Large Synoptic Survey Telescope

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March 6, 2009

Dr. Iain M. Johnstone
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Stanford University
450 Serra Mall
Stanford, CA 94305-2070

Dear Dr. Johnstone:

Enclosed please find the report of the Committee of Visitors to the Physics Division, which met February 4-6, 2009. The report includes:

1. The COV's consensus assessment of the physics program
2. Individual reports from the 10 subpanels
3. The agenda
4. The membership of the COV
5. The charge to the panel
6. The completed report template

The COV came away with a renewed appreciation of the quality of both the physics research program supported by the NSF and of the staff that manages the program so well.

On behalf of the COV,

Sidney C. Wolff
Chair, 2009 COV

Report of the Committee of Visitors

Physics--2009

The Committee of Visitors (COV) for the Division of Physics met for three days, February 4-6, 2009 in order to, as described in the charge, provide NSF with an assessment of the quality and integrity of the program operations pertaining to proposal decision; and to comment on how the results generated by awardees have contributed to the attainments of NSF's mission and strategic outcome goals.

The agenda for the meeting and the members of the sub-panels are provided in Appendices A and B. The charge to the panel is in Appendix C.

This overview portion of the report is divided into five sections: 1) an analysis of the proposal review process, with the overall assessment detailed in the Report Template, which is included as Appendix D; 2) comments on program balance; 3) some issues and questions that arose during our meeting and merit further review by physics division staff; 4) some program highlights that illustrate the contribution of physics to NSF's goals; and 5) suggestions for improving the COV process. The overview is followed by more detailed reports from each of ten subpanels, which examined specific programs within the physics division.

1. The Review Process

The subpanels are unanimous in concluding that the process of reviewing proposals submitted to the physics division is excellent. As detailed in the individual reports, the selection of referees and panel members is appropriate as measured in terms of both expertise and diversity; conflict of interest issues are addressed appropriately; the review reports are thorough and provide a clear basis for decisions; both proposers and reviewers address both merit criteria as required by NSF policy; the program officers generally follow the recommendations of the reviewers, but it is important that they continue to have some discretion in making final decisions; the balance of the portfolio is appropriate; and outstanding science is being delivered.

The summary reviews by the program officers are judged to be outstanding in terms of analyzing the proposals and providing the basis for the ultimate funding decisions. These analyses are for internal use and cannot be transmitted verbatim to proposers, but the COV encourages program officers to convey as much content as they can via email or telephone. The program officers can in effect serve as mentors, an especially valuable support for new faculty in institutions where such advice may not be readily available.

As is typical throughout the NSF, little or no growth in funding in recent years has led to decreasing success rates and/or lower funding per grant. Many excellent proposals cannot be funded at all. After detailed examination of individual jackets, however, panel members concluded that they agreed with the difficult decisions made by the program officers. As is also typical of other divisions in the NSF, we find that the program officers have a very heavy workload.

The COV strongly endorses the use of both written and panel reviews. The two types of input provide complementary information that is extremely valuable in deciding which proposals to fund.

Most funding decisions are made within six months. A few proposals, particularly interdisciplinary ones, do take longer than six months. This is very appropriate because these proposals often need to be seen by multiple panels in order to assess the science.

COV members find that Fastlane meets their requirements and is much easier to use than Grants.gov.

2. Program Balance

Physics is carried out in a variety of institutional settings from table-top experiments by individual investigators to large scale programs at facilities like the LHC. Currently, slightly more than 55% of the funding of the physics division goes to individual investigators. We believe this allocation is appropriate and should be maintained.

The remaining funds are used to operate facilities such as LIGO, which is a bold attempt to detect gravitational waves; Auger and other experiments that study cosmic rays; LHC participation; etc. The Physics Frontier Centers (PFCs) currently receive about 10 percent of the budget, and the COV judges this level of investment to be appropriate. These facilities and centers serve as a magnet for bringing together talented individuals, including several Nobel laureates, to attack large-scale problems, many of which require a multidisciplinary approach. Some important accomplishments of the PFCs are summarized in the subpanel report.

The Kavli Institute for Theoretical Physics (KITP) at Santa Barbara is unique among the PFCs. It functions as a multi-disciplinary “laboratory” for theorists. Its primary purpose is to host outside groups of theorists, who can be thought of as “users” and who come together for typically a few weeks to work intensively on problems in areas that overlap traditional subfields and require expertise not normally found within a single institution.

The synergy created by the PFCs is producing not only transformational research but also innovative educational initiatives designed to attract young people with diverse backgrounds to careers in science.

In short, progress at the frontiers of physics requires investments at all scales—from principal investigators to large facilities.

3. Comments

Instrumentation and Equipment

We concur with previous COV reports that more funding and more flexibility in funding amounts are needed to support the acquisition of instrumentation and equipment. Indeed, after some improvement in success rate and/or grant size, this should probably be the highest priority for new funding. The dollar limits on such awards should range widely. Table-top experiments commonly cost in the range $50K-$500K, and projects approaching the threshold of MREFC (~$100M) might occasionally be appropriate. Currently, it is extremely difficult to fund equipment falling in this very broad cost range.

The physics division clearly recognizes the need for funding of this type and in response to previous COV recommendations has established the Accelerator Physics and Physics Instrumentation program. At the present time, however, given the budget constraints of the past few years, APPI remains unfunded, has no presence on the NSF website, and has issued no calls for proposals.

Large Projects

The physics division is engaged in several technically challenging projects that are in the MREFC queue or candidates for it, including Advanced LIGO, IceCube, and DUSEL, which is in the planning stage. If these projects are to be carried out without damaging the balanced portfolio that is essential to the health of the overall physics program, it is essential that they be well managed and that the total life cycle costs be clearly and accurately established before construction is authorized. Achieving this goal requires experienced project managers, and we are pleased that the physics division has made key hires in this area. It also requires sufficient funding to develop designs to a mature enough state so that construction costs can be estimated accurately. Determining true life-cycle costs will also require a sound estimate of operations costs, including replacement of equipment and the cost of an associated grants program for users of the facility.

A brief presentation to the COV indicates that this type of planning is indeed in progress for DUSEL. It is likely, however, that both the design and development phase, as well as the operations phase of a project of this scale, will require a commitment from the Foundation as a whole. The cost of developing a mature, fully-costed design is a very significant fraction of the annual budget of the physics division. An attempt to fully fund the design effort for DUSEL within the physics division would either extend the design phase over many years; distort the current healthy balance of the physics portfolio; or result in such a limited engineering effort that costs would be uncertain and overruns probable. It is also unlikely that closing existing facilities can generate sufficient funds to operate a major new facility like DUSEL, although the physics division should be expected to make a partial contribution through phasing out of some of existing operations.

Increasingly, large-scale projects will be carried out through partnership between the NSF and other agencies or other countries. Often it is difficult to get partners to commit without a clear signal from the NSF, which can be challenging given the annual budgeting process within the US. It is likely that major initiatives such as DUSEL, as well as similar projects in the other divisions of NSF, will require support and assistance from the highest levels of the Foundation in establishing appropriate partnerships. These partnerships should have the dual advantages of enhancing the scientific return from the project and lowering the costs to NSF.

Engaging the Community in Large Projects

One challenge for big facilities projects is engaging community participation. It should be possible for individual investigators and groups of investigators to contribute to many aspects of the project—development of technology, algorithms, and analysis tools; detector characterization; and analysis of data. LIGO offers an interesting model for other projects. The LIGO Laboratory is responsible for construction and operation of the facility. Members of the LIGO science collaboration, which now includes several hundred scientists, propose directly to NSF physics to pursue LIGO-related research, development, and analysis projects. The LIGO lab then conducts its own evaluation of these proposals, with emphasis on how critical they are to LIGO, as input to the normal NSF review process.

The subpanel on gravitational physics carefully examined proposals that were given this dual review and concluded that the LIGO Lab reviews were of high standard, appropriately critical, and not influenced by self interest.

Because of the close working relationship between the LIGO Lab and the science collaboration and the wide variety of supporting tasks required, scientists in a variety of institutional settings are able to contribute to gravitational wave science. For example, undergraduates at a four-year liberal arts school have analyzed LIGO data to evaluate noise sources.

Interdisciplinary Research

Many transformational programs lie on the boundary of physics and other disciplines. Also, not surprisingly, some of the most compelling examples of the broader impacts of physics research involve interdisciplinary programs. Proposals for interdisciplinary research currently are handled largely through personal relationships within the Foundation. In most but not all cases this works well. Some barriers, however, do remain for proposals that do not fit one of the standard categories. We offer several suggestions:

- Proposals that are not easily assigned to one of the existing programs should be assigned to an entrepreneurial "owner/incubator/champion." The program officer in charge of Education and Interdisciplinary Research appears to be taking on this role effectively. We were told, however, that it is sometimes difficult to obtain reviews from other divisions either because of timing or because the proposal does not fit that division's portfolio. The "incubator" should be empowered to obtain reviews wherever the necessary expertise lies.
- Interdisciplinary proposals that require joint panel reviews involving more than one division or even more than one agency, as is the case for example, for DUSEL proposals, should not be included in evaluating success in meeting the metric of completing reviews within six months. The different timing of reviews in different divisions or agencies may inevitably mean that the review process

takes longer. All proposals merit not only a timely review but also a careful, thorough, and fair review.

- Some universities encourage interdisciplinary appointments/programs through co-funding from a level higher than the department level; this model might work to encourage interdisciplinary initiatives within the NSF.
- The health of a new interdisciplinary program should be monitored for several years after it is established. We found evidence that it is easier to launch an interdisciplinary program than to sustain it. For example, growing proposal pressure led to the establishment of a program in the Physics of Living Systems. In the face of funding pressures, however, it has proved difficult to grow the funding in this area, and the success rate of proposals (~10%) is lower than typical for physics as a whole.

Changes in the Portfolio

Many fields within physics are changing rapidly. Some areas, like the Physics of Living Systems, are growing rapidly. Breakthroughs in numerical relativity make it possible to calculate observational consequences of black hole mergers and are stimulating renewed interest in this field. LIGO with its potential for detecting gravitational radiation is generating growing interest in gravity research. The distribution of proposals among the subdisciplines within Atomic and Molecular Physics (AMOP) is changing. In some cases, including AMOP, research would benefit from a closer coupling of theory and experiment. Changes in priorities in other divisions in the NSF, such as appear to be occurring in materials science, may redirect proposals to physics. Commercialization of capabilities originally developed to support science, such as grid or cloud computing, may require a re-examination of the requirements for NSF support.

The organization of the physics division and of its review of proposals needs to be flexible enough to respond rapidly to changing scientific opportunities. This flexibility may require reallocation of funds among or within various programs, a reorganization of the way that review panels are set up, changes in the portfolio, or changes in the review process to engage other divisions or agencies. The physics division has been innovative in devising new ways of reviewing proposals, with the LIGO and DUSEL reviews being just two examples. Some specific suggestions for consideration for additional changes are made in the subpanel reports (e.g., AMOP and PIF).

Criteria for CAREER Awards

The panel uniformly supports the goals of the Faculty Early Career Development (CAREER) program, which makes awards to early-career scientists "who exemplify the role of teacher-scholars through outstanding research, excellent education and the integration of education and research within the context of the mission of their organizations. Such activities should build a firm foundation for a lifetime of leadership in integrating education and research." However, several members of the panel expressed the concern that the review of proposals to the CAREER program may place too much emphasis on innovation in evaluating the education component of the application. In physics, at least, there is an active program of physics education research that has advanced greatly our understanding of what constitutes effective education.

Physics education research is a significant discipline in its own right. To expect young faculty to become expert in physics research and also to advance, in effect, physics education research at the same time by developing innovative curricula or education programs is perhaps asking too much.

We suggest that the goals of the CAREER program, which we endorse, could be achieved by allowing—indeed encouraging—applicants to take advantage of existing programs and resources and to translate them to their own classrooms or to diverse student audiences. Examples of some of these programs are listed in the subpanel report on Physics Education and Interdisciplinary Research.

Research Experience for Teachers

We were disappointed to learn that funding from the OMA for the Research Experience for Teachers (RET) program is no longer available. Those who have hosted the RET program have found it to be highly effective in building connections among students, teachers, and researchers. One engaged teacher influences many students, and sustaining funding for this highly leveraged program would seem to be an appropriate priority for the NSF.

Support of Young Scientists

In the current economic climate, university hiring freezes are likely, and the decline in retirement savings may well delay faculty retirements. The dearth of new positions means that we may lose a generation of young scientists. We discussed a number of options for addressing this issue, but all have the potential for unintended consequences. The NSF is certainly aware of this problem, and we encourage that consideration be given to whether anything can or should be done about it.

Four-year colleges

Data show that four-year liberal arts schools are disproportionately successful in producing graduates that go on to obtain advanced degrees in science. It is important to nourish professors in this environment even though their research may be limited either by their heavy teaching loads or restricted access to facilities. Perhaps extra weight could be given to the broader impacts portion of proposals from such institutions to enhance their competitiveness. Also, it is important not to create unnecessary barriers for proposers from such institutions; one person on our panel from a 4-year institution had difficulty developing a compelling budget that would meet the minimum amounts for a CAREER award—although this is perhaps an unusual case!

4. Program Highlights

The subpanel reports describe some of the significant results achieved through NSF funding. These results are impressive in terms of the diversity of topics addressed, their impact on other scientific fields and on education, and the number of prizes and other recognition garnered. We repeat a few of those highlights here simply as illustrations.

Electron g-factor: The electron g-factor was measured to an accuracy of one part in a trillion by isolating and suspending a single electron for months in a mini-cyclotron cooled below 100 mK.

Brain magnetic fields: Techniques originally developed to study CPT violation were used to map brain magnetic fields evoked by auditory stimulation. The magnetometer operates at room temperature and provides higher sensitivity, higher spatial resolution, and simpler operating conditions than superconducting sensors.

Dark Matter: Several experiments, including most notably XENON10 and the Cryogenic Dark Matter Search have put stringent limits on the spin-independent cross sections of dark matter particles. These new limits are beginning to overlap theoretical predictions. More sensitive experiments, which are now being planned, should be able to challenge the theories.

Neutron-rich isotopes: Experiments to determine how many neutrons a certain number of protons can bind show that neutron-rich matter is more bound than expected. This result has implications for the understanding of neutron stars and the formation of the elements.

Atomic clocks: Relativistic many-body calculations have quantified the effects of temperature differences on atomic clocks. More accurate clocks lead to more accurate global positioning systems (GPS).

I2U2: "Interactions in Understanding the Universe" has created an infrastructure that facilitates the development of hands-on laboratory course content and provides, according to its website, "an interactive learning experience that brings tangible aspects of each experiment into an accessible 'virtual laboratory' setting for education at different levels and in various venues." The goal of the I2U2 collaboration of scientists, computer scientists, and educators is to grow and sustain the scientific workforce.

Stochastic gene expression: Genetically identical cells under identical conditions can exhibit different biological behavior. New data show that biological cells can improve fitness by optimizing phenotypic diversity originating from the stochastic nature of gene expression. In these cases noise is not a nuisance, but essential for survival.

New type of neuron: Instruments developed to look for the fundamental elementary particles of nature have been used to study neural systems. A new ganglion cell, first observed in cats more than 40 years ago, has now been detected in primates for the first time. The properties of these newly discovered cells suggest that they may contribute to the perception of motion.

Einstein@home: Modeled on the SETI@home project, Einstein@home has harnessed 150,000 home computers to search LIGO and GEO data for the gravitational-wave continuous signals from rapidly-spinning neutron stars.

5. The COV Process

A number of the recommendations of the previous COV were followed in preparation for this COV. The materials for the meeting were available on the web several weeks in advance of the meeting; the pre-meeting conference call with sub-panel chairs was very helpful in organizing the meeting; initial presentations to the full group were limited to part of the first morning so that the working sessions for reviewing the jackets could start sooner; and statistics covering a 10-year rather than a 3-year baseline were made available.

It was extremely valuable that the chair of the COV was able to move around to the various subpanels to answer questions and also to learn about the types of issues that were being discussed. Apparently in previous years, the chair was also a member of a subpanel, and that dual responsibility would make it much more difficult for the chair to obtain a good overview of the entire program.

There were, however, a number of frustrations, particularly with access to the jackets. This was the first COV for which access to the jackets was entirely electronic, and it is perhaps not surprising that there were problems. Initially, only those jackets selected by the program officers were available. It was possible to select additional jackets individually and have them entered into the system. However, on the first day the lists of accepted/declined proposals were in some cases incomplete and in most cases not available in a format that made selection easy. The physics staff was very responsive to requests from the sub-panels and provided more useful lists on the morning of the second day. The additional proposals selected by panel members were then reviewed.

It would be far better, however, if it were possible, taking into account the requirement to avoid conflicts of interest, to simply browse through all the proposals so that COV members could easily sample a range of actions beyond those that are pre-selected.

The review process benefited from the fact that examination of jackets began much earlier on the first day than was the case for the previous COV meeting. However, the work would have been facilitated if each subpanel breakout session had begun with a brief (~30 minutes) overview of that specific program—evolving scientific directions, funding trends, success rates, size of grants, etc.—prior to beginning the review of the jackets.

The COV is charged with examining a broad range of issues:

- the integrity and efficacy of processes used to solicit, review, recommend, and document proposal actions;
- the quality and significance of the results of the Division's programmatic investments;
- the relationship between award decisions, program goals, and Foundation-wide programs and strategic goals;
- the Division's balance, priorities, and future directions;

- the Division's response to the prior COV report of 2006; and
- any other issues that the COV feels are relevant to the review.

The material presented to us addressed the first three bullets in this list clearly and adequately, and the written material described the response to the previous COV report. We were given a lengthy initial presentation about the division as a whole, which included some discussion of priorities and future directions. However, we then turned immediately to review of the jackets without further discussion. For future COVs it might be useful to confine the initial plenary presentation to an overview of the current status of the physics division and defer a presentation of priorities and future directions to, say, the end of the second day when the review of jackets is essentially complete. The morning of the third day could then provide time for discussion of these important issues.

Subcommittee Reports

1. AMOP Program Subcommittee Report

Introduction. The atomic, molecular, optical, and plasma physics (AMOP) program supports a vibrant and diverse spectrum of research. Because of rapid developments in laser technology, materials, and methods for cooling and confining atoms, AMOP finds itself increasingly on the frontiers of science and technology where it has impact both inside and outside PHY in such diverse fields as astrophysics, nuclear and particle physics, condensed matter physics, and quantum information science. While this diversity offers tremendous opportunity for the program, it also presents significant organizational and managerial challenges.

The Subcommittee examined the process of proposal review and the results of proposal funding for the period of 2006-09. Our task included speaking with current and recent past Program Officers, Robert Dunford, Richard Berger, Charles Conover, and Denise Caldwell, as well as the most recent past AMO Theory Program Officer, Barry Schneider. We also examined approximately 30 proposal jackets spanning the range of the Program activities. Our overall impression of the integrity, quality, and outcome of this process is extremely positive. We are gratified to find talented and hard-working people who have made this Program a success, and view the Program as a model for other funding agencies.

Balance Between the AMO and Plasma Programs. The Program is divided into AMO physics and Plasma physics, with Dunford handling the former, while Berger manages the latter. Such a division is appropriate due to the decreasing overlap between the AMO and Plasma programs. Individual AMO grants, excluding Centers, receive approximately \$15M of funding annually, while Plasma Physics currently receives about \$2.4M. These levels of support have remained essentially constant for years.

The plasma physics program continues to operate in close collaboration with the Department of Energy – Office of Fusion Energy Sciences (DOE-OFES) through the NSF/DOE Partnership in Basic Plasma Science and Engineering. The NSF/DOE partnership is a major source of support for non-fusion-related laboratory plasma science, for both theory and experiment. OFES provides approximately 70% of the total program funding. We endorse the continued partnership of the NSF and the DOE in this activity.

A. Integrity and Efficiency of the Process

Referee Process. A fair, efficient, and transparent referee process is at the heart of any successful peer-reviewed system. We found that the referee process functions smoothly. The choice of referees was done with care as the referees and proposals were well matched. Reviews from individual reviewers vary in thoroughness, but almost all referee reports that we examined were pertinent and useful. Reviewers generally place scientific excellence as their top priority, but reviewers did note and penalize proposals that do not address the Foundation's Broader Impact or Educational goals.

Panel Reviews. We are enthusiastic about the combination of individual reviews and panel reviews, as they complement each other's strength and weakness. In several instances, we noted that the panel picked up on issues that were missed by several of the individual reviewers. The AMO panels are stretched, in our opinion, by the increasing number of proposal submissions and the diversity of research topics. The number of AMO proposals is approaching 100 per year. Panels consisting of only 13 or 14 members do not have enough breadth to adequately review the diversity, and the numbers threaten to overburden the panels.

Proposals in the AMO portion of the program are currently divided into four categories: precision measurements, optical physics, atomic and molecular dynamics, and atomic and molecular structure. Atomic and molecular dynamics comprises the linear and nonlinear response of atoms to electromagnetic fields, cooling and trapping of atoms and ions, low temperature collision dynamics, and the collective behavior of quantum degenerate atomic gases. Approximately one half of all the reviewed proposals in FY08 were in this category. The optical physics component is the next largest category, comprising atom-radiation interactions at high fields and high-harmonic and attosecond pulse generation, quantum properties of the electromagnetic field and the interaction of atoms with single photons, and entangled quantum states.

In the Plasma Program, the three-year cycle of the NSF-DOE partnership has created a large year-to-year variation in the number of proposals (FY06: 215; FY07: 80; FY08: 60). Nonetheless, the program has managed to maintain high reviewer standards during these variations.

The Subcommittee expects an increasing number of proposal submissions pertaining to ultracold atoms which address issues in many-body and strong correlation physics. Since these are issues that fall normally in the purview of condensed matter physics, it is likely that a panel consisting of mainly AMO experimentalists does not have sufficient expertise to provide an adequate review. We do not favor co-review of proposals in this particular area because the overlap is only with a part of CMP, and in particular, the overlap with CMP experiment is small.

Program Officer Role. Review analyses by the Program Officers are generally are thorough and carefully prepared. Individual reviews, panel reviews, and the Program Officer's own experience were synthesized into thoughtful and well-reasoned documents.

Review Process Outcome. The Subcommittee largely agreed with decisions to fund or not fund the proposals which we examined, although it is clear that the number of proposals worthy of funding is greater than can be supported with available resources.

Time to Decision. The time to decision has approached 6 months, which is sufficiently rapid.

Women and Underrepresented Minorities. The low number of women and underrepresented minorities funded by the Division reflect the corresponding low number of submitted proposals from these groups. The review process is appropriately affirmative.

