DARK ENERGY SURVEY

FERMILAB-SLIDES-18-115-AE

Calibrating the Dark Energy Survey: The Role of DA White Dwarfs

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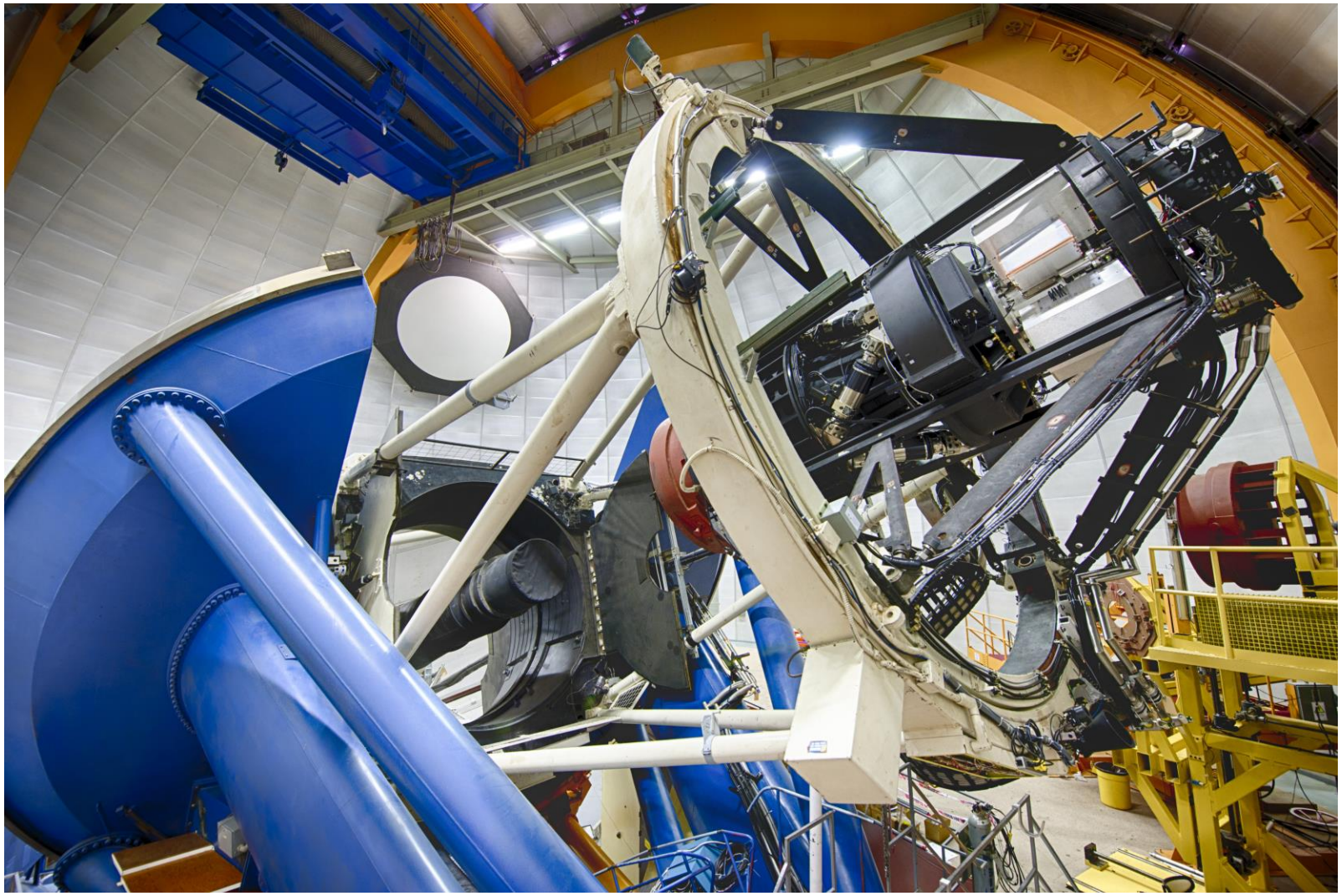
SURVEY

Blanco + DECam



Ancillary Hardware

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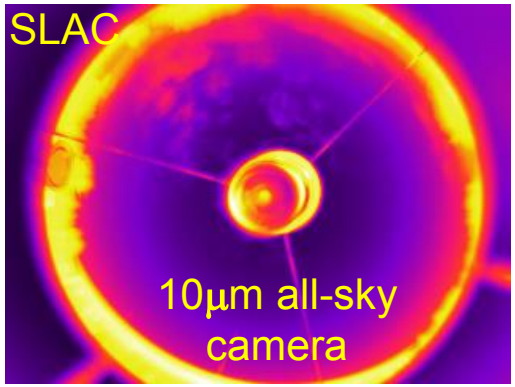
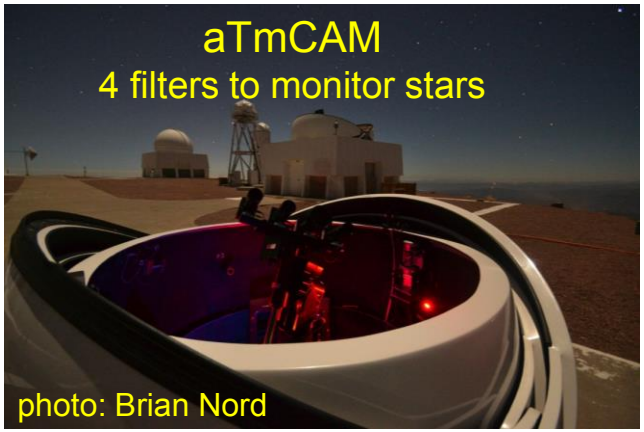
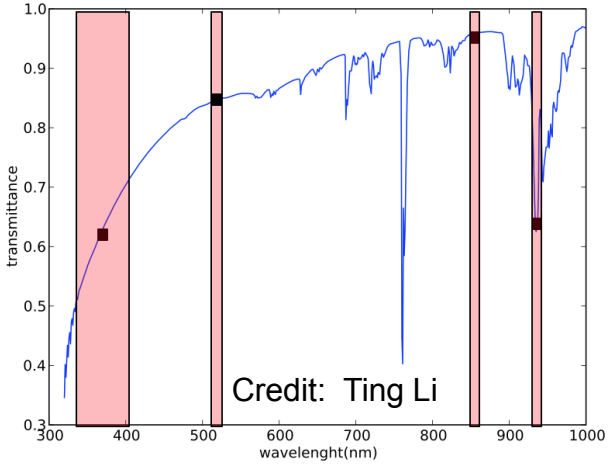
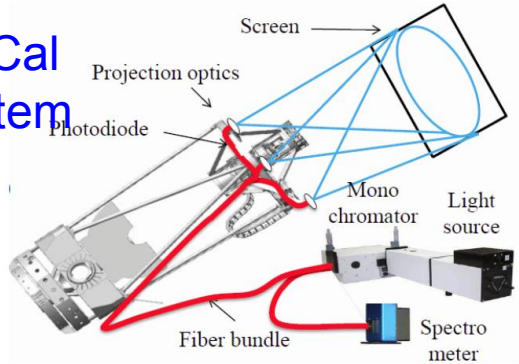


