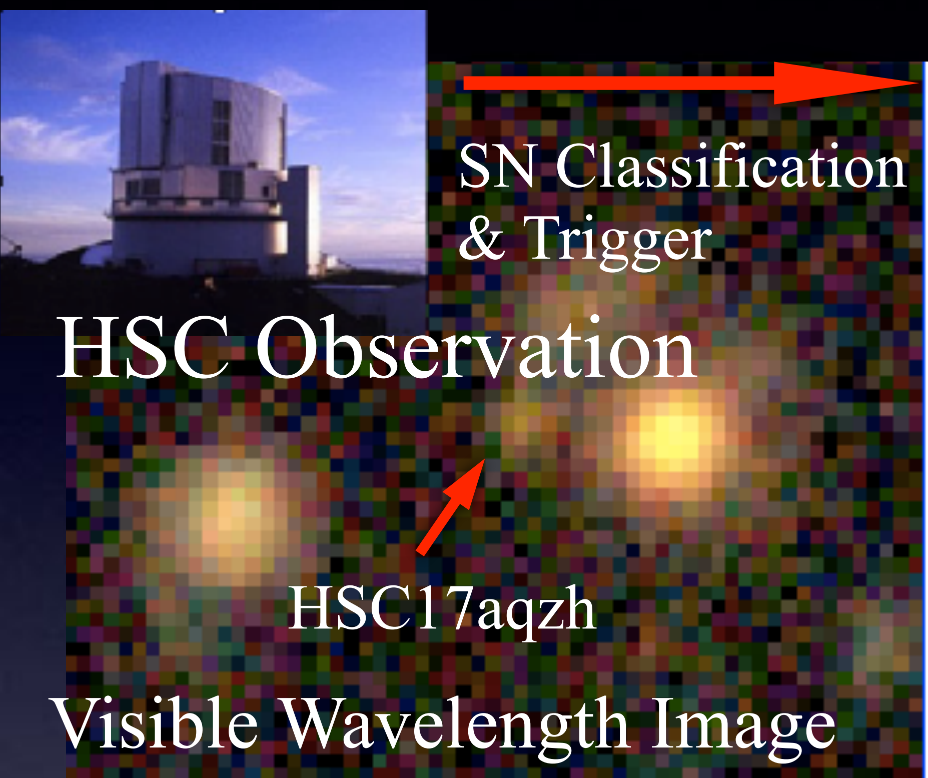
Perfect Blackbody Stars as Primary Flux Standards

Nao Suzuki (Lawrence Berkeley National Lab / LPNHE)

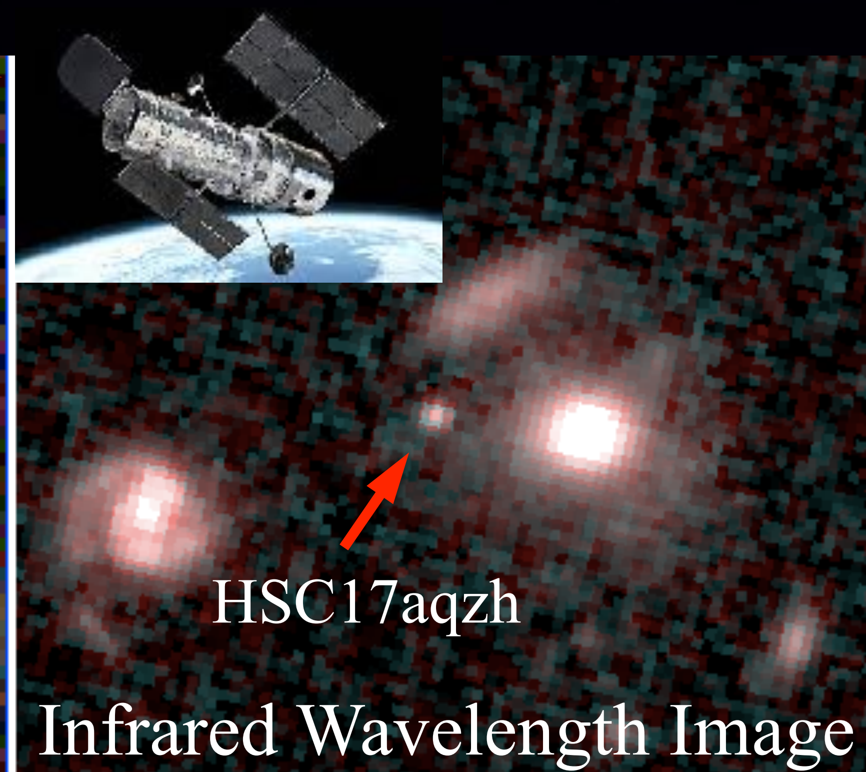
- Vega Spectrum & CALSPEC problems
- Discovery of Blackbody Stars (Suzuki & Fukugita 2018)
- More Blackbody Stars (XShooter, SOAR, Lick)
- UV-Opt-IR Calibration

HSC SNIa Cosmology for Dark Energy

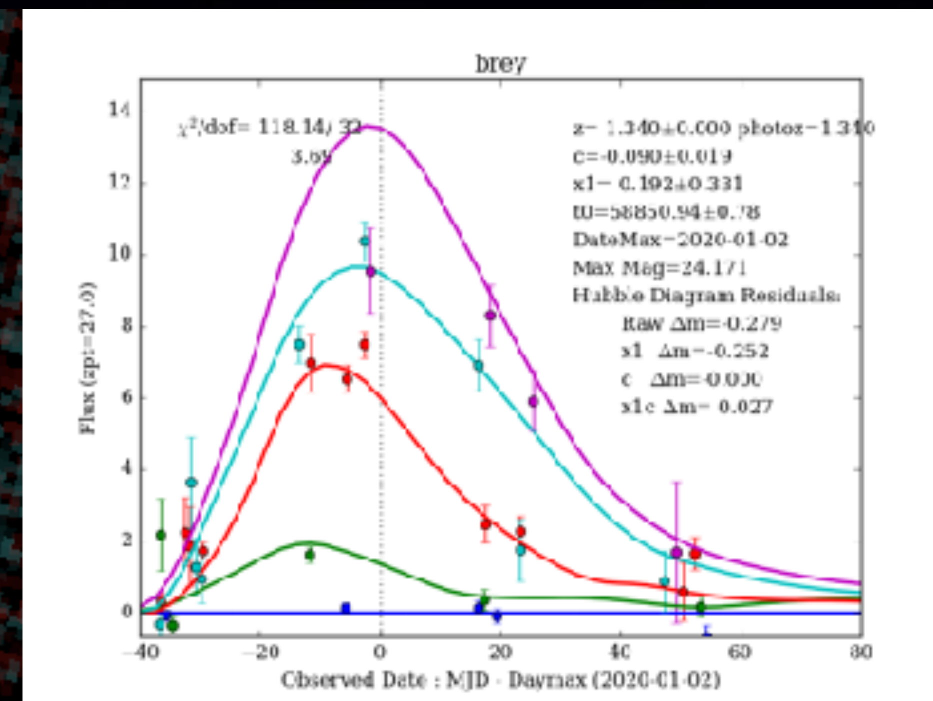
Subaru HSC Discovery



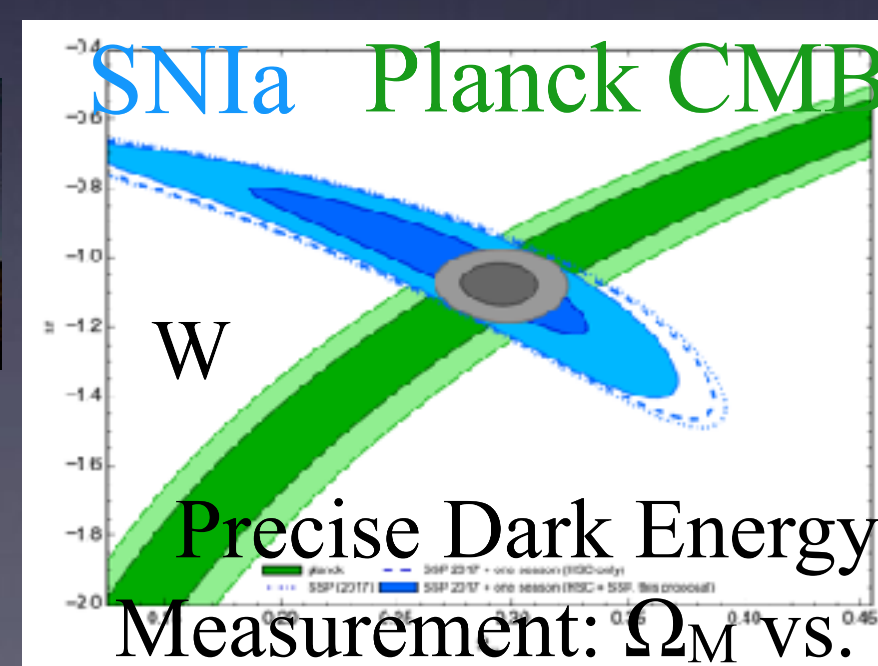
Hubble Space Telescope



HSC SNIa Light Curve: z=1.34



Spectroscopic Follow-up by International Collaborators
Berkeley Lab (US), LPNHE (Paris), Barcelona (Spain),
Lancaster (UK) , Australian National University



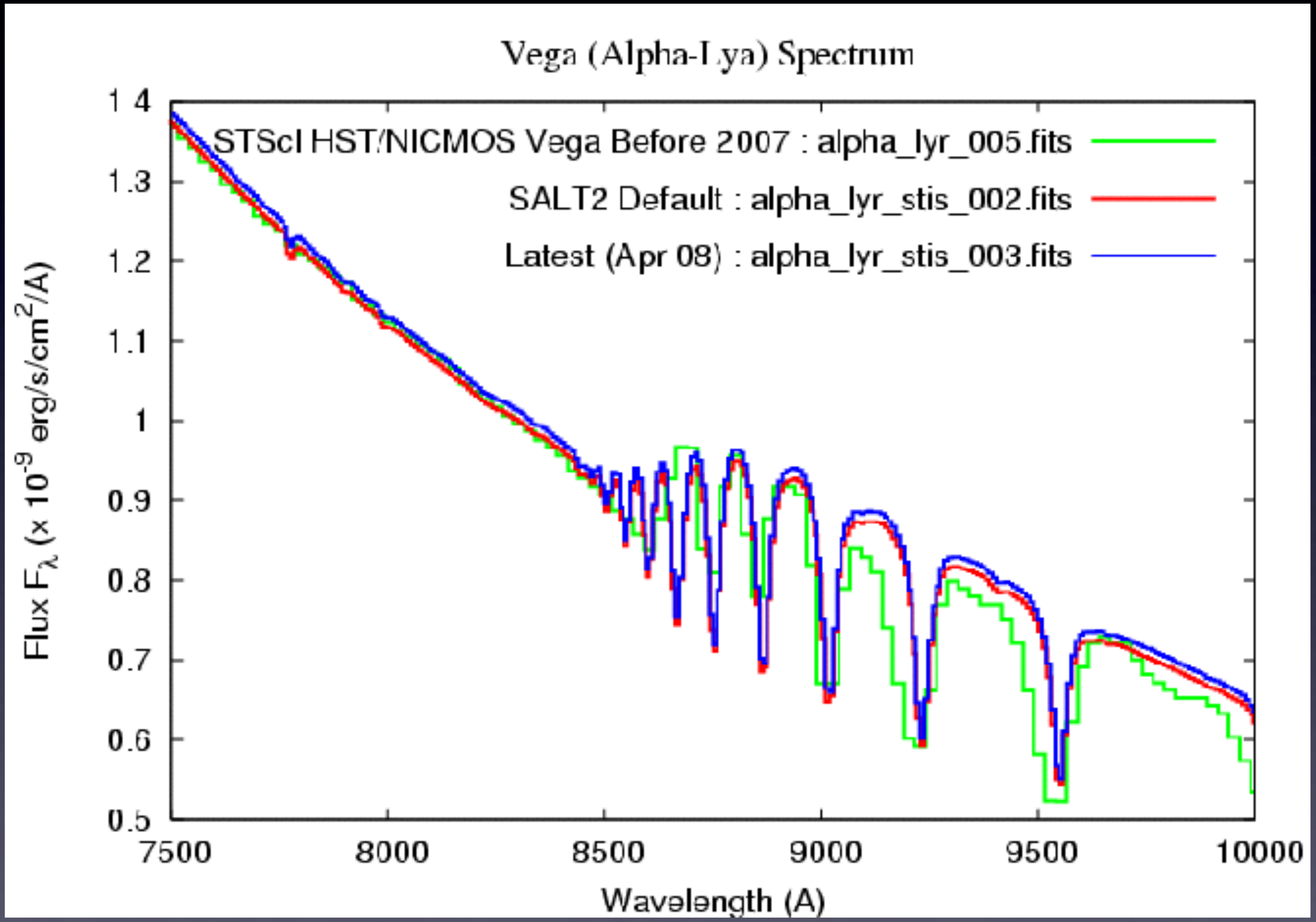
Calibration Giants

@IAU 2018 Focus Meeting on Calibration

Susana Deustua (STScI) : New Vega Spectrum

Vega Mag System

1: Why Vega Spectrum?
Only Star tied to Absolute Physical Units



- Hayes 1985 : $3.44 \pm 0.05 \times 10^{-9}$ @ 5556Å

Definition of Vega Mag

A0 Stars which Satisfies:
U-B=0
B-V=0

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME 117 MAY 1953 NUMBER 3

FUNDAMENTAL STELLAR PHOTOMETRY FOR STANDARDS OF SPECTRAL TYPE ON THE REVISED SYSTEM OF THE YERKES SPECTRAL *ATLAS**

H. L. Johnson and W. W. Morgan
Yerkes and McDonald Observatories
Received November 29, 1952

ABSTRACT

A system of photoelectric photometry is outlined which utilizes the revised zero point of the visual magnitude scale of the North Polar Sequence and which returns to the original definition for the zero point of color indices in terms of main-sequence stars of class A0; the interval A0–gK0 is 1 mag. The revised Yerkes *Atlas* system (MK) of spectral classification is taken as standard. The latter is described briefly, and a list of standard stars is included.

Magnitudes and color indices from measures in three wave-length bands are given for stars selected by spectral type and luminosity class to be representative of the principal regions of the H-R diagram. A few white dwarfs are also included.

A standard main sequence is defined for the new color–absolute magnitude diagram by the use of stars of large parallax, together with the galactic clusters NGC 2362, the Pleiades, the Ursa Major nucleus, and Praesepe. A standard main sequence is also defined for the relationship between the two systems of color index.

A purely photometric method for determining spectral types and space reddening for B stars in galactic clusters is described.

TERMINOLOGY

- y. Deflection through yellow filter, corrected for sky.
- b. Deflection through blue filter, corrected for sky.
- u. Deflection through ultraviolet filter, corrected for sky.
- C_y. Observed blue-yellow color index, reduced to outside the earth's atmosphere.
- C_u. Observed ultraviolet-blue color index, reduced to outside the earth's atmosphere.
- V. Observed magnitude through yellow filter, reduced to outside the earth's atmosphere. This is approximately equivalent to the photovisual magnitude on the International System.
- B. Observed magnitude through blue filter, reduced to outside the earth's atmosphere and including a zero-point correction to satisfy the condition

$$B - V = 0$$

for main-sequence stars of class A0 on the MK system.
- U. Observed magnitude through ultraviolet filter, reduced to outside the earth's atmosphere and including a zero-point correction to satisfy the condition

$$U - B = 0$$

for main-sequence stars of class A0 on the MK system.

Vega Mag

Average of 6 A0V Stars

TABLE 2—*Continued*

Class III—*Continued*			Class IV			Class V—*Continued*		
B9.5	III	δ Cyg	B2	IV	γ Peg	B3	V	6300
A0	III	α Dra	B2	IV	δ Cet	B3	V	35 Ari
A3	III	β Eri	B5	IV	τ Her	B3	V	η Aur
A3	III	θ Gem	B7	IV	16 Tau	B3	V	ν Ori
A5	III	β Tri	A0	IV	γ Gem	B3	V	η Hya
A5	III	α Oph	F0	IV	μ Cet	B3	V	η UMa
A7	III	θ² Tau	F0	IV	ε Cep	B3	V	178849
A7	III	γ Boo	F2	IV	β Cas	B3	V	191263
A9	III	γ Her	F2	IV	υ UMa	B3	V	16 Peg
F0	III	ζ Leo	F6	IV	α Tri	B3	V	218537
F2	III	14 Ari	F6	IV	40 Leo	B5	V	4142
F2	III	16 Per	F6	IV	θ UMa	B5	V	ν And
F4	III	36 Per	F7	IV	σ Peg	B5	V	14372

followed a procedure similar to the latter; the zero point of the present color systems has been set by the mean values for six stars of class A0 V on the MK system; the stars are: α Lyr, γ UMa, 109 Vir, α CrB, γ Oph, and HR 3314. For the mean of these stars

$$U - B = B - V = 0\,.$$

			Class V					
K0	III	δ Tau				B8	V	ι And
K0	III	ε Tau				B9	V	α Del
K0	III	θ¹ Tau	O9	V	46202	B9.5	V	ω² Aqr
K0	III	δ Aur	O9	V	52266	A0	V	4 Aur
K0	III	β Gem	O9	V	57682	A0	V	HR 3314
K0	III	α UMa	O9	V	14 Cep	A0	V	γ UMa
K0	III	τ CrB	O9	V	10 Lac	A0	V	109 Vir
K0	III	κ Cyg	O9.5	V	34078	A0	V	α CrB
K0	III	ε Cyg	O9.5	V	σ Ori	A0	V	HR 5859
K2	III	α Ari	O9.5	V	ζ Oph	A0	V	HR 6070
K2	III	ι Dra	B0	V	υ Ori	A0	V	γ Oph
K2	III	κ Oph	B0	V	δ Sco	A0	V	α Lyr
K2	III	β Oph	B0	V	τ Sco	A1	V	HR 875
K2	III	ξ Dra	B0	V	206183	A1	V	HR 1046
K3	III	δ And	B0	V	207538	A1	V	ι Ser
K3	III	51 And	B0.5	V	8965	A1	V	39 Dra
K3	III	ρ Boo	B0.5	V	40 Per	A1	V	HR 7784
			B0.5	V	ε Per	A1	V	ε Aqr
K4	III	β Cnc	B1	V	7252	A2	V	θ And
			B2	V	208947	A7	V	θ Cas
M2	III	83 UMa	B2	V	218440	A7	V	ι UMa

Vega=α Lyr Magnitude

U=0.02 B=0.03 V=0.03

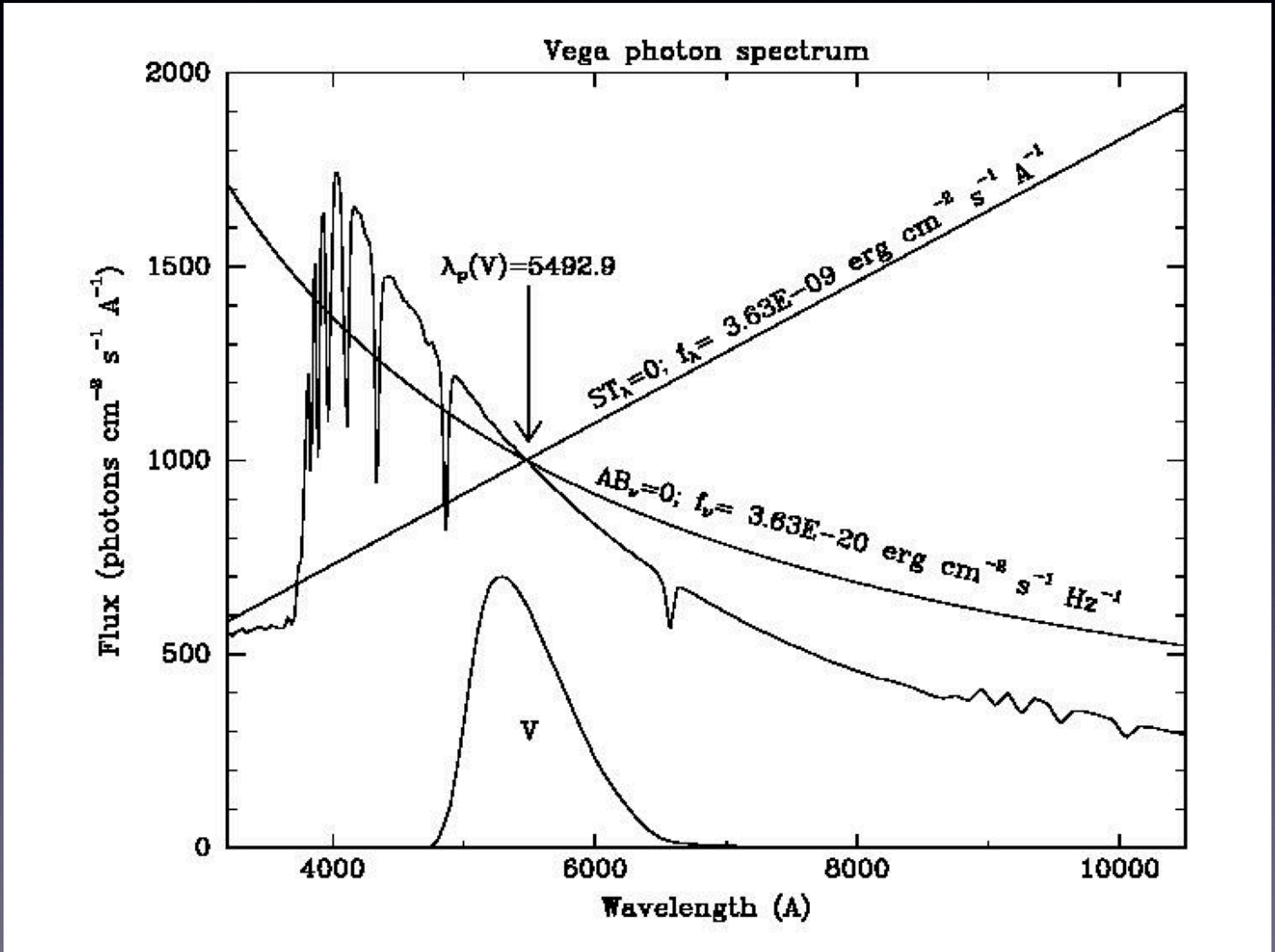
Table 3 : V B-V U-B

196	......	Ross 137	18 21.6	+04 01	1	12	13.98	+0.02	-0.59	......
197	170153	χ Dra	18 22.9	+72 41	3	8	3.58	+0.50	-0.07	F7 V
198	172167	α Lyr	18 33.6	+38 41	8	6	0.03	0.00	-0.01	A0 V
199*	173648	ζ Lyr A	18 41.3	+37 30	2	9	4.37	+0.18	+0.17	Am
200*	173649	ζ Lyr B	18 41.4	+37 30	2	9	5.74	+0.28	+0.06	F0 IV

Vega Mag:

Magnitude : Ratio in log

$$m_i = -2.5 \log_{10} \frac{\int R_i(\lambda)\lambda F_\lambda(\lambda)d\lambda}{\int R_i(\lambda)\lambda F_\lambda^{\mathrm{VEGA}}(\lambda)d\lambda} + 0.03$$



ST Mag

Vega Mag

AB Mag

Credit: O'Connell Lecture Note

Why Vega Spectrum?

