

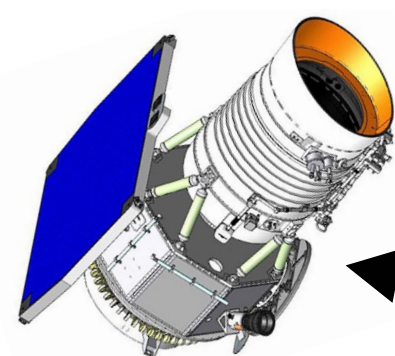
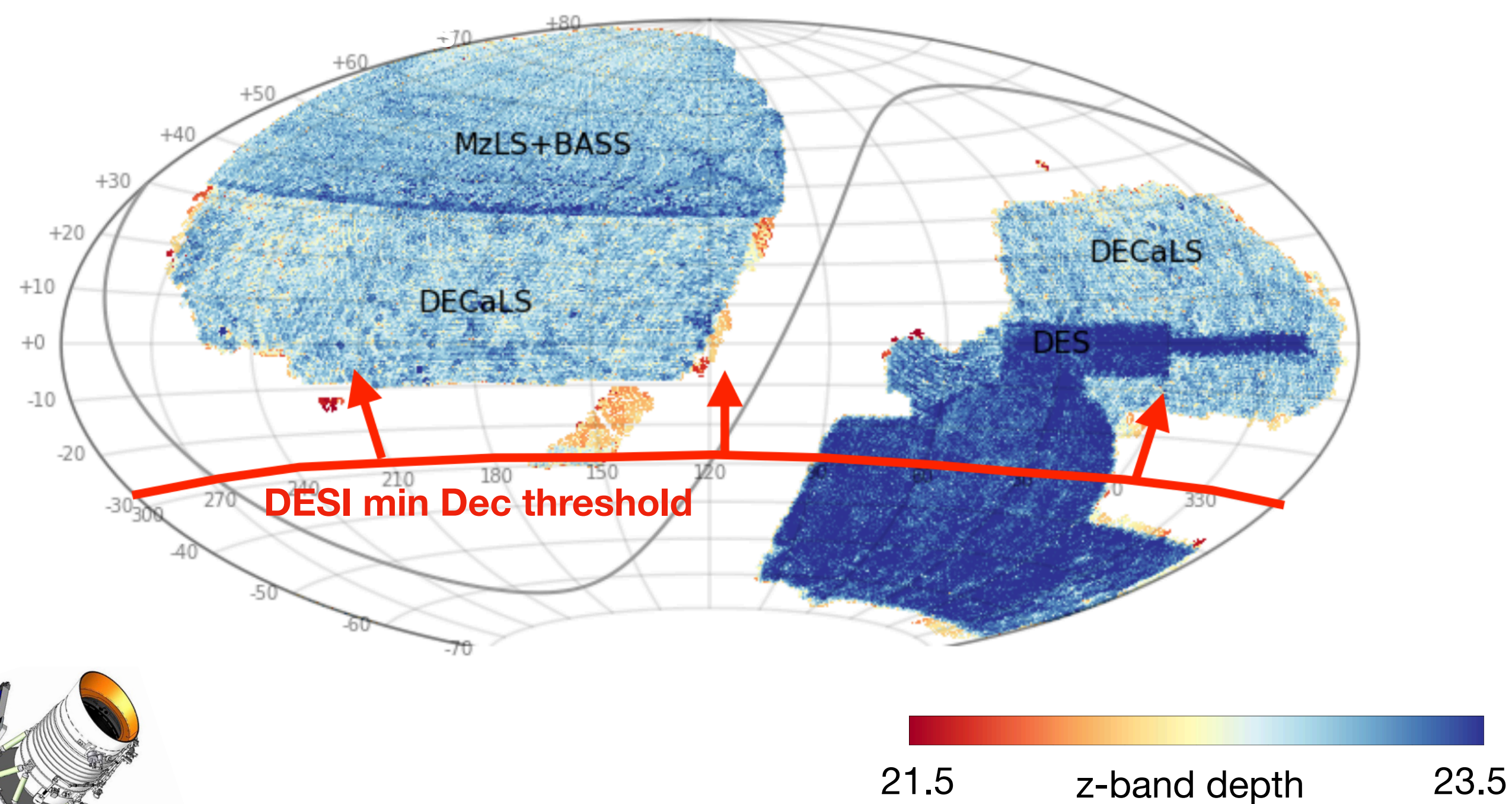
DECaLS DR10: Updating the Dark Energy Camera Legacy Survey

Aaron Meisner (NSF's NOIRLab) on behalf of the DECaLS team

2022 September 13

original DECaLS motivation — DESI targeting

DESI requires ~14,000 sq. deg. of optical imaging deeper than SDSS, PS1



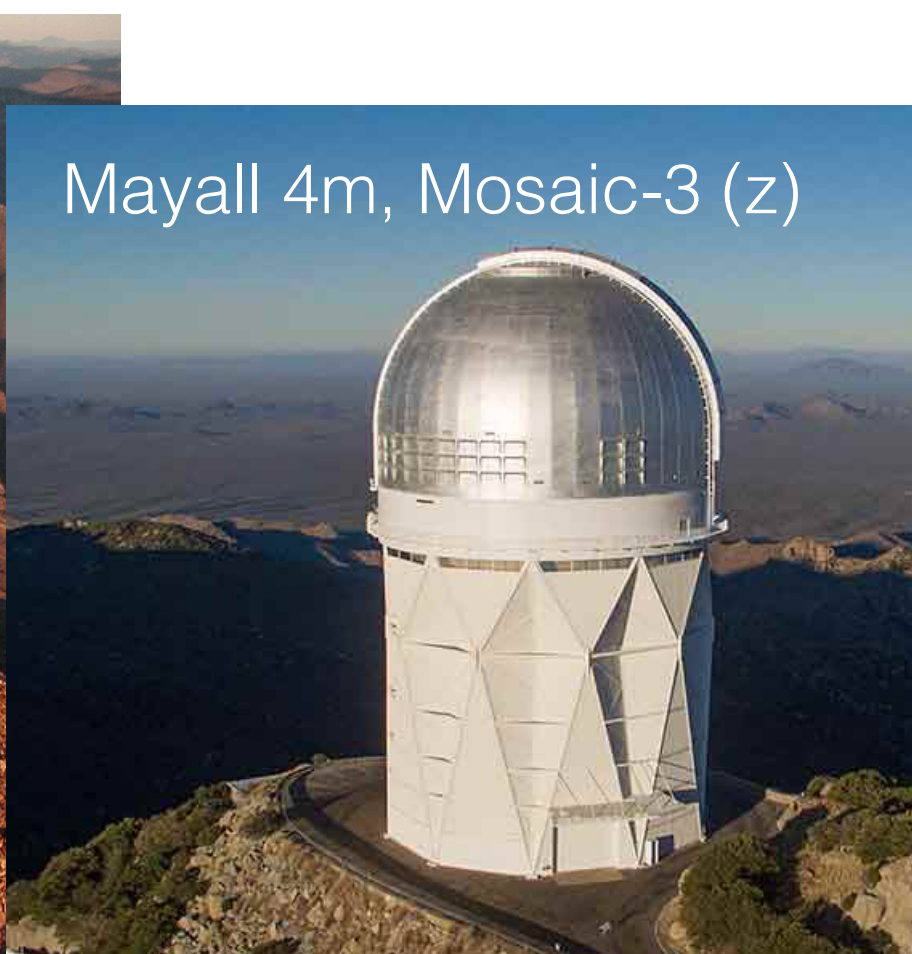


WISE (entire sky)

DECaLS = **D**ark **E**nergy **C**amera **L**egacy **S**urvey

DESI = **D**ark **E**nergy **S**pectroscopic **I**nstrument

DECam: centerpiece of DESI's pre-imaging multi-telescope, multi-year observing campaign

 <p>Bok 2.3m, 90prime (g+r)</p>	 <p>Blanco 4m, DECam (g+r+z)</p>	 <p>Mayall 4m, Mosaic-3 (z)</p>
<p>BASS</p> <p>Beijing-Arizona Sky Survey</p>	<p>DECaLS</p> <p>Dark Energy Camera Legacy Survey</p>	<p>MzLS</p> <p>Mayall z-band Legacy Survey</p>

“DESI Legacy Imaging Surveys”

what is DECaLS?

DECaLS is a public survey...

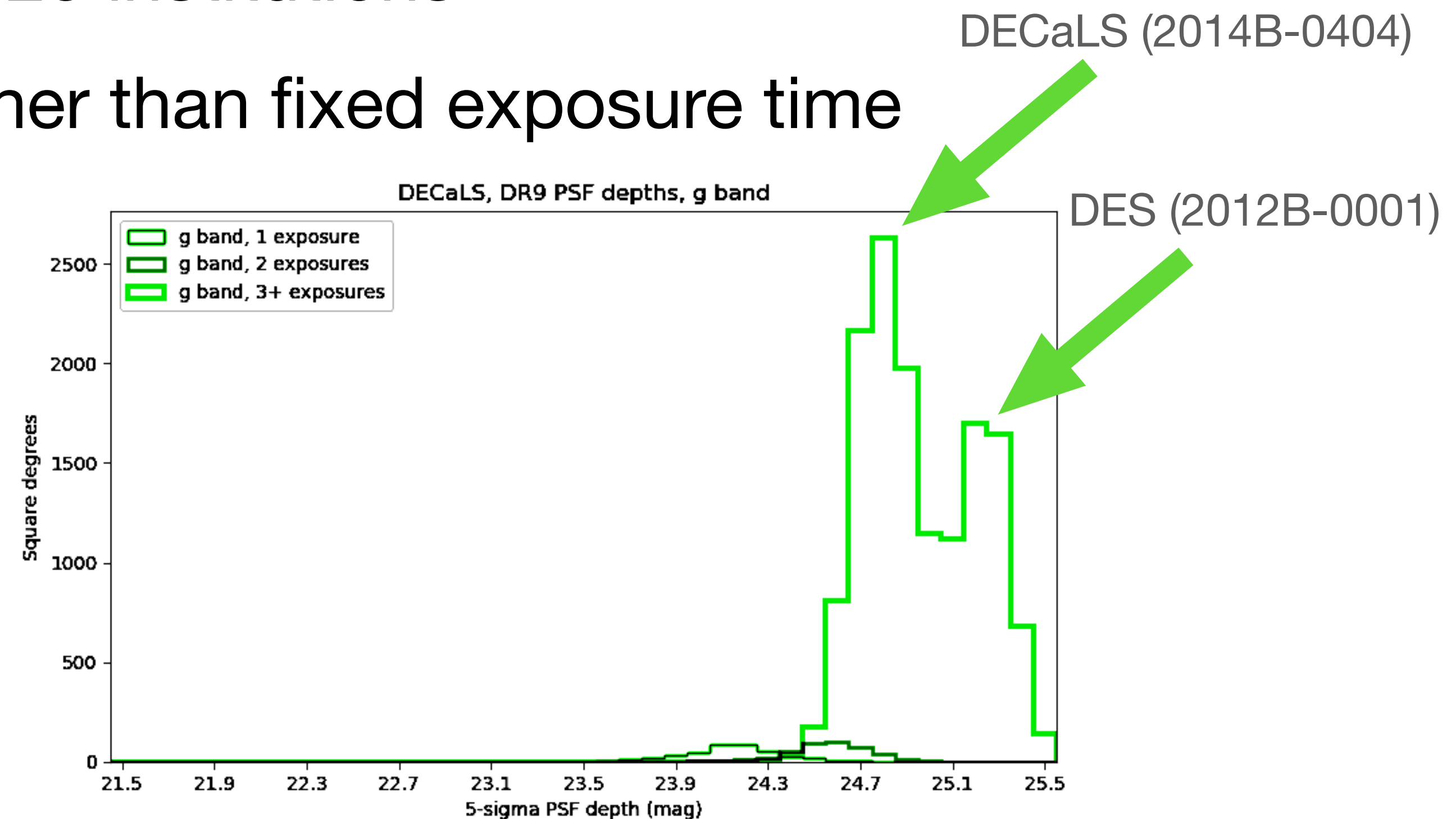
- No proprietary period, anyone can join
- Folds in all (public) archival DECam imaging (e.g., DES, DeROSITAS, ...)
- Inference-based model of the sky (“The Tractor”, Dustin Lang)
 - Inherently multi-instrument/multi-wavelength (includes WISE, Gaia)
- Frequent world public data releases
 - 10 data releases in ~8 years since first DECaLS observations
- <https://www.legacysurvey.org/>, <https://www.legacysurvey.org/viewer>

Band/Number of Passes	≥ 1	≥ 2	≥ 3
<i>g</i> -band	19,919 deg ²	19,256 deg ²	16,606 deg ²
<i>r</i> -band	19,915 deg ²	19,177 deg ²	16,333 deg ²
<i>z</i> -band	20,242 deg ²	19,420 deg ²	16,972 deg ²
All bands jointly	19,721 deg ²	18,813 deg ²	14,756 deg ²

DR9, including DECaLS,
MzLS & BASS

multi-year DECaLS observing campaign

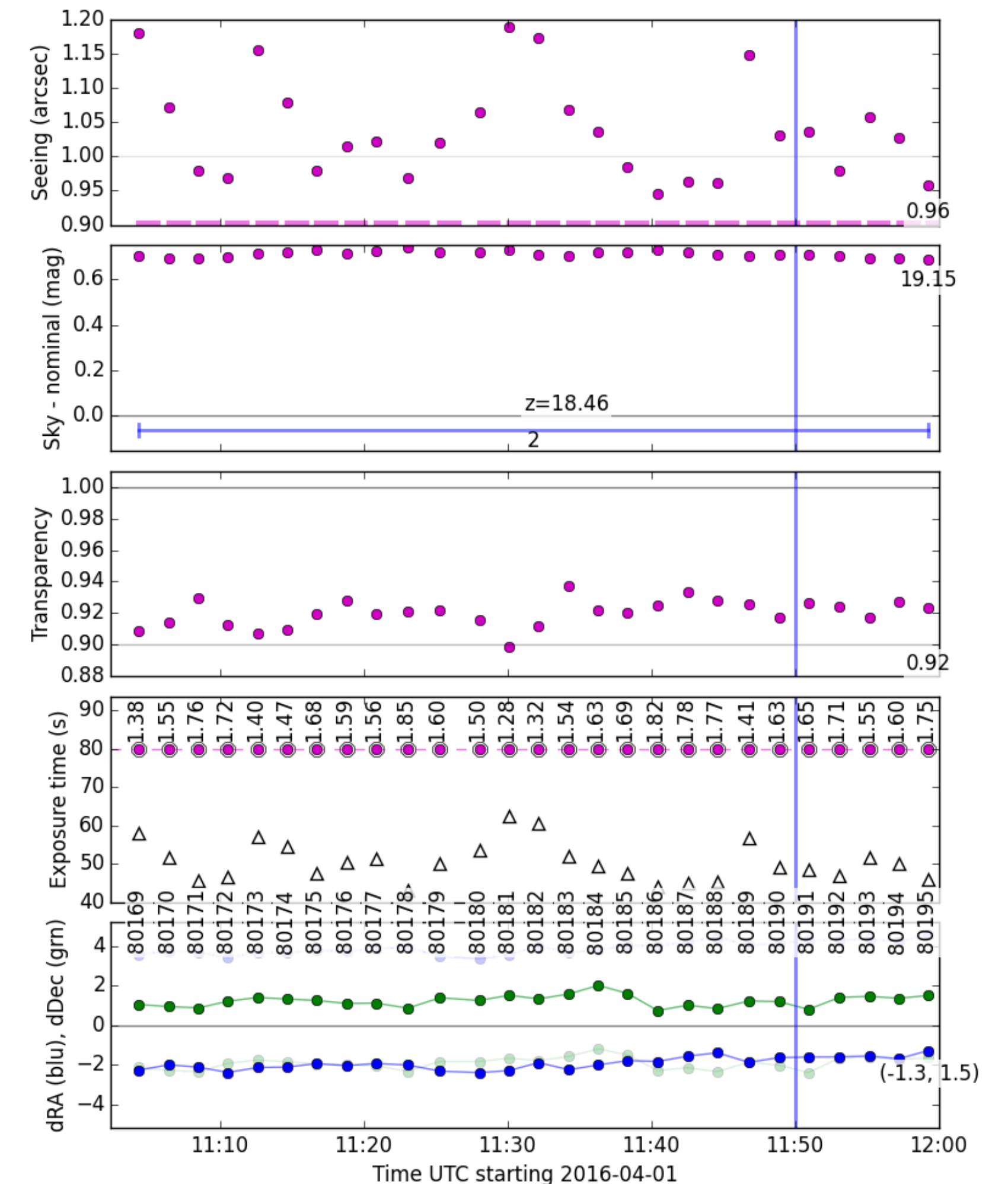
- 203 scheduled nights between 2014 August and 2019 March
 - DECaLS observations (2014B-0404) only in grz
 - 3 “passes” (exposures) per band per sky location
- ~150 unique observers drawn from ~25 institutions
- Uniform depth for each exposure rather than fixed exposure time



DECaLS dynamic observing strategy

observing on autopilot...

