The Dark Energy Survey science & current status

DARK ENERGY SURVEY

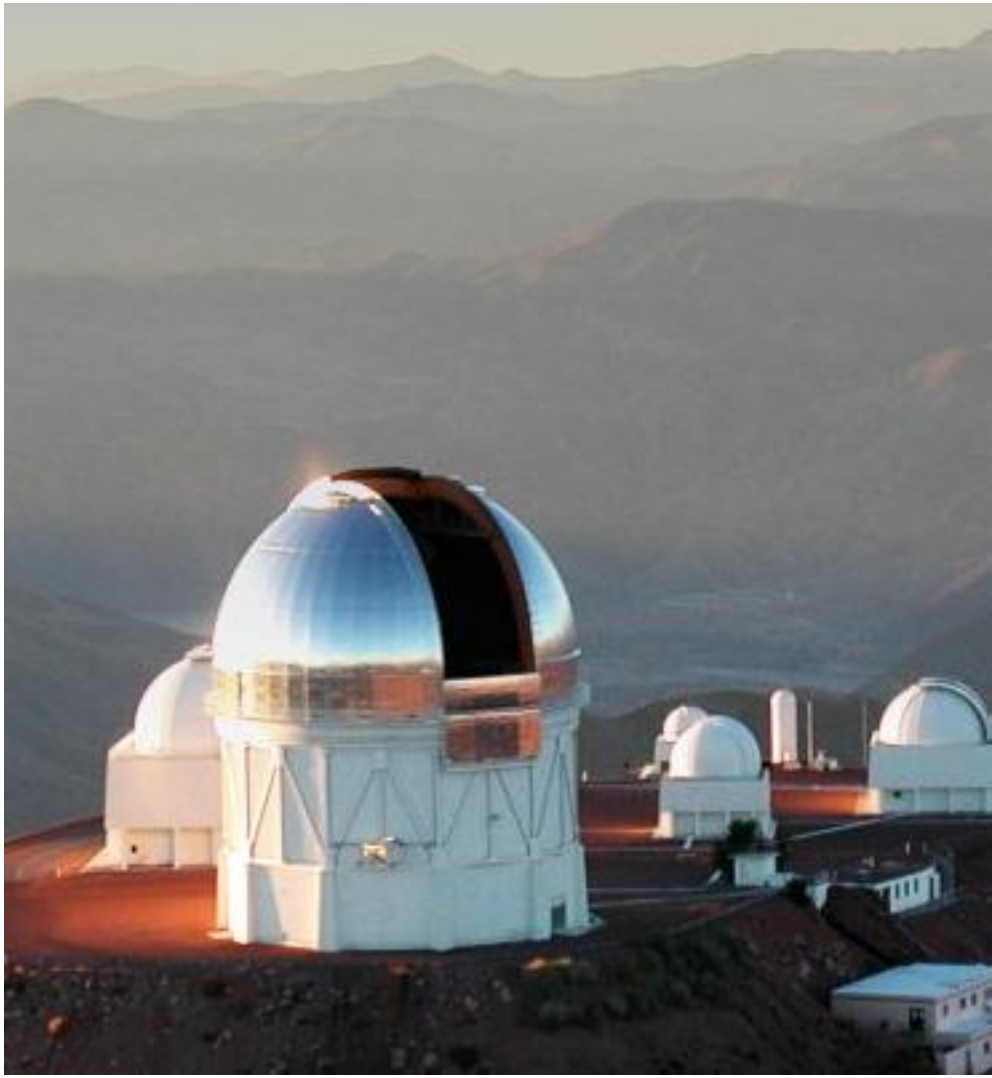
Stephanie Jouvel
Jun 2012, Crete

Contribution slides from Josh Frieman & Brenna Flaugher & Filipe Abdalla

DARK ENERGY SURVEY

Outline

1. Modern Cosmology Framework
2. Weak-Lensing overview (one of the main DES probe)
3. Dark Energy Survey
   - overview
   - survey strategy
   - current status



Standard model of Cosmology FLRW

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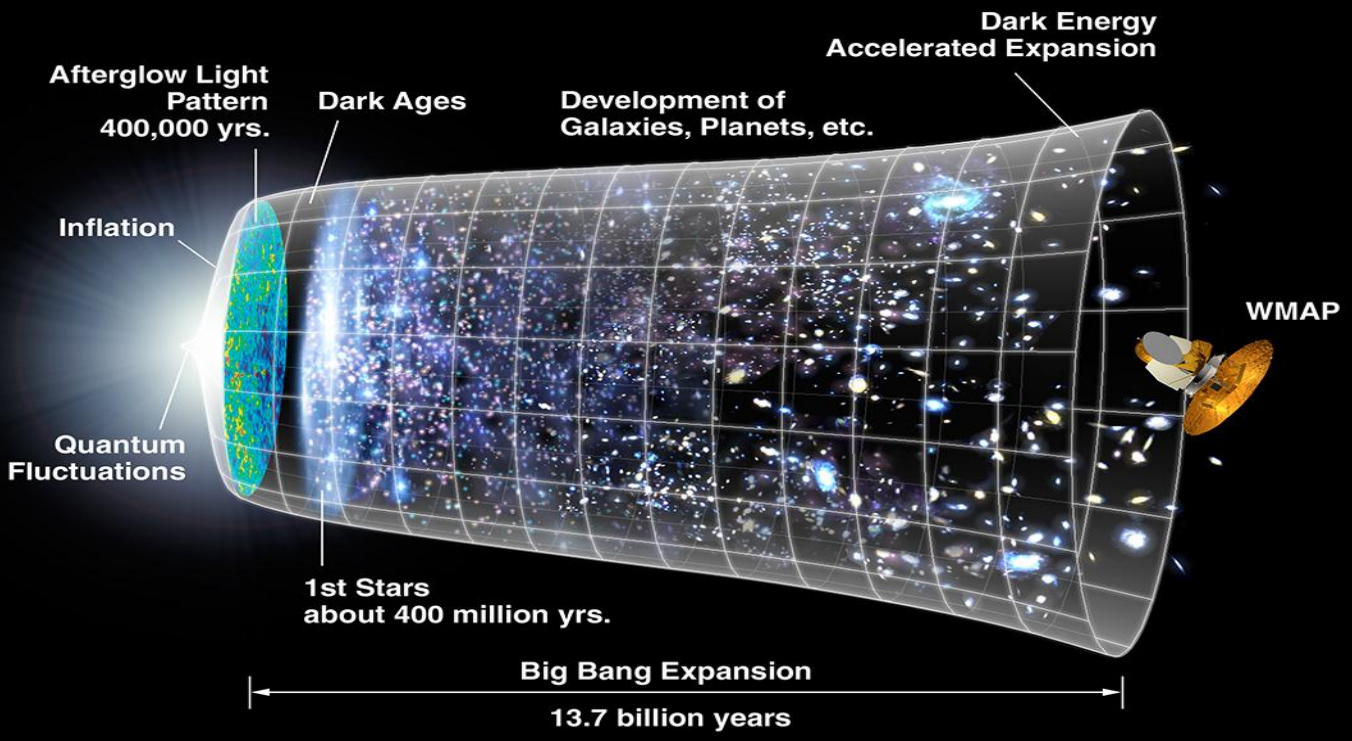

General relativity and cosmological parameters

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Einstein field equations :

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} - \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$g_{\mu\nu}$ **RW**

Isotropic and homogeneous universe

$$H^2 = \frac{\dot{a}(t)}{a(t)} = \frac{8\pi G}{3}\sum_i \rho_i - \frac{k}{a^2}$$

Hubble parameter : Parametrisation of the expansion

Cosmological parameters

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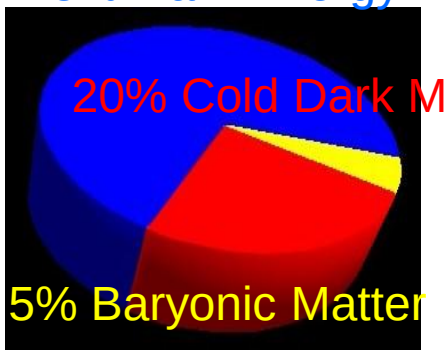
75% Dark Energy



$$\Omega_k = -\frac{k^2}{a^2 H} \qquad \Omega_i = \frac{8\pi G}{3H^2}\rho_i$$

Curvature density parameter

Ω_Λ

Dark Energy density parameter

Ω_m

Matter density parameter

Ω_r

Radiation density parameter

$$\sum \Omega_i = 1$$

Equation of state for each of these parameters

$$w_i = \frac{p_i}{\rho_i}$$

Dark energy equation of state ?

Cosmological probes

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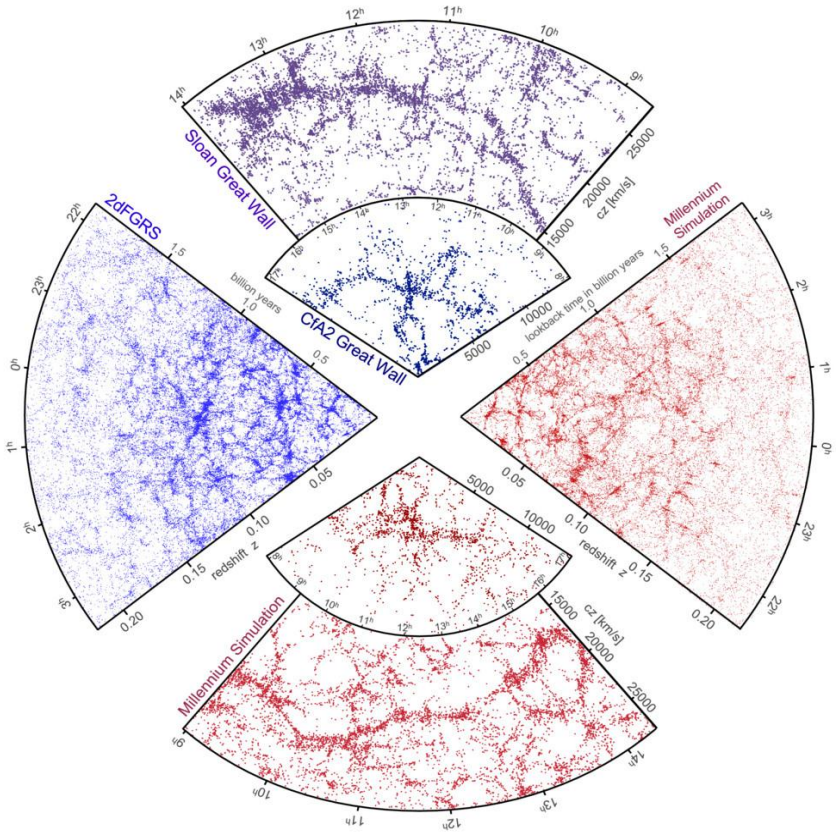
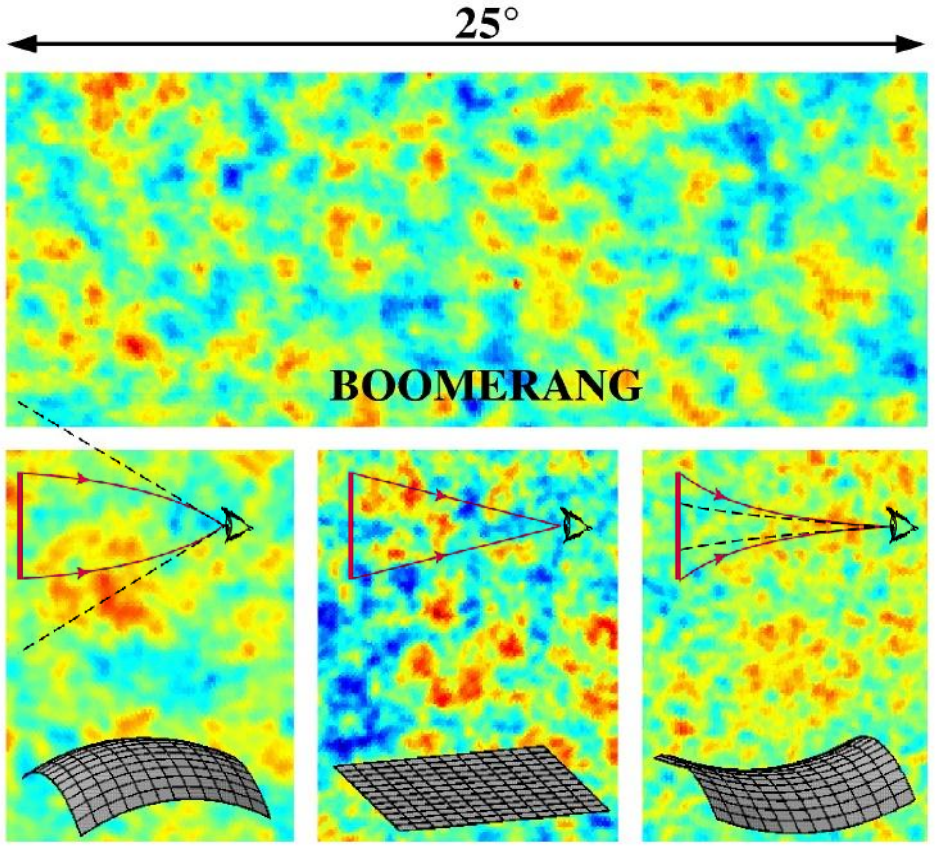
1. CMB + LSS : The Universe is isotropic and homogeneous on large scale (>10-100Mpc)
2. CMB : The Universe is flat





