FY 2015 REPORT TEMPLATE FOR
NSF COMMITTEES OF VISITORS (COVs)

The table below should be completed by program staff.

Date of COV: February 4-6, 2015
Program/Cluster/Section: [all]
Division:PHY
Directorate: MPS
Number of actions reviewed: 430 **Awards: 216** **Declinations: 207** **Other: 7**
Total number of actions within Program/Cluster/Division during period under review: **Awards: 1457** **Declinations: 1926** **Other: 77**
Manner in which reviewed actions were selected: **Provide a representative sampling that included varying size of the award (individuals through centers and facilities), and varying review strength (obvious awards, obvious declinations, borderline and special cases).**

Report of the 2015 Committee of Visitors
Division of Physics
National Science Foundation

Meeting Dates
February 4-6, 2015

Submitted on behalf of the Committee by
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To
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Assistant Director for
Mathematical and Physical Sciences

Submitted March 6, 2015

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I. Summary and Recommendations

The 2015 Committee of Visitors (COV) for the Physics Division (PHY) of the National Science Foundation (NSF) met at NSF on February 4-6, 2015.

The COV was 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 2012; and
- any other issues that the COV feels are relevant to the review.

This document is the resulting report.

Sections II through V contain summary remarks on various topics, extracted from subcommittee reports and from oral discussion during COV plenary sessions. Section II covers the review processes. Section III covers PHY management and staff handling of the FY 2013 rescission. Section IV covers Broadening Participation, and Section V covers other specific questions.

The individual subcommittee reports are included as sections VI.A through VI.J.

The COV's inputs to standard NSF template for COV responses are in Appendix A. The meeting agenda is Appendix B. The COV's membership and subcommittees are listed in Appendices C and D. The charge to the committee is in Appendix E.

Immediately below are the observations, suggestions and recommendations developed in the course of the COV's plenary deliberations.

Observations, Suggestions and Recommendations

1. *Observation*: The Physics Division invests in a very diverse and broad array of scientific and educational projects. The resulting portfolio of activity is pushing out the frontiers of human knowledge and educating the next generation of scientists and technologists. The program is serving our nation well, in terms of laying the intellectual and human-resource foundation for our future technological competitiveness. Projects supported by the Physics Division have annual budgets that vary by at least a factor of one thousand in size, and the topics covered range from biomechanics to neutrinos. Managing such an enterprise presents challenges enough in ordinary times, but doing so during the FY 2013 rescission was particularly fraught. During the period under review, FY12-14, the Division's top management changed, and there were a number of key personnel changes elsewhere in the staff. The COV finds that throughout all this, Division management and staff performed with commendable professionalism, fairness, creativity and industry, responding to short-term crises while not losing track of longer-term goals.

2. *Observation:* The COV was uniformly pleased with the quality, rigor, and fairness of the proposal review process. The process is conducted in a transparent fashion, and the COV believes the results have been excellent. There are some variations in procedure from one program to another within physics, but this is fully appropriate given the different sorts of activities being funded. The high quality process reflects well on the Division leadership and on the individual program officers.

3. *Observation*: The COV notes that the question of whether to participate in a given Priority Area is not a simple one. We endorse the Division's approach of paying close attention to these issues, and taking these decisions on a case-by-case basis. In this way the division can continue to be responsive to short-term national needs without compromising the Division's prominent role in building the fundamental foundation of our nation's long-horizon technological competitiveness. Program Officers might point out to proposal writers the value of using project summaries and Broader Impact statements to emphasize the connection between the proposed research and Priority Areas, even when the program in question is not a financial participant in a given Priority Area.

4. *Suggestion:* The COV was intrigued to learn of a PHY pilot program that has panel members take the "Harvard Implicit Bias Test" on their own before arriving at NSF to discuss proposals. A short discussion among panel members about the experience after they arrive at NSF then forms the basis for panel members understanding how to uncover and hopefully to minimize the effect of one's own unconscious biases. We suggest that if this pilot seems to be leading to positive outcomes, then the process could be implemented more widely across the Division.

5. *Suggestion:* During COV discussions we learned that one program within PHY has been making use of the SBIR program to fund some of their needed technology development. While many on the COV felt we did understand the program well enough to make a specific recommendation, we suggest the Physics Division explore whether expanded divisional participation in the SBIR program could benefit certain programs within Physics.

6. NSF processes for collecting and analyzing of demographic data on funded programs are in such a dire state that the data are not useful for informing efforts to broaden participation. The Committee recognizes that there are a number of obstacles presented by privacy laws and regulations; however, a mechanism to solicit this information directly from the participants exists. This is done via an email sent from the Foundation to the individual as named by the PI as participating in the awarded program. The level of participation is low, perhaps due in large part to the timing of the distribution of these emails, weeks after the program is completed.

Recommendation: Make the triggering event to submit a participant's name and email address for demographic data collection be when the person starts on the project, instead of the end of the project. We expect this will lead to significantly higher response rates.

The Committee discussed with program officers and directors opportunities for gaining access to NSF participant demographics. It soon became apparent that existing tools for this task are inadequate. This is due to a variety of reasons, including database systems not being connected adequately and lack of readily available software.

Recommendation: Make improvements to the data acquisition, transfer and display systems to facilitate easy and rapid retrieval of data on diversity for funded programs. This should help NSF and other stakeholders analyze and identify best practices that enhance the participation of underrepresented groups, potentially providing a positive feedback mechanism to build upon success.

We do note that this topic was addressed in the 2012 COV report. The response to this was written in the response from the Division (*PHY_Response_to_1012 PHY_COV_report_FY13_update.pdf*, p. 11) and is as follows:

> *With regard to data collection and sharing, the Division appreciates the comments from the panel but is not in a position to undertake any action beyond passing the comments on to the Division of Information Systems, which is the NSF body responsible for maintaining the NSF database.*

In retrospect, this answer has not proven to be a very effective strategy. The Committee urges the Division to take a leadership role in driving this issue to completion with the Division of Information Systems, perhaps by getting aid from high-level administration to make this a priority. We encourage an effort to find creative solutions in the face of an urgent national need.

7. The new PHY leadership has been presenting the diverse PHY-funded activity in terms of portfolios. The COV likes this concept-based (rather than program-based) framework and believes it will have real value for organizing the division, for setting internal priorities and for tying PHY activity to the framework of national priorities and initiatives.

The Division's programs are scientifically broad and complex from a funding perspective, including individual investigator research grants, long term operational responsibilities, frontier centers and facilities. With the portfolio concept in place, the next logical step is to assess the funding balance within the division, a process which has begun in many areas.

Recommendation: We strongly encourage the use of all available mechanisms to assess the funding balance with proper emphasis on forward-looking activities, even if this requires a higher level of justification for historical funding levels on long standing programs.

II. Proposal Review Process

The 2015 COV was uniformly pleased with the quality, rigor and fairness of the Division's reviewing processes. During plenary discussions the term "state of the art" was used on several occasions.

Prior to our face-to-face meeting at NSF in February, 2015, the COV members were given access to more than 150 review jackets, corresponding to proposals that were either "slam-dunk" Accepts, or borderline Accepts. Most of the subcommittees had one or more teleconferences to discuss what they had read, and many requested that the Division make additional jackets available to them. Division staff vetted the jackets to make sure the requesters had no Conflicts of Interest associated with the reviews. Once COV members arrived at NSF, we were able to look at declined jackets. The COV broke into subcommittees to discuss their reading and to get further clarification from Program Officers about the reviewing process. During the three-day COV meeting, the subcommittees all came together in several plenary sessions to share impressions and discuss ongoing efforts of the subcommittees. The most detailed account of our findings is to be found in the various subcommittee reports, but a number of conclusions apply across the entire COV and are discussed in this section. See also the material in the response template for responses to specific NSF-posed questions.

Review Methods

The most common pattern for reviewing within the Division is a three-tiered structure consisting of ad hoc reviews, followed by panel discussion, followed by program officer summary and recommendation. Although the tiered approach is obviously labor intensive both for Division staff and for the broader community of physicists, the COV feels the final results of these processes are consistent in their fairness and in their quality.

There are variations on the theme: In the IAP program, the panel process is sometimes omitted due to the diversity and eclecticism of the proposals received, but the COV does not see this as a source of concern. For large grants, the process is supplemented with site visits or reverse site visits. Several COV members noted the importance of site visits for some of the largest grants, although it was acknowledged they are expensive to run.

Members of one COV subcommittee were enthusiastic about the 2013 pilot program for "asynchronous" panel reviews, where some exchange of views took place among panel members via the Sharepoint site before the panel met in Arlington, making the few-day face-to-face meeting time more productive. Not all technological innovations met with approval, however. For example, replacing face-to-face meetings with teleconference panel meetings was found to be "less efficient."

Hard choices

The COV was pleased to observe that in these difficult funding years, the Division avoided the easy route of always preserving funding to senior scientists with clout, and instead considered proposals on an equal footing, even if it meant turning off funding to distinguished members of our community.

Ad Hoc Reviewers

Across the subcommittees there was consensus that the program officers selected a good variety of well-qualified reviewers, with expertise in the relevant topics. We found that in the overwhelming majority of cases, the reviewers did a commendable job. There were occasionally "hiccups," but the multiple-tiered reviewing system seems resilient. The COV was happy to see that program officers are taking diversity (including geographical diversity) into account as they select reviewers. We were also pleased to see that a sampling of more junior but already accomplished scientists was invited to participate in panels. This not only serves to broaden the perspective of panels but also provides a mechanism to educate promising new investigators on the overall review process.

The ad hoc reviews were generally found to be on point and useful, providing a critical review of the details that became a solid basis for the panel work, which, by its nature, is comparative.

Panels

Panel summaries are often quite concise but convey the necessary information. They reflect a deeper evaluation than one would obtain by simply collecting the individual letter grades from all the reviewers. The rationales panels use to for reach their recommendations are stated clearly.

Program Officers

The COV was impressed, with very few exceptions, with the quality of the PHY Program Officers' critical summaries and recommendation. These summaries are what tie the whole process together. The multi-tiered review system employed by the Division is a great thing, and allows for a very robust

evaluation of proposals. Sitting at the hub of the process is the Program Officer, and the process works only as well as the PO. The Division is fortunate to have talented and committed POs. The importance of retaining talented people and recruiting new ones as needed cannot be overemphasized. If the caseload per PO gets too high, there is a risk of burning out talented staff, or of having these serious intellects reduced to "filling in the boxes" in a perfunctory way.

Feedback to PIs

Our review of the jackets showed that feedback to the PI was generally very good, with ad hoc reviews and panel summaries being conveyed to PIs. PIs on declined proposals are encouraged to call their Program Officers to get additional oral feedback. It is not always possible to tell from the jackets to what extent this actually happens. There is a risk that less experienced or less self-confident PIs could miss out on taking advantage of this valuable opportunity.

Conflicts of Interest (COI)

The COV is pleased to see that the NSF in general and Physics Division in particular take the COI issue very seriously, and do an excellent job of recognizing and resolving problems as they arise. The COV subcommittees reviewing the Gravity and EPP-E programs were pleased with schemes the respective program officers have developed rigorous but workable methods for dealing with COI in cases where almost everyone in a particular field has been a co-author on the same paper.

Improving the process

On the rare occasion when an ad hoc review goes awry, it can be because the reviewer spends too much ink summarizing the work, a summary which is already available in the proposal itself, and not enough time in evaluation. An interesting possible solution, proposed by EPP-E subcommittee and discussed in committee, would be to arrange for the ad hoc reviewers to keep their summary separate from their evaluation. The COV as a whole has no recommendation on this.

The Nuclear Physics subpanel developed a number of ideas for mentoring ad hoc reviewers and for improving the panel review process, as described in their subcommittee report. While most of these ideas are currently at the level of suggestions and not recommendations, and while most won't be recapitulated here in this COV-wide summary, the NP subcommittee report is well worth reading.

A possible tactic for reducing implicit bias is to have each panel member do a preliminary ranking of proposals based on reading proposal summaries from which all identifying information has been removed. Later, the panel members would revisit their rankings after gaining access to the full proposal. This suggestion attracted interest during a plenary session of the COV, but there was by no means consensus that it was a good idea. Perhaps, as suggested in more detail in the NP report, this idea could be tried out in a pilot.

Another idea proposed is to have each panel member take the Harvard Implicit Associate Test before coming to the panel, so as to enlighten the panelists to their own unconscious biases. To be effective, this needs to be followed by a discussion at the beginning of the panel of the possible impact of those biases and encouragement to work diligently to be fair despite those biases. The COV found this idea very intriguing, and there was widespread support for giving this idea a try, at least in some panels. Many of us are interested in hearing what effects this procedure will have.

III. Management in the Time of Budget Stress

During the period under review, the top-level management changed: from Joe Dehmer as Division Director and Denise Caldwell as deputy, to Denise Caldwell as Division Director and Bradley Keister as deputy. At about the same time, the Division suffered a severe budget crunch started by the FY 2013 rescission. It was initiation by fire for the new management, and a severe challenge for the entire Divisional staff.

Despite the best efforts of PHY management and staff, the cuts hit the physics community hard. The details are contained in the various subcommittee reports, but a uniform result is that the rescission exacted a cost in terms of science accomplished and human resources developed.

In some programs there was a large drop in proposal success rate. In other programs, grant size and duration was decreased. Many excellent proposals were declined due to lack of funds. The numbers of, in particular, undergraduates and postdocs supported declined. In some programs, the decline in support for postdocs was precipitous, which has led to not exactly a lost generation, but to a generation with a notch cut out of it. In order to continue to offer support to new programs, support for highly productive existing programs had in some cases to be reduced or turned off. The loss of momentum and continuity may or may not be recoverable for those programs.

There was a consensus among the COV that the cuts must be reversed at once lest the damage to the Division's scientific and educational productivity become irreversible.

The COV feels that the PHY management and staff are to be commended for their professionalism, fairness, and creativity in dealing with a very difficult situation. As one COV member remarked during our discussions, "This was an event that could have torn our community apart, had everyone had everyone else's throats. But that didn't happen, and it was thanks to our Program Officers." The cuts were managed with transparency and with a hard-nosed sense of priorities, in such a way as to maintain confidence in the NSF, and to preserve as much as possible the morale of the community of practicing scientists.

The PHY division supports a very diverse range of programs and communities, and there was not a one-size-fits-all approach adopted. Clearly, some program officers went more with reducing grant size, others with reducing success rate, but this was appropriate given the different situations in different programs. The various COV subcommittees felt that in most cases, the approach taken was the correct one. In some cases, the key to preserving scientific productivity was to encourage collaborations, and the program officers were quite creative in this respect.

Meanwhile, the temptation in difficult times must have been to "put management on hold," to hunker down and make no major course changes. But in fact, during these difficult years, the Division responded to shifting priorities and opportunities by starting a new program, and terminating another one. This showed an admirable ability on the part of the Division management to continue to think long-term in the midst of short-term extreme stress.

Across all the COV subcommittees, a consensus emerges that the program officers are doing an excellent job. The rescission is not an event we could readily weather again. The community was fortunate to have had PHY division in good hands during this particularly difficult time.

IV. Broadening Participation

There is a significant amount of underutilized talent in this country. Progress with respect to women has been made. The situation with respect to under-represented minorities (URMs) remains unacceptable. Numerous congressional and National Academy of Sciences reports explain and document this issue. This untapped talent is a waste of a precious national resource. The NSF PHY is in an excellent position to take a leadership role in issues of broadening participation. Because NSF holds the power of the purse, it can leverage that leadership to encourage best practices among the scientists it funds. Putting more emphasis on broadening participation as part of the Broader Impact criterion is one step. So is providing a higher level of support to those who demonstrate good citizenship in this regard. The data collection and implementation question has been discussed extensively elsewhere. Beyond that, we are thrilled to see that the NSF continues to examine its own solicitation and review processes to reduce the possible impact of implicit bias and to provide opportunities to a broader demographic of scientists.

Division leadership should be commended for recent actions to broaden participation in physics. This includes expanding eligibility for the CLB# initiative to all PHY PIs, not just those who have CAREER awards, participation in the AGEP-GRS# program, and PHY's own diversity fund whereby a program director has an opportunity to make a difference with modest additional funds. Requests for REU supplements and conference support are being queried about the potential impact of the requested supplement on diversity should it be funded.

One area where we see a need for urgent improvement is in demographic data collection and assessment. You can't fix what you can't measure! There is a need for better demographic data for participants at all levels in NSF-funded activities, from panel membership through PIs all the way to undergraduates, especially with regard to involvement of under-represented minorities. The Physics Division has funded a number of programs that include proposed activities designed to improve participation in underrepresented groups (both for gender and minority involvement). This is especially true for the Physics Frontier Centers. Many of the COV members found that the lack of reliable and timely demographic information about participation these programs made it difficult to measure the efficacy of these programs in improving underrepresentation. Similar issues arise when evaluating REU programs.

The problem associated with this scarcity of data is tied to several key constraints in the system: PIs may not directly report the demographic information of the group being funded; emails that are sent to the individual participants requesting demographic information are not sent in a timely manner due to the fact that the trigger for sending these email waits until a report is sent to NSF after the grant is completed; and the lack of good tools to aggregate and disseminate the data collected to the relevant program offices/directors.

It is in NSF's interest to start collecting data on the efficacy of particular programs designed to broaden participation. Presently the collection of data is stuck in a circular problem. The level of data collection currently is sub par, which makes it not very useful and not very used. Since the data isn't used there is no incentive for PIs to collect the data. This cycle must be broken. One improvement would be to adjust the triggering mechanism to collect data so that a person is asked to volunteer their demographic data when they join a project rather than 3 months after the project is over. This, coupled with encouraging PIs to get their people to respond to the request (which includes the option to say I don't want to reveal), could help to increase the data collection rate to the point that it might be useful. Additionally the options should be expanded to include "other" in addition to "male," "female," and "don't wish to reveal."

Moreover, the Division and the Foundation as a whole should consider improvements the data acquisition, transfer and display systems to facilitate easy and rapid retrieval of data on diversity for funded programs. Having data that would help analyze and identify best practices that enhance the participation of underrepresented groups, potentially providing a positive feedback mechanism to build upon success.

V. Additional Specific Issues

PHY management asked the COV to address issues at a level beyond what is required to complete the COV template. These issues included Broadening Participation and the Division's handling of the rescission, discussed above in Sections III and IV, respectively. The COV was also asked to look at the Division's "Portfolio" approach to understanding its cross-cutting program, the Division's possible new take on the Broader Impact criterion, and the Division's participation. These three topics are discussed below.

V.A. The Question of Portfolio Presentation

The COV was pleased to learn that the Physics Division management has been increasingly emphasizing a "cross-cutting portfolios" description of the overall Division program. PHY has chosen to define itself as a set of "frontier scientific areas" rather than "a collection of programs". In this description, the individual funding programs within the Division do not provide the primary conceptual organizing rubric for the Division's range of activities. Instead, the collection can be rediagonalized such that the primary focus is on a number of portfolios each defined by big cross-cutting scientific topics.

Examples of such big topics include "Complex Systems and Collective Behavior," which includes the study of living cells, biological systems, ultracold fermions and bosons, quark-gluon liquids, and so on. From an administrative point-of-view, the projects may be funded out of such disparate programs as Physics of Living Systems, Atomic and Molecular Dynamics, or Nuclear Physics. But from a scientific point-of-view, the scientists are working on projects with considerable intellectual ground in common.

This approach has compelling intellectual appeal, and moreover the COV believes that this view of the Physics Division programs also has value for organizing the division, for setting internal priorities and for tying the Division's activities to national priorities and initiatives.

The Division's programs are scientifically broad and complex from a funding perspective, including individual investigator research grants, long-term operational responsibilities, frontier centers and facilities. With the portfolio concept in place, the next logical step is to assess the funding balance within the division, a process which has begun in many areas.

V.B The Question of Broader Impacts

In the subcommittee reports are extensive examples of the impressive Broader Impact success resulting from the Physics Division's investments. Rather than summarize them in this "global" portion of the report, we recount the results of a discussion that arose in response to Physics Director Denise Caldwell's specific query to the COV:

> "Physics has a broad definition of what constitutes broader Impact. Would there be a benefit to more narrowly defining this?"

It is said that if you query any two scientists you will get three different opinions as to the proper interpretation of NSF's Broader Impact merit criterion. Whether this is true or not, the COV, consisting of 30 members and ten subcommittees, did not develop a consensus response to this question. There were a number of interesting points raised in our oral conversation, and in subcommittee reports (look in particular the reports of the Particle Astrophysics, the Nuclear Physics, and the Gravity Physics subcommittees). We are not able to provide any recommendations in this summary portion of the COV report.

Considerable emphasis was placed by some members of the COV on the importance of having the NSF better communicate the intended meaning of "Broader Impact" as a criterion in the peer-review process and to offer more guidance to prospective PIs planning to submit proposals. In addition, the CoV reported that some peer-reviewers felt unable to fairly evaluate proposals on this criterion, and that additional input from NSF was needed to clarify the intent of the criterion and how it might be satisfied by PIs. In response to similar concerns in the past, several "Dear Colleague" letters were written to help elucidate the Broader Impacts criterion. A large and diverse set of examples were provided on the web to help proposal writers and evaluators better understand the criterion and its use. A major outcome of the work in this area was the formation of an NSF-sponsored annual forum that spawned the *National Alliance for Broader Impacts - NABI*. The group focuses explicitly on the broader impacts of NSF-sponsored research; what it is, how to effectively communicate its importance (and meaning) to stake holders, and how to better communicate to the taxpaying public the vast number of ways in which NSF-sponsored research directly impacts society - both technologically and socially. *NABI* currently consists of ~ 100 member universities and institutions and has an established web presence (broaderimpacts.net). The NSF played a central role in bringing this group together and initial results of the NSF Broader Impacts summits and their related work are presented in a glossy special report released on November 12, 2014, entitled: "Broader Impacts - Improving Society". The report is publicly available on the web and linked to NSF Press Release 14-149 ("New special report highlights NSF-funded broader impacts" (http://www.nsf.gov/od/iia/special/broaderimpacts/).

The topic of Broader Impacts also comes up in the section on Priority Areas, section V.C just below.

V.C. The Question of Participation in National Priority Areas

The COV notes that the question of whether to participate in a given priority area is not a simple one. We endorse the Division's approach of paying close attention to these issues, and taking these decisions on a case-by-case basis. In this way the division can continue to be responsive to short-term national needs without compromising the Division's prominent and fundamental role in laying the *foundation* of our nation's long-horizon technological competitiveness.

During the 2015 PHY CoV meeting, the committee as a whole looked at the issue of how NSF-PHY could best align itself with National Priorities as set by the Executive Branch to increase both the visibility of PHY contributions to these and enhance potential funding opportunities through the National Priorities. While there are potentially many mechanisms to accomplish this, one avenue in particular seemed to be a straightforward alignment, where appropriate, of the National Priorities with the Broader Impact criteria. Thus, we encourage all NSF-PHY program officers to inform PIs (and proposal reviewers) that one option for a focus of the broader impact aspect of their work is to describe, when appropriate, how their research aligns with and supports National Priorities. In addition, we suggest that, again when appropriate, PIs are encouraged to do this for their proposal abstracts as well as public versions of their final report summaries.

VI. Reports of the Subcommittees

A. Gravity/LIGO

Introduction

The National Science Foundation is the main source of funding for gravitational physics in the United States, and its gravity program the scientific home of LIGO, one the largest NSF experimental projects. With advanced LIGO in its commissioning stage, it is poised to detect gravitational waves in the next few years and, in collaboration with VIRGO, to begin a new era of gravitational-wave astrophysics. Associated theoretical studies of the inspiral of compact binaries exploiting numerical relativity and analytic approximations have produced waveforms accurate enough to maximize detections and are nearing the accuracy needed to extract the physical parameters of the systems. A parallel effort is using a Pulsar Timing Array (PTA) comprising the most accurately timed pulsars to search for lower-frequency gravitational waves. This includes the NSF funded NANOGrav collaboration which also may plausibly make a detection within this decade. Space based gravitational wave detection, although scientifically compelling, has had its implementation delayed due to funding constraints. This year, the gravitational reference mass technology will be demonstrated by the launch of the LISA Pathfinder mission in fall 2015. Improvements in modeling of general relativistic systems increasingly incorporate magnetic fields and the microphysics of matter, providing, in particular, more realistic simulations of binary coalescence and supernovae. Work in experimental tests with unprecedented range of scales and accuracy of general relativity and alternative theories involves lunar ranging and search for deviations from the inverse square law. Theoretical investigations of quantum geometry show promise of unveiling physics close to the Big Bang and inside black holes.

Gravity is the dominant interaction at astrophysical and cosmological scales, determining the large scale structure of the Universe. The weakness of gravity at small scales that makes gravitational waves so difficult to detect is also what makes them so attractive as a probe of the universe: They freely emerge from the electromagnetically opaque environments of binary coalescence, supernovae and the early Big Bang. Interferometric detectors like LIGO are our best chance of detecting gravitational waves at least with Earth-based detectors. The detection threshold and the accuracy of parameter extraction from gravitational waves can be dramatically improved if one knows precisely the waveforms that the various sources produce. This underlies theoretical and numerical efforts in modeling waveforms from systems like supernova explosions or black hole binaries. In addition to matters related to gravitational waves there is interest in studying fundamental issues in gravity. Since the latter is described via the geometry of space-time this creates natural overlaps with areas of mathematics. There is also particular interest in how the theory merges with quantum field theory and particle physics. This last topic constitutes perhaps the ultimate frontier of fundamental physics since it involves all the main theories of physics at present. Since gravity is the dominant interaction at large scales in the universe it also naturally interfaces with cosmology, where important topics at the moment include the accelerated expansion of the universe. Among the potential explanations are modifications to the laws of gravity. Some of these in turn can be tested in experimental settings in the lab, creating another area of activity. Finally, gravity is a subject that traditionally captures the imagination of the public in various aspects ranging from black holes to wormholes and to cosmology in general, offering unique opportunities for outreach.

A challenge facing the gravity program at the NSF is to balance all of these research sub 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. This is in a large part because of the excellent work the program directors over the years, all of whom have brought strong expertise in the area to bear on the grant decision making process.

Recent progress

Over the past three years, NSF-supported gravitational physics has made significant progress.

During the 2012-2014 period the assembly of advanced LIGO was completed. The Livingston Observatory achieved lock in late 2014 and met its acceptance criteria five months ahead of schedule. The Hanford observatory is expected to be completed by February 2015. An initial science run is scheduled for fall 2015, and a year of data taking at design sensitivity is expected for FY17-18. A third interferometer to be installed in India is ready for shipment while the government of India's approval of the project is expected soon. Advanced new interferometric techniques using squeezed light were demonstrated very successfully and are principal risk-mitigation techniques that could be used to ensure that advanced LIGO reaches design sensitivity.

These successes lend compelling support to the expectation that within the next few years, LIGO will detect gravitational waves from the inspiral and coalescence of compact binaries: double neutron-star systems and binaries with two black holes or with one black hole and one neutron star. As sensitivity increases and additional detectors come on line, we may also detect burst and continuous sources, including supernovae and rapidly rotating neutron stars with small bumps and/or oscillations. The most sensitive science runs of initial and enhanced LIGO and the prospect of imminent detection by advanced LIGO spurred major efforts that substantially improved search algorithms and computational infrastructure and that accelerated the speed of analysis pipelines. In collaboration with electromagnetic observatories, low-latency protocols were developed to allow rapid searches for gravitational waves triggered by gamma-ray bursts and rapid searches for electromagnetic counterparts of gravitational wave observations.

Related work by several groups has enhanced the prospect of using gravitational wave observations of binary inspiral as standard sirens to measure the Hubble constant: Simultaneous observations of the inspiral GWs and signatures in the electromagnetic band can give direct independent measurements of the luminosity distance and redshift to a possible 1% precision for 30 events. With no electromagnetic counterpart, tidal effects in NS-NS inspiral and waves from post-merger oscillations each break the degeneracy of vacuum solutions and thereby can supply the additional information needed to determine absolute distance.

NSF has also supported the work of the North American nanoHertz Observatory for Gravitational-waves (NANOGrav). NANOGrav uses the world's two most sensitive radio telescopes, the Green Bank Telescope and the Arecibo Observatory, to monitor millisecond pulsars. NANOGrav aims to directly detect low-frequency gravitational waves which cause small changes to the times of arrival of radio pulses from pulsars. NANOGrav's sensitivity has sharply increased in the past few years, and with continued improvement a detection is plausible by the end of the decade.

In addition to gravitational wave-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. In particular during this period the project APOLLO (Apache Point Observatory Lunar Laser-ranging Operation) achieved a relative accuracy of 10^{-14} in the Earth-Moon distance.

In numerical relativity, collisions of ultrarelativistic black holes with extremal energies and spin were studied, showing that a large part of the center of mass energy can be radiated. It was also shown that collisions of neutron stars can produce strong electromagnetic counterparts, opening an interesting possibility for multi-messenger astronomy with LIGO. Collaborations of groups working in numerical relativity, post-Newtonian and effective-one-body approximations, and in data-analysis have quantified the errors needed in simulations to construct templates for detection of compact binaries and extraction of their physical parameters. Gravitational-wave observations provide a *model-independent* way to measure neutron-star radius and deformability and thereby constrain the equation of state of matter above nuclear density. Highly accurate waveforms are essential to this effort and to tests of general relativity. Advances in the extreme mass ratio inspiral approximation have been relevant not only to the sources of a future space-based antenna but have been used to find high-order post-Newtonian corrections relevant for earth-based interferometers.

An interesting synergy is developing between numerical and mathematical relativity. As the numerical codes become more capable and more robust to explore extreme regimes of the theory, they can be used to test certain theorems. In particular, inequalities relating the spin and area of black holes were tested this way and shown to hold. An instability predicted theoretically years ago in higher dimensional black holes called black strings was confirmed numerically and the numerical insights led renewed interest in the topic and in turn to new theoretical developments.

In quantum gravity there were some interesting results in symmetry reduced models in loop quantum gravity. In cosmological contexts, where loop quantum gravity predicts that the big bang singularity is replaced by a non-singular bounce, if one studies perturbations living on the space-time there are corrections to the spectrum of perturbations for long wavelength modes. The corrections depend on the value of the inflaton at the bounce so it is not a definite prediction. However, the “tilt” of the spectrum has a prediction that differs from standard inflation in a unique way, opening for a possible experimental test in the near future. In spherically symmetric models the exact solution of the quantum Einstein equations was found. This is a quantum version of the Schwarzschild solution and it shows that the singularity inside the black hole is eliminated in favor of tunneling into another region of space-time. Interesting results connecting condensed matter physics and general relativity using the AdS/CFT correspondence have been obtained, for instance a relationship between general relativity and the cuprates.

