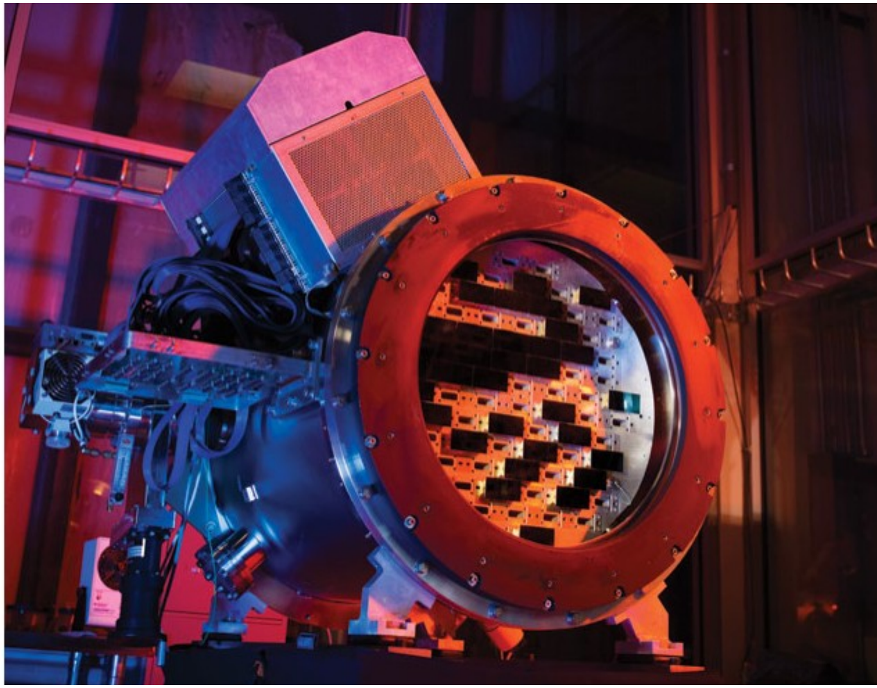
Observational Cosmology

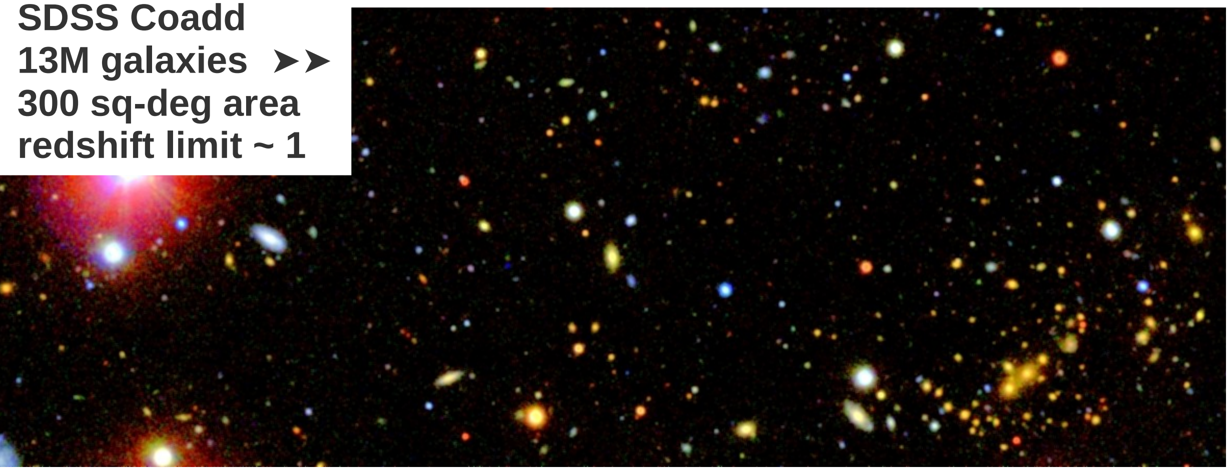
Marcelle Soares-Santos

University of São Paulo & Fermilab

Dark Energy Survey
570 mega pix camera ➤➤
first light: Fall 2011
300M galaxies
5000 sq-deg area



SDSS Coadd
13M galaxies ➤➤
300 sq-deg area
redshift limit ~ 1



Fermilab Users' Meeting ♦ Jun 3, 2010

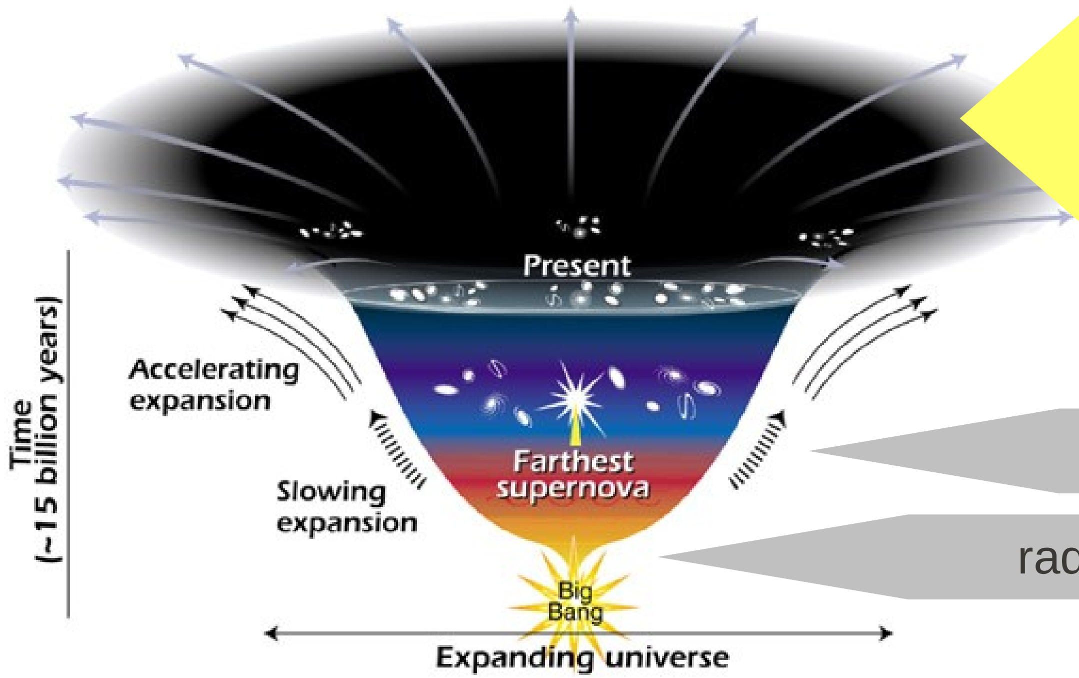
Accelerated expansion and dark energy

space-time geometry → $G_{\mu\nu} = T_{\mu\nu}$ ← energy content

dark energy: $p(\rho) = ?$

$$p < -\rho/3$$

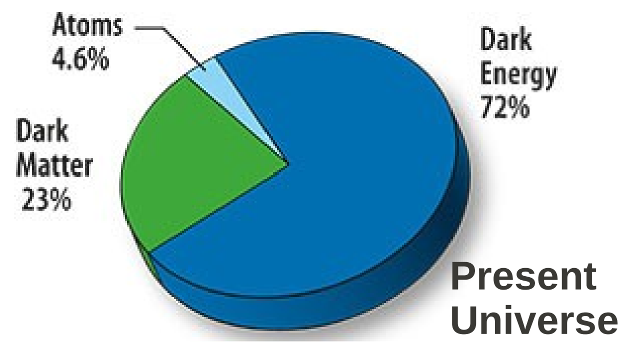
$$p = w\rho$$



cold dark matter: $p = 0$

radiation: $p = \rho/3$

scale factor → $\frac{\ddot{a}}{a} = -(3p + \rho)$ ← equation of state



Outline

Fermilab's observational cosmology program aims at studying Dark Energy

This is how well we know the Dark Energy equation of state today. ➤➤ Combining WMAP, SN, BAO (Komatsu et al. 2010).	$$w = -0.93 \pm 0.12$$ $$w' = -0.38 \pm 0.65$$

exploring 4 ways to probe the expansion of the Universe:

1) Galaxy clusters
2) Weak Lensing
3) Baryon Acoustic Oscillations
4) Supernovae

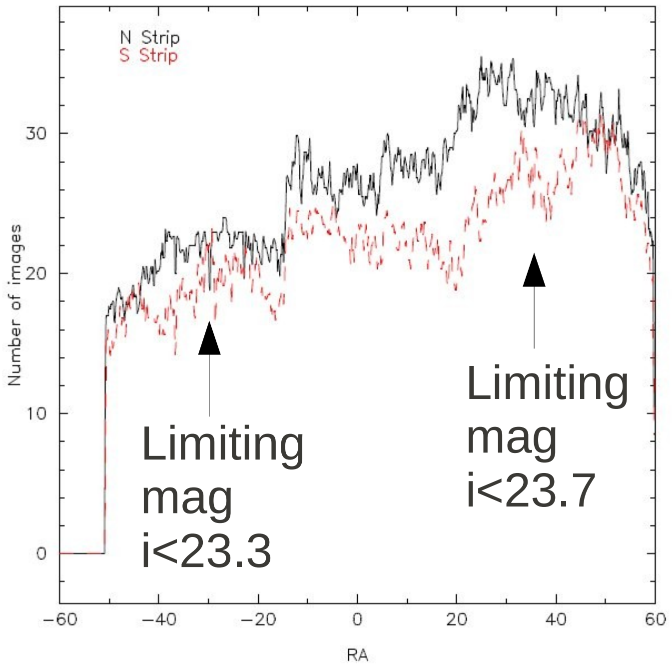
In this talk we:

Explore these avenues now using the SDSS Coadd data.

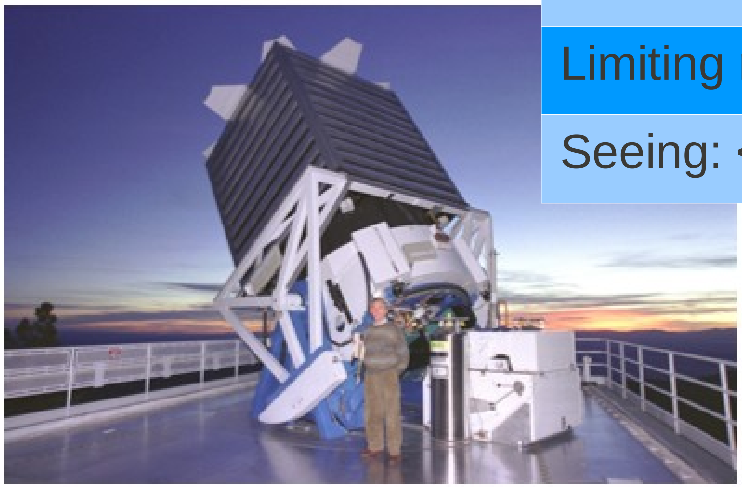
Discuss the current status for the upcoming Dark Energy Survey.

Have a glimpse of a next generation project, the JDEM mission.

