DARK ENERGY PHYSICS WITH COSMIC SURVEYS IN THE 21ST CENTURY

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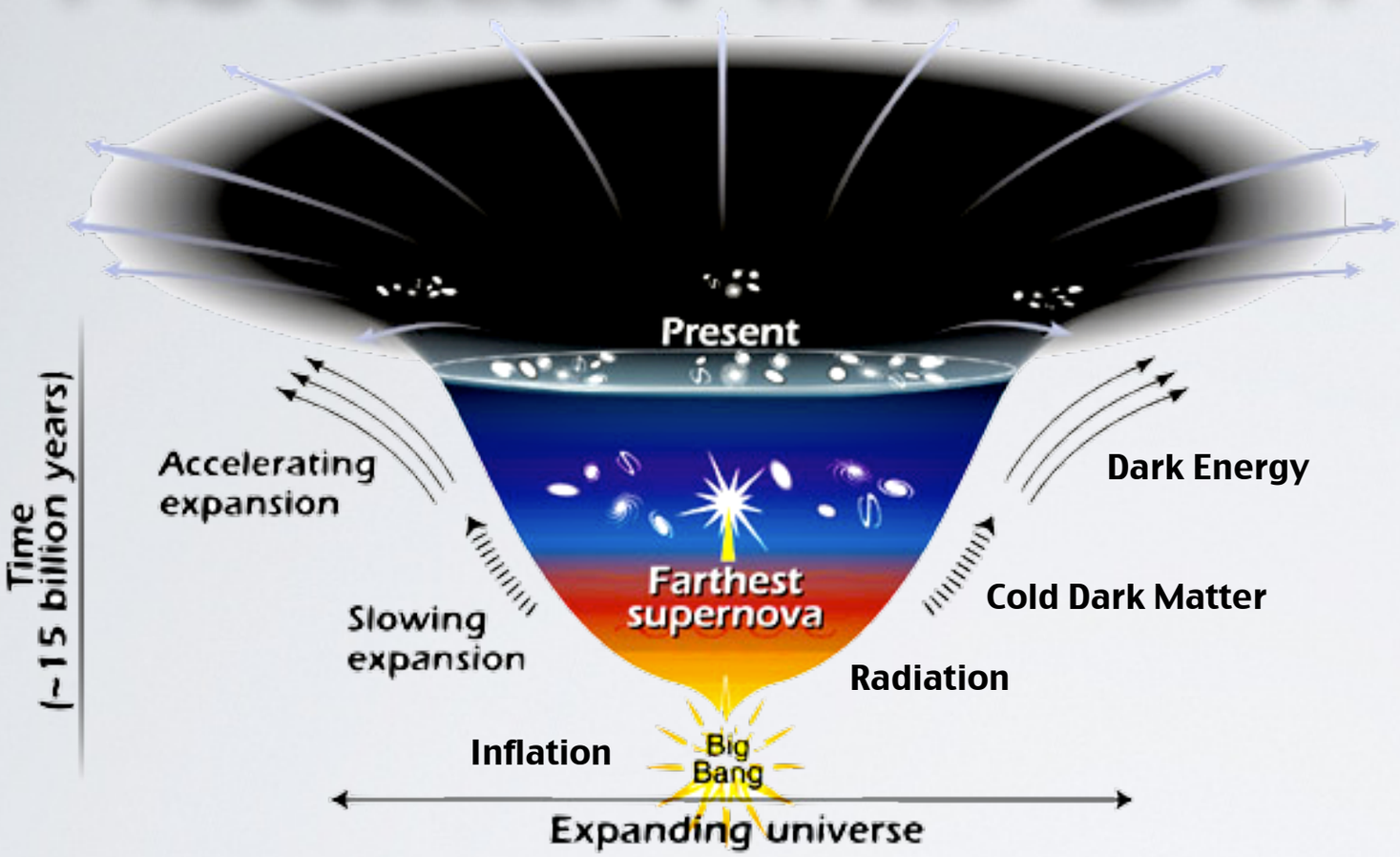
DES Collaboration

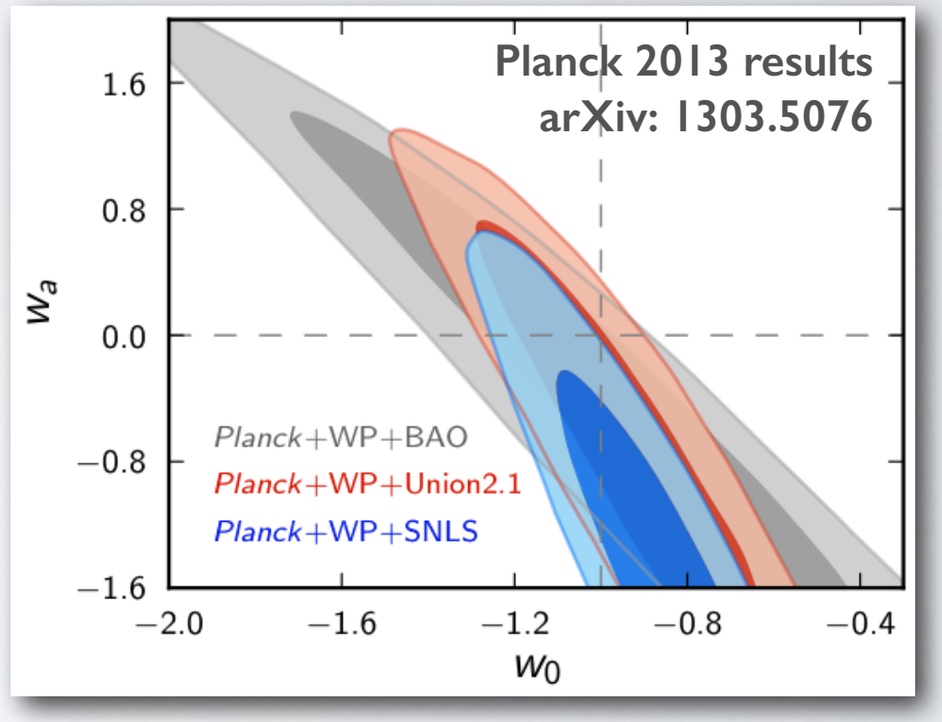
LISHEP Conference — Manaus, Brazil — August 4, 2015

DARK ENERGY & ACCELERATED EXPANSION



Dark Energy candidate: Cosmological Constant (Λ)

$$w = -1$$



$$\ddot{a}/a = -(3p + \rho)$$

spacetime geometry (scale factor) — **energy content (equation of state)**

$$p = w(a)\rho$$

$$w(a) = w_0 + w_a(1 - a) + \cdots$$

ASTROPHYSICAL OBSERVABLES

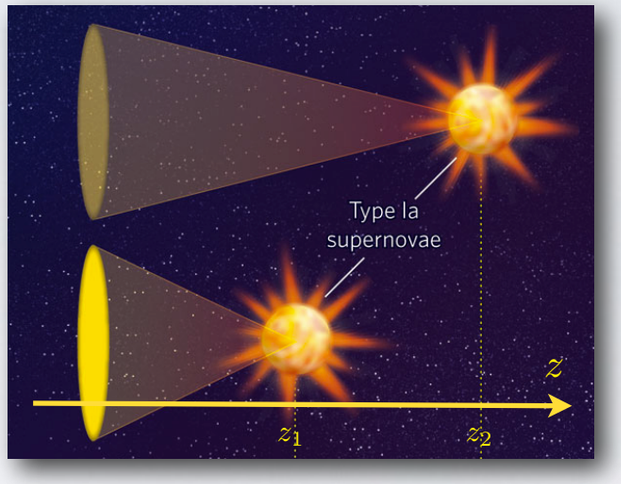
redshift & scale factor

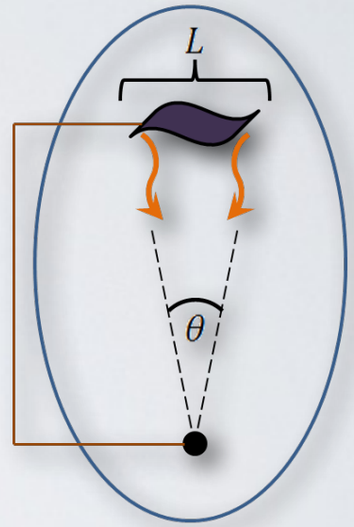
$$a = \frac{1}{1+z}$$

$$z = \Delta\lambda/\lambda$$

$D_L(z)$ Luminosity distance: **standard candle**

1. supernovae (SNe)



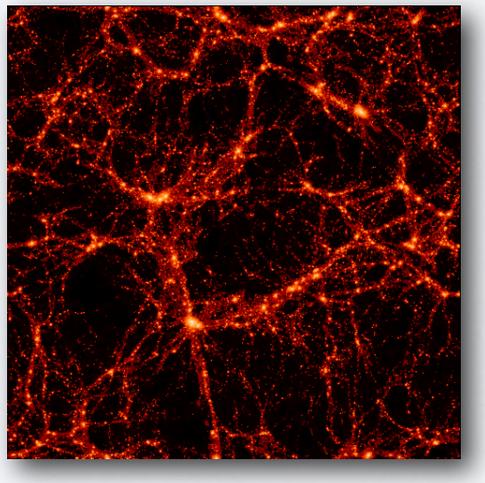


$D_A(z)$ Angular diameter distance: **standard ruler**

2. baryon acoustic oscillations (BAO) , cosmic microwave background (CMB)
3. weak gravitational lensing (WL)
4. galaxy cluster abundance (Clusters)

$G(\rho, z)$ Growth of structure: **galaxy clustering**

3. weak gravitational lensing (WL)
4. galaxy cluster abundance (Clusters)



DES is sensitive to Dark Energy via 4 probes.

Planck results are used in DES analyses.

BASIC OBSERVABLES

Positions on the sky (RA, Dec)

correct for distortions

Fluxes (counts/pix/sec)

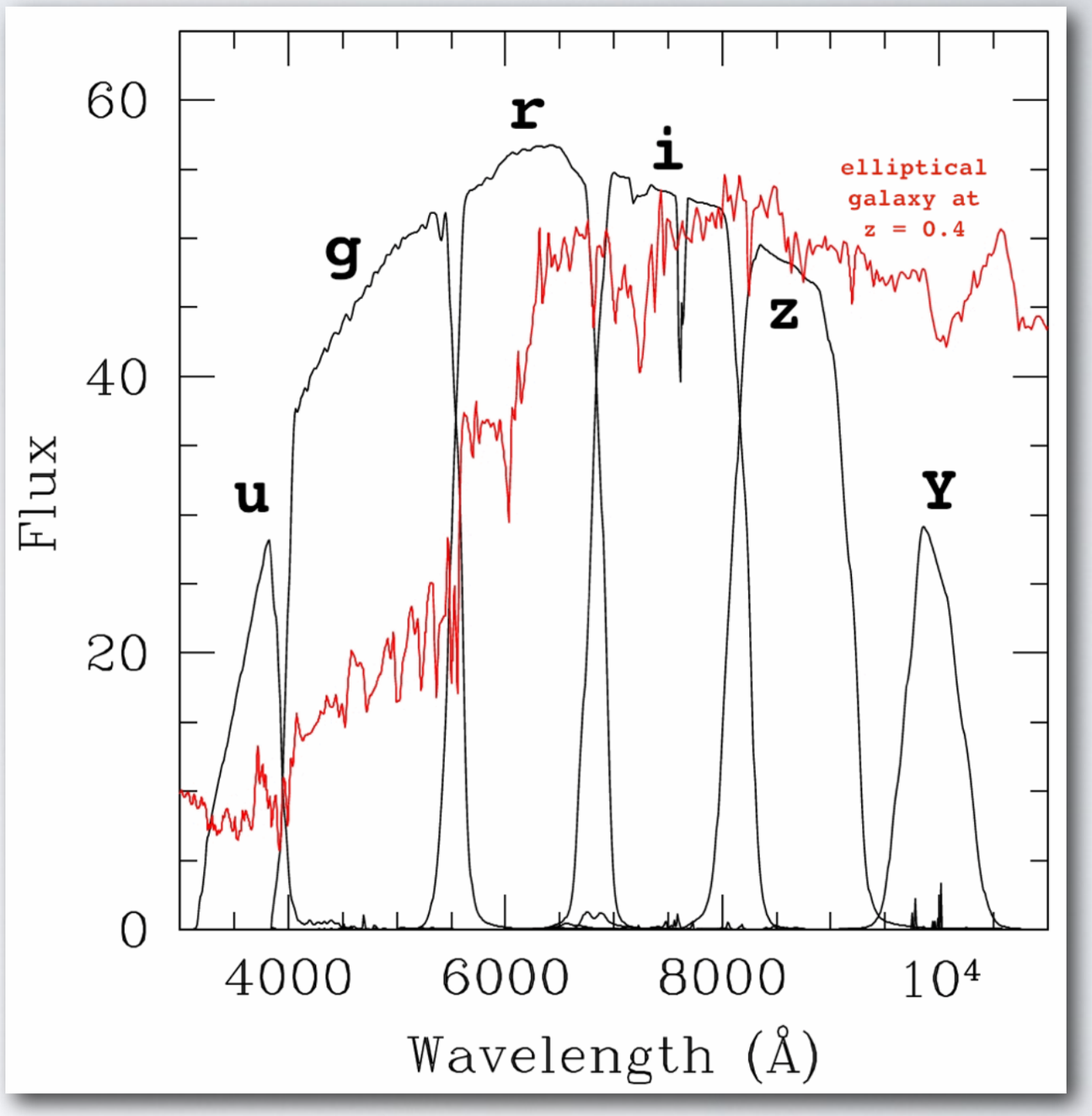
take **spectra**, or images in **broadband filters**

calibrate from instrumental units to physical units

compute (photometric) redshifts

Shapes (ellipticity, size)

