Status of the Dark Energy Survey

Dark Energy Surveys

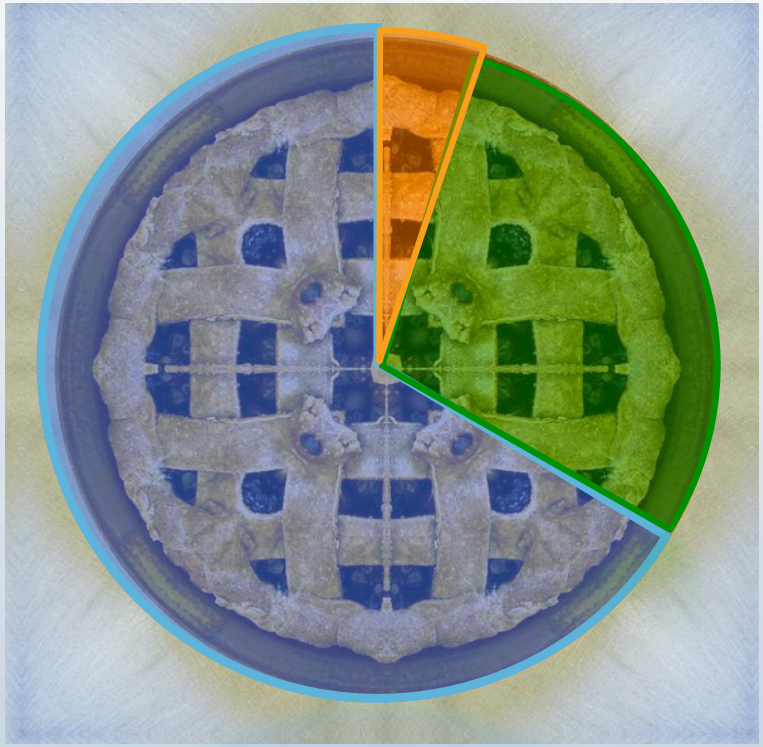
The Dark Energy Survey (status)

DES science and DES@CIEMAT

Current cosmological model accounts for all observations

The so-called **ΛCDM model** explains observed Universe and dynamics at large scales.

Cosmic pie



Atoms 5%
Dark Matter 27%
Dark Energy 68%

Assumptions:
Homogeneity and isotropy

Initial conditions:
Big-Bang origin (+ inflation)

Evolution:
General Relativity

Quantum fluctuations → Large Scale Structure
Cold Dark Matter 'seeds' of structure
Acceleration in recent times (cosmo. constant)
…

Only six parameters!! ($\Omega_b h^2, \Omega_m h^2, \Omega_\Lambda, \tau, n_S, \Delta$)

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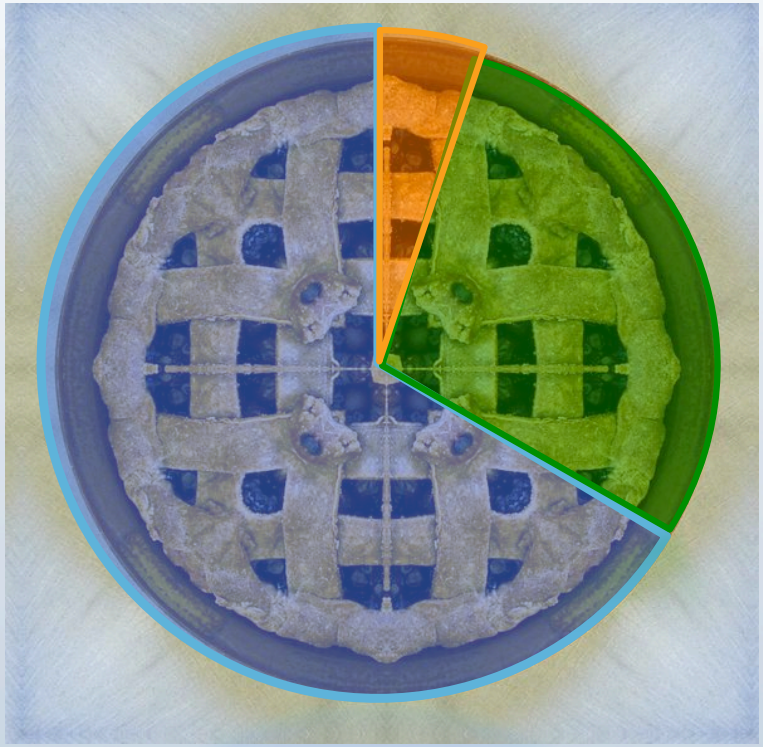

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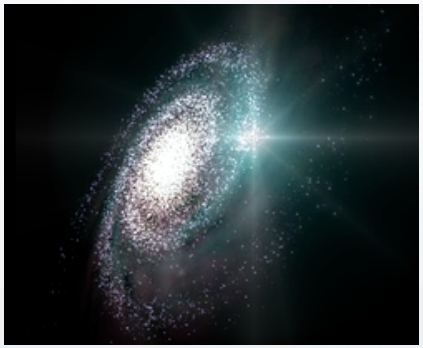
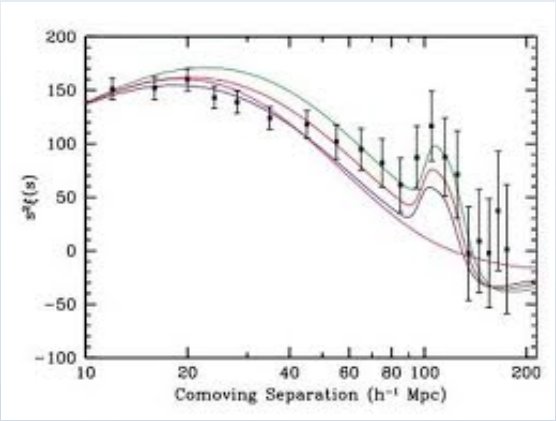
Dark Energy Task Force determined the most promising probes

Supernovae Ia

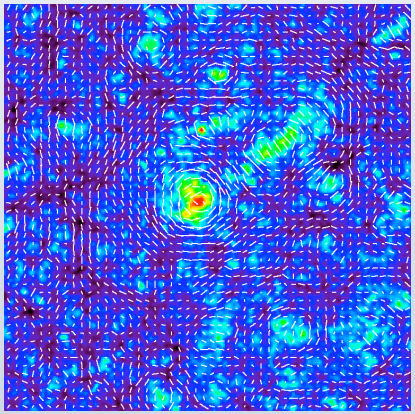


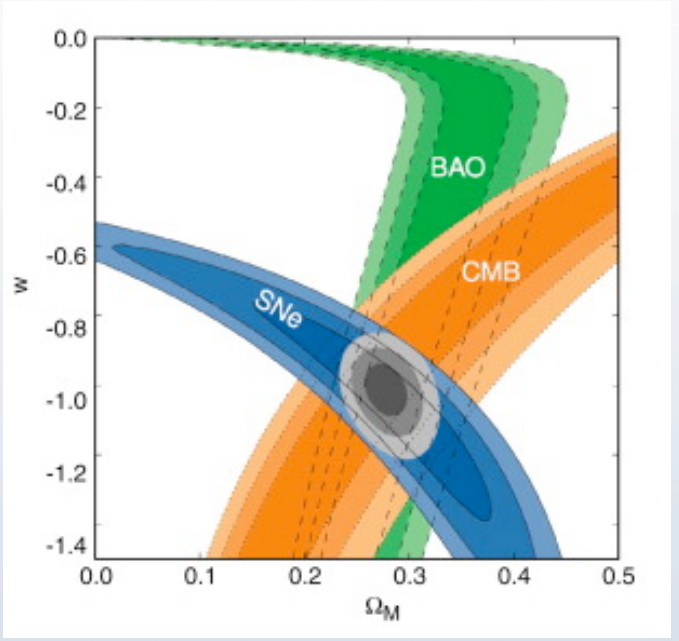
Cluster density

Baryon Acoustic Oscillations



Weak lensing





Kerschaggl et al. 2011

In 2000's, Dark Energy Task Force determined the most promising probes to characterize Dark Energy and distinguish competing hypothesis.

What is measured in a DE project?

We need **large** (deep, extense) (1e6 (current) – 1e10 (LSST)) **surveys of galaxies** (*galaxies will be the 'events' of our ROOT trees*).

Telescopes are used to gather as much light as possible (large mirrors) in **visible and infrared wavelengths** (needs high and dry places).

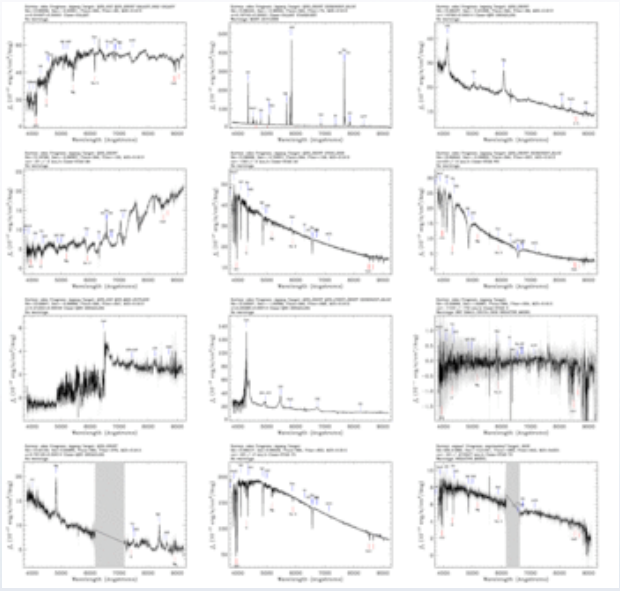
CCDs are the primary detectors, using **filters** or **spectrographs**.

Observables (*ntuple columns*):

- **Position** in the sky (+ time of measurement for SN)
- **Flux** at each wavelength
- **Shape** (in photometric mode)
- A secondary product from flux: **redshift** (high precision in spectroscopic mode)

(*for DES, this turns out to be several hundred columns per galaxy*)

Photometry vs. Spectroscopy



Type	Pros	Cons	Examples
Photometric	Statistics Weak Lensing	$\sigma(z) \sim 10$ % Galaxy type	DES, LSST
Spectroscopic	$\sigma(z) \sim 0.01$ % RSD	Low statistics Selection bias	WiggleZ,BOSS
Spectro-phot	Statistics, $\sigma(z) \sim 0.35$ %		PAU, J-PAS

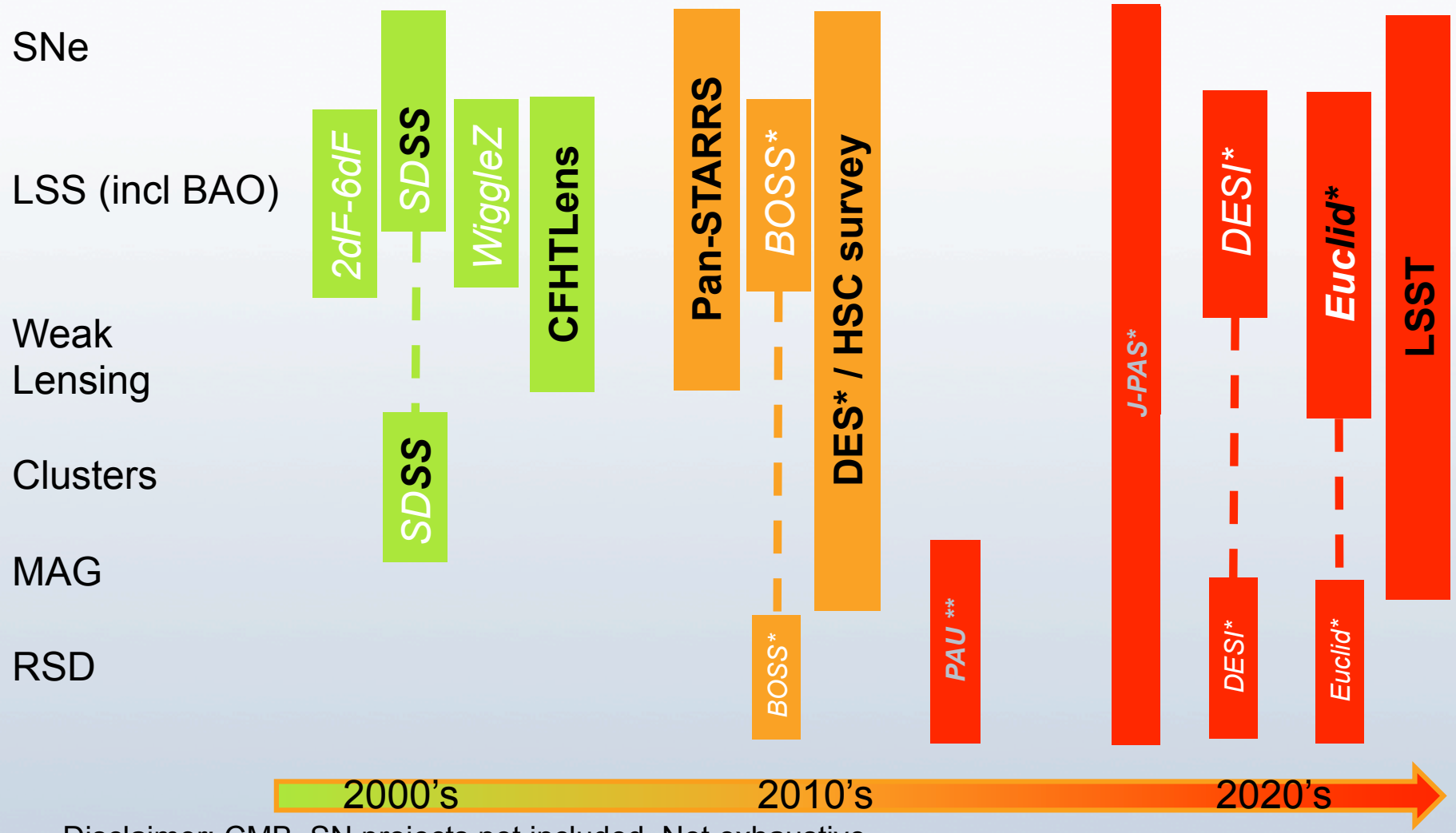
Galaxy Survey (very partial) Landscape

DARK ENERGY SURVEY

Ciemat

DE - question *What is w today?* *Does w evolve?* *Alternatives to Λ?*

Probe



Disclaimer: CMB, SN projects not included. Not exhaustive.

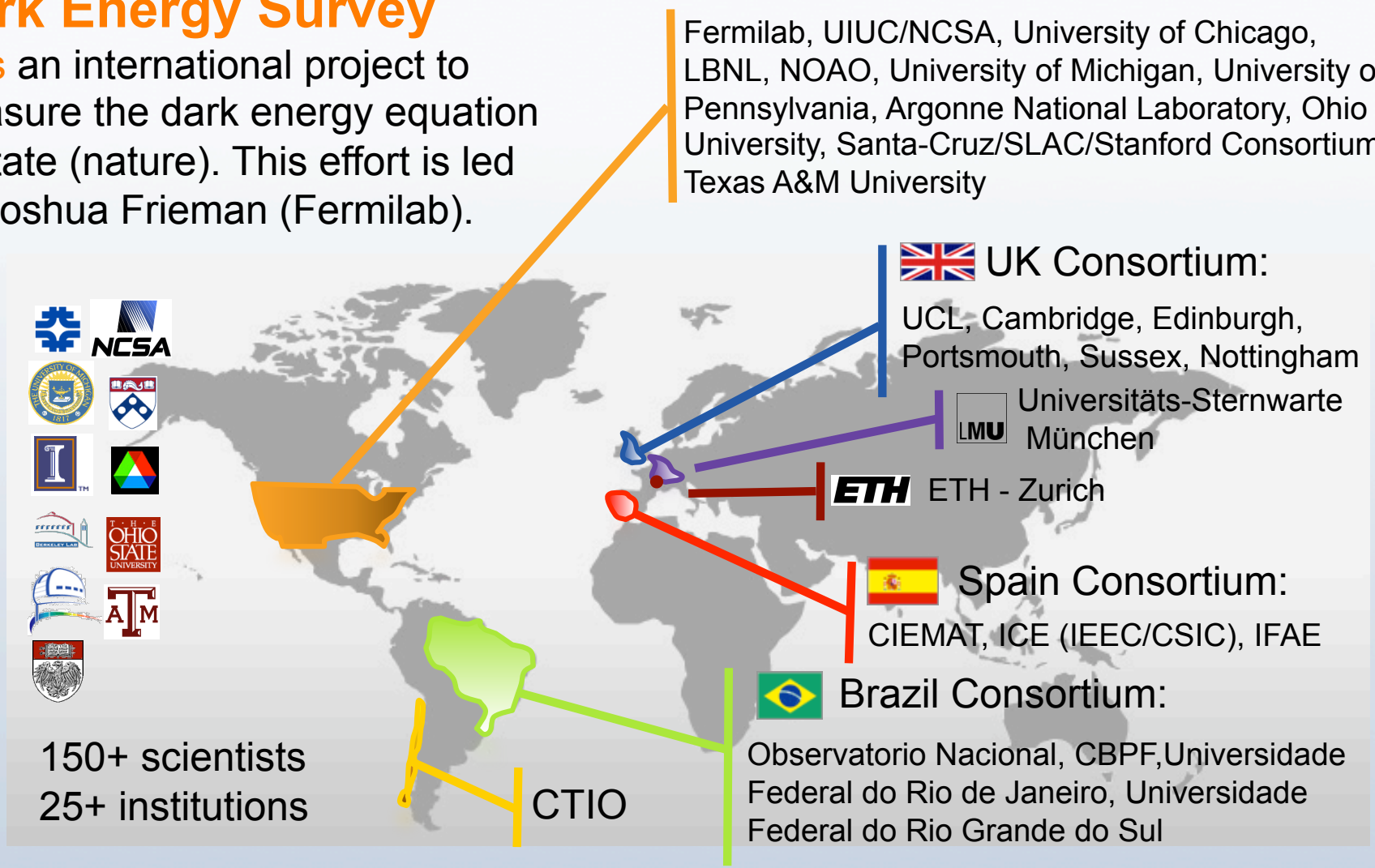
* Contribution from Spanish Institutions.
** PAU is integrally funded by Spain

Black: photometric
White: spectroscopic
Gray: spectro-photometric

The inevitable collaboration slide

Dark Energy Survey

… is an international project to measure the dark energy equation of state (nature). This effort is led by Joshua Frieman (Fermilab).



Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of Pennsylvania, Argonne National Laboratory, Ohio State University, Santa-Cruz/SLAC/Stanford Consortium, Texas A&M University

UK Consortium:

UCL, Cambridge, Edinburgh, Portsmouth, Sussex, Nottingham

Universitäts-Sternwarte München

ETH - Zurich

Spain Consortium:

CIEMAT, ICE (IEEC/CSIC), IFAE

Brazil Consortium:

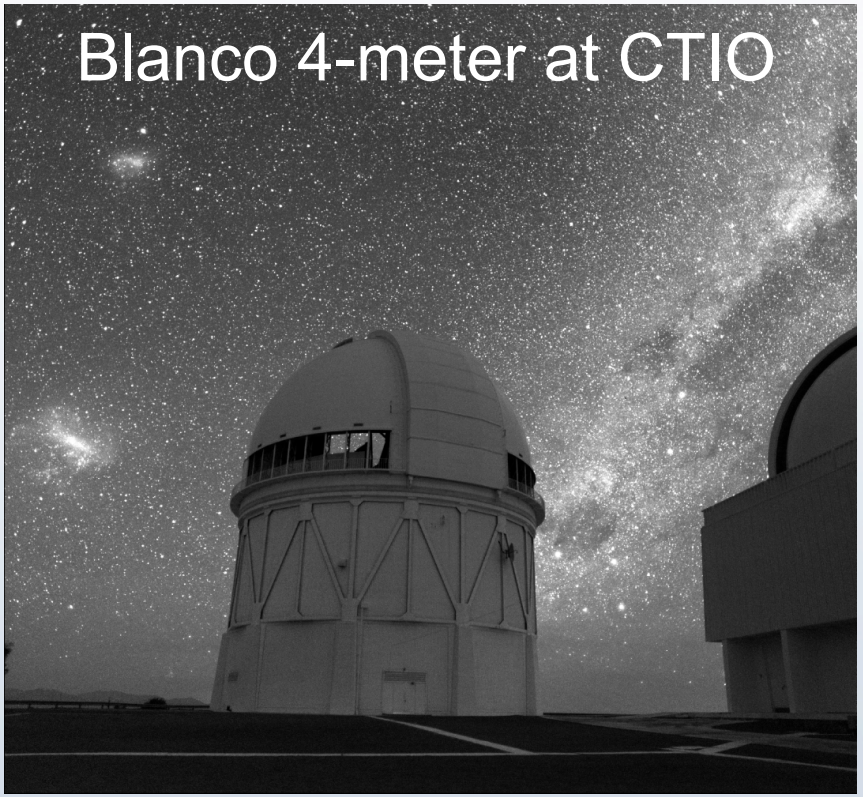
Observatorio Nacional, CBPF,Universidade Federal do Rio de Janeiro, Universidade Federal do Rio Grande do Sul

CTIO

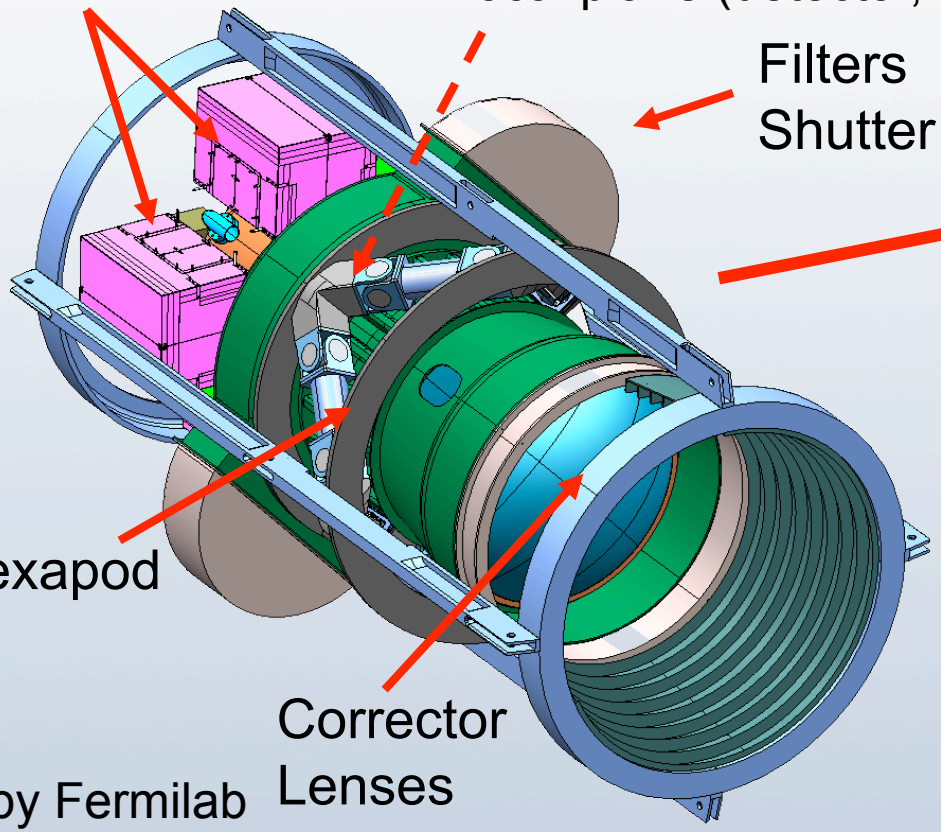
150+ scientists
25+ institutions

DES in a nutshell

- Survey project using **4 complementary techniques**:
  - I. Cluster Counts
  - II. Weak Lensing
  - III. Large-scale Structure
  - IV. Supernovae
- Measure with precision, focus on controlling systematic errors.
- Two multiband **(photometric)** surveys:
  - **5000 deg^2** *grizY* to **24th mag** AB ***griz***
  - 30 deg^2 repeat (Sne)
- **Build new 3 deg^2 FOV multi-CCD camera**, Data management system, improve Blanco facilities

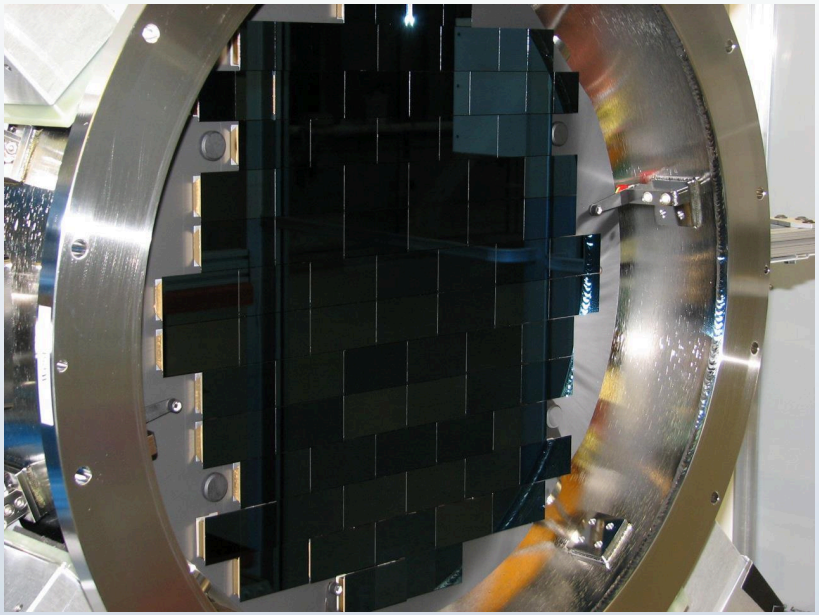


DECam is the instrument to carry out the survey from the primary focus



Led by Fermilab

The detector system consists of a 520 Mpixel camera with 62+ red-sensitive CCDs



DECam with science-grade CCDs installed

570 Mpixels – 3 square degrees

Survey strategy combines calibration, overlaps, SN regions in 5 filters for 5 years

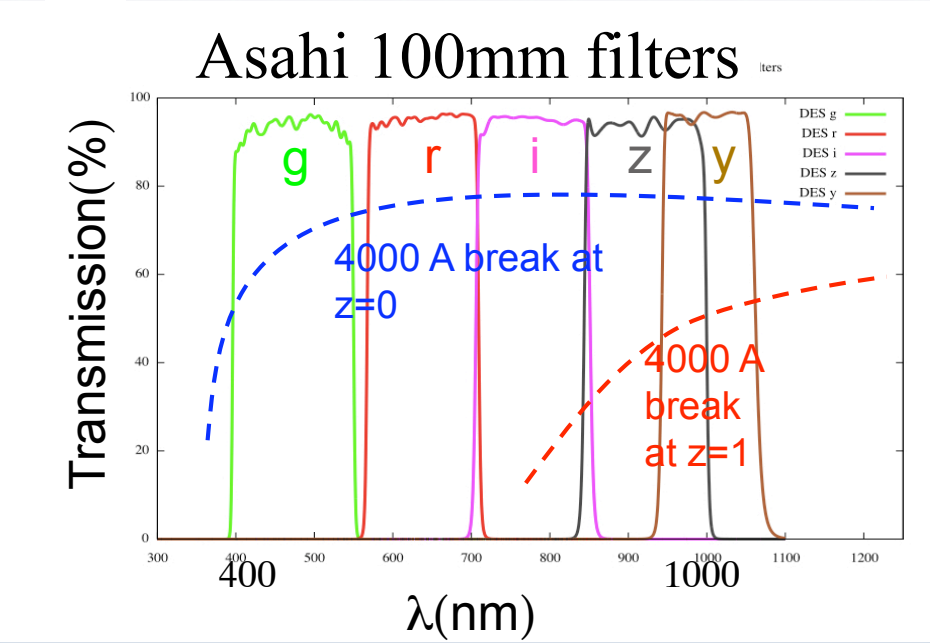
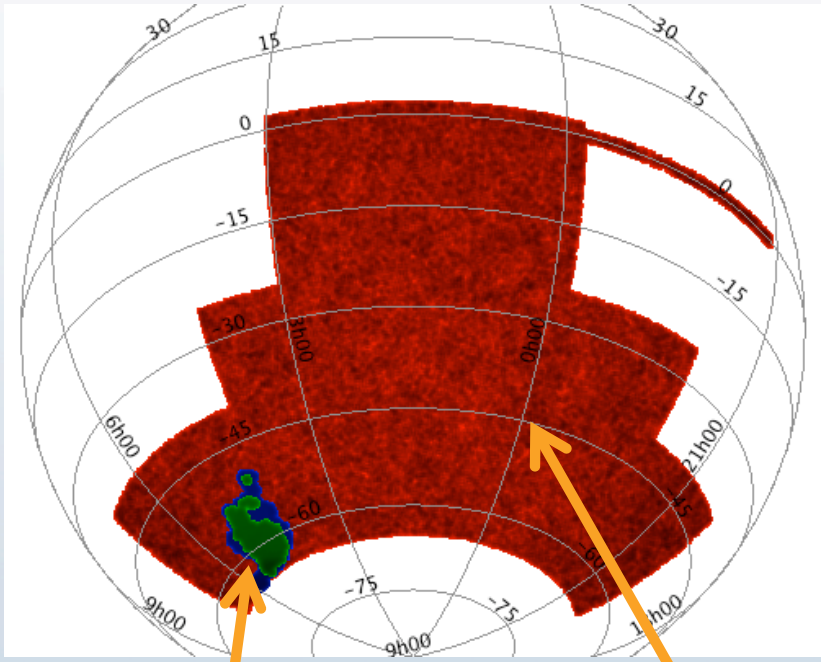


Photo-z precision = **0.05(1+z)**

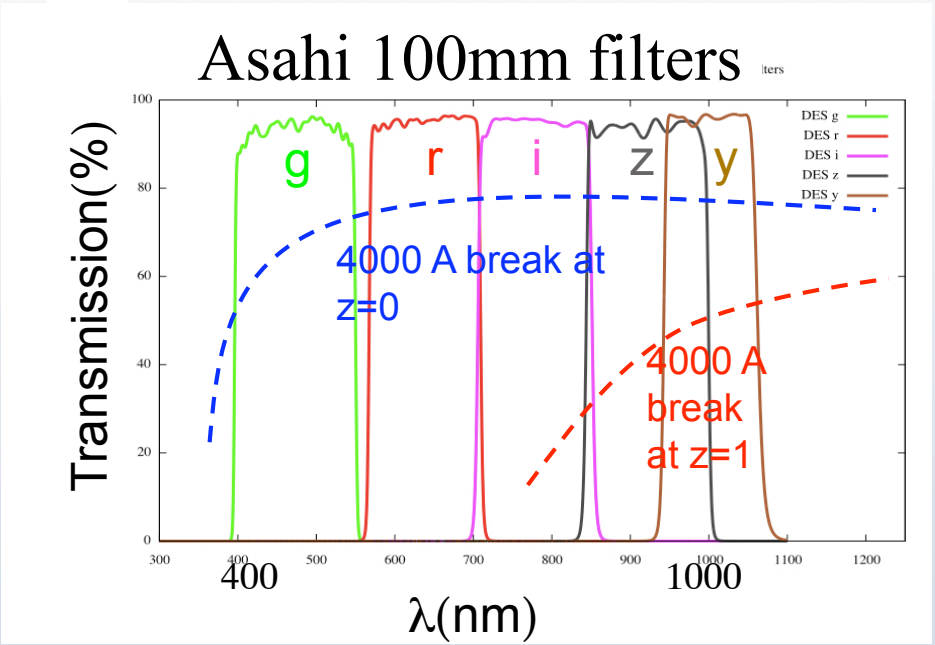
Survey Area



Year 0 (2012-13)
+ SN regions

After 5 years

Survey strategy combines calibration, overlaps, SN regions in 5 filters for 5 years



