DPF 2009
2009 Meeting of the Division of Particles and Fields of the American Physical Society (DPF 2009)
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Wayne State University, Detroit, MI

The Dark Energy Survey

Klaus Honscheid
Ohio State University
On behalf of the DES Collaboration

The accelerating universe

Evidence for dark energy is two-fold:

Accelerated expansion of the Universe, measured from supernovae type Ia

Universe is ~= **flat** (CMB) but **matter content is ~27%** (LSS)

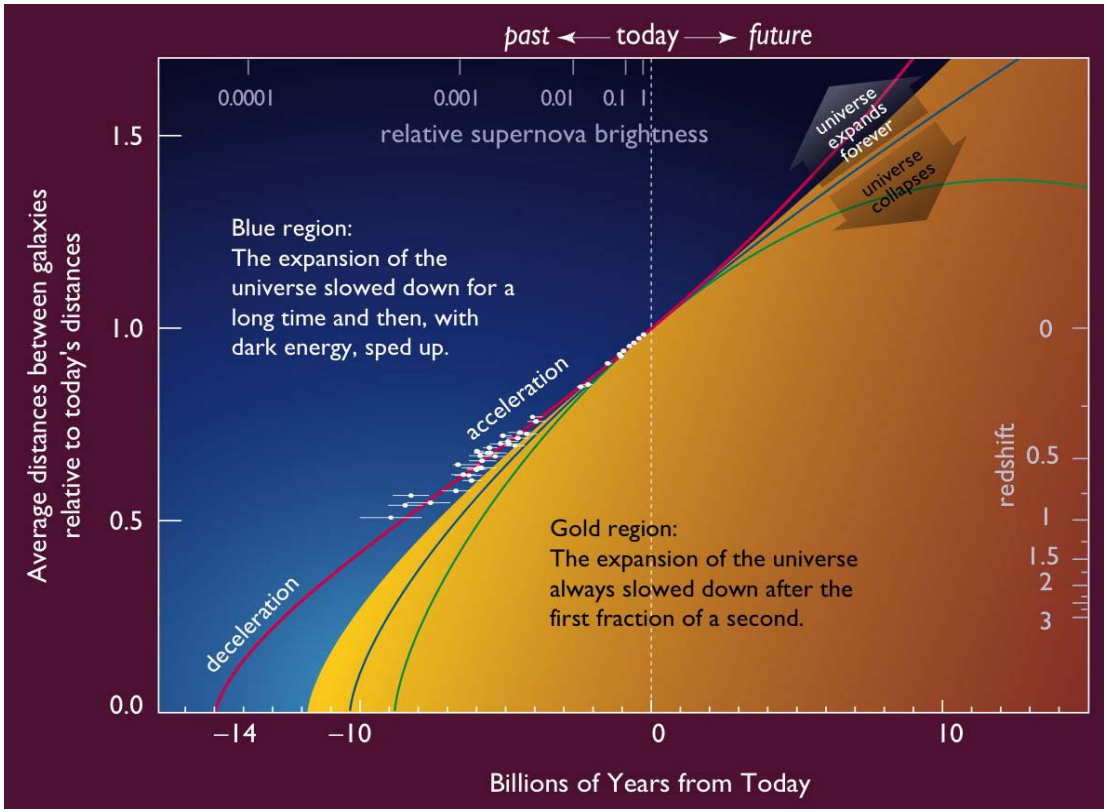
Which means either

Additional unknown stress energy component with *negative* pressure.

Dark Energy

or

Break-down of general relativity at large distances



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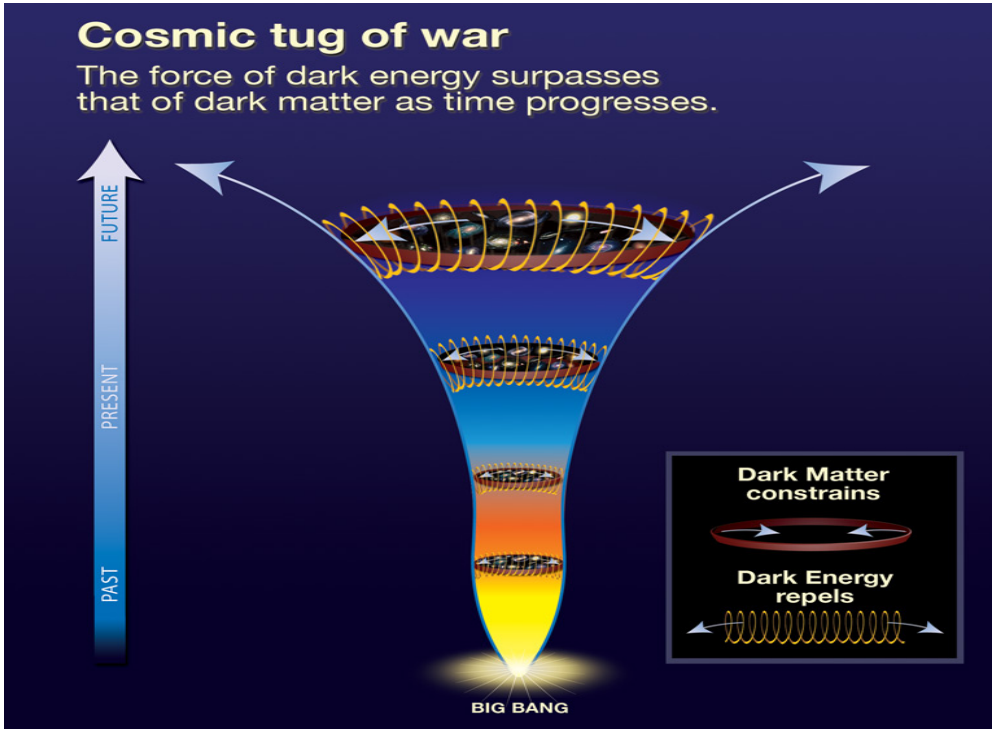


Describing Dark Energy

The expansion history of the universe

$$H^2(z) = \left(\frac{\dot{a}}{a}\right)^2 = H_0^2\left(\Omega_m(1+z)^3 + \Omega_{de}(1+z)^{3(1+w)}\right)$$

The DE equation of state

$w = p/\rho$; $w(a) = w_o + w_a\,(1-a)$

Is w = -1? Is w(z) constant (w_a = 0)?

$\omega_X = p_X/\rho_X$

From M. Turne
astro-ph/0108

Candidate	ω	$d\omega/dz$
Cosmological Constant	-1	0
Rolling Scalar Field (Quintessence)	$-1 \rightarrow 1$	$\frac{1/2\dot{\phi}^2 - V(\phi)}{1/2\dot{\phi}^2 + V(\phi)}$
False Vacuum State	-1	~ 0
Topological Defects (N=1 strings...)	-N/3	~ 0
Others	?	?

