Report of the Committee to Review the International Center for Theoretical Physics of the Tata Institute for Fundamental Research (ICTS–TIFR)

Bangalore, January 11-13, 2018

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1 INTRODUCTION AND PROCEDURES

Our international committee of experts convened for a three–day meeting at the ICTS (Bangalore) in January of 2018. The committee members were Beverly Berger (NSF (retired), general relativity), Curtis Callan (Princeton, particle theory and biophysics), Bertrand Halperin (Harvard, condensed matter), Itamar Procaccia (Weizmann, fluid mechanics and statistical and soft matter physics), Kavita Ramanan (Brown, mathematics), and Ashoke Sen (Harish–Chandra Institute, string theory), with Callan serving as chair. The committee membership was chosen to provide expertise across the broad range of scientific activities carried out at the ICTS.

Before the meeting, the committee was provided with extensive documentation on the charter, organization, and activities of the ICTS. The meeting itself was organized as follows (detailed agenda provided as Annex 1): We began with an hour–long teleconference with the TIFR director, Sandip Trivedi, to receive his charge to the committee and to clarify various questions on the history and context of the ICTS that had arisen in the minds of the committee members. The director emphasized the unique four–fold mandate of this new institution (doing frontier research across a broad range of fields of theoretical science, providing graduate education across these fields, enhancing the skills of Indian theoretical scientists through programs that bring them into contact with the highest level of international expertise, and exciting the interest of the lay public in fundamental science through innovative outreach programs) and asked the committee both to evaluate how well the ICTS had been executing these mandates and to offer advice on how the institute should direct its future growth in the light of this complex mandate. A letter from the TIFR director to the committee chair laying out this charge is provided as Annex 2. The meeting with the TIFR director was followed by a discussion with the ICTS director, Rajesh Gopakumar, to get his perspective on the questions we were asked to address.

During the rest of the first day, the committee received research presentations from the various groups (delivered in the presence of director Gopakumar and the whole faculty). On the second day, the committee received an overview of ICTS academic governance, followed by more detailed reports from the faculty members in charge of the graduate program, the postdoctoral program, the scientific meeting program, the outreach program and the visiting student/scientist program. In addition, the administrative staff, the computing staff, and the buildings and infrastructure staff presented separate reports on the situation in their respective areas of responsibility. Finally, the committee had collective meetings with the graduate students and, separately, the postdocs (roughly 40 members in each group) in order to get their views on what is working and what needs improving at ICTS. The morning of the third day was devoted to an executive session of the committee in order to organize our thoughts and construct an outline of this report. In the afternoon we had an exit interview (again by teleconference) with the TIFR director to present our summary conclusions, followed by a face–to–face meeting with the ICTS director to inform him of our overall conclusions and communicate specific items that we felt were not appropriately included in our report to TIFR management.

2 EXECUTIVE SUMMARY

We begin our report with a summary of the major observations and recommendations that we would like to bring to the attention of TIFR management.

2a. ICTS is a powerful new asset for Indian science and science education. Much remains to be achieved, but a solid foundation for a future of great importance to Indian science and Indian society has been laid. ICTS has a unique multi–faceted mandate: to perform interdisciplinary research in theoretical science at the highest level across a broad intellectual frontier; to educate a new generation of PhD scientists in these disciplines; to facilitate the diffusion of frontier scientific developments and theoretical techniques across the Indian scientific enterprise through focused topical programs; to excite and inspire the public, especially the young who will be the scientists and technologists of India's future, through outreach programs. It is our assessment that ICTS, despite its youth as an institution, is doing an impressive job on all four fronts.

2b. We strongly support the plan of growing the faculty to a strength of about 35 over the next decade. This growth should be deliberate, with careful attention to how new disciplines are brought on board, and uncompromising in its focus on quality. ICTS has been following the path laid out in the Detailed Project Report that was discussed and approved by the TIFR management board in 2009. An important aspect of the original plan was the judgment that a faculty of at least 35 scientists would be needed to support the multiple goals set for the ICTS. This judgment was based on a census of the sub–disciplines in physical and mathematical sciences that would need to be represented, coupled with the idea that, in the spirit of encouraging interdisciplinary interactions, each such faculty subgroup would be modest in size (although larger than some critical size that might depend on the discipline). Despite the rapid evolution of science since 2009, it is our judgment that the original estimate of the faculty size necessary to execute the ICTS mission continues to be valid, and should be reaffirmed.

2c. We strongly support the notion that the intellectual scope of the ICTS should be expanded beyond the traditional boundaries of theoretical physics into new domains where mathematical modeling and comprehension of data are fast becoming not only possible, but essential (as, for example, quantitative cellular biology, theoretical neuroscience, and the general theory of large data exploitation). The original concept of the ICTS was founded on the notion that the ICTS could play a unique role in facilitating this movement in science, and that concept is even more valid today. We applaud and support the intention of the ICTS to move carefully and deliberately in this direction.