Cosmological probes

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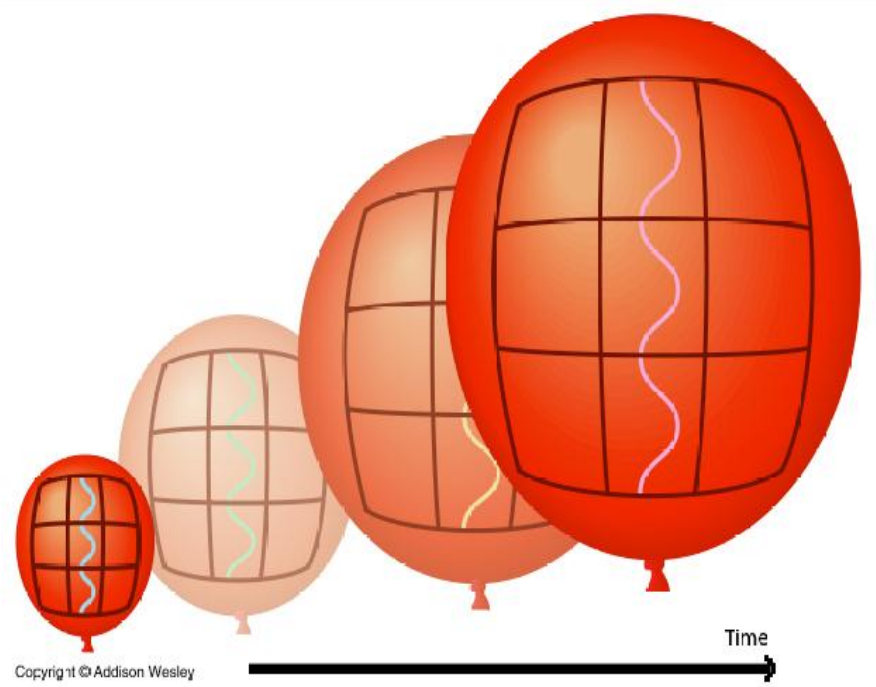
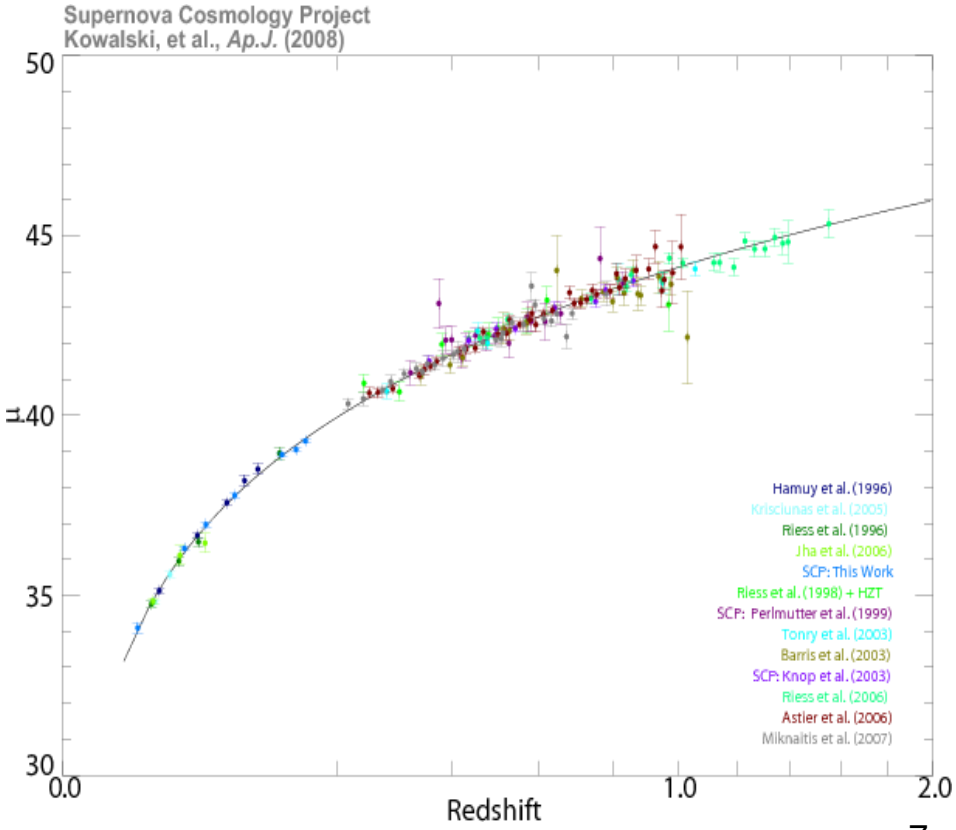
3. redshift survey : The Universe is in expansion
4. SN : The Universe expansion is accelerating





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Questions of cosmology

- What is the nature of Dark Matter ?
- What is the geometry of the Universe ?
- What causes the acceleration of the expansion ?
- What is the nature of Dark Energy ?
- What is the mass content (3D mass map) ?
- Is the GR a good description of the laws of gravity ?
- What is the contribution of neutrinos in the Universe evolution ?

Cosmological Probes

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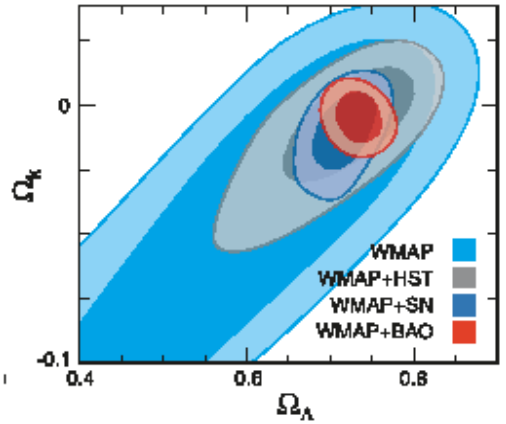

- Nucleosynthesis
- Hubble constant
- CMB: angular distances and …

Main probes of future dark energy surveys

- SN: Luminosity distance
- Weak-Lensing: Traces mass of structures and angular distances
- Baryon Acoustic Oscillation: angular distances and Hubble Law
- Redshift distortion
- Cluster counts, f_{gaz}, ISW, strong lensing …

New Cosmological probes : Baryon Acoustic Oscillation

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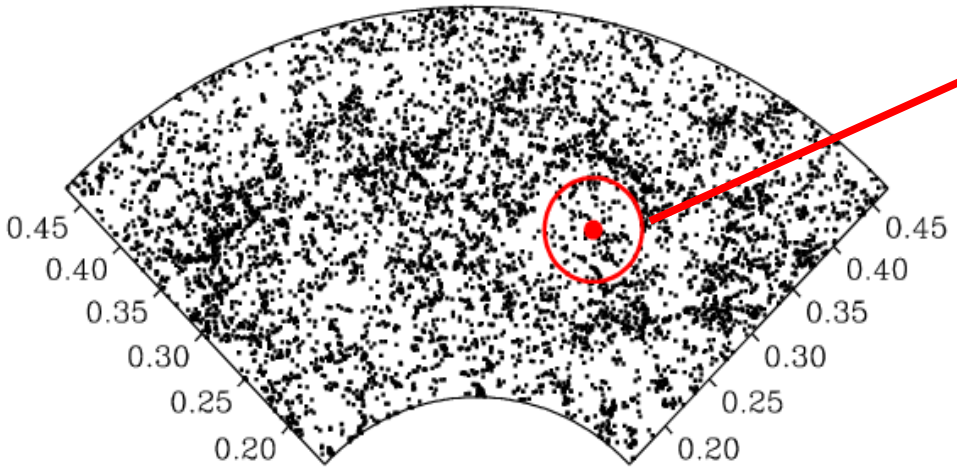
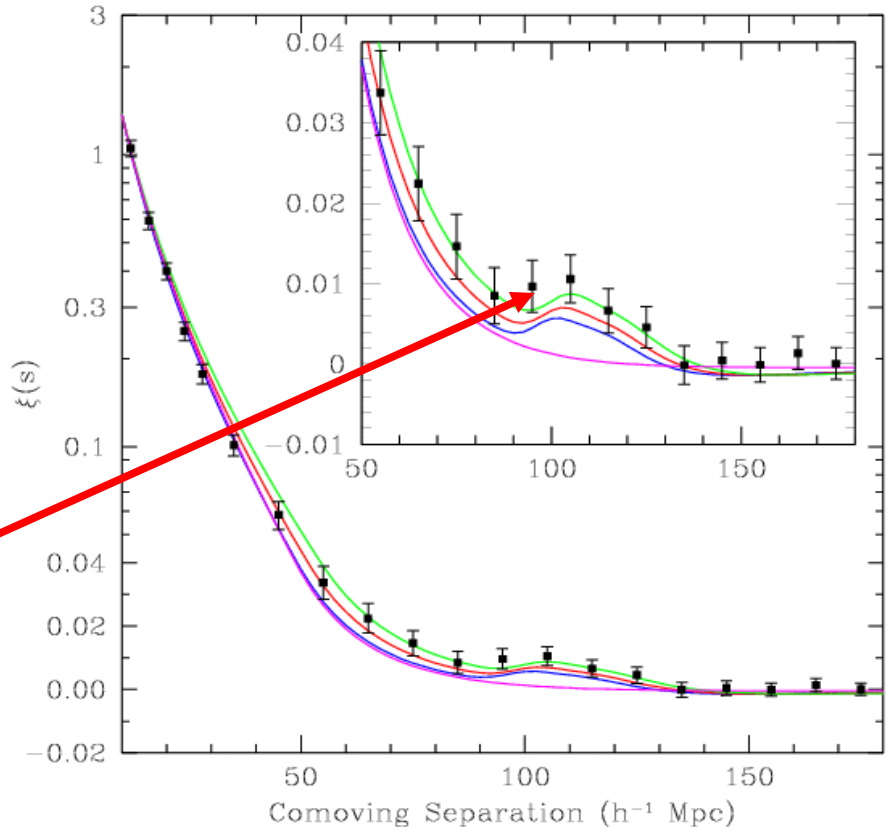
Measuring spatial correlation of galaxies