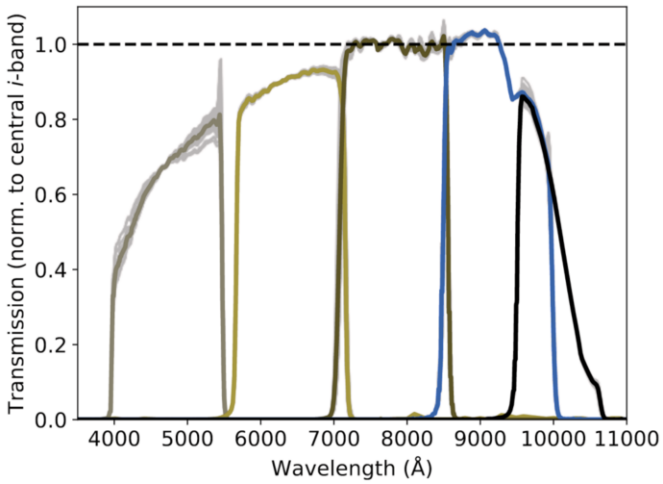


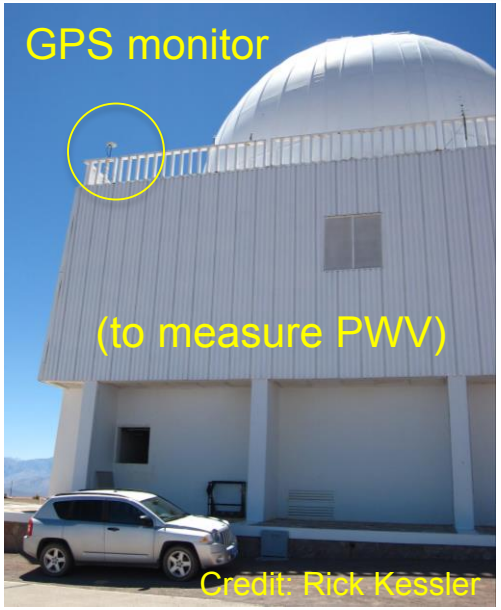


DECal system



Marshall et al. 2013





Slide Credit: William Wester

The Dark Energy Survey (DES)

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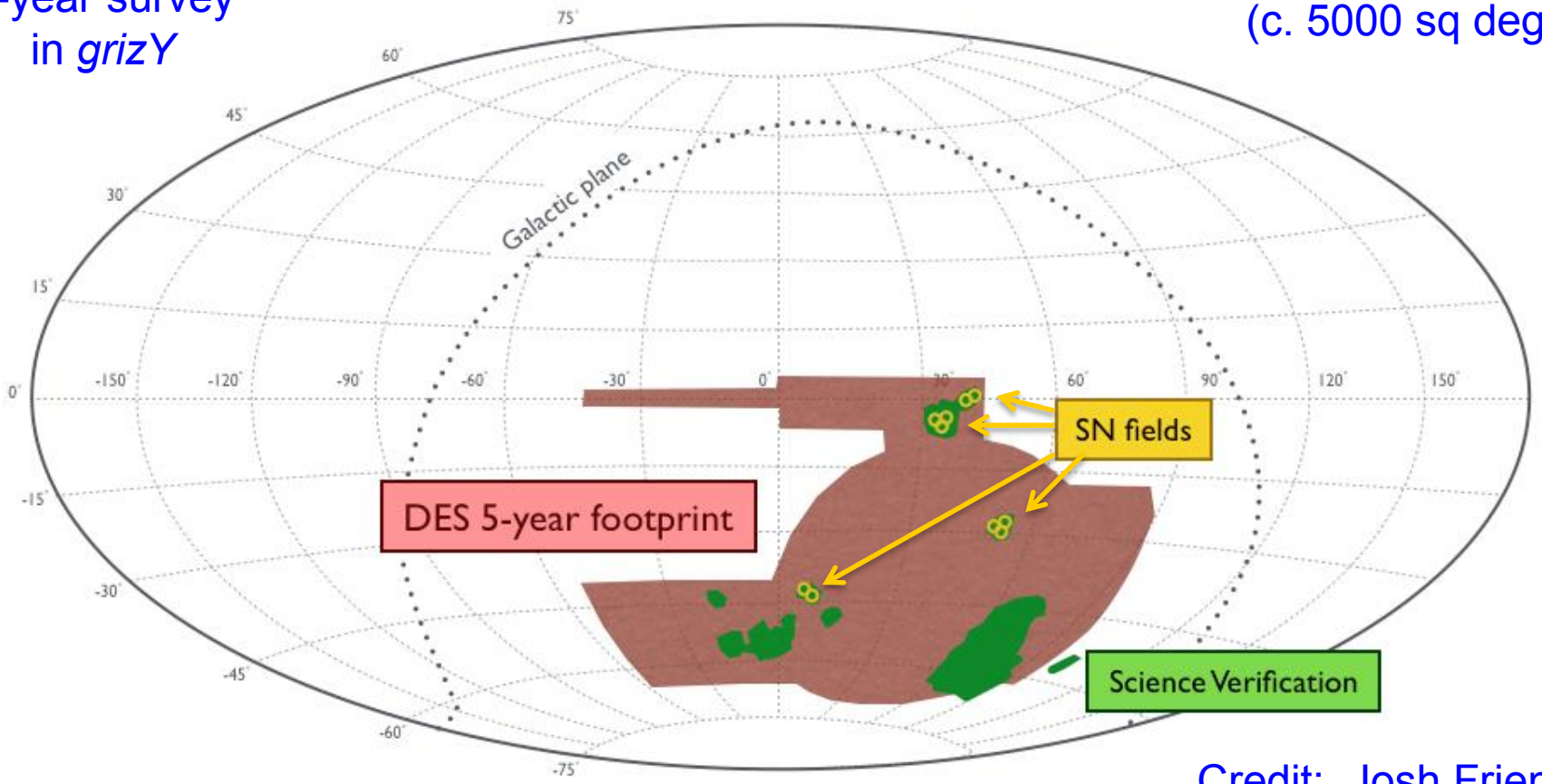
5-year survey in *grizY*

