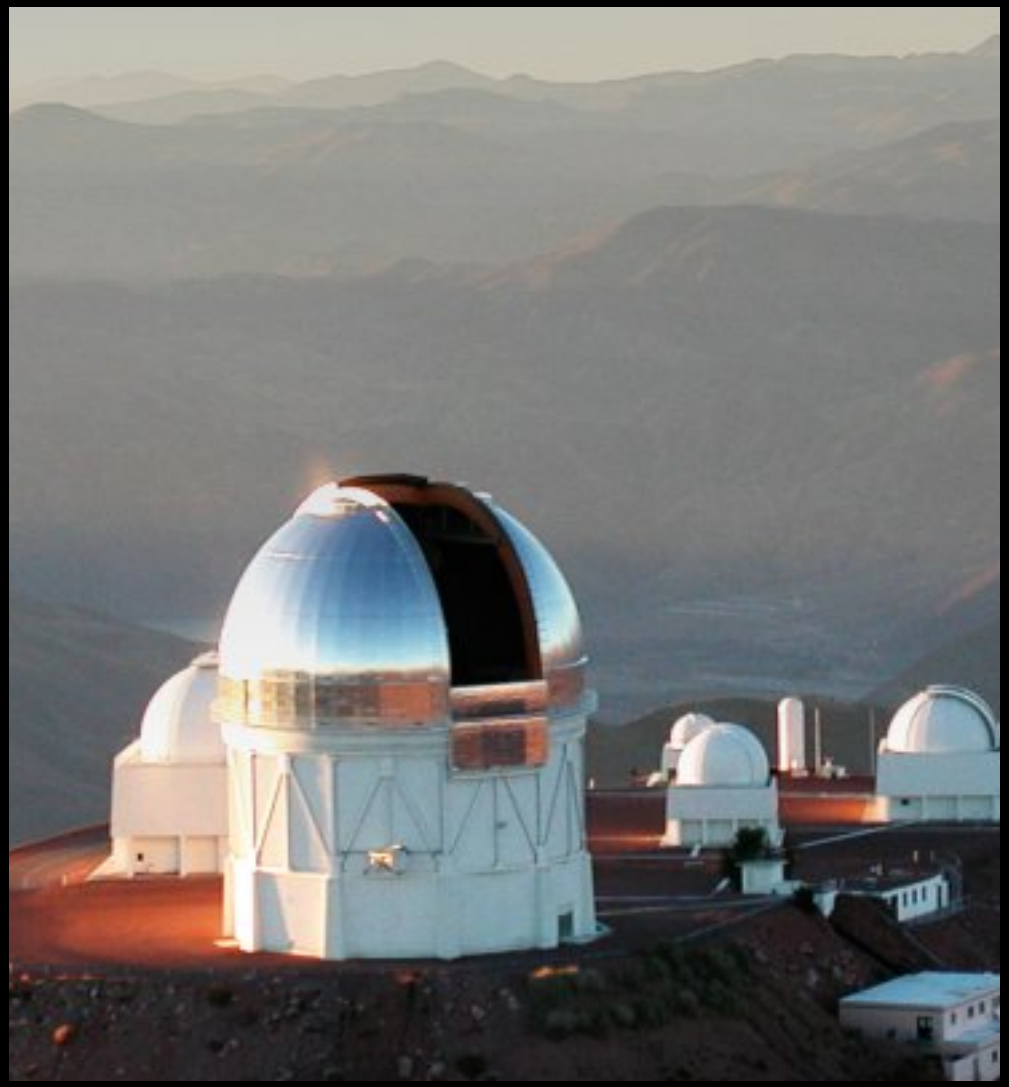
The Dark Energy Survey

Sarah Bridle (University College London)
DES Weak Lensing Working Group Co-Coordinator

The Dark Energy Survey

- Dark Energy
- DES Collaboration
- DES Science
- DECam
- Survey Strategy
- Data Management
- Status



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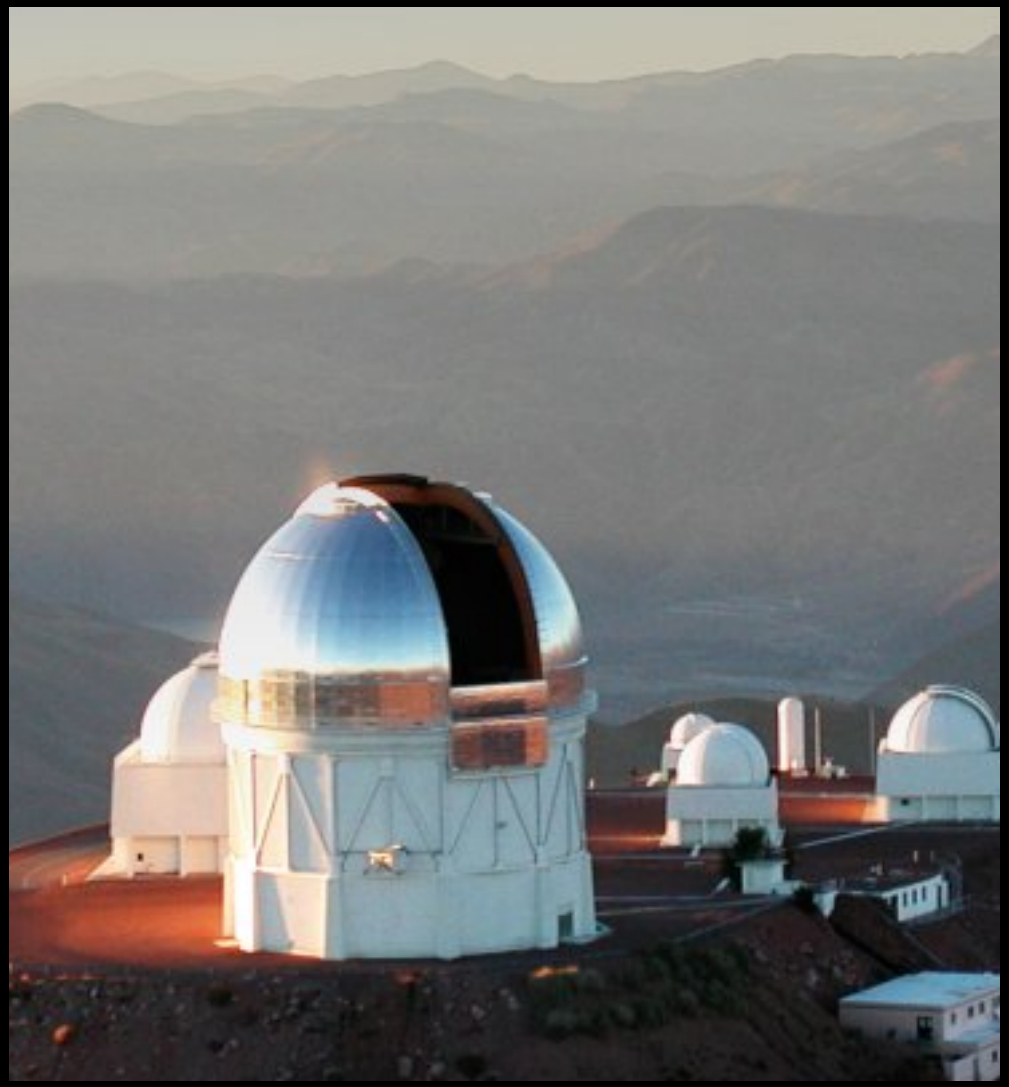
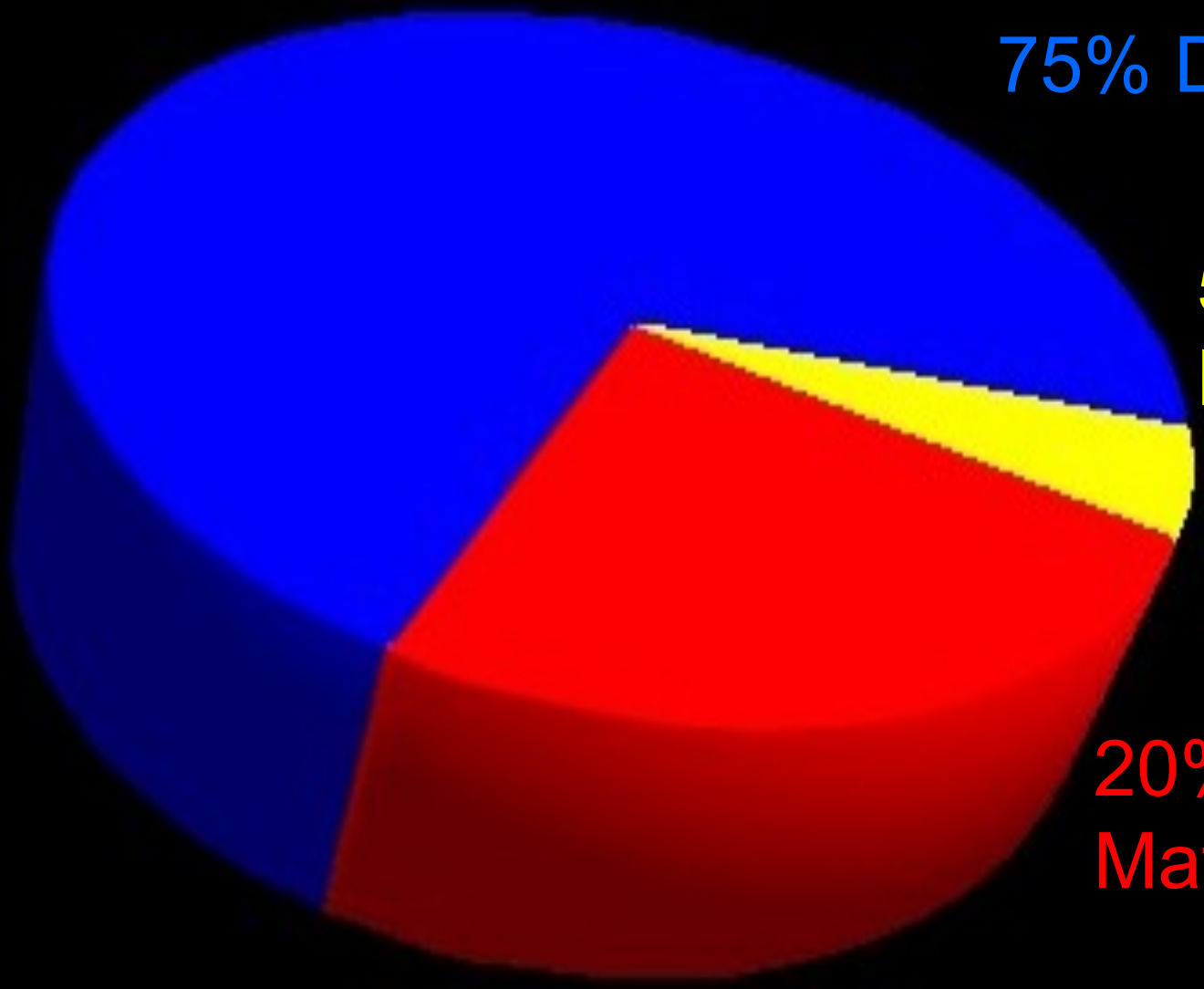


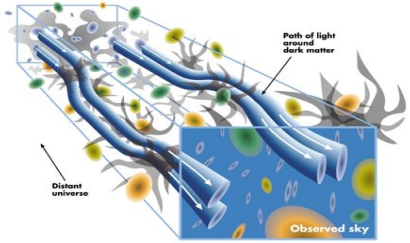
Concordance Model



Probes of Dark Energy

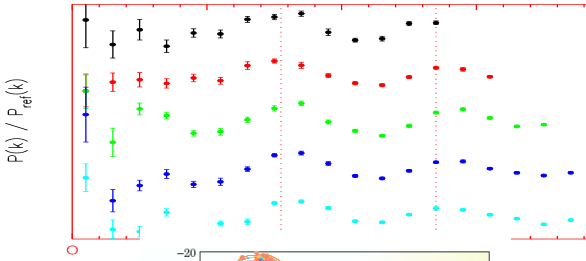
Cosmic Shear

Evolution of dark matter perturbations
Angular diameter distance
Growth rate of structure



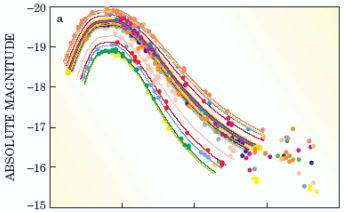
Baryon Wiggles

Standard ruler
Angular diameter distance



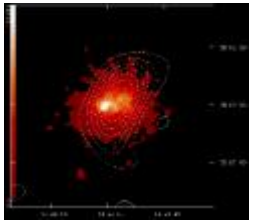
Supernovae

Standard candle
Luminosity distance



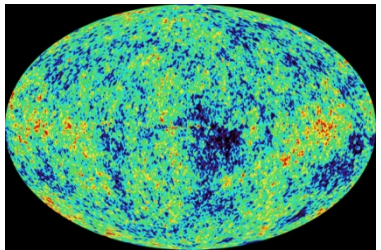
Cluster counts

Evolution of dark matter perturbations
Angular diameter distance
Growth rate of structure



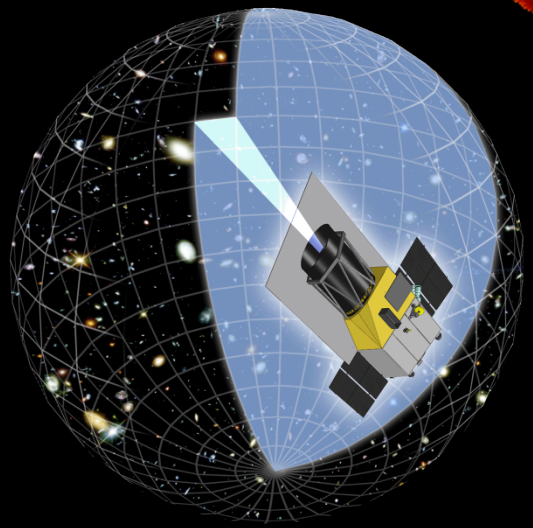
CMB

Snapshot at ~400,000 yr, viewed from z=0
Angular diameter distance to z~1000
Growth rate of structure (from ISW)



Future Dark Energy Surveys

The Dark Energy Survey



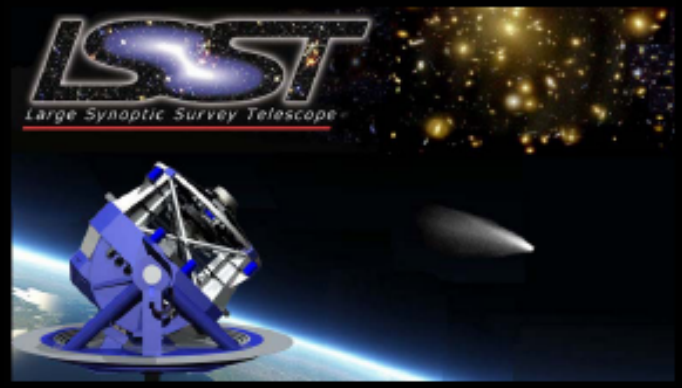
EUCLID

Pan-STARRS

SuMIRe Project

Subaru Measurement of Images and Redshifts

FIRST - 最先端研究開発支援プログラム -



WFIRST

SKA
SQUARE KILOMETRE ARRAY

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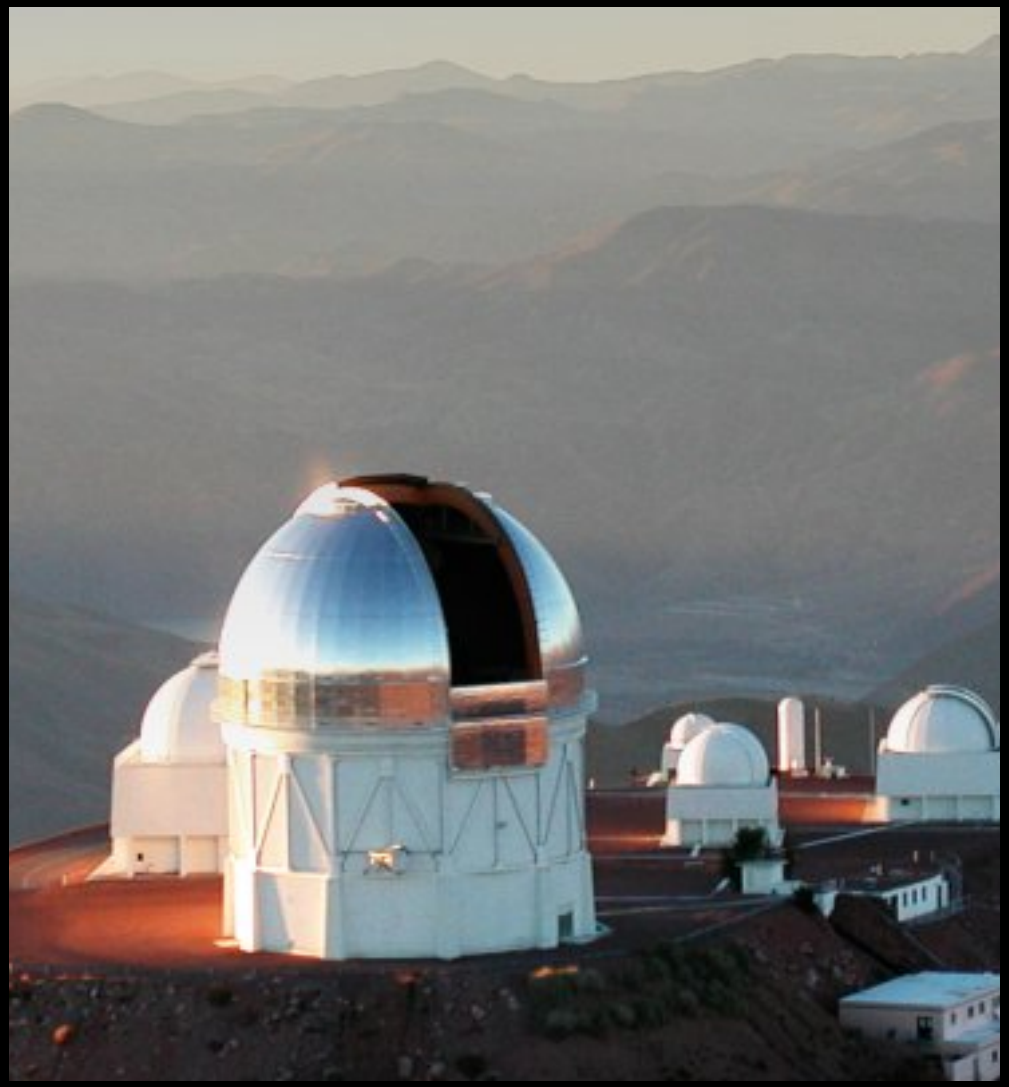


The Dark Energy Survey

- Survey project using 4 complementary techniques:
  - I. Cluster Counts
  - II. Weak Lensing
  - III. Large-scale Structure
  - IV. Supernovae
- Two multiband surveys:
  - 5000 deg^2 *grizY* to 24th mag
  - 30 deg^2 repeat (SNe)
- Build new 3 deg^2 FOV camera and Data management system
  - Survey 2012-2017 (525 nights)
  - Facility instrument for Blanco

