study MSC migration in response to the chemo-attractant gradient

**Project 2: Intracellular delivery of a small molecule NF-κB inhibitor from PLGA microparticles modulates human mesenchymal stem cell (hMSC) secretome and attenuates pro-inflammatory responses** [Sudhir Ranganath, Maneesha Inamdar, Jeffrey Karp]

The main objectives of this project are to use small molecules to modulate pro-inflammatory hMSC secretome in response to inflammatory stimuli and develop a platform tool for translation into clinics using drug delivery tools. Over the past two years, we have comprehensively reviewed the available literature about various signaling pathways in hMSCs to obtain control over specific secreted pro-inflammatory factors such as IL-6, MCP-1, RANTES, etc. Recently we published this in our review article (Ranganath et al., 2012) published in Cell Stem Cell. Also, we have demonstrated that a small molecule inhibitor of NF-κB activation, TPCA-1 modulates the pro-inflammatory hMSC secretome. The resultant secretome contributes in reducing the migration of monocytes in vitro, which might potentially be therapeutic in treating monocyte-mediated atherosclerosis. The reasons for choosing small molecules are their easy availability, specificity and flexibility for controlled delivery from micro/nanoparticles into hMSCs.

**Project 3: Development of Novel nanostructures for delivery of molecules** [Dr. Shiladitya Sengupta, Harvard-BWH; Dr. R.A. Mashelkar, NCL Pune; Dr. Sudipta Basu, IISER Pune, Dr. Shankar Ghosh, TIFR Bombay).

While the JNCASR-NCBS-Karp Lab core (Core I) focused more on the mechanobiology of stem cells and identification of targets that control the process, the Sengupta Lab-IISER-NCL-TIFR core (Core II) focused more on the development of Nanoscale tools that allow targeting specific cellular targets. As the traditional approaches for encapsulating pharmacophores or RNAi in nanoparticles pose significant challenges in translation, Core II focused on evolving a completely new field of nanotechnology, called supramolecular nanochemistry, which is based on bridging nanotechnology with structure activity relationships.
Publications


Patents Granted/filed

  The invention is directed to modified polymers with increased drug-loading including compounds of formula.

  The invention is directed to biocompatible conjugated polymer nanoparticles including a copolymer backbone, a plurality of sidechains covalently linked to said backbone, and a plurality of platinum compounds dissociably linked to said backbone.


• These patents have been licensed by Brigham and Women’s Hospital to Invictus Oncology and Vyome Biosciences, both of which are India-registered companies. Based on these patents, the companies have raised Rs. 33 Crores for further development of these technologies in India (including attracting Rs. 18.5 Cr in FDI). The companies have also attracted top science talents from all over the globe back to India.

Other Outcome

Two start-ups have evolved based on technologies evolving from these projects. Additionally, the program has fostered the Bioengineering Research Initiative at NCBS, which has started attracting top talents. One of the postdocs hired on this project has already received the Wellcome Trust –DBT India Alliance Early Career Fellowship to be sponsored at InStem.
Mathematical and Computational Sciences
Indo-US Joint Center on
Advanced Research in Machine Learning, Game Theory and Optimization

About the Center
In knowledge economy, leadership positions will be occupied by countries that can parse the deluge of data that is being generated in almost every field and can transform this data into meaningful scientific conclusions. Machine learning, game theory, and optimization are three fields that are critical for analyzing and understanding large-scale data and complex systems. While each field has been studied and developed separately over the last several decades, the future lies at the intersection of these three fields, hence creating an urgent need to develop capacity at the interface.

To this end, Joint Center brings together core strengths in the fields of machine learning, game theory and optimization at IISc, Microsoft Research India, Harvard, MIT, and Carnegie Mellon University in order to facilitate the highest quality research at the interface of these disciplines, and to help define the techniques that will be used to analyze data in the future. Team anticipates that in the longer term, the joint center will also help to establish stronger ties between Indian and US institutions in the mathematical and engineering sciences.

In the above context, the primary objective of the Joint Center is to facilitate high quality research at the interface of machine learning, game theory and optimization, and to help establish long-term collaborations between Indian and US institutions in these disciplines.

Achievements
• Training and mentoring of several research students
• Several high-impact publications
• Organized Indo-US Lectures Week in Machine Learning, Game Theory and Optimization at IISc, Bangalore in January 2014; all lecture materials publicly available online at http://drona.csa.iisc.ernet.in/~indous/activities.html
• Continuing joint interactions and upcoming publications
• Following interactions facilitated by the Joint Centre, some of the PIs together with their current and former PhD students/postdocs (namely Shivani Agarwal, David Parkes, Devavrat Shah, Hossein Azari, Guy Bresler, Sewoong Oh and Arun Rajkumar) jointly organized a Workshop titled ‘Analysis of Rank Data: Confluence of Social Choice, Operations Research, and Machine Learning’ at the prestigious Neural Information Processing Systems (NIPS) 2014 Conference in Montreal, Canada in December, 2014.
Partnering Institutions

**INDIA**
- Indian Institute of Science, Bangalore
- Microsoft Research India

**US**
- Harvard University
- Carnegie Mellon University
- Massachusetts Institute of Technology

**Publications**

**Exchange Visits**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
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</thead>
<tbody>
<tr>
<td>2.</td>
<td>Shivani Agarwal</td>
<td>Harvard University</td>
<td>May 5 - July 27, 2013</td>
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<td>3.</td>
<td>Arun Rajkumar</td>
<td>University of Chicago</td>
<td>Oct 1 - Dec 31, 2013</td>
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<td>4.</td>
<td>David Parkes</td>
<td>IISc, Bangalore</td>
<td>Jan 2014</td>
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<td>5.</td>
<td>Devavrat Shah</td>
<td>IISc, Bangalore</td>
<td>Jan 2014</td>
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<td>6.</td>
<td>Avrim Blum</td>
<td>IISc, Bangalore</td>
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<td>John Santerre</td>
<td>IISc, Bangalore</td>
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<td>8.</td>
<td>Bo Waggoner</td>
<td>IISc, Bangalore</td>
<td>Jan 2014</td>
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<td>Jasper Snoek</td>
<td>IISc, Bangalore</td>
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<td>10.</td>
<td>Alex Kulesza</td>
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<td>Jan 2014</td>
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<tr>
<td>11.</td>
<td>Shivani Agarwal</td>
<td>Harvard University</td>
<td>March 2014</td>
</tr>
<tr>
<td>12.</td>
<td>Shivani Agarwal</td>
<td>Harvard University</td>
<td>May 31 - July 26, 2014</td>
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<td>13.</td>
<td>Harikrishna Narasimhan</td>
<td>Harvard University</td>
<td>Sep 1 - Dec 7, 2014</td>
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<td>14.</td>
<td>Shivani Agarwal</td>
<td>Harvard University</td>
<td>Sep 6 - Dec 27, 2014</td>
</tr>
</tbody>
</table>


- Harikrishna Narasimhan and Shivani Agarwal...


About the Center

The knowledge of protein complex (quaternary) structure using X-ray crystallographic methods offer an atomistic glimpse into the basis of this interaction. Therefore, structural genomics of protein complexes has been one of the frontier areas in structural biology. However, structure solution of protein complexes must precede identification of natural/cognate binding partners in cell to allow attempt to protein co-crystallization and structure determination. As part of this Joint Center, the groups will enhance methodology of identification of natural/cognate binding partners of proteins in a genomics scale. An already established ProLinks database of genomic-context derived functional linkage information will be used to get an initial set of physically interacting candidates at 95% expected coverage. These candidates will thereafter be screened and ranked using our interaction forcefield and expectation maximization method. The sequences will be modeled to assess and interpret the basis of the interaction as rigid bodies, and subsequently subjected to molecular dynamics simulations to confirm the viability of the protein interaction.

The candidates will be experimentally tested for protein-protein interaction screening and if successful, followed up with crystallization and structure determination. The work is expected to give a significant boost to the structural genomics of protein complexes.

The center is expected to bring forth new ideas and lay groundwork for long term future collaborations.

Principal Investigators

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David S. Eisenberg  
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Los Angeles, USA  
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Partnering Institutions

**INDIA**  
• Indian Institute of Science, Bangalore  
• Indian Institute of Technology, Kharagpur

**US**  
• University of California, Los Angeles  
• Los Alamos National Laboratory (LANL)  
  Los Alamos
About the Center

The goal of this center is to provide a vibrant INDO-US center on two important topics of mutual research interest: Nanostructure Materials and Biological Molecules. The proposed work plans to capitalize on expertise from both sides of the Atlantic with particular focus on close collaboration between high performance predictive computational (HPPC) methods with the state of the art experimental investigations.

The center will provide a unique platform for basic scientists, engineers and physicians to interact actively, addressing fundamental questions keeping in mind possible applications through design of new atomic scale materials and biomolecules. Specifically, the group will collaborate on the fundamental study of new and emerging nanostructured materials with potential applications in low power high speed transistors, chemical and biological sensors, energy devices such as super capacitors, growth and application of robust and novel substrates (using coherent inclusion of plasmonic materials in silicon substrates) for Surfaces Enhanced Raman Spectroscopy (SERS) that enable to detect single molecule detection, metal clusters controlled in the proteins that could be used as an anti-tuberculosis drug, designing of new protein-nanostructure interfaces that could control or provide superior biosensors. The team would focus on two broad thrusts:

1. Design of 2-dimensional Functional Nanostructures
3. Our team will leverage various existing and future funding for the success of the proposed activities.

Publications

Joint R & D Centers

Medical Sciences
Indo-US Joint Center on
Biomaterials for Healthcare

About the Center
The Joint Center focuses on the following objectives:-

• To conduct research on the development of engineered Nanobiomaterials for bone tissue replacement application.
• To develop and conduct clinical trials on Polymer based scaffold materials for cartilage tissue engineering application.
• To formulate strategies based on injection molding as well as CAD/CAM based manufacturing route to fabricate complex shaped implant materials.
• To have a focused discussion on how Biomaterials education in India and USA can be strengthened.
• Feasibility study for commercialization of successful biomaterial products with the help of private industry.
• To train next generation of scientists in an international interdisciplinary collaborative arena.

Work plan/Methodology

FOCUS AREA –I

• HARD TISSUE REPLACEMENT

Collaboration between IIT Kanpur and UTSA
• Fabrication and in vitro properties of Polymeric scaffolds for bone tissue engineering (IIT, Kanpur)
• In-vitro and In-vivo studies of polymeric scaffolds (USTA)

Collaboration between IIT Kanpur and UoW
• Functionally graded porous Ti (UoW)
• In vitro studies of functionally graded porous Ti (IIT Kanpur)

Collaboration between NFTDC and Brown University
• CAD/CAM based designing of Ti based scaffolds (NFTDC)
• CNT coated anodized Ti (Brown University)

Collaboration between IIT Kanpur and Shaping Concepts, LLC
• HAp/Mullite, Glass Ceramic processing and In-vitro studies (IIT-K)
• Injection molding of polymer/ceramics based complex shaped implants (Shaping Concepts, LLC).

FOCUS AREA –II

• SOFT TISSUE REPLACEMENT

Collaboration among IIT K, IITB, NML, UTSA and Brown University
• Scaffolds for cartilage tissue engineering (a) Cryogel (IIT Kanpur) (b) In-situ gelling (IIT Bombay)
• Designing bio-mimetic polymeric nano composites (NML)

Collaboration between NML and Brown University
• Designing bio-mimetic polymeric nano composites (NML)

Principal Investigators

Bikramjit Basu
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IIT Kanpur, India
bikram@iitk.ac.in

Thomas J Webster
Division of Engineering & Dept. of Orthopedics
Brown University
Rhode Island, USA
thomas_webster@brown.edu
Achievements

In particular, the Center oversaw the joint development of HA-based electro conductive composites for bone replacement applications. IIT Kanpur created the composites using the spark plasma sintering (SPS) route, and the research group of Amar Bhalla and Ruyan Guo at UTSA evaluated their functional properties. Using fluorescent-activated cell sorting and reverse-transcription polymerase chain reaction techniques, researchers at Brown University investigated the cellular apoptosis at genome level of HA-based nanoceramic composites fabricated using the SPS route at IIT Kanpur.

IIT Kanpur researchers used electro spinning techniques to develop poly(vinyl alcohol)–carbon nanofibers and poly (lactic-co-glycolic acid)–CNF hybrid bio composites, while cardiomyocyte cell-fate processes are studied at Brown University in the context of their potential applications as synthetic patches to treat heart diseases. NML (Jamshedpur) has developed PVA based transparent hydrogels for corneal tissue engineering applications followed by Brown University’s in vitro study of such materials. Also, IIT Bombay synthesized hydrogel scaffolds for minimally invasive cartilage tissue engineering applications. Brown researchers then investigated the cell adhesion and differentiation of chondrocyte cells in external electric field stimulated culture conditions.

Important milestones achieved by the team at the Joint Center are:

- Development of Hydroxyapatite based electroconductive and osteoconductive bone replacement material using spark plasma sintering route
- Injection molding of complex shaped polymer-ceramic hybrid biocomposites with better osseointegration properties
- Methods for the nanoparticle-based multiple growth factor delivery and Fe2O3 nanoparticle as well as Lyposome surfactants for PVA hydrogels have been established for the osteoarthritis and bacterial infection treatment
- Electrospinning of nanofibers with novel architectures, injectible hydrogel scaffolds, and transparent PVA-tripeptide hydrogel scaffolds for the cartilage tissue engineering, corneal tissue regeneration, and dermal tissue engineering
applications, respectively.

- Polymer based scaffold materials (PLGA-CNF based composites) for cardiovascular tissue engineering application (cardiac patch)
- With the participation of two academic institutes from India (IIT Kanpur and IIT Mumbai) and three from USA (Brown University, University of Texas, San Antonio and University of Washington, Seattle) as well as two national research labs from India (National Metallurgical Laboratory (NML), Non-Ferrous Technology Development Centre (NFTDC)) and one private company from USA (Shaping Concepts, LLC), this centre is one of the largest of all the Indo-US research centers, being funded by Indo-US Science and Technology Forum.
- With twenty five (25) exchange visits of senior researchers and young PhD students between India and USA, this center has been able to achieve the overall objective to combine the cutting edge technologies of fabrication and testing of materials science with the knowledge of biological sciences. It has come up with strategies to develop shaped implant materials in some of the emerging material systems for the purpose of the enhancement of public health. This network center has demonstrated a synergistic flow and utilization of scientific concepts, technological ideas and expertise in an international team of recognized scientists from India and USA. The success of this center is reflected on the clinically relevant outcome of multiple bilateral projects in the area of orthopaedics, corneal, dermal, cartilage and cardiovascular tissue engineering applications. In particular, the collaborative research between IIT Kanpur (Basu’s group) and Brown University (Webster’s group) on developing PLGA-carbon nanofiber based cardiac patches has received media attention worldwide.

**Publications**

- Justin T Seil and Thomas J Webster (2011); Spray deposition of live cells throughout the

Illustration showing the research highlights of Center activities in the area of bone-tissue engineering applications
## Exchange Visits

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
<th>Institution(s) Visited</th>
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<tbody>
<tr>
<td>1</td>
<td>Dhirendra S. Katti</td>
<td>University of Texas San Antonio &amp; Brown University</td>
<td>23 April- 1 May, 2009</td>
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<td>2</td>
<td>Bikramjit Basu</td>
<td>UTSA, Shaping concepts, LLC &amp; Brown University</td>
<td>9 July- 21 July, 2009</td>
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<td>3</td>
<td>Suprabha Nayar</td>
<td>Brown University</td>
<td>12 July- 27 July, 2009</td>
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<td>4</td>
<td>Rajendra K. Bordia</td>
<td>IIT, Kanpur, India</td>
<td>8 August- 4 Sep., 2009</td>
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<td>5</td>
<td>C. Mauli Agarwal</td>
<td>University of Texas, San Antonio</td>
<td>9 Sep-12 Sep., 2009</td>
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<td>6</td>
<td>Justin Seil</td>
<td>IIT Kanpur, India</td>
<td>15 Sep.- 17 Oct., 2009</td>
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<td>7</td>
<td>Teja Guda</td>
<td>IIT Kanpur, India</td>
<td>24 Oct.- 22 Nov., 2009</td>
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<td>8</td>
<td>Deepthi Dyondi</td>
<td>Brown University</td>
<td>31 Oct.- 23 Dec., 2009</td>
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<td>9</td>
<td>Nhiem Tran</td>
<td>NML Jamshedpur</td>
<td>15 Dec 2009-8 Jan 2010</td>
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<td>10</td>
<td>Ashutosh Kumar Dubey</td>
<td>Univ. of Texas, San Antonio</td>
<td>25 Feb-24 Apr., 2010</td>
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<td>11</td>
<td>Sushma Kalmodia</td>
<td>Brown University</td>
<td>6 Jun-30 Aug., 2010</td>
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<td>13</td>
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<td>25 May-17 Jun., 2012</td>
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<td>14</td>
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<td>Brown University</td>
<td>23 May-23 Aug., 2010</td>
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<tr>
<td>15</td>
<td>Erik Taylor</td>
<td>IIT Bombay</td>
<td>1 Aug.- 7 Sep., 2010</td>
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<td>16</td>
<td>Sarika Misra</td>
<td>University of Washington, Seattle</td>
<td>31 Oct.-7 Dec, 2010</td>
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<tr>
<td>17</td>
<td>Alexander Chase Turner</td>
<td>IIT Kanpur, India</td>
<td>22 Aug.- 24 Sep., 2010</td>
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<td>18</td>
<td>Nik Hrabe</td>
<td>IIT Kanpur, India</td>
<td>7 Nov.- 11 Dec., 2010</td>
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<td>19</td>
<td>A. Rajyalakshmi</td>
<td>Brown University</td>
<td>16 Sep.- 15 Nov., 2010</td>
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<td>20</td>
<td>Siddhi Gupta</td>
<td>Brown University</td>
<td>16 Sep.-16 Nov., 2010</td>
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<td>21</td>
<td>David Stout</td>
<td>IIT Kanpur, India</td>
<td>4 Jan.-5 Feb., 2011</td>
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<td>A. K. Dubey</td>
<td>University of Texas, San Antonio</td>
<td>5 Sep.-14 Nov, 2010</td>
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<td>23</td>
<td>David A. Stout</td>
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<td>24</td>
<td>Alok Kumar</td>
<td>Brown University</td>
<td>20 May-21 Aug., 2011</td>
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<td>25</td>
<td>Shilpee Jain</td>
<td>Brown University</td>
<td>20 May-21 Aug., 2011</td>
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</table>


- S. Jain, Thomas J. Webster, A. Sharma and B. Basu (2013); Intracellular reactive oxidative stress, cell proliferation and apoptosis of Schwann cells on carbon nanofibrous substrates. Biomaterials 34: 4891-4901.


Incidents of stroke in children and young adults (<45 years) is an important cause of morbidity and mortality throughout the world, especially in developing countries. Despite few studies reported from India on stroke in young, most involved ischemic stroke conducted before the widespread use of modern neuro-imaging methods; and thus with a few exceptions, did not identify stroke subtypes, etiopathogenesis, and their long term outcomes. Stroke prevention planning, reliable epidemiological information on pattern of disease, exposure to major risk factors and morbidity/mortality trends for cerebro-vascular disease in defined populations is an imperative. Nations have to face enormous socioeconomic burden to meet the costs of treatment of stroke victims. There is a great need to monitor these trends in a simple and reproducible way.

The major objectives of Indo-US Joint Networked Center on Cerebrovascular Diseases are:

• Study the risk factors for stroke in young, including homocysteine, lipoprotein, triglycerides and other lipid fractions, procoagulant states, hemoglobin, and infections;
• Assess stroke recurrence after first ever stroke in young and possible contributing factors; and
• Assess pattern of distribution of atherosclerotic lesions intra-and extra-cranially in stroke in young.

The goal is to develop academic and scientific ties between the clinicians and health researchers in MGH and UMASS in the US and AIIMS and NIMS in India, targeting the development of programs to improve the understanding of stroke etiopathogenesis, risk factor profiles and recognition between the different ethnic communities, awareness, and acute stroke management with a focus towards the development of cutting-edge tertiary care center’s and community programs targeting the population at risk for cerebrovascular disorders with special reference to stroke in young. The data obtained in a specifically designed registry will help better understand this unique cohort of patients.

Substantial progress has been made in developing the database through joint center work. In addition, a great deal of information has been exchanged about stroke care and ongoing research between the participating institutions. This would be the first prospective comparative study of stroke in young, their demographics, risk factors, stroke profiles and prognosis between two different ethnic and socio-demographic populations in the world.

**Research Needs**

**In the United States**

Asians make up approximately 4% of the total U.S. population and is the largest growing racial-ethnic group in the country. One of the objectives in the Healthy People 2010 prevention agenda for the nation
is to eliminate health disparities among segments of the population including differences that occur by gender, race-ethnicity, education or income, disability, geographic location.

In US, there is a great emphasis on examining race-ethnic distributions of stroke incidence and mortality in order to define the burden of disease and to develop directed prevention programs. A significant effort is needed to improve the treatment of stroke and vascular disease in Indian/Asian population, especially in:

- Recognition of Stroke risk factors with special reference to stroke in young
- Use of both preventive and acute therapies
- Much work also needs to be done to understand the pathophysiology of vascular disease in the Asian population.

**In India**

Despite the advances in the understanding of the pathophysiology of stroke, the rapid and impressive developments in neuroimaging technology and their wide availability, majority of the patients are unable to seek appropriate medical evaluation and intervention for stroke. This is largely due to lack of awareness, widespread ignorance regarding stroke; the prevailing nihilistic attitude amongst both public and medical personnel as well as clustering of medical services to few urban localities which are unable to cater to the vast millions of semi-urban and rural sectors of the country. A multi-pronged approach, which can offer:

- Prevention strategies
- Acute stroke management
- Risk modification in the high-risk patient population
- Increase awareness among the general population and health professional would be of paramount importance in dealing with the stroke burden in the society.