¼ of southern sky (c. 5000 sq deg)



Credit: Josh Frieman

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Photometry

DES Photometric Calibration Requirements* (5-year, coadded)

*From DES Scientific Requirements Document

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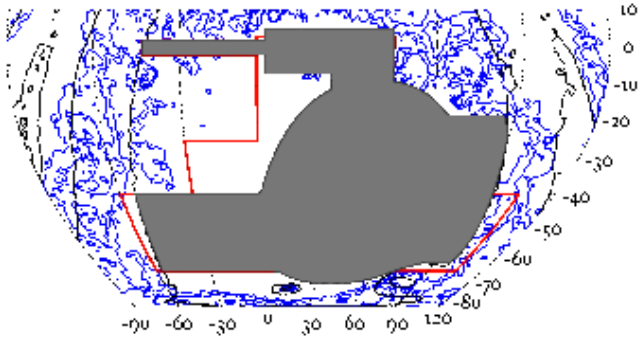
1. **Internal:** 2% rms on scales of 0.05º- 4º.

   Goals: 1% rms and/or over 160º in RA, 30º in DEC.

   → angular galaxy clustering

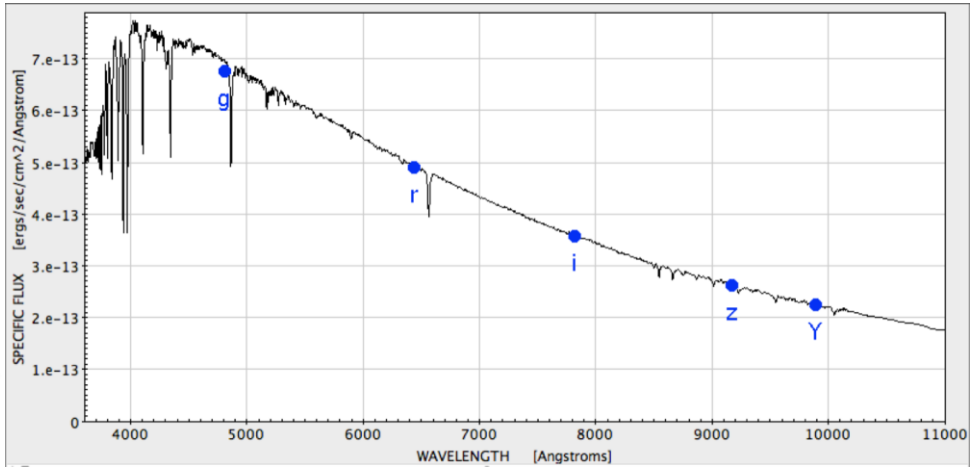


2. **Absolute Color:** 0.5% (*g-r, r-i, i-z*); 1% (*z-Y*).

   "Between-filters" calibration.

   Photometry as a "low-res. spectrum"

   → photo-z's, SNe k-corrections



3. **Absolute Flux:** 0.5% in *i*-band.

   Relative to standard star ~~BD+17 4708~~ C26202.

   Zeropointing the overall filter system.

   → comparison with other surveys (esp. for SNe)

Many parts to calibration

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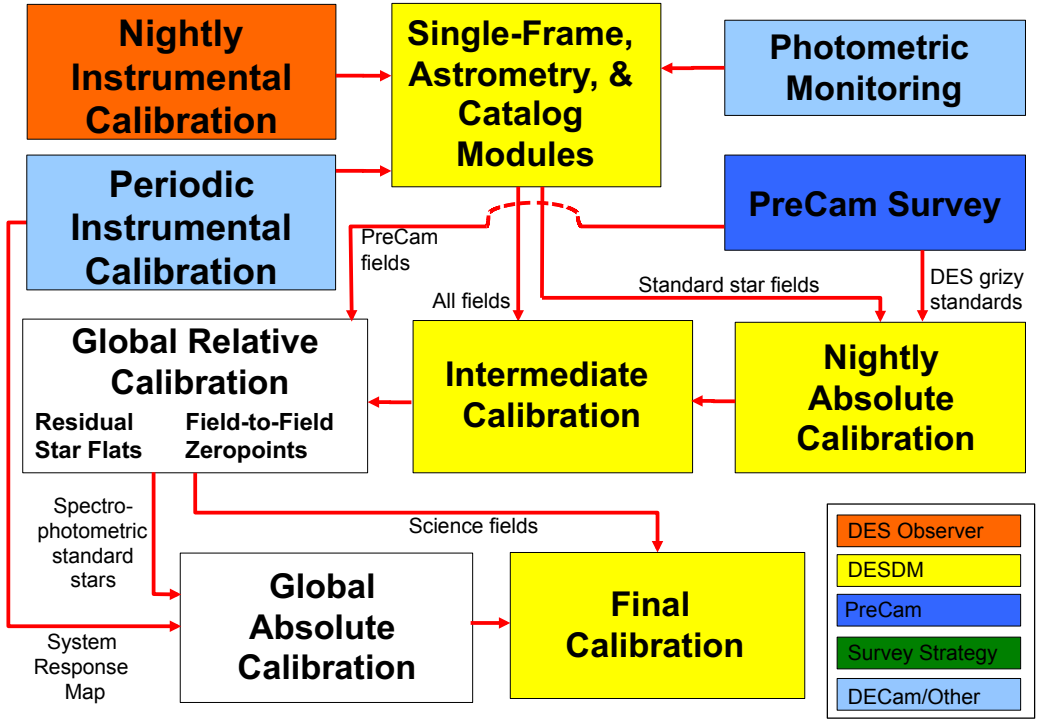
DES Photometric Calibrations Flow Diagram (v4.1)