2d. At the same time, we believe that this overall expansion of the intellectual scope of ICTS must be accompanied by a focused expansion of the mathematics faculty. The scientific and educational missions of ICTS are founded on the notion that progress in many areas of quantitative science will increasingly rely on bringing frontier methods in mathematics to bear on the problems and data of new areas of science. The current size of the ICTS mathematics faculty is simply too small to properly exploit the expected synergies, or to provide the necessary in–house teaching support for the graduate education program. Put another way, mathematics is not just one among many disciplines pursued at ICTS, it is a foundation for all the others. In our opinion, an expansion of the mathematics faculty, taking care to expand in directions that will engender collaborations with the physical and biological sciences, is an urgent priority. Cooperation with the TIFR Center for Applicable Mathematics in nearby Bangalore could be very helpful in this regard.

2e. Increasing the size of the ICTS LIGO effort would enable ICTS to take a leadership role in the development of the enlarged scientific community that will be needed to support LIGO India. The gravity group at ICTS has already played a role in LIGO physics out of proportion to its size. This could be built upon by making two strategic hires: one in simulation of gravitational wave sources and one in multi– messenger (gravity plus electromagnetism plus neutrinos) astronomy. Doing what needs to be done to make LIGO India a success should be a national (and TIFR) priority, and it would be completely appropriate to direct extra resources to ICTS in support of this goal.

2f. Concentrating the graduate student experience on the ICTS campus is a matter of high priority. In particular, we believe that construction of a student hostel on or next to the campus is essential. Graduate education at ICTS suffers from the fact that many courses are given in other institutions, and from the fact that a large fraction of the students are housed at distant off–campus locations. Both things mean that students spend an inordinate amount of time traveling by an ICTS–provided shuttle between the ICTS campus and other Bangalore institutions. The first problem will eventually be solved as the faculty grows in size, but near–term workarounds (perhaps involving technological fixes such as web–based teaching) should be vigorously pursued. The second problem can only be solved by the construction of on–campus physical housing. These problems are well–known to prospective graduate students, and the graduate education program will not be competitive with other elite Indian institutions if this problem is not dealt with expeditiously.

2g. We strongly urge that a significant number of new regular administrative posts be allocated to ICTS by TIFR management. The current model, in which a skeleton crew of regularly appointed administrators is assisted by more numerous temporary project staff, is not sustainable, given the diversity and intensity of the activities that ICTS is required to support. The overall size of the administrative contingent has not grown to match the growth of the Center. The limited term of project--specific posts means that requisite training must be given over and over again. In addition, temporary staff members receive no benefits and have no clear career path ahead of them, circumstances that have a negative impact on morale. It is essential that TIFR provide additional regular administrative positions as quickly as possible. While we commend the efficiency and effectiveness of the current administrative staff, we feel that the current model is not sustainable in the long run. We would note that “normal” standards for faculty/staff ratios should not be rigidly applied to ICTS in view of its complex and multi–faceted mission.

3 ASSESSMENT OF CURRENT FUNCTIONING

3a. Research Groups

RESEARCH AT THE ICTS is currently carried out within six identifiable research groups. Because the ICTS is a "work in progress", these groups are of different sizes and degrees of maturity. Because of the ICTS' expansive intellectual mandate, we can expect that the research landscape at ICTS will become even more diverse over time. In this section, we will provide a description of the work of each existing group, commenting as appropriate on strengths, weaknesses, and standing in the international context.

1) The Mathematics Group

The math group at ICTS currently comprises 4 people: Amit Apte and Vishal Vasan, who work in dynamical systems and partial differential equations, and are an important component of the applied math effort at ICTS, Riddhipratim Basu, who works in Probability Theory, and Rukmini Dey, who works in Geometry. The research of members of the Mathematics Group has synergies with other groups at ICTS, including the fluid dynamics group, string theory and statistical physics group. Although small, this group is producing high–quality research. In addition, the existence of a mathematics group significantly enhances the interdisciplinary mission of ICTS. Some significant research contributions of the group are described below.

The *Applied Math group*, in collaboration with people from the Fluid Group (S. Ray and R. Govindarajan at ICTS, and S. Vadlamani from TIFR CAM) has played an important role in developing the Monsoon Initiative. This is the first interdisciplinary attempt to develop a theory that seeks to explain monsoon behavior. It is complementary to other (more phenomenological) monsoon modeling efforts at other institutions in the country including CAOS–IISc, IITM–Pune, etc., and also involves collaborations with people at various institutions within India (such as TIFR–TCIS, JNCASR TIFR–CAM) and the United States (UNC, Chapel Hill and Columbia University). This project has combined mathematical modeling with statistical methods to analyze large amounts of data such as Markov random fields and Bayesian inference, with computer simulations of turbulent fluid flows in order to generate theoretical models of monsoon rainfall patterns that are also physically relevant. Other significant research from the group includes the study of water– waves, Bayesian inverse problems and filtering problems and data assimilation for high–dimensional dynamical systems.