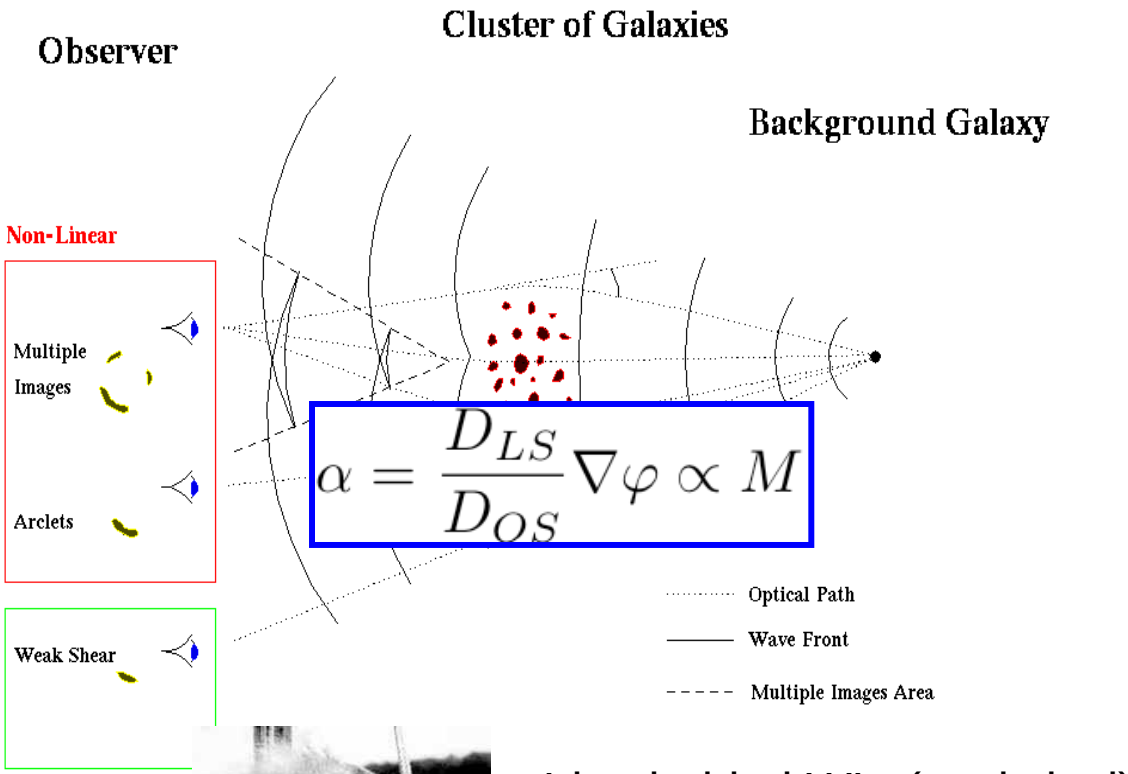
characteristic scale at which you expect an galaxy over-density
=> BAO peak

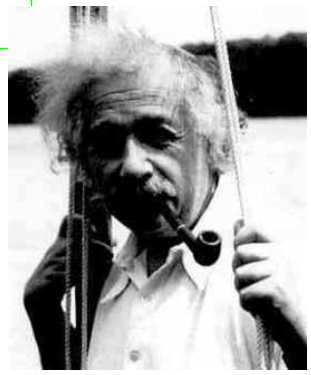
spot size in the CMB



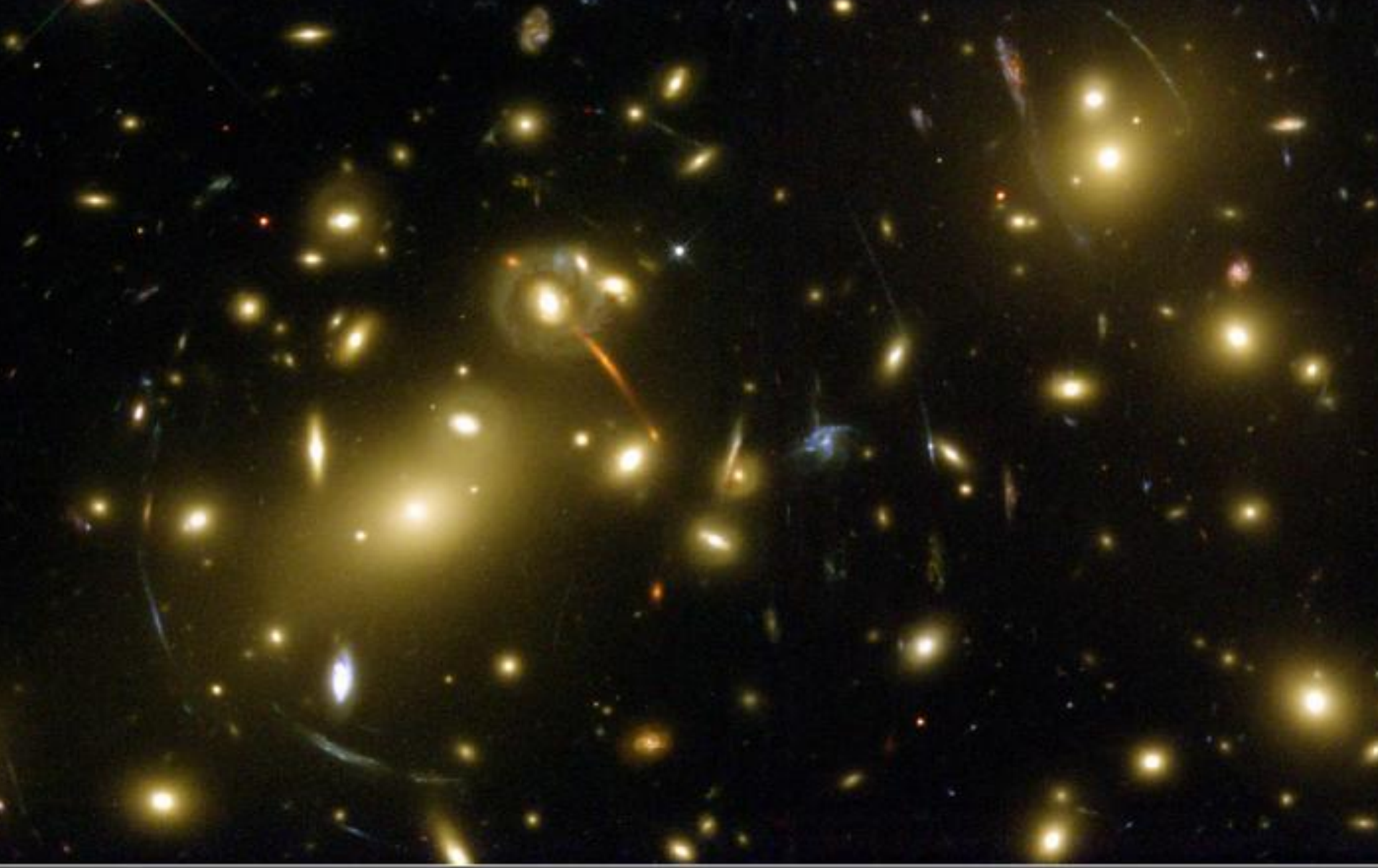


Gravitational lensing : RG prédiction





Idea behind WL: (statistical) measurement of galaxy shape deformations induced by LSS gravitational field(s) to infer the spatial/temporal evolution of the latter(s)



Galaxy Cluster Abell 2218

Hubble Space Telescope • WFPC2

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SURVEY

Weak-Lensing (WL) : methodology

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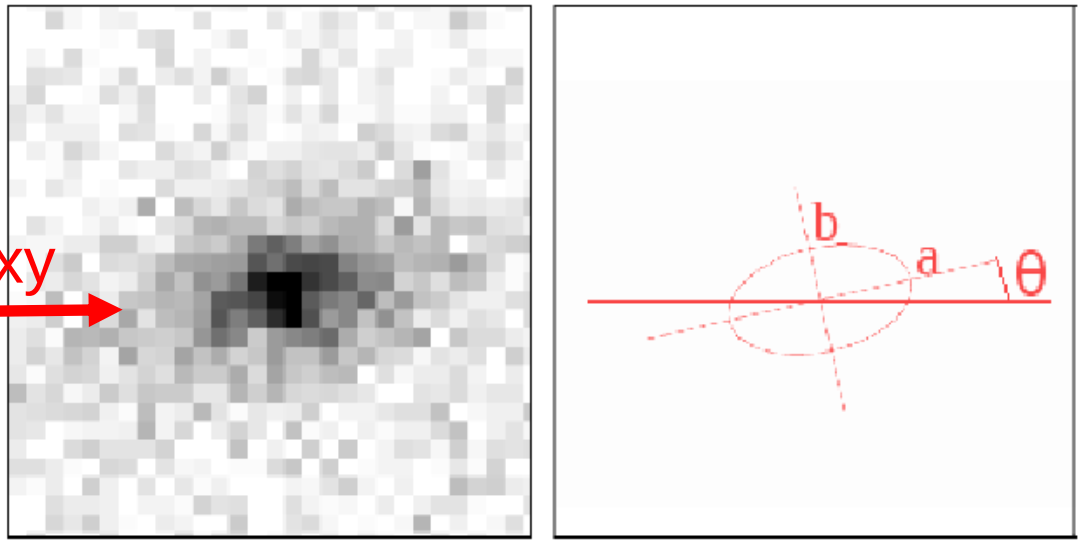
Image of galaxy



Galaxy shape = intrinsic shape x gravitational shear x instrumental/atmospheric modifications

1. Measure the instrumental PSF from stars
2. Measure galaxies ellipticities
3. Remove the PSF from galaxies shapes
4. Calculation of the shear correlation fonctions

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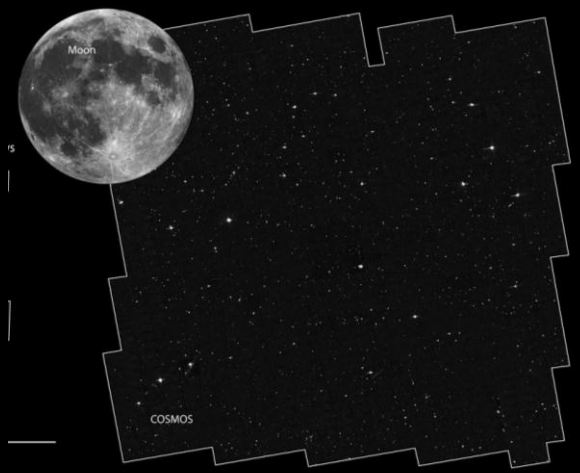
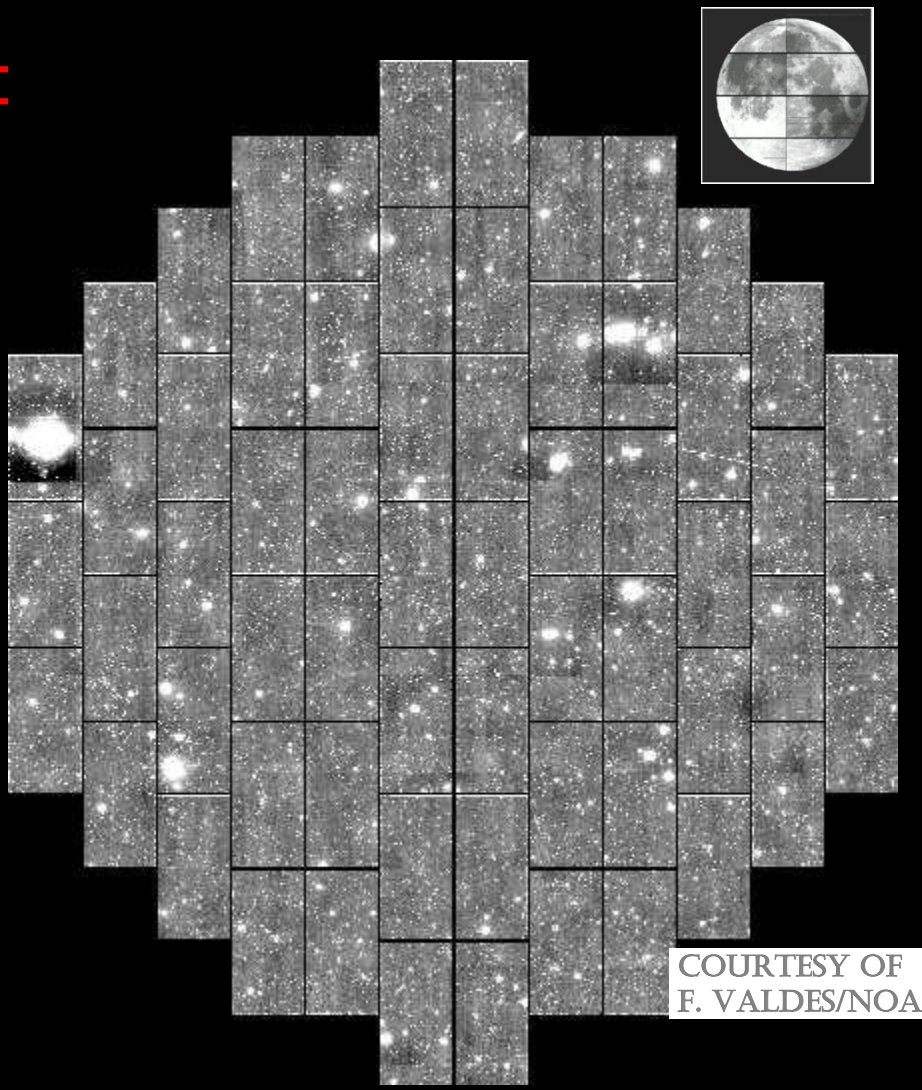
COSMOS → DES



