

# The **D**ark **E**nergy **S**urvey:

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## Overview and New Results

Brian Nord (@briandnord, [nord@fnal.gov](mailto:nord@fnal.gov))  
for the DES Collaboration

Fermilab User's Meeting  
June 15, 2016

# Sneak Preview

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- The Dark Energy Survey (DES)
  - Instrument: *Dark Energy Camera*
  - Footprint and Survey Progress
- Recent results from early DES data
  - Strong lens discoveries
  - Mapping dark matter with weak lensing
  - Supernova samples

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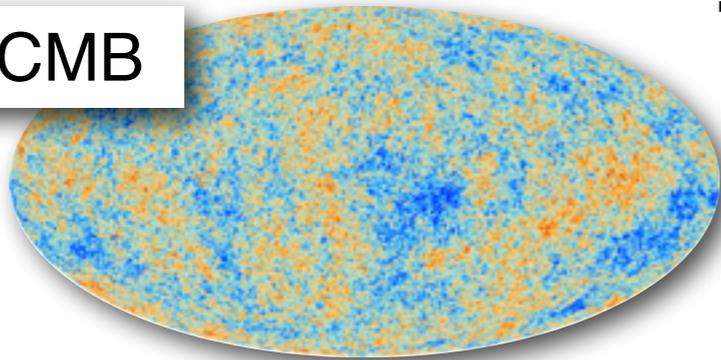




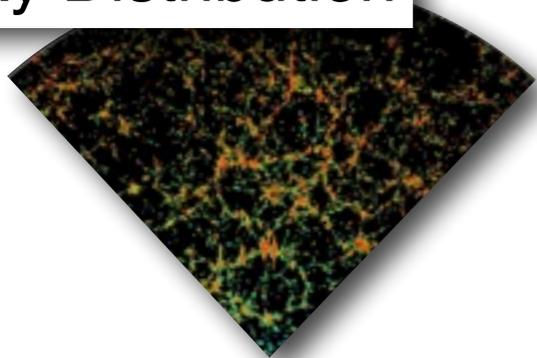
50 billion years  
in the future

# A Tug of War: Complementary Probes

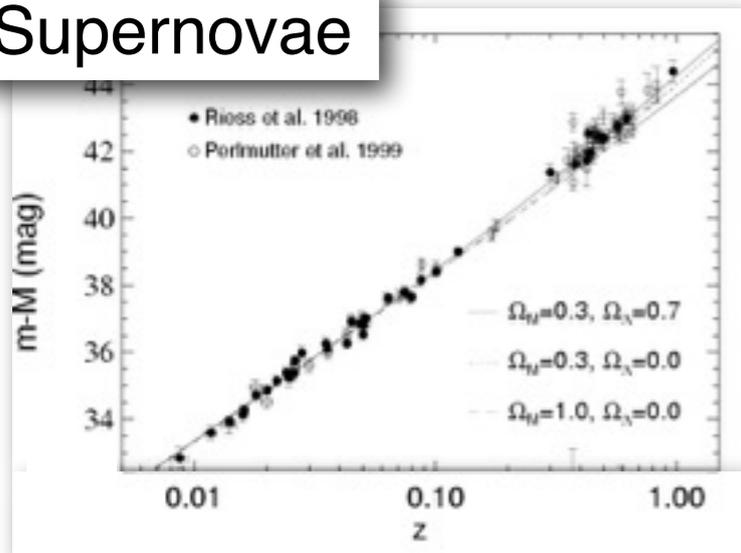
CMB



Galaxy Distribution

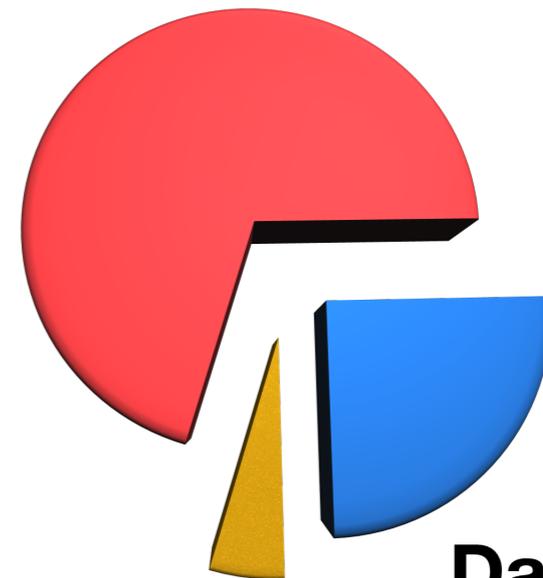


Supernovae



Geometry  
+  
Expansion  
+  
Structure  
Growth

**Dark Energy**  
**70%**

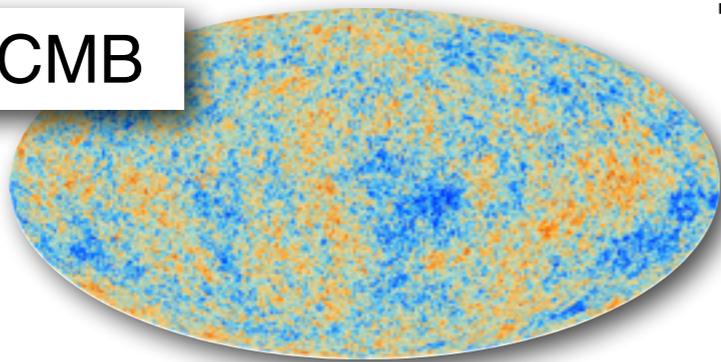


**Baryons**  
**5%**

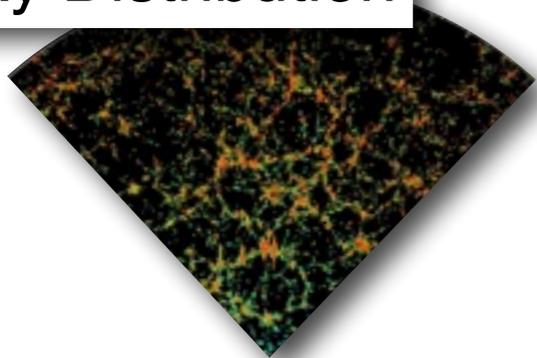
**Dark Matter**  
**25%**

# A Tug of War: Complementary Probes

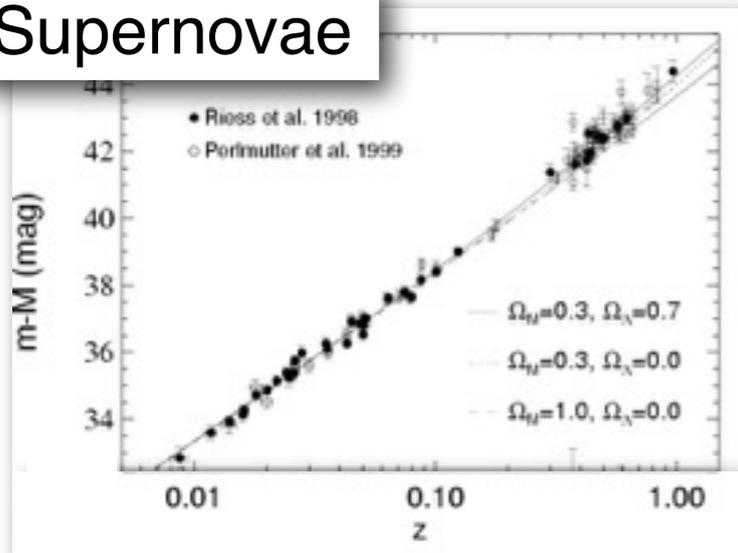
CMB



Galaxy Distribution



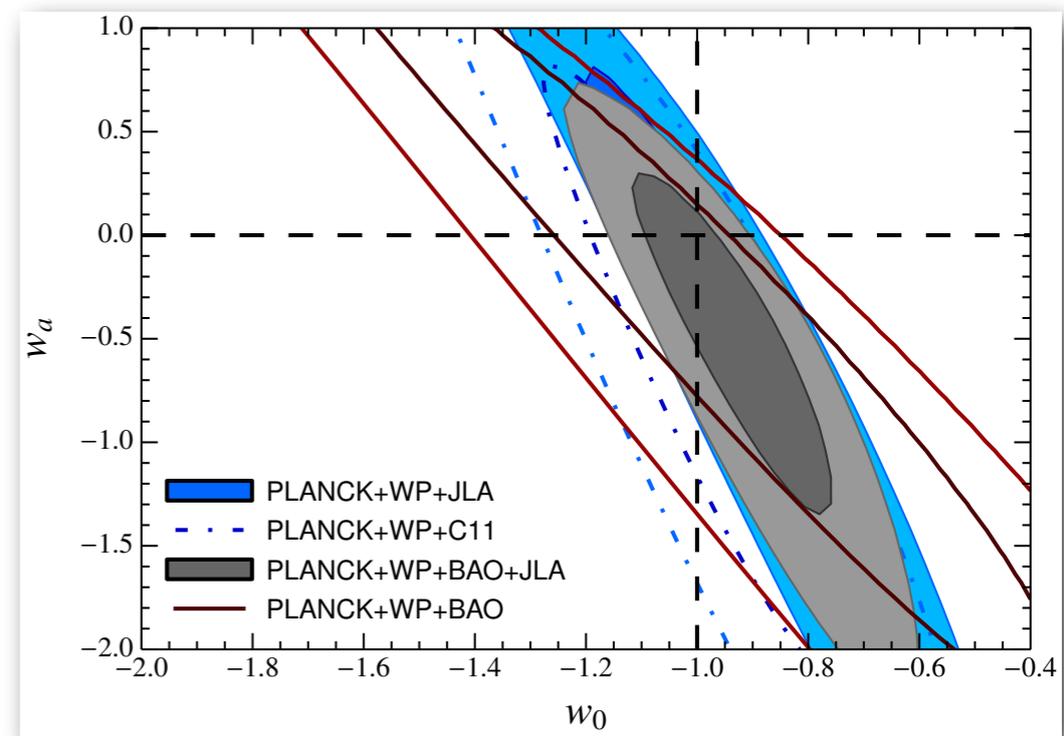
Supernovae



Geometry  
+  
Expansion  
+  
Structure  
Growth

Evolving DE equation of state:

$$w(\alpha) = w_0 + (1 - \alpha)w_a$$

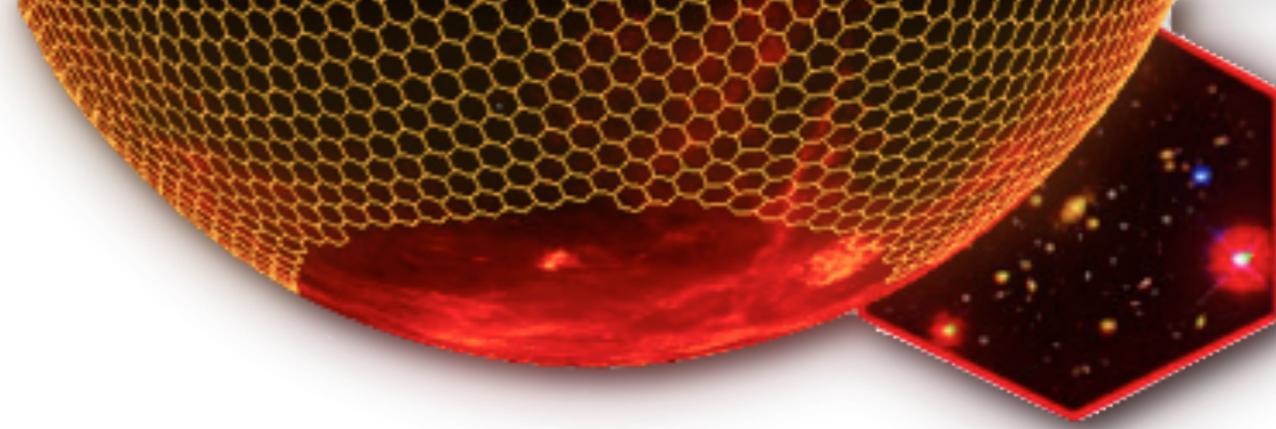


**State of the art constraints:**

$$w_0 = -0.957 \pm 0.124 \quad (\sim 13\%)$$

$$w_a = -0.336 \pm 0.552 \quad (\sim 164\%)$$

Betoule++2014



# Dark Energy Survey

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*Hello from the dark side*





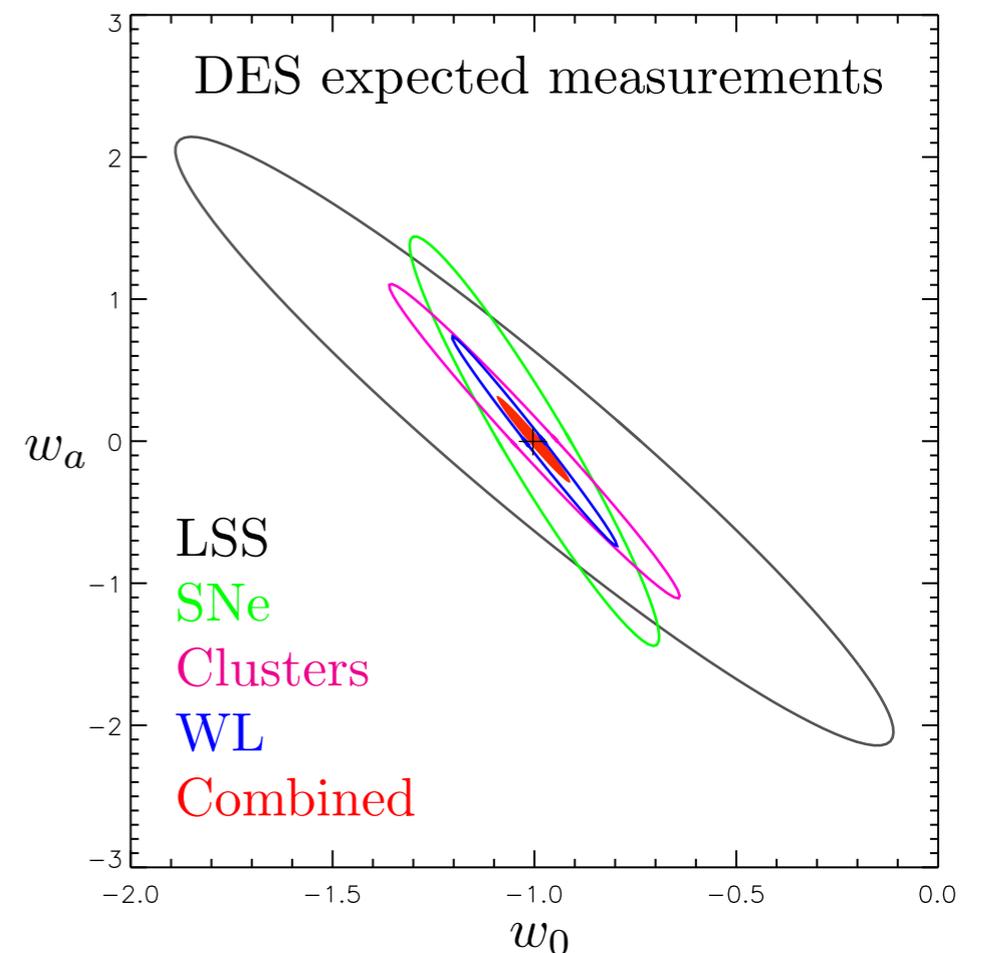
# Expansion and Structure Growth

## Multiple Probes, One Experiment

- Weak Lensing: (structure)
  - 200 million galaxy shapes
- Supernovae: (expansion)
  - ~3000 well-sampled SNe Ia to  $z \sim 1$
- Galaxy Clusters: (structure)
  - ~10,000s clusters to  $z > 1$
- Large-scale galaxy distribution: (expansion)
  - 300 million galaxies to  $z > 1$

Evolving DE equation of state:

$$w(\alpha) = w_0 + (1 - \alpha)w_a$$



Predicted DES Constraints:

$w_0$  to ~5%

$w_a$  to ~30%



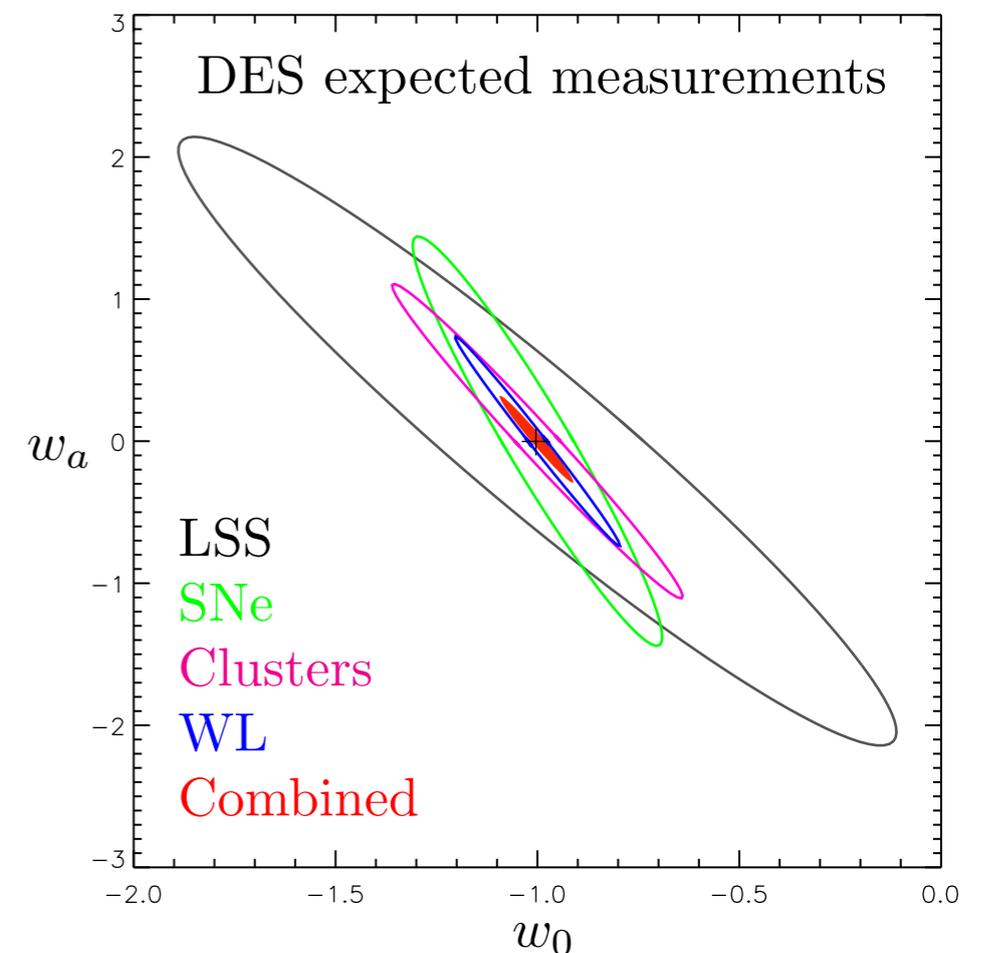
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- Large-scale galaxy distribution: (expansion)
  - 300 million galaxies to  $z > 1$
- Strong Lensing: (structure and expansion)
  - ~2,000 galaxy-/cluster-scale lenses

Evolving DE equation of state:

$$w(\alpha) = w_0 + (1 - \alpha)w_a$$

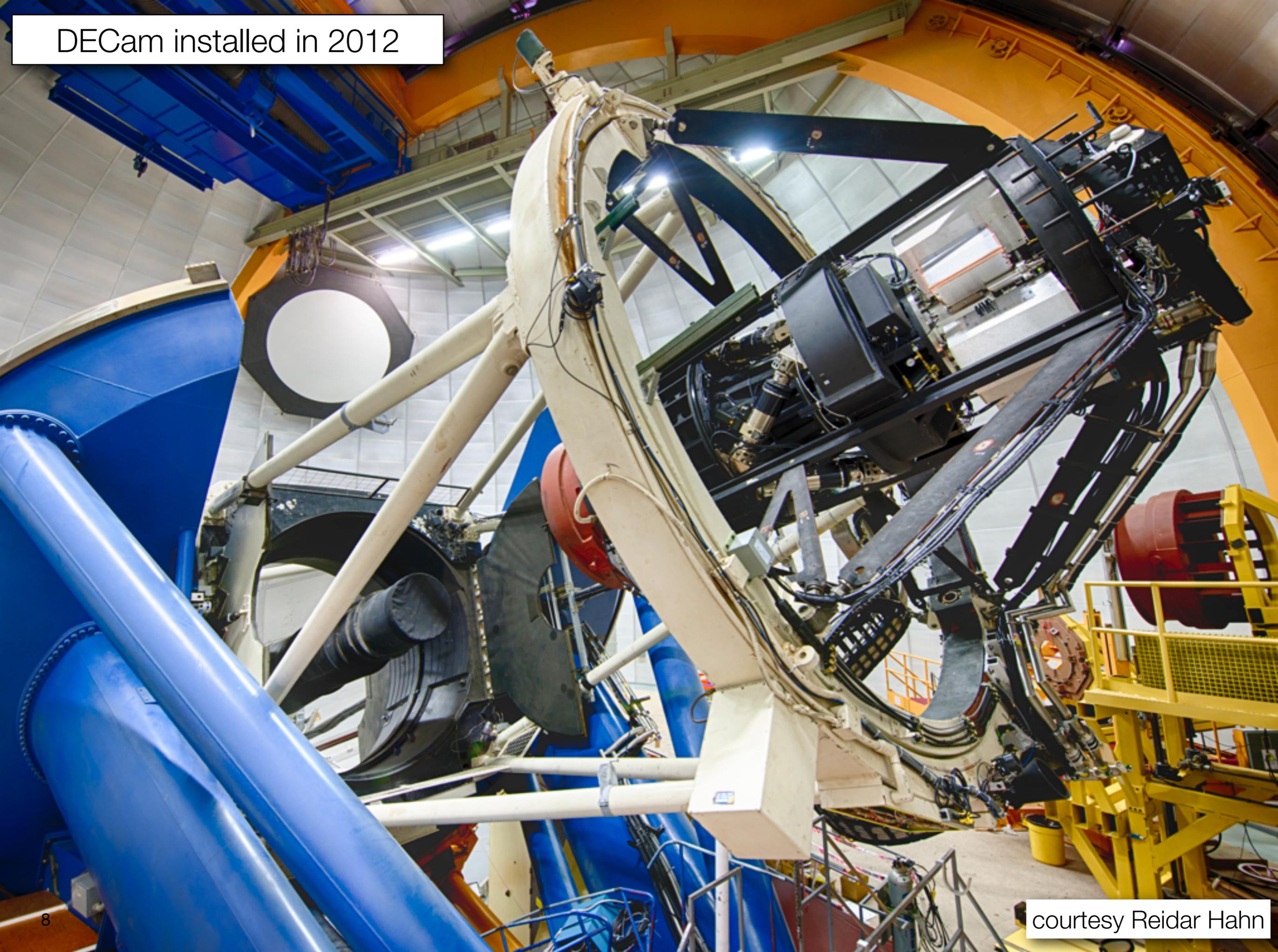


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DECam installed in 2012





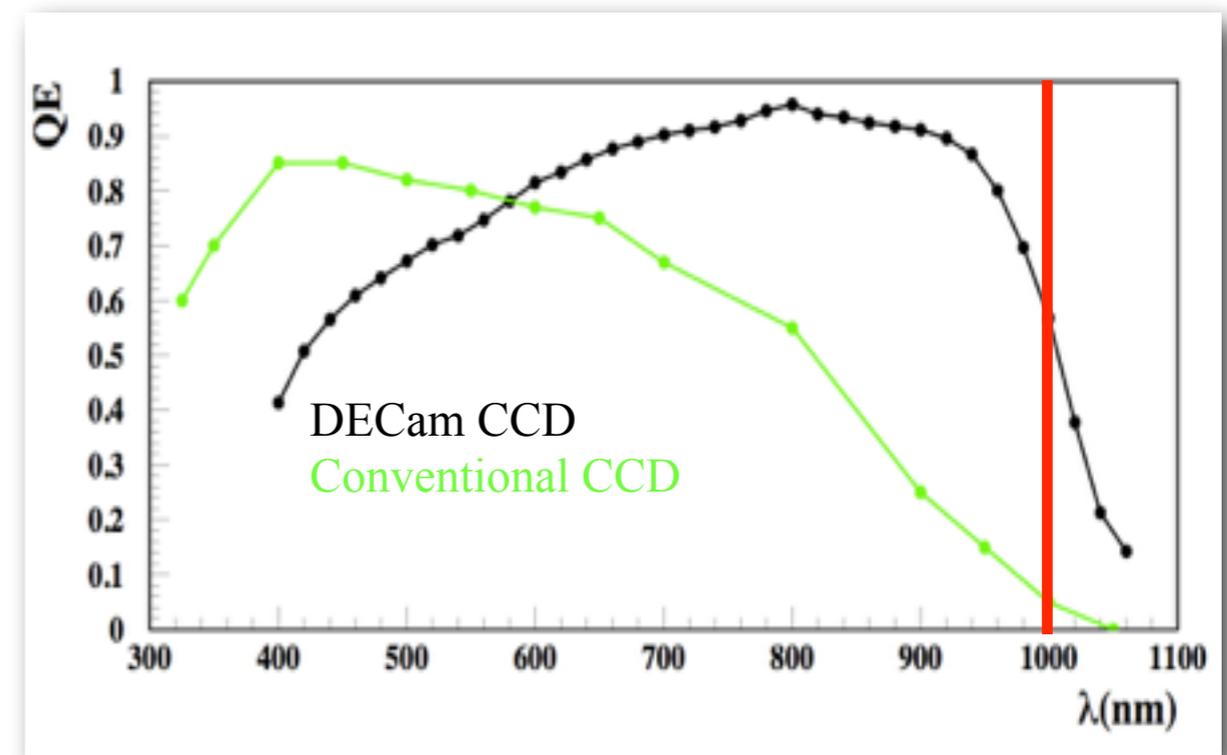
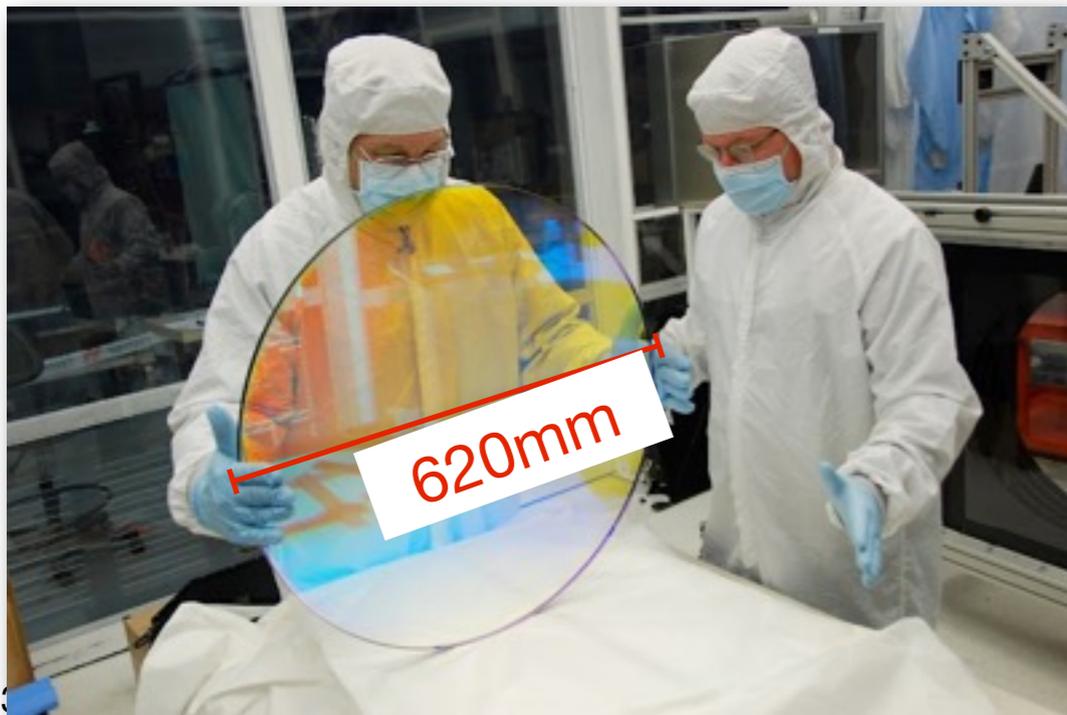
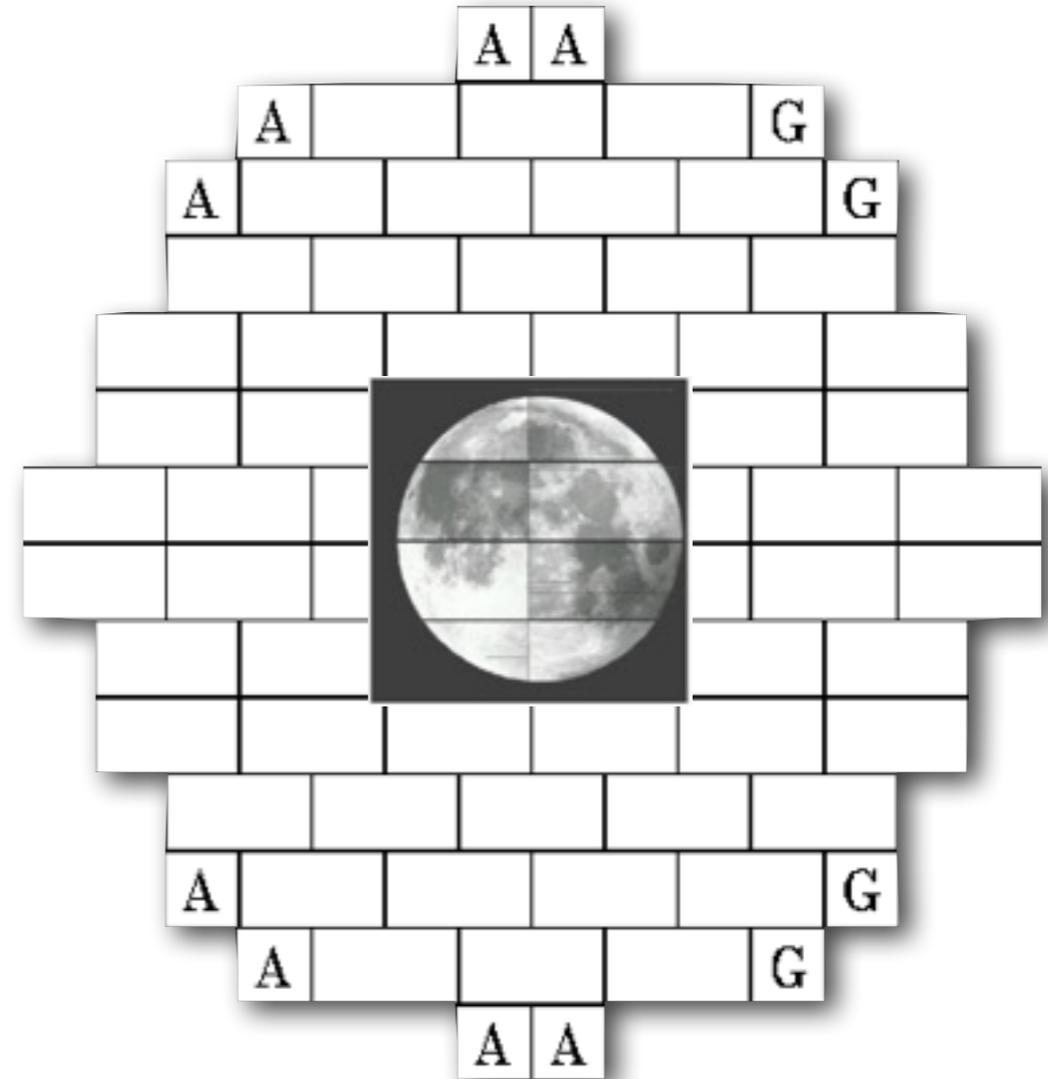
Shape

Position

Flux

# Dark Energy Camera

- Imager
  - 74 Chips, 570 Megapixels
  - 3-sq.-deg. FoV, 0.27"/pixel
  - Red-sensitive: QE > 50% @ 1000nm
- Filters
  - *grizY* bands: similar to SDSS
  - largest broadband filters for an astronomical instrument



**NOAO Announcement of Opportunity & Project Start**

# DES Timeline

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**2003**

**2004**

**2005**

**2006**

**2007**

**2008**

**2009**

**2010**

**2011**

**2012**

**2013**

**2014**

**2015**

**2016**

**2017**

**2018**

**R&D**

**Construction  
& Assembly**

**Installation**

**First Light  
Sept 12, 2012**

**Commissioning**

**Science Verification**

**Season 1**

**Season 2**

**Season 3**

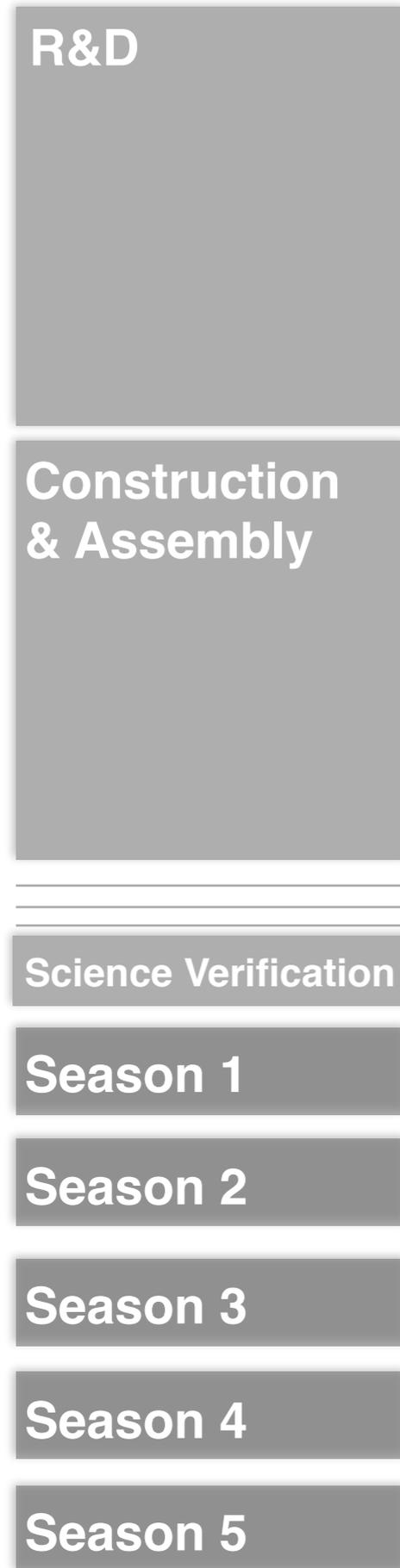
**Season 4**

**Season 5**

# DES Timeline

NOAO Announcement of Opportunity & Project Start

2003  
2004  
2005  
2006  
2007  
2008  
2009  
2010  
2011  
**2012**  
2013  
2014  
2015  
**2016**  
2017  
2018