Some outreach activities are funded or co-funded by the program. For instance a set of modular outreach programs designed to communicate the beauty of general relativity to the public was put together at Montana State University known as “Celebrating Einstein”, including an immersive experience involving the field of view near a black hole, a danced lecture and an original film and music score.

Fig. A1:N. Yunes interviewing S. J. Gates at Bozeman, MT. credit: www.celebratingeinstein.org

EINSTEIN@HOME is a distributed computing undertaking in which volunteers from the general public offer spare cycles in their computers to the search for gravitational waves. It was developed with support

from the Gravitational Physics Program and is still partially maintained by it. This is patterned after other successful similar efforts in protein folding and other areas. In 2013 it established upper limits in the search for sources of continuous gravitational waves that was published in Physical Review.

LIGO has a series of outreach activities. At the Livingston observatory operates a Science Education Center with interactive physics demonstrations that is visited by tens of thousands of high school students each year. A smaller version operates at the Hanford observatory. These activities are co-funded with the Interdisciplinary Activities Program of the Physics Division.

The field of gravitational physics is growing rapidly, driven primarily by the interest in the emerging field of gravitational wave astronomy. The program was damaged by the funding climate, but during the review period, awards were made to 18 new PIs (within 10 yrs of Ph.D.), including 7 CAREER researchers.

Program processes and management

The CoV looked in detail at a number of proposals in gravitational physics (including LIGO research support, gravitational theory, and gravitational experiment) submitted over the past three years, including both accepted and declined proposals. We studied the review process, the selection of reviewers and panels, the role of the Program Officer, and the final outcomes.

In the opinion of the CoV, every proposal awarded met NSF standards. The stringent funding climate was handled in three ways: by awarding significantly less than the full amounts requested, by adopting a cutoff that necessarily leaves out excellent investigators and by co-funding with other programs. This strategy allowed a higher proposal acceptance rate and access to funding for new investigators. The program has incorporated a healthy number of new PI's.

We are happy with the review process. The cases were well documented and the final summaries by the program officer usually paint a good picture to understand the decision making process. Panel decisions reflect a deeper evaluation than simply collecting letter grades and include evaluation of the Foundation's strategic goals.

The reviewing process for proposals directly related to LIGO has a unique feature: reviews are accepted from people who have coauthored papers with the PI provided they are the papers of the collaboration where all members are listed as authors and that is the only source of conflict of interest. This approach to reviewing the LIGO proposals was implemented by the current program officer and replaces a previous process with greater potential for conflicts of interest. The program in general appears to be conscientious in recognizing and resolving problems of conflict of interest.

Portfolio balance

As in previous reports, we need to stress the importance of keeping thematic balance, particularly given how diverse the subfield is and the presence of a large project like LIGO in it. Diversity ranging from mathematics to astrophysics and computational physics imply different rates of publications and citations that have to be carefully weighed in judging the proposals. This seems to be holding well, with active management by the program officer, but we strongly encourage vigilance in maintaining thematic balance.

The program is also unusually diverse geographically. Theoretical grants were awarded in 18 states and experimental proposals were funded in 24 states.

Broader impacts

The CoV does not see major issues within the program with the "broader impacts" issue. The only exception is in the CAREER awards, where it appears that the requirement has become slightly onerous because of the fierce competition among proposals. It would be good if the CAREER program allowed more flexibility to researchers to tailor their proposals to their talents allowing varying levels of commitment to outreach among the successful proposals.

Overall approach of the division

We support the overall approach of the Division that science questions should drive the NSF direction. As outlined in the memorandum from OMB to OSTP on July 18th 2014, articulating the science priorities of the White House, "Key among these is the fundamental, curiosity-driven inquiry that has been a hallmark of the American research enterprise and a powerful driver of unexpected, new technology." Gravity is naturally a field that is curiosity driven, so it aligns well with this priority.

The Gravitational Physics Program is an example of how the science drives collaboration. We have projects co funded with AMO, AST, DMS, ACI, this includes projects both in theory, computation and experiment, amounting to slightly over 10% of the budget. We strongly encourage co-funding to continue and be expanded when possible.

Improving CoV Process

The past and present CoV format involves several ad-hoc discussions of important division-wide issues that are brought up during the meeting. It is difficult to be thoughtful in a large group in a short time and impossible to gather the information needed to make informed recommendations to NSF.

We suggest that a request to identify division-wide issues be made to CoV members well in advance of the physical meeting as part of the advance preparation. Issues that several members regard as important can then be studied in advance by a small subgroup of CoV members who could make recommendations to the full CoV membership prior to meeting. It would be helpful if issues that the NSF division leadership wants the CoV to consider could be similarly included in the advance preparation.

There should still be time at the meeting allotted to open discussion of additional issues that are identified during the meeting. If a few of these need more in-depth consideration, they could be taken offline by an ad-hoc subcommittee who then reports back to the larger group later in the meeting and prior to making recommendations to NSF.

Concerns from previous CoVs

We note that these suggestions, from the 2013 and 2009 reports respectively, do not appear to have been addressed, and we think both are important:
1)"Providing a collaborative word processing environment similar to the Panel Review System for CoVs would be very helpful for preparation of the report"

and

2) "Our committee had a concern that the CoV does not contain sufficient members who have recently experienced having a highly-rated proposal turned down by NSF, and there may therefore be a bias in the

CoV's assessment of how well this process is working. We therefore recommend including in future CoV's people who are not currently funded as a result of having highly-rated proposals declined."

We recommend including in each CoV 2-3 people who are in this category: strong researchers who are not funded by NSF because of a recently rejected proposal. Program officers could each submit names of potential members, consistent with the conflict of interest that prevents someone with a pending proposal from participating in a CoV; a total of 2-3 of these proposed members could be randomly selected.

B. Atomic, Molecular, Optical, Plasma and Quantum Information Science

Introduction

The experimental and theoretical atomic, molecular, and optical physics AMO programs are now regarded as separate from the plasma physics program. This subpanel has been charged with reviewing those three, along with a fourth program, quantum information science (QIS). These four programs are highly diverse and they are typically handled by three or four Program Directors. The issues confronting these programs are also diverse and reflect different histories as well as different dynamics right now.

For around a decade or more, the vibrant field of AMO physics has been one of the fastest growing areas in the American Physical Society. In this review, we have grouped the field of AMO experiment and theory into four subfields, namely Precision Measurement, Cold Atoms and Molecules, Collisions, and Optics and Photonics. Recent growth areas in AMO physics have included quantum optomechanics which aims to develop mechanical measurement capabilities down to the quantum limit, artificial gauge potentials, and the simulation of interesting Hamiltonians from condensed matter and other areas of physics, both in experiment and theory. One expanding field under optics and photonics is ultrafast laser science, which has received focused attention from DOE particularly over the past decade. Optics and photonics has seen developments in quantum-related areas, such as the development of single photon sources and repeaters, of particular interest in quantum information studies. An interdisciplinary NSF Program that has extensive overlap with AMO theory and experiment, condensed matter physics, and other areas, the QIS Program is now comparable to the AMO Theory program in total funding.

During the periods 2012-2014, the proposal success rates in the four reviewed programs in successive years were: AMO experiment, AMO Theory, and QIS were comparable to those in the rest of the PHY for corresponding years. Plasma, in contrast, had considerably lower proposal success rates in some years. The chart below shows that funding has **largely been flat in all four programs reviewed by our subpanel. The increase in funding percentage over this p**eriod in the AMO programs despite this flat funding scenario appears to have derived from especially active outreach by the Program Directors who managed to arrange co-funding of projects with other NSF Programs both within the MPS Directorate and in other Directorates.

The AMO theory program is the principal (80%) supporter of ITAMP, the Institute for Theoretical Atomic, Molecular, and Optical Physics at the Harvard-Smithsonian Center for Astrophysics. The remaining 20% of ITAMP funding comes from the QIS program, which also supports the CQuIC, Center for Quantum Information and Control, at the University of New Mexico. The field of QIS also benefits from theoretical and experimental efforts carried out at two PFCs, namely at Caltech and at JQI/Maryland. Two others, the JILA PFC and the Center for Ultracold Atoms (CUA) PFC at Harvard and MIT, have strong ties to the communities of AMO experiment and theory and quantum information as well; those PFCs are particularly important for the field of ultracold atoms and molecules, but they cover other areas of physics as well.

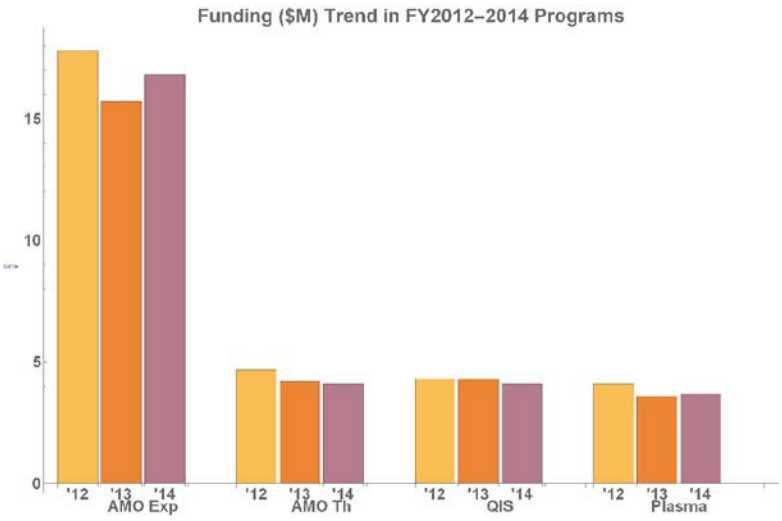


Fig. B1

The Plasma Physics program is funded through the NSF/DOE Partnership in Basic Plasma Science and Engineering. The NSF contributes about $3.7M/yr to the partnership, matched approximately equally by DOE. The major research areas are low-temperature, non-neutral and dusty plasmas; turbulence and magnetic reconnection in laboratory and space plasmas; laser-plasma interactions; and high energy density plasmas. The NSF program emphasizes graduate education integrated within the research programs, and excludes research directly related to fusion plasmas. The Partnership funding is critical for the viability of discovery-based plasma research as a distinct area of intellectual inquiry within Physics, and for training of the next generation of plasma physicists. The bulk of the funding is for single-PI research programs, with the exception of continuing shared support of $1.7M/yr for the Basic Plasma Science (user) Facility at UCLA.

The NSF/DOE Partnership in Basic Plasma Science and Engineering was begun in 1997, and renewed in 2011, in order to "provide enhanced opportunities for university-based research in fundamental processes in plasma science and engineering; and stimulate plasma science and engineering education in US universities." This aligns with the 2007 NRC "Plasma Science" report recommendation that DOE incorporate "magnetic and inertial fusion energy sciences; basic plasma science; non-mission-driven high-energy-density plasma science; and low-temperature plasma science and engineering. The fusion research remains within DOE, and all of the 3 remaining areas fall within the Partnership.

Integrity and efficiency of the program review process and management

This subpanel has tremendous confidence in the integrity, breadth of knowledge, and fairness of the Program Directors associated with these 4 programs. The overall efficiency of the management has undoubtedly been hampered to some extent by the extensive turnover of the Program Directors in recent years. It had been recommended in the 2012 COV Report that more permanent appointments in the Program Director positions would benefit the broad subfields spanned by AMO experiment and theory, quantum information science, and plasma physics. The difficulties associated with having frequent changes in the Program Directors should be greatly improved by the appointment of a new permanent PD in AMO experiment. On the other hand, a talented rotating Program Director will leave NSF in late 2015, and this will be a difficult loss to replace. The Plasma Physics management has also done an excellent job of managing this diverse range of projects, and it is transitioning this year to a new full time Program Director who will oversee both Plasma and the new Accelerator Science.

One excellent positive that has emerged from this COV review is the fact that the Program Directors for these four programs have been highly proactive in establishing as many relevant connections and cooperative agreements with other Divisions and Directorates. It is entirely evident that their energetic seeking of co-funding for many proposed projects has significantly multiplied the impact of the resources NSF has been able to allocate to AMO experiment and theory, as well as quantum information.

An encouraging sign is the number of first-time investigators that the programs have been able to fund, also with several CAREER awards that can immediately jump-start an assistant professor's success in academia.

We saw no evidence that the distribution of funded proposals among subfields within each of the four programs is inappropriately balanced.

Executive Summary of Assessments and Recommendations

1. Overall, the proposal review, selection, and funding process is a good one as long as individuals with good judgment are in charge, and it is highly desirable for NSF to make these positions attractive to such talented individuals. This would be helped by retaining such talented Program Directors as permanent staff when possible. While there are understandably barriers to making permanent hires in the federal system, the resulting gains in continuity and efficiency will often reward the effort, particularly in areas like AMO where there has been extensive recent turnover.

2. One challenging aspect for many Program Directors at NSF is the unequal distribution of PD workload. It is currently tied to the dollar amounts dealt with by the programs, but it seems more appropriate to apportion workloads based instead on the number of proposals dealt with. As a target number of proposal actions, 100 is probably a realistic target number, while 200 is almost certainly going to dilute the effort of any PD far too thinly.

3. The efforts of Program Directors to creatively seek other Divisions within the MPS Directorate and even in other Directorates for joint funding of proposals is to be highly commended and encouraged to continue in the future. The mechanism for supporting such joint funding with dollars outside of the cooperating programs, as in the matching contributions from the Office of Multidisciplinary Activities, is an excellent idea that should be continued in the future.

4. We fully support the ongoing NSF/DOE Partnership in Basic Plasma Science and Engineering, and we encourage the development of new connections with other funding programs within and outside NSF. We note that this recommendation was also made by the 2012 COV, but that available Plasma funding has remained essentially flat like most other programs within the Physics Division despite the continuing very strong proposal pressure.

5. There continues to be growing concern, not only in our subpanel but in the national AMO community, about the shrinking sizes of typical grants, most notably in NSF's AMO Theory program where the average grant size is only around $70K per year. Here the Program Director is forced to walk a difficult line between wanting to fund projects at a level that enables a successful outcome, versus wanting to make sure to support (frequently early career) faculty talent in the field at least at a level that helps to get their research careers off the ground. This subpanel supports the current general approach which is to try to balance these two competing desires as sensitively as possible, but we advocate re-thinking this strategy if average or median grant sizes drop much lower.

COV review of jackets

The review of 42 jackets that were provided to the subpanel by the programs in AMOP and QIS show ample evidence that the process is fair and takes the relevant issues into careful consideration. Some jackets warranted additional inquiry into the reasoning followed, such as when a Program Director's funding decision deviated from the rankings of proposal merit by the Panel, and/or from the rankings by the individual reviewers. In the cases where such questions were raised by the subpanel, the Program Directors were able to give a thoughtful and convincing explanation of the reasons for the differences of opinion, and a sensible explanation for how those differences were weighed when arriving at the final funding decision.

The following is an overview of the research areas of interest in these four programs.

AMO Experiment

Atomic, Molecular and Optical (AMO) physics is a subfield of physics with very diverse goals, united largely by the energy scale of the extremely sensitive probes that are employed. Recently funded AMO proposals fall into four categories: (1) precision measurements, (2) cold atoms and molecules, (3) collisions, and (4) optics and photonics. These categories now have very fuzzy boundaries since, for example, cold molecules are typically probed optically to make precision measurements. The current practice is to fund the best physics proposals whatever the category or blend of categories, and this subpanel endorses that practice.

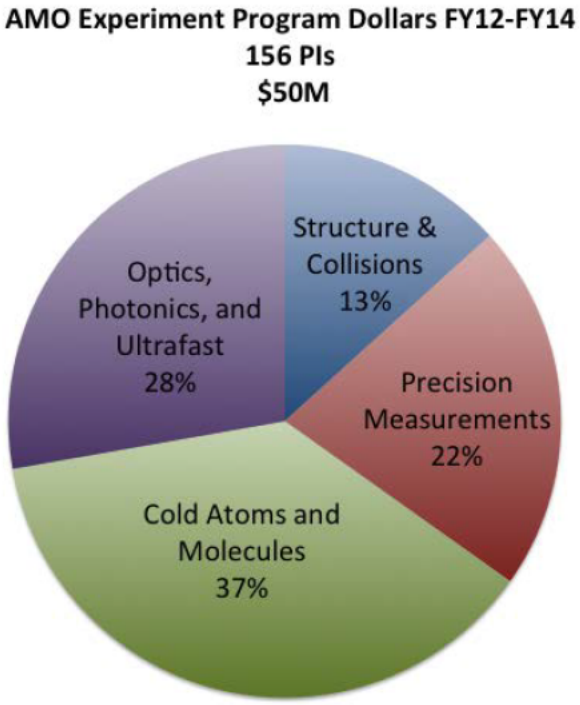


Fig. B2: The pie chart shows the cumulative funding distribution in AMO experiment for 2012-2014.

Precision measurements typically have goals that cross disciplinary boundaries, and they are increasingly funded jointly with other programs. For example, the high sensitivity and precision of AMO methods make it possible to test both the most precise predictions and the symmetries of the Standard Model of particle physics, as well as to probe for new physics beyond the Standard Model. Another set of examples include extremely precise laser spectroscopy and extremely precise mass spectroscopy to determine nuclear sizes and to test nuclear theory predictions of the binding energies of stable and unstable nuclei.

One recent measurement used magnetometers at the South Pole to very sensitively test the Lorentz invariance built into the Standard Model. Improved nuclear spin magnetometers are being developed to search for a possible interaction between spin and mass, mediated by axions or other light pseudo-scalar particles. It should be possible to probe spin-gravity interactions with related methods. Another example is the most sensitive ever measurement of the electron electric dipole moment that, like the LHC, probes for physics beyond the Standard Model at TeV energy scales and above.

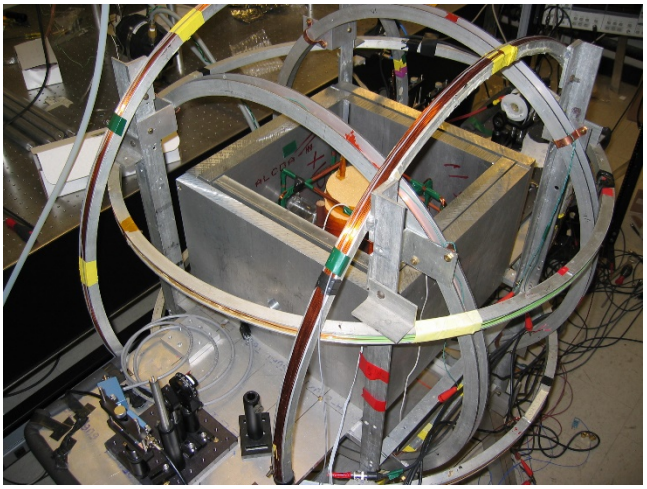


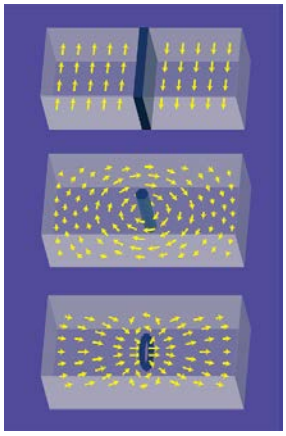
Fig. B3: Magnetometry apparatus in Romalis Lab at Princeton.

As noted in the 2012 COV report, experiments in this area tend to be expensive and last many program cycles, so good management oversight is essential; mere "paper-counting" is not an adequate measure of research importance and quality. NSF, with some help from NIST, provides most of the US funding for the tests of fundamental symmetries, tests of precise standard model predictions, and measurements of fundamental constants.

Ultracold atoms and molecules

Ultracold atoms have emerged as a novel playground where one can study collective behavior that occurs in many systems ranging from superconductors to neutron stars. The rich tapestry of phenomena has led to a diverse program in the US that is considered world leading. PHY-funded investigators reside in a range of locations from powerhouse institutions with Physics Frontier centers (JILA, Harvard-MIT, and University of Maryland) to small undergraduate colleges, allowing a continuous, diverse pipeline to train students. Ultracold atoms have the advantage that their properties can be controlled at will, providing a tunable platform to study various macroscopic phenomena, including e.g. phase transitions. At sufficiently cold temperatures, ~100 nanokelvin, a cloud of atoms forms a superfluid into which topological defects can be introduced. One such example involves using a three-dimensional tomographic reconstruction technique, to conclusively demonstrate that the previously observed long-lived solitary wave was indeed a solitonic vortex (middle image in Fig. B4), which was proposed to

bridge the gap between solitons and vortices. Such experiments illustrate the universality of critical phenomena. Mark J.H. Ku, Wenjie Ji, Biswaroop Mukherjee, Elmer Guardado-Sanchez, Lawrence W. Cheuk, Tarik Yefsah, and Martin W. Zwierlein, "Motion of a Solitonic Vortex in the BEC- BCS Crossover," *Phys. Rev. Lett.* **113,** 065301 (2014).



From Physics Viewpoint – Solitons with a twist.

Fig. B4: Different types of topological defects can form in a superfluid contained in an elongated trap. A soliton (top) is a wall-like separation between two regions where the phase of the superfluid's wave function points in opposite directions. A solitonic vortex (middle) is an open line, while a vortex ring (bottom) is a circular ring, around which the phase loops. For both the solitonic vortex and vortex ring, the phase becomes roughly uniform (i.e., like in the soliton case) far from the defects. (APS/Joan Tycko)

Collisions between particle, atoms and molecules are a second category of AMO measurements. These have long been part of AMO physics. The collisions of most interest these days however, are collisions that take place under unusual circumstances – at extremely low energies, for example.

The range of AMO physics is illustrated by recently studied collisions between polarized electrons and a vapor target of bromocamphor – an organic compound. DNA is always twisted like a right handed screw, and many biochemical molecules have either right or left handedness. The fundamental question is whether this chiral symmetry could have been caused by polarized electrons from nuclear decay during the early days of evolution.

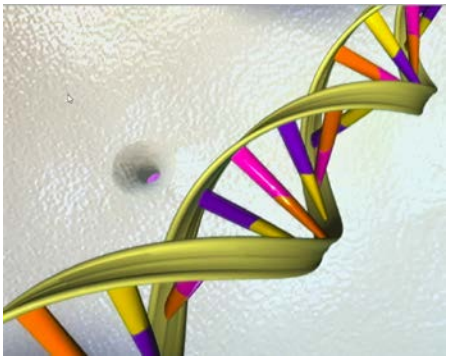


Fig. B5

The intriguing new result is that the rate at which twisted chiral molecules come apart depends on the handedness of low energy polarized electrons which collide with these chiral molecules – the first hint of a possible mechanism for forming molecules with a specific handedness. [J. M. Deiling and T. M. Gay, Phys. Rev. Lett. **113**, 118103 (2014).]

Optics and Photonics

Optics and photonics represent a core enabling capability for AMO physics, and many other disciplines and industries. Indeed 2015 has been named the International Year of Light sponsored by the United Nations, wherein the societal and economic impact of optics and photonics is featured. For AMO physics, the ability to control matter with tailored coherent electromagnetic radiation lies at the core of studies in cold atom and molecule dynamics, precision measurement, and ultrafast dynamics. New developmental areas include frequency comb extension to the XUV, quantum optics in cavity QED, ultrashort single-photon generation, and, ultrafast, coherent short-wavelength sources of radiation that can access timescales down to the attosecond regime. The latter can be replacements for large-scale facilities such as the new suite of x-ray free-electron lasers in the US, Japan and Europe for some classes of experiments, notably ultrafast magnetization, electronic structure dynamics, and spatio-temporal molecular imaging. An example is shown below where freeze-frame molecular movies on ultrashort timescales can be achieved using a few-cycle long-wavelength laser pulse to free an electron wavepacket and recollide it with the parent molecule. The resulting electron diffraction pattern allows molecular structure to be deduced on timescales that freeze molecular vibration. Junliang Xu, Cosmin I. Blaga, Kaikai Zhang, Yu Hang Lai, C.D. Lin, Terry A. Miller, Pierre Agostini & Louis F. DiMauro, Nature Communications **5**, 4635 (2014).

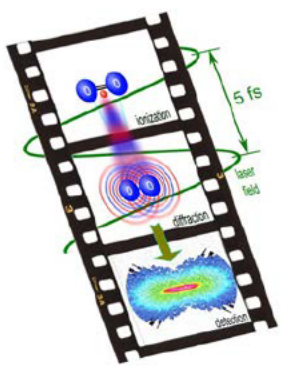


Fig. B6

AMO Theory

Theoretical AMO physics has historically been closely coupled with experiment, and in particular it has contributed in fundamental ways to many of the advances already mentioned above in the sub-areas of AMO experiment. In some cases it has led experiment while in other cases theory has been led and stimulated by experimental developments. And frequently theory and experiment are tightly coupled collaborations that advance hand in hand. Recent areas of particular interest in the program include Rydberg gases with or without photons coupled, ultracold atomic few-body and many-body systems, quantum control, ultrafast laser-atom and laser-molecule interactions, as well as quantum simulation and other related areas already mentioned above.

Quantum Information Science (QIS)

The decision to start QIS as its own Program within the Physics Division was driven by the interdisciplinary nature of the subject. The development of theoretical and experimental understanding of qubits and their controlled manipulation and entanglement involves investigators in AMO physics,

computer science, mathematics, and condensed matter physics, as well as electrical engineering. Our subpanel seconds the statement in the 2012 COV Report that it continues to be appropriate to maintain an independent home for the QIS Program that can continue to stimulate and be receptive to projects from all of these related areas that tend to approach quantum information science from differing perspectives. This continues to be a popular field for graduate students to enter and the NSF is a major supporter of this area, adding continuity to the often generous support from DOD agencies which tends to be more susceptible to budgetary fluctuations.

Plasma Physics

Great breadth characterizes the topics funded by the Plasma program, grouped as low temperature plasmas (including non-neutral, 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 proposal load on the Plasma Program has been very high, with 145, 167, and 119 proposals received in 2012 to 2014. The scientific merit of the proposals has been normally high, but the budget only allowed funding rates well below the Division average. We note that 2010 - 2011 were similarly problematical. The 2012 COV described the Partnership as "too thinly spread", and this description is still appropriate.

The new Accelerator Science Program within Physics (separately reviewed) will probably have a small positive funding effect on the Partnership, by funding some proposals which would otherwise go to the Partnership. For instance, some areas that might have been funded by the Plasma Program in previous years are now eligible to receive funding in Accelerator Science, such as research in the area of plasma acceleration.

A sense of the breadth of the Plasma Physics Program is clear from a few recent research accomplishments described here:

Chaos in Magnetic Flux Ropes - The chaotic dynamics of magnetic flux ropes is being measured in the Basic Plasma Science Facility at UCLA. Magnetic flux ropes are twisted bundles of electrical current and magnetic field which strongly interact with each other. These structures are ejected from the Sun, and may travel to Earth where they can have significant impact on satellites and the electrical grid. Fig. B7 shows the magnetic field in two ropes (red & blue), and the resulting plasma flows (cross-hatched). Quantitative data allows analysis of the local dissipation of complexity and energy.

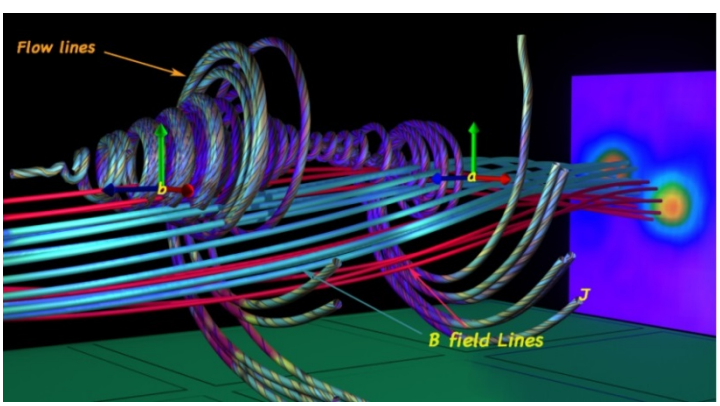


Fig. B7: Courtesy: Walter Gekelman at UCLA

Plasma Oxidation/Reformation at a Gas-Liquid Interface - A new experimental approach has been developed at Ohio State University to study the use of plasmas for oxidation and reforming of liquid fuels initially at room temperature. A Fast Ionization Wave Plasma develops along the interface of a liquid fuel and an oxidizing agent, propagating at speeds up to 1000 km/sec. These "plasma catalysts" can significantly enhance combustion at high speeds, such as found in supersonic aircraft.

Plasma Dynamos - In a large plasma chamber at the University of Wisconsin, a hot, fast flowing, magnetic-field-free plasma has been created and characterized. The experiments characterize the viscous flow of momentum from the magnetized edge to the unmagnetized central. Flows can be adjusted to model the Keplerian-like flows in proto-stellar accretion disks, and may help understand the plasma dynamo creating magnetic fields in stellar objects.

Anti-matter Plasmas - Positron beams are useful in many applications, ranging from fundamental physics studies to the characterization of materials. To this end, the positron group at UC San Diego has developed techniques for accumulating large numbers of positrons, and for extracting specially tailored beams into magnetic-field-free regions. These and other techniques from the AMO and Plasma communities have contributed significantly to the successful creation and trapping of anti-hydrogen at CERN, created from separately trapped plasmas of positrons and anti-protons. This enables a wide range of future antimatter experiments.

On the Division's response to the 2012 CoV recommendations in AMO, QIS, and Plasma Physics

1. The encouragement given in 2012 to invest in the more fundamental areas of AMO appears to have been followed admirably.

2. The interdisciplinary subfield of cold atoms that is of interest to both AMO and condensed matter physics has been supported strongly, with co-funding of some proposals, as was recommended.

3. The merging of the subfield of Atomic and Molecular Structure with the other subareas of AMO physics has basically happened, as was recommended.

4. The recommendation to reduce the number of grants in order to support adequately those who are funded has probably not been fully implemented, although the PDs are sensitive to this point and are doing a reasonable job of trying to balance the need for maintaining a healthy size of grant amounts against the importance of protecting junior faculty PIs. For theory grants, this continuing shrinkage of grant size for normal research grants is approaching a limit that might require addressing more pointedly, however.

