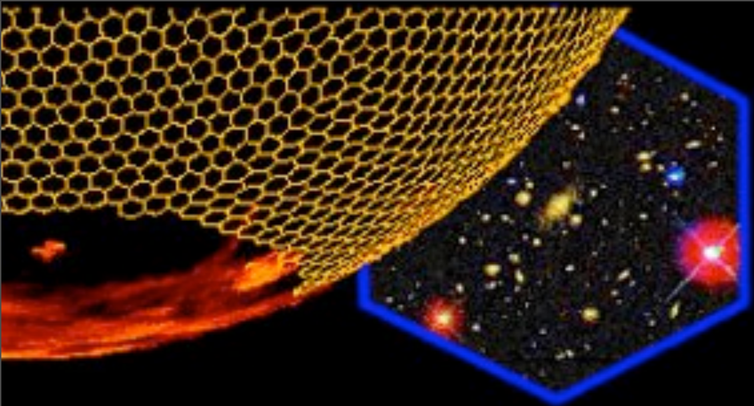


Dark Energy Survey

Jiangang Hao

Center for Particle Astrophysics

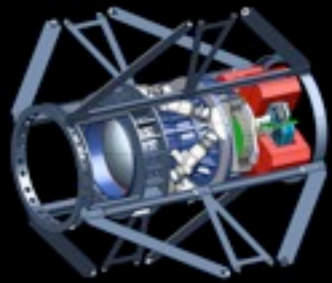
Fermilab

for the DES collaboration







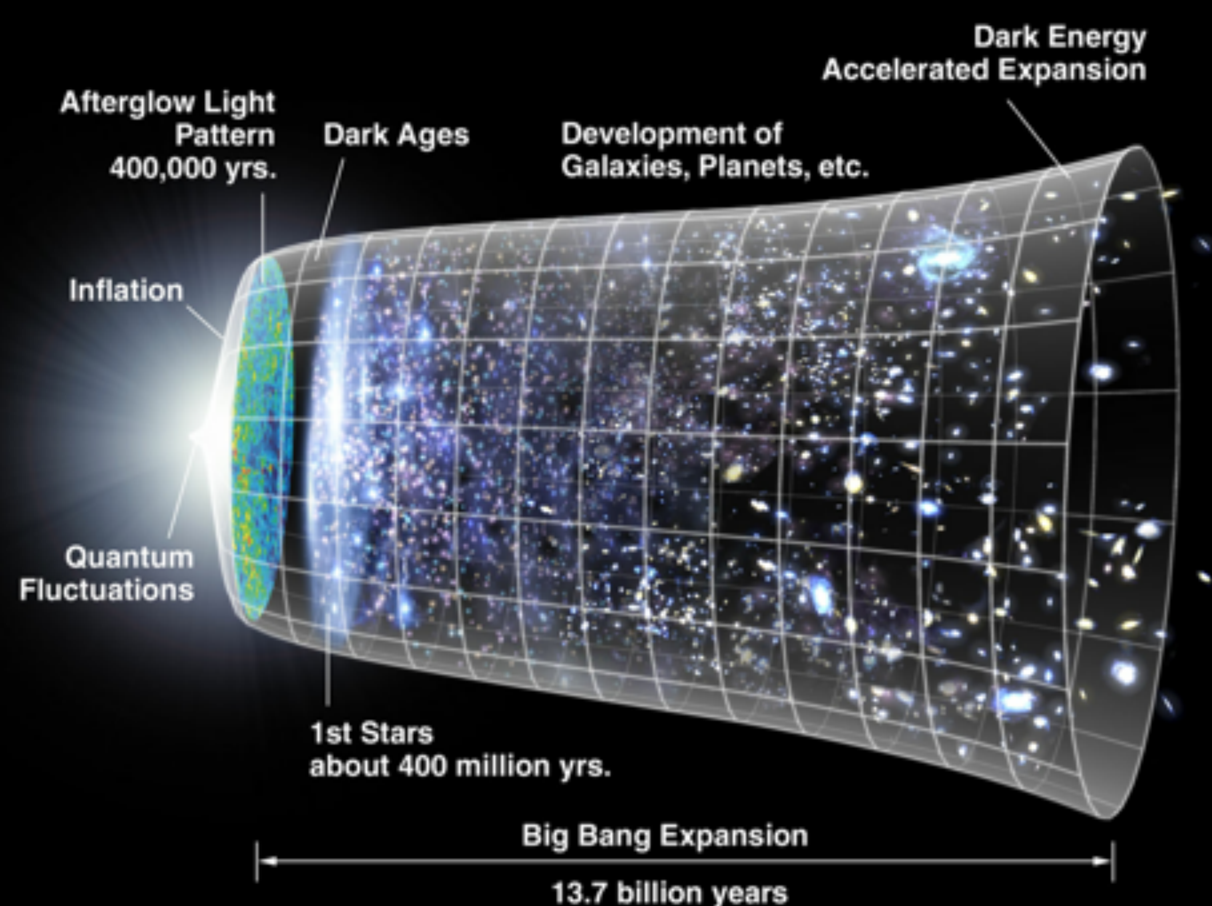


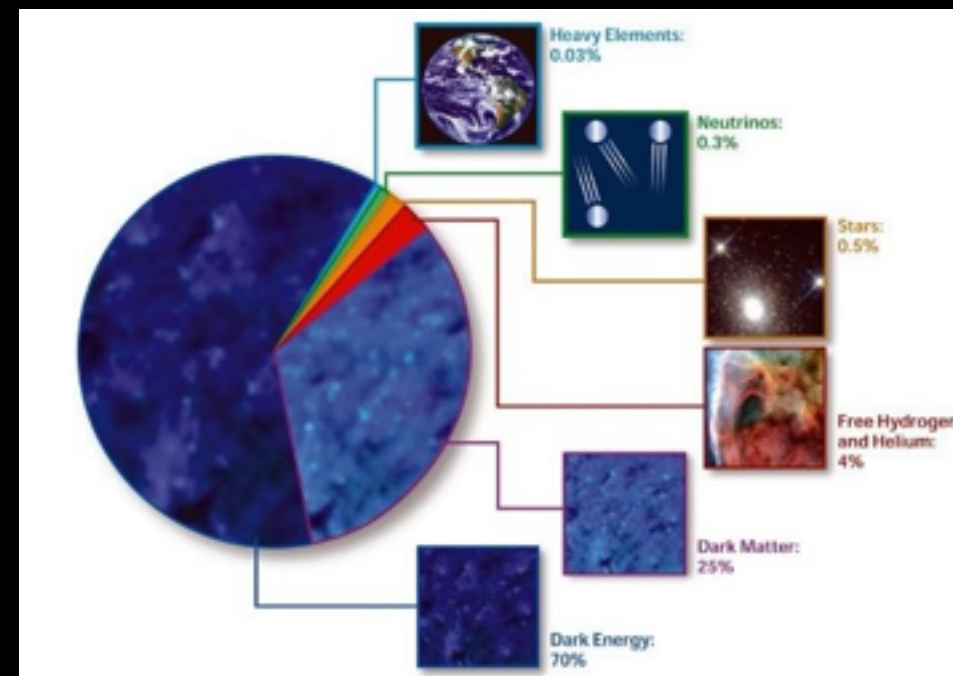
Outline

- Current Understanding of the Universe
  - Cosmic History and Compositions
  - Observational Evidence of Dark Energy
  - Theoretical Framework
- Dark Energy Survey (DES)
  - DES and DES collaboration
  - Four Cosmological Probes
  - Dark Energy Survey Camera - DECam
  - Current Survey Plan
- Beyond DES: Large Synoptic Survey Telescope (LSST)
- DESpec: An Idea for Spectroscopic Followup for DES