The *probability group*, currently represented at ICTS by R. Basu, is complemented by a number of probabilists in the Bangalore area, including S. Vadlamani from TIFR–CAM, M. Krishnapur and A. Ayyer at IISc and S. Athreya from ISI, Bangalore. R. Basu has made significant contributions to problems at the forefront of current research in discrete probability theory, some of which are motivated by problems in Statistical Physics and Theoretical Computer Science. He has worked on mixing times for Markov chains, random matrices, concentration of zeros of Gaussian processes, and he has made particularly significant contributions (joint with A. Sly and other co–authors) to various questions related to percolation models. The latter include Lipschitz embeddings of random sequences (which can be seen as a generalization of what are known as oriented percolation problems), tail bounds in first passage and large passage percolation problems, and properties of geodesics in last passage percolation. R. Basu has already produced very interesting work since he joined ICTS (in September, 2017) and he is likely to attract other

strong researchers in probability theory to ICTS.

Geometry is represented at the ICTS by Rukmini Dey. She has done significant work in the geometric quantization of various moduli spaces, which is motivated by problems in physics. She has also made important contributions to the theory of minimal and maximal surfaces.

2) The String Theory Group

ICTS has been able to attract many internationally renowned string theorists and the string theory group at ICTS has grown into one of the most active groups in India. Currently it has six members: P. Basu, A. Dhar, R. Gopakumar, R. Loganayagam, S. Raju and S. Wadia. Their work covers a wide range of topics, including black holes, Chern–Simons theory, holography with two dimensional conformal field theories, dissipative hydrodynamics, open quantum systems, eigenstate thermalization hypothesis in conformal field theories, SYK model and many more. The group is highly sought after by prospective graduate students, postdoctoral fellows, and faculty applicants. The following is a sampling of the results coming out of ICTS that have had major impact on the field:

Understanding the quantum physics of black holes is a problem that has been with us since Hawking's discovery that black holes have finite temperature. The problem was sharpened by Mathur, and later by Almheiri, Marolf, Polchinski, Sully and Stanford, who argued that the existence of a smooth black hole horizon is incompatible with quantum mechanics. The work of S. Raju and collaborators showed that it is possible to make the existence of a smooth horizon compatible with quantum mechanics if one gives up the requirement that the effective field theory description near the horizon continues to hold even for correlation functions with exponentially large number of operator insertions. One of the novel results of this analysis is that the modes in the interior of the black hole are scrambled versions of the degrees of freedom living outside the black hole. Another novel feature of their result is that the description of the modes inside the horizon depends on the specific quantum state of the black hole and not just the classical geometry of the black hole. Even though the analysis was done in the context of black holes in anti de Sitter spaces, the results are likely to have far–reaching impact on our understanding of black holes in general.

S. Wadia and his collaborators found exact solutions to SU(N) Chern–Simons theory coupled to vector matter in the large N limit. Besides providing a new class of examples of soluble quantum field theories, these models provided a dual description of Vasiliev higher–spin theories in certain limits, and led to the discovery of fermion–boson duality symmetry in these theories. Another surprising result coming out of this analysis is the modification of the usual crossing symmetry relations due to long–range interactions induced by the Chern–Simons gauge fields.

Recent years have seen a revival of the conformal bootstrap approach to conformal field theories. Most of the papers on the subject use a numerical approach to implementing crossing symmetry after imposing the constraints coming from the conformal invariance and operator product expansion. R. Gopakumar and his collaborators developed an analytical approach to the conformal bootstrap by starting with an ansatz that has manifest crossing symmetry and then imposing the requirement coming from the operator product expansion. This approach led to the computation of the operator dimensions and the OPE coefficients of the Wilson– Fisher fixed point in the epsilon expansion.
A different analytic approach, introduced by Rychkov and Tan, was used by P. Basu and his collaborators to compute anomalous dimensions of operators in scalar field theories.

Loganayagam and his collaborators gave a reformulation of the Schwinger–Keldysh formalism for non–equilibrium/open quantum systems that is more efficient for understanding the low–energy limit of quantum field theories out of equilibrium.

This is likely to have long–term impact not only on the understanding of quantum field theories but also the physics of black holes via the holographic principle.

Overall, the string theory group has a good mixture of senior and junior members, working in varied aspects of the field. At present there does not seem to be any compelling need for the group to grow, but exceptions can always be made for exceptional candidates.

3) The Astrophysical Relativity Group

The group consists of Assoc. Prof. P. Ajith, Simons Visiting Prof. B. Iyer, 4 postdocs, and 2 graduate students. The primary focus of the group has been analysis of LIGO (and Virgo) data with a broader interest in applications of general relativity and particular interests in improved ways to analyze and interpret the data and in using gravitational waves to test general relativity. The group performs most of its work within the LIGO Scientific Collaboration.

The significance of the recent LIGO detection of gravitational waves from a binary black hole merger cannot be overstated. Gravitational waves had never been directly detected before nor had there ever been observational evidence for a binary stellar system consisting of two black holes. In short, a new window on the Universe was opened. The first detection by LIGO and Virgo of a binary neutron star merger was comparably significant because it marked the first event detected both by gravitational waves and by electromagnetic signals. The latter were at all wavelengths from radio waves to gamma rays and made it possible for optical telescopes to identify the merging object and its host galaxy.

