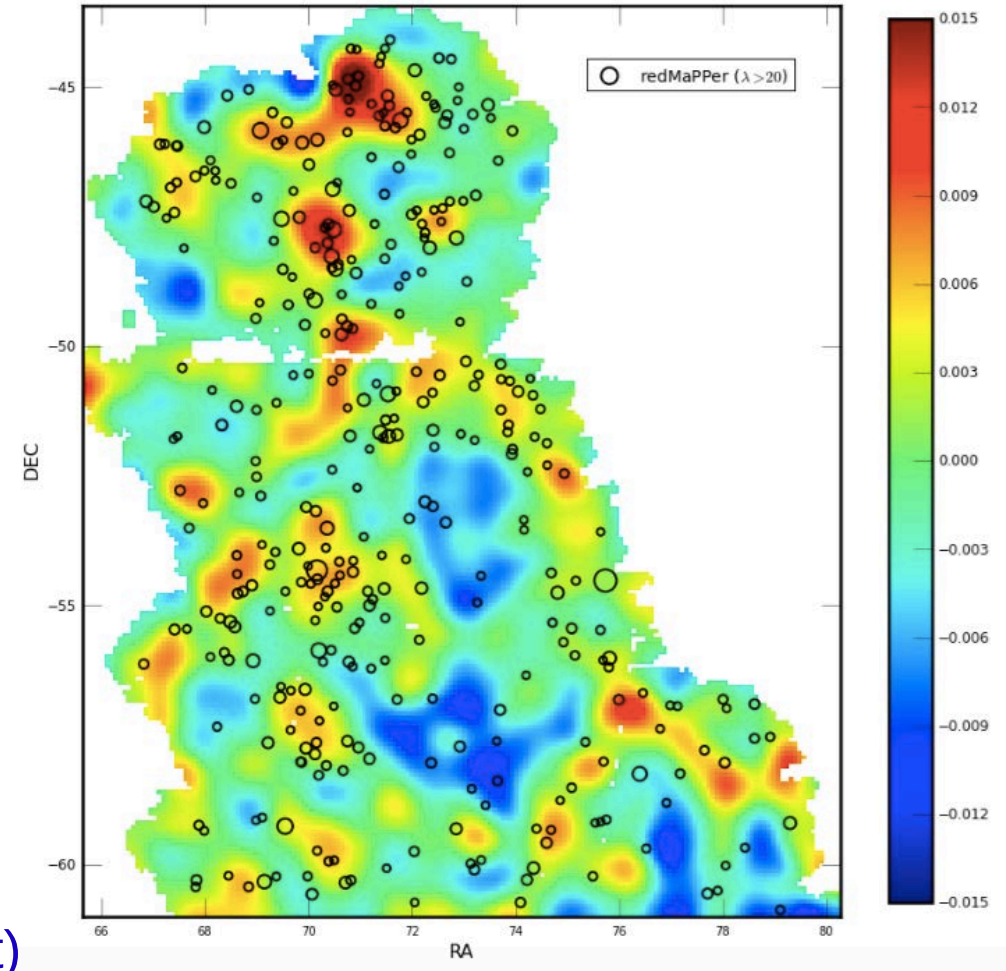
# The Dark Energy Survey

DARK ENERGY SURVEY

## OUTLINE

- Introduction
- DES & DECam
- Observing Efficiency & Results for DES 1st and 2nd Seasons
- The Path to DE Science
- Recent Publications
- Summary




Chang et al (DES) sub. to PRL
arXiv:1505.01871

Tom Diehl (DES Operations Scientist)
Fermi National Accelerator Laboratory
June 24, 2015

# The Dark Energy Survey Collaboration

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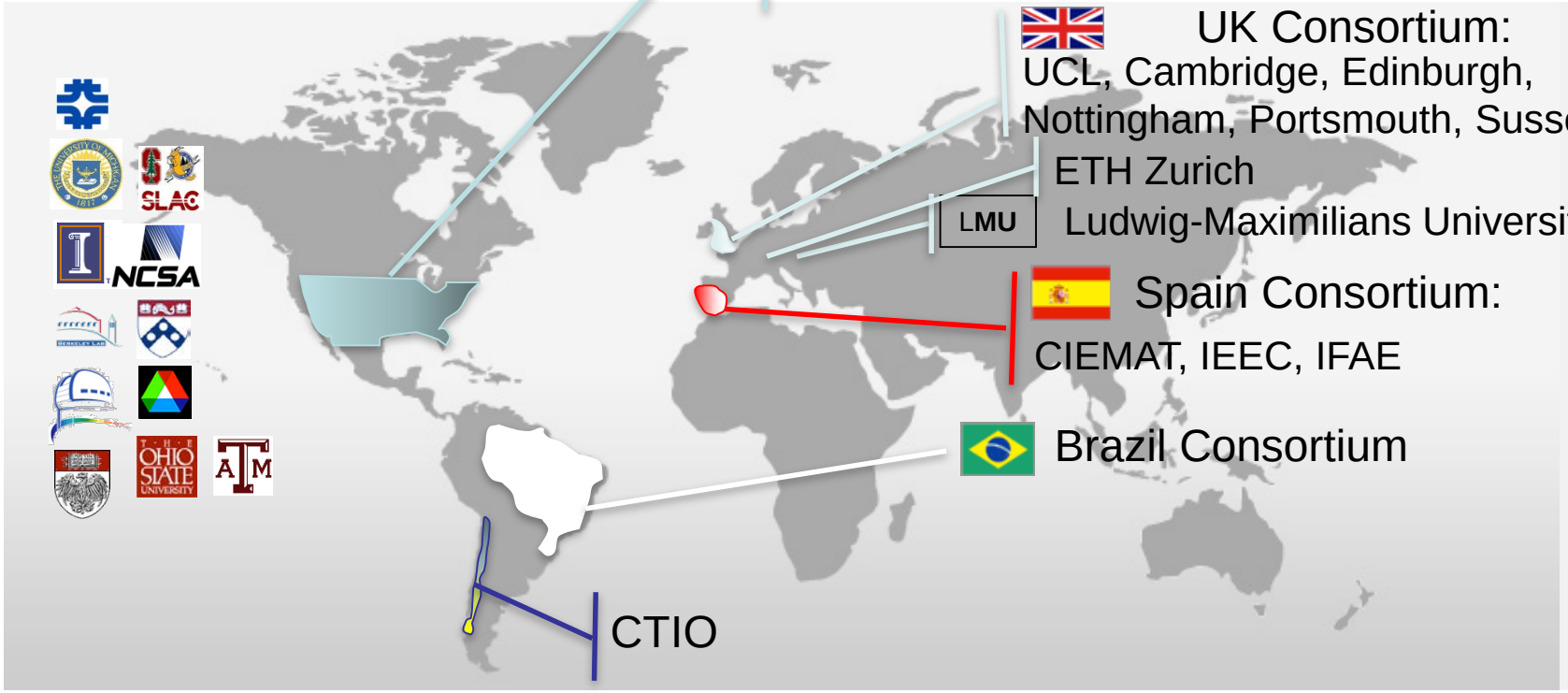
~300 scientists
US support from DOE+NSF

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




Membership DB lists: 424 scientists, 108 PD, 106 students

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# Cosmological Dynamics

P5 Science Drivers for DES:
- **Understand Cosmic Acceleration**
- Pursue the Physics associated with Neutrino Mass

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\sum_i \rho_i\left(1+3w_i\right)$$

Acceleration Equation from General Relativity

Equation of state parameter: $w_i = p_i / \rho_i c^2$

Non-relativistic matter: $p_m \sim \rho_m \mathrm{v}^2, \quad w \approx 0$

Relativistic particles: $p_r = \rho_r c^2 / 3, \qquad w = 1/3$

Acceleration ($\ddot{a} > 0$) requires component with negative pressure:

Dark Energy: $w_{DE} < -1/3$

Cosmological Constant (vacuum energy): $w_\Lambda = -1$

or Replace GR dynamics with another gravity theory

# Current Dark Energy Constraints from Supernovae, CMB, and LSS

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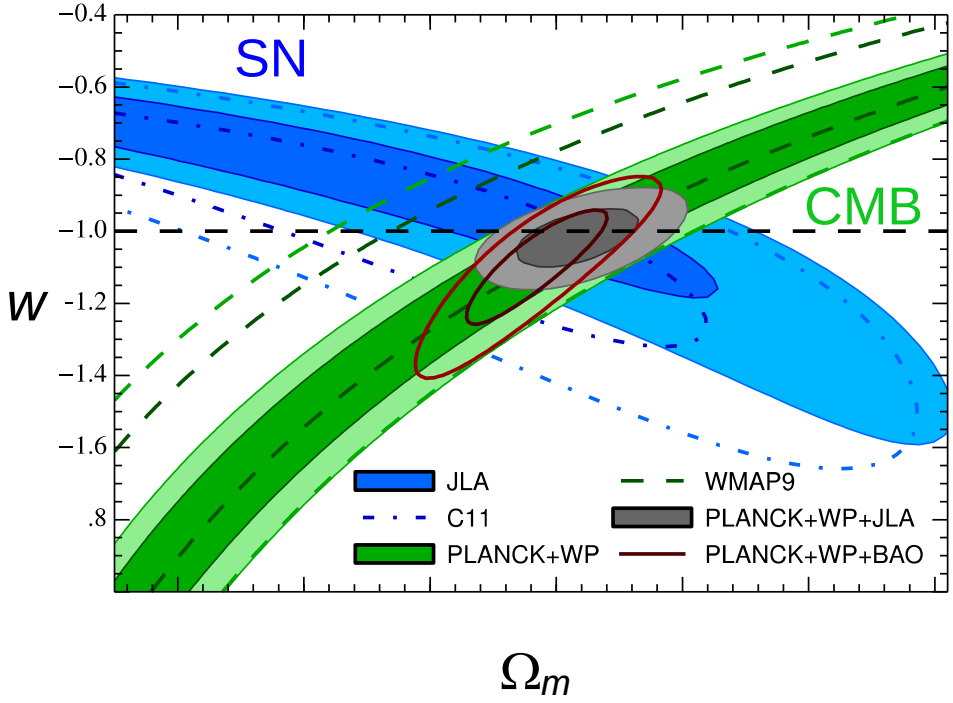
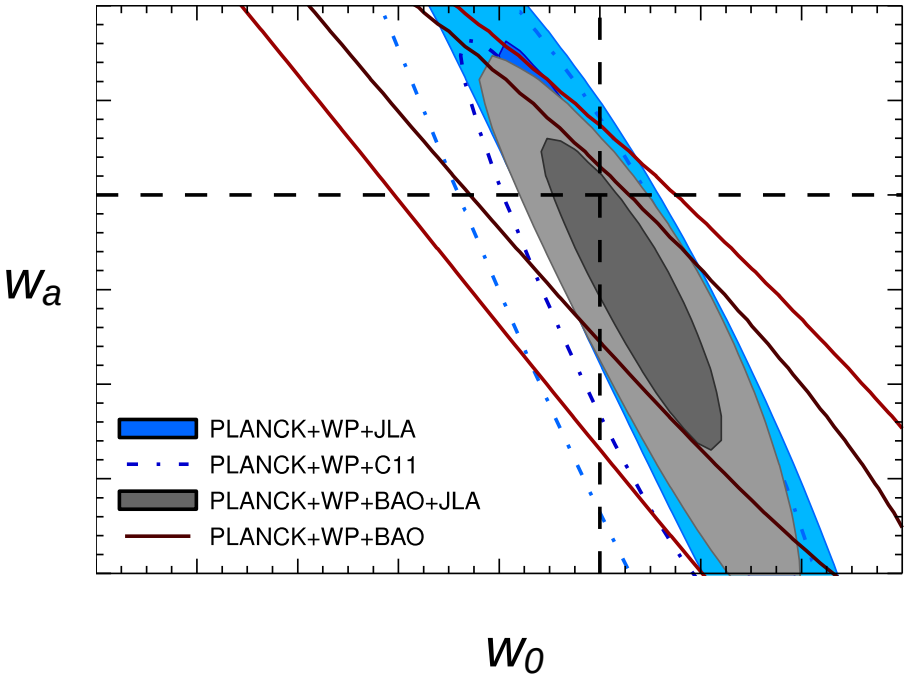
Assuming constant *w*:
*w*=−1.027±0.055

Assuming $w=w_0+w_a(1-a)$:
$w_0$=−0.957±0.124 $w_a$=−0.336±0.552



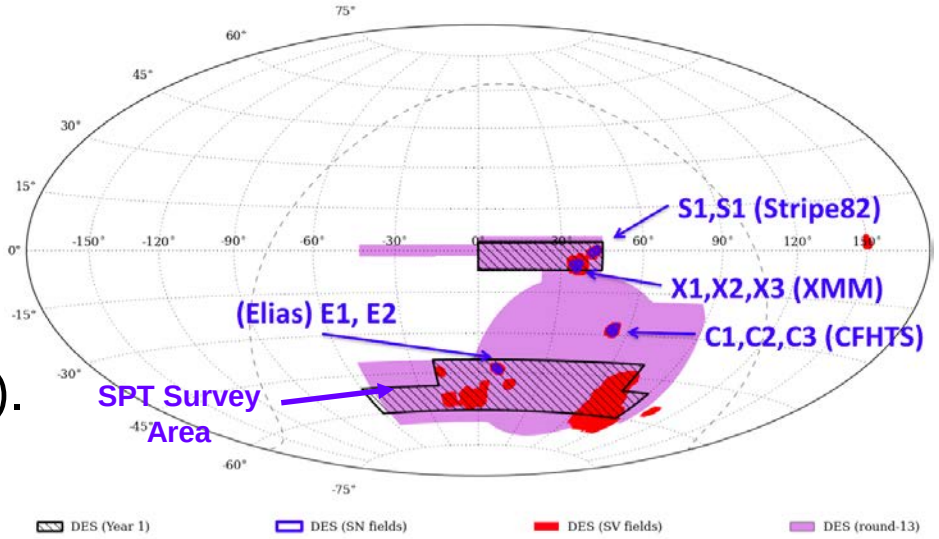

Betoule etal 2014

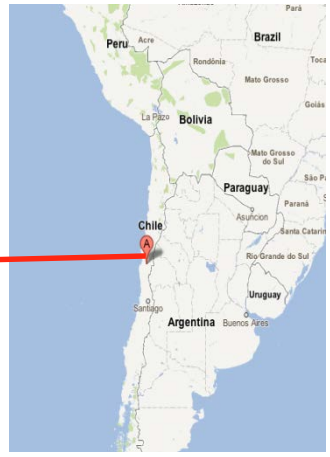
Consistent with vacuum energy (Λ): $w_0$=−1, $w_a$=0

# The Dark Energy Survey

DARK ENERGY SURVEY

- DES Built DECam, a 3 deg$^2$ FOV camera for the Blanco 4m telescope at CTIO
  - Survey 2013-2018 (525 nights)
  - Facility instrument for astronomy community (DES uses 30% time).
- DES uses 4 complementary techniques to measure acceleration of the Universe
  - I. Cluster Counts
  - II. Weak Lensing
  - III. Large-scale Structure (BAO)
  - IV. Supernovae
- Two multiband imaging surveys:
  - 5000 deg$^2$ *grizY* to 24th mag
  - 30 deg$^2$ repeat *griz* (SNe)