The DES Collaboration

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

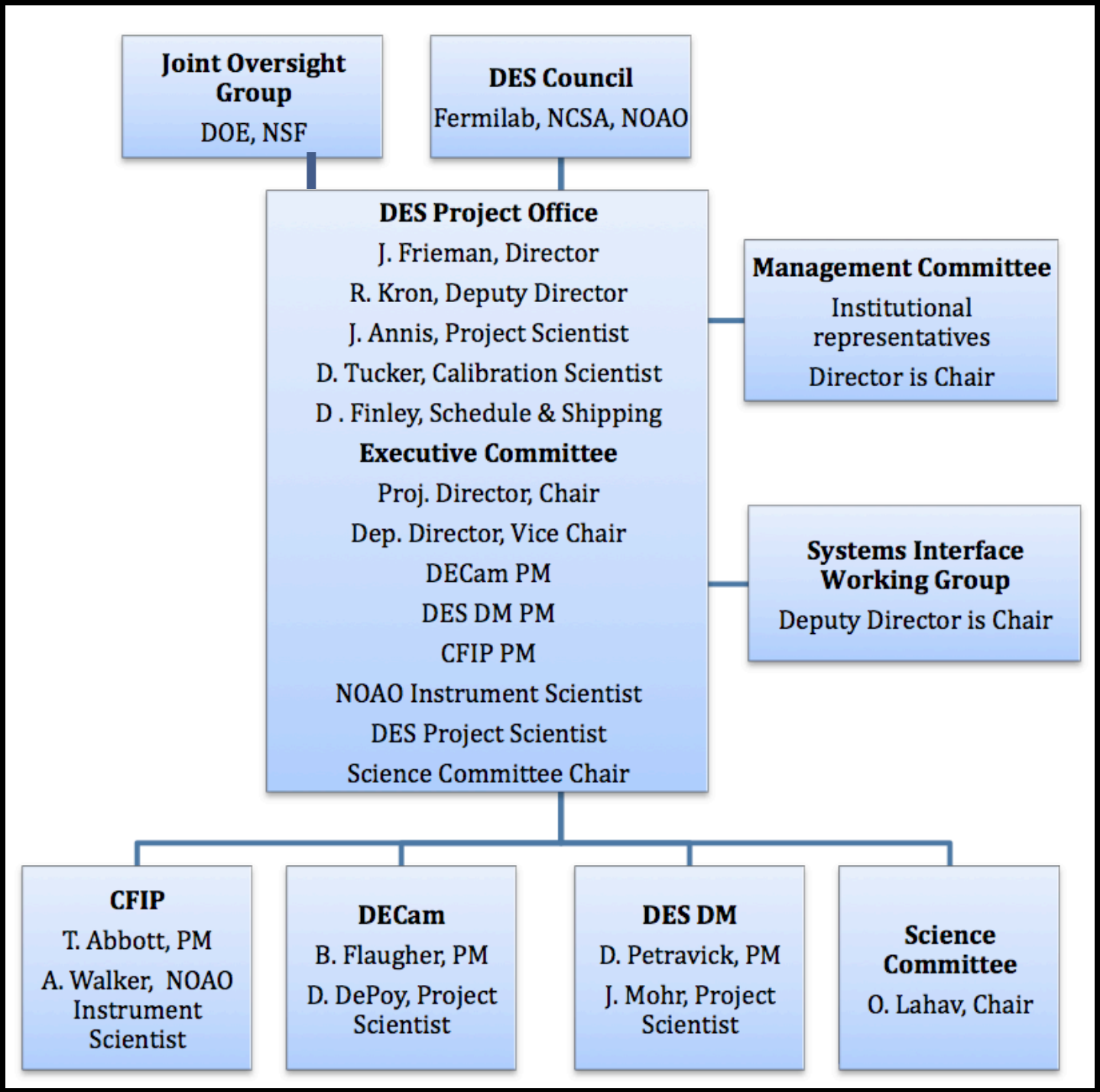
Over 120 members plus students & postdocs

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

DARK ENERGY SURVEY

The DES Collaboration (Oct 2010)

DARK ENERGY SURVEY



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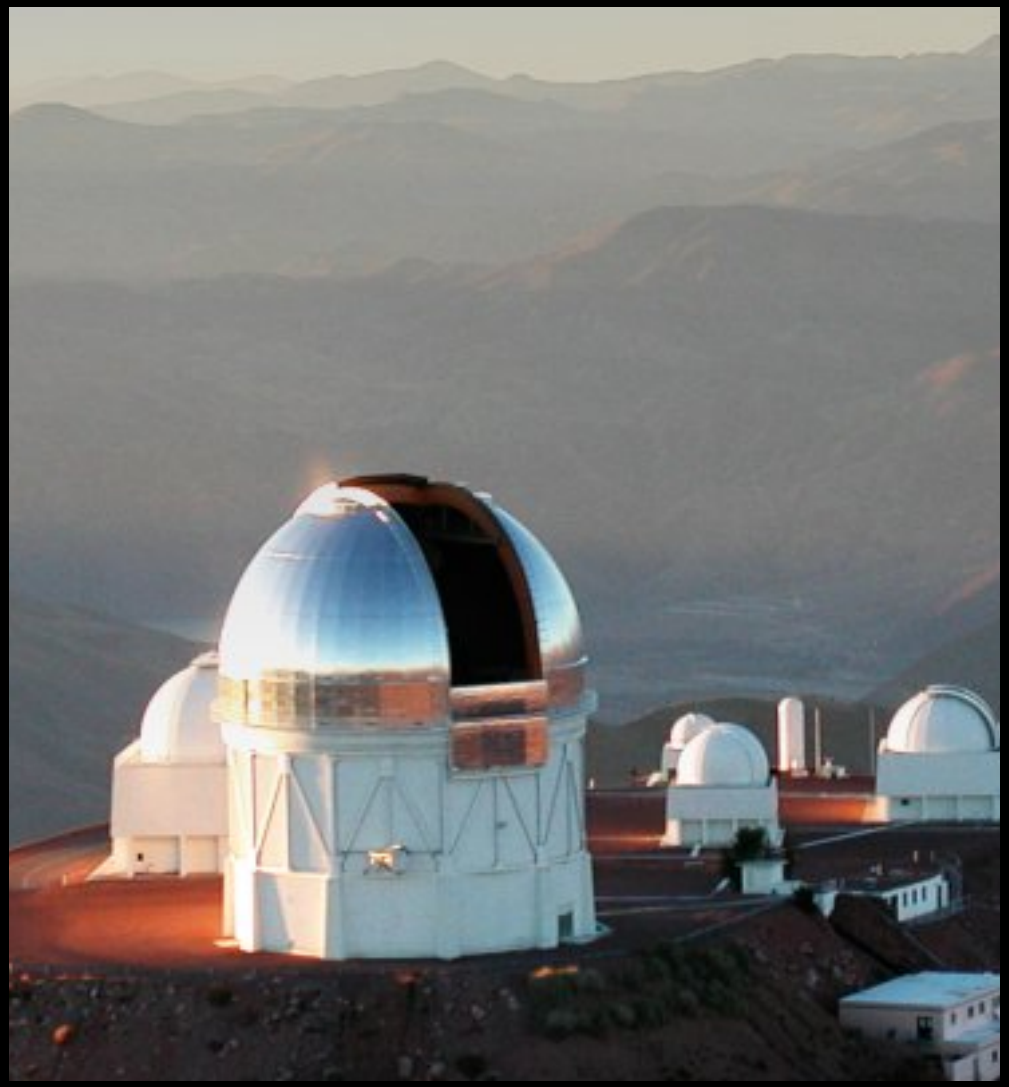


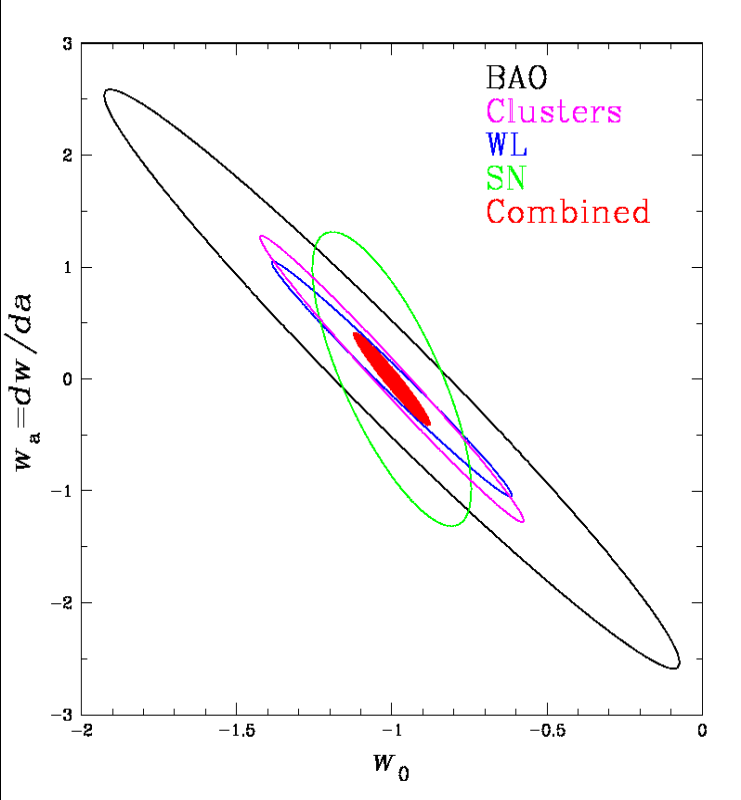
DES Science Committee

- 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

DES Science Summary

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 300 million galaxies
  - Sensitive to growth of structure and geometry
- Baryon Acoustic Oscillations
  - 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



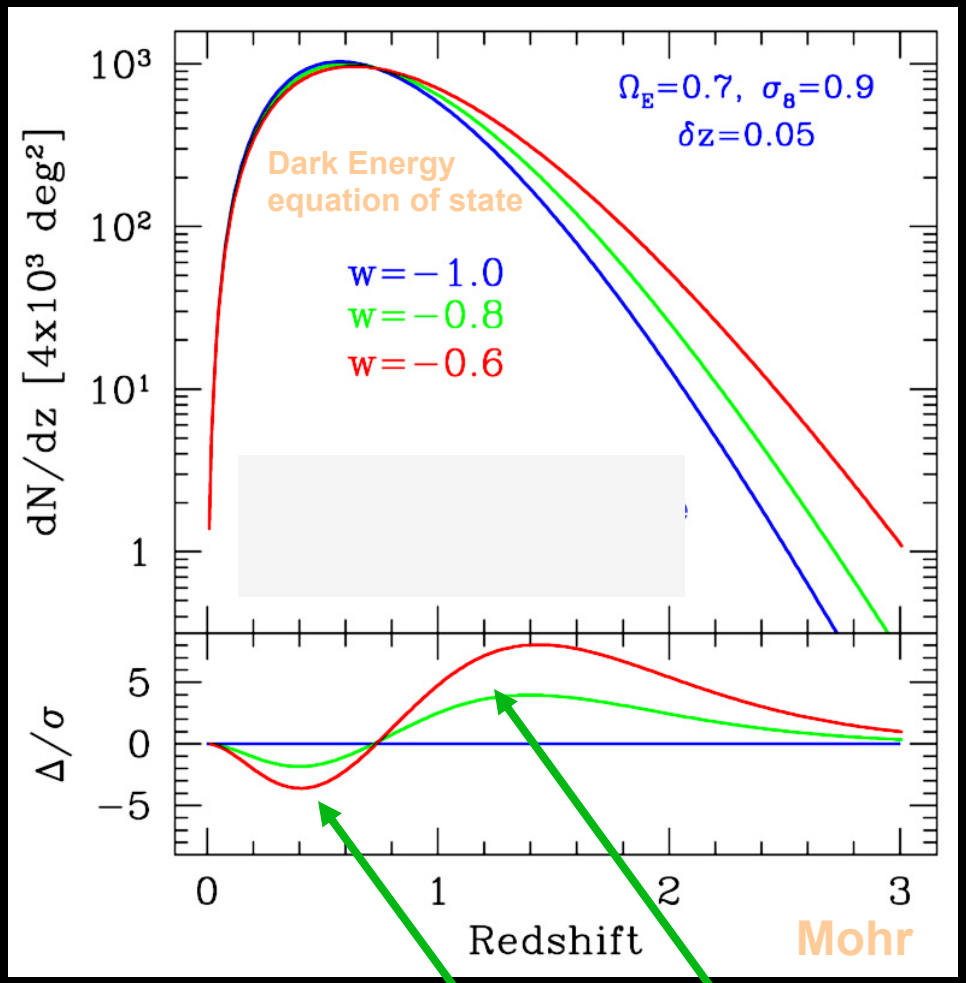
Factor 3-5 improvement over Stage II DETF Figure of Merit

Cluster counts

- 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

Number of clusters above mass threshold

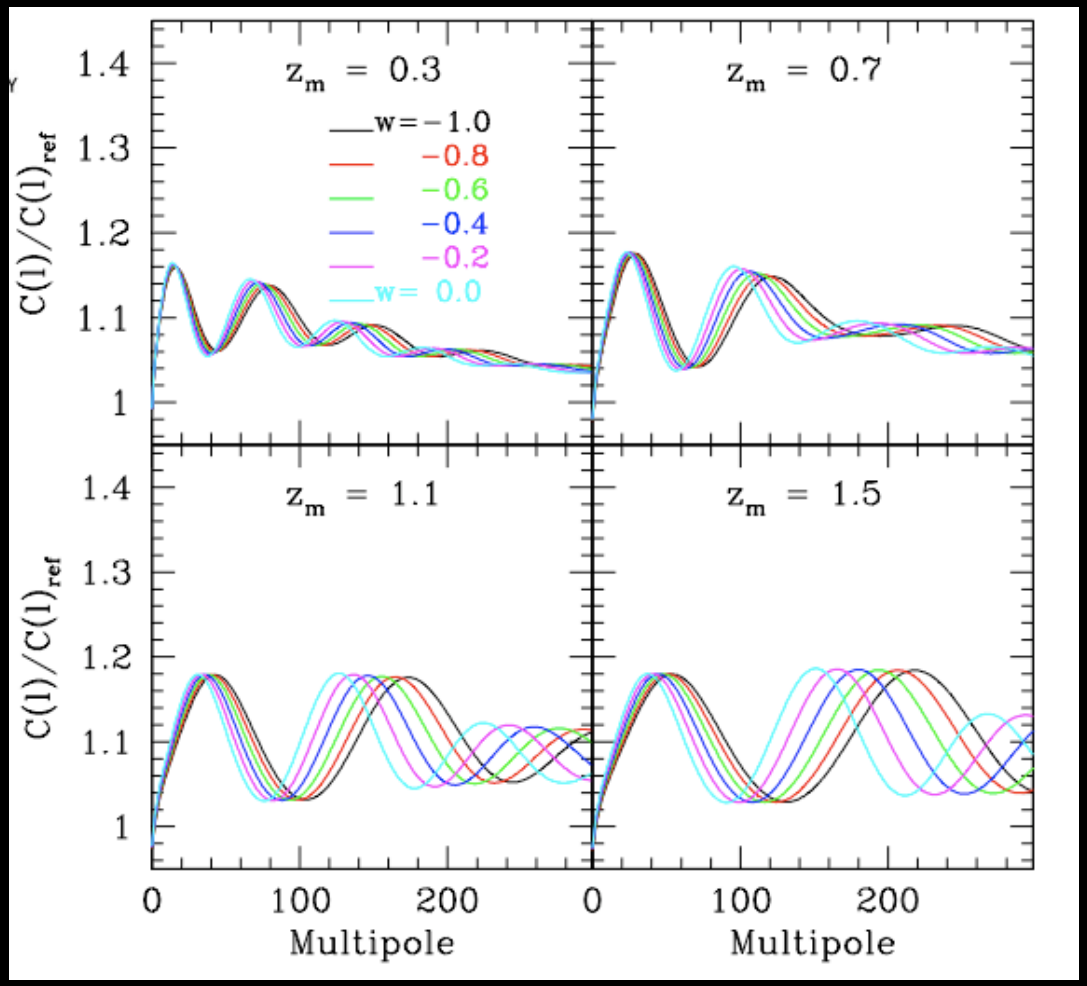


Volume Growth

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

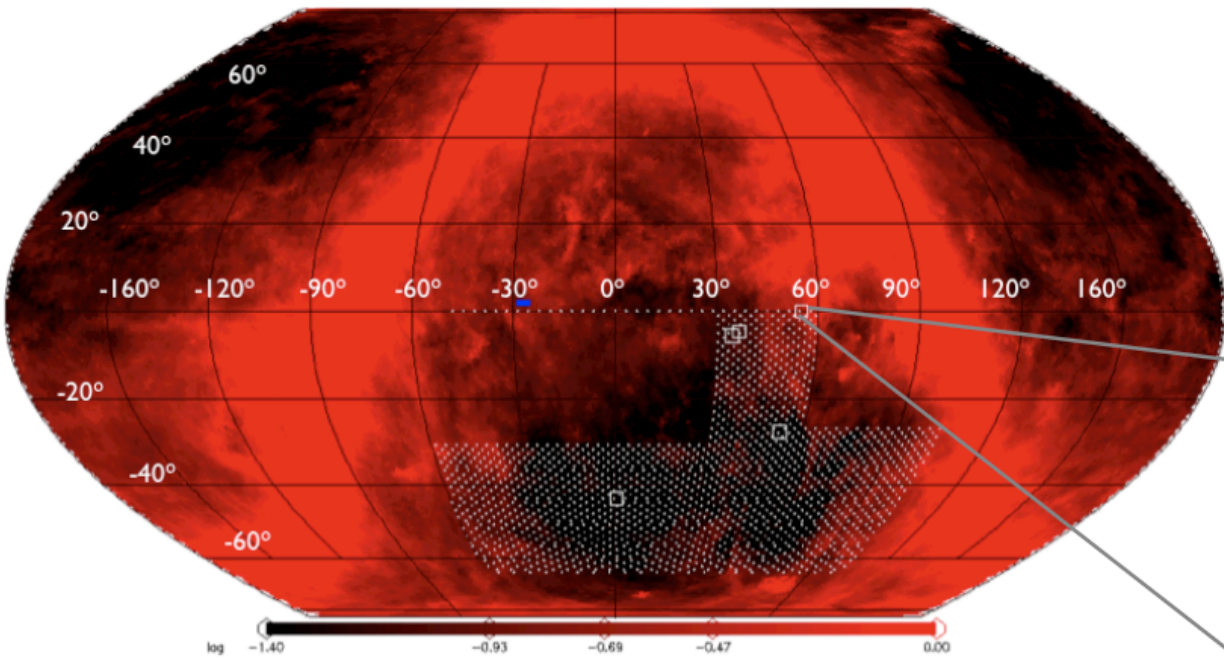
- 300 million galaxies to z = 1 and beyond
- Sensitive to geometry

Total Neutrino Mass
DES+Planck vs. KATRIN
$M_\nu < 0.1$ eV $M_\nu < 0.6$ eV

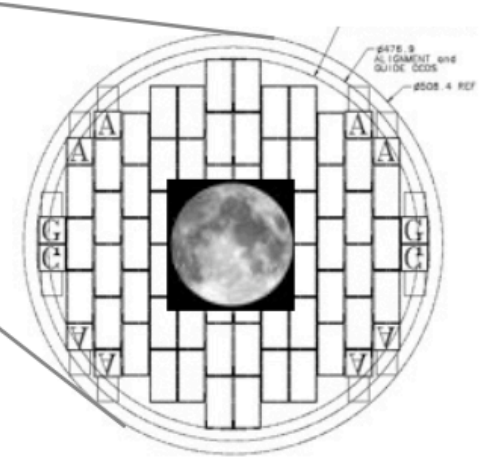
Lahav, Kiakotou, Abdalla and Blake (2010) 0910.4714

DES SN Survey

DARK ENERGY SURVEY



Fields to overlap with existing and near-future deep imaging (e.g., CDF-S, SNLS, VIDEO) and spectroscopic surveys (DEEP2, VIPERS, VVDS, WiggleZ, GAMA I/II).



10 DES fields

Visit once every ~4 days.

