



KAVLI INSTITUTE FOR PARTICLE ASTROPHYSICS AND COSMOLOGY

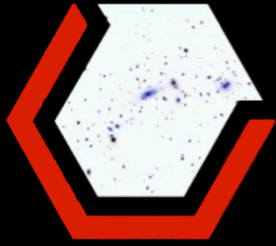
# The Dark Energy Survey



DARK ENERGY  
SURVEY

Carlos Cunha  
Stanford University

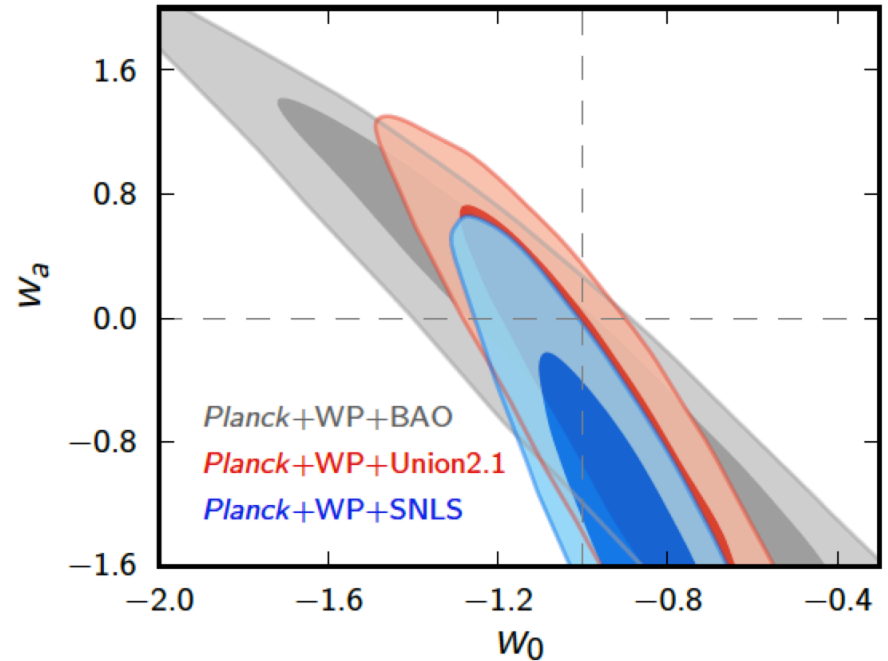
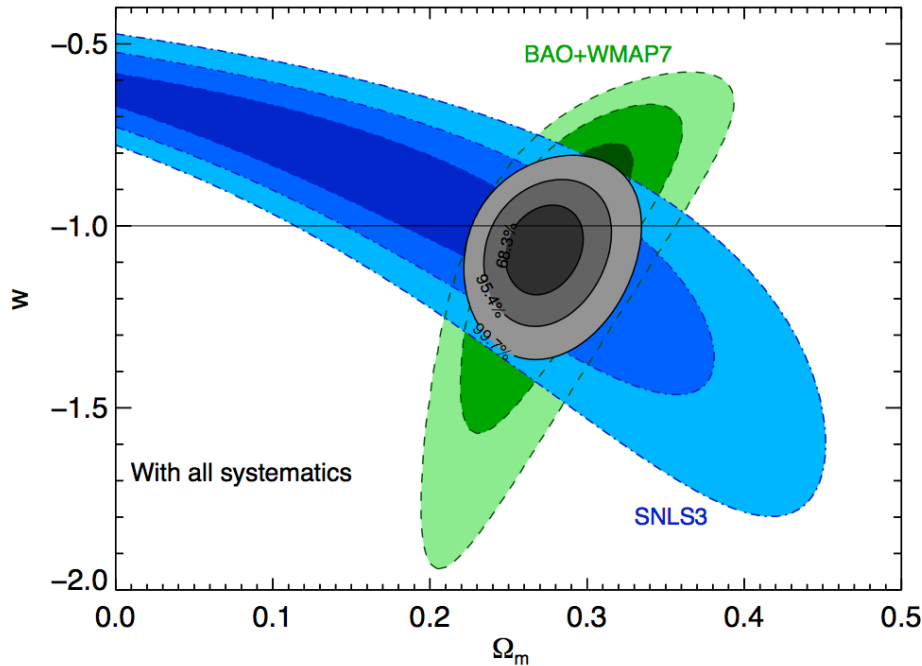
DFP Meeting, August 14, 2013



# Constraints from Supernovae (SDSS, SNLS), CMB (WMAP, Planck), and Large-scale Structure (SDSS)

Assuming constant  $w$

Assuming  $w=w_0+w_a(1-a)$





Sullivan et al 2011

Ade et al 2013



# The 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

 [NCSA](#) [UIUC/NCSA](#) — The University of Illinois at Urbana-Champaign

 [LBL](#) — 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


 [ETH-Zuerich](#) — Eidgenoessische Technische Hochschule Zuerich


 [OSU](#) — The Ohio State University

 [TAMU](#) — Texas A&M University

[Munich—Universitäts-Sternwarte München](#)

-  [Ludwig-Maximilians Universität](#)
-  [Excellence Cluster Universe](#)

 [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



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# The Dark Energy Survey

[www.darkenergysurvey.org](http://www.darkenergysurvey.org)

## 3 projects

- New 3 deg<sup>2</sup> FoV camera (DECAM) in Blanco 4-m
- Data management system (NCSA)
- CTIO Facilities Improvement Project (telescope)

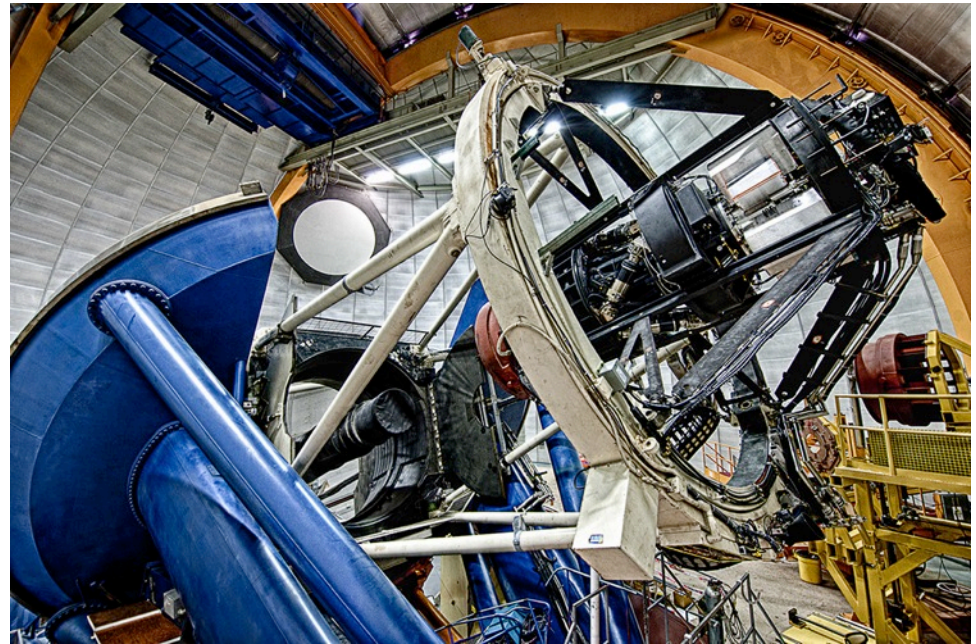
## Two multiband surveys

**Main:** 5000 deg<sup>2</sup>  $\approx 5 (h^{-1}\text{Gpc})^3$

**300 million galaxies**

*g, r, i, z, Y* to 24th mag

**SNe:** 30 deg<sup>2</sup> repeat



- Survey 2013-2018 (525 nights)
- Camera available for community use the rest of the time (70%) + u-band



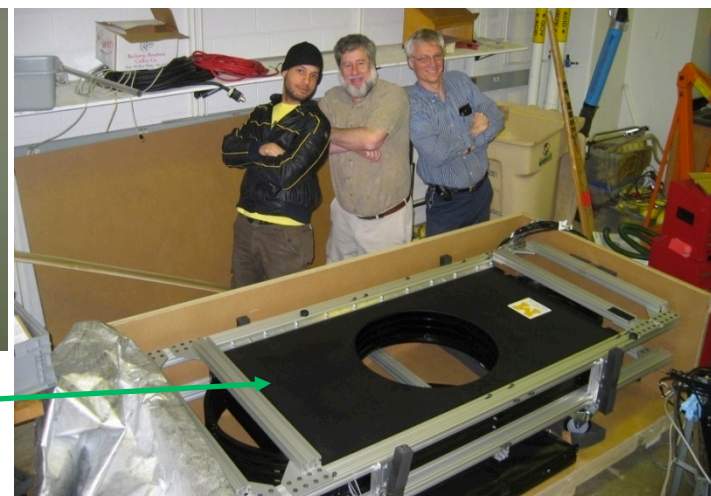
# DECam Systems



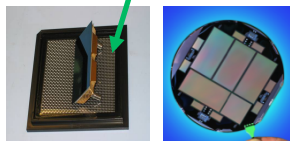
Imager, FNAL



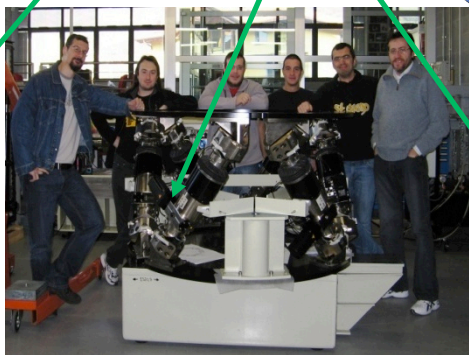
Filters, Japan



Filter changer, Univ. of Michigan



CCDs, wafer from LBNL, packaged at FNAL



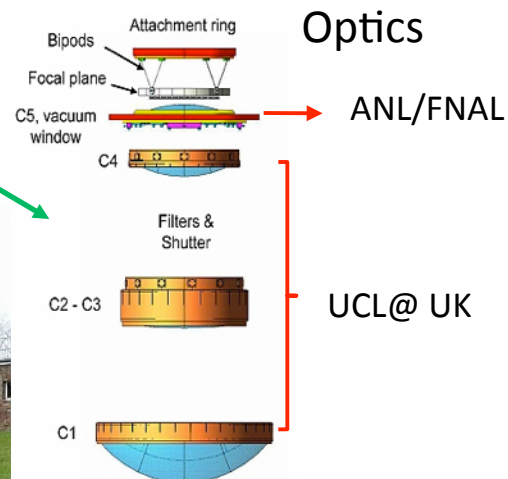
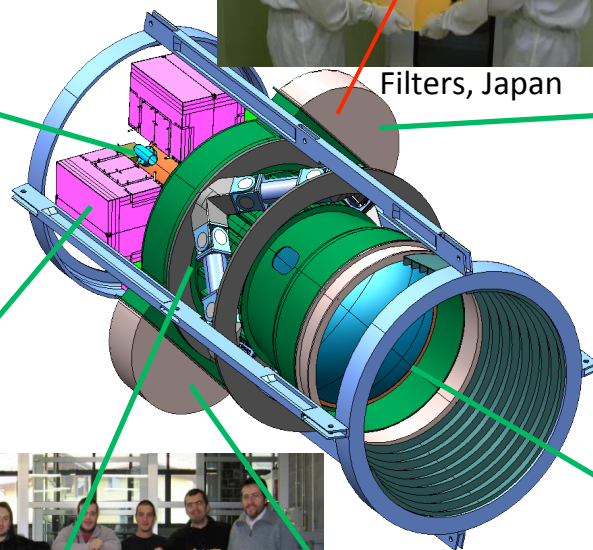
Hexapod, Italy