Vega is the only star measured with physical units

IAU Definition (1985) is an average of 5 measurements

Note the definition is associated with 5% error

STELLAR ABSOLUTE FLUXES AND ENERGY DISTRIBUTIONS FROM 0.32 to 4.0 μm

D. S. Hayes

Kitt Peak National Observatory
National Optical Astronomy Observatories[1]

TABLE I

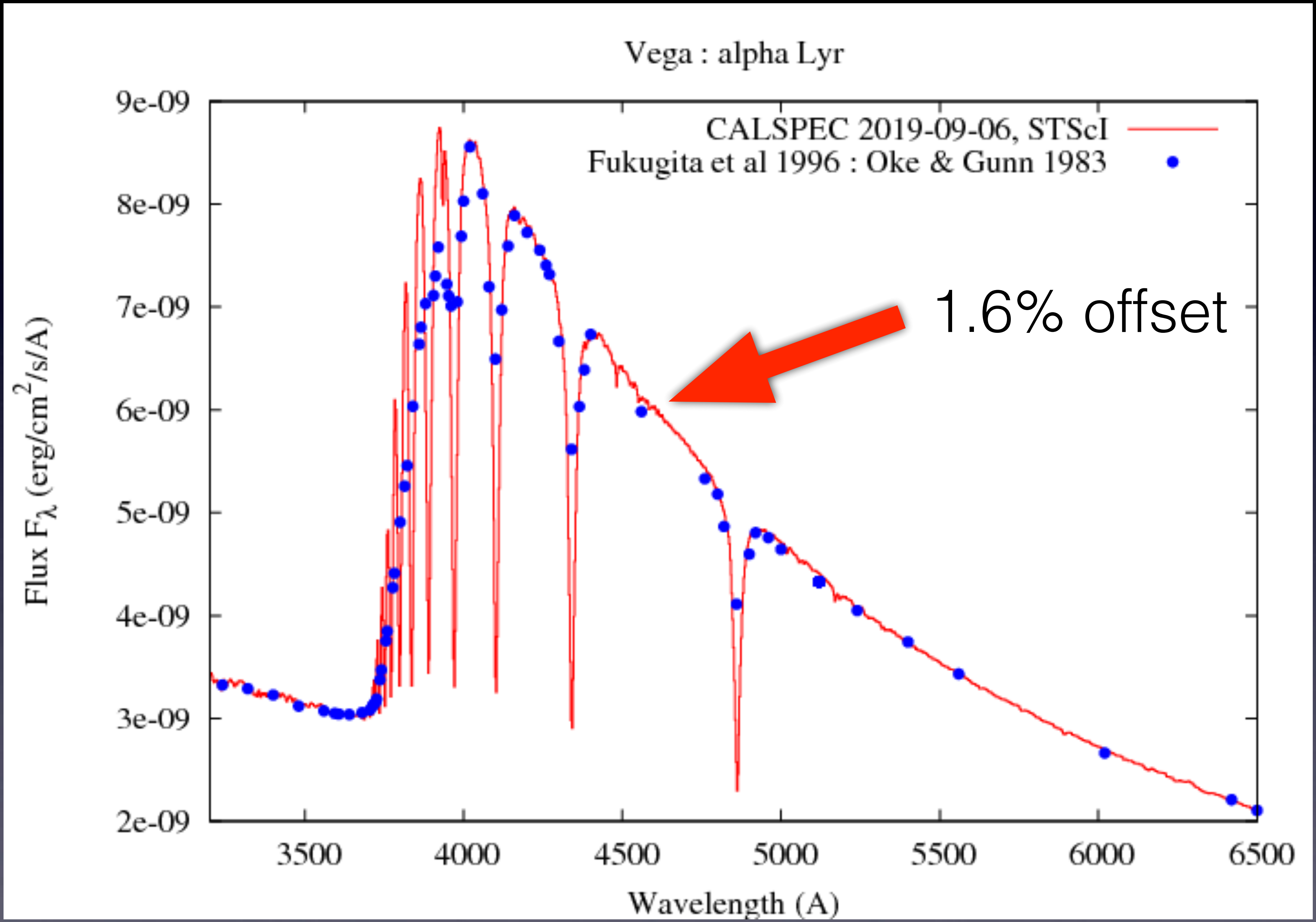
WEIGHTS AND FLUXES FOR CALIBRATION OF VEGA

Calibration	flux, E-9	f	Weights 3300–7500	Weights 7000–9040	Weights 9040–10500
HAYES AND LATHAM (1975)	3.39	2	2	2	2
TUG, ET AL. (1977)	3.47	1	1	1	–
TEREZ AND TEREZ (1979)	3.42	1	–	–	–
KHARITONOV, ET AL. (1980)	3.54	1	1	–	–
TEREZ (1982)	3.44	1	1	–	–
ARKHAROV AND TEREZ (1982)		–	–	1	1
Mean	3.44 ± 0.05				

- Hayes 1985 (IAU) : $3.44 \pm 0.05 \times 10^{-9}$ @ 5556Å

CALSPEC &
DA White Dwarfs

Vega Spectrum: Do you see the problem?



CALSPEC Vega is stitched at 4200A

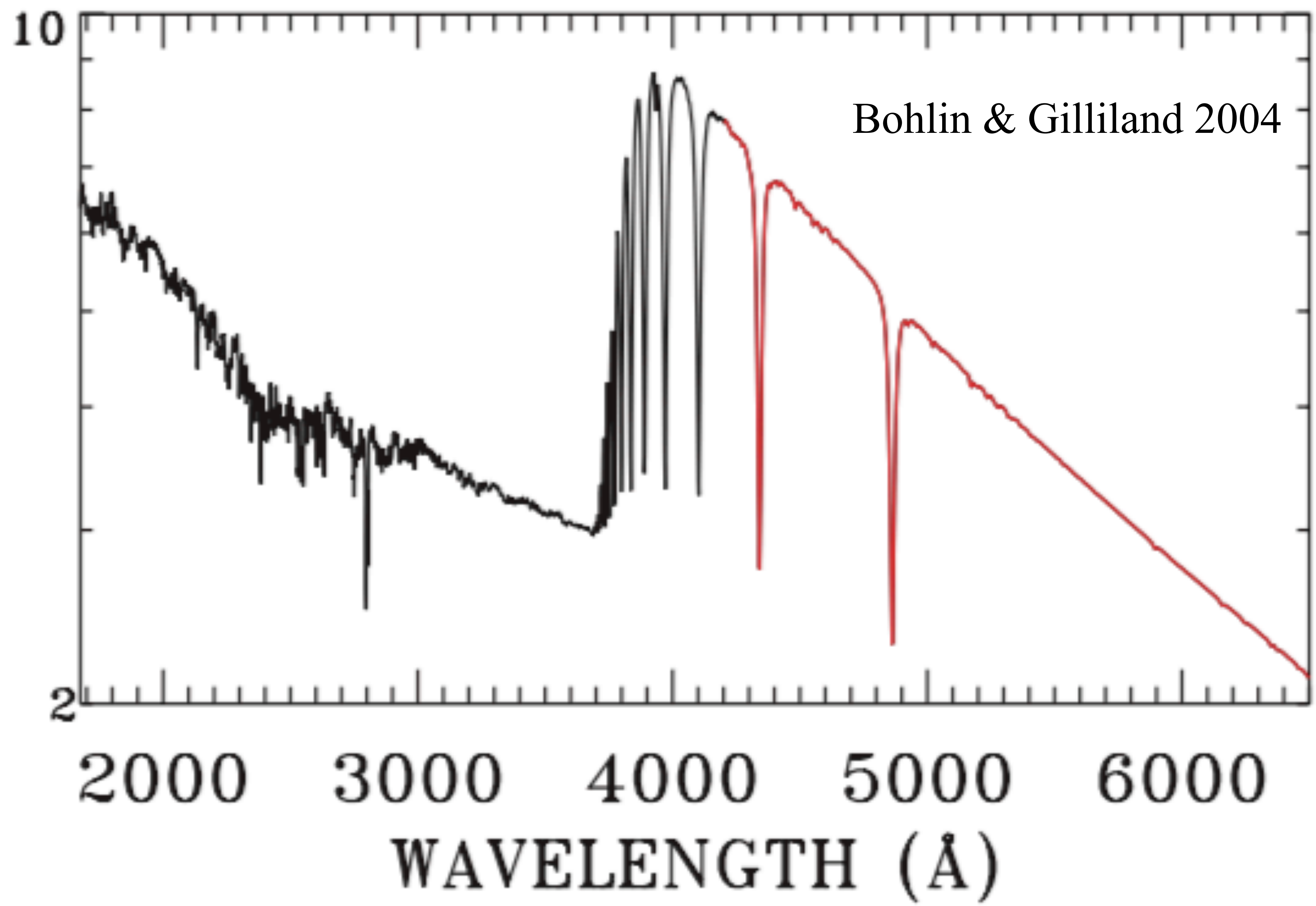
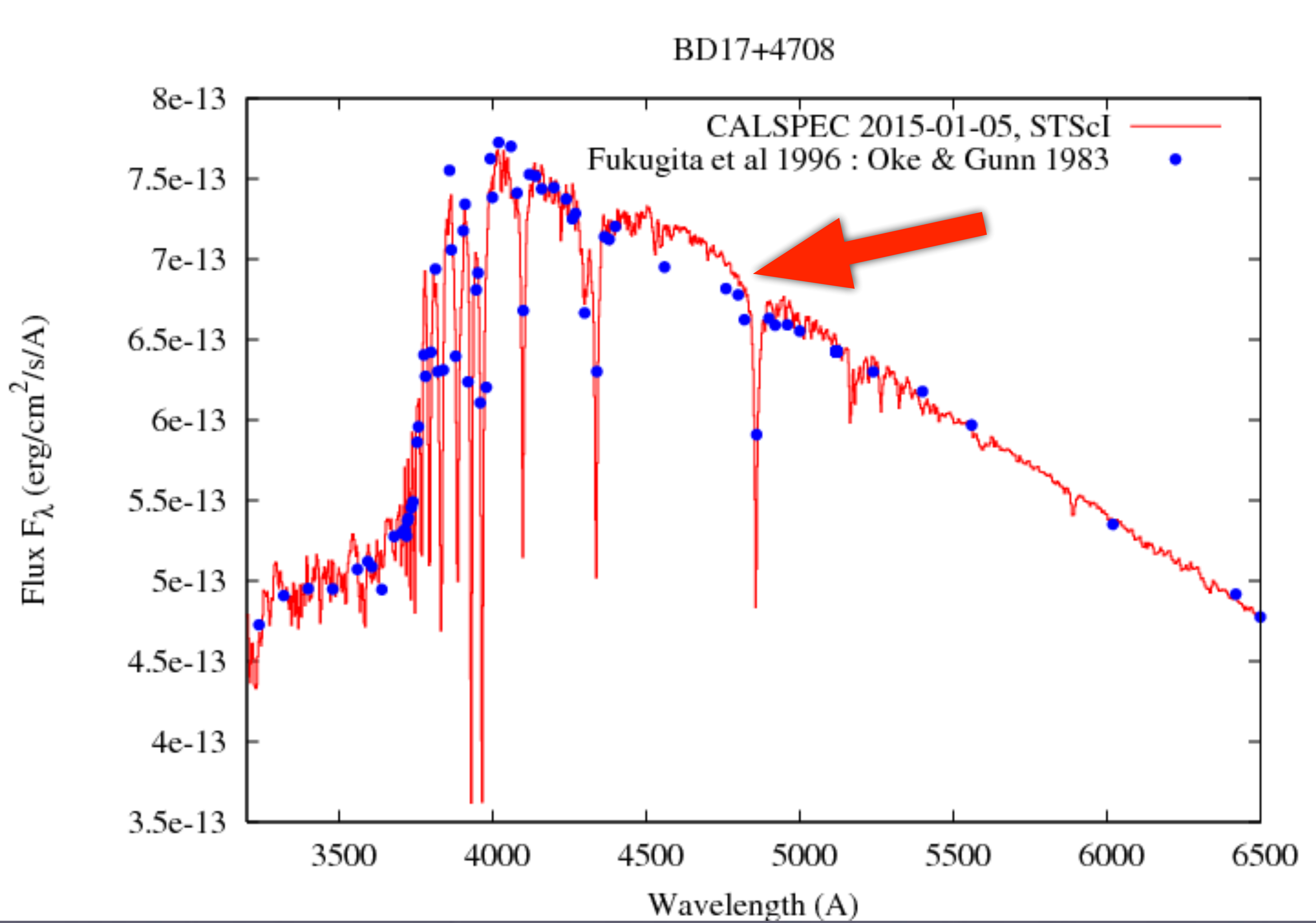
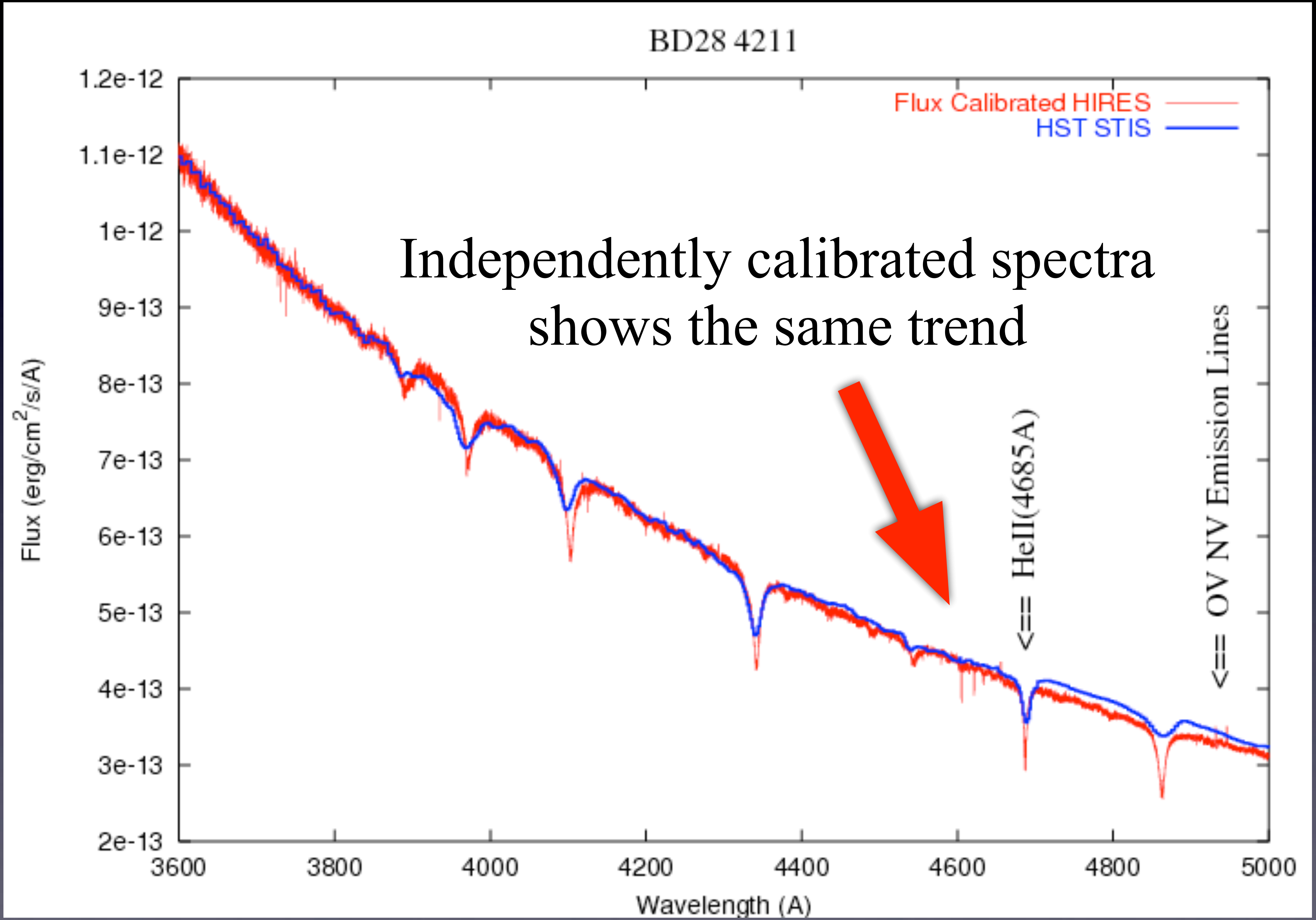


FIG. 5.—Absolute flux distribution of Vega as measured by STIS below 4200 Å and as determined by the Kurucz (2003) $R = 500$ model at the longer wavelengths. Below 3000 Å the spectrum is dominated by metal-line blan-

BD17 Spectrum: Vega Error Propagates



BD28 Spectrum: Vega Error Propagates



BD17 is a variable

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doi:10.1088/0004-6256/149/4/122

THE CALSPEC STARS P177D AND P330E

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Received 2015 January 2; accepted 2015 February 5; published 2015 March 9

ABSTRACT

Multicolor photometric data are presented for the CALSPEC stars P177D and P330E. Together with previously published photometry for nine other CALSPEC standards, the photometric observations and synthetic photometry from *Hubble Space Telescope*/STIS spectrophotometry agree in the *B*, *V*, *R*, and *I* bands to better than ~1% (10 mmag). Photometry over the 1986 to1991 period indicates that BD+17°4708 brightened by ~ 0.04 mag.

Key words: stars: fundamental parameters – stars: individual (P177D, P330E, BD+17°4708) – techniques: photometric

•

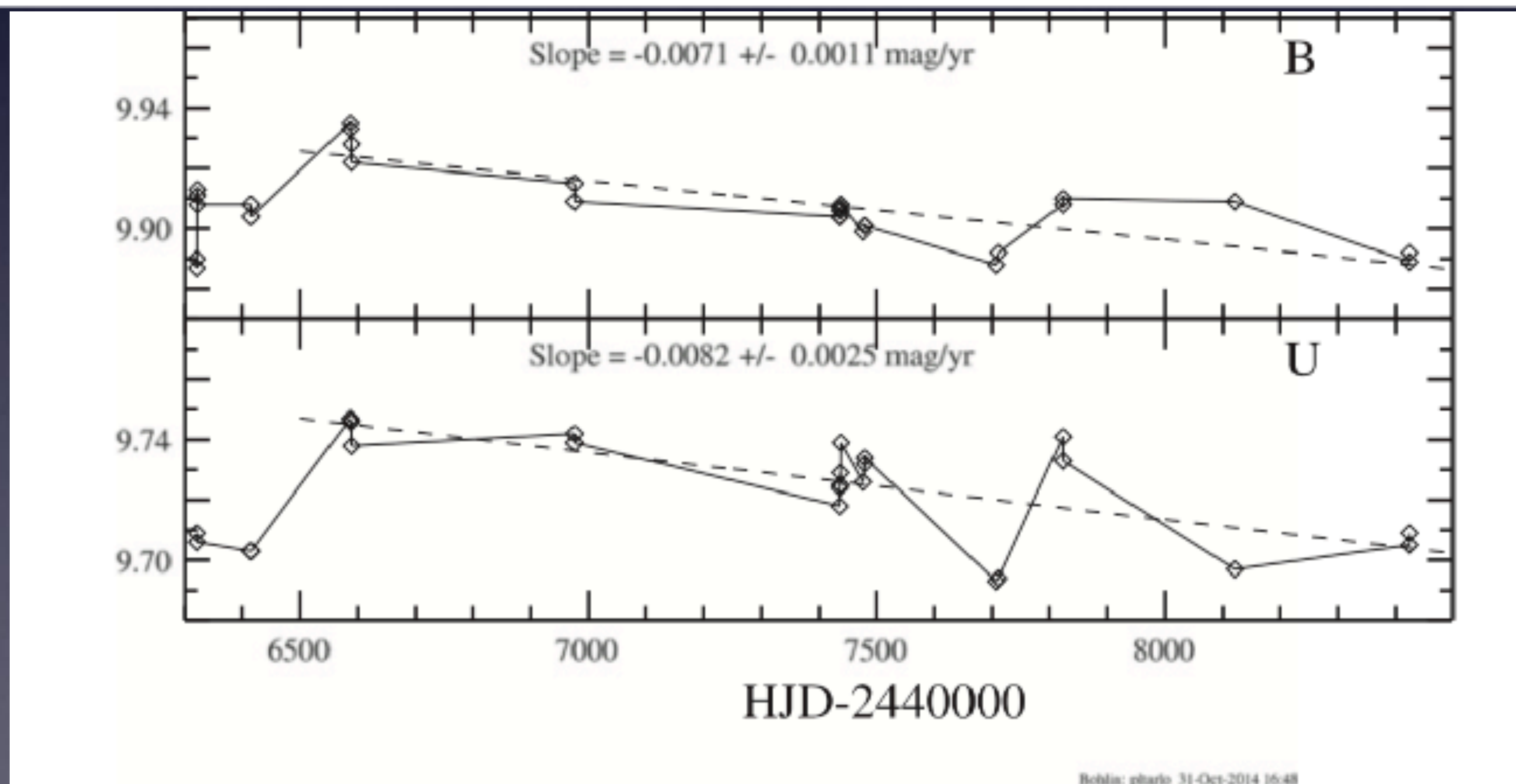
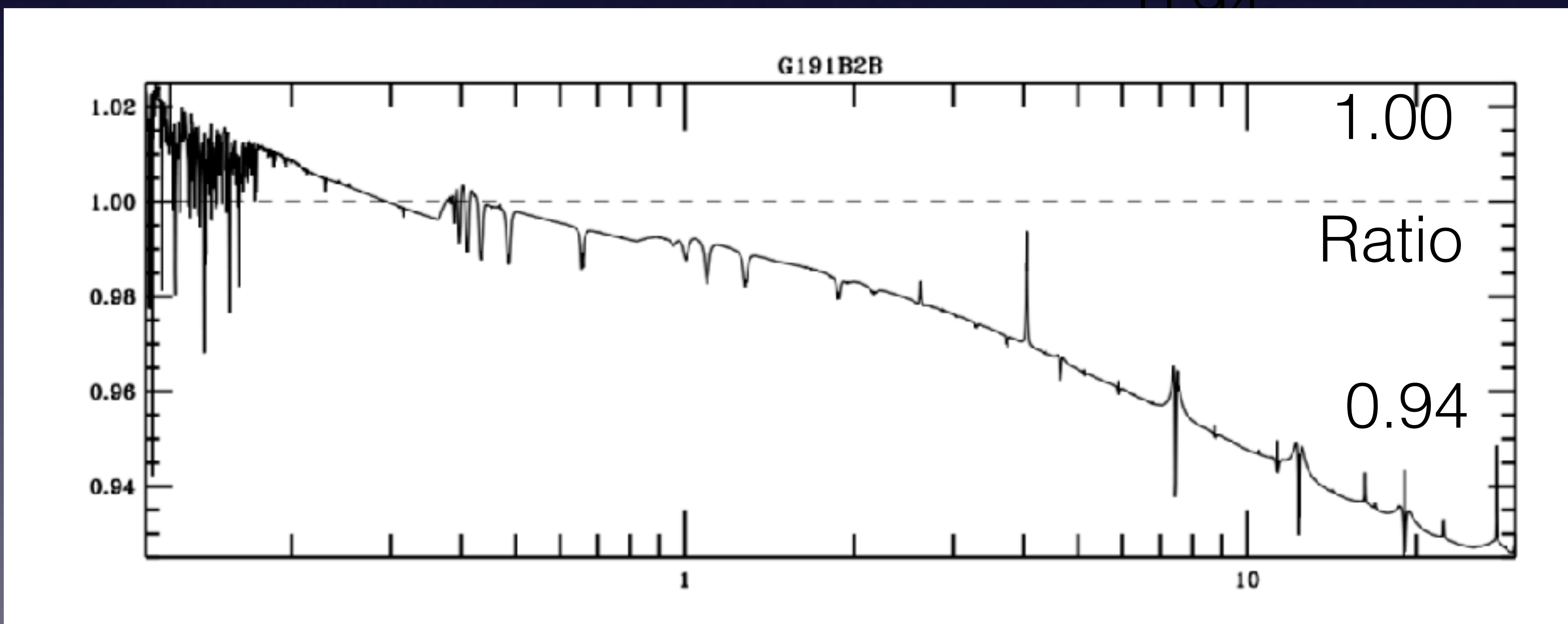


Figure 1. Variation of the brightness of BD+17°4708 in various bands.

