The Dark Energy Survey

Josh Frieman
DES Project Director
Fermilab FCPA
KICP, University of Chicago

FCPA/KICP/ANL Retreat
June 5, 2012

Dark Energy Camera Project awarded CD-4 by DOE

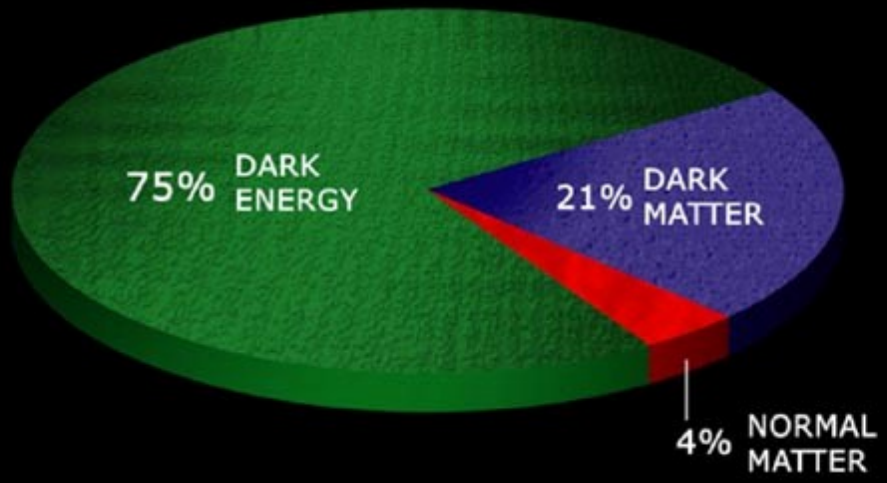
Congratulations to Brenna and the entire DECam team for delivering a world-class instrument on-time and on-budget!

This instrument will be used to carry out the forefront Dark Energy experiment over the next half-decade.

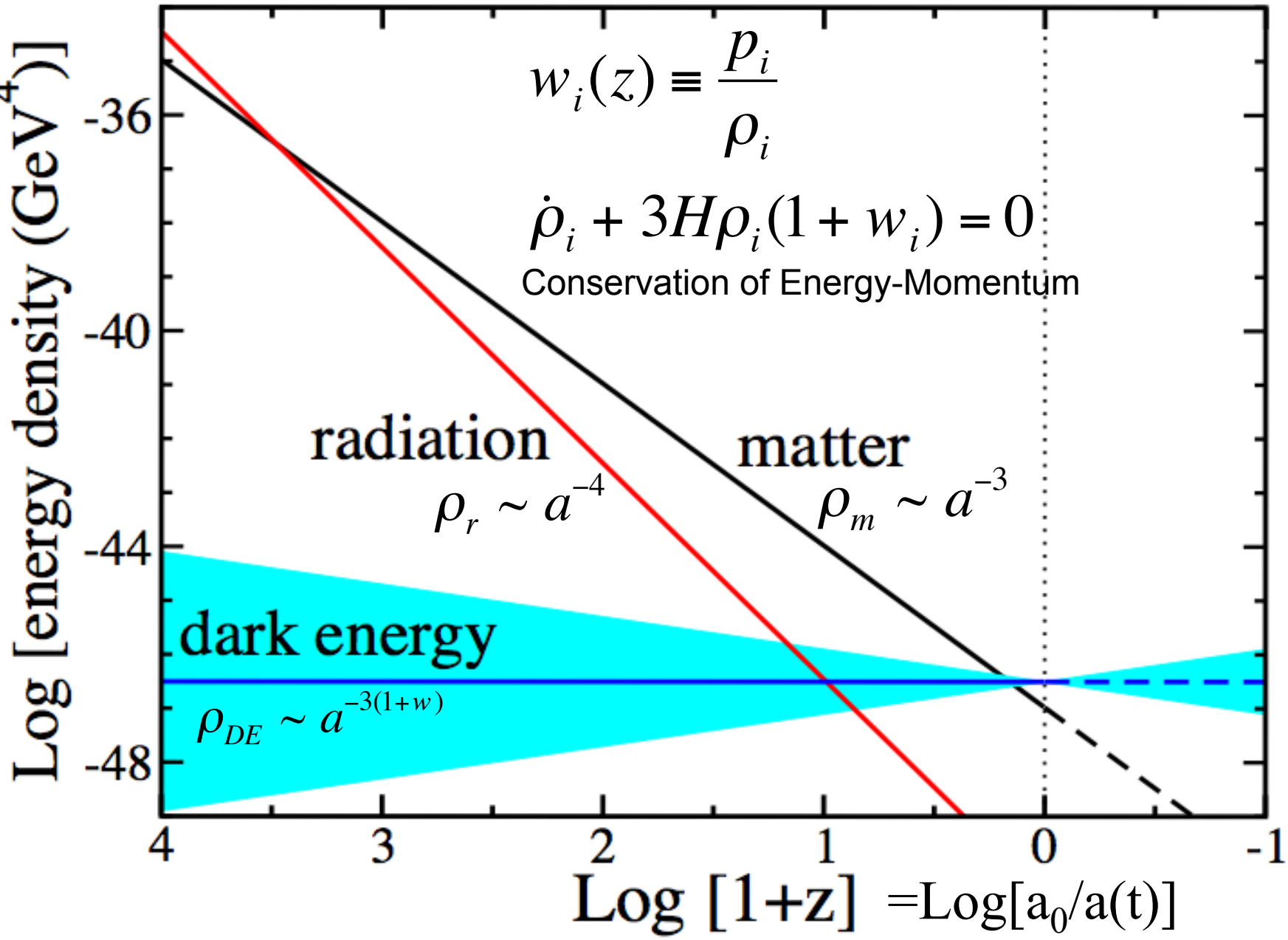
DARK ENERGY SURVEY

Dark Energy

- What is the physical cause of cosmic acceleration?
  - Dark Energy or modification of General Relativity?
    - If Dark Energy, is it Λ (the vacuum) or something else?
      - What is the DE equation of state parameter *w*?



Equation of State parameter *w* determines Cosmic Evolution



www.darkenergysurvey.org

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)
- New 3 deg^2 FOV camera and Data management system
  - Survey 2012-2017 (525 nights)
  - Facility instrument for Blanco

Blanco 4-meter at CTIO

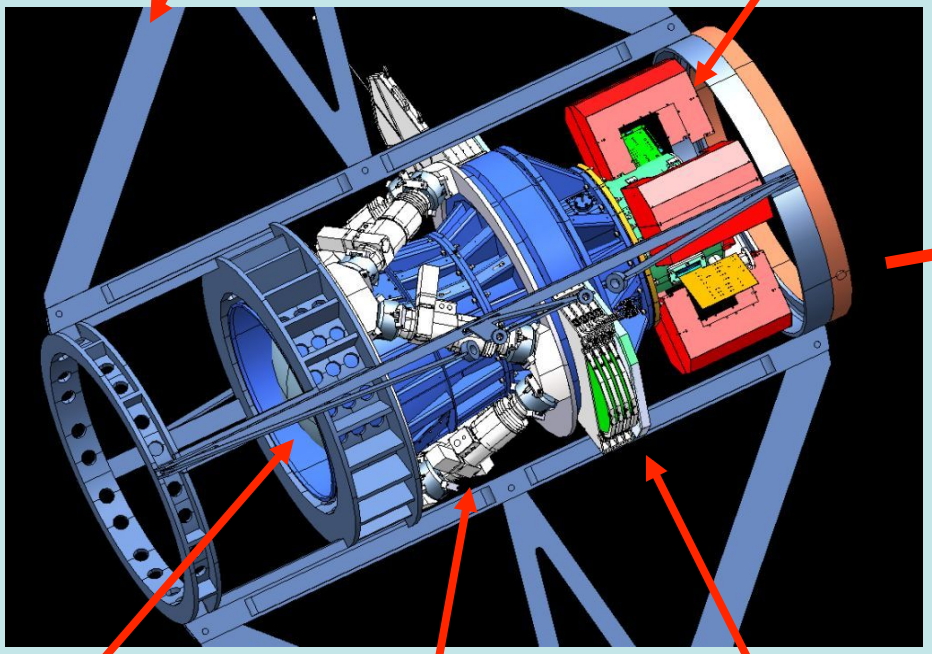
Project Structure & Timeline

- 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
    - Camera construction 2008-11
    - All components now on the mountain
    - New Prime Focus Cage with corrector installed early May
    - Imager installation and commissioning start: early August
    - First light with DECam on telescope: Sept. 1
    - Commissioning runs to Oct. 22
    - Science Verification: Oct. 23-Nov. 15
    - Survey operations begin: Nov. 20