COSMOS



One DES image (3 sq deg)

Cf whole DES survey 5000 sq deg

WL and Cosmology

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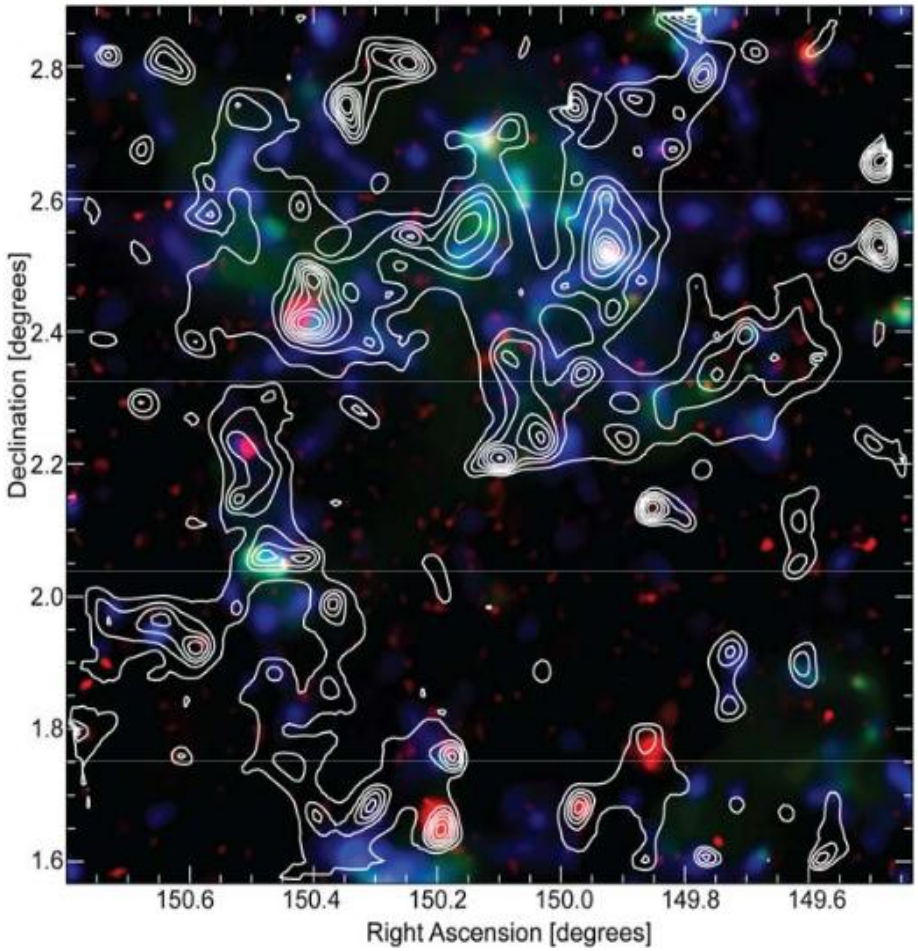

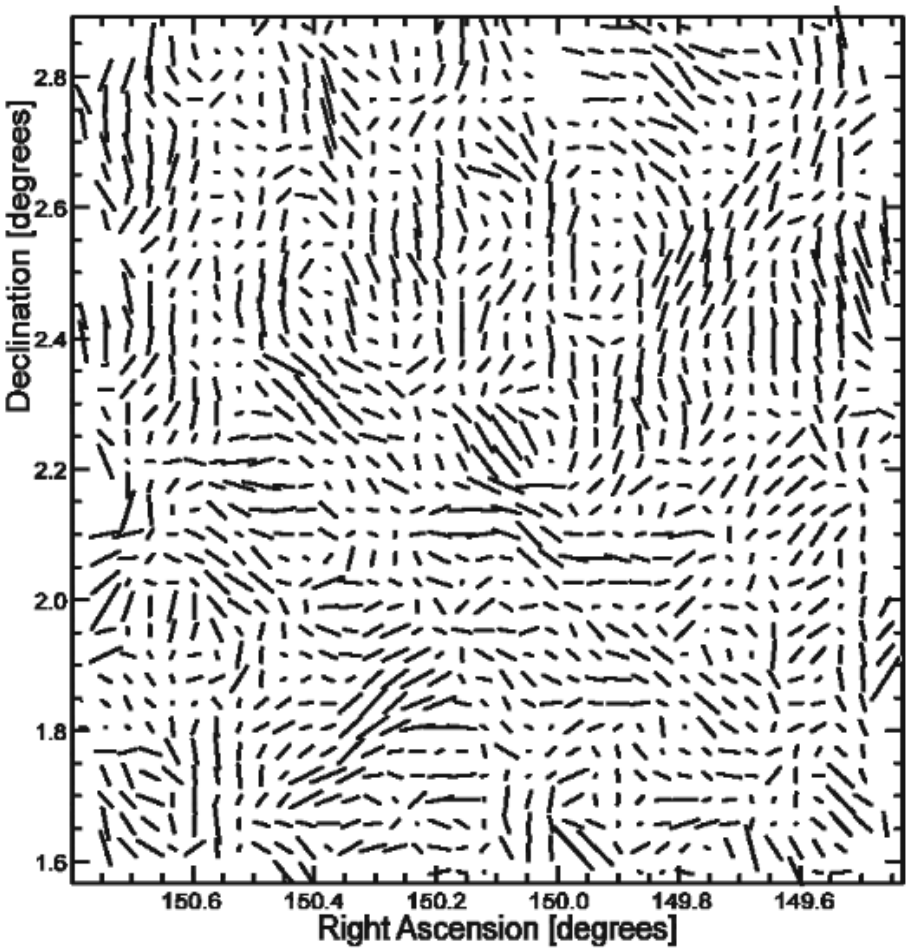

Measure the ellipticity of background galaxies to reconstruct the 2D mass of structures through the shear correlation function

WL tomography

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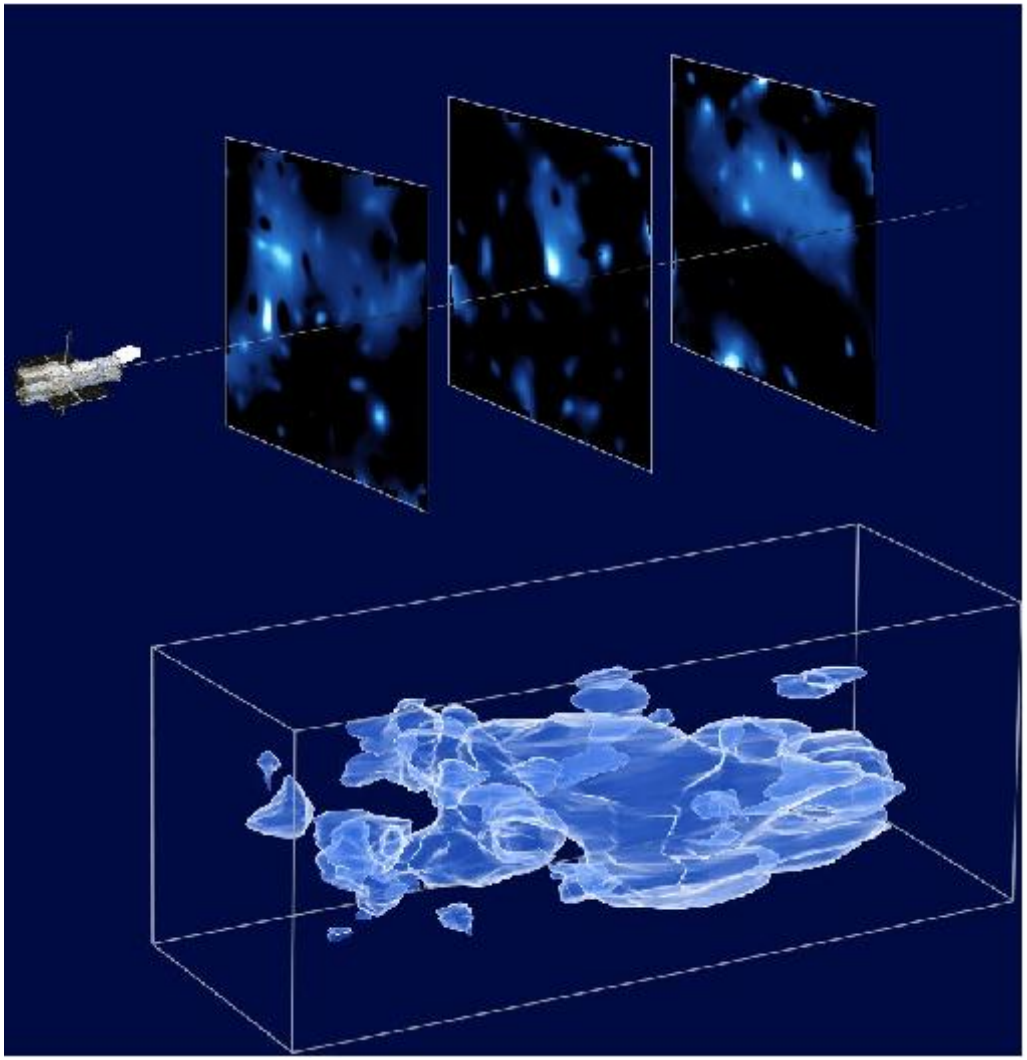
Shear correlation function
on small and large scale structures in redshift slices

