3 Project Description:

A List of Participants

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The key to the school and departmental abbreviations used throughout the proposal:

GT	Georgia Institute of Technology
COS	College of Sciences

COE	College of Engineering
Bio	School of Biology
AE	School of Aerospace Engineering
CE	School of Civil & Environmental Engineering
ECE	School of Electrical & Computer Engineering
ME	School of Mechanical Engineering
Chem	School of Chemistry and Biochemistry
Math	School of Mathematics
Phys	School of Physics

B Vision, Goals and Thematic Basis

[1] [2] The impact of nonlinear science across the broad spectrum of disciplines is easily documented, and is likely to grow for the coming generation of scientists. In its 2001 report "Physics in a New Era: an Overview" [1], the National Research Council identifies six "grand challenges", among them "understanding complex systems", "applying physics to biology", and "creating new materials", fields where there are no boundaries between physics, mathematics, engineering and life sciences. Within the American Physical Society, the recently created Topical Group on Statistical and Nonlinear Physics is already the largest topical group, while the Division of Biological Physics is one of the fastest growing divisions.

In order to prepare young researchers for these challenges, we propose to move away from the traditional structure of graduate programs and offer a training in the tools and methods of nonlinear science that bridges departmental and school boundaries, national and international research. We envision the **IGERT: School in Nonlinearity & Complexity**(IGERT SINC), fostering

- **Cross-cutting research initiatives, with nonlinear science as the unifying theme**, based on common concepts which unify a broad range of problems of basic science, such as pattern formation and control, high-dimensional dynamics, turbulence/stochasticity, and chemical sensing and communication between aquatic organisms living in a turbulent flow environment. Research and advanced training will be cross-disciplinary, emphasizing the diverse range of applications in many fields, from biology and neuroscience to engineering problems involving fluids, interface motion, flows at nanoscales, and nonlinear control.
- **Training in cross-cutting methodologies**, stimulating cross-disciplinary research and communication skills through a balanced core curriculum that includes both lecture-based and project-based

[1] NSF requires: Limit the narrative to a combined **total length of 7 pages**, inclusive of list of participants (1 page), tables, figures, or other graphical data. Describe the vision, goals, and anticipated impact of the proposed IGERT project. Describe the thematic basis and unifying aspects of the interdisciplinary research and educational activities to be offered. Include a discussion of what is currently missing from graduate education and training or what could be done more effectively, and how the proposed project will address these issues. Summarize the value-added aspects of the proposed project, and be specific about what is new and innovative. (Limit: 1 page)

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courses. A key innovation is an early research experience, with small teams investigating topics guided by faculty members with complementary perspectives. The IGERT will form the core of a vibrant, highly cooperative environment through a combination of cross-departmental student-run seminars, regional workshops, and a visitor program. Global perspective will be enhanced through internships at, and schools organized with sister institutions abroad.

- **Outreach**: GT has a notable record in minority recruitment and retention [2]; IGERT would seek to encourage a career choice in science or engineering, by involving undergraduates from Atlanta-area colleges (Clark-Atlanta, Morris-Brown, Morehouse and Spellman) in the IGERT summer research projects. Educational outreach will be also served by the development of a web-based advanced nonlinear science course.

- **Strategic impact**: GT is the premier science and technology institution in the Southeast, with strong state and industrial support. Already possessing a leading program in nonlinear science, GT teams up faculty in cross-disciplinary facilities and has moved aggressively into several allied areas, establishing new centers in nonlinear science, bioinformatics, biotechnology, computing, and the Biomedical Engineering Department, unique in that it is run jointly with Emory University Medical School.

IGERT SINC will offer advanced nonlinear science training and a highly cooperative and cross-disciplinary environment to IGERT Fellows A coherent program which synthesizes research, lecture, workshop, and internship components will replace rigid major/minor disciplinary boundaries of a traditional graduate degree program.

C Major Research Efforts

[3] [4] Nonlinear science is a rich subject, already sufficiently developed to form the core of the training proposed under this IGERT. However, available tools largely fail for systems involving many strongly coupled degrees of freedom. Conceptually new methods applicable to high numbers of deterministic degrees of freedom as well as to mixed systems of chaotic, integrable, and stochastic components need to be developed; the present dearth of such methods remains a fundamental barrier for the direct application of the concepts of nonlinear science to many fields.

This IGERT will seek to break this impasse by bringing together teams of IGERT Fellows and faculty with complementary skills; experimental, numerical and theoretical. In what follows the core faculty listed in sect. (C).a are indicated by initials, (i.e. [LAB] for L.A. Bunimovich). The IGERT will actively seek participation of GT nonlinear sciences faculty across the campus in Fellow co-advising, as well as other key IGERT activities. Not divisible into neatly disentangled Major Research Efforts, all research under this IGERT addresses the same grand challenge of high-dimensional dynamics along two interwoven major themes: (1) the interplay between *stochasticity and nonlinearity*, and (2) the role of *patterns and coherent structures in high-dimensional dynamics*.

Stochasticity & nonlinearity, or "getting messages across in a turbulent world": As objects move through fluids, they shed complex but characteristic wakes [JY,FS]. For aquatic organisms, these coherent patterns may reveal the identity of a prey, predator, or mate; the identification taking place in turbulent sea, with characteristic hydrodynamic turbulence of size comparable to the biologically induced coherent structures. Rather than interfering with sensory perception, this turbulence sometimes seems to enhance it. How do such organisms recognize biologically-

Figure 1: Planktonic copepods accelerate their swimming appendages up to $50m/s^2$. Two vortices are created by 4 pairs of legs galloping twice within the field of view [3].

[3] NSF requires: Describe the major research efforts that are intended to serve as the foundation of the IGERT project. Emphasize their cutting-edge aspects and how they are interwoven and integrated to form the thematic basis for the interdisciplinary project. They should be described in sufficient detail for reviewers to assess their scientific merit and relevance to the project theme. If an international component is included, describe how it is to be grounded in the core research, education, and training activities of the IGERT project.

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created flows, distinguish them from background turbulence? One surprising answer comes from what initially was a basic discovery [4] in nonlinear science [KW]. In vitro experiments [5] showed that hair cells exhibit *stochastic resonance*, a counterintuitive nonlinear phenomenon where detection of weak signals is *enhanced* by the presence of external noise. From experimental and theoretical points of view, hair cells are a particularly apt testbed, both for the precise measurements of influence of noise, and because the physiology of hair cells is so well characterized that it is possible to write down accurate equations describing their dynamics.

Turbulence thus not only fails to obscure the message, but can help get it across, not only for living organisms but also in environmental science (pollutant dispersion, mixing pesticide dispersal [PKY,FS]). Similar challenges arise in the study of the brain activity during epileptic seizures: neuronal noise masks nonlinear dynamics of comparable magnitude [PC]. Put succinctly, a central question across many disciplines, and one of the driving questions motivating this IGERT is: *"How do sensory systems manage to be so sensitive in a world so noisy?"*

This challenge simply cannot be addressed from the confines of a traditional departmental PhD program, specialty-specific funding. Numerical analysis of turbulent flow, experimental detection of signal transmission through fluid media, neurophysiological and behavioral studies of living organisms, and information processing of signals acquired by sensory arrays are all required and can be provided only by cross-disciplinary teams.