Current Understanding of the Universe

Cosmic History and Compositions

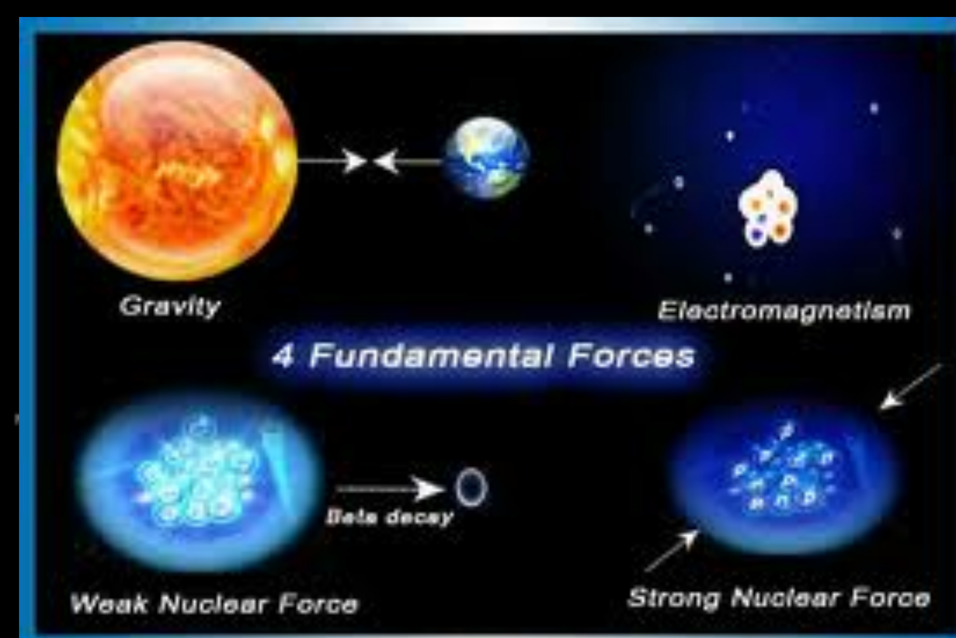




~5% SM particles

~25% Dark Matter

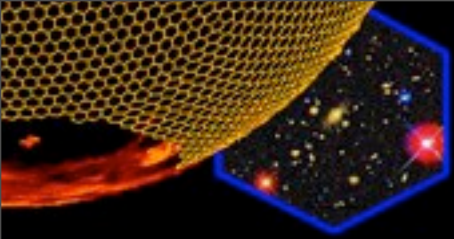
~ 70% Dark Energy



Big Bang - Inflation - Structure Formation - Cosmic Acceleration

deceleration - acceleration - deceleration - acceleration

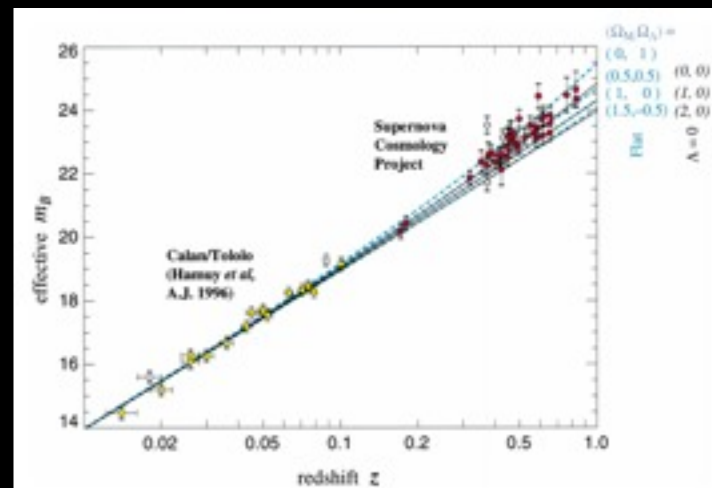
driving in a busy street

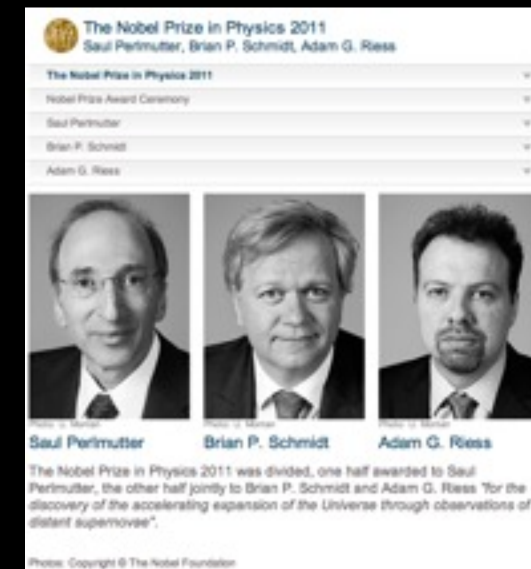


Observational Evidences of Dark Energy

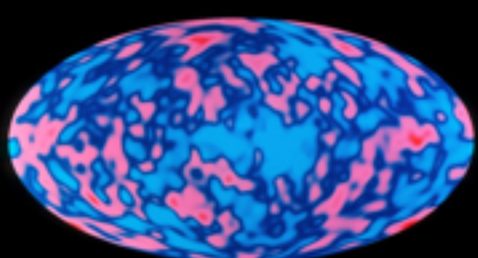
1. Type Ia Supernovae

Direct Evidence of cosmic acceleration

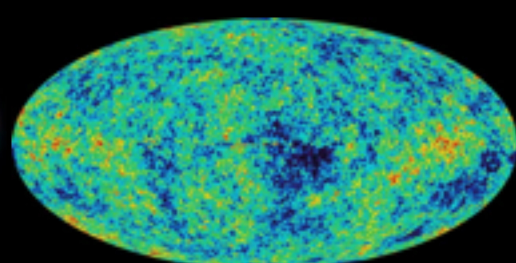




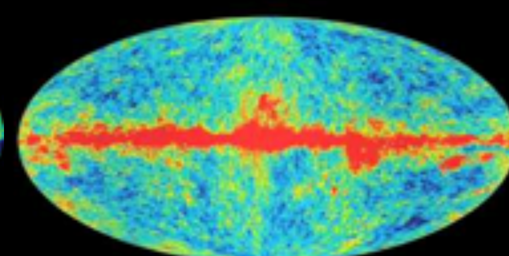
2. Cosmic Microwave Background Radiation (CMB)



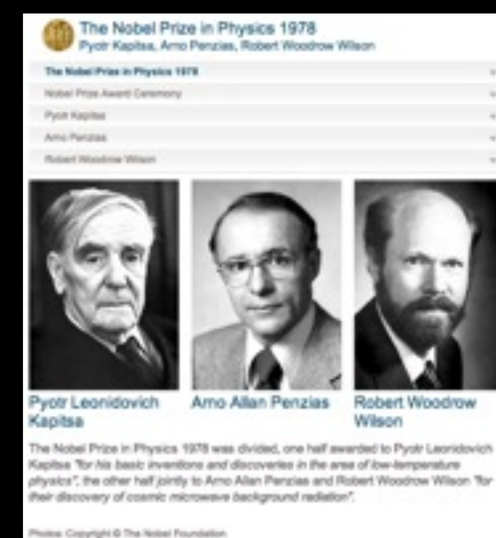
COBE, 1990s

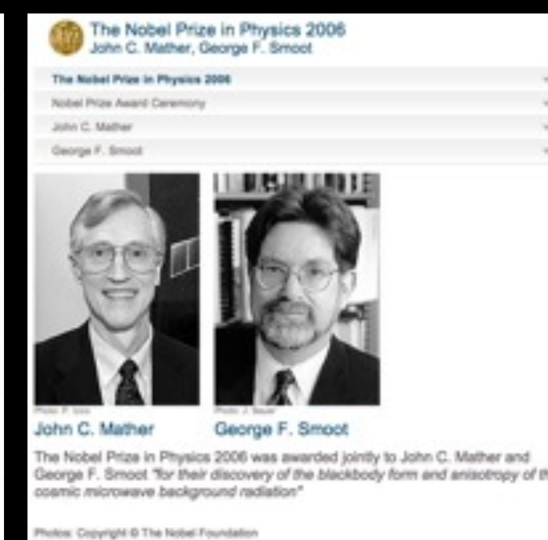


WMAP, 2000s



PLANCK, 2010s

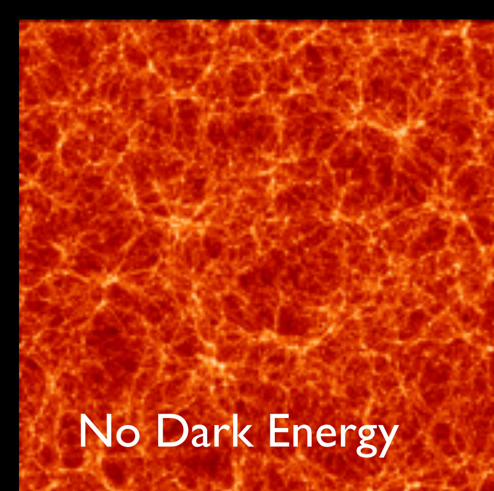




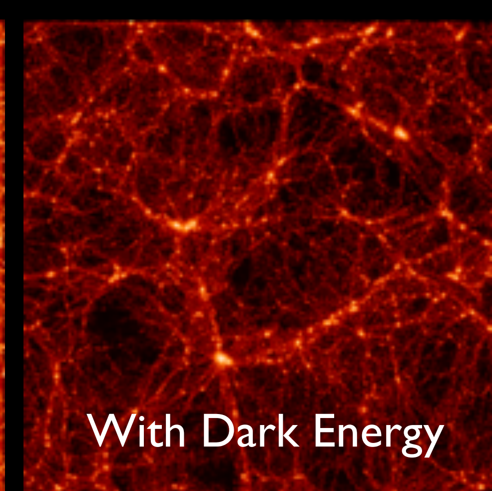
3. Large Scale Structure Clustering

The amount of dark energy determines the relative strength of gravitational push and pull, which determines galaxies clustering and distribution

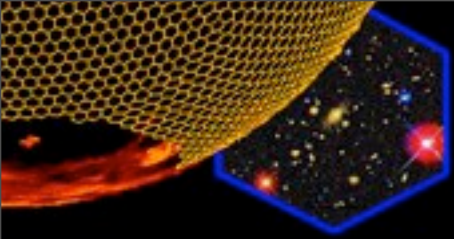
These distort the path of light, leading to different gravitational lensing signal



No Dark Energy



With Dark Energy



Theoretical Framework

General Relativity + Dark Energy + S.M. Particles + Dark Matter

To explain cosmic deceleration and acceleration , we need to have both attractive and repulsive interactions at large scale

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\sum_i \left[\rho_i + 3p_i\right]$$

$$p_i = w_i \rho_i$$

Equation of state: w_i; Pressure: p_i; Density: ρ_i

To be consistent with the current cosmic acceleration, the dominant component should have

$$w < -\frac{1}{3}$$ Dark Energy

$$w = -1$$ Vacuum energy

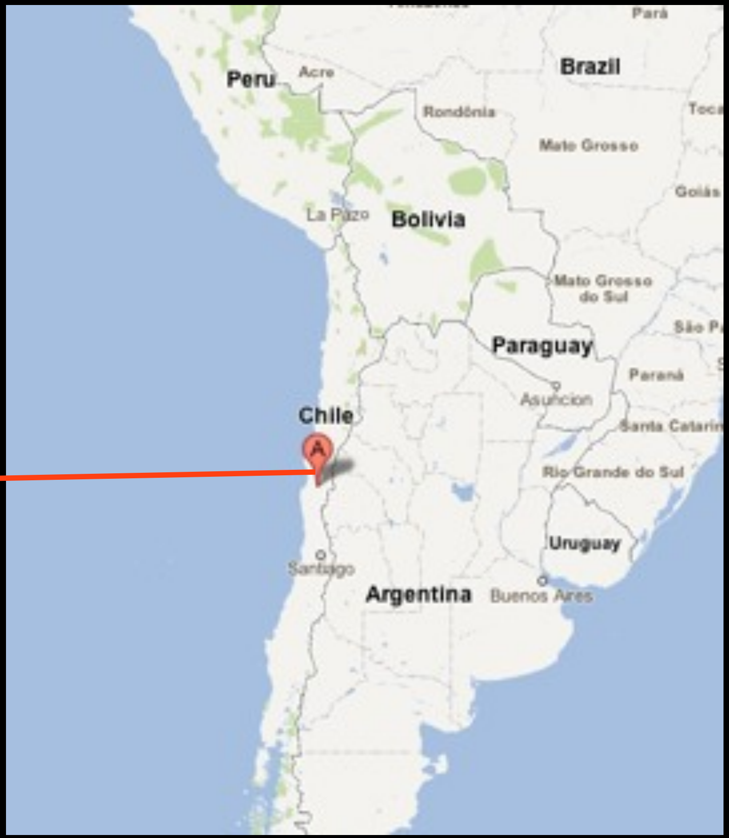
$$w(z) = w + w' \frac{z}{1+z}$$ Evolution of w is different for different dark energy models

dark energy
equation of state
$w = P/\rho$

$$w = -0.93 \pm 0.12$$
$$w' = -0.38 \pm 0.65$$

Current best results:
WMAP+SN+BAO (Komatsu+11)

