Community Dark Energy Task Force Report

The DOE/HEP Dark Energy Science Program: Status and Opportunities

10 August 2012

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The Community and the Task

- Report by and for the DOE Dark Energy Community (US HEP Program)
  Focus on Dark Energy Program within DOE Cosmic Frontier

- The task:
  Provide an overview of the current dark-energy science reach
  Identify opportunities & key missing components in the current program

- Letter from Kathy Turner sent 14 May, 2012

- First Phonecon 25 May, 2012
- Roughly weekly phonecons
- Report submitted 10 August, 2012

77 days!

- Independent of other agencies and scientific communities

- Not project or facility specific

The Nature of Dark Energy

- Dark Energy Science recognized as important
- Dominant component of present mass-energy
- DOE leadership in field from beginning
- Part of Cosmic Frontiers Program


Photo: Lawrence Berkeley National Lab

Saul Perlmutter


Photo: Belinda Pratten, Australian National University

Brian P. Schmidt


Photo: Scanpix/AFP

Adam G. Riess

The Nobel Prize in Physics 2011 was awarded *"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"* with one half to Saul Perlmutter and the other half jointly to Brian P. Schmidt and Adam G. Riess.

- Nature of Dark Energy unknown
  - 120 orders of magnitude larger than naïve estimates
  - Beyond Standard Model of Particle Physics
  - Einstein's cosmological constant?
  - Multiverse?
  - Evolving ultralight scalar field?
  - Modified gravity?

- The acceleration of the Universe is, along with dark matter, the observed phenomenon which most directly demonstrates that our fundamental theories of particles and gravity are either incorrect or incomplete

The Nature of Dark Energy

- Goal: determine the nature of the dark energy that causes the Universe to accelerate and seems to comprise most of the mass-energy of the Universe

  Exclude ΛCDM (null hypothesis test)

  Probe the expansion dynamics by measuring as well as possible the time evolution of dark energy

  Search for a possible failure of GR through comparison of cosmic expansion with growth of structure.

- Cross-braced latticework of observational drawing upon different techniques is crucial to reach the goal

- "DETF Stages" I, II, III, IV: Paleolithic, Early Modern, Modern, Post-Modern

  Stage I: Discovery Phase — Supernova Cosmology Project, Hi-z, …
  Stage II: Largely completed — SDSS, SNLS, Essence, …
  Stage III: Ongoing program — BOSS, DES, SN projects, …
  Stage IV: Ground — LSST, …
  Stage IV: Space — Euclid, WFIRST, …

The Nature of Dark Energy

- No single technique can tell us everything: use multiple techniques
  - Different techniques have different strengths and weaknesses
  - Different systematic uncertainties in different techniques
  - Different techniques sensitive to new physics in different ways