Here the proposed IGERT will foster the necessary collaborations. It will draw inspiration from the already running GT "Signals in the Sea" (SiS) IGERT (NSF award #0114400) which focuses on empirical biology data and field work, synergistically adding theoretical training to the SiS IGERT Fellows. Conversely, the insights of SiS biologists will provide invaluable stimulus to this IGERT. The computationally demanding investigations of turbulent fluid flow [PKY,FS] will be essential to addressing the fluid dynamics aspects. For example, Lagrangian dynamics makes it possible to understand the fact that even stationary fluid flows can give rise to chaotic particle paths. In this context, ergodic theory has already inspired a non-intrusive experimental technique [6] for visualizing 3D fluid flows [FS]; in neurodynamics of epileptic focii, ergodic theory is the basis for new tools for analysis of very noisy neuronal data [7]. This IGERT offers a unique angle of attack on such problems, through hybrid systems which are part living tissue and part electronic circuitry.

"Riding the wave" or high-dimensional dynamics: [5] Hybrid simulations/experiments of neurons [8], and thermally actuated control of thin films [9] pioneered here [RJB,MS] both rely on modern electronics being much faster than the neuronal or fluid dynamics. The RJB group, with expertise in real-time programming and cellular electrophysiology, can both observe and simulate in real time small neuronal systems. Were the theoretical models of comparable sophistication, this strategy could be reversed, and the real-time simulations could be used to *control* spatiotemporal patterns, neuronal ensembles, perhaps even entire organs. The IGERT teams need to quantify the dynamics underlying synchronization between ensembles of neurons and interaction of coherent structures in turbulent flows; the IGERT will address these challenges relying on hybrid neuronal and other experiments, such as the real-time 3D optical measurements of wakes in fluids [3], and fluid dynamic simulations of such wakes [6]. This wealth of observations drives the other theme of this IGERT: *"How to characterize and control high-dimensional, spatially extended, and very noisy dynamics?"*

Spatially extended systems are systems with very many coupled degrees of freedom whose dynamics range from ordered to very disordered and turbulent. Theoretical challenges in learning to control such systems require understanding the instability mechanisms arising from the interplay between nonlinearity, transient dynamics, and stochasticity, often resulting in rather surprising dynamics. For instance, the onset of turbulence observed in shear flows occurs well within the Reynolds number regime, where the laminar flow is still linearly stable. Transient amplification in such systems leads to extreme sensitivity to noise, precluding any spatially localized control, even at physically unrealistic low levels of noise [10].

[5] PC: and how to control it

A theorist exploring classical field theories (for instance hydrodynamics, or systems modeled by the Ginzburg-Landau equations) faces a truly bewildering wealth of solutions. In order to understand how such systems go turbulent, one needs to determine, classify, and assign relative importance to the coherent structures they exhibit [11]. This research is still in its infancy, but it has led to a working hypothesis that the dynamics explores an approximate *finite* alphabet of unstable recurrent patterns, a hypothesis which IGERT SINC is uniquely poised to explore. On one hand the periodic orbit theory [12] offers the mathematical implementation of this intuitive picture [PC,FB,LAB], and on the other, the MS group possesses a unique skill: by means of their multipoint thermal actuation technique, they are able to *design* spatio-temporal patterns, and thus create and test experimentally the patterns singled out by the theory.

Why is IGERT essential to the success of the proposed research training? IGERT SINC will provide the kind of PhD support not available from individual grants, but vitally important to initiating, stimulating and sustaining cross-disciplinary research.

Experience from sister programs already demonstrates that IGERTs are very attractive to the best graduate students, as IGERT Fellows are given a great deal of independence in choosing co-advisers, and pursuing collaborative research projects nationally and internationally. IGERT SINC will seed the infrastructure that should outlive the NSF grant, supporting the new research directions through workshops and visitors, both from other nonlinear science research centers, and from institutions which could potentially apply the IGERT fostered methodologies to outstanding challenges in other disciplines. At present, no framework provides such a meeting place for the advancement of our cross-disciplinary research goals.

IGERT SINC will address the grand challenge of nonlinear science: Explore experimentally and describe theoretically the dynamics of high-dimensional nonlinear, noisy systems. Furthermore, this IGERT will foster applications of the methods thus developed to problems in engineering and biosciences.

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D Education and Training

[6] [7] [8]

In order to address the nonlinear science challenges detailed above, graduate education must transcend traditional departmental boundaries and produce a new breed of scientists of necessary breadth and versatility.

The proposed IGERT training initiative will emphasize the integration of knowledge and foster research independence and self-reliance through a nonlinear science curriculum based on novel lecture-based / project-based courses as well as co-advised independent research. Combined with seminars, internships, workshops and international schools this curriculum will equip IGERT Fellows with the methodology, basic tools and techniques of nonlinear science, as well as an understanding of their applications to specific problems of fundamental and practical significance.

Competitive IGERT Fellowships will be offered to outstanding students pursuing a minor in Nonlinear Science in conjunction with the PhD degree program in Fellow's home department. The IGERT four-level training sequence, detailed below, is coordinated with IGERT Fellow's home departments core requirements:

Level 1: Introduction to Nonlinear Science

Incoming IGERT Fellows will be introduced to the program with a **Welcoming Workshop/Retreat**, before the start of each Fall semester. Incoming Fellows will pair up with a nonlinear science advisor, external to

[6] NSF requires: The IGERT program has been developed to meet the challenges of educating U.S. PhD scientists, engineers, and educators with the interdisciplinary backgrounds, deep knowledge in chosen disciplines, and technical, professional, and personal skills to become in their own careers the leaders and creative agents for change. The program is intended to catalyze a cultural change in graduate education, for students, faculty, and institutions, by establishing innovative new models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries. It is also intended to facilitate greater diversity in student participation and preparation, and to contribute to the development of a diverse, globally-engaged science and engineering workforce.

[7] NSF requires: Describe the graduate education and training mechanisms that are central to the IGERT project, and how they are to be integrated with the research. Novel aspects should be emphasized to enable assessment of their innovation and potential impact. Discuss career development opportunities and provision for developing professional and personal skills, an international perspective, and integrated instruction in ethics and the responsible conduct of research.

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her/his home department, who will oversee the Fellow's progress in tandem with a departmental advisor. In the Spring semester of the first year, Fellows will begin coursework with a lecture-based offering that introduces the mathematical and computational techniques of nonlinear science. This course will provide IGERT Fellows with the knowledge of basic concepts of nonlinear science (dynamics, stability, bifurcations) and establish a common language bridging the linguistic barriers between disciplines.

Level 2: Applications of Nonlinear Science.

Targeted primarily at the second-year students, this rotating sequence of courses will be based on the research interests of individual faculty and cover applications of the tools and techniques of nonlinear science to problems in physics, chemistry, biology, materials science, and engineering. Examples might include pattern formation, ecological models, turbulence and mixing, or dynamics of neuronal networks. Offered every Fall semester, this advanced course can be taken by IGERT Fellows more than once as the topics will change from year to year. The main objectives of this lecture-based course is to demonstrate how the common toolkit of nonlinear science can be used to address different disciplinary problems and to develop initial communication skills necessary for interdisciplinary research. Level 1 and 2 precursor courses [13] are already attracting a wide spectrum of students.