Credit: Douglas Tucker

- Nightly
  - Bias, darks, flat fields
- Periodic
  - Spectral scanning
  - Transfer function
  - Star flats
- Monitoring
  - Atmosphere aTmCAM / GPS
  - Cloud cover
- Absolute scale
  - White Dwarf
  - CALSPEC standards

DES Photometry: SV, Y1, (Y3)

PGCM

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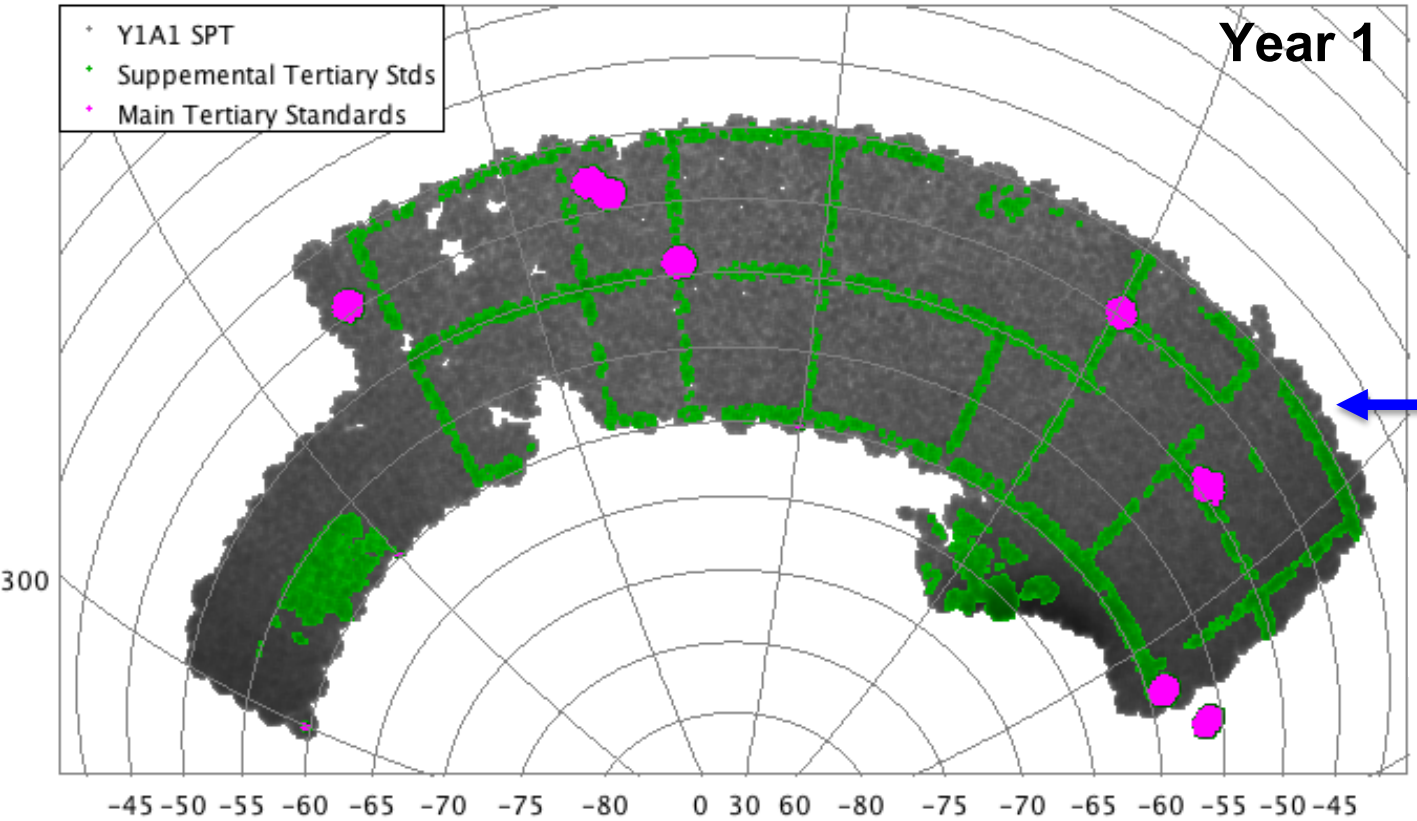
- **Photometric Global Calibration Module (PGCM)**
  - Observe nightly standards to create a sparse gridwork of tertiary standards.
  - Use overlapping exposures to tie DES photometry to tertiary network.



For DES Year 1, each part of the covered footprint had 3-4 overlapping exposures in each band.

DES Photometry: SV, Y1, (Y3)

