Excerpt from the
Mission Need Statement
for a
Ground-Based Dark Energy Experiment

Office of High Energy Physics
Office of Science

SYSTEM POTENTIAL: Non-Major System

A. Statement of Mission Need

The mission of the High Energy Physics (HEP) program is to understand energy and matter at a fundamental level and to explore the evolution of the universe through basic interactions of matter, energy, space and time. The HEP Program Goals are to understand the unification of 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. These goals include investigating the nature of “dark energy”, which is pushing the universe to expand at an accelerating rate

Scientists have long assumed that the expansion of the Universe is slowing down due to the gravitational attraction of matter. The original discovery of dark energy, using type Ia supernovae, was made in 1998 by two teams using ground-based and space-based measurements. This type of supernova always explodes with a known brightness and its apparent brightness can therefore be used as a measure of distance. The measurement of the brightness versus the redshift (the redshift is a measure of the distance or elapsed time since the light has reached us) of the supernova explosion indicates how much the Universe has expanded since that time. What the scientists found was that the Universe wasn’t slowing down as expected, but rather it is speeding up, due to a previously unknown dark energy. The discovery of dark energy was named Science Magazine’s Breakthrough of the Year in 1998.

The discovery has since been confirmed by a number of methods and experiments, such as measurements of the Cosmic Microwave Background from ground-based experiments and NASA’s Wilkinson Microwave Anisotropy Probe, and measurements of large scale galaxy clusters from experiments such as the Sloan Digital Sky Survey (SDSS). Higher redshift supernovae found with the Hubble Space Telescope show that while the universe is now accelerating, it was decelerating at earlier times, confirming that dark energy has the expected effects on the universe. Combining results from these independent measurements, the dark energy is currently estimated to make up 73% of the matter-energy content of the Universe. The rest of the Universe is dark matter (providing gravitational force holding rotating galaxies together) (23%) and baryonic matter (4%). The confirmation of dark energy by these experiments was named Science Magazine’s Breakthrough of the Year in 2003.

There is an array of possibilities for the nature of dark energy. It could be the energy of the vacuum (Einstein's cosmological constant). However, efforts to calculate the cosmological constant from quantum theory give a value at least 10^{120} times too large to explain the dark energy. Other ideas are that it could involve the existence of a new, scalar field that permeates space (quintessence) or that it could be signaling new physics such as unseen additional dimensions. Whatever it is, dark energy appears to be a new and fundamental feature of space itself; it cannot be incorporated into our current models of the nature of matter, energy, space and time.

To fully probe the nature of dark energy, we need to measure its effects on the history of the expansion rate of the universe, from the current epoch back to approximately 10 billion years ago, with greater precision, as well determining the equation of state parameter, w, which is the pressure in the universe divided by the energy density. This calls for a coherent Dark Energy program consisting of a sequence of incremental steps of increasing scale, technological complexity, and scientific reach.

In recent years, a number of promising new methods have been developed, with different errors and different dependencies on the cosmological parameters. Because the nature of dark energy is such an important question, a number of complementary methods must be pursued in order to form a robust program. Ground-based telescopes can be used for measurements of Type Ia supernovae, the most mature method, as well as newer, independent methods. The newer methods include measuring the rate of galaxy cluster formation as a function of the age of the universe. Another method is measuring mass distributions using weak gravitational lensing, due to light being bent in the presence of matter, as a function of the age of the universe. A third method is to measure the imprint of baryonic oscillations from the early universe on matter distributions.

Ground-based facilities do not exist for the precision needed to pin down the nature of dark energy and to constrain the theoretical models. The project to build a ground-based detector or facility capable of studying dark energy will support the Department of Energy's Science Strategic Goal within the Department's Strategic Plan dated September 30, 2003: *To protect our National and economic security by providing world-class scientific research capacity and advancing scientific knowledge*. Specifically, it will support the two Science goals: 1) *Advance the fields of high-energy and nuclear physics, including the understanding of dark energy*… and 7) *Provide the Nation's science community access to world-class research facilities*…

Determining the nature of dark energy is a high priority science objective for the DOE High Energy Physics program. The National Research Council's April 2002 report entitled "*Connecting Quarks with the Cosmos*" outlined a program using multiple techniques from space and the ground to get at the nature of dark energy. The report supported a Large Survey Telescope (LST) "which has significant promise for shedding light on the dark energy". The LST project is also ranked high among major initiatives in the National Research Council's 2001 report "*Astronomy and Astrophysics in the New Millennium*".

