Excerpt from
Mission Need Statement for a

Mid-Scale Dark Energy Spectroscopic Instrument (MSDESI)

Non-major Systems Acquisition
Major Item of Equipment

Office of High Energy Physics
Office of Science
U.S. Department of Energy

1. STATEMENT OF MISSION NEED

The mission of the Department of Energy (DOE) High Energy Physics (HEP) program is to understand how our universe works at its most fundamental level. This is achieved by progressing on the three experimental frontiers of particle physics, Cosmic, Energy and Intensity, towards the program goal of exploring the fundamental interactions of energy, matter, time and space.

This Mission Need Statement is for the support of a new, next-generation, state-of-the-art (dubbed "Stage IV") ground-based dark energy experiment of medium scale. This initiative for the HEP program is to study the nature of dark energy, which is causing the expansion of the universe to accelerate.

2. CAPABILITY GAP/MISSION NEED

The HEP community continues to progress in the Energy and Intensity Frontiers of the program using particle accelerator facilities to study and look beyond the Standard Model (SM) of particle physics. The SM describes fundamental particles and the forces between them in the universe. Significant progress in the understanding of the SM was recently made with the July 2012 announcement of the discovery of the Higgs boson at the Large Hadron Collider in Geneva, Switzerland. However, the SM cannot be the full theory of matter, space and time, since it does not incorporate gravity.

Even more fundamentally, SM particles account for only 4% of the contents of the Universe. The majority of gravitationally interacting matter is in fact “Dark Matter,” not present in the SM.

In 1998, two teams, including a DOE-supported team led by Saul Perlmutter at Lawrence Berkeley National Laboratory, discovered that the expansion of the universe is accelerating, due to a mysterious “Dark Energy”. These two teams shared the 2011 Nobel Prize in Physics for this discovery. That 96% of the present mass and energy of the universe is dark matter and dark energy is the clearest illustration that there must be physics beyond the SM.

To date, there are no compelling theoretical explanations for the dark energy and observational exploration is the focus of the effort. Understanding the nature of dark energy will provide exciting new discoveries that will change the way we view the universe and have profound implications for fundamental physics.

The HEP community has increasingly turned a significant part of its research program towards the Cosmic Frontier and especially to the 96% of the universe that is “dark”. Experiments in the Cosmic Frontier investigate fundamental properties of matter, energy, space and time that are best-studied using data from astrophysical sources. Such investigations reveal phenomena and information about the makeup of the universe that cannot be observed with particle accelerators. Experiments to study the nature of dark energy offer new insights and a deeper understanding of fundamental physics and the makeup and ultimate fate of the universe.

Community planning for a coordinated dark energy program began in earnest with the Dark Energy Task Force[1] (DETF). The 2006 DETF report listed three main scientific goals of a properly executed program for this extraordinary challenge of dark energy:

> *1. Determine as well as possible whether the accelerating expansion is consistent with a cosmological constant.*
>
> *2. Measure as well as possible any time evolution of the dark energy.*
>
> *3. Search for a possible failure of general relativity through comparison of the effect of dark energy on cosmic expansion with the effect of dark energy on the growth of cosmological structures like galaxies or galaxy clusters.*

Four experimental techniques for studying the nature of dark energy were described in the DETF report, including using type Ia supernovae, weak gravitational lensing, baryon acoustic

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[1] The Dark Energy Task Force was a joint subpanel of the High Energy Physics Advisory Panel, which is charged with providing advice to DOE and NSF on the high energy and particle physics program, and the Astronomy and Astrophysics Advisory Committee, which is charged with providing advice to the DOE, NSF, and NASA, on overlapping research and projects in astronomy and astrophysics.

oscillations (BAO) and galaxy clusters. Since then, other techniques have been developed including using redshift space distortions (RSD). Each of these techniques has its particular strengths and different sources of systematic error. Distinguishing between competing hypotheses for the nature of dark energy, to determine if it's a cosmological constant, a breakdown in Einstein's General Relativity, or something else, requires precise measurements using a combination of techniques. Current experiments are either photometric imaging (multiple images with different colored filters) or spectroscopic surveys and are optimized for one technique, but can typically use several others.

The DETF developed a figure of merit to characterize the sensitivity of experiments for studying the nature of dark energy and developed a staged approach, with stage I representing the current level sensitivity (in 2006) and stage II representing the level expected when then-current experiments were completed. Stage III experiments are currently being carried out and stage IV experiments are being developed. These will extend the figure of merit over stage II by at least a factor of three (stage III) or ten (stage IV).

The DETF recommended a balanced, staged program in which multiple techniques are employed by one or more experiments.

> "*We recommend that the dark energy program include a combination of techniques from one or more Stage IV projects designed to achieve, in combination, at least a factor of ten gains over Stage II in the DETF figure of merit…*"

Subsequent community planning activities reaffirmed the DETF program, with the 2009 report from the Particle Astrophysics Science Assessment Group (PASAG)[2] calling for "*a portfolio of experiments that approach the astrophysical limitations for each dark energy method*."