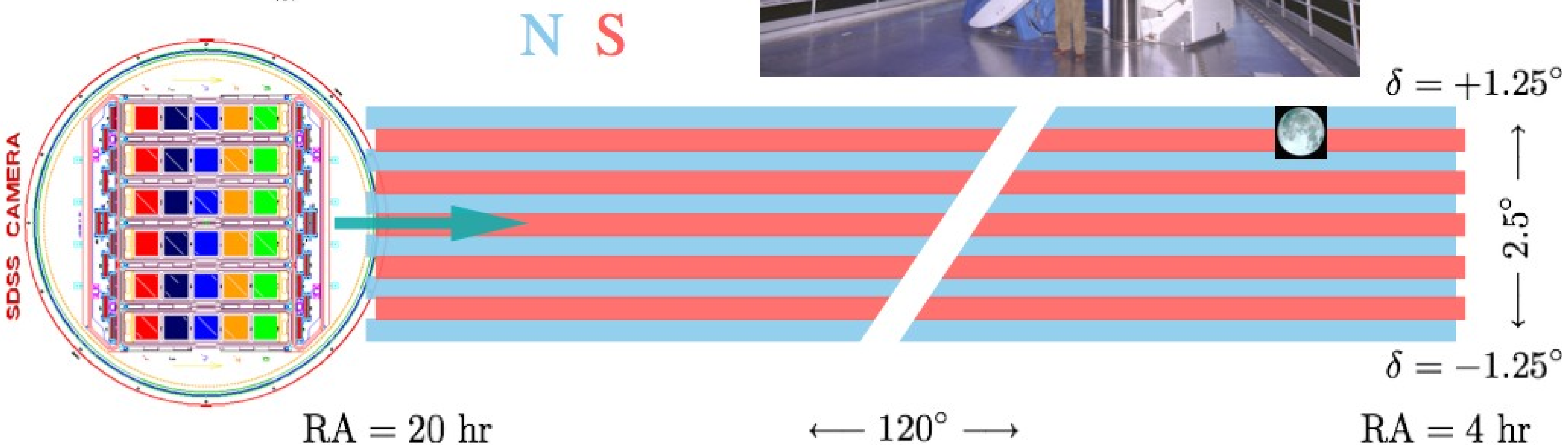
The Sloan Digital Sky Survey Coadd



SDSS telescope at the Apache Point Observatory

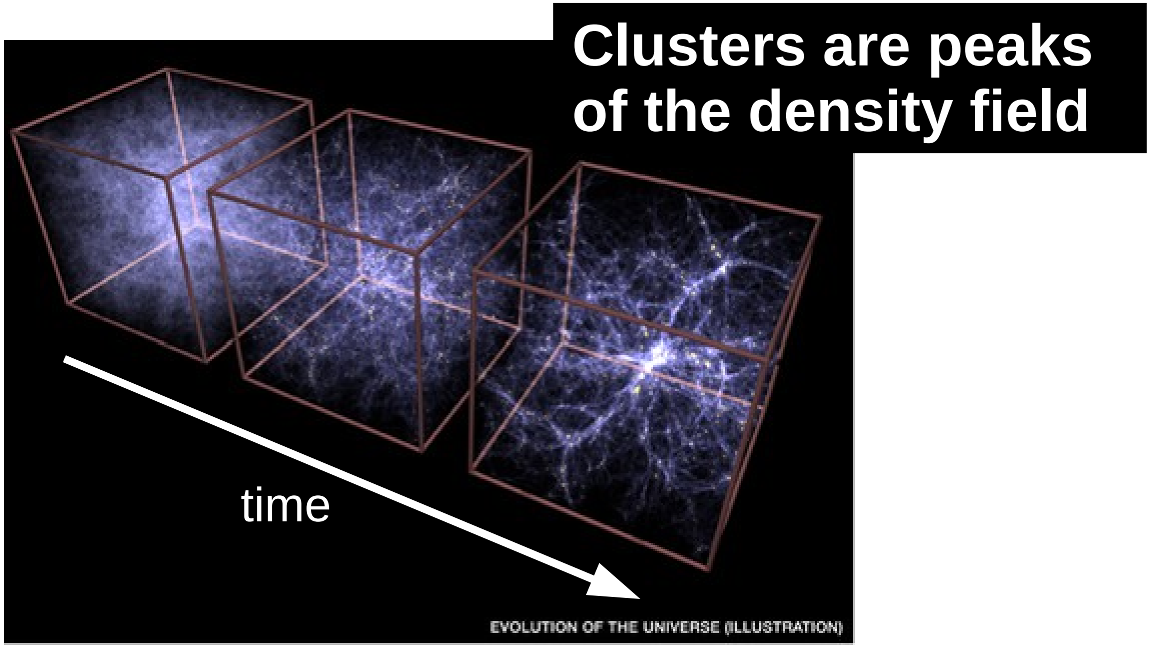


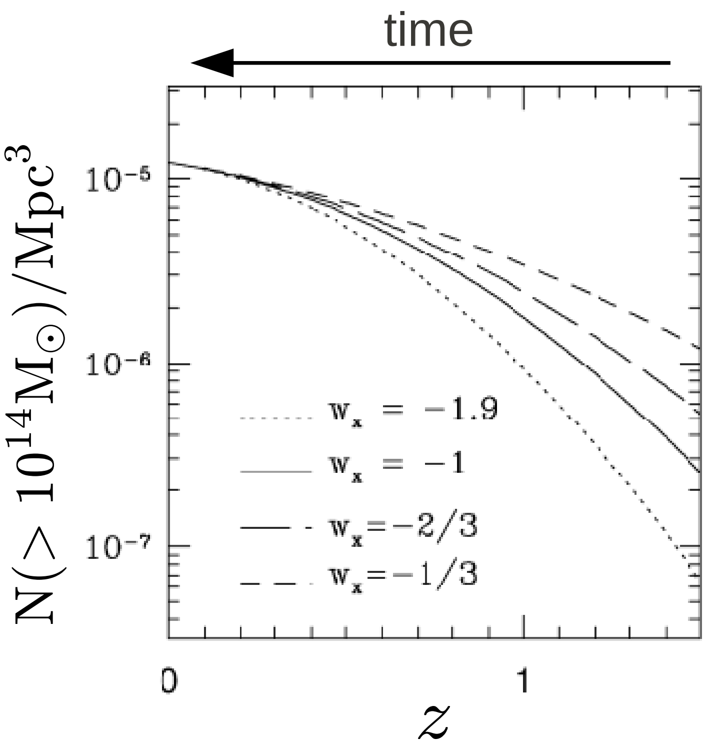
SDSS Coadd
Area: 275 sq-deg
Bands: ugriz
Limiting mag: i<23.7
Seeing: <1.5"