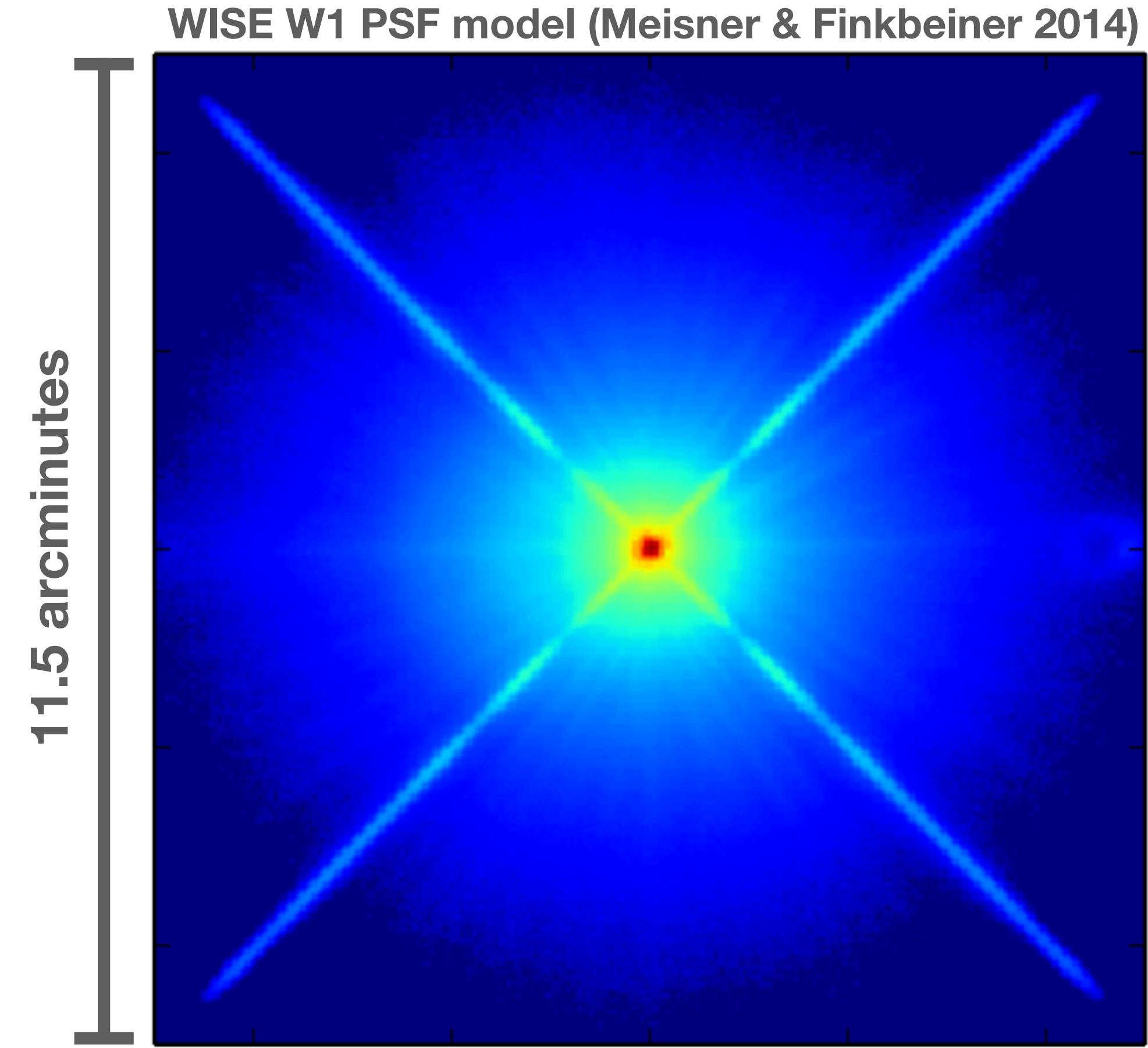
- “copilot” software (Dustin Lang) measures seeing, transparency, sky brightness, pointing offsets in as soon as raw DECam data read out
- Each exposure’s requested integration time is dynamically adjusted based on prior two samples
- DECam ICS API access thanks to Klaus Honscheid
- See David Schlegel’s talk later today for more details!



DECaLS copilot example screenshot (Dustin Lang)

Tractor processing inputs

- NOIRLab Community Pipeline DECam reductions (Frank Valdes)
- WISE/unWISE — custom all-sky coadds (Aaron Meisner, Dustin Lang, Eddie Schlafly)
- Gaia — astrometry
- PS1 — where available, for photometric zeropoints
- PSF models — optical & infrared
- Custom calibration products —
 - ubercal: Eddie Schlafly
 - fringes: Rongpu Zhou



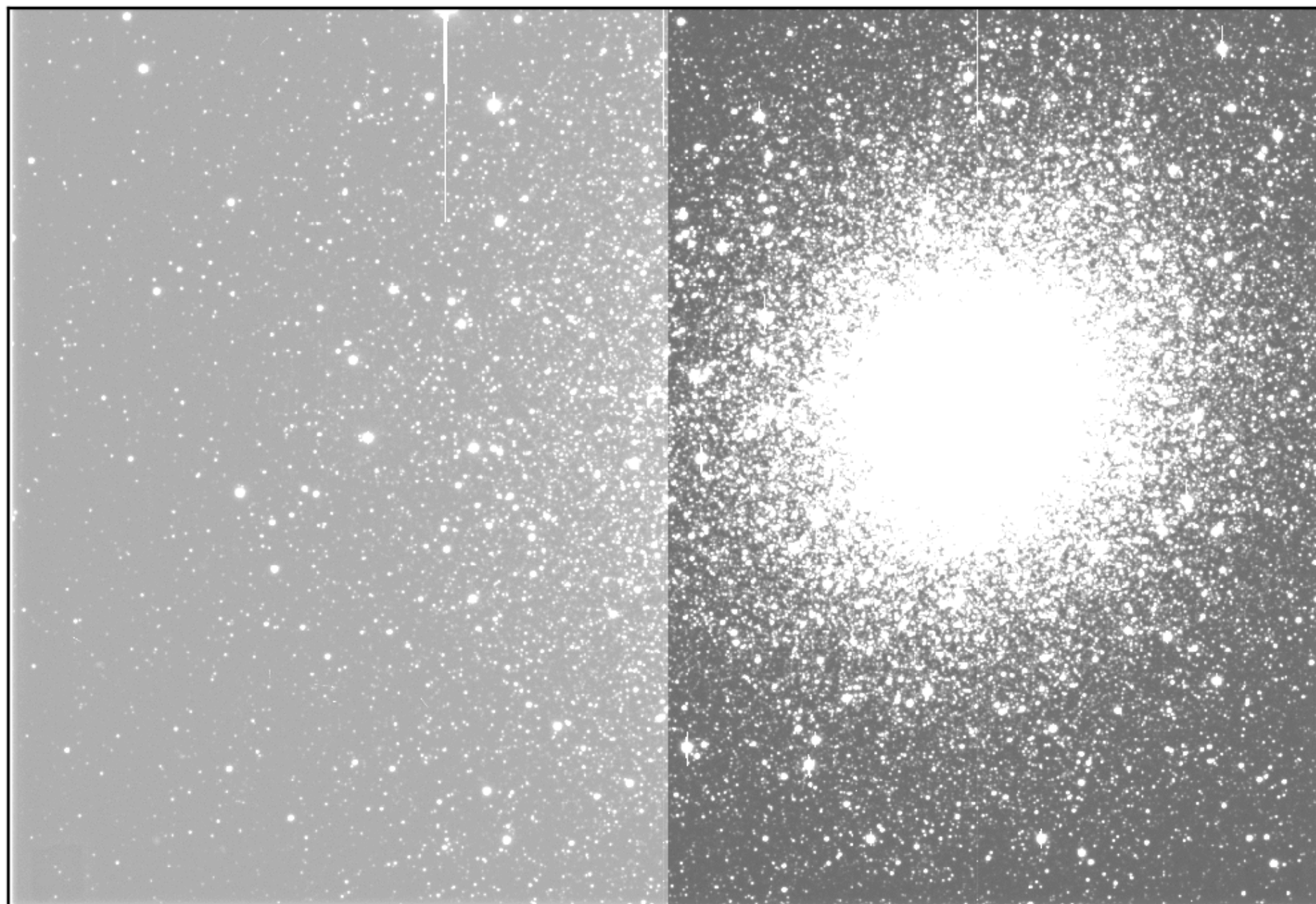
reducing DECam data en masse with the LSST pipelines

DECaLS is our proof-of-concept data set

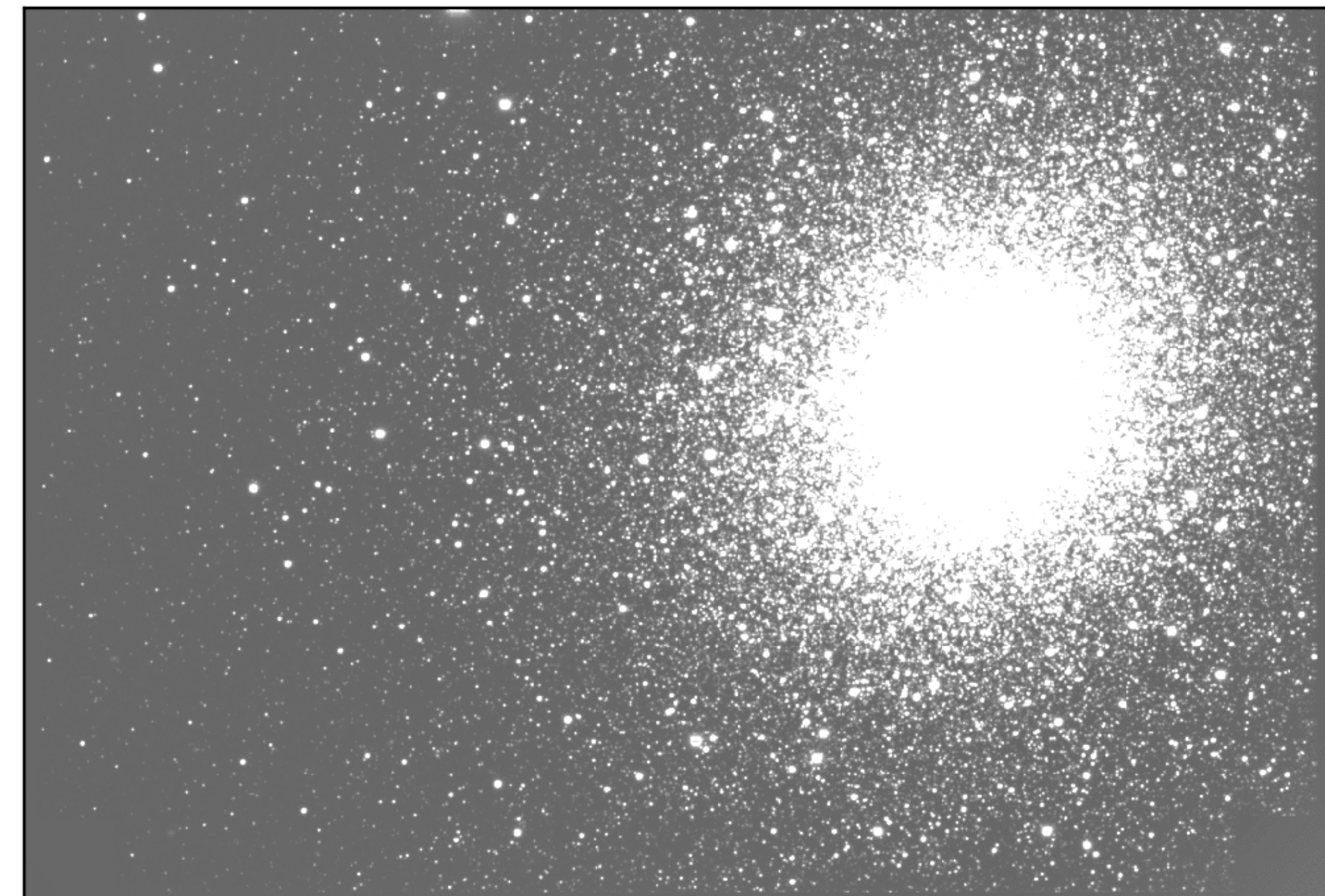
Ongoing R&D work at NOIRLab/CSDC by
Aaron Meisner, Shenming Fu and Tom Matheson



