

# DESI Imaging Legacy Surveys

Martin Landriau  
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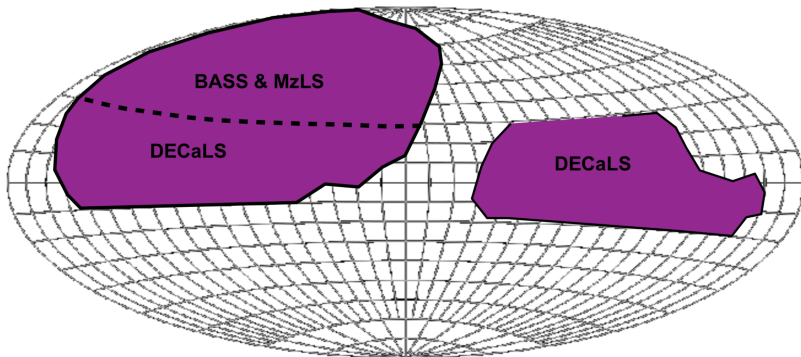
Dark Energy Spectroscopic Instrument  
U.S. Department of Energy Office of Science  
Lawrence Berkeley National Laboratory

# Introduction

- The Dark Energy Spectroscopic Instrument will map 25M galaxies and quasars out to  $z = 3.5$  over 14000 deg<sup>2</sup> of sky.
- The purpose of the imaging surveys is to provide data from which to select targets for DESI.
- Three ground based optical surveys, whose combined footprint matches the DESI footprint, are underway or completed:
  - ▶ DECam Legacy Survey (DECaLS):  $g$ ,  $r$  and  $z$  bands using the Blanco telescope at CTIO
  - ▶ Mosaic  $z$ -band Legacy Survey (MzLS):  $z$  band using the Mayall telescope at KPNO
  - ▶ Beijing-Arizona Sky Survey (BASS):  $g$  and  $r$  band using the Bok telescope at KPNO
- In addition, the WISE satellite is providing near infrared all-sky coverage in two bands ( $3.5\mu\text{m}$  and  $4.6\mu\text{m}$ ).



# Introduction (cont'd)



# Goal of the imaging surveys

The imaging surveys will be used to select targets for DESI. To this end, they will provide the following prior to the start of DESI in 2019:

- Imaging in  $g$ ,  $r$  and  $z$ -bands covering the  $14000 \text{ deg}^2$  of the DESI footprint
- The tractor code to produce catalogs meeting targeting requirements
- Depth maps
- Ability to Monte Carlo fake sources through the imaging pipeline



# The team

- The Legacy Surveys core team consists of (in alphabetical order): Bob Blum, Kaylan Burleigh, Arjun Dey, Joe Findlay, Doug Finkbeiner, David Herrera, Stéphanie Juneau, Martin Landriau, Dustin Lang, Ian McGreer, Aaron Meisner, John Moustakas, Adam Myers, Eddie Schlafly, David Schlegel, Frank Valdes, Alistair Walker, Ben Weaver, Jinyi Yang and Christophe Yèche.
- More than 100 observers, many of whom are not DESI collaboration members.



# Methodology

- Image level raw data from the three telescopes are currently processed at NOAO using the community pipeline (CP):
  - ▶ Bias subtraction
  - ▶ Flat fielding
  - ▶ Bleed trail and cosmic ray removal
- Both raw and CP-processed images (publicly accessible immediately through the NOAO data archive) are copied at NERSC (DoE supercomputing facility at LBNL) where they are coadded, and catalogues generated using the tractor code (details next slide).
- Final data release products are copied to NOAO.
- Data accessible from NERSC or through NOAO database and is released to the public at the same time as to the DESI collaboration.

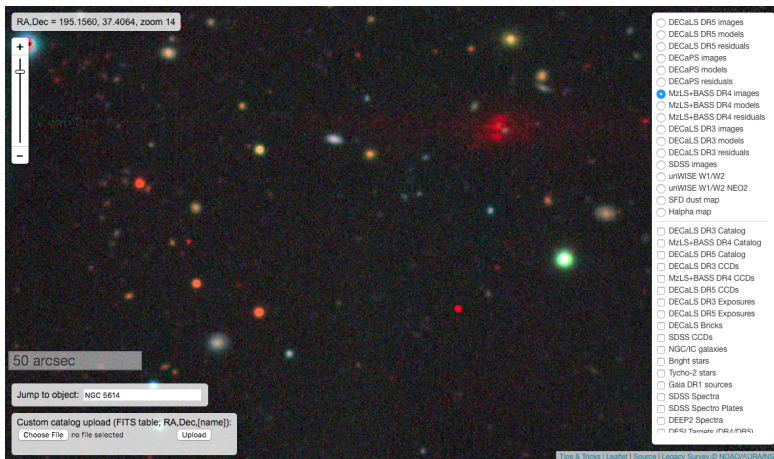


The open source tractor code implements a novel algorithm to generate source catalogues