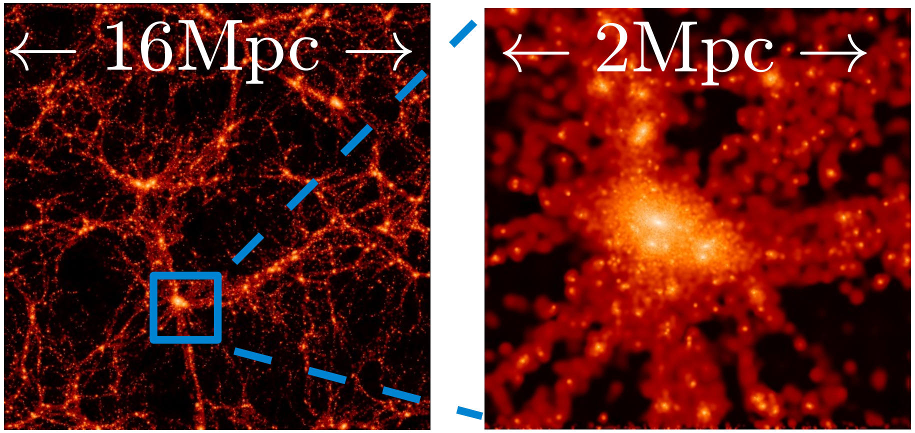


Scanning the sky with the SDSS camera

Galaxy clusters and dark energy equation of state





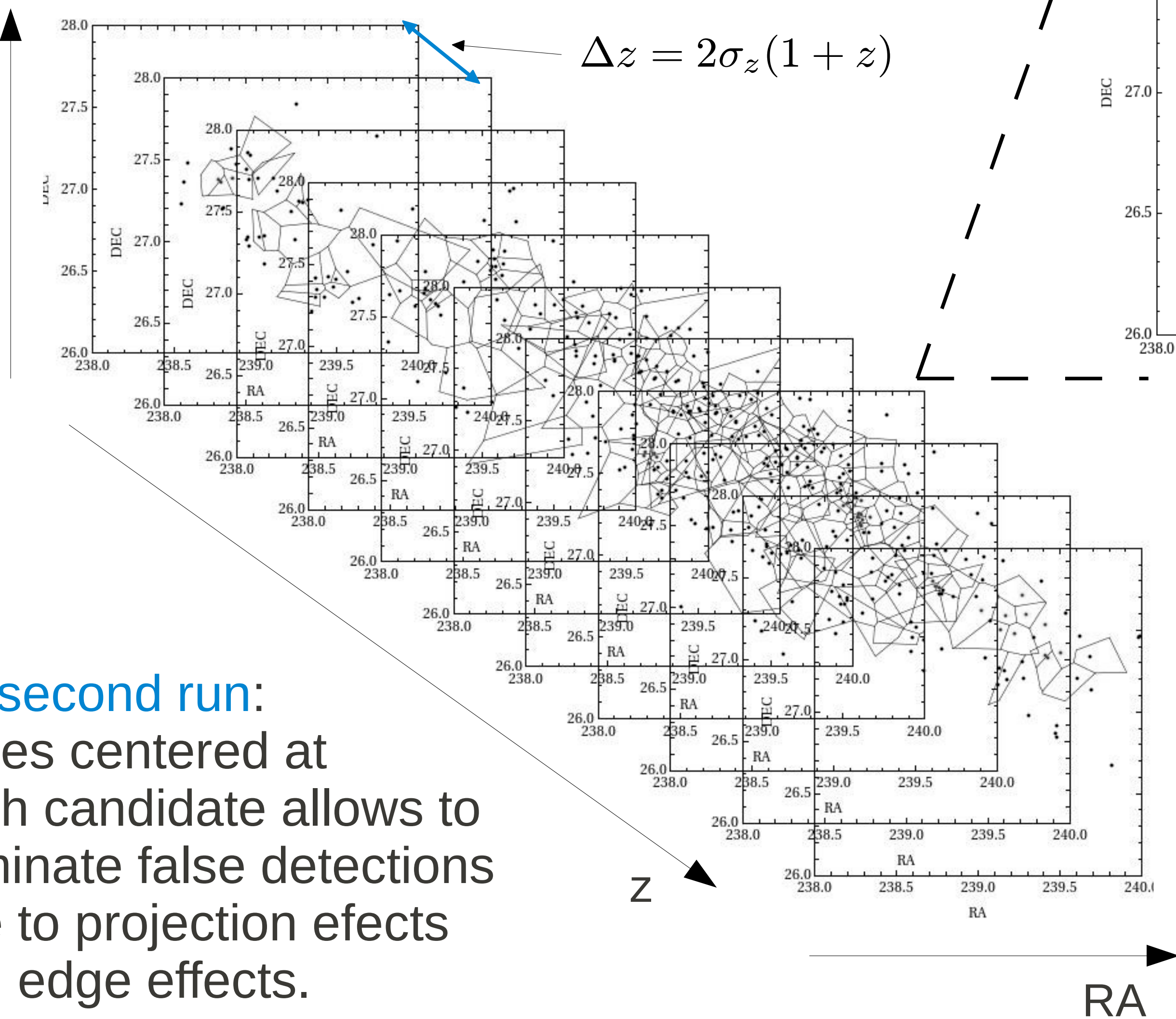


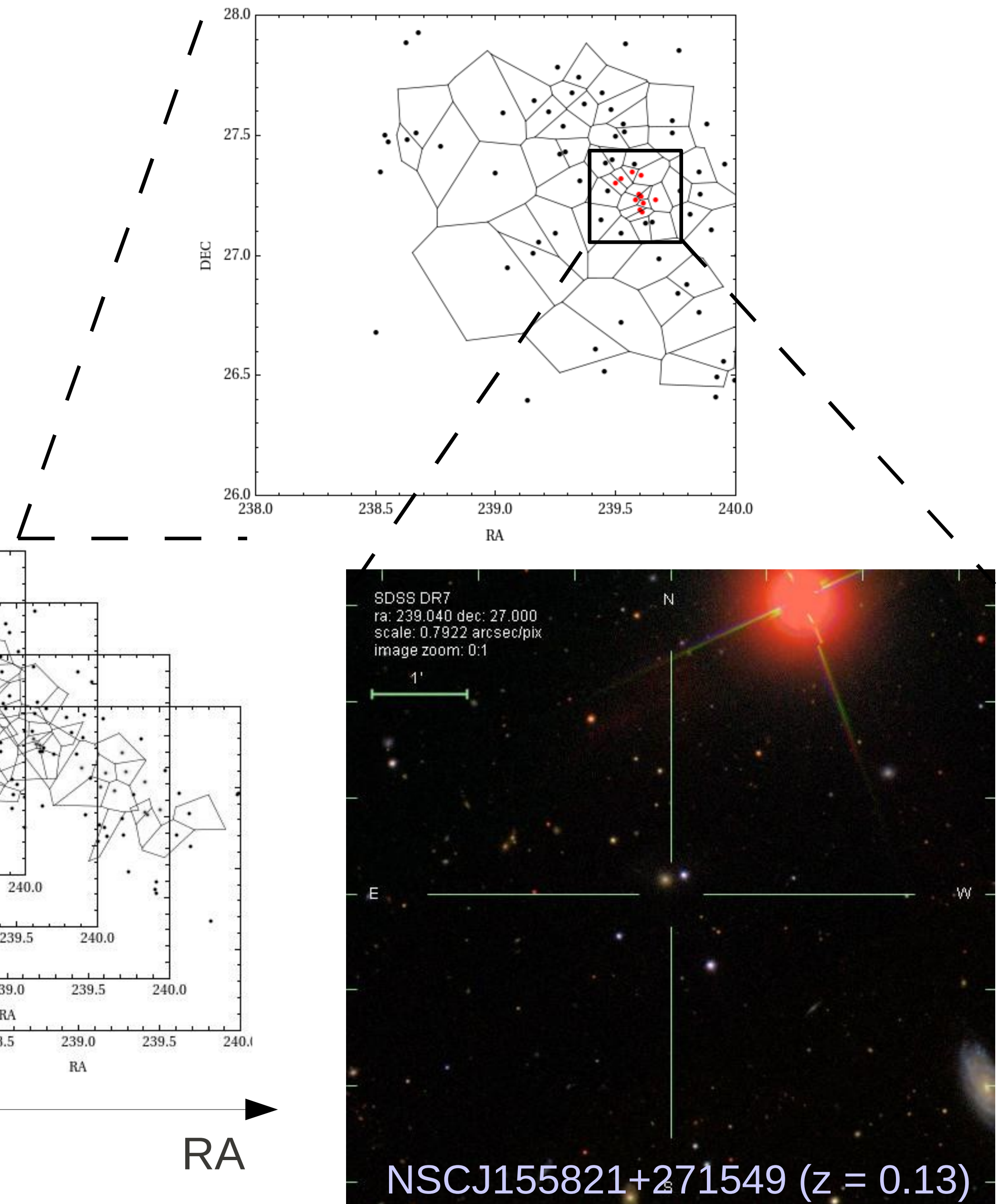
$$\text{mass function} = \frac{dN}{d\Omega dz\, dM}$$

Growth of structures in a expanding universe

VT cluster finder in 2+1D

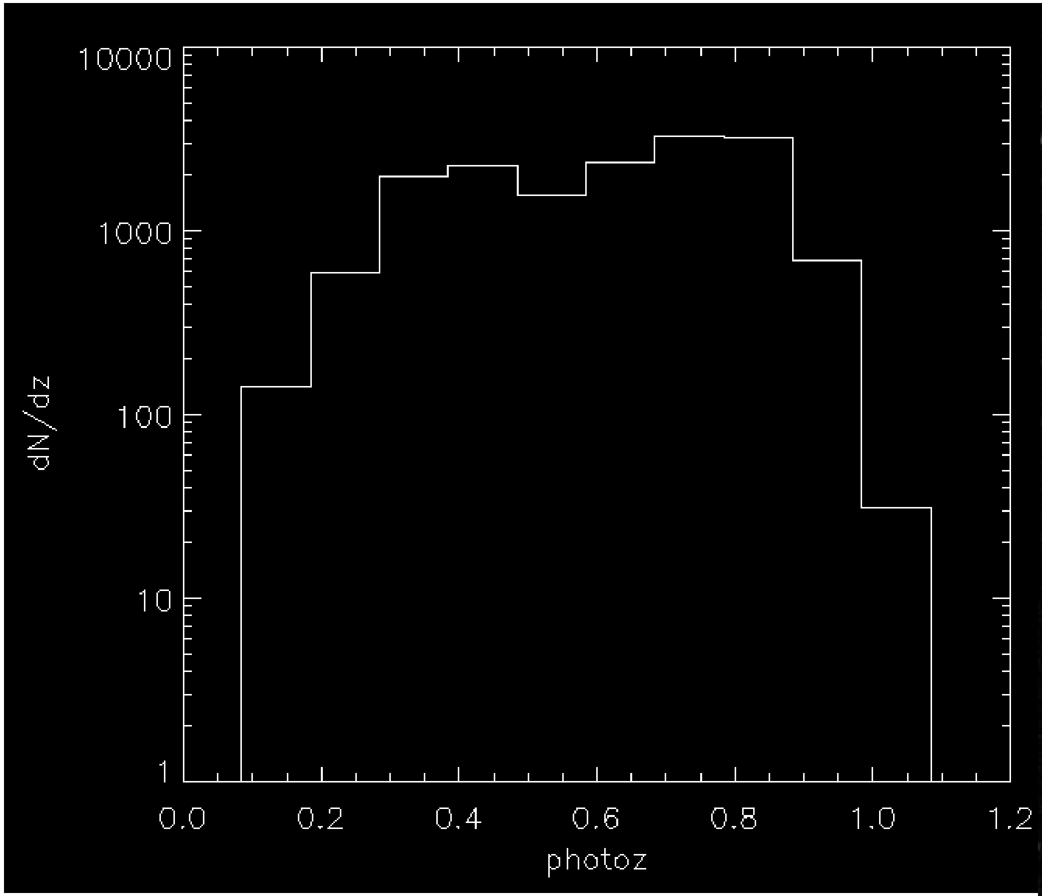
VT first run: cluster candidates detected in photo-z shells

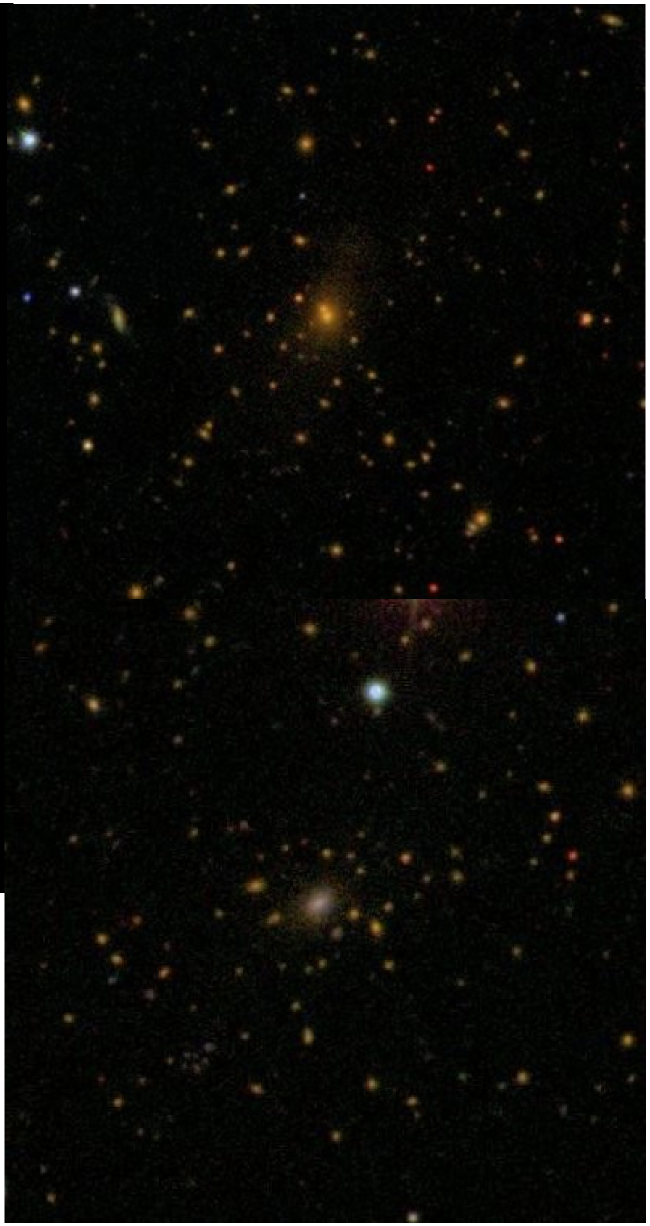




VT second run:
boxes centered at each candidate allows to eliminate false detections due to projection efects and edge effects.