correct for distortions



A ROADMAP

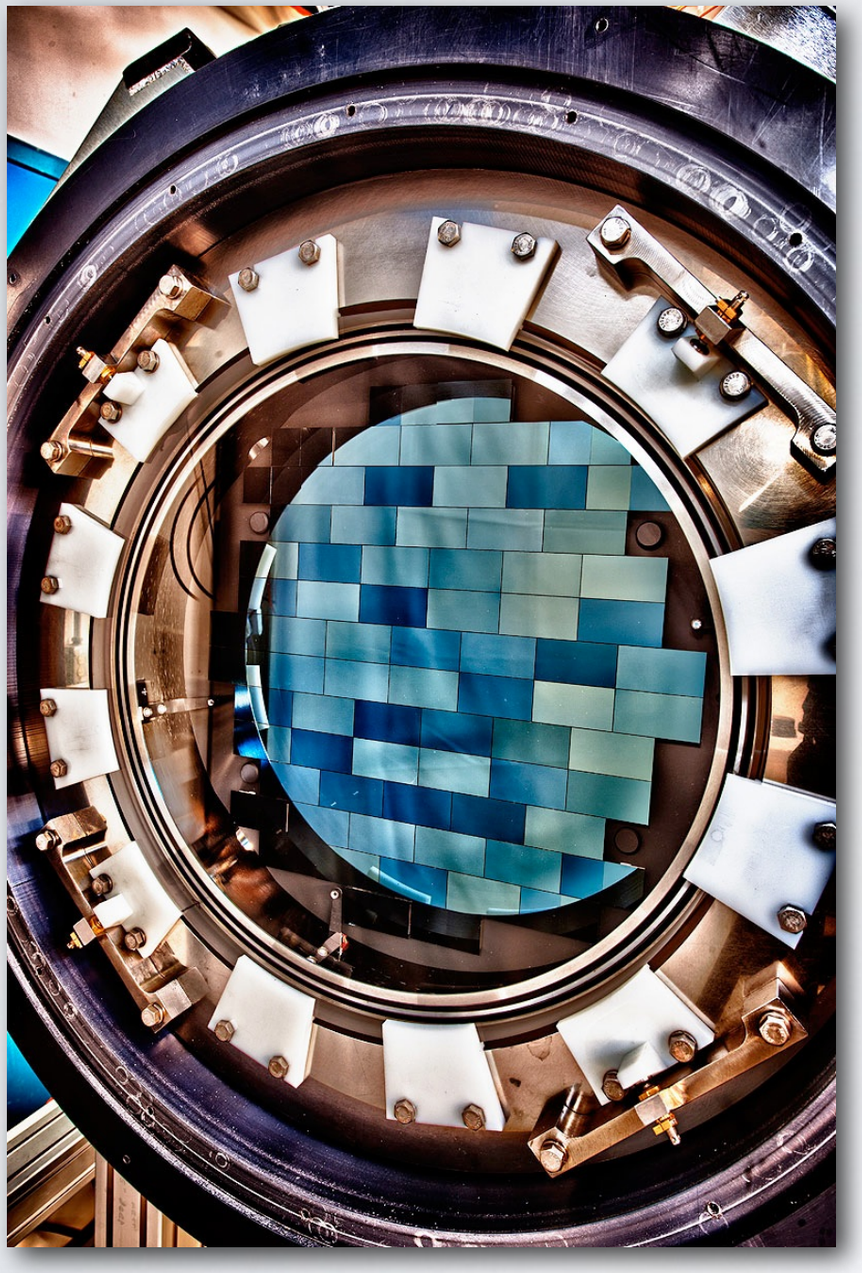
Current and planned experiments:

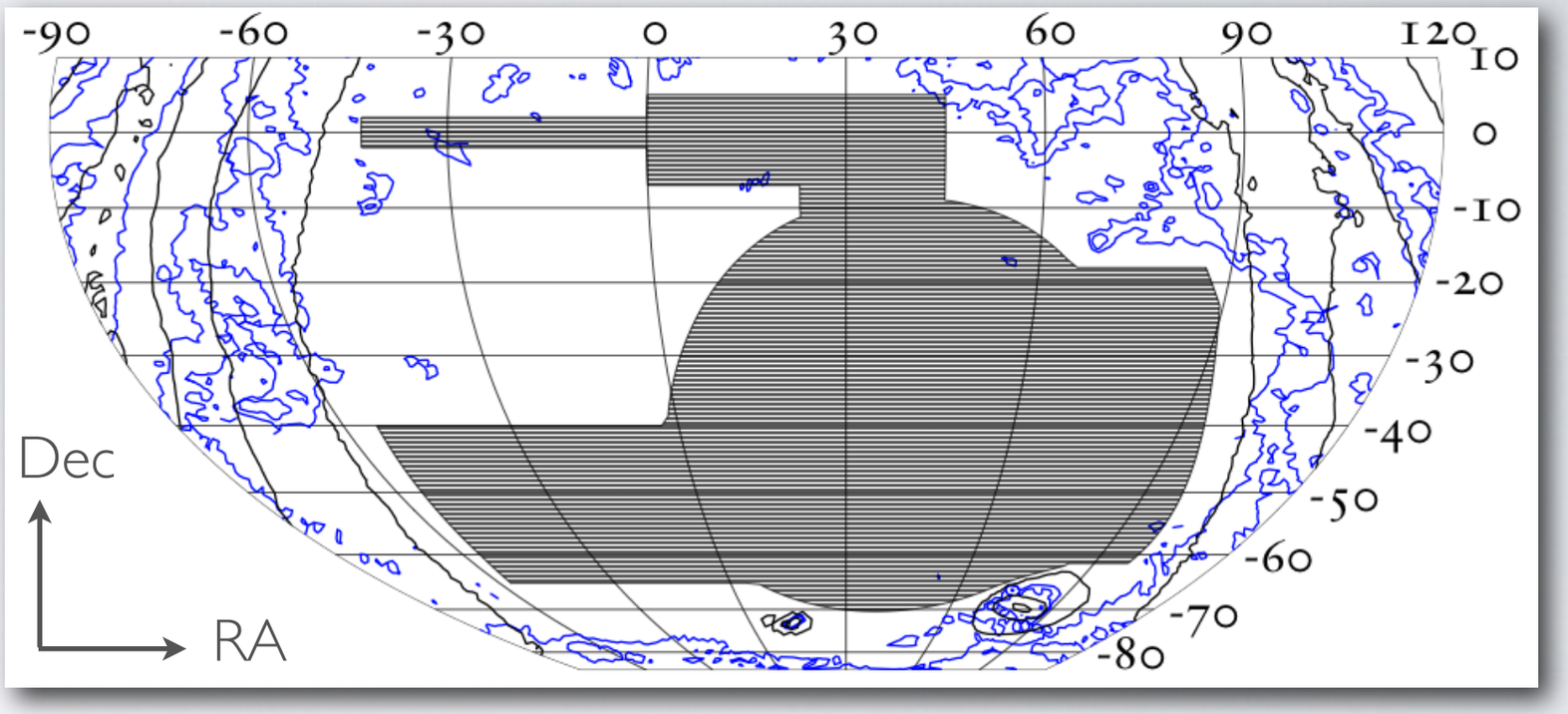
Dark Energy Survey (DES): 2012–18 [S]
Dark Energy Spectroscopic Instrument (DESI): 2019–22 [N]
Large Scale Synoptic Survey Telescope (LSST): 2022+ [S]

Opportunities for future projects:

Next generation experiment: spectroscopic survey [S]
New technologies: MKIDS (spectra + imaging)
New probes: Cosmic Sirens

DARK ENERGY SURVEY





DEcam

3 sq deg FOV, **570 Mpix** optical CCD camera

Facility instrument at **CTIO Blanco 4-m telescope in Chile**

First light: Sep 2012

Survey

5000 sq deg grizY to **24th mag** overlaping with SPT and VISTA

30 sq deg SNe survey
0.9 arcseconds seeing

525 nights: 2013-2018

DES SITE: CERRO TOLOLO, CHILE

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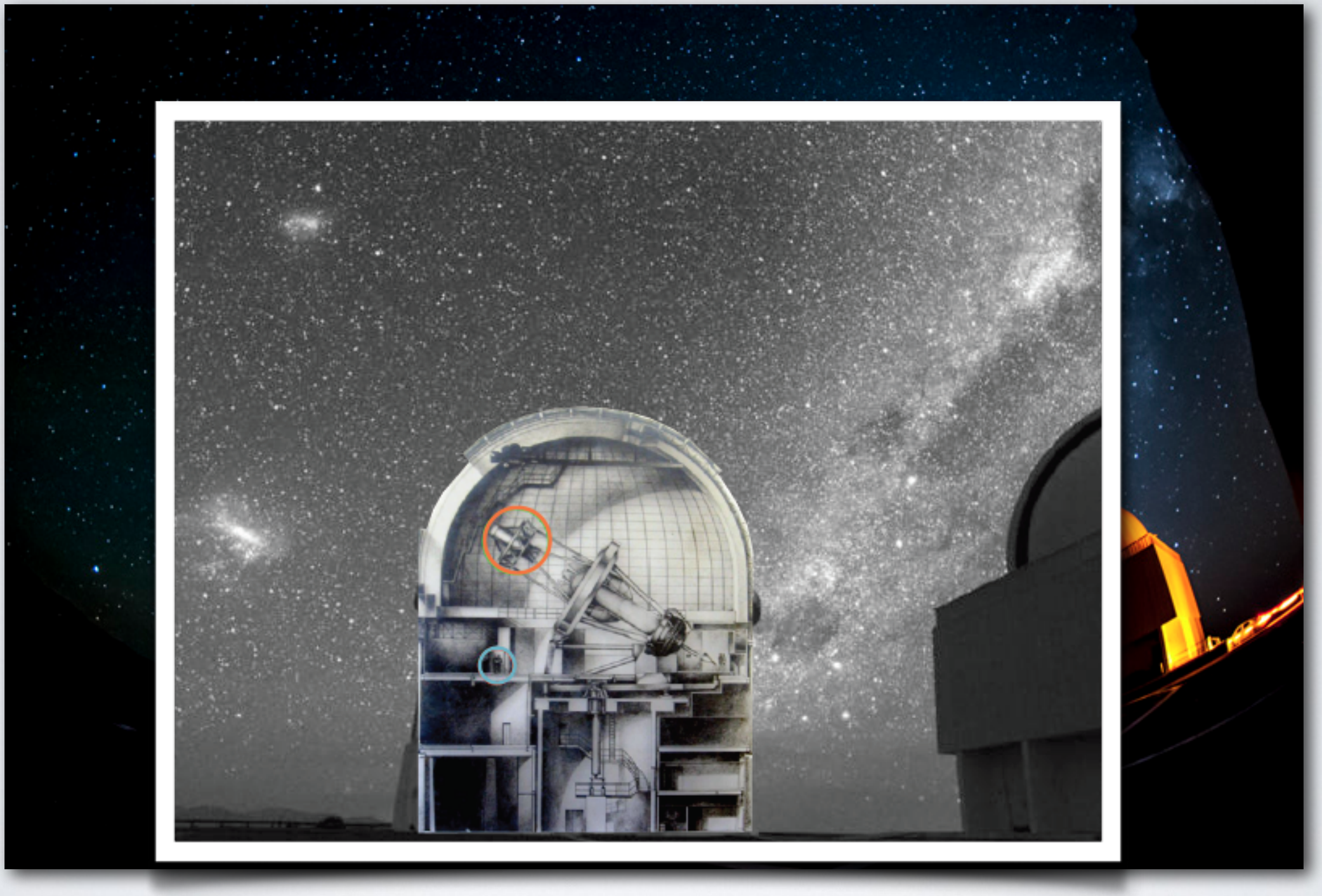
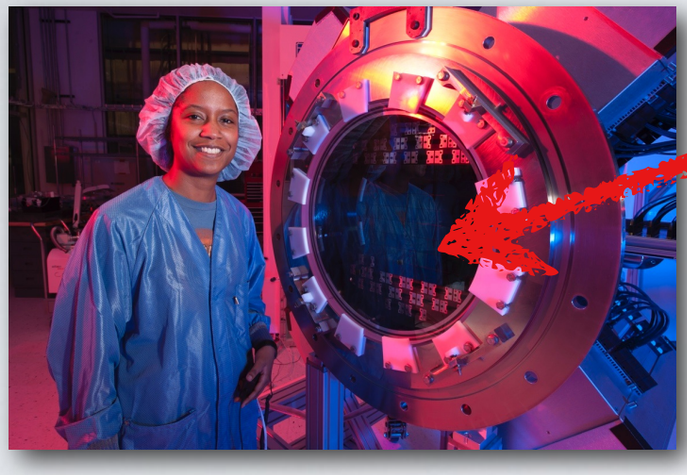
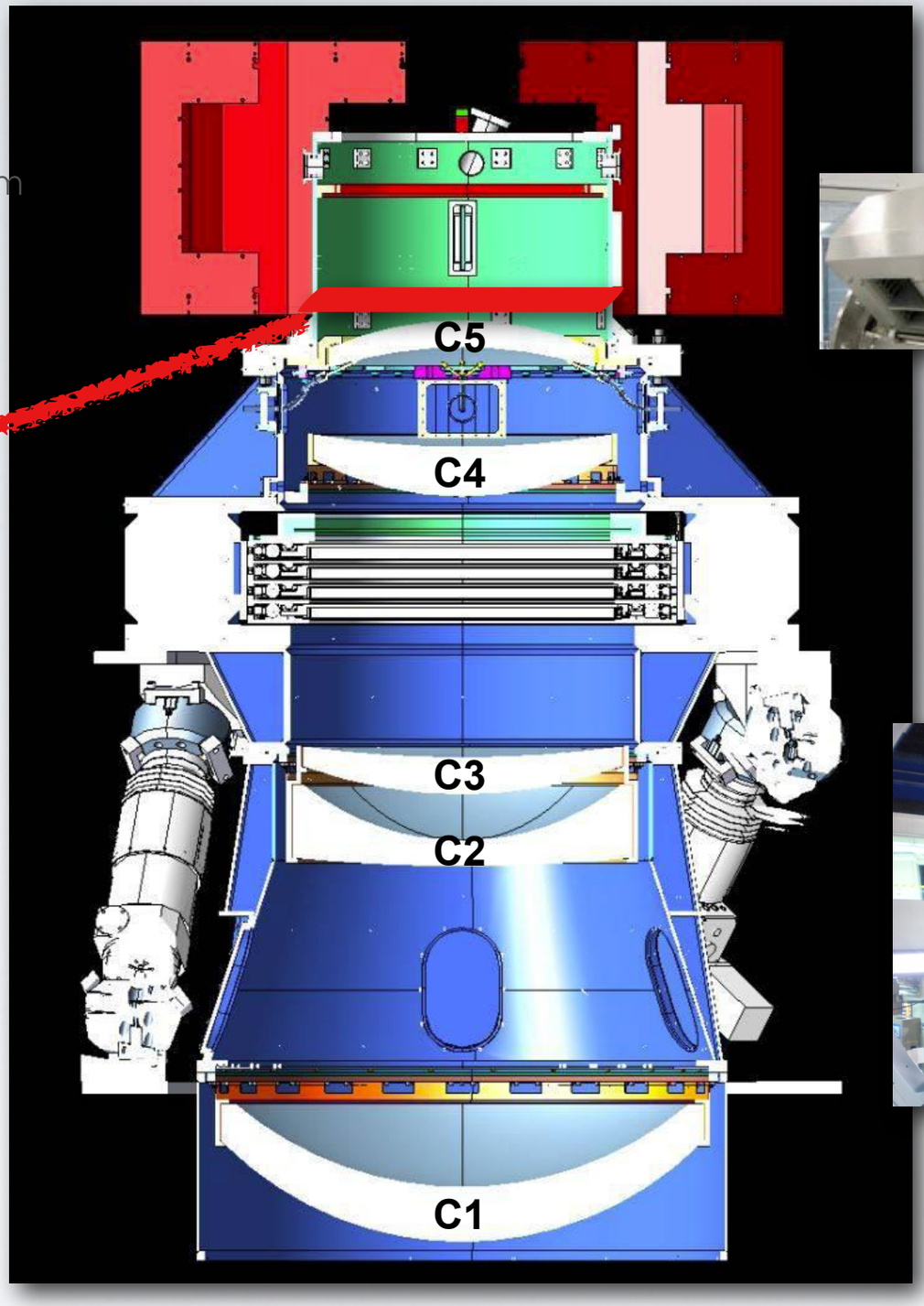