- Sky split into  $0.25^\circ \times 0.25^\circ$  bricks
- Forward-modeling for source-identification + measurements is designed to make use of the diversity of the imaging data, e.g. the 1" and 2" optical PSF and the 6" infrared PSF
- Operates on the individual epoch images, where errors are uncorrelated
- $g$ ,  $r$  and  $z$ -band images are fit simultaneously (when available)
- WISE data is fit post-facto using forced photometry
- Allows us to get the morphology right even when using one band has better seeing than the other two in the MzLS / BASS region



# Raw image v. tractor model

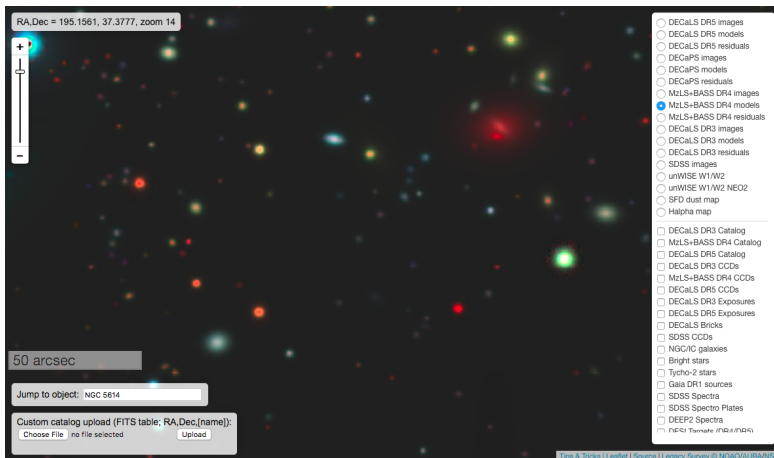


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M. Landriau  
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# Raw image v. tractor model



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# Legacysurvey code

The Legacy Survey code base, used to process the CP-processed images is open source. This includes the following packages:

- `legacypipe` Main work engine for the tractor processing as well as post-processing tools, including summary plots, e.g. some of those shown in this presentation.
- `legacyzpts` To compute zeropoints (aperture or PSF-normalized).
- `obsbot` Code that plans subsequent observations for Mosaic 3 and DECam.
- `obiwan` Fake source injection code.



# Computing resources

- Our last three data releases (DR4, DR5 and DR6) take up 30.5TB, 19.5TB and 10TB of disk space, respectively. The drop in usage from DR5 onwards is due to the implementation of a more aggressive compression scheme.
- These three DRs used 280k, 1.6M and 1M CPU hours at NERSC, respectively.
- We project that to complete the imaging surveys and their processing will require an extra 325TB (including space for raw data) and 15M CPU hours.



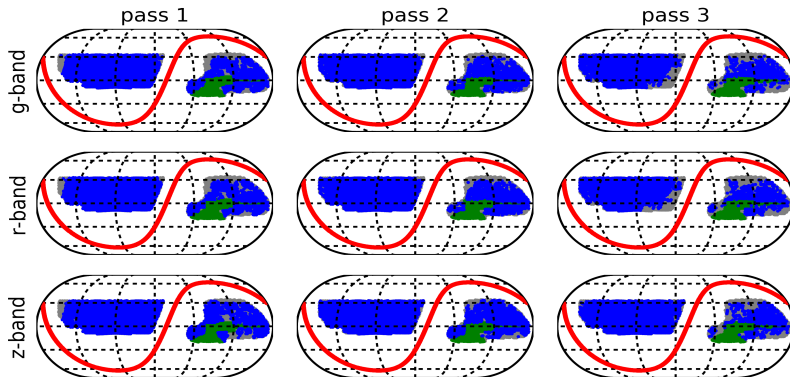
# Survey operations

- All three ground-based surveys observe the sky in three passes:
  - ▶ Pass 1: Photometric conditions and good seeing.
  - ▶ Pass 2: Photometric conditions or good seeing.
  - ▶ Pass 3: Neither photometric conditions nor good seeing, but overall acceptable condition.
- Exposure time is adjusted in real-time for conditions (with 1-2 exposures' delay).



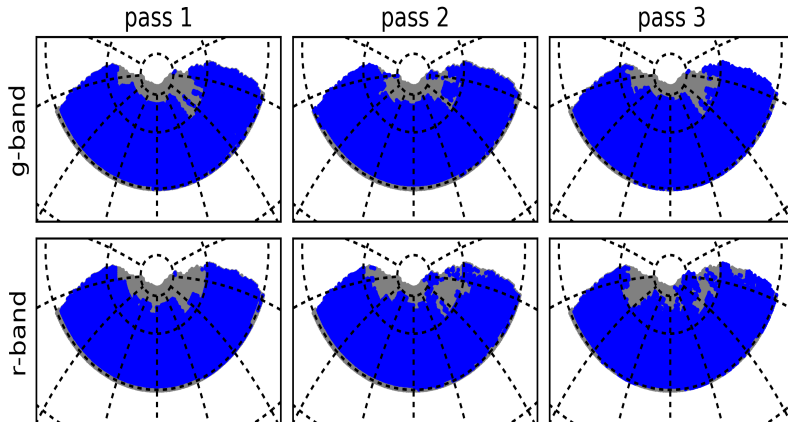
# Status

- DECaLS is expected to complete by January 2019 and is (as of 18 May 2018)
  - ▶ 89.6% complete in the NGC
  - ▶ 49.2% complete in the SGC



