

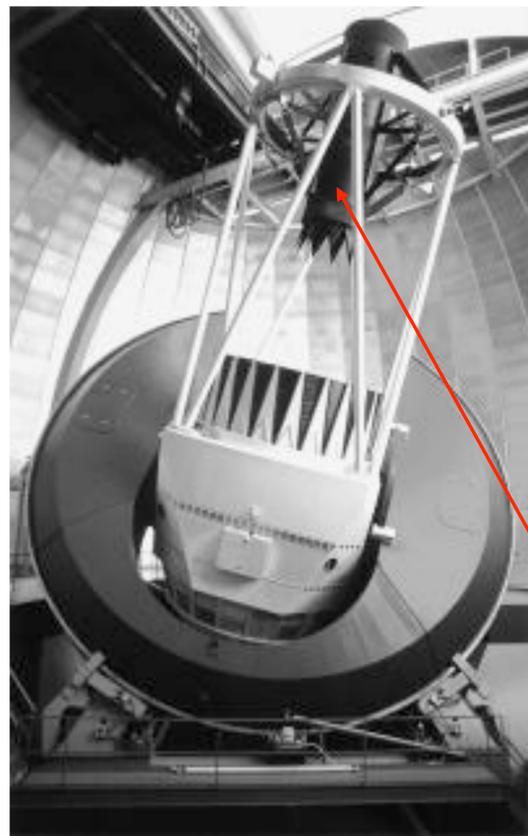
# Future Dark Energy Programs at Fermilab

Douglas L. Tucker, presenting for the FNAL members of DES and SNAP



## The Dark Energy Survey

Fermilab, UIUC, U of Chicago, LBNL, U of Michigan, NOAO/CTIO, CSIC/Institut d'Estudis Espacials de Catalunya (Barcelona), Institut de Fisica D'Altes Energies (Barcelona), CIEMAT (Madrid), University College London, Cambridge, Edinburgh, Portsmouth, Sussex



### Proposal

Perform a 5000 sq deg imaging survey of the Southern Galactic Cap  
 Obtain 2% global photometry in *griz* via multiple tilings of the survey area (cluster photo-*z*'s to  $\Delta z \sim 0.02$  out to  $z \sim 1.3$ )  
 Probe the nature of the Dark Energy by constraining its equation of state parameter  $w$  and its energy density

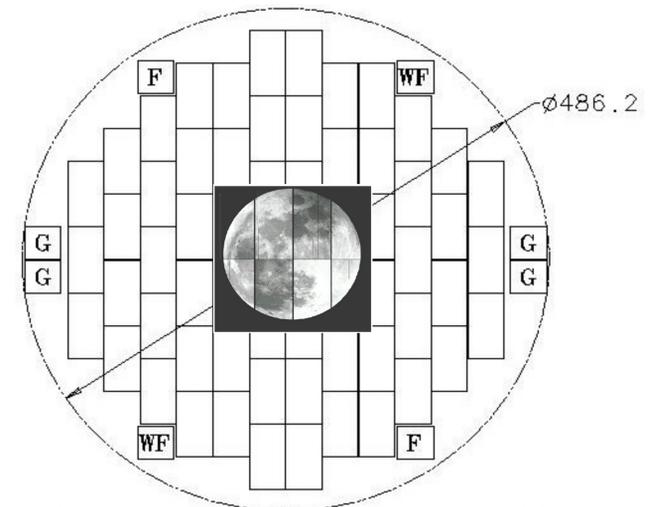
### New Equipment

Replace the Prime Focus cage on the CTIO Blanco 4m telescope with a new 2.2 deg FOV optical CCD camera (DECam), including active focus & aberration sensors and a new optical corrector which will deliver excellent images

### Survey Period

30% of the telescope time (525 nights) from 2009-2014 (September - February)

### DECam Focal Plane



62 2k x 4k imaging CCDs, 3 sq deg

520 megapixels

0.27 arcsec/pix

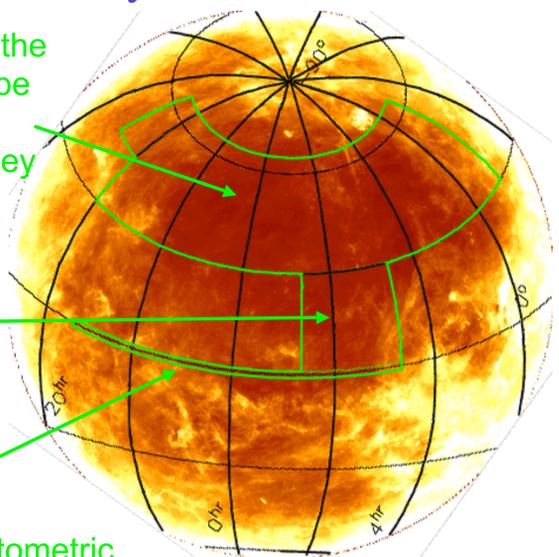
LBNL design (fully depleted, 250 micron thick, 17 sec readout time, QE > 50% at 1 micron).

