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Proposal No.	**SI**	**DCG**

General LDRD Proposal Template

[This general template must be used for Competitive Grants pre-proposals **(3 page max)** and full proposals **(5 page ma**x) and for Strategic Initiative full proposals **(8 page max)**. It may also be used for Strategic pre-proposals but is not required in this case. *Double click box to make entry.*]

This is a ☒ PRE- or a ☐ FULL (**Check One**) Proposal submitted to the ☐ Competitive Grants or ☒ Strategic (**Check One**) component of LDRD.

Project Title: Astrophysics Initiative

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Check ONE box only for each of the two questions below:

The proposed research and investigators ☒ do, ☐ do not comprise a multidisciplinary effort.

The proposed research is primarily of ☒ basic, ☐ applied, ☐ development character. [See General Guidance document for definitions]

Fill in percentages for the project character and project relevance (each line must sum to 100%)

Project Character: Theory 20 % Simulation/Modeling 20 % Experiment 50 % Software Development 10 %

Project Relevance: National Defense ______% Homeland Security (HS) _____% Non-Defense/Non-HS 100 %

(1) Funding Profile ($K)	TOTAL (All Years)	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Staff/STA Effort	863			91	378	394
Post Doc Effort	1143			120	501	522
M&S	2128		39	431	813	845
Operating Total	4134		39	642	1692	1761

(2) Scientific/Technical Opportunity

Astrophysics is going through an exciting period. Astronomical observations, covering the full spectrum of wavelengths, have revealed new and unexpected phenomena that will fundamentally influence our understanding of Nature. On Earth we have started to simulate some of these processes in the laboratory and together with improved computational capabilities considerable advances have been made in understanding the events observed in the cosmos. The many facets involved in such an ambitious undertaking have led to a multi-pronged approach, which can best be pursued at a multi-purpose National Laboratory like Argonne. This is demonstrated by the wide spectrum of astrophysics theory and experiments under way at several Argonne divisions. Although small steps aimed at combining the efforts of the various groups have been made in the past, a lab-wide interdivisional astrophysics initiative would give a critical boost to Argonne's impact in this all-important field.

A committee of representatives from the Materials Science, Physics, and High Energy Physics divisions has been seeking opportunities for a joint project or suite of projects that would constitute a lab-wide initiative in astrophysics. We have reviewed the current programs in each division, identified common areas of scientific interest, and surveyed new and ongoing experimental projects. We have identified supernova science as the most promising science theme that combines existing expertise and facilities at Argonne, common interests among divisions, potential for funding growth, and national scientific priority. Supernova science has important roles to play in defining the nature of dark energy and in understanding the origin of the elements.

Within the next decade, experiments currently under development in the astrophysics community will produce supernova data sets orders of magnitude larger than those currently available. Effective use of those data to constrain dark energy and nucleosynthesis will depend on understanding both observational systematics and the properties of supernovae. The data will also provide important constraints and tests for models of multiple types of supernovae. Nucleosynthesis in several environments, including supernovae, is already a focus of both experimental and theoretical activity at Argonne. The proposed astrophysics initiative will build up and extend these efforts so that astronomical, accelerator, and meteoritic measurements combine with theoretical work to make Argonne a recognized center for supernova science.

(3) Benefits/beneficiaries/customers

Argonne and its scientific community will benefit from the enhanced program in astrophysics. The general scientific community will benefit from an astrophysics center combining observational, accelerator, and trace element measurements with theoretical work. The most likely sources of new funding would be from the Department of Energy and the National Aeronautics and Space Administration.

(4) Hypothesis/Objectives/Approach (nature of work, deliverables, milestones, leveraging of external activities, FY2007 work and expected results)

Supernovae represent the intersection of many areas of astrophysics, and their observed properties connect to forefront areas of nuclear and particle physics. Core collapse supernovae (all types except Type Ia) arise from the collapse of the burnt-out cores of stars with eight or more times the mass of the sun. The collapse releases a vast amount of energy in neutrinos, which somehow couples to the rest of the star's matter so that one percent of the neutrino energy disrupts the outer parts of the star. For a few weeks, the resulting explosion outshines entire galaxies, as it begins dispersing the star's nuclear-processed inner material into the general interstellar medium (ISM). Supernovae of Type Ia are caused by thermonuclear detonation of carbon/oxygen white dwarfs. They disrupt the progenitor completely, also producing explosions that outshine galaxies and disperse freshly-produced nuclei. Together, these two types of events are the sources of almost all of the nuclei in the universe that are neither hydrogen nor helium.