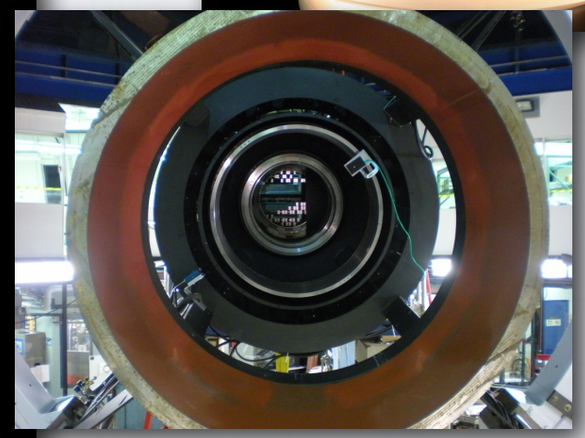
DECAM

CCD focal plane is housed in a vacuum vessel (**the imager**)





CCD readout electronic crates are actively cooled to eliminate thermal plumes



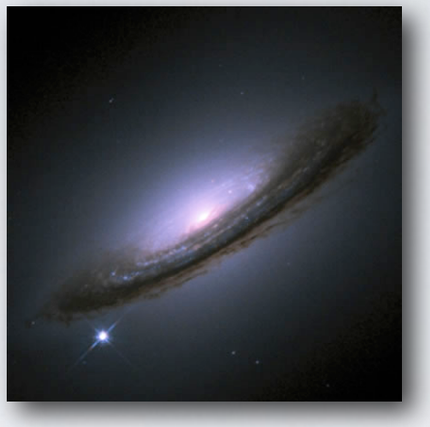
Filter changer with 8 filter capacity and **shutter** fit between lenses **C3** and **C4**

Hexapod provides focus and lateral alignment capability for the corrector-imager system

Barrel supports the **5 lenses** and imager

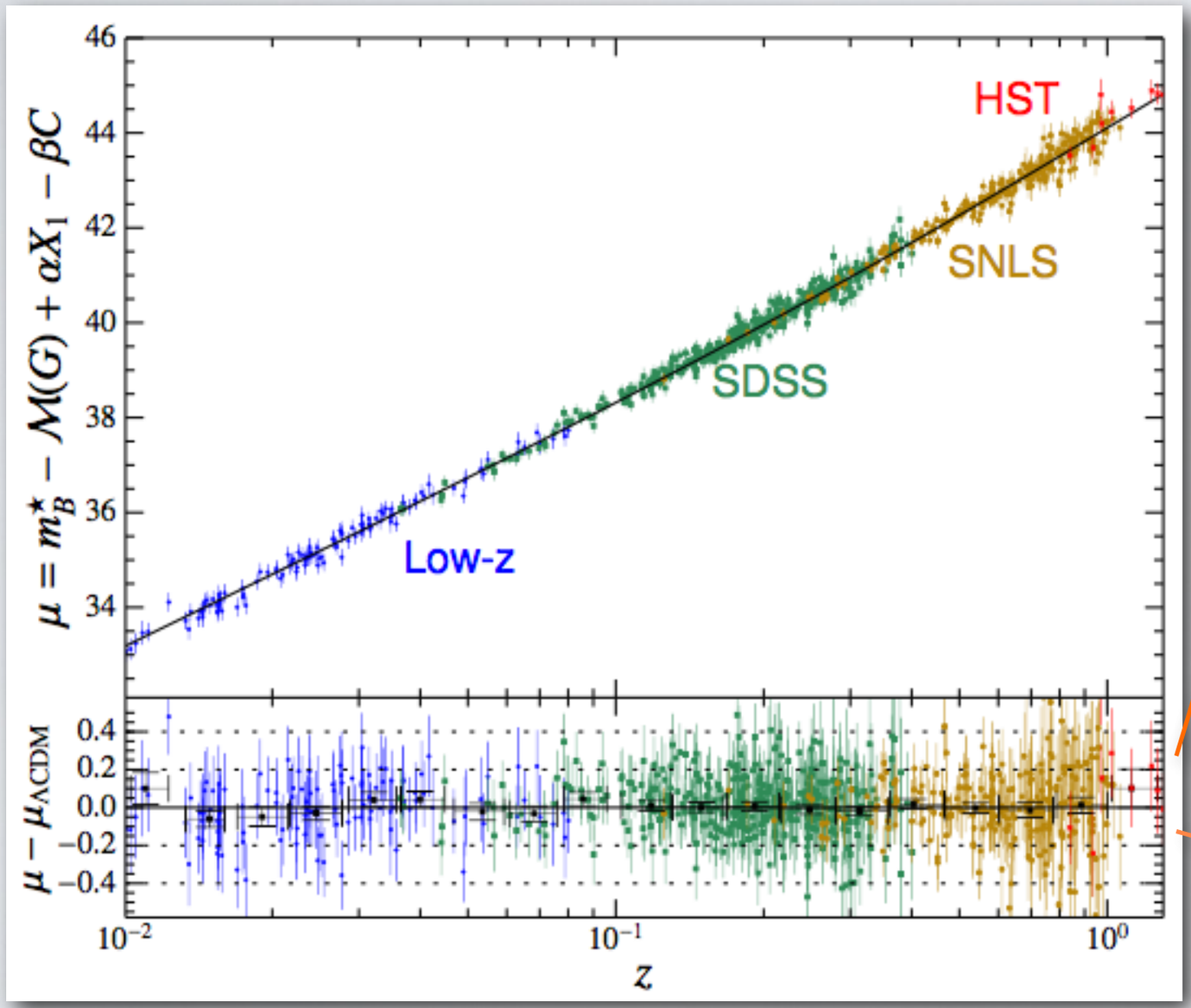
LN2 is pumped from the telescope floor to a heat exchanger in the imager: cools the CCDs to -100 C

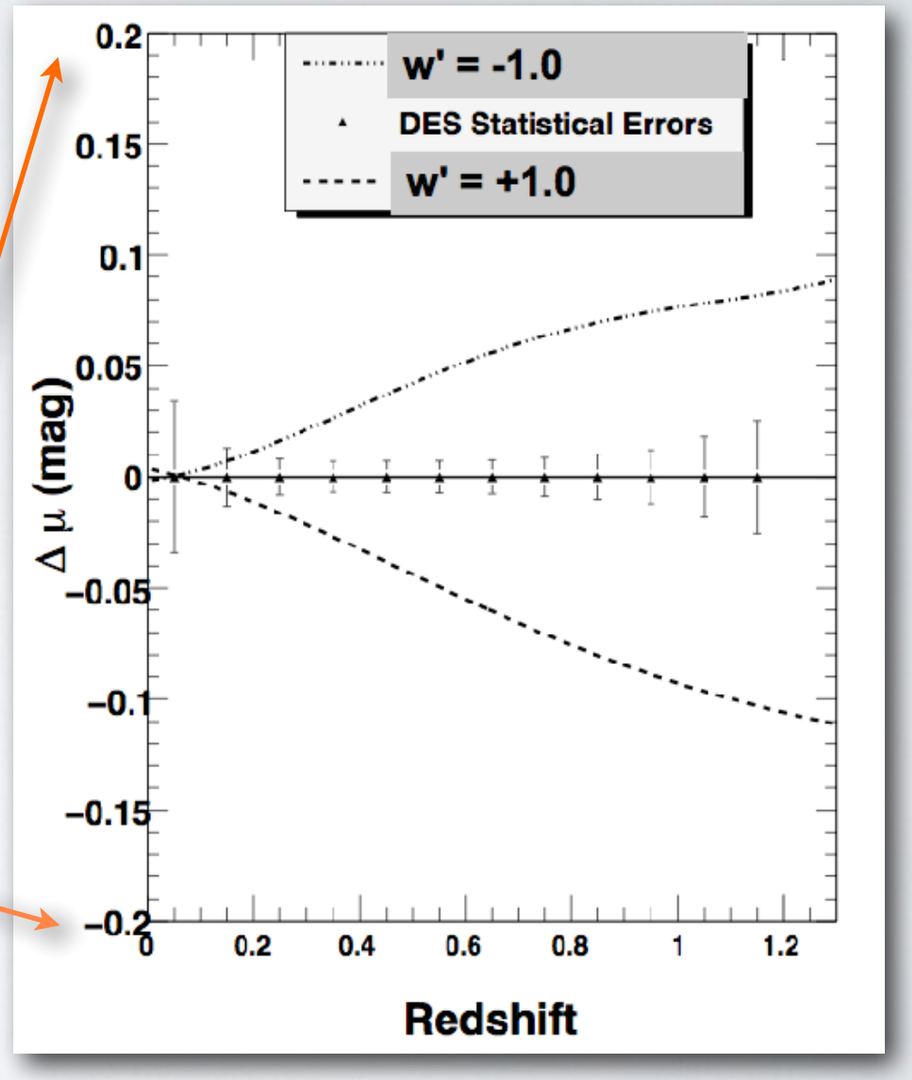
DES SCIENCE: SN



DES expected sensitivity, based on simulations.
3500 photometrically selected Type Ia SNe up to z = 1.2 in 30 sq-deg.

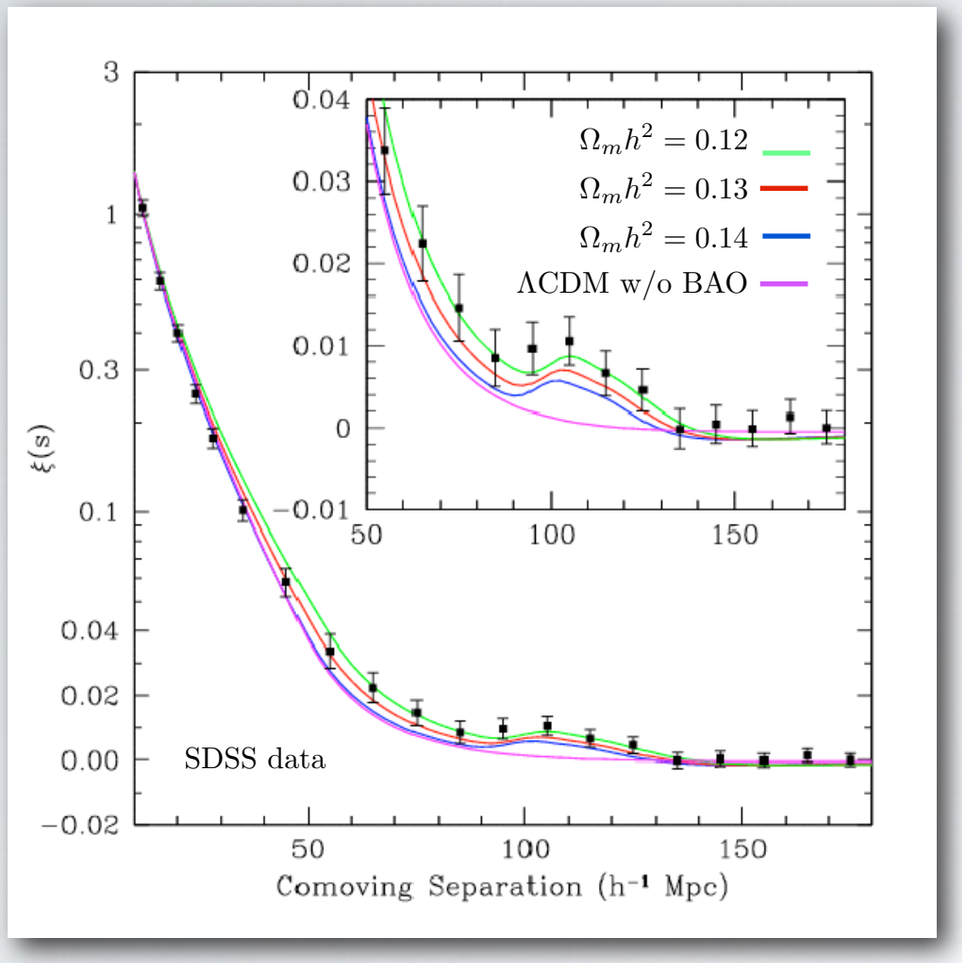
Joint SDSS-II and SNLS results: Hubble diagram using 740 spectroscopically selected SNe (Betoule et al. 2014).