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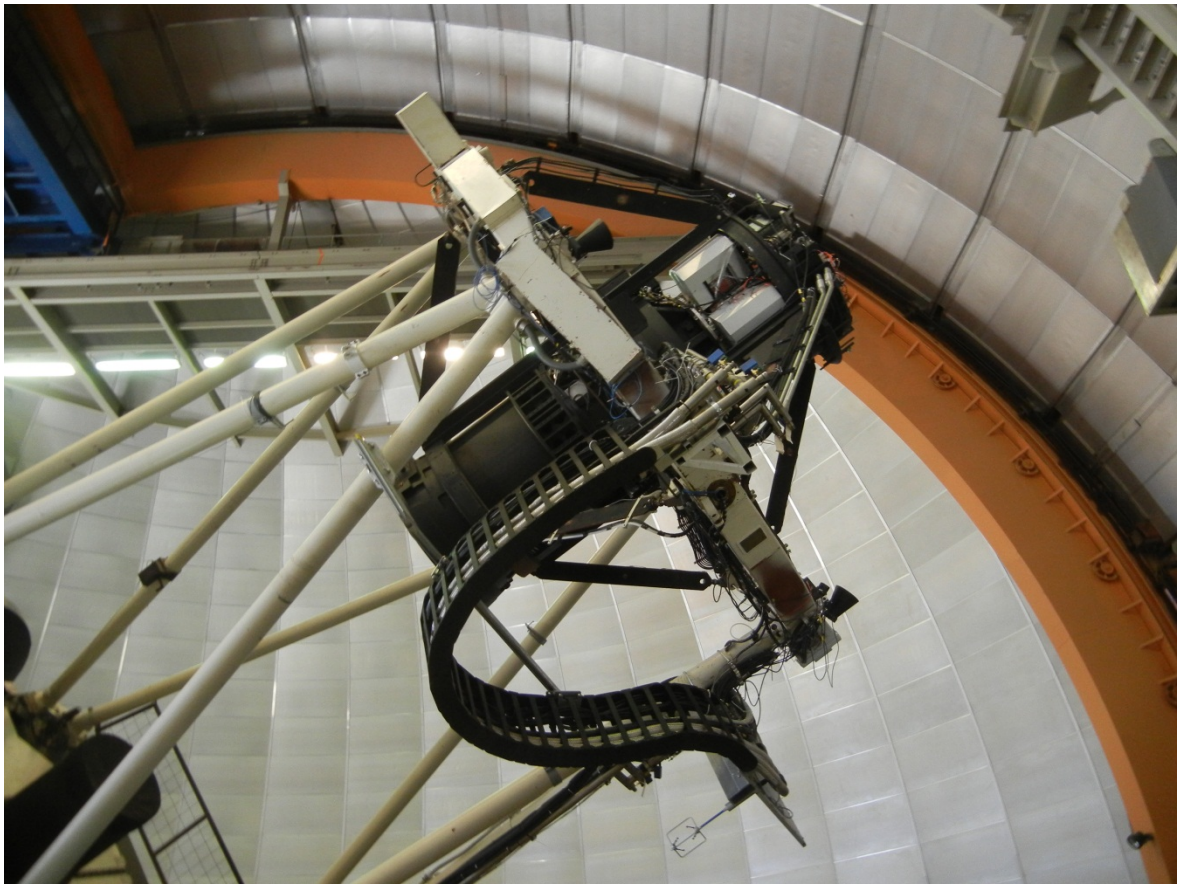
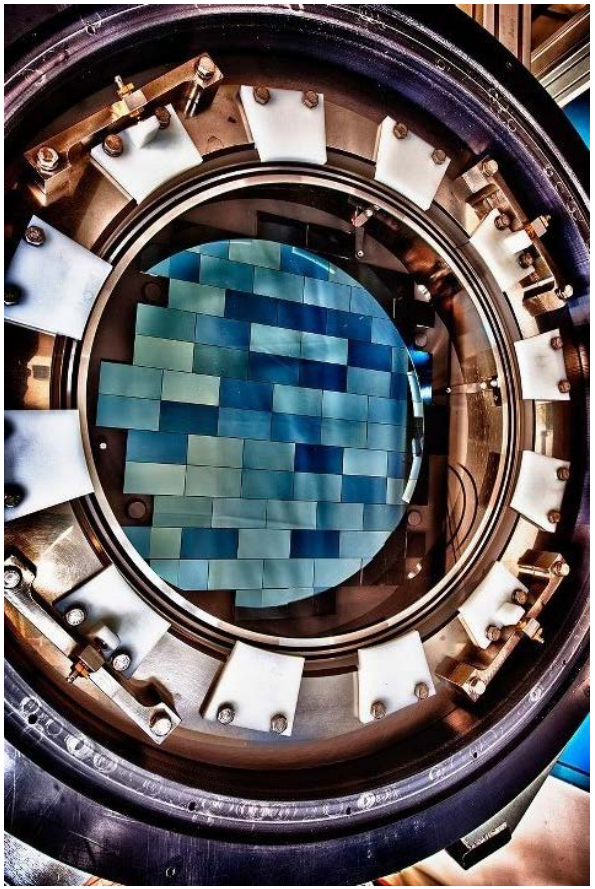
# The Dark Energy Camera

Flaugher et al., arXiv:1504.02900



The Dark Energy Camera on the Blanco Telescope



The Dark Energy Camera Focal Plane 62 CCDs

# DECam Strengths

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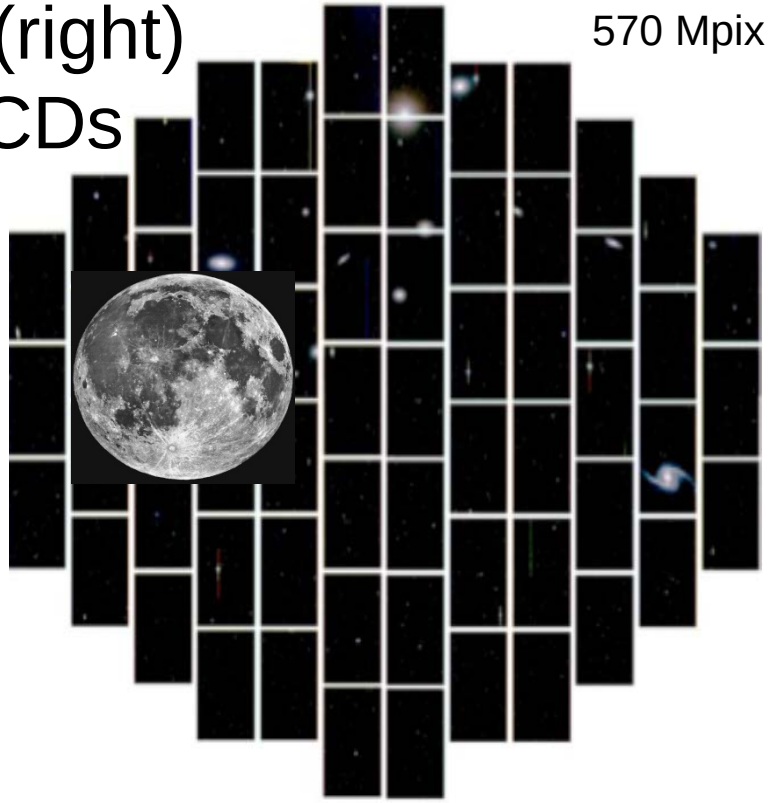
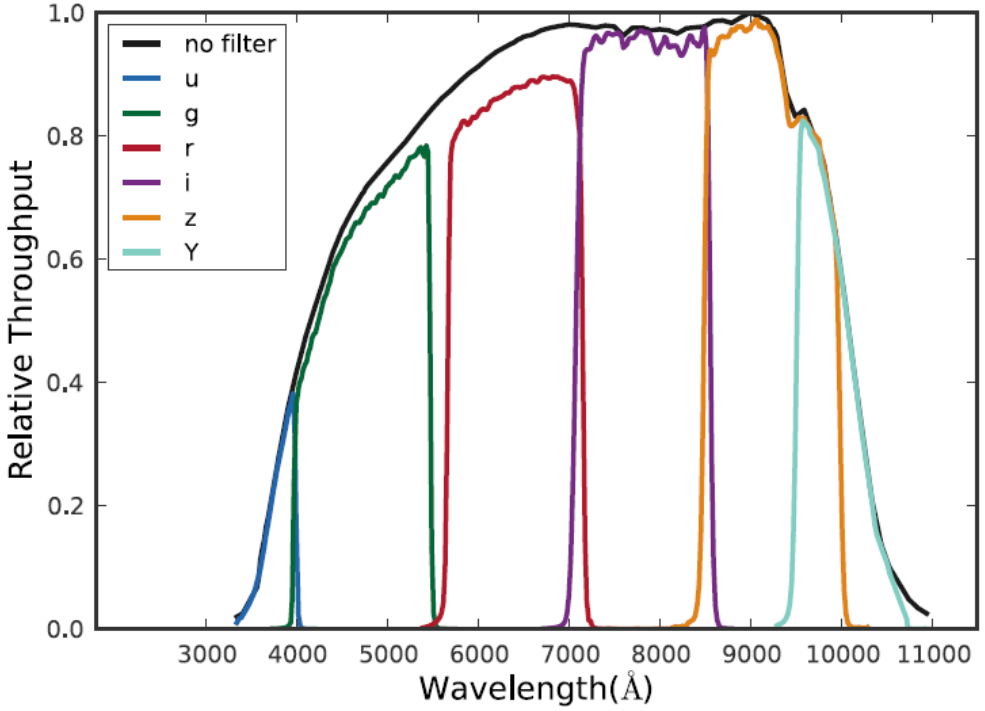
- Wide FoV (2.2 deg), 3 sq-deg (right)
- Fully-depleted red-sensitive CCDs
- Telescope w/ 4-m primary
- Excellent site conditions



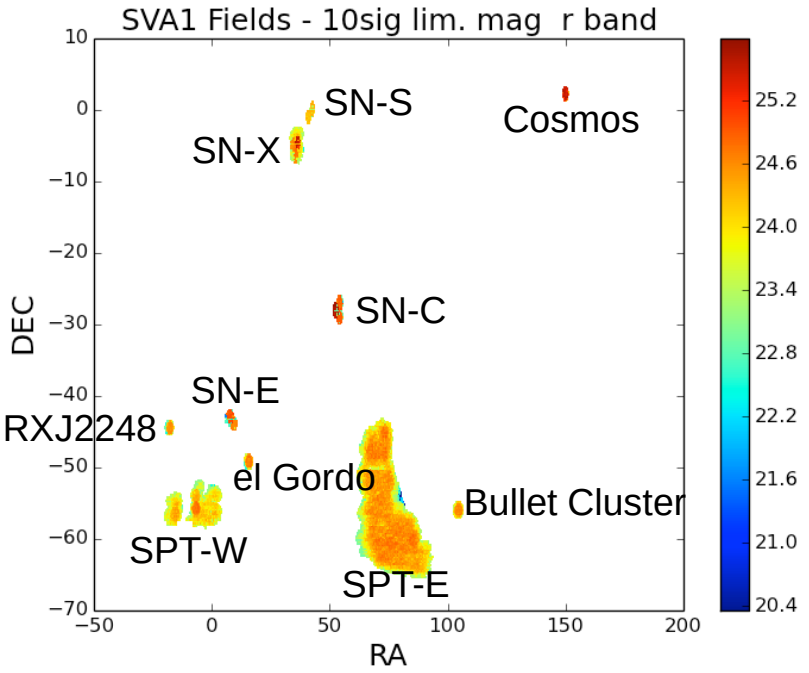

- (left) camera throughput vs λ

# SV & Y1

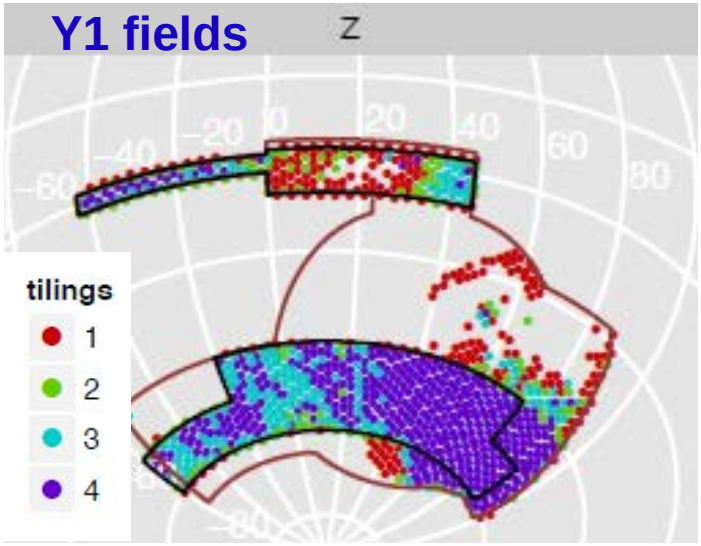
DARK ENERGY SURVEY

- "1st Light": Sept. 2012, Commissioning Oct. & Nov. 2012
- "Science Verification" to Feb. 2013
  - 330 sq. degrees in selected fields **to full depth** to verify the readiness of the camera/telescope
  - Many results in this presentation use SV data
- "DES Year 1" Aug. 2013 – Feb. 2014
  - Goal was 4 tilings in the "Y1" fields (outlined in black) + SN survey
  - A slow start from Aug. to Oct. but turned into a pretty good 1st season
  - z-band (right) shows typical observing coverage
- "DES Year 2" Aug. 2014 – Feb. 2015
- "DES Year 3" Aug. 2015 – Feb. 2016

**SV fields**




**Y1 fields**



# DES Operations Efficiency & DECam Reliability

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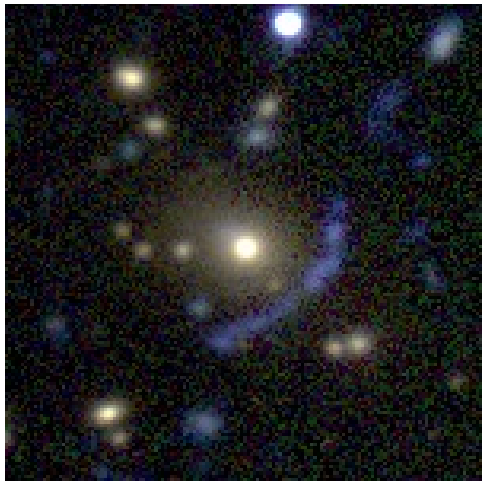
| Operation | DES Yr. 1 Hrs. | (%) | DES Yr. 2 Hrs. | (%) |
|---|---|---|---|---|
| **Observing Time Available** | 888 | (100) | 929 | (100) |
| **Observing Time** | 752 | (84.6) | 783 | (84.2) |
| **Bad Weather** | 90 | (10.2) | 140 | (15.1) |
| **Telescope or Infrastructure Failure => can't observe** | 18 | (2.0) | 3 | (0.3) |
| **Camera Systems Failure => can't observe** | 26 | (2.9) | 3 | (0.3) |



- Camera and Telescope combined for >95% up time in Y1 & >99% in Y2
- Y2 had 2nd worst weather in 29 Yrs of records, particularly Aug. to end Oct. partially compensated by more efficient observing
  - Improvements to the observing sequence and to the dome positioning lead to increased livetime starting late in Y1. With 90 second exposure time and only ~27s between exposures if we don't slew the Shutter was open 63% of "Observing Time" during Y1 and 68% of the time in Y2.