Electronics, Spain and FNAL



Shutter, Germany



**DECam project manager:  
Brenna Flaughter**



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## Project Timeline

- Project initiated 2003
- DECam R&D 2004-8
- Camera construction 2008-12
- Imager installation: Aug. 30 (2012)
- First light: Sept. 12 (2012)
- Commissioning: late Aug. to Oct. (2012)
- Science Verification: Nov – Feb
  - ~115 deg<sup>2</sup> of data to full depth are now public
- First season: starting Sept. 2013



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# DES Survey Strategy

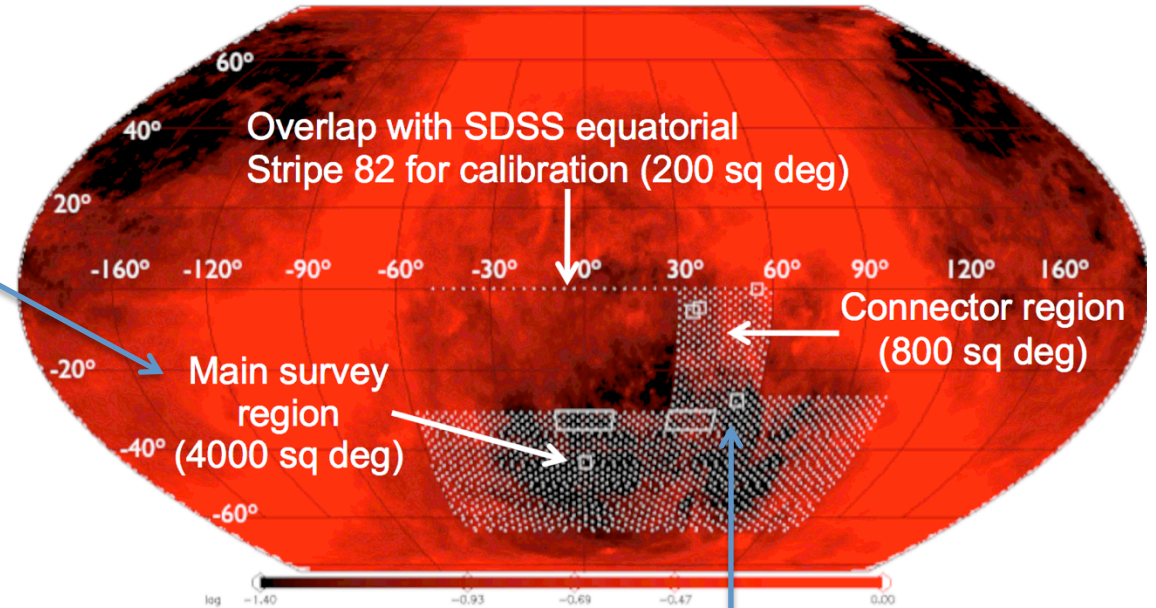


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# Survey Strategy: Footprint

Overlap with SPT

Overlap with as many surveys as possible:  
Stripe82, GAMA, VVDS,  
eRosita, BOSS, DEEP2-EGS,  
PRIMUS, ...



Supernovae fields





# Survey Strategy: Exposure Time

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Sept-Feb observing seasons

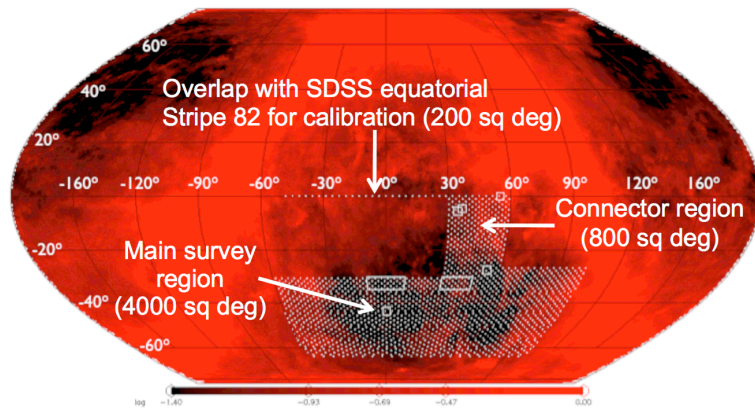
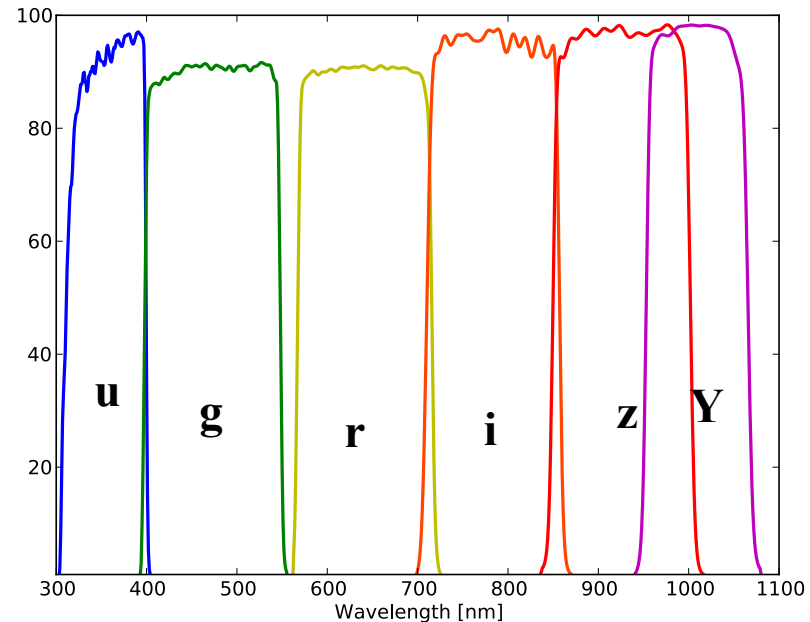
80-100 sec exposures

2 filters per pointing (typically)

*gr* in dark time

*izy* in bright/grey time

2 survey tilings/filter/year





# Survey Strategy: Exposure Time

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Sept-Feb observing seasons

80-100 sec exposures

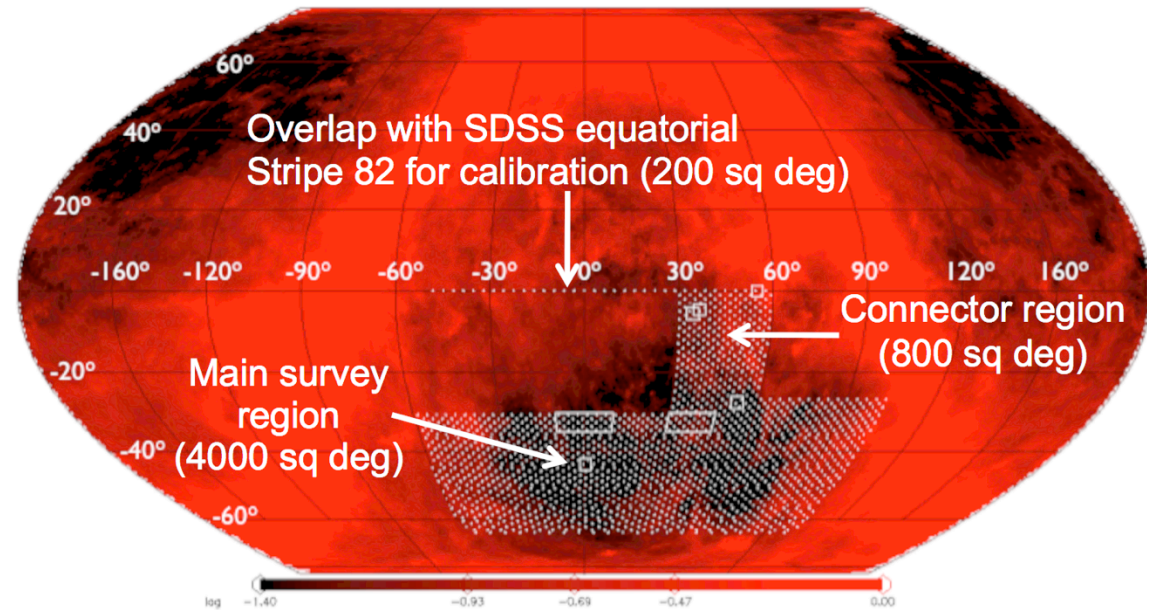
2 filters per pointing (typically)

*gr* in dark time

*izy* in bright/grey time

2 survey tilings/filter/year

**Total:** 4000 secs per patch,  
equally distributed between  
griz, minus 160 secs for *y*.





# Survey Strategy: Exposure Time

## DARK ENERGY SURVEY

Sept-Feb observing seasons

80-100 sec exposures

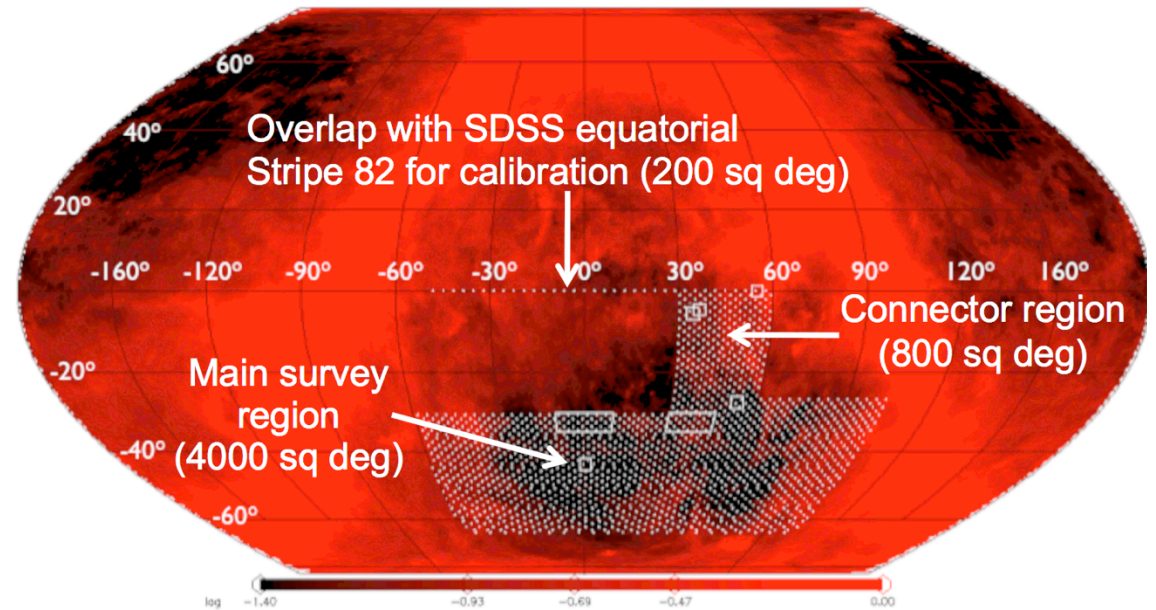
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*gr* in dark time

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2 survey tilings/filter/year

**Total:** 4000 secs per patch,  
equally distributed between  
griz, minus 160 secs for *y*.



Equal exposure times:

- maximizes galaxies usable for weak lensing,
- yields best photometric redshifts, and cluster finding
- most spatially homogeneous survey strategy