Dark Energy Camera

Mechanical Interface of DECam Project to the Blanco

CCD Readout

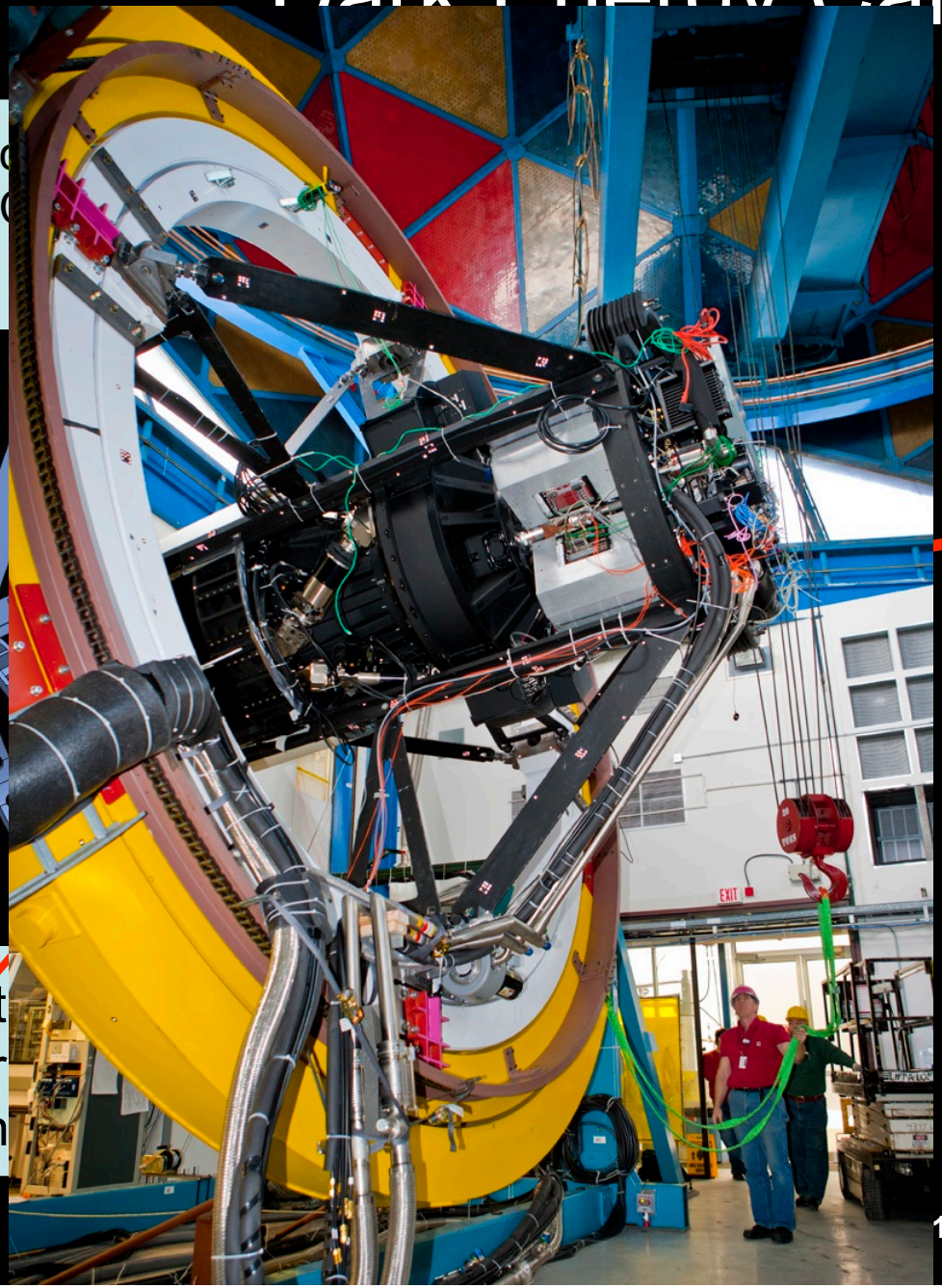


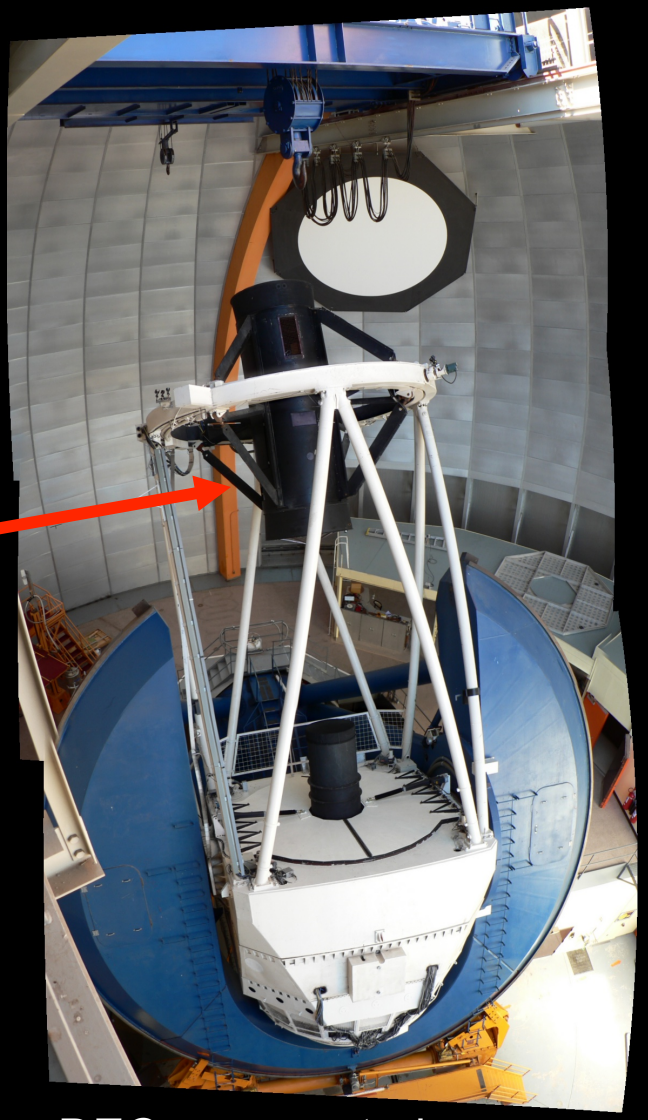
Optical Corrector Lenses

Hexapod: optical alignment

Filters & Shutter

Dark Energy Camera

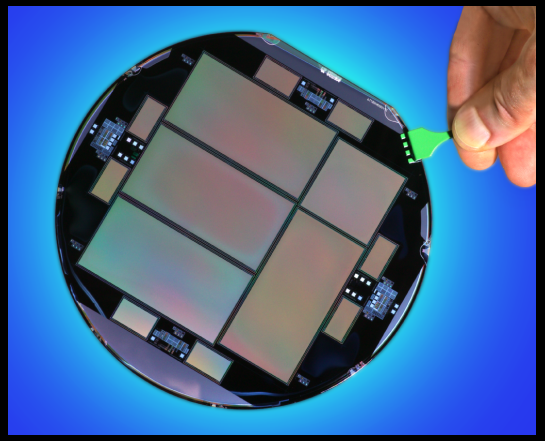




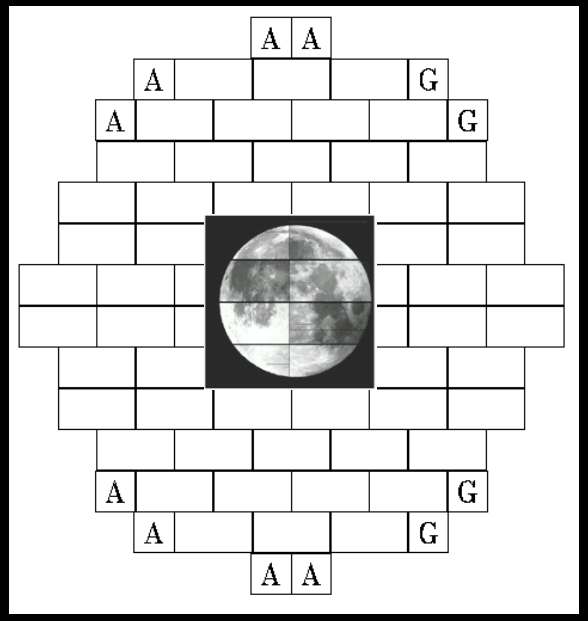
DECam mounted on
Telescope Simulator
at Fermilab in early 2011

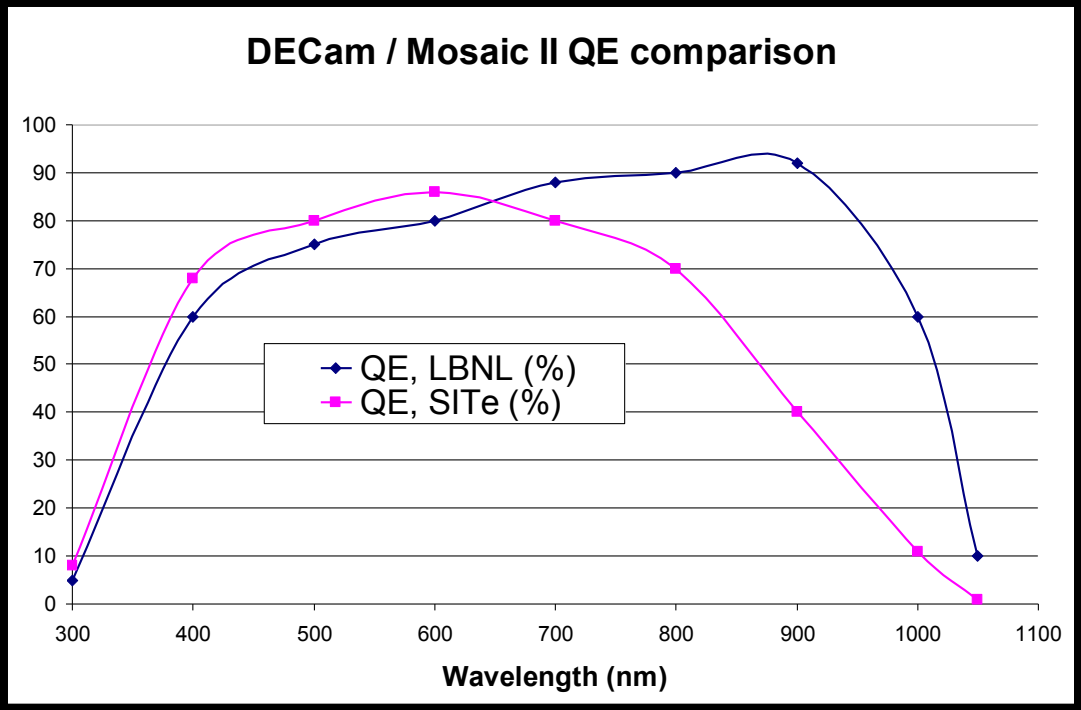
DECam CCDs

- 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



Developed by LBNL





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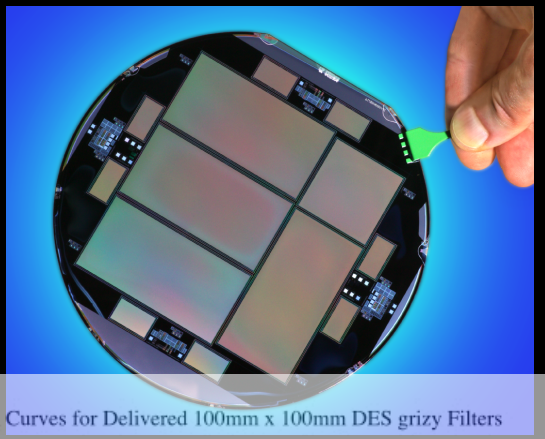

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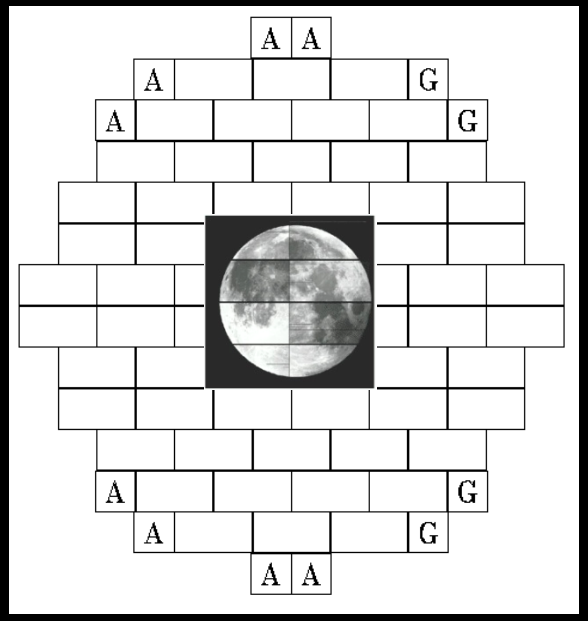
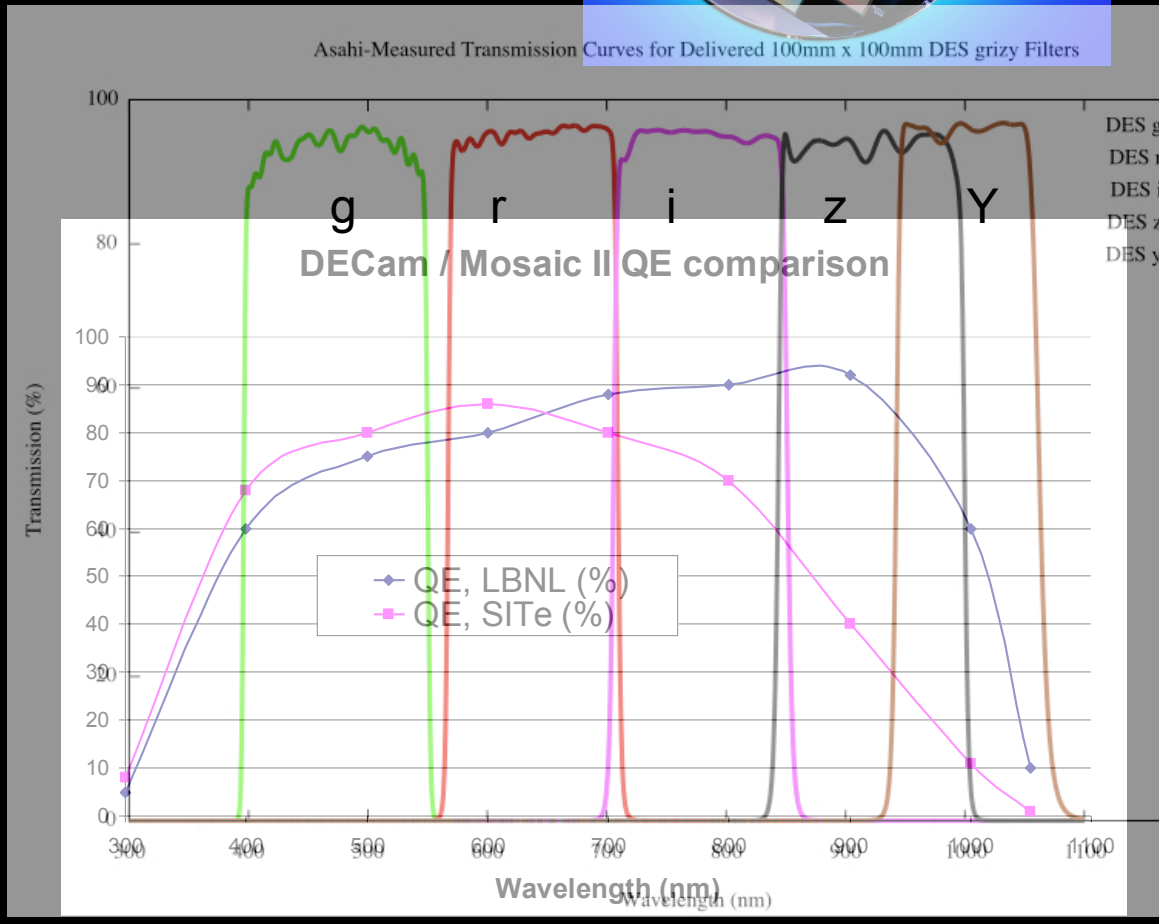




