The Time Domain Spectroscopic Survey: Stellar Variables

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SDSS-IV Meeting, 2019

Ensenada, Mexico

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SDSS-IV TIME DOMAIN SPECTROSCOPIC SURVEY

- Adds dedicated spectra to era of time domain imaging.
- First large-scale, *inclusive* spectroscopic survey of variable sources
  - No color selection
  - Generic variability, i.e., no requirement for periodicity, flares, etc.
- Extending Survey Science to the Time Domain/Spectroscopy through:
  - ***Systematic discovery*** of celestial variables
  - ***Population studies*** of variable stars and quasars
  - ***Exploring the unknown:*** rare objects

Overview:

Three principal components of TDSS, piggy-back on eBOSS

Main survey

eBOSS ELG plates

- TDSS main (90%) survey: SES=single-epoch spectroscopy BOSS classification/characterization spectra of imaging variables from Pan-STARRS 1, 3π imaging survey (PS1); ~10^5 fibers in SDSS-IV (10/deg^2)
- TDSS (10%) FES=few-epoch spectroscopy of potential spectral variables of interest (e.g., known from SDSS I-IV spectra) ~$10^{3\text{-}4}$ fibers in SDSS-IV
- TDSS RQS=repeat quasar spectroscopy of SDSS I-IV quasars; ~10^4 fibers in SDSS-IV

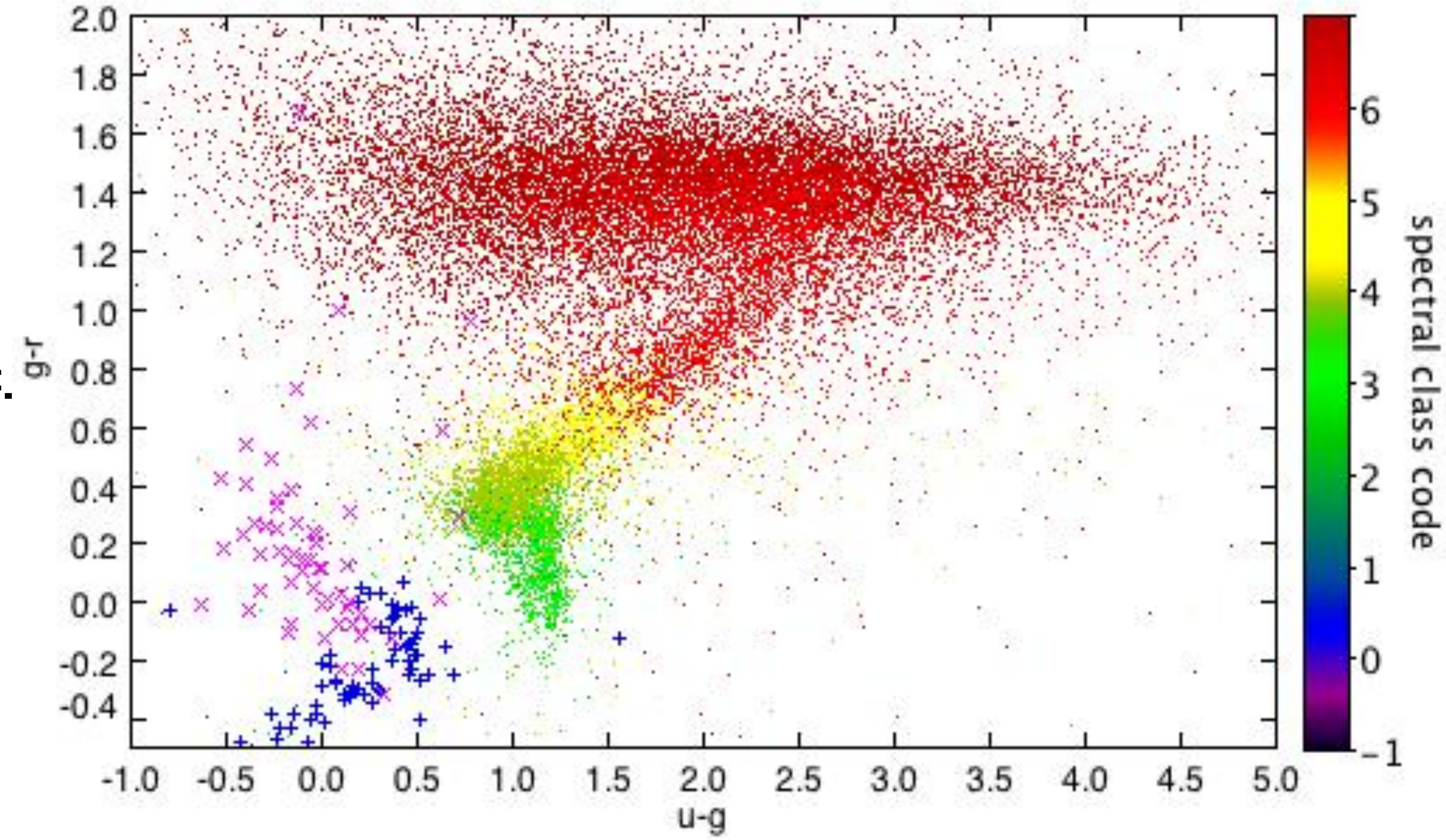
10% of TDSS fibers for special FES programs:

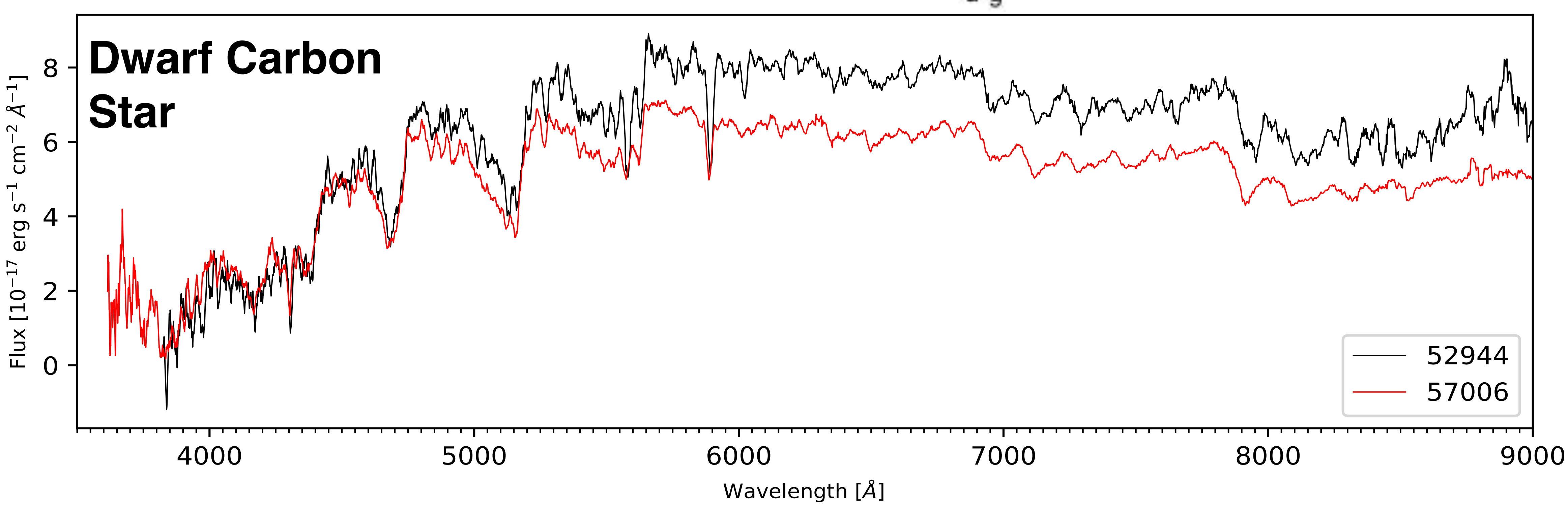
Target Type	Number	Observed (March '19)
Total **(~1 deg^{-2})**	**9143**	**6261**
WD/dM Binaries	1036	214
Dwarf Carbon Stars	830	370
Ultracool Dwarfs	402	556
Hypervariable Stars (≳0.3m)	1150	727
BAL Quasars	2900	1926
High S/N Quasars	1100	593
Double Peaked Emitters	900	576
QSO MGII Line Shifts	70	62
Hypervariable Quasars	1555	1237

(Target Selection Details in MacLeod et al. 2018)

TDSS/SES update (through DR14)

STAR subclasses (pipe) range from O/B, through A/F (green), to K/M (orange/red). Flaring M stars dominate, but thousands are in A/F-star regime that includes pulsating RR Lyrae. >710 have cataloged periodic light curves, e.g., also includes eclipsers. Large symbols highlight ~60 each CVs (purple x's) & variable WDs (blue +'s).