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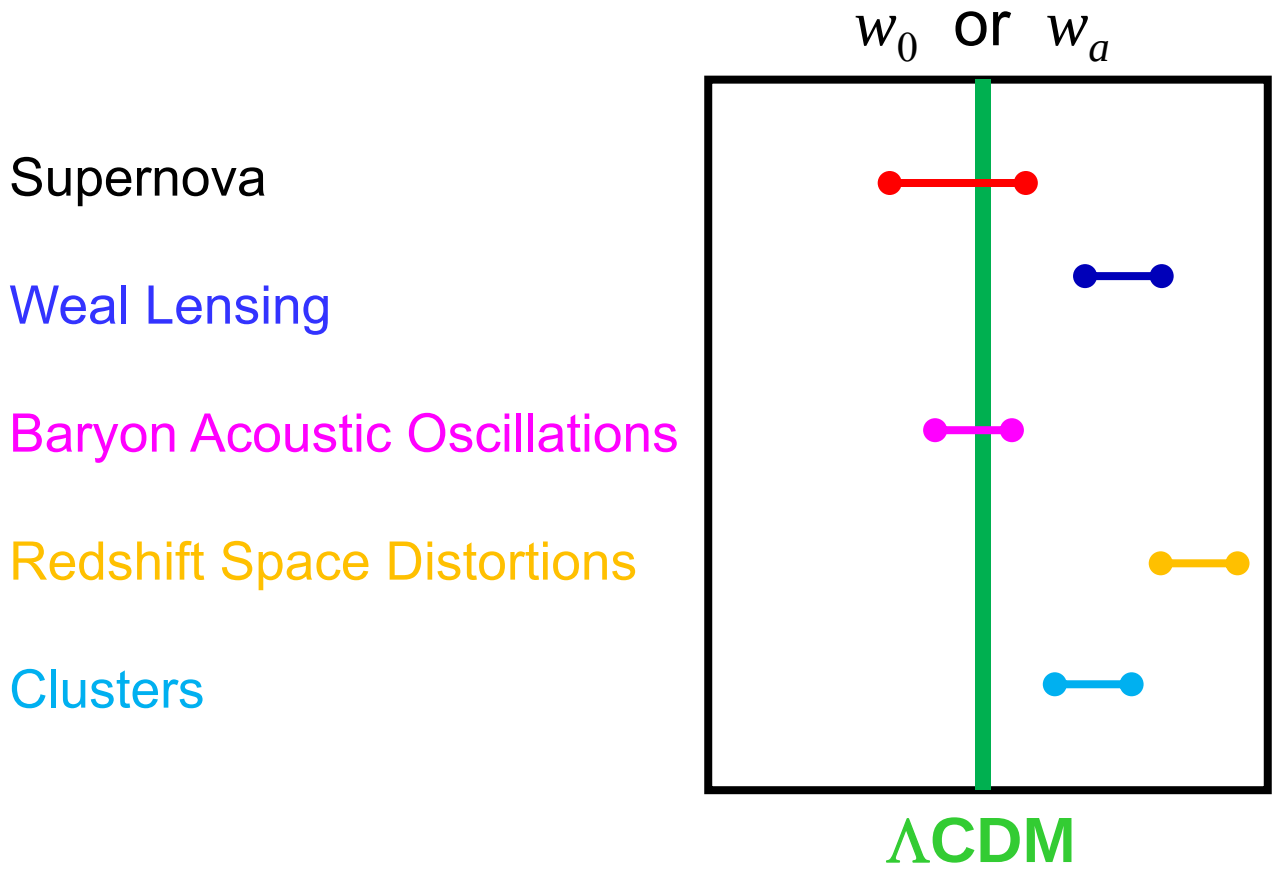

The Nature of the Higgs

- No single decay mode can tell us everything: use multiple decay modes
  - Different decay modes have different strengths and weaknesses
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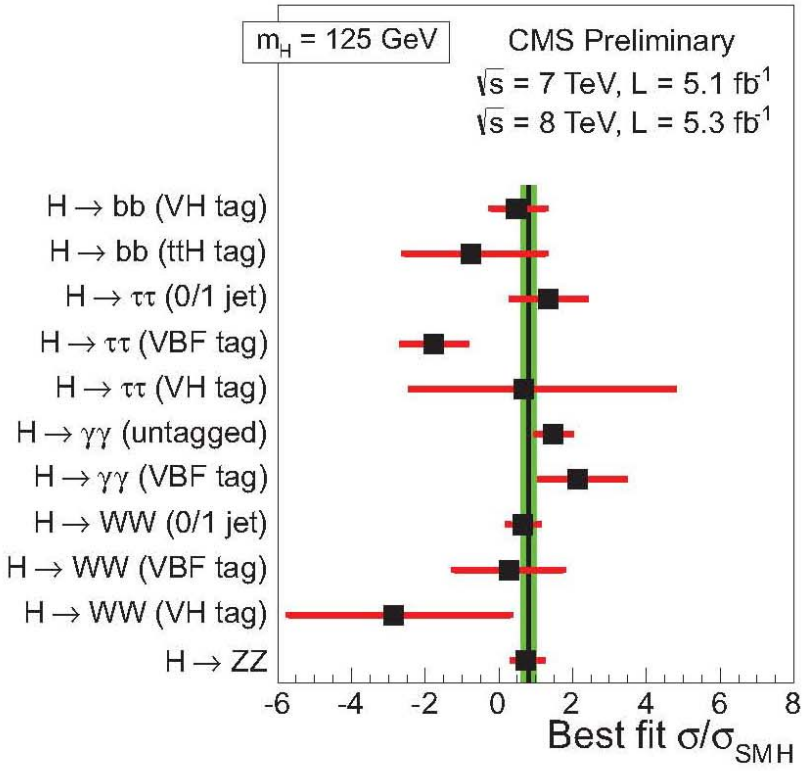