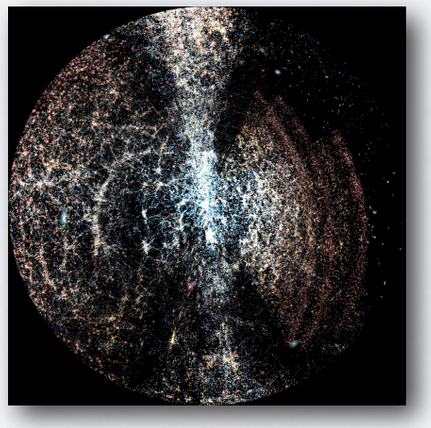


DES SCIENCE: BAO

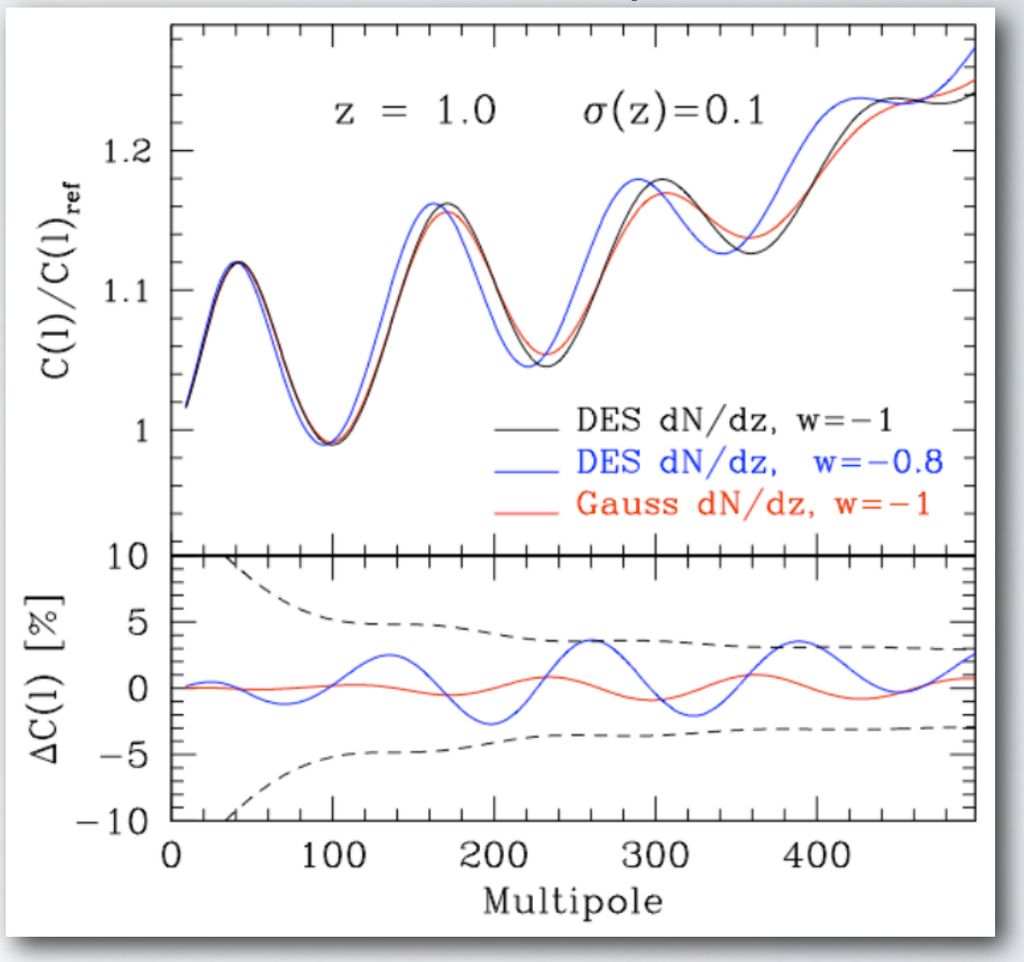
real space



SDSS: mean spectroscopic redshift ~ 0.35. (Eisenstein et al. 2005)

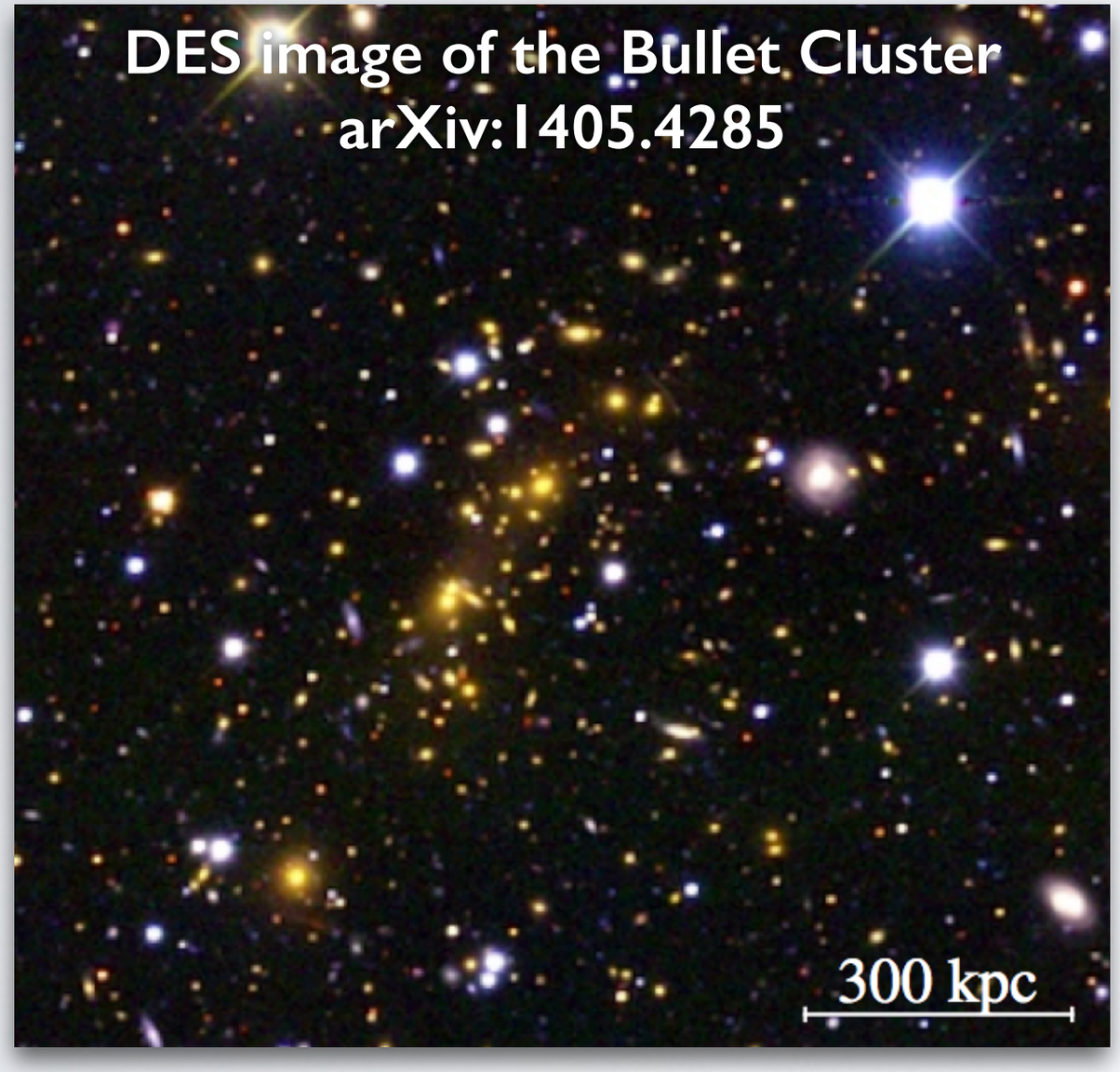


Fourier space



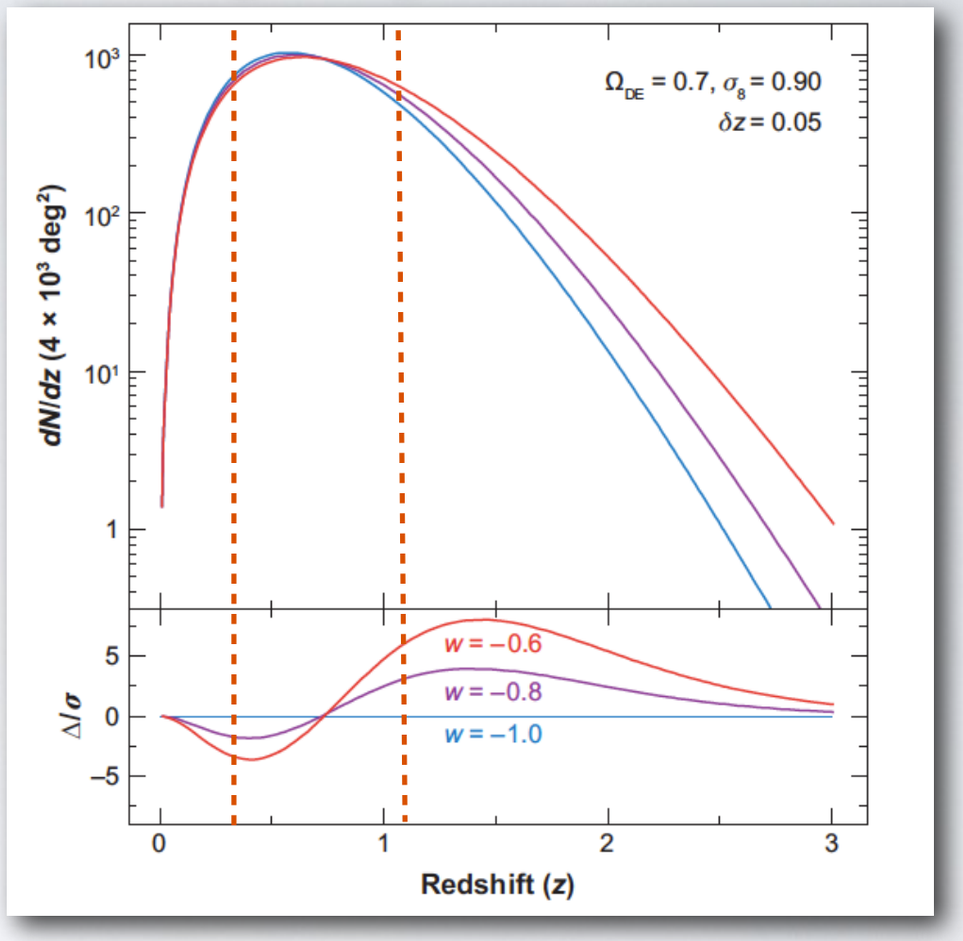
DES expected sensitivity. Can measure w by probing deeper and slicing in z.

