# ABSOLUTE CALIBRATION FOR WIDE-FIELD SURVEYS

GAUTHAM NARAYAN
STSCI



CALSPEC+
NOAO: Abi Saha, Tom Matheson, Sean Points, Jenna Claver
UA: Tim Axelrod, Ed Olszewski, Jay Holberg, Ivan Hubeny
STScI: Annalisa Calamida, Ralph Bohlin, Susana Deustua, Elena Sabbi, Armin Rest, John MacKenty
Harvard: Christopher Stubbs
Cambridge: Kaisey Mandel

# WHAT THE FLUX

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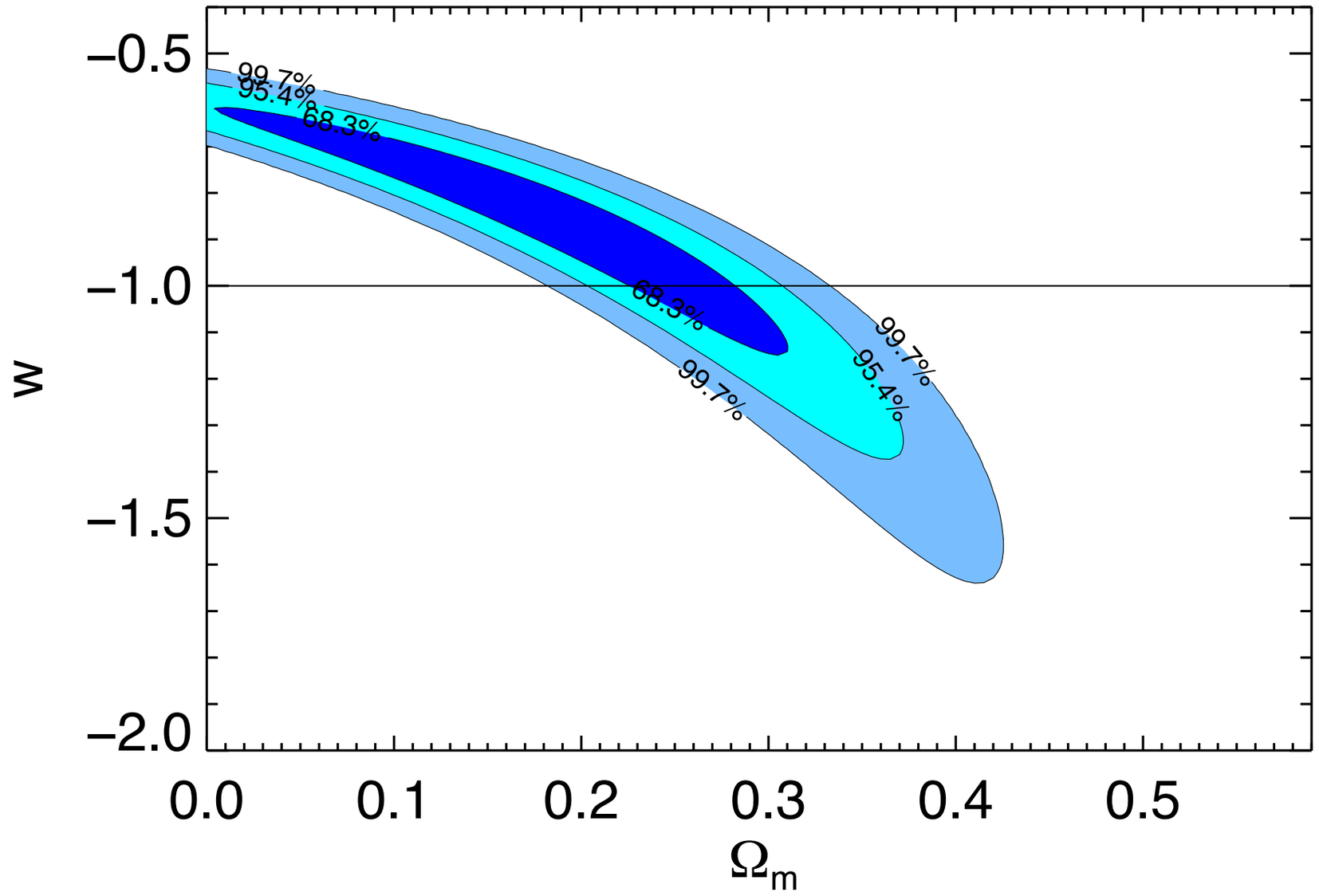
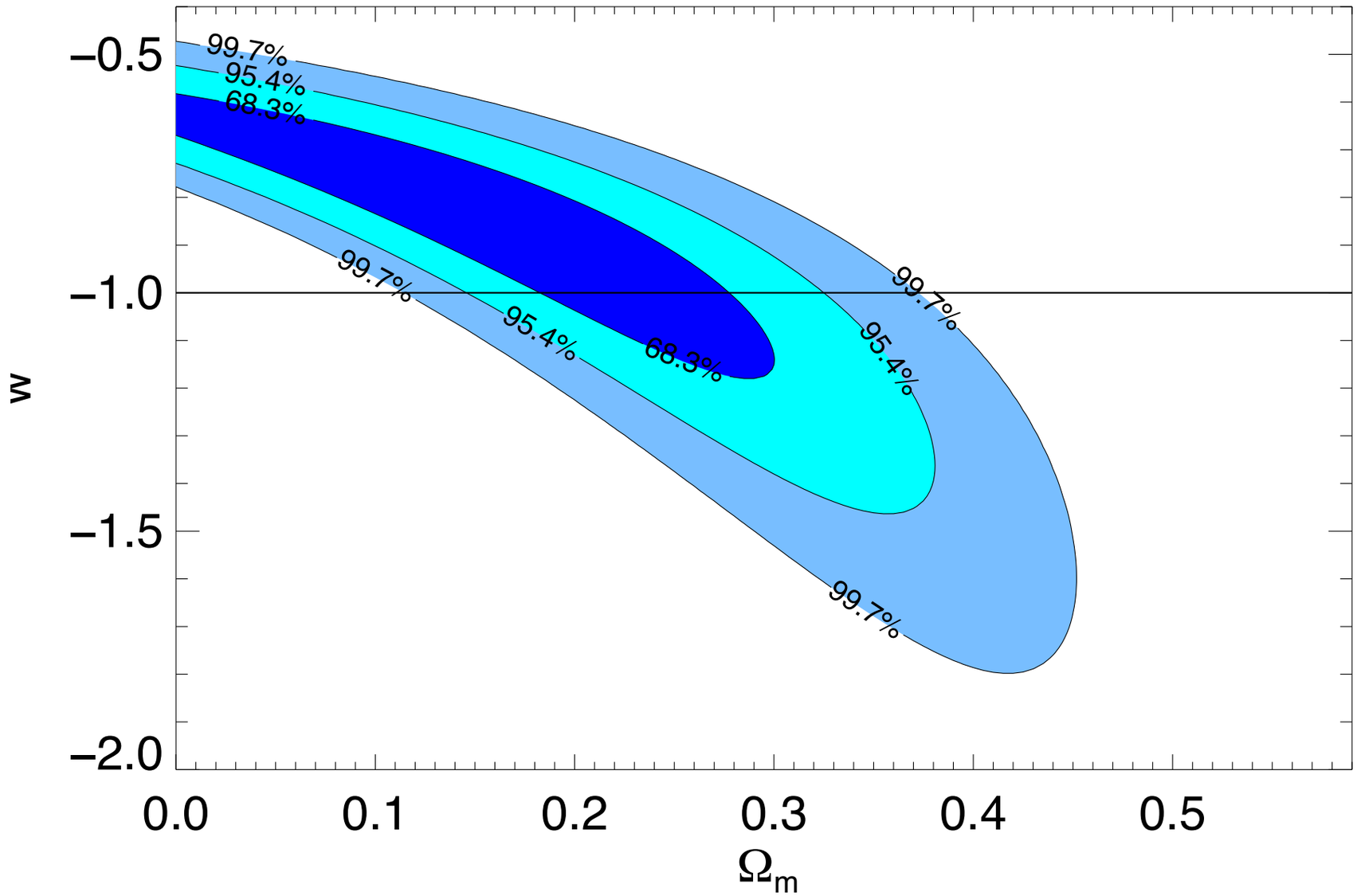



The statistical errors tell us that we should have a robust sub-10% measurement of the equation of state of dark energy with our current sample size

SNLS3 year analysis

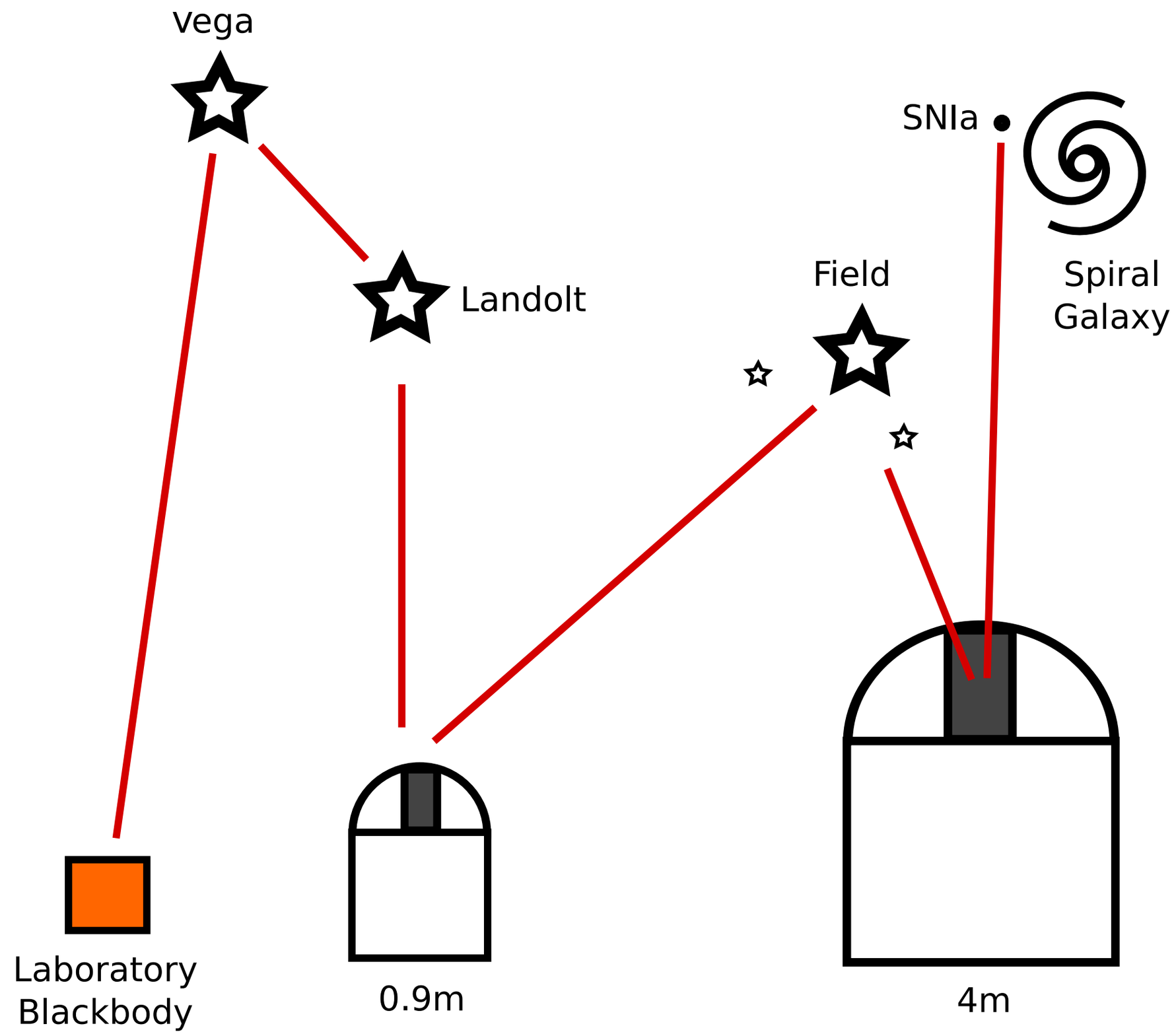
“What could possibly go wrong?”



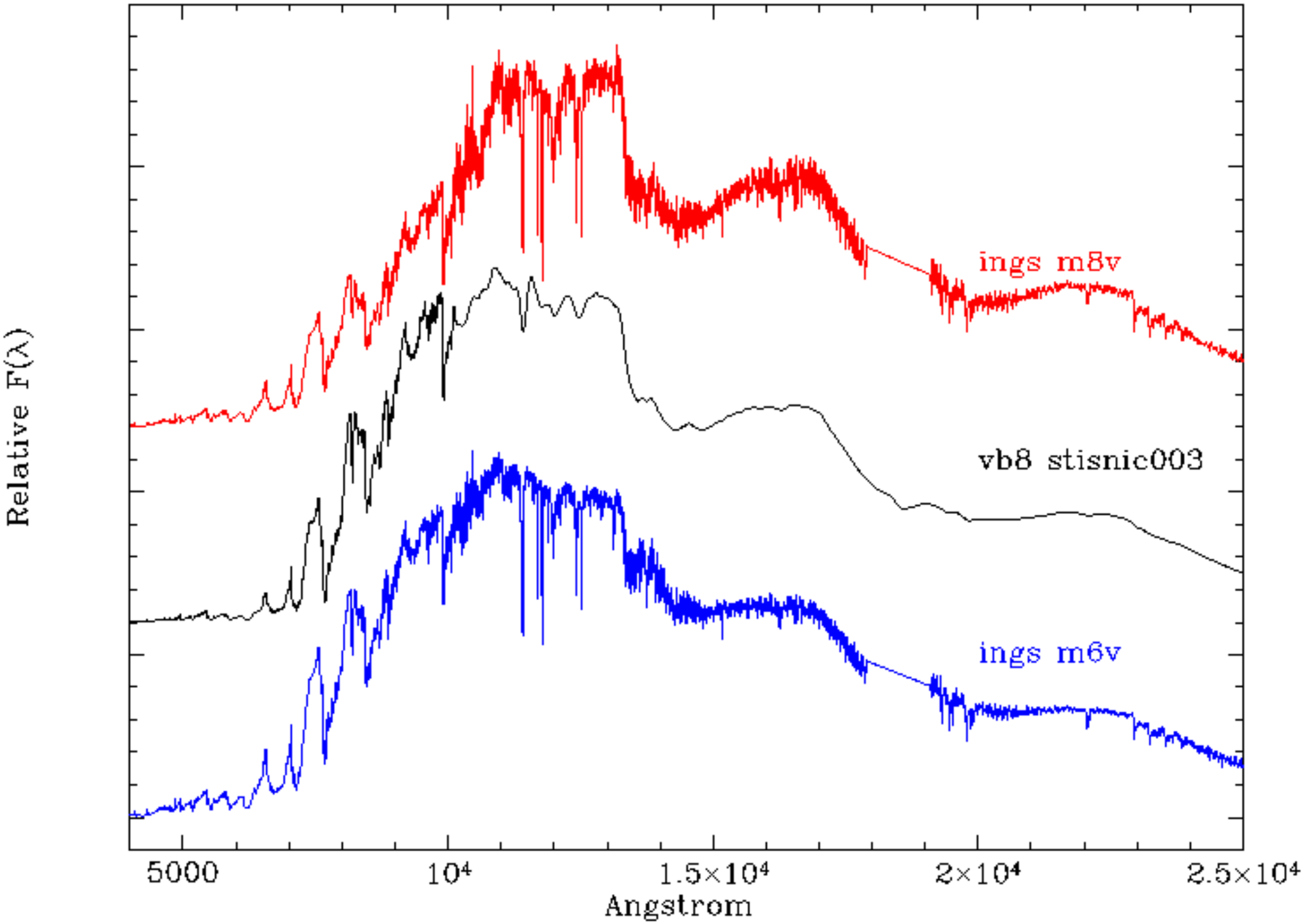

# WE DON'T.

If you are sick of hearing that w = -1 but we're systematics dominated, then you should care about calibration.