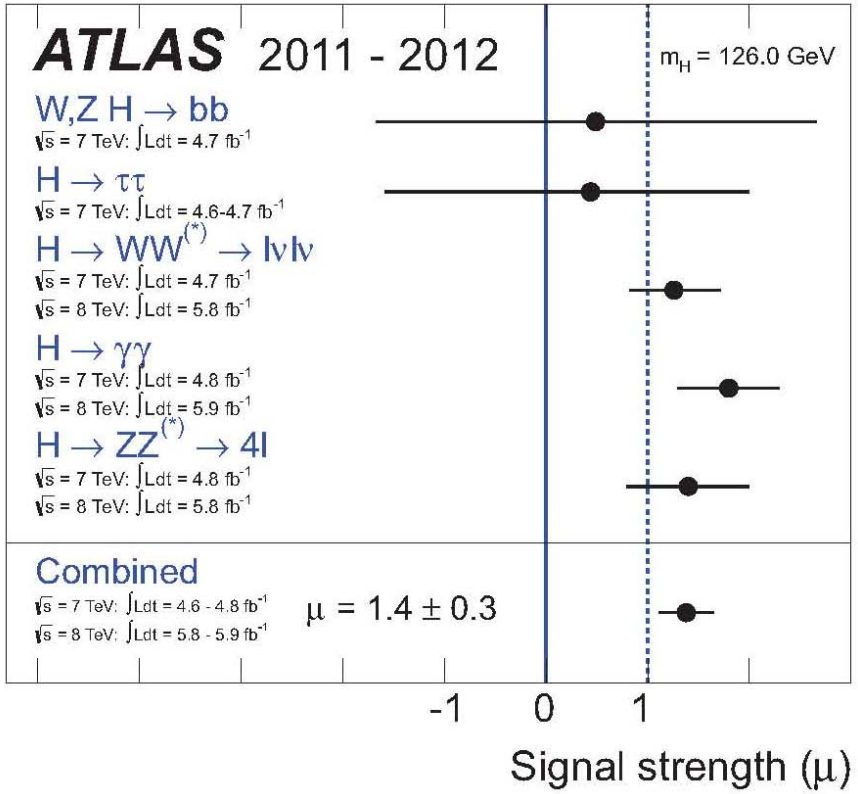

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- Dark Energy changes history of expansion rate of the universe
  - Measure distances as function of redshift (*i.e.*, luminosity distance by SNe)
  - Measure growth rate of structure as function of z ($\ddot{\delta} + 2H\dot{\delta} - 4\pi G\rho\delta = 0$)
- Acceleration may be due to modified gravity (MG)
  - Measure growth rate of structure & infall of galaxies

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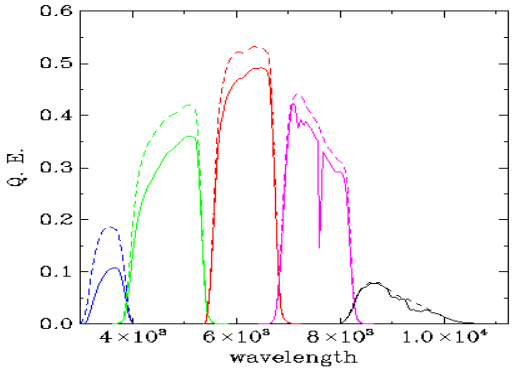
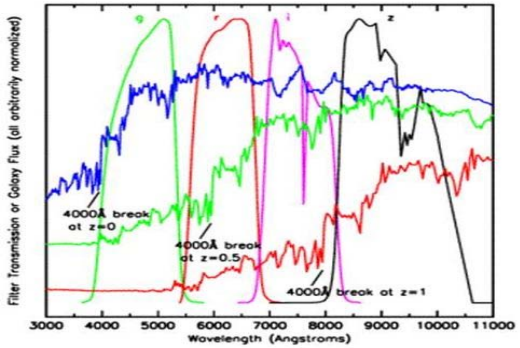
- Simple description of Dark Energy effect on expansion:
  - w_0 : present value of Dark Energy equation of state (for "Λ" $w_0 = -1$)
  - w_a : time change in Dark Energy equation of state (for "Λ" $w_a = 0$)