The Dark Energy Survey



- DES is an optical imaging survey with CTIO 4 meter Blanco telescope in Chile
- DECam: 570 Megapixel Camera (iphone camera is 8 Megapixels)
- 5000 square degrees in *grizY* passbands
- 24th magnitude, redshift ~ 1.2
- 300 million galaxies, 4000 SNs, 100,000 galaxy clusters
- Starting from 2012 for 5 years, 525 nights

Dark Energy Survey Collaboration

Fermilab — The Fermi National Accelerator Laboratory

Chicago — The University of Chicago

NOAO — The National Optical Astronomy Observatory

United Kingdom DES Collaboration

- UCL - University College London
- Cambridge - University of Cambridge
- Edinburgh - University of Edinburgh
- Portsmouth - University of Portsmouth
- Sussex - University of Sussex
- Nottingham - University of Nottingham

DES-Brazil Consortium

- ON - Observatorio Nacional
- CBPF - Centro Brasileiro de Pesquisas Fisicas
- UFRGS - Universidade Federal do Rio Grande do Sul

OSU — The Ohio State University

TAMU — Texas A&M University

Munich—Universitäts-Sternwarte München

- LMU Ludwig-Maximilians Universität
- Excellence Cluster Universe

UIUC/NCSA — The University of Illinois at Urbana-Champaign

LBNL — The Lawrence Berkeley National Laboratory

Spain DES Collaboration

- IEEC/CSIC - Instituto de Ciencias del Espacio,
- IFAE - Institut de Fisica d'Altes Energies
- CIEMAT - Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas

Michigan — The University of Michigan

Pennsylvania — The University of Pennsylvania

ANL — Argonne National Laboratory

Santa Cruz-SLAC-Stanford DES Consortium

- Santa Cruz - University of California Santa Cruz
- SLAC - SLAC National Accelerator Laboratory
- Stanford - Stanford University

- More than 120 Scientists
- 23 Institutions
- 5 countries:
  US, Brazil, Spain, Germany and UK

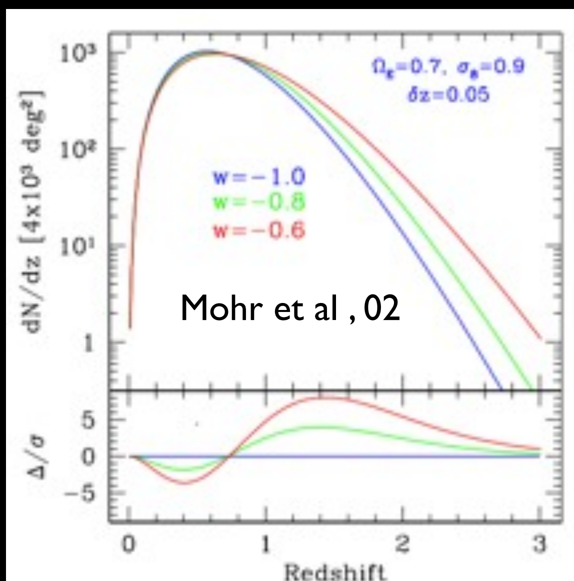
11 Science working groups

- Clusters
- Galaxy Evolution
- Large-Scale Structure
- Milky Way
- Photo-z
- Quasars
- Simulation
- Strong Lensing
- Supernova
- Theory
- Weak Lensing