**Achievements**

The project was designed to compare the research activities on-going at AIIMS, NIMS and MGH and UMASS stroke services as regards the acute care including hyperacute interventional strategies with the specific goal of refining the existing modalities and initiate newer strategies of re-perfusion/neuroprotection; stroke preventatives with specific target population such as stroke in young; emerging/ unconventional risk factors for stroke with special reference to India and other developing countries such roles of homocysteine, lipids (triglycerides), infections, genetic factors etc; pattern and distribution of intra and extra-cranial atherosclerotic lesions in cerebral circulation and compare and contrast the differences between the Indian pattern and Western pattern. The data obtained in the specifically designed stroke in young registry was designed to help understand better this unique cohort of patients; the etiopathogenesis, the predisposing risk factors; predilection of sites for atherosclerosis and thus derive at realistic preventative/management protocols specifically designed for stroke in young.
Exchange Visits

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<tr>
<td>1</td>
<td>M. V. Padma&lt;br&gt;Professor, All India Institute of Medical Sciences (AIIMS), New Delhi</td>
<td>MGH, Boston and UMASS, Worcester</td>
<td>November, 2009</td>
</tr>
<tr>
<td>2</td>
<td>Subhash Kaul&lt;br&gt;Professor, Nizams Institute of Medical Sciences (NIMS), Hyderabad</td>
<td>MGH, Boston and UMASS, Worcester</td>
<td>November, 2009</td>
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<td>3</td>
<td>Ashu Bhasin&lt;br&gt;PhD, Stroke Fellow</td>
<td>MGH Boston, UMASS, Worcester</td>
<td>November, 2009</td>
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<td>4</td>
<td>Aneesh Singhal&lt;br&gt;Associate Professor, Associate Professor, Massachusetts General Hospital (MGH), Stroke Research Center, Boston</td>
<td>AIIMS, New Delhi</td>
<td>December, 2009</td>
</tr>
<tr>
<td>5</td>
<td>Aneesh Singhal&lt;br&gt;Associate Professor, Massachusetts General Hospital (MGH), Stroke Research Center, Boston</td>
<td>AIIMS, New Delhi</td>
<td>January, 2011</td>
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<td>6</td>
<td>M. Moonis&lt;br&gt;Professor, University of Massachusetts (UMASS), Worcester</td>
<td>AIIMS, New Delhi</td>
<td>March 2011</td>
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<tr>
<td>7</td>
<td>M. Moonis&lt;br&gt;Professor, University of Massachusetts (UMASS), Worcester</td>
<td>AIIMS, New Delhi</td>
<td>December, 2010</td>
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<tr>
<td>8</td>
<td>M.V. Padma&lt;br&gt;Professor, All India Institute of Medical Sciences (AIIMS), New Delhi</td>
<td>MGH, Boston and UMASS, Worcester</td>
<td>January, 2011</td>
</tr>
<tr>
<td>9</td>
<td>Subhash Kaul&lt;br&gt;Professor, Nizams Institute of Medical Sciences (NIMS), Hyderabad</td>
<td>MGH, Boston and UMASS, Worcester</td>
<td>April, 2011</td>
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</table>

Way Forward

The experience and database generated through the above project during the two years period has enabled the PI from USA (Dr. Aneesh Singhal) to design and submit to the NIH a project on a comprehensive stroke registry to be established between India and the USA. This project if funded will give a tremendous impetus and thrust to this movement of bilateral collaboration and understanding in the field of stroke between the two countries.
About the Center
The objectives of the Joint Center are:
• Implement volumetric MRSI acquisition and reconstruction, MR-diffusion, and MRI-perfusion imaging, on MRI instruments at the Sanjay Gandhi Post Graduate Institute of Medical Sciences.
• Evaluate combined advanced MRI methods for diagnostic studies of brain cancer, with emphasis on untreated glioma.
• Develop a database of imaging markers for characterization of different brain lesions.
• Develop computational methods for multiparametric image-based tissue classification, for characterization of multiple tissue types associated with brain cancer, including brain edema, infiltrative tissue, cancer, and abscess.
• Develop new collaborative research and educational programs in the area of brain imaging.

Scientific Results and Conclusions
Results: Completion of MR studies of 94 subjects, including 7 of normal controls. Of these 56 studies were selected for analysis as confirmed glioma and being of...
Work Plan/Methodology
The specific activities undertaken in the project period were as follows:

<table>
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<tr>
<th>Date</th>
<th>Tasks</th>
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<tbody>
<tr>
<td></td>
<td>Finalized development and evaluation of the volumetric MRSI sequence on 3T GE MRI (Spielman).</td>
</tr>
<tr>
<td></td>
<td>Finalized licensing issues for installing this sequence in the GE MRI in Lucknow.</td>
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<tr>
<td></td>
<td>Final specification of clinical research plan, and completion of human research approvals (Gupta).</td>
</tr>
<tr>
<td></td>
<td>Exchange of ideas and information to design image analysis methods (all PIs).</td>
</tr>
<tr>
<td>Feb. 2010 to Sept. 2010</td>
<td>Installation and testing of MRSI acquisition and processing software at SGPGIMS. Visits of Dr. Maudsley and Mr. Sheriff to Lucknow, India, for software installation and testing, and training. The MRSI and MRI methods were evaluated using studies in phantom objects and normal volunteer subjects. Final definition of multiparametric image analysis methods and instruction on incorporation into the MIDAS software environment (Maudsley, Spielman, and Rathore).</td>
</tr>
<tr>
<td>Nov. 2010</td>
<td>Initiation of MR studies in patients referred with evaluation of brain tumor (Gupta). The MRSI sequence was added to the routine brain tumor imaging protocol. Development of image analysis methods for diffusion and perfusion (Rathore). Ongoing support and software development for data processing and image display in the MIDAS package (Maudsley).</td>
</tr>
<tr>
<td>Feb. 2011</td>
<td>Dr. Gupta’s visit to Miami for the purpose of reviewing the existing data, performing an initial data analysis, planning of additional development projects and publications.</td>
</tr>
<tr>
<td>July 2011</td>
<td>Ms. Roy’s visit to Miami and Stanford for the purpose of completing integration of data processed in Lucknow into the MIDAS database, and for planning of additional processing and analysis software.</td>
</tr>
<tr>
<td>Mar. 2012</td>
<td>Dr. Maudsley’s visit to Lucknow. A final review and analysis of all data was carried out for evaluating the efficacy of the multiparametric imaging methods was initiated. A manuscript describing this work was drafted.</td>
</tr>
<tr>
<td>July 2012</td>
<td>Dr. Alperin’s visit to Lucknow. Additional MRI methods were implemented for the purpose of measuring intra-cranial pressure in patients with brain cancer.</td>
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</table>

adequate quality in all imaging studies for analysis. The image data was incorporated into the database used for data processing and analysis at the University of Miami site. Several software developments were implemented to deal with specific requirements of the acquired data.

Figure 1 illustrates the primary image parameter maps that were obtained. Data was obtained from a subject with histology-proven glioblastoma (GBM).

Scientific Outcomes: The ROC analysis indicated that DCE-MRI derived relative CBV is most efficient for the aim of glioma grading, and that a combination of parameters from DCE-MRI, DTI, and whole brain MRSI enables classification of gliomas into high and low grade with accuracy near to the classification based on histopathology. The finding supports the use of a multiparametric MR protocol for tumor diagnosis. Additional findings
support the use of the volumetric whole-brain MRSI method for improved sampling of brain tumors relative to standard MRS methods provided by the MR instrument manufacturers.

The study demonstrated the value of multiparametric MR data acquisitions and comprehensive data processing approaches enabling combination of MRS and multiple MRI features, benefit for aiding visual clinical diagnosis.

**Bilateral Cooperation and Interactions:** Exchange of information, imaging technology, and a unique set of data obtained for an important clinical group of patients.

**Publications**


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**Fig. 1:** Cross-sectional images at six slices through the brain out of the full volume image data for different MRI maps: a) T2 MRI; b) T1-post contrast MRI; c) NAA; d) Creatine; e) Choline; f) Lactate; g) apparent diffusion (ADC); h) Fractional Anisotropy; and i) cerebral blood volume (CBV).
Indo-US Joint Center on

Cell Targeted Diagnostics and Therapy Using Nanomaterials

About the Center
In 2010, Amrita University in Kochi, Kerala, India; Cellworks, Bangalore, India; Rice University, Houston, Texas; University of Texas School of Dentistry; UConn Health, Farmington, CT, USA; and Stanford University, CA, USA, began a substantial collaboration with the support of the Indo-US Science and Technology Forum (IUSSTF) on cell-targeted diagnostics and therapy using nanomaterials.

The foundation of this collaborative effort was the recognition that nanomaterials in many structural forms have specificity for cells and that this behavior could be exploited for diagnostics and therapy, including the use of targeted structures in scaffolds that can tune the properties of tissues generated from them. Some of the areas of focus were cancer diagnostics, cancer therapy, and regeneration of complex tissues and quantification of directed regeneration based on targeted flow of factors in a milieu using micro-fluidics. Although six institutes officially were part of the collaboration, the Rice University effort included contributions from another institute at the Texas Medical Center, MD Andersen Cancer Center, Houston, Texas. Thus the overall collaboration grew to a seven institutional collaboration. Amrita was the lead university led by Professor Shantikumar Nair, director of the Centre for Nanosciences and Molecular Medicine at Amrita University, Amrita Institute of Medical Sciences and Research Centre. In the USA the lead PI was Professor Antonios G. Mikos, Louis Calder Professor of Bioengineering and Chemical and Biomolecular Engineering at Rice. The other investigators were Dr. Mark E. Wong (D.D.S.), Chair of the Department of Oral and Maxillofacial Surgery of the University of Texas School of Dentistry; Professor Sarah Heilshorn from Stanford University; Dr. Lakshmi S. Nair from UConn Health; Dr. Shireen Vali from Cellworks; Dr. F. Kurtis Kasper from Rice University; Dr. Manzoor Koyakutty, Dr. Krishna Prasad Chennazhi and Dr. Deepthy Menon from Amrita. Dr. Jorge Cortes (M.D.) of MD Andersen Cancer Center also contributed to the collaboration.

Achievements
Significant accomplishments included development of nanoscale layered structures for bone tissue engineering, combination of micro- and nanostructures to enhance tissue regeneration, development of nanoribbons of recombinant elastins, microfluidic setup to quantify factor gradients and how it affects tissue regeneration from nano-sources in the form of factor-encapsulated nanoparticles, use of gel-based nanostructures for drug delivery to oral giant-cell cancer, use of protein nanoparticles for drug delivery to overcome drug-resistant leukemia, osteochondral

Principal Investigators

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tissue engineering using nanoparticle in nanofiber structures and nanocomposite gels, computational systems biology to understand the interaction of nanoparticles and factors on intra-cellular pathways of action. These collaborations have significantly raised new avenues of collaborations of both a fundamental and applied nature.

In addition to this, the center has facilitated more than 14 exchange visits of faculties and doctoral students between India and the USA. Graduate students from Rice University, UConn Health Center and Stanford University visited Amrita University, India, during 2011-2013. The students were trained in electrospinning of multiscale fibers, processing of fibrin nanofibrous materials, electrospinning of nanoparticle in nanofiber polymers with and without drugs and electrospinning of recombinant protein nanomaterials. Likewise, students from Amrita visited all of the above three Universities in the USA. At Stanford University training in microfluidics experiments to study the effect of growth factor gradients took place, while at Rice, Amrita students addressed the problems of biomaterial-based drug delivery design for treatment of giant cell oral carcinoma and also were trained in in-vivo studies using Amrita’s layered scaffolds for bone tissue engineering. At UConn Health, the visiting student was trained in human embryonic stem cell culture and methods to develop injectable hydrogels as cell delivery vehicles to support tissue regeneration. Students also were introduced to MD Andersen Cancer Center for planning nanomedicine development, which may lead to a strong future collaboration.

The activities under the Joint Center resulted in a dozen publications and one potential patent.
Work done in Collaboration with Stanford University

We identified two specific projects based on our expertise in electrospinning natural polymers and our collaborator’s expertise in microfluidics. A novel, sequence-specific, sequential process comprised of vapor-phase initiation and aqueous completion of crosslinks was adapted to electrospun multivariately tunable family of recombinant elastin-like proteins (ELPs) into an implantable, nanofibrous fabric from aqueous solution. Stable ELP nanofibers are characterized to determine if nanofiber morphology, mechanics, and cell adhesion can be tuned to fall within the range necessary for use as tissue engineering scaffolds. Fibers are spun from pure ELP solutions of two concentrations: 20% and 35% w/w, both of which produced ribbon-like nanofibers.

• To confirm that the RGD ligand retains its bioactivity during electrospinning and crosslinking, the adhesion and metabolic activity of rMSCs is evaluated. Ultimately, the ability to orthogonally stabilize nanofibrous protein matrices that are electrospun from tunable ELPs has the potential to deliver a new level of control over the behavior of cells and engineered tissues.

• CARS microscopy of rat marrow stromal cells (rMSC) after 24 h in standard conditions on electrospun ELP-RGD.

In the second project, to analyze the effect of growth factor gradients on endothelial cell migration, a microfluidic channel for dynamic culture was designed. Polydimethylsiloxane (PDMS) was used to fabricate 3D microfluidic device by soft lithography technique against a silicon template having distinct patterns for source channel, sink channel and central cell culture chamber. After standardizing the required concentrations of growth factors- VEGF and Ang-1- we encapsulated the growth factors within fibrin nanoparticles and embedded them in a 3D matrix. The effect of eluted VEGF and Ang-1 on the patterned alignment of endothelial cells and subsequent migration of smooth muscle cells was studied, and we found that endothelial cells were aligned into tube like structures surrounded by the migrated smooth muscle cells.

Work done in Collaboration with Rice University

Amrita students spend time at Rice studying the role of layered scaffolds in the formation of vascularized bone tissue. Remarkably the scaffold containing a critical sized defect showed significant vascularization as well
as bone formation through the thickness which is a significant accomplishment.

**Work done by Rice students at Amrita:**
The objective of this work was to study the feasibility of utilizing our in-house developed fibrin based electrospun scaffolds for cartilage tissue engineering applications. For this, multiscale electrospun scaffolds consisting of fibrin and poly(ε-caprolactone) (PCL), was fabricated. Images of scaffold cross-sections taken using SEM reveal that when nanofibers are incorporated into a microfiber mesh using the dual extrusion electrospinning process with a rotating mandrel, nanofibers are truly interspersed throughout the entire construct.

Interestingly, it was found that as time progresses scaffolds containing nanofibers (PμPn and PμFn) exhibit more deposition of GAGs than scaffolds composed of microfibers alone. Also, the scaffolds containing fibrin nanofibers (PμFn) bear greater amounts of GAGs than the other two scaffold types. Thus, we found that nanofibers composed of bioactive polymers, such as fibrin, have the potential for maintaining scaffold cellularity while at the same time promoting the deposition of ECM.

**Work done in Collaboration with University of Connecticut**
Our collaboration with Connecticut was aimed at exploring the potential of the composite approach to develop covalently cross-linked hydrogels with tuneable physical, mechanical, and biological properties.

The composite approach can be used to modulate the mechanical properties of the hydrogel. We have developed an injectable composite gel from sodium alginate and hyaluronate. The hyaluronic and alginic acid gels showed significant interaction with the cationic macromolecule BSA. Since hyaluronic acid gels are degradable in vivo, the composite gels could be engineered to control the release profile of similar macromolecules via diffusion and degradation mediated mechanisms.

**Publications**
- Praveen.G, Hui Xu, Sarah. C. Heilshorn, Shanthikumar. V. Nair and Krishna Prasad Chennazhi. Optimization of reciprocal growth factor delivery on 3D microfluidic platform and micro matrices to induce In-vitro...
angiogenesis. Submitted to Microfluidics and Nanofluidics.


- Patrick L. Benitez, Jeffrey A. Sweet, Helen Fink, Krishna P. Chennazhi, Shantikumar .V. Nair, Annika Enejder, and Sarah C. Heilshorn. Sequence-specific crosslinking of electrospun elastin-like protein preserves bioactivity and native-like mechanics. Accepted in Advanced Healthcare Materials.


- Sowmya Srinivasan, R. Jayakumar, K. P.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name &amp; Affiliation of the Scientist/Student</th>
<th>Institution(s) Visited</th>
<th>Duration/Time Period</th>
</tr>
</thead>
</table>
| 1.    | Shantikumar Nair  
_DEAN, Amrita_ | Rice, Stanford and UConn | 3 visits of 2 weeks each |
| 2.    | Krishnaprasad Chennazhi  
_ASSOCIATE PROFESSOR, Amrita_ | Stanford University | 2 visits of 1 week each |
| 3.    | Manzoor  
_PROFESSOR, Amrita_ | Rice University | 1 visit of 1 week |
| 4.    | Tony Mikos  
_PROFESSOR, Amrita_ | Amrita Vishwa Vidyapeetham and Cellworks | 3 visits of 1 week each |
| 5.    | Sarah Heilshorn  
_ASSISTANT PROFESSOR, Amrita_ | Amrita Vishwa Vidyapeetham and Cellworks | 1 visit of 1 week |
| 6.    | Lakshmi Nair  
_ASSISTANT PROFESSOR, Amrita_ | Amrita Vishwa Vidyapeetham | 2 visits of 2 weeks each |
| 7.    | Cato Laurencin  
_PROFESSOR_ | Amrita Vishwa Vidyapeetham | 1 visit of 1 week each |
| 8.    | Nitya  
_STUDENT_ | University of Connecticut | 3 months |
| 9.    | Girdharan  
_STUDENT_ | Rice University | 2 months |
| 10.   | Praveen  
_STUDENT_ | Stanford University | 2 months |
| 11.   | Binulal Sathay  
_STUDENT_ | Rice University | 3 months – to be completed in Dec |
| 12.   | Patrick Benitez  
_STUDENT_ | Amrita Vishwa Vidyapeetham | 2 months |
| 13.   | Erica Levorson  
_STUDENT_ | Amrita Vishwa Vidyapeetham | 3 months |


- Patents in preparation (to be filed and requires some additional data in process)


- A distributed nanostructured scaffold for growth of vascularized tissue, Binulal Sathay, Shantikumar Nair and Antonios Mikos

- Micro-nano scaffolds for cartilage tissue applications, Erica Levorson, Antonios Mikos, Krishnaprasad Chennazhi and Shantikumar Nair, in preparation
About the Center

The goals identified for the Joint Center are:

- Research in the area of biomass related COPD (Chronic obstructive pulmonary disease) and other lung diseases in non-smokers by utilizing the cohort set up in rural Pune, India, to decrease the burden and mortality of environmental lung diseases.
- Improve the understanding of COPD in non-smokers and help develop novel prevention and therapeutic strategies directed to the affected population in future.

Work Plan/Methodology

- Organize a joint meeting between the US and Indian partners, with the objectives of: meeting each other, identifying the key priority research questions, understanding the research expertise of the collective group, designing appropriate study methodology and planning the research studies to be undertaken.
- Collecting particulate matter samples from indoor homes in India that use biomass fuel for in vivo animal exposure studies and in vitro cell culture studies to generate pilot data to help and understand the potential biological mechanisms of how biomass fuel smoke particle mediate biological responses.
- Breysse and Diette visit to India and assist in building up a system (particulate cyclone collector) to help collecting particulate matter samples from homes using biomass fuel for cooking. The collected particles to be shipped to IGIB and Johns Hopkins for characterization and mice model studies to study the effect on innate immune response, lung function and carcinogenicity. (Time duration: 6-12 months.)
- Designing of epidemiological and basic research studies to develop the research in the area of biomass related COPD and other lung diseases in non-smokers by utilizing the cohort set up in rural Pune, India to decrease the burden and mortality of environmental lung diseases.
- Submission of research proposal to appropriate funding agencies in USA, India and other places interested to fund such an initiative. Potential funders aimed to target were: The Welcome Trust, The Bill Gates Melinda Foundation, The Bloomberg Foundation, WHO and NIH. Grant applications to be submitted to different agencies.

Achievements

Multiple brainstorming sessions and meetings were held to address the key problem related to environmental lung disease in India. Biomass fuel use related pollution was identified as one of the most pressing
### Partnering Institutions

**INDIA**
- Chest Research Institute (CRF), Pune
- KEMS Hospital Research Centre, Pune

**US**
- Johns Hopkins University
- National Institute of Environment Health Sciences

### Exchange Visits

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name of the Scientist/Student Affiliation</th>
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<th>Duration/Time Period</th>
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<td>1</td>
<td>Jesse Negherbon</td>
<td>CRF</td>
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<td></td>
<td>Johns Hopkins</td>
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<td>2</td>
<td>Shyam Biswal</td>
<td>CRF, IGIB</td>
<td>2 weeks</td>
</tr>
<tr>
<td></td>
<td>Johns Hopkins</td>
<td></td>
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<tr>
<td>3</td>
<td>Shyam Biswal</td>
<td>CRF, IGIB</td>
<td>1 week</td>
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<tr>
<td></td>
<td>Johns Hopkins</td>
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<tr>
<td>4</td>
<td>Shyam Biswal</td>
<td>CRF, IGIB</td>
<td>2 weeks</td>
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<td></td>
<td>Johns Hopkins</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>Patrick Breysse</td>
<td>CRF</td>
<td>1 week</td>
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<td></td>
<td>Johns Hopkins</td>
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<tr>
<td>6</td>
<td>Anurag Agrawal</td>
<td>Johns Hopkins</td>
<td>1 week</td>
</tr>
<tr>
<td></td>
<td>IGIB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Rajesh Pandey</td>
<td>Johns Hopkins</td>
<td>3 months</td>
</tr>
<tr>
<td></td>
<td>IGIB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Anurag Agrawal</td>
<td>Joint meeting at ATS</td>
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<tr>
<td></td>
<td>IGIB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Sundeep Salvi</td>
<td>Joint meeting at ATS</td>
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<td></td>
<td>CRF</td>
<td></td>
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<tr>
<td>10</td>
<td>Veena Muralidharan</td>
<td>Johns Hopkins</td>
<td>3 months</td>
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<td></td>
<td>VRHC</td>
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</tr>
<tr>
<td>11</td>
<td>Sneha Limaye</td>
<td>Johns Hopkins</td>
<td>1 month</td>
</tr>
<tr>
<td></td>
<td>CRF</td>
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- Sampling instrument at rural houses, India
- Sample collection from Households
problems. Approximately 3 billion people—half the worldwide population—are exposed to extremely high concentrations of household air pollution due to the burning of biomass fuels on inefficient cookstoves, accounting for 4 million annual deaths globally. Yet, our understanding of the pulmonary responses to household air pollution exposure and the underlying molecular and cellular events is limited.

