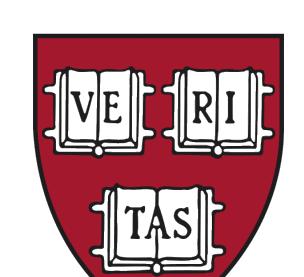
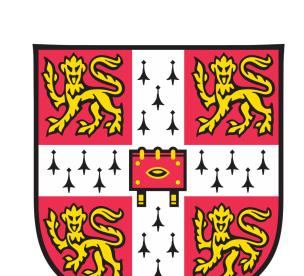


# SUB-PERCENT PHOTOMETRY: FAINT DA WHITE DWARF SPECTROPHOTOMETRIC STANDARDS FOR ASTROPHYSICAL OBSERVATORIES



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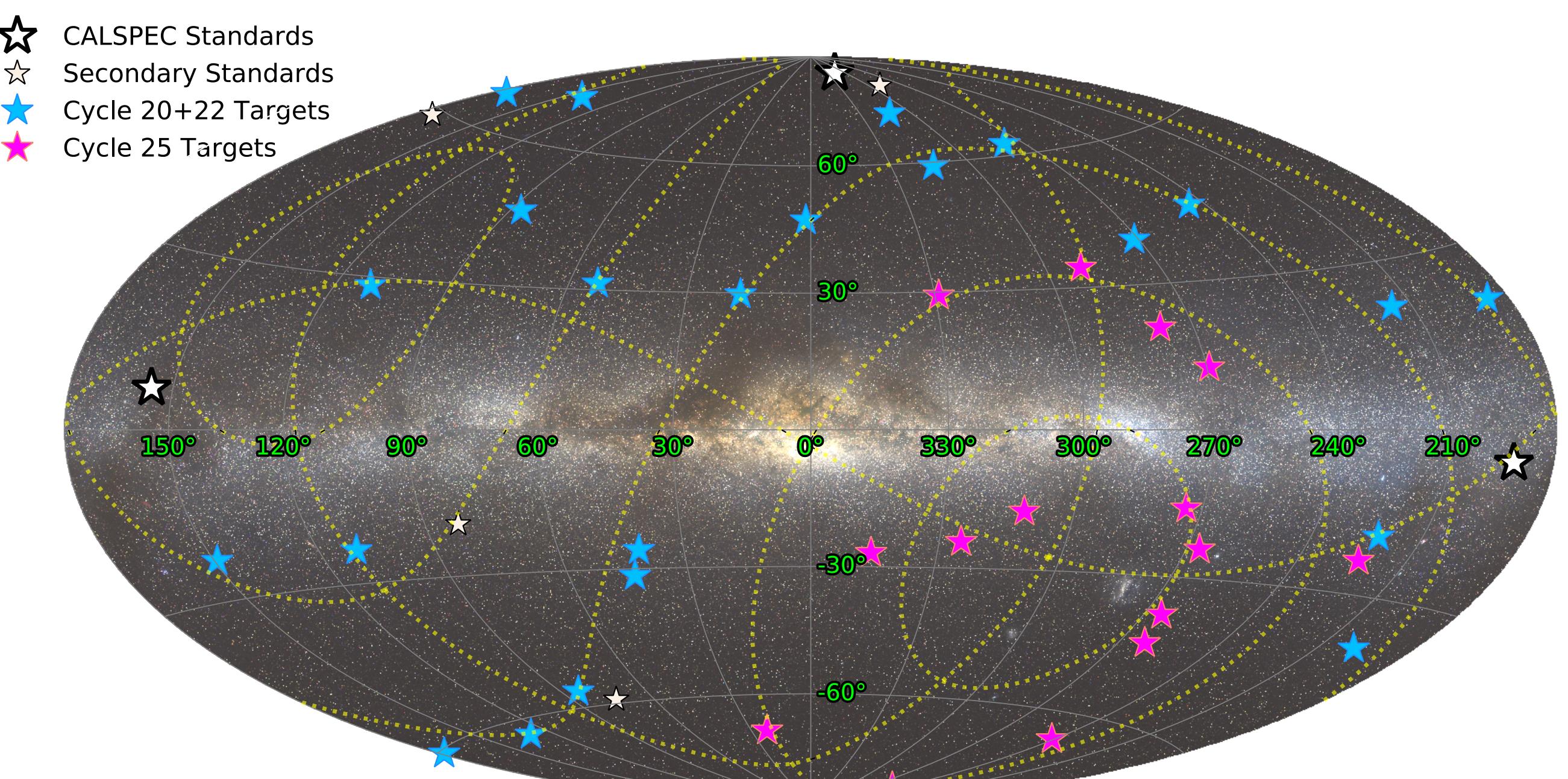