Asahi filters

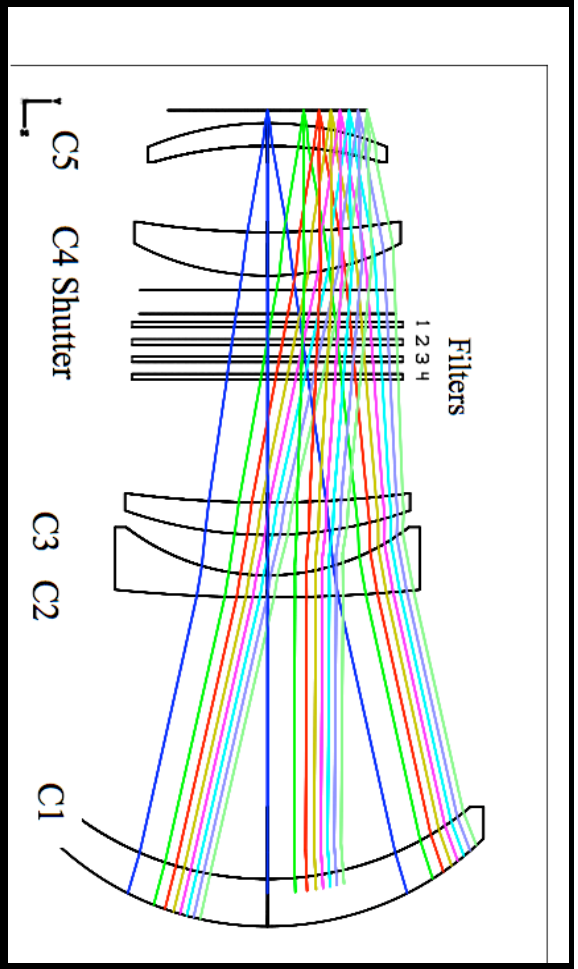
DARK ENERGY SURVEY

DECam in Chile

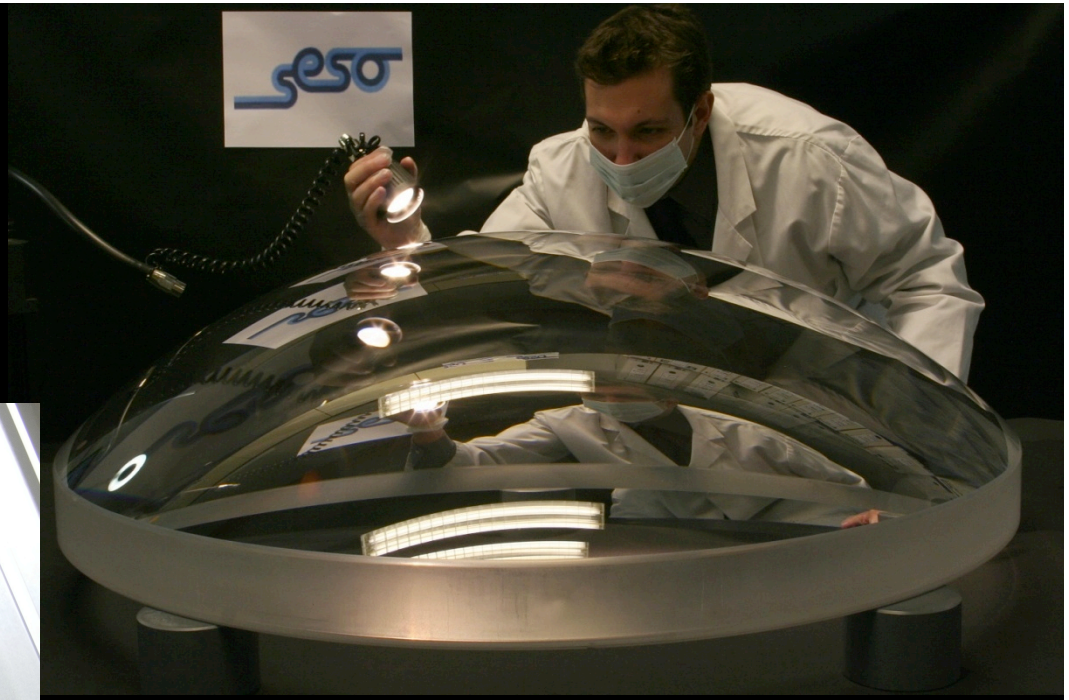
Optics

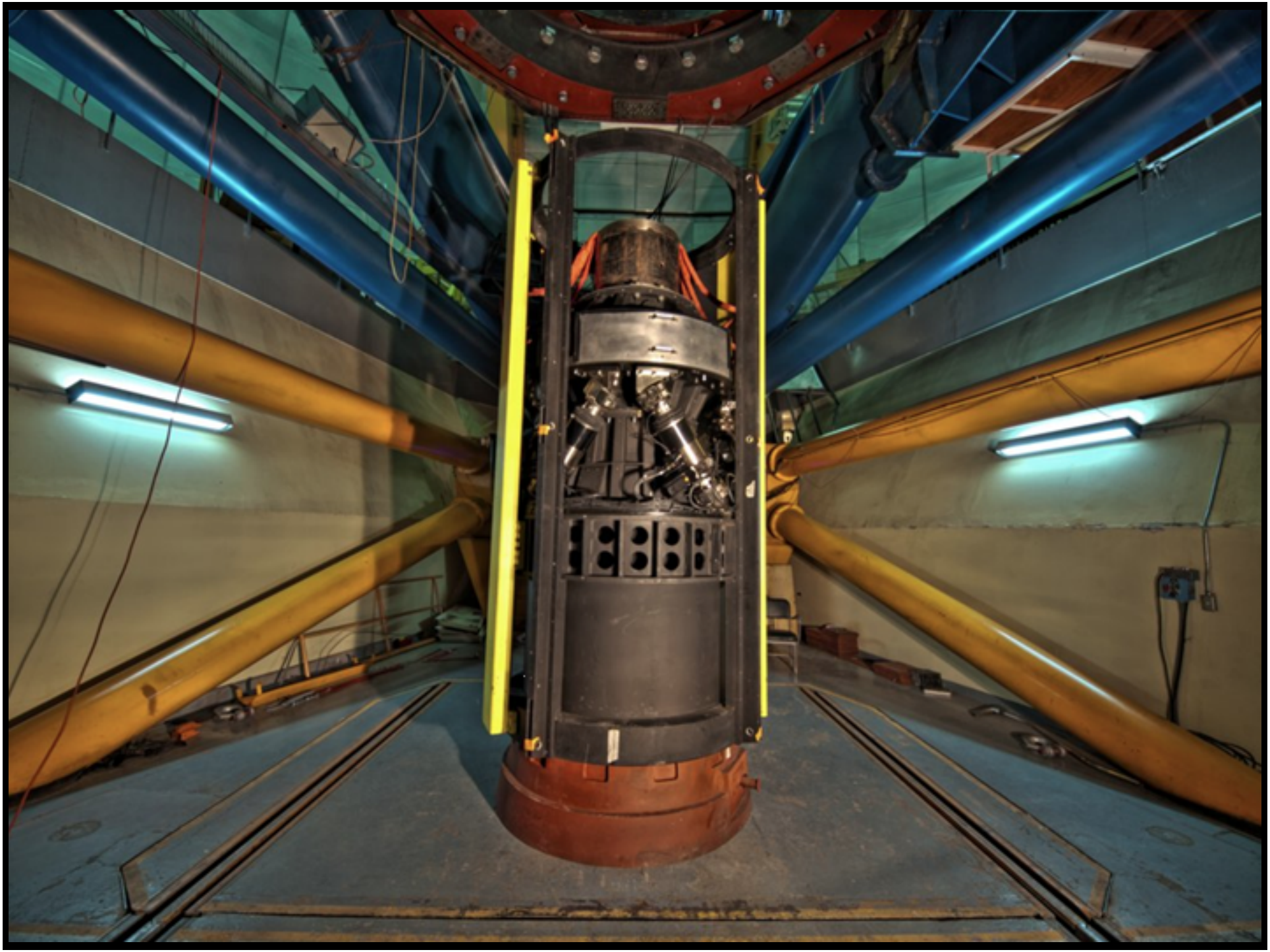
- Field of view: 2.2^{o} diameter
- Good image quality across FOV
- Optical elements aligned at UCL

S. Kent (FNAL)



DARK ENERGY
SURVEY





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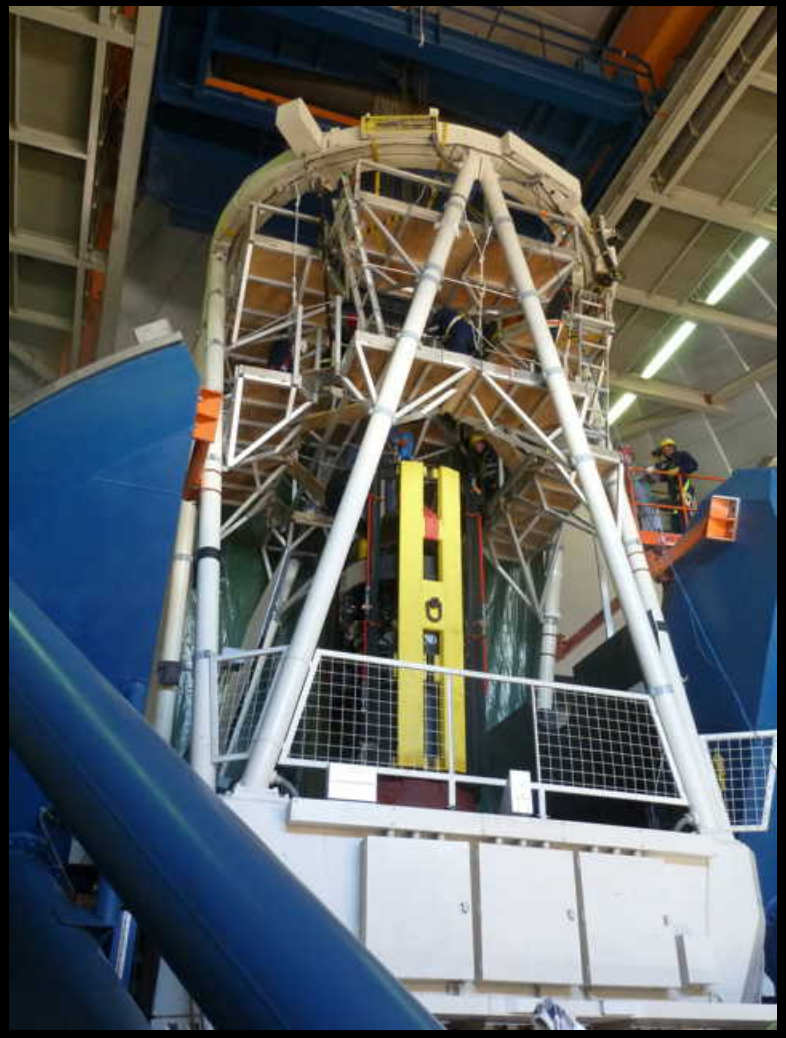

DARK ENERGY
SURVEY

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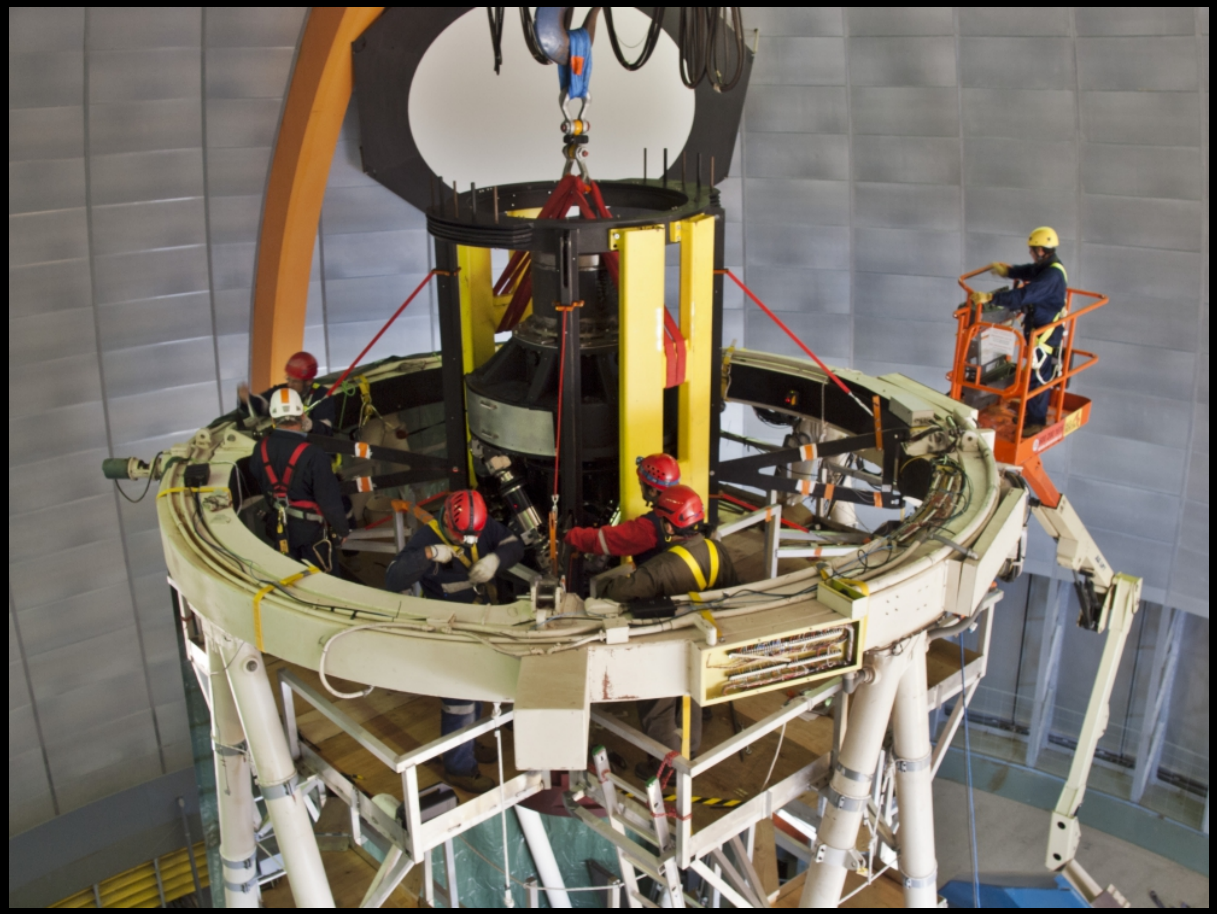
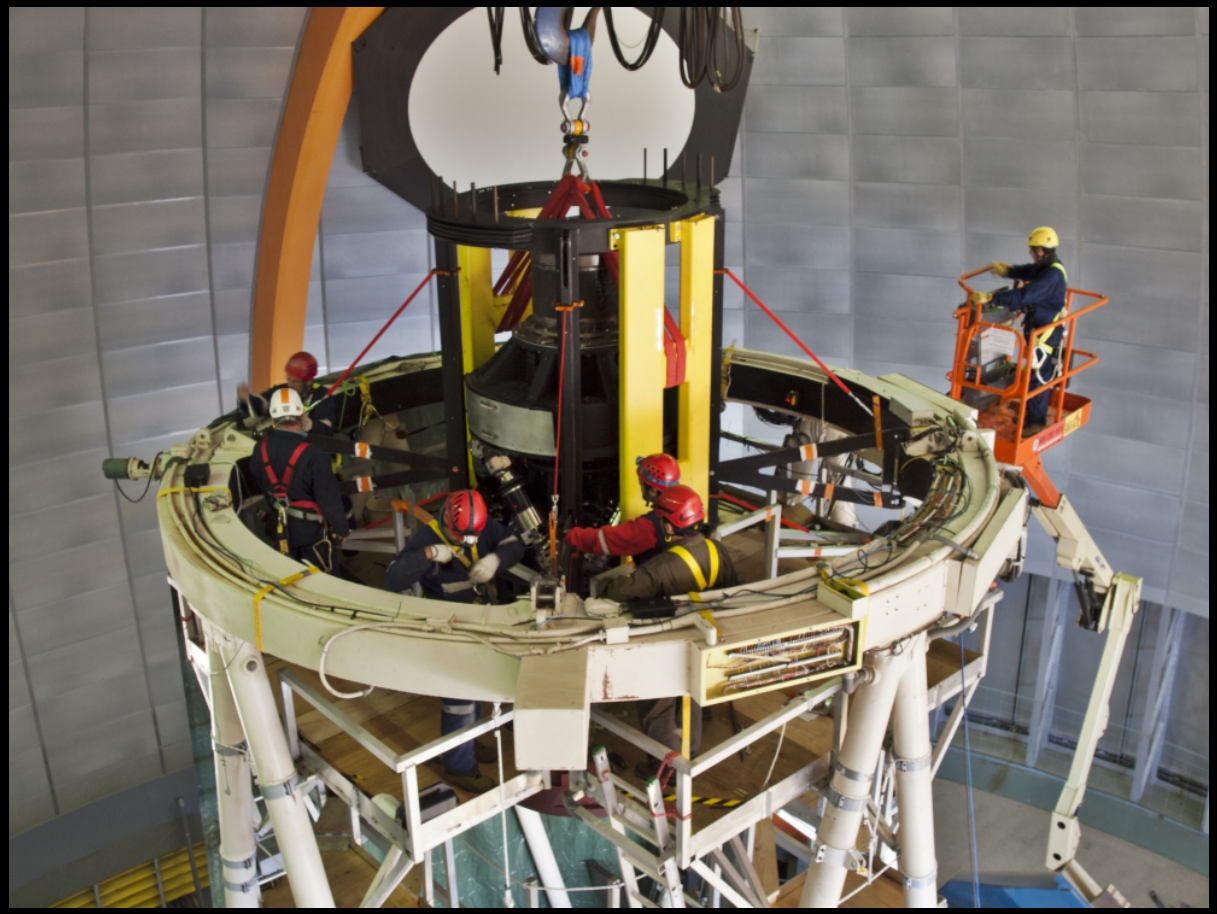
DARK ENERGY SURVEY