Program Specific Recommendations:

- AMO Panels: The current categorization of proposals in the AMO program is antiquated, and in some cases inaccurate. We recommend that the subfield categories be updated and that the panel be broken into two separate ones. We further recommend that the panel reviewing ultracold atom physics include experts in CMP theory (these experts could come from either the AMO or CMP theory communities). Such a panel could also review those CMP proposals that overlap most into AMO, such as quantum optics with solid state systems.
- AMO Theory: AMO theory is vital in conducting AMO research, but it plays almost no role in the AMOP program. We recommend tighter coupling between the programs, and in particular, that AMO theorists participate in the individual review and panel reviews of AMOP proposals. AMO experiment suffers from inadequate support of AMO theory. Many AMO experimental programs are highly dependent on theory, but with the exception of just a handful of institutions, AMO theoretical activity in the US is relatively weak. We believe that this is a missed opportunity, but one which is relatively inexpensive to fix.
- Plasma Physics: Funding for plasma physics represents only 10% of the AMOP budget, its average grant size is significantly lower than the rest of the program, and the proposal success rate has fallen under 20%. Highly rated proposals in the "Must Fund" category are routinely declined due to a lack of program funding. Additionally, some areas of plasma sciences, especially those that intersect with other areas of physics such as low temperature plasma science, high energy density plasmas, and plasma based accelerators, are not strongly represented in the plasma physics program. As it now constituted, the AMOP program cannot maintain a viable plasma physics enterprise. Furthermore, while there have been historical connections between plasma and AMO physics, the present connections to AMO physics are tenuous. We thus recommend a clear separation of the plasma physics and AMO programs, and that the funding base for plasma physics be shored up.
- AMO Grant Size: The size of grants in real dollars continues to decline year after year, while at the same time, the overall funding rate has decreased to the lowest level (35%) in more than a decade. The average grant is now insufficient to support a mid-size table-top AMO experiment, requiring investigators to obtain funding from multiple sources to maintain even a low-level program. As this situation worsens, the impact of NSF support of AMO physics will diminish, endangering the basic-research effort which is the wellspring of discovery and innovation. We thus recommend that the current grant size establishes a floor, and that the Program Officer exercise greater flexibility in tailoring grant sizes to the cost and scope of the proposed effort. A continued decrease in program funding should result in fewer grants rather than smaller ones.
- Equipment: Support for instrumentation in the NSF AMOP program is woefully weak, with a de facto $80k limit placed on equipment expenditures in a typical three-year grant. Instrumentation needs in the $50k - $500k range are common for table-top experimental work which is the core of AMOP research; yet, with the MRI program receiving so few proposals (only 1-2 per University) and other

programs remaining unfunded, such table-top needs remain unmet, greatly restricting progress by US researchers in these fields. As a partial solution to this problem, we recommend the $80k limit on equipment be eliminated. Since universities do not charge overhead on funds spent on capital equipment, directing NSF support toward such equipment allows more resources to support the research project directly.

- PFC's: While the PFC's in AMO and Plasma Physics are exemplary, individual grants are the heart of the program. PFC funding should not exceed 10% of the Physics Division budget.
- Growth Opportunities: We recommend that the highest priorities should be increasing the funding level of individual grants, shoring up plasma physics, ensuring that the success rate for young researchers does not drop further, and the establishment of funds for equipment items in the $50-$500k range, perhaps via the Accelerator Physics and Instrumentation Physics Program. As presently structured (no money, no calls for proposals, no presence on the NSF website), the APPI is an ineffective response to this need and to prior COV recommendations. As stated above, the MRI program cannot cover these needs given the limited access to the program, particularly for researchers at large universities with many table-top experimentalists vying for support.
  Also, the CM/AMO interface is among the hottest developments in both fields. To secure adequate funding for basic research at this interface, coming from both disciplines, it may be a good time to establish a new targeted program (as was done with QIS, for example). While this work is "interdisciplinary," at least according to the divisions among programs at the NSF (between PHY and DMR), it is by no means exotic. Rather, it represents research that is central to both AMO and materials research, and which lies squarely within the domains of most Physics Departments.

General Recommendations:

- 4-Year Colleges: Reviewers are often asked to review and rank a group of proposals where some originate from 4-year colleges and others from research universities. We recommend that there be an explicit recognition that expectations are different for the two categories by asking reviewers to rank them separately.
- CAREER Awards: We believe strongly that the CAREER Award, since it is aimed at faculty at the beginning of the academic careers, should emphasize the development of their research programs and that emphasis on innovation in education and outreach in early career is misplaced. We note that this recommendation appears in previous COV reports. The Foundation's failure to address it is at odds with NSF's usual practice of working in tandem with the academic community.
- Grants.gov: While grants.gov is poorly received by the community, FastLane is viewed favorably.

- Longer Term Funding: We recommend a greater utilization of the 5-year grant period for renewing PI's. This would lower the grant-writing burden on successful researchers while giving them greater freedom to explore new scientific frontiers. To maintain sufficient oversight, the Program Officer could be entrusted to conduct a mid-period assessment, and to terminate grants where the progress is insufficient.
- Instrumentation development: While funding is available for the development of instrumentation with specific applied goals, a gap in the funding portfolio is support for the development of new cutting-edge technologies for the pursuit of basic research, e.g. several-year science/engineering collaborations to explore and develop new technologies. Such proposals will not fare well in a science-focused review process.

B. Program Results

Awards and Honors:

PECASE: Ben McCall (2005); Xiaoqin Li (2008).

National Medal of Science: Daniel Kleppner (2007)

Francis M. Pipkin Award (Precision Measurement): Ronald Walsworth (2005); David DeMille (2007)

Selected Highlights:

1. AIP Physics Story of the Year 2006. Electron g-factor Measurement

PI: Gerald Gabrielse, Harvard

This was the first improved measurement of the electron *g*-factor in nearly twenty years, improving the precision of the value by more than a factor of six. The Harvard team watched the motion of a single electron for months as it moved in a very precisely built cyclotron. Using their tiny cyclotron, Gabrielse and his students were able to make a measurement that was accurate to better than a part in a trillion! Using their measured value and a recent theoretical work calculating the electron *g*-factor in terms of a second independently measured constant called the fine-structure constant, the new measurement has yet again failed to find any problems with the theory of quantum electrodynamics.

2. Slowing and cooling atoms and molecules using coil-gun technology and Maxwell's Demon

PI: Mark Raizen, University of Texas

Even as research on ultracold atomic gases is expanding its scope and achieving great scientific progress, it remains limited to a small fraction of the elements, and essentially to no molecules. Addressing this limitation, Mark Raizen and colleagues at the University of Texas have pioneered two new scientific methods which give comprehensive control over the motion of an enormous range of new gaseous species. Adapting the military technology of a coil-gun to scientific use, they demonstrated that paramagnetic gases emitted from a high-pressure nozzle could be slowed to a standstill by climbing an orchestrated series of pulsed magnetic potentials. To cool such gases further, the researchers implement a "Maxwell's Demon" that siphons entropy by a form of informational cooling. These techniques have been adopted in an effort to cool and trap tritium in order to measure the neutrino mass.

3. Demonstration of sub-quantum-limited metrology in an atomic clock

PI: Vladan Vuletic, Massachusetts Institute of Technology

One of the immediate uses of quantum entanglement is the improvement of measurement precision beyond the standard limits imposed by quantum mechanics on unentangled systems. Recent work by Vuletic and colleagues at the Massachusetts Institute of Technology demonstrates a milestone in pursuit of quantum metrology, wherein quantum entanglement, in the form of spin-squeezing, is demonstrated conclusively in a setting immediately applicable to improved atomic clocks. This work combines elements and technologies of ultracold atomic physics and quantum optics to illuminate both fundamental limits and practical requirements relevant to many future metrological targets.

4. Faraday waves and nonlinear mechanical phenomena in a Bose-Einstein condensed gas

PI: Peter Engels, Washington State University

Faraday waves are an important example of pattern formation in driven systems and relevant to hydrodynamic systems, oscillatory chemical reactions, biological media, and nonlinear optics. Peter Engels, along with strong undergraduate students at Washington State University, has observed Faraday waves in tightly confined and strongly driven Bose-Einstein condensates. Close collaboration with theorists at NIST, Boulder and elsewhere provided a close comparison between observation and the output of analytic theories based on the one-dimensional non-linear Schrodinger equation. Additional explorations are utilizing quantum degenerate matter as a testing ground for nonlinear dynamics.

5. Magnetic Brain Imaging - Michael Romalis, Princeton

Romalis' group demonstrated the first detection and mapping of brain magnetic fields evoked by auditory stimulation with a new magnetometer that operates at room temperature. It has higher spatial resolution, simpler operation, and greater flexibility than superconducting sensors. The optical magnetometer is based on the measurement of electron spin precession in an optically-pumped vapor of potassium atoms.

6. Collapse of Optical Vortices

PI: Alex Gaeta, Cornell University

In their recent research, Gaeta's group investigated what happens to a light pulse when the initial beam consists of an "optical vortex." The experiments show that the vortex is unstable, which results in the beam's breaking up into a ring of filaments. They have also performed a theoretical analysis that is able to predict how many filaments should occur as a function of the laser power and of the twist of the vortex, and their experiments confirm this ability to control the formation of these filaments. There are a number of possible applications for light filaments. They have been shown to be effective in remote sensing of the atmosphere, where three-dimensional distributions of different gases and small particles need to be mapped. Filaments can also be used for laser micromachining and lightning control.

7. Laboratory Observation of Nonlinear Interaction between Shear Alfven Waves

PI: Troy Carter, UCLA (CAREER award)

Alfven waves are fundamental, low-frequency waves that propagate in a plasma embedded in a magnetic field. They are important in transferring energy and heating the solar corona, in the earth's ionosphere, and in laboratory plasmas confined by magnetic fields. Because they are a wave phenomenon, they undergo interference, although, because they are imbedded in a plasma, some of their wavelike behavior is not easy to observe. Recently, a large-amplitude three-wave interaction between Alfven waves was observed in the laboratory for the first time. This observation was made in the so-called Large Plasma Device (LAPD) at UCLA. When two large amplitude Alfven waves were simultaneously driven in the LAPD, the waves were observed to beat together and lead to a strong low-frequency wave. This low-frequency mode scatters the original Alfven waves, leading to a series of sidebands, as might happen with light waves interfering non-linearly.

2. EPP Program Subcommittee Report

Introduction

The Experimental Particle Physics (EPP) program supports experimental research in accelerator-based particle physics. In FY08, the most recent of the three years we reviewed, EPP had a budget of $56M to support the University grant program, CESR, LHC operations and accelerator and detector R&D for ILC and MICE. The EPP program is managed by one permanent federal employee and three full-time rotators. The EPP division works closely with the NSF Particle and Nuclear Astrophysics (PNA) staff (one federal employee and one rotator), providing additional support and institutional depth. EPP also coordinates closely with the DOE High Energy Physics (HEP) office on programs of mutual interest such as the Large Hadron Collider (LHC) and International Linear Collider (ILC) R&D.

Overall, we found the EPP program to be very well managed, supporting a portfolio of research that is aligned with the national priorities for high-energy physics. Grants are awarded in a competitive, fair peer-review process that emphasizes excellence in research, education and outreach. The Program Officers have deep knowledge of the field and the institutions they support, and they exercise careful stewardship in their decision making. We especially commend EPP for pro-active efforts to build cooperative relationships within NSF that broaden support for high energy physics through partnerships to support large-scale computing, innovative educational programs and interdisciplinary research.

A. Integrity and Efficiency of the EPP Program Processes and Management

A1. Quality and Effectiveness of Merit Review Process

The Physics Division has embraced the electronic submission and review system. FastLane , and the continuing expansion of this electronic systems facilitates the management and review process. We were given access to the electronic proposals, or E-Jackets, and spent several hours perusing the E-Jackets that were selected for us by the Program Officers to review. We also had a list of all funding decisions for FY08, and when we requested access to additional proposals from this list, they were quickly added. However, we did not have unencumbered access to all proposals from the past three years, a shortcoming that we hope can be addressed by the time of the next COV.

The review methods, which include panels, ad hoc mail-in reviews, site visits and reverse site visits, are very appropriate and effective. Proposals are handled uniformly, and treated individually with a lot of attention. Both merit review criteria are addressed in all individual reviews, with some variation from reviewer to reviewer. In the panel summaries and Program Officer review analyses they are always addressed very uniformly and in depth.

Individual reviewers provide substantive comments to explain their assessment of each proposal. Again, it varies somewhat from reviewer to reviewer, but because there are always several reviews, there was always sufficient analysis in the E-Jackets we reviewed. Panel summaries and the Review Analysis provide excellent summaries of the proposal, the reviews, the panel opinions and provide a cogent rationale for the consensus or decision made, including all input and considerations. The documentation in the E-jacket always provides the rationale for the award/decline decision. This is the case for awarded as well as declined cases.

The timescale to arrive at a decision of about 6 months seems appropriate, given all the things that need to be done, though surely from the proponents' viewpoint it takes too long. In general the review process is outstanding and it is hard to imagine how it could be improved.

A2. Selection of Reviewers

The EPP division has used 406 individual reviewers over the past three years to evaluate proposals. The pool of reviewers is well balanced and it includes well-respected scientists from diverse academic institutions and national laboratories across the US. Scientists from industry, Europe, and Canada have also contributed to the review process. The conflict of interest system appears to work. Most panels had documented and properly dealt with conflicts of interest, which were most common on larger proposals. The diversity of the reviewers appears to match the level of diversity that has been achieved in the field.

A3. Portfolio of Awards

The overall quality of the EPP program is very high. There is a good mix of university groups from across the country, serving a variety of communities and pursuing a healthy mixture of research of different types that reflects the national priorities in particle physics. Education and outreach is an important component, with a number of innovative programs in addition to support for the established REU and Quarknet programs. There are a few larger grants to universities that have large groups and significant infrastructure, and many smaller grants that support smaller research efforts in a geographically and programmatically diverse way. The average award per faculty is about $180-$200K/year, and about twice that for faculty at the three largest institutions (Chicago, Columbia and Cornell). Women and minorities are well represented among the recipients of EPP support, and it is especially notable that 50% of younger faculty (within 10 years of PhD) with grants from EPP are women.

The renewal rate for funded university groups is high, about 90%, but this is appropriate given the long time scales involved in the design, construction, data taking and data analysis cycle typical of large high energy physics experiments. The success rate for new proposals is about 20%, and CAREER grants are especially competitive, with success rates of 10-20% depending on the funding available each year. The funding requested is almost double the available funds in any given year.

One possible area of concern is that the PI at Hampton University, a historically black university (HBU), has moved to Yale University. The program at Hampton has been notable for the fact that it involved minority students enrolled at Hampton and other HBUs in hands-on research, including fabrication of detector components for the LHC. While we applaud the success of this PI in obtaining a faculty position at Yale, we are concerned that it will be difficult to find a replacement who will keep this flourishing program at Hampton going and continue to attract under-represented minorities into particle physics.

A4. Management of the EPP Program

EPP continues to benefit from rotators for planning, coordinating, and managing its scientific program. EPP has been able to recruit well-connected, established members of the particle physics community who are both knowledgeable and committed to the programs in which EPP invests. The committee is pleased to note that one permanent staff member has been added to the division for the PNA program. This individual works closely with EPP and has expertise from prior roles as an EPP rotator. We believe that this addition will help preserve institutional memory and continuity.

The Division continues to make progress in reducing the proposal dwell time, which is defined as the time between proposal receipt and NSF action. For the three years under review, the Physics Division completed 61% of proposals processed within six months in FY 2006, 71% in FY 2007, and 76% in FY 2008.

The EPP division has been especially successful in their collaboration and partnership with other programs such as CISE, OISE, and EHR. The partnership between NSF EPP, NSF NPA and DOE will be critical to the support of DUSEL. Collaboration between NSF directorates and offices has also been critical for the CHEPREO project, centered at Florida International University in Miami, which has been especially successful in reaching the Latino community.

We commend the division for their quick response to 2006 COV comments. For example the EPP has announced the MRI solicitations through the DPF mailing lists to communicate this opportunity more widely to the community. We hope that this action will increase the percentage of MRI funding for EPP.

EPP and the Physics Division have also strengthened the management and oversight of large projects in response to the shortcomings that became evident with the cancellation of the RSVP project in 2005. Several members of the EPP team and the Physics Division now have expertise in management of large projects.

One of the biggest management challenges in the EPP program in the past three years has been handling the transition at Cornell, where the CESR accelerator ceased operations for particle physics collisions in March 2008. The future of this facility and its staff is an important issue for EPP and for the field. The Laboratory for Elementary Particle Physics (LEPP) at Cornell operated the CESR accelerator very successfully for a long running period stretching over decades, with an annual budget of about $20M.

EPP convened a special panel, the "Witherell Panel", in April 2006 to evaluate the current and future LEPP program. The panel endorsed the plans of the Cornell particle physics group to join the CMS experiment at LHC, and the plans of the accelerator physics group to construct an accelerator test facility, CESR-TA, to carry out R&D on damping rings for the ILC and to maintain their strong SCRF cavity program. At the time of this COV review, LEPP was in its last year of funding under the CESR Cooperative funding agreement, and the CMS research at Cornell was being supported through PI-led grants funded through competitive peer-reviewed proposals submitted to the University program. The CESR-TA program is in the second of three years of accelerator R&D funding from EPP. This grant was awarded in response to a proposal that received high marks from an international group of five experts in accelerator physics experts. CESR-TA funding is supplemented by additional contributions from DOE.

As reviewers, we found the situation at Cornell to be difficult to understand, and it took some effort to piece together the funding situation and grapple with the complex issues that EPP is dealing with. The table below represents our best understanding of the funding for the Cornell/CESR program.

	Historic	**FY06**	**FY07**	**FY08**	**FY09**	**FY10**
CESR	$20M	$14.6M	14.7M	$10.7M	$5.5M	0
Cornell PI			0.6M	$1.9M	1.9M?	?
CESR TA (NSF)				$5.3M	$5.1M	$5.2M
CESR TA (DOE)				$1.0M	$2.0M	$2.2M
Total	$20M	$14.6M	$15.3M	$18.9M	$14.5M?	

We commend EPP for the management of this difficult transition to date. The use of competitive, peer-reviewed proposals to establish the funding level for Cornell participation in CMS appeared to us to be handled in an appropriate and fair way. As the CESR Cooperative agreement funding comes to an end, the CESR-TA funding maintains valuable expertise in accelerator physics at Cornell, while supporting important accelerator R&D for the ILC. However, the uncertainty currently clouding the future of the ILC complicates the situation for the future of the CESR-TA program. LEPP is also pursuing funding from another NSF Division for an energy recovery linac (ERL) as a future large facility; if successful, this will assure a productive future for accelerator physics at Cornell.

B. Results of NSF Investments

B1. OUTCOME GOAL for Discovery

The EPP program has supported significant scientific achievements during the past three years. Here are a few highlights from this rich discovery program:

> Measurement of the single top production with D0. This is one of the rarest processes that has been unveiled at the Tevatron. The measurement yields the first direct constraints on the electroweak parameter V_{tb}. The observation of single top quark production validates new analysis techniques that provide scientists with improved tools to search for the Higgs boson. (Shaevitz et al., PHY-0758118, Brock et al., PHY-0757741)
>
> Significant improvement on the measurement of the top mass in the single-lepton channel. This result, which is the best single measurement of the top mass, reduces the principle systematic uncertainty due to the jet energy scale by simultaneously fitting bottom quark and *W* boson masses. Based on the world's best measurements of the top quark mass and the W boson mass, a more stringent upper limit for the mass of the Higgs boson can be derived. (Oreglia et al., PHY-0757196)

B2. OUTCOME GOAL for Learning

EPP makes a dedicated effort to foster diversity in the physical sciences. The CAREER grants provide resources and opportunities for early career faculty. Women have been extremely successful in competing for CAREER awards and currently 50% of the EPP career awardees are women.

Most EPP proposals develop well thought-out plans to increase the participation of minorities in science. Here are a few examples:

- A primary emphasis of the Columbia programs is to target underrepresented groups and increasing minority representation. The activities range from individual faculty outreach efforts (lectures, tours, etc) to structured programs like the Research Experience for Undergraduates, Quarknet, and Fermilab Public Affairs Internship Program. Building on their previous South Africa program, they are leading a program for outreach in grid-computing supported by the Open Science Grid. Columbia has also developed "The Manhattanville School of Science", a collaborative effort with the City of New York, which provides an excellent opportunity to recruit minority high school students in the physical sciences. (Shaevitz et al., PHY-0758118)
- The Chicago group is strongly committed to outreach and participates in the Chicago Public Schools and the Illinois Math and Science Academy. (Oreglia et al., PHY-0757196)
- The Cornell group brings real science and the experience of world-class research to K-12 students and teachers in the south central New York state region, which is economically deprived and where many local school districts operate with marginal resources.
- QuarkNet provides valuable research experience to teachers enabling them to teach the basic concepts of introductory physics in a context that students find exciting. Important instructional initiatives have emerged from QuarkNet such as the Cosmic Ray e-Lab, which allows the exchange of data collected by different high school.

- The PIRE program brings undergraduate and graduate students from several mid-West universities, as well as one minority-serving university in Puerto Rico, to Switzerland to work on cutting edge LHC detector R&D at PSI and ETH in Zurich. This program makes direct connections between US students and foreign collaborators. (Bean et al. (PIRE), 0730173)

B3. OUTCOME GOAL for Research Infrastructure

The EPP program has supported significant research infrastructure during the past three years. Here a few highlights:

- LHC
  - Completion , maintenance, and operation of the CMS experiments (Cousins, UCLA, PHYS-0612805)
- Grid computing
  - Sustaining and extending Open Science Grid (OSG), an integral part of LHC grid. Also support LIGO, STAR at RHIC, Tevatron, Sloan,etc.. PHY-0621704, M. Livny, Univ. of Wisconsin, Madison. Reviewer quote: "Without OSG it will be difficult or impossible for the USA to optimally exploit the LHC competitively"

C. Other topics

- Funding for medium-sized projects:

The “funding desert” that exists between the level of MRI awards (<$2M) and MREFC awards (>$100M) was noted by the previous COV, and it remains a problem. The Accelerator Physics and Physics Instrumentation (APPI) program was intended to address the need for funding for small experiments and/or large R&D programs, but due to funding constraints it was not continued. We urge the Physics Division to make a healthy APPI program (~$10M/year) a top priority, if NSF budgets see the increase in funding that we hope the new administration will support.

- Suggestions for the next COV:

We were provided with a written overview of the EPP program, and the Program Officers met with us to go through the details. However, we felt that a 30 minute formal presentation of the EPP program, budget, funding trends and programmatic directions would have been helpful, and provided a better opportunity for interaction between the reviewers and Program Officers. Most of this information is probably available in the three annual reports from EPP, but these are rather lengthy and do not provide a concise view of the most important issues and trends. Some of the budget information we were provided with was confusing and it took some time to sort out the details.

We hope that the electronic proposal system will allow access to all E-Jackets by the time the next COV is convened in three years. While it was helpful that the Program Officers had pre-selected a representative cross section of proposals for us to review, we felt that due diligence would be better served by allowing us to freely access all proposals.

3. Gravitational Physics Subcommittee Report

Gravitational physics in the last six years has reached major milestones: LIGO attained and surpassed design sensitivity and gathered one year's worth of data at that sensitivity; and construction of Advanced LIGO has begun. The holy grail of numerical relativity, an effort spanning more than three decades, was dramatically attained: Codes can follow the inspiral of a binary system of two black holes from inspiral through merger, with striking implications for LIGO and for the kick-velocities of merging black holes. These developments and their future implications have led to an explosive growth in the number of young scientists in the field: Forty of the approximately 100 current PIs and CoPIs received their first NSF award since 2002.

These advances in gravitational wave detection and in numerical relativity are only the most striking advances in a diverse field that encompasses observation, experiment and theory. The last three years have seen significant progress in precision observational cosmology and precise measurements of gravity at a submillimeter scale; in relativistic astrophysics and neutron- star physics; in the recent work that joins numerical relativity and gravitational-wave data analysis; in grid computing; in cooling without cryogenics to micro-Kelvin temperatures that allow a near ground state of a 4-km cavity; and in approaches to quantum cosmology and quantum geometry near black holes.

The great excitement driving much of the work in gravitational physics is the anticipated dawn, within the next several years, of gravitational wave astronomy. Enhanced LIGO will start taking data this year and continue through 2011, surveying a volume of the Universe roughly 10 times larger than that of initial LIGO. Advanced LIGO's construction is scheduled to be completed in 2015, and it will have a survey volume roughly 1000 times that of initial LIGO. According to the best current estimates by astrophysicists, this sensitivity will yield several events per year for even the most pessimistic scenarios. These include the most energetic events of the present universe, the coalescence of black-hole binaries, which may be invisible to electromagnetic detectors. More frequent events (but not necessarily to be more frequently observed) are the coalescence of neutron-star binaries and neutron-star black-hole binaries. These are the leading candidate sources of detected short-hard gamma-ray bursts. The breakthroughs in numerical relativity open the way for future advances in relativistic astrophysics, in realistic modeling of coalescence of double neutron stars and and black-hole- neutron-star systems that incorporates microphysics and magnetic fields.