2 deep + 8 shallow (30 deg^2)

deep: 6600 sec per visit (*griz*)

shallow: 800 sec per visit (*griz*)

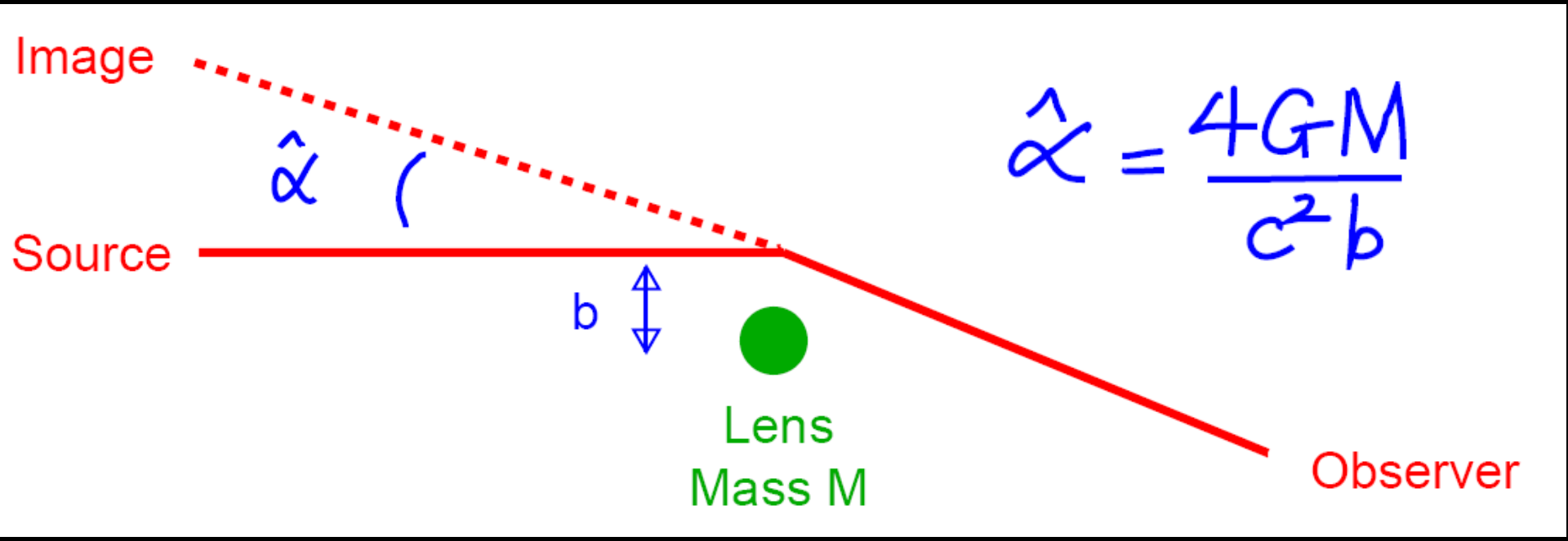
good *z*-band efficiency (~4x higher than CFHT/MegaCam) and target high-z SN Ia

→ good rest-frame *g*-band light curves of z~1 SN Ia.

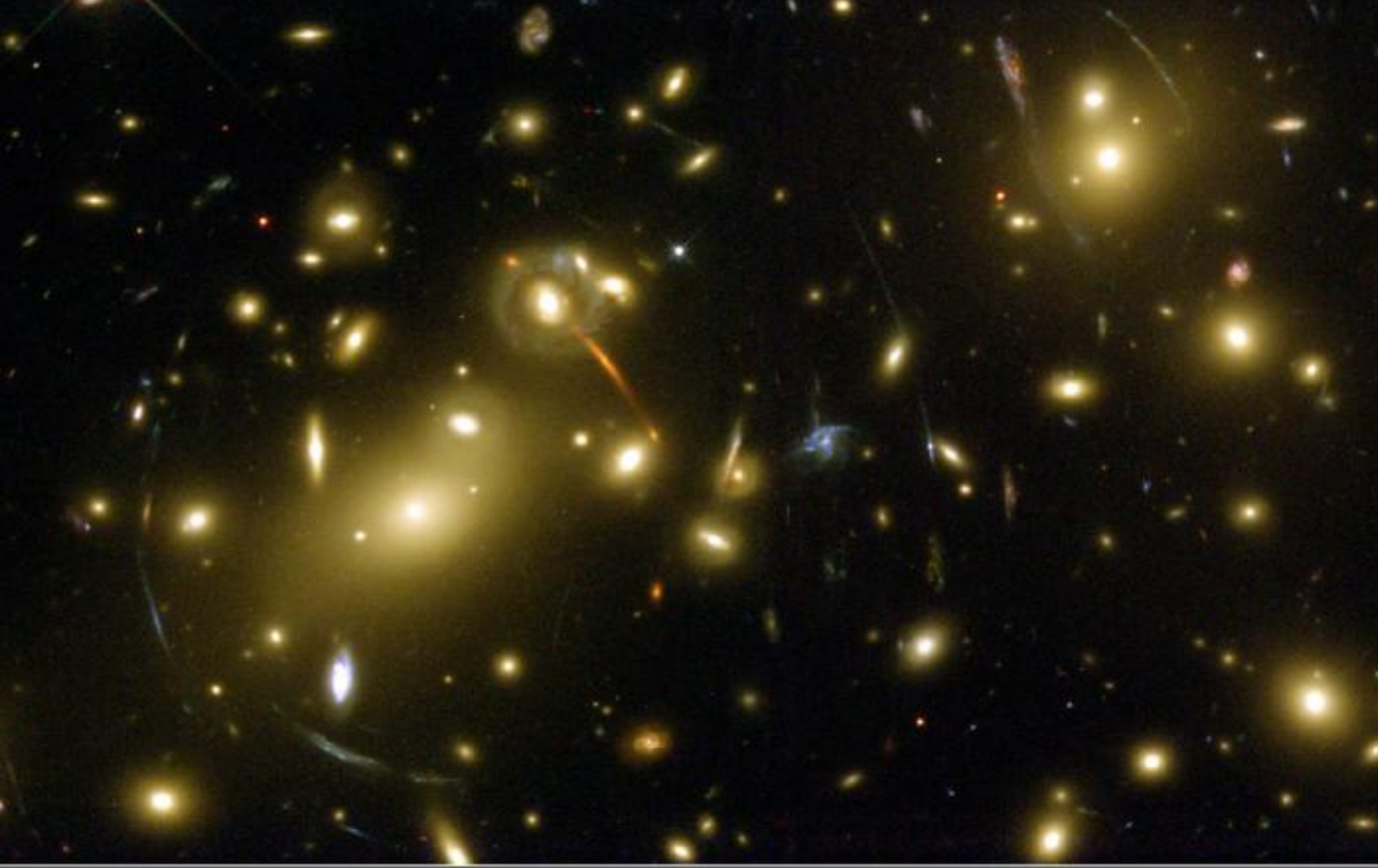
~4000 well-sampled SNe Ia to z ~1

Weak Lensing

Just one Equation from General Relativity



$$\hat{\alpha} = \frac{4GM}{c^2 b}$$



Galaxy Cluster Abell 2218

Hubble Space Telescope • WFPC2

DARK ENERGY
SURVEY

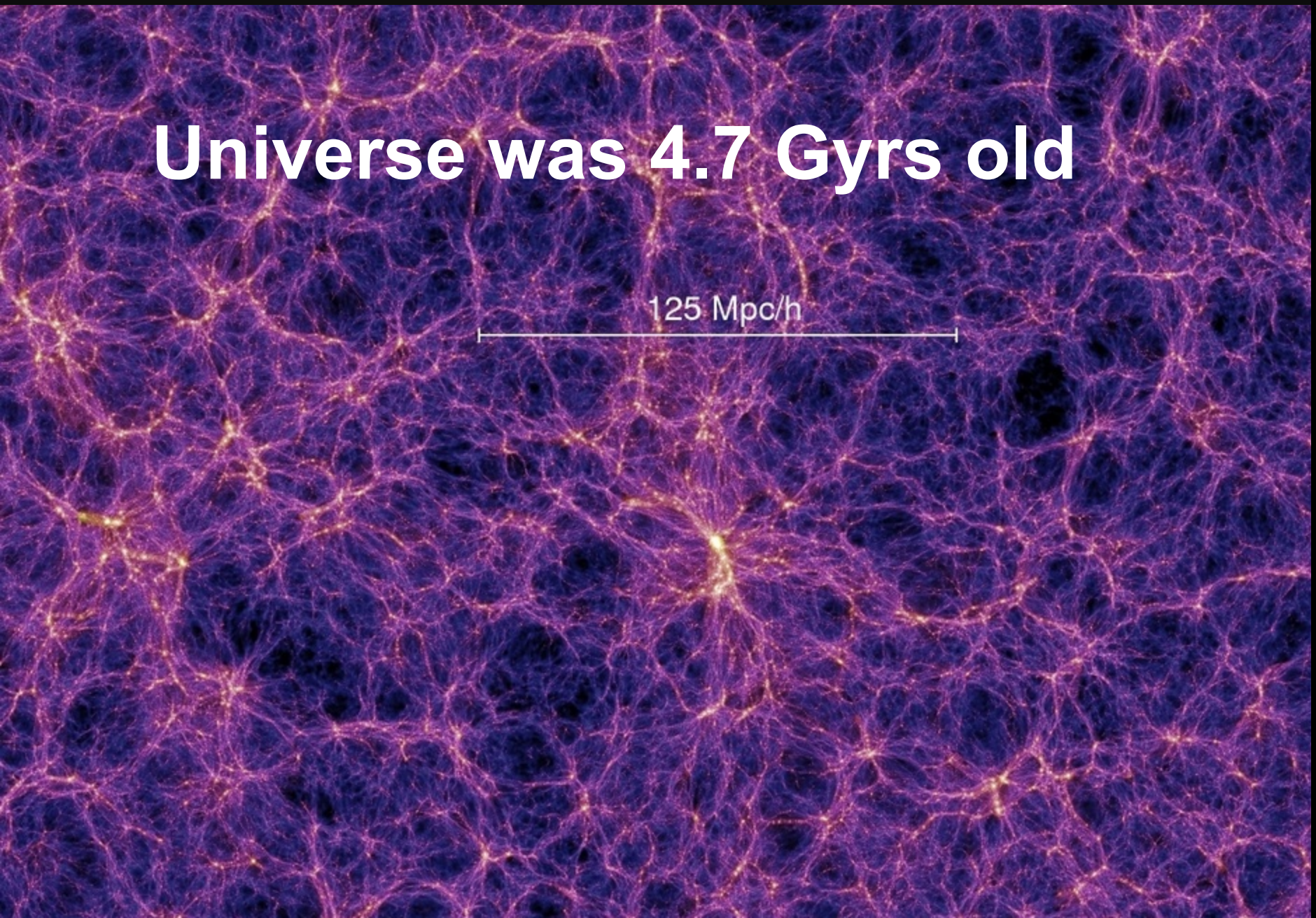
Universe was 0.2 Gyr old

Credit: Springel et al. (2005)

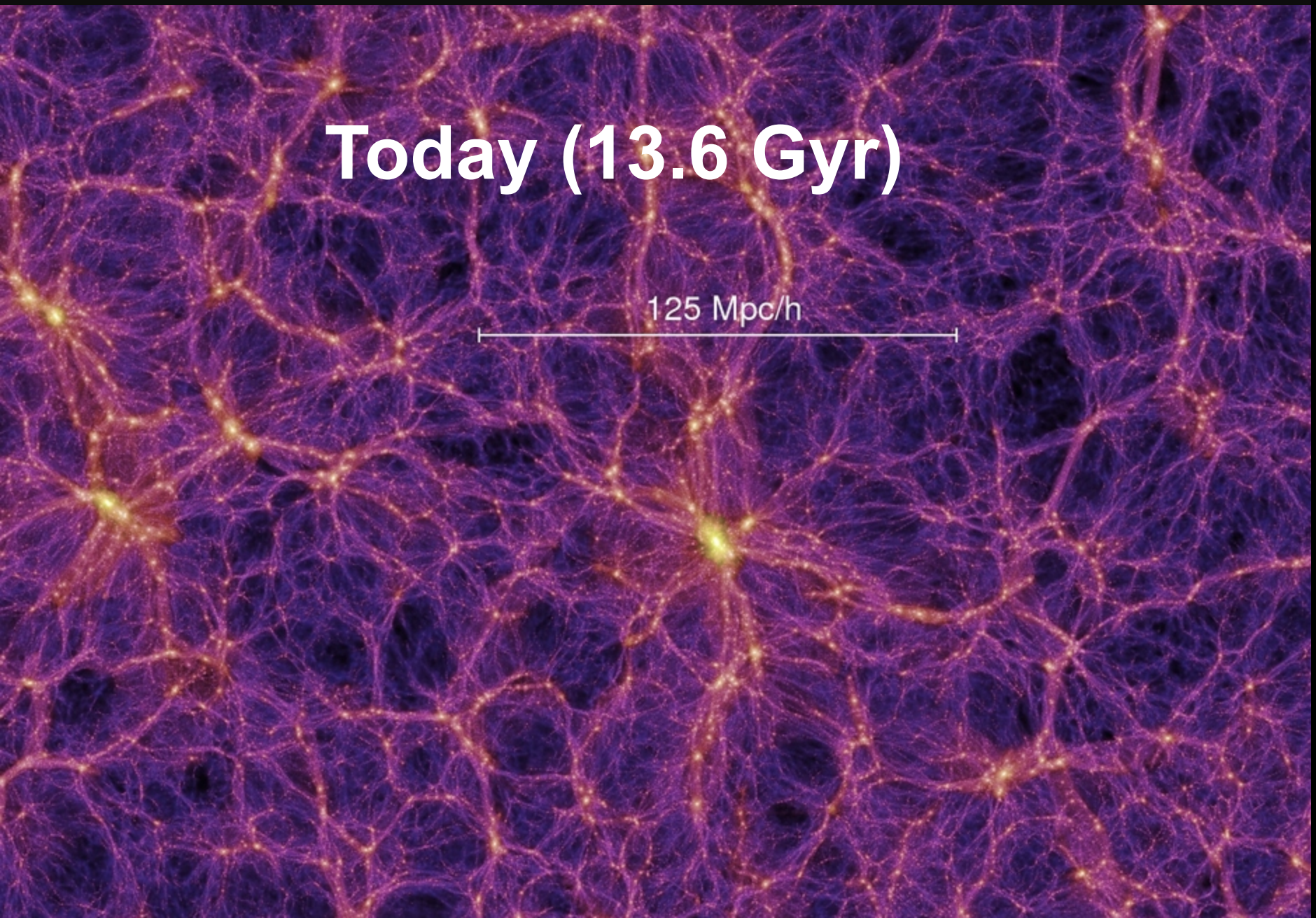
Universe was 1 Gyr old

Credit: Springel et al. (2005)

Universe was 4.7 Gyrs old

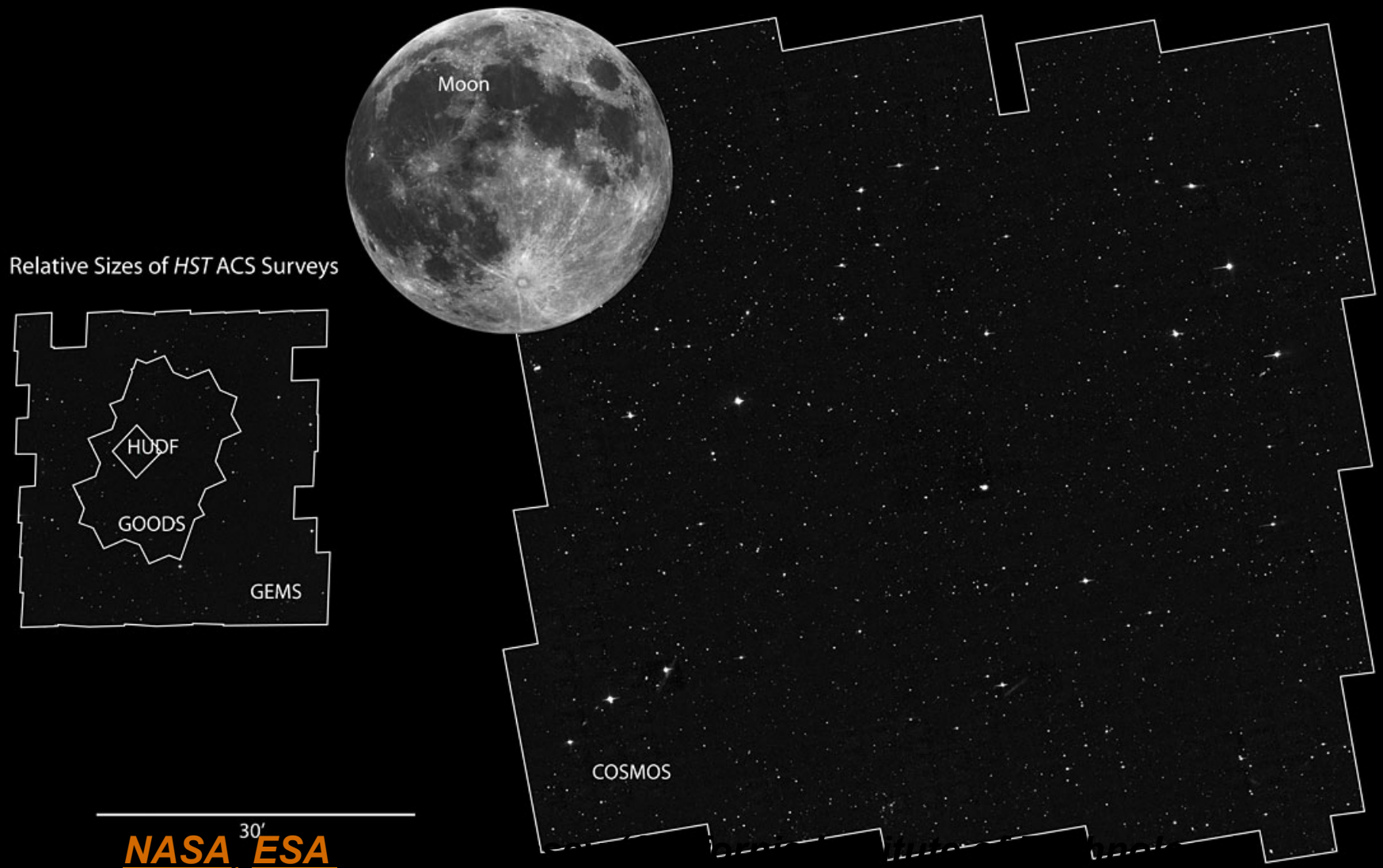


Credit: Springel et al. (2005)



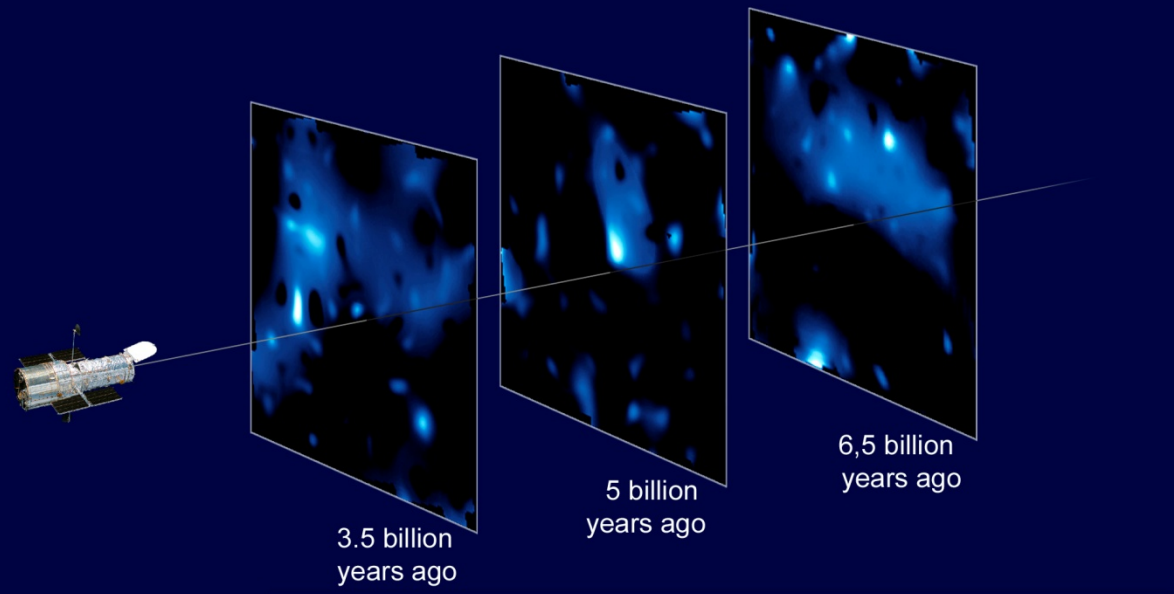
Credit: Springel et al. (2005)