5. The recommendation to fund graduate student tuition as a fixed amount rather than simply paying full tuition in all cases has not been implemented, and our subpanel agrees with NSF that this is a matter beyond the domain of this COV review of the AMO, QIS, and Plasma Physics programs.

6. Apparently this recommendation that Fastlane not be eliminated until a satisfactory alternative was in place has been followed by NSF.

7. This type of an ombudsman support is happening. Refer to point #3 above in our Executive Summary of Recommendations.

8 and 9. These two recommendations about supporting instrumentation initiatives have benefitted the AMO experimental program, but apparently to date they have not benefitted projects in Accelerator Science nor in Plasma Physics.

10. This has been addressed in Point #4 of our Executive Summary above.

11. The view expressed in the 2012 COV report that it worked well to combine AMOP, AMO theory, and QIS is no longer applicable because Plasma Physics has evolved into its own program, and "AMOP" is now simply AMO experiment. Because there is a new program in Accelerator Science as well, we recommend for the next COV that the Plasma Physics Program and Accelerator Science Program should be grouped together as their own separate subgroup.

C. Elementary Particle, Theory

1. Introduction

Theoretical high energy physics lies at the core of advancing our understanding of the universe, being driven by powerful ideas and guiding powerful instruments.

The NSF Particle Theory Program and Theoretical Cosmology program, which we will together refer to as EPP theory, have a strong phenomenological component as well as a focus on formal aspects of modeling the fundamental laws of physics. During the 2012-2014 funding periods there was also a Mathematical Physics program, with an emphasis on the mathematical aspects of string theory as well as a broad portfolio of innovative research that cut across many disciplines. The Mathematical Physics program was dissolved at the end of FY14.

The EPP theory program has a leading presence in many subfields. These include, for example, understanding the physics of the Large Hadron Collider (LHC), discovering the properties of neutrinos - from the sky to the earth, and modeling the identity of Dark Matter, as well as investigating string theory as a model for physics at the highest energies. As such, the EPP theory program plays a significant role in supporting the development of ideas aiming to understanding the laws of nature.

The EPP Theory subpanel members have reviewed the processes and outcomes of proposals in the three programs: Theoretical HEP, Theoretical Cosmology and Mathematical Physics. The subpanelists examined a large number of jackets and selected a broad variety of jackets for further discussion that were both representative of the program and illustrative of various issues. The subpanel also requested additional jackets beyond those originally provided, and examined a number of declination files for comparison purposes. The program directors were very cooperative and forthcoming in all discussions.

2. Science Highlights

The discovery of the Higgs boson at the LHC in 2012 captured the attention of the world and proved the power of theoretical ideas in determining the properties of the Universe. The novel idea of the Higgs mechanism to originate the mass of fundamental particles was developed by theoretical physicists about half a century ago. In 2012, the LHC - the most expensive, most complicated, most ambitious machine ever built- enabled the discovery of the Higgs boson particle, and therefore validated the Higgs mechanism. NSF-supported theorists contributed significantly to the discovery through the development of new software codes that are essential for the proper extraction and interpretation of the data, as well as for performing detailed higher order calculations essential for interpreting LHC physics. Refinement of the codes, as well as detailed NNLO (next-to next-to leading order) calculations and beyond, is essential and is continuing. The question of whether the Higgs boson has the exact properties predicted by the original theory is of critical importance and measurements of Higgs boson decay rates are sensitive to potential new high scale physics effects. Prof. Concha Gonzalez-Garcia (NSF grant PHY/1316617) and her colleagues at SUNY Stony Brook performed one of the first global analyses of the measured Higgs boson properties in the context of an effective field theory, and demonstrated that 10-20% deviations from the predictions of the standard model of particle physics are allowed by the LHC data. Prof. Kirill Melnikov of Johns Hopkins University (NSF grant PHY/1214000) proposed a method using existing measurements of $pp \rightarrow ZZ$ cross sections at the LHC in a broad range of ZZ invariant masses to derive a model-independent upper bound on the Higgs boson width.

The identification of dark matter is an outstanding puzzle in particle physics. A large and diverse suite of experiments is ongoing and upgrades of existing ones, as well as development of new technologies, are

underway. Dark-matter physics is data-driven, with a strong experiment-theory interplay. For example, direct-detection experiments set bounds on the cross section for a given dark-matter particle of a given mass, as shown in Fig. C1.

Many of the features depicted in Fig. C1 are directly related to the research output of NSF-funded theorists. Prof. Paolo Gondolo of University of Utah (NSF grant PHY/1415974) computed predictions of supersymmetric models that are shown in the shaded (pink) area towards the lower, right region of the figure. His computer code DARKSUSY is one of the tools that is used by the international community to compute the dark-matter abundance and the code is presently being updated to include non-supersymmetric models as well. One of the main limitations for direct detection experiments is the so-called neutrino floor (lower yellow-shaded region in the figure). Prof Louis Strigari of University of Indiana (NSF grant PHY/1417457) was one of the first to recognize that neutrino-induced recoil events from solar, atmospheric and diffuse supernova neutrinos constitute an irreducible background to direct dark matter searches. He has recently revisited the situation and proposed various alternatives to greatly enhance the subtraction of the neutrino background.

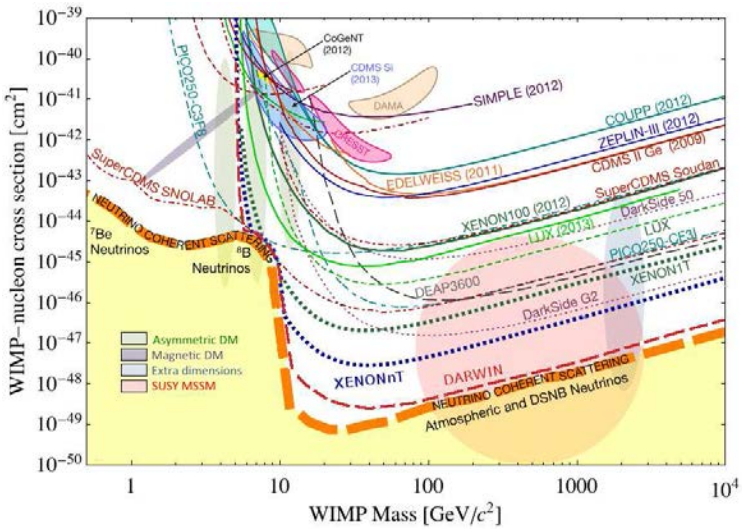


Fig. C1: Limits on the WIMP cross-section as a function of the WIMP mass. Solid (dashed) lines indicate current (projected) bounds. The yellow region indicates the so-called “neutrino floor”, while the red region indicates the parameter range predicted in supersymmetric models.

Indirect dark matter detection and structure formation are at the boundary between Particle Physics, Astro-particle Physics and Cosmology, and many NSF-funded theorists contribute to the field with innovative ideas, simulations and analyses. For example, Prof. Kevork Abazajian of UC Irvine (NSF grants PHY/1159224 and PHY/1451435) is an expert on astrophysical indirect detection as well as the effects on small- scale galactic structure. His work on astrophysical and dark matter interpretations of extended gamma-ray emission from the Galactic Center has had high impact in the community as well as in many public venues.

The EPP Theory program has a long history of strong focus on formal theory supporting, for example, most of the leading discoveries in string theories in past decades. In particular, in the past three years

there has been renewed interest in understanding the black-hole information paradox. It was discovered that information flowing out of a black hole was incompatible with an otherwise smooth space-time at the event horizon. Such a vacuum discontinuity would manifest itself as very energetic particles - a “firewall” - just outside the event horizon. The firewall paradox questions the validity of some of the fundamental building blocks of physics such as the equivalence principle, unitarity in quantum mechanics, or quantum field theory. NSF-funded physicists have largely been responsible for driving the revival of this activity. The original 2012 observation of Prof. Joseph Polchinski of UC Santa Barbara (NSF grants PHY/1316748 and PHY/1205500) of the apparent existence of a firewall was responsible for triggering this surge of activity. Prof. Leonard Susskind of Stanford University (NSF grant PHY/1316699) was the first to notice the entanglement between particles in the Hawking radiation and others emerging later. More recently, Prof. Susskind suggested that wormholes might preserve the connection between the Hawking radiation and particles inside the horizon. By contrast, Prof. Raphael Bousso of UC Berkeley (NSF grant PHY/1214644) disagrees, thinking we need to accept and understand firewalls and provided further arguments for their existence. This line of research is at the top of the physics discussions within the formal EPP theory community and has also received quite an amount of attention in press articles.

In work funded by the Math Phys program, Prof. David Poland at Yale University (NSF grant PHY/1350180) used a bootstrap approach to study the constraints of crossing symmetry and unitarity in general 3D Conformal Field Theories (CFT). His line of work can lead to a solution of the CFT describing the three dimensional (3D) Ising model at the critical temperature. The critical 3D Ising model belongs to the same universality class as second-order phase transitions in a number of real-world systems, such as liquid-vapor transitions and transitions in binary fluids and uniaxial magnets. This work provides an example of how abstract mathematical questions has direct applicability to physical problems.

3. Distinctive Programs

EPP Theory funds unique and highly successful programs that enhance the research training of junior researchers. The Theoretical Advanced Study Institute (TASI) (DeGrand NSF grant PHY/1305809) is a critical component of the research development for graduate students in the field. The majority of talks in the extensive parallel sessions at the PHENO conference (Han NSF grant PHY/1214781, 1417115) are given by junior scientists (43% students, 36% postdocs) with many students presenting their first work. The LHC Theory Initiative (Bagger NSF grant PHY/1419008) funded graduate student and postdoctoral fellowships to train early career scientists in hadron collider physicists in order to meet the needs of the LHC physics program.

The Coordinated Theoretical-Experimental Project on QCD (CTEQ) (Huston, NSF grants PHY/1213672, 1417352) is a multi-institutional collaboration devoted to a broad program of projects, including an annual summer school on QCD analysis and phenomenology as well as an on-going comprehensive analysis of parton distribution functions that are critical for calculations of high energy physics processes at the LHC.

4. Management

A. Ethics and Efficiency of Program Process

The subpanel was greatly impressed with the quality, fairness, transparency, prioritization and attention to detail of the program managers in EPP Theory. A combination of mail reviews and panel reviews was employed, leading to an effective and fair methodology. The reviewers were well chosen with significant expertise in the appropriate areas and the level of substance and thoughtfulness in the reviews was

impressive. While some ad hoc reviews contained more detail than others, overall the level of substance and thoughtfulness in the reviews was impressive.

The panel summaries gave clear discussions of the physics and excellent summaries of the reviews and panel discussions. The Review Analyses written by the program directors were even more thorough, explaining the physics context behind each proposal, presenting highlights of the reviews, 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. For awards where significant issues arose, the reviews were quite detailed. Hard choices were made in turning off funding for a number of distinguished members of our community who have become less productive.

The subpanel was favorably impressed with the quality, fairness, transparency, balance, prioritization, and attention to detail of program management in EPP Theory. The transparency of the Review Analyses also appears to extend to communications with the PIs. We commend the PD for emphasizing the importance of communicating the logic behind his decisions with the PIs.

B. Selection of reviewers

The choice of ad hoc reviewers reflected both institutional and geographic balance, as well as gender and ethnic diversity. The in- house panels were comprised of about a dozen researchers with proportionate representation from women and under-represented minorities. It is quite difficult to compose balanced panels and collections of ad hoc reviewers 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.

C. Management of the program

The subpanel is highly impressed with the quality of management of the EPP Theory program. The current EPP Theory program director inherited a portfolio with high commitment levels, but worked successfully and with great fairness to rebalance the commitment levels of the program. This was accomplished with the crucial assistance of funds directed from the PHY Division management, who are also to be commended. By 2012, the program was financially healthy with a small funding cushion.

The FY13 sequester caused serious issues for EPP Theory with a funding cut of 10.6%. The PD responded professionally and fairly in addressing the severe challenges caused by the funding cut and maintaining the most critical programs. Most university grants were cut substantially and many excellent proposals were not funded. The PD worked diligently to communicate the necessity for difficult budget choices to the PIs and to the high energy theory community at large. The program director is to be commended for his professionalism and ethical approach to managing the program in this difficult funding environment.

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

The EPP Theory program balances well- established research directions in string theory and the more formal areas of particle physics with topics in phenomenology and cosmology. 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 the calculations of processes at the Large Hadron Collider, to understanding new physics at the LHC. The EPP Theory program is well equipped to address emerging results from the LHC and to set research directions accordingly.

Over the past decade, there has been an increasing emphasis on interdisciplinary connections to astrophysics, cosmology and nuclear physics and the EPP program has been responsive in addressing

these critical areas. The relative balance between EPP theory and cosmology is fluid and the PD has appropriately adjusted to changing priorities.

E. Program planning and prioritization

It is apparent that given highly constrained budgets, the PD's priority has been to maintain support for students and post-docs, along with the ability to support new faculty members. A number of steps were taken to enable these priorities and to cope with severe financial stresses: (a) 5 year grants were converted to 3 year grants upon renewal, (b) a cap was instituted on summer salary support, and (c) many university grants were cut substantially in cases where faculty members productivity had declined.

We concur that the priority must be to protect the support of the more junior members of our field and commend the program director for setting priorities and making difficult choices.

5. Broader Impacts

Capturing the excitement of the discovery of the Higgs Boson, NSF-funded particle theorist Prof. David E. Kaplan of Johns Hopkins University produced a dramatic documentary film *Particle Fever*. Kaplan led a group of camera crews and filmed particle physicists throughout the preparation and start of operations of the LHC, and the footage was edited by Academy Award winner Walter Murch. As the final film was being assembled in 2012/13, specific NSF funding was provided (Bagger NSF grant PHY/1248619) to bring the project to completion. This award was co-funded by EPP TH, EPP EXP, EIR and OMA, demonstrating the interdisciplinary nature of this project and cooperation between the PHY Division programs and programs outside the division. The film received overwhelming critical acclaim (including a 5-star rating from the well-known aggregate website *Rotten Tomatoes*), played 17 weeks in major movie theaters across the U.S., and has been nominated for numerous best documentary awards, including the 2014 Grierson Award for Best Science Documentary. Over a million viewers have seen the film since it was released on Netflix a few months ago. The film triggered an immense outreach effort by NSF-funded researchers nationwide who regularly made public appearance to discuss particle physics and cosmology. The subpanel believes this is one of the most successful outreach efforts in our field.

Fig. C2

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. For example, after the discovery of the Higgs, Prof. Neil Weiner of New York University (NSF grant PHY/1316753) discussed the event in the *New York Times*, quotes from Prof. Marc Sher of William and Mary (NSF grant PHY/1068008) were picked up by the AP, Prof. Sher was also interviewed on NPR's *All Things Considered*, Prof. Jonathan Feng of UC Irvine (NSF grant PHY/1316792) was quoted in *USA Today*, Prof. Nima Arkani-Hamed of the Institute for Advanced Study (NSF grant PHY/0907744) was interviewed online by CNN, and an interview with Prof. Steven Weinberg of UT Austin (NSF grant PHY/1316033) appeared in the *Washington Post*.

In addition, the EPP Theory program supports investigators involved in the more traditional 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. TheoryNet, created by Prof. T. Taylor at Northeastern University (NSF grant PHY/0600304), is currently operated by NSF supported theorists and the program brings particle theorists into high school classrooms on a continuing basis and provides direct interaction between Boston area theorists and high school students reaching ~2000 students/year.

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.

6. Broadening Participation

The EPP Theory program supports broad participation by women and minorities. Over 20% of the grants have PIs or co-PIs who are women and 6% of the grants have Hispanic PIs and co-PIs as of the end of FY14. The subpanel commends the efforts of the PD to increase diversity.

7. Interdisciplinary Activities

Co-funding has been a pillar of interdisciplinary activity in PHY. The EPP Theory program director has been aggressive about securing co-funding arrangements with other programs in the Division (EPP, PNA, Gravity, Nuclear Theory, PIF/Computational Physics) and with other NSF Divisions (AST and DMR). The EPP theory program was also able to secure co-funding from EPSCoR and international programs.

8. Responsiveness of program to previous CoV comments and recommendations

The 2012 CoV report was concerned with the smallness of the budget for mathematical physics, given the size of the community and excellence of the program. Given the termination of this program in FY14, this issue is no longer relevant.

The 2012 CoV report discussed the severe financial stresses on the program. One of these was the small support available for new faculty members (at that time $30K/year). Since then, the PD has worked to increase the floor for new awards to $40-50K/year, despite the sequester budget cuts. This level of funding is still inadequate, which is evidence of the continued external financial stresses on the program.

The 2012 CoV was concerned with the ability to support graduate students and the PD has made it a priority to maintain support for graduate students, although this remains a significant concern.

9. Concerns

A. Dissolution of Math Physics

We are deeply concerned about the implications of the dissolution of the Math Phys program and the long-term effects of this action. Much of the most formal HEP theory community has traditionally been co-funded or fully funded under the Math Phys program. These researchers are primarily members of high energy theory groups within US physics departments, working to develop mathematical tools with which to study the most complex and challenging physics problems, e.g. strongly coupled gauge theories, mathematical applications of string theory, etc. As such, they represent a distinct group of researchers who are tightly connected intellectually. We examined several random jackets within this program and noted that these researchers are highly respected members of the HEP theory community and typically fall in the top of the must-fund category. For example, three of these were recent CAREER awards from the Math Phys program.

We are concerned that this community will no longer have a proper home within the physics division. If this additional intellectual thrust is to become part of the portfolio of the EPP theory program, then appropriate funds from the Math Phys program must follow into the base budget of the EPP program. Alternatively, another home should be found for this community.

B. Financial Stress on Program

The EPP theory program is under severe financial stress, but we cannot judge how the situation compares to other programs. We leave it to the division leadership to make the difficult choices in an era of declining budgets. We commend the EPP theory program directors for making difficult and thoughtful decisions and for communicating the rationale for the decisions carefully to the community.

D. Nuclear, Theory and Experiment

The Nuclear Physics (NP) program supports a broad range of research activities undertaken to understand the way in which the strong interaction gives rise to the protons, neutrons, mesons, and nuclei that populate our universe. The program supports individuals and groups in universities, and also a major university-based nuclear physics facility: the Michigan State University National Cyclotron Laboratory (NSCL). In addition, the program supports university laboratories at Notre Dame University and Florida State University. These groups operate smaller accelerators with which they perform in-house experiments as well as performing experiments at other larger facilities.

General Findings

The nuclear physics program at NSF funds world-class science. The cuts in the program caused by the sequester, while managed deftly by the program directors, must be reversed to maintain the health of the field. In the theory program the overall funding level for the program is currently so marginal that there are essentially no postdocs being funded in new grants; FY14 saw 0.83 of a postdoc funded for 15 faculty. This level of support cannot sustain a vibrant field that attracts young people. Finally, vigilance must be maintained to continue the balance between individual investigators / large groups / small facilities / and the NSCL operations, particularly in times of constrained budgets.

The nuclear physics program has been well managed. During the past three years there has been a transition in the management of the program as Brad Keister has ascended to the role of Deputy Division Director. During much of the past two years the program was managed without any permanent personnel using IPA[#], VSEE[#], and expert positions. Gail Dodge is to be commended for her outstanding stewardship of the program during this period. We are pleased to see that the torch of steady leadership has been passed from Brad to Allena Opper and Bogden Mihaila.

The review process generally operates very well but could be enhanced both by the education of panelists to reduce implicit bias and by instituting some level of blind review. Written and communicated best practices would be helpful both for new ad hoc reviewers and for new program managers. We note that effective and efficient program directors are critical to a fair and thorough review process.

Broadening participation in physics is critical to the health of the field and to the NSF national mission. The physics division should take a leadership role in broadening participation. We recommend that in the new solicitation the physics division require broader impacts and broadening participation to be addressed in "results of prior support." Additionally we recommend that proposals include results of student mentoring, including information on their immediate subsequent career path.

The nuclear physics program should be commended for its leadership role in providing research opportunities for undergraduates. In addition to support for undergraduates in the research programs through regular grants, the NP program awards REU supplements. Additionally the NP program has long supported the Conference Experience for Undergraduates program, which is a model program, and should be considered for adoption in the wider physics community.

Recommendations.

Our recommendations are as follows:

1. Demographic information should be requested for all personnel funded by NSF grants. That data should be easily accessible by all relevant NSF database systems as well as by NSF staff. We

suggest that the triggering mechanism for requesting demographic data of undergraduate students happen before the end of their NSF funded research experience.

2. Ad hoc reviewers should be mentored and provided feedback so that they can be as effective as possible.
3. We applaud the adoption of the NSF pilot program for addressing implicit bias of NP panelists. In addition to encouraging panelists for all programs in the division to take implicit association tests, we recommend that discussions about implicit bias take place at the start of each panel.
4. We applaud the adoption of simultaneous panelist voting for NP panelists. We recommend this for all programs in the division.
5. Continuation proposals should include results from the "broader impact" criterion as well as results from the "intellectual merit" criterion.
6. Continuation proposals should include results from student mentoring, including publications involving them, and their subsequent placement, if known.
7. New program officers should be mentored and trained so that they can maintain the standard of excellence and thoroughness set by the current ones.
8. We recommend that the "broader impacts" criterion be more uniformly described and more uniformly judged by reviewers.

Suggestions:

1. We suggest that the division consider ways to further reduce implicit bias in the proposal review process, for example by doing an initial blind review of program summaries as detailed below.
2. We suggest that the Division consider raising the "broader impacts" standards for all proposals.
3. We suggest that the "broader impacts" criterion include a mandate to address "broadening participation."
4. We suggest that language used in the databases be both more descriptive, and less open to negative interpretation. Problematic examples include labels such as "women involvement" and "minority involvement."
5. We suggest that the staffing issue be addressed so that all jackets within a subcommittee's purview, including declined proposals, can be made available to the subcommittee members before their arrival at the NSF.

Review process

The review process that has been refined over the years in nuclear physics has three layers of review for most proposals. It begins with the solicitation of ad hoc reviews of proposals. The reviewers are chosen because they have specific expertise to review the proposal in detail. The reviews are then used as input to the panel, which provides a greater perspective and a comparative element as it considers all proposals at the same time. The third and final level of review of a proposal is done by the program director, who takes both the ad hoc reviews and panel discussion into account as well as information such as overall portfolio balance. In addition, the program director considers information that may have become available since the time of the reviews and panel. It is important that the program director have the time to read all of the jackets as input to his/her analysis. We saw several instances where checks and balances were critical to a fair review process, and this worked well when the program director had full information. Instead of having the process be so program director dependent, we propose that new program directors be trained/shadowed/mentored so that there is a seamless continuation of excellence in the review process.

If a proposal is declined, the Fastlane template invites the PI to contact the program director for additional information. It was evident to us that some of the PIs took this opportunity seriously and were given useful feedback since we saw several resubmissions in subsequent years that addressed the previous

major concerns and were subsequently funded. This mentoring by the program director of new investigators should be applauded.

We didn't notice any unresolved conflicts of interest. We appreciate the careful attention the NSF gives to this issue.

Overall it seems that the reviewers are well chosen, conscientious, and not overly biased in their review, either positively or negatively. While many of the reviewers produced in-depth analyses of the proposals drawing on their own expertise, some reviewers declined the opportunity to demonstrate their expertise. Most reviewers made an effort to report on both Intellectual Merit and Broader Impacts. However, what constitutes broader impacts and the relative weighting of these criteria in the review varies greatly. It is important that this be addressed at both the PI and reviewer level. Some senior PIs seem to be given a "pass" by reviewers more often than more junior people. We understand this inclination by reviewers to judge established people less harshly because "they are known to be excellent" when they would be more critical of a similar proposal written by someone they did not know so well. But this tendency should be monitored carefully to ensure that both newer and established researchers are held to the same standards of excellence.

Providing feedback to the ad hoc reviewers could improve their subsequent reviews. This could take the form of discussions of best practices, allowing reviewers to see other reviews of the same proposal after final decisions have been made, and/or including more new investigators in panels so that they can learn first hand what constitutes a useful and appropriate review.

The review analyses largely seem well written and reflect the statements from the panels and ad hoc reviewer reports. They contain a lot of pertinent information and also explain how decisions were arrived at, particularly if they appeared different from the panel's recommendations. For some of the jackets the review process was exemplary: the ad hoc reviews were detailed; if they didn't catch something, the panelists did, and if the panelists missed something, the program director caught it. It was particularly pleasing that the program director did his own due diligence and was able to update the panelists' findings in meaningful ways. This is perhaps a reflection of experience from many years running the program. We did find isolated cases where the review analyses were less diligently constructed, and we encourage Division leadership to continuously pay particular attention to this key aspect of the review process.

It was sometimes unclear whether the information in the review analysis was transmitted to the PI. This can be critical both for successful and unsuccessful proposals when the information is not contained in the reviews made available to the PI – namely the ad hoc reviews and the panel reviews. It may be that the information was transmitted orally over the phone, but because there is no record of this it was difficult to ascertain. We do not recommend a change in procedure, just that attention be paid to making sure that any new observation important to the PI that occurs during the review analysis is indeed transmitted to the PI.

While senior investigators are familiar with the system and comfortable calling their PI, new ones may be unfamiliar with the etiquette and the program directors should emphasize to those newer to the NSF application process that phone discussions, both while preparing the proposal and after the decision has been made, are appropriate.

We understand that the NP panel process will undergo further evolution via the inclusion of two new elements beginning this year; a process of simultaneous rating by the panelists, so as not to let the rating of one panelist influence others in a sequential voting scheme; and implicit bias awareness raising at the beginning of the panel. (We understand that some programs in Chemistry already do this.) We applaud both of these new elements. The simultaneous voting could easily be accomplished by clickers, which

would enable both instantaneous feedback without identities and the ability for the program director to know the ratings of individual panelists for her/his further deliberations. This will work both for panelists in place at the NSF and those who attend remotely. Taking the Harvard Implicit Association Test before coming to the panel will alert the panelists to their own unconscious biases. To be effective this needs to be followed by a discussion at the beginning of the panel of the possible impact of those biases and encouragement to work diligently to be fair despite those biases.

We make three recommendations and one suggestion for improving an already robust process:

We recommend that a mechanism be developed to mentor the ad hoc reviewers so that they provide more useful reviews. We also recommend that all programs follow the upcoming NP pilot policy of simultaneous panelist voting. Finally, we recommend that all programs follow the upcoming NP pilot program of beginning panel discussions by addressing potential bias. We suggest that a layer of blind review be instituted at the beginning of the panel deliberations.

Below is a suggestion for a pilot review process for an NSF physics panel that includes an element of a blind review:

1. The panel, before arriving at the NSF, first reads and ranks the project summaries with all identifying information (if any) removed. The program directors should make PIs aware that this will be happening so that the PI can take care to include the appropriate level of motivation and detail in the project summary.

2. Each panelist ranks the project summaries based upon (a) importance of the physics to be addressed and (b) appropriateness of the methods proposed. Once the reviewer has provided this "blind" score, the reviewer has access to the rest of the jacket.

3. Panelists proceed as usual but now they have to justify how and why they deviated from their first ranking. These scores will often be legitimately distinct; more information is often needed to determine whether a PI has the infrastructure, for example, to perform the proposed work. But we think that the process of going through the first ranking will partially mitigate the impact of implicit bias.

Mechanisms for training and mentoring ad hoc reviewers might include:

1. Sharing best practices; e.g., there is no need for an extensive summary of the proposal by the ad hoc reviewer; what the NSF desires is a critical judgment about the importance of the physics and the likelihood of successful completion of the projects proposed. Explicitly identifying strengths and weakness is very helpful.
2. Having a phone discussion or webinar, either one-on-one with the PI or in concert with a group of new ad hoc reviewers, where advice can be given and questions asked and answered.
3. Allow ad hoc reviewers access to reviews the NSF has found particularly helpful.
4. Allow an ad hoc reviewer to access other ad hoc reviews of the same proposal once his/hers has been submitted

<u>Broader Impact</u>

Via the training and education of undergraduates, graduates students and postdoctoral researchers in accelerator and nuclear physics, the NSF nuclear physics program is playing a key role in the basic research being undertaken at our Universities. The leadership of scientists trained in basic nuclear physics has realized many significant enhancements in sectors of national importance, such as energy, national security and medicine. A number of accelerator developments have been driven by the nuclear

physics community; the NSF funded NSCL facility is notable in its role of fulfilling the national needs for trained accelerator physicists. Some nuclear physics PIs are actively reaching out to students beyond physics with unique courses such as “Physics Methods and Techniques in Art and Archeology” taught at Notre Dame. (http://isnap.nd.edu/Lectures/phys10262_2014/)

The COV at large had various opinions of what should constitute broader impacts. It would be helpful to both the PIs, ad-hoc reviewers, and panel members if the NSF made further attempts to foster a greater community understanding of the interpretation of Criterion II “Broader Impacts.” We appreciate that this criterion is currently intentionally left open to broad interpretation so that PIs are able to think creatively about what will work for their program. However this leads to some confusion, especially among the newer PIs and reviewers, as to what is expected and how this is weighted compared to the Intellectual Merit criterion.

There is a need to be more specific in the broader impact guidelines and to hold people accountable. Indeed it was noted that there was significant variation in the detail and substance of the broader impacts suggested by the PI and the importance placed on this criterion by the reviewers. One particularly good example from a site-visit report on this topic was: ``Given the exceptional nature of the funding and resources available to this group, the committee would have preferred to see an elevated commitment to outreach and/or to recruiting and mentoring members of underrepresented groups. " This is exactly the attitude the reviewers need to have and should communicate to PIs. However, while there was evidence that applications lacking obvious statements about broader impact were being denied, and importance is being placed in this area, there was also some evidence that grants from established scientists with good track-records were not reviewed as severely in the “boarder impact” area as those from less recognized scientists.

Currently, the "broader impact" criteria mostly seem to be "teaches the next generation of scientists." There was no data available to assess if they actually produce successful PhD's and/or if their undergraduates go on to PhD's somewhere. We recognize that we are not in agreement with other COV members evaluating other programs, but in NP we think that more should be required. Educating students is part and parcel of the scientific mission, and benefits the PI, the NSF, and Society. At the same time, Physics is facing a well-documented problem by not tapping into the huge scientific potential existing in under-represented minorities and women. Particularly for the largest grants, especially for those located where minority and/or economically disadvantaged populations live, we think the group has the responsibility to be good citizens of Physics and help broaden the demographic of young scientists.