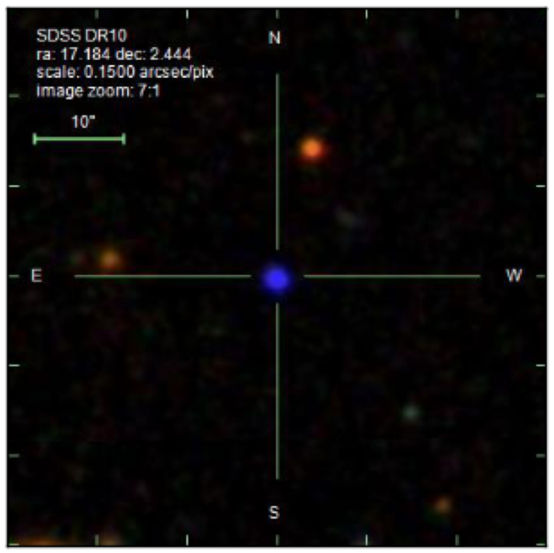


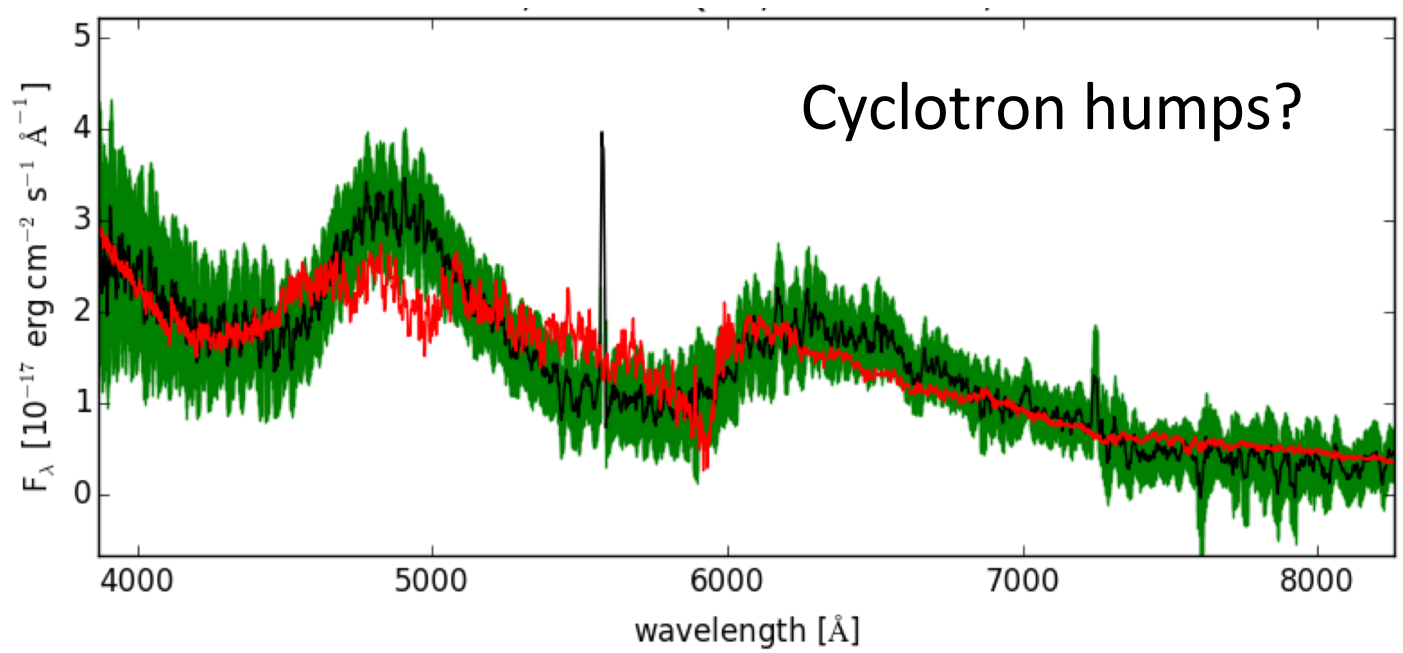


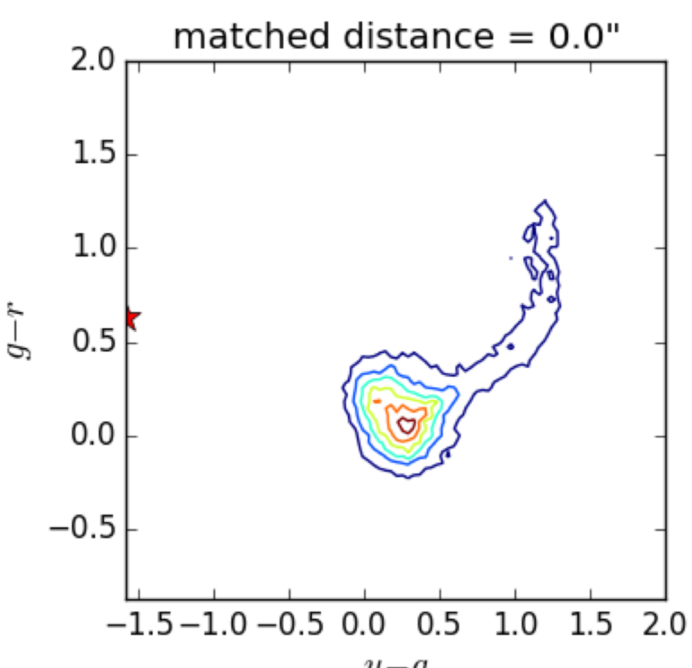
TDSS Stellar Science Opportunities

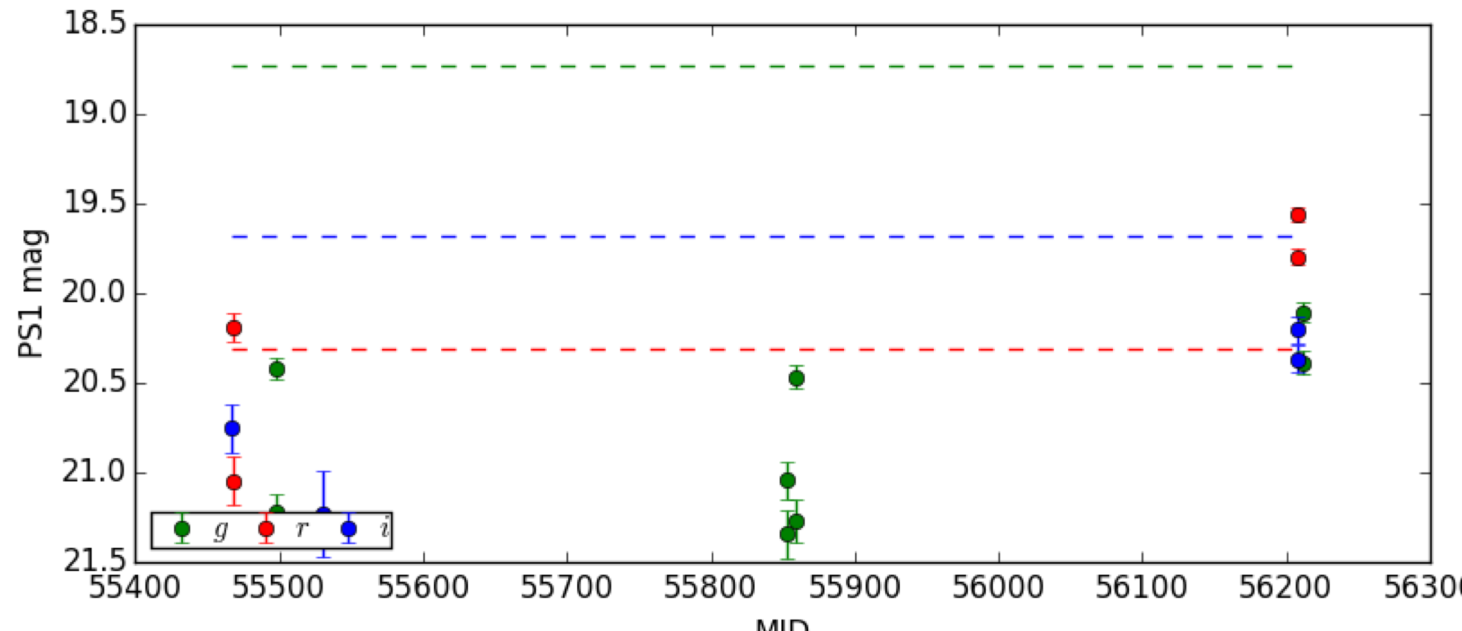
- Expect ~25,000 stellar variables in TDSS (pulsating, eclipsing, accreting, active)
  - ~ 4,000 off the main sequence
  - ~ 1,000 RR Lyr
  - ~ Handful of
    - WDs
    - CVs
    - Carbon stars
- ~10% of variables are periodic (logProb < -10)

TDSS Stellar Exotica: LARP?