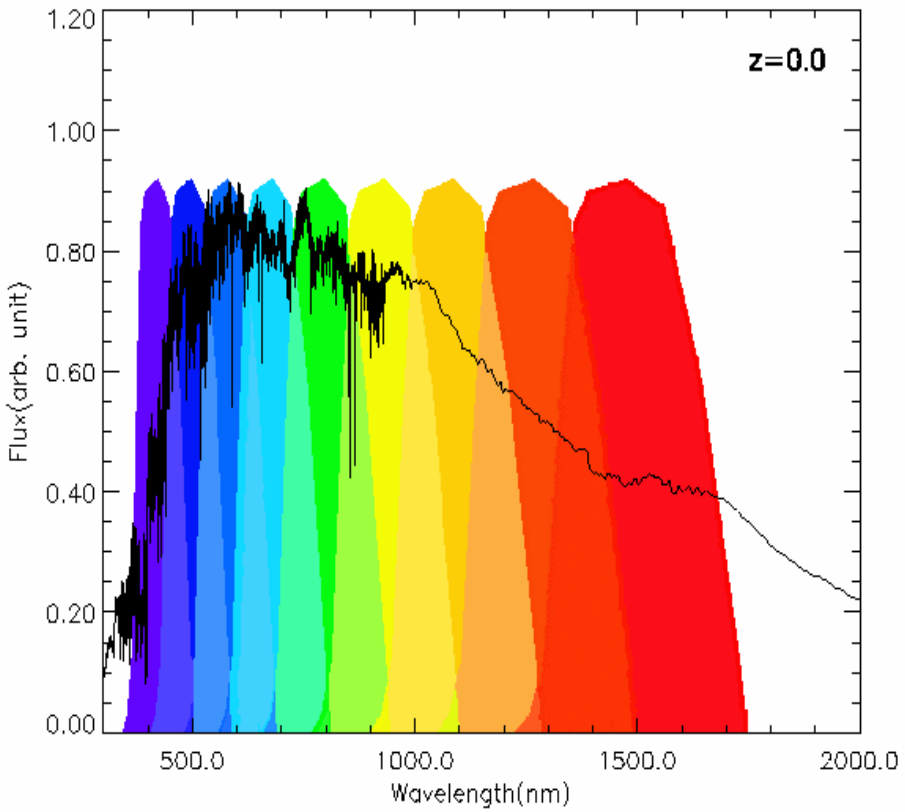
Mass maps of the Universe

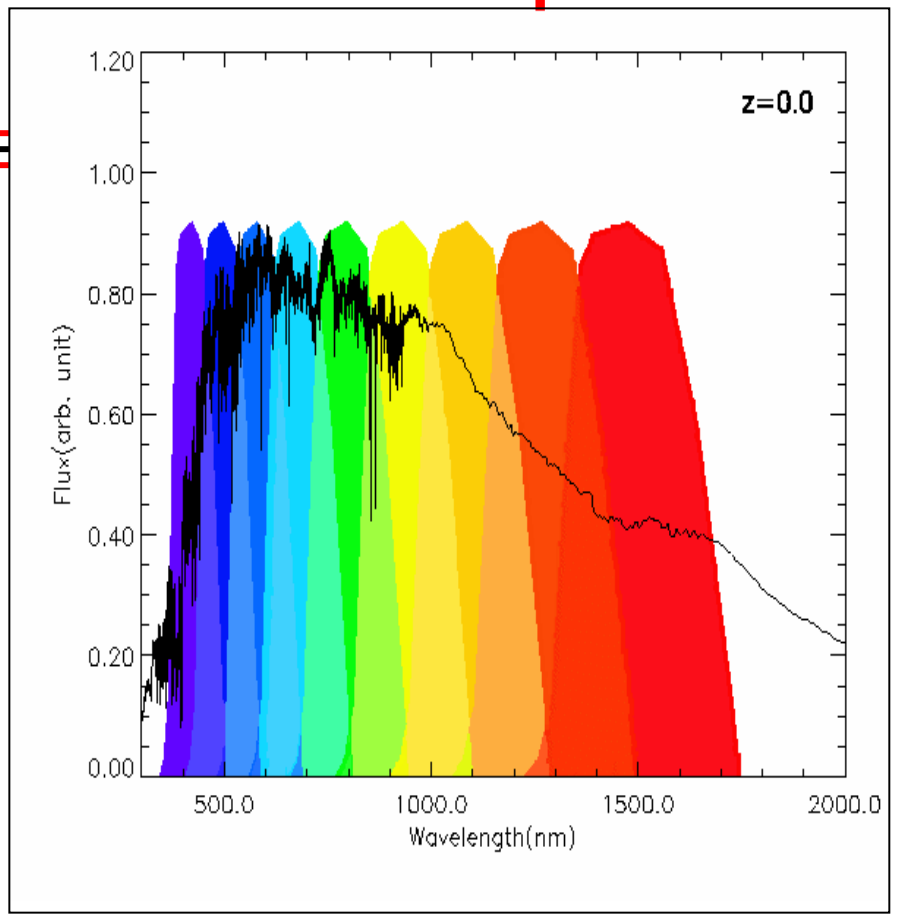
Measure the growth of structure, the cosmological parameters



WL is a weak signal + needs a large number of galaxies with a redshift

Photometric redshift technique





1. Construction of a library of spectra
2. Integrated through filters => predicted colors

Le Phare code Arnouts & Ilbert
Ilbert et al. 2006, 2009

Match between observed and predicted colors with a χ^2

Future dark energy mission : Optical/Near-Infrared Observables

- **Imaging survey:**
  - galaxy position: 2D correlation function
  - galaxy shape: Weak Lensing
  - redshift (Weak lensing & BAO)

  => multi-band photometry
  - (transients detection: SuperNovae)

- **Spectroscopic survey:**
  - galaxy position: 3D correlation function: BAO & Redshift distortions
  - (redshift of SuperNovae Ia)

Dark Energy Survey Status

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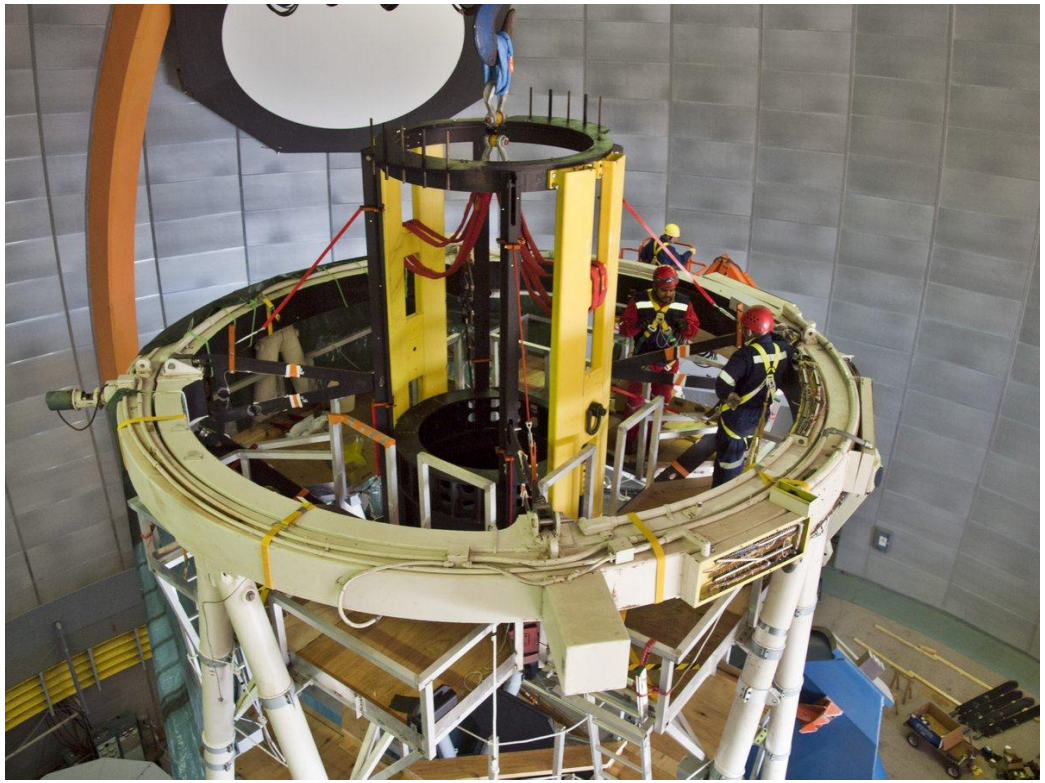

Slides from Josh Frieman

DOE Pre-Operations Review

May, 2012

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Physics Nobel Prize 2011

- Congratulations to DES collaborator Saul Perlmutter, Adam Riess, Brian Schmidt & their teams on the prize for SN discovery of cosmic acceleration using the Blanco
- Highlights the importance of our field & our endeavor
- 1998-present: confirmation of the discovery
- Coming decade: aim to understand *why* the universe is accelerating: dark energy? Modified gravity? Λ?
- Answer likely to have profound impact on our understanding of fundamental physics
- DES designed to address these questions, using multiple, complementary approaches

21

The DES Collaboration

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Fermilab
University of Illinois at Urbana-Champaign/NCSA
University of Chicago
Lawrence Berkeley National Lab
NOAO/CTIO
DES Spain Consortium
DES United Kingdom Consortium
University of Michigan
Ohio State University
University of Pennsylvania
DES Brazil Consortium
Argonne National Laboratory
SLAC-Stanford-Santa Cruz Consortium
Universitats-Sternwarte Munchen
Texas A&M University

plus Associate members at: Brookhaven National Lab, U. North Dakota, Paris, Taiwan

Over 120 members plus students & postdocs

Funding: DOE, NSF; UK: STFC, SRIF; Spain Ministry of Science, Brazil: FINEP, Ministry of Science, FAPERJ; Germany: Excellence Cluster; collaborating institutions

DES-Brazil Dark Energy Survey

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The DES Collaboration (Oct 2010)

The Dark Energy Survey

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- Stage III DE project using 4 complementary* techniques:
  - I. Cluster Counts
  - II. Weak Lensing
  - III. Large-scale Structure
  - IV. Supernovae

- Two multiband surveys:
  - 5000 deg2 *grizY* to 24th mag
  - 30 deg2 repeat (SNe)

- Build new 3 deg2 FOV camera and Data management system

Survey 2012-2017 (525 nights)

Blanco 4-meter at CTIO

*in systematics & in cosmological parameter degeneracies

*geometric+structure growth: test Dark Energy vs. Gravity

DES Science Summary

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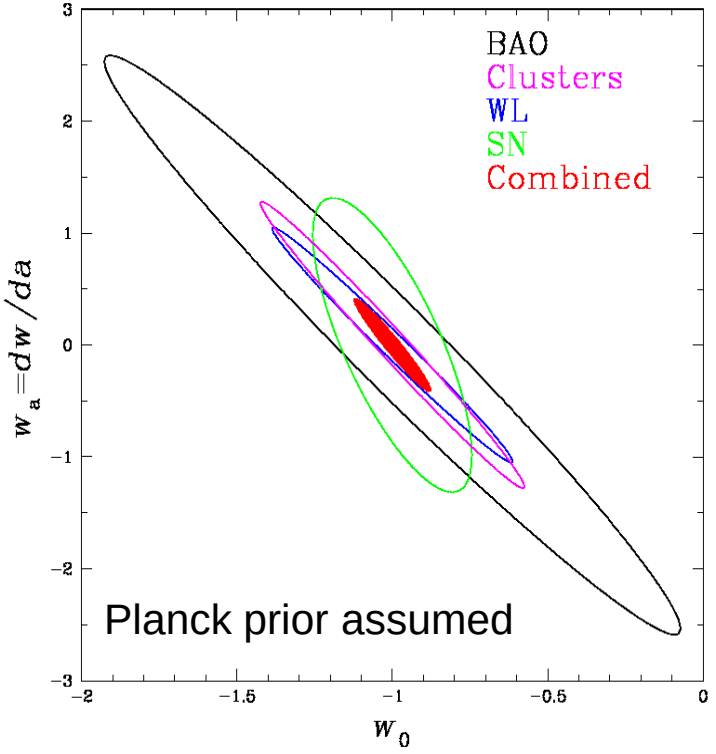
Four Probes of Dark Energy

- **Galaxy Clusters**
  - ~100,000 clusters to z>1
  - Synergy with SPT
  - Sensitive to growth of structure and geometry
- **Weak Lensing**
  - Shape measurements of 200 million galaxies
  - Sensitive to growth of structure and geometry
- **Large-scale Structure (BAO)**
  - 300 million galaxies to z = 1 and beyond
  - Sensitive to geometry
- **Supernovae**
  - 30 sq deg time-domain survey
  - ~4000 well-sampled SNe Ia to z ~1
  - Sensitive to geometry

Forecast Constraints on DE Equation of State



Factor 3-5 improvement over Stage II DETF Figure of Merit

Project Structure & Timeline: Construction

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- 3 Construction Projects:
  - DECam (hosted by FNAL; DOE supported)
  - Data Management System (NCSA; NSF support)
  - CTIO Facilities Improvement Project (NSF/NOAO)

- Project initiated 2003
- DECam R&D 2004-9
- Instrument construction, integration, testing 2008-11; DECam complete. DESDM development continuing
- All DECam components shipped to Chile and checked out (except CCD spares)

Project Structure & Timeline: Toward Operations

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Installation schedule v8.7

- Telescope shutdown for Installation began Feb. 20, 2012
- Old prime focus cage removed, mid-April
- Practice installation of new cage (empty), April 23
- Installation of new cage (with corrector), early May
- Rebalance and dress telescope with cables and hoses, June-July
- Imager installation on telescope: Aug. 2012
- Imager first light on telescope: Sept. 1, 2012
- Commissioning and Science Verification*: Sept.-mid. Nov. 2012
- Survey: ~late-Nov. 2012-late 2017 (typically 105-night seasons)

*At end of SV, CTIO Director recommends to NOAO Director that DECam System be accepted for science operations for community and DES: system should meet community and DES requirements

Tremendous Recent Progress

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- Prime focus cage, hexapod, corrector barrel with lenses, filters, filter changer, shutter, imager with CCDs, cooling system all safely arrived on the mountain, tested, and many components installed, including SISPI computers, RASICAM, new flat screen.
- CTIO glycol system overhauled, clean room prepared
- Installation has begun and well underway
- Data Management secured major NSF grant for operations; progress on astronomy codes, processing capability, database, data access; release of Data Challenge DC6B to collaboration Oct. 2011
- Progress on Community Pipeline, v1.3 installed at NOAO and being tested
- Collaboration actively engaged in data quality testing and analysis code development and testing.