Breysse and Diette visited India and assisted in building up a system (particulate cyclone collector) to help collecting particulate matter samples from homes using biomass fuel for cooking. The two most prevalent biomass fuels in India are wood and cow dung, and typical 24-hour mean particulate matter (PM) concentrations in homes that use these fuels are 300 to 5,000 μg/m³. Pulmonary responses were studied in mice given acute or subchronic exposure to wood or cow dung PM collected from rural Indian homes. It was found that subchronic exposure to PM collected from households burning biomass fuel elicits a persistent pulmonary inflammation largely through activation of TLR and IL-1R pathways, which could increase the risk for chronic respiratory diseases. In addition, the PM were characterized in terms of content, which may provide further insights.

In conclusion, the findings provided important insights that may guide policy making and affect the health of billions of people in time to come.

**Publications**

Indo-US Joint Center on
Inflammatory Bowel Diseases

About the Center
The Joint Center focuses on a multifaceted approach to address certain critical questions. These are:

• Genome wide gene expression analysis for target genes to differentiate patients with Intestinal tuberculosis and Crohn’s disease
• Defining the Tim3 –Gal9 interaction in human colonic tissue and evaluating if Tim3 and Gal9 represent novel cell surface targets to modulate antimicrobial immunity and control mycobacterial infection in the intestine
• Cytokine signatures of inflammatory micro-domains in patients with Crohn’s disease and Intestinal tuberculosis with respect to Th1 and Th17 effector sets
• Smoking and oral tobacco as an epidemiological factor for IBD
• Pathogen sensing in granulomas of Crohn’s disease
• Resource nurturing by holding a symposium on basic immunology
• Capacity building of the trained manpower involved in these experiments so that their respective expertise can be used as a model for elucidating translational immunological perspectives

Work Plan/Methodology
First 12 months:
• The first proposed activity to be undertaken is to organize a joint meeting between the US and Indian partners preferably in India with the objectives of: meeting each other, defining areas of responsibility identifying the key priority research questions, understanding the research expertise of the collective group, fine tuning the objectives of the center and working out the time line for all the research domains as per the proposal.
• Enrolling a pilot group of patients with ITB and CD ( 10 each ) an collecting the mucosal samples for whole genome microarray
• Enrolling a group of 10 naïve patients with CD and UC each and collecting mucosal samples at presentation, after 3 months of therapy and thereby maintaining their longitudinal follow up to investigate the cytokine signatures in inflammatory micro-domains in these patients
• Enrolling a group of ITB patients before starting therapy and looking at Tim3-Gal 9 interactions in colonic mucosa.
• Deep sequencing of CD biopsies in USA to search for pathogen sequences in microgranulomas.

Principal Investigators

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Partnering Institutions

**INDIA**
- All India Institute of Medical Sciences (AIIMS), New Delhi
- Translational Health Science & Technology Institute, Gurgaon

**US**
- Brigham and Women’s hospital of Harvard Medical School, Boston
- Massachusetts General Hospital, Boston

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Exchange Visits

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<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
<th>Institute(s) Visited</th>
<th>Duration/Time Period</th>
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<tr>
<td>1</td>
<td>Vijay Yajnik</td>
<td>AIIMS</td>
<td>10 days&lt;br&gt;24.11.13- 2.12.13</td>
</tr>
<tr>
<td>2</td>
<td>Vijay Kuchroo</td>
<td>AIIMS</td>
<td>12 days&lt;br&gt;24.11.13-04.01.14</td>
</tr>
</tbody>
</table>

- From the Indian side there will be 4 faculty visits each for a period of 14 days and 2 student visits for 12 weeks of training and research.
- From the US side there will be 3 faculty visits for a period of 2 weeks.

Next 12 months:
- Whole genome microarray for ITB and CD samples
- Deep sequencing of tissue granulomas for pathogens in Indian cohort of ITB and CD
- Maintaining longitudinal follow up of naïve patients enrolled and collecting and analyzing samples at various stages of activity to define inflammatory micro-domains which would serve as a road map for therapeutic planning
- A 2 day symposia on Immunology will be organized in India for capacity building of trained resources
- From the Indian side there will be a total of 4 faculty visits each for a period of 14 days and 2 student visits for 12 weeks of training and research during the two years.
- From the US side there will be 4 faculty visits for a period of 2 weeks.
- To sustain the program, the data generated will be analyzed and scope for further work will be ascertained and thereafter we plan to write research proposals to appropriate grant agencies in USA, India and other places who would be interested to fund such an initiative.

Publications

Achievements

Brief Summary of the work done:

**Objective A**
Genome wide gene expression analysis for target genes to differentiate patients with Intestinal tuberculosis and Crohn’s disease.

**Lead Persons** - Vineet Ahuja, Amit Awasthi (India) ; Vijay Kuchroo, Vijay Yajnik, Matthew Meyerson (USA)

**Work Done** - There is no biomarker to differentiate between Crohn’s disease and Intestinal TB and this study has been planned to search for a potential biomarker. 10 cases each of Intestinal TB and Crohn’s Disease have been recruited and followed up for one year for accurate categorization of phenotype. Colonic Biopsy samples as well as faecal samples have been collected for metagenome sequencing and transcriptome analysis. The laboratory analysis will be done in India and advanced bioinformatics analysis will be done in USA.

**Work to be done** - Samples have been collected and stored for metagenome sequencing and transcriptome analysis by next generation sequencing methods.
**Objective B**

Defining the Tim3 – Gal9 interaction in colonic tissue and evaluating if the in vivo responses mirror the mice study;

Can Tim3 and Gal9 represent novel cell surface targets to modulate antimicrobial immunity and control infection *in-vivo*.

**Lead Persons** - Vijay Kuchroo (USA); Vineet Ahuja (India)

**Work Done** - Over the last two years the US-PI has extensively published on Tim3 and Gal 9 in various disease states. Publications on this aspect over last two years

*In which US-PI is the corresponding author or co-author include:*

- Fragile TIM-4-expressing tissue resident macrophages are migratory and immunoregulatory. J Clin Invest. 2014 Aug 1;124(8):3443-54.

**Work to be done** - Indian PI has enrolled 81 patients of Crohn’s Disease, 24 patients of Intestinal TB and 41 controls and taken the colonic biopsy samples for subsequent analysis for Tim3- Gal9 interactions. The analysis will be done by Indian students after 12 weeks training in Dr Kuchroo’s Lab in USA.

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**Objective C**

Cytokine signatures of inflammatory micro-domains in patients with Crohn’s disease and Intestinal tuberculosis with respect to Th1 and Th17 effector sets.

**Lead persons** - Amit Awasthi , Vineet Ahuja (India); Vijay Kuchroo (USA)

**Work Done** - Blood samples and colonic biopsy samples have been taken from control group and Th1, Th2, Th17 and T regulatory responses with and without Vitamin A (retinoic acid) have been assessed. Dendritic cell studies from peripheral blood have also been done.

**Work to be done** - Protocols of Dendritic cell isolation from colonic biopsy are being established with the guidance of US – PI and further studies on effect of Retinoic Acid on immune responses generated by dendritic cells from inflammatory tissue will be studied. Subsequently, IBD patients will be recruited and cytokine responses will be studied.

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**Objective D**

Smoking and oral tobacco as an epidemiological factor for IBD

**Lead Persons** - Ashwin Ananthkrishnan (USA), Vineet Ahuja, Govind Makharia (India)

**Work done** - A cohort of 3000 patients of IBD is on follow up at AIIMS. To evaluate the effect of smoking and in particular oral tobacco, a structured proforma has been generated and all the patients are being interviewed for the same.

**Work to be Done**: Data on around 1000 patients has been collected and rest is on going.

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**Objective E**

Pathogen sensing in granulomas of Crohn’s disease

**Lead persons**: Vineet Ahuja, Govind Makharia (India); Vijay Yajnik, Matthew Meyerson (USA)

**Work Done**: A cohort of 130 patients of Int TB and Crohn’s Disease has been recruited and are on regular follow up to ascertain disease course and responses to therapy. Colonic biopsy specimens have been taken and two groups have been made: biopsies with granulomas and biopsies without granulomas.

**Work to be completed** - *in-situ* PCR has to be done on the collected samples to assess for enteroadhesive E.coli and intracellular bacteria.

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**Objective F**

Resource nurturing by holding a symposium on basic immunology
<table>
<thead>
<tr>
<th><strong>Objective G</strong></th>
<th><strong>Lead Persons</strong>- NK Mehra, SK Acharya (India); Vijay Kuchroo, Vijay Yajnik (USA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity building of the trained manpower involved in these experiments so that their respective expertise can be used as a model for elucidating translational immunological perspectives.</td>
<td><strong>Work Done</strong>- A two day symposium on Gastrointestinal Immunology was done in Jan 2013 in India which was attended by 170 students (basic sciences as well as clinical sciences). In addition, one student visit from India to US has taken place. <strong>Work to be done</strong>- Three student visits from India to USA are planned. These are all Ph.D students and will undergo training in Dr. Vijay Kuchroo’s Lab and IBD core facility at MGH, Boston. Another two day GI Immunology symposium is planned.</td>
</tr>
</tbody>
</table>

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<tr>
<th><strong>Objective H</strong></th>
<th><strong>Lead persons</strong>- Vineet Ahuja, Amit Awasthi (India); Vijay Kuchroo (USA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relationship of high salt diet with H. pylori induced gastric inflammation and premalignant lesions of gastric cancer in high altitude inhabitants with dyspepsia.</td>
<td><strong>Work Done</strong>- The US- PI has shown in a recent landmark study that high salt intake leads to increased Th17 inflammation. Wu C, Yosef N, Thalhammer T, Zhu C, Xiao S, Kishi Y, Regev A, Kuchroo VK. Induction of pathogenic TH17 cells by inducible salt-sensing kinase SGK1. Nature. 2013 Apr 25; 496(7446):513-7. <strong>Work to be done</strong>- Indian PI has planned to recruit patients from Ladakh where he has already in a previous study shown a 90% prevalence of H. pylori with atrophic gastritis in a population with a high salt intake. This recruitment work will include endoscopic biopsies from patients with dyspepsia in Leh, Ladakh and is planned in last week of August 2014 and subsequently mRNA expression of SGK1 will be seen in gastric biopsies of this select group.</td>
</tr>
</tbody>
</table>
About the Center
The Joint Center are to provide a mechanism for eye care practitioners and vision scientists in the United States and India. Primarily to achieve the following objectives:

• Develop an understanding of the level of training and scope of practice of US optometrists.
• Develop an understanding of the level of training and scope of practice of Indian ophthalmologists and optometrists.
• Provide an opportunity for beneficial exchange to enhance clinical training and research opportunities and relationship-building between US and Indian eye-care providers and vision scientists.
• Develop a long-term relationship for exchange of ideas on clinical care and vision research.
• Develop collaborative research programs that span from basic to clinical and community.

Work plan/Methodology
In November 2012, Drs. Cantor, Soni, and Don Lyon, all Indiana University faculty travelled to India (photos attached) to visit each of the four partner sites, to meet all of the eye-care professionals involved in the exchange program and to review and develop detailed educational plans. Plans were developed for faculty and residents who were to participate in this exchange program. The goals for the program were to provide extensive clinical opportunities for US visitors and clinical, teaching and research opportunities for Indian visitors. The process for selection and training was developed and implemented by February 2013.

The first group of Indian eye-care professionals visited the US in April-June 2013.
Partnering Institutions

**INDIA**
- SankaraNethralaya, Chennai
- Hinduja Hospital, Mumbai
- Shroff Eye Hospital, Mumbai
- LVP Eye Institute, Hyderabad

**US**
- Indiana University School of Medicine, Indianapolis (IUSM)
- IU School of Optometry, Bloomington (IUSO)
- Ohio State University College of Optometry (OSU)

The first group of US residents visited India in April-May 2013. The second group of Indian visitors visited US between May-September 2014, and the second group of residents is in the midst of their visits to India which were scheduled between March - October 2014. The second group of US residents, as had been proposed, included one from IUSO and two from the Ohio State University College of Optometry. The IUSO residency director, Dr. Lyon visited LVPEI in April 2013.

The work plan was developed for each visitor in consultation with their mentors at the visiting site and the home departments. These plans included opportunities to engage in observation of patient care, participation and consultation on research and teaching activities. Each visitor kept a daily log of activities. Brief summaries of goals and achievements of each visitor are listed below in order of their visits.

**US visitors (2013)**

**Dr. Sill’s** goals at LVPEI were to gain more exposure to advanced anterior and posterior segment disease as well as working with specialty contact lenses. Her mentors approved her goals which for the most part, she was able to achieve while at LVPEI. In her exit survey she noted that patient care is different at LVPEI compared to IUSO because of the large patient volume, the severity of diseases and differences in treatment medications (i.e., different antibiotics used). As a result of the visit Dr. Sill became more skilled at diagnoses and treatment of anterior segment disease conditions and is now in private practice.

**Dr. Eugenio’s** goals at LVPEI were to gain more exposure to the different types of ocular disease conditions and learning about the health care system in India. Her mentors at LVPEI were Dr. Jalali and Dr. Sangwan. Dr. Lyon approved the goals. In the exit survey Dr. Eugenio declared that she was able to meet her goals, and learned more than she expected especially about conditions that she would not typically see in the US and that the knowledge she gained at LVPEI has already helped her to become a better doctor.

**Indian visitors (2013)**

**Ms. Hussain** visited IUSO’s Vision Development Laboratory and worked with Dr. Rowan Candy. Drs. Candy and Kumar approved her goals that included study of binocular vision in infants. Specifically, she worked on understanding aspects of infant vision including psychophysical techniques of assessment, such as photo-refraction. Her long term goal is to establish collaborative research between Elite School of Optometry, Sankara Nethralaya and Indiana University’s Vision and to establish a Vision. While at IUSO Ms. Hussain also worked with Drs. Arthur Bradley on visual performance in myopia, Dr. Vidhya Priya in Dr. Thibos’ lab understanding image quality measurements in myopia and visited Dr. Don Lyon’s...
Vision Therapy Clinic. Rizwana Hussain visited IU again in October 2013. Dr. Candy is scheduled to visit SN/ESO in 2015, this collaboration will continue.

**Dr. Samant’s** visit to IU focused on observation of the various clinical patient care protocols at IUSM, the surgical facilities and procedures at IUSM, to take part in the various academic activities of IUSM and visit the various research labs at IUSO.

**Ms. Mody’s** goals were focused on learning new techniques and procedure in treating patients with binocular vision disorders. She had identified a specific interest in Binocular Vision and Vision Therapy clinic. She studied with Dr. Don Lyon, Adrianna Hempalmann, Wong, Jarrad and Annie Sill.

**Mr. Parthasarathi Kalaisel** was interested in research, clinical care and teaching. He worked with Dr. Begley on Dry Eye and Tear Film research, engaged in observation of clinical treatment and management strategies for various eye diseases and use of contact lenses to treat eye disorders. He worked with clinical faculty at IUSO to develop an understanding of strategies that IUSO faculty use to train optometry students in clinical care. Mr. Kalaisel also worked with Drs. Neil A. Pence, Jane Ann Grogg, Dr. Todd Peabody, Jeffrey D. Perotti and Dr. Malinovsky.

All visitors to IUSO in 2013 have commented on and demonstrated their understanding of optometry training at IUSO as very comprehensive, challenging and quite different from their own institutions.

### Exchange Visits

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<tr>
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<th>Institution(s) Visited</th>
<th>Duration/Time Period</th>
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<td>1</td>
<td>Sarita Soni – not paid by IUSSTF</td>
<td>SN/ESO, LVPEI, Hinduja and Schroff</td>
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<td>LVPEI</td>
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<td>Eilene Eugenio</td>
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<td>Don Lyon</td>
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<td>Rizwana Hussain</td>
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<td>Preetam Smant</td>
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<td>IUSO &amp; Pediatric Optometry Clinic</td>
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<td>Shroff &amp; Hinduja</td>
<td>3/27/14 to 4/19/14</td>
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<td>Nazia M Sarwar</td>
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<td>5/25/14 to 6/20/14</td>
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<td>Seema Satpute</td>
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<td>5/25/14 to 6/20/14</td>
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<td>Tamara Oechslin</td>
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<td>16</td>
<td>Greg Hopkins</td>
<td>LVPEI</td>
<td>9/28/14 to 9/18/14</td>
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</table>
To the person, all participants agreed that it is critical to initiate contact with the mentors early in order to develop realistic, focused and detailed plans that can be accomplished in the limited time available through this funding mechanism.

**US visitors (2014)**

Dr. Obechain in consultation with Dr. Lyon (his US mentor) decided to visit Schroff and Hinduja Hospitals in Mumbai. His goals included gaining perspective on Indian Eye Care delivery and exposure to new examination techniques, treatment and management theory, and unique pathology unlikely to be seen in the U.S. Specifically, he was interested in observing and participation in pediatric eye exams and surgery, in particular with strabismus and amblyopia, retina specific eye exams and surgery and patient examination with anterior segment, neuro-ophthalmology, and glaucoma. He was mentored by Dr. Ashwin Sainani and Dr. Anand Shroff.

Dr. Tamara, her mentor Dr. Earley at OSU and Ms. Rizwana at SN/ESO developed a detailed plan for her visit to SN/ESO. Her goals included visiting schools for vision screenings, observation in binocular vision clinic and teaching at ESO. Dr. Oechslin hopes to develop a long term collaborative relationship around research with the staff and faculty at SN/ESO.

Dr. Hopkins worked with Dr. Earley at OSU and Dr. Bharadwaj at LVPEI to develop a program that will focus on Low Vision research and patient care. He will work with Dr. Prem Nandhini Satgunam on pediatric contrast sensitivity measurement. Dr. Hopkins will also work with Dr. Vijaya Gothwal, Head of LVPEI Centre for Sight Enhancement on the LVP-FVQ survey(s) and Dr. Beula Christy, Head of Centre for Rehabilitation of Blind & Visually Impaired to explore the interdisciplinary model of rehabilitative care at the LVPEI. During the final week, Dr. Hopkins will work with Mr. Ganesh Jonnadula, Head of Optometric academic affairs to expand his understanding of the management of vision loss from anterior segment disease.

**Indian visitors (2014)**

Ms. Narayanan worked with Drs. R Krishna Kumar and Sarita Soni on her goals that include understanding the impact of uncorrected vision in young children. She spent her time (May-June 2014) at IUSO identifying and studying quality of life questionnaires. Ms. Narayanan reviewed myopia and hyperopia literature with a focus on review of the questionnaires used and the questions posed to address “why children do not wear glasses which improves their vision?” She has a long term plan to study this question in collaboration with Dr. Soni. She visited the various clinics that form the larger Atwater Patient Care Center at IUSO.

**Ms. Sarwar's** goals which were approved by Dr. Nayak (Hinduja Hospital) and Dr. Lyon did not include research but were focused on learning new techniques and procedure in diagnosing and treating patients with binocular vision disorders. She had identified a specific interest in Binocular Vision and Vision Therapy clinic. Her goal was to enhance her skills in patient management while at IUSO in May-June 2014.

**Ms. Satpute's** goal while at IUSO (May –June 2014) was to “learn contact lens fitting and prescription along with dispensing of glasses at a higher level along with basics of low vision aid”. She did not express an interest in research. She wanted to enhance her own skills so that she could contribute to her Institution’s “Quality Healthcare for Eyes” program. Dr. Abha Shroff and Dr. Neel Pence worked with Ms. Satpute to develop her plan that included observations in the Contact Lens Clinic, Low Vision Clinic and in the Ophthalmic Dispensary. Her commitment to improving her own skills and then enhancing services in her own department at Shroff Eye Hospital was the reason she was selected.

Mr. Maseedupalli is visiting IUSO from August 24 to September 22, 2014. His mentors Dr. Bharadwaj (LVPEI) and Dr. Brooks (IUSO) agreed on a program that is focused on understanding teaching methodologies in Ophthalmic Optics, to observe the edging process of the spectacle lenses and dispensing the spectacles in the
dispensary. Mr. Maseedupalli is attending Dr. Brooks’ lectures in Geometrical and Ophthalmic Optics to optometry students and working with Dr. Brooks and his teaching assistants in laboratory.

Achievements

- Every Indiana visitor has commented on the comprehensive training and education that US optometrists receive and their ability to diagnose and treat ocular disorder including eye diseases.
- All US visitors to India understand the extensive training that ophthalmologists receive and are concerned that optometrists who can be substantial partners in providing eye care are not being trained to fully diagnose and treat eye disorders and diseases.
- Developing long term collaborations in research. The three researchers who have already visited IUSO continue to collaborate with IUSO faculty.
- ESO is organizing an International Vision Science & Optometry Conference in 2015 in which faculty from Indiana and LV Prasad Eye Institute play a significant role in research collaboration.
- IUSO and SN faculty led by Professor SP Srinivas recently received a collaborative research award Prevention of Corneal Blindness: Collaboration between IUSO and SN from the Obama-Singh 21st Century Knowledge Initiative.
About the Center
The Joint Center proposes to test an innovative sustained local drug release nanoparticle platform for head and neck cancer (HNC) capable of locally radiosensitizing the specific HNC malignant site and minimizing systemic toxicity and reducing the radiation dosage. The proposed design involves using poly(lactic-co-glycolic acid) (PLGA) nanoparticles loaded with a model radiosensitizing drug Docetaxel (DTX) which will be administered intratumorally to provide localized in-situ delivery of the sensitizer to the tumor site. This is expected to avoid the toxicity associated with current systemic delivery of radiosensitizers. It is anticipated that the proposed nanoparticle will improve the therapeutic ratio of radiation therapy without introducing additional patient interventions. This innovative approach is expected to result in new modalities in localized chemotherapy (LCT) and localized chemo-radiation therapy (LCRT).