Level 3: Advanced Topics in Nonlinear Science.

Offered in the Spring semester, this project-based course will stress the development of communication skills. The main objectives will be to provide the second-year students with the collaborative skills and develop the independent learning ability necessary for genuine cross-disciplinary research. The course will be more structured than an independent project would be; with the research focusing on specific projects carried out by small IGERT Fellow teams, supervised by faculty members with complementary expertise and perspectives. The faculty will select the problems and advise the Fellows on the approaches an experienced researcher would employ in similar research settings. A typical project will have a well documented research literature core, leading up to open research questions. Proposed topics include: synchronization in arrays of live and artificial neurons; pattern formation, selection, and control; mixing and stirring by coherent structures in turbulent flows; spatiotemporal dynamics of communicating ecological communities.

Level 4: Independent Research

By the third year IGERT Fellows will be expected to have started independent research. This phase of the training program will emphasize the integration of research expertise from several disciplines, for solution of problems lying at their interface. In order to ensure and nurture the cross-disciplinary focus of their research program, all IGERT Fellows will be co-advised, with one advisor from the Fellow's home department and the other one external.

A **Graduate Student Seminar** organized for and by the advanced students will give the IGERT Fellows an opportunity to present their research in a supportive setting, and enhance their communication skills. While the ultimate responsibility for teaching a student the ethical way to conduct research lies with the advisor, this graduate seminar, sometimes run jointly with the parallel GT SiS IGERT ethics seminar, and sometimes advised by the GT Ethics Officer, [9] will also provide a forum for directed discussions on ethics and conflicts of interest in research.

IGERT internships will offer the Fellows participation in collaborative cross-disciplinary research at the highest level, international and national. Perhaps more so than any other discipline, nonlinear science is driven by the flux of ideas across disciplinary boundaries. Given the essential role students at all levels play in conducting research, such flux is most effectively nurtured through a cross-disciplinary training program which integrates research, education, and training. In cases where the thesis research clearly warrants it, IGERT will sponsor 3-6 month Fellow internships at international or national nonlinear science sister centers [15] [16], and will in return host interns sent to GT by sister centers. Internships will, on the one hand, offer the Fellows invaluable expertise needed in their research and, on the other hand, bring into IGERT foreign interns, thus enhancing (nonlinearly!) the quality of IGERT Fellows research environment.

While the nationally highly ranked IGERT faculty has broad expertise across several branches of nonlinear science, many research projects will require expertise and/or collaborations not available locally within

[9] PC: cross-check

GT. Much of the cross-disciplinary GT research already has a significant international component, and an intern might be hosted by the Bayreuth University, the Niels Bohr Institute (Copenhagen), the Max-Planck-Institute for Complex Systems (Dresden), or another sister center, in order to receive additional training in experimental or theoretical pattern formation, granular media and complex fluids programs, or perhaps study an organism not available in the US.

The courses and projects will envelop IGERT Fellows in an intellectual community that stresses commonalities among disciplines. As the level of courses described above will vary from advanced undergraduate to second-year graduate, the sequence will target the range of students, both inside and outside of the IGERT program. The recruiting efforts will also benefit from another IGERT initiative, a web-based year-long advanced graduate nonlinear course [12], reaching students well beyond GT. The IGERT competitive Fellowship will assist in recruitment of the very best students, making careers in science/engineering more attractive to a wider range of students. IGERT Fellowships will be used exclusively to support co-advised Fellows, enabling them to concentrate on the study and research already during the first two years of their PhD programs.

In order to offer students a deep learning experience outside the PhD thesis research, the educational core of the training program will be supplemented by the further key components:

An **Interdisciplinary Nonlinear Science Seminar series** [14], initiated in January 2001, draws a wide attendance across GT and other Atlanta based institutions. IGERT would broaden the scope to engineering and biological applications.

A **visitor program** to promote and maintain national, international, and industrial collaborations, with priority given to visitors whose research demonstrate potential as external mentors to IGERT fellows.

An annual **Regional Nonlinear Workshop** organized jointly with other Southeastern universities (Duke, U. of Alabama, U. of Florida) will expose students to the cutting edge research, and give them an opportunity to present their own work.

A **Nonlinear Science School**, a bi-yearly summer school program hosted by the IGERT in conjunction with the CNS and a sister international center, will start with a sequence of tutorial-style lectures, preparing IGERT Fellows as well as students from other participating programs for the research level part of the School. For instance, IGERT proposes to host a summer school in the “Stochastic nonlinear processes in biology” series, sponsored by NIH, either in Atlanta or at the Centro Internacional de Ciencias, Cuernavaca, Mexico [15].

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Proposed IGERT training program ... nonlinear science: describe and apply to problems of engineering and biosciences nonlinear dynamics of high-dimensional nonlinear, stochastic systems. ⇑PRELIMINAR

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E Management, Assessment, and Institutional Commitment

[10]

[11] The director of the proposed IGERT: School in Nonlinearity & Complexity program is P. Cvitanović (School of Physics). Prior to moving to GT, Cvitanović co-founded and directed (1993-1998) the Center for Chaos and Turbulence Studies [17] at the Niels Bohr Institute, Copenhagen, [12] a leading international center *par excellence*. PC led the initiative to create a Center for Complex Systems at the Northwestern University, and was the PI on the NSF "IGERT: Complex Systems in Science and Engineering" program, awarded to Northwestern in 2000 (see sect. C.g). He currently holds the Glen Robinson Chair in Nonlinear Sciences and is the director of the newly created Center for Nonlinear Science.

Due to the full cross-disciplinary integration of the proposed IGERT, the day-to-day training, research, and other activities of the program will be supervised by a single, annually faculty elected 5-person *Executive Committee*, which will administer fellowships, internships, visitor invitations, and other IGERT resources in accordance with the goals of the program. Faculty status implies no entitlement to IGERT resources; the Executive Committee will base its decisions solely by proposal's quality and cross-cutting impact.

The evaluation of the program will rely on detailed feedback from students, internship hosts, faculty, visitors, and thesis advisors. The program will assess annually the performance of the IGERT Fellows, interns, research progress, nonlinear science course sequence, seminar, visitor program, summer school and Regional Conference. Starting with the third year, the assessment will also involve the IGERT sponsored research impact, recruitment, retention, PhD theses time-to-degree measures, publications, and a visit of an external expert committee.

[10] NSF requires: Describe the strategies for management of the IGERT project, for formative and summative assessment of the projects effectiveness in its impact on students and faculty, and the commitment that the institution will make to furthering project plans and goals and to creating a supportive environment for interdisciplinary research and education. Indicate how diversity will be promoted as an integral part of the project.

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[12] PC: comment out?