Cluster abundance measured in the SDSS Coadd



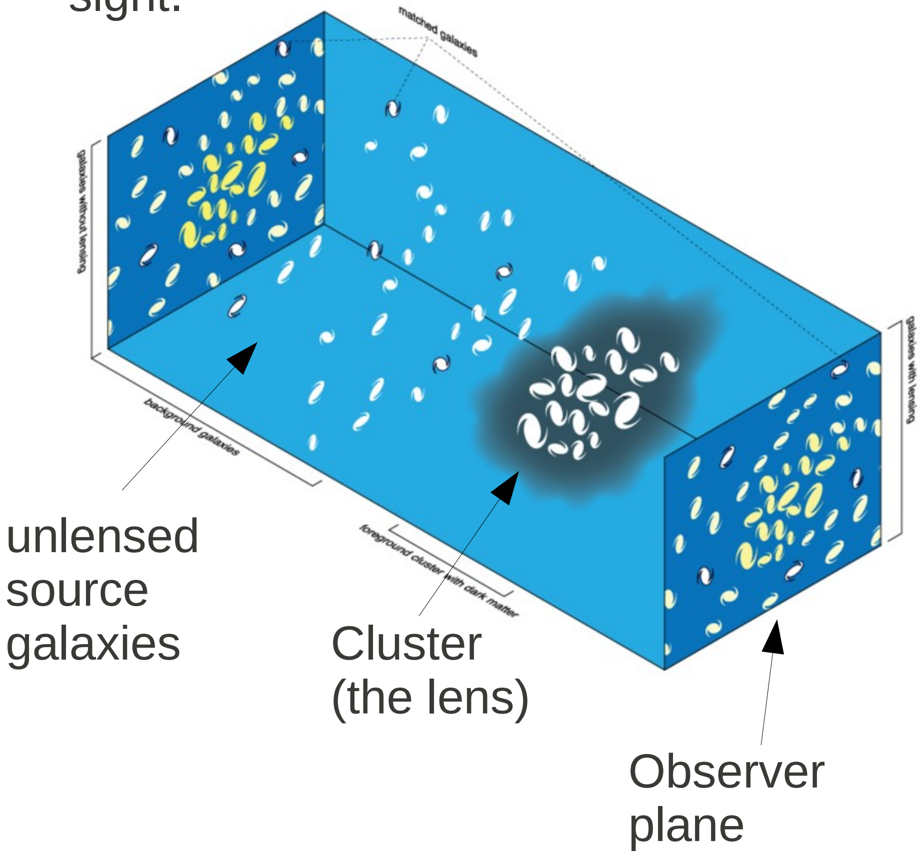


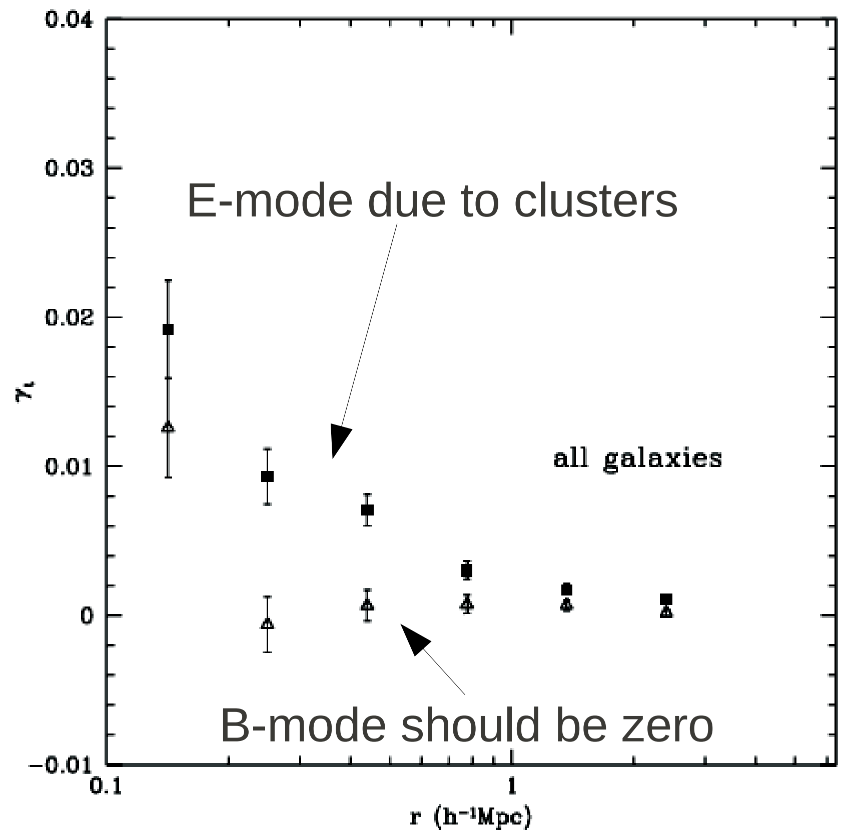
Top: Redshift distribution for galaxy clusters found in the SDSS Coadd. Using the GMBCG cluster finder (Hao et al. 2009).

Left: Examples of clusters selected.

Cluster mass calibration via weak lensing

Lensing effect: Photon trajectory is distorted by the presence of a massive structure along the line of sight.

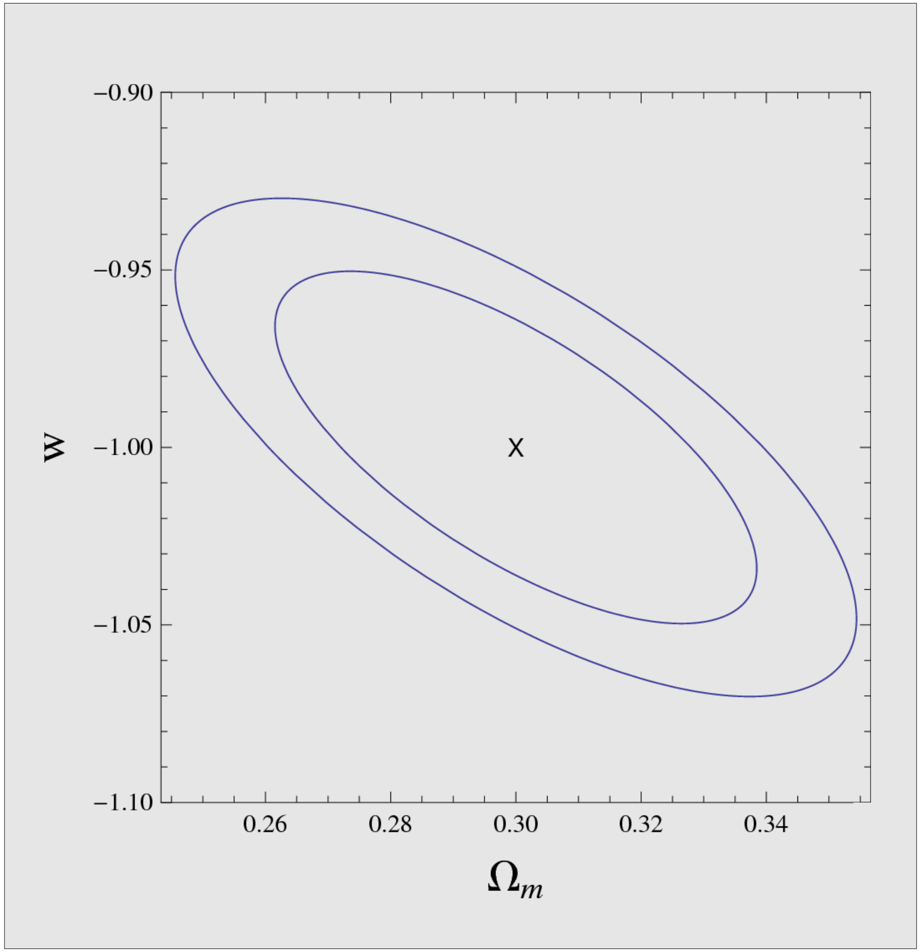




Tangential shear profiles using 150 clusters within 0.1< z < 0.2 and Coadd galaxies as source (Kubo et al. 2010).

Systematics are sub-dominant.

Constraints on w-Ω_m space with the SDSS Coadd



Fiducial model: **ΛCDM**

Fixed parameters:

$\sigma_8 = 0.8$

$h = 0.72$

$\Omega_x = 1 - \Omega_m$

Redshift range: $\boldsymbol{z \leq 0.8}$

Area: ***300* sq deg**

Mass threshold: ***10^{14}* solar masses**

Optimistic contours from Fisher Matrix. The figure of merit degrades by a factor of ~10 when the uncertainties are considered. **With the SDSS Coadd we can measure w with ~40 percent precision from clusters alone**.

The Dark Energy Survey

- **Survey:**

  5000 sq. deg. survey of the southern galactic cap up to i=24

  525 nights: 2012-2016

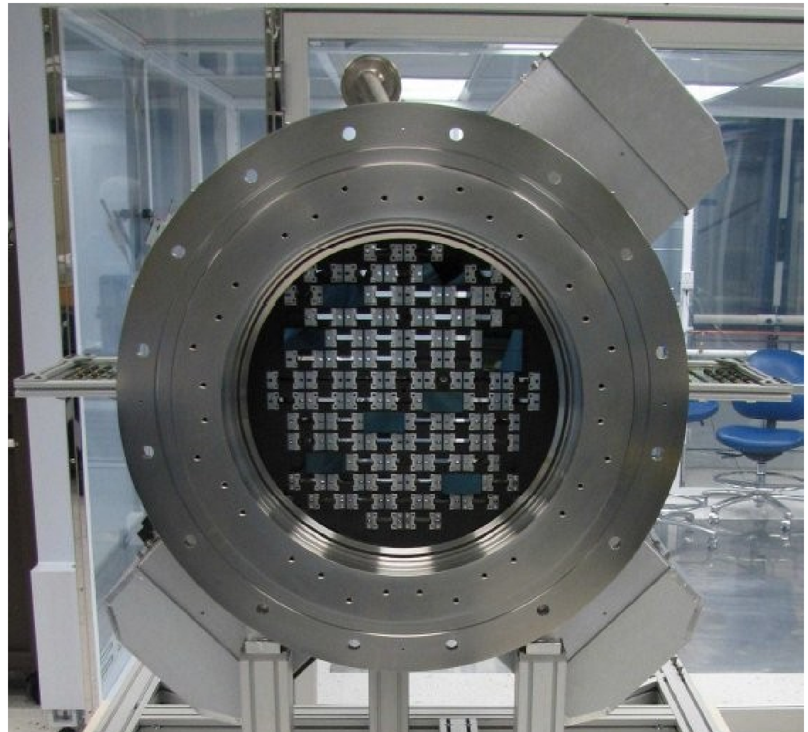
  Overlapping with SPT SZ survey and VISTA VHS survey

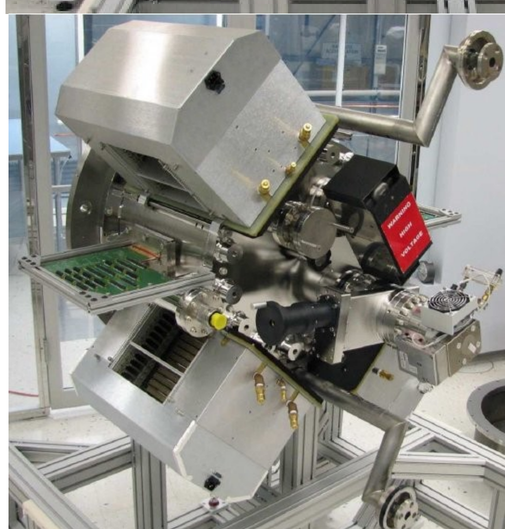
- **DECam:**

  2.2 FOV, 520 Mega pixel optical CCD camera

  Camera delivery: Summer 2011

  First light: Oct/2010





Use the Blanco 4M Telescope at the Cerro-Tololo Inter-American Observatory (CTIO)

Cluster cosmology in the DES era

A well-coordinated simulation efforts allow us to develop the analysis methods for DES – and we apply them back on the SDSS Coadd.