## Three major components

- DECam:  
led by Fermilab (DOE)
- Data Management  
led by NCSA (NSF)
- Telescope Facilities Improvement  
led by CTIO (NSF/NOAO)

## Data Releases to the Public

- Raw data  
Released after 1-yr proprietary period  
Y1 and Y2 images available
- Value-added, reduced data  
[SV object catalogs and more](#)

# It takes a (big) village

~500 Scientists from  
~30 Institutions  
7 Countries



- Fermi National Accelerator Laboratory
- Lawrence Berkeley National Laboratory
- Argonne National Laboratory
- National Optical Astronomy Observatory
- Chicago
- Ohio State
- Texas A&M
- Michigan
- Pennsylvania
- Santa Cruz-SLAC-Stanford DES Consortium
- Illinois at Urbana-Champaign
- National Center for Supercomputing Applications
- Ludwig-Maximilians Universität
- Excellence Cluster Universe
- College London
- Cambridge
- Edinburgh
- Portsmouth
- Sussex
- Nottingham
- Institut d'Estudis Espacials de Catalunya
- Consejo Superior de Investigaciones Científicas
- Institut de Física d'Altes Energies
- CIEMAT
- DES-Brazil Consortium
- ETH-Zurich
- OzDES: Australian Universities and Observatories

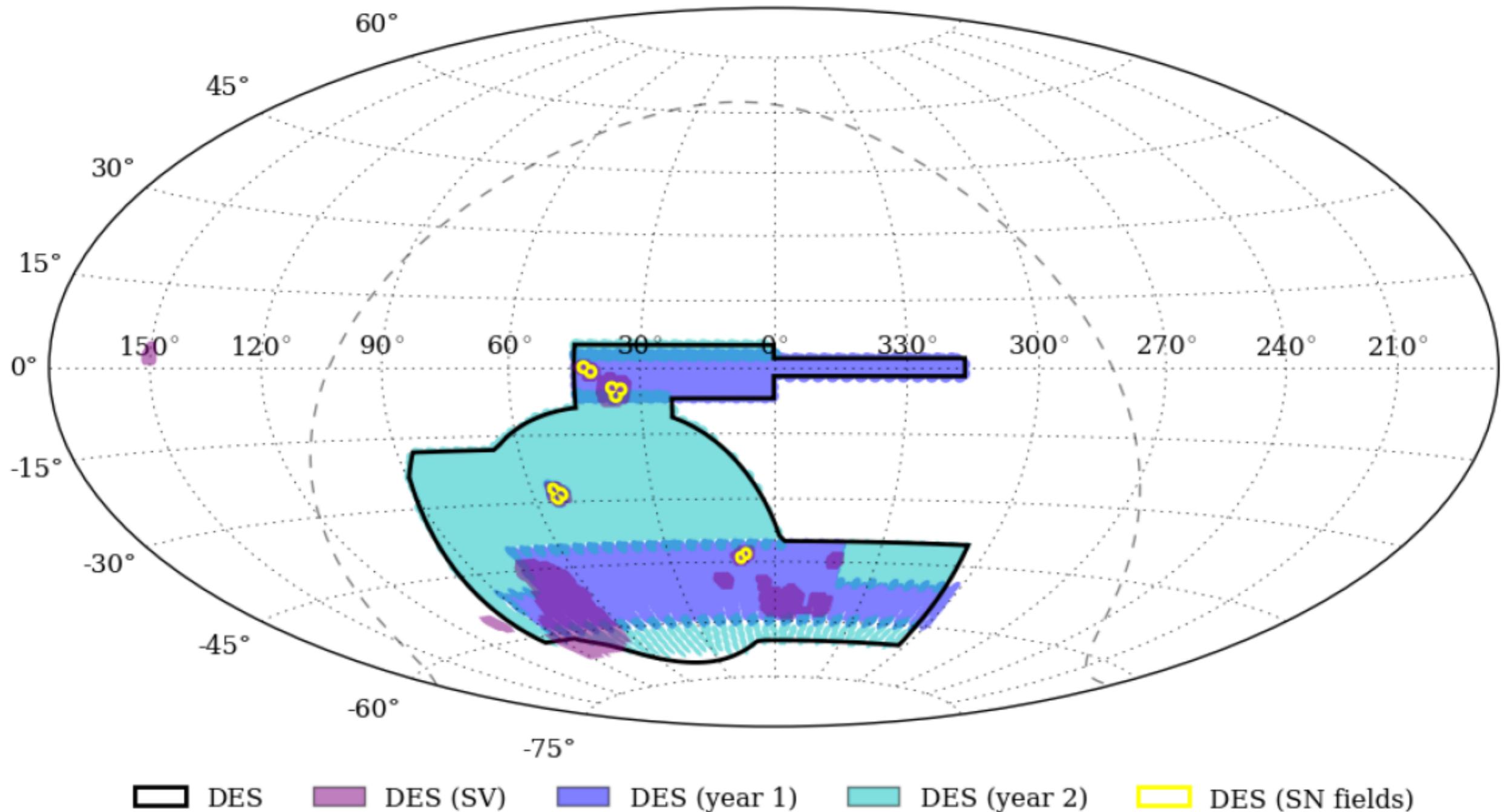
# Observing Progress

<b>Operations</b>	<b>Year 1 Hrs. (%)</b>	<b>Year 2 Hrs. (%)</b>	<b>Year 3 Hrs. (%)</b>
Total Observing Time Available	888.25 (100%)	928.75 (100%)	969.75 (100%)
<i>Observing Time</i>	<i>751.50 (84.6)</i>	<i>782.50 (84.2)</i>	<i>636.50 (65.6)</i>
<i>Bad Weather</i>	<i>90.25 (10.2)</i>	<i>140.00 (15.1)</i>	<i>293.75 (30.3)</i>
Engineering Observations	0.00 (0)	0.00 (0)	1.75 (0.1)
Telescope or Infrastructure Failure	18.00 (2.0)	2.88 (0.3)	28.00 (2.9)
Camera Systems Failure	25.75 (2.9)	3.12 (0.3)	9.75 (1.0)
Other	2.75 (0.3)	0.25 (0)	0.00 (0)



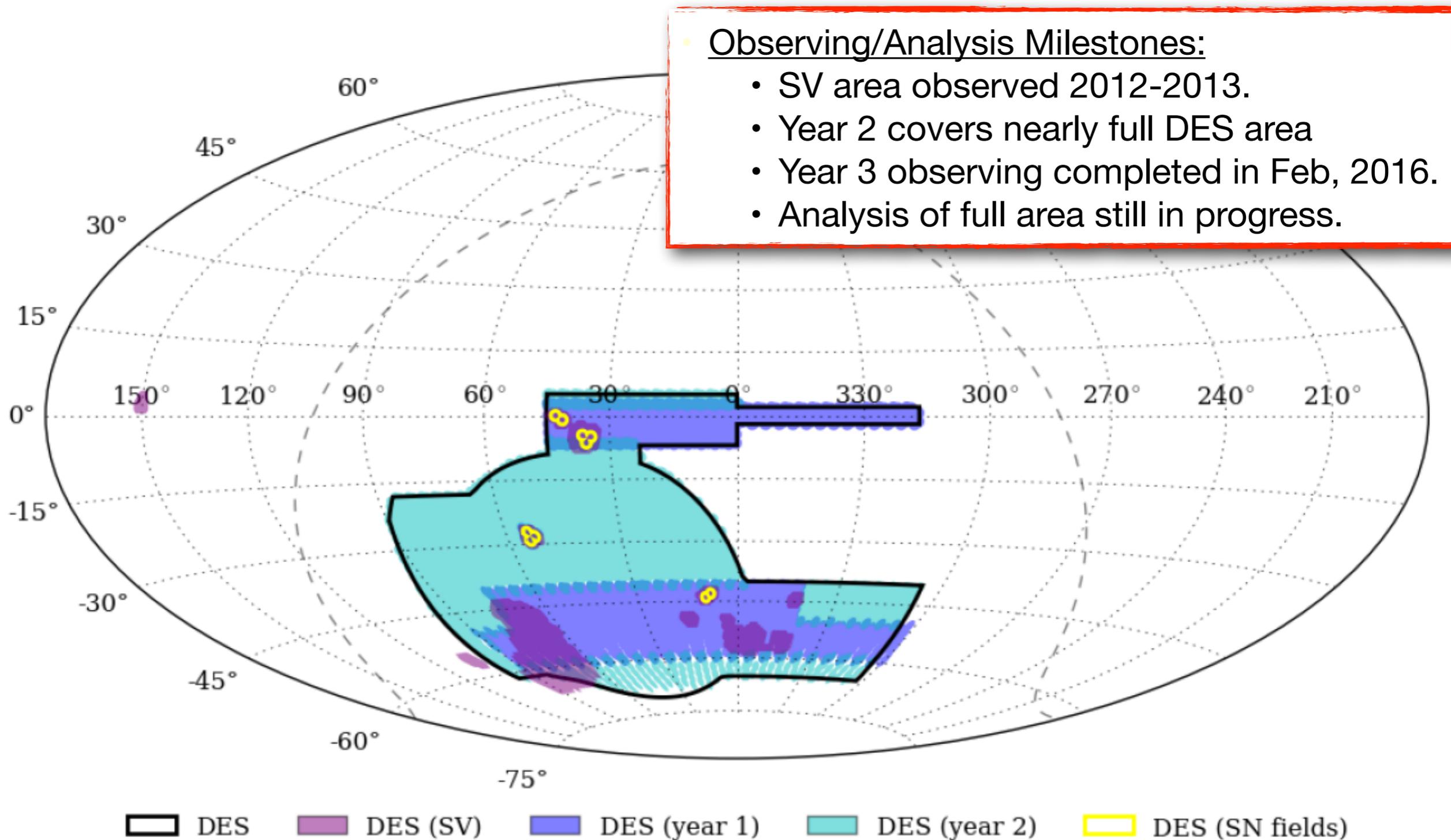
# Survey Footprint

- 250 sq. deg.: Science Verification (SV)
- 5000 sq. deg.: Total area



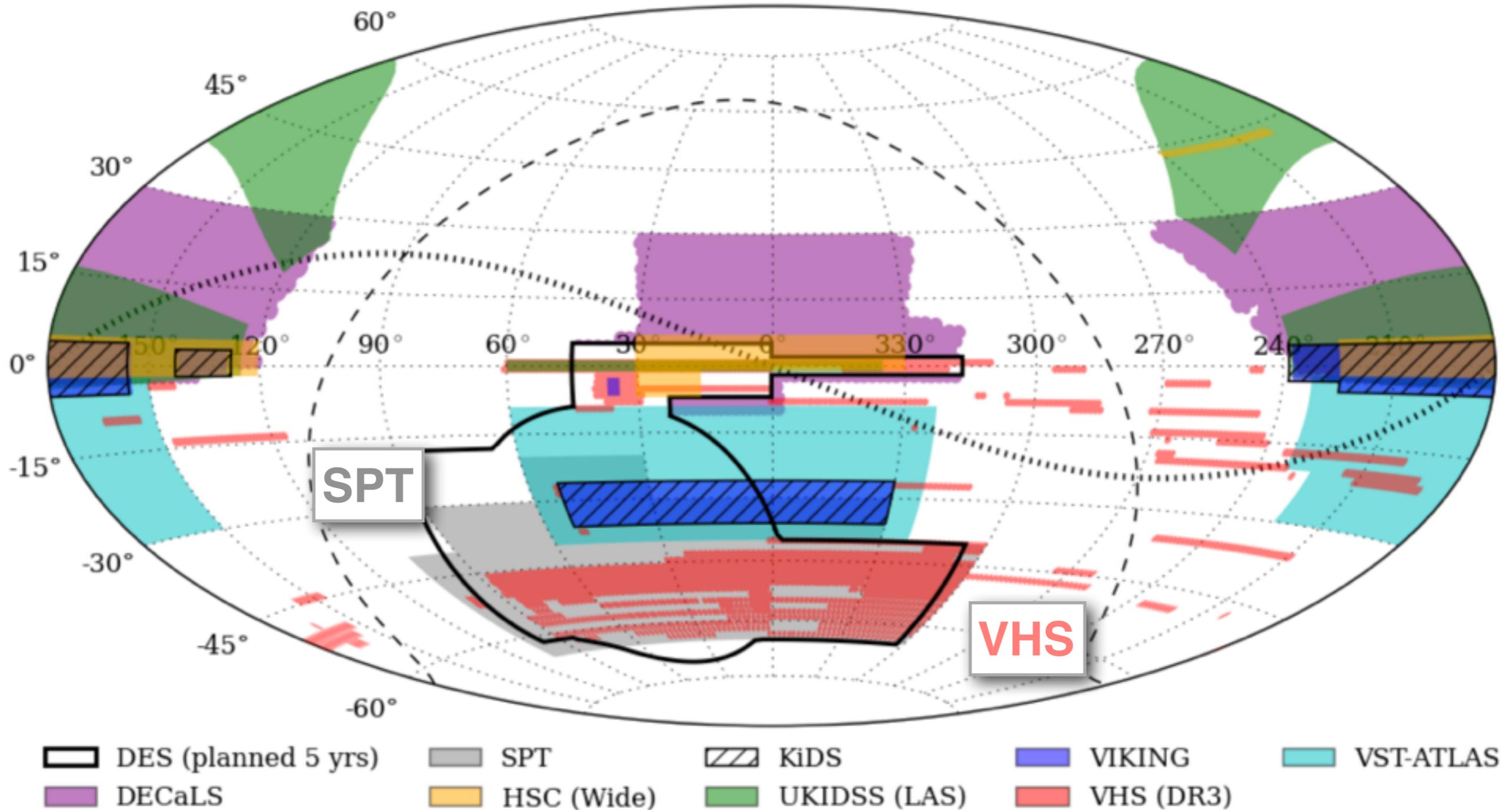
# Survey Footprint

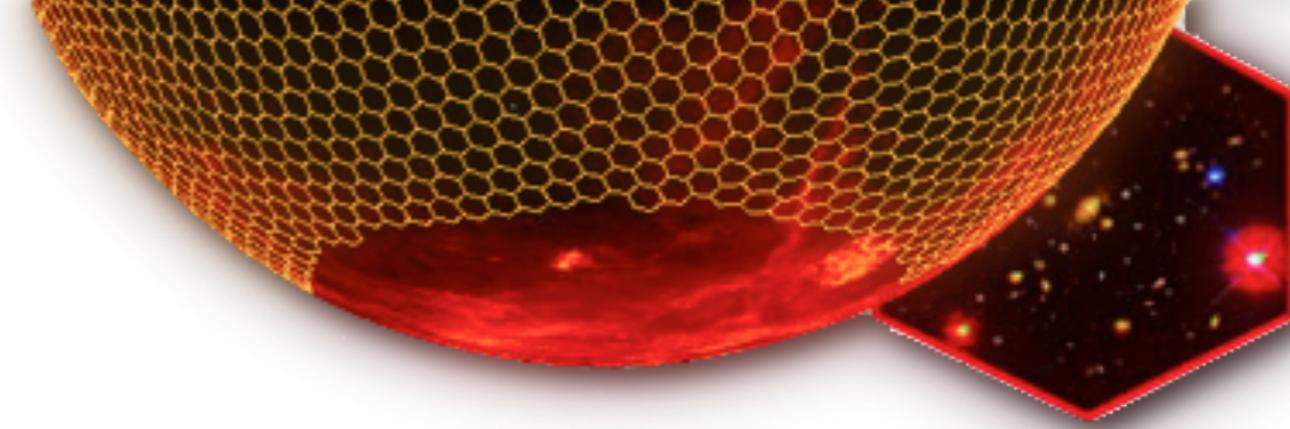
- **250 sq. deg.: Science Verification (SV)**
- **5000 sq. deg.: Total area**