2: DA White Dwarf Model Uncertainty
Models do not agree with each other
Bohlin et al 2014 : Rauch / Tlusty

G191B2B   Bohlin et al 2014



Wavelength (μm)

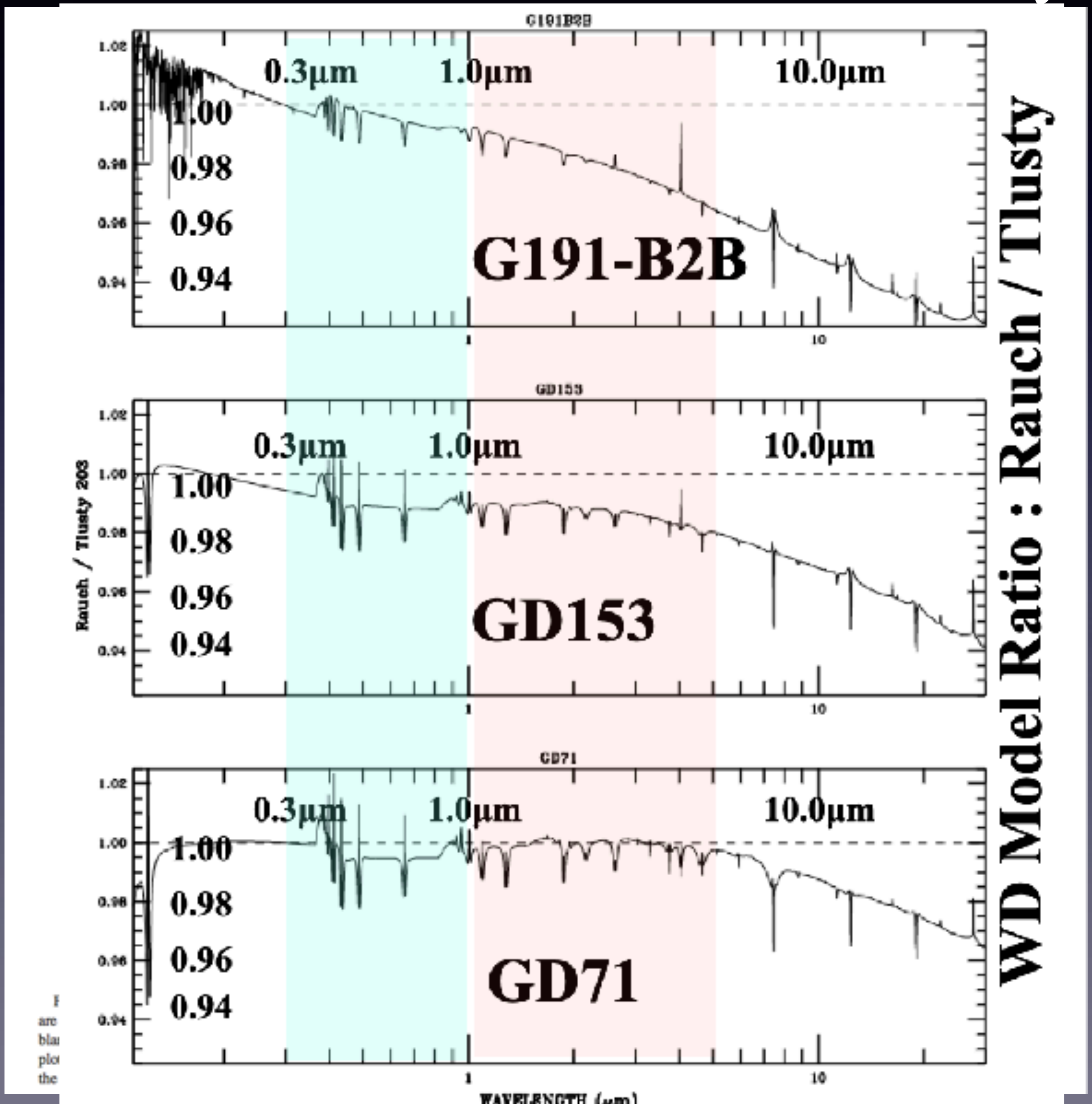
Models do not work in wide range

Bohlin et al 2014 : Rauch model / Tlusty model

G191B2B

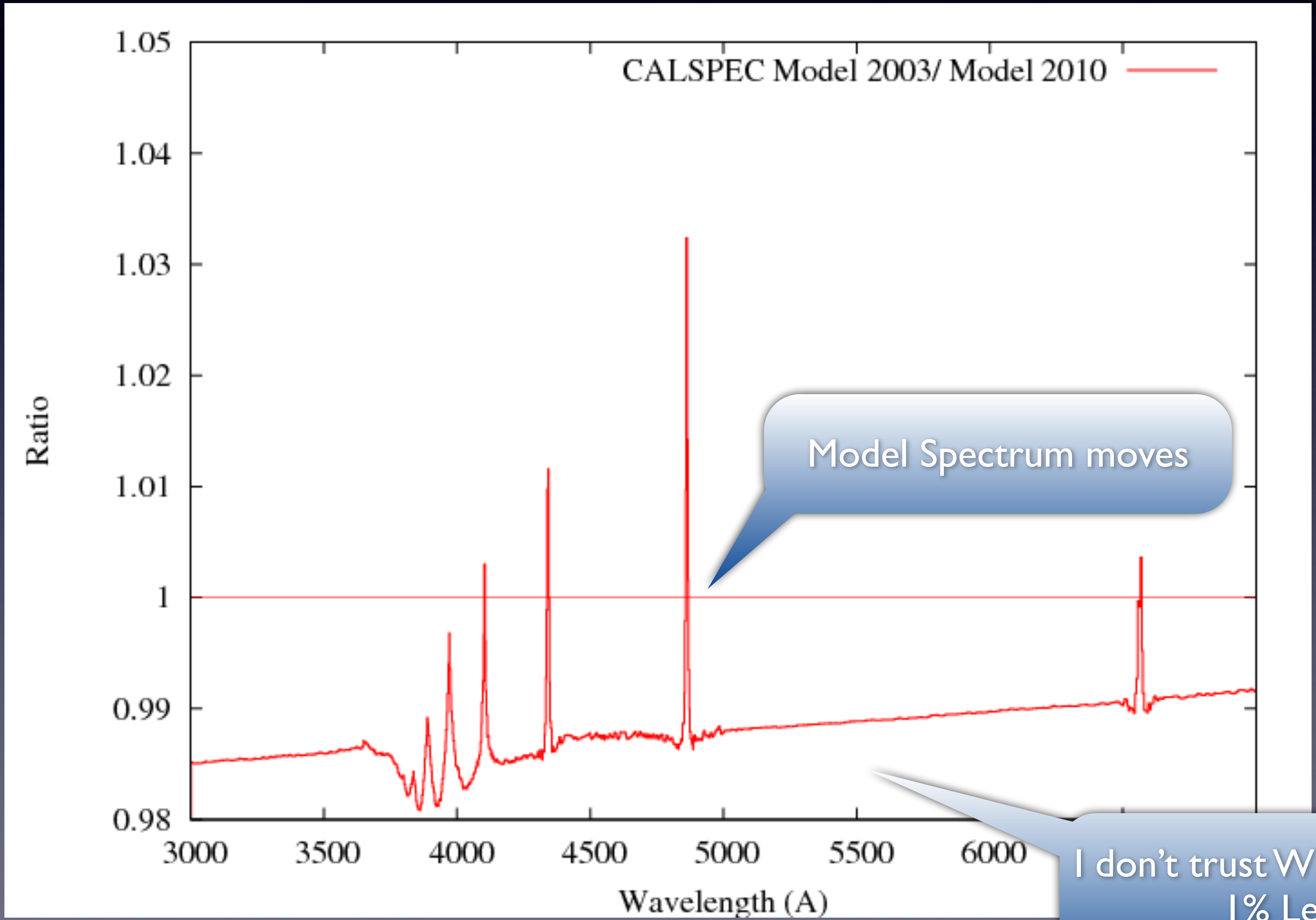
GD153

GD71



CALSPEC Model 2003 / Model 2010
Model is evolving in time

DA White Dwarf Models are not working at 1% level…..



Model Spectrum moves

I don't trust WD Models in 1% Level

Model Uncertainties
CALSPEC Primary Standards

	V	$B-V$	$T_{\rm eff}$ [K]	$\log g$	spectral type
G191-B2B	11.781	-0.33	61193 (241)[a]	7.492 (0.012)[a]	DA0
			60929 (993)[b]	7.55 (0.05)[b]	
GD 153	13.346	-0.29	38686 (152)[a]	7.662 (0.024)[a]	DA1
			40320 (626)[b]	7.93 (0.05)[b]	
GD 71	13.032	-0.25	32747 (92)[a]	7.683 (0.023)[a]	DA1
			33590 (483)[b]	7.93 (0.05)[b]	

[a] (Finley et al., 1997)
[b] (Gianninas et al., 2011)

Nicolas Regnault

The Astrophysical Journal, 951:78 (23pp), 2023 July 1 https://doi.org/10.3847/1538-4357/acd333

All-sky Faint DA White Dwarf Spectrophotometric Standards for Astrophysical Observatories: The Complete Sample

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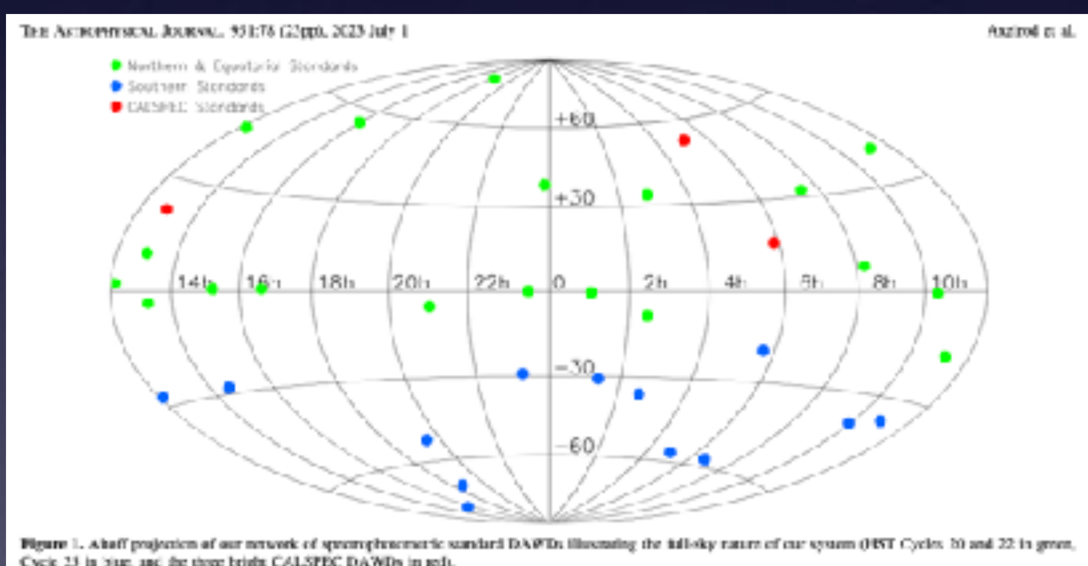
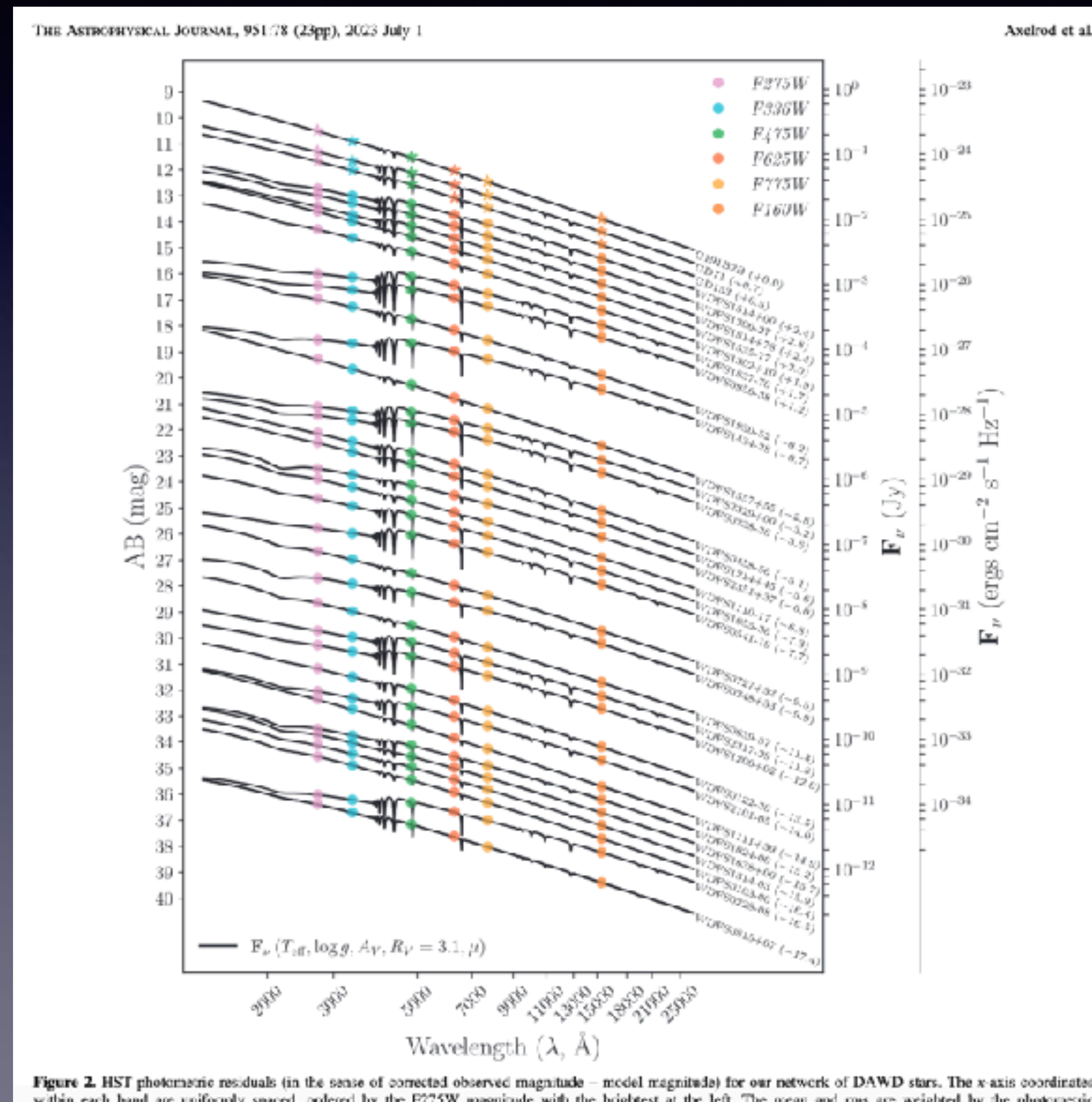
Abstract

Hot DA white dwarfs (DAWDs) have fully radiative pure hydrogen atmospheres that are the least complicated to model. Pulsationally stable, they are fully characterized by their effective temperature $T_{\rm eff}$ and surface gravity $\log g$, which can be deduced from their optical spectra and used in model atmospheres to predict their spectral energy distributions (SEDs). Based on this, three bright DAWDs have defined the spectrophotometric flux scale of the CALSPEC system of the Hubble Space Telescope (HST). In this paper we add 32 new fainter ($16.5 < V < 19.5$) DAWDs spread over the whole sky and within the dynamic range of large telescopes. Using ground-based spectra and panchromatic photometry with HST/WFC3, a new hierarchical analysis process demonstrates consistency between model and observed fluxes above the terrestrial atmosphere to <0.004 mag rms from 2700 to 7750 Å and to 0.008 mag rms at 1.6 μm for the total set of 35 DAWDs. These DAWDs are thus established as spectrophotometric standards with unprecedented accuracy from the near-ultraviolet to the near-infrared, suitable for both ground- and space-based observatories. They are embedded in existing surveys like the Sloan Digital Sky Survey, Pan-STARRS, and Gaia, and will be naturally included in the Large Synoptic Survey Telescope survey by the Rubin Observatory. With additional data and analysis to extend the validity of their SEDs further into the infrared, these spectrophotometric standard stars could be used for JWST, as well as for the Roman and Euclid observatories.

