IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

Dark Energy Survey

Why do particle physicists care ?

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HEP Roadmap: Science Questions

- The question of mass:
  How do elementary particles acquire their mass?
  How is the electroweak symmetry broken?
  Does the Higgs boson –postulated within the Standard Model- exist?
- The question of undiscovered principles of nature:
  Are there new quantum dimensions corresponding to Supersymmetry?
  Are there hidden additional dimensions of space and time?
  Are there new forces of nature?
- The question of the dark universe:
  What is the dark matter in the universe?
  What is the nature of dark energy?
- The question of unification:
  Is there a universal interaction from which all known fundamental forces, including gravity, can be derived?
- The question of flavor:
  Why are there three families of matter?
  Why are the neutrino masses so small?
  What is the origin of CP violation?

What drives the universe to accelerate ?

- For particle physicists who take the field theory seriously, the simplest solution would be a vacuum energy.

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi G (T_{\mu\nu} - \frac{\Lambda}{8\pi G} g_{\mu\nu})$$

$$T_{\mu\nu}^{\text{vac}} = -\frac{\Lambda}{8\pi G} g_{\mu\nu} = -\rho_{\text{vac}} g_{\mu\nu}$$ (The vacuum is Lorentz scalar.)

$$p_{\text{vac}} = -\rho_{\text{vac}}$$

$$\rho_{\text{vac}} = \rho_{\Lambda} \equiv \frac{\Lambda}{8\pi G}$$

Λ is not a dimensionless parameter. It has dimensions of L^{-2}.

A gravitational length scale

- A dimensional analysis

For $\hbar = 1$ and $c = 1$, $[L] = [E]^{-1} = [M]^{-1} = [T]$.

$$L'_{\rm p} = \sqrt{8\pi G} \sim 10^{-34}\ \text{m}$$

$$M'_{\rm P} = \frac{1}{L'_{\rm p}} \sim 10^{18} \times 10^{9}\ \text{eV} = 10^{18}\ \text{GeV}$$

$$\Lambda^{\rm expected} \sim \frac{1}{(L'_{\rm p})^2} = (M'_{\rm P})^2 = (10^{18}\text{GeV})^2$$

$$\rho_{\rm vac}^{\rm expected} = \frac{\Lambda}{8\pi G} = (M'_{\rm P})^4 = (10^{18}\text{GeV})^4 \sim 10^{112}\ \text{erg/cm}^3$$

$$\rho_{\rm vac}^{\rm observed} \sim (10^{-3}\ \text{eV})^4 \sim 10^{-8}\ \text{erg/cm}^3 \sim 10^{-120}\,\rho_{\rm vac}^{\rm expected}$$

Why not exactly zero ?

- Gauge symmetry → Massless gauge bosons (photons and gluons)
- Massive gauge bosons ($W^{\pm}$ and Z) → Symmetry breaking mechanism via Higgs scalar particle
- Tiny but non-zero mass of neutrinos => Existence of extremely massive neutral particles ($10^{14\text{-}16}$ GeV)

Zero ⟺ Symmetry

- Deviation from zero implies the symmetry breaking (often dynamical in nature) mechanism.
- Therefore, a non-zero, tiny value of vacuum energy is intriguing. We smell New Physics behind it.

Understanding Dark Energy

- The key to understand DE is the behavior of the equation state (w=pressure/energy density) as a function of time measured by the redshift z.
- The goals of a dark energy observational program may be reached through measurement of the expansion history of the universe (measured by the dependence on z of luminosity distance, angular-diameter distance, expansion rate and volume element), and through measurement of the growth rate of structure (suppressed during epochs when the dark energy dominates).

Dark Energy Survey

- The proposed observational program focuses on four techniques.
    1. Baryon Acoustic oscillations as observed in large-scale surveys of the spatial distribution of galaxies.
    2. Galaxy cluster surveys, which measure the spatial density and distribution of galaxy clusters.
    3. Supernova surveys using Type Ia supernovae as standard candles to determine the luminosity distance versus redshift, which is directly affected by the dark energy.
    4. Weak lensing surveys, which measure the distotion of background images due to bending of light as it passes by galaxies or clusters of galaxies.

Targeted errors of planned surveys

$$w = w_0 + (1 - a)w_a, \text{ where } a = (1 + z)^{-1}$$

	w_0	w_a
Stage III	4%	± 0.3
Stage IV	1 - 2%	± 0.1

Stage III : HSC, DES, Pan-STARRS, BOSS

Stage IV : JDEM, LSST, WFMOS

If w_a is non-zero, dark energy has most likely a dynamical origin.