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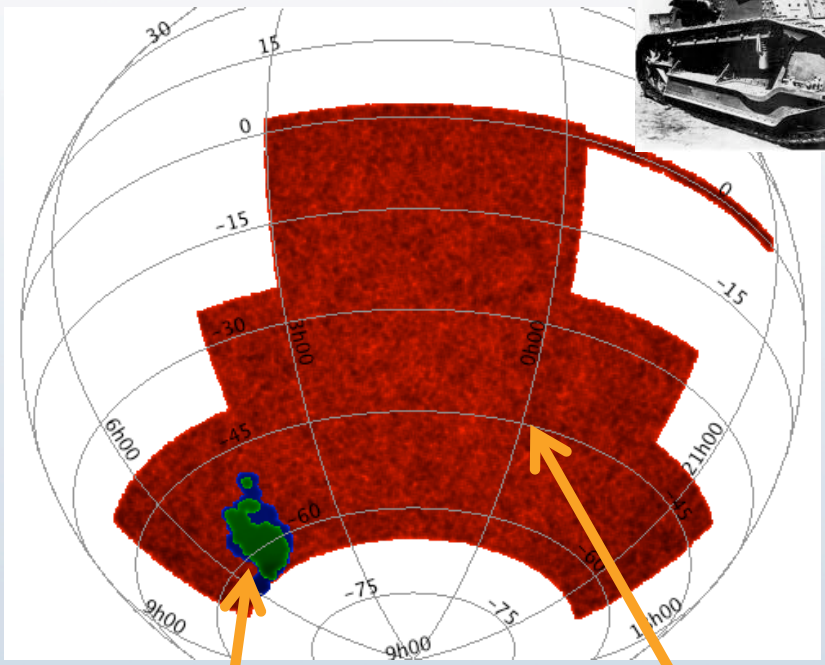
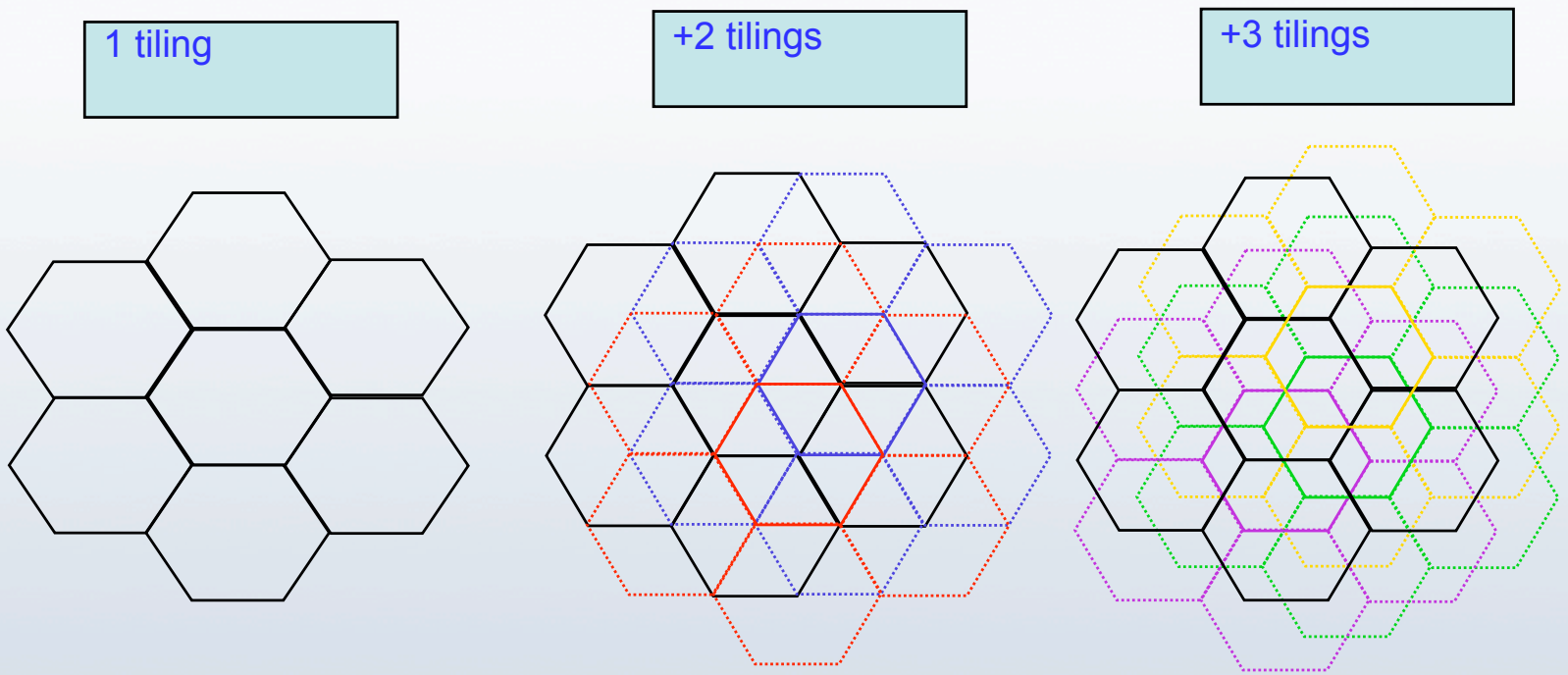


Year 0 (2012-13)
+ SN regions

After 5 years

The survey will be conducted in tilings: 2/year/filter nominally



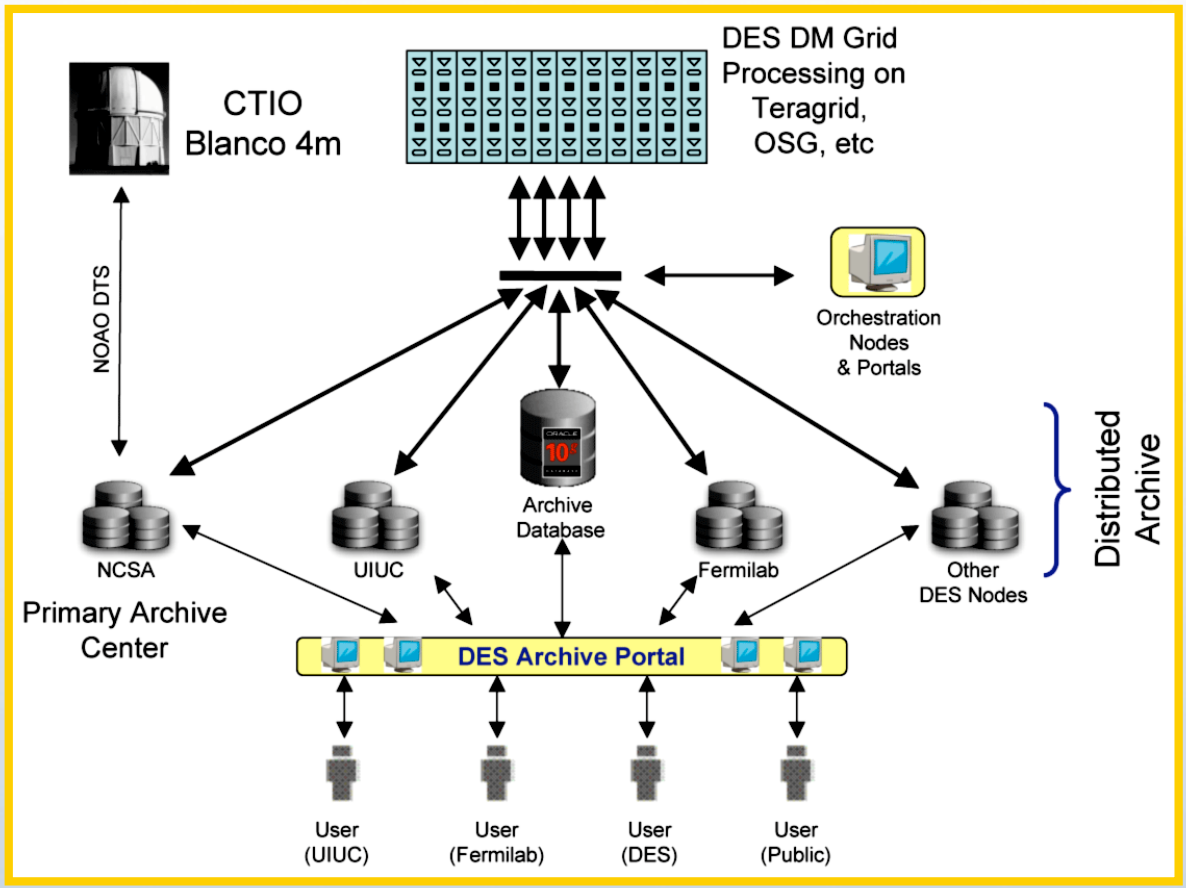
105 nights/year in Sep-Apr; rest of the time is a facility instrument

Data management of O(PB) data will be carried out by NCSA

Transfer

Processing

Archival

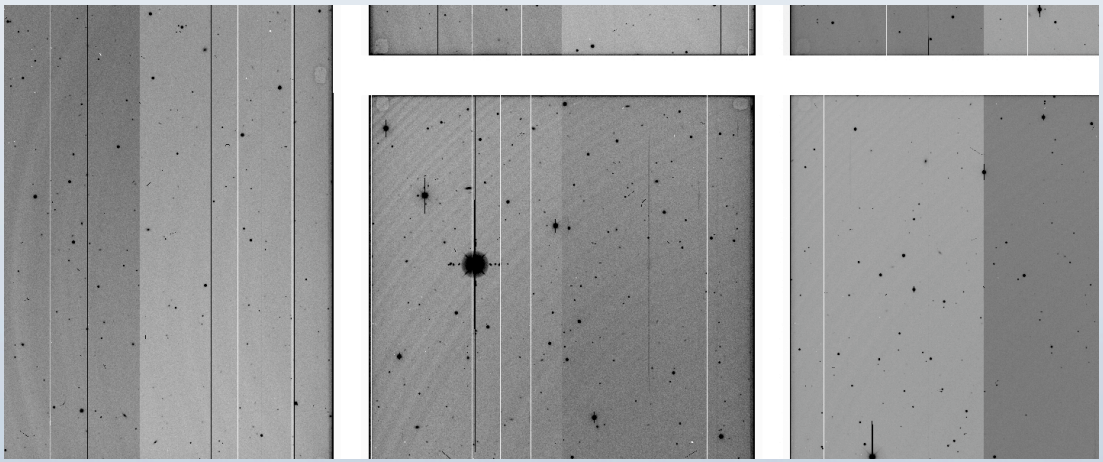


Led by U.Illinois/NCSA

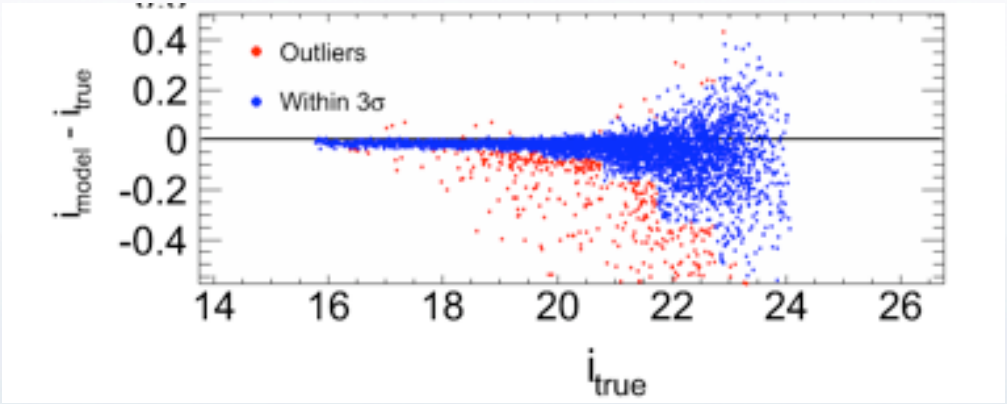
Pipeline is tested through the data challenge process as in a particle physics project

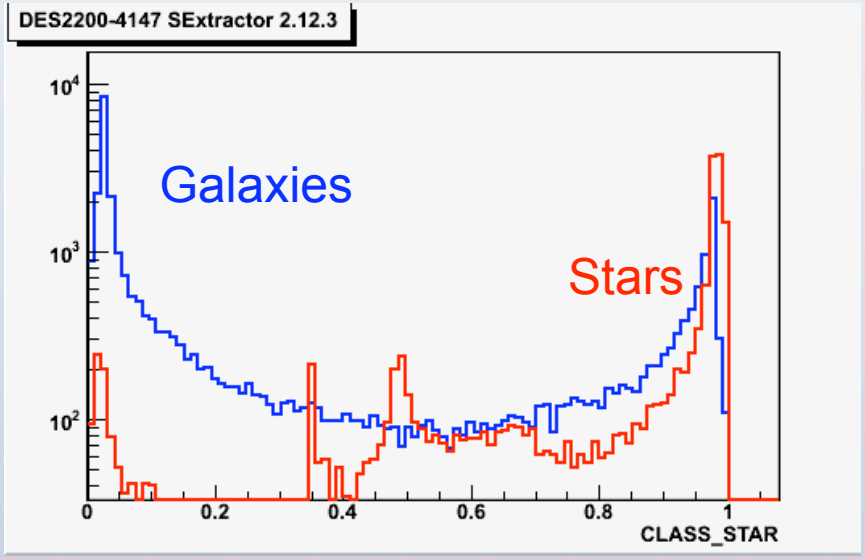
Produce cosmological simulations

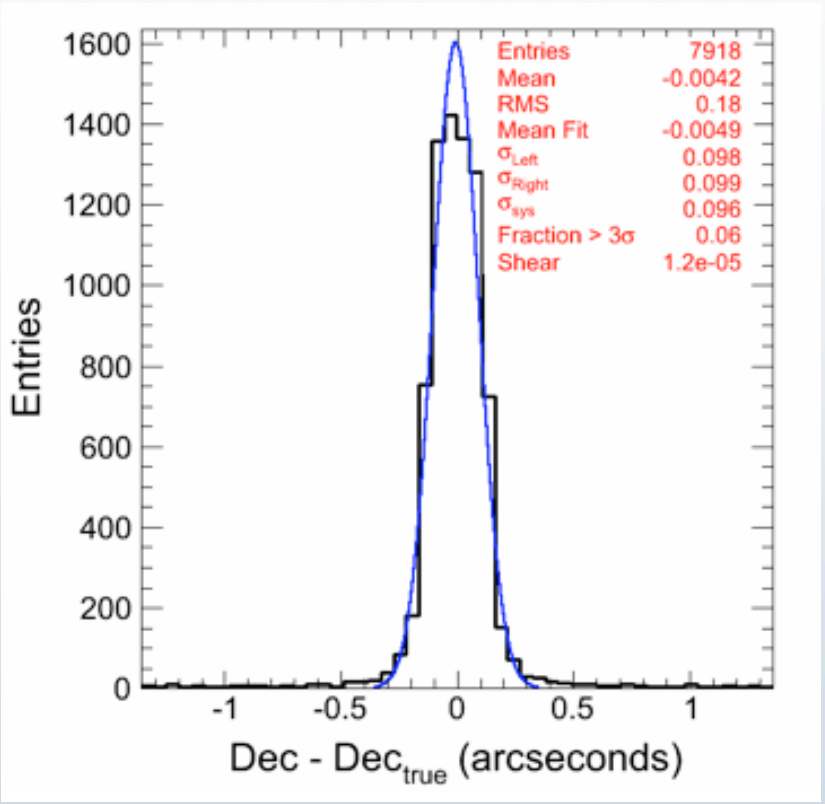
Process through atmosphere, detectors, include ‘nasty’ stuff



Science Working Groups study the quality of data through these Data Challenges (~200 sq.deg.)







(Importante participación del CIEMAT Nacho, Eusebio).