F Expected Resource Commitments

[13] [14] [15] GT faculty in nonlinear sciences was ranked 5th nationally in the most recent U.S. News and World Report survey (1999). Its commitment to this field is demonstrated by recent chaired faculty appointment in physics (PC), continued recruiting efforts in mathematics and physics (junior and/or senior experimental nonlinear physics searches in 2001-03), and the expansion in biosciences, including a biophysics chair search.

GT encourages cross-departmental and cross-disciplinary research training. The *GT Center for Nonlinear Science* (CNS) which began operation July 2001, already spans nonlinear science efforts across eight science and engineering departments [18]. The IGERT office and the common meeting room will be housed in CNS, Howey Physics building. Shared office space and computer facilities will be provided to the IGERT Fellows, with the IGERT experimental training laboratories housed in proximity to the participating faculty laboratories. An experimental computation laboratory is operational in the Math building [19]. The IGERT will require substantial parallel processor computing resources to implement its objectives. GT's CCMST, (its co-director RH is on the IGERT faculty) already provides a 72-processor IBM SP2. Up to one third of this resource will be available to the IGERT Fellows.

The Deans of the participating Colleges and the Institute Vice-President for Research and Dean of Graduate Studies support the initiative and are already funding the CNS for an initial three-year period. As a seed cost-sharing contribution, GT has committed $147K/year for the fiscal years 2002-2004, providing funding for 2-3 postdoctoral research associates, a distinguished lecturer series, visitors, workshops, the Nonlinear Science seminars, secretarial and part-time computer/web support, and ca. $80K in the annual Nonlinear Sciences Chair endowment, and $30K for equipment funds to cover the equipping of research associates' offices, research infrastructure including a Linux network, a platform for intensive computation, and office equipment.

[13] NSF requires: Describe anticipated resource commitments to the IGERT project by other organizations expected to participate, such as industry, government, non-U.S. institutions, and private foundations. Applicants proposing international activities may wish to consult the INT member of the IGERT Coordinating Committee, listed in Section VIII, Contacts.
[14] PC: throughout: always stress things that would not happen without IGERT
[15] **file** resources.tex - Sep 28 2002

In addition, if this proposal is funded, GT will support additional graduate students in the IGERT program (the precise number to be negotiated), cover the differential tuition for out-of-state graduate students, and match the capital equipment expenditure of the IGERT experimental and computational training program.

G Recent Traineeship Experience and Results from Prior NSF Support

[16] [17]

Two prior NSF grants form the basis for this IGERT preproposal: P. Cvitanović, PI (until moving to GT) - **IGERT #9987577**: Northwestern University *Dynamics of Complex Systems in Science and Engineering* (2000-2004), and L.A. Bunimovich, CoPI and Director - **GIG #9632032**: *Southeast Applied Analysis Center* (1996-2001).

SAAC [20] has been very successful in establishing regional educational initiatives (detailed in sect. (C).d) which the proposed IGERT intends to extend and build upon.

PC follows closely activities of the Northwestern IGERT, and the proposed IGERT would interact closely with the NWU sister program, with the GT SiS IGERT, and the Arizona and Cornell IGERT programs. Significant aspects of this proposal already are built upon our colleagues' IGERT experiences. The student satisfaction with the programs is high, and they are an invaluable resource in breaking down departmental walls. PC has moved to GT because of its commitment to nonlinear science (see sect. C.f), because of its requirement for minor in PhD studies actively fosters cross-disciplinarity, and because the departments facilitate cross-disciplinary teaching.

European PhD programs typically require that their students spend 3-12 months abroad, with support from their home institutions. As the European Dynamics Days Advisory Committee Secretary, PC has

[16] NSF requires: Describe your experience with and outcomes of any related graduate traineeship project during the past five years. In this description, address not only the outcomes of the prior project, but also, in a comparative manner, describe the value-added aspects of the proposed IGERT project.

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close working relations with the leading nonlinear science centers in Europe and elsewhere. Foreign interns hosted so far have been of significant benefit both to PC's research program, as well as to US students who interacted with the interns. IGERT will provide a framework for enhancing these student exchanges. [18]

[18]PC: add Mogul collaboration in Predrag's CV

4 References

[19] [20]

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[13] `www.cns.gatech.edu/courses`

[14] `www.cns.gatech.edu/research`.

[15] `www.cns.gatech.edu/centers/sorelle.html`.

[16] `www.cns.gatech.edu/centers/sisters.html`.

[17] Center for Chaos And Turbulence Studies, `www.nbi.dk/CATS`.

[18] Center for Nonlinear Science, `www.cns.gatech.edu`.

[19] Analysis, Computation, and Experiment Lab, `www.ace.gatech.edu`.

[20] The Southeast Applied Analysis Center, `www.math.gatech.edu/saac`. ⇓PRELIMINAR

[21] Center for Dynamical Systems & Nonlinear Studies, `www.math.gatech.edu/cdsns`.

[22] Northwestern U. Dynamics of Complex Systems in Science and Engineering, `www.complex-systems.northwestern.edu`.

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[39] Georgia Tech Center for Education In Science Mathematics and Computing, `www.ceismc.gatech.edu`.

[40] Center for Computational Molecular Science & Technology, `www.ccmst.gatech.edu`.

[41] `www.cns.gatech.edu/CNS/Bylaws.html`. ⇑PRELIMINAR

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5 Five-Year Budget

[21]

6 Budget Justification

[22]

EVERYTHING FROM HERE TO sect. E IS OF INSPIRATIONAL VALUE ONLY - WILL BE DROPPED FROM THE PREPROPOSAL:

[23] A unique aspect of nonlinear science is that research is driven by the flux of ideas across disciplinary boundaries. Given the essential role students at all levels play in conducting research, such flux is most effectively generated through the establishment of a **cross-disciplinary training program** integrating research, education, and training with the dual goals of attracting a wide range of undergraduate, graduate, and postdoctoral students to physics and providing them with a stimulating and thoroughly modern learning environment. To ensure the success of the program, a large fraction of the IGERT funded graduate students will be co-advised, with one advisor from student's home department and the other external, at least one of the advisors being a IGERT member. This arrangement will greatly assist in initiating new cross-disciplinary collaborations.

On the other hand, equipping students with skills that are cross-disciplinary, method based, rather than discipline specific, nonlinear science is uniquely positioned to **offer the students a broad, diverse education**, and prepare them for today's rapidly evolving professional environment. Coupled with the cross-disciplinary nature of IGERT, such training will meet the recommendation of the NRC report [1] to

[21] NSF requires: (uploaded as NSF Form 1030): A one page, five-year summary. Anticipated Funding Amount up to $2.95M per award over 5 years. Additional funding of international activities for some awards of up to $500K per award over 5 years.
[22] NSF requires: 1-page justification uploaded to NSF
[23] **file** outreach.tex - Sep 9 2002

physics departments “to review and revise their curricula to ensure that they are engaging and effective for a wide range of students and that they make connections to other important areas of science and technology”. In order to effectively achieve these goals, the proposed research and training programs will transcend departmental boundaries, differing from the conventional training model in a number of significant ways.

