Ground-Based Dark Energy Experiment

Status: CD-0 Approved in November 2005

<u>Mission Need</u>

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 of the supernova 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 has since been confirmed by a number of methods. The discovery of dark energy was named Science Magazine's Breakthrough of the Year in 1998 its confirmation was named 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). It could involve the existence of a new, scalar field that permeates space (quintessence) or 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 using ground- and space-based telescopes.

In recent years, a number of promising new methods have been developed, with different errors and different dependencies on the cosmological parameters. Ground-based telescopes can be used for measurements of Type Ia supernovae, the most mature method, as well as newer, independent methods. These include measuring the rate of galaxy cluster formation or 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.

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 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. In addition to a space-based mission, the report recommended that a high-priority, ground-based approach using the weak lensing method be developed. It also recommended that to "provide independent verification and increase the precision of the overall [dark energy] measurements", galaxy clusters measurements using various techniques from space and the ground be done.

Ground-based facilities do not exist for the precision needed to pin down the nature of dark energy and to constrain the theoretical models. A 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*…

Options

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

Option 1: 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. 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.

Option 2: Build a spectrograph to be used on an existing wide field of view telescope for baryonic oscillation measurements. Such a detector would be 10 times more powerful than any yet built and would obtain a massive galaxy redshift survey. The measurements of the variation in baryon particle densities would be used to determine the nature of dark energy at higher redshift, $2 < z < 4$, than is possible with other experiments.

Option 3: Build a next-generation wide-field telescope along with the world's largest optical imaging camera and associated data acquisition system. This concept would allow measurements of galaxy shape distortions caused by weak gravitational lensing to determine the growth of galaxy clusters over time. It is expected that other agencies or institutions would provide funding for the telescope. Such a facility could obtain sequential images of the entire visible sky every few nights and the data collection area would be two orders of magnitude larger than any existing facility. Data will be of use to the larger astrophysics and astronomy community for many different science topics. The data would provide high precision dark energy constraints at the approximately 2 – 3% level.

Option 4: Do nothing. Some progress in the ground-based methods of determining dark energy may be made with existing detectors and facilities in the U.S. funded by other agencies or in Europe.