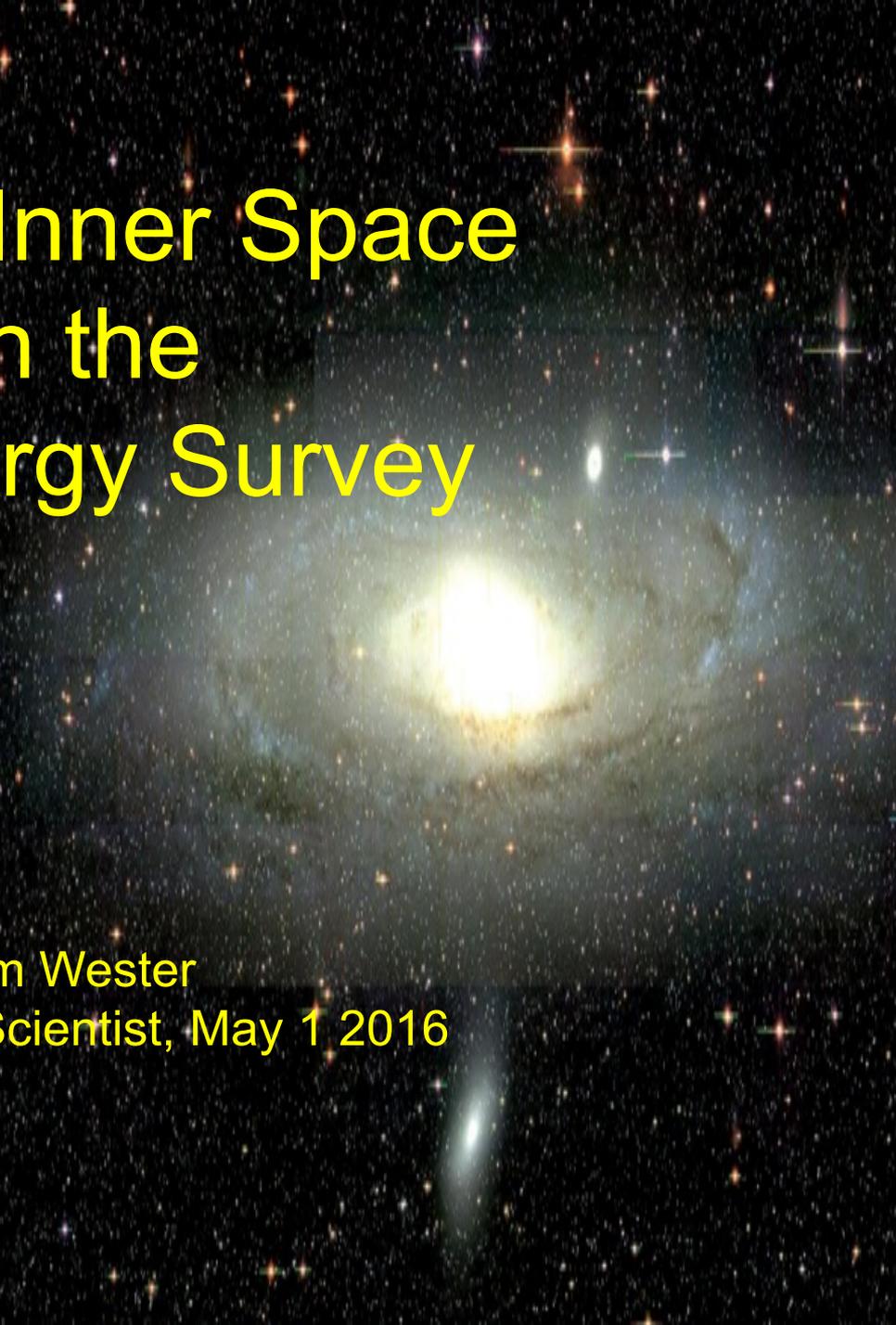
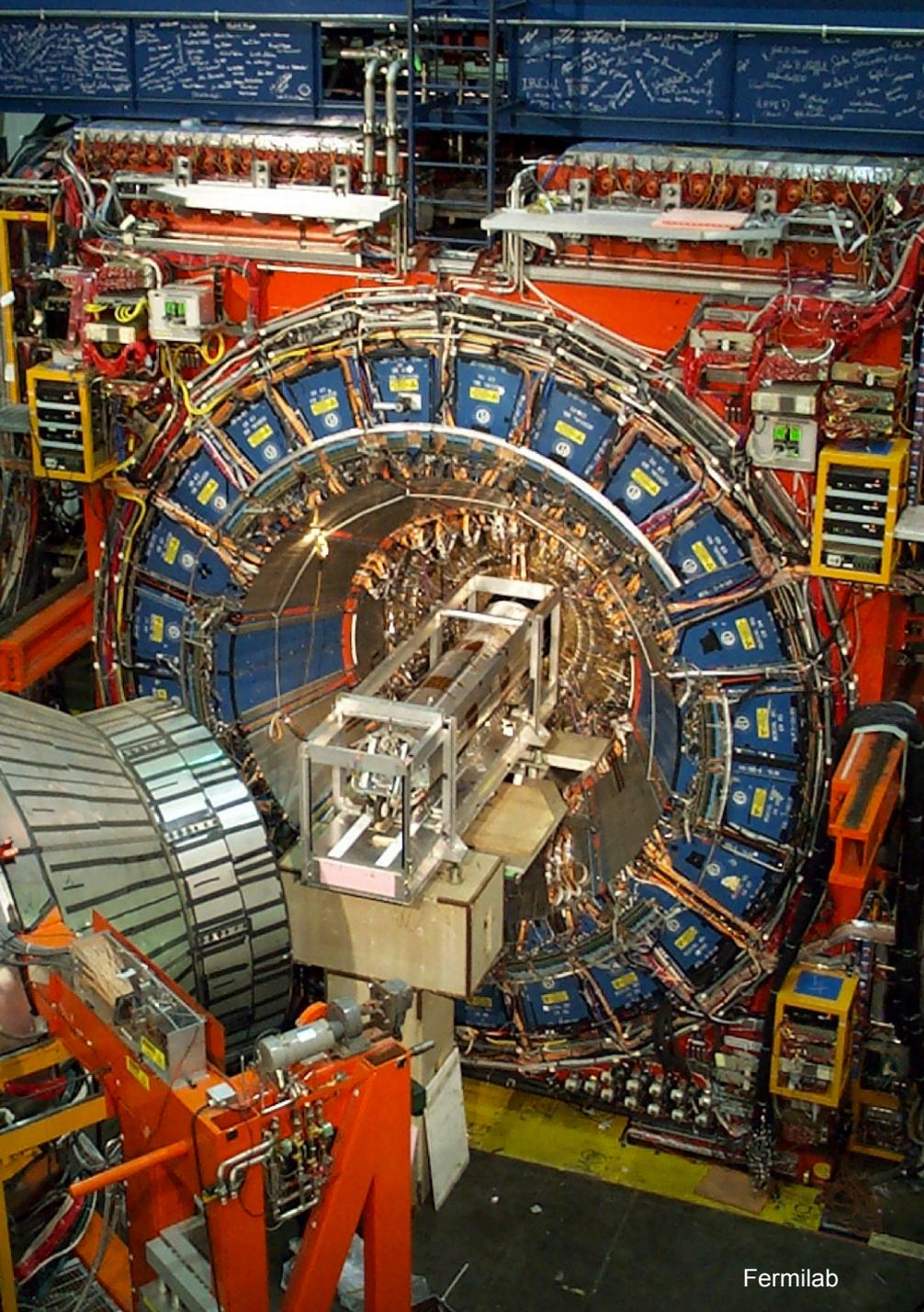
A complex network of blue lines representing the cosmic web, with a single red line extending from the center towards the top right. The lines are dense and tangled, radiating from a central point.

Exploring Inner Space with the Dark Energy Survey

A large, bright, yellowish-white galaxy cluster with a diffuse, blueish-purple halo, set against a dark background filled with numerous smaller stars.

