Report of the Committee of Visitors

Division of Physics - 2012

I- Introduction

The Committee of Visitors (COV) for the Division of Physics of the National Science Foundation met during February 1-3, 2012, with the following charge: to review

- 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 2009; and
- Any other issues that the COV feels are relevant to the review.

These charges were addressed in much detail, both by the committee at large as well as by the subpanels, comprised of a subset of the committee members and addressing each sub-discipline of the Division. The conclusions are presented in this report, which is divided into sections: I) introduction, II) the review process and the management of the Physics Division, III) some comments about the new programs, IV) societal benefits, V) special focus and IV) cyber infrastructure at the Physics Division, in addition to the required assessment. In addition, the committee has addressed all questions in the required report template that can be found as Appendix A to this report.

Finally, the agenda for the three-day meeting, the list of participants, the membership of each panel and the detailed COV charges are presented as Appendices B-E.

II. The review process and management of the Physics Division

The committee was unanimous in their overall assessment that the management of the Physics Division was excellent. Much of this success was attributed to the leading team of Joe Dehmer and Denise Caldwell. Having two permanent, extremely qualified and committed people in the leadership of the Division makes all the difference. We understand that the NSF is moving towards having a substantial fraction of their officers to be rotators. While we understand the need for fresh blood to avoid stagnation and that the Division has benefited from excellent rotating program managers, NSF management should also recognize the challenge in continually recruiting such high-quality individuals and the advantages provided by having greater continuity and more experienced program managers.

1. Quality and effectiveness of the review process

There was consensus among the committee members that the three-tier review process is a critical component of excellence in review. We really like the fact that every program review process involved the request of outside reviews from experts on the respective proposals that was followed by a panel evaluation (which usually took place at the NSF). Finally, program directors made decisions based on these two factors. In addition, for larger proposals in programs such as Nuclear Physics, site visits are conducted by a panel of 3-5 independent reviewers for proposals by larger experimental groups (multi-PI awards of more than $1M). Although most panel conclusions were able to reconcile any differences that existed in the collection of individual reviews, we were particularly satisfied with how program directors were able to make decisions when there was no uniform consensus. They were able to consider all different points of view, take into account the PI funding history, and finally make a case for a final decision. A special review process was established for the Physics Frontier Centers where both external reviews and panel evaluations were much more detailed.

Both merit review criteria are always addressed at all levels of evaluation (individual reviews, panel summaries, and program officer analysis). Most of the external reviewers demonstrated knowledge of the review process and the panels played an important role in balancing the importance of the two criteria. Some reviewers, however, had difficulty in properly weighting the “broader impacts” criterion. The level of detail in the postdoctoral mentoring plan varies significantly among proposals. Although much effort has been done in explaining these points to reviewers, we believe that an ongoing effort from the program directors educating the reviewers on both of these points is needed.

There were two general recommendations. First, since the program officers’ evaluation makes a careful analysis of the review process and a clear discussion of the funding decision, we felt that this information, after the removal of any confidential data, should be made available to PI’s. This is especially important for PI’s that were close to the funding range and really could use this information in preparing their resubmission. Second, several sub-panels raised concern about award sizes. We feel that, in special cases of really great research, larger awards should be made. We understand that this will come at the expense of reducing the total number of awards.

2. Selection of reviewers

There was most support for the quality of the reviewers selected. Some subpanels raised the concern that in some highly specialized areas it was very hard to find sufficient reviewers. Even when difficult, the committee felt that a minimum of 3 ad hoc reviews should be requested for each proposal, and at least 2 ad hoc reviews should be received in each case. In the majority of the cases, the program satisfied these conditions.

Some minor concerns about conflict of interest were raised. Although this was not a problem in the majority of the cases, some sub-panels observed several cases where conflicts of interest were not uncovered until the review process was under way. The program directors were able to respond quickly and address these issues in real time.

3. Program Balance

Overall the subpanels were very satisfied with the program's portfolio goals and balance. We were satisfied with the balance of renewals versus new investigators. Details can be found in the subpanel reports.

4. The COV process and response to previous COVs

Most of the subpanels have been very satisfied with the responsiveness of the Physics Division handling the requests and recommendations of the previous COV report. Specific details can be found in the subpanel reports.

The only major concern raised during the current COV was regarding the subpanel for computational physics. This panel also addressed the topic of cyber infrastructure, which also reviews computational physics. It was composed of members of other subpanels and so its activities caused some disruption to the activities of those subpanels, which were affected by not having their full membership during some deliberations. Other than that, everybody was extremely happy with the format of the COV and with what we were able to accomplish during these three days.

III. Program portfolio and balance – creation of new programs.

The Physics Division is composed of several science programs covering diverse areas of physics. According to the Division's master plan, at least 50% of its budget should be allocated to grants to investigators funded by these programs. The actual percentage is slightly larger. Typical awards vary for different programs. Some programs tend to fund more groups of investigators, while other focus on single or few investigator awards. Even with these differences, the subpanels were very satisfied with the overall planning, development and management of the portfolio. The Physics Frontier Centers are allocated no more than 10% of the budget and currently they are using about 8%. The remainder of the budget is used to cover facilities and instrumentation resources, together with some small additional expenses. More recently, additional funds have been saved for the instrumentation program. For more details about this program, please read the report by the subpanel on APPI and the discussion below on Facilities and Instrumentation.

The committee paid special attention to the new programs and were clearly satisfied with most of what they have been achieving. The programs in particle and nuclear astrophysics have now been consolidated as the program in Particle Astrophysics and are clearly fulfilling a necessary scientific niche that was missing in the Physics Division portfolio. As can be seen from their subpanel report, this is a well-established program with great scientific achievements. The program in Physics of Living Systems has grown and has provided leadership for this new and interdisciplinary area of physics. We were particularly happy with the evolution of this program, an area of research that could overlap with programs in Biology and DMR Divisions. The program has a set of priorities for POLS that clearly distinguishes this program from work in other Divisions. First, the research must address the physics of living systems, not the use of biomolecules as materials (a purview of DMR). Second, to distinguish this program from BIO, the research must emphasize working on biological systems with a physics approach and must include a theoretical component that allows for quantification and for the development of new ideas. Biological research is, at times, mostly descriptive and cannot be easily generalized to other systems. There were concerns about the goals and breadth of the computational physics program and this concern is clearly raised in the subpanel report.

Similarly to the POLS program, we would like to reinforce the need to extend the boundaries between fields that traditionally have not had strong interactions. We were also struck by the high level of relevance of AMO cold atom simulation experiments to significant problems in condensed matter physics, and the close collaborations between some CMP theorists and AMO experimental groups. We agree that this aspect should be encouraged. The AMO subpanel report provides more details on how to improve this connection.

There was strong support for the Physics Frontier Centers program. This program clearly fosters major advances at the intellectual frontiers of physics and has been one of the flagships of the Division. The subpanel report describes the many achievements of this program. It is important, however, to highlight one crucial recommendation. We recommend that the NSF charge an appropriate high-level body, possibly the National Academy of Sciences, to conduct a retrospective review of the PFCs, outside of the context of a funding competition for renewal and new starts.

IV. Societal Benefits

The impact of physics in creating the new technologies that have revolutionized our society during the last 50 years has been enormous. The interesting aspect is that most of these technological advances did not happen by design. They came as a consequence of basic research in physics. Advances in knowledge created the fertile ground for these new discoveries. NSF has been at the center of the creation of these many advances. In addition to these specific technological advances, it is important to highlight the importance of the NSF in training qualified people with the technical skills needed in our modern society. Students that obtained a Ph.D. in physics are currently leading laboratories in industries and in universities well outside of the purview of physics departments. Examples include, but are not limited to, medical schools and hospitals, electronic industries, energy creation and developments, biotech companies and big pharmaceutical companies, and even economics. In the following we describe a few examples of the recent advances that came from physics. Such a short selection does not do justice to all physics that has been done, but it does provide a few concrete examples of great technological advances that were only possible due to unplanned basic research.

The advances in optics and atomic and molecular physics have been enormous. The internet, modern communication, entertainment, displays, and information services would be unrecognizable or even impossible without the results of advances in AMO science, including lasers, fiber optics, MRI, surgery, drug design, GPS, and more. For example, airport security's most recent innovation is the terahertz-wave whole-body scanner, which is a direct result of advances in laser and AMO science in the 1980-2000 time frame. This non-invasive and safe scanning technology started out in AMOP research labs at IBM and Bell Laboratories, moved to universities under NSF and other federal agency funding, and then quickly to industry and homeland security to help post-9/11 needs for increased security. On a completely different topic, the low-temperature plasma physics program has had enormous impact on integrated circuit processing, and on atmospheric and space communication. The main applications for plasma research are generally in the energy sector, including lighting, displays, and fusion energy.

The subpanel in physics of living systems has focused on the impact of physics in living systems. As an example, the current *in vivo* research reflects an aspiration to work on living biological systems in all their complexity, and there can be immediate applications. Important results along this line include the development of a new diffusion MRI imaging technique to noninvasively study the mammalian cortex. This technique, called diffusion spectrum imaging, had been used successfully to study brain white matter, but its extension to the cortex required qualitative understanding of the anisotropy of cortical matter and the physics of diffusion in a complex environment, as demonstrated by a team of scientists led by Van Wedeen (Harvard U), Stanley and Rosene (Boston U). (The figure shows a diffusion spectrum image.)

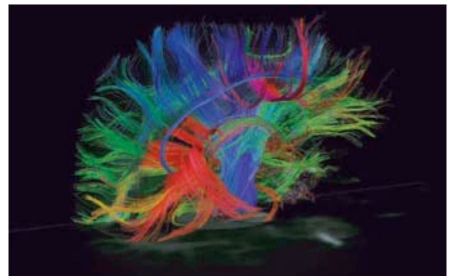


Image of the connectivity of neurons in the brain obtained by studying the diffusion of water in the brain cortex.

The nuclear physics subpanel highlighted that the instrumentation and techniques developed by nuclear physicists for their research also has an impact on society and across other scientific disciplines. For example, Accelerator Mass Spectrometry is a basis for radioactive dating, and a program at the University of Notre Dame is currently contributing to many areas. In another case, a low energy accelerator at Hope College is being used in collaboration with the FBI Lab for forensic analysis of paint chips. Using differential PIXE, which is a non-destructive method, it takes a matter of minutes to analyze each sample. The alternative method used in forensic science is to painstakingly remove individual layers by hand (7 – 12 layers), followed by destructive chemical analysis.

Particle physics is a particularly interesting case, since many of their advances were not directly related to particle physics. A few examples include: EPP scientist Alan Litke's work in developing CCD readout systems for particle-physics experiments, which led to collaborative research with neuroscientists that discovered a new set of retinal cells that had never been previously seen in primates; and Henry Frisch and his group at the University of Chicago doing R&D to develop ultra-fast time-of-flight measurements and applying particle physics techniques in data acquisition and simulation that may be of use for time-of-flight measurements in biomedical imaging. Seed money from EPP is being used to develop front-end electronics, analog-to-digital conversion, pipeline readout, etc. for real-time display in both particle physics and biomedical imaging systems. Finally we cannot ignore the role played by physics in the development of the World-Wide Web. When physicists were involved in its creation they had no idea of the enormous impact that this discovery would have in a very short time.

Particle astrophysics projects require technological advances in detector technologies that have strongly impacted the wider society through interaction with industry and national security. A few examples of areas where cutting edge advances in technology are being made that are of direct interest to companies include: development of new, high-purity materials and techniques (from double beta decay and dark matter experiments), production of new photo-sensors with greater efficiency and reliability (from the high energy cosmic particle and dark matter fields), and the development of new techniques for sensitive neutron detection (dark matter searches). The latter is directly relevant to homeland security applications. Similarly, gravitational physics experiments have led to the creation of important new technology, including electro-optical control systems, mirror coatings for precision metrology, and low-noise lasers; LIGO has now set up a technology transfer office to help link such developments to outside opportunities.

We conclude with one more example of how the NSF basic research in physics has affected national defense and homeland security. A prime example of how very arcane research finds its way quickly to the forefront of national security is neutrino physics. Detector technologies developed for long-baseline neutrino oscillation studies are increasingly being identified as the tool of choice for cooperative reactor monitoring and treaty verification, and may soon enter the application space of medium-range clandestine reactor monitoring.

The subpanel reports below include many more amazing details about the examples described above. This, then, is just a short summary of a few examples of the impact of physics in today's society. The importance, the breadth, and the economic impact of basic physics research are enormous. It has transformed the way our society lives and behaves.

V. Special focus in addition to the required assessment.

1. Broader impact in addition to society impacts and benefits

In addition to the discussion on society benefits described above, the Division has been involved in many other aspect of broader impact. The main one is a wide variety of mentoring and educational programs as well as outreach to K-12 education and science diffusion to the general society. Every subpanel has discussed their effort in this topic in their specific report.

2. Interdisciplinary programs and participation in Division-wide programs

This has been an important growth area for PHY. There are multiple levels of this. One is how the Division responds to the big NSF-wide priority areas such as SEES, CIF21, BioMAPS. SAVI, and the NNI nanoscale initiative, which are all labeled as "multidisciplinary." Another is how the Division interacts with other Divisions and within the Division on individual proposals. All the subpanels have discussed this topic at length in their specific reports. Let me highlight a few topics.

We were mostly happy with the efforts of the Physics Division in being proactive towards participation in NSF-wide programs. Careful analyses have been made to understand the value for the Division and how and if they should participate. There were are a few cases like SEES where the committee believed that there were many important aspects suitable for the Physics Division in which no appropriate response took place. We recommend a more organized effort responding to all these calls in order to avoid missing opportunities like this one.

There are cases of enormous success. The BioMaPS initiative operates across the MPS, BIO and ENG directorates at NSF with the purpose of stimulating interdisciplinary research. The current funding for BioMaPS is $27M, with $9M per directorate. Given the interdisciplinary character of PoLS, the program has benefited from the BioPS program. The long-standing efforts between Physics and Biology are the origin of this program, and Physics was a key player on pushing this interface for more than one decade. Physics has also one of the first programs in SAVI. The PoLS network has developed as a model of a Science Across Virtual Institutes (SAVI), which integrates training and research in an international environment. It is the most widespread of the existing SAVI programs, involving multiple institutions within the US and several countries.

Two new efforts are either underway or proposed to improve the support structure for interdisciplinary research:

- Beginning in 2012, CREATIV (Creative Research Awards for Transformative Interdisciplinary Ventures): a pilot grant mechanism under the Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE) initiative to support bold interdisciplinary projects in all NSF-supported areas of science, engineering, and education research was launched.
- Under consideration by the Physics Division is the identification of "a

Program Officer who will act as an "ombudsman" to keep an eye on interdisciplinary proposals and help the POs who handle them find appropriate POs at NSF to complement the managing PO's expertise."

We applaud both of these new efforts, and have recommendations as follows:

For the Program "ombudsman", we recommend that the Division create a fund specifically held in reserve to supplement Cross-Disciplinary grants. This will create an incentive for the POs of regular programs to pursue cooperation with the Cross-Disciplinary PO.

3. Facilities and instrumentation

There was an enormous consensus supporting an instrumentation program across a scale that could benefit all disciplinary programs by all subpanels. Different programs have different needs for this new program but they all highlight that much is missing without it. The subpanels give specific reports for the needs of the different programs. The report by the APPI subpanel is particularly instructive and summarizes the importance of such a program and the recommendations of our committee. Let me summarize the action items proposed by this subpanel:

- There is a sense in certain program communities that there are very limited funds for instrumentation at NSF. Physics and all the members of the COV should inform the community that there is money for equipment requests as part of the science proposals as long as the proposal is clear that the instrumentation is necessary for the success of the science.
- Physics should consider writing a Dear Colleague Letter to make sure that the community is aware that they can request equipment money in their science proposals.
- Observation: It is necessary to increase the documentation on how the allocation of the resources toward co-funding of science awards happens.
- Special attention should be given to make sure that such a program does not affect the balance between theoretical and experimental funding.

4. Broadening participation

Although the Physics Division has put much effort toward increasing broadening participation, there was a general consensus in the committee that much more needs to be done. There was a general agreement that the number of woman PIs appears to be increasing to appropriate levels in a slow and consistent way. The news appears to be good but we recommend that continuing efforts toward this goal are needed. The situation for underrepresented minorities, however, is very problematic. This is not a problem singular to the Physics Division but clearly much more needs to be done. There was much discussion in all subpanels (as can be seen in their specific reports) and by the committee at large. The EIR subpanel has done a careful job describing the committee recommendations and I highlight them here: The Physics Division is tackling broadening the participation of PIs and reviewers, a complex challenge. The Division should focus on its own practices as well as try to leverage change through partnerships where possible. Actions the Division can take include:

- Improve demographics data collection / sharing
  - Reviewer demographic data wasn't easily accessible for the COV, due to the separation of the PARS and Fastlane database systems. Data from these systems should be shared across the system to better assess the demographics of the reviewers.
  - REU participant information is collected in Fastlane through self-reporting by students. This information, however, is not available to the PI and does not appear easily accessible to POs. Thus communication between Fastlane, the PIs and the POs could be improved to better assess REU participant demographics.
- The Physics Division broadening participation report prepared for the CoV indicates that POs provide information about potential funding opportunities to faculty at small institutions in order to foster successful submissions. This could be broadened to provide several options for improving proposal preparation, such as:
  - Suggesting successful "proposal writing" mentors who have a strong track record of writing high quality proposals in that field.
  - Making unsuccessful new PIs aware of the ROA program that could facilitate mentoring relationships between young faculty at institutions that do not have strong research traditions and established researchers.
  - Making young PIs aware of ongoing "How to build research programs at small colleges" workshops (for example, those held by the Council on Undergraduate Research - CUR).
  - Mentors should develop their skills, such as through the NSF-supported Research Mentor Training seminar program. The physics community, possibly through APS/AAPT, could help to make these opportunities available to new PIs.

- New REU site proposals could be broadened through a similar mentor model with established REU sites.
- The PHY broadening participation working group is encouraged to work with the MPS broadening participation working group to share ideas and practices across divisions.

VI. Cyber infrastructure at the Physics Division.

Computation plays an increasingly important role in physics research, and in the sciences in general. This is primarily for two reasons.

First, the computer and digital technologies that have been developed during the past few decades now allow the collection and "automated" analysis of huge data sets. These in turn enable new science to be done. A good example is the "pinning down" of the precise rate of expansion of the universe (the value of the so-called Hubble constant) by the Supernova Cosmology Project and by the High-z Supernova Search Team. This work was awarded the Nobel Prize in 2011.

Second, this same technology permits the accurate numerical simulation of physical systems which are either too complex to analyze analytically, or which are inherently simple but which are governed by mathematical equations that cannot be solved by analytic means. For example it is now possible to calculate the emission of gravitational waves when two black holes coalesce and merge, even though an analytic solution of the Einstein equations is not possible in this case.

PHYSICS AND COMPUTING: A HISTORICALLY PRODUCTIVE RELATIONSHIP

Physics and computing have been closely linked ever since the modern computer architecture (or computing model) was invented by the physicist and mathematician John von Neumann and by the applied mathematician Alan Turing. The first generations of electronic computers were built by physicists before "computer science" became a recognized and distinct academic field.

Historically, Physics has also "pushed the envelope" in terms of computational developments. The needs of physics experiments and research have led the development of tools for computation, data storage and data handling. Physicists have pioneered the use of large data sets, grid computing, high-speed computer networks, and many other important areas of computing, with wide-ranging repercussions.

Some of the most widely used computer tools and methods trace their origins directly to the physics community. For example the first web browser (or browser-editor, called WorldWideWeb) was written by Tim Berners-Lee, whose undergraduate degree (from Queen's College, Oxford is in Physics and who was working at. the time at the European Particle Physics Laboratory (CERN)

A number of NSF-supported Physics projects are continuing this historical tradition. For example the Laser Interferometer Gravitational-wave Observatory (LIGO), the Large Hadron Collider (LHC), and the Large Synoptic Survey Telescope (LSST) are all pushing the envelope in large data sets, grid computing, and high-performance computing.

NSF INITIATIVES IN COMPUTING AND CYBER-INFRASTRUCTURE

The primary program that supports computing activities within Physics is the Physics at the Information Frontier (PIF) program. PIF was originally created as a follow-on to an NSF-wide ITR initiative. Such NSF-wide initiatives can play an important and positive role for the Physics division, as they provide funding for cyber and computing efforts in physics that could not otherwise be supported. They also allow novel computer techniques to be applied to important physics problems. Continued involvement of Physics in such programs and initiatives is thus valuable from multiple perspectives. This synergy works best when Physics is involved in the drafting of the program solicitations and the formulation of the review processes, so that these are also compatible with the needs and interests of the Physics programs.

An example of the issues that may otherwise arise can be taken from this review period: the NSF-wide Cyber-enabled Discovery and Innovation program (CDI), which included a $2.25M contribution from the PIF-CP program. This program was created with built-in constraints that excluded much of the forefront computational research being done in the Physics division.

In creating new programs and initiatives, the following points should be considered:

First, the program and review guidelines need to recognize the fact that physics research often provides early real-world applications of ideas and methods that have previously only been prototyped or described theoretically in the computer-science community. Using such methods in the real world to solve physics research problems at the boundaries of knowledge is a necessary step in completing this work and bringing it to fruition. Thus one needs to be cautious about the criticism that the work is "nothing new" or is "not scientifically innovative" because the methods and tools that are being applied are "old hat". In other words, one must recognize that important "scientific computing" activities are often not "computer science".

Second, the programs and review guidelines need to recognize that, as described above, in many cases Physics is already at the forefront in Cyber-related research. Yet this leadership position can make it appear that physics work is "old" in comparison with proposals from other fields that seek to apply such methods in new contexts. Program solicitations should be worded so that they do not penalize physicists who are already at the cutting edge of the field, i.e. "already doing it".

The COV notes that these same issues can arise when physics researchers apply for time at national supercomputing facilities. The review panels used to evaluate those applications should recognize that physics work may be of great scientific interest, even if it "merely" continues work in an area that has "already been explored", or does not break new ground in computational methods.

It is also important to inform and educate the physics community about NSF-wide programs and initiatives that overlap physics interests. In many cases, physics researchers are unaware of these programs and initiatives.

In order to ensure that the physics community benefits from the various cyber-related initiatives and to address the issues described above, we suggest that the Division provide program managers with the time and incentive to take part in the formulation of these programs and solicitations, and with the time and funds to travel to conferences and meetings where these programs and initiatives can be presented to the research community.

We welcome the increasing emphasis on computation and computational infrastructure across the NSF. The COV encourages the Physics Division to remain closely involved in the development of future NSF-wide or multi-division programs for Cyber and Computational research and development.

THE DIVISION’S BALANCE, PRIORITIES AND FUTURE DIRECTIONS

The Physics Division’s balance, priorities and future directions with respect to scientific computing were discussed at some length within the COV sub-group responsible for computing and data management. Although the members of this group represented quite a diverse range of scientific interests and backgrounds, a number of common themes quickly emerged.

DATA MANAGEMENT, OPEN DATA AND SOFTWARE

We applaud the Physics Division's implementation of the new NSF data-management plan requirement. The choice to have this plan monitored by reviewers and panels within each sub-field provides the flexibility needed to meet the disparate needs of researchers pursuing different kinds of science. Based on evidence from the first year after this requirement was introduced, this approach seems to be working well.

More generally, investigators and projects in several areas of physics (gravity-wave detection, particle physics, and astrophysics) are coming under pressure to make their data and results "open". This means making the data sets available to the public (This is standing policy at NASA, sometimes with a proprietary period of six months or a year.) and perhaps also providing software that has been developed in the course of research. The logic for this is simple: taxpayers paid the costs of obtaining the data or developing the software, and it contains no personal information (e.g. medical history) that needs to be protected. Therefore everyone should have the benefit of access to these results. In addition, one might argue that this is in the best interests of science, which has always prospered in an atmosphere of transparency and open exchange; releasing data and software increases the opportunities for related and similar science.

However this open approach comes with at least two costs.

The first cost is that forcing experimental or theoretical groups to release their data and/or software may have a de-motivating or detrimental effect on the quality of the scientific work. This is because the motivation and reward structure in scientific and academic life are largely based on "being the first" to publish a result or finding or discovery. Being forced to release experimental data or software before it has been fully exploited by the individuals or group that obtained or developed it can interfere with this reward structure, and may have a negative rather than positive effect on overall scientific productivity.

The second cost is obvious: to release data and/or software to the public domain costs money. In addition to the hardware infrastructure costs (servers to distribute the data over the Internet or to copy it to disks or tape) there is the "hidden" cost of documenting the real and/or simulated data and data formats, and creating and distributing "easy to use" tools for reading and interpreting it. Significant human support is required for this process. In the case of software, effort is required to package all the software for distribution with one or more operating systems. Interpreting the data may also require access to large sets of Monte Carlo simulations, requiring still more software to be documented, packaged and distributed.

In addition, the software infrastructure must to be maintained over the long-term. This is unlike the traditional model of Physics funding, where when the main scientific results of some work have been published in the open literature, the work is regarded as available to all. Here, in contrast, there is a continuing financial cost for maintenance and support; one which the NSF award structure (unlike, perhaps, a government laboratory) is not well structured to financially bear over long periods.

Addressing these issues is a challenge to the Physics Division in implementing part of NSF's Stewardship mission and responsibilities. We suggest that the Physics step cautiously and thoughtfully in this area, and carefully study the implications of any proposed actions regarding open data and/or software. We recommend following the flexible model implemented in the case of data-management plans, rather than mandating a one-size-fits-all solution.

In cases where long-term, continuing support for dissemination and upkeep of data or software is warranted, the Division should explore possibilities to help bear this cost. In particular, when a software package has become a successful standard tool used by many researchers and research groups, it probably makes sense to look for ways of supporting it. In short we recommend that NSF explore ways to provide structures that support "software development, packaging and maintenance" which is important for physics but is not in and of itself a research activity. That is to say, the work itself is not discovery, but instead the creation of infrastructure for that process. One understands, however, the difficulties of the current funding situation and also that support for these costs may have to involve other partners in addition to the Physics Division.

Some examples of tools that have proven to be very productive are:

- The Berkeley Open Infrastructure for Network Computing (BOINC) software toolkit used for volunteer distributed computing projects such as Einstein@Home, Rosetta@Home, Milkyway@Home, Docking@Home;
- The GEANT4 toolkit for the simulation of the passage of particles through matter, used in high energy and nuclear physics, as well as for studies in medical and space science;
- The Virtual Data Toolkit (VDT) used by the LIGO and LHC collaborations;
- The Cactus and the Einstein Toolkit used by many members of the numerical relativity community.

One might argue that the need for such software support should extend more broadly, to include tools that facilitate collaboration. An example is the EVO videoconferencing system, used by many scientists working in large collaborations; EVO was developed with a combination of NSF and DOE support. Currently, the Physics Division is ill-equipped to provide such software infrastructure support; the competitive funding model discourages it in favor of work that more directly advances the scientific frontier. In contrast, DOE labs have been successful in providing such infrastructure support. For example Argonne National Laboratory supports and distributes MPICH, a freely available portable implementation of the MPI message-passing standard used for distributed-memory applications in parallel computing.

We encourage Physics and DOE to explore the possibility of working together in the future to ensure that such infrastructure support is available where needed.

DIVERSE COMPUTING SOLUTIONS FOR A DIVERSE RANGE OF PHYSICS PROBLEMS

A great deal of physics research work can be done with standard off-the-shelf computing resources: laptops and desktops equipped with low-cost or open-source software packages. However, other scientific work requires more: small, medium or large-scale clusters of computers or compute-farms, or specialized high-performance supercomputers at various scales. Therefore PHY, and NSF generally, should seek to maintain a balance in the spectrum of computing resources that are available to researchers.

Through the Office of Cyber Infrastructure (OCI) the NSF funds a number of national supercomputer centers to provide compute cycles at the largest scale. Compute cycles at these centers can be obtained through a competitive peer-review process. NSF also supports a number of grid- and cloud-oriented computing initiatives, such as the Open Science Grid (OSG) and Teragrid. It is important for Physics to ensure that suitable funding for resources at the small- to large-sized cluster scale is also available. These are more cost-effective for a certain class of problems, and they also function as an essential training ground for students and postdocs, as they allow young researchers to experiment with software and hardware systems in a way that would not be permitted or acceptable on large-scale shared facilities. Funding such systems can be difficult within the scope of a typical single-investigator grant. We encourage the development and perpetuation of suitable programs (for example APPI) for this purpose.

In a similar vein, the Physics Division should continue to express the need for alternative and novel approaches to provide compute cycles. A good example is public volunteer computing, which can provide very large numbers of compute cycles at extremely low marginal cost. This approach is only appropriate for a particular class of computational problems, characterized by a very high ratio of computing to input/output data, and which are of interest to the general public. Public volunteer computing currently delivers more CPU cycles than the sum of all the NSF supercomputer centers. "On paper", volunteer computing roughly equals the computing power of the fastest machine on the TOP-500 list. However in practice it is much more powerful, because unlike the current TOP-500 computer, public volunteer computing delivers this performance running real-world applications rather than just on a LINPACK benchmark.