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DECam at CTIO

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Blanco Telescope Upgrades

- CTIO Facilities Improvement Project –
  - Primary mirror radial supports redesigned & swapped out
  - Telescope Control System upgraded
  - Telescope Environmental Control System improved
  - Various other Facility Improvements completed or underway:
    - Clean Room built inside the Blanco Coudé Room
    - Upgrades to the building glycol system
    - Relocated and enlarged Control Room & Computer Room
    - Installation of utility & cryogen lines for DECam and NEWFIRM
    - Enhanced bandwidth from La Serena to the USA
    - Data Transport System for reliable data transfer

30

Landscape of (Potential) Collaborating Projects

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- South Pole Telescope (SPT)
  - 2500 sq deg completed. MOU to facilitate collaboration approved
- Vista Hemisphere Survey (VHS)
  - Deeper JHK imaging over DES footprint underway. MOU will be drafted
- Vista VIDEO Survey
  - Near-coincident NIR imaging of SN fields planned. Informal agreement exists
- eBOSS: participated in internal proposal to AS3, discussions underway
- BigBOSS: Joint Working Group just reported. Revised footprint overlaps ~600 sq deg w/ BigBOSS/eBOSS. Larger overlap would degrade image quality, given 525-night constraint. Solution: e(xtended)-DES, in collaboration w/ other projects, optimally scheduled with DES.
- DESpec: spectroscopy over DES/LSST footprints
- Euclid: letter of support for collaboration, will discuss in Munich
- Skymapper, HSC, PanSTARRS, LSST: cross-calibration
- Community users of DECam
  - DECam Community Use Workshop demonstrated community interest in mini-survey-scale projects and in collaboration with DES. Discussion of north equatorial survey.

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Concluding Remarks

- **DES project** has made great progress over the last year, though with some schedule slippage.
- **DECam** complete.
- **Installation** well underway.
- **Commissioning and transition to survey operations** this year: commissioning and operations plans exist, details being refined, Year-1 science program/strategy mature & flexible.
- **Data Management system** has made good recent progress, but needs support to deliver on science requirements and operational readiness; will need to phase in functionality.
- **SWG activity** continuing to ramp up and will be critical during commissioning, Science Verification, and early operations.
- We will soon have a fantastic instrument on a world-class telescope and embark on a great, discovery-filled survey.

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DECam Project and DES Operations Management

Slides from Brenna Flaugher,
DECam Project Manager, DES Operations Manager

Dec. 2010

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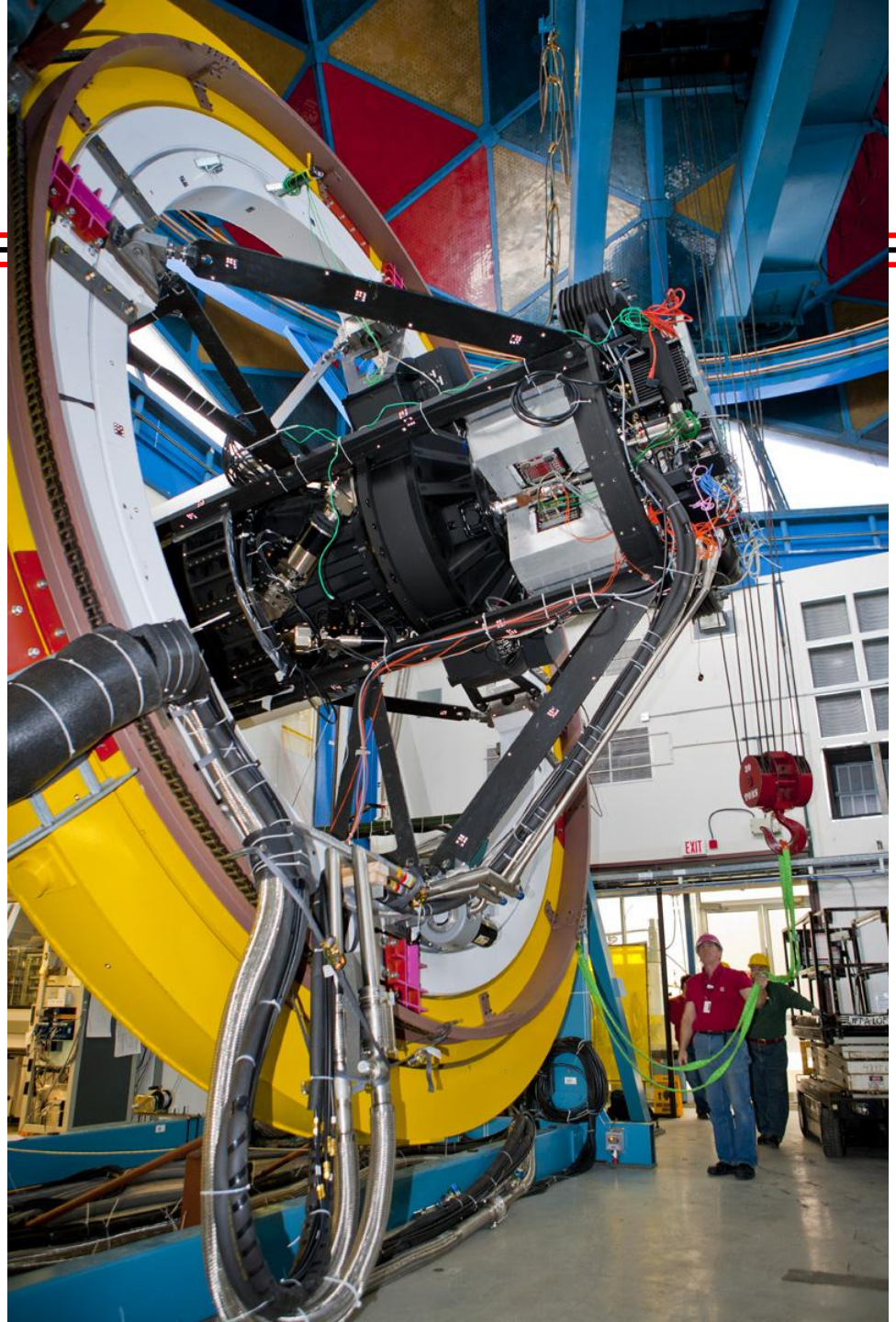
- Most DECam systems complete and full system tests (except the optics) on telescope simulator

  Imager with 28 CCDs installed, Filter changer, shutter, hexapod, LN2 cooling, CCD readout crate cooling, all exercised in multiple positions.
- Mock Observing Feb. 2011
- Rest of 2011:
  - Packing, shipping, checkout in Chile
  - Installation of science CCDs in imager



nipping

DARK ENERGY SURVEY

Large heavy parts were shipped by boat

- Oct 2010 F/8 handling system
- June 2011 Cooling system parts
- Aug 2011 Cage, NW platform, etc.
- Dec 2011 Final cooling sys parts

More delicate pieces by truck and air

- May 2011 RASICAM
- June 2011 Hexapod, Filter Changer and Shutter
- June 2011 Parts of LN2 Cooling system
- July 2011 i and z filters (from Japan to Chile) [delayed by volcano eruption]
- Aug. 2011 r and y filters (from Japan to Chile)
- Nov 2011 The Imager (with CCDs installed!)
- Dec 2011 The corrector (with lenses installed)
- April 2012 The g filter!

July 25-Aug. 5: Shutter, FCM, Hexapod testing @ CTIO

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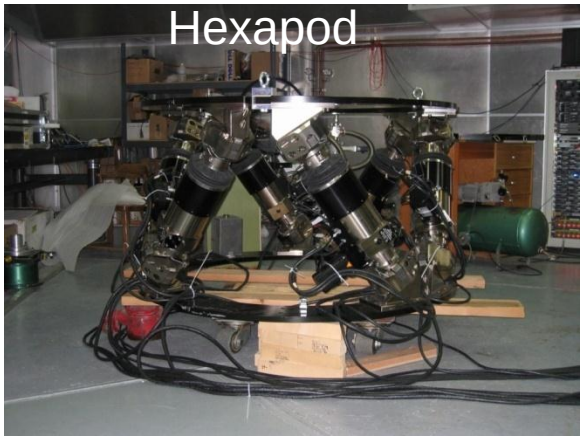
Tom Diehl exercising the shutter

Filter changer operating in the Coudé room

- Hexapod operating at CTIO



Team of 3 -7 people from Fermilab in Chile from early July – Mid August

A year ago (May 2011) we were just starting to install science grade CCDs into the imager

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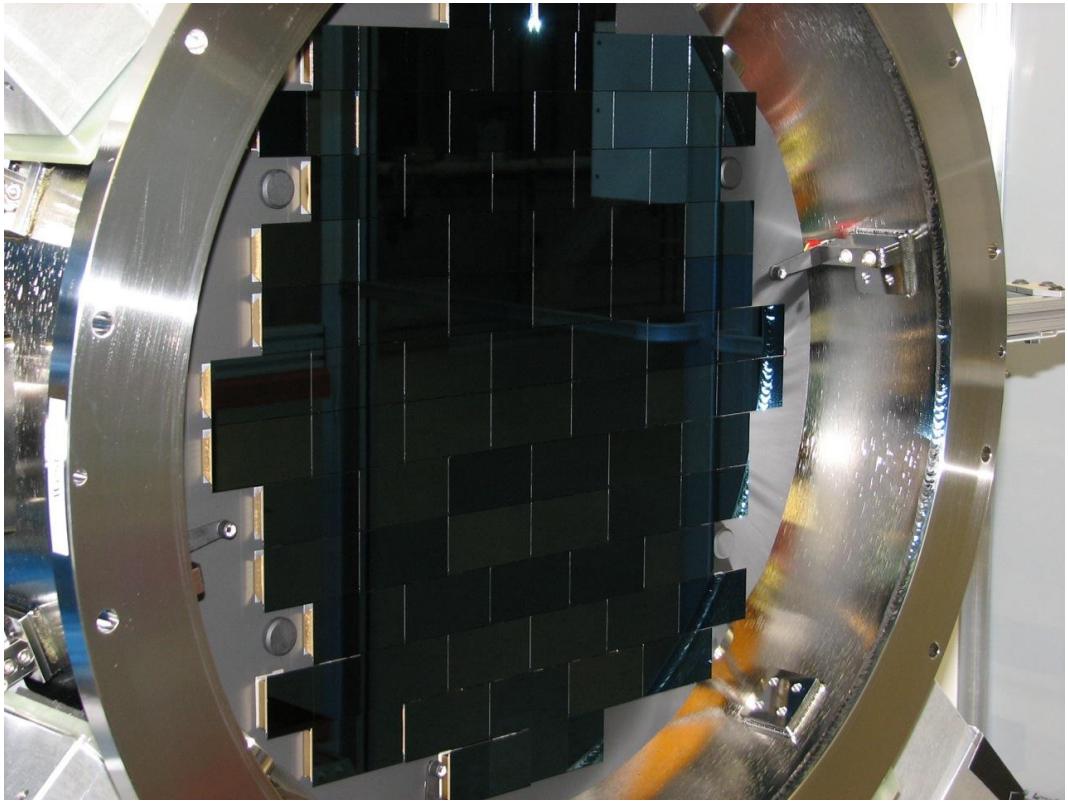
By end of July 2011 imager had all the science grade CCDs installed and tested.

~ 2 years experience with CCDs in prototype imager helped this go smoothly



Cooled down & Reading Out!