Currently: $\sigma(w_o) \sim 0.1$

$w_o < -0.85$ 95% CL

much weaker for w_a

The probes

- Supernovae
- Weak Lensing
- Cluster Counts
- Baryon Accousitc Oscillations

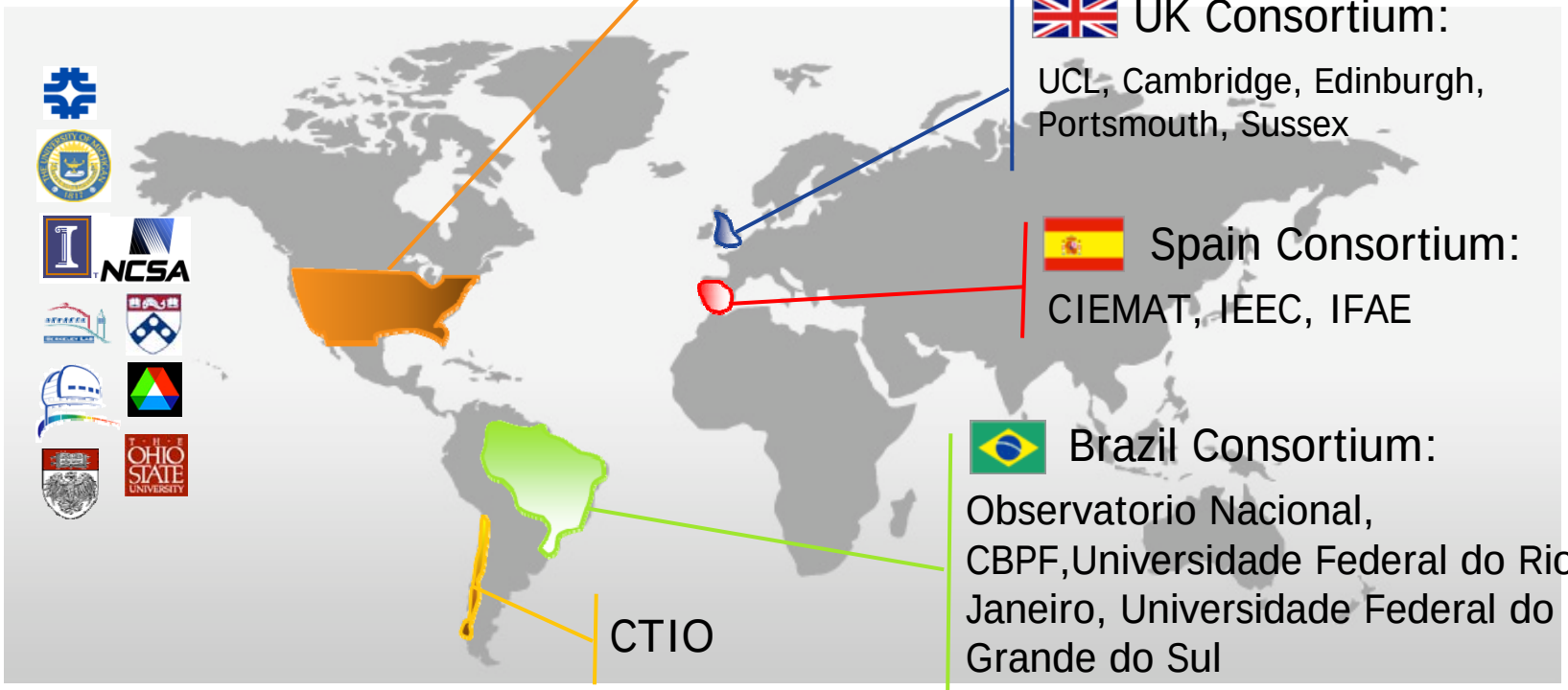
For a real explanation see
J. Frieman's plenary talk tomorrow

The DES Collaboration

The Dark Energy Survey

is an international collaboration of
~100 scientists from ~20 institutions

Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of Pennsylvania, Argonne National Laboratory, Ohio State University, Santa-Cruz/SLAC Consortium



UK Consortium:

UCL, Cambridge, Edinburgh, Portsmouth, Sussex

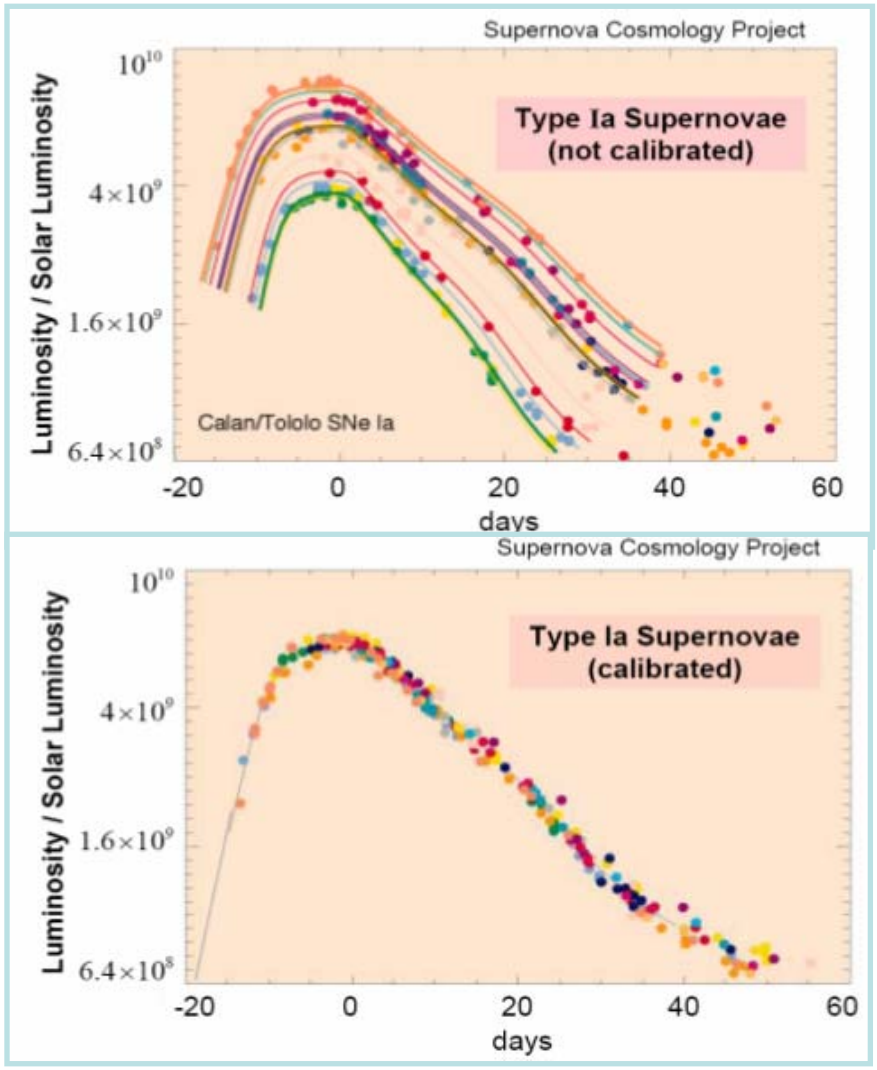
Spain Consortium:

CIEMAT, IEEC, IFAE

Brazil Consortium:

Observatorio Nacional, CBPF,Universidade Federal do Rio de Janeiro, Universidade Federal do Rio Grande do Sul

Supernovae Ia



Strategy: distance probe

•Obtain light curves + calibrate: shape in different bands relates to luminosity.

• Luminosity + app. magnitude + redshift:

$$\chi^2 = \sum_{objects} \frac{(\mu - 5\log(d_L(z;\theta,w))/10\,pc)^2}{\sigma^2}$$

DES:

•Measure ~2000 SN photometrically, up to z=~1.

•Large sample and improved z-band response

•10% of the survey time will be devoted to SN search revisiting an area of 40 sq.deg.

•Photometric errors will be addressed w/ on-site measurements of photometry, spectroscopic follow-ups.

Systematics: dust, evolution, calibration...

'mature', photometric redshifts

Cluster density

Strategy: structure probe

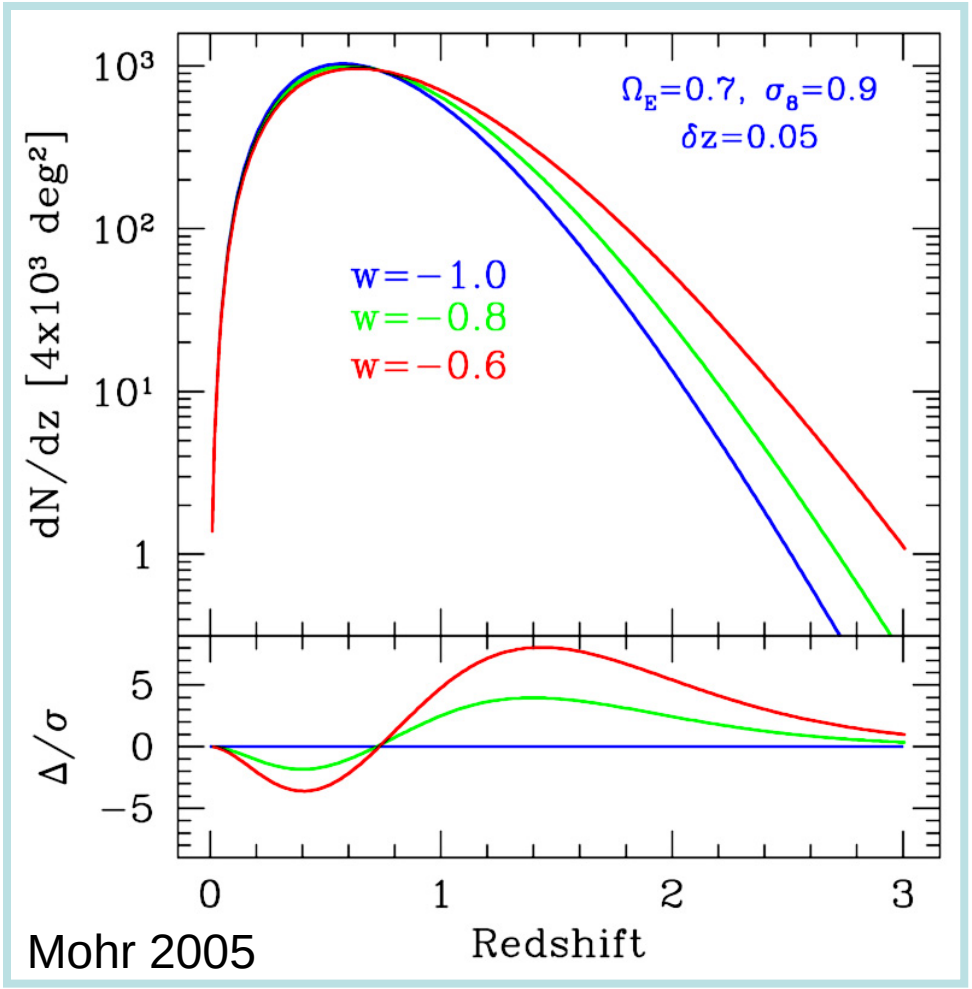
• Obtain number count of galaxy clusters per unit volume.
• counts + cluster mass predictions + redshift:

$$\frac{d^2N}{dzd\Omega} = \frac{c}{H(z;\theta,w)} D_A^2 (1+z)^2 \int_0^\infty f(O,z)dO \int_0^\infty p(O \mid M,z) \frac{dn}{dM}(z;\theta)dM$$

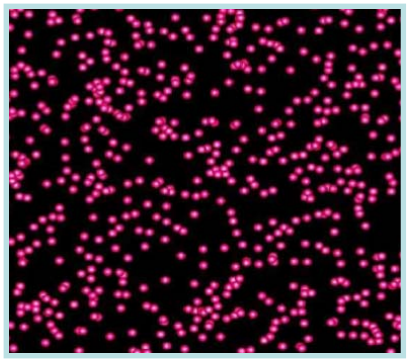
DES:
• Measure ~20000 clusters up to z~1.3
• Identification using partnership with South Polar Telescope (using Sunyaev-Zeldovich effect) + weak lensing

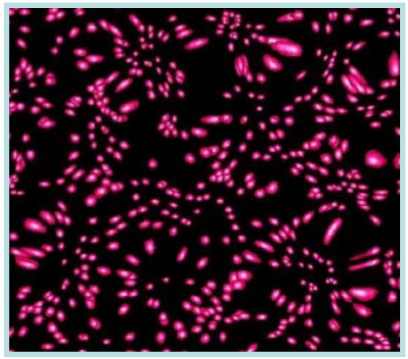
Systematics: observable-mass relation, photometric redshift, completeness and purity of cluster sample…

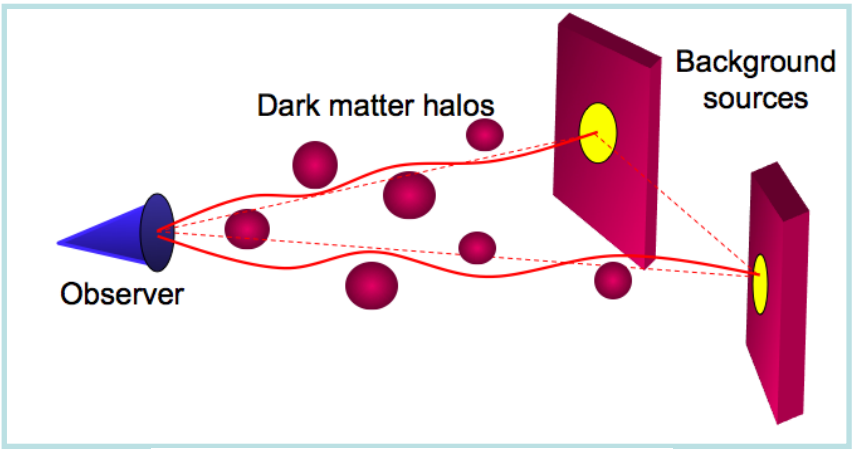
Very sensitive, systematics, untested

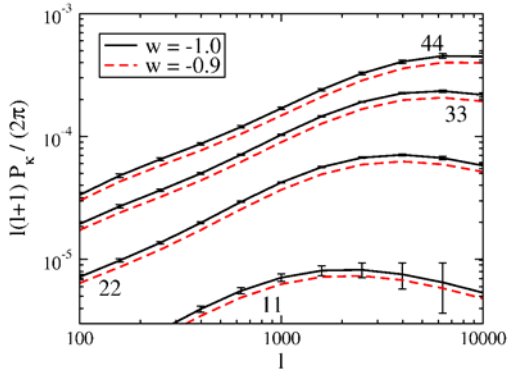


Weak lensing









Strategy: structure probe

•Statistical measurement of distortions of background objects created by intervening matter (shear-shear).

• Foreground galaxy cross-correlations with shear (galaxy-shear).

•Shear angular power spectrum as function of redshift:

$$P_l(z_s) = \int_0^{z_s} \frac{H(z)}{D_A^2(z)} \left|W(z,z_s)\right| P(k;z)\,dz$$

•It means measuring shapes and redshifts.

DES:

• Shapes of ~3e8 galaxies.

• PSF < 0.9” FWHM

Systematics: photo-z’s, PSF anisotropy, shear calibration

Theoretically well-founded, untested

Galaxy angular clustering

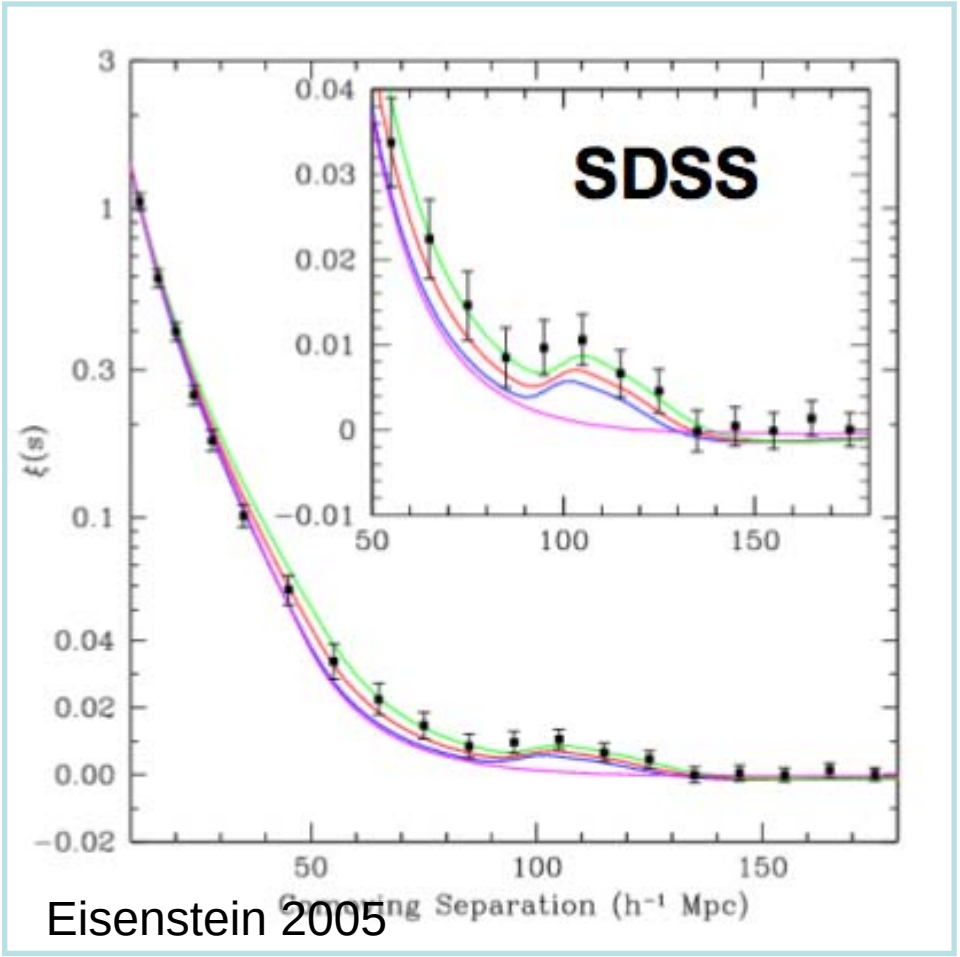
Strategy: distance probe

•CMB provides scale of acoustic peak.
•Search for this peak in angular two-point correlation function of galaxies (of a certain type) in redshift shells.
•This gives an estimation of the expansion history.