PGCM

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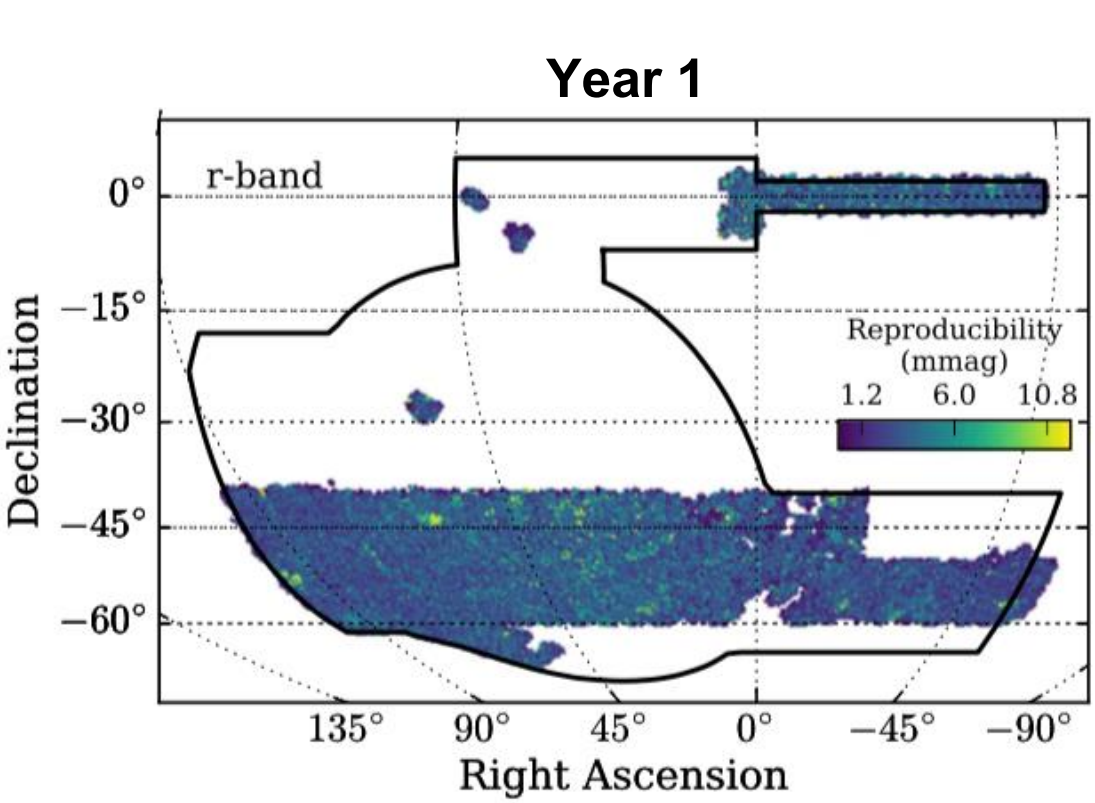
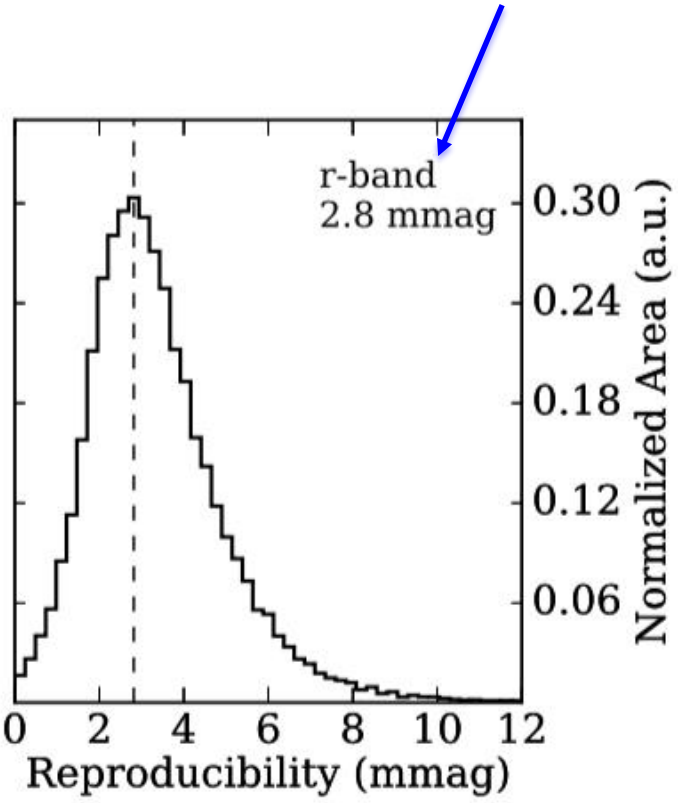
Internal Photometric Reproducibility (overlapping CCDs): c. 3 mmag

Year 1





Drlica-Wagner et al. 2018, ApJS, 235, 33 (Y1A1-Gold paper)

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Photometric Equation

$$m_{inst} - m_{std} = a_n + b_n \times (stdColor - stdColor_0) + kX$$

Credit: Douglas Tucker

- m_{inst} is the instrumental magnitude, $m_{inst} = -2.5log(counts/sec)$ (input)
- m_{std} is the standard ("true") magnitude of the standard star (input)
- a_n is the photometric zeropoint for CCD n (n = 1-62) (output)
- k is the first-order extinction (input/output)
- X is the airmass (input)
- b_n is the instrumental color term coefficient for CCD n (n = 1-62) (input/output)
- $stdColor$ is a color index, e.g., $(g-r)$ (input)
- $stdColor_0$ is a constant (a fixed reference value for that passband) (input)
- DES calibrations will be in the DECam natural system, but there may be variations from CCD to CCD within the DECam focal plane or over time.

a_n: Zeropoints and uncertainty as a function of exposure and CCD number

General Idea for Absolute Calibration with DA WDs

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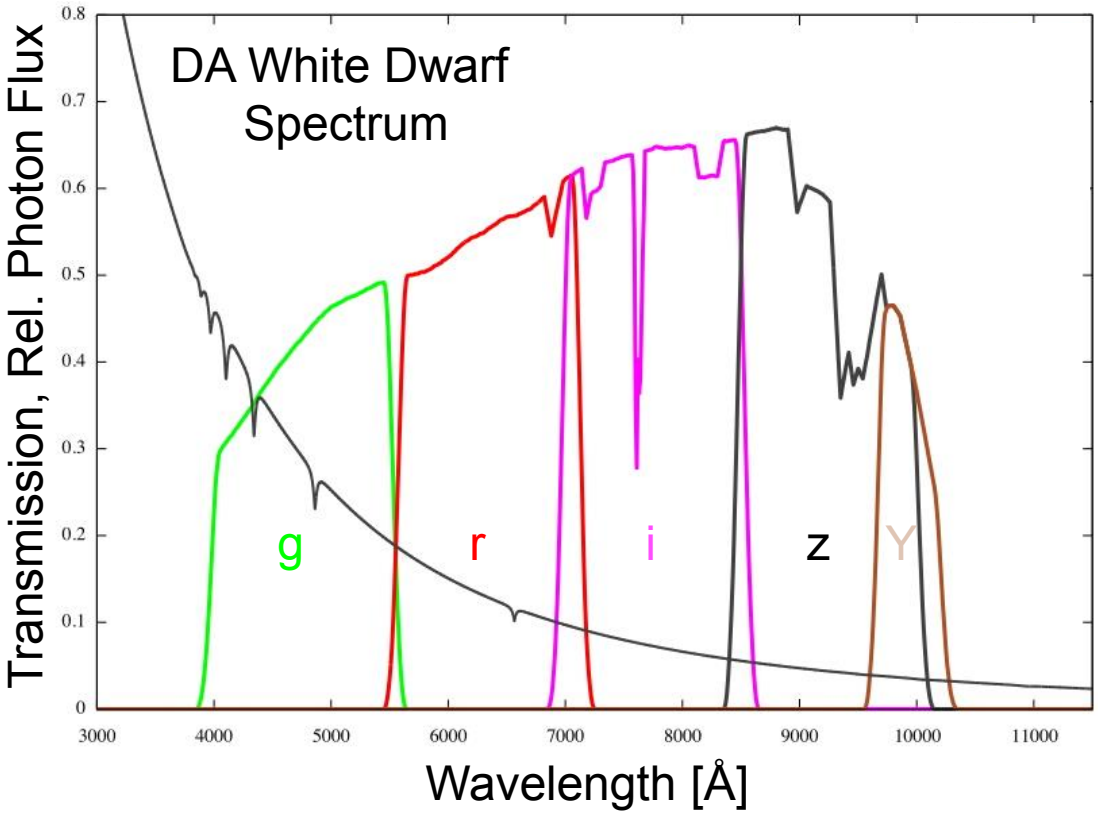
- Compare the synthetic magnitudes to the measured magnitudes of one or more DA WDs observed by the DECam.
- The differences are the zeropoint offsets needed to tie the DES mags to an absolute flux in physical units (e.g., ergs s^{-1} cm^{-2} $Å^{-1}$).
- For the synthetic photometry, the fit *model* spectra of the white dwarfs are generally used.