We understand that with the new solicitation there will be a requirement to include broader impacts in the results of prior support. This is a good thing. We recommend that there also be a requirement to include the results (e.g. numbers of students, their papers and presentation, and subsequent placement) of student mentoring in the results-of-prior-support section of all proposals. If the NSF adopts the ORCID[#] system they could consider the possibility of having the ORCID ID entered for all individuals are supported on the project as part of the annual reporting. Depending on the universality of the adoption of the ORCID ID system this would greatly simplify the tracking of students and postdocs.

<u>Broadening Participation</u>

There is a significant amount of underutilized talent in this country. Progress with respect to women has been made. The situation with respect to URMs remains unacceptable. Numerous congressional and National Academy of Sciences reports explain and document this issue. This untapped talent is a waste of a precious national resource. The NSF PHY is in an excellent position to take a leadership role in issues of broadening participation. Because NSF holds the power of the purse, it can leverage that leadership to encourage best practices among the scientists it funds. Putting more emphasis on broadening

participation as part of the Broader Impact criterion is one step. So is providing a higher level of funding to those who demonstrate good citizenship in this regard. The data collection and implementation question has been discussed extensively elsewhere. Beyond that, we are thrilled to see that the NSF continues to examine its own solicitation and review processes to reduce the possible impact of implicit bias and to provide opportunities to a broader demographic of scientists.

Division leadership should be commended for recent actions to broaden participation in physics. This includes expanding eligibility for the CLB# initiative to all PHY PIs, not just those who have CAREER awards, participation in the AGEP-GRS# program, and PHY's own diversity fund whereby a program director has an opportunity to make a difference with modest additional funds. Requests for REU supplements and conference support are being queried about the potential impact of the requested supplement on diversity should it be funded.

It is in NSF's own enlightened self-interest to start collecting data on the efficacy of particular programs designed to broaden participation. Presently the collection of data is stuck in a circular problem. The level of data collection currently is sub par, which makes it not very useful and not very used. Since the data isn't used there is no incentive for PIs to collect the data. This cycle must be broken. One improvement would be to adjust the triggering mechanism to collect data so that a person is asked to volunteer their demographic data when they join a project rather than 3 months after the project is over. This, coupled with encouraging PIs to get their people to respond to the request (which includes the option to say ``I don't want to reveal"), could help to increase the data collection rate to the point that it might be useful. Additionally, the options for gender should be expanded to include "other" in addition to "male," "female," and "don't wish to reveal." And the options should be expanded for race to include "other" and "don't wish to reveal."

Another area for improvement is to solve the technical issues associated with various NSF databases that don't presently interface with each other. For example, individuals should not be responsible for entering their demographic data into multiple separate NSF databases (PI, reviewer, panelist).

We anticipate that, with renewed emphasis on this important issue, the data collection problem will be solved shortly. That will allow the efficacy of new and existing programs to be measured. The COV discussed a few possibilities, including broadening the recent offer to provide supplementary support to URM students beyond just those PIs with current or recent AGEP# involvement, but critically on a cost-sharing basis. There was some discussion about whether a committee should be formed to develop/choose such programs. We suggest that the physics division make a concerted effort to develop a comprehensive plan to broaden the participation in physics.

<u>Broadening Participation as part of Broader Impact</u>

There was not uniform agreement among the COV about this, but there is support for the NSF to consider making broadening participation an integral part of the "broader impact" criterion. The NSF is well positioned to play a leadership role to solve what is a well-identified but not at all well-addressed problem; the under-representation of women and minorities in physics. One important step the NSF Physics division could take is to require all proposals to include a plan for broadening participations. Some PIs at some institutions will be better placed than others to make progress, but as a community we all need to make some effort to address this problem. This could involve, for example, teaching a single science class to a minority-serving middle school, writing an op-ed article, or helping the APS with their budding minority mentoring program by encouraging their own minority undergraduates to join. The effort need not be extensive, but the NSF is in a position to send a signal about how important this effort is by making it a proposal requirement.

Program Management

The portfolio managed by the NP theory and experiment programs is wide both in scope and in size. The program is organized around grants that range from a single PI and their students to large umbrella grants that support the operation of world-class facilities. The grants awarded covered the spectrum of ongoing NP research in the US and abroad. We found no specific area identified that is being ignored. Not every experiment is getting funded, or funded at the level requested, but the net is being spread widely across the field. We salute the high-quality work performed by the program managers throughout the review period, especially in the context of challenging funding circumstances and turnover of personnel. We are pleased to see the personnel situation stabilize.

Though the overall NSF nuclear physics programs are community driven, the final award recommendations are made by the program directors. It is therefore essential that program directors have time to make some difficult award decisions, and that their work load be carefully managed. In the program director turn-over that the program experienced over the 2012-2014 review period, it is clear that transferring information from one program director to the other one is essential. Current program directors mentioned the implementation of systems that go further than informal communication (e.g. the development of a wiki page). We encourage continuation of this endeavor. Since ad hoc reviewers and panelists do not have access to previous proposals or previous reviews (unless they happened to be one of the earlier reviewers or panelists), it is left to the program officers to keep any sort of longitudinal data about whether recommendations made in previous reviews were actually addressed in current proposals. This sort of explicit accountability would be appropriate for both science and broader impact criteria. The program directors reported multiple times that PIs are encouraged to talk to them directly when in search of guidance. We encourage the program directors to share this information widely with the community at large and especially with prospective PIs (e.g., graduate student and postdocs). As a side note, we encourage program directors to keep in mind that open-door policies are often utilized by powerful, self-assured individuals, but younger members of the community may need more encouragement.

The reduced funding level due to sequestration has had a profound impact on the community supported by NP programs. We commend the program directors for their balanced approach and diligence in dealing with the problem. The ENP program officers employed several measures:

- Many PIs that were getting renewal funding received a cut.
- Funds in each renewal grant were scrutinized and unspent funds were used to balance reduction in the new award.
- Fewer standard grants were funded, thus using up some of the ARRA cushion.
- Five groups (in ENP) that had received long term funding were not renewed.

The theory program made fewer awards in FY13 as a result of reduced available funds and has not been able to keep up with inflation, with the average funding per PI relatively constant over the past four years. This has resulted in a gradual reduction of postdoc support to the point that it is now virtually non-existent. If this continues the path from PhD to faculty member in NT will have a gaping hole, resulting in graduate students finding employment outside of academia and new faculty being hired from outside of the country. Ultimately this will drastically reduce the impact that the NSF has in the field of NT.

To allow the NP community to continue to shape its own future through NSF, we encourage the program directors to keep following closely the deliberations and recommendations of the NSAC long Range Plan. New initiatives will likely be required to continue a flagship role for NSF in nuclear physics research once FRIB comes on-line.

Facilities

The program supports a major university-based nuclear physics facility: the Michigan State University National Superconducting Cyclotron Laboratory (NSCL). This is an efficiently run, world-class facility with unique capabilities to address strategic questions in the scientific areas of the NP program. In addition, the program supports university laboratories at Notre Dame University and Florida State University. These groups operate smaller accelerators with which they perform in-house experiments. The nuclear physics program directors (and the NSF in general) should be applauded for the stewardship of these facilities.

The NSCL is the premier laboratory in North America for generating rare isotopes using the beam fragmentation method. The intensities of fragmented beams are presently among the highest in the world. With the completion of ReA3 the NSCL is now unique in that it is the only single facility in the world that can provide fast, stopped, and reaccelerated beams. The resulting increase in physics reach is extremely compelling. However, due to the constrained budgets since the cooperative agreement was put in place, the NSF has not been able to fund the facility at the board-approved level. This has resulted in a decrease in the number of operating hours available to users. A recent visiting committee expressed the "hope[s] that new money can be found for operations to realize the potential of this world unique facility." This panel echoes that sentiment.

The Nuclear Science Laboratory at Notre Dame University represents a world leading institution in the area of experimental nuclear astrophysics. Recent upgrades provide for new exciting scientific opportunities and put the NSL into a unique position that would enable experiments that are not possible anywhere else at present. The combination of the new high current low energy linear accelerator 5U St. Ana and the state-of-the-art recoil separator St. George holds the key for direct measurements of the astrophysically-important alpha-capture reactions with unprecedented sensitivity. The strong nuclear structure component of the NSL scientific program covers a wide range of topics from nuclear matter equation of state to collective degrees of freedom.

The John D. Fox superconducting accelerator laboratory at Florida State University operates a two-stage accelerator comprised of a 9MV Super-FN tandem van-de-Graaff accelerator and an 8MV superconducting linear accelerator (linac). Among the beams available is the radioactive isotope ^{14}C. Additional radioactive beams are available from RESOLUT. RESOLUT is an in-flight radioactive beam facility, which uses beams from the TANDEM-LINAC to create exotic, radioactive isotopes not found in nature. The isotopes, which are created through a nuclear reaction in the production target, are separated in mass by the combined effect of the electrical fields in the superconducting RF-resonator and the magnetic fields of the spectrograph.

Research Highlights

Q_{WEAK}

Researchers from the Q_{WEAK} collaboration have measured the weak charge of the proton to be 0.064± 0.012 in dimensionless units. The weak charge is to the weak force what the electric charge is to the electromagnetic force. Though the weak force is prominent in radioactive decays, its effect is minute compared to that of the electromagnetic force. To determine the weak charge of the proton, researchers measured the difference of the probability of electron-proton elastic scattering when they toggle the direction of the spin of the electron (from aligned to anti-aligned). This difference exists because the weak force, unlike the other three fundamental forces, violates parity symmetry. Because this difference is tiny (about 280 ppb), researchers built a large azimuthally symmetric magnet and detector apparatus, a 2.5 kW liquid hydrogen target, and large scale tracking system. They took data for about 2 years using the intense ultra stable electron beam produced at the Thomas Jefferson National Accelerator Facility in Virginia. In their article, ``First Determination of the Weak Charge of the Proton," D. Androic et al. Phys. Rev. Lett. 111, 141803 (2013), researchers not only present their measurement of the weak charge of the proton but also combine it with existing atomic parity violation measurement on Cs. This allows them to put significant constraints on the weak charges of the up and down quarks (see figure). The measurement, based on just 4% of their available data, agrees well with theoretical predictions of the Standard Model of Particle Physics. However, the analysis of all the data may potentially uncover a discrepancy that would be evidence of new physics beyond the Standard Model. The NSF supported the construction of the tracking system with a collaborative MRI grant as well as a dozen PIs and their students through standard grants.

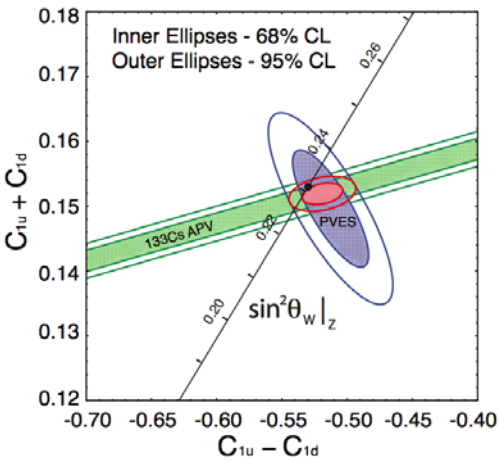


Fig. D1 Comparison of the neutral-weak quark coupling constants predicted by the Standard Model of Particle Physics (black dot) with the ones measured by QWeak (noted PVES) and atomic experiments (noted APV).

Observation of electron-antineutrino disappearance at Daya Bay

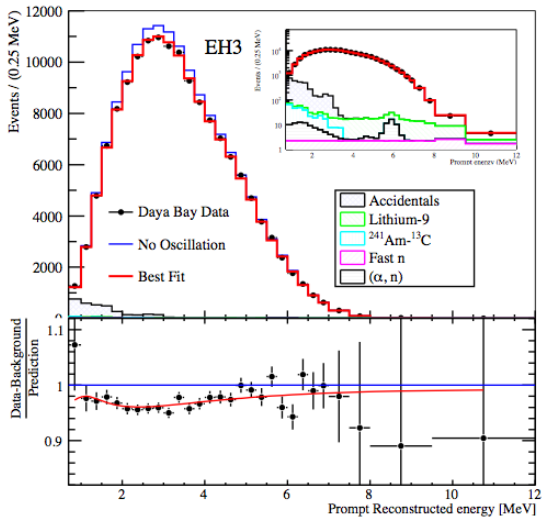


Fig. D2

Since discovering that neutrinos oscillate, we have enlarged our understanding of the Standard Model and sought to map out the mixing parameters that describe how neutrinos behave. The last mixing angle, Θ_{13}, was measured to better than 5 sigma by the Daya Bay experiment. Not only is this an important component to complete our understanding of the Standard Model, this last angle opens up the possibility of a CP-violating phase in the neutrino sector. This, in turn, could have critical consequences for our understanding of the baryon-anti-baryon asymmetry in the universe. The paper, Phys.Rev.Lett. 108 (2012) 171803, has over 1000 citations. NSF-funded scientist J. C. Peng is the leader of the Daya Bay team at Illinois and has been involved with the experiment since its inception. A Daya Bay analysis led by NSF-funded postdoc J.J. Ling, "Search for a Light Sterile Neutrino at Daya Bay" has led to the PRL "editor's suggestion" that provides severe constraints on the existence of sterile neutrinos.

Lattice Effective Field Theory

One of the open questions highlighted in the NSAC LRP is the need to understand nuclear structure from QCD. Because QCD is nonperturbative at such energies, there are two rigorous ways to proceed: either use an effective field theory (EFT) that encodes the symmetries of QCD in physical degrees of freedom, or use lattice/numerical techniques. A recent paper co-authored by NSF PI Gautum Rupak, "Ab initio calculation of the spectrum and structure of ^{16}O", has combined elements of both to study ^{16}O. The paper was cited as a Physical Review Letters "editor's suggestion."

The authors use chiral nuclear EFT in lattice Monte Carlo simulations they call "Nuclear Lattice Effective Field Theory" (NLEFT). The separation of scales in the problem, low momentum transfer Q over the chiral symmetry breaking scale, $\Lambda\chi$, provides an expansion parameter $Q/\Lambda\chi$ that systematically determines the importance of each possible operator. The calculation was carried out to next-to-next-to-leading order, which includes all of the considerable technology, including three body contact forces, developed for few nucleon systems. The authors find that the ground state of ^{16}O is a tetrahedral configuration of alpha clusters, providing the first ab initio evidence of what otherwise has been a model-dependent assumption. They also provided results for some excited states, in good agreement with data, to begin to map out the theoretical understanding of the structure of ^{16}O. The techniques of NLEFT show great promise for further advancing our understanding of nuclei from basic QCD symmetries.

Two-neutron radioactivity in the decay of ^{26}O.

At the NSCL a new technique was developed to measure the lifetimes of neutron unbound nuclei in the picosecond range. The decay of $^{26}O \rightarrow {}^{24}O + n + n$ was examined as it had been predicted to have an appreciable lifetime due to the unique structure of the neutron-rich oxygen isotopes. The half-life of ^{26}O was extracted as 4.5ps. This corresponds to ^{26}O having a finite lifetime and, thus, represents the first evidence for a new type of radioactivity, where the extremely neutron-rich ^{26}O nucleus decays by emission of two neutrons. This research by NSF supported PIs was reported in Phys. Rev. Lett. **110,** 15201 (2013).

Unexpected double ridge correlation at the LHC

The highly productive p-Pb runs at $\sqrt{s}$ = 5.02 TeV at the Large Hadron Collider, CERN have produced a wealth of interesting and unexpected results. Chief amongst them is the symmetrical double ridge structure, shown above, observed in high multiplicity events by Jia and collaborators on the ATLAS experiment (PRL 110, 182302 (2013))). This long-range pseudorapidity correlation, which remains after the expected short-range jet fragmentation, resonance decay, and momentum conservation contributions are removed, has also been reported by ALICE and CMS. In addition a similar feature is now observed in d-Au collisions at RHIC. The cause of these intriguing correlations remains unexplained, but a similar phenomenon is observed in heavy-ion collisions and attributed to collective hydrodynamic expansion in the thermalized, nearly perfect fluid, Quark Gluon Plasma. However, the size of the collision region in p-Pb events was expected to be too small to allow for the development of significant collective motion.

QCD calculations can provide an alternative explanation if color-glass condensate arguments are invoked, implying a saturation of the gluon density.

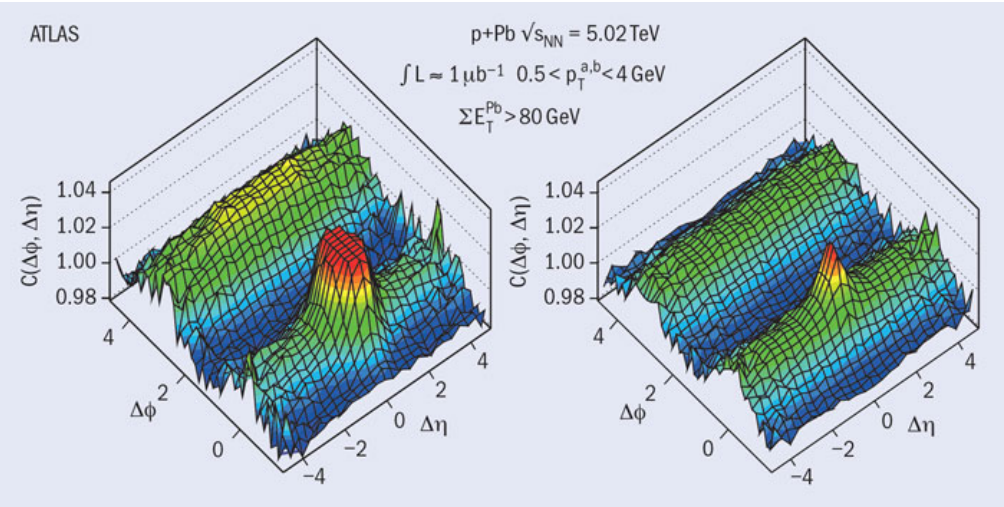


Fig. D3: At the LHC a double ridge structure is evident after background subtraction (right panel) but not before (left panel) in p-Pb collisions

<u>Responsiveness of program to previous COV comments and recommendations</u>

The program has responded well to many of the recommendations of the previous COV. However there are a few areas where the division has not carried out the recommendation of the previous COV. The last COV recommended that the division "improve demographic data and sharing." There is no evidence that any progress has been made on this issue. We believe that this is very important. While one cannot require anyone to provide the actual information, funded scientists should be encouraged (if not required) to at least respond to a request from the NSF.

The previous NP subpanel of the COV including the following language in their report: `` 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. Considerations should also be given to asking for further elaboration or clarification to points in a review when it seems unsatisfactory in some regard…"

While this recommendation was categorized as "minor" in 2012 we would like to give it greater priority in this 2015 report. The ad hoc reviewers play a critical role in the success of the NSF review process and some minimal level of feedback and mentoring could greatly improve the ad hoc reviews. The 2012 COV report went into some detail (page 50) about the inconsistencies they saw and their suggestions for improvement. We see in 2015 that some of these issues remain and that the NSF needs to do more to address them.

There was also a recommendation for outreach to undergraduate institutions, but no evidence that it has been followed up on. While the NSF only deals with proposals that they receive, and the nuclear physics program actually makes a number of awards to PUI, we propose an email to new faculty (list available from APS) to make potential PIs aware of submission dates and invite them to submit proposals.

Recommendations for future COV

The subpanel has two major recommendations for future COVs; better handling of identified COI issues and more complete information available to panelists at the outset of the process. It is understood that the data takes time to compile, hence the NSF should work on getting it together well in advance of the COV meeting date.

Three of the four panelists had significant COI issues. Two had served on panels that were under review and hence were conflicted with all of the proposals in those panels. The third was not told when first contacted about being on the COV that she would not be able to have a pending action in front of the division until the COV report had been accepted by the MPS advisory committee. This news was delivered AFTER the blackout period had begun. This has caused a snowball of implications where all of her co PIs (and subsequently their co PIs are being flagged for having a due report. Additionally there is a proposal in another division that, if chosen for funding, will not be able to be awarded once the "due" report becomes "overdue." This all could have been avoided if the panelist was informed and encouraged to submit her annual REU report between the time she was informally asked to be on the panel and the official invitation that started the blackout clock.

All jackets (not just a selection of those funded) should be made available ahead of time rather than a small selection at first and then additional ones only by request. These jackets should include declined ones. In order for the COV to legitimately provide a complete and thorough analysis of the program – in order to effectively address its charge – the COV needs more information sooner. The fact that jackets are not all electronically available to the subpanel to do preparatory work before arriving at the NSF reduced the time available for discussion during the COV.

We understand that at the moment the vetting of COI required in order to make all subcommittee-relevant proposals available to that subcommittee is a huge burden that falls on the program officers. Since we do not wish to further task the program officers' valuable time, we suggest that alternative methods of vetting be employed. For example, searching for affiliation and authorship conflicts can be automated. An additional level of scrutiny could be undertaken by an intern hired for the purpose. An alternative could be that all jackets that are under the purview of a subcommittee become accessible only to members of that subcommittee and not the whole COV. This could be supplemented with a much smaller set being available to the whole COV.

A list of all proposals, including requested and awarded funding levels (on an annualized level) should be made available in advance of the COV arrival at the NSF. The list was provided to the subcommittee after being requested.

It is also important for the COV to receive the panel rankings from all panels under consideration.

Most demographic data requested was never provided to the panel. Demographic data for all personnel involved in funded projects should be provided to the COV. While the demographic data on PIs and coPIs should be available for all submitted proposals, we recognize that data on students and postdocs may only be available once the project is funded – and may change throughout the course of the project.

Finally, we suggest that presentations made by NSF staff be more concise and focused on providing only information that will help the COV undertake their review.

Footnotes (#)
AGEP: Alliance for Graduate Education and the Professoriate
AGEP-GRS: AGEP - Graduate Research Supplements

CLB: Career Life Balance
IPA: Intergovernmental Personnel Agreement
NSCL: National Superconducting Cyclotron Laboratory
ORCID: a persistent digital identifier that distinguishes you from every other researcher http://orcid.org
URM: Underrepresented Minority
VSEE: Visiting Scientist, Engineer and Educator

E. PFC, Midscale Instrumentation, and Computational Physics

E1. Physics Frontier Centers

Introduction

The Physics Frontier Centers (PFC) program has been in existence for 13 years. It currently funds 10 Centers across the country (see the NSF webpage for links, http://www.nsf.gov/mps/phy/facilities.jsp). The PFCs are university-based centers and institutes through which the collective efforts of larger groups of individuals enable transformational advances and major breakthroughs at the frontiers of physics. The Centers are supported at levels not usually available to individual investigators or small groups. Activities span all subfields of physics supported by the Physics Division. Interdisciplinary projects at the interfaces between Physics and other disciplines are encouraged. The NSF web site says that a successful PFC must demonstrate (1) the potential for a profound advance in physics; (2) creative, substantive activities aimed at enhancing education, diversity, and public outreach; (3) potential for broader impacts and benefits to society; (4) a value-added rationale that justifies a center- or institute-like approach. The fourth element is essential to a successful proposal.

PFCs are funded for an initial six-year term (formally, five years plus a one-year extension). At the end of that time, they may re-compete for another six-year term. (There is no limit on the number of terms.) During recent years, the program has solicited proposals every three years.

The PFC program provides significant resources to a group of investigators, offering them tremendous opportunity. With that opportunity comes great responsibility, both for the investigators and for the NSF. For the investigators comes the necessity to carry out frontier research in an environment offering superb teaching and mentoring with special attention to communication and outreach. For the NSF comes the obligation to carry out the review process with care and integrity to ensure that proposals are considered in a fair and balanced way. The review process consists of three major phases: pre-proposal, full proposal, and reverse site visit. Separate panels evaluate the pre-proposals and conduct the reverse site visits. Ad hoc reviewers examine the full proposals. The process is extremely well conceived and methodical; potential conflicts of interest are investigated at each phase of the review.

We are very pleased by the superb work of the PFC program officers in running this excellent program. The officers have been successful in securing co-funding for this program from other divisions across NSF.

General Overview and Impressions from the 2015 COV

The PFC program currently funds 10 Centers. The current list is:

Started or renewed in 2011

- Kavli Institute for Theoretical Physics (UC Santa Barbara)
- JILA Physics Frontier Center (University of Colorado)
- Kavli Institute for Cosmological Physics (University of Chicago)
- Center for Ultracold Atoms (MIT)
- Institute for Quantum Information and Matter (Caltech)

Started or renewed in 2014/15

- Joint Institute for Nuclear Astrophysics (Michigan State University)
- Center for the Physics of Living Cells (University of Illinois Urbana-Champaign)
- Center for Theoretical Biological Physics (Rice University)
- Joint Quantum Institute (University of Maryland)
- One additional award is in process

During the 2014/5 cycle, four Centers were renewed, one was phased out, and one new PFC was started. The PFC program has an annual budget of $21M, approximately 8% of the Physics budget. This is consistent with the recommendations of previous COVs, which recommended that this fraction be kept at less than 10%. Two additional PFCs could potentially be funded within the 10% envelope.
The Physics Division funding is augmented by a number of partnerships, as shown in the Table below. About 20% of the total program cost is borne by eight other programs within NSF.

Table: Combined PFC Funding

Funding Source	FY2012	FY2013	FY2014	FY2015	FY2016
PFC Program	$20.6M	$21.3M	$21.3M	$21.3M	$21.3M
BIO/MCB	$1.9M	$1.9M	$2.0M	$2.0M	$2.0M
CISE/CCF		$0.2M	$0.2M	$0.2M	$0.2M
GEO/PLR	$0.02M	$0.02M	$0.02M	$0.02M	$0.02M
MPS/AST	$0.3M	$0.3M	$0.3M	$0.8M	$0.8M
MPS/CHE	$0.25M	$0.25M	$0.35M	$0.35M	$0.35M
MPS/DMR	$1.58M	$1.28M	$1.31M	$1.31M	$1.31M
MPS/OMA				$2.0M	
MPS/PHY - Other	$2.0M				
Total	**$26.7M**	**$25.3M**	**$25.5M**	**$28.0M**	**$26.0M**

Table E1.1

These partnerships extend the PFC impact far beyond the field of physics. They allow the PFCs to serve as ambassadors from physics to the broader science community.

The 2015 PFC subcommittee did not have the time, expertise or information to do a comprehensive review of the PFC program. Nevertheless, it was clear that the PFCs are extraordinary. They carry out important research, attract first-rate students and generate positive press for the physical sciences. The Division receives far more quality proposals than can be funded.

Given the impact of the Centers – on science and on the Division's budget – we repeat the call of the previous COV for an external review of the PFC program. Our charge was to evaluate process, and in that regard the program comes through with flying colors. However, there is much more to the story. We believe that the Center program would benefit from a dedicated comprehensive review by a high-level body with the time, access and expertise to evaluate the PFC program. One would like independent confirmation that the PFCs add value in a way that individual investigator grants do not. Are the claims of synergy justified? And if they are, should the fraction of the Physics Division budget be increased? These are questions we were not equipped to address, but clearly need answering.

Integrity and Efficiency of the Program Process and Management

Since the previous COV, the program issued one solicitation for Centers to start in FY14. Forty-six pre-proposals were received and reviewed. Based on panel rankings and discussions between all Physics program directors, the NSF invited 14 groups to submit full proposals. The full proposals were sent for ad hoc individual reviews. Based on the reviews and discussions among all the program officers, NSF invited 10 groups to present their proposal to a panel at a reverse site visit.

The COV looked in detail at 7 jackets. The COV found that individual reviewers were careful to address the two NSF criteria. Most discussed the critical "value-added" component of the proposal. The reviewer comments varied in their level of detail. Some of the reviewers gave extensive commentary on the proposal; others provided more summary comments. Independent of style, however, it was clear that NSF received valuable and incisive critiques to assist their decision-making. The ad hoc reviews were generally consistent with one another, so the feedback represented real and valuable information for the PI and for NSF.

Likewise, the records of the panel reviews were 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 important, and the panel was attuned to that criterion as a primary metric by which a PFC proposal would rise or fall. The reasoning was clearly communicated in the panel consensus.

The program directors should be commended for designing and maintaining a review process of the highest quality. At each stage, choices were made thoughtfully and carefully, and the program directors were clearly respectful of the scientific judgment of the external expert reviewers.
The program is managed rigorously and well. As a consequence, the PFCs have established themselves as an invaluable feature of the overall Physics program. There is a well-established oversight regime 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 after year two, and another after year four. All help identify possible issues in Center operations.

It is important for the Division to remain vigilant so that the Centers do not become entitlements, unfairly leveraging their history and momentum in competitions. So far, 4 of the 14 Centers have not been renewed, which provides evidence that the system works to some degree. Whether 4/14 is the correct fraction is an issue for the external review to consider.

The 2012 PFC subcommittee noted the "striking" fact that of the 10 ongoing Centers, 4 are focused in "Quantum Many-Body/Quantum Information" (Maryland, MIT, JILA, Caltech). The subcommittee concluded that the situation reflects the fact that the NSF takes a "free-market" approach to science, with intrinsic excellence its primary metric for funding. Whether the portfolio of PFCs requires more shaping is another issue for the external review to discuss.

Intellectual Merit

The PFC program is intended to catalyze transformational advances that might not be possible with individual investigator grants. While its success should be evaluated by the external review, some recent results include:

2014 - JINA: Neutron Star Cooling
"Strong neutrino cooling by cycles of electron capture and beta-decay in neutron star crusts,"
H. Schatz, S. Gupta, P. Moller, et al., Nature 505, 62-65, 2014.

Neutron stars are excellent laboratories for studying the properties of dense, nuclear matter. Recent observations of accreting neutron stars show surface temperatures that are much hotter than expected. These observations have motivated the study of the detailed physical processes involved in heating and cooling neutron star crusts. A cross-disciplinary team of JINA researchers, including astrophysicists and nuclear physicists, has developed a model that includes the full electron capture and inverse beta-decay cycles for neutron-rich nuclear species at finite temperatures throughout the neutron star crust. The resulting rapid neutrino cooling forces fundamental changes in the current understanding of thermonuclear bursts on the surface of neutron stars and observations of cooling neutron stars.