Halo – Mock true dark matter object with galaxies bounded to its potential well.
Cluster – (RA, DEC, z) coordinates + list of member galaxies

Raw Completeness – Fraction of halos with a cluster counterpart
Raw Purity – Fraction of clusters corresponding to real halos

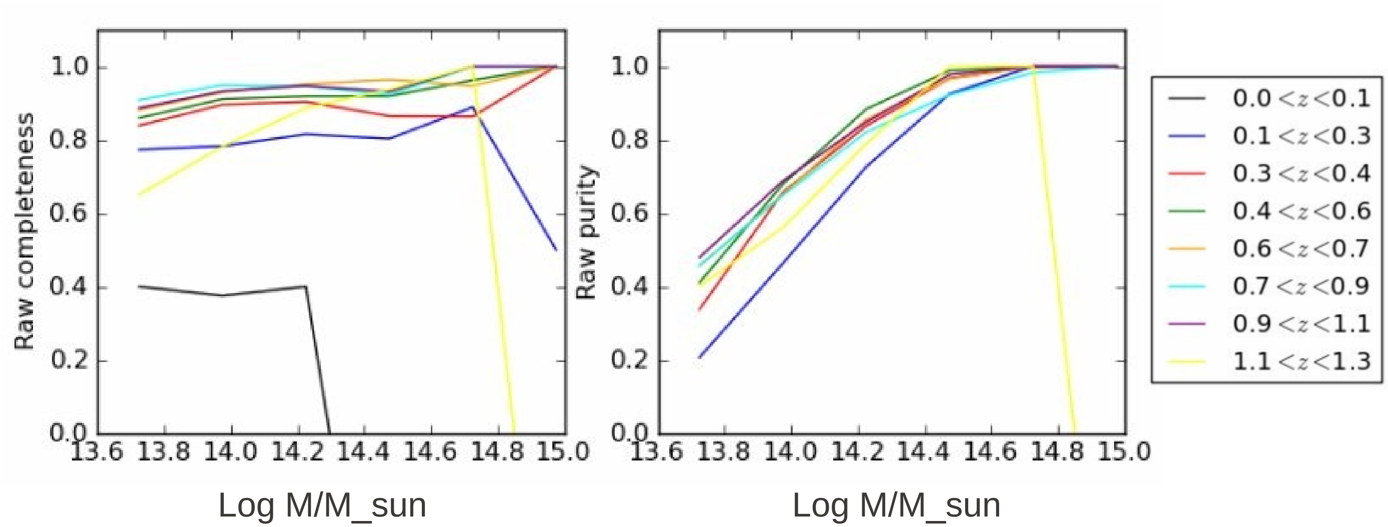
Mtrue-Mobs scatter

Completeness – C(M,z)
Purity – P(M,z)

selection function

$$dn(M,z) = \frac{dN}{dMdV}\frac{C(M,z)}{P(M,z)}$$

Completeness and purity evaluation using DES mock catalogs



Efficiency of the VT cluster finder as a function of mass in bins of redshift.

Area: 580 sq-deg (2x the SDSS Coadd area)

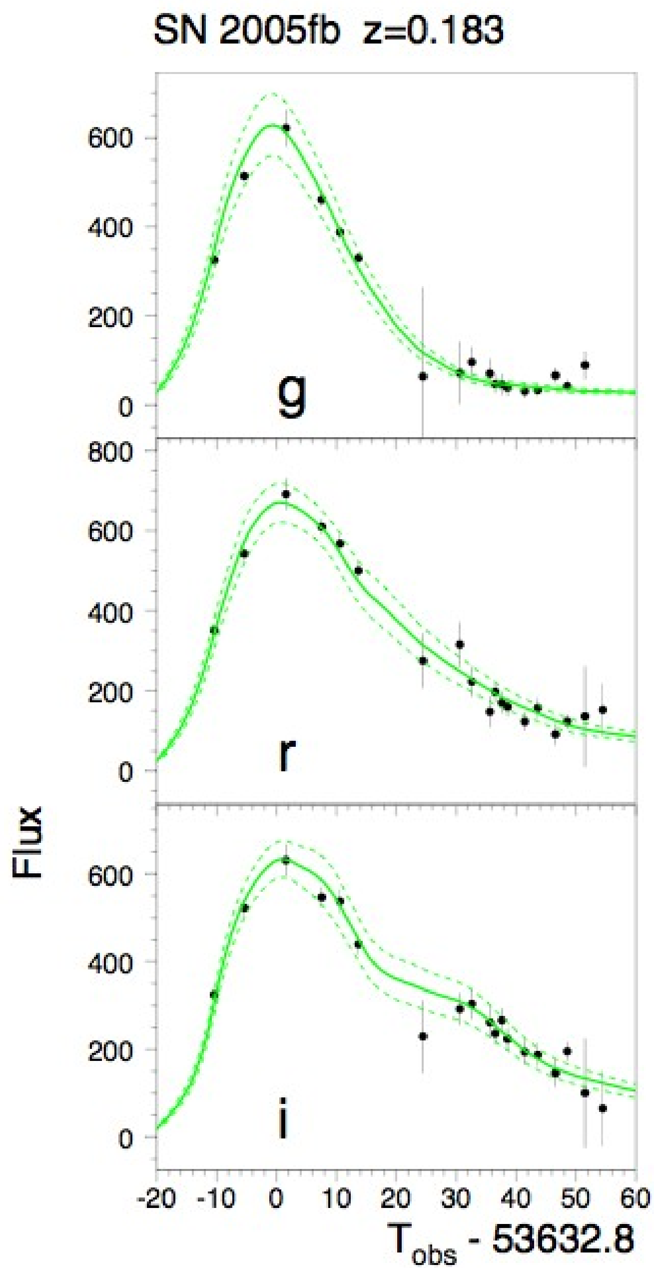
Low statistics regions:

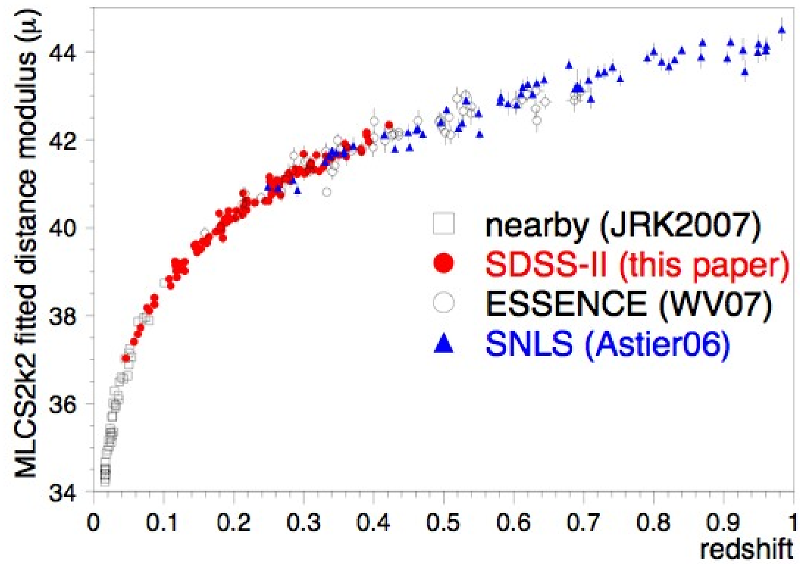
At low z: small volume.

At high z: massive clusters are less abundant.

Constraints from the SDSS Coadd are in fact possible – and coming soon.

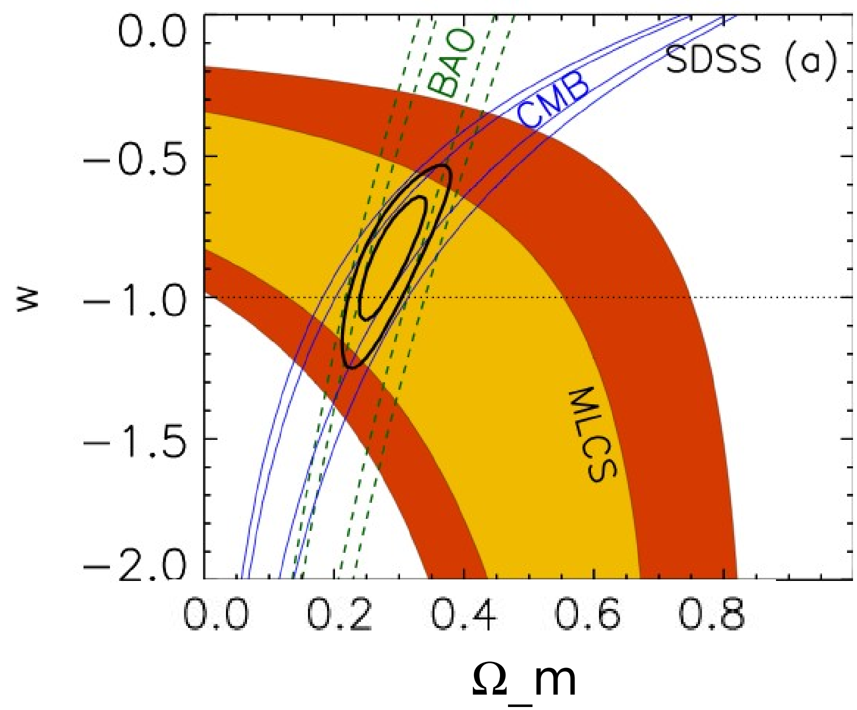
Cosmology with SDSS Supernovae





Kessler et al. 2009

1st year sample
103 SN Ia

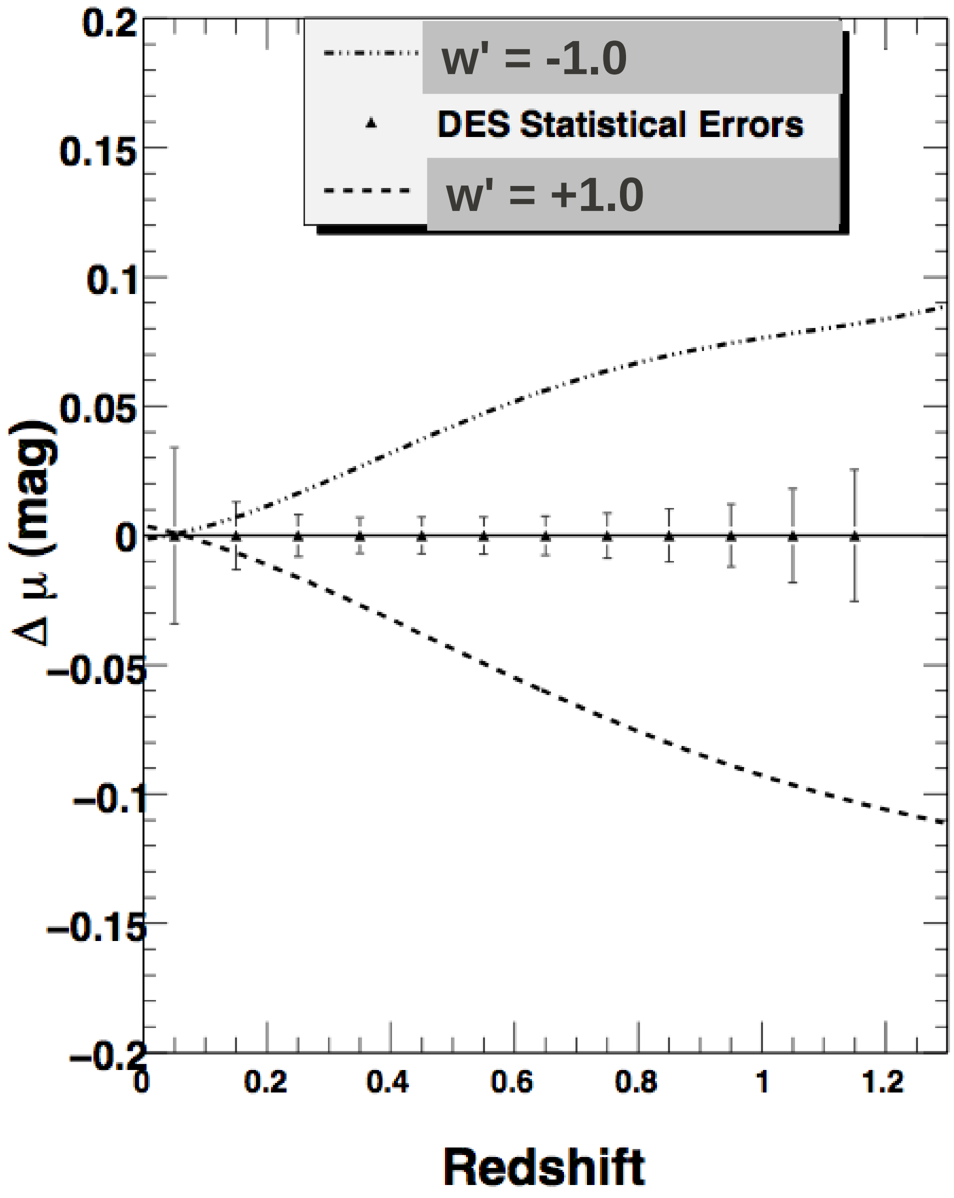


Expectations for Supernovae analysis on DES

DES expects to observe

~3000 SN Ia

and have sensitivity to the parameter w'