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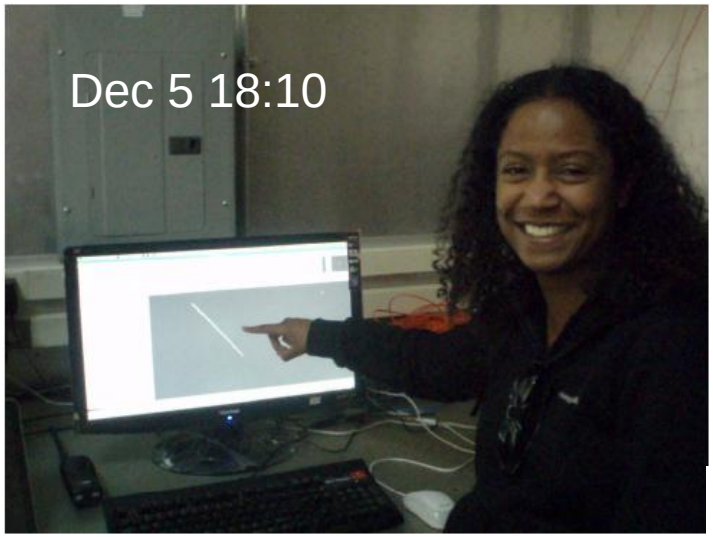
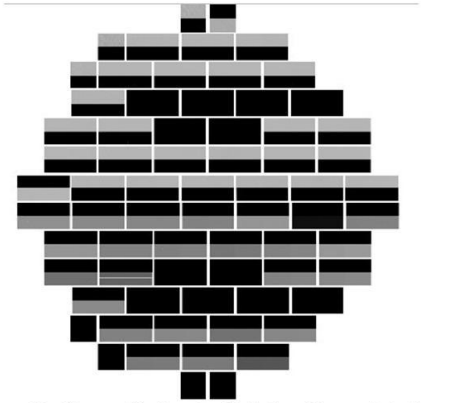
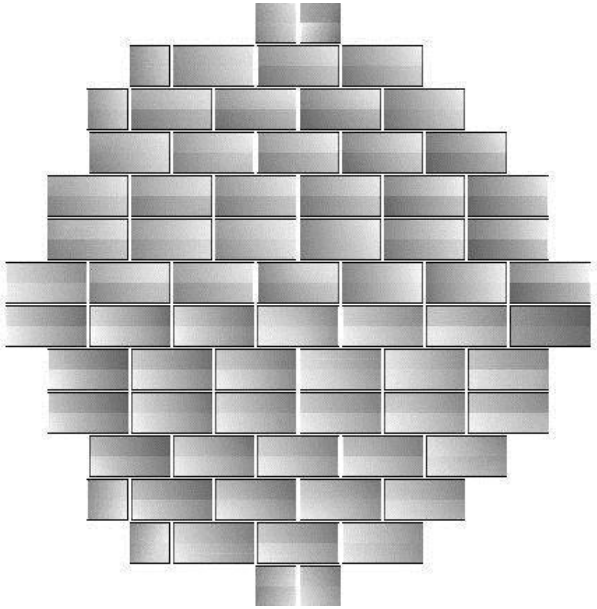




The horizontal line 5th row up 2nd ccd over is a ds9 display artifact, not a bad column.

Later on Dec. 5



Dec. 6: Beautiful flat field Image!!

Optics

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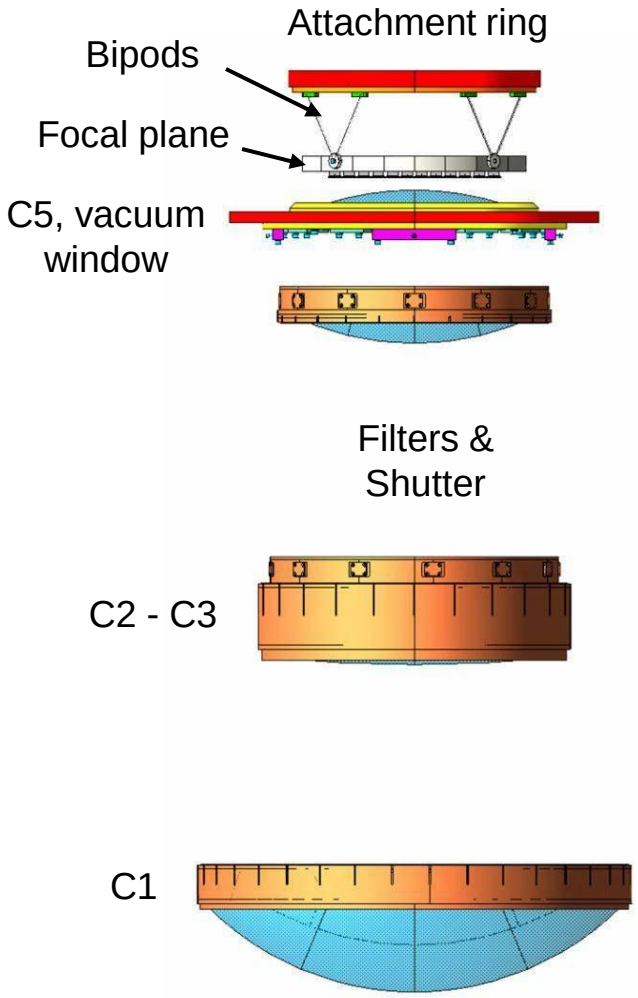
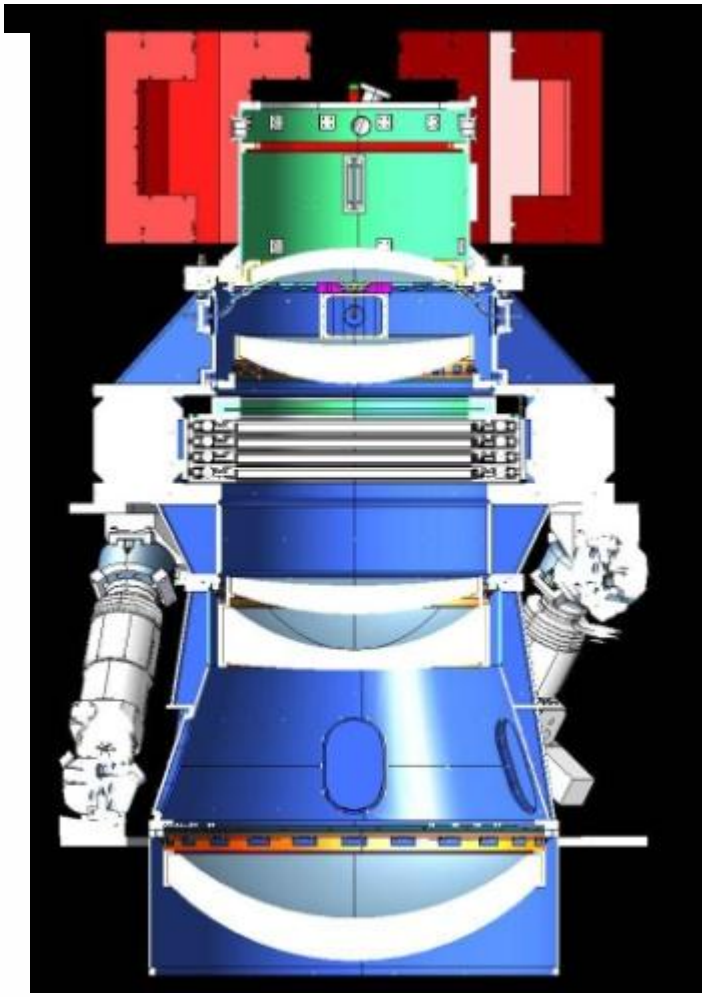
- Univ. College London led the production of the optics with funding from STFC
- Ordered the Blanks ~ July 2007 (~1M$) using funds from DES Universities in the UK and US
- Coating finished June 2011: 4 Years!!!
- UCL installed the lenses in the cells and barrel @ UCL then shipped barrel in 2 parts to CTIO





Lens Fabrication 2007-2011

Steve Kent inspecting the C1 Blank (980mm diameter) at Corning Jan. 2008

C1 polishing complete Jan. 2011
C4 coating complete June 2011
Barrel delivered to CTIO Dec. 2011

Optics Alignment check @ CTIO

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Jan. 2012:
UCL alignment frame and rotary table, laser frame in cleanish area on G floor @ CTIO

Alignment of lenses C2,C3, C4 checked after shipping with laser alignment system

Then barrel was assembled and alignment of the whole system was checked.

Optical corrector assembly at CTIO

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Peter, Mich and David from UCL assembling the DECam optical corrector

Jan. 19, 2012

By Jan. 20th we had confirmed that everything is within specifications!

page

Filters

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620mm substrate, 600mm clear aperture, largest ever, tight uniformity constraints.

Contract placed in Sept. 2009.

Asahi built and commissioned a huge coating chamber as well as custom cleaning, polishing and testing equip.

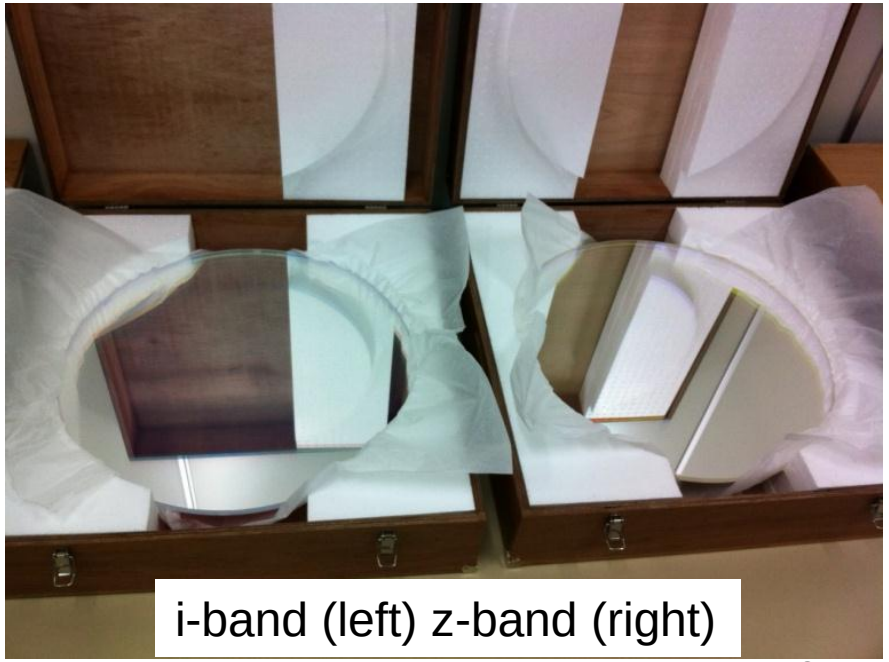
At the time of the last review (May 2011) Asahi had completed 3 sides of 3 filters and then had the earthquake and Tsunami, and this procurement was on the DOE watchlist

By August the r, i, z and y were complete and in Chile

Early August another earthquake!

April 2012: the g filter arrived safely in Chile!

Asahi has now demonstrated repeatable and excellent filter production for DES as well as HyperSuprimeCam

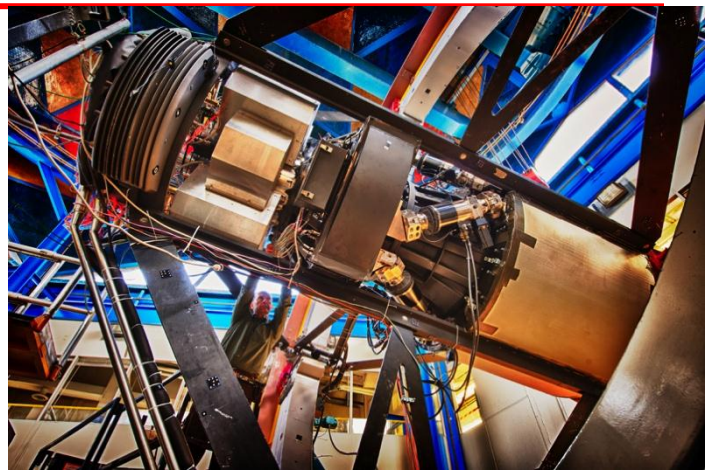


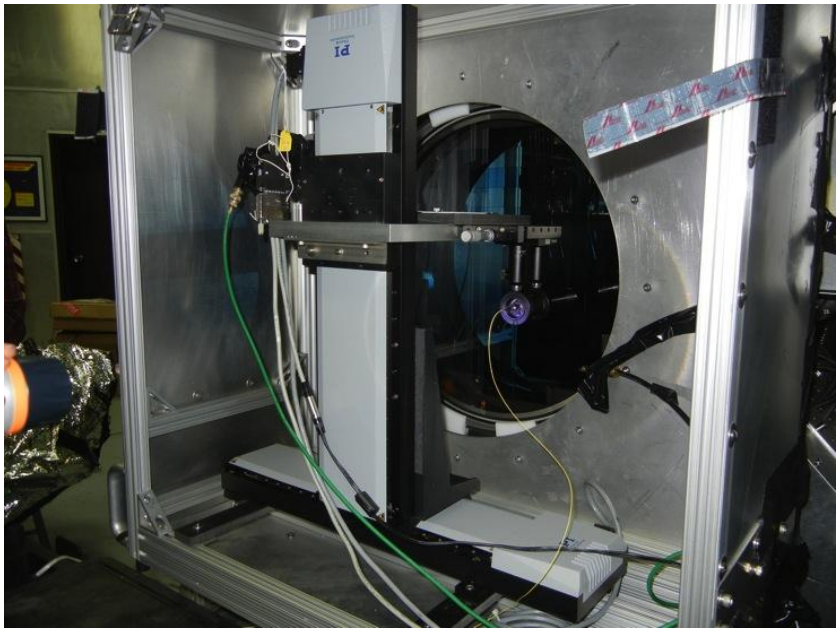
i-band (left) z-band (right)

Mock Observing

DARK ENERGY SURVEY

Feb. 2011 first full system tests
@ FNAL on telescope simulator, operations tested with DECam in different orientations
Experienced observers provided feedback





Jan. 2012 @ CTIO imager in Coude Room, tests with new guide star projector during Mock observing run uncovered a problem with the guider transition cards.