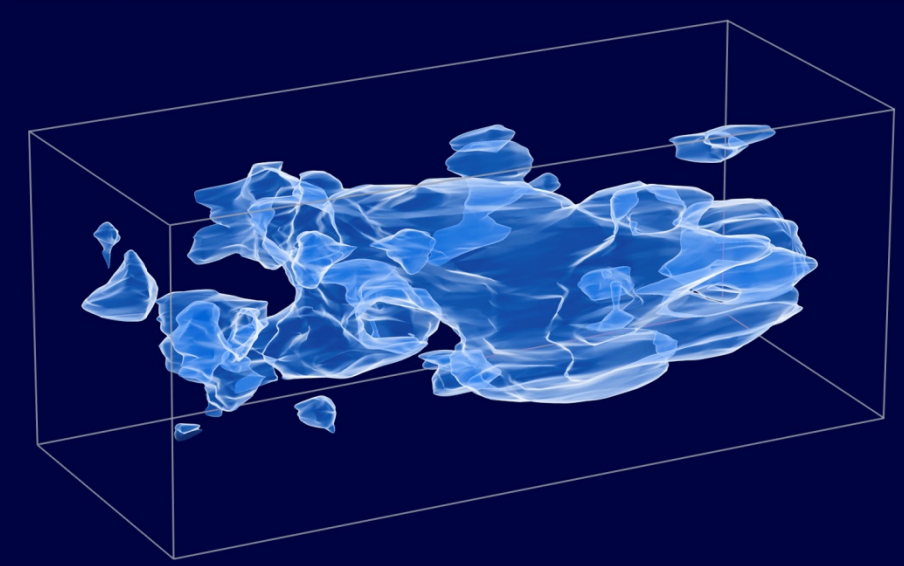
COSMOS:
The Largest ever Survey with HST



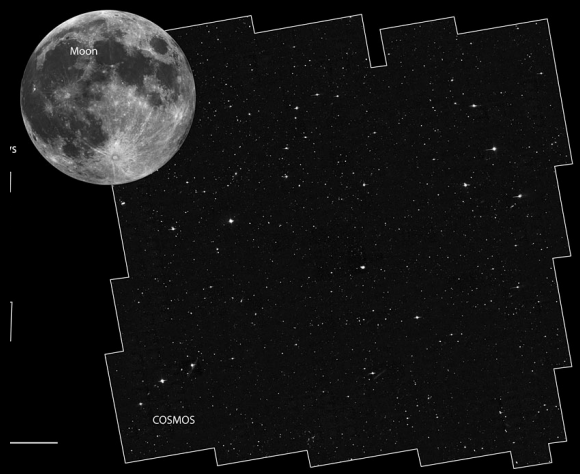
NASA ESA

In 3 Dimensions

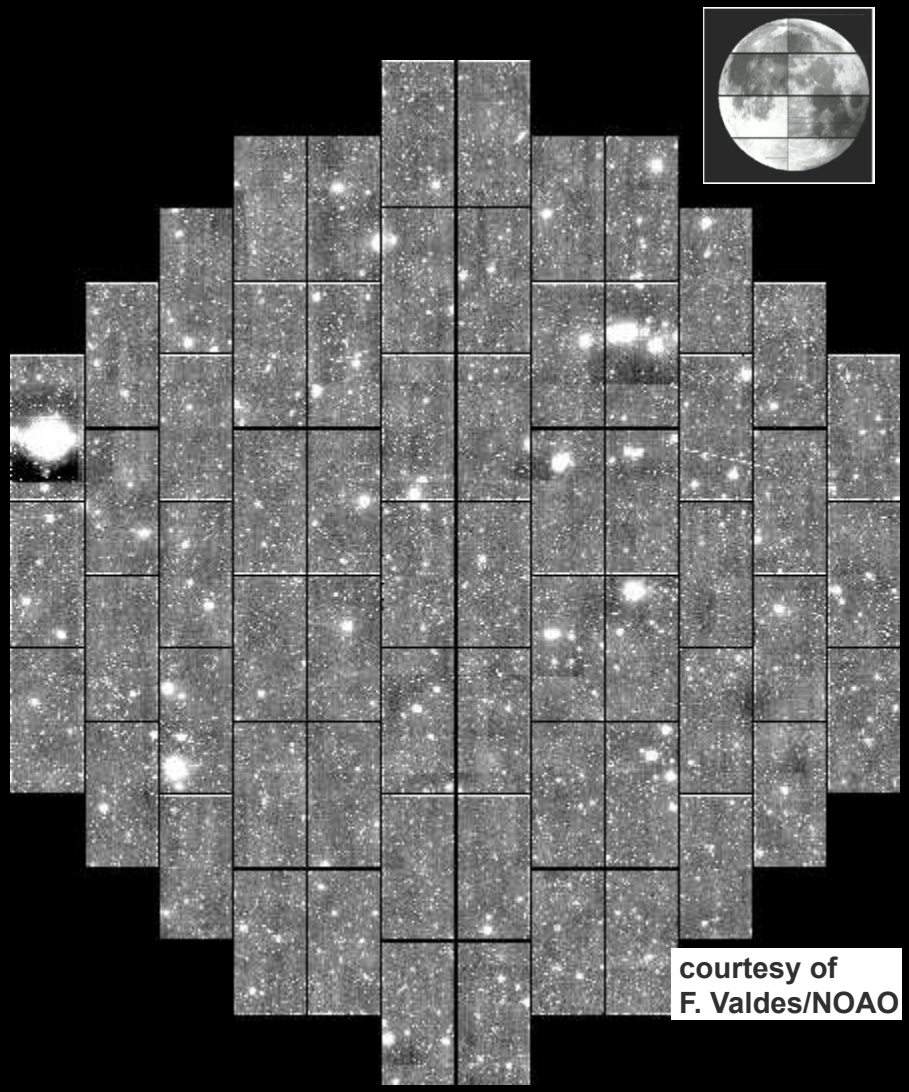




COSMOS → DES



COSMOS



One DES image (3 sq deg)

Cf whole DES survey 5000 sq deg

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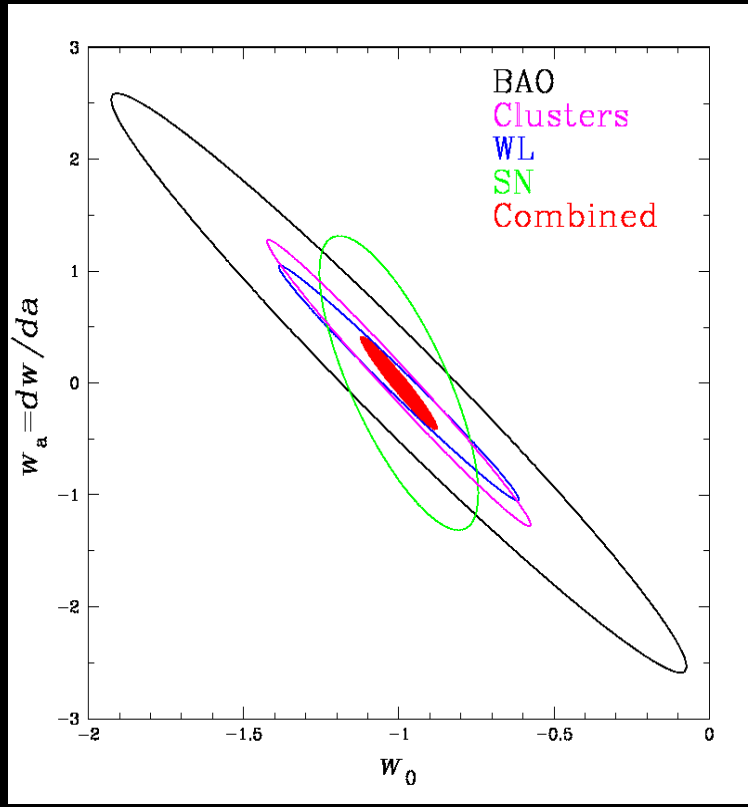


Factor 3-5 improvement over Stage II DETF Figure of Merit

The Shear Measurement Problem

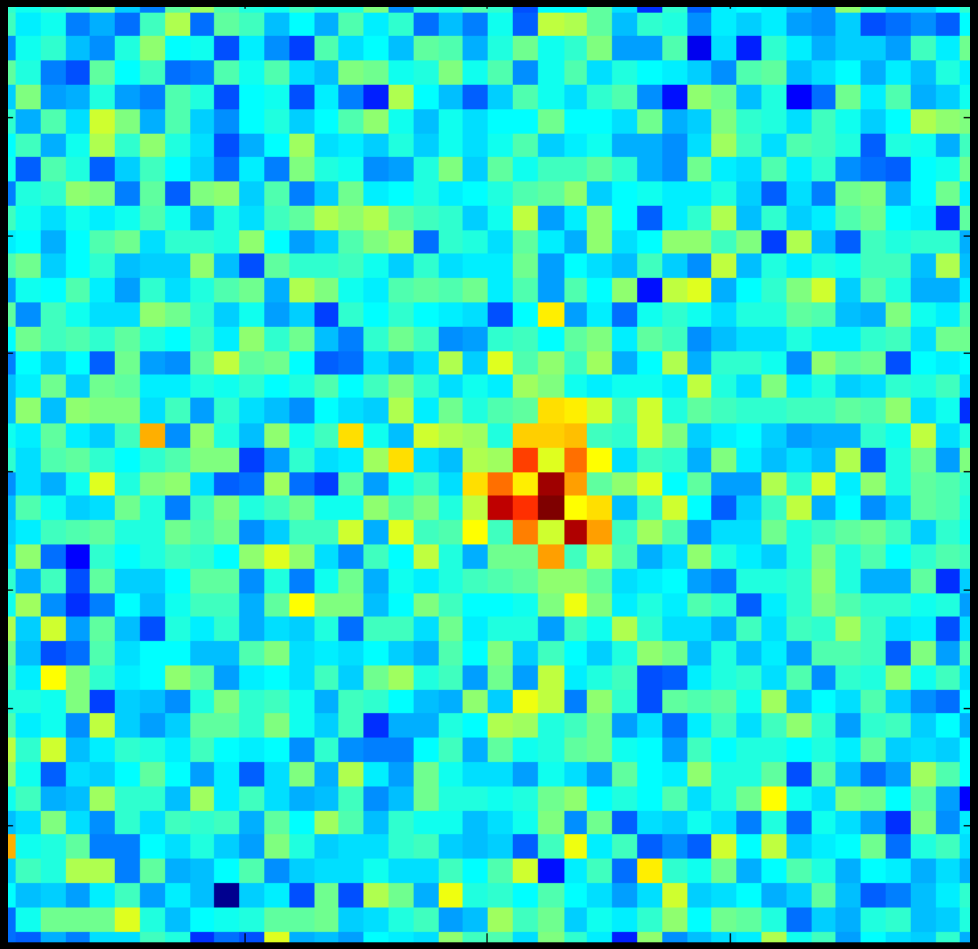
The Forward Process.

Galaxies: Intrinsic galaxy shapes to measured image:

Intrinsic galaxy (shape unknown) → Gravitational lensing causes a ***shear (g)*** → Atmosphere and telescope cause a convolution → Detectors measure a pixelated image → Image also contains noise

The GREAT08 Challenge Handbook (Bridle et al. 2008)

A Typical Galaxy



Results of the GREAT08 Challenge (Bridle et al. 2010)
See GREAT10 - ongoing

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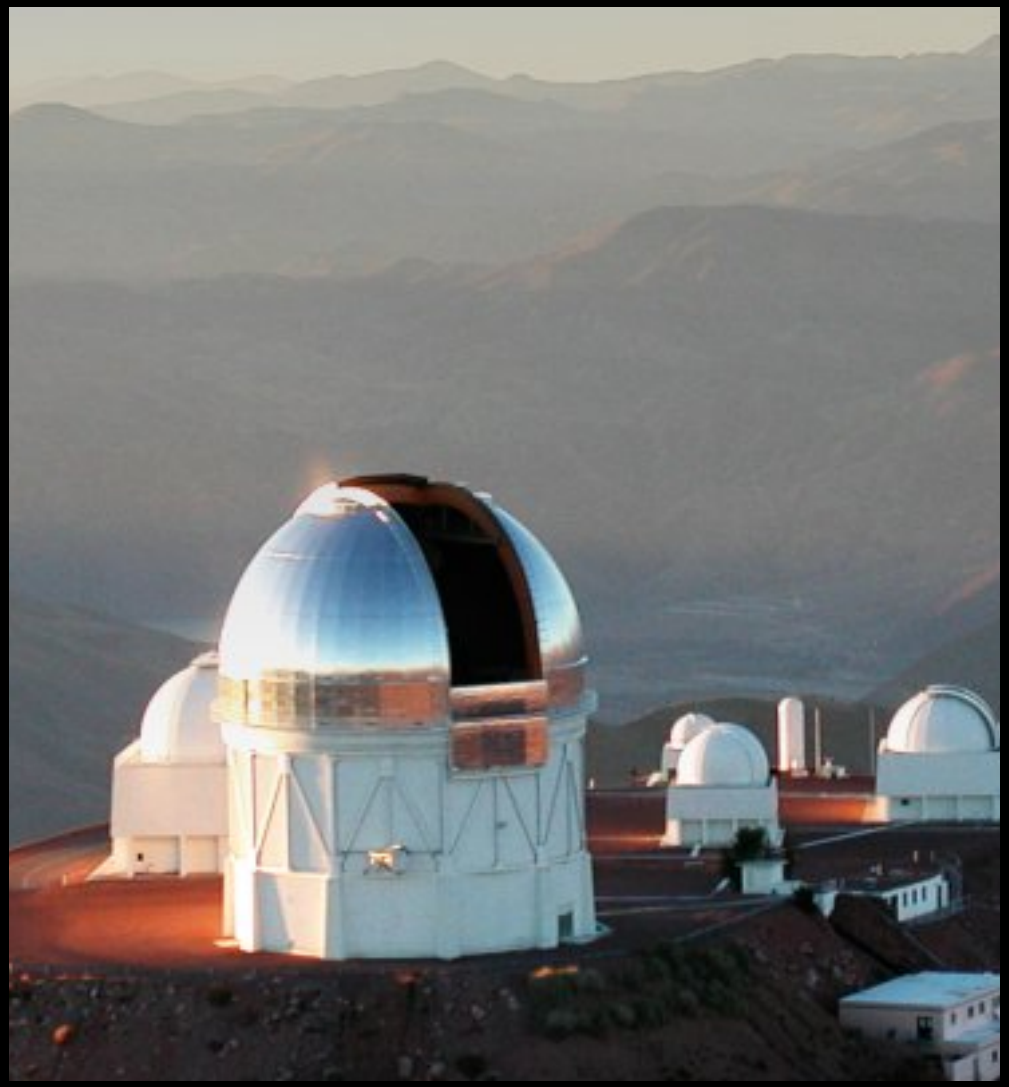
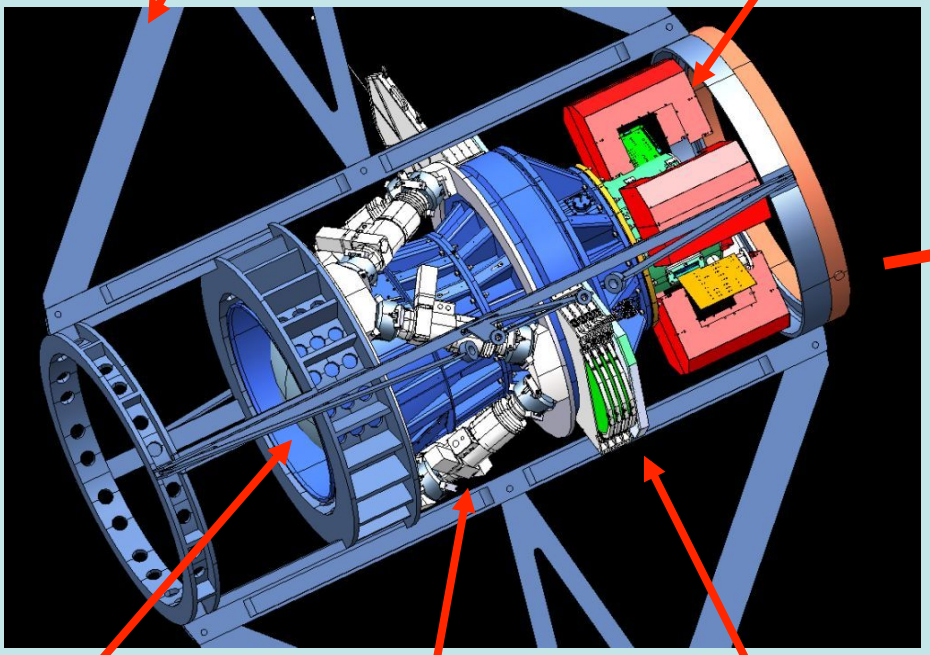
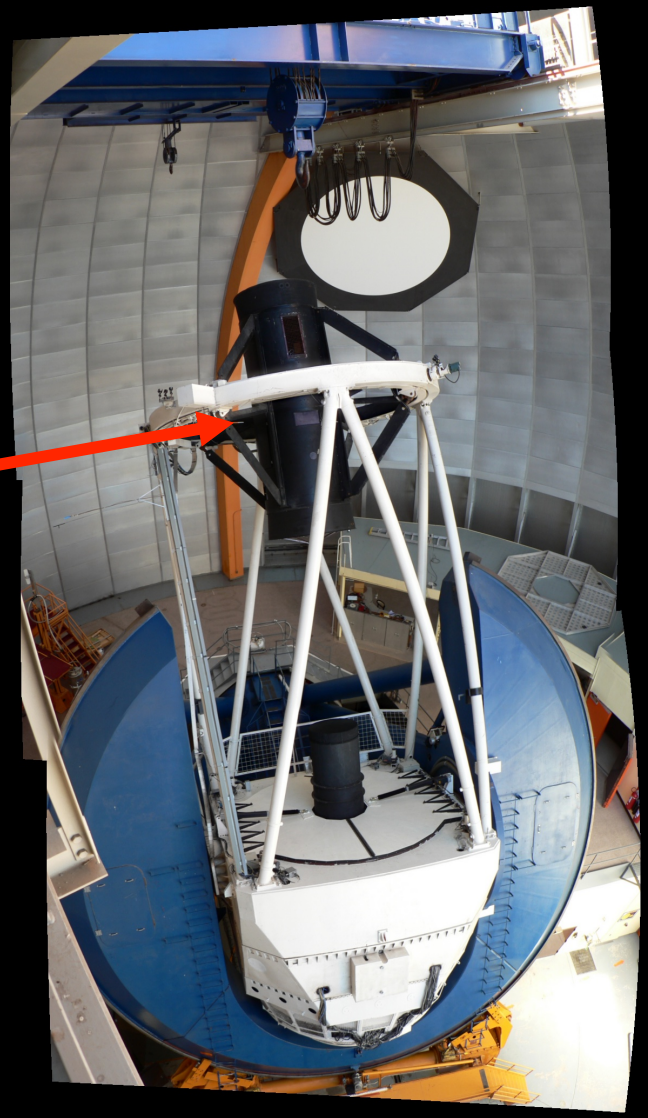