M2 ; raw



M2 ; reduced



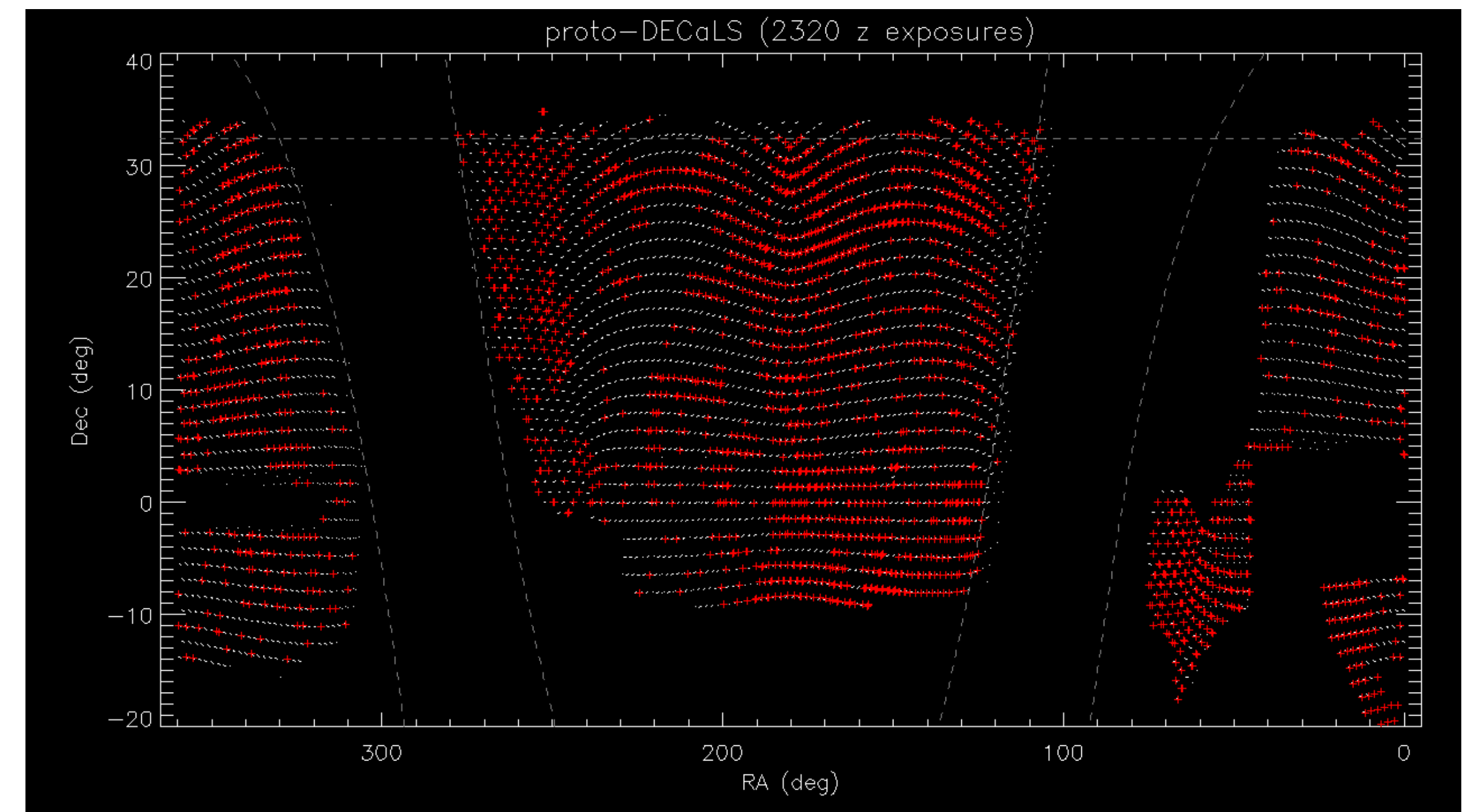
example of DECam CCD-level calibration (detrending, astrometric and photometric calibration) performed with the LSST pipeline

reducing DECam data en masse with the LSST pipelines

DECaLS is our proof-of-concept data set



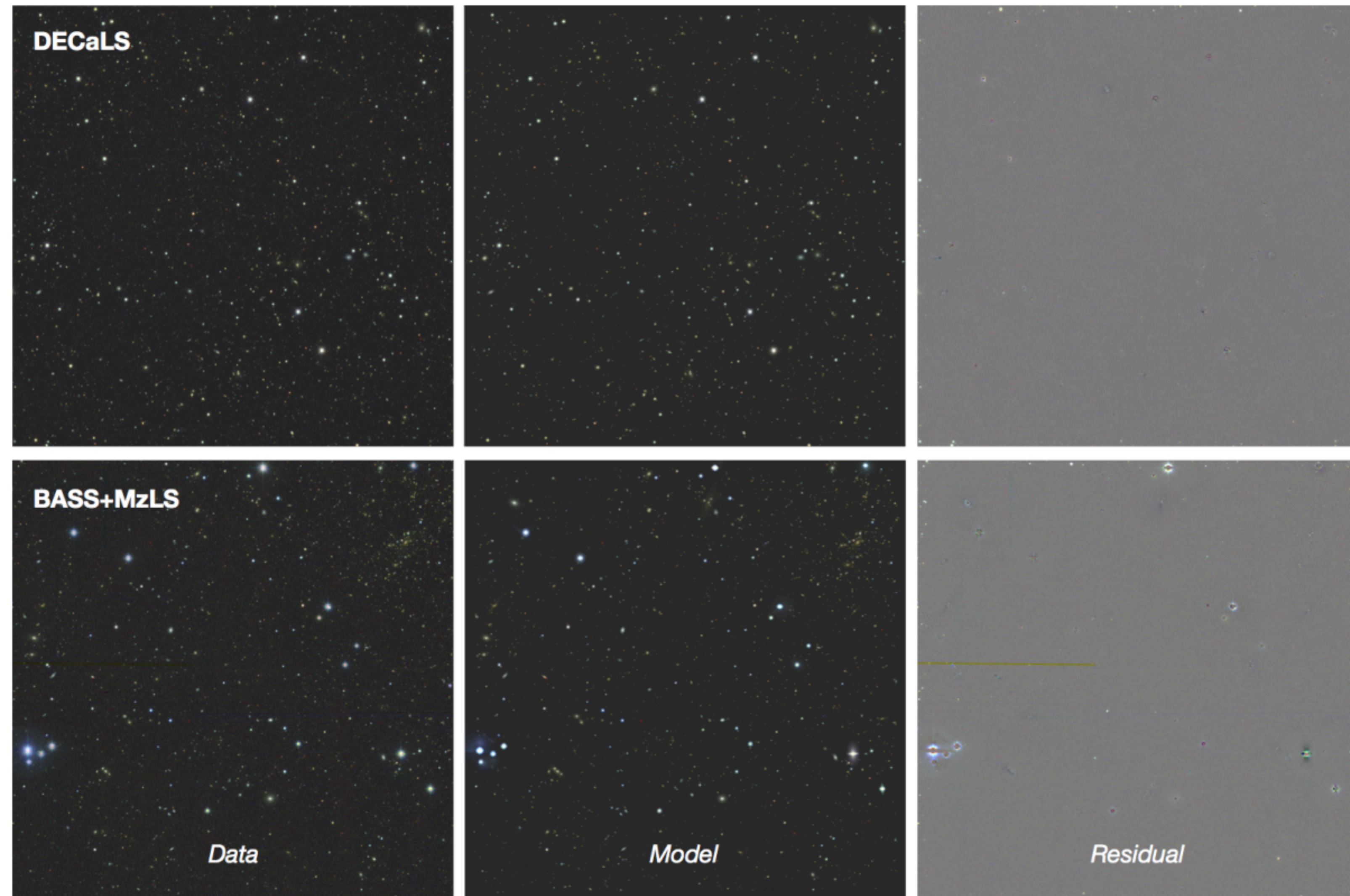
- Demonstrated ability to rapidly reduce ~20% of DECaLS imaging with the LSST pipeline
- > 99.7% of CCDs reduce successfully
 - The few failures are bad weather, otherwise unusable raw images
- Could reduce all DECaLS exposures using only ~500 NERSC charge hours



z-band sky coverage from recent (partial) DECaLS processing,
~7000 exposures in total

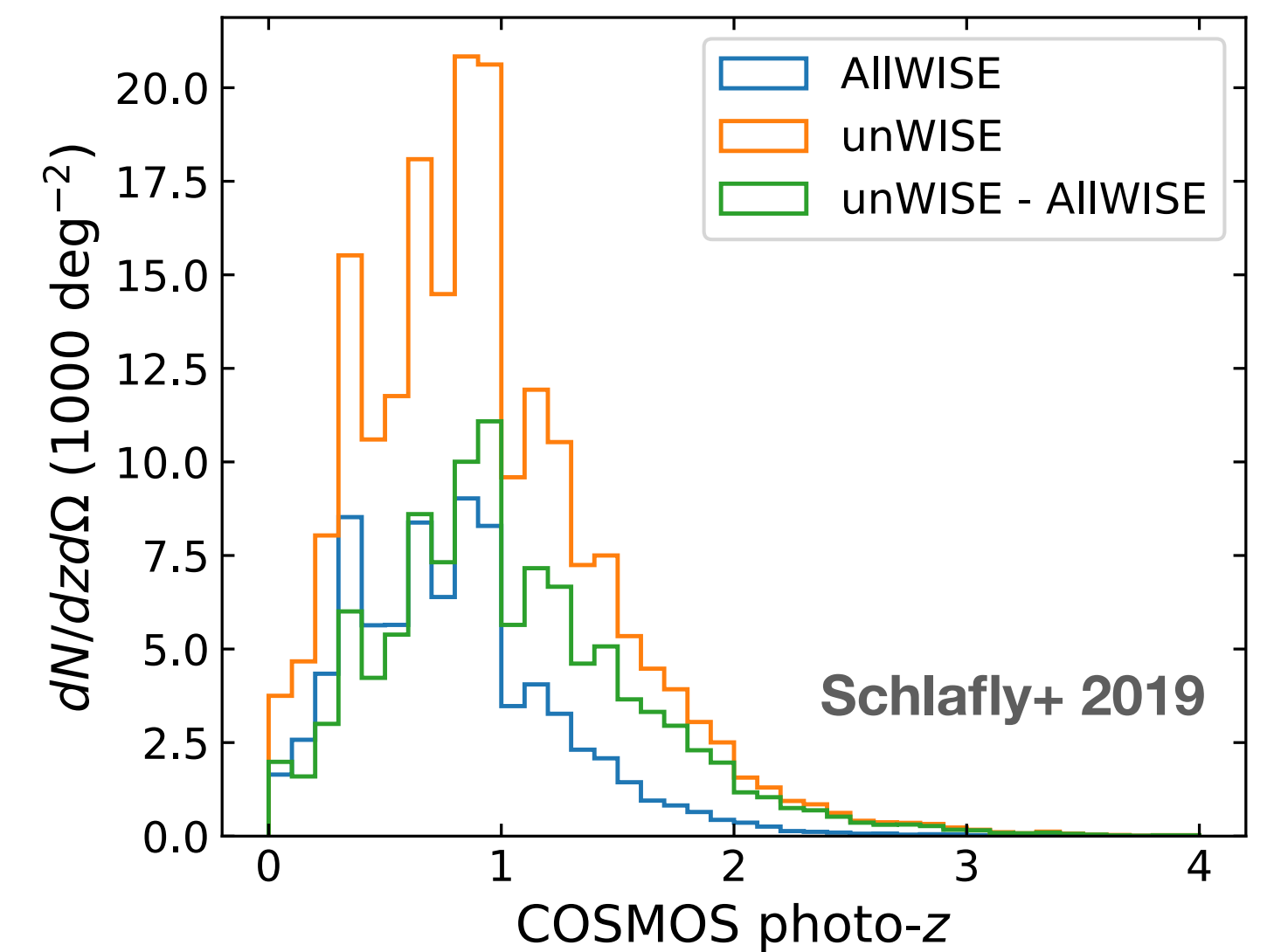
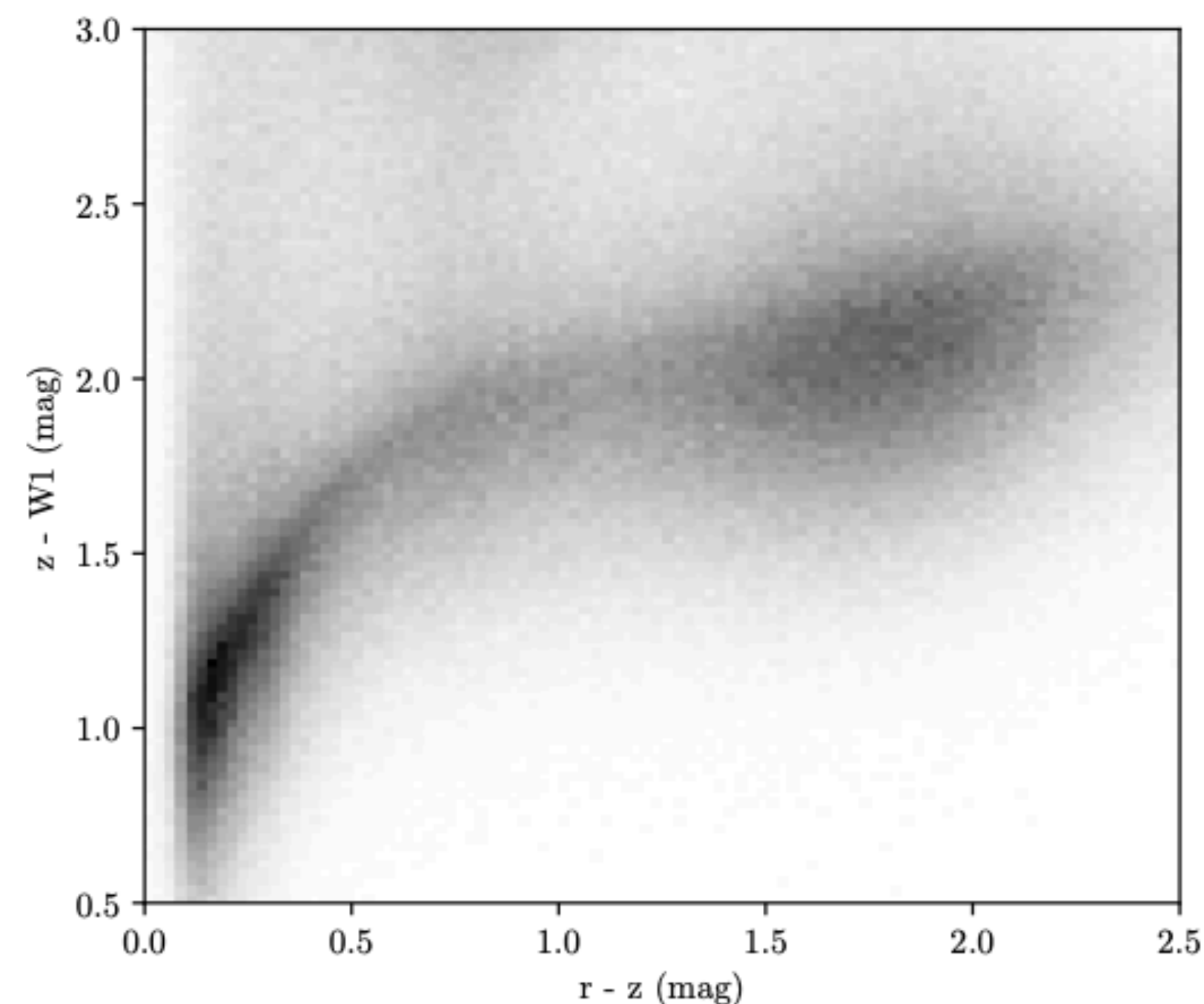
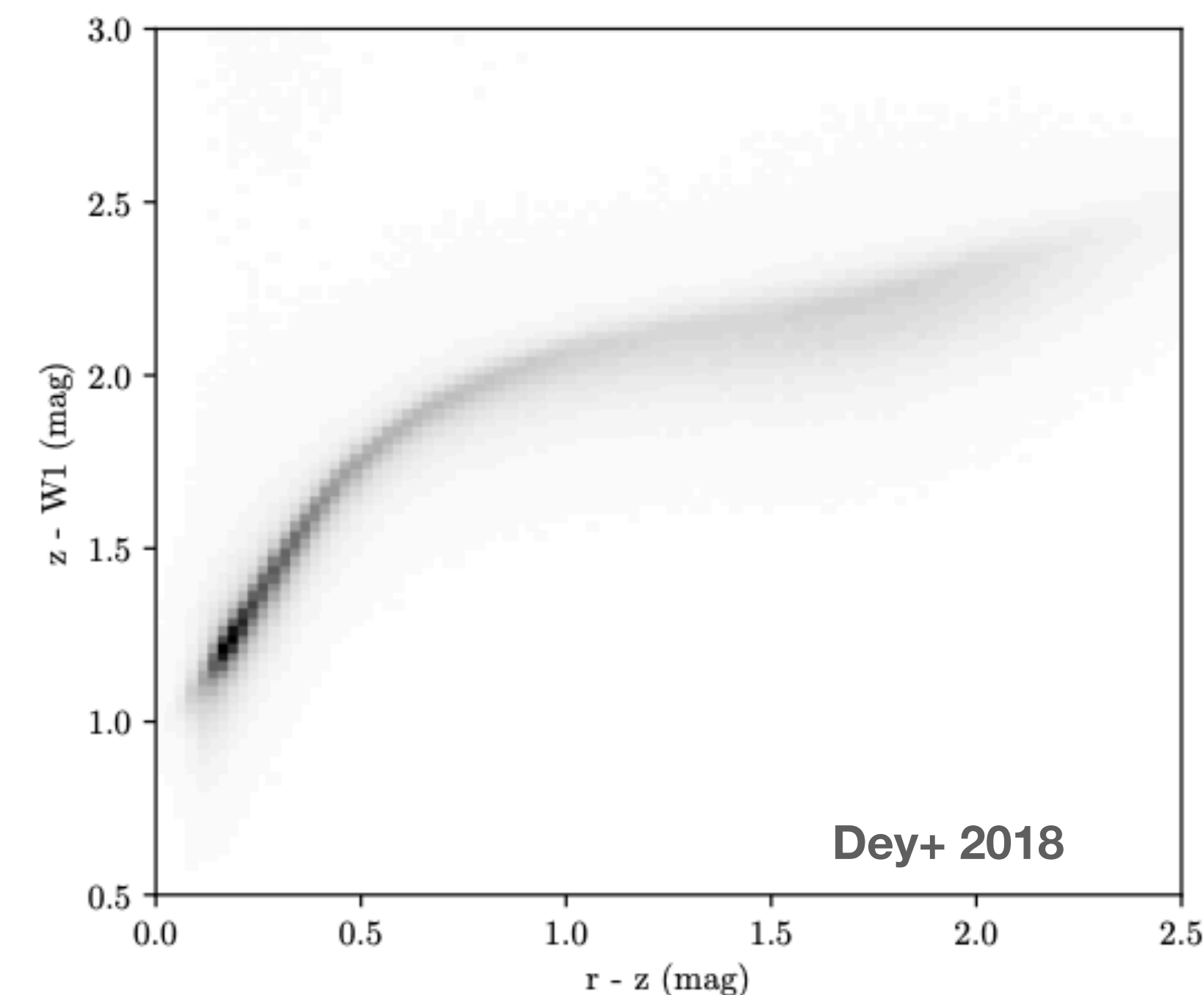
The Tractor

