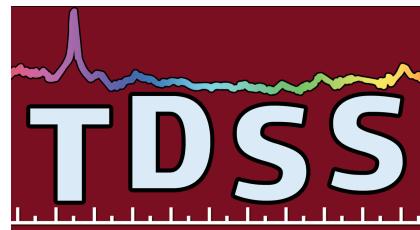


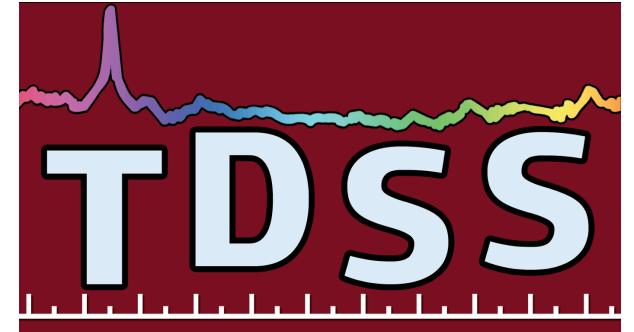
# **THE TIME DOMAIN SPECTROSCOPIC SURVEY**

**Benjamin Roulston (BU/SAO/CfA)**  
***SDSS-IV Meeting, 2019***  
***Ensenada, Mexico***

Paul Green (P-I, CfA), Scott Anderson (P-I, UWa), Michael Eracleous (PSU), Eric Morganson (UIUC), John Ruan (UWa), Jessie Runnoe (UMich), Niel Brandt (PSU), Don Schneider (PSU), Yue Shen (UIUC), the TDSS Team, the SDSS-IV Collaboration, and the Pan-STARRS1 Science Consortium



# SDSS-IV TIME DOMAIN SPECTROSCOPIC SURVEY



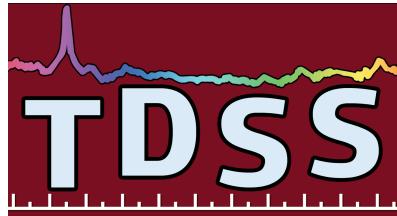
- Adds dedicated spectra to era of time domain imaging.
- First large-scale, *inclusive* spectroscopic survey of variable sources
  - No color selection
  - Generic variability, i.e., no requirement for periodicity, flares, etc.
- Extending Survey Science to the Time Domain/Spectroscopy through:
  -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

Three principal components of TDSS, piggy-back on



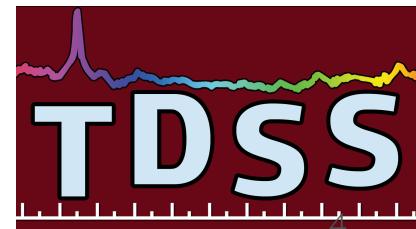
- TDSS main (90%) survey: **SES**=single-epoch spectroscopy BOSS classification/characterization spectra of imaging variables from Pan-STARRS I, 3π imaging survey (PSI);  $\sim 10^5$  fibers in SDSS-IV ( $10/\text{deg}^2$ )
- TDSS (10%) **FES**=few-epoch spectroscopy of potential spectral variables of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