Four Cosmological Probes

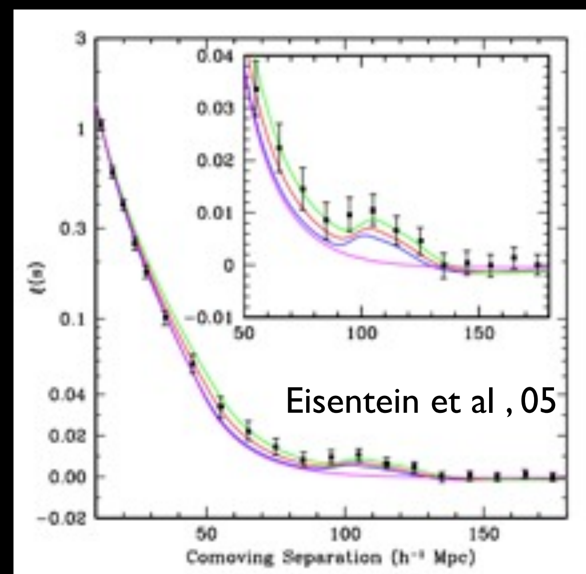
Galaxy Cluster Counts

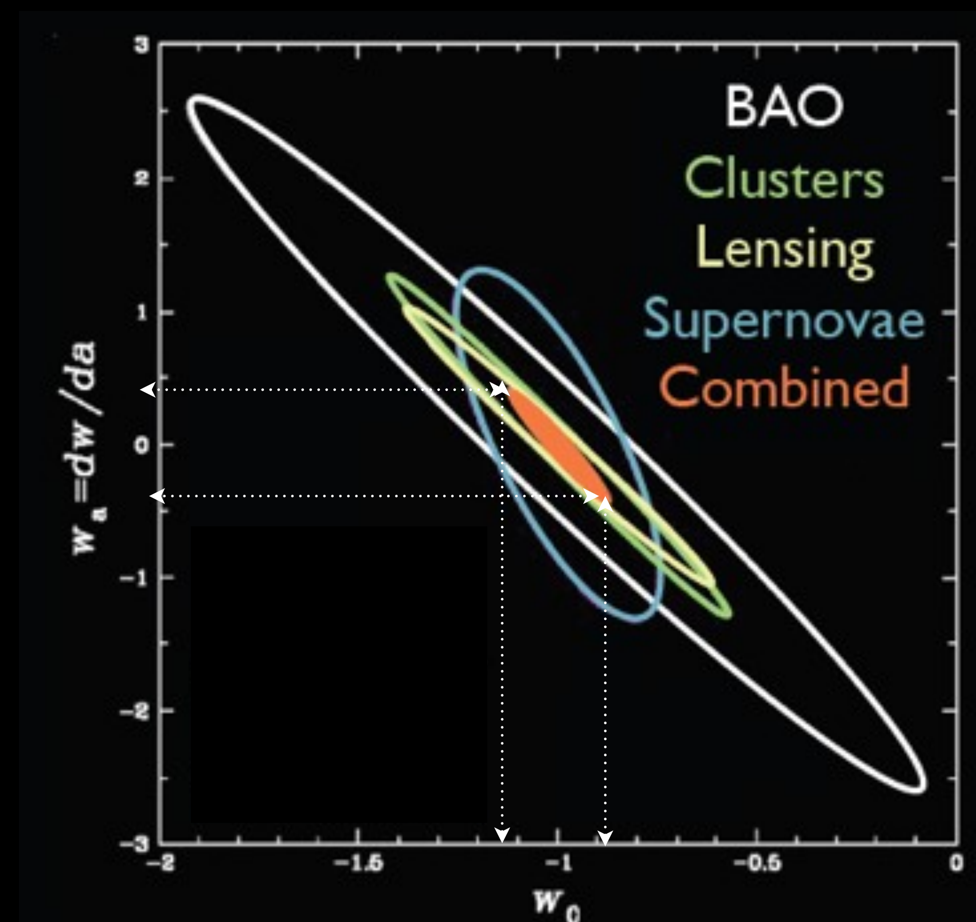
Growth of structures and Geometry



Baryon Acoustic Oscillation

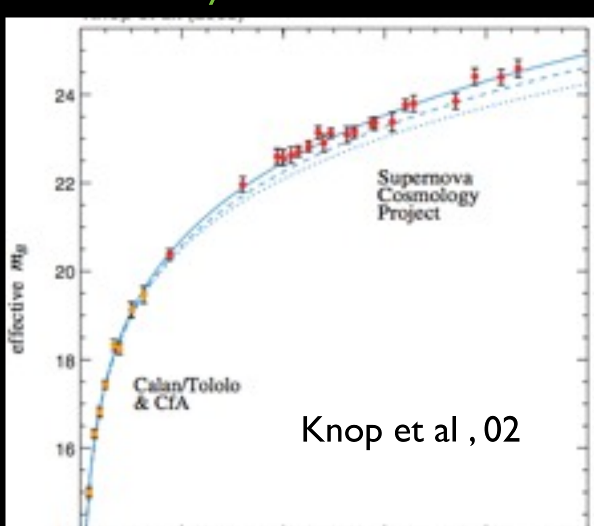
Geometry





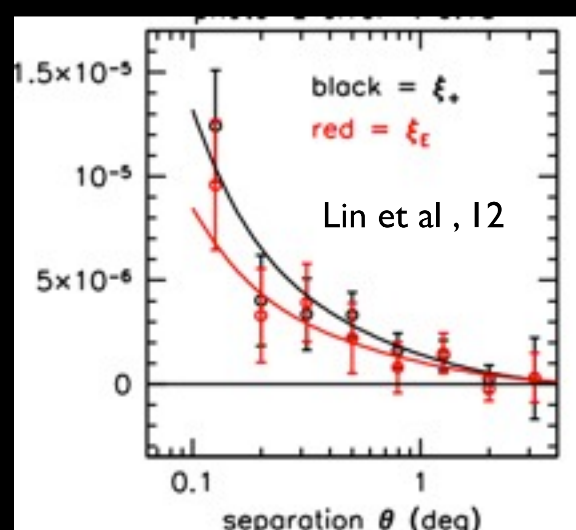
Type Ia Supernovae

Geometry



Weak Lensing

Growth of structure and Geometry



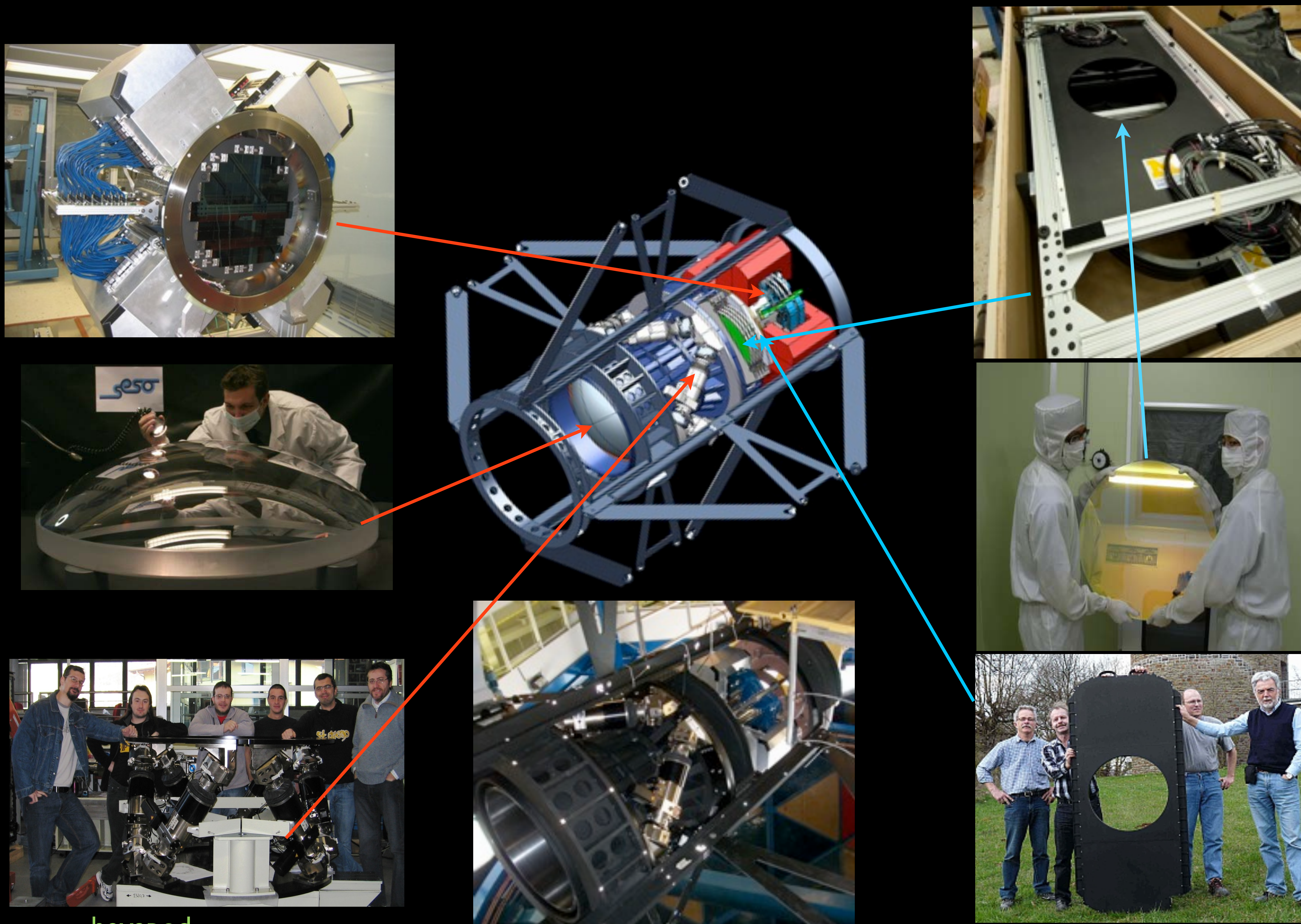
Improving the constraints on w(z) by a factor of ~ 3 - 5

The Dark Energy Camera
DECam

Dark Energy Camera - DECam

imager
(Fermilab)

optics
(UCL)



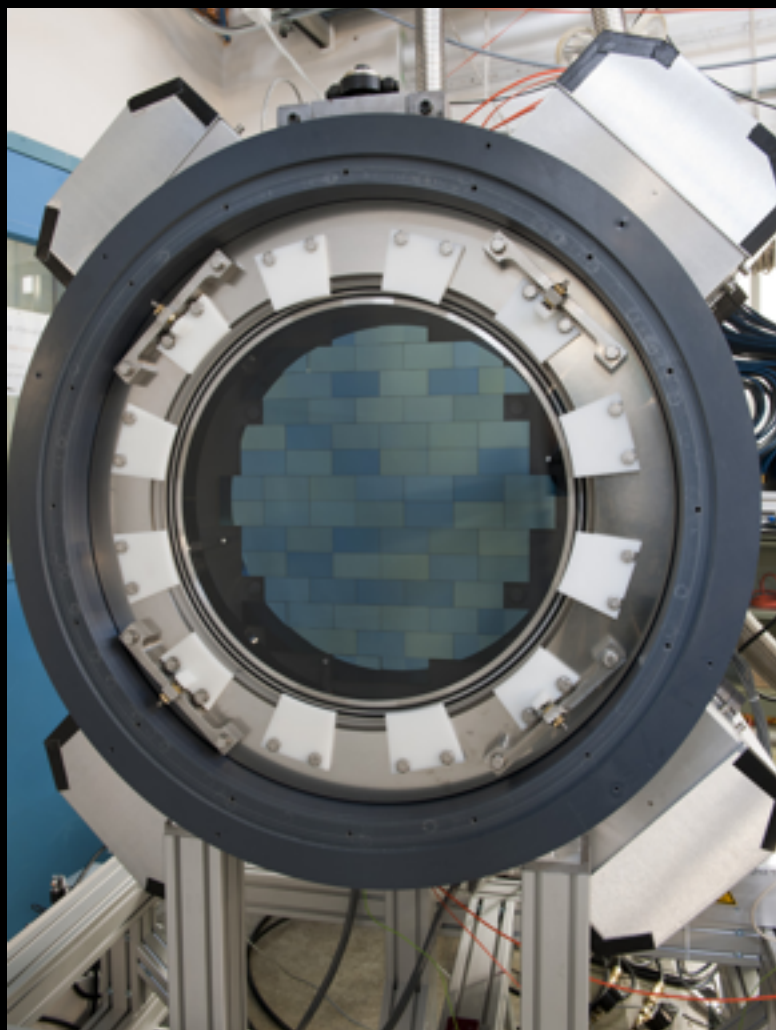
filter changer
(U of Michigan)

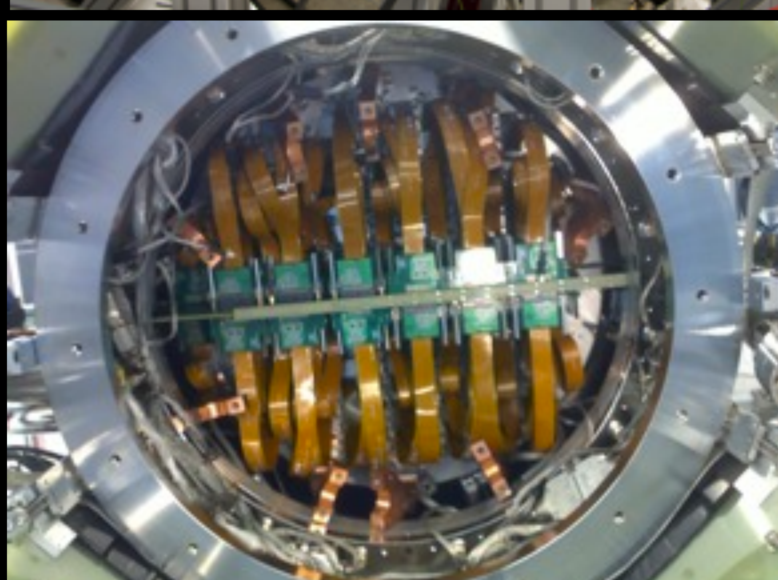
filter
(Japan)

shutter
(Germany)

hexapod
(Italy)

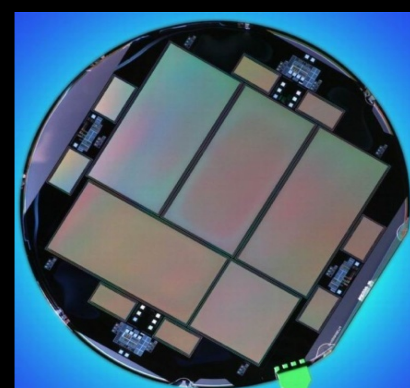
DECam Imager and CCD

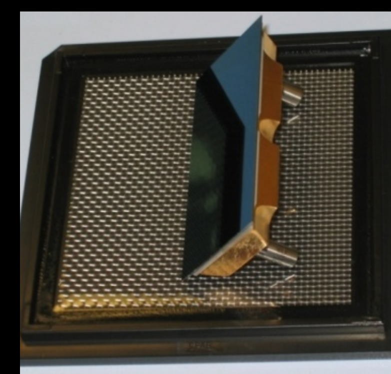


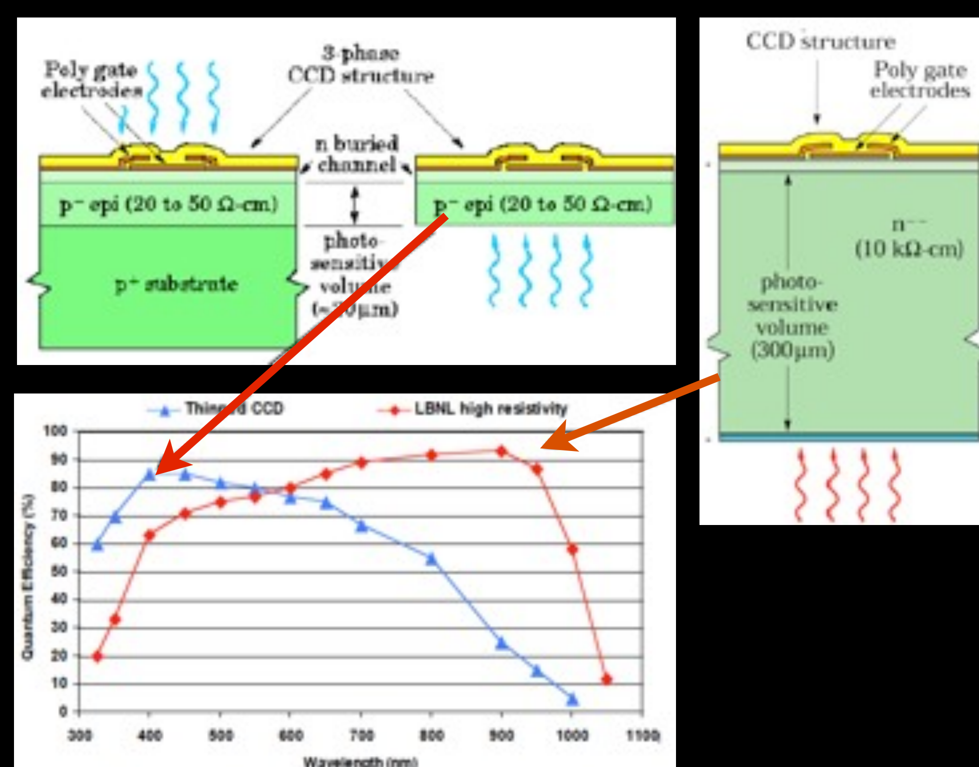


Most of the R&D of the imager is at Sidet of Fermilab

Sixty two 2k x 4k CCDs for imaging
Twelve 2k x 2k CCDs for focusing and guiding







Red sensitive CCD wafers designed by LBNL and processed at LBNL and DALSA

- QE > 50% at 1000 nm
- 250 microns thick
- Pixel size: 15 microns
- readout speed: 250 kpix/sec
- 2 RO channels/detector
- readout time: ~ 17 sec