DECam Prime Focus Cage Installed



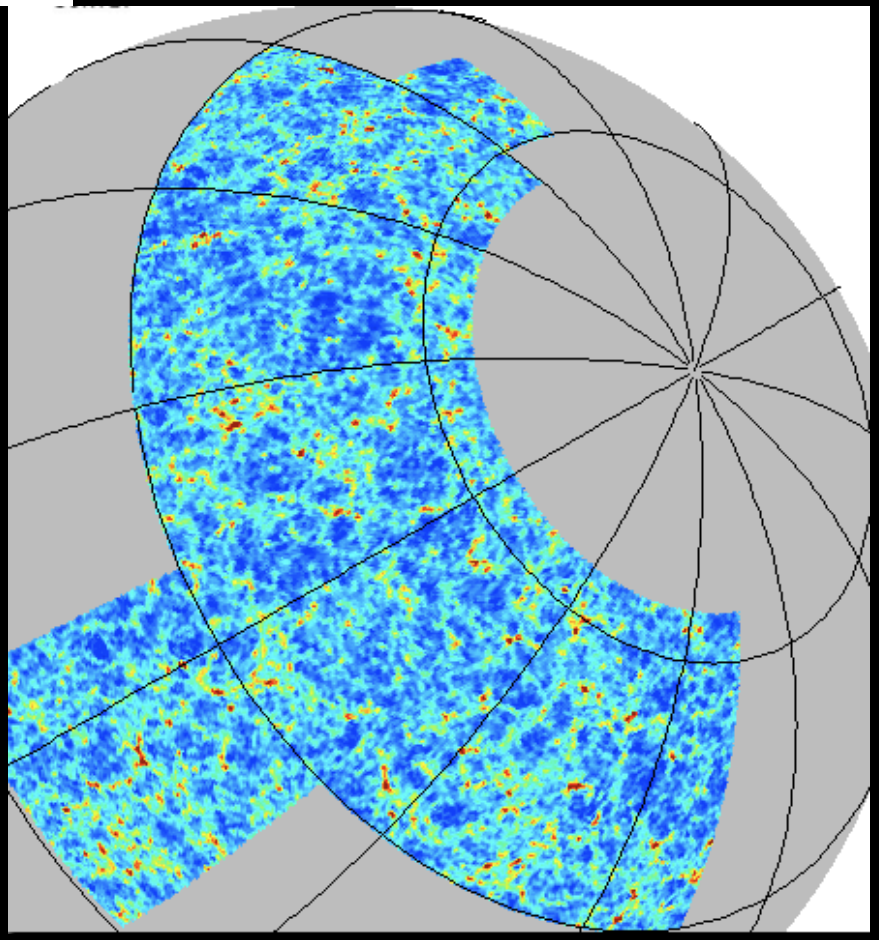
DARK ENERGY SURVEY

DECam+DESpec Cage Installed



Synergy with South Pole Telescope

DES footprint: 5000 sq deg



DES survey area encompasses SPT Sunyaev-Zel'dovich Cluster Survey
Also partnering with VISTA Hempishere Survey (NIR): improve photo-z's

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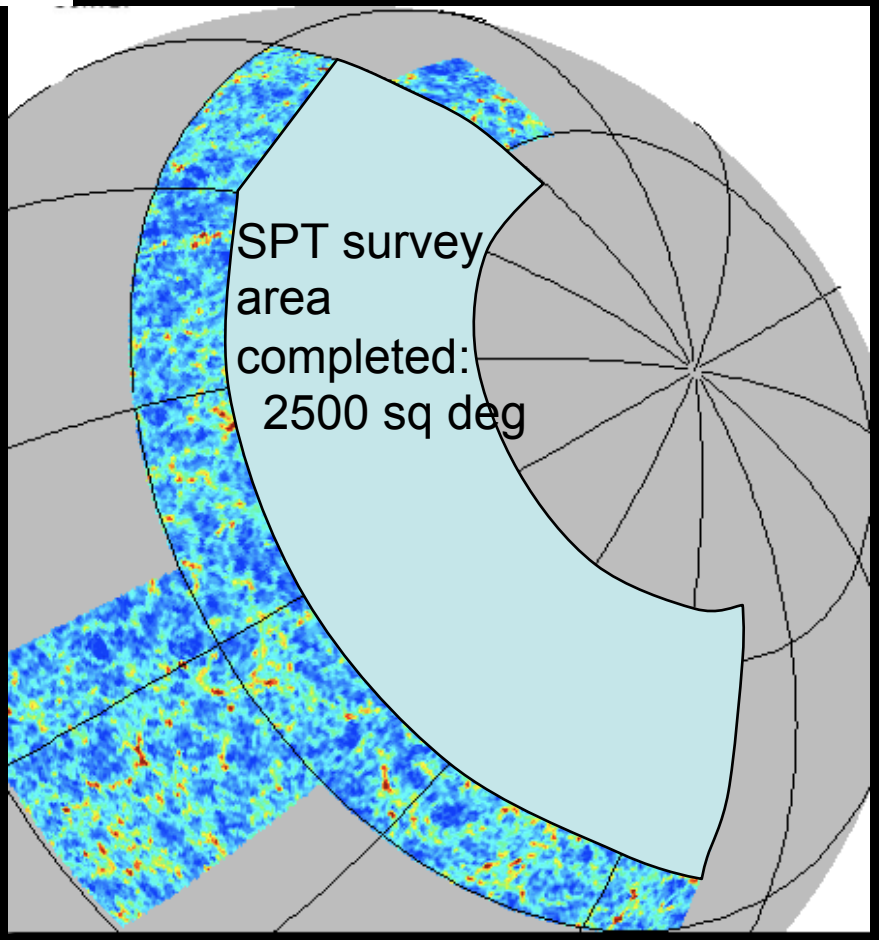

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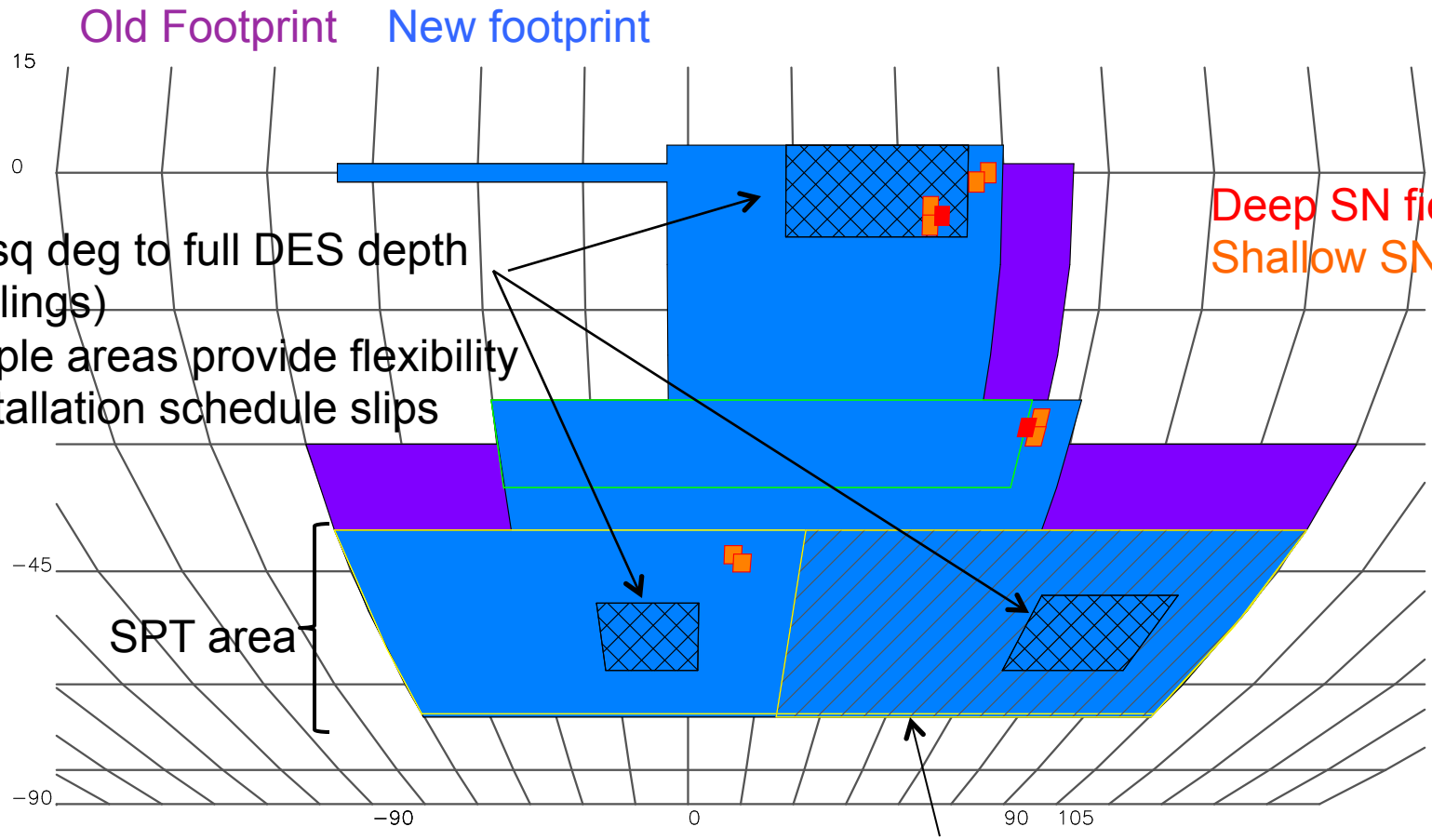
Plans for First Season



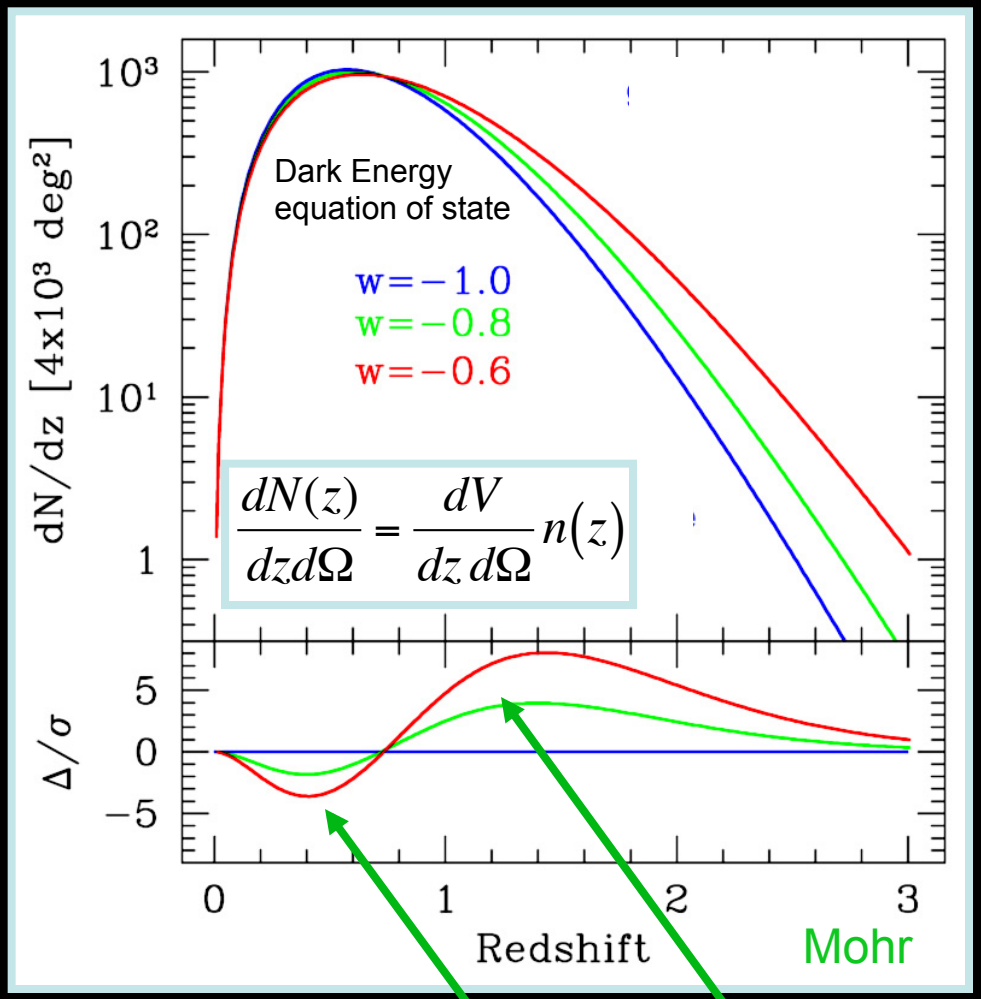
Proposed 20 first-half nights for SV,
Expect <45 nights for 2012B, based on
current installation schedule (Nov. 20 start)

