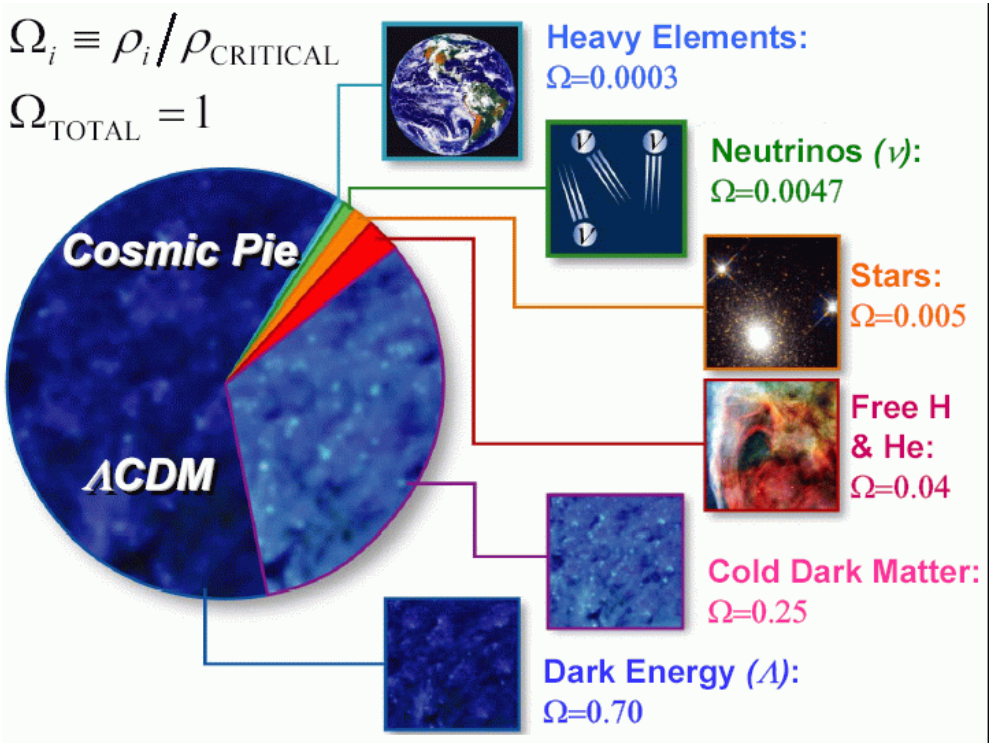
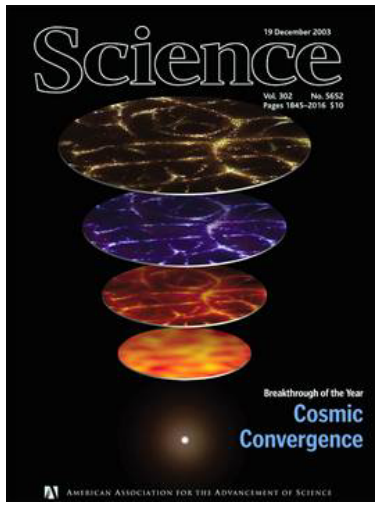
Dark Energy Survey Motivation

DARK ENERGY SURVEY



Dark Energy is the dominant constituent of the Universe
Dark Matter is next

95% of the Universe is in Dark Energy and Dark matter for which we have no understanding

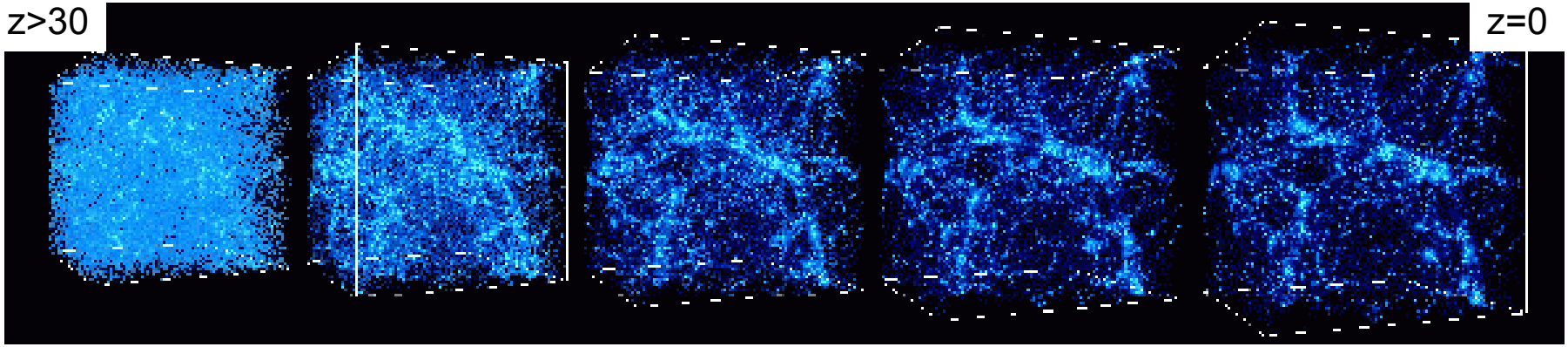


1998 and 2003 Science breakthroughs of the year

New Probes of Dark Energy: Map the cosmological density field

DARK ENERGY SURVEY

The rate of growth of structure is determined by the amount and distribution of dark matter, dark energy and by the expansion rate of the universe



Count the Galaxy Clusters as a function red shift and cluster mass

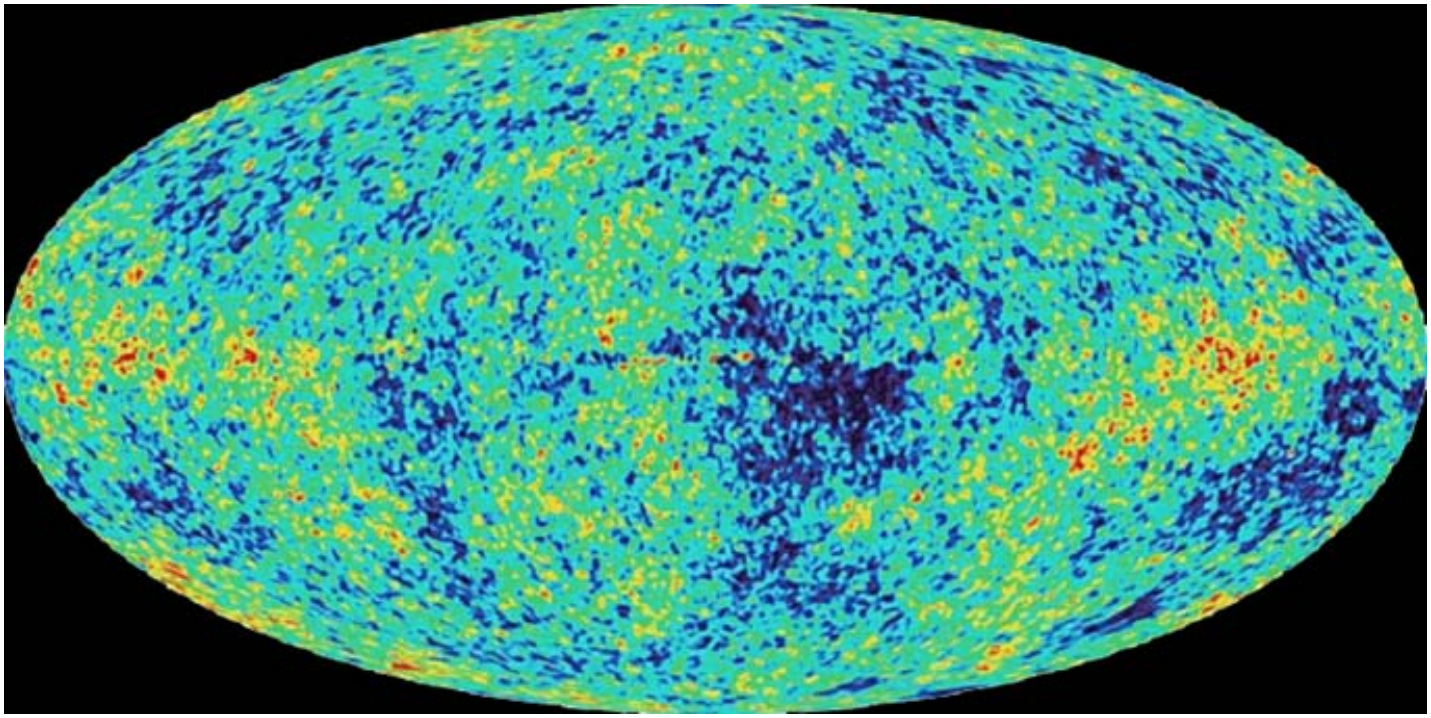
Measure the spatial clustering of galaxies as a function of red shift (angular power spectrum)

Measure the distortion in the apparent shape of galaxies due to intervening galaxy clusters and associated clumps of dark matter (weak lensing)

Picture of the early universe

DARK ENERGY
SURVEY

Quantum fluctuations grew during inflation – these led to galaxies & other structures
The CMB is the most distant light we'll ever be able to see, probes the initial conditions for structure formation.