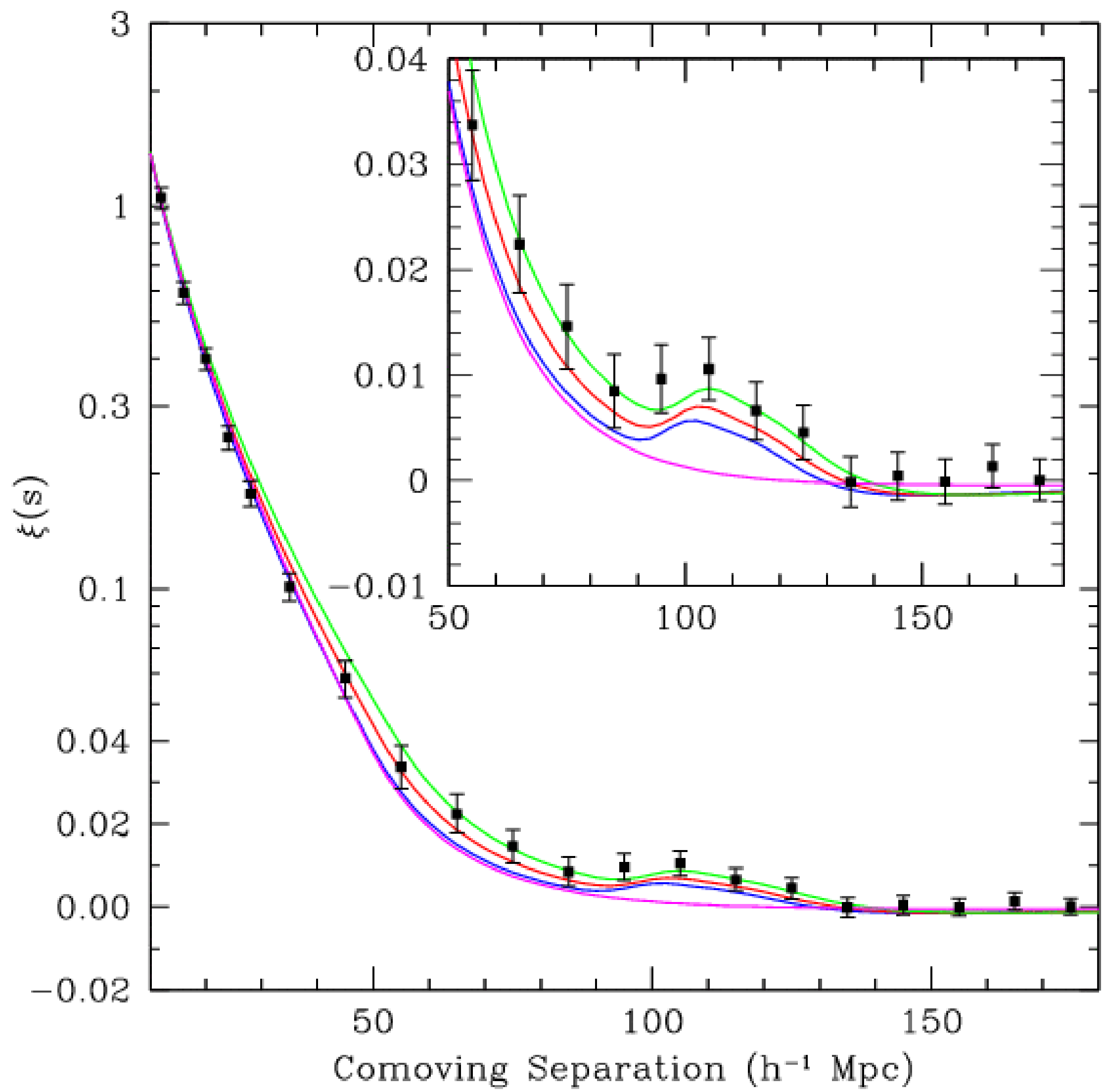


Baryon Acoustic Oscillations in the SDSS LRGs

Redshift-space Correlation Function

$$\xi(r) = \langle d(\vec{x})\, d(\vec{x} + \vec{r}) \rangle$$

Warning: Correlated Error Bars



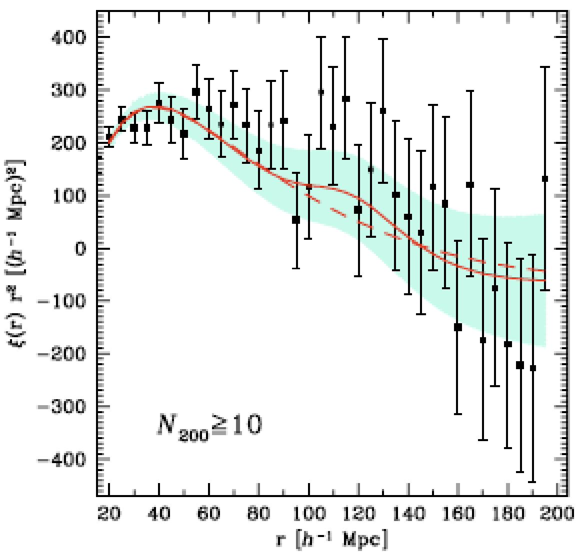
Eisenstein et al. 2005

Baryon Acoustic Oscillations seen in Large-scale Structure:

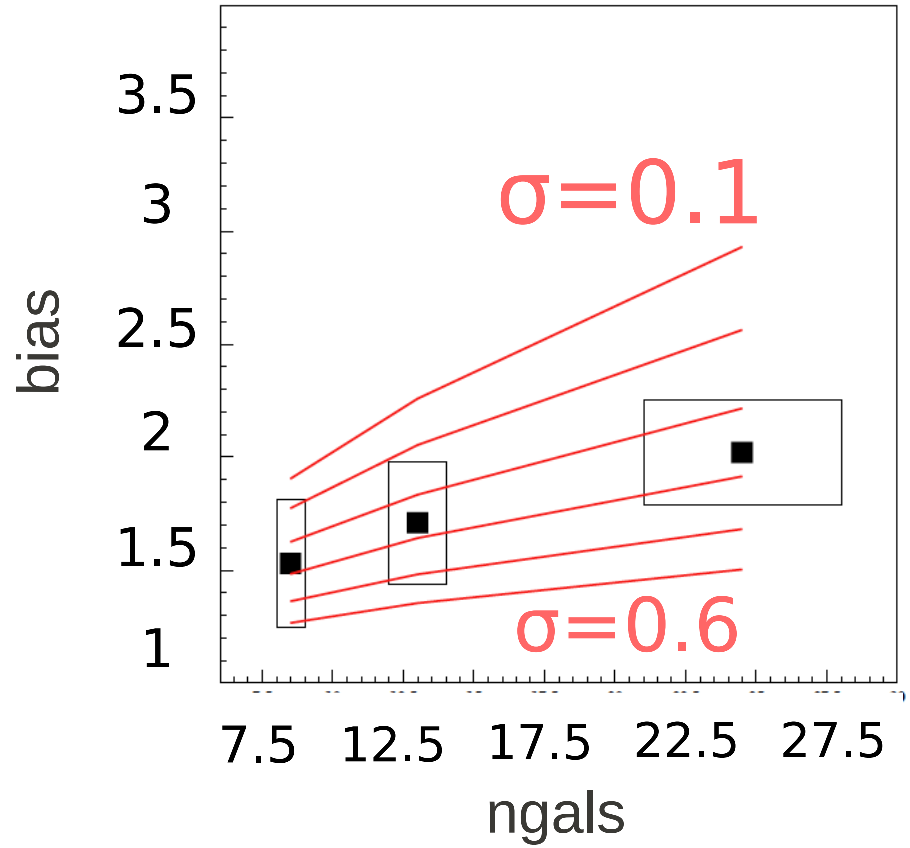
mean distance to galaxies at z~0.35

Baryon Acoustic Oscillations with clusters

Clusters are mass tracers with smaller photo-z error than galaxies. 3D correlation function is possible. CF also has information about mass calibration for clusters.



Hint of BAO seen on CF for 14K maxBCG clusters from SDSS (Estrada et al. 2009).



Measured bias in DES mock catalogs by Julia Campa.

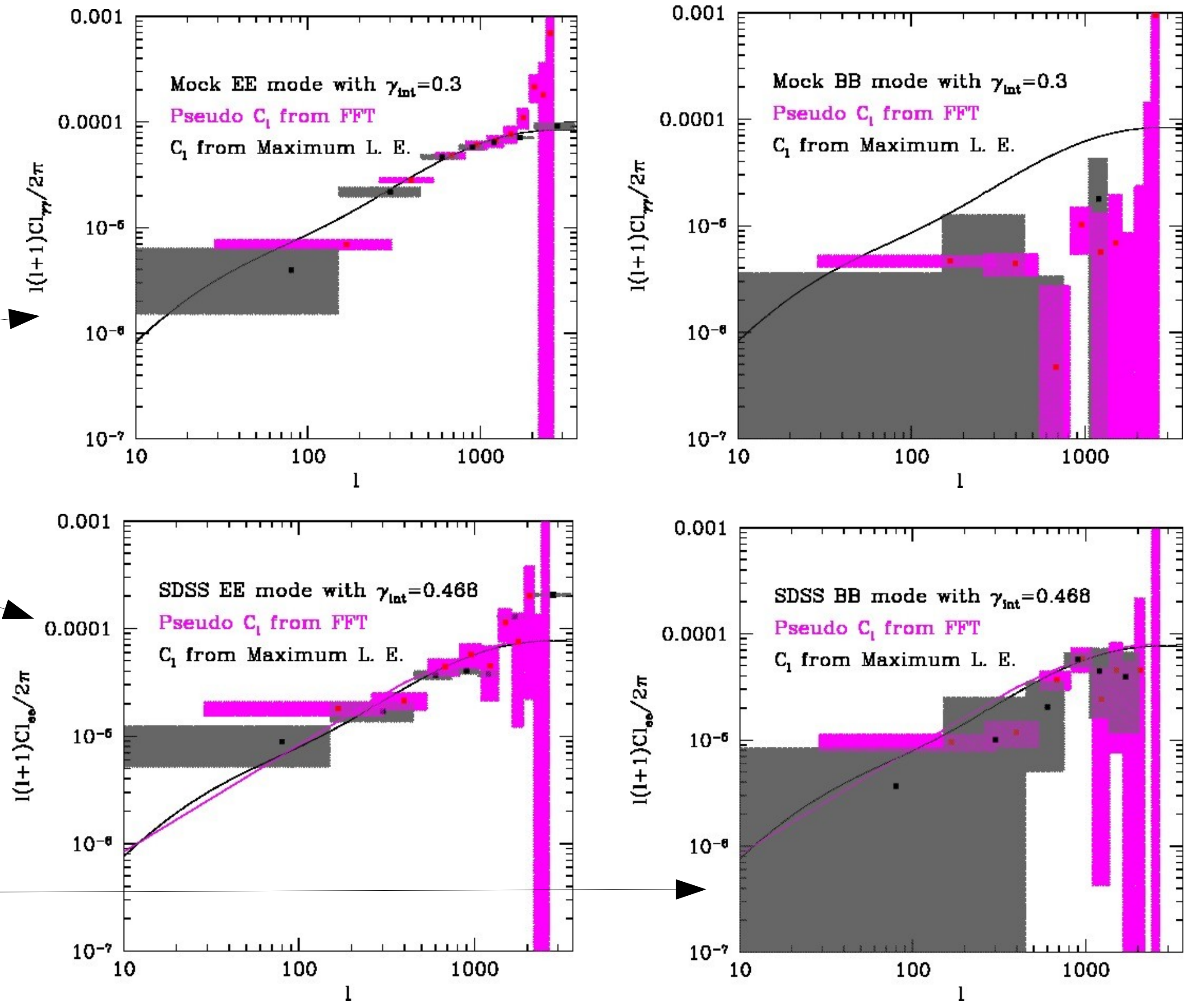
Weak lensing cosmic shear in the SDSS Coadd

Cosmic shear: shear-shear correlation function power spectrum.