1200 sq deg to single-season depth
(2 tilings)

I. Clusters

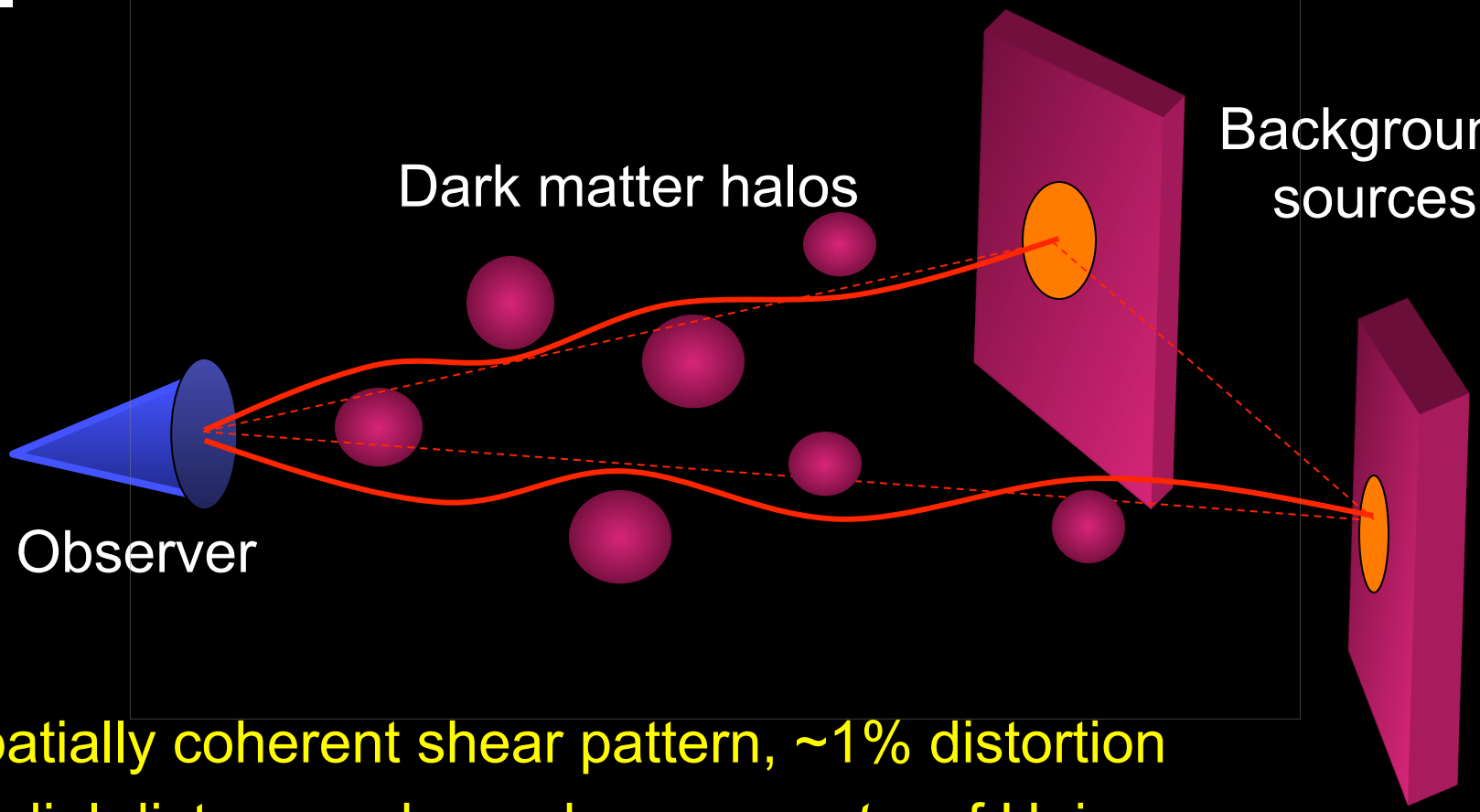
- Clusters are proxies for massive halos and can be identified optically to redshifts z>1
- Galaxy colors provide photometric redshift estimates for each cluster
- Observable proxies for cluster mass: optical richness (DES), SZ flux decrement (SPT), weak lensing mass (DES), X-ray flux (eRosita)
- Cluster spatial correlations help calibrate mass estimates
- Challenge: determine mass-observable relation *p(O|M,z)* with sufficient precision

Number of clusters above mass threshold



DARK ENERGY SURVEY

II. Weak Lensing: Cosmic Shear



- Spatially coherent shear pattern, ~1% distortion
- Radial distances depend on *geometry* of Universe
- Foreground mass distribution depends on *growth* of structure

Weak Lensing Tomography

DARK ENERGY SURVEY

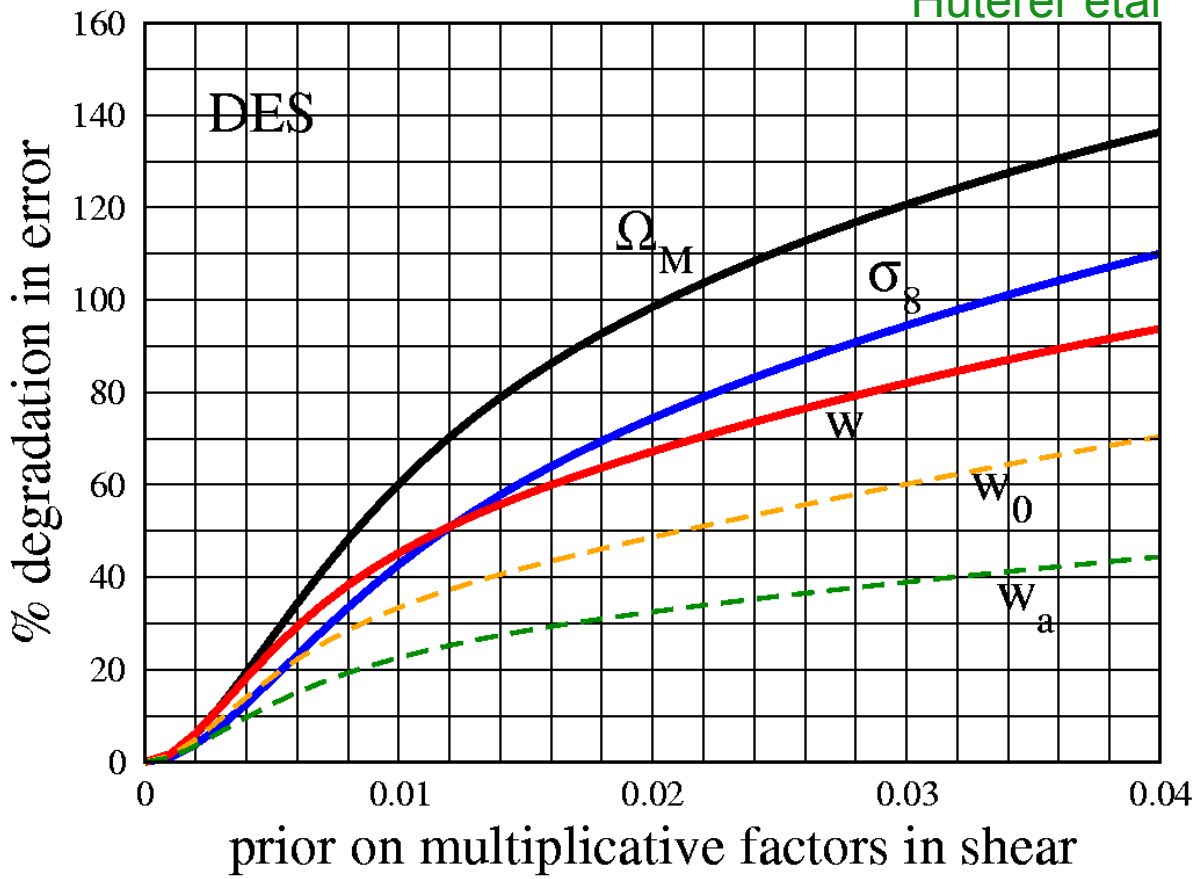
- Cosmic Shear Angular Power Spectrum in Photo-z Slices

- Shapes of ~300 million well-resolved galaxies, $\langle z \rangle = 0.7$

- Challenges: photo-z's, intrinsic alignments, PSF anisotropy, shear calibration, nonlinear +baryon *P(k)* effects

- Extra info in bispectrum & galaxy-shear: robust

Huterer etal



Expect n_{eff}~10/arcmin^2 for median 0.9" PSF

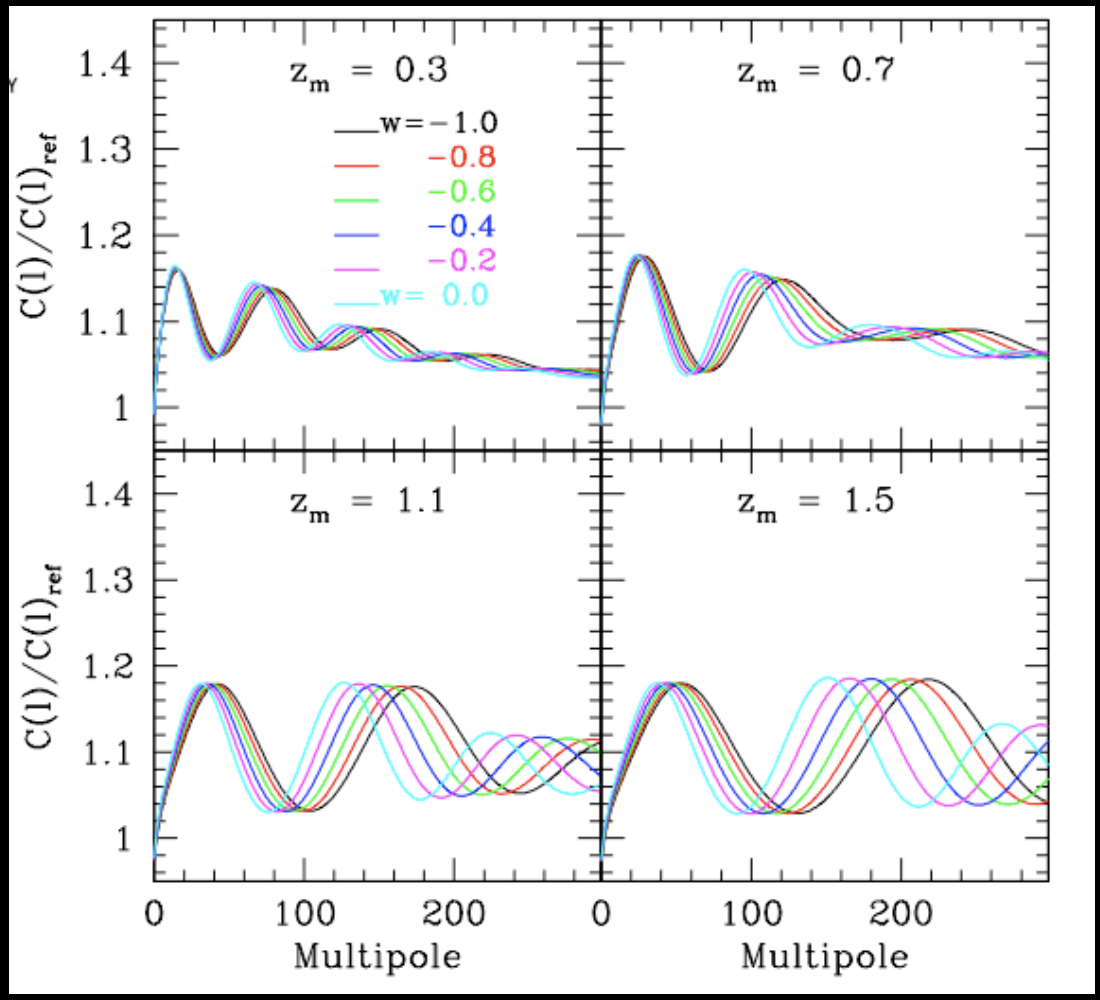
$$C_\ell^{x_a x_b} = \int dz \frac{H(z)}{D_A^2(z)} W_a(z) W_b(z) P^{s_a s_b}(k = \ell / D_A; z) \qquad \Delta C_\ell = \sqrt{\frac{2}{(2\ell+1) f_{sky}}} \left(C_\ell + \frac{\sigma^2(\gamma_i)}{n_{eff}} \right)$$

III. Baryon Acoustic Oscillations

Galaxy angular power spectrum in photo-z bins (relative to model without BAO)

Photometric surveys provide angular measure

Radial modes require spectroscopy (DESpec)