William Wester
Fermilab, Ask-a-Scientist, May 1 2016

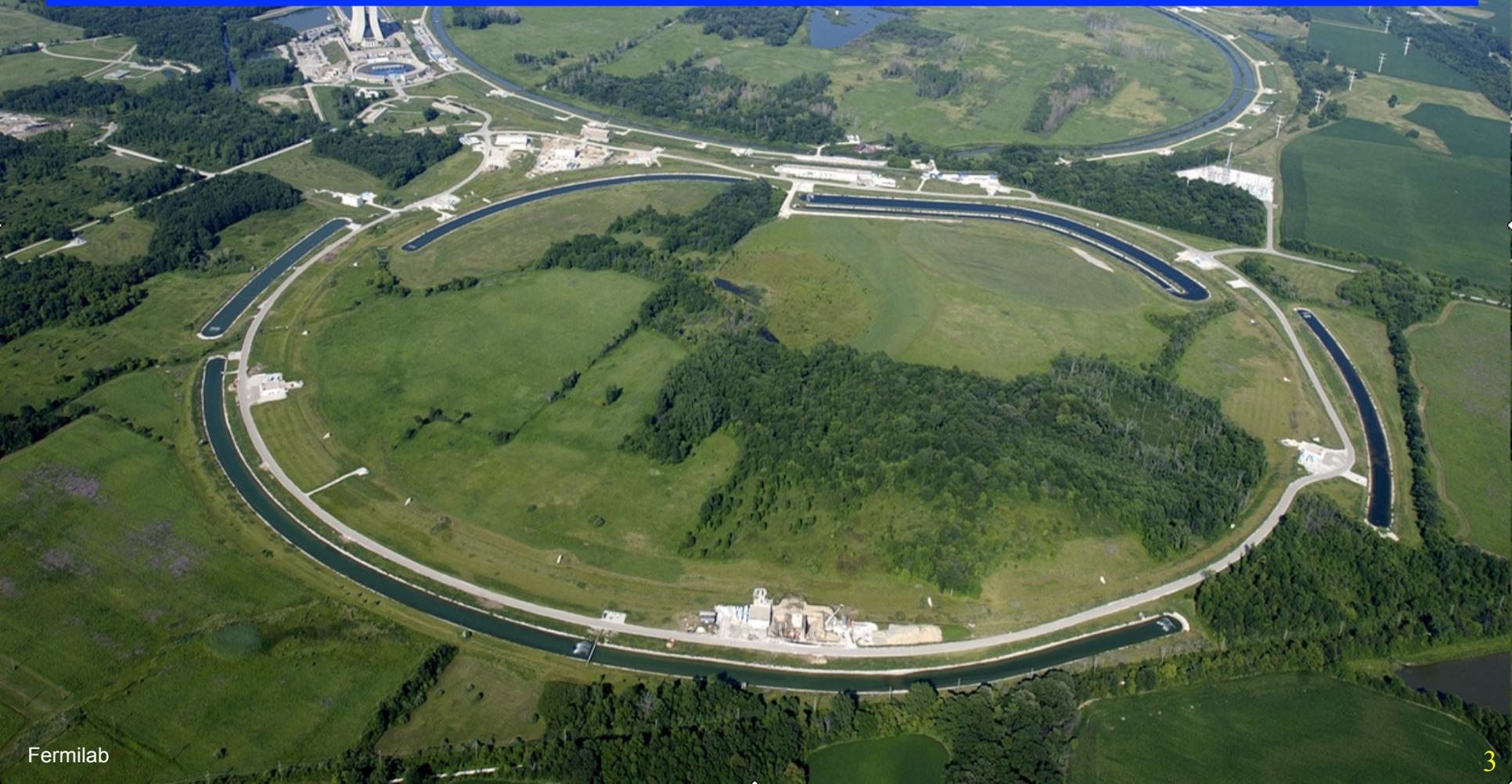


Fermilab

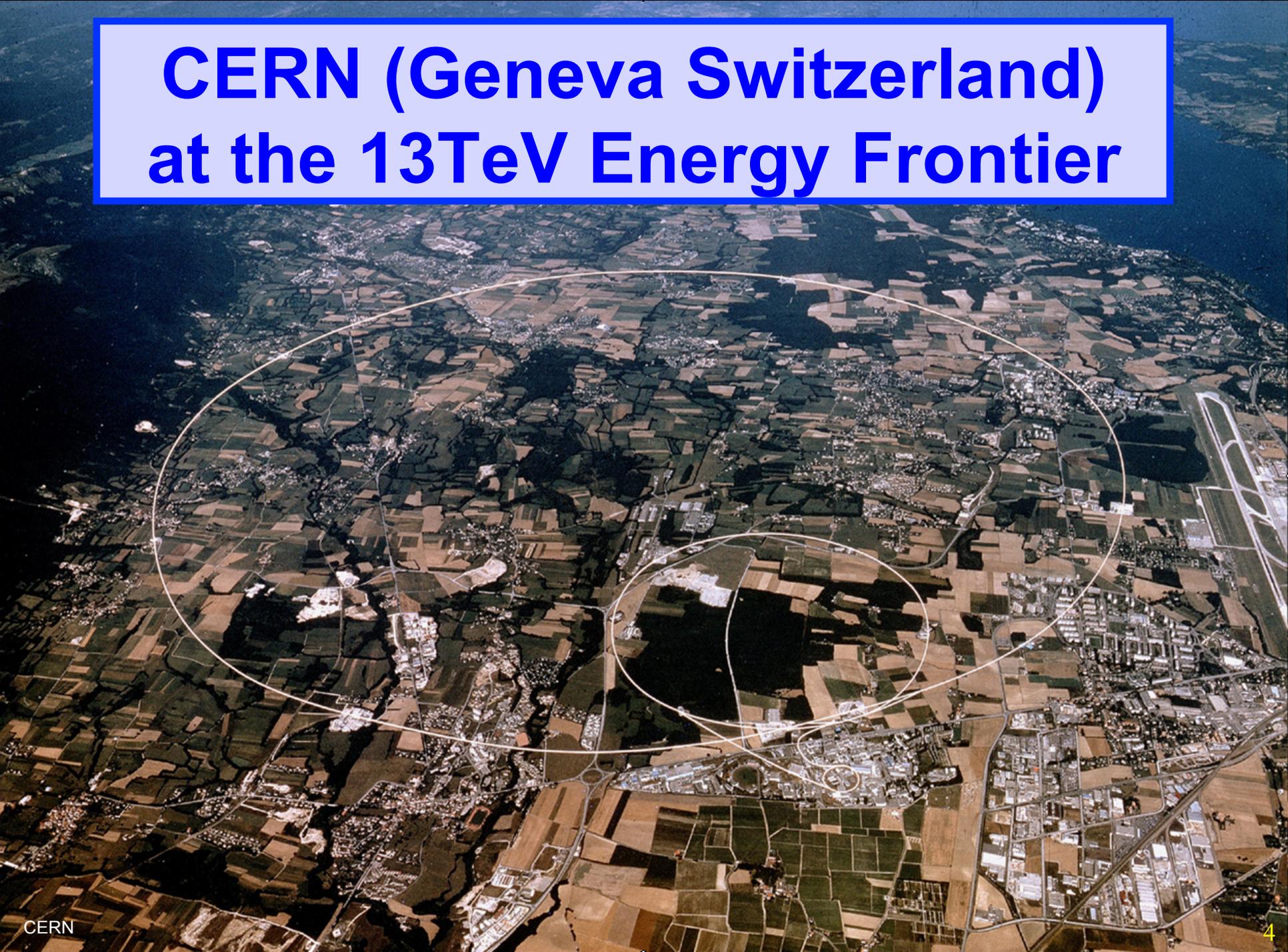


NOAO/AURA/NSF²

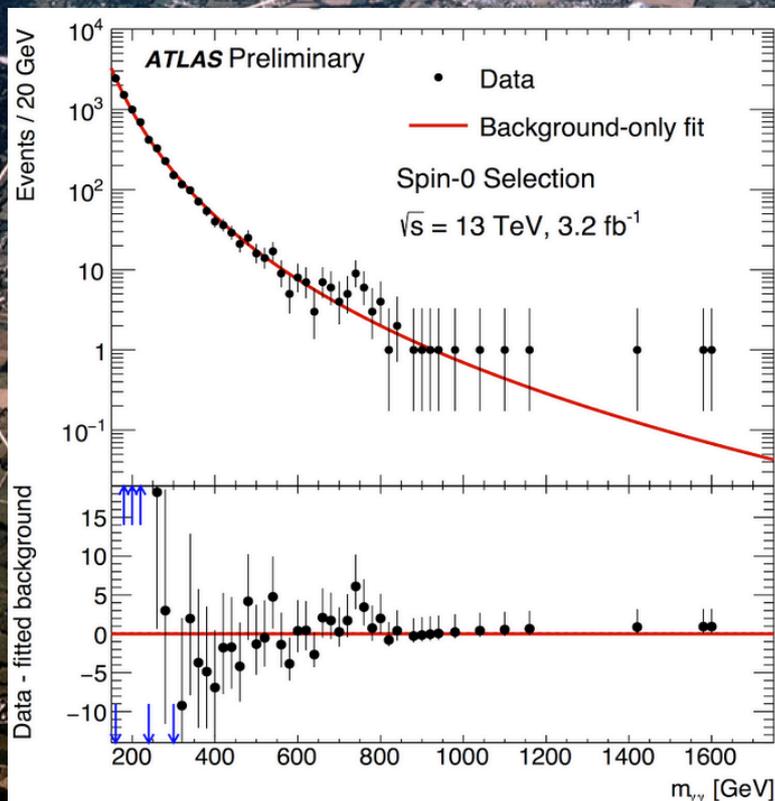
**Fermilab – ~25 yrs as the world's
most powerful atom smasher!
Now the most intense ν beams!**



CERN (Geneva Switzerland) at the 13TeV Energy Frontier



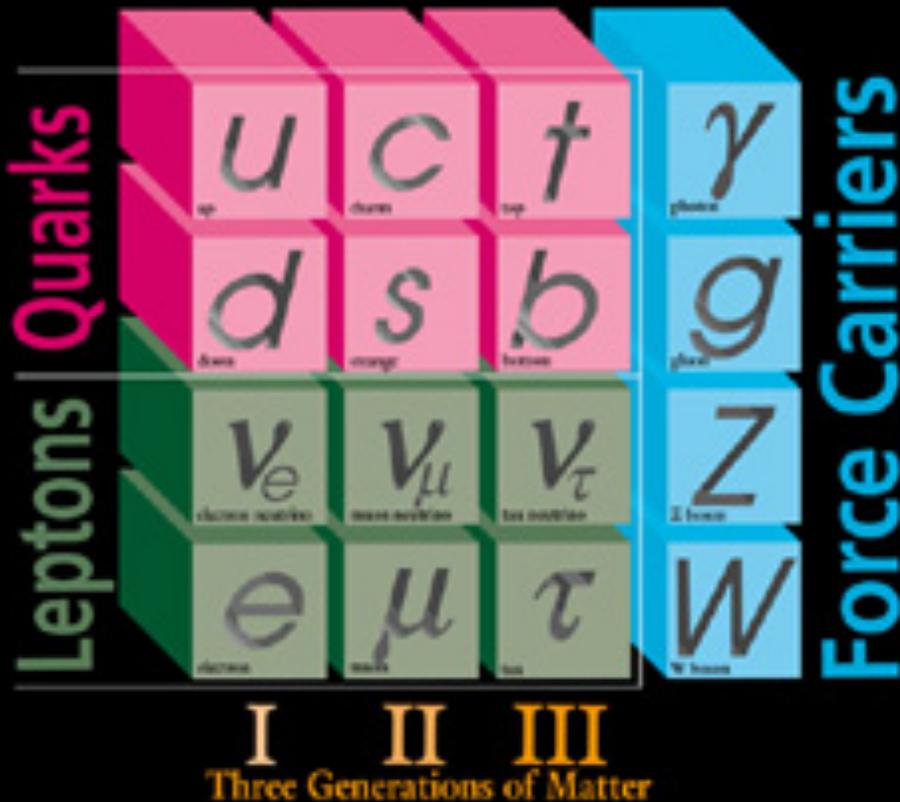
CERN (Geneva Switzerland) at the 13TeV Energy Frontier



Maybe??? something
new at 750 GeV is
emerging (CMS too!)

What we know about particles

ELEMENTARY PARTICLES



The Standard Model:

-Quarks

- Proton: uud
- Neutrons: udd

19 parameters+

ν parameters

-Leptons

- Electrons
- Muons (cosmic rays)
- Neutrinos (beam to MN)

-Force Carriers

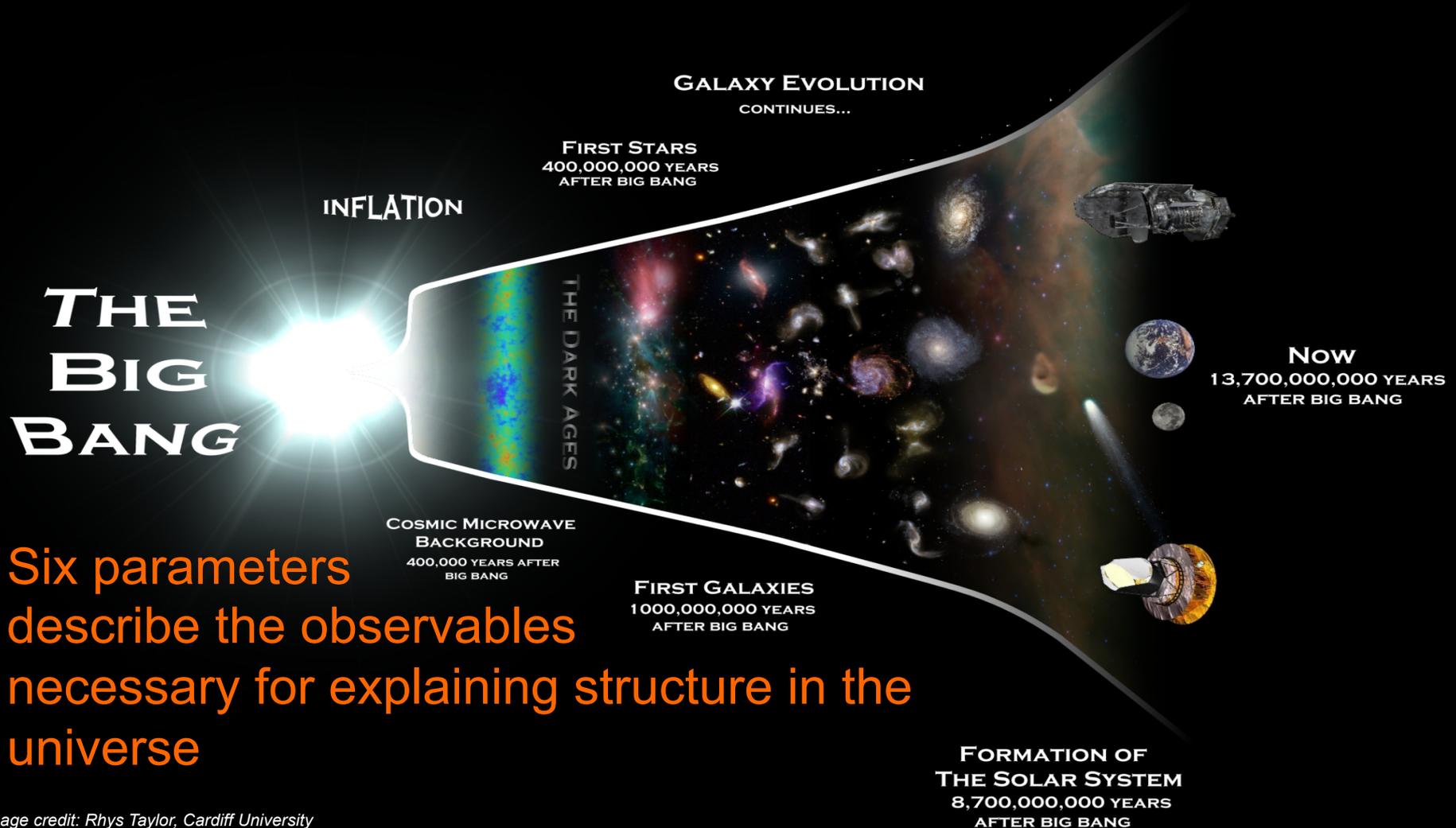
- Photons (Electricity + Magnetism)
- W/Z's (radioactive decay)
- Gluons (hold quarks together)

-Higgs Boson

- Connects Force Carriers
- Gives particles mass

What we know about the universe

The Standard Cosmological Model: Λ_{CDM}



Six parameters describe the observables necessary for explaining structure in the universe

What we don't know



EINSTEIN'S DREAM OF UNIFIED FORCES

Are there undiscovered principles of nature: New symmetries, new physical laws?

How can we solve the mystery of dark energy?

Are there extra dimensions of space?

Do all the forces become one?

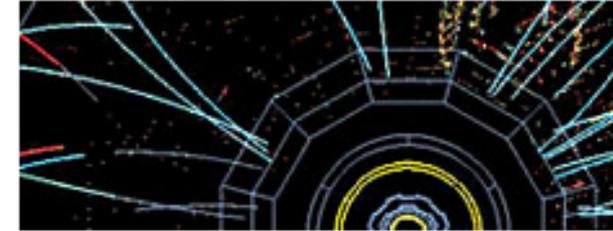


THE PARTICLE WORLD

Why are there so many kinds of particles?

What is dark matter? How can we make it in the laboratory?

Answers lie in developing theories and doing experiments that connect inner and outer space.



THE BIRTH OF THE UNIVERSE

How did the universe come to be?

What happened to the antimatter?

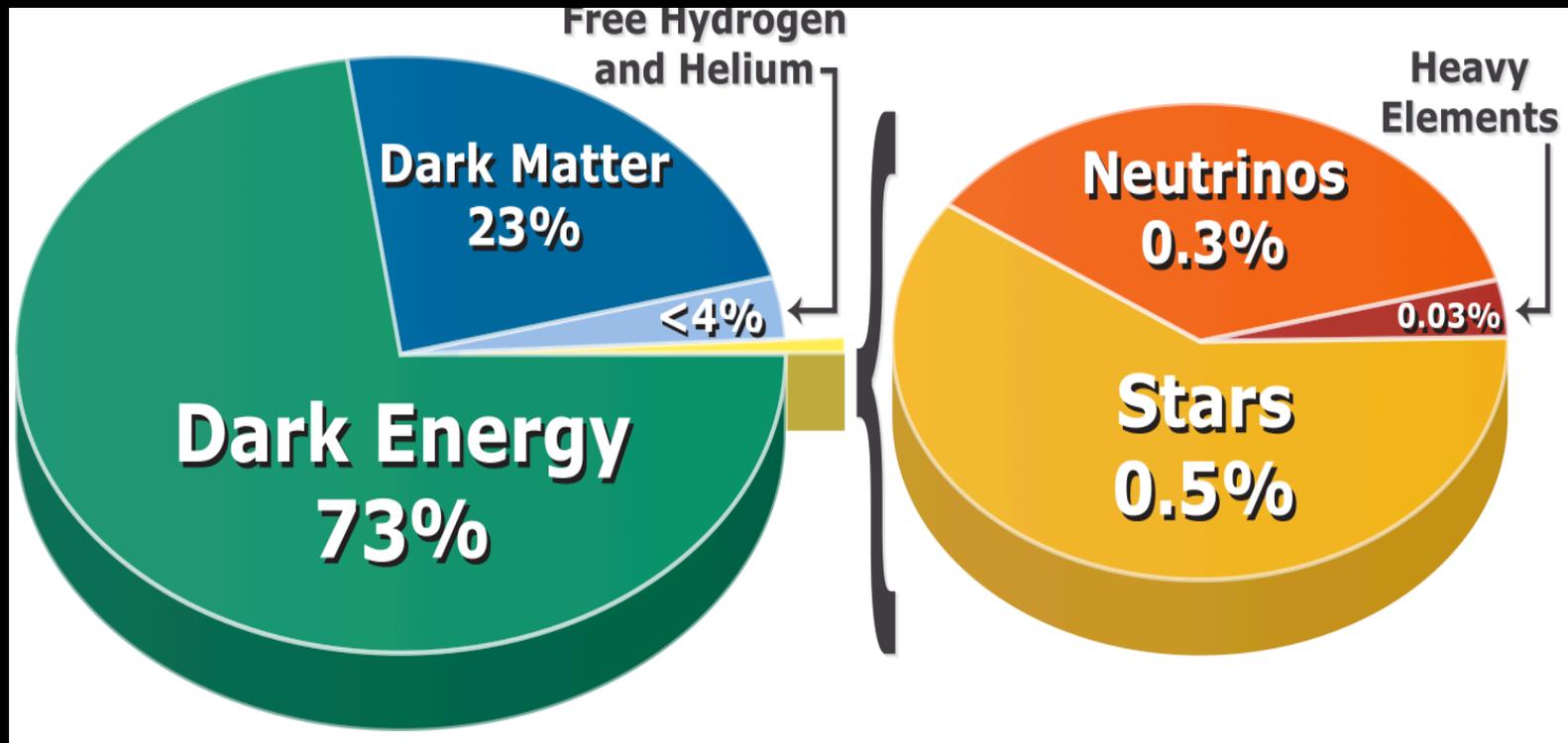
Two Darth Mysteries: Dark Matter and Dark Energy



Two Darth Mysteries: Dark Matter and Dark Energy



Our understanding about the universe is not complete



Only about 4% of the universe is known.
Dark Matter dominates over ordinary matter and then there is Dark Energy which used to be small and now is the largest piece of the energy budget of the universe.