The striking increase in the number of young investigators has meant a similarly striking in- crease in the number of universities involved in gravitational physics. Graduate and advanced undergraduate programs increasingly include courses in general relativity, spurred both by the field's excitement and by superb new textbooks. As noted by the previous COV report, undergraduates and high-school students are drawn to outreach programs in this field by the clear prospects for fundamental discoveries.

The broad sweep of gravitational physics, from abstract theory to large scale experiment, is supported almost entirely by the NSF. In particular, despite flat NSF funding for gravitational physics, the postponement of the ESA/NASA space-based gravitational-wave observatory LISA means that NSF's funds now represent a larger fraction of total US support in this field. The diversity in the type and scale of NSF-supported activities in gravitational physics presents a challenge to the NSF, and requires careful stewardship to maintain a broad and vital program.

In response to these developments the committee makes the following points:

- The program directors and staff have done an excellent job in managing this diverse and growing field, even in times of severe budget constraints. Doing so required making many difficult decisions; we reviewed many examples of these nontrivial choices and agree with all of them. The program provides strong stewardship to the gravitational physics program.
- Gravitational wave astronomy is already a reality, even before the first detections. For example, data from LIGO's S5 science run yielded an upper bound on the ellipticity of the Crab pulsar which is more stringent than previous upper limits based on radio observations. Also LIGO was able to firmly refute the speculation by astronomers that the gamma ray burst GRB070201 was caused by an inspiral of two neutron stars in the Andromeda galaxy. With increasing interest of the astronomical community in gravitational wave physics, and assuming that LIGO will detect gravitational radiation well within the next decade, we anticipate that the field will continue to grow rapidly.
- The 2005 breakthrough in numerical relativity, allowing for the dynamical simulation of black hole mergers, has transformed the field. Simulations of binary black hole mergers are "routine" by now, and have opened the door for many applications. Numerical relativity predictions for gravitational waveforms are now being used in LIGO data analysis efforts. Important astrophysical results include black hole recoil in binary black hole mergers and its consequences for supermassive black holes at the centers of galaxies. The techniques developed for binary black hole merger simulations are also being applied to other astrophysical objects, for example mixed black hole-neutron star binaries, addressing a broad range of important astrophysical problems, including the origin of gamma-ray bursts. We anticipate that these developments will result in a further increase in the field.
- The substantial need for computational infrastructure for numerical relativity has been and must continue to be met primarily by resources outside the gravitational physics program.
- The field has undergone very rapid growth in the past years, resulting in a number of new faculty hires. This trend has been reflected in the NSF support: of the approximately 100 PIs currently supported by the gravitational physics program, 40 have been added since 2002. Given that the overall budget of the program remained approximately flat over this period, adding this support has put a significant strain on the program. In particular, it has meant a significant loss of funding for very strong proposals in both theory and experiment. Despite what the committee regards as judicious choices, the program has not been able

simultaneously to support its strongest young investigators and to respond to the the growing need and demand for funding graduate graduate and postdocs in highly ranked proposals. Looking towards the future, we are concerned that the current funding level is insufficient to support the anticipated growth in both gravitational wave physics and numerical relativity.

- Research identified by the LIGO lab as being "critical path" for LIGO takes high priority for funding. While we agree with this priority, it exacerbates the overall squeeze on the program discussed above, and in particular a large number of very deserving and highly-rated theory proposals have gone unfunded. For example, in 2008 only 7 out of 17 theory proposals ranked as "fund" were funded, and some of these at severely reduced levels and through EPSCoR funding (a special NSF program that promotes geographical diversity). This issue was also highlighted in the previous COV report. We emphasize that the issue is primarily the amount of resources available to the program; we feel that the available resources have been used judiciously. Nevertheless we recommend that in the future careful attention be paid to maintaining a broad and vital non-LIGO theory program.
- In response to a suggestion in the previous COV report, we considered the possibility of an external advisory mechanism for gravitational physics to aid the program officers in setting priorities in a time of dramatic evolution. Our view is that there is no immediate pressing need for such a mechanism, since a forthcoming roadmap from the Gravitational Wave International Committee (GWIC) will set priorities related to large gravitational wave detector projects. Beyond that, it may be useful sometime in the future to establish an ongoing mechanism whereby the APS Topical Group on Gravitation can provide input from the community to the NSF program.

Integrity and efficiency of the program's processes and management

Quality and Effectiveness of merit review process:

Are the review methods (for example, panel, ad hoc, site visits) appropriate?

Proposals to the gravitational physics program are reviewed in four separate categories (LIGO operations, LIGO research support, gravitational theory, and gravitational experiment), which seems appropriate. We find that the current practice of combining ad hoc mail reviews with panels works very well, as the two methods complement one another.

Are both merit review criteria addressed?

Ad hoc reviews focused mainly on the criterion of intellectual merit, which is not surprising in a fundamental field like gravitation. Panel summaries and program officer review analyses did address both intellectual merit and broader impact.

Do the panel summaries provide the rationale for the panel consensus (or reasons consensus was not reached)?

Panel summaries normally provided a good summary of the panel discussion, but occasionally the program officer's documentation was more informative and provided more background and context.

Does the documentation in the jacket provide the rationale for the award/decline decision?

The rationale was always very clearly explained in the program officers comments. We were impressed by the diligence, attention to detail, and wise judgment of the program officer.

Does the documentation to PI provide the rationale for the award/decline decision?

When proposals were not funded, the documentation provided to the PI (the panel summaries and reviews) did always contain some negative comments that contributed to the no-fund decision. However often the program officers documentation provided more substantive and germane reasons and context. We encourage program officers to share this more detailed information with proposers that have been turned down to the extent possible consistent with confidentiality requirements.

Additional comments on the quality and effectiveness of the program's use of merit review process:

The gravity program (excluding LIGO operations) supports a broad range of subjects including relativistic astrophysics, quantum gravity, issues in mathematical relativity, numerical relativity, laboratory tests of gravity, and also research in support of LIGO (eg data analysis). LIGO related proposals are reviewed by the LIGO laboratory. We were pleased to see that these reviews did not hesitate to make negative comments for the weaker proposals, which in some cases resulted in proposals being denied. We were also pleased that only the strong and vitally necessary LIGO-related proposals were rated by the LIGO lab as "critical path".

Selection of Reviewers:

Did the program make use of reviewers having appropriate expertise and/or qualifications?

The subcommittee felt that the selection of reviewers was as optimal as possible given the constraints inherent in the system, such as conflicts of interest within a small research community.

Did the program recognize and resolve conflicts of interest when appropriate?

The program appears to be very conscientious in this regard.

Resulting Portfolio of Awards:

Overall quality of the research and/or education projects supported by the program.

The subcommittee felt that the quality of supported research was uniformly excellent. Rather than being concerned about quality of funded research, we are concerned about the amount of excellent or potentially excellent research that could not be funded.

Does the program portfolio promote the integration of research and education?

Supported research groups generally involve undergraduates in the research and also frequently train graduate students and postdocs. Many supported PIs participate in a broad spectrum of outreach programs. We also note that due to recent research breakthroughs, gravitational physics has become more visible and prominent in the general public. There is now a welcome trend for including courses on general relativity in the undergraduate curriculum. This trend has been aided by the appearance of some new excellent textbooks such as that by James Hartle, who is supported by the NSF.

Are awards appropriate in size and duration for the scope of the projects?

Generally the award size and duration are appropriately chosen, given the budget constraints. We also note that the question seems to presuppose that the duration of the award is essentially equivalent to the duration of the project. However, for theory research, awards normally support ongoing diverse research programs rather than well defined, individual projects. The duration of individual projects can be longer or shorter than the duration of the award.

Does the program portfolio have an appropriate balance of innovative/potentially transformative projects?

Most of the resources in the gravity program are devoted to making gravitational wave astronomy a reality. The detection of gravitational waves would be a truly transformative event. The subcommittee enthusiastically supports the high priority given to LIGO in the program.

Does the program portfolio have an appropriate balance of inter- and multi-disciplinary projects?

Research in the gravity program has overlaps with astrophysics, mathematics, high performance computing and theoretical particle physics. Many proposals are co-funded by other NSF programs or other funding agencies.

Does the program portfolio has an appropriate balance of awards to new investigators?

The gravity program has supported a large number of new investigators over the last few years, and the program gives a high priority to funding new investigators. The panel felt that this was appropriate.

Does the program portfolio have an appropriate balance across disciplines and sub-disciplines of the activity?

An obvious potential concern is that LIGO-related research might be crowding out funds for other gravitational research, especially theory. While we are reassured that these effects are not large, the high priority given to LIGO "critical path" research, together with severe budget constraints in 2008, adversely affected the acceptance rate of other highly ranked proposals. We agree with the priorities adopted by the program, but recommend that this issue be monitored carefully in the future.

Management of the program under review:

Responsiveness of the program to emerging research and education opportunities.

Given the breakthroughs and recent growth in numerical relativity, the gravitational physics program has responded to the extent possible by increasing funding for this field from approximately \$1.2M /yr in 2005 to \$1.5M /yr in 2008. However the overall budget of the gravity program has not increased. The previous COV report quoted a joint NASA-NSF task force that recommended “increasing the funding level for this area from about \$1M per year to about \$5M (for all areas of source modeling, with the bulk being for numerical relativity)”. Since then Advanced LIGO has been approved, with the total construction cost of over \$200M and operating costs of \$30 to \$40M per year (although LISA has been delayed). Compared to this scale of investment, in the words of the previous COV, “the concomitant spending on theoretical support is woeful”.

Program planning and prioritization process (internal and external) that guided the development of the portfolio.

Of the approximately 100 PIs and Co-PIs currently funded by Gravitational Physics, about 40 have received their first NSF funding since 2002. We agree with the high priority given by the program to supporting new researchers, as it is important for the future of the field. However, we also note that this has been achieved in part by a reduction in the average award size, so that a smaller fraction of current awards support graduate students or postdocs.

Outputs and Outcomes of Program Investments

Broader Impacts and Outreach:

The gravity program interacts in multiple ways with cyberscience and infrastructure: LIGO is an early participant in the development and use of grid computing, through the recent LIGO Data Grid award and LIGO participation in the Open Science Grid. The LIGO Data Grid provides more than 300 scientists access to hundreds of terabytes of LIGO data, petabytes of storage, and over 10,000 processing cores distributed across more than eight LIGO computing centers throughout the world. Spare cycles from LIGO Data Grid sites are made available to Open Science Grid users, and contributions from LIGO to the Open Science Grid have supported analyses from a diverse set of communities including high energy physics, bioinformatics, and nanotechnology.

High-power, low noise optical sources and active optical control elements have been designed specifically for LIGO, and related technical breakthroughs have been transferred to industry. In particular, LIGO’s accurate laser optics led to the development of a high-power Faraday isolator. Unique in its ability to handle high-intensity beams, the isolator has been patented and licensed to commercial firms.

Einstein@home is a massive computing network that allows anyone with access to the web to join in searching LIGO data for gravitational waves from undiscovered asymmetric, spinning neutron stars. It began as one of the major components of the US participation in the World Year of Physics. Einstein@home has proven invaluable in capturing the public imagination, in vastly expanding the computing power available for the LIGO search, and in improving the effectiveness of the @home collaborative software infrastructure for other projects. Over 200,000 volunteers in more than 22 countries have participated in the program. Among this enormous set of volunteers are many with technical expertise, and software primarily designed by one of these participants has significantly increased the speed of Einstein@home, from about 60 teraflops to over 140 teraflops. In the past year, the program has expanded its reach to mine data from the Arecibo radio telescope for undiscovered radio pulsars.

The worldwide scope of LIGO and its partners offers an opportunity for young scientists to gain international experience. Starting with a pilot program supporting two or three students per year, the LIGO group at the University of Florida has completed one year of hosting the first international LIGO Research Experience for Undergraduates (REU) Site. This unique REU Site collects the students initially at the Florida campus for orientation and then distributes them around the world to partners in the UK, Germany, Australia, Japan, and Italy.

The LIGO Livingston lab maintains a major outreach program, the LIGO Science Education Center, housed in a new, award-winning building at the observatory. The Science Education Center is a partnership among LIGO, the Exploratorium, Southern University Baton Rouge, and the Louisiana Board of Education to improve mathematics and physical science teaching and learning by tying them to hands-on experience with Exploratorium-furnished exhibits related to LIGO's science and technology. Southern University Baton Rouge, part of the nation's Historically Black College and Universities system, has restructured its training of pre-service and in-service teachers to focus on LIGO-related and LIGO-inspired science.

LIGO's Hanford site has inaugurated partnerships with local school districts, local colleges, including the Hispanic-serving Columbia Basin College, and a local amateur astronomy club to provide opportunities for students, their families, and their teachers to experience the excitement of LIGO science. More than 4,000 visitors per year come to the Hanford site. Serving roughly 900 students, and attracting thousands of visitors each year, the Hanford outreach programs received state and local awards in 2007.

The NSF has commissioned a 20-minute LIGO documentary called "Einstein's Messengers". This was professionally produced by LUCAS Productions, and has been provided to journalists, shown to LIGO Observatory tour groups, made available on DVD for teachers, and posted for viewing on the NSF and LIGO web sites. It received a Golden Eagle award from CINE.

Gravitational physics continues to attract young, talented, and highly-trained experimental and theoretical physicists, and it provides a superb training ground for graduate and postdoctoral students. This training is often uniquely interdisciplinary, involving physics, mathematics, astronomy, engineering, and computer science, and it prepares students for a wide variety of careers. Graduate students and postdoctoral students, and in some cases undergraduates, have played integral roles in NSF-funded research in gravity, developing their expertise and gaining hands-on experience while at the same time making valuable contributions to science. With the new expansion of faculty positions, including some in undergraduate institutions, this student involvement should grow. Historically, many of these students have used their skills to move on into jobs in high tech industries, and corporations, enhancing our nation's competitiveness.

IDEAS:

Research in gravitational physics encompasses a broad range of activities from quantum gravity to relativistic astrophysics to gravitational wave experiments. Recent exciting developments in the field include the following:

- The LIGO laboratory and collaboration achieved a significant milestone by accumulating one year of data at design sensitivity, and analyzing that data to search for a variety of sources. Enhanced LIGO will start taking data this year and continue through 2011, surveying a volume of the Universe roughly 10 times larger than that of initial LIGO. Advanced LIGO's construction is scheduled to be completed in 2015, and it will have a survey volume roughly 1000 times that of initial LIGO.
- We have already witnessed a first glimpse of the era of gravitational wave astronomy, through interesting astrophysical constraints that have come from LIGO data. In February 2007, a gamma ray burst, likely caused by the inspiral and merger of two neutron stars, appeared to come from a region of the sky that overlapped the nearby Andromeda galaxy. Astronomers naturally wondered was the burst caused by a binary neutron star (or neutron star - black hole) coalescence in Andromeda? For the first time, there is a completely new way to answer this question. LIGO data showed that no signal was present, so either the burst was not in Andromeda or it was caused by a different mechanism. In a similar vein, for many years the best available upper limit on the ellipticity of the Crab pulsar has come from radio observations. Recently, data from LIGO's fifth science run has superseded those observations and now sets the strongest constraint.
- The past few years have seen major breakthroughs in numerical relativity. For the first time, it has became possible to evolve black hole binaries in 3D for several orbits. The key to the advance was the nearly simultaneous discovery by several groups that it was essential to allow the black holes to move through the computational grid during the evolution. This breakthrough means that codes can now run long enough to be understood and optimized bringing the physics of this important system within reach. Numerical relativity has now taken its place as an

important tool for astrophysics. A surprising prediction was that the final black hole can receive a kick of up to several thousand kilometers per second due to linear momentum carried off by the gravitational waves, which has interesting astrophysical implications. Another discovery is that simulations of neutron star - black hole mergers show in some cases the formation of massive disk, which supports the idea that these mergers could be a source of gamma ray bursts. Simulation of high speed collisions of black holes have provided new evidence in favor of cosmic censorship, the outstanding open question in classical general relativity. Finally, highly accurate simulations have been used to confirm and fine-tune the analytic post-Newtonian approximation method.

- Theorists have been very creative in developing scenarios for physics beyond the Standard Model of particle physics including string theory, extra dimensions, and brane-worlds. Many of these ideas predict deviations from the inverse square law force of gravity formulated by Newton at distances smaller than one millimeter due to new, but tiny, additional forces. Experimental searches to probe ever smaller distance scales for ever tinier new forces have gone on for many years. These searches have included the development of novel precision instruments and techniques such as elaborate torsion balances and gravity gradiometers that have had broader application. Recently, two instruments have been developed to probe deviations from Newtonian gravity at distances of 100 micrometers and smaller. The first, developed by Professor Jens Gundlach of the University of Washington and his group uses a planar pendulum at its core, and is searching for new physics at ranges around 75 microns. The second, made by a group led by Professor Aharon Kapitulnik at Stanford University, aims to probe distances of order 5 microns by miniaturizing the apparatus and using cryogenics.
- In the past few years, evidence has accumulated that quantum gravity effects can resolve the unwanted singularities of general relativity, and in particular the singularity at the start of the big bang. In a simplification of loop quantum gravity called loop quantum cosmology, it has been shown that a collapsing universe will "bounce", i.e. reach maximum (but not infinite) density and then re-expand. Loop quantum gravity replaces the space-time continuum with a discrete structure. Recently, correct incorporation of this discreteness into loop quantum cosmology yielded bouncing universes whenever the density reached the Planck scale.
- LIGO Researchers have employed laser light to cool a macroscopic object — a 1-gram mirror — from room temperature to less than one degree above absolute zero. The experiment, reported in the scientific journal Physical Review Letters, uses techniques called optical trapping and optical damping to cool the mirror to a record-breaking 0.8 Kelvin (0.8C above absolute zero), and subsequent experiments have attained much lower temperatures. The group, led by Nergis Mavalvala of MIT and comprising researchers from MIT, Caltech, LIGO, and the Albert Einstein Institute in Potsdam and Hannover, Germany, hopes to refine the experimental system to attain microKelvin temperatures, where macroscopic quantum effects might be observable.

TOOLS:

The primary tool of the gravitational wave community is LIGO. Research and development for LIGO has led to a number of spin-off technologies, including high-power ultra-stable lasers, large optical elements with sub-Angstrom smoothness, advanced techniques for vibration isolation, software for data analysis, and high power Faraday isolators, the last of which has been commercialized.

Other gravitational experiments test the inverse-square law at millimeter to micron distance scales. Some of the devices built to measure the attonewton scale forces benefit from advances such as scanning tunneling microscopes in condensed-matter and materials physics, and may in turn cross fertilize these fields.

Work in numerical relativity has driven the development of some computational infrastructures (e.g. CACTUS and CARPET) for high-performance supercomputer applications, some of which are now being used in other fields of computational physics as well. Recent codes use advanced techniques and algorithms (e.g. adaptive mesh refinement and high-resolution shock-capturing techniques) that allow for highly accurate simulations.

The subcommittee discussed the possibility of support for the continuing development and maintenance of a "community code infrastructure" for the numerical relativity community (several groups already use the CACTUS code infrastructure.) Given the increasing complexity of numerical relativity codes, it may be desirable to further encourage the development and usage of a common code infrastructure, in the interest of efficiency and avoiding duplication of effort. This issue has previously been discussed within the numerical relativity community. While these discussions have not yet led to a community-wide effort, we suggest revisiting this question in the next few years.

On a related subject, the subcommittee also discussed the possibility of making working numerical relativity codes publicly available, as is often done, for example, by cosmologists and supernova theorists. While this would certainly be a desirable goal, it will require incentives to convince individual groups to put effort into making their codes available and usable, potentially on a number of different computational platforms. One possibility would be to dedicate partial postdoc support to this purpose.

Other Topics

Suggestions for future COVs:

Our committee had a concern that the COV does not contain sufficient members who have recently experienced having highly-rated proposals turned down by the NSF, and that there may therefore be a bias in the COV's assessment of how well the process is working. We suggest including in future COVs people who are not currently funded as a result of having highly-rated proposals declined.

4. Nuclear Physics Subcommittee Report

1. Introduction

The Nuclear Physics (NP) program at the NSF supports an extremely strong suite of research and educational activities focused primarily on the study of the strong interaction, with the goal of understanding strongly interacting matter and its roles in the universe. Given that this program supports foundational work in this area, there is considerable overlap with the Theory, Particle and Nuclear Astrophysics, and Experimental Particle Physics programs. Funding for nuclear physics research in the United States is primarily from the NSF and the Department of Energy Office of Science. Both agencies use advice from the U.S. Nuclear Science Advisory Committee (NSAC) on the broad scientific goals of the field as well as on establishing the priorities. This has allowed both agencies to work in a well coordinated manner.

The program is the steward of one of NSF major research facilities, namely, the Michigan State University National Superconducting Cyclotron Laboratory's (NSCL) Coupled Cyclotron Facility. The NSCL is a world class center for research using radioactive ion beams to probe the nature and interactions of atomic nuclei. Recently, MSU/NSCL was selected to be the site of the future Facility for Rare Ion Beams – the nation's powerful future accelerator for studying the limits of stability.

The NSF NP program supports very significant research in all the major research opportunities identified by NSAC. It covers a broad range in scale: one major facility, two university accelerators, group grants, and grants to a number of individual investigators. This diversity in size is appropriate to the span of research initiatives in nuclear physics, where experiments can range in size from a few to five hundred collaborators. The NP program office does an excellent job in dealing with the different research scales in a fair and effective way. For the health of this enterprise, we strongly endorse the NSF commitment to maintain individual investigator grants awards at greater than 50% of the program.

2. Integrity and efficacy of the processes used to solicit, review, recommend, and document proposal actions

A subpanel of the COV investigated in detail the operation of the NP program. The COV subpanel was very impressed by the quality of the review process for proposals submitted during the 2006 to 2008 time period under review. The review always included at least two *ad hoc* reviewers (usually at least three), a panel review and the review analysis conducted by the program director (PD). When appropriate (normally for larger grants), the review included additional *ad hoc* reviewers and site visits. Each level of the review addressed both of the merit review criteria in a substantive way. The COV noted that the reviews have encompassed a wider definition of "broader impacts" over the three-year time period, which probably reflects a growing awareness in the community of the intention of this review criterion. We view this as a positive sign and encourage NSF to continue efforts to help reviewers understand the meaning of broader impacts.

The vast majority of the individual *ad hoc* reviews were substantive and thorough. The panels considered the individual reviews but often added additional insight regarding the two review criteria. The COV found that the analysis review by the PD was extremely helpful in understanding the final funding decision. In general, the review analysis added additional information about the history of the group, the science, or the proposal and was able to put the funding decision in context. The COV studied several jackets that were borderline in terms of whether the proposals would be funded or not funded. In every case the COV concluded that the PDs showed excellent judgment in the funding decision.

Although the analysis review does not go back to the PI, the COV found that the PD routinely conveys additional information regarding the funding decision, if any, to the PI, either by phone or by email. This feedback is very valuable to the PI. The COV commends the PDs on the timeliness of the review process, which averages about 6 months to concurrence by the Division Director. In 2008 the time was roughly 5.6 months. The COV found that the total number of proposals fell from roughly 50 in 2006 and 2007 to 30 in 2008.