The Physics of Life Sciences (POLS) community is a good example: it uses a full, diverse set of computational resources. This community is one of the largest users of Supercomputer Center cycles, but it also employs volunteer distributed computing (Folding@Home) and dedicated clusters. One recent POLS development is the Anton computer. This is a special-purpose "boutique" machine, which is a single-purpose, molecular dynamics (MD) computer. It has enabled the DDE Shaw group to run continuous MD trajectories that are a thousand times longer than with general-purpose computers. This opens the possibility of discovering new physics in the area of biological function and dynamics. The (million dollar) cost of boutique hardware like Anton is between one and two orders of magnitude lower than that of a Supercomputer Center.

Another example comes from AMO physics. Here, theory can provide precise quantitative predictions for many-body systems of ultra-cold atoms that are being studied in the laboratory. In this context, a useful technique is the time-evolving block decimation (TEBD) algorithm, which is capable of simulating entangled one-dimensional many-body systems such as ultra-cold atoms confined in one-dimensional optical lattices. The TEBD algorithm can be efficiently implemented on platforms containing both shared-memory and non-shared-memory components. There are problem of high current interest that can be solved on clusters consisting of a modest (10-50) numbers of multi-core nodes perhaps also equipped with GPU capability. There is strong interest in the coming years in formulating algorithms that generalize the TEBD method to higher dimensions.

This sort of boutique hardware has also been used within the experimental particle physics, lattice QCD, and gravity communities. The Division should continue to encourage the development of such novel hardware approaches, when they offer substantially more cost-effective ways to study important systems.

Currently, many boutique machines are being built around GPUs. While these offer order-of-magnitude improvements in computational power per dollar, they also require a different data structure and software design. Success, however, will require work on "smart compilers" that will allow current productive code to migrate to such new/better hardware. This type of work is effectively an interdisciplinary collaboration between compiler builders and physicists and software designers.

As these examples show, novel computational strategies involving boutique hardware, small and large clusters, and volunteer distributed computing enable cost-effective solutions to forefront science problems. It is crucial that the Physics Division continue to fund and encourage NSF-wide support for such endeavors, and appropriately balance their resource demands against those of more visible computational infrastructure, i.e. supercomputers. This will require diligent management, especially given the constraints anticipated on science funding in the near term.

HIGHLIGHTS AND FUTURE DIRECTIONS

In 2011 PHY-funded work on numerical solutions of Quantum Chromodynamics (QCD) revealed that the H-dibaryon (a novel form of matter involving equal amounts of up, down, and strange quarks) could be stable; a finding with potentially large consequences for our understanding of high-density matter and neutron-star structure. In the near future, related lattice QCD (LQCD) efforts stand to make significant progress in calculating–directly from QCD–the forces which bind nuclei. Computational "ab initio" solutions of the N-body Schroedinger equation for nuclear Hamiltonians could also yield new understanding for the "triple-alpha process" by which Carbon-12 is formed in stars, or in the prediction of neutrino-less double-beta nuclear matrix elements for Calcium-40. But, to take these next steps requires peta- to exa-flop-years of computational cycles. Until now, the US LQCD community has led these advances, but it is severely limited by the availability of time on suitable computers, containing large numbers of tightly coupled cores. Other nations are investing in suitable new, peta-scale machines. To maintain the USA's leadership position, significant investments in computational infrastructure are required.

The Einstein@Home project uses computer time donated by more than 300,000 volunteers to search for weak astrophysical signals in gravitational-wave, radio-telescope, and gamma-ray telescope data. Each week, more than 100,000 computers contact the Einstein@Home servers to download new work and to upload results. Currently Einstein@Home is delivering more than 600 Tflops of CPU power on a 24x7 basis. Using LIGO data, Einstein@Home has set new upper-limits from an all-sky blind search for continuous gravitational waves from rapidly rotating neutron stars. Einstein@Home has discovered more than twenty new radio pulsars in data from the Arecibo and Parkes telescopes, and several new gamma-ray pulsars in data from the Fermi satellite. The project is getting ready to release applications for ATI GPUs, which should further increase the computing throughput; as the data accumulates and improves, the discovery rate is expected to increase. With proper support, this and other volunteer distributed computing projects should enable certain classes of computing problems and data analysis problems to be addressed in a very cost-effective way, that also provides a highly visible and effective form of public outreach.

For the past few years, Physics has supported the development of a computing grid that is currently being heavily used to analyze the current LHC data. This grid development will need substantial enhancements in the near future to handle the anticipated increase in data as the upgraded LHC will deliver both increased luminosity and energy.

Recent advances in numerical relativity include new understanding about the physics of binary black hole mergers. Results from such simulations have been used to extend and improve gravitational wave data analysis techniques. To bring this to fruition requires the complication of a comprehensive gravitational wave template catalog. However this is a significant challenge: it requires covering a vast parameter space. Other recent advances include simulations of black holes in three or more spatial dimensions to explore cosmic censorship in previously untested regimes. In a complementary effort, several groups have started to simulate black holes in non-vacuum spacetimes. Examples of great astrophysical interest include simulations of circumbinary disks, emission of jets from binary black holes, and magnetized black hole-neutron star binaries.

Subpanel Reports:

1. Physics of Living Systems
2. Elementary Particle Physics Theory and Mathematical Physics
3. Atomic, Molecular, Optical and Plasma Physics and Quantum Information Science
4. Nuclear Physics
5. Elementary Particle Physics Experiment and Grid Computing
6. Particle Astrophysics
7. Gravitational Physics
8. Educational Physics and Interdisciplinary Research
9. Computational Physics/Physics of the Information System
10. Physics Frontier Centers
11. APPI

1. Physics of Living Systems

The Physics of Living Systems (PoLS) subpanel reviewed the process used to evaluate proposals and the results of NSF investments by the program. The program supports a portfolio of research that focuses on the description of biological systems with physics approaches and to provide a theoretical, quantitative description that can lead to new discoveries. The PoLS program funds theoretical and experimental projects that cover individual molecular, cellular, and whole-organism levels. The program has grown from $4.7 M in 2008 to over $9 M in 2011. Currently, the program has around 50 active awards (including 8 woman and 2 minority PIs).

During the three-year period 2009-2011 the number of proposal submitted has remained near 90 annually, including about 15 CAREER proposals per year. They can be divided into two categories: the first spanning molecules to cells and the second ranging from cells to organisms and populations. The merit review mechanism is a three-tier process that includes external reviews, panel review, and the program director analysis and review. There are two panels, corresponding to the categories above. Proposals concerned with single molecule physics are co-reviewed with similar proposals in the MCB program in Biology.

The sub-panel examined 37 jackets to assess the evaluation process. Nine jackets describing funded proposals were provided before the meeting. Fifteen jackets of unfunded proposals were added by NSF directors at the beginning of the meeting. To better understand the review and decision processes, the sub-panel requested thirteen additional jackets selected from the list of proposals that were not funded by the program. The sub-panel was provided with a complete list of submitted and funded proposals. The quality of the external reviews was found to be very good. The reviews contained detailed descriptions of the weaknesses and strengths of the proposals. These reviews are provided to the PIs. The panel summary statements were brief, but described the panel discussion. The program director provides an extensive and detailed review of the proposal and highlights the strengths and weaknesses of a proposal. Unfortunately, this extensive review is not provided to the PIs. The committee found that the process is robust, fair and accurate. All funded proposals were deemed to meet the program goals. We also found that there are many strong proposals that do not get funded. The integrity of the review process and the efficiency of the program management are described in Section A.

Over the last three years the program has funded outstanding projects and has generated some excellent scientific results. Two outstanding scientific outcomes are described in Section B of this report. The subpanel recommendations are described in Section C.

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

1. Effectiveness of the process

The review process consists of a three-tier process that involves external (ad hoc) reviews, a panel review, and a program director review. The external reviewers are representative of the PoLS, biology and chemistry scientific communities. The interdisciplinary nature of the PoLS program demands some reviewers who are experts in fields other than Physics. Reviewers with the appropriate expertise in the subject of the proposals have been recruited for this process. The review panels were also representative of the broad community and included renowned scientists such as NAS members. Each panel had at least two biologists in order to assess the biological impact of the proposed research. The two broad categories of the program, one above the cell and the other below, also required that two separate panels be convened.

Analysis of the jackets shows that the review process is thorough and fair. External reviews are detailed and contain valuable criticisms that the PI can use to strengthen proposals, in case that a resubmission is needed. The most revealing part of the process is the program director's review analysis. This analysis is complete and carefully summarizes strengths and weaknesses of the proposals, possible impact in the scientific community and relevance to the goals of the program. Clearly, the expertise of the program director in the PoLS area of research plays an important role in the success of the mechanism.

Given the limited amount of funding available, the funding rate for this program is 22% over the last three years, and declined from 26% in FY09 to 16% in FY11. A mechanism used by the program director to accomplish the goals of the program has been to co-fund 10% of the proposals with the MCB program in BIO.

2. Broader impacts and interdisciplinary research

The PoLS is an interdisciplinary program that excels in the area of broader impacts. The PoLS network has developed as a model of a Science Across Virtual Institutes (SAVI), which integrates training and research in an international environment. This is particularly important in a growing field, where it can support local groups who would otherwise be sub-threshold competitively. The SAVI allows for training and exchange of students between different programs and across disciplinary boundaries in physics and biology, and makes it possible to develop a culture of problem-focused research where fundamental researchers are empowered by the interaction with applications.

We would like to commend the program for showing strong improvement in the representation of female PI's. 20% of the funded proposals in FY09-11 are from female PI's, up from 0% in the previous CoV period. The current funding portfolio has two minority PIs. We are aware that the program director has also been arranging mentoring to develop strong proposals from the limited pool of minority applicants. We expect that this will show results in the future.

Broader impacts also include the influence that research within the program affects other disciplines. The focus on *in vivo* research reflects an aspiration to work on living biological systems together with all their complexity, and there can be immediate connections. Important results along this line include the development of a new diffusion MRI imaging technique to noninvasively study cortex in mammals. This technique, called diffusion spectrum imaging had been used successfully to study brain white matter, but the extension of this technique to cortex required qualitative understanding of the anisotropy of cortical matter and the physics of diffusion in complex environment, as demonstrated by a team of scientists led by Van J. Wedeen (Harvard U), Stanley and Rosene (Boston U). (The figure shows a water diffusion spectrum image of gray matter. The colors highlight connectivity within the cerebral cortex.)

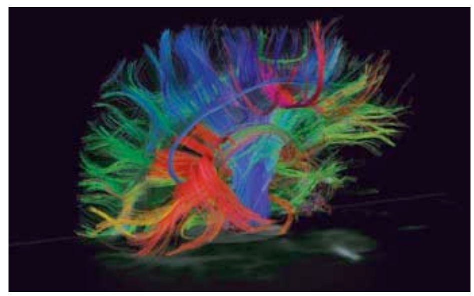


Fig. 1 - Image of the connectivity of neurons in the brain obtained by studying the diffusion of water in the brain cortex.

The PoLS program also provides the opportunity for broad dissemination and outreach to the general public. Using funds from her NSF CAREER grant, Prof. Andrea Trache, from Texas A&M Health Science Center in College Station, organized an outreach program called 'The Saturday Morning Biophysics: Image Life!. The goal of this program is to stimulate interest in science among high-school girls from the surrounding rural Texas area and to communicate the excitement of research while also providing information on career paths at the interface between physics and biology.

The BioMaPS initiative operates across the MPS, BIO and ENG directorates at NSF with the purpose of stimulating interdisciplinary research. The current funding for BioMaPS is $27M, with $9M per directorate. Given the interdisciplinary character of PoLS, the program has benefited from the BioMaPS program. The BioMaPS program enables proposals submitted to PoLS to be evaluated by BioMaPS, and upon recommendation by BioMaPS, be funded by PoLS with allocations from BioMaPS funds. This mechanism helped PoLS increase their funding allocation in 2011.

3. Resulting Portfolio of Awards

The PoLS program has a diverse research portfolio that includes 14 CAREER awards. Funded proposals are of excellent quality and focus on the understanding of biological systems using physics approaches. The PoLS program funds research in areas that are not currently supported by other biophysics, biology or DMR programs. A measure of the caliber of the research is that three PIs have become members of the NAS while funded by the program.

The funding recommendations reflected the evolution of the program and more awards were made *for in vivo* research than for *in vitro* investigations in the most recent period.

4. Management

The subpanel finds that the program is very well managed and that it uses its resources in an effective way. The PoLS program director has identified unique opportunities that are distinct from research supported by Biology and DMR Divisions. The research must address the physics of living systems, not the use of biomolecules as materials. The research must also emphasize working on biological systems with a physics approach and must include a theoretical component that allows for quantification and the development of new ideas. These goals help create an identity for the program and are also used to make funding decisions. We have found many examples where proposals are highly ranked by adhoc reviewers but were declined for funding because they would fit better in other Divisions. Communication and coordination with BIO programs are effective and collegial.

The subpanel finds that co-funding of proposals together with BIO MCB programs has helped strengthen the portfolio of the program and maximize the extent to which funds are used for advancing research in the area of PoLS.

The PoLS program director has done an outstanding job in correcting the low participation by minorities and woman in the program, as described during the past COV report. Currently the program funds eight woman and two minorities. Also, mentoring efforts have been undertaken to improve the quality of revised proposals submitted by under-represented groups.

B. Results of NSF Investments

In what follows we briefly describe two projects currently funded by PoLS.

1. Nanotechnology and Accelerated Evolution – work by R.B. Austin, Princeton.

Is it possible to accelerate bacterial evolution using spatial gradient? In a recent report in Science (Zhang et al., 2011), Robert Austin and his collaborators at Princeton University used nanotechnology to fabricate a device dubbed the "Death Galaxy" based on physical design principles. Galaxy refers to the structural design used - an interconnected array of micro-ecologies – similar to the stars comprising an astronomical galaxy. They used this galaxy of micro-ecologies to apply a spatially well-defined concentration gradient of the antibiotic ciprofloxacin (cipro). They monitored bacterial growth as a function of position inside the gradient, and observed how quickly a subpopulation acquires the necessary mutations allowing it to thrive in the cipro-rich region. The resistance to cipro developed in a mere 10 hours and even from an initial population as small as 100 cells. Knowledge about how the heterogeneous conditions in our bodies can accelerate the emergence of antibiotic resistance may aid us in understanding the emergence of drug resistance during chemotherapy.

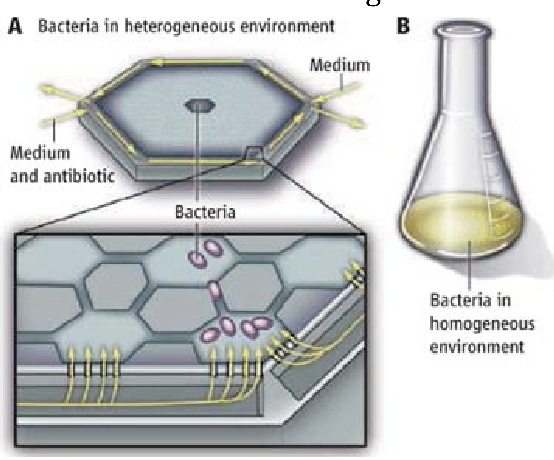


Fig. 2 - Accelerated evolution that occurs in a heterogeneous environment that consists of hexagonal wells etched into a silicon wafer helps understanding the rapid emergence of antibiotic resistance

2. Swimming in Sand – work by* Daniel Goldman*, Georgia Tech.

Many desert organisms like lizards, snakes and scorpions spend time within sand, a granular medium. An example of a successful desert organism is the sandfish lizard. This little (~10 cm long) lizard spends the majority of its life within the material, coming to the surface to forage. The properties of the medium it


Fig. 3 - The movement of a sandfish lizard (picture) on sand serves as a model for studying motions in granular media.

encounters vary with the compaction of the granular medium. For example, loosely and closely packed sand differ in occupied volume by approximately 10%, but drag resistance of the closely packed state is nearly double that of the loose material. In contrast to the understanding of locomotion of organisms like eels and nematodes (soil worms) that swim within fluids like water, the understanding of movement within granular media is less developed, in part because fundamental equations to model the relevant thrust and drag forces are not available. In addition, since granular materials are typically opaque to visible light, visualizing the subsurface movements is a challenge.

Prof. Daniel Goldman's group in the School of Physics at the Georgia Institute of Technology have used high-speed x-ray imaging and developed empirical granular drag laws to reveal how the sandfish "swims" within laboratory sand (Maladen et al, Science, 2009). Above surface the animal uses limbs to propel itself across the ground. Once it buries (within half a second), it no longer uses limbs to move, but instead propels itself forward rapidly (up to two body-lengths/sec) using an undulatory wave that propagates down its body. The animal swims with a fixed wave efficiency of 0.5, the ratio of the forward speed to the wave speed, independent of the compaction of the medium. The group has used the empirical drag laws to develop a resistive force model for granular media. The model correctly predicts the wave efficiency and indicates that the organism swims in a frictional fluid in which drag and thrust are dominated by the inter-particle friction. Their work could have applicability to robots that must crawl, burrow and swim within unconsolidated material like desert sand or rubble from a disaster site.

C. Recommendations

We recommend that the funding level for the program be increased. We noticed that the rate of proposal funding has declined from 26% in 2009 to 16% in 2011.

We encourage continued efforts to increase the representation of women and minorities, and believe that the principal efforts should now be to grow the population of trained scientists from under-represented groups.

We believe that it would be beneficial to demonstrate broad impact, to track over time the career development of students, postdocs and staff funded by the program. Modern social networks and the framework of a PoLS network can facilitate this.

There is a need for investment in cutting-edge instrumentation and computers to deal with measurements in complex living systems, which cannot be dealt with by the existing grant scheme. We recommend that a competitive capital equipment grant scheme be instituted. This argues that the APPI program should not have a fixed lower limit.

2. Elementary Particle Physics Theory and Mathematical Physics

Introduction

Theoretical physics advances the intellectual underpinnings of the science and makes the connections between disparate phenomena that guide experiments towards new discoveries.
Theoretical High-Energy Physics, Theoretical Cosmology and Mathematical Physics constitute a fraction of the theory activity within PHY. A decade ago the strongest focus of these programs had been on string theory, supporting most of the leading discoveries in this field. However Math-Phys supports a very broad portfolio of innovative research that cuts across many disciplines, and over the past decade the EPP Theory programs have developed a leading presence in the phenomenology of the Large Hadron Collider, as well as direct searches for dark matter.

The four members of the subpanel reviewed the processes and outcomes of awards and related issues in all three programs: Theoretical High-Energy Physics, Theoretical Cosmology (these two will be collectively referred to as EPP Theory) and Mathematical Physics (Math-Phys). We discussed 17 award jackets selected by the two program directors as both representative of the program and illustrating various challenges and issues that they had faced over the past three years. The sub-panel also examined a number of declination jackets, and several additional CAREER award and declination jackets requested by the subpanel for comparison purposes. The program directors were very helpful and forthcoming in all of our discussions.

A. Highlights of NSF investments

In recent work funded by the Mathematical Physics program Garnerone, Zanardi, and Lidar (arXiv:1109.6546) developed an algorithm that runs on an adiabatic quantum computer and calculates the Google matrix, which forms the foundation of Google's search algorithm. Currently, this matrix requires weeks to compute (even with Google's enormous computer power), and speeding up this computation has immediate impact on the quality of search results. In fact, recently Google has invested in research that aims to benchmark the algorithm on an adiabatic quantum computer manufactured by D-Wave. Interestingly, it turns out that a detailed understanding of the eigenvalue spectrum of the Google matrix is critical to determining the degree of speedup that is achievable. Thus, this work provides an example in which quite abstract mathematical questions have immediate impact on advances with direct applicability to important practical problems.

EPP Theory has enabled many of the most important breakthroughs in string theory and related approaches to quantum gravity and unification. One recent innovation is the incorporation of anisotropic scaling and renormalization group flow into quantum gravity (P. Horava Phys.Rev. D79 (2009) 084008), leading to a framework in which gravity, spatial dimensions and Lorentz invariance are emergent properties of the underlying short-distance theory.

Recently Steven Weinberg (Phys. Rev. D81 (2010) 083535) has proposed a new scenario for inflation in the early universe. He found a very interesting theoretical solution for a period of exponential spatial expansion in the framework of a finite quantum theory of gravitation. This is an exciting result towards reaching a realistic description of an inflationary universe.

In the light of the recent excitement for the Higgs boson searches at the CERN Large Hadron Collider, L. Hall and collaborators (arXiv:1112.2703) explored a variety of weak-scale supersymmetric models. A Higgs mass about 126 GeV strongly points towards a non-minimal implementation of supersymmetry. Naturalness is significantly improved in theories with the introduction of a singlet field coupled to the Higgs fields, allowing for a natural light Higgs boson over a wide range of parameters. This observation leads to rich and predictive signals for SUSY theory at the LHC.

J. Feng and collaborators (Phys. Lett. B703 (2011) 124) studied a very interesting scenario with a light dark matter candidate, in which the ratio of neutron to proton couplings with the dark matter is not taken to be unity, as commonly assumed in the literature. They discovered that for a single choice of the coupling ratio, the DAMA and CoGeNT signals are consistent with each other and with current XENON constraints, and they unambiguously predict near-future signals at XENON and CRESST. This work provides an important direction to systematically examine the direct dark matter searches in a more general framework.

Rajaraman and Tait (Phys. Rev. D84 (2011) 095013) made an important observation that the interactions of dark matter with quarks can be intimately connected to the dark matter direct searches. Consequently, the current LHC search for missing energy events (dark matter search) translates into bounds on the parameter space of dark matter direct searches. More importantly, the limits indicate tension with isospin-violating models satisfying minimal flavor violation, indicating that either a light mediator or nontrivial flavor structure for the dark sector is necessary for a viable reconciliation of CoGeNT with XENON.

B. Integrity and efficiency of the Program Process and Management

Overall the subpanel was favorably impressed with the quality, fairness, transparency, balance, prioritization, and attention to detail of program management in EPP Theory and Math-Phys. A combination of ad hoc mail reviews and a panel review was employed in most cases; this is an effective and fair methodology. While some ad hoc reviews contained more detail than others, overall the level of substance and thoughtfulness in the ad hoc reviews and panel reviews was impressive; for awards where novel issues arose, such as the LHC Theory Initiative, the reviews were sometimes 2-3 times the usual length and filled with useful insights. The Review Analyses written by the program directors were even more thorough, explaining the physics context behind each proposal, presenting highlights of the reviews both favorable and unfavorable, giving a clear discussion of broader impacts, and providing a transparent explanation of the program directors' final evaluation and the reasoning behind adjustments in the proposed budgets. In addition, the EPP Theory PD provided a very open and illuminating discussion of a number of challenges that he faced during his first two years managing the program. The transparency of the Review Analyses also appears to extend to communications with the PIs. For example, in two cases of an EPP Theory award where the summer salary of several senior co-PIs was cut, the PD composed a very detailed and gracefully worded explanation of this action, communicated by email or phone to the PIs.

C. Selection of reviewers

The review panels were each comprised of about a dozen researchers with proportionate (for U.S. physics) representation from women and under-represented minorities. The composition of the panels as well as the choice of ad hoc reviewers reflected both institutional and geographic balance. It is quite difficult to compose balanced, unconflicted panels and collections of ad hoc reviewers year after year from a limited pool of experts. The program officers are to be commended for their skill and perseverance in this crucial aspect of the award process. They also appeared to maintain a vigilant attitude towards conflicts of interest. In one case the EPP Theory PD identified a COI even after receiving misleading information from a co-PI, and resolved the conflict by excluding one of the ad hoc reviews.

D. Management of the program

The CoV is highly impressed with the quality of management of the EPP Theory and Math-Phys programs. Both program officers have excelled in the area of Broadening Participation, as evidenced by the levels of BP funding secured (through a competitive Division-wide program) for their programs, enabling two CAREER awards that would not otherwise have fit within the budget constraints. Of special note is the fact that the EPP Theory program director inherited a portfolio with seriously high commitment levels but has worked heroically and with great fairness, ingenuity, and resolve to rebalance the commitment levels of his program in just two years. This feat was accomplished with the crucial assistance of funds directed from the PHY Division management, who are also to be commended.

D.1 Responsiveness of the program to emerging research and education opportunities.

The Math-Phys program nicely balanced well-established research directions in statistical physics and string theory with support for emerging areas including quantum gases, quantum information processing, and the study of systems far from equilibrium. Research supported by EPP Theory includes the hottest topics in particle physics over a broad spectrum, from novel spacetime structures to new approaches to dark matter to innovations in modeling hadronic processes at the Large Hadron Collider.

D.2 Program planning and prioritization

We heard from the PDs that their priority given constrained budgets is to protect support for students and postdocs. In keeping with reducing commitment levels, the EPP Theory PD has begun to convert 5-year grants, upon renewal, to 3-year awards. We concur that re-evaluation of the progress and results from Theory proposals every three years is more appropriate for these fast-moving fields.

D.3 Responsiveness of program to previous CoV comments and recommendations.

The 2009 CoV commented on the distressingly small size of the typical awards in the PHY Theory program, sometimes insufficient even to fund ½ of a graduate student. In the EPP Theory program report this problem is directly addressed, and two program management strategies are described to partially alleviate this problem: maintaining a funding “floor” for awards to new assistant professors, and reserving some funding for supplements to grants in cases where graduate students lose other means of support (such as TA positions). The CoV commends this forthright approach to a problem that is an inevitable consequence of chronically tight budgets.

E. Issues

E.1 During the general discussion, the CoV expressed concern to the PHY leadership about the possible negative impacts of new major initiatives on the core support for small individual investigators. Any such negative impacts would be likely to disproportionally affect PHY theory programs. The Division Director expressed his sensitivity to this issue and the intention to pay special attention to maintaining the vitality of PHY Theory.

E.2 Mathematical Physics has the smallest budget of the PHY Theory programs but serves a growing community of physicists working on the cutting edge of developing mathematical tools and algorithms with far-reaching interdisciplinary impact. The number of proposals received each year is growing, increasing from 40 to 50 between 2010 and 2011. In the current fiscal year of approximately 25 proposals ranked as Must Fund or Fund if Possible by external reviewers, perhaps as few as 7 can be awarded. These numbers also emphasize the more general point that the marginal impact for every dollar redirected towards individual investigators in the Theory Program is large.

E.3 In our review of EPP Theory we saw ample documentation of serious financial pressures in the program. The best new faculty proposals receive awards of only $30K per year, barely enough for summer salary with no support of students or postdocs. Other emerging systemic problems include university cutbacks on TA positions, which have disproportionate impact on theory graduate students. In addition the long-standing funding gap between NSF and the Dept. of Energy for awards to junior and senior investigators is widening, making even CAREER awards less attractive to HEP theorists.

The EPP program director presented several short-term and longer-term initiatives and goals for HEP Theory and Cosmology Theory. He will establish and deploy an emergency reserve for grad student support, with the added goal of slowly building grad student support into long-term grant profiles. He will establish a two-month floor for summer salaries for assistant professors, and is already taking steps to increase the minimum grant size to $40K/yr, with commensurate readjustments for mid-career physicists whose funding levels have been frozen over long periods. The CoV encourages implementation of these plans and requisite support from PHY leadership.

Possible new initiatives for EPP Theory include partnering with SAVI to develop international "networks" for LHC phenomenology, leveraging the strong international connections in this field and enabled by communication tools in common use such as EVO. Another promising idea is a Theory Initiative for

Underground Science and the Intensity Frontier, complementing the existing LHC Theory Initiative fellowships for postdocs and students.

E.4 Issues raised by 2009 CoV

The 2009 CoV suggested that NSF consider possible bridge funding for new young faculty hires in a time of reduced hiring and of hiring freezes. We discussed this with the Theory program directors, but the proposal-driven nature of NSF does not seem to offer any mechanism to implement such an idea, even if funds were available.

The 2009 CoV also suggested that the next CoV would benefit from receiving a 30-minute formal presentation from the program directors on the Theory program, budget, funding trends, and programmatic directions. This suggestion was adopted for this meeting.

E.5 Theory integration

The presentation of the Physics Division's programs to the CoV, with a single box for "Theoretical Physics" does not do full justice to the scope and integration of theory activity in PHY. The NSF website gives a more accurate picture. We urge PHY to adopt the presentation used on the website more generally, as this will highlight the strength of the rich and diverse theory components of PHY.

F. Broader Impact

The Math-Phys and EPP Theory programs support investigators involved in a wide variety of mentoring and education programs for graduate students, undergraduates, high school students, and teachers. These include well-established national programs such as QuarkNet and TheoryNet, and local initiatives such as MARIACHI, which involves high school students in hands-on cosmic ray physics. NSF Theory has supported the TASI national summer school for 30 years, including putting all lectures on-line as both video and written form. The annual PHENO conference supported by NSF Theory has the most student speakers of any conference in the field.
This mentoring and outreach at many levels serves to recruit, train and inspire the future STEM workforce, as well as broadening participation in physics research. NSF-supported theorists excel in outreach to the general public, through TV shows, blogs, popular books, Physics Cafes, and lectures available on YouTube and iTunes.

G. Interdisciplinary Research

Co-funding has been a pillar of interdisciplinary activity in PHY. Both the Math-Phys and EPP Theory program directors have been aggressive about securing co-funding arrangements with each other, with other programs in the Division (EPP, PNA, Gravity, Nuclear Theory, PIF/Computational Physics) and with other NSF Divisions (AST and DMR). These theory programs are also involved in cross-cutting programs such as EPSCoR and OISE. For the immediate future, both EPP Theory and Math-Phys are strongly positioned to participate in SAVI, because of the many well-established international and national collaborations involving Theory-supported investigators.