DES SCIENCE: CLUSTERS



SDSS sample:
up to z ~ 0.3

DES sample:
up to z ~ 1

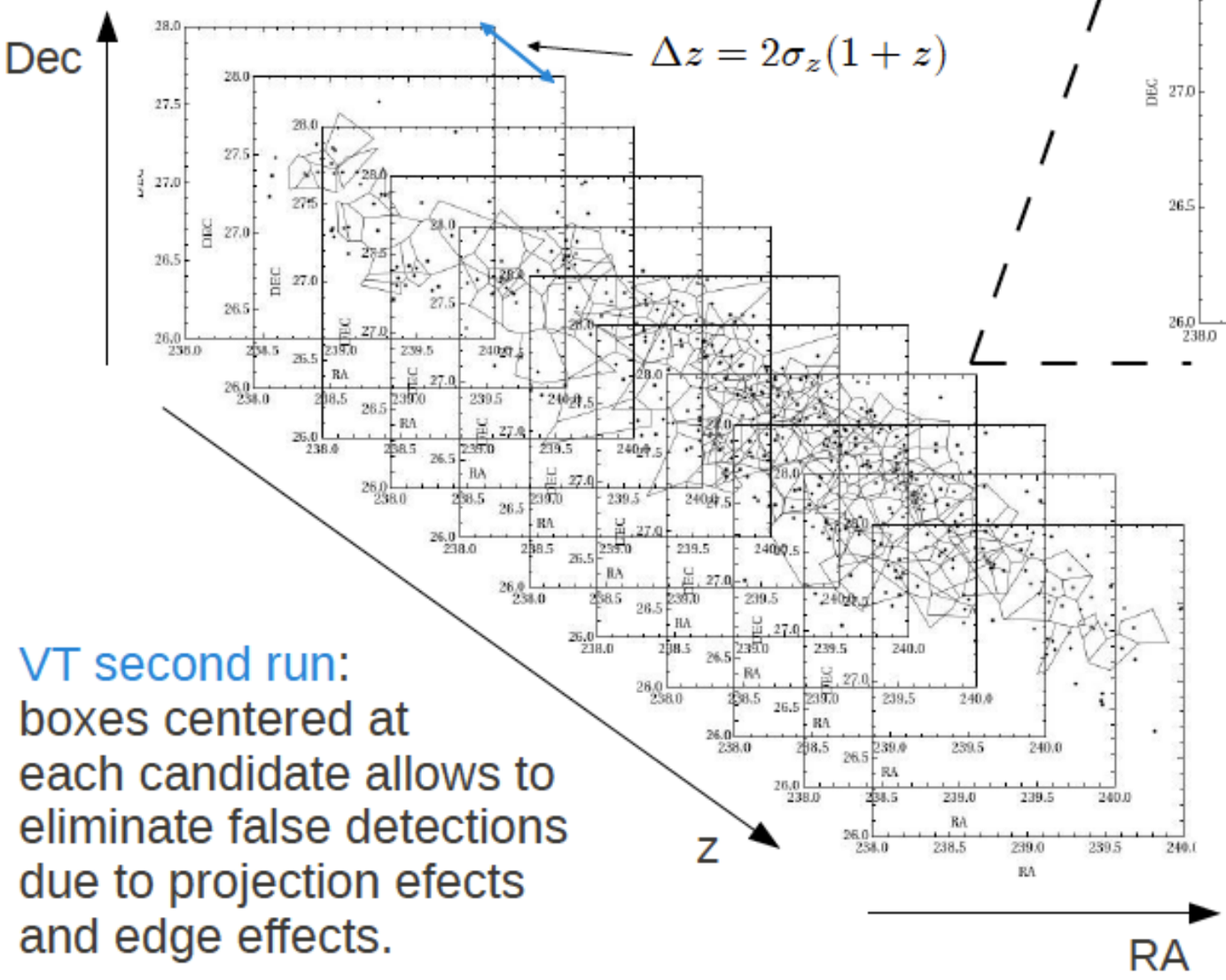


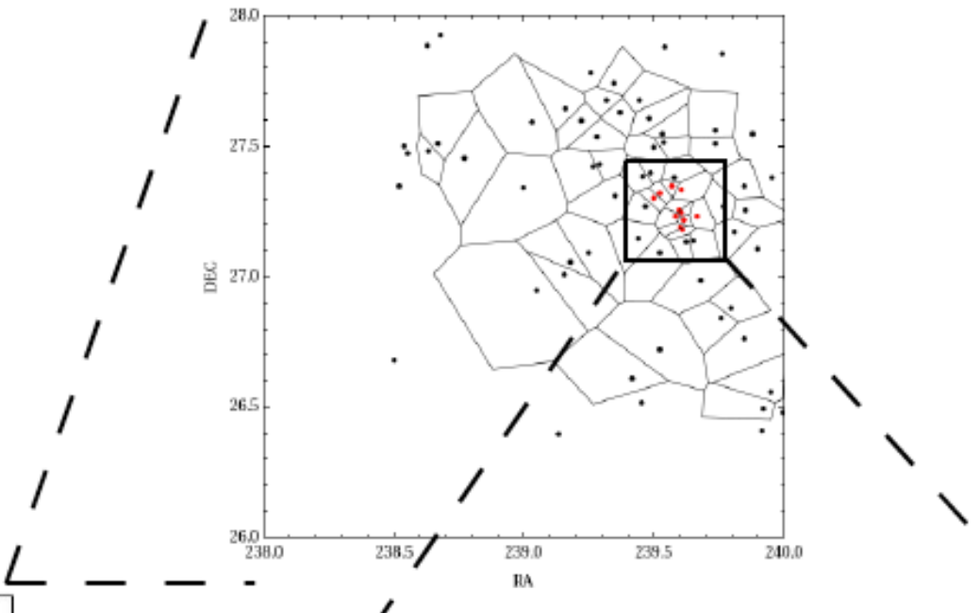
Number of clusters above $10^{14.5}$ solar masses as a function of z, for a 4000 sq-deg survey in 3 different cosmologies.

CLUSTER FINDER

VT cluster finder in 2+1D

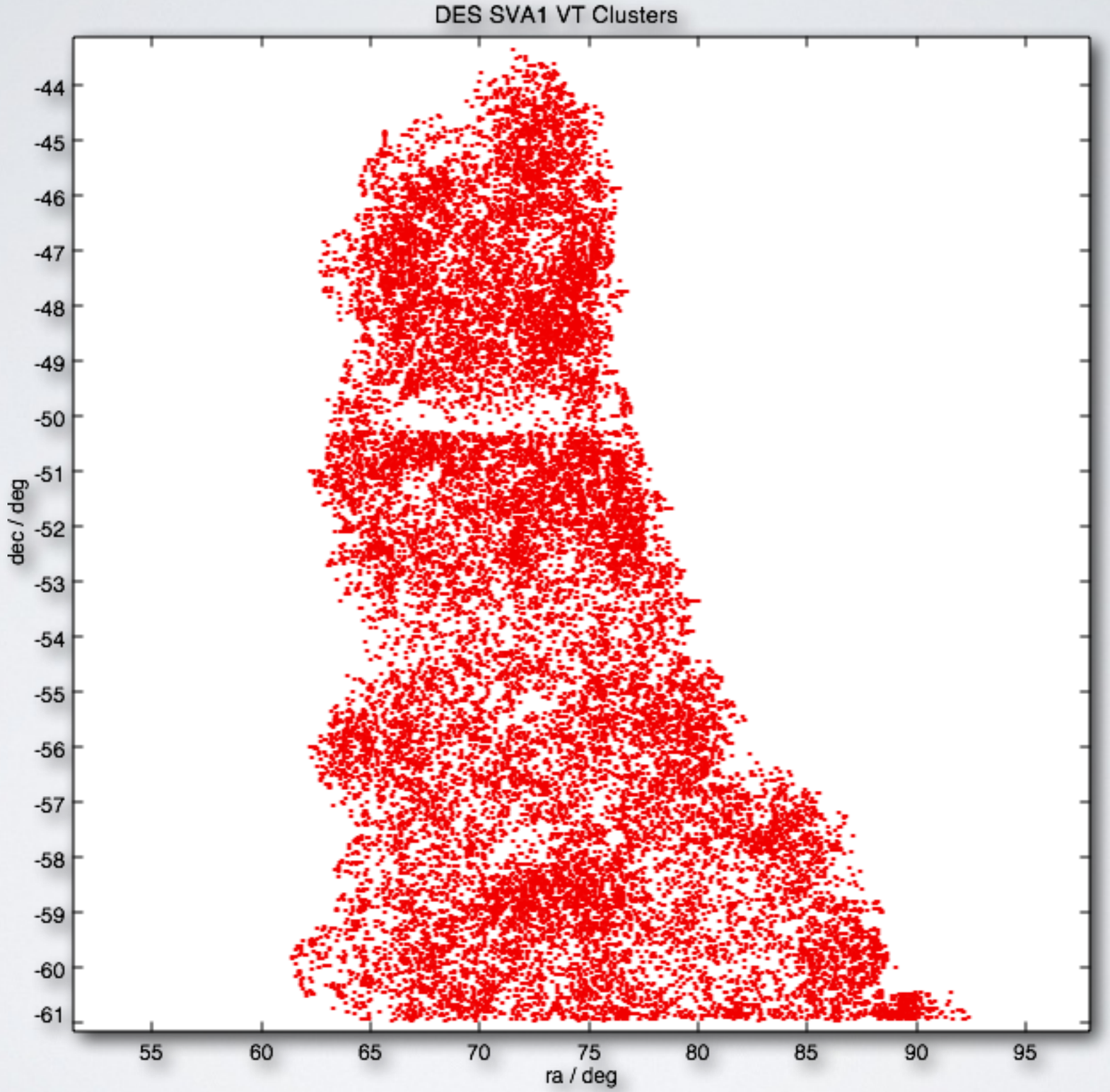
VT first run: cluster candidates detected in photo-z shells



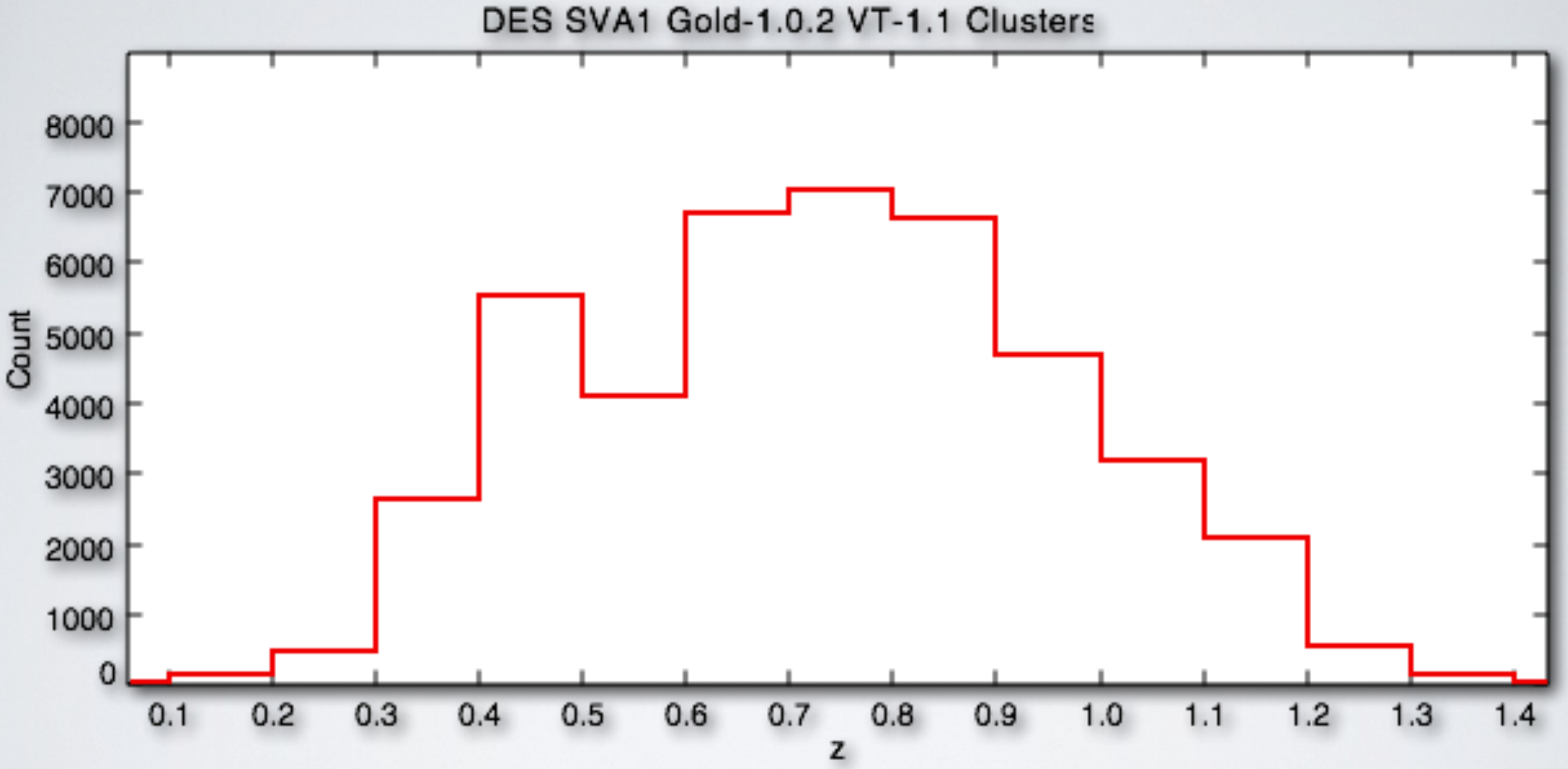


VT second run: boxes centered at each candidate allows to eliminate false detections due to projection efects and edge effects.