# Improvements to DECam/Blanco during 2014/15

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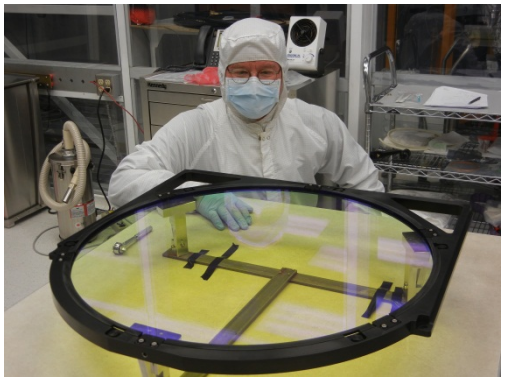
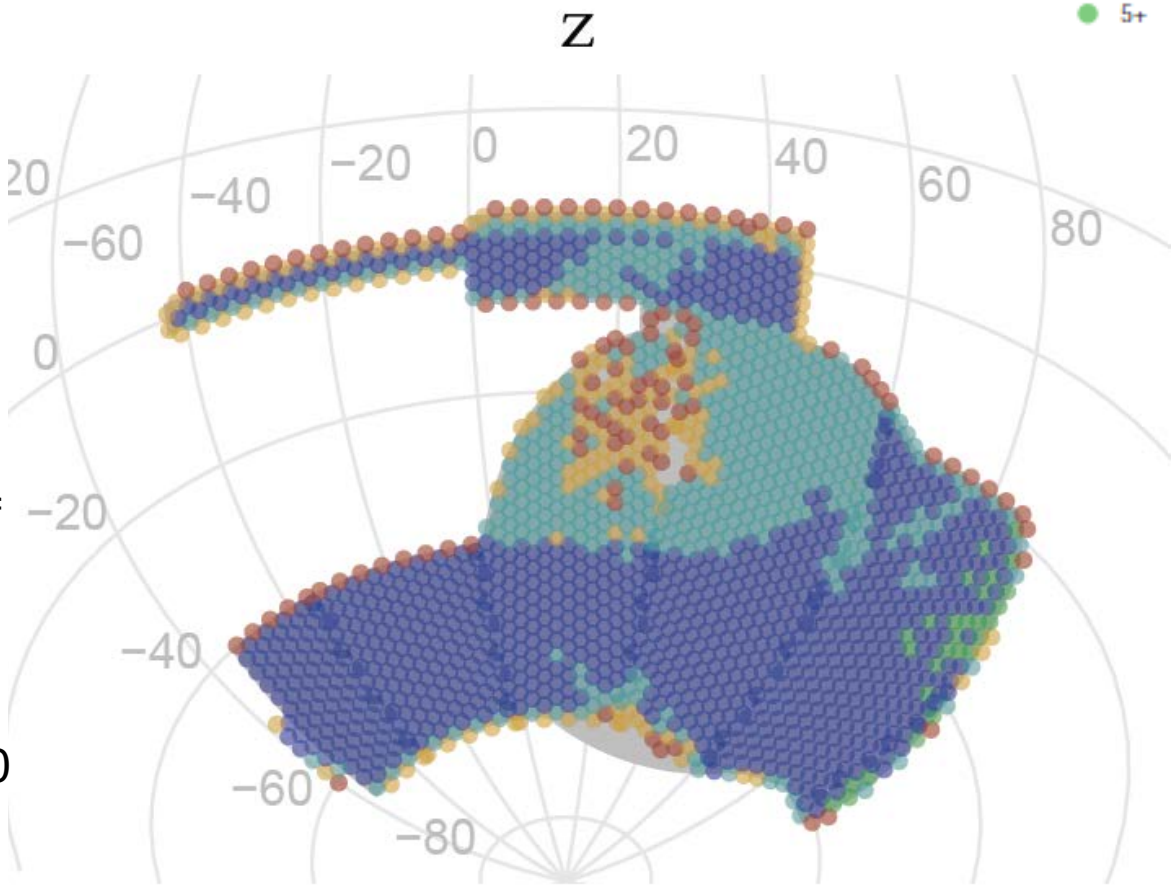
- New VR-band filter for community observers
- New Dome Environmental Controls: 2 large glycol-cooled air-handlers better maintain the primary mirror at or just below the air-temperature, w/ minimal temperature gradient within the dome, and w/ internal and external air temperatures matched.
- Newly adjusted Adaptive Optics zeropoint (Oct 21, 2014) and LUT (January 4, 2015) reduces coma
- New Primary Mirror Support Pad air-pressure controls and LUT *(work ongoing)*
  - The system controls the mirror shape depending on gravity vector with an astigmatic correction.
  - D0Nut studies indicate that primary mirror aberrations could be better zeroed-out but that higher-resolution air-pad controls were required. These were replaced in August 2014
  - After more studies a new astigmatic correction was applied after DES Y2. A new LUT is being tested.



# Y1 + Y2 DES WF Survey

DARK ENERGY SURVEY

- Goal for Y2 was to finish the survey field 4 tiles in 5 filters.
- Plot on RHS shows what we got:
  - 14436 (Y1) + 14447 (Y2) “good” images
  - z-band (right) is typical of the result by the end of Y2 observations
  - 3 or 4+ tile coverage except an area at RA ~20
  - After Y2 we have observed 90% of our original Y1 + Y2 goal.



# SNIa Fields

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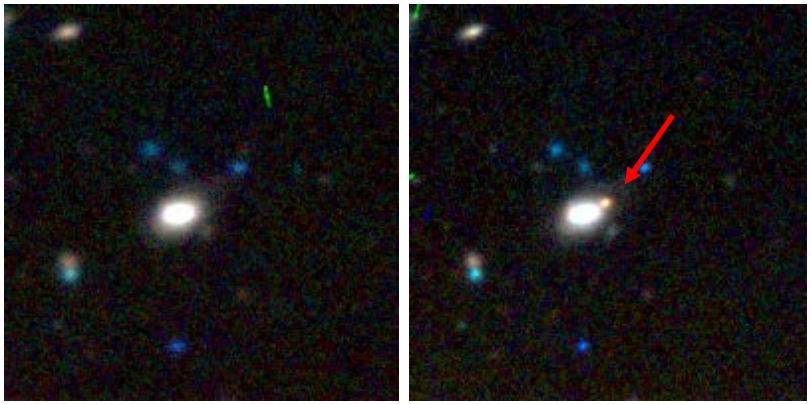
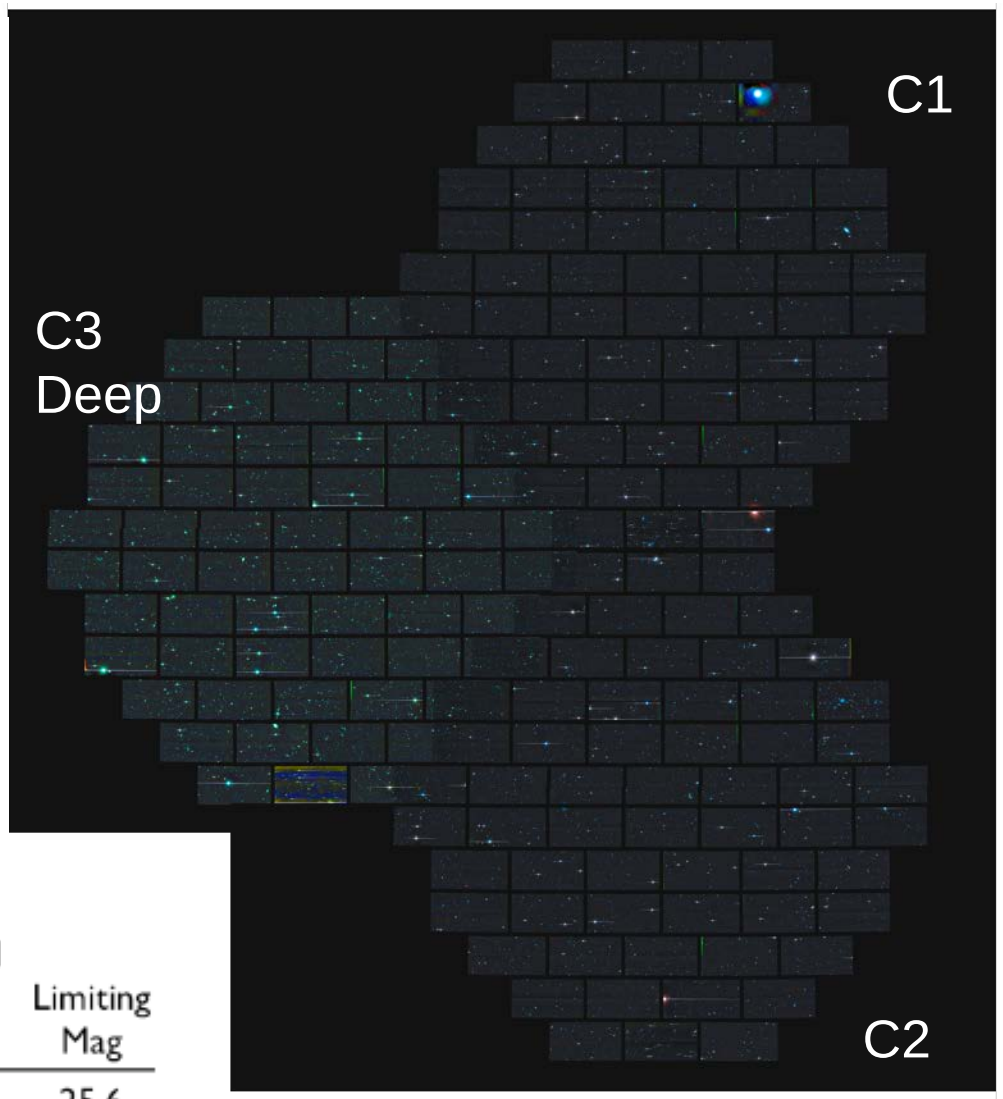
10 SN Fields; 8 “shallow” & 2 “deep”






| Filter | Shallow Field Exposure Time (s) | Shallow Field Limiting Mag | Deep Field Exposure Time (s) | Deep Field Limiting Mag |
|---|---|---|---|---|
| g | 175 | 24.9 | 600 | 25.6 |
| r | 150 | 24.3 | 1200 | 25.4 |
| i | 200 | 23.9 | 1800 | 25.1 |
| z | 400 | 23.8 | 3630 | 24.8 |

# Y1 & Y2 SN Survey

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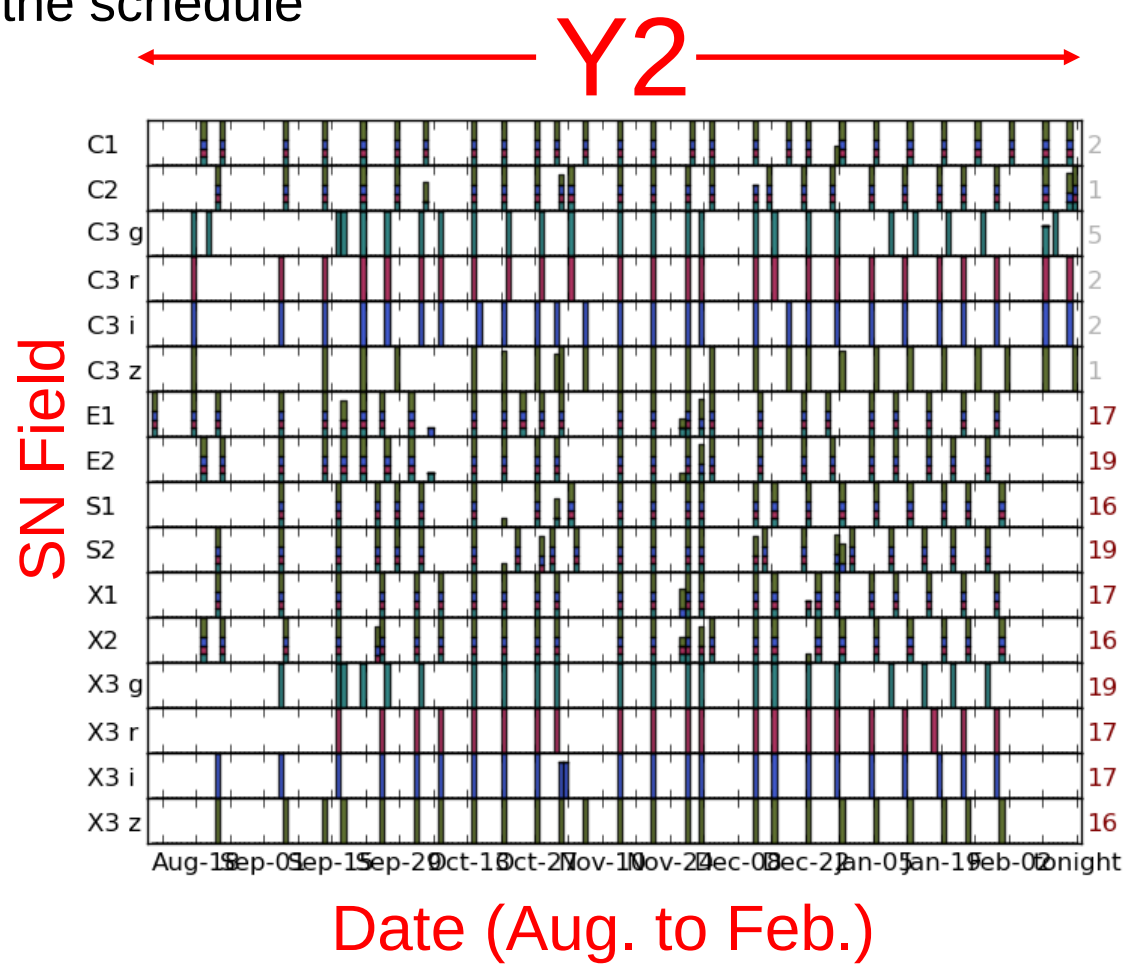
- When the weather and seeing is good each SN field is imaged every 6 nights apart from gaps in the schedule
- Roughly 25% of observation time goes to SN survey
- Typically 25 visits per field per season
- In Y1 we found ~1700 transients classified as SN. About ½ of those are SN Ia.
- Host galaxy redshifts from spectroscopy (AAT)



# Data Handling & DESDM Nightly Processing

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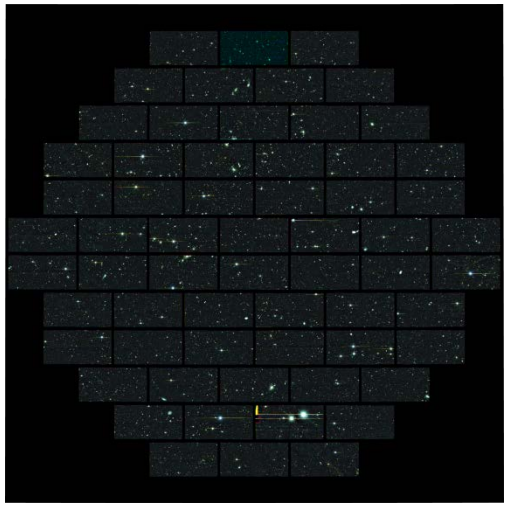
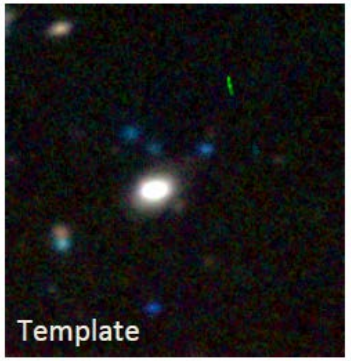
- Images are transferred by NOAO to NCSA/UIUC, usually within 5 minutes after the shutter closed. Copies stored in La Serena and Tucson.
- DESDM “First Cut Processing” for WF Images provides detrending
  - Overscan removed and bias subtracted, mean dome flat is applied
  - CCD crosstalk, linearity, fringe and pupil ghost corrections are applied
  - Star flat is applied to subsections of each CCD. Astrometric solution found.
- DESDM SN Difference Imaging Pipeline to identify transients
  - Similar to WF 1st Cut
  - Coadds the deep SN fields before difference imaging



