Particle-Astrophysics
Experiments at SLAC:
*Fall 2016 Graduate Student Orientation*

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Standard cosmology: An inventory of the universe

- **Baryon acoustic oscillations**
- **WMAP**
- **3 Kelvin cosmic microwave background**
- **Supernovae**
- **Matter density**
- **Energy density**
- **Units of critical density**
- **BAO**
- **CMB**
- **No Big Bang**
- **Supernova Cosmology Project**
- **Union2 SN Ia Compilation**
- **perlmutter, Phys. Today**

**SDSS-III / BOSS**
Physical theories of dark energy
Fate of the Universe?

- What is Dark Energy?
  - a Cosmological Constant?
  - a Quantum Field?
  - Or does General Relativity need to be modified?

\[ w = \frac{P}{\rho} \]

Rip Apart Space-Time
Expand Forever
Study Dark Energy with Multiple Methods

Complementary techniques, including:
- The mass function and clustering of Galaxy Clusters
- The power spectrum of Weak Gravitational Lensing shear
- The statistical distance scale in the galaxy distribution, the Baryon Acoustic Oscillations
- The distance-brightness relation of Type Ia Supernovae
Dark Energy Survey

in 3rd Year of 5 Yr Survey
Dark Energy Survey

Year 3 of 5 Yr Survey

dark matter maps
dwarf galaxy candidates
Large Synoptic Survey Telescope

Construction now underway!
LSST Camera

Camera construction in new SLAC clean room

20 billion galaxies (DES ~ 200M)

Lab tour 4-5 pm
Cosmology Measurements

Figure 15.3: Joint $w_0 - w_a$ constraints from LSST BAO (dashed line), cluster counting (dash-dotted line), supernovae (dotted line), WL (solid line), joint BAO and WL (green shaded area), and all combined (yellow shaded area). The BAO and WL results are based on galaxy–galaxy, galaxy–shear, and shear–shear power spectra only. Adding other probes such as strong lensing time delay ($\S$ 12.4), ISW effects ($\S$ 13.7), and higher-order galaxy and shear statistics ($\S$ 13.5 and $\S$ 14.4) will further improve the constraints.

The aforementioned results are obtained either with the assumption of matter dominance at $z > 2$ and precise independent distance measurements at $z > 2$ and at recombination (Knox 2006) or with a specific dark energy EOS: $w(z) = w_0 + w_a z (1 + z)^{-1}$ (Knox et al. 2006b; Zhan 2006).

However, if one assumes only the Robertson-Walker metric without invoking the dependence of the co-moving distance on cosmology, then the pure metric constraint on curvature from a simple combination of BAO and WL becomes much weaker:

$$\Omega_0^k \lesssim 0.04 \frac{1}{2} \text{sky} \left(\frac{z_0}{0.04}\right)^{1/2}$$ (Bernstein 2006).

Our result for $\Omega_0^k$ from LSST WL or BAO alone is not meaningful, in agreement with Bernstein (2006). However, because WL and BAO measure very different combinations of distances (see, e.g., Figure 6 of Zhan et al. 2009), breaking the degeneracy between $\Omega_0^k$ and other parameters, the joint analysis of the two leads to $\Omega_0^k = 0.017$, including anticipated systematics in photometric redshifts and power spectra for LSST. This result is better than the forecast derived from the shear power spectra and galaxy power spectra in Bernstein (2006) because we include in our analysis more information: the galaxy–shear power spectra.

15.1.6 Results of Combining BAO, Cluster Counting, Supernovae, and WL

We show in Figure 15.3 $w_0 - w_a$ constraints combining four LSST probes of dark energy: BAO, cluster counting, supernovae, and WL. The cluster counting result is from Fang & Haiman (2007) and the supernova result is based on Zhan et al. (2008). Because each probe has its own parameter degeneracies, the combination of any two of them can improve the result significantly. As mentioned, $\Omega_0^k$ affects both the co-moving distance and the mapping between the co-moving distance and the angular diameter distance, while $\Omega_0^k$ affects only the latter. See Equation 13.12.
Spectroscopic Survey
Dark Energy Spectroscopic Instrument

Passed 2nd of 3 Critical reviews

Complements LSST - fewer objects (20M) / better redshift
Dark matter searches

Scattering experiment

WIMP

density, speed

dark matter halo

10^{16} WIMPs/year

detector

10^{-16} light years

Cross section: WIMP scatters once in a light year of lead

Rate ~ few events / year
SuperCDMS and LZ

Updated from
Snowmass Community Summer Study 2013
CF1: WIMP Dark Matter Detection

limited by nuclear scatter background? reach to $10^{-49}$ cm$^2$
neutrino floor depends on rejecting $pp$ solar
Akerib/Shutt (SLAC): Dark Matter with LUX and LZ

LUX: world-leading search experiment, 4850 ft underground at SURF, South Dakota
LUX ZEPLIN

• Funded. In design phase. Expected turn on in 2019.

• Largest dark matter experiment.

• 300 times more sensitive than LUX.