# Survey Footprint

• Overlap with past and future surveys

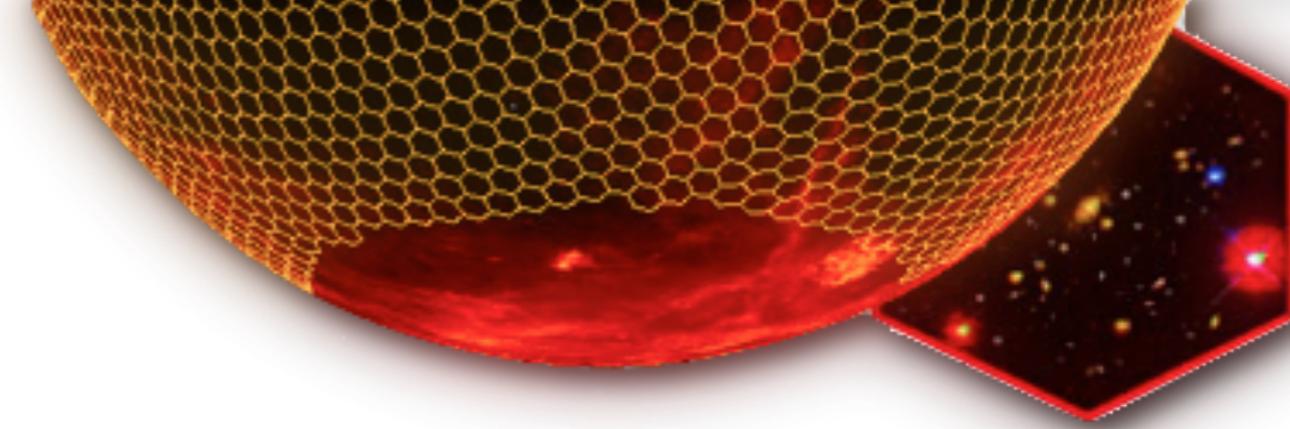




# New Results

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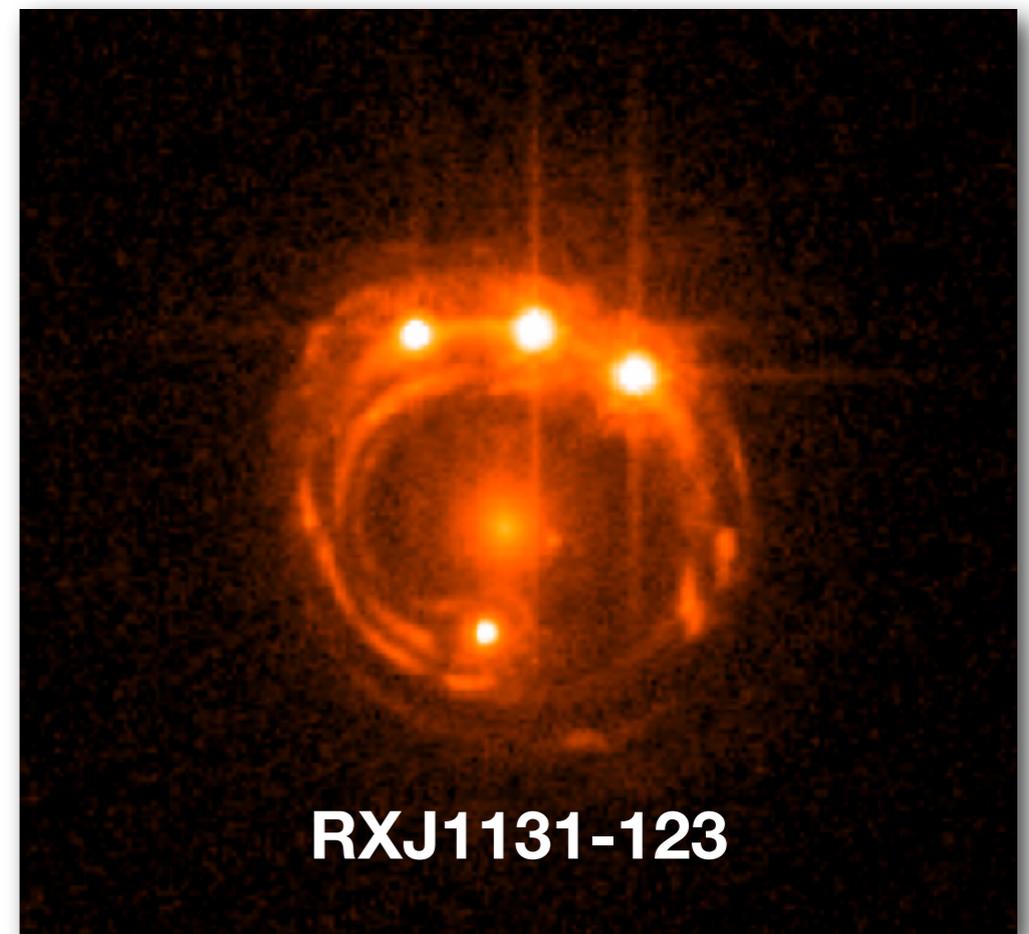
Strong Lensing  
Weak Lensing  
Supernovae

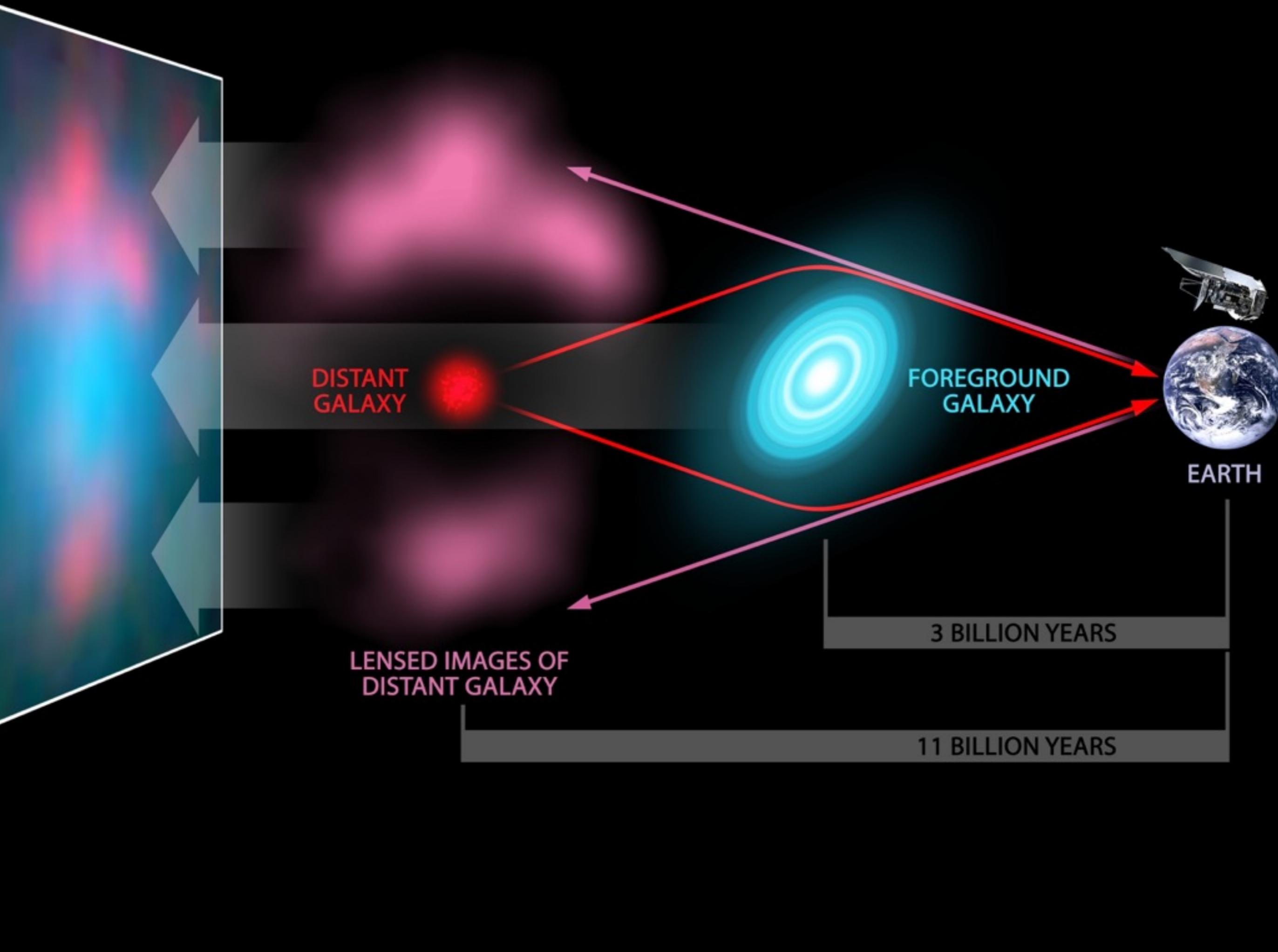


# New Results

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**Strong Lensing**  
Weak Lensing  
Supernovae





DISTANT GALAXY

FOREGROUND GALAXY

EARTH

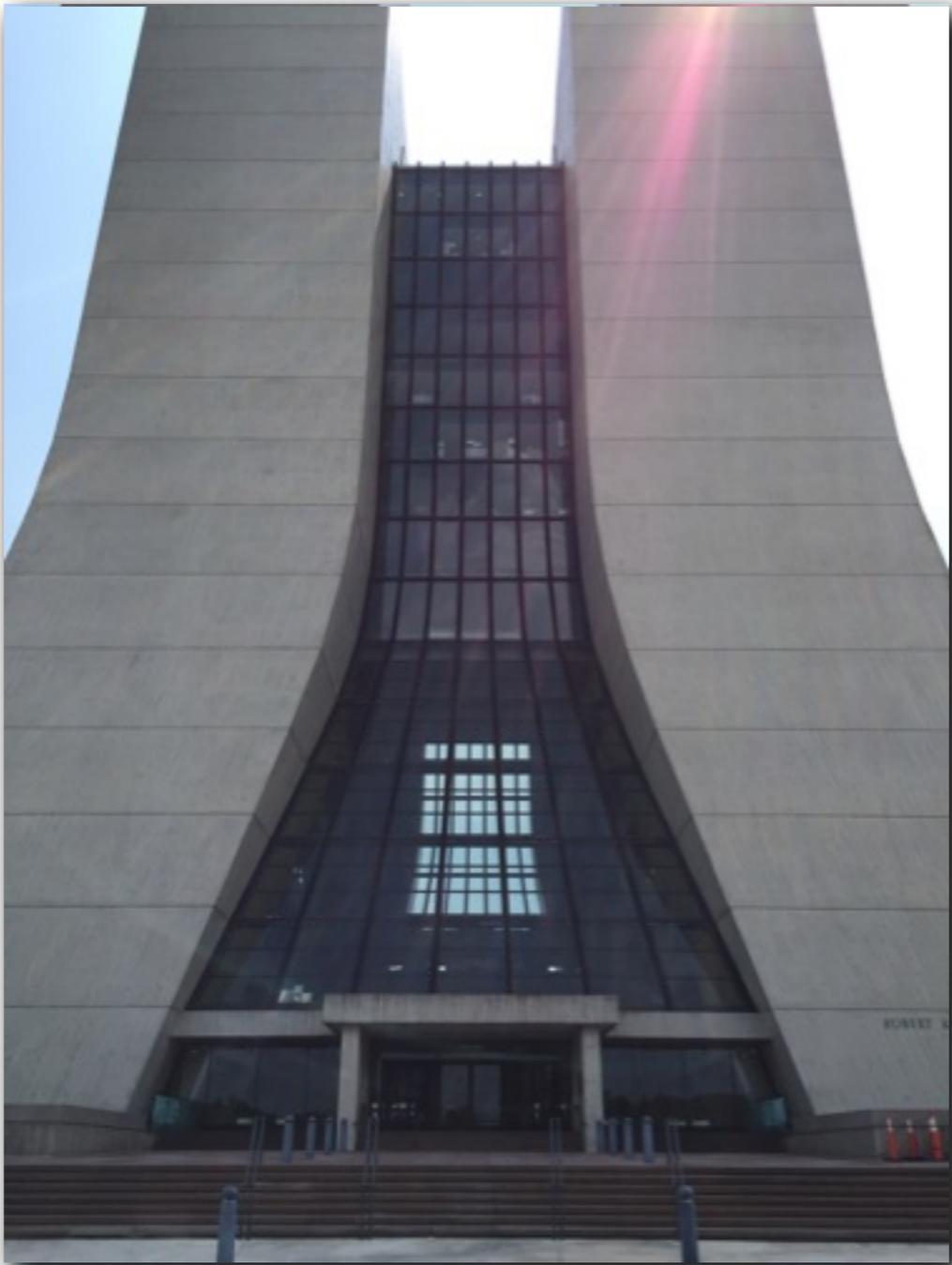
LENSED IMAGES OF DISTANT GALAXY

3 BILLION YEARS

11 BILLION YEARS

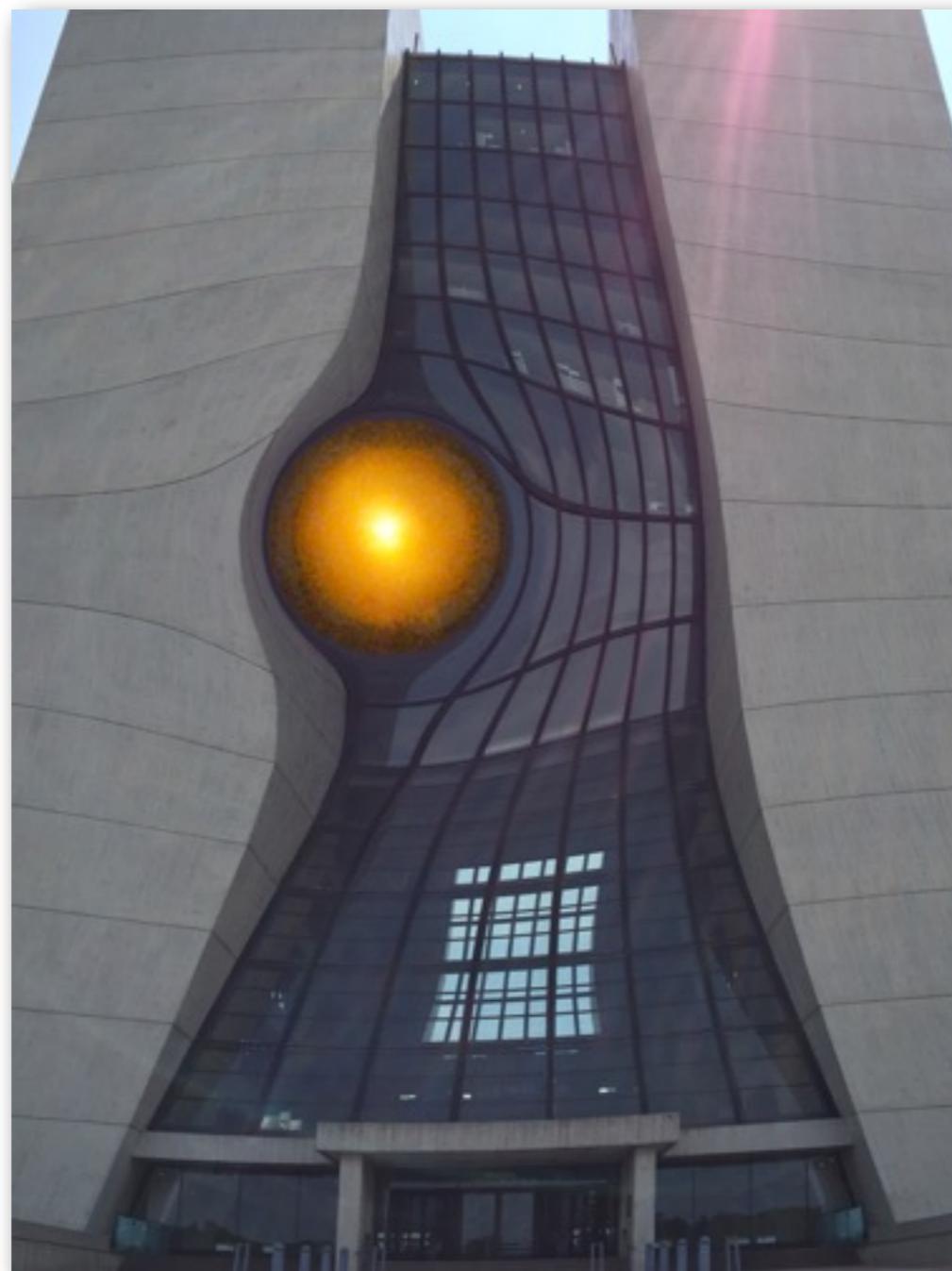
# Wilson Hall Lensed

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# Wilson Hall Lensed

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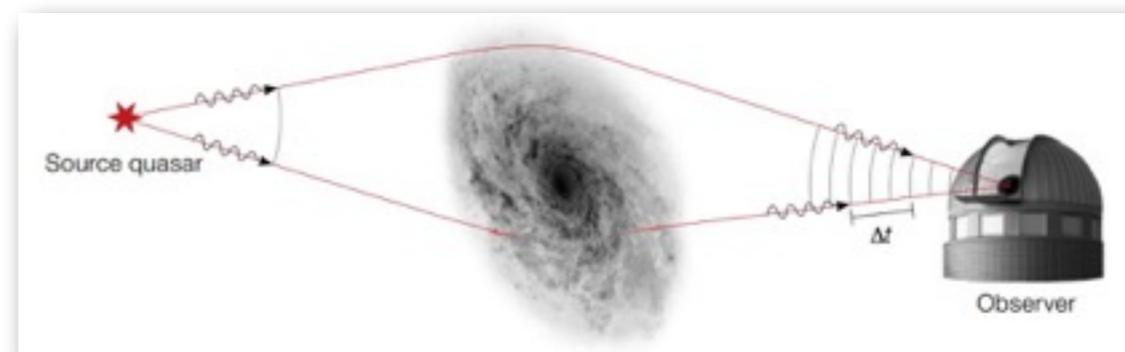