The overall scientific goal for the project is to study the efficacy of LCT and LCRT using docetaxel loaded PLGA nanoparticles. It was projected to achieve this goal through three specific aims where aim 1 constituted the significant part for first year study along with initial studies for aim 2 and aim 3.

Aim 1: Fabrication and characterization of DTX-loaded PLGA nanoparticles (DTX-PLGA-NP) and In-vitro kinetic studies to optimize release kinetics.

Aim 2: In-vivo time dependent intra-tumoral distribution profile using optical near infrared fluorescence imaging and therapeutic efficacy of LCT with the DTX-PLGA-NP administered intra-tumorally.

Aim 3: Studies of the efficacy of LCRT combining chemo- and radiation using DTX-PLGA-NP with brachytherapy I125 seeds.

Aim 4: Data analysis for planning the phase I clinical studies of the DTX-PLGA-NP System.

Achievements
- Successfully synthesized PLGA-DTX nanoparticles at Northeastern University, Boston and two students at NPL has been trained for the same by our collaborators from NEU during their visit.
- Carried out the preliminary in-vivo imaging studies in tumored animals to evaluate the imaging potential.
- The release kinetics profile and In-vitro results are promising and formed the basis for further animal studies which are planned to be accomplished at IITR Lucknow.
- Synthesized fluorescent gold nanoclusters at NPL whose toxicity and feasibility for enhancing radiation therapy have been tested at NEU. Preliminary results are encouraging.
As a spinoff to these interactions the center has planned to host an international conference on translational nanomedicine at Institute of Life Sciences, Ahmedabad University during 15-17, December, 2014, where our collaborator Prof. Rishi Shanker is working on in-vivo experiments.

Scientific Value Addition
We have followed the work plan and methodology that has been proposed in the submitted proposal. In first year we were supposed to synthesize and characterize PLGA-DTX nanoparticle drug conjugate system and evaluate drug release kinetics and their In-vitro efficacy on cancer cell lines through cytotoxicity assay and In-vitro cellular uptake assay. The PLGA-DTX system has been synthesized at NEU. The students (Ms. Manjri Singh and Ms. Richa Baronia) at NPL got trained in synthesizing these nanoparticles by Dr. Rajiv kumar from NEU. The designed nanoparticle systems has been given to IITR, Lucknow for In-vitro and in-vivo studies. One student (Ms Parul Gupta) is getting trained at IITR, on culturing oral cancer cell lines FaDU and SCC-9. She is optimizing the process and protocols on FaDU cells using a simple nano drug delivery vehicle (GO-DOx) prepared at NPL. The students at NPL and IITR has already started working in unison and are getting some promising results. Now they have started working with PLGA-DTX nanoparticles synthesis characterization and In-vitro studies on SCC-9 oral cancer cell lines. With this background they will visit to their counterpart at NEU to work with radiation therapy, which the student at NEU has already started.

Center has synthesized PEGylated PLGA nanoparticles encapsulating DTX using simple nanoprecipitation method in a single step. This novel nanoprecipitation method yields PLGA nanoparticles of uniform size with PEG decorated surface as shown in figure 1. A surfactant is used to create negatively charged surface of the nanoparticles so that on systematic administration...
they can rapidly opsonized by the reticuloendothelial system (RES).

**Characterization of Nanoparticles**: Both the nanoparticles formulations (DTX/Cy7.5/PEG-PLGA and DTX-Cy7.5-Silica nanoparticles) were extensively characterized using various techniques. The Photophysical characterization was done using UV-Visible and Photoluminescence spectroscopy and the Physico-chemical characterization was done using Transmission Electron microscopy (TEM), Dynamic Light Scattering (DLS) and zeta potential studies.

Figure 1 shows the physico-chemical characterization of DTX/Cy7.5/PEG-PLGA nanoparticles encapsulating Cy7.5 and DTX. Figure 1a and 1b shows the size and morphology of the nanoparticles as studied by TEM and DLS respectively. TEM image shows a spherical morphology of the nanoparticles with a narrow size distribution and average size of 120 nm in diameter. The size of nanoparticles were further correlated with DLS measurements which showed the hydrodynamic diameter of ~150nm which is in agreement with TEM results. The size of the nanoparticles measured by TEM shows the actual core size as opposed to the hydrodynamic diameter measured with DLS. The zeta potential measurements were also carried out to measure the net surface charge of the nanoparticles. The results obtained from this study showed a partial negative charge due to the presence of PEG molecules on the surface of nanoparticles. A partial negative charge on the nanoparticles surface is known to help in reducing the serum protein binding to the nanoparticles which usually results in rapid clearance via the hepatobiliary route in systemic circulation in-vivo.

Figure 1c and 1d represents the photophysical characterization of DTX/Cy7.5/PEG-PLGA nanoparticles. Figure 1c shows the absorption spectra of the Cy7.5 encapsulated PLGA nanoparticles with a distinct absorption band at λmax 800nm which is a characteristic optical signature of Cy7.5 in solution. Figure 1d shows the comparative photoluminescence studies with different formulations of Cy7.5. Free Cy7.5 in DMSO showed a strong emission band at 830nm when excited using 770nm wavelength. The emission peak from Cy7.5 encapsulated in PLGA nanoparticles appeared at almost similar wavelength ~825nm, the slight hypsochromic shift and reduced intensity of Cy7.5 inside nanoparticles can be due to aggregation and solvent effect on the Cy7.5 molecules. Free cy7.5 molecules being hydrophobic in nature did not showed any fluorescence in aqueous environment. This clearly shows that Cy 7.5 is encapsulated inside the core of PLGA which protects and stabilize the dye molecules in aqueous environment.

**Release Kinetics Studies**: The encapsulation efficiency (EE) and the rate of release of DTX from DTX/Cy7.5/PEG-PLGA nanoparticles was quantified using HPLC at 30 oC with a mobile phase of methanol/H2O (70/30, v/v) and a flow rate of 1.0 ml/min using a C18 reverse phase column. The DTX EE was calculated as the ratio between the encapsulated DTX over the initial drug amount used for synthesis. DTX was extracted from the dialysed nanoparticles using dichloromethane (DCM) and quantified the drug in DCM to get the encapsulated drug. The concentration of drug remaining in the nanoparticles was subtracted from the encapsulated drug and plotted against time. Figure 2a shows the release profile of the encapsulated DTX from the DTX/Cy7.5/PEG-PLGA nanoparticles (EE~70%) in buffered solution as measure by the HPLC method. The release of the drug from nanoparticles was monitored by the dialysis method against the infinite pool of buffered tween 80 solution. It can be visualized from the figure that nanoparticles encapsulating DTX showed a slow

![Figure 3: in-vivo optical imaging with live mice injected with Cy7.5-PLGA nanoparticles. Nanoparticles were injected intratumorly in tumored mice. The mice were imaged everyday with same settings and same exposure time.](image)

![Figure 4. Morphology of FaDu cells treated with Dox and GO-Dox](image)
and sustained release of the encapsulated drug with over 60% of the drug released in 9 days. Figure 2b shows the release of DTX from DTX-Cy7.5-Silica nanoparticles over a period of 6 days. The release profile shows a slow and sustained release of DTX from the nanoparticles with almost 60% of the encapsulated drug released over 6 days. This slow and sustained release of the DTX from the nanoparticles is very favorable in case of combined radiation therapy where in conventional approach the drug clears out faster due to the burst release within a day. However, upon radiation therapy combined with nanoparticles encapsulating DTX, in addition to radiosensitization from the DTX molecules, the repair mechanism of the cancer cells will be hindered because of a continuous supply of DTX to the cancer cells from the nanoparticles.

**Preliminary in-vivo imaging studies with Cy7.5/PEG-PLGA nanoparticles:** To evaluate the imaging capability of the Cy7.5/PEG-PLGA nanoparticles we injected the nanoparticles intratumorly in a tumored mice model. Figure 3 shows the live in-vivo fluorescence imaging of the mice injected intratumorly with Cy7.5/PEG-PLGA nanoparticles. The mouse was imaged every day to see the localization and clearance of nanoparticles from the tumor. Day 1 fluorescence image of the mice showed a bright fluorescence from the tumor which over a period of 36 days continuously spread around the tumor area. It is very encouraging to see the localization of the nanoparticles inside the tumor even at 36th day. A slight decrease in fluorescence intensity on 36th day as compared to the 16th day can be attributed to the bleaching of the fluorophore as well as because of the distribution of the nanoparticles over larger area. The fluorescence imaging on the ressected tumor from the mice showed a bright fluorescence from the tumor showing the localization of nanoparticles in the tumor. Also the fluorescence signal from the mice after the tumor resection suggests the distribution of the nanoparticles around the tumor area. Further in-vivo experiments with the nanoparticles encapsulating both the DTX/Cy7.5/PEG-PLGA nanoparticles for combined therapeutic approach are underway in prostate cancer orthotopic mice model. These preliminary in-vivo imaging results clearly shows a great potential of these nanoparticles in simultaneous tracking along with delivery of therapeutic to the target site.

**In vitro cellular uptake studies:** Three students Ms Manjri Singh, Ms Richa Baronia and Ms Parul Gupta have been trained in material synthesis, characterization and in vitro studies. The initial cell viability studies at CSIR-IITR has been carried out with graphene oxide (GO) and doxorubicin nanoconjugate (synthesized and characterized at CSIR-NPL) on FaDu hypopharyngeal carcinoma cell lines using the MT T and LDH assay. From figure 4, GO-Dox has been found to be more cytotoxic and selective in comparison to the free drug. Further the bright field microscope pictures clearly indicate that the cellular viability gets seriously compromised after contact with the GO/Dox compared to free DOX. Various cell death factors including generation of intracellular reactive oxygen species and mitochondrial membrane potential responsible for cell viability has been investigated to understand the mechanism responsible for cell death. Both graphene oxide and GO/Dox exhibits cell viability in a dose

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Figure 5. In-vitro cytotoxicity of the free DOX and GO+Dox on the viability of FaDu Cells
dependent manner (Figure 5). The exact mechanism through which a GO/Dox exerts oxidative stress is relatively difficult to identify and still remains to be elucidated. To assess whether or not the increased ROS levels may have originated from GO- and GO/Dox induced alterations in mitochondrial processes, the nanomaterials’ effect on the mitochondrial integrity was investigated. It was observed that exposure to GO and GO/Dox resulted in a decrease in fluorescence intensity in the MMP assay indicating mitochondrial membrane depolarization and/or down regulating mitochondrial functions.

Further, based on these preliminary studies and as described in our specific aim we have started dose-dependent cytotoxic assays docetaxel and PLGA-DTX on HNSCC cell line SCC-9 and FaDu. We have planned to investigate the particle uptake study using different approaches i.e. confocal microscopy, transmission electron microscopy (TEM) and flow cytometry. Furthermore we will investigate docetaxel-induced cell death with annexin V, propidium iodide staining, and poly (ADP-ribose) polymerase cleavage assays. For the study we will examine the contribution of these apoptotic routes to the cell killing effect of PLGA-Docetaxel on SCC-9 and FaDu cell lines. Caspase activity and cleavage assays will also be investigated.
About the Center

Dr. Rajesh S. Gokhale, Institute of Genomics and Integrative Biology and Dr. Thomas Alber, University of California initiated a collaborative project on tuberculosis (TB) in India and Bay area of the USA. The project aimed in providing fundamentally new approaches to TB drug discovery and vaccine development.

As per the mandate of the project, a trip to US in July, 2012 was organized in order to discuss collaborative proposals with the Human immune monitoring centre (HIMC), Stanford University and attend the two day meeting on “India-Bay Area TB Research Conference” at the University of California, Berkley, USA.

There were discussions to develop the most recent technologies like CytoF based immune monitoring system and further, transfer the technology to India and use Mtb samples.

However, few exchange visits were carried out between both the partner countries, but the objectives were only partially achieved due to sudden medical problem which led to untimely demise of Prof. Thomas Alber, the program could not achieve what it was supposed to.

Scientific Value Addition

The project was initiated at a very good note with few exchange visits between the two partner countries.
However, little scientific work could be transformed into technology because of poor health leading to untimely demise of the initiator of the program, Prof. Thomas Alber from the USA side.

**Way Forward**
Because of the poor health of the initiator of this program, the program could not achieve what was perceived. Prof. Thomas Alber passed away as a result of his illness and hence no future commitments could be made.
Physical Sciences
Indo-US Joint Center on
Astronomical Object and Feature Characterization and Classification

About the Center
The main objectives of Joint Center are:

- To classify astronomical objects and features using dense and sparse light curves and other data taken in multiple wavelengths by combining the expertise available at the participating institutes on individual aspects of the problem.
- To aid the astronomical community in developing new characterization and classification tools in the era of large synoptic sky surveys, facilities data re-use and sharing and stimulate further development of virtual observatory capacities.

Achievements
We have developed some new features derived from light-curves and experimented with them both on sparse (e.g. CRTS data) and non-sparse light-curves (e.g. Kepler data). In addition to that the resulting features have been subjected to various feature selection strategies to help fight the curse of dimensionality that results from a datasets that are big not only in number of rows but also number of columns.

The light-curves themselves often lead directly to the application of other methods. We have been exploring the light-curves using points pair-wise as well as looking for periodicities in previously unexplored classes. Advanced statistical techniques need to be gently unfurled on to relative newcomers. The R-based tool, astRowRap helps do just that. The broader GUI-based statistical tool, AstroStat, also underwent some improvements thanks to the IUSSTF project. The final vindication of selected candidates is by taking spectra. The spectra need to be reduced meticulously. Automation of an existing pipeline spectral reduction pipeline has been carried out during the ClassACT collaborative visits, and the reductions have resulted into several Astronomers Telegrams. The images on which all the CRTS light-curves are based were transferred to IUCAA and are being served from there. Part of the work was also done during the visit by A. Mahabal to IUCAA. Thus so far we have worked on all aspects from images, light-curves, spectra and statistical methods pertaining to surveys like CRTS and Kepler. The value addition from the center has been immense as diverse expertise could be brought to bear on the problems being faced separately.

Way Forward
The formation of the Joint Center has helped spin off a lot of collaborative work which continues in many ways. We also conducted a joint meeting with another IUSSTF funded center and that was also helpful in building on the research we were already conducting. In Jan 2015 we will be holding another meeting, again jointly with the SUNY Oswego/New Delhi center at New Delhi. That should help taking closer
to completion many publications that are currently under preparation. Some of the work has involved data preparation as well as data processing in different ways to bring out some details (e.g. new light-curve based features being developed and feature selection being done on the comprehensive set). Newer transients keep getting discovered, and data continue to get added to existing transients (e.g. light-curve points). But we expect to wrap up most of the work that has already started as part of the center by the middle of 2015. But the number of ideas that have been generated through the meetings will far outlast the center and we will be seeking newer avenues to take them even farther. A few undergrads from Caltech and IIT, Gandhinagar have benefited from the work for instance and they continue working separately on related projects at no cost to IUSSTF. The work will also be extended to other surveys, and incorporate other features as they are created.

Various Citizen Science related projects were discussed so that non-experts can also be included in the classification endeavor. This is important since most data will not be seen by experts and we need to develop machine learning methods that can bootstrap on to classification from all possible inputs, including non-experts. Work on this will likely form an important aspect going ahead.

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<td>Ninan Sajeeth Philip St. Thomas College</td>
<td>Caltech</td>
<td>Summer, 2014</td>
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Publications

• S Abraham, A. Mahabal and N S Philip, Pyraf based Spectral Reduction Pipeline, in-preparation.[1]
• A K Kembhavi, A Mahabal et al., AstroStat, in preparation.[5]
• Arun Kumar, A., Ashish Mahabal, Ninan Sajeeth Philip, Kepler Feature Selection, In preparation.[6]
• A Mahabal et al., Serving a billion images, in prep. http://crts.iucaa.in.[7]
• A. Mahabal et al., Classifying light-curves using pairs of observations, in prep.[8]
• Several Astronomer’s Telegrams (ATel) have resulted from the Spectral Reduction Pipeline.[9]
Indo-US Joint Center on
Research Excellence on Fabrionics

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About the Center
The primary research areas chosen by the collaborative centre were (i) microsystem technology, (ii) microfluidics based systems, (iii) microforming, (iv) microlithography, (v) microactuators and microdevices of different types. Shape and pattern generation by Self Assembly of materials was one major aspect in some chosen R & D projects. Development and actuation of micro machines using short material based actuators, development of micro battery, design and development of inexpensive and accelerated diagnostics devices for multiple illness like dengue, malaria etc. were some of the objectives of the joint projects envisaged. The primary objectives of the Centre are:

• To conduct R & D in the area of “Fabrionics”
• To develop new technologies
• To develop new course modules for institutions to offer new courses in the emerging area of “Fabrionics”
• Publishing books and research papers
• To help growing a close knit international family of researchers, and Networking among the participating universities and institutions of India and USA

In the second phase the scope of the activities was expanded as follows:

• To conduct R & D in the area of “Fabrionics”
• To develop new technologies
• To develop new course modules for institutions to offer new courses in the emerging area of “Fabrionics”
• Publishing books and research papers
• To help growing a close knit international family of researchers, and Networking among the participating universities and institutions of India and USA

Achievements/Outcomes

Workshops and Short Courses Organized
Workshops and conferences, one of the major activities of this Joint Centre. Provided the platform of discussion and evaluations of the research works. A total of 14 international workshops had been organized under the joint centre. And each of the workshops had
been appreciably taken both by the faculties and the students. Three workshops were organized in USA one each at North Western University, University of California Irvine and in Alaska Cruise Ship (planned and organized by University of Illinois at Urbana Champaign). In India the workshops were organized in all the participating institutions and one was hosted by Jawaharlal College of Engineering, Aurangabad.

**Coining the Term ‘Fabrionics’**

It was being increasingly felt that the subject we attempted describing in relation to the Indo-US Joint Centre by the word ‘manufacturing’ did not convey the scientific nature and the complexities involved. One of the workshops at IIT Kanpur in October 2007 was devoted a session to the task of coining an appropriate term. To describe the futuristic processes for making things keeping in mind that such processes would heavily depend on advanced and emerging topics in physical, chemical, engineering and life sciences.

The recent R&D indicates that futuristic manufacturing would have to be suitable for complete automation and capable of producing parts at micro and nano levels at low cost and in large batches. Quite often this would lead to the adoption of ‘bottom up’ approaches and biological processes would be imitated. So the fabrication processes would have to be manipulated suitably. It was also clear that the word ‘manufacturing’ was originally derived from hand based operations. ‘Fabrication’ could be a better generic word to describe the futuristic techniques of making things and modifying matter. The future techniques would require considerable manipulation of the fabricational means and we could adopt a more scientific word to describe the whole class of engineering for futuristic processes. The Centre was renamed as “Indo-US Centre for Research Excellence on Fabrionics”.

**Fabrionics Course Modules**

The course modules identified as the founding subjects for Fabrionics are mentioned below. These modules can be offered under special programmes or as electives under regular academic programmes.

- **A1** Microsystems
- **A2** Simulation & Modeling
- **B1** Microfluidics
- **B2** Scaling Laws
- **C1** Principles of Synthetic Biology
- **C2** Smart Materials
- **D1** Micro/Nano Fabrication
- **D2** Self-assembly & Futuristic Manufacturing

**Fabrionics Family**

Not withstanding the above academic achievements one of the major gain was the gradual consolidation of an international family of academicians and researchers with a common interest in Fabrionics. These family members are continuing their relationships. It is hoped that this will continue and will lead to more collaborative research.
Scientific Value Addition
The technologies developed based on research work under the Centre programme can be summarized as:
- Development of New Materials and Fabrication techniques for C-MEMS
- Incremental sheet metal forming process for macro and micro scales
- A new EAP based on Nafion for micro actuation devices
- Laser enhanced/magnetic-assisted EDM Technology
- CD based micro-fluidic medical diagnostic device for inexpensive multiple disease identification
- Technology for incremental forming
- AFM – tip technology for fast genome sequencing and other biotechnological applications
- Development of efficient thermoelectric materials for harnessing waste industrial heat
- Cheap diagnostic device based on nano-crystalline porous silicon
- Improvement of efficiency of photo voltaic cells using nano-coatings
- Micro-systems for advanced machining

Exchange Visits
A major component of the Centre’s activities was exchange visits by faculty members and scientists and research scholars and students. The faculty members were supported for 15 days stay plus travel whereas the students were supported for a stay of 3 months. In total 37 faculty members from India and 38 faculty members from USA visited under this Centre activities. Similarly 21 Indian students and 17 students from US universities completed their exchange visits during this period.

Publications
- Generating sponsored research was one of the most important objective of the joint centre programme. The collaborative research work led to the approval of a number of research projects in USA and in India.
- On the Indian side the participating researchers were able to get 12 projects sponsored by agencies like the DST, DBT, CSIR and Intel. At the same time the Centre activities led to the sanction of 7 projects by agencies in USA like NSF and CHU.
- The participating researchers were able to get about 42 research papers published in good and excellent quality research journals. The numbers of conference papers published were around 35. Two monographs were published based on the Centre activity and 2 patents were granted for technologies developed through the Centre research work.
Indo-US Joint Center on
Gravitational-Wave Physics and Astronomy

About the Center
Indo-US Center for Gravitational Wave Physics and Astronomy was set up with the aim to facilitate collaboration between Indian and US scientists working in the emerging field of gravitational-wave (GW) astronomy, especially, with an eye to setting up large-scale experimental facilities, and building expertise in India. The center played a key role to facilitate initiation of cutting-edge research in experimental gravitational-wave (GW) physics and observational GW astronomy in collaboration with the international community.

