Joint Executive Summary from the Nuclear Astrophysics and Low-Energy Nuclear Physics Town Meetings

In preparation for the 2015 NSAC Long Range Plan (LRP), the DNP town meetings on Nuclear Astrophysics and Low-Energy Nuclear Physics were held at the Mitchell Center on the campus of Texas A&M University August 21-23, 2014. Participants met in a number of topic-oriented working groups to discuss progress since the 2007 LRP, compelling science opportunities, and the resources needed to advance them. These considerations were used to determine priorities for the next five to ten years. Approximately 270 participants attended the meetings, coming from US national laboratories, a wide range of US universities and other research institutions and universities abroad.

The low-energy nuclear physics and the nuclear astrophysics communities unanimously endorsed a set of joint resolutions. The full text of the resolutions adopted at the Town Meetings is included at the end of this document. The joint resolutions were condensed from the individual recommendations of the two town meetings in order to recognize the highest priorities of the two fields. The resulting joint resolutions reflect hard choices, as not all priority items from the individual meetings are included. The communities strongly hope that the broader needs can be realized in time.

The resolutions represent a plan to address the compelling scientific opportunities in the study of atomic nuclei and their role in the cosmos. The intellectual challenges of our subfields were captured well in overarching questions from the 2012 NRC *Decadal Survey of Nuclear Physics*:

- How did visible matter come into being and how does it evolve?
- How does subatomic matter organize itself and what phenomena emerge?
- Are the fundamental interactions that are basic to the structure of matter fully understood?
- How can the knowledge and technological progress provided by nuclear science best be used to benefit society?

Answers to these questions require a deeper understanding of atomic nuclei, both theoretically and experimentally, than we have now. The last decade already saw considerable progress in understanding of the nucleus and its role in the universe. New ideas, combined with new experimental techniques, major leaps in computing power and impressive improvements in experimental capabilities resulted in discoveries leading to quantitative and qualitative changes in our understanding of nuclear and astrophysical phenomena.

A comprehensive discussion of the broad scientific opportunities and challenges will be provided in the individual town meeting reports. Low-Energy nuclear physics research addresses the existence of atomic nuclei, their limits, and their underlying nature. It also aims to describe interactions between nuclei and dynamical processes such as fission. The ultimate goal is to develop a predictive understanding of nuclei and their interactions grounded in fundamental QCD and electroweak theory. Nuclear astrophysics addresses important scientific questions at the intersection between nuclear physics and astrophysics: the chemical history of the Universe, the evolution of stars, stellar explosions, and the ultimate fate of visible matter.

Both fields are poised for breakthroughs. New astronomical data, such as high resolution abundance distributions from very early stars; the neutrino fluxes from our sun, nearby supernovae, or possibly even the Big Bang; and anticipated gravity waves detected from merging neutron stars, will only be interpreted successfully if the relevant nuclear processes are understood. Exploration of elements and isotopes at the extremes of N and Z will provide the insights needed for a comprehensive understanding of nuclei. This exploration may reveal novel quantum many-body features and lead us toward a deeper understanding of complex quantum systems and of the mechanisms responsible for the emergent features found in atomic nuclei.

More broadly, science and society rely on our understanding of the atomic nucleus. Its relevance spans the dimensions of distance from 10^{-15} m (the proton radius) to 12 km (neutron star radius) and the evolutionary history of the universe from fractions of a second after the Big Bang to today; i.e., 13.8 billion years later. As reaffirmed by the 2012 National Academies of Sciences' decadal study "*Nuclear Physics: Exploring the Heart of Matter*," the path to understanding the nucleus requires the completion of the Facility for Rare Isotope Beams (FRIB) and its effective operation. Unprecedented access to a vast new terrain of nuclei will result in scientific breakthroughs and major advances in our understanding of nuclei and their role in the cosmos, and will open new avenues in cross-discipline contributions in basic sciences, national security, and other societal applications.