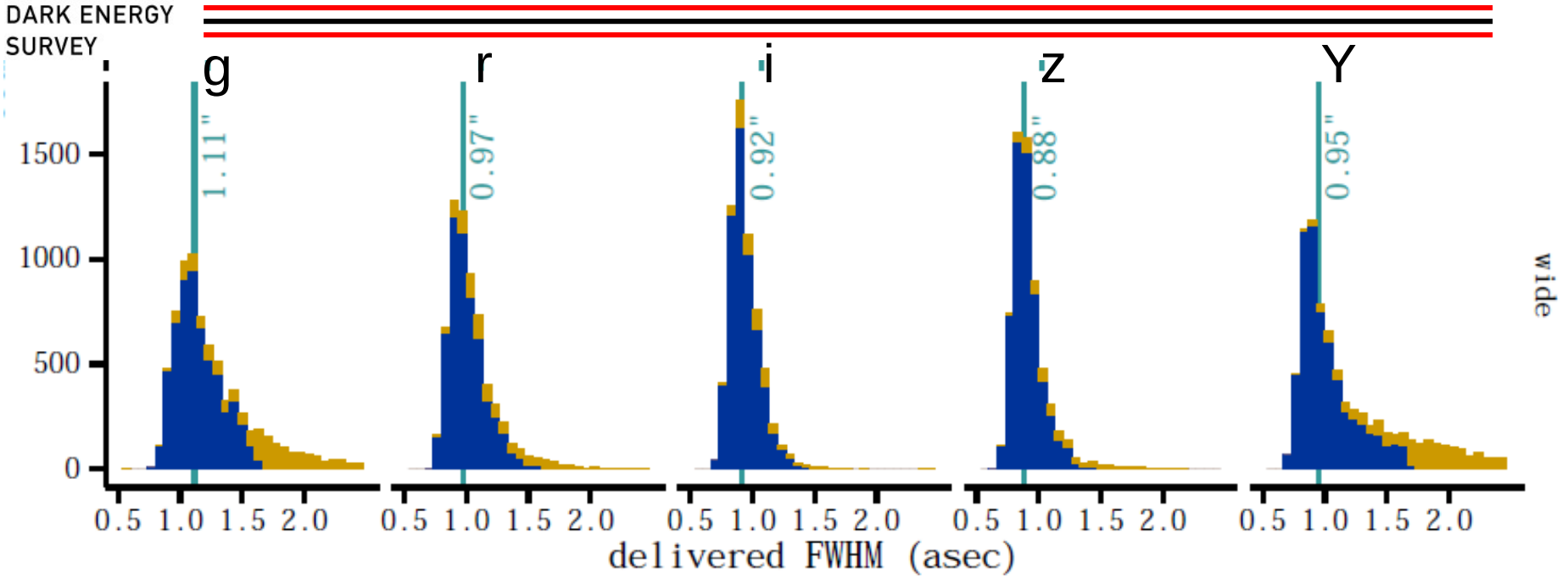




(Above) One of the SN Fields
(Right) SN Processing: subtract Template from Search Image

- DQ determination is often available in time for observations next night.
  - based on FWHM of the seeing, the sky brightness, and the extinction due to clouds.

# Y1 +Y2 Image Quality




- The plots show the image PSF achieved in our good and bad exposures
- Median PSF are as good as we need for the DES science.
  - Note that the g-, and Y-band are sometimes selected during periods of marginal seeing (explains why they are a bit worse). We don't use g and Y-band for weak-lensing.

# DES WF Survey Seeing Compared to DIMM

(Differential Image Motion Monitor)

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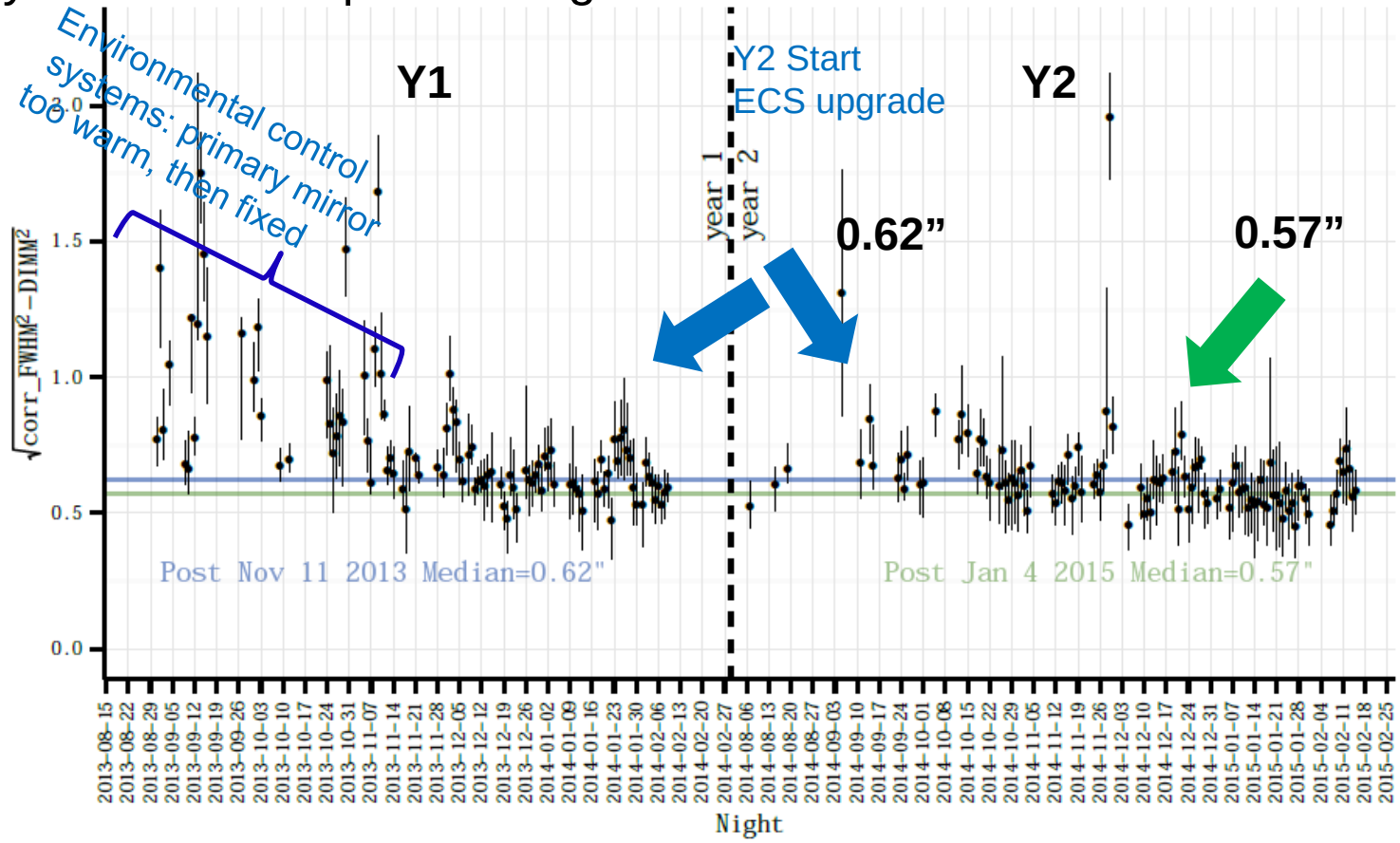
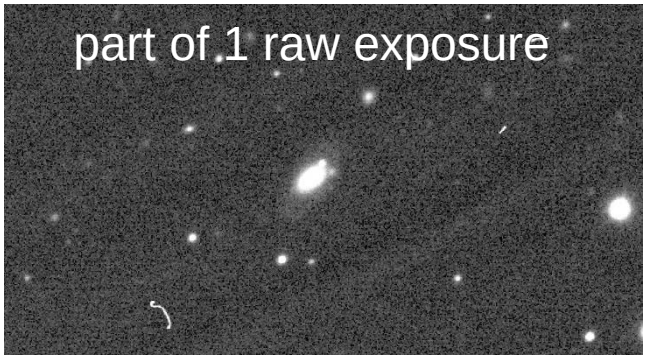
* The horizontal lines are the median contribution to the seeing from the primary mirror and DECam optics before (after) improved AOS LUT. It's now very close to the optical design of 0.55".

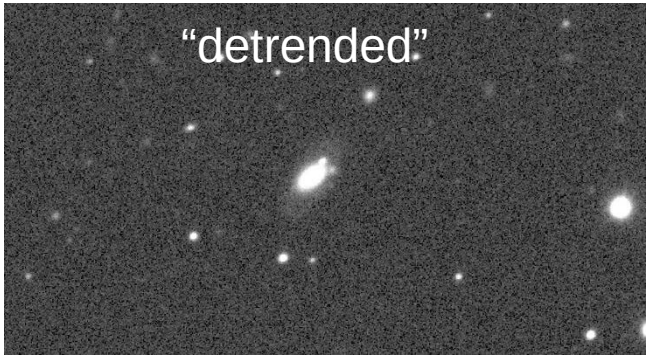


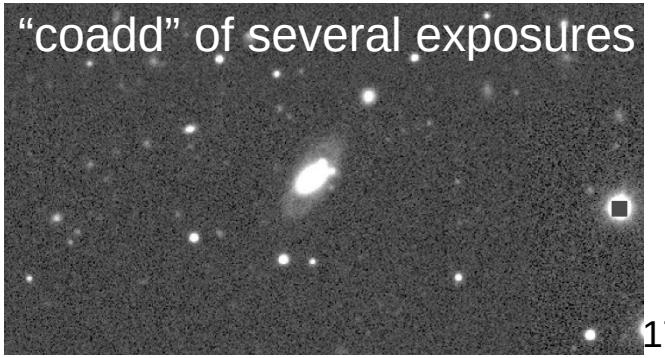
# DESDM Annual Release (Re)Processing

DARK ENERGY SURVEY

- NCSA assembles, maintains, archives, and serves data releases of calibrated image files and catalogs of source parameters produced by the pipelines.
- Super-calibrations: combine ~100 exposures per band
- FinalCut pipeline removes instrumental signatures
  - using the super-calibration files, also does astrometric refinement, remapping, cataloging with PSF-modeling, and solves for the photometric zero-points.
  - Improvements implemented for Y2+Y1



# DESDM Annual Release Processing

- Coadd pipeline produces coadd images and catalogs with global photometric calibration
- Served to Collaboration
  - Y1: late December 2014
  - Y2: roughly a year later
- Science Portal provides one of our methods for accessing catalog information and storing “added value” (next slide)

# Science Portal

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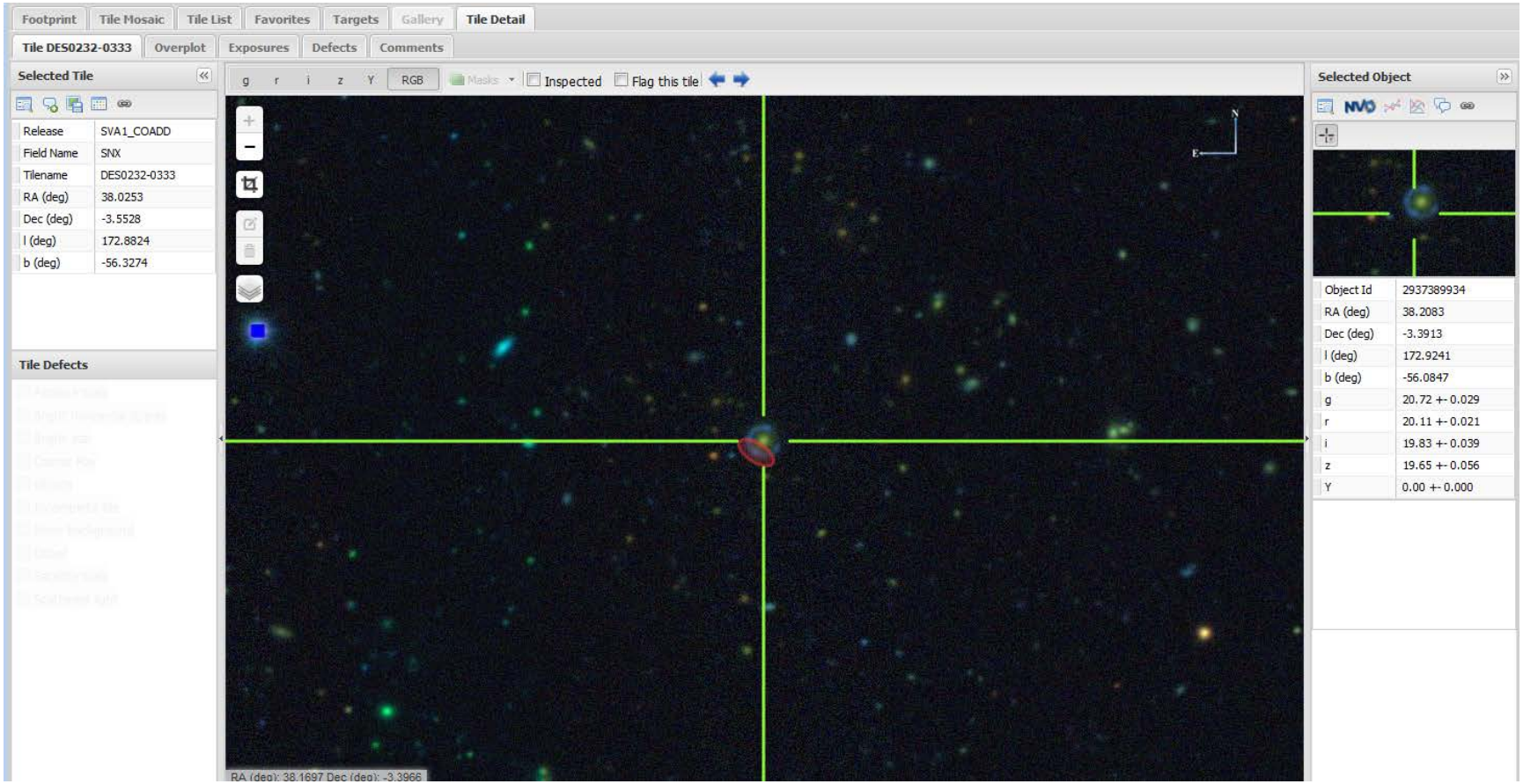


- Science Analysis Computing is within larger DES and includes resources from FermiLab, NERSC and elsewhere

# Public Data Releases

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- Rolling release after 12 months of raw and calibrated, detrended single-epoch images. NCSA provides the calibrated files to NOAO for public serving.
  - The Y1 public data has already been used by the community for science
  - The release cycle would normally start for Y2 on or about August 15th.
- NCSA will create and serve two public data releases of coadded images and catalogs derived from the coadds:
  - DR1: target Aug. 2017, with data from the first two observing seasons (Y1+Y2)
  - DR2: Aug. 2020 at the earliest, with data from all seasons
- NOAO will provide long-term data curation for the community.