Achievements
The most visible achievement of the joint center has been to nurture the LIGO-India mega-science project proposal to construct and operate an advanced gravitational-wave detector on Indian soil in collaboration with LIGO laboratory in USA. LIGO-India presents an extremely attractive possibility to propel Indian science at the experimental frontier with the very lofty scientific goal of opening the new observational window GW astronomy worldwide. The project is currently awaiting final approval from Union cabinet in India. On the US side NSF has obtained assent from its National Science Board. The joint center facilitated jointly undertaken feasibility study and exchange of experimental researchers required for the same. The LIGO-India project proposal document was submitted to DAE and DST by the IndIGO consortium with significant utilization of inputs and direct contributions from IUSSTF partners from US who contributed to the document. In addition, IUSSTF funds were used for the publication of the proposal document.

The center allowed joint theoretical studies investigating the science potential of upcoming advanced GW detector network, important work on GW source modeling, detector characterization, etc. It also promoted active involvement of the Indian scientists in the search for GWs using the data already collected by the previous generation of detectors in USA and Europe. Another important aspect was to facilitate the training Indian students and young scientists in the emerging research frontier of GW physics and astronomy. The center has helped provide the vital initial momentum to the development of an active GW-observer community who would be the potential subscribers of the data of advanced GW detectors to maximize the scientific output once these detectors are operational.

The joint center has also provided crucial support to the Indian Initiative in GW Observations (IndIGO) consortium. The consortium single member group of the LIGO Scientific Collaboration (LSC). LSC is an international collaboration of scientists working on GW-observation program, and is responsible for analyzing
the data collected by the LIGO observatories in the USA and the GEO600 observatory in Germany. The IndIGO is currently contributing to the LSC working groups searching for GW signals from compact binary coalescence, stochastic GW sources and continuous GW sources. The IndIGO LSC participation has grown to about 50 members making it one of visible large groups in 700 member LSC international LSC collaboration.

Another key development facilitated by the joint center is the LIGO Tier-3 grid computing site that has been set up at IUCAA. The computationally intensive task of analyzing GW data collected by LIGO observatories is performed at such large computational clusters, part of the LIGO data grid. The center has greatly facilitated the visits of core system administrators to the Tier-1 facility at Caltech for training and technical knowledge transfer. The IUCAA facility is currently serving as a major resource for the Indian GW community.

Scientific Value Addition
The Center has played an important part in growth in India in the emergent frontier area of GW astronomy. The LIGO-India detector on Indian soil would provide the requisite long baseline with detectors in the US to allow fine enough sky localisation of GW event to allow other more conventional astronomical facilities in Electromagnetic spectrum such optical telescopes, X-ray satellites and Radio antennae to study the same event, immensely enriching the now widely accepted observational paradigm of multi-messenger astronomy.

By facilitating the joint study by Indian and US researchers on the feasibility of the LIGO-India proposal, the center has supported the first steps towards the consolidation of a core team of Indian experts in high-end Laser science, vacuum technology and controls systems. The center has also helped conduct training exercise that has reached out to large number young researchers and students in the country. It has also indirectly supported the IndIGO consortium in putting together a pan-Indian single group participation in the international LIGO Scientific Collaboration. The group has grown to 50 member which is a sizable, visible fraction of 700 strong collaboration.

The first direct detection of GWs by Advance LIGO detectors would a major milestone in science and certainly in the class of Nobel prize winning discoveries. The discovery of GW also has ramifications for fundamental science as strong field test of Einstein’s theory of Gravitation. GW observations will open up a fundamentally new observational window to the Universe, providing a wealth of information pertaining to fundamental physics, astrophysics and cosmology.

Way Forward
The Joint Center oversaw the start of an exciting entry into a emergent
Joint R & D Centers

Joint R & D Centers

frontier that is expected to grow rapidly in the coming decades. The growth of Indian community in the field has been timely. Closer and more intense collaborative effort in GW science, expected in the coming years, will call for future support through similar mechanisms. IndIGO consortium and the LIGO-India mega-science initiative represent major focus points of growth in frontier science in the country that need proactive support and funding to ensure complete success.

Publications


• P. Ajith et al. (NINJA Collaboration), The NINJA-2 catalog of hybrid post-Newtonian/numerical-relativity waveforms for non-precessing black-hole binaries, Class. Quantum Grav. 29 124001 (2012).


• A. Patruno, P. Balt, A. Gopakumar, J. Hartman, R. Wijnands, M. van der Klis and D.


Software Produced

**LIGO Science collaboration**

The project members have contributed several pieces of important software to the *LSC Algorithm Library*. Notable contributions include codes to compute upper-limit skymaps of stochastic GW background, codes to generate GW signals from the inspiral, merger and ringdown of binary black holes, codes to compute the template-space metric of spinning black-hole binaries, codes to construct stochastic template banks for GW signals from spinning black-hole binaries, and codes to study the effect of noise artifacts on GW signal searches in order to develop effective vetoes against them, etc. A good subset of these codes have been used in several “flagship” searches of the LIGO Scientific Collaboration and the remainder are being prepared to run during the first Observation Runs of the Advanced LIGO detectors.

**Multidet**: The software package in Matlab/Python is under development that can compute the projected errors in estimating the parameters of binary black holes (assuming different waveform models) using GW observations of arbitrary networks of GW detectors. Once the project is completed, the package will be made openly available.
About the Center

A fundamental objective of the GEON Project (www.geongrid.org) is to develop data sharing frameworks—in the process, identifying best practices and developing capabilities and tools to enable advances in how geosciences research is done. The GEON portal framework, which plays a key role in facilitating this objective, is implemented using a portal based framework that provides a uniform authentication and authorization environment with access to a rich set of functionality, including the ability to register data and ontologies into the system; smart search capability; access to a variety of geo-science related tools; access to Grid-enabled geoscience applications; and a customizable private work space from which users have access to the scientific workflow environment, which allows them to easily author and execute processing “pipeline” for data analysis, modeling, and visualization.

In practice, deploying a portal network like GEON portal requires an understanding of the various middleware components, and their dependencies, that go into engineering such a system. On the basis of this experience, there had been developed a modular packaging of the various components of the system to allow easy installation and configuration of the hardware, middleware, and other software components.

The data portal middleware infrastructure consists of the following components:

- A Portal Server, which runs the portal software
- A Data Server, which provides storage and other data management services.
- A Certificate Authority (CA) Server, which manages user accounts.

The goal of iGEON-India is to promote the use of cyberinfrastructure at participating institutions in India to facilitate the sharing of geosciences data and tools via GEON middleware.

Deploying the GEON portal middleware framework provides capabilities to:

- Develop and deploy services, tools and serve datasets for the users at their site and for the broader iGEON –India community
- Help the partner site integrate local department or campus resources
- Provide a platform for other research organizations and universities to come together and collaborate.

Achievements

Integration of geophysical, geological, structural and remotely sensed data sets.

- New data in the interpretation of the geology and morphology of Maddur area, Andhra Pradesh
Partnering Institutions

**INDIA**
- University of Pune
- University of Jammu

**US**
- University of Oklahoma
- Penn State University

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**through remote sensing** - Various inferred structural and morphological features such as faults, fractures, dykes, domal forms and structures traced from the LISS III images show the complex nature of the surface. Integration of geophysical, geological and remote sensing data brought out the (a) six major faults including fractures (b) Intersections of faults/lineaments & domal structures are likely loci for potential kimberlite zones identified from the Euler deconvolution method of potential field data.

- **Structural Mapping and Analysis using Remote Sensing Data at Chintalapudi sub-basin, Godavari Graben** - The result of present study has shown the lithological boundaries of the Chintalapudi sub-basin between the Archean and the Gondwana rocks as well as the north and south boundaries within the basin by E - W trending lineaments near Mulkalapalli and Epigunta. This is supported by the gravity high along these lineaments in the bouguer anomaly map. The sub-basins of the Godavari graben are separated by lineaments (faults) and these are clearly shown as linear gravity highs in the bouguer anomaly map, while the basins are showing low gravity anomaly. Most of the interpretations made from the image are correlatable with the geological and geophysical data.

- **Integration of Geophysical and Geological Data of Kimberlites in Narayanpet–Maddur Field, Andhra Pradesh, India** - Regional Bouguer gravity and magnetic data clearly depicted the subsurface features depending on the density and susceptibility variations respectively along with the main geological trends. Potential field data also clearly brought out the concealed features in the area. 2D gravity and magnetic profile modeling

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Elevation contour map of Narayanpet, Maddur and Kotakonda area with faults traced based on the remote sensing image, gravity lineaments, and magnetic lineament

LISS III image of Chintalapudi sub-basin with lineaments (L-Lineament, Fr-Fracture, F-Fault; yellow dotted line) and folds. Lithological boundary is drawn from the geological map
Joint R & D Centers

across the schist belt covering the area of the Narayanpet – Maddur - Kotakonda clusters shows the depth and shape of the subsurface structures and the structural disturbance of the area with the intrusion of mafic dykes. The Euler deconvolution technique was applied to geophysical data to find the depth of kimberlite pipes and to identify new potential zones for the emplacement of kimberlite pipes.

• A Comparative Geophysical Study of Major Basins in the Pranhita–Godavari Rift, India and Rio Grande Rift, USA - In the study, the comparison and contrasting of major basins in the Pranhita–Godavari rift in eastern India (Chintalapudi basin) and the Rio Grande rift in the western United States (Albuquerque basin) using gravity data analysis and integrated profile modeling was carried out. The goal of the study was to provide some new insight about the process of continental rift basin development.

The Chintalapudi basin is associated with a 60 mGal negative gravity anomaly that is mostly due to Gondwanan fluvial sediments of late Carboniferous (~350 Ma) to early Cretaceous age (~120 Ma). The negative gravity anomaly associated with the Albuquerque basin is 55 mGals and the Cenozoic sediments were deposited on Mesozoic and Paleozoic strata with Precambrian crystalline rocks being exposed along the basin flanks. Major faults that bound these basins were delineated via an integrated analysis in which geologic, drilling, and seismic data were used to constrain gravity models. The average depth to the basement at the basin centers calculated from gravity modeling is 5-6 km. The subsurface structure derived from gravity maps and models for these basins is compared and the similarities suggest these basins both formed along older zones of weakness in the lithosphere in response to stress that originated primarily from a nearby continental margin. They also both formed topographic depressions in which major river systems formed.

Elevation contour map of Narayanpet, Maddur and Kotakonda area with faults traced based on the remote sensing image, gravity lineaments, and magnetic lineament

LISS III image of Chintalapudi sub-basin with lineaments (L-Lineament, Fr-Fracture, F-Fault; yellow

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Exchange Visits

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
<th>Institution(s) Visited</th>
<th>Duration/Time Period</th>
</tr>
</thead>
</table>
| 1     | V. Naga Lakshmi and T.Vani  
Senior Research Fellows, UCESS | University of Oklahoma, USA | October 2009 - January 2010 4 months |
| 2     | Arun Agarwal  
Department of Computer and Information Sciences | University of Illinois, Urbana-Champaign, USA, San Diego Supercomputing Center and GeoVista Centre at Pennsylvania State University, USA | September 24-27, 2007 |
| 3     | A. Siva Parvathi  
Research Associate, UCESS | SDSC | 2 months |
| 4     | K.V.Subbarao  
Professor, UCESS | SDSC | 2 months |
| 5     | S. Srilakshmi  
Assistant Professor, UCESS | University of Oklahoma | 1 month |
Lithological boundary is drawn from the geological map.

Way Forward
The plan of action for iGEON-India is to (i) complete the ongoing database creation, such as for hydrology, geophysics (i.e., gravity, magnetic, aeromagnetic), geomorphology, geochemistry, paleontology and dinosaur data, geological maps, topographic maps, followed by an integration of all of these various datasets into a common scheme, (ii) make these databases available via the iGEON portal, and (iii) make new applications available tools to the iGEON community. Finally, an important goal is to train UoH and other students and professionals in India in the areas of cyberinfrastructure and geoinformatics through short courses and Masters Programmes.

Publications
- Arun Agarwal, Grid Initiative at University of Hyderabad, an invited article for Anniversary Issue of C-DAC Connect, March 2006, pp 7.
Indo-US Joint Center on
Nanomaterials for Energy

Principal Investigators

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Timothy S. Fisher
Purdue University
Indiana, USA
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About the Center
The Joint Center has the following objectives:
• A new cohort of globally engaged researchers in nanotechnology and energy with appreciation for diverse professional and international cultures.
• Creation of joint research programs of both academic-academic and industry-academic types leading to new discoveries at the interface between nanotechnology and energy.
• Enhancement of collaborative use of cyber infrastructure research and educational resources such as nanoHUB.org and thermalHUB.org.
• Organization and hosting of summer schools and related tutorial materials offered annually to attract strong participation from industrial and academic participants.

Work Plan/Methodology
• Information to be made available on the web and also through personal interactions to all possible applicants from JNC/ICMS, Purdue and GE.
• Based on the discussions among the PIs and the Co-PIs involving colleagues from both sides, the suitability of a prospective visitor is evaluated and the concerned is invited.
• After scrutinizing the work proposal and obtaining concurrence from the host, a bilateral or a trilateral exchange visit is formally approved by the PIs.
• The joint Centre members also assist in logistics related to visa, travel and stay. Usually, the exchanges produce publication(s) based on the joint work carried out. This serves as a report of the visit.

Achievements

Metal-semiconductor superlattice thermoelectrics
To understand the microscopic aspects of ScN, ZrN, and HfN relevant to the thermoelectric properties of nitride metal/semiconductor superlattices, the electronic structure was determined, vibrational spectra and thermal properties using first-principles calculations based on density functional theory with a generalized gradient approximation of the exchange correlation energy. There had been found a large energy gap in the phonon dispersions of metallic ZrN and HfN, but a gapless phonon spectrum for ScN spanning the same energy range, this suggests that a reduced thermal conductivity, suitable for thermoelectric applications, should arise in superlattices made with ScN and ZrN or ScN and HfN. To obtain an electronic energy band gap of ScN comparable to experiment, a Hubbard correction with a parameter U (=3.5 eV) was used.

Exfoliated graphite/graphene materials for enhanced interfacial transport
There is a catalyst-free synthesis of cantilevered carbon nanosheet extensions, or petals, from graphite fibers by
microwave plasma CVD. Results reveal that the petals grow from the fiber surface layers while preserving graphitic continuity from fiber to the petals. Subtraction of Raman signatures from pristine and decorated fibers reveals a convolution of two underlying peaks at 2687 and 2727 cm⁻¹ that are consistent with profiles of multilayer graphene flakes between 5 and 25 layers. Such structures offer the possibility of minimizing interfacial losses in transport applications, improved interactions with surrounding matrix materials in composites, and a route toward substrate independence for device applications.

Liquid nanosolder for electrical contacts and thermal interfaces

An easy and elegant method of CNT nanocircuit fabrication using a metal organic precursor of Pd, namely, Pd hexadecanethiolate, is presented. This precursor directs the self-assembly of individual CNTs spanning a gap between Au electrodes. This is achieved by first, patterning the precursor along the edges or the gap electrodes, as it enables direct patterning by e beam. Further, thermal activation of the precursor at 250 degrees C leads to metallization and the ohmic electrical contact between the CNTs and the electrodes beneath. A resistive fuse action of the soldered CNTs is observed as well.

Integration of carbon nanotubes for solar, thermal and lighting applications

Interaction of single-walled carbon nanotubes with electron-donor and -acceptor molecules causes significant changes in the electronic and Raman spectra. Electron-donating molecules such as tetrathiafulvalene and aniline cause changes opposite to those caused by electron-withdrawing molecules such as nitrobenzene and tetracyanoethylene. Thus, a proportion of the semiconducting SWNTs become metallic on electron donation through molecular charge transfer. Electrical resistivity measurements reveal a systematic variation with electron-donating or -withdrawing power of the interacting molecules.

Solid-state hydrogen storage

Cyclic strain caused by addition and depletion of hydrogen in metal hydride beds results in brittle fracture and subsequent formation of micron-sized, faceted particles which inhibits hydride formation because of poor inter-particle heat conduction that increases the bed’s temperature during exothermic hydriding reactions. This work involves the development of a model for generating loose configurations of metal hydride powder and for assessing the commensurate quasi-static loading characteristics. Triaxial strain is applied to simulate evolution of the solid fraction, coordination number, force network connectivity, and internal pressure as consolidation occurs in the absence of interparticle friction. These modeling elements form the mechanical basis of a model that will ultimately predict the thermo-mechanical behavior of metal hydride powders and compacts.

Behavior of Attolitre water droplets

Working with a biased atomic force microscope (AFM) tip in the tapping mode under ambient atmosphere, attoliter (10⁻¹⁸ L) water droplet patterns have been generated on a patterned carbonaceous surface.

Au Nanoparticle-PDMS Composites

A simple, green synthesis technique for preparing Au nanoparticle-PDMS composites is described. The solid solution nature of the PDMS combined with the surface properties of the nanoparticles imparts unique properties to this composite. We demonstrate the utility of this material for water purification and for chemically-triggered storage and release of compounds toward-drug delivery applications.

Other Activities

(Workshops/Training Programs/Course delivery)
- JNC-Purdue-GE joint Workshop (August 19 and
## Exchange Visits

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
<th>Institution(s) Visited</th>
<th>Duration/Time Period</th>
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<tr>
<td><strong>Student Visits</strong></td>
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<tr>
<td>1.</td>
<td>Narendra Kurra</td>
<td>Purdue University</td>
<td>June 01 – Aug 15 2010</td>
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<tr>
<td>2.</td>
<td>Kyle Smith</td>
<td>JNCASR</td>
<td>Jan 06 – Feb 10 2010</td>
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<td>3.</td>
<td>Kyle Smith</td>
<td>Purdue University</td>
<td>18 - 23 Aug 2010</td>
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<td>4.</td>
<td>Ritu Gupta</td>
<td>Purdue University</td>
<td>July - Oct 2011</td>
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<td>5.</td>
<td>Sridhar Sadasivam</td>
<td>JNCASR</td>
<td>Jan 07 – June 09, 2014</td>
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<td>6.</td>
<td>Soumik Siddhanta</td>
<td>Purdue University</td>
<td>July 15 – Dec 15, 2014</td>
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<td>7.</td>
<td>T. Bhuvana</td>
<td>Purdue University</td>
<td>Nov 2008 - Sept 2009</td>
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<td>8.</td>
<td>Adina Scott</td>
<td>JNCASR</td>
<td>June 24 – Nov 16, 2009</td>
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<tr>
<td>10.</td>
<td>Kevin McMullen</td>
<td>JNCASR/GE</td>
<td>June 01 - Aug 09, 2009</td>
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<td><strong>Faculty Visits</strong></td>
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<tr>
<td>2.</td>
<td>Timothy Fisher</td>
<td>JNCASR</td>
<td>08 – 16 Feb 2010</td>
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<tr>
<td>3.</td>
<td>U. Waghmare</td>
<td>Purdue University</td>
<td>May 2010</td>
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<tr>
<td>5.</td>
<td>Timothy D. Sands</td>
<td>JNCASR</td>
<td>18 - 23 Aug 2010</td>
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<tr>
<td>6.</td>
<td>David Janes</td>
<td>Purdue University</td>
<td>18 - 23 Aug 2010</td>
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<td>Timothy S. Fisher</td>
<td>Purdue University</td>
<td>18 - 23 Aug 2010</td>
</tr>
<tr>
<td>10.</td>
<td>Xiulin Ruan</td>
<td>JNCASR</td>
<td>18 - 23 Aug 2010</td>
</tr>
<tr>
<td>11.</td>
<td>Timothy Fisher</td>
<td>Purdue University</td>
<td>19 – 29 Mar 2011</td>
</tr>
</tbody>
</table>
20, 2008): Indo – US Workshop on “Frontiers in Application on Carbon Nanotubes and Graphene” This was a precursor to the project proposal. The event was sponsored by IUSSTF, JNC, ICMS and GE.

- Indo-US workshop on Nanoscale Materials And Interfaces, 10-12 March 2009 at Purdue University, USA
- A short course and Indo - US Workshop on “Basics of Nanomaterials and Applications in Energy Conversion, Transport and Storage” (20 – 21 August, 2010), JNCASR, Bangalore
- Symposium on Nanomaterials for Energy (16-17 April 2012), Purdue University, JNCASR
- Joint Networked Centre on Nanomaterials for Energy (JNCNE) at Purdue University, West Lafayette, IN USA during 17-18 September 2014
- JNC-Purdue Workshop during March 2015, JNCASR, India

Publications

- Gupta, R; Reifenberger, RG; Kulkarni, GU (2014) Cellphone Camera Imaging of a Periodically Patterned Chip as a Potential Method for Point-of-Care Diagnostics. ACS Applied Materials & Interfaces, 6, 6: 3923-3929 (DOI: 10.1021/am4050426)
- Rout, CS; Kumar, A; Fisher, TS; Gautam, UK; Bando, Y; Golberg, D (2012) Synthesis of chemically bonded CNT-graphene heterostructure arrays. RSC Advances, 2, 22: 8250-8253 (DOI: 10.1039/c2ra21443a)
• Smith, KC; Fisher, TS; Alam, M (2011) Isostaticity of constraints in amorphous jammed systems of soft frictionless Platonic solids. PHYSICAL REVIEW E, 84, 3: 030301
• Hodson, SL; Bhuvana, T; Cola, BA; Xu, XF; Kulkarni, GU; Fisher, TS (2011) Palladium Thiolate Bonding of Carbon Nanotube Thermal Interfaces. JOURNAL OF ELECTRONIC PACKAGING, 133, 2: 020907
• Kurra, N; Prakash, G; Basavaraja, S; Fisher, TS; Kulkarni, GU; Reifenberger, RG (2011) Charge storage in mesoscopic graphitic islands fabricated using AFM bias lithography. NANOTECHNOLOGY, 22, 24: 245302
• Saha, B; Sands, TD; Waghmare, UV (2011) First-principles analysis of ZrN/ScN metal/ semiconductor superlattices for thermolectric energy conversion. JOURNAL OF APPLIED PHYSICS, 109, 8: 083717
• Saha, B; Sands, TD; Waghmare, UV (2011) Electronic structure, vibrational spectrum, and thermal properties of yttrium nitride: A first-principles study. JOURNAL OF APPLIED PHYSICS, 109, 7: 073720
• Rout, CS; Kumar, A; Kumar, N; Sundaresan, A; Fisher, TS (2011) Room-temperature ferromagnetism in graphitic petal arrays. NANO SCALE, 3, 3: 900-903
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Indo-US Joint Center on

Nanoparticle Aerosol Science and Technology

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About the Center
The Joint Center aims at:-
• Nanoparticle synthesis through aerosol routes to support inorganic nanomaterial powder manufacturing and nano-biotechnology applications in the pharmaceutical industry; and
• Computational simulations of atmospheric aerosols and nanoparticles on multiple spatial scales toward understanding their climate and health effects.