WMAP measures the CMB radiation density field at z ~ 1000

Current picture of the universe

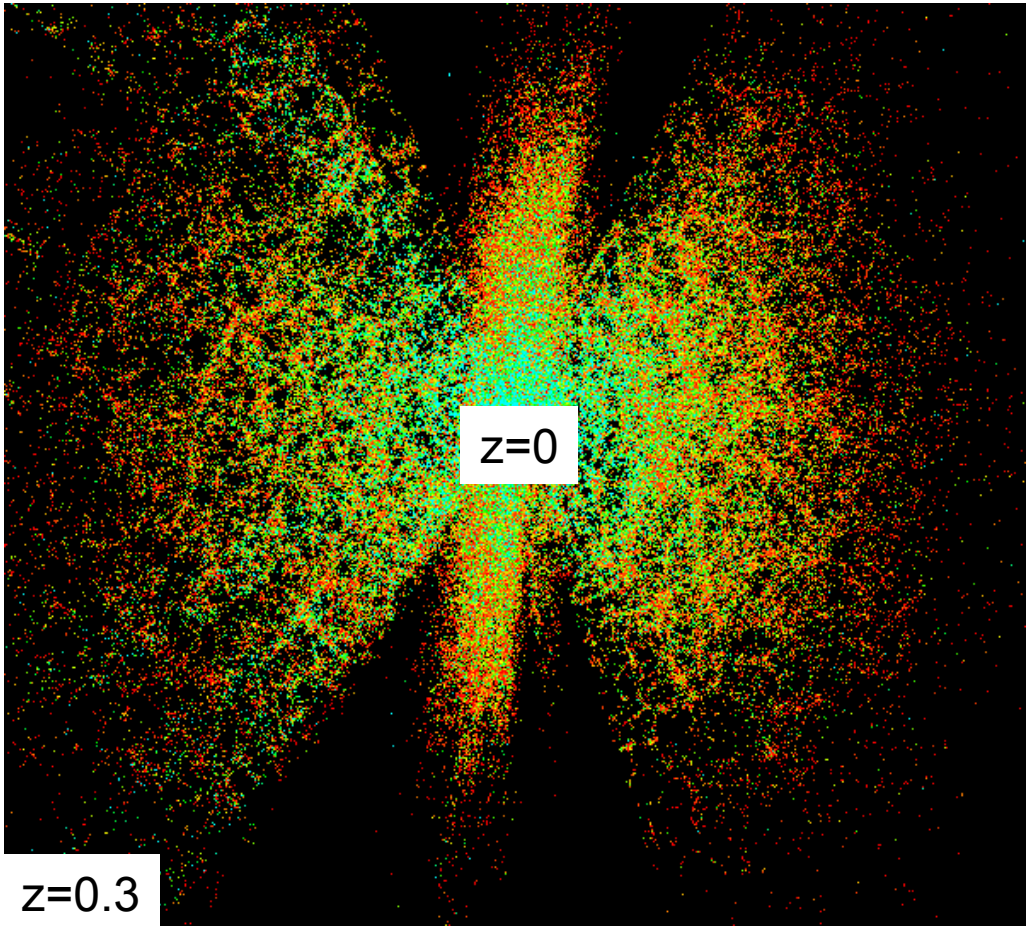
DARK ENERGY
SURVEY

Sloan Digital Sky Survey measures the galaxy density field out to z ~ 0.3

filamentary structure is evident

sample density drops off with z: fainter, harder to see

At z ~ 0.7 DE and DM are about equal, DE dominates now.



DARK ENERGY SURVEY

A Cluster of Galaxies in SDSS Data

What is the cluster redshift?

What is the cluster mass?

not completely different from jet clustering in collider physics but also have depth (red shift) info.

Dark Energy and the Accelerating Universe

Brightness of distant Type Ia supernovae, along with CMB and galaxy clustering data, indicates the expansion of the Universe is accelerating, not decelerating.

This requires *either* a new form of stress-energy with negative effective pressure *or* a breakdown of General Relativity at large distances:

DARK ENERGY

Characterize by its effective equation of state: $w = p/\rho$

and its relative contribution to the energy density of the Universe: Ω_{DE}

Current Status: $\sigma(w) \sim 0.15$*, $w < -0.76$ (95%) from CMB+LSS+SNe; no *single* dataset constrains *w* better than ~30%

The Dark Energy Survey (DES)

DARK ENERGY SURVEY

Proposal:

- Perform a 5000 sq. deg. survey of the southern galactic cap
- w to ~ 5% with 4 complementary techniques

New Equipment:

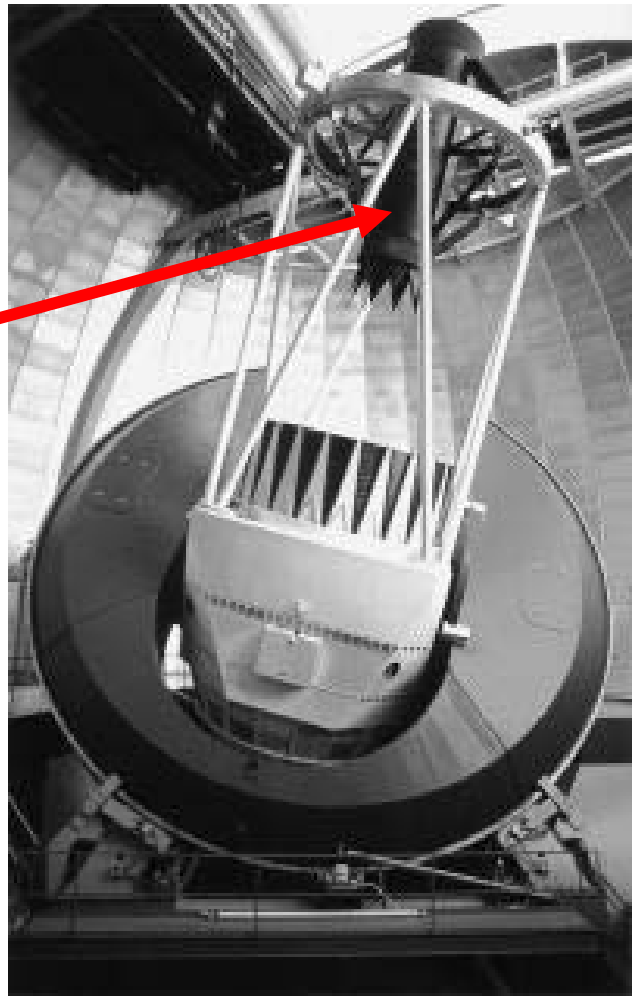
- Replace the PF cage with a new 500 Mega pixel digital camera

Time scale:

- Instrument Construction 2005-2009

Survey:

- 30% of the telescope time from 2009-2013
- Data released to public within a year of observations



Use the Blanco 4M Telescope at the Cerro-Tololo Inter-american Observatory (CTIO)