DES is currently analyzing Science Verification data

First light took place in September 12 ✔

Commissioning period: Sep 12 – Oct 31 ✔

Science Verification period: Nov 1 – Feb 22 ✔

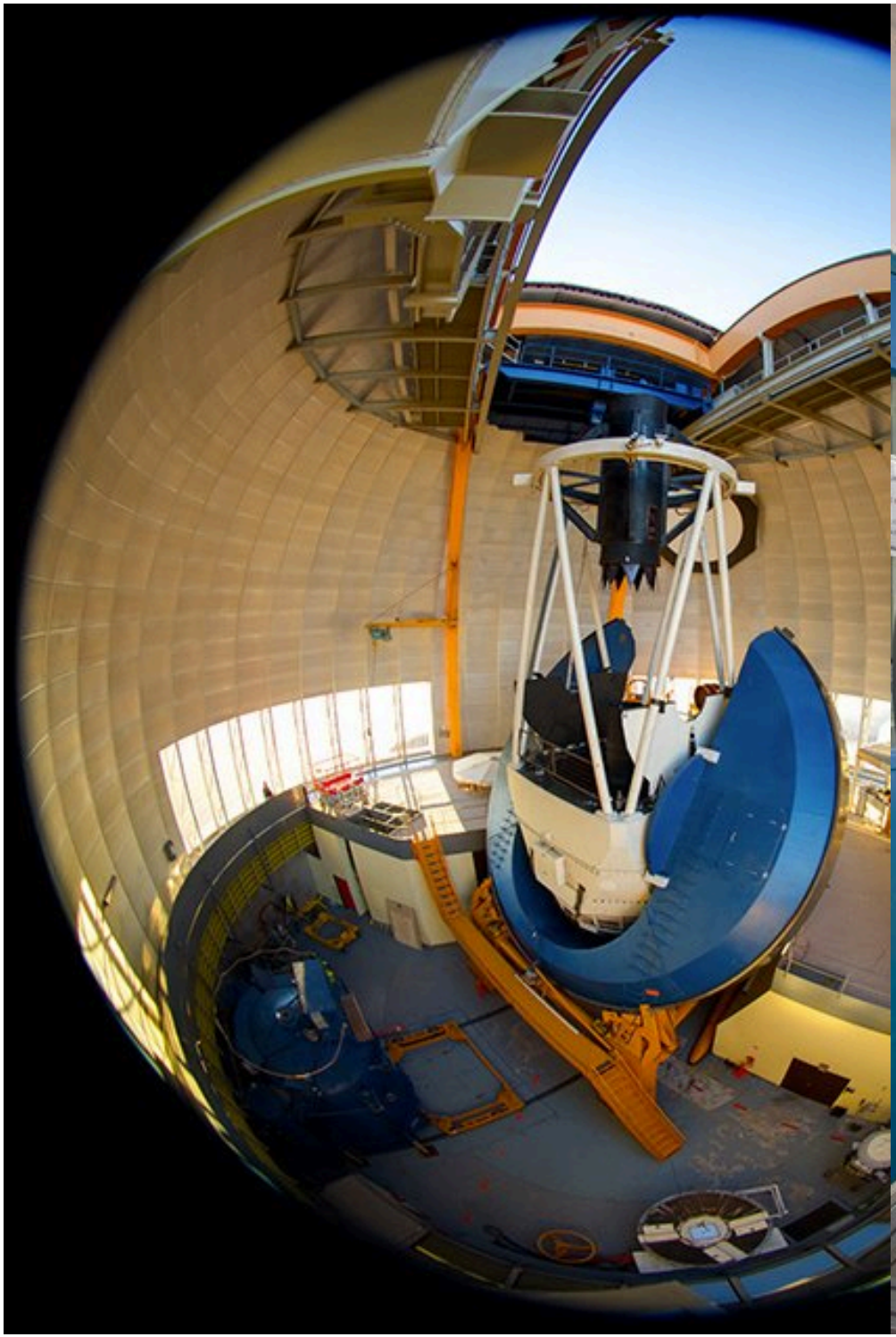
Start of survey operations: Sep 2013

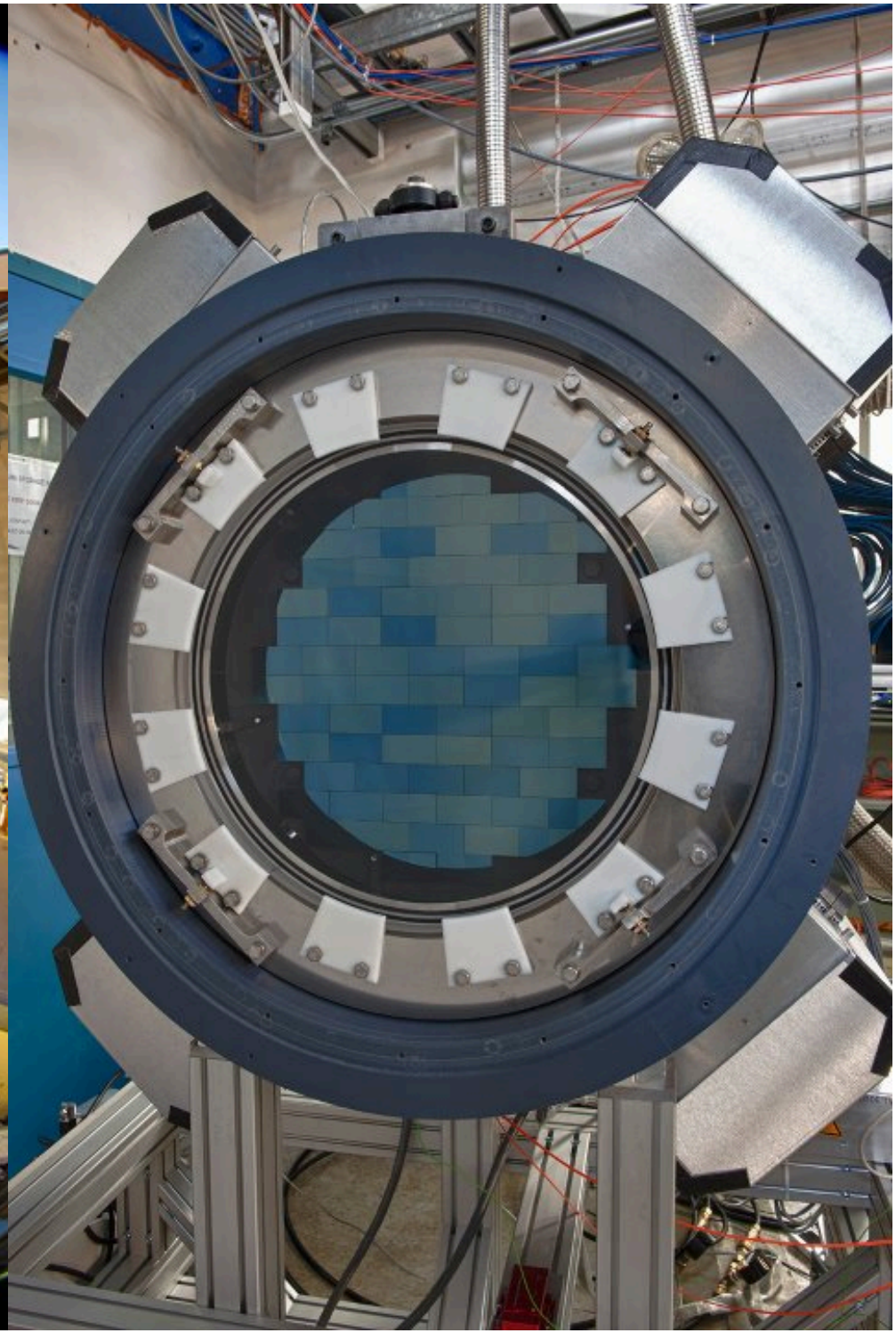
(subsequent years 105-night periods from 2013 to 2018)

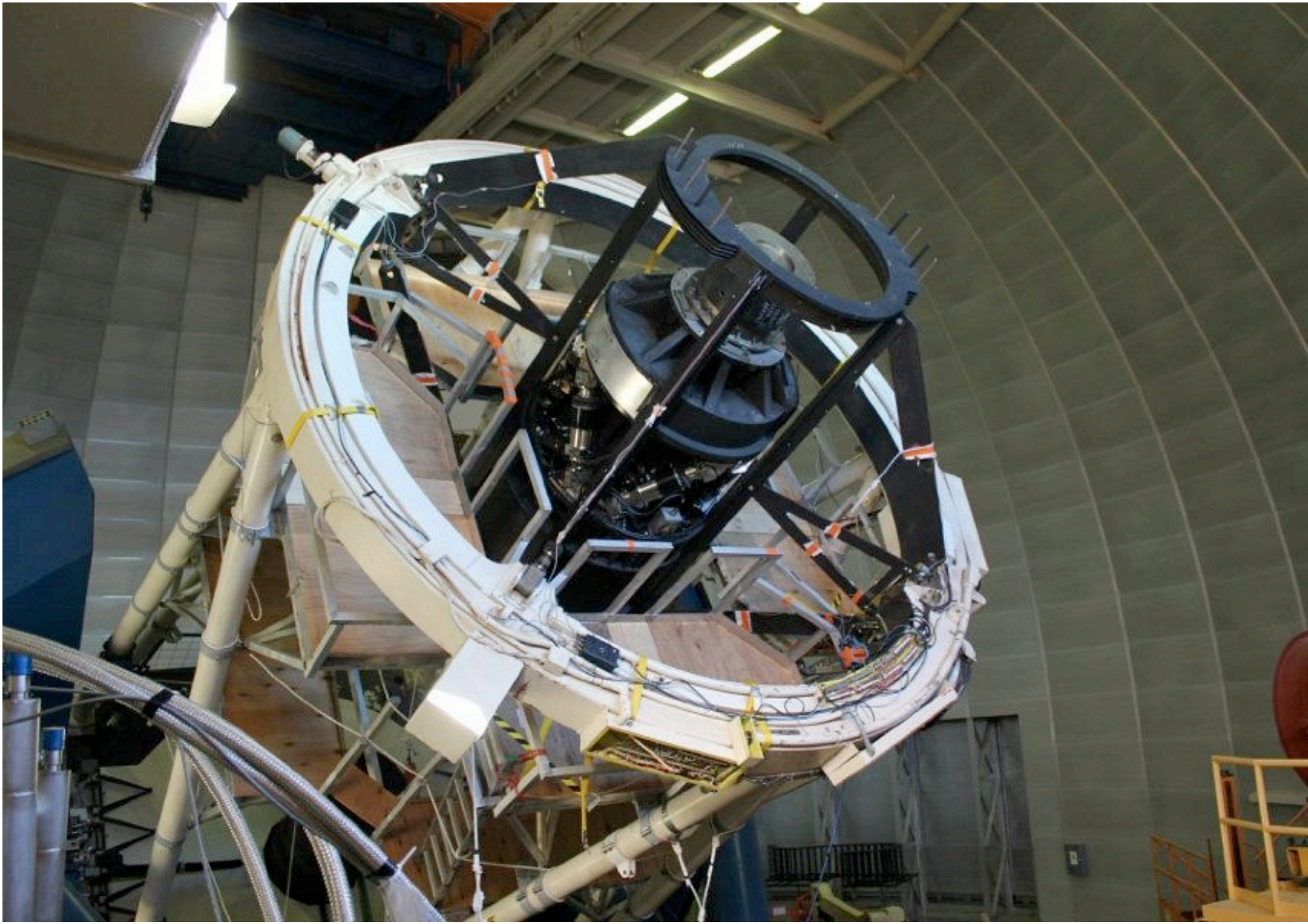
Some problems have been found during SV which are being worked on:

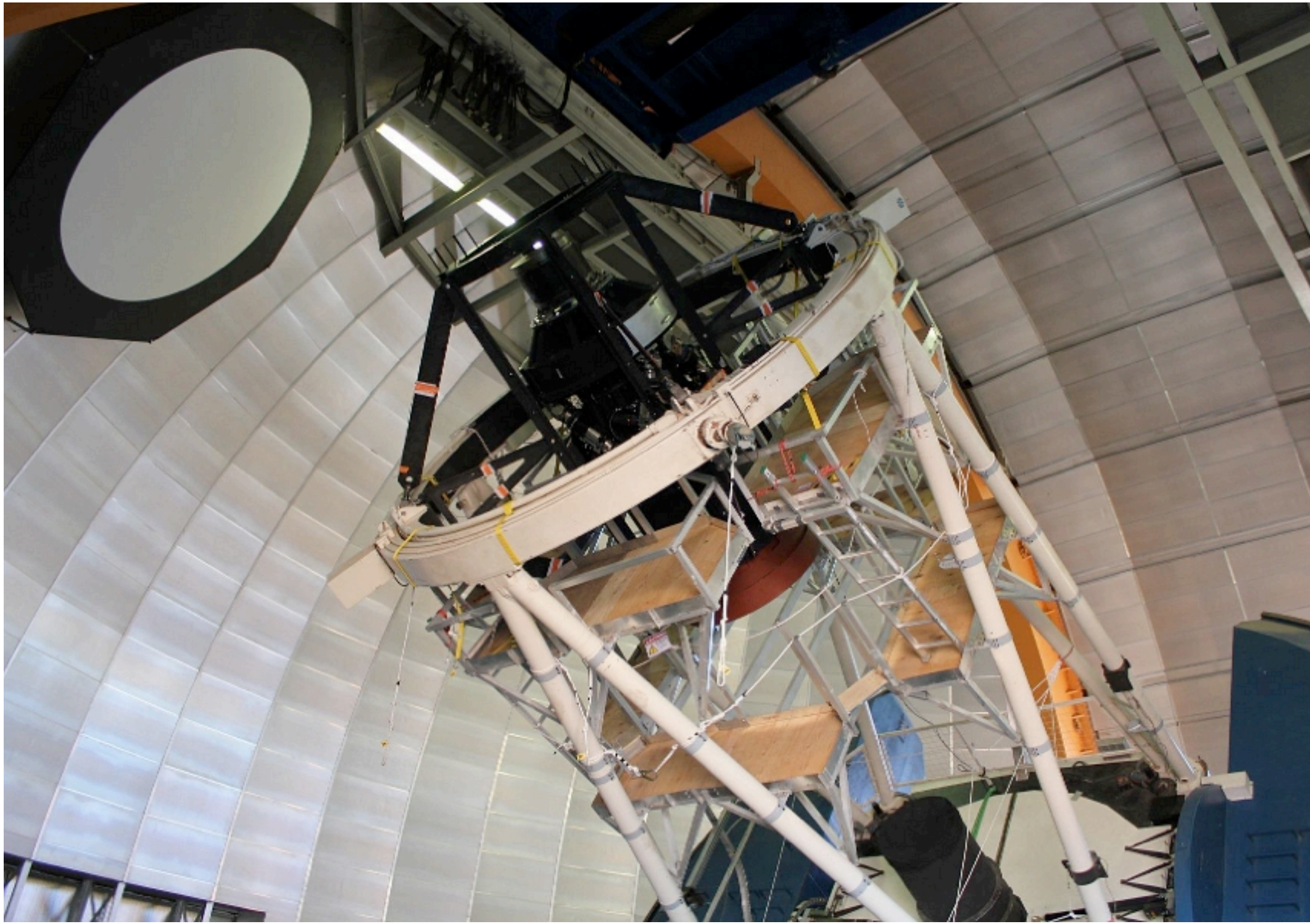
- Detector 'features'
- Image Quality
- Survey Efficiency

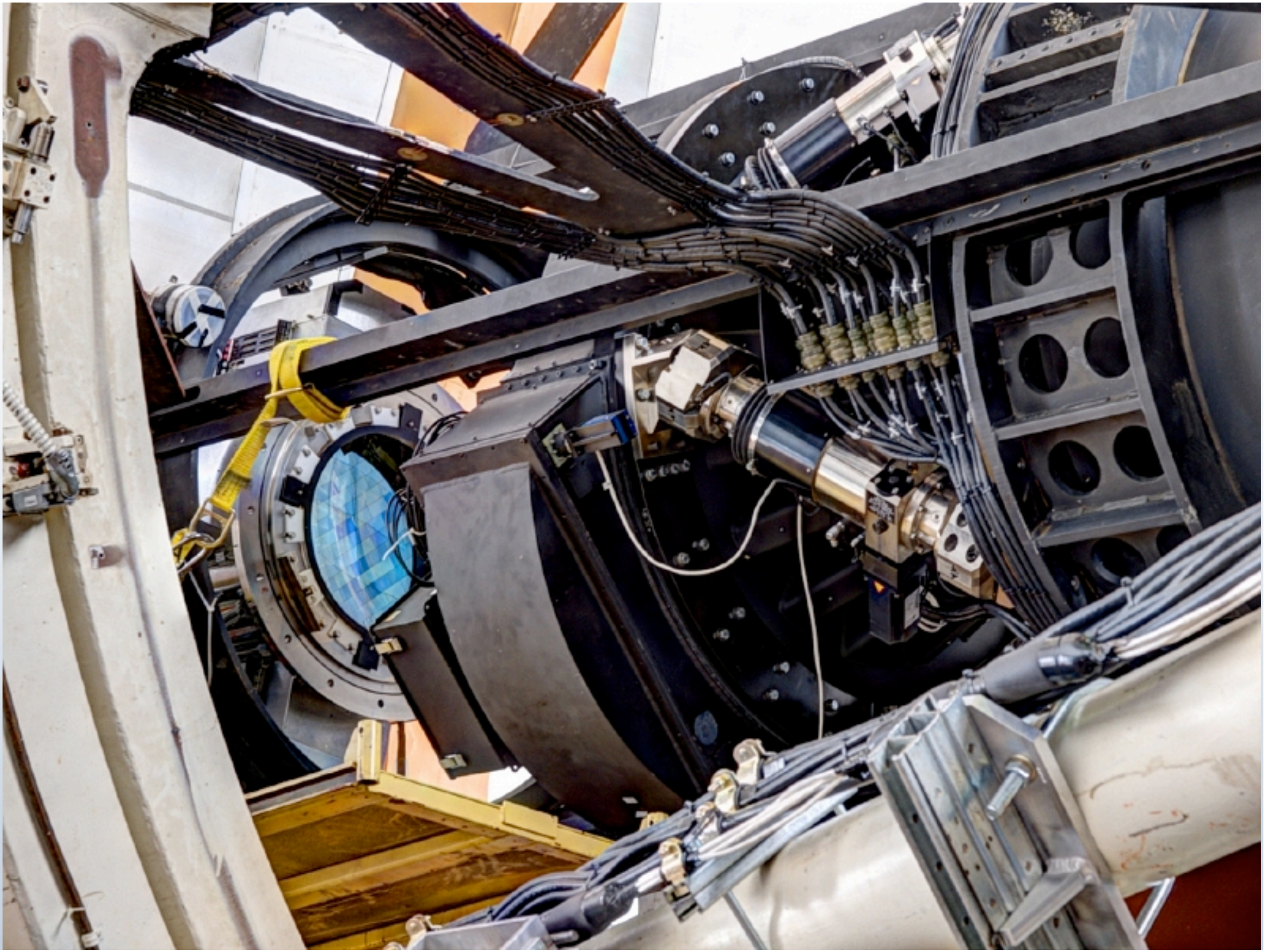
But overall excellent performance!

