



**DARK ENERGY
SURVEY**

The Absolute Color Calibration of the Dark Energy Survey: A Spectrophotometric Sample of DA White Dwarfs in the Southern Sky

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Abstract: The Dark Energy Survey (DES), which is nearing the completion of the analysis of its full data set, is an imaging survey of one-quarter of the Southern sky down to an apparent magnitude of $i \sim 24.5$. The survey observations were conducted between 2013 and 2019 with a 3-square-degree wide-field CCD mosaic camera (the Dark Energy Camera, or DECam) on the Blanco 4-meter telescope at the Cerro Tololo Interamerican Observatory in the Chilean Andes. The primary scientific goal of the DES was to measure properties of Dark Energy. In order to achieve its science goals, the DES had tight requirements on both its relative and absolute photometric calibrations. In this poster, we describe the sample of pure-hydrogen-atmosphere (“DA”) white dwarfs which were instrumental in working to establish the requirement on the absolute color calibration -- i.e., the calibration across the filter bands -- of the DES.

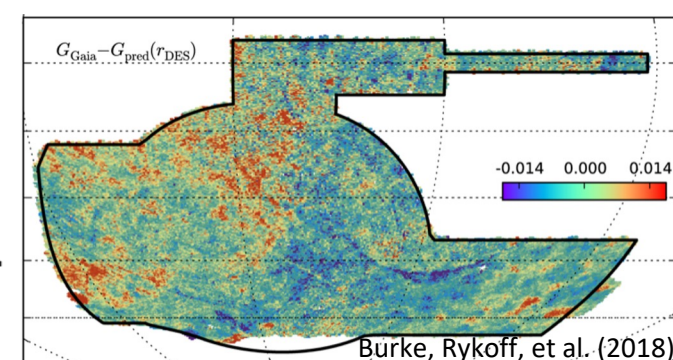
DES Photometric Calibration Requirements* (5-year, coadded)

*From DES Scientific Requirements Document

- Relative:** 2% rms on scales of $0.05^\circ - 4^\circ$.
Goals: 1% rms and/or over 160° in RA, 30° in DEC.

Uniformity \rightarrow angular galaxy clustering

(The Forward Global Calibration Module (FGCM; Burke, Rykoff, et al. 2018) has achieved uniform relative calibration for the full DES footprint at the 0.7% level for DES DR1 [Abbott et al. 2018] and at the 0.3% level for DES DR2 [Abbott et al. 2021].)

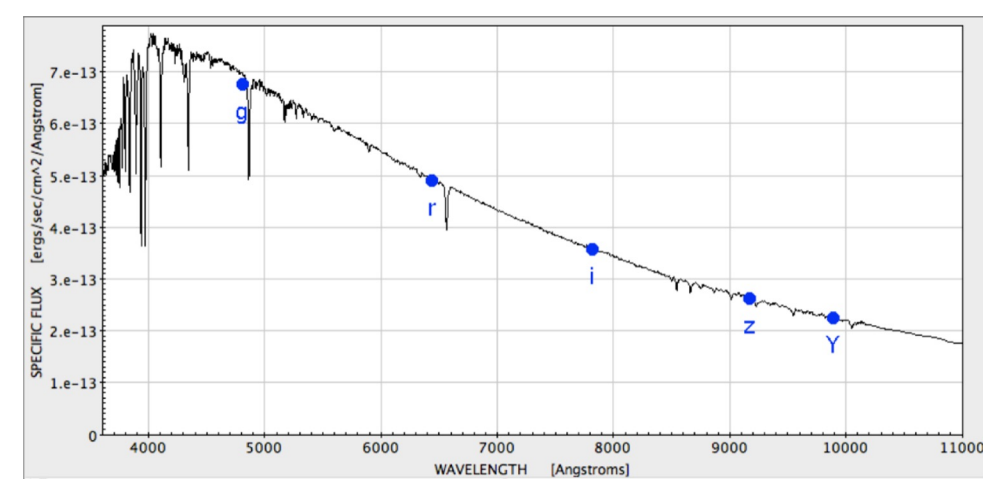


- Absolute Color:** 0.5% ($g-r$, $r-i$, $i-z$); 1% ($z-Y$).

“Between-filters” calibration.

Photometry as a “low-res. spectrum”

\rightarrow photo-z’s, SNe k-corrections



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

Relative to standard star C26202.

Zeropointing the overall filter system.