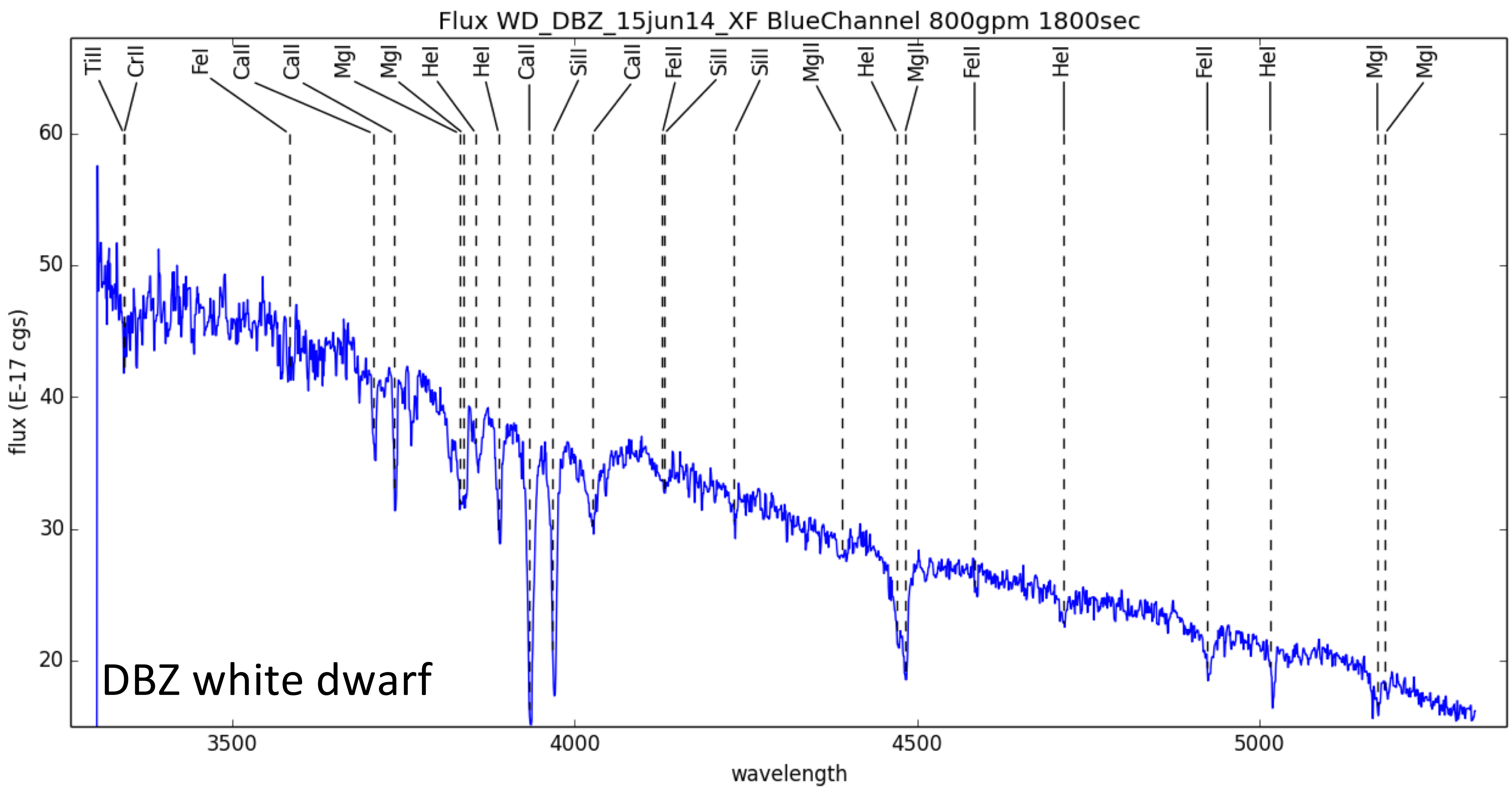






Low accretion rate polar? Highly variable. GALEX detected.

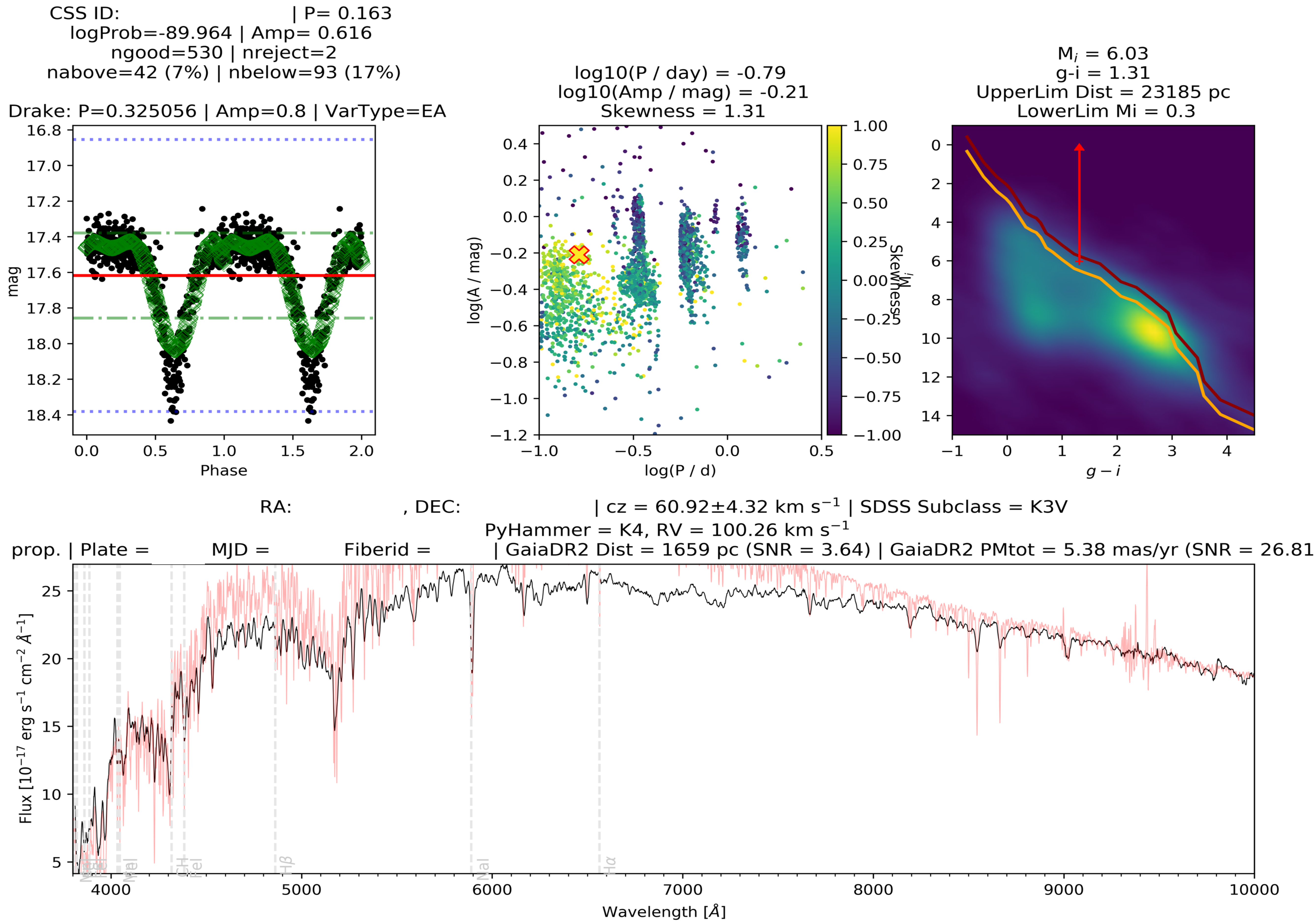
TDSS Stellar Exotica: DBZ WDs



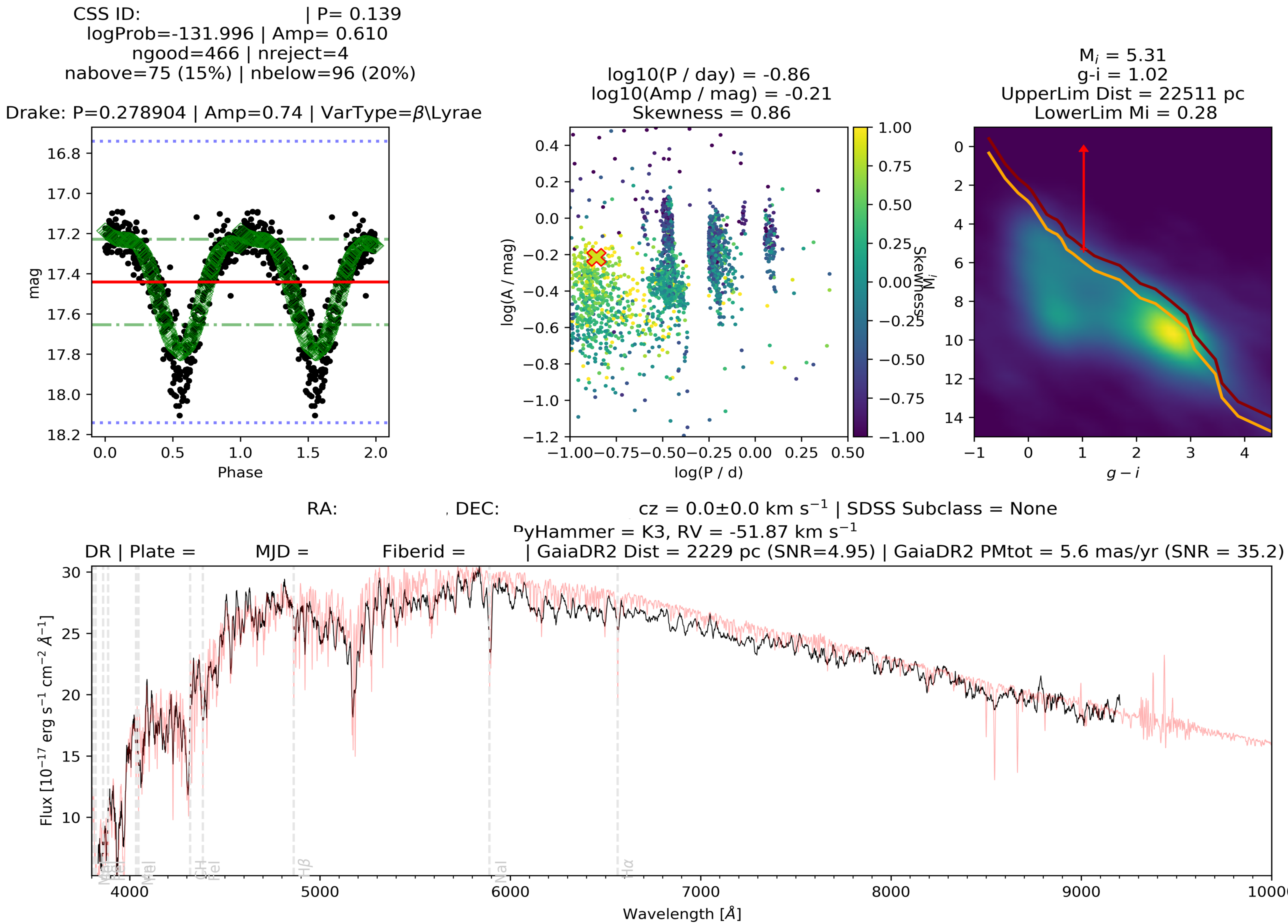
6.5m MMT followup spectrum. Analysis pending via EC Dufour.