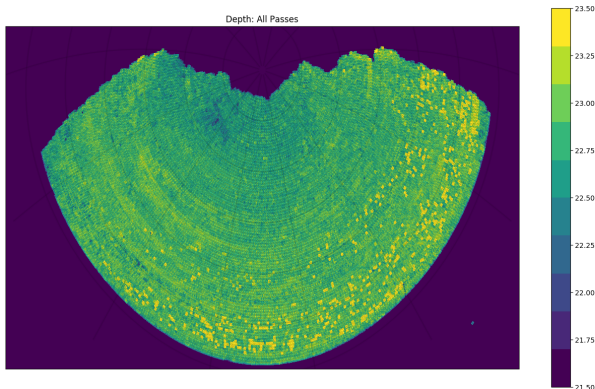
# Status (cont'd)

- BASS is 86.6% complete as of 20 May 2018 and is expected to finish by August 2018.



# Status (cont'd)

- MzLS is 100% complete as of 31 January 2018.



- WISE is 125% complete for our purposes.



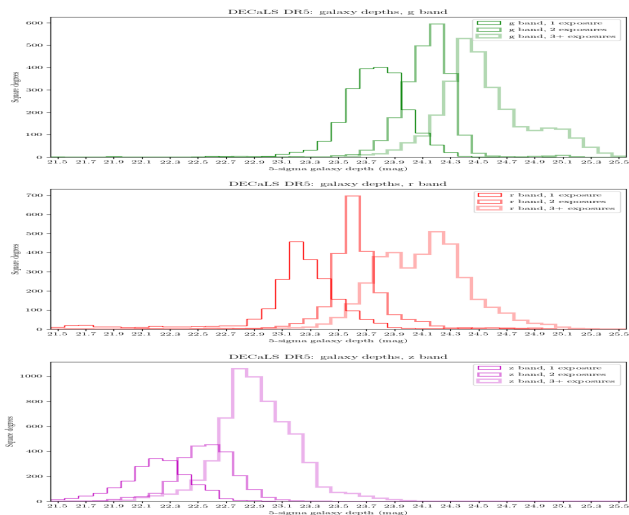
# Data releases

- DR1: DECaLS through December 2014, WISE original mission data; 19 May 2015.
- DR2: DECaLS through June 2015, NEOWISE-r year 1; 22 January 2016.
- DR3: DECaLS through March 2016; 17 October 2016.
- DR4: BASS + MzLS through July 2016, GAIA DR1 astrometry, NEOWISE-r year 2; 30 June 2017.
- DR5: DECaLS through May 2017; 26 October 2017.
- DR6: BASS + MzLS through July 2017, NEOWISE-r year 3; 26 February 2018.





# DR5 (DECaLS) depths



# DR6 (BASS+MzLS) depths



- We are currently preparing our 7th data release.
- It will be comprised of all the DECaLS data up the end of March 2018.
- It will be the data used when we first go on sky with the commissioning instrument.
- Notable changes from previous DRs:
  - ▶ Will use Gaia DR2 (1 DR ahead of schedule)
  - ▶ Will use NEOWISE-r year 4 (1 year beyond what was planned)



# Future data releases

- The current plan is to have two more data releases, both of which will comprise of the data from all three ground-based surveys.
- DR8 (early 2019) will have all of BASS+MzLS and most of DECaLS and will be used for DESI science validation.
- DR9 (mid 2019) will be the final data release and contain all our data and will be used for final DESI target selection.



# Summary

- DECaLS is one of three ground based imaging surveys that will be the basis for DESI target selection.
- Imaging surveys are progressing well and are expected to complete on time:
  - ▶ MzLS: 100%
  - ▶ BASS: 86.6%
  - ▶ DECaLS: 89.6% / 49.2% (NGC / SGC)
  - ▶ WISE: 125%
- Data reduction plan and releases have been successful:
  - ▶ DR1-6 completed and DR7 is underway.
  - ▶ Final release (DR9) prior to DESI survey start in 2019.
- Raw and processed data as well as our code are publicly available without any proprietary period.



# Links

- Legacy Survey website: [legacysurvey.org](http://legacysurvey.org)
- Legacy Survey data @ NERSC Portal:  
[portal.nersc.gov/project/cosmo/data/legacysurvey](http://portal.nersc.gov/project/cosmo/data/legacysurvey)
- Legacy Survey data @ NOAO Data Lab:  
[datalab.noao.edu/decals/ls.php](http://datalab.noao.edu/decals/ls.php)
- Legacy Survey code base: [github.com/legacysurvey](https://github.com/legacysurvey)
- Tractor: [github.com/dstndstn/tractor](https://github.com/dstndstn/tractor)