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# DES Science Program



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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

Plus, tons of auxiliary science:

- Stars and Milky Way
- Quasars
- Galaxy Evolution
- Milky Way

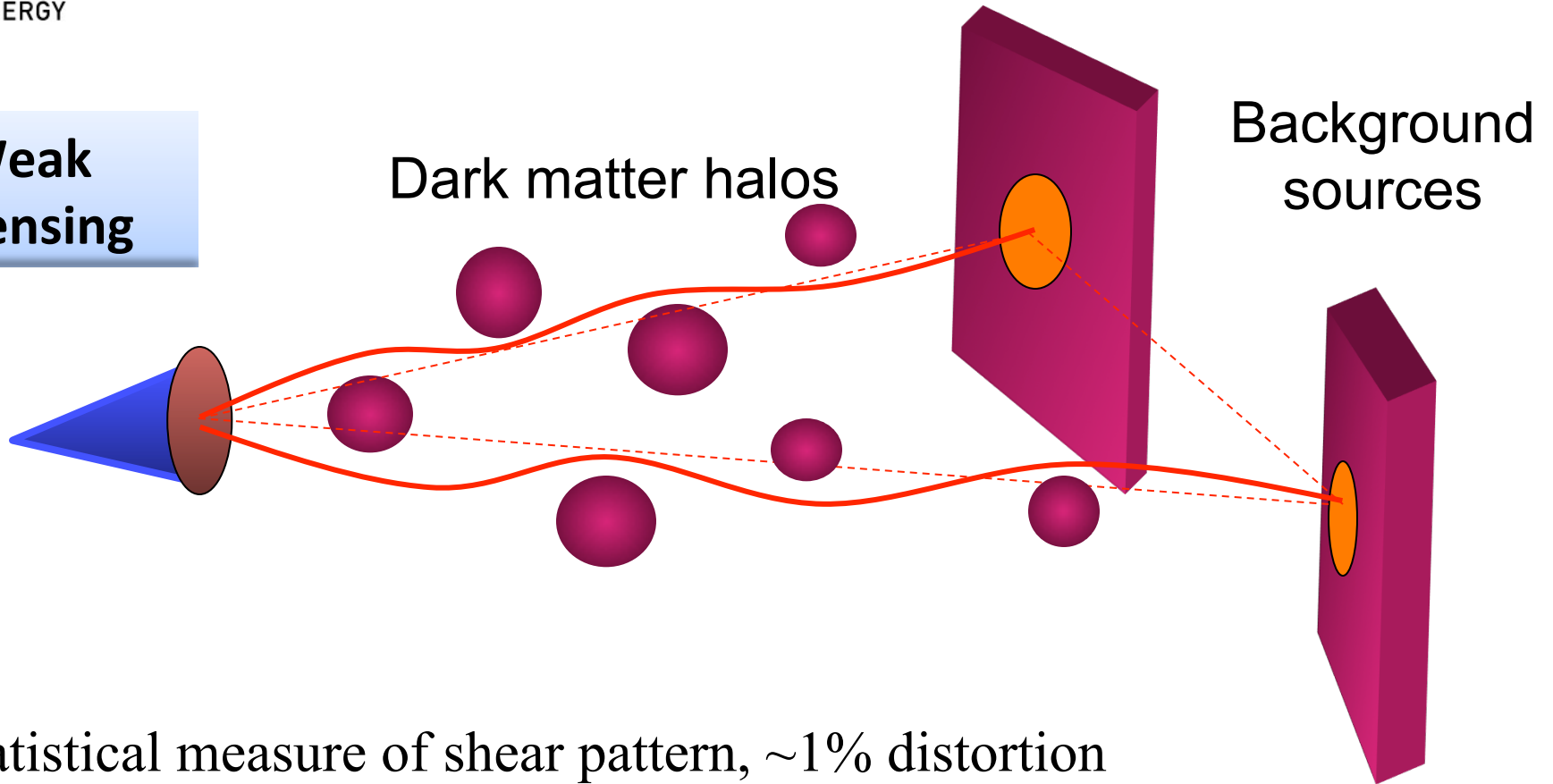




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# DES Science program

Weak  
Lensing



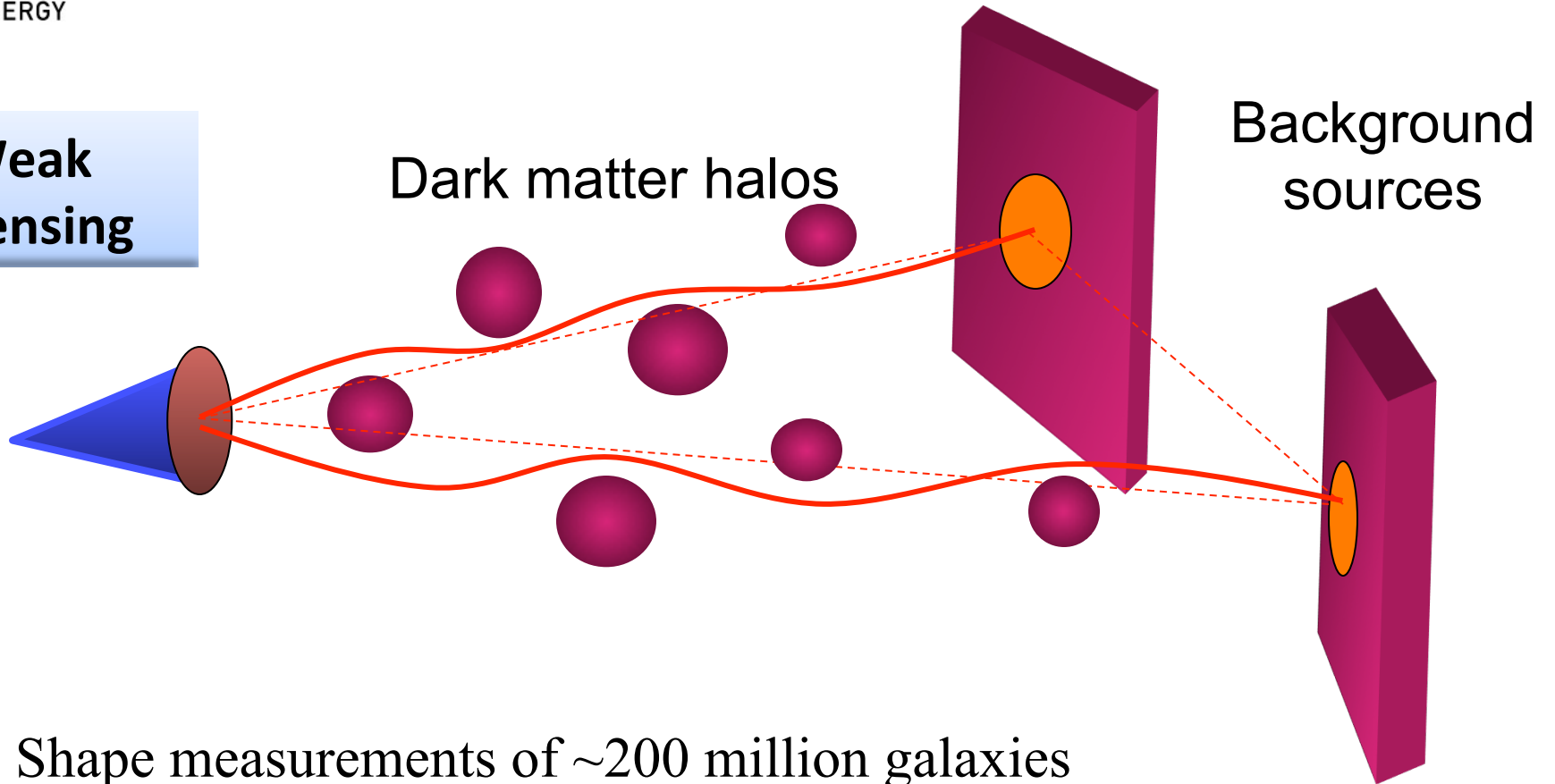
- Statistical measure of shear pattern,  $\sim 1\%$  distortion
- Radial distances depend on *geometry* of Universe
- Foreground mass distribution depends on *growth* of structure



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# DES Science program

Weak  
Lensing



- Shape measurements of  $\sim 200$  million galaxies
- Shear-shear + shear-galaxy + galaxy-galaxy correlations
- Complementary probe: magnification



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# DES Science Program

## Galaxy Clusters Counts

The mean number of clusters with mass  $M > M_{th}$  is given by

$$\bar{m}(M > M_{th}, z) = \underbrace{\int dV}_{\text{Depends on geometry.}} \int_{M_{th}}^{\infty} d \ln M \underbrace{\frac{dn}{d \ln M}}_{\text{Mass Function (eg. Jenkins). Derived from power spectrum. Depends on cosmology through growth of structure.}}$$

Depends  
on  
geometry.

Mass Function (eg. Jenkins).  
Derived from power spectrum.  
Depends on cosmology through  
growth of structure.





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# DES Science Program

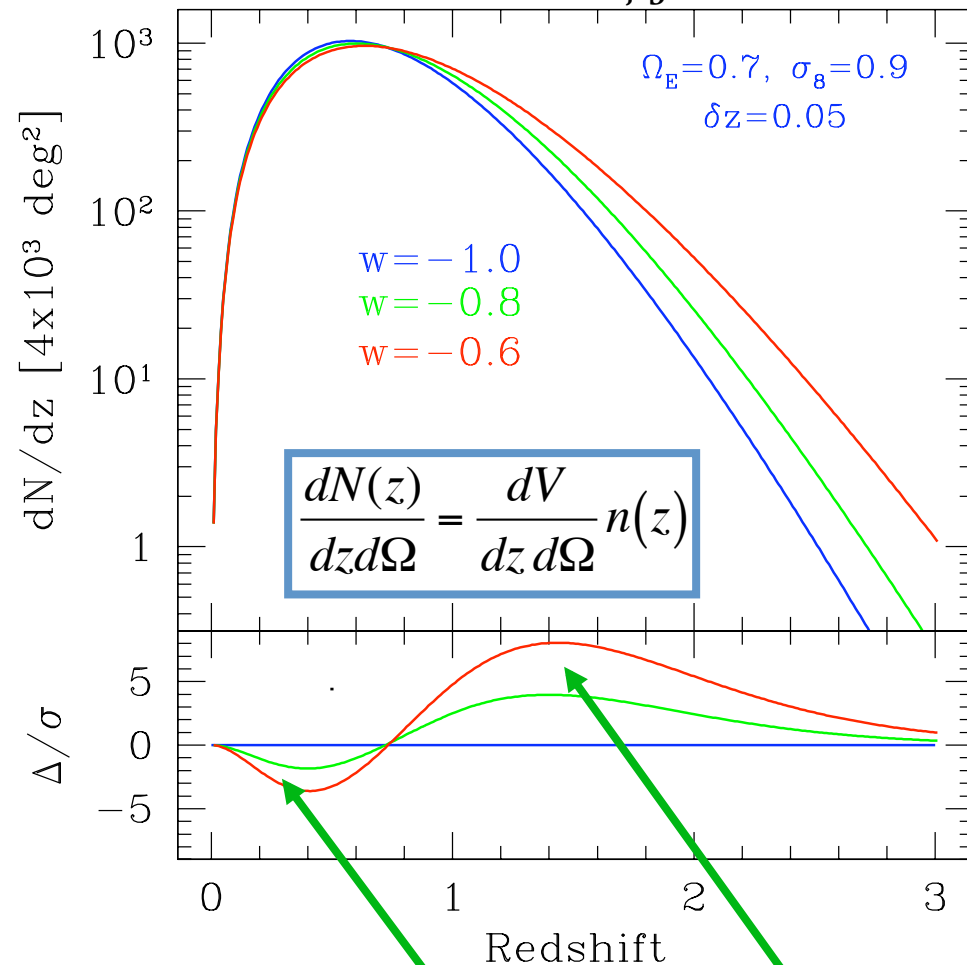
## Galaxy Clusters Counts

For models with **larger w**:

- **less** volume --> **less** clusters at **low** redshift.
- structure grows **less** rapidly --> **more** clusters at **high** redshift.