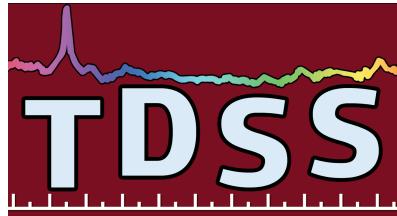




# TDSS Spectroscopic Data: Early 2019

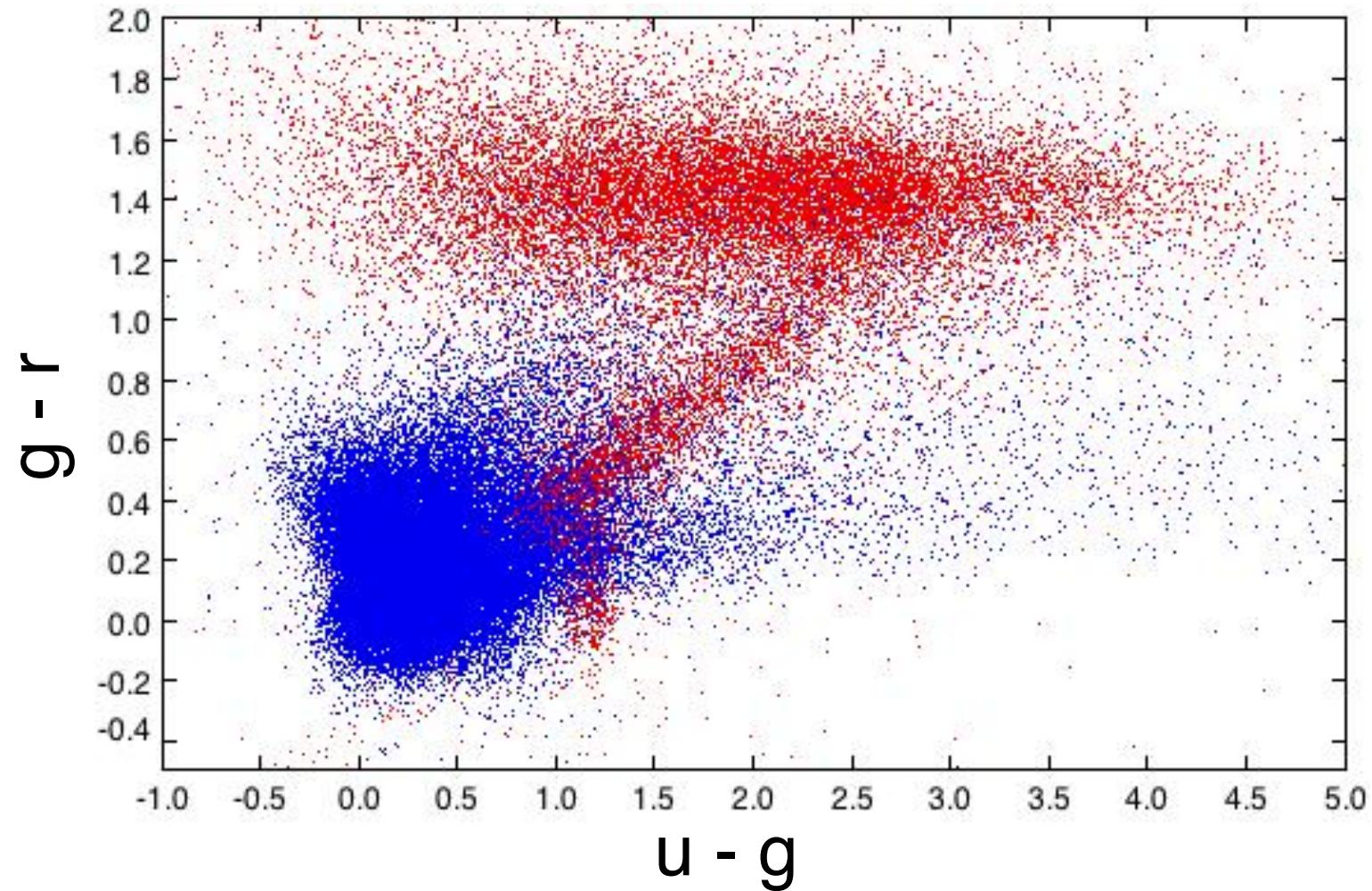
- 103,700 SES selected or co-selected targets (not including archival)  
56,200 are quasars (~54% of SES targets)
- 6,500 FES targets, including 4700 FES quasars (~72% of FES)
- 16,500 RQS targets, all quasars
- From recent spAll TDSS file for SDSS-III+SDSS-IV (spans from earliest TDSS targets on SDSS-III 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)





# TDSS/SES update (through DR14)

Pipeline: 53,912 QSOs, 25,035 stars, 2,210 other variables (galaxies/unks/glitches; not plotted)