H. Centers

The Aspen Center for Physics is a center for theoretical physics funded through the EPP theory program. The programs that the Center sponsors are interdisciplinary in nature, including programs that span from quantum computing to biological sciences to galaxy formation to LHC phenomenology to string theory and mathematics. In particular, the Center takes care to overlap the schedules of the interdisciplinary programs to foster cross-fertilization between areas. The Center sponsors numerous activities which have a broader impact: (i) a series of public lectures that are also broadcast over TV and the internet, (ii) participants give lectures at local high schools and civic organizations, (iii) a weekly event called Physics for Kids, (iv) a series called Dialogues in Physics that provides a forum for the public to ask questions to scientists, and (v) collaboration with the Aspen Institute to discuss science policy. The Center strives to achieve a broad participation in its programs and ensures that a healthy fraction of participants and program directors come from under-represented communities.

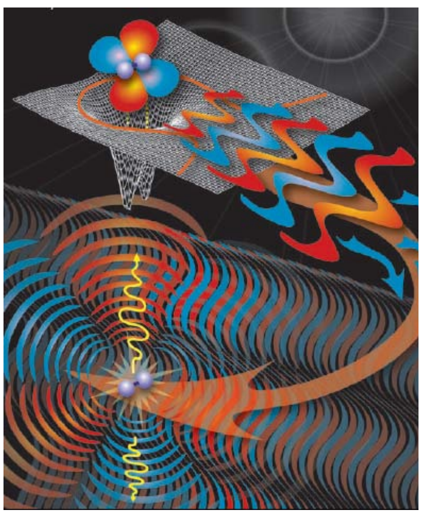
I. Broadening Participation

During the period under review, the program directors of both EPP Theory and Math-Phys succeeded in making additional CAREER awards supplemented by Division funding reserved for Broadening Participation. The CoV believes that this is a good practical mechanism towards achieving this important goal.

3. Atomic, Molecular, Optical and Plasma Physics and Quantum Information Science

Introduction

This report combines reviews of the AMOP (atomic, molecular, optical and plasma physics) program and QIS (quantum information science). Combining the review of these programs satisfies one of the recommendations from the last COV for physics programs in 2009. There are several sub-topics combined in this sub-panel that fall within one of these two programs. These subfields are: Precision Measurement, Optical Physics, Atomic and Molecular Dynamics, Atomic and Molecular Structure, and Theory in AMO; Plasma Physics; and Quantum Information Science.



Attosecond pulses developed in this program can probe molecules on the timescale of internal electron motion. [U. Thumm, Kansas State University]

Our first task is to make some comments on the balance within and between these areas.

Since NSF relies on a proposal-driven agenda, an important task of the COV is to spot trends in the applicant pool that may necessitate a rebalancing over time of the portfolio. Certainly AMO Physics has seen this in dramatic fashion over the past twenty years. AMO has often found itself at the frontier of new science enabled by new technology in lasers, computers and materials, and this has led to strong transitions in funding pressure. An obvious example is the rise of cold atom science relative to precision measurement science. One may argue that an even faster shift has taken place with respect to Quantum Information Science, which to some extent has grown out of ideas from both the precision measurement and the quantum optics communities, and attracted early strong funding from DOD sources. QIS was also recognized early by the NSF, so that this area now has its own program, which we are reviewing together with AMO specifically to be able to comment on the balance question. Other new areas of note are ultrafast optical science and x-ray optical science, which have enjoyed similar rapid expansion and have attracted strong sponsorship from DOE. These areas attract NSF support from the Optical Physics sub-program and also somewhat from plasma physics. Finally, it is our opinion that NSF's support for basic Plasma Physics in partnership with the DOE is absolutely critical for the very survival of the field as a distinct area of intellectual enquiry within Physics.

Executive summary of our recommendations

1. In light of limited resources, the COV supports the strategy of program managers to invest in the more fundamental areas of AMO, even though this consequently makes it harder to increase support for the development of new cutting-edge technologies for the pursuit of basic research.

2. The current investment in the new interdisciplinary subfield between atomic and condensed matter physics is strongly supported by the COV.

3. Atomic and Molecular Structure is the smallest subfield of the AMO program, and it has shrunk substantially over the past few funding cycles to the point that it may be time to consider merging this area with another, such as the AMD subfield.

4. We support the statement of the previous COV to reduce the number of grants if necessary in order to support adequately those that are funded. We recommend, however, that care be taken to protect junior faculty PIs. We also note that the issues are different for theory grants, so the balance between grant number and grant size may also be different.

5. We recommend that the Division consider adopting the same tuition policy for NSF funded graduate students that they have already established for NSF Graduate Fellows: namely that the grantee institution receive a fixed fee in lieu of any tuition charges to the grant.

6. We commend NSF for not moving too rapidly to switch away from Fastlane until a decent alternative government funding website is commissioned.

7. For the new Cross-Disciplinary-Research Program "ombudsman" suggested by PHY, we recommend creating a fund specifically held in reserve to supplement Cross-Disciplinary grants. This will create an incentive for the POs of regular programs to pursue cooperation with the Cross-Disciplinary PO.

8. An instrumentation initiative will be most germane to the Plasma Physics and the proposed Accelerator Physics programs. The COV discussed this and agree with the general need for this new program, but have some concerns about the effect of the recurring costs of operating the new instruments on the core programs.

9. The AMO program manager described plans to establish an instrument improvement fund within the program, to satisfy equipment upgrades at the level of approximately $200k or less. We believe this is a prudent action that will over time substantially improve the quality of small-scale research infrastructure in the program.

10. We strongly support the ongoing partnership between the NSF and DOE in Basic Plasma Science and Engineering. To grow the program we encourage the Plasma

Physics PO to make new connections with other programs within and outside of the NSF. We support the proposed Accelerator Science initiative as this presents an opportunity to explore new intellectual frontiers in the generation, acceleration and focusing of charged particles and entirely new paradigms for producing coherent radiation.

11. This COV combined AMOP experiment, AMO theory, and QIS. We believe that this worked extremely well and has led to a more complete view of the balance and directions in our field.

Balance and diverse science in AMOP/QIS

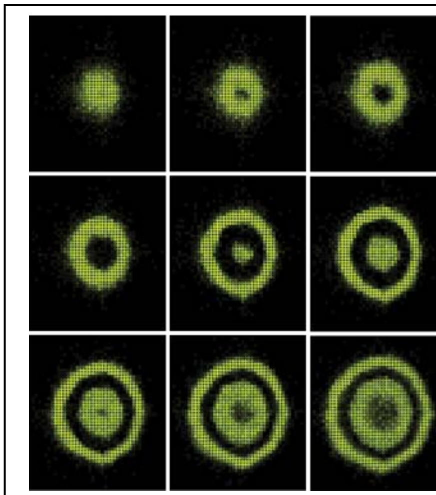
The program is sufficiently diverse that there are four separate subDivisions for pooling proposals: AMO (experiment), AMO Theory, Plasma, and QIS. These have distinct teams of program officers (with some overlap therein) and generate separate summary reports. Our committee used these reports to help us collect and sort material.

AMO

Precision Measurements

Precision measurements is an area where the contributions from AMO are unique, often providing key validation for particle physics at much lower cost; and also contributing to society in ways such as GPS that cut across the economy broadly. It is, however, a relatively small enterprise, using only 13% of the awards and 23% of the funds in AMO in FY11. Experiments tend to be expensive and last many program cycles, so good management oversight is essential: mere “paper-counting” won’t produce quality in this field. NSF and NIST handle most of the funding in the U.S. in this area, for work on fundamental constants, symmetry searches such as time-reversal violation, and QED. Our panel found that though small, this field appears healthy, with a reasonable percentage of new starts (including a CAREER grantee) as well as long-term renewals for programs that are doing extremely difficult measurements.

One of the trends to look for here is a relative rise in costs. The scientific instrumentation required in this field is growing in scale and complexity. An example is ultrafast lasers for frequency combs. According to the analyses presented by the program officer, these predicted increases are not yet apparent, but may be in the future.



Mott rings in an ultracold atomic gas. [M. Greiner, Harvard U.]

Optical Physics

Optical physics constitutes the second largest category within AMO, 26.4% of the awards and 25.2% of the investment. Optical physics is a broad field that has benefited from technical advances in disparate areas, from attosecond laser pulses to x-rays to single-photon interactions to entanglement for quantum information. The program officer points out, and it is evident from reviews, that there is a trend against NSF funding science that is purely related to demonstrations of new technical capabilities, even if these could improve the scientific opportunities in the field. This would be a disturbing case of "eating the seed corn," were it not for two important factors: first, that many of the applicants combine technical advances with exciting new science, and these proposals do relatively well; and second, that technical aspects of this field have other funding sources, both within and outside of NSF. Examples include NSF Engineering Research Centers, DOE supported National Laboratories, and NIST.

There are two trends that bear watching here. The reliance on support by outside agencies for technical advances should be both acknowledged and monitored to spot any potential shortfalls that could affect the science research. In addition, the expanding diversity of the field of Optical Physics means that it may be increasingly difficult to maintain the proper balance.

In light of limited resources, the CoV supports the strategy of program managers to invest in the more fundamental areas of AMO (outlined in the AMO Program Summary), even though this consequently makes it harder to satisfy one the prior CoV recommendations – to increase support for the development of new cutting-edge technologies for the pursuit of basic research.

Atomic and Molecular Dynamics

This is the largest subcategory within AMO. About 52% of the active grants fall into this category comprising 44% of the program's financial investment. A large number of proposals in this subarea are related to the use of cold atoms or molecules for the exploration of many-body and strong correlation physics, with direct links to condensed matter research (e.g. high-temperature superconductivity, quantum magnetism), but also to nuclear physics. Cold atoms can be viewed as quantum emulators for model Hamiltonians that are realized in pristine fashion. There are naturally strong connections to quantum information science, and in fact cold atoms in optical lattices, imaged with single-site imaging and control, could potentially realize quantum computations.

The large number of young faculty hires in this particular area is expected to further increase proposal pressure. So far NSF has done a remarkable job providing the backbone for the research of faculty even in the early stages of their career. We note, however, that, in the last few years, proposals from several young faculty have repeatedly, in consecutive years, been right at the losing edge of the funding decisions.

The investment into this new interdisciplinary subfield between atomic and condensed matter physics is strongly supported by the COV. There are, however, a significant number of submissions that have no overlap with condensed matter (i.e. interactions of atoms with coherent light fields, non-linear response of isolated atoms to intense electromagnetic fields, coherent control via laser light of the dynamics in atomic and molecular systems).

Atomic and Molecular Structure

This is the smallest subfield of the AMO program, and it has shrunk substantially over the past few funding cycles to the point that it may be time to consider merging this area with another, such as the AMD subfield. It currently comprises only 8% of the funding, and only had two proposals funded out of three submitted in the most recent panel review. Yet the panel feels strongly that the work in this field can still be of substantial importance to the broader community, especially in areas such as astrophysics and plasmas. The COV noted further that the funded proposals had themes and techniques that would also fit well into the AMD program. Finally, we note that Physical Review A combines Atomic and Molecular Structure and Dynamics into a single section, further demonstrating their close connection.

Theory

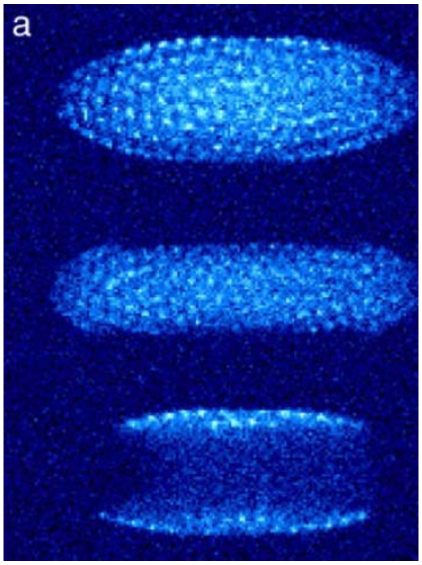
The sub-area of Theoretical Atomic, Molecular, and Optical Physics (TAMOP), as currently defined by the NSF, is concerned with a quantitative description of the interaction of electrons, atoms (ions) and photons with other atomic and molecular systems. The support of NSF for this sub-area consists primarily of single-PI awards in these areas plus the Institute for Theoretical Atomic and Molecular Physics (ITAMP). The TAMOP sub-area is currently in a period of rapid growth and change. This was emphasized by the final report of a workshop, supported by NSF and held at NSF Headquarters during August 18-19, 2011, entitled "TAMOP – Recent Developments and a Vision for the Future". The participants of this workshop identified seven scientific themes of TAMOP research for the next decade and made several recommendations for future funding. This report is available from panda.unm.edu/TAMOP. This represents a consensus view of the community and we recommend that the program managers take note of it. One of the greatest concerns expressed in this document is the shrinking grant size. Remedying this problem is one of our main recommendations (see the Executive Summary Recommendations).

Plasma Physics Program

The goals of the Plasma Physics Program are to support research and education that explores all the fundamental aspects of the properties and behavior of plasmas and their implications to other fields. The principal topics include low temperature plasmas (including ultra-cold, and dusty plasmas), turbulence in laboratory and space plasmas, magnetic reconnection in the laboratory and space, laser plasma interactions, and high energy density plasmas. The program's goal is to support theoretical, computational, observational, and experimental work in these areas.

The NSF has contributed approximately $4 M/yr to the Plasma Physics program in the past three years. In any one year there have been about 100 proposals submitted to this program. To help meet this large demand from the community, a joint NSF/DOE Partnership in Basic Plasma Science and Engineering has been set up. This partnership, in existence since 1997, has an important impact on funding mostly university single investigator grants in basic plasma physics. The DoE is interested in supporting basic research in magnetized plasmas. Even with this load sharing with the DOE's OFES the NSF portfolio is too thinly spread. For instance in FY 2011 only 19 of 93 proposals received were funded. (This includes 10 that were funded by DOE Office of Science, and 2 by NSF's Division of Atmospheric and Geospace Sciences). The solicitation for this program is managed through the NSF's Fast Lane and the reviews organized jointly by the NSF and DOE program officers. The NSF's previous program officer Dr. Richard Berger and the current P.O. Dr. Steve Gitomer, both part time program managers, have done an excellent job of coordinating this important activity with the DOE without which there would be no support for PI driven basic Plasma Science in this country.

We have found that the quality of research questions being addressed is very high. Here we site but a few representative examples. For instance why do some planets and stars have strong surface magnetic fields while others do not? How exactly do low temperature plasmas aid nano-scale manufacturing? How does plasma behave under the influence of super-intense laser pulses? The intellectual content of the program is additionally maintained at a competitive level by the Plasma Physics PIs who have won one Physics Frontiers Center at Wisconsin, a 5-year renewal for major space plasma physics facility (BaPSF) at UCLA and by vigorous laser-plasma interaction activities that have attracted worldwide attention. The Plasma Physics PIs have been successful at winning several midsize MRI awards that range from a GPU based cluster, Dawson II for computational plasma physics at UCLA to a Plasma Dynamo Facility, again at Wisconsin, to the Magnetized Dusty Plasma Facility at Auburn University.



Two isotopes of thorium ions segregate in a Wigner crystal. This technique can be used to address qubits for quantum computing. [A. Kuzmich, Georgia Tech.]

The Plasma Physics program currently receives proposals not only in Plasma Physics but in advanced accelerator science and in the emerging area of High Energy Density Science. In order to meet the demand of a large number of proposals and improve the percentage of the funded proposals, the Plasma Physics program must continue to seek synergies with other programs (e.g. the proposed Accelerator Physics program) both within the NSF and externally with other funding agencies.

Quantum Information Science

This is a relatively new program that was established as the Physics Division's component of the Information Science Frontier (PIF) initiative at NSF. In the past decade this topic has become recognized as a separate sub-discipline within Physics, linked to specific programs with related concerns both within and outside the Physics Division, including the technical frontier to develop modalities for revolutionary computing as well as basic research in quantum information. QIS is an area of particular importance to NSF in part because QIS provides a significant fraction of the support for US university research in quantum information.

The program supports a number of centers: (1) the Institute for Quantum Information (IQI) at Cal Tech, which will now be incorporated in the new PFC, the Institute for Quantum Information and Matter (IQIM), and (2) the Center for Quantum Information and Control at New Mexico and Arizona. PHY also separately supports QIS studies in the PFC at Maryland at the Joint Quantum Institute (JQI). There are also major connections between the PIF – QIS Program and other Divisions of the NSF, particularly DMR and to CISE (CCF). In PHY there are connections to AMO and TAMOP and to Mathematical Physics (MP).

It is very healthy to have QIS as a separate Program in physics because it supports research across a range of disciplines (atomic, molecular, optical, condensed matter, electronics, computer science, mathematics), and because it facilitates interactions between theory and experiment. Another positive aspect is that it provides an alternative venue in which to seek funding for work that might otherwise fall into cracks between standard disciplines.

Although NSF Physics does have mechanisms in place (see "Managing Non-

Standard (Cross-Disciplinary) Proposals within PHY – Bridging the Gaps") for handling cross-disciplinary proposals, we strongly support the continuation of QIS as a designated home for proposals in this area. The Program provides a home for incubation of what might become one of the most important future areas of physics.

The present balance of projects supported by QIS appears to us to be appropriate.

The integrity and efficacy of processes used to solicit, review, recommend, and document proposal actions.

Much of our effort on this COV was devoted to reviewing all aspects of the proposal process. It appears to this panel that the level of integrity is very high. In a subject-driven proposal process extreme care must be taken to avoid not only obvious conflicts of interest but also less visible but no less important conflicts that come as a result of relationships that are recent and therefore not reflected in the publication record, or relationships through student or postdoctoral connections. In all cases when such conflicts escaped the initial screening and came to light during a panel review, the program handled it in a professional manner and so as to eliminate even the appearance of a conflict.

The program uses a combination of panel and mail-in "ad hoc" reviews in such a way as to optimize the efficiency and the accuracy of the review process. This crisp professional attitude has an important pay-off in the level of cooperation and sheer dedication of the reviewers, who are all volunteers from the community. We conclude that a well-run review process actually reinforces itself, and we commend the program management for having created and maintained this good cultural attitude towards review.

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

There are a number of indications of the quality and significance of the AMOP/QIS programmatic investments. Here are just a few examples of groundbreaking science results:

The emerging field of Quantum-Regime Optomechanics: New methods in optical physics have used laser light to cool the motion of macroscopic objects to temperatures so low that they approach the quantum mechanical ground state, where the temperature is effectively at absolute zero. One application of such low-temperature motion is to increase the sensitivity of interferometric gravitational wave detectors, such as the Laser Interferometer Gravitational-wave Observatory (LIGO), which is seeking to detect gravitational waves emitted by violent cosmic events such as supernova explosions and collisions of neutron stars and black holes.

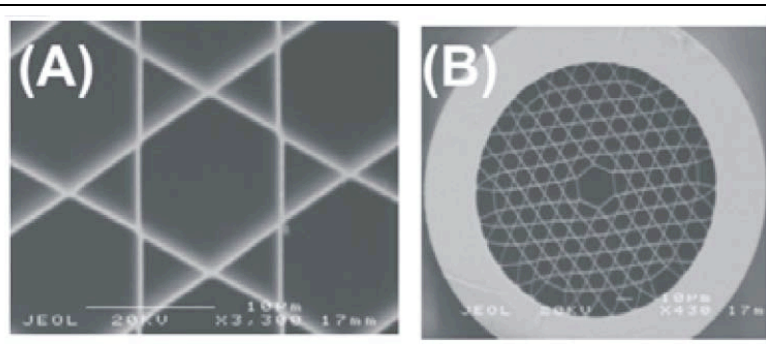
“The bouncing gas“: AMO scientists have collided two clouds of fermionic ^{6}Li atoms of unequal spin with resonant interactions. In this “Little Fermi Collider” (LFC), the gas clouds are observed to bounce off each other, despite densities a million times thinner than air. Spin diffusion is here as slow as allowed by quantum mechanics, with a diffusion constant given by hbar divided by the atomic mass.

Quantum Gas Microscope: Scientists image and control atoms trapped in optical lattices with single-site resolution. In this breakthrough work, the transition from a superfluid to a Mott insulator, a many-body effect, could now be studied at the level of individual atoms. [Probing the Superfluid-to-Mott Insulator Transition at the Single-Atom Level, W. S. Bakr, A. Peng, M. E. Tai, R. Ma, J. Simon, J. Gillen, S. Foelling, L. Pollet, M. Greiner, Science 329, 547 (2010)]

Quantum Concatenated Code Hamiltonians: Work in the QIS program has led recently to the discovery of a way to construct subsystem codes that involve few body spatially local Hamiltonians. This was the result of collaboration between a PI and an REU student and represents a major new class of subsystem codes that are likely to be useful for fault-tolerant quantum computing.

Robust matter-light entanglement generation and distribution: This award supported work on advancing the state of the art in quantum information processing with cold-trapped neutral atoms, and the initiation of a program to trap and laser cool triply charged thorium. Major results of this work included: Increased quantum memory time by more than two orders of magnitude, in excess of 6 milliseconds; multiplexing of a dozen quantum memory elements into a cold atomic sample; magnetic compensation of Stark hyperfine shifts leading to storage of coherent light for longer than 0.3 second, and storage of spin-wave qubits for longer than 0.1 second; and first realization of laser cooling of a multiply charged ion (triply charged 232-Thorium).

Generation and Trapping of Antihydrogen: One of the highlights of AMOP accomplishments since the last COV is the conclusive proof of generation and trapping of antihydrogen atoms after nearly two decades of painstaking work at CERN. The work uses both plasma physics and AMO techniques to create low loss traps and cool both the positrons and the antiprotons. More than 300 atoms have been trapped. At this time antihydrogen atoms are not detected directly when they are formed in the trap; rather the formation of antihydrogen in the trap in inferred by turning off the trap and allowing the antihydrogen atoms to escape. Recent work has improved the trapping time of antihydrogen up to 2000 seconds.



Kagome lattice fibers have unique properties for nonlinear optics and vuv light conversion. [Benabid, Univ. of Bath]

Quantum Optics with Superconducting Circuits: An important new area has been pioneered by AMO-supported researchers -- quantum optics with superconducting integrated circuits. This is based on the paradigm of "circuit QED," in which superconducting qubits are combined with microwave transmission line resonant cavities to realize the physics of the Jaynes-Cummings (two-level system) model with ultra-strong coupling. This allows the generation, manipulation, and measurement of non-classical states of the electromagnetic field at microwave frequencies. Superconducting devices act as single qubits, allowing new possibilities for nonlinear optics at the single-quantum level, for example a quantum non-demolition measurement capable of detecting single microwave photons. This work is opening a new area for fundamental studies of the quantum measurement of the electromagnetic field.

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

This Division directs all of its funding, efforts, and procedures to enabling scientists in the United States to perform research in areas that their fellow scientists deem most important for the progress of the science enterprise overall. The cornerstone method to decide how to distribute the portfolio is peer evaluation through individually submitted reports and through panel consensus. ***The fundamental science research mission is unique in the United States, and as a result there are many areas of science where American scientists would simply not participate in any significant numbers were it not for NSF funding.*** Ultracold atoms, one of the faster growing areas of the portfolio, is squarely in this category of serving fundamental science. The same goes for most precision measurement science.

In areas where AMO fundamental science research also enables clear applications in other fields, there has been a variety of approaches to include AMO programs. A successful example is the Plasma program, which has also been reviewed by our panel in the COV. This program is jointly reviewed and supported by the DOE office of Fusion Energy Science (OFES) and the NSF Plasma program. By itself, NSF would likely not be able to have a viable plasma program because so much of the experimental effort needs the expensive infrastructure of the DOE labs. On the other hand, fundamental plasma science is more difficult for OFES to fit within its mission of support for the international efforts in controlled fusion. Together, the two agencies have constructed and maintained an excellent program, which also satisfies an important strategic goal of the Foundation to support plasma science.

Another strategic success is Quantum Information Science, which emerged as an area combining existing disciplines of quantum physics, mathematics and computer science. The AMO program has been a good home for incubating the new QIS program, and it has produced some of the early successes that launched the growth of the field.

<u>The Division's balance, priorities, and future directions</u>

In light of limited resources, the CoV supports the strategy of program managers to invest in the more fundamental areas of AMO (outlined in the AMO Program Summary), even though this consequently makes it harder to satisfy one of the prior CoV recommendations – to increase support for the development of new cutting-edge technologies for the pursuit of basic research.

A major problem has arisen over the past decade for individual-PI tabletop experimental programs, in particular those funded under AMO: While the cost at many universities for supporting one PhD student as a research assistant has literally doubled in ten years, the size of grants has barely kept pace with inflation. As also pointed out in the previous CoV report, a typical grant can no longer support a minimally sustainable project. We define a minimally sustainable experimental project as supporting one senior PhD student, one junior PhD student for continuity, and two or three weeks of PI summer support, along with reasonable supplies and small equipment purchases, plus the occasional larger equipment purchase. (Note this does not include a postdoc.) It is not reasonable to expect that every project of a PI will be able to be supported by resources from NSF combined with those of other agencies.

We therefore support the statement of the previous CoV to reduce the number of grants if necessary in order to support adequately those that are funded. We realize that this is a painful choice, which the community should not have to make, but it appears to be necessary in a flat funding environment. We recommend, however, that care be taken to protect younger faculty PIs.

<u>The Division's response to the prior COV report of 2009</u>

A major change in the program structure took place since the previous CoV report, which recommended that Plasma Physics be separated from AMO Physics. This has been implemented, and the AMOP program was separated into AMO Physics and Plasma Physics programs. We believe that the separated Plasma program is working well, as we have described above.

Other recommendations of the previous CoV AMOP report are listed here, with brief comments on their implementation:

1. The COV recommended that the subfield categories be updated and that

the panel be broken into two separate ones. This was completed successfully.

2. The 2009 COV recommended tighter coupling between the AMO theory and experimental programs. This has been addressed, and we feel that the couplings are as important as ever.

3. A continued decrease in program funding after accounting for inflation should result in fewer grants rather than smaller ones. This recommendation appears to have been accepted, but the decreases in funding are small so far.

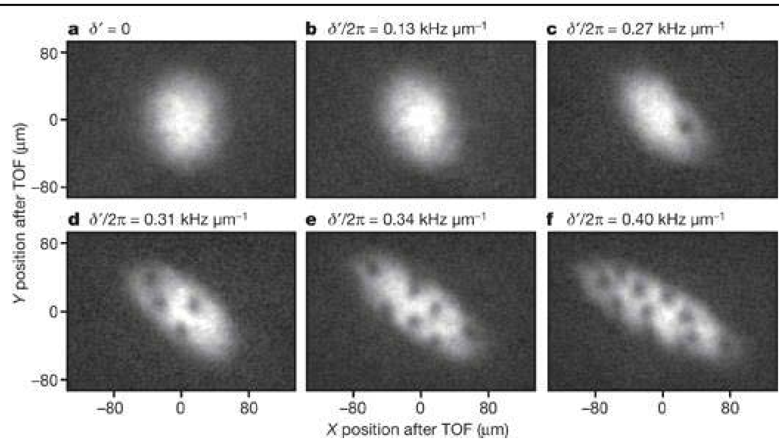
4. The 2009 COV recommended the $80k limit on equipment be eliminated. It is no longer there.

5. PFC funding should not exceed 10% of the Physics Division budget. ... and the establishment of funds for equipment items in the $50-$500k range. This is implemented.

6. The 2009 COV recommended adequate funding for basic research at the CM/AMO interface. New opportunities such as the CREATIV program now exist to address this.

7. The 2009 COV recommended that there be an explicit recognition that expectations are different for proposals from 4-year colleges and others from research universities, by asking reviewers to rank them separately. We don't agree with this, nor has it been implemented.

8. 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 emphasis on innovation in education and outreach in early career is misplaced. Management has explained that this is not a decision that can be taken at this level, and probably won't happen.



Patterns of vortices in a superfluid Bose-Einstein condensate.

9. Fastlane should continue to be the medium for proposal submission, not grants.gov. Fastlane is still in place and working.

10. The 2009 COV recommended a greater utilization of the 5-year grant period for renewing PI's. We agree, but this has not yet happened.

11. A gap in the funding portfolio is the lack of support for the development of new cutting-edge technologies for the pursuit of basic research. We agree that this is still a gap, but do not see an effective way to fill it.

As was the case in the previous CoV report, we find that the use of a combination of external written reviews and panel members' reviews and face-to-face meetings is an excellent way to review proposals. It allows tapping expertise among external reviewers while allowing also the personal give and take of a panel meeting, required for the difficult task of comparing relative merits across a wide range of proposals.

Other issues that the COV feels are relevant to the review.

Graduate student tuition: Graduate student training in AMOP research is the most important outcome that is enabled by this program. The COV notes that an important cost driver that has driven us to recommend actually reducing the number of grants to maintain a minimum viable grant size is the rapid increase in graduate student tuition. We therefore recommend that the Division adopt the same tuition policy for NSF funded graduate students that they have already established for NSF Graduate Fellows: namely that the grantee institution receive a fixed fee in lieu of any tuition charges. Such a move would make it possible to extend as much as possible the number of graduate students that can be trained in research in the program. This is especially critical in a funding environment where the AMOP/QIS Program Offices may be forced to reduce the number of grants in order to maintain the viability of those that are funded.