Strengths: Ajith and Bala are outstanding scientists with international reputations. Bala retired from RRI and is now supported by the Simons Foundation. He was one of the pioneers in developing post–Newtonian solutions to general relativity and the approximate waveforms that eventually led to the template bank used to find the LIGO signals. More important, perhaps, were his tireless efforts to form the IndIGO collaboration within the LIGO Scientific Collaboration (LSC) and to promote LIGO India both in India and in the US. Ajith is one of the leading young scientists in the LSC. He came to ICTS from a postdoctoral position at MPI (AEI) and now leads a Max Planck Partner Group with them. His research on improved waveforms and algorithms to test GR have been applied by LIGO/Virgo to interpret the data in these transformational discoveries and to use this interpreted data to test GR. Future efforts by Ajith and his students and postdocs will focus on development of more general waveforms including, e.g., orbital eccentricity and spin and on improved tests of GR to take advantage of statistical tests enabled by expected high event rates. The group is also extremely active in outreach. These outreach efforts, such as the annual GW summer school, could be built upon to become a major resource crucial to the development of the community of experimental researchers necessary for LIGO India.

Weaknesses: The primary issue for the group is the lack of a critical mass of faculty. Since Bala is on soft money, there is essentially a single faculty member. While this is somewhat ameliorated by effective interactions with the large GW collaborations and other ICTS groups, there is no substitute for onsite, expert faculty to mentor students and postdocs. Many directions for expanding the group's activity are possible, including computer simulations of binary systems containing neutron stars and/or black holes and theory and data analysis for multi–messenger astronomy.

Augmentation of the local computational cluster from tier 3 to tier 2 will be needed to meet the increased analysis load to be expected in the next few years as Advanced LIGO's sensitivity improves. This computational infrastructure improvement would be of significant benefit to GW science in India in general.

In summary, growing this group in this exciting era of GW discovery should be an extremely high priority. As we point out elsewhere, the ICTS astrophysical relativity group is well–placed to play a key role in the development of LIGO India.

4) The Fluid Mechanics and Turbulence Group

This group includes two faculty members, R. Govindarajan and S. Shankar Ray. Together with two postdoctoral fellows and five students they study both fundamental and applied problems in nonlinear fluid physics. The research activity includes a small laboratory

for table–top experiments, but the main effort is theoretical. The review committee is very favorably impressed by the efforts related to geophysical issues, especially that of trying to understand the Indian Monsoon and the physics of rain formation in clouds. Rain formation is a recognized riddle and the ICTS group has made valuable suggestions to explain the growth of small drops to rain drops on the basis of turbulent dynamics. These are subjects in which this group can have original contributions that are unique to Indian science. The Monsoon project in particular is very exciting: the Monsoon is significantly less understood than other geophysical phenomena like the El Nino and an Indian effort on this front is highly desirable. It also involves a strong collaboration with several Applied Math researchers, including A. Apte and V. Vasan. Other activities of the group include classical turbulence with a stress on turbulent transport and intermittency. The small experimental lab focuses in viscous dynamics of moving bodies and filament–fluid interactions. All these activities are highly professional with a good degree of high–level international collaboration.

In the future the group should increase in size by adding one or two additional faculty with interests in nonlinear physics. Potential subjects could be 1) glasses and granular matter with application to geophysics or 2) nonlinear dynamics in Bose– Einstein condensates. Such subjects integrate well with the present interests but open up new horizons for research and teaching.

5) The Statistical Physics and Condensed Matter Group

The group working on statistical physics and condensed matter contains five faculty members, including one, C. Dasgupta, who is a Simons Visiting Professor and is an emeritus professor at the Indian Institute of Science. The group also lists five postdoctoral fellows and four graduate students. A large portion of the group's work is focused on non–equilibrium phenomena in classical systems, but the group is also involved in quantum mechanical many–body problems, both equilibrium and non–equilibrium.

Three of the five members of the group joined ICTS within the last few years, and they are at relatively early stages in their research careers. They are all engaged in cutting–edge research, and show promise to have considerable impact in their fields. The two more senior members have established international reputations and continue to do exciting research.

S. Bhattacharjee, who joined ICTS in 2015, has interests in quantum many–body problems, particularly frustrated magnetic systems, topological phases, and systems with both strong electron–electron interactions and strong spin–orbit coupling. He has a strong ongoing collaboration with the group at the Max Planck Institute for Complex Systems, where he was a postdoctoral fellow before 2015.

A. Kundu, who also joined ICTS in 2015, specializes in stochastic and transport processes in non–equilibrium situations. Some of his recent work is done in collaboration with S. Majumdar and D. Mukamel, studying low dimensional systems in nonequilibrium steady states. Kundu is using both fluctuating hydrodynamics and microscopic considerations to advance the understanding of these questions. In the near future Kundu plans to extend his studies to situations where the system is always connected to reservoirs and the dynamics is not purely Hamiltonian. This is an interesting set of questions where Kundu can be expected to make original contributions.

M. Kulkarni, who joined ICTS in 2016, works on non–equilibrium open quantum systems, as well as classical problems of non–linear hydrodynamics, integrable models, and mathematical physics. Kulkarni has collaborated with A. Dhar on a number of recent papers, including work on non–equilibrium steady states in a one– dimensional quasiperiodic system at the critical point between localized and delocalized eigenstates.