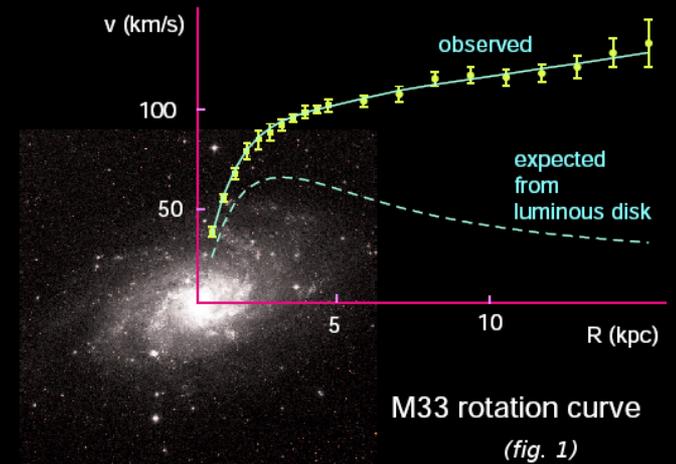
Dark Matter



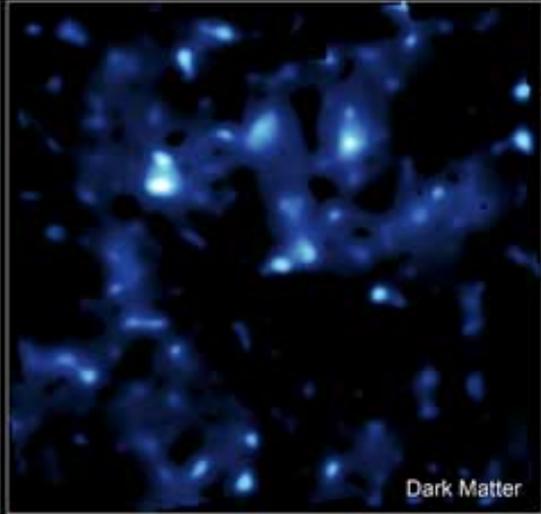
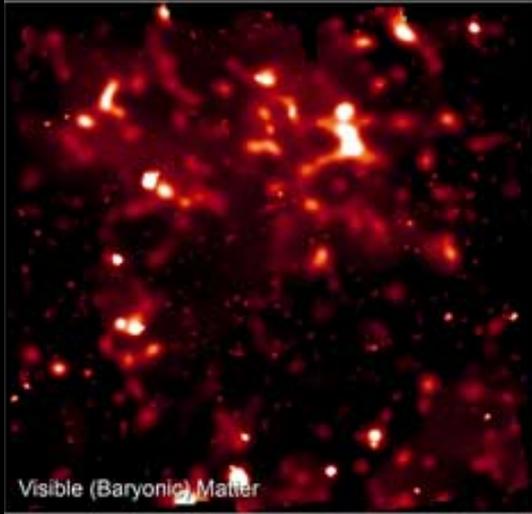
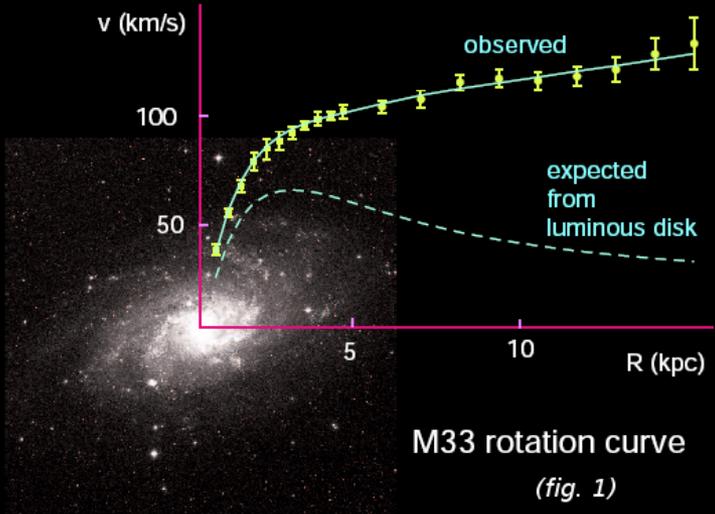
1930s: Jan Oort and Fritz Zwicky notice the amount of light in galaxies and clusters of galaxies underestimate the amount of matter



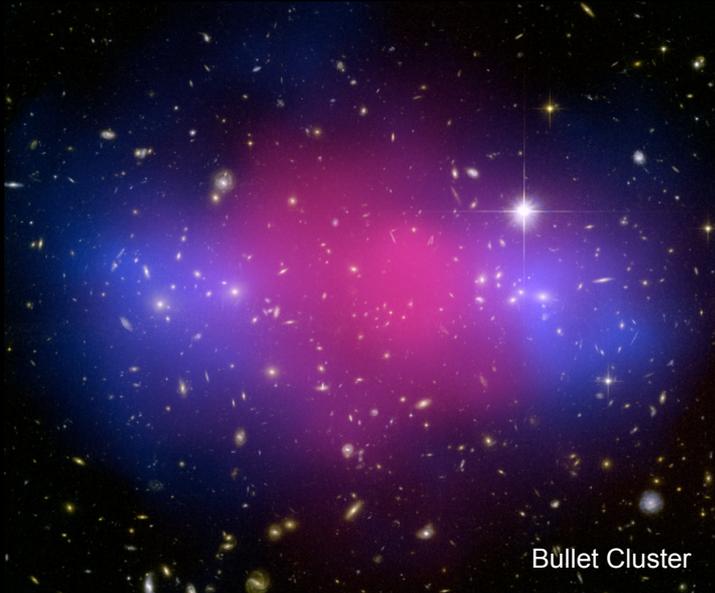
1975-80: Vera Rubin makes precise measurements of the velocities of stars around nearby galaxies firmly establishing "dark matter"



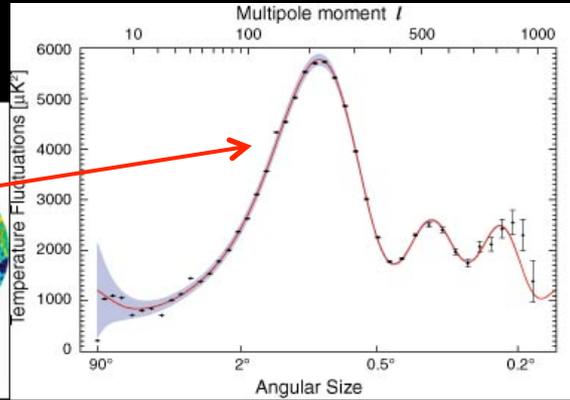
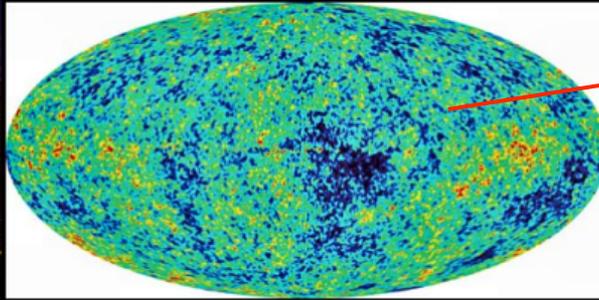
Evidence for Dark Matter exists on a variety of scales



Distribution of Visible and Dark Matter - Cosmic Evolution Survey
Hubble Space Telescope - Advanced Camera for Surveys

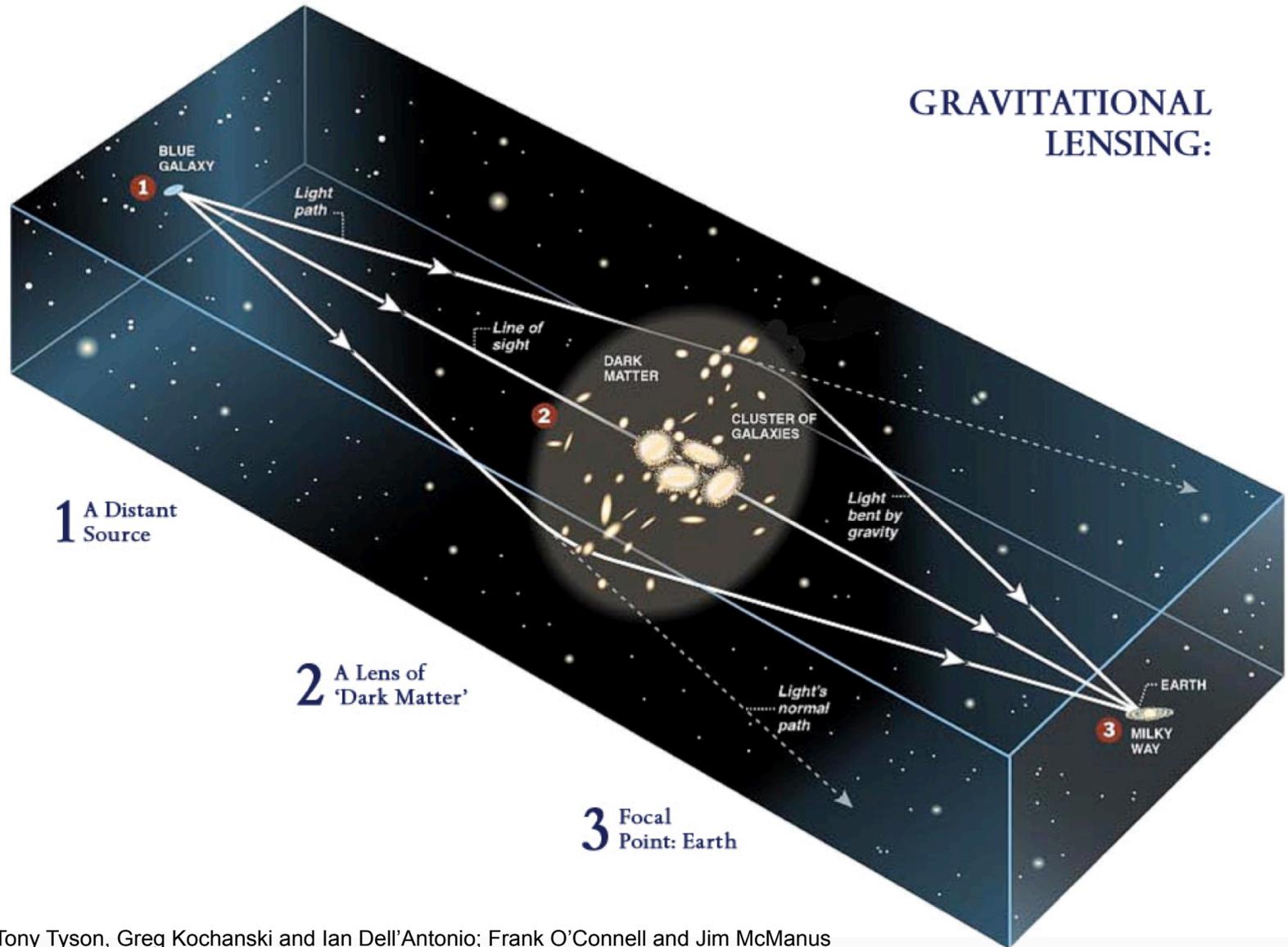


Cosmic Microwave Background Temperature Anisotropy



Gravitational Lensing

GRAVITATIONAL LENSING:

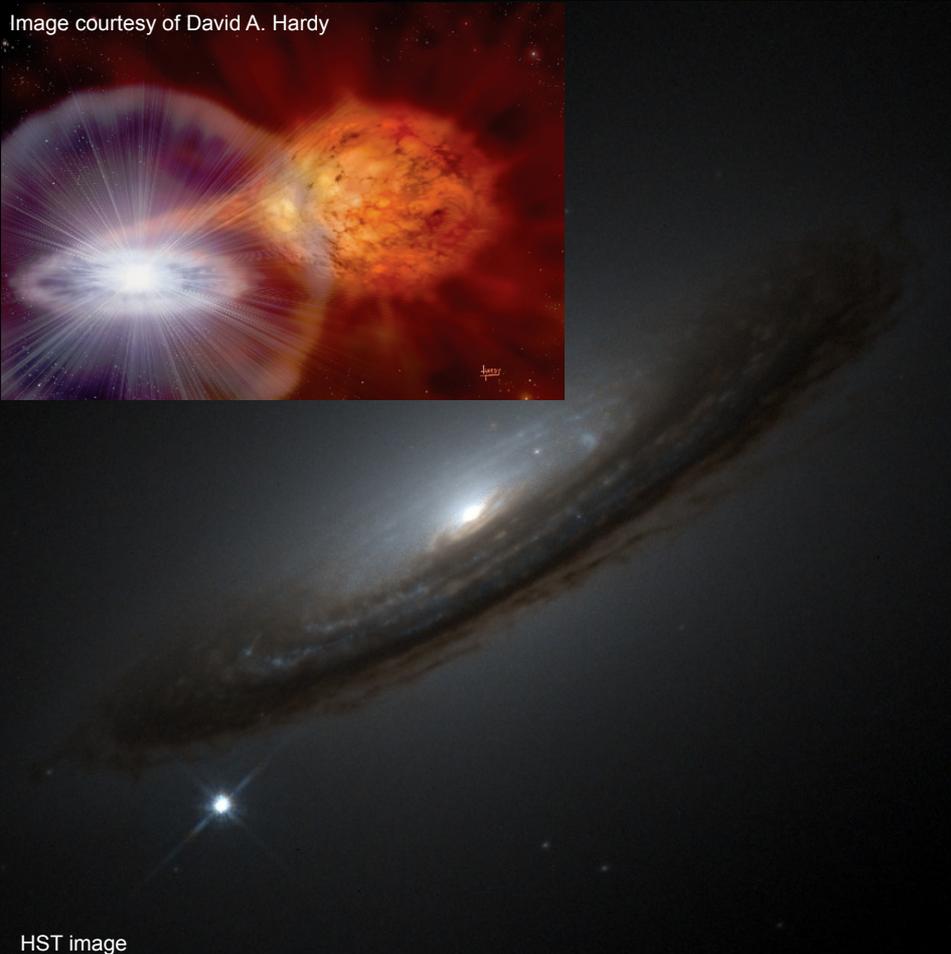


Tony Tyson, Greg Kochanski and Ian Dell'Antonio; Frank O'Connell and Jim McManus

Dark Energy – ~73% of the energy in the Universe

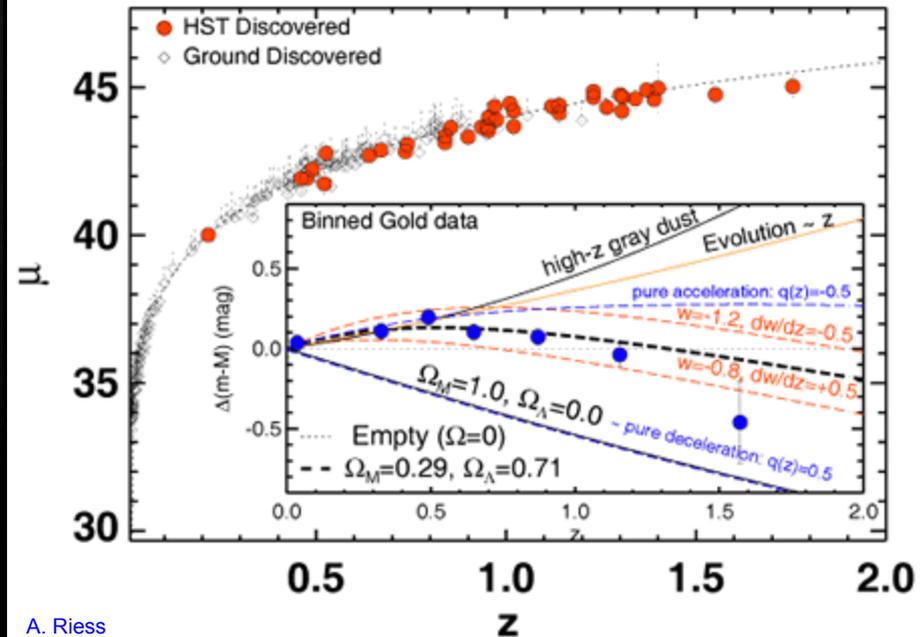
Big surprise in 1998, distant supernova appear dimmer than expected because the universe's expansion is accelerating!