Based on this the first joint resolution was: **1. The highest priority in low-energy nuclear physics and nuclear astrophysics is the timely completion of the Facility for Rare Isotope Beams and the initiation of its full science program.**

While FRIB is the top priority of both subfields, there are other capabilities needed to reach the scientific goals of the field. In arriving at a joint set of resolutions, the Town Meeting participants addressed priorities for the field as a whole. What emerged is a coherent plan that pursues key scientific opportunities by leveraging existing and future facilities. The plan involves continuation of forefront research activities, development of needed theory, and initiation of a focused set of new equipment initiatives. While many specific ideas were discussed, it was decided to approve wording that made clear that the community is asking for the base set of needs while recognizing that some initiatives may have to be delayed. The consensus minimum need is outlined in the following.

The science goals of Low-Energy Nuclear Physics and Nuclear Astrophysics require studies with probes ranging from stable and radioactive nuclei, to photons, neutrons, and electrons. While FRIB will explore uncharted regions of the nuclear chart and produce rare isotopes important for study of explosive environments, there is a key component of the program that links this exploration to studies of near-stable isotopes. The ATLAS stable beam facility has world-unique capabilities that will enable necessary precision studies near stability and at the limits of atomic number. Many aspects of stellar evolution, in particular the long quiescent phases of stellar evolution defining the conditions and providing the seed for subsequent cataclysmic developments, are driven by reactions of stable isotopes that will be studied at stable-beam accelerators. The electron beam at JLAB provides a unique capability for probing the short-range part of the nuclear force in nuclei and the modification of nucleons in the nuclear medium. The photon beam at HIγS and the neutron beams at Los Alamos provide unique, important information. The university accelerator labs have a special role. They contribute cutting edge science, targeted research programs of longer duration, critical developments of techniques and equipment, combined with hands-on education.

For success in the long term, including success of FRIB, we must adequately operate current low-energy facilities and support the research groups that utilize these facilities to advance science and to foster an experienced and engaged research community. Adequate operations require that planned upgrades, already in baseline budgets, proceed, and current levels of research activities be enhanced. Significant facility reductions have occurred since 2007, including the closure of HRIBF and WNSL. These closures, coupled with limited availability of research hours at facilities worldwide, has resulted in a loss of research opportunities that can be restored in part by the development of a multi-user capability at ATLAS.

The Town Meetings recognized that the NSF has played a leading role in the establishment and operation of one of the nation's flagship nuclear science facilities, NSCL, as well as in supporting university laboratories that carry out forefront nuclear physics and nuclear astrophysics research. There is the opportunity for continued leadership by support of cutting edge nuclear physics and transformative research extending well into the era of FRIB operations. This LRP can make the case for continued strong nuclear physics funding by NSF. Continued NSF leadership in the study of nuclei and nuclear astrophysics can be accomplished by an exciting plan that includes the effective operations at NSCL and NSF university laboratories, proposed upgrades to ReA3 at NSCL, and support for nuclear astrophysics initiatives such as an underground accelerator.

Hence, the Town Meeting participants recommended: **2a. We recommend appropriate support for operations and planned upgrades at ATLAS, NSCL, and university-based laboratories, as well as for the utilization of these and other facilities, for continued scientific leadership. Strong support for research groups is essential.**

Significant progress in the theory of nuclei and the astrophysical environments in which they are embedded is a key component of the scientific goals of the field. A strong theory effort needs to go hand in hand with future experimental programs. The proposed FRIB Theory Center, a modest-scale national effort comprising a broad theory community, will therefore be important for the success of FRIB. (A brief overview of this effort will be summarized in a separate document.) The FRIB Theory Center will complement the NSF funded Joint Institute for Nuclear Astrophysics that facilitates the communications within the nuclear astrophysics community. JINA's efforts are essential for the interpretation of nuclear physics experiments and stellar observations in the framework of new theoretical developments. Its continuous operation is a main goal for the entire nuclear astrophysics community. This need for broad theory support resulted in part two of the second recommendation: **2b. We recommend enhanced support for theory in low-energy nuclear science and nuclear astrophysics, which is critical to realize the full scientific promise of our fields.**