Models are normalized to produce same cluster abundance at low redshifts

Mohr, J. 2005



Volume

Growth

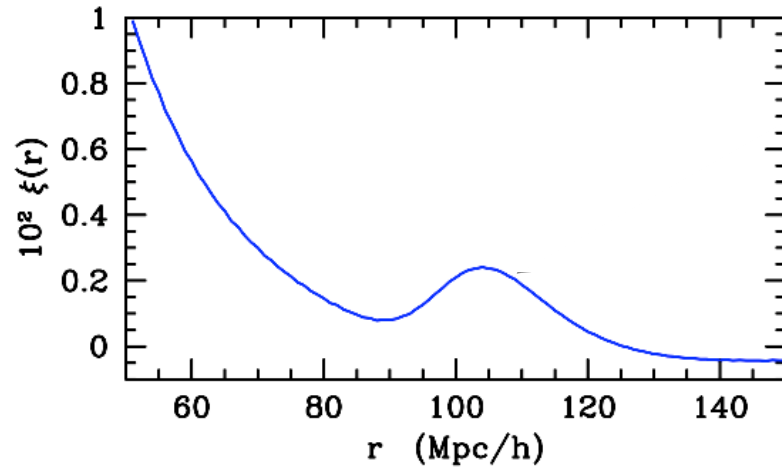
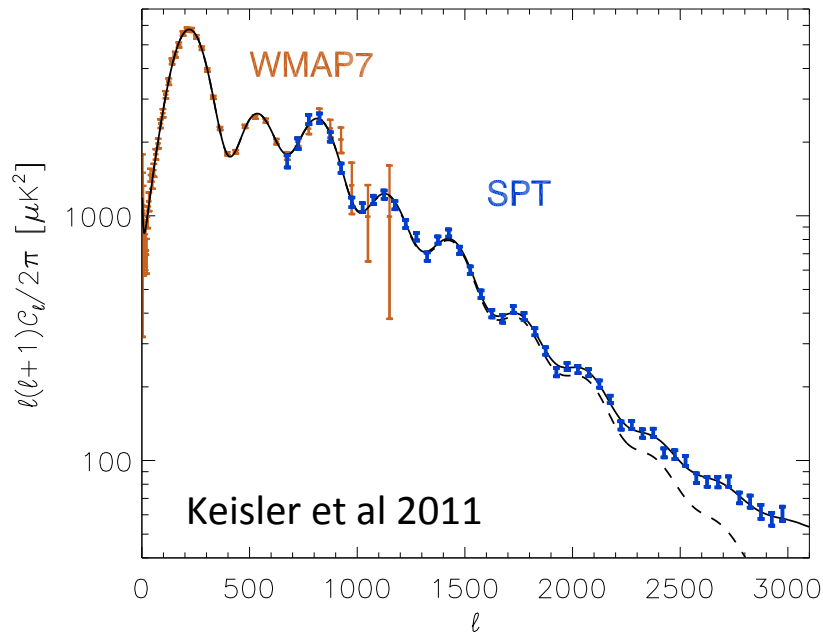
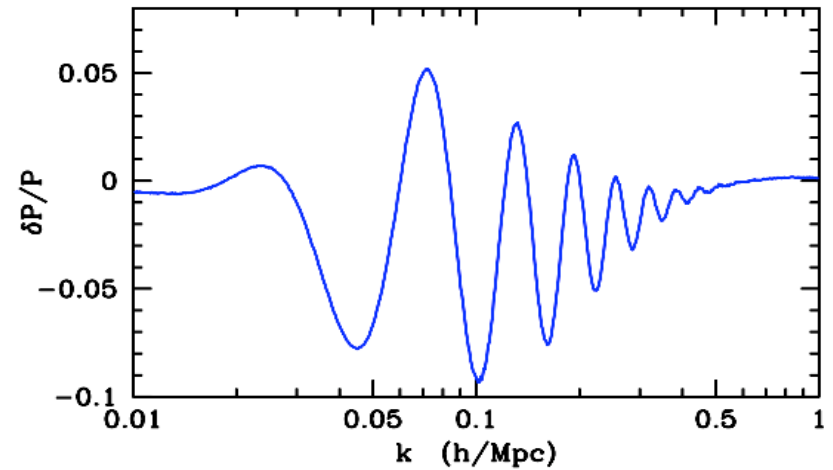


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## Baryon Acoustic Oscillations

Acoustic scale provides  
standard ruler.  
Scale set by last-  
scattering surface  
( $s=c_s*t_{ls}$ )





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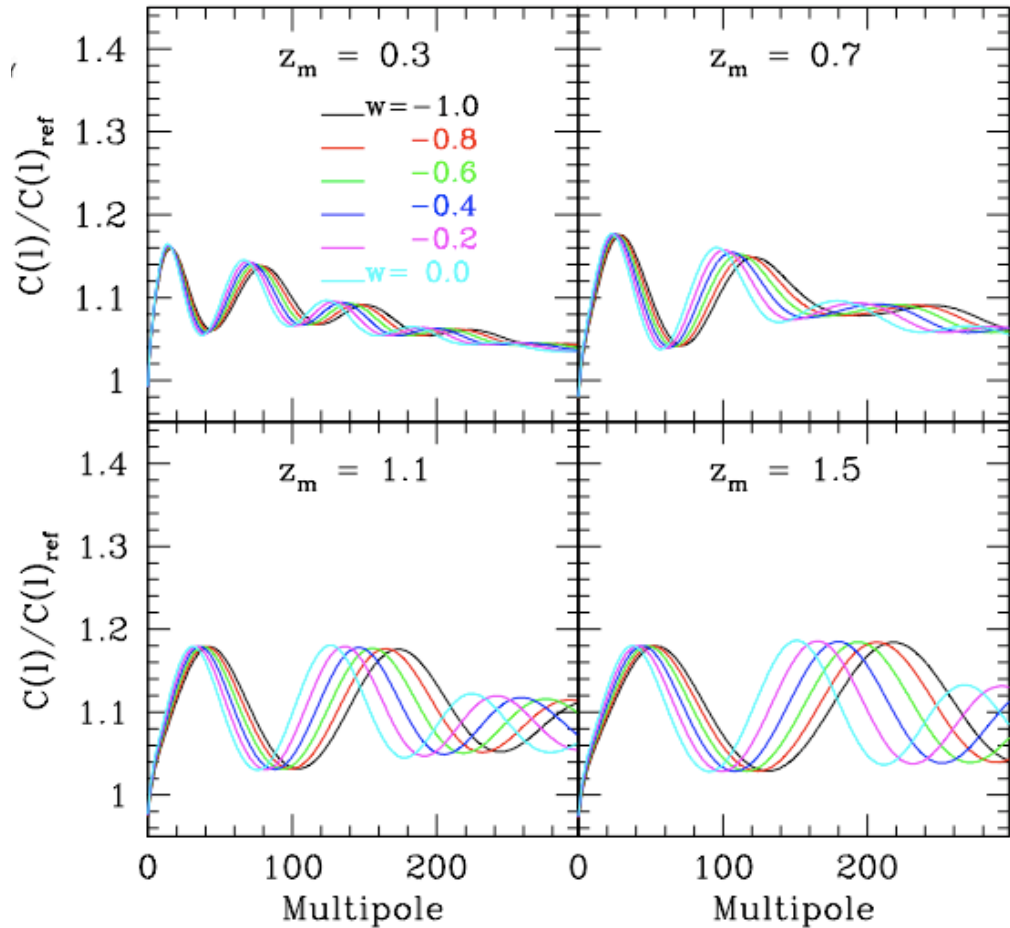
# DES Science Program

## Baryon Acoustic Oscillations

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



Probe deeper than SDSS  
redshift survey (x10  
increase in volume)



Fosalba & Gaztanaga



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## Supernovae

- Standard candles
- Probe geometry

# DES Science Program

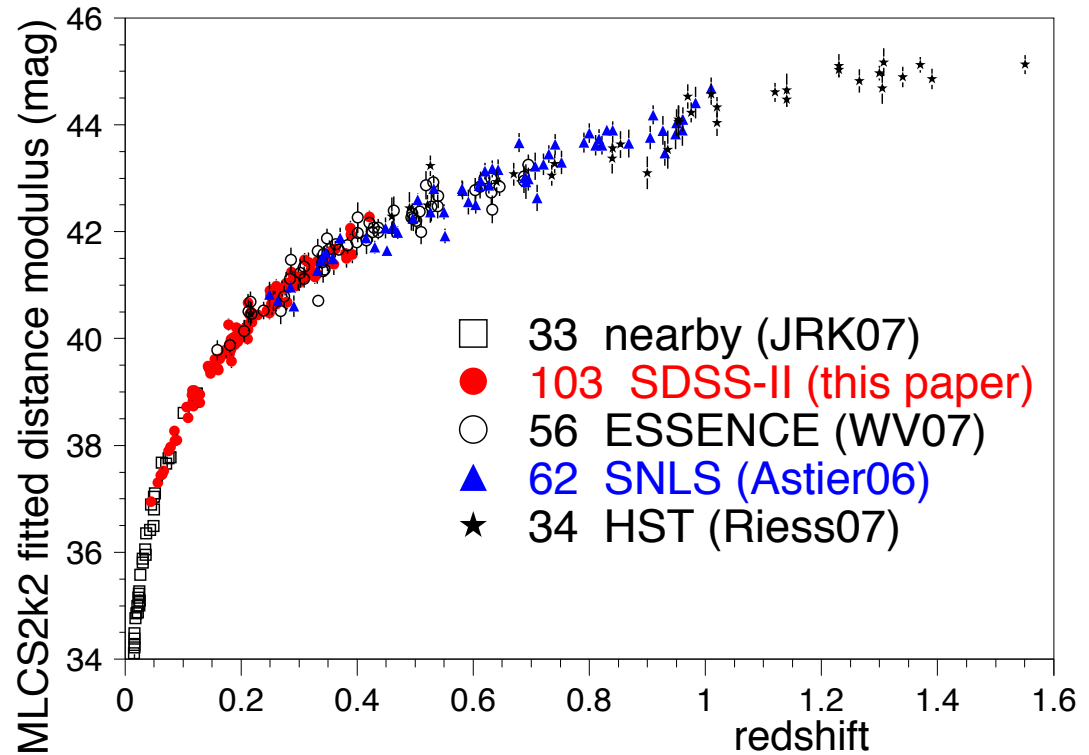


FIG. 23.— Fitted distance modulus (from MLCS2K2) versus redshift for the 288 SNe Ia from the five samples indicated on the plot.