Dark Energy Survey Science Program

Four Probes of Dark Energy

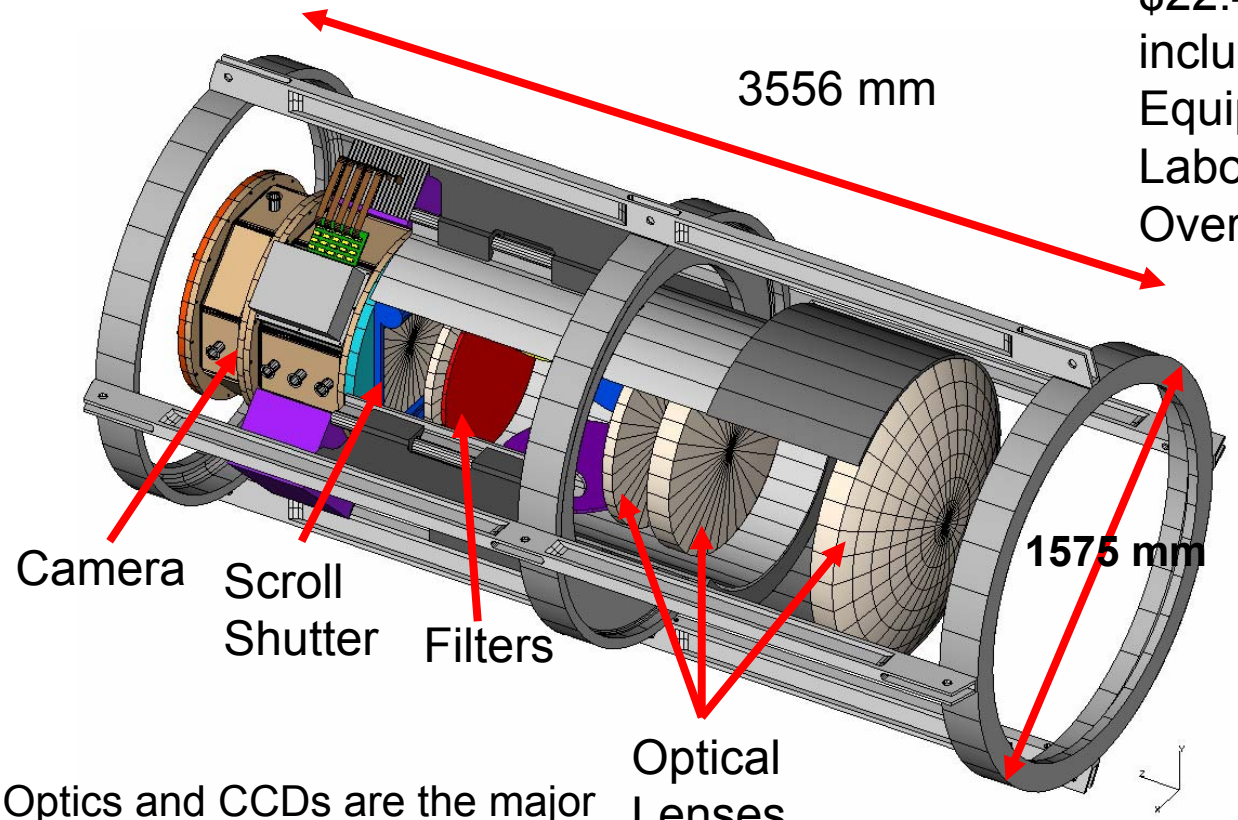
- Galaxy Cluster Counting: N(M,z)
  - Measure red shifts and masses
  - 30,000 clusters to z=1 with $M > 2 \times 10^{14} M_{\odot}$
- Weak lensing
  - 300 million galaxies with shape measurements over 5000 sq deg.
- Spatial clustering of galaxies
  - 300 million galaxies to z = 1

    and beyond
- Standard Candles
  - 2000 SN Ia, z = 0.3-0.8

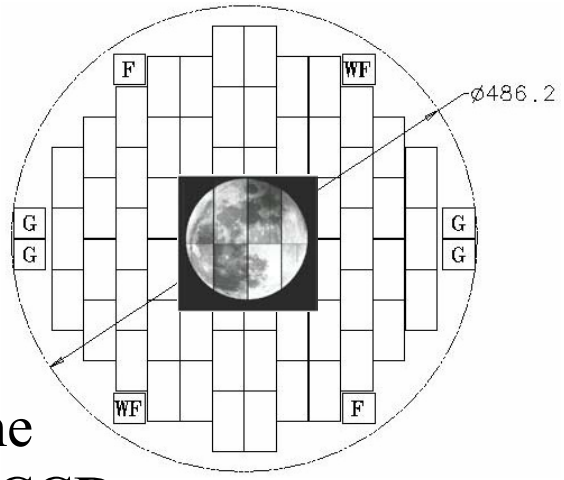
DES Instrument Reference Design

DARK ENERGY SURVEY

Instrument total cost (June 2004):
$22.4M then yr $
includes ~35% contingency
Equipment $11.4 M
Labor $7 M
Overhead $4 M



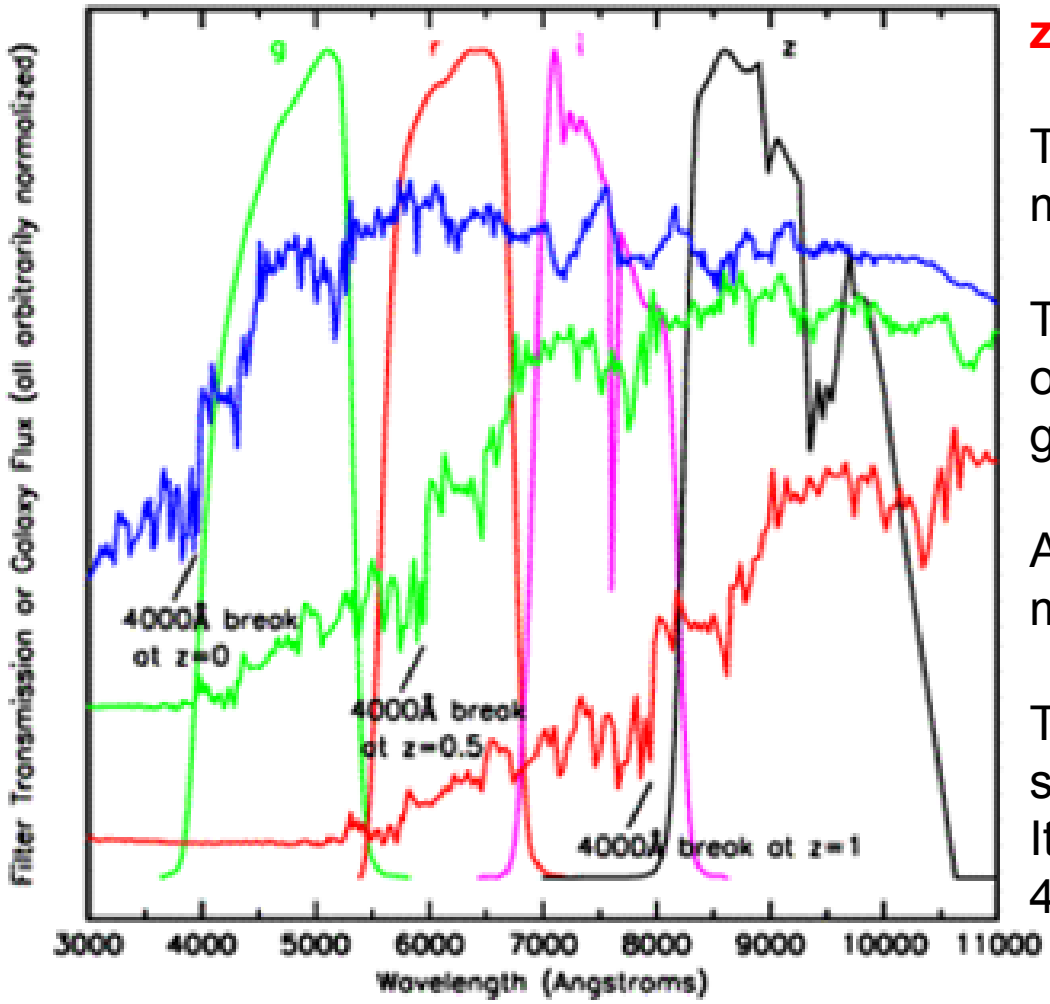
Optics and CCDs are the major cost and schedule drivers
Optics Total ~ $2M + $1M cont.
CCD Total ~ $2M + $1M cont.



Focal plane
62 2kx4k CCDs
8 2kx2k align/focus

Redshifts

DARK ENERGY
SURVEY



Elliptical galaxy spectra at redshifts z = 0, 0.5, and 1.