The 2004 report from the National Science and Technology Council provided a Federal cross-agency strategic plan, "*The Physics of the Universe*" for discovery at the intersection of physics and astronomy in response to the NRC's "*Connecting Quarks with the Cosmos*" report. The NSTC report gave dark energy measurements as its highest priority, proposing a multi-pronged strategy. The report recommended that a high-priority, ground-based approach using the weak lensing method, which is the goal of LST, also be developed. In addition, it recommended that to "provide independent verification and increase the precision of the overall [dark energy] measurements", galaxy clusters measurements using various techniques be done.

B. Analysis to Support Mission Need

There are several concepts that could provide complementary ground-based measurements of dark energy as the next step in a ground-based dark energy program. All concepts are optimized for one type of measurement, but several other methods can be used in a complementary fashion in each experiment.

An Option is to construct a large-scale charged-coupled device (CCD) camera for galaxy cluster counting and other dark energy measurements. The camera could be installed on the Blanco 4m Telescope in Chile, operated by the Cerro Tololo Inter-American Observatory for NSF, in exchange for 30% of the telescope observing time over five years. The combination of this telescope and camera with the necessary sensitivity will make it more than 10 times more powerful than any existing facility. In combination with galaxy cluster mass measurements from other telescopes, the data would provide the first high precision (5 – 10% statistical errors) dark energy constraints.

C. Importance of Mission Need and Impact If Not Approved

The DOE strategic goal to advance scientific understanding includes determining the nature of the dark energy which is causing the universe to expand at an accelerating rate. Since the discovery of dark energy in 1998, it has been an important component of DOE's High Energy Physics program.

Our knowledge of the nature of dark energy, beyond the fact that it exists, is minimal. The fact that we don't understand the nature of dark energy, which makes up greater than 70% of the energy-matter content of the universe, leaves a gaping hole in our understanding of the nature of matter and energy. The next step in a coordinated dark energy program is to use complementary methods to study the nature of dark energy to a higher precision. A ground-based facility would provide this opportunity. Without continued studies of dark energy, its nature and composition will remain largely unknown. This scientific research was pioneered in-part by DOE researchers, but intellectual ownership and discovery credit could be ceded to other agencies or to Europe, if DOE chooses not to participate in future experiments. If not approved, DOE will not be fulfilling our strategic science goal to provide the Nation's science community with access to world-class research facilities in the study of dark energy as described in section A above.

G. Development Plan

The High Energy Physics Advisory Panel (HEPAP) and the Astronomy and Astrophysics Advisory Committee (AAAC) have cooperatively established a Dark Energy Task Force (DETF) as a joint sub-committee to advise the National Science Foundation (NSF), the National Aeronautic and Space Administration (NASA) and DOE on the future of dark energy research. The DETF has been asked to advise the agencies on the optimum near- and intermediate-term programs to investigate dark energy. The report from the DETF, due December 2005, will help guide DOE's decisions on the appropriate ground-based dark energy experiments to invest in, on the way to developing a next-generation space-based mission.

The recommendations from the DETF will help guide DOE's decisions on the appropriate ground-based dark energy experiments to invest in. The selection of individual experiments that best fulfill the goals of the dark energy program will be done based on the recommendation of the DETF. This will be used as input to the CD-1, Approve Alternative Selection and Cost Range. The prioritization of the experiment relative to other efforts in the HEP program will be done by Particle Physics Project Prioritization Panel (P5), a HEPAP subpanel. Since accurate cost information will needed by P5, a P5 recommendation will occur at or after CD-2, Approve Performance Baseline.

Several technologies are being considered for the optical or infrared imaging of the cameras. The technologies have been developed but the properties of the sensors will need to be tested and shown that they can be scaled up to the larger array size required. An R&D effort will be required before a final technology choice is made.