- Tractor jointly models all exposure-level pixels overlapping a given sky region
- Tractor uses a generative model including point-like and extended sources
- Coadds are only made for visualization, not for scientific measurements

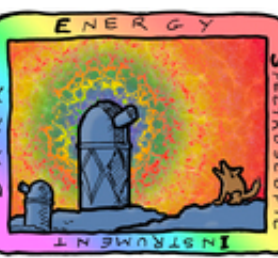
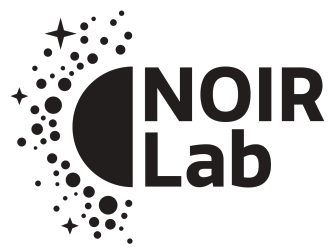


unWISE forced photometry for DECaLS

- DR10 custom ‘unWISE coadds’ uniformly combine 8 years of WISE/NEOWISE imaging at 3-5 microns, allowing DECaLS to go much deeper than AllWISE
- Forced photometry of unWISE coadds performed using optical positions/morphologies
- unWISE forced photometry was critical for DESI’s luminous red galaxy & quasar targeting



2× more galaxies at $0 < z < 1$
3× more galaxies at $1 < z < 2$
6× more galaxies at $z > 2$



DECaLS data processing at NERSC

National Energy Research Scientific Computing Center



- 245,000 DECam exposures (~39,000 with DECaLS PROPID)
 - 110 TB of input raw DECam exposures
- 41 million WISE W1/W2 exposures
 - 280 TB of input WISE exposures
- Roughly 20-25 million CPU hours per data release

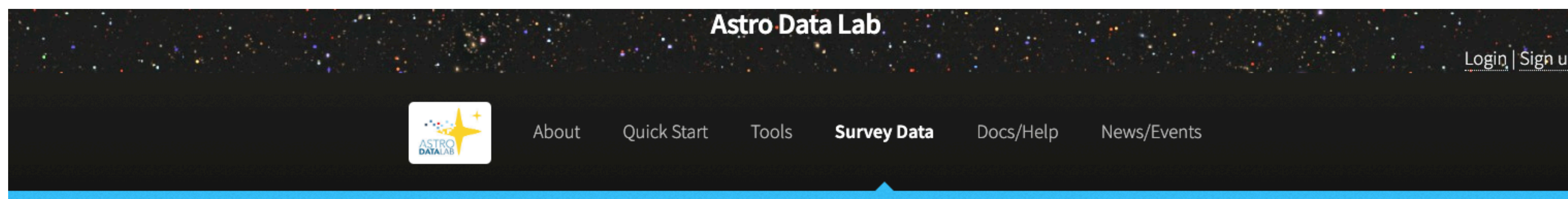


data access

NOIRLab Astro Data Lab & NERSC



- File-based access: NERSC, <https://www.legacysurvey.org/>
- Databases: NOIRLab Astro Data Lab, <https://datalab.noirlab.edu/ls/ls.php>
 - Astro Data Lab kindly hosts other auxiliary DECaLS products, including photo-z catalogs (R. Zhou) & the unWISE Catalog (E. Schlafly, A. Meisner)



Overview

DECaLS

MzLS

BASS

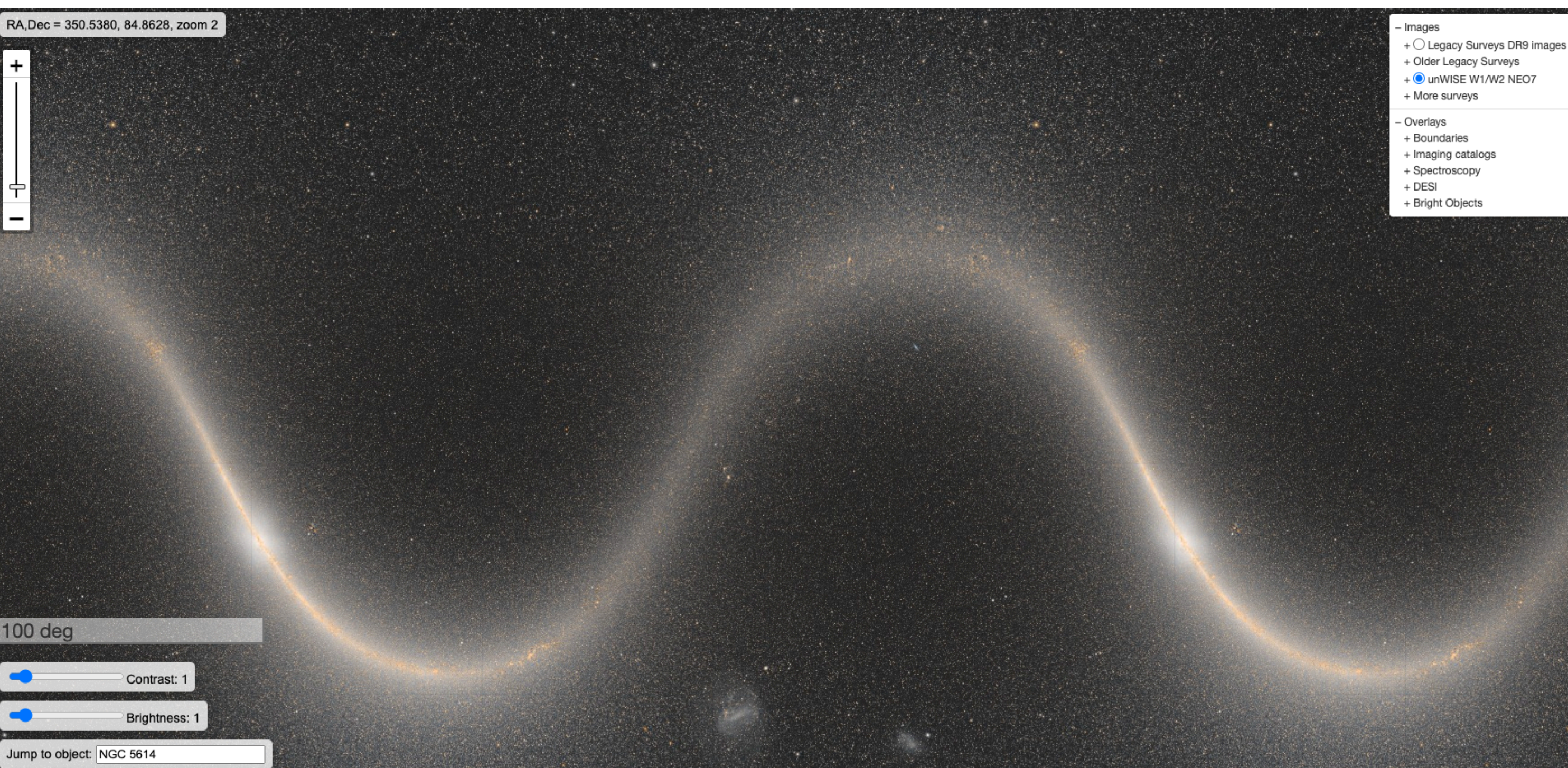
Legacy Survey - Overview

The Legacy Surveys cover 14,000 square degrees of the extragalactic sky, and yield high-quality optical and near-infrared photometric catalogs. The sky coverage is approximately bounded by $-18^\circ < \delta < +84^\circ$ in celestial coordinates and $|b| > 18^\circ$ in Galactic coordinates. Resulting images, models, and catalogs will enhance current and future wide area surveys such as SDSS/BOSS/eBOSS and DESI.

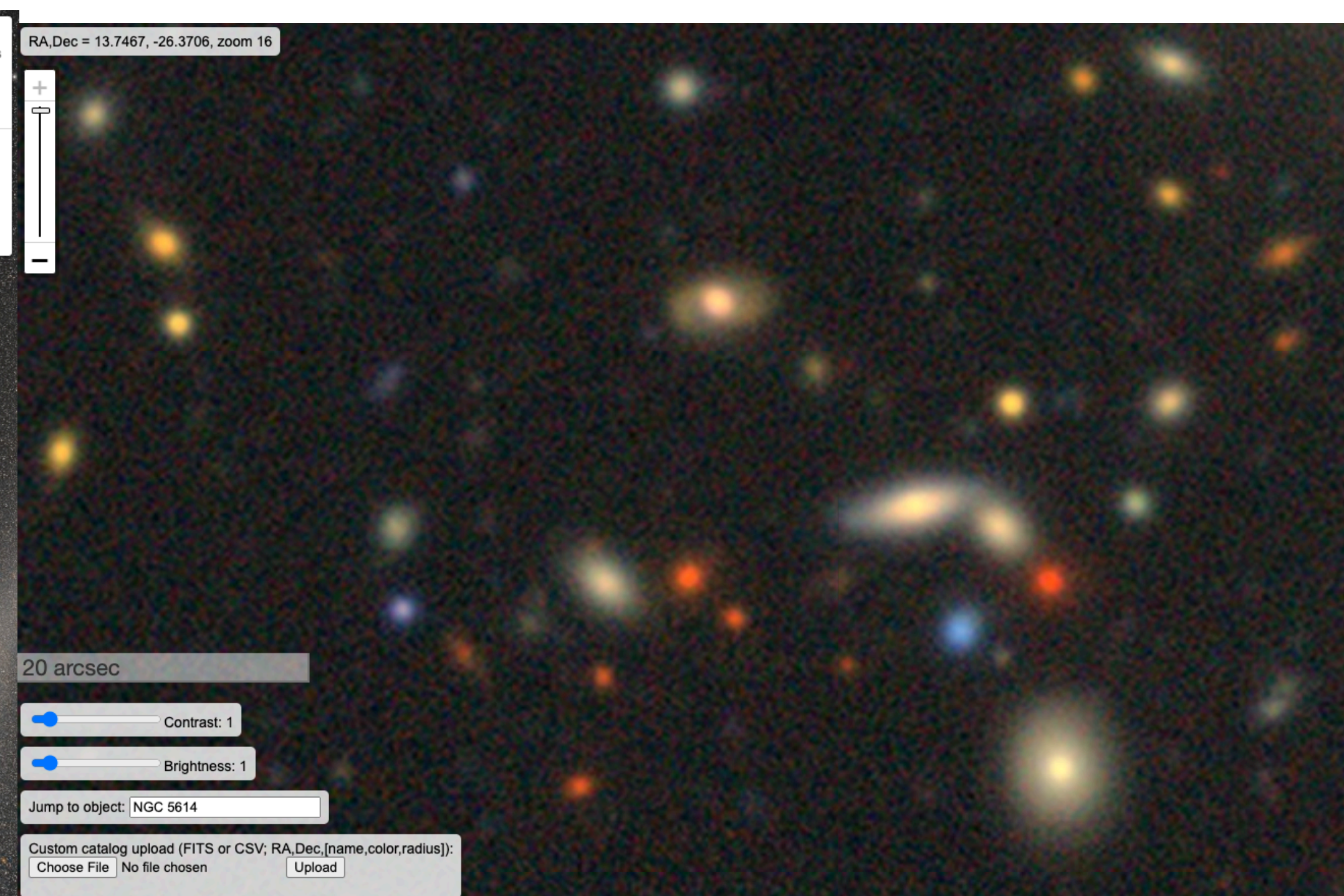
DESI Legacy Imaging Surveys Sky Viewer

created by Dustin Lang

- Interactively explores a factor of $\sim 20,000$ in zoom!