### Survey Area

Overlap region with the South Pole Telescope Sunyaev-Zeldovich Galaxy Cluster Survey (4000 sq deg)

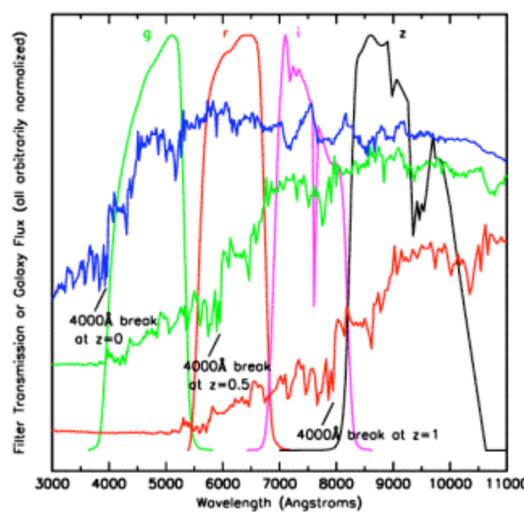
Connector region (800 sq deg)

Overlap region with the SDSS Stripe 82 for redshift and photometric calibration (200 sq deg)

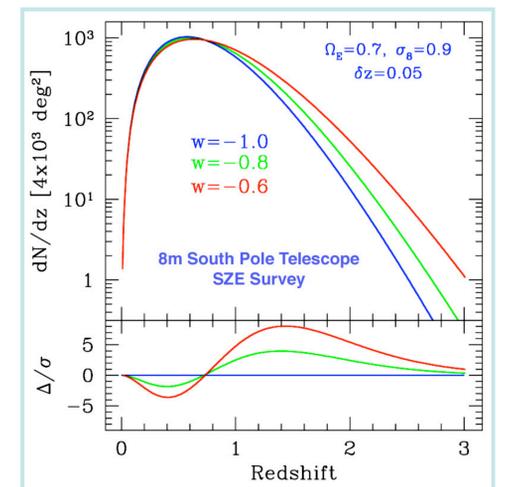


DIRBE dust map, celestial coordinates

### Filters (*griz*) and photo-*z*'s

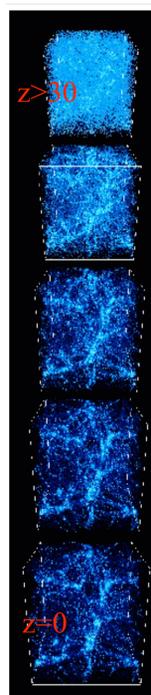


### Cluster Counting



### Four Probes of Dark Energy:

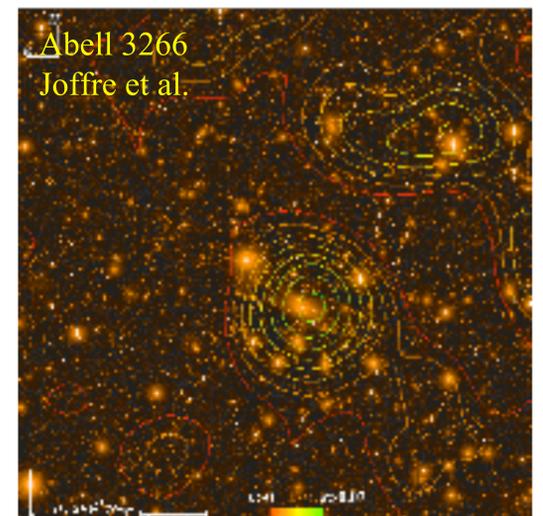
- Galaxy Cluster counting
  - Many thousands of clusters to  $z=1$  with  $M > 2 \times 10^{14} M_{\text{sun}}$
- Weak Lensing
  - 300 million galaxies with shape measurements over 5000 sq deg
- Baryon Acoustic Oscillations
  - Angular clustering of 300 million galaxies to  $z > 1$
- Standard Candles
  - 1900 Type Ia Supernovae,  $z = 0.25-0.75$