Image courtesy of David A. Hardy



HST image

Use Type Ia supernova and plot the brightness difference as a function of distance (z)



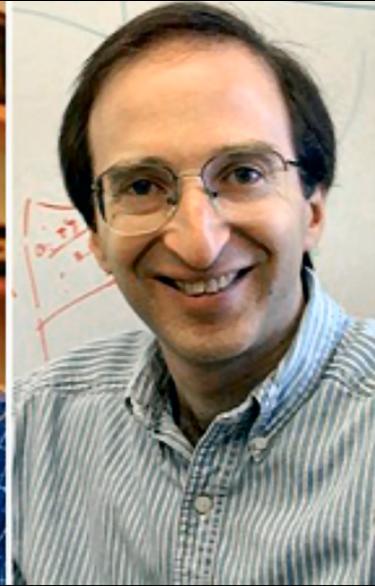
2011 Nobel Prize in Physics



http://www.nobelprize.org/nobel_prizes/physics/medal.html



Adam Riess



Saul Perlmutter



Brian Schmidt

for the discovery of the accelerating expansion of the Universe through observations of distant supernovae

Now, what is the nature of dark energy?

Cerro Tololo Inter-American Observatory (CTIO)

Located at 2200m near La Serena Chile
Excellent weather (except El Niño's)
and seeing conditions
Home to the 4m Blanco telescope



DES Collaboration

450 Scientists

Funding from DOE, NSF, foreign funding agencies, and DES institutions

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

 UK Consortium:
UCL, Cambridge, Edinburgh,
Nottingham, Portsmouth, Sussex

ETH Zurich
LMU Ludwig-Maximilians Universität

 Spain Consortium:
CIEMAT, IEEC, IFAE

 Brazil Consortium:
Observatorio Nacional, CBPF,
Universidade Federal do Rio Grande
do Sul

CTIO



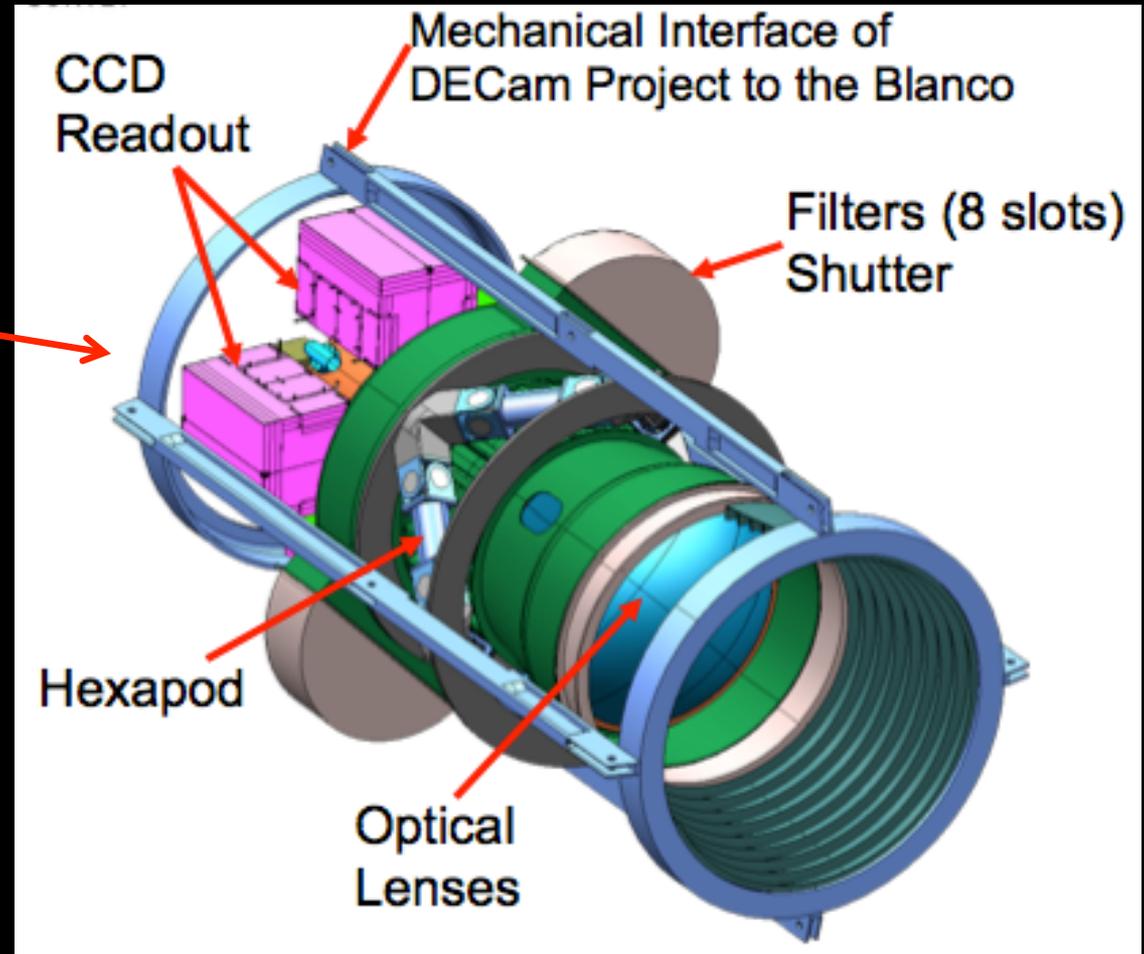
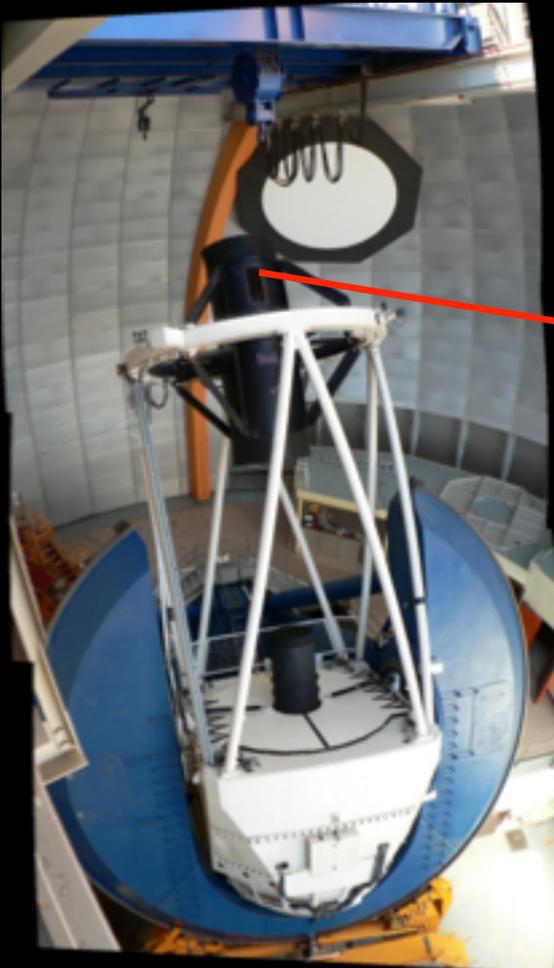
130+ scientists
27 institutions

History of DES

- Fermilab was looking for a next project after the Sloan Digital Sky Survey when an opportunity to build a $\sim 10x$ better new camera for telescope time on a $\sim 10x$ larger telescope
- Also, some of us were used to building silicon detectors for HEP collider experiments
- 2003-2013, Design, R&D, project approval, (international) agreements, construction, shipping, installation, data software, commissioning, and collecting first data.
- First three seasons: 2013-2016

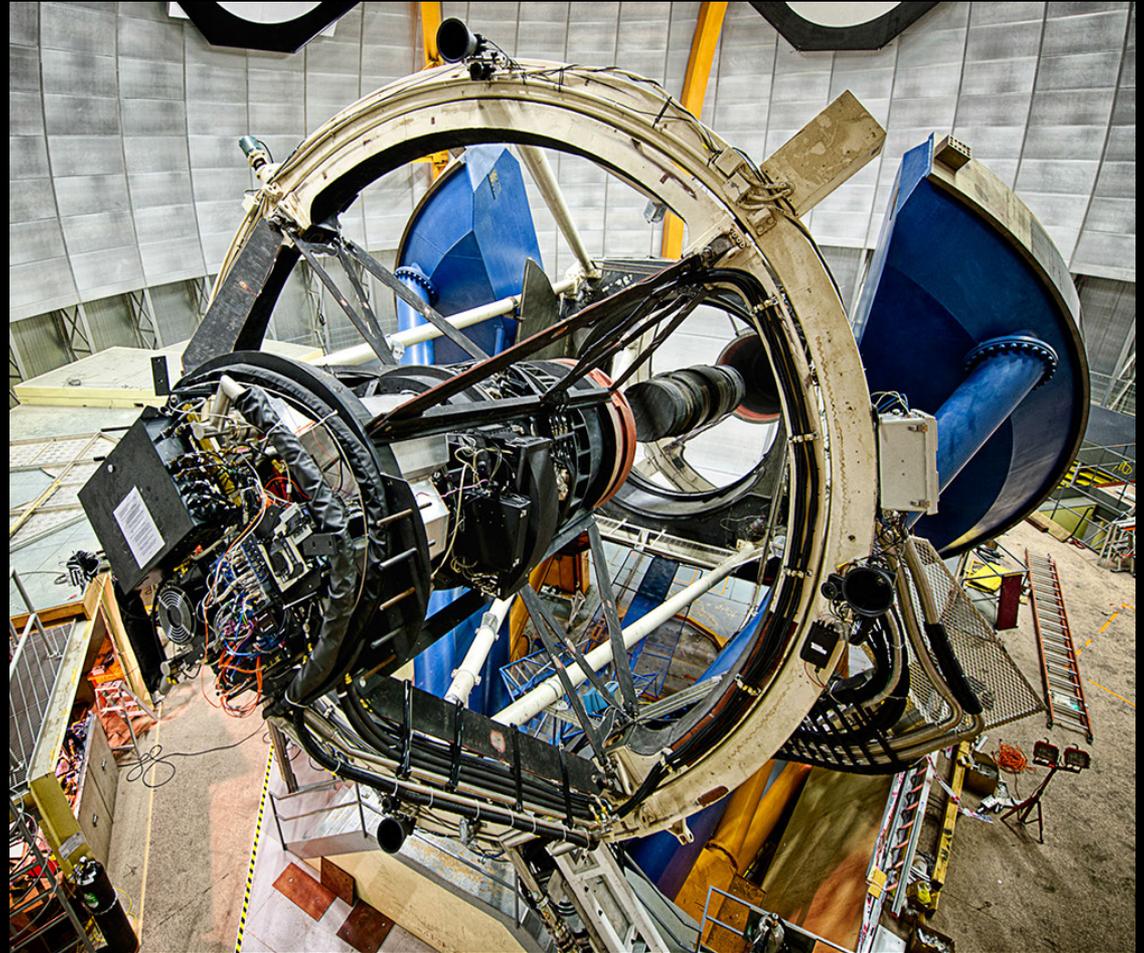
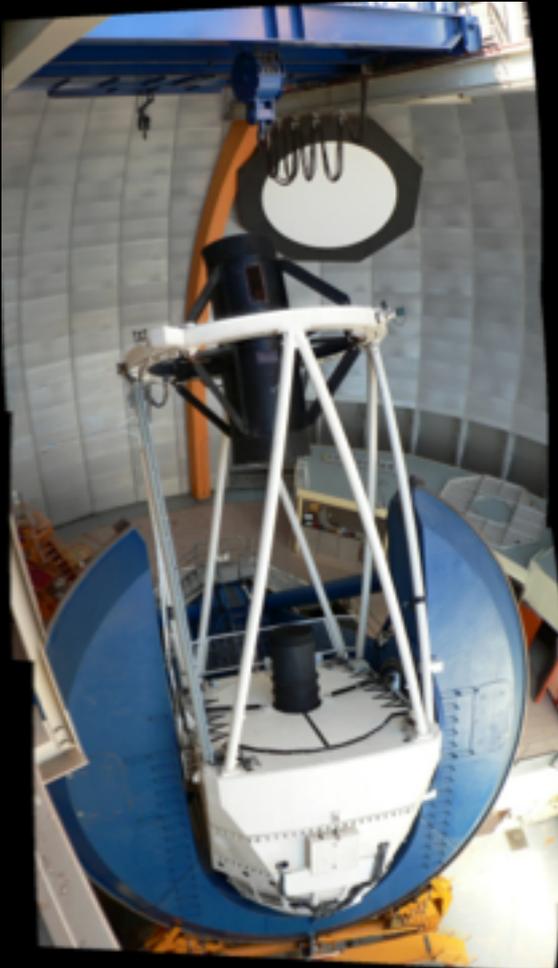
DECam

The deliverable was a new prime focus cage camera with a large CCD focal plane, filters, optics, and mechanical support



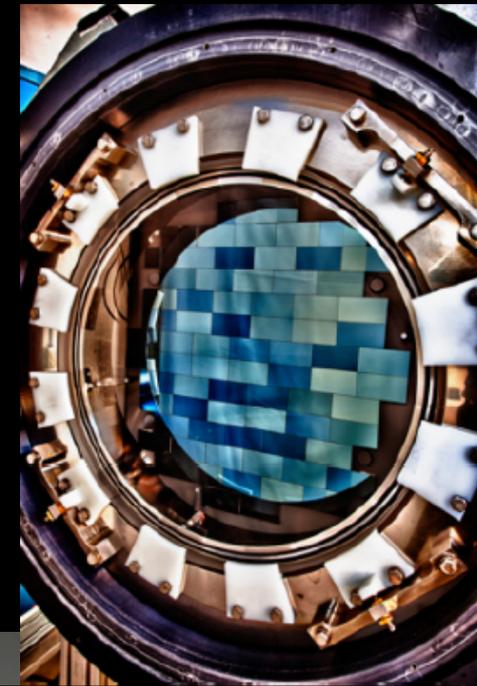
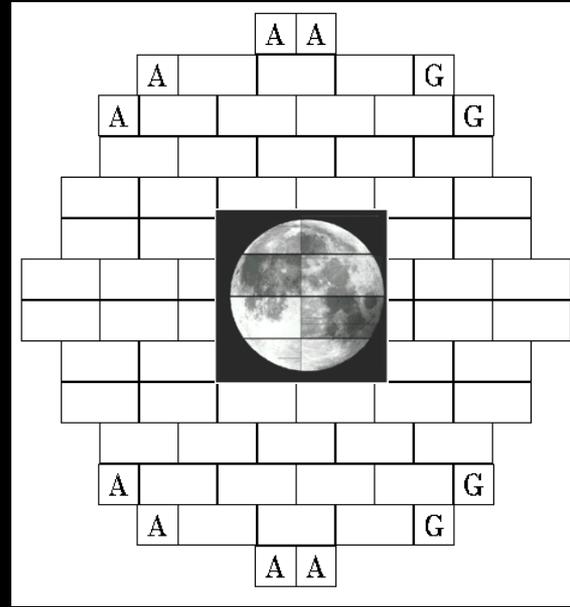
DECam