Unified Astronomy Thesaurus concepts: Spectrophotometric standards (1555); DA stars (348); White dwarf stars (1799); HST photometry (756)

32 DA White Dwarf Observed by HST





CALSPEC
Primary G191B2B

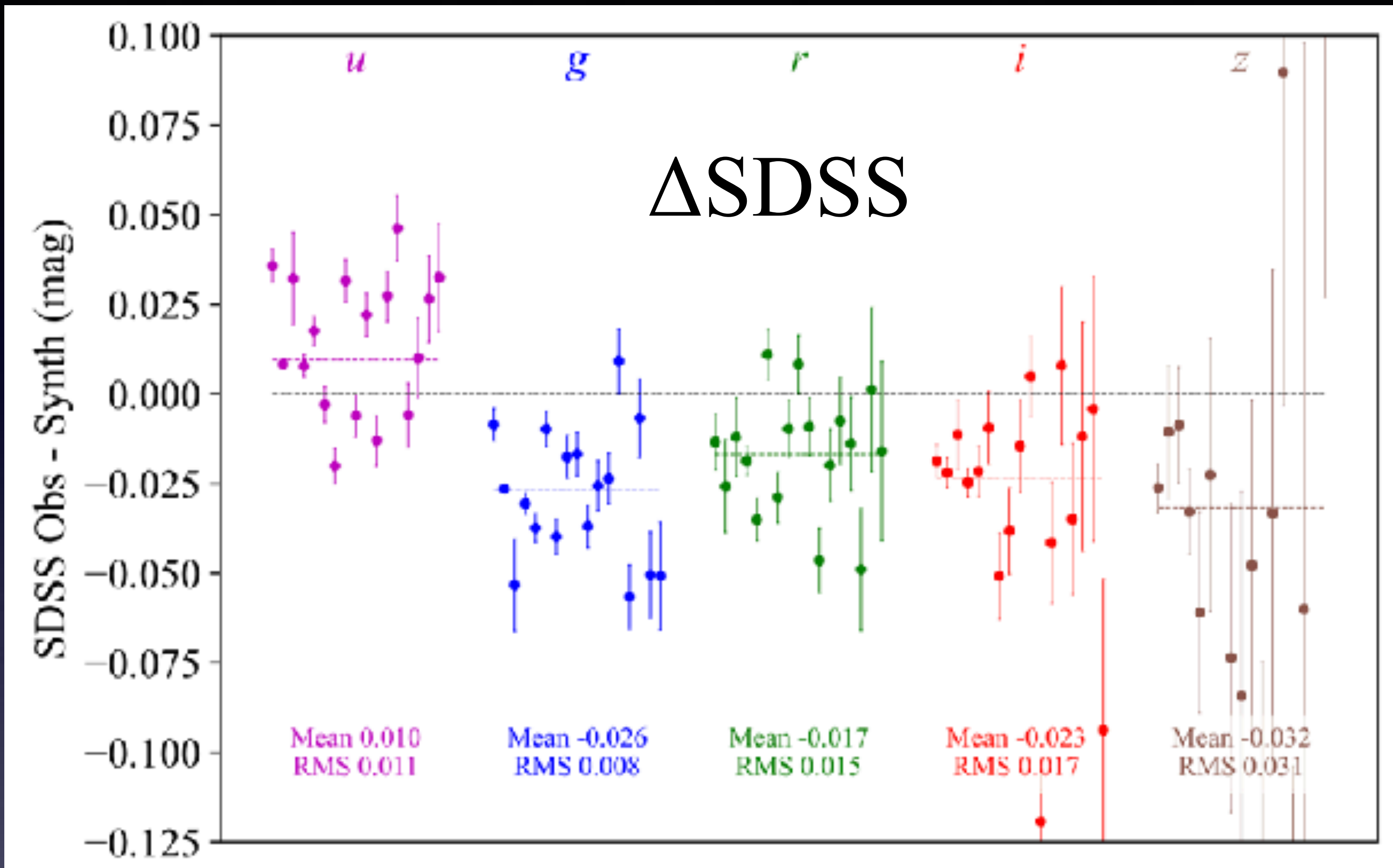
T=61,993±241 K (Finley 1997)
T=63,200±447K (new study 2023)

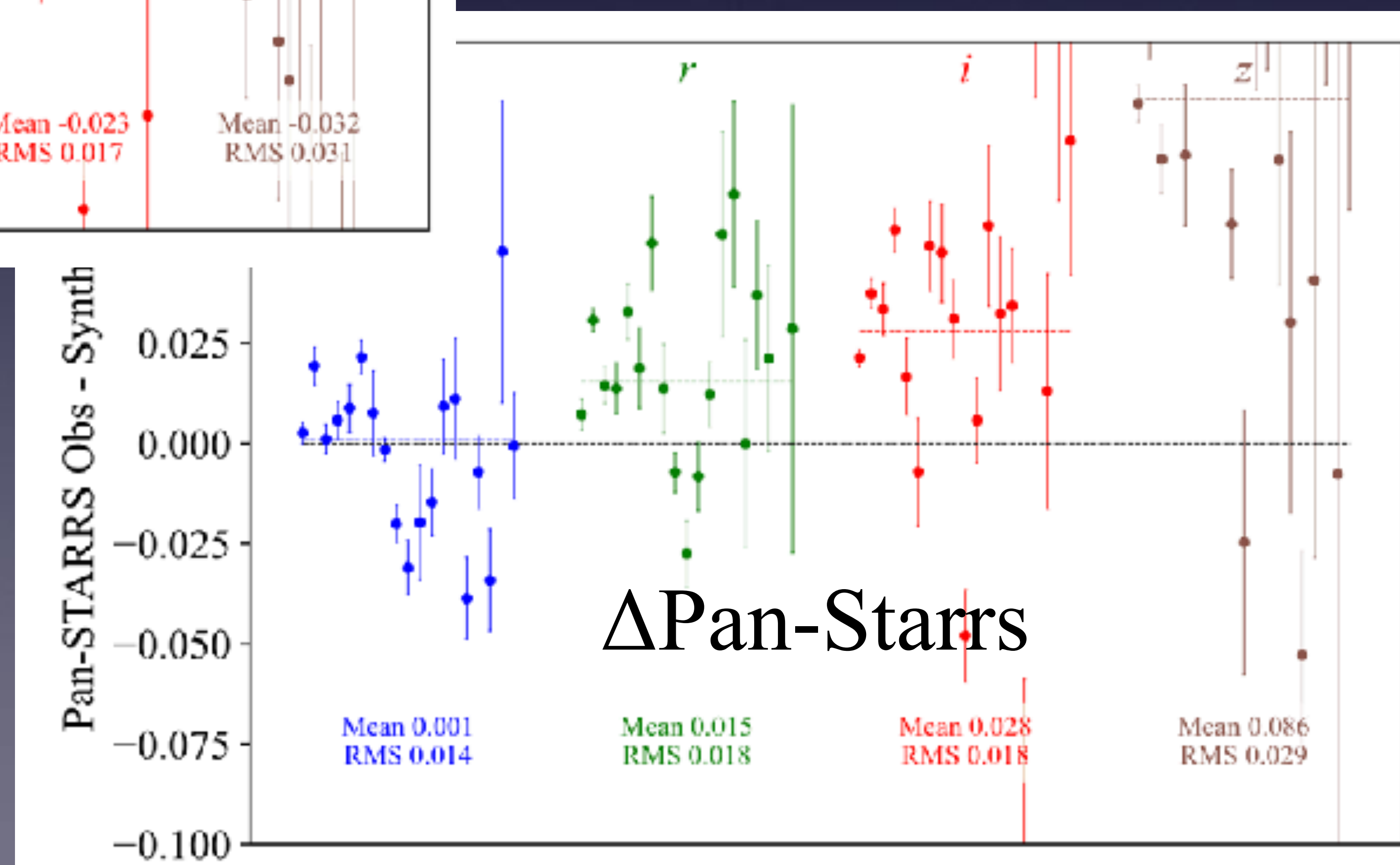
Temp Terr Av

Table 5
Derived Object Parameters[a]

Object	$T_{\rm eff}$ (K)	$T_{\rm eff}\sigma$ (K)	log g (dex)	log g σ (dex)	A_V (mag)	A_V σ (mag)
G191B2B	63,200	447	7.588	0.032	0.001	0.001
GD153	38,765	185	7.720	0.036	0.001	0.001
GD71	32,705	90	7.782	0.020	0.003	0.001
WDFS0103-00	57,959	2366	7.678	0.081	0.119	0.008
WDFS0122-30	33,964	215	7.771	0.031	0.048	0.005
WDFS0228-08	23,026	269	7.831	0.041	0.156	0.014
WDFS0238-36	23,169	84	7.880	0.014	0.171	0.005
WDFS0248+33	33,148	393	7.103	0.043	0.305	0.007
WDFS0458-56	30,111	78	7.788	0.018	0.014	0.003
WDFS0541-19	20,436	83	7.829	0.014	0.053	0.006
WDFS0639-57	54,760	890	7.898	0.048	0.162	0.004
WDFS0727+32	53,516	1364	7.697	0.064	0.167	0.005
WDFS0815+07	35,008	758	7.297	0.049	0.076	0.012
WDFS0956-38	19,219	63	7.875	0.012	0.078	0.005
WDFS1024-00	36,021	959	7.654	0.125	0.240	0.015
WDFS1055-36	29,503	103	7.930	0.025	0.106	0.005
WDFS1110-17	46,442	1014	8.011	0.080	0.159	0.005
WDFS1111+39	56,874	1226	7.799	0.041	0.022	0.005
WDFS1206+02	23,647	203	7.886	0.021	0.056	0.011
WDFS1206-27	33,884	169	7.901	0.033	0.111	0.004
WDFS1214+45	34,169	255	7.846	0.038	0.022	0.005
WDFS1302+10	41,577	634	7.927	0.017	0.080	0.005
WDFS1314-03	43,200	1397	7.823	0.091	0.110	0.010
WDFS1434-28	20,332	86	7.818	0.016	0.177	0.005
WDFS1514+00	28,576	127	7.903	0.013	0.120	0.005
WDFS1535-77	50,524	806	9.080	0.029	0.034	0.004
WDFS1557+55	57,758	983	7.551	0.070	0.029	0.004
WDFS1638+00	58,415	2133	7.749	0.108	0.210	0.008
WDFS1814+78	31,048	130	7.802	0.014	0.021	0.004
WDFS1837-70	19,199	63	7.869	0.012	0.094	0.005
WDFS1930-52	36,263	191	7.669	0.020	0.132	0.003
WDFS2101-05	29,187	239	7.766	0.026	0.145	0.009
WDFS2317-29	23,120	48	7.851	0.019	0.001	0.002
WDFS2329+00	20,557	196	7.957	0.030	0.129	0.011
WDFS2351+37	41,208	842	7.702	0.081	0.332	0.007

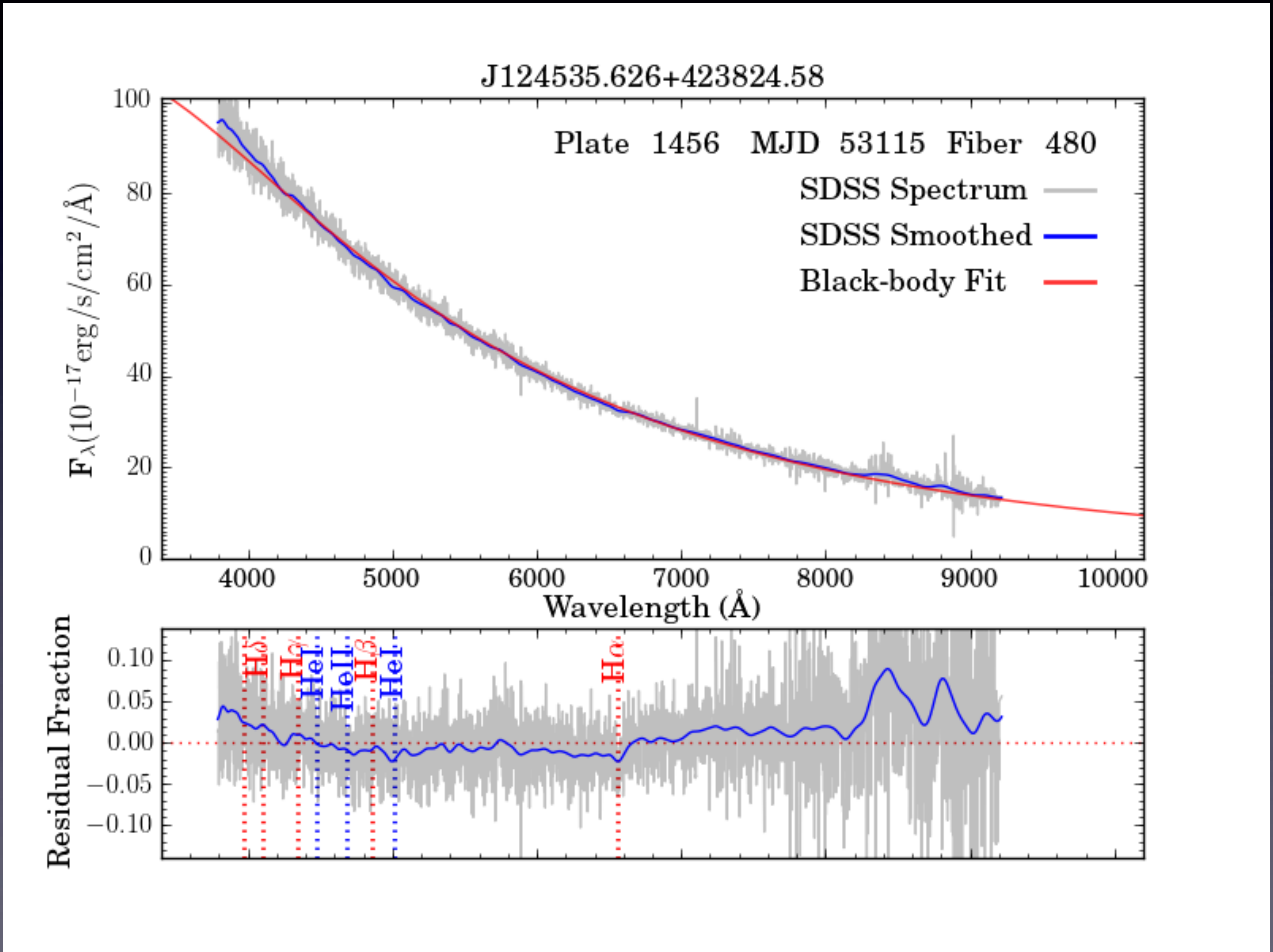
Comparison against SDSS & PS1





Moment of Zen
Quasar Spectra Inspection

Moment of Zen
SDSS Quasar Candidate



Blackbody Stars

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CrossMark

Blackbody Stars

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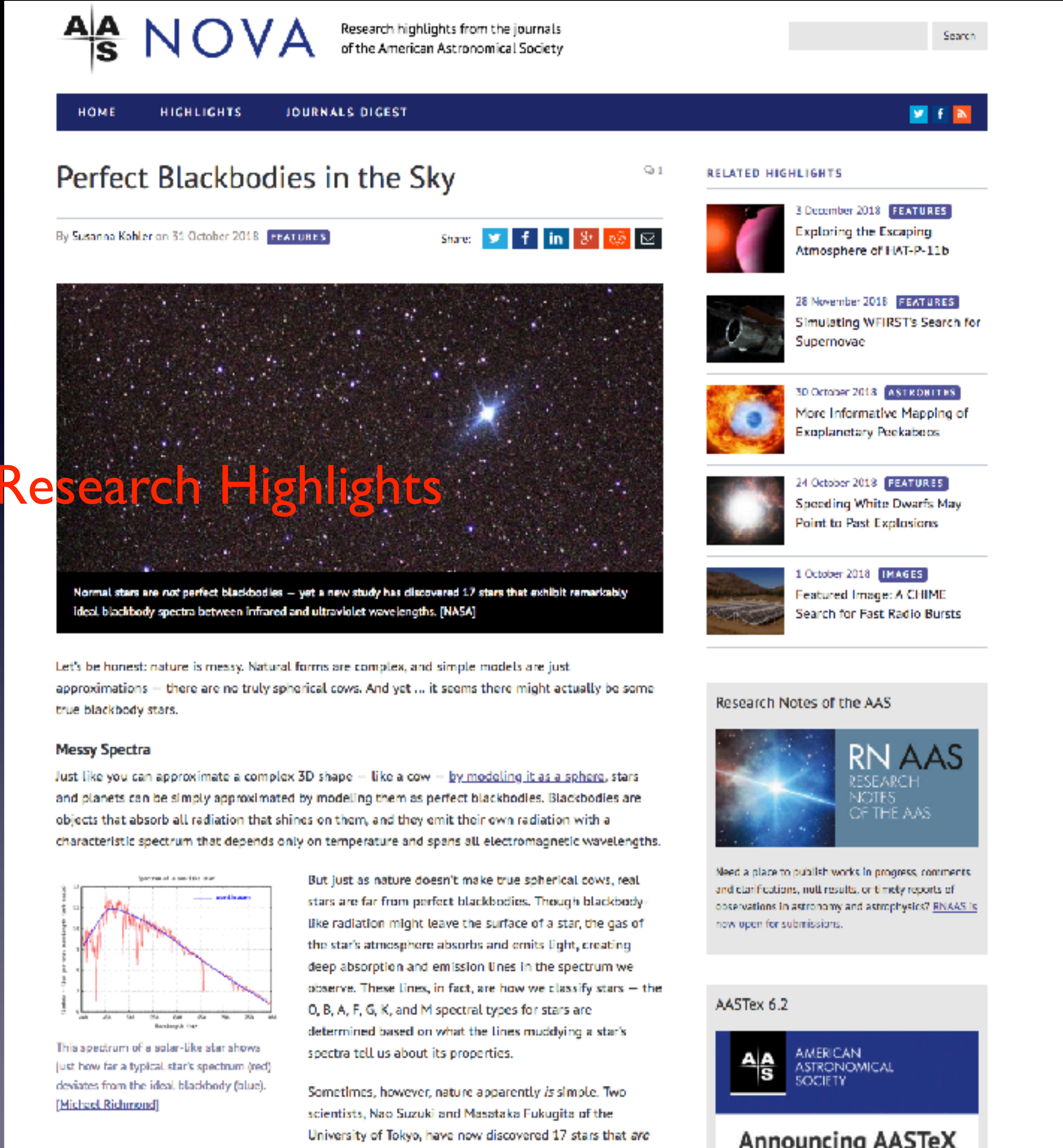
[2] Institute for Advanced Study, Princeton NJ 08540, USA
Received 2017 October 17; revised 2018 February 2; accepted 2018 February 6; published 2018 October 24

Abstract

We report the discovery of stars that show spectra very close to blackbody radiation. We found 17 such stars out of 798,593 stars in the Sloan Digital Sky Survey (SDSS) spectroscopic data archives. We discuss the value of these stars for the calibration of photometry, regardless of the the physical nature of these stars. This gives us a chance to examine the accuracy of the zero point of SDSS photometry across various passbands: we conclude that the zero point of SDSS photometric system is internally consistent across its five passbands to the level below 0.01 mag. We may also examine the consistency of the zero points between UV photometry of *Galaxy Evolution Explorer* and SDSS, and IR photometry of *Wide-field Infrared Survey Explorer* against SDSS. These stars can be used not only as photometric but also spetrophotometric standard stars. We suggest that these stars showing the featureless blackbody-like spectrum of the effective temperature of 10000 ± 1500 K are consistent with DB white dwarfs with temperatures too low to develop helium absorption features.

Key words: cosmological parameters – cosmology: observations – dark energy – standards – stars: distances – white dwarfs

AAS Research Highlights



AAS NOVA Research highlights from the journals of the American Astronomical Society

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Perfect Blackbodies in the Sky

By Susanna Kohler on 31 October 2018 FEATURES

Share:

Normal stars are *not* perfect blackbodies — yet a new study has discovered 17 stars that exhibit remarkably ideal blackbody spectra between infrared and ultraviolet wavelengths. [NASA]

Let's be honest: nature is messy. Natural forms are complex, and simple models are just approximations — there are no truly spherical cows. And yet … it seems there might actually be some true blackbody stars.

Messy Spectra

Just like you can approximate a complex 3D shape — like a cow — by modeling it as a sphere, stars and planets can be simply approximated by modeling them as perfect blackbodies. Blackbodies are objects that absorb all radiation that shines on them, and they emit their own radiation with a characteristic spectrum that depends only on temperature and spans all electromagnetic wavelengths.

This spectrum of a solar-like star shows just how far a typical star's spectrum (red) deviates from the ideal blackbody (blue). [Michael Richmond]

But just as nature doesn't make true spherical cows, real stars are far from perfect blackbodies. Though blackbody-like radiation might leave the surface of a star, the gas of the star's atmosphere absorbs and emits light, creating deep absorption and emission lines in the spectrum we observe. These lines, in fact, are how we classify stars — the O, B, A, F, G, K, and M spectral types for stars are determined based on what the lines muddying a star's spectra tell us about its properties.

Sometimes, however, nature apparently *is* simple. Two scientists, Nao Suzuki and Masataka Fukugita of the University of Tokyo, have now discovered 17 stars that *are*

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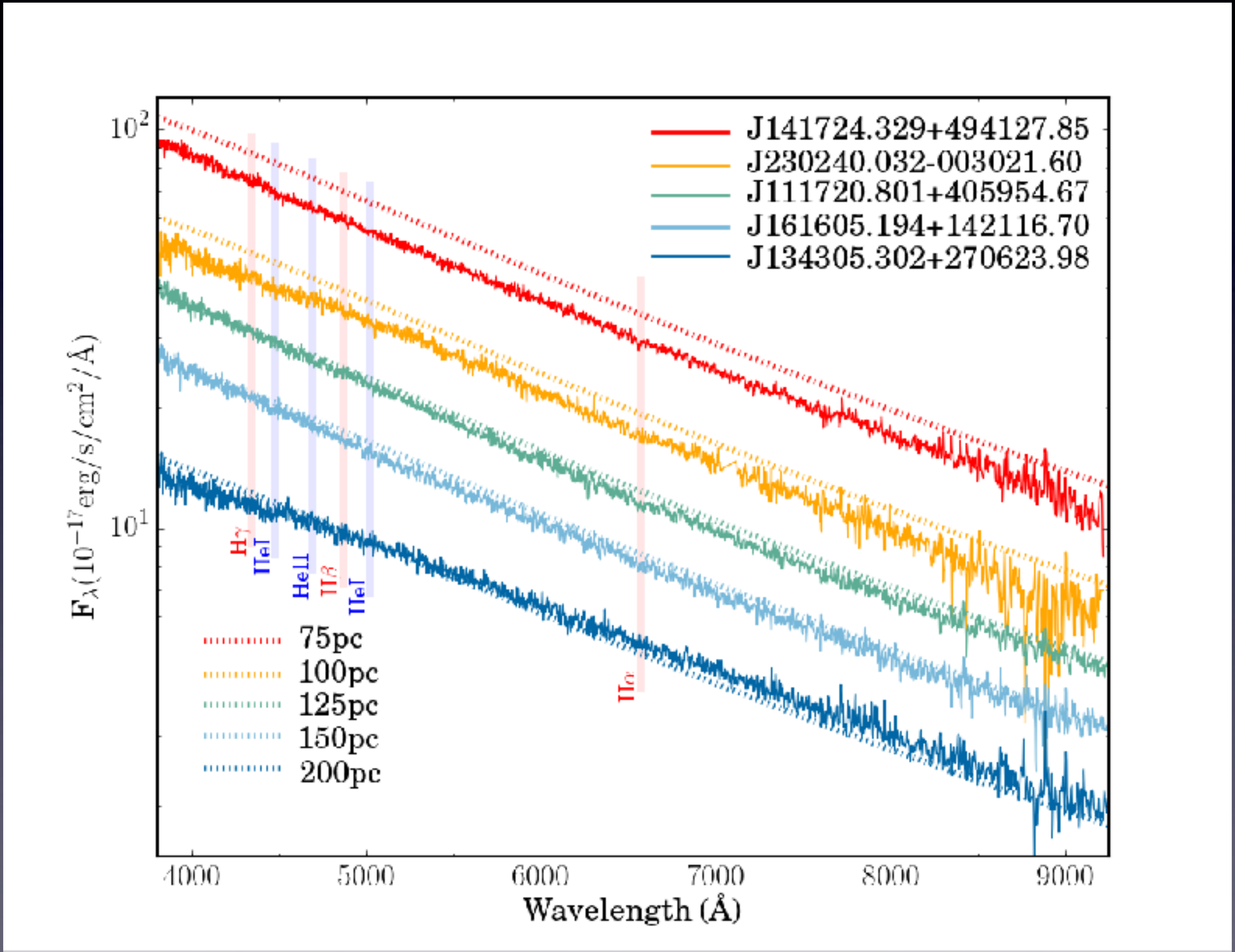
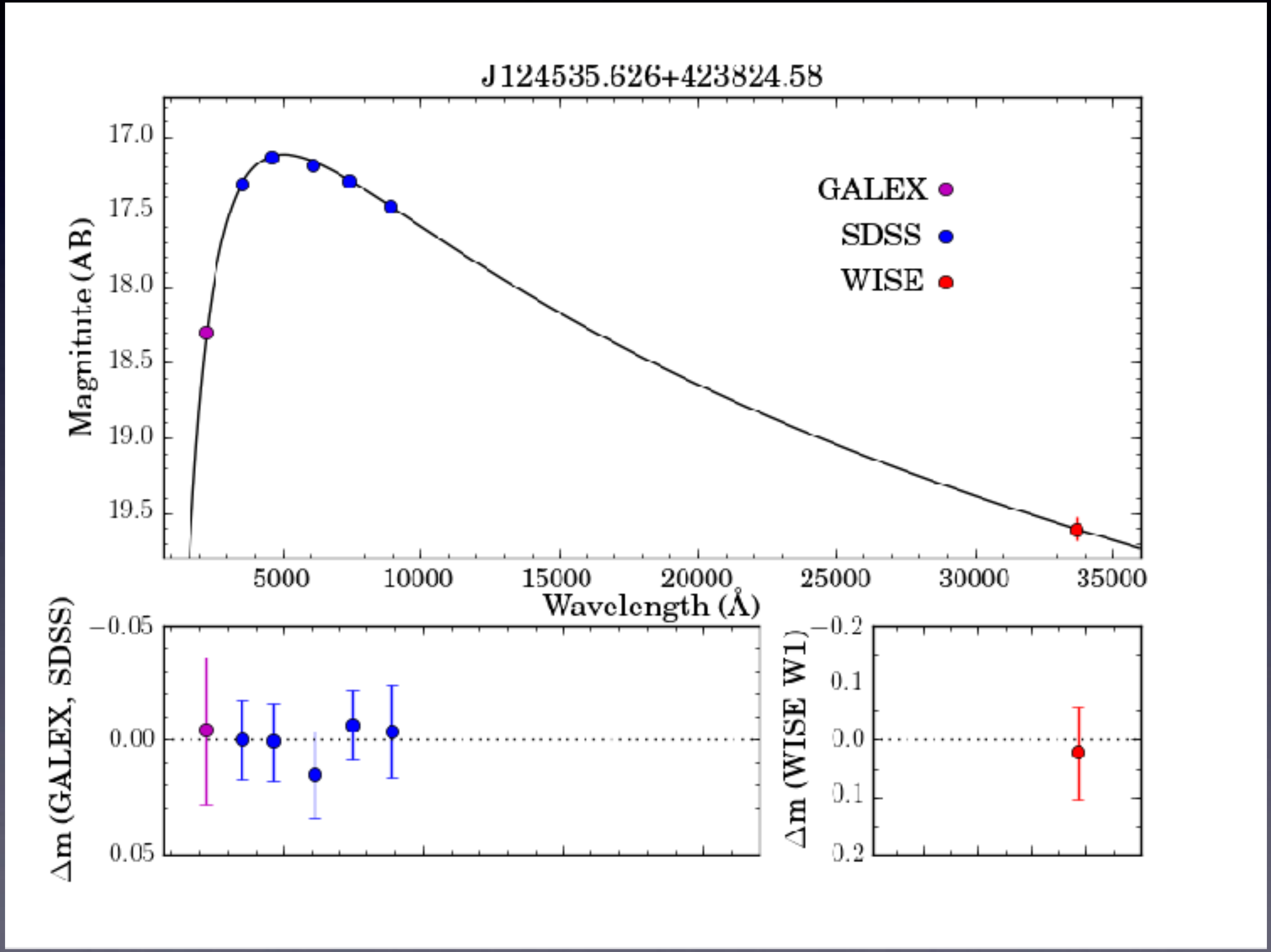
Announcing AASTeX