Grants.gov: NSF was slated to move to Grants.gov, however, they managed to hold out long enough that this severely troubled federal grant portal will soon be replaced. Fastlane is far better than grants.gov. While we support the idea of a standard portal, we commend NSF for not moving too rapidly until a decent website is commissioned.

Instrument improvement fund: The AMO program manager described plans to establish an instrument improvement fund within the program, to satisfy equipment upgrades at the level of approximately $200k or less. We believe this is a prudent action that will over time substantially improve the quality of small-scale research infrastructure in the program.

<u>Cross-cutting questions</u>

1. Cyber infrastructure

NSF has identified Cyberscience / Cyberinfrastructure as an area of emphasis. One example of the Plasma program's involvement in this important initiative is the development of the Dawson II GPU-based cluster that is being carried out at UCLA's Institute for Digital Research and Education. This is a modest scale ($1.78 M) initiative, funded through the MRI program. Under this grant it is proposed to build a 96-node dual quad-core (768 i7 processors) cluster with 192 Nvidia GPU cards. The network is based on QDR Infiniband with full cross section bandwidth. Peak speed in a single precision of 200TFLOPS is expected. This cluster will provide a testbed for porting parallel particle-in-cell codes used to study a variety of problems to GPU based systems. If this should prove to be possible, then the cluster will be an instrument for enabling breakthroughs in new particle accelerator techniques, fusion energy, space plasmas, astrophysics and basic science. Viewed in this light this undertaking is not just the development of a scientific tool but it will enable scientific enquiry into fundamental plasma related problems.

The computational challenges in the area of Atomic, Molecular, and Optical (AMO) Physics, lie in the precision analysis of atomic structure, scattering of atoms and molecules, and in understanding the behavior of ultra-cold atoms modeling many-body systems. These computational tasks are smaller in scale than in some other sub-areas of physics. However, many projects in this area involve high-precision quantitative comparison with experimental data obtained from table-top experiments in which the theoretical answer often must be produced on the time scale of days to weeks. The current state of AMO physics is unique in that many-body systems being studied in the laboratory are ones for which theory can provide precise quantitative comparison. This is especially true for ultra-cold atom systems. While there are plenty of problems in AMO which are computationally intractable, there are also many problems of high current interest that can be practically solved on clusters consisting of a modest (10-50) number of multi-core nodes perhaps also equipped with GPU capability.

2. Broader impact

The societal impacts of AMOP science have been enormous, touching nearly all aspects of society. The internet, modern communication, entertainment, displays, and information services would be unrecognizable or even impossible without the results of advances in AMO science, including lasers, fiber optics, MRI, surgery, drug design, GPS, and more. Here we provide one of the more recent examples.

Airport security's most recent innovation is the terahertz-wave whole-body scanner, which is a direct result of advances in laser and AMO science in the 1980-2000 time frame. This non-invasive and safe scanning technology started out in AMOP research labs at IBM and Bell Laboratories, moved to universities under NSF and other federal agency funding, and then quickly to industry and homeland security to help post-9/11 needs for increased security.

The low-temperature plasma physics program has had enormous impact on integrated circuit processing, and on atmospheric and space communication. The main applications for plasma research are generally in the energy sector, including lighting, displays, and fusion energy.

The NSF Broader Impacts document of 2007 lists 39 different ways that research programs can demonstrate their commitment to broader impacts, and we note that the AMO program has examples of almost all of these. One reason for this is that AMOP science is generally conducted at the table-top level within a research university environment, where there are many opportunities for contact with students at the college and pre-college level and with the general public. We support the Division's approach to defining broad impact in a way that takes advantage of the strengths of different programs and different PIs.

We believe it is generally a positive thing to encourage researchers to consider the potential broader implications of their work, to try to place it in a larger framework, whether of science or society, and even to try to come up with creative ways to give their work an educational component. From this point of view, a good, believable broad impact statement may be considered as "value added" to a proposal, and it could plausibly make the difference between two proposals of equal scientific merit, when only one of them can be funded.

3. Interdisciplinary Research

3. Interdisciplinary Research. This has been an important growth area for PHY. There are multiple levels of this. One is how the Division responds to the big NSF-wide priority areas such as SEES and NNI nanoscale (w/in AMO) initiative, which are all labeled as "multidisciplinary." Another is how the Division interacts with other Divisions and within the Division on individual proposals.

As cutting-edge, emergent research often arises at the interfaces between established areas, we would like to see more explicit efforts made to strengthen avenues for proposals in interdisciplinary research. Currently interdisciplinary research proposals in Physics are handled by two main mechanisms:

- Ad hoc handling by POs of regular programs, who may contact other Physics POs or POs from other Divisions for mutual reviewing and cooperative funding. This ad hoc mechanism may not be best for fostering successful outreach between POs, who are highly burdened dealing with their core proposals. Some additional incentive to cooperate may be in order.

- Processing and facilitation may be handled by the Education and Interdisciplinary Research (EIR) Program. In principle, EIR can allocate some of its 8M budget to funding such interdisciplinary research proposals, but recently this has not occurred, or only very rarely. Most of the EIR budget is allocated to education research.

Two new efforts are either underway or proposed to improve the support structure for interdisciplinary research:

1. Beginning in 2012, CREATIV (Creative Research Awards for Transformative Interdisciplinary Ventures) is a pilot grant mechanism under the Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE) initiative, to support bold interdisciplinary projects in all NSF-supported areas of science, engineering, and education research.

2. Under consideration by the Physics Division is the identification of a new Program Officer who will act as an "ombudsman" to keep an eye on interdisciplinary proposals and help the POs who handle them find appropriate POs at NSF to complement the managing POs expertise.

We applaud both of these new efforts, and have recommendations as follows:

For the Program "ombudsman," we recommend that the Division create a fund specifically held in reserve to supplement Cross-Disciplinary grants. This will create an incentive for the POs of regular programs to pursue cooperation of the Cross-Disciplinary PO.

4. Facilities and Centers, and the Instrumentation Initiative

The Physics Division supports eight Centers connected to AMOP/QIS science, in addition to the core single investigator programs. The COV finds that this mix creates an extremely strong and well-balanced combination, where the single investigator programs are strengthened by the many interconnections to and between the centers. The eight Centers include the Center for Ultracold Atoms (Harvard-MIT), ITAMP (Harvard-Smithsonian Center for Astrophysics), Joint Quantum Institute (Maryland-NIST), JILA (Colorado-NIST), Institute for Quantum Information and Matter (Caltech), the Basic Plasma Science Facility (UCLA), Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas (U Wisconsin), and the Center for Quantum Information and Control (UNM-UA).

These vibrant communities create an outpour of exciting novel techniques for precision metrology, transformative ideas, and ground-breaking discoveries. An excellent example of the synergy provided by such Centers is the achievement of ground-state dipolar molecules via the use of frequency combs. Another example is the demonstration of artificial gauge fields that make neutral atoms experience effective magnetic and electric fields, an example of a transformative idea that connects the fields of atomic physics and condensed matter physics.

The Centers with their critical mass of creative minds transform AMOP and open it up to other fields of physics such as condensed matter, nuclear physics and accelerator physics. AMOP techniques transpire into novel atom-like systems such as color centers in diamond used for quantum information or mechanical oscillators that are cooled to their ground state via laser cooling.

These ideas now lead to new proposals from outside the Centers aiming to harvest this new quantum control for quantum computing or creation of model systems for condensed matter materials. A major impact of the Centers lies also in education of graduate students and postdocs. The Centers act as major talent magnets, as incubators for new ideas, and then as a source of outstanding young investigators who take the ideas with them and consistently advance to leadership positions in academia or industry. Through sponsorship of workshops, visitor programs, summer schools and workshops, the Centers share their vision and expertise with the scientific community.

The **Instrumentation Initiative** will be most germane to the Plasma Physics and the proposed Accelerator Physics programs. The COV discussed this and agree with the general need for this new program, but have some concerns about the effect of the recurring costs on the core programs.

5. Outreach Activities

Outreach, particularly to broaden exposure to AMOP science, is practiced at all levels in the program. Single investigators frequently give public talks or take on summer interns from high schools. However, single-PI efforts are generally too small for extensive outreach activities. Therefore, leadership in outreach comes in this program from the PFC and other centers. Here are two examples:

The AMO Physics Frontier Center at JILA has a significant community outreach component. In fact the JILA AMO Physics Center's K–12 education outreach program is now under the auspices of the Partnerships in Informal Science Education in the Community (PISEC) program, funded by the National Science Foundation. The informal science education program offers semester-long weekly science classes after school at Mountain View and Spangler elementary schools, Sunset and Heritage Middle Schools, as well as at Casa de la Esperanza (House of Hope), a largely Hispanic residential community in Longmont operated by the Boulder County Housing Authority. The program also offers science mini-courses at Boulder Preparatory High School, a charter school for at-risk students.

The Basic Plasma Science Facility (BaPSF) at UCLA has an extensive outreach effort aimed at high school student and teachers in the Los Angeles area. Associated with this facility is a plasma laboratory created specifically for high school seniors and their mentors where students can carry out measurements on plasma properties and waves in magnetized plasmas. Each year several students present papers at the annual APS DPP meeting . Several high school teachers similarly have published papers in the American Journal of Physics. This activity is a model of a successful outreach effort that benefits both the community and the host facility.

Broader participation and diversity: One of the important avenues for broader participation in the program are REU supplements, which target underrepresented groups. The Division also supports the programs that target underrepresented groups. It's not clear that programs such as EPSCOR are effective because they target borderline proposals rather than uniformly support underrepresented segments.

Unfortunately, some of the NSF programs that have provided important funding for outreach to underrepresented groups are disappearing. For example, the NSF Graduate STEM Fellows Program in K-12 Education (GK-12) in the Cross Cutting Program sent graduate students to high schools, particularly in economically distressed communities. This program is no longer accepting applications.

4. Nuclear Physics

A. Introduction

The NSF Nuclear Physics Program effectively manages a diverse research portfolio encompassing forefront experimental and theoretical research on the properties and behavior of hadrons and nuclei, nuclear matter under extreme conditions, fundamental interactions, symmetries, and the role of nuclear physics in astrophysical phenomena. The program focuses on projects and investigators with a clear critical contribution or leadership role. The experimental program includes facilities and instruments with a wide range of scales and capabilities including low-energy to multi-GeV electrons and photons; intermediate-energy light ions; low-energy to relativistic heavy ions including radioactive beams; cold and ultra-cold neutrons; as well as non-accelerator-based experiments. The program supports a flagship national user facility, the National Superconducting Cyclotron Laboratory (NSCL), and two university accelerator laboratories with broad capabilities. A large fraction of the program consists of university-based experimental and theoretical groups who are working at these research frontiers.

Our subpanel reviewed funding decisions for the past 3 years in both experimental and theoretical nuclear physics. It should be noted that funding decisions for experimental and theoretical proposals are treated separately, with two independent panels providing funding recommendations. However, both programs are managed by the same program office following similar policies and procedures. Many findings are common to both the experimental and theoretical programs. Here we provide a combined report on both programs, but specific comments may pertain only to the experimental or theoretical program. We begin with a brief summary of the primary findings and recommendations.

B. Findings and Recommendations

- The NSF Nuclear Physics Program supports research at the frontiers of nuclear science. Support for facilities and forefront instrumentation is important to allow NSF to take a leadership role in some of the most compelling research initiatives. Despite budgetary challenges, the program has thus far been able to effectively respond to emerging opportunities and provide support for new initiatives and young investigators. However, the size of most individual investigator grants is now marginal. Without growth in the base funding for nuclear physics, the success rate for established programs and/or the level of support for the larger groups may have to decrease to continue to allow for new initiatives. Careful consideration must be given to balancing these concerns in times of constrained budgets.

- The NSF Nuclear Physics program has world-wide visibility. Part of the strength of the program results from the leadership by the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University that conducts research in the structure of exotic nuclei and their role in astrophysical phenomena. The Facility for Rare Isotope Beams (FRIB) is now under development by the U.S. Department of Energy on the NSCL site and will provide forefront capabilities for U.S. science for decades to come. However, vigilance must be maintained to ensure that the transition is effectively managed, especially if delays in the implementation of FRIB occur. The nuclear-physics community and the NSF must carefully shape the NSF nuclear physics scientific portfolio in the post-NSCL era. New initiatives will likely be required to continue a flagship role for NSF in nuclear physics research, and the APPI Program may play a crucial role. We strongly endorse the APPI initiative.
- We find that the NSF Nuclear Physics Program is very well managed. The expertise and experience of Program Manager Brad Keister is a great asset to the program. The rotators in the program, Allena Opper and Kyungseon Joo, have also done an impressive job over the last period in effectively managing major parts of the program. While the performance thus far has been exemplary, we are concerned about the workload on the program managers. The management of the NP experimental and theoretical program as well as the NSCL is already a challenge, but the addition of the PIF-Computational Physics Program stretches the program managers beyond what we feel is reasonable. We are concerned that such a high workload may have an adverse impact on the program if it is maintained.
- The review process that is in place for the NP Program has been refined over many years and is very effective and should be maintained. We have some minor recommendations for consideration. We recommend that emphasis be placed on encouraging ad hoc reviewers to provide specific reviews that make clear the rationale for their conclusions and overall score. The form letter used in requesting reviews could be improved by making it much shorter and emphasizing only the most important aspects. Many of the details (e.g. instructions for Fastlane access) could be referred to a website link as they are familiar to most referees. Consideration should also be given to asking for further elaboration or clarification to points in a review when it seems unsatisfactory in some regard. We also find that the panel reviews are particularly important for evaluating proposals within the scope of the overall program and for assigning appropriate weight to the many factors that go into the overall evaluation of a proposal.

C. Review methods

A combination of different review techniques is used in evaluating proposals. A minimum of three ad hoc reviews is always requested for each proposal, and at least two ad hoc reviews were received for each case we reviewed. Independent panel reviews of the experimental and theoretical programs are also conducted annually. Panel members provide an independent review of the proposals (led by a primary and secondary reader on each proposal), thereby augmenting the information in the ad hoc reviews. In addition, site visits are conducted by a panel of three to five independent reviewers for proposals by larger experimental groups (typically multi-PI awards of more than $1M). Such visits are particularly helpful for evaluating groups with a variety of research activities and substantial infrastructure. Panels use input from the ad hoc reviews and from site visit reports (when available). A numerical scoring system is used in the panel so that each member makes an independent and democratic contribution to a final, ranked list of proposals. Ad hoc reviews, site-visit reports, and panel discussions therefore all play an important role in a very thorough evaluative process.

In all the jackets reviewed, both merit-review criteria were addressed at all levels of evaluation (individual reviews, panel summaries, and program-officer analyses). Typically, the ad hoc reviewers demonstrate significant experience with the NSF review process and provide substantive commentary on both criteria. The panel reviews play a particularly important role in weighing the relative importance of the two merit-review criteria in assessing the overall merit of proposals. The level of detail in the postdoctoral mentoring plan varies significantly between proposals, and the level of scrutiny applied to evaluating the mentoring plan also varies between reviewers and panelists. This is perhaps to be expected as this is a new requirement, but proposers, reviewers and panelists could improve their approach to the postdoctoral mentoring plan.

Reviewers generally provide substantive comments to explain their assessment of proposals. The program officer requests that reviewers *"provide detailed comments on the quality of this proposal with respect to each of the two NSF Merit Review Criteria"* when soliciting reviews. Most ad hoc reviews show careful consideration of the issues and specifically address the strengths and weaknesses of the proposal that led to their conclusions. However, there is wide variation in the quality of reviews, and some (a non-negligible minority) are not satisfactory in this regard. Despite the guidelines provided, there is also inconsistency in the grading scales applied by different reviewers. It is helpful to the panel and program officer when reviewers provide insight to the rationale behind the overall score they assign, but this is not always done. Perhaps reminding reviewers more forcefully of these facts in the review solicitation is a good idea. Changes to the format of the review form may also encourage more specific feedback. There are arguments for modifications, but it seems likely that the quality of reviews will remain varied, and some reviews will be subpar in their level of detail irrespective of any efforts in this direction. Continuing to push for at least three ad hoc reviews is perhaps the best mechanism for ensuring each proposal is fairly evaluated, with balanced information presented to the panels and program officers.

The panel reviews do an excellent job in describing the rationale behind their recommendation and in interpreting the ad hoc reviews. The panel reviews also help place the proposals in the context of the entire field and assist in assigning relative weight to the intellectual merit and broader impacts, which can vary between proposals. We feel the panel review is a particularly important aspect of the review process for the NP Program. The panel summaries generally provide the clearest feedback to the PI as to the sometimes complex factors that influenced the funding decision. The panels should continue to be reminded of the importance of the panel summaries and be encouraged to provide clear and thoughtful feedback. However, it must also be recognized that some very good proposals are not funded because the scientific merit and/or broader impacts were less compelling than other proposals.

The expertise and qualifications of the reviewers were well matched to the proposals. This is a challenge, given the large number of proposals, and also the large number of conflicts of interest within such an interconnected community. The program has done an outstanding job finding an appropriate, well-qualified, and diverse set of reviewers for each proposal and should be commended. Conflicts of interest were taken extremely seriously: the program diligently looks for conflicts of interest and deals with them appropriately when identified.

The program officer's analysis in the jacket provides a clear and cogent description of the rationale behind the funding decision. Sometimes this analysis includes insights that are not contained in the review or panel summaries provided to the PI. The large amount of information in the jacket provides a complete picture of the salient factors that contributed to the funding decision. On the rare occasions that significant factors in the funding decision are not clear in the review information provided to the PI, we encourage the program officer to communicate them privately to the PI–when appropriate.

The combination of review approaches (ad hoc, panel, site visits, and program officer analysis) maximizes the likely scientific and broader impacts that will be realized from funding decisions, and the process is well documented. This process has been refined in years of application and is now being used extremely effectively in evaluating proposals. We commend the program on its approach.

D. Program Management

The NSF NP Program supports research efforts at the frontiers of nuclear science that vary widely in scope. Individual investigator grants are a core part of the program that capitalize on innovative ideas, yield critical contributions, and are central to the training and mentoring of graduate students and postdocs. Large, multi-investigator awards in both experimental and theoretical nuclear physics provide a leadership role in complex, high-profile scientific initiatives that would not be viable without their involvement. RUI awards sponsor research at undergraduate institutions that is central to developing the pipeline of future scientists and to NSF's educational mission. Flagship facilities and instrumentation are also critical to enable a leadership role in forefront experimental initiatives. The scope of these efforts range from the NSCL, a national user facility funded by the Physics Division at a level of about $21M/year, to RUI awards which may receive 1000 times less funding. Each of these efforts plays a vital role in NSF's research program in nuclear physics.

Maintaining the appropriate balance between diverse scientific thrusts on such differing scales is a challenge, but is crucial to the overall health and productivity of the nuclear physics research portfolio. The NP program has done an excellent job over the past three years in striking an appropriate balance. Panels have recognized the role and value of each component of the program. While each proposal is evaluated individually on its own merits, consideration is also given by the panels in balancing the varied efforts in the portfolio. Panel reviews are crucial in part because they provide the only opportunity (outside of the program manager) for evaluating such balance across the portfolio.

The program has been able to effectively respond to emerging opportunities. Notable opportunities that are now becoming available include the 12 GeV upgrade at Jefferson Lab, the development of the ReA3 facility for reaccelerated beams of radioactive ions at the NSCL, a new high-intensity electrostatic accelerator at the University of Notre Dame, and capabilities in underground science at the Sanford Lab. These opportunities are being realized due to investments from outside the NSF base program in nuclear physics, but the program has invested in R&D, instruments, and research awards that aim to capitalize on these new capabilities. The success of the program in pursuing these new opportunities has been aided by careful management of programmatic funds, and by the injection of ARRA funds in 2009. It is important that the program be aggressive in pursuing such new opportunities. We are concerned, however, that constrained budgets that might be encountered in the next years may make it difficult to maintain an appropriate balance in the program. The need to provide opportunities for new ideas and young investigators will put pressure on large established groups and facilities. Diligence may be needed to maintain a healthy balance between these various demands.

Much credit must be given to Program Manager Brad Keister, whose years of experience have proven very valuable in guiding the program through challenging issues. The rotating program managers, Allena Opper and Kyungseon Joo, have also provided impressive leadership in managing major parts of the program efficiently and effectively despite their limited previous experience. Challenges over the previous period included the infusion of substantial increased temporary funding from ARRA in 2009, cuts to the overall program base in 2011, and the 5-year renewal of the NSCL grant following its selection as the site for FRIB. The creative use of "standard grants" from program funds during this period helped calm financial disruptions by reducing out-year commitments and distributing the impact of the expiration of awards from ARRA funds. This strategy smoothed out what would otherwise have been a rather disruptive funding pattern for the program. Despite cuts to the overall base last year, the program was still able to balance funding for large continuing programs with new initiatives, including funding new NSF grants for two young investigators. Indeed, in each of the last two years the program has added the research of two beginning faculty members to its portfolio. The NSCL renewal was also well managed (led by Kyungseon Joo). It effectively dealt with the new ReA3 initiative developed by MSU and issues related to FRIB development. A strong package was prepared for the Science Board that helped position the NSCL to continue to be a world-leading facility in the pre-FRIB era.

While the performance of the Program Managers thus far has been exemplary, we are concerned about the workload. The management of the NP experimental and theoretical program as well as the NSCL is already a challenge. The addition of the PIF-Computational Physics Program stretches the program managers beyond what we feel is reasonable. We are concerned that the high work load may have an adverse impact on the program if it is maintained. While the program has benefited from excellent rotating program managers, NSF management should also recognize the challenge in continually recruiting such high-quality individuals and the advantages provided by having greater continuity and more experienced program managers.

E. Cross-disciplinary and computational physics in the NP program

Modern nuclear physics is connected to many other sub-fields of physics, and to other disciplines. About 10% of the proposals submitted to the nuclear-physics program were co-reviewed and co-funded. The most frequent connection is to Astronomical Sciences. There is also cross-fertilization with methods that have applications in Chemistry and Materials Science. We found that such cross-program and cross-disciplinary proposals were well handled by the program, and saw no evidence that any inter-disciplinary research is “falling through the cracks”. The experience of Program Manager Keister has aided in identifying and negotiating co-funding of proposals with other programs in PHY and MPS.

A notable example of such cross-disciplinary efforts, although it is outside the NP funding profile, is the Joint Institute for Nuclear Astrophysics (JINA) Physics Frontiers Center. JINA fosters an interdisciplinary approach that connects subatomic physics to astronomical observations and computational initiatives. It is an excellent example of how the scientific impact of a center can exceed the sum of its components.

Nuclear energy and nonproliferation issues will likely be key to the Nation's sustainable energy future. However, it seems unlikely that the NP program at NSF is a good match to the science portfolio of SEES as that program is presently framed. Careful consideration should be given to whether participating in the SEES program is beneficial to PHY.

Computation plays a critical role in contemporary nuclear theory. Co-funding of proposals between the Computational Physics portion of the Physics at the Information Frontier (PIF-CP) program and NP has successfully encouraged such work. It is important to ensure both that the NP community is aware of future initiatives in this direction, e.g. CIF-21, and that these initiatives support forefront science.

A number of important results have been obtained in the last three years thanks to joint funding by Nuclear Physics and PIF-CP. For example, a combination of novel techniques and large-scale computing recently enabled the first lattice QCD calculations of the excitation spectrum of the proton. NSF funding also supports investigations of two- and three-nucleon forces within lattice QCD. Constraints from QCD inform the construction of nuclear Hamiltonians–in which neutrons and protons are the degrees of freedom–that reproduce data obtained in few-nucleon systems. Significant effort in nuclear physics is devoted to obtaining essentially exact, "ab initio" solutions of the N-body Schrodinger equation for these nuclear Hamiltonians. Combined NP & PIF-CP funding supported development of both more efficient large-basis diagonalizations for this N-body problem, and a novel Monte-Carlo technique where spin and isospin degrees of freedom are sampled, rather than being summed over exactly. These new techniques should facilitate ab initio calculations in the oxygen isotopes and beyond, thereby delineating the limits of stability of neutron-rich nuclei.

F. Broader impacts

The NSF Nuclear Physics program plays an important role in the training and education of graduate students and postdoctoral researchers that are key to the basic research conducted within university groups. This experience in basic nuclear physics research prepares young investigators for leadership roles in many related sectors of the economy, including energy, national security, and medicine. This includes areas of critical need for the nation; for example, about one quarter of staff at U.S. National Laboratories is currently of retirement age.

Another particular national need is for trained accelerator physicists. The NSF directly funds accelerator physics research and development, most notably at the NSCL, the home of one of the few graduate programs in this field. Nuclear physics has been a leading driver for developments in accelerator science since its inception. The move toward superconducting cyclotrons in nuclear research has allowed the development of super-compact cyclotrons, which can be gantry mounted, for radiation therapy (see Fig. 1). Other spin-offs from basic nuclear physics with strong impacts on medical science include magnetic resonance imaging and nuclear medicine, which is used both in imaging and therapy.

Nuclear physics researchers at the University of Notre Dame are currently contributing their technical expertise to a diverse range of problems in archaeology, art and history, e.g. "To what degree did the Romans devalue their money by mixing less valuable metals into their silver denarius coin?"; "How much of the copper found in Native American jewelry from the 18th century originated in Britain or France?" and "Are the pigments used in this work of art consistent with those from the period, or is it a forgery?" Using the PIXE technique (see image) the elemental composition of a sample can be found by looking at characteristic X-rays emitted after electrons from the inner shells of an atom are liberated by bombardment using a beam of protons.

Another example of instrumentation and techniques developed by nuclear physicists for their basic research having an impact on society is provided by a low-energy accelerator at Hope College that is being used in collaboration with the FBI Lab for forensic analysis. Using differential PIXE, which is a non-destructive method, samples from paint chips –typically from cars involved in auto accidents, or in a crime–are analyzed in a matter of minutes. The alternative forensic-science method is to painstakingly remove 7-12 individual paint layers by hand and perform destructive chemical analysis.

Fig. 1: The gantry-mounted cyclotron rotates around the patient to delivery proton-therapy treatment to cancer patients. Photo, taken from ProCure, is from their proton therapy center in Oklahoma City.

Fig. 2: Cover of the January 2012 edition of Physics Today showing PIXE being used at the University of Notre Dame to study the tools, pigments, and techniques used to create the artwork

G. Facilities

Competitive facilities and instrumentation are crucial for NSF to take leadership in forefront nuclear physics research. The NSCL in particular is a world-leading facility for studying the structure of exotic nuclei, the underlying processes that drive astrophysical phenomena, and the origin of the elements. The Facility for Rare Isotope Beams is now under development by the U.S. Department of Energy on the NSCL site and will provide forefront capabilities for U.S. science for decades to come. A Joint Oversight Group has been formed, and a plan has been developed for the transition from NSCL to FRIB. Vigilance must be maintained to ensure that the transition is effectively managed, especially if delays in the implementation of FRIB occur. An additional issue is what efforts will define the leadership thrusts for the NSF nuclear physics program in the post-NSCL era. Establishing new flagship initiatives is crucial. The Accelerator Physics & Physics Instrumentation (APPI) program is well matched to the scale of projects that could drive major future directions in the NP program. We strongly encourage the development of this important program.

H. Broadening Participation and Outreach

Broadening participation by women and underrepresented minorities continues to be a challenge for the entire Physics Division. While some progress has been made in the participation of women, it is still insufficient. Markedly less progress has been seen for underrepresented minorities. The nuclear physics program seems to be on par with the rest of the Physics Division, but we find understanding and tracking progress is difficult. The NSF could do a better job in tracking and evaluating PI participation. Data is unreliable and co-PI's seem not to be counted in statistics. Efforts to improve tracking and analysis of data for those that share it should be improved.

I. Research highlights

In this section we present highlights from the NP program during the FY09-FY11 period reviewed by the COV.

i. Proton and neutron form factors

Experiments performed by NSF-NP grantees, working in partnership with staff scientists at Jefferson Laboratory (Newport News, VA), have challenged both the way in which we measure the

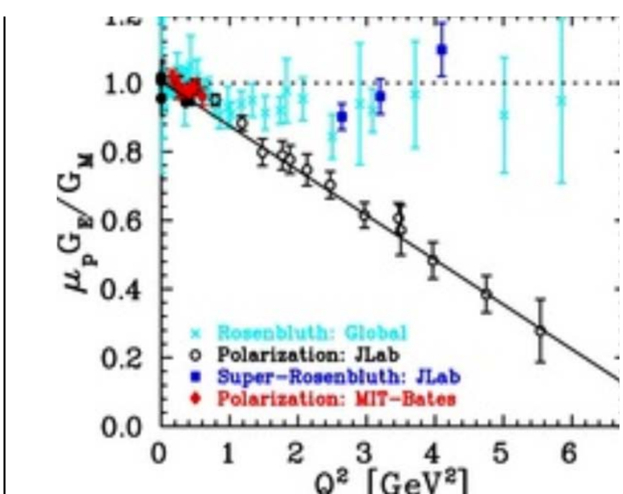


Fig. 3: Ratio of electric vs. magnetic properties of the proton extracted from polarized protons (red diamonds and black open circles) are different than measurements using unpolarized protons (blue squares) and disagree with a simple model assuming single photon interactions. Credit Charles Perdrisat (College of William and Mary).