The success of the training program will crucially depend on the availability of the infrastructure that can only be created by a Center such as the proposed IGERT. The need for a strong foundation in the analysis of nonlinear dynamical systems is common to many research programs in science, engineering, and mathematics. At GT, courses on nonlinear dynamics [14] are currently taught in the mathematics and physics departments, each from a different perspective, and draw students from biomedical, chemical, aerospace, civil, electrical and mechanical engineering, materials science, and chemistry. While students would clearly benefit from a program based on a broad, coherent, and unified view of nonlinear science, college and school boundaries need to be superseded by a framework that integrates what otherwise would be isolated collaborations between individual faculty members. The program built around the IGERT initiative will generate a new level of integration in graduate and post-graduate education by involving faculty in different departments in an effort to unify the nonlinear science curriculum across the participating schools. Equally important, combining the resources of the Center’s MREs will make it possible to offer undergraduate level cross-disciplinary courses to students from participating institutions.

The core of the cross-disciplinary training program will consist of an **Introductory Nonlinear Science** course on the mathematical and computational techniques of nonlinear science followed by a rotating sequence of **Applications of Nonlinear Dynamics** courses based on the research interests of individual Center members and rounded out by a semester of **Special Topics in Nonlinear Science** featuring research on specific projects carried out by small teams supervised by faculty members with complementary expertise and perspectives. The level of courses will vary from advanced undergraduate to second year graduate, targeting the range of students that can be most effectively recruited into research programs. As one of the new initiatives, IGERT will offer an advanced web-based year-long gradute nonlinear course [12], which will play an important role in reaching and educating students at remote locations and attracting them to the program. The courses will gather all nonlinear science students in an activity that stresses commonalities among various fields, and it will provide a sense of intellectual community fundamental to the success of the program. The course work will require coordinated collaboration with peers and teachers from different backgrounds, helping students develop communication skills that will prove invaluable in future careers in industry or academia.

This training will equip young researchers with the tools and intuition needed to tackle complex nonlinear problems arising in many guises and various technical fields. In order to offer students a deep learning experience outside the Ph.D. thesis research, the educational core of the training program will be supplemented by the following important components. A **welcoming workshop/retreat**, before the start of each fall semester, will introduce the incoming young researchers to the IGERT. New students will pair up with a nonlinear science advisor, preferrably from outside their own department, who will oversee the student's progress during the first two years in tandem with the departmental advisor. An **Interdisciplinary Nonlinear Science Seminar** series [14], initiated in January 2001, has drawn a wide attendance from the participating departments and institutions. IGERT would enable us to run the seminar on an ongoing basis and to broaden its scope to engineering and biological applications. **Graduate Student Seminars** organized for and by the students will give them opportunity for public presentation of their own research in a supportive setting, engage them in mutually beneficial exchange of ideas, and generally enhance their communication skills; it will also provide a forum for directed discussions on ethics and conflict of interests in research. An active **visitor program** will help promote and maintain national, international, and industrial collaborations. Priority will be given to visitors whose research relates to that of participating IGERT faculty, and who demonstrate potential as external mentors to our graduate students and junior researchers. A **Regional Nonlinear Workshop**, a yearly cross-disciplinary meeting organized jointly with other Southeastern universities such as Duke, U. of Alabama, and U. of Florida, will expose students from regional universities to the forefront of research, and give them an opportunity to present their own work in poster sessions. **Joe Ford Fellowships**, named in honor of late GT Professor Joseph Ford, one of the pioneers of classical and quantum chaos, will sponsor several outstanding postdoctoral fellows each year. These Fellows, associated with the Center, rather than its individual members, will have complete freedom in choosing their research directions and serve as a glue between different research projects. In addition, by combining the resources of the Center, the Departments, and the Institute, the IGERT will be able to make competitive **graduate fellowship** offers to incoming graduates, making the program more attractive to a wider range of students. These fellowships will be primarily used to support co-advised students, covering the first two years during which students are normally supported as teaching assistants, allowing them to concentrate on the study and research in nonlinear science.

Joining the forces of the affiliated faculty and students is instrumental in making a coherent contribution to a number of outreach programs organized under the umbrella of the GT Center for Education Intergrating Science, Mathematics, and Computing (CEISMC) [39] and targeted at the middle and high school students and teachers. For instance, participation in such programs as **FutureScape** and the NSF-sponsored **Integrating Gender Equity And Reform** (InGEAR) will help educate girls and young women about careers in nonlinear science, broaden their horizons and raise their aspirations by exposing them to careers they may not have contemplated otherwise. The Center will also actively participate in the new **Post-secondary Readiness Enrichment Program** (PREP) created by the University System of Georgia. This program addresses primarily the seventh grade and is designed to assist students and their parents in making timely, informed decisions that will adequately prepare young people for their higher education and career goals. The Center will also provide the foundation for continuing educating in the area of Nonlinear Science of those high school and middle school science and mathematics teachers enrolled in the year-round **Georgia Industrial Fellowships for Teachers** (GIFT) program, whose primary goal is to provide the exposure to the cutting edge research in the academic and industrial settings.

At the college level, following up on the success of the NSF Southeast Applied Analysis Center [20] outreach program, IGERT members will be sent to deliver lectures on various topics of modern physics, biology and mathematics as **Center Ambassadors** to Southeast region non-research educational institutions and historically black colleges and universities. IGERT will offer teaching reduction to the members who perform exceptionally as such lecturers, and implement a series of measures to aid recruitment and retention of students from under-represented groups, such as offering **Summer Internships for Minority Undergraduates**. Both GT Physics and GT Chemistry run highly successful NSF-funded **Research Experience for Undergraduates** (REU) programs, bringing some 30 gifted undergraduates to GT every summer, some of which are advised by the IGERT faculty. In summary, the goals of the IGERT outreach program are to bring the inspiration of cutting edge physics research to bright undergraduates, K-12 students, and teachers, to build bridges to faculty isolated at non-research institutions, and to inform talented students about the attractiveness of GT graduate programs.

The *assessment* of effectiveness of IGERT outreach program is detailed on p. **??**. **The assessment** of the program's success will rely on detailed feedback from students, internship hosts, participating faculty, long-term visitors, and thesis advisors. Annual assessments will concentrate on the performance of the IGERT J. Ford Fellows, student internships, MREs progress, Nonlinear Science Course, Nonlinear Science Seminar, Center Ambassador program, Visitor Program, and Regional Conference. Starting with the third year, the assessment will also involve the MREs research impact, recruitment, retention, PhD theses time-to-degree measures, publications, and a visit of an external expert committee.

The above range of activities, while highly desirable, cannot be sustained by the individual grants. The very existence of the proposed program hinges on the availability of cross-disciplinary funding, something that only IGERT can make possible.