A. Dhar has been a member of ICTS since 2012. He works on non–equilibrium problems in classical and quantum transport, stochastic processes, and the theory of large deviations. Dhar is well–known for his work on heat transport in low– dimensional systems. In the past two years, his work has included collaborations with Kundu, as well as with Kulkarni,

on a variety of problems involving one– dimensional systems, classical and quantum.

C. Dasgupta's interests span a range of problems in classical statistical physics. These include dense fluids near a structural glass transition, non–equilibrium dynamics of complex fluids, and the glass transition in active systems. In collaboration with A. Dhar, he is currently studying problems of heat conduction in a liquid close to a glass transition as well as in the aging regime of a glass formed by quenching to a temperature slightly below the glass transition. He is also studying models of a glass–forming liquid, where the properties can be significantly altered by the presence of active (i.e. self–propelled) particles.

It should be noted that statistical and condensed matter physics cover a broad range of topics, which together form a major portion of the theoretical investigations in many physics departments. From this point of view, coverage of the field at ICTS is thin in some respects. While Kundu, Kulkarni, Dhar and Dasgupta have overlapping interests, and in fact have collaborated on multiple projects, Bhattacharjee's research, focused on the properties of exotic forms of order in quantum many–body systems, is relatively distant from other work in the group. Although appointments in some other areas may have higher priority for ICTS at present, recruitment of an additional faculty member in this general area would enhance the ability of the center to attract the highest caliber of students and postdoctoral fellows in this important field.

6) The Physical Biology Group

The physical biology group consists of basically one faculty member: V. Krishnamurthy. He is joined by P. Basu of the String Theory group (who is beginning to shift his focus to biology) and S. Thutupalli (joint faculty with NCBS). The group includes five postdoctoral fellows and together they study problems at the interface of physics and biology. The following is a sample of the interesting questions and results that have resulted from this group's work:

1) Morphogenesis and the emergence of patterns in developing embryos. This subject has interesting physics ingredients, especially due to the interplay between active mechano–chemical stresses and the transport of morphogens that can lead to the emergence of spontaneous patterns.

2) The statistical mechanics of active Brownian particles. These are minimalistic realizations of scalar active matter and throw light on the workings of molecular motors.

3) The study of "synthetic biology" to understand the emergence of specific, quantifiable, and characteristic properties of living matter.

4) Studying colonies of insects that show large–scale navigational skills to find and carry back food to their nests.

The review committee strongly supports an increase in the size of this group from 1 to at least 3 faculty members in the near term. At its present size, the group finds it impossible to attract graduate students, a severe handicap for carrying out a successful research program, and an initial increase in the size of this group should be accomplished sooner rather than later. This would, in addition, provide a more solid foundation for planning what will surely be a more significant expansion over the longer term.

3b. Programs

Throughout its history, ICTS has run programs primarily designed to connect Indian researchers and students with an array of international experts for purposes ranging from pedagogical skill development, to fostering research collaborations, to initiating new avenues for research. While many of the topics align with the research interests of the ICTS faculty, this is by no means a requirement, although the engagement of ICTS faculty, postdocs, and students in the programs is a major strength of the Center.

There is an open process for anyone from the international science community to propose a new program topic. ICTS has a program review committee (with members from across the Indian science community) that actively interacts with program proposers to shape original proposals so that the actual event is of excellent quality. Once a program is accepted, ICTS provides the necessary program infrastructure, including advertising, lodging, appropriate meeting spaces and IT. The statistics on the number of proposals mounted per year, together with the census of program participants, are extremely impressive[1] and testify to the fact that the ICTS program activity is meeting a sorely felt need in India.

We single out for particular praise the schools to introduce young scientists or students, primarily from India but also from abroad, to a variety of topics, especially those related to in house research at ICTS. Examples are the annual gravitational wave summer school, and the quadrennial hosting of the Asian string theory school.

Equally important are the workshops to initiate new research topics that could potentially be developed effectively in India, but that are not currently being pursued. A recent example is the program on Laser Plasma Acceleration that led to the formation of a working group to formulate a white paper proposing this topic to the Indian government as a new national research direction.

An important concern for this extremely successful activity is the administrative policy that severely limits travel funding for bringing international experts to India for the programs. This is, to put it mildly, in direct contradiction with the mandate given to ICTS to mount programs that make international expertise available to Indian science. The ICTS has succeeded in raising some private funds to ameliorate this problem, but it seems illogical to make the ICTS find alternate funding for a core activity like this.

3c. Outreach

An important attribute of ICTS, and one that distinguishes it from other research institutions in India, is its treatment of outreach to the lay public, especially the young, as a core activity. India, a country whose economic growth is focused on technology, has an ever–growing need for scientifically trained personnel, a need that can only be met by encouraging more of its vast population of young people to seek training in a wide range of scientific disciplines. A concerted effort to interest Indian youth in science and inspire them to seek a scientific education is called for, and ICTS has already demonstrated that it is able to make a significant impact in this direction through its outreach activities.