DES:
•Power spectrum of ~3e8 galaxies up to z~1.5.
•Probe larger volume and redshift range than current state-of-the-art (SDSS)

Systematics: photo-z's, projection effects, non-linear evolution, galaxy-mass relationship (bias).

doable (SDSS), spectrograph

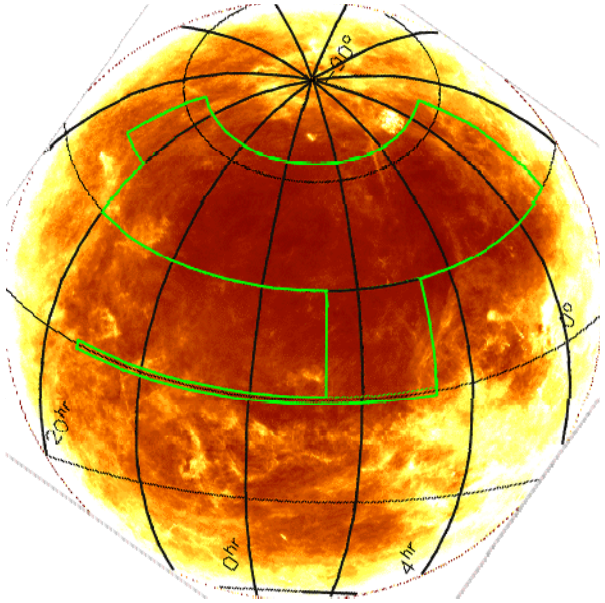


Eisenstein 2005

The Dark Energy Survey

5000 sq deg in 5 filter bands

Overlap with SPT, Vista, SDSS



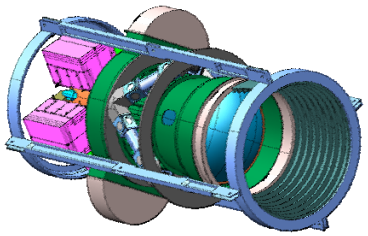
Overlap with South Pole Telescope Survey (4000 sq deg)

Connector region (800 sq deg)

Overlap with SDSS equatorial Stripe 82 for calibration (200 sq deg)

Components

+



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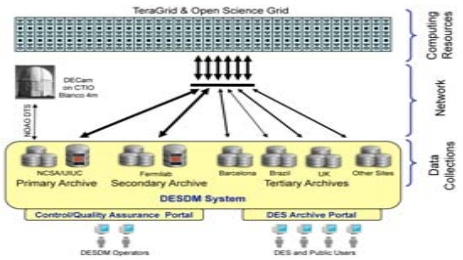
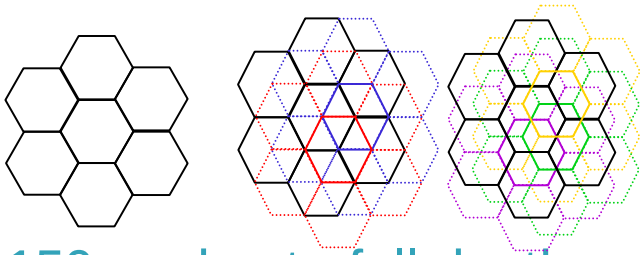


Tiles



1st year: 150 sq deg to full depth

Blanco 4 m Telescope at CTIO

Located on Cerro Tololo (Chile)

- Site delivers median seeing of 0.65” (Sept-Feb)
- Current instrument, telescope achieve only 0.9” (median)

Commissioned in 1974

Near twin of Mayall 4-m on Kitts Peak

Mirror

- Solid primary mirror
  - 50 cm thick, 15 tons
- Mechanical radial support
- Controllable axial support

Blanco Upgrade Project

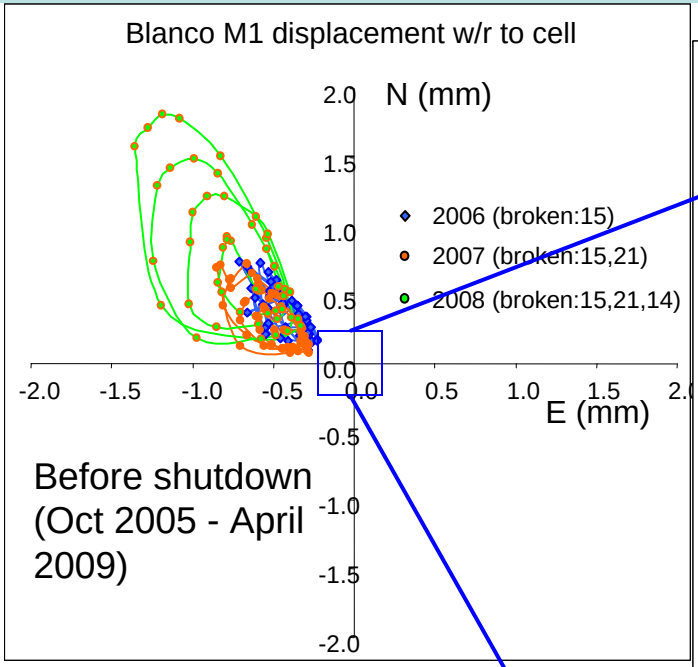
Successfully upgraded primary radial mirror support