In order to judge the qualifications of the reviewers the COV read approximately 80 *ad hoc* reviews and examined the spreadsheet provided by the NP Office, listing the 374 reviewers consulted over the past three years. The COV conclusion is that the office has made use of an excellent pool of reviewers. In particular, the NP Program Office should be commended for their selection of reviewers with appropriate expertise. In only one of the approximately 80 reviews in the e-jackets was there any indication that the selection was inappropriate. Overall the balance of reviewer qualifications in terms of type and length of employment appears excellent. The diversity of the reviewers is good with approximately 15% female. This percentage reflects the percentage in the pool of qualified personal. The program officer described their efforts to maintain a database of reviewers from under-represented groups, and their use of it to ensure fair representation is achieved. The COV commends the office for these efforts.

3. The quality and significance of the results of the Division's programmatic investments

The COV found that the quality of the results from the NP program was excellent and that the significance was high. This is illustrated by selecting a small number of highlights from the many the program has generated:

3.1 Probing the limits of stability at NSCL

Experiments on more neutron-rich isotopes provide new insight into the strong interaction, which ultimately dictates the limit to how many neutrons a certain number of protons can bind. This limit, called the neutron drip line, is essentially unknown yet is one of the key benchmarks for nuclear models. It is the complement of efforts to determine the maximum number of protons a nucleus can hold, and the search for the heaviest elements in nature. Recent attempts at the National Superconducting Cyclotron Laboratory (NSCL) to produce the most neutron-rich isotopes of Al and Mg indicate that the drip line for these elements is further from natural Al and Mg than previously thought. This indicates that neutron-rich matter is more bound than expected, which has implications for the understanding neutron stars and the origin and evolution of elements over time.

3.2 The spin structure of the proton

Protons and neutrons—the nucleons at the heart of every atom—are complex, dynamic objects composed of quarks and gluons that are bound tightly together by the strong force. One property of intense interest is the intrinsic angular momentum—the "spin"—of the nucleon: it is precisely 1/2 (in units of $h/2\pi$), and is used daily in the medical diagnostic technique of magnetic resonance imaging. If we are to claim any understanding of QCD, we must be able to identify how this value arises from the nucleon's internal structure. Experiments to understand nucleon spin are a major priority at both Jefferson Lab and Brookhaven National Lab. We know from previous experiments that the quark spins account for only about 25% of the proton's spin. Recently, much anticipated measurements at the Relativistic Heavy Ion Collider using polarized proton beams and detectors built by NSF funding have constrained the contribution from the spin of the gluons, leaving the sharing of the nucleon spin still as an open puzzle.

3.3 The 10^{th} Anniversary of the Conference Experience for Undergraduates

Educational research consistently shows that undergraduate participation in the scientific process is one of the primary factors that determines if students continue in scientific research. The Conference Experience for Undergraduates (CEU) offers about 100 undergraduates participating in research in nuclear physics nationwide the opportunity to attend the annual meeting of the Division of Nuclear Physics (DNP) of the American Physical Society (APS). The students prepare a poster on their research and the poster session where the ~ 800 conference attendees meet the students in person is the highlight of the annual meeting of DNP. The NSF provides funds to support travel and local accommodation. 2007 marked the tenth anniversary of CEU and over 700 students have participated since its inception.

CEU is widely admired and APS has now initiated a similar program for the April meeting.

NSF funded nuclear physics research has been recently recognized by the award of prestigious prizes:

Prof. Thomas Glassmacher from MSU was the 2006 co-recipient of the Raymond and Beverly Sackler Prize in the Physical Sciences `*for the development of new, ultra-sensitive techniques to study nuclear structure*.'

Prof. Robert D. McKeown from Caltech is the winner of the 2009 Tom W. Bonner Prize from the APS `*for his pioneering work on studying nucleon structure using parity-violating electron scattering, in particular the first measurement of the strange quark contribution to the electromagnetic structure of the proton*.'

Steven M. Clayton from the University of Illinois, Urbana-Champaign is the 2009 co-recipient of the Dissertation Award in Nuclear Physics from the APS `*for measurement of the rate of muon capture in hydrogen gas and determination of the proton's pseudoscalar coupling'.*

4. The relationship between award decisions, program goals, and Foundation-wide programs and strategic goals

The COV reviewed the nuclear physics program and found that the portfolio is well balanced in terms of risk, subfield, and distribution of PI. The COV studied the decisions made by the NP program and found them to be well aligned with the NSF strategic plan and the national scientific priorities.

The broader impacts of the NP program were considered. Education and training of young physicists is an essential element of the NSF NP program and is fully integrated into the research activities. Diversity and outreach are priorities across the program but progress is slow. The COV noted a number of initiatives: the efforts at MSU to achieve a more diverse faculty, and the attraction of African-American students into the historically black colleges associated with the Jefferson Lab program. Nuclear physics remains a field of research with substantial societal benefit, particularly in the areas of medicine, energy, and security.

5. Other issues

The implementation of a mid-scale (2-100 M$) instrumentation initiative would offer many new opportunities in the area of nuclear physics. The COV welcomes it.

The COV notes that the recent economic downturn may result in a short term decrease in job opportunities for post-doctoral researchers. The COV encourages the NSF to explore mechanisms which can safeguard the careers of young researchers.

5. Particle and Nuclear Astrophysics Subcommittee Report

Introduction

The Particle and Nuclear Astrophysics (PNA) subdivision supports university research in a wide range of areas associated with the detection of astronomical particles and photons, and with particle studies using underground facilities. The program covers a very diverse set of science topics, including the study of ultra high energy cosmic-rays, gamma-rays, and neutrinos; solar, underground, and reactor neutrino physics, searches for dark matter and studies of dark energy, and searches for neutrino-less double beta decay. The Committee was impressed with the breadth of the PNA physics portfolio and the accomplishments over the past three years.

Due to the diversity of the PNA program, many of the supported projects are interdisciplinary across divisions and agencies, which can lead to special needs in handling reviews, management and funding. The PNA program office is aware of these issues and has done well in addressing special circumstances. PNA is growing to be one of the co-partners for the DUSEL project and is now actively involved in the development of the detectors and physics program. Managing this growth while also supporting the other components of PNA will be a challenging task over the next decade.

The PNA report is organized in three sections: 1) Program Process and Management 2) Outcomes of Program Investments, and 3) General Comments and Recommendations.

1. Program Process and Management

Effectiveness of PNA's use of the merit review procedure

COV review of jackets
The Program Officers had identified 18 jackets that spanned all three years and a range of scientific topics, and covered both awards and declinations. The suggested jackets were very useful in demonstrating some of the difficult issues that are faced in the review and awards process, such as conflicting reviews from panels in different programs or divisions, proposals that involve a project funded by multiple agencies, and decreased availability of funds in the second or third year of an award, to name a few. However, it would be preferable to have browsing access to all jackets in future COV reviews.

Jacket documentation
The jacket documentation is very thorough. The diary notes often provided very useful supplementary material that allowed us to see the full picture from the viewpoint of the program manager..

Review process and actions

Our evaluation is that the process of ad hoc reviewers and panels is working well. There were generally enough ad hoc expert reviews (typically at least three) to provide very useful input, even when the reviews were not all consistent. The average number of review panel members over the past seven years has been 9, with membership spanning the broad range of areas represented in the proposals. The Program Officers are taking the advice of the ad hoc reviewers and the review panels seriously and are using it fairly. We commend the Program Officers for making appropriate accommodations when a graduate student or postdoc would be left stranded by a denied award.

The PNA funding has been fairly flat for the past three years, after rising each year since the program was established in FY2000. The annual number of proposals received has averaged near 50 over the past two years (not including the underground science R&D proposals), after averaging near 20 proposals for the previous four years. The success rate for renewals and new funding for the past three years was 51%, which is on the high side for PHY, but did not seem inappropriate given the quality of the proposals as reflected in the reviews.

There are complications for reviews that involve several divisions or agencies as to how the various funding sources are to be applied and how the project is to be managed. The Committee suggests that, for panels where appropriate, reviews be set up jointly with the various divisions/agencies and that the panel members be given a complete picture with respect to funding and management.

For proposals that are expected to be reviewed by different divisions or subdivisions, the proponents should be informed of this possibility and encouraged to write their proposals appropriately for the possible different communities. The program officers have shown themselves to be sensitive to these situations.

Special panels and reviews

The joint reviews by NSF and DOE of R&D proposals for underground science in 2007 and 2008 appear to have been very effective. We encourage such joint reviews when appropriate.

For the DUSEL site selection, a special panel of 22 individuals spanning all the relevant areas of expertise was constituted by the divisions of PHY, ENG and GEO. The broad expertise of the panel and the careful and thorough process reflected in the jacket is a good example of how large projects can be reviewed so that the community has confidence in the outcome.

Program's use of the NSF review criteria

Both criteria – intellectual merit and broader impact – were addressed in all parts of the proposal and review process.

Reviewer selection

Reviewers were fully appropriate and well qualified. No unfair reviewing or conflicts of interest were observed.

Resulting portfolio of awards

The awards have been sorted by the Program Officers into eleven categories. The six categories with the largest total funding are (i) cosmic rays, (ii) dark matter, (iii) high-energy gamma rays, (iv) ultra-high-energy neutrinos, (v) solar neutrinos, and (v) neutrinos and proton decay. Other funded areas include double-beta decay, neutrino mass, dark energy, nuclear astrophysics and projects co-funded with AST. This suite of topics represents a very diverse portfolio of important topics in particle and nuclear astrophysics. A number of the awards have produced important results in the past three years (see Outcomes from Investment section below).

Underrepresented groups

The number of women and minority PIs and co-PIs on PNA awards has been gradually increasing. In 2008, 18 of 122 PIs and co-PIs are women or minority. The funding rate for proposals with under-represented PIs or co-PIs has been healthy.

Management

The 2006 COV noted that "we are concerned that, in the future, this diverse and growing program needs to have a Program Manager Group with a stable continuity of individuals." We are pleased to see that the PNA program now has at least some of the attention of two permanent employees (Jim Whitmore and Marv Goldberg) and two IPAs initially Ani Aprahamian and now Allena Opper as well as Jon Kotcher, with Kotcher taking primary responsibility for managing DUSEL. It is important, especially, for the extended projects to have long term officers to provide continuity. Since the DUSEL project is so large, having the project in PNA split between Jon Kotcher as the main person for the facilities part and Jim Whitmore for the physics and detector program is appropriate as long as they also work closely together.

2. Outcomes of Program Investments

People

The science goals of PNA are well aligned with fostering an interest in science by the public at large. In addition, the projects in PNA provide an excellent platform to educate a new workforce at every level. The PNA awards have included strong efforts in education and outreach over the last three years, linked to projects such as Auger (CROPS), VERITAS (at Adler Planetarium), and CDMS, and to undergraduate involvement through the REU program (seven total sites have PNA associated experiments such as TUNKA, Borexino, EXO, SONIC). One new RUI grant was awarded each year reaching the level of four awards funded in FY08 (one new and three renewals).

There were five CAREER Awards made through PNA during the last three year showing that PNA provides a good area for young scientists to develop innovative forefront projects.. Graduate student and postdoctoral training is also an important outcome of the PNA program and is needed to provide the future scientists for this growing area. Future projects and facilities associated with PNA (e.g., DUSEL) have great potential to increase the participation of underrepresented minorities in science endeavors.

Discoveries and Science Highlights

PNA is a highly interdisciplinary field at the intersections of particle and nuclear physics, astrophysics, and cosmology. PNA projects address eight of the eleven science questions identified by the "Connecting Quarks with the Cosmos" report. What is the dark matter? What is the nature of dark energy? How did the universe begin? What are the masses of the neutrinos and how have they shaped the evolution of the universe? How do cosmic accelerators work and what are they accelerating? Are protons unstable? How were the elements from iron to uranium made? These questions span a large number of interrelated areas that need to be addressed by interdisciplinary programs such as those fostered by PNA.

Major accomplishments by PNA efforts during the last three year period

1. *The most stringent limits on dark matter particle interactions*

Results have been obtained by many experiments using complementary techniques in experiments such as PNA supported CDMS, XENON10, and COUPP projects. These results include the world leadership in constraining theoretical dark matter models and could reach a discovery in the near future. XENON10 was chosen as one of the "6 most important experiments in the world" by Discover magazine in 2007. The Deep Underground Science and Engineering Laboratory (DUSEL) facility will significantly improve the reach of these direct searches for dark matter and could provide an excellent location for future experiments such as Super CDMS, LUX, WARP, ZEPLIN-II, and DRIFT-II.

2. *Top rated scientific discoveries for ultra-high energy cosmic-rays*

Auger finished construction in 2008 and had accumulated enough data during construction to produce what Science Magazine rated 3rd on their list of "breakthroughs of the year in 2007". The result is the correlation between the arrival direction of ultra-high energy cosmic rays and active galactic nuclei in the nearby universe. Results also confirmed the predicted attenuation of ultra-high energy cosmic rays in traversing extra-galactic distances (referred to as the GZK effect) observed by HiRes and Auger in the spectrum. These measurements herald a new era for cosmic-ray physics as experiments achieve the ability to do charged particle astronomy. This result was also chosen by the AIP as one of its "top 10 Physics stories of 2007" and by Nature magazine as one of the "research highlights of 2007".

3. *The discovery of a number of new sources of high-energy gamma rays by STACEE, Milagro and VERITAS.*

In particular, supernova remnant IC443, co-discovered by VERITAS and MAGIC, is the most luminous TeV-energy source known to date. The acceleration mechanisms involved in these galactic sources are likely to unveil the origin of galactic cosmic rays. More distant extragalactic TeV sources will enable the study of photons and cosmic backgrounds at high energies including tests on fundamental physics. These telescopes are searching for gamma-rays from particle dark-matter annihilations with an increased discovery potential during the Fermi Space Telescope era.

4. Initial results from the IceCube neutrino telescope at the South Pole.
IceCube will transform the field of high-energy neutrino observations by significantly increasing the sensitivity to neutrinos from TeV to PeV and EeV energy scales. The construction of the IceCube detector is progressing well with 59 of the 70 strings deployed to date (3 more than foreseen at this point). Science results are being reported and should become highlights by the next CoV. R&D on acoustic neutrino detection (SAUND II) is also progressing well.

5. Important new results in solar neutrino physics
The program with neutrinos is very broad, ranging from solar neutrinos to neutrino properties. Borexino reported the first real-time spectral measurement of sub-MeV solar neutrinos from ^{7}Be. The result is consistent with the Standard Solar Model and with neutrino oscillation with the LMA-MSW parameters but inconsistent with no oscillations. The result for the first time mapped out the transition region between vacuum oscillation for low energy solar neutrinos becoming matter oscillations at high energy. Solar neutrino oscillations have now become well established and understood using the combination of results from Borexino, Super-K, Kamland, and SNO.

Facilities, tools, techniques

PNA has a very broad program with a wide range in project funding levels and management needs. PNA has managed to maintain a healthy level of individual investigator awards while shepherding the successful completion of large inter-agency and international facilities. Of particular note are the IceCube and Auger projects that involved very large installations along with mutli-agency and international funding. The success of these projects owes much to the dedicated oversight and management by PNA and NSF in general.

Future Prospects

Investments in this new and vibrant field are starting to pay off, as we see from the recently highlighted physics results. The current experiments and facilities should lead to many new important science results in the coming years and the possible answers to some of the eleven questions identified by the “Quarks to the Cosmos” and “Physics of the Universe” reports.

The future plans that build on recent successes will likely lead to increased funding requests. In particular, new large facilities or projects, such as DUSEL, will need thoughtful planning to insure good use by the community of these facilities for new opportunities.

3. Comments and Recommendations

PNA and NSF Stewardship of the DUSEL Project

In the COV2006 report the DUSEL initiative was mentioned as an important step for the PNA program because significant parts of its portfolio would be influenced. We commend the Physics Division for having put the personnel and process into place to guide the solicitations through to site selection and start of DUSEL R&D. Of particular note is the very successful procedure used for making the site selection where extensive use of expert panels, site visits, and reviews led to a well informed final decision.

DUSEL and its physics program will be a joint partnership between NSF, DOE, and international partners. The full DUSEL funding plan and schedule needs to be developed in detail covering all aspects from the initial R&D to the long term operations and physics program in order to plan for how DUSEL can fit in with the general NSF and DOE programs. It is especially encouraging to see cooperation, in the form of joint solicitation and review on the R&D side, between NSF and DOE. While NSF has had little experience in the past with projects of this scale, scope and time horizon, the steps taken and reviews performed have been timely and excellent in guiding the project. In order to ensure success and provide planning confidence for the research community , local communities and agencies, we see the need for increased support and involvement by the NSF leadership in this major undertaking. It is also important that the various components of the program go forward in parallel such as the DUSEL site design, the various detector R&D efforts, and the establishment of the desired neutrino beams.

The DUSEL R&D Program

The Committee feels that PNA has done very well in establishing the DUSEL R&D program in 2007 and 2008. The program provides R&D funding for underground physics in general but recently somewhat weighted towards projects related to DUSEL. The high community interest is reflected in the ~50 proposals received each year and the work being funded will be very important for establishing the physics program at DUSEL. Many of the proposals have involved joint submissions to NSF and DOE, typically as part of collaborative proposals.

The review process involved a joint review panel reporting to NSF and DOE. This allowed for the panel to see the entire proposed program and allowed for collaborative proposals between DOE groups including National Laboratories, and NSF groups. For the 2007 and 2008 period, about 12% and 20% of the proposals were funded; these included nearly all of the awards that were rated as “high priority” by the review panel. The outcome of this award process appears to have gone well, leading to a diverse suite of funded projects. One issue that may become a problem is that many of the experiments associated with the DUSEL physics program are reaching the stage where initial-phase experiments are the next step. Such efforts will probably require funding beyond that available in the R&D program and should be provided by the S4 and S5 steps in the ongoing DUSEL solicitation process.

Accomplishing Large Projects

As the NSF Physics Division has shown with the DUSEL project, it is important to put a planning process in place for large, multiagency projects that takes the life-cycle and development costs into account. In the PNA program, it can be anticipated that several large detector projects, related or unrelated to DUSEL, will be put forward in the coming years. For these projects, a complete assessment of the project costs will allow better management and planning and also provide reviewers with a full picture of the project, leading to better informed decisions. NSF would need to develop a budget threshold (or other criteria) at which this process would set in, with funding being provided to accomplish a preliminary design effort establishing a reliable cost estimate.

For large projects, there is also a possible problem with supporting the physics and operations efforts as the construction phase of the project is completed. As indicated previously, the plan for this transition should be made during the initial planning for the complete project which is being done for the DUSEL project. For example in the IceCube project, even though the funding plan for the operations and physics program was not set up at the start, NSF has worked with the experiment to develop funding through M&O and base grants to cover this very important stage of the project.

Support for Mid-scale (>$2M) Projects

As noted in the COV2003 and COV2006 reports, a NSF program extending the popular and successful MRI program to larger equipment costs (specifically in multi-institutional proposals) might be very beneficial for the PNA and the total PHY program and could foster increased university collaboration. This type of funding could specifically give young faculty and researchers the ability to propose and carry through innovative projects where they can take a leadership role. This would not only give a clear boost to their careers but also foster the development of new leaders for the field.

Interagency and International Projects and Project Management

The interdisciplinary nature of the PNA program frequently requires joint funding of projects, specifically with the Department of Energy. The PNA staff has sought the cooperation of their counterparts at other agencies and so far seems to have been able to steer the large PNA projects to success. As mentioned above, the reviewers of individual PI proposals related to these collaborative projects would benefit from a more comprehensive presentation of the complete project plan for funding and management. This comprehensive information would include planning for the complete cycle of the project from design to construction and then to research. This type of information would also provide young researchers, involved in the early stages of these large experiments, with information both for their own planning and for presenting their career plans to others. It should again be noted that the DUSEL process could provide an example to be followed.

6. Theoretical Physics Subcommittee Report

Introduction

The seven members of the Theoretical Physics Subcommittee reviewed the processes and outcomes of awards and related issues in four programs, Theoretical Atomic, Molecular, Optical, and Plasma (TAMOP); Nuclear Theory (NT); Elementary Particle Theory (EPT); and Mathematical Physics (MP). Significant time was spent examining jackets, and raising and discussing issues. At every stage the program managers were very knowledgeable and helpful.

A. Integrity and efficiency of the Program Process and Management

The Theoretical Physics Subcommittee found that basically the review process, the choice of reviewers, panel members, the merit review criteria, the quality of individual reviews, time to process, and balance were very good. Panels play a very important role in the review process, and selecting their members to get expertise in all the needed areas for ten to a hundred proposals can be very subtle and needs care. The Program Managers did this rather well.

Panel summaries provided to PIs, particularly for declined proposals, should be improved, with better rationales provided for outcomes. Once the program manager's review analysis was included the material in the jackets was good, but the review analysis is not currently provided to PIs. NSF policy in this area needs examination, and at least some summary of the review analysis should be provided to the PIs.

The balance and integration of educational and scientific aspects in proposals and in their consideration in reviews was satisfactory. Educational activities are important, but care is needed to have an appropriate level of emphasis on education and outreach relative to scientific activity.

A.1 Size and number of grants

The size and number of grants are a significant problem. This is basically because the budget for theory grants is too low for the theory program to be thought of as a fully healthy one. Years of flat budgets, some cuts, and only an occasional increase have eroded the support level until it became a problem that needs to be addressed. In particular, the funding allocated in recent years has not increased commensurately with the increase in the number of proposals by very able researchers. Healthy, not large, funding for a leading theorist should include at least a postdoc and a student, and summer salary, and travel is very important for theorists – meetings and workshops and discussions are theorists' laboratories. A few numbers allow one to get a good perspective on the problems. The total funding for theory grants under the auspices of the subcommittee is about $20M. Averaging 2007 and 2008 (because of the 5% cut for 2008 and fluctuations) this funds 278 senior people, 85 postdocs, and 162 graduate students. The total number of senior people funded is clearly low, the number of postdocs relative to senior people too low by nearly a factor of three, and the number of graduate students too low by arguably a factor of two.

Different program managers have responded differently to this funding shortfall. Some have kept the minimum individual grant size larger, although still smaller than needed for a healthy research program, and therefore are only able to fund 1/3 to 1/2 of the highest quality proposals. Others have noted the fact that in university departments young theorists who do not get grant funding are unlikely to get tenure, and so have funded a larger fraction of new, highly rated proposals. The cost of the higher funding rate is that the award sizes for the new proposals are about half as large as the minimum in other programs, and insufficient to fund even half a graduate student. The subcommittee wishes to focus attention on the funding level, and on the difficult issues, rather than argue for any particular outcome.

Another aspect of the situation is important too. There is agreement that there is a postdoc bottleneck in theory, with significantly too few of the most promising postdocs getting good positions, and with some very promising people being pushed out of the field. At the same time, maintaining a number of strong theory groups at leading institutions is essential for frontier progress and for training top young people, so the problem cannot be solved by shifting funds from strong and large groups.

NSF's stewardship of theoretical physics is under challenge by the issues raised here.

B. Results of NSF Investments

The subcommittee would like to present a few of the many significant results obtained by NSF theory funding in recent years. We emphasize that with hundreds of grants in many areas the number of important results that could have been chosen is very large.