Expected Periodic Stellar Variable Types to r < 18.5 (*Drake et al.* 2014, ApJ, 213, 1)

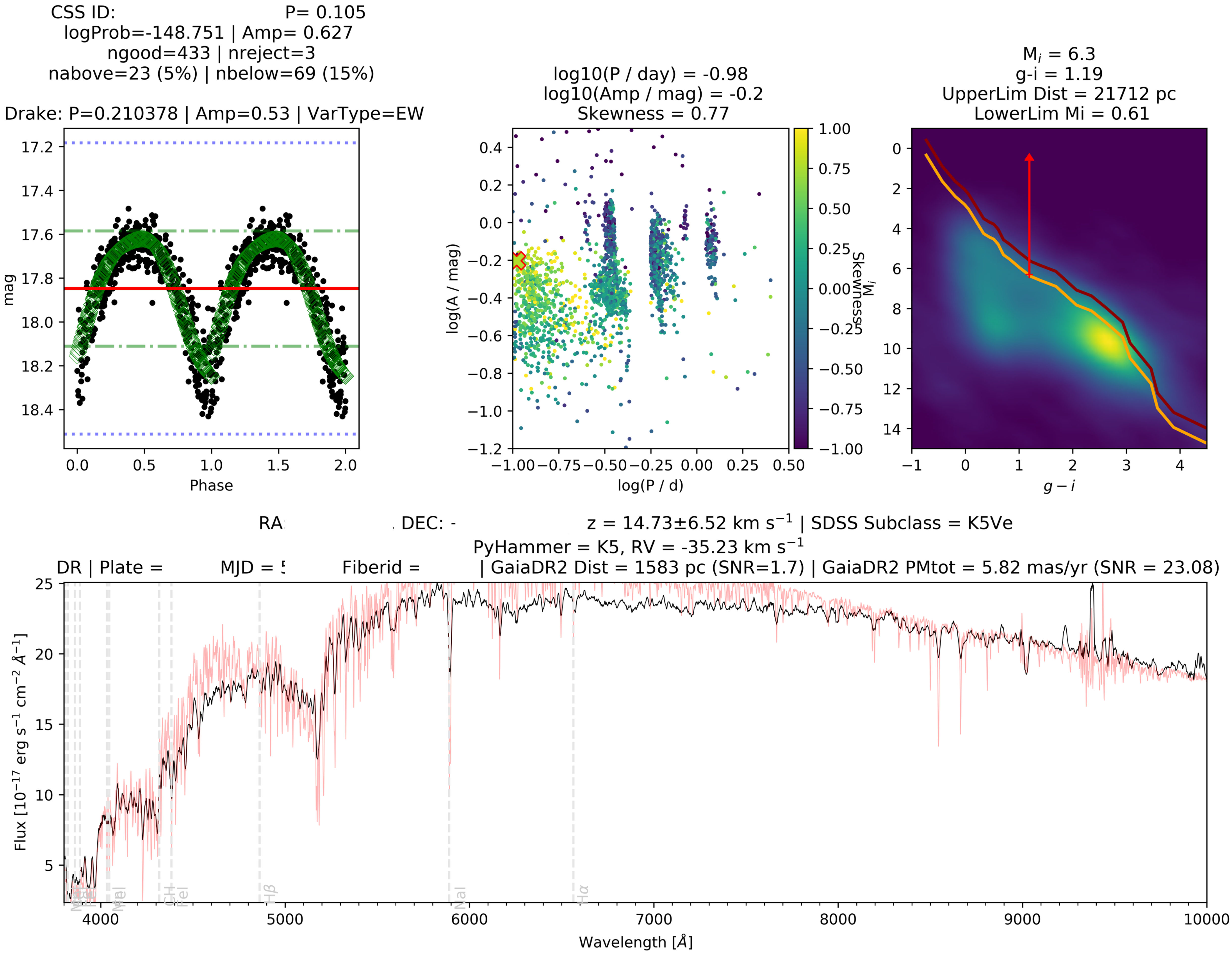
	Type	Percent	Description
Eclipsing:			
	EW	50.5	contact eclipsing binary
	EA	7.6	detached (Algol) eclipsing binary
	betaLyrae	0.5	semi-detached eclipsing binary
RR Lyr:			
	RRab	27.3	RR Lyrae (fundamental mode pulsators)
	RRc	8.9	RR Lyrae (multi-period pulsators)
	RRd	0.8	RR Lyrae (both)
	Blazkho	0.4	RR Lyrae (quasi-periodic)
CEPHEID:			
	ACEP	0.1	anomalous Cepheid
	Cep-II	0.2	type II Cepheid
	HADS	0.4	high amplitude delta Scuti
MISC:			
	RSCVn	2.5	spotted rotator
	LPV	0.8	Mira or semi-regular AGB variables



CSS ID: | P= 0.163
logProb=-89.964 | Amp= 0.616
ngood=530 | nreject=2
nabove=42 (7%) | nbelow=93 (17%)
Drake: P=0.325056 | Amp=0.8 | VarType=EA
mag
Phase
log10(P / day) = -0.79
log10(Amp / mag) = -0.21
Skewness = 1.31
log(A / mag)
log(P / d)
Skewness
M$_i$ = 6.03
g-i = 1.31
UpperLim Dist = 23185 pc
LowerLim Mi = 0.3
M$_i$
$g - i$
RA: , DEC: | cz = 60.92±4.32 km s^{-1} | SDSS Subclass = K3V
PyHammer = K4, RV = 100.26 km s^{-1}
prop. | Plate = MJD = Fiberid = | GaiaDR2 Dist = 1659 pc (SNR = 3.64) | GaiaDR2 PMtot = 5.38 mas/yr (SNR = 26.81)
Flux [10^{-17} erg s^{-1} cm^{-2} Å^{-1}]
Wavelength [Å]
CH
FeI
Hβ
NaI
Hα



CSS ID: | P= 0.139
logProb=-131.996 | Amp= 0.610
ngood=466 | nreject=4
nabove=75 (15%) | nbelow=96 (20%)
Drake: P=0.278904 | Amp=0.74 | VarType=β\Lyrae
mag
Phase
log10(P / day) = -0.86
log10(Amp / mag) = -0.21
Skewness = 0.86
log(A / mag)
log(P / d)
Skewness
M_i = 5.31
g-i = 1.02
UpperLim Dist = 22511 pc
LowerLim Mi = 0.28
M_i
g − i
RA: , DEC: cz = 0.0±0.0 km s^-1 | SDSS Subclass = None
PyHammer = K3, RV = -51.87 km s^-1
DR | Plate = MJD = Fiberid = | GaiaDR2 Dist = 2229 pc (SNR=4.95) | GaiaDR2 PMtot = 5.6 mas/yr (SNR = 35.2)
Flux [10^-17 erg s^-1 cm^-2 Å^-1]
Wavelength [Å]



CSS ID: P= 0.105
logProb=-148.751 | Amp= 0.627
ngood=433 | nreject=3
nabove=23 (5%) | nbelow=69 (15%)
Drake: P=0.210378 | Amp=0.53 | VarType=EW
mag
Phase
log10(P / day) = -0.98
log10(Amp / mag) = -0.2
Skewness = 0.77
log(A / mag)
log(P / d)
Skewness
M_i = 6.3
g-i = 1.19
UpperLim Dist = 21712 pc
LowerLim Mi = 0.61
M_i
g − i
RA DEC: - z = 14.73±6.52 km s^-1 | SDSS Subclass = K5Ve
PyHammer = K5, RV = -35.23 km s^-1
DR | Plate = MJD = Fiberid = | GaiaDR2 Dist = 1583 pc (SNR=1.7) | GaiaDR2 PMtot = 5.82 mas/yr (SNR = 23.08)
Flux [10^-17 erg s^-1 cm^-2 Å^-1]
Hβ
NaI
Hα
Wavelength [Å]

