U.S. DEPARTMENT OF ENERGY

DOE Office of High Energy Physics
Dark Energy Program

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The Cosmic Frontier

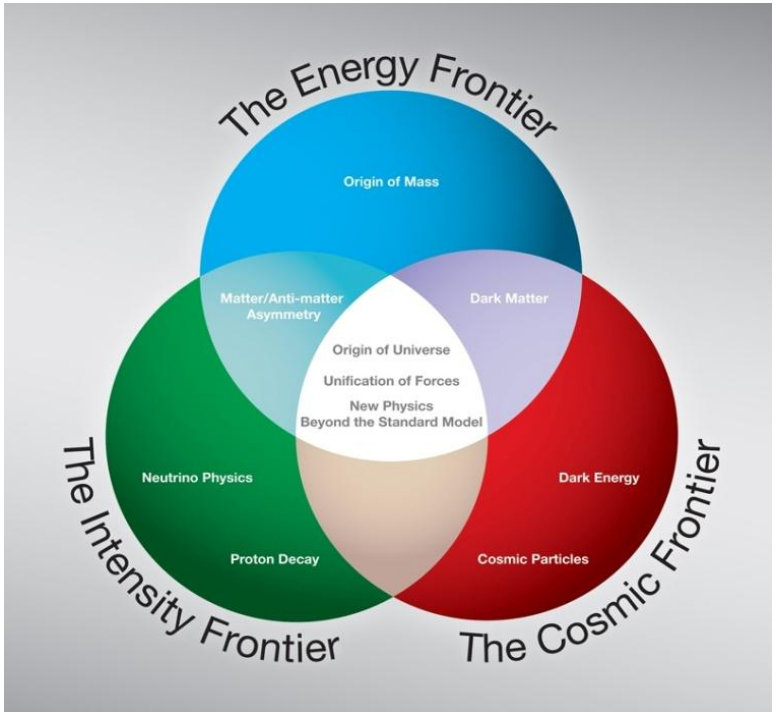
DOE HEP's long range plan is to maintain a leadership role for the US in the 3 scientific frontiers.

We get advice specifically regarding the DOE OHEP program from HEPAP

- P5 and PASAG (Oct. 2009)

➢ Cosmic Frontier: Deploy selected, high impact experiments

DOE, NASA and NSF have been coordinating efforts and planning for Dark Energy since soon after it was discovered.



Program Planning at the Cosmic Frontier

2006 – report from the Dark Energy Task Force (DETF), a subpanel of both the HEPAP and AAAC

- Recommended a program of medium (stage III) and longer term (stage IV) experiments and provided a Figure of Merit against which to measure their improvement in the understanding of dark energy

Dark Energy could be Einstein's cosmological constant, new exotic form of matter or may signify a breakdown in Einstein's General Relativity. There are no compelling theoretical explanations and, therefore, observational exploration must be the focus. Two or more techniques that provide complementary information on dark energy must be used, at least one of which is a probe sensitive to the growth of cosmological structure in the form of galaxies and clusters of galaxies.

March 2010 – Astronomy & Astrophysics Advisory Committee (AAAC) annual report to DOE, NASA & NSF:

- Identify a lead agency for executing each project recommended by Astro2010
- Engage agency heads to facilitate implementation of Astro2010 recommendations.

~ Sept. 2010 – Report from Astro2010 (Decadal Survey) will recommend priorities for the next decade

- Agencies will be briefed in August, in time to affect the FY12 budget submission.
- DOE (and NSF, NASA) await the report before moving forward on major projects
- Will influence the opportunities for DOE participation and inform us on scientific/technical aspects.

Oct. 2010 – Report from the OECD Global Science Forum Astro-particle Physics Working Group (APP)

- Two-year study of global coordination and planning of particle astrophysics experiments
- Follow-on from the European ASPERA roadmap

HEPAP (PASAG) Report

Recommended an optimized program over the next 10 years in 4 funding scenarios:

Scenario A - Constant effort (3.5% inflation) at the FY 2008 funding level

Scenario B - Constant effort (3.5% inflation) at the FY 2009 President's Request level

Scenario C - Doubling of funding (inflate by 6.5%) over a 10-year period starting FY09

Scenario D - Additional funding above funding scenario D, in priority order

Defined Prioritization Criteria for Contributions to Particle Astrophysics Projects

- Science addressed by the project necessary (significant step towards HEP goals)
- Particle physicist participation necessary (significant value added/feasibility)
- Scale matters (particularly at boundary between particle physics and astrophysics)