Bare diced wafters were delivered to Fermilab

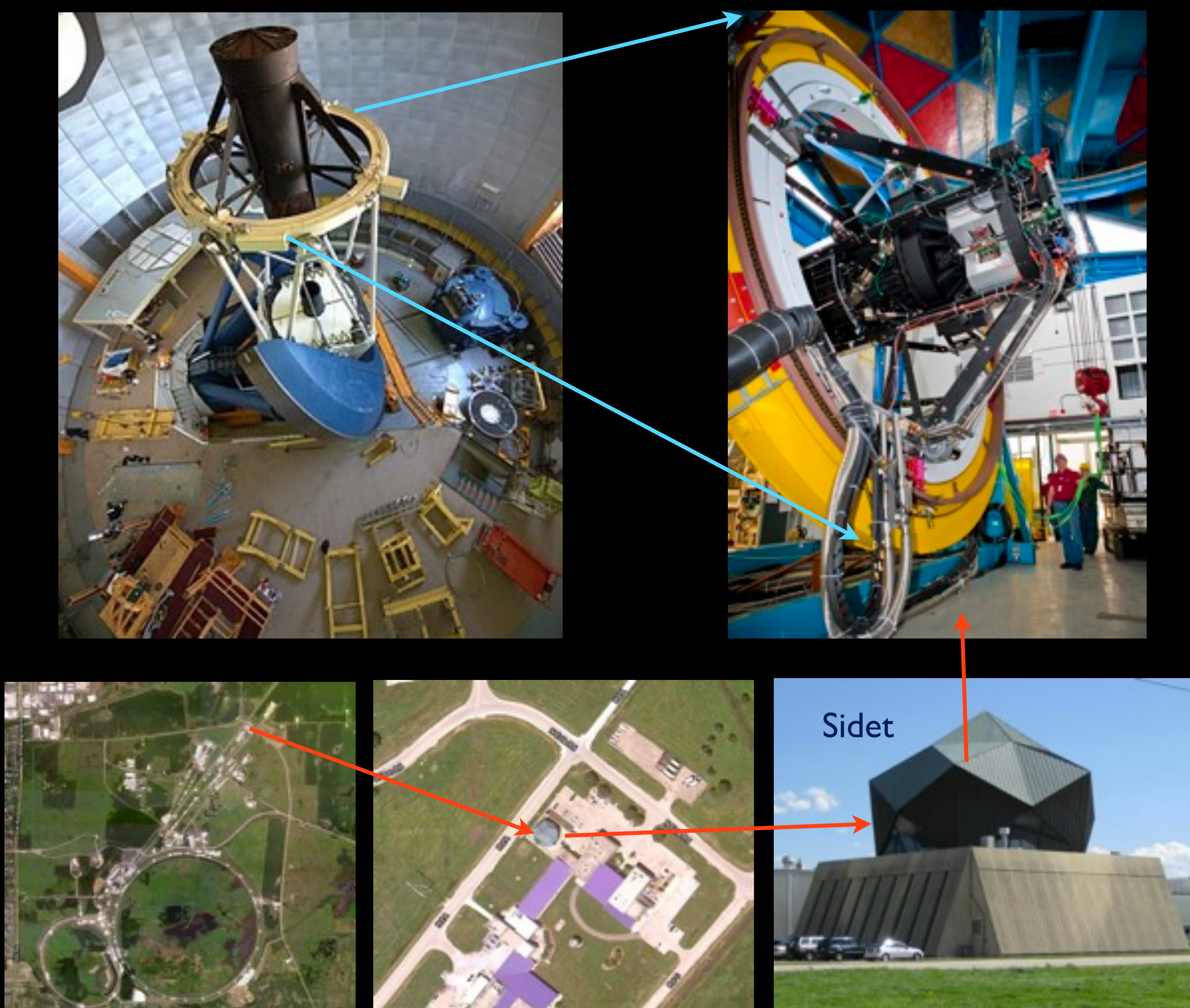
CCDs are packaged and tested at Fermilab

Size of **each** DECam CCD
62.94 mm x 30.72 mm

Size of iphone CCD: 4.54 mm x 3.39 mm

Integration Test @ Fermilab: 2010 - 2011

A telescope simulator was built at Fermilab to test the DECam system in a realistic setting



Testing:

- Cooling system
- Vacuum system
- Instrument control system
- SISPI end user interface
- Imager stability
- Shutter
- Hexapods
- Filter Changer

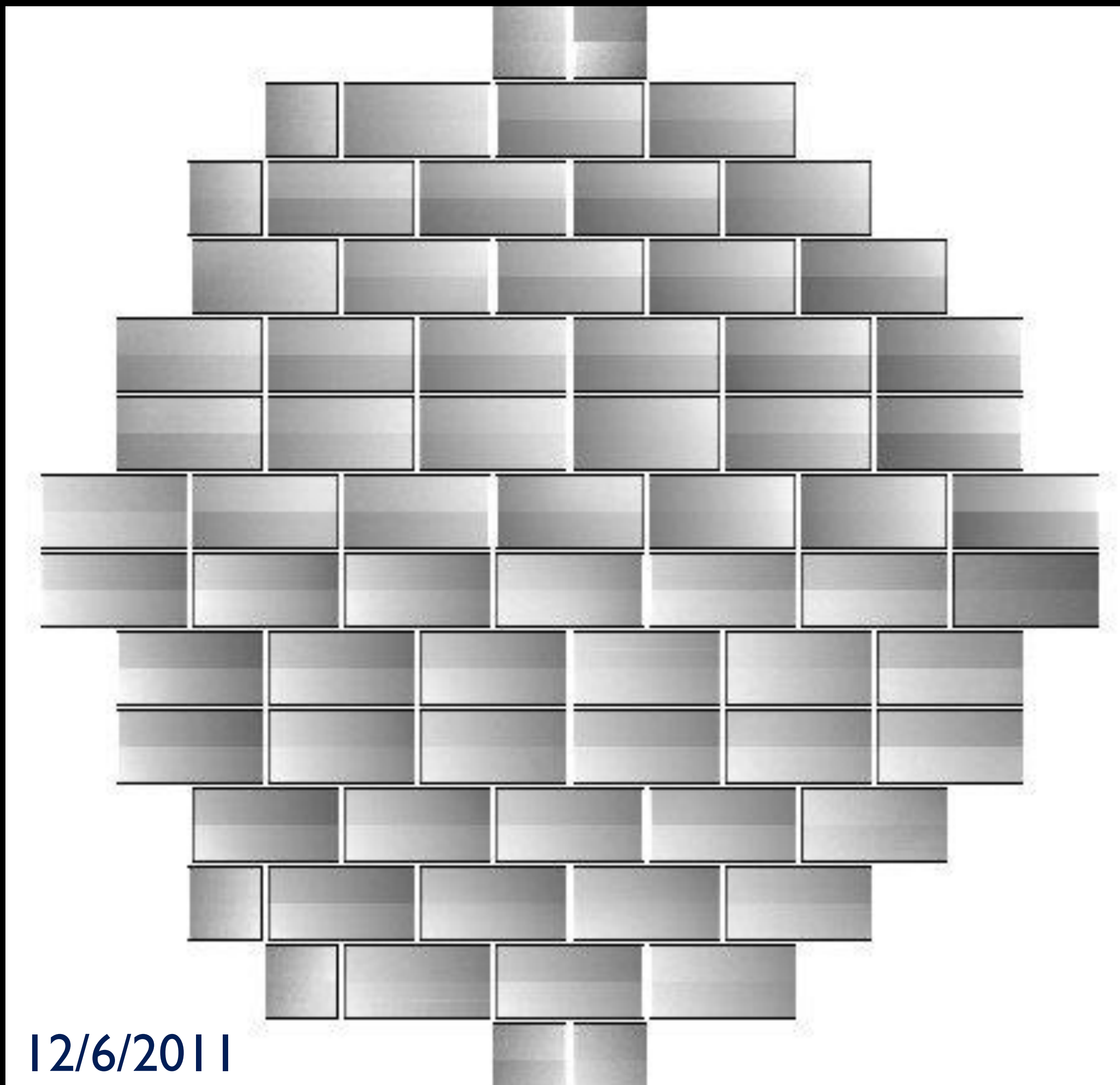
Both software and hardware works great!

Shipping To CTIO: 2011 - 2012

The clean room of Blanco Telescope

Imager arrived at CTIO on Nov. 23, 2011 and has been successfully checked out in the clean room.