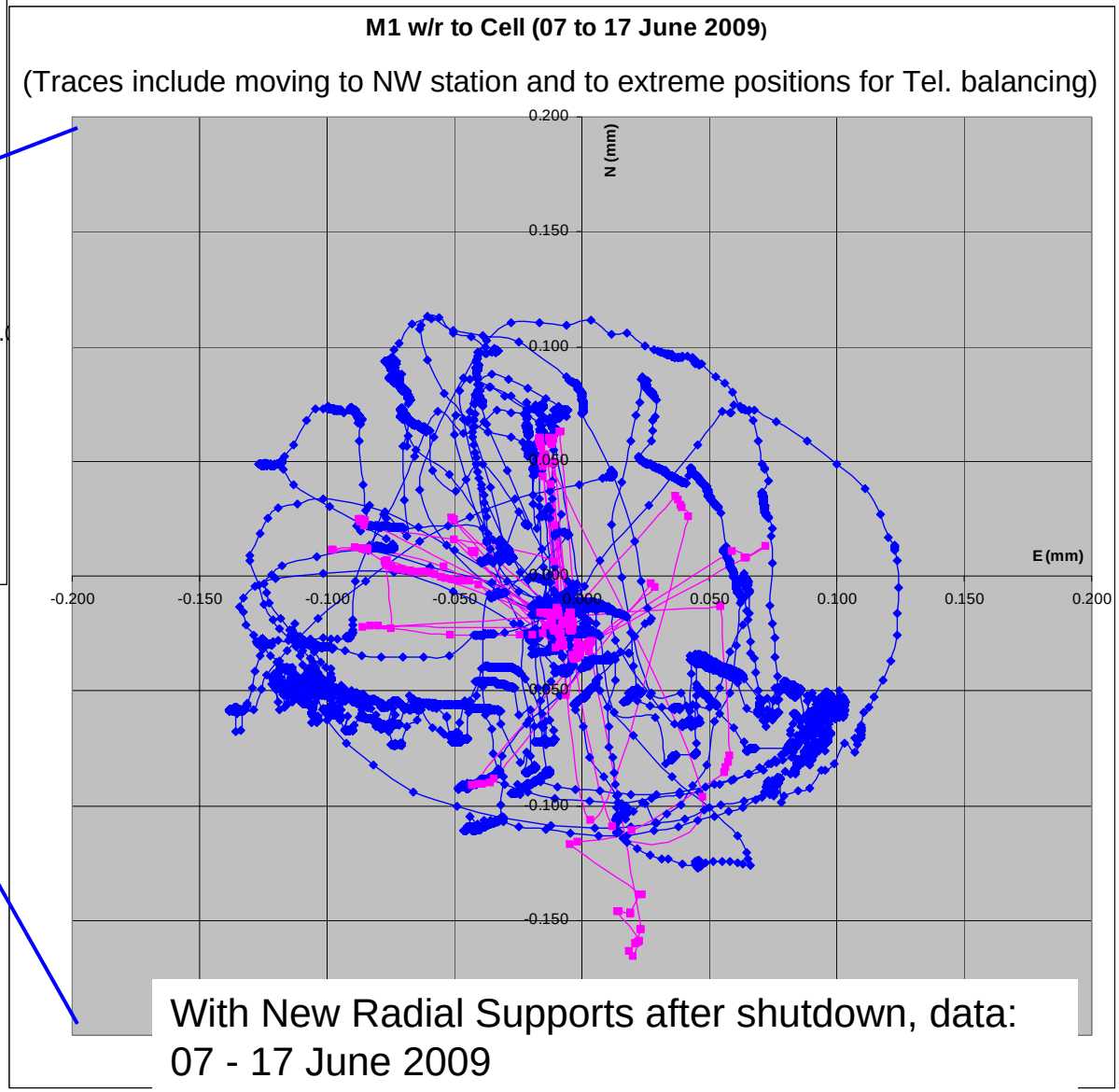
New telescope control system

- New servo controller, encoder
- Improved tracking & pointing
- Faster slew time
  - 2 degrees in 17 seconds (DECam readout)

Construct clean room for DES/DECam

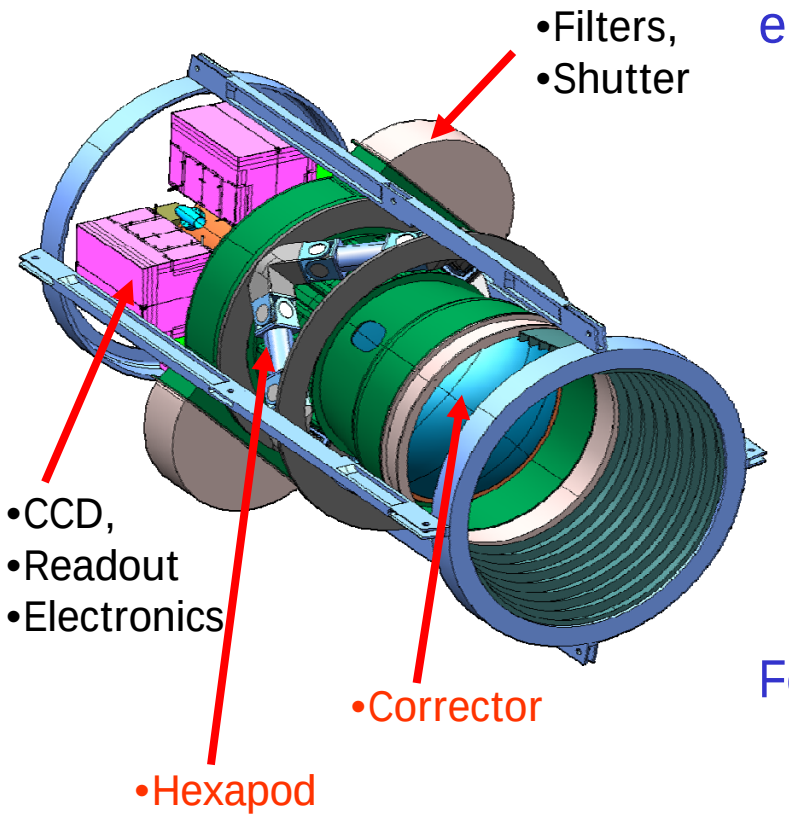
Blanco Status





The M1 walk w/r to cell is within a circle of maximum radius ~100um centered in the center of the mirror cell to within ~50um.

The DECam Instrument

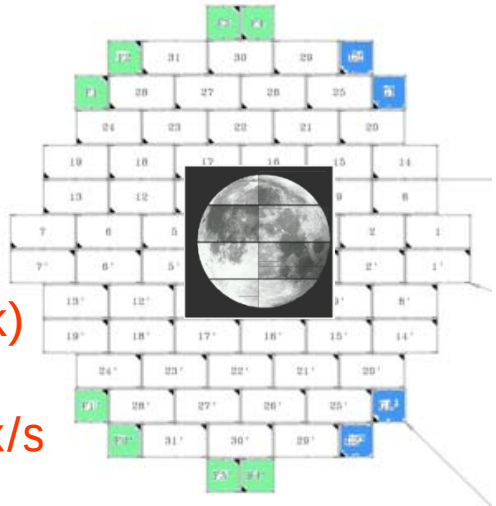


The DECam instrument will replace the entire prime focus cage of the Blanco.

- 520 megapixel CCD camera
- Low noise electronics
- Combination shutter-filter system
- Wide field optical corrector (2.2 deg. FOV)
- Hexapod to provide adjustability

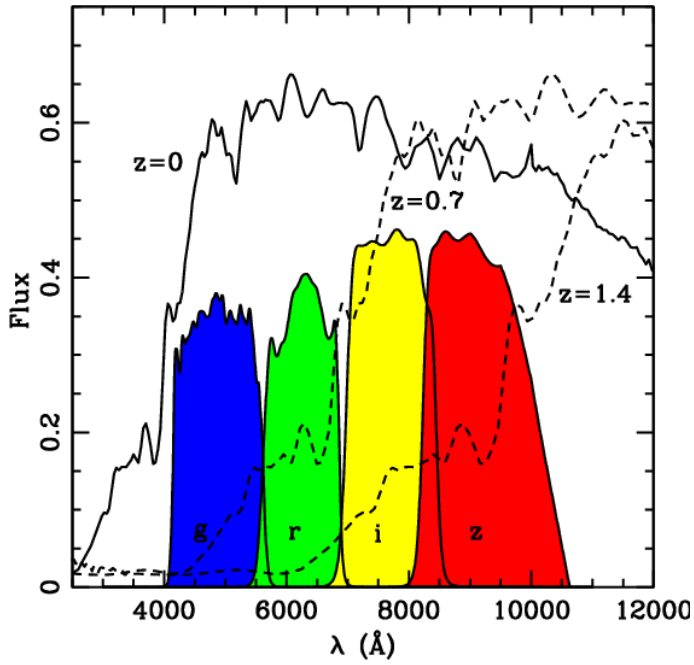
Focal plane parameters:

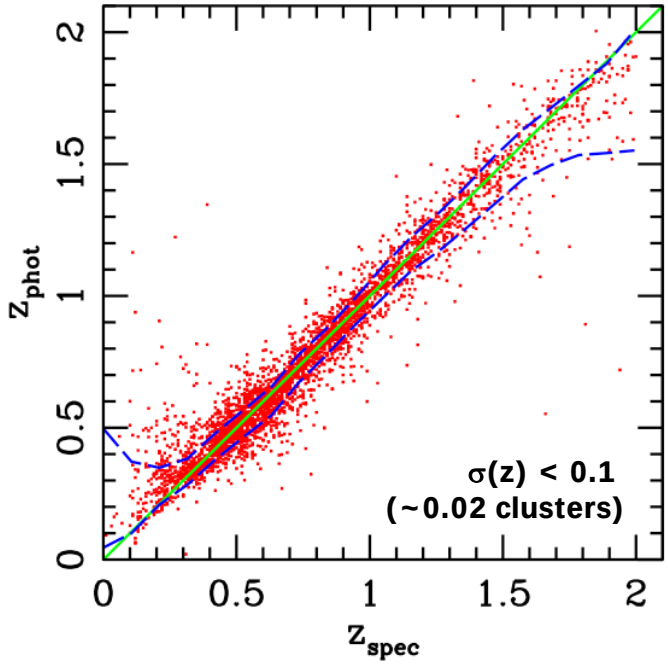
- 62 Image CCD (2kx4k)
- 4 Guide, 8 Focus (2kx2k)
- Pixel size 0.27” /15μm
- Readout speed 250 kpix/s