In addition to the needs articulated above, a targeted set of new instrumentation and accelerator investments are necessary. FRIB will be a world-leading accelerator and will yield the best science when coupled with world-leading equipment. The community has identified and prioritized key detector systems and re-accelerator upgrades that will enable effective utilization of FRIB with the highest science potential. In the 2007 LRP the major new detector endorsed was GRETA and, at that time, it was recognized that an astrophysics separator would be needed (which is now named SECAR). These state-of-the-art systems are still top priority and highly anticipated by the community. While existing equipment can and will be used at FRIB, major advances in other detector and separator technology continue to take place. To this end, the community has developed exciting ideas for critical new equipment. Not all can be realized immediately, but a targeted suite to address the highest-priority research programs is needed.

In the area of accelerator investments, there is an opportunity for NSF to play a leading role by upgrading ReA3 and by establishing an underground accelerator for nuclear astrophysics. The community has long advocated for these developments.

In order to prepare the future and advance the science goals of the community, the third part of the second resolution states: **2c. We recommend targeted major instrumentation and accelerator investments to realize the discovery potential of our fields.**

Two additional joint resolutions were adopted to support the main conclusions of the Computational Town Meeting and the Education and Innovation Town Meeting.

Full text of the joint resolutions:

Science and society rely on our understanding of the atomic nucleus. Its relevance spans the dimensions of distance from 10^{-15} m (the proton's radius) to 12 km (the neutron star radius) and timescales from fractions of a second after the Big Bang to today, i.e. 13.8 billion years later. As reaffirmed by the 2012 National Academies of Sciences' decadal study "*Nuclear Physics: Exploring the Heart of Matter"*, the path to understanding the nucleus requires the completion of the Facility for Rare Isotope Beams (FRIB) and its effective operation. Unprecedented access to a vast new terrain of nuclei will result in scientific breakthroughs and major advances in our understanding of nuclei and their role in the cosmos, and will open new avenues in cross-discipline contributions in basic sciences, national security, and other societal applications.

- **The highest priority in low-energy nuclear physics and nuclear astrophysics is the timely completion of the Facility for Rare Isotope Beams and the initiation of its full science program.**

In support of our science goals we must continue forefront research, exploiting existing facilities, develop new capabilities and equipment, and enable major advances in nuclear theory.

- **We recommend appropriate support for operations and planned upgrades at ATLAS, NSCL, and university-based laboratories, as well as for the utilization of these and other facilities, for continued scientific leadership. Strong support for research groups is essential.**
- **We recommend enhanced support for theory in low-energy nuclear science and nuclear astrophysics, which is critical to realize the full scientific promise of our fields.**
- **We recommend targeted major instrumentation and accelerator investments to realize the discovery potential of our fields.**

Realizing the scientific potential of Low Energy Nuclear Science and Nuclear Astrophysics demands large-scale computations in nuclear theory that exploit the US leadership in high-performance computing.

- **We endorse the recommendations of the 2014 Computational Nuclear Physics Meeting: "*Capitalizing on the pre-exascale systems of 2017 and beyond requires significant new investments in people, advanced software, and complementary capacity computing directed toward nuclear theory."***

Education, outreach, and innovation are key components of any vision of the future of the field of nuclear science. Our fields play a leading role in education and training of the nation's nuclear science workforce. They are ideally positioned to advance applications in medicine, energy, national security, and material science. The health of this field is required to train the talented national workforce needed to assure continuing societal benefits in these critical areas. Continuation of this role is a major goal of our fields.

- **We endorse the recommendation of the DNP Town Meeting on Education and Innovation.**