The deliverable was a new prime focus cage camera with a large CCD focal plane, filters, optics, and mechanical support



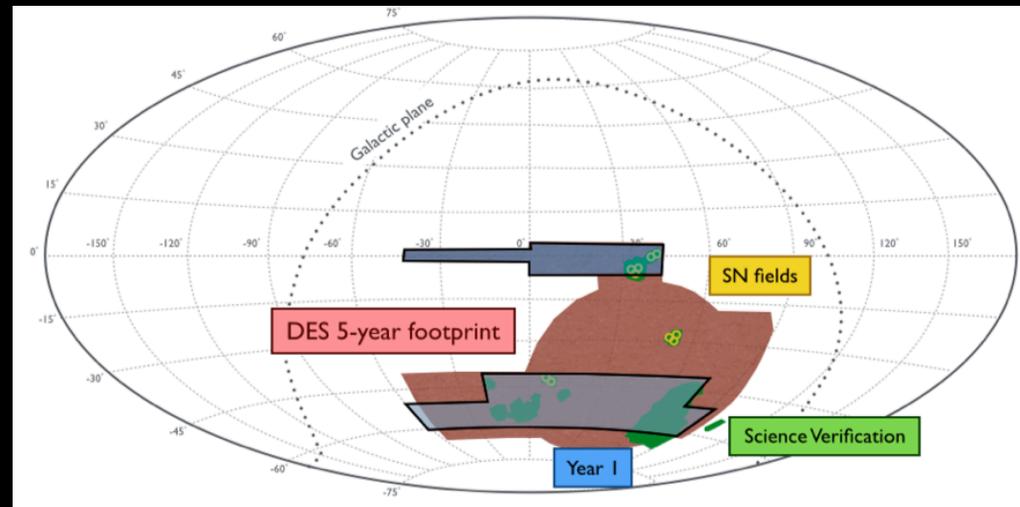
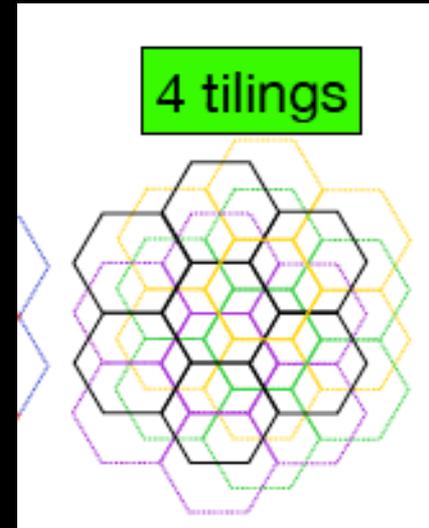
Focal Plane – Largest Digital Camera

- CCDs 570 Mpixels
15x15 μm , 0.27"/pixel
62 2Kx4K imaging, four
2Kx2K guiders, and eight
2Kx2K focus chips
- Cryogenic vessel 120K
- <15 e⁻ noise @ 250kpix/s
- 3 sq deg, 0.5m diameter
- (u),g,r,i,z,Y broad filters
- Typical exposure 100s,
readout during ~25s slew
- Each exposure ~300MB
- 2 weeks from hanging in
the dome to first image

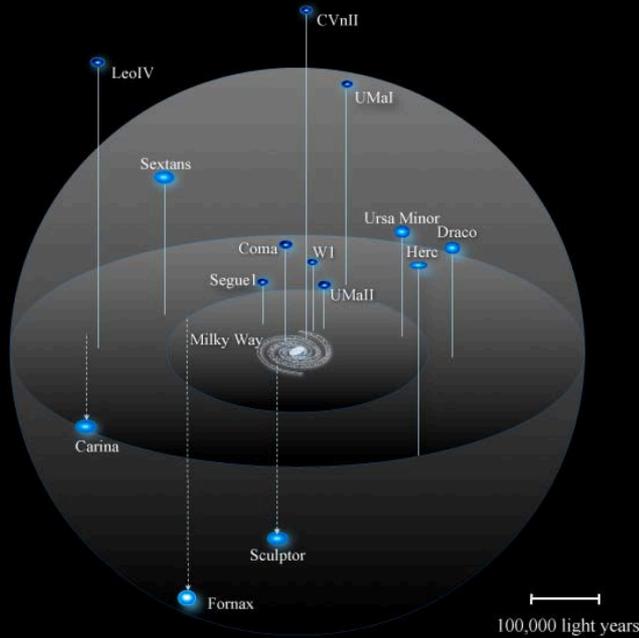


DES Survey

- 5000 sq deg nominally covered by 2 tilings per year x 5 yrs
 - Overlap with South Pole Telescope
 - Minimal dust looking out of the Milky Way
 - Overlap with other surveys for calibration or areas with galaxy spectra
- Ten supernova fields
 - Visit ~weekly or if seeing not ideal
- Depth to $\sim 24^{\text{th}}$ magnitude
- Redshifts to ~ 1.5
- Expect 300M galaxies and 100K galaxy clusters
- Expect 4000 Type IA SN



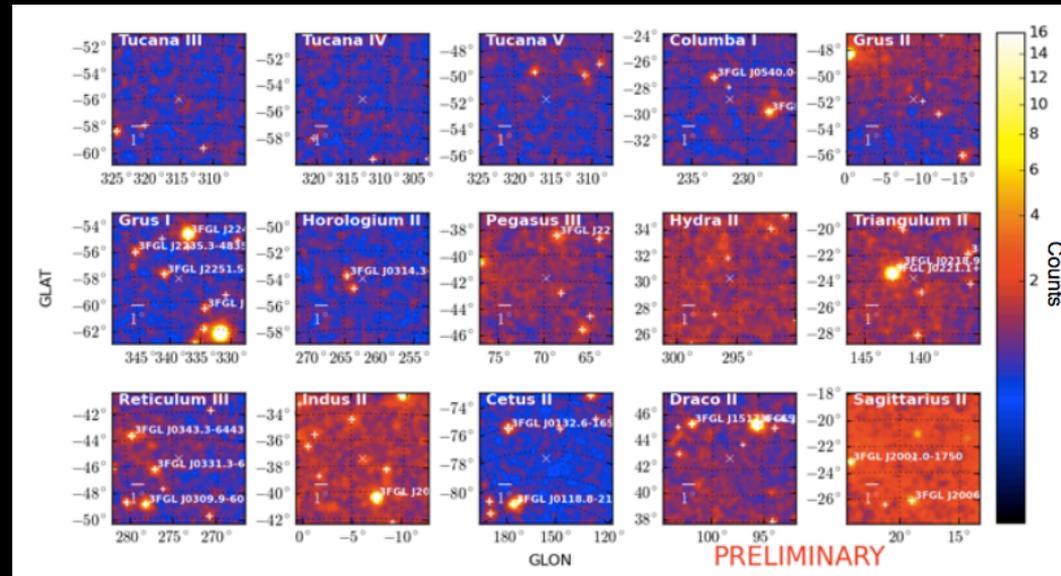
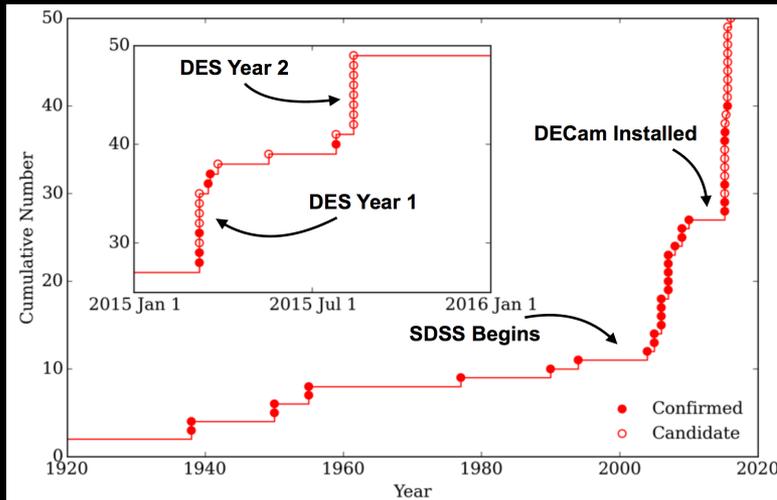
Dark Matter in Dwarf Galaxies



Shankar Agarwal and Hume Feldman

Simulations show galaxies are accompanied by dwarf galaxies which are rich in Dark Matter

DES has discovered new dwarf galaxies that can now be studied for gamma ray emission if WIMP dark matter is annihilating

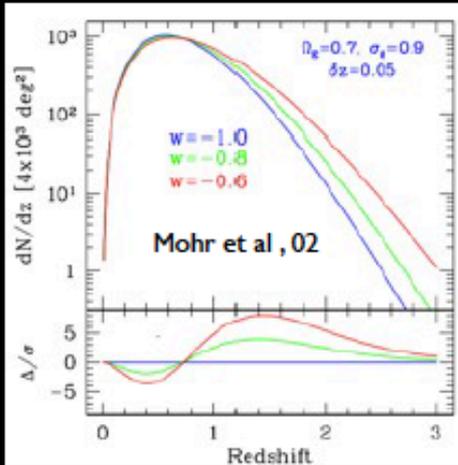


Fermi Team

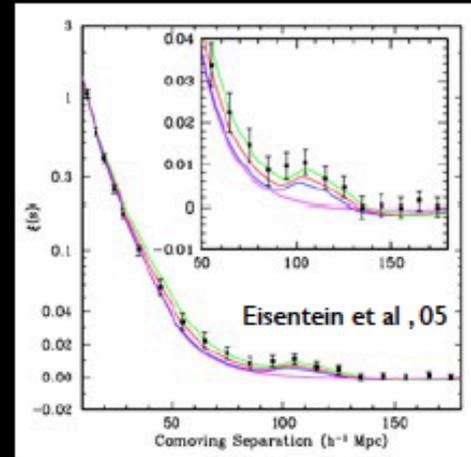
Preliminary limits are set that exclude WIMP Dark Matter below about 100 GeV

Dark Energy: Four Probes

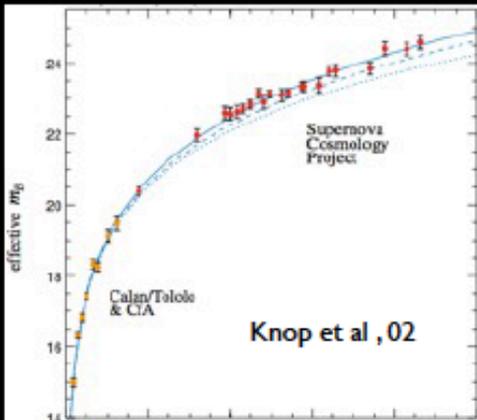
Galaxy Cluster Counts



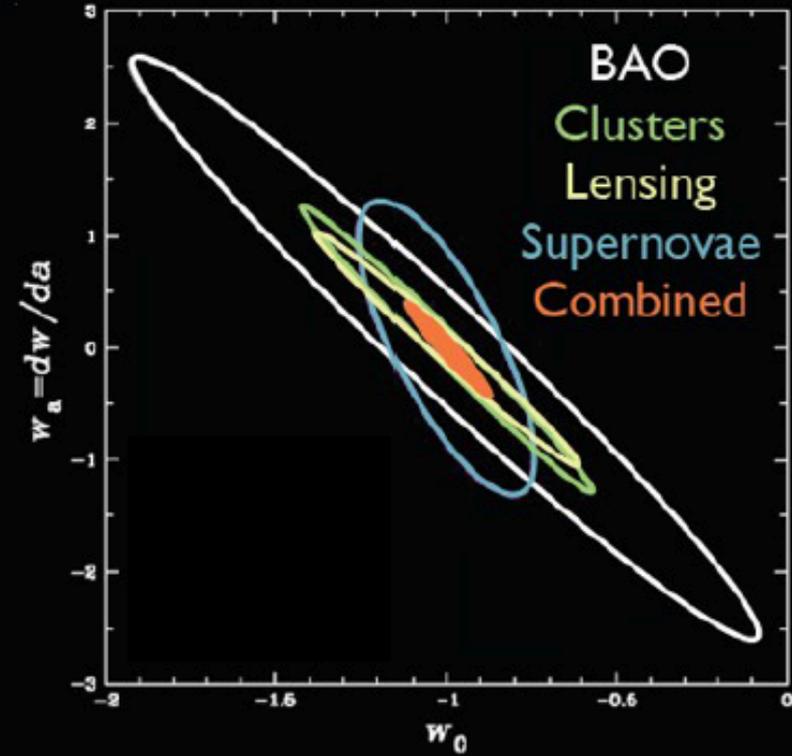
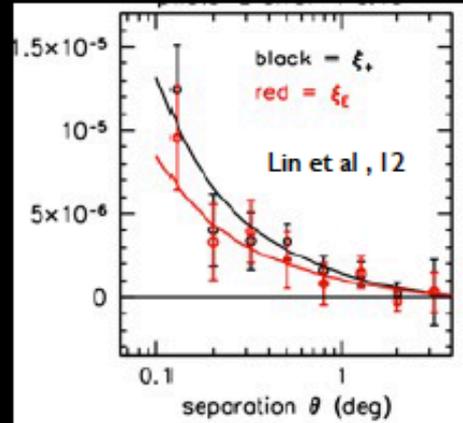
Baryon Acoustic Oscillation