Our Survey Said…

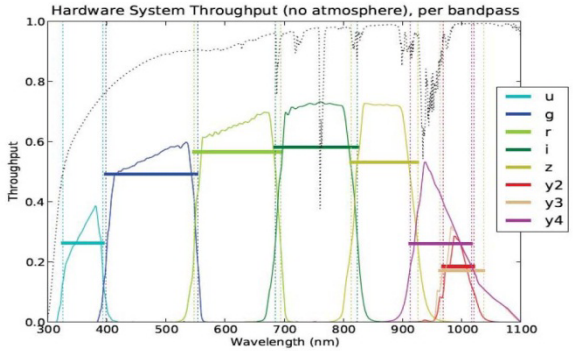
- Multicolor photometric surveys (SDSS, DES, LSST, …) and "photo z's"



SDSS (5 colors)

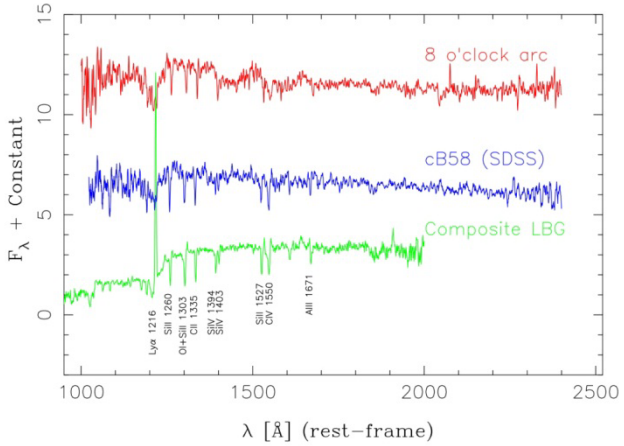


DES (5 colors)

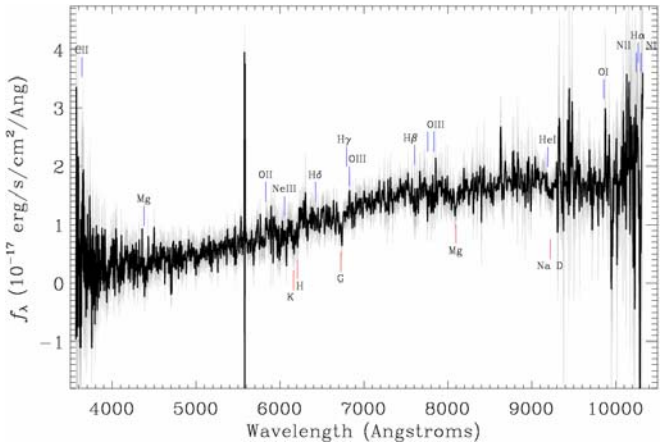


LSST (6 color)

- Multiobject spectroscopic surveys (SDSS, BOSS, …)



SDSS (640 fibers; $R \sim 1800$)



BOSS (1,000 fibers; $R \sim 2400$)

Techniques to Study Dark Energy

Technique	Measure	Sensitive to dark energy through	Probe MG?	Photometric/ Spectroscopic
Supernova (SN)	Luminosity and redshift of Type Ia supernovae	Apparent magnitude and z of Sne, $d_L(z)$, geometrical	No	Photometric surveys, with targeted spectro. follow-up
Weak Lensing (WL)	Small distortion of shapes by large-scale structures	Distances $H(z)$, growth of structure, geometrical & dynamical	Yes	Photometric surveys, spectroscopic info. for training sets
Clusters (CL)	Number and masses of galaxy clusters as fn. of z	Angular size and z, growth of structure, geometrical & dynamical	Yes	Photometric surveys, spectroscopic info. for velocity dispersions
Baryon Acoustic Oscillations (BAO)	3-dimensional spatial distribution of galaxies	Angular size and $H(z)$, geometrical	No	Spectroscopic surveys
Redshift Space Distortions (RSD)	3-dimensional velocity distribution of galaxies	Galaxy infall to structures, geometrical & dynamical	Yes	Spectroscopic surveys