Fosalba & Gaztanaga

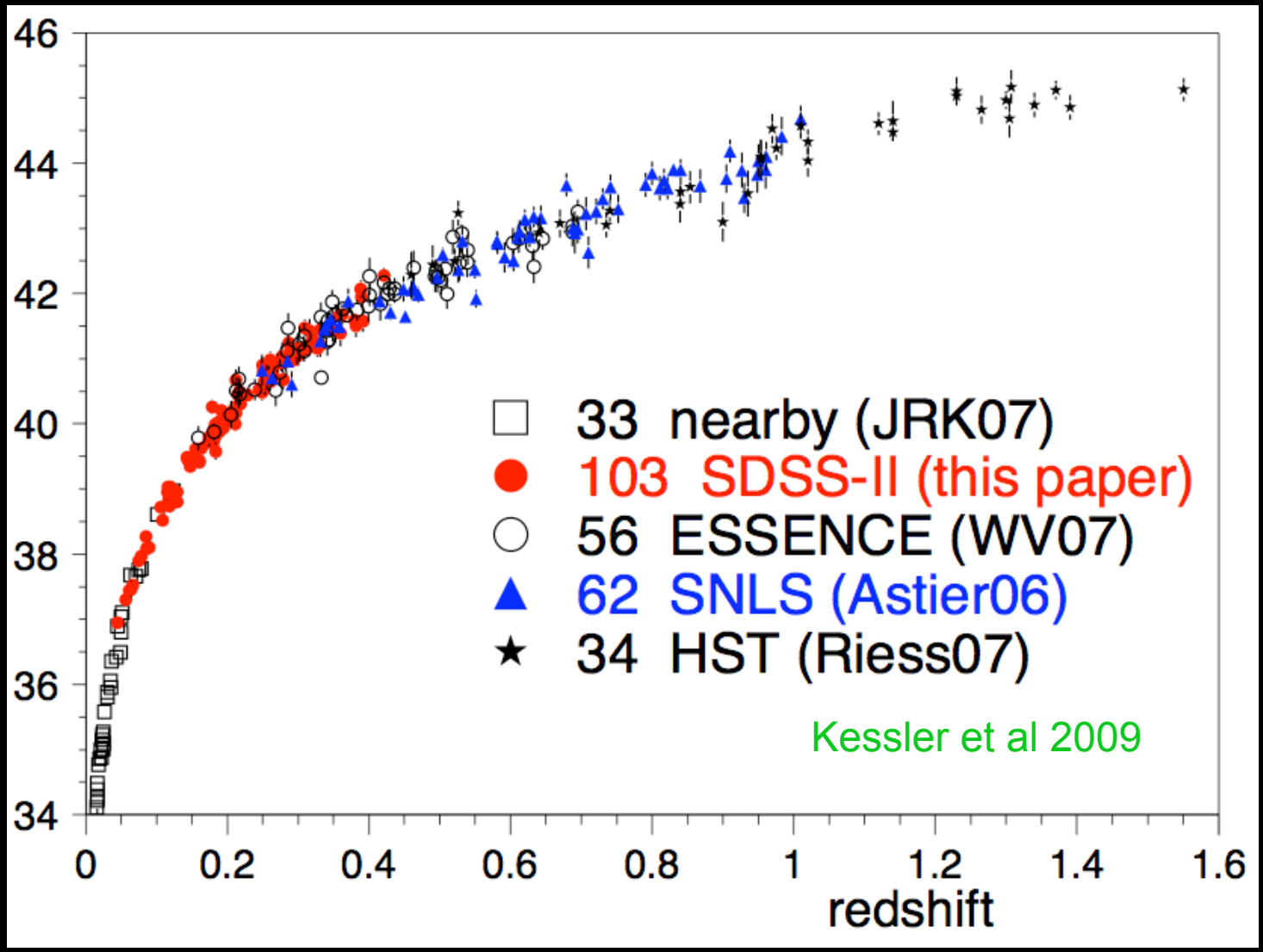
IV. Supernovae

B. Dilday

SDSS-II: 500 spectroscopically confirmed SNe Ia,
>1000 with host redshifts from SDSS-III

DARK ENERGY SURVEY

Supernova Hubble Diagram



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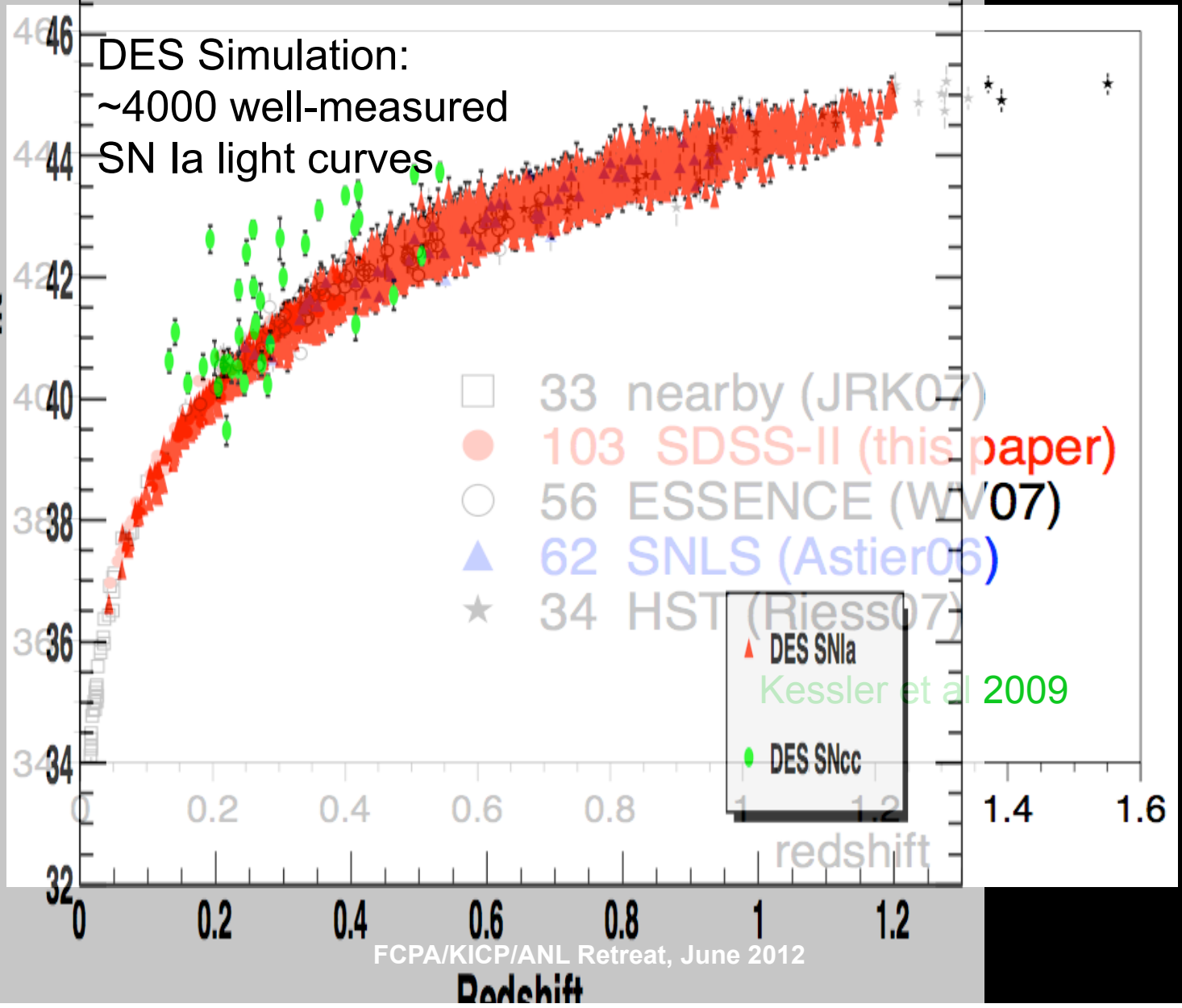


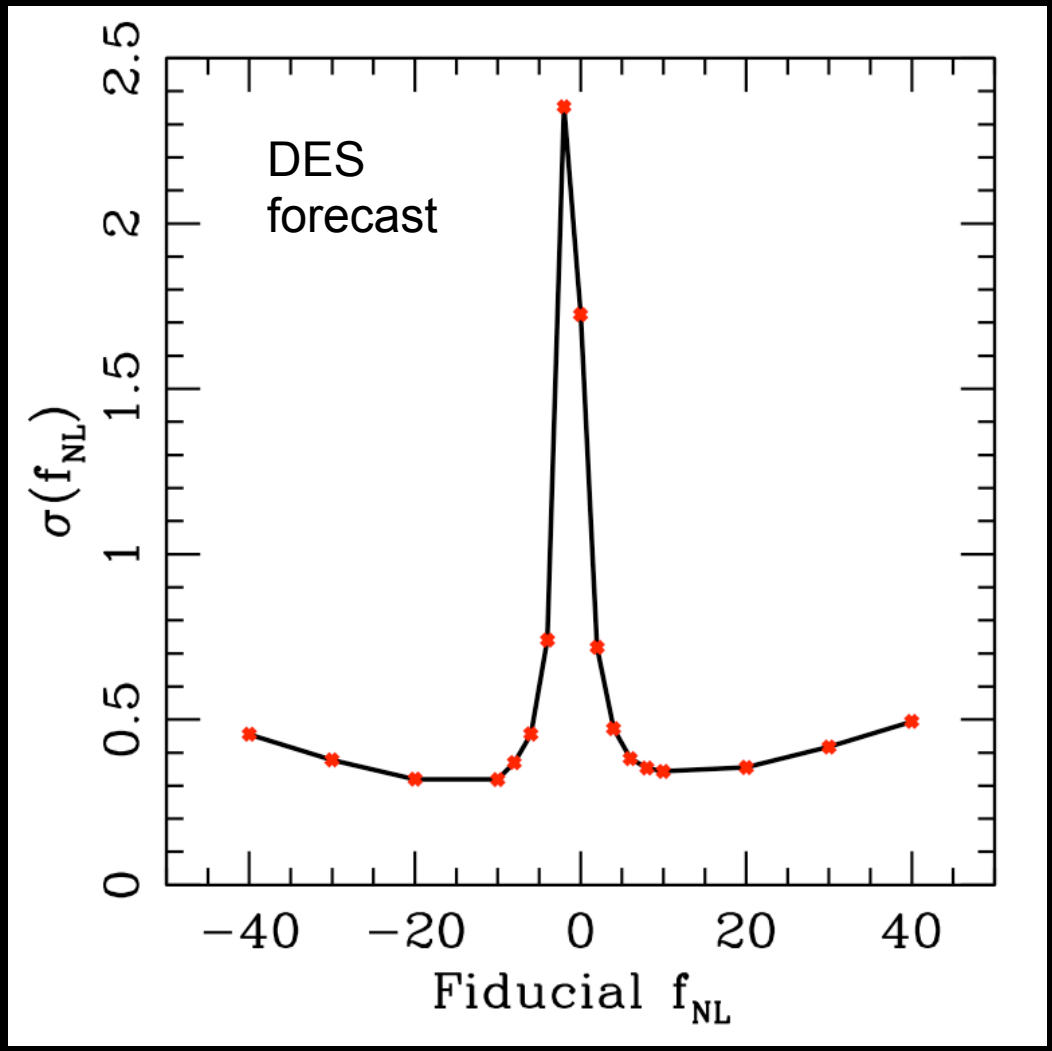
Probing Inflation with DES: Constraining Non-Gaussianity

- Primordial non-Gaussianity generates scale-dependent bias of dark halos on large scales — Dalal, Dore, Huterer, Shirokov 2008
- Test with Observations:
  - Covariance of Cluster Counts — Cunha, Huterer, Dore 2010
  - Halo Power Spectrum — Shandera, Dalal, Huterer 2010
  - Weak Lensing — Park & Dodelson 2012

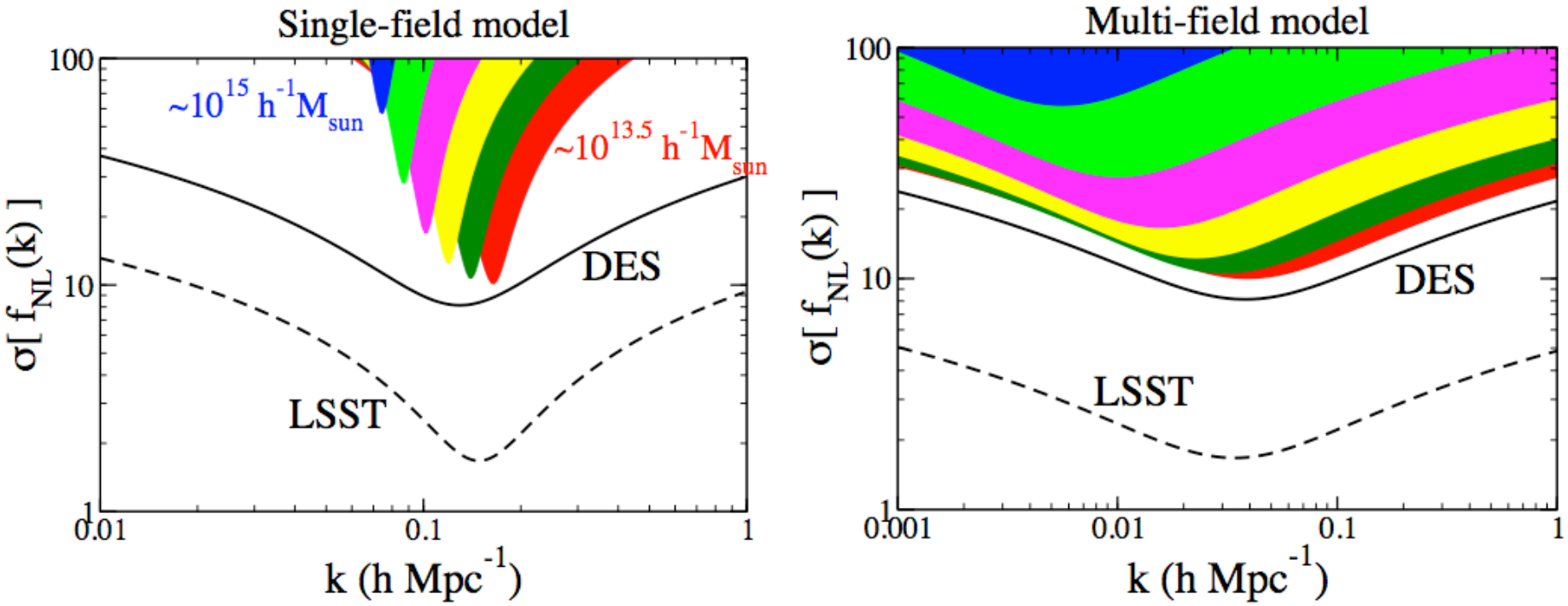
Covariance of Cluster Counts

- Forecast constraints robust to uncertainties in cluster mass-observable relation, halo bias, and photo-z errors