Dark matter & dark energy both remain high priorities

Guidance:

- **Dark energy funding (recommended for largest budget portion) should not significantly compromise US leadership in dark matter, where a discovery may be imminent**
- **Dark energy and dark matter together should not completely zero out other important activities**

PASAG – Dark Energy Recommendations

Scenario A

Not possible to have major hardware and science contributions to any large project -- participation supported only in very limited areas

Scenario B

May have just enough funding for significant participation in 1 large project but there are risks since costs are uncertain; fast start may not be possible

Scenario C

- A world-leading program is enabled, with coordinated experiments in space and on the ground
- Significant HEP role in 1 large experiment plus a moderate-scale project and/or substantial role in 2nd large project. Project start may need to be pushed out due to funding profile

Scenario D

Funding would allow major roles in 2 large experiments

Needless to say…since this area is at the intersection of fields, there are many more experiments/surveys going on than we are able to contribute to.

→ Important to follow P5 and PASAG criteria and use our funds for maximum impact in selected experiments.

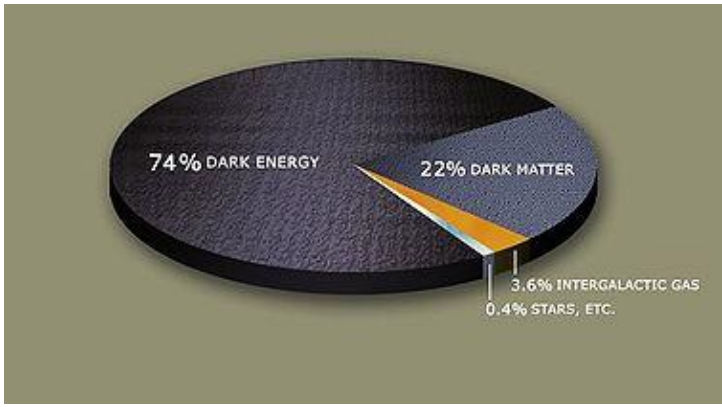
Dark Energy – Goals and Methods

Complementary methods are needed at each stage to determine the nature of Dark Energy - compare the effect of dark energy on cosmic expansion (growth of space) with the effect on the growth of cosmological structures. Is it:

- A cosmological constant or an evolving dark energy density?

OR

- A failure of General Relativity?



Methods for studying dark energy:

Weak gravitational lensing (WL) - Need large-scale multi-band imaging survey
– used to map the mass distributions as a function of redshift to measure the growth of structure and of space.

Baryon acoustic oscillations (BAO) - need large-scale spectroscopy and imaging survey
- Measure fluctuations in the early universe imprinted on galaxy distributions to determine the expansion rate of space.

Type Ia supernovae (SN) - need to monitor a wide field for SNe discovery, with follow-up spectroscopy
- used as standard candles to measure growth of space

Galaxy Clusters & Distributions – need large scale surveys to determine the growth of structure

Other methods continue to be developed, including using visible, infrared, radio, x-rays, etc.

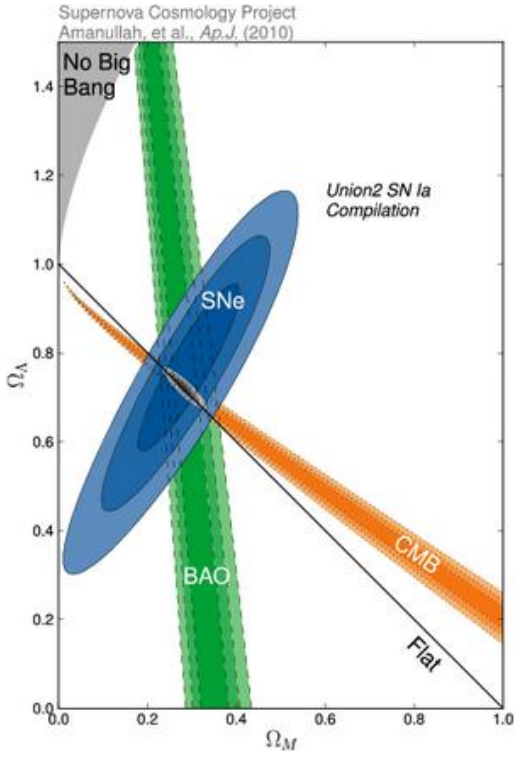
Type Ia Supernova Studies

DOE is playing a leading role in several of the world's key supernova surveys. The aim is to continue collection of supernovae to increase statistics over a wide range of redshifts and to reduce errors – with the longer term goal of providing the ground-based ingredients for the next generation (stage IV) experiments . DOE is funding:

Supernova Cosmology Project (SCP) – one of the two collaborations that originally discovered the dark energy in 1998 continues to use the Hubble Space Telescope, Keck, Gemini, Subaru, VLT, and other telescopes to discover/study supernovae between z=0.2 and z=1.7 develop new approaches to study z>1 SNe and combine the data sets.