@gsnarayan

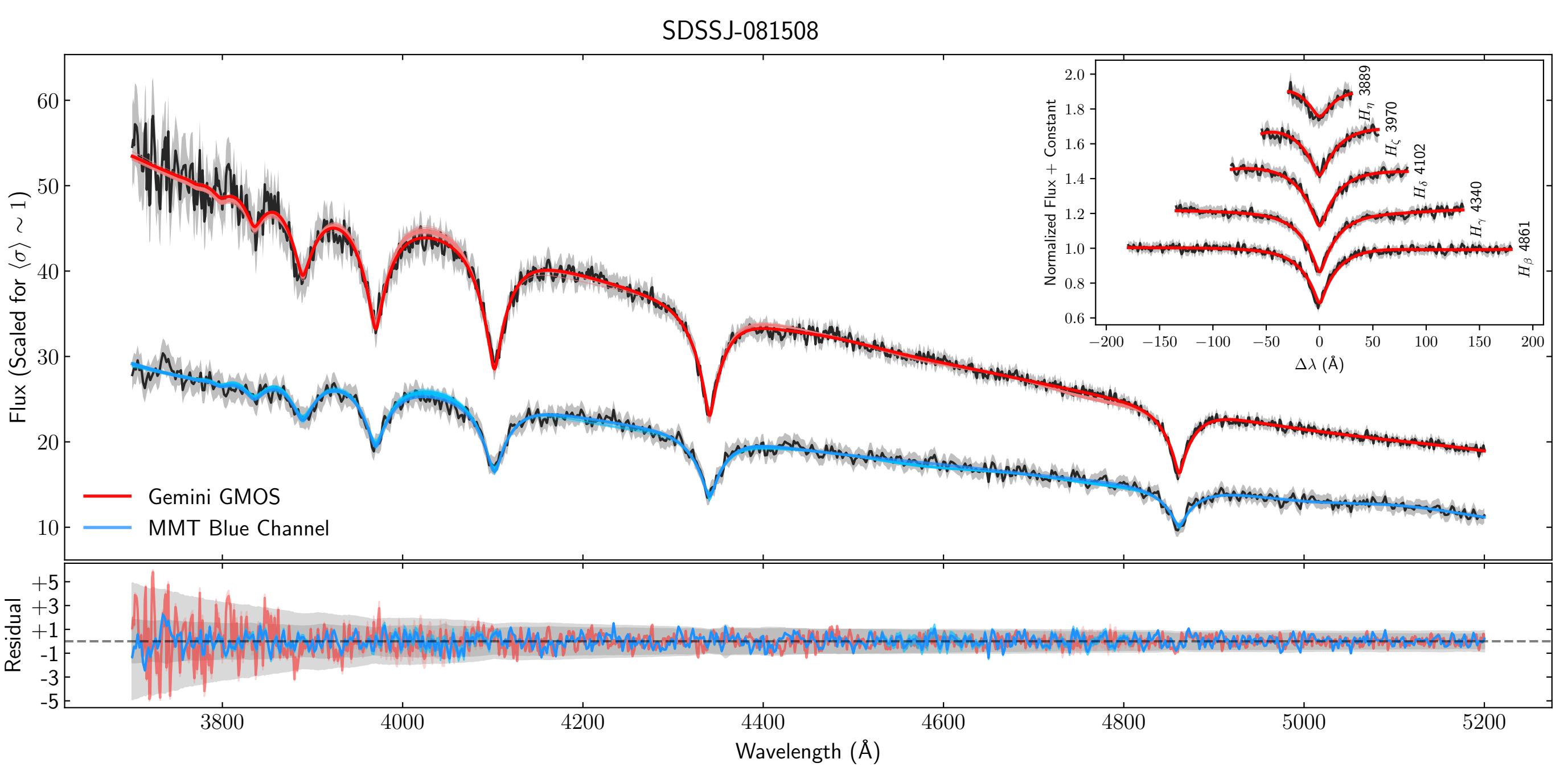
We have established a network of faint ( $16.5 < V < 19$ ) hot DA white dwarfs as spectrophotometric standards for present and future wide-field observatories. Our standards are accessible from both hemispheres and suitable for ground and space-based covering the UV to the near IR. The network is tied directly to the most precise astrophysical reference presently available - the CALSPEC standards - through a multi-cycle program imaging using the Wide-Field Camera 3 (WFC3) on the Hubble Space Telescope (HST). We have developed two independent analyses to forward model all the observed photometry and ground-based spectroscopy and infer a spectral energy distribution for each source using a non-local-thermodynamic-equilibrium (NLTE) DA white dwarf atmosphere extincted by interstellar dust. The models are in excellent agreement with each other, and agree with the observations to better than 0.01 mag in all passbands, and better than 0.005 mag in the optical. The high-precision of these faint sources, tied directly to the most accurate flux standards presently available, make our network of standards ideally suited for any experiments that have very stringent requirements on absolute flux calibration, such as studies of dark energy using the Large Synoptic Survey Telescope (LSST) and the Wide-Field Infrared Survey Telescope (WFIRST).