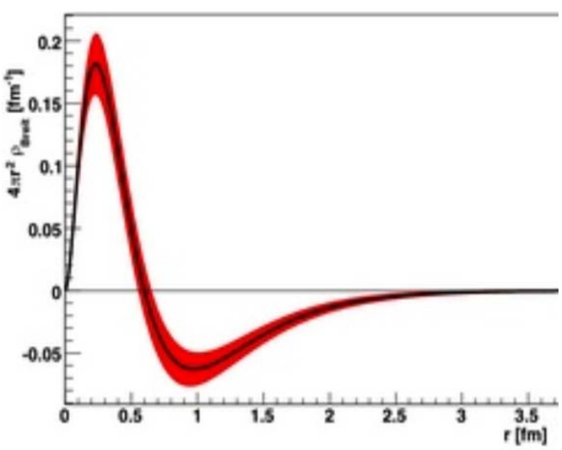


Fig. 4: The distribution of charge within the neutron, the combined result of polarized electron scattering experiments. The width of the colored band represents the uncertainties. There are regions of both positive and negative charge density, adding up to zero net charge. Credit: Ricardo Alarcon (ASU).

proton's electromagnetic properties and our knowledge of the properties themselves. Until recently, the scattering of electrons from the proton was thought to be dominated by single-photon exchange. However, experiments at Jefferson Lab that used beams of polarized electrons show two-photon interactions between the electron and proton play an important role in determining the outcome of traditional measurements with unpolarized electron beams. These same data also reaffirm that the proton cannot be understood as constructed solely from three, slow-moving quarks. Such a picture predicts a very specific relationship between the electric and magnetic properties of the proton–a relationship which is not borne out by the new data taken with polarized electrons.

Meanwhile, scientists have also made significant progress in mapping the distribution of electric charge inside the neutron. Even though the neutron is uncharged, its interior contains a mixture of positive and negative charge, due to motion of the quarks that make up the neutron, as well as more complex effects in quantum chromodynamics. As in the proton case, a beam of electrons is scattered from the neutron, in order to map out its interior charge distribution. These measurements can be greatly refined by orienting the spin and momentum of the electron beam in the same direction as the nuclear spin of the neutrons. Ricardo Alarcon (Arizona State University) combined these techniques, enabling unprecedented precision in mapping the neutron's interior charge.

ii. Magic numbers for neutron-rich isotopes

Researchers have recently found evidence for a new "magic number" in unstable isotopes of oxygen. Stable atomic nuclei are known to be more tightly bound when the number of constituent neutrons and protons hits certain "magic" values. The seven known magic numbers for stable nuclei are 2, 8, 20, 28, 50, 82 and 126. However, nuclei that are rich in neutrons or protons compared to their naturally available counterparts can still exhibit the "magic" behavior when one compares them to neighboring nuclei. An interesting case study concerns the isotopes of oxygen. The naturally occurring isotope is oxygen-16, which has a magic number (8) of both protons and neutrons.

Recently experiments performed by researchers at the National Superconducting Cyclotron Laboratory

Fig 5: The plot shows the energy of selected excited states of isotopes of various atomic nuclei as a function of neutron number. The key feature is the dramatic increased in energy for oxygen near neutron number 16. Credit: Sam Tabor, Florida State University.

(NSCL) measured the energy of lowest excited states in the oxygen isotopes. Professional scientists and physics undergraduates from research universities and four-year colleges all worked together to obtain these data, using the Modular Neutron Array (MoNA), which was built by a similar broad collaboration with funding from an NSF MRI award. The collaboration found that a particular excited state in oxygen-24 has a higher energy than the corresponding state in neighboring isotopes, demonstrating the magic nature of neutron number 16 for oxygen, which is not observed in heavier elements. The importance and quality of this work was highlighted by a "News & Views" article in Nature and the garnering of the 2010 Dissertation Award in Nuclear Physics from the American Physical Society by the graduate student, C. Hoffman from Florida State University, who performed the experiment with the MoNA group.

iii. A new tool at RHIC for dissecting a proton

Quantum Chromodynamics is the underlying theory of the strong interaction, but the way in which the proton's spin emerges from the underlying quark and gluon degrees of freedom continues to challenge scientists' understanding. One complication is that there are several types, or "flavors" of quarks, as well as their anti-matter partners, anti-quarks, and the spin and angular momentum of each type contributes to the proton spin. To date, it has been difficult to disentangle the contributions from different quark flavors, or even to separate the effects of quarks from anti-quarks. A new technique, recently demonstrated using RHIC's STAR detector at Brookhaven National Laboratory, means that researchers will now, for the first time, be able to "image" quarks inside the proton in a way that distinguishes up and down quarks, and quarks from anti-quarks. In particular, they will be able to map out the contribution of each species: up, down, anti-up, and anti-down, to the total spin of the proton.

The new method works through observing the formation of a W boson in a collision between two high-energy protons, via the fusion of a quark from one proton with an anti-quark from the other. This process provides potent information: the electric charge of the W reveals the flavors of the colliding quarks; the direction of the W indicates which proton provided the quark or anti-quark; and the "weak" nature of the W decay allows us to follow the spin throughout the process. Using this method, scientists at RHIC will not only be able to separate the spin contributions from the different flavors of quarks, but also gain insight into the nature of the "sea" of anti-quarks that we know exists within each proton and plays a key role in determining its properties.

iv. Forefront nuclear-reaction theory provides new insights into "halo" nuclei

"Halo" nuclei are so-called because they contain an extended distribution of neutrons far beyond the region where the protons in the nucleus are located, in contrast to stable nuclei where the protons and neutrons stay in close proximity to one another, kept together by the strong nuclear force. In halo nuclei, neutrons are still bound to the nucleus, but some orbit at large distances from the protons in the core. One example is the ^{11}Be nucleus, which can be thought of as ^{10}Be core and an extra neutron. A recent study involving NSCL theorist Filomena Nunes has probed the nature of this nucleus by examining what happens when a beam of ^{10}Be nuclei impinge on a target containing deuterium nuclei (consisting of one proton and one neutron). By examining the spectrum of protons ejected in this "(d,p) reaction" clues about the structure of ^{11}Be can be inferred.

However, any structure interpretation from these data relies on an accurate description of the reaction mechanism. Nunes and her collaborators implemented a new model for (d,p) reactions, that was benchmarked against a full treatment of the quantum-mechanical ^{10}Be-n-p three-body problem. The new model is much easier to use and computationally less expensive than the full three-body equations. The two methods were compared in a number of cases and found to agree very well for reactions on halo nuclei. The new treatment by Nunes *et al*. is a significant improvement on the approximations that have previously been used to analyze (d,p) reaction data. This advance provides the opportunity to enhance the quality of information extracted from experiments that use this technique at a number of nuclear-physics labs around the world.

v. Detecting "failed supernovae" by their neutrino signal

Stars more massive than about 8 times that of our Sun die when their core collapses catastrophically under its own weight. The collapse is accompanied by strong emission of neutrinos, the only particles that can propagate through the very dense stellar matter. The final outcome of the collapse may be a supernova or collapse to a black hole. Recently it was realized that neutrinos are the only emission (besides gravitational waves) that always accompanies a collapse, even when the star collapses to a black hole. For these "failed supernovae", the star simply disappears from the sky, and the neutrino burst is the only messenger of this dramatic event.

In a 2009 *Physical Review Letter* Cecilia Lunardini (Arizona State University and RIKEN BNL Research Center) pointed out the possibility to reveal failed supernovae with neutrino detectors. She showed that the neutrinos produced by all the failed supernovae in the universe can generate a detectable neutrino background. This potentially exceeds the neutrino background from successfully exploding supernovae because the failed-supernova's neutrinos tend to be more energetic. Working with a student, Lunardini has also shown that the neutrino burst from a failed supernova as far away as 4-5 Megaparsecs could be seen by a neutrino detector. This provides the intriguing possibility of watching the star collapse into a black hole using neutrinos, thereby opening a new window on this still mysterious phenomenon. Lundardini's research receives funding from the NSF's Nuclear Physics program within the PHY Division, and the Stellar Astronomy and Astrophysics Program in the AST Division.

5. Elementary Particle Physics Experiment and Grid Computing

Introduction

The Experimental Particle Physics (EPP) program supports research on the properties and interactions of elementary particles – the fundamental building blocks of matter. This research uses accelerators and detectors operating at the frontiers of energy and sensitivity to discover and study the most basic properties of matter, energy, space and time. For FY11, the most recent of the three years reviewed by this committee, EPP expended a total of $47M to support the University grant program ($25M), the Large Hadron Collider (LHC) operations ($18M) and accelerator and detector R&D ($4M). To ensure full support for all three pillars of the US particle physics roadmap at the Energy, Intensity, and Cosmic Frontiers, EPP works closely with the NSF Particle Astrophysics (PA) program and coordinates with the DOE Office of High Energy Physics (OHEP) on projects of mutual interest such as the LHC and International Linear Collider (ILC) R&D.

This subpanel finds that the EPP program is exceptionally well managed and that support for Grid computing for particle physics experiments is appropriately matched to the enormous task of providing sufficient resources to successfully exploit the huge datasets from LHC. The EPP subpanel wants particularly to identify the Program Director (PD) team members Moishe Pripstein and James Reidy who have retired and Marv Goldberg for doing an exceptional job with the EPP program over the past 3 years. The entrepreneurial spirit and excellent leadership of this team sets a high bar for the current EPP team.

Grants are awarded in a competitive peer-review process that is fair and conducive to excellence in research, education, and broader impacts for society. The 4 full-time EPP program officers are well-apprised of programmatic situations in all areas of EPP and are superb stewards of NSF investments in people and facilities. EPP is especially commended for successful efforts to add value across NSF programs through partnerships, broadening participation, and education, outreach, and broader impacts initiatives. As an example, EPP is a funding partner for the Open Science Grid (OSG), providing all of the support for the Tier 2 centers at US universities, which enables the operation of these data distribution centers and their federation with international partners.

- **Integrity and Efficacy of the EPP Program Processes and Management**

A1. Appropriate Use of NSF Merit Review Criteria

The review process for proposals includes ad hoc mail-in reviews, Special Emphasis panels, and site visits. The sub-panel finds the entire process, including the use of all three methods of review, to be very effective and appropriate to the NSF core values. Proposals are evaluated in terms of their ability to advance our knowledge at the

Energy or Intensity Frontiers through the excellence and visionary nature of the research, the quality of the researchers, the degree of learning and growth provided to graduate and undergraduate students, and the degree to which the research will be carried out in a way that is broadly inclusive. Both merit review criteria are addressed in all individual reviews, although not all reviewers report on both in equal degrees of detail. The panel summaries and program officer review analyses do address both merit review criteria in depth and are incisive.

A2. Selection of Reviewers

The 200 reviewers used by EPP in the past 3 years are balanced across the diversity of academic institutions and national laboratories in the US. In addition, scientists from Europe, Canada, and industry have contributed to the review process. Every review panel examined by the subpanel had documented and appropriately dealt with conflicts of interest. The diversity of the reviewers appears to match the level of diversity in the field of particle physics.

A3. Program Officer Decisions and Documentation

The review analyses by the EPP program officers are generally thorough and thoughtfully prepared. The funding decisions largely follow the panel recommendations, as informed by the ad hoc reviews, but in all cases reflect the judgment of the program officers. Reports accurately reflect the final funding decisions.

A4. Portfolio of Awards

The subpanel finds the overall quality of the EPP program to be excellent. Despite the tight fiscal constraints, the university program is funded at a level that allows world-class research and a quality of educational experiences for students which is very high. Broader impacts are reflected in both the interdisciplinary nature of some of the awards and the ability of the program officers to encourage broadened participation and outreach, particularly through programs like CHEPREO, QuarkNet and Research Experiences for Undergraduates (REUs).

The mix of university groups from across the country is good and reflects a variety of communities and research approaches that span physics at the colliders, neutrino experiments, development of new detector technologies, and accelerator research. Grants to university groups differ in size with a few larger grants to large groups that contribute significant infrastructure to existing experiments and many smaller grants to individual investigators and groups with fewer faculty members. The awards are geographically and programmatically diverse. The average funding per FTE faculty member was about $190K for FY08 and averages $214K for FY09 and FY10 with ARRA funds included.

The renewal rate for funded university groups for all Principal Investigators (PI's) is 68.6% for FY09-11. For new PI's with new proposals, the success rate is 38.5% for the same three years. This leads to an overall funding rate for all proposals of 62%. These figures appropriately reflect the long time scales involved in the design, construction, data taking and analysis for frontier particle physics experiments. CAREER grants over the three year period were funded at about a 25% success rate. This is considerably higher than the norm of 10-20% due to the presence of ARRA funds. The CAREER grants funded for FY11 represent an especially diverse set of researchers with half of the twelve awards going to women and underrepresented minorities.

For the three years covered in this report the funding per PI was as follows: $280.4k for FY09, $229.7k for FY10, and $193.2k for FY11. The FY09 and FY10 numbers were increased due to ARRA funding. For comparison, the FY08 funding per PI was $190.5k so that the overall profile of approximately flat funding rate of $190k per year per PI is being maintained. Dealing with support of university groups now that ARRA funds are expended and NSF funding is expected to remain flat for the near term will be a significant challenge.

A5. Overall Management of the EPP Program

For FY11, EPP had one permanent federal employee and three rotators (all full-time) to handle the planning, coordination, and management of the program. These tasks are daunting: EPP supports more than one third of the university groups in US high energy physics, manages the Cornell CESR-TA effort, the LHC experiments ATLAS, CMS, LHCb. EPP also supports TOTEM and the computing work at the LHC and Tevatron experiments, the ILC R&D program, broader impact efforts. It also supported the Deep Underground Science and Engineering Laboratory (DUSEL) R&D effort. In addition, EPP works closely with the Particle Astrophysics program. The sum total of the efforts leads to support of a world-leading program across the Energy, Intensity, and Cosmic Frontiers. For the next decade, it is expected that research at each frontier will lead to new discoveries on the nature of matter and energy at perhaps their most fundamental level and perhaps even into the nature of spacetime itself. Given the exceptional promise for great discoveries in the near future, the high-energy physics community is fortunate that the EPP management team is composed of well-established members of the particle physics community who possess an impressive depth of knowledge about the science, the facilities and the scientists engaged in this research.

EPP management is also to be commended for their especially successful collaborations and partnerships with other NSF directorates and programs such as EIR, OISE, and CISE. In addition, the EPP program works well with NSF PA and DOE - particularly with respect to support of the Intensity Frontier research efforts. As noted above, EPP has made notable progress at reaching broader audiences for particle physics through the CHEPREO project, which has been successful in outreach to the Latino community.

- **Results of NSF Investments**

B1. Cyber Infrastructure

EPP has many contributions to the development of cyber infrastructure in the nation by contributing planning and funding to this effort with partner Divisions and programs within NSF - CISE, SBE, OCI, EHR, OISE, EPSCoR, and OMA and outside of NSF – DOE/OHEP and SCIDAC/ASCR. EPP also provides all support for Tier 2 centers at US universities and is a funding partner for OSG, enabling operations and federation of the Tier 2 centers with international partners.

In addition, funding for the Grid activities (OSG) that are currently at the heart of the computing model for LHC analysis came from EPP. LHC experiments were a major motivation for expanded networking support via the UltraLight project using funds from Physics at the Information Frontier (PIF) and an MRI involving 11 universities to increase the T3 capability of US ATLAS. This follows on an MRI to Syracuse University that expanded the compute cluster shared by LHCb and LIGO. Finally, we note that EPP funding provided support for new and innovative ways to access large data volumes using the CMS experiment as a focus of activities.

There are many examples of EPP-funded proposals that address the fundamental question of electro-weak symmetry breaking by supporting the ATLAS and CMS detectors at the LHC. The search to see if the standard model Higgs exists is the driving reason for the LHC and many groups are hard at work in these experiments. This support is for instrumentation, calibration, “as built” detector systematics studies and analyses looking for the new physics. It also supports efforts to develop the new detector elements needed for the LHC machine upgrades.
Another EPP-supported project is to address issues of analysis of massive petabyte-scale data sets arising from astrophysics as well as the LHC. It will develop a "numerical laboratory" whose concepts could prove useful throughout science. Large-scale simulations, massive observations, and data analysis would work in parallel, with results providing input to further simulations. Specifically, the project will study the formation of the Milky Way galaxy, with implications for the understanding of dark matter. Industrial collaboration with Microsoft and NVIDIA is included.

A third proposal is to change the way scientists access and study large volumes of data such as data from the CMS experiment at the Large Hadron Collider. The proposal has a goal of simplifying data access for end users distributed across various computing clusters known as Tier 2 and Tier 3 clusters. The present computing model relies on users having their jobs executed where the data are --i.e. requiring co-location of data and CPU. This naturally leads to inefficiencies, including non-usage of much of the resident data and idle CPU's. The proposal calls for optimizing the data access and CPU usage patterns. This proposal also calls for transparent access to data on demand, where the core work is done behind the scenes for locating the data and making it available to end clients. The ultimate benefit is that those extracting the science through rapid data access at local clusters can focus more on data analysis and less on trying to access the data. This implies increased productivity and thus scientific progress.

B2. Broader Impacts

B2-1. Societal Impacts and Benefits

The societal impact of EPP research has been extensive over a number of years. Just a few examples of these are listed below.

- EPP scientist Alan Litke's work in developing CCD readout systems for particle physics experiments led to collaborative research with neuroscientists that discovered a new set of retinal cells that had never been previously seen in primates.
- Henry Frisch and his group at the University of Chicago are doing R&D to develop ultra-fast time-of-flight measurements and applying particle physics techniques in data acquisition and simulation that may be of use for time-of-flight measurements in biomedical imaging. Seed money from EPP is being used to develop front-end electronics, A-to-D conversion, pipeline readout, etc. for real-time display in both particle physics and biomedical imaging systems.
- CyberBridges and Global CyberBridges are education programs that encourage graduate students to enhance their PhD dissertation research by developing interconnections (or bridges) between their domains of scientific research and advanced computing techniques. The domain sciences vary from particle physics to medical and biological problems but the cyber infrastructure uses grid computing and international connections via global networking and was spawned, in part, by CHEPREO.
- Informal education and interdisciplinary research are both included in the Broader Impact of an EPP Career Award winner at Michigan State who uses domed theatres (like planetariums) for science films that draw in diverse audiences. This effort is now being expanded by LHC researchers for films that highlight their exciting research.
- Finally, we mention two items that have public appeal, that came out of particle physics and have had surprising trajectories in the world outside of physics but are not necessarily connected only to NSF support:
  - The World-Wide Web.
  - Carl Haber and Earl Cornell partnered with the Library of Congress and the National Museum of American History to use particle physics electronics quality assurance technology to read out original wax recordings of Alexander Graham Bell that had been thought to be permanently lost.

B2-2. Broadening Participation and Outreach

Particle physics experiments offer many opportunities for engaging teachers and students from high school all the way through post-doctoral study in frontier research. Some especially notable programs are:

- Columbia University's EPP-supported particle physics group has a "superb history" of reaching out to underrepresented groups, particularly women through Barnard College.
- The U. of Chicago EPP group is creating change in science education for the city of Chicago by working with the Illinois Math and Science Academy and directly with the top official in the Chicago public schools for science education on curriculum, facilities, and use of computers and the Enrico Fermi Summer Intern Program.
- SUNY – Stony Brook and Brookhaven National Laboratory anchor the Mariachi Project – an outreach program spawned through their QuarkNet center. Mariachi engages Long Island secondary school teachers and students in the search for ultra-high energy cosmic rays using radio reflection from ionization trails of the air showers these cosmic rays produce combined with the detection of shower particles in a ground array of scintillation detectors.
- Florida International University has the Physics Undergraduate Reform Network Alliance (PURNA). The ultimate goal of PURNA is to create a transformative reform initiative targeting physics departments and institutes to get them to use research-validated methodologies that support all students, especially those from historically underrepresented minority groups and women.
- The Partnership for International Research and Education (PIRE) program brings undergraduate and graduate students from several mid-West universities and one minority-serving university in Puerto Rico to Switzerland to work on LHC detector R&D at PSI and ETH in Zurich.
- CHEPREO is a partnership of Florida International University (FIU) and EPP to advance education at both the university and secondary school levels. The physics component is based around CMS data using a Tier 3 center for analysis. The education component includes a Physics Learning Center on the FIU campus, Physics Modeling instruction for high school and for university students, a QuarkNet center, and connections to South America. As a Hispanic-serving institution, FIU is ideally suited to attract underrepresented students into STEM fields, particularly particle physics.
- QuarkNet has more than 50 centers supporting teacher education and is, as of last year, involving secondary school teachers and students in analyzing actual data from CMS and also in analysis of data sets from a worldwide array of cosmic ray detectors located at secondary schools.
- I2U2 (Interactions In Understanding the Universe) builds upon broad research science, cyber-infrastructure (grid computing) and education to bring research experiences directly into the formal education setting through eLabs and into informal education settings with iLabs.
- LHC communications and awareness are enhanced through EPP support of a US liaison to the CERN communications group.

B3. Interdisciplinary Research

This has been an important area for growth of the EPP program. There are multiple levels of this. One is how EPP responds to the big NSF-wide priority areas which are labeled as "multidisciplinary." Another is how EPP interacts with other Divisions of NSF and with other programs within the Physics Division on individual proposals. Some examples of all three kinds of interdisciplinary research activity are listed below.

- PA and EPP co-review proposals regularly.
- OISE frequently co-funds with EPP proposals that use international research as a basis for education.
- QuarkNet has multi-disciplinary activities which are funded by EIR, EHR, and DOE OHEP.
- I2U2 has support from several NSF Divisions within EHR and EIR.
- The PIRE program has EPP and OISE support.

OSG has funding from OCI and DOE OHEP as well as EPP support through PIF.

B4. Facilities and Centers

The EPP subpanel supports the current policy of the Physics Division that less than 10% of the Division budget goes to Centers and that less than 50% of the budget goes to the combination of Centers and Facilities. For EPP, the primary funding for what can be called "facilities" is for the Open Science Grid and operation of the CMS and ATLAS experiments.

DUSEL:

The DUSEL project constituted a large effort by NSF at developing the future of the US Intensity Frontier. A broad program of science had been planned which was well reviewed by the EPP community and by a National Academy Panel. In December 2010, after almost a decade of scientific effort, the National Science Board made the decision to discontinue DUSEL development, effective immediately after the decision. The EPP subpanel believes, on the basis of information requested by the COV during this review, that the PHYS Division followed established procedures for evaluating and developing large projects. The EPP subpanel strongly regrets the decision by the National Science Board to abruptly terminate DUSEL development. The impact of this decision stretches beyond NSF. Exploring the particle physics frontiers requires projects whose technical difficulty and expense stretch the time scale from conception to science to more than a decade. Young scientists who invest a large fraction of their careers in the development of such projects are best served by procedures that support long-term investments directed toward transformative experiments. Decisions should transparently follow the evaluations that are done as projects are developed.

• NSF Strategic Outcome Goals and Recommendations

C1. Discovery

NSF-supported upgrades to the LHC experiments have the potential to remake the roadmap for 21st Century particle physics. Advances in, for example, computational capacity, enhanced precision, and material longevity may provide a window onto questions previously thought to be unapproachable without a lepton machine. The EPP subpanel recommends continued support of cyber infrastructure programs to meet the ever-increasing data challenges to be expected with the LHC upgrades.
The EPP subpanel also supports NSF efforts to develop novel acceleration mechanisms and to train the next generation of accelerator physicists. We particularly support such mechanisms that enhance the workforce by training students and making connections to industry. The ongoing partnership between the NSF and DOE should remain strong and we encourage the creation of the proposed Accelerator Science initiative which will explore new intellectual frontiers in the generation, acceleration and focusing of charged particles and entirely new paradigms for producing coherent radiation.

C2. Learning

The NSF QuarkNet program sponsors many STEM activities that directly help teachers and their students within the US to interact with the "big science" physics community. There are many good examples of this, one of which is the program to fund participation of 5 US high school teachers in the CERN High School Teachers program. QuarkNet has supported this summer program for several years and it has been approved again for this summer. Teachers will spend 3 weeks at CERN July 1-21, 2012 with NSF supporting their travel, per diem, and a stipend. A full description of the program can be found at http://teachers.web.cern.ch/teachers/.

This is a 3-week residential program, taking place every year at CERN during the month of July, open to Physics High School Teachers from all CERN member and observer states who would like to update their knowledge of particle physics, its associated technologies and related subjects. The goals of the High School teachers' program are to
promote the teaching of physics and, in particular, of particle physics, in high schools; to promote the exchange of knowledge and experience among teachers of different nationalities; to expose teachers to international research projects; and to stimulate activities related to the popularization of physics within and beyond the classroom. The EPP subpanel supports these goals and strongly urges continued support for QuarkNet.

C3. Response of EPP to 2009 COV report

The principal recommendation of the 2009 EPP subpanel was that Program Officers deliver more information in the proposal evaluation summaries that are sent to Principal Investigators (PI's). This subpanel has reviewed a number of the review summaries sent to PI's and concludes that the information provided is sufficient to have PI's understand the rationale for the decisions made. The response of EPP to the 2009 COV report is laudable.

6. Particle Astrophysics

Introduction

The Particle Astrophysics (PA) program was recently renamed after the nuclear astrophysics component of the program was moved to the Nuclear Physics program. (Established in FY2000, the previous name of the program was Particle and Nuclear Astrophysics, PNA.) PA provides funding for a growing field of science that straddles the interface between particle physics and astrophysics, combining searches for particles and phenomena underground with detection of astrophysical particles and photons aboveground.

The committee commends PA for developing an exciting and diverse program in this area, for its proactive approach to nurturing the university groups that it supports and for the impressive science progress made since the last review. The topics covered have included dark matter; double beta decay; underground, solar, and reactor neutrinos; and the study of very high energy gamma-rays, and ultrahigh energy cosmic-rays and neutrinos. The program is also expanding to include aspects of dark energy and other interdisciplinary activities. The committee commends this action to further broaden the field but cautions also that its high standard in achieving balance between topics needs to be maintained as the portfolio develops.

PA faces particular challenges in the review and stewardship processes due to the interdisciplinary nature of the science covered, which often leads to across-agency funding and international collaborations. The PA program directors are aware of these challenges and have generally done well in addressing these special circumstances. However, a greater challenge recently has been the precipitous collapse of the NSF stewardship of DUSEL. In view of this major event, the committee requested an update on the issue, specifically the clear flaw in NSF processes by which this withdrawal from DUSEL came prior to submission by that collaboration of the PDR requested of them and of the NRC report. This action caused significant damage to the community and lowered confidence in the integrity of the process. (This event is further discussed in section 3 below.)

PA program directors are to be commended for the efforts made to manage this situation that was outside of their control and to continue to support the underground physics community. The committee is gratified to hear that funds will be made available to promote further development of engineering and R&D studies towards future underground experiments.

The following PA 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

Effective use of the merit review procedure

COV review of jackets

The Program Directors identified 46 jackets that spanned all three years and a range of scientific topics and covered both awards and declinations. The panel reviewed these jackets, which included 35 awards and 11 declinations paying close attention to a few decisions which were not straight forward. In particular, collaborative and new R&D proposals required a more careful stewardship from the PDs. The jackets were very useful in demonstrating some of the complex issues involved in the review and awards process, such as conflicting reviews from reviewers and panels, projects funded across Divisions or by multiple agencies, and the highly varying availability of funds during this period.

Jacket documentation

PA jacket documentation is very thorough. Carefully composed Review Analysis notes provided very useful supplementary material that allowed the committee to see the full picture from the viewpoint of the program director.

Review process and actions

The three prong approach to reviewing proposals and projects; ad hoc reviewers, panel reviewers, and site visits, provides an effective and proactive approach to ensuring a healthy program to advance the intellectual frontier. There were generally enough ad hoc expert reviews (at least three) to provide very useful input, even when the reviews were not all consistent. The number of review panel members has grown to 14 in 2011 from a seven year average of 9 in 2009, with membership spanning the broad range of areas represented in the proposals and as diverse as the proposers' pool. The Program Directors take the advice of the ad hoc reviewers and the review panels seriously and use it fairly.

Special panels and site visit reviews

PA supports large projects that are best reviewed through site visits and are often prioritized in National Review Panels such as the Particle Astrophysics Scientific Assessment Group (PASAG) which reported in late 2009 and the NRC Astro2010 (Decadal Survey) panel reporting in mid 2010. The relevance of these national prioritization panels to the PA portfolio led to an increased number of withdrawals during the prioritization process.

In 2011, the program director attended 28 meetings related to the oversight of PA projects. The organization and participation of Program Directors on site visits and joint agency reviews (of large projects) and subfield planning meetings are important for guaranteeing effective and efficient stewardship of the program and the scientific success of the projects.

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. The broader impact criterion is discussed in more detail below.