Type Ia Supernovae



Weak Lensing

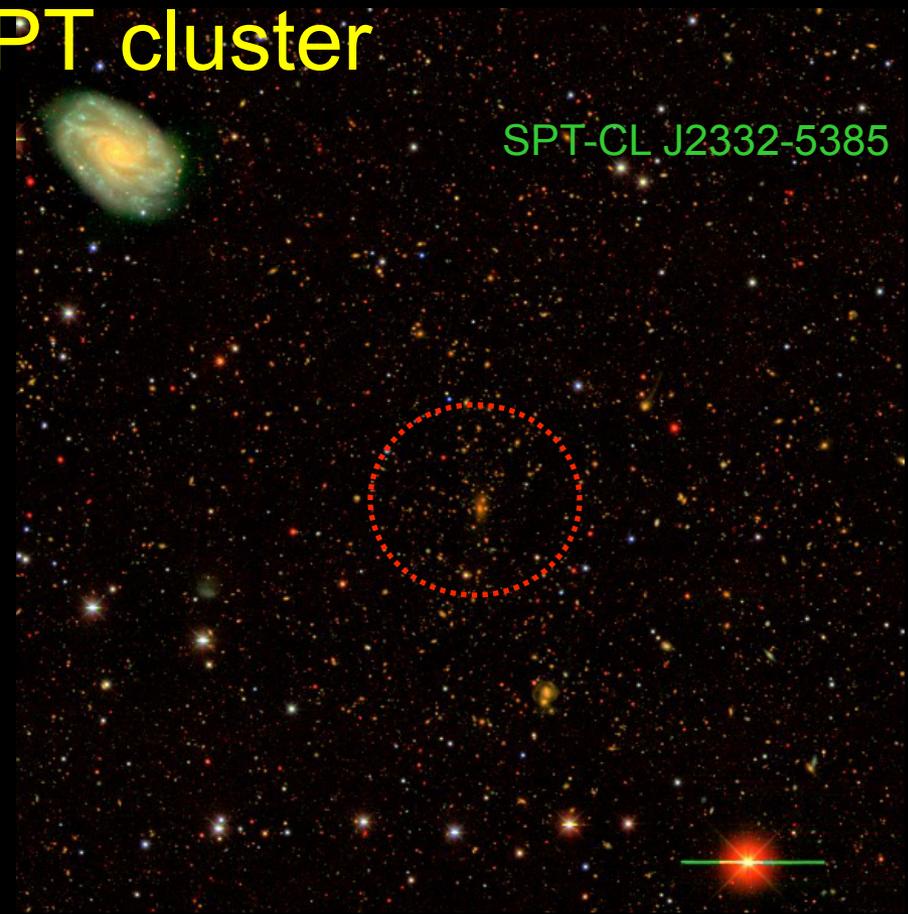


DES will improve the constraints on equation of state by a factor of $\sim 3 - 5$

Galaxy clusters

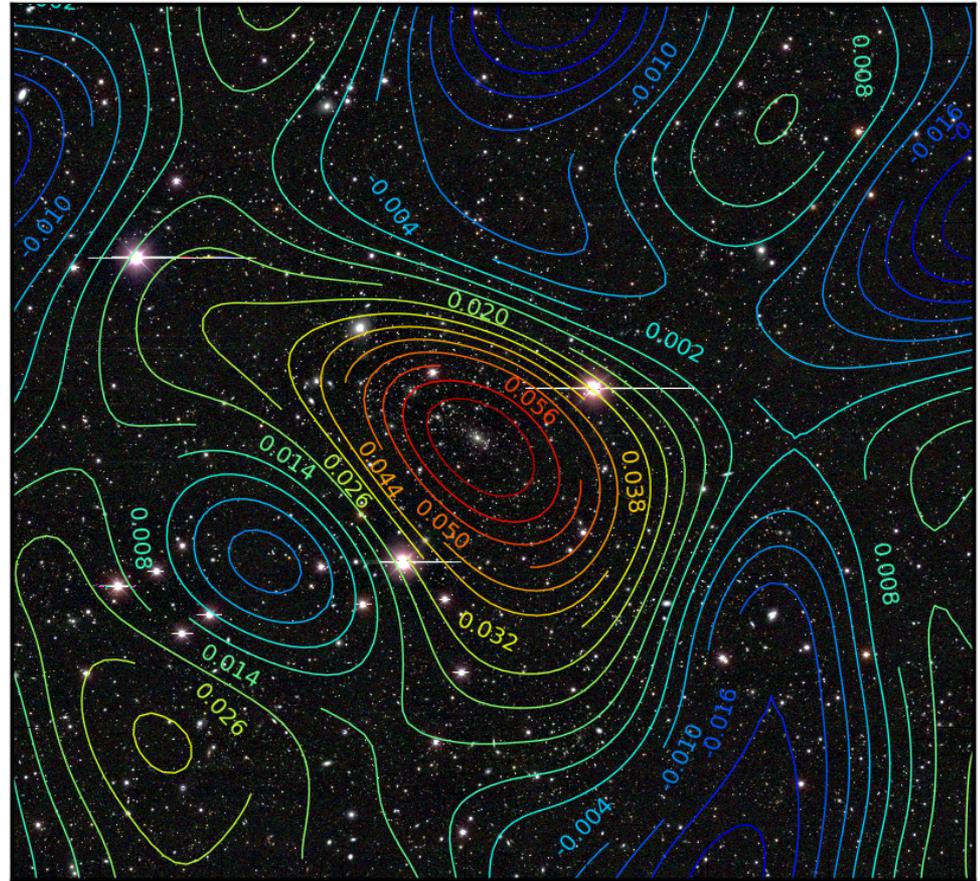
- Discovery of new clusters of galaxies identified by photometric redshift
- Optical follow-up of SPT cluster

Redshift $\sim 0.8-0.9$ discovery



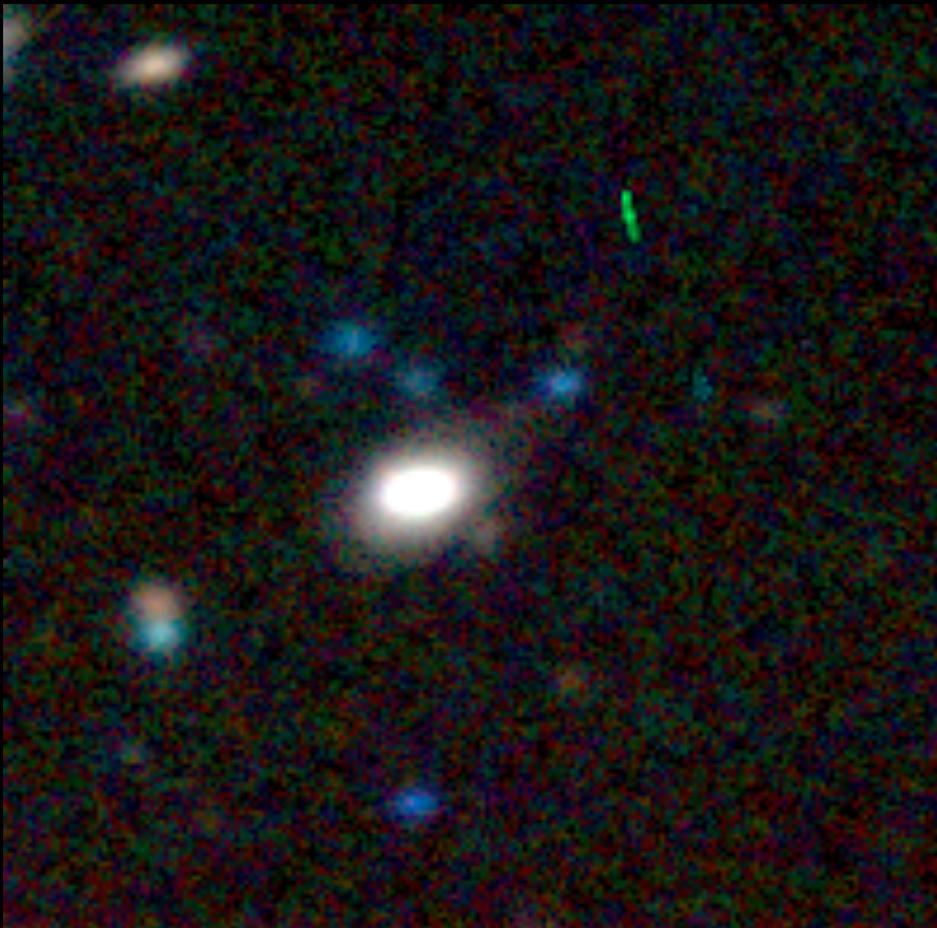
Weak lensing

- DES cluster with a map showing the dark matter mass distribution (preliminary) obtained by statistical analysis of the weak lensing distortion of galaxies



Type IA Supernova

- “Standardizable candles” that map the expansion history of the universe.



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Present Time: 4 Apr 2013; 02:31 UT

Telegram Index

All Telegrams ([30 Days](#))

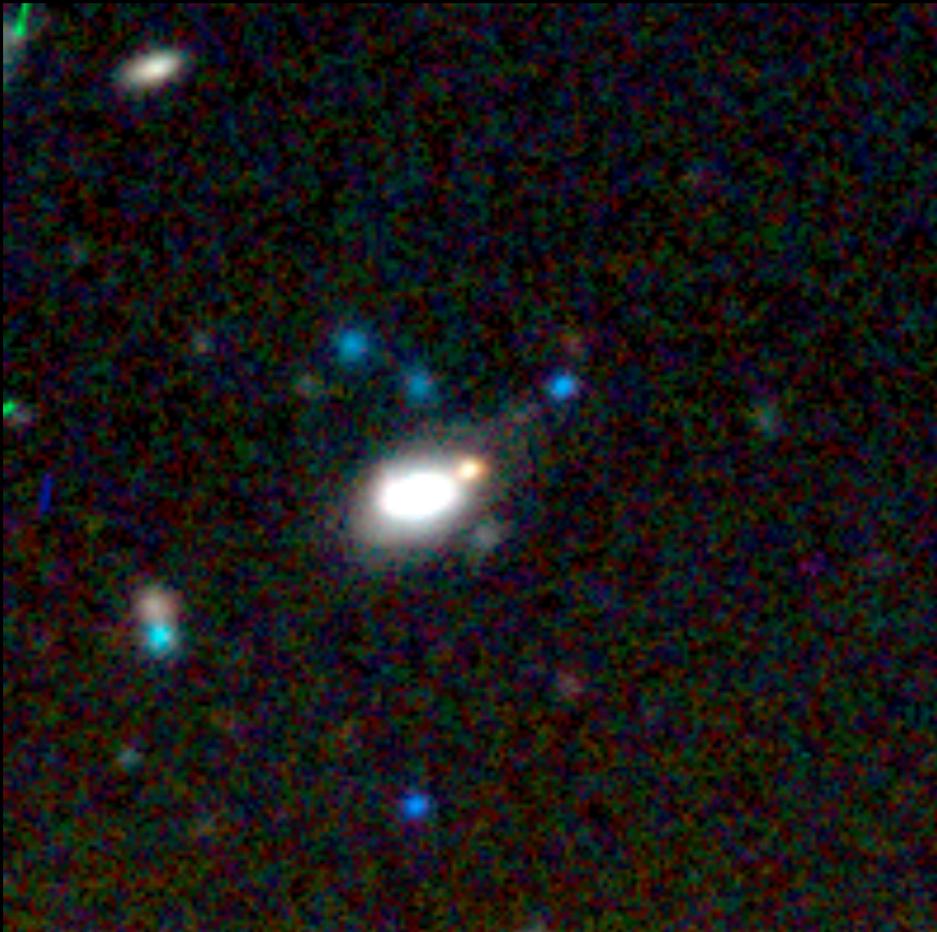
Telegramms Containing **All** of the Keywords:
dark, energy, survey

5 Selected of 4949 Telegramms

- 4826 [Spectroscopic confirmation of DES12S2b](#) S. B. Cenko, K. I. Clubb (University of California, Berkeley), G. Aldering, J. S. Bloom, A. Kim, P. Nugent,..... -- 20 Feb 2013; 01:10 UT
- 4800 [Spectroscopic confirmation of DES12S2a](#) P. J. Brown, K. Krisciunas, J. Marshall, N. Suntzeff (Texas A&M University), E. Ahn, D. Finley, J..... -- 8 Feb 2013; 19:02 UT
- 4741 [Spectroscopic confirmation of DES12S1a](#) P. J. Brown, K. Krisciunas, J. Marshall, N. Suntzeff (Texas A&M University), K. Barbary, J. P. Bernstein,..... -- 17 Jan 2013; 21:21 UT
- 4725 [Spectroscopic confirmation of DES12C3a](#) C. Lidman, A. Hopkins (Australian Astronomical Observatory), E. Ahn, D. Finley, J. Frieman, J. Murriner,..... -- 11 Jan 2013; 04:22 UT
- 4668 [First SN Discoveries from the Dark Energy Survey](#) T. Abbott (1), F. Abdalla (2), I. Achitouv (3), E. Ahn (4), G. Aldering (6), S. Allam (4), D. Alonso..... -- 22 Dec 2012; 14:34 UT

Type IA Supernova

- “Standardizable candles” that map the expansion history of the universe.



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Present Time: 4 Apr 2013; 02:31 UT

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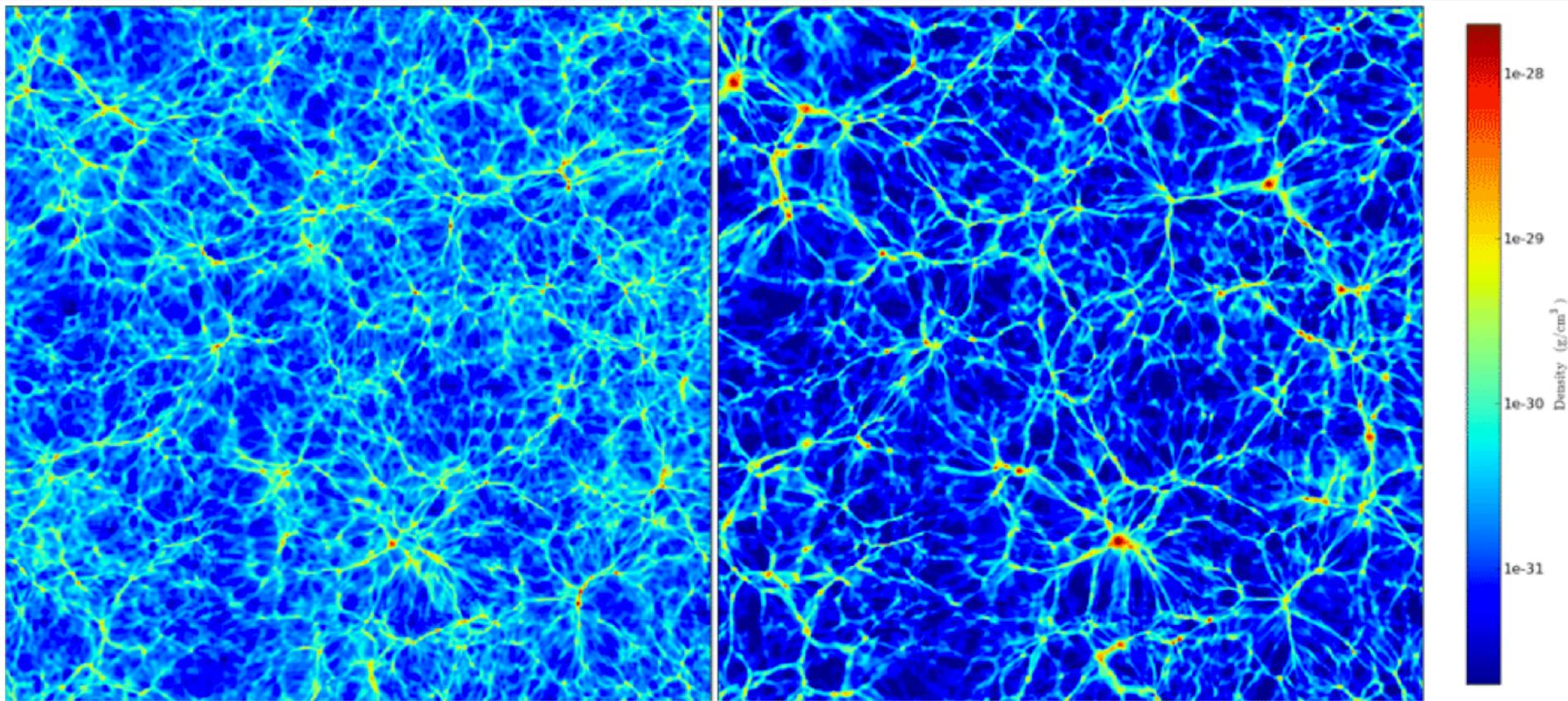
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Neutrinos and Cosmology