\rightarrow comparison with other surveys (esp. for SNe)

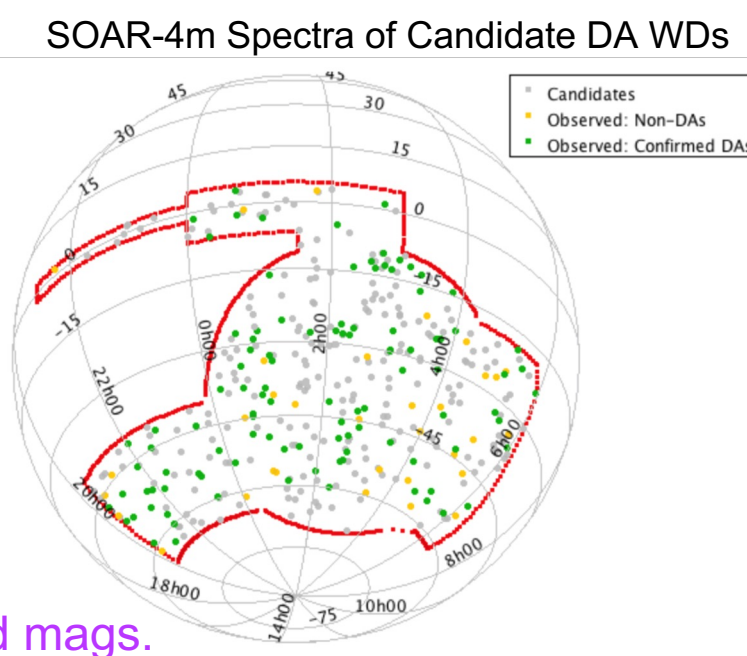
DES DR1 DES Absolute Calibration

(DES DR1 is described in Abbott et al. 2018)

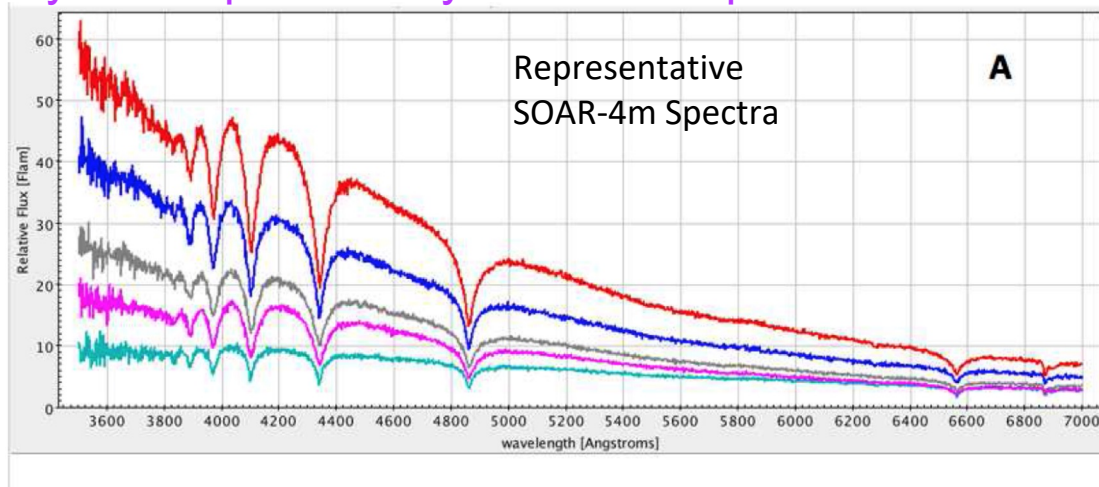
- Three CALSPEC standards in DES footprint. Only one is a faint standard. FGCM has absolute scale set to C26202.

- 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.



Synthetic photometry can be compared with observed mags.