[24]

Cross-disciplinary workshops, internships and other training initiatives will make use of the extensive connections the IGERT faculty has with other institutions and labs. We now provide a few examples of such cross-fertilization initiatives already in place. First, the already established **institutional cross-**

[24] **file** national.tex - Sep 14 2002 version

connections:

- IGERT will collaborate intensively with the *NSF IGERT* programs at Northwestern [22], Cornell and U. of Arizona, as well as with a number of other leading centers for nonlinear science (check the Center webpage [16] for a complete list). The ties are particularly close to the Northwestern IGERT, originally led by P. Cvitanović.
- GT is one of the six university partners in the team which operates the *Oak Ridge National Laboratory* (ORNL), linking the lab to academic research. Geographically close, and with common interests in complex and nonlinear systems, GT IGERT and ORNL already plan several collaborative initiatives (detailed below).
- The IGERT fluid dynamics GT Physics & ME program [MS,RG,G.P. Nietzel] interacts the *Institute of Paper Sciences & Technology* (C. Aidun) housed at GT, where the fundamental problem of pattern formation is relevant to increased efficiency in coating of paper.
- GSB and KW have formed a "Hyperscanning Consortium" with colleagues at Baylor College of Medicine, Princeton University and Caltech, in order to perform synchronized MR scanning of people interacting with each other, and study brain patterns of interacting groups of humans.

Every IGERT faculty member has extensive external collaborations. Here we highlight a few examples of **cross-institutional research ties** that would be enhanced by the IGERT visitor, internship and workshop programs:

- KW and R. York (UC Santa Barbara, Electrical Eng.), T. Heath (GT Research Inst. staff scientist) - *Fast Dynamical Control of Antenna Arrays*: Experiments at Santa Barbara are testing a new scheme for very fast manipulation of electromagnetic beams, scheme based on GT theoretical advances in understanding how synchronized nonlinear oscillators behave under variations of the element parameters.
- KW and F. Jaramillo (Carleton College, Biology) - *The role of noise in the auditory system*: The

"stochastic resonance" experiments are being performed at Carleton College, and a model for the hair cell is under development at GT (see p. **??**).

[25]

Internships: We have contacted a number of potential hosts who have expressed their interest in participating in the internship program (see p. 37). Close contacts between the interns' advisors and hosts will contribute substantially to turning internships into full-fledged collaborations. To give a flavor of what we have in mind, we give here two examples of potential hosts and what they would offer. Others will be contacted on case by case basis, pending specific IGERT student or host research initiatives.

- *D. del-Castillo-Negrete, Oak Ridge National Laboratory.* Theorist, expert on the application of dynamical systems methods to the study of transport problems in fluids and plasmas, dynamics of many-body Hamiltonian systems with long range interactions, and pattern formation in reaction-diffusion systems, research interests shared with the IGERT faculty. GT and ORNL are already partners on the institutional level, with long experience of GT students working at ORNL.
- *R.E. Ecke and R. Mainieri, Los Alamos National Laboratory.* Experiments on pattern formation in fluids. Theory of nonlinear dynamics, statistical mechanics of chaotic systems. [26]

An internship at ORNL and LANL will provide a student with a unique opportunity to explore the research environment at a National Laboratory.

Workshops: IGERT plans a series of workshops. On the national level, IGERT will propose to host the *Dynamics Days 2005*, the main US annual meeting in nonlinear science, possibly in collaboration with the Oak Ridge National Lab. The *Regional Nonlinear Workshop* (see p. 37) currently under preparation is

- **ORNL-IGERT Interdisciplinary Workshop on Transport**

  DATE: June 2003

  LOCATION: Oak Ridge National Laboratory

[25] PC: perhaps include PC, Mogul
[26] PC: add details

ORGANIZERS: D. del-Castillo-Negrete (ORNL) and P. Cvitanović (IGERT)

FUNDING: Shared ORNL/IGERT, with emphasis on graduate student stipends. 40 participants

PROCEEDINGS: A focus issue of the CHAOS journal

SPEAKERS: *(preliminary list) C. Jones (Brown, transport in oceanographic flows), R. Pierrehumbert (U. Chicago, transport in atmospheric flows), T. Tel (Eotvos U., Hungary, transport in chemical active flows), D. Astumian (U. of Maine, transport in biological systems), S. Wiggins (Bristol U., UK, transport in dynamical systems), R. Behringer (Duke, transport in granular flows), J. Gollub (Haveford College, experiments on transport), G. Zaslavsky (Courant Institute, NYU, transport in plasmas).*

ABSTRACT: The study of transport is an important problem of common interest to many areas of science and technology including plasma physics, biology, chemistry, oceanography, atmospheric sciences, engineering, and dynamical systems. The goal of this cross-disciplinary workshop is to bring together experts from these areas for a discussion of nonlinear dynamics and complex systems techniques in the study of transport.

IGERT academic environment: No less important than ties to other institutions is the immediate context in which IGERT will operate. The overriding concern in setting up the Center structure (see sect. **??**) is ensuring sufficient fluidity in faculty composition to enable us to recruit new talent into IGERT as new cross-disciplinary research directions open up. GT and EU provide rich intellectual environment which will greatly enhance IGERT effectiveness as a platform for cross-disciplinary interactions. GT School of Mathematics CDSNS [21] contributes excellent visiting researchers, seminars, and training opportunities in mathematical methods for nonlinear science. To name but a few, preeminent scientists such as E. Carlen, M. Loss, L. Erdos, E. Harrell (GT mathematical physics group), K. Mischaikow (GT Mathematics / director CDSNS), W. Gangbo (GT Mathematics / CDSNS), M. Borodovsky (GT Biomathematics), D. Dusenbery, R. Wartel (GT Biology), G. Hentschel and F. Family (EU Physics), and N. Chernov and N. Simanyi (U. Alabama Mathematics, Birmingham) will interact with IGERT faculty and visitors. These excellent researchers could have equally well already been listed as IGERT faculty, and they and others in Atlanta area will be inducted if new research directions merit their joining IGERT.

[27]

IGERT plans to co-organize a number of international workshops. P. Cvitanović is the *Secretary of the European Dynamics Days Governing Board*, a *Honorary Chair of the Let's Face Chaos* conference (Maribor, Slovenia May 2002), and a member of other international conference committees. Since 1981 he has organized or co-organized more than 25 conferences, workshops and schools in Europe and US, and has a well established international partner network. Internationally, some fifteen *"Sister Nonlinear Science Centers"* located in Mexico, Germany, Denmark, United Kingdom, Italy, Israel, Argentina, Hungary, Chile and Austria are IGERT's potential partners in organizing workshops, exchanging researchers, and hosting interns (for a complete list, please check the Center webpage [15]). A few examples:

- *Center for Chaos and Turbulence Studies* [17] - M.H. Jensen, director. A leading European center in physics of complex systems ranging from neuronal activity to quantum chaos, housed at the Niels Bohr Institute, Danish Technical University, and Nordita, Copenhagen. CATS will host IGERT researchers and interns. IGERT will host the Danish Research Academy *Danish Ph.D. School in Nonlinear Science* supported students and visitors. As many European Ph.D. programs require research training abroad, these and other similar exchanges will be very beneficial to the overall IGERT recruiting effort.
- *Centro Internacional de Ciencias*, Cuernavaca, Mexico - T.H. Seligman, director. Promotes scientific exchange, with particularly strong Latin American visitor and conference program. IGERT and CIC have a tentative agreement to co-organize two "pan-American" workshops, the first one on "Classical and quantum chaos in few- and many-body systems" in winter 2004 and the the second one in winter of 2006.
- *Max Planck Institute for the Physics of Complex Systems*, Dresden - H. Kantz, Head, Nonlinear dynamics and time series analysis group. The main European meeting ground for young researchers

[27] **file** international.tex - Sep 9 2002 version - npuBeT BaIIIuM

and leading international scientists in physics of complex systems, with intensive workshop, visitor, postdoctoral and exchange program. Collaboration with IGERT desired in order to strengthen ties to US.