Efforts under way to determine the mechanisms by which the neutrino energy produces the explosion in core collapse and by which a Type Ia supernova is detonated are ambitious undertakings. This work requires sophisticated computer models of neutrino transport and hydrodynamics, as well as accurate nuclear-physics inputs for neutrino scattering, electron capture, and the high-density equation of state. Any successful model will have to stand up to testing against observations of actual supernovae. These events are visible across great distances, so that they constrain not only the supernovae themselves but also the properties of the universe through which the resulting photons and neutrinos propagate.

The discovery of dark energy in 1998 was universally hailed as the science breakthrough of the year and is an underpinning of the ΛCDM cosmology – the present model of how the universe is put together at the largest length scales. The dark energy's effect on the expansion rate of the universe was discovered by measuring the brightness of Type Ia supernovae as a function of redshift, using an empirical relation between peak luminosity and time required for the brightness to drop. Supernovae are surely more complicated than this simple relation suggests, and this is confirmed by spectral and polarization data. Until they are better understood, these complications will constitute important sources of systematic error in future, more precise measurements of the dark energy and its evolution.

Argonne has existing efforts aimed at several aspects of supernovae, and these form a natural base from which to begin building expertise and to build our visibility to the world as a center for supernova science. The Physics Division theory group has strong ties, through a joint staff appointment, to the effort to understand thermonuclear supernova explosions at the University of Chicago Flash Center, and particularly to efforts to compute nucleosynthesis in the burned material. This effort is the subject of a DOE nuclear astrophysics milestone for year 2009. A closely-related matter under experimental investigation in Physics Division is the low-energy suppression of fusion reactions, which might affect the conditions for initiation of the explosion by the $^{12}C+^{12}C$ reaction. For core-collapse supernovae, members of both Physics and HEP divisions have been involved in discussions of a supernova neutrino detection experiment, known as ADONIS.

In both types of supernovae, both charged-particle and neutron-capture reaction rates are important for the nucleosynthesis; the low-energy experimental effort in Physics Division is oriented toward providing such rates, which are the subject of the DOE nuclear astrophysics milestone for year 2012. A particularly successful example is the effort during the last few years to constrain the production of the radioactive nuclide ^{44}Ti. Efforts of this kind connect not just to gamma-ray lines potentially or actually observable in supernova remnants (^{44}Ti, ^{26}Al, ^{60}Fe...), but also to optical and X-ray observations constraining the nucleosynthetic outputs of supernovae. They also link to presolar stardust grains, some of which formed in supernovae and contain the best if not the only source of information on the isotopic composition of newly-synthesized material. Stardust grains are the focus of a strong effort in the Materials Science Division, which leads the world in measuring isotopic compositions of trace elements in such small samples. Supernova grains are rare among stardust grains, comprising about 1-2% of all pristine stellar matter, and are distinguished from other grains by certain characteristic isotopic signatures. To gain meaningful insights into supernova nucleosynthesis many grains must be analyzed individually. MSD is currently working on methods to automate searches of meteoritic residues for SN grains and analyze them for isotopes of trace elements from iron to uranium that are important in understanding SN nucleosynthesis, such as ^{96}Ru, ^{100}Mo, ^{154}Sm, and others. This will in turn provide information about supernova explosions and mixing. MSD is also currently engaged in a search for live supernova-produced ^{244}Pu (half-life = 8×10^7 years) in deep-sea sediments. The successful detection would not only confirm the origin of recently-detected ^{60}Fe (half-life = 1.5×10^6 years) in related terrestrial materials, but would also provide strong evidence that supernovae are in fact the site of the *r*-process and would constrain theories of explosive nucleosynthesis. Current supernova models make predictions about the ^{244}Pu / ^{60}Fe production ratio that depend on the nuclear physics inputs and the mechanism of explosion; thus we have a unique opportunity to directly constrain current and future supernova models. These and other aspects of the *r*-process are also topics of theoretical effort in Physics Division.

As the ejected material continues to expand outward for several thousand years before finally mixing with the general ISM, it plows up large amounts of the surrounding medium at a shock. Such shocks are thought to be the main acceleration site for Galactic cosmic rays. A major target of study for gamma-ray telescopes like VERITAS, a gamma-ray telescope in which HEP division is already a partner, is the TeV gamma-ray emission from these shocks. In addition to enabling study of the remnants themselves (complementary to X-ray observations), the energy spectra observed by VERITAS will shed light on the role of supernova remnants in Galactic cosmic ray acceleration: acceleration of hadrons should be accompanied by π^0 production, so a spectrum characteristic of π^0 decay would be strong evidence that supernova shells are the main acceleration site for cosmic ray nuclei.