2014 - JILA: Light-Conversion Devices
"Bidirectional and efficient conversion between microwave and optical light,"
R. W. Andrews, R. W. Peterson, T. P. Purdy, K. Cicak, R. W. Simmonds, C. A. Regal, K. W. Lehnert, Nature Physics 10, 321-326, 2014.

At JILA, a cross-disciplinary team, led by Regal and Lehnert, is developing a device that reversibly converts low-frequency microwave light to high-frequency infrared or visible light without losing any information. At the heart of the device is a silicon nitride drum that can "talk" to both microwave and optical light. Infrared laser light passes through the drum near, but not touching, a miniature electronic circuit. Microwaves in the circuit cause the drum to vibrate, which alters the phase or amplitude of the laser light. Conversely, changes in the phase or amplitude of the laser light cause the drum to vibrate, producing an electrical signal that encodes the information in microwave light. The next step is quantum state transfer between microwave and optical light.

2013 – CPLC: HIV Structure
"Mature HIV-1 capsid structure by cryo-electron microscopy and all-atom molecular dynamics,"
G. Zhao, J. R. Perilla, E. L. Yufenyuy, X. Meng, B. Chen, J. Ning, et al., Nature 497, 643-6, 2013.

The human immunodeficiency virus (HIV) capsid enters the cell and engages cellular proteins to guide it towards the cell nucleus, helping HIV integrate its genes into the host genome. Schulten and Perilla, who was recruited through the CPLC postdoctoral fellowship competition, in collaboration with researchers at the University of Pittsburgh, succeeded in resolving the atomic structure of the capsid. In a series of 64-million-atom simulations, the largest ever carried out and published, they studied the properties of the capsid and discovered that the 1300 capsid proteins show a significant conformational variation despite their identical sequence.

2013 – CUA: Two Photon Molecule
"Attractive photons in a quantum nonlinear medium,"
Firstenberg, Peyronel, Liang, Gorshkov, Lukin and Vuletic, Nature 502, 71-75, 2013.

Researchers at the Center for Ultracold Atoms, led by Lukin at Harvard and Vuletic at MIT, have demonstrated a quantum nonlinear medium in which photons behave as molecules, defying conventional wisdom that photons don't interact. In an ultracold gas of atomic rubidium, individual photons travel as massive particles with strong mutual attraction, such that the propagation of photon pairs is dominated by a two-photon bound state. This discovery could enable a wide range of optical communication and computing applications.

Broader Impacts

The PFCs have a responsibility not only to do great science, but also to have great impact. The PFCs stand as pillars of excellence in the Division's portfolio. The broader impacts must match that level of scientific excellence.

The PFCs attract excellent students, but the COV was presented no data on whether PFC student outcomes exceed those from individual investigator grants. Likewise, the COV was presented no data to demonstrate that the PFC student body is more diverse than the general student body across the Division. When access to the data was discussed with the COV, it became apparent that the program officers do not have the tools to answer these basic questions. It is imperative that NSF improve its systems to allow easy and rapid retrieval of information about its programs. Having data that would help PIs and program officers analyze and identify best practices and provide a positive feedback mechanism for the PFCs to build upon success.

Research shows that students need support and mentorship, especially students from minority and less privileged backgrounds. A PFC offers the possibility of creating cohorts of such students, supporting each other and moving through the program together. The Division should consider the possibility of jump-starting such a PFC, perhaps at an HBCU, and perhaps with an industrial or laboratory partner, with a primary focus on broadening participation. Such a PFC has the potential to have real success.

The PFCs represent a great resource to the Division. They have sufficient funding to experiment with fresh approaches to broadening participation. The subcommittee was pleased to learn that each Center is being asked to write a formal diversity plan, and to execute against its plan. If the Division enforced some common metrics across Centers, outcomes could be compared and the most promising approaches adopted more broadly. The subcommittee was happy to hear that the Center directors meet periodically to share experiences and learn from each other.

Going forward, it would perhaps be helpful if Center communications and outreach coordinators were to meet and form a network as well. That way the PFCs could serve as a distributed "laboratory" for "experiments" in communications and outreach, with best practices being shared across Centers.
In each case, the subcommittee believes that the lessons learned by the PFCs could be propagated to other investigators supported by the Physics Division, and perhaps even more broadly across NSF writ large.

Recommendations

- We recommend that the Physics Division charge an appropriate high-level body to conduct a retrospective review of the PFCs, outside of the context of a funding competition for renewal and new starts. This is a repeat recommendation from the last COV.
    - The charge should identify (i) the research breakthroughs that can be attributed to the Centers; (ii) the broader impacts of the Centers; and (iii) any other items that are clearly attributable to the structure and coherence of a PFC.
    - With the input from this retrospective review, the NSF should revisit the issue of the appropriate level of funding for the PFC program, being open to the possibility that the number might grow.
- We further suggest that the Physics Division use the PFCs as laboratories to explore the most effective ways to broaden participation and communicate effectively. The Division should continue to seek ways for the PFC directors to learn from each other, and at the same time, transmit that learning to the broader community.

The Division should consider pro-actively jump-starting a PFC aimed squarely at diversifying the nation's talent pool. Such a PFC would be in line with the NSF's broader mission of service to the nation.

E2. Midscale Instrumentation

The Midscale Instrumentation Fund (MIF) was created from the Accelerator Physics and Physics Instrumentation (APPI) Program, which no longer exists. The MIF has existed for about a year. This program's explicit purpose is to provide essential, one-time funding for instrumentation that enables NSF to maximize the productivity of NSF researchers who are participating in large-scale experimental projects.

The potential funding envelope for the Fund lies between the maximum for the Major Research Instrumentation (MRI) program ($4M) and the minimum for the Major Research Equipment and Facilities Construction (MREFC) program ($130M in the Physics Div.). A Dear Colleague Letter (http://www.nsf.gov/pubs/2014/nsf14116/nsf14116.jsp) has been issued to the community outlining the elements of the program. Requests for resources from the Fund arise only in conjunction with a proposal to a disciplinary program in Physics as part of larger project: there is no direct access to this Fund by proposal. The disciplinary program reviews the scientific merit of the proposed activity and the Program Officer will make an application for resources from the Fund as needed. The disciplinary program is responsible for funding any research and development prior to the acquisition of the instrumentation and for providing any operations funding.

The current awards for the Midscale Instrumentation program include nEDM, the CMS phase 1 upgrade, the ATLAS phase 1 upgrade, the upgrade to LHCb. Planning in currently under way to understand likely requests in the out-years.

As a funding mechanism to bridge the 'valley of death' between the $4M MRI cap and the $130M MREFC minimum, the Midscale Instrumentation Fund is well oversubscribed at the current levels. The program is fully encumbered through FY18 with quite a few projects known to be in the pipeline. The current level of funding restricts the use to opportunistic participation in large-scale projects that are primarily funded by other agencies or entities. Given the scale of projects that are in the planning stages and the need for the NSF to respond to a changing landscape from scientific discovery, anticipating needs and planning for the out-years with in an increased budget seems essential.

The Midscale Instrumentation program has benefited some communities within the Division more than others, while other programs such as PFCs are better tuned to other communities. Having a variety of models affords the Division flexibility and there is a conscious effort to balance the needs of theory and experiment.

NSF Physics is to be congratulated for establishing this <u>vitally important program</u>, especially during tight budget times. Instrumentation costs are continuing to rise, so the demand for this program will grow. The program is currently being managed with the expertise and experience to plan for the future, working directly with the program directors, and to establish robust transparent procedures for selection and review and for cost control.

One concern that is seemingly hard to resolve is the very wide funding span presented by the range for this fund: $4M to $130M. With an annual budget that is approximately twice that of the lower limit of the fund, this makes it problematical to award funding for projects higher than

even 25% of this span. This is the one area that was not successfully addressed from the 2012 COV recommendations. Funding projects in this range is an NSF wide issue.

Recommendation: The Division should seek funding to increase the resources available for the Midscale Instrumentation Fund.

Broadening Participation (Diversity)

The Physics Division has funded a number of programs that include proposed activities designed to improve participation in underrepresented groups (both for gender and minority involvement). This is especially true for the Physics Frontier Centers. Many of the COV members found that the lack of reliable and timely demographic information about participation these programs made it difficult to measure the efficacy of these programs in improving underrepresentation.
The problem associated with this scarcity of data is tied to several key constraints in the system: PIs may not directly report the demographic information of the group being funded; emails that are sent to the individual participants requesting demographic information are not sent in a timely manner due to the fact that the trigger for sending these email wait until a report is sent to NSF after the grant is completed; and the lack of good tools to aggregate and disseminate the data collected to the relevant program offices/directors.

The Committee recognizes that there are a number of obstacles presented by privacy laws and regulations; however, a mechanism to solicit this information directly from the participants exists. This is done via an email sent from the Foundation to the individual as named by the PI as participating in the awarded program. The level of participation is low, perhaps due in large part to the timing of the distribution of these emails, weeks after the program is completed. If the triggering event were changed, to a date when the person starts the participation in the program, it seems that the person is more likely to respond.

Recommendation: Consider moving the triggering event to submit a participant's name and email address when the person starts on the project, not after it is over.
When access to the data on the part of the program officers and directors was discussed with the Committee, it became apparent that the tools provided were inadequate for this task. This is due to a variety of reasons, including of systems not being connected adequately and software that is readily available.

Recommendation: Consider improvements the data acquisition, transfer and display systems to facilitate easy and rapid retrieval of data on diversity for funded programs. Having data that would help analyze and identify best practices that enhance the participation of underrepresented groups, potentially providing a positive feedback mechanism to build upon success.

We do note that this topic was addressed in the 2012 COV report. The response to this as written in the response from the Division (*PHY_Response_to_1012 PHY_COV_report_FY13_update.pdf*, p. 11) is as follows:

> With regard to data collection and sharing, the Division appreciates the comments from the panel but is not in a position to undertake any action beyond passing the comments on to the Division of Information Systems, which is the NSF body responsible for maintaining the NSF database.

In retrospect, this answer has not proven to be a very effective strategy. The Committee urges the Division to take a leadership role in driving this issue to completion with the Division of Information Systems, perhaps by getting aid from high-level administration to make this a priority.

E3. Computational Physics

Digital technology is playing an increasingly important role in scientific discovery. Computer and digital technologies are essential for collection and "automated" analysis of experimental and observational data sets that are collected by large-scale experiments. A good example is the discovery of Higgs Boson at CERN in 2012. This work confirmed theoretical predictions made in 1964, work that was awarded the Nobel Prize in 2013. Additionally, ever increasing computational power 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.

To support the use of digital technology for frontier physics, the NSF Physics Division has long supported a Computational Physics Program (CP), in part through the Physics at the Information Frontier/Computational Physics (PIF/CP) program. PIF/CP is the PHY representative in the Computational and Data-Enabled Science and Engineering (CDS&E) program. The CDS&E program crosses multiple divisions within the Directorate for Mathematical and Physical Sciences (MPS), the Directorate for Engineering (ENG), and the Division of Advanced Cyberinfrastructure (ACI) in the Directorate for Computer and Information Science and Engineering (CISE).

(The second PIF component is Quantum Information Science, which is covered by a different sub-panel) The Computational Physics program has evolved significantly over the several years, moving towards a closer coupling to the other PHY programs and the attendant science. This is welcome and should be continued. In FY12, the CP Program Directors were Bradley Keister and Pedro Marronetti. In FY13, Bogdan Mihaila became the CP Program Director as a 50% time commitment. As an active researcher using computational methods, Dr. Mihaila brought a wealth of experience to the management of the program. Since his appointment, Dr. Mihaila has worked to connect the CP program to the other physics program areas and to engage the other PHY Program Directors. As noted above, Dr. Mihailia is also working across the foundation with CISE Program Directors. As the program has been evolving, although we received information for FY11-FY14, we focus our comments on FY14.

Characteristics of the Computational Physics Program:
This program aims to facilitate scientific discovery by developing novel algorithms along both theoretical and experimental lines of inquiry, while also exploring the utilization of state-of-the-art computational architectures. Ultimately, this program is positioning itself to make strategic investments that will encourage new numerical approaches. There are scientific problems for which there currently are no tractable computational solutions. This program would provide the opportunity for researchers to take tackle high risk, high reward numerical challenges that are relevant for scientific progress. We note that there may be considerable intellectual value in understanding computational approaches that did not result in breakthroughs and the strength of this program would be enhanced by the dissemination of such work. The members of this subpanel applaud the concept having part of the program invested in innovative approaches.

Since by construction, this program focuses on proposals that are driven by new science and techniques, the Computational Physics program does not fund long term software sustainability. If the research in the computation method proves worthwhile, it is intended that more domain-based or infrastructure-based programs will fund the longer-term life of the code base. It is worth stressing the distinction, as it appropriately places the focus of the CP program on cutting edge scientific advances.

Budget:
The program has two funding allocations: the PIF-CP account and a direct Computational Physics line. Between the two funding allocations, the budget for computational physics is approximately $3M/year. Additionally, the Data [FY12] (DASPOS) [FY12], the SSI [FY13] and the Open Science Grid (OSG)[FY14] were awarded through Computational Physics with funds beyond the base allocation. It would lead to some simplification in administration and transparency to combine the PIF-CP account and the Computational Physics funding lines.

The review and solicitation process was changed during FY14. Due to the cross cutting nature of the Computational Physics Program, it is appropriate to gather proposals from multiple sources. One is a direct solicitation, the other via referral from the other PHY program directors. From the perspective of Computational Physics, the proposals are then reviewed in a single consistent process of mail in-reviews followed by a panel review of the proposals. In order to insure comprehensive expertise on the panel, the CP program director works extremely closely with the other PHY program directors to select a team of qualified reviewers who can span all areas of expertise. The PHY program directors are invited to take place in the entire process, including observing the panel deliberations, discussing the ranking and participating in funding decisions. Participation has been strong and much appreciated by the PHY program directors.

The FY14 awards have led to a portfolio that features the development of novel algorithms to enable new science in the fields of study within the purview of the Physics Division. The Computational Physics Program portfolio is as naturally diverse as the portfolio of the Physics Division. Supported programs include Modeling for Gravitational Waves, Particle in Cell codes, Lattice QCD calculations, Multidomain Multiscale Simulation of the Coupled Maxwell-Schroedinger Equations, Worm Algorithm and Diagrammatic Monte Carlo in Atomic and Condensed Matter Physics, and Computational Nuclear Many-Body Physics. An interesting new element into the portfolio is the inclusion of the development of novel algorithms for non-grid analysis of data or virtual organization software associated with LIGO and LHC. Keeping in mind the future, there is also the development of novel algorithms to take advantage of state-of-the-art computational architectures. As a note, the FY14 awards included 10% self-identified women. While small statistics and short time scales, we were pleased to see to the information tracked and presented.

The program management appears to be excellent. We reviewed 22 jackets and 13 declines and found that the NSF Merit Review Criteria were applied uniformly. Overall, within Computational Physics in FY14, 24 proposals were received, with 7 awards. One obstacle in a cross cutting program such as this is that the reviewers can have very different perspectives on the merit of the proposed work, sometimes because the proposals aren't written for the broad audience or different disciplines have different conventions. It is vitally important to give clear feedback after the review process, particularly for the cases when the proposal evaluations scores span the full dynamic range.
The proposal and review process for FY14 was superb and insures that the Computational Physics Program has broad relevance to the rest of the Physics Division. The success of this approach has moved the program's center of gravity into the Physics Division, as was apparent in the large number of PHY co-funded awards. Computational Physics co-funded 18 awards in FY14.

Given that the program changes are relatively recent, it is too soon to evaluate their impact, although the direction of the program and the engagement of the other program directors is something that this subpanel found extremely exciting. We strongly suggest that before the next COV the program directors give thought to success criteria for the program as the traditional measures and metrics might not apply, or worse, might understate the importance and impact of the Computational Physics program.

Broader context within NSF:
The NSF wide initiative ‘Cyberinfrastructure Framework for 21st Century’ (CIF21) will end in FY16. The goal of the initiative is to “provide a comprehensive, integrated, sustainable, and secure cyberinfrastructure to accelerate research and education and new functional capabilities in computational and data-intensive science and engineering, thereby transforming our ability to effectively address and solve the many complex problems facing science and society."

The committee notes that given the increasing importance of the topics covered by the initiative, and the current emphasis on moving towards exascale class computing (which may lead to petascale computers ‘down the hall’ for some researchers), resources to achieve scientific progress, reduce duplication of efforts and observe best practices are essential for maintaining, developing, and promoting the state of the art in high performance computing.

F. Particle Astrophysics

The Particle Astrophysics subcommittee report comprises three main sections. The first section describes the program process and management in response to parts (a) and (b) of the CoV charge. The second section, responding to parts (c) and (d) of the CoV charge, provides highlights derived from the portfolio investments while the third section, responding to part (e) of the CoV charge, details comments and recommendations by this subcommittee of the CoV in the context of recommendations made by the previous CoV as well as significant current issues.

1. Program Process and Management

A. Effective use of the merit review procedure

CoV review of jackets

A total of 39 "jackets" were reviewed during the CoV process for the PA subcommittee: 20 award jackets (16 selected by program officers, 4 selected by CoV panelists for sampling); 19 declines selected by program officers. The award jackets were reviewed prior to arrival for the CoV meeting at NSF while the declines were reviewed at NSF. The jackets reviewed represented a cross-section of the full range of issues the program officers work with including the various review processes (panel, ad-hoc, site and special); management of conflict of interests; renewals and new actions; proposals submitted in response to CAREER, RUI, Dear Colleague Letters (DCL) and those that were co-reviewed and/or co-funded by other programs within Physics, within the agency or cross-agency. The reviews by the CoV panel members encompassed cases that were very clear-cut in both award and decline rationale as well as many reviews of cases where the decisions were not as clear-cut. For the latter, this involved situations for example where there may have been a wide range of ad-hoc review grades, or the proposal was in the "fund-if-possible" category but there were insufficient funds in the program to make an award, or there was input from separate review panels) where the panels arrived at very different rankings. There was one particular case where the proposal was declined and a reconsideration of the proposal was performed by request of the PI; the declination was ultimately upheld. The CoV panel looked in great detail at these declines (as well as some of the less clear-cut awards) and in each case determined that they conformed at the highest levels to the merit review process.

Jacket documentation

For the awards reviewed, in most cases, the documentation in the jackets was sufficient to determine why specific actions were taken when the PO review analysis and panel rankings were considered. The decisions for the bulk of the awards were appropriately communicated to the PI when the context statement, panel summary and ad-hoc reviews are considered. For specific proposals requiring special cross-agency (or cross-division) panels and/or site visit reviews, the additional documentation was sufficient to determine why specific award actions were taken. For declined proposals however, there were cases, especially where specific actions were recommended for the PI by the review panel, where it was unclear from the jacket whether these recommendations had been communicated to the PI or not. In addition, in cases where it was abundantly clear to the sub-committee that the decline was solely due to lack of funds, there was not enough information in the jackets to determine whether this information was communicated to the PI. It was felt by the CoV subcommittee that this information was important for PIs to know, especially during difficult budgetary times.

Review process and actions

The main review process utilized by the POs for a proposal submitted to PA is a combination of ad-hoc and panel reviews. Special panels and site visit reviews are initiated at the PO's discretion (see below). In 2013, due to the growing number of proposals submitted to the program (a 23% increase between 2012 and 2013 alone), the POs implemented an NSF-piloted, asynchronous review process. Instead of setting up one panel to discuss the merits of ~60 proposals on site in three days, the asynchronous process allowed for the discussion of the proposals to begin one week prior to the face-to-face meeting through a Sharepoint site specifically set up with prerequisite security features. The feedback from the panelists indicated that this increased the efficiency of the face-to-face meeting significantly although there were considerable complaints about the actual technological implementation. **This CoV subcommittee would like to note that we see this review mechanism as a real step forward and would like to encourage the agency to support this mechanism by enabling appropriate technology.**

In 2014, the number of panel-review proposals had increased to 70 and the program officers decided to implement two separate panels where each panel had a reduced number of reviewers compared to previous single panels. One panel comprised reviews of underground projects while the other panel reviewed the "above ground" portion of the PA portfolio. The CoV subcommittee discussed with the POs the impact of this split on the quality of the review process finding that while the split did decrease the breadth and diversity of viewpoints found in the single, larger panels, the reviewers for the separate panels could be more focused on the prevailing techniques appropriate to each panel.

Special panels and site visit reviews

For proposals whose budgets are in excess of $1 million, it is appropriate to request review through special panel(s) or site visit reviews, depending on the stage of project development. As the PA program has one large facility (IceCube) and several projects with significant proposed or ongoing construction or operations costs and/or potential overlap with other divisions or agencies, the program officers must spend a significant amount of time and effort organizing special panels and on site visits and reviews. **It is critical that the agency recognize this important work for optimizing the PA portfolio and continue to enable these review channels.**

In FY2012, a special panel was convened to review proposals in response to a Dear Colleague Letter (DCL) that was announced with the purpose of redirecting the funding of detector development and related activities in underground physics to be non-DUSEL specific after the roll-off in funding for DUSEL completed. In FY2014, a special solicitation for Direct Detection Dark Matter (DDDM) project proposals was issued in conjunction with DOE-HEP

B. Program's use of the NSF review criteria

With very rare exceptions, PA proposals and reviewers explicitly and adequately address the Broader Impact criterion required as part of the NSF grant review process. PA POs provide clear and concise instructions to all reviewers (ad hoc and panel) about the intended broad and inclusive meaning of the NSF Broader Impacts requirement. PA panels explicitly address the Broader Impacts of a proposal in their formal meetings and a concise summary of those discussions is included in each proposal jacket.

C. Reviewer selection

Reviewer selection is at the heart of the merit review process and thus significant effort is spent making sure that each proposal has the correct review type (ad-hoc, panel, site, etc), sufficient number of well-

qualified reviewers who, critically, do not have any conflicts of interest with the proposal. We commend the Particle Astrophysics POs for carrying this duty out diligently and effectively as the review of the jackets demonstrated. Further, we applaud their creative use of reviewers outside the division such as NSF-AST, from other agencies such as DOE and NASA and even international reviewers where appropriate. Finally, we note that the POs are paying attention to critical details such as the diversity balance of panels and have started the practice of, where appropriate, inviting new and/or young investigators to participate on review panels. This not only serves to broaden the perspectives on the panels but also acts as a mechanism to educate these promising new investigators on the process.

D. Resulting portfolio of awards

Given the complexity of balancing the various kinds of input from the diverse elements of the review process with the available advice from various external committees such as P5 (see below), it is remarkable that the resulting portfolio of awards remains, on the whole, very balanced and broad. While all subfields represented in PA could certainly use more support, the unfortunately restricted resources have been divided in what the CoV subcommittee feels is a very fair manner with respect to the importance of the science that needs to be done. PA has to deal with experiments going from eV energies to the highest ever observed and with a concomitant breadth in range of instrumentation and research group size. The balance that has been achieved is confirmed by the breadth of the important scientific results highlighted below, which range from reactor measurements of neutrino oscillations, the first definitive observations of cosmogenic neutrinos, the detection of gravitationally lensed B-modes in the CMB, increasingly sensitive limits on direct dark matter detection and important results from TeV gamma-ray astronomy and ultra-high energy cosmic ray physics.

The full list of awards, withdrawals and declinations, including collaborative, CAREER, and MRI submissions; and the submissions related to the Dear Colleague Letter of 2012 and the Direct Detection of Dark Matter solicitation in 2014, shows that over the past three years the PA acceptance rate is down substantially (~40%) compared to previous COV review period. The change reflects the impact of budget cuts and the overall monotonic increase in the number of submitted proposals from 126 in 2012 to 158 in 2014.

Supplements were not counted in the above exercise however the subcommittee looked in detail at the fraction of total dollars in the PA program going to supplements (small) and determined that supplements were awarded appropriately after careful consideration by the POs.

Size of awards

Given the severe budgetary constraints during the review period, the sub-panel was concerned that PA awards were reduced in some cases to near-threshold, but recognized the importance of cutting awards from requested amounts in order to fund a larger number of excellent proposals that otherwise would have been declined purely for budgetary reasons. It was noted that even with the decreased funding levels of most awards given, 8 out of 63 (or 12.7%) of the proposals ranked in the “high-priority” category in 2012-2014 recommended by PA for funding were not able to be supported. The POs were commended for their creative and collaborative approach to funding as many excellent proposals as possible in difficult budgetary times.

Distribution of awards across institutional type and underrepresented groups

The CoV subcommittee looked at the distribution of awards from PA across underrepresented groups as well as across institutional type. For the distribution across institutional type, we carefully analyzed the number of awards relative to the number of submitted proposals for each of the three fiscal years 2012,

2013, 2014 and found that while there were a high number of awards given to Research Universities with Very High levels of research activity (RU/VH - formerly known as Research 1 institutions[1]), we found that the number of awards for each institution type tracked reasonably well with the number of submissions.

Likewise, for underrepresented groups, the subcommittee looked at information voluntarily provided by PI's and Co-Is that identify gender and ethnicity. We analyzed the number of awards relative to the number of submitted proposals over the three fiscal years concerning this CoV. We found that the percent funded tracked reasonably well with the percent submitted.

Broader Impact

It is clear from the award histories, reviews, panel summaries and PA staff award recommendations that PA considers Broader Impacts an important Merit Review criterion for each proposal it reviews. As examples, the PA award portfolio includes support for the QuarkNet project, a long-standing widely distributed program that provides teachers with experiences and resources to promote the understanding of the process of research; the Astrophysics Science Project Integrating Research and Education (ASPIRE) program that develops internet-based resources for middle-school teachers and students that provide interactives integrated into lesson plans on a wide range of STEM topics and Adler Planetarium's "Astronomy Conversations" project that enables museum visitors to engage in discussions with scientists, including those working on the South Pole Telescope, through a variety of visualizations of cosmology and astrophysics.

Overall Management of the Particle Astrophysics Portfolio

The PA program is primarily overseen by Jean C. Allen and Jim Whitmore with some assistance in the past three years by Saul Gonzalez (Permanent Employee), Randy Ruchti (IPA from Notre Dame) and Jim Shank (IPA from Boston University). The committee commends the team, in particular Allen and Whitmore, for an extraordinary job in very difficult budgetary circumstances. Our judgment is based on a careful evaluation and study of the statistics of awards, the individual award jackets, the past three years of PA reports and a discussion of relevant issues with them. The PA program continues to grow with increased number of proposals (from fewer than 50 proposals/year for panel reviews in 2012 to more than 80 in 2014) and increased size and complexity of experiments. At the same time, the program budget has decreased (from ~28 to 20 M$). The approach they have taken requires an effort to end certain projects in order to start others while simultaneously following advisory committee recommendations. The importance of fair and scrupulous review and judgment by the Program Directors in balancing the ad-hoc and panel reviews with available funding and NSF priorities cannot be overstated, and the subcommittee strongly believes that the current management team is performing this balancing act with great skill.

2. <u>Outcomes of Program Investments-Science and Technical Highlights</u>

In the following, we highlight several discoveries or important science outcomes from the PA program investment. We also present several important new experimental facilities, tools or new techniques that will have (and in most cases already have had) a major impact on the field of particle astrophysics.

[1] http://en.wikipedia.org/wiki/Carnegie_Classification_of_Institutions_of_Higher_Education#Doctorate-granting_Universities

IceCube: ***Observation of extra-atmospheric neutrinos***

Fig. F1

The IceCube detector is a large array of optical sensors located at depths of 1.5 to 2.5 km in the glacial ice near the South Pole and is the major NSF facility supported through PA. The completion of IceCube, with the final string-of-detectors deployed in late 2010, has transformed the field of high-energy neutrino observations by significantly increasing the sensitivity to neutrinos from TeV to PeV and EeV energy scales. 28 high-energy neutrino events were found in data collected from May 2010 to May 2012 and a clear indication of a deviation from the steeply falling atmospheric neutrino spectrum was found with two events reaching energies of 1 PeV. Nine more events were recently found in data from 2012-2013 in the same energy region. The total signal now rejects a purely atmospheric origin hypothesis at the 5.7 sigma level and thus constitutes a discovery. The observed flux is consistent with being isotropic and equal-flavor E^{-2} power law spectrum in agreement with expectations. Events fall into two categories: contained events consistent with being produced by electron neutrinos; and horizontal and upward-going muons produced by muon neutrinos. The latter have good angular resolution and will make the search for neutrino point sources much easier. This is the culmination of the first part of a monumental effort, whose origins go back to the 1970's and finally heralds the real beginning of neutrino astronomy. With this knowledge of the extra-atmospheric neutrino flux, realistic plans for expansion of the IceCube observatory and ancillary experiments can now develop and more precise physics goals can be delineated.

HAWC: ***Completion of a New Gamma-ray Observatory***

Fig. F2

The High-Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory has begun full operations at its site in Mexico. HAWC is designed to study the origin of very high-energy cosmic rays and will search for signals from dark matter and from some of the most extreme and energetic objects in the known universe, such as super-massive black holes and exploding stars. It is a high-duty cycle, large field-of-view instrument capable of monitoring the gamma-ray sky between roughly 50 GeV and 100 TeV, an energy equivalent to a billion times the energy of visible light. The observatory uses an array of water-Cherenkov detectors to record both steady and transient gamma-ray sources and to provide an unbiased survey of the northern sky. In recent years, the Fermi Gamma-Ray Space Telescope, which detects photons with energies up to 300 GeV, has provided a tremendous wide-field map of the gamma-ray universe, and identified hundreds of point sources that have been studied in detail by non-survey telescopes. HAWC will provide a similar all-sky gamma-ray map up to 100 TeV. The HAWC Collaboration has already reached one of their

milestones: the observation of the Crab Nebula at > 10sigma. HAWC will work cooperatively with TeV point-source telescopes like VERITAS, HESS and MAGIC.