17 Blackbody Stars
out of 798,593 SDSS DR12 stellar spectra



IR Excess is checked

5 Stars showed IR excess and excluded



Radius of Blackbody Stars

0.7% accuracy in radius!

0.6% error on Temperature

Table 1. Black-Body Stars : GAIA DR2

Name	Teff (K)	Radius (km)	Radius (Earth)	Distance (pc)	Parallax (mas)	Fractional Error
J002739.497-001741.93	10662±60	8315±655	1.304±0.103	229.02±18.05	4.366±0.344	0.079
J004830.324+001752.80	10639±40	7045±209	1.105±0.033	136.71±4.07	7.315±0.218	0.030
J014618.89[illegible]05150.51	11770±48	8147±390	1.277±0.061	180.45±8.65	5.542±0.266	0.048
J022936.715-[illegible]113.63	8901±31	6842±354	1.073±0.056	155.32±8.05	6.438±0.334	0.052
J083226.568+3[illegible]55.48	7952±95	6941±296	1.088±0.046	118.24±5.04	8.457±0.361	0.043
J083736.557+542[illegible]	7449±61	6781±160	1.063±0.025	91.43±2.17	10.937±0.259	0.024
J100449.541+121[illegible]	9773±136	8120±794	1.273±0.125	222.38±21.77	4.497±0.440	0.098
J111720.801+405954[illegible]	10950±121	6786±196	1.064±0.031	134.26±3.88	7.448±0.215	0.029
J114722.608+171325.21	9962±109	7066±420	1.108±0.066	156.94±9.34	6.372±0.379	0.060
J124535.626+423824.58	10086±67	6349±42	0.995±0.007	70.84±0.48	14.116±0.095	0.007
J125507.082+192459.00	8882±98	6997±182	1.097±0.029	118.17±3.09	8.462±0.221	0.026
J134305.302+270623.98	10678±151	6330±374	0.992±0.059	176.02±10.40	5.681±0.336	0.059
J141724.329+494127.85	10503±112	7095±46	1.112±0.007	88.37±0.58	11.316±0.075	0.007
J151859.717+002839.58	9072±131	6328±494	0.992±0.078	169.83±13.27	5.888±0.460	0.078
J161704.078+181311.96	8568±88	6139±132	0.963±0.021	111.77±2.41	8.947±0.193	0.022
J230240.032 003021.60	10478±42	7447±137	1.168±0.022	121.45±2.24	8.234±0.152	0.018

What is the identity of Blackbody Star?

Astronomy & Astrophysics manuscript no. ms
April 5, 2018

On the nature of the black-body stars

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April 5, 2018

ABSTRACT

We study the physical nature of the black-body stars recently discovered. We use sets of white dwarf (WD) model atmospheres with pure-He, pure-H, and H/He mixtures to compute synthetic spectra and compare theoretical expectations with observations of the black-body stars. We find that the spectral properties of the black-body stars in the UV and the optical are reproduced to high-accuracy by helium dominated atmospheres possibly with trace amounts of hydrogen below the spectroscopic detection limit, $-8 \leq \log(N_{\rm H}/N_{\rm He}) \leq -6$, and typical $\log g = 8$ values corresponding to WDs of 0.6 $M_{\odot}$. Pure-He models with $\log g = 8$ also provide a good match from 12000 down to $T_{\rm eff} = 8500$ K, but fail to simultaneously fit the UV and optical colors for the cooler stars in the sample. However, pure-He models with $\log g = 9$ show a better match with the data, implying that black-body stars could be massive white dwarfs, around $\sim 1.2\ M_{\odot}$. We find that the emerging spectrum has a Planck distribution shifted towards the blue compared to the expected shape based on the model effective temperature. The black-body temperatures determined from colors overestimate the actual $T_{\rm eff}$ of these stars by 400 K and up to 1000 K, depending on temperature and $\log(N_{\rm H}/N_{\rm He})$. We finally show that precision of end-of-mission Gaia parallaxes should allow disentangling whether the black-body stars have typical white dwarf masses or represent a massive, peculiar population.

Key words. white dwarfs — stars: atmospheres — stars: evolution — opacity

DA, DB, DC stars

DC stars are not always blackbody stars

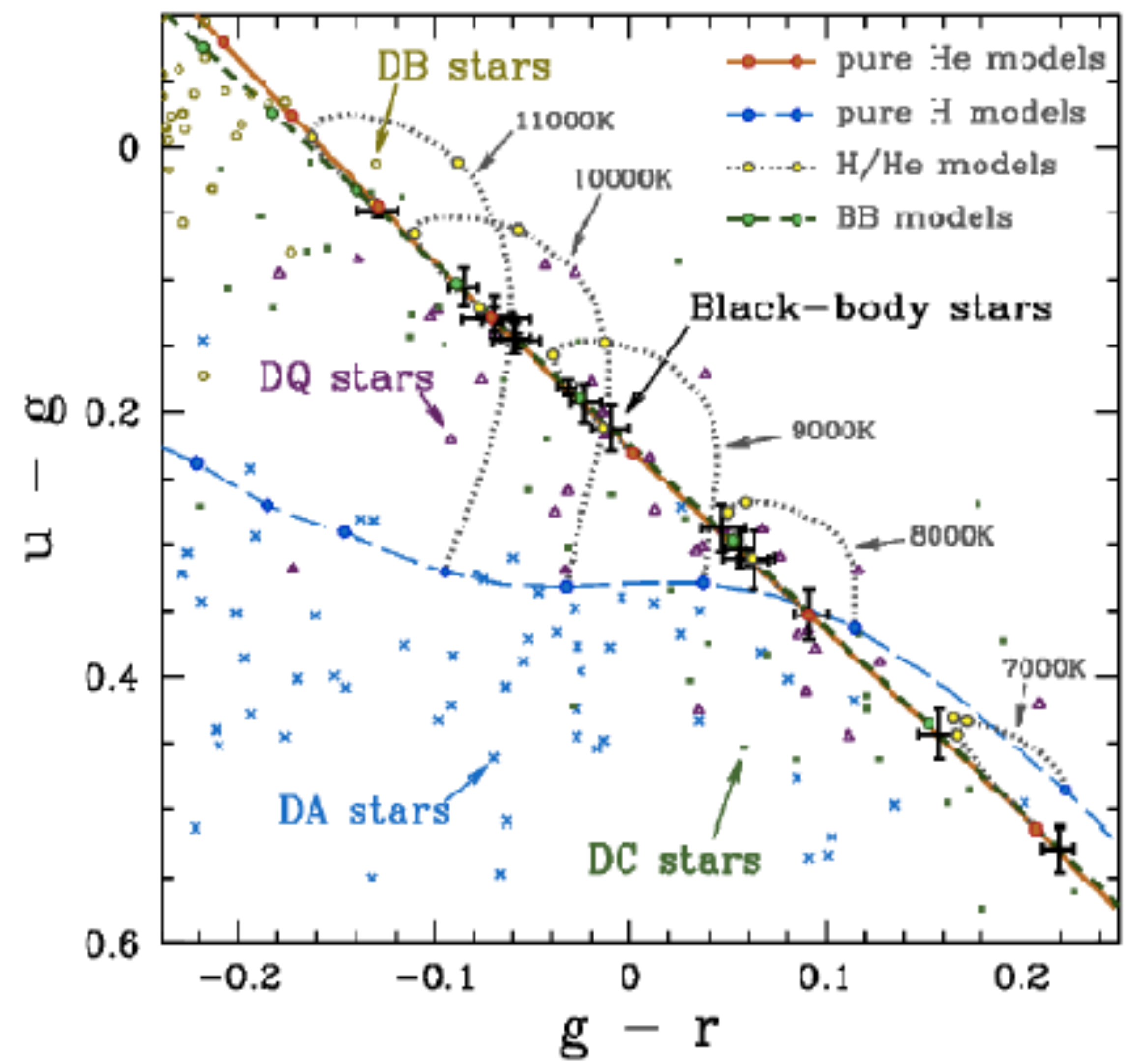


Fig. 1. Color-color diagram for a sample of white dwarf stars from the SDSS DR7 catalog (Kleinman et al. 2013). Black-body stars from SF17 are shown with error bars. Lines denote theoretical color-color curves for black-body (green short-dashed), pure-He (red/orange solid), pure-H (blue long-dashed), and mixed H/He (dotted) atmosphere models as indicated in the figure legend, in the range 12000-7000 K. Small circles on top of the curves showing black-body, He atmosphere and H atmo-

Cooled He Star?

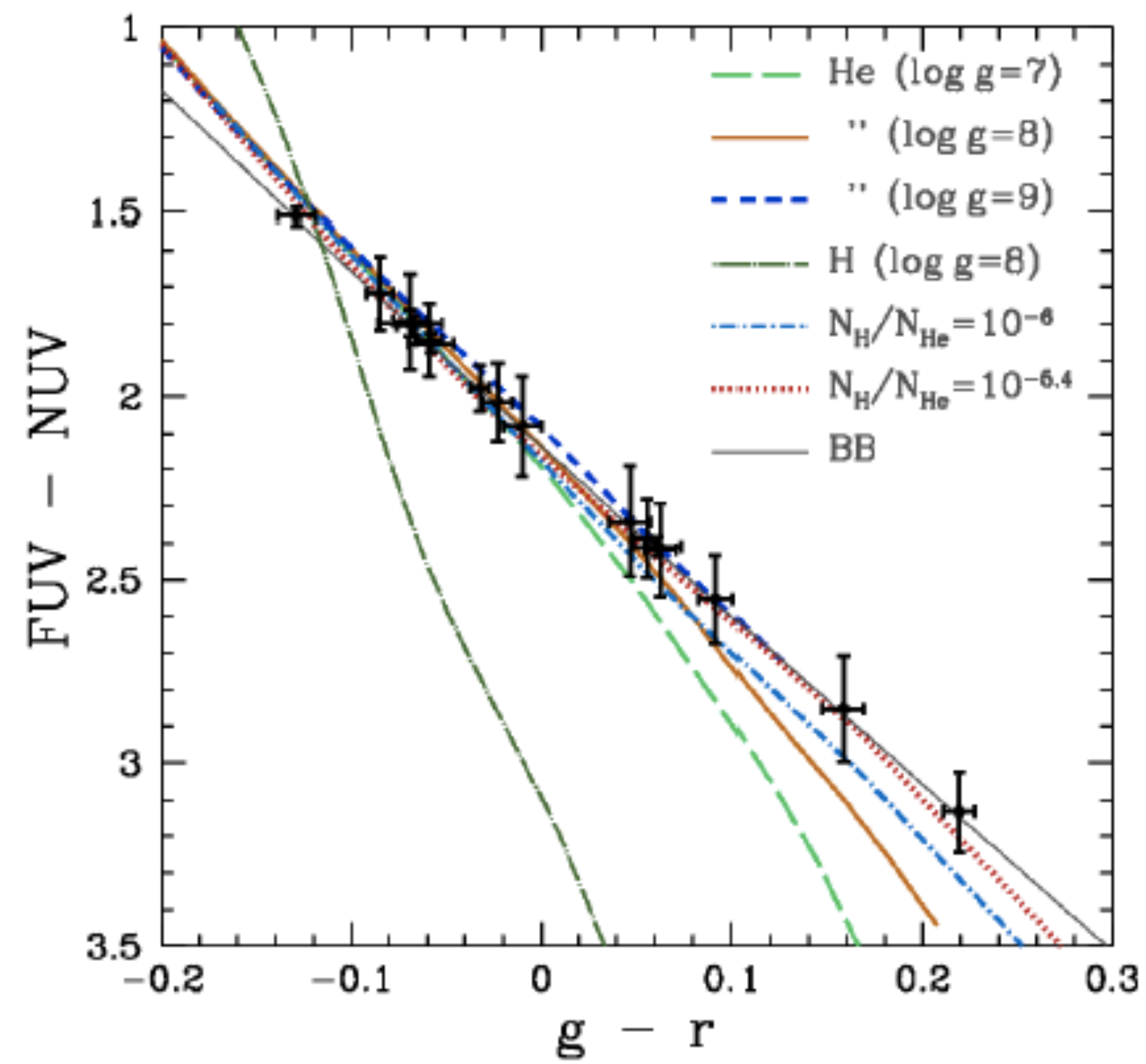


Fig. 2. (FUV-NUV)-($g-r$) color-color diagram. BB-stars are shown as black dots with error bars. Lines denote theoretical models as indicated in the legend. Models with H/He mixtures correspond to $\log g = 8$. The H/He models with $\log(N_H/N_{He}) = -6$ reproduce all BB-stars data.

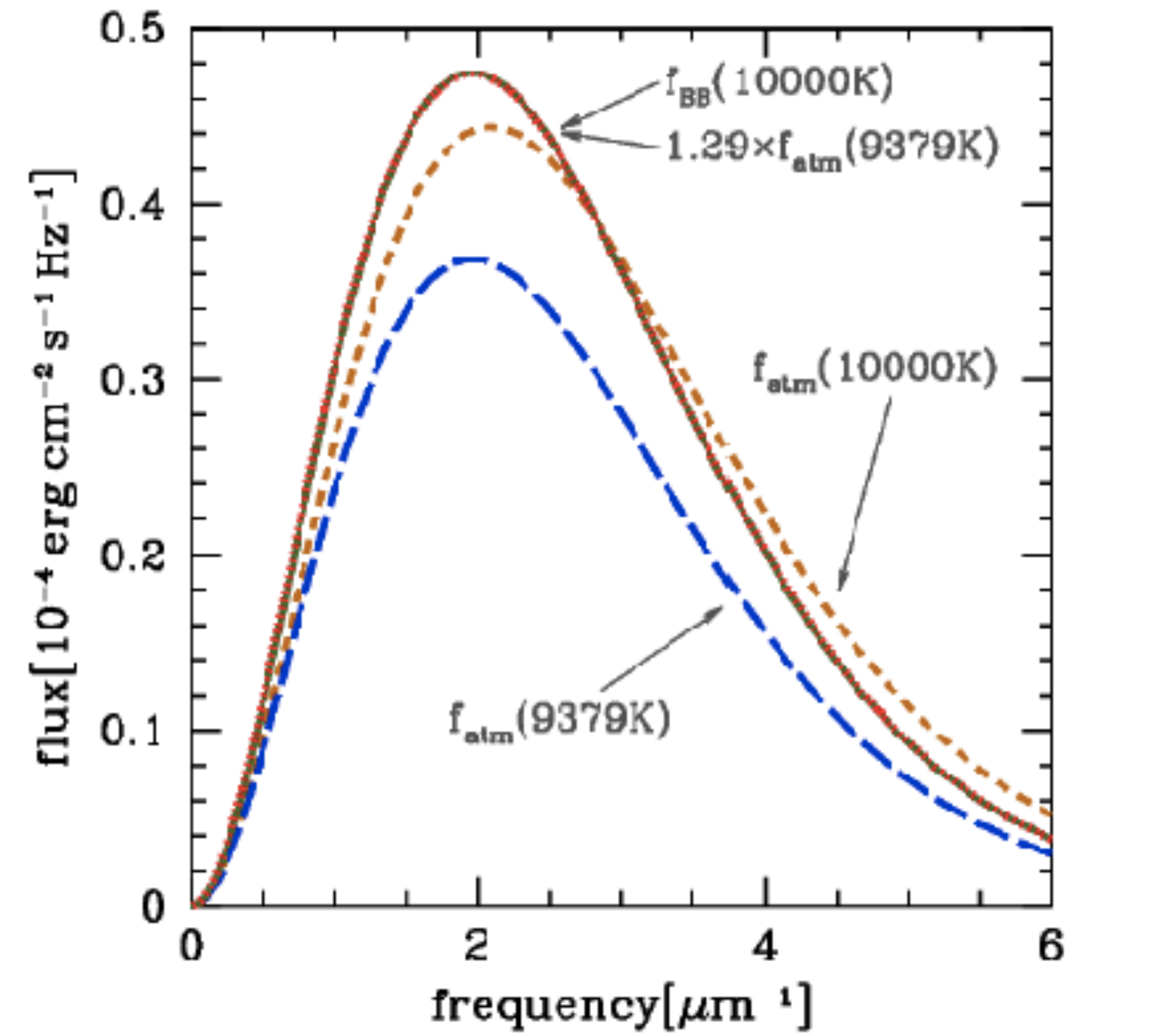
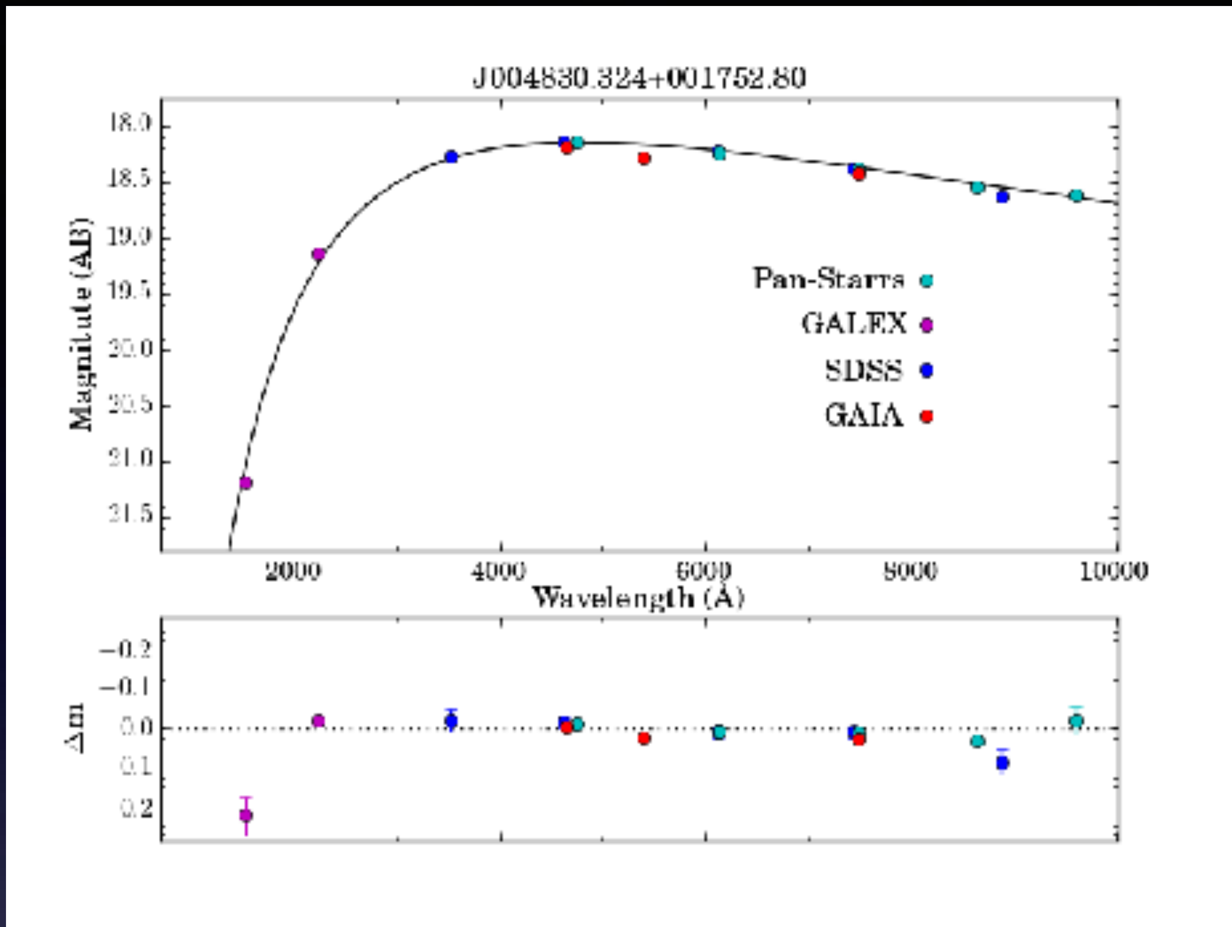
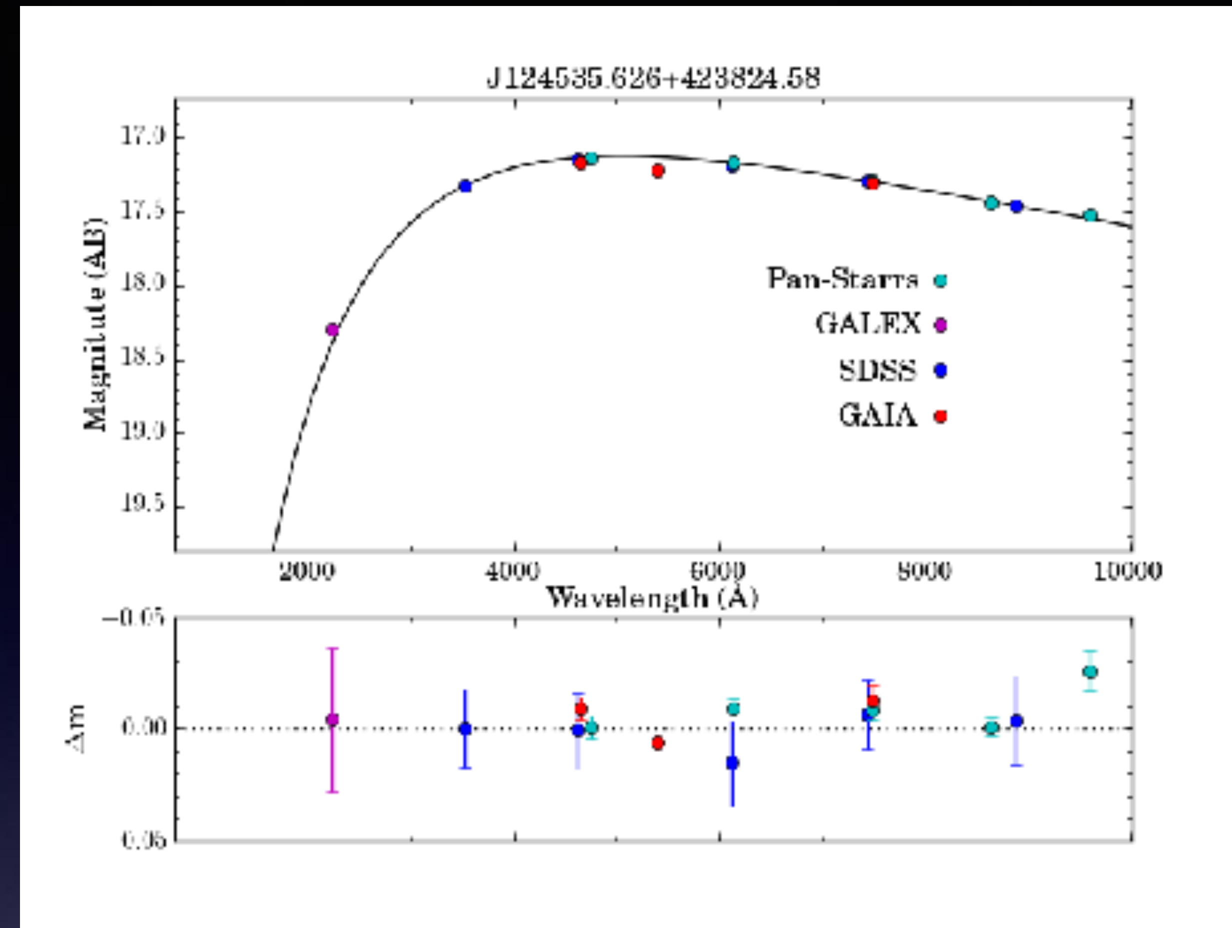