Reviewer selection

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

Resulting portfolio of awards

It is the PA COV members' opinion that the resulting portfolio was a balanced program that will most effectively advance the scientific frontiers of particle astrophysics. There has been particular growth in recent years in awards to the dark matter sector, however this is justified by the recognized importance of that field and the quality of proposals received.

The full list of awards, withdrawals, and declinations, showed that over the past three years, PA awarded 144 awards (new and renewed) and declined 70, while 80 proposals were withdrawn. The success rate for renewals and new funding from 2006 to 2008 was 51%. In 2009, ARRA stimulus funding raised the success rate of 2009 to 74%, in 2010 it was 67%, and in 2011 it was 58%. The success rate does not represent the complete dynamics of the reviewing process in PA where the complex nature of collaborative proposals and large projects requires strategic planning. A clear example is the number of withdrawals (80) that were similar to those of declinations (70) over the past 3 years. This shows the effect of National Review Panels such as PASAG and Astro2010 and the delicate stewardship and proactive approach of the Program Directors. Many PA projects were being considered by these panels for cross agency prioritization causing a number of collaborative requests to be withdrawn until panels made their recommendations.

Underrepresented groups

The number of underrepresented PIs and Co-PIs awarded in PA over the last three years averaged 23%, which represents a significant increase from 15% in 2008. The funding rate for proposals with underrepresented PIs or Co-PIs has been healthy. In FY2011, the number of underrepresented reviewers in panels was 26% (7/27).

Management

We are pleased to see that the PA program has added Jean C. Allen as a program director who recently joined Jim Whitmore in overseeing PA. In addition, Jon Kotcher has the primary responsibility for managing the future of underground science in the aftermath of the DUSEL decision. The committee commends Jon Kotcher for his careful handling of the DUSEL situation imposed upon him and for the proactive support he has given to the community in coping with this situation. It is important, especially, for the extended projects to have long term program directors to provide continuity and vision.

The PA portfolio is highly interdisciplinary requiring a wide range of expertise for proper review. The program directors have proactively pursued the appropriate range of review and advice from a broad group of expert reviewers and strategic planning committees. **The current program has a good balance that will need continued care in adapting to new pressures in the years to come.**

2. Outcomes of Program Investments

People

The science goals of PA are well aligned with fostering an interest in science by younger students and the public at large. In addition, the projects in PA provide an excellent platform to educate a new workforce at every level. PA awards have included strong efforts in education and outreach over the last three years, both by individual PIs (Girls Science Investigations) or linked to projects such as Auger (CROPS, AMNH bulletin), Telescope Array (ASPIRE), VERITAS (Adler Planetarium), CDMS (Compass), and HAWC.

Over the past 3 years, PA supported 9 of the highly competitive CAREER awards (5 new), 6 MRI awards, and 6 RUI awards (5 renewal and 1 new). In addition, 5 Early-concept Grants for Exploratory Research (EAGER) were awarded during this period. In 2011, the number of young PIs (less than 10 years from PhD) funded by PA was 18 (including 4 of the CAREER awards).

Discoveries and Science Highlights

Major accomplishments by PA efforts during the last three year period

1. Direct Dark Matter Searches

It is known that around 23% of the matter content of the Universe is non-luminous so-called dark matter most likely comprising a new class of particles generically termed Weakly Interacting Massive Particles (WIMPs). Direct laboratory searches performed underground using detectors of ever increasing sophistication form a major component of the PA portfolio, reflecting the extreme importance that identification of dark matter holds across particle physics, astrophysics and cosmology. The field has become highly excited in the last 3 years with many new results that includes several claims of WIMP detection. The NSF PA program is playing the most prominent role in this field worldwide. A particular highlight was the first results of the PA-supported XENON-100 at the Gran Sasso laboratory to produce a new record for the most sensitive experiment. This complements well the pioneering CDMS experiment funded by PA at Soudan that has also recently produced new world-leading results using their quite different, bolometric, technology. Meanwhile the COUPP experiment also of PA, emphasizing searches for WIMPs with a different, spin dependent, type of interaction, has also produced leading results. Interestingly, however, in a further twist, the PA-supported CoGent experiment recently released their observation of unexpected effects in their new experiment, interpreted as a possible real detection of WIMPs. This result, combined with other new results from elsewhere claiming detections has produced much excitement and controversy. Resolving this will be challenging but NSF has positioned itself very well to play a key role in the field not just through the existing experiments but also by R&D programs that have advanced rapidly, in particular towards building a WIMP "telescope" to identify that events are really of galactic DM origin.

2. Indirect Dark Matter searches with VERITAS.

PA funded VERITAS took 48 h of data on Segue 1 in 2010-11, the most dark-matter dominated dwarf galaxy, known. Limits from these high energy gamma-ray observations constrain the velocity weighted cross section of WIMPS, the decay lifetime of other candidates, and potential boost factors. It also strongly disfavors a DM interpretation of the cosmic ray lepton anomalies reported by ATIC & Pamela.

3. Ultrahigh energy cosmic-rays: iron or change in interactions

Cosmic rays at the highest energies, above 10^{19} eV, have an unexpected shower development behavior. Astrophysical expectations were that they would be protons, but shower development observed by the PA funded Pierre Auger Project shows a tendency towards iron as a function of energy. An alternative interpretation is that hadronic interactions display an interesting change at energies around 100 TeV (CM). In the next few years, Auger and the Telescope Array (also funded by PA) will accumulate statistics at these energies, clarifying this puzzling trend.

4. Double Beta decay

The best limit on neutrino mass currently comes from the non-observation of neutrino-less double-beta decay ($\beta\beta 0\nu$). This is a lepton number violating process where a nucleus (A, Z-2) decays to (A,Z) +2 e- . This process might also occur through the exchange of scalar bosons and other mechanisms involving physics beyond the standard model, but it has been shown that a finite double beta decay rate requires neutrinos to be Majorana particles, no matter what mechanism produces the process. Thus an observation of zero neutrino double beta decay would be evidence for a non-zero Majorana neutrino mass. The decay amplitude is proportional to a weighted average Majorana neutrino mass parameter, $<m>$, where the sum is done over all light neutrinos. The current best experimental searches lead to limits on $<m>$, which are less than 1 eV. Precise numbers depend on the particular calculation of the nuclear matrix element involved. The results on neutrino oscillations from atmospheric and solar neutrinos imply a Majorana neutrino mass in the range of 0.01 to 1 eV, so it is important to be able to improve the sensitivity of these experiments and confirm the mass scale by actually observing double beta decay and by so doing, revealing the Dirac or Majorana nature of the neutrinos. The PA-funded Majorana Demonstrator Project is scheduled to be installed in the Sanford Underground Laboratory in March. The PA funded CUORE experiment is under construction at the Gran Sasso Laboratory in Italy. The PA funded EXO experiment has constructed a 200-kg detector and was the first to observe 2-neutrino double beta decay in Xe-136. PA supported NEMO-3 continues to run at the Modane Laboratory and has set the best limits on zero-neutrino double beta decay in both Mo-100 and Se-82. PA supported SNO+ is under construction at the Sudbury Laboratory and will study the zero-neutrino double beta decay of Nd-150.

7. Reactor neutrino

There is now convincing evidence for flavor conversion of atmospheric, solar, reactor and accelerator neutrinos. Thus, neutrinos do have masses, and neutrino oscillation is the most promising scenario to explain the data. Reactor neutrino experiments measure the survival probability of electron anti-neutrinos emitted by nuclear power stations at a given distance. This disappearance probability does not depend on the Dirac CP phase. Furthermore, thanks to the combination of the MeV range neutrino energies and the short baselines (less than a thousand kilometers) the modification of the oscillation probability induced by the coherent forward scattering from matter electrons (so-called matter effect) can be neglected in the first approximation.

Considering only the three known neutrino families, the neutrino mixing matrix is parametrized by three mixing angles. The angle θ12 has been measured to be large, by the combination of the solar neutrino experiments and KamLAND. The angle θ23 has been measured to be close to maximum by atmospheric neutrino experiments as well as the long baseline accelerator neutrino experiment K2K. However, we only have an upper limit to the mixing angle θ13, given mainly by the Chooz experiment. The large value of both θ12 and θ23 indicates a strong difference between the leptonic and quark mixings, whereas the smallness of θ13 testifies to the peculiarity of the neutrino sector. The value of θ13 is not only of fundamental interest to understand leptonic mixing, but it is also necessary to plan for the future experimental program in neutrino physics, since CP-violating effects are proportional to sin2θ13.

New accelerator neutrino beams coupled with off-axis detectors, will search for an electron neutrino appearance signal. The observation of an excess in an almost pure muon neutrino beam would be major evidence for a non-vanishing θ13. But on the top of the statistical and systematic uncertainties, correlations and degeneracies between θ13, θ12, Δm231, and the CP delta phase degrade the accessible knowledge on θ13. Both reactor and accelerator programs will provide complementary results to better constrain the last undetermined oscillation parameters.

In order to improve the Chooz results with reactor experiments, two (or more) identical detectors close to a power station are required. The first detector has to be located at a few hundred meters from the reactor cores to monitor the flux and spectrum before the oscillations. The second detector has to be placed between 1 and 2km away from the core, to search for a departure from the overall $1/L^2$ behavior of the energy spectrum. Two identical detectors allow relative comparison, leading to a large reduction in the systematic errors.

A number of new reactor experiments are competing in this search for θ13: PA supported Double-Chooz in France, PA supported Daya Bay in China and RENO at the Younggwang site in Korea. Double-Chooz was the first of these to report and has published evidence of a θ13 observation that is non-zero, in agreement with an earlier T2K result. Further results from all three reactor experiments are expected this summer at the International Neutrino Conference in Kyoto.

Facilities, tools, techniques

PA has a very broad program with a wide range in project funding levels and management needs. PA program directors have 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 in remote areas along with multi-agency and international funding. The success of these projects owes much to the dedicated oversight and management by PA and NSF in general.

Two highlights are the end of IceCube construction which allowed them to place the most stringent limits on high energy cosmic neutrino fluxes, and the beginning of HAWC construction in Mexico.

Future Prospects

Investments in this new and vibrant field are starting to pay off, as shown from the highlighted recent 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", "Physics of the Universe", and "New Worlds New Horizons" reports.

Future plans built on recent successes should lead to increased funding requests. In particular, new large facilities or projects will need thoughtful planning to insure good use by the community of these facilities for new opportunities.

3. Comments and Recommendations

NSF Stewardship of the DUSEL Project

Beginning in 2001 and accelerating during the last decade, there was a tremendous effort by the community to develop a Deep Underground Science and Engineering Facility (DUSEL). The effort was strongly supported by the NSF. Several potential sites submitted proposals and an expert panel selected the Homestake mine in South Dakota. As detailed in numerous studies, the laboratory was to have a broad scientific program spanning from biology to particle physics. A project group was funded at the Laurence Berkeley Laboratory to develop the Preliminary Design Report and the National Academy instituted a panel to study the science planned for the laboratory. NSF funded R&D for many of the experiments that planned to use the facility. In December 2010, before the PDR was released and before the Academy study was completed, the National Science Board voted to discontinue DUSEL development.

Since several major DOE experiments had planned to use this facility, the DOE began a process to reevaluate their possible role at the site. This process has not yet completed. The scope of the future science program at the site now depends strongly on the DOE decision.

Whatever the eventual decision, the abrupt termination by the NSB has been extremely disruptive to the community, certainly causing significant delays in the scientific programs. Fortunately, the State of South Dakota, a private benefactor, and DOE intervention, have enabled early science to continue at the site in the interim.

The NSF is redirecting its attention to the immediate scientific needs of the community. We commend them for this effort.

Instrumentation Program

Support for the instrumentation (APPI) fund is very important for the PA community because there is a clear match to the scale of many of the projects currently being developed and proposed by the community in several of the sub-

fields. Notable is the dark matter area where experimental efforts have grown in recent years into so-called G2 detectors of the few M$ scale with foreseen lifetimes of order 2-5 years. Similar mid-scale scenarios are also applicable to high-energy cosmic particles, and other PA efforts. It is also recognized that funding equipment at this intermediate level is beneficial to fostering university collaborations and good for younger faculty researchers because it provides new routes to developing leadership skills.
The PA awards funded through APPI ranged from $190k (Double Chooz front electronics) to the construction of HAWC over 4 years (totaling 6.7M$). Most projects lay in between, such as CDMS, Double Chooz, CUORE, and ADMX.

Interagency and International Projects and Project Management

The interdisciplinary nature of PA programs requires the close interaction and coordination with other national agencies particularly the DOE. The PA staff has been very successful in developing such cooperation benefiting the projects by the common steering and financial management. The committee recommends that this process be maintained and developed and that the regular meetings and joint oversight actions should continue to be evolved as appropriate to match the experiments funded. The international nature of the PA program, for instance whereby experiments are located abroad and/or involve multiple foreign funding agencies, also means that there needs to be good communication, joint financial planning and coordination between the relevant bodies. This is critical to mitigate risks that may develop from changes in financial circumstances or development of unanticipated experiment bottlenecks. **The PA staff is to be commended in their proactive approach to international planning by attending project finance boards overseas to discuss and agree on actions that mitigate fluctuations in funding cycles that often occur.** The committee recommends that these interactions are maintained and developed in the future and that the office also ensures that due consideration is given to this international planning aspect by PIs, even at the proposal stage of projects.

Broader impact: Education and Public Outreach

The broad nature of particle astrophysics, with its focus on seeking a deeper understanding of the fundamental workings of the Universe, has great capacity to inspire young people and the wider society. The PA program has been very active in exploiting this opportunity for societal benefit and training of highly skilled workforce. Noteworthy examples include the highly successful open days held at Soudan where the public is encouraged to interact with scientists working on PA experiments, and the hugely successful and novel outreach program developed at Yale with local schools (Girls Science Investigations). Here the focus is particularly towards encouraging girls to become interested in science. In addition there is an increasingly active program to make data from PA-funded projects openly available to the wider community. In particular, the AUGER and ICECUBE experiments are actively developing this approach including providing free software and user guides to help participants make best use of the available data.

The need to understand the “leaky pipe” aspect of the underrepresentation of women and minorities in STEM fields would benefit from **a pilot project within PHY to track the total number of junior researchers in each category (undergraduates, graduate students, and postdocs) funded in their grants and their gender, ethnicity, and race.** (This could be designed such that individuals would voluntarily enter directly to the database their information on an annual basis.) Tracking these numbers over a decade will allow quantitative studies of the progress and challenges faced by diversifying efforts.

Broad Impact: innovation for society

PA projects require technological advances in detector technologies that provide great opportunities to impact the wider society through interaction with industry and national security. A few examples of areas where cutting edge advances in technology are being made of direct interest to companies include: development of new high purity materials and techniques (from double beta decay and dark matter experiments), production of new photo-sensors with greater efficiency and reliability (from the high energy cosmic particles and dark matter fields), and the development of new techniques for sensitive neutron detection (dark matter searches). The latter is directly relevant to homeland security applications. Two recent examples are discussed below.

Double Beta Decay and the Development of Point Contact Germanium Crystals

The Majorana experiment is one of the leading Ge double beta decay experiments in the world. Success requires very low background high-resolution detectors. A key aspect of these detectors is that they are constructed in the P-type configuration with a compact Point Contact electrode geometry (hence the PPC name). This results in slow drift times of charge that, together with the electrode geometry, enables similar background rejection (with lower cost and complexity) to highly segmented detectors via tagging and rejection of multiple-site interactions. These detectors also have good energy resolution and low energy thresholds that may also allow simultaneous dark matter (WIMP and axion) search capabilities. This development has resulted in technology transfer to manufacturers for commercial applications and has relevance to applied missions at DOE laboratories, including improved Ge detectors for threat reduction and nuclear forensics.

LBNE and Gadolinium R&D and PMT Development

The R&D for a far detector for the Long Baseline Neutrino Detector (LBNE) included the development of a technique to employ a salt of gadolinium in the water. This would give the detector the ability to detect neutrons with high efficiency. In addition to its use in basic science, this development would produce a technology capable of detecting the antineutrino flux from reactors over long distances. This capability would respond directly to a mission need identified in the NNSA Strategic Plan for 2011- the enabling of plutonium production monitoring in distant reactors via the detection of their antineutrino flux.

The massive LBNE detector requires significant light collection to achieve low threshold and for track topology identification. Vast numbers of inexpensive high efficiency phototubes are necessary. Currently, a single foreign manufacturer dominates the PMT market. The collaboration engaged this manufacturer and also cultivated a domestic manufacturer to produce samples of new advanced devices.

7. Gravitational Physics

Introduction

The NSF is the principal source of funding for gravitational physics – both theoretical and experimental -- in the United States. This gives the gravitational physics program a critical role in American science, even more so given the uncertain future of gravitational wave detection in space. The gravity program is also the scientific home of the LIGO, the largest NSF experimental project. This juxtaposition of a $70 million dollar a year experiment and a $15 million dollar research program creates enormous opportunities, but also presents some challenges.

The arguments for a strong research program in gravitational physics are compelling. At the subatomic level, gravity is by far the weakest interaction, but because it is long range and unscreened, it dominates at astrophysical and cosmological scales, determining the large scale structure of the Universe. Since the Universe is virtually transparent to gravitational waves, signals generated by energetic events can travel practically unimpeded to our detectors, making gravitational radiation a unique probe of processes such as neutron star and black hole mergers and perhaps supernovae. Of course, these same properties make gravitational waves hard to detect, necessitating major experimental efforts such as LIGO. At the same time, the need to predict signals from strong field regions and to construct templates to aid detection requires an unusually complex mixture of numerical and analytic techniques. We also note that despite the complex technical nature of the subject (or perhaps because of it), gravitational physics generates considerable interest in the general public.

The dissolution of the NASA/ESA partnership on the LISA project in the spring of 2011 has made the future of space-based gravitational wave detection less certain, further increasing the importance of Advanced LIGO to the gravitational wave community. Should the research funding associated with NASA's gravitational astrophysics program also disappear, NSF's Gravitational Physics program will become the sole source of US funding for research areas such as source modeling and data analysis for gravitational waves. On a more positive note, a successful Advanced LIGO should generate enormous excitement within the broader scientific community that will help make the case for future space-based gravitational wave detectors.

Gravity has other unique features as well. As the dominant interaction at large scales, gravity is fundamental to our understanding of cosmology, and it is possible that cosmological observations such as the acceleration of the Universe will require modifications of our theories of gravity. Experiments at small distances may potentially reveal the need for modifications, such as the introduction of a new "fifth force" suggested by many extensions of the Standard Model of particle physics. These experiments represent an opportunity that is increasingly rare in physics: the ability to make a measurement that could potentially revolutionize our fundamental understanding of the universe on a budget and scale suitable for an individual researcher.

As a geometric theory, general relativity has a strong overlap with frontier questions in mathematics, and important physical questions such as cosmic censorship are likely to require new mathematical approaches. And alone among the fundamental interactions, gravity is not yet described by a quantum theory, posing one of the deepest and most important mysteries of fundamental physics.

A basic problem facing the gravity program at the NSF is to balance all of these vital research areas. This requires not only a good understanding of current research in all its breadth, but also a vision for the future of the field. In our view, the NSF gravity program has succeeded admirably, especially in a tight budgetary climate, in a large part because of the excellent work of the departing program director, Beverly Berger. We would like to take this opportunity to thank her for her leadership and service to the gravitational and the broader physics community.

Recent progress

Over the past three years, NSF-supported gravitational physics has continued to make great strides. A 15-month science run (S6) was completed with the LIGO detectors in the "enhanced" configuration, an improvement in sensitivity of roughly a factor of two over the initial LIGO design. Analysis of these data is currently ongoing and, while not yielding the detection we are all waiting for, has nonetheless produced some interesting results. The absence of detected gravitational radiation associated with a short-hard GRB potentially located in M81 provided constraints on the class and distance of the burst progenitor. Targeted searches for gravitational radiation from the Crab and Vela pulsars have placed constraints on the ellipticity of these neutron stars and consequently on their equations of state. The LIGO collaboration's analysis and review procedures were tested with a blind hardware injection that was carried to the point of drafting a discovery paper before the injection key was checked. The rigor demonstrated by this test will be important for convincing the broader community of the validity of the first detections. Einstein@home, a volunteer distributed computing project originally designed to search LIGO data for gravitational radiation from pulsars, has now used signals from the Arecibo radio telescope and the Fermi gamma ray satellite to detect more than a dozen new neutron stars, some of them quite unusual. During the review period, 28 papers on LIGO observations were published, including joint analyses of LIGO, GEO, and VIRGO data.

The LIGO detectors are now undergoing a major upgrade to Advanced LIGO. Installation of the detector is due to be completed by 2015, followed by a commissioning period that will eventually yield a survey volume 1000 times larger than initial LIGO. Even the most pessimistic estimates of signal rates predict that we should then have at least a few gravitational wave detections per year. Progress on

Advanced LIGO installation is proceeding according to schedule and expenditures are in line with the budget profile. During this upgrade time, opportunities have been taken to utilize the LIGO facilities to do ancillary experimental science such as laser-cooling of mirrors and injection of squeezed light into the interferometers.

One area for which we anticipate rapid growth is multi-messenger astronomy with LIGO. In previous LIGO science runs, gravitational wave data analysis has been targeted towards specific objects using information from electromagnetic observations (e.g. targeted pulsar searches). During the S6 run, it became possible for LIGO to provide low-latency event candidates to a handful of telescopes. This type of work will become critical for integrating LIGO into the existing network of astronomy instruments.

In addition to LIGO-related activities, the Gravity Program supports a number of PI-led experimental efforts in other areas, including tests of the equivalence principle, measurements of gravity on small scales, and tests of gravity through lunar laser ranging. One highlight during the review period was the re-discovery of a 'lost' lunar retroreflector placed on the moon by the Soviet Luna 17 mission but not detected since 1971. NASA's Lunar Reconnaissance Orbiter spotted the rover and the NSF-funded Apache Point Lunar Laser-ranging Operation (APOLLO) program confirmed the find by targeting the probe with its laser system. The APOLLO system is capable of making millimeter scale measurements of the Earth-Moon orbit, which provide information on Lunar and terrestrial geology as well as gravity.

Much effort in numerical relativity went into further pursuing the binary black hole simulations that became possible with a breakthrough in 2005, and further exploring the astrophysical implications of the results. One example is the extension of simulations to binary mass ratios of 1:100, signaling important progress towards covering the vast parameter space of possible binary black hole configurations. This, in turn, is a key step towards assembling gravitational wave templates, which are extremely valuable for the identification of gravitational wave signals in gravitational wave detector data. In a related effort, the numerical relativity community has joined the gravitational wave data analysis community in the Numerical INJection Analysis (NINJA) project, which injected numerically produced waveforms into observational data in order to test search algorithms and our capabilities to identify such signals. Other highlights include simulations of head-on collisions of black holes that explore cosmic censorship in a previously untested regime. In a complementary effort, several groups have started to simulate black holes in non-vacuum spacetimes. Examples of great astrophysical interest include simulations of circumbinary disks, emission of jets from binary black holes, and magnetized black hole-neutron star binaries.

In classical general relativity, much of the most interesting work has revolved around the question of cosmic censorship: are singularities always hidden by event horizons? Significant progress has been made toward proving cosmic censorship for simplified but increasingly complex systems obtained by imposing symmetries on the Einstein field equations. Numerical studies of colliding solitons have also provided evidence for cosmic censorship, showing the formation of horizons well before any potential singularities might become visible. At the same time, though, there is now fairly convincing evidence, from a combination of analytic and numerical techniques, which black strings in five spacetime dimensions can fragment into black holes in a way that violates cosmic censorship and produces naked singularities. In addition, very new results strongly suggest that anti-de Sitter space is unstable, in a manner that may also lead to violations of cosmic censorship.

In quantum gravity, the main progress has been in the understanding of relatively simple systems: notably black holes and "minisuperspace" models of quantum cosmology. NSF-funded research has led to a new possible picture of black hole formation and evaporation, in which the singularity is replaced by a highly quantum region and the "information loss" problem may be resolved. Investigations of loop quantum cosmology similarly suggests that the Big Bang singularity may be replaced by a highly quantum region and a "bounce." Work in this field has also touched on the foundations of quantum mechanics, both in the newly developed "Montevideo interpretation," in which the role of physical clocks is fundamental, and in the decoherent histories approach to cosmology.

The field of gravitational physics is growing rapidly, primarily driven by the interest in the emerging field of gravitational wave astronomy. Statistics from the program during the review period bear this out: awards were made to 41 new PIs (within 10 yrs of Ph.D.) and 8 CAREER researchers. While we are extremely pleased with these numbers, this rapid growth in a constrained funding environment is already presenting challenges that may become more severe in the future.

Program processes and management

The CoV looked in detail at 40 proposals in gravitational physics (evenly split between LIGO research support, gravitational theory, and gravitational experiment) submitted over the past three years, including both accepted and declined proposals. We also examined the review process, the selection of ad hoc reviewers and panels, the role of the Program Officer, and the final outcomes.

Of the proposals we examined, every approved proposal clearly met NSF standards, and was deserving of funding. Indeed, had the money been available, the program could have easily maintained the standards of excellence with a higher acceptance rate.

We believe that the overall review process has worked well. Some subfields of gravitational physics are quite small, and it can be difficult to find reviewers with the appropriate expertise who have no conflicts of interest, but between the ad hoc reviewers and the panel, the program was able to obtain suitable reviews. Reviewers and panels dealt with both the intellectual merit and broadening participation criteria and generally provided clear and substantive critiques of proposals. The panels' summaries and Program Officer's notes provided clear rationales for the final decisions.

The gravitational physics program has a unique feature: with the PI's permission, proposals directly related to LIGO are reviewed independently by the LIGO Laboratory, which ranks proposals both on the basis of merit and on relevance to LIGO. The LIGO review does not serve as a veto -- the NSF may choose to fund a proposal as "best science" even if it is not considered high priority for LIGO -- but it provides valuable input. The LIGO reviewers (four per proposal) are anonymous to the panel and to us, and while the most blatant conflicts of interest -- reviewing one's own proposal -- are avoided, the LIGO reviews do not adhere to the same strict standards for conflict of interest as the NSF. This situation is probably unavoidable, given the nature of the LIGO collaboration, and is acceptable since the LIGO reviews are only used as advisory input to the panel review process. We encourage the Program Officers to make sure that panelists are made aware of the nature of the LIGO review process.

The program has done a good job in funding new PIs. We also note, with approval, that the program has been willing to reject funding of several "big names" who presented weak or unconvincing proposals.

The review analyses provided by the Program Officer provided valuable context and clear rationales for the decisions. They were the single most useful piece of information for understanding the process. The NSF should consider providing PIs with redacted copies of these analyses to facilitate more competitive proposals in the future.

Portfolio balance

As noted above, gravitational physics covers a wide range of subfields, from experiments, both large and small, to numerical approaches, to abstract theory. LIGO is the "elephant in the room," and LIGO critical path proposals are given high priority. As the last two CoV reports both observed, the arguments for a strong focus on LIGO are persuasive -- the detection of gravitational waves will transform the field -- but there is also a danger that an overemphasis can lead to neglect of other vital areas of research. This is especially true given the rapid growth of gravitational physics over the past few years, without a concomitant growth in funding. Given the funding constraints, this balance has been adequately maintained, but the Program Officers must remain vigilant in the future.

The field of gravitational physics is growing rapidly, and with Advanced LIGO on the verge of success, we foresee the potential for explosive growth in the near future. It will be vital for funding to rise to account for this growth.

While Advanced LIGO justifiably remains the top priority for NSF-funded research in gravitational wave instrumentation, some attention is beginning to be paid to technologies needed for '3rd-generation' gravitational wave detectors. Thus far, most of this funding has been targeted towards technologies that can provide incremental upgrades to Advanced LIGO and do not require significant changes in the basic architecture of the Advanced LIGO detector. If the US is going to have a leadership position in ground-based gravitational wave instrumentation in the coming decades, early investment in 3rd-generation detector technologies must be made. In addition, the multi-decade development time associated with designing a gravitational wave detector means that now is the time for the NSF to begin preliminary design studies for 3rd-generation detectors.

During the deliberations of CoV as a whole, a proposed new initiative to support mid-scale physics instrumentation was discussed. We feel that the gravitational physics program could benefit from such an initiative, especially in the area of experimental and computer infrastructure. As we noted above, the current balance between theory and experiment in the gravity program is appropriate, and we strongly recommend that this balance not be upset through the inclusion of new resources in experimental programs without a corresponding increase in theory support. Special attention will have to be paid to Gravitational Theory in this context, as it is one of the few theoretical programs not contained within the Theoretical Physics Program.

Broader impact

The gravity program covers an extremely broad range of science, from highly abstract theory to complex computation to both small and large experiments. The fundamental questions covered in the program are very effective in drawing the public into science, and attracting large numbers of students to undergraduate and graduate STEM programs. NSF funding helps train these students in skills that are widely useful throughout society, and, in fact, many of these students go on to careers in high tech industry and other areas of science. Gravitational experiments have led to the creation of important new technologies, including electro-optical control systems, mirror coatings for precision metrology, and low-noise lasers; LIGO has now set up a technology transfer office to help link such developments to outside opportunities.