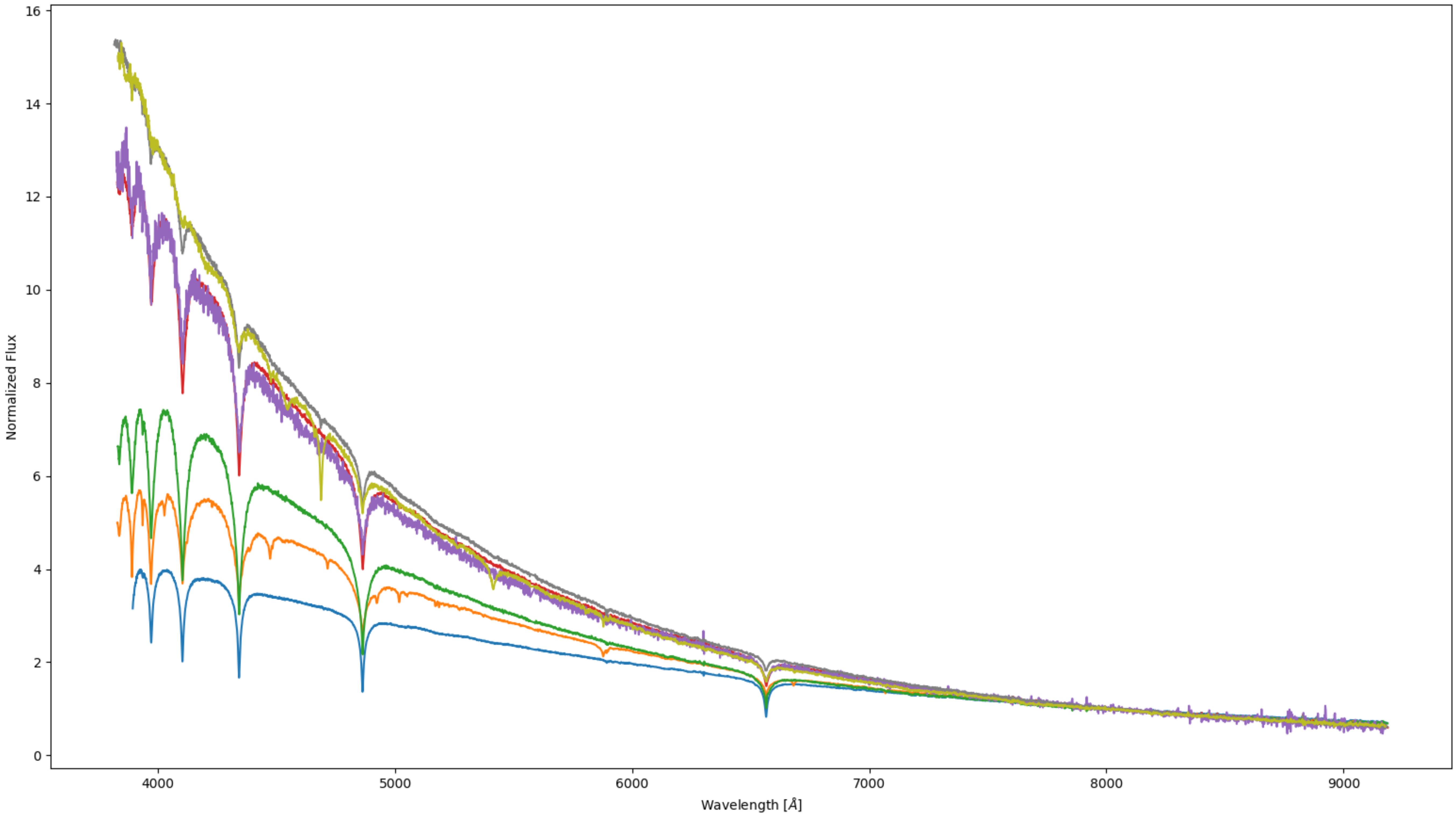
TDSS Stellar Science Opportunities

- 1000 RR Lyr w/RVs and metallicity estimates, could help identify streams
- Flare stars
- Active WD+dM systems
  - Follow FES dC paper and get separations
  - new post-CE?
  - Statistically examine the activity variation of close pairs as a function of spectral type, measure the white dwarf cooling age, and (possibly the) metallicity of the system
- **identify SB2s within the sample**

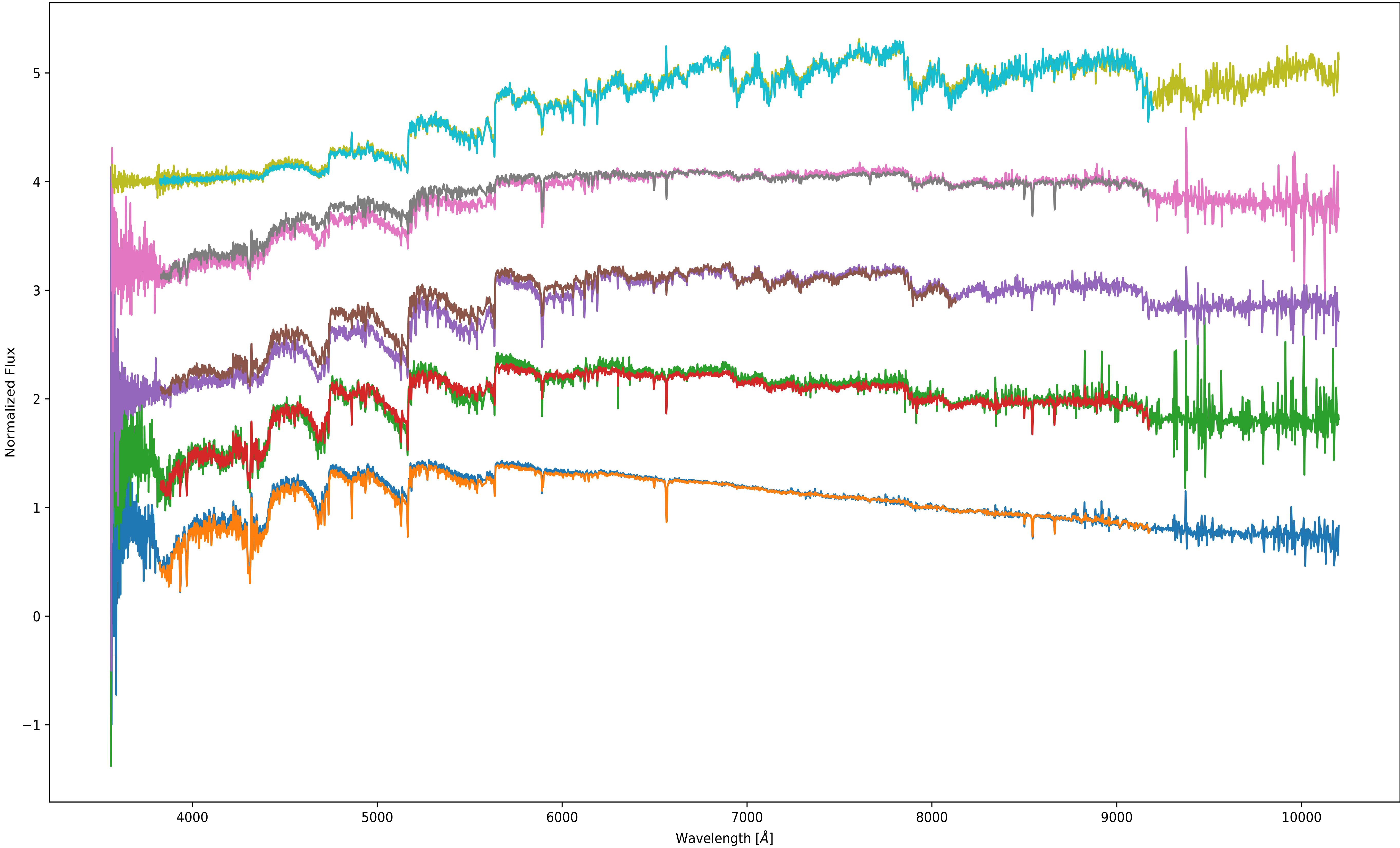
PyHammer & Extension

- PyHammer (Kesseli et al. (2017), https://github.com/BU-hammerTeam/PyHammer)
- Add additional C and WD templates (from TDSS)
- Developing tool to identify SB2s within the sample
  - Stellar templates from: A (Pickles+1998)
    FGKM (MaStar, Yan+2018)
    WD (Levenhagen+2017)