The 4000 Å break in the spectrum moves with redshift

The difference in brightness of an object seen through the different filters gives a measure of the redshift

At a redshift of 1, only the z filter gets much light

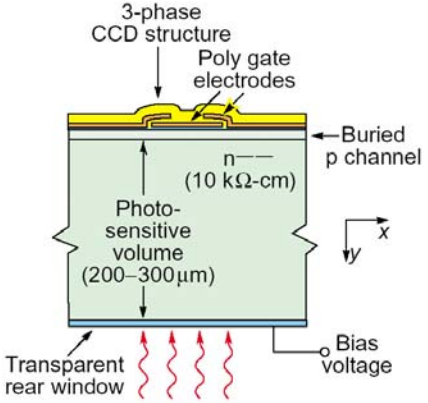
This is not as precise as taking a full spectrum but it is good enough!
It is MUCH faster and can go fainter:
45 min for spectra, 55sec for photo-z

ES CCDs

DARK ENERGY SURVEY •

Reference Design: LBNL CCDs

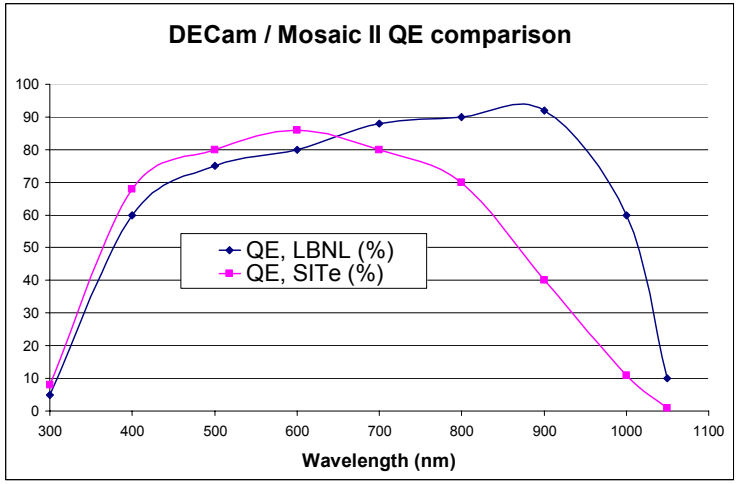
- **QE> 50% at 1000 nm**
- **250 microns thick**
- **readout 250 kpix/sec**
- **2 RO channels/device**
- **readout time ~17sec**



LBNL CCDs in use on WIYN telescope. From S. Holland et al, LBNL-49992 IEEE Trans. Elec. Dev. Vol.50, No 1, 225-338, Jan. 2003

LBNL CCDs are much more efficient in high wave lengths (z-band: 825 -1050nm)

To get redshifts of ~1 DES will spend 46% of survey time in z –band



DES is the 1st production quantity application for LBNL CCDs

DES CCD design has already been used on telescopes in small numbers (3)
SNAP CCDs are the next generation, optimized for space

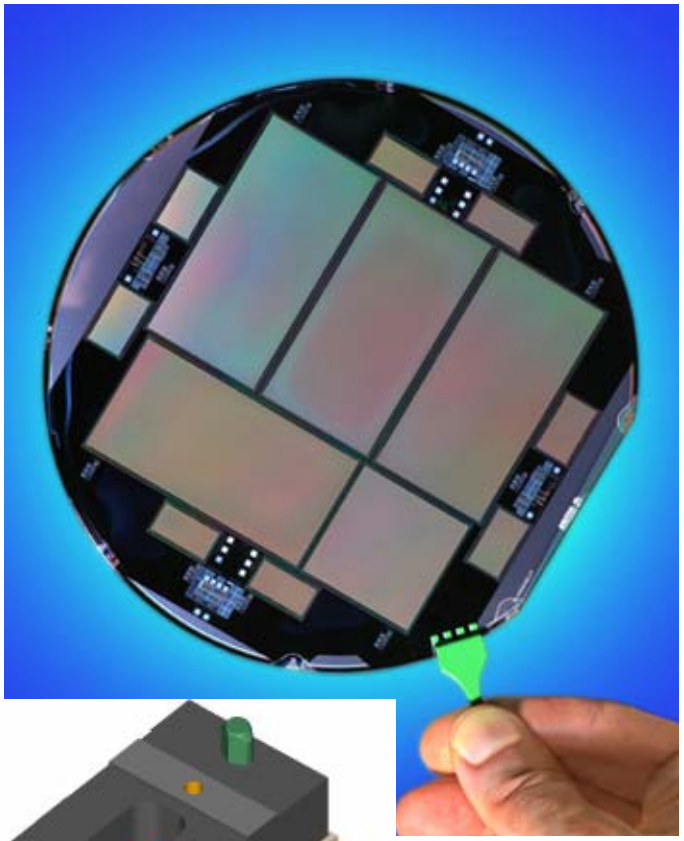
CD Acquisition Model

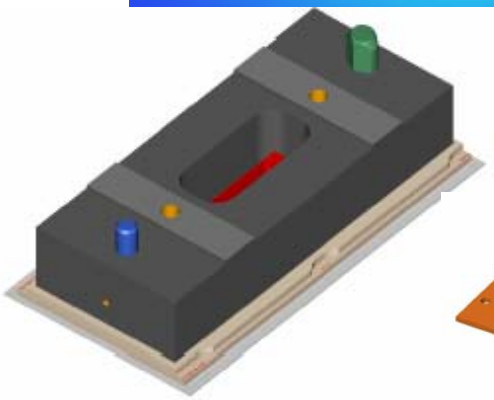
DARK ENERGY SURVEY

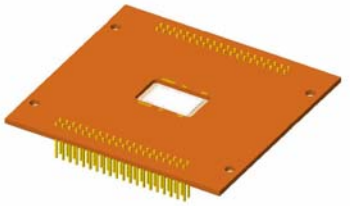
Reference Design Acquisition Model

- Order CCDs through LBNL – good relationship with commercial foundry
- Foundry delivers wafers to LBNL (~650 microns thick)
- LBNL
  - oversees thinning (250 microns thick)
  - applies front and backside coatings for back illuminated operation
  - tests all devices on cold probe station
- LBNL delivers all tested, unpackaged devices to FNAL
- FNAL packages and tests CCDs
- Prepared to package ~ 160 CCDs (spare yield)

DES Wafers – June 2005!