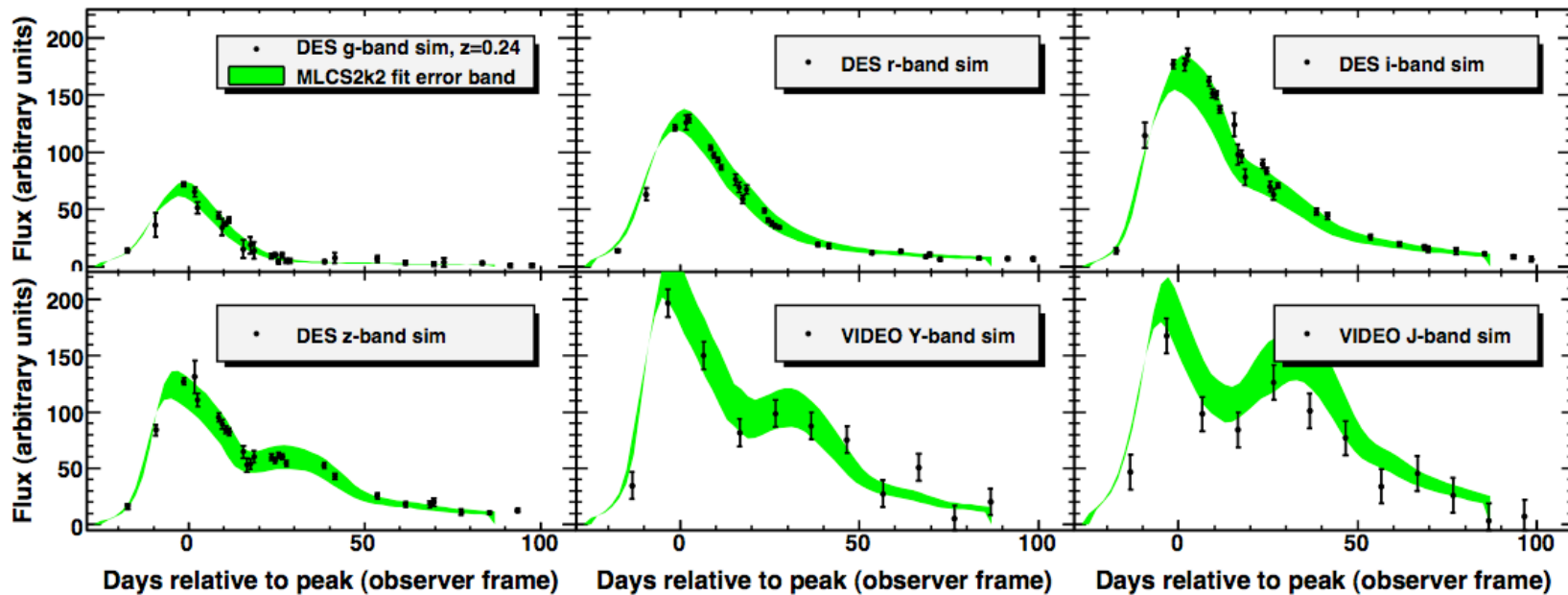
Existing samples  
circa 2009.



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## Supernovae



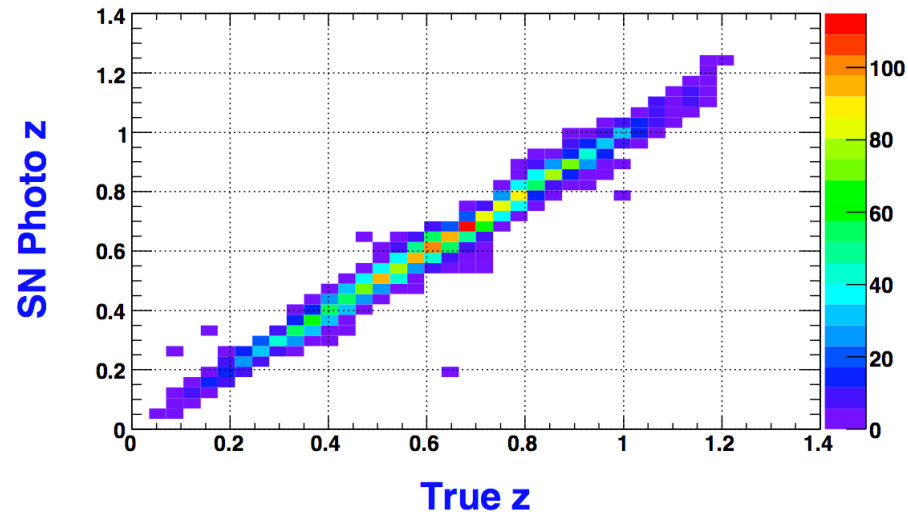
- 30 sq deg time-domain survey
- $\sim 4000$  well-sampled SNe Ia to  $z \sim 1$  (plus 8000 okay ones)
- Factor  $\sim 2-4x$  statistics vs. other samples around 2018
- $\sim 5$  days cadence



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## Supernovae

# DES Science Program



Bernstein et al

- Broader redshift range than SDSS SN
- Higher S/N in red passbands than SNLS
- Add NIR from VISTA VIDEO survey
- Redshifts from spectroscopic follow-up, SN photo-zs and galaxy photo-zs

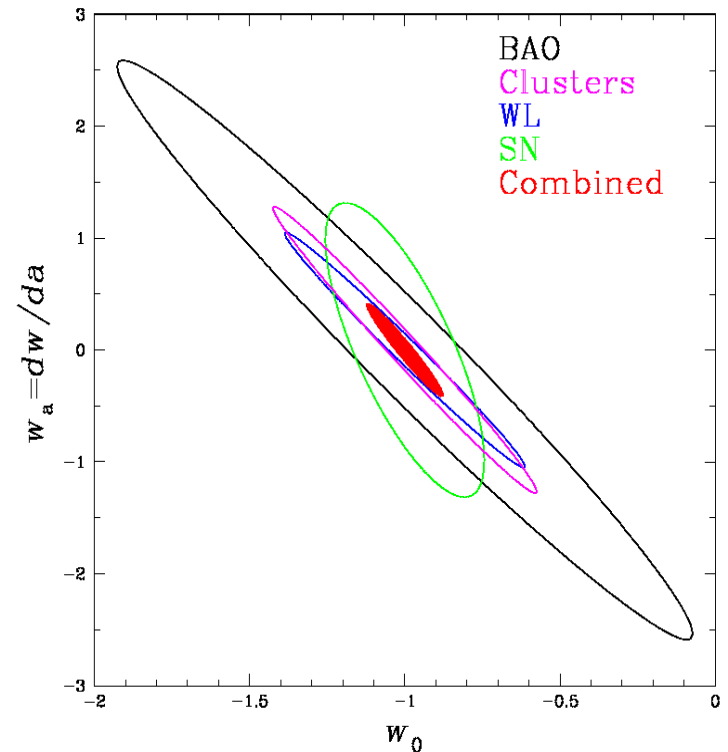


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# DES Science Program

## Four Probes of Dark Energy Working together

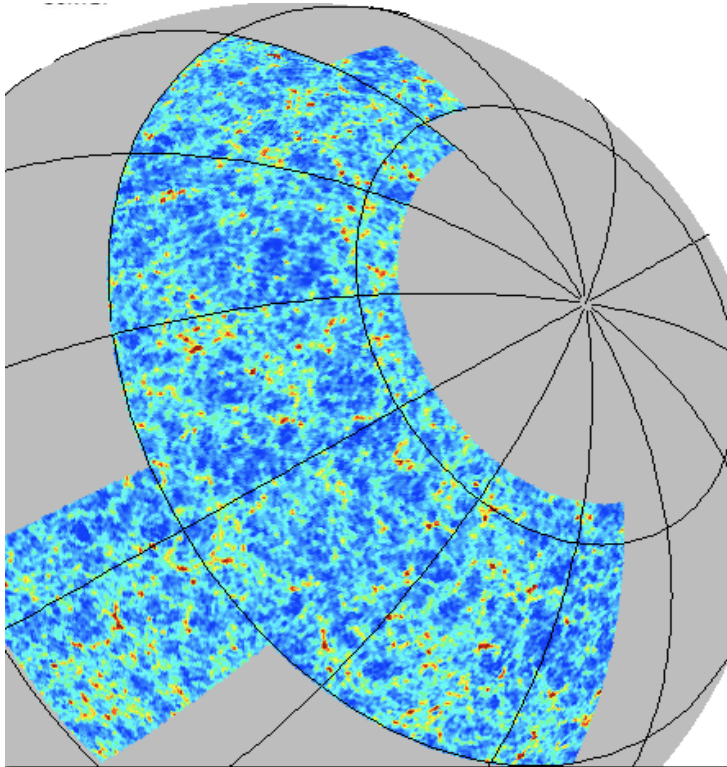
- **Galaxy Clusters**
  - ~100,000 clusters to  $z > 1$
  - Sensitive to growth of structure and geometry
- **Weak Lensing**
  - Shape measurements of 300 million galaxies
  - Sensitive to growth of structure and geometry
- **Baryon Acoustic Oscillations**
  - 300 million galaxies to  $z = 1$  and beyond
  - Sensitive to geometry
- **Supernovae**
  - 30 sq deg time-domain survey
  - ~4000 well-sampled SNe Ia to  $z \sim 1$  (+ 8000 okay ones)
  - Sensitive to geometry





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# DES-SPT Synergy



DES survey area encompasses South Pole Telescope SZE Survey  
~100,000 optical clusters to  $z > 1$ : ~1,000 with SPT measurements