First DECam Flat Image@CTIO



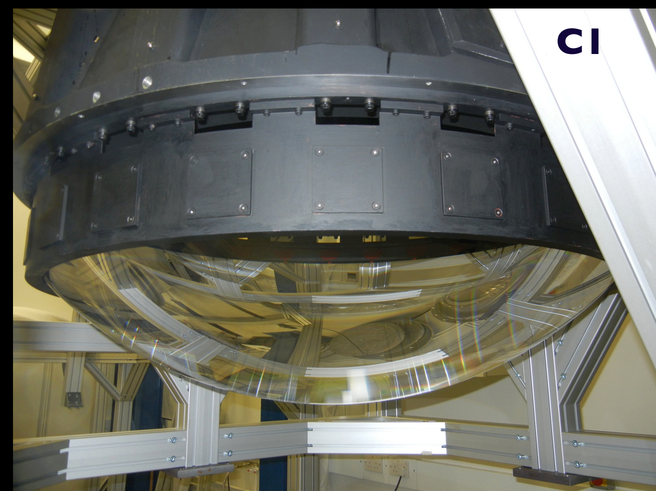
The old Mosaic Camera
at Blanco Telescope

Successful Mock Observing to test the SISPI
and Imager readout @ CTIO control room

1/23/2012

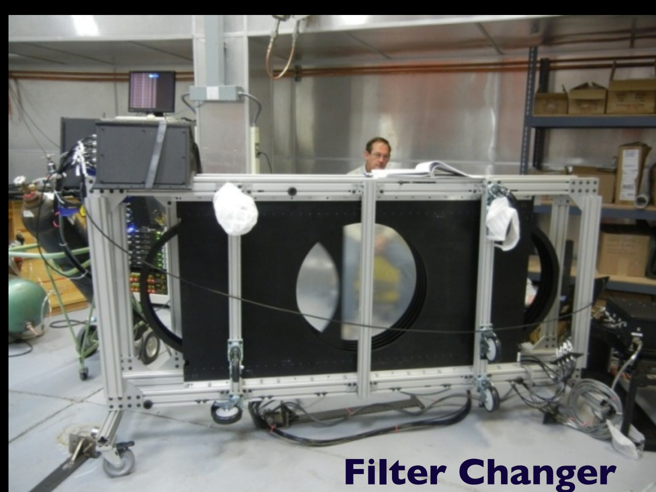
Other Essential Parts @ CTIO


Lens Barrel


C1

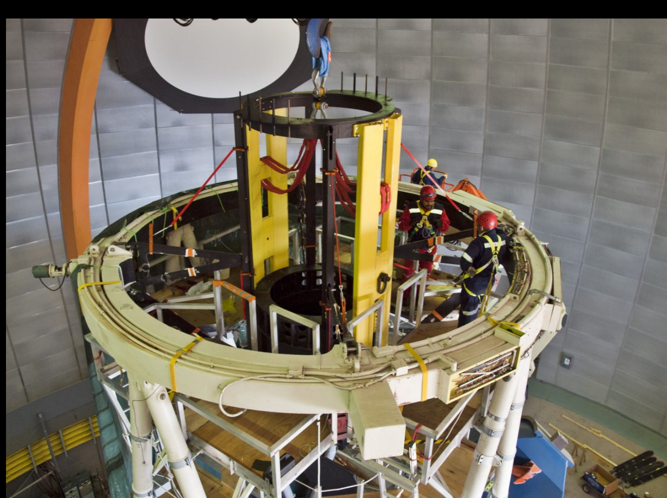

C2 and C3


C4


Filter Changer


Filter


Hexapod

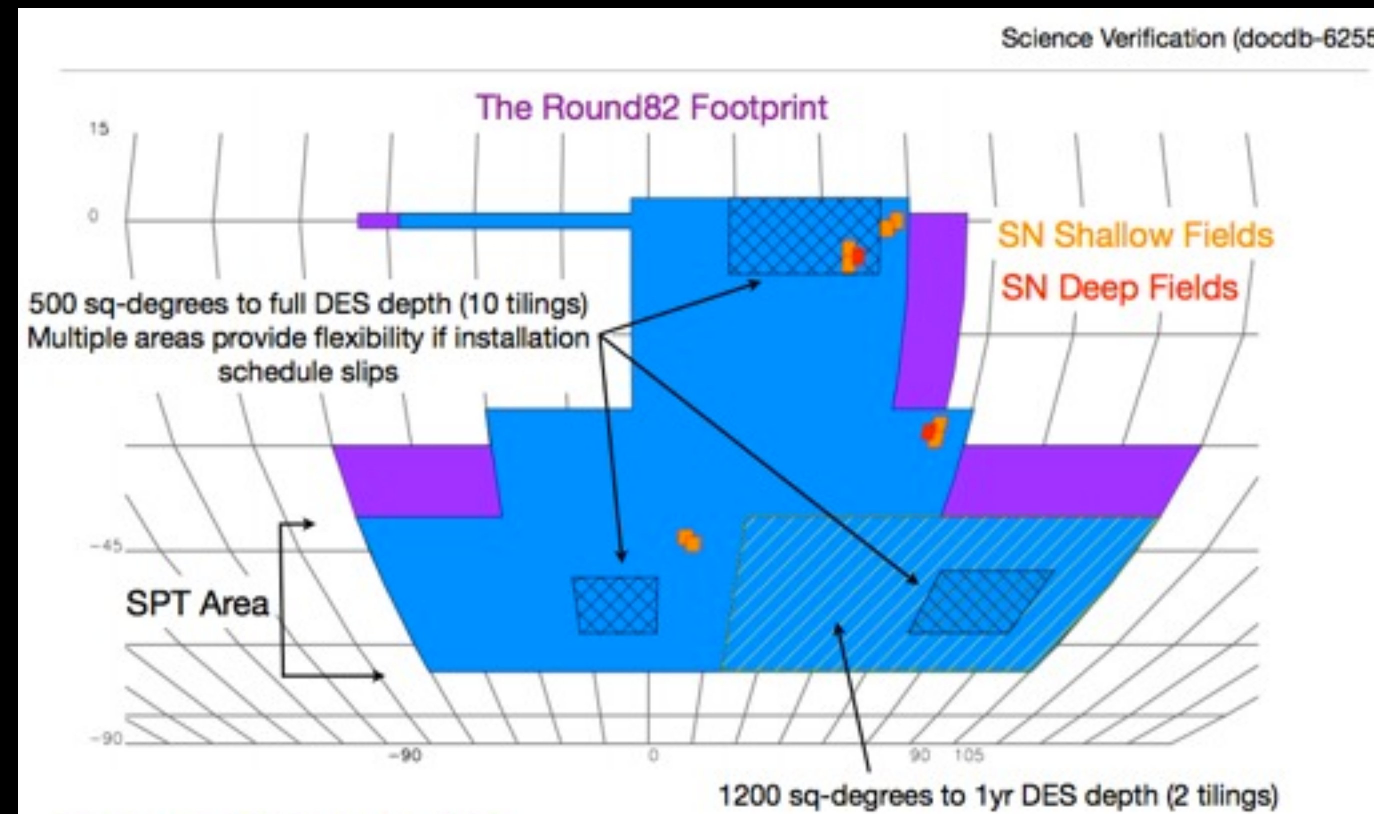


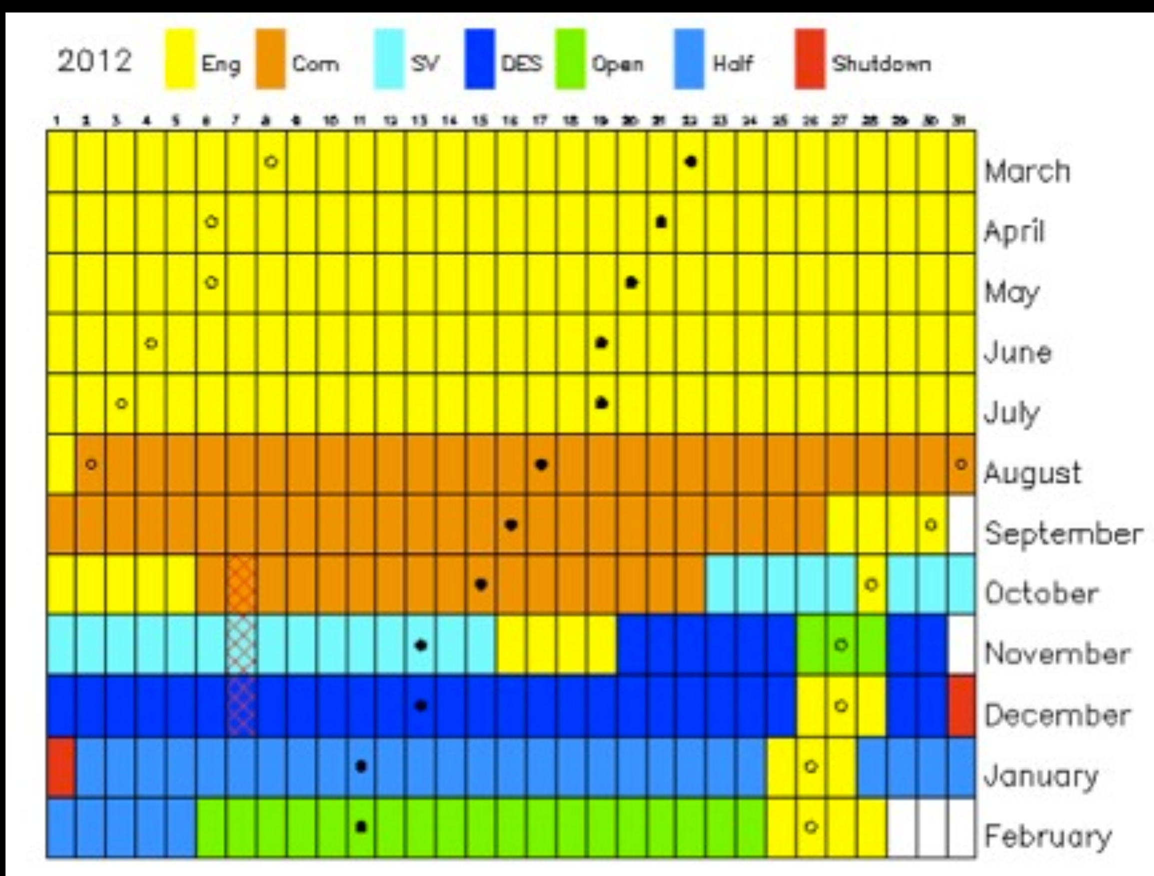
Assembly and installation of these parts are ongoing at CTIO now

Current Schedule

Aug. 2012: Imager Installation
Sept. 1, 2012: First light
Sept.-mid. Nov. 2012:
Commissioning and
Science Verification
Late Nov. 2012: Survey Starts