Cunha, Huterer, Dore 2010



Constraints on non-Gaussianity vs. scale



Shandera, Dalal, Huterer 2010

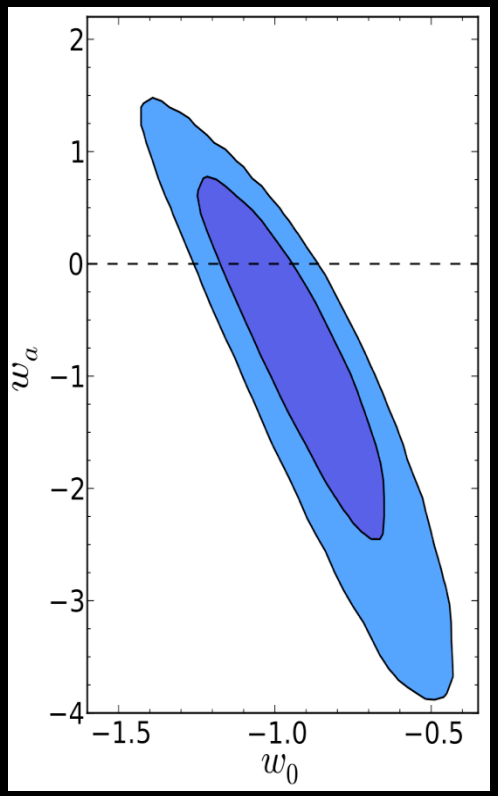
DES Science Summary

DARK ENERGY SURVEY

Four Probes of Dark Energy

- **Galaxy Clusters**
  - ~100,000 clusters to z>1
  - Synergy with SPT, VHS
  - Sensitive to growth of structure and geometry
- **Weak Lensing**
  - Shape measurements of 200 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

Current Constraints on DE Equation of State



Sullivan, etal

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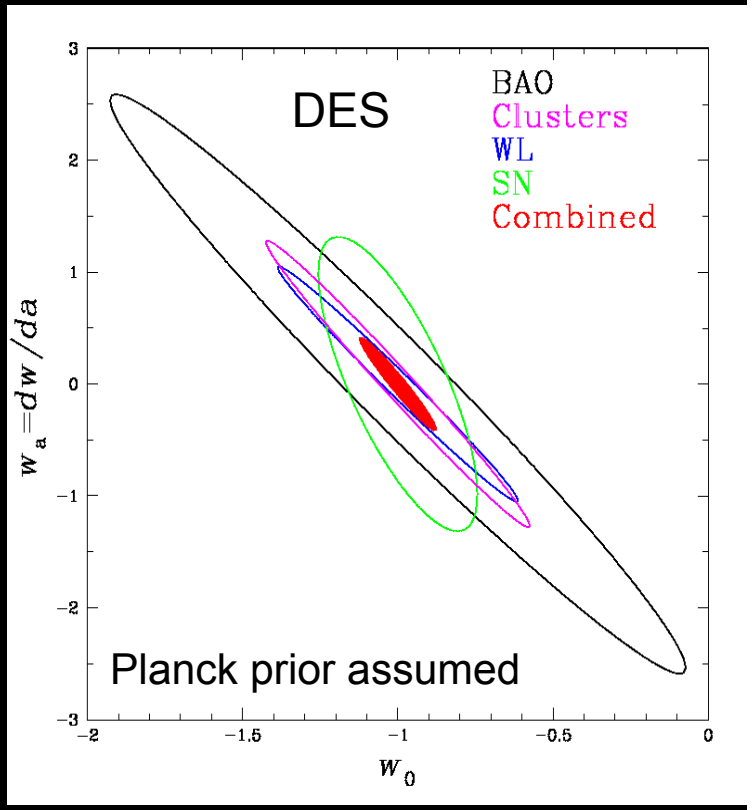
Forecast Constraints on DE Equation of State



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

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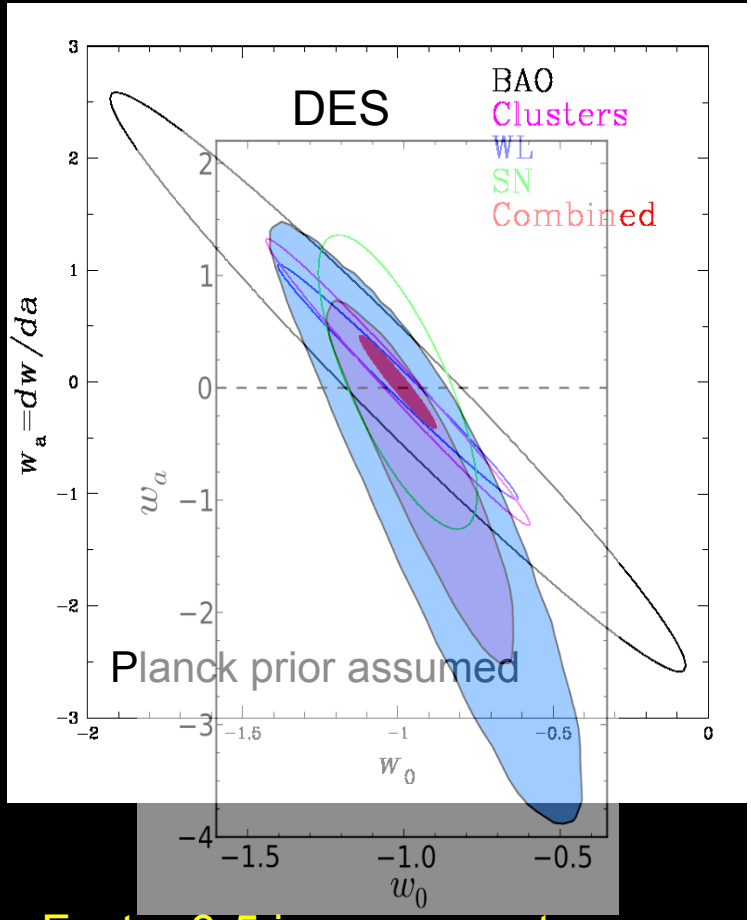


Factor 3-5 improvement over Stage II DETF Figure of Merit

FCPA/KICP/ANL: Synergistic Activities

- Galaxy Clusters
  - KICP Joint Analysis Hub meets biweekly
  - Joint mass-observable calibration strengthens DE constraints
- Weak Lensing
  - Galaxy-galaxy lensing
  - CMB lensing: cross-correlate DES and SPT
- Supernovae
  - Heritage from SDSS SN; KICP SN Hub
- Primordial Non-Gaussianity
  - KICP Non-Gaussianity Hub
- Theory & Combined Probes
- Large-scale Simulations
- DESpec R&D, LDSS3 Magellan upgrade

Massive Spectroscopic Follow-up in the Southern Hemisphere

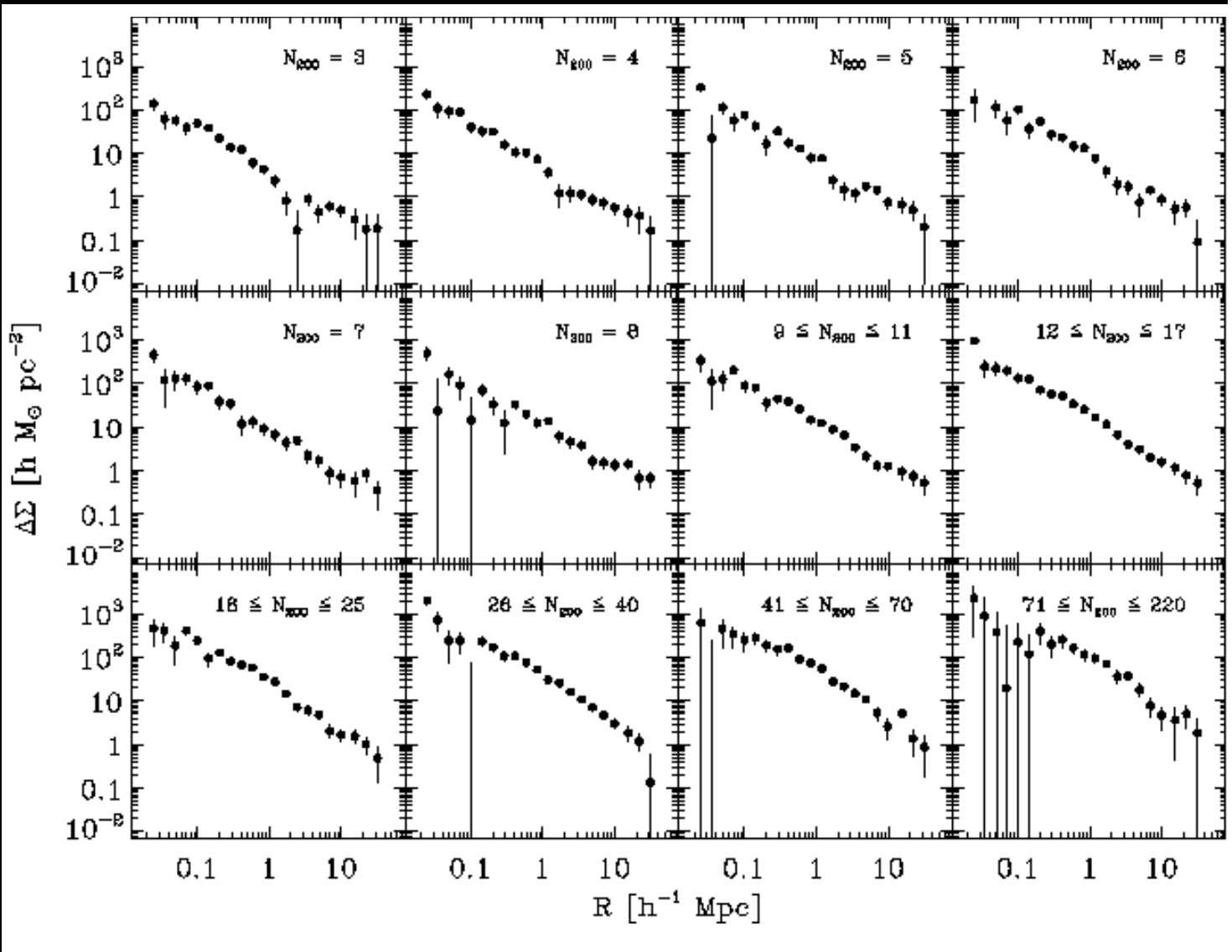
- ~10 Million Galaxy Redshift Survey with DESpec
- Uniform, deep imaging catalogs from DES+LSST for targeting: enable powerful new science beyond what either redshifts or imaging alone can provide
- Maximally enhance science reach of DES: improve all the DE methods+enable new methods (RSD, radial BAO)
- Hemispheric synergy with LSST: part of a broader eventual strategy for LSST follow-up: extend to ~15,000 sq deg
- Excellent site: 0.65” seeing (0.9” Mosaic), high number of useable nights (80%) yield fast (hence cheap) survey
- Low cost & schedule risks reuse/capitalize on many DECam components: optics, CCDs, cage, hexapod, shutter

Stay tuned for early data and get involved in analysis!

Statistical Weak Lensing by Galaxy Clusters

DARK ENERGY SURVEY

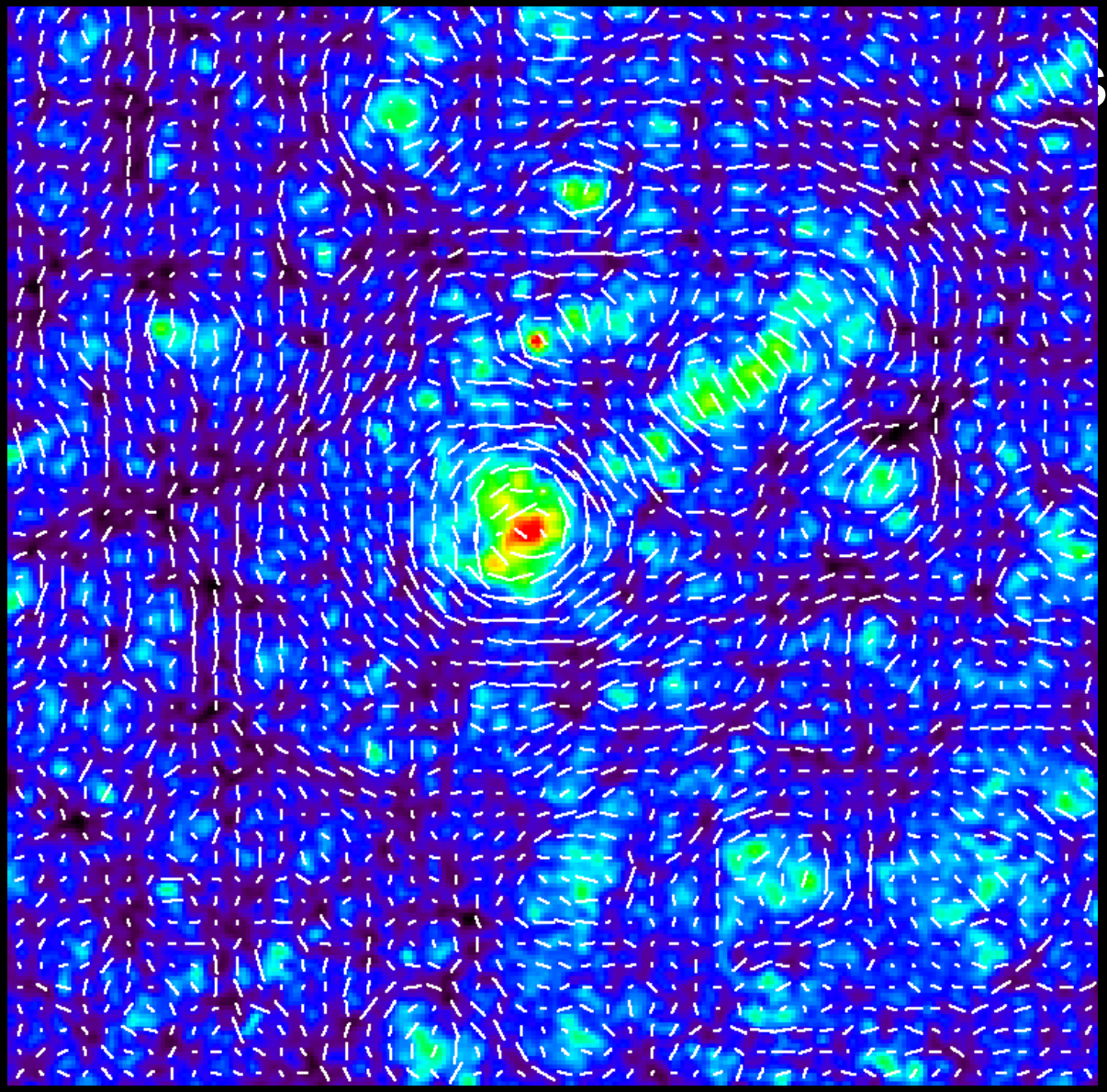
Mean Tangential Shear Profile in Optical Richness (N_{gal}) Bins to 30 h^{-1}Mpc