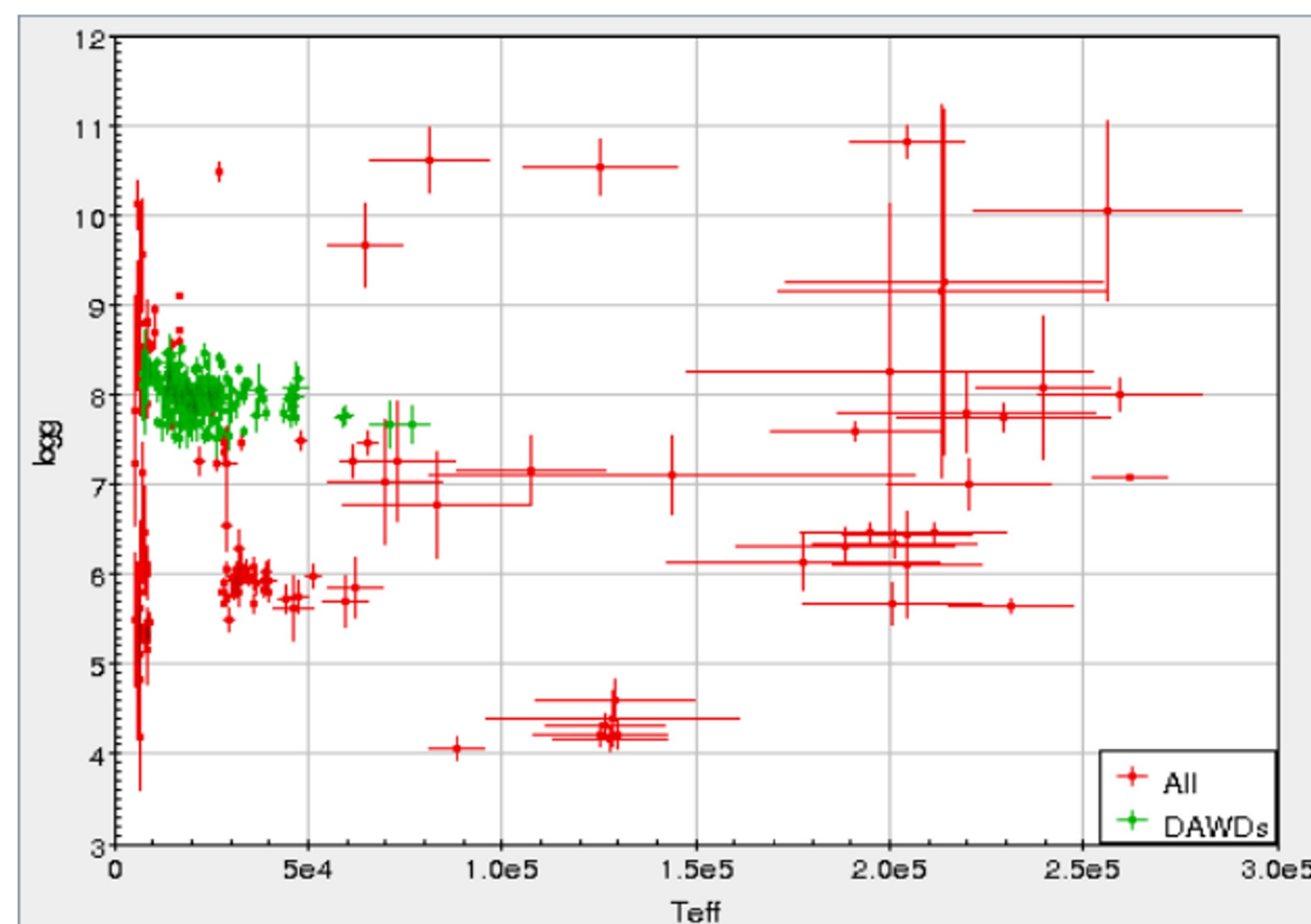


DA WD atm. model fits (P.-E. Tremblay) (Also using G. Narayan’s WDmodel)

Slide credit: William Wester

Cuts Applied to the Candidate List: 1. Remove non-DAWDs

DAWDs: $7.5 \leq \log(g) \leq 8.5$



Basically removes non-DAWDs from the sample (DBs, DCs, magnetic WDs, DAWDs, stars with low-S/N spectra, ...)

Not all blue high-proper-motion stars are DAWDs!

Cuts Applied to the Candidate List: 2. Remove DAWDs with Poorly Determined T_{eff} ’s

DAWDs_good: DAWDs &&
 $\sigma(T_{\text{eff}}) < 1000\text{K}$ &&
 $\sigma(T_{\text{eff}})/T_{\text{eff}} < 0.1$

Cuts Applied to the Candidate List: 3. Remove DAWDs with No Good Gaia Match

DAWDs_good_bprp: DAWDs_good &&
 $\text{not}((g-r)_{\text{fgcm}} > 0.1 \text{ \&\& } (bp-rp)_{\text{gaia}} < 0.245)$

Creating a “Golden” Sample of DA WDs: Imaging Observations

Our sample of candidate DA white dwarfs came from many datasets, including:

- SDSS** (color selected via $u-g$, $g-r$ colors)
- SuperCosmos Survey** (proper motion photographic survey; Rowell & Hamby 2011)
- VST Survey** (color selected via $u-g$, $g-r$ colors)
- GALEX+DES** (color-selected from GALEX UV mags and DES optical mags)
- Gaia DR2 & DR3** (proper motion selected)