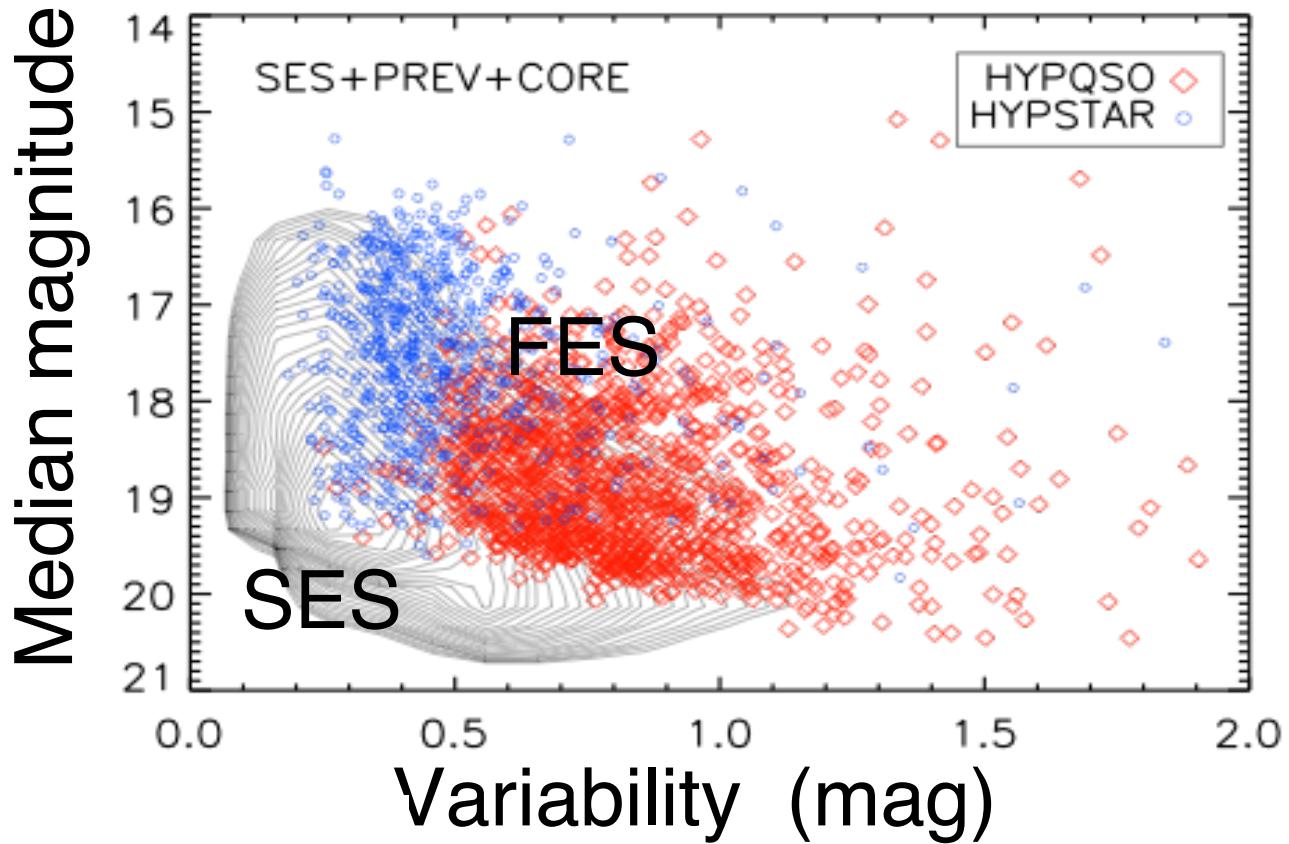


10% of TDSS fibers for special FES programs:

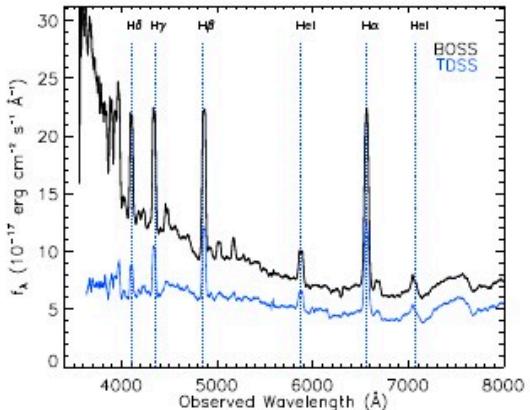
Target Type	Number	Observed (March '19)
<b>Total (~1 deg<sup>-2</sup>)</b>	<b>9143</b>	<b>6261</b>
WD/dM Binaries	1036	214
Dwarf Carbon Stars	830	370
Ultracool Dwarfs	402	556
Hypervariable Stars ( $\gtrsim 0.3m$ )	1150	727
BAL Quasars	2900	1926
High S/N Quasars	1100	593
Double Peaked Emitters	900	576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

