Excerpt from the Mission Need Statement for a Dark Energy Stage IV Experiment(s) (DE-IV)

1. STATEMENT OF MISSION NEED

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. This initiative for the High Energy Physics (HEP) program is to determine the nature of dark energy, which is causing the acceleration of the expansion of the universe.

The mission of the High Energy Physics (HEP) program is to understand how our universe works at its most fundamental level. This is achieved by our program goal of exploring the fundamental interactions of energy, matter, time and space in order to understand the unification of fundamental particles and forces, and the mysterious forms of unseen energy and matter that dominate the universe; search for possible new dimensions of space; and investigate the nature of time itself.

2. CAPABILITY GAP/MISSION NEED

Astronomical observation prior to 1998 indicated that the expansion of the universe is slowing down due to the gravitational attraction of matter. However, in 1998, two teams using ground-based and space-based supernova measurements found that the expansion of the universe is actually accelerating. The previously unknown energy in the universe causing this acceleration has been dubbed "dark energy." It has now been established that only about 5% of the universe is made of the normal, visible matter, including the earth, stars and all other objects we see. The remaining 95% of the universe consists of dark matter and dark energy whose fundamental nature remains a mystery.

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 U.S. is presently a leader in the exploration of the Cosmic Frontier. This area investigates fundamental properties of matter, energy, space and time that are best studied using data from astrophysical sources, such as cosmic rays, electromagnetic radiation, and neutrinos. 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.

In the 2006 Dark Energy Task Force[1] (DETF) report, dark energy experiments were classified in stages with higher numbered stages reflecting more sophisticated and powerful experiments. Stage I represents what is now known. Stage II represents the anticipated state of knowledge upon completion of ongoing dark energy projects. Stage III comprises near-term, medium-cost, currently proposed projects that are anticipated to increase the DETF figure of merit by a factor of 3 relative to Stage II. Stage IV comprises future proposals and is anticipated to increase the DETF figure of merit by a factor of 10. The DETF figure of merit is derived from parameters describing the composition and expansion of the universe and its change measures the improvement of the measured values of those parameters.

<u>Capability Gap</u>

The Dark Energy Task Force stated in its report:

> "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…"

A ground based dark energy survey is an important technique in meeting this recommendation. Further progress in the investigation of the nature of dark energy requires a combination of more sensitive and larger instrumentation and telescopes at Stage IV. No existing facility in the DOE, 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."

<u>Other Potential Capabilities</u>

The Department of Energy (DOE) is supporting the science enabled by a number of Stage II experiments and on two Stage III experiments. These experiments use existing ground- and space-based telescopes such as the Hubble Space Telescope, Cerro Tololo Inter-American Observatory's Blanco Telescope, the Sloan Digital Sky Survey telescope at Apache Point Observatory, and many other U.S. and international telescope facilities. In partnership with the National Science Foundation (NSF), DOE provided instrument upgrades for the Baryon Oscillation Spectroscopic Survey (BOSS), which is now taking data, and new instrumentation for the Dark Energy Survey (DES), which is being fabricated. Further progress will require new facilities either in space or on the ground.

<u>Impact if Gap is Not Resolved</u>

Through investments in facilities and research programs, the DOE's High Energy Physics Program has built a program that has made leadership contributions to measurements of dark

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[1] The Dark Energy Task Force was a joint subpanel of the High Energy Physics Advisory Panel and the Astronomy and Astrophysics Advisory Committee charged with providing advice to the DOE, NSF, and NASA on the optimal intermediate- and long-term programs to study dark energy.

energy. Lack of approval of future dark energy experiments 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.

Failure to approve this mission need will run contrary to the advice of the National Research Council (NRC) and Federal Advisory panels and will leave the U.S. 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 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.

The Particle Astrophysics Science Assessment Panel (PASAG), also a HEPAP subpanel, 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 both from 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 NRC's Astronomy and Astrophysics Decadal Survey (Astro2010) released its report in August 2010. It was charged by the National Aeronautics and Space Administration (NASA), the (NSF), and DOE with setting priorities for the coming decade for ground- and space-based projects in astronomy and astrophysics, including dark energy projects considered by PASAG. The Astro2010 report recommended experiments which study dark energy as the highest priorities for future large ground- and space-based experiments and gave guidance on a coordinated, optimized dark energy program. Dark energy projects are now being considered by all three agencies. For DOE, the report recommended that our highest priority should be participation in the ground-based experiment, since that is where our contribution would be most critical.

Benefits from Closing the Gap

The pursuit of a Stage IV dark energy program would position the U.S. at the forefront of a world-leading program of investigation of the nature of dark energy and could lead to significant discoveries with profound implications on our understanding of fundamental physics and the makeup and future of the universe.

Internal/External Drivers

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

3. POTENTIAL APPROACH

The NRC Astro2010 panel publicly released its report on August 2010. This report listed the four highest priorities for large ground-based facilities. Of these the two highest can advance the study of dark energy.

Large Synoptic Survey Telescope (LSST)

A wide-field optical survey telescope that will transform our observation of the variable universe and will address broad questions from indicating the nature of dark energy to determining whether there are objects that may collide with the Earth.

Mid-Scale Innovations Program Augmentation

A program that will provide the capability to respond rapidly to scientific discovery and technical advances with new telescopes and instruments.

A new ground-based facility, expressed in the first priority, would need to have a new telescope fabricated and will not need interfaces with any existing telescope facility. The second priority is for an NSF competed program for mid-scale projects, which could include a new instrument on an existing telescope to study dark energy. It may be that a combination of experiments, including the first priority and a dark energy project selected in the second priority, each optimized for different dark energy techniques are needed to fully provide the complementary data sets needed for determining the nature of dark energy.

There are several options available for DOE to participate in the next-generation ground-based dark energy studies. In any option, it is expected that DOE would partner with NSF, since NSF is the primary supporter of ground-based astronomy research telescopes in the U. S. It is also assumed that NSF or other institutions will be responsible for the operations of any telescope utilized by this project. For all options, the roles and responsibilities of all partners (international or other agencies) would have to be established through appropriate agreements.

The agencies work together to advance the first Astro2010 priority, the LSST, which would include building a new telescope facility with associated instrumentation.