• As-yet unmeasured Astrophysical neutrinos should be limiting background to dark matter signal.
LZ at SLAC

- SLAC group has major role in LZ
  - Central Xe detector
  - LXe purification systems
  - Removal of Kr from Xe to $10^{-14}$ g/g
  - Data processing and simulations
  - Control systems

- System Test Platform
  - Design and testing of LZ detector components
  - Fundamental studies, advanced electronics development, blue-sky detector R&D

- Graduate opportunities in all these areas
- LZ dark matter data starting in 2019.
SLAC LZ System Test Platform

- Thermosyphon Dewar
- Breakout system / Thermosyphon lines
- Clean-tented area for detector assembly
- Lab tour 4-5 pm
- Xe purification gas system
- RGA+ Cold-trap sampling system (U. Maryland)
- Detector test volume - COLD - xenon condensed.
- Purification Tower
Internal dangers: radioactive krypton

Krypton:
- $10^{-1}$ T$_{1/2}$ beta decay
- can’t self-shield
- ~$100$ ppb in purchased Xe
  - 20 ppt ~ 122 PMTs
- noble gas: non-reactive

Charcoal chromatography removal system @ Case
- processed 400 kg LUX xenon from 150 ppb to 4 ppt
- cold-trap leak-valve analytics - C. Hall / UMd.
Conceptual Design for SuperCDMS SNOLAB

CDR baseline design contains 31 tower positions, fulfilling mission need with capability of reaching neutrino floor in future upgrade.
Detector Tower payload

- Connector to cable to 300K
- 4K stiffener w/HEMTs
- 4K stage
- ST stiffener w/SQUIDs
- CFRP truss
- ST stage
- CFRP truss
- CP stiffener w/R_{sh}
- CP stage
- Ti 15-3-3-3 truss
- MC stiffener/heat sink
- MC stage
- Tower flex cable
- Detector packages
Tower Assembly Stand

SQUID Modulation Curve
CDMS Tower Test Stand in Cleanroom

Lab tour 2-3 pm
Fermi Gamma Ray Space Telescope

constructed at SLAC

Advanced reconstruction analysis: “Pass 8”

Isotropic Diffuse & Dark Matter

Galactic Diffuse

Point Sources

TGFs

Solar Flare/GRBs

Background reduction

Energy [MeV]

10^6

10^5

10^4

10^3

10^2

10

1

FIG. 1. LAT counts maps in 10^4–10^6 events/GeV/cycle for differential point-source analysis in 24 logarithmically-spaced energy bins and 0.25 Gaussian kernel. All 3FGL sources in the ROI are indicated with white ‘+’ symbols, and those with red ‘x’ symbols were not selected in the LAT analysis; specifically the di-agnostic Pass 8 compared to the previous iteration of the LAT event-level analysis, produced significant improvements in all areas of LAT analysis: specifically the di-agnostic Pass 8 sensitivity improves by 20–40% in an energy range of 2–200 GeV.

To search for gamma-ray emission from these new dSph candidates, we used six years of LAT data (2008 August 4 to 2014 August 5) passing the 7 Reprocessed LAT analysis; specifically the di-agnostic Pass 8 data without accounting for the energy dispersion, we performed a binned maximum-likelihood analysis for each candidate for energies >1 GeV.

We used 10 differential point-source analysis in 24 logarithmically-spaced energy bins and 0.25 Gaussian kernel. All 3FGL sources in the ROI are indicated with white ‘+’ symbols, and those with red ‘x’ symbols were not selected in the LAT analysis; specifically the di-agnostic Pass 8 compared to the previous iteration of the LAT event-level analysis, produced significant improvements in all areas of LAT analysis: specifically the di-agnostic Pass 8 sensitivity improves by 20–40% in an energy range of 2–200 GeV.

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We used a di-agnostic analysis of 3FGL sources and self-similar models for Galactic diffuse radiation.
**Fermi Highlights and Discoveries**

- Dark Matter searches
- Terrestrial γ-ray Flashes
- Binaries
- Gravitational Waves
- Neutron Stars
- Black Holes
- Gamma-Ray Bursts (GRBs)
- Blazars
- Radio Galaxies
- Starburst Galaxies
- Globular Clusters
- SNRs & PWN
- Novae
- Fermi Bubbles
- LMC & SMC
- Sun: flares & CR interactions
- Terrestrial γ-ray Flashes
- Unidentified Sources

**e^+e^- spectrum**
Particle-Astro Experiments at SLAC

- SLAC history of particle physics experimentation & experiment development
- Large scale facilities & technical support
  - Complements campus

- Dark Energy Survey
  - Profs. Allen, Burke, Roodman, Weschler,

- Large Synoptic Survey Telescope
  - Profs. Kahn, Roodman, Burchat, Allen, Schindler, Weschler

- Dark Energy Spectroscopic Instrument
  - Profs. Weschler, Roodman

- SuperCDMS
  - Prof. Cabrera, Dr. Partridge (SLAC Sr. Scientist)

- Fermi-LAT
  - Dr. Madejski (SLAC Sr. Scientist)

- LUX / LZ
  - Profs. Akerib, Shutt
Three tours today

- 2-3 SuperCDMS
- 3-4 Visualization Lab
- 4-5 IR2 - LZ and LSST