Plan: establish a "Golden Sample" of 30-100 well-calibrated DA white dwarfs across the DES footprint.

Status: been collecting data since 2012.

FGCM Absolute Calibration

(also relevant to other calibration methods)

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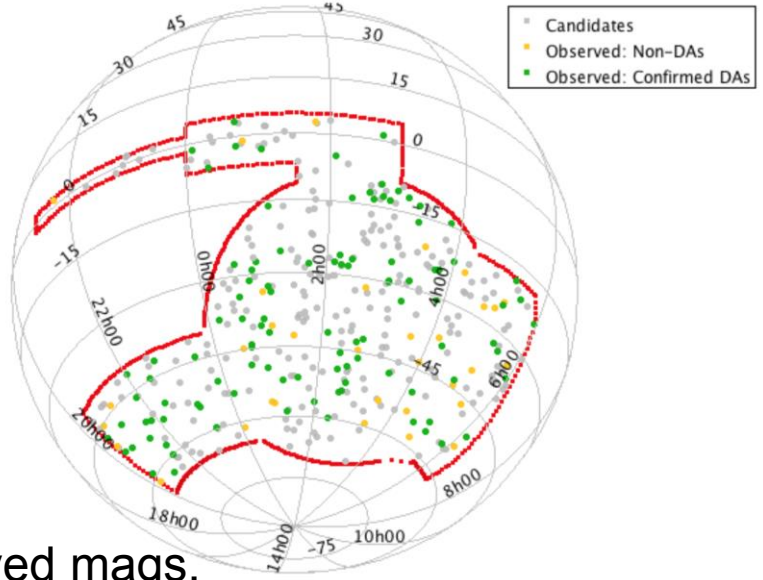
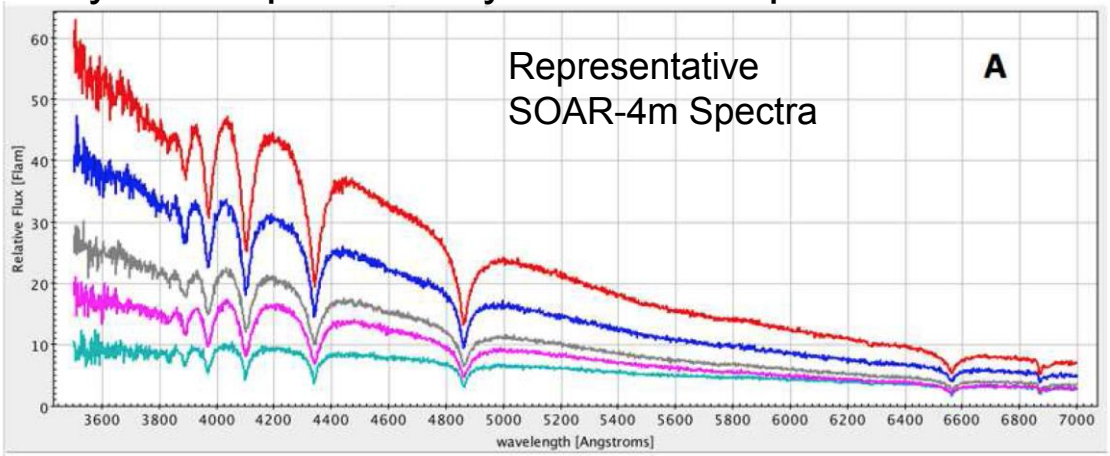
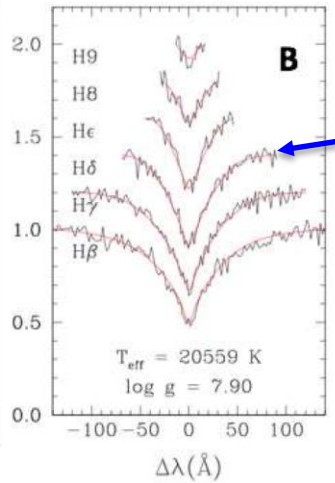
- Three CALSPEC standards in DES footprint. Only one is a faint standard. FGCM has absolute scale set to C26202.
- DES DR1: 3-5 mmag uncertainty, relative to C26202.
- Multi-year program of identifying white dwarf candidates (~100), obtaining spectra, and performing model fits giving synthetic spectra.

SOAR-4m Spectra of Candidate DA WDs



Synthetic photometry can be compared with observed mags.