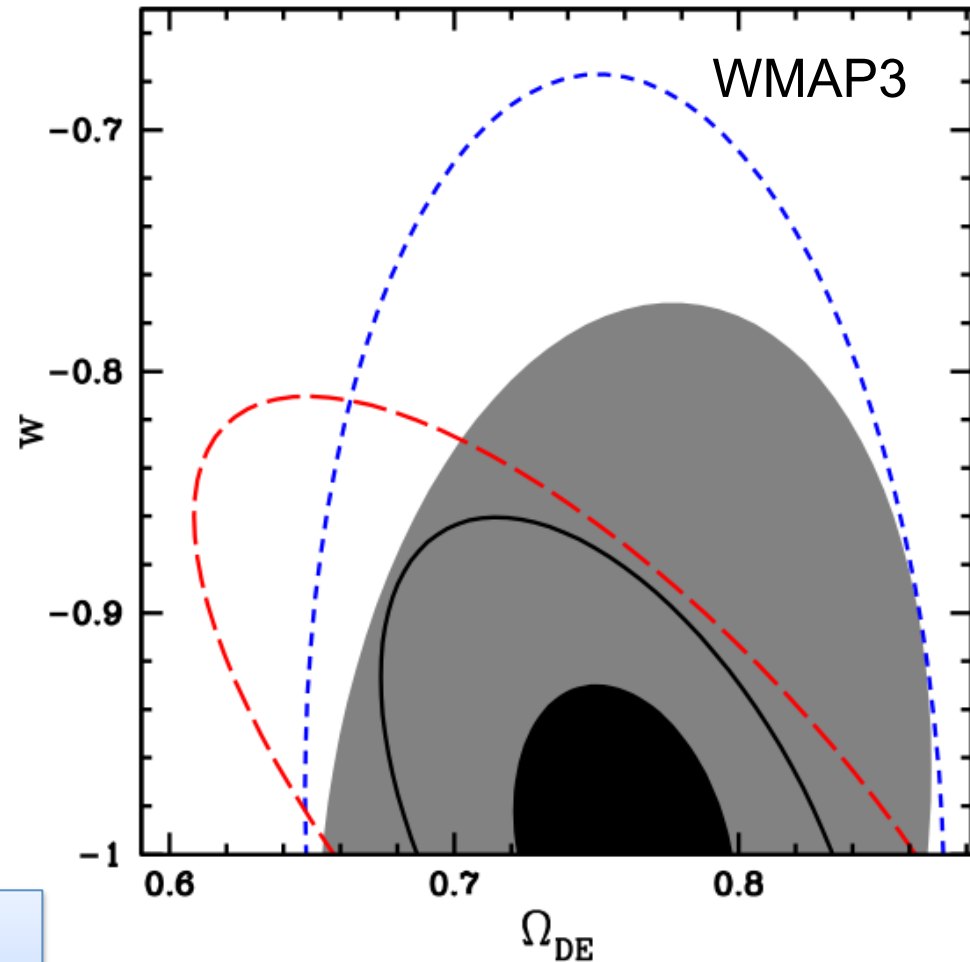




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# Synergy with SPT

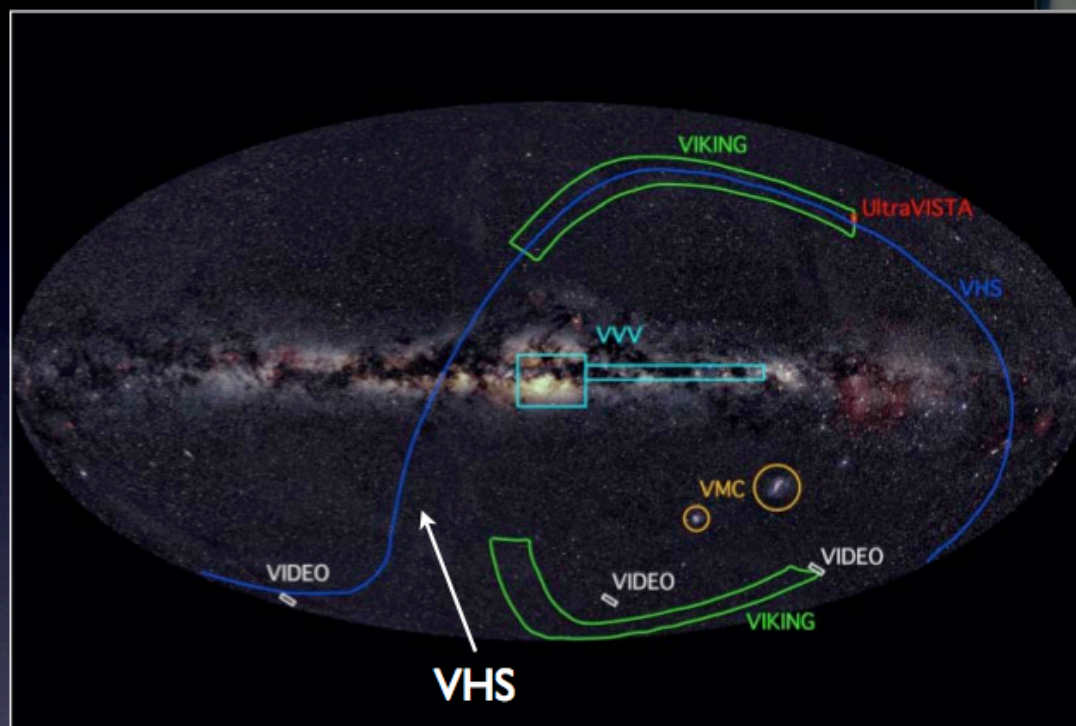
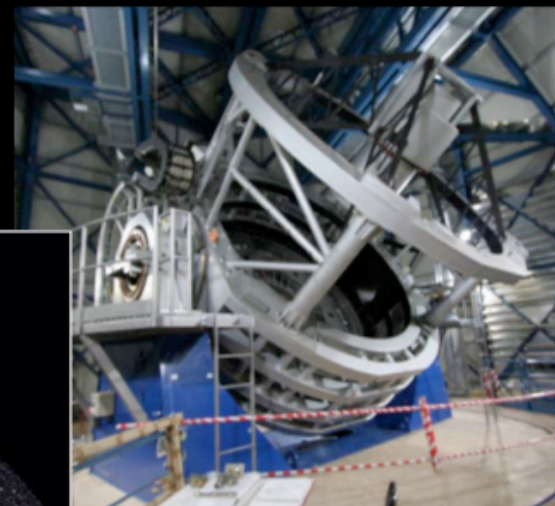
- SZ (SPT)
- OPT (DES)
- SZ + OPT
- Cross. cal. using only SZ  $\cap$  OPT
- Full cross-calibration



SZ+OPT over the same patch of sky = 2x better than if in different parts of the sky (Cunha 2009)

Cunha (2009)

# VISTA Hemisphere Survey



120 sec JHK exposures

## VISTA

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

## VHS

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

VHS limiting magnitudes

[AB system;  $5\sigma$ ]

	deg <sup>2</sup>	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

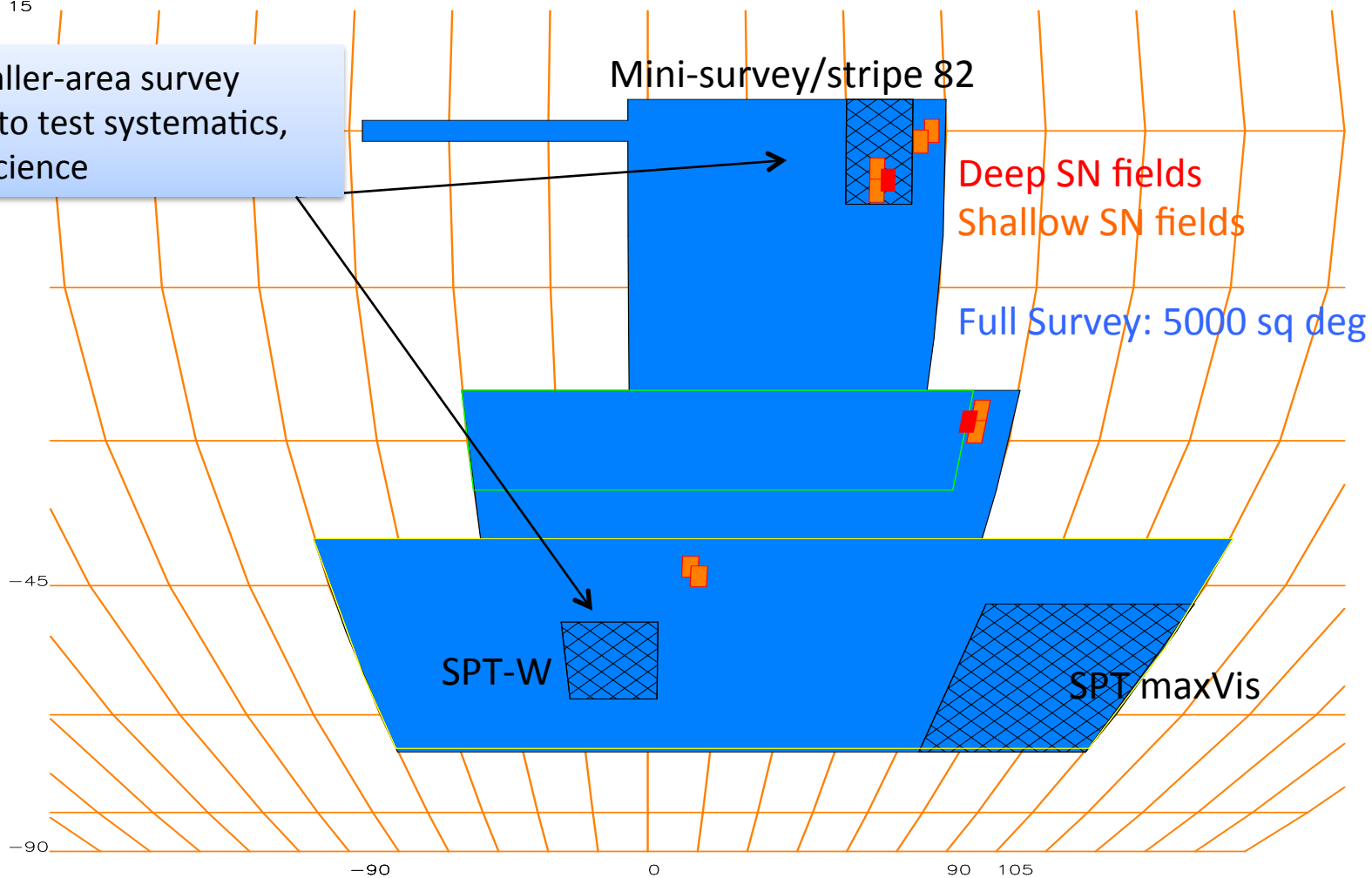


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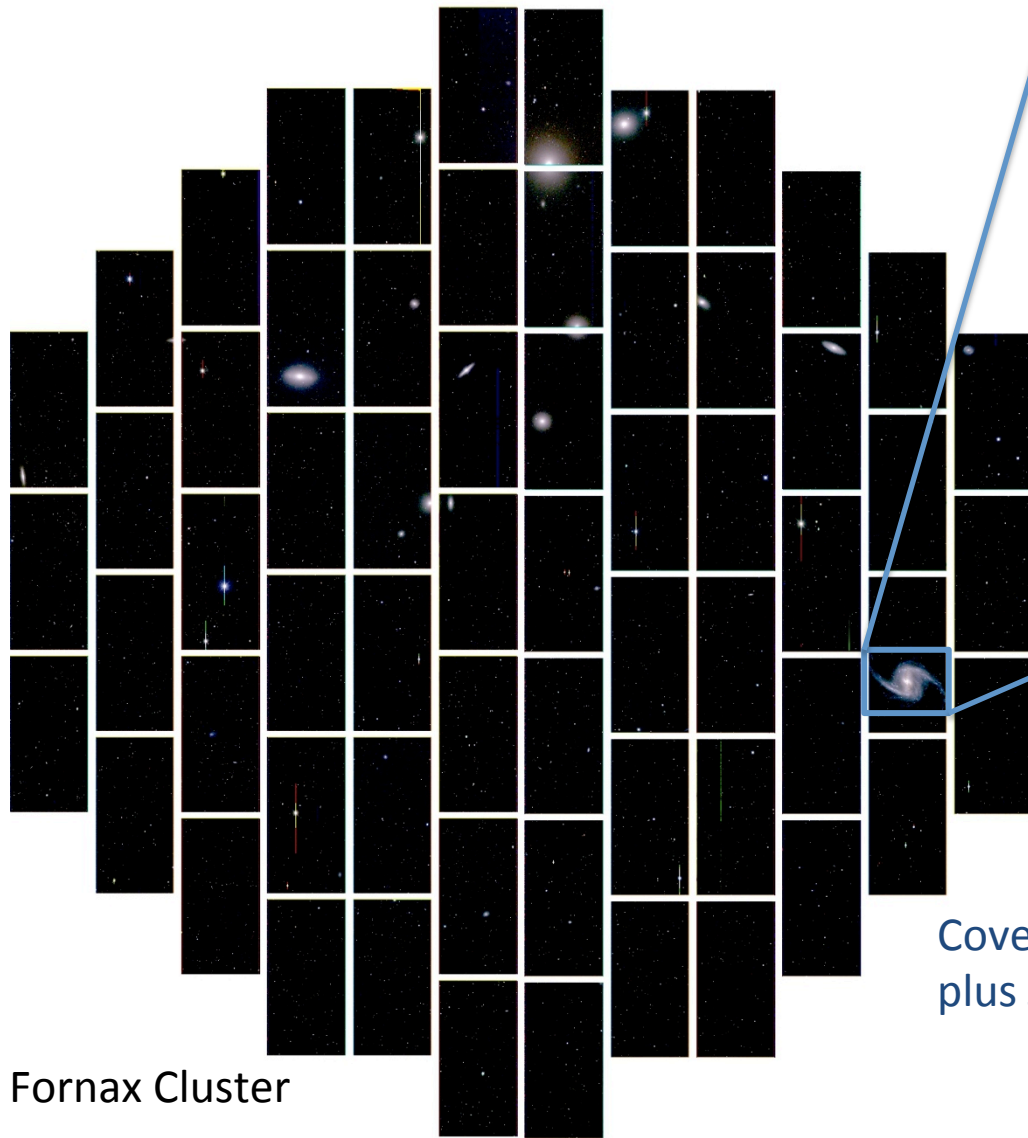
# The first data