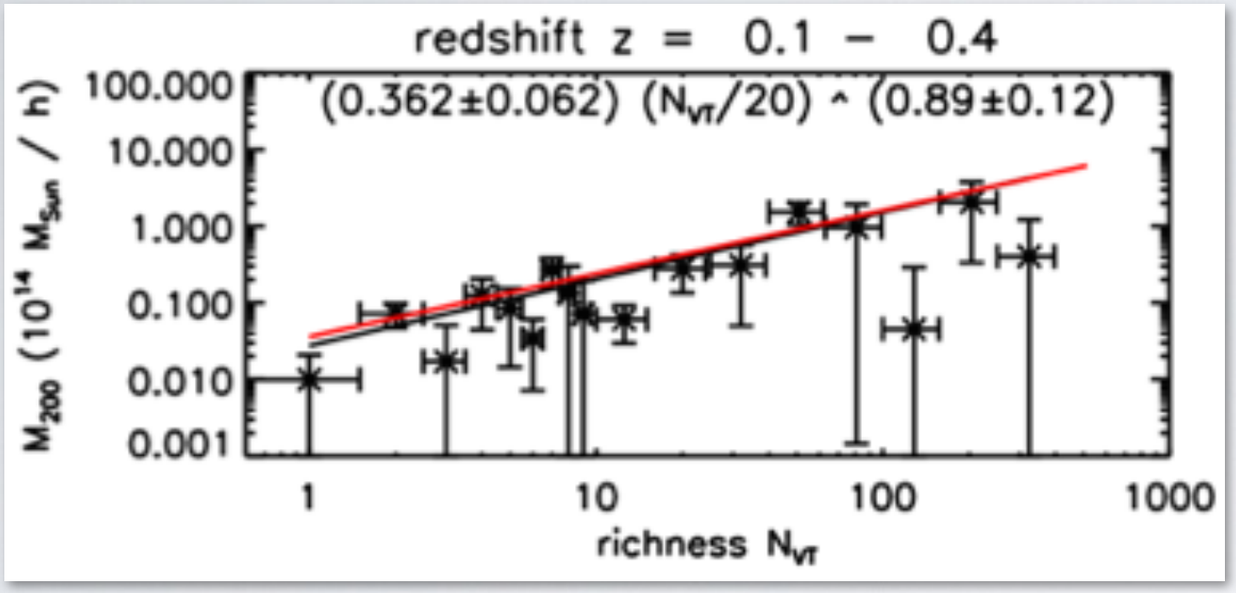
DES SV: VT CLUSTERS



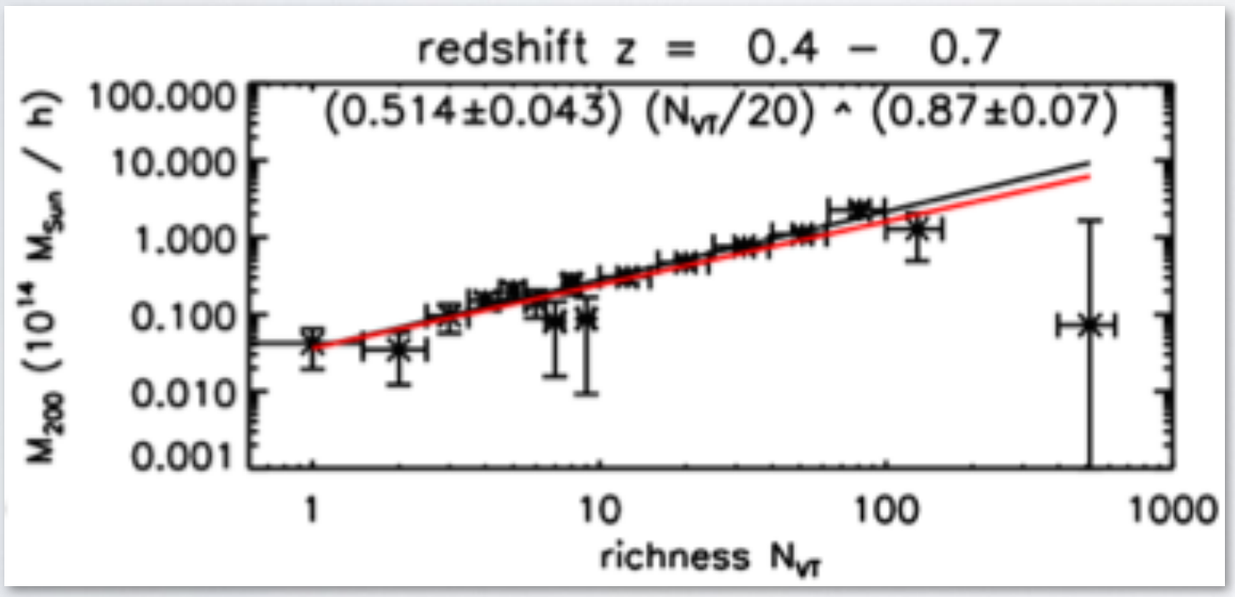
DES SV: VT CLUSTERS

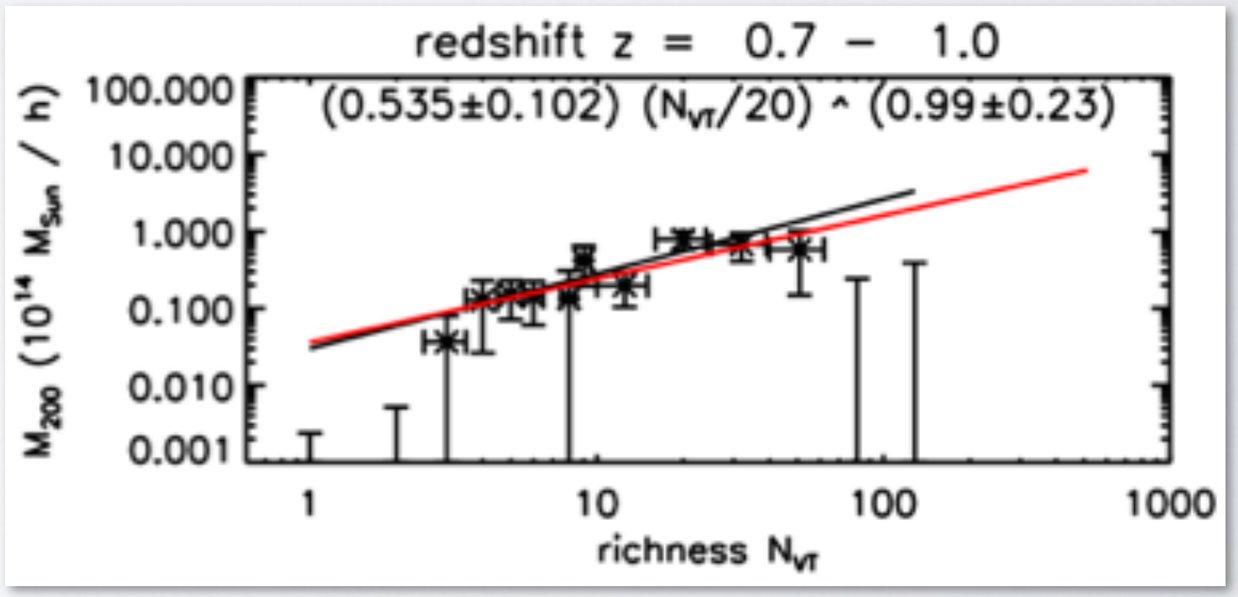


DES SV: VT CLUSTERS

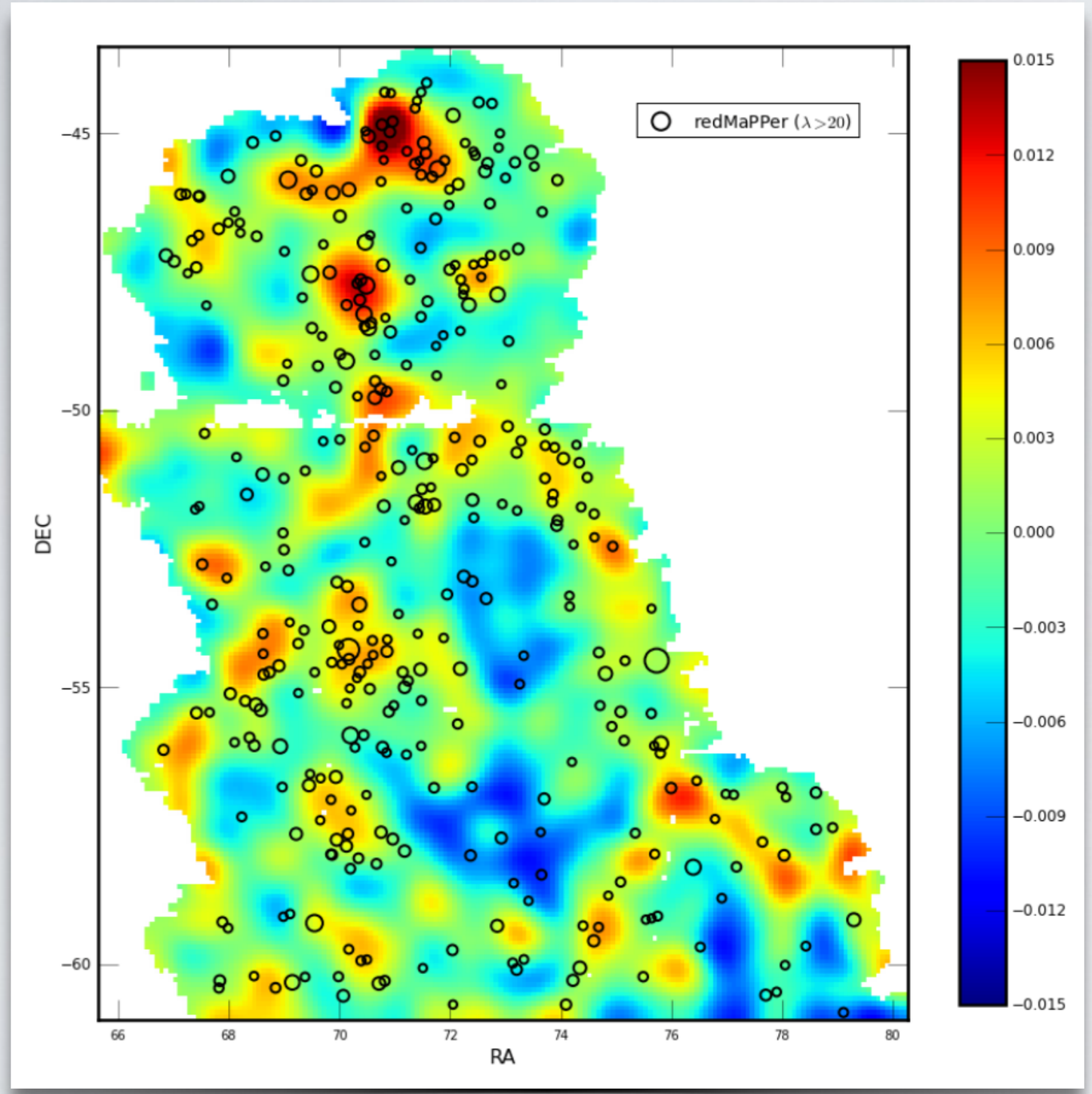


Weak lensing richness–mass calibration for DES VT clusters





DES SCIENCE: WL

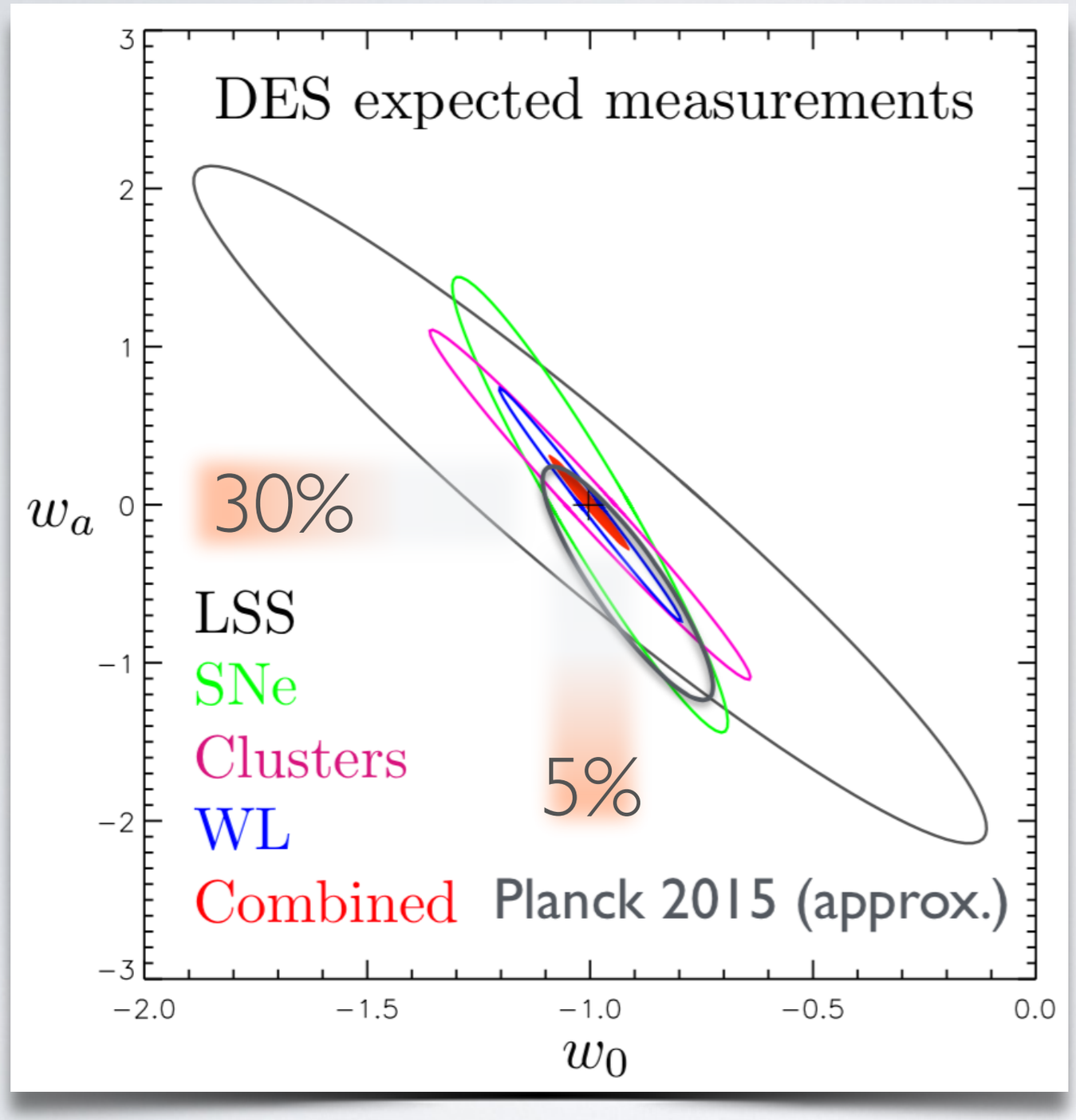


arXiv:1504.03002

Map of projected mass
$z < 0.5$

See Rosenfeld's talk for more related DES results!