Status: Contine data collection and analysis; major publications recently

Collaboration: LBNL and other US institutions, Sweden, Japan, UK, Spain, France, Canada.



Type Ia Supernova Studies, cont.

SNFactory (Nearby Supernova Factory) discovers and collects detailed data on nearby SNe in order to significantly improve systematic errors in their use as standard candles, and provide the baseline for high redshift studies for future experiments.

Status: First phase data collection completing this summer & 2nd phase will begin Fall 2010.

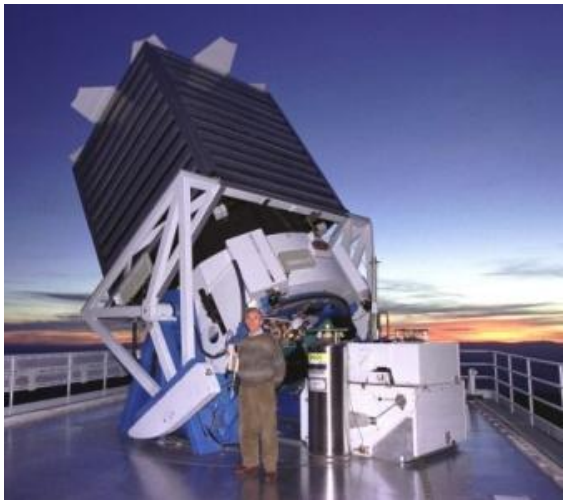
Collaboration: LBNL, Yale, France, Germany

The **QUEST** (QUasar Equatorial Survey Team) 112-CCD camera is used find the SNe used by the SNFactory and for feeding the infrared follow-up program.

Status: It was used on the Palomar telescope through 2009 It has now been moved and is operating on the ESO-Schmidt telescope in La Silla Observatory telescope in Chile.

Collaboration: Yale, Indiana, CalTech, LBNL, JPL, Illinois, Carnegie.

Baryon Oscillation Spectroscopic Survey (BOSS) on the Sloan Digital Sky Survey (SDSS) Phase III

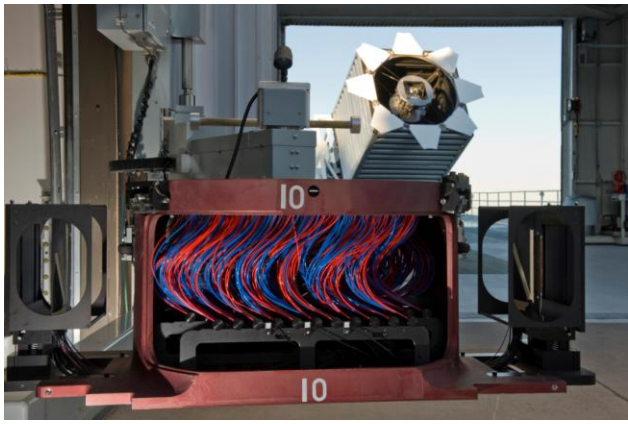


The SDSS-II survey (thru 2008) used the 2.5 meter telescope at Apache Point Observatory , the world's premier facility for wide-field spectroscopy. Dark Energy was studied using galaxy clustering and supernovae and the first BAO measurement was made.

BOSS is the primary survey (out of 4) on SDSS-III and will collect spectroscopic data on:
1.5 million Luminous Red Galaxies at z = 0.3–0.8 over 10,000 sq deg.
160,000 quasars at z = 2.3 to 3.5 over 8,000 sq deg.

Collaboration: DOE, NSF-Astronomy, Sloan Foundation, member institutions from US, Brazil, France, Germany, Japan, Korea, UK.