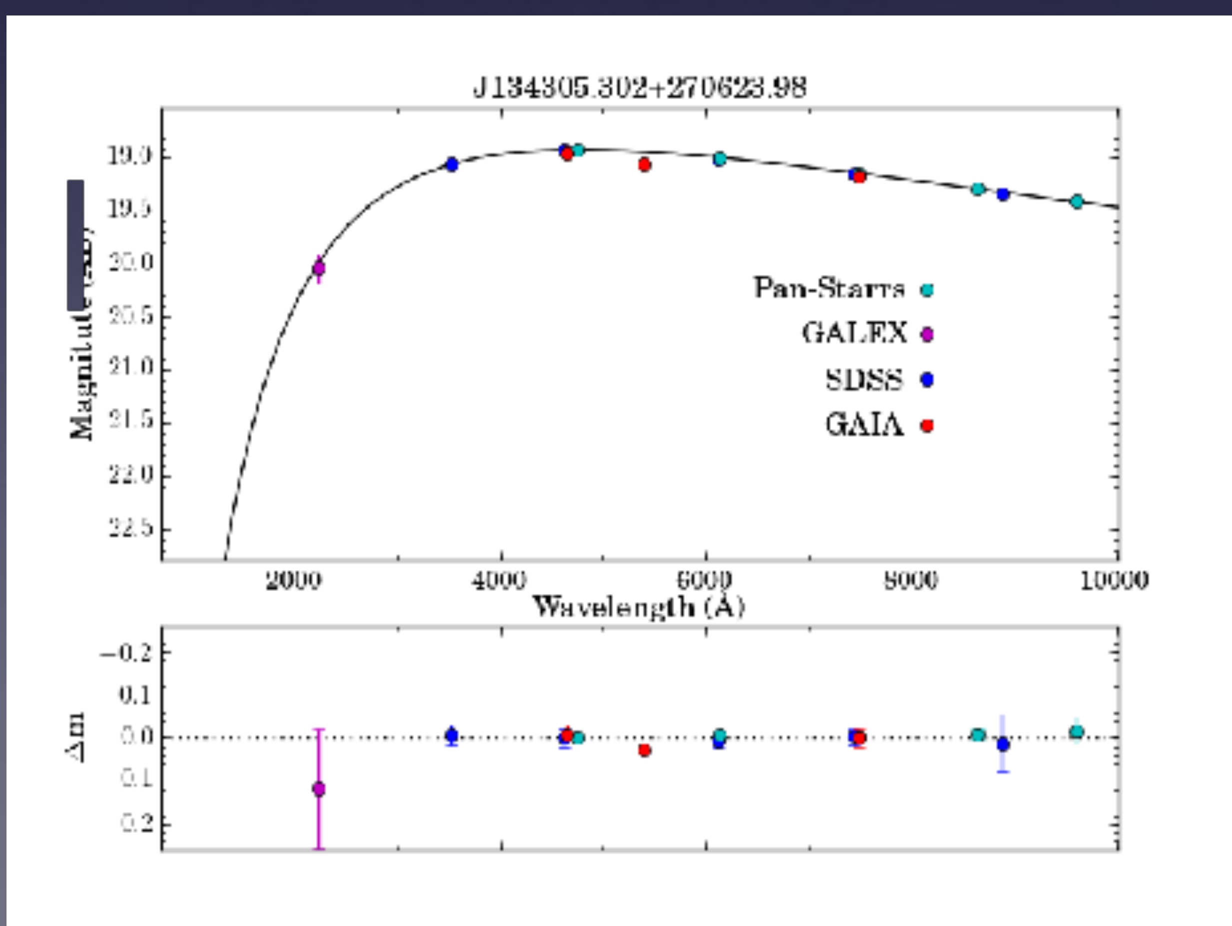
Fig. 3. Emerging monochromatic flux. Orange short dashed line: pure-He atmosphere with T_{eff} = 10000 K; solid green line: black-body spectrum with T_{eff} = 10000 K; blue long dashed line: pure-He atmosphere with T_{eff} = 9379 K; red dotted line: pure-He atmosphere with T_{eff} = 9379 K scaled up by a factor 1.29 to match the total flux of a T_{eff} = 10000 K spectrum. Model atmospheres correspond to $\log g = 8$.

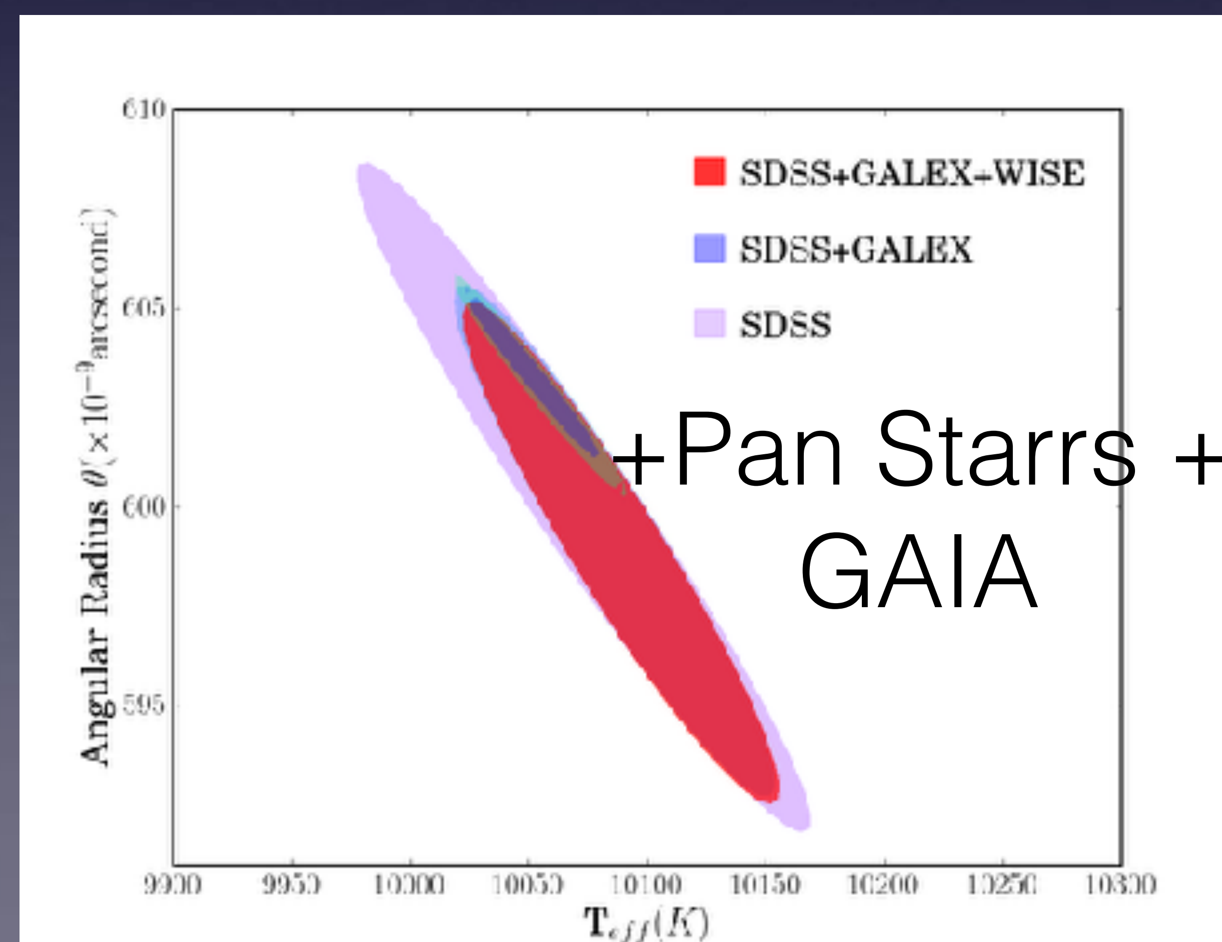
Serenelli et al 2018

Pan-Starrs & GAIA data makes it better



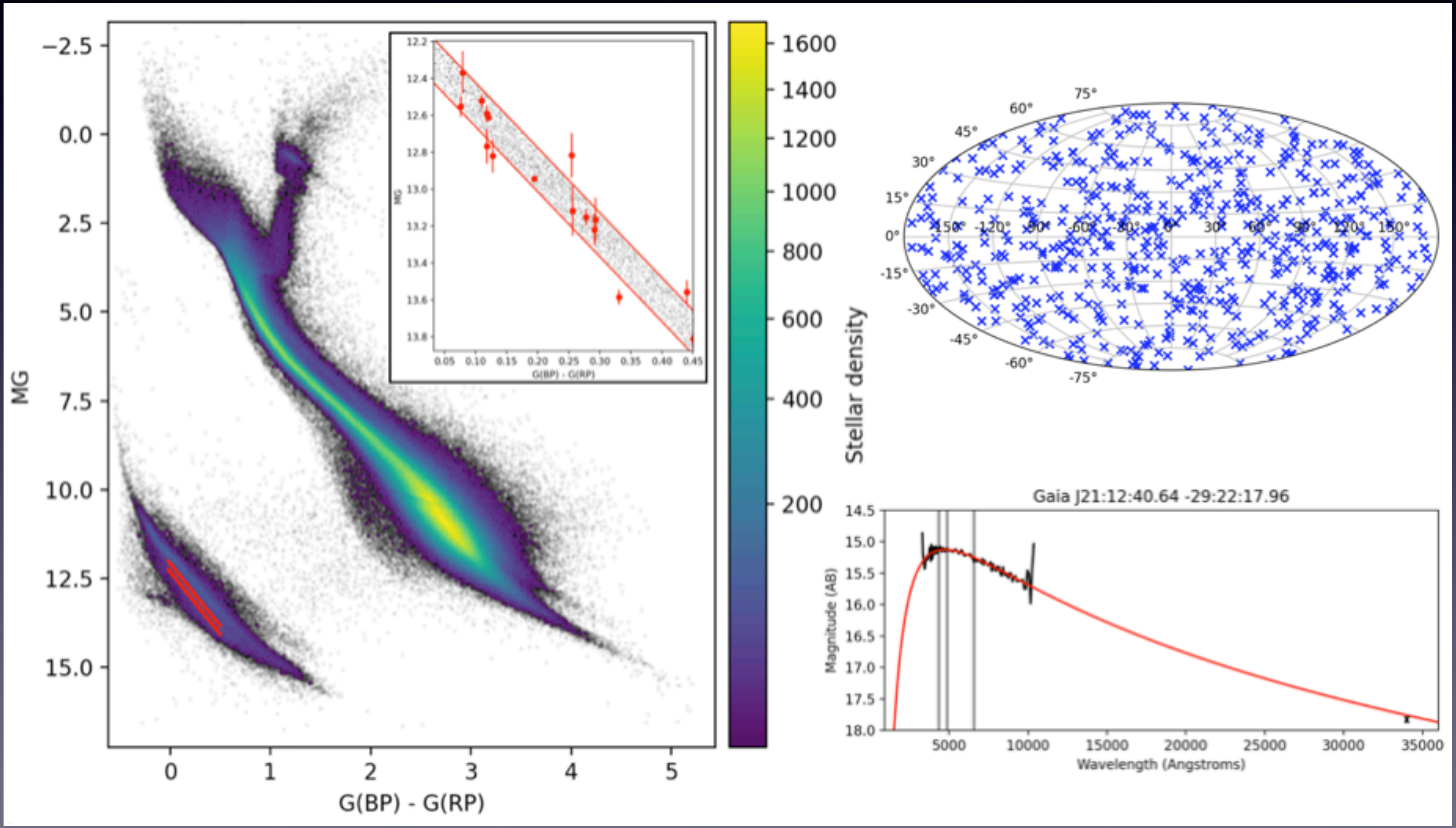






GAIA DR3 : 1.81 billion Stars

Ryan Cooke (Durham) identified 441 Candidates



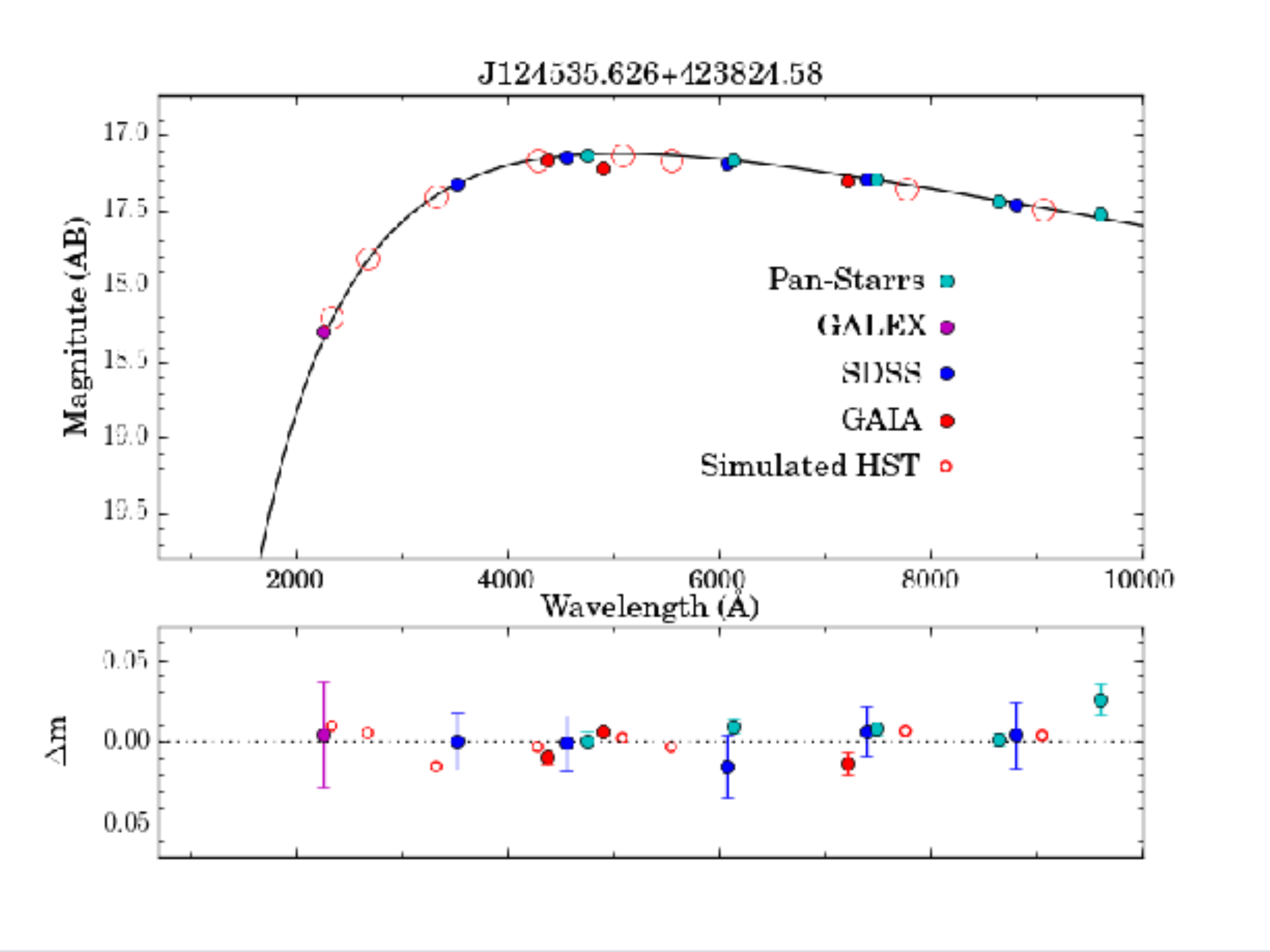
Follow-up Observations by

VLT (XShooter), SOAR(Goodman), Lick(KAST)

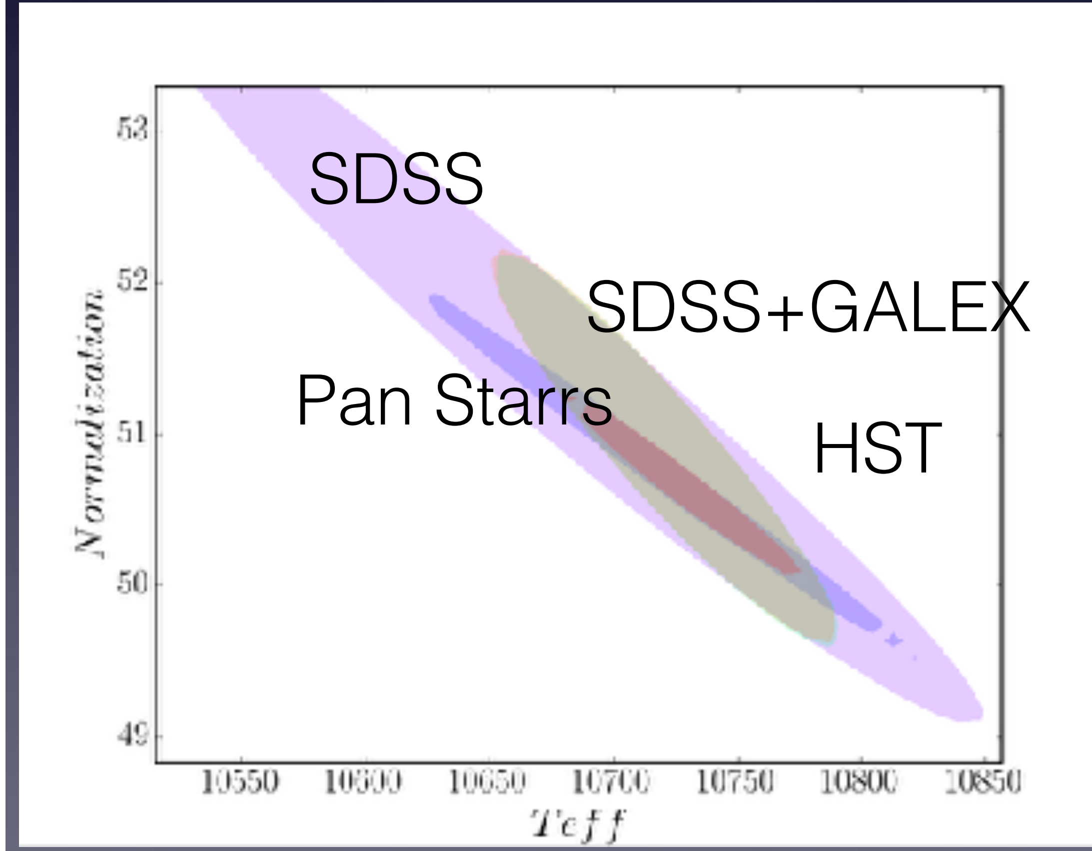
15 New BB stars from Lick, 12 New BB stars from VLT/SOAR
Out of 400 candidates : In GAIA DR3, 1-2 in 100 million stars