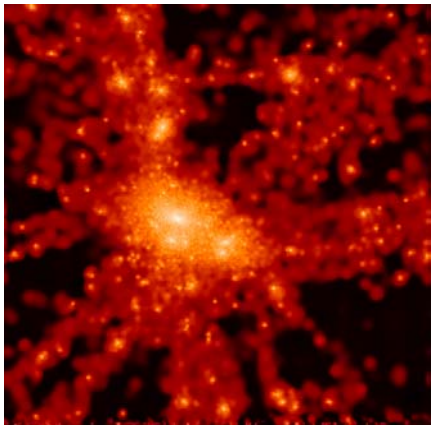


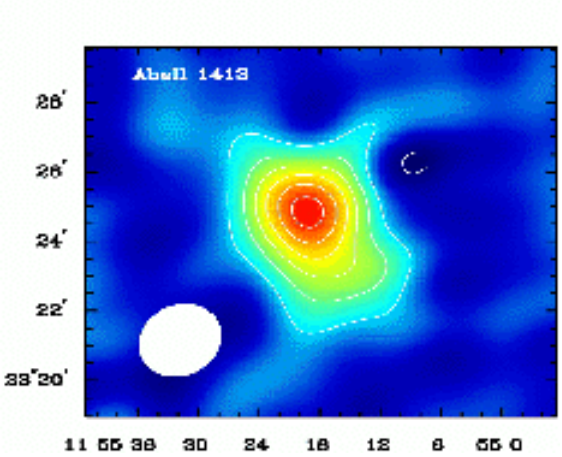




Galaxy Cluster Masses

DARK ENERGY
SURVEY





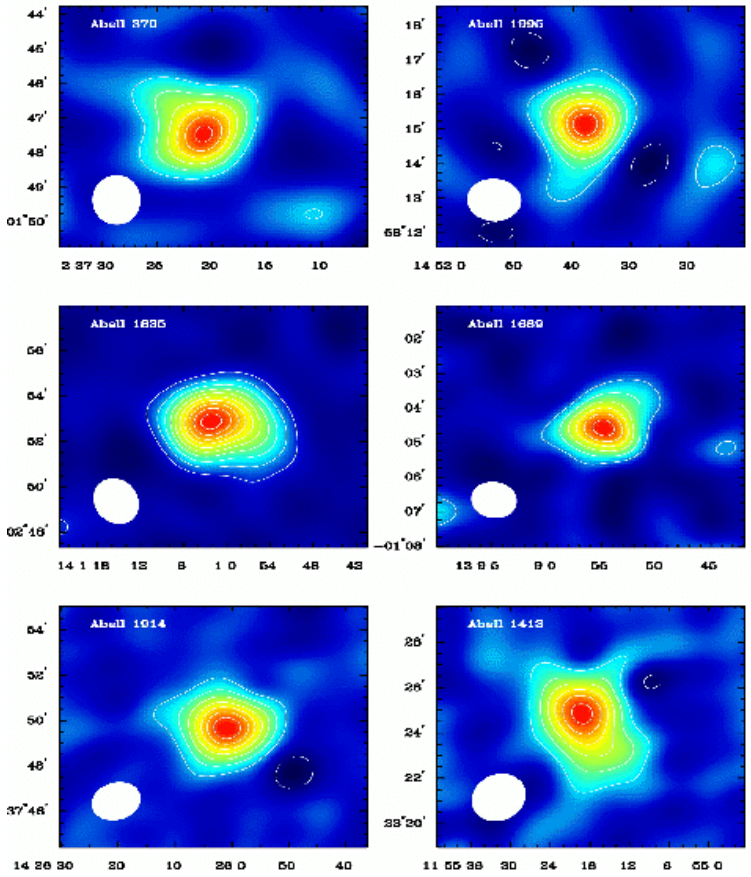
- DES Mass estimators (multiple methods!)
  - Count Galaxies (or luminosity) in a cluster
  - Weak lensing
  - Sunyaev-Zeldovich (SZ)
    - hot electrons in clusters scatter CMB photons, distorting the frequency spectrum
    - scattering is proportional to cluster mass
    - insensitive to redshift

The South Pole Telescope (SPT)

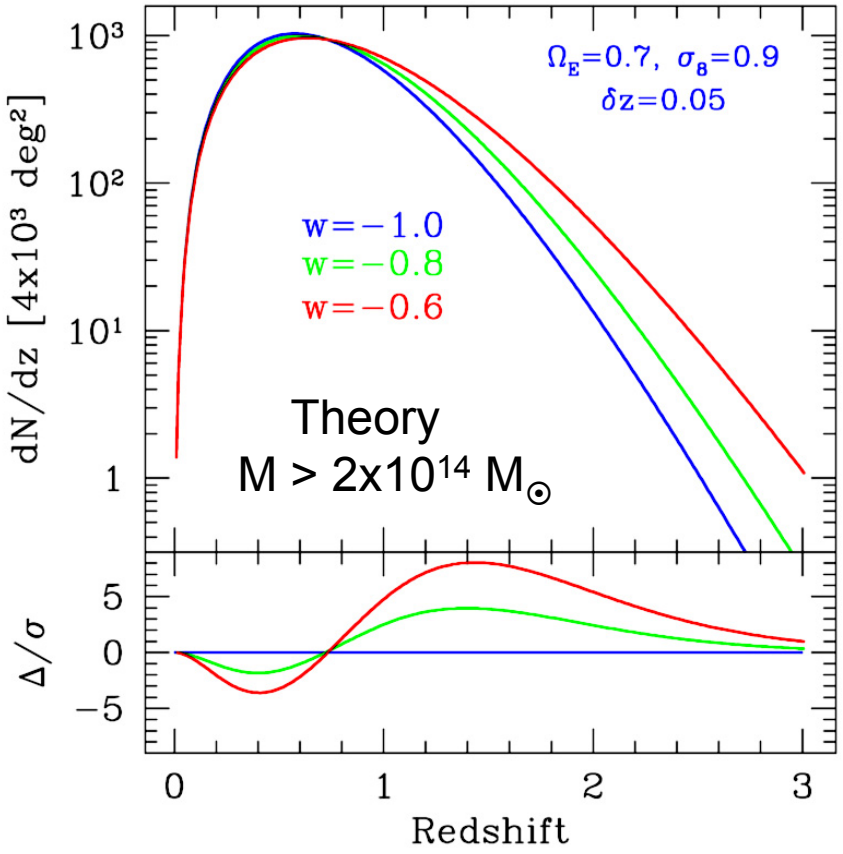
- 4000 sq. deg. survey Southern Galactic cap
- measures cluster masses using SZ effect
- funded and in construction – expect first data in 2006

Simulation of SPT 4000 sq degree Survey with DES redshifts

DARK ENERGY SURVEY



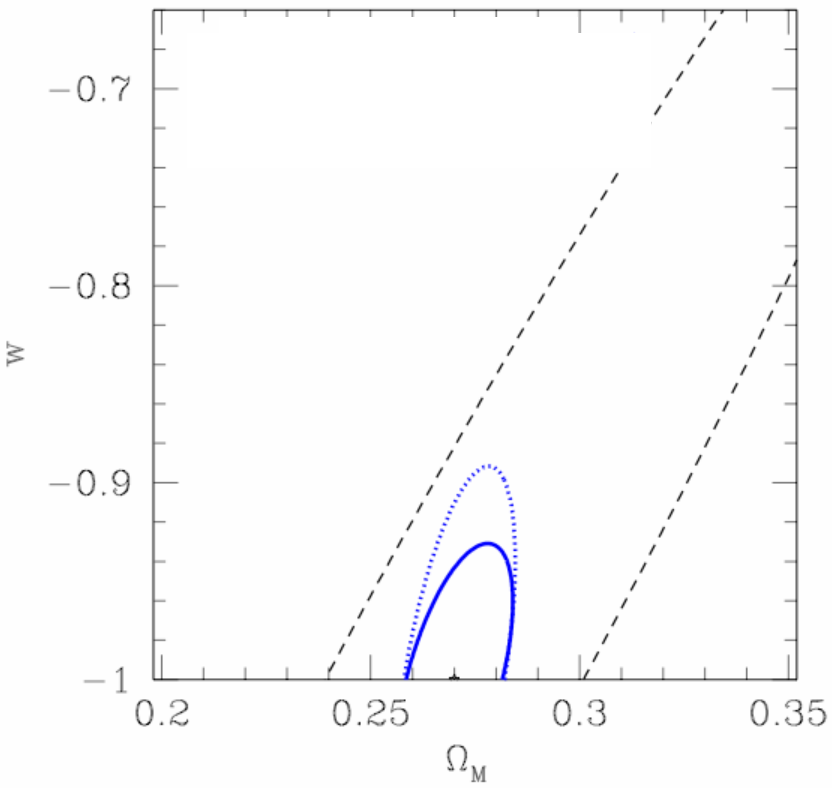
SZ observations of clusters



Combine SPT and DES Cluster Surveys

DARK ENERGY SURVEY

- Combination of SPT mass measurements and DES redshifts place joint constraints on w and Ω_m :
  - Fiducial cosmology parameters from WMAP: σ_8=0.84, Ω_m=0.27, w = -1
  - 29000 clusters in the 4000 deg^2 DES+SPT survey area
  - Curvature free to vary (dashed); one sigma uncertainty on w is 0.071
  - Curvature fixed @ 0 (solid); one sigma uncertainty on w is 0.046



DES + SPT: Majumdar & Mohr 2003
WMAP: Spergel et al 2003

Galaxy Angular Power Spectrum

DARK ENERGY SURVEY

- DES main survey will yield photo-z's on approximately 300 million galaxies extending beyond a redshift z~1
- We can study the angular clustering within redshift bins to z~1
- Theory predicts how the shape of the angular power spectrum depends on redshift