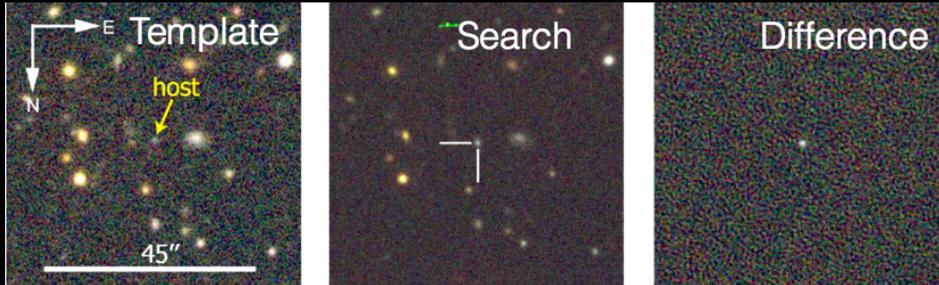
The universe today has a look that depends on the mass of the neutrino
Studying the large scale structure of the universe might give the best indication of the absolute mass of the neutrino

With massive neutrinos

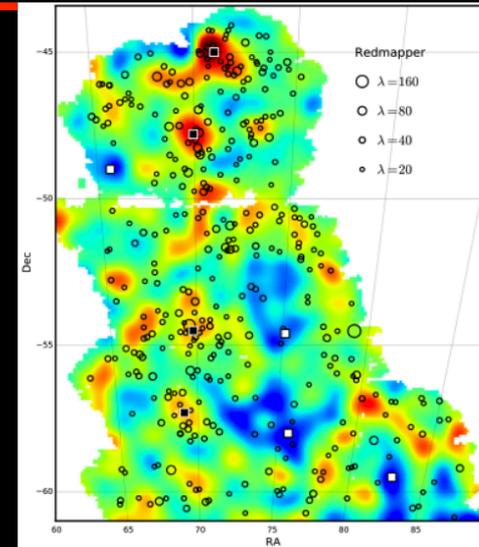
Without massive Neutrinos



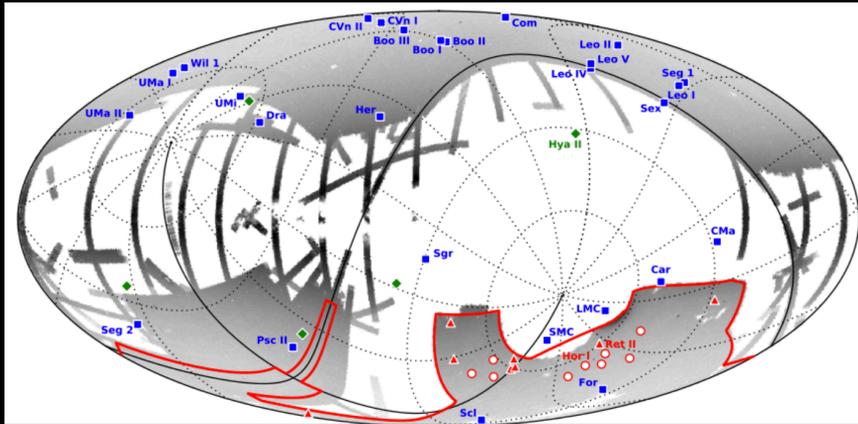
The survey is finished collecting the Year 3 data and publishing science:
43+ papers submitted and 10+ papers since Dec 2015



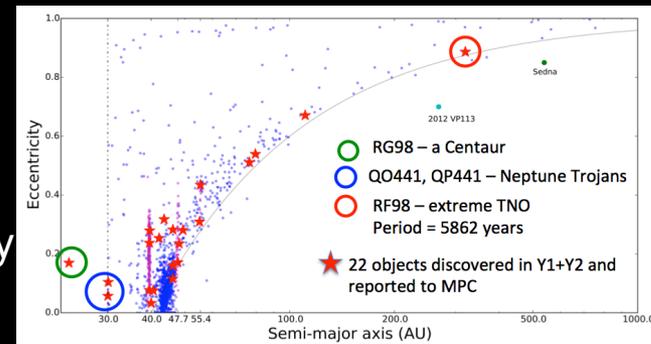
Supernova discoveries, Papadopoulos et al. 2015



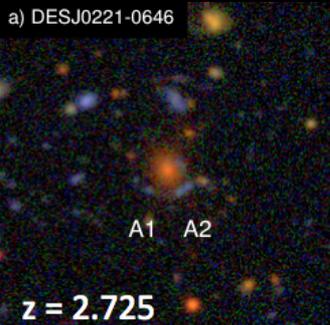
Maps of mass as determined by weak gravitational lensing with matches to newly discovered clusters of galaxies and CMB distortions
Vikram et al. 2015
Chang et al. 2015
Giannantonio et al. 2015



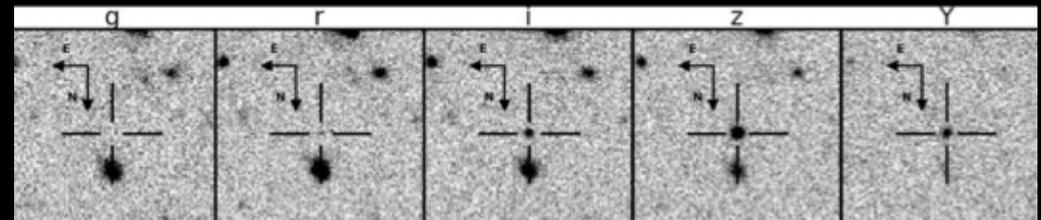
New dwarf galaxies discovered about our Milky Way
Bechtol et al. 2015 and Drlica-Wagner et al. 2015



Trans-Neptunian objects
Gerdes et al. 2015



Strong gravitationally lensed distant galaxies
Nord et al 2015



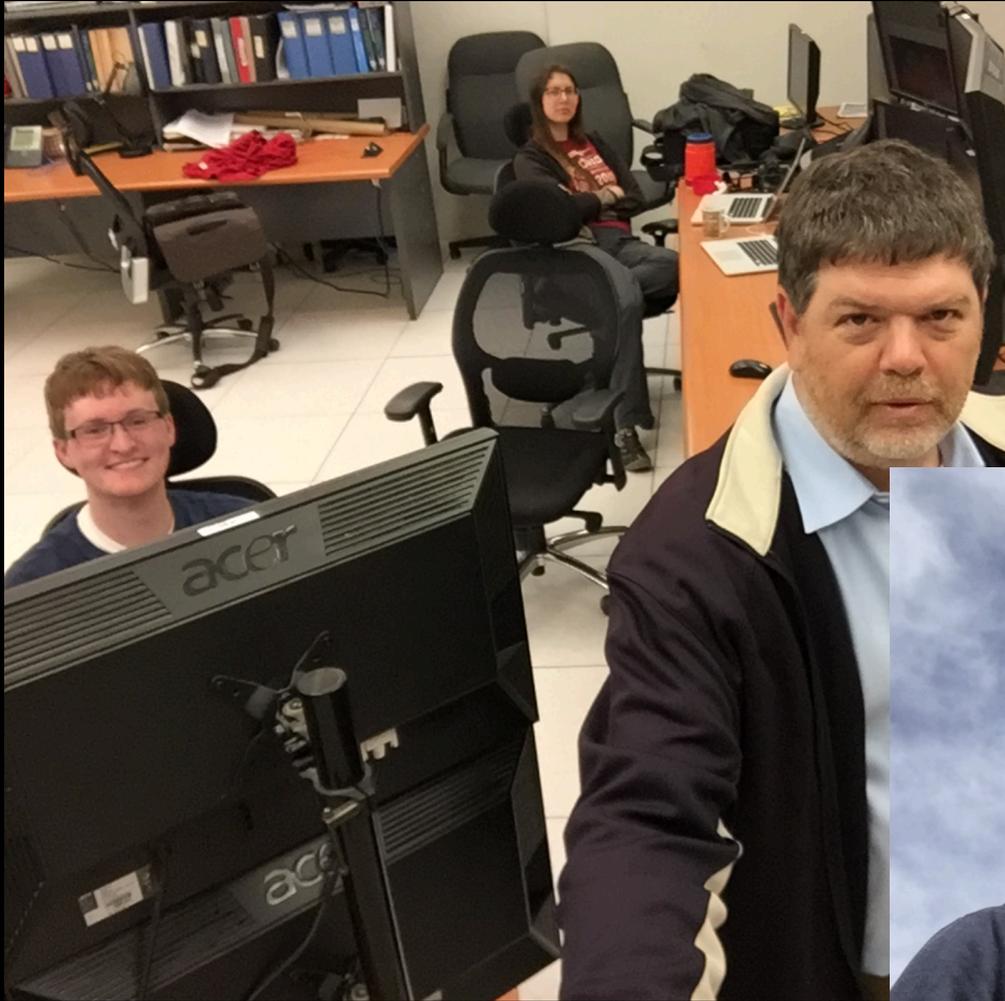
First $z > 6$ quasar, Reed et al. 2015

Summary of my trip this year to Chile

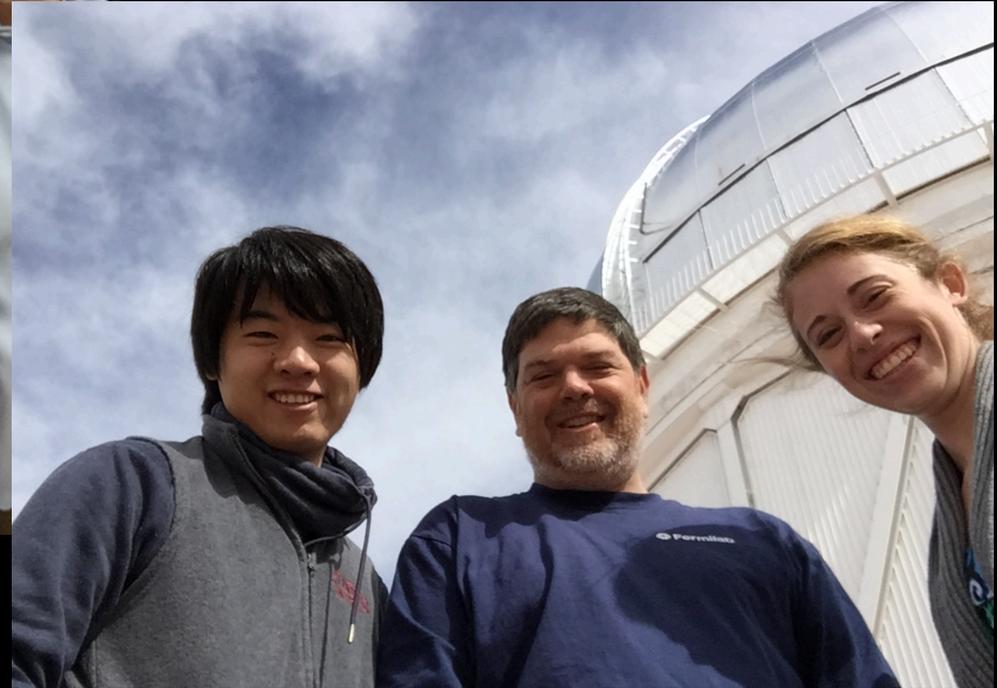
9 nights on the mountain. About 1/2 the nights were mostly cloudy weather.



Summary of my trip this year to Chile



Three people on shift
Run Manager
Observer 1: DAQ
Observer 2: monitoring
plus a telescope operator