The U.S. and, in particular, the HEP community continue to be leaders in the study of the nature of dark energy. To continue this leadership, and ensure a strong, balanced dark energy program, it is important to progress towards the sensitivity of stage IV dark energy measurements using multiple techniques, as well as ensuring that scientific data is available on a continuing basis, without gaps between operational experiments.

Capability Gap

As described below, there is a gap in capabilities for the BAO and other spectroscopic survey techniques following the completion of the current program, as well as a time gap in which there are no DOE dark energy experiments collecting data. A combination of experiments, each optimized for different dark energy techniques, is needed to fully provide the complementary data sets needed for determining the nature of dark energy.

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[2] The Particle Astrophysics Science Assessment Group was a subpanel of the High Energy Physics Advisory Panel.

The DOE currently has a program of stage II and stage III imaging and spectroscopic surveys. Several stage II supernovae survey experiments and the stage III Baryon Oscillation Spectroscopic Survey (BOSS) experiment on the Sloan Foundation 2.5 meter telescope at the Apache Point Observatory in New Mexico, which primarily uses the BAO technique, will complete their data-taking by FY 2015. The stage III Dark Energy Survey (DES) experiment, a partnership with the National Science Foundation (NSF), is currently undergoing installation and commissioning on the Blanco telescope at the Cerro Tololo Inter-American Observatory in Chile. Its five-year imaging survey will start in FY 2013.

Following DES, the next step in imaging surveys is the stage IV Large Synoptic Survey Telescope (LSST) experiment, a joint DOE and NSF partnership that is being developed for a construction start as early as FY 2014. LSST's ten-year survey would start in FY 2022 and will provide definitive ground-based weak lensing measurements as well as make progress using the supernovae and galaxy clusters techniques.

The DOE made critical instrumentation contributions to these experiments, including upgrades to the spectrograph for BOSS, fabrication of the camera for DES, and camera fabrication for LSST. In addition, DOE brings both its history and expertise in large scientific collaborations and computing capabilities, and the simulations and algorithm planning needed to perform precision measurements with large data sets.

A recent community report titled; "The DOE/HEP Dark Energy Science Program: Status and Opportunities", 10 August 2012, by A. Albrecht et. al., was developed at HEP request. With a focus on the DOE dark energy program, it described the science reach of current and planned projects, and identified key missing components in the study of the nature of dark energy and opportunities for reaching full stage IV levels.

First in their list of opportunities was:

1) There is compelling case for an advanced wide-field spectroscopic survey, which would enable dark-energy information at the Stage IV level through the techniques of Baryon Acoustic Oscillations and Redshift Space Distortions. A spectroscopic survey would produce important dark-energy science results in the period between the completion of the Stage III Dark Energy Survey (DES) photometric project and the arrival of results from the Stage IV LSST photometric project.

A wide-field spectroscopic survey experiment, that would take data starting in approximately FY 2018 or FY 2019, would provide further progress towards a balanced program of stage IV dark energy measurements using multiple techniques and ensure a continuous stream of experimental data. Such an experiment would provide definitive ground-based BAO measurements and will allow the DOE to maintain leadership in the study of dark energy. It will provide complementary measurements to DES and LSST and will extend the BAO and other technique using spectroscopic measurements to stage IV. No existing facility in the DOE program, the U.S., or internationally satisfies this capability gap.

The physics program enabled by stage IV experiments to study the nature of dark energy is fully consistent with the Secretarial Strategic Priority of Science, Discovery, and Innovation. The program would demonstrably "Advance fundamental knowledge in high energy physics and nuclear physics that will result in a deeper understanding of matter, energy, space and time."

Other Potential Capabilities

As described above, there are other DOE-supported experiments using imaging and/or spectroscopic surveys to study the nature of dark energy, but there is a gap in capabilities in progressing on techniques using spectroscopic surveys and in the schedule of producing data on a continuous basis.

The European Space Agency (ESA)-led Euclid mission, with contributions by the National Aeronautics and Space Administration (NASA) has been selected for implementation with launch planned for 2019. It has both spectroscopic and imaging survey capabilities and will provide stage IV measurements but over a different range in redshift than available from the ground. In addition, since the area of sky in the space-based survey will be much less than available with a wide-field ground-based survey, the precision available for BAO measurements of dark energy is expected to be similar or even less than from the ground. Other ground-based experiments without DOE participation will also be operating in the coming years but will not provide stage IV measurements, including PanSTARRS-1 (imaging) and HETDEX (spectroscopic).

Impact if Gap is Not Resolved

Through investments in facilities and research programs, the DOE's HEP program has built a program that has made leadership contributions to measurements of dark energy. Lack of approval of future dark energy experiments, with increasing progress in precision using a variety of techniques, would deny U.S. researchers the opportunity to maintain and enhance a world-leading program and access to world-class research facilities in the study of dark energy with continuous data-taking capabilities.

Failure to approve this mission need will run contrary to the advice of Federal Advisory panels and will leave the U.S. and DOE with a significantly diminished program for understanding the nature of dark energy.