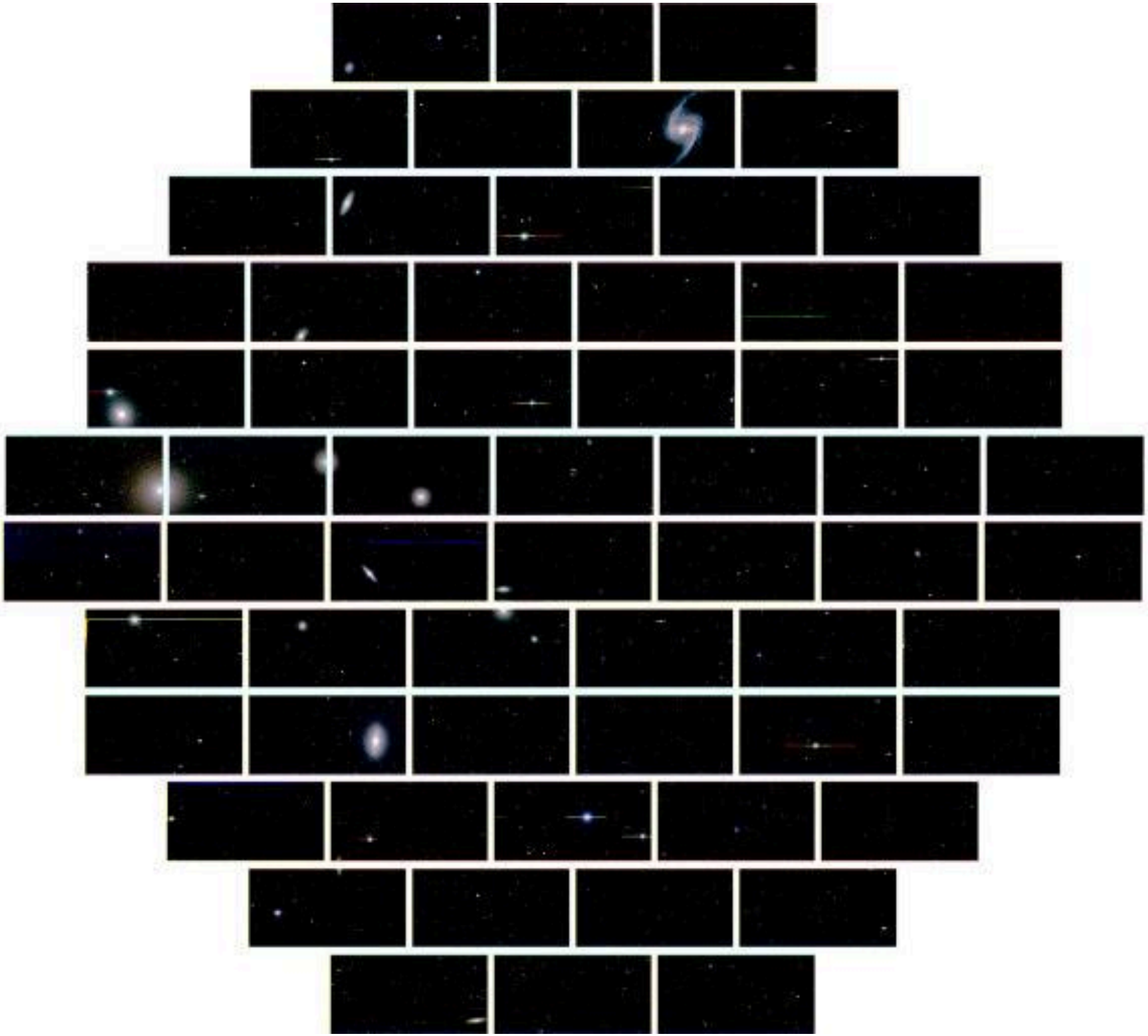


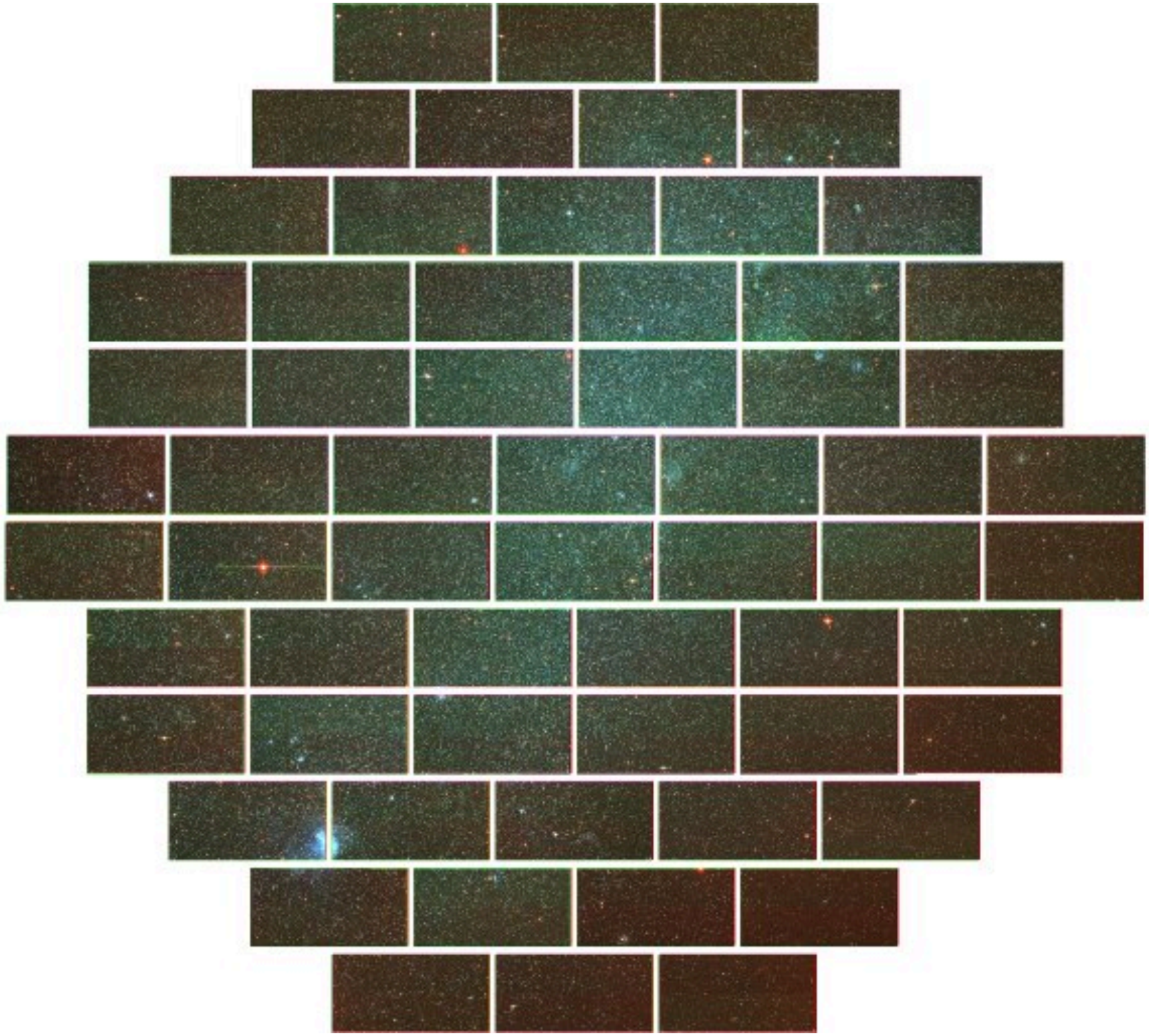


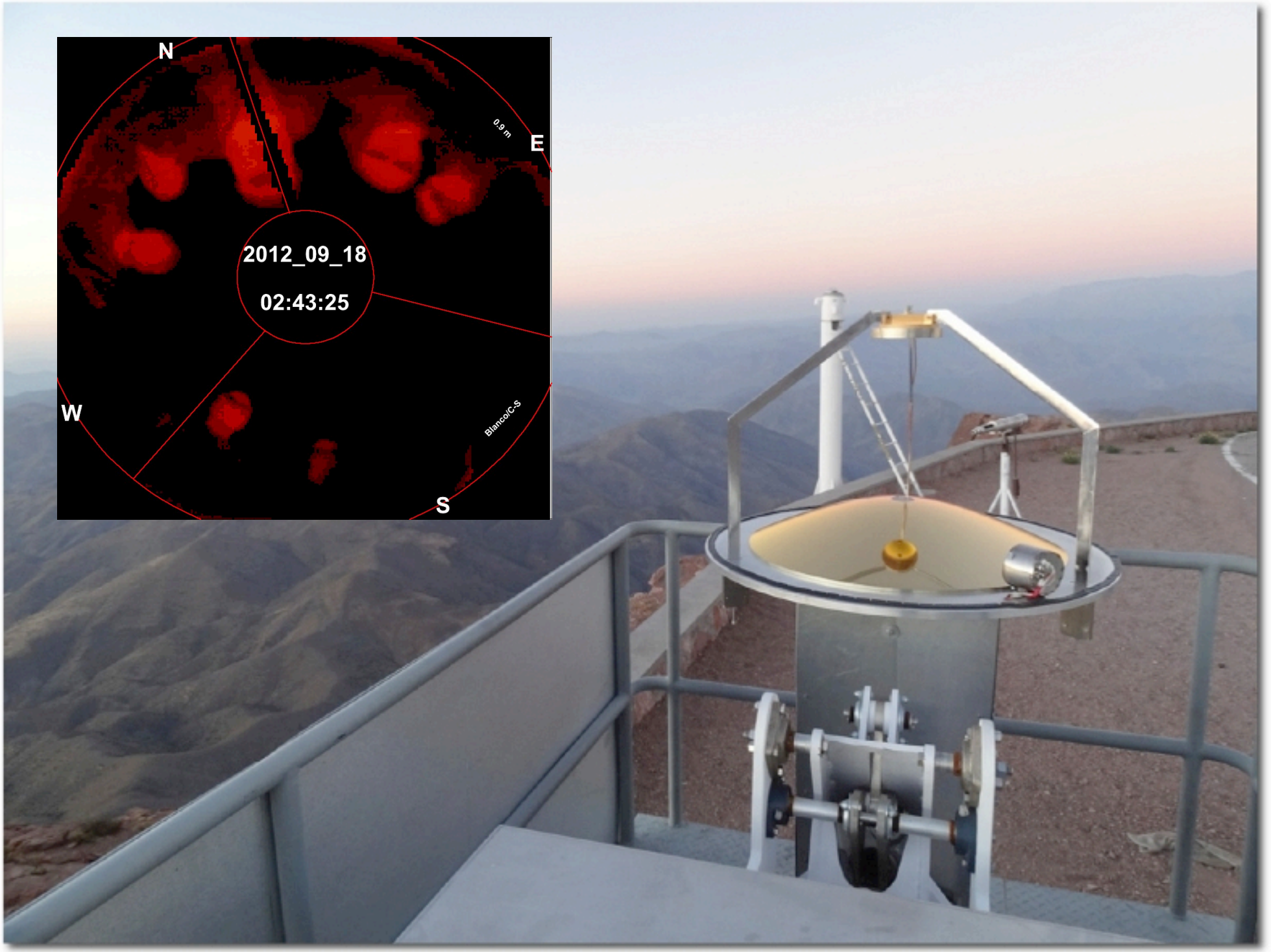








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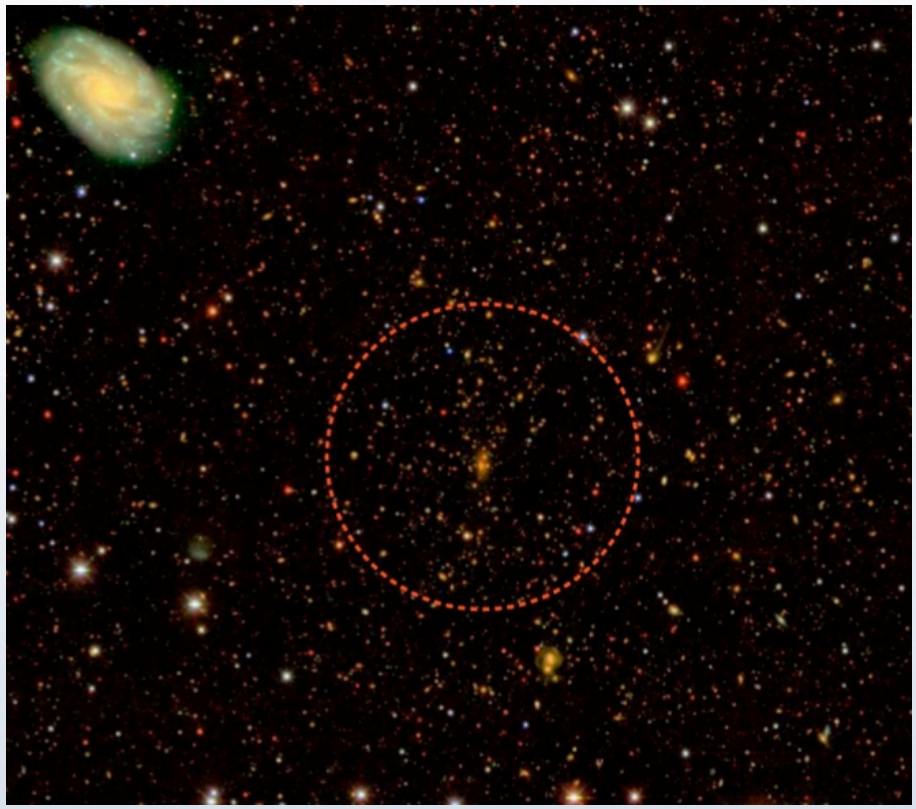
Blanco/C.S

DES Science: First results!

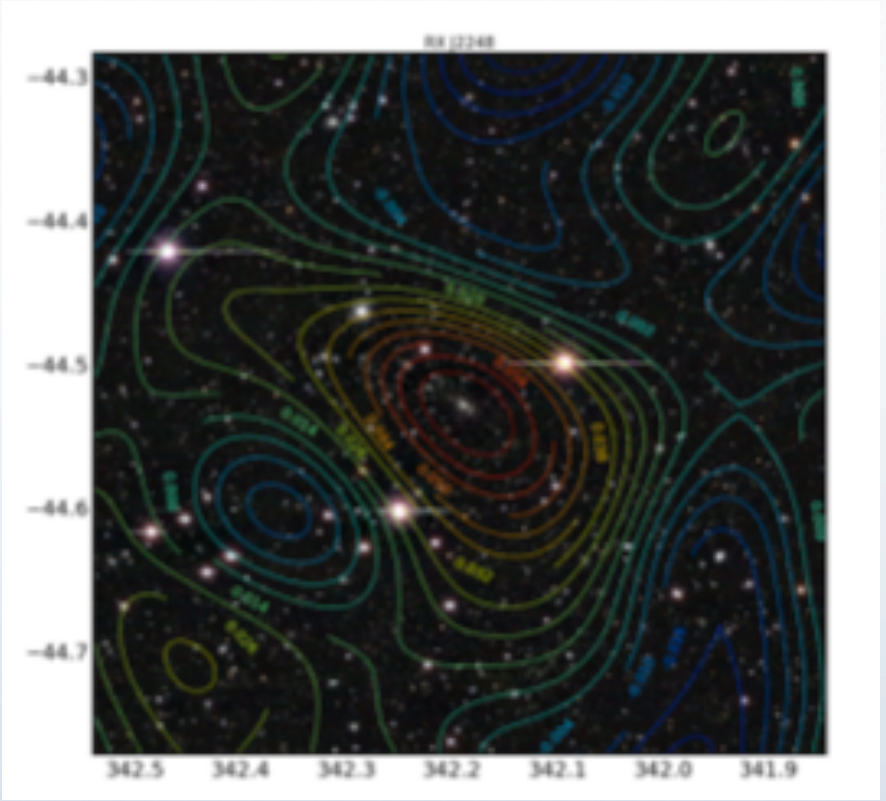


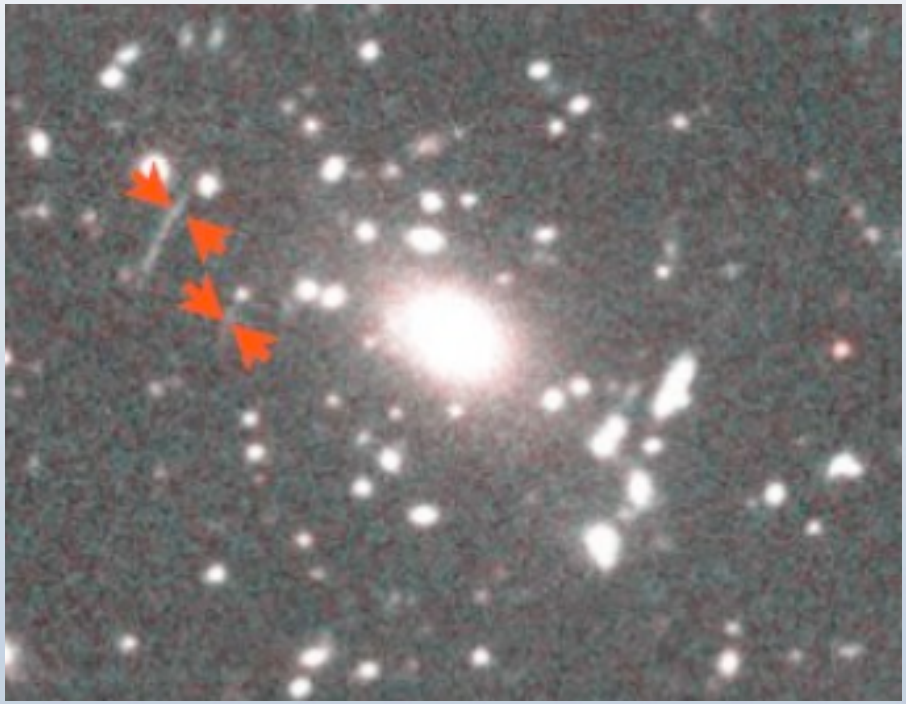
Discovery of high redshift clusters from SPT observations.