# Recent DES Papers

snapshot June 11, 2015

DARK ENERGY SURVEY

- Starting late 2014
- 26 refereed publications
  - 8 Technical/Simulation, 18 on science.
  - 10 from SV and 8 from Y1.
  - Of the papers on SV or Y1 data, 17 submitted , 9 accepted, 6 in print.
- 11 of these papers submitted *en masse* just before the APS Meeting in Baltimore in April. 16 talks from DES.
- Another big push coming soon
- The following slides sample the papers

Publication Board Reviews

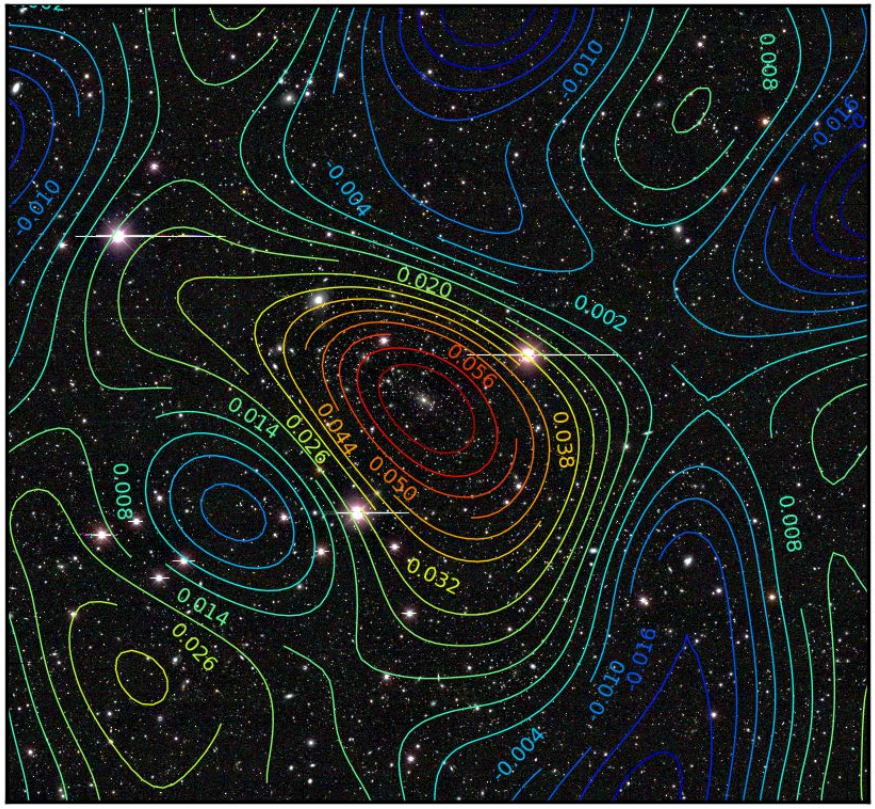
| DES Publication | Corresponding Author(s) | CWR End Date | Assigned PB Reader | CWR Comments | Status | arXiv/ Telecon |
|---|---|---|---|---|---|---|
| DES 2015-0071 | C. Chang | May 6, 2015 | R. Miquel | DES-2015-0071_Comments | Accepted | 1505.01871 |
| DES 2015-0066 | C. Chang | Apr 10, 2015 | R. Miquel | DES-2015-0066_Comments | Accepted | 1504.03002 |
| DES 2015-0065 | K. Kuehn | Apr 10, 2015 | H. Lin | DES-2015-0065_Comments | Submitted | 1504.02996 |
| DES 2015-0064 | J. Simon | Apr 10, 2015 | K. Honscheid | DES-2015-0064_Comments | Submitted | 1504.02889 |
| DES 2015-0057 | A. Saro | Apr 15, 2015 | A. Roodman | DES-2015-0057_Comments | responding to CWR | |
| DES 2015-0051 | A. Drlica-Wagner | Mar 7, 2015 | K. Honscheid | DES-2015-0051_Comments | Resubmitted | 1503.02632 |
| DES 2015-0047 | C. Lidman | Apr 8, 2015 | R. Kessler | DES-2015-0047_Comments | Submitted | 1504.03039 |
| DES 2015-0044 | D. Goldstein | Apr 3, 2015 | T. Diehl | DES-2015-0044_Comments | Submitted | 1504.02936 |
| DES 2015-0043 | K. Bechtol | Mar 6, 2015 | A. Walker | DES-2015-0043_Comments | Accepted | 1503.02584 |
| DES 2015-0042 | T. Diehl | Mar 10, 2015 | DES | DES-2015-0042_Comments | Submitted | 1504.02900 |
| DES 2015-0040 | Y. Zhang | Apr 8, 2015 | T. Jeltema | DES-2015-0040_Comments | Submitted | 1504.02983 |
| DES 2015-0039 | D. Gruen | Jan 10, 2015 | T. Diehl | DES-2015-0039_Comments | Accepted | 1501.02802 |
| DES 2014-0038 | C. Bruderer | Feb 28, 2015 | D. Bacon | DES-2014-0038_Comments | Submitted | 1504.02778 |
| DES 2014-0037 | A. King | Mar 25, 2015 | L. daCosta | DES-2014-0037_Comments | Submitted | 1504.03031 |
| DES 2014-0032 | D. Hatt | Feb 25, 2015 | A. Amara | DES-2014-0032_Comments | Submitted | |
| DES 2014-0031 | E. Sanchez | Oct 10, 2014 | R. Kessler | DES-2014-0031_Comments | Submitted | |
| DES 2014-0029 | C. Chang | Oct. 20, 2014 | T. Jeltema | DES-2014-0029_Comments | Published | 1411.0032 |
| DES 2014-0024 | C. D'Andrea | Aug 5, 2014 | H. Lin | DES-2014-0024_Comments | Published | 1501.07232 |
| DES 2014-0021 | S. Reed | Feb 12, 2015 | A. Roodman | DES-2014-0021_Comments | Submitted | 1504.03264 |
| DES 2014-0020 | A. Plazas | June 4, 2014 | T. Diehl | DES-2014-0020_Comments | Published | 1403.6127 |
| DES 2014- | | August 27 | | DES-2014- | | |

# 1st Submitted Science Paper (2014) Cluster Weak Lensing

DARK ENERGY SURVEY

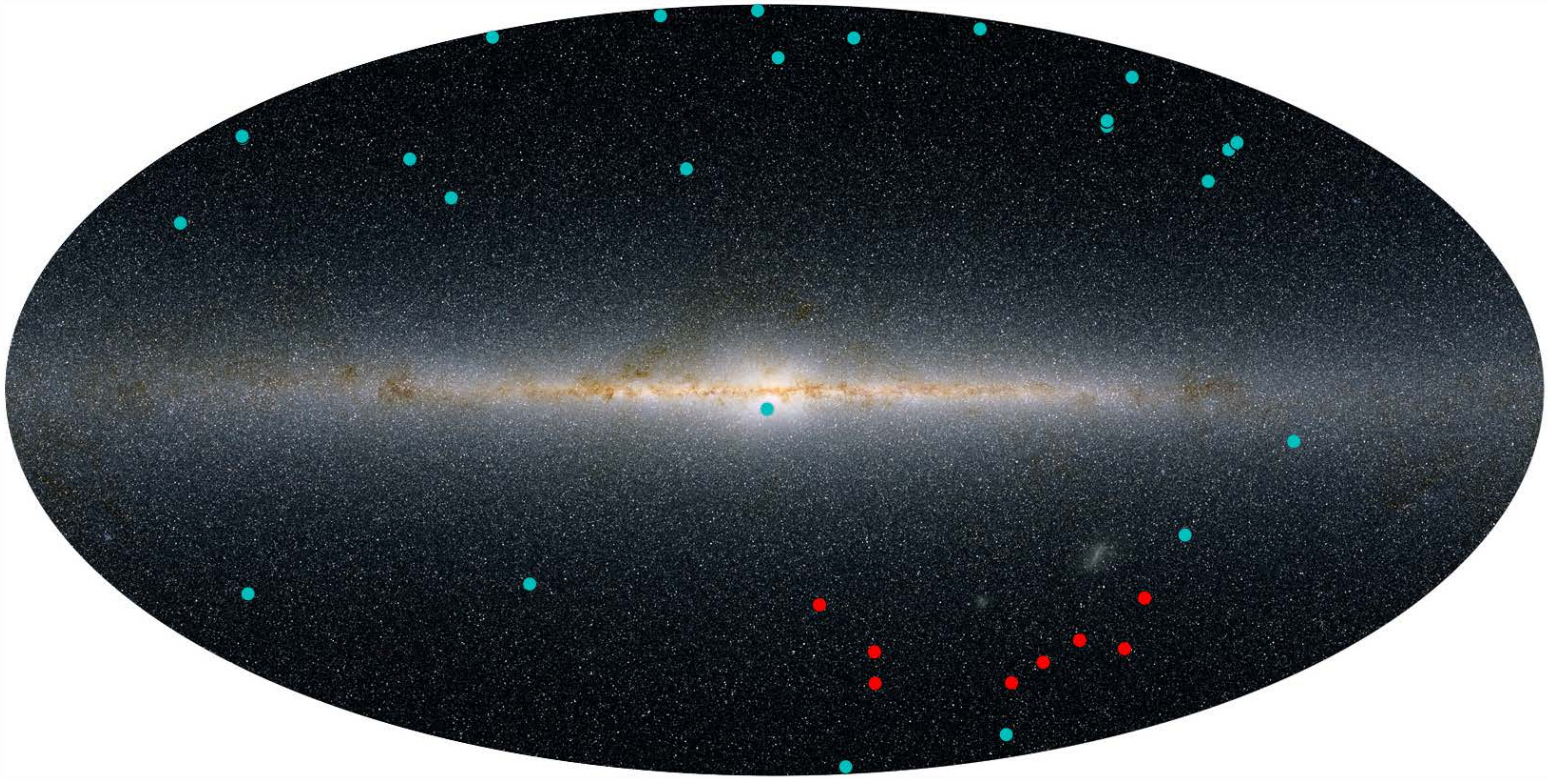
Cluster WL mass map
Melchior et al. (DES) MNRAS Pub. 2015

- Weak Lensing around 4 clusters provided mass maps with very large angular sizes because of the DECam field-of-view.
- Masses agree with published results




| Cluster name | $M_{200c}$ | $\lambda$ | $z_\lambda$ | Literature value $M_{200c}$ |
|---|---|---|---|---|
| RXC J2248.7-4431 | $17.5^{+4.3}_{-3.7}$ | $203 \pm 5$ | $0.346 \pm 0.004$ | $22.8^{+6.6}_{-4.7}$ (Gruen et al. 2013), $20.3 \pm 6.7$ (Umetsu et al. 2014), $16.6 \pm 1.7$ (Merten et al. 2014) |
| 1E 0657-56 | $13.0^{+6.5}_{-5.2}$ | $277 \pm 6$ | $0.304 \pm 0.004$ | 17.5 (Clowe et al. 2004)[i], 12.4 (Barrena et al. 2002, D) |
| SCSO J233227-535827 | $9.6^{+3.9}_{-3.3}$ | $77 \pm 4$ | $0.391 \pm 0.008$ | $11.2^{+3.0}_{-2.7}$ (Gruen et al. 2014b), $4.9 \pm 3.3 \pm 1.4$ (High et al. 2010, R) |
| Abell 3261 | $6.4^{+3.2}_{-2.5}$ | $71 \pm 3$ | $0.216 \pm 0.003$ | — |

# Milky Way Satellites



Bechtol et al. (DES) arXiv:1503.02584: 8 satellites in DES Y1 co-adds

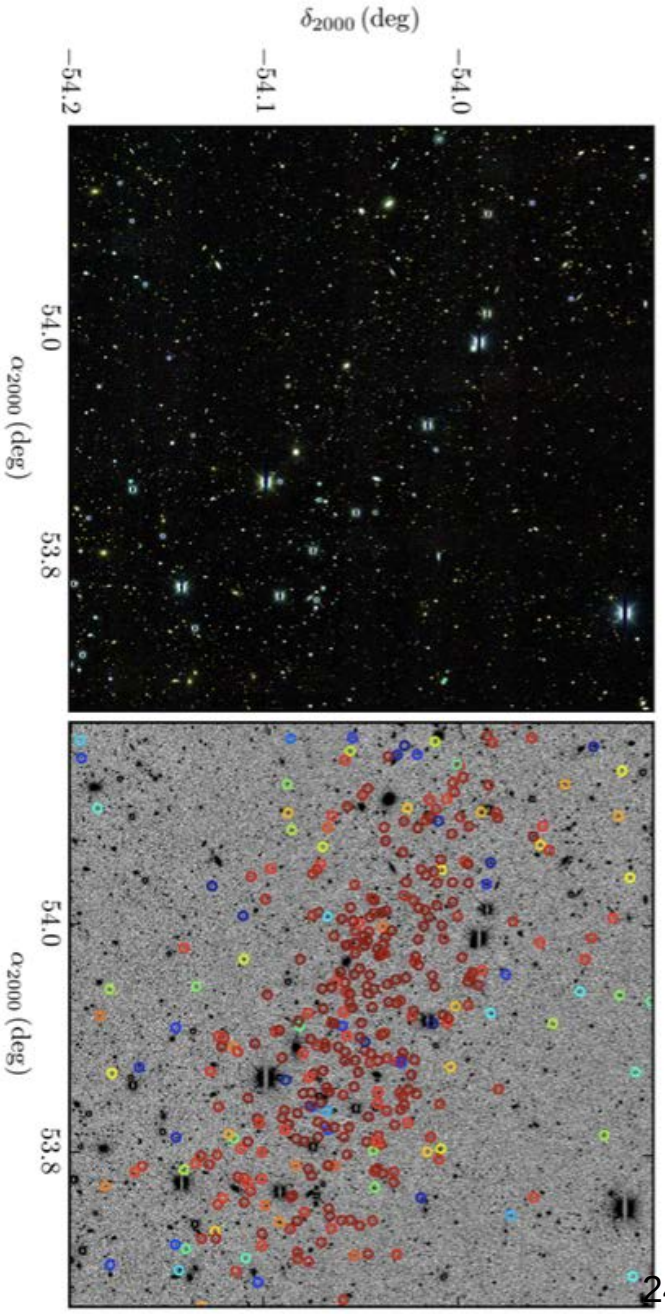
Koposov, et al: 9 satellites in DES Y1 public data

# DM Annihilation

DARK ENERGY SURVEY

- Milky Way satellites (distinct from globular clusters) are the most dark matter dominated systems known
- The nearest of new “dwarf galaxy” is Ret 2, at a distance of 32 kpc.
- DES joint analysis with Fermi LAT collaboration shows no excess gamma-ray signal from any of the new dwarfs (Drlica-Wagner, et al) arXiv:1503.02632
  - An independent analysis using public Fermi LAT data claims gamma-ray excess consistent with dark matter annihilation signal (Geringer-Sameth, et al)