Dark Energy Camera

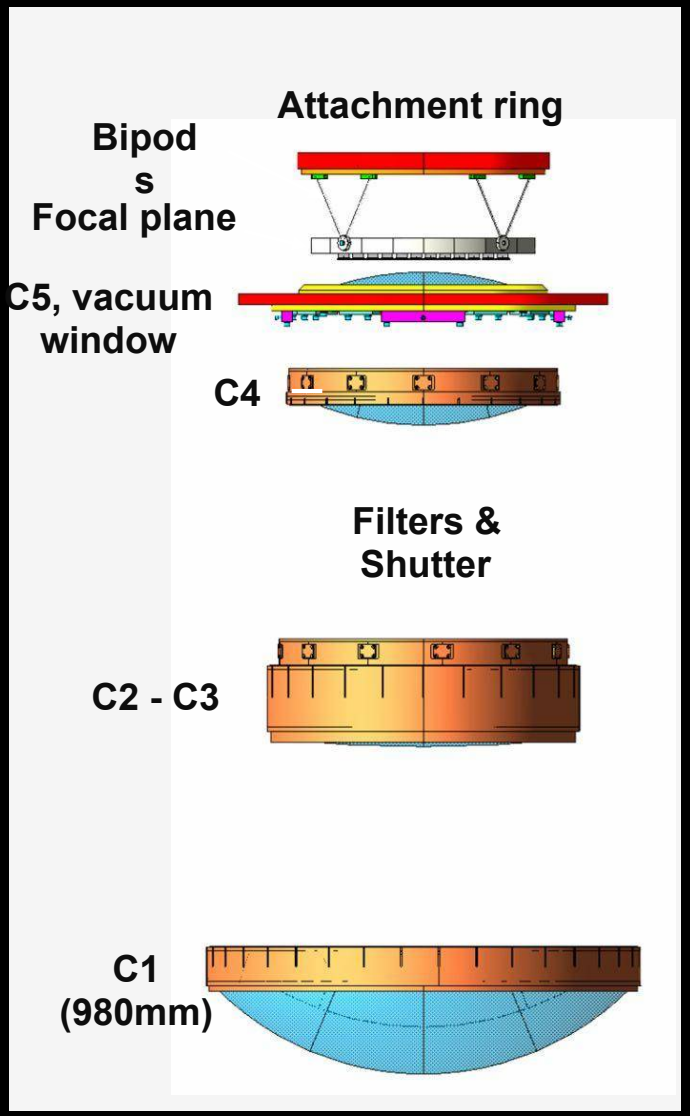




Optics

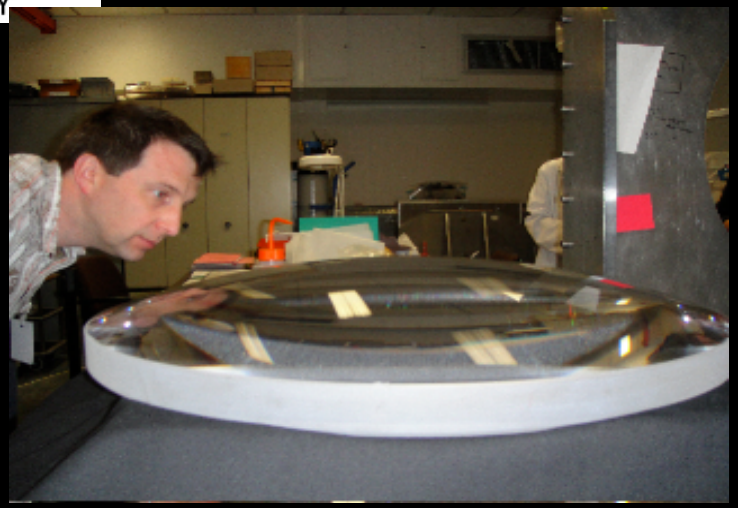
- Field of view: 2.2° diameter
- Good image quality across FOV
- Optical elements being aligned in barrel at UCL, will ship to CTIO Aug/Sept

S. Kent (FNAL)



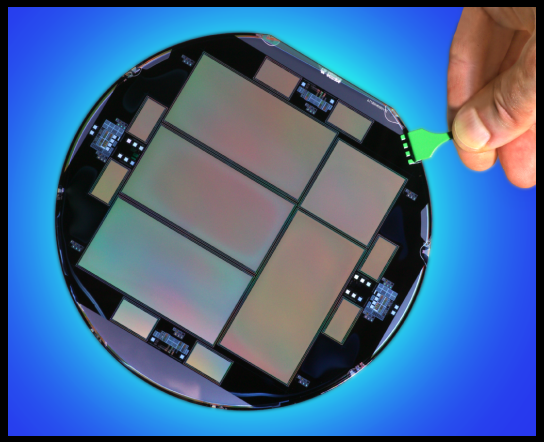
The 5 lenses are nearly ready

C3



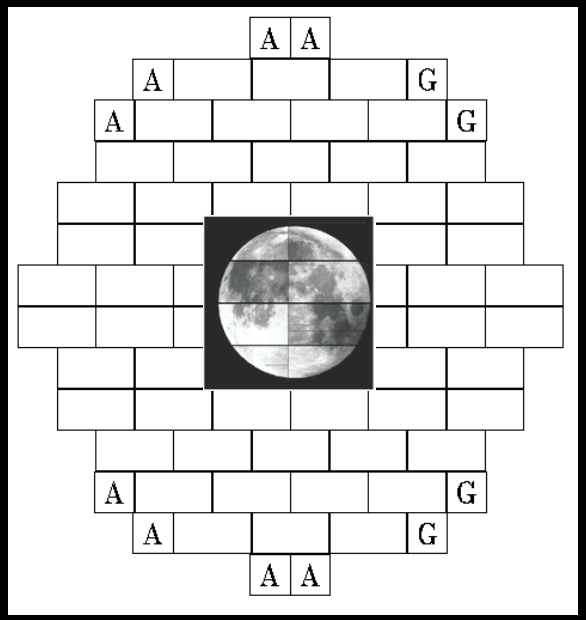
Polishing & coating coordinated by UCL (with 1.7M STFC funding)

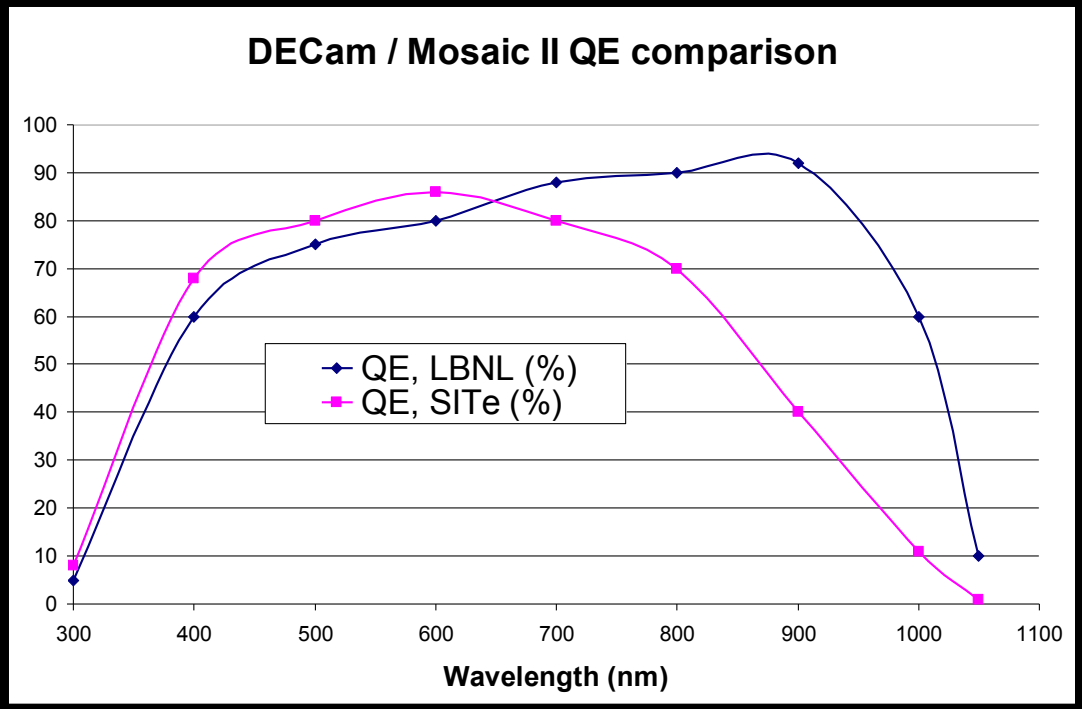
DECam CCDs



Developed by LBNL

- 62 2kx4k fully depleted CCDs: 520 Megapixels, 250 micron thick, 15 micron (0.27”) pixel size
- 12 2kx2k guide and focus chips
- Excellent red sensitivity
- Roughly twice the number of science-grade CCDs packaged and ready to install



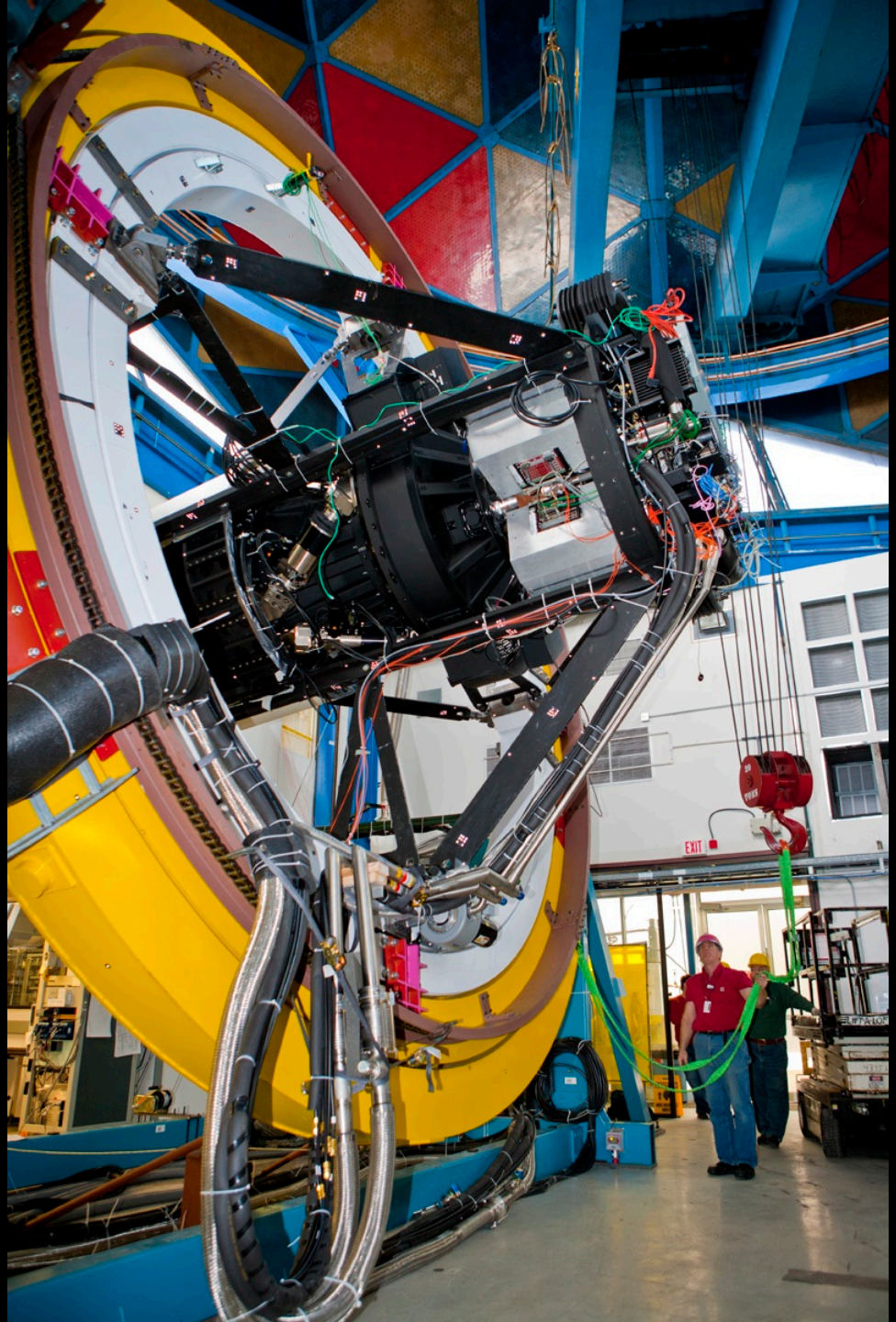


Filters

- Filter contract awarded to Asahi in 2009
- 620mm substrate, 600mm clear aperture
- Asahi has built and commissioned a huge coating chamber as well as custom cleaning, polishing and testing equipment
- i and z filters completed and about to ship to Chile. 1 side of Y done

DARK ENERGY SURVEY

- DECam mounted on Telescope Simulator at Fermilab in early 2011
- DECam both DES survey instrument and CTIO facility instrument
- The CTIO Director has scheduled the telescope shutdown to start on Nov. 8.



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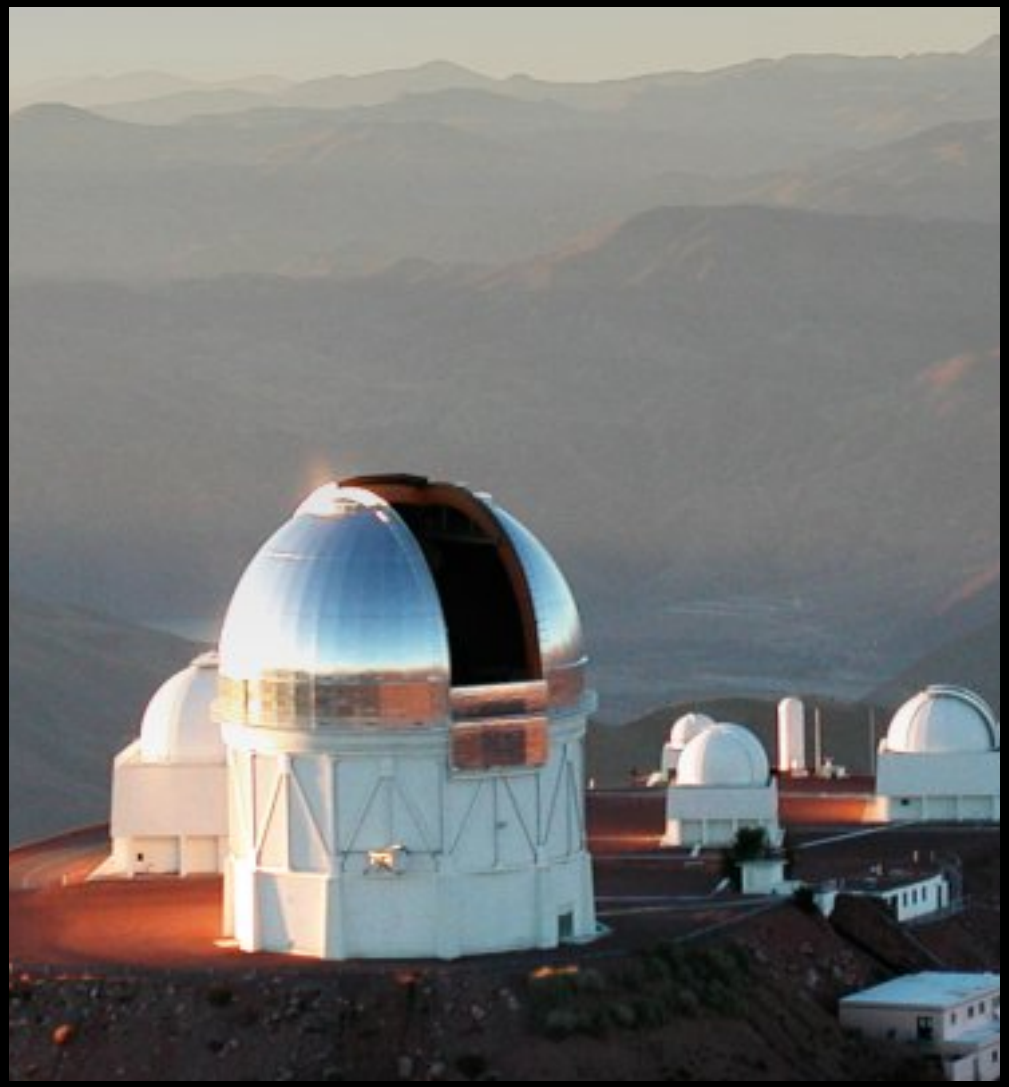
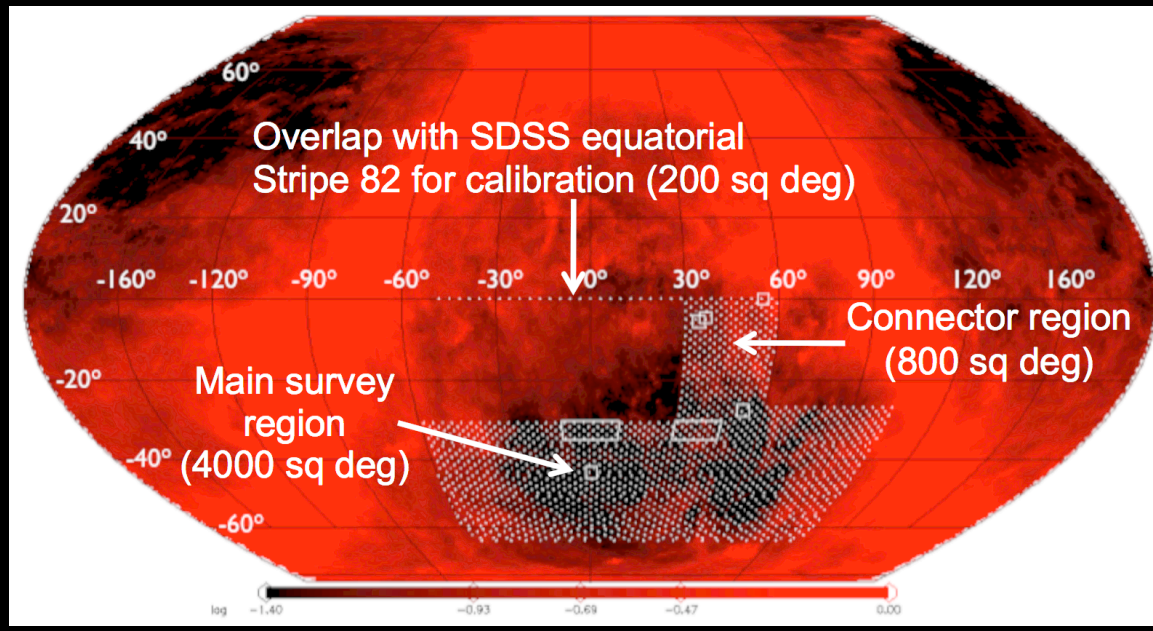
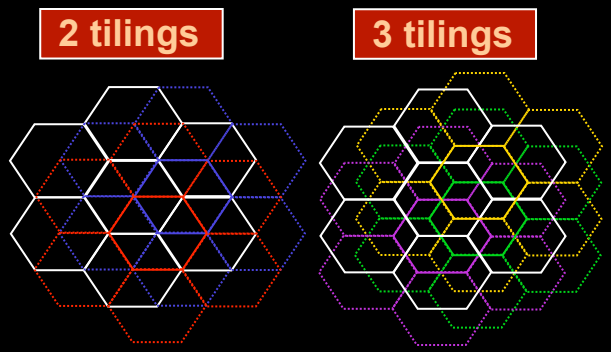


DES Observing Strategy

- Sept-Feb observing seasons
- 80-100 sec exposures
- 2 filters per pointing (typically)
  - *gr* in dark time
  - *izy* in bright/grey time
- Photometric calibration: overlap tilings, standard stars, spectrophotometric calibration system, preCAM
- 2 survey tilings/filter/year
- Interleave 10 SN fields in *griz* if non-photometric or bad seeing or time gap (aim for ~5 day cadence)