The list of ICTS outreach activities in the few years since its foundation includes:

a) A number of one–time events including: an exhibition on the planet and climate change at the Visvesvaraya Industrial and Technological Museum (VITM), Bangalore, in November, 2013, and the ICTS partnership in the international Mathematics of Planet Earth initiative in 2013.

b) "Kaapi with Kuriosity": started in the second half of 2016, these events are 1.5 hour long popular science presentations by ICTS faculty (or visiting scientists). Each event comprises a 45–minute presentation and 45–minute discussion and question session. These events are well–advertised and held in held in the Jawaharlal Nehru Planetarium and other public venues, and the proceedings are archived on YouTube. The success of these talks is evident from the large audiences (typically over 250, with a diverse age distribution), and the large number (9000) of views of the archived YouTube videos.

c) Einstein Lectures: these are lectures by ICTS faculty (or noted visitors) on a wide

[1] Since its inception in 2007, ICTS has organized 125 Programs, 49 Discussion Meetings, 28 Named Lecture Series, and several Abdus Salam Public Lectures. These programs reach an annual average of nearly 1200 researchers (or 17000 participant--days). In the past three years, the student participation has been 49% and 42% respectively in the Programs and Discussion Meetings, with foreign participation at 31% and 23% respectively. Female participation in both activities was about 20%.

spectrum of topics in the sciences and mathematics that are given at schools, colleges and other organizations all over India. To date, approximately 20 such lectures have been given, typically to large and enthusiastic audiences.

d) Public lectures: these are talks aimed at a lay audience on exciting developments in research, that are delivered by eminent visitors to the ICTS, typically on the ICTS campus. This includes the specially named "*Vishweshara*" Lectures, initiated in 2018. The Review Committee was able to attend the first of these, delivered by Kip Thorne. It was attended by over 1500 students from the local Bangalore area, and the level of enthusiasm of the crowd gave it the feel of a rock concert.

We note that the number and quality of these activities is made possible by the continuous engagement of the ICTS faculty in their planning and execution. A concrete sign of the importance attached by ICTS to the investment of its faculty in outreach is the fact that it is explicitly given weight in the evaluation of faculty for promotion to tenure. We also note that, as is the case for the program activity, the success of the outreach program requires significant administrative support in addition to the input of faculty time and effort. This needs to be kept in mind in thinking about overall administrative staffing levels for ICTS

3d. Graduate Education

The committee met with the graduate students to hear directly from them how they feel about their experience at the ICTS. The graduate program is very new (the first intake of students occurred in 2015) and there have been no PhD graduates as yet. At the time of the review there were a total of 41 graduate students.

In general the students reported a positive experience, especially in terms of the intellectual support provided by the faculty. There are however some outstanding issues that need to be addressed by the ICTS:

1. The relatively small number of courses offered on campus requires the students to travel to nearby institutions, notably the IISc, in order to participate in courses that are not available locally. This is particularly acute for mathematics students. This requires students to commute between three places, sometimes in the same day: their home, the ICTS and another academic institution. Taking into account the quality of roads and traffic congestion, this results in a considerable amount of wasted time that could be used for better purposes. Until the faculty in ICTS grows to the size that can offer the majority of courses locally, innovative techniques of teaching courses should be pursued, with preference to web–based courses of the type that are offered by the Center for Applied Mathematics. Reciprocal arrangements with this and other Bangalore institutions of higher learning should be aggressively pursued.

2. ICTS does not have student dormitories, and this aggravates the commuting issue discussed in point 1. Since traffic congestion is not likely to be remedied soon, building on–campus dormitories for ICTS students should be a priority. A related complaint was that students who want to work late at night do not have anywhere to rest or catch a nap. This is an easier problem to solve, probably by assigning some existing space for such purposes.

3. ICTS appears to have difficulties in attracting students specializing in quantitative biology, presumably due to the competition from other established centers specializing in biology. If ICTS plans to continue to develop this discipline, some special incentives should be offered to potential students to attract them to join.

4. There were some complains about the inadequacy of the medical services on campus, including treatments for snake bites and availability of over–the– counter medicines. These issues should be dealt with by the director's office locally, probably by simply insisting on better service by the local clinic.

3e. Postdoctoral Fellows

The committee met with a large group of postdoctoral fellows to get their perspective on their experience at ICTS. The postdocs had prepared for this, and they came to our meeting with a written document detailing their concerns.

The postdocs had many positive things to say about their experience. They liked the fact that applications are centralized and that postdocs have a reasonable degree of independence. They praised the fact that ICTS provides ample opportunities to interact with a constant flux of visitors, as well as with in–house faculty and students. They felt that ICTS has become one of the most attractive places to apply for a postdoctoral position in India and that it is probably the research institution with the most thriving research program in India. However, they felt that there was still need for improvement.

In particular, the postdocs felt that their salary level was low and non–competitive, even by Indian standards. Aside from the economic consequences, they felt that low salaries tend to perpetuate the widespread notion that students who choose to remain in India for their postdoctoral experience are primarily those who could not get a more attractive position abroad. This perception is painful for the current ICTS postdocs, and will not be helpful in attracting top candidates to ICTS in the future.