Achievements
Aerosols routes for production of nano-sized controlled-release drug particles.
• Development of a mathematical model from first principles approach to study lung deposition of aerosolized drugs (at IIT Bombay).
• Design nano-sized drug carriers of appropriate sizes to be delivered into deep lung for systemic use (at IIT Bombay and WUSTL).
• Validation of model predictions by available experimental data. (at WUSTL and IIT Bombay).

Rational design of pulmonary delivery systems for biocompatible nanoparticles.
• Synthesis of nano-sized liposome for maximum drug encapsulation and in-situ characterization of liposome morphology and stability (at IIT Bombay).

• Aerodynamic size of droplets and structural damage to liposomes measured by drug leakage (at IIT Bombay).
• Experimental system design and training on electrospray for aerosolization of liposome suspensions (at WUSTL).
• Development of electrospray based aerosolization system for liposome suspension and measurement of aerosol properties of droplets and drug leakage (at IIT Bombay).
• Successful establishment of flame and furnace aerosol reactors for inorganic nanomaterial synthesis at IIT Bombay in collaboration with Washington University.
• Development of a mathematical model from first principles approach to study lung deposition of aerosolized drugs.
• Aerosol synthesis of drug-loaded biodegradable nanoparticle aerosol matrices with controlled particle properties.
• Techniques for the study of aerosol delivery of nanometer-size liposomal drug-matrices developed in collaboration with U Maryland.
• An exchange with Washington University in St. Louis lead to capacity building in electrospray technology for mono-disperse aerosol generation from liposomal suspensions through ongoing work of doctoral student.
**Partnering Institutions**

**INDIA**
- Centre for Development of Advanced Computing, Pune

**US**
- The University of Iowa
- University of Maryland

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**Rational design of pulmonary delivery systems for biocompatible Nanoparticles.**
- Nanometer size liposome production and air jet aerosolization at IIT Bombay

**High-temperature aerosol routes for nanoparticle synthesis: Preparation, characterization and applications**
- Development of high temperature aerosol reactors (FLAR, FUAR) for gas phase Nanoparticle synthesis.
- One step synthesis and characterization of nanometer-sized crystalline calcium phosphate using FUAR setup for their application as bone substitute material.

**Modeling atmospheric transport of aerosols and nanoparticles**
- The latest version of STEM model (STEM 2K3, Tracer version) had been ported in parallel mode on a multi-core Linux system at C-DAC, Pune and coupling of WRF model to generate meteorological conditions for driving the chemical transport model.
- The STEM emission pre-processor module is redeveloped in the study domain over the Indian region.

**Publications**
- Chattopadhyay S, C. Venkataraman, and P.
## Exchange Visits

<table>
<thead>
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<th>Activity</th>
<th>India</th>
<th>US</th>
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| **Aerosols routes for production of nano-sized controlled-release drug particles** | • Prof. Daren Chen visit to IIT Bombay (29th Nov- 2nd Dec 2009)  
• Prof. Pratim Biswas visit to IIT Bombay (9th -13th January, 2010) | • Preshit Dandekar visit to WUStL (6th April- 13th June 2009)  
• Amol Ashok Pawar visit to WUStL (29th March- 02nd June 2011) |
| **Rational design of pulmonary delivery systems for biocompatible nanoparticles** | • Prof. Seryl Ehrman visit to IIT Bombay (August 10-23, 2008).  
• Prof. Biswas to IITB (9th -13th January, 2010) | • Prof. Pratim Biswas made two visits during 2008 (supported with his own funding) to enable interaction on the collaborative work and participated in NAST centre meeting on December 18, 2008.  
• Prof. Chandra Venkataraman’s visit to Washington University (May 17-22, 2009)  
• Prof. Anurag Mehra’s visit (5th October–12th October, 2009) with Prof. Biswas at WUSL and Prof. Ehrman at UMCP  
• Saptarshi’s visit to WUSL (28th June 2009 - 17th Jan 2010)  
• Saptarshi visited UMCP from 17th Jan-28th Feb 2010 |
| **High-temperature aerosol routes for nanoparticle synthesis: Preparation, characterization and applications** | • Dr. Biswas’ visit (14-16 June 2008) and meetings at WUSL (Washington University in St. Louis)  
• Dr. Biswas visit to WUSL (15-18 December 2008)  
• Professor Virendra Sethi visit to WUSL (27 September - 17 October 2009)  
• PhD student Ratish Menon visit to WUSL (November 2009- February 2010) | |
| **Modeling atmospheric transport of aerosols and nanoparticles** | • Prof. Greg Carmichael visited CDAC, Pune during (December 8-13, 2008)  
• Prof. Greg Carmichael visited IIT Bombay and CDAC, Pune during (January 4-11, 2010) | • Pankaj Sadavarte visit to U. Iowa (May 10-November 10, 2009)  
• Mohit Dalvi visit to U. Iowa (May 10-31, 2009)  
• Prof. Chandra Venkataraman visit to U. Iowa (May 10-17, 2009) |


About the Center

The Joint Center focuses on following issues:

- **Rare earth free hard magnets**: to explore the stability of these materials after an optimized growth parameters with the desired phase formations. High performance magnets such as Mn-Al(C) of hard magnetic properties are important without either ferromagnetic elements such as Fe, Co and Ni or rare earth ions. In this work the understanding and stabilizing the τ-phase (fct) among the various phases of this system; Ĉ (h.c.p) and Ĉ’ (orthorhombic) phase is a challenging job. The τ-phase possesses hard magnetic properties. The development of rare earth free permanent magnets is exceptionally cost effective.

- **Multilayers and thin film nanostructures**: thin films of various kinds of magnetic materials need to be explored for the evaluation of magnetic field in conjunction with nano-grained microstructures, grain boundaries and the magnetic microstructures of various domain, domain walls and point and line defects obstructing the movements of domain walls.

- **Helimagnets of FeGe**: the compositional variants of helimagnets like FeGe\textsubscript{1-x}Si\textsubscript{x} will be studied to evaluate the magnetic twin structure, crystallization temperature, magnetic chirality across twin boundaries, magnetic fields, etc.

The objectives would be achieved by carrying out detailed electron microscopy observations to investigate the various microstructural and excitations pertaining to magnetic materials of various kinds in the form of multilayers, thin films, interfaces and bulk. Important case studies will be pursued on FeGe and Perovskites based magnetic materials. In this work high resolution electron microscopy encompassing various techniques of Lorentz microscopy and Electron holography will be employed to evaluate the important aspects.

The Synthesis of rare-earth free hard magnets is a crucial problem. For example the τ-a magnetic phase in Mn-Al system is a metastable phase and needs significant experimentation towards its single phase formation in the alloy. Normally the powder metallurgy (ex. ball milling) and melting (arc melting, induction melting, etc.) are the methods of processing the basic material. In some cases a combination of these routes, melting followed with powder metallurgy are also tried. In these processes, the ε-phase (a stable phase) is formed first and by annealing of the ε-phase (between 400 to 600 °C for 10 to 40 min) the formation of τ-phase is expected. However in addition to τ-phase, the signals of β and γ-phases are also noted, which are stable phases at room temperature. Under such conditions, the in depth electron microscopy experiments are important to evaluate the material to recognize the formation of τ-phase, its uniformity in the alloy and chemistry of the material.
Partnering Institutions

**INDIA**
- Indian Institute of Technology, Delhi

**US**
- Argonne National Laboratory, Lemont, IL

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**Work Plan/Methodology**

The measurements pertaining to magnetic characteristics of the materials will be carried out at US counterpart by exploiting the dedicated high resolution electron microscopes for magnetic materials. The material preparation in bulk and thin films, extensive specimen preparation and detailed characterization will be taken care at India, whereas dedicated magnetic measurements employing highly sophisticated electron microscopy with all modes of magnetic materials characterization will be performed at US. The highly ordered nanomagnet array samples, both in the form of 2-d arrays of nanowires/rings as well as 3-d periodic multilayered nanowire arrays will be prepared at IIT. Moreover, the microwave measurements as well as detailed micromagnetic modeling of the dynamic switching response of such arrays will be performed at IIT. The Advanced Photon Source (APS at ANL) synchrotron x-rays will be exploited to delineate the knowledge about the structure and function of magnetic materials. Access to the APS, a major user facility at Argonne, operated by the US Department of Energy, is by approval of peer-reviewed proposal. These experiments would be iterative to do the best experiments. The goal is to obtain optimal properties of the processed magnetic materials for various applications.

**Scientific Results**

_A nanodevice laboratory:_ In order to explore and understand electronic, magnetic and photonic properties of new novel materials, in particular superconducting / magnetic thin films, nanowires and carbon nanotubes, the NPL has fabricated nanostructures/ nanodevices by using state of the art lithography tools such as focused ion beam (FIB) microscope or ebeam lithography (EBL). Successful creation of these nanodevices gives access to many novel experiments to investigate the quantum phenomena. A focused ion beam microscope (Fig. 1a) from M/S Zeiss (model: Auriga 39-71) is a unique microscope, can be used for high resolution imaging, localized metal or insulator deposition, elemental analysis, micromanipulation of objects, localized milling / circuit modifications. Its potential...
results demonstrate the functioning of this facility and subsequently show that nanodevices can be formed from 1D or 2D materials, nanolayers or nanowires. Moreover, this facility can be used as a micro- and nanomachining tool at the nanoscale which will boost the nanofabrication activity at the laboratory and hence the nanodevice research. As an illustrative example, Fig. 1b demonstrates that first nanowires were localized by using FESEM, further nanowires were connected to gold pads by localized platinum deposition, and finally FIB milling was used to remove unwanted connections. Such systems and devices are made and ready for the transport measurements.

**Magnetic nano-rings structures for high memory data storage applications:** Magnetic ring shaped nanostructures are of great interest as they are most suitable candidate in the field of developing high storage capacity RAM. Out of all the magnetic nanostructures, ring geometry has following features which make it unique: (i) removal of highly energetic inner core makes this configuration much more stable than a disc geometry, and (ii) existence of ring in two stable magnetization states i.e. flux closure state called vortex state and onion state called two domain state. Synthesis of such devices poses a challenge in terms of fabrication techniques and measuring instrument. It has been able to successfully develop ring shaped magnetic nanostructures using Electron beam lithography (EBL), which is a part of a state of art facility, nanodivice laboratory (FIB). The FESEM images of the rings having ring width 340 nm, centre to centre distance 2.8 µm, outer diameter 1.7 µm and inner diameter 1.03 µm are displayed as in Fig. 2. The sample size was 9mm² on which 11,000 rings were fabricated by EBL followed by deposition in high vacuum (3×10⁻⁷ mbar) sputtering system. The edge roughness is very important in ring shape as they act as demagnetizing centres. Hence, each step in fabrication is very crucial for the formation of stable magnetization states. The magnetic rings were then analysed in Superconducting Quantum Interface Device (SQUID) installed in the laboratory. The observed results confirmed the formation of both the stable vortex and onion magnetization states. Magnetic film having a ring shaped patterned, which support a “vortex” magnetization state, results in zero stray filed which provides the freedom to densely compact these elements with minimum magnetic interaction with neighbouring elements.

**MnAl - a metastable τ-phase:** A large fraction τ-phase of MnAl prepared by a suitable combination of arc melting and ball milling with subsequent annealing has been extensively characterized by employing high resolution transmission electron microscopy (HRTEM, model: Tecnai G2 F30 STWIN, operating at an electron accelerating voltage of 300 kV with field emission electron source). A large size elongated grains with a common origin of τ (tetragonal)-phase are seen throughout in the microstructure (Fig. 3a).

### Exchange Visits

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name and Affiliation of the Scientist</th>
<th>Institution(s) Visited</th>
<th>Duration/Time Period</th>
</tr>
</thead>
</table>
| 1.   | Samuel D. Bader  
Argonne National Laboratory, USA | National Physical Laboratory, India | 08 -11 December 2013          |
| 2.   | R. C. Budhani  
National Physical Laboratory, India | Argonne National Laboratory and  
Brookhaven National Laboratory, USA | 27 May - 04 June 2014          |
| 3.   | Yimei Zhu  
Brookhaven National Laboratory, USA | National Physical Laboratory, India | 7 - 12 July 2014               |
| 4.   | A. K. Srivastava  
National Physical Laboratory, India | Argonne National Laboratory, USA | 17 - 30 July 2014              |
The ample existence of this phase with a coarse grain microstructure is noteworthy. It is also important to mention that at instances, it was difficult to distinguish τ-phase with the remaining microstructure of the sample. The regions were constituted of mixed τ-phase with the other two structures of β (cubic)- and γ (cubic)- phases in the matrix of the sample. At high magnifications, the evidence of overlaps due to different phases was obvious. In Fig. 3b, a single grain in length of τ-phase was magnified to resolve features at atomic scale. However due to magnetic anisotropy in the microstructure, instead of sharp planes, a set of parallel thick fringes are delineated (Fig. 3b). At Argonne National Laboratory the MnAl specimens are looked into a transmission electron microscope (JEOL JEM 2100F, aberration corrected and designed for Lorentz microscopy) with the help of Prof. Amanda K Petford-Long and Prof. Samuel D. Bader and several interesting features of conventional elongated structures of -MnAl (magnetic phase) and its corresponding magnetic microstructures revealing Fresnel fringes have been observed and recorded. The results are being interpreted in depth.

Two–dimensional electron gas-like charge transport at the interface between a magnetic Heusler alloy and SrTiO₃: Remarkably low residual resistivity, giant residual resistivity ratio, free-electron-like Hall resistivity, and high mobility (=10⁴ cm² V⁻¹ s⁻¹) charge transport in epitaxial films of Co₂MnSi and Co₂FeSi (CFS) grown on (001) SrTiO₃ (STO), has been reported. This unusual behavior is not observed in films deposited on other cubic oxide substrates of comparable lattice parameters. The scaling of the resistivity with thickness of the films allows the extraction of interface conductance, which can be attributed to a layer of oxygen vacancies confined within 1.9 nm of the interface as revealed by atomically resolved electron microscopy and spectroscopy (Fig. 4). The high mobility transport observed here at the interface of a fully spin polarized metal is potentially important for spintronics applications. Ref.: P.K. Rout et al. Phys. Rev. B 89, 020401 R, 2014.

Kondo scattering in δ-doped LaTiO₃/SrTiO₃ interfaces: Renormalization by spin-orbit interactions: A study of δ doping at the LaTiO₃/SrTiO₃ interface with isostructural antiferromagnetic perovskite LaCrO₃ that dramatically alters the properties of the two-
dimensional electron gas at the interface, has been reported. The effects include a reduction in sheet-carrier density, prominence of the low-temperature resistivity minimum, enhancement of weak antilocalization below 10 K, and observation of a strong anisotropic magnetoresistance (MR). The positive and negative MR for out-of-plane and in-plane fields, respectively, and the field and temperature dependencies of MR suggest Kondo scattering by localized Ti$^{3+}$ moments renormalized by spin-orbit interaction at $T < 10$ K, with the increased $\delta$-layer thickness. Electron-energy-loss spectroscopy and density functional calculations provide convincing evidence of blocking of electron transfer from LTO to STO by the $\delta$ layer, Fig. 5. Ref.: S. Das et al. Phys. Rev. B 90, 081107(R), 2014.

**Publications**


**Other Activities**

Following seminars / invited talks were organized during this period of the execution of the project:

- R.C. Budhani, Novel electronic phases and phase transitions at oxide interfaces.
Joint R & D Centers

Indo-US Joint Center on
Physics Beyond Standard Model

Principal Investigators

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About the Center
Our current understanding of nature can be summarized in terms of two Standard Models: one for extremely large cosmological scales – standard model of cosmology; and another for extremely tiny sub-nuclear particle physics scale - standard model of particle physics. Both these models have been extremely successful at their respective scales but are however unable to describe nature completely.

The beginning of Large Hadron Collider (LHC) at CERN, Geneva, ushered in a new era in particle physics. “New physics”, whose presence is evident from observation of neutrino oscillations and existence of dark matter, might reveal itself in the experiments planned at the LHC. The Indo-US Networked Center on Physics beyond standard model (BSM) phenomenology investigates the properties of this “new physics” in three focused areas:

(i) Neutrino physics: Among phenomenological aspects, a detailed study of capabilities of a Long Base Line and Atmospheric neutrino detector with emphasis on DUSEL-based detectors will be undertaken. Studies
of avor structure of very high energy astrophysical neutrinos will be carried out.

(ii) **Top physics**: Top physics will be looked at as a probe of BSM physics with the focus on use of the top polarization in isolating its nature at the LHC.

(iii) **Supersymmetry**: Here the Joint Center will address connections between dark matter studies and avor physics; and correlations between direct and indirect dark matter searches and LHC experiments.

**Achievements & Scientific Value Addition**

**Neutrinos**

The work done on Neutrinos can be divided into two parts: one done by a group which involved Profs. Raj Gandhi, Danny Marfatia and Vernon Barger and the other by a group involving Profs. Sandip Pakvasa, Subhendra Mohanty and Anjan Joshipura.

Prof. Raj Gandhi’s work was in collaboration with US collaborators at the University of Wisconsin-Madison (Vernon Barger) and University of Kansas (Danny Marfatia). Over the full course of the project, in addition, several of his graduate students (Atri Bhattacharya, Animesh Chatterjee, Mehedi Masud) along with other Indian faculty (Srubabati Goswami and Uma Sankar) and graduate students from other Indian institutions (Sushant Raut and Suprabh Prakash) and a postdoc (Pomita Ghoshal) participated in various aspects of the work.

a) The potential of a Liquid Argon detector vis a vis atmospheric neutrinos was studied and it was
demonstrated that such a detector could determine the neutrino mass hierarchy with greater than 4 sigma sensitivity, and the octant at 2-3 sigma sensitivity with moderate exposure times. It is to be noted that these are currently two of the most important goals over the next decade for neutrino physics. This work has resulted in a paper included below.

b) After this attention was focussed on comprehensive sensitivity studies for the Long baseline Neutrino Experiment (LBNE) for all of its major goals. LBNE will be one of the flagship International effort contributing to resolving the hierarchy, the octant and detection of CP violation over the next decade. Its configuration is a matter of active current discussion in the community. This work considered all possibilities, detector locations (underground versus surface), sensitivities a) with or without a near detector and/or b) the addition of atmospheric data, c) the presence or absence of a magnetic field and d) with increased exposure. This work resulted in two papers.

Over the course of the project, students and postdocs were involved, which in several cases, constituted their first experience of international collaboration and thus added a valuable component to their training. The group interacted constructively with each other and various members are now well positioned to take on new projects in smaller sub-groups.

Prof. Subhendu Mohanty worked along with Prof. Sandip Pakvasa and Prof. Anjan Joshipura which has resulted in two publications listed below. A summary of the work is given below.

c) The phenomenology of high energy neutrinos in the energy range 100 TeV to 1 PeV was studied. These are a measure at the IceCube experiments. The neutrino flux measured at 100 GeV energies correlated with Gamma ray bursts and observed a deficit by a factor of 4 compared to the Bahcall-Waxman prediction. The possibility of neutrino oscillations into sterile neutrinos was studied. This would take place in a model where the three active neutrinos are augmented by three sterile neutrinos and the neutrino masses are pseudo-Dirac. It was found that the pseudo-Dirac scenario could account for a deficit by a factor of 4 of the observed GRB neutrinos. The possibility of neutrino decay from the higher mass eigenstates to the lower mass eigenstates to account for the observed neutrino deficit was also explored. Subsequently IceCube experiment has measured neutrino events at PeV energies which are supposed to originate from Active Galactic Nuclei. The surprising feature of these PeV neutrino observations is the deficit of the Glashow resonance events which are expected to arise when electron-anti-neutrinos annihilate electrons in the medium to produce real W-bosons which decay into shower events. These Glashow resonance events are expected at 6.2 PeV and so far have not been seen. A possible explanation of this is the decay of neutrinos in an inverted mass-hierarchy to the lowest mass eigenstate which have a very small component of electron-type neutrinos. The other explanation is oscillations in to sterile species. Future observations at IceCube of PeV will verify or rule out these models.

Beyond Standard Model

In the context of investigations on the theme of Beyond the Standard Model, other than on issues mentioned under the heading ‘Neutrinos’ above, the Indo-US funding led to interactions and collaborations which have opened up a number of research projects among the investigators. A few major ones are being listed below. The first three are the ones which resulted from interactions between Profs. Tao Han, X. Tata and B. Mukhopadhyaya.

Alongside the Higgs boson discovery, a thorough and sustained analysis of the LHC data has been performed from new angles, to indicate the scope of physics beyond the standard model lying hidden within the data. The implication of the data for some new physics scenarios, especially those explaining neutrino masses and the dark matter content of the universe, have been investigated, and interesting results have been found.