	A	B	C	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Mask	F?	Name	pmra_arcsec	pmdc_arcsec	Epoch	Mag	Best	Planned Inst.	Telescope/Instrument	Total exposure time (s)	Date Observed	2nd Obs	3rd Obs	4th Obs	Features observed in spect
206	4		BB232415+241227	+0.07344	-0.00384	2016.0	G = 17.33		Kast							
207	0	f	BB233900+442721	+0.00178	-0.01290	2016.0	G = 17.23		Kast	KAST	1200	2023-08-16				Featureless
208	32		BB234259+275812	+0.00580	-0.05490	2016.0	G = 16.54		Kast							
209	0	He	BB234324+030202	+0.02626	-0.02948	2016.0	G = 17.25		Kast/Goodman	KAST	1200	2023-08-16				He features
210	16		BB234447+893855	+0.05983	-0.02271	2016.0	G = 16.94		Kast							
211	16		BB234518+641040	+0.07792	-0.04318	2016.0	G = 17.34		Kast							
212	4		BB235517+231426	+0.14301	+0.03332	2016.0	G = 16.66		Kast							
213	0	He	BB235828+374359	+0.04224	-0.04954	2016.0	G = 16.25		Kast	KAST	1200x2(1) 1200(2) check	2023-07-23	2023-08-15			He abs features. NOTE :: T
214	0	,Ca,	BB000058-625654	+0.07259	+0.06661	2016.0	G = 17.41		Goodman	XSHOOTER		2023-07-19				
215	0	C2,C	BB000243-460442	-0.02593	-0.01046	2016.0	G = 17.14	YES	Goodman	XSHOOTER	470 (UVB) 426 (VIS)	2023-05-21				C2 Swan, maybe O I 6300
216	0	C2,C	BB000445-612339	+0.13125	-0.10416	2016.0	G = 16.59	YES	Goodman	XSHOOTER		2023-07-18				C2 swan, O I 6300 absorpti
217	0	,C2	BB001628-355627	-0.02077	-0.01767	2016.0	G = 16.58		Goodman	XSHOOTER		2023-07-19				
218	0	C2,C	BB001641-334152	-0.05736	-0.18863	2016.0	G = 16.63	YES	Goodman	XSHOOTER		2023-07-18				C2 swan, O I 6300
219	0	He,(	BB002011-440236	+0.03418	-0.00344	2016.0	G = 16.89		Goodman	XSHOOTER		2023-07-19				
220	0	-,He	BB002047-515353	-0.03853	+0.02066	2016.0	G = 17.45		Goodman	XSHOOTER		2023-07-19				
221	0	C2	BB002132-374518	-0.02866	-0.14986	2016.0	G = 16.65	YES	Goodman	XSHOOTER		2023-07-18				C2 Swan
222	0	He	BB003026-585638	+0.01795	-0.00710	2016.0	G = 15.90		Goodman	XSHOOTER		2023-07-19				
223	0	,C2	BB003225-624224	+0.19532	-0.02977	2016.0	G = 17.49		Goodman	XSHOOTER		2023-07-19				
224	32		BB003941-765244	-0.01204	+0.01229	2016.0	G = 17.02		Goodman							
225	0	,C2	BB011614-385202	-0.06216	-0.02223	2016.0	G = 16.56		Goodman	XSHOOTER		2023-07-26				
226	0	,C2	BB011620-385501	+0.03603	-0.03795	2016.0	G = 17.41	YES	Goodman	XSHOOTER		2023-07-18				Ca II, C2, H
227	0	C2	BB012029-414554	+0.19181	-0.14130	2016.0	G = 16.70	YES	Goodman	XSHOOTER		2023-07-08				C2 Swan
228	0	le,C	BB012726-502205	-0.02449	-0.07861	2016.0	G = 17.02		Goodman	XSHOOTER		2023-08-09				
229	0	le,C	BB013002-265106	+0.04668	+0.00024	2016.0	G = 17.41		Goodman	XSHOOTER		2023-07-19				
230	0	,C2	BB013018-425015	+0.13685	+0.07406	2016.0	G = 16.66		Goodman	XSHOOTER		2023-07-26				
231	0	C2,C	BB013237-274427	+0.14709	-0.12196	2016.0	G = 16.37	YES	Goodman	XSHOOTER		2023-07-18				C2, O I
232	0	le,C:	BB013349-390943	-0.02769	-0.02527	2016.0	G = 17.20		Goodman	XSHOOTER		2023-07-26				
233	0	,C2,	BB013902-400225	+0.03021	+0.05047	2016.0	G = 17.15	YES	Goodman	XSHOOTER		2023-07-18				
234	0	,He,	BB014328-403851	-0.02177	+0.01538	2016.0	G = 16.90		Goodman	XSHOOTER		2023-07-19				
235	0		BB014953-612916	+0.00370	-0.16154	2016.0	G = 17.09	YES	Goodman	XSHOOTER		2023-07-18				He II 4686? + C2 + O I

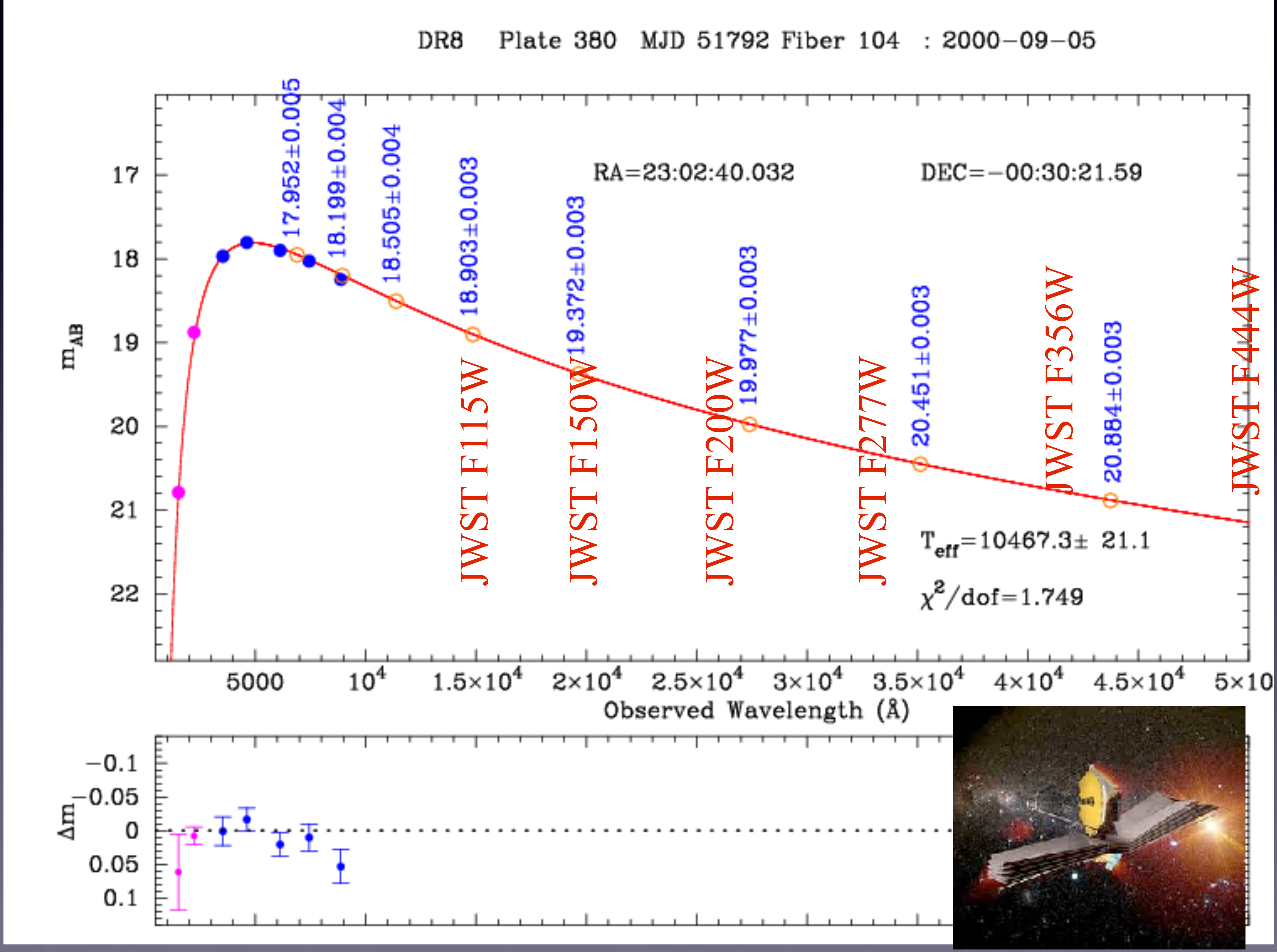
New Data from HST is being taken now



Expected



Looking at the Future with JWST today 0.3%, but we can do 0.1%



Summary

- 17 SDSS Blackbody Spectra (2018)
- 27 New Blackbody Stars being Observed (2023 ongoing)
- Aim to predict 0.1-0.3% precision 0.1-0.3% from UV-VIS-IR
- HST-Euclid-Roman-JWST network

Backup Slides

Av is a bit too much?!

Draft version March 15, 2016
Preprint typeset using LaTeX style emulateapj v. 5/2/11

TOWARDS A NETWORK OF FAINT DA WHITE DWARFS AS HIGH PRECISION SPECTROPHOTOMETRIC STANDARDS

C. Narayan[1], T. Axelrod[3], J. B. Holberg[2], T. Matheson[1], A. Saha[1], E. Olszewski[3], J. Claver[1], C. W. Stubbs[5,6], R. C. Bohlin[4], S. Deustua[4], A. Rest[4],

Draft version March 15, 2016

ABSTRACT

We present initial results from a program aimed at establishing a network of hot DA white dwarfs to serve as spectrophotometric standards for present and future wide-field surveys. These stars span the equatorial zone and are faint enough to be conveniently observed throughout the year with large-aperture telescopes. Spectra of these white dwarfs are analyzed to generate a non-local-thermodynamic equilibrium (NLTE) model atmosphere normalized to *HST* colors, including adjustments for wavelength dependent interstellar extinction. Once established, this standard star network will serve ground-based observatories in both hemispheres as well as space-based instrumentation from the UV to the near IR. We demonstrate the effectiveness of this concept and show how two different approaches to the problem using somewhat different assumptions produce equivalent results. We discuss lessons learned and the resulting corrective actions applied to our program.
Subject headings: Cosmology: Observations, Methods: Data Analysis, Stars, White Dwarfs, Surveys

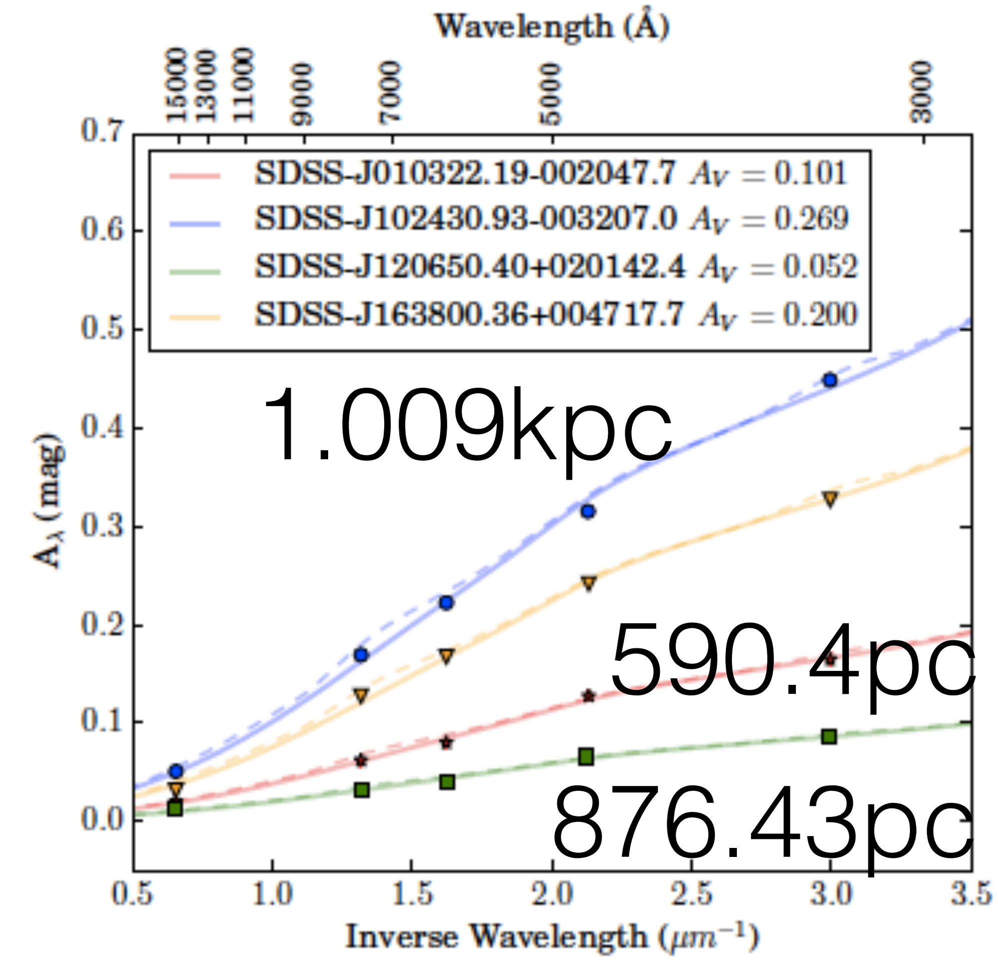
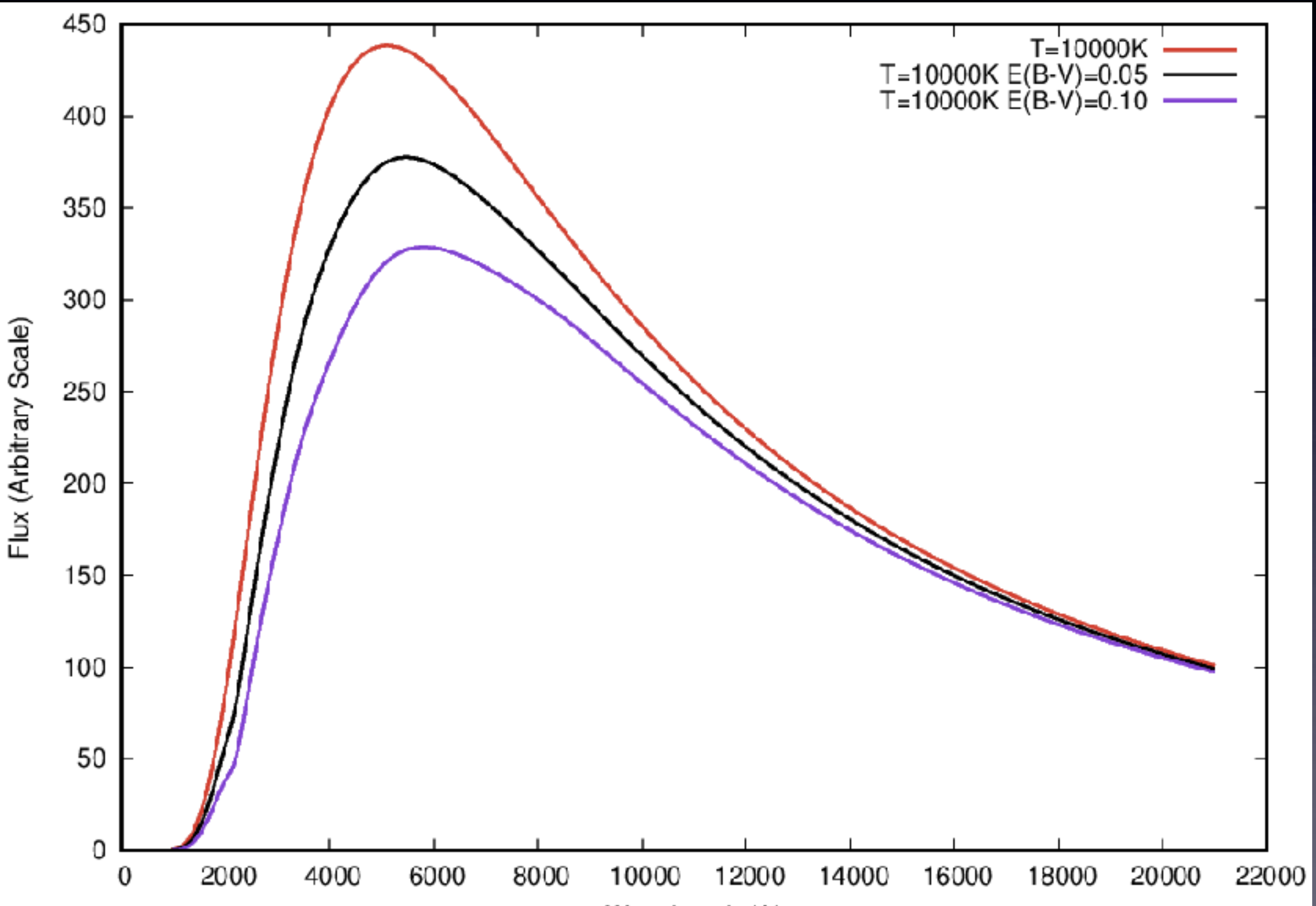


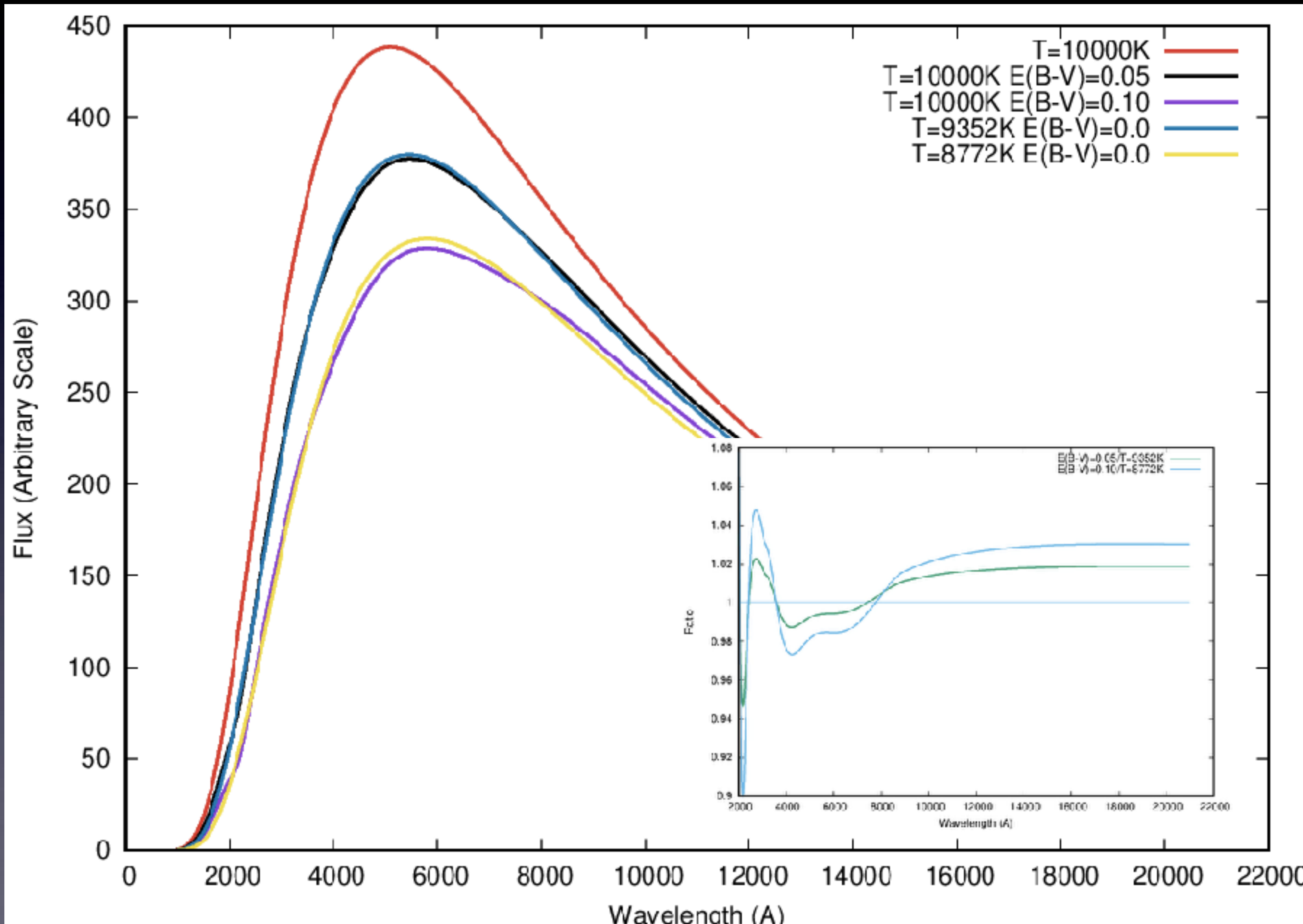
Fig. 7.— Extinction curve fits with $R_V = 3.1$ using the reddening law of Fitzpatrick (1999) (solid) and O'Donnell (1994) (dashed) for four objects in our sample, spanning a range from low to high reddening. The largest differences in the derived value of A_V using the two different extinction laws is seen for SDSS-J010322.19-002047.7 and SDSS-J120650.40+020142.4 where it is 0.001 mag. The mean residuals between the data and the fit extinction curve are 3 mmag.