(Target Selection Details in MacLeod et al. 2018)

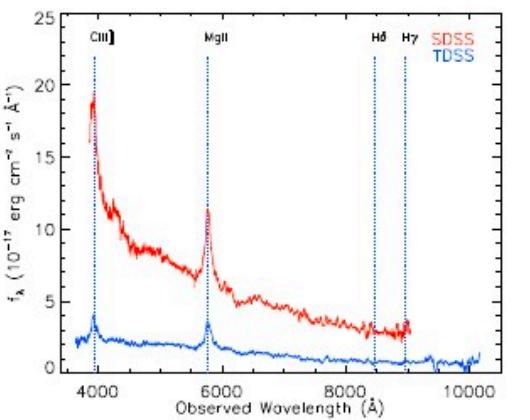
# HYPERVARIABLES



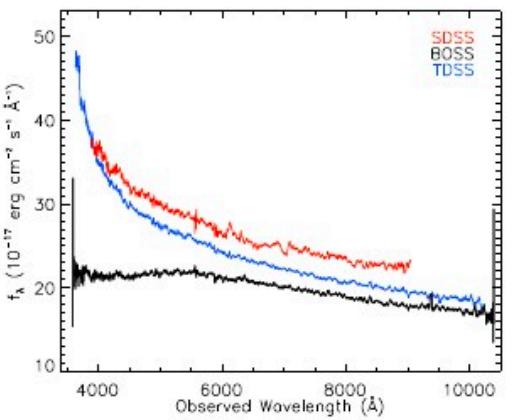
**CV:**

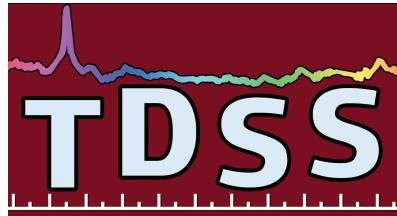


**QSO:**



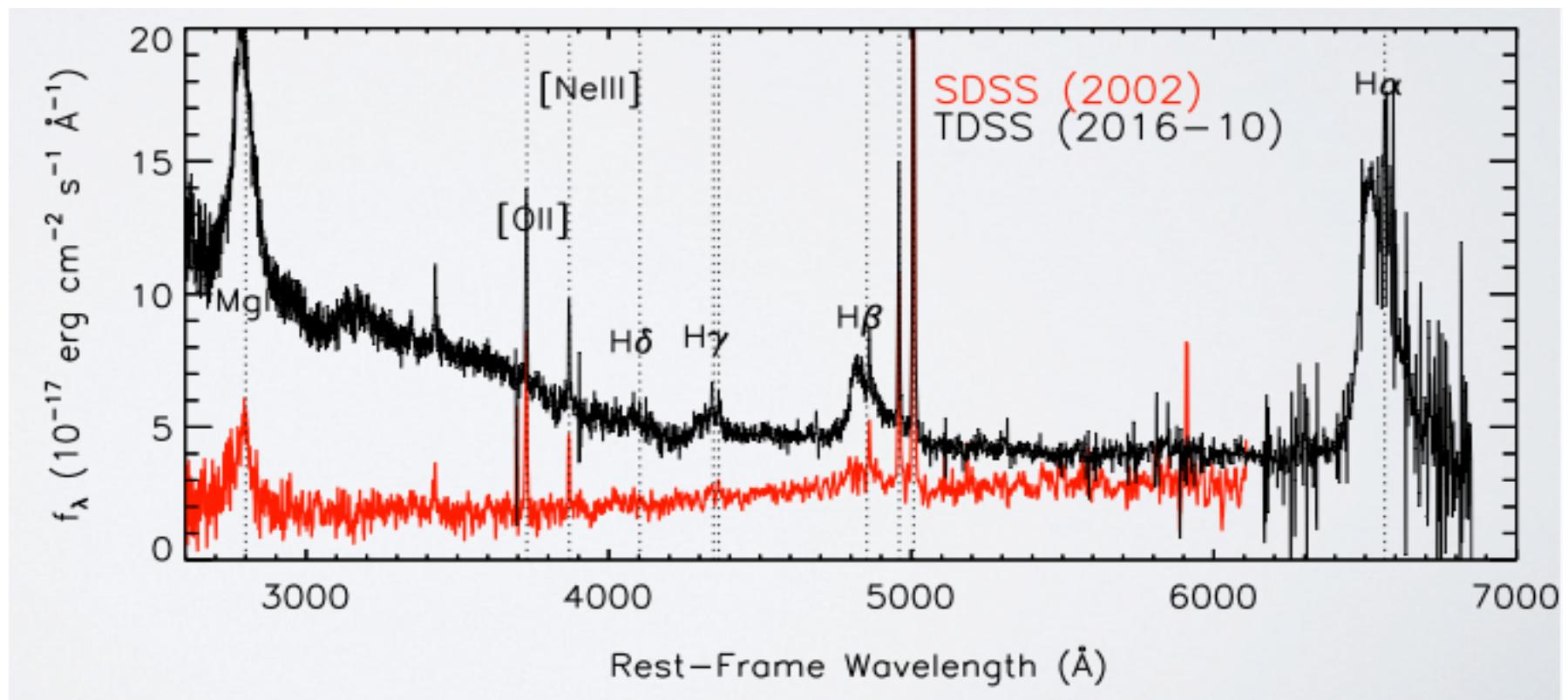