The possibility of supersymmetric theories in the light of the LHC data has been studied. In particular, definite conclusions have come out concerning scenarios with light third family sfermions, taking both LHC data and dark matter constraints into account.

Some hitherto unexplored potentials of a muon collider have been unearthed. This includes the possibility of exploiting radiative return to probe new physics in the Higgs sector.

“Vectors and Unification” Profs. Godbole, Han, Tata and Vempati have considered a scenario where additional vector like particles exist beyond standard model which lead to unification of the gauge couplings. The question then arises what happens to the stability of the Higgs potential in the presence of these extra particles? Preliminary investigations have revealed the various minimum configurations of vector particle content required for unification of gauge couplings at the high scale. Work is on to study the constraints on the Higgs potential. Students and Postdoctoral fellows at both the institutes are involved in this project.

In another project the status of degenerate supersymmetric scenarios was investigated by Debosh
Chowdhury, K. Patel, X. Tata and S. Vempati.

This work is almost complete and ready for publication. In this work, the consequences of assuming a degenerate soft spectrum in MSSM are investigated. The interplay between the implications of the Higgs mass measurement and the rare decay process $b \rightarrow s + \gamma$ and anomalous magnetic moment of $g-2$ was shown. Interestingly, while this scenario might not satisfy the relic density of dark matter observed in Nature, it predicts signals at future direct detection experiments.

R. Godbole and X. Tata with students at the IISc have also been discussing possibilities of probing the mixing in the stop sector via top polarization for the top quark produced through gluino decays. A gluino decays to a top-stop pair. If only one of the stop mass eigenstate has mass lower than the gluino mass, then the produced top will be polarised and the resultant top polarisation depends directly on the mixing. The work has yielded interesting results which need to be written up soon.

**Exchange Visits**

Collaboration and interaction has been strengthened between Harish-Chandra Research Institute, Indian Institute of Science, Bangalore, Physical Research Laboratory, Ahmedabad, The University of Pittsburgh and the University of Hawaii. The expertise available in all the three places has been effectively pooled, with special significance in the aforementioned areas.

To facilitate discussion and problem formulation, two visits of one month each by one of the investigators Raj Gandhi were made under the aegis of the project to the University of Wisconsin at Madison in the summers of 2011 and 2012.

- Prof. Tao Han, University of Pittsburgh, and Prof. Xerxes Tata, University of Hawaii, have delivered pedagogic lectures at Harish-Chandra Research Institute.
- Prof. Biswarup Mukhopadhyaya delivered a colloquium and a seminar at the University of Hawaii during his visit. These have served in scientific manpower training.
- Prof. S. Mohanty visited University of Hawaii 14th April 2014 to 30 April 2014 and University of Pittsburgh from 1st May-15th May 2014.
- Prof. Sudhir Vempati visited University of Hawaii 14th April 2014 to 30 April 2014 and University of Pittsburgh from 1st May-15th May 2014.
- Prof. Rohini Godbole visited University of Pittsburgh from May 5 to May 10, 2014.

**Figure 11.** Sensitivity to CP violation for a 350 kt-yr unmagnetized FD exposure assuming $\sigma(\sin^2 2\theta_{13}) = 0.05 \times \sin^2 2\theta_{13}$. 
She gave a talk at the PHENO-2013 meeting and discussed possibilities of probing the anomalous Higgs couplings in VBF and VH production. She then visited from May 10 to May 29, the University of Hawaii, where she gave a department seminar on “CP violation in Higgs sector at the LHC”. She then visited (along with Prof. X. Tata and Prof. T. Han) the KITP at the University of California at Santa Barbara to attend the meeting “Snowmass on the Pacific” from May 30 to June 2, where she participated on the discussions about the future directions of progress in high energy physics.

**Way Forward**

As mentioned above, the basis for future collaborative work has been established, and it is expected that the interaction so fruitfully initiated under the ambit of this Center will continue in the future.

The funding under the project made it possible for a major fraction of the collaborators to get together at meetings in India (at HRI) and in the USA (at PHENO in Pittsburgh), providing a platform for interaction of the members of this project with scientists working in the same area in the other country. This has broadened the scope of International collaborations that could be seeded even further.

In case of Neutrino physics, the topics studied under the project require further work now since LBNE is undergoing an expansion which may result in a redefinition of its goals and a possible expansion in its scope. Having done detailed preliminary work in this direction, members of the group are well-positioned to undertake further studies in related directions.

Observations of high energy neutrinos at IceCube and other experiments can reveal the nature of the sources -whether they are astrophysical or that these neutrinos arise from Dark Matter annihilations or decay. One can also learn something about the nature of neutrino mass matrix and the underlying Grand Unified Theories giving rise to neutrino masses.

The LHC results on the discovery of the Higgs, the detailed measurements of its properties and signal strengths as well as the results on searches for new particles expected in various extensions of the BSM has resulted in constraints on the allowed region in the parameter space of the BSM models. At the same time the low mass of the Higgs makes possible tantalising hints of BSM physics at scales of $10^{11}$ to $10^{12}$ GeV. This connection between the Higgs mass, the high scale physics and the hints thrown by the dark matter searches at colliders nor otherwise, has thrown open a lot of issues that need to be investigated and which are a logical end for many of the projects that have been started during the project.

All the visits, collaborations and pedagogical activities are expected to be repeated in the years to come. The expanding horizon of elementary particle physics, especially in the directions of the LHC and dark matter results, will be more effectively tackled in the presence of such intensified interactions.

**Publications**

- V. Barger, A. Bhattacharya, A. Chatterjee, R. Gandhi, D. Marfatia and M. Masud Configurations of the Long-Baseline Neutrino Experiment.
About the Center

The Solar Eruptive Phenomena comprise of Solar flares and coronal mass ejections (CMEs), representing huge amounts of energy release from sites of high magnetic field on the Sun. The released energy can be as high as $10^{27}$ joules, representing the most energetic process in the heliosphere. Flares and CMEs are not only intriguing physical phenomena, but also have important implications for life on Earth. Flares can change the conductivity of Earth’s ionosphere thereby affecting radio communication over a time scale of tens of minutes to hours. Microwave bursts from solar flares can drown GPS signals resulting in the loss of service for the duration of flares. CMEs have a longer-term effect on Earth’s space environment. As soon as fast CMEs leave the Sun, they drive a shock that accelerates protons to very high energies. These particles can disable space instrumentation by destroying spacecraft electronics. CMEs continue to accelerate particles as they propagate away from the Sun for days. CMEs contain magnetized plasma at very high speeds (often exceeding 1000 km/s). If such CMEs occur on the Earth-facing side of the Sun, they can arrive at Earth within one or two days and collide with Earth’s magnetosphere. This collision causes what is known as a geomagnetic storm and represents the flow CME plasma and energy into the magnetosphere. Geomagnetic storms can induce huge surge currents in transformers resulting in their destruction. Since the human society relies increasingly on space technology for all kinds of activities, there have been worldwide efforts to understand the eruptive phenomena and their impact on Earth’s space environment under a subject area known as “space weather.”

The purpose of the IUSSTF Joint Center on Solar Eruptive Phenomena was to address some of the outstanding issues on solar eruptions that can be addressed making use of the new observations from space and ground that became available in India and the United States. One of the goals of the Joint Center also was to train young postdocs and graduate students in exploiting the currently available data sources to address issues on solar eruptive phenomena.

Achievements

The training involved using of CME data available at the CDAW Data Center of NASA Goddard Space Flight Center in conjunction with H-alpha observations from ARIES Nainital and the Interplanetary Scintillation observations from the Ooty radio telescope. The participants were also introduced to the Radio Telescope Network (RSTN) data that provide information on shock waves associated with CMEs. Team visits were arranged to the three institutions involved (ARIES Nainital; Radio Astronomy Center, Ooty; and NASA Goddard Space Flight Center) to

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gain valuable experience in data acquisition, access, and analysis. Additionally visits were also arranged to Physical Research Laboratory, Ahmedabad and California State University, Northridge USA.

The Joint Center activities resulted in making progress in answering some of the outstanding questions on solar eruptive phenomena: when and where do shocks form during a solar eruption, how these shocks accelerate energetic particles, and how the energetic eruptions are distributed over a solar cycle. An important backdrop to these investigations was the peculiar state of the Sun and the heliosphere surrounding it due to the unusually weak solar activity during solar cycle 24.

Solar Sources of Eruptive Events

One of the key ingredients of solar eruptive events is the free energy stored in closed magnetic field regions such as active regions and quiescent filament regions. Emergence of new magnetic flux from below the photosphere results in twisted magnetic field lines that add to free energy content of the magnetic regions. This free energy is then released in the form of flares and CMEs. The magnetic field configurations of these active regions relax to near potential-field configuration after energy release through solar flares and coronal mass ejections. One of the JC activities was to study the relation of flare productivity of active regions with their evolution of magnetic flux emergence, flux imbalance and free energy content. Changes in the sunspot area and number were considered for a large number of active regions for this flux emergence study. The magnetic flux imbalance and the free energy were estimated using magnetograms obtained by NASA's Solar dynamics Observatory and the Virial theorem method. It was found that the active regions that undergo large changes in sunspot area are the most flare productive. The active regions become flare-productive when the free energy content exceeded 50% of the total
energy. Flare-productive active regions also showed magnetic flux imbalance, but this parameter alone is not a good indicator of imminent flaring.

A case study was performed on the pre-cursor and main phases of a major flare (X-ray class M1.8) using multi-wavelength observations. EUV observations from NASA's Solar Dynamics Observatory revealed a multi-loop system that destabilized systematically during the precursor and main phases (See Fig.1). It was possible to infer the connection between energy releases during the precursor and main phases of the flare: the precursor phase emission originated via a conduction front that resulted from the partial filament eruption over the neutral line. The heated leftover S-shaped filament then underwent slow-rise and heating due to magnetic reconnection and finally erupted to produce emission during the impulsive and gradual phases.

**When & where do shocks form in the solar corona?**

On the question of when and where do shocks form in the corona, the images obtained at extreme ultraviolet wavelengths by NASA's Solar Terrestrial Relations Observatory (STEREO) mission provided the key information. The shock was observed as a diffuse feature surrounding the earliest manifestation of CMEs when they were merely at a distance of 350,000 km (0.5 solar radii) above the solar surface (1 solar radius = 700,000 km). The shock formation time coincided with the start of a type II radio burst, which is a direct result of electrons energized by the shock. By looking at images taken by STEREO at EUV and optical wavelengths and in white light, the height of the shock at the start time of the type II burst was directly measured for a large number of events. By analyzing more than 30 CMEs with shock features and type II radio bursts, it was found that shocks can form at distances as short as 0.25 solar radii and as large as 2 solar radii. The average distance of 0.5 solar radii is consistent with the assumptions researchers have made in explaining the distance at which accelerated high energy particles are released from the Sun. From the CME kinematics measured from the STEREO images, it was possible to infer that CMEs associated with type II radio bursts attained sufficient speeds to drive shock and accelerate particles. Observationally, the distance of particle release during solar eruptions has been estimated to be about 2 solar radii. This is consistent with the requirement that the shock needs to travel an additional distance from the formation height to...
Joint R & D Centers

allow enough time for the particles to gain the highest possible energies. The solar particles that reach all the way to Earth’s troposphere are thus confirmed to be due to very fast CMEs that form shocks at a height of 0.5 solar radii and release particles at a height of 2 solar radii.

CME interaction and Particle Acceleration

When a CME propagates into a preceding CME or its aftermath, the CME-driven shock propagates into a medium different from that of the normal corona. This is called CME-CME interaction. Statistical studies suggested that the CME interaction somehow enhances the efficiency of particle acceleration. In particular, it was found that CMEs interacting with preceding CMEs result in higher intensity of SEP events in solar cycle 23. The Indo-US team found that CME interaction is the key factor in all high-intensity SEP events of solar cycle 24. In-depth analysis of one of the largest SEP events in cycle 24, viz., the January 23, 2012 event confirmed the importance of CME interaction. The interacting CMEs were both fast: a 2000 km/s CME overtook a 1400 km/s CME (see Figure 2). Unlike the cycle-23 events, it was possible to track the CME interaction closely because of the multiple views provided by the STEREO and the Solar and Heliospheric Observatory (SOHO) missions. The January 23, 2012 CMEs were observed by the STEREO mission taking advantage of the extended field of view of its coronagraphs made it possible to observe the interacting CMEs much closer to the Sun, capturing CME interaction in more detail. It is significant that the metric type II burst was very weak but the interplanetary type II burst was very intense. This may be attributed to different combinations of CME speed, Alfven speed and the physical conditions of the ambient medium. The temporal coincidence of the CME interaction with the onset of the intense interplanetary type II burst confirms the increase in the efficiency of particle acceleration.

In another investigation, it was shown that CME interaction can enhance the possibility of a type II burst association with weak CMEs if the CME is preceded by another slower CME. Two slow CMEs of similar speeds (334 and 337 km/s) and apparent widths (43° and 44°) had different radio signatures. The second CME was associated with a metric type II burst while the first one was not. The STEREO inner coronagraphs on board the STEREO spacecraft clearly showed that the second CME propagated into a preceding CME that occurred 50 min before. These observations further confirm that CME-CME interaction is a key process in exciting the type II radio emission by slow CMEs.

We present a comparative study of the properties of CMEs and flares associated with the solar energetic particle (SEP) events in the rising phases of solar cycles (SC) 23 (1996-1998) (22 events) and 24 (2009-2011) (20 events), which are associated with type II radio bursts. Based on the SEP intensity, we divided the events into three categories, i.e. weak (intensity < 1 pfu), minor (1 pfu < intensity < 10 pfu) and major (intensity => 10 pfu) events. We used the GOES data for the minor and major SEP events and SOHO/ERNE data for the weak SEP event. We examine the correlation of SEP intensity with flare size and CME properties. We find that most of the major SEP events are associated with halo or partial halo CMEs originating close to the Sun center and western-hemisphere. The fraction of halo CMEs in SC 24 is larger than the SC 23. For the minor SEP events, one event in SC23 and one event in SC24 have widths < 120° and all other events are associated with halo or partial halo CMEs as in the case of major SEP events. In case of weak SEP events, majority (more than 60%) of events are associated with CME width < 120°. For both the SC the average CME speeds are similar. For major SEP events, average CME speeds are higher in comparison to minor and weak events. The SEP event intensity and GOES X-ray flare size are poorly correlated. During the rise phase of solar cycle 23 and 24, we find north-south asymmetry in the SEP event source locations: in cycle 23 most sources are located in the south, whereas during cycle 24 most sources are located in the north. This result is consistent with the asymmetry found with sunspot area and intense flares.

Solar Cycle Variation of Energetic Particle events

Solar cycle 24 is much weaker than the previous cycle in sunspot number, but not in the rate of CMEs. In order to see how this might affect SEP events, a statistical study was undertaken to compare the flare and CME properties of SEP events during the rise phases of solar
cycles 23 and 24. There were similar number of events in the two cycles: 22 events in cycle 23 compared to 20 in cycle 24. The events were into three categories, i.e. weak (intensity < 1 pfu), minor (1 pfu < intensity < 10 pfu) and major (intensity >/= 10 pfu) events. It was found that most of the major SEP events were associated with halo or partial halo CMEs originating close to the sun center and western-hemisphere. One of the surprising results was that the fraction of halo CMEs in cycle 24 was larger than that in cycle 23. The minor SEP were also associated with halo or partial halo CMEs similar to the major SEP events. In the case of weak SEP events, more than 60% were associated with non-halo CMEs indicating the importance of CME width for high-intensity events. While the average CME speeds were similar in both cycles, it was higher for major SEP events in comparison to minor and weak events. Furthermore, this study revealed that SEP events correlate better with CMEs rather than with flares, thus providing an important clue to the mechanism of particle acceleration: CME-drive shocks seems to be the main source of particle acceleration.

**Scientific Value Addition**

The Joint Center provided an opportunity to collectively approach several issues related to the mass and electromagnetic emissions associated with solar eruptions. The availability of observations from multi-instrument in multi-wavelengths helped to make concrete progress in understanding complex physical processes involved in solar eruptions. Concrete identification of shock formation heights is a crucial step in understanding the particle acceleration mechanism by the Sun. The case studies performed served as an excellent source of training for younger members of the team and helped clarify the importance of CME interaction in particle acceleration. The statistical studies on solar energetic particle events, geomagnetic storms, and solar source active regions highlighted the key aspects that need to be considered in converting research on these phenomena to usable space weather forecast.

**Way Forward**

The process of answering scientific questions leads to newer and more pointed questions and the Joint Center activities are no exception. A wealth of data have been accumulated during the investigation, which need to be analyzed for further progress on the solar sources, magnetic structures, interplanetary propagation, and Earth impact of the coronal mass ejections. The weak solar cycle has shown different implications for energetic particle events and geomagnetic storms, which needs to be understood in terms of the altered state of the heliosphere.
Publications


Indo-US Joint Center on

Accelerators and Detectors for future High Energy Physics Experiments

About the Center

International Linear Collider (ILC) and Project-X R&D programs at Fermilab is extremely beneficial for Indian and US institutions, as these allows them to share resources, man-power and expertise in an interesting, topical and fast developing area of accelerator and detector technology. The strong motivation for establishing the Indo-US networked center on accelerators and detectors for future high energy physics experiments was due to the following reasons:

(i) Fermilab is host to the world’s current highest energy accelerator along with its state-of-the-art detectors and is playing a major role in the ILC program.

(ii) Delhi University, through the Centre for Detector and Related Software Technology (CDRST), has been actively involved in ongoing and future high energy physics experiments through significant contributions in detectors and physics analysis.

The ILC provides a tool for scientists to address many of the most compelling questions of the 21st century including questions about dark matter, dark energy, extra dimensions and the fundamental nature of matter, energy, space and time.

Achievements

As the name of the Centre highlights, this Centre had twin goals related with the two integral aspects of the Experimental High Energy Physics – Accelerator and Detector R&D.

Goals achieved on the Accelerator R&D:

• We designed beam transport system for proposed high intensity Project-X continuous wave (CW) linear accelerator (linac) to achieve high performance and reliability of machine using accelerator software codes.

• We designed superconducting radio frequency (RF) cavities for high energy section of high intensity CW linac for Project-X facility.

• We understood the various mechanisms of beam losses through linac, such as stripping of H ions and misalignment of beam transport elements.

• We studied the effects of failure of beam transport elements through linac and developed techniques to compensate it.

• We analyzed and understood the coupler’s effects, i.e. coupler RF kick and coupler wake kick in main linac and bunch compressor of the proposed international linear collider (ILC) like lattice and developed techniques to compensate emittance dilution due to coupler’s effects.

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We studied and understood the preservation of small transverse beam emittances through the main linac and bunch compressors of the proposed ILC using beam dynamics simulations.

- We analysed and developed techniques of beam based alignment to limit the transverse emittance growth because of static misalignments of the beamline elements.
- We also understood the effect of dynamic misalignments, like ground motion on the emittance growth and developed 5-Hz feedback system to perform dynamic tuning.

**Goals achieved on the Detector R&D.**

- We designed the ac-coupled, single sided silicon detectors, which can be a possible choice for the future lepton collider.
- We performed optimization studies for the geometry of the single sided silicon detectors, which improved certain characteristics of these devices, like breakdown voltage.
- Single sided, ac-coupled, silicon detectors were fabricated in collaboration with Indian industry at Bharat Electronics Limited (BEL), Bengaluru. Initial characterization results showed that these sensors are meeting most of the quality criteria. Some further R&D is needed to improve the remaining characteristics. It may be noted that these detectors are fabricated only once or twice in India and hence it has already been a major boost for technology development in Indian industry.
- Detector characterization setup has been installed at Delhi University to perform basic characterization of these detectors.
- The device simulation studies were performed on these detectors to get better insight into the detector and to use it as a feedback for future detector fabrication.
- Test structures were included in the design to extract various process parameters and to give insight into the effects of geometric parameters on detector performance.

<table>
<thead>
<tr>
<th>Partnering Institutions</th>
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<tbody>
<tr>
<td><strong>INDIA</strong></td>
<td><strong>US</strong></td>
</tr>
<tr>
<td>• University of Delhi, Delhi</td>
<td>• Fermi National Accelerator Laboratory (Fermilab), Illinois</td>
</tr>
<tr>
<td>• Bharat Electronics Ltd, Bangalore</td>
<td>• Argonne National Laboratory, Illinois</td>
</tr>
</tbody>
</table>

Detector Dimensions: 3.4 cm x 6.0 cm Strip width: 30 μm, Strip pitch: 55 μm
No. of Strips in each detector: 512
Scientific Value Addition

Project-X has been the proposed high intensity proton facility to be built at Fermilab, U.S.A. First stage of the Project-X consists of 3-GeV, 1-mA CW superconducting linac which will provide high intensity beam for variety of physics projects like neutrino, kaon and muon based precision experiments. Beam optics has been optimized to achieve high beam quality. Studies of emittance dilution, longitudinal and transverse acceptance through the linac have been performed. A superconducting (SC) cavity is an expensive device in terms of material, technology of mechanical and chemical processing, and conditions of work: vacuum, liquid helium, adverse effect of outside magnetic fields, etc. It makes design of SC cavity very critical. Two families of SCRF cavity have been designed using electromagnetic field solver code for the acceleration of particles travelling at 61% and 90% of the speed of light.

Beam losses in high intensity CW linac are very critical as it may result in activation. To ensure that beam losses are below the threshold limit, various mechanisms of beam losses are studied such as beam losses due to misalignment of beam transport elements like cavities, quadrupoles and solenoids, beam stripping and beam losses due to dynamic imperfection such as phase jitter. Failure of beam transport elements like cavity, solenoids and quadrupole alters the focusing period of beam, resulting in a mismatch of beam with subsequent sections. This, in turn, causes beam losses. To achieve high performance and hence reliability of the machine, this scenario is included in lattice design.