Supernovae detections

DES Science: First results!

Mass profile of cluster RXJ 2248

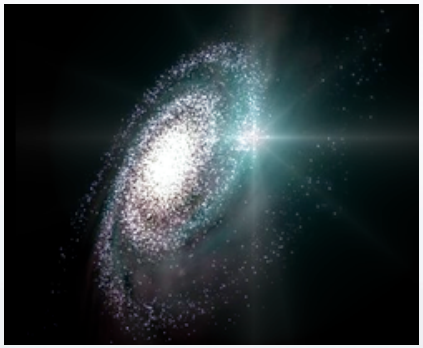




Strong lens candidates in cluster RXJ 2248

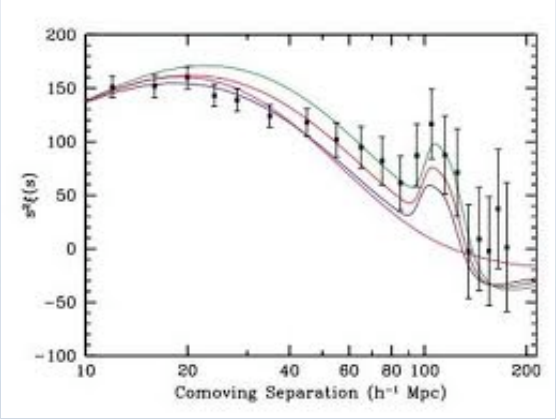
Dark Energy Task Force determined the most promising probes

Supernovae Ia

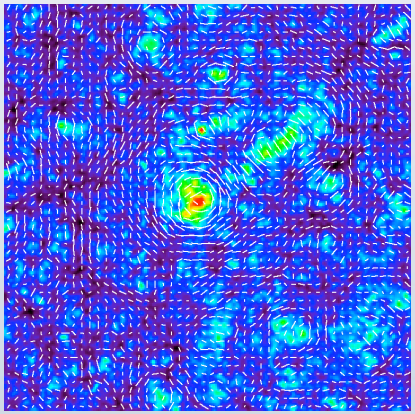


Cluster density

Baryon Acoustic Oscillations



Weak lensing



Much more!: galaxy evolution, strong lensing, QSOs…

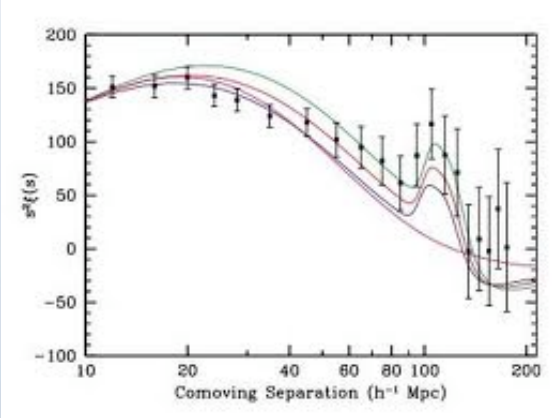
Dark Energy Task Force determined the most promising probes

Supernovae Ia

Observe **objects of known absolute brightness** to measure relative distances → expansion rate as function of time H(z)

Cluster density

Baryon Acoustic Oscillations



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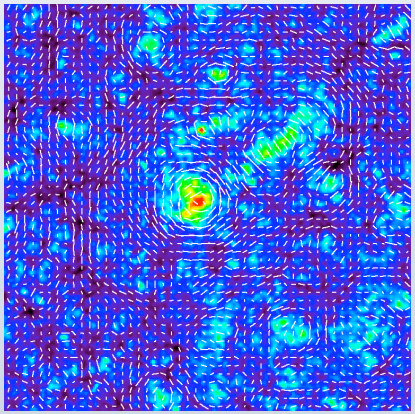
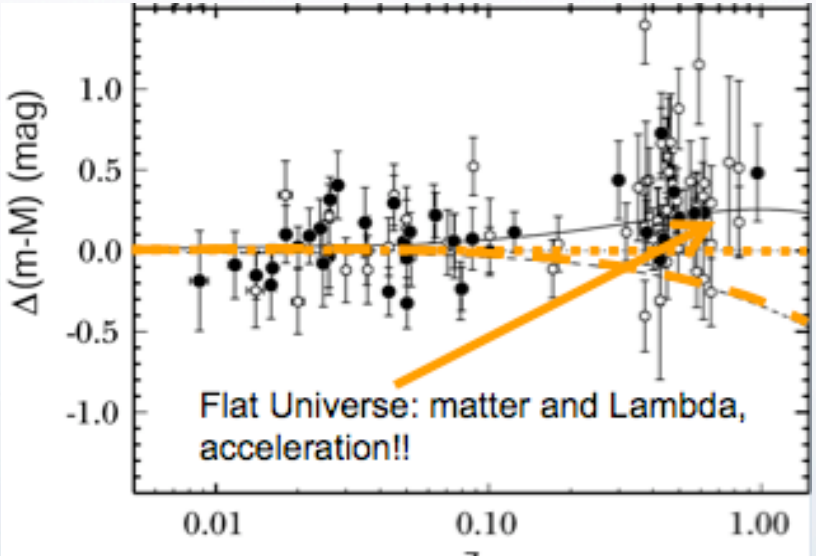
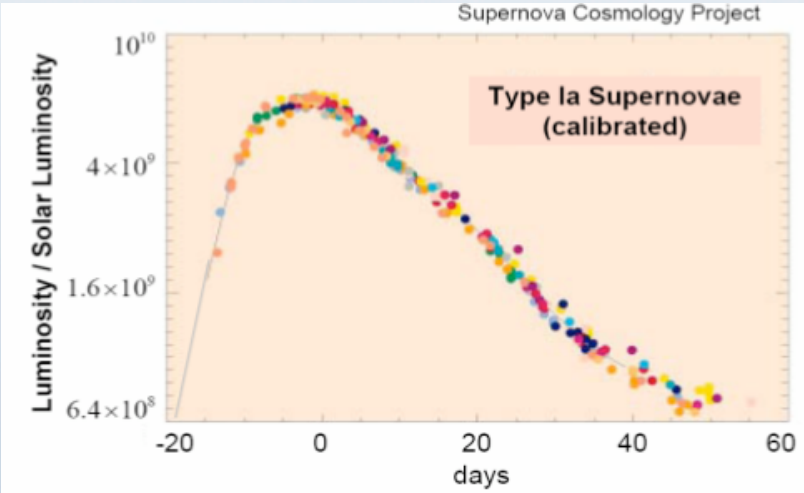


Supernovae Ia



Credit: Riess et al. 1998; Perlmutter et al. 1999



Strategy: standard candles

- Measure apparent brightness, redshift.
- Infer type, absolute brightness (from light curve)
- Luminosity + app. magnitude + redshift,

$$\chi^2 = \sum_{objects} \frac{(\mu_{obs} - \mu_{th}(z;\theta))^2}{\sigma^2}$$

- Measure repeatedly same area, photometry for id and redshift

DES:

- Measure ~3000 SN photometrically, up to z=~1

- 10+% of the survey time will be devoted to SN search revisiting an area of 30 sq.deg.

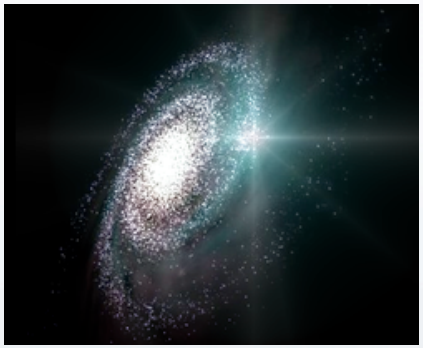
- Photometric errors will be addressed w/ on-site measurements of photometry, spectroscopic follow-ups.

Systematics: dust, evolution, calibration…

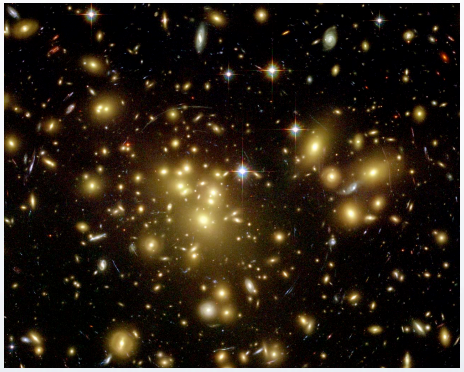
'Mature', photometric identification and redshifts

Dark Energy Task Force determined the most promising probes

Supernovae Ia

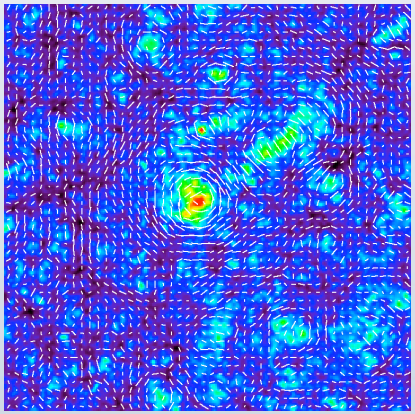


Cluster density



Baryon Acoustic Oscillations

Weak lensing



Observe **'objects' of known absolute size** to measure distances → expansion rate as function of time H(z)

Baryon Acoustic Oscillations

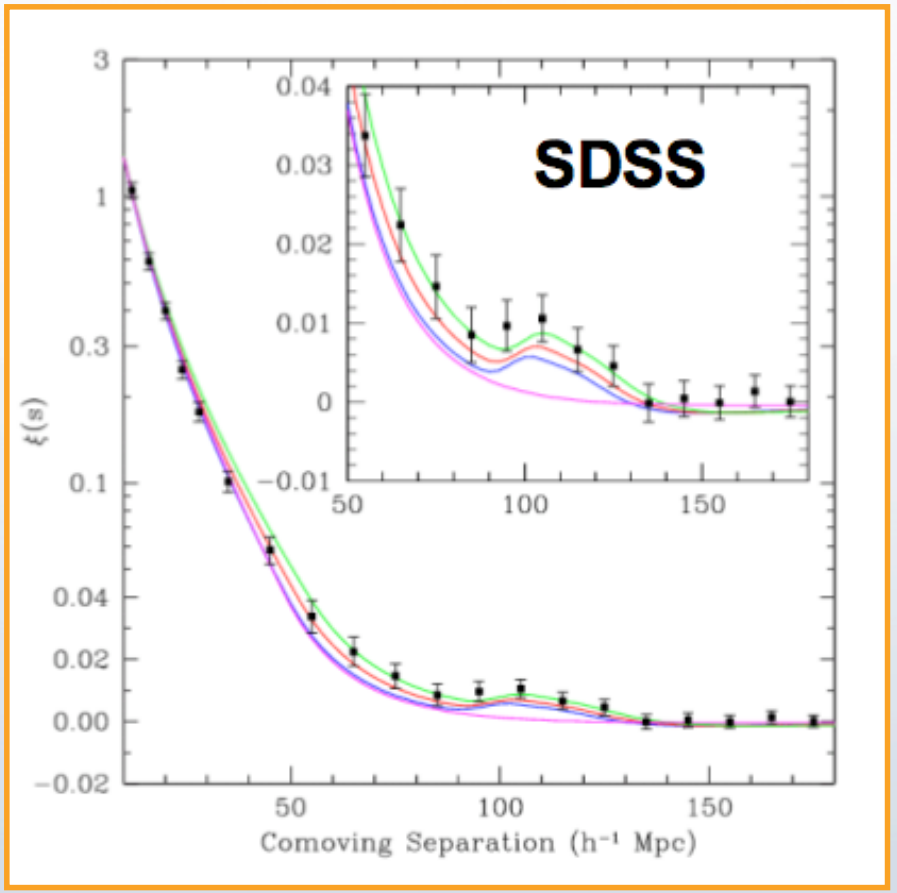
Strategy: standard rulers

- CMB provides scale of acoustic peak.
- Search for this peak in angular two-point correlation function of galaxies in redshift shells.
- This gives an estimation of the expansion history.
- Measure a huge amount of galaxies in a large area and volume.

DES:

- Correlation function of ~2e8 galaxies up to z~1.5.
- Probe larger volume and redshift range than current state-of-the-art

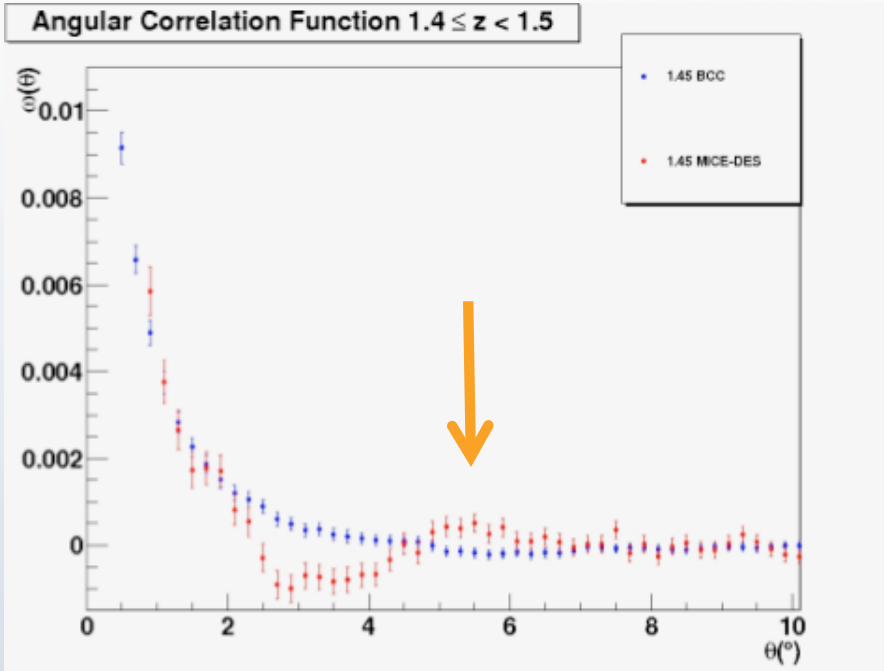
Systematics: photo-z's, projection effects, non-linear evolution, galaxy-mass relationship (bias).

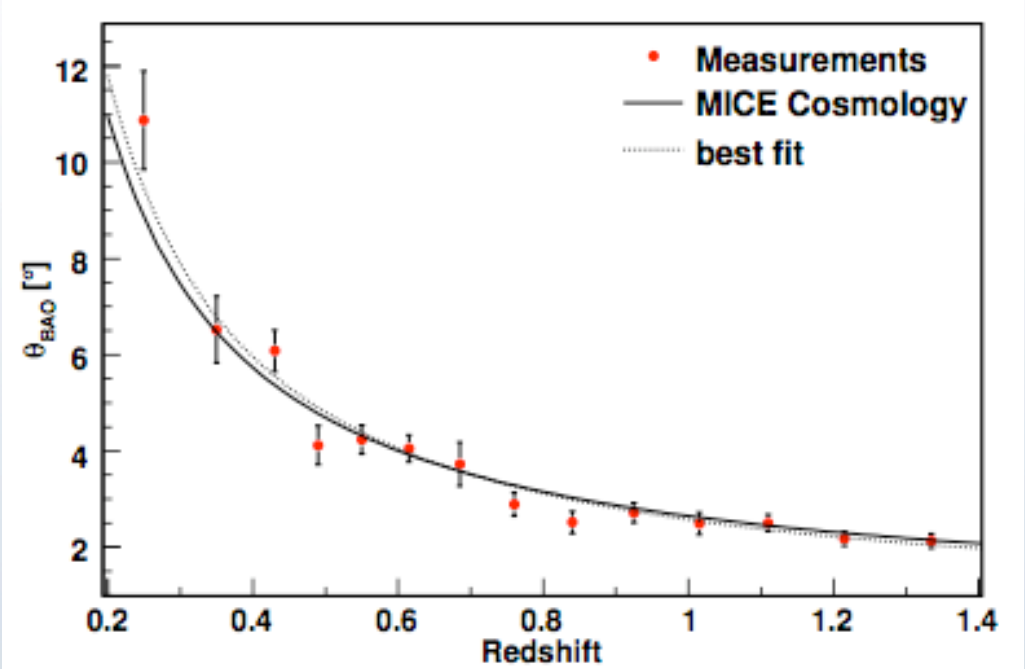


Eisenstein 2005

Robust, weakest constraints

Baryon Acoustic Oscillations (@ CIEMAT)