### Clustering of Galaxies

Credit: Andrey Kravtsov

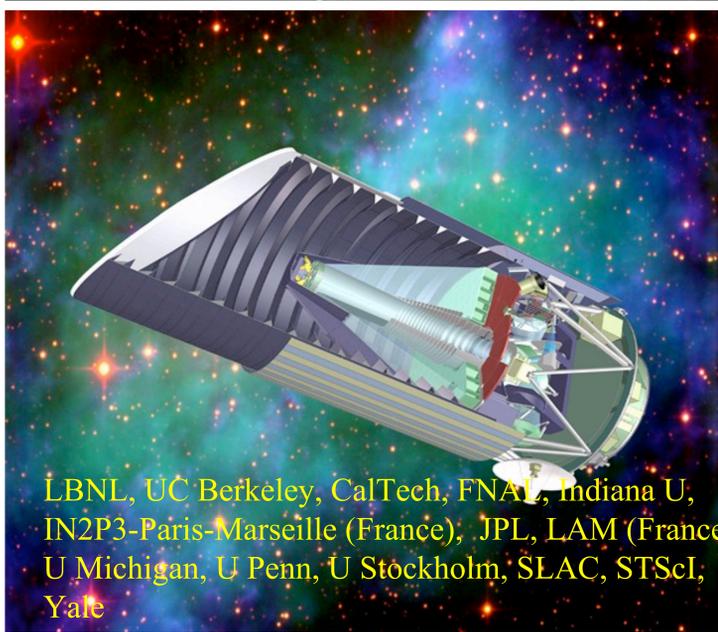
### Weak Lensing



**Fermilab Contributions:** Project Management, CCD Testing and Packaging, Optical Design, Simulations, Software, Calibrations, Overall Responsibility for Camera Construction

J. Annis, H.T. Diehl, S. Dodelson, J. Estrada, B. Flaugher, J. Frieman, S. Kent, P. Limon, H. Lin, K.W. Merrit, J. Peoples, V. Scarpine, A. Stebbins, C. Stoughton, D. Tucker, W. Wester





LBNL, UC Berkeley, CalTech, FNAL, Indiana U,  
 IN2P3-Paris-Marseille (France), JPL, LAM (France),  
 U Michigan, U Penn, U Stockholm, SLAC, STScI,  
 Yale

## The SuperNova Acceleration Probe

### The SNAP Mission Outline

A 2m space telescope with visible light CCDs, NIR detectors, and a spectrograph.

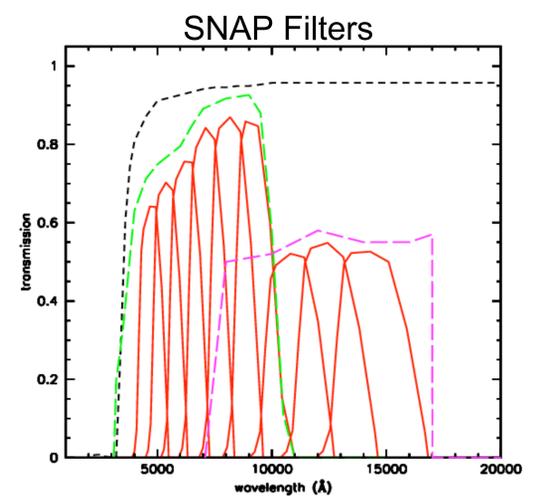
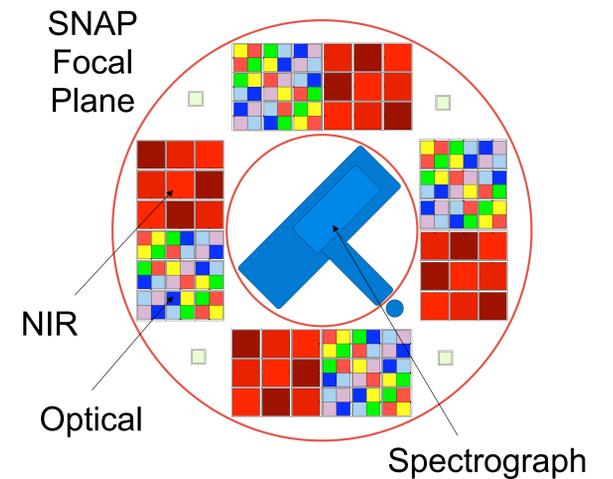
### The Instrument

The focal plane is like an HEP detector, larger than any present astronomical camera, but smaller than a vertex detector.

Contains both optical and near infrared devices. There are 9 filters covering a wavelength range of 0.35 -1.7  $\mu\text{m}$ . The total number of pixels is  $\sim$ 600 million.

The detectors are low noise, high QE.

Spectrograph covers both optical and near infrared



## Complementary Measurements of Dark Energy

Supernovae Survey to explore dark energy

- 15 sq. deg. to AB magnitude  $\sim$ 30 (28/scan)
- 9000 times the area of Hubble Deep Field, same resolution,  $\sim$ 1.5 magnitudes deeper.