Insertion of coupler into RF cavity breaks rotational symmetry of cavity, resulting in an asymmetric field. This asymmetric field results in transverse RF kick. This RF kick transversely offsets the bunch from the nominal axis and it depends on longitudinal position of particles in bunch. Insertion of coupler also generates transverse wake which is independent from transverse offset of particles. These effects cause emittance dilution and hence are very crucial for ILC like lattice where emittance budget is limited. Study has been performed to calculate coupler’s effect in main linac and bunch compressor of ILC like lattice. The beneficial effects of implementing emittance bumps after dispersion free steering for the proposed ILC machine is also investigated.

2) Silicon detectors have become indispensable for the current and future HEP experiments. However, these detectors, in various configurations, will see unprecedented radiation fluence (both charged and neutral) and geometrical constraints in future collider physics experiments. Thus, design, development and characterization of these detectors for the future needs of the HEP experiments have become one of the major challenges in the detector technology. To
Joint R & D Centers

Joint R & D Centers develop radiation tolerant detectors for the proposed SiD Experiment of the ILC, Delhi University, ANL and Fermilab have worked in collaboration with Bharat Electronics Limited (BEL), Bangalore on the feasibility studies of producing double sided silicon detectors (DSSDs) for the ILC experiment. Since DSSD is a complex device and BEL has a past experience of successfully fabricating single sided silicon detectors (SSSDs), so we started by exploring the feasibility of fabricating single sided, ac coupled detectors at BEL on 4 inch wafer technology. The initial ILC design geometry was chosen after reviewing designs of the detectors used at earlier experiments like D0 at Fermilab.

Starting with the initial design, the detailed simulations were carried out using TCAD device simulator to optimize the detector geometry for the SSSDs. In the SSSD design, we have included various test structures, which provided better understanding of the detectors and using which we can also extract various parameters like flatband voltage, oxide charge density etc. The masks needed for detector fabrication were first designed and fabricated and further the SSSDs were also designed and fabricated at BEL. To carry out I-V & C-V characterization of single sided detectors, the characterization setup is installed at Delhi University. Results of the detectors showed that these detectors are meeting major tolerances like interstrip and detector capacitance. However, certain parameters like individual strip currents etc. are needed to be further studied. To work on the double sided detectors, we also optimized the design of the insulation technique which can be used to separate n⁺ strips, which otherwise get electrically connected with each other.

In summary, Single sided detectors were fabricated under this Project and the basic detector characterization unit was installed at Delhi University. Further, simulation work for double sided detectors were carried out to understand the insulation problem in the double sided silicon detectors.

It may be noted that these kind of detectors are fabricated only once or twice in India and hence this will continue to help Indian Industry to streamline their processing chain for fabricating complex silicon detector designs in future. Since needs of the future HEP experiments are imposing stringent quality criteria on silicon detectors, like double-sided detectors, development of detectors on 6 inch silicon wafers, working with variety of high resistivity n- and p- type substrates etc., this project has provided the first step into the development of more complex detector configurations.

Way Forward

The Joint Center strengthened R&D work on accelerators and detectors between Indian and US institutes.

1) India has been collaborating with Fermilab on the super conducting RF technology for the high intensity proton machine, which can be used in variety of studies, starting from neutrino factory to the accelerator driven sub-systems. The work done in this Project provided the first step for the design and development of the SCRF cavities. Further work may be carried out for fabricating...
these cavities, characterizing them for their quality control and commissioning them as well.

2) In this project we also designed, developed and characterized the ac-coupled, single sided silicon detectors. As already mentioned, detectors of this kind are made only once or twice in India and this may be considered as the first step in the technology development for future needs. This work was made possible because of strong collaboration between Institutes and Industry. Such collaboration would be invaluable for developing more complex technologies in future. It may be noted that BEL has been able to fabricate these complex devices only because of our earlier work in the CMS Preshower devices (in year 2000 or so). In future, Indian HEP community has been planning to participate in R&D on future lepton colliders and also in the Tracker Upgrade of the ongoing CMS experiments. Detector development for these collaborations at large scale, meeting desired specifications, would be possible only through successive iterations of detector fabrication cycles like this. Also, Institute-Industry partnership like this can be extremely beneficial for carrying out future R&D work in Nuclear and HEP and advancing our Industry to develop state-of-the-art technology.

Publications

- “Calculation of Acceptance of High Intensity superconducting proton linac for Project-X”, A. Saini, C.S. Mishra, K. Ranjan, N. Solyak and V.P. Yakovlev, Particle Accelerator Conference (PAC), 2011, New York, USA.
- “Study of effects of failure of Beam line elements & their compensation in CW superconducting linac”, A. Saini, C.S. Mishra, K. Ranjan, N. Solyak and V.P. Yakovlev, PAC 2011, New York, USA.
- “Lattice design for superconducting CW linac for Project-X facility at Fermilab”, A. Saini, K. Ranjan, J.P. Carneiro, S. Mishra, J.F. Ostiguy, N. Solyak, A.Vostrikov and V. Yakovlev Indian Particle Accelerator Conference (InPAC), 2011, New Delhi, India.
- “Compensation of failure of RF cavity in CW superconducting linac”, A. Saini, K. Ranjan, Solyak, S. Mishra and V. Yakovlev, InPAC 2011, New Delhi, India.
- “Optimization of end cells of low beta cavity of higher energy part of Project X”, A. Saini, C.S. Mishra, K. Ranjan, N. Solyak and V.P. Yakovlev, IPAC 2010 Kyoto, Japan.
• “Study of Coupler’s Effects on ILC Like Lattice”, A. Saini, A. Latina, A. Lunin, K. Ranjan, N. Solyak and V.P. Yakovlev, IPAC 2010 Kyoto, Japan.


• K. Ranjan, “Emittance preservation for the ILC Main Linac,” Invited talk, InPAC 2011, New Delhi, India.


• “Isolation Characteristics of Silicon Sensors Using Simulation Approach”, 20th RD50 Workshop on Radiation hard semiconductor devices for very high luminosity colliders, Bari, Italy, 30 May - 1 June 2012.
About the Center

By setting up an Indo-US Knowledge R&D Joint Networked Center for the Analysis of Variable Star Data, this Center is leveraging existing networking infrastructure to combine current expertise in variable stars in India and the USA and consequently develop powerful new statistical methods to link the structure of variable star light curves to stellar physics. The Center has facilitated the application of these new methods to current and projected new variable star databases. The development and application of the Fourier decomposition methods along with accurate automated data analysis techniques like Principal Component Analysis (PCA) and Artificial Neural Networks to the analysis of variable star light curves.

- The extraction of fundamental stellar parameters from their light curve data – asteroseismology.
- A detailed study of the Oosterhoff dichotomy for RR Lyrae stars in the Milky Way and other galaxies such as M31.
- The development of the use of Cepheid Period-Luminosity relations in the infrared and mid-infrared wavelengths using new and existing satellite and ground based data.
- The automated analysis of variable star data taken from DOME-A in Antarctica. The location of this telescope will provide unprecedented quality ground based variable star light curves.
- Analysis of the highly accurate Kepler and Gaia data on variable stars.

The Center is also providing extensive training for a new generation of globally engaged scientists by involving Indian and American undergraduate and graduate students jointly on these cutting edge research projects.

Achievements

- Developed collaborations between Texas A&M, University of Florida, SUNY Oswego, University of Delhi, IUCAA, Pune.
- University of Delhi and IUCAA faculty and students visited SUNY Oswego in December 2013. Two faculty and one post-doc spent 2 weeks each at Oswego and one student spent 4 weeks there.
- Faculty and students from SUNY Oswego, Texas A&M, University of Florida visited Delhi University and IUCAA, Pune in January 2014.
- 3 students from SUNY Oswego visited Delhi University in July 2014 funded by other sources but working on projects for the Joint Center.
- There was also a joint meeting with another Joint Center (CLASS ACT) and enabled collaborations between the two Joint Centers organized in Kerala in January 2014.
• S. Kanbur and a student from SUNY Oswego visited Drs. A Mahabal and M. Graham at Caltech Astronomy Department and the CLASS ACT Joint Center.
• D. Wysocki, a student from SUNY Oswego presented preliminary results on Principal Component Analysis of Variable Star Data at the summer meeting of the American Astronomical Society meeting in June 2013.
• S. Kanbur presented an invited talk at the MIAPP workshop on the Extra-Galactic Distance scale in Munich June 2014.
• H. P. Singh gave a talk on the theme of the Joint Center at Marburg University, Germany in May 2014.

**Exchange Visits**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
<th>Institution(s) Visited</th>
<th>Duration/Time Period</th>
</tr>
</thead>
</table>
| 1.    | S. M. Kanbur  
SUNY, Oswego | University of Delhi    | 14 days             |
| 2.    | Lucas Macri  
Texas A&M University | University of Delhi    | 7 days              |
| 3.    | H. P. Singh  
University of Delhi | SUNY, Oswego           | 14 days             |
| 4.    | Ranjan Gupta  
IUCAA, Pune | SUNY, Oswego           | 14 days             |
| 5.    | Sukanta Deb  
AND College, DU | SUNY, Oswego           | 15 days             |
| 6.    | Shivam Arora  
University of Delhi | SUNY, Oswego           | 30 days             |
| 7.    | Rachel Wagner-Kaiser  
University of Florida | IUCAA, Pune           | 13 days             |
| 8.    | Ryal Oelkers  
Texas A&M University | IUCAA, Pune           | 11 days             |
| 9.    | Earl Bellinger  
SUNY, Oswego | IUCAA, Pune           | 11 days             |

**Scientific Value Addition**

• Paper [1] presents a careful and detailed light-curve analysis of publicly available data on fundamental mode RR Lyrae (RRab) stars of the Large Magellanic Cloud (LMC) obtained by the Optical Gravitational Lensing Experiment (OGLE). The study indicates that the formation of the LMC disk predates the formation of the inner halo. It has also been proposed that there is no metallicity gradient as a function of the galactocentric distance.
• Paper [2] provides new empirical Period-Color and Amplitude-Color relations for Cepheids and RR Lyraes in the Galaxy/LMC and SMC using the latest extensive and high quality data. This paper also provided a unique and innovative theoretical framework with which to explain the PC relations as a function of period, pulsation phase and metallicity. A primary result of this paper is that...
short period First Overtone Cepheids are just like Fundamental mode RR Lyrae stars in terms of Period-Color relations at minimum light.

- Paper [3] develops new methods for analysing data collected from small, remotely operated telescopes and has results in a large quantity of data that is currently being analyzed for the second year of the project.

- Paper [4] has resulted in the development of the most extensive and accurate Cepheid Period Luminosity relation for the LMC at JHK wavelengths. The paper also calibrated TRGB and RGB distance indicators in the LMC. Together with recent work that provided a 2% distance to the LMC using eclipsing binaries, this will provide a very secure anchor for the extra-galactic distance scale that will help to provide a CMB independent estimate for Hubble’s constant that is accurate to less than 2-3%. Such estimates will be vital in order to place constraints on the dark energy equation of state. This paper also provides data with which to compute the structure of the LMC using JHK wavelengths.

- Paper [5] provides the first systematic quantitative study of the variation of Cepheid light curves as a function of period, wavelength and metallicity. These light curves were studied using the method of Fourier decomposition. The paper also studied the variation of the Hertzsprung progression with metallicity. The main results were a detailed set of quantitative light curve structure measures that can place strong constraints on theoretical stellar pulsation models.

- Paper [6] provides a novel twist to determining the quantitative structure of the light curves of Periodic Variable Stars. A long standing problem in the Fourier decomposition of Variable stars is the determination of the order of the fit. The method presented in this paper describes a new technique that is almost always better than existing methods (Baarts condition). As such it will be a very useful technique for large scale wide field surveys such as OGLE IV and LSST.

**Way Forward**

- The Center is currently analysing CSTAR data in order to:
  1. Calculate the metallicites of 3 RR Lyrae stars observed by CSTAR.
  2. Study the light curve structure of Delta Scuti stars observed by CSTAR.

- Study the consequences of our new LMC JHK PL relation for various distance scale problems.
- Study the LMC JHK survey for other transient phenomena.
- Use the LMC JHK PL relation to calculate the distance to M31 and compare with distances calculated using a Galactic Cepheid PL JHK calibration.
- Use the new LMC JHK PL relation to determine the structure of the LMC.

- Collaborate with Italian researchers to:
  1. Extend the analysis of the light curve structure of Cepheid variables at multiple wavelengths to the SMC.
  2. Use the results of [4] to constrain theoretical stellar pulsation models.

- Use multiphase Cepheid PL relations to develop a novel measure of the metallicity dependence of the Cepheid PL relation.
- Study the use of conditional entropy methods to detect the periods of variable stars.
• Strengthen the results of [5] using other statistical methods and connect these detected nonlinearities to changes in the light curve structure of variable stars.
• Use Artificial Neural Networks to classify variable stars based on their light curve structure.
• Undertake a chemical and structural analysis of the Small Magellanic Cloud using the fundamental mode RR Lyrae stars.

Publications

Planned Publications
Indo-US Joint Center on Excellence on Advanced Materials Research

About the Center
The goal of this Joint Centre is to help build a strategic partnership between India and USA in “Advanced Materials Research” under the SERC, DST–IUSSTF Program. The short-term objectives of the Joint Centre are to (a) establish grass-root collaborations and cross institutional bridge, (b) identify and focus on the grand challenge problems with out-of-the-box ideas, and (c) develop initiatives for longer-term sustainable interaction involving global education, training and outreach programs. The proposed research areas of collaboration spanned a broad range of emerging materials critical for advances to the next generation Information Technology (IT), Energy and Environment and Biotechnology, which include Nanomaterials, Soft Matter, Molecular Electronics, Materials for Energy Conversion, Structure-Property Relationships and Computational Materials Science. The Joint Centre supported the exchange of graduate students (PhD), post-doctoral fellows and faculty members between JNCASR and NU and other partnering institutions. Through exchange visits of faculty members and brain-storming discussions during JNCASR-NU workshops, longer visits of students and postdocs were effectively used to accomplish important milestones of research in the following areas:

- 2-dimensional Nano-materials with focus on (a) basic science and characterization of graphene and group VI transition metal chalcogenides, and (b) their use in nanoelectronic devices such as field effect transistors.
- Molecular Electronics, covering fast, low power flexible devices based on polymers.
- Nano-lithography, covering dip-pen nanolithography, polymer pen lithography, development of better tips, nano-particle superlattices and cantilever-free nano-printing and patterning.
- Interaction of nano-particles and graphene with biomolecules.
- Chemistry of Materials, covering non-centro-symmetric oxyfluorides.
- Graphical representation of the network of collaborations established through the Joint Center.

Other Activities/Accomplishments (Workshops/Training Programs/Course delivery)
Joint R & D Centers

Partnering Institutions

INDIA
- Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bangalore

US
- Northwestern University, Evanston, Illinois

- Kanishka Biswas (trained at NU partly through activities of the Joint Centre) joins the faculty of JNCASR, Bangalore (area: thermoelectrics and other semiconductors).
- D Late (trained at NU through activities of the Joint Centre) joins as a Ramanujan Fellow at NCL, Pune (area: nano-electronics based on 2-D materials).
- M Dey (trained at JNCASR&NU through activities of the Joint Centre) joins the faculty of Inorganic and Physical Chemistry Department of IISc, Bangalore (area Nano-bio).
- JC liaised and brokered collaborative program and access to Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL), TN
- Similar efforts are ongoing for access to and collaborations with ANL-APS/CNM.

International Materials Lectures at JNCASR:
- Tobin Marks (December, 2009)
- Chad A Mirkin (June, 2012)
- Mercouri Kanatazidis (December, 2013)

Key Faculty Participants

<table>
<thead>
<tr>
<th>Prof. C N R Rao</th>
<th>JNCASR, Bangalore, INDIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prof. Chad Mirkin</td>
<td>Northwestern University, USA</td>
</tr>
<tr>
<td>Prof. Kenneth Poeppelmeier</td>
<td>Northwestern University, USA</td>
</tr>
<tr>
<td>Prof. K S Narayan</td>
<td>JNCASR, Bangalore</td>
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<tr>
<td>Prof. S. M. Shivaprasad</td>
<td>JNCASR, Bangalore</td>
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<tr>
<td>Prof. Mark Hersam</td>
<td>Northwestern University, USA</td>
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<tr>
<td>Prof. Jiaxing Huang</td>
<td>Northwestern University, USA</td>
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<tr>
<td>Prof. G U Kulkarni</td>
<td>JNCASR, Bangalore</td>
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<table>
<thead>
<tr>
<th>Prof. Mercouri Kanatzidis</th>
<th>Northwestern University, USA</th>
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<tbody>
<tr>
<td>Prof. Matthew Grayson</td>
<td>Northwestern University, USA</td>
</tr>
<tr>
<td>Prof. Chandrabhas Narayana</td>
<td>JNCASR, Bangalore</td>
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<tr>
<td>Prof. Tobin Marks</td>
<td>Northwestern University, USA</td>
</tr>
<tr>
<td>Prof. K Biswas</td>
<td>JNCASR, Bangalore</td>
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<tr>
<td>Prof. George Schatz</td>
<td>Northwestern University, USA</td>
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<tr>
<td>Prof. C Narayana</td>
<td>JNCASR, Bangalore</td>
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<tr>
<td>Prof. A Sundaresan</td>
<td>JNCASR, Bangalore</td>
</tr>
<tr>
<td>Prof. Richard P. Van Duyne</td>
<td>Northwestern University, USA</td>
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</tbody>
</table>
Significant collaborative efforts have led to a chapter in a book and a good number (~33) of publications in reputed journals in many areas of current relevance. More than 14 faculty members each from JNCASR and NU worked together in teams of three or more research groups at a time. Three of the junior researcher participants have taken up faculty positions in three different institutions (NCL, IISc and JNCASR) in India. In the course of last four years, both the partner institutions have learnt how to work together efficiently. Researchers from NU and JNCASR have a number of joint projects presently continuing through other funding, and they are keen to plan a stronger and more effective Joint Centre to support their research activity that has involved optimal use of complementary skills from both the institutions.

Scope of Activities

<table>
<thead>
<tr>
<th>Theme</th>
<th>Faculty Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular Electronics</td>
<td>T. J. Marks, K. S. Narayan, M.C. Hersham</td>
</tr>
<tr>
<td>Nano-lithography</td>
<td>G. U. Kulkarni, C. A. Mirkin</td>
</tr>
<tr>
<td>Interaction of nano-particles and graphene with biomolecules</td>
<td>C. A. Mirkin, Mrinmoy De, V. P. Dravid</td>
</tr>
</tbody>
</table>

Publications

**Exchange Visits**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name and Affiliation</th>
<th>Institution(s) Visited</th>
<th>Duration/Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B. Radha JNCASR</td>
<td>Northwestern University</td>
<td>February 6, 2013 – August 5, 2013</td>
</tr>
<tr>
<td>2</td>
<td>Ramakrishna Matte (Postdoc) JNCASR</td>
<td>Northwestern University</td>
<td>March 10, 2013 – March 9, 2014</td>
</tr>
<tr>
<td>3</td>
<td>K. S. Subrahmanyam (Postdoc) JNCASR</td>
<td>Northwestern University</td>
<td>March 30, 2013 – March 26, 2014</td>
</tr>
<tr>
<td>4</td>
<td>Dattatray Jaising Late (Postdoc) JNCASR</td>
<td>Northwestern University</td>
<td>July 1, 2011 – September 23, 2012</td>
</tr>
<tr>
<td>5</td>
<td>Kalyan Raidongia (Postdoc) JNCASR</td>
<td>Northwestern University</td>
<td>June 15, 2011 – October 31, 2012</td>
</tr>
<tr>
<td>6</td>
<td>Subi J George (Assistant Professor), JNCASR</td>
<td>Northwestern University</td>
<td>June 23 – July 30, 2011</td>
</tr>
<tr>
<td>7</td>
<td>Govindaraju T (Assistant Professor), JNCASR</td>
<td>Northwestern University</td>
<td>June 23 – July 30, 2011</td>
</tr>
<tr>
<td>8</td>
<td>Tapas Kumar Maji (Assistant Professor), JNCASR</td>
<td>Northwestern University</td>
<td>June 23 – July 30, 2011</td>
</tr>
<tr>
<td>9</td>
<td>A Sundaresan (Associated Professor), JNCASR</td>
<td>Northwestern University</td>
<td>March 10-April 10, 2011</td>
</tr>
<tr>
<td>10</td>
<td>Swapan K. Pati Professor, JNCASR</td>
<td>Northwestern University</td>
<td>March 26-April 20, 2011</td>
</tr>
<tr>
<td>11</td>
<td>Umesh V. Waghmare Professor, JNCASR</td>
<td>Northwestern University</td>
<td>July 2011 (2 days)</td>
</tr>
<tr>
<td>12</td>
<td>Chandrabhas Narayana JNCASR</td>
<td>Northwestern University</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>S.M. Shivaprasad JNCASR</td>
<td>Northwestern University</td>
<td>May 6 – May 27, 2014</td>
</tr>
<tr>
<td>14</td>
<td>Steven Girard (Graduate Student) Northwestern University</td>
<td>JNCASR</td>
<td>February 10-February 28, 2011</td>
</tr>
<tr>
<td>15</td>
<td>Prakash Parida JNCASR</td>
<td>Northwestern University</td>
<td>15 June – 15 September, 2010</td>
</tr>
<tr>
<td>16</td>
<td>Anupama Ghosh JNCASR</td>
<td>Northwestern University</td>
<td>15 June – 14 September, 2010</td>
</tr>
<tr>
<td>17</td>
<td>Partha Pratim Kundu JNCASR</td>
<td>Northwestern University</td>
<td>15 June – 15 September, 2010</td>
</tr>
</tbody>
</table>


- Ahn, K., Biswas, K., He, J., Chung, I., Dravid,
Indo-US Science & Technology Forum


March 2015