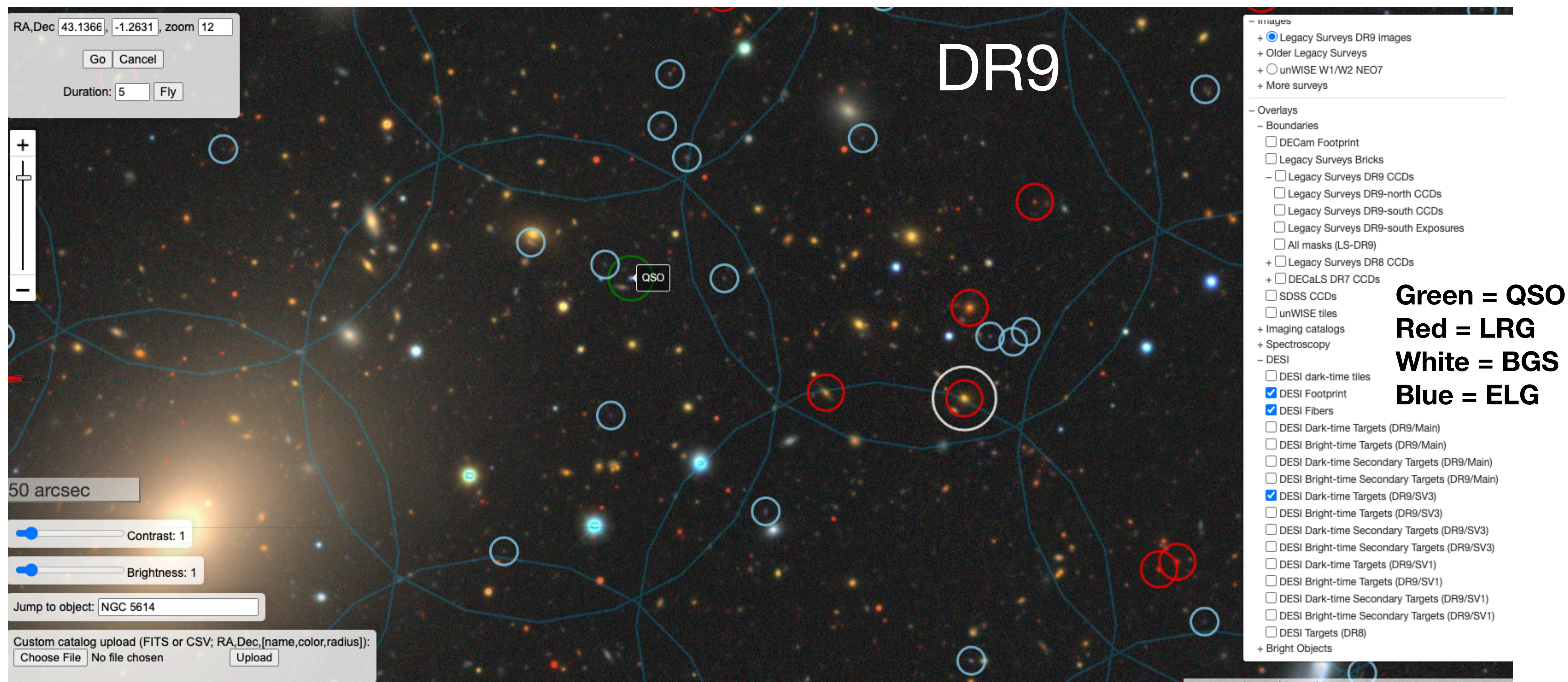
8-year static sky unWISE coadds (entire sky rendered)



DECaLS DR9 grz (max zoom)

DECaLS for DESI targeting

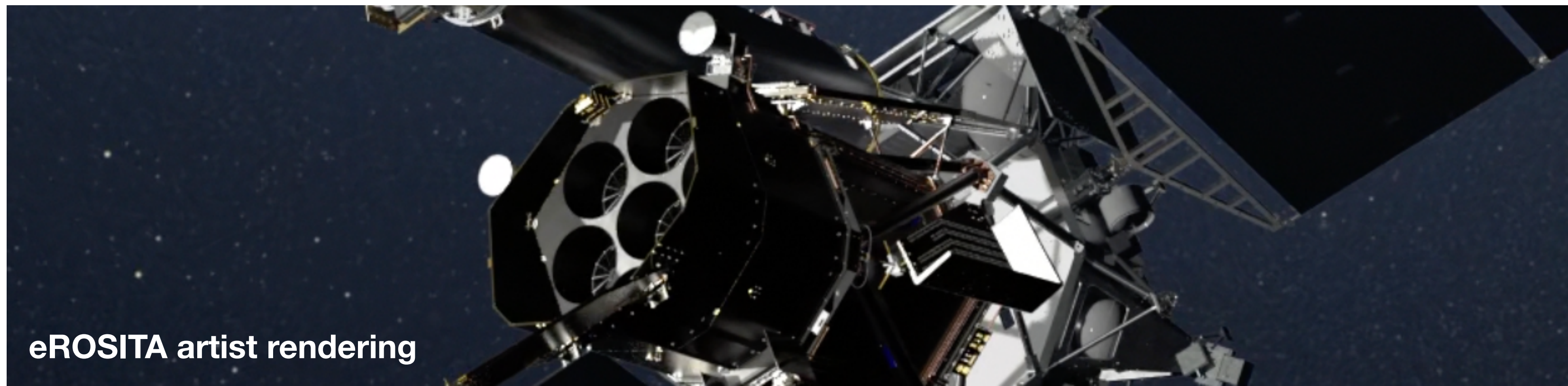
DESI meets all of its targeting requirements, thanks in large part to DECaLS



blue lines = DESI fiber patrol regions

What's new for DECaLS DR10?

- DECam i-band included for the first time
- 1 more year of NEOWISE infrared data relative to DECaLS DR9 (7 yrs -> 8 yrs)
- Large-scale incorporation of publicly available DeROSITAS and DELVE imaging
- DR10/DeROSITAS will be used by the eROSITA team for galaxy cluster science
- DR10 expected to be used for SDSS V targeting
- DR10 expected to also be used for 4MOST targeting
 - 4MOST Chilean AGN/Galaxy Evolution Survey (ChANGES)

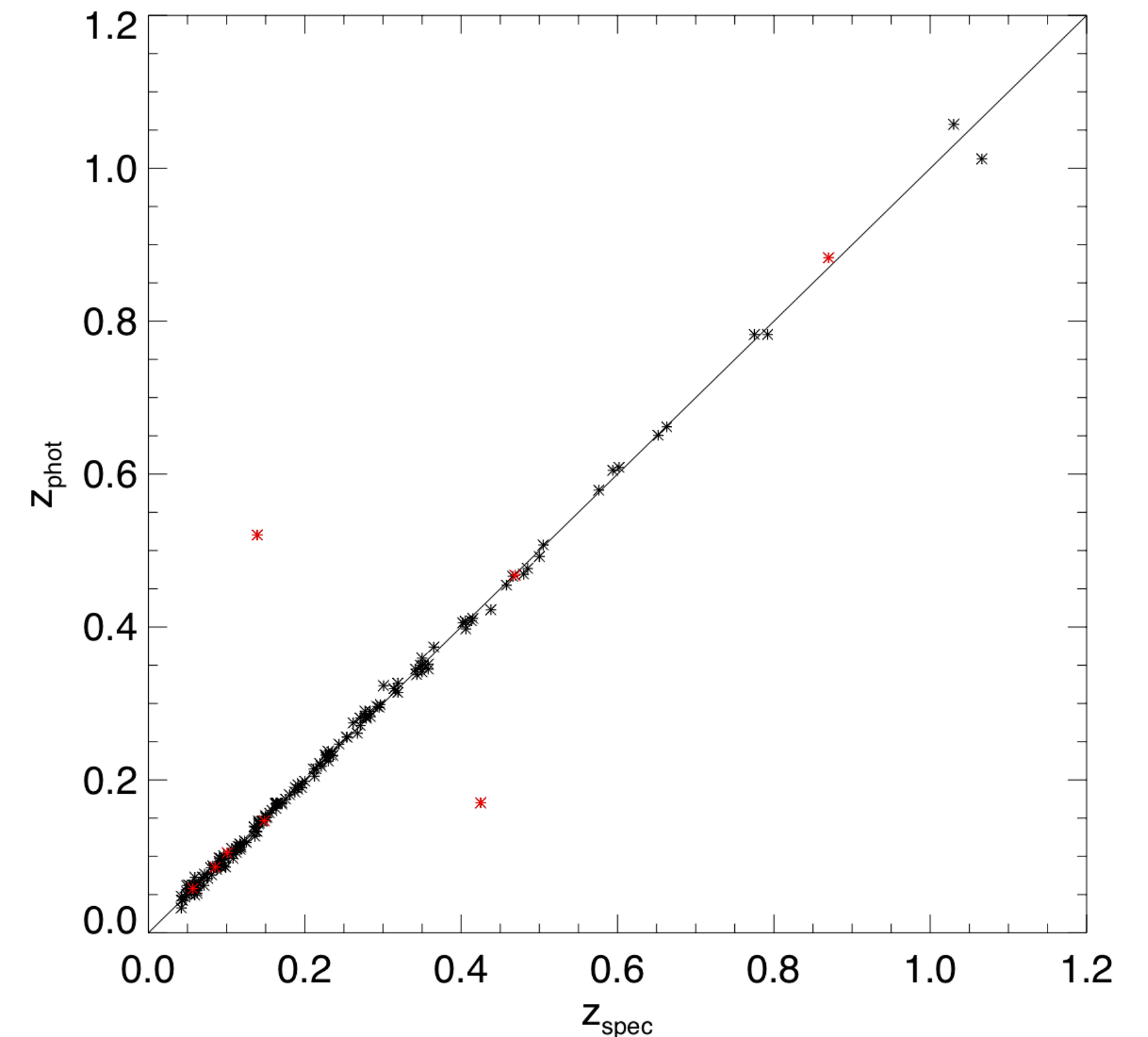


eROSITA artist rendering

DeROSITAS

The DECam eROSITA Survey (PI: Alfredo Zenteno)