## THE ELEVATOR PITCH

- Many experiments are highly sensitive to absolute flux calibration (e.g. understanding dark energy with SNe Ia)
- Legacy astrophysical spectrophotometric calibrators are too bright for facilities such as LSST and WFIRST
- We have established an **all-sky network** of faint, hot DA white dwarfs as spectrophotometric standards
- Our standards are tied directly to the bright CALSPEC primary standards to **better than 1%**



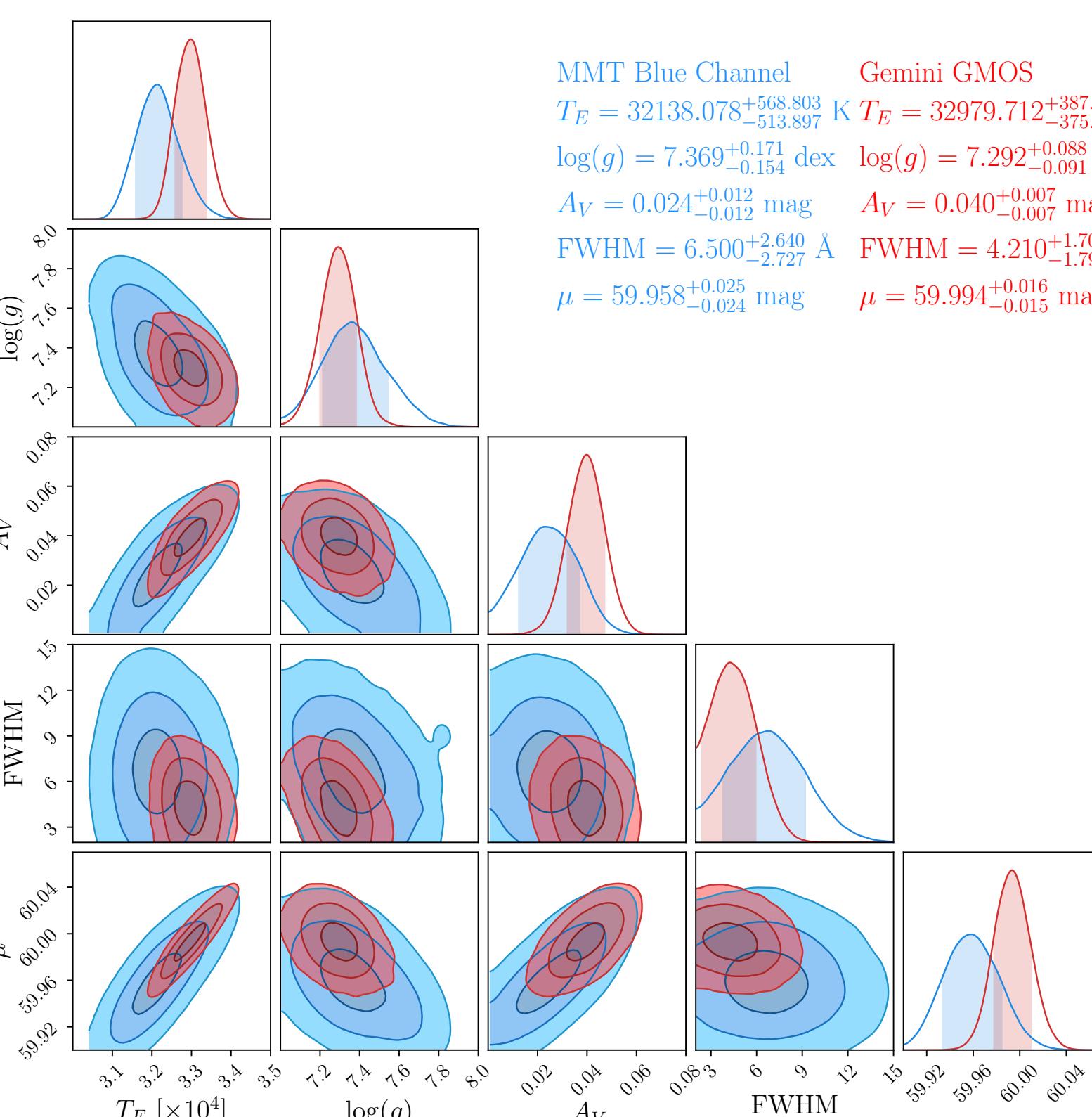
ALL-SKY GALACTIC MAP OF OUR NETWORK OF DA WHITE DWARFS & BRIGHT STANDARDS. DATA FROM CYCLE 20 AND 22 IS PRESENTED HERE.



FITS OF TWO SPECTRA OF SDSS-J081508 (RED: GMOS, BLUE: MMT). THE MODEL AROUND THE EACH BALMER LINES ARE SHOWN IN THE INSET. RESIDUALS SHOWN BELOW ARE CONSISTENT WITH WHITE NOISE, AND THE ESTIMATED MODEL ERRORS (GREY SHADED REGIONS).

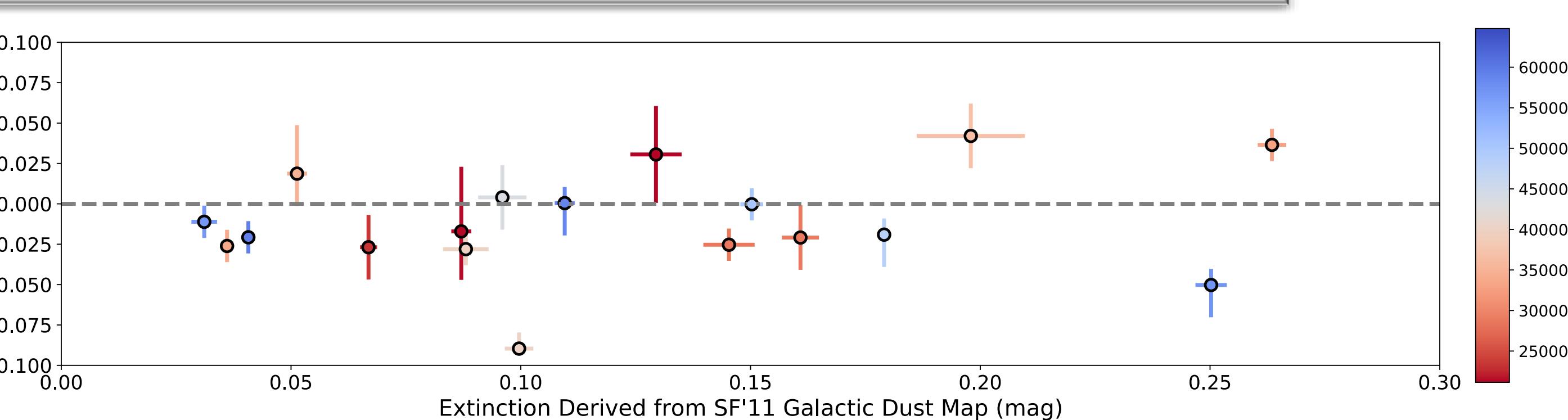
## OBSERVATIONS

- **Ground-based spectroscopy** (MMT, Gemini, SOAR) to constrain temperature and surface gravity
- **132 orbits with HST/WFC3** to establish absolute flux scale & constrain reddening with multi-epoch UVOIR imaging (GO 12967, 13711 & 15113: ongoing; PI: A. Saha)
- Continuous ground-base **monitoring for variability** with Las Cumbres Observatory network 1m/Sinistro
- Photometry validated with three separate pipelines



MMT Blue Channel      Gemini GMOS  
 $T_E = 32138.078^{+288.803}_{-312.807}$  K       $T_E = 32979.712^{+387.952}_{-375.670}$  K  
 $\log(g) = 7.369^{+0.171}_{-0.154}$  dex       $\log(g) = 7.292^{+0.088}_{-0.091}$  dex  
 $Av = 0.024^{+0.012}_{-0.012}$  mag       $Av = 0.040^{+0.007}_{-0.007}$  mag  
 $FWHM = 6.500^{+2.640}_{-2.727}$  Å       $FWHM = 4.210^{+1.701}_{-1.795}$  Å  
 $\mu = 59.958^{+0.025}_{-0.021}$  mag       $\mu = 59.994^{+0.016}_{-0.015}$  mag

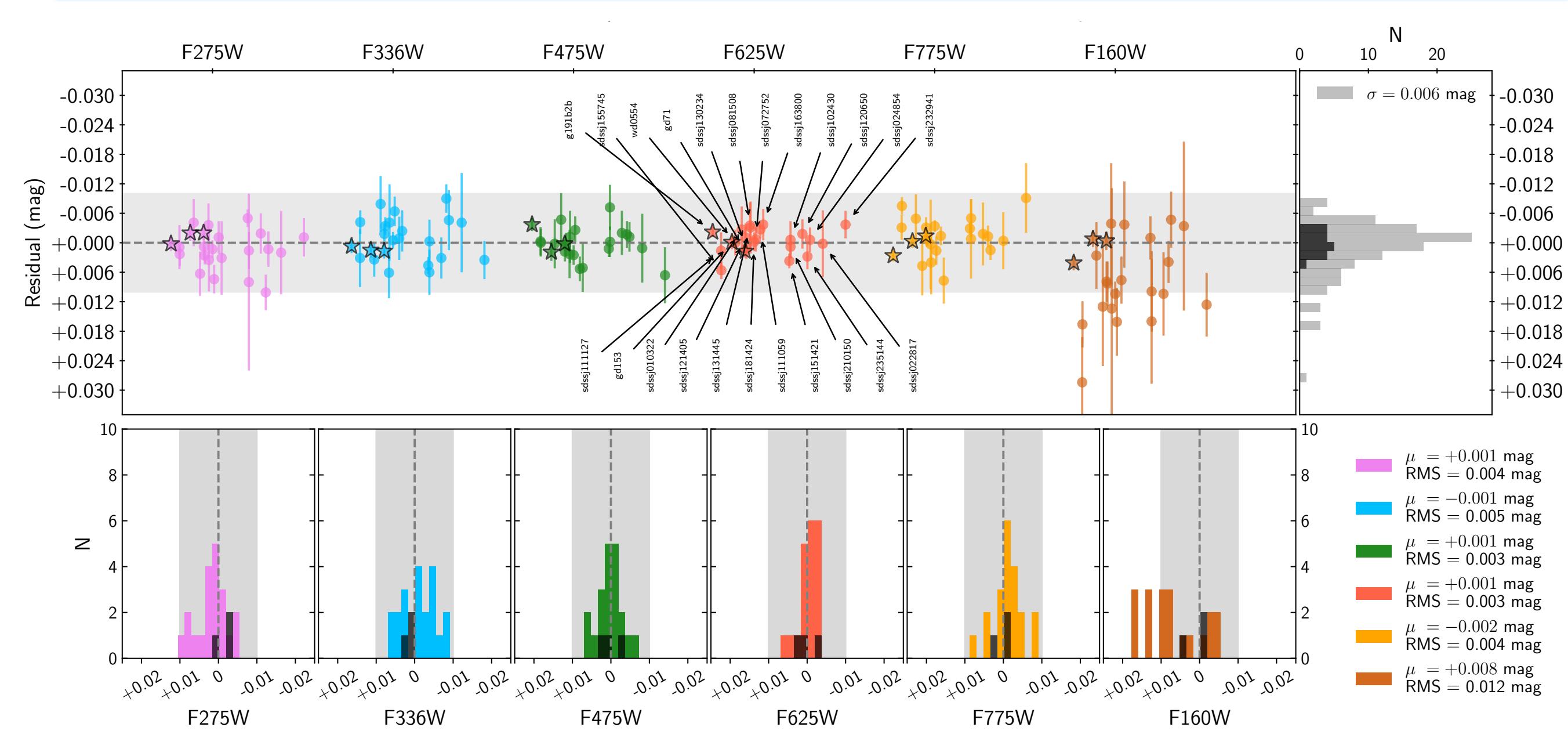
JOINT DISTRIBUTIONS AND THE 1D MARGINALIZATIONS FOR THE TWO SPECTRA OF SDSS-J081508. THE TWO SPECTRA WERE TAKEN USING DIFFERENT INSTRUMENTS WITH DIFFERENT TELESCOPES AND DIFFERENT SITES, DURING DIFFERENT OBSERVING CONDITIONS. THE GEMINI SPECTRUM HAS A S/N MORE THAN THREE TIMES THAT OF THE MMT SPECTRUM. DESPITE THESE DIFFERENCES, THE INFERRED INTRINSIC PARAMETERS DETERMINED BY THE WDMODEL CODE ARE IN GOOD AGREEMENT WITH EACH OTHER.



INFERRED EXTINCTION COMPARED AGAINST THE AVERAGE EXTINCTION FOR THE REGION AROUND EACH WHITE DWARF, DERIVED FROM THE SCHLAFLY AND FINKBEINER, 2011 CALIBRATION OF THE GALACTIC DUST MAP. THE INFERRED EXTINCTION IS GENERALLY LOWER, CONSISTENT FOR GALACTIC SOURCES.

## ANALYSIS

- LCO monitoring to-date indicate that at least two objects are variable. Analysis of *HST* photometry & spectroscopy suggest both have faint, red companions
- Model magnitudes agree to better than 0.01 mag with measurements – **better than 5 mmag in the optical**
- F160W mags show weak residual trend with brightness – possibly reddening or *WFC3/IR* count rate non-linearity



RESIDUALS (OBSERVED – MODEL) FOR CYCLE 20+22 OBJECTS IN OUR NETWORK. THE OVERALL SCATTER IS 6 MMAG. MEASUREMENTS WITHIN EACH BAND ARE OFFSET BY OBSERVED COLOR.

## RESULTS

- Our network extends *HST*'s legacy of precise absolute calibration to future facilities. **Overall scatter of ~6 mmag.**
- Data release : Calamida+ '18 (in prep)  
Analysis : Narayan+ '18 (in prep)