15

Deeper, smaller-area survey  
( $\sim 115 \text{ deg}^2$ ) to test systematics,  
yield early science



First Light, Sept. 12, 2012



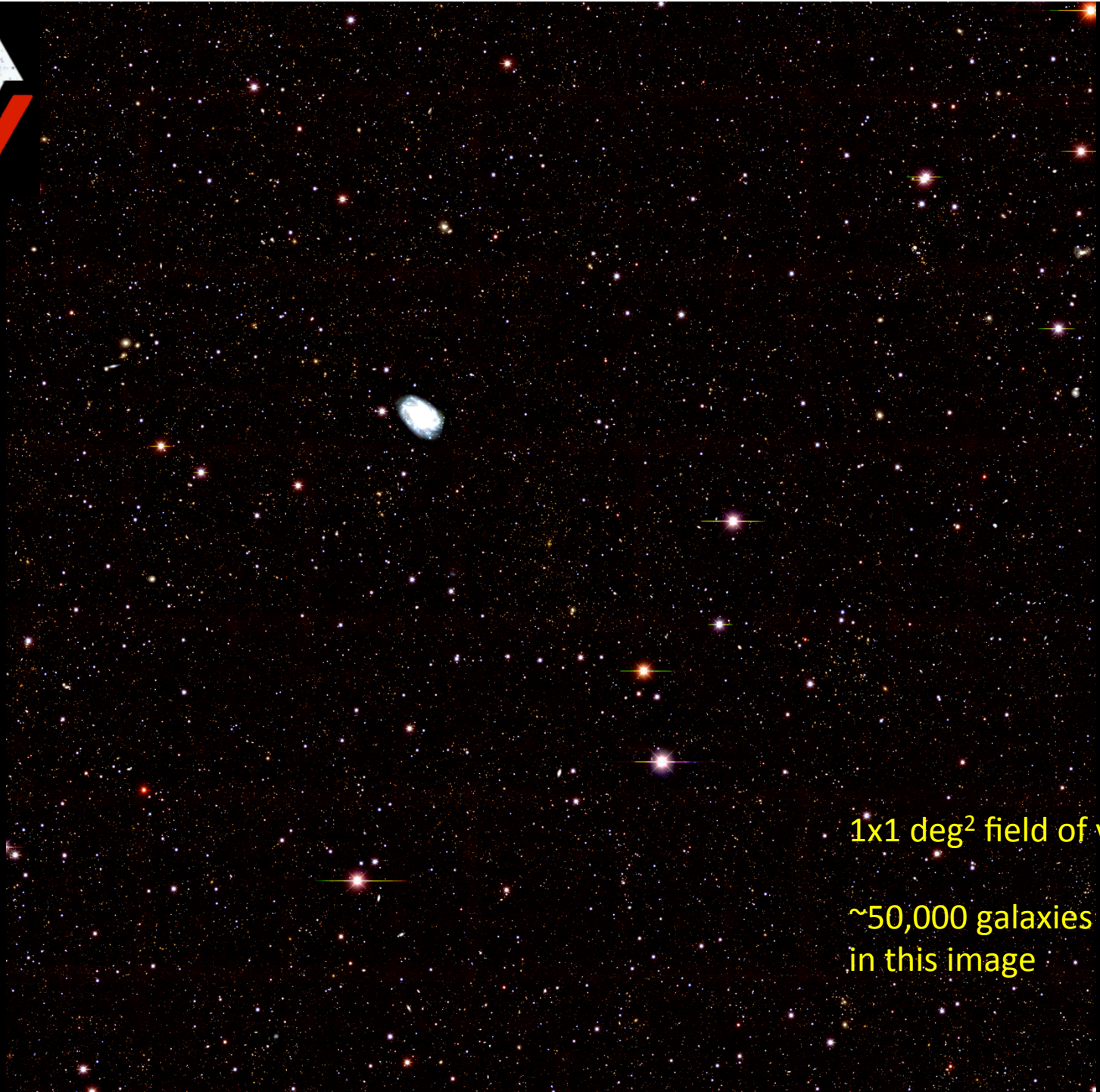
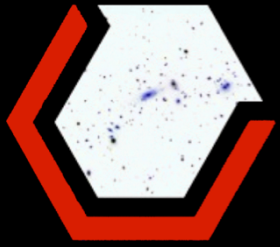
Fornax Cluster



NGC 1365

0.8" images recorded within first few nights of first light!

Covered in 258 publications in 36 countries, plus Jay Leno's monologue



1x1 deg<sup>2</sup> field of view

~50,000 galaxies  
in this image



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# Supernovae – early results



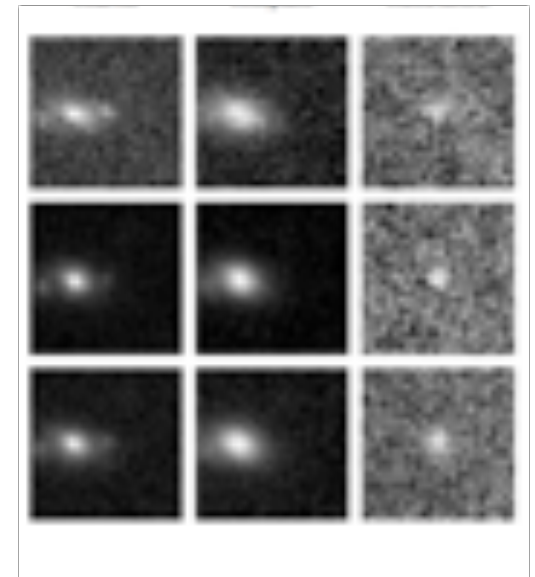
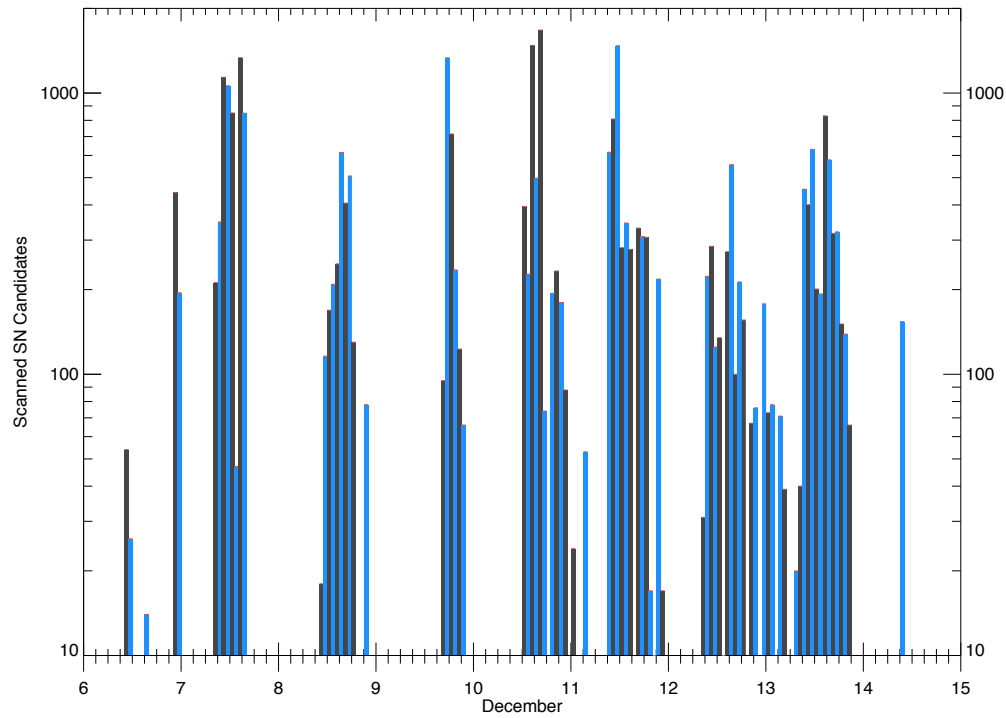
Day -4 (Dec 2)



Day 1 (Dec 6)



Day 4 (Dec 9)

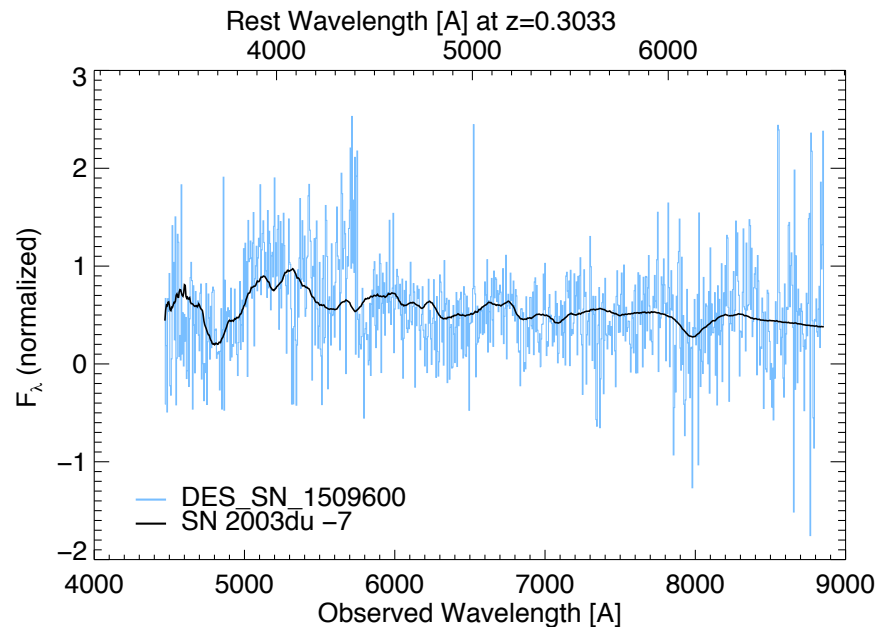
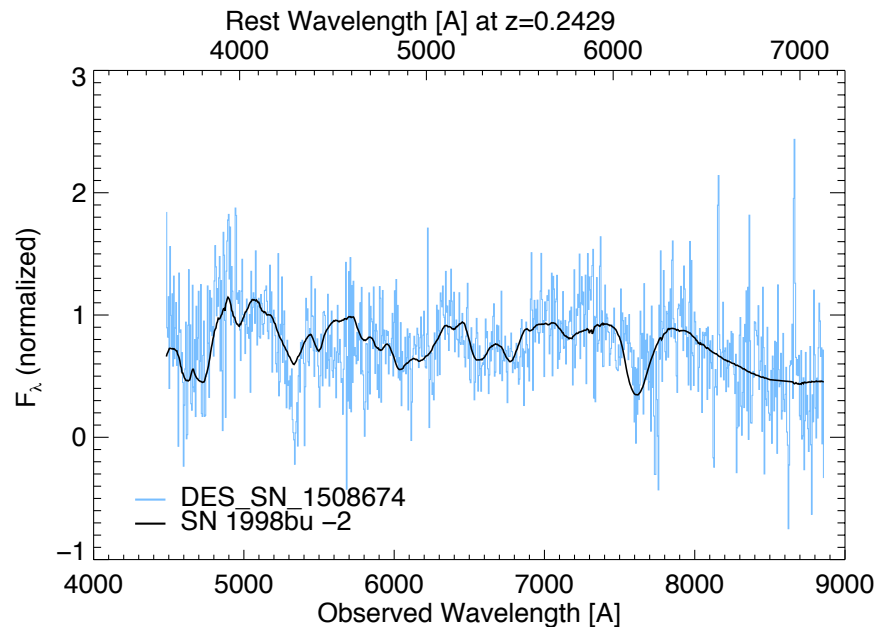




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# Supernovae – early results

- Spectroscopic confirmation of the first supernovae with AAT.
- Ongoing spectroscopic observation of many more at AAT, HET, Keck and SALT.