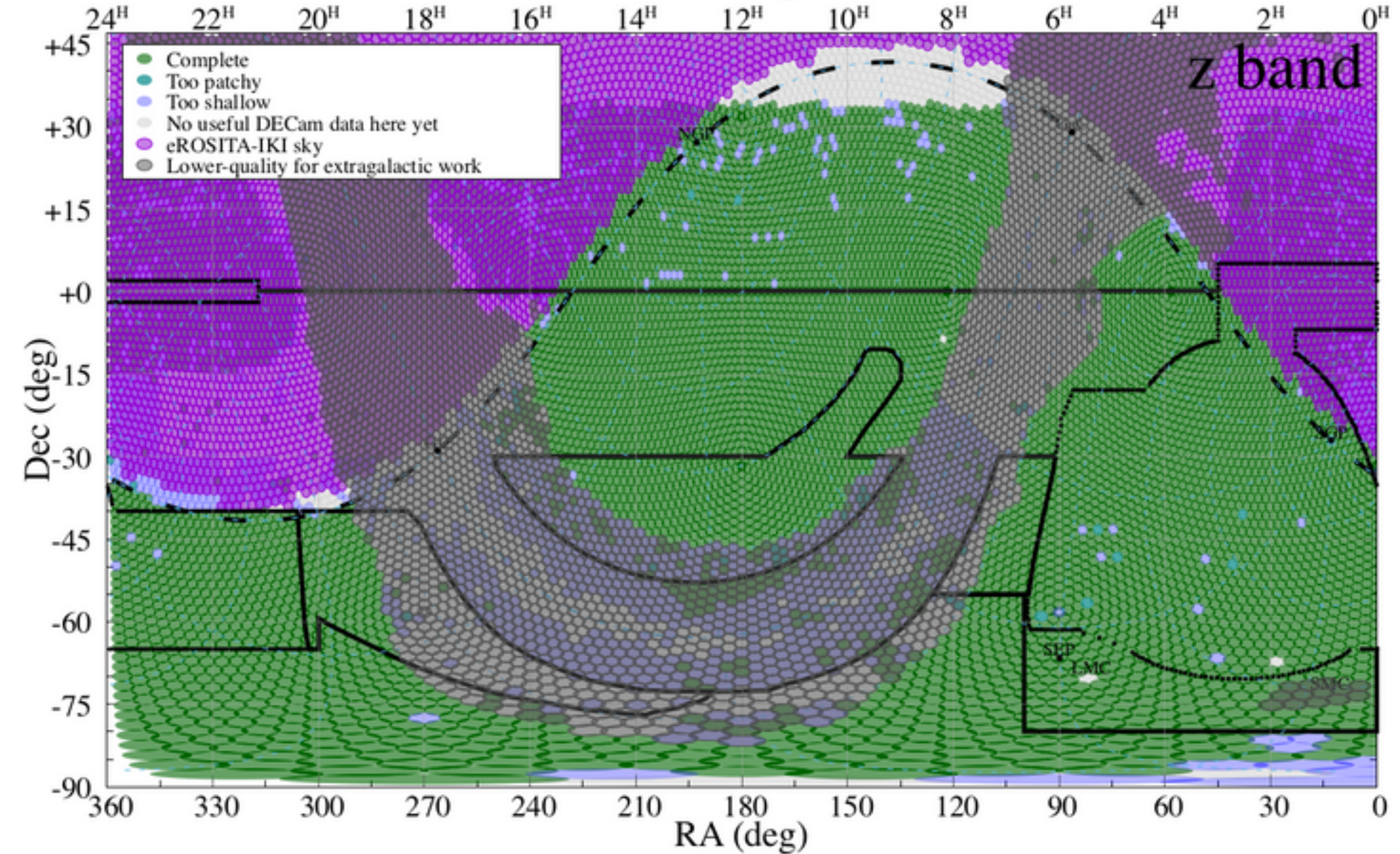
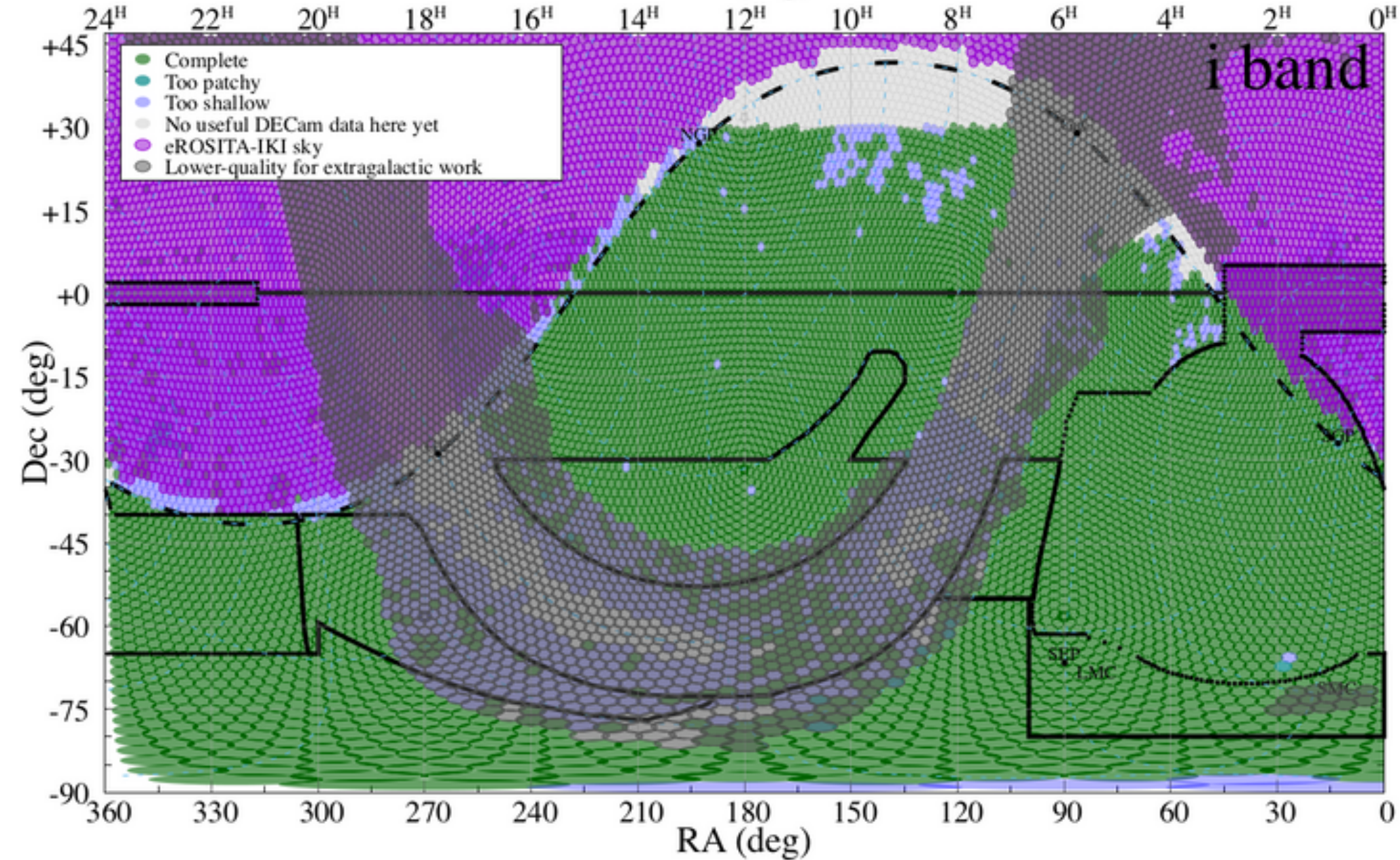
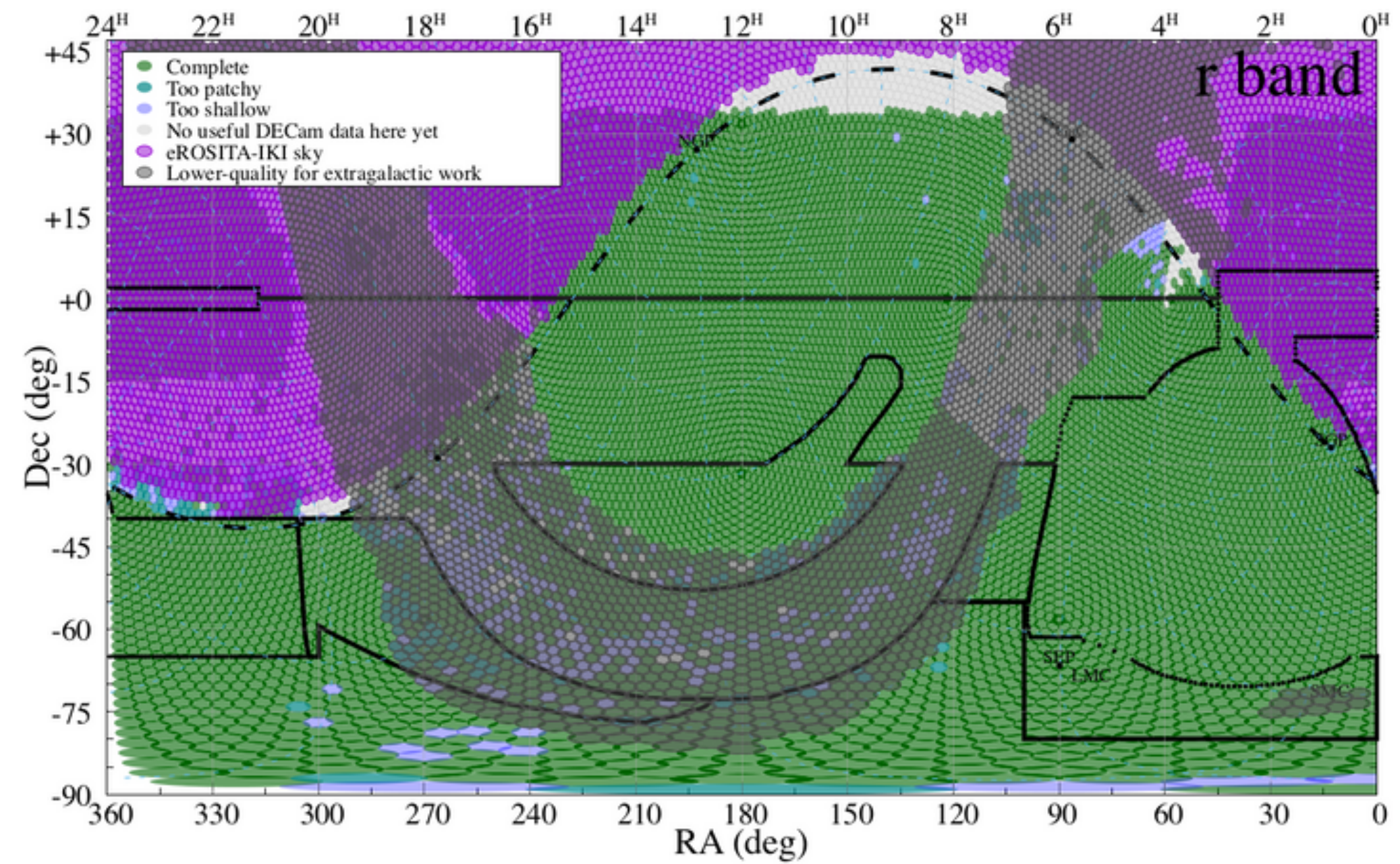
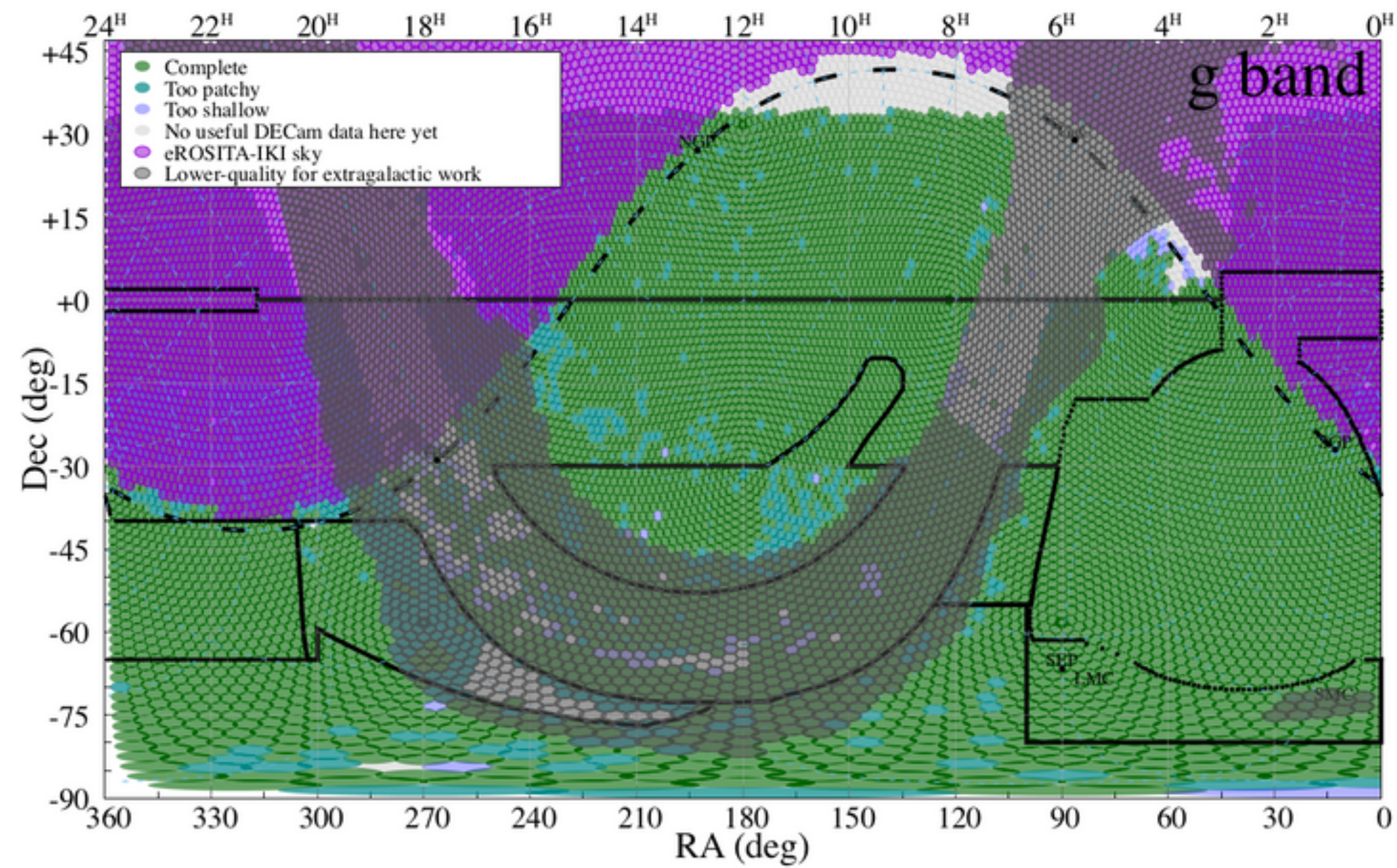
- 100+ observing nights; griz bands; major contribution to DECaLS DR10 i-band coverage
 - iz depths similar to those of DES Y3 data set
- Optimized for accurate galaxy cluster photometric redshifts ($z = 0-1$)
- Close coordination of observations with DELVE e.g., same sky tiling strategy



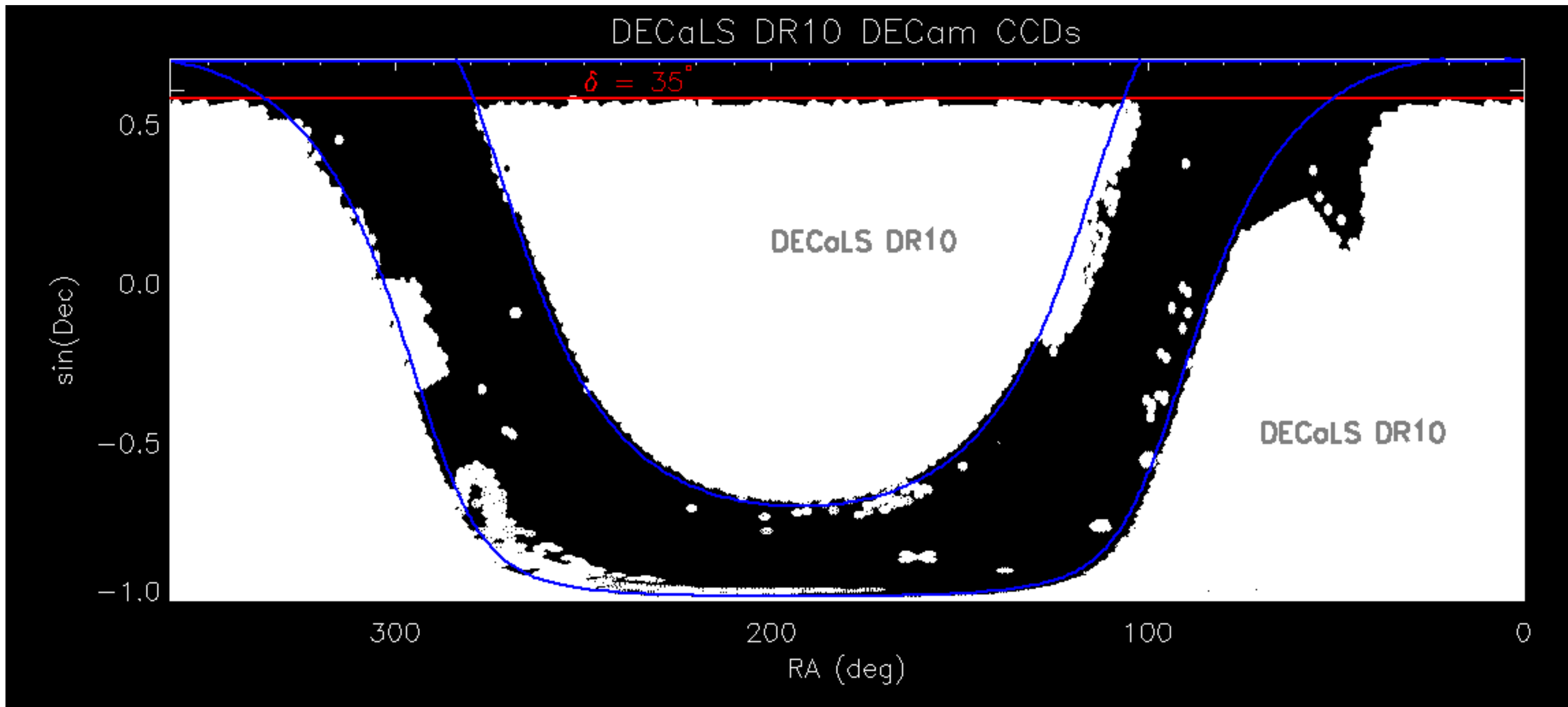
courtesy of Matthias Klein (2020+2021) $\sigma \sim 0.01 \times (1+z)$

DeROSITAS team: Alfredo Zenteno, Daniel Hernandez-Lang,
Jose Luis Nilo-Castellon, Mara Salvato, Patricia Arevalos, Héctor Cuevas, Rodrigo Carrasco,
Valeria Mesa, Amelia Ramirez++

DeROSITAS: helping DECam fill in the southern sky

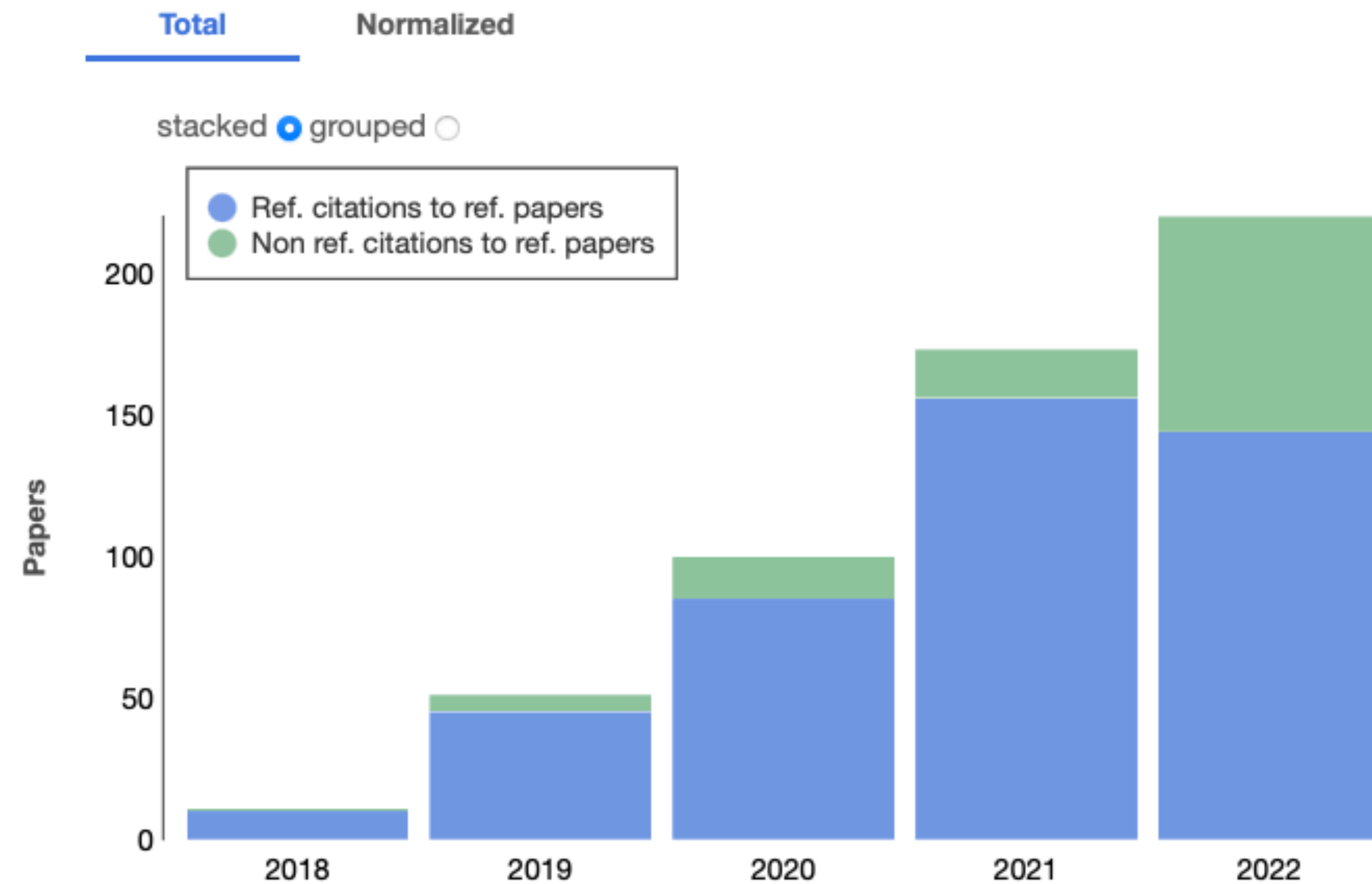


DR10 sky coverage



- 2.5 billion unique objects!
- Approximately 22,850 square degrees — more than half the sky.