DES PROJECTIONS



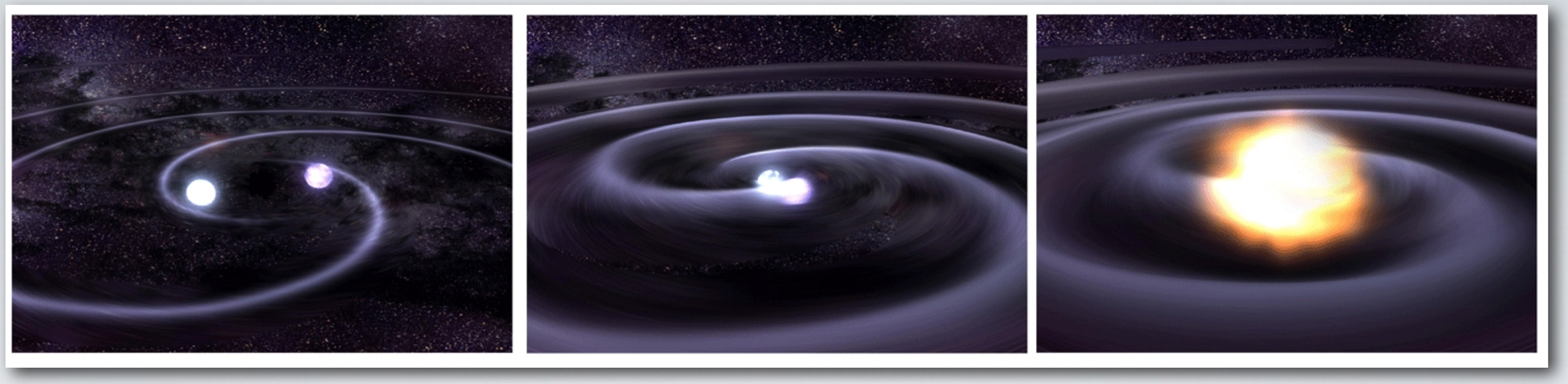
5000 deg^2, 0.9" seeing,
24th mag (redshift~1.4)

300M galaxies, shapes,
100K clusters, 4K SNe

4 combined probes

3-5x improved Dark Energy measurement

A NEW DARK ENERGY PROBE ?



Coordinated detection of electromagnetic and gravitational radiation from mergers of compact objects (neutron stars, black holes).

- Search for optical counterpart of events detected by the advanced LIGO/VIRGO detectors

Standard Cosmic Sirens: Hubble diagram with distance from GW signal, redshift from optical data.

DES-GW PROGRAM

GW trigger

time stamp
sky region
distance

DECam/DES search system

build template image
schedule observations
take new images
perform image subtraction
detect, model counterpart

- Near term goal: background rate studies, preparations for searches starting in Sep 14, 2015
- Long term goal: a large scale program for 2016 and beyond
  - DECam — available throughout the LIGO-Virgo ramp up
  - LSST — to start in ~2022, will be faster than DECam
  - Synergy with future neutrino experiments — ToF experiment including neutrinos?

DESI

Instrument

3 sq deg FOV, **5000 fiber** optical CCD spectrograph

Facility instrument at **KPNO**
Mayall 4-m telescope in Arizona

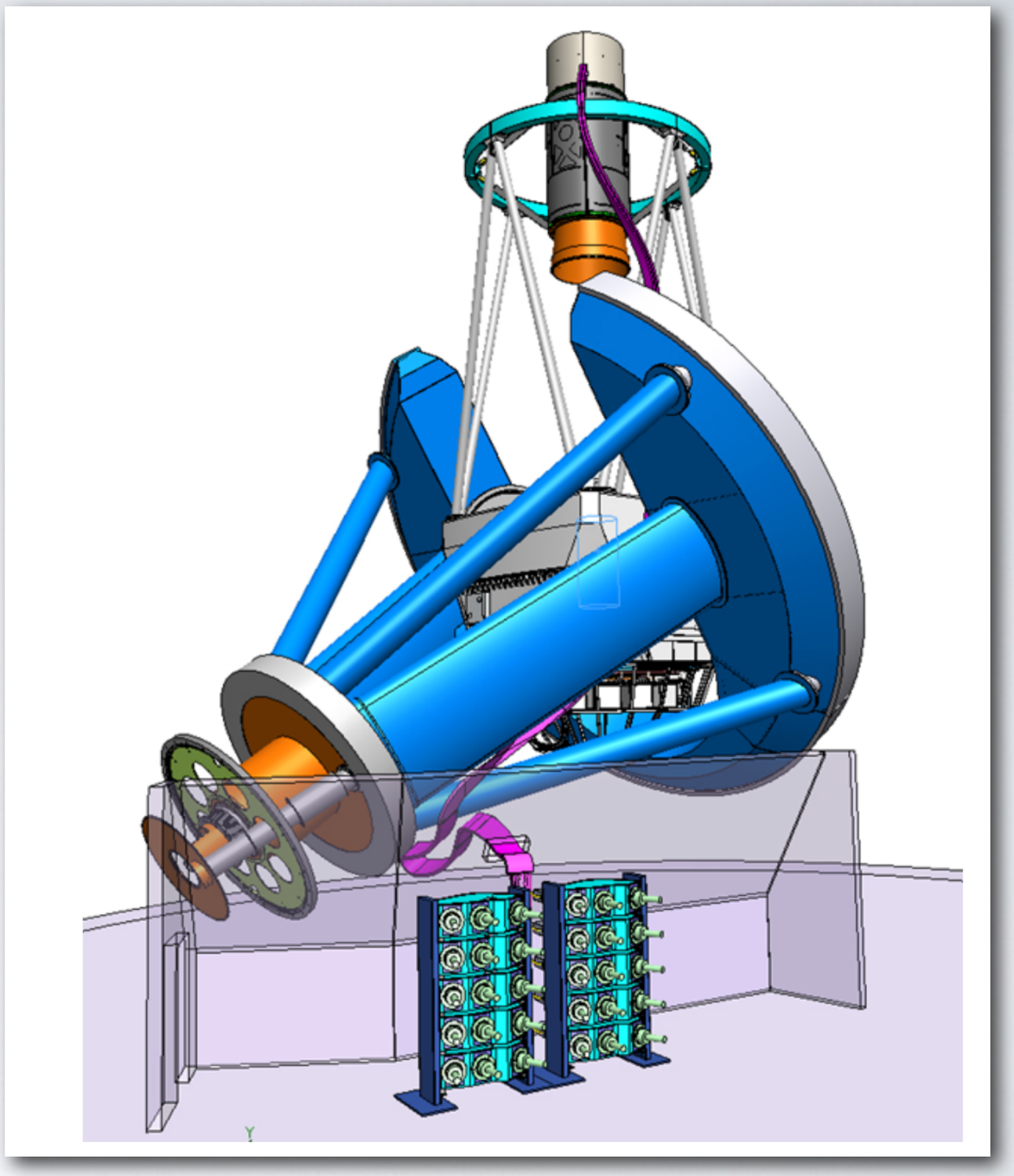
First light: 2018

Survey

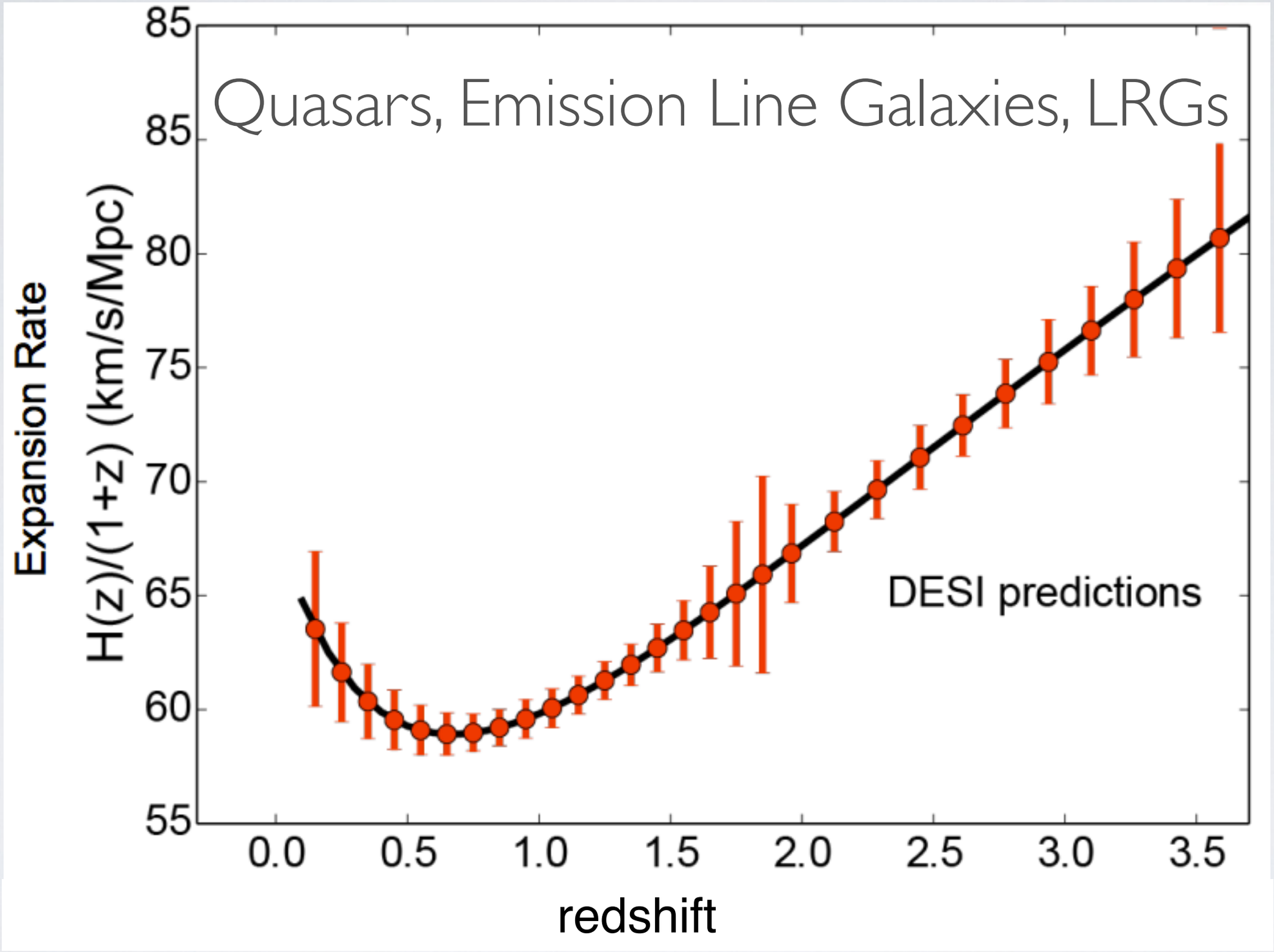
14000 sq deg
35M galaxies to redshift ~3.5
time scale: 2019-2022

Science

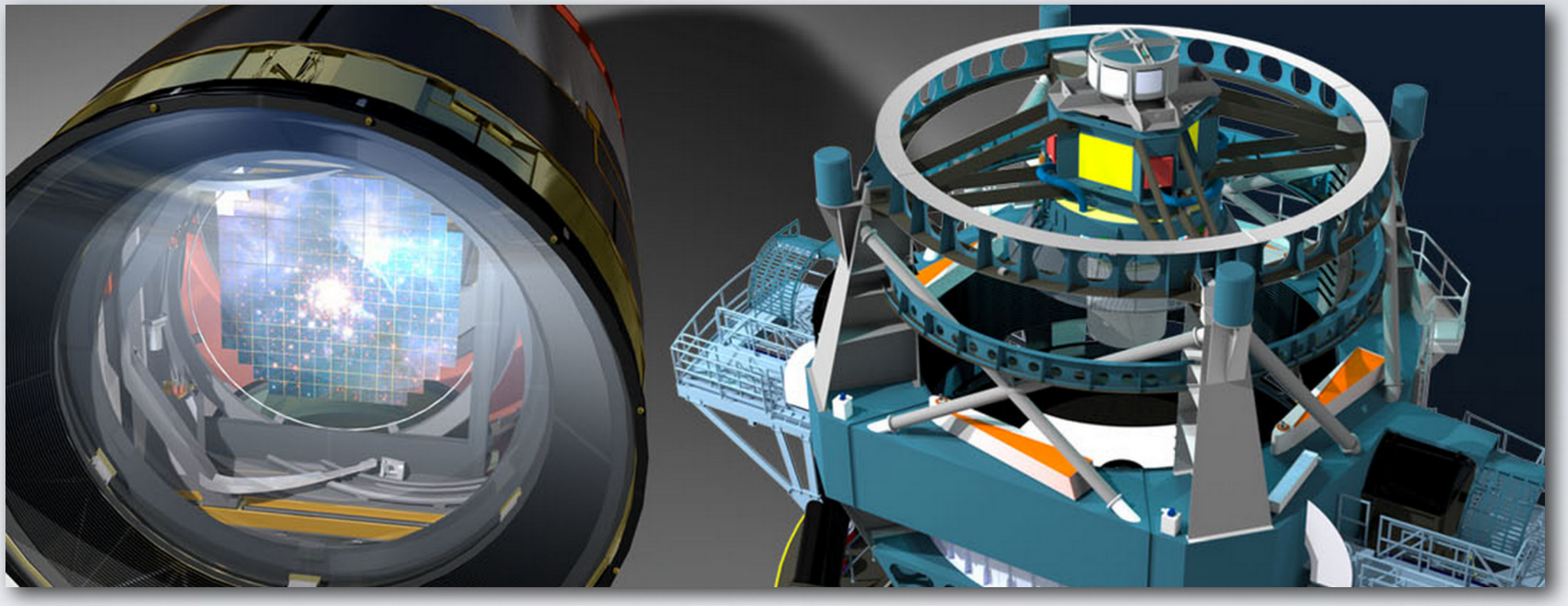
Main Dark Energy probe: BAO
Also explores other clustering-related probes (**RSD**, **clusters**, etc.)