First Season Survey Footprint





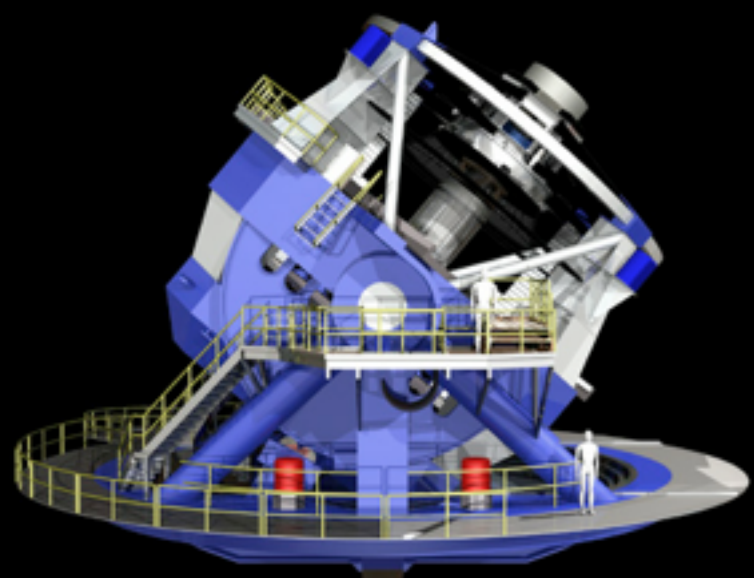
First Season Survey Schedule

DES only use 2/3 of the time between Sept. and Feb. each year

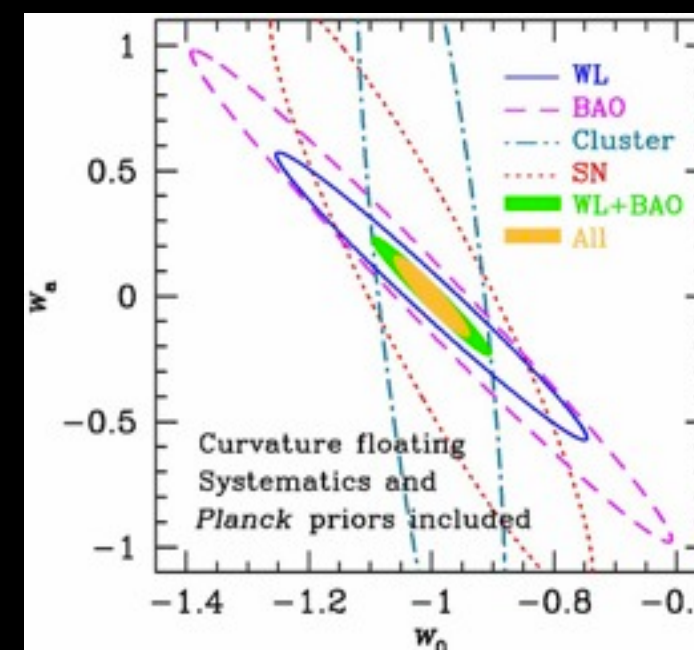
The DECam will be used by the Astronomy community the rest of the year!

It is a great community tool!

Large Synoptic Survey Telescope: LSST



LSST	DES
8.4 Meter Telescope	4 Meter Telescope
9.6 deg^2 Field of View	3 deg^2 Field of View
3200 MPix camera	570 Mpix camera
201? to 201? +10 years	2012 to 2017
20,000 deg^2	5000 deg^2
390 Million USD	35 Million



from LSST website

Fermilab is an institutional member of LSST now!

Our experience with DES will be valuable for LSST

DES data will provide real calibration tests for LSST

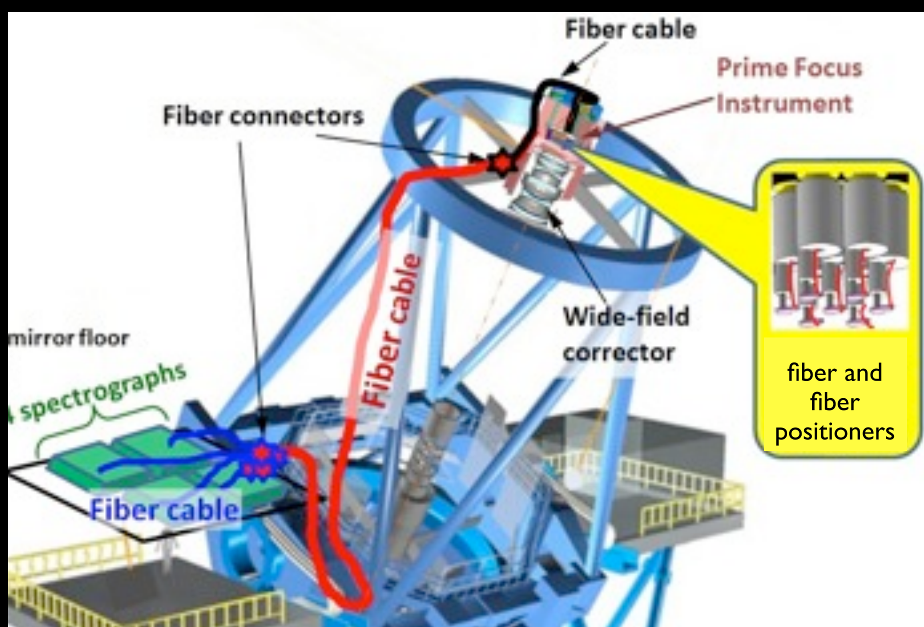
We visited LSST site during our last DES trip in 2011

LSST will improve the constraints on w(z) by 3 - 4 times over DES

Another new idea: DESpec

DESpec is a spectroscopic followup of DES:

- 4000 - 5000 Fibers, 7 million spectra
- Get 3D information of the galaxy distribution



from Subaru Telescope website

DESpec: benefits per probe

- Photo-z/spec: better photo-z calibration (also via cross-correlation)
- LSS: RSD and radial BAO, FoM improved by several (3-6)
- Clusters: better redshifts and velocity dispersions, FoM up by several
- WL: little improvement for FoM (as projected mass), but helps with intrinsic alignments
- WL+LSS: offers a lot for both DE and for ModGrav
- SN Ia: spectra of host galaxies and for photo-z training, improving FoM by 2
- Galaxy Evolution: galaxy properties and star-formation history
- Strong Lensing: improved cluster mass models

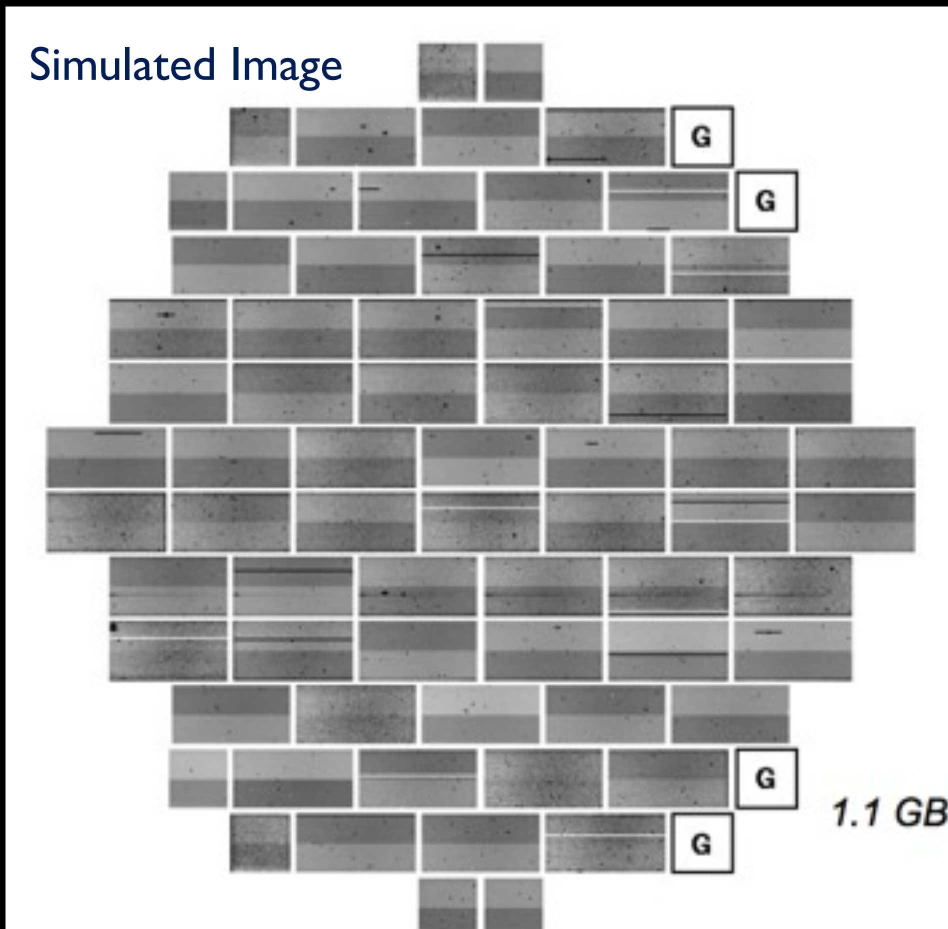
from Lahav's Slide

DESpec will improve the constraints on w(z) by a factor of 2 - 3 over DES.

Thanks to all my colleagues who made this possible !!