The Institute for Theoretical Atomic, Molecular and Optical Physics has a number of programs and activities which it runs for the benefit of the theoretical AMO Physics community. ITAMP fellow Ana Maria Rey, in collaboration with other scientists, investigated New Phases and Fractal Behavior of Atoms in Optical Lattices (A. M. Rey, I. I. Satija, and Charles W. Clark, Phys. Rev. A 73, 063610 (2006)). Some of the highlights of this work include the discovery of new insulating phases due to the interplay between disorder and interaction, the recognition that a shot-noise interference pattern exists even in the insulating phases, and the discovery of fractal behavior and new signatures of "fermionization" of bosons. [K. Kirby and M. Lukin, PHY-06653021 and 0653575: Institute for Theoretical Atomic and Molecular Physics]

Researchers at the University at Nevada (K. Beloy, U. I. Safronova, and A. Derevianko, Physical Review A 97**,** 040801 (2006)) helped to reduce the uncertainty in the Cs atomic clock by focusing on how temperature differences affect the device. They have reported results of relativistic many-body calculations of the black-body radiation shift, one of the leading systematic corrections in the ^{133}Cs frequency standard and a subject of recent controversy revalidating high-precision Stark shift measurements. More accurate atomic clocks lead to more accurate global positioning system (GPS), potentially improve deepspace navigation and help scientists probe fundamental laws of nature. [A.

Derevianko, PHY-0653392: Tests of Fundamental Symmetries with Atoms and Molecules].

The collaboration of nuclear theorists (PI, postdoc, student and collaborators) led by Bruce Barrett of University of Arizona, predicted an interesting property of light nuclear and atomic systems, namely that the size of the system is connected to its properties when viewed in a mirror (a physical property known as parity). A system appears the same in a mirror when it is small in size, and it appears inverted when big. These insights result from ab-initio calculations of deuterium, trititum and helium, which are relatively fluffy in the sense that their sizes are much larger than the distance over which the force between two of their constituents (protons or neutrons) acts, thereby suggesting the need for a three-body force that simultaneously acting on three constituents to describe the binding correctly. These findings have a chance to be experimentally verified in future experiments with atoms in a laser trap, where the size of the atomic system can be systematically controlled. This research is an example of important findings in a discipline impacting other fields.

The interaction between QCD and String theory continues to lead to major new advances. For instance NSF CAREER award winner Anastasia Volovich (PHY–0643150) has been able to use the twistor string theory methods initiated by Witten (PHY- 0503584) to uncover unexpected simplicity in perturbative gluon scattering amplitudes and undertake computations that would be too difficult to do via traditional field theory methods. The AdS/CFT duality continues to yield advances in surprising new directions, such as an all orders calculation of the leading piece of the anomalous dimension for certain large spin twist 2 operators (Klebanov, PHY – 0756966).

The recent report of an excess in the positron cosmic ray data from the PAMELA experiment could be either an indirect signal of the decays or annihilation of the long sought dark matter, or an unexpected astrophysical background. The reported excess has inspired new ideas in particle theory dark matter (Weiner, CAREER award PHY-0449818, Pierce, CAREER award PHY – 0743315, Nomura, PHY – 0555661, Randall PHY-0556111, Dimopoulos, PHY – 0756174, Murayama, PHY - 0757616), and new astrophysical calculations of the possible high energy positron sources (Profumo, PHY – 0757911).

Shing-Tung Yau (PHY 0714648) studied the structures of geometric vacua in string theory. One of the most important problems in string theory is to understand the space of vacua. For many years, the study of vacua in heterotic string theory focused on compactifications on Calabi–Yau manifolds. While Calabi–Yau vacua can be rigorously shown to exist, the presence of a large number of scalar moduli fields prevents predictions for the coupling constants. Therefore it became necessary to go beyond Calabi–Yau metrics and to investigate non-Kähler geometries. Preserving supersymmetry leads to a set of conditions on geometry and gauge bundle proposed by A. Strominger. Already the construction of solutions that satisfy these conditions was a challenging mathematical problem. A class of solutions has been constructed rather recently by S.-T. Yau and J.-X. Fu. Together with NSF supported postdoctoral fellow Li-Sheng Tseng and Melanie Becker, Shing-Tung Yau has now investigated properties of these solutions which contributes significantly to understanding the geometry of supersymmetric flux vacua (M. Becker, L.-S. Tseng and S.-T. Yau, Adv. Theor. Math. Phys. 12 (2008)).

Elliot Lieb (PHY 0652854) is studying the stability of matter. In 1988, E.H. Lieb and H.-T. Yau showed that stability of relativistic matter holds for nuclear charges Z up to the critical value $Z\alpha = 2/\pi$. Since then it had remained an open problem whether the same holds true in the presence of a magnetic field. In collaboration with R. Seiringer and postdoctoral fellow R. Frank (partially supported by the NSF) Elliot Lieb established stability for arbitrary magnetic fields and nuclear charges up to the same critical value as in the absence of a field (R. Frank, E.H. Lieb and R. Seiringer, Comm. Math. Phys. 275, p. 479 (2007)).

The mysterious and ghostlike neutrinos play a surprisingly important role in the cosmos. In environments like core-collapse supernovae, neutrinos carry off 99% of the energy released in the even. As a result, neutrinos can more than make up for their feeble interaction with huge numbers. Early calculations have suggested that the weak nature of neutrino interactions would lead to a very small neutrino flavor oscillation effect in a supernova. A full calculation by NSF funded George Fuller of UCSD takes into account non-linear effects due to the very high density of matter inside a collapsing star. New large-scale numerical simulations show surprising results: the non-linear effects give rise to large oscillation effects. This alters dramatically our picture for neutrino emission in supernovae and could be important for models of nucleosynthesis, supernova dynamics, and the neutrino signal that would be measured on earth. Moreover, the large amplification effects could provide signals for key neutrino physics parameters that may never be measurable in a terrestrial laboratory.

C. Other issues

C.1. Kavli Institute for Theoretical Physics (KITP), Santa Barbara

The KITP is a unique and powerful resource and facility for theoretical physics in all areas, nationally and even internationally. It is valuable for the vitality of theoretical physics. The subcommittee was surprised to see that it was in the Physics Frontier Center (PFC) program, which is not consistent with the actual role of the KITP.

KITP has only a few faculty, and mainly responds to proposals from outside groups of theorists who can be thought of as users, from all areas of theoretical physics and mathematics. The proposals are reviewed by an advisory panel, and some accepted. It functions as a laboratory or facility. It is highly multidisciplinary. For theorists, interactions and discussions about ideas and how to test them are very important, and are their laboratory and equipment. Having a center with the infrastructure to host such gatherings is very important – to reproduce that infrastructure in many places would be very costly in many ways.

The best analogy for KITP is to think of it as the CERN of theoretical physics, a unique facility. Priorities are set for scientific reasons by its advisory committees and reviews are frequent and thorough. The level of funding is set with respect to scientific goals, not with respect to a number of other labs. The approximately 10% limit on total PFC funding for NSF leads to an inappropriate constraint on KITP's budget.

C.2 Stimulus Funding

The subcommittee wants to make a few comments on issues that could be relevant if there is stimulus funding. Even if NSF is not included in the stimulus package these issues could be considered.

Possibilities discussed included helping to reduce the postdoc bottleneck with a step in the total theory budget, which could then be stabilized as the total budget increased over the next years. A similar step could be taken for KITP finding, with an increase of 15-20% followed by regular increases as the total budget grew.

Another issue generated by the current economic situation is possible bridge funding for new young faculty hires in a time of reduced hiring and of freezes. In the past the DoE OJI program was started in the 1970s for similar reasons, and worked very well; university departments would choose a candidate and the department and candidate together would propose a hire with DoE support for some years before tenure. That program has since evolved in other directions. The Riken support in nuclear areas has also been effective, with Riken paying half the support for some specific hires for five years. Such a program has been used very successfully by Jefferson Laboratory and nearby universities.

C.3. Theory structure in NSF

Theoretical activities significantly affect and enrich all the areas that NSF supports, as well as being a major frontier endeavor itself. At present there are growing and changing NSF programs that should have active theory participation, such as Particle and Nuclear Astrophysics (PNA) and DUSEL. At the same time, it is important that theory funding in those areas, whether directly or by additional grants in existing programs, should not be taken from the existing, already strained, programs.

7. Education and Interdisciplinary Research Subcommittee Report

Introduction

The EIR program in the Physics Division provides opportunities for members of the physics community to pursue NSF goals for outreach and education, broadening participation in physics by women, under-represented minorities, and people with disabilities, and in providing a mechanism for support of interdisciplinary physics proposals that either do not fit well in other PHY programs or through coordinating truly interdisciplinary projects which fall into the purview of several Divisions or Directorates. The EIR program has acted as an incubator for new interdisciplinary areas and has been successful in doing this in the past as demonstrated by the success of the relatively new Physics of Living Systems program in the Physics Division which started in EIR.

EIR has a diverse portfolio of programs and, as such, requires a Program Office (P.O.) with an understanding of educational issues and emerging interdisciplinary research in physics as well as the skills needed to navigate the many divisions and directorates at NSF. The EIR program now has a full-time P.O. with these credentials and the vision to "take advantage of opportunities presented by such national initiatives and effectively integrate efforts across divisions and programs," a need emphasized in the last COV report.

The committee is concerned about the perceived role of "designing innovative courses or curricula" in the CAREER proposals. The perception, that CAREER awards require *development* of innovative courses (as opposed to *implementing existing* innovative curricula), may lead to abandonment of the education component of CAREER awards or dissuade new faculty from applying to the program. Expecting a new faculty to do top notch science, while developing new curricula, all leading to a positive tenure decision represents an extremely high challenge. High quality, research based curricular development generally requires a team and five or more years; expecting a new PI to commit to that level of development is far fetched. On the other hand, the intention of the CAREER is to foster excellent teaching in young faculty, in order to move away from ineffective lecture methods and embrace effective research-based teaching methodologies, critical for an increasingly technological society.

We found that the EIR program has many strengths, including the ability to fund high quality proposals in interdisciplinary areas that are emerging in Physics as well as in physics education research. We also are pleased with the funding of programs that support under-represented minorities and women. We anticipate that the EIR program will continue to support innovation and improvements to all aspects of physics education and outreach.

General Comments about Review Process:

Overall, the review procedures used in all areas of EIR were exemplary. Details of our findings are included below.

Review Methods:

- Most proposals undergo individual reviews, panel reviews, or both.
- When appropriate, proposals are reviewed internally.

Merit Review Criteria

- The merit review criteria have been addressed appropriately in both the proposals and the reviews examined by the committee (particularly for REU's)
- Proposals submitted through the EIR exhibibt a high correlation with the NSF "broader impact" requirement

Documentation of Review Process

- Individual review summaries are substantive
- Panel review summaries are substantive and provide adequate rationale for decision
- Research analysis by P.O. is thorough (including strengths/weaknesses) and adequately explains the rationale for funding or declination
- Documentation returned to the PI is useful and provides rationale for decision
- Time to decision is appropriate – interdisciplinary proposals require longer times to review because of the multiple perspectives needed (different directorates and few qualified reviewers) – *See recommendations below*

Qualifications of Reviewers:

- Reviewers are broad-based
- Reviewers hold appropriate credentials for specific proposals reviewed
- Reviewers are diverse (women and underrepresented minorities, different types of institutions, early career vs. experienced, geographical representation)
- P.O. has expertise in HBCU and education providing important perspective
- Reviewers / P.O. recognize and resolve conflicts of interest when necessary

Award Portfolio

- Overall quality of proposals selected for funding is excellent
- Program portfolio promotes integration of research and education
- Awards are appropriate in size and duration for project scope
- Proposal portfolio exhibits an appropriate balance of innovative / transformative / interdisciplinary projects – *See recommendations below*
- Proposal portfolio has an appropriate balance across disciplines / subdisciplines
- Proposal portfolio has appropriate participation from underrepresented groups

- Program is extremely relevant to national priorities, agency mission, relevant fields and constituent needs

Program Management

- Program management is excellent
- Program is extremely responsive to emerging research and educational opportunities
- Multiple proposals were examined by the COV who agreed that the appropriate decision to fund or not fund had been made in all

Challenges Facing EIR:

Interdisciplinary (ID) proposals:

Interdisciplinary proposals remain a primary source for transformative research across disparate fields as encouraged by the NSF. Unfortunately, such initiatives are often impossible to place within a single funding opportunity or division, require additional support during both formative and operational stages and often fail to find a strong advocate. The EIR remains an ideal place for the incubation of such interdisciplinary proposals in physics; however, this role should be expanded to include:

- The development of a framework within EIR (1) identifying current and future ID proposals within PHY and (2) providing them a permanent advocate throughout the incubation / maturation process; and
- A separate funding line for the co-funding of ID proposals should be established in order to enhance their success probability. (The EPSCOR model provides one possible template.)
- Additionally, a framework (NSF-wide) should be developed to provide support of the type described above for ID research across all divisions within the foundation.

RET (Research Experience for Teachers) funding:

The OMA has provided roughly $500,000 annually to support the RET proposals. This funding is being discontinued. RET Fellowships provide teachers with a summer experienced engaged in cutting-edge research at an institution. Teachers then bring their experiences back to the classroom, thus building connections between their students, the research, and the university. These connections reinvigorate teachers who, in turn, excite students in their classrooms. Post program assessment indicates that teachers routinely feel increased stature in their positions; that they are treated more professionally by students and parents upon return from a RET experience. Many RET Fellows develop strong, continuing relationships with host sites. Thus there is strong evidence for the transformative nature of the RET program and its support must continue. We encourage

- The NSF must identify a sustainable funding mechanism for continued support of this proven program without adversely affecting current REU site funding (both new and existing) as well as the overall EIR portfolio.

REU capacity:

REU's have provided valuable experiences to undergraduate physics students in preparing them for future careers in graduate school, industry, or K12 teaching. However, we wonder if enough opportunities exist for any student interested in participating in a Physics REU.

- REU's continue to provide excellent research opportunities for students with many of these being "transformative" in nature for participating undergraduates.
- Hearsay from students indicates a possible need for additional REU sites ("harder to get into an REU than graduate school").
- Steve Turley (at Brigham Young University) is analyzing data collected from all current REU site directors to determine whether there are adequate slots for all interested, qualified students. EIR should continue to encourage Dr. Turley to complete this analysis and share it with the physics community and NSF.

Physics Education Research (PER):

Two types of Physics Education Research (PER) proposals are under the purview of EIR: pure PER proposals and proposals integrated within other research areas in PHY and EHR. EIR provides a crucial role in both types of proposals through stewardship during the review process as well as by providing full or partial funding to a number of proposals. For the pure PER-type proposals, EIR supports proposals that are important to the physics domain but may not generate full support elsewhere due to limited impact. For example, intermediate / upper level quantum mechanics is vital to the foundation to broad areas of physics, but has somewhat limited appeal to education researchers when compared to introductory physics courses. The integrated proposals also play a crucial role in expanding participation of traditionally under-represented groups and deepening broader impacts by leveraging off of the research mission of proposals.

The committee finds that the EIR is carrying out its mission to support PER, and that

- The quality of the PER proposal reviews and review analyses is excellent, and well-served by the P.O.'s experience.
- The P.O. has a very good working relationship with other PHY P.O.'s and EHR P.O.'s, critical for successful stewardship of PER proposals.
- The PER proposals broaden participation by building and offering best practices in education initiatives.

Broader impacts:

EIR continues to play a critical role in the broader impact education component of proposals. EIR amplifies the opportunity to leverage the excitement of cutting-edge science and parlay that into increasing understanding and participation by all citizens. It also affords the opportunity to expand participation of traditionally under-represented minorities and women in science, putting research-based methodologies into practice. EIR has the potential to expand these opportunities by providing best-practice examples to all proposers and encouraging collaboration with successful sites.

- The committee encourages the NSF to expand the role of EIR as a clearinghouse in the promotion and stewardship of education outreach to all proposals.

CAREER awards:

The committee is concerned about the perceived role of "designing innovative courses or curricula" in the CAREER proposals as stated in the introduction. The committee recommends that EIR foster the education component of CAREER proposers both by providing examples/resources of best practice teaching methodologies, by providing training for CAREER proposers, and by providing information to CAREER reviewers on best-practice teaching methodologies. The APS New Faculty Workshops may also offer a knowledge base for proposers, by either having CAREER awardees attend the existing workshops or by adding additional workshops for CAREER awardees.

Highlights

Transformative research:

- The portfolio of REU sites as a whole represent a crucial education and outreach component that impacts over 500 students per year, providing them with a multitude of opportunities that represent the best science. Sites span all fields of physics, are located in diverse geographic regions, and include the innovative CERN REU site where students experience the largest laboratory in the world.
- "Interactions in Understanding the Universe" (I2U2) – This award is for an "educational virtual organization" which is designed to strengthen the education and outreach activities of scientific experiments at U.S. universities and laboratories by providing an infrastructure support and a program framework for a portfolio of coherent, collaborative online science education laboratories. I2U2 maintains a growing online portfolio of educational laboratories for a diverse range of disciplines and provides tools and support services to assist developers in creating educational resources. These educational laboratories use the national Grid cyberinfrastructure for education in the same way that science increasingly uses the Grid. I2U2 collaborations take two similar but distinct shapes. E-labs, delivered as web-based portals accessible in the classroom and at home, are implemented with the ever-expanding capabilities of web-based media. I-labs are delivered as interactive interfaces typically located within science museums and

similar public venues. I2U2 will also extensively evaluate and assess the effectiveness and use of the portfolio of science education laboratories.

- "Physics & Aerospace Catalyst Experiences in Research – Minority Focus" – one REU-like site was funded at Louisiana State University (LSU) which involves supporting a faculty-student team from a minority-serving institution in the summer at LSU to perform small balloon science experiments and flight of these payloads to the very edge of space. The main emphasis of this funding is to attract students from underrepresented groups into STEM (science, technology, engineering, and math) programs and, in doing so, establish a core of expertise at multiple HBCU institutions around which a local sustainable student research experience program can develop, and partner with these institutions as they implement their local student research experience program. One HBCU (Grambling State) was involved in summer of 2007 and two (Norfolk State University and University of Puerto Rico) were involved in summer of 2008.
- 21st Century Astronomy Ambassadors – a summer school program involving high school students in Astronomy and Gravitational Wave research at University of Texas at Brownsville (UTB), targeting under-represented minorities. UTB is a minority-serving institution where more than 90% of students are of Hispanic origin in one of the most economically underdeveloped yet fastest growing regions of the U.S. The goal of the summer academy is to introduce young local high school students often belonging to underprivileged minority groups to physics and astronomy as an exciting field of study. Students who have an interest in science will gain exposure to university research and also a first hand knowledge of cutting edge research done by the Center for Gravitational Wave Astronomy (CGWA). The summer academy gives 12-16 high school students the opportunity to work directly with faculty and staff of the CGWA.

We note the increase in number of REU's at international sites (e.g., CERN and University of FL's REU for gravitational wave science) which could be used as models and provide a list of best practices (important for science students to have global experiences)

We commend the funding of workshops for women and minorities funded by EIR and support continuing this important funding.

We would like to thank Kathy McCloud, the Program Officer for EIR, for her help during this review.

8. Physics of Living Systems Subcommittee Report

Introduction

The Physics of Living Systems subcommittee reviewed the process used to evaluate proposals and the results of NSF investments in the Physics of Living Systems (PoLS) program. This exciting program supports a diverse portfolio of research projects unified by their focus on elucidation of how basic physical laws constrain and control living things. Research in PoLS includes both experimental and theoretical projects focused on phenomena at the individual molecule, cellular, and whole-organism levels. In 2008 the program budget was roughly 4.7 M, divided between approximately 40 active grants.

PoLS is a young program established in 2005; the first round of awards were made in 2006 so this is the first COV review of PoLS. The NSF merit review process varied slightly from 2006 to 2008, but has converged to the following:

1) solicitation of external (mail) reviews by between four and six expert reviewers

2) review and ranking of proposals by a selected panel of experts who meet at the NSF to examine the proposals and the external reviews

3) preparation of a review analysis by the Program Director that recommends award or declination of each proposal

The subcommittee reviewed 22 ejackets to assess the evaluation process integrity. The quality of the external reviews was found to be very good, in the suitability of the experts chosen and the scientific excellence of the reports, and in its attention to the broader impact criterion. The committee found the process to be robust, fair and accurate, and free from biases originating from conflicts of interest. Review process integrity is described in more detail in Sec. A.

Despite its youth, this program has already generated some excellent scientific outcomes which are presented in Sec. B of this report. Sec. C presents committee comments and recommendations for possible improvements to program procedures and development, and also discusses a few recommendations that might be applied more broadly at the NSF.

A. Integrity and Efficiency of the Program's Processes and Management

1. Effectiveness of merit review process

The committee reviewed 22 jackets using a two-step process. These jackets included 20 which had been selected by the program director as being representative of the program review process and portfolio (12 awards, 8 declinations). The proposals studied included regular and CAREER applications. Two additional proposals (one award, one declination) were requested from the Program Director. Jackets were distributed between committee members for detailed reading of proposals, reviews, panel discussions, and review analyses, and then the committee discussed the results, with an emphasis on examination of conflicts arising during the review process and their resolution.

The committee was highly satisfied with the review process, and was confident of its thoroughness and fairness. Most proposals received between four and six mail reviews; those reviews plus at least two additional panel member reviews and a panel summary were integrated into the review analysis. The reviewers were appropriately chosen and in general provided incisive, technically informed reviews. The committee did observe cases where substantially different conclusions were reached by different mail reviewers, and this made very clear that the panel review was essential to a fair and correct review outcome. In all cases examined the committee concurred with the panel recommendation and the review analysis.

2. Broader impact criterion

Broader impacts were addressed by all proposals examined, in a variety of ways. Research in PoLS tends to be highly interdisciplinary, and research results are likely to have impact on biological sciences. Reviews analyzed broader impacts of proposals appropriately. Funded proposals are achieving broad impacts in tangible ways, often by taking advantage of opportunities to develop new teaching curricula in biological physics, including laboratory courses. In addition some groups are involved in outreach; in one case all members of a research group are involved in primary and secondary school outreach activities (Mazur). The committee was satisfied that broader impacts are being analyzed and emphasized in review, and also that broader impacts are being achieved by funded proposals.

3.Resulting portfolio of awards

Funded proposals were all of excellent quality, and are all based on study physics in the context of living systems. The portfolio supports research on interactions and physical properties of biological molecules, and quantitative studies of processes in and behavior of cells and whole organisms. The committee was satisfied that the portfolio addresses areas of research which are not supported by other biophysics or quantitative biology funding programs (e.g., NIH, NSF-BIO) and which are likely to lead to substantial scientific discoveries.

One aspect of the portfolio which was discussed with the Program Manager was its balance between studies of biomolecules "*in vitro*", versus studies of physical processes in living cells "*in vivo*". Some of the *in vitro* studies funded in PoLS are similar to projects in NSF-BIO (e.g., Molecular Biophysics in NSF-BIO-MCB), and a decision was made in 2007 to co-review future *in vitro* proposals jointly with appropriate NSF-BIO programs, defining a sharper focus for PoLS on experiments in living systems. The committee endorsed this plan as well as the decision process leading to it which involved discussion with experts in the field outside of NSF. Indicators favoring the focus for PoLS are the large opportunities for scientific discovery exist in the area of quantitative biophysical study of living cells, plus the fact that other funding agencies are not emphasizing this area of research.