VERITAS - ***Observation of Pulsed TeV Gamma-Ray Emission from the Crab Pulsar***

VERITAS, located in Arizona, is a ground-based array of four 12-m telescopes sensitive to gamma rays with energies above 100 GeV. The major construction was completed in Fall 2007 and was recently upgraded through an NSF MRI-funded project that was completed in Summer 2012 replacing all VERITAS PMTs with higher quantum efficiency versions. Among many significant observations and discoveries, the VERITAS Observatory recently detected emission from the Crab pulsar at energies above 100 GeV, much higher than predicted by current pulsar models. The Crab pulsar is one of the most powerful and extensively studied pulsars, yet the VERITAS experiment produced a significant surprise: pulsed gamma-ray emission with energies above 100 GeV cannot be explained by the current models of pulsar emission. These VERITAS measurements, enabled by the recent upgrade, therefore provide important new constraints on models for how pulsars accelerate material to generate high-energy radiation. The VERITAS upgrade was the first use of large production super-bialkalai photomultiplier tube technology. The manufacturer thus gained experience in the refinement of the photomultiplier tube manufacturing process, including reduction in noise levels in the tubes, and increased photocathode uniformity. The technology developed for the large-scale production and test of the photomultiplier tubes may have a significant impact on the capabilities of next generation CAT and PET scanners, which use similar photomultiplier tube technologies.

Telescope Array: ***Indication of a "hot spot" in the arrival directions of the highest energy cosmic rays in the northern hemisphere***

The Telescope Array experiment utilizes a hybrid technique (air-fluorescence telescopes together with a 700 km^2 array of scintillation counters) to study the spectrum, composition and anisotropy of the highest energy cosmic rays. Data recorded by TA between May 11, 2008, and May 4, 2013 yielded 72 cosmic rays with energies greater than 57 EeV. They report on a cluster of events that they call the "hotspot," found by oversampling using 20 deg radius circles. This hotspot, located beneath the Big Dipper, and approximately 19 degrees from the super-galactic plane, was emitting a disproportionate number of the highest-energy cosmic rays. 19 of those cosmic rays were detected coming from the direction of the hotspot (representing 6 percent of the Northern sky), compared with only 4.5 that would have been expected if the cosmic rays came randomly from all parts of the sky. The probability of a cluster of events with this significance appearing by chance in an isotropic cosmic-ray sky is calculated to be 1.4×10^{-4} (3.6σ). An additional year of data has been analyzed and the significance is now at the 4σ level. This indication moves us another step toward identifying the mysterious sources of the most energetic particles in the universe and provides a strong impetus for an improved effort to study the origin of UHECRs.

South Pole Telescope: ***First observation of B-mode CMB polarization***

Fig. F3

The South Pole Telescope (SPT) at NSF's Amundsen-Scott Station is optimized for low-noise, high resolution imaging surveys at millimeter and sub-millimeter wavelengths to observe the Cosmic Microwave Background (CMB). The research being pursued with the SPT addresses some of the most basic and compelling questions in science. The project consists of three major instruments. The first is the SPT-SZ camera survey, which produced the 2500-square-degree SPT-SZ survey, completed in late 2011. The second is the SPT-POL instrument, installed in 2012, which improves over SPT-SZ in raw sensitivity, and, most importantly, is capable of measuring the polarization of CMB radiation. Analysis of the 2012 SPT-POL data produced a major scientific milestone: the detection of B-mode polarization in the CMB. Working with combined data from the Herschel Space Observatory, SPT was able to find a 7-sigma B-mode polarization in the CMB due to the conversion of the larger E-mode signal by gravitational lensing. This has significant implications for cosmology and constraints on neutrino mass as well as establishing a base line for searches for B-mode polarization due to inflationary gravitational waves. The third phase SPT-G3 camera is expected to be installed in the 2015/2016 austral summer with the aim of increasing the mapping speed by an order of magnitude and delivering a gravitationally-lensed B-mode map among many other cosmological studies.

Dark Matter Searches

World-leading direct-detection dark matter experiments funded by NSF (PA) have made impressive progress and demonstrated remarkable results in the past three-years. WIMP direct-detection experiments

in the NSF-portfolio (including XENON, LUX, CDMS and others) individually achieved milestones and collectively demonstrated the importance of deploying multiple detector technologies and targets in the search for WIMPs. Despite a lengthy down-select process (as part of the P5 process – see below) that substantially delayed concrete planning for next-generation (G2, G3) direct-detection experiments, WIMP-search teams generally took the opportunity to concentrate intently on experimental operation and data analysis. The flurry of activity in this sector yielded ever-improved detector operation, better-understood and more detailed modeling of critical backgrounds, and reanalysis and cross-analysis of WIMP search data performed both within and beyond collaborations. The SuperCDMS Soudan collaboration demonstrated with a clever extension of existing detector technology (known as CDMS-lite) sensitivity to WIMP-nucleon spin-independent parameter space for WIMP masses below 6 GeV/c^2. Particularly notable were the science results from XENON100 who published the most stringent limits so far (improved by ~two orders-of-magnitude) for elastic spin-dependent WIMP cross-sections for both WIMP-neutron and WIMP-proton interactions. Another truly impressive development came from the LUX collaboration who successfully installed and deployed their experiment in the Sanford Laboratory (Davis Laboratory) and published first results that included a spin-independent exclusion limit of 7.6×10^{-46} cm^2 for a WIMP mass of 33 GeV/c^2. The complementary G2 direct-detection experiments now in preparation will provide unprecedented sensitivity to an increased range of WIMP mass and WIMP couplings. Some G2 or G3 experiments should also be able to reach the solar neutrino background which will naturally lead to a host of additional and compelling science results.

Daya Bay Experiment: ***Measurement of θ_{13}***

The flavor of each of the three kinds of neutrinos oscillates with time and the first two mixing angles describing this oscillation have been well-studied but the last mixing angle, θ_{13}, is the least known. Its value controls how electron-neutrino type neutrinos oscillate. A complete knowledge of the mixing angles and other parameters can lead to answers to fundamental questions such as the values of the three neutrino masses and the nature of matter-antimatter imbalance. The report from the Daya Bay Reactor Neutrino experiment on a measurement of the anti-electron neutrino disappearance rate is the first observation of a non-zero value for θ_{13}. The measurement was performed using six antineutrino detectors. These were deployed in two near and one far underground experimental halls. Analysis of a 55 day exposure led to a 5.2 sigma observation of a non-zero value of θ_{13}.

Borexino: ***Observation of pep chain solar neutrinos***

Solar neutrino experiments have proven to be sensitive tools to test both astrophysical and elementary particle physics models. Two distinct processes, the main pp fusion chain and the subdominant carbon-nitrogen-oxygen (CNO) cycle, are expected to produce solar electron neutrinos with different energy spectra and fluxes. Until recently, only neutrino fluxes from the main branch of the pp chain have been measured. Solar models also predict that a second reaction should occur in the sun in which two protons form deuterium. The proton-electron-proton, or pep, reaction should also produce deuterium that can feed into the pp chain. The signature for the pep reaction is a neutrino with a distinct energy of 1.44 million-electron-volts (MeV). The Borexino experiment was designed to detect neutrinos in this energy range. The neutrinos interact through elastic scattering with electrons in the ~278 ton organic liquid scintillator target of Borexino in the Gran Sasso Laboratory in Italy. The collaboration has observed, for the first time, solar neutrinos in the 1.0-1.5 MeV energy range and has determined the rate of pep solar neutrino interactions.

3. ***Comments and Recommendations***

Based on the above assessment of the Particle Astrophysics portfolio and the full 2015 NSF-PHY CoV meeting discussions, the 2015 Particle Astrophysics CoV subcommittee wishes to convey the following

comments and recommendations. Where appropriate, these take into account several of the key recommendations made by the 2012 NSF-PHY CoV.

1. NSF Staffing in Particle Astrophysics

Of PHY-wide importance: The 2012 CoV commended the NSF for hiring two new permanent staff at the PO level, Jean Cottam-Allen and Saul Gonzales, who are assigned to the Particle Astrophysics program and oversight of the LHC, respectively. This move appears highly successful. PHY has also continued the practice of using rotating (non-permanent) positions for PO support. This two-pronged approach in hiring has proven to be an efficient and effective way to maintain and enhance program vitality, and has helped PHY stay abreast of constituency needs, ongoing research developments and innovations, disciplinary trends. This has been especially important for PA because of the influx of researchers in the field in the past decade and the vastly increased workload of the POs as they work to find ways to support a growing experimental community with limited funds available.

2. Stewardship of PA through budget difficulties

The Particle Astrophysics program officers are to be commended on managing an increasingly difficult task – that of funding as many highly meritorious projects as possible across the wide range of sub-areas within their portfolio with an effective 30% budget decrease for new proposals. At the same time, the number of proposals submitted has risen sharply year-to-year – no doubt including many resubmissions of the ever-increasing number of proposals that had been declined in previous years. It was clear from the CoV subcommittee review that while many difficult decisions had to be made, the program officers considered the overall health of the program to be paramount and have thus taken pains to optimize as much as possible, supporting new proposals along with renewed support of PIs on ongoing projects. One strategy employed was to apply a rational funding metric that matched the effort of the PI on the project: for a 50% committed PI (one month summer salary) there would be less support for post-docs and graduate students than for a fully committed PI (two months summer salary).
It was also noted that severe budget constraints on PA during the 3-year cycle under review caused many excellent proposals to be declined due to lack of funds. The PA sub-panel expressed great concern that physicists will start to leave the pipeline in greater numbers if funding levels are not improved in the near future. The loss of new PIs in PA would impact the vitality of the field significantly. In addition, the breadth and depth of training students get when working on PA research projects makes it a particularly attractive training ground for next-generation physicists, no matter their ultimate career path.

3. Reduction of Personnel on PA Projects During Lean Funding Years

The total number of faculty (FTE) funded by recent PA awards went from 59.8 in 2012 to 51.7 in 2014. Over the same three-year period, support of post-docs in new grants decreased from 54.3 FTE in 2012 to 46.0 FTE, while the number of graduate students funded remained statistically unchanged at 112 FTE. (The tradition in physics to offer longer-term commitments to less-expensive yet science-useful graduate students likely protected them over this period.) On the other hand, the number of undergraduates supported in new PA awards declined monotonically from 87.5 (2012) to 53.0 (2014). This was traceable to budget cuts in 2013 imposed by the government mandated sequester: It appears one triage strategy PI's took to keep their research programs moving forward during particularly lean funding years was to cut undergraduate researcher support, since doing so would impact immediate science outcomes far less than some other cost-saving options, such as reducing graduate student support. Some PIs were also forced to fund fewer post-docs, even knowing any significant cost savings would be offset by a substantial decrease in-group productivity. Clearly this approach to managing severely limited budgets is not a sustainable strategy for physics. The decrease in undergraduate support, in particular, will likely impact the number of graduate students entering the field as well as affect the production of the highly technically trained

workforce this country needs. Post-docs are critical to the success of the experimental programs funded by the NSF and a continued decline in their support will likely begin to affect the ability to do the first-class science that NSF has historically produced.

4. Communication with PI's on proposal outcomes

In response to the 2012 CoV report, the Division of Physics piloted a process in FY 2013 intended for all declined awards where at least the primary argument on which a declination was based would be included as a Program Officer comment in the electronic file for the proposal and visible to the PI. In this context, the 2015 PA subcommittee discussed with the PA program officers the communications that occur with proposal PIs especially in the case of declines. We were pleased to note that the POs send to each individual PI an email notification that their proposal has been declined including an explicit invitation for the PI to contact their PO directly either by phone or email to gain additional feedback or discuss any clarifications or concerns. The POs reported that a relatively small fraction of declined PIs avail themselves of this invitation and generally these conversations are not documented in the electronic jackets. While the PA subcommittee appreciates that there is an additional, not insignificant burden to the POs in posting summaries of all communications with the PI to the electronic proposal jacket, we note that it would be very helpful to follow-on CoVs if significant communications could be documented. This is particularly true when a panel review makes recommendations for specific actions for the PI to take or when the decline was due to the extremely difficult budget situation. We do note that for the specific cases we reviewed that led us to these conclusions, we found through our discussion with the POs that the essential aspects of those specific cases were in fact communicated to the PI. **Thus, following on the 2012 CoV report and recommendation therein, we strongly encourage PA program officers, as well as all NSF-PHY program officers, to provide in the electronic jacket a brief summary of communications with the PI in instances where the proposal has been declined. In particular this is important when specific follow-on actions were recommended through the review process for the PI. This will allow for future CoVs to better track the outcomes of the review process.**

5. Broader Impacts

The vast array of new technologies and ideas developed in the particle astrophysics community, the rich diversity of scientists (and their interests and talents) in PA, and the fundamentally captivating subjects studied by PA groups present innumerable opportunities for meaningful education and outreach to scientists and non-scientists alike. It is clear from the award histories, reviews, panel summaries and PA staff award recommendations that PA considers Broader Impacts an important Merit Review criterion for each proposal it reviews.
In the 2012 Physics CoV report, considerable emphasis was placed on the importance of having the NSF better communicate the intended meaning of "Broader Impact" as a criterion in the peer-review process and to offer more guidance to prospective PIs planning to submit proposals. These points as well as other related points have been addressed in the top-level 2015 Physics CoV report. **In sum, the subcommittee strongly urges the PA program officers to continue to communicate the importance of the Broader Impact review criteria to the program PIs and reviewers alike including through making available links to the resources provided by the *National Alliance for Broader Impacts - NABI* (http://broaderimpacts.net/) and a 2014 special report: "Broader Impacts - Improving Society". The report is publicly available on the web and linked to NSF Press Release 14-149 ("New special report highlights NSF-funded broader impacts" (http://www.nsf.gov/od/iia/special/broaderimpacts/).**

During the 2015 PHY CoV meeting, the committee as a whole looked at the issue of how NSF-PHY could best align itself with National Priorities as set by the Executive Branch to increase both the visibility of PHY contributions to these and enhance potential funding opportunities through the National

Priorities. While there are potentially many mechanisms to accomplish this, one avenue in particular seemed to be a straightforward alignment, where appropriate, of the National Priorities with the Broader Impact criteria. **Thus, we encourage PA program officers, as well as all NSF-PHY program officers, to inform PIs (and proposal reviewers) that one option for a focus of the broader impact aspect of their work is to describe, when appropriate, how their research aligns with and supports National Priorities. In addition, we suggest that, again when appropriate, PIs are encouraged to do this for their proposal abstracts as well as public versions of their final report summaries.**

6. Broadening participation

The previous CoV was concerned by the lack of searchable (or readily available data) on the ethnic, racial and gender, etc. breakdown of NSF PIs, the group members, etc. While it remains difficult to locate this type of detailed information directly from NSF web sites, a wealth of statistical data on NSF groups and other cohorts related to STEM (and other areas) is readily available at http://www.nsf.gov/statistics/. Substantial work is presented in multiple formats, including summary papers, direct links to related background publications, analysis summaries, etc. It continues to be difficult if not impossible to locate statistical information on NSF awards made (or declined) according to race, gender, etc. However, a good amount of reduced data is tabulated in the 2013 report to the National Science Board on the NSF's Merit Review process: "*FY 2012 Report on the NSF's Merit Review Process*" (NSB-13-33 available at http://www.nsf.gov/nsb/publications/2013/nsb1333.pdf. The NSF has several links to APS appropriate reports and announcements that closely related to demographics, career and other outcomes, etc.

7. Data management & software

Data management is an area of increasing concern for PA. The size and complexity of the data sets being collected are increasing dramatically and pushing infrastructure limits. For example, total IceCube and CMB telescopes' daily data transmission from the South Pole are reaching 200 Gbytes; this represents the total current capacity available at the South Pole. While the U.S. Antarctic Program is continuously seeking options to increase the bandwidth, it is limited by available geosynchronous satellites seen from Pole, and funds available to pay for data transmission. Therefore, the storage and archiving of the science data, and the analysis and eventual opening of the data to the larger community are problems that must be addressed and planned for systematically. Another example of a project that requires very significant data management and analysis resources is LSST (a 3.2 gigapixel camera with expected data rates of 40 TBytes per night!). In addition, the maintenance and continued availability of generally used simulation programs such as GEANT and Corsika are critical to almost every experiment in the area of PA. It is fair to say that PA is in transition between handling these issues informally "in house" within an experimental collaboration and requiring the kind of broader coordination found in EPP, for example. It would be helpful if the various cyber-related initiatives became more broadly known to the PA community, with program managers having the time and incentive to take part in the formulation of these programs and solicitations.

8. The Particle Physics Project Prioritization Panel (P5) recommendations and PA

The PA sub-panel commends the active engagement of the NSF Physics Division, and the PA program officers in particular, in the recent P5 (Particle Physics Project Prioritization Panel) process that helped the US Particle Physics community collaboratively define its scientific priorities for the next decade. The plan, summarized in the 2014 P5 report, identifies key projects that should be supported to maintain a scientifically strong and sustainable Particle Physics program in the US. These projects include both accelerator and non accelerator-based experiments that will require funding that is beyond the scope of any one NSF program. The types of experiments funded by PA that relate to the P5 recommendations and beyond are well-aligned with the national interest in developing and advancing new technologies that will

likely have meaningful, long-term and unexpected positive impacts on society well beyond the confines of PA. Three of the five intertwined scientific drivers distilled from the results of the year-long, P5 community-wide study are relevant to PA: (i) Pursue the physics associated with neutrino mass, (ii) Identify the new physics of dark matter and (iii) Understand cosmic acceleration: dark energy and inflation.

The NSF charged a Math and Physical Science Advisory Committee (MPSAC) subcommittee headed by Prof. Y. K. Kim to recommend ways to implement the P5 recommendations that maximized the impact by NSF while balancing support across small thru large scale projects. The Kim report[2] was delivered to MPSAC in January 2015. The top-level recommendation is quoted "**The major role of NSF is to support a broad range of first-class scientific research and to assist in the education of the next generation of scientific leaders. This should remain the top overall research priority of the Division of Physics.** Quality, breadth and flexibility are the hallmarks of the NSF particle physics program. Based on the science drivers and priorities identified in the P5 report, **NSF should invest broadly while also targeting a few specific resource-intensive projects."**

It is important to note that while the outcome of the P5 recommendations as they pertain to PA will mostly be evidenced in the following CoV, there were clear impacts to the PA portfolio already apparent to this CoV. These are detailed in the immediate paragraphs below as well as throughout the remainder of this PA subcommittee report where relevant. In sum, **this committee recognizes the importance of the extensive P5 process in emphasizing the significance of the recommended projects and encourages the alignment of related programs within NSF-PHY consistent with these recommendations. At the same time, careful consideration of the impact this may have on the overall programmatic balance between accelerator-based and non-accelerator-based physics as well as facilities versus PI-driven research is recommended.**

The results of P5 were instrumental in the decision for NSF to formalize support and provide immediate investments in Direct Detection of Dark Matter (DDDM)-generation 2 (G2) experiments, whose ultimate success will require continued close cooperation between NSF, DOE and the National Labs management to make limited funds at both agencies stretch sufficiently to make funding of important experiments possible. The G2 down-select process was a very difficult one for PA and we commend the POs for their continued stewardship through the final stages of the award finalization process. The PA support of multiple technologies and their insistence that, despite requisite overlap with DOE National Labs in the new budgetary climate, NSF university groups must be able to maintain some level of autonomy was most important. This includes, but is not limited to, the ability for university groups to continue serving in science-critical roles, to have flexibility in carrying out portions of the large collaborative projects, and to continue supporting students and post-docs who clearly gain tremendously by being able to work and develop a wide range of experimental skills in a university lab environment.

The subpanel recognizes and appreciates the added burden this difficult and critical coordination effort adds to PA staff and appreciates the NSF's creative and effective approach to keep NSF groups on these experiments supported and able to continue their science and leadership roles within DDDM G2 experiments. The first priority of the PA program in the area of DDDM is to implement the G2 experiments but some continued investment in R&D towards G3 is also in the planning stage.

[2]The Kim report can be found at this link:
http://www.nsf.gov/mps/advisory/mpsac_other_reports/nsf_mpsac_p5_subcommittee_report_2015-01-08-final.pdf

To support the goal of indirect detection of dark matter, P5 recommended investing in the Cherenkov Telescope Array (CTA) ground-based gamma-ray observatory with the acknowledgment that funding from NSF-AST would be needed to successfully complete a US contribution to an otherwise European-led project. The US contribution would enable a valuable increase to the dark matter signal sensitivity among other important science goals significant to both Physics and Astronomy. The PA portfolio reviewed by this CoV subcommittee has funded an MRI prototype of the novel telescope at the foundation of the US contribution as well as smaller R&D efforts as aspects of individual investigator awards. In addition, the PA program officers have attended CTA Resource Board meetings. Discussions between NSF-PHY and AST, as well as DOE, are in process to coordinate funding of a US contribution to CTA and the CTA-US project has been informed of the funding mechanisms available. As the science studied using very-high-energy gamma-rays has been a major component of the NSF-PHY PA program, it is expected that the CTA-US project will respond with coordinated proposals in the near future.

9. Interdisciplinary links, programs and participation

The PA CoV sub-committee spent some time with the PA program officers together with Vladimir Papitashvili from the PLR program discussing the joint funding mechanisms between PA and PLR especially with regard to IceCube and the joint CMB efforts. In addition, we discussed extensively with the PA program officers the particular pressure on PA for co-funding given the inherent interdisciplinary nature of the program. We found that the Particle Astrophysics program officers continue to be proactive, effective and collaborative in their approach to jointly fund excellent proposals that also impact areas beyond PA. The effect of such collaborative efforts is important to the health and vitality of PA and NSF at-large. **We commend PA for their ability and willingness to help identify additional avenues for funding groups that straddle disciplinary boundaries.** Nonetheless, it was also noted that severe budget constraints on PA during the 3-year cycle under review caused many excellent proposals to be declined due to lack of funds. The PA sub-panel expressed great concern that physicists will start to leave the pipeline in greater numbers if funding levels are not improved in the near future. The loss of new PIs in PA would impact the vitality of the field significantly. In addition, the breadth and depth of training students get when working on PA research projects makes it a particularly attractive training ground for next-generation physicists, no matter their ultimate career path.

In the bigger picture, since CoV 2012, NSF MPS has become more effective at advertising available opportunities for PIs to compete for division-wide or interdisciplinary funding opportunities: there is now an effective search option on the NSF web page http://www.nsf.gov/funding/pgm_list.jsp?type=xcut (under Interdisciplinary Research) that picks out agency-wide opportunities for different PI cohorts. Additionally, there is a particularly informative FAQ section on interdisciplinary research available at http://www.nsf.gov/od/iia/additional_resources/interdisciplinary_research/faqs.jsp. It was clear from discussions with PA that they are forward-thinking in opportunities to help PIs plug-in to NSF-wide opportunities including, e.g., CREATIV (Creative Research Awards for Transformative Interdisciplinary Ventures) and INSPIRE (pilot grant mechanism under the Integrated NSF Support Promoting Interdisciplinary Research and Education), and others.

10. Interagency and International Projects and Project Management

As noted in the 2012 CoV, the 2015 PA subcommittee found the PA staff continues to do an exemplary job at developing, maintaining and strengthening ties to their counterparts nationally (e.g. DOE-OHEP) with the goal of facilitating top-quality research in tough financial times. In particular, the community has benefited tremendously these past three years from PA's co-leadership and stewardship of the P5 process that led to several difficult decisions affecting in one way or another many groups in PA - an example of which is the DDDM G2 down-select process described above. In addition, the POs implemented regular, periodic management calls with the major instruments overseen by PA in coordination with other

agencies when relevant. The POs are also involved in a range of activities geared towards strengthening international ties such as sitting on International Finance Boards for specific projects with large international components (such as IceCube and Auger) and participating in bilateral discussions with foreign agencies such as INFN and IN2P3. These activities help ensure that NSF-funded university groups in the many growing collaborations (international and otherwise) of PA will continue to play important science roles in experiments that may be hosted by one of the National Labs or at an international facility.

11. Facilities and instrumentation – significant funding pressure

The Particle Astrophysics community is undergoing a transition from smaller, single-or-few-PI-led experiments to experiments that are becoming increasingly large and complex with many PIs, placing immense pressure on the instrumentation and facilities budgets. Increased support for instrumentation at all scales (small, medium and large) is critical if the PA program is to respond to the slate of projects coming out of the community-supported prioritization processes such as P5 or the Decadal Survey. This is necessary if NSF is to achieve its stated goal of getting more hardware and hands-on experience for next-generation physicists. In addition, such funds are essential for some small and medium-sized PA experiments whose work feeds directly into larger research programs already in the pipeline, e.g., physics experiments that would not succeed (or be severely delayed) without science or targeted R&D input made possible with small instrumentation-related grants. In the broader picture, even modest support of unique small instrumentation projects can be critical both for rapid scientific development and potential discovery, and for noticeably improving research opportunities to develop or enhance technologies that can simultaneously impact industry and the public at-large.

The PA sub-panel urges NSF to continue to support small or medium sized-instrumentation projects that the peer-review community identifies as particularly important in the context of fundamental R&D or potential physics discovery. Particular attention might be given to fund instrumentation grants or supplements that align well with the overarching goals of NSF, and/or would lead to a potentially transformative prototype directly related to well-defined future work. The Accelerator Physics and Physics Instrumentation (APPI) program is an example of such a program that was created within the Division to address the ongoing critical need for instrumentation that is essential for scientific progress but which is of a level that is not easily affordable by an individual disciplinary program.

G. Physics of Living Systems

A. DEFINITION OF THE PROGRAM

The Physics of Living Systems (PoLS) program supports a portfolio of research that focuses on using physics-based approaches to discover the underlying basic principles governing complex biological phenomena. To that end, the proposals in this program focus on a coupling of theory and experiment, creating experimentally verifiable models for complex biological systems. The portfolio of proposals covers multiple scales from the molecular, the cellular, the multicellular, the organismal, through to populations. Research aimed at novel interactions in these systems, particularly at the level of complex organisms and groups of organisms, is beginning to be emphasized, representing an exciting new direction for the program. Another strength of this program is that it also encourages the use of complexity in biological systems to develop new physics. Given that this program does not deal with proposals that apply established physical techniques to characterize biological phenomena at the molecular and/or cellular levels, the opportunities in this program are distinct from research supported by the BIO and DMR divisions. Indeed, the research addresses the physics of living systems, not a description of living systems, whether computational or experimental, and not the use of biomolecules as materials.

The systems represented can be divided into two broad categories: the first spanning molecules to cells and the second ranging from cells to organisms and populations. In general, proposals concerned with single molecule physics are co-reviewed with the MCB program in BIO. The program in PoLS, while distinct from the programs in Biophysics/MCB/BIO, provides a significant potential for synergy. The NSF recognizes this and, in order to foster research at the interface between the Physics Division (MPS) and the Division of Molecular and Cellular Biosciences (MCB/BIO), special advisory panels are held to review proposals at the interface between the Physics and MCB disciplines. These panels are made up of experts who are experienced in connecting the research areas normally supported by MCB with the research areas normally supported by the Physics Division in the life sciences area. In fact several of the funded proposals that were reviewed by this sub-committee were co-sponsored with MCB (variously through the Cellular Dynamics and Function now Molecular Biophysics, the Genetic Mechanisms, and the Physiological Networks and Regulation programs) This long standing collaboration between PHY and MCB was also responsible for the creation of BioMaPS, that is an excellent example of a highly integrated foundation-wide program that encourages cross-directorate interdisciplinary research and has been uniquely successful in leveraging foundation-wide funds.

B. INTEGRITY AND EFFICIENCY OF THE PROCESS AND MANAGEMENT OF THE PROGRAM

1.Effectiveness of the Review Process

A three-tier review system consists of written reviews provided by several panel members (usually 3) prior to convening of panel. This is followed by a panel discussion involving all panel members and classification (described in detail below). Finally, an overall evaluation is made by the program director taking the reviews, the panel recommendations, and factors relating to portfolio balance into account to make the final funding decisions.

The program reviewed 102 proposals divided into 2 panels (50, 52) in 2012, 95 proposals divided into 4 panels (21, 32, 21, 21) in 2013, and 84 proposals divided in 2 panels (38, 46) in 2014. Given the breadth of research areas that are in the PoLS portfolio (as described above), the first panel dealt with mechanisms

and interactions in molecular and cellular systems and the second panel was involved with systems of greater complexity.

These panels were generally held in person at the NSF in Arlington Virginia. The 4 panels in 2012 were exceptions being held by teleconference. However, it was felt that the teleconference-based panels did not provide the proper format that allowed for a detailed and comprehensive discussion of the proposals and the committee felt that the in-person panels were far more efficient.

The panels consisted of 13-15 members for the in-person panels and 6-8 members for the panels held by teleconference. The panel members were chosen well and represented a broad range of expertise. The panel included several members with significant biological expertise and they were well suited to judge the biological relevance of the proposed research. In addition to experienced members the panel often included recent CAREER awardees. The committee felt that this provided these young researchers with valuable experience.

The 24 representative jackets reviewed by the committee had between 2 and 4 (mostly 3) written reviews provided by members of the panel prior to convening the panel. Additional reviews from external experts were solicited by the program directors in case of major disagreement or lack of consensus. The panel discussion consisted of an initial classification of the proposals followed by a final classification into 4 categories – High Priority, Medium Priority, Low Priority and Non-competitive. The first and last categories contained the lowest number (sometimes none) of proposals. The decision to classify proposals as High Priority was arrived at only after all the proposals were thoroughly discussed.

A close analysis of the jackets showed that the external reviews were generally quite detailed and were found to clearly describe the strengths and weaknesses of the proposals both in terms of the Intellectual Merit as well as the Broader Impacts. The panel summaries were generally very brief but conveyed the necessary information. The program director's synthesis of the comments of the external reviewers and the panel discussion was extremely detailed and provided clear insight into the final funding decision. While this document was not released to the PI, the various factors that contributed to the funding decision were communicated to the PIs who called the program director, often at the urging of the program director.

2. Broader Impacts

There are a number of Broader Impacts derived from this program. The international PoLS graduate student research network has developed as a model of a Science Across Virtual Institutes (SAVI), which integrates training and research in an international environment. Broader impacts also include the influence that research within the program has on other disciplines. The focus on *in vivo* research reflects goal of the program to describe living systems together with all their complexity in quantitative terms, and to determine the connections that such complexity provides.

Finally, the PoLS program also provides the opportunity for broad dissemination and outreach to the general public. An example of PoLS funded research that has caught the attention of the general public is from an award entitled "*How do animals harness water entry and exit dynamics?*". In this research the PI, Sunghwan Jung (Virginia Tech) along with his co-PIs John Socha (Virginia Tech) and Pavlos Vachos (Purdue) have described the basic physics behind the differences in how dogs and cats drink water compared to humans. It was understood that dogs (and cats), unlike human do not possess the facial characteristics to generate sufficient suction to draw water from a container into their mouths. Dogs use a lapping motion to create a water column below their tongues generating acceleration greater than several times that of gravity.