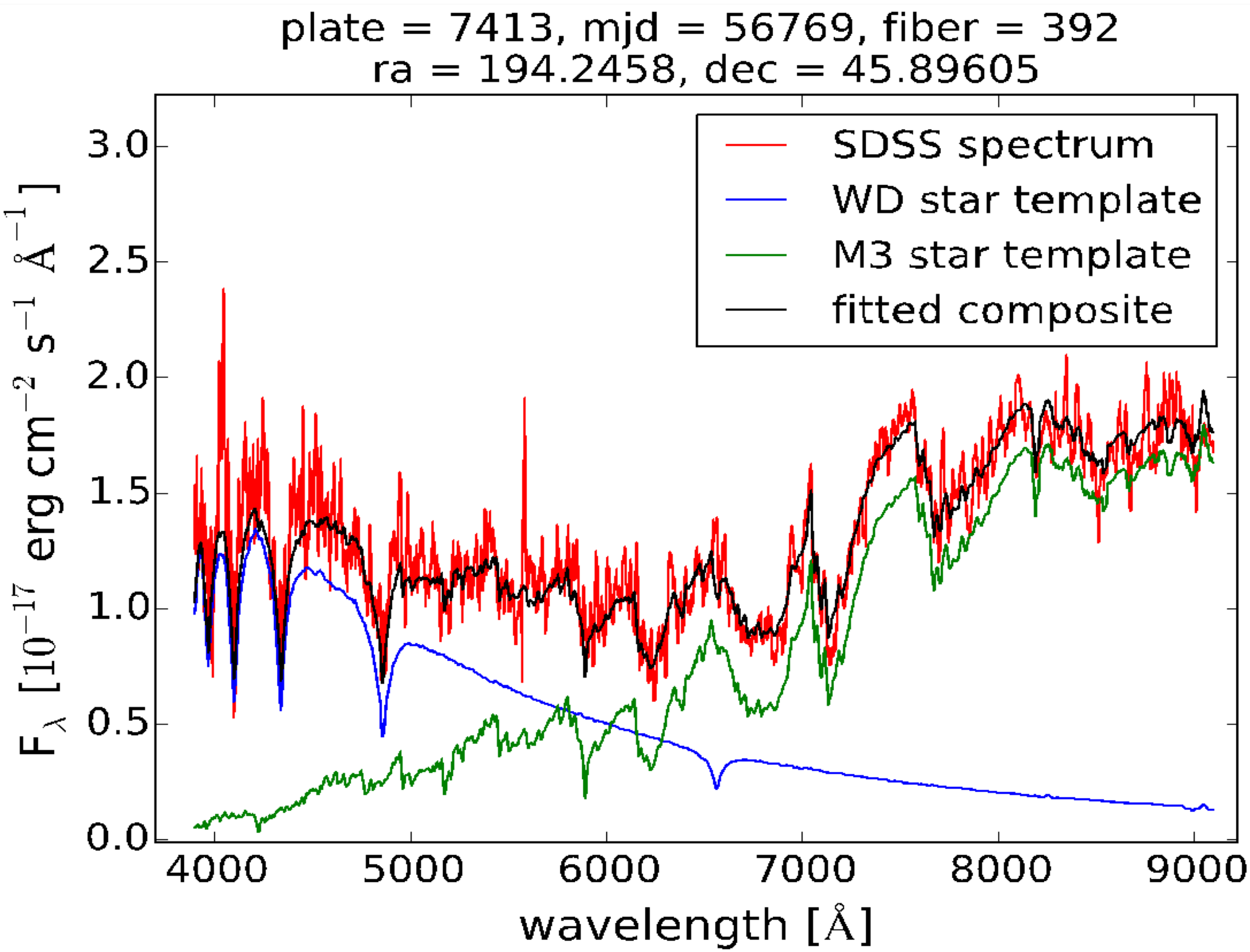
TDSS PyHammer WDs



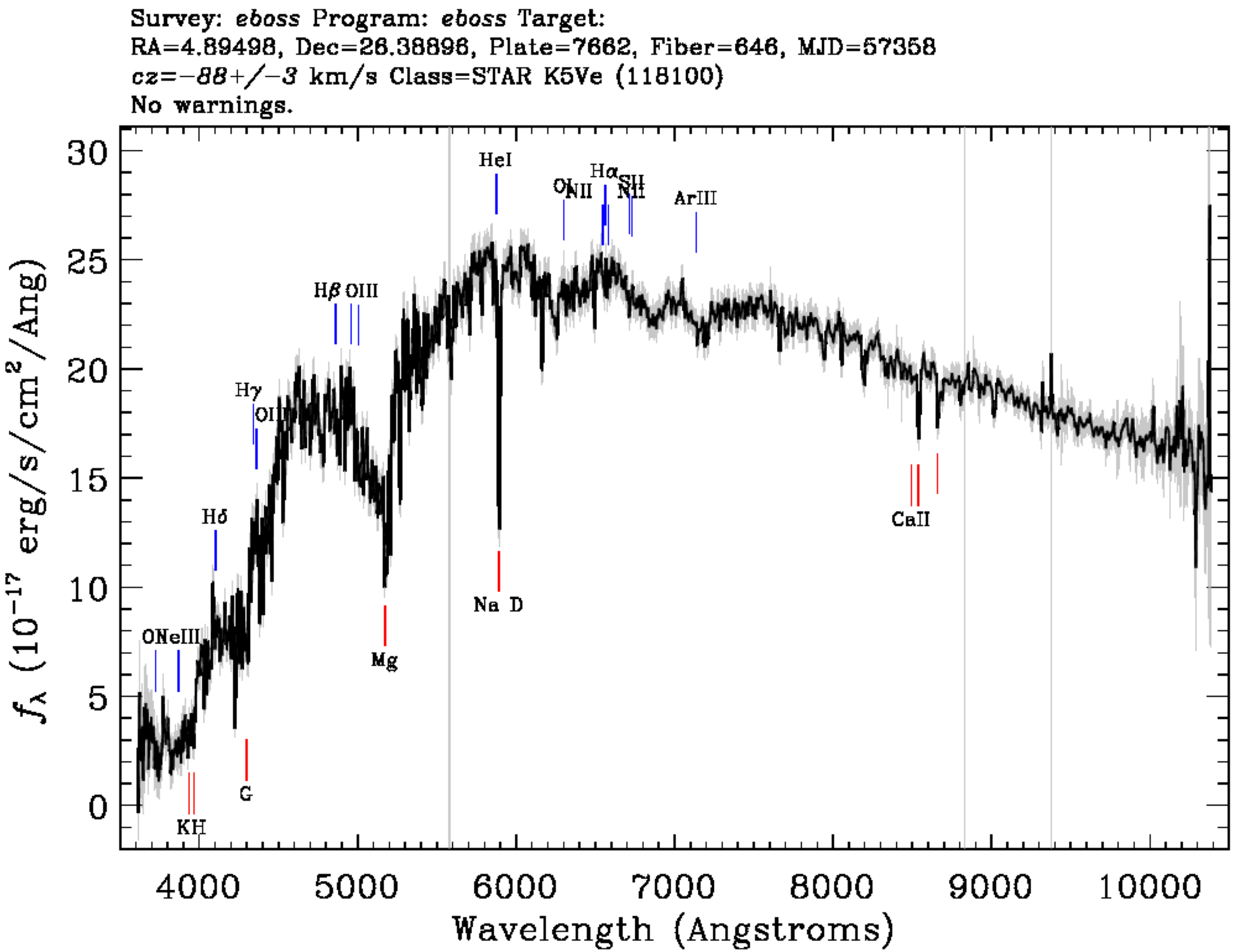
TDSS PyHammer Carbon Stars



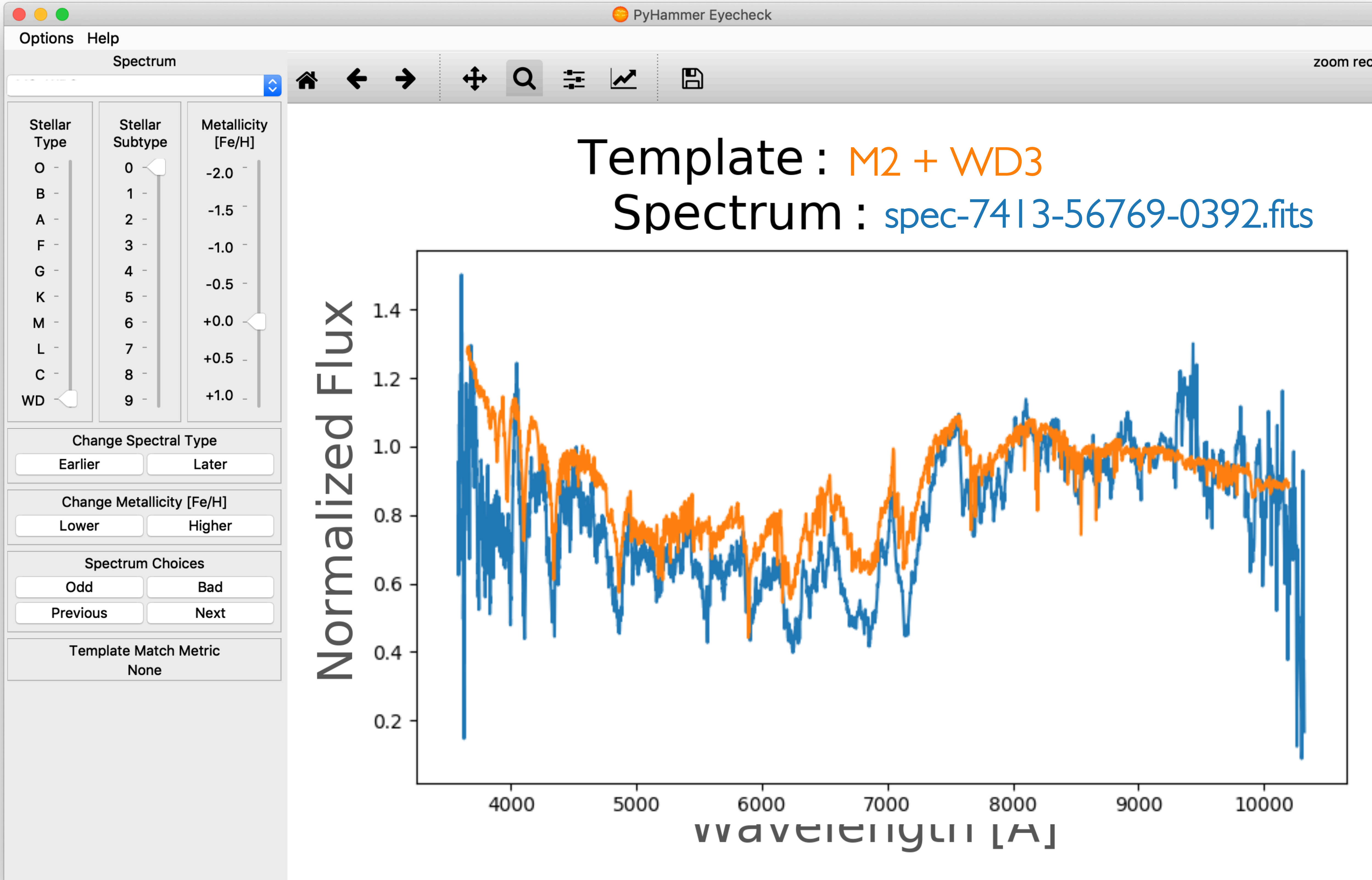
Composite-spectrum Binaries (a.k.a. SB2) Can sometimes be obvious!