4. Management

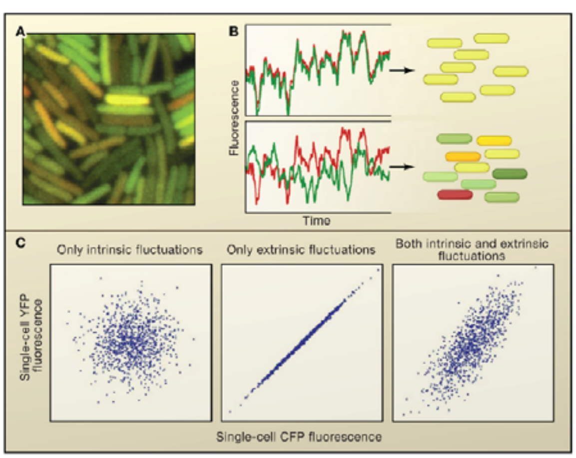
The committee spoke both to the present Program Director (Blagoev, 2008-present) and the past Program Director (Caldwell, 2005-2007), and was impressed with the high level of scientific expertise in this rapidly developing field that Blagoev has brought to the program. There has been a rapid increase in the number of proposals reviewed by this program (2006: 24, 2007: 56, 2008: 118, summing regular and CAREER proposals), and it is likely that numbers of submissions will continue to increase in the near future. Managing review and funding decisions is likely to be challenging, especially given the low rate of funding (26 of 147 regular proposals and 7 of 41 CAREER proposals were funded during 2006-8, for a total funding rate for reviewed proposals of about 18%). The committee has a high degree of confidence in the present Program Director and was particularly pleased with his cooperation with other NSF programs so as to maximize the impact of NSF resources.

B. Results of NSF Investments

1. Scientific discoveries

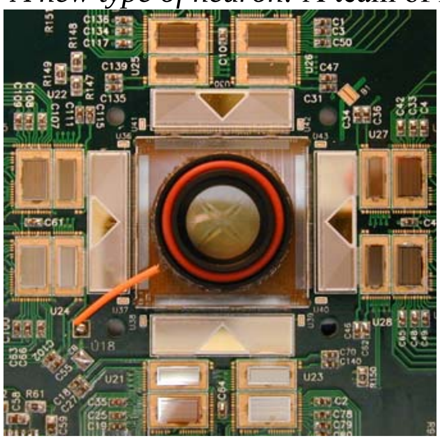
PoLS-funded researchers are contributing to understanding of physics underlying biological phenomena at various levels (molecular, cell, tissue, organism) and using a wide variety of approaches. A few particularly exciting results include:

Stochastic expression of genes: A key objective of PoLS is identification of physical mechanisms that drive or constrain biological behavior. One such example is analysis of how randomness in the expression of individual genes can explain why genetically identical cells can be very different under identical conditions. In cells genes are present in very small numbers, and as a consequence fluctuations in their expression can lead to easily detectable differences between genetically identical cells. One observation has been that an increase in dose leads to an increase in the frequency of cells displaying a high level of expression rather than a uniform increase in expression in every cell. Recent work by Oudenaarden and co workers at MIT (reported in Nature Genetics, 40:471-475 (2008)) have tested this experimentally in vivo by introducing a bistable gene network in yeast. Their data suggest that tuning phenotypic switching rates may constitute a simple strategy to cope with rapidly fluctuating environments. According to this study, populations can improve their fitness by optimizing phenotypic diversity originating from the stochastic nature of gene expression.



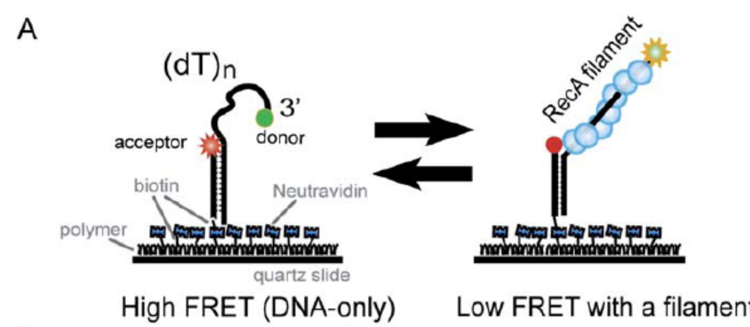
Above: Intrinsic and Extrinsic Contributions to Noise in Gene Expression. (A) Fluorescent image of individual E. coli displaying marked cell to cell variability in the expression of two identically regulated fluorescent proteins. (B) Schematic depiction of the temporal behaviors of extrinsic noise (upper) and intrinsic noise (lower). (C) Expressed cell-to-cell variations when fluctuations are intrinsic, extrinsic, or both. Figure 1 from A. Raj and A. Oudenaarden (Cell 135: 216 (2008)).

A new type of neuron: A team of researchers from the University of California at San



Diego and the Salk Institute in La Jolla, California led by Alan Litke (UC at Santa Cruz) discovered a new ganglion cell, first observed more than 40 years ago in cats, but never seen in primates. The discovery was enabled by the development of a 512-electrode array by Litke and his colleagues. It is believed that the upsilon cells went undetected by traditional physiological techniques for so long because they are a tiny fraction of all ganglion cells in the primate retina. The qualities of the newly discovered cells suggest that they may contribute to the perception of motion. Litke and his team started out developing instruments to look for the fundamental elementary particles of nature. They soon realized that they could apply some of those technological concepts to studying neural systems. In addition to helping discover and characterize new neurons, the new technology will guide the design of future retinal prosthetic devices.

Real-time observation of RecA filament dynamics: RecA is a protein partially responsible fluorescence assays and hidden Markov modeling, the group led by T Ha at UIUC, have revealed the molecular mechanism of the process. For the first time, researchers have for maintaining genomic integrity throughout recombination. Using single molecule directly observed how a protein (Rec A) captures and processes a DNA molecule before it searches and replaces another DNA of identical sequence. Their experiments show that a RecA filament grows and shrinks primarily one DNA monomer at a time and only at the extremities. Both ends grow and shrink, contrary to expectation, but a higher binding rate at one end is responsible for directional filament growth. Quantitative rate determination also provides insights into how RecA might control DNA accessibility in vivo. This work was reported in an article by Joo et al. Cell 126:515(2006). Ha was the recipient of a CAREER award and is the PI of a recently funded Physics Frontier Center.



Above. Direct Observation of Mechanism of Gene Recombination. A double stranded DNA with a 3'-$(dT)_n$ single strand DNA tail is immobilized on a surface. FRET between fluorescent labels report on the changes in the average end-to-end distance of the single stranded DNA. This figure is taken from C Joo et al. (Cell 126:515(2006)).

2.Development of human resources

In the three years 06-08 a total of 33 proposals were funded, 7 CAREER and 26 regular awards. In addition 3 SGERs were funded.

A similar proportion of CAREER awards were successful (7/41 = 17 %) to regular proposals (26/147=18%). The panel further notes that a high fraction of awards have been made to younger researchers (15/36 = 42 % of the awards were made to researchers within 10 years of their PhD).

Of the seven CAREER awards five were female and one a minority, counteracting the regrettable absence of female and minority PI's amongst the 26 successful regular awards, an imbalance that the committee thinks requires attention. The predominance of female researchers among the younger cohort promises much better balance in the future.

A number of the researchers – especially the CAREER awardees – are actively involved in outreach, educational and diversity programs. Amongst many outstanding examples, one CAREER proposal builds on the interdisciplinary nature of the research platform to develop the graduate biophysics program at Indiana University, Bloomington, with the development of courses at three levels, for non-scientists, undergraduate science majors as well as advanced graduate students.

C. Committee Recommendations

1. PoLS program areas

The committee saw the funding rate (about 17% of submitted proposals are funded over the three year period, and the rate fell to near 10% in 2008) as a major challenge for the program. This low funding rate is a result of mounting pressure for support combined with a low budget. In order to support the program the Program Director was forced to substantially cut proposed budgets, and in some cases excellent proposals that received high priority ratings could not be supported. The committee felt that acceleration of program funding is in order, if at all possible.

The pressure to identify the very best proposals for support requires a very high confidence in the review process. It is essential to use successive mail and panel reviews in order to achieve this. The committee saw clear examples where both levels of review were necessary and urges the continuation of this system.

A need for greater representation of women and minorities in PoLS funding was seen. While the CAREER program has a very strong representation of female awardees and some minority representation, the regular grants lack diversity.

The committee was impressed by the quality of educational programs in the CAREER proposals, and in general with the level of commitment to ensuring broader impacts. The current crop of CAREER awardees is likely to act as effective role models for future researchers in the field.

A major challenge before PoLS is making sure that both *in vitro* and *in vivo* research is represented in the total NSF portfolio, in part through cooperation with other PoLS programs. The committee saw some danger that excellent proposals might "fall between the cracks" of program coverage; the committee applauds joint efforts between PoLS and other programs to avoid this (e.g., joint panels, joint funding, especially with the Molecular Biophysics program). At the same time, the committee urges the Program Director to work with the community to make sure researchers know which program is most receptive to a given type of proposal. The committee suggested the possibility of having an NSF Workshop on Opportunities in Physics of Living Systems where researchers could meet and discuss research directions with NSF staff.

2. NSF-wide issues

Some special opportunities exist this year thanks to the impending economic stimulus package, which may include short-term funding for special NSF programs. The committee saw the opportunity to fund fellowships for both graduate students and postdoctoral researchers to be particularly attractive. The low numbers of graduate fellowships (< 400 in physics per year) could certainly be increased while continuing to fund top-notch students. Fellowship funding provides a fast and effective way to fund research, since most NSF-funded projects rely on graduate student and postdoc work. Research in PoLS, typically small-scale single-investigator projects, could greatly benefit from additional graduate student or postdoctoral researcher fellowship support.

The committee felt able to accomplish its first goal of essentially auditing the proposal review and award process. However, when asked to examine division-wide strategic and planning issues, the committee found the overarching problem of budget limitations to severely impede meaningful discussion. The reality is that dwindling real budgets are forcing mean grant sizes into a regime where they are insufficient to support even one graduate student or postdoctoral researcher. This trend is systematically reducing productivity of labs in existing programs, and is blocking growth of new programs and initiatives.

Should budget constrains relax sufficiently that future CoVs might consider adjusting overall strategy and program balance, this would be helped by having comparative data available (e.g., time since PhD) of awardees and applicants; tracking of researcher history (e.g., are senior researchers moving between fields); trends in grant size and numbers of grants; comparable data from cognate subprograms in other directorates (e.g., DMR, BIO). If the CoV had access to this type of data it would facilitate evaluation of research trends, and opportunities for co-funding.

9. Physics at the Information Frontier Subcommittee Report

Background

The Physics at the Information Frontier (PIF) program has not been reviewed by any previous COV. It was a new program in 2005, too new to be included in the 2006 review.

However, the origin of the program, though not under the name PIF, goes back further, to 2000 when the first awards began under NSF's Information Technology Research (ITR) initiative. ITR was NSF-wide, but as part of the initiative PHY received new funding at about the $9M/yr level to support physics research related to ITR. New activities started by PHY under ITR included physics grid computing, quantum information science, and computational physics.

When ITR ended in 2005, PHY decided that activities started under ITR deserved to be sustained and the PIF program was created for that purpose. PIF still has a budget comparable to the old ITR program in PHY, about $8.5M, which is split between three subprograms: roughly 40% for grid computing (GC), 40% for quantum information science and revolutionary computing (QIS), and 20% for computational physics (CP). All three of these subprograms overlap substantially with other programs within PHY and beyond, but we recognize the benefits of keeping these subprograms under the separate umbrella of PIF, so that they can be nurtured and protected more effectively than if they were merged into other programs.

Grid Computing

Nearly 75% of GC is spent on a single award, the Open Science Grid (OSG) involving joint projects spread across 15 institutions (PHY- 0621704). The goal of OSG is, in effect, to build a widely accessible world-wide computer, providing thousands of users with access to 100,000 CPUs and 10s of PB of storage (1PB=10^{50} bytes), located at hundreds of sites connected by 10 Gb/s network links. A key part of OSG has been the development of middleware that makes remote computer clusters operate together seamlessly.

PIs who propose to the GC program within PIF should clearly understand that their projects must have a compelling physics motivation. These projects should contribute to the advancement of physics, and furthermore the outcome of the project should be a capability that could not have been developed and provided by industry or the shareware community.

OSG relates to the mission of PHY because it is essential to the two largest projects supported by PHY, LHC and LIGO. Both are large international collaborations that require distributed data management and analysis of petabytes of data. OSG will be an integral part of the LHC Grid and the LIGO Grid, and this need would not have been met without NSF support. The NSF GC program has been closely coordinated with DOE efforts in high energy physics and in high performance computing. This cooperation should continue.

An impending issue is that the current five-year OSG award, which began in 2006, will terminate in FY2010. Continuing GC development may be needed to keep up with advances in data rates and computational needs at LHC and LIGO. PHY can cooperate with NSF's Office of Cyberinfrastructure (OCI) and with DOE in fostering these developments.

We understand that OSG may deserve support from PHY, but we are not convinced that GC belongs inside the PIF program. The rationale for PIF is to provide support for projects that might not be able to garner support from other existing programs. But since the strongest argument for the PHY's role in OSG is that OSG is needed by LHC and LIGO, it might make sense for OSG to be reviewed by panels that can balance that need against the other priorities of these large projects. We also hope that OCI can provide a larger share of the resources needed to maintain and advance OSG in the future.

Advances in grid computing have clear broader impacts. The grid has other important uses beside large physics projects, for example enabling large-scale computations for analysis of global climate. The OSG project includes support for campus grids allowing users to tap into underused computing power in a fiber optic campus network. Grid computing, under the name "cloud computing," is starting to be offered to users by corporations such as Dell, IBM, and Sun. While this may be evidence of the impact of PHY supported research, at the same time we wonder: if industry now recognizes the potential of grid computing and is contributing heavily to its development, will special purpose PHY-supported grid computing efforts continue to be necessary to meet the needs of large physics projects? In any case, we expect that the people trained working on GC physics projects will be an important national resource.

Quantum Information Science

QIS is a relatively new field which draws upon physics, mathematics, computer science, and engineering. Its central aim is to understand how the fundamental principles of quantum physics might be harnessed to dramatically improve the acquisition, transmission, and processing of information. In particular, much of the intellectual excitement driving QIS stems from the theoretical discovery that quantum computers can be exploited to perform important information-processing tasks that are beyond the reach of classical digital computers. Some of the central research themes include: What problems can quantum computers solve and what can't they solve? Can quantum computers perform reliably despite the damaging effects of decoherence and noise? How can scalable quantum hardware be realized? What kinds of collective behavior can occur in highly entangled quantum many-body systems?

The problems that must be solved to realize large-scale quantum computers are deep and challenging. This is not a mere engineering problem; rather it is vital to strengthen the foundations of the field, and to train a new generation of experts on quantum science and technology who can help address the myriad of issues raised by the horizon of Moore's law scaling in silicon. This is an appropriate role for PHY that is not well addressed by other NSF programs or by the more mission-oriented DOD agencies that have also supported some quantum computing research. We also note that there has been heavy international investment in the basic science of QIS, for example in Canada, Europe, Australia, and Japan.

The QIS subprogram supports both theoretical and experimental research in quantum information science. In 2008, 30% of the proposals received were funded (11 of 36, according to the program director). These projects often have substantial intellectual overlap with other programs, such as AMOP inside PHY, DMR and Math inside MPS, and the CCF (computing and communication foundations) program in the CISE directorate. Appropriately, some proposals were co-reviewed by these other programs, and in some cases funding was shared with other programs. After reading some of the panel summaries, we feel strongly that it is useful to get the perspective of a well informed panel that judges QIS proposals broadly on the basis of their potential to advance quantum information research rather than attempting to rank them against other proposals in atomic physics, condensed matter physics, etc. This is especially true for the theoretical proposals.

[Full disclosure: The chair of the PIF subpanel is also the PI for a large award under the PIF QIS subprogram, which is shared equally with CISE.]

On the experimental side, one important outcome of the QIS subprogram has been the demonstration of a quantum memory with unprecedented coherence properties composed of individual electron and nuclear spins in diamond at room temperature (PHY-0653555). For several years, the leading physical realizations of quantum bits ("qubits") with potential for scalability to large-scale quantum computers have been trapped ions, superconducting circuits, and electron spins in quantum dots. Now, thanks to the encouraging recent results, devices that process electron and nuclear spins in diamond have joined the ranks of the most promising candidates for scalable quantum hardware.

On the theoretical side, QIS-supported research has led to new proposals for reading out a topological quantum computer using "anyon interferometry." (PHY-0456720). Topologically encoded quantum information, potentially realizable using suitable fractional quantum Hall states in two-dimensional electron gases, is intrinsically resistant to the damaging effects of local noise, and hence provides an especially appealing route to realizing quantum memory and computing. Developments in the theory of quantum computing have energized the experimental study of fractional quantum Hall physics, as experimentalists around the world have joined the quest to demonstrate and study the topological features of these exotic quantum states of matter. This and other connections between quantum computing and quantum many-body physics illustrate the broader impact of QIS on other areas of physics.

We remark that a PFC largely devoted to QIS research was awarded this year: the Joint Quantum Institute (JQI) at the University of Maryland and NIST. This new center has very high scientific merit, in our judgment.

Computational Physics

Dramatic increases in CPU speed, data storage capability, and the rate of data transfer are enabling more detailed numerical tests of both established and new ideas in physics, while generating new insights into the detailed mechanisms underlying observable phenomena. For example, lattice QCD, which can provide quantitative answers to questions about the nonperturbative physics of hadrons, requires substantial computational resources to achieve the accuracy needed to make contact with experimental data. Similarly, a theoretical understanding of highly nonperturbative behavior in the interactions of atoms with intense sub-femtosecond light pulses is essential for understanding the formation of molecules in "real time." Modeling the temporal evolution of strongly perturbed small diatomic molecules remains a computational challenge, and breakthroughs will be needed to simulate and understand the behavior of larger molecules and ultimately bio-molecules, potentially leading to very high-impact discoveries.

The objective of the computational physics (CP) subprogram of PIF is to provide support for computing projects that would be difficult to support within the disciplinary research programs. For example, development of new algorithms and computational methods are sometimes important to make scientific progress, even when the computations are based on well established theory, but such proposals often get poor reviews within the research programs. The PIF program provides a mechanism for such projects to be evaluated fairly.

On the other hand, we believe that a CP project should be judged based on its potential to advance physics; in particular, as for the GC subprogram, if a major goal of project is to develop new hardware or software tools, then it should be clear that comparable tools could not be developed and provided by industry. CP projects are intellectually diverse, including computations relevant to lattice gauge theory, cosmology, gravitational physics, and atomic physics, among other topics. We found that the reviewers and panels tend to put primary emphasis on the physics content of the proposals, which is appropriate in our view.

We noted that the majority of the CP proposal jackets we reviewed were for collaborations of PIs who submitted separate proposals that were reviewed together. Many of these made large requests, and successful proposals typically received a fraction of what was requested. Furthermore, the total number of CP proposals received was relatively small, and the success rate was correspondingly high, about 50% (according to the program director, 6 of 11 proposals were funded in 2008). CP awards are often shared with other programs, which has further boosted the subprogram's success rate and influence.

We expect the number of CP proposals to increase as PIF support for computational physics becomes better known in the community. Assuming that happens, it might become appropriate to rebalance the priorities within PIF by increasing CP's share of the program and shrinking GC's share. A reasonable goal would be to increase CP to 40% of PIF while decreasing GC to 20%. This shift of resources may be feasible if OCI ramps up support for GC, which seems appropriate to us anyway. Furthermore, in the interest of program balance, and in view of the small CP budget, the CP subprogram should encourage more small proposals from individual investigators relative to the number of requests from large collaborations.

One notable outcome from the CP subprogram has been the Einstein@home project PHY-0555655, which was funded jointly by PHY, the Office of Multidisciplinary Activities (OMA) and the Office of Cyberinfrastructure (OCI). LIGO scientists formed a partnership with the team that started SETI@home to take advantage of unused cycles of computers around the world to analyze LIGO data. Einstein@home has become one of the largest distributed computing projects in the world, providing close to 100 teraflops of computing power around the clock. Einstein@home has more than 150,000 volunteers, who download a computer program onto their personal computers. The program searches LIGO and GEO data for the gravitational-wave continuous signals from rapidly-spinning neutron stars. The Einstein@home has improved upon the Berkeley Open Insfrastructure for Network Computing (BOINC), which can also provide distributed computing capabilities for other science projects. Aside from the benefit of involving the general public in an exciting scientific enterprise, this project combines a strong physics component with the development of useful new tools.

The CP subprogram also supported an innovative recent contribution to computational atomic physics, resulting in improved methods for computing electron-atom and photo-ionization cross sections (PHY-0555226), A widely used R-matrix code was modified by relaxing the orthogonality constraints imposed on the atomic basis functions, which for many years had complicated the interpretation and compromised the accuracy of R-matrix calculations. Electron scattering cross sections computed using the improved program package agree better with experimental results, providing an accurate description of, for example, the electron-impact excitation of mercury.

Program Management

Until recently, the PIF program has been led by Barry Schneider (CP and QIS) and Marv Goldberg (GC). In fact, though, because of the highly interdisciplinary nature of PIF, directors of other programs such as AMOP and gravitational physics have also been actively involved in the evaluation of PIF proposals.

We reviewed the jackets of about 25 proposals. Generally, we felt that reviewers were well chosen and took their responsibilities seriously, and that panels had appropriate expertise and wrote useful summaries. We were especially impressed by the clarity and thoroughness of the review analyses written by the program directors. The process seemed to work, and decisions on proposals were reasonable.

Barry Schneider has been assigned (temporarily?) to OCI, running the TeraGrid, another NSF computing project. For now Bev Berger is covering CP, while Bob Dunford covers QIS. Soon, Dick Pratt will arrive and become the program director for CP and QIS. We hope this succession of staff changes will not cause disruptions in management of the program.

We think that PIF is a successful and well run program. PHY deserves praise for seizing the opportunity provided by the ITR initiative to support some exciting interdisciplinary science, and for the judgment and perseverance to extend that success under PIF when ITR ended.

To recapitulate some of our earlier comments, we are not sure whether GC really belongs in PIF, or whether PHY should be expected to support grid computing for much longer. Now that grid ("cloud") computing has developed momentum within industry, it might make sense to redirect some PIF resources toward other computing needs of modern physics experiments that are not being adequately addressed by industry or the shareware community. We would like to see a more balanced CP program, with a larger number of individual investigator awards. For now, CP is hampered by the surprisingly small number of incoming proposals, and we encourage the program directors to redouble their efforts to publicize the CP subprogram.

As quantum information science continues to grow, we expect that competition for PIF proposals will become increasingly tight. The PIF program directors have done a good job on the challenging task of expanding NSF support for QIS by cooperating productively with managers of other programs, especially in DMR and in CISE/CCF. Ultimately, the cause of fostering the development of QIS might be best served by a highly visible coordinated program cutting across the MPS and CISE directorates that is well matched to the highly interdisciplinary character of QIS. But we recognize that the creation of such a cross-divisional program will require high enthusiasm from the NSF leadership, and cannot be achieved by PHY alone.

10. Physics Frontiers Centers Subcommittee Report

Introduction

Physics Frontier Centers are designed to support large university-based groups to foster transformational advances in the most promising research areas. The criteria for selection are:

- (1) the potential for a profound advance in physics;
- (2) creative, substantive activities aimed at enhancing education, diversity, and public outreach;
- (3) potential for broader impacts, e.g., impacts on other field(s) and benefits to society;
- (4) a synergy or value-added rationale that justifies a center- or institute-like approach

General overview

Support for the nine current PFC's amounts to about 9% of the total Physics Division budget. The support for a center ranges from $1M to $4M per year. NSF support is provided in the form of Cooperative Agreements with a 5 year duration. In most cases, based on reviews and site visits, extensions of these agreements have been granted in order to establish a regular review calendar.

Unlike NSF S&T centers, PFC's do not automatically sunset after two terms, but may apply for renewal in competition with new PFC proposals. Half the centers are to be included in each competition, planned on a three year calendar. This process is designed to assure that the most successful PFC's receive continued support.