SNLS3 year analysis

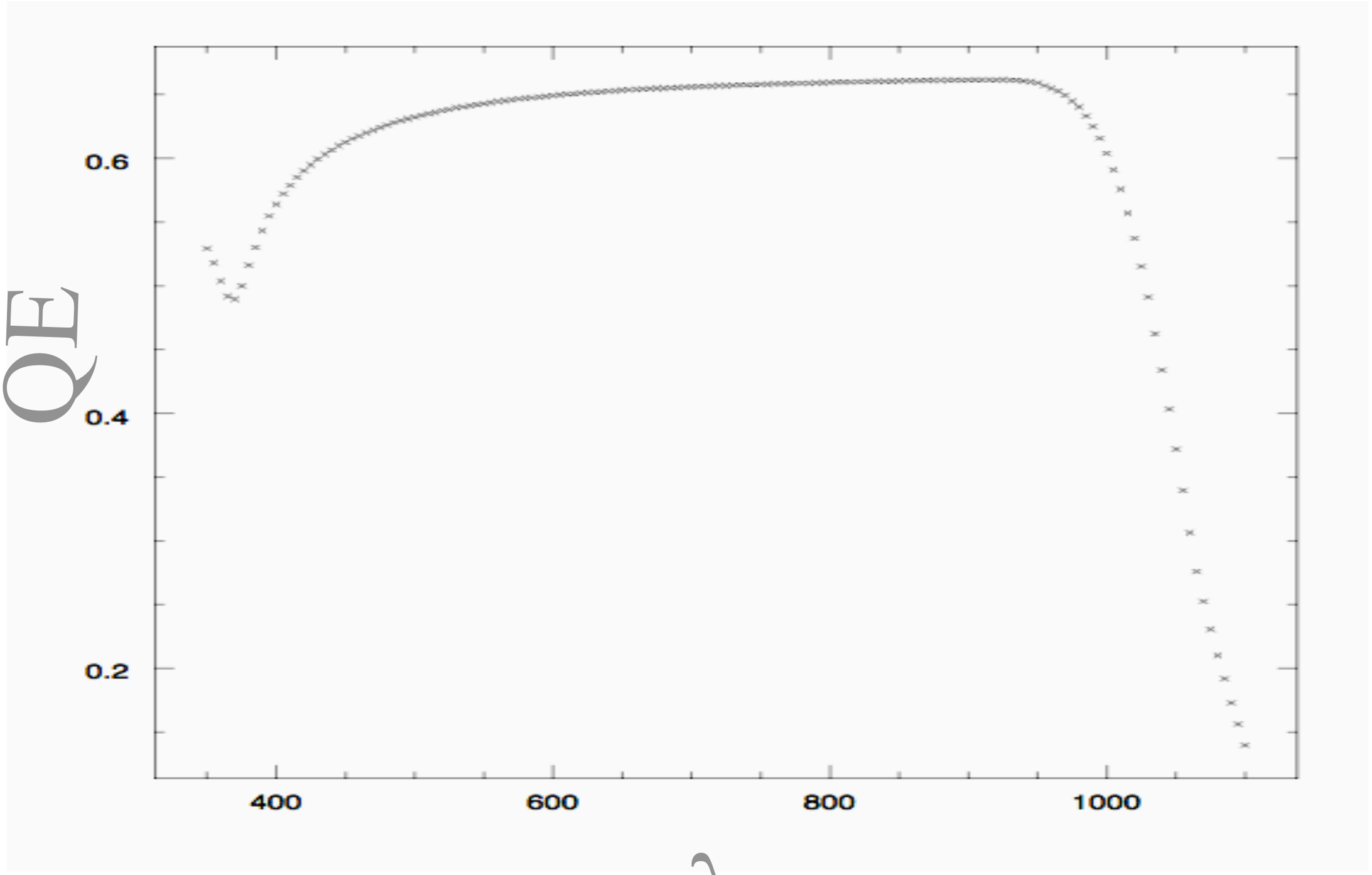



The typical calibration chain for wide-field surveys




Most standards are extremely complex and hard to model

From A. Pickles INGS for VB8 - M7V standard

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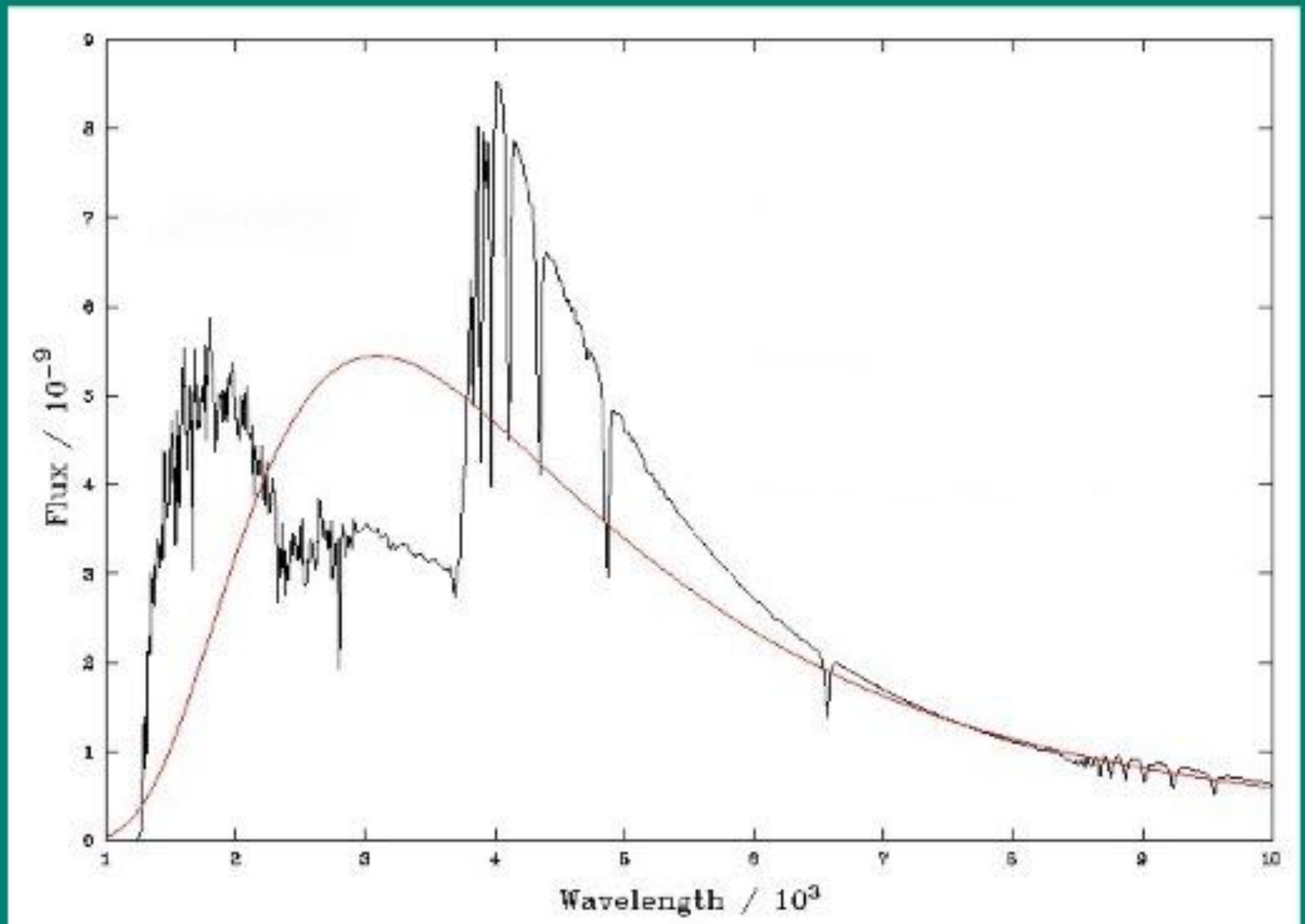
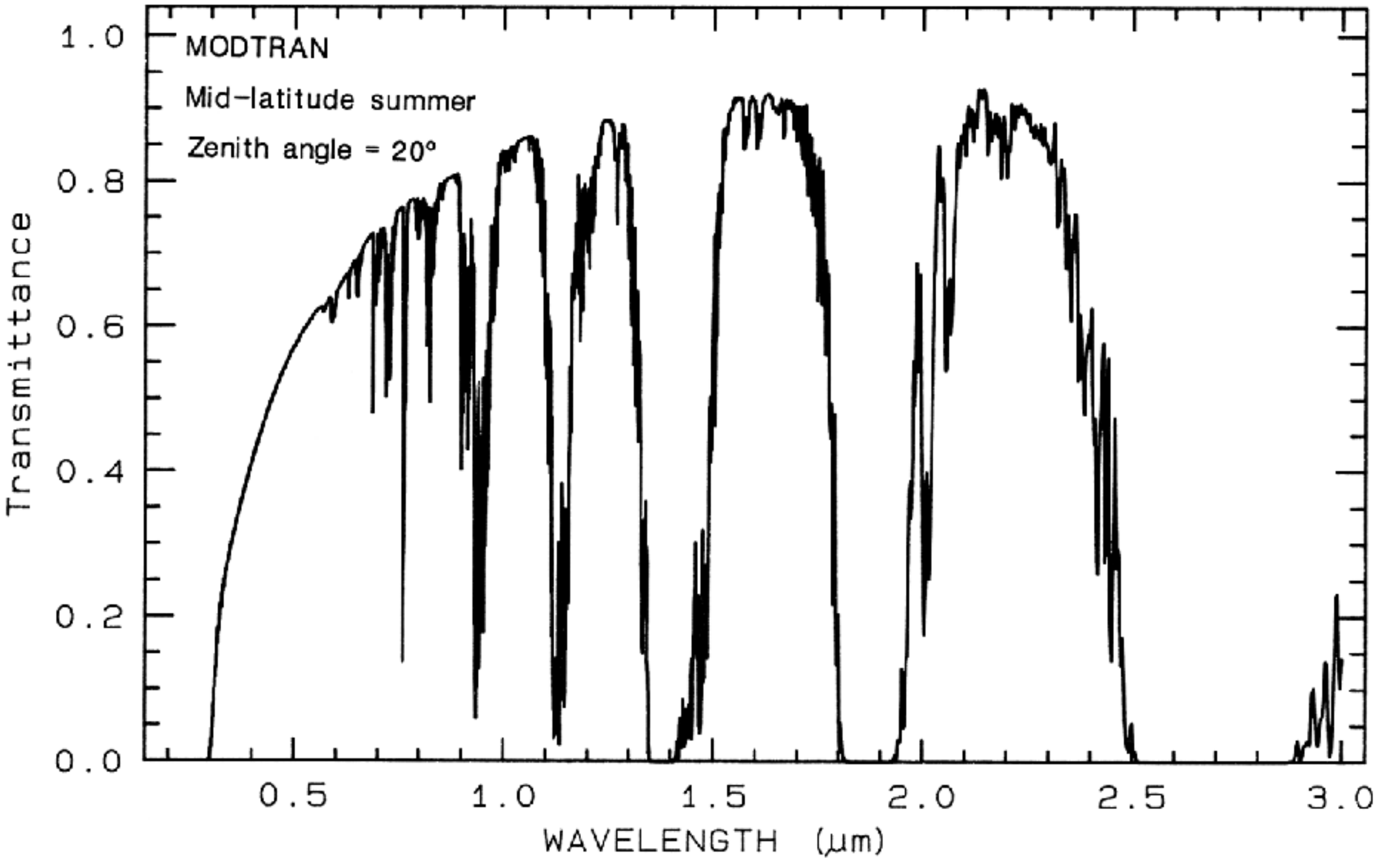
Definitely not a blackbody.

Or a tree.

I am not really confident, but I think it's a map of the tree.

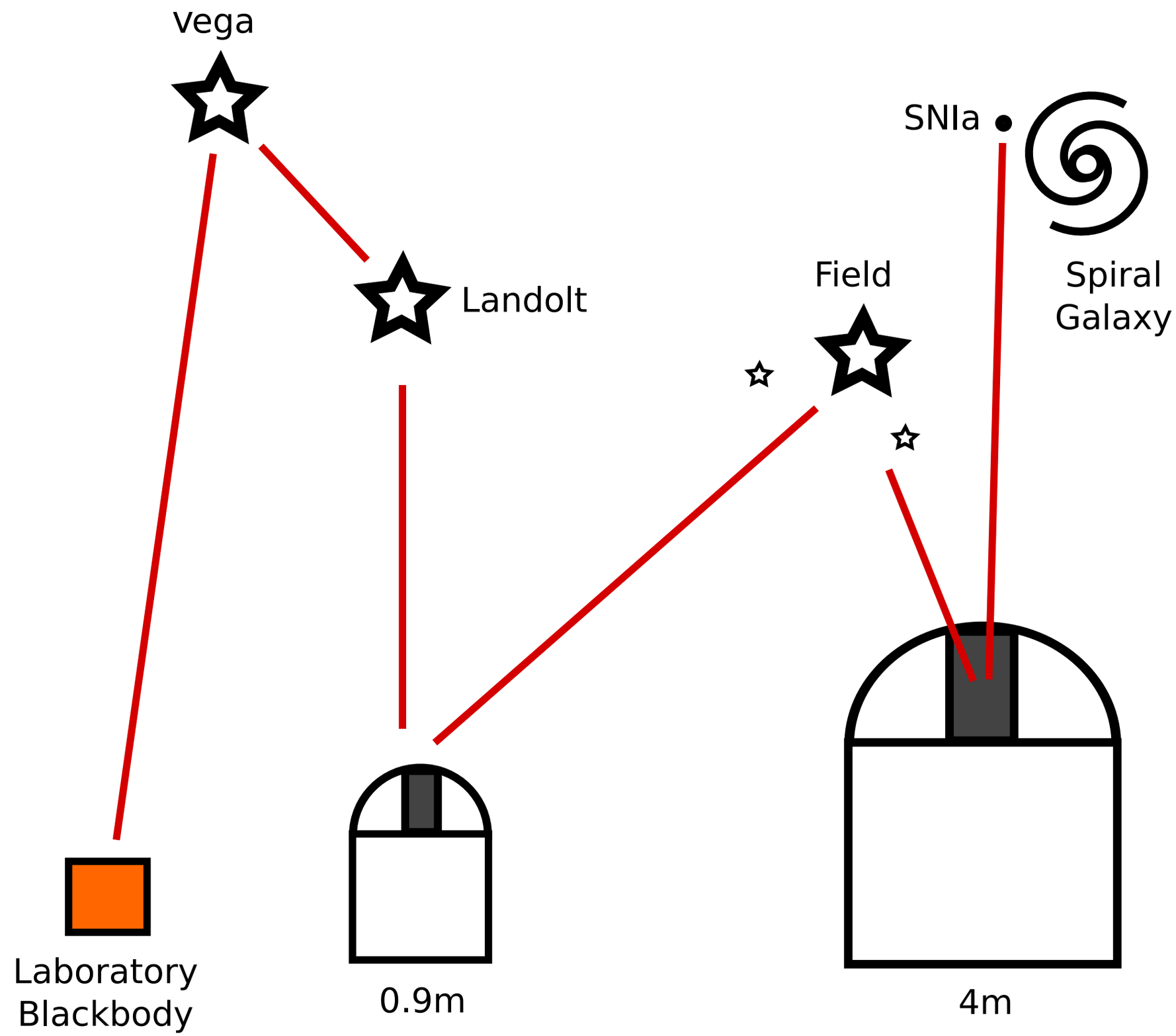




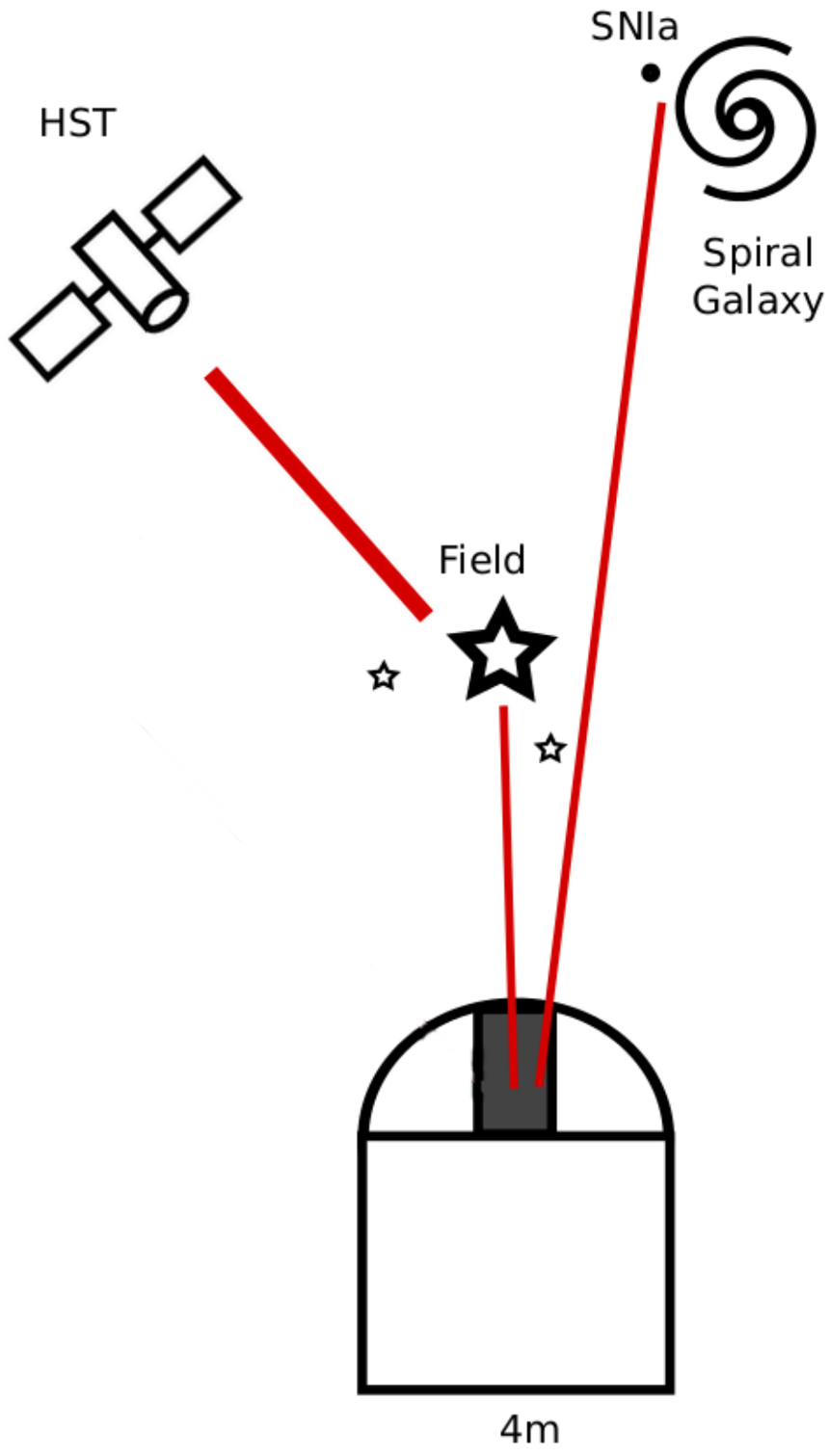

Establishing new standards from the ground is hard, particularly in the NIR

(where supernovae are better standard candles, dust is less of an issue, and where JWST and WFIRST are going to look)

# OUR MOST PRECISELY CALIBRATED PHOTOMETRIC SYSTEM ISN'T ON THE GROUND




It’s possible to simplify this mess.




Much cleaner!

# EXTENDING HST'S CALIBRATION TO THE ENTIRE SKY

# REBUILDING CALSPEC

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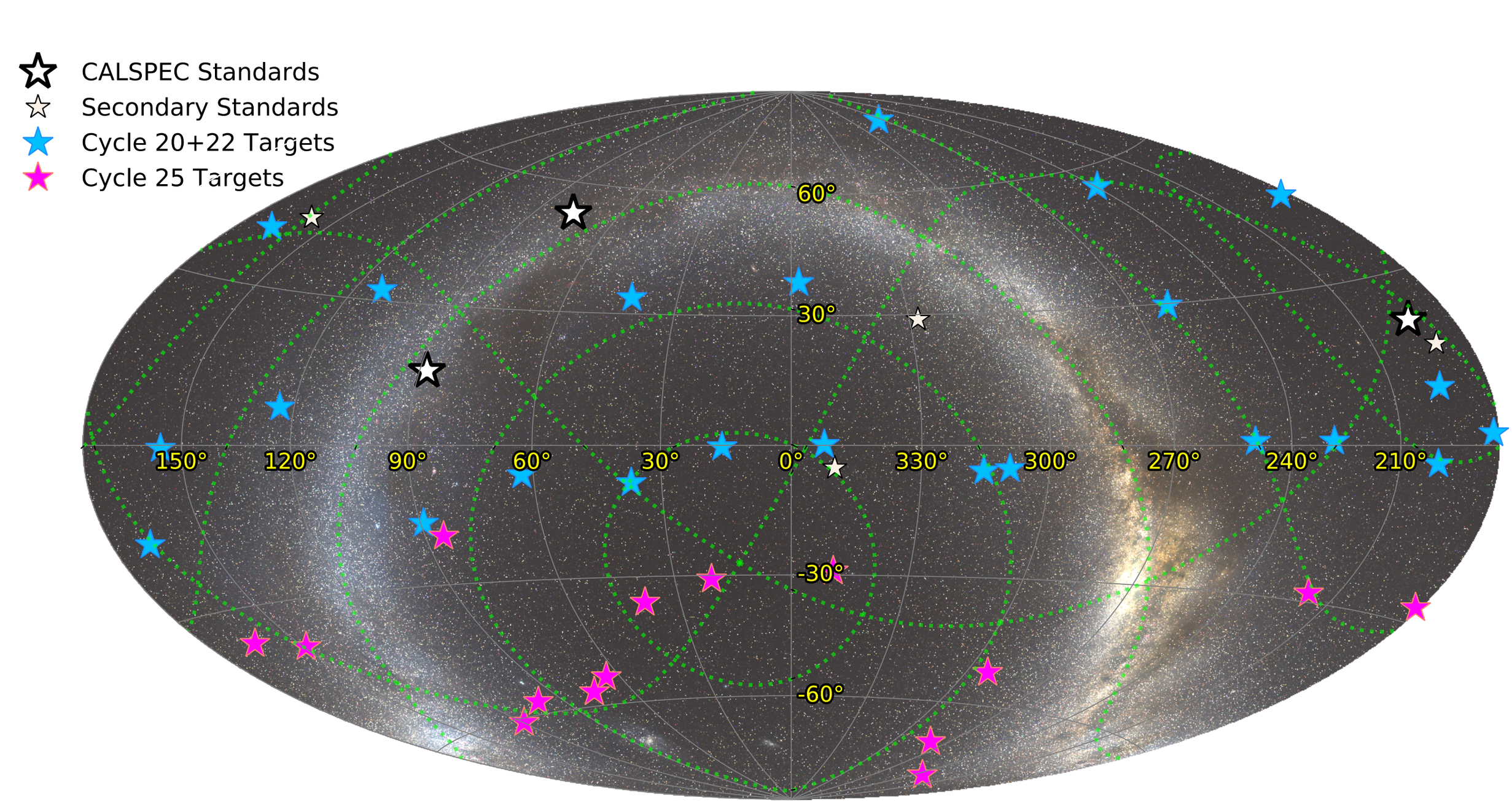
- Why DA WDs? Simple pure Hydrogen atmospheres - most accurate models we have

- Faint - V~ 16.5-19.5 - can observe them directly with LSST




Spectra for ~35 DA WDs (MMT, Gemini, SOAR)

HST photometry for 23 northern + equatorial candidates

Always at least three standards from any site - some close to proposed LSST deep drilling footprint

Proof-of -concept with first four objects we had data for in Cycle 20 (Narayan+, 2016)

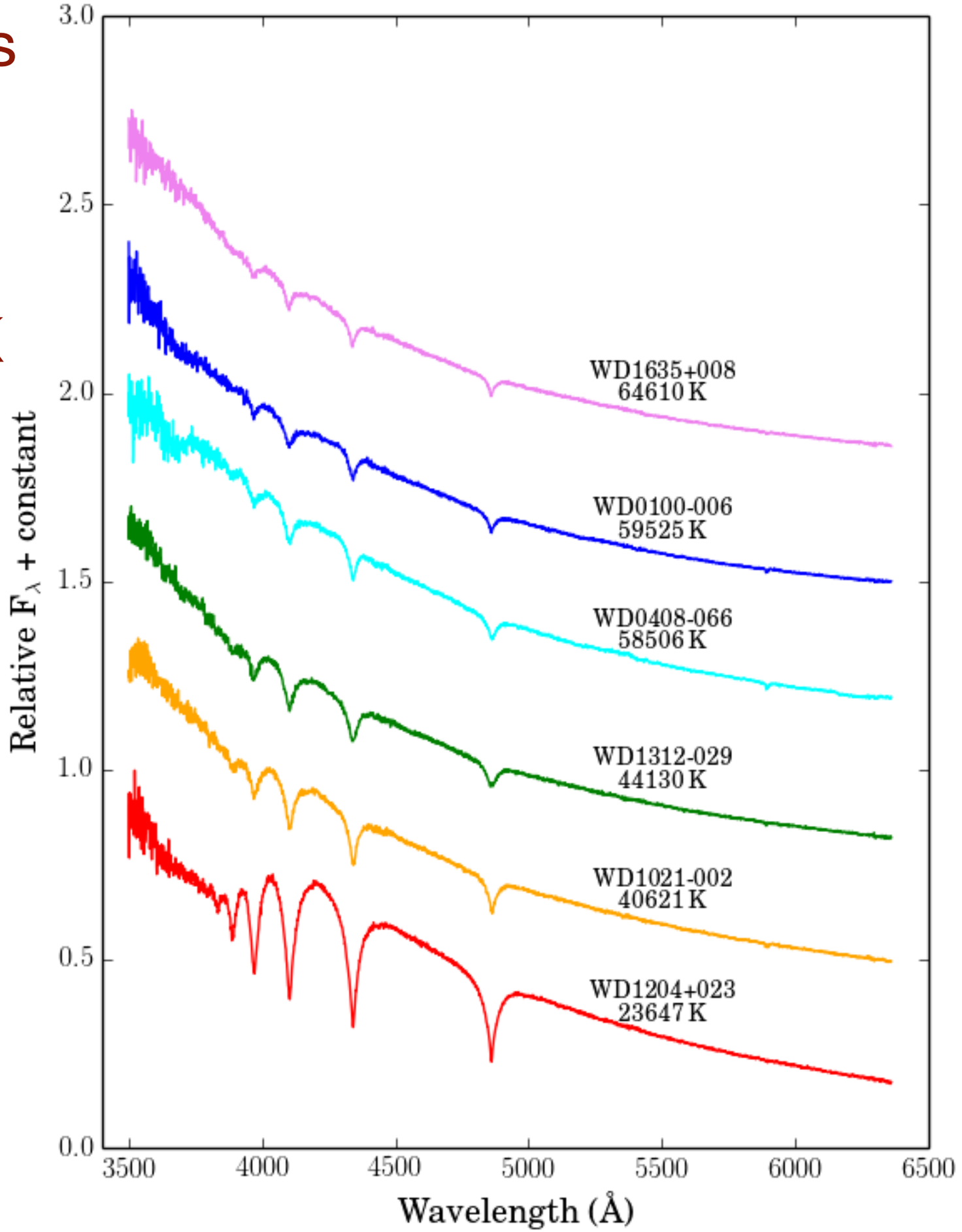
“What could possibly go wrong? Part Deux”

Spectroscopy constrains $T_{eff}$ , log(g)

Pick targets with
22000K $< T_{eff} <$ 75000K
$7 <$ log(g) $< 8.5$

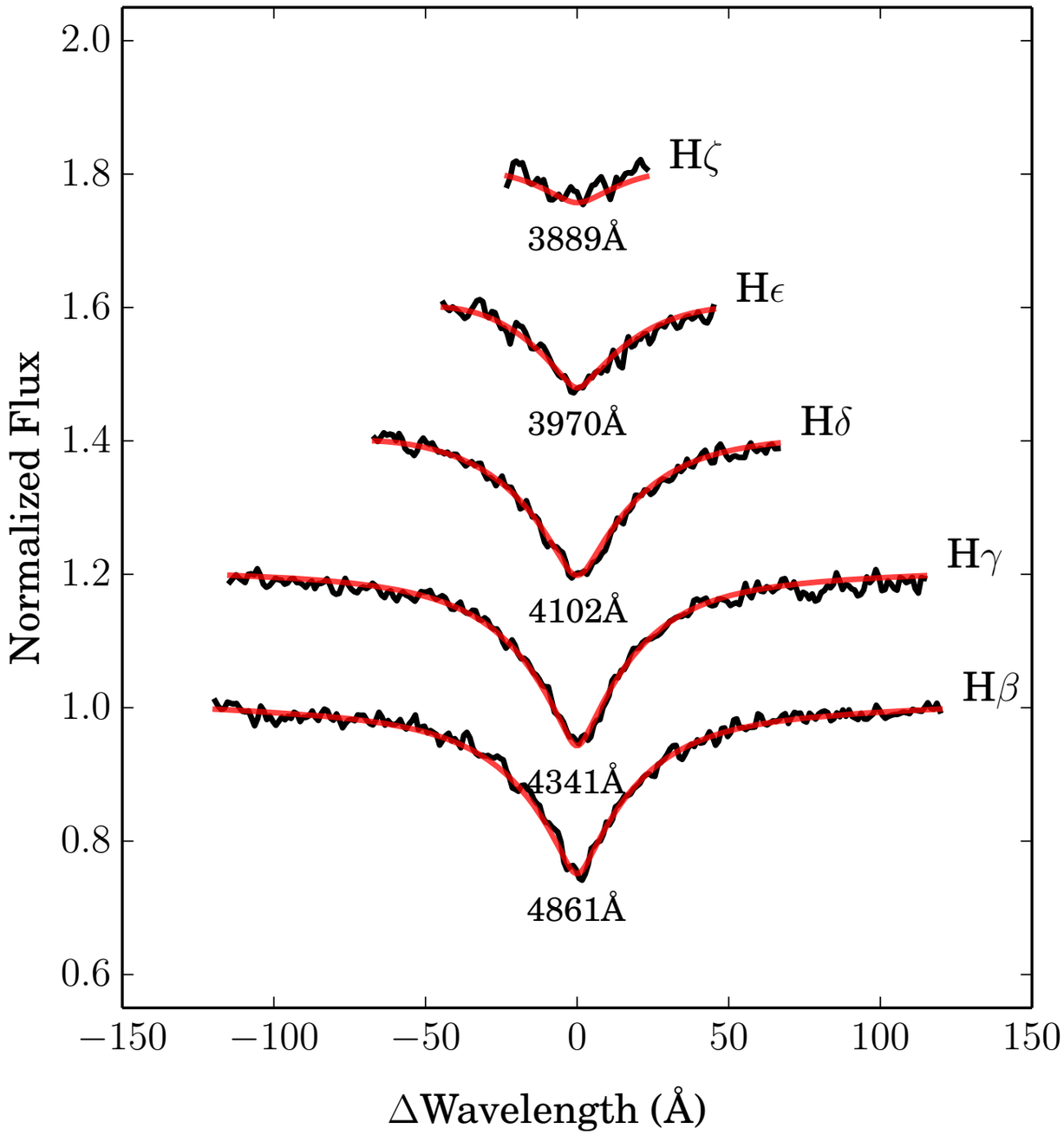
Faint targets are distant
- interstellar extinction

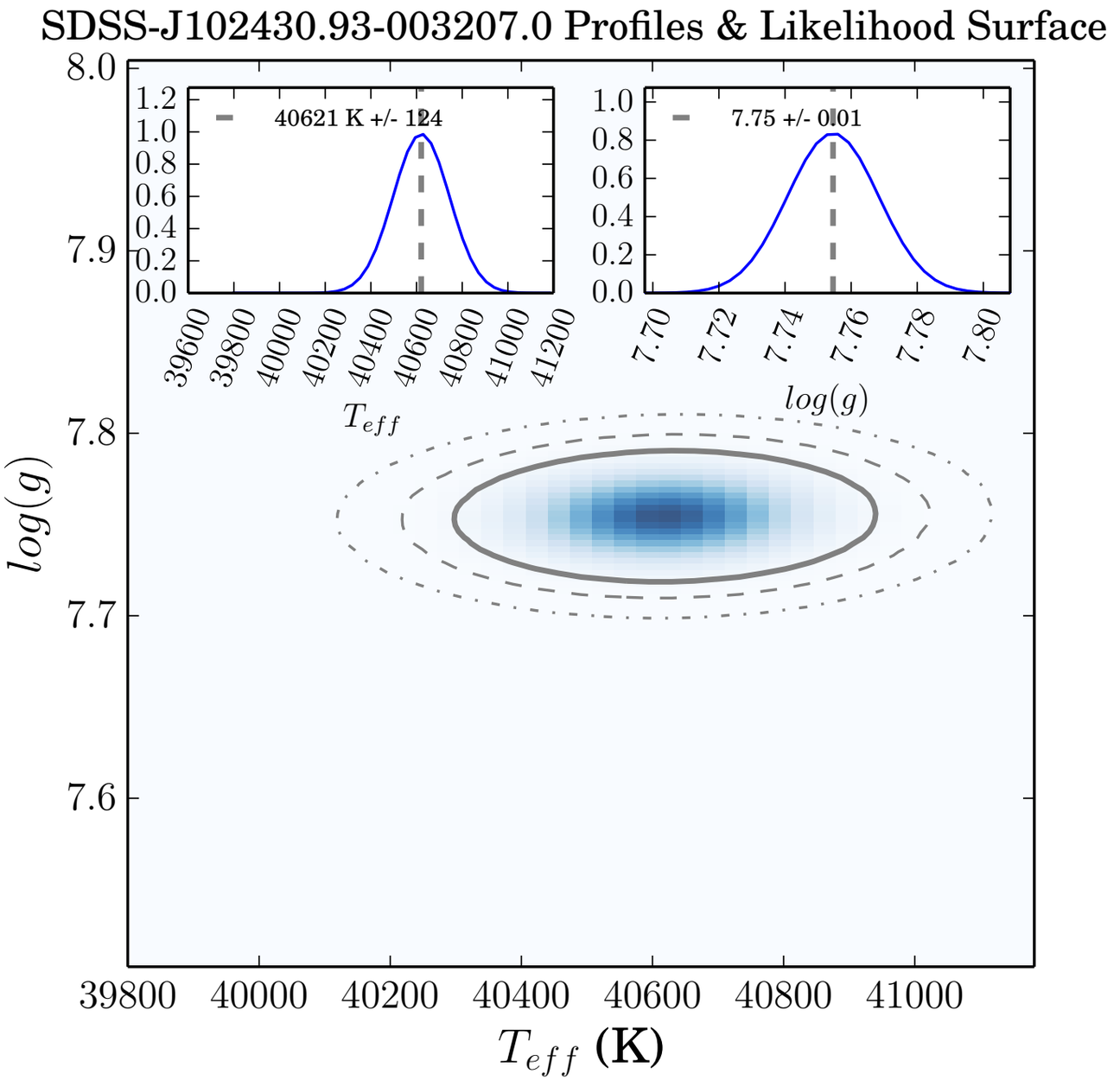
Multiband HST photometry from drizzled images to establish absolute flux, constrain reddening

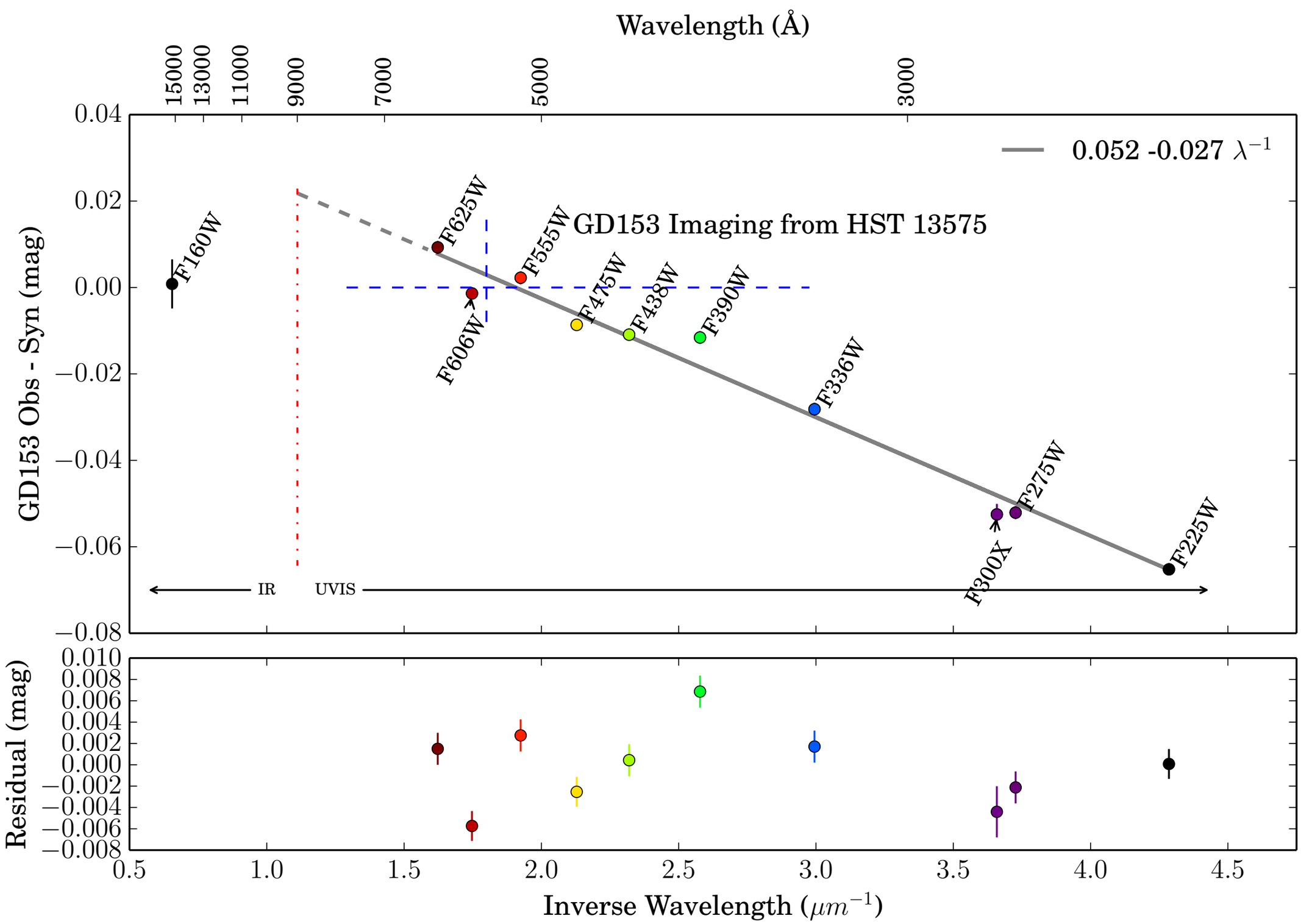


Last generation of white dwarf atmosphere codes = de-reddened and flattened spectra, extracted Balmer lines, separately fit for reddening.

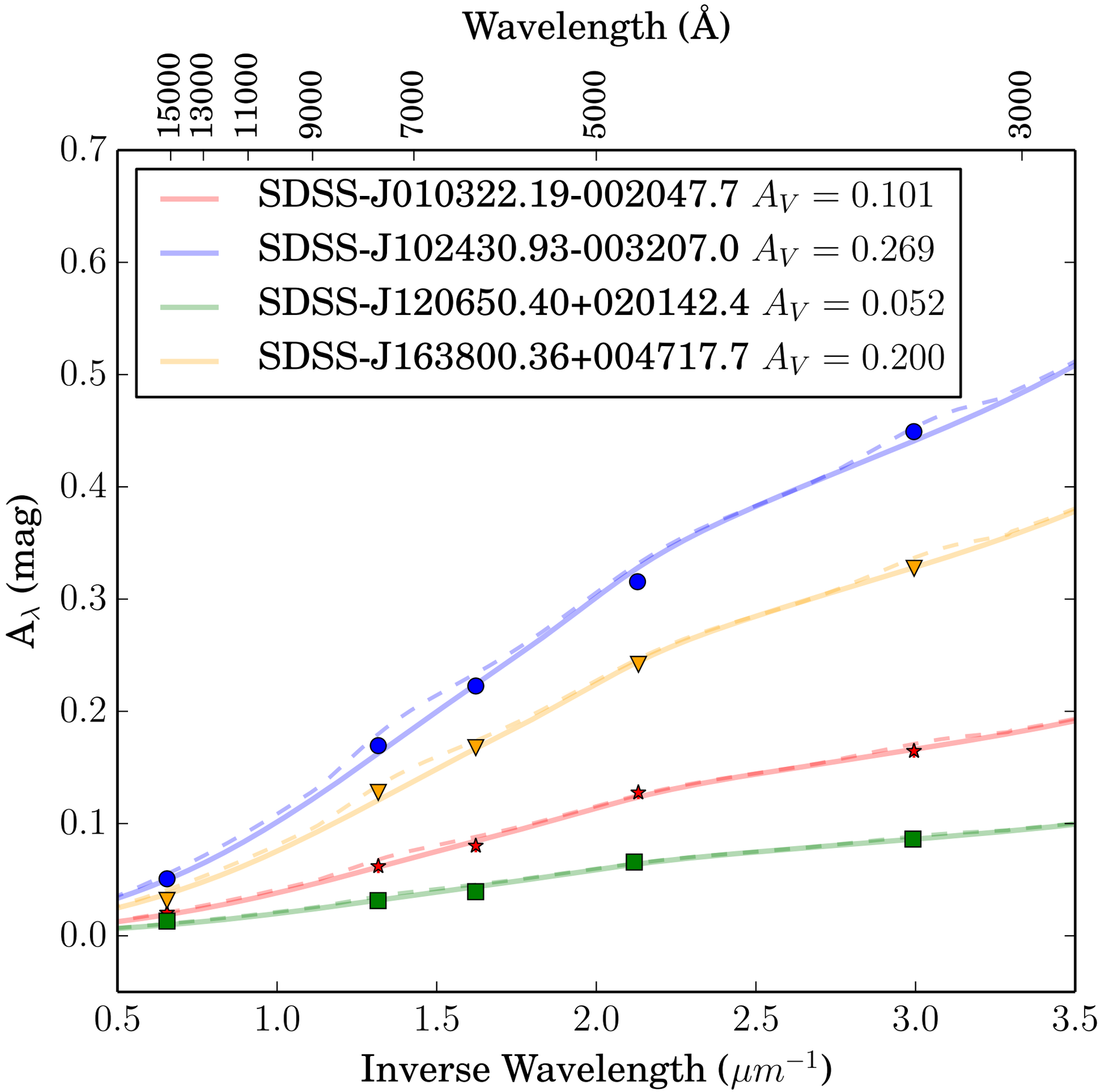
Ignored covariance, between parameters, correlated residuals, was very susceptible to bias with lower S/N data



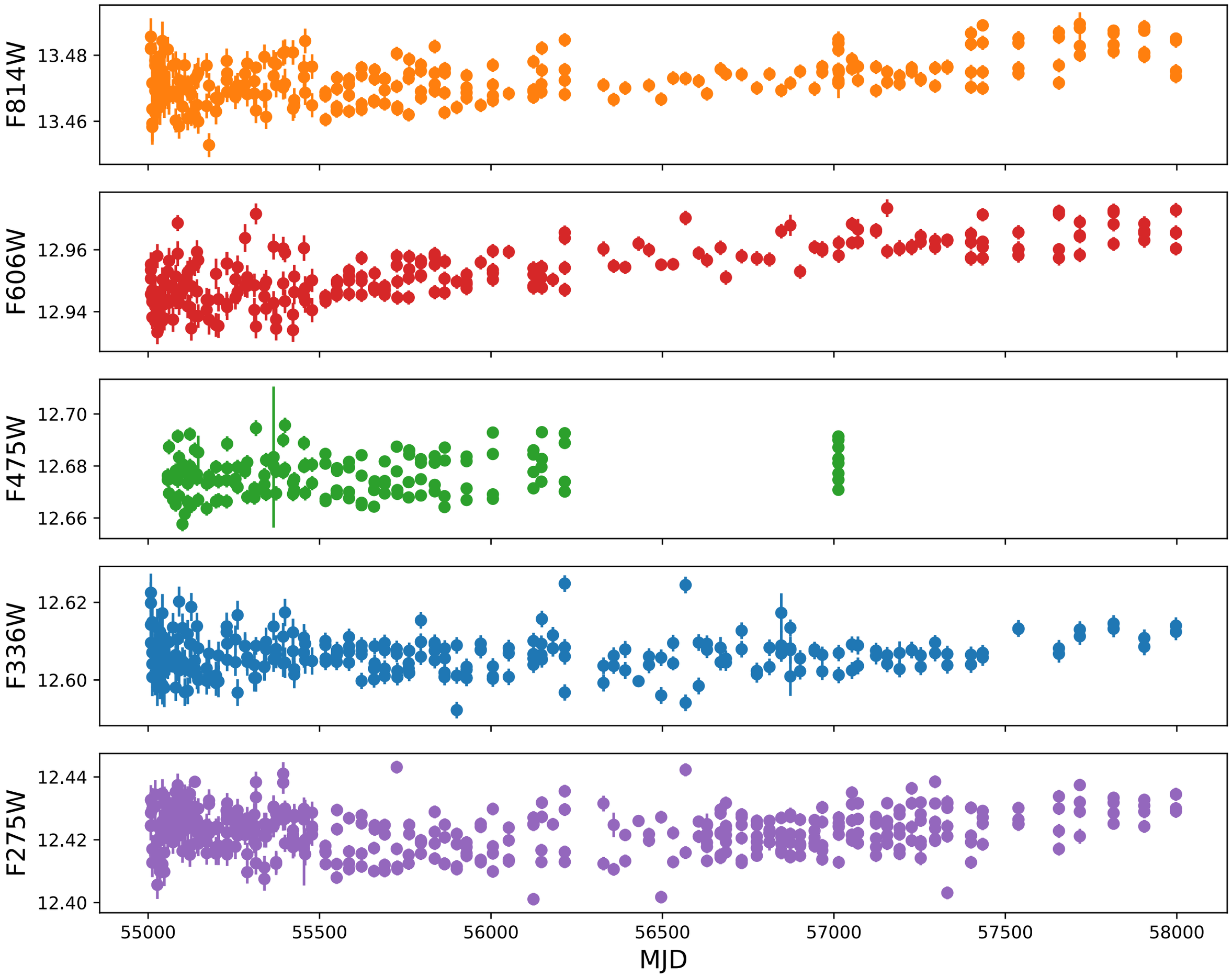






We took our calibration, checked against GD153 & we found issues!
UVIS1/2 have very different QE.
MAST data products  from late 2016 on now reflect this.


Wavelength (Å)
15000
13000
11000
9000
7000
5000
3000
SDSS-J010322.19-002047.7 $A_V = 0.101$
SDSS-J102430.93-003207.0 $A_V = 0.269$
SDSS-J120650.40+020142.4 $A_V = 0.052$
SDSS-J163800.36+004717.7 $A_V = 0.200$
$A_\lambda$ (mag)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Inverse Wavelength ($\mu m^{-1}$)

"This is good, but that trend we corrected for was kinda shocking! Ralph/Susanna - how well do we know these WFC3 zero points actually?"


F814W
13.48
13.46
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12.96
12.94
F475W
12.70
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12.66
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12.44
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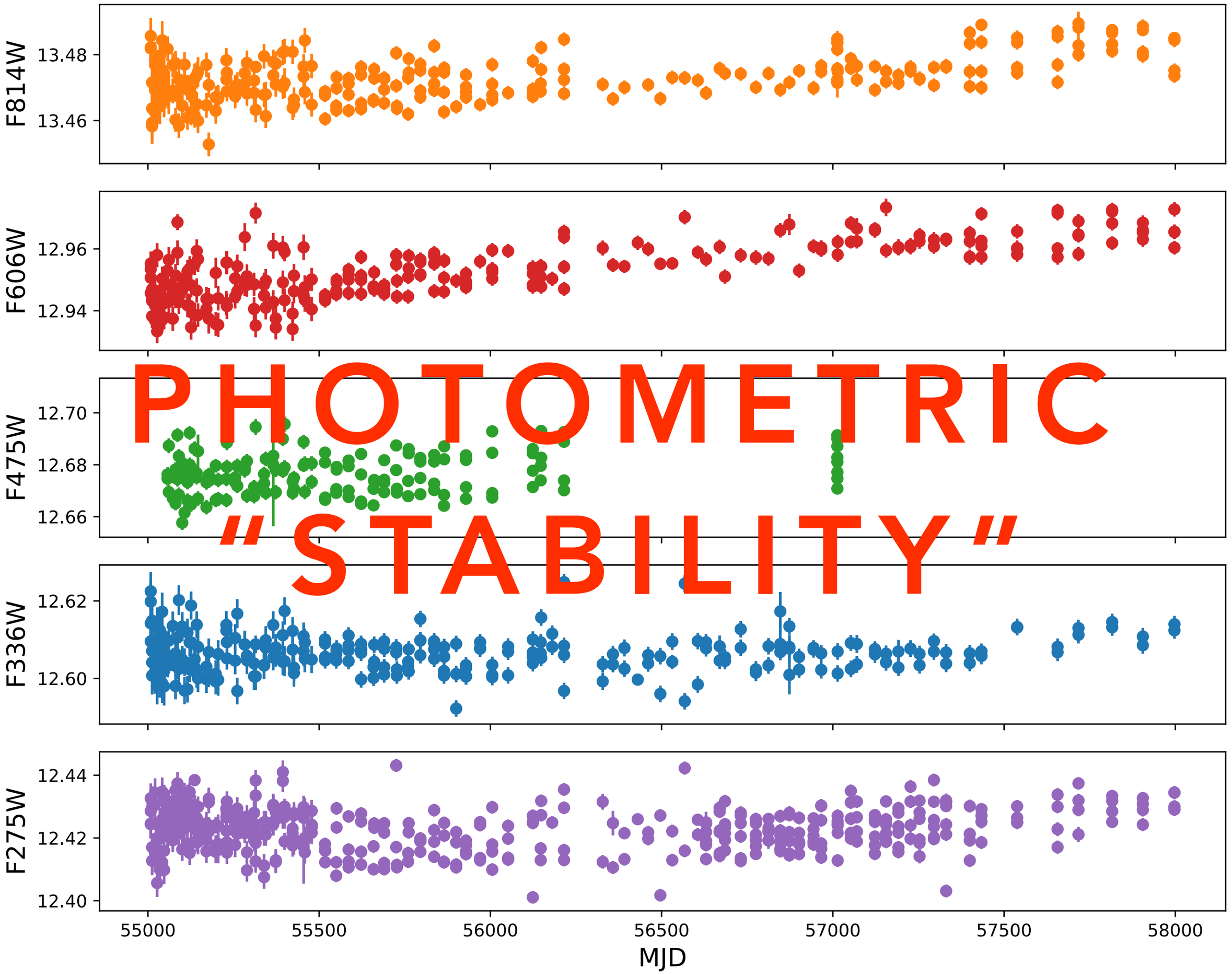
55000
55500
56000
56500
57000
57500
58000
MJD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"STABILITY"

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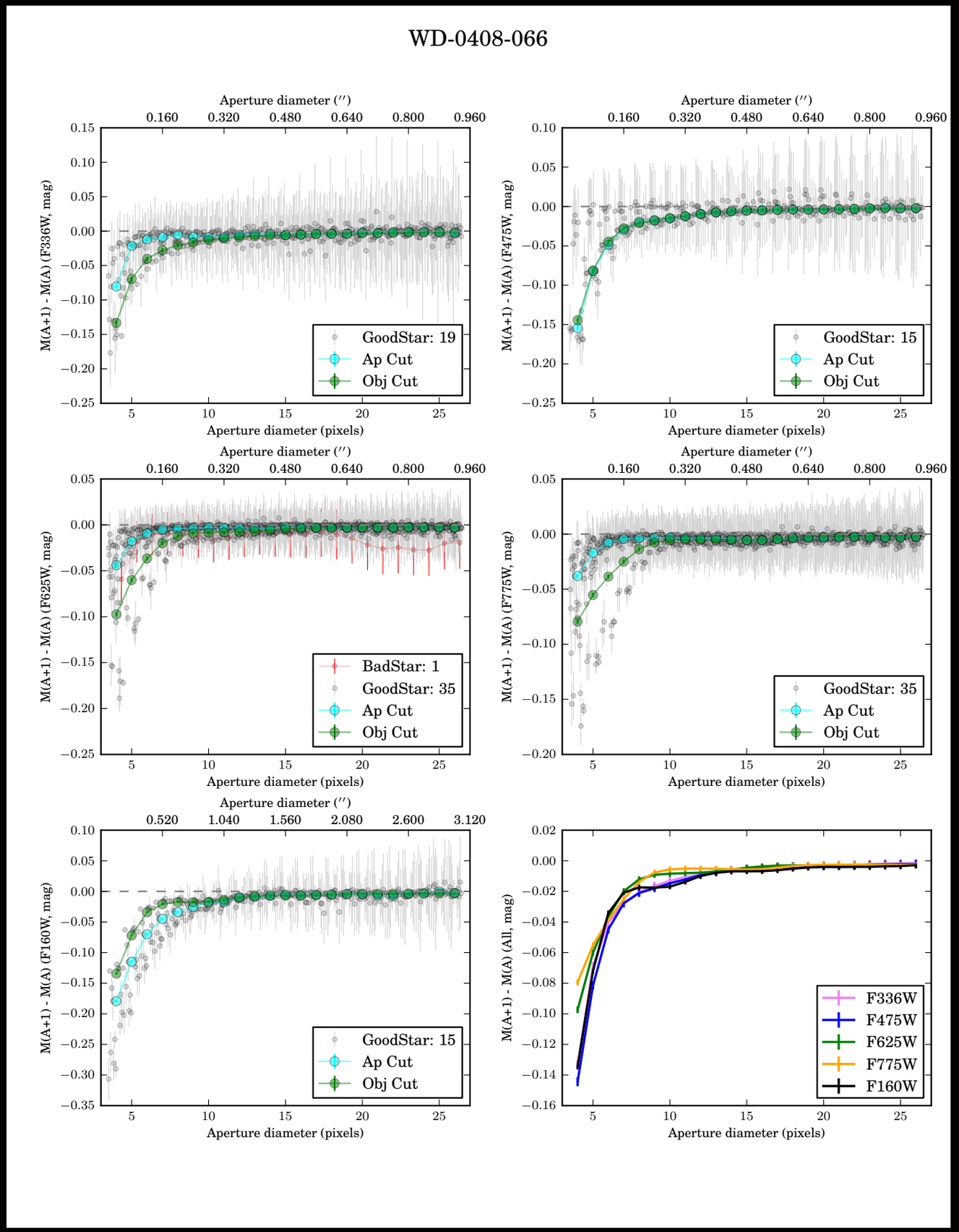
**1% photometry is hard. Below 1% is very hard.**

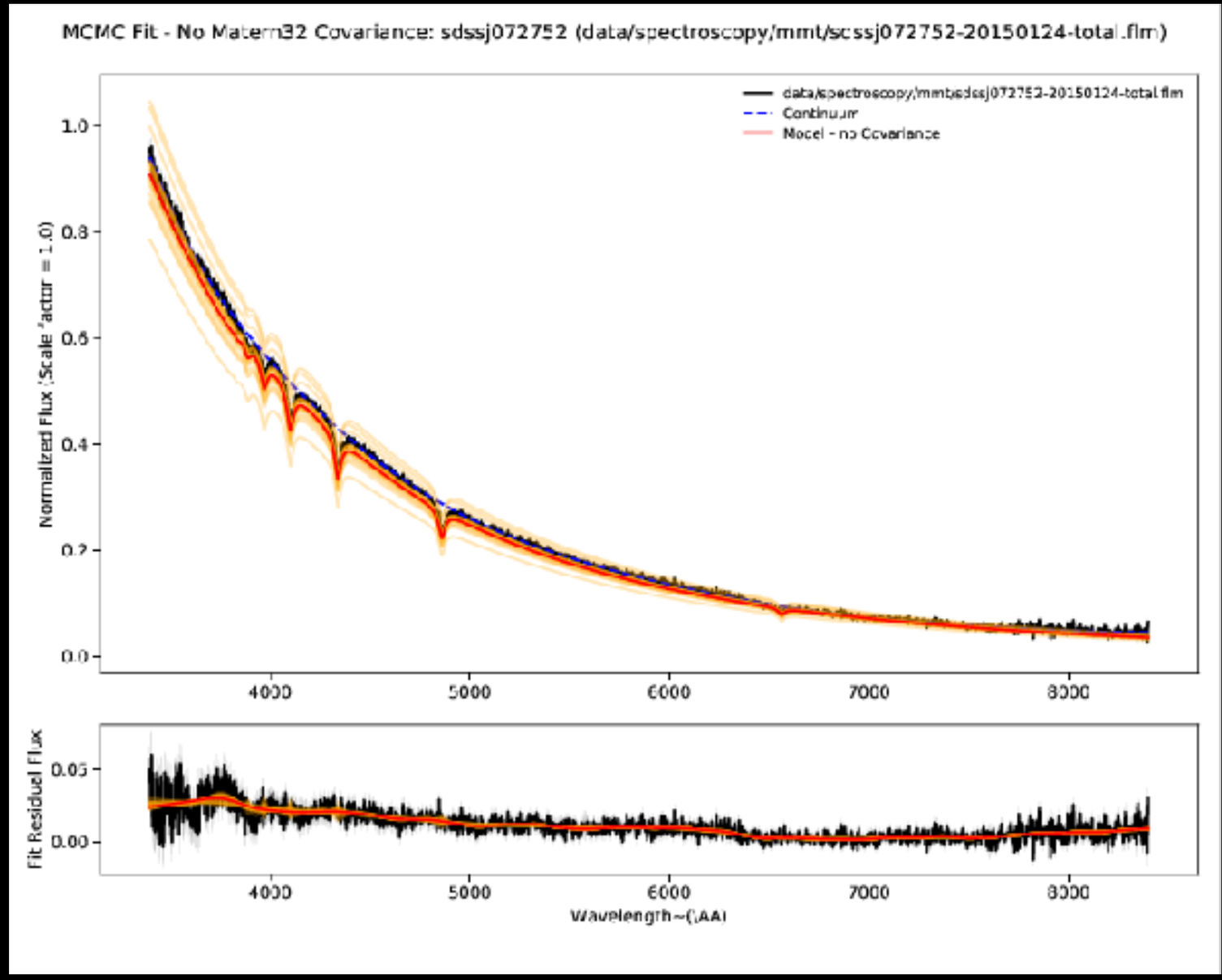
"So if we just fix those things, we're good right?"

# NEW PHOTOMETRY PIPELINE

- Construct flc images from MAST data products to get rid of CTE bleed trails
- Turn of CR rejection since it can change PSFs (F625W, F775W)
- Photometry in sequence of apertures, careful aperture corrections for every image
- Bayesian hierarchical model to solve for mean magnitudes, C20 to C22 zeropoint offsets, zero points, WFC3 dispersion*



# NEW MODELS




- Approach 1: Fit spectra + apparent magnitudes (i.e. tied to CALSPEC standards) http://wdmodel.rtfd.io
- Approach 2: Fit spectra + instrumental magnitudes of CALSPEC standards + our DA WDs to put everything on a common system https://github.com/taxelrod/WDFitPhot
- Colors, parameters should agree with both methods

SDSSJ-081508

Flux (Scaled for $\langle\sigma\rangle \sim 1$)

Gemini GMOS

MMT Blue Channel

Normalized Flux + Constant

$H_\upsilon$ 3889

$H_\zeta$ 3970

$H_\delta$ 4102

$H_\gamma$ 4340

$H_\beta$ 4861

$\Delta\lambda$ (Å)

Residual

Wavelength (Å)

Photometric Residual (mag)

F275W

F336W

F475W

F625W

F775W

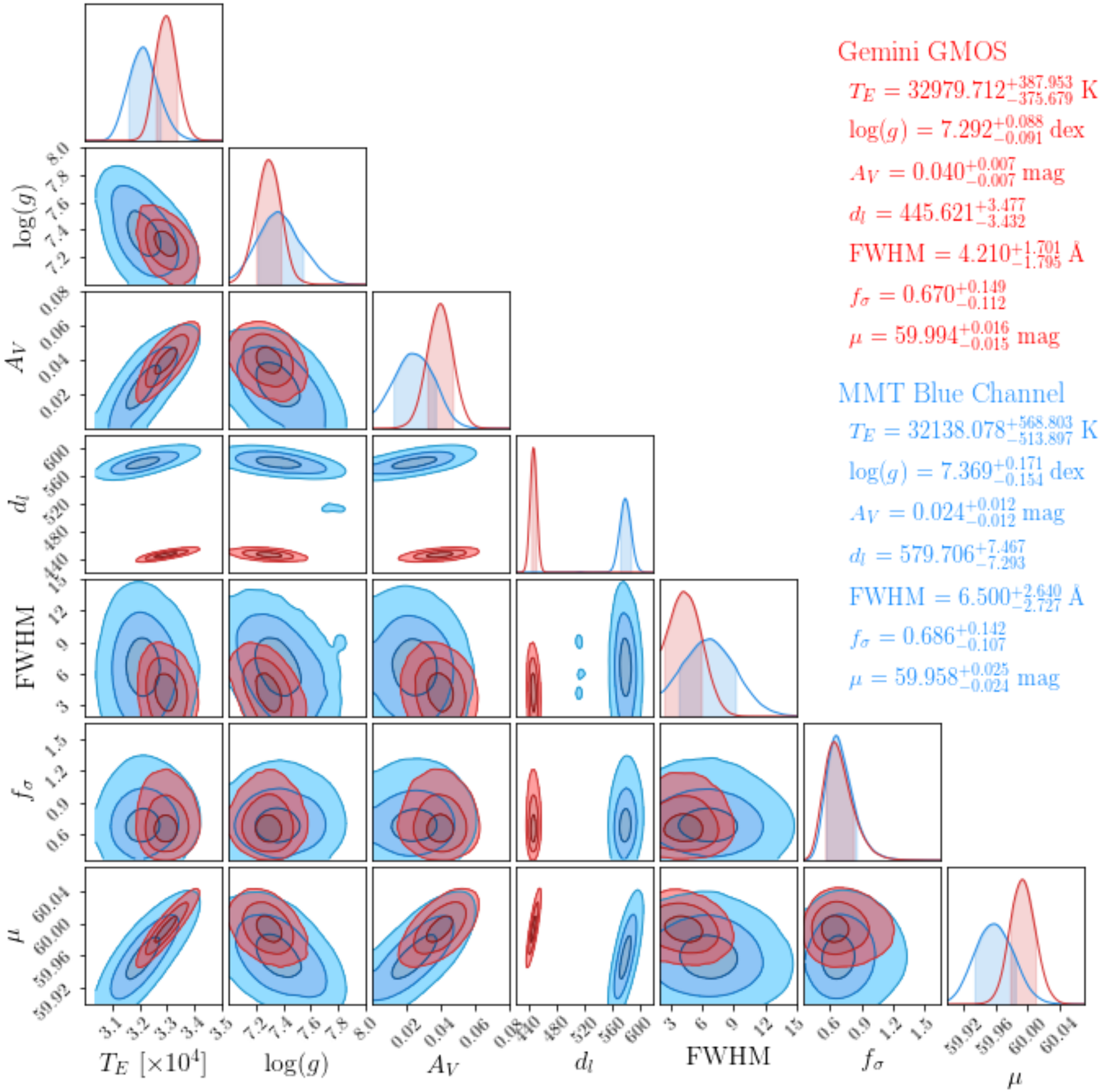
F160W

Passband

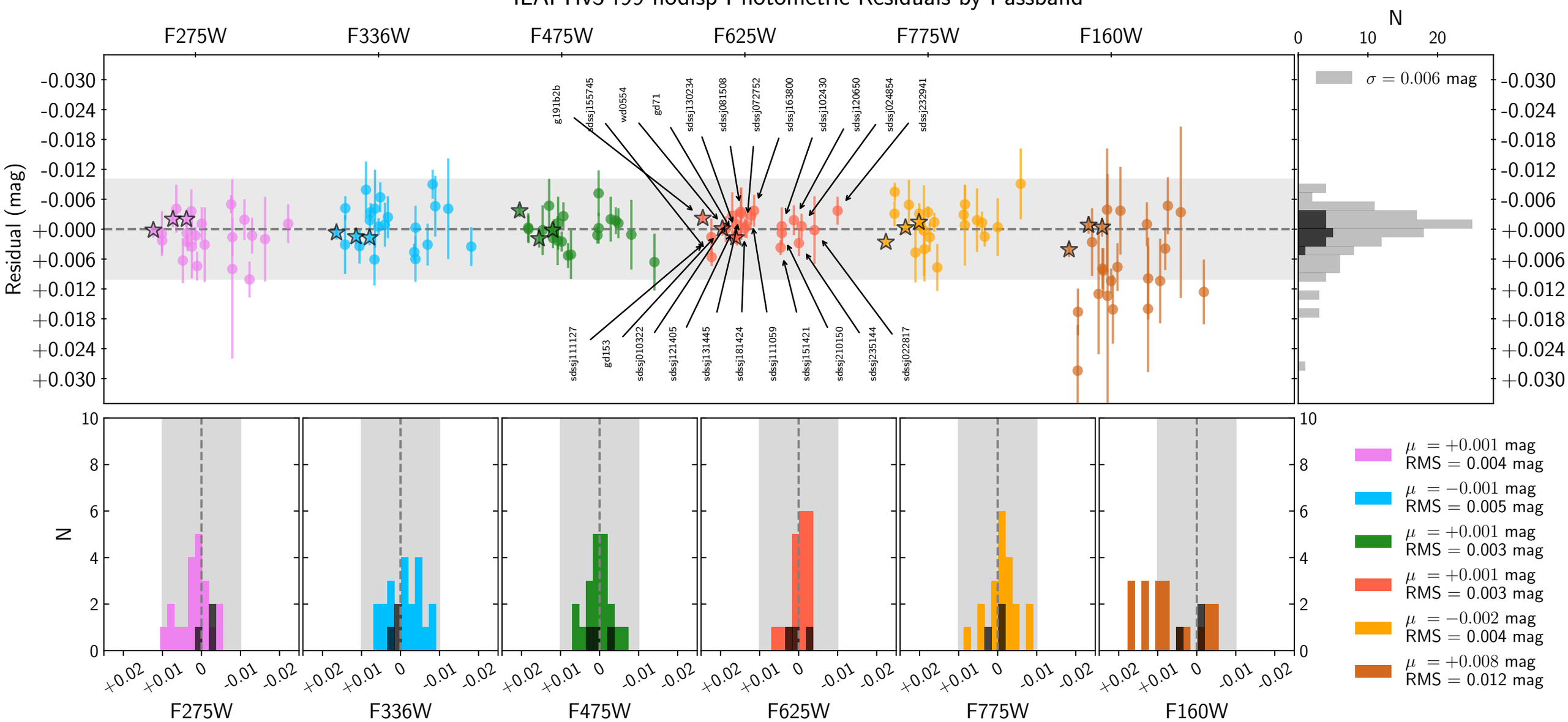
Model HST photometry + spectroscopy (observations AND their noise properties) at the same time

Gaussian Processes for the noise, MPI to distribute computation (we've run it on 32 nodes at once)

Easily extensible if you want to model binary WD spectra or add other parameters



“What could possibly go wrong? Round Three”



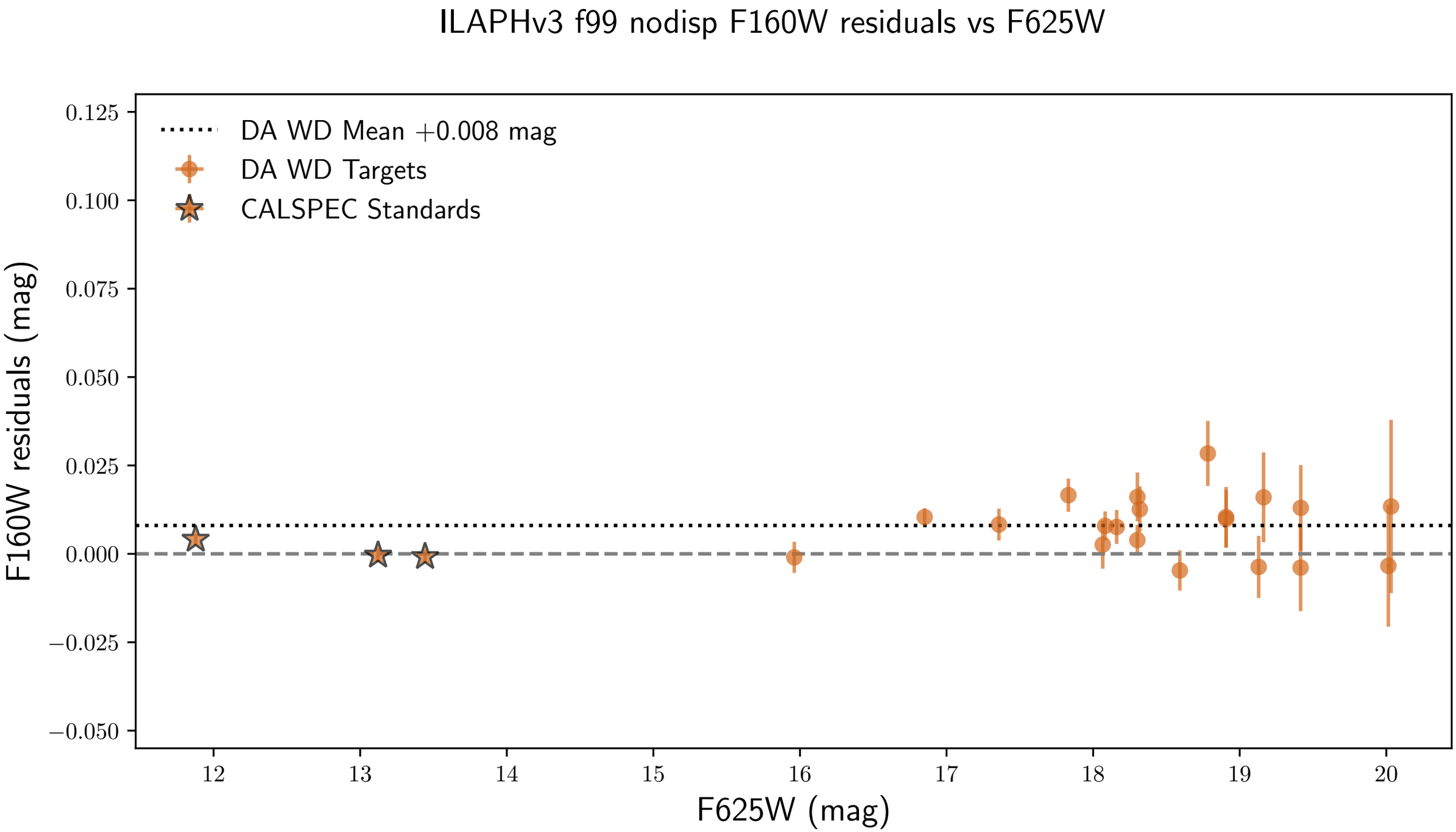

Done with analysis of Cycle 20 + 22 data

We can characterize zeropoint differences relative to CALSPEC (minuscule), overall dispersion, and the RMS

The RMS is less than 0.01 mag in every single band (covering NUV to NIR) - better than 0.005 mag in the optical

WHO ORDERED THAT?

# F160W?????



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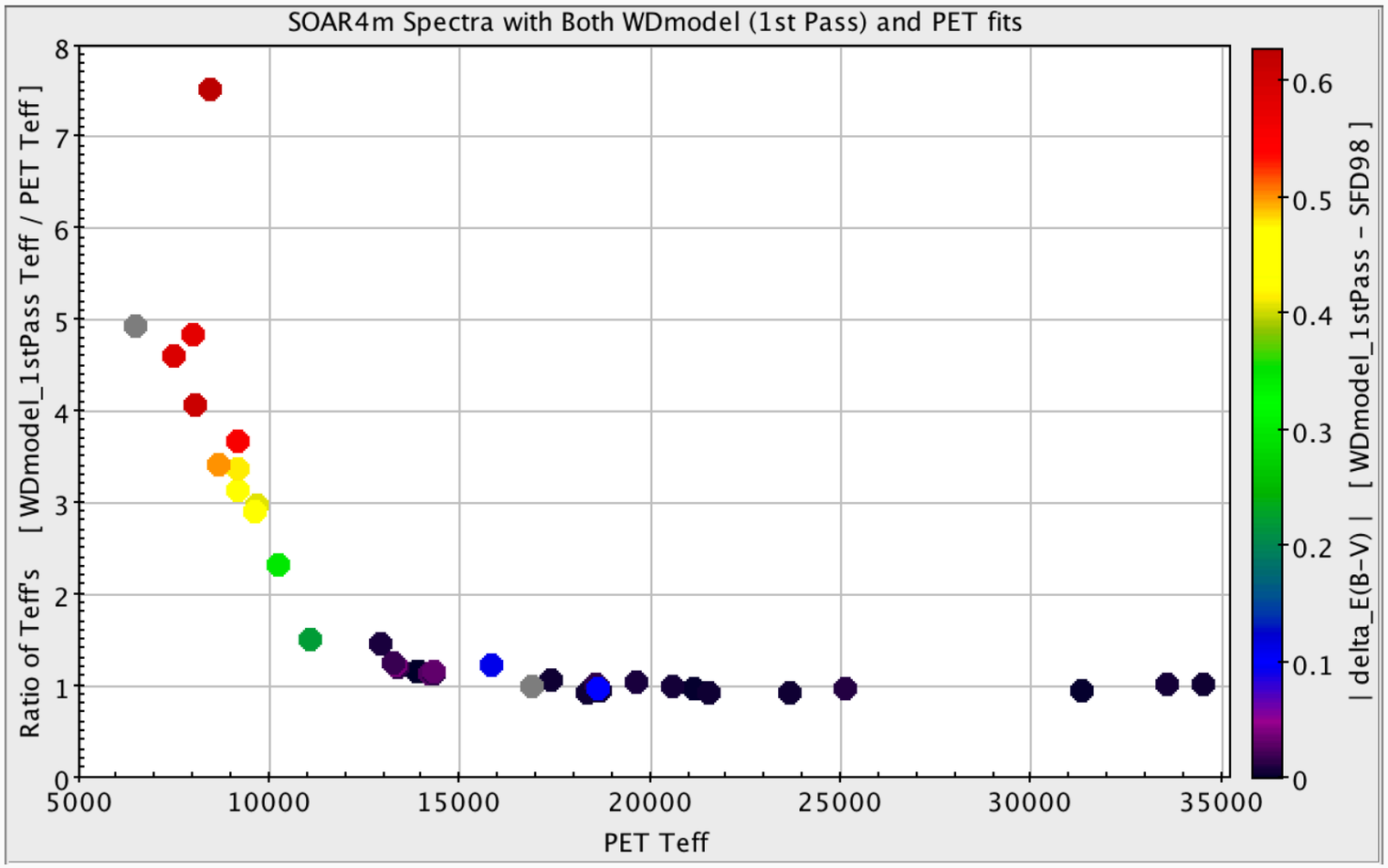
    - WFC3/IR exhibits some count rate non-linearity

# WDModel Conservative Fit Results

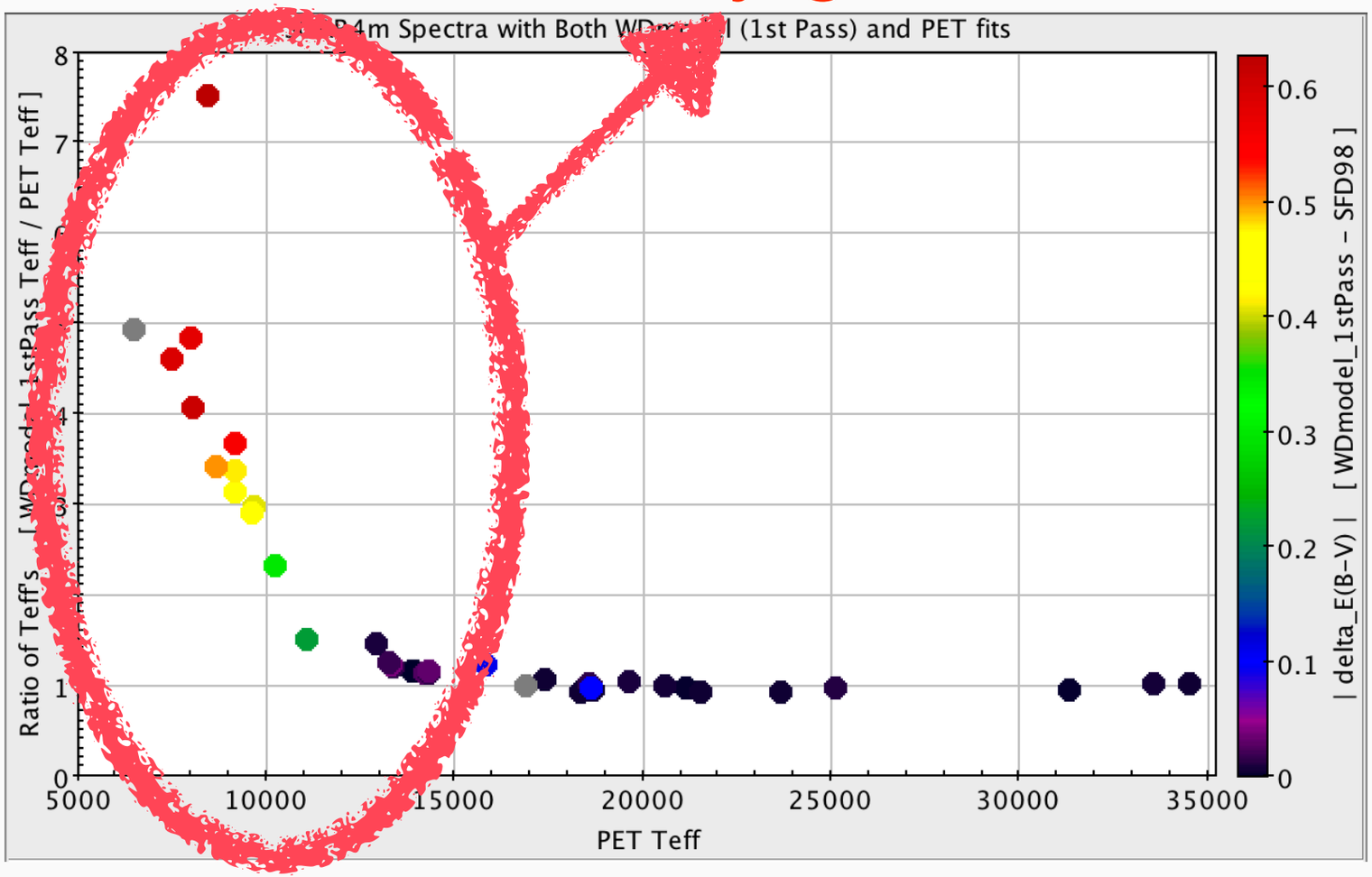



Plot created by Douglas Tucker showing the ratio of the fit values for Teff from the 2 sources vs. the Teff from Pier-Emmanuel's fits. Color-coded to show the absolute deviation of the WDmodel fit value for E(B-V)

Courtesy, Douglas Tucker, Deborah Gulleidge, DES

# WDModel Conservative Fit Results

Grid only goes down to 16,000K

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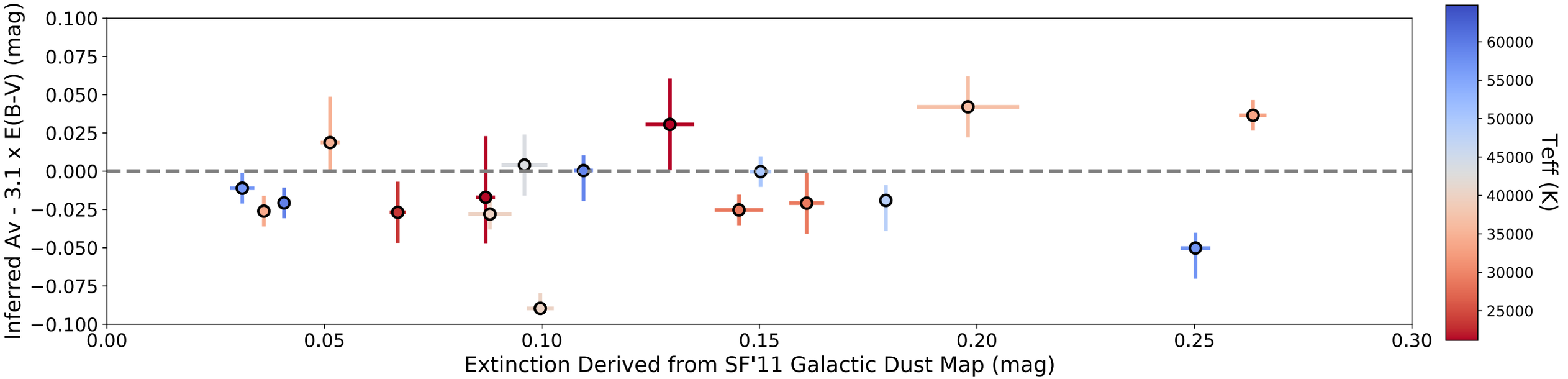
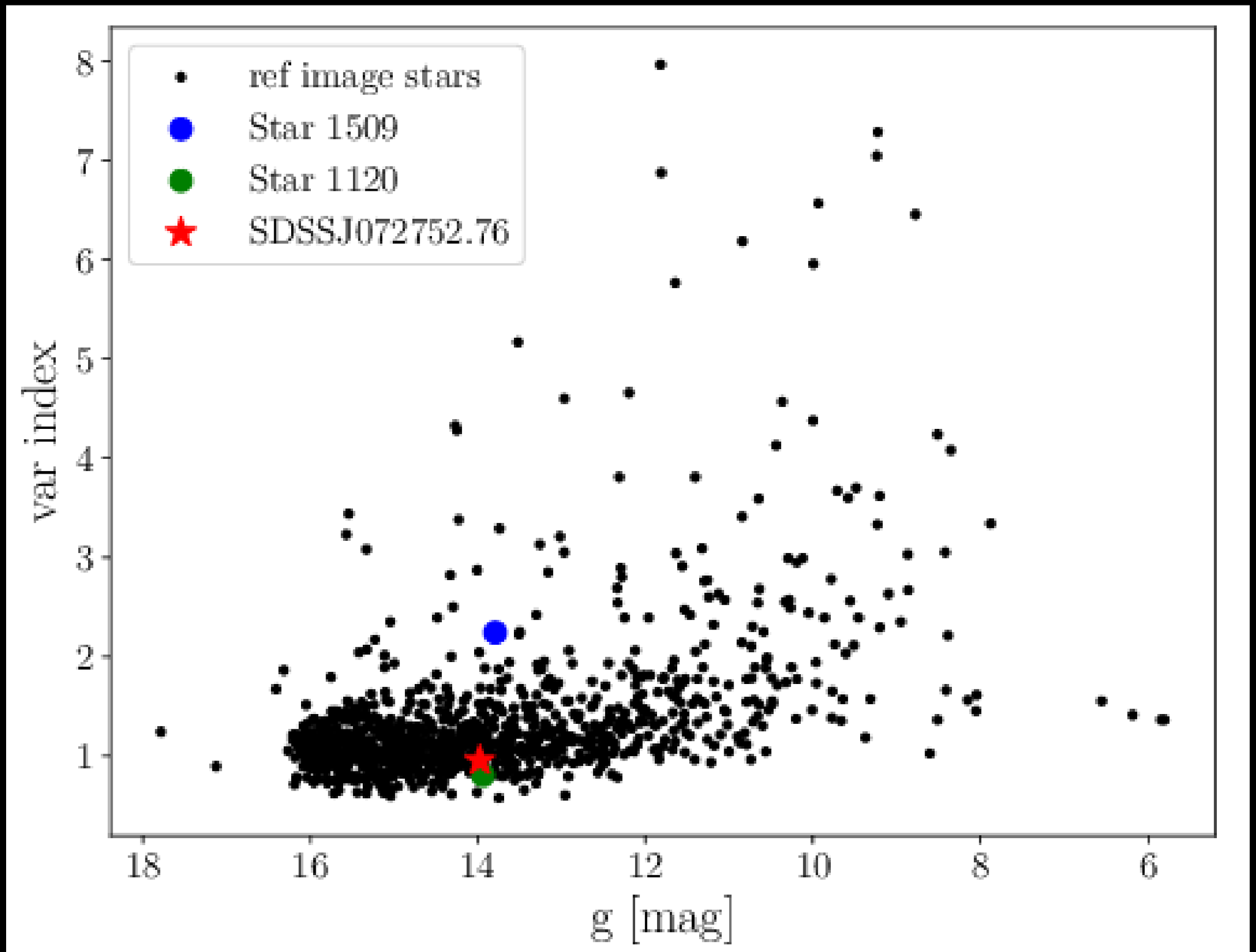
# EXCELLENT AGREEMENT WITH DUST MAP




Also in good agreement with estimates from Green et al. 3D dust map from PS1

With full sample, should be able to fit for dust law shape independently from entire sample (assumes all objects have the same dust law).

# MULTI-YEAR LCO MONITORING TO DETECT VARIABILITY



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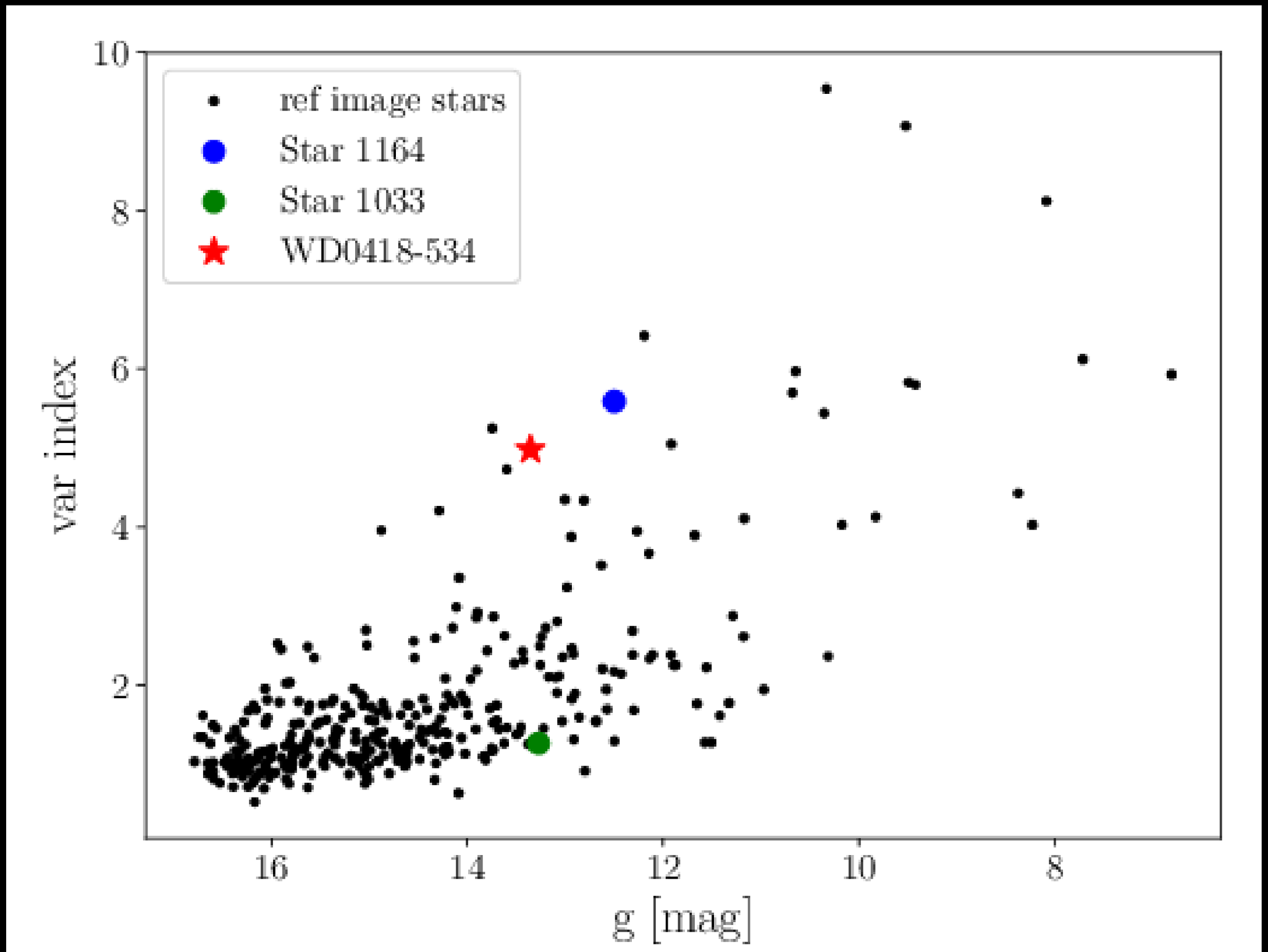

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- Excellent agreement between both fitting approaches, dust map, different model grids

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# CALSPEC+ STATUS

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- Extends CALSPEC across the sky - Data (Calamida+ in prep) and analysis (Narayan+ in prep)

FOR JWST

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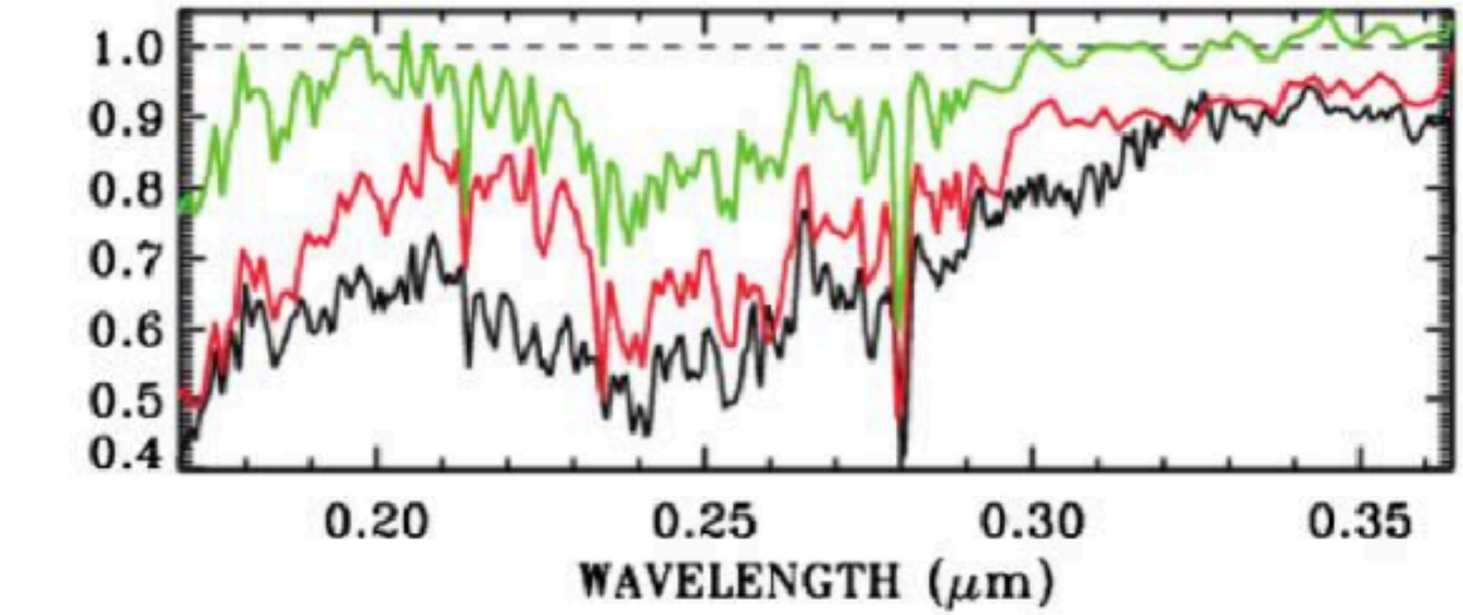
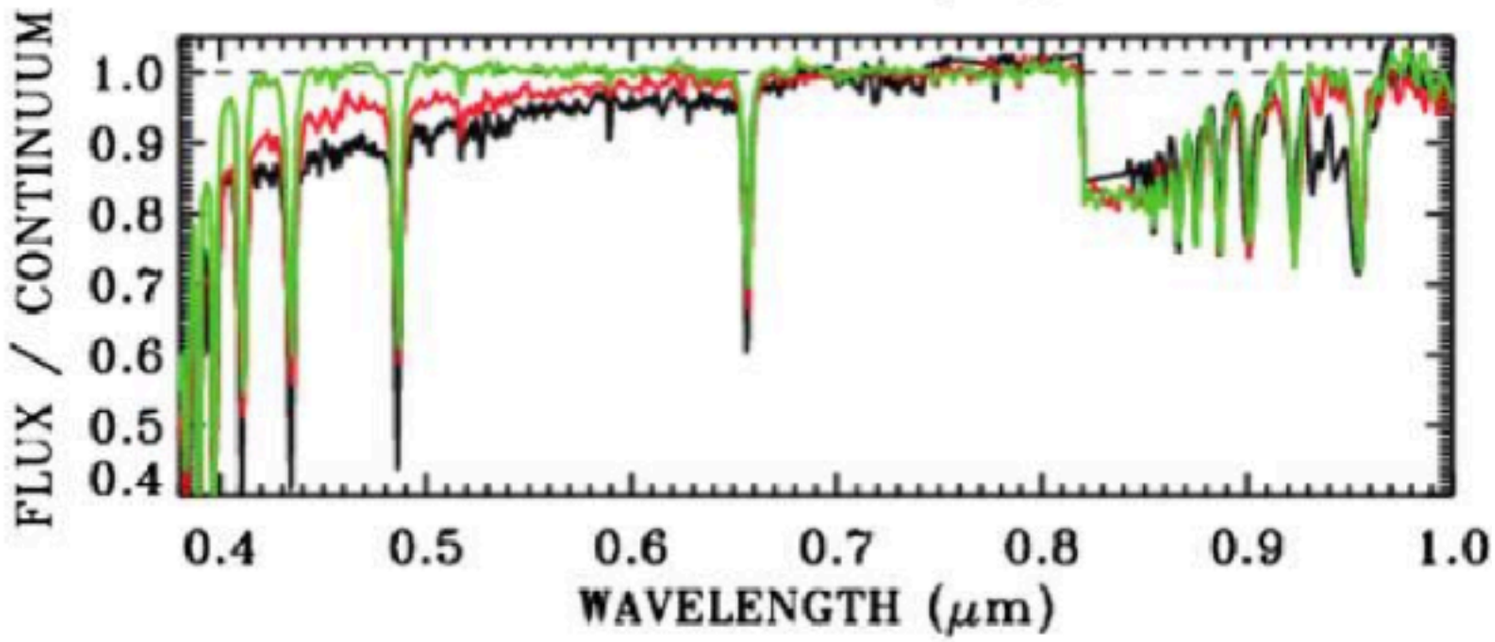
# Modeling in the NIR has large differences

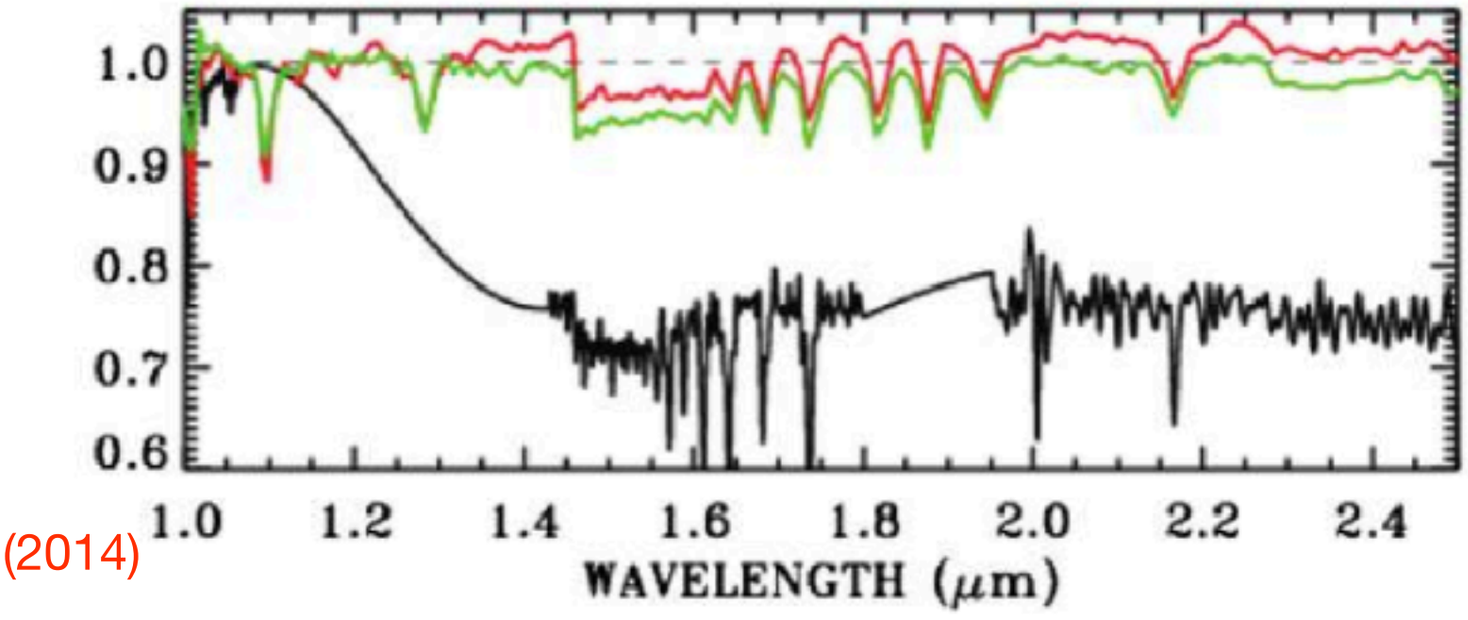
Three stellar SEDs, each 8790 K

Black = Pickles SED
Red = 1732526*
Green = 1802271*

* (STIS + NICMOS)




From R. Bohlin, K. Gordon and P. E. Tremblay (2014)

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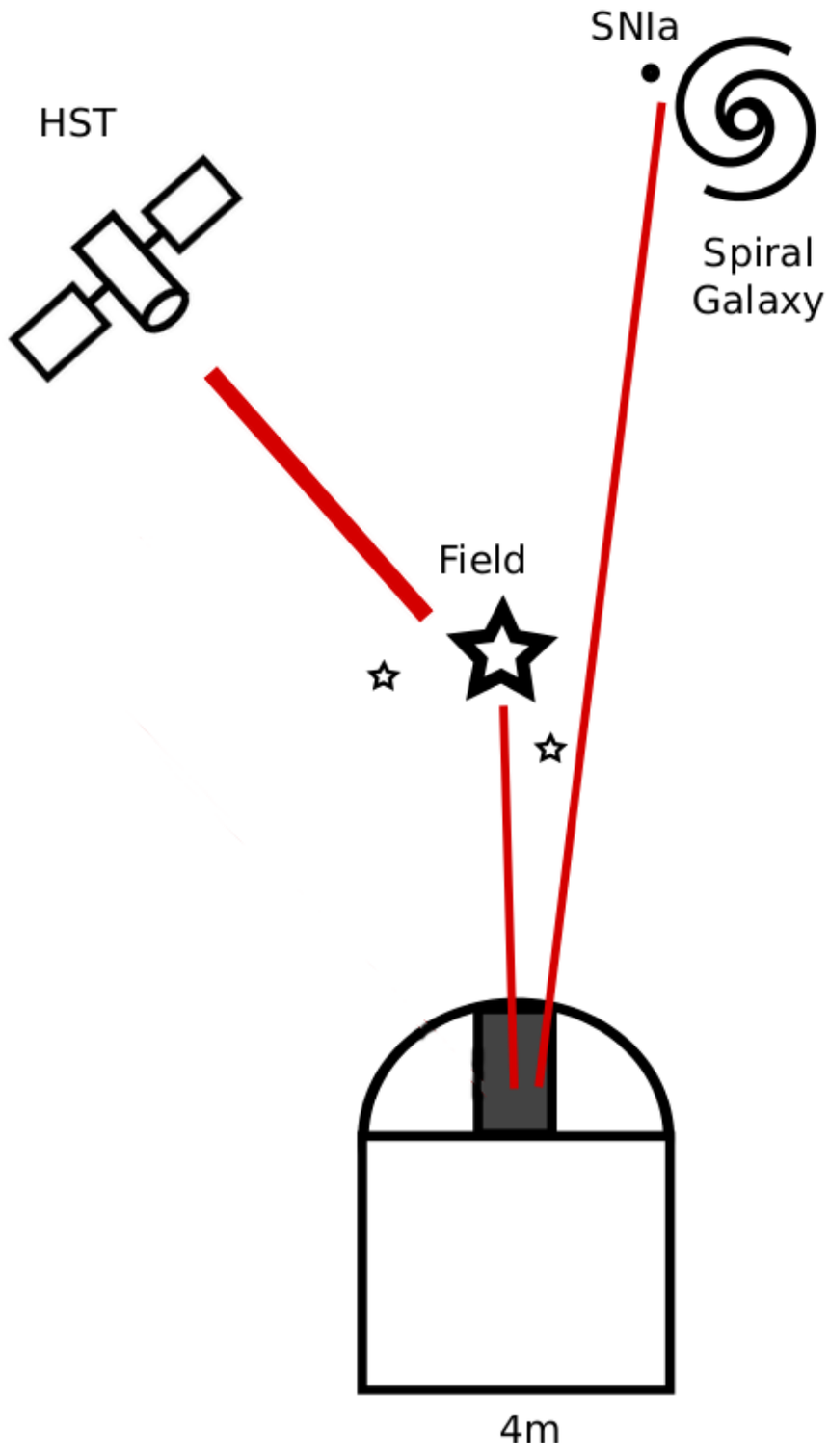
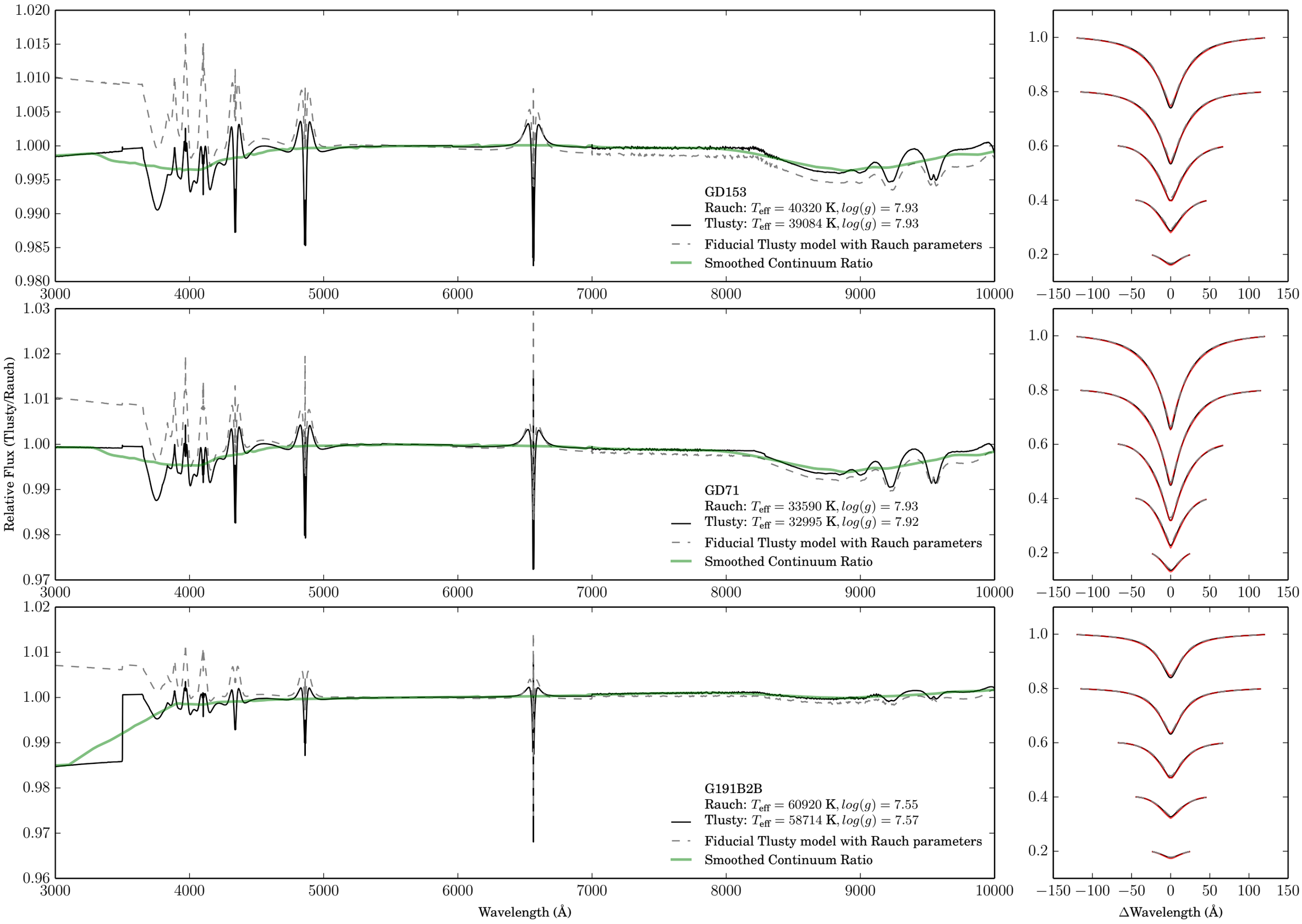
- ALL NEW SYSTEMATICS GUARANTEED!




**For now, do this with our white dwarfs. The End.**


GD153
Rauch: $T_{\rm eff} = 40320$ K, $log(g) = 7.93$
Tlusty: $T_{\rm eff} = 39084$ K, $log(g) = 7.93$
Fiducial Tlusty model with Rauch parameters
Smoothed Continuum Ratio
GD71
Rauch: $T_{\rm eff} = 33590$ K, $log(g) = 7.93$
Tlusty: $T_{\rm eff} = 32995$ K, $log(g) = 7.92$
Fiducial Tlusty model with Rauch parameters
Smoothed Continuum Ratio
G191B2B
Rauch: $T_{\rm eff} = 60920$ K, $log(g) = 7.55$
Tlusty: $T_{\rm eff} = 58714$ K, $log(g) = 7.57$
Fiducial Tlusty model with Rauch parameters
Smoothed Continuum Ratio
Relative Flux (Tlusty/Rauch)
Wavelength (Å)
ΔWavelength (Å)