April 2012 @ CTIO imager in Coude Room, new guide trans. cards tested during another Mock observing run:
The new cards work!
Network problems gone!

DES Trip Plans: Commissioning Phase 2

DARK ENERGY SURVEY

Commissioning Phase 2 begins after all the DECam components are installed, connected and individually checked

We assume we will need to support 4 people on DOE funds on average at CTIO over this 6 week period to help with for example focus, alignment, SISPI, guiding, Obstac, Calibrations, various training and debugging

Commissioning will be followed by a 4 week science verification period and we have assumed 2 DOE supported people will be needed at CTIO on average over this period

DARK ENERGY
SURVEY

Andean Condor

DARK ENERGY
SURVEY

END

Thanks for your attention!

DES Filters & Photo z's

DARK ENERGY SURVEY

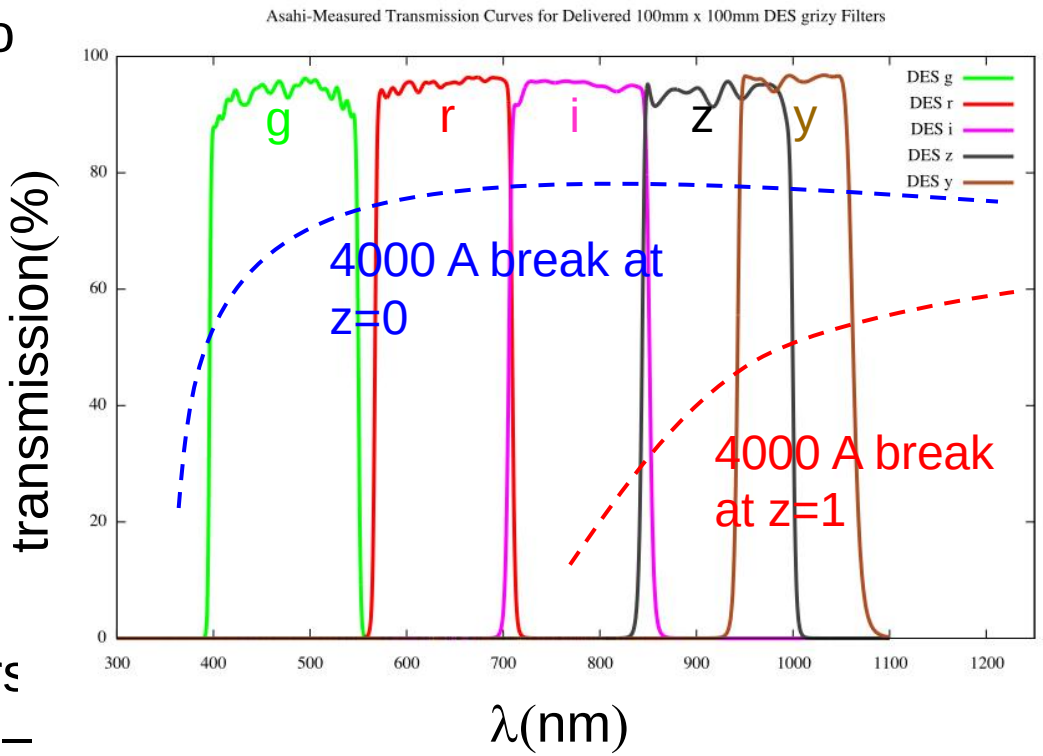
- Measure relative flux in *grizY filters* and track the "4000 Angstro break"

- Estimate individual galaxy redshifts with accuracy $\sigma(z) < 0.1$ (~0.02 for clusters)

- Filters produced by Asahi Spect (Japan)

- They also produced100mm filters for the Precam calibration survey – excellent transmission!

Asahi 100mm filters



DES Science Committee

SC Chair: O. Lahav

Large Scale Structure: E. Gaztanaga & W. Percival

Weak Lensing: S. Bridle & B. Jain

Clusters: T. McKay & J. Mohr

SN Ia: J. Marriner & B. Nichol

Photo-z: F. Castander & H. Lin

Simulations: G. Evrard & A. Kravtsov

Galaxy Evolution: D. Thomas & R. Wechsler

QSO: P. Martini & R. McMahon

Strong Lensing: L. Buckley-Geer & M. Makler

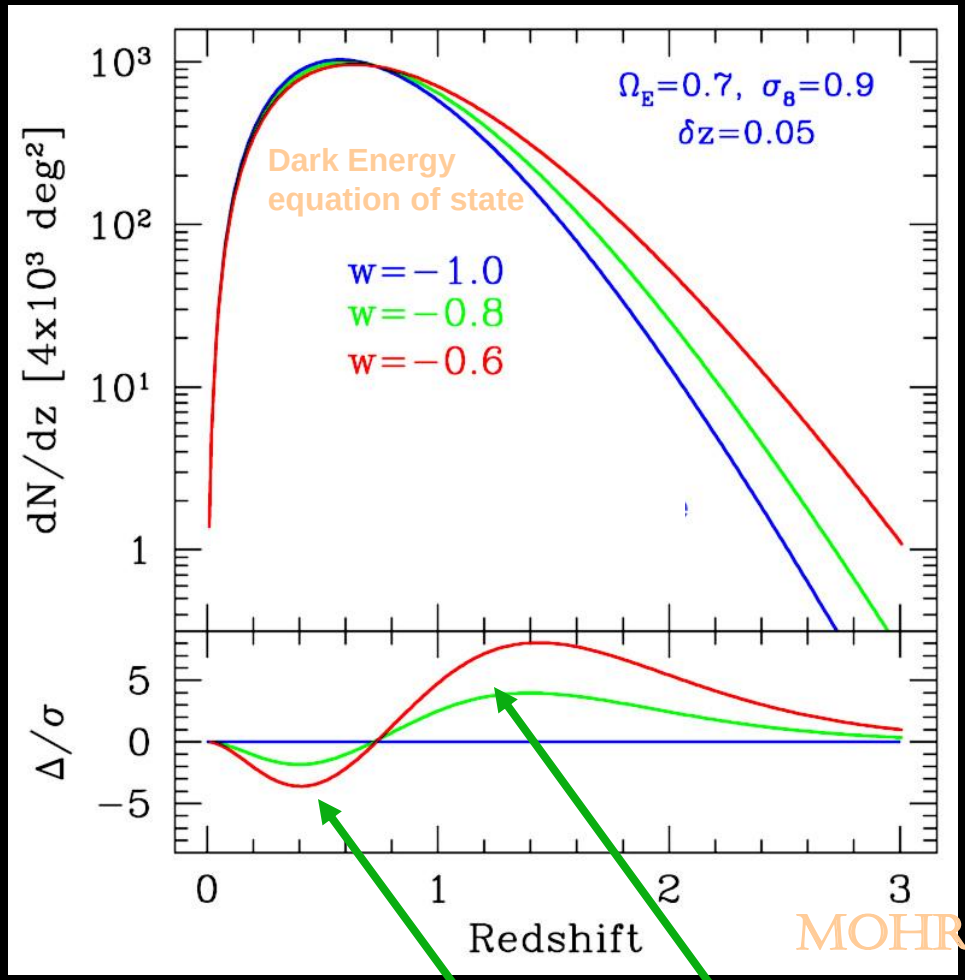
Milky Way: B. Santiago & B. Yanny

Theory & Combined Probes: W. Hu & J. Weller

Cluster counts

Number of clusters above mass threshold

- Elements of the Method:
  - •Clusters are proxies for massive halos and can be identified optically to redshifts z>1
  - • Galaxy colors provide photometric redshift estimates for each cluster
  - • Observable proxies for cluster mass: optical richness (DES), SZ flux decrement (SPT), weak lensing mass (DES), X-ray flux (eRosita)
  - • Cluster spatial correlations help calibrate mass estimates



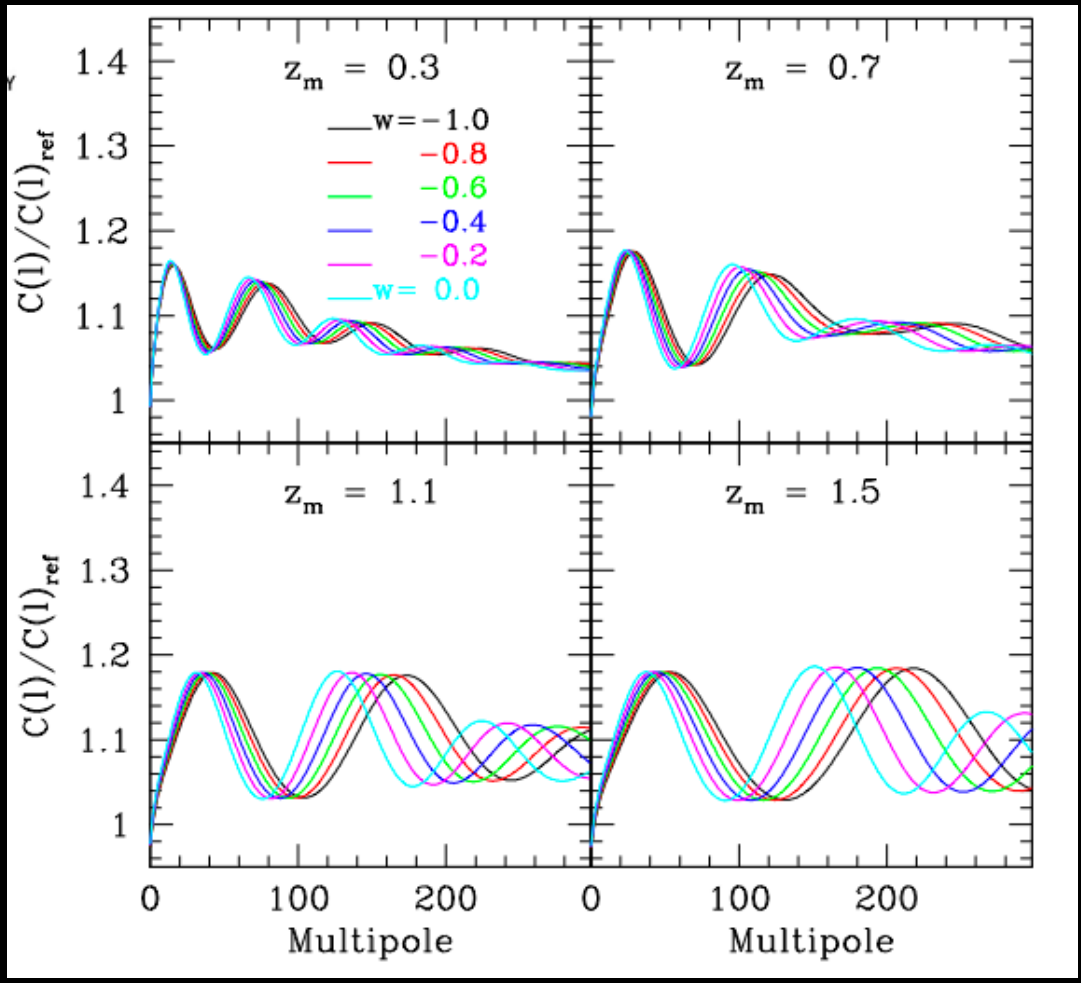
- •~100,000 clusters to z>1
- •Synergy with SPT
- •Sensitive to growth of structure and geometry

DARK ENERGY SURVEY

LARGE SCALE STRUCTURE

Galaxy Angular Correlation Function in Photo-z bins -> baryon acoustic oscillations

Systematics: photo-zs, correlated photometric errors, non-linearity, scale-dependent bias



Fosalba & Gaztanaga

- 300 million galaxies to z = 1 and beyond
- Sensitive to geometry