DOE fabrication: upgraded spectrograph, CCDs and optics



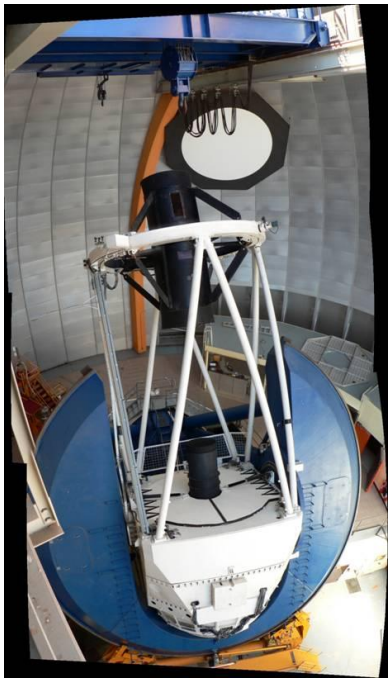
Status - Imaging data-taking started in Aug. 2009, 5 years of spectroscopic observations started Dec. 2009

DOE and NSF held a joint review of SDSS-III and BOSS operations in April 2010.

Dark Energy Survey (DES)

"Stage-III" experiment to study the nature of dark energy using 4 methods:

- galaxy cluster counting & spatial distributions of clusters at 0.1 < redshift (z) < 1.2
- weak lensing measurements to z~1
- 3000 type Ia supernovae at z < 1
- baryon acoustic oscillations to z~1



Will provide photometric redshift values for ~ 300 million galaxies out to z~1 -- will be largest CCD imaging survey to date

Project will build and install a new 3 sq-deg FoV camera with half-billion pixels (optical/NIR) on the existing Blanco telescope at Cerra-Tololo Inter-american Observatory (CTIO) in Chile

Collaboration: DOE, NSF + Brazil, Spain, UK

DOE responsibility (Fermilab): Dark Energy Camera (DECam)

NSF responsible for the Data Management system (DESDM) and CTIO upgrades and telescope time

Status: Fabrication through 2011; project is going well; joint DOE/NSF review planned for late June 2010

Astro2010

In June 2009, Astro2010 was presented with proposals for:

BigBOSS – NSF-AST and DOE partnership for a ground-based project to build new instrumentation for use on an existing telescope. The major technique would be BAO.

JDEM (Joint Dark Energy Mission) – NASA and DOE partnership for a space-based mission

- Two concepts, IDECS and OMEGA, proposed, each able to do all 3 main dark energy techniques: BAO, Supernovae, Weak Lensing

LSST - LSST (Large Synoptic Survey Telescope) - NSF-AST and DOE partnership for a new ground-based telescope facility, with associated instrumentation, in Chile. The primary technique would be weak lensing; plus there are many more astronomical measurements.

The Agencies are looking to Astro2010 to recommend a coordinated ground and space-based US Dark Energy program, with complementary techniques and data sets, to do the best job possible, within available resources, in determining the nature of dark energy.

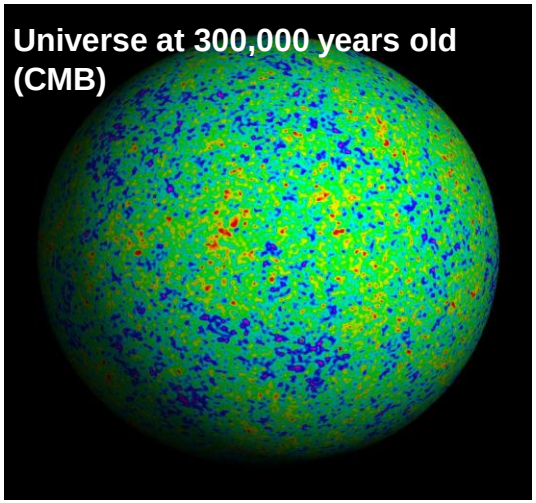
Big BOSS (proposed)