In addition - the space allotted does not allow a detailed listing - each individual IGERT faculty member maintains **international research ties** that will enhance and be enhanced by the IGERT visitor, internship and workshop programs.

- LAB and Ruedi Stoop, Institute of Neuroinformatics, ETH/Univ. of Zuerich, experimental, numerical and theoretical studies of systems of neocortical neurons
- LAB and Mikhael Blank, Institute for Information Transmission Problems, Moscow, Russian Ac. Sci.,dynamics of multi- component systems (deterministic and stochastic) and their phase transitions
- LAB and Carlo Boldrighini, Univ.di Roma 1, Dept. of Math. transport coefficients, long tails in models of statistical physics and in dynamical systems

[28] It is the very essence of nonlinear science that the same researchers contribute to widely different fields, here split into different MREs. Research advances in nonlinear science are inseparable from the training it offers, and that is the core effort that all IGERT participants will contribute to: Integration of the research, educational, and training with the dual goals of attracting a wide range of undergraduate, graduate, and postdoctoral associates to physics and providing them with a stimulating and thoroughly modern learning environment. In equipping the students with skills that are cross-disciplinary, method based, rather than discipline specific, nonlinear science is uniquely positioned to offer the students a broad, diverse education, and prepare them for today's rapidly evolving professional environment. Coupled with the cross-disciplinary nature of IGERT, the training offered will meet the recommendation of the NRC report to physics departments "to review and revise their curricula to ensure that they are engaging and effective for a wide range of students and that they make connections to other important areas of science and technology". In order to effectively achieve these goals, a number of novel **cross-cutting methodologies** for education

[28] **file** school.tex - Aug 10 2001, printed October 30, 2005

and training will be developed. The proposed research and training will transcend departmental boundaries, differing from the conventional model of disciplinary education in a number of significant ways.

The need for a strong foundation in the analysis of nonlinear dynamical systems is common to many research programs in science, engineering, and mathematics. At GT, courses on nonlinear dynamics are currently taught in the mathematics and physics departments, each from a different perspective, and draw students from biomedical, chemical, aerospace, electrical, and mechanical engineering, materials science, and chemistry. (For a current listing of courses, seminar series, workshops, and other activities, consult the Center webpage [14]). While students would clearly benefit from a program based on a broad, coherent, and unified view of nonlinear science, college and school boundaries need to be superseded by a framework that integrates what otherwise would be isolated collaborations between individual faculty members. The program built around the IGERT initiative will generate a new level of integration in graduate and post-graduate education by involving faculty in different departments in an effort to unify the nonlinear science curriculum across the participating schools. Equally important, combining the resources of the Center's MREs will make it possible to offer undergraduate level cross-disciplinary courses to students from participating institutions.

The core of the cross-disciplinary training program will consist of an **Introductory Nonlinear Science** course on the mathematical and computational techniques of nonlinear science followed by a rotating sequence of **Applications of Nonlinear Dynamics** courses based on the research interests of individual Center members and rounded up by a semester of **Special Topics in Nonlinear Science** featuring research on specific projects carried out by small teams supervised by faculty members with complementary expertise and perspectives. The level of courses will vary from advanced undergraduate to second year graduate, targeting the range of students that can be most effectively recruited into research programs. As one of the new initiatives, IGERT will offer an advanced web based year-long graduate course [12]. The courses will gather all nonlinear science students in an activity that stresses commonalities among various fields, and it will provide a sense of intellectual community fundamental to the success of the program. The course work will require coordinated collaboration with peers and teachers from different backgrounds, helping students develop communication skills that will prove invaluable in future careers in industry or academia.

This training will equip young researchers with the tools and intuition needed to tackle complex nonlinear problems arising in many guises and various technical fields. In order to offer students a deep learning experience outside the Ph.D. thesis research, the educational core of the IGERT training program will be supplemented by the following important components:

Internships at other institutions, such as external academic, government, or industrial research centers will provide young researchers with additional cross-disciplinary perspectives by exposing them to different experimental, computational, and theoretical approaches, using the expertise not available at GT/EU, as well as forging new collaborations.

The above range of activities, while highly desirable, cannot be sustained by the individual grants. The very existence of proposed program hinges on the availability of cross-disciplinary funding, something that only IGERT can make possible.

Our plans for recruiting graduate students to the proposed IGERT program build on the existing graduate recruitment efforts of the individual departments. The students will enroll in one of the following Ph.D. programs associated with the participating departments: Biomedical Engineering, Chemical Engineering, Electrical and Computer Engineering, Engineering Sciences and Applied Mathematics, Materials Science and Engineering, Mathematics, Mechanical Engineering, Physicas and Astronomy, and the Neuroscience.

[29]

We propose to recruit approximately seven new Ph.D. students to the IGERT program each year, with fellowship offers that cover the first two years of graduate study. Experience with recruiting graduate students to our individual departments indicate that multiple-year fellowship offers are extremely attractive to prospective students. Such fellowships give students freedom to focus on their studies, and also to choose their thesis topic and advisors with less focus on faculty funding situations. In many instances the

[29] PC: insert?: the Nonlinear Science Program offers to students funded by IGERT a minor in Nonlinear Science, harmonized with their departmental requirements. Such broadening of student's Ph.D. profile should significantly improve employment prospects.

fellowhip offers will combine IGERT funding with existing departmental and University fellowships; most of the participating departments already offer prospective graduate students nine-month fellowships for the first year of study. By combining resources, we will be able to make more competitive fellowship offers (*e.g.* \$19-\$20K/year), and also to offer some continued funding to more senior IGERT program graduate students who have begun cross-disciplinary thesis research. Such extensions of funding will be made on a competitive basis; see section **??** for details of fellowship resource allocation. Student retention will be facilitated by a close student-program advisor relationship that is established as soon as the student arrives at GT and continues until the student completes the Ph.D. (see section **??**.**??**).

The program will be advertised in three primary ways: (1) through the participating departments graduate program brochures and webpages, as well as on the GT Nonlinear Science webpage `www.cns.gatech.edu`, (2) by the participating faculty contacting colleagues at other academic institutions to alert them to the new program, (3) by announcements posted at research conferences, in nonlinear dynamics electronic newsletters, and in newsletters aimed at minority and women scientists, mathematicians, and engineers (*e.g.* the Association for Women in Mathematics Newsletter), and (4) by targeted contact and/or visits by participating faculty members to relevant summer undergraduate research programs, in particular those enrolled by minority students. Prospective candidates will be invited to visit GT, where a graduate student already in the program will serve as a host, and where they will meet the faculty and other students in the IGERT.