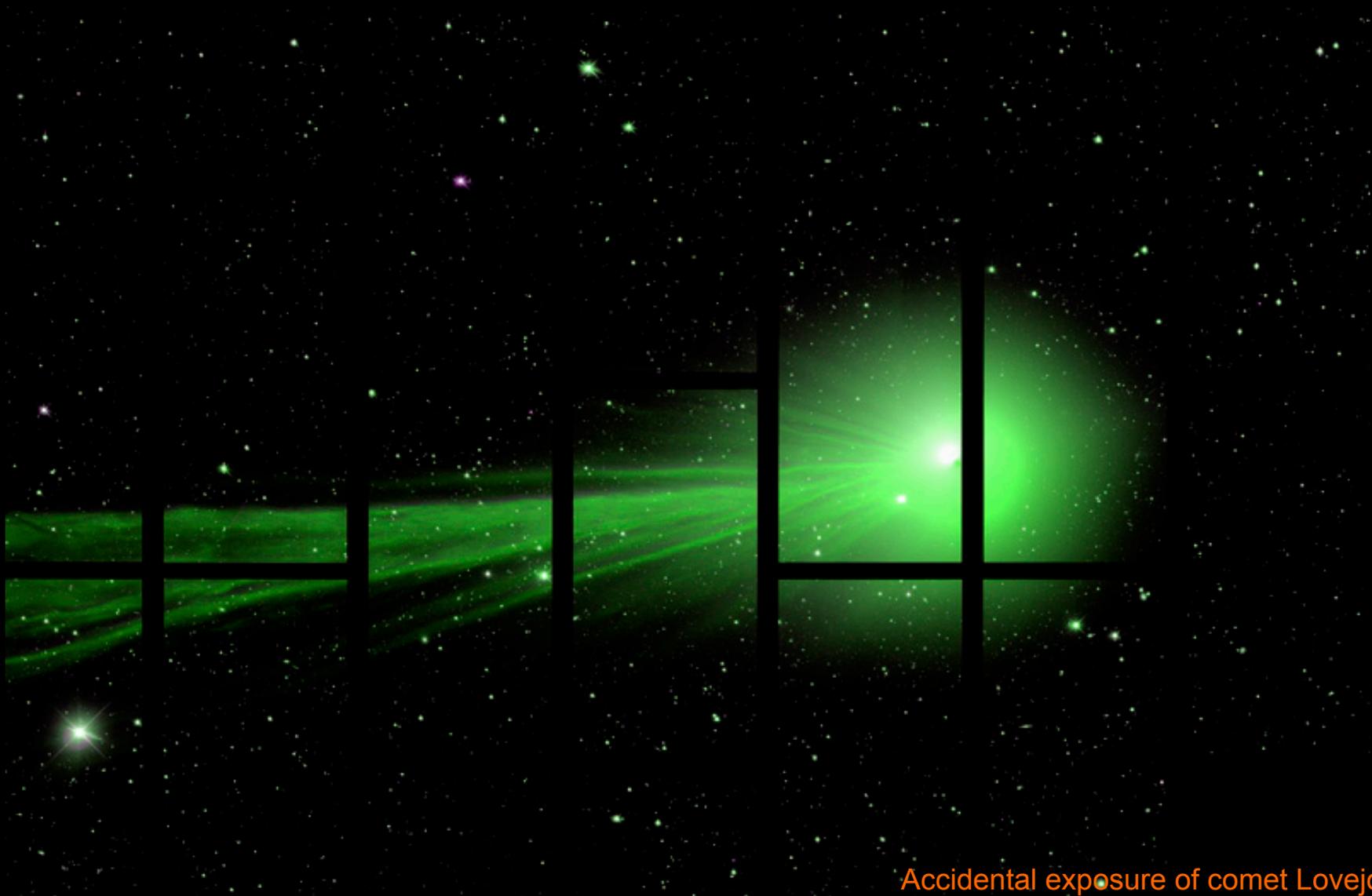
Summary of my trip this year to Chile



A touch of astronomy



A touch of astronomy

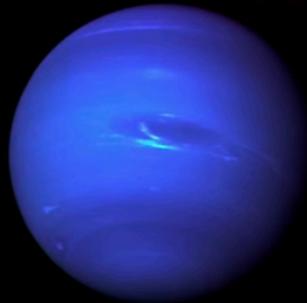
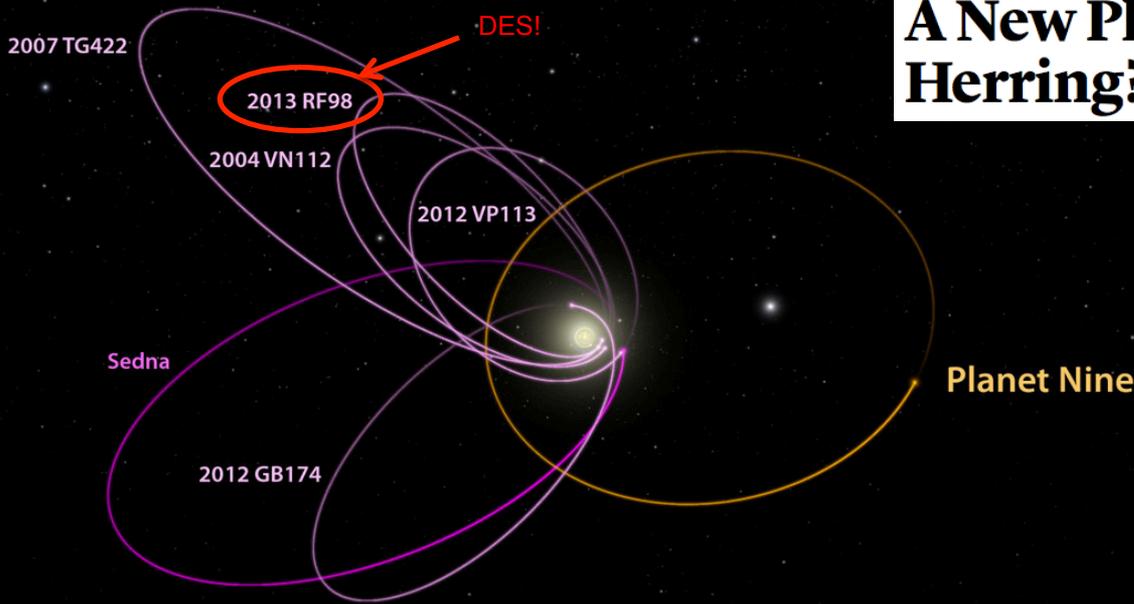


Accidental exposure of comet Lovejoy



Planet Nine – 10+ pages of Google

<http://arxiv.org/pdf/1601.05438v1.pdf> and <http://www.findplanetnine.com>



9TH PLANET

1 to 10 times the mass of Earth

A New Planet or a Red Herring?

DISCOVERING PLANET NINE

COULD YOU LIVE ON PLANET NINE?

The Meaning of Planet Nine

Space raiders from Planet Nine won't be friendly

'Planet Nine' evidence uncovered using computer simulations

New evidence suggests a ninth planet lurking at the edge of the solar system

David Bowie fans want Planet 9 to be named in his honour

They've just discovered Planet Nine. But is it really so 'planety'?

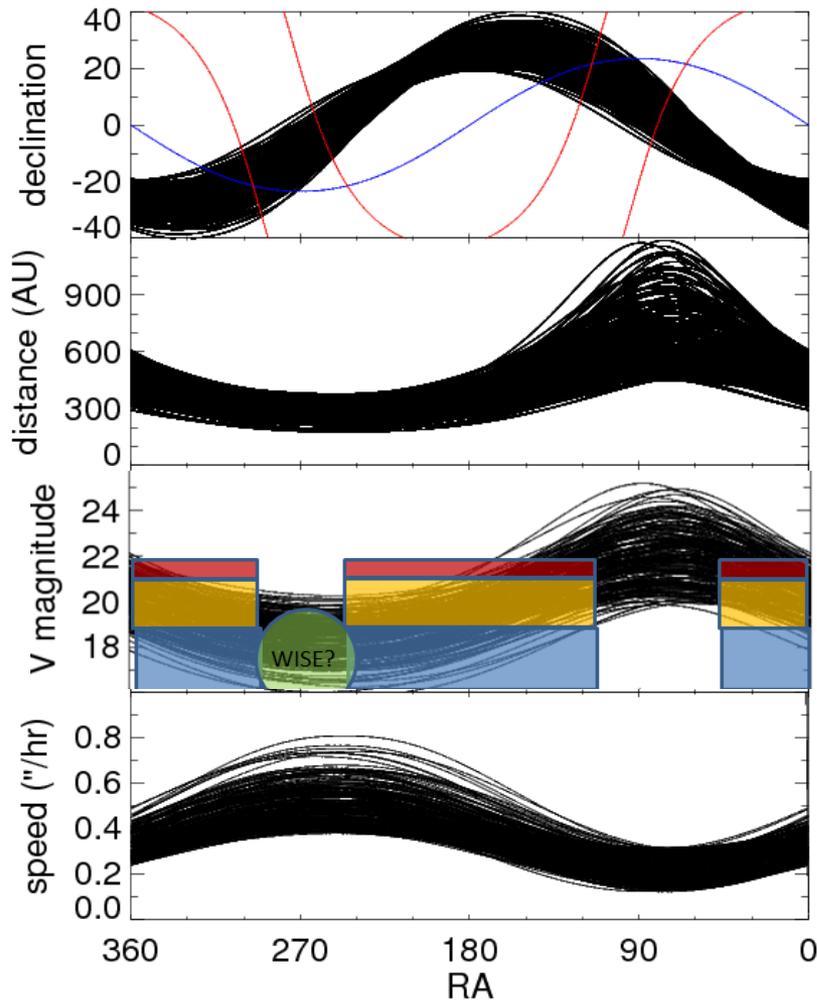
27 JAN 2016
WHY HAVE WE ONLY JUST DISCOVERED PLANET 9'S EXISTENCE?

Newsletter Today: Earth Is Hot. Planet Nine, Cool.

This week in science: planet nine from outer space

Planet Nine isn't a Death Star or the killer planet 'Nibiru.' It may not even exist.

The “treasure map”



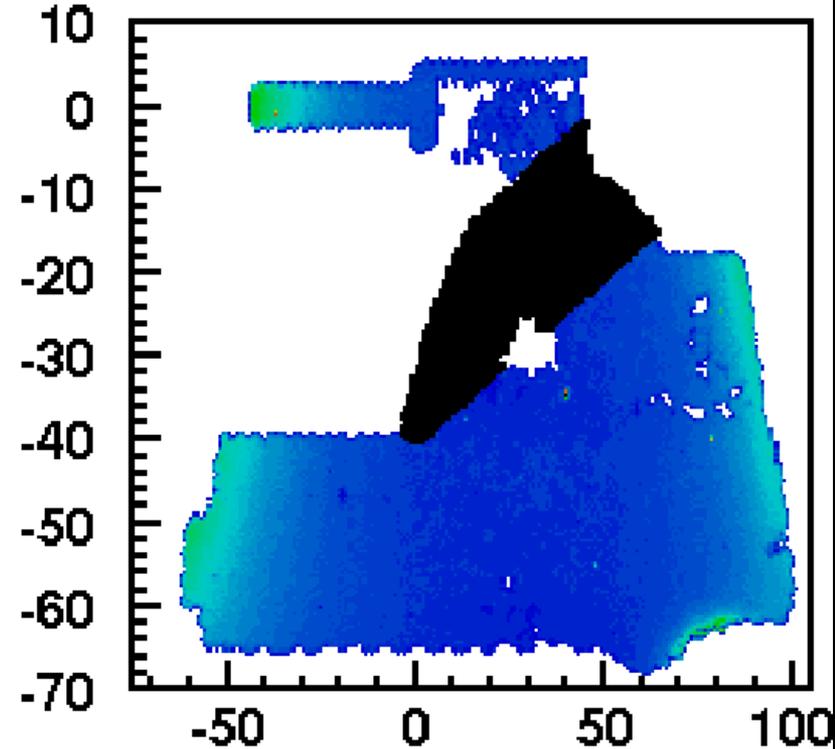
RA / dec
includes MW
and part DES
footprint

DISTANT!!
(near limit
for main
survey)

FAINT!

PS moving
PS transient
Catalina

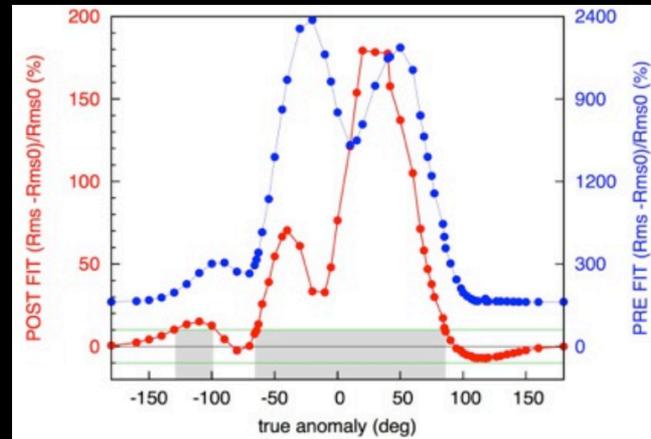
SLOW!!
(1 night \approx
1-few arcsec)



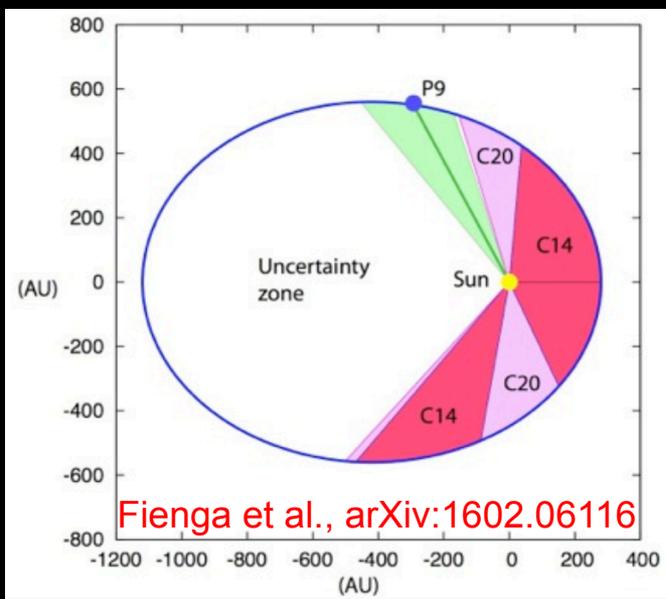
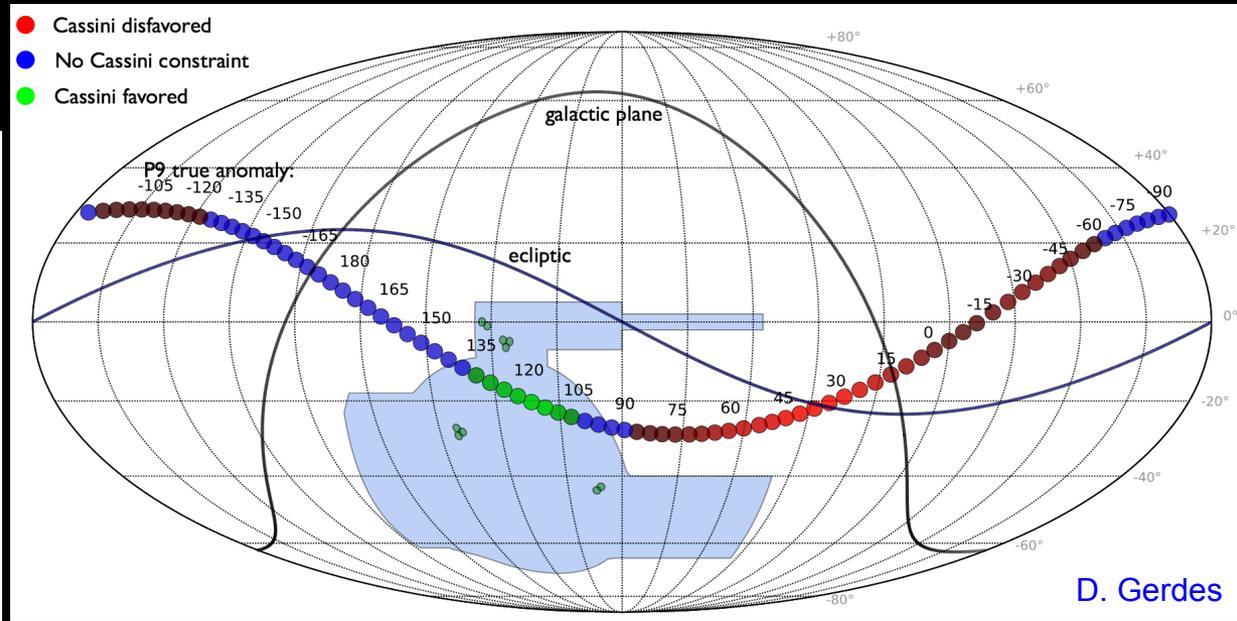
DES footprint covers some of the interesting region of interest. Mostly Y2 observations and the “hole” filled in by Y3.

New evidence from Cassini

Global fit to all data of orbiting bodies with and without the nominal Planet Nine as a function of its true anomaly. Slight evidence for something in our footprint, but only having the Planet Nine near perihelion ruled out.



- Cassini disfavored
- No Cassini constraint
- Cassini favored



Stay tuned! – and as a particle physicist, maybe P9 might shed light on dark matter?

Conclusions

- The Dark Energy Survey has begun
 - Impressive results as first data is analyzed
 - Now in Y3 of 5 years. Perhaps a 6th year.
- This survey should achieve its goals of improving upon knowledge of Dark Energy and other unknowns of “Inner Space”
 - Four different probes + strong lenses + quasars +
 - It’s about the details to achieve the required precision and accuracy
- The data is very rich for a variety of other topics in astronomy and astrophysics