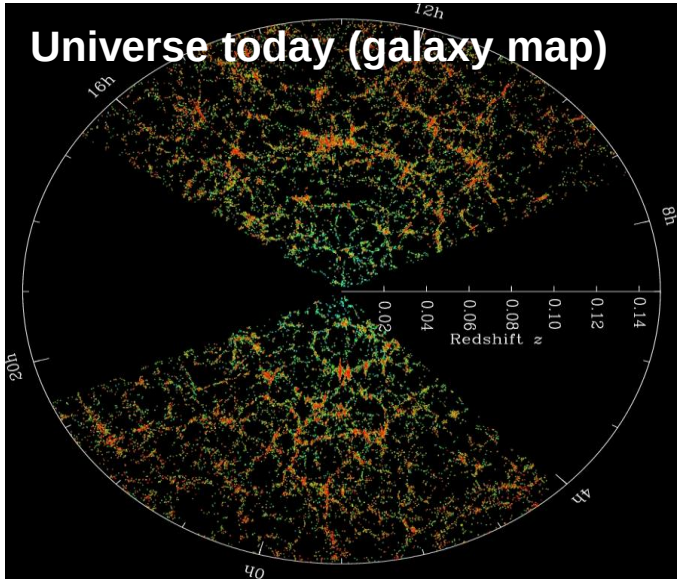
BigBOSS is a Stage IV ground-based dark energy experiment to measure the growth history of the universe by observing the pattern of galaxies during the last 9 billion years.
→ Primary method is BAO: Fluctuations in the early universe imprinted on galaxy distributions.

Project: Fabricate a new 5000 fiber spectrograph covering a 3-degree field to mount on the existing Mayall 4m telescope at Kitt Peak

Status:
April 2009: Proposal was submitted to Astro2010
July 2009: Proposal submitted to PASAG
March 2010: letter of intent in response to call from National Optical Astronomy Observatory (NOAO).
Oct. 2010: will submit a detailed proposal to NOAO

Collaboration:
NSF-AST and DOE





Large Synoptic Survey Telescope - Proposed

Stage-IV experiment to study the nature of dark energy – main method is Weak Gravitational Lensing but it will also do galaxy clusters, Sne, etc. The facility will also be used by a large community doing a wide variety of astronomical studies, including the search for Near Earth Objects.

Project:

New 8.4m-telescope facility and associated instrumentation to be located on Cerra Pachon (8,800 ft) in Chile.

- SLAC leads the development of the 3.2 gigapixel camera with 3 degree field-of-view. BNL also has a large role in the detector design.
- Separate dark energy science collaboration has been set up.

Survey:

- Will provide photometric redshift values for ~ 300 million galaxies out to z~1.
- Will survey half the visible sky in 6 optical bands every few nights.
- Database will include billions of galaxies with well-measured colors and shapes.

Collaboration: NSF-AST, DOE, Private, France, Chile + others are interested.

Status:

- December 2009 - NSF review of continued design & development (DOE attended as an observer.)
- Agency program managers are talking regularly & coordinating plans forward. (proto-JOG)
- Agencies are looking to Astro2010 for a coordinated , national ground and space dark energy program.

JDEM Basics

2007 – Joint DOE/NASA planning was initiated following the recommendations by the NRC Beyond Einstein Program Advisory Committee (BEPAC)

2008 - The mission framework was laid out in a DOE-NASA MOU.

- JDEM is a joint DOE-NASA mission with NASA as the lead agency with overall responsibility for success of the mission.
- JDEM would be a medium-class strategic mission with competitively selected Principal Investigators
- DOE's responsibilities would include fabrication of a major science instrument and development of an operations center.
- Both Parties would participate in the dark energy science operations and support science investigations

JDEM is an optical-IR survey mission with Dark Energy as its major goal.

- Must perform as a precision cosmology experiment with tight error control.
- Ancillary science comes as a by-product of dark energy surveys.

2008 - JDEM Project Offices established at GSFC and LBNL

2009 - A DOE and NASA Interagency Management Group (IMG) was established, chaired by Jon Morse and Dennis Kovar. and is meeting regularly.

JDEM Concepts - Proposed

June 2009

JDEM-IDECS - presented to Astro2010

- HgCdTe (near infrared) and CCD imagers, plus HgCdTe spectrometers.
- WL shape measurement with CCDs in visible

JDEM-Omega - presented to Astro2010

- HgCdTe imager and spectrometers. No CCD imager.
- WL shape measurement with HgCdTe in space-unique NIR, at some risk. Visible photo-z data from ground.

– The costs of both of these missions are large, putting both of these in a "facility-class" (i.e.; designed for a broader science goal and community than just dark energy).

– The costs of both of these missions are not obviously compatible with current budget projections (for both NASA and DOE) without significant revision of priorities (for both agencies).

Therefore, in September 2009, NASA and DOE agreed to examine a "**Probe** class" cost-capped mission concept, with a cost goal of $650M in FY09$ plus launch services.

- Tasked the Project Office's to develop a concept(s)
- Scientific input from an independent Interim Science Working Group (ISWG)

The Agencies informed Astro2010 that it is important to understand what can be done with "available" resources and the request of this new option.