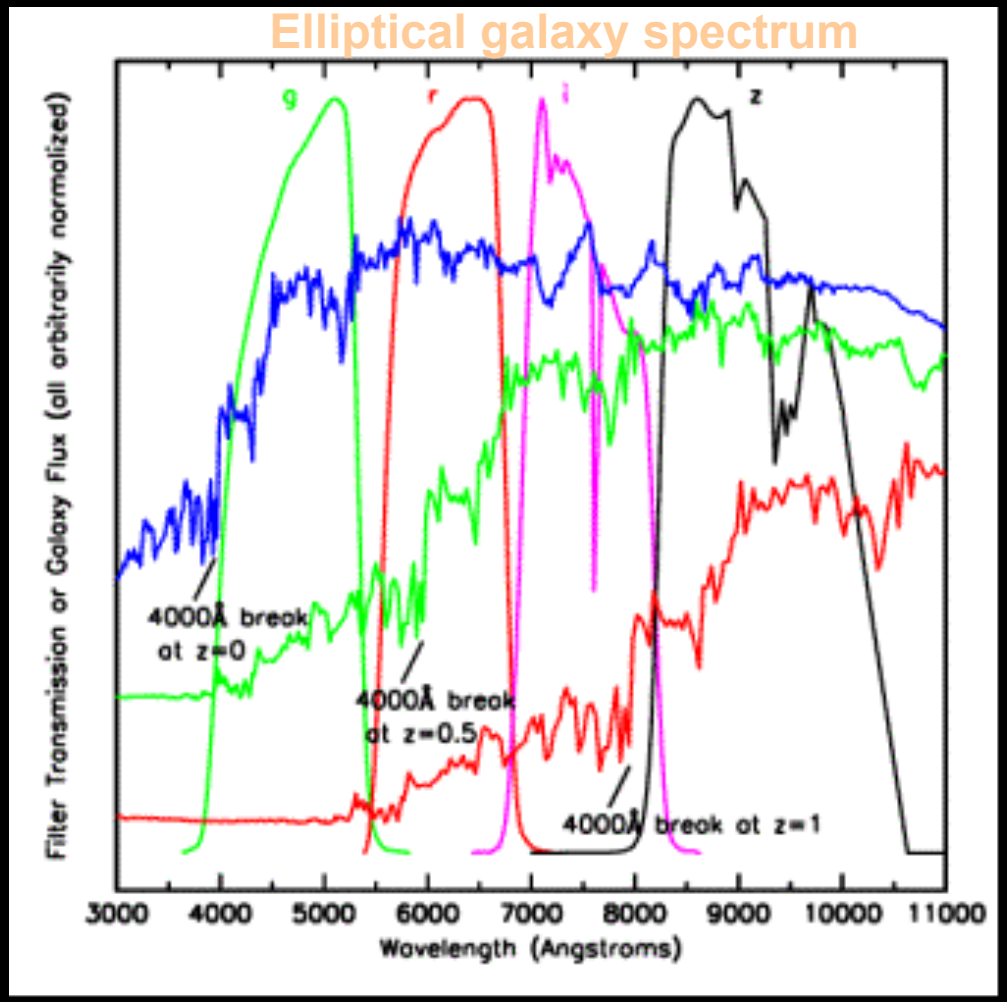
Survey Area **5000 sq deg**



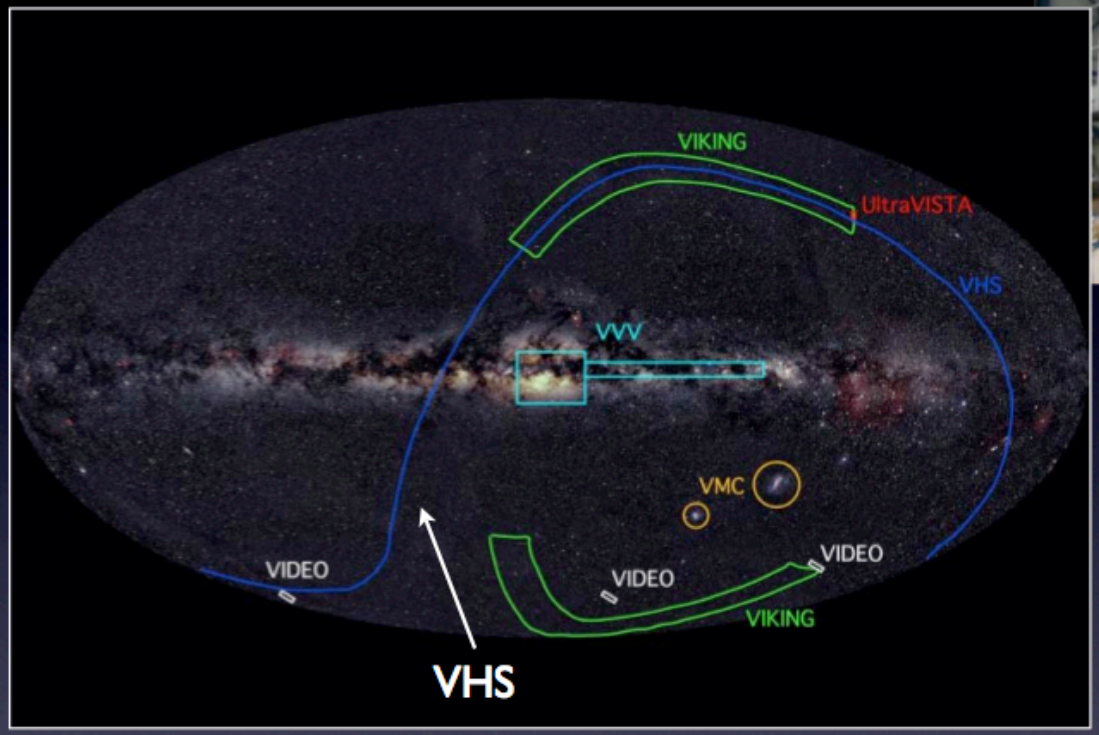


Photometric Redshifts

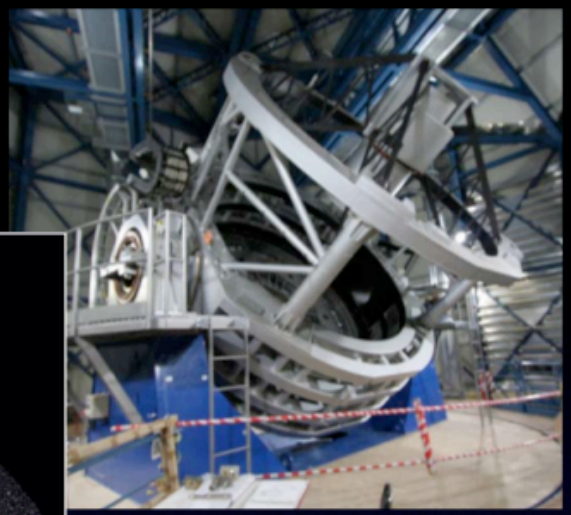
- Measure relative flux in multiple filters: track the 4000 A break
- Estimate individual galaxy redshifts with accuracy $\sigma(z) < 0.1$ (~0.02 for clusters)
- Precision is sufficient for Dark Energy probes, provided error distributions well measured.



VISTA Hemisphere Survey



120 sec JHK exposures



VISTA

4.1m primary mirror
1.5deg field of view
16 2kx2k HgCdTe

VHS

380 nights over 5 yrs
120 sec JHK exposures
Richard McMahon, PI

VHS limiting magnitudes

[AB system; 5σ]	deg²	Y	J	H	K
VHS-DES	5000	21.9	21.2	20.8	20.2

DES collaborates with VHS: DES acquires Y imaging, VHS shares JHK data

Galaxy Photo-z Simulations

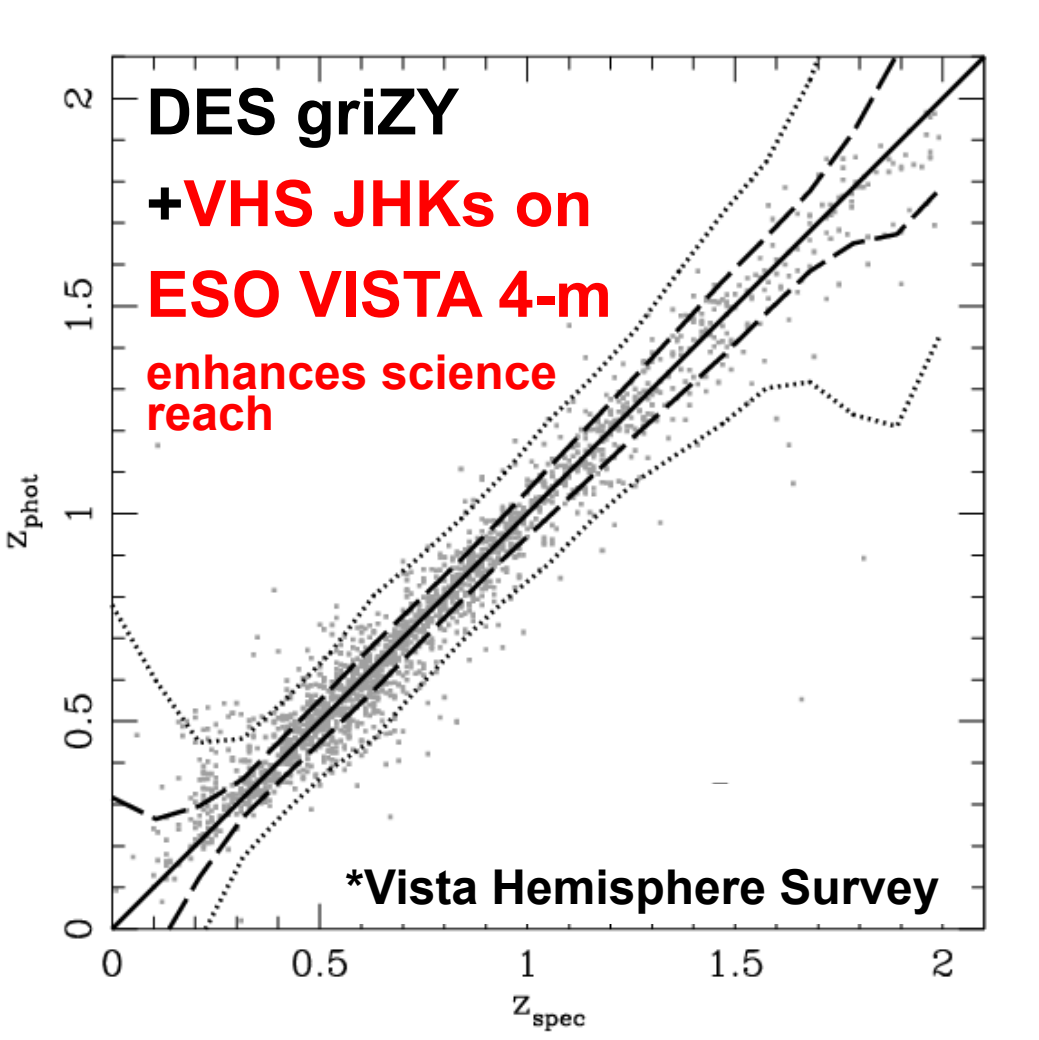
DES+VHS*

10σ Limiting Magnitudes

g	24.6		
r	24.1		
i	24.0	J	20.3
z	23.8	H	19.4
Y	21.6	Ks	18.3

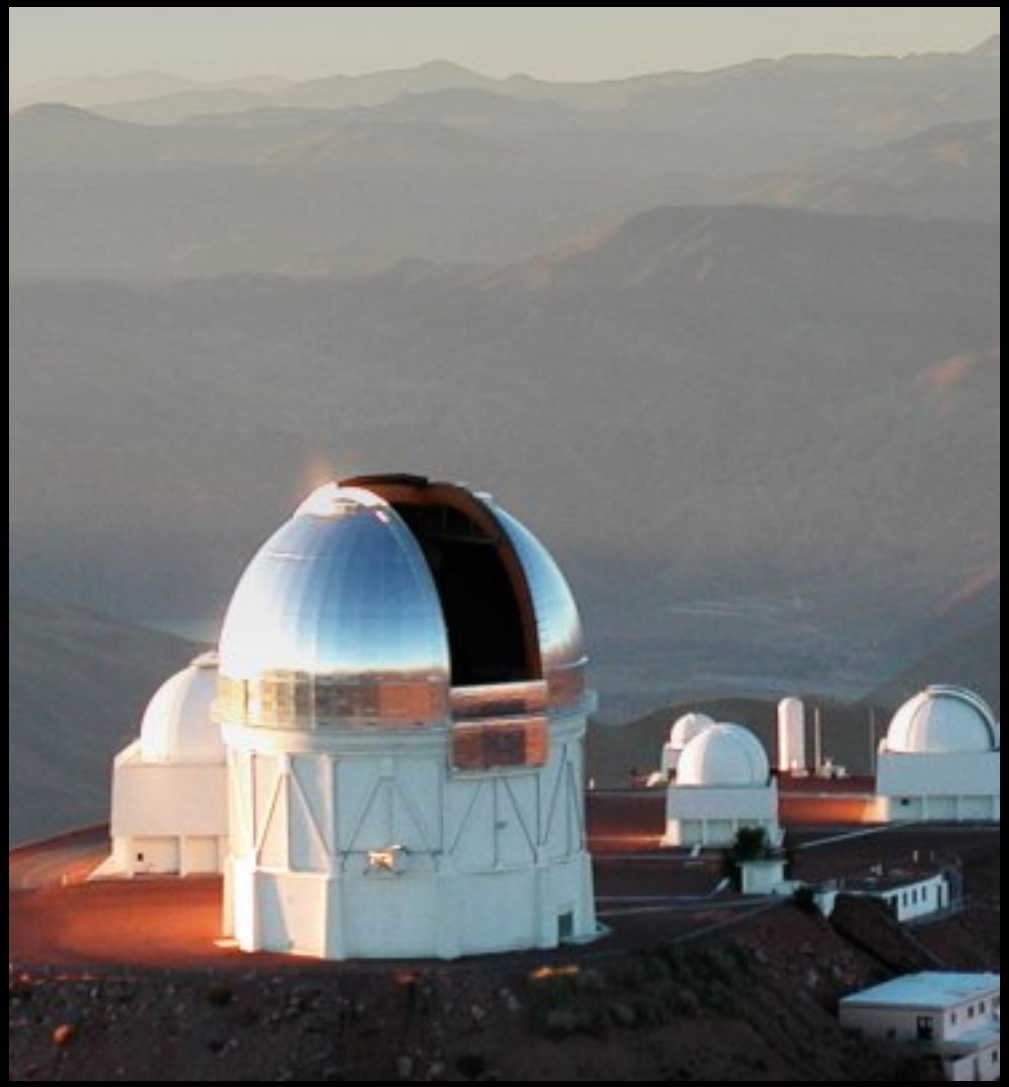
+2% photometric calibration error added in quadrature

Spectroscopic training sets comparable to DES depth exist



The Dark Energy Survey

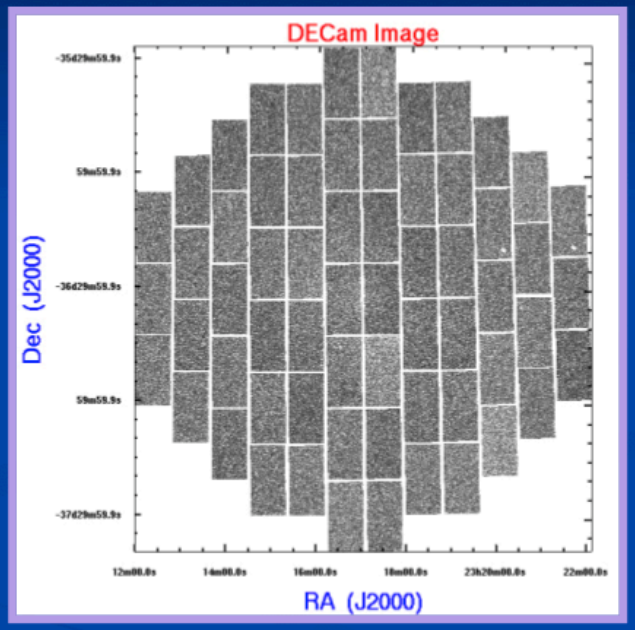
- Dark Energy
- DES Collaboration
- DES Science
- DECam
- Survey Strategy
- Data Management
- Status



DES Data Management

http://cosmology.illinois.edu/DES/

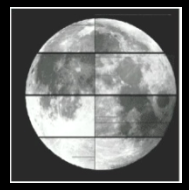
- The DESDM system:
  - Process DES data at NCSA
  - Archive DES data over the long term
    - ~4PB total, ~350TB database
  - Distribute data to Collaboration
  - Distribute data to public
    - NOAO Raw/reduced data after 1 yr
    - NCSA Co-adds/catalogs at midpoint and end of survey



Exposure consists of 62 2kX4k CCD images - 3deg^2

Survey is ~150,000 exposures over 525 nights

DECam Simulated Image



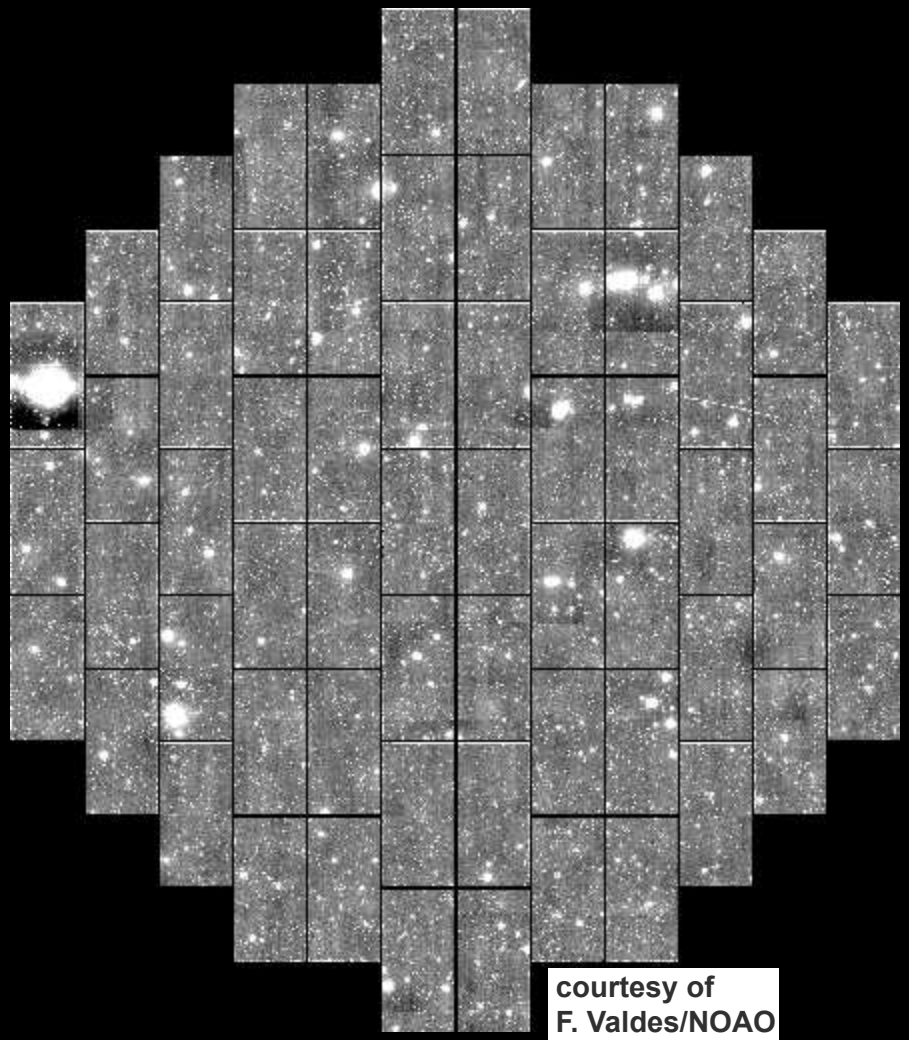
Each image

- 3 sq. deg.
- ~ 20 Galaxy clusters
- ~ 200,000 Galaxies
- 520 Mega pixels (62 CCDs)