In addition to these general recruiting strategies, IGERT funding will enable us to implement the following measures to aid recruitment and retention of students from under-represented groups:

- **Summer Internships for Minority and Women Undergraduates**

  We propose to offer 3 summer internships per year to promising women and/or minority undergraduates for the summer between their junior and senior year. Each student will be paired up to work with one of the IGERT faculty, either by assisting in a lab, implementing numerical computations, or working on a small-scale research project with the first year graduate students in the IGERT program. Many of the participating IGERT faculty have considerable experience directing undergraduate honors thesis research projects, as well as guiding undergraduates in summer research projects *e.g.* as part of NSF's REU program (see section **??**). Each undergraduate will be assigned a IGERT graduate student who will serve as a "junior mentor". Minority students will also participate in the activities of GT's summer "Minority Research Opportunity Program"[30] which will provide them with an additional network of peers.

The goal of the internship is two-fold: the participating students benefit from exposure to nonlinear science research and graduate student life at the critical time in their education, and the IGERT benefits by establishing a relationship with strong prospective graduate students.

[31]

The unique position of nonlinear science lying on the interface of two or three different disciplines is reflected in the funding patterns specific to cross-disciplinary research: although established research programs have somewhat broader funding opportunities, it is substantially more difficult to find individual funding opportunitities for new research directions, since typically they will not be given priority by either of the core disciplines. This puts special emphasis on the availability of **seed funding in emerging areas**, especially high-risk ones.

The IGERT will be able to provide such funding quickly and in an extremely flexible way. The highest priority will be given to collaborative research lying on the interface of different disciplines and involving faculty from different departments. Second priority will be assigned to joint research by the faculty members in the same department or discipline. In both cases at least one of the investigators will come from the IGERT faculty. In general, the goal of seed funding will be to initiate and stimulate preliminary research in the novel and promising areas of opportunity, where no existing patterns of funding exist. Once the potential of a given direction is proven at the preliminary stage, individual and/or group funding from more conventional sources will be sought.

[30] PC: this program is not GT, it is Northwestern

[31] **file** emerging.tex - Sep 9 2002

The availability of seed funds will be especially critical for the success of **junior faculty members** who typically do not have other sources of funding which can be used to initiate new research directions. The criteria and mechanisms for selecting and evaluating projects are addressed in sect. **??**. Given the difficulties that even senior faculty members face in funding new research directions, this task becomes especially and unnecessarily complicated for junior faculty, who do not yet have a track record of successful research to warrant favorable consideration by the granting agencies. Providing junior faculty with such flexible funding will save a lot of time required otherwise to prepare, submit, and undergo a review of several full-scale exploratory proposals, enabling the junior faculty to concentrate instead on the proposed research. All of this is especially true where nonlinear science with its cross-disciplinary focus is concerned.

As was repeatedly stressed throughout this proposal, a distinguished feature of nonlinear science is that it is driven by cross-pollination of ideas between different disciplines as well as between different fields within natural sciences, engineering and medicine. As a means to promote such cross-pollination, IGERT will organize and host a series of bi-annual **Applied Nonlinear Science Workshops**, bringing together IGERT faculty and students and researchers from regional universities, national laboratories, and industrial research centers. Each year the workshops will target a different application area (e.g., neural dynamics, control of extended systems, plasma physics, biological excitable systems, etc.), fostering collaborations and transfer of ideas, creating new approaches, and stimulating new research directions by bringing together specialists with complementary research expertise.

Organization of such workshops depends crucially on the availability of centralized funding and infrastructure. On the other hand, by limiting the scope of the meeting and bringing together a sharply focused group of researchers, such meetings will play a role that neither the individual contacts nor the very broad international conferences such as the SIAM Snowbird meeting play. The workshops will serve the dual purposes of disseminating the methodology developed by the nonlinear community to other fields with the latter providing the focus for the research directions in the nonlinear science and, at the same time, establishing new collaborations between members of different institutions.

Complementing the above research-oriented activities will be a range of education-oriented activities, such as a Regional Nonlinear Workshop, internship support for outstanding students, and the development of a web-based nonlinear courses, all of which are expected to have a strong impact on the research component.

The **Regional Nonlinear Workshop** will differ significantly from the Applied Nonlinear Science Workshop in that it will be oriented primarily towards students of all levels. Scheduled yearly, this cross-disciplinary meeting will be organized jointly with other Southeastern universities such as Duke, U. of Alabama, and U. of Florida, it will be hosted on an alternating basis by the IGERT and the fellow institutions. The main goal of the workshop will be to expose students from regional universities to the forefront of research, and give them an opportunity to present their own work in poster sessions. This workshop will have a broader scope, encompassing the whole field of nonlinear science. This broad scope will give the students the sense of diversity and at the same time closeness of the nonlinear science community, highlighting the many existing and prospective links between different directions pursued by different research groups.

IGERT will offer to students and post-doctoral fellows of exceptional promise (either from IGERT, or from outside) **internship support**, the goal of which is to significantly broaden and strengthen their education and provide young researchers with additional cross-disciplinary perspectives by exposing them to different experimental, computational, and theoretical approaches, using the expertise not available at GT/EU. For example, a trainee working on theoretical projects in the home institution might intern in an experimental lab in a host institute, or *vice versa*. In other cases the internship would provide a specific experimental technique or theoretical approach not readily available at the home institution, but important for the trainee's thesis research. In addition to this, the internship program will play an instrumental role in forging new collaborations and finding new areas of opportunity.

The trainee, aided by the home institution advisor, will make the initial contact with the internship advisor. A brief proposal will then be written that clearly states the goals of the internship, which is expected to last 3-6 months and possibly form the basis for a publication. The internships will be reviewed after the first three months by the IGERT and home institution advisors to determine whether progress is sufficient to warrant an extension. The trainee will present his/her results in the Graduate Seminar Series, and, upon returning to the home institution, in the form of a written report.

Yet another component of the educational activity of the center, and an integral part of its outreach program, a **web-based nonlinear course** will play an important role in reaching and attracting students from remote locations, providing them with the inside look at the current research topics in classical and quantum chaos. Such course could be based on the ChaosBook [12], a hyperlinked web-based course currently under design by P. Cvitanović and coauthors, a novel and unique approach to teaching an advanced graduate level nonliner physics course. In addition to the extremely valuable potential of accessing the broadest possible audience, the major advantage of a web-based course compared to a textbook-based course is a unique opportunity to incorporate the dynamical aspects into the presentation. Such dynamical aspects realized through animations, java applets, interactive scripts, and so on, can only be implemented with a considerable investment of time and resources. Given the scope of the material, this will require involvement of a group of advanced undergraduate and/or graduate students for an extended period of time. Although clearly innovative and beneficial for the whole nonlinear science community, such a project cannot be supported by any individual grant and requires a centralized approach.

Reviewer Information

[32]

⇑PRELIMINAR

[32] NSF requires: (THIS PART UPLOADED SEPARATELY TO NSF) - Enter the following information into the FastLane "List of Suggested Reviewers" form: (1) a list of individuals (and their affiliations) outside the participating institutions whose participation in the review of the full proposal might constitute a conflict-of-interest through association with the participants, and (2) a list of individuals who are suitable to serve as impartial reviewers.