via GravLensHD by Eli Rykoff

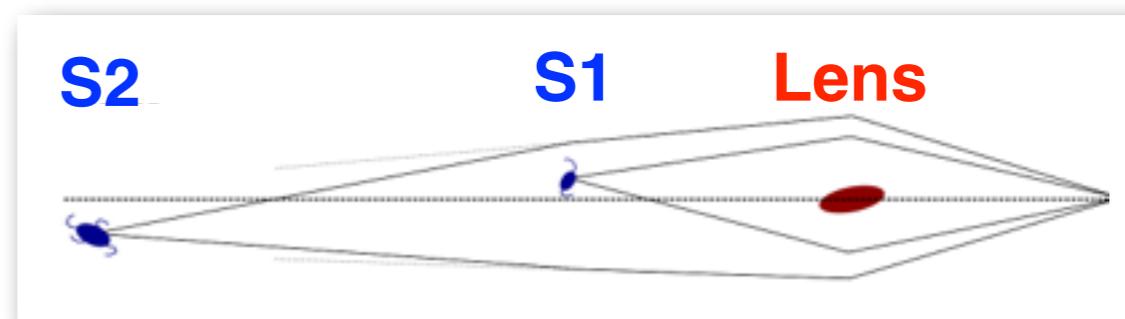


# Lenses for Cosmology

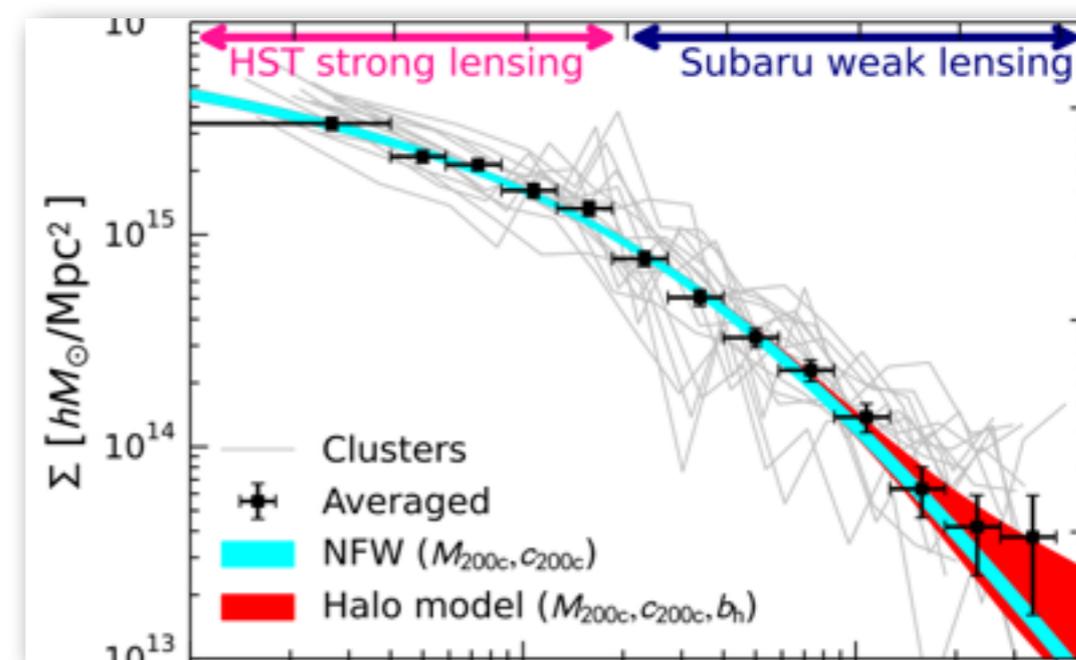
**Hubble constant,  $H_0$ :** proportional to the time delay between different light paths (Refsdal, 1964, Tewes++2012).



**Dark energy density,  $\Omega_\Lambda$ :** constrained by ratio of distances in rare multi-source systems (Collett++2015, Linder, 2016).



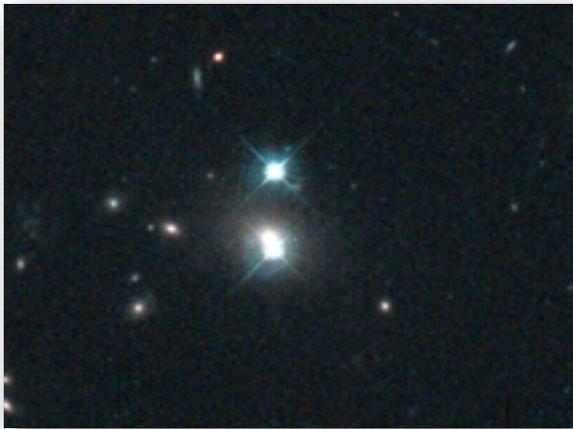
**Dark matter halo profiles** reveal the growth of structure and constrain cosmological models (Jullo++2015).



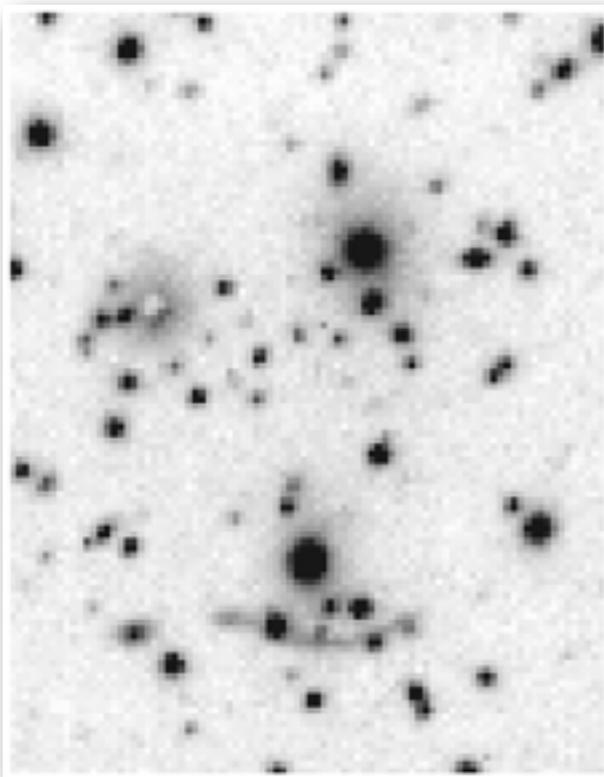
# Strong Lenses in DES

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- 1979: First lensed Quasar



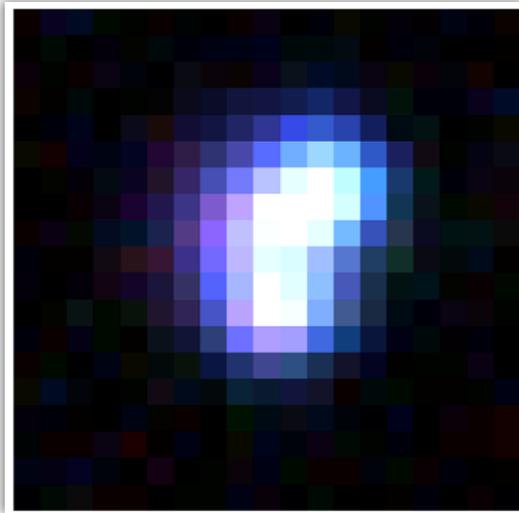
- 1986: First lensed galaxy



- Before DES, **~1000 lenses** have been discovered across all wavebands.
- Predictions for DES
  - **2000 lenses** (galaxy- to cluster-scale)
  - **120 lensed quasars**
  - **5 lensed supernovae** (Oguri & Marshall, 2010)
- Discoveries in DES
  - **55** galaxy-/cluster- scale in SV (Nord++2015)
  - **200** in Y1 (Nord++2016, Diehl++2016, in prep)
  - **5** lensed QSOs (Agnello++2015, Lin++2016, in prep.)
- New Search Techniques
  - Includes Deep Learning (e.g., convolutional neural nets)
  - Citizen Science (e.g., SpaceWarps)

# Strong Lenses in DES

- DES Lensed Quasar



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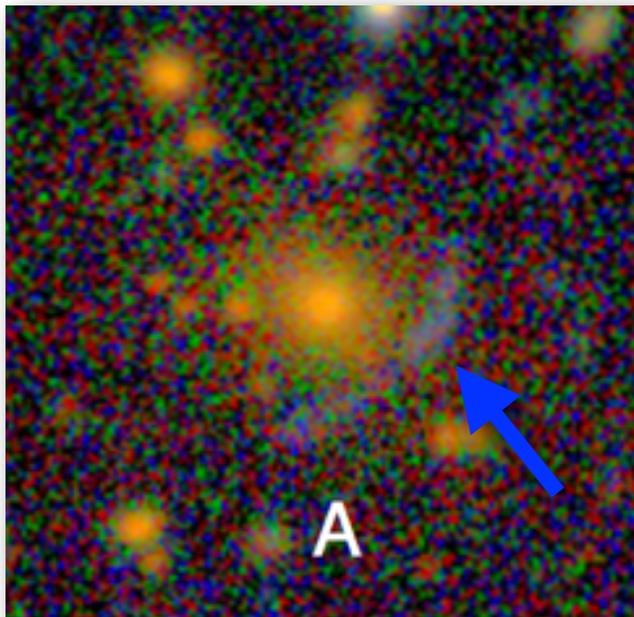
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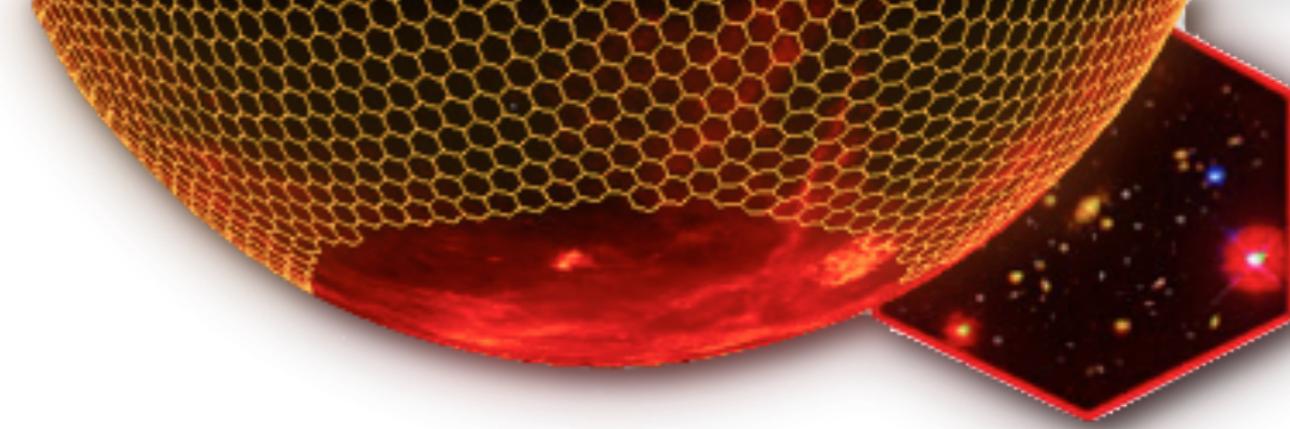
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- DES Lensed Galaxy





# New Results

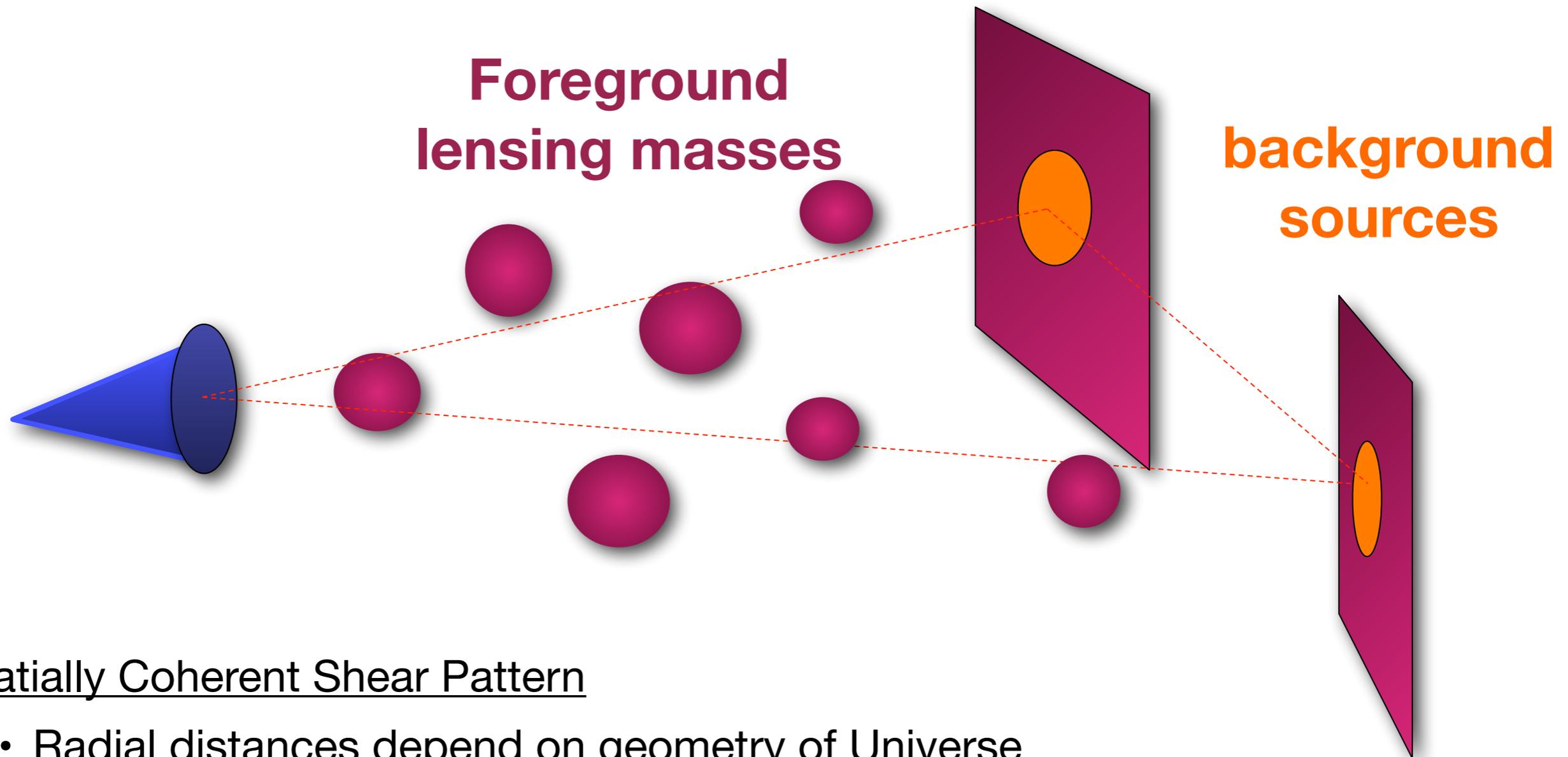
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Strong Lensing  
**Weak Lensing**  
Supernovae



# Structure Formation: Cosmic Lensing

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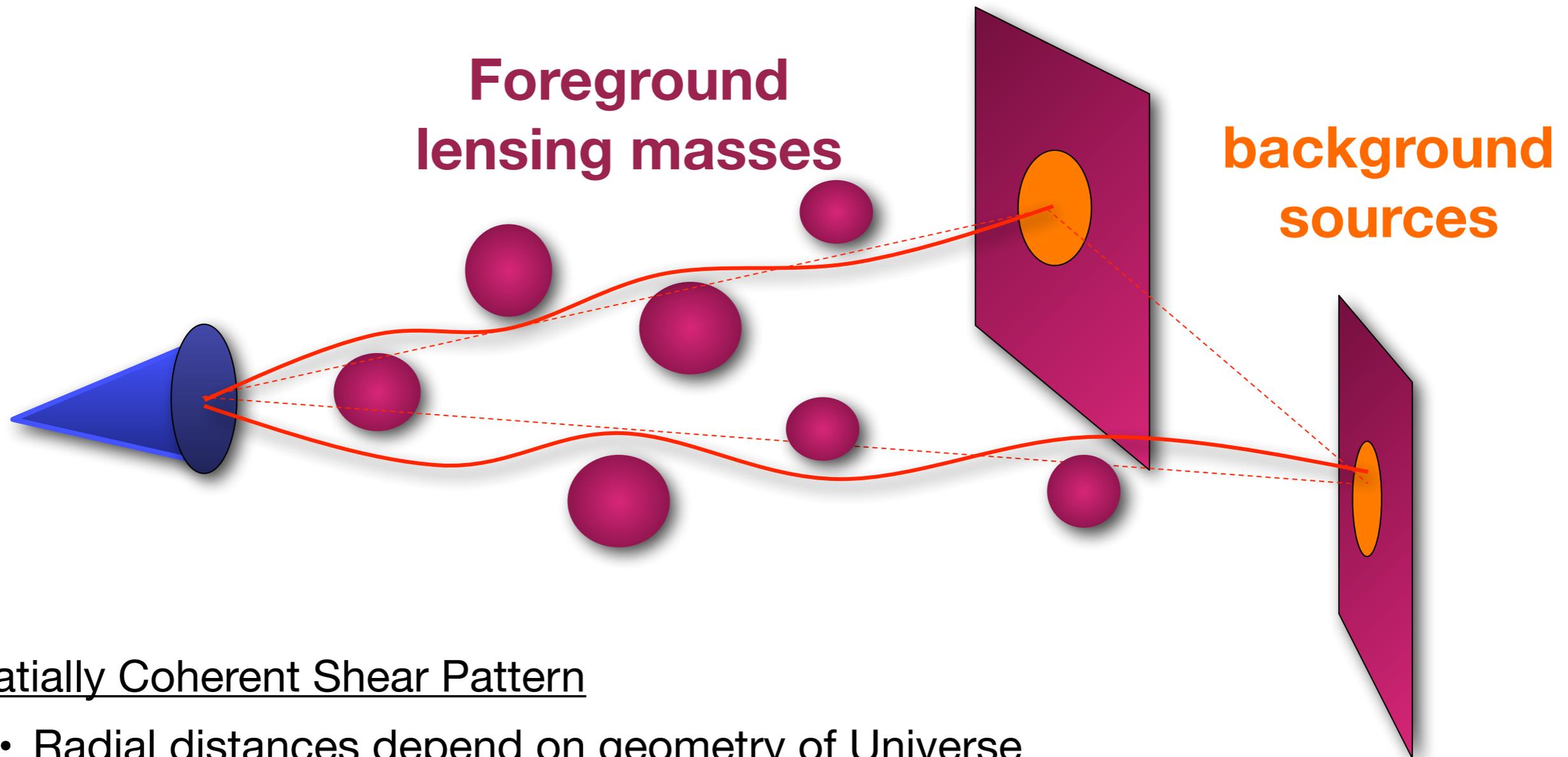