DECaLS scientific impact























THE ASTRONOMICAL JOURNAL, 157:168 (29pp), 2019 May
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<https://doi.org/10.3847/1538-3881/ab089d>

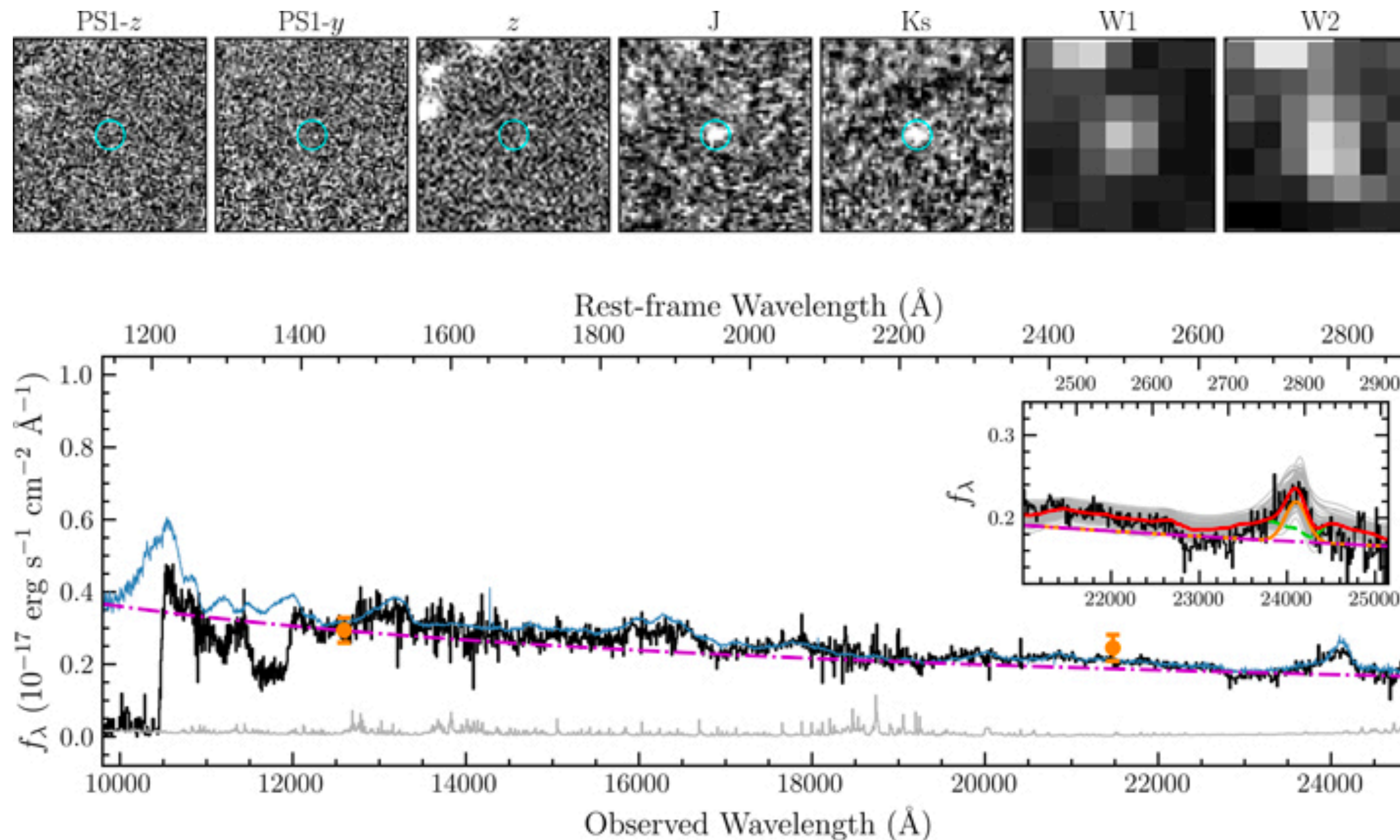


Overview of the DESI Legacy Imaging Surveys

Arjun Dey¹ , David J. Schlegel² , Dustin Lang^{3,5,4} , Robert Blum^{1,6} , Kaylan Burleigh², Xiaohui Fan⁷ , Joseph R. Findlay⁸,
 Doug Finkbeiner⁹ , David Herrera¹ , Stéphanie Juneau¹ , Martin Landriau² , Michael Levi² , Ian McGreer⁷ ,
 Aaron Meisner² , Adam D. Myers⁸, John Moustakas¹⁰ , Peter Nugent² , Anna Patej⁷, Edward F. Schlafly² ,
 Alistair R. Walker¹¹ , Francisco Valdes¹ , Benjamin A. Weaver¹, Christophe Yèche¹² , Hu Zou¹³ , Xu Zhou¹³ 

$z = 7.64$ quasar redshift record

supermassive black holes, reionization, early Universe

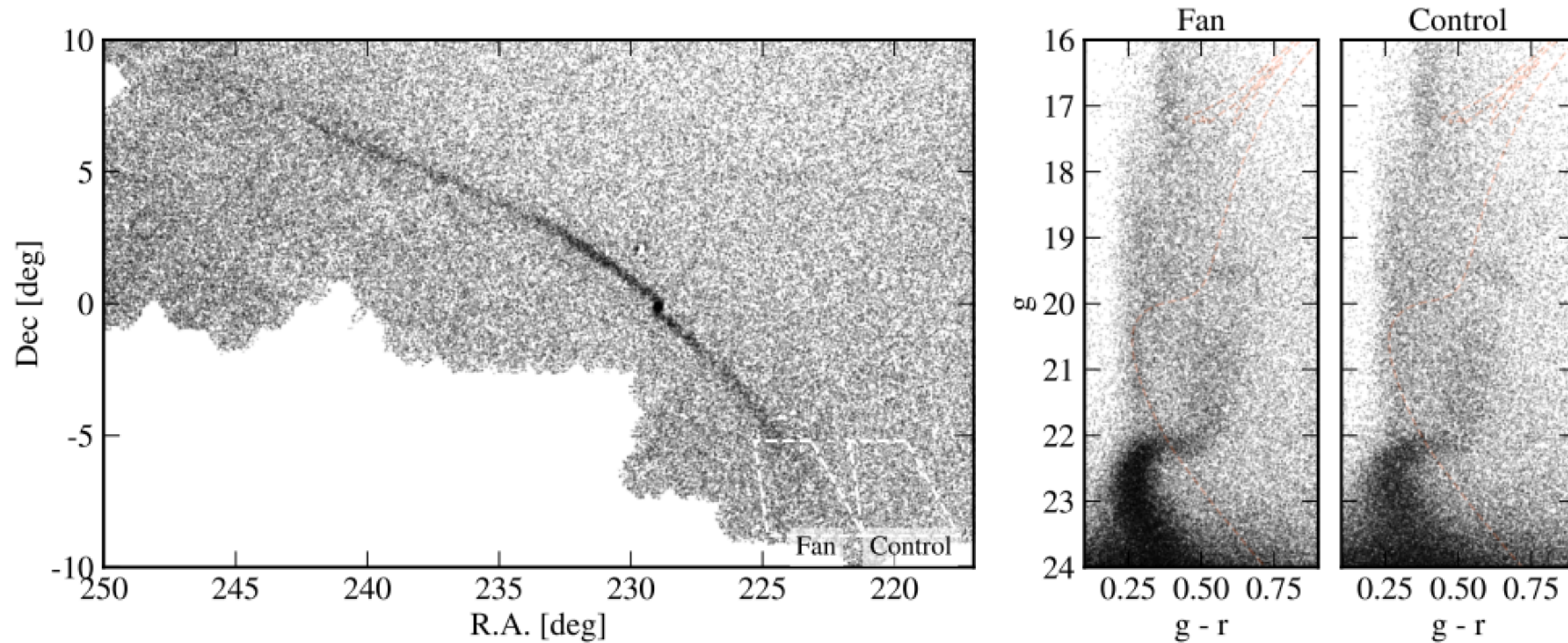


A Luminous Quasar at Redshift 7.642

Wang et al. 2021

exquisitely detailed portrait of Pal 5 stream

Milky Way, stellar streams, dark matter



Variations in the Width, Density, and Direction of the Palomar 5 Tidal Tails

Bonaca et al. 2020

Pegasus V dwarf — at Dec = 33.5° !