Imaging follow-up of the candidates was performed on the following telescopes, both to obtain u -band data (to help with color-selection) and to monitor candidates for any variability:

- CTIO-1.0m**
- CTIO-0.9m**
- WIYN-0.9m: (S2KB, HDI)**

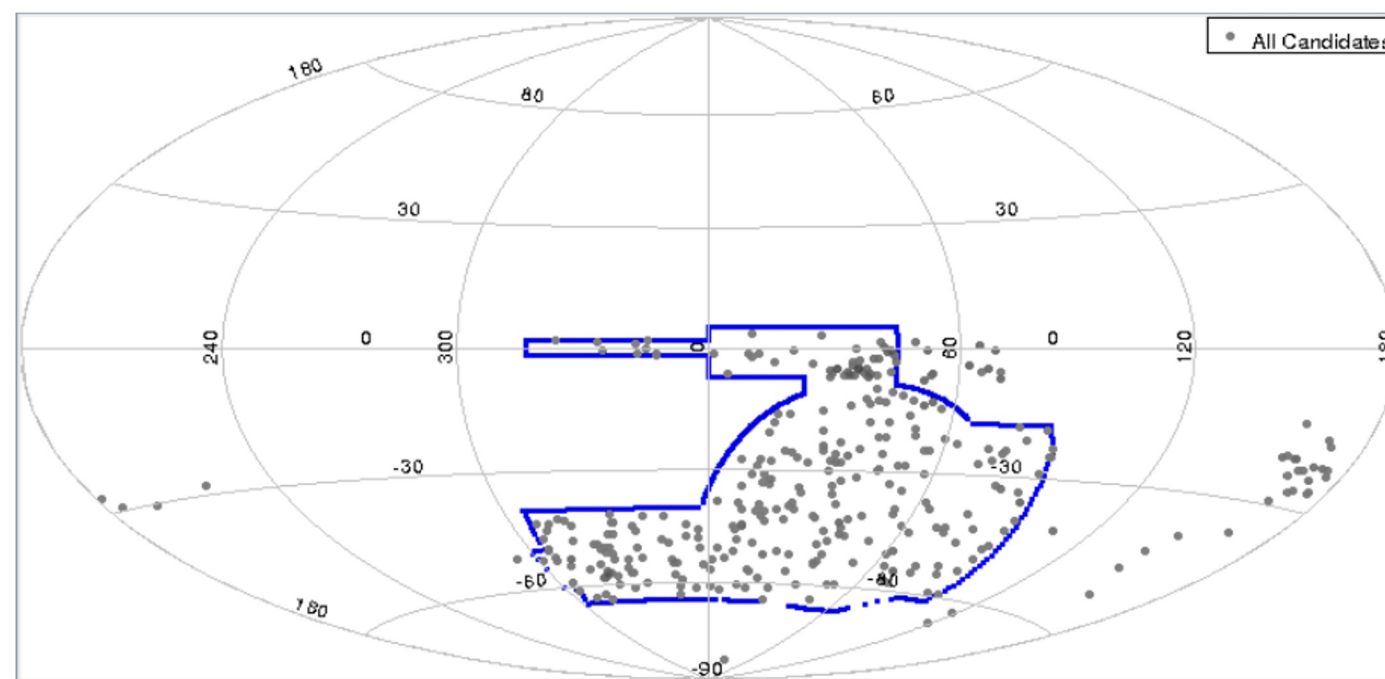
An Updated Master List of Candidate DES DA White Dwarfs for DES DR2

(DES DR2 is described in Abbott et al. 2021))

- Contains synthetic DES AB colors for all the candidates with fitted model DA spectra.

- Fit by our white dwarf modeling expert, Pier-Emmanuel Tremblay.

- Stars matched to Gaia DR2, Gaia DR2 distance tables (Bailer-Jones et al. 2018), SFD98 E(B-V) maps, FGCM Y6A1 standard star catalog, the Y6-Gold-v1 catalog, and Katelyn Stringer’s Y6Q1 variable star catalog.