This work was presented in the November 15, 2014 in the APS Division of Fluid Dynamics meeting in San Francisco was also highlighted by the popular press.

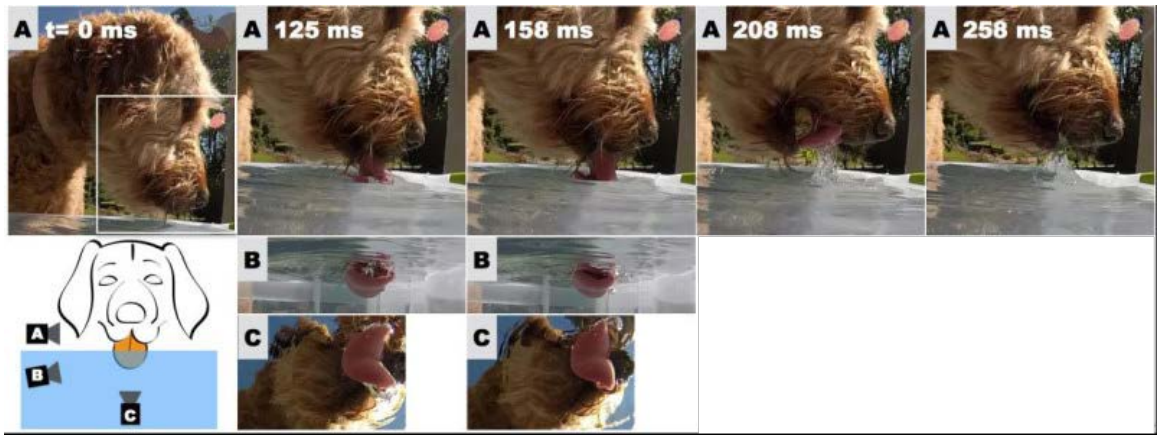


Fig. G1: A time series was generated using 3 sets of cameras as shown in the bottom left image. A video of the entire sequence can be found in the New York Times website: http://www.nytimes.com/video/science/100000003273592/how-dogs-drink.html

3. Portfolio of Awards and Management

Awards cover a broad spectrum of physics approaches in biology, ranging from the physical principles and mechanisms at the single cell level such as architecture and dynamics inside cells, energy metabolism, gene regulation and intracellular and intercellular communication, to collective behavior and evolution of complexity in life forms and living populations of organisms. The program portfolio is constantly evolving and tracking frontier areas that are consistent with the areas of priority designated by the NSF. The program director has shown a unique sense of understanding as to where the most important and forward looking areas of research are that can benefit specifically from the contributions that physics can make to biological sciences. These areas are inevitably at the leading frontiers of the science, and have the potential to be transformative in the future.

Among the several cross-directorate efforts the collaboration of the program director from PoLS (Krastan Blagoev) and from Biophysics (MCB/BIO) (Kamal Shukla) has been especially effective and ensures that the two programs remain distinct while maintaining a synergy between their different areas of expertise.

The program director aimed to sustain a high level in the quality of proposals that were funded from year to year. The proposal success rates dropped significantly from FY12 to FY14. The large drop in success rates can be attributed to the significant budget cut in 2013 and also to a lower number of high-quality proposals. The program supports research investigators that are widely distributed across the United States. The number of projects from female researchers funded by the program has grown consistently and currently stands at about 25%. This number is higher than the percentage of tenure-track and tenured female Physics faculty in the United States. The committee recognizes that the number of under-represented minority applicants continues to be low in spite of efforts by the program director. However, the success rates of these under-represented minority applicants is high.

C. RESULTS OF NSF INVESTMENTS

As discussed above, the PoLS program funds research at the molecular, cellular and multicellular/organismal levels. Below, we provide one example of each broad class. We expect that these

standout projects have the ability to produce significant impact on our understanding of complex dynamics in biological systems.

PROJECT 1: MOLECULAR

Cells respond to external stimuli through a cascade of events involving messenger elements that transduce information at diverse scales. Considerable progress has been made in revealing individual signaling pathways. However most signal transducers are shared by multiple pathways. This creates significant complexity in the flow of cellular information. In fact, cells are excellent multiplexing and de-multiplexing devices, handling large amounts of information within an interconnected signaling network. One of the most multi-tasking messenger elements is the calcium ion, which is involved in many aspects of cellular function. In a predominantly experimental proposal, the processes of receiving and parsing information within a complex and interconnected cellular signaling network are being studied using microfluidic devices. The model system is an engineered mammalian cell line that expresses two sets of receptors – one responsive to ATP and the other to the odorant eugenol. The cytosolic calcium dynamics in response to these two sets of signals is used to develop a model of how cells encode complex information at the cellular level.

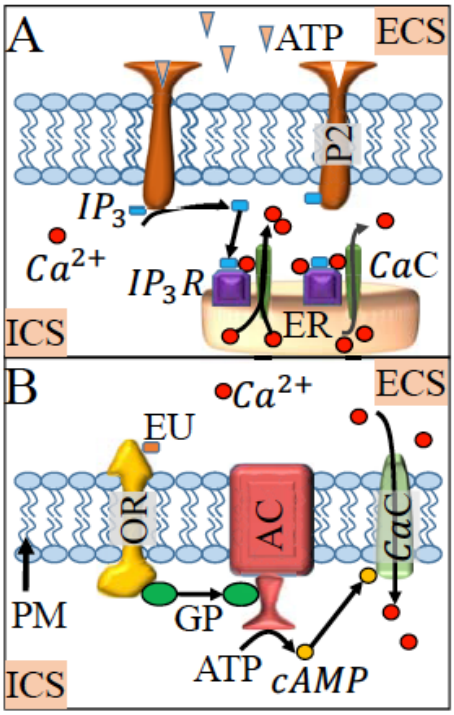


Fig. G2: (A) Binding of the P2 receptors to ATP leads to the diffusion of Inositol 1,4,5 phosphate (IP3) into the cytosol and engagement of the IP3 receptor (IP3R) located on the endoplasmic reticulum (ER). This leads to the opening of the calcium channel (CaC) and the release of calcium from the ER into cytosol. (B) Binding of the odorant eugenol (EU) to the olfactory receptor (OR) converts ATP to cAMP leading to the opening of the CaC and an influx of extracellular calcium across the plasma membrane (PM). Therefore in the overall response to ATP or EU is the flow of calcium ions.

This project (PHY1400968) from a young investigator (Bo Sun) is jointly supported by the Physics of Living Systems program in the Division of Physics and the Cellular Dynamics and Function Program (now Biophysics program) in the Division of Molecular and Cellular Biosciences.

PROJECT 2: CELLULAR

The processes of self-assembly and collective behavior play a central role in a multitude of scales from bacterial quorum sensing to movement of a large herd of animals. Using the bacterium *Myxococcus xanthus* as a model system an experimental proposal aims to investigate the role of forces in controlling the directionality of motion, cell speed at the level of single cells and cellular clusters.

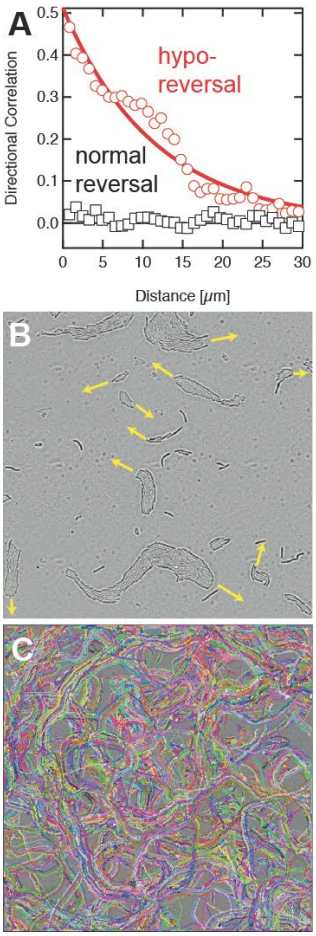


Fig. G3: (A) At the initial stages of a response to starvation, normal reversing cells (black) lack significant correlations in their direction of motion with their neighbors whereas hypo-reversing cells (red; hypo-reversing cells lack FrzE, a chemotaxis receptor that controls cell reversal) form highly correlated groups, displaying a correlation length of ~12 μm in the example shown. (B) Hypo-reversing cells form flock-like moving groups. Yellow arrows denote group motion direction. (C) An overlay of the trajectories from the ~500 cells shown in (B) after four hours of motion.

This project (PHY1401506) from a mid-career investigator (Joshua Shaevitz) is jointly supported by the Physics of Living Systems program in the Division of Physics and the Cellular Dynamics and Function Program (now Biophysics program) in the Division of Molecular and Cellular Biosciences.

D. SUMMARY AND RECOMMENDATIONS

1. The current program director of PoLS has significantly contributed to the dynamism of the program by identifying exciting problems in life sciences that can be enormously impacted by physics-based approaches (both theoretical and experimental). He has also encouraged the use of the inherent complexity in biological systems as excellent incubators for new physics such as active materials and complex systems. The current program director has the ability to recognize and readapt the program to meet exciting new areas in this highly evolving field it is very important that and he should be encouraged to continue to use his talents to keep abreast of changing science. This intellectual leadership should be maintained.
2. The PoLS program has demonstrated the ability to work in synergistic fashion with other directorates in significant cross-disciplinary, cross-directorate endeavors. An excellent example of this synergy is the BioMaPS initiative. Also, the collaboration between the program director of PoLS (Krastan Blagoev) and the program director of Molecular Biophysics (MCB/BIO) (Kamal Shukla) has been very effective while ensuring that the two programs remain distinct. This kind of close collaboration outside the division of PHY should be encouraged.
3. The program director has paid significant attention to broader impacts in general. A special example of effort in this area is the PoLS graduate student network has had an enormous impact on the training and development of graduate students and postdocs at the interface of physics and biology. This program has also fostered significant international student-to-student contact. This is a unique program and all possible efforts should be made to expand it.
4. The three-tier proposal review instituted by the program director is effective in funding the best science while balancing the portfolio of research areas, geographic and demographic considerations. The committee finds that the in-person panel based review is preferred over teleconference based panel reviews. The latter format does appear to be conducive for efficient in-depth discussion of proposals.
5. The committee recognizes that the number of under-represented minority applicants continues to be low in spite of efforts by the program director. This is, however, not a problem that is unique to the PoLS program. However, the success rates of these under-represented minority applicants is high. The program does very well in funding female and early career investigators.

H. Integrative Activities in Physics

Introduction

The IAP program covers interdisciplinary physics proposals and supports research at the interface between physics and other disciplines and extending to emerging areas. It also covers programs that are not supported by other disciplinary programs within the physics program, for example the REU program, conferences and other initiatives specifically addressing broadening participation.

Comments about Review Process and Program Management

Quality and Effectiveness of Merit Review Process

Because of the many unique proposals submitted to this program, panels are not always used in the proposal evaluation process. The REU program uses panel reviews after individual reviews; however, ad-hoc reviews are used in cases where few proposals with similar project types and research theme are submitted. In all cases, if the proposed project is interdisciplinary, the IAP program officer works with the appropriate program officer from other NSF programs to solicit additional reviews. Site visits have also been successfully used in appropriate situations.

Both merit review criteria are properly addressed in all stages of the review process and the Program Officer review analyses. There have been a few instances of reviewers not addressing the broader impact criteria well. However, in these cases other reviews allowed for a complete review of merit criteria when evaluating the proposals. Reviews generally include substantive comments to explain proposal assessment and panel summaries provide the rationale for the panel consensus. Any inconsistencies in the reviews and/or panel summaries are addressed in the review analysis and it is quite clear what factors were used to determine whether an award is made or not. The decisions made by the program officers that were reviewed by this committee were all well-founded. Overall, the merit review process of the IAP program is effective and kept to high standards.

Selection of Reviewers

Reviewers and panelists have appropriate expertise and/or qualifications. Due to the mix of unique proposals that are submitted to the program and the focus of some of them, selection of qualified reviewers may pose a challenge at times. However, the Program Officer has several creative ideas for how to identify new reviewers (including soliciting reviews from the international community) to address this issue.

Management of the Program

The eclectic nature of the IAP program leads to many unique and challenging situations which the program officer seems to turn into opportunities for co-funding. The ability to deal with these unique projects and provide support for projects which do not fit in traditional programs is a strength of this program. DoD has been a funding partner in several REU sites, as has EPSCoR and HBCU-UP. The APS Bridge program for enhancing diversity in graduate education was co-funded with the AGEP HBCU-UP programs in EHR. We commend the Program Officer for striving to secure co-funding of awards across divisions. The portfolio balance reflects proposal demands appropriately and is flexible to meet new opportunities. The REU component of the program is a resource that needs to be preserved in the future while allowing for flexibility when new opportunities arise. The division seems to respond appropriately to these needs by investing additional funds in the REU program within overall budgetary constraints

when possible. We encourage the Program Officer and the Physics Division to keep pursuing additional funding for the REU program.

Resulting Portfolio of Awards

The major funding activity for the IAP program is the REU site program, accounting for about two thirds of the awards. Education is the second largest funding category (about one third of awards). Other activities include outreach, conference support, broadening participation and interdisciplinary activities. This portfolio has an appropriate balance of awards across these components. Awards are appropriate in size and duration for their scope. Within limits imposed by budgetary constraints, the program funds a reasonable number of innovative and potentially transformative awards. The distributed REU is an example of a potentially transformative award that was made through the IAP program and may lead to a new paradigm for REU programs. The geographical distribution of REU sites is factored into the decision process, as well as the different types of institutions which are funded. In the REU program new sites are more relevant than new investigators. About 10% of the funded sites are new. The demographic distribution of the PIs is consistent with the demographics of the physics academic community. Several REU sites are located at minority serving institutions and at predominantly undergraduate institutions. More data should be collected with respect to demographics of all participants (i.e., undergraduate researchers) to determine if appropriate participation levels of underrepresented groups in undergraduate research have been achieved.

Comments about Broadening Participation

Demographic Data

The current demographic data collection system for staff scientists, post-docs, undergraduate students and graduate students makes it difficult to determine if programs of all types are engaging diverse populations AND enabling these junior scientists to advance through their careers to become senior scientists. Therefore it is difficult to evaluate if programs are effective in broadening participation. This information is needed to guide future funding decisions. If programs are not supporting diverse groups of students and post-docs, how will we ever improve the representation of underrepresented groups in at the senior level? The data need to be used to identify programs that are making a positive impact in this area so that best practices can be disseminated. In addition, programs that are not making progress can be held accountable for this lack of progress.

An effective method for collecting the data needs to be developed. Perhaps a group of PIs and program officers can work together with IT professionals to determine a more effective method. PIs and the scientists that are supported by their awards need to be encouraged to complete the demographic data forms, even if they select “choose not to report” when they complete the form. While voluntary reporting levels are currently atrocious, they will improve when participants know that the data are being used to guide program improvement. Thus the NSF needs to let PIs know that the data collection system has been improved and that the data will be used in order to identify best practices.
For programs that support larger numbers of students, it would be helpful if PIs could have access to the program aggregate demographic data (so that students are not asked to report the exact same data to the PI).

Reviewer and panelist demographic data are also not well known. Many reviewers and panelists do not report demographic data. This could be due to the fact that many PIs/reviewers think that their Fastlane demographic data are automatically transferred into the panel review system (and they are not). Program officers need to let reviewers know that the information they report in Fastlane as a PI (or program

participant) does not transfer automatically into the panelist database and that it is important that they complete the demographic data forms.

Beyond demographic data collection - new NSF actions to improve broadening efforts

Collecting data without undertaking specific actions is not likely to move the needle with respect to the long-term engagement of groups underrepresented physics. The following actions may begin to impact the diversity of the physics community. Of course, immediate improved demographic data collection as discussed above will enable the Physics community to evaluate the impact of the activities described below.

- Deliberate efforts to mentor young, non-PI physicists supported by NSF grants should be required of all funded programs. Mentoring plans are currently required for all projects that include support for post-doctoral researchers. This program should be expanded to all students (undergraduate and graduate) supported by NSF awards. The mentoring plans should include career development components, including exposure to and preparation for careers outside of academia and the national lab system. (Please stop calling these non-traditional paths, since the majority of physics bachelors recipients are not pursuing careers in these areas.) The Physics Research Mentor Training program may be a valuable resource for PI looking for ideas with respect to developing mentoring programs for undergraduate and graduate students and also for ideas to help train post docs and graduate students who may serve as mentors to younger physics researchers supported by their NSF award. (http://www.aps.org/programs/education/undergrad/faculty/mentor-training.cfm)
- A broadening participation impact statement should be included in all proposals, even if that statement is N/A. Collecting these statements will make PIs more deliberate in reflecting on their own efforts and will allow the NSF to more easily identify best practices when they couple these statements with the findings from their own demographic data collection program.
- Reviewers should be encouraged to participate in implicit bias training at some level. For panel reviews, this could involve having panelists take implicit bias tests (https://implicit.harvard.edu/implicit/takeatest.html) and then discussing implicit bias before the panel begins discussions (other NSF programs are already doing this). For ad-hoc reviews, the quiz could still be recommended and a cyber-enabled discussion could be held before they begin their reviews.
- Reviewers should discuss the big-picture of broader impacts BEFORE discussing proposals in panels. Web resources (webinars, etc) should be available for use by ad-hoc reviewers.
- Outreach by NSF to potential PIs will help reduce confusion and improve the quality of submissions. While web-based materials are available, more engaging methods should be employed. In particular, professional society presentations/panels/etc could be held in order to:
  - reduce confusion about what broader impacts "means"
  - disseminate best practices in mentoring
  - disseminate best practices in broadening participation

General Summary

The overall review process and program management are quite well done. Success of efforts to broaden participation within NSF Physics programs in general cannot be evaluated without better demographic data collection. However, demographics of all physicists (students through senior scientists) supported by awards should be considered when reviewing the success of NSF programs with respect to engaging and supporting diverse populations. Simply focusing on the undergraduates in the REU site programs, the PIs awarded grants and then special programs focusing on broadening participation is ignoring a significant amount of the Physics program.

We would like to thank the two program officers for IAP (Kathleen McCloud and Claudia Rankins) for their excellent work (and cogent review analyses) that helped the review team understand the award decision process. We also thank Kathleen McCloud, the current program officer, for her assistance during this review.

I. Elementary Particle, Experiment and Grid Computing

Introduction

The experimental particle physics (EPP) program supports fundamental research on the nature of matter, energy, space, and time. To explore these basic and profound questions, this research depends on the most advanced accelerator systems operating at the highest generated energies and intensities, and relies on the most advanced and sensitive detectors to study very rare interactions in the laboratory. The research in EPP lays the foundation for future technologies and trains the next generation of scientists in this field and beyond. For FY14, the EPP program expended a total of $44.3M, of which $18.7M to support the university program, $17.8M for Operations of the Large Hadron Collider (LHC) program, and $8.2M toward Phase-1 LHC upgrades. The EPP successfully works with other programs within NSF and the DOE Office of HEP to sustain research areas in particle physics as well as prepare and align the EPP program with the recommendations of the Particle Physics Project Prioritization Panel (P5).

The world-wide nature of particle physics research is exemplified by the current distribution of 59% of supported PI's working in energy forefront physics research and 11% of the PI's working in the area of Neutrino physics, in addition to other areas during this review period. The maintenance of international participation is of critical importance in these fundamental areas of investigation, since the efforts are costly and require nation state investments that train future investigators and promote international cooperation.

I. Quality and Effectiveness of the Merit Review Process

A1. Appropriate Review Methods

The review methods applied to proposals utilize review panels, ad hoc reviews, and the availability of site visits. The sub-panel finds that all these methods are very effective and play complementary roles in assessing the full scope of a supported research program. Based on the jackets examined, the COV finds that both panelists and ad hoc reviewers properly addressed the Intellectual Merit of each proposal. The Broader Impact criteria were fulfilled among funded proposals, and adequately satisfied the education and science requirements of NSF.

The subpanel notes that no site visits were listed among the proposals. Because this method is complementary to the others in reviewing research programs, the COV recommends site visits to be resumed when necessary, particularly for larger grants with multiple PI's, despite the budget constraints for such visits.

The subpanel also examined the inclusion of RUI's in comparison to major research institutions in Particle Physics research. The procedure of reviewing the individual PI's from both types of institutions and awarding support based on the merit review process is applied in a fair and professional manner.

A2. Merit Review Criteria

Both merit review criteria were addressed among the panels and individual reviewers, although review of the Broader Impact criteria varied noticeably among the reviewers. The panel summaries were consistent in reporting the activities of proposals that included undertakings engaged in broader impacts that provided public education and were connected to established successful outreach efforts. The program

officers review analyses address both merit review criteria and reflect support for proposals that are consistent with NSF core values and a competitive program.

A3. Individual Reviewers Comments

Individual reviewers' comments are insightful and in general direct in assessing a proposal. The subpanel notes that many reviewers spend approximately 50% of the review summarizing the proposal. The panel recommends providing a separate section of comments that is the exclusive summary of the proposal, and the rest of the review is the evaluation of the proposal.

The subpanel also observes that proposal review panel members are not included among the individual ad hoc reviewers. It may be beneficial for the PI to receive this additional feedback from the panelists.

A4. Panel Summaries and Consensus

The panel summaries were clear and precise, although sometimes very concise, in reaching a consensus and reporting the recommendation. This is particularly true for the proposals that were not recommended for funding, in that the rationale was specifically stated. One thing that the subpanel noted, which was also evident in the panel summaries, is that it is extremely difficult to tease out the contributions of individual investigators in large umbrella-grant proposals. This is increasingly important in an era of decreasing funding. The subpanel supports the efforts of the program directors to hold each PI, regardless of institution, accountable. The program directors might consider requiring additional supplemental documentation where PIs self-report their efforts in order to aid in proposal review.

A5. Documentation for award decision in the Jacket

The panel was provided with a representative sample of the proposals submitted to EPP in the past three years. The documentation in the jacket provides a rationale for the decision reported by the panel. In all cases the project officer review analysis and the panel summary agreed on the merit assessment of the proposal.

A6. Documentation to the PI for award decision

The documentation provided to the PI was consistent with the internal documentation provided in the jacket. As stated above, the sub-panel recommends to augment the information provided to the P.I. with additional feedback from Panelists in the form of any ad hoc reviews created during the panel session.

The NSF merit review process is well developed and well respected within the research community. The program's use of these criteria is very effective. The subpanel was impressed by the scope of broader impact and outreach activity seen in the proposals. However, the subpanel also recommends a continual dialogue on the appropriate balance between the weight given to the intellectual merits and broader impact criteria in evaluating proposals.

II. Selection of Reviewers

The program made excellent use of the many highly qualified scientists who are engaged in particle physics research. Most reviewers were selected from major research institutions. Since the scope of the largest projects also included PI's from RUIs, the subpanel noted that the EPP panel usually included a reviewer from a RUI institution and RUI grants had at least one ad hoc reviewer from undergraduate institutions. This configuration provided a unique evaluation from the perspective of both small and large institutions that was balanced, enabling a better grant review based on merit.

The program recognized and resolved conflicts of interest when appropriate. Fifty-nine percent of the PI's in EPP are working on LHC collaborations, and questions of conflict of interest are examined closely**.** This scenario has been successfully managed since the two major LHC experiments have in excess of 3,000 people each, and selecting persons concentrating on different parts of the physics research program is possible.

III. Program Management

1. Management of the program.

This subpanel finds that over this past three-year period the EPP program was well managed and very effective in allocating the available funds to support a broad set of activities at the forefront of particle physics. In particular, the Program Directors should be commended for their success in securing funding for the Phase-I LHC upgrades, and working very productively with DOE to manage the LHC program.

The EPP subpanel notes the past service of Program Directors Marv Goldberg and Randy Ruchti for their exceptional contributions to a professional team managing a successful and competitive research program, promoting education and innovation in science, and thereby intensifying the broader impacts on society.

The addition to the NSF EPP team of an experienced Program Director such as Saul Gonzalez helped the division stay strong even in difficult times. The more recent additions of IPAs Jim Shank and Brian Meadows, with help from Mark Coles, further strengthen the program.

While the recent performance of the EPP program has been excellent, the COV is slightly concerned with Saul Gonzalez being currently on detail at OSTP. Certainly this assignment is a success for Saul and the NSF because it recognizes the high quality of his many contributions and it is an opportunity for the voice of Physics to be heard inside OSTP. On the other hand, his new assignment also poses concerns because no permanent NSF staff will cover his duties in EPP while he is away, placing additional burdens on the remaining staff. These are extremely important times for EPP. As the implementation of the P5 recommendations moves forward, we anticipate that large new programs, such as the LHC Phase 2 upgrades, will become part of the EPP portfolio. Already, the LHC Phase 1 projects have started. These new responsibilities will require more attention and focus from the program directors, and will stress the management structure further. The Division should consider adding additional personnel for the next few years to supplement the existing team.

2.a Responsiveness of the program to emerging research opportunities

Recently, the US Particle Physics community has converged in defining its scientific priorities for the next decade. The plan, which is summarized in the P5 report, identifies the key projects that should be supported to maintain a scientifically strong and sustainable Particle Physics program in the US. Several of these projects are within the EPP domain. In particular, the LHC program has been deemed the highest priority in the near timescale, and the Fermilab long baseline neutrino program was identified as the main priority after completing the LHC upgrades.

The NSF has promptly responded to the P5 report and a Panel of experts was charged to identify the areas in which the NSF could most effectively contribute to the P5 goals. The Panel, chaired by Prof. Y. K. Kim, delivered its preliminary conclusions in which three main areas of opportunities were identified: the LHC Phase 2 upgrades, the participation in the Fermilab-based Long Baseline Neutrino program, and the IceCube upgrades. First and foremost, the Kim subcommittee "strongly supports the NSF investment in the LHC Phase-2 upgrades as a way to enable and participate in fundamental discoveries. Funding at the

MREFC level is required for NSF to play significant and visible leadership roles". In addition, the Kim sub-committee recommends that "when the project is better defined and the shape of the international contribution begins to emerge, NSF should evaluate its participation in the LBNF." Fermilab will be the host lab for a world-class neutrino program. As this effort evolves, we expect the NSF to play a critical role in supporting the university groups who will lead these important experiments.

Finally, the Kim sub-committee pointed out that the potential for major discovery in particle physics depends on the funding of mid- and large-scale projects but also on funding the scientists who perform their research on the resulting facilities through PI driven research awards. The universities supported by NSF are crucial to the field of particle physics because of their scientific leadership and performing the unique task of training graduate students, the next generation of scientists for the field of particle physics and for a wide range of professions that are key to future American competitiveness.

The subpanel commends the active engagement of the MPS Division in the examination of and planning for the long-term future of particle and particle-astro physics, and accelerator science. The recommendations of the P5 Panel and the interpretation of its adoption as outlined by the Kim subcommittee represent a strong vision for the future of the field.

Another important element in the future program is continued coordination with the DOE in the planning and execution of major projects. This inter-agency engagement has been extremely successful in the past few years. The subpanel hopes that this cooperation will continue or expand as necessary for effective management of the program.

2.b Responsivenes of the program to emerging educational opportunities

In reviewing the overall program, the subpanel was impressed by the agility with which the program officers reacted to possibilities for funding innovative programs with associated educational components. Often, co-funding was arranged with other programs within the NSF, resulting in significant funding leverage for the initial EPP investment. The subpanel encourages the division to maintain this level of flexibility going forward.

IV. Program Portfolio

The subpanel finds the overall quality of the EPP program to be excellent. Despite shrinking budgets, the university base program is still funded at a level that allows world-class research and a high quality of educational experiences for students. 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 QuarkNet and Research Experiences for Undergraduates (REUs).

The diversity 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, and the development of new detector technologies. 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. There appears to be a good balance between RUI institutions and university groups at major research institutions, with 7 of the 59 awards funded belonging to non-Ph.D.-granting institutions. The RUI proposals are reviewed and ranked along with those from Ph.D. granting research universities, and thus compete on completely equal footing. Some of them have ranked quite highly in the annual panels

In terms of programmatic variation, for 2014 the breakdown in research sub-areas was: 59.4% in energy-frontier collider physics; 22.1% in neutrino physics; 17.8% in heavy quark physics; 14.6% in other intensity frontier physics; 8.2% in accelerator science (ongoing funding for programs supported by EPP prior to the availability of the Accelerator Science program); 4.7% in computational science; and 5.7% in broader impacts activities. This distribution seems appropriate for the current priorities of the science program.

For the awards funded in each fiscal year, the average funding levels per PI/Co-PI in the base program was $175k (2012), $195k (2013), and $201k (2014). The variations in funding have less to do with the overall EPP budget, which declined dramatically during this period, than the profile of the groups that were up for renewal in a given year. Forward-funding to avoid out-year commitments also skews these values. An overall value of $190k per PI/Co-PI, averaged over 2012-2014, represents a benchmark. This is identical to representative figures from 2008 (pre-ARRA) and 2011. The subpanel wishes to commend the program directors for keeping the base program solid in such a difficult budget environment.

The renewal rate for funded university groups of all types for FY12-14 is very high. This appropriately reflects the continued support of strong groups making significant contributions during the long time scales involved in the design, construction, data taking and analysis for frontier particle physics experiments. The overall funding rate for all proposals to the base program over the same time frame is comparable to that of PHY as a whole. New proposals specifically from non-Ph.D.-granting institutions had a success rate also comparable to PHY as a whole. We note the addition of US LHCb groups to the base program during this period.

There were three Career grants in EPP funded during 2012-2014, from an overall number of 32 submissions. However, ten new young investigators were funded on standard base program grants. Funding young researchers through the Base Program is an important approach, given that these are up to 3-year awards (rather than 5 year for the Career), are less demanding in terms of broader impacts, and can potentially fold a young researcher into an ongoing program or start a new program at an RUI institution. Out of the 10, three of the new investigators are from non-Ph.D.-granting institutions. The success rate for young investigators applying to the base program, regardless of institution, was again comparable to that of PHY as a whole.

Attraction of Allied Funding: the Program Directors have worked tirelessly to bolster the shrinking EPP budget by attracting cost-sharing from other Directorates or cross-NSF programs. For the three years of this review, the Allied Funding level has been $24.4M (2012), $15.6M (2013), and $12.9M (2014). This activity has helped temper the slide in overall budget, allowing the program to support a number of multi-disciplinary efforts, instrumentation projects, and outreach efforts.