## Spatially Coherent Shear Pattern

- Radial distances depend on geometry of Universe
- Foreground mass distribution depends on growth of structure
- **only ~1% distortion of galaxy shapes**

# Structure Formation: Cosmic Lensing

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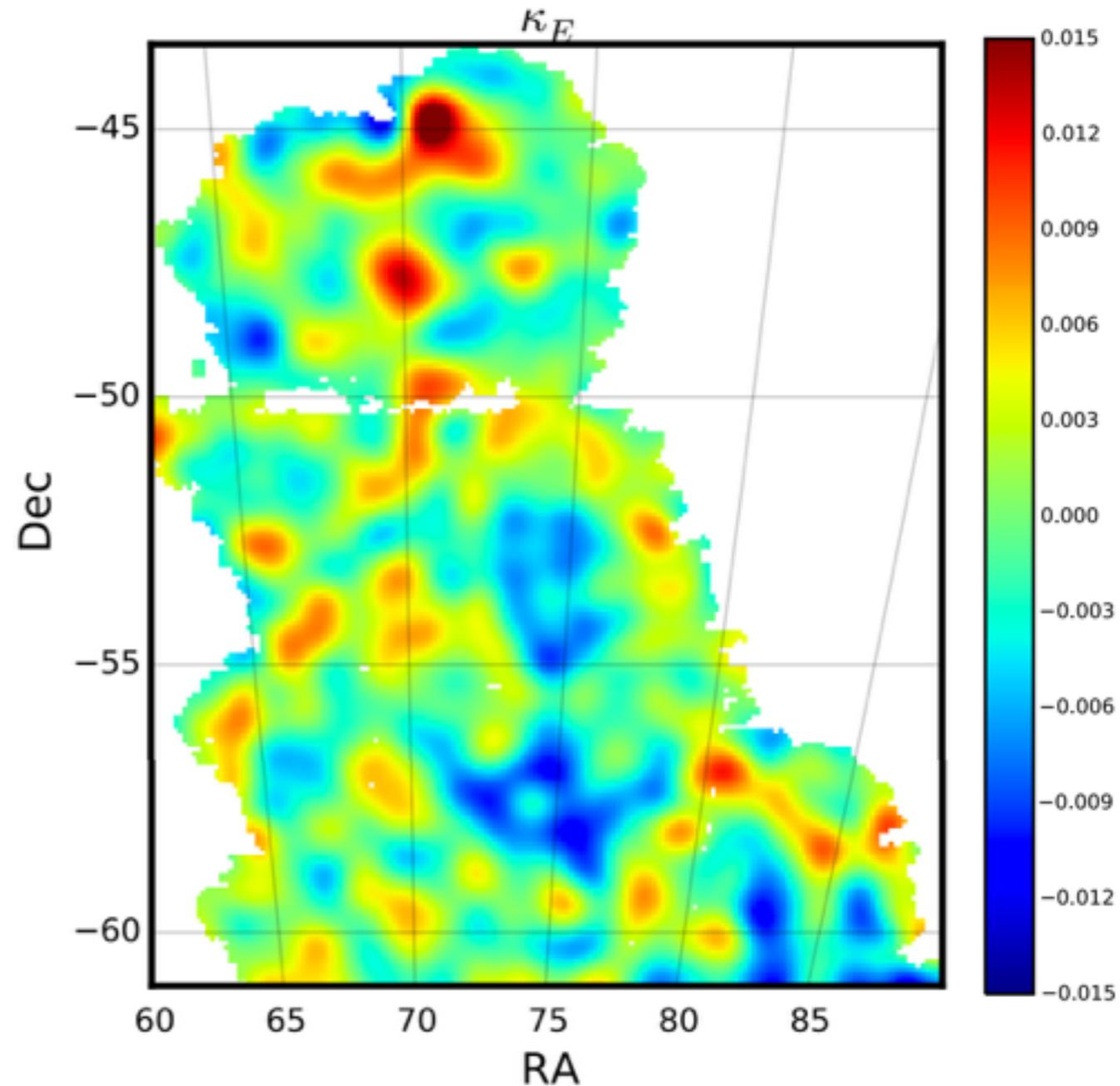
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# Mapping dark matter with SV data

[Vikram, Chang++2015; arXiv:1504.03002]

- redder = higher matter density, higher lensing signal
- bluer = voids

- Largest contiguous map of dark matter ever created
  - shear signal: a galaxy stretched by 1-2%
  - *shape noise* ~20%: need many galaxies to overcome intrinsic unknown ellipticity
- Motivation:
  - compare with light maps
    - e.g., CMB lensing and DE evolution
  - 2-point correlation functions of shear measure the large-scale structure in the region of the *foreground lensing galaxies*:
    - mean matter density,  $\Omega_M$
    - spatial variation,  $\sigma_8$



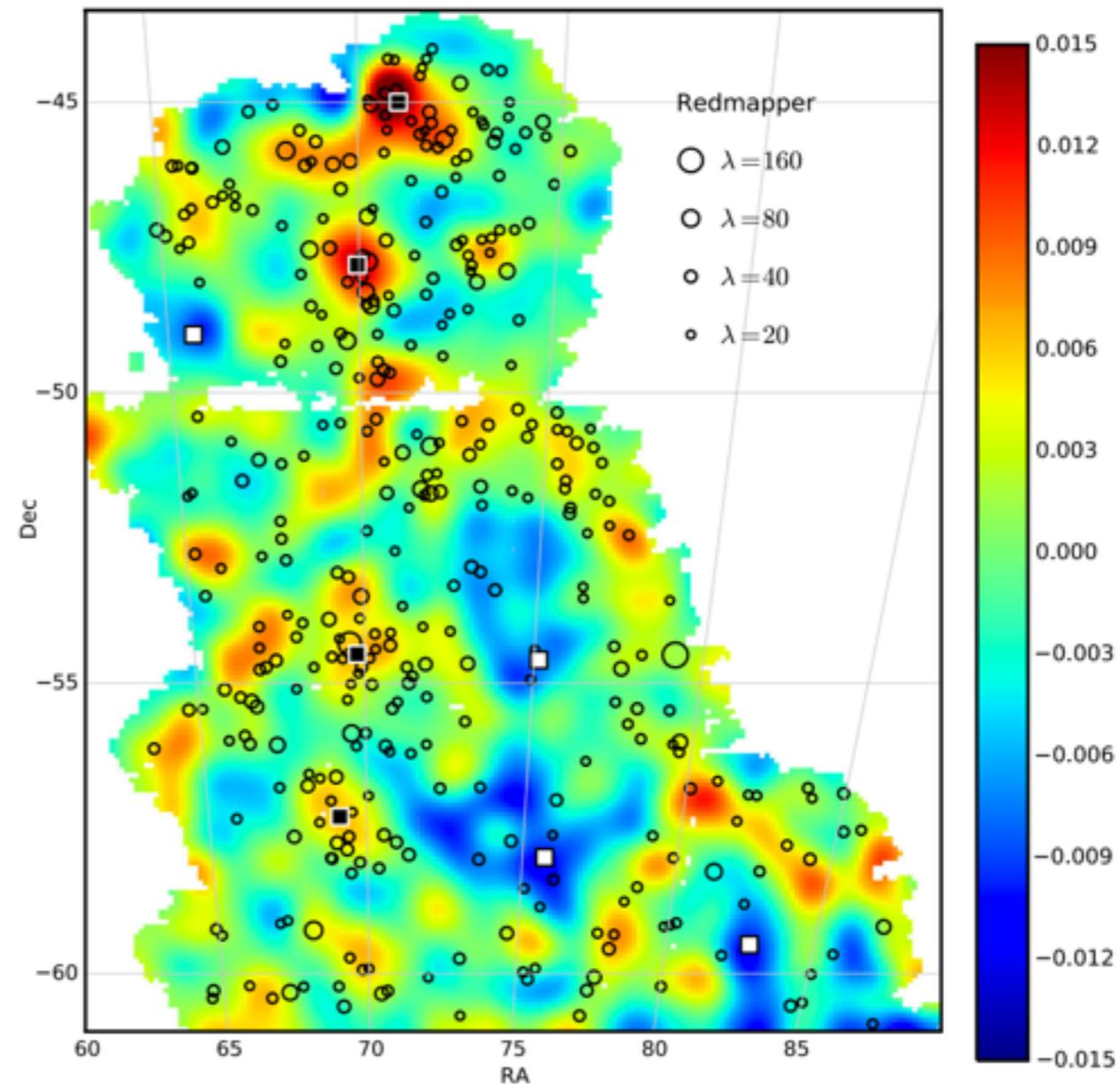
- 139 sq. deg (<3% full area)
- ~3 million galaxies (shapes)

- open circles represent known

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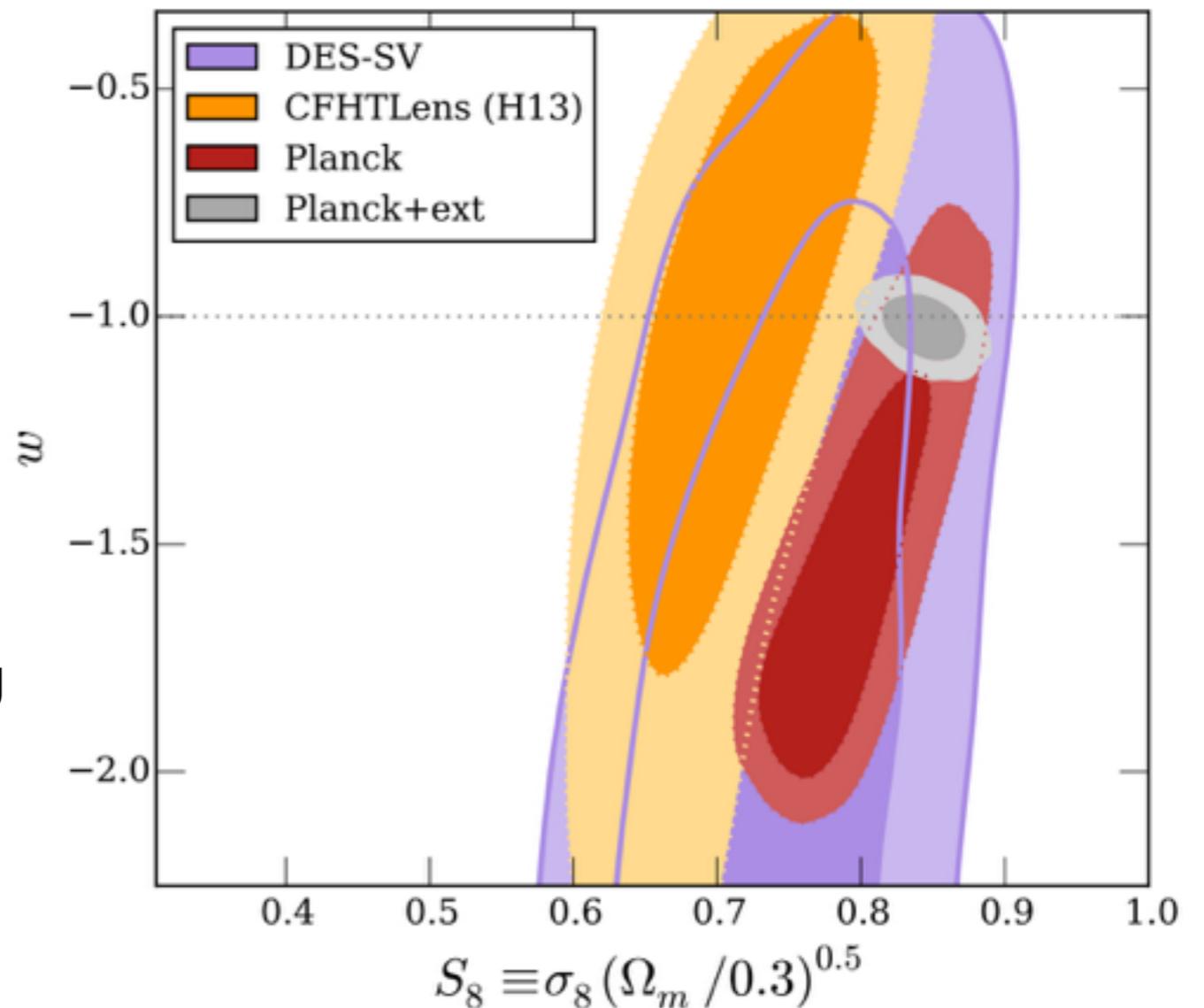


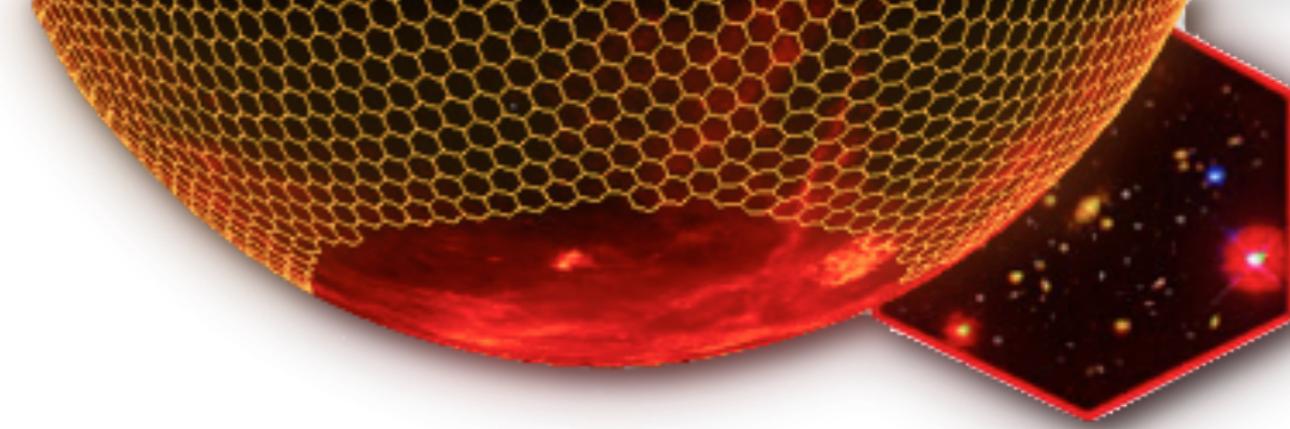
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# Cosmological Constraints from Shear

[DES Collaboration, 2015 arXiv:1507.05552]

- current constraints on dark energy
  - **CFHTLenS: deep galaxy survey**  
154 sq. deg, ~7.5 million galaxies,  
6 redshift bins
  - **Planck**
  - **DES:**  
139 sq. deg. ~3 million galaxies,  
3 redshift bins
- Future
  - DES uncertainties 30% larger due to lower number density of shear catalog
  - This only 3% of DES full area.