More Typical Composite-Spectrum Binaries



PyHammer SB2 Extension



TDSS WIKI

https://trac.sdss.org/wiki/TDSS

- Telecon number/minutes
- Documents and brief primer
- Instructions/software info for VIP (Ruan et al.)
- spAllTDSS file (an spAll file for TDSS targets, with SDSS-IV spectro pipeline parameters): spAllTDSS-v5_10_10-01Jul2018_v0.txt
- PS1/SDSS-IV data-sharing file

TEAM

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EXTRA SLIDES

TDSS Spectroscopic Data: Early 2019

- From recent spAll TDSS file for SDSS-III+SDSS-IV (spans from earliest TDSS targets on SDSS-III SEQUELS plates, through January 2019 SDSS-IV plates). Approx numbers:

- 1350 good-quality plates, with more than 10^5 TDSS spectra taken through January 2019 (including ~77k of quasars)

- 103,700 SES selected or co-selected targets (not including archival)
  - 17,400 TDSS_A (SEQUELS pilot, but very similar algorithm)
  - 42,400 TDSS_B (Morganson et al. 2015 final algorithm)
  - 43,900 TDSS_CP (" "; most also chosen by eBOSS core)

  56,200 are quasars (~54% of SES targets)

- 6,500 FES targets, including 4700 FES quasars (~72% of FES)

- 16,500 RQS targets, all quasars

TDSS Stellar Science Opportunities

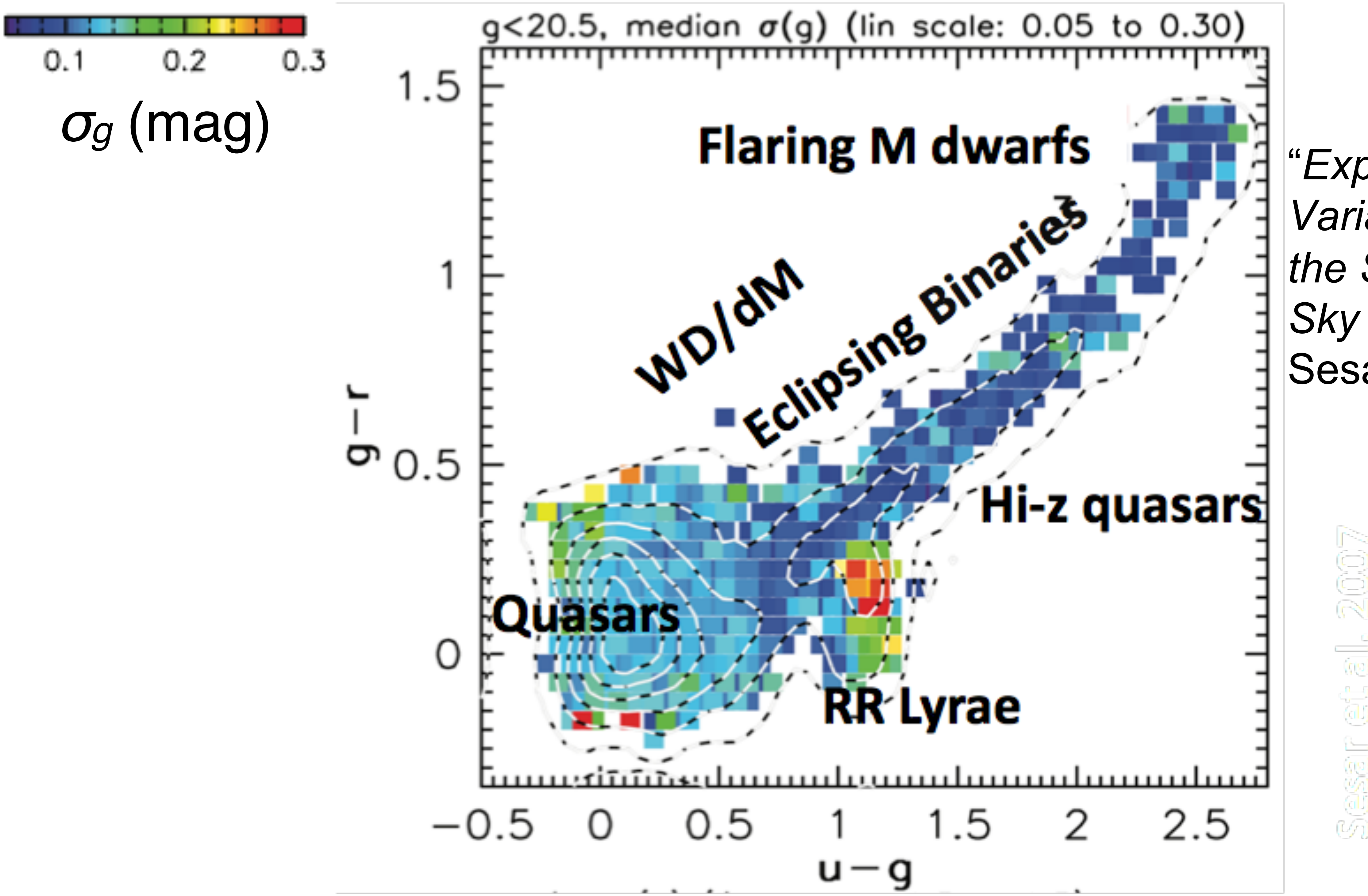
- Classify all variables with RF/Clustering algorithms
  - Light curve statistical features:
    - e.g. ChiSq, amplitude, period, skew, flare detection
  - Gaia DR2 parallax and proper motion
  - Spectroscopy provides:
    - Spectral type and emission line activity
    - RV for kinematics(with Gaia DR2 parallax & proper motions)
    - T_{eff}, sometimes logg and metallicity estimates
    - SB2 probability?

TDSS TECHNICAL DETAILS

- eBOSS subprogram in SDSS-IV (2014 - 2020; Blanton et al. 2017)
- Targets selected as variables from SDSS and Pan-STARRS1 (PS1)
- ~140k new spectra + ~80k archival spectra
- 10 fibers deg^{-2} on eBOSS spectrograph

- **Main Program:** single-epoch spectroscopy ("**SES**")
  - 90K spectra for discovery/classification (Morganson et al. 2015)
- **Spectroscopic Variability:**
  - 10% fibers reserved for few-epoch spectroscopy ("**FES**") programs
  - 12K Repeat Quasar Spectra ("**RQS**") (MacLeod+2017)