DA WD atm. model fits (P.-E. Tremblay) (Also using G. Narayan's WDmodel)

Slide credit: William Wester

A Representative Model Fit (SOAR-4m spectrum)

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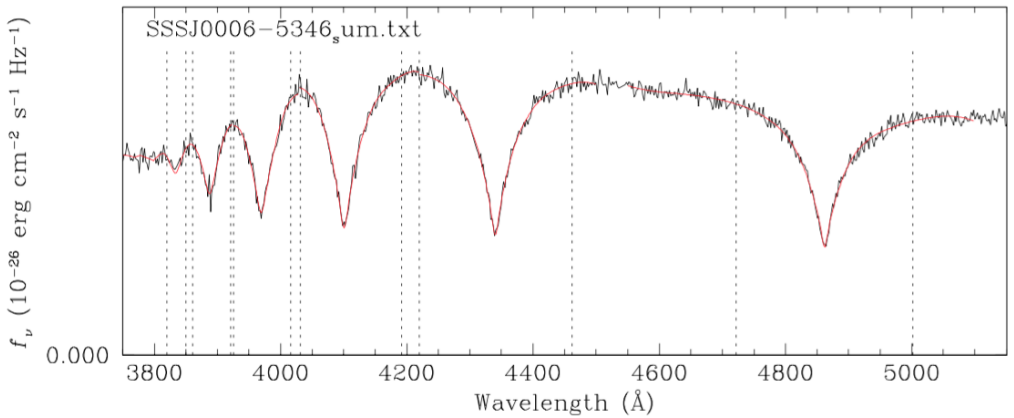
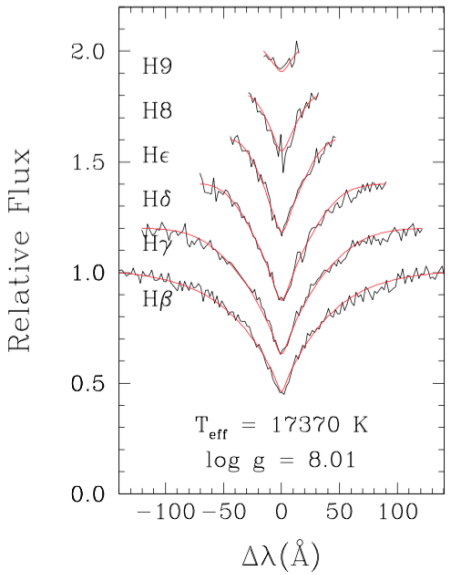
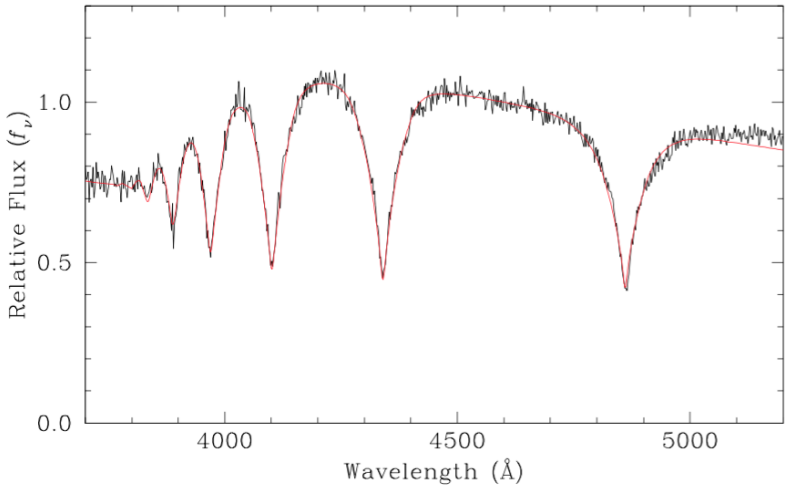
Credit: Pier-Emmanuel Tremblay







A Representative Model Fit: Tremblay vs. Narayan codes

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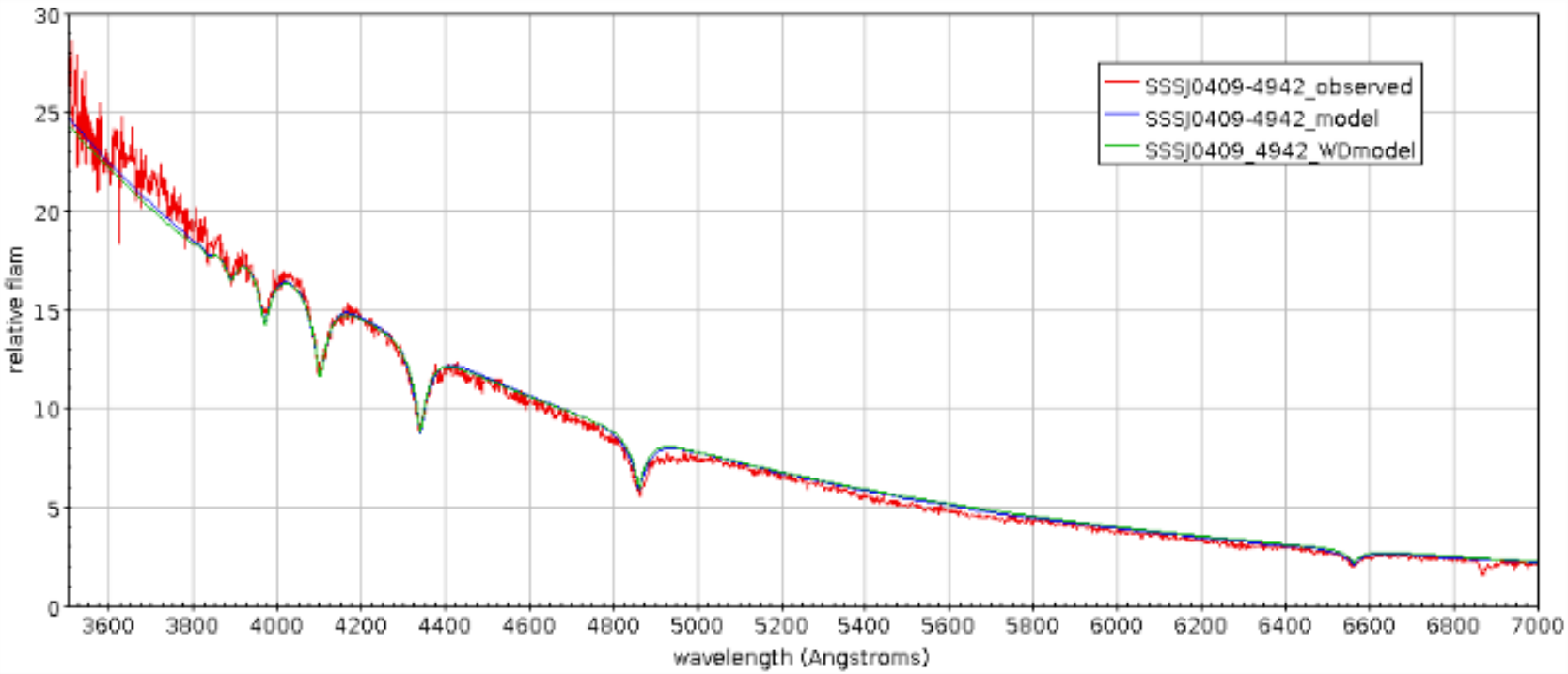

What about Interstellar Reddening?