A very small fraction of core collapse supernovae in very massive stars become gamma-ray bursts (GRBs). It is not yet known whether the signal in these events produces photon energies in the TeV range, but the VERITAS collaboration is actively searching for such a signal. The recently-appointed named fellow in HEP, Deirdre Horan, is currently PI on a proposal to look for a TeV component of the bursts. There is also some indication that the absolute luminosities of GRBs can be determined from other characteristics of the burst. If this turns out to be true, GRBs can also be used to constrain properties of dark energy. Since they are observed at much higher redshift than Type Ia supernovae, they may be particularly good for measuring the time evolution of dark energy.

(5) Resources required (dependencies, key skills, new hires)

We propose to spend the next year to fully define the future program. Ultimately, we want to find synergistic ways to build up existing efforts along with a major new experimental project involving at least HEP Division. This will depend on opportunities to join experiments that have been initiated elsewhere, or to identify areas where we can get in from the beginning. Identifying our best opportunity will depend partly on outside factors – such as the recommendations of the DOE Dark Energy task force and the availability of roles in major collaborations – and partly on the internal process of investigating science opportunities (not necessarily pre-existing projects) and matching them with local strengths. Opportunities to link this effort with potential nearby collaborators like the Flash Center also need more investigation.

We propose several new programs for the next year, beginning this summer. Bringing in visitors and hosting workshops will raise our visibility and make our options clearer. A seminar series in astrophysics with funding for outside speakers, as well as funds for travel by committee members, will also serve these goals. Including an outside advisory committee to help identify visitors, we estimate that these programs need a total of $39K in FY06 and $225K in FY07.

In addition to seminar and visitor programs, we envision hiring post-docs, and/or junior staff, in each division in the second half of FY07, as well as initiating a new experimental effort. New hires in FY07 and FY08 will carry out much of the expanded effort. We estimate that these hires will require $253K in FY07. M&S and equipment funds in FY07, totaling $164K, will support the new experimental initiative, as well as supporting the related work of the lab's first named fellow in astrophysics.

In the second fiscal year we would launch the program defined in FY07. The seminar series, visitor program, and workshops would continue. It is expected that significant equipment funds for new experimental programs will be required in the second and third years. This together with completion of the manpower expansion is expected to require about $1.7M per year. We will be pursuing external funding for the program starting in FY08.

(6) Future funding opportunities (direct follow-on and related programs) for next year and subsequent years

Astrophysics generally, and supernova science in particular, are the focus of substantial effort across multiple funding agencies. A report commissioned jointly by NASA, DOE and NSF, Connecting Quarks with the Cosmos, the National Academy of Sciences identified the origin of the elements heavier than iron and the nature of the dark energy as two of the eleven Grand Challenges for physics and astronomy for which the prospect of a breakthrough in the next decade is high. Because supernovae are excellent candidates for the site of the *r*-process, these topics are both aspects of supernova science. The opportunities for long-term funding of a supernova center based at Argonne are excellent.

DOE HEP and DOE Nuclear Physics both have large investments in supernova modeling, and many aspects of supernovae and their associated nucleosynthesis have been made milestones for the DOE Nuclear Physics program in the coming years. Moreover, a large portion of the scientific benefit from proposed exotic beam facilities in nuclear physics will be the measurement of nuclear properties required to understand nuclear processes in stars and supernovae. The *r*-process will place the greatest demands both on experiments at such a facility and on their theoretical extrapolation to still other nuclei that cannot be made. In light of all this, we expect that for many years to come, DOE will support a large amount of effort in this area. This will be necessary both to meet the goals that have been set and to get maximum benefit out of any exotic-beam facility.

In addition, dark energy research, being intimately connected with vacuum energy, is a priority for DOE HEP. Among the experiments that they have recently given CD-0 approval is a generic ground-based dark energy experiment. The budget for dark energy studies is indeed one of the fastest growing line items for DOE HEP. Funding for an astrophysics initiative will allow us to identify other funding opportunities, for example NASA's Astrophysics Theory, Astronomy and Physics Research and Analysis, and Cosmochemistry programs, the Cosmochemistry portion of which is already an important source of funding for the related efforts in MSD. The initial effort proposed here, coupled with the unique combination of facilities and scientific expertise that Argonne can provide, should provide a good foundation for future base funding of this work.