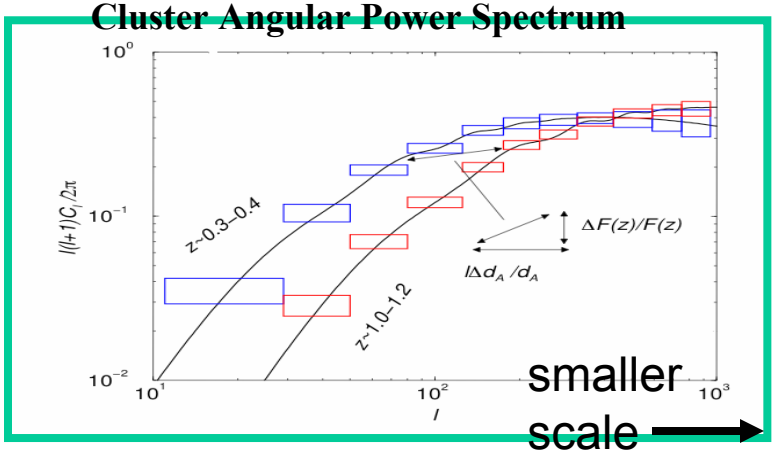


Figure from Cooray et al ApJ 2001

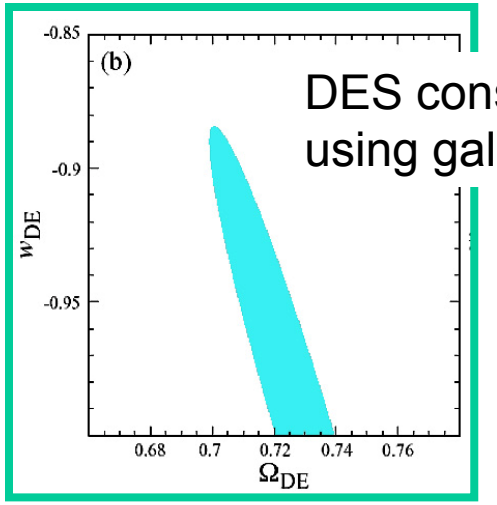
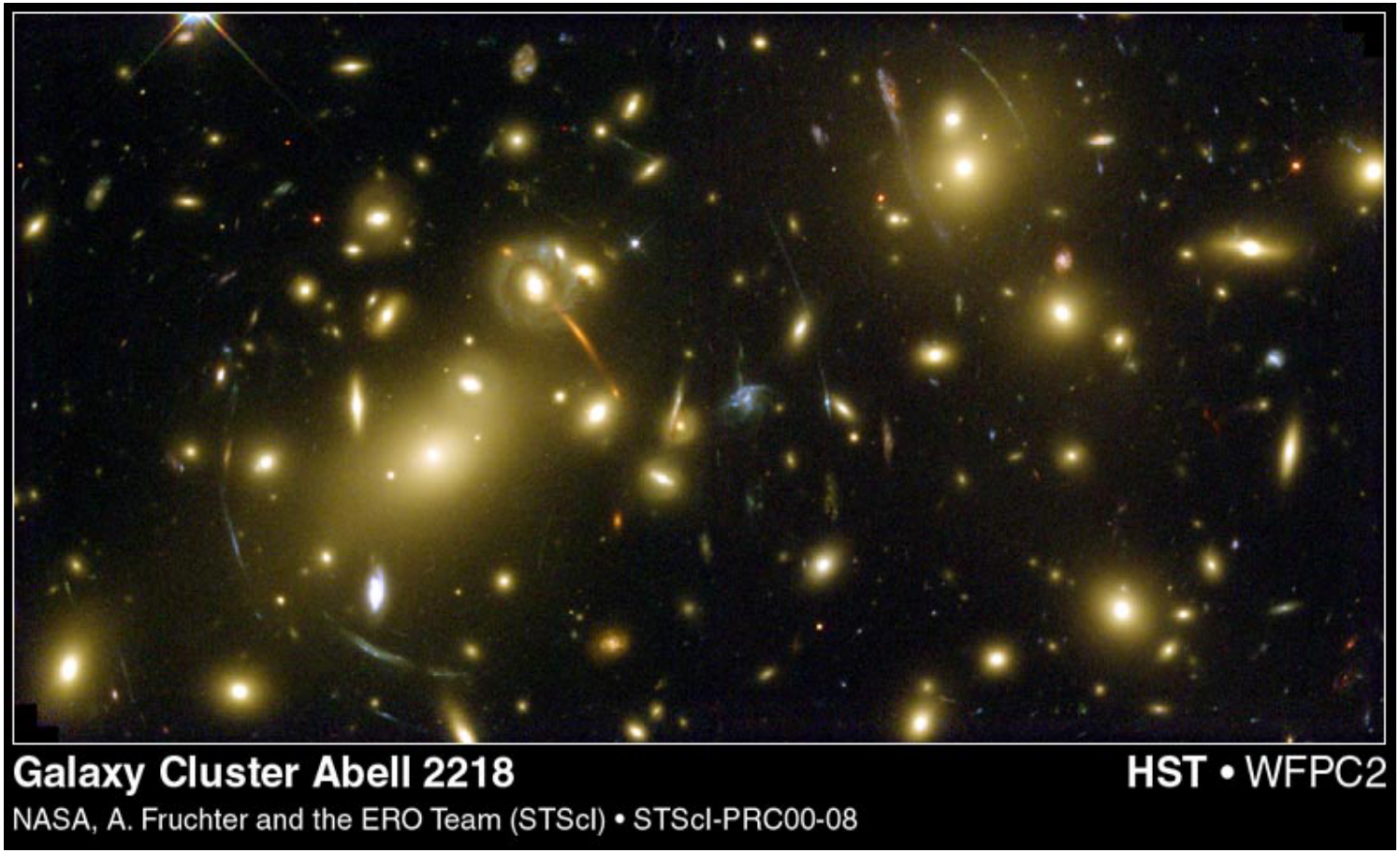


Figure from Wayne Hu 2004

DARK ENERGY SURVEY

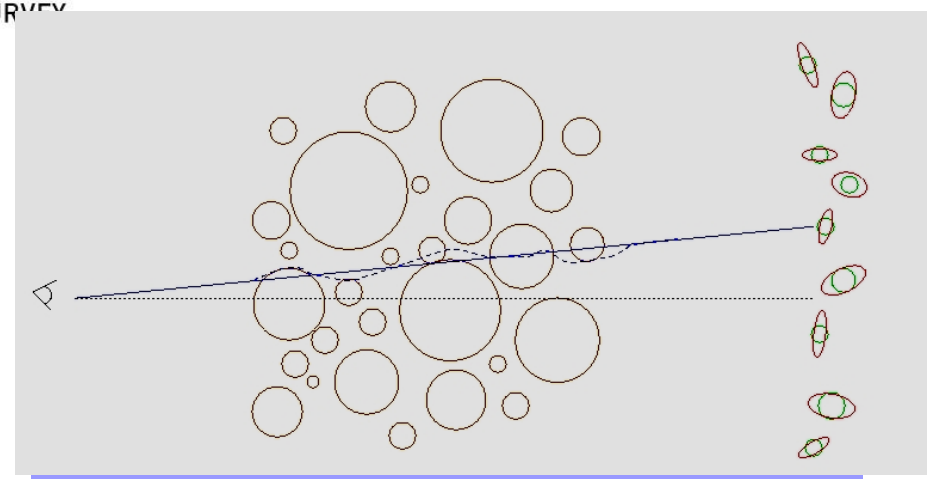
Gravitational Lensing

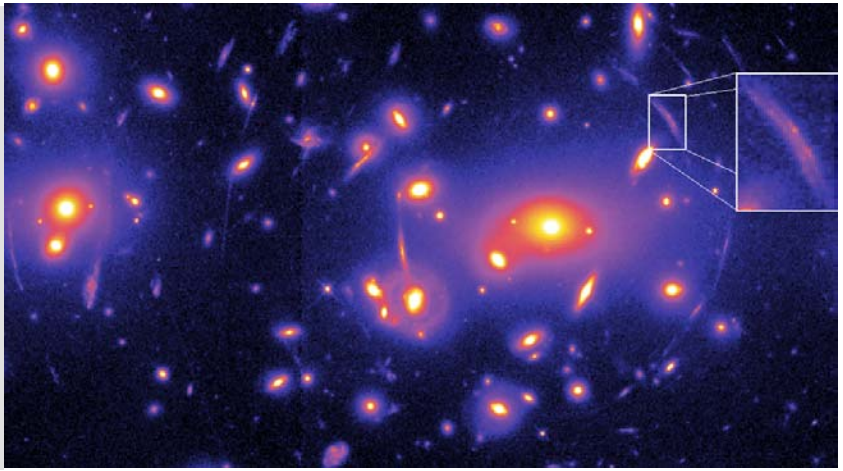
giant arcs are galaxies behind the cluster, gravitationally lensed by it