National Academy of Science, Beyond Einstein Report

Committee Members

Astrophysics Physics Eng/Mgmt

- Eric Adelberger, *U Washington*
- William Adkins, *Adkins Strategies, LLC*
- Thomas Appelquist, *Yale*
- James Barrowman, *NASA (retired)*
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- Joseph Fuller, *Futron Corp.*
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- Michael Witherell, *UC Santa Barbara*
- Edward Wright, *UCLA*

Committee Staff

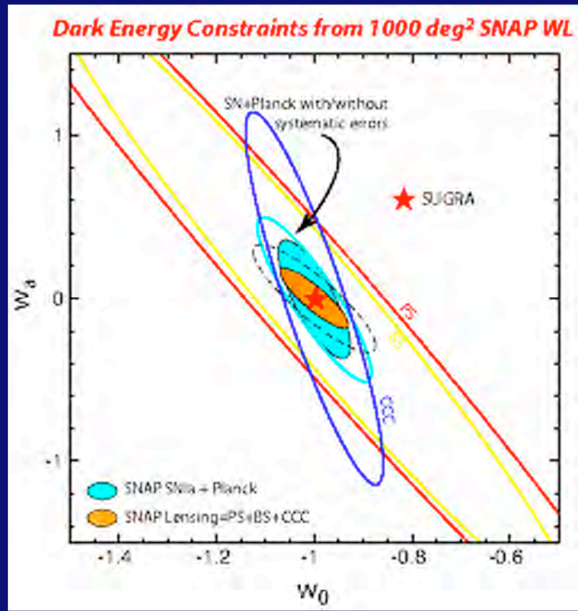
- Brian Dewhurst, *Study Director, BPA*
- Sandra J. Graham, *Study Director, SSB*

Oversaw Review

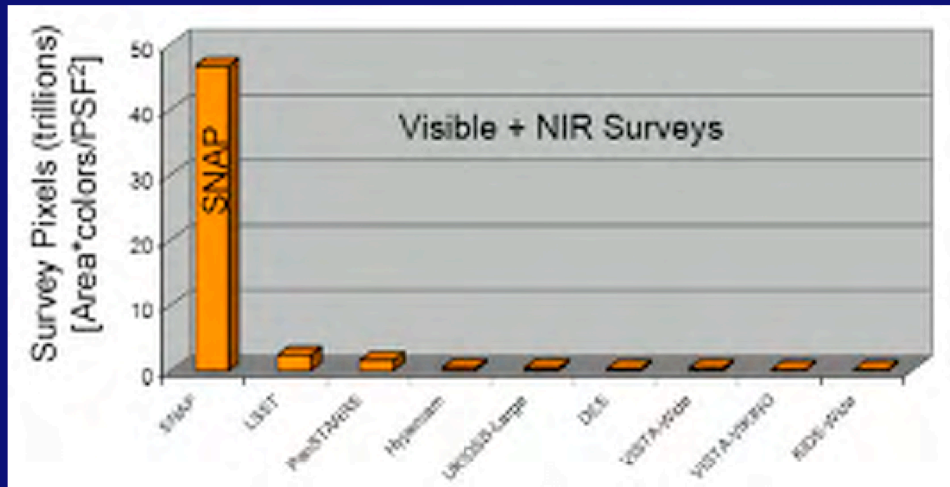
- Martha Haynes, *Cornell*
- Kenneth Keller, *JHU*

Joint Dark Energy Mission: Science Goals

- Beyond Einstein science
  - precisely measure the expansion history of the universe to determine whether the contribution of dark energy to the expansion rate varies with time
- Broader science
  - investigate the formation and evolution of galaxies
  - determine the rate of star formation and how that rate depends on environment



- Missions
  - SNAP: SN & WL
  - Destiny: SN & WL
  - ADEPT: SN & BAO
  - [DUNE: WL & BAO]



Recommendation 1

- NASA and DOE should proceed immediately with a competition to select a Joint Dark Energy Mission for a 2009 new start. The broad mission goals in the Request for Proposal should be
- (1) to determine the properties of dark energy with high precision and
- (2) to enable a broad range of astronomical investigations.

  The committee encourages the Agencies to seek as wide a variety of mission concepts and partnerships as possible.

There are four “bins” of complexity beginning with JDEM on the low end and culminating with the large observatories (LISA and Con-X) as most complex. Approximate development cost (Phase B, C, and D) and schedule regimes are as follows for the Beyond Einstein mission areas:

• Large Observatories (LISA and Con-X)	$2B	8 years
• BHFP (EXIST, CASTER)	$1.5B	7 years
• JDEM (SNAP, ADEPT, DESTINY)	$1B	6 years
• IP (CIP, CMBPol, EPIC-F, EPIC-I)	$1B	6 years

Note that inclusion of launch service ($200M or $300M) and MO&DA (varies but on the order of $25M per year) is above and beyond the development cost numbers noted above.

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- Hope I was able to convey to you a (particle) physicists' motivation for studying Dark Energy. It is fundamental and, after all, mysterious.
- Is it dynamical at all ?
- Many ambitious projects and tight international competition.
- Hope we bring in many bright people to the HSC project and make a compelling (unified) survey proposal.