Pseudo estimator is slightly biased with respect to the true C_l.

The signal detected is consistent with the predictions for a Lambda-CDM model (solid lines).

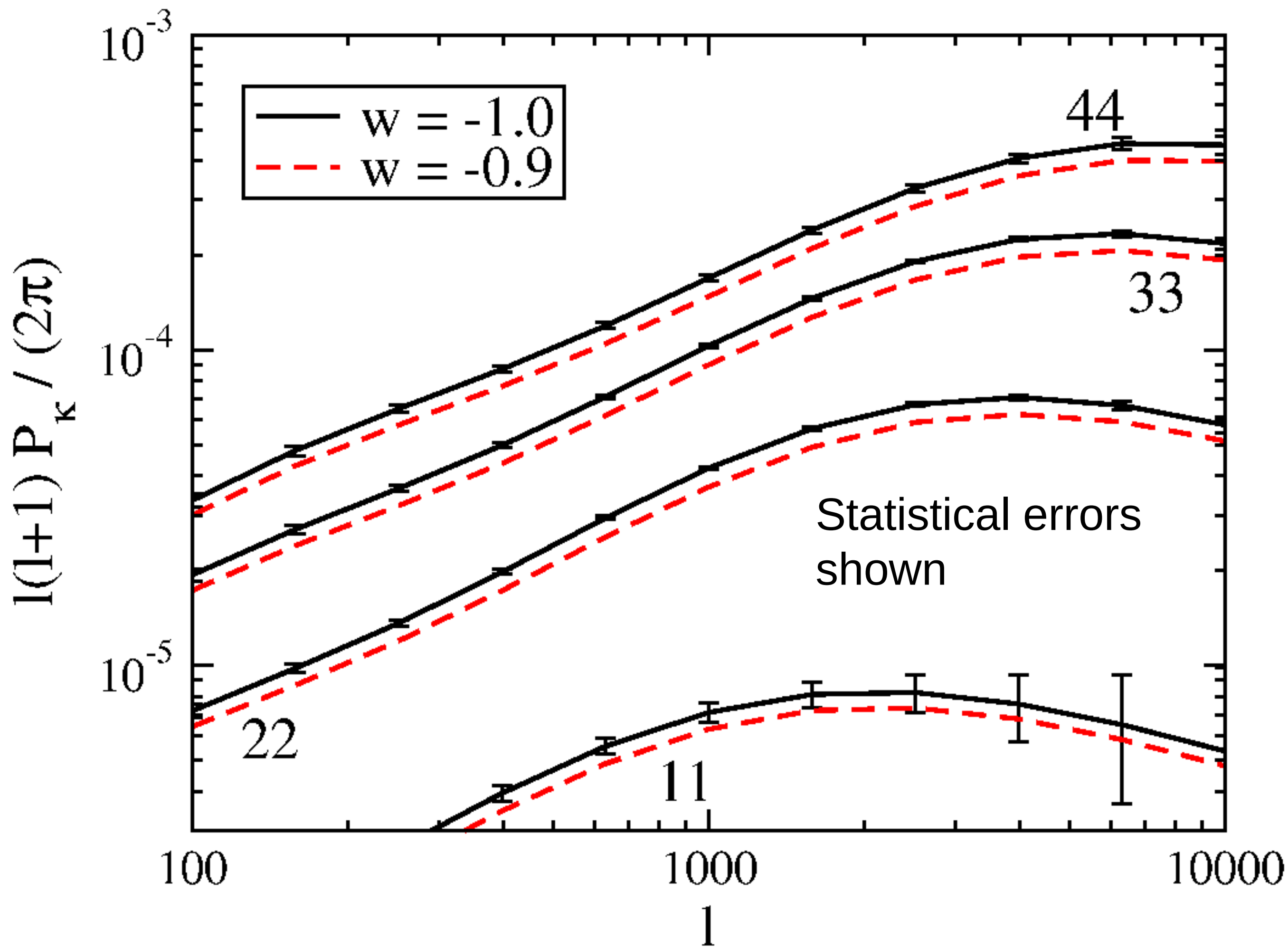
Warning: BB-mode is non-negligible. Systematic effects are not yet understood.



Hee-Jong Seo et al. 2010

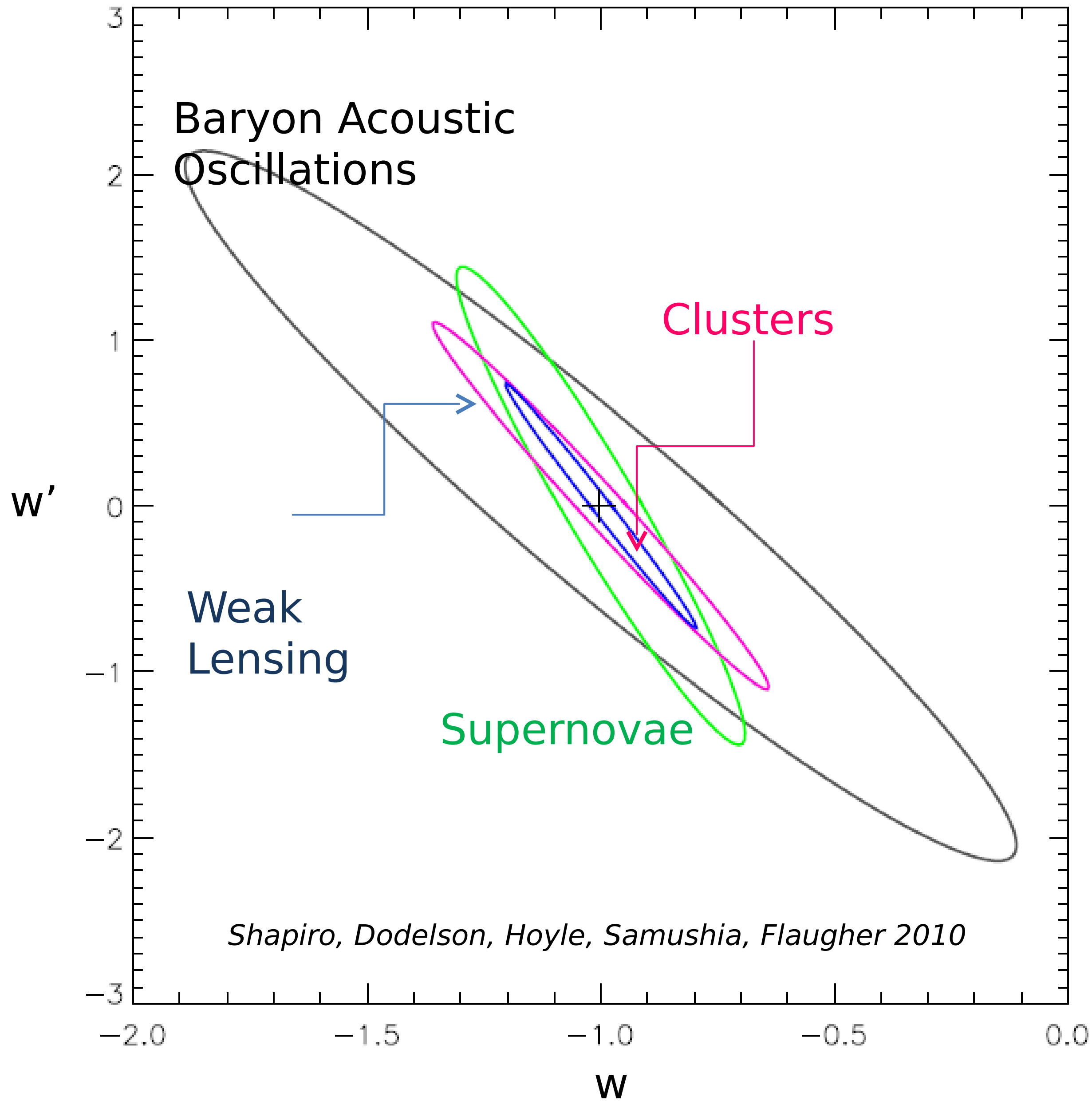
DES prediction for Weak Lensing

- Cosmic Shear Angular Power Spectrum in Photo-z Slices
- Shapes of ~300 million well-resolved galaxies, $\langle z \rangle = 0.7$
- Primary Systematics: photo-z's, PSF anisotropy, shear calibration
- Extra info in bispectrum & galaxy-shear: robust



DES WL forecasts conservatively assume 0.9" PSF = median *delivered* to existing Blanco camera: DECam should do better & be more stable

Dark Energy constraints from DES



Joint Dark Energy Mission (JDEM)

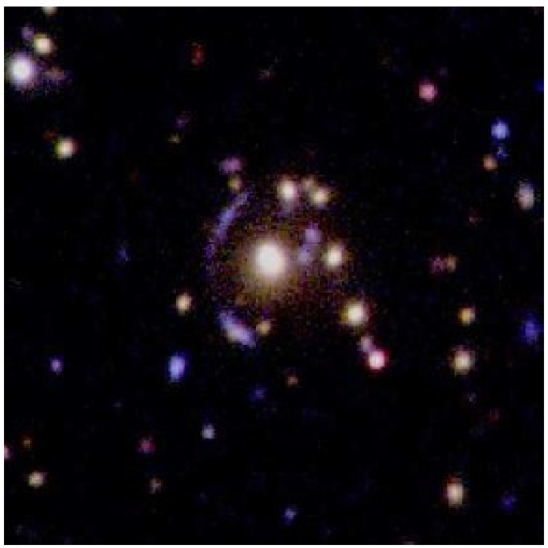
- Goal - Measure history of expansion rate of universe in order to probe nature of Dark Energy
  - Baryon Acoustic Oscillations; Supernovae; Weak Lensing
- “Stage IV” experiment – 10x improvement over current measurements
- Jointly funded and developed by NASA and DOE/OHEP
- Fermilab interest – Science Operations Center