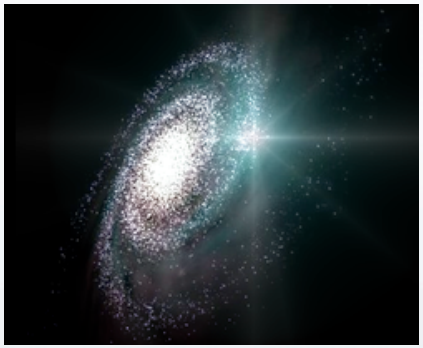




- Método por Eusebio, Aurelio et al.
- Aplicado a datos (Aurelio et al.)
- Aplicado a simulaciones recientes (Javi et al.)
- También en la función de correlación radial (no DES), 'counts in cells', fractal index (Javi, Eusebio, Nacho)

Dark Energy Task Force determined the most promising probes

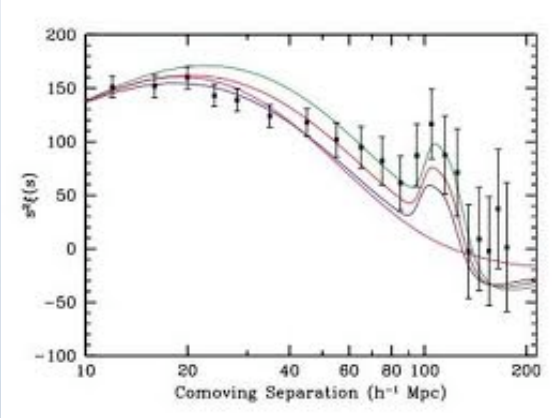
Supernovae Ia



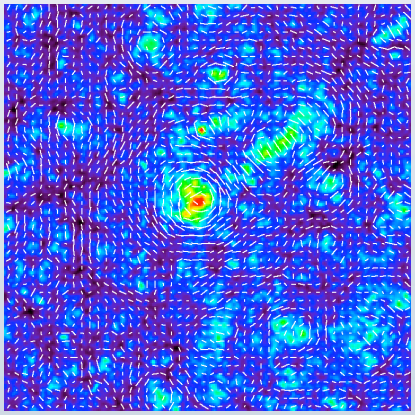
Cluster density

Count clusters of galaxies at different distances → expansion rate and growth of structure as function of time
dV(z), f(z)

Baryon Acoustic Oscillations



Weak lensing

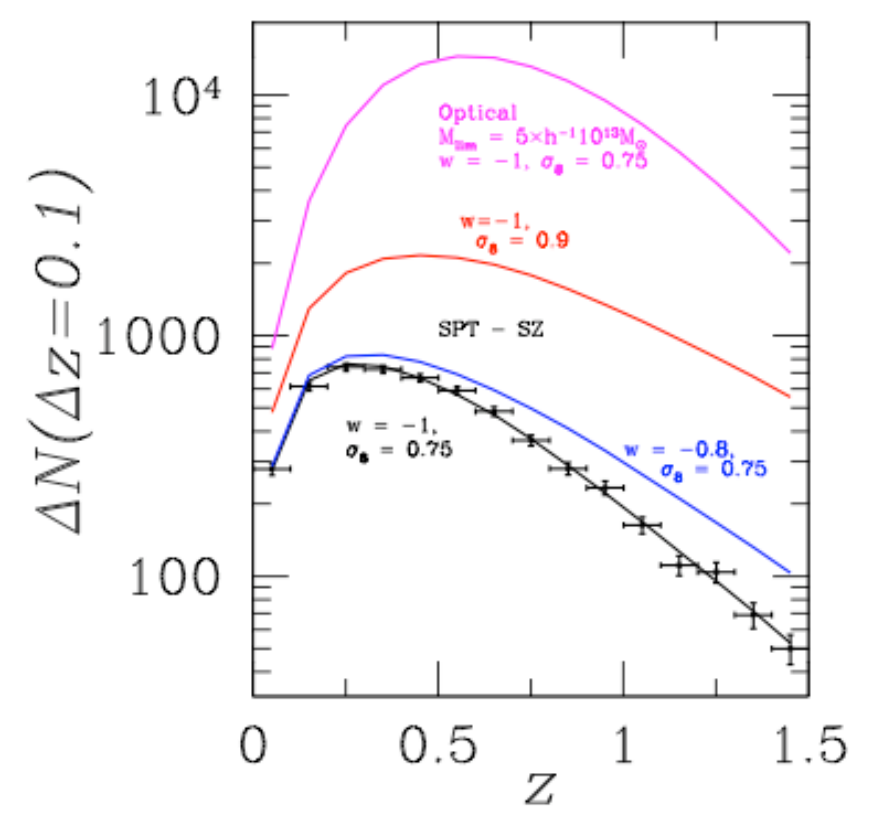


Cluster density

Strategy: structure and geometry probe

- Obtain number count of galaxy clusters per unit volume.
- Combine counts with cluster mass predictions (theory) + selection function + observable-mass relationship.

$$\frac{d^2N}{dzd\Omega} = \frac{c}{H(z;\theta,w)} D_A^2 (1+z)^2 \int_0^\infty f(O,z)dO \int_0^\infty p(O\,|\,M,z)\frac{dn}{dM}(z;\theta)dM$$



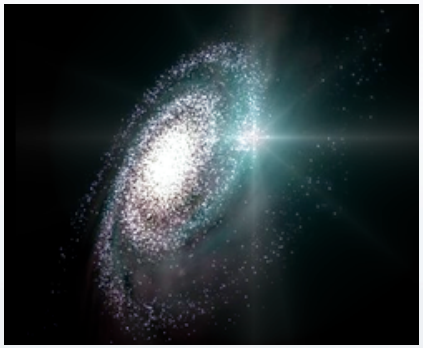
DES:
- Measure ~1e5 rich clusters up to z>1
- Mass using partnership with South Polar Telescope (using Sunyaev-Zeldovich effect)

Systematics: observable-mass relation, completeness and purity of cluster sample

Very sensitive, mass uncertainty, untested for cosmology

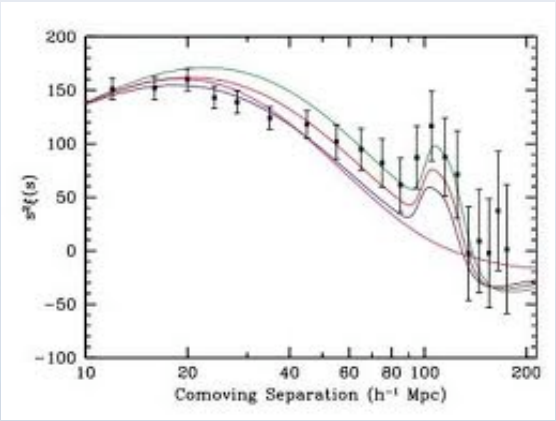
Dark Energy Task Force determined the most promising probes

Supernovae Ia



Cluster density

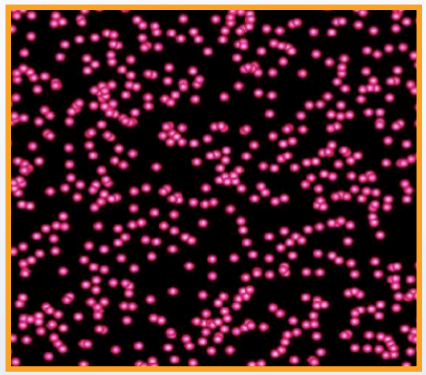
Baryon Acoustic Oscillations

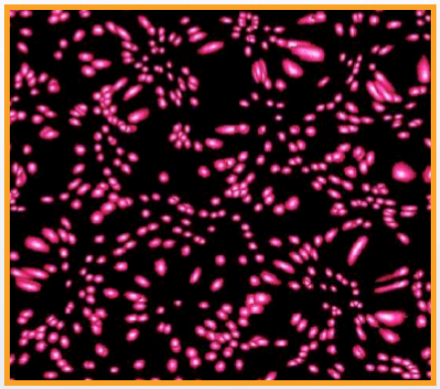


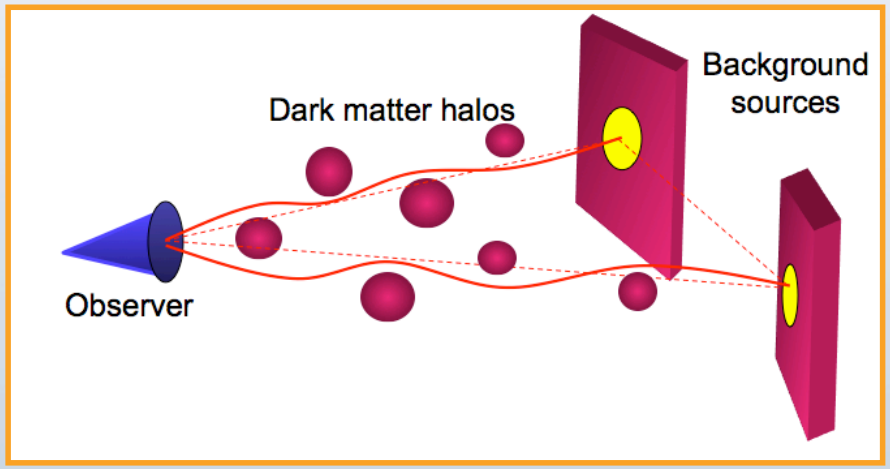
Weak lensing

Measure **background light distortions due to foreground mass** at different distances → expansion rate and growth of structure as function of time

Weak lensing







Strategy: structure and geometry probe
- Statistical measurement of distortions of background objects created by intervening matter (shear-shear) in redshift shells.
- Foreground galaxy cross-correlations with shear (galaxy-shear).
- It means measuring shapes and redshifts.

DES:
- Shapes of ~2e8 galaxies.
- PSF < 0.9” FWHM

Systematics: photo-z’s, PSF anisotropy, shear calibration

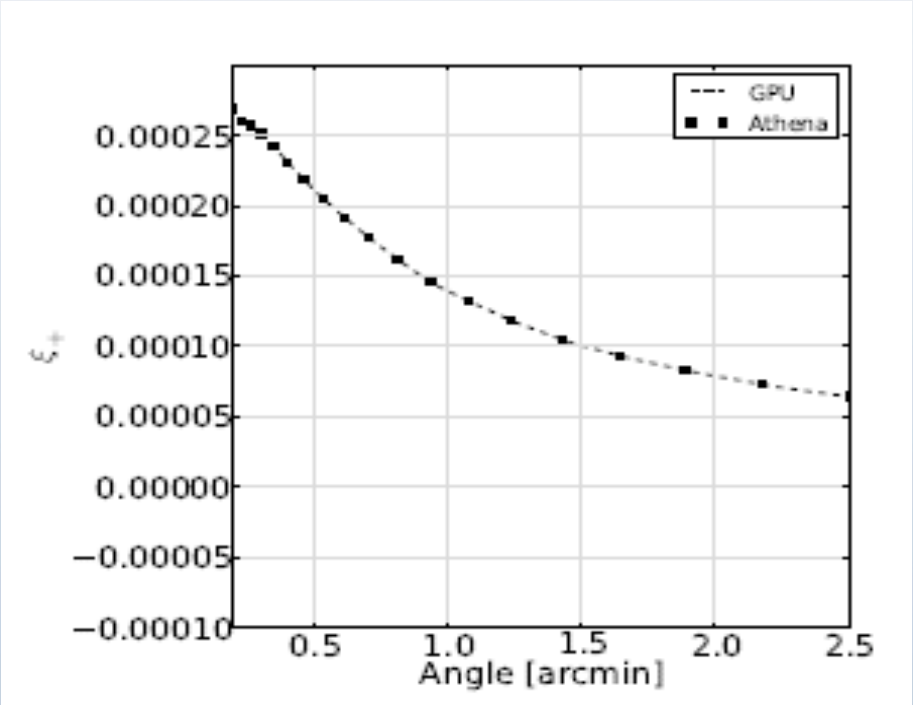
Theoretically well-founded, instrumental systematics

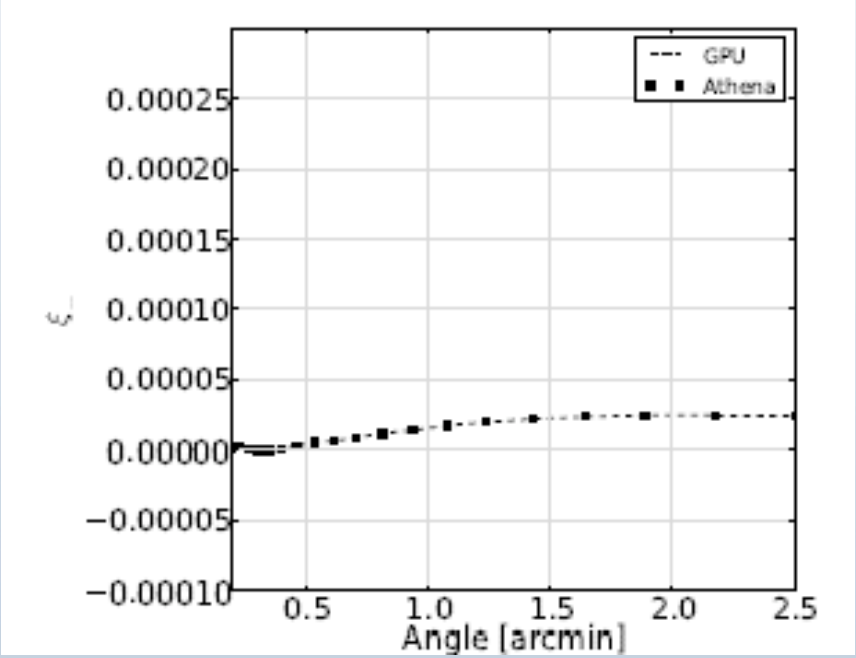
Weak-lensing: the shear-shear correlation (@CIEMAT)

Podemos medir las correlaciones entre las amplitudes o las orientaciones de los *shears*. Contiene información cosmológica en función de z.

$$\xi_{\pm}(\theta) = \langle \gamma_t \cdot \gamma_t \rangle(\theta) \pm \langle \gamma_\times \cdot \gamma_\times \rangle(\theta)$$

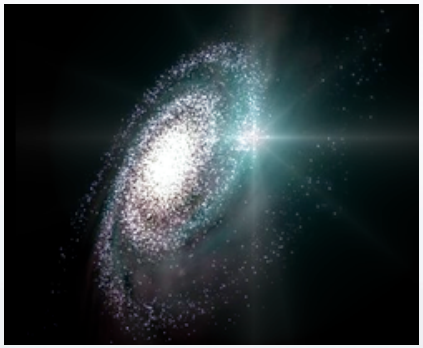
Desarrollado código muy rápido en GPU para atacar el problema computacional (Miguel + Rafa + Nacho + Eusebio + Juanjo)





Dark Energy Task Force determined the most promising probes

Supernovae Ia

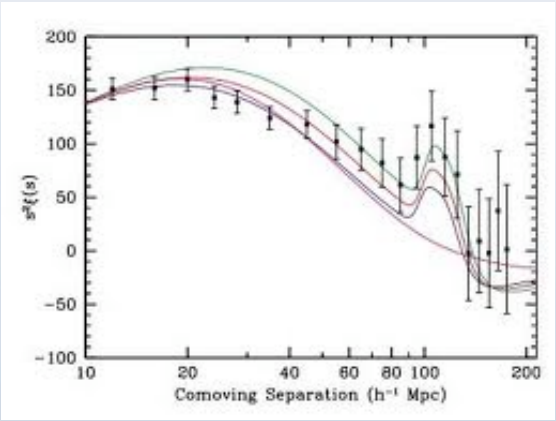


Cluster density

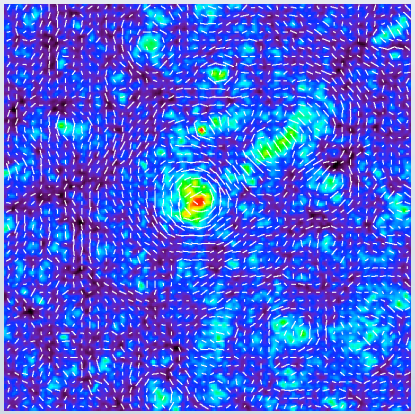
Redshift Space Distortions

Measure how mass distorts redshift determination → growth of structure as function of time f(z)