Lensing Survey to explore dark energy and dark matter

- 1000 sq. deg. to AB magnitude  $\sim$ 28.

## 2000 Type 1a Supernovae:

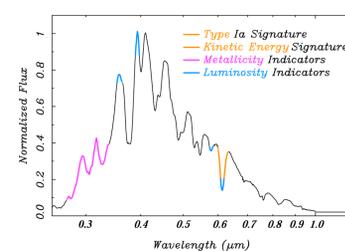
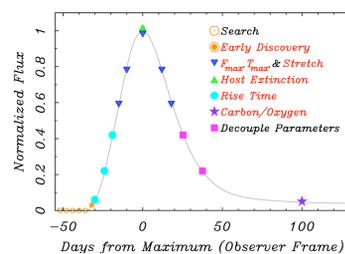
Identify Type 1a SN with CCD and NIR detectors in redshift range  $0.3 < z < 1.7$ .

Fit peak of SN1a lightcurve with  $\langle S/N \rangle$  of 50:1.

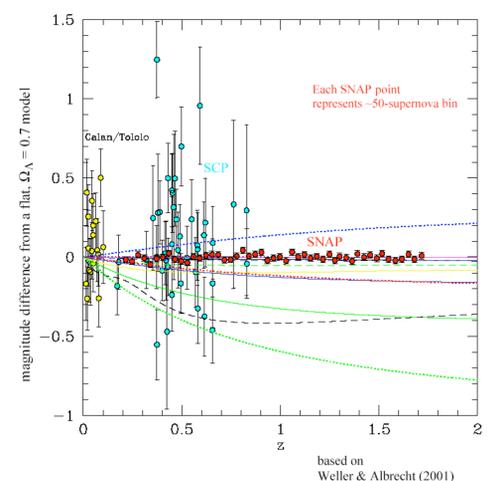
Obtain spectrographic observations near peak intensity with a resolution  $R \sim 100$  over  $\lambda = 0.35$  to 1.7 microns.

Tightest Control of Systematics in individual supernovae measurements.

### Light Curve & Spectrum



Current ground-based data compared with binned simulated SNAP data and a sample of Dark Energy models.

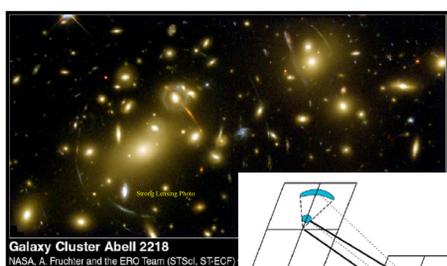


## Weak Gravitational Lensing:

A 1000 sq-deg survey.

Direct measurement of  $P(k)$  vs  $z$ .

Mass selected cluster survey vs  $z$ .



Gravitational Weak Lensing  
 Observed galaxy shapes are distorted (smeared tangentially) by the gravitational field of mass concentrations along the line-of-sight between the galaxy and our telescopes. This effect can be very small and yet detectable statistically after averaging over the measured ellipticity of many galaxies.

## The Science Return:

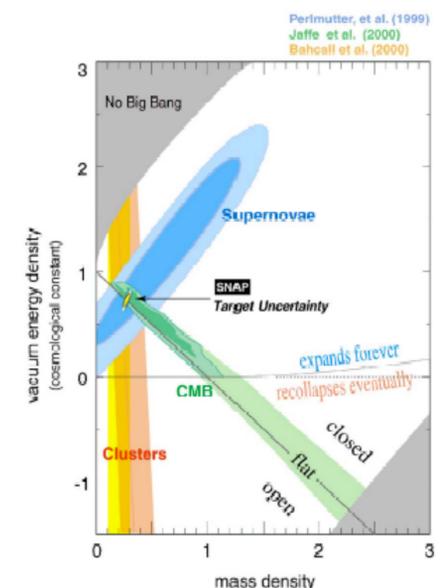
Premier measurement of the dark energy density  $\Omega_{DE}$ , its equation of state  $w$ , and dynamical physics of  $w' = dw/dz$ .

Complementary cosmological properties measurements.

Map the expansion history  $a(t)$ , probing dark energy, higher dimensions, or alternative gravity.

## Fermilab Contributions:

- Electronics (Mass Memory & Data Manager)
- Cosmic Ray Shield Conceptual Design Studies
- Calibration
- Photo-z Simulations
- Simulations & Software Management
- CCD Testing



S. Allam, J. Annis, F. DeJongh, H.T. Diehl,  
 S. Dodelson, J. Frieman, S. Kent, P. Limon,  
 H. Lin, J. Marriner, J. Peoples, V. Scarpine,  
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