Each night ~ 300 GB of image data

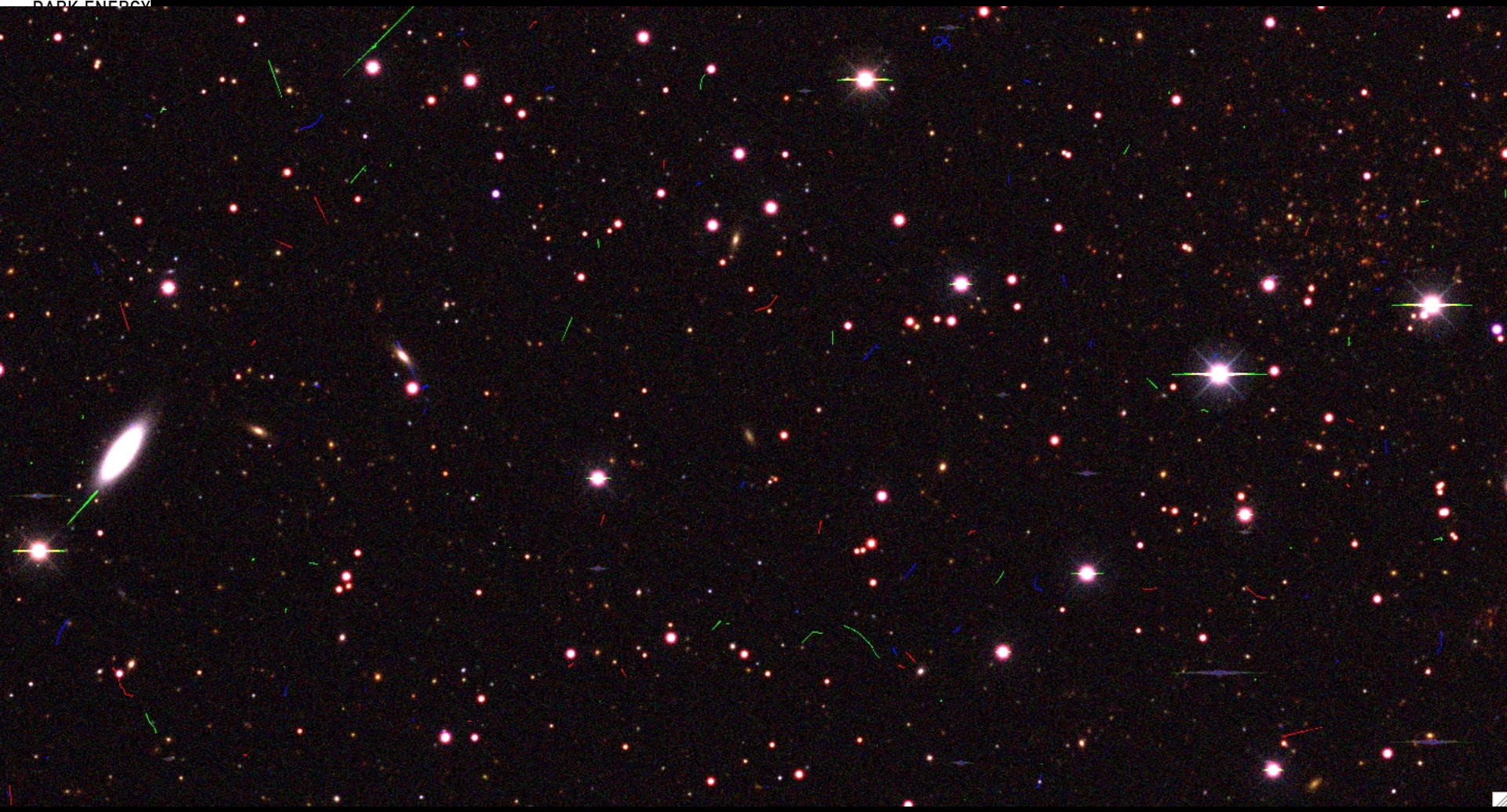
We will use 500 nights for the Dark Energy Survey

The large field of view lets us cover the sky in a reasonable amount of time.



courtesy of F. Valdes/NOAO

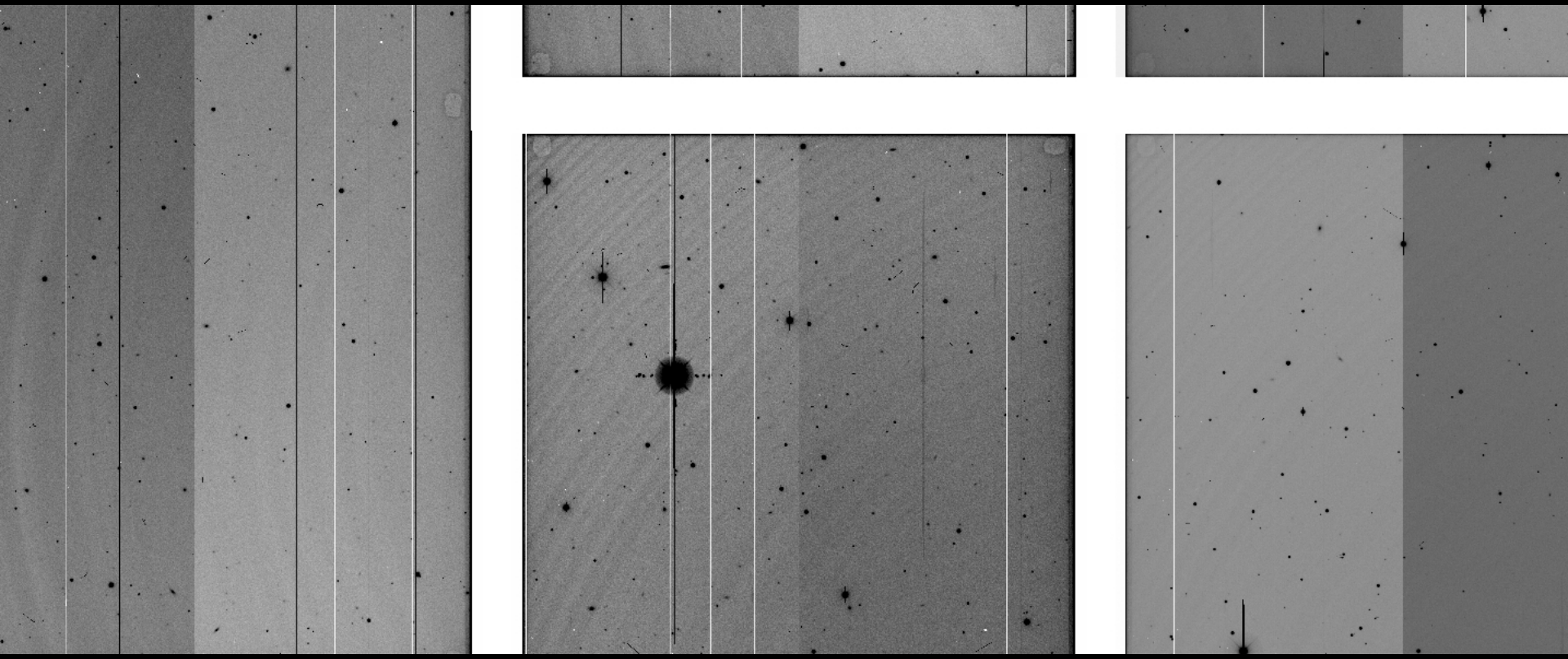
DECam Image Simulations



Populate N-body sims w/ galaxies drawn from SDSS+evolution+shapes

DECam Image Simulations

Series of Data Challenges to test Data Management System



Note bright star artifacts, cosmic rays, cross talk, glowing edges, flatfield (“grind marks”, tape bumps), bad columns, 2 amplifiers/CCD.

The Dark Energy Survey

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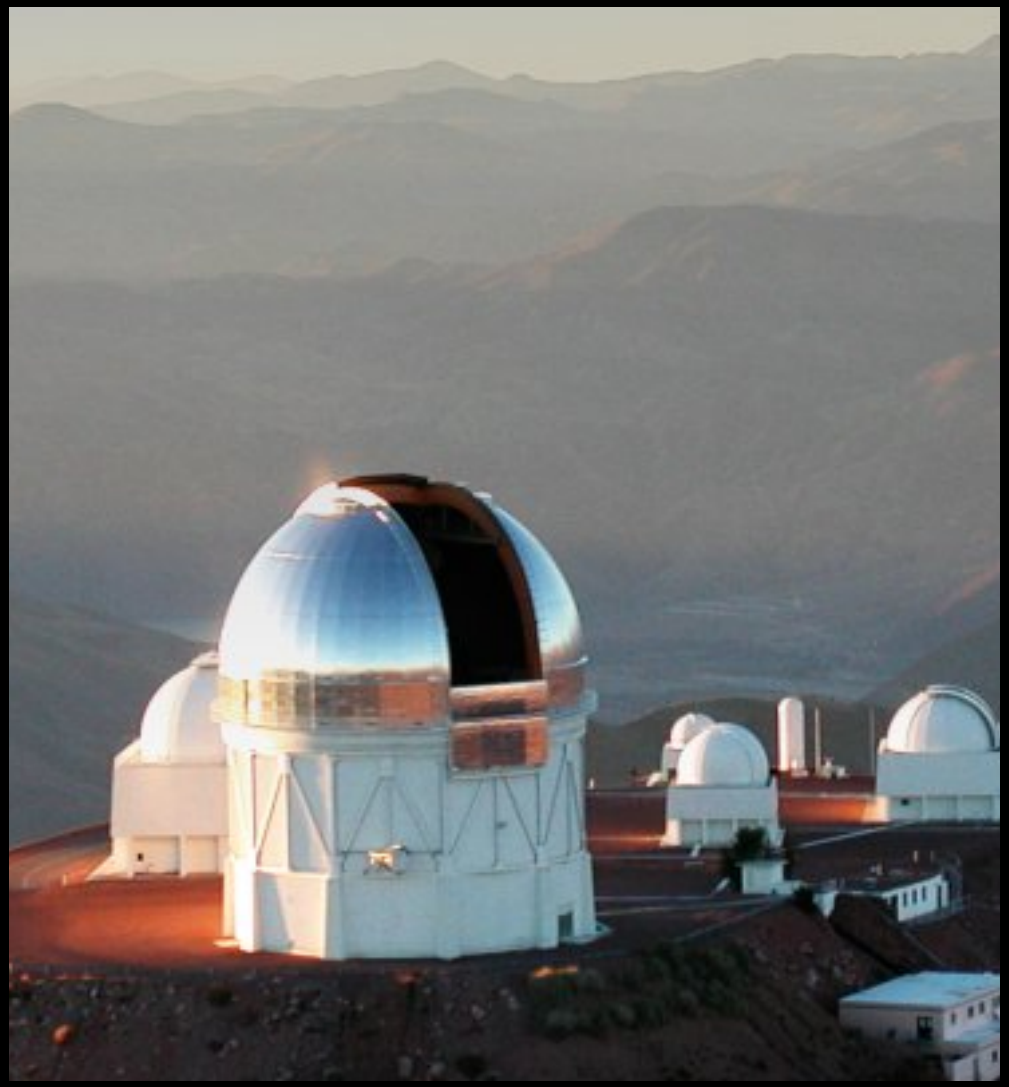

Project Structure & Timeline

- **3 Construction Projects:**
  - **DECam (hosted by FNAL; DOE supported)**
  - **Data Management System (NCSA; NSF support)**
  - **CTIO Facilities Improvement Project (NSF/NOAO)**
    - NOAO Blanco Announcement of Opportunity 2003
    - DECam R&D 2004-8
    - Camera construction 2008-11
    - Final construction, testing, integration now on-going
    - Ship components to Chile this year
    - Installation of imager ~Nov/Dec 2011
    - First light on telescope: ~Jan 2012
    - Commissioning and Science Verification: Jan-April 2012
    - Survey operations begin: Sept 2012

DESpec: Spectroscopic follow up of DES

- Proposed Dark Energy Spectrometer (DESpec)
- 4000–fibre instrument for the 4m Blanco telescope in Chile, using DES optics and spare CCDs
- 10 million galaxy spectra, target list from DES, powerful synergy of imaging and spectroscopy, starting 2017-18
- DES+DESpec can improve DE FoM by 3-6,

  making it DETF Stage IV experiment
- DES+DESpec can distinguish DE from ModGrav
- Participants: current international DES collaboration

  + new teams

Project Structure & Timeline

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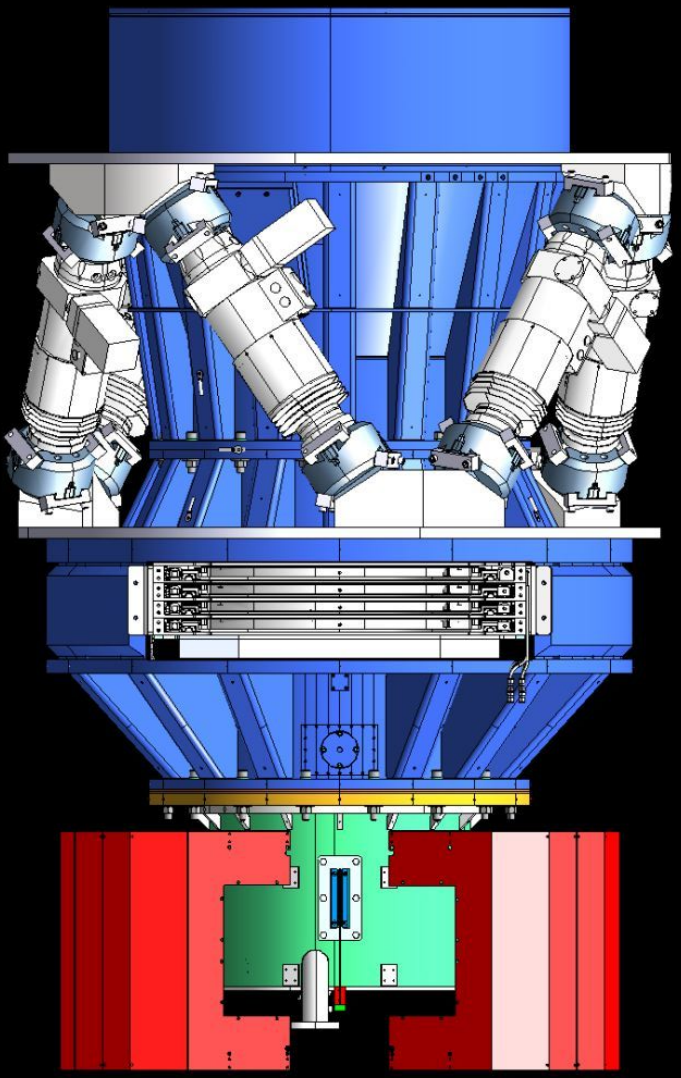
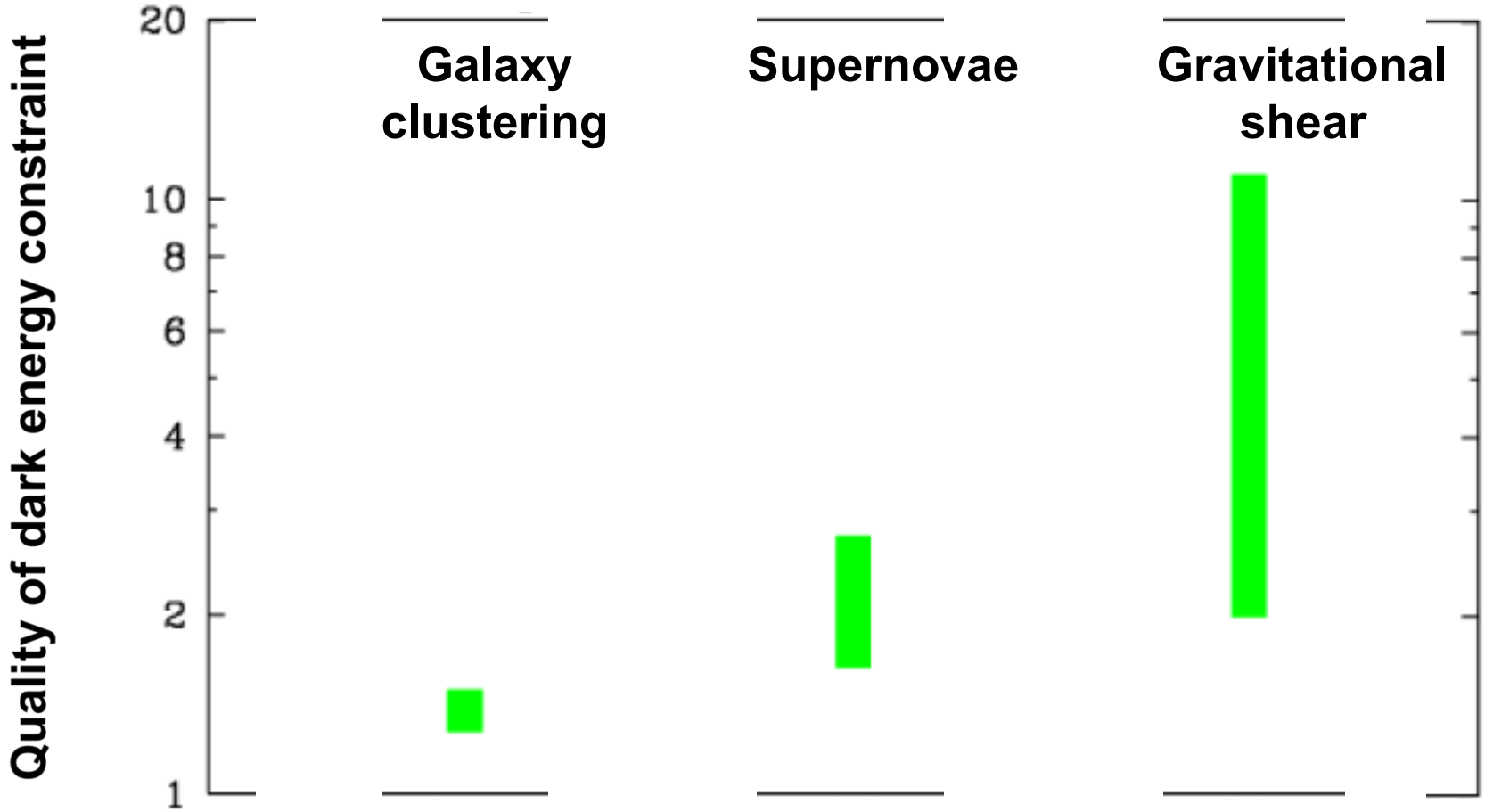
DARK ENERGY
SURVEY