Centers and Individual Investigators

The PFC concept is based on the premise that the synergy created by the large group support results in added value as compared to spending the same resources on the core program. It recognizes that some truly transformational frontier research requires the coordinated, often interdisciplinary group attack to catalyze breakthrough. The goals are to

- Capture exciting breakthroughs
- Bring together talents, skills, disciplines
- Bring together different communities
- Act as a major educational magnet
- Support areas ripe for advances by teams

The currently supported Centers are:

- Joint Institute for Nuclear Astrophysics – University of Notre Dame
- Center for the Physics of Living Cells – UIUC
- Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas – University of Wisconsin
- Center for Theoretical Biological Physics – UC San Diego
- Joint Quantum Institute – University of Maryland
- Kavli Inst. for Theoretical Physics – UC Santa Barbara
- JILA AMO Physics Frontier Center – University of Colorado
- Kavli Institute for Cosmological Physics – University of Chicago
- Center for Ultracold Atoms – MIT

As a group, the PFC's represent a stellar collection of outstanding clusters of leading scientists, including multiple Nobel laureates. The impact of the work carried out in the PFC's is profound.

As seen from the external reviews, PFC's are well-respected by the scientific community. The following quotes are representative:

"By encouraging the broad interchange of ideas, new areas of cross-disciplinary investigation are opened up and the unity of different subfields of physics are promoted."

"The [center] is a national treasure for science."

"This Physics Frontier Center has done exactly what it was intended to do. It has served as the catalyst to bring groups from different fields together to attack a very important problem."

"New capabilities have been added to broaden the linkage between the nuclear and astrophysics communities."

"The Center brings together the astronomy, astrophysics, and gravitational physics communities."

Integrity and Efficiency of the Program Process and Management

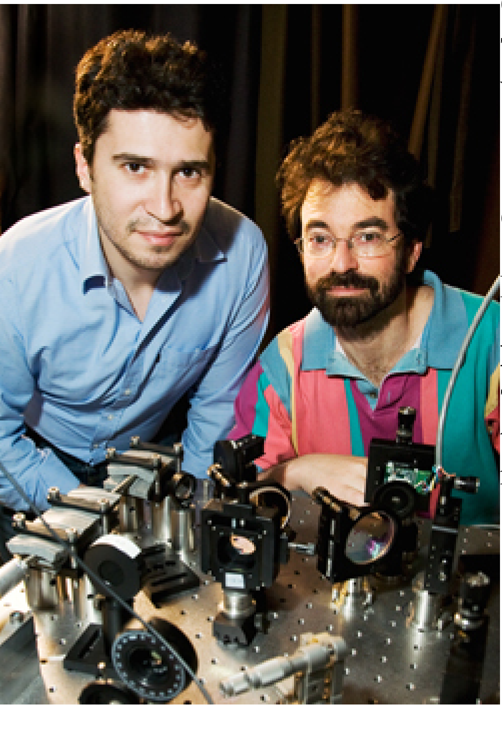
Four of the original Centers were renewed in 2006 based on full proposals and ad-hoc reviews. Due to lack of funds, no solicitation of new proposals were included at this time.

The Subcommittee paid special attention to the 2008 round of PFC competition. In response to the program solicitation, 69 pre-proposals were received. Most of these were deemed responsive to the solicitation, and were subject to a thorough panel review. Based on the report of the panel 19 groups were invited to prepare and submit full proposals. Full proposals were sent for ad-hoc reviews, and each of these received generally between 5 and 7 reviews. Based on advice from the Program Directors in the relevant subject areas (including other Divisions and Directorates where appropriate) 12 of the groups were invited for reverse site visits. The panel assembled for the reverse site visit met for 3 days, and prepared reports on each of the proposing Centers. Based on all the information available, the Program Director, with the benefit of co-funding from

Other Divisions and Directorates, recommended funding for 5 Centers. Three of these were renewals, and two were new. The other two existing Centers applying for renewal are being phased out.

The subcommittee had extensive discussions with the Program Director, and free access to all of the full proposals, ad-hoc reviews, panel reports, correspondence, as well as the Review Analyses by the Program Director. A sample of the pre-proposal files that were not invited to submit full proposals were also examined. The documentation was found to be exemplary in its thoroughness and clarity. Actions were clearly justified and based on the reviews. The subcommittee feels that the three-step procedure (panel for pre-proposal, ad-hoc plus panel for full proposals), is an excellent and fair way of consulting both subject matter experts, and balancing the widely different (and often interdisciplinary) fields covered by the proposals.

To oversee the functioning of the Centers, the Program Director organizes 2-day site visits with a panel in the third year of operation, and additional site visits as deemed necessary. The Directors of the Centers meet once a year giving them and the Program Director the opportunity to exchange information, share ideas and best practices, especially in the areas of education and outreach.



Outputs and Outcomes of Program Investments

The following illustrative highlights were collected from the websites of individual Centers:

Center for the Study of Living Cells, UIUC

PNAS *April 22, 2008 vol. 105 6016-6021*

Dance of the Chromosomes

The intricate dance of cell division, by which the genetic code is transferred to daughter cells, is little understood. In a new study, researchers in Paul Selvin's group, in collaboration with scientists at

Columbia University, reveal how a key motor protein choreographs chromosome movements at a critical stage of cell division.

Just how chromosomes move during mitosis, when they must line up at the middle of a parent cell to allow for their separation between the two daughter cells, is of fundamental importance to biology. Errors in coordination result in disease or cell death.

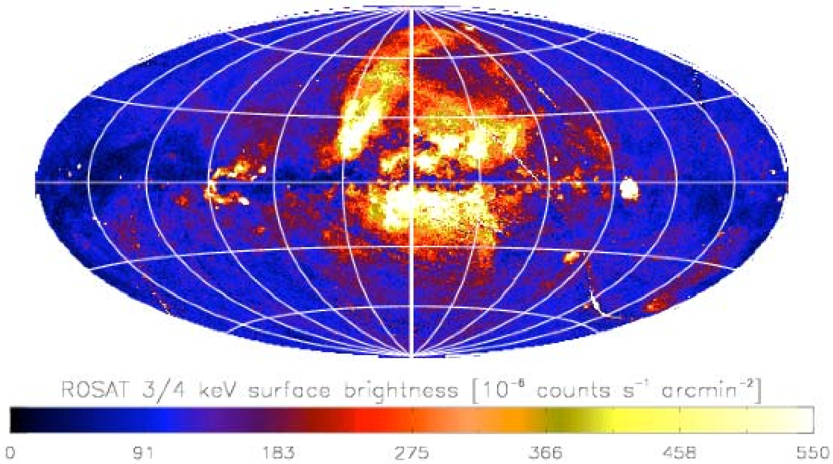
Selvin's group made single-molecule measurements of centromeric protein E (CENP-E), which plays a key role in the movement of chromosomes during mitosis. They showed that CENP-E takes 8-nm hand-over-hand steps, analogous to the motor protein kinesin-1.

To play a movie of CENP-E, labeled with a quantum dot, walking along an axeoneme *in vitro* see http://www.physics.uiuc.edu/people/selvin/CENP-E_Qdot.avi

Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas

Galactic Winds Driven by Cosmic Rays

The inner parts of our galaxy may be a dramatic example showing how small scale fluctuations can act in concert to drive large scale flows. The figure below shows x-ray emission from the inner galaxy, emitted by gas at several million degrees. The gas was probably heated over millions of years by multiple supernova explosions, and in previous models it has been assumed to be at rest, supported against the galactic gravitational field by its own pressure. However, supernovae also create the relativistic nuclei known as cosmic rays. As the cosmic rays stream away from the supernovae, they excite short wavelength magnetic fluctuations, which transfer momentum to the gas. We showed that this process can impart enough momentum to actually drive the gas out of the galaxy. This galactic wind carries away about 2 solar masses of gas each year, making it important for galactic evolution. The wind model is a better fit to current observations than the static model, and we are in the process of developing additional observational tests based on the synchrotron and gamma radiation expected from cosmic rays in the wind. Cosmic ray driven winds of this type may also have been important in young galaxies, and for heating the intergalactic medium.



Soft x-ray emission from the inner Milky Way galaxy, showing the presence of hot (several million degree) gas. Figure from J. Everett, E. Zweibel, R. Benjamin, D. McCammon, L. Rocks, J. Gallagher, "The Milky Way's Kiloparsec-Scale Wind," Astrophysical Journal, V. 674, 258 (2008).

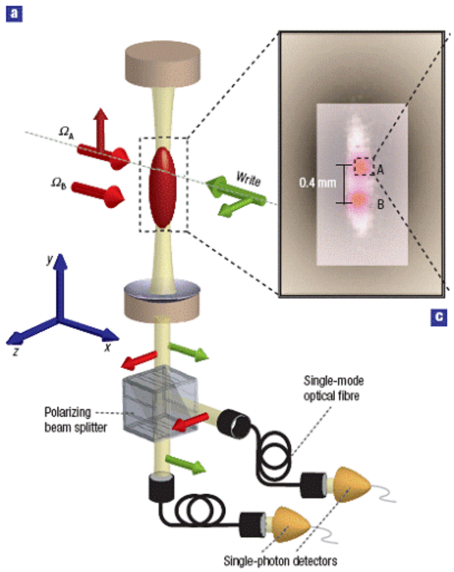
Center for Ultraacold Atoms

Single-photon bus connecting spin wave quantum memories

(J.Simon, H.Tanji, S.Ghosh, and V.Vuletic, Nature Physics **3**, 765 (2007)).

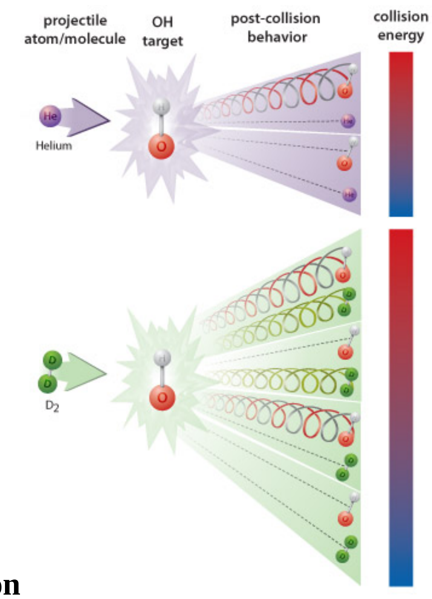
Generation of non-classical correlations (or entanglement) between particles is at the heart of quantum information science. Of particular interest are material systems serving as quantum memories that can be interconnected optically. An ensemble of atoms can store a quantum state in the form of a magnon—which is a quantized collective spin excitation—that can be mapped onto a photon with high efficiency.

In order to transfer a magnon from one ensemble to another via the mode of an optical resonator, it may appear necessary to convert the magnon in ensemble A into a photon, and absorb the photon in ensemble B to create a magnon. Now quantum mechanics permits such a process even if the photon involved is only virtual, i.e. if it exists only with vanishingly small probability. Such a process via a "dark photon" or "dark state" of the resonator can be used to avoid loss of the photon from the resonator. We have demonstrated such a phase coherent transfer of a single magnon from one atomic ensemble to another via an optical resonator serving as a quantum bus that in the ideal case is only virtually populated. Partial transfer of a single magnon then deterministically creates an entangled state with one excitation jointly stored in the two ensembles. The entanglement is verified by mapping the magnons onto photons, whose correlations can be directly measured.



Set-up for phase-coherent optical transfer of a spin-wave quantum between two ensembles and entanglement generation. Two ensembles, A and B, are defined within a cloud of laser-cooled cesium atoms by two laser beams. Transfer of a single spin-wave quantum between ensembles A and B is accomplished via a “dark state” of the optical resonator, i.e. the photon connecting the two samples in the ideal limit exists only “virtually”, avoiding photon loss from the resonator. Transfer of “half a spin-wave quantum” creates deterministically an entangled state between the two ensembles.

JILA Center for AMO Physics



Beams In Collision

Cold collision studies show that the behavior of a He atom hitting a molecule of OH is much different from a D_2 molecule hitting it. D_2 experiences a collision resonance, giving credence to the idea that collisions of H_2 molecule with OH masers in interstellar clouds could stimulate masing.

Credit: Greg Kuebler

Last year the Ye group conducted an actual laboratory astrophysics experiment. Graduate students Brian Sawyer, Ben Stuhl, and Mark Yeo, research associate Dajun Wang, and Fellow Jun Ye fired cold hydroxyl (OH) radicals into a linear decelerator equipped with an array of highly charged electrodes and slowed the OH molecules to a standstill. These molecules were then loaded into a permanent magnetic trap where they became the stationary target for collision studies. Next, Sawyer and his colleagues aimed supersonic beams of either helium (He) atoms or deuterium molecules (D_2) at the OH molecules. They then studied the resulting low-energy collisions, which took place at temperatures of 80–300 K.

With respect to the D_2 collisions, they wanted to see if their findings would shed light on the action of OH masers (See *JILA Light & Matter*, Spring 2008). Some theorists posit that OH masers emit coherent radio-wavelength photons after being excited by collisions with H_2 molecules at temperatures only a few tens of degrees K lower than those in the laboratory experiment.

For this reason, the researchers planned to use H_2 supersonic beams in their collision studies. However, their turbo pumps didn't work with H_2. Luckily, D_2 molecules are chemically similar to H_2, and their collision behavior was expected to be very similar to that of H_2. The D_2 molecules also had the advantage of being as massive as the He atoms, so the pumps worked.

The results of the experiments depended on whether the molecular beam contained He atoms or D_2 molecules. In a He—OH collision, the billiard ball-like He atom would either start an OH molecule spinning in an inelastic collision, or it would bounce off the OH molecule without rotating the molecule (elastic collision). When the collision energies fell below the rotational excitation energy in OH, the inelastic collisions stopped.

Things were more interesting when the incident beam consisted of D_2 molecules. Here, the D_2–OH collisional energies were the lowest ever measured in the laboratory. The much more complex D_2 molecules were excited by some of the OH molecules via a collisional resonance that set both molecules spinning, as shown in the lower portion of the figure. Similar resonant energy transfer may also occur when H_2 molecules collide with OH molecules in interstellar clouds where the average temperature is 30–50 K. The laboratory astrophysics project supported the idea that H_2 molecules may be involved in stimulating OH masers.—*Julie Phillips*

Reference:
Brian C. Sawyer, Benjamin K. Stuhl, Dajun Wang, Mark Yeo, and Jun Ye, **Physical Review Letters** 101, 203203 (2008).

Joint Quantum Institute

LONG-DISTANCE TELEPORTATION BETWEEN ATOMS

Landmark Result May Hasten Advent of Quantum Repeaters, Networks

For the first time, scientists have successfully teleported information between two separate atoms in unconnected enclosures a meter apart – a significant milestone in the global quest for practical quantum information processing.
Teleportation may be nature's most mysterious form of transport: Quantum information, such as the spin of a particle or the polarization of a photon, is transferred from one place to another, but without traveling through any physical medium. It has previously been achieved between photons over very large distances, between photons and ensembles of atoms, and between two nearby atoms through the intermediary action of a third. None of those, however, provides a feasible means of holding and managing quantum information over long distances.
Now a team from the Joint Quantum Institute (JQI) at the University of Maryland (UMD) and the University of Michigan has succeeded in teleporting a quantum state directly from one atom to another over a substantial distance.*

In the Jan. 23 issue of the journal Science, the scientists report that, by using their protocol, atom-to-atom teleported information can be recovered with perfect accuracy about 90% of the time – and that figure can be improved.

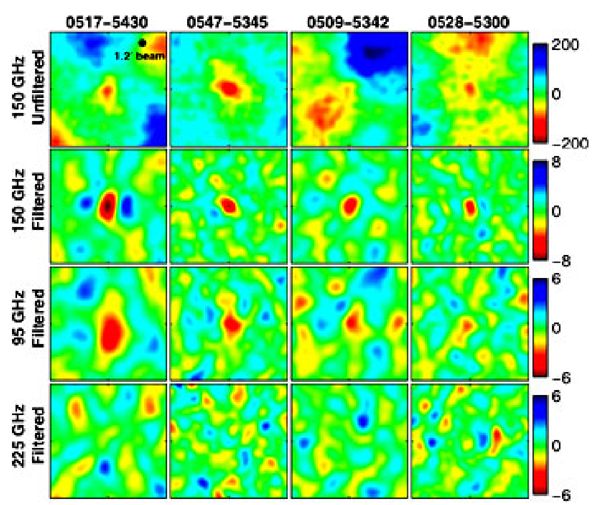
“Our system has the potential to form the basis for a large-scale ‘quantum repeater’ that can network quantum memories over vast distances,” says group leader Christopher Monroe of JQI and UMD. “Moreover, our methods can be used in conjunction with quantum bit operations to create a key component needed for quantum computation.” A quantum computer could perform certain tasks, such as encryption-related calculations and searches of giant databases, considerably faster than conventional machines. The effort to devise a working model is a matter of intense interest worldwide.

* "Quantum Teleportation Between Distant Matter Qubits," S. Olmschenk, D. N. Matsukevich, P. Maunz, D. Hayes, L.-M. Duan and C. Monroe. *Science*, **323**, 486 (23 January 2009).

Kavli Institute for Cosmological Physics

Galaxy clusters discovered with the South Pole Telescope

The first major scientific results from the South Pole Telescope initial survey were released on October 10, 2008. A paper submitted to the Astrophysical Journal describes the detection of four distant, massive clusters of galaxies in an initial analysis of South Pole Telescope (SPT) survey data. Three of these galaxy clusters were previously unknown systems and, therefore, represent the first clusters detected using observations of the interaction between the hot gas in the cluster and Cosmic Microwave Background photons --- a process known as the Sunyaev-Zel'dovich (SZ) effect. These first four galaxy clusters are the most significant SZ detections from a subset of the ongoing SPT survey. As such, they serve as a demonstration that SZ surveys, and the SPT in particular, can be an effective means for finding galaxy clusters.



Kavli Institute for Theoretical Physics

The Scaling Laws of Human Travel

The goal of this project was to assess the statistical properties of human traffic on length scales of a few to a few thousand kilometers. A very simple question that initially motivated this was “What is the probability of a human being travelling a certain distance in a short period of time?” taking into account all possible means of transportation. Simple as it is, this question is difficult to answer because in order to do so one would have to collect and compile date for various involved human traffic networks: air transportation, highway traffic as well as railroad networks.

Movie 1: The scaling laws of human travel: Television Feature on DW-TV. (Click on image to watch.)

In this project we approached the problem from an unusual angle. Instead of measuring the geographical movement of individuals, we evaluated data collected at the online bill tracking system www.wheresgeorge.com in order to assess the statistical properties of the geographic circulation of money instead. The idea behind this project was to use the dispersal of money as a proxy for human travel as bank notes are primarily transported from one place to another by traveling humans.

Wheresgeorge.com, which was invented by Hank Eskin in 1998, is a popular US internet game in which participants can register individual dollar bills for fun and monitor their geographic circulation. Since its beginning a vast amount of data has been collected at the website, over 100 millions of dollar bills have been registered by over 3 million registered users and over 10 million bills have had "hits", that means they resurfaced somewhere else.

Our initial study was based on a dataset of roughly a million individual displacements. We found that the dispersal of dollar bills can be described by a set of simple mathematical laws. First, the probability of traveling a distance in a short period of time days decays as a power law, i.e.

$$p(r) \sim \frac{1}{r^{1+\beta}} \qquad \beta \approx 0.6$$

This observation lead us to conjecture that the trajectories of dollar bills are reminiscent of Lévy flights, superdiffusive random walks characterized by a power law in the single step distribution.

The situation turned out to be more complex, as also broadly distributed waiting time distributions play a role which leads to a subdiffusive component of money dispersal and a competition of long jumps and long waiting times. Effectively money dispersal can be described with a bi-fractional diffusion equation.

UCSB's Kavli Institute Makes Pioneering Physics Accessible to High School Educators

December 1, 2008

(Santa Barbara, Calif.) — Award-winning classroom science presentations produced by outstanding teachers and selected by one of the country's pre-eminent physics research centers are now available for use by educators everywhere.

The Kavli Institute for Theoretical Physics (KITP) at UC Santa Barbara has awarded $7,000 in cash prizes to six science teachers for their exceptional multimedia classroom presentation on particle physics in the age of the Large Hadron Collider. The teachers' winning presentations can be viewed and downloaded at: http://www.kitp.ucsb.edu/kitpnews/item/?id=55.

The prize recipients were among 78 educators who recently took part in a popular and important Kavli Institute program that brings high school teachers from around the country to UCSB each year to interact with renowned scientists on the most exciting and current areas of modern physics research. The annual teachers' conference, like all research and educational activities at the KITP, is supported by the National Science Foundation. The prizes are funded by a generous gift from local donors.

The conference was held in conjunction with a KITP research program on the Large Hadron Collider. Conference lecturers were chosen from among the leading international researchers who were invited to the institute to advance research in particle physics.

The Large Hadron Collider at the European Laboratory for Particle Physics (CERN) in Geneva, Switzerland, involves scientists from 111 nations who are expected to carry out experiments that will change our understanding of the fundamental makeup of the universe.

Participating teachers were asked to prepare a talk summarizing the conference lectures and accompanying discussions, suitable for presentation during a single science class period. Entries in the competition were reviewed by a panel of peer teachers and distinguished physicists. The prizes, which recognize excellence in teaching high school physics, were established by Simon and Diana Raab, of Santa Barbara.

First prize was awarded to Kevin McKone, Copiah-Lincoln Community College, Wesson, Miss. Jon Anderson from Centennial Senior High School, Circle Pines, Minn., won second prize. Four teachers shared third prize: Steven Brehmer, Mayo High School, Rochester, Minn.; Cheryl Harper, Greensburg Salem High School, Blairsville, Pa.; Nick Nicastro, Wachusett Regional High School, Holden, Mass.; and Gail Van Ekeren, Gill St. Bernard's School, Gladstone, N.J.

In addition to funding visiting scholars and graduate fellows, the KITP undertakes many outreach activities, including a popular public lecture series, visits by KITP postdoctoral researchers to local high schools to talk about their research, conferences that foster interaction between the humanities and sciences, a journalist-in-residence program to promote excellence in scientific journalism, and an artist-in-residence who fosters exploration of relationships between science and art.