Weak Lensing

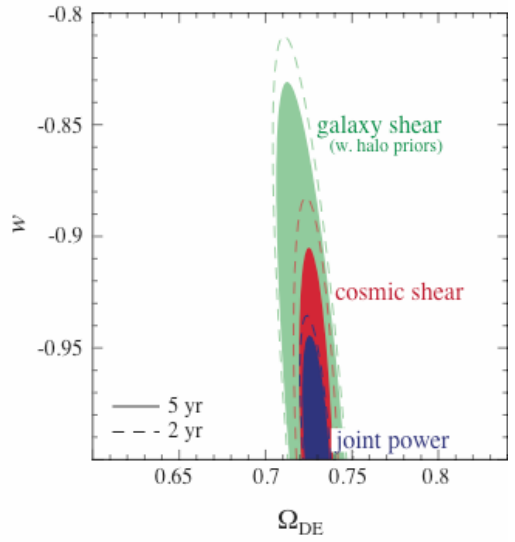
DARK ENERGY SURVEY





$$\Psi_{ij} = \frac{\partial \delta\theta_i}{\partial \theta_j} = \int dz\, g(z) \frac{\partial^2 \Phi}{\partial \theta_i \partial \theta_j}$$

Distortion Matrix



Measure shapes for ~300 million source galaxies with ⟨z⟩ = 0.7

Direct measure of the distribution of mass in the universe,

as opposed to the distribution of light, as in other methods (eg. Galaxy surveys)

Independently calibrates SZ cluster masses

SN Ia: "Standard" Candles

DARK ENERGY SURVEY

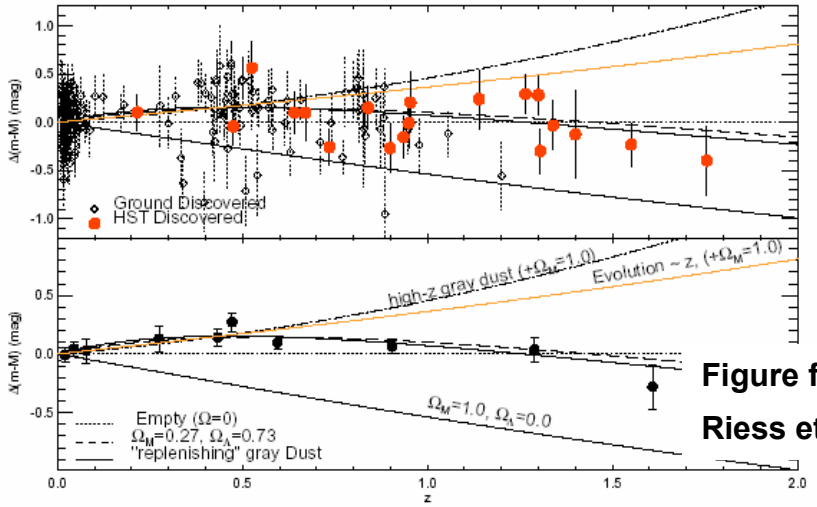
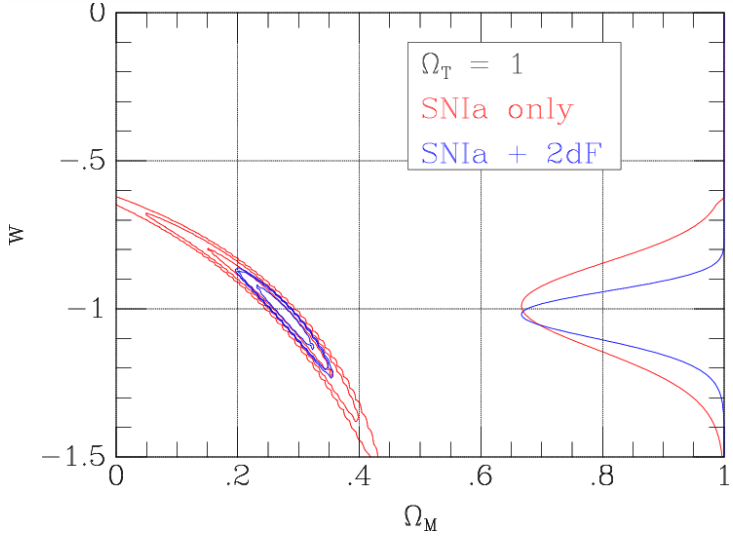


Figure from Riess et al 2004



- Type Ia Supernovae magnitudes and redshifts provide a direct means to probe dark energy
  - Standardizable candles
  - Dark Matter dominates for z> ~0.75
  - Dark Energy dominates at low z (now)

- DES will make the next step:
  - Image 40 sq-degree repeatedly
  - 2000 supernovae at z= 0.3-0.8
  - Well measured light curves
  - photo-z's for all, + some spectroscopic redshifts
  - SN photo-z are important technique for LSST

DES Dark Energy Constraints

DARK ENERGY SURVEY

- **4 Dark Energy Techniques**
  - **Galaxy clusters**
  - **Weak lensing**
  - **Angular power spectrum**
  - **Type Ia supernovae**
- **Statistical errors on constant w models typically σ(w) = 0.05-0.1**
- **Complementary methods**
  - **Constrain different combinations of cosmological parameters**
  - **Subject to different systematic errors**

Forecast statistical constraints on constant equation of state parameter w models (DES DETF white paper, astro-ph/0510346)

Method/Prior	Uniform	WMAP	Planck
Galaxy Clusters:			
abundance	0.13	0.10	0.04
w/ WL mass calibration	0.09	0.08	0.02
Weak Lensing:			
shear-shear (SS)	0.15	0.05	0.04
galaxy-shear (GS) + galaxy-galaxy (GG)	0.08	0.05	0.03
	0.03	0.03	0.02
SS+GS+GG	0.07	0.03	0.03
SS+bispectrum			
Galaxy angular clustering	0.36	0.20	0.11
Supernovae Ia	0.34	0.15	0.04