Sheldon, Johnston, etal SDSS

DARK ENERGY SURVEY

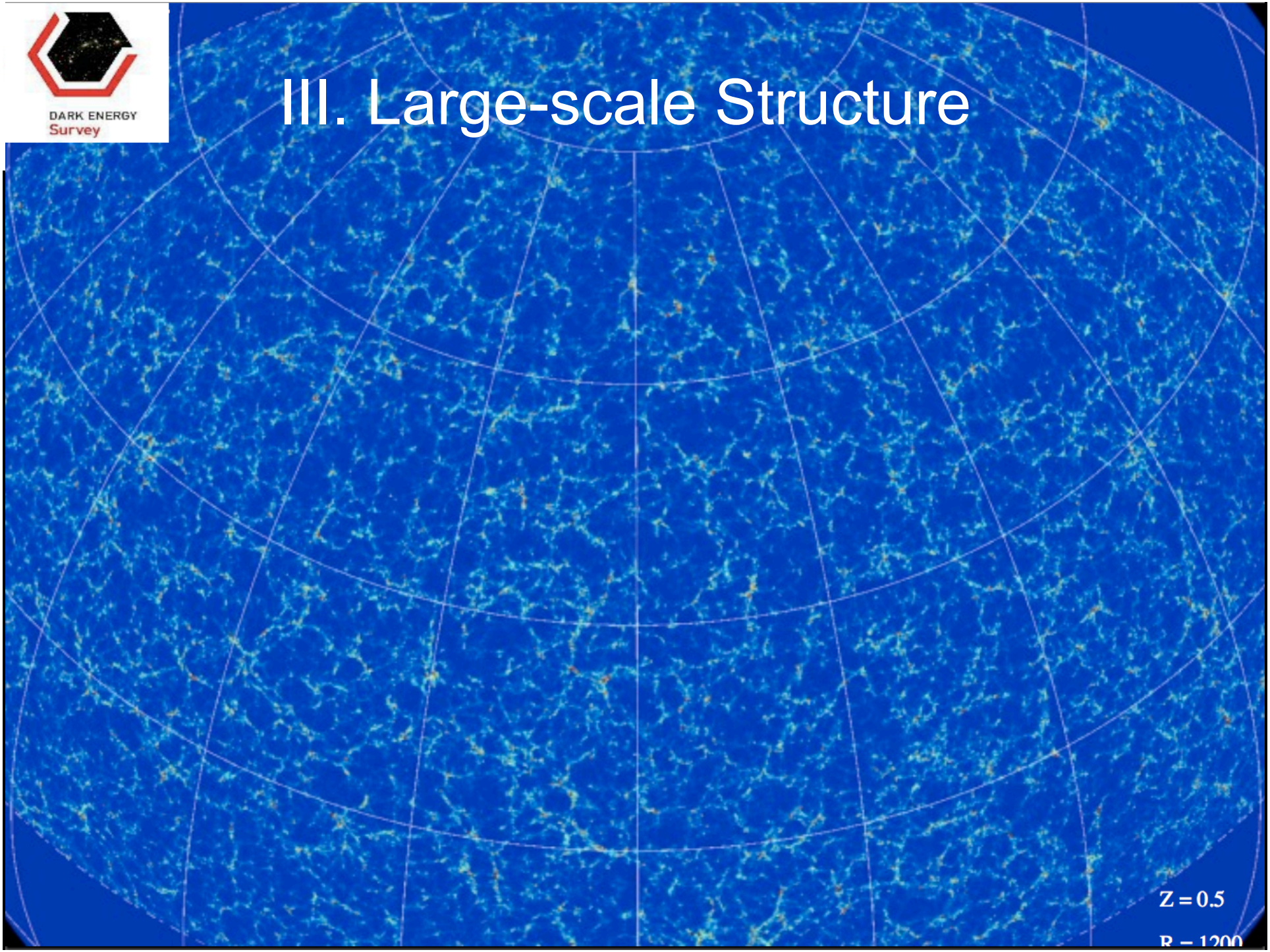
Weak Lensing Mass and Shear

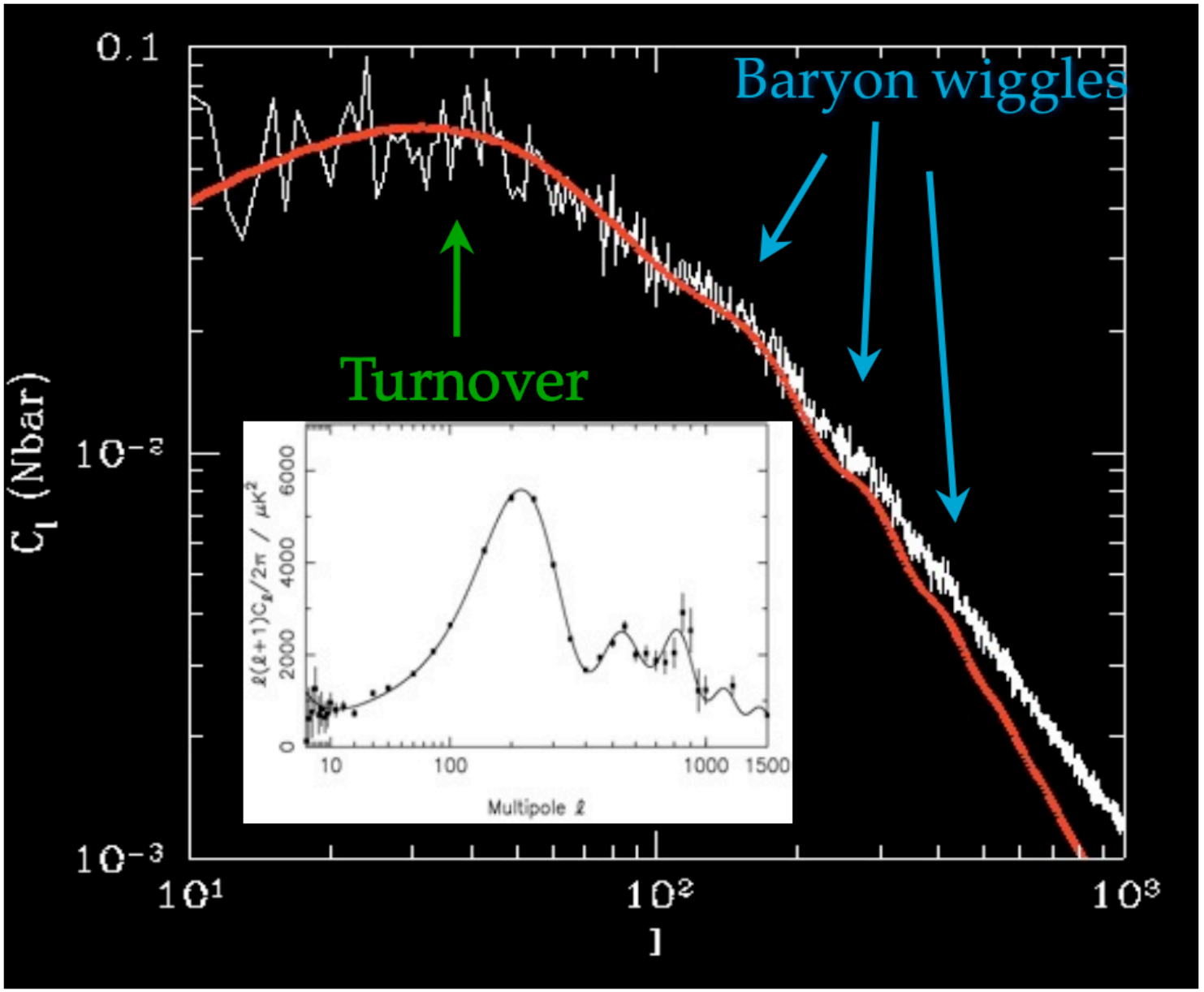


Takada

DARK ENERGY
Survey

III. Large-scale Structure





DARK ENERGY Survey

Angular Spectrum For single redshift slice: z =0.9-1.0

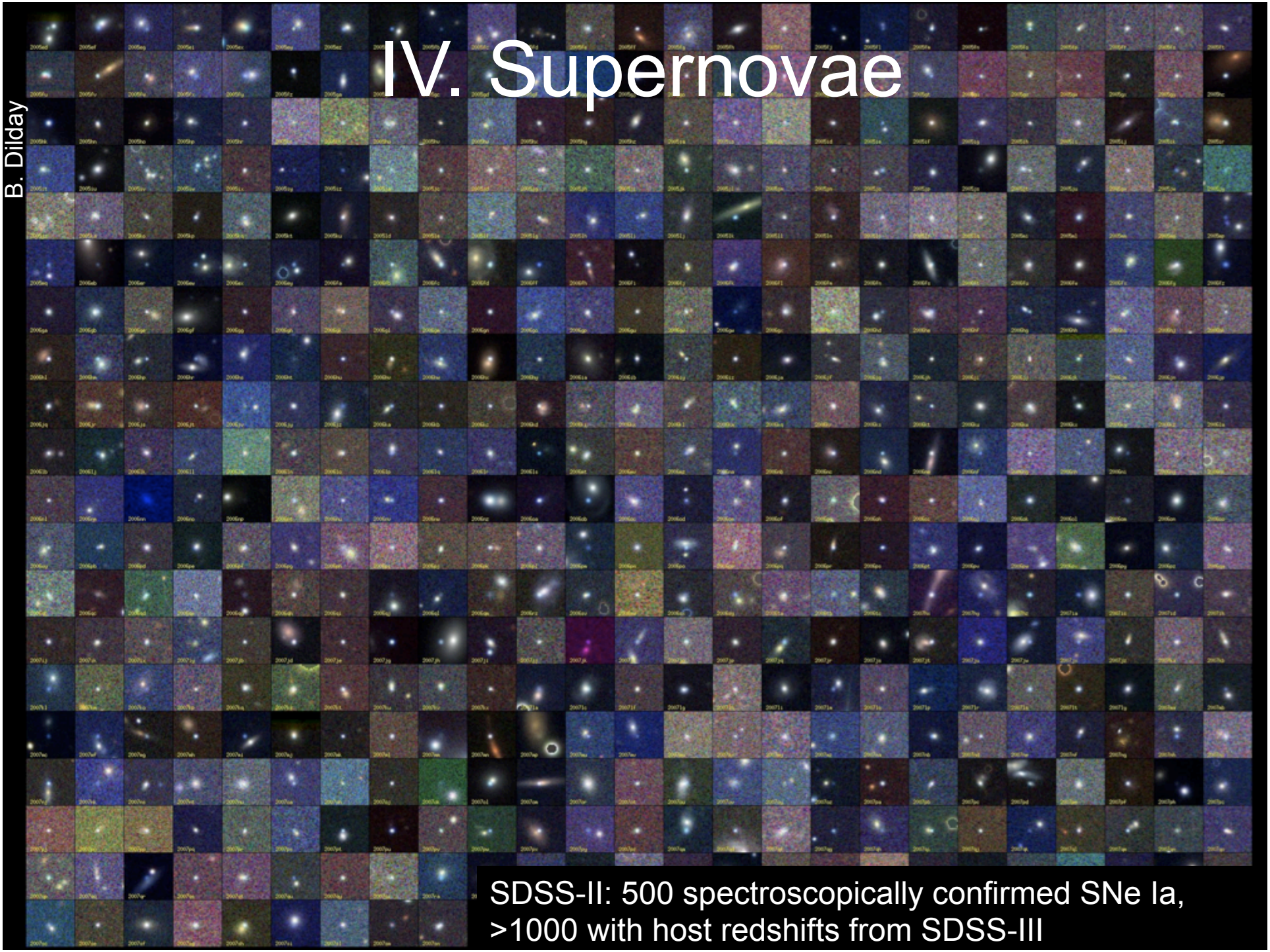
Out of MICE Simulation

www.ice.cat/mice

Measurements can provide both with:
1. BAO scale (DM & Baryon density)
2. distance to BAO scale (DE)

$$c\Delta z_{BAO} = r_{BAO} H(z) \qquad \Delta\theta_{BAO} = \frac{r_{BAO}}{d_A(z)}$$

IV. Supernovae



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