JDEM Concepts – Proposed (cont.)

Dec. 2009 – The JDEM ISWG was constituted by NASA and DOE
– provide scientific assistance during JDEM pre-phase A activities
– to inform the Agencies on their findings (i.e. reports independently to Agencies)

It is assumed that the ISWG will continue until a competitive process for selecting the JDEM science team has been started. The ISWG will be disbanded at an appropriate time in advance of any competitive process for selecting scientific participation on a possible mission.

The ISWG and Project Offices worked closely together. A wide range payload concepts were studied with different combinations of techniques

May 2010 – The ISWG and Project Offices presented an option for a **Probe concept A** that will do the SN and BAO techniques and fit within the cost box.

- This will go out for an Independent Cost Estimate and will be further developed.
- In the process they developed a new design concept with an unobstructed telescope and recommended new survey strategies.

They also looked at a **Probe concept B** that also does WL, but costs more. They plan further scientific studies of this and other methods.

Euclid - Additional Space-based Dark Energy Possibility

Starting in Jan 2010

ESA asked NASA if there is interest in collaboration on their 3 medium-class missions under consideration in their Cosmic Visions program: **Euclid,** Plato and Solar Orbiter

Euclid would use the BAO and WL methods and is not driven by the SN method. SN observations may be possible in an extended mission.

NASA and ESA developed a framework for a partnership w/ESA as the lead agency.

- The total US contribution is not to exceed 20% of total mission costs (~ 470 million euros) with proportionate membership on the science team
- NASA has appointed 2 scientists to the Euclid Science Advisory Panel

NASA sent a letter to the Astro2010 describing these opportunities for partnership with ESA.

Euclid Timeline:

Through June 2010: ESA is doing a few-month engineering optimization, and possible de-scope, study of Euclid.

Mid-June 2010: ESA will release an AO calling for proposals for the science team and contributions of instrumentation

June 2011: ESA will make decision on a maximum of 2 of these 3 missions to implement.

The US Dark Energy Program – Possible Paths Forward

No commitments can be made until after Astro2010's report is released.

NASA is pursuing Dark Energy mission on 2 tracks:

1. JDEM Probe (SN and BAO method) with DOE

Following the MOU, DOE would provide a major instrument, a science operations center and would take part in data operations and analysis. Scientists would take part in a competitive selection to join.

2. Euclid (WL and BAO method) with ESA

Total US contribution not to exceed 20% of total mission costs.

DOE could make a relatively small contribution to Euclid in 2 ways:

1. DOE scientists can apply as leader or as part of a PI-led science investigation and instrumentation contribution which will be competitively selected by NASA through their Announcement of Opportunity (AO) process.
2. DOE scientists could join a European-led team and apply through the ESA AO competitive process. NASA would not provide funding for these contributions but could take oversight and validation responsibility if needed.

DOE is also pursuing several options:

1. JDEM with NASA

2. LSST (primarily WL method) and/or BigBOSS (BAO method) with NSF-AST

Constraints & Considerations

NASA and ESA both appear to be motivated to deliver the most science across a portfolio of activities
- driven by constrained funding for both agencies.

It appears that Euclid is one of ESA's highest priorities, with a launch planned 2018.
→If selected, it is likely that ESA will go forward on it with or without the US.

Due to NASA's budget constraints and priorities, it is unclear whether funds will be available to develop and launch JDEM (even the cost-effective Probe concept) until after Euclid flies.
→ NASA may decide that it doesn't make sense to duplicate missions.

DOE's funding projections are also restrictive.

There are pros & cons regarding each experiment or set of experiments reflecting varying

- Costs
- Levels of participation (leadership, enabling or minor role)
- Amounts of participation in the design/development
- Methods, sets of methods, and precision

Dark Energy Program - Optimizing

The agencies are awaiting recommendations from Astro2010 before making commitments.

Astro2010 will likely recommend a coordinated ground and space US program to study dark energy.

Starting Points:

- Due to the multi-agency nature of the field, DOE, NASA and NSF will need continued coordination to determine how each agency can best contribute to an optimized US program that will best impact the study of dark energy.
- Ensure resources are used to enable a program of next generation experiments with complementary methods that will provide the most opportunities and best data for the community.

DOE may consider participation in experiments or sets of experiments (ground-based and/or space-based) in which:

- the most scientific opportunities are provided,
- particle physics participation is necessary, and
- we can play leadership and/or enabling roles.