DES Project Status

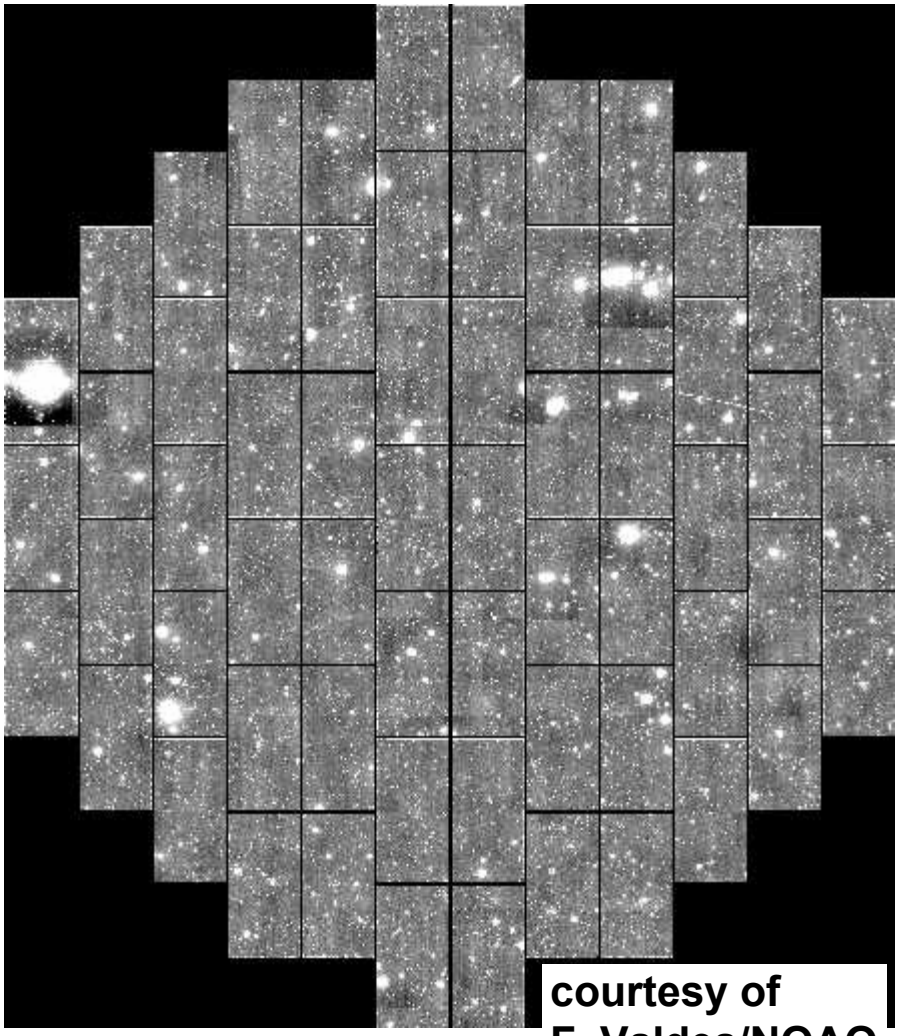
DARK ENERGY SURVEY

- **1st Collaboration Meeting Dec. 2003**
- **June 2004 Temple/Directors review**
- **July 2004: Fermilab Director gives DES Stage 1 approval**
  - **Fermilab resources can be used for R&D**
- **Aug 2004: NOAO Director accepts DES proposal for partnership**
  - **525 nights of CTIO 4m time in return for new instrument and archive**
- **May 2005: Science working groups form**
  - **write Dark Energy Task Force white paper (astro-ph/0510346)**
- **FY05 and 06 are Pre-conceptual and R&D years**
  - **CCDs: establish yield, learn to test CCDs, demonstrate packaging**
    - **25 wafers in FY2005 and FY2006**
  - **Optics: finalize design, develop firm cost estimate**
    - **order glass in FY2006, figure and polish in FY2007**
- **FY07 and FY 08 are construction years**
- **Jan 2009: ship instrument to Chile**
- **Sept 2009: start survey**

DARK ENERGY SURVEY

DES Image Simulation

- DES will be the largest CCD camera of its time.
- Each image:
  - 3 sq. deg.
  - ~ 20 Galaxy clusters
  - ~ 200,000 Galaxies
  - 500 Mega pixels (62 CCDs)
- Each night ~ 300 GB of image data
- Entire survey ~ 500 TB
- Image is derived from SDSS data to simulate DES images.

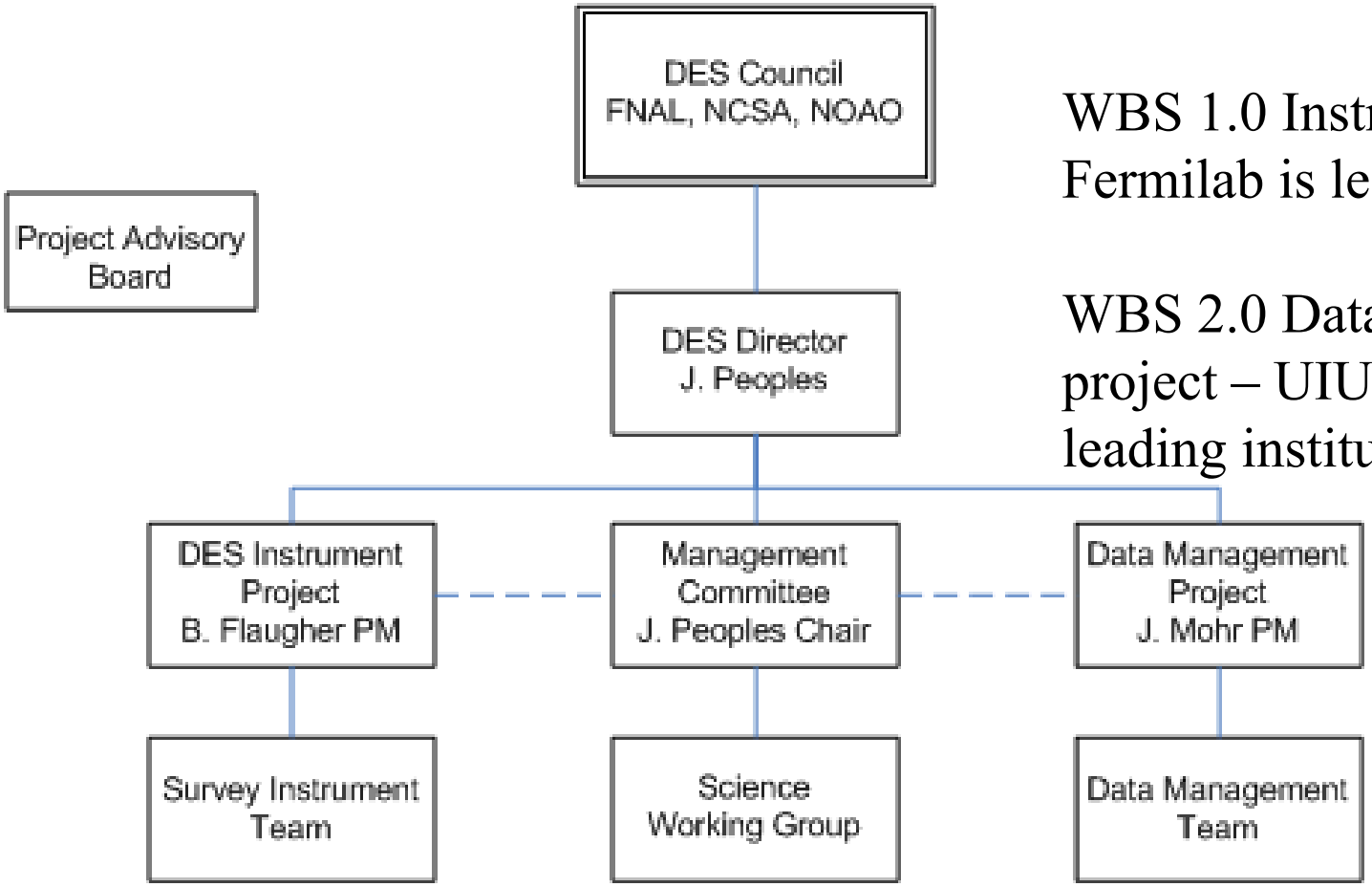


courtesy of F. Valdes/NOAO

DARK ENERGY SURVEY

DES Organization

DES is divided into 2 projects under direction of the Project Director



WBS 1.0 Instrument project – Fermilab is leading institution

WBS 2.0 Data Management project – UIUC/NCSA is leading institution

The DES Collaboration

61 scientists at 12 institutions

DARK ENERGY SURVEY

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

University of Illinois at Urbana-Champaign: C. Beldica, R. Brunner, I. Karliner, J. Mohr, R. Plante, P. Ricker, M. Selen, J. Thaler

University of Chicago: J. Carlstrom, S. Dodelson, J. Frieman, M. Gladders*, W. Hu, E. Sheldon, R. Wechsler. * Carnegie Observatories until summer 2006

Lawrence Berkeley National Lab: G. Aldering, N. Roe, C. Bebek, M. Levi, S. Perlmutter

NOAO/CTIO: T. Abbott, C. Miller, C. Smith, N. Suntzeff, A. Walker

Institut d'Estudis Espacials de Catalunya: F. Castander, P. Fosalba, E. Gaztañaga, J. Miralda-Escude

Institut de Fisica d'Altes Energies: E. Fernández, M. Martínez

University College London: O. Lahav, P. Doel, M. Barlow, R. Bingham, S. Bridle, S. Viti, J. Weller

University of Cambridge: G. Efstathiou, R. McMahon, W. Sutherland

University of Edinburgh: J. Peacock

University of Portsmouth: R. Nichol

University of Michigan: R. Bernstein, A. Evrard, D. Gerdes, T. McKay

DES time scale and Conclusions

Image credit: Roger Smith/NOAO/AURA/NSF

Present to 2008:

$\sigma(w) \sim 0.1$ SNE+WMAP combined

~ 0.3 alone

2009 to ~ 2013: DES will constrain the dark energy parameter w to $\sigma(w) \sim 0.05$ using four independent techniques, capitalizing on existing infrastructure and technology

DES will be the largest optical CCD camera of the time and provide the next logical step in both technology and science

- 3 deg^2 camera (70% of time available to community), x7 larger area and x7 faster readout than existing mosaic camera on the Blanco
- 500TB image and catalog archive (10x deeper than SDSS, similar solid angle) available to the public 1 year after data is collected
- Capitalizes on Fermilab experience in SDSS and in building silicon vertex detectors
- Development of analysis techniques for photo-z's, cluster masses, weak lensing, and treatment of systematic uncertainties for DES are the next step towards the science of the more aggressive projects of the future (LSST, JDEM)