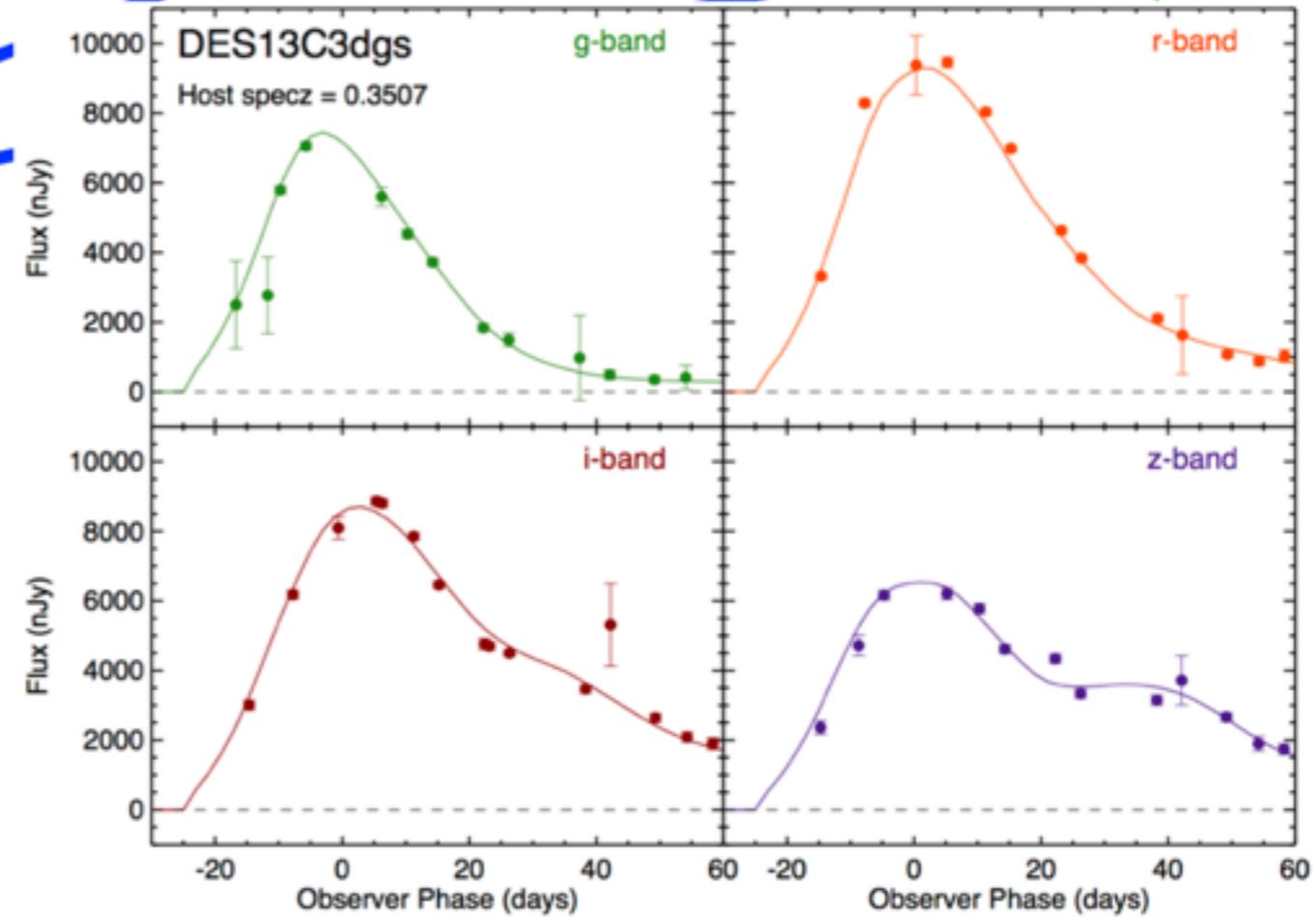
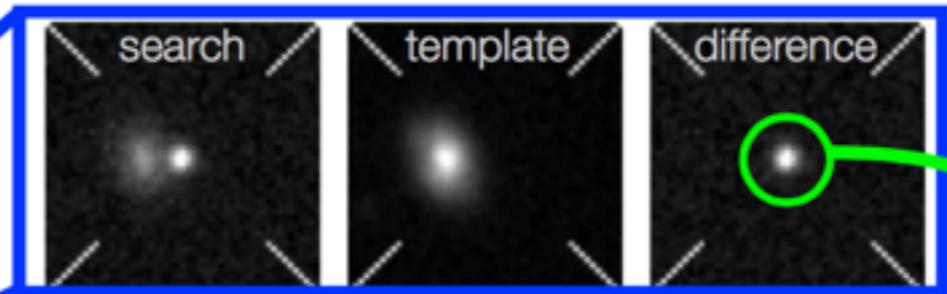
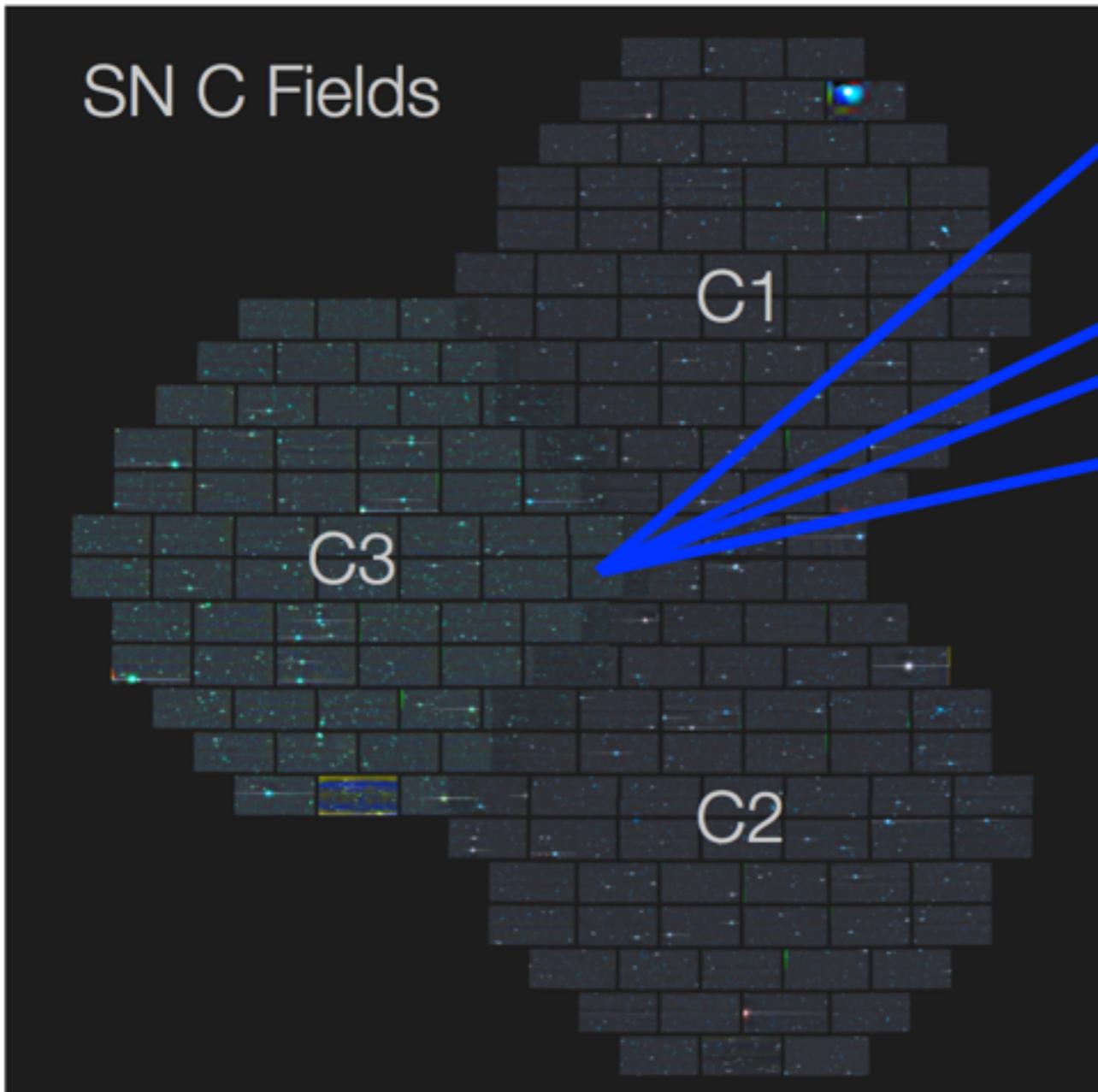
# New Results

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Strong Lensing  
Weak Lensing  
**Supernovae**

# Supernovae

Fields monitored for ~5 months  
each week for last 4 years



# Hubble Diagram

[D'Andrea++, 2015 in prep]

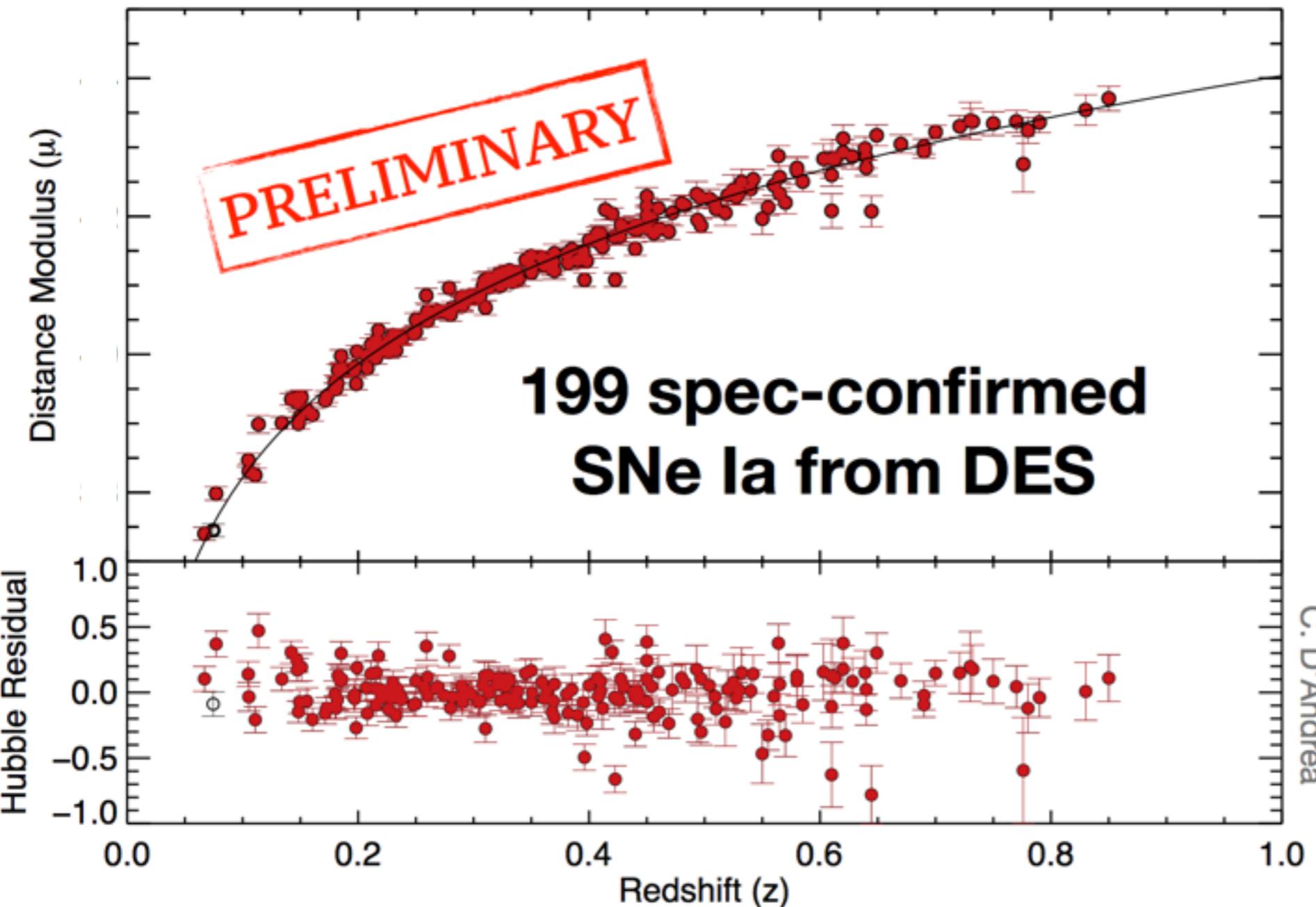
AAT, SALT, VLT, Magellan, Gemini,  
Keck, MMT, GTC, SOAR

## SNe Ia by Year

Year	# Confirmed
1	24
2	75
3	129

## SNe by Type

SN Type	# Confirmed
Ia	228
II	33
Ib/c	10
IIb	1
SLSN	13

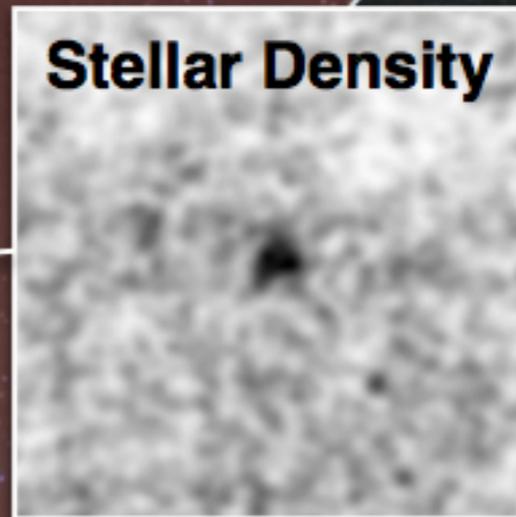


# Milky Way Satellites

Large Magellanic  
Cloud

Small Magellanic  
Cloud

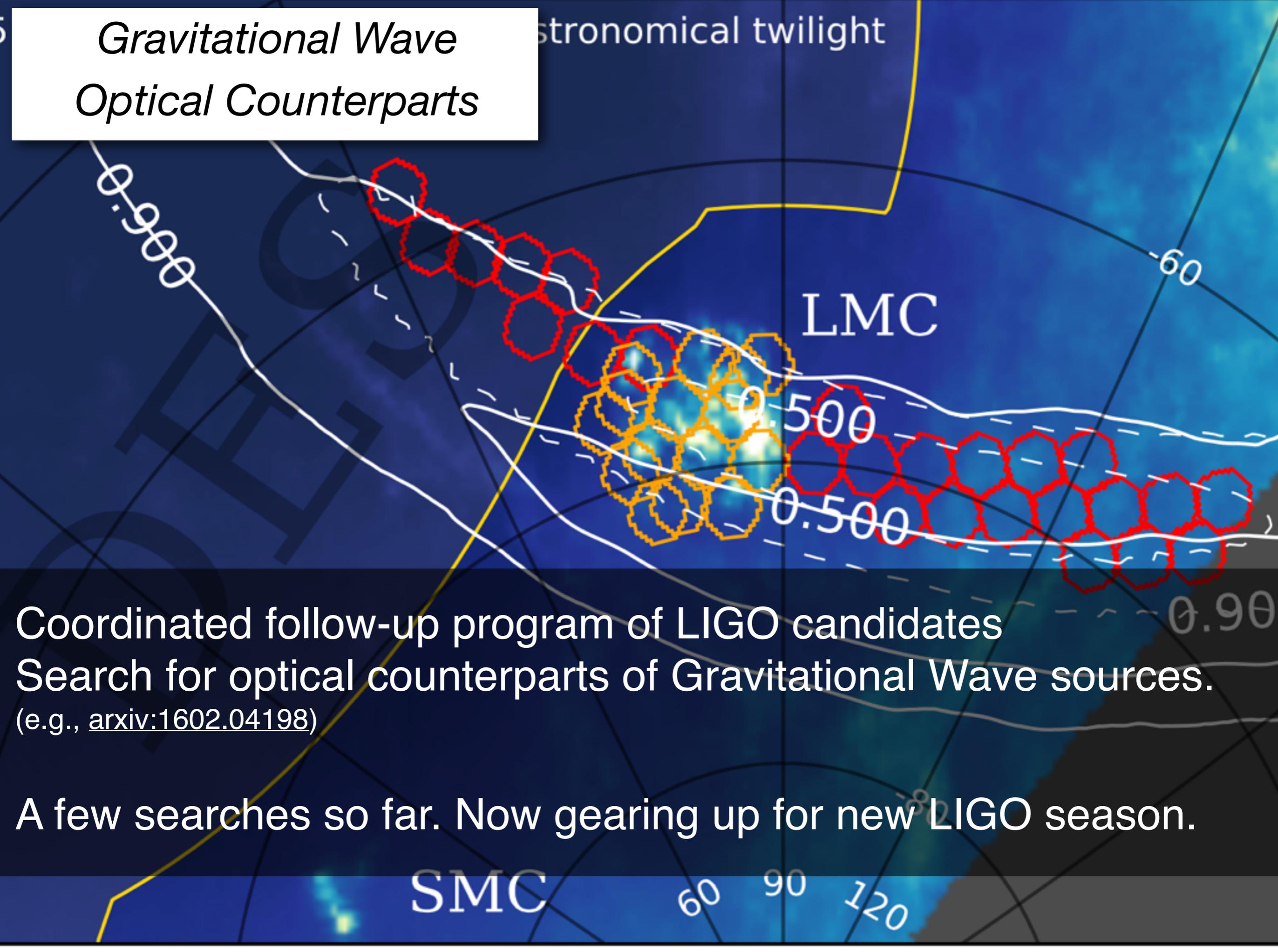
Stellar Density



**17** new dwarf galaxies discovered by DES (e.g., [arXiv:1508.03622](https://arxiv.org/abs/1508.03622))  
27 known before DES

See Alex Drlica-Wagner's Tollestrup Award talk at 16:55 today.