Ongoing & Future Dark-Energy Projects

Ongoing & approved future dark-energy projects with major DOE support

Status	Photometric/ Spectroscopic	Dark Energy Technique	Project	Comments
Current (Stage III)	spectroscopic	BAO/RSD	BOSS	Through 2014
	photometric (discovery) targeted spectroscopic (follow-up)	SN	SCP	$z > 1$ surveys 2014-17
			SN Factory	Continued through about 2018 to reach needed sample of ca. 500 nearby SNe.
			PTF	
			QUEST	
	photometric	WL, SN, Clusters, BAO	DES	Late 2012-2018
Planned (Stage IV)	photometric	WL, SN, Clusters, BAO	LSST	CD-1 (DOE) NSB action (NSF)

Ongoing & Future Dark-Energy Projects

Some possibilities for projects potentially with major DOE support

Status	Photometric/ Spectroscopic	Method	Project	Comments
Future	spectroscopic	BAO/RSD	eBOSS	Follow-on to BOSS (APO)
	spectroscopic	BAO/RSD	BigBOSS	Proposed for Kitt Peak
	spectroscopic	BAO/RSD	DESpec	Proposed for Cerro Tololo

Ongoing & Future Dark-Energy Projects

Ongoing/planned projects without major DOE support (not all DE primary goal)

Location	Survey Type	Project	Comments
US	Spectroscopic	HETDEX	BAO
	Imaging	Pan-STARRS1, SkyMapper	SNe primary probe
	Space	WFIRST*	NASA, DOE scientist support
	Millimeter	ACTpol, SPTpol (SZ)	Clusters NSF/some DOE
	21cm	BAOBAB *, PAPER, MWA	Signal detection is initial goal, dark energy in future
Non-US	Spectroscopic	Subaru PFS (Japan+), PAU, JPAS (Spain+), 4MOST* (Europe)	BAO primary method
	Imaging	KIDS (Europe), Subaru HSC (Japan+)	WL is the primary probe
	Space	Euclid (Europe led + NASA)	DOE scientist support
	21cm	CHIME* (Canada+)	Other projects planned, but not primary dark energy
	Space	eROSITA (Germany+)	Galaxy Clusters via X ray

* Yet to obtain (to our knowledge) substantial funding.

Status and Progress

- Goal: determine the nature of the dark energy that causes the Universe to accelerate and seems to comprise most of the mass-energy of the Universe
- Cross-braced latticework of observational drawing upon different techniques is crucial to reach the goal
- Need Stage IV information in all techniques
- Progress in individual techniques in Report.
- Overall, much progress in 14 years. DOE has played a leadership role.

  Stage III in progress for Clusters from DES, WL from DES, BAO/RSD from BOSS, SN (from several projects)

  Stage IV in the future for WL from LSST . LSST will also contribute to other techniques

  Stage IV in the far future for Clusters, BAO/RSD, WL (Euclid, WFIRST?)

Opportunities & Missing Ingredients

1. Advanced wide-field spectroscopic survey in time frame roughly between DES and LSST (& Euclid/WFIRST)
   - Stage IV BAO/RSD information
   - Provide calibration data for systematic error mitigation to improve dark-energy constraints from photometric surveys like DES & LSST (in particular, helps WL & CL)

2. Advance SN technique to Stage IV
   - Clearest path: DOE participation in SNe at high-redshift from space (example: DOE-led modest upgrade to WFIRST)
   - Explore vigorously ground-based alternatives (R&D effort for near-IR technology and sky-line suppression)

3. Pilot studies to generate new ideas for the future
   - Deep spectroscopic calibration data needed for LSST. Pilot study to determine exact needs and how to meet them.
   - Pilot studies combining theory and targeted observations to chart an effective modified gravity program to study transition to modified gravity.

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