DESI PROJECTIONS: BAO



LSST



Telescope/Camera

9 sq deg FOV, **3.2 Gpix** optical CCD camera

New 8 meter telescope at **Cerro Pachon in Chile**

First light: 2022

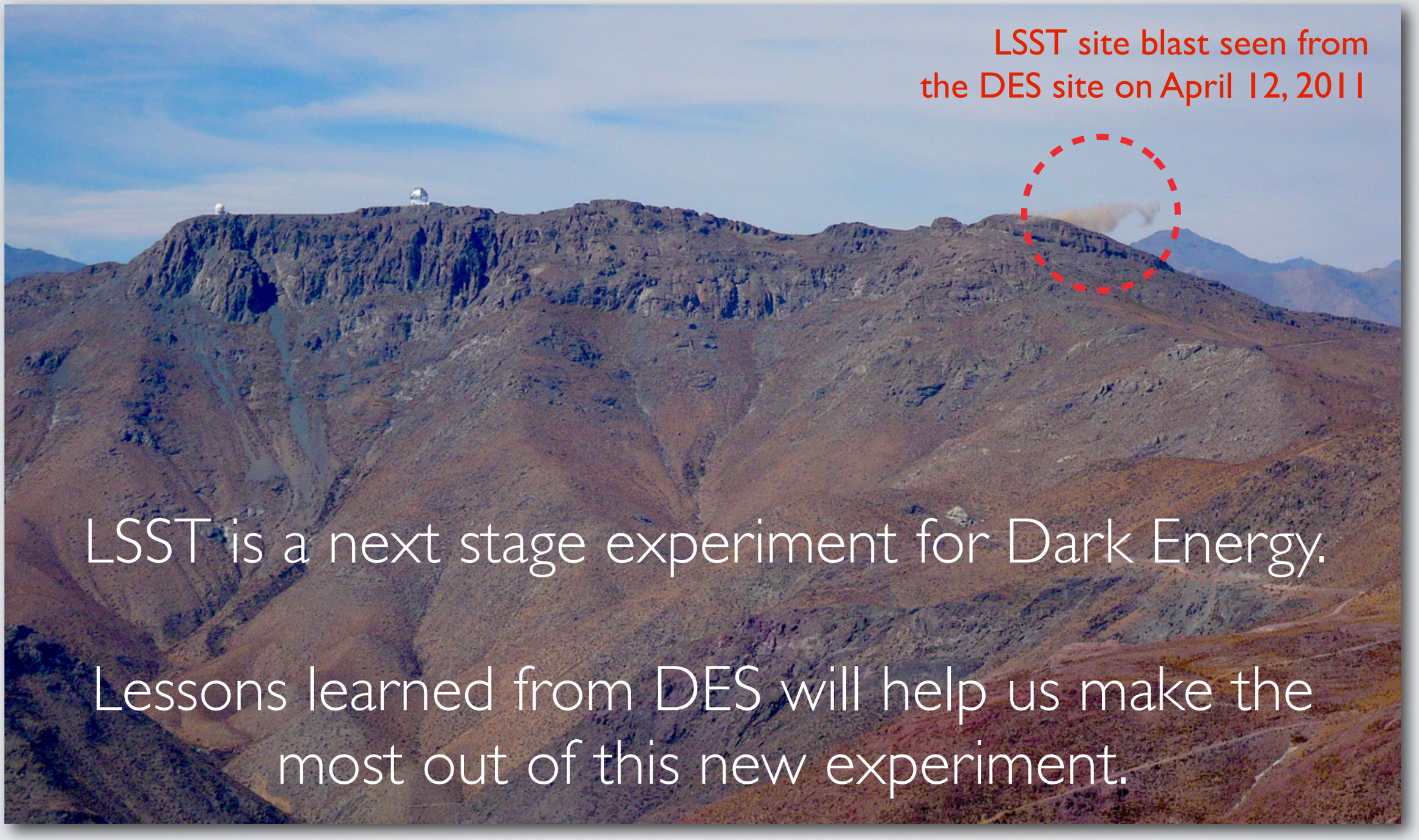
Survey

Map the entire visible sky in just a few nights.

37 billion galaxies and stars
Filters: ugrizY

All nights for 10 years.

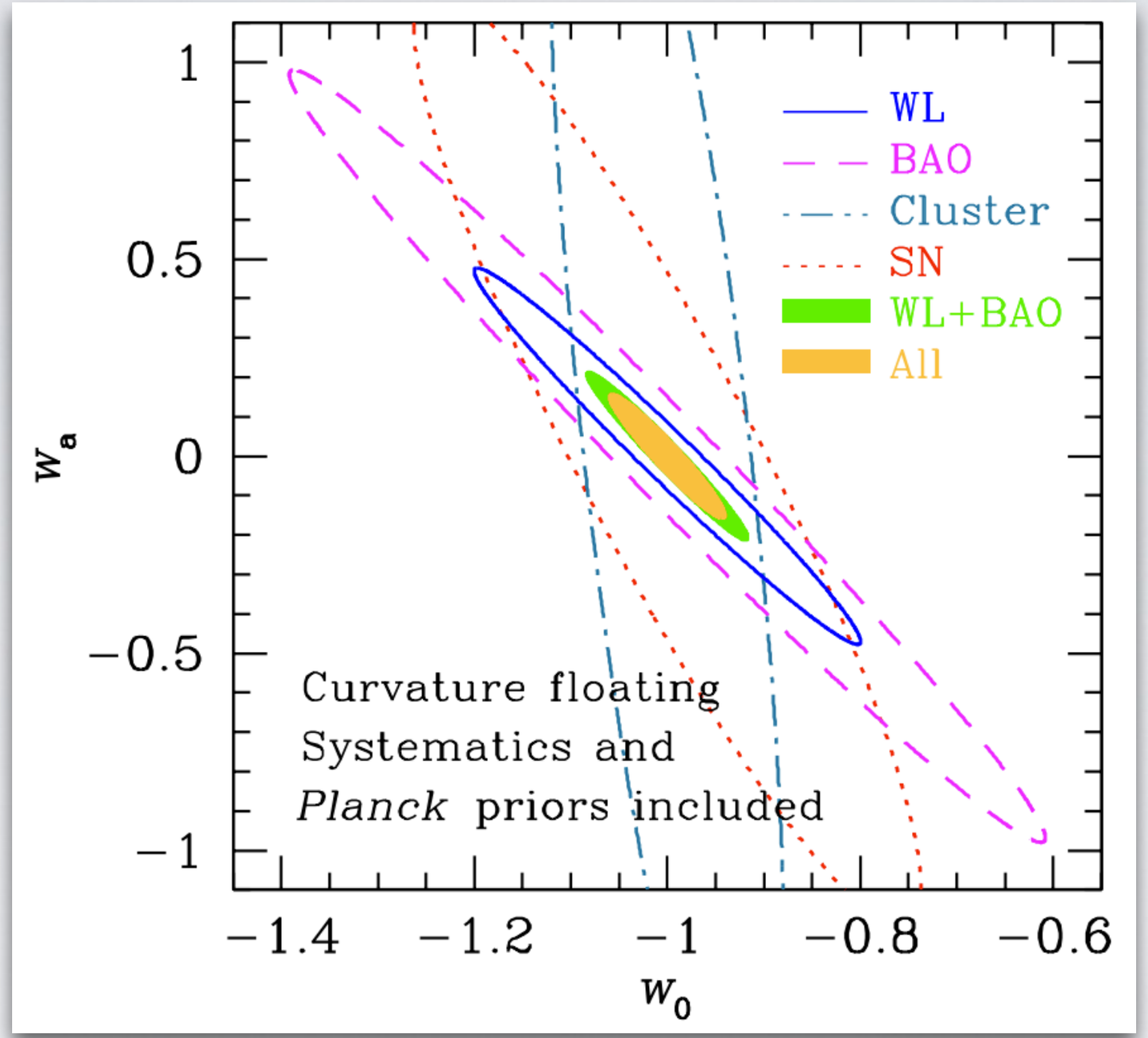
FROM DES TO LSST



LSST is a next stage experiment for Dark Energy.

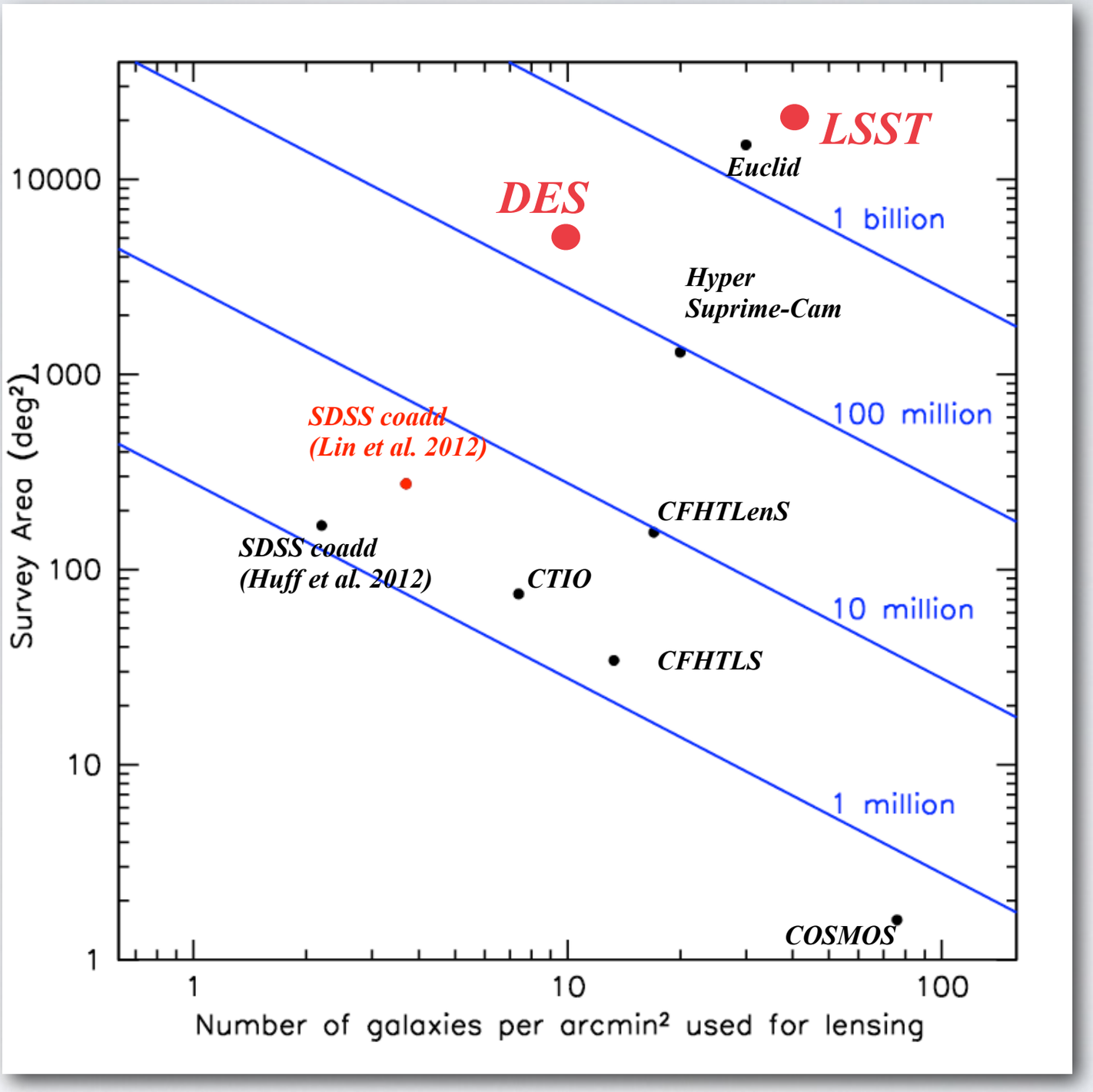
Lessons learned from DES will help us make the most out of this new experiment.

LSST PROJECTIONS



SURVEY LANDSCAPE

Recent and upcoming imaging surveys by area and depth.



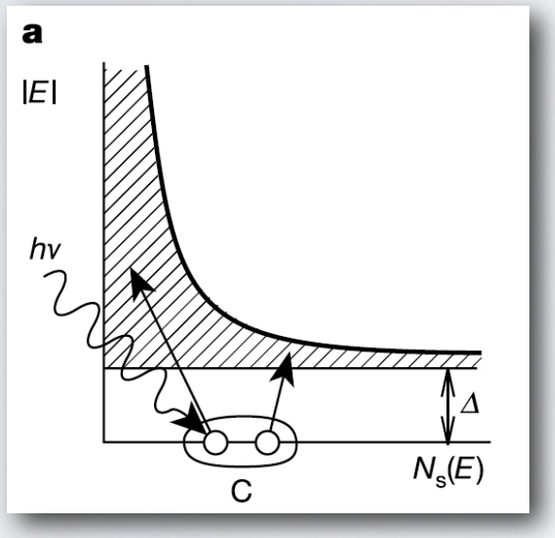
Blue lines indicate constant numbers of galaxies

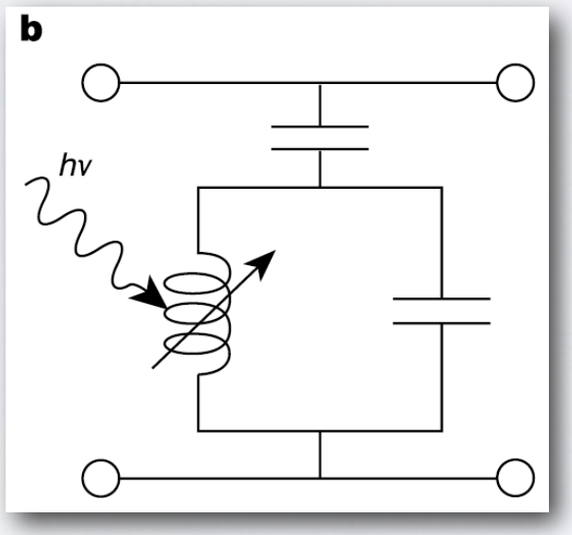
Note:
DESI will take spectra of 30M galaxies.

MKIDS

A game changing development is needed to provide spectra information at the scale of LSST and beyond.

Microwave Kinectic Inductance Detectors might be the solution to this problem.





MKID principle:

a) A photon strikes the superconductor breaking a few thousand Cooper pairs.

b)The broken Cooper pairs change the inductance of the resonator.

Obtain image and spectrum of every object !

SUMMARY

These are exciting times for Dark Energy research!

Multiple DES analyses ongoing, results emerging (see Rosenfeld's talk for details).

Coming up next: GW pilot program

Exciting prospects for future projects, such as LSST.

Opportunities to get involved in NEW developments:
LSST-scale spectroscopic survey (perhaps using MKIDs)
Large scale cosmic sirens program