Bechtol, et al

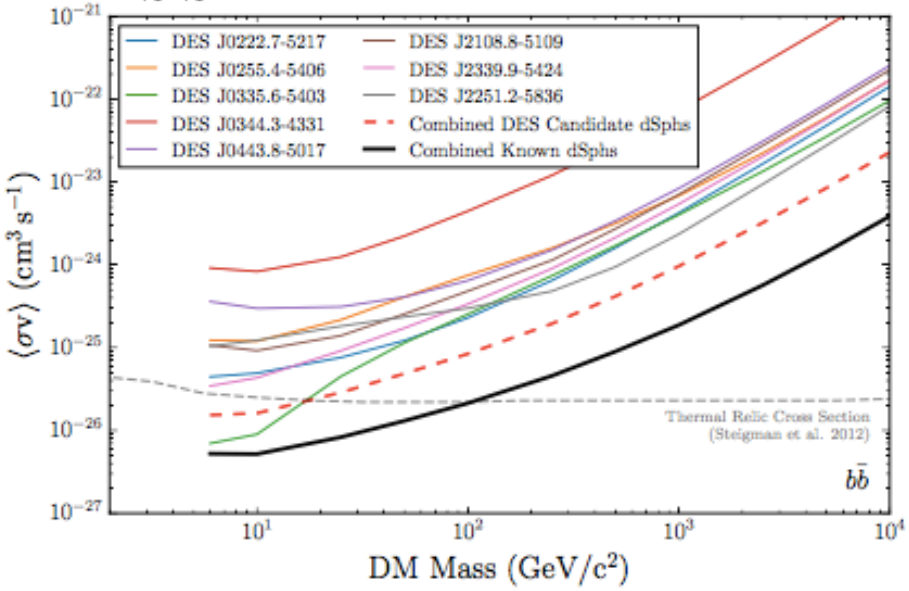


# DM Constraints

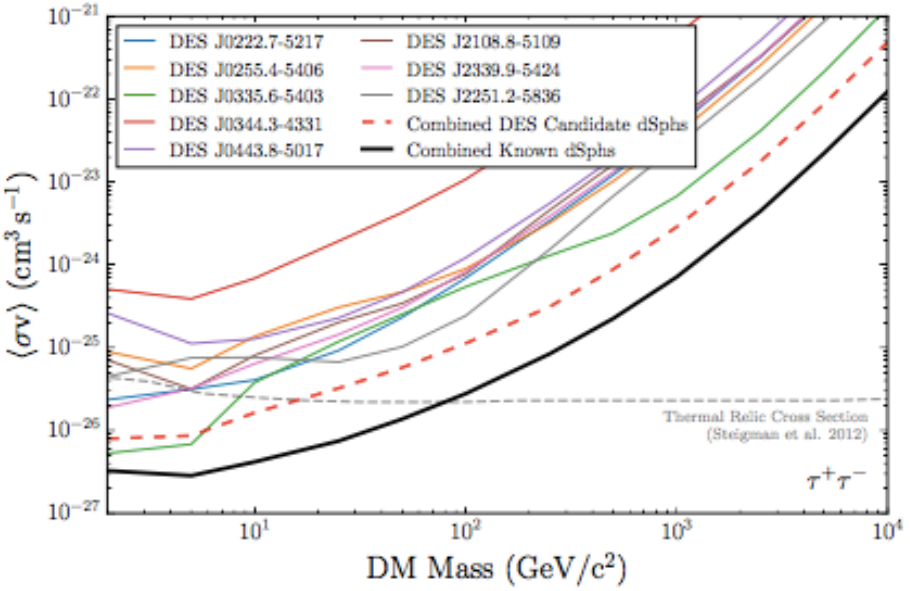
DARK ENERGY SURVEY

Drlica-Wagner et al (DES) arXiv:1503.02632

$b\bar{b}$



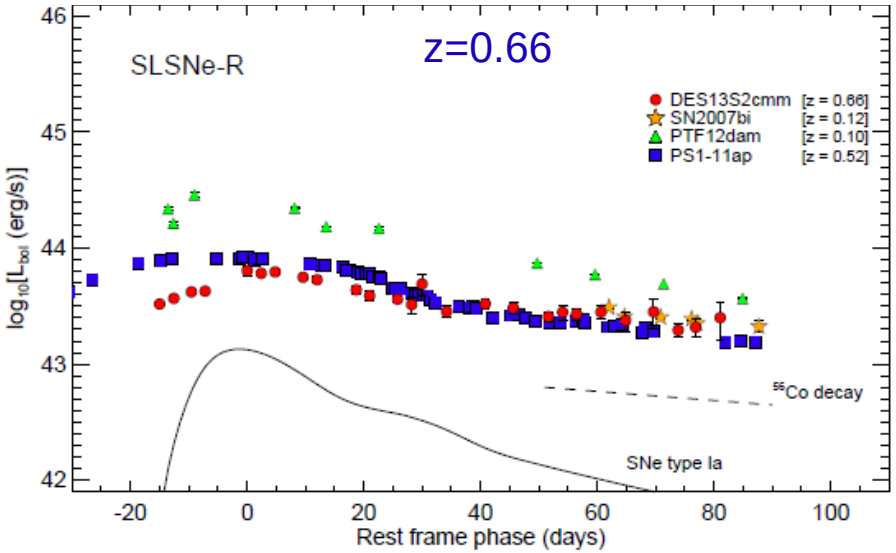

$\tau\bar{\tau}$

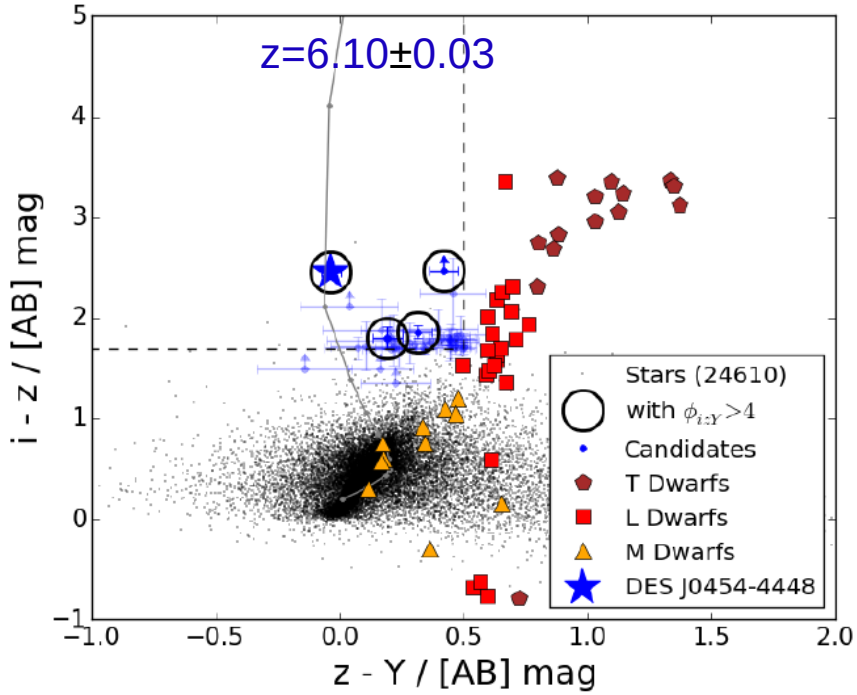



New dwarf candidates constrain thermal WIMP cross-section for DM masses below 20 GeV.
Caveat: need spectroscopy to confirm dwarfs and determine expected annihilation signal.

# SuperLum'sSN & z>6 QSO

DARK ENERGY SURVEY




- Two imperfect models
  - Prodigous 56Ni production
  - Rapid spin down of a nearby neutron star pumps energy into the SN eject

Papadopolous (DES) MNRAS 2015

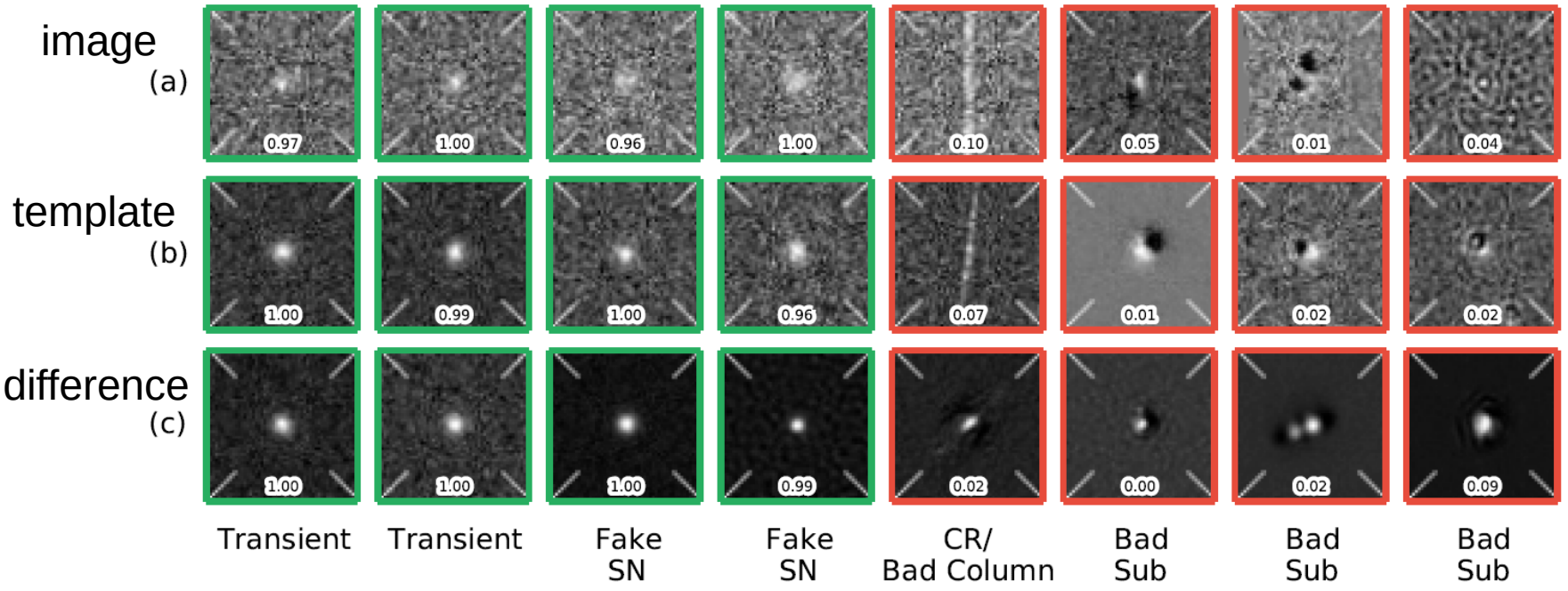
- Probes epoch of reionization
- "i-band dropout"
  - Ly $\alpha$ absorption lines redshifted to 8626A
- Expect 50 to 100 z>6 in DES

Reed (DES) arXiv:1504.03264

# Automated Transient ID in DES

DARK ENERGY SURVEY

D. A. Goldstein et al. (DES) arXiv:1504.02936



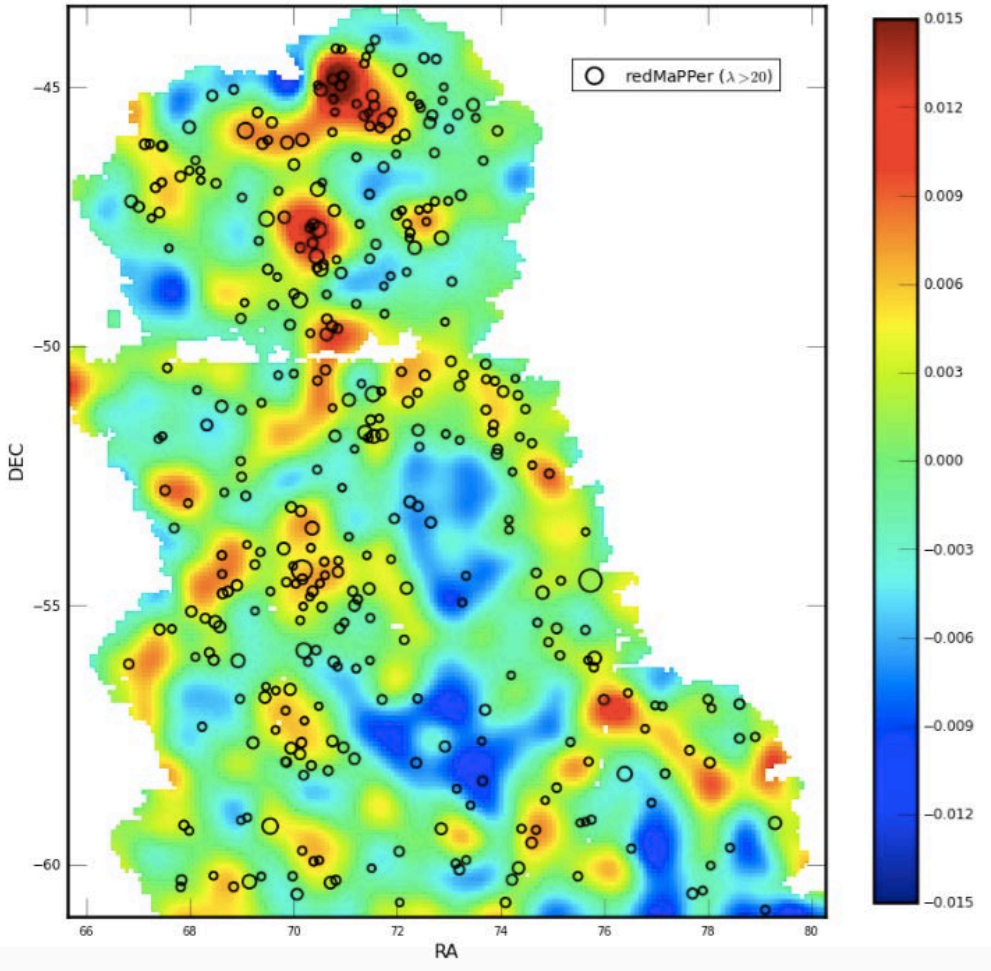

- Describes a “machine-learning” algorithm now part of the SN pipeline
- Reduces the number of SN that need to be “eyeballed” by 13.4x w/ 99+% efficiency for dropped-in “fake” SN

# Weak Lensing Shear

DARK ENERGY SURVEY

Chang et al (DES) sub. to PRL
arXiv:1505.01871
Vikraman et al (DES) to PRD
arXiv:1504.03002

- Divide the data into two samples of about 1M galaxies each:
  - the lens galaxies: 0.1<z<0.5
  - the source galaxies 0.6<z<1.2
- Plot the distortion of the sources. These map the matter distribution in the (foreground) lenses
- Plot the galaxy clusters (circles). See correlation.
- Largest contiguous map and it is only 3% of DES coverage



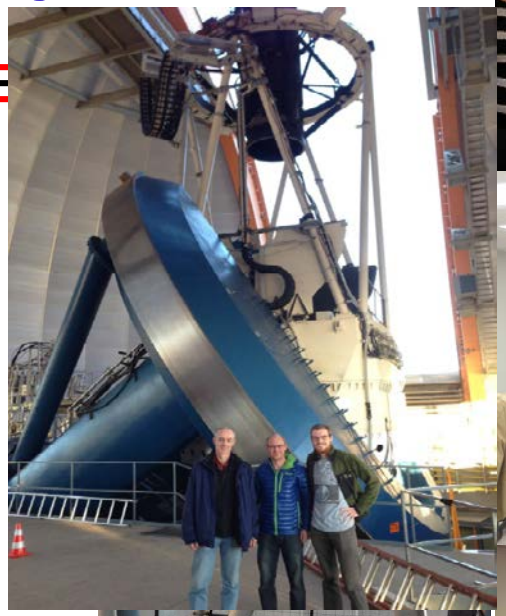

Blue: underdensities
Red: overdensities
(Some are large, 3D structures)

# Summary

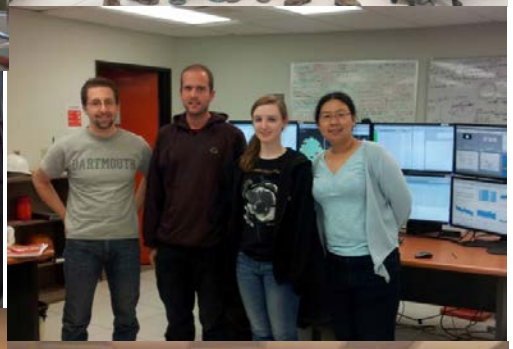
DARK ENERGY SURVEY

- DES has completed 2 or 5 observing seasons
- Camera systems are working very well
- WF has completed 90% of the original plan for end of Y2. SN going as expected.
- Y3 to begin in August 2015.