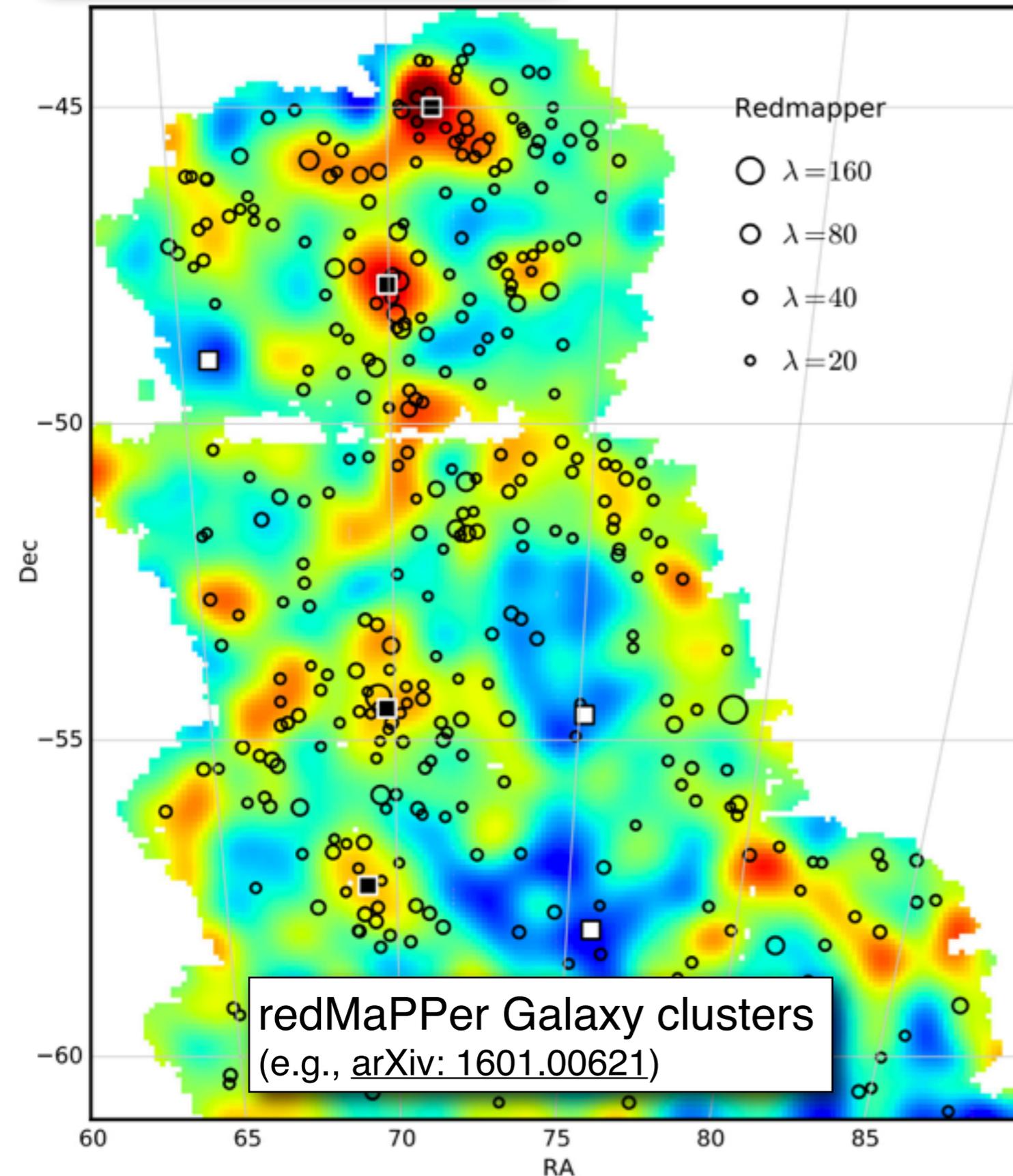
*Gravitational Wave  
Optical Counterparts*



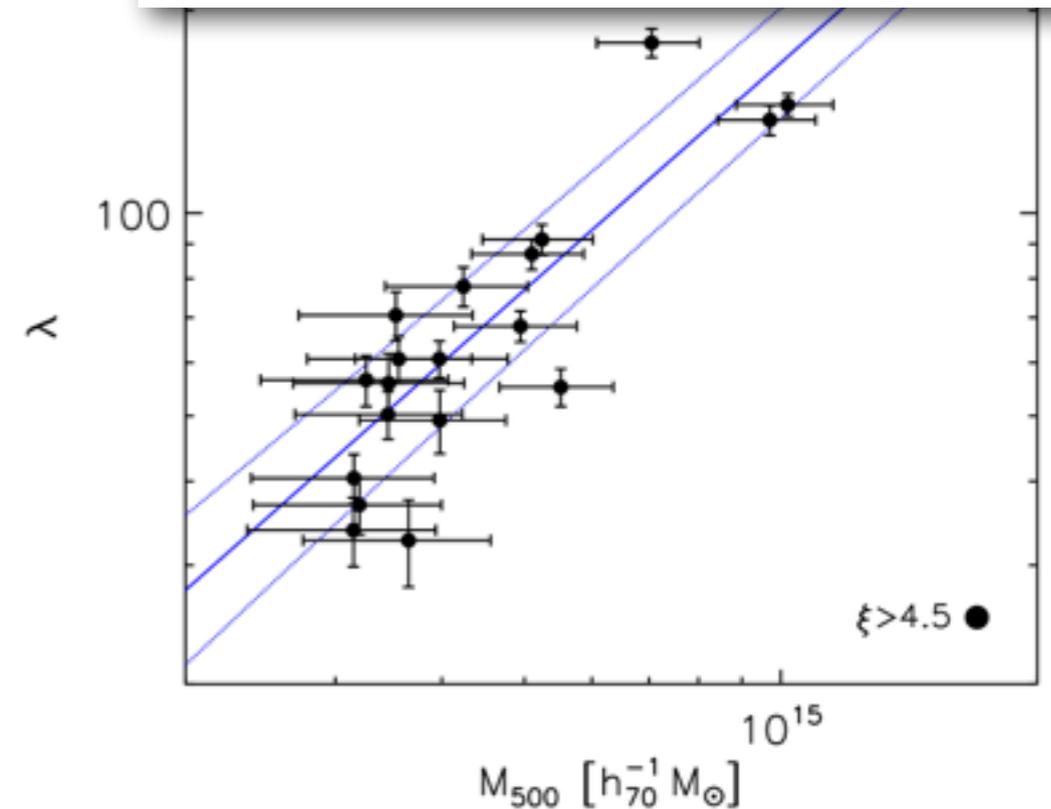
Coordinated follow-up program of LIGO candidates  
Search for optical counterparts of Gravitational Wave sources.  
(e.g., [arxiv:1602.04198](https://arxiv.org/abs/1602.04198))

A few searches so far. Now gearing up for new LIGO season.

# Galaxy clusters



## Masses of SPTxDES Clusters (e.g., [arXiv: 1605.08770](#))



- SPT and DES footprints overlap.
- Measure same galaxy clusters in optical and sub-millimeter wavebands
- Provides complementary measures of clusters for more accurate masses.

# Publications

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- Since April 2015 we have submitted ~50 papers using SV, Y1 and Y2 data
- Currently 30 have been published
- Some recent papers
  - Cosmology from shear statistics (Kacprzak++, arXiv:1603.05040)
  - Optical follow-up of grav. wave source (Soares-Santos++, arXiv: 1602.04198)
  - Galaxy-galaxy lensing (Clampitt++, arXiv: 1603.05790)
  - Detection of Kinematic SZ effect (Soergel++, 1603.03904)
  - DES-CLASH cluster RXJ2248 (Palmese++, arXiv:1601:00589)
  - Chromatic errors (Li++, arXiv:1601:00117)
  - Non-DE overview (Abbott++, arXiv:1601:00329)
  - Photo-z for LSS, simulations (Asorey++, arXiv:1601:00357)
  - Biasing - simulation (Pujol++, arXiv:1601:00160)
  - Biasing - data (Chang++, arXiv:1601:00405)
  - SV Redmapper (Rykoff++, arXiv:1601:00621)
  - WL CMB x WL DES (Kirk++, arXiv:1512.04535)
  - New SL SN (Smith++, arXiv:1512.06043)
  - New Strong Lensing systems (Nord++, arXiv:1512.03062)

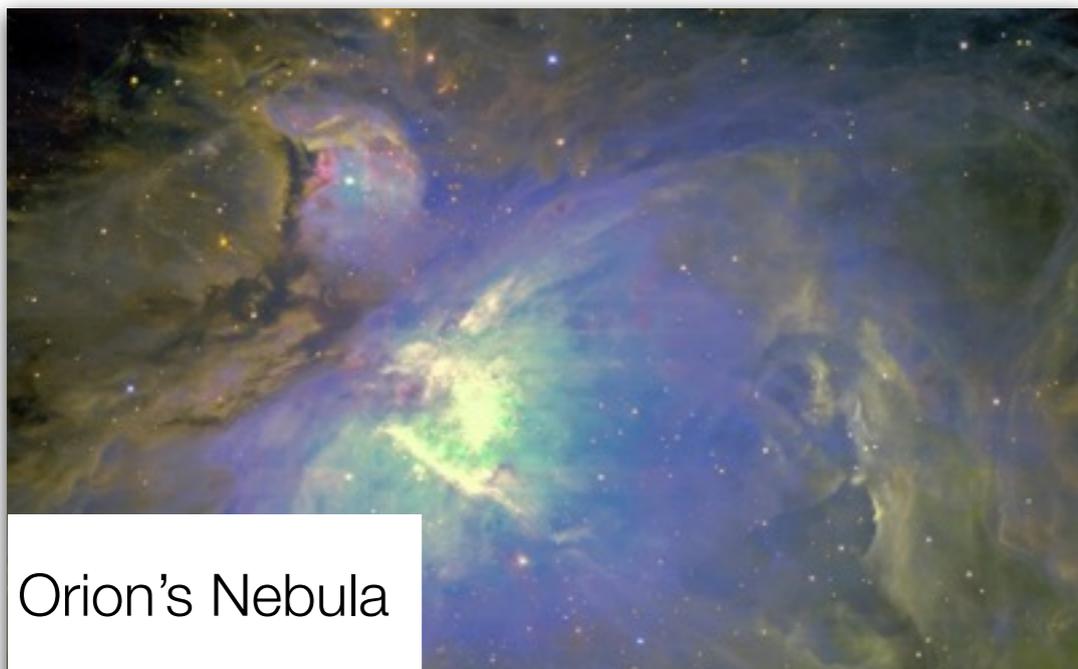
# Public Engagement

@TheDESurvey 

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We have developed a system that is flexible, led by scientists, tunable to the needs of the scientists.

- Goals:
  - connect the public with scientists
  - share the lives of scientists
  - maximize reach of science product
- Tools:
  - Social Media, Art, Writing, Reporting



Orion's Nebula

## Projects

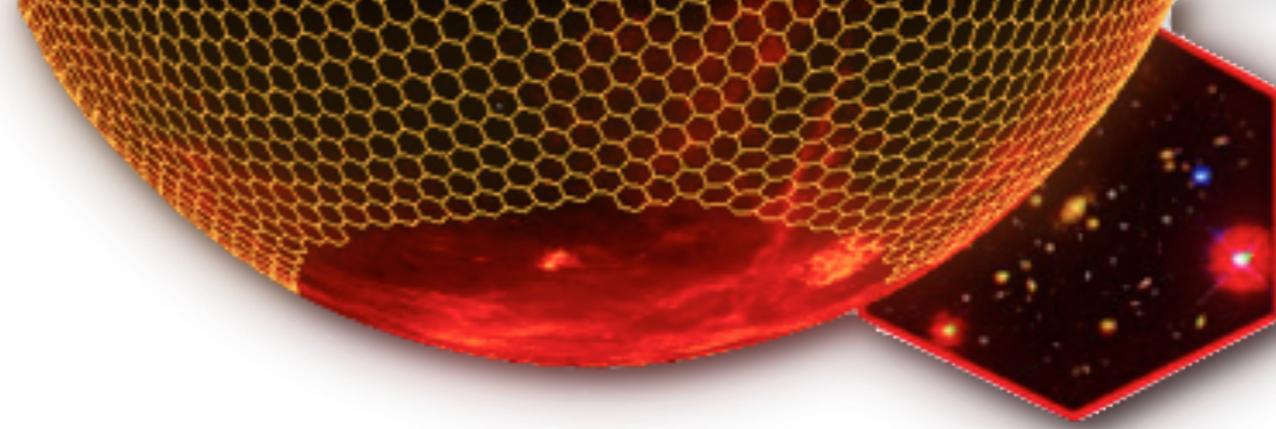
- [DArchives](#):  
500-word summaries of DES papers for the public.
- [DarkBites](#):  
Astounding facts about the universe, accompanied by artful sketches.
- [Scientist of the Week](#):  
Interviews with DES scientists about physics and life outside work.
- [Thought for the Day](#):  
Social media posts of ideas and images from scientists.
- [Art Exhibits and Visualizations](#):  
*Art of Darkness* at Fermilab



# Summary: @TheDESurvey

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- **DES** uses multiple signatures of structure growth and expansion to investigate dark energy and dark matter to new depths.
- > 50 Publications to date, mostly from SV data
- Year 4 of observing starts August 2016
- Constraints on dark energy
  - *slated for release* some time in 2017
  - will use full survey area, Y1 and Y2 data sets
- Data is public!
  - *raw* images from Y1, Y2 is currently available
  - recent release of value-added data from [SV \(object catalogs and more\)](#)
- Related talks (both Thesis and Tollestrup Award winners)
  - *Daniel Gruen* (Stanford) at 16:30: “Weak Gravitational Lensing: From Pixels to Cosmology”
  - *Alex Drlica-Wagner* (FNAL) at 16:55: “Searching for Dark Matter in Dwarf Galaxies”



# Extras

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# DES in Context:

## Past, Current and Future Large Optical Surveys

SDSS I-II

2000-08

2.5-meter mirror

$z < 0.4$

$O(10^8)$  Galaxies

10k sq. deg.

200 Gb/Night

DES

2013-18

4-meter

$z < 1$

$O(10^8)$  Galaxies

5k sq. deg.

500 Gb/Night

LSST

2022-32

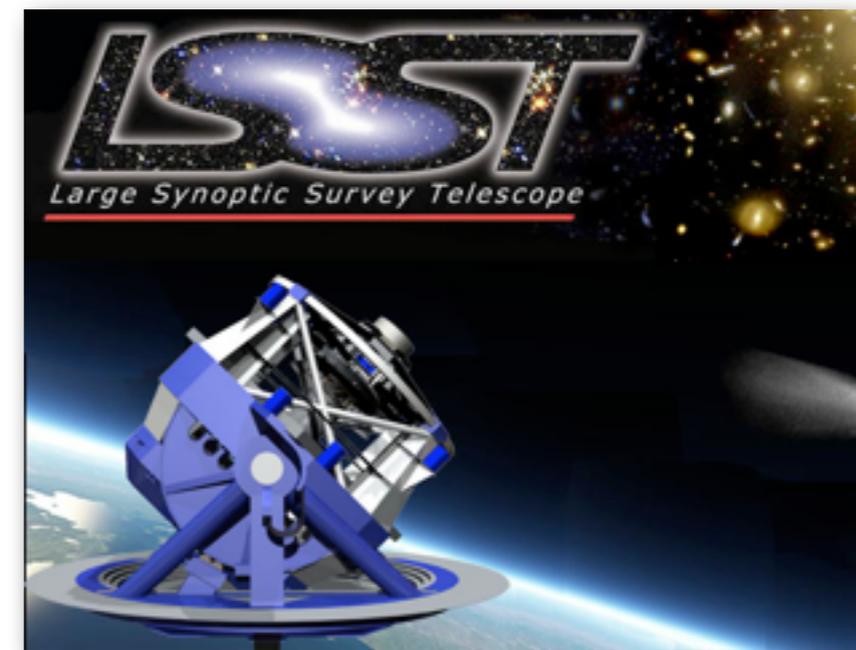
8.4 -meter

$z < 1$

$O(10^9)$  Galaxies

20k sq. deg.

1,500 Gb/Night



# Collaboration Statement on Diversity and Inclusivity

[Link to Full Text](#)

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The success of the Dark Energy Survey (DES) relies on a truly collaborative, team-oriented approach. Maintaining a strong and healthy collaboration requires open, respectful communication and a shared commitment to a set of values that include ethical conduct, civility, inclusiveness, and diversity. As a collaboration, we are committed to the following values:

- We are committed to honesty, integrity, and the highest professional and ethical standards of conduct in our research, management, and communications.
- We are committed to respecting the full spectrum of views held by our members. Each person's contribution is valued, and his/her opinion should be treated with civility. We strive to uphold a collegial spirit rooted in respect for all people, free of discrimination and non-inclusive behavior.
- We strive to create a collaborative environment in which all scientists feel comfortable, free of inappropriate or offensive language or behavior.
- We recognize the intrinsic relationship between diversity and excellence in our collaboration and acknowledge that an inclusive environment creates opportunities for participation and innovation that benefits the collaboration as a whole.

# Turning a chore into a game



DES exposure checker    Viewer    Tutorial    FAQ    Statistics    API    Gallery    Hodge-podge    SVA1    **Y1A1**

## DES exposure checker

See how real DES images look. Discover flaws we would otherwise have missed.  
Make our data better!

[Log in](#)    [Sign up](#)

**1996**  
images checked

**152**  
today

*Melchior et al. 2015*

## What's this good for?

We all want to do science with the DES data. However, no data set is perfect, so we need to identify and account for imaging artifacts in our data. This application helps in two ways:

- It gives you convenient access to the DES annual release finalcut images and shows the processing steps that are already in place to identify and correct for known problems.
- It enables everyone to search for undetected artifacts. We gather your submissions, analyze them, and feed them back to the science working groups and DESDM. This way, we can refine the processing pipelines to catch the flaws that we know are there.

## How can I start?

Check out our [Tutorial](#) and you'll know what to do in no time.

## How are we doing so far?

The basic [statistics](#) are computed in real time. More detailed analyses will become available once we have gathered enough submissions, but you can go to our [API page](#) and download the

## Top contributors for Y1A1

# 1	kadrlica		514
# 2	ynzhang		430
# 3	rpoulton		400
# 4	pmelchior		159
# 5	erykoff		137
# 6	pmartini		100
# 7	bellido		82
# 8	menanteau		52
# 9	rgm		39
# 10	mhubbard		28