local group, dwarf galaxies, galaxy formation

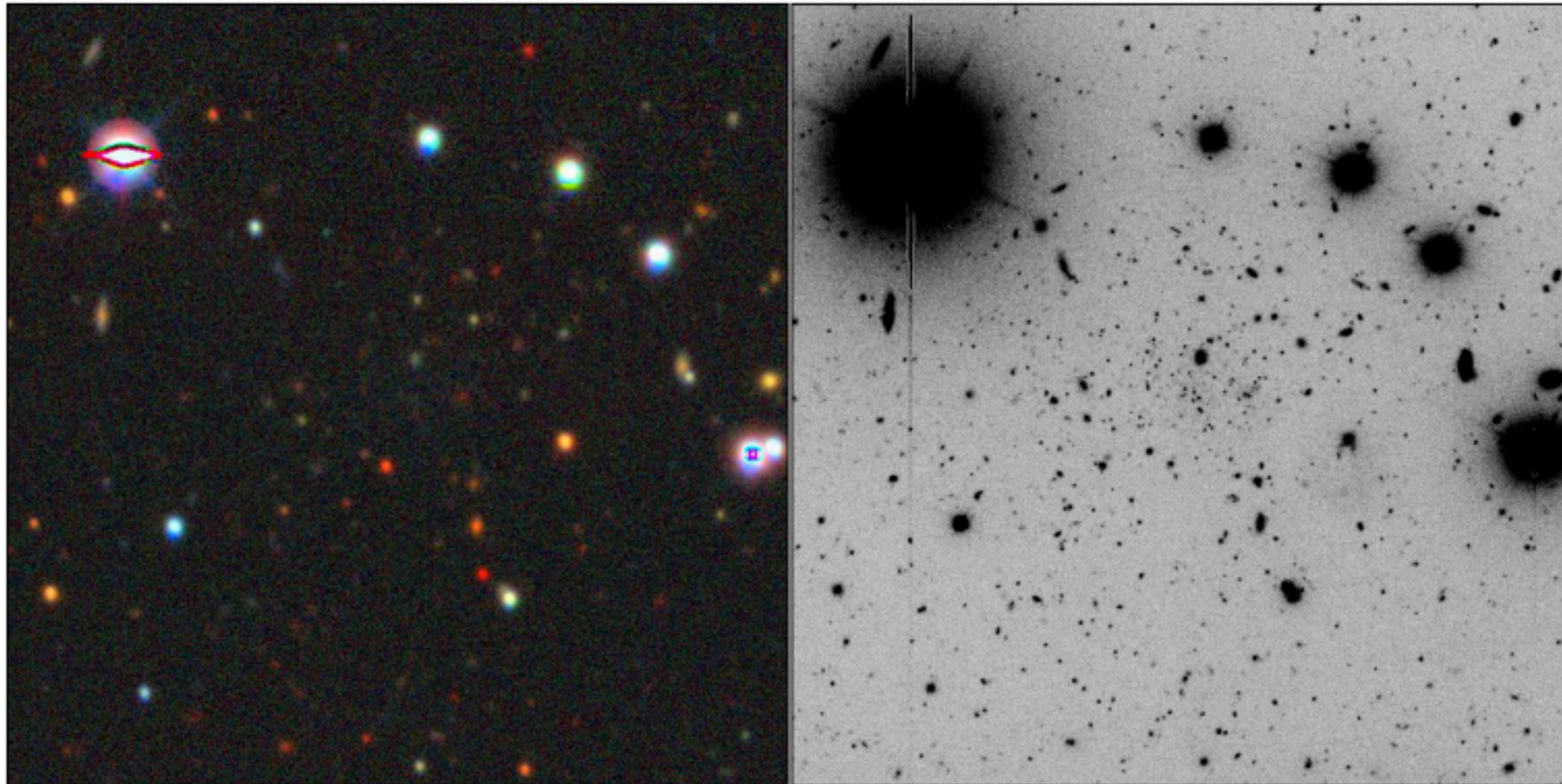


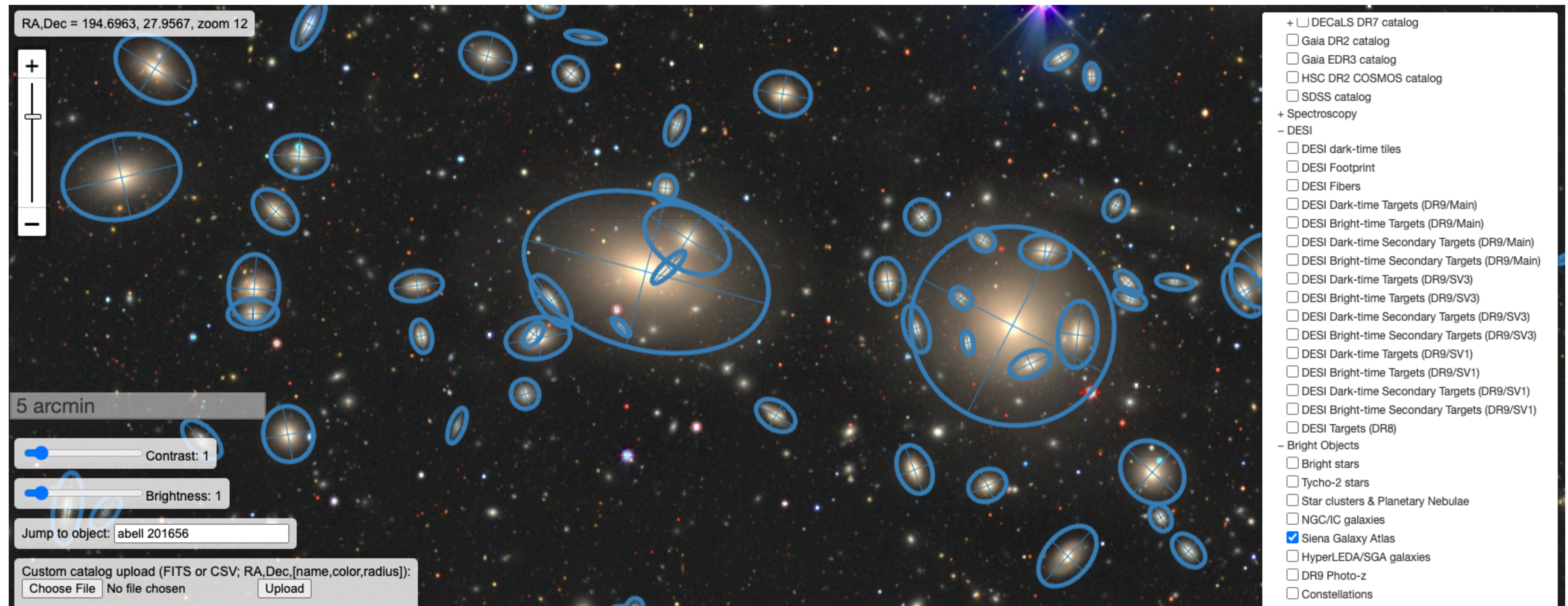
Figure 1. *Left panel:* Image of the dwarf galaxy Peg V from the DESI Legacy Imaging Survey. *Right panel:* Gemini/GMOS-N combined g - and r -band image of the galaxy obtained from Gemini follow-up observations (see Sec. 2). North is up, East is left. In both images, the field of view is $150'' \times 150''$.

Pegasus V - a newly discovered ultra-faint dwarf galaxy on the outskirts of Andromeda

Collins et al. 2022

Siena Galaxy Atlas (SGA)

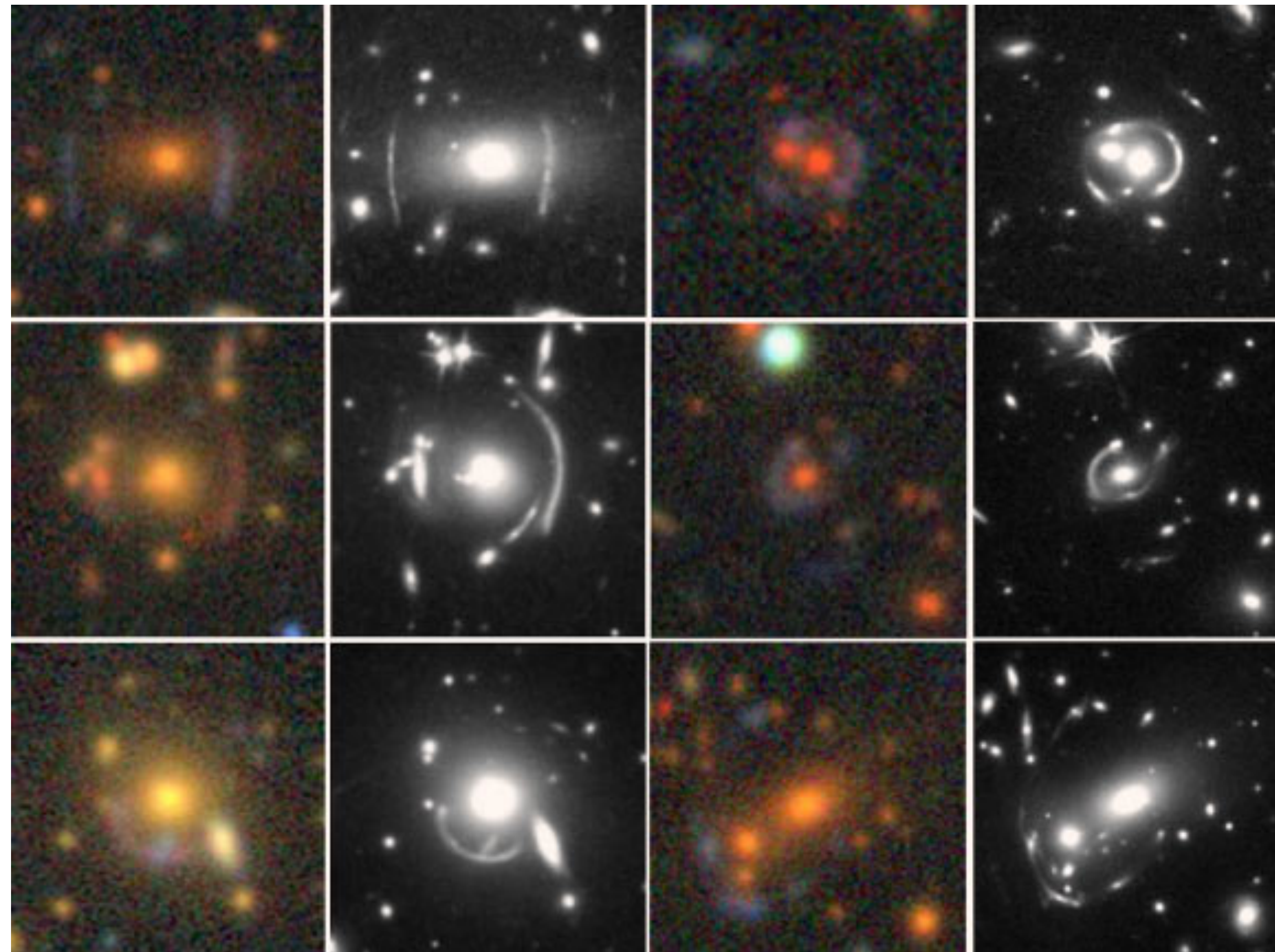
John Moustakas, Dustin Lang et al.



- 383,620 nearby galaxies, based in large part on DECaLS data products
- More details in the following talk by Stephanie Juneau!

thousands of newly discovered strong lenses

cosmology, dark matter, machine learning



“NeuraLens”
deep learning discovery engine

<https://sites.google.com/usfca.edu/neuralens>

Finding Strong Gravitational Lenses in the DESI DECam Legacy Survey

Huang et al. 2020, 2021, 2022

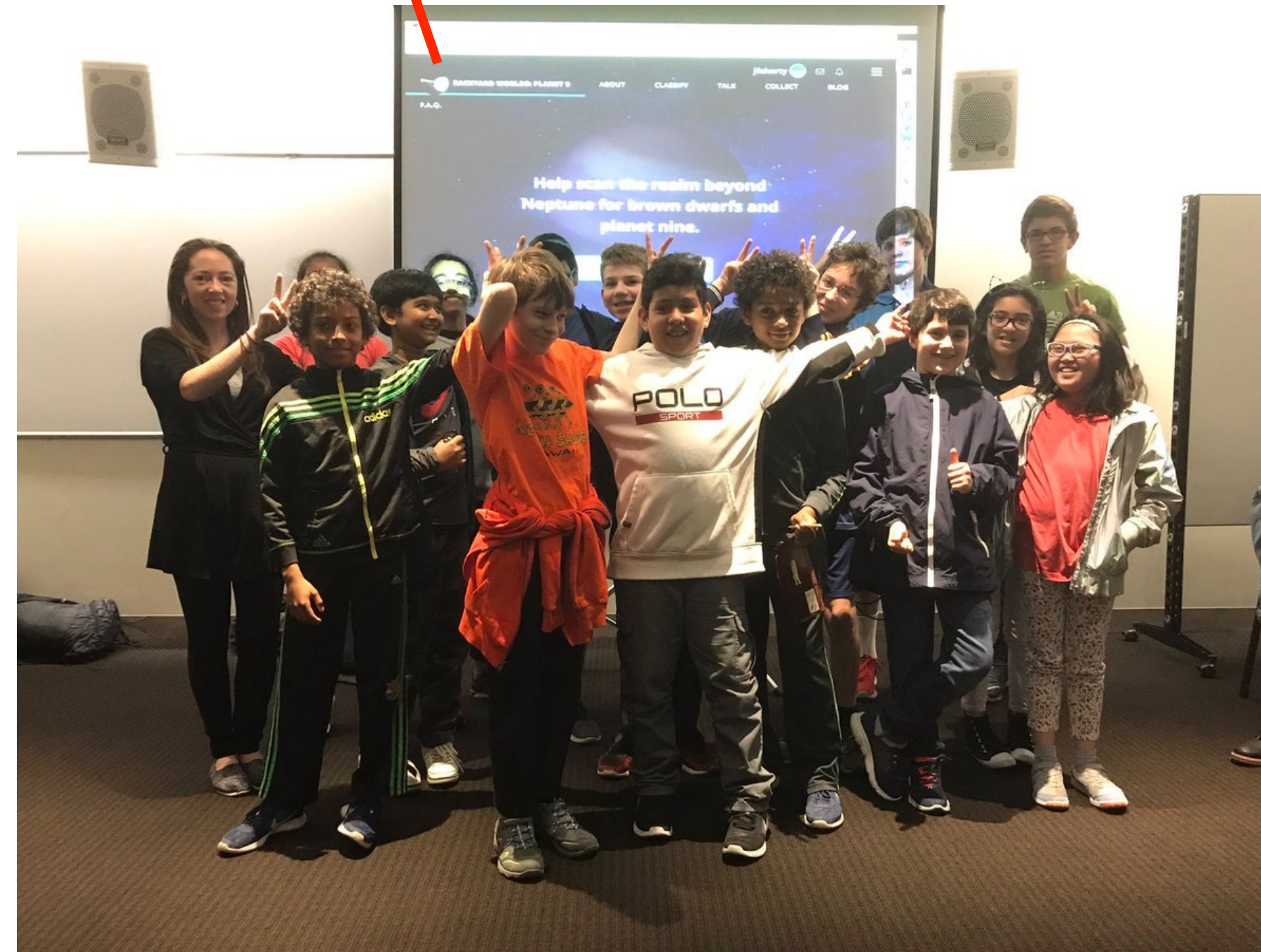
DESI Legacy Imaging Surveys broader impacts

DESI imaging unWISE coadd

Backyard Worlds citizen science project web interface



Mr. Blake's 6th grade class
Brampton, Ontario

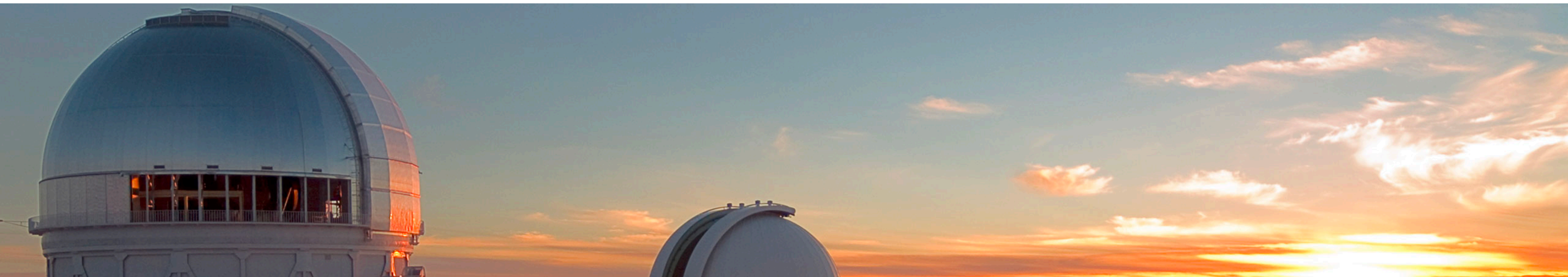


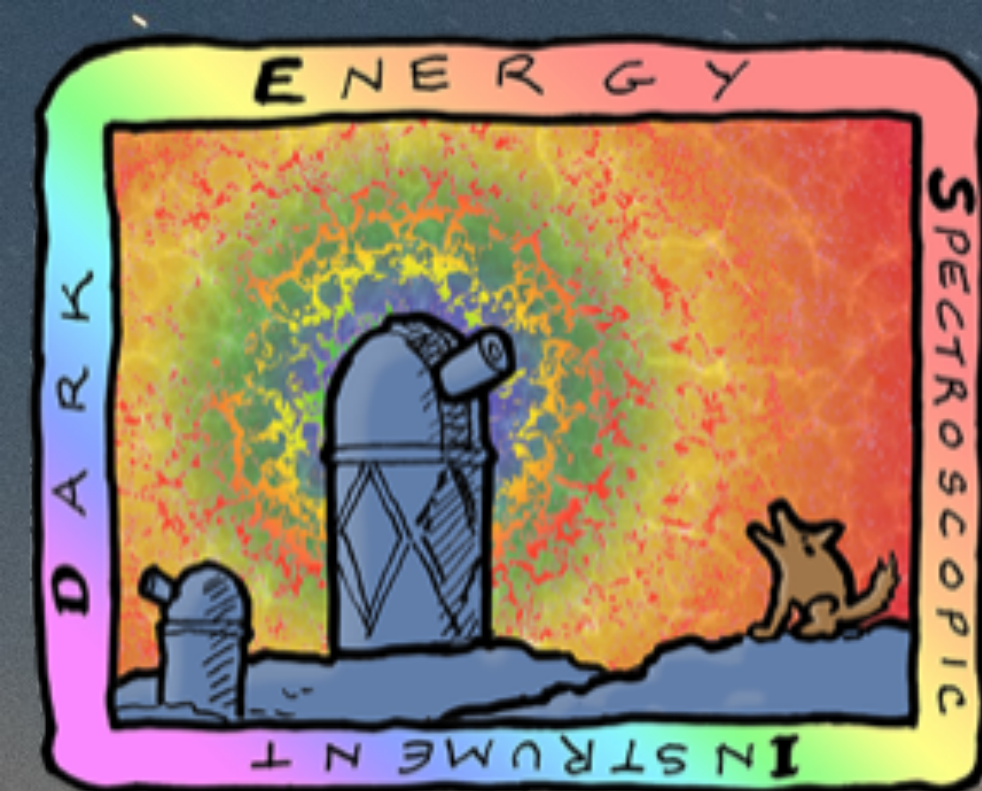
World Science Fest
New York, New York

DESI imaging 'open data' practices have allowed us to reach a broad audience, including hundreds of thousands of members of the general public.

DECaLS: future outlook

- Potential upgrades for future DECaLS releases
 - Include more recent DECam observations (2021 September onward)
 - Even more NEOWISE sky passes
 - 2021 onward, at least 2.5 more years compared to DR10
 - Include Y band?
 - Narrow-band filters?
 - Pad out DR9/DESI footprint to allow increased DESI spectroscopic sky coverage?





DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science



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