DECam presentation in Detector Session on Friday

Photometric Redshifts





DES griz filters

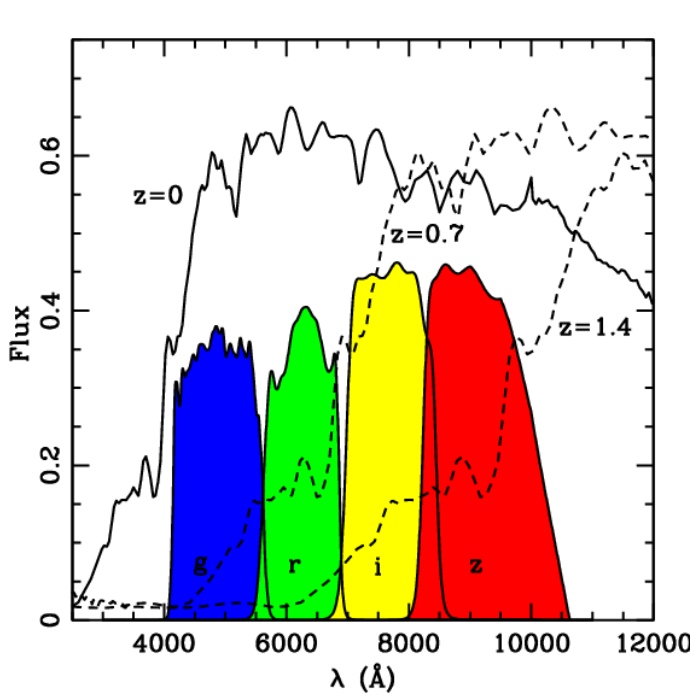
(Y not shown)

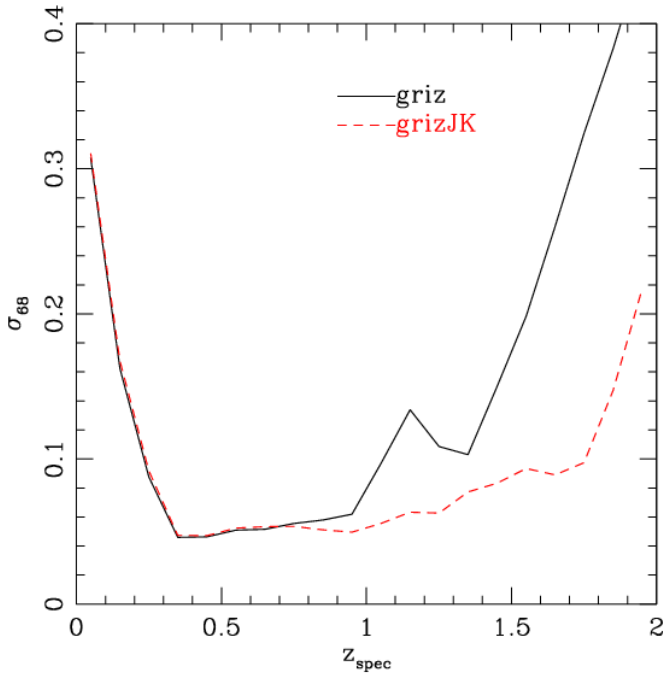
10σ Limiting Magnitudes around 24
(~ 20 for JHK)

σ(z)~0.1 to z~1.3

Photometric redshift vs. true redshift
for simulated DES galaxy survey, including
DES *grizY* and *JHK* near-infrared imaging
from the planned Vista Hemisphere Survey at ESO
(Frieman, Cunha, Lin et al)

Photometric Redshifts





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DES Data Management Components

Receive Images from CTIO

- 520 Mpix per image (1 GB or 0.6 GB compressed)
- Microwave link to CTIO
- Fiber link to NCSA (NOAO)