- DES is producing a steady stream of science results based on SV and Y1 data and these show we expect to be able to produce our DE science deliverables
- 1st DE results will be on SV+Y1+Y2



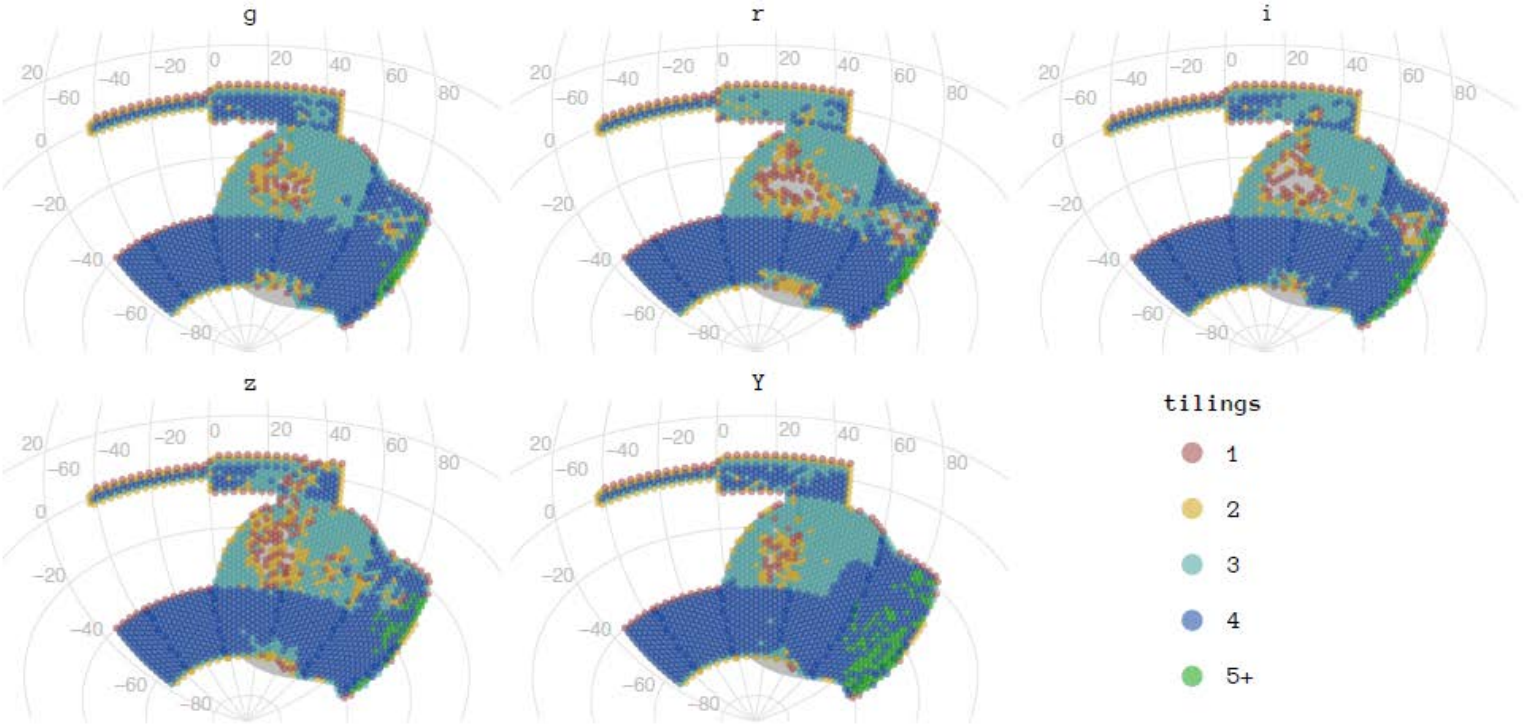



# Extra Slides

DARK ENERGY SURVEY

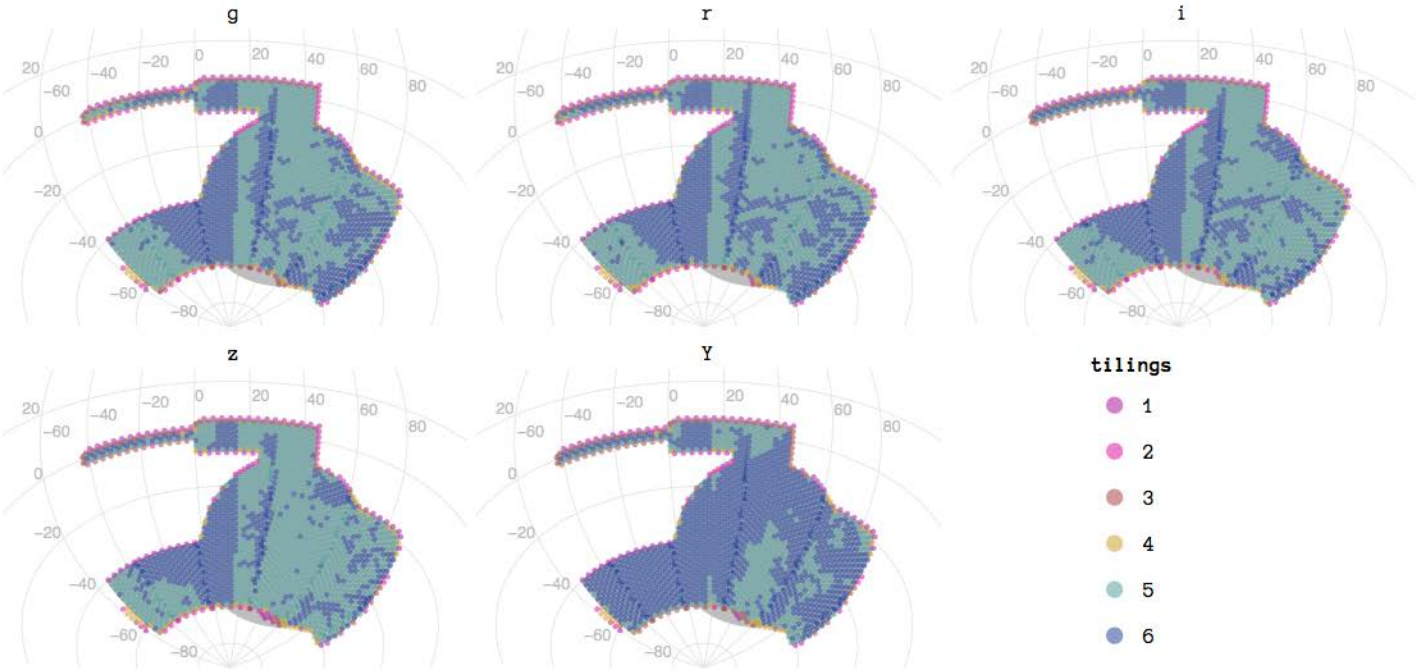
Completion of g,r,i,z,Y
filter bands band after Y2



# Y3 Simulation*

DARK ENERGY SURVEY

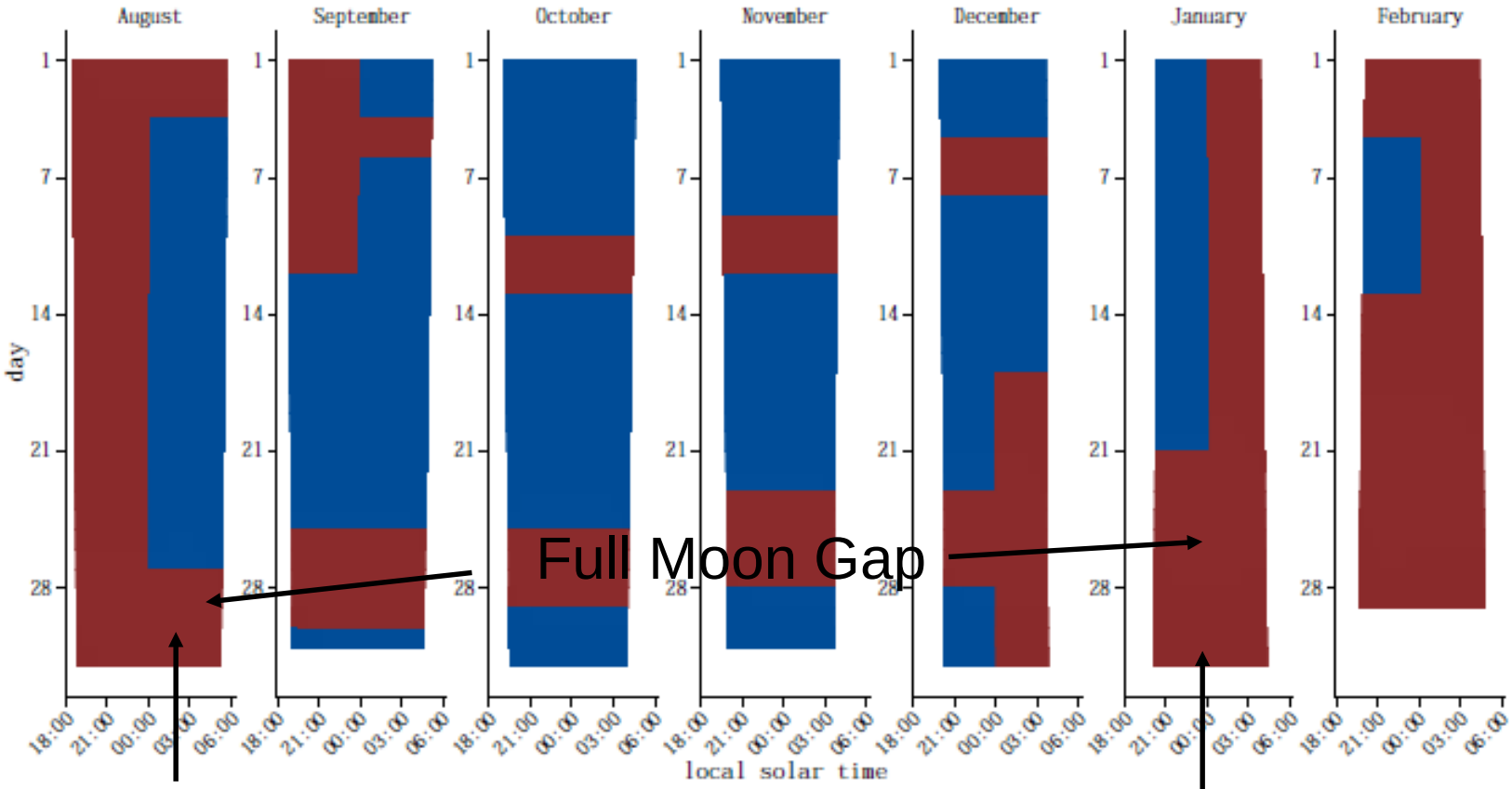
Simulated Completion of g,r,i,z,Y
filter bands band after Y3
Goal 6 tiles in all filters




*Needs to be updated for actual schedule

# Y3 Schedule

DARK ENERGY SURVEY

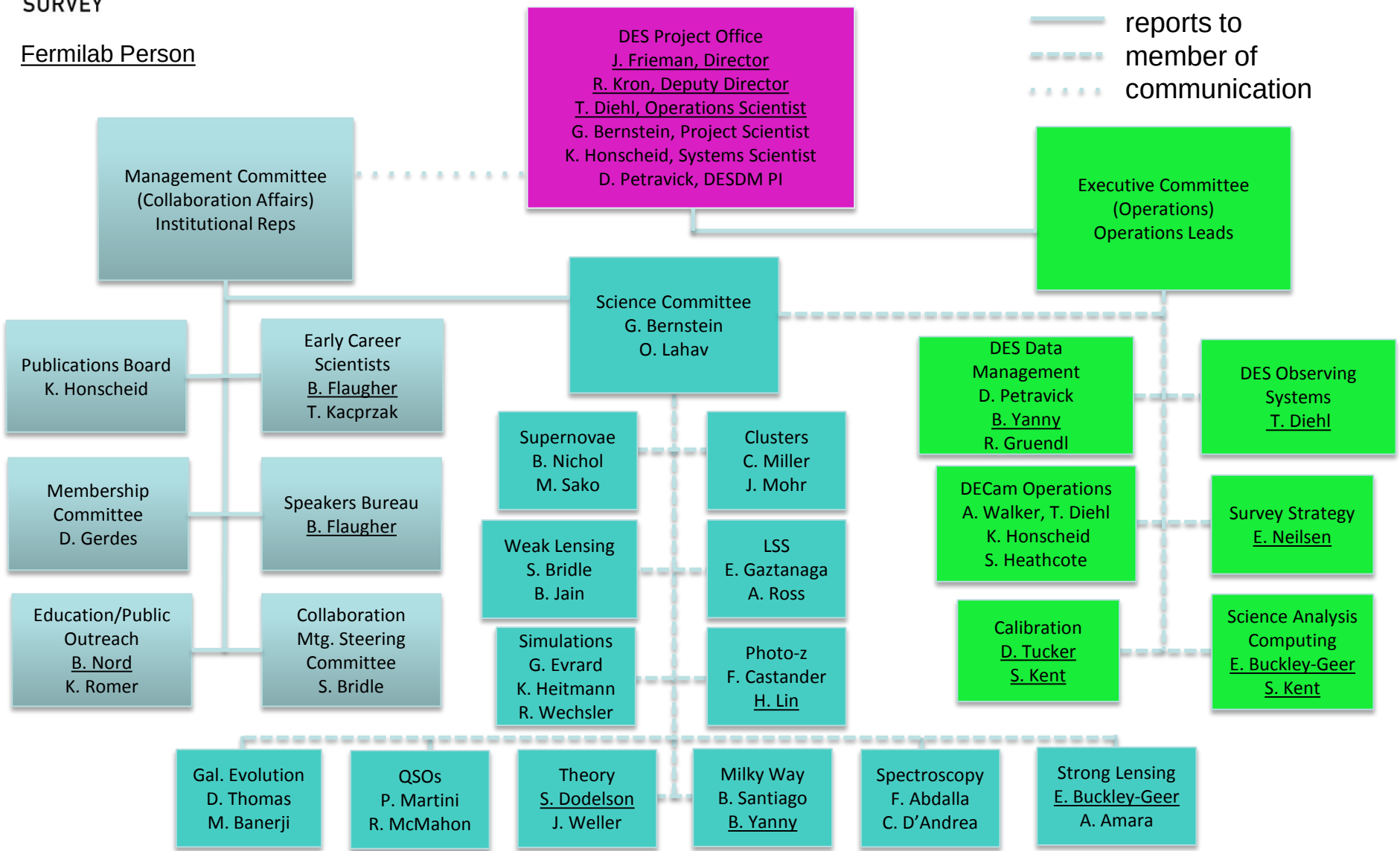



DES observes

# DES Organization Chart
## (a wee bit out-of-date)

DARK ENERGY SURVEY

Fermilab Person




# Fermilab Group

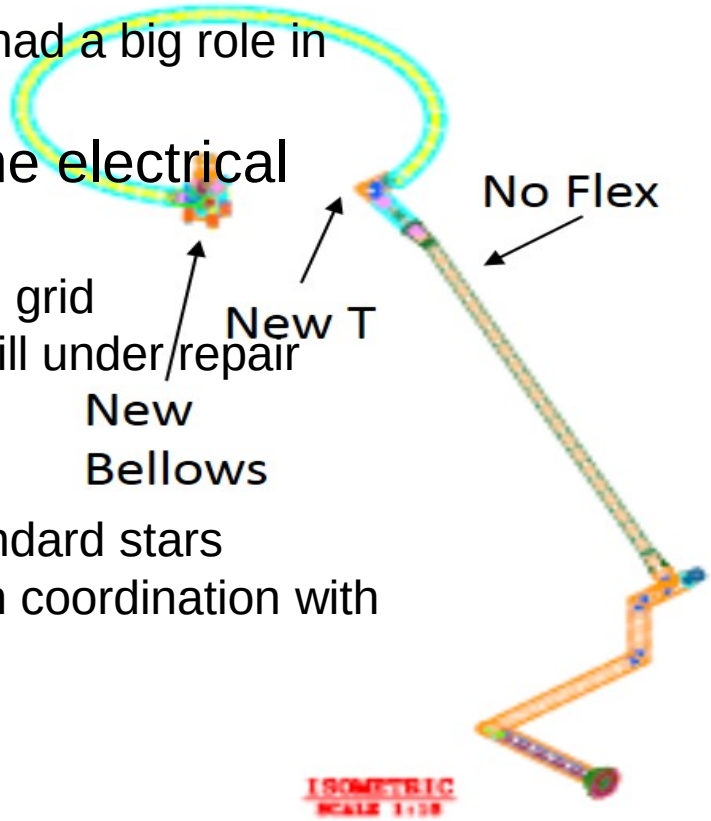
- Flaugher*, Annis, Diehl, Tucker, Buckley-Geer, Yanny, Lin, Kent*, Kron*, Soares-Santos, Wester*, Finley, Frieman$^{T}$, Estrada*, Dodelson$^{T}$, Kuropatkin, Neilsen, Nord**, Drlica-Wagner**, Jennings$^{T}$**