The optics and CCD imager are positioned by the hexapod

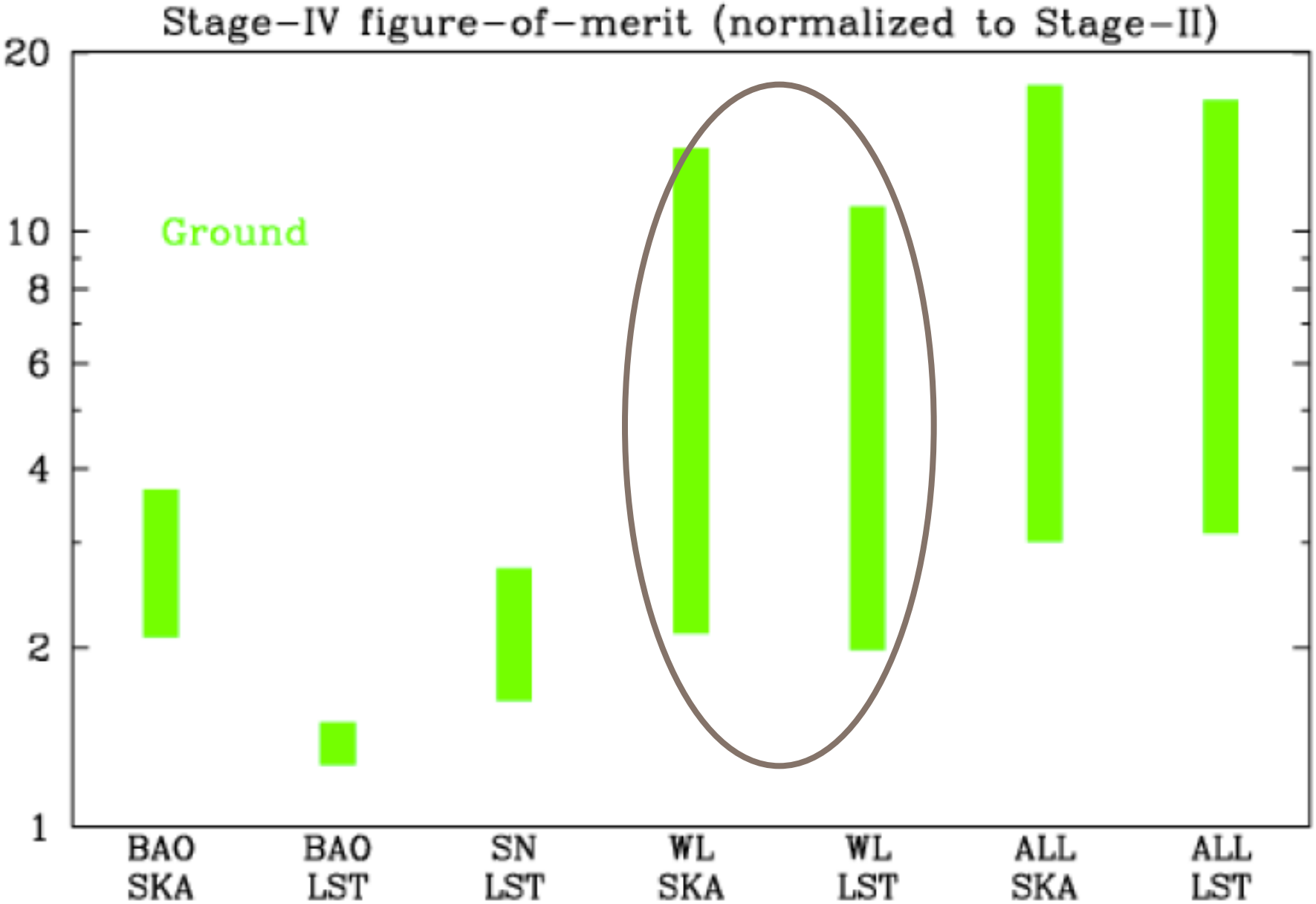


Comparison of different methods



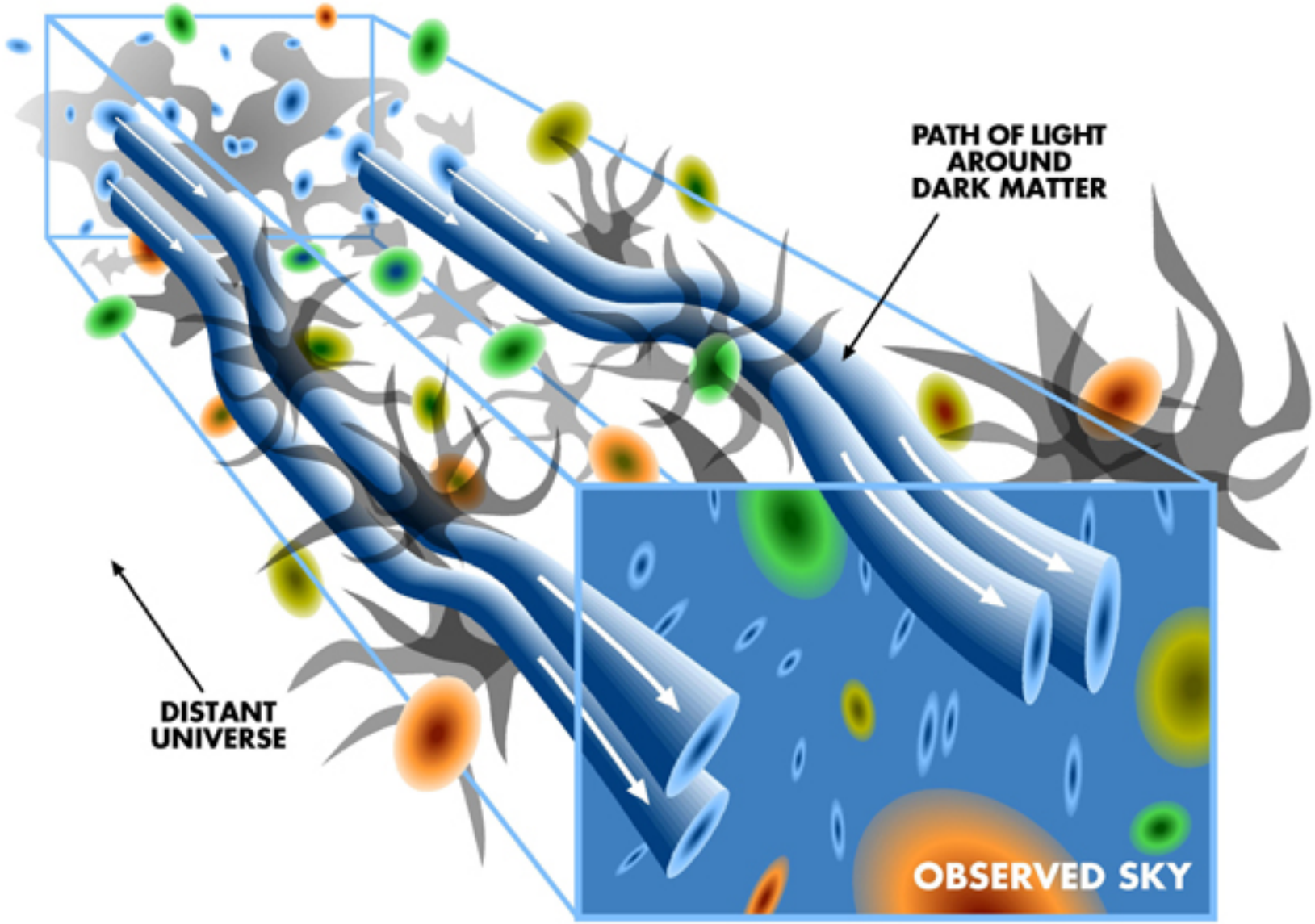
Gravitational shear has the greatest potential
Big uncertainty largely due to shear measurement techniques

Example for optical ground-based surveys
Dark Energy Task Force report astro-ph/0609591



Dark Energy Task Force report astro-ph/0609591

SKA calculations based on predictionso by Abdalla & Rawlings 2005

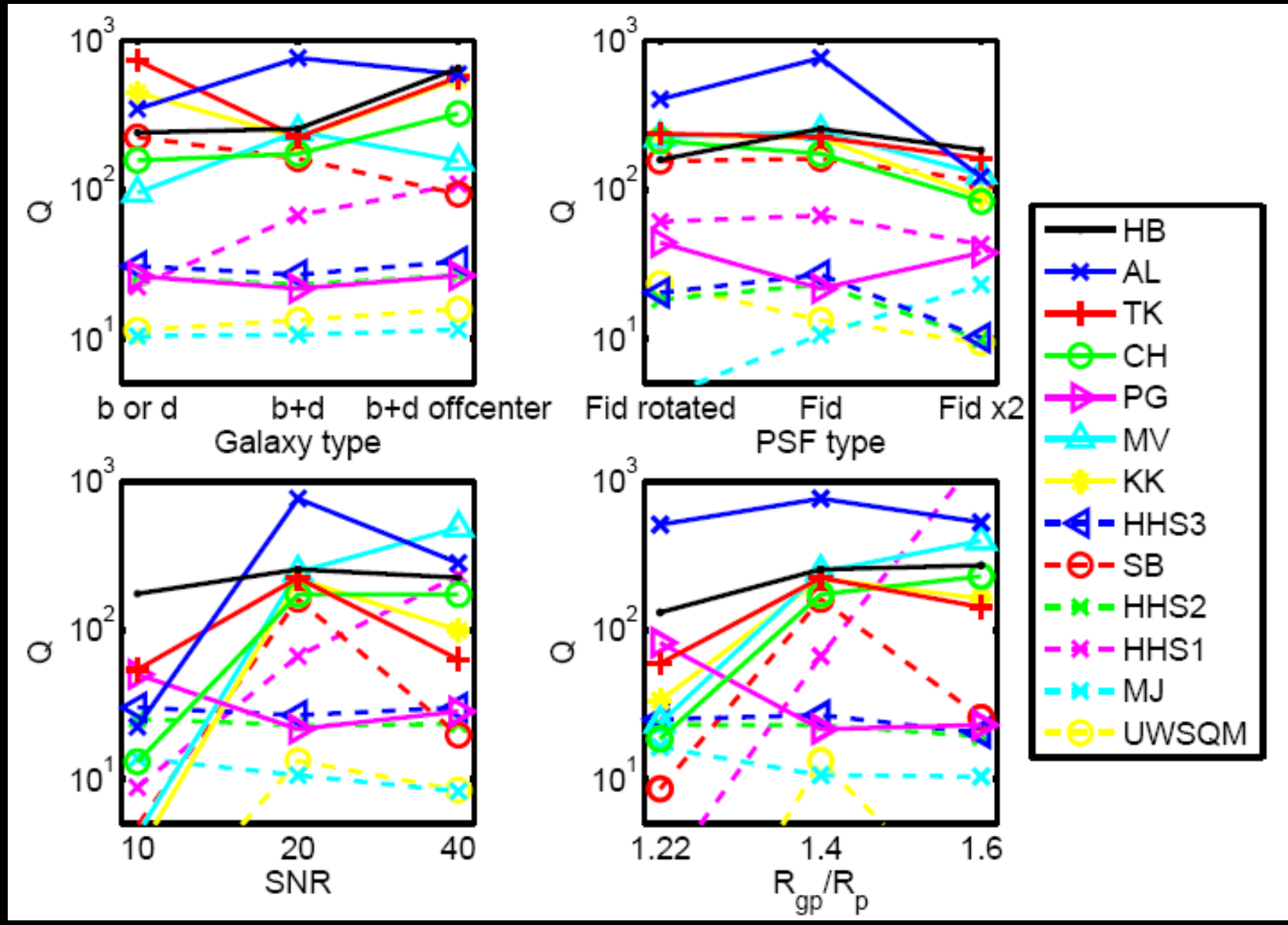


Credit: Nature, Tyson et al. (2000)

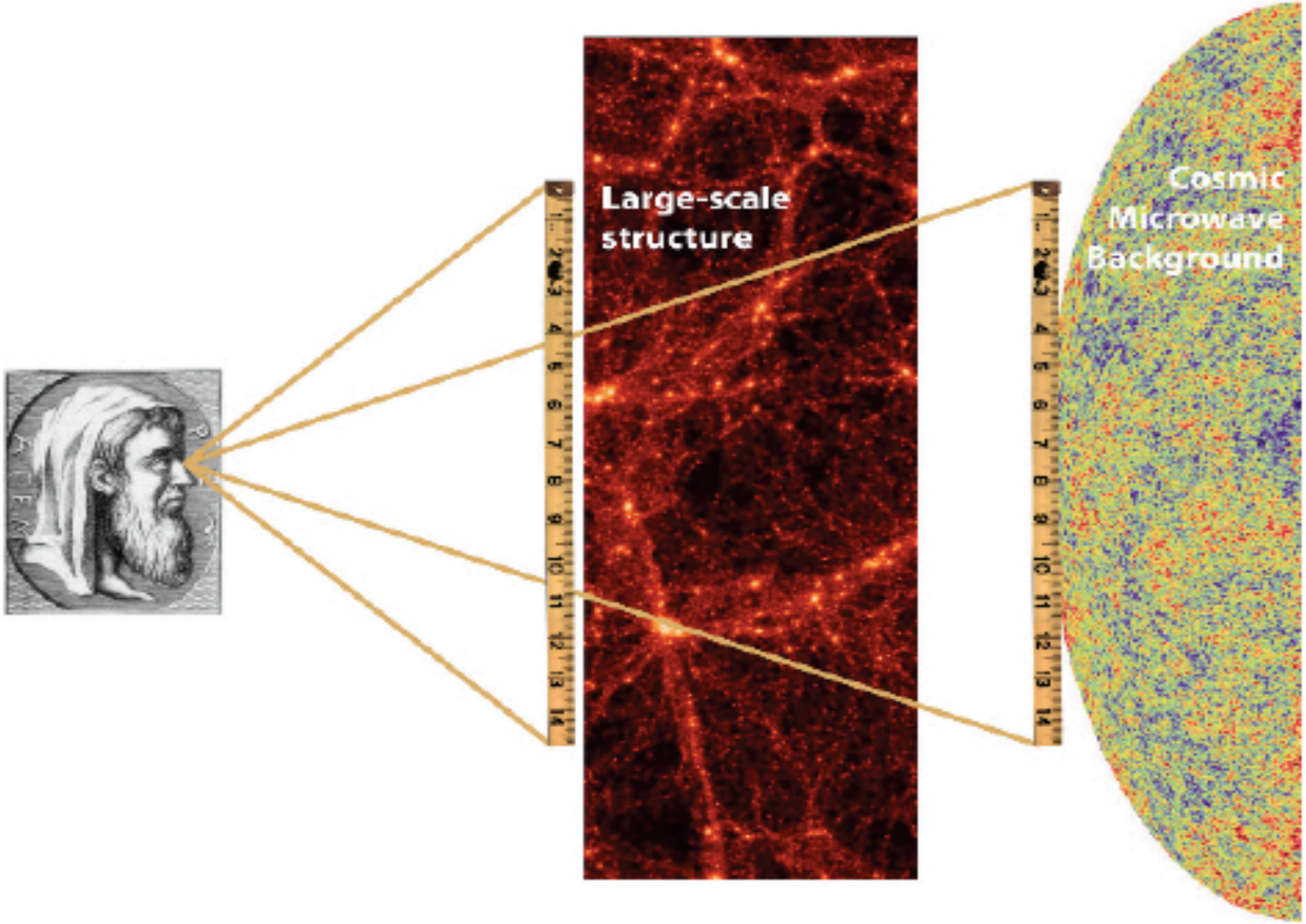
GREAT08 Final Leaderboard

Rank	Author	Method	Q
1	HB	CVN Fourier	210.9
2	AL	KK99	131.4
3	TK*	Lensfit	118.8
4	CH*	KSBf90	52.3
5	PG	galaxy fitting	32.0
6	MV	KKshapelets with flexion	28.6
7	KK*	KKshapelets	23.0
8	HHS3	GaussStackForwardGaussCleaned	22.4
9	SB*	im2shape	20.1
10	HHS2	GaussStackForwardGauss	19.9
11	HHS1	Gauss	12.8
12	MJ*	BJ02 deconvolved shapelets	9.8
13	UWSQM*	UWSQM	?

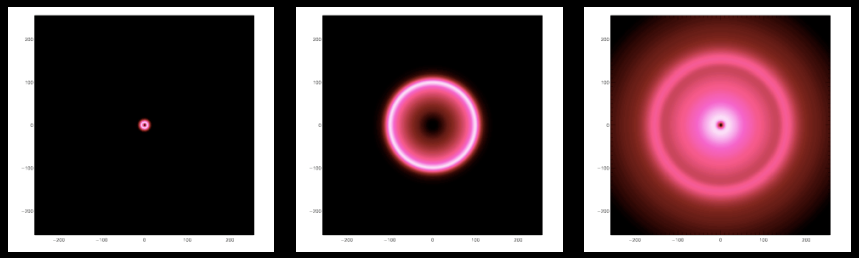
GREAT08 Breakdowns



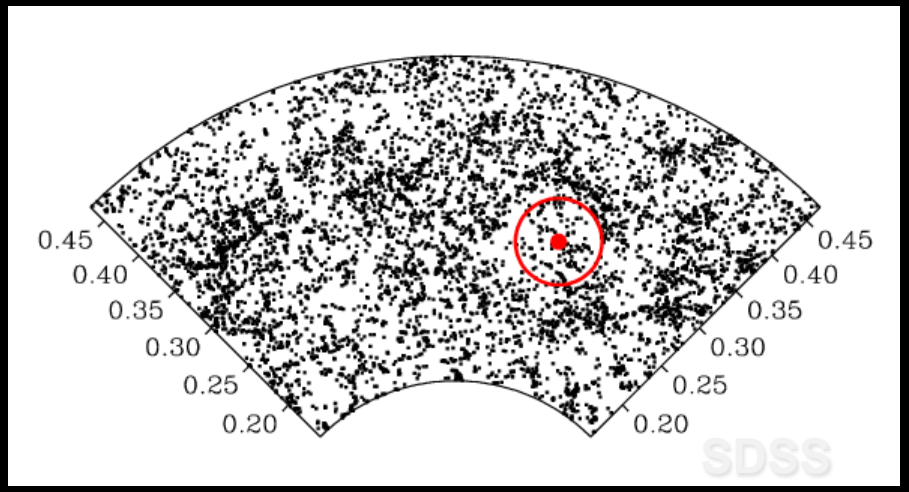
Standard rulers

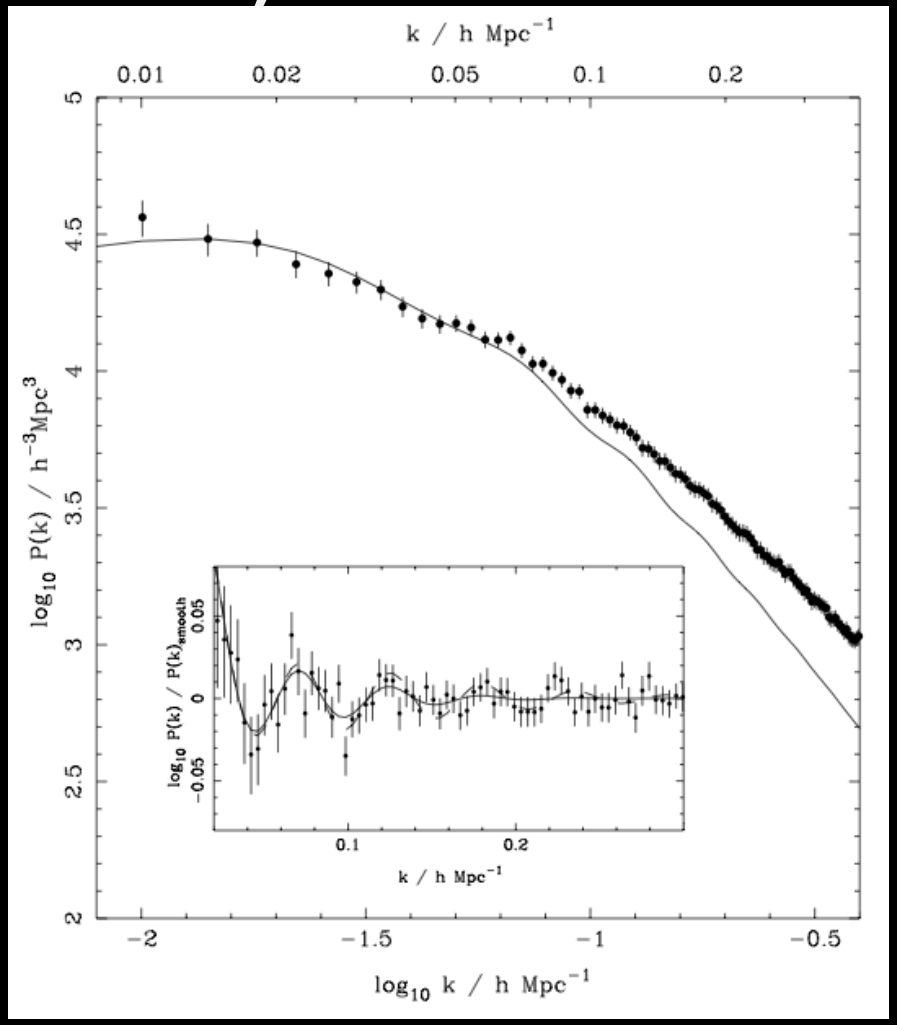


Baryon Acoustic Oscillations (BAO)



(images from Martin White)





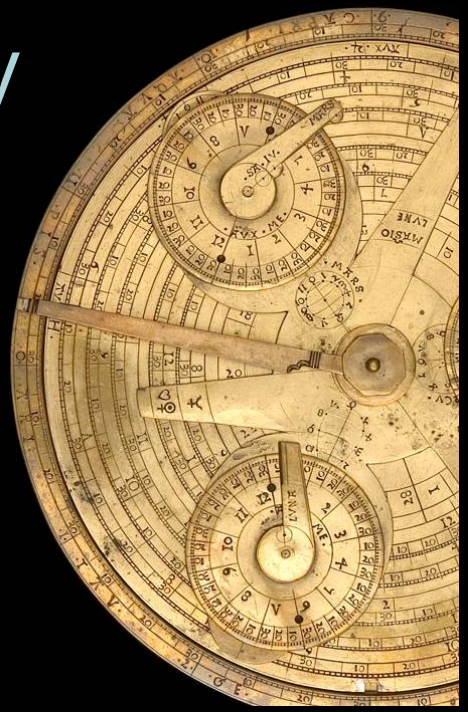
Percival et al. (2007)

Why is the Universe Accelerating?

- Einstein's cosmological constant

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

- A new fluid called Dark Energy
  - Equation of state $w = p/\rho$
  - $w = w_0 + w_a (1-a) + \ldots$



- General Relativity is wrong