Nightly Processing

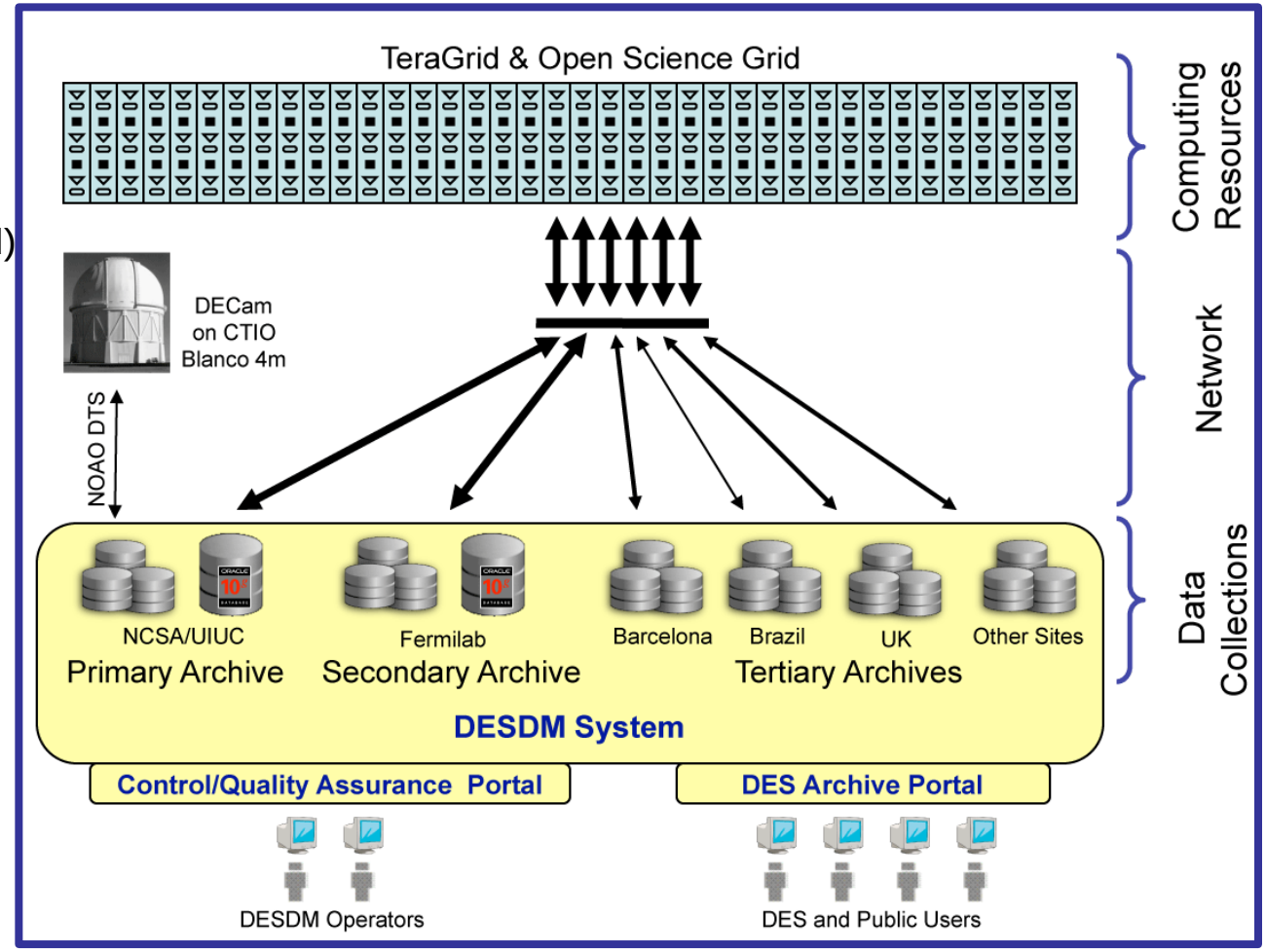
- Use grid

Data Archive

- Image Data
- Catalogs
- ~ 4PB

Data Access Portal

- Data becomes public after 1 year

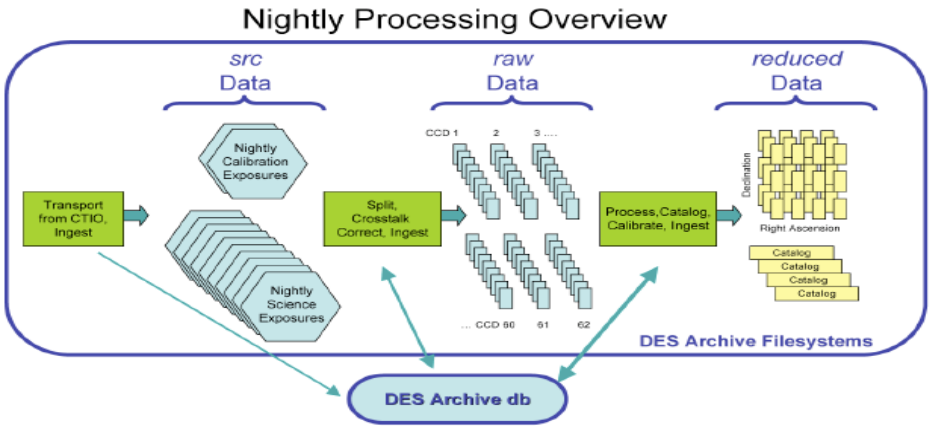


Nightly Processing

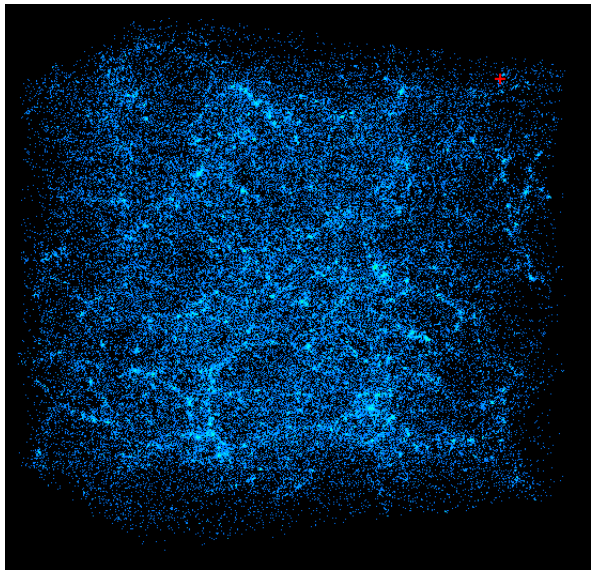
Develop integrated set of tools for processing data

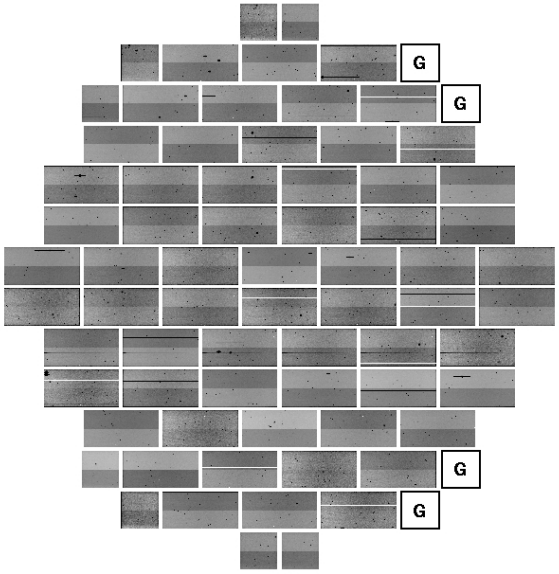
- Nightly processing pipeline
  - Detrending, astrometric refinement, remapping for coaddition and difference imaging, cataloging, ingestion to DES Archive and photometric calibration
- Coaddition pipeline (w/PSF Homogenization)
  - Build and catalog deeper images of the sky
- Weak Lensing Pipeline
  - Extract shear measurements from the survey data
- Difference Imaging Pipeline
  - Catalog variable objects
- Photo-z Pipeline

Data Challenges



Simulation





N-Body Simulation
- Dark Matter

Add galaxies
- Realistic distribution
- Model shapes
- Shear

Add Stars
- SDSS Stripe 82
- Catalogs

Observation Model
- Atmosphere
- Extinction
- Sky brightness

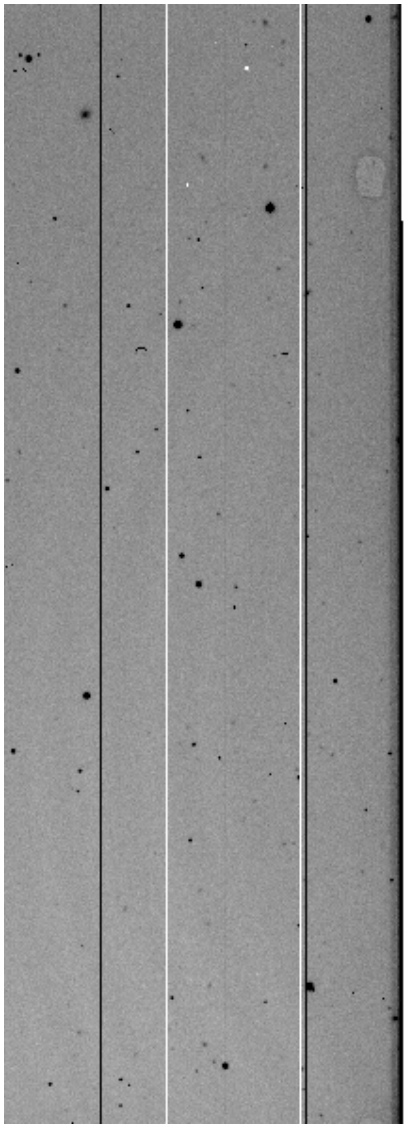
Optics
- Blanco telescope
- DES Corrector
- Pupil ghost etc.

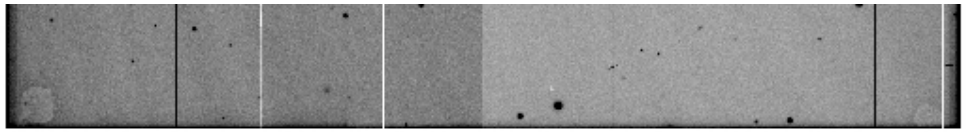
Detector
- QE, Gain
- Bias, Noise
- Bad columns

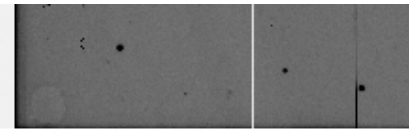
Images
Catalogs
- Data Challenges
- Science Groups

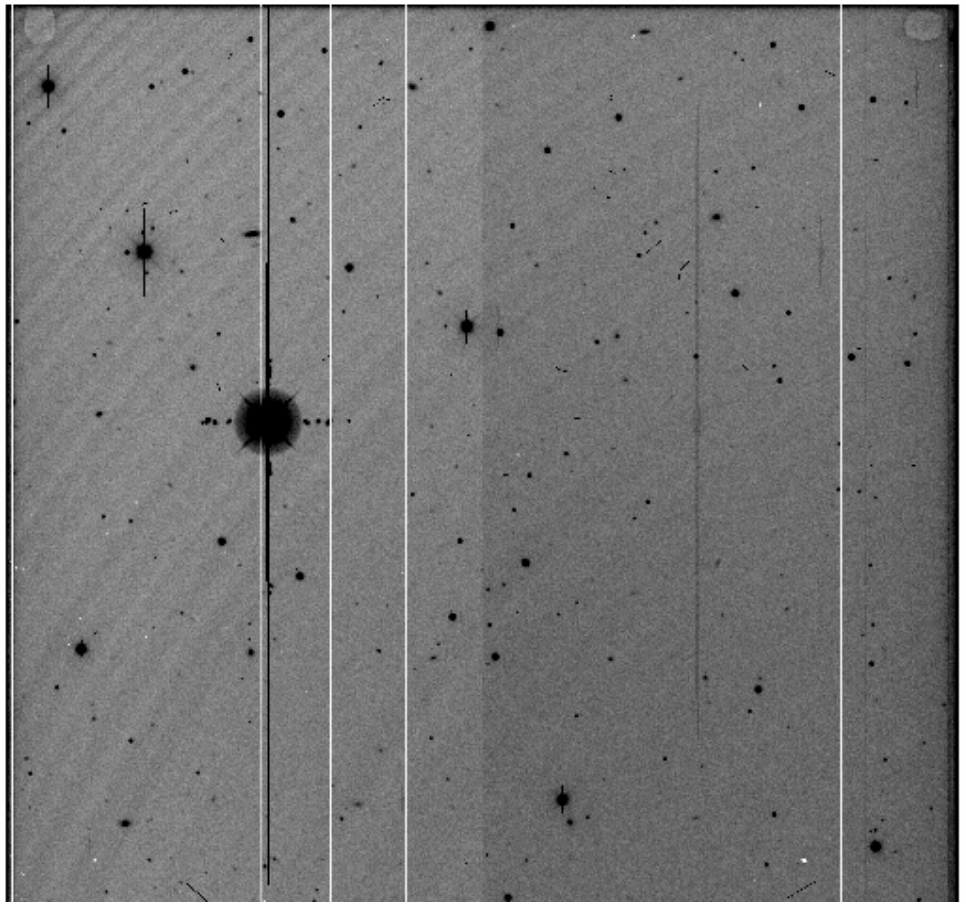
Data Challenge 4
- ~2600 science images
- Calibration images
- Standard star images