Backup slides

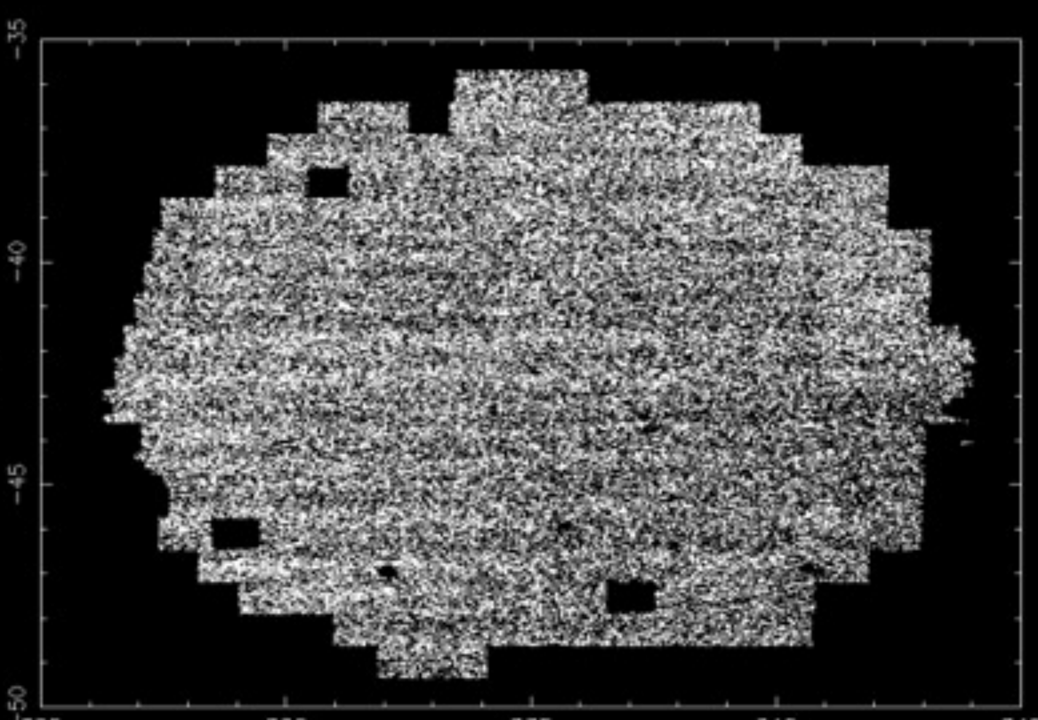
DES Data Challenge: Simulation



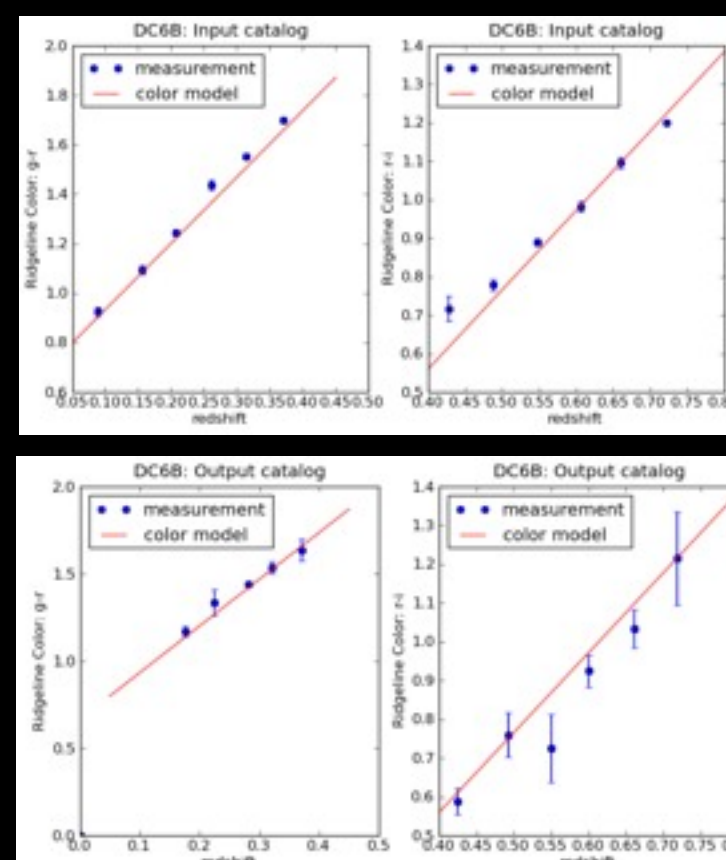
Simulate the DES images with known galaxy/star magnitudes/shape

Run the data reduction pipeline to extract the objects and compare with the input

comprehensive consistency test on the data management and data reduction before we have the real data



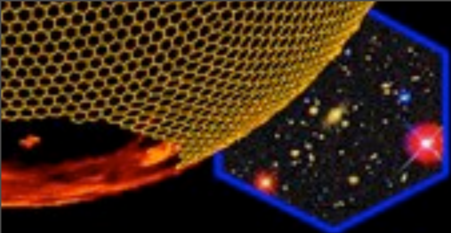
Data Challenge 6B footprint



Red sequence recovery

200 square degree
~ 10 nights observing

A new round of DC7 is ongoing!!



Theoretical Challenge (backup slide)

To explain all the evidences, we need to have both attractive and repulsive interactions at large scale

General Relativity:

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\sum_i \left[\rho_i + 3p_i\right]$$

$$p_i = w_i \rho_i$$

Equation of state (w_i), Pressure (p_i), Density (ρ_i)

To be consistent with the current cosmic acceleration, the dominant component should have

$$w < -\frac{1}{3}$$ Dark Energy

$$w = -1$$ Vacuum energy

$$w(z) = w + w' \frac{z}{1+z}$$

Evolution of w is different for different dark energy models

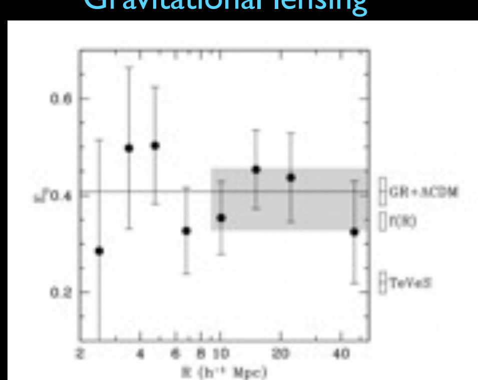
dark energy equation of state $w = P/\rho$

$$w = -0.93 \pm 0.12$$
$$w' = -0.38 \pm 0.65$$

Current best results: WMAP+SN+BAO (Komatsu+11)

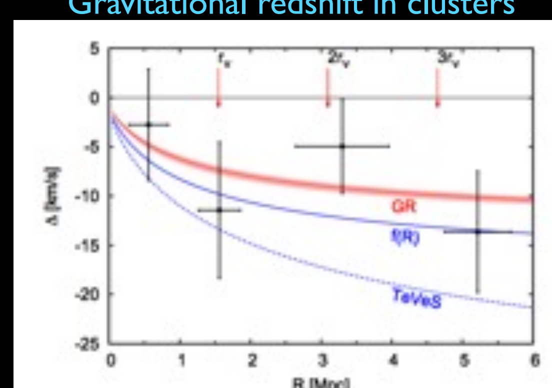
Modified Gravity: No need to add additional substance with negative pressure

Gravitational lensing



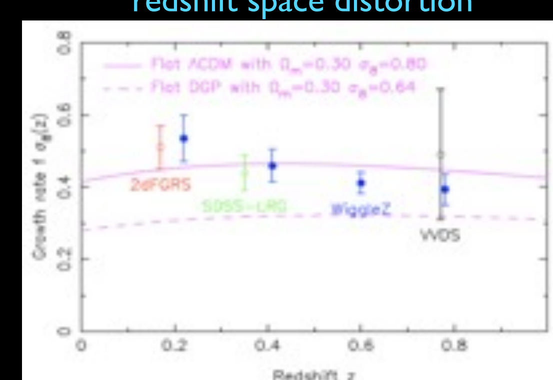
Reyes et al 2010, Nature

Gravitational redshift in clusters



Wojtak et al 2011, Nature

redshift space distortion

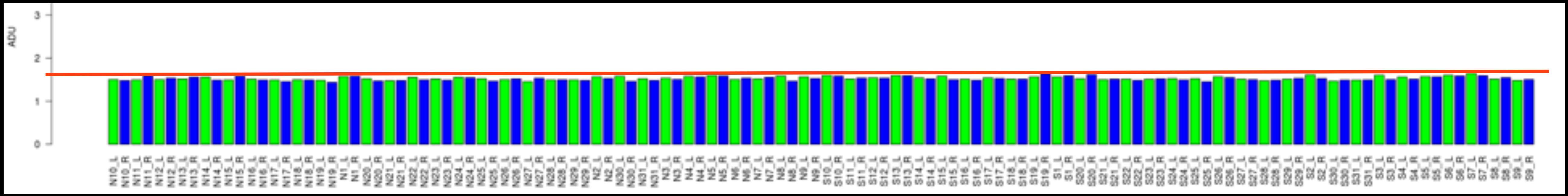


Blake et al 2011

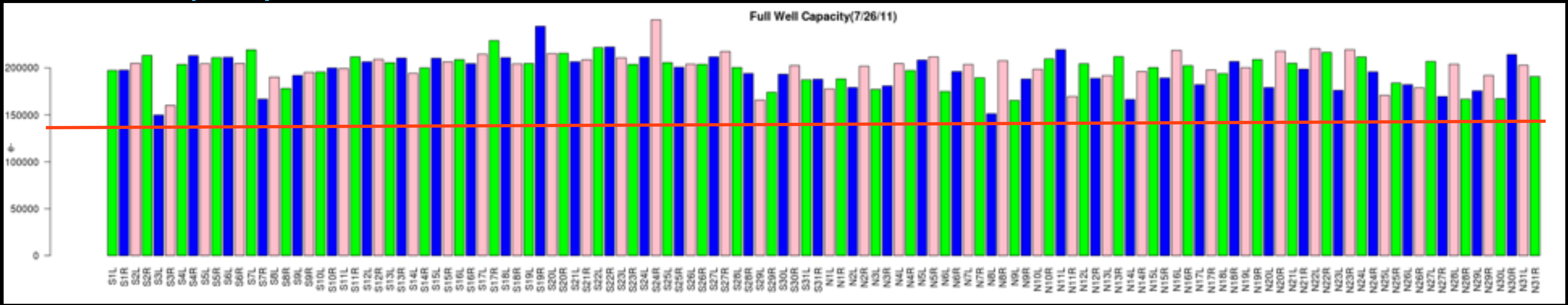
G.R. is favored !

CCD and Electronics Performance

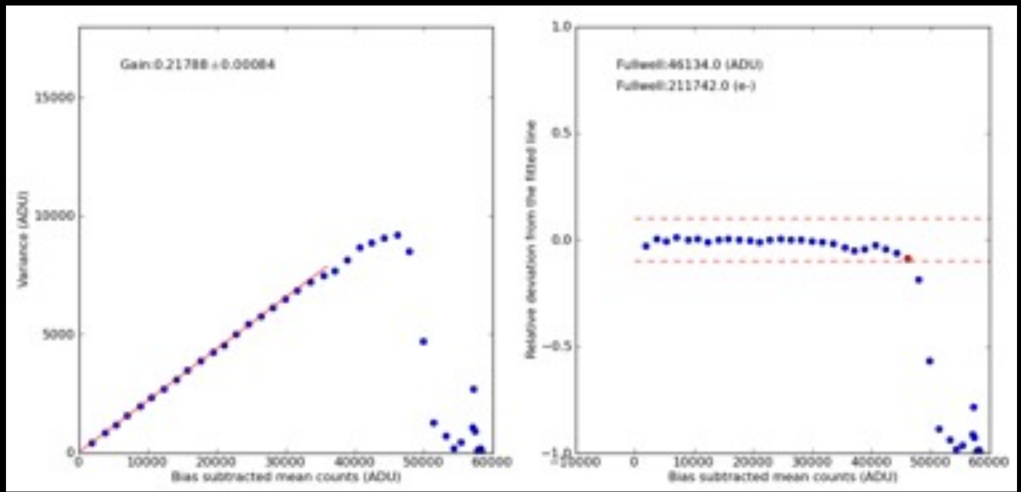
Readout noise: < 8 e-



Fullwell Capacity: > 130,000 e-



Good linearity



Readout speed: 17 sec

Dark Current < 25 e-/pix/hour