Response to recommendations from previous CoVs

The Gravitational Physics Sub-panel Report of the 2009 Physics Division CoV made the suggestion to include in future CoV membership "people who are not currently funded as a result of having highly-rated proposals declined." We note that two out of the three members of the 2012 CoV Gravitational Sub-panel received no NSF support, although not as a result of having proposals declined.
While this may not reflect the specific recommendation of the 2009 CoV, it does address the issue of potential positive bias arising from a CoV made entirely of people who have been successful securing NSF funding.

Suggestions for future CoVs

The assignment of some individuals to more than one subpanel during this review caused considerable disruption, seriously cutting into our ability to have a successful meeting. We strongly urge that future CoVs assign each reviewer to only a single subpanel, even if this requires increasing the total number of participants.

Providing a collaborative word processing process similar to the Panel Review System for CoVs would be very helpful for preparation of the report.

We recognize the importance of the CoV members having control over the content of the final report. However, it would be helpful to have more guidance about the format and context of the program section of the report.

8. Educational Physics and Interdisciplinary Research

Introduction

The Education and Interdisciplinary Research (EIR) program in the Physics Division supports projects that cut across multiple sub-fields in physics and Divisions in the NSF as well as projects that provide education and outreach opportunities to all physics fields. The Physics Research Experience for Undergraduate (REU) Site program is a major component within EIR and supports all physics subdisciplines. EIR supports projects that broaden the participation in physics research and education by women, historically under-represented minorities, and people with disabilities, including outreach projects directly connected to Physics Division research initiatives. Physics Education Research (PER) projects targeting upper-level physics content are also within EIR. Further, the program supports interdisciplinary research programs that do not naturally fit within an existing research program within the Physics Division.

The EIR program officer (PO) shepherds a wide variety of proposals through the review process, a process that can require a combination of reviewers with unique expertise and/or multiple panels. Further, the PO collaborates with POs from other programs in the Division and throughout the NSF to identify appropriate funding sources and proposal reviewers, as many proposals cross multiple programs. This ability to identify connections between programs and to work with a wide range of scientists has served the EIR program well and the PO has become a crucial resource for proposals that cross Division or program boundaries, as well as the POs that receive these proposals.

Overall, the EIR COV subpanel felt that the EIR program is very well managed and found no significant concerns. There are multiple strengths in the EIR program, given its broad reaching structure and due to the strong support of the Physics Division for the programs housed in this program. The EIR COV subpanel includes suggested modifications that will further improve the program, described throughout the document. We begin with a set of general comments about the review process, followed by direct responses to questions posed to the COV, and conclude with several challenges facing the EIR program.

General Comments about Review Process:

Due to the variety of programs in its portfolio, the review process in EIR consists of the 3 most common methods of reviews: panel, ad hoc, and internal. The largest program supported by EIR is the Physics REU Site program. Primarily REU Site proposals are handled through panel reviews which is accepted as the most appropriate review method since REU programs are sufficiently similar and numerous. For REU Site proposals that span multiple disciplines, the PO arranges to have the proposal co-reviewed by additional REU panels in the appropriate discipline(s) or supplements the physics panel with ad hoc reviews from disciplinary specialists.

Other proposals received by EIR are generally reviewed through ad hoc reviewers, occasionally supplemented by site visit review teams (when appropriate). The ad hoc reviews are appropriate as the proposals vary widely in scope, requiring specialized expertise to assess the projects. In the EIR program, a two-tier review process (ad hoc reviews followed by panel review) is not appropriate as many proposals vary widely in scope and content. Internal reviews are used for conference proposals, following NSF guidelines.

Merit Review Criteria

Both merit review criteria were addressed in all individual reviews, panel summaries, and review analyses. Several examples of terse individual reviews were noted, but more than sufficient detail was provided when examining the panel summaries or considering all ad hoc reviewer discussions. In all cases, the PO review analyses provided thorough and detailed discussion of both review criteria.

Documentation of Review Process

In general, the individual reviews provided substantive feedback. This was especially important for the EIR program, given the diverse nature of the proposals considered. The review analyses by the PO were complete and thorough in all cases, with additional supporting details provided in the correspondence and diary notes. A clear picture of the decision making process was evident through the reviews, panel summaries, and review analyses. In one case, additional notes for an unresponsive PI could have provided a slightly clearer picture of the situation. The rationale was also well justified in the most challenging cases, i.e., when examining proposals close to the award/decline threshold. All of the reviews and summaries provided clear documentation on the award/decline decisions. We did not find any cases where insufficient individual reviews or panel summaries required additional explanation from the PO.

Qualifications of Reviewers:

The reviewers utilized by EIR come from a wide range of organizations, represent a variety of areas of expertise, and also reflect the diversity of the population impacted by the proposals. In cases where specialized expertise was required, the PO sought out experts in these areas to provide input on the proposal, such as including museum experts for proposals involving museum exhibits. The care taken by the PO to assemble diverse panels (including that of this COV team) is evident. REU panel members represent research-intensive institutions, liberal arts colleges, two-year colleges, and minority-serving institutions as well as non-academic organizations. Racial/ethnic and gender diversity of reviewers was achieved as well.

Award Portfolio

The awards within the REU program reflect a wide range of physics sub-fields and are located at a wide range of locations that reflect the diversity of the Physics research enterprise. The funded sites are consistently excellent, and there is a pool of unfunded but fundable sites. In education research, the program supports a modest number of projects, in part because many education research projects can also find a “home” in the DUE-TUES or other programs. Physics projects that impact broadening participation in physics (conferences, workshops and outreach activities) also find a home in EIR. Based on currently available funds, the current distribution of the portfolio (<50% of the budget in REU sites and the remainder supporting all other projects) is appropriate. The PO has been very proactive at seeking out co-funding to maximize impact of EIR projects and should be commended for this approach. However, should additional funds become available, the priority should be expanding the REU Site program while retaining a commitment to innovative education and interdisciplinary projects.

Program Management

The PO should be commended for the quality of the review process, especially given the diversity of the portfolio of proposals, both in size and subject area. The PO has been innovative in working across traditional boundaries to fund high potential projects. The PO has increased the impact of program by shared funding of multiple projects, freeing up budget for core projects. The resulting program portfolio is well balanced, with the majority of funding supporting Physics REU sites and the remainder distributed across outreach, education, and interdisciplinary projects.

EIR Responses to Questions posed to the COV:

Cyber Infrastructure:

The EIR program includes education/outreach projects as well as interdisciplinary projects that incorporate large cyber infrastructure components. These projects rely on large data sets or remote access to cutting edge research facilities. For projects engaging K-12 students and/or teachers, the curricular materials involve adapting research techniques and tools to be accessible using the K-12 classroom tools (i.e. web-based or spreadsheets). The Interactions in Understanding the Universe (I2U2) project is an exemplar of this type of project. The cyber-based education/outreach projects include a strong broader impact component in addition to their intellectual merit components. Further, EIR can facilitate opportunities to build effective broader impact components by partnering with cyber infrastructure projects.

Broader impacts:

Education and outreach programs inherently have broad impacts in addition to their intellectual merits. The majority of EIR projects have significant workforce development components or provide opportunities for PIs to share their research results with the public-at-large. EIR is a natural program to foster outreach activities and stewardship of the discipline. Examples of these include

Examples:

- PhysTEC: major initiative to develop the quality and quantity of K12 physics teachers led by the American Physical Society and thus broadly impacting the physics discipline.
- Decadal Survey of PER: study by the National Academy of Science of Physics Education Research that will provide a broad view of the state of PER as a discipline.
- REU Sites: experiential research programs for undergraduates operated at ~50 sites that provide stewardship of the discipline.
- LIGO-traveling exhibit: innovative outreach project for LIGO that has engaged over 20,000 people at over 15 sites.

Interdisciplinary (ID) proposals:

The EIR program is the natural home for interdisciplinary proposals. However, individual programs also receive proposals spanning multiple subfields in physics and multiple disciplines within the NSF. The Physics Division has proposed that the PO for EIR serve as a **cross-disciplinary ombudsman** supporting POs in other programs to facilitate the inherent challenges associated with evaluating and supporting interdisciplinary proposals. The EIR PO has informally served this role for program officers that have requested help; however, it is important to formalize this process. Formalizing the role of the ombudsman provides a single contact for POs both within Physics and from other Divisions. It also allows the NSF administration to recognize the dedicated efforts required to effectively shepherd complex proposals through multiple programs. We also note that the Division of Materials Research does not have an explicit education program, yet does co-fund multiple EIR education and interdisciplinary projects. The ombudsman has the potential to improve facilitation of projects that serve both Divisions, as well as the Broader Impact of many projects.

The existing funding mechanisms seem to be working well for EIR projects and interdisciplinary projects funded in other physics programs. The PO has sufficient flexibility in funding and consistently builds partnerships with other programs for funding. A dedicated funding source does not appear fruitful, as it could negatively impact long-standing, cross-disciplinary partnerships.

The EIR subpanel could not find evidence of any missed opportunities, i.e. high potential cross-disciplinary projects not being funded. This is not surprising as missed opportunities would have been reviewed by another program and thus the panel would not have learned about it. However, we did find multiple examples where the EIR PO brought together many programs to fund a project. Notably, the Sante Fe Institute that was funded by 12 programs after being reviewed by over 70 reviewers and multiple panels (it was reviewed in the period covered by the previous COV). Additional multi-program projects are noted below.

Examples:

PhysTEC: PhysTEC: major initiative to develop the quality and quantity of K12 physics teachers led by the American Physical Society and thus broadly impacting the physics discipline is co-funded and co-reviewed by Physics, DUE, and DMR.
REU Site projects: Several REU Site proposals each year are multi-disciplinary and are reviewed and, if appropriate, funded by two or three Divisions.

Facilities and Centers:

EIR is not currently directly supporting any facilities and centers. EIR has funded education/outreach projects that support large research initiatives (such as the LIGO Science Education Center and the Traveling LIGO Exhibit).

Broadening Participation

The Physics Division is tackling broadening the participation of PIs and reviewers, a complex challenge. The Division should focus on its own practices as well as try to leverage change through partnerships where possible. Actions the Division can take include:

- Improve demographics data collection / sharing
    - Reviewer demographic data wasn't easily accessible for the COV, due to the separation of the PARS and Fastlane database systems. Data from these systems should be shared across the system to better assess the demographics of the reviewers.
    - REU participant information is collected in Fastlane through self-reporting by students. However, that information is not available to the PI and does not appear easily accessible to POs. Thus communication between Fastlane, the PIs and the POs could be improved to better assess REU participant demographics.
- The Physics Division broadening report indicates POs provide information about potential funding opportunities to faculty at small institutions in order to foster successful submissions. This could be broadened to provide several options for improving proposal preparation, such as:
    - Suggesting successful "proposal writing" mentors who have a strong track record of writing high quality proposals in that field.
    - Making unsuccessful new PIs aware of the ROA program that could facilitate mentoring relationships between young faculty at institutions that do not have strong research traditions and established researchers.
    - Making young PIs aware of ongoing "How to build research programs at small colleges" workshops (for example, those held by the Council on Undergraduate Research - CUR).
    - Mentors should develop their skills, such as through the NSF-supported Research Mentor Training seminar program. The physics community, possibly through APS/AAPT, could help to make these opportunities available to new PIs.
- New REU site proposals could be broadened through a similar mentor model with established REU sites.

Challenges faced by EIR

Breadth of portfolio of EIR

One unique aspect of EIR is the breadth of the portfolio, covering REU sites, outreach proposals, interdisciplinary projects, and PER projects. Since the portfolio is quite broad and since EIR provides a home for projects that do not fit into other programs, it is difficult to anticipate the community's submissions as well as associated funding levels. There are many one-of-a-kind proposals that must be accommodated within the budget. The PO has done an admirable job of ensuring these projects receive full consideration. Accommodating these complex and potentially innovative projects must remain a priority.

RET (Research Experience for Teachers) funding:

While NSF-wide funding of the RET program is no longer available, the Physics program continues to support RET programs at approximately the same number of "seats" as in the past. The Physics program should be proud of their commitment to providing opportunities to teachers that have the potential to transform how those individuals teach their students. The broader impacts of these programs are significant. In tight budget situations, distribution of these funds relative to other programs can be a concern. However, the overall program should continue, given its impact on teachers and their students. Care should be applied to balance the support of multiple opportunities for individual teachers (i.e. who participate multiple summers in a given RET program) with providing RET experiences for as many teachers as possible. It should be the responsibility of the project PIs to justify their participant model, with funding determined by the review process.

REU capacity:

As indicated in the previous COV report, the perception is that it is more difficult for an undergraduate physics major to get an REU position than it is to get into graduate school. The EIR program budget, like most at the NSF, has not grown in recent years. The Physics Division is to be commended for continuing to invest in both the REU and RET programs and for keeping the number of REU sites at approximately 50 sites.

Budget cuts and changes to the cost sharing rules have both served to reduce the number of students directly served by the REU site program, even though the number of sites has not decreased. However, REU supplements and other sources of funding often lead to sites impacting more students than just those directly funded by the site grant, so the impact is still greater by having 50 slightly smaller sites than by having 45 larger sites. Also, reducing the number of sites also reduces the diversity of options for students (not only in terms of physics subfields represented by the sites, but in terms of the institution size, type, and geographical location).

Thus the decision by the PO to maintain the number of sites while reducing site sizes is very reasonable and appropriate.

While the number of physics sites (and seats) has been stagnant for over 10 years, the number of physics majors has increased significantly. The Division should make increased funding for the REU Site program a priority. The expansion will provide additional opportunities for students in traditional REU site programs. However, the PO should be open to innovative/creative sites that have the potential to expand or broaden participation.

Closing Comment:

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

9. Computational Physics/ Physics of the Information Frontier

Scope

This section of the FY2011 COV report covers the area of Computational Physics (CP) within the Physics at the Information Frontier (PIF) Program. We refer to this as PIF-CP. PIF-CP is a program across the entire Physics Division.

Introduction

Computation plays an increasingly important role in physics research, and in the sciences in general. This is primarily for two reasons.

First, the computer and digital technologies that have been developed during the past few decades now allows the collection and "automated" analysis of huge data sets. These in turn enable new science to be done. A good example is the "pinning down" of the precise rate of expansion of the universe (the value of the so-called Hubble constant) by the Supernova Cosmology Project and by the High-z Supernova Search Team. This work was awarded the Nobel Prize in 2011.

Second, this same technology permits the accurate numerical simulation of physical systems which are either too complex to analyze analytically, or which are inherently simple but which are governed by mathematical equations that cannot be solved by analytic means. For example it is now possible to calculate the emission of gravitational waves when the two black holes collide and merge, even though an analytic solution of the Einstein equations is not possible in this case.

Programmatic Description of PIF-CP

Within NSF Physics, computational work is carried out both within the relevant program areas, and as a separate activity via the Computational Physics portion of the Physics at the Information Frontier (PIF) program. Overall, PIF includes support for data-enabled science, community research networks, and new computational infrastructure as well as for next-generation computing. PIF is intended to provide support for physics proposals in three subareas: 1) computational physics (PIF-CP), 2) information or data intensive physics, and 3) quantum information science and revolutionary computing.

PIF-CP focuses on cyber-infrastructure for the disciplines supported by the Physics Division but also recognizes and fosters the broader impacts on other disciplines and on more general cyber-infrastructure. The computational physics sub-area emphasizes infrastructure for high performance computing in physics requiring significant long-term code or tool development, and/or medium to large community research networks involving physicists or physicists interacting with applied mathematicians and computer scientists.

Because the PIF-CP program covers all of physics, it is somewhat different in its nature than most other programs in physics, which cover a narrower subject area. This introduces some special challenges. For example in constructing a reasonable-sized review panel, one must ensure that the range of expertise is broad enough to cover the entire range of proposals. Similarly, a program officer will probably need to spend more time than is usually needed to find competent ad-hoc reviewers, because the program manager's personal expertise does not cover the entire range of the physical sciences. This breadth can also complicate the award process internally. Many PIF-CP awards are co-funded both with programs within PHY (e.g., Gravitational Physics, Nuclear Theory, Elementary Particle Theory, and Plasma Physics) and beyond (e.g., AST, DMR, DMS, OMA, CISE, and OCI).

History of PIF-CP

Computational Physics is part of the PIF program. The PIF program was created in 2005, and was first reviewed by the FY2008 COV. 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 has three subprograms: grid computing (GC), quantum information science and revolutionary computing (QIS), and computational physics (CP). All three of these subprograms overlap substantially with other programs within PHY and beyond, but are collected under the separate umbrella of PIF.

This subsection of the FYI2011 COV report mainly concerns the PIF-CP program within PIF, but also contains remarks that apply to the entire PIF program, and more broadly to the PHY policy direction.

PIF-CP Budget

PIF-CP had a budget of about $4.9M in FY2009 ($2.4M from one-time ARRA funds), $2.6M in FY2010 and $2.5M in FY2011, including funding that was not awarded or managed by PIF-CP but was a required contribution to the NSF-wide Cyber-enabled Discovery and Innovation (CDI) initiative. Taking inflation into account, the $7.5M remaining amounts to about $2.5M/year. When the one-time ARRA funding is removed, this is roughly comparable to the fraction (20%) of the original ITR program described above, which was targeted to computational physics.

The integrity and efficacy of processes used to solicit, review, recommend, and document proposal actions
In reviewing PIF-CP, the COV examined both the overall breadth of the PIF-CP portfolio, and the specific award (and non-award) decisions that were made. In this program, during the three-year period 2009-11 there were 17 funded proposals and about 40 declinations. Note that this acceptance rate is in line with Physics and NSF averages. About 1/3 of the awards went to young investigators, also in line with Physics and NSF goals. Women and underrepresented minorities were among the PIs and co-PIs of the funded proposals, again at rates comparable to overall NSF goals and rates.

We reviewed 15 of the funded awards and 10 of the declined proposals.

Referee Process

A fair and impartial referee process is the central part of an effective peer review process, and is one of the strengths of the NSF and its culture. Our overall finding is that the process by which proposals are reviewed, awarded and managed is professional and competent.

In general, a two-step process of review is used. In the first step, adhoc written reviews are solicited, typically from three to five expert reviewers. In the second step, a panel evaluates and ranks all the proposals in a given fiscal year. These are ranked in the categories Fund, Fund if possible, and Do not fund.

Our detailed examination of the proposal review process shows that the anonymous reviewers and review panels are highly qualified, are free of conflicts of interest, and appear to have given their honest and unbiased opinions about the quality of the work. The number of reviewers is adequate to avoid small-number fluctuations; the proposals have generally been evaluated by three or more expert mail reviewers, and in most cases there is also a written overall panel review or summary.

As explained earlier, the range of topics in the PIF-CP program is wider than that in a typical Physics program. Nevertheless the panels are constructed well enough to include expertise in all of these areas, and the panel review system appears to work well in spite of this challenge.

The program directors and the foundation have evaluated the proposals and reviews in light of the NSF merit review criteria and their special knowledge of the field, and have documented the resulting process of selection, decision and award or declination.

In all respects, this central and fundamental part of the award process has been administered in a way that meets the NSF performance and integrity goals and exceeds our expectations.

Appropriate use of NSF merit review criteria

In examining the proposal review process, we found that the review process always focused around the two principal NSF merit review criteria: the intellectual merit of the proposed activity, and the broader impacts of the proposed activity. Typically in the PIF-CP program, the intellectual merit was related to an advance in basic physics knowledge or to an advance in algorithmic or computing methods, and the broader impact was in enabling advances within related areas of physics and computing, and in the training of students and postdocs.

The funded proposals are ones that suggest and explore creative, original, or potentially transformative concepts, are well conceived and organized, and include sufficient resources to carry out the proposed work. They advance discovery and understanding while also promoting teaching, training, and learning. They enhance the infrastructure for research and education, and disseminate their findings broadly impact the overall body of scientific knowledge and benefit society.

Documentation related to program officer decisions regarding awards and declinations

The process of reviewer consultation, panel consultation, and the grounds and logic for decisions have been documented in a clear and auditable way. The analyses by Program Officers are thorough and carefully prepared. Individual reviews, panel reviews, and the Program Officer's own experience were synthesized into thoughtful and well-reasoned decisions.

We commend NSF Physics for having transitioned to a completely automated and web-based system for documenting the entire process from the receipt of a proposal to its eventual funding and completion or declination. This leaves a clear written audit trail of the entire decision and management process.

Characteristics of the Award Portfolio

The Computational Physics portfolio that has resulted from this peer-review process is broad, and includes projects in many areas. These include: Monte-Carlo simulations of up to 100 nucleons that provide information on the nuclear- and neutron-matter equation of state (Schmidt, 1067777); the first computations of the nucleon excitation spectrum in lattice Quantum Chromodynamics (Morningstar, 0969863); the development of highly efficient Cell Broadbank Engine-based numerical simulations of the gravitational waves produced by point-masses orbiting a spinning black hole (Khanna, 0902026); the development of the volunteer distributed computing platform Einstein@Home for computationally-intensive analysis of data from the Laser Interferometer Gravitational Observatory, and subsequent discovery of many new radio pulsars with this infrastructure (Allen, 1104902); and a broad range of other topics. The overall characteristics of the award portfolio reflect the broad balance that one would expect from such a wide

scientific area, and the research work which is funded is of high quality and significance. For example:
-The computational challenges in the area of Atomic, Molecular, and Optical (AMO) Physics lie in the precision analysis of atomic structure, scattering of atoms and molecules, and in understanding the behavior of ultra-cold atoms trapped in optical lattices. These often involve high-precision quantitative comparison with experimental data obtained from tabletop experiments in which the theoretical answer often must be produced in days to weeks. Thus one of the hallmarks of cutting-edge computation in AMO is innovative computational algorithms. In the project “Worm Algorithm and Diagrammatic Monte Carlo in Atomic and Condensed Matter Physics", the PIs (Kuklov, 1005527; Svistunov, 1005543) developed a diagrammatic Monte Carlo algorithm that applies to any problem where the answer is specified in terms of either convergent or re-summable series of integrals/sums such as Feynman diagrams. Formally, DiagMC is a set of generic prescriptions for organizing a Metropolis-type process for sampling the corresponding series with controllable systematic errors. The PIs are applying this algorithm to systems of strongly correlated bosonic and/or fermionic atoms confined in optical lattices. However, the underlying algorithm has applications to the solution of computational problems in many other areas of physics.

-Quantum Chromodynamics governs the emergent structures and dynamics of systems that are bound by the strong interaction. In the past twenty years advances in computation have greatly enhanced the understanding of strongly-interacting systems from first principles. PIF-CP plays an important role in this effort. It supported the use of a combination of novel techniques and large-scale computing which recently enabled the first lattice QCD calculations of the excitation spectrum of the proton (Morningstar, 0969863). Constraints from QCD also inform the construction of nuclear Hamiltonians–in which neutrons and protons are the degrees of freedom–that reproduce data obtained in few-nucleon systems. Significant effort in nuclear physics is devoted to obtaining essentially exact, "ab initio" solutions of the N-body Schrodinger equation for such Hamiltonians. PIF-CP funds support development of more efficient large-basis diagonalizations within the "No-core shell model" for this purpose (Barrett, 0854912). An alternative technique involves Monte Carlo sampling of the pertinent integrals, but this has proven feasible only for systems up to Carbon-12, due to the rapid increase in the number of spin and isospin degrees of freedom with nucleon number. PIF-CP has invested in the development of a novel Monte-Carlo technique, in which spin and isospin degrees of freedom are sampled, rather than being summed over exactly (Schmidt, 1067777). This technique could, in the near future, produce ab initio calculations of Oxygen and Calcium isotopes, thereby delineating the limits of stability of neutron-rich nuclei.

-Examples of numerical relativity activities supported by the computational physics program include the improvement of computational techniques currently used in high-accuracy simulations of black hole or neutron star binaries. Simulating these objects, which is important for the prediction of likely signals to be detected by LIGO and other gravitational wave detectors, has recently become possible. However, the computational cost of each of these simulations, coupled to the high dimensionality of the configuration space, leaves the exploration of the parameter space with current numerical techniques essentially intractable. The computational physics program supports activities that aim at improving these techniques through a number of different approaches, including improving current spectral and finite difference algorithms, modifying algorithms so that they can run efficiently on heterogeneous platforms (GPUs), and significantly faster than on traditional CPU clusters, improving the efficiency of following the adiabatic inspiral phases of binary evolutions by using implicit time stepping, and improving the efficiency of codes with improved and automated algorithms for adaptive domain decompositions and load-balancing (Teukosky, 1005426; Lindblom, 1005655; Tiglio, 1005632; Khanna, 0902026). Almost all of these techniques can also be applied in other fields of computational physics.

[Full disclosure: the chair of this sub-panel is the PI and Director of the Einstein@Home project.]

Overall Program Management

The overall program management appears to be excellent. As described above, the program director and the NSF have evaluated the proposals and reviews in light of the NSF merit review criteria and their special knowledge of the field, and have documented the resulting process of selection, decision and award or declination. The post-award research activities have been reviewed and followed on a regular and continuing basis. In short, we commend the Physics Division on its compliance with the NSF's strategic and performance goals, and on the clear "paper trail" of documentation for individual awards.

We note that computational physics is unusually broad, in the sense that the common aspect of all the proposals is their computational side, but that they otherwise span the entire field of physics. This makes it more difficult to manage in a balanced way, because a single program manager can not have the necessary expertise in all areas of physics. To address this, the review process for many of the proposals, and subsequent program management, has been divided among program managers from programs outside of PIF-CP. While we are sure that this has made the program more difficult to manage and administer, we applaud the results and urge NSF Physics to continue this collaborative and inter-disciplinary approach. We trust that PIF-CP will maintain a portfolio of research which represents a broad spectrum of physics research, paying due attention to the balance between different sub-fields of physics, while also ensuring that the program continues to support forefront science. We encourage program managers from across PHY to ensure that their communities are aware of the opportunities afforded by PIF-CP.

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

The award decisions have been made based on the NSF Merit Review Criteria as described above, and based on the goals of the program.

As stated by the program manager, the program goals were the following. A strong PIF-CP proposal must have strong science and a computational advance or new enabling capability and either innovation in computing such as (but not limited to) algorithm development, new architecture, etc. or community computational infrastructure improvement. It cannot be only more of the same, use of canned software, and/or routine methods. These criteria are well-aligned with the NSF's strategic goals:

Discovery - The program's science element emphasizes discovery, and indeed the program has delivered that. The discoveries include new neutron stars, precise ways of predicting the fundamental masses of new particles, as well as preparatory work for new discoveries, such as the detection of gravitational waves.

Training - Almost all of the funded programs involved students and postdoctoral scientists as active and central members of the research activities. This helps the US to create a world-class, broadly inclusive science and engineering workforce. In this computational physics program, the program goals required advances in computational science or infrastructure. These directly support the computer industry and computer science, which are both important parts of the US economy.

Infrastructure - Many of the funded projects create public software libraries or computational and group infrastructure. These directly build our nation's research capability.

Stewardship - The excellence demonstrated in the review, award, and management process means that NSF Physics is helping the NSF to reach its goal of being a capable and responsive organization.

The Division's response to the FY2009 COV report

The FY2009 COV report said "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."

Nevertheless, the NSF's own "cloud computing" model (the Open Science Grid and the NSF supercomputing centers plus Teragrid) still receive the majority of funding going into computational infrastructure.

The FY2009 COV report said "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."

This recommendation has been followed. We have confirmed that during the FY2009-11, only a single (relatively small) award from the gravity program has been made in support of computational infrastructure (hardware or software) for numerical relativity. In contrast, substantial computational infrastructure support for numerical relativity has come from outside gravitational physics, specifically from PIF-CP, from MRI, and from OCI.

The authors of the FY2009 COV report argued that as the PIF-CP program became better known, "it might become appropriate to re-balance 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%."

The CP funding is now distinctly larger than the GC funding, but the ratio still appears to be smaller than 2:1 recommended in by the FY2009 COV.

The FY2009 COV report said "We understand that OSG may deserve support from PHY, but we are not convinced that GC belongs inside the PIF program."

Grid Computing is still within the PIF program.

Other issues relevant to the review

TIMEFRAME OF REVIEWED PROPOSALS -- Currently, the COV reviews only grants that were awarded within the last three years, meaning that most of them are still active, and that only a few final project reports are available. In some cases it might be interesting to compare the final reports with the proposal, or, for example, to evaluate whether proposals reviewed as “overly ambitious” truly turned out to be too ambitious. In order to provide some of this information, the NSF could consider giving future COVs access to proposals from the previous four to five years, instead of just the previous three years.[c][d]

MATERIALS FOR THE COV REVIEW -- the second concerns the materials created for the COV review. Materials were circulated in a variety of forms including paper "snail" mail, email, Microsoft Word documents, PDF files, and Excel Spreadsheets. Many of these were organized on a web page that in the end contained over 100 documents. Committee members also received a series of letters from different NSF staff and from members of the COV. This provides plenty of material for the review, but is also overwhelming in its complexity and cacophony: the flood of disparate information is difficult for someone from outside the NSF to organize and integrate. In the future, we recommend that NSF Physics try to find a way to simplify or reduce this information flood. Unfortunately we don't have specific suggestions about how to do this.

SUBPANEL FOR THE COV REVIEW -- In the future, we strongly recommend that the PIF-CP COV review panel be assigned dedicated members from each of the relevant physics programs that receive PIF-CP support, or for which a significant number of PIF-CP proposals were received. For this FY2011 COV report, the PIF-CP COV panel had only a single full-time member; the others were "borrowed" from their respective COV sub-panels. It is impossible for those people to be in two different places at once; the review process would work better with dedicated sub-panel members from the different specialties represented in PIF-CP.