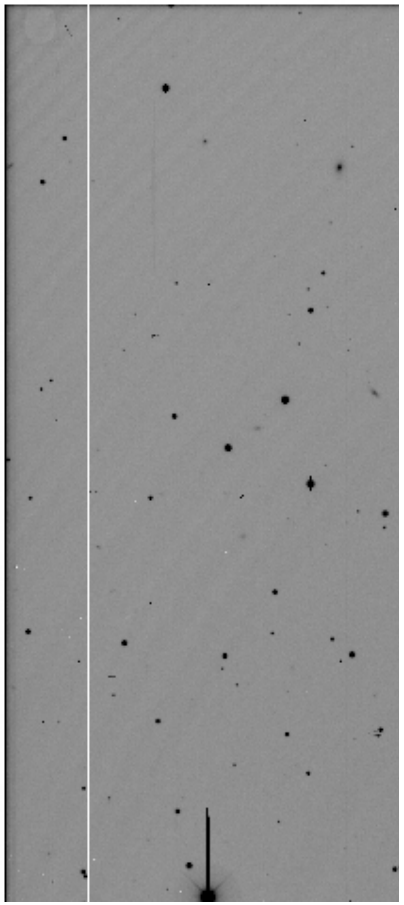
DC 5: Artifacts, Cosmic Rays, Cross Talk











Summary and Forecast

The **Dark Energy Survey** is been a near term project to explore the nature of **Dark Energy**

Using 4 complementary probes

- **Supernovae**
- **Cluster counting**
- **Weak lensing tomography**
- **BAO**

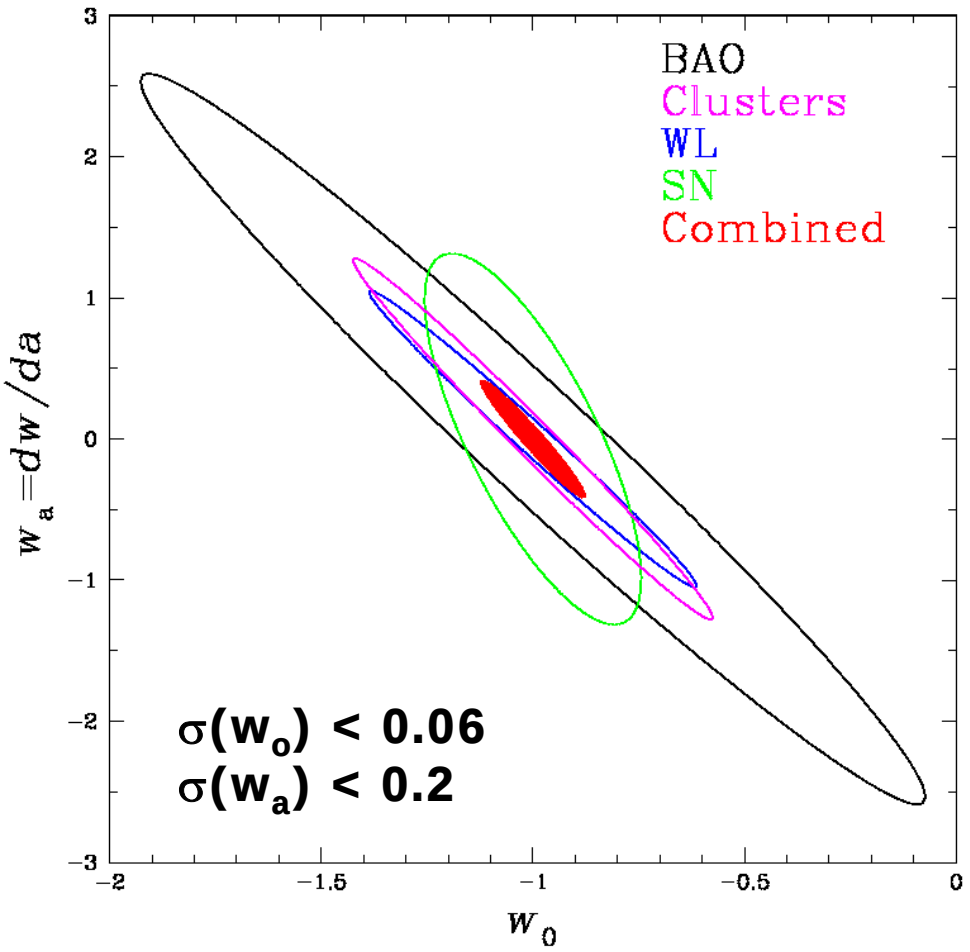
Combined with a

- **New wide field camera**
- **Upgraded Blanco 4-m Telescope**
- **High Performance Data Management system**

Will lead to tight systematics control and a factor of **4.6** in the DETF figure of merit over Stage II.

On schedule to start in **September 2011**

$w(z) = w_0 + w_a(1-a)$ 68% CL



Fine Print:
- statistical + photo-z systematic errors only
- spatial curvature, galaxy bias marginalized
- Planck CMB prior

DES Timeline

Now	Finalize design; select and test CCDs
	Complete Blanco Telescope Upgrades
	Start Data Challenge 5
During 2010	All camera elements (except optics) will be integrated and tested at Fermilab with a fullsize telescope simulator.
Early 2011	Camera arrives at CTIO
	Installation
Summer 2011	Commissioning
Fall 2011	First Light
	Survey begins

Additional Slides

Expected Uncertainties for DES

Table 1: Example forecast marginalized 68% CL statistical DES constraints on constant equation of state parameter w.

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

Assuming CDM, negligible neutrino masses, adiabatic Gaussian primordial perturbations w/ power law spectrum, flat Universe.

DES Forecast (Planck priors)

Method	$\sigma(\Omega_{DE})$	$\sigma(w_0)$	$\sigma(w_a)$	z_p	$\sigma(w_p)$	$[\sigma(w_a)\sigma(w_p)]^{-1}$
BAO	0.010	0.097	0.408	0.29	0.034	72.8
Clusters	0.006	0.083	0.287	0.38	0.023	152.4
Weak Lensing	0.007	0.077	0.252	0.40	0.025	155.8
Supernovae	0.008	0.094	0.401	0.29	0.023	107.5
Combined DES	0.004	0.061	0.217	0.37	0.018	263.7
DETF Stage II Combined	0.012	0.112	0.498	0.27	0.035	57.9

Table 1: 68% CL marginalized forecast errorbars for the 4 DES probes on the dark energy density and equation of state parameters, in each case including Planck priors *and* the DETF Stage II constraints. The last column is the DETF FoM; z_p is the pivot redshift. Stage II constraints used here agree with those in the DETF report to better than 10%.

Principle Systematic Uncertainties

Table 2: Dominant sources of systematic error and methods for controlling them; see text.

Method	Dominant Systematic Errors	Primary Controls
Clusters	Sample selection Mass-observable relation	SZE + optical cluster selection; simulations Self-calibration; statistical WL masses
Weak Lensing	Multiplicative shear Additive shear Photo-z biases Small-scale power spectrum	Measurement algorithm; shear vs. gal. size PCA; active focus; wave-front sensing & alignment control Spectroscopic calibration sets Null small-scale power; high-res. simulations
Angular clustering	Bias prescription errors Large-scale photometric calibration errors Photo-z biases	Angular bispectrum; clustering by type Calibration strategy; clustering by color; angular sub samples Spectroscopic calibration sets
Supernovae Ia	SN evolution Photometric errors Extinction Photo-z errors & biases	Low and high z SNe comparison Calibration strategy; artificial SNe SN color and host galaxy information SN spectroscopic calib. sub sample