The committee believes it should be a very high priority of ICTS to maintain a vibrant postdoctoral program, one able to attract the very best candidates from within India as well as excellent candidates from abroad. This is important not only because first–rate postdocs contribute directly to the quality of research carried out at an institution, but because they contribute to the scientific atmosphere, and they can provide an important boost to the education and research of students and faculty as well. Consequently, we recommend that ICTS should look carefully at the current compensation levels of its postdoctoral fellows, and should take steps to raise these levels if they are not as competitive as they should be.

Postdocs requested improvements in the program of travel grants. They felt that a minimum travel grant should be promised to every postdoc, which could be used for travel both within India and abroad, and which could be used for academic visits, talks, and conference attendance. They complained that the current criteria for awarding travel grants are not sufficiently clear, and that allocations a not equitably distributed.

Postdocs requested that ICTS make a greater effort to help them find positions at the end of their tenure. Suggestions included dedicated notice boards and e–mail updates on job opportunities, and perhaps having administrative personnel assigned to look after career–related matters. Another suggestion was that ICTS should build and maintain a network of alumni, whose interest could benefit ICTS in various ways, in addition to helping with job placements.

Several of the issues raised by the postdoctoral fellows were similar to issues raised by the students. The shortage of housing on the ICTS campus was a problem for a number of them. They suggested that a temporary provision for them to stay back on campus to work even at late hours would be a positive step. Postdocs also felt that there were too few faculty members in certain fields of study. Postdocs complained about the quality of the medical insurance available to them, which is a complement to complaints we heard from students about the on–campus medical services.

Postdoctoral fellows suggested that creation of a scientific ethics committee would be a welcome step. Although the committee did not hear reports of any specific incidents that would warrant investigation by such a committee, it might be wise to have established procedures for dealing with possible conflicts that could arise in the future.

There were also complaints that the presently available computing power is insufficient and not optimally managed. The postdocs had some specific suggestions, which they have passed on to the director.

4 THOUGHTS ABOUT THE FUTURE TRAJECTORY OF ICTS

4a. Intellectual Scope

THE ORIGINAL VISION FOR THE ICTS was in part a response to the observation that major trends in modern science imply that theory–based explanations of phenomena, in the manner of theoretical physics, must expand their domain of applicability well beyond the historic base in the physical sciences. If nothing else, the ability of modern experimental methods, in all areas of science, to generate increasingly large data sets has the consequence that understanding what the data mean, and using the data for predictive purposes, will necessarily require bringing the data into sophisticated theoretical and mathematical frameworks. This theory/experiment symbiosis has been central to the way we practice physics for a long time, and it now seems inevitable that something like it will have to evolve in all the sciences, including biology in all its aspects (cellular biology, neurobiology, embryonic development, evolution, ecology, etc.). In addition, it seems clear that, at least for the foreseeable future, people trained in theoretical physics and mathematics are likely to be major players in driving this evolution. With these considerations in mind, the ICTS was conceived as an institution with the overarching mission of catalyzing this type of development in the context of Indian theoretical science.

In order to create, in a short period of time, a totally new institution of high–quality research and education in theoretical science, the bulk of the initial ICTS faculty recruitments were made in areas in the classic core of theoretical physics (relativistic astrophysics, string theory, fluid dynamics, condensed matter, statistical physics) and mathematics. This initial strategy has worked well and has created a solid base to build on. Indeed, elsewhere in this report we have advocated for modest strengthening of some of these areas in the near term.

However, to be faithful to the founding philosophy of ICTS, the institute should begin to think seriously about how to expand the intellectual scope of the ICTS beyond the traditional boundaries of theoretical physics and into those new domains where mathematical modeling and theoretical comprehension of data are fast becoming essential. There are many possible directions for this expansion, including quantitative cellular biology, theoretical neuroscience, and the general theory of large data exploitation, and managing the expansion so as to maintain productive contact with the existing core will be a delicate matter. We would therefore encourage ICTS to develop a strategic plan for the future expansion of its intellectual scope. ICTS programs would provide an ideal mechanism for "previewing" areas contemplated for expansion, as well as candidate hires in such areas. In assessing the suitability of new areas, consideration should be given to their potential for synergy with existing doctoral programs, in order to minimize the danger that the faculty and students of a nascent research area could become isolated. Finally, any such plan should be flexible, both because "hot" areas will certainly evolve over time, and because the institute should be prepared to exploit targets of opportunity.

This brings up the question of the desired equilibrium size of the faculty. From inception (see Minutes of meeting of Management Board 17 Feb 2009) the planned/desired ultimate size of the academic faculty of ICTS was taken to be about 35 (compared to the current number of fewer than 20). The review committee considers this size to be the minimum that will be needed to achieve anything like the expanded intellectual scope recommended above, and may even be somewhat small for achieving that goal. The reasons for this caveat

are twofold. An essential ingredient of ICTS is the graduate school and, with the present physical isolation of ICTS, one needs to be able to cover the bulk of the core and elective courses in– house. This cannot be achieved without a faculty of the size necessary to provide the required curriculum. Related to, but additional to the curriculum requirement, is the issue of critical mass within research areas. Every "core subject" within the faculty research program must have a minimal number of faculty who can jointly offer a range of research subjects for incoming graduate students and postdocs. No scientist can achieve optimal performance without discussions, group seminars, and collaboration with peers working in close physical proximity. Within reasonable limits on the total faculty size of ICTS (taking 35 as a benchmark), and doing a speculative census of the different research areas that will have to be represented in the mature version of ICTS, it is clear that the individual research groups will have to be limited in size. The hope is that the culture of cross–disciplinary collaboration that the ICTS aims to foster, together with the opportunities for collaboration offered by the programs, will allow small groups to "*punch above their weight*".