$^{T}$ Theory
** RA
* Major Commitments to other duties or experiments

# Status & Improvements for DECam/Blanco for Y3

DARK ENERGY SURVEY

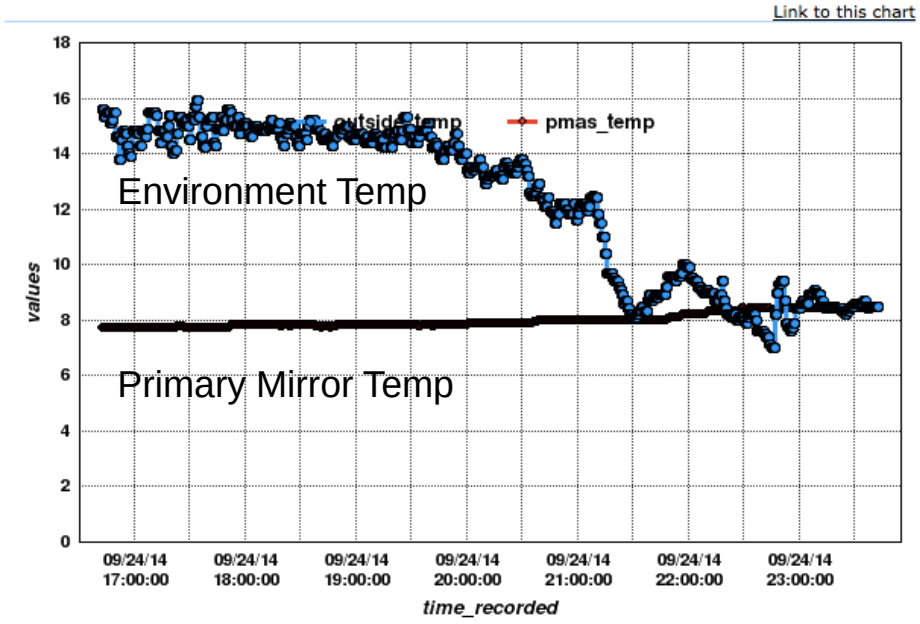
- ✓ New 4MAP LUT tested (decreases astigmatism)
  - New 4MAP LUT to be installed before Y3
  - Aaron Roodman, Roberto Tighe, Alistair W. had a big role in this.
- ✓ Fighting March 19th storm damage to the electrical power
  - CTIO and Gemini knocked off Chilean power grid
  - Power transformer on CTIO damaged and still under repair
  - Diesel generator supplying
- ✓ New windblind camera
  - Avoid obscuring part of the mirror during standard stars
  - Optimize control of the wind blind, perhaps in coordination with the anemometer
- July 2015 Maintenance trip
  - LN2 pump replacement,
  - probable replacement of two LN2 line segments to reduce LN2 consumption,
- Testing new pump bearings at Fermilab



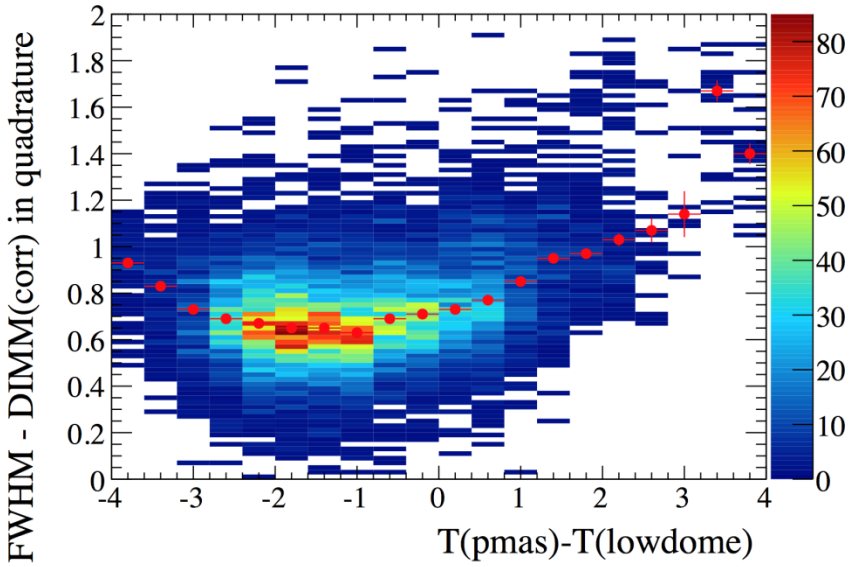
# Image Quality Improvements

DARK ENERGY SURVEY

- Start Y2: New Environmental Controls in the Blanco Dome:
  - 2 large, glycol-cooled air-handlers better maintain primary mirror at or just below air-temperature, and minimize temperature gradients within the dome. Now commissioning automatic controls. 40T chiller that DES supplied made this possible.



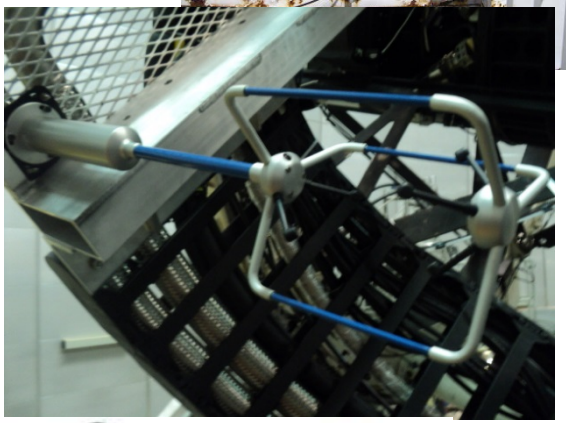

Seeing due to dome environment and camera

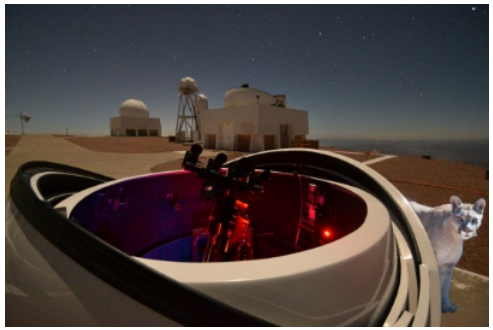


# Status of auxilliary systems

DARK ENERGY SURVEY

- ✓ GPSMon monitors precipitable water vapor in the atmosphere
- ✓ Anemometer
- ✓ CTIO DIMM measures true seeing
- ✓ RasiCam (all-sky IR camera) measures cloud cover, informs Calibration WG if photometric conditions
- ✓ aTmCam (new) measures atmospheric transmission

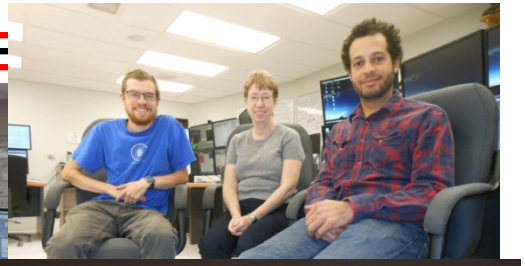




# Some Y2 Observers

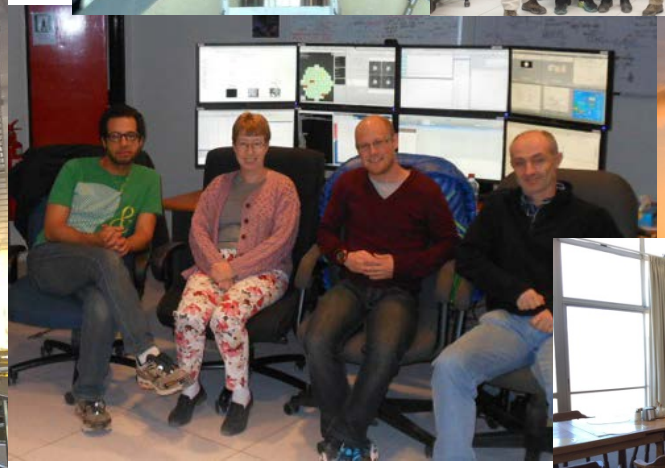
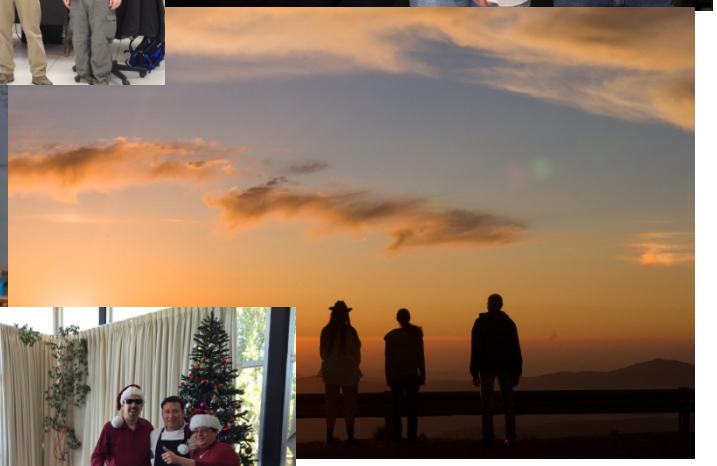
DARK ENERGY SURVEY





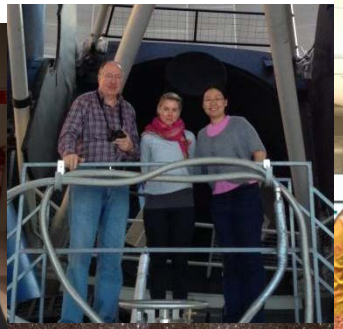


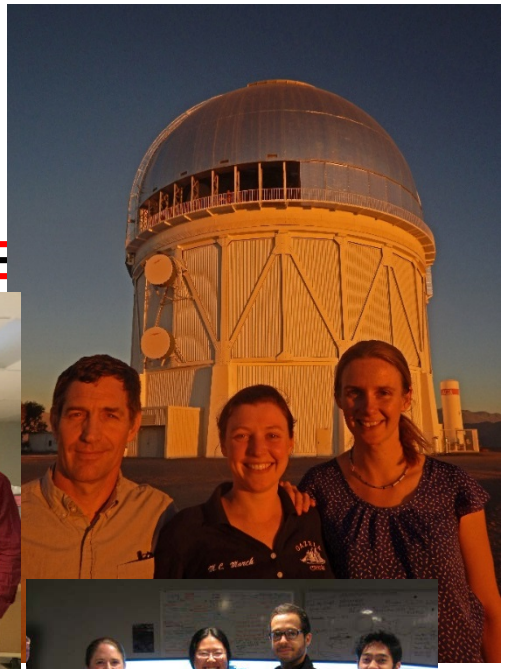


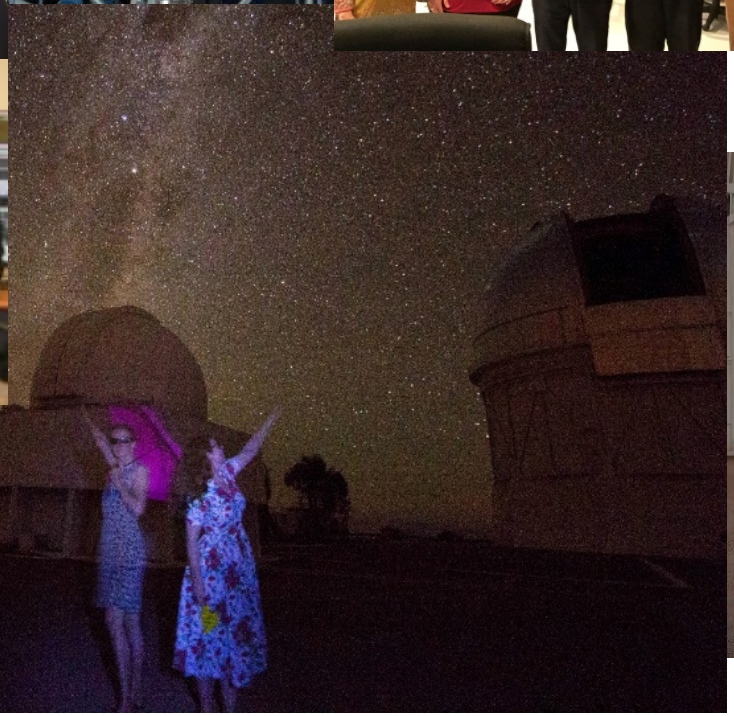




DARK ENERGY SURVEY

# More Y2 Observers



# Stuff

| Field Name | RA | DEC |
|---|---|---|
| E1 | 7.8744 (00:31:29.9) | -43.0096 (-43:00:34.6) |
| E2 | 9.5000 (00:38:00.0) | -43.9980 (-43:59:52.8) |
| S1 | 42.8200 (02:51:16.8) | 0.0000 (00:00:00.0) |
| S2 | 41.1944 (02:44:46.7) | -0.9884 (-00:59:18.2) |
| C1 | 54.2743 (03:37:05.8) | -27.1116 (-27:06:41.8) |
| C2 | 54.2743 (03:37:05.8) | -29.0884 (-29:05:18.2) |
| C3 | 52.6484 (03:30:35.6) | -28.1000 (-28:06:00.0) |
| X1 | 34.4757 (02:17:54.2) | -4.9295 (-04:55:46.2) |
| X2 | 35.6645 (02:22:39.5) | -6.4121 (-06:24:43.6) |
| X3 | 36.4500 (02:25:48.0) | -4.6000 (-04:36:00.0) |