The priority of fulfilling the mission need relative to other programs

In 2008, the Particle Physics Project Prioritization Panel (P5), a High Energy Physics Advisory Panel (HEPAP) subpanel, developed a strategic roadmap for high-energy physics that called for investments on the three frontiers of particle physics: the Energy Frontier, Intensity Frontier, and the Cosmic Frontier. P5 explicitly recommended "support for a staged program of dark energy experiments as an integral part of the U.S. particle physics program" as a major part of the Cosmic Frontier program.

As noted previously, the PASAG recommended that dark matter and dark energy remain extremely high priorities in their 2009 report. They recommended the timely pursuit of a coherent overall strategy for a stage IV program in dark energy, which can obtain another order of magnitude or more improvement beyond stage III in metrics for dark energy and gravity tests, by optimizing observations from both the ground and space, and taking into account the priorities of both the astronomy and physics. *"The panel believes that this planning process should result in a world-leading program that delivers a portfolio of experiments that approach the astrophysical limitations for each dark energy method."*

The National Research Council's Astronomy and Astrophysics Decadal Survey (Astro2010) released its report in August 2010. It was charged by the NASA, the NSF, and the DOE with setting priorities for the coming decade for ground- and space-based projects in astronomy and astrophysics, including dark energy projects. It recommended that DOE participate in LSST, which was the top-ranked, large ground-based that includes dark energy as one of its primary goals. Other ground-based, mid-sized projects, such as a spectroscopic survey, were described and recommended for consideration as part of a mid-scale program.

<u>Benefits from Closing the Gap</u>

The pursuit of a stage IV dark energy program, with capabilities for a spectroscopic survey that would provide stage IV results during the gap in data-taking between the current imaging surveys, would position the U.S. and the DOE to continue at the forefront of a world-leading program of investigation of the nature of dark energy using multiple techniques and could lead to significant discoveries with profound implications on our understanding of fundamental physics and the makeup and future of the universe.

<u>Internal/External Drivers</u>

The discussion above outlines the scientific interest, which is the sole driver on this mission need.

3. POTENTIAL APPROACH

There are several options available for the DOE to participate in the next-generation ground-based dark energy studies using a spectroscopic survey. The DOE will explore providing mission critical components, which could include the instrument, data acquisition system, data processing and other related systems critical to the experiment and the DOE dark energy program. In any option, it is expected that the DOE would either collaborate with another agency or purchase time on a telescope belonging to another agency or private institution. Since NSF is the primary supporter of ground-based astronomy research telescopes in the U.S., coordination with NSF is likely needed.

For all options, the roles and responsibilities of all partners (international or other agencies) would have to be established through appropriate agreements.

> **Option 1**: DOE will provide new instrumentation and expanded capabilities to an existing NSF or private ground-based observatory for studying dark energy using a spectroscopic survey. In this Option, DOE is responsible for the required operations of the telescope facility.
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> **Option 2**: DOE will provide new instrumentation and expanded capabilities to an existing ground-based observatory for studying dark energy using a spectroscopic survey, similar to that described in Option 1, in a partnership with NSF. NSF will provide the telescope operations. Since the DOE has unique capabilities in instrument development, the DOE will investigate supplying the instrument and associated equipment.
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> **Option 3**: DOE could do nothing further. The DOE has significant intellectual investment in dark energy and will be collaborating in more than just this project. Currently, DOE funded scientists are contributing to the data analysis and dark energy science of stage II and stage III spectroscopic and imaging survey experiments and already have plans for a stage IV imaging survey experiments. Failure to participate in this project could severely compromise continued DOE participation in the study of dark energy and the fundamental nature of the universe.

There are no foreseen operational limitations in regard to effectiveness, capacity, technology, or organization. The criteria for the operation of this type of instrumentation or telescope are similar to those for existing instruments and telescopes. All technologies being considered are well understood by experimenters in high-energy physics. The data collection and processing would require similar systems to those currently used.

Possible telescopes for which a new spectroscopic instrumentation could be built are located at existing facilities both in the U.S. and in Chile. All the observatories already exist and have road access, power and Internet connectivity. The sites are sparsely populated and have low levels of light, necessary for telescope observations.

Environmental, Safety and Health

All work at DOE sites will be conducted under DOE-approved Integrated Safety Management System (ISMS). All facilities will comply with the requirements of the National Environmental Policy Act (NEPA). Based on the nature of the projects, and their planned locations at an existing observatory, impacts to the environment are anticipated to be minimal. For telescope locations in foreign countries, the ES&H policies of the host country will be observed.

Cost Risks

The cost risks vary between the differing approaches, but in all cases first generation detectors exist. The cost risk associated with the technically challenging project can be mitigated through the application of appropriate contingency.

Schedule Risk

The schedule risks vary between the differing approaches, but in all cases first generation detectors exist. Schedule risks would be mitigated through contingency and close communication and monitoring of the vendor(s).

For Option 2 the funding and Critical Decision profiles will need to be closely coordinated with that of the NSF. The DOE has successfully conducted joint projects with NSF. This project will follow the lessons learned from those projects.

Safeguards and Security

There are no known safeguards and security issues at this stage of the project for the various approaches discussed above.