Appendix A: Division of Physics Committee of Visitors
February 4-6, 2009 - Agenda

Wednesday, February 4 - Room 555 II

7:30 am	Continental Breakfast
8:00 am	Welcome and Charge to Committee of Visitors (COV) Tony F. Chan, Assistant Director, Directorate for Mathematical and Physical Sciences (MPS)
8:20 am	Introductory Remarks Sidney Wolff, Chair, COV
8:40 am	COV Guidelines Morris Aizenman, Senior Science Associate, OAD/MPS
9:10 am	PHY Overview, Priorities, and Directions Joe Dehmer, Director, Division of Physics (PHY)
10:00 am	Break
10:15 am	Response to 2006 COV Report and Instructions for Breakout Sessions – Joe Dehmer, CoV Chair
10:45 am	Demonstration on the Use of the NSF E-jacket System (Optional)
11:15 am	Review of Individual PHY Programs (Move to Breakout Rooms) Examination of Jackets to Address • Integrity and Efficacy of Program Processes for Proposal Actions • Quality and Significance of the Results of Program Investments • Relationship to Foundation-wide Programs and Strategic Goals
12:30	Lunch
1:30 pm	Review of Individual PHY Programs (Continued in Breakout Rooms) Examination of Jackets (Continued)
4:45 pm	Executive Session with Panel and Designated Federal Official only
5:30 pm	Adjourn for Informal Reception in Room 1020

Thursday, February 5

7:30 am	Continental Breakfast (Room 1020)
8:00 am	Review of Individual PHY Programs (Continued in Breakout Rooms)
	Overview of Program – Program Directors (30 minutes)
10:00 am	Preparation of Individual Program COV Reports
12:00 pm	Working Lunch
2:00 pm	Break and Distribution to COV Chair of Individual Program Reports
2:30 pm	Presentation of COV Reports by Program COV Chairs (Room 555 II)
4:30 pm	Introduction to Division-Level Review – Joe Dehmer • Division's Processes, Results, and Relationship to NSF Goals • Division's Balance, Priorities, and Future Directions • Any Other Issues the COV Considers Relevant to the Review
5:30 pm	Adjourn

Friday, February 6 - Room 555 II

7:30 am	Continental Breakfast (Room 555 II)
8:00 am	Division-Level Review - Continued
10:30 am	Preparation of Division-Level Report
12:00 pm	Working Lunch
2:00 pm	Complete Draft of Division-Level Report
2:30 pm	Closeout Session with AD/MPS and PHY Staff
3:00 pm	Adjourn

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Dr. Hendrick Weerts
High Energy Physic
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Dr. Min Xiao
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Fayetteville, AR 72701

Dr. Sidney Wolff (Chair)
National Optical Astronomy Observatory
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Tucson, AZ 85726

Division of Physics – Committee of Visitors
List of Disciplinary Program Sub-Panel Members

AMOP
Randy Hulet (Chair)
Dan Stamper-Kurn
Edward Thomas
Min Xiao

EIR
Beth Cunningham (Chair)
Truell Hyde
Laird Kramer

EPP and LHC
Daniela Bortoletto
Natalie Roe (Chair)
Harry Weerts

Gravity and LIGO
Thomas Baumgarte
Eanna Flannagan (Chair)
John Friedman

Nuclear Physics and NSCL
Gail Dodge
Richard Milner (Chair)
Brad Sherrill

Physics of Living Systems
Angel Garcia
Peter Littlewood
John Marko (Chair)

Particle and Nuclear Astrophysics and DUSEL
Pat Burchat
Uwe Greife
Angela Olinto
Mike Schaevitz (Chair)

Physics at the Information Frontier
John Preskill (Chair)
Uwe Thumm

Theoretical Physics
Mark Edwards
Charlotte Elster
Barbara Gentz
Gordon Kane (Chair)
Ann Nelson
Jorge Piekarewicz
Marianna Safronova

Physics Frontiers Centers
Larry Gladney
Janos Kirz (Chair)

Appendix C: Charge to Panel

NATIONAL SCIENCE FOUNDATION
4201 Wilson Boulevard, Arlington, Virginia 22230

Office of the Assistant Director
Mathematical and Physical Sciences

October 23, 2008

Dr. Sidney Wolff
Director Emeritus, NOAO
P.O. Box 26732
Tucson, AZ 85726

Dear Dr. Wolff:

Thank you for agreeing to serve as Chair of the FY 2009 Committee of Visitors (COV) for the Division of Physics (PHY). The COV Review will take place at the NSF in Arlington, Virginia, on Wednesday through Friday, February 4-6, 2009; we expect to begin early Wednesday morning and conclude by 5 pm on Friday. The COV is an *ad hoc* subcommittee of the Mathematical and Physical Sciences Advisory Committee (MPSAC). Your appointment to the COV commences December 1, 2008 and ends with the presentation of the COV report to the MPSAC on April 3, 2009.

By NSF policy, each program that awards grants and cooperative agreements must be reviewed at three-year intervals by a COV comprised of qualified external experts. NSF relies on their judgment to maintain high standards of program management, to provide advice for continuous improvement of NSF performance, and to ensure openness to the research and education community served by the Foundation. Reports generated by COVs are used in assessing agency progress in order to meet government-wide performance reporting requirements, and are made available to the public. The COV is charged to address and prepare a report on:

- the integrity and efficacy of processes used to solicit, review, recommend, and document proposal actions;
- the quality and significance of the results of the Division's programmatic investments;

- the relationship between award decisions, program goals, and Foundation-wide programs and strategic goals;
- the Division's balance, priorities, and future directions;
- the Division's response to the prior COV report of 2006; and
- any other issues that the COV feels are relevant to the review.

A more complete description of the charge to the COV is provided as an enclosure below. The COV report is made available to the public to ensure openness to the research and education community served by the Foundation.

Decisions to award or decline proposals are ultimately based on the informed judgment of NSF staff, based on evaluations by qualified reviewers who reflect the breadth and diversity of the proposed activities and the community. Systematic examination by the COV of a wide range of funding decisions provides an independent mechanism for monitoring and evaluating the overall quality of the Division's decisions on proposals, program management and processes, and results.

The review will assess operations of individual programs in PHY as well as the Division as a whole for three fiscal years: FY 2006, FY 2007, and FY 2008. The PHY programs under review include:

- Atomic, Molecular, Optical, and Plasma Physics
- Education and Interdisciplinary Research
- Elementary Particle Physics
- Gravitational Physics
- Nuclear Physics
- Particle and Nuclear Astrophysics
- Physics at the Information Frontier
- Physics Frontiers Centers
- Physics of Living Systems
- Theoretical Physics

The meeting will begin with introductory sessions that will provide background on the COV process by MPS Staff and an overview of the Division's programs and activities by the Division Director, Joseph L. Dehmer. Following these presentations, the COV will have an opportunity to examine program documentation and results and to gather information for their report. The Committee will also be given time for general discussion and conversation with program staff. The last day of the meeting will be spent primarily drafting the report.

As Chair of the COV, you will finalize and submit the full report by March 2 to allow time for comment and distribution of the report to the full MPSAC prior to their meeting on April 2-3, 2009. We hope that you will be available to present the report to the MPSAC at this meeting and summarize it.

Denise Caldwell, the Deputy Division Director, (703-292-7371, dcaldwel@nsf.gov) will send you an agenda and instructions for accessing a password-protected website that will contain background information to assist you in conducting this review. You should expect to receive this letter just prior to December 1, which is the starting date of your appointment. Please feel free to contact Denise or Joe if you have questions about the review.

The PHY Division Secretary, Denise S. Henry (703-292-7386, dshenry@nsf.gov), will contact you within the next week or so with information about making travel and hotel arrangements.

Thank you again for your willingness to participate in this important activity.

Sincerely,

Tony F. Chan
Assistant Director

Enclosures: Excerpt from COV guidelines
List of Members of FY 2009 PHY COV

cc: Dr. Iain Johnstone, Chair MPSAC

Attachment: From Subchapter 300 of the NSF COV Guidelines:

366. The COV Core Questions and Reporting Template will be applied to the program portfolio and will address the proposal review process used by the program, program management, and the results of NSF investments. Questions to be addressed include

a) the integrity and efficiency of processes used to solicit, review, recommend and document proposal actions, including such factors as:

(1) selection of an adequate number of highly qualified reviewers who are free from bias and/or conflicts of interest;
(2) appropriate use of NSF merit review criteria;
(3) documentation related to program officer decisions regarding awards and declines;
(4) characteristics of the award portfolio; and
(5) overall management of the program.

b) the relationships between award decisions, program goals, and Foundation-wide programs and goals;

c) results of NSF investments for the relevant fiscal years, as they relate to the Foundation's current strategic goals and annual performance goals.

d) the significant impacts and advances that have developed since the previous COV review and are demonstrably linked to NSF investments, regardless of when these investments were made. Examples might include new products or processes, or new fields of research whose creation can be traced to NSF-supported projects.

e) the response of the program(s) under review to recommendations of the previous COV review

Appendix D

CORE QUESTIONS and REPORT TEMPLATE
for
FY 2009 NSF COMMITTEE OF VISITOR (COV) REVIEWS

Guidance to NSF Staff: This document includes the FY 2009 set of Core Questions and the COV Report Template for use by NSF staff when preparing and conducting COVs during FY 2009. Specific guidance for NSF staff describing the COV review process is described in Subchapter 300-Committee of Visitors Reviews (NSF Manual 1, Section VIII) that can be obtained at <www.inside.nsf.gov/od/oia/cov>.

NSF relies on the judgment of external experts to maintain high standards of program management, to provide advice for continuous improvement of NSF performance, and to ensure openness to the research and education community served by the Foundation. Committee of Visitor (COV) reviews provide NSF with external expert judgments in two areas: (1) assessments of the quality and integrity of program operations and program-level technical and managerial matters pertaining to proposal decisions; and (2) comments on how the results generated by awardees have contributed to the attainment of NSF's mission and strategic outcome goals.

Many of the Core Questions are derived from NSF performance goals and apply to the portfolio of activities represented in the program(s) under review. The program(s) under review may include several subactivities as well as NSF-wide activities. The directorate or division may instruct the COV to provide answers addressing a cluster or group of programs – a portfolio of activities integrated as a whole – or to provide answers specific to the subactivities of the program, with the latter requiring more time but providing more detailed information.

The Division or Directorate may choose to add questions relevant to the activities under review. NSF staff should work with the COV members in advance of the meeting to provide them with the report template, organized background materials, and to identify questions/goals that apply to the program(s) under review.

Suggested sources of information for COVs to consider are provided for each item. As indicated, a resource for NSF staff preparing data for COVs is the Enterprise Information System (EIS) –Web COV module, which can be accessed by NSF staff only at http://budg-eis-01/eisportal/default.aspx. In addition, NSF staff preparing for the COV should consider other sources of information, as appropriate for the programs under review.

Guidance to the COV: The COV report should provide a balanced assessment of NSF's performance in two primary areas: (A) the integrity and efficiency of the ***processes*** related to proposal review; and (B) the quality of the ***results*** of NSF's investments that appear over time. The COV also explores the relationships between award decisions and program/NSF-wide goals in order to determine the likelihood that the portfolio will lead to the desired results in the future. Discussions leading to answers for Part A of the Core Questions will require study of confidential material such as declined proposals and reviewer comments. *COV reports should not contain confidential material or specific information about declined proposals.* Discussions leading to answers for Part B of the Core Questions will involve study of non-confidential material such as results of NSF-funded projects. The reports generated by COVs are used in assessing agency progress in order to meet government-wide performance reporting requirements, and are made available to the public. Since material from COV reports is used in NSF performance reports, the COV report may be subject to an audit.

We encourage COV members to provide comments to NSF on how to improve in all areas, as well as suggestions for the COV process, format, and questions. For past COV reports, please see http://www.nsf.gov/od/oia/activities/cov/covs.jsp.

FY 2009 REPORT TEMPLATE FOR
NSF COMMITTEES OF VISITORS (COVs)

The table below should be completed by program staff.

Date of COV:	4-6 February 2009
Program/Cluster/Section:	All programs
Division:	Division of Physics
Directorate:	Mathematical and Physical Sciences
Number of actions reviewed:	340
Awards:	190 (Awards from competitive actions only)
Declinations:	139 (Declinations from competitive actions only)
Other:	11 (Supplements, Pre-proposals)
Total number of actions within Program/Cluster/Division during period under review:	2,352
Awards:	995 (Awards from competitive actions only)
Declinations:	1,397 (Declinations from competitive actions only)
Other:	550 (Includes supplements, pre-proposals, admin withdrawn)
Manner in which reviewed actions were selected:	
Program Directors in the Division made an initial selection of proposal actions for review, including some clear awards and some clear declinations, but focused primarily on borderline cases. Special cases of large projects such as LIGO, LHC and DUSEL were also included in the initial list. CoV members then added to this list from entirely open and random selections of their choice among all the actions of the three years within the restriction that no member could look at a proposal with which he or she had a COI.	

PART A. INTEGRITY AND EFFICIENCY OF THE PROGRAM'S PROCESSES AND MANAGEMENT

Briefly discuss and provide comments for *each* relevant aspect of the program's review process and management. Comments should be based on a review of proposal actions (awards, declinations, and withdrawals) that were *completed within the past three fiscal years*. Provide comments for *each* program being reviewed and for those questions that are relevant to the program under review. Quantitative information may be required for some questions. Constructive comments noting areas in need of improvement are encouraged.

A.1 Questions about the quality and effectiveness of the program's use of merit review process. **Provide comments in the space below the question**. **Discuss areas of concern in the space provided.**

QUALITY AND EFFECTIVENESS OF MERIT REVIEW PROCESS	**YES, NO, DATA NOT AVAILABLE, or NOT APPLICABLE[1]**
1. Are the review methods (for example, panel, ad hoc, site visits) appropriate? Comments: The COV favors the continued use of both written and panel reviews because they provide complementary information.	Yes
2. Are both merit review criteria addressed a) In individual reviews? b) In panel summaries? c) In Program Officer review analyses? Comments: All levels of review recognize the importance of both merit review criteria and assess the likely contributions to each.	Yes

[1] If "Not Applicable" please explain why in the "Comments" section.

3. Do the individual reviewers provide substantive comments to explain their assessment of the proposals? Comments:	Yes
4. Do the panel summaries provide the rationale for the panel consensus (or reasons consensus was not reached)? Comments:	Yes
5. Does the documentation in the jacket provide the rationale for the award/decline decision? (Note: Documentation in jacket usually includes context statement, individual reviews, panel summary (if applicable), site visit reports (if applicable), program officer review analysis, and staff diary notes.) Comments: The program officers' review analyses were judged to be excellent, and the COV encourages the program officers to convey as much of this information as possible to proposers.	Yes

6. Does the documentation to PI provide the rationale for the award/decline decision? (Note: Documentation to PI usually includes context statement, individual reviews, panel summary (if applicable), site visit reports (if applicable), and, if not otherwise provided in the panel summary, an explanation from the program officer (written or telephoned with diary note in jacket) of the basis for a declination.) Comments: The program officers' review analyses provide the clearest rationale for funding decisions, and as indicated above, we encourage the program officers to convey as much of this information as they can, either via telephone or email.	Yes

7. Is the time to decision appropriate? Note: Time to Decision --NSF Annual Performance Goal: **For 70 percent of proposals, inform applicants about funding decisions within six months of proposal receipt or deadline or target date, whichever is later**. The date of Division Director concurrence is used in determining the time to decision. Once the Division Director concurs, applicants may be informed that their proposals have been declined or recommended for funding. The NSF-wide goal of 70 percent recognizes that the time to decision is appropriately greater than six months for some programs or some individual proposals. Comments: In general we find the time to decision to be within six months and appropriate. We recommend, however, that some leeway be granted to interdisciplinary proposals, which because of different timing of reviews in different divisions, may require more time for review.	Yes
8. Additional comments on the quality and effectiveness of the program's use of merit review process: The COV is very satisfied with the quality and integrity of the review process.	

A.2 Questions concerning the selection of reviewers. **Provide comments in the space below the question. Discuss areas of concern in the space provided.**

SELECTION OF REVIEWERS	YES , NO, DATA NOT AVAILABLE, or NOT APPLICABLE[2]
1. Did the program make use of reviewers having appropriate expertise and/or qualifications?	**Yes**

[2] If "Not Applicable" please explain why in the "Comments" section.

Comments:	
2. Did the program use reviewers balanced with respect to characteristics such as geography, type of institution, and underrepresented groups? Note: Demographic data is self reported, with only about 25% of reviewers reporting this information. Comments:	**Yes**
3. Did the program recognize and resolve conflicts of interest when appropriate? Comments:	**Yes**

4. Additional comments on reviewer selection: There is a strong effort by the physics division staff to ensure diversity at all levels of the review process, including on the COV. Indeed, in many cases we found that women were overrepresented relative to their overall percentage within the physics community as a whole. The physics division should be sure to spread the work around so that women and minorities do not become overburdened with administrative tasks**.**

A.3 Questions concerning the resulting portfolio of awards under review**. Provide comments in the space below the question. Discuss areas of concern in the space provided.**

RESULTING PORTFOLIO OF AWARDS	**APPROPRIATE, NOT APPROPRIATE[3], OR DATA NOT AVAILABLE**

[3] If "Not Appropriate" please explain why in the "Comments" section.

1. Overall quality of the research and/or education projects supported by the program. Comments:	Appropriate
2. Does the program portfolio promote the integration of research and education? Comments:	Appropriate
3. Are awards appropriate in size and duration for the scope of the projects? Comments: As is true throughout the NSF, several years of constrained funding have resulted in declining success rates, and there is a tendency to alleviate this problem by holding down award amounts. In many cases, grants are insufficient to support the optimal number of students or to acquire needed equipment. This COV reiterates the concern of previous COVs about the difficulty of obtaining funding for instrumentation with costs in the range of a few hundred thousand dollars to a few million dollars. If new funds become available, the physics division should give high priority to funding the Accelerator Physics and Physics Instrumentation Program. The COV also felt that, in the case of particularly meritorious and productive research, the program officers might be somewhat more aggressive than they currently are about extending 3-year grants to 5 years, an action which apparently the program officers can initiate.	Appropriate
4. Does the program portfolio have an appropriate balance of: • Innovative/potentially transformative projects? Comments:	Appropriate

5. Does the program portfolio have an appropriate balance of: • Inter- and Multi- disciplinary projects? Comments: The narrative portion of this report makes some suggestions for improving the review of interdisciplinary projects. In times of constrained funding, some new interdisciplinary programs, with the Physics of Living Systems being an example, have not been able to grow rapidly enough to bring the success rate of proposals in line with those of more traditional programs.	Appropriate

6. Does the program portfolio have an appropriate balance considering, for example, award size, single and multiple investigator awards, or other characteristics as appropriate for the program? Comments: Progress in physics depends on projects of all sizes, from table-top experiments to facilities as large as the LHC. The mix of programs within the physics division, which awards somewhat more than 50 percent of its funds to individual investigators, appears appropriate. We believe the current ratio should be maintained. The 10 percent of funds that goes to Physics Frontiers Centers also appears to be appropriate.	Appropriate
7. Does the program portfolio have an appropriate balance of: • Awards to new investigators? NOTE: A new investigator is an investigator who has not been a PI on a previously funded NSF grant. Comments: In general, we find that there is an appropriate number of awards to either PIs or Co-Is who have not previously been funded by NSF. The numbers of new investigators is especially impressive in fields with recent major breakthroughs or new opportunities, with gravitational research being an example. There is concern, however, about the adequacy of support for new investigators in other fields, most notably theory, where it appears that funding limitations are forcing unhealthy choices between providing support for high quality new faculty and continuing the support of productive senior people above a reasonable threshold.	Appropriate

8. Does the program portfolio have an appropriate balance of: • Geographical distribution of Principal Investigators? Comments:	Appropriate
9. Does the program portfolio have an appropriate balance of: • Institutionnel types? Comments: Some special consideration might be given to supporting science in four-year colleges, which are disproportionately successful in producing students who go on to earn PhDs in science.	Appropriate
10. Does the program portfolio have an appropriate balance: • Across disciplines and sub disciplines of the activity? Comments: In some subdisciplines, changing priorities and changing opportunities may make it appropriate to change the organizational structure of the reviews. For example, one subpanel found that the position of plasma physics has become very tenuous within the AMOP program. Both the average grant size and the success rate are lower than for other components of the AMOP program. Because the historical connections between plasma physics and AMO are weakening, it may be appropriate to separate the programs.	Appropriate
11. Does the program portfolio have appropriate participation of underrepresented groups? Comments: A primary challenge for physics is addressing the pre-college pipeline. Given the small numbers of women and minorities in the field who are engaged in research, the balance of the portfolio seems appropriate.	Appropriate

12. Is the program relevant to national priorities, agency mission, relevant fields and other constituent needs? Include citations of relevant external reports. Comments: See the subpanel reports for more details on research achievements and national recognition.	Appropriate
13. Additional comments on the quality of the projects or the balance of the portfolio:	

A.4 Management of the program under review. **Please comment on:**

1. Management of the program. Comments: We were very impressed with the quality of program management.
2. Responsiveness of the program to emerging research and education opportunities. Comments: The program has tried to respond to opportunities but funding constraints have limited its ability to do so.
3. Program planning and prioritization process (internal and external) that guided the development of the portfolio. Comments: Physics has a strategic plan and is doing full life-cycle costing for its major facilities. We were impressed with the quality of the planning.

4. Responsiveness of program to previous COV comments and recommendations. Comments: The physics division has been very responsiveness to previous reports both in terms of improving the COV process and, as funding allowed, addressing issues like portfolio balance.
5. Additional comments on program management:

PART B. RESULTS OF NSF INVESTMENTS

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The NSF mission is to:

- promote the progress of science;
- advance national health, prosperity, and welfare; and
- secure the national defense.

To fulfill this mission, NSF has identified four strategic outcome goals: Discovery, Learning, Research Infrastructure, and Stewardship. The COV should look carefully at and comment on (1) noteworthy achievements based on NSF awards; (2) ways in which funded projects have collectively affected progress toward NSF's mission and strategic outcome goals; and (3) expectations for future performance based on the current set of awards.

NSF investments produce results that appear over time. Consequently, the COV review may include consideration of significant impacts and advances that have developed since the previous COV review and are demonstrably linked to NSF investments, regardless of when the investments were made.

To assist the COV, NSF staff will provide award "highlights" as well as information about the program and its award portfolio as it relates to the three outcome goals of Discovery, Learning, and Research Infrastructure. The COV is not asked to review accomplishments under Stewardship, as that goal is represented by several annual performance goals and measures that are monitored by internal working groups that report to NSF senior management.

B. Please provide comments on the activity as it relates to NSF's Strategic Outcome Goals. Provide examples of outcomes ("highlights") as appropriate. Examples should reference the NSF award number, the Principal Investigator(s) names, and their institutions.

B.1 <u>OUTCOME GOAL for Discovery: "</u>*Foster research that will advance the frontier of knowledge, emphasizing areas of greatest opportunity and potential benefit and establishing the nation as a global leader in fundamental and transformational science and engineering."*

Comments: Several examples of significant research achievements are described in each of the subpanel reports.

B.2 <u>OUTCOME GOAL for Learning:</u> "*Cultivate a world-class, broadly inclusive science and engineering workforce, and expand the scientific literacy of all citizens.*"

Comments: Women and minorities remain underrepresented in physics. The physics community, as represented by the members of the COV as well as by the evidence provided by the jackets, has a genuine commitment to changing this. The problem, however, begins early in the pipeline, and much needs to be done to improve science education at all levels. Research, some of it supported by NSF, has shown how to make physics education more effective. The results of this research can be applied not only to college-level physics but also to pre-college classrooms.

B.3 <u>OUTCOME GOAL for Research Infrastructure: "</u>*Build the nation's research capability through critical investments in advanced instrumentation, facilities, cyberinfrastructure and experimental tools.*"

Comments: As outlined In the narrative portion of this report, physics has contributed in many ways to the development of broadly applicable technologies. Grid or cloud computing initially emphasized support of physics research. Technologies devised for studying elementary particles are being applied to the study of living systems. Facilities like LIGO and IceCube not only develop new technologies but offer the possibility of greater understanding of the laws of physics and the fundamental properties of matter.

PART C. OTHER TOPICS

C.1. Please comment on any program areas in need of improvement or gaps (if any) within program areas.

C.2. Please provide comments as appropriate on the program's performance in meeting program-specific goals and objectives that are not covered by the above questions.

C.3. Please identify agency-wide issues that should be addressed by NSF to help improve the program's performance.

Physics relies for some its significant advances on the construction of very large, technically challenging, and expensive facilities. Many of these initiatives depend for their success on partnerships with other agencies or countries. It is challenging to mesh the funding schedules, etc. of multiple partners, and it is likely that the most senior management of NSF will have to be engaged in the process of formulating these partnerships and will have to signal NSF intentions as clearly as possible given the restrictions of the annual budgeting process.

Cost overruns in major projects can completely distort the balance of the overall program. Sufficient funds must be available during the early stages of design in order to enable the development of a robust cost estimate. The required funding, typically at least 10 percent of the construction cost but dependent on the maturity of the technology, may exceed what a division can support with its own funds.

C.4. Please provide comments on any other issues the COV feels are relevant.

C.5. NSF would appreciate your comments on how to improve the COV review process, format and report template.

SIGNATURE BLOCK:

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For the [Replace with Name of COV]
[Sidney C. Wolff]
Chair