A significant portion of the Allied Funding for EPP goes to support the efforts of the Open Science Grid, a multi-disciplinary effort that provides high performance distributed computing for many researchers across the world. The majority of users are, in fact, from the LHC experiments, so this represents an important resource used to extract the science from the massive LHC dataset. Additional computing support is provided by the Tier 2 computing centers that are funded through the cooperative agreements for ATLAS and CMS operating funds. The Tier 2 centers are the true backbone of LHC data analysis and their efficient operation is essential for the production of physics results. Also, university groups on LHC experiments are increasingly relying on the resources of local Tier 3 computing installations for analysis. Computation support is, of course, crucial for all experimental efforts. The subpanel encourages the EPP to maintain flexibility to allocate resources where needed to support the computing needs of the investigators.

Science Highlights

The current three-year cycle has been an eventful one for particle physics. Some of the science highlights include:

- **The discovery of the Higgs boson**. On July 4, 2012, experimenters from the CMS and ATLAS experiments at the LHC announced the observation of a Higgs-boson-like particle with a mass of approximately 126 GeV. Over the following two years, many measurements suggest that the new particle is indeed a Higgs boson, the first fundamental scalar ever discovered. Within errors, its coupling strength to the known fundamental fermions are measured by ATLAS and CMS physicists to be close to those predicted by the Standard Model. This discovery was recognized by the awarding of the Nobel Prize in Physics to Peter Higgs and Francois Englert in 2013.
- **SUSY and Exotic particles.** The 8 TeV LHC run has produced the most stringent limits to date on the existence of supersymmetric particles, pushing the allowed mass scales for first and second generation squarks and gluinos well past 1 TeV in most models. Significant exploration of a possible third-generation squark sector has yielded new limits, but no evidence for new physics. The same can be said for gaugino and slepton searches. Many searches for other new types of physics beyond the Standard Model have been successful in dramatically extending the excluded mass ranges, but have been unsuccessful in observing anything new. These new constraints provide a wealth of information on the type of new physics that is possible at the electroweak scale. At this point, all eyes look to the upcoming 2015 run at high energy for the possibility of a new discovery.
- **Searches for Dark Matter at colliders.** During the past three years, many novel searches for Dark Matter have been published at the LHC. These analyses look for pairs of Dark Matter particles produced in proton-proton collisions. These new Dark Matter searches are complementary to those carried out in underground experiments and provide the most stringent limits in the low-mass regions for many models.
- **The observation of the decay Bs->mumu.** Both LHCb and the CMS experiment have announced the observation of the rare B decay Bs->mm. A combination of the data released in 2013 shows a decay rate consistent with that predicted by the Standard Model. This measurement strongly constraints SUSY models with light gauge particles.

1. Societal Impacts and Benefits

At the NSF the role of scientific research takes into consideration the value to the society that supports this work, as well as the broader impact of the research on other areas of science and society in general. The materials examined for this period indicate that broader impacts of the proposals were taken into consideration and the overall efforts of the EPP program continues to benefit society. In addition to the direct research component, attention to broadening participation and outreach of underrepresented groups is also evident in the evaluation of this program.

The broader impacts of the EPP portfolio include the impact of accelerator research,, which was funded through EPP before being designated a new program of Accelerator Science in 2013. The development within EPP of novel particle detectors, computer control of research operations equipment, and large scale data analysis are pioneering technical contributions that have provided many benefits to society at large.

The quality of the EPP program also impacts the full scope of the world's educational system, by not only providing a structure for exceptional and unique professional training in physics, that impacts the development of the technical workforce, but through the Quarknet master classes that provide the opportunity for high school students to interact with international scientists in many world laboratories.

2. Broadening Participation and Outreach

To the extent possible, the EPP program seeks to engage under-represented minorities. Over the past three years, several AGEP grants have supported graduate students at institutions such as Rutgers and MIT. There have also been several awards to Minority Serving Institutions, such as Cal State Fresno, Purdue Northwest, and Florida International University.

EPP has a long history of extensive outreach projects. Some of the highlights from the current portfolio are:

- **IMAX Movie.** EPP program directors were involved and strongly supported the NSF award to K2 Communications, Inc (in collaboration with the UC Davis Department of Physics, the Stephen Low Company, and the Franklin Institute) to develop "Secrets of the Universe", a full-scale development project comprised of a 40-minute Giant Screen/IMAX documentary filmed in 3D that explores the most fundamental laws of nature under investigation at the LHC. The film will utilize live-action footage filmed at the LHC facility, "stunning scientific visualizations", and artistic interpretation to reveal some of the most compelling scientific stories of our time—recreation of the conditions that occurred immediately following the Big Bang, and the discovery of the elusive Higgs boson. CERN has provided unprecedented access to the LHC, ATLAS and CMS, including filming inside the LHC tunnel while it was open for Long Shutdown (LS1) in 2013-2014.
- **QuarkNet.** In FY12, QuarkNet, which was begun in 1999, was successfully reviewed by a joint NSF/DOE panel with funding recommended for another 5-year period. In FY13, the DOE announced that funding for Education Programs such as QuarkNet would be eliminated beginning in FY14. This was especially challenging as DOE support constituted approximately 40% of the funding support for FY13 program activities. Hence NSF provided bridging supplement to allow the program to make sensible course correction. This sustained program has involved more than 50 centers around the U.S., more than 500 teachers, and, through classroom materials and activities, tens of thousands of students. Along with progams such as I2U2 and through the development of Master Classes and e-Labs, hudreds of students world-wide are able to analyze data from LHC and other experiments.

How does the EPP program align with the NSF Strategic Goals of NSF and the National Priorities?

The EPP program is well aligned with the strategic goals of the NSF. Particle Physics continues to make strides in transforming the frontiers of science by exploring matter at its most fundamental level. Recently, the discovery of the Higgs Boson has given us new insight on the subatomic world. The LHC run that is about to start will allow us to explore uncharted territory and may uncover the first glimpse of particles never observed before. The EPP program also contributes very strongly to the education of the young scientists that become leaders in industry, especially in the fields of high-tech, computing, finance, medical physics and engineering.

The EPP program is also well aligned with the National Priorities, including training students and postdocs to contribute to cyberinfrastructure and tools for big data analytics. To fully exploit the scientific potential unlocked by the LHC, young researchers are trained to analyze in the most efficient way the gigantic datasets collected by the ATLAS, CMS and LHCb detectors. The training they receive prepares them well to become leaders and innovators inside and outside the academic world.

Response to 2012 COV Recommendations

In terms of the Division response to the 2012 COV recommendations, the subpanel was pleased that the items pertaining to EPP were implemented, and in some cases with major impact on the program. The implementation of the Mid-Scale Instrumentation Fund has enabled support of the Phase 1 upgrades for ATLAS and CMS at a critical juncture for the program. Continued investment and innovation in cyberinfrastructure, as recommended, has been increasingly important to exploit the research potential of large datasets across the entire program. The successful creation of the Accelerator Science program fills a long-standing need for a coherent approach in this important area. In the area of outreach and broader impacts, sustained support for the Quarknet program has brought access to data from the LHC and other experiments to thousands of students around the world.

2015 EPP Subpanel Recommendations

1) The subpanel commends the active engagement of the MPS Division in the examination of and planning for the long-term future of particle physics, particle-astro physics, and accelerator science. The recommendations of the P5 Panel and the interpretation of its adoption as outlined by the Kim subcommittee represent a strong vision for the future of the field. **This committee recognizes the importance of the extensive P5 process in setting the directions for our field and encourages the alignment of EPP priorities consistent with these recommendations, while being open to innovation.**

2) **The COV recommends that the coordination with the DOE in the planning and execution of major projects be continued in the future.** This inter-agency engagement has been extremely successful in the past few years. The subpanel hopes that this cooperation will continue or expand as necessary for the most effective management of the particle physics program.

3) **The COV encourages the EPP to maintain flexibility to allocate resources where needed to support the computing needs of the investigators.**

4) The COV was impressed overall with the quality of the review process in the EPP program. Nevertheless, a few improvements could be easily implemented. **The COV recommends that in the ad hoc review the evaluation of the scientific merit and broader impact is kept separate from any summary of the proposal, which could be added in a separate, optional section. The COV also recommends an appropriate balance between the weight given to the intellectual merits and broader impact criteria be maintained in evaluating proposals.**

5) **The COV recommends site visits to be resumed when necessary, particularly for larger grants with multiple PI's, despite the budget constraints.**

J. Accelerator Science

Accelerator Science is a new program that was established at the end of 2013. The first round of proposals was reviewed in June 2014. The NSF has funded in the past some accelerator research primarily through the EPP and ENP divisions. In addition NSF has supported and is supporting accelerator facilities. CESR at Cornell was supported as a facility by EPP until 2009 and CHESS, the Cornell light source is presently supported by DMR. Particle physics and accelerator science research at Cornell are competing now for funding in the respective programs in EPP and AS. NSF has also funded construction and operations of the NCLS facility at MSU and is committed to continue its support until the DOE ONP FRIB accelerator becomes operational around FY19-20. Consistently with the overall NSF strategy, the support of NSF for accelerators is evolving from a facility based support to the support of a competitive research portfolio. The subcommittee endorses this evolution and the establishment of a program focused on transformational accelerator research at universities.

A total of about 60 proposals were submitted in response to the call for AS proposal for a total request of ~70 M$. The total AS allocation for FY14 was ~9M$/year, so that resulted in a very competitive process.

The proposal review process consists of ad-hoc reviews (at least 3 are contacted for every submitted proposal) and of a review panel of 15 experts, of the appropriate NSF program directors and of a non-voting observer from DOE. At the end of the review process the panel establishes the ranking and issues recommendations for funding: funding if possible, funding if possible with lower priority and no funding. The decision to fund a proposal ultimately resides with the AS program director. The main criteria are intellectual merit and broader impacts but the ranking and funding decisions also take in consideration the proper balance among accelerator physics sub-areas to insure a diversified research portfolio.

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

In order to assess the integrity and efficacy of the processes used to solicit, review, recommend and document the proposal actions, the subcommittee on Accelerator Science reviewed all the jackets made available by the program managers and went through a detailed analysis of all stages of the review process from the mail-in review, to the panel to the final funding decisions. We requested and analyzed a few more jackets during the COV meeting to clarify some of the steps in the process.

Generally we found that the choices for referees and panelists were excellent. This is to be highlighted even more when considering that the program is in its first year of existence. The program managers should be commended for having drafted an outstanding class of experts in the field which provided a diversified and broad view of the field of accelerator science at its frontier. Naturally the NSF leveraged the expertise and connections with the DOE accelerator programs by using their existing pool of referees. One issue that deserves attention is the requirement to educate the referees on the differences between DOE and NSF criteria for ranking the proposals. In particular we recommend a better explanation of the educational aspects and the broader impacts requirement since these are not formally considered in DOE proposals.

The entire review process is very transparent and is conducted with extreme clarity and professionalism. There have been only few isolated instances for concern that we mention here to improve the reviewing process in the coming years. It should be noted here that we refrained from comparing the merit of the

individual funded proposals and our comments only aim at improving the review process as mandated by the charge of the COV.

In those particular cases where the outcome of the proposal decision is not completely aligned with the recommendation of the reviewers and the panelists, it is important that the program officers document in detail the reasons for declining or funding a proposal in their review analysis. We also note that, especially for the awards that are recommended for funding, a minimum of two reviewers should be used to evaluate the proposals.

Another issue in the program is the large disproportion between the size of the average efforts in this program and one of the awards which amounts to ~ 30 % of the entire Accelerator Science budget. The subcommittee understands that this is an artifact of legacy commitments in the research portfolio in the Physics division. In fact in this particular case we feel that the program managers for Accelerator Science did an excellent job in trying to reconcile the extremely large initial budget requests of this particular proposal with the constraint associated with a starting program. Nevertheless, in the future the NSF should resolve this issue preferably by separating such large awards into multiple proposals either by single investigators or small group of co-PIs which would be easier to rank in comparative reviews.

Finally, we note that both at the panel level and in the final funding decision there has been attention to balance among the different sub-areas of frontier accelerator science. This is certainly the right approach but we feel that it could help new applicants to outline more explicitly the various interests and subfields relevant to the Physics Accelerator Science program.

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

The AS program has been established too recently to allow an assessment of the results of the programmatic investments only 6 months from the first awards. The creation of an independent program for accelerator science is an excellent outcome from the 2012 report and is an important development for accelerator science, with its emphasis on innovative and transformative university based R&D. The proposals funded in 2014 have the potential of resulting in an excellent and diversified portfolio in accelerator science.

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

The position of Accelerator Science in the five perspectives on the frontiers of physics needs to be articulated. It is our view that AS for fundamental research is an integral part of "Neutrino and beyond the Higgs" and AS for novel accelerator techniques is relevant to the laser-matter interactions of "Strongly-interacting systems".

As a novel program it is important that the NSF AS be well coordinated with existing accelerator focused R&D programs in DOE, particularly the GARD (General Accelerator R&D), the accelerator Stewardship program in DOE OHP and other R&D programs in DOE, in order to avoid duplication of effort and to optimally leverage the specific goals of the NSF AS program. The coordination with the grant programs in DOE OHP seems to be off to good start, communication between program managers is already in place. We encourage the NSF to maintain the lines of communication with OHEP and initiate or strengthen communication with other DOE programs supporting accelerator R&D, such as ONP and BES. Although the R&D support from BES and ONP is typically programmatic there is potential for synergies there too. Another area that could benefit from agency coordination is the SBIR programs.

Participation and coordination in this area has again the potential of optimally leveraging agency resources. (We will discuss this in more details later in the report).

The AS program was established at the end of 2013 and we noticed that within the past 14 months 3 different program directors rotated into the position. We are fully aware of the circumstances that informed these decisions and we fully support those decisions. However the AS program is new and it is critical to have continuity and a program director who is fully focused on establishing the program on firm ground and on growing it.

The NSF with the establishment of a focused program in Accelerator Science is optimally positioned to be a relevant presence in the accelerator community. With more than 30000 accelerator operated in the world the accelerator community is increasingly relevant in fundamental science and in society. We encourage the NSF Physics Division to partner with DOE and professional societies such the APS and IEEE in supporting accelerator community conferences (example: IPAC series, International Particle Accelerator Conference) and educational initiatives (example: USPAS, US Particle Accelerator School). We are very glad to learn that initiatives in this direction are already starting.

Portfolio

The AS program has been around only one year, but thanks to the outstanding work of the program managers, it can already count on a diverse portfolio in many sub-fields of frontier accelerator science as well as in the educational aspects of charged particle physics. The breadth of the large number of proposals received supports the vision of the PHY division in starting this program. Most of the awards are appropriate in size and duration for the scope of the project and have the promise for transformative progress in accelerator science. The program participation in inter and multi-disciplinary program is limited and can certainly be increased as is the number of young investigator supported. At this stage this is a normal consequence of the very recent birth-day of the program.

Division level issues

One question that was raised in the discussion is the participation of the Accelerator Science program and of the Physics division in general to the SBIR/STTR program. This is a congressionally-mandated set-aside program and an important tool to foster the partnership between academia and small industries. In particular this program can serve to promote technology application of the research performed in the accelerator sciences and provide a diverse career path to the students involved in the small business developments. These considerations could perhaps be extended to the other Physics programs (AMO, plasma, detectors for EPP).

It should be noted that other funding agencies (DOE, DOD) rely heavily on the SBIR/STTR program to fund R&D that would otherwise be difficult to support programmatically. We encourage the Physics division to consider taking a closer look at actively leveraging this program.
Another issue is the role of the NSF in increasing diversity in accelerator science. We resonate with the Committee at large in the request for better data to capture the status and quantify the progress in this important aspect as well as in encouraging NSF Physics to take a mentoring role in increasing diversity . Considering geographic, ethnicity and gender diversity could be an important differentiation element of the NSF program from existing DOE and DOD accelerator physics programs.

Recommendation point summary

- It is critical to provide continuity to the Accelerator Science program in the form of a program director focused on establishing on firm ground and fully dedicated to gain momentum for this program.

- We recommend that at least 2 reviewers should be ensured for every proposal.

- Separate largest umbrella awards into multiple proposals either by single investigators or small group of co-PIs

- We suggest the Physics division to take a closer look at actively leveraging the SBIR/STTR program.

- We encourage the NSF to maintain the lines of communication with OHEP and reach out to other entities in DOE that are supporting accelerator R&D such as ONP and BES.

- We encourage the NSF Physics Division to strengthen the partnership with DOE and professional societies such the APS and IEEE in supporting accelerator community conferences (example: IPAC series) and educational initiatives (example: USPAS, US Particle Accelerator School).

- It could help new applicants to list (in a non exclusive way) the various interests and subfields relevant to the Physics Accelerator Science program.

- Given the overlap in the basic physics, in some of the proposals and program managers, it would make sense for future COVs to have one common reakout session between the plasma physics sub-committee and the accelerator science one.

VII Appendices

Appendix A. Template Response

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(s) 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: The COV was uniformly pleased with the quality and rigor of the Division's reviewing processes. The most common pattern for reviewing within the division is the three-tiered structure of ad hoc reviewers, followed by panel discussion, followed by program officer summary and recommendation. Although obviously labor intensive both for Division staff and for the broader community of physicists, the COV feels the final results of these processes are consistent in their fairness and in their quality.	YES
2. Are both merit review criteria addressed a) In individual reviews? b) In panel summaries?	 YES YES

c) In Program Officer review analyses? Comments: Extensive reviews of proposal jackets from many different proposals confirm that both merit criteria are addressed. Occasionally, individual ad hoc reviewers might give the Broader Impact criterion short-shrift, but this was almost always compensated for by the comments of other ad hoc reviews of the same proposal.	YES

3. Do the individual reviewers giving written reviews provide substantive comments to explain their assessment of the proposals? Comments: Across hundreds of jackets including order of one thousand reviews, there was some variation, of course, but a rule the individual reviewers provided useful, substantive comments to explain their assessments.	YES
4. Do the panel summaries provide the rationale for the panel consensus (or reasons consensus was not reached)? Comments: Panel summaries are often brief but conveyed the necessary information. They reflect a deeper evaluation than simply collecting the letter grades from the ad hoc committees. The rationales for reaching their recommendations were stated.	YES

5. Does the documentation in the jacket provide the rationale for the award/decline decision? [Note: Documentation in the jacket usually includes a context statement, individual reviews, panel summary (if applicable), site visit reports (if applicable), program officer review analysis, and staff diary notes.] Comments: Yes, the jackets contained ad hoc reviews, panel summary, and program officer's summary. Together these provided a very clear explanation of the rationale for decisions.	YES

6. Does the documentation to the 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 in the PO Comments field or emailed with a copy in the jacket, or telephoned with a diary note in the jacket) of the basis for a declination.] Comments: Our review of the jackets showed that feedback to the PI was generally very good, with ad hoc reviews and panel summaries being conveyed to PIs. PIs on declined proposals are encouraged to call their program officers to get additional oral feedback. It is not always possible to tell from the jackets to what extent the PIs are taking advantage of this valuable opportunity.	YES
7. Additional comments on the quality and effectiveness of the program's use of merit review process: The multi-tiered review system employed by the Division is a great thing, and allows for a very robust evaluation of proposals. Sitting at the hub of the process is the program officer, and the process works only as well as the PO. The Division is fortunate to have talented and committed POs. The importance of retaining talented people and recruiting new ones as needed cannot be overemphasized. If the caseload per PO gets too high, there is a risk of burning out talented staff, or of having these serious intellects reduced to "filling in the boxes" in a perfunctory way.	

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: Across the COV subcommittees there was consensus that the program officers selected a good variety of well-qualified reviewers, with expertise in the relevant topics. We find that in overwhelming majority of cases, the reviewers did a commendable job. There were here and there "a few hiccups" but the multiple-tiered reviewing system is resilient. The COV is happy to see program officers taking diversity including geographical diversity into account as they draft reviewers.	YES
2. Did the program recognize and resolve conflicts of interest when appropriate? Comments: The COV is pleased to see that the NSF in general and Physics Division in particular takes the Conflict-of-Interest (COI) issue very seriously, and does an excellent job of recognizing and resolving problems as they arise. The COV subcommittees reviewing Gravity and EPP-E programs were pleased with schemes the respective program officers have developed rigorous but workable methods for dealing with COI in cases where almost everyone in a particular field has been a co-author on the same paper.	YES
Additional comments on reviewer selection: N/A	

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: The COV was uniformly pleased with the diligence, fairness, judgment, and overall quality of Divisional management. While hard decisions had to be taken during difficult budget times, management and staff remained alert to new research opportunities.
2. Responsiveness of the program to emerging research and education opportunities. Comments: The subcommittee reports contain a wealth of detail with respect to examples of the various programs within the Division responding well to emerging research and education opportunities. At a higher level of organization, new programs have been started and older ones subsumed, as part of the process of responding to emerging and shifting opportunity.
3. Program planning and prioritization process (internal and external) that guided the development of the portfolio. Comments: The COV commends the Division for adopting a vision of the portfolio that is driven by key intellectual topics rather than administrative categories. We believe this can be an increasingly useful tool for evaluating the balance and future directions of the Division.
4. Responsiveness of program to previous COV comments and recommendations. Comments: For the most part, the Division was quite responsive to comments and recommendations in the 2012 COV

report. In situation where recommendations were not implemented, there typically good reasons provided. The COV notes that the 2012 COC was concerned about demographic data collection and the accessibility of the collected data. This continues to be a concern of the 2015 COV.

IV. Questions about Portfolio. Please answer the following about the portfolio of awards made by the program under review.

RESULTING PORTFOLIO OF AWARDS	APPROPRIATE, NOT APPROPRIATE, OR DATA NOT AVAILABLE
1. Does the program portfolio have an appropriate balance of awards across disciplines and sub-disciplines of the activity? Comments: The COV members come from a very wide range of subdisciplinary backgrounds, and there were lively discussions about balance across disciplines and subdisciplines. The COV as a whole identified no serious problems here.	APPROPRIATE
2. Are awards appropriate in size and duration for the scope of the projects? Comments: As a result of the rescission, there were cuts in award size and duration, and in the number of awards. How this played exactly varied from program to program within the division, which is appropriate, given the variety of different communities supported. The consensus is that in most cases the Division has threaded this needle as well as they can.	APPROPRIATE
3. Does the program portfolio include awards for projects that are innovative or potentially transformative?	

Comments: Yes, many of the projects are innovative, and some are already proving to be transformative. Details of these projects are presented in many of the subcommittee reports.	APPROPRIATE
4. Does the program portfolio include inter- and multi-disciplinary projects? Comments: Absolutely. The entire PoLS program is interdisciplinary by its nature, and many of the AMO projects have strong overlap with concepts formerly in the province of DMR. The PFC program is a rule extremely multi-disciplinary. The subcommittee reports contain examples of a number of such projects. In some cases the inter-disciplinary nature is based on overlap of scientific concepts; in others it is made explicit by joint funding and shared personnel.	APPROPRIATE
5. Does the program portfolio have an appropriate geographical distribution of Principal Investigators? Comments: Due to an oversight, the COV during its brief three-day meeting neglected to look carefully at geographical distribution of PIs. We are aware of no concerns along these lines, however.	DATA NOT AVAILABLE
6. Does the program portfolio have an appropriate balance of awards to different types of institutions? Comments : There appears to be balance between RUI institutions and research groups at large universities. For example, the EPP-E panel reports that 7 of 59 grants in their area were to non-PhD-granting institutions.	APPROPRIATE
7. Does the program portfolio have an appropriate balance of awards to new investigators? NOTE: A new investigator is an investigator who has not been a PI on a previously funded NSF grant. Comments: The COV sees evidence that the Division has been able to continue to make grants to new investigators even during difficult times.	APPROPRIATE

8. Does the program portfolio include projects that integrate research and education? Comments: Yes, a number of such projects can be identified.	APPROPRIATE
9. Does the program portfolio have appropriate participation of underrepresented groups[3]? Comments: As discussed elsewhere in the report, the COV feels that the data was just not there to allow for a thoughtful response to this question.	APPROPRIATE
10. Is the program relevant to national priorities, agency mission, relevant fields and other constituent needs? Include citations of relevant external reports. Comments: The program is highly relevant to the national priority of maintaining competitiveness in an increasingly high-tech, increasingly global economy. The Physics Division as much as any other division in the Agency has an eye on the long horizon. The fundamental questions addressed in the projects funded in this portfolio are the seed corn for innovation a decade from now. The students and postdoc trained in cutting-edge scientific techniques in the programs funded in the Physics Division go multiple ways as their days as junior scientists come to an end. Some go on in academia, but most of them become vectors of high-tech ideas, and represent the ultimate Broader Impact – a legion of technological elites spreading out across the countryside and looking for a rumble, looking for a way to make their mark in American industry and education. They will be the authors of innovation, in 2025.	APPROPRIATE
11. Additional comments on the quality of the projects or the balance of the portfolio:	

[3] NSF does not have the legal authority to require principal investigators or reviewers to provide demographic data. Since provision of such data is voluntary, the demographic data available are incomplete. This may make it difficult to answer this question for small programs. However, experience suggests that even with the limited data available, COVs are able to provide a meaningful response to this question for most programs.

The COV was struck by the very high quality of the projects funded. It has been an honor for us to review the program.	APPROPRIATE

OTHER TOPICS

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

In our summary recommendations the COV provides a few suggestions. Broadening participation remains a serious concern here as elsewhere in the physical sciences. The COV feels improved data collection is important. One improves things by trying out ideas and learning from experience. An absence of data makes it very difficult to see what is working and what isn't.

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.

N/A

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

The issue of collection of demographic data (which we allude to in this template and discuss more elsewhere in the report) is properly understood as an Agency-wide issue, and not merely a Divisional issue. We emphasize this point in our review of the Division simply because the Division is what is in our purview!

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

See the plenary section of our report for a number of other comments and observations.

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

The COV did not have time to discuss this issue, so what follows is just an inclusive list of suggestions culled from subcommittee reports. The COV as a whole takes no position on the suggestions.

(i) Presentations by NSF staff to COV should be more concise, allowing more time for discussion.

(ii) We suggest that a request to identify division-wide issues be made to CoV members well in advance of the physical meeting as part of the advance preparation. Issues that several members regard as important can then be studied in advance by a small subgroup of CoV members who could make recommendations to the full CoV membership prior to meeting. It would be helpful if issues that the NSF division leadership wants the CoV to consider could be similarly included in the advance preparation. There should still be time at the meeting allotted to open discussion of additional issues that are identified

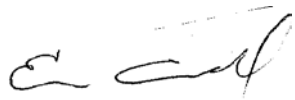
during the meeting. If a few of these need more in-depth consideration, they could be taken offline by an ad-hoc subcommittee who then reports back to the larger group later in the meeting and prior to making recommendations to NSF.

(iii) Increased care should be taken in handling COV panelist COI issues. See the Nuclear Subcommittee's report for more details.

(iv) More review information – jackets, panel reports, demographics, etc, should be provided to COV before they arrive. See Nuclear Subcommittee's report for more details.

(v) Given the overlap in the basic physics, in some of the proposals and program managers, it would make sense for future COVs to have one common breakout session between the plasma physics sub-committee and the accelerator science one.

SIGNATURE BLOCK:



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For the 2015 Physics Division COV

Eric Cornell

Chair

Appendix B: Division of Physics

Appendix B: Division of Physics
Committee of Visitors
February 4-6, 2015
Agenda

Wednesday, February 4 - Room II-555

7:30 am	Refreshments (Room II-555)
8:00 am	Introductions, Welcome and Charge to Committee of Visitors (COV) F. Fleming Crim, Assistant Director, Directorate for Mathematical and Physical Sciences (MPS)
8:20 am	COV Guidelines Eduardo Misawa, Staff Associate, OAD/MPS
8:40 am	Introductory Remarks Eric Cornell, Chair, COV
9:00 am	Overview of PHY organization, operating principles Denise Caldwell, 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 5 – Room II-555

7:30 am	Refreshments (Room II-555)
8:00 am	Introduction to Division-Level Review – Denise Caldwell (Room II-555) ▪ Division's Processes, Results, and Relationship to NSF Goals ▪ Division 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)
5:30 pm	Adjourn

Friday, February 6 - Room II-555

7:30 am	Refreshments (Room II-555)
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	Meet with Fleming Crim, Celeste Rohlfing and Eduardo Misawa (closed session with MPS/OAD; no PHY staff present)
3:00 pm	Closeout Session with PHY Staff
3:30 pm	Adjourn

Appendix C: 2015 Physics Division COV Participants

PHY COV FY2015 Membership List

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Appendix D: 2015 Physics Division COV Subpanels

Physics of Living Systems
Jose Onuchic (Chair)
Dagmar Ringe
Ranajeet Ghose

EPP Theory and Math Physics
Sally Dawson
Joanne Hewett (Chair)
Marcela Carena

AMOP Theory+Experiment and QIS
Chris Greene (Chair)
Linda Young
C. Fred Driscoll
Gerald Gabrielse

Nuclear Physics Theory+Experiment
Roxanne Springer
Julie Roche
Helen Caines
Sherry Yennello (Chair)

EPP Experiment
Gabriella Sciolla
Michael Hildreth
Herman White (Chair)

PA
Lucy Fortson (Chair)
Pierre Sokolsky
Betty Young

Gravity (incl LIGO)
Jeffrey Livas
Jorge Pullin (Chair)
John Friedman

EIR+BP
Cathy Mader (Chair)
Marco Cavaglia
Anderson Sunda-Meya

Accelerator
Fulvia Pilat (Chair)
Pietro Musumeci

PFC+midscale+CP
Jonathan Bagger
Paul LaMarche
Amber Boehnlein (Chair)

Appendix E: Division of Physics Charge to 2015 Committee of Visitors (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 2012; 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 2012, FY 2013, and FY 2014. The PHY programs under review include:

- Accelerator Science
- Atomic, Molecular, Optical, and Plasma Physics
- Computational Physics
- Education and Interdisciplinary Research
- Elementary Particle Physics
- Gravitational Physics
- Midscale Instrumentation
- Nuclear Physics
- Particle Astrophysics
- Quantum Information Science
- Physics Frontiers Centers
- Physics of Living Systems

Where appropriate these include both experimental and theoretical research programs.

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