An Updated Master List of Candidate DES DA White Dwarfs for DES DR2 (cont’d)

430 spectrophotometric model fits (349 unique stars)

- Some repeated fits to same observed spectrum
 - 42 unique spectra were fit multiple times
 - 25 unique spectra were fit twice.
 - 17 unique spectra were fit 3x.
 - $430 - 25 \times (2-1) - 17 \times (3-1) = 371$

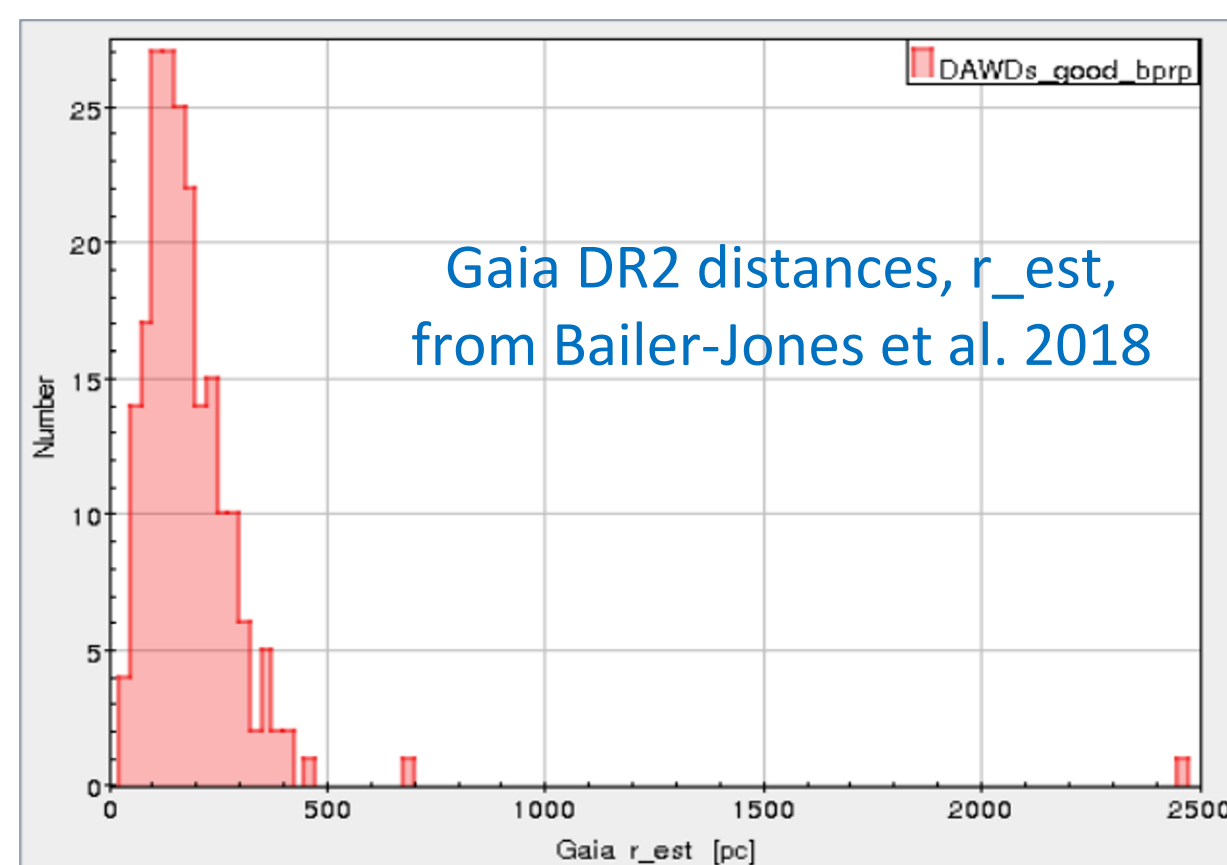
Useful checks on systematics.

- A handful of stars have repeat observations
 - 20 unique stars were observed multiple times
 - 18 unique stars observed twice
 - 2 unique stars observed 3x.
 - $371 - 18 \times (2-1) = 2 \times (3-1) = 349$

Cuts Applied to the Candidate List: 4. Remove Distant DAWDs

DAWDs_good_bprp_dist:

DAWDs_good_bprp && $r_{\text{est}} < 300 \text{ pc}$



Removes potentially over-luminous stars and helps reduce effects of Galactic dust.

References

Abbott, T.M.C., Abdalla, F.B., Allam, S., et al. 2018, “The Dark Energy Survey: Data Release 1,” *ApJS*, 239, 18
Abbott, T.M.C., Adamow, M., Aguena, M., et al. 2021, “The Dark Energy Survey Data Release 2,” *ApJS*, 255, 20
Burke, D.L., Rykoff, E., Allam, S., et al. 2017, “Forward Global Photometric Calibration of the Dark Energy Survey,” *AJ*, 155, 41

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