Baryon Acoustic Oscillations



Weak lensing

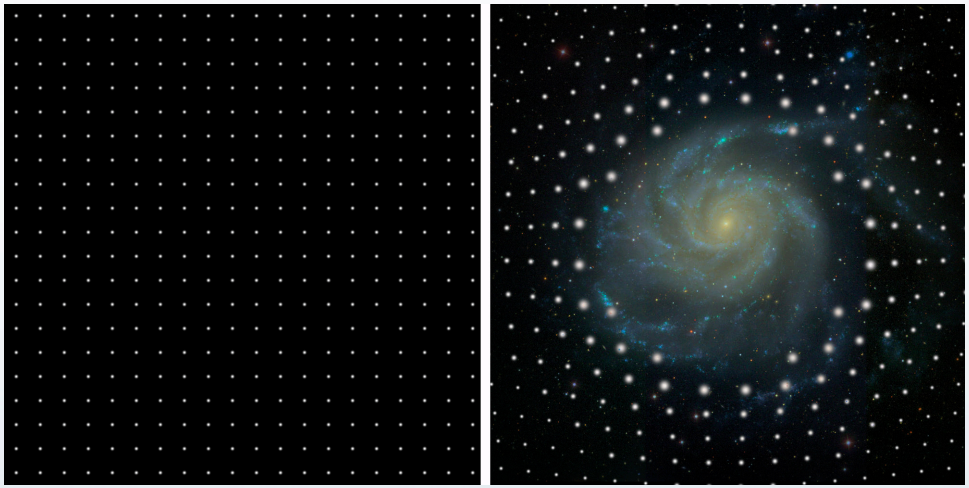


Magnification Bias

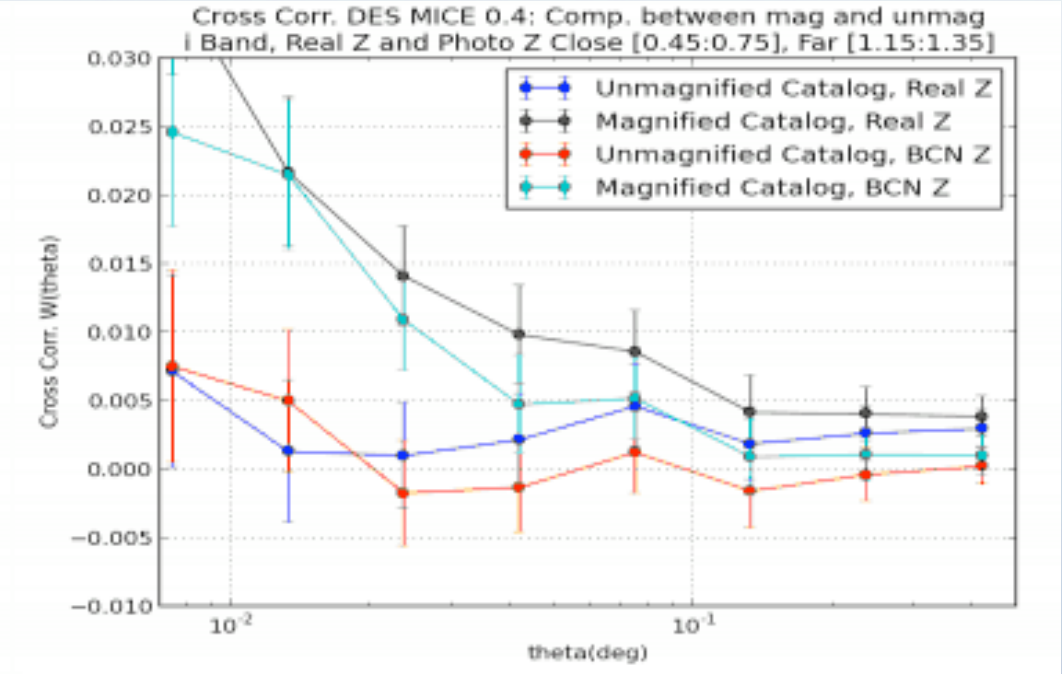
Measure cross-correlations between foreground and background galaxies → growth of structure as function of time f(z)

In later years, new probes have been identified.

Magnification bias (@ CIEMAT)



Correlación de galaxias a distintos redshifts → COSMIC MAGNIFICATION

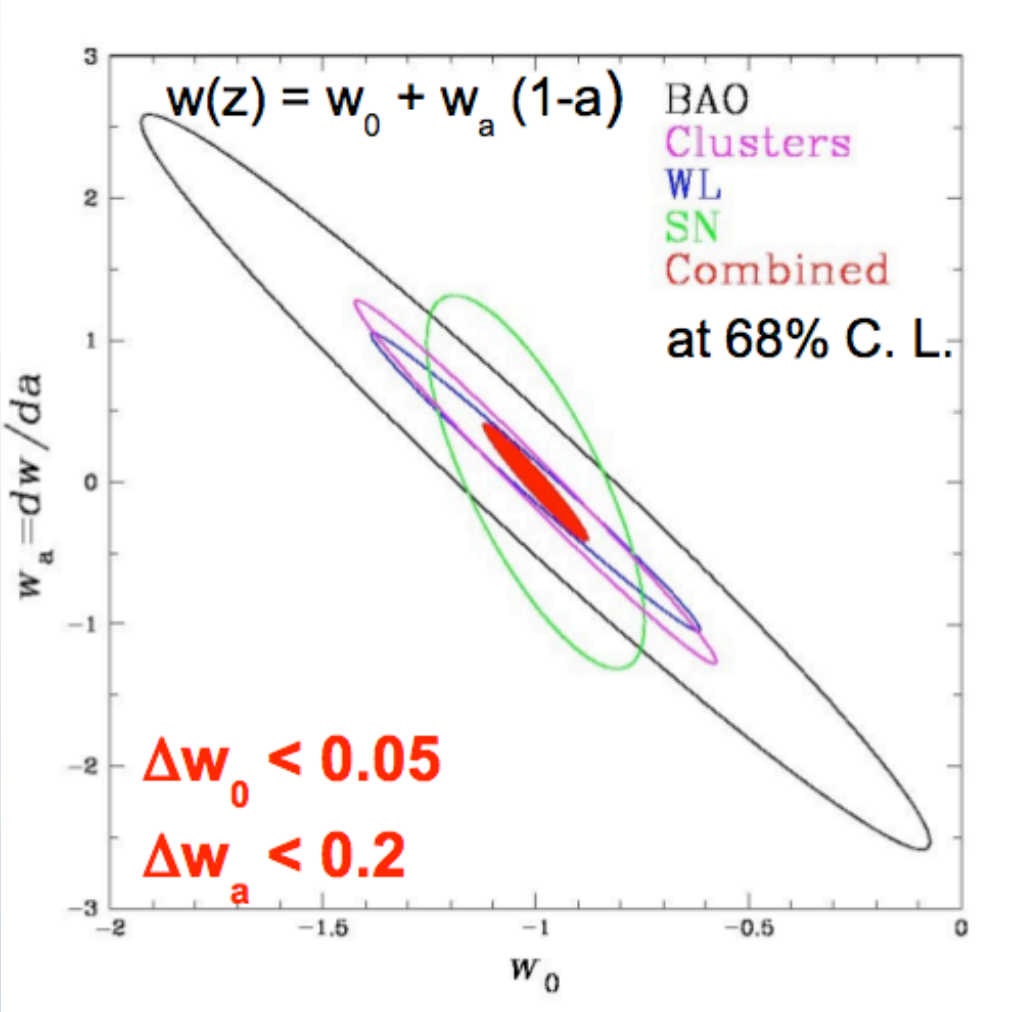


Buscamos los sistemáticos más relevantes y una posible detección en los primeros datos de DES, junto con las perspectivas para DES-5000 y PAU. (tesis de Rafa).

Expected performance

Assumptions:

- statistical+photo-z systematic errors only
- spatial curvature, galaxy bias marginalized
- Planck CMB prior
- Factor 4.6 improvement over Stage II
- Deep systematics study



DES-Spain contributions

- Partners since almost the inception of the project, full membership.
- Types of contributions:

  Hardware (CCD electronics: design, production, test)
  - **CIEMAT**, IFAE

  Simulations (cosmological)
  - IEEC

  Mountain-top software (guiding)
  - IEEC

  Quality Assessment (data challenges, science verification).
  - **CIEMAT**

  Contribution to CCD characterization
  - IFAE, (IEEC, CIEMAT)

  Outreach (Spanish version of the official webpage)
  - **CIEMAT**

  Science (LSS, photo-z, clusters, supernovae, weak lensing, theory)
  - **All**

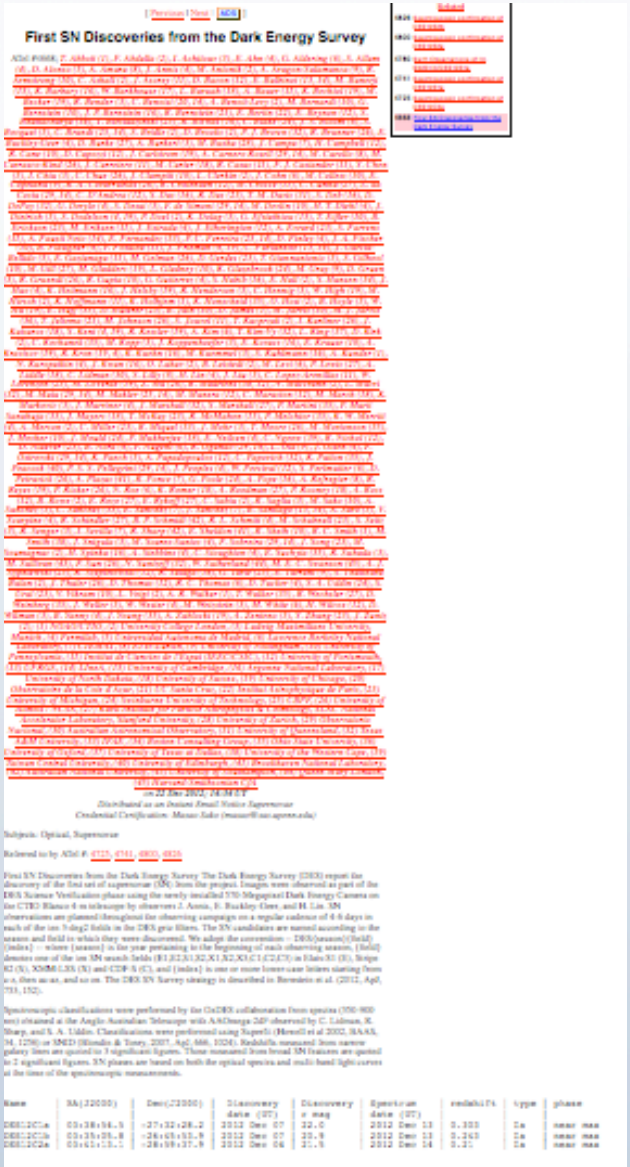
  Management
  - **All**

CIEMAT contributions (science)

Large Scale Structure and Quality Analysis

- Quality analysis of large scale simulations (Javi, Eusebio, Rafa)
- Quality analysis of detector simulations, early data (Nacho)
- Analysis of magnification bias (Rafa, Nacho)
- BAO analysis, counts-in-cells (Eusebio, Javi)
- Cluster mass-observable calibration and cluster correlation function (Julia)
- Development of GPU code for correlation functions (Miguel, Rafa, Nacho, Eusebio)
- Morphological classifiers (Nacho)

¡Papers! ¡Bien!


First SN Discoveries from the Dark Energy Survey

“First SN discoveries from the Dark Energy Survey”
Astronomer’s Telegram #4668

* (Método medidas BAO angulares)
E.Sánchez, A.Carnero et al. (MNRAS 2011)
* (Aplicación a datos de Sloan Survey)
A.Carnero, E.Sánchez et al. (MNRAS 2012)
* (Método medidas BAO radiales)
E.Sánchez, F.J.Sánchez, I.Sevilla et al. (MNRAS 2013)
* (Método de separación estrellas/galaxias en DES)
M.Soumagnac, I.Sevilla et al. (MNRAS, enviado)
* (Cálculo de funciones de correlación con GPUs)
M.Cárdenas-Montes, E.Sánchez, I.Sevilla, R.Ponce
et al. (Computing Physics, enviado).
* Varios más en escritura.

Otros:
*Tesis de Aurelio
*Trabajos de fin de máster de Aurelio, Rafa, Penélope
*Tres tesis (Julia, Rafa y Javi) y otro trabajo fin de máster (Manolo) en marcha.

Resumen

• **DES ha comenzado a tomar datos en septiembre**. NO forman parte del survey final si no que se emplean para probar las capacidades científicas. Aun así, resultados en “opportunity science” (supernovas, lentes individuales, papers técnicos…)

• **El funcionamiento de la cámara ha sido excelente** (reconocido por usuarios externos). Pequeños problemas hardware: no-linealidad, CCD defectuoso, cross-talk en CCD, reflejos sobre la cámara. Problemas no tan pequeños: calidad de imagen, ineficiencias del survey.

• **El survey final comienza en septiembre 2013.** Primeros papers de colaboración para finales de año.

• **Muchos papers (con participación directa CIEMAT) en marcha.**

http://www.darkenergysurvey.org
(también en Facebook)

DES-Spain collaborators

Consortium currently made up of the following institutions / people:

CIEMAT (Madrid)
E. Sánchez (fac.)
J. Campa (predoc)
J. Castilla (eng.)
G. Martínez (eng.)
R. Ponce (predoc)
F.J. Sánchez (predoc)
I. S. (postdoc)
J. de Vicente (eng.)

ICE (IEEC/CSIC) (Barcelona)
E. Gaztañaga (fac., IP)
J. Asorey (predoc)
A. Bauer (postdoc)
C. Bonnett (postdoc)
F.J. Castander (fac.)
M. Crocce (postdoc)
M. Eriksen (predoc)
S. Farrens (postdoc)
P. Fosalba (fac.)
K. Hoffman (predoc.)
S. Jouvel (postdoc)
S. Serrano (eng.)

IFAE (Barcelona)
R. Miquel (fac.)
O. Ballester (eng.)
L. Cardiel-Sas (eng.)
E. Fernández (fac.)
P. Martí (predoc)
C. Sánchez (predoc)

UAM (Madrid)
J. García-Bellido (fac.)
D. Alonso (predoc)
A. Bueno (predoc)
S. Nesseris (postdoc)

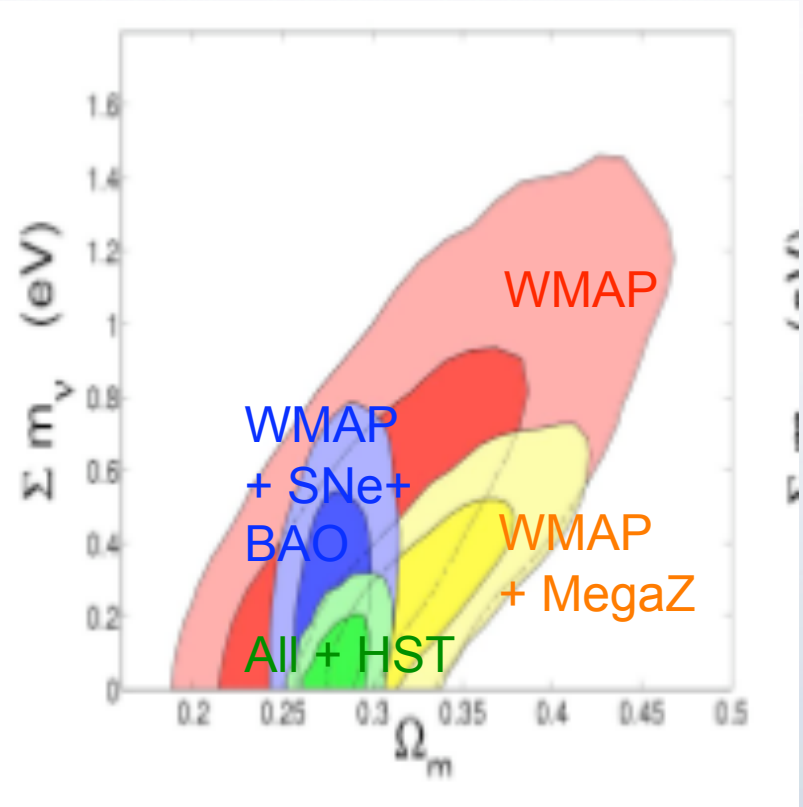
Currently seven faculty members + several students, engineers, postdocs (~30 total)

Neutrino mass constraints with in DES

A photometric survey such as DES
can constrain the sum of neutrino masses.

Currently limit is $\Sigma m_\nu <\sim 0.3$ eV (95% CL)

In combination with Planck, can constrain
to $\Sigma m_\nu <\sim 0.1$ eV (95% CL, Lahav et al. 2010)



Thomas, Abdalla, Lahav 2010

Also see Lesgourgues & Pastor: astro-ph/0603494

Summary

• The **Dark Energy Survey** is an international project to characterize the dark energy equation state ($\sigma(w_0)=5\%$ and $\sigma(w_a)=20\%$).

• This is will be done building a **wide field imaging camera at the Blanco telescope** to simultaneously use the four probes recommended by the DETF: **supernovae; cluster density; weak lensing tomography; baryon acoustic oscillations**.

• A big effort is going into **understanding the systematics** from astrophysical effects.

• Huge **legacy value**, valuable **facility instrument** for the community.

• Survey to start scientific operations tomorrow(!) for five years.

http://www.darkenergysurvey.org
(also can follow on Facebook for latest news)

Some references on arXiv

http://www.darkenergysurvey.org
(also can follow on Facebook for latest news)

DES Collaboration astro-ph/0510346 DES White Paper (outdated)

Albrecht et al. astro-ph/0609591 Report of the Dark Energy Task Force

Frieman et al. astro-ph/0803.0982 The accelerating Universe

Weinberg et al. astro-ph/1201.2434 Observational Probes of Dark Energy

Durrer & Maartens astro-ph/0811.4132 Dark Energy & Modified Gravity