In our discussion of the existing ICTS research groups, we endorsed an expansion of the mathematics faculty to support the doctoral program in that area. Here we would like to point out that an augmented mathematics group is also important for any future ICTS expansion into non–traditional areas. The ICTS mission is founded on the notion that progress in many areas of quantitative science will increasingly rely on bringing frontier methods in mathematics to bear on new areas of science, but it is clear that the current size of the ICTS mathematics faculty is too small to properly exploit the expected synergies. For that reason, we believe that an expansion of the mathematics faculty, taking care to expand in directions that will engender strong collaborations with the physical and biological sciences, is an important priority. Put slightly differently, we would say that expansion of the ICTS base in mathematics should go hand–in–hand, to the largest extent possible, with the effort to expand the overall intellectual scope of the institution. Managing these parallel expansions, given the realistic upper limit on faculty count, will of course be a delicate matter.

4b. Gender Issues

We commend the ICTS faculty for recognizing that they have a problem with gender balance and the lack of representation of other minorities at the student, postdoc, and (especially junior) faculty levels. We are also pleased that the women they do attract report a welcoming environment.

We recommend the following as first steps toward increasing the representation of women in the ICTS graduate program, and also in the ICTS scientific programs, where the gender balance is also very skewed. Similar recommendations could be followed to also increase representation of other under–represented minorities.

1. Establish recruitment pipelines to women's colleges and also start targeted outreach programs (e.g., summer camps like ICERM's "Girls–Get–Math" for high–school and undergraduate students) that could help identify potential candidates early on, and in the process also contribute more broadly to ICTS' outreach efforts.

2. Examine and track the ICTS recruitment processes at all levels to identify where the fraction of women drops. It might be useful to increase the size of the applicant pool, e.g., by N% at each level of the recruitment process where N is such that the fraction of women at a subsequent stage increases significantly. In the long run, take advantage of the graduate and postdoc alumni pool and visitor pool to help with recruitment efforts.

3. Be aware of well–documented gender biases related to exams, standardized test scores, and letters of recommendation.

4. Practice affirmative action to the extent it is legally allowed and does not cause an adverse reaction. The mildest form would be to prioritize women and other under–represented minorities when comparing within a group with comparable competence.

5. Increase representation of women in conferences, distinguished lectures, etc. by ensuring that the relevant committees follow up to make sure that they have not overlooked any obvious candidates; possibly consult the international advisory board or other friends of ICTS when needed.

5 ANNEXES

We append to this report two annexes. Annex 1 is the detailed agenda for our three–day meeting. Annex 2* is the letter from the TIFR director, Sandip Trivedi, laying out his charge to the committee.

Annex 1

January 11, 2018

9:00 – 9:40 am
Closed door meeting Sandip Trivedi and Committee *Venue*: Obaid Siddiqui Meeting Room

9:45 – 10:15 am
Overview of ICTS by Rajesh Gopakumar

10:15 – 10:45 am
Presentation on LIGO and Astrophyiscs

10:45 – 11:15 am Break

11:15 – 12:15 am
Presentation on Complex System Physical Bio - 15 minutes, Stat Phy and Cond Mat -25 min, Fluid Dynamics– 20 minutes

12:15 – 1:00 pm
Mathematics

1:00 – 1:15 pm
Monsoon Project

1:15 – 2:15 pm
Lunch at Ajanta Guest House

2:15 – 3:00 pm
Presentation on String Theory

Kip Thorne Lecture

7:30 pm
Dinner at Ajanta Guest House

January 12, 2018

9:00 – 9:30 am
Presentation on ICTS programs

9:30 – 10:00 am
Presentation on ICTS Outreach activities

10:00 – 10:15 am
Presentation on Academic Governance

10:15 – 10:45 am
Presentation on Graduate Programs

10:45 – 11:05 am
Presentation on Post docs

11:05 – 11:15 am
Presentation on Visiting Students

11:15 – 12:15 pm
Campus Tour

12:15 to 12:45 pm
Presentation on General Administration

12:45 to 1:00 pm
Presentation on Services and Infrastructure

1:00 to 1:15 pm
Presentation on Computing

1:15 – 2:30 pm
Lunch

2:30 – 3:30 pm
Meeting with Faculty

3:30 – 4:00 pm
Meeting with Admin Section Heads

4:00 – 4:15 pm
Tea Break

4:15 – 5:00 pm
Meeting with Students/ Postdocs

5:30 – 7:30 pm
Time for individual meetings with committee

7:30 pm
Dinner at Ajanta Guest House

January 13, 2018

9:00 – 1:00 pm
Committee drafts report

1:00 – 2:30 pm
Lunch at Ajanta Guest House

2:30 – 4:00 pm
Feedback to TIFR Director/ ICTS Director

5:00 pm
Leave for Dinner in City

* not included here

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