CELESTIAL VARIABLES



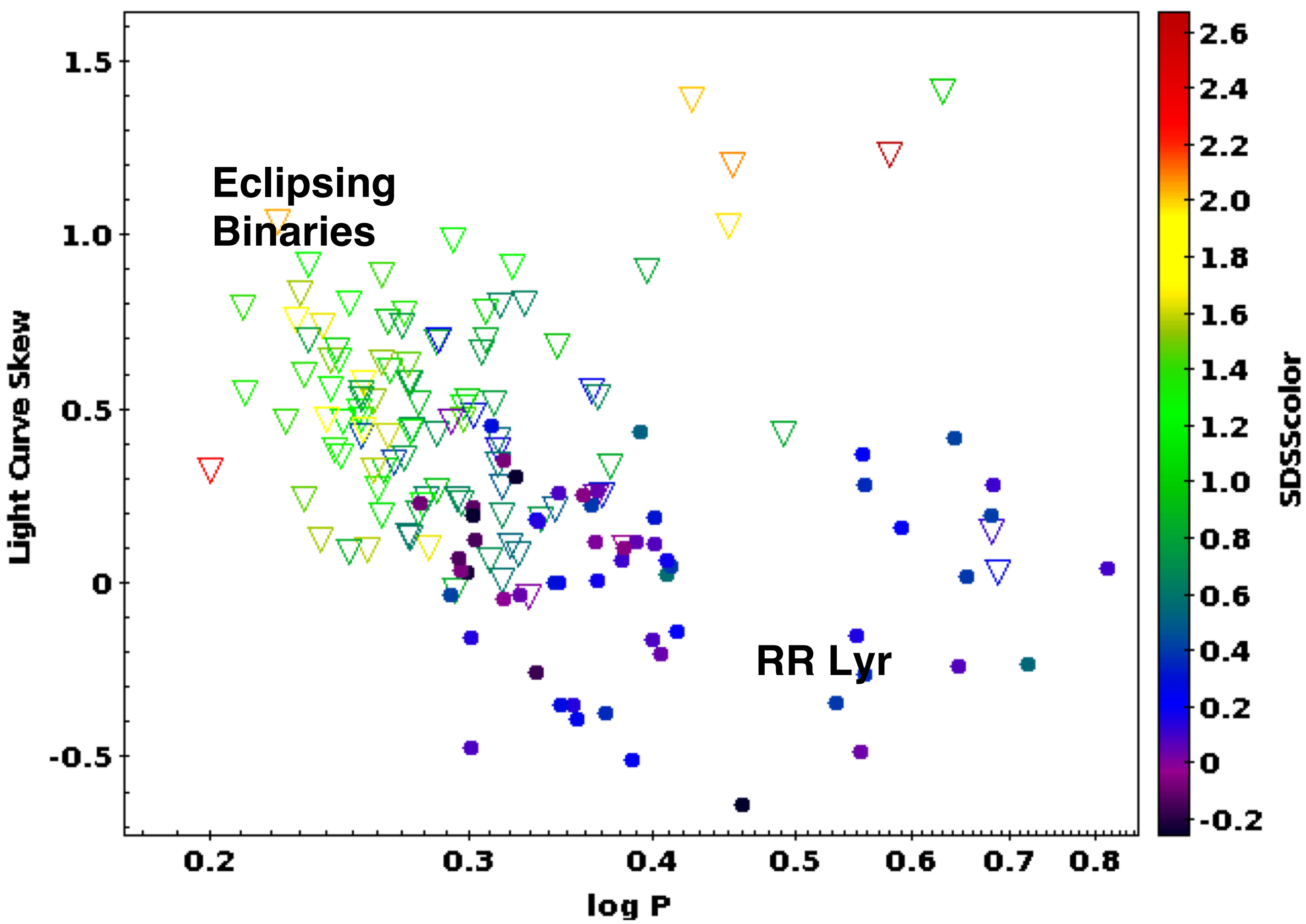
"Exploring the Variable Sky with the Sloan Digital Sky Survey," Sesar et al. (2007)

PURITY

- Must be robust to bad measurements
- Precision: 0.1 mags
- Sample of variable objects expected to be 96% pure and comprising the following:
  - 8 deg $^{-2}$ with existing SDSS spectra,
  - 10 deg $^{-2}$ with new TDSS spectra, and
  - 15 deg $^{-2}$ with new spectra from eBOSS.

Periodic Stars in TDSS

- Classify using: period, amplitude, skew, color & spectral type, Gaia parallax
- Spectroscopy provides
  - RV for kinematics (w/ Gaia parallax & proper motions)
  - log *g*, T_{Eff} and metallicity estimates



TDSS Spectroscopic Data: 2017 Update

- From a recent spAll TDSS file for SDSS-III+SDSS-IV (spans from earliest TDSS targets on SDSS-III SEQUELS plates, through latest SDSS-IV ELG plates):
- 675 total good-quality plates taken through June 2017
- 66618 SES targets selected or co-selected
  3266 FES targets
  2166 RQS targets
- RQS (Repeat Quasar Spectroscopy)
  1443 RQS1
  344 RQS2
  29 RQS3
  176 RQS2v
  174 RQSv3
- FES (Few Epoch Spectroscopy)
  309 DE
  526 HYPQSO
  32 MGII
  426 NQHISN
  1210 VARBAL
  195 ACTSTAR
  189 DWARFC
  295 HYPSTAR
  84 WDDM

TDSS Spectroscopic Data: 2017 (SES)

- SES (Single Epoch Spectroscopy of PS1 variables)

17,511 TDSS_A (SEQUELS pilot, but very similar algorithm)
25,016 TDSS_B (Morganson et al. 2015 final algorithm)
24,091 TDSS_CP (" " " " " "; most also chosen by eBOSS core)

- Among the total 66,618 SES-relevant TDSS spectral targets

34,726 quasars (many also TDSS_CP)	~	52%
29,603 stars (mainly TDSS)	~	45%
2,289 galaxies. unknowns, etc	~	3%

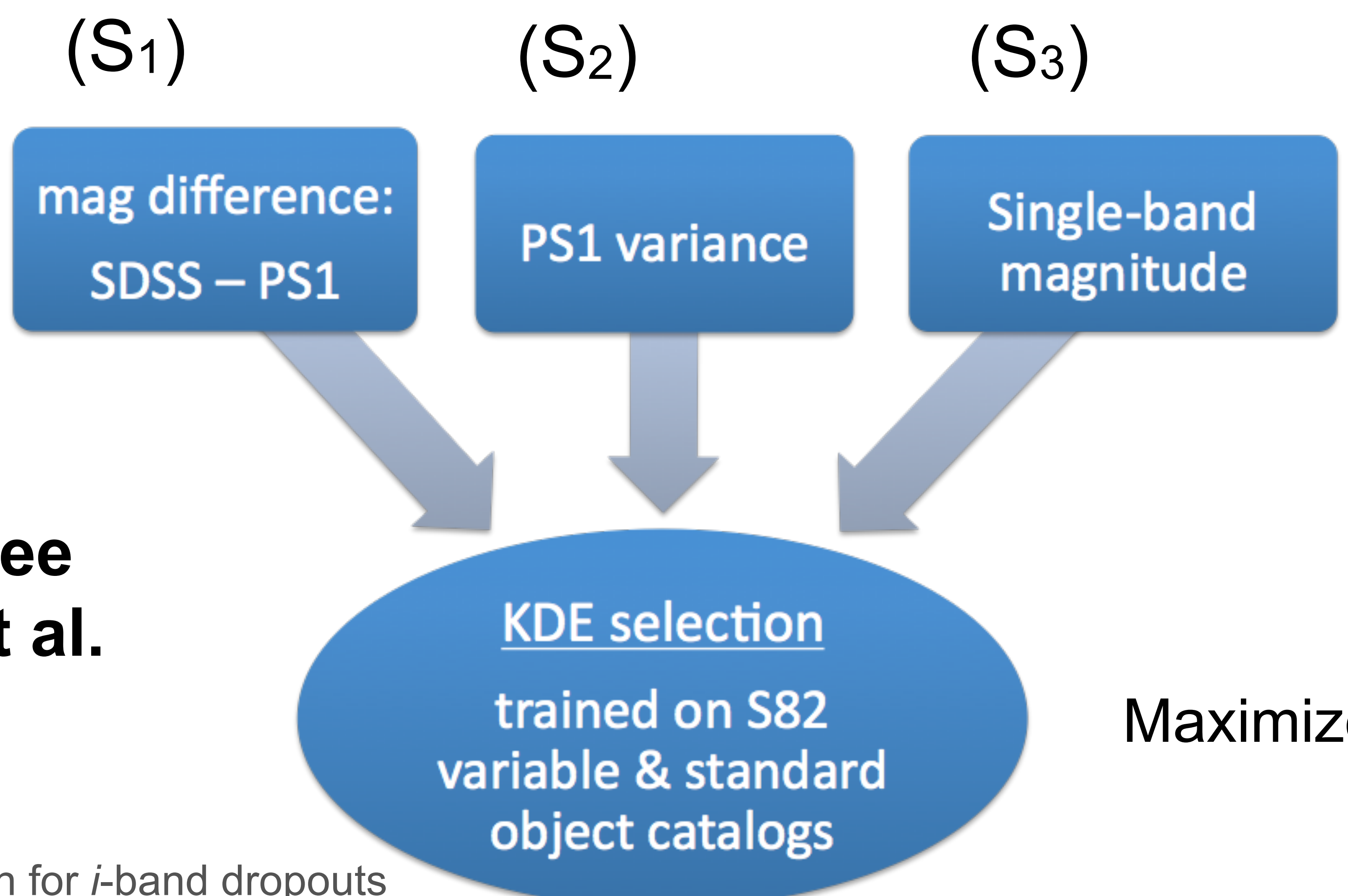
- Full SES sample now large enough to include reasonable subsamples of unusual/rare classes, e.g.,~10^2 each of variable CVs &WDs, and ~30 C stars

- There are a further ~6-8/deg^2 spectra for additional TDSS/PS1 photometric variables (mainly quasars) in the SDSS I-III archive (pre-SEQUELS,).

- So far from SDSS-IV, there are ~35k TDSS-*only* spectra on-hand across SES, FES, and RQS (not counting TDSS co-selections w/ SDSS-IV fibers charged to others). This is ~40% of intended TDSS-only fiber allocation in SDSS-IV.

SES VARIABLE SELECTION

- 17 < *i* < 21, unresolved sources
- Require 2* good bands (from among *griz*) in PS1, SDSS
- 3D Kernel Density Estimator



Maximize $E = \frac{\rho_{var}}{\rho_{star}}$

For details see Morganson et al. (2015)

*With small exception for *i*-band dropouts