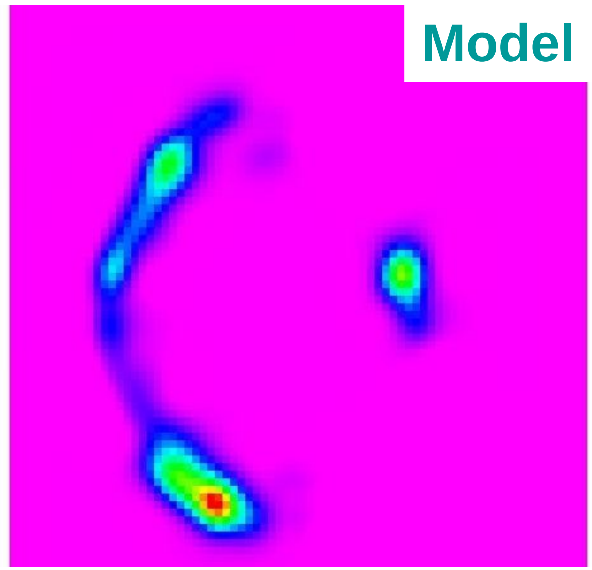
JDEM – current status

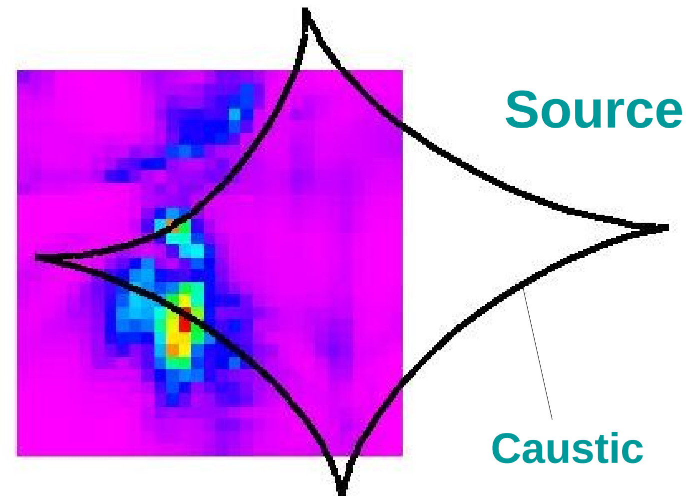
- May 2010 – NASA/DOE project offices & ISWG study
  - Probe A: concept meets $650 million cost cap (excluding launch); only BAO+SN
  - Probe B: exceeds cost cap; BAO+SN+WL
- Next steps
  - Summer 2010 - Independent cost estimate (ICE)
  - Aug. 2010 - Astro2010 Decadal Survey report
- Competition
  - EUCLID – European (ESA) dark energy mission currently in Phase B study

An example of space and ground-based images combined: the Sloan Bright Arcs Survey

Systems with strong gravitational lenses discovered in the SDSS data.





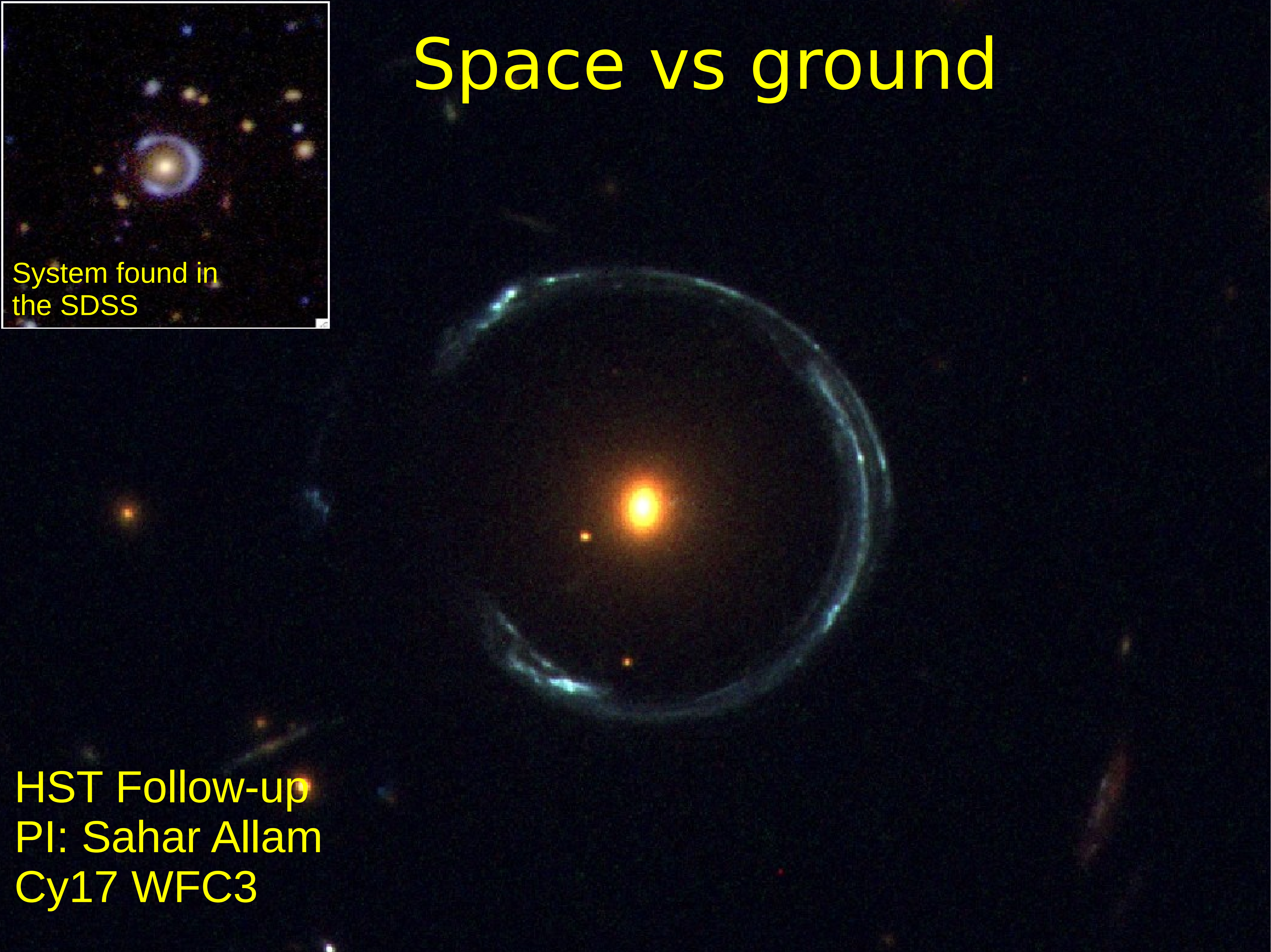


LRG 3-817
θ_E = 7.7 ± 1.1"
M(< θ_E) = 9.6±2.7 × 10^{12} solar masses
(work of Anderson West, IMSA student)

18 systems discovered and fully modeled so far:

The 8 o'clock arc (Allam et al. 2007)
The Clone (Lin et al. 2008)
6 systems at z ~ 1 (Kubo et al. 2009)
4 systems at z ~ 2 (Diehl et al. 2009)
6 systems up to z ~ 3 (Allam et al. 2010, in prep.)

Space vs ground



Summary

The Dark Energy Survey aims at constraints on w with 5% uncertainty and constraints on w' with 30% uncertainty exploring 4 ways to probe the expansion of the Universe.

In this talk we:

Explored these avenues now using the SDSS Coadd data.

- Science with the SDSS Coadd is being released.

- Challenges for the upcoming DES analysis have been addressed.

Discussed the current status for the upcoming Dark Energy Survey.

- Preparatory work for DES benefits from work on simulations and data.

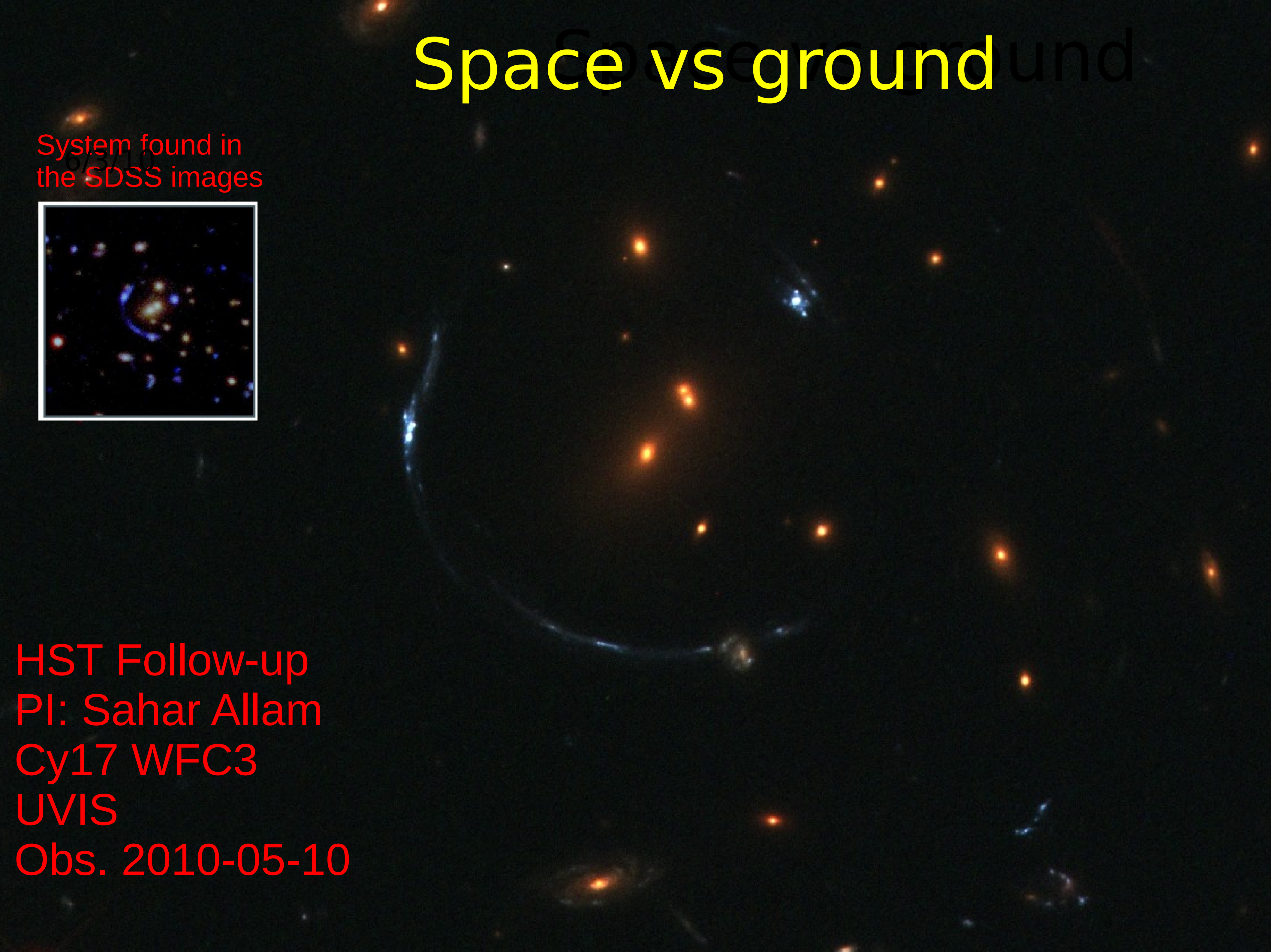
Had a glimpse of a next generation project, the JDEM mission.

- Space-based mission has can improve the current constraints by a factor of 10.

Space vs ground

Space vs ground

6/3/10



System found in the SDSS images

HST Follow-up
PI: Sahar Allam
Cy17 WFC3
UVIS
Obs. 2010-05-10