**BLLac:**

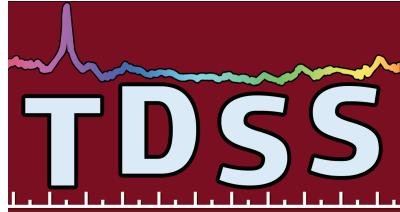




## TDSS/RQS FES-like Extension (post-DR14) in ELG region: **Repeat Quasar Spectroscopy** (MacLeod et al. 2018)

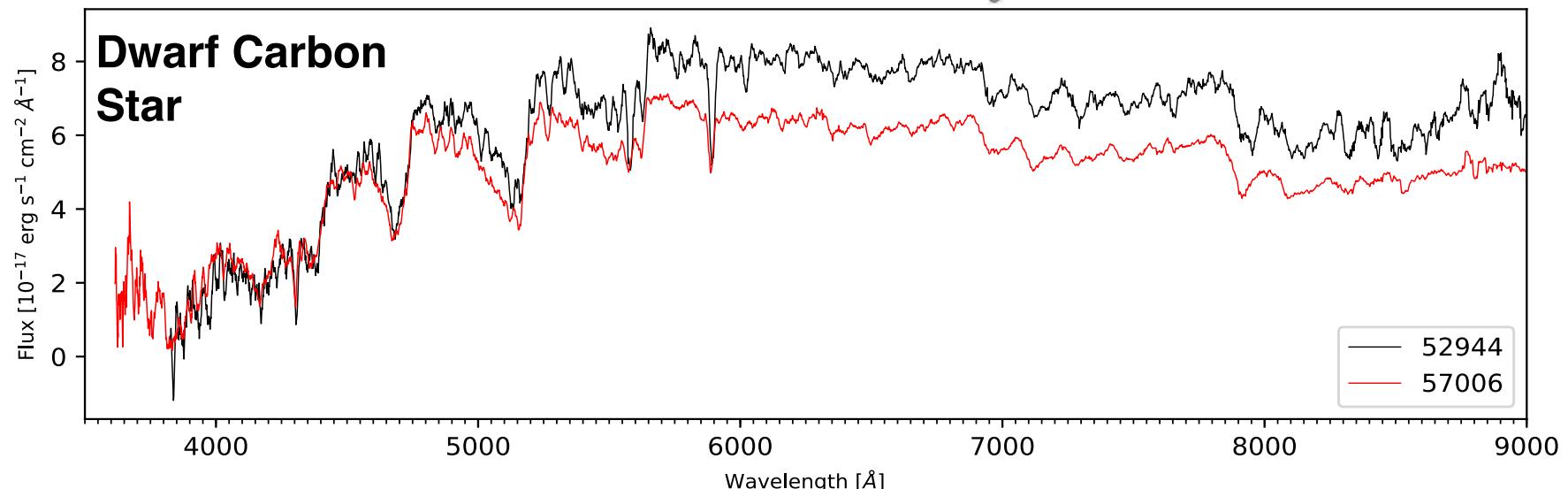