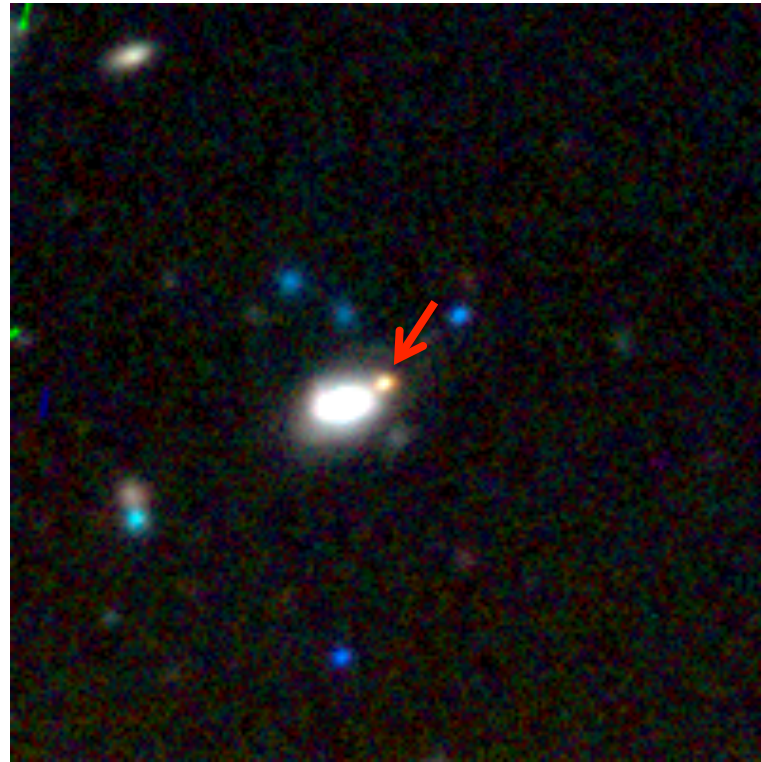
Spectra taken by C. Lidman, R. Sharp, and S. Uddin



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# Supernovae – early results

- 5 Type Ia and 2 Type II already spectroscopically confirmed.
- 500 good candidates scheduled for spectroscopic follow-up next season.



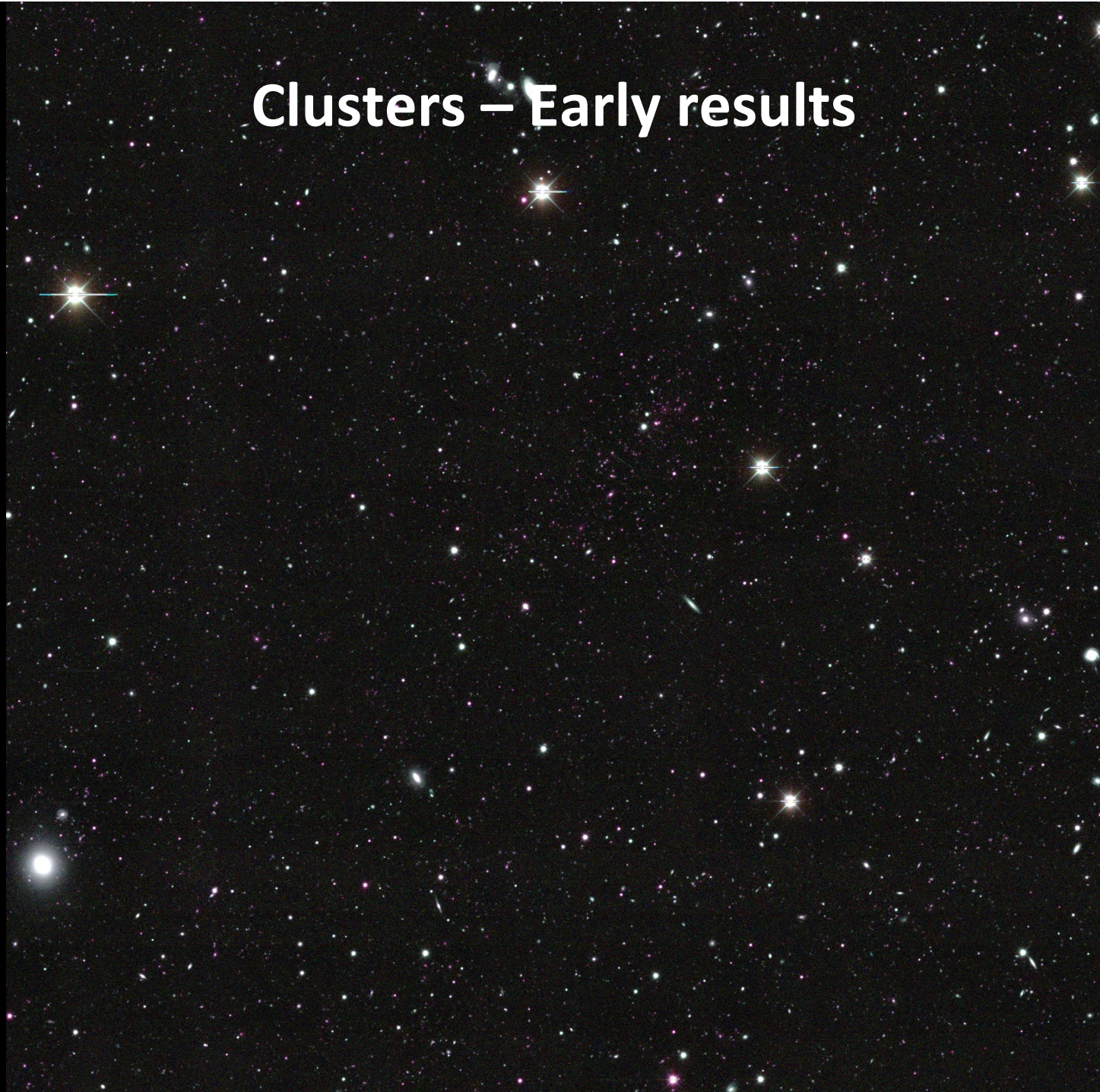


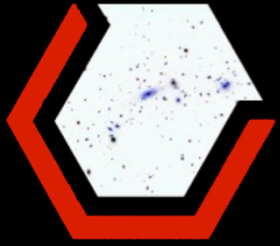


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# Clusters – Early results

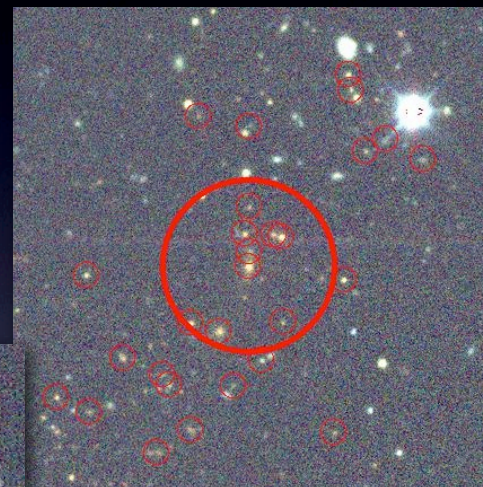
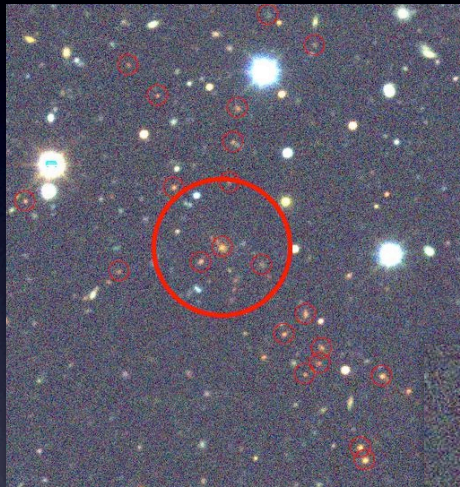
El Gordo  
Cluster  
riz image  
 $z=0.87$





## Clusters – early results

- All new discoveries in cluster fields



Found by E.  
Rykoff, using  
RedMapper

**$z > 0.8$   
clusters!**





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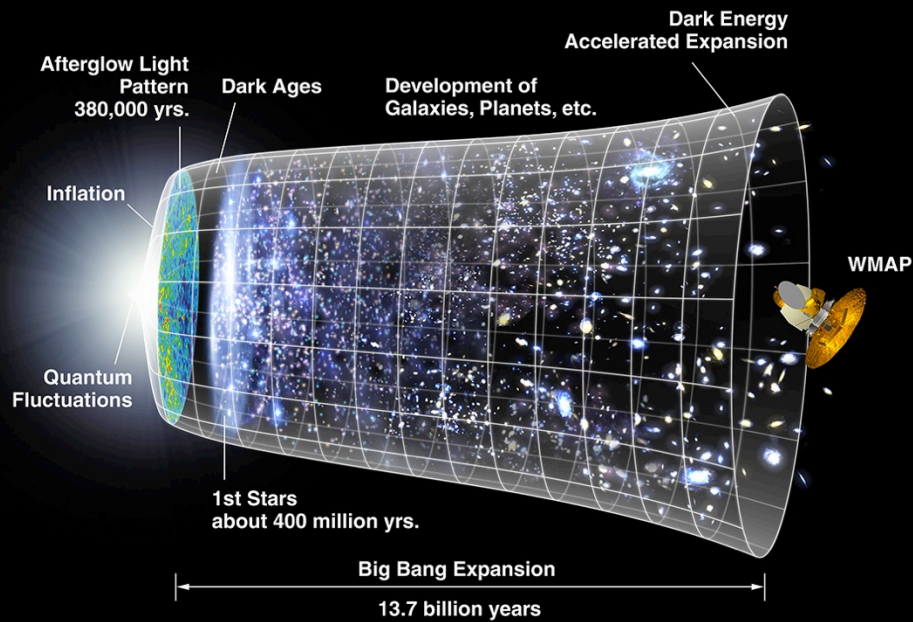
Quote from a non-DES user during community time:

This is a shockingly awesome "shared risk" instrument. Already mature enough to do excellent science, and a joy to use, DECam is a superb achievement. I have to congratulate everybody at CTIO, FermiLab, and everyone else who contributed.



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# History and Composition of the Universe



NASA/WMAP Science Team