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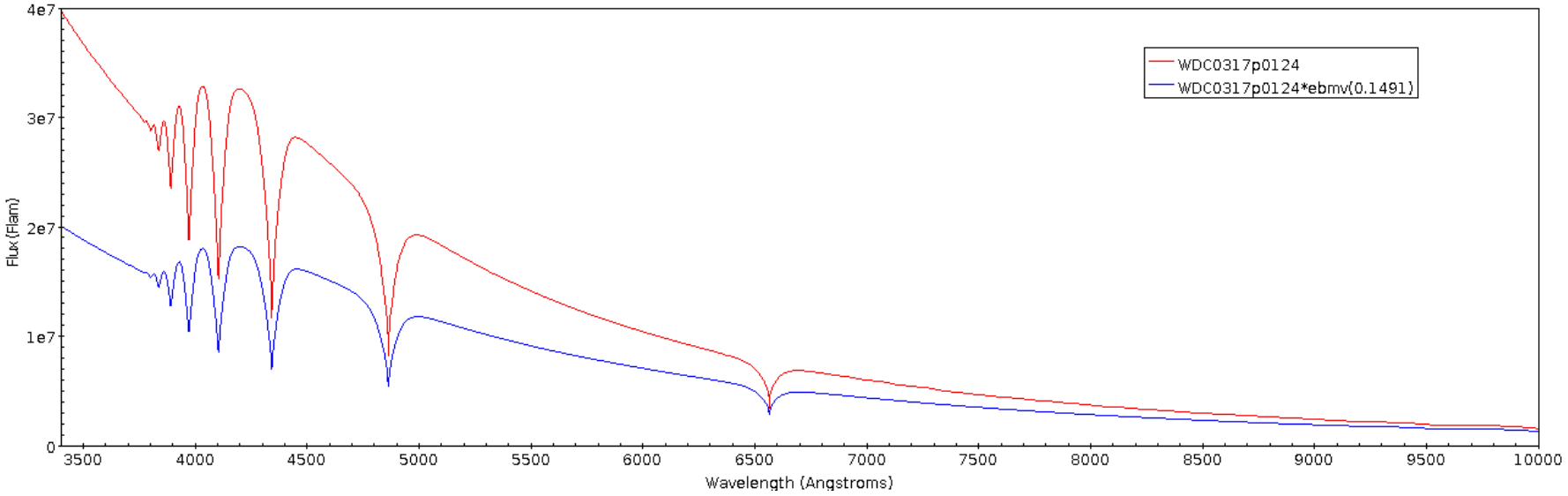
One of the highest amounts of line-of-sight E(B-V)'s for our current sample.

But is this WD within the Local Bubble? Behind the screen of MW dust? *Or embedded within it?*



Credit: Deborah Gulledge

Test Run by FNAL Group

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	g	r	i	z	Y	
C26202	**0.0285**	**0.0007**	**-0.0489**	**-0.0492**	**0.0034**	AB offset
	0.0026	0.0029	0.0034	0.0025	0.0045	σ(AB offset)
LDS749B	**0.0293**	**-0.0126**	**-0.0656**	**-0.0630**	**0.0316**	AB offset
	0.0022	0.0039	0.0050	0.0030	0.0062	σ(AB offset)
WD0308-565	**0.0221**	**-0.0237**	**-0.0805**	**-0.0822**	**0.0259**	AB offset
	0.0066	0.0054	0.0058	0.0040	0.0047	σ(AB offset)
weighted avg	**0.0285**	**-0.0072**	**-0.0592**	**-0.0598**	**0.0179**	

We had to be careful as the synthetic magnitude can be mis-calculated if the HST Spectra doesn't cover the full DES wavelength range.

Future study will be to look at chromatic effects (LDS749B and WD0308-565 are White Dwarfs, C26202 is a solar analog) and other ways to reduce the σ(AB offset) or improve precision (check airmass of observation, for instance).

Bottom line: is that there are initial offsets that can be used to put the FGCM onto the AB scale. Future work will improve the precision.

Current Spectroscopic Results – 1.5m

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- CTIO 1.5m:
- 154 total objects reduced:
  - 25 were targeted for the WD program: 8 identified WDs
  - Generally, they are too bright to use for DES calibration, but worked well as a training set.
  - Paper in preparation: Gulledge et al. (2019?)

- See Smith Poster for some of these.

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Current Spectroscopic Results

- SOAR: (SuperCosmos + ATLAS selections):
  - 145 targets (so far): 11 DAs/ 12 DBs/ 2 magnetics/ 20 “other”
- APO – 3.5m: Mostly SDSS color selected
  - 83 targets: ~75% DA/ 2-QSOs/ 1-CV/ Handful of DB/Other
- AAT – 4m: 32 spectra obtained. Still in reduction
- Magellan: 12 spectra (2016): 11 DAs
  - Still working on 2017 data and waiting for 2018 night

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Imaging Follow-up

CTIO-0.9m, WIYN-0.9m

1. To obtain SDSS u-band photometry of Rowell & Hambly sample (to use color selection to improve success rate)
2. To monitoring candidates for signs of variability.

Currently, ~400 candidate white dwarfs have been imaged as part of the imaging follow-up program.

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Conclusions

- DES continues to evolve in its calibrations
  - Advanced knowledge of the devices and readout
  - External inputs for clouds and the atmosphere
- FGCM reaches 2% requirements in magnitudes
- With knowledge of SEDs, 0.5% color uncertainties and sub-1% photometry has been achieved
- Work on absolute calibration continues and the white dwarf sample will have legacy with LSST etc.