10. Physics Frontier Centers

Introduction:

The Physics Frontier Centers (PFC) program started a little over a decade ago (2001) and currently funds ten centers across the country (see the NSF webpage for links to the specific centers http://www.nsf.gov/mps/phy/facilities.jsp). Proposals from any sub-discipline of physics are within the purview of the Physics Division are eligible to compete for a PFC. Centers are funded for an initial term of six years, and at the end of which they may re-compete for another term (there is no limit on the number of renewals). The program has tried to put out a solicitation for proposals every three years.

The program web page states that:

> 1) This program fosters major advances at the intellectual frontiers of physics by providing needed resources, e.g., combinations of talents, skills, disciplines, and/or specialized infrastructure, not usually available to individual investigators or small groups.
>
> 2) The program supports university-based centers and institutes where the collective efforts of a larger group of individuals can enable transformational advances in the most promising research areas.
>
> 3) Activities supported through the program are in all sub-fields of physics within the purview of the Division of Physics. Interdisciplinary projects at the interface between these physics areas and other physics sub-fields and disciplines are also included.

The PFC program is unique in that it reflects the entire breadth of NSF Physics within the purview of the Physics Division. (Condensed matter physics is housed in DMR.) This requires that the whole process be carried out with great care to ensure comparative review that deals with proposals from widely disparate sub-fields in a high quality, fair and balanced way. The review process consists of four major phases: pre-proposal, proposal, ad hoc review, and reverse site visit. The process is extremely well conceived and methodical. Potential Conflicts-of-Interests are examined not once, but at each phase of the review.

We are very pleased with the hard work of the program officers of the PFC and all the division has done to start and maintain this excellent program, which includes several Nobel Prize winners. They have also been very successful on securing co-funding for this program from other division all across NSF.

General Overview and Impressions of the 2012 COV:

The PFC program currently funds ten centers; five started their cycle three years ago; four of the other five were recently renewed and the fifth initiated in 2011. The budget of the program is about 9% of the total Physics budget, and previous COV's have recommended that this be kept to fewer than 10% of the total budget of the division.

The current list of centers is:
Started or renewed in 2008

- Joint Institute for Nuclear Astrophysics (Notre Dame-Michigan State)
- Center for the Physics of Living Cells (University of Illinois Urbana-Champaign)
- Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas (University of Wisconsin at Madison)
- Center for Theoretical Biological Physics (University of California San Diego)
- Joint Quantum Institute (University of Maryland)

Started or renewed in 2011

- Kavli Institute 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-Harvard)
- Institute for Quantum Information and Matter (Caltech)

The sub-panel of the 2012 COV charged with examining the PFCs did not have the time, expertise or access to all the requisite information to do a comprehensive review of all ten extant Centers. Nevertheless, it was abundantly clear that the PFCs are truly extraordinary; they rank among the "crown jewels" of the NSF scientific enterprise. The quality of the proposals, even going well below the cut-off line for awardees, was so impressive, that it was clear that the review and selection process posed a difficult task for the reviewers, panelists and NSF directors.

While the charge to the COV was mainly to review the *process* by which NSF selects and manages the PFCs, our examination of the material and the difficult down-selection process to determine awardees raised many questions that we believe merit a dedicated, comprehensive review by a high-level body which will have the time, access and expertise to evaluate. Given the program has been running for a decade, this would be a propitious time for a retrospective review, to examine, among other questions, whether the fraction of the Physics Division budget for PFCs might not be significantly increased (e.g. that the natural number of Centers should be 15 or 20).

Integrity and Efficiency of the Program Process and Management

There was a solicitation for renewal and new centers in 2010. The COV looked in detail at the response of the community to the solicitation. Fifty-three pre-proposals responsive to the solicitation were received and reviewed by a panel. Based on the rankings and after discussions among all the Physics program directors, NSF invited 17 groups to submit full proposals. These full proposals were then sent for ad hoc individual reviews; eight reviews on average were received. The individual reviewers were diligent in addressing the two NSF criteria. Most of them also commented on the critical 'value-added' criterion advertised by the center in their proposal; the perceived value-added ultimately playing the most critical role as a selection metric, after scientific excellence. Based on the individual reviews and discussions among all the program officers, the program invited 11 groups to a 'reverse site visit' (RSV) to present their proposal to a panel.

The comments from the reviewers varied in level of detail. Some of the reviewers gave extensive and detailed commentary on the proposal; others gave more summary comments. Independent of style, however it was clear that NSF was receiving valuable and incisive critique to assist them in their decision-making. The proposals were structured into different Major Activities (MA), and most of the reviewers responded to each MA individually. The ad hoc reviews were generally consonant with one another, which indicates that that feedback represents real and valuable information both to the NSF and the PI.

The records of the panel reviews were likewise highly detailed and gave ample information to support the consensus. The value-added criterion ("is the whole greater than the sum of the parts?") was all-important, and the panel was clearly attuned to that criterion as a primary metric by which a PFC proposal would rise or fall. That reasoning was clearly communicated in the panel consensus.

The program directors are to be commended for maintaining a review process of the highest quality for the PFCs. The PFCs present an additional challenge to review insofar as they are large, complex, scientifically disparate, and are all very, very good. At each stage, down-selections were made thoughtfully and carefully, and the program directors were clearly respectful of the scientific judgment of the external expert reviewers. The NSF review process being nearly a pure meritocracy, however, can lead to a tension between excellence and portfolio balance (see below); this is another thorny issue that a retrospective review will need to grapple with.

The program is managed rigorously and well. As a consequence, the PFCs have been in existence for more than a decade now, and have established themselves as an invaluable feature of the overall NSF Physics program. There is a well-established oversight program carried out by the NSF once the award starts. It includes an NSF site visit a year after the first start date, a site visit with an external panel at the end of year two, and another at the end of year four. All these help follow up the centers and identify possible issues in their operations. That the PFCs are not entitlements, or that existing PFCs are not able to unfairly leverage their history and momentum, is witnessed by the fact that three existing Centers have been turned down for renewal.

The COV sub-committee that examined the PFC did note the striking fact that of the 10 ongoing Centers, 4 are focused in one area, that may be described as "Quantum Many-Body/Quantum Information" (Maryland, MIT, JILA, Caltech) – three of which were just approved in the last round. While each of them would likely argue that they are significantly differ from the other three, the plain fact of the matter is that they do tightly cluster from a disciplinary point of view, and represent an enormous focusing of NSF resources on one narrow topic, albeit a fast-breaking and exciting one.

This situation simply reflects that, for better or worse, NSF takes a "free-market" approach to science; intrinsic excellence is its primary metric for funding. This may make for a fruitful discussion topic among the NSF Physics leadership at an internal retreat.

Examples of recent results from the renewed centers:

KITP: Basic theoretical framework for study of CMBR (1985); roadmap for architecture of a quantum computer (1995); string program leading to AdS/CFT revolution; cold atom, and strongly correlated electron systems breakthroughs (2004).

JILA: World's most precise neutral atomic clock (Ye); amplifiers far below the standard quantum limit (Lehnert); ultra-monochromatic phase coherent light without a laser (Holland); ultracold molecules, a 1000 times colder than polar molecules (Ye, Jin, Bohn); attosecond pulse production by HHG (Kapteyn-Murnane).

KICP: While working at the frontier shared by cosmology and particle physics, it helped seed research related to the Dark Energy Survey (DES), the South Pole Telescope (SPT), Scientific collaboration for very sensitive measurements of the Polarization of the Cosmic Microwave Background Radiation (QUIET), and the Chicago Observatory for Underground Particle Physics (COUPP).

CUA: Fermionic superfluidity with imbalanced spin populations; polarons in a tunable Fermi liquid of ultracold atoms; quantum noise to characterize many-body correlations; quantum control of atom-like impurities in diamond; practical new approaches to cold atoms and molecules; squeezed atomic clock below the standard quantum limit; quantum gas microscope; obtained long quantum coherence lifetime of trapped ions.

Student Impact:

The NSF is a prime supporter of students across the higher education institutions in the country. The PFC's seem to have had a remarkable effect in terms of establishing a high-visibility 'brand' for the hosting universities. This is one of the most important 'signals' coming out of the first decade of experience with the PFC. We learned the establishment of a PFC at one university produced a dramatic increase in the number of their AMO applicants – the number increasing from 25 to 250 per year! There was a similar anecdote at another PFC institution, in the Cosmology area.

Recommendations:

- We recommend that the Physics Division charges an appropriate high-level body, possibly the National Academy of Sciences, to conduct a retrospective review of the PFCs, outside of the context of a funding competition for renewal and new starts.

  - The charge should include identifying (i) the human resource impact in undergraduate, graduate, postdoctoral and visitors of the center (ii) the research breakthroughs that one can unambiguously attribute to the Center, (iii) the new Intellectual Property and its exploitation (e.g. companies), and (iv) any other items that are clearly attributable to the structuring and cohering effect of a PFC.
  - With the input from this retrospective review, the NSF should revisit the issue of the appropriate level of funding for PFCs, being open to the possibility that the right number grow from 10 to e.g. 15 or 20 (corresponding to a growth from 10% to 15-20% of the Division's budget).
- We further recommend that the Physics Division examines how the PFC selection process can incorporate disciplinary portfolio balance as a metric, with the goal of securing a strategic US position internationally in all critical subfields of physics, without sacrifice of its traditional excellence-based criteria in Intellectual Merit, and Broader Impact.

11. Accelerator Physics and Physics Instrumentation (APPI)

The Accelerator Physics and Physics Instrumentation program within Physics is a new program, not accepting proposals directly, that targets clear needs of the community, identified by the management, previous COV's, and the MPS Advisory Council. The program aims to support instrumentation needs across the Division and accelerator physics.

The closing of the accelerator facility at Cornell and the cancellation of DUSEL freed up enough funds to start the program as an internal way to fund instrumentation and some efforts in accelerator science.

Physics has benefitted from the MRI program that is NSF wide. This program gives money for instruments and for development, but does not provide money for funding the science: operating costs of the instrument, graduate students, and postdoctoral associates. The money has to come from the program directly once the instrument is delivered. A further complication of this program is that MRI is submission limited per university (two acquisition and one development). The universities tend to select instruments that will have the greatest impact on their institutions, not necessarily the research of an individual investigator.

The program started allocating funds in 2009, mostly to the instrumentation side of the program. By having roughly ten million dollars per year (2011) in its budget the Division has been able to fund instrumentation across all the programs, from AMO to PNA and PFCs. The program will be able to capitalize the construction and or development of instrumentation over a few years necessary to complete enabling new scientific proposals.

The lower bound for funding is rather flexible, but should be equivalent to the cost of equipment that will heavily tax an individual program (prevent it from funding another excellent proposal). The higher bound could be contributing to large facilities that have to be approved by the National Science Board ($40,000,000). The structure that the proposals are reviewed by the program and judged by their science seems appropriate. This helps select excellence among different programs, that then the program director can negotiate APPI funds to fund the instrumentation.

In the 6 proposals (three PFC, three individual investigator grants) we examined where APPI funds were applied by the cognizant PD, the use of these funds was certainly appropriate and used to advantage to jump-start that project. The documentation in the jacket concerning the APPI was rather minimal, however. As the APPI program grows, it would seem appropriate to provide some more transparency of the process by which these funds are used in each case.

Action Items:

There is a sense in certain program communities that there are very limited funds for instrumentation at NSF. Physics and all the members of the COV should inform the community that there is money for equipment requests as part of the science proposals as long as the proposal is clear that the instrumentation is necessary for the success of the science.
Physics should consider writing a Dear Colleague Letter to make sure that the community is aware that they can request equipment money in their science proposals.

Observation: It is necessary to increase the documentation on how the allocation of the resources happens.

APPENDIX A

CORE QUESTIONS and REPORT TEMPLATE

for

FY 2011 NSF COMMITTEE OF VISITOR (COV) REVIEWS

Guidance to NSF Staff: This document includes the FY 2011 set of Core Questions and the COV Report Template for use by NSF staff when preparing and conducting COVs during FY 2011. 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 (2) managerial matters pertaining to proposal decisions.

The program(s) under review may include several sub-activities 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 sub-activities 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.

For section IV addressing portfolio balance the program should provide the COV with a statement of the program’s portfolio goals and ask specific questions about the program under review. Some suggestions regarding portfolio dimensions are given on the template. These suggestions will not be appropriate for all programs.

Guidance to the COV: The COV report should provide a balanced assessment of NSF's performance in the integrity and efficiency of the ***processes*** related to proposal review. 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.*** The reports generated by COVs are made available to the public.

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 2012 REPORT TEMPLATE FOR

NSF COMMITTEES OF VISITORS (COVs)

The table below should be completed by program staff.

Date of COV: 1-3 February 2012
Program/Cluster/Section: All programs
Division: Division of Physics (PHY)
Directorate: Directorate for Mathematical and Physical Sciences (MPS)
Number of actions reviewed: **Awards:** 257 (Awards from competitive actions only) **Declinations:** 191 (Declinations from competitive actions only) **Other:** 11 (Pre-proposals)
Total number of actions within Program/Cluster/Division during period under review: (FY 2009-2011) **Awards:** 1207 **Declinations:** 1610 **Other:** 600 (this includes pre-proposals, supplements, withdrawals and other actions)
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, NSCL, and LHC 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.

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.

I. Questions about the quality and effectiveness of the program's use of merit review process. **Please answer the following questions about the effectiveness of the merit review process and provide comments or concerns in the space below the question.**

QUALITY AND EFFECTIVENESS OF MERIT REVIEW PROCESS	**YES, NO, DATA NOT AVAILABLE, or NOT APPLICABLE**
1. Are the review methods (for example, panel, ad hoc, site visits) appropriate? Comments: There was overall strong support for the three-tier review process used by all programs in the Physics Division. A minimum of 3 ad hoc reviews are requested for each proposal, and at least 2 ad hoc reviews are received in each case. Independent panel reviews are always conducted. A subset of panel members (typically a primary and secondary reader) is assigned to provide an in-depth, independent review of the proposals in addition to the ad hoc reviews. In addition, for larger proposals (larger experimental groups, multi-PI awards of more than $1M) in programs such as Nuclear Physics, site visits are conducted by a panel of between 3-5 independent reviewers.	Yes
2. Are both merit review criteria addressed a) In individual reviews? YES b) In panel summaries? YES c) In Program Officer review analyses? YES Comments:	Yes for all 3

Both merit review criteria are always addressed at all levels of evaluation (individual reviews, panel summaries, and program officer analysis). The ad hoc reviewers generally demonstrate significant experience with the NSF review process and provide substantive commentary on both criteria. The panel reviews play a particularly important role in weighing the relative importance of the two merit review criteria and in assessing the overall merit of proposals. Some reviewers, however, have difficulty in properly weighting the "broader impacts" criterion. The level of detail in the postdoctoral mentoring plan varies significantly between proposals, and the level of scrutiny applied to evaluating the mentoring plan also varies between reviewers and panelists. This may not be unexpected as this is a new requirement, but proposers, reviewers and panelists could improve their approach to the postdoctoral mentoring plan. There was consensus that the PO review analyses were extremely good in synthesizing the full review process and the final decision-making. The panel believe that a version removing the confidential information would be very useful to be released to the PI's, particularly to the ones that were just below the funding range.	

3. Do the individual reviewers provide substantive comments to explain their assessment of the proposals? Comments: Yes in the majority of cases. The program officer always requests that reviewers *"provide detailed comments on the quality of this proposal with respect to each of the two NSF Merit Review Criteria"* when soliciting reviews. Most ad hoc reviews show careful consideration of the issues and specifically address the strengths and weaknesses of the proposal that led to their conclusions. There is, however, a wide variety in the quality of reviews, and there are some that are not satisfactory in this regard. Also, despite the guidelines provided, there is also substantial variety in the grading scales applied by different reviewers. Panels play a major role in distinguishing these reviews and calibrating their scores. Therefore, despite all difficulties, we strongly encourage continuing to obtain multiple ad hoc reviews, in order to minimize these distortions. Reinforcing what we already discussed in the answer above, broader impact comments are not always as uniformly substantive as the intellectual merit comments.	Yes
4. Do the panel summaries provide the rationale for the panel consensus (or reasons consensus was not reached)? Comments:	Yes

Yes. The panel reviews do an excellent job in describing the rationale behind their recommendation. A subset of panel members (typically a primary and secondary reader) is assigned to provide an in-depth, independent review of the proposals prior to the panel discussion. This additional consideration combined with the panel discussion is beneficial in evaluating the ad hoc reviews, which can vary in quality and in the interpretation of the grading scale. The panel reviews also play an important role in placing the proposals in the context of the entire field and in assigning due relative weight to the intellectual merit and broader impacts. This is particularly important when disparate scores are assigned to a proposal. It is not uncommon to see a Division among the mail-in reviews (say a single F among a cluster of E's). In such a case the panel naturally tends to spend a large effort analyzing the outlier, which is appropriate. But the Program Officer then has the task of reconciling the different points of view and making a case for a single decision. The reviews for the physics frontier center are extremely detailed and provide much more detailed information.	
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 information in the jackets provides a very complete picture of the entire assessment of the proposals. The combination of the panel summary and the program officer's analysis provide a clear description of the rationale behind the decision and the major contributing factors. Several subpanels commented on the impressive work by program officers when the reviews were mixed. They described how the decisions were made not only taking into account the reviews and the panel summaries but all the entire funding history of the PI. A special situation that applies to PoLS must be highlighted. PoLS supports an area of research that could overlap with programs in Biology and DMR Divisions. The program manager has determined a set of priorities for POLS that clearly distinguishes this program from the others. First, the research must address the physics of living systems, not the use of biomolecules as materials (a purview of DMR). Second, to distinguish this program from BIO, the research must emphasize working on biological systems with a physics approach and must include a theoretical component that allows for quantification and for the development of new ideas. Biological research is, at times, mostly descriptive and cannot be easily generalized to other systems.	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: Generally this was true. The individual reviews and panel summary typically provide sufficient rationale for an award, but not so much when the proposal is declined. This reasoning, however, is very important for the PI. For example, the committee has identified a few proposals where the reasons for the decline were very unclear or not sufficiently well documented.	Yes
7. Additional comments on the quality and effectiveness of the program's use of merit review process: It is interesting that in several cases panel summaries appear to reach a very different conclusion from the individual reviews. It was noticed that in those cases more weight appears to be attached to the panel's conclusions, which is probably the correct decision. Overall, program officers appear to have done a great job under very difficult budget constraints. There was a general consensus that program officers should be allowed to travel more frequently to visit scientists and to participate in meetings.	

II. Questions concerning the selection of reviewers. **Please answer the following questions about the selection of reviewers and provide comments or concerns in the space below the question**.

SELECTION OF REVIEWERS	YES , NO, DATA NOT AVAILABLE, or NOT APPLICABLE
1. Did the program make use of reviewers having appropriate expertise and/or qualifications? Comments: In general reviewers were consistently experts in closely related fields and often had specific knowledge of the work being reviewed. Therefore the expertise and qualifications of the reviewers were well matched to the proposals being evaluated. This is a challenging task given the large number of proposals and the large number of conflicts of interest within such an interconnected community. Likewise mostly the composition of the panels was excellent. In rare cases where this was not true, the committee noticed that, when the reviewers were not appropriate, this problem was corrected by the panel. The computational science subpanel raised a concern that the process by which reviewers were selected was not clear. Since this area was very broad, it was very hard to do a full assessment of the overall quality and breadth of the reviewers. There was evidence, however, to lead us to believe that the reviewers did reflect the needed quality and breadth.	**Yes**
2. Did the program recognize and resolve conflicts of interest when appropriate? Comments: Although this was true in most of the cases, some concerns were raised. For example, in a few cases it was observed that conflicts of interest were not uncovered until the review process was under way, although the conflicts were resolved at the appropriate time.	**Yes**
Additional comments on reviewer selection:	

Some sub-panels raised the concern that many subfields in this area are both small and highly specialized, so it can be hard to find reviewers with no conflicts of interest. Overall, the program has done a very good job.	

III. Questions concerning the management of the program under review**. Please comment on the following:**

MANAGEMENT OF THE PROGRAM UNDER REVIEW
1. Management of the program. Comments: Comments were very positive about the management of the programs. Overall they have used the merit review process effectively, funding projects that maximize scientific and broader impacts while also balancing a diverse scientific program. Program officers were closely engaged with the progress and helped to resolve difficulties. Positive comments were also available for situations where multiple agencies were involved in supporting the research.
2. Responsiveness of the program to emerging research and education opportunities. Comments: Most of the programs appear to be quite aware of emerging research. For example, AMO has really explored possibilities in Quantum Information Science. Gravity has really moved towards numerical relativity. Nuclear physics commented on the notable opportunities that are now becoming available, including the 12 GeV upgrade at Jefferson Lab, the development of the ReA3 facility for reaccelerated beams of radioactive ions at the National Superconducting Cyclotron Laboratory (NSCL), a new high intensity accelerator at University of Notre Dame, and capabilities in underground science at the Sanford Lab. EPP noted that great use has been made of opportunities to exploit the LHC for research and for education with programs like QuarkNet. Computational physics commented on how hard program managers are trying to stay on the cutting edge of current research, including leveraging any opportunity to have an impact on education.
3. Program planning and prioritization process (internal and external) that guided the development of the portfolio. Comments:

Different programs have very different challenges as balancing their portfolios. For example, some of them are heavily influenced by facilities and/or big experiments while others are less affected by these large items. Also, some programs tend to fund more groups of investigators, while others focus on single or few investigator awards. Even with these differences the sub-panels were very satisfied with the overall planning, development and management of the portfolio. We refer you to the subpanel reports for details on the portfolio management of individual programs.

4. Responsiveness of program to previous COV comments and recommendations.

Comments:

Most of the subpanels were very satisfied with the responsiveness of the Physics Division in handling the requests and recommendations of the previous COV report. Specific details can be found in the various subpanel reports. There are, however, several concrete recommendations and we strongly request that the Physics Division address the specific comments in these reports.

IV. Portfolio Review. Please provide comments on whether the program's portfolio goals are appropriate and whether the program has achieved its goals for portfolio balance.

Programs should provide materials to the COV regarding portfolio goals and can insert specific targeted questions about their portfolios. *(Some dimensions of portfolio balance to consider include: balance across disciplines and sub-disciplines, award size and duration, awards to new investigators, geographical distribution of awards, awards to different types of institutions, innovative/potentially transformative projects, projects with elements of risk, inter- and multi-disciplinary projects, projects that integrate research and education, and projects that are relevant to agency mission or national priorities).*

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

Overall the subpanels were very satisfied with the program's portfolio goals and balance. We were satisfied with the balance of renewals versus new investigators.
Details can be found in the subpanel reports.

We want to highlight, however, the situation with the Physics Frontier Centers. The COV did note the striking fact that of the 10 ongoing Centers, 4 are focused in the area that may be described as "Quantum Many-Body/Quantum Information" (Maryland, MIT, JILA, CalTech) – three of which were just approved in the last round. While each of them would likely argue that they are significantly different from the other three, the fact of the matter is that they do tightly cluster from a disciplinary point of view

This situation simply reflects that, for better or worse, NSF takes a "free-market" approach to science; intrinsic excellence is its primary metric for funding. This may make for a fruitful discussion topic among the NSF Physics leadership at an internal retreat.

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.

As far as we can see, the program has met its goals.

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

The instrumentation program was highlighted here as an example of a program that should go beyond the Physics Division, especially at the midscale level.

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

We believe it is important that the program officers are kept current on the state of the field, and are given a reasonable amount of leeway in shaping and guiding the programs. So we encourage NSF to (1) let the program officers spend a significant amount of time (up to a day per week, on the average "on the road" at meetings, workshops and seminars. We also congratulate the NSF for allowing the program officers to have free time to carry out their own research work.

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

The streamlined report template and electronic access to review materials are a considerable improvement.

SIGNATURE BLOCK:

For the Physics Division COV
José N. Onuchic
Chair

APPENDIX B: Division of Physics
Committee of Visitors
February 1-3, 2012
Agenda

Wednesday, February 1 - Room 595 II

7:30 am	Refreshments (Room 595 II)
8:00 am	Introductions, Welcome and Charge to Committee of Visitors (COV) H. Edward Seidel, Assistant Director, Directorate for Mathematical and Physical Sciences (MPS)
8:20 am	COV Guidelines Morris Aizenman, Senior Science Associate, OAD/MPS
8:40 am	Introductory Remarks Jose Onuchic, Chair, COV
9:00 am	Overview of PHY organization, operating principles Joe Dehmer, Director, Division of Physics (PHY)
9:40 am	Instructions for Breakout Sessions – CoV Chair
9:50 am	Adjourn to Breakout Rooms
10:00 am	Review of Individual PHY Programs
	PD Presentations on Individual Programs
10:20 am	Examination of Jackets to Address Items I, II, III on Template ▪ Integrity and Efficacy of Program Processes for Proposal Actions ▪ Quality and Significance of Program Investments ▪ Relationship to Foundation-wide Programs and Strategic Goals
12:30	Working Lunch
1:30 pm	Review of Individual PHY Programs (Continued in Breakout Rooms)
3:30 pm	Program chairs collect input to Items I, II, III on Template
4:30 pm	Executive Session to Discuss Input to Items I, II, III
5:30 pm	Adjourn for Informal Reception in Room 1020

Thursday, February 2 – Room 555-II

7:30 am	Refreshments (Room 555 II)
8:00 am	Introduction to Division-Level Review – Joe Dehmer (Room 555-II) ▪ Division's Processes, Results, and Relationship to NSF Goals ▪ Division's Balance, Priorities, and Future Directions
8:40 am	Full panel Discussion of Division-Level Questions
10:00 am	Individual Program Groups Discuss Division-Level Questions
12:00 pm	Working Lunch
1:00 pm	Individual Program Reports on Division-Level Questions (Program chairs)
3:00 pm	Break
3:15 pm	Preparation of Program Reports (Breakout Rooms) Computation Group meets separately to discuss computation
5:30 pm	Adjourn

Friday, February 3 - Room 555 II

7:30 am	Refreshments (Room 555 II)
8:00 am	Presentation of Preliminary Program Reports
10:30 am	Complete drafts of Program Reports
12:00 pm	Working Lunch
2:00 pm	Complete Draft of Overall Report
2:30 pm	Closeout Session with AD/MPS and PHY Staff
3:00 pm	Adjourn

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APPENDIX D – 2012 Physics Division COV Subpanels

Physics of Living Systems
Angel Garcia (Chair)
Taekjip Ha
Peter Littlewood

EPP Theory and Math Physics
Sue Coppersmith
Tao Han
JoAnne Hewett
Joseph Lykken (Chair)

AMOP and QIS
Phil Bucksbaum (Chair)
Mark Edwards
Julio Gea-Banacloche
Michael Raymer
Martin Zwierlein
Chan Joshi

Nuclear Physics
Ricardo Alarcon
Jeff Blackmon (Chair)
Kate Jones
Daniel Phillips

EPP Experiment and Grid Computing
Larry Gladney (Chair)
Terry Schalk
Sally Seidel

PNA
Angela Olinto (Chair)
Henry Sobel
Neil Spooner

Gravity
Thomas Baumgarte
Steve Carlip (Chair)
James (Ira) Thorpe

EIR
Laird Kramer (Chair)
Cathy Mader
Willie Rockward

Computation
Bruce Allen

PFC and APPI
Luis Orozco (Chair)
Karl Van Bibber

APPENDIX E – 2012 Physics Division COV Charge

NATIONAL SCIENCE FOUNDATION
4201 Wilson Boulevard, Arlington, Virginia 22230

Office of the Assistant Director
Mathematical and Physical Sciences

October 27, 2011

Dear Member of the Committee of Visitors:

Thank you for agreeing to serve on the FY 2012 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 1-3, 2012; we expect to begin early Wednesday morning and conclude by 3:00 pm on Friday. The COV is an *ad hoc* sub-panel of the Mathematical and Physical Sciences Advisory Committee (MPSAC). Your appointment to the COV commences December 5, 2011 and ends with the discussion of the COV report by the MPSAC on April 6, 2012. Dr. José Onuchic has graciously agreed to be the chair of the COV.

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 2009; 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 2009, FY 2010, and FY 2011. 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

All material for the review will be in electronic form only. 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 5, which is the starting date of your appointment. She will also arrange a webinar in early January 2012 in order to cover the logistics of the panel meeting, with a focus on how to access electronic award records and special goals of the review. Panel members will be given access to the award records themselves two weeks prior to arrival at the NSF. Confidentiality rules prohibit providing knowledge of, or access to, proposals that were declined. This information will be available upon arrival at the NSF on February 1, 2012.

The meeting itself will begin with brief 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 second day of the meeting will focus on addressing issues that impact the Division as a whole. The last day of the meeting will be spent primarily drafting the report. The Chair of the COV 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 5-6, 2012.

Ms. Jennifer Sherman (703-292-7388, jasherma@nsf.gov) from the Physics Division 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,

H. Edward Seidel
Assistant Director

Enclosures: Excerpt from COV guidelines
List of Members of FY 2012 PHY COV
cc: Dr. James Berger, Chair MPSAC

Enclosure: 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.