Reddening: Dust or Intrinsic

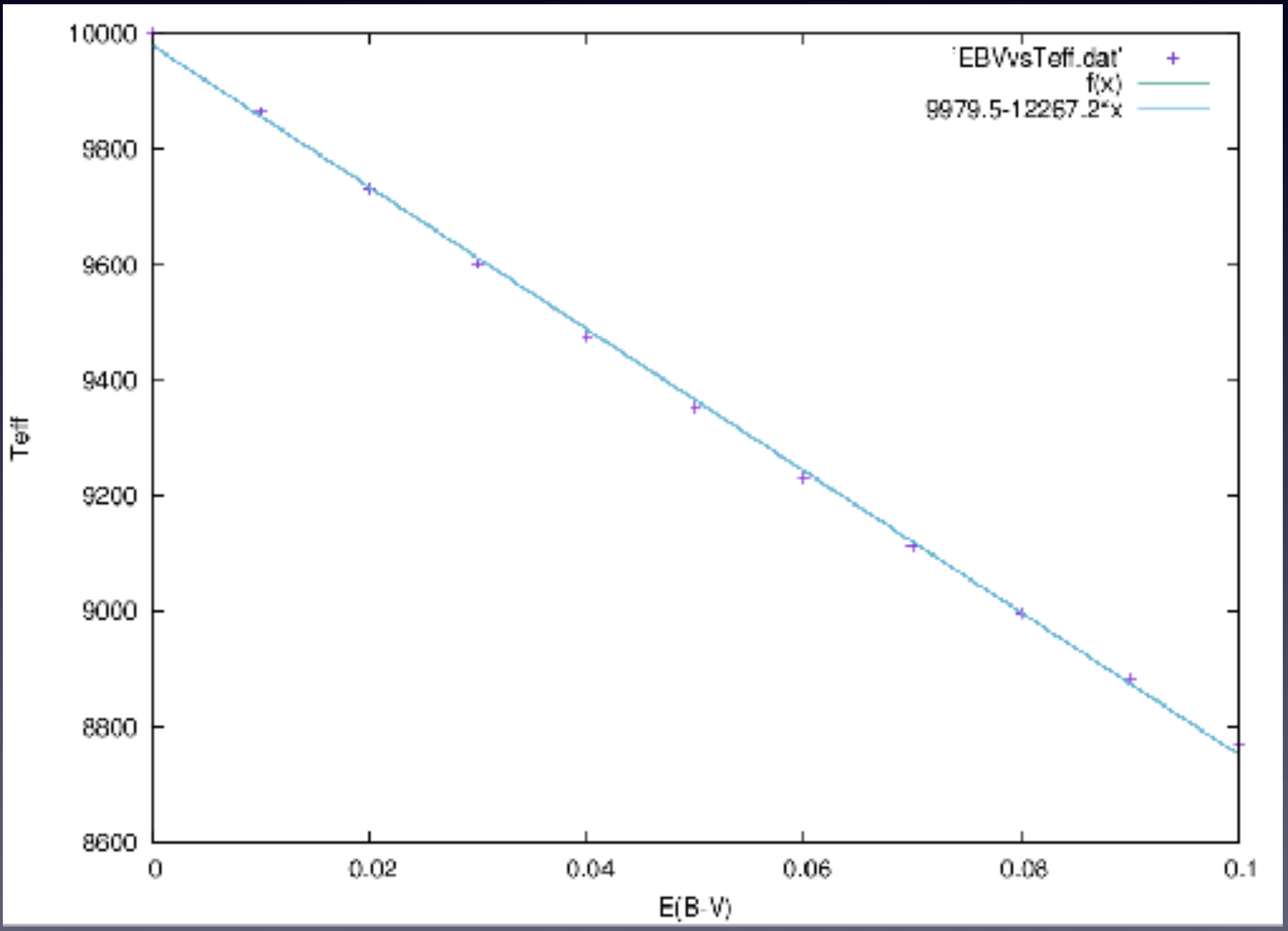
Can you tell which is which?

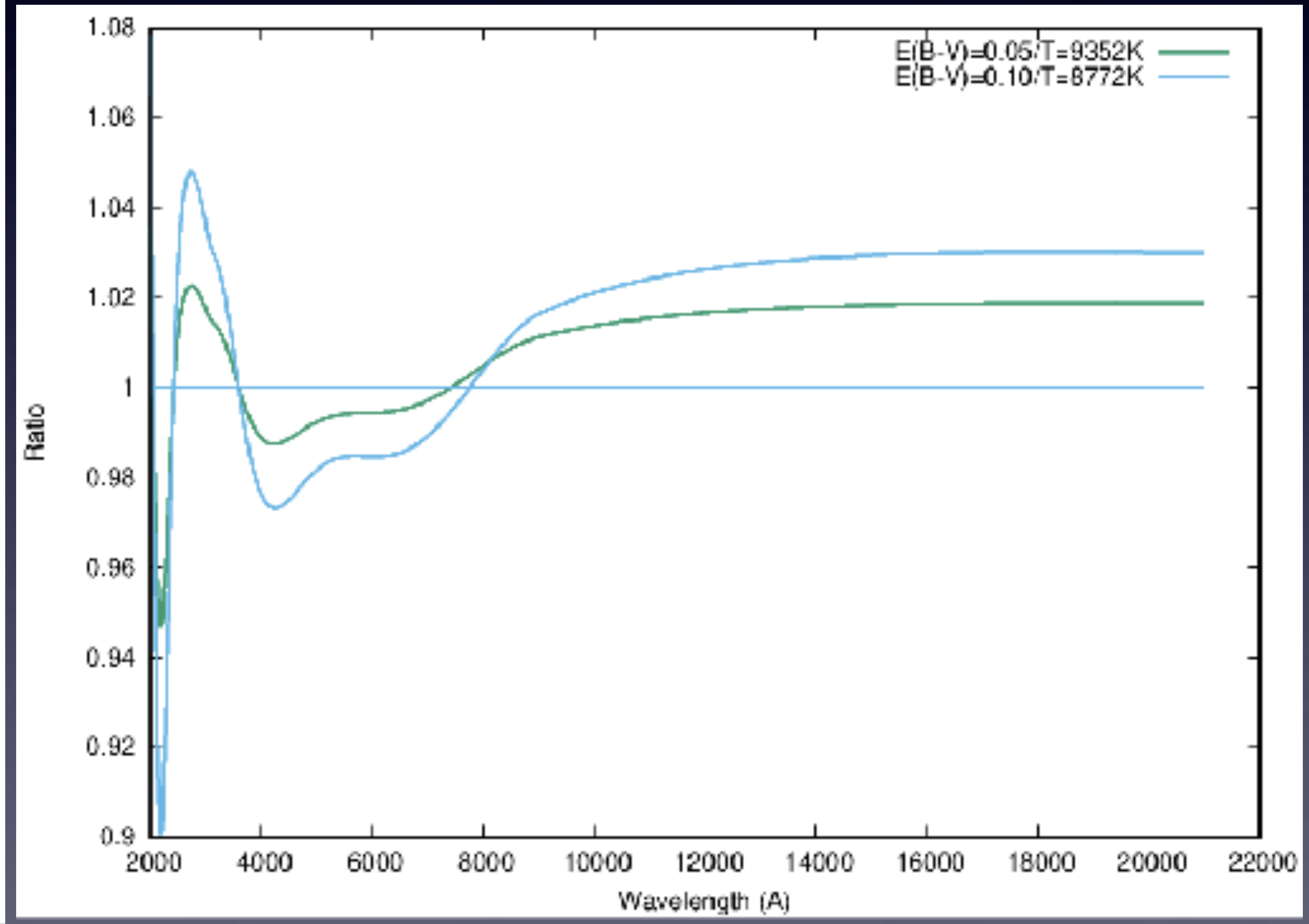


Extinction can be fitted by different Temperature



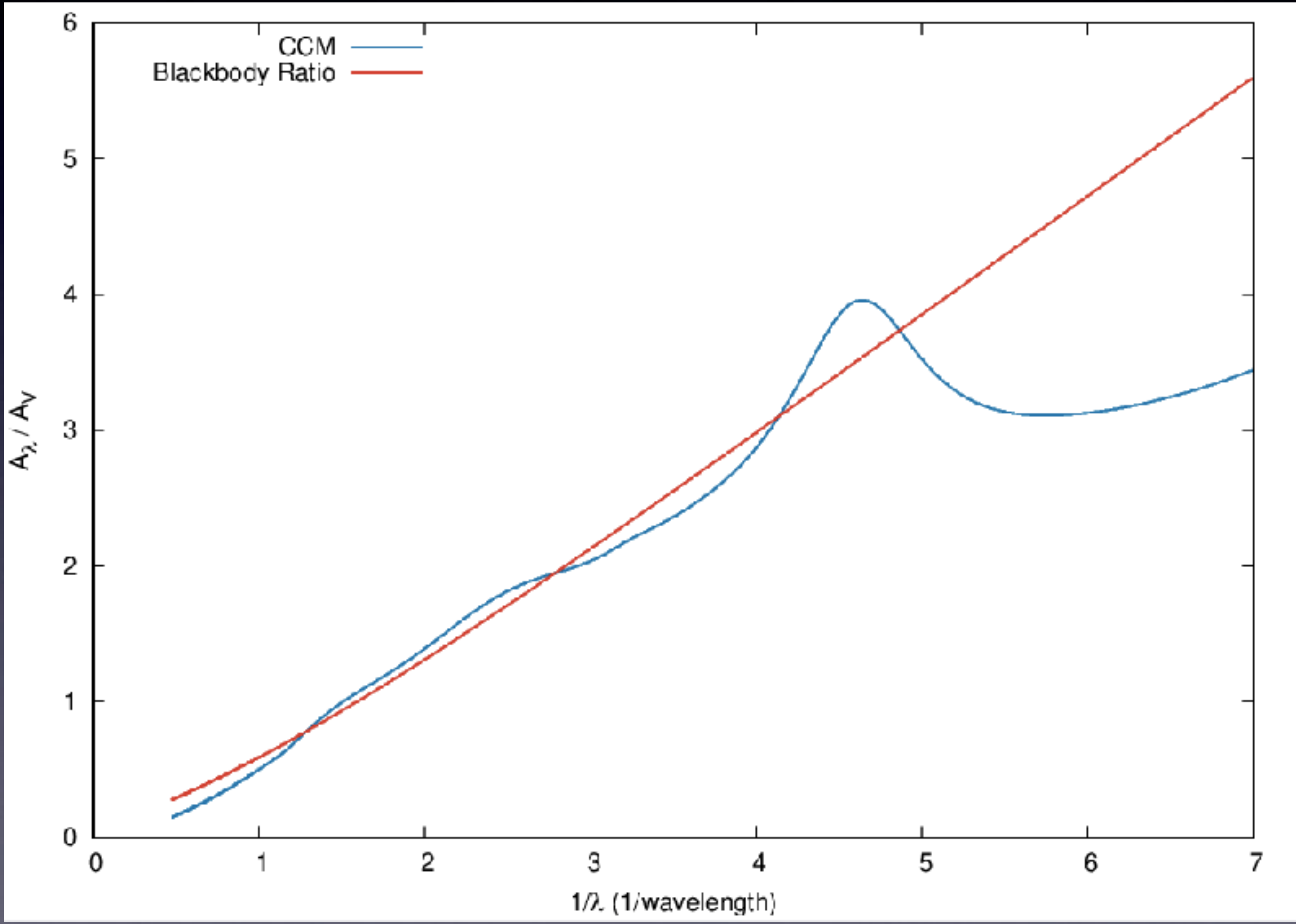
Temperature vs Extinction
It behaves in the same way
No way to distinguish which is which





Physics behind

CCM Dust Model vs. Temperature Effect
Mie Scattering vs. Rayleigh Jeans



AB Mag != SDSS Mag
Suggested by D. Hogg (SDSS-I)
Holtzman (SDSS-II)

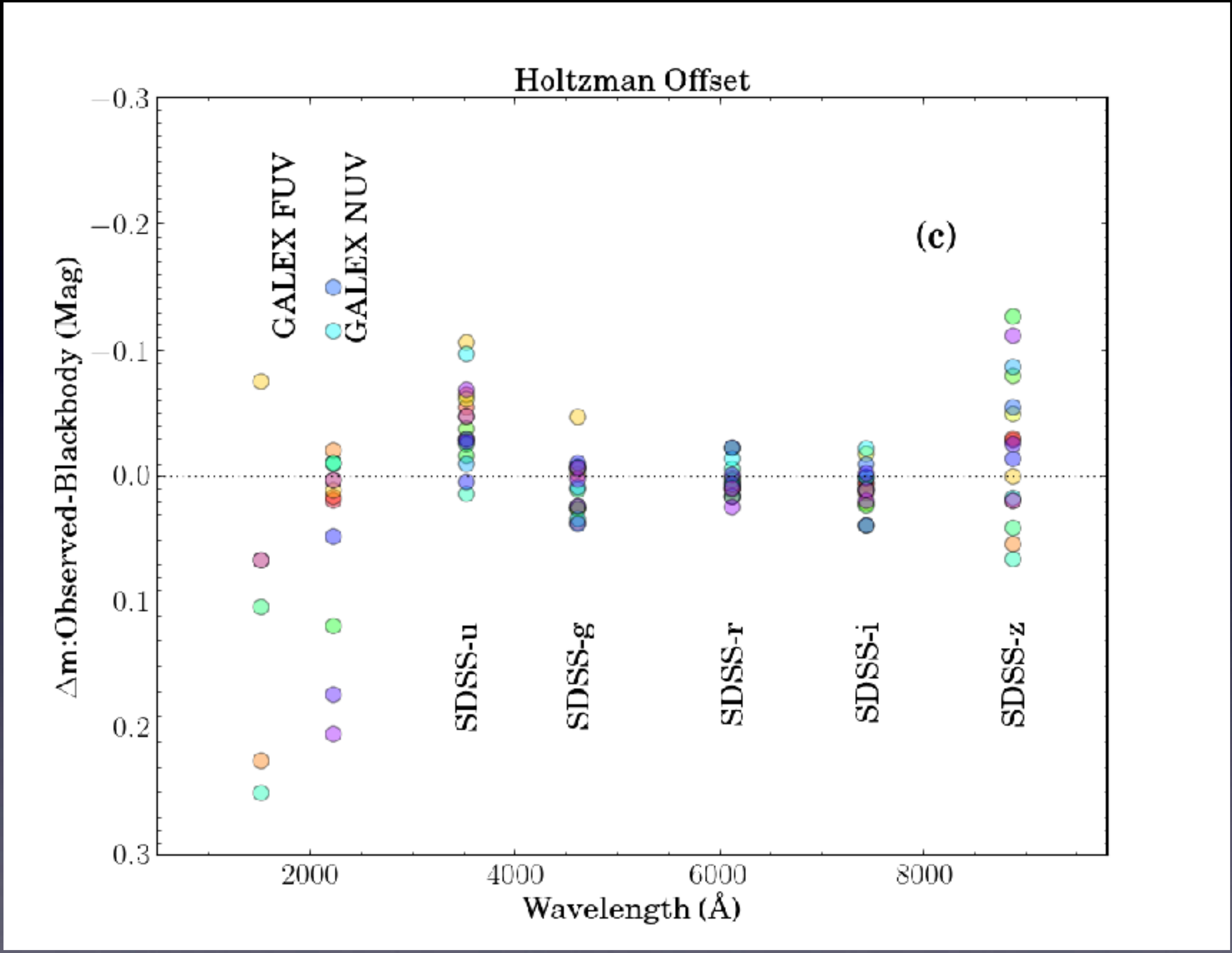
$$ABmag(u) = -2.5log_{10}\frac{\int \lambda R f_\lambda d\lambda}{\int \frac{R}{\lambda} d\lambda} - 2.407948 - 0.042$$

$$ABmag(g) = -2.5log_{10}\frac{\int \lambda R f_\lambda d\lambda}{\int \frac{R}{\lambda} d\lambda} - 2.407948 + 0.036$$

$$ABmag(r) = -2.5log_{10}\frac{\int \lambda R f_\lambda d\lambda}{\int \frac{R}{\lambda} d\lambda} - 2.407948 + 0.015$$

$$ABmag(i) = -2.5log_{10}\frac{\int \lambda R f_\lambda d\lambda}{\int \frac{R}{\lambda} d\lambda} - 2.407948 + 0.013$$

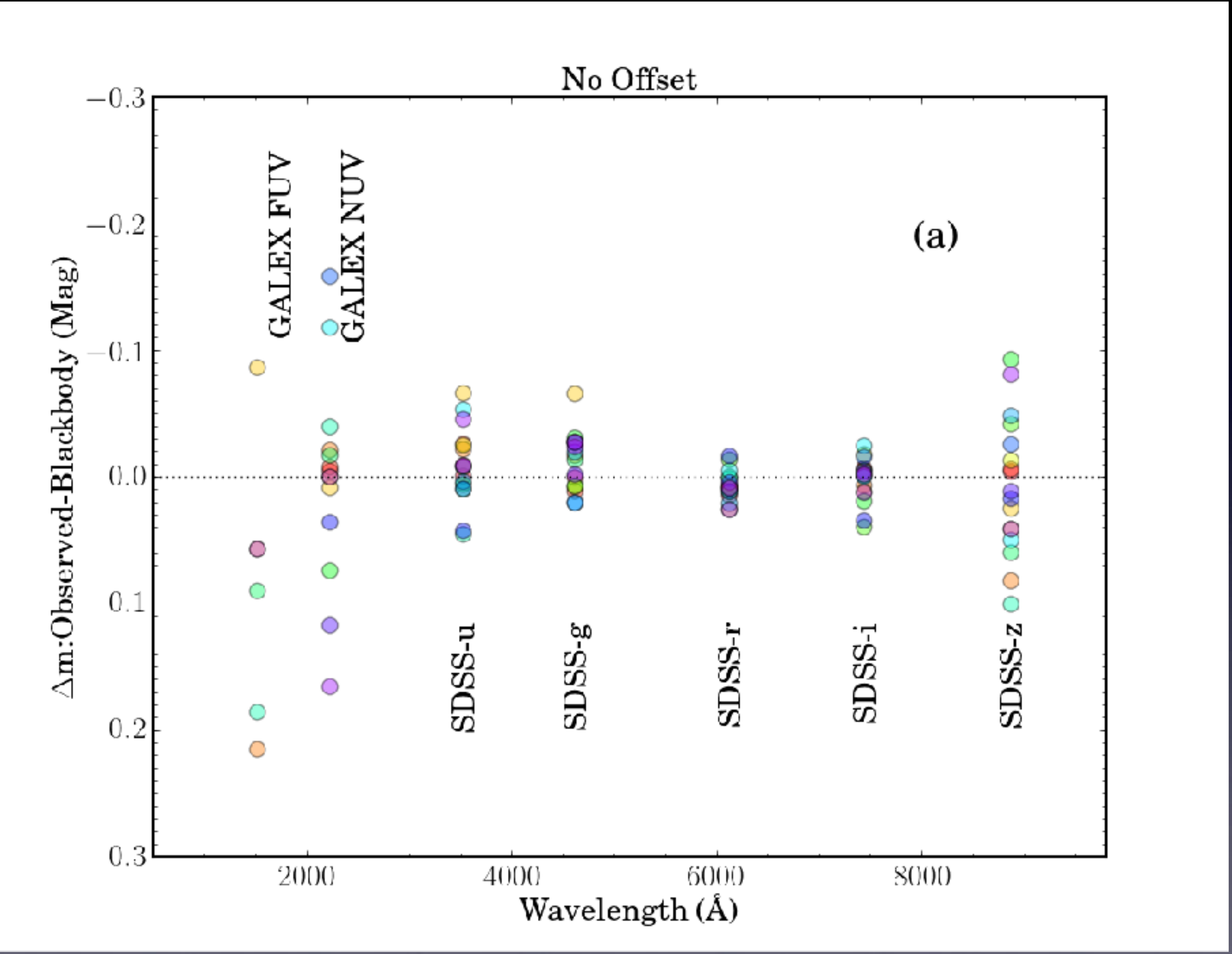
$$ABmag(z) = -2.5log_{10}\frac{\int \lambda R f_\lambda d\lambda}{\int \frac{R}{\lambda} d\lambda} - 2.407948 - 0.002$$


Holtzman Offset
(c)
GALEX FUV
GALEX NUV
SDSS-u
SDSS-g
SDSS-r
SDSS-i
SDSS-z
Δm:Observed-Blackbody (Mag)
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
2000
4000
6000
8000
Wavelength (Å)

HST may be off
SDSS original could be more accurate

Table 3. Mean of residuals from the black-body fit (Δm=data − black-body fit): The 17 black-body stars are used in this calculation. Row 1 is with the raw value of brightness given in SDSS data release DR8; Row 2 gives the offsets suggested by Hogg to make the SDSS magnitude closer to the AB system, and row 3 is the mean residuals for this case. Row 4 gives the offsets suggested by Holzman (2009) to make the SDSS magnitude closer to the AB system with CALSPEC, and Row 5 is the mean residuals.

Data Name	GALEX FUV	GALEX NUV	SDSS-u	SDSS-g	SDSS-r	SDSS-i	SDSS-z
Mean Residuals without Offset	0.191±0.202	-0.000±0.081	-0.006±0.031	-0.008±0.025	0.007±0.012	0.002±0.017	0.003±0.052
Hogg's Offset to SDSS			-0.042	0.036	0.015	0.013	-0.002
Mean Residuals with Hogg Offset	0.218±0.215	0.016±0.097	-0.047±0.034	0.020±0.025	0.007±0.014	-0.002±0.016	-0.019±0.054
Holtzman et al Offset (CALSEPC)			-0.037	0.024	0.005	0.018	-0.016
Mean Residuals with Holtzman Offset	0.215±0.213	0.018±0.093	-0.038±0.033	0.013±0.025	0.003±0.013	0.009±0.016	-0.027±0.054



No Offset
Δm:Observed-Blackbody (Mag)
Wavelength (Å)
(a)
GALEX FUV
GALEX NUV
SDSS-u
SDSS-g
SDSS-r
SDSS-i
SDSS-z
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
2000
4000
6000
8000

SDSS (2.4m) & Calibration Telescope (0.5m)

- Vegaは明るすぎるので、Oke & Gunn (1983)でVegaと紐付けられているBD17をAB Magの原点とする
- 同時刻に標準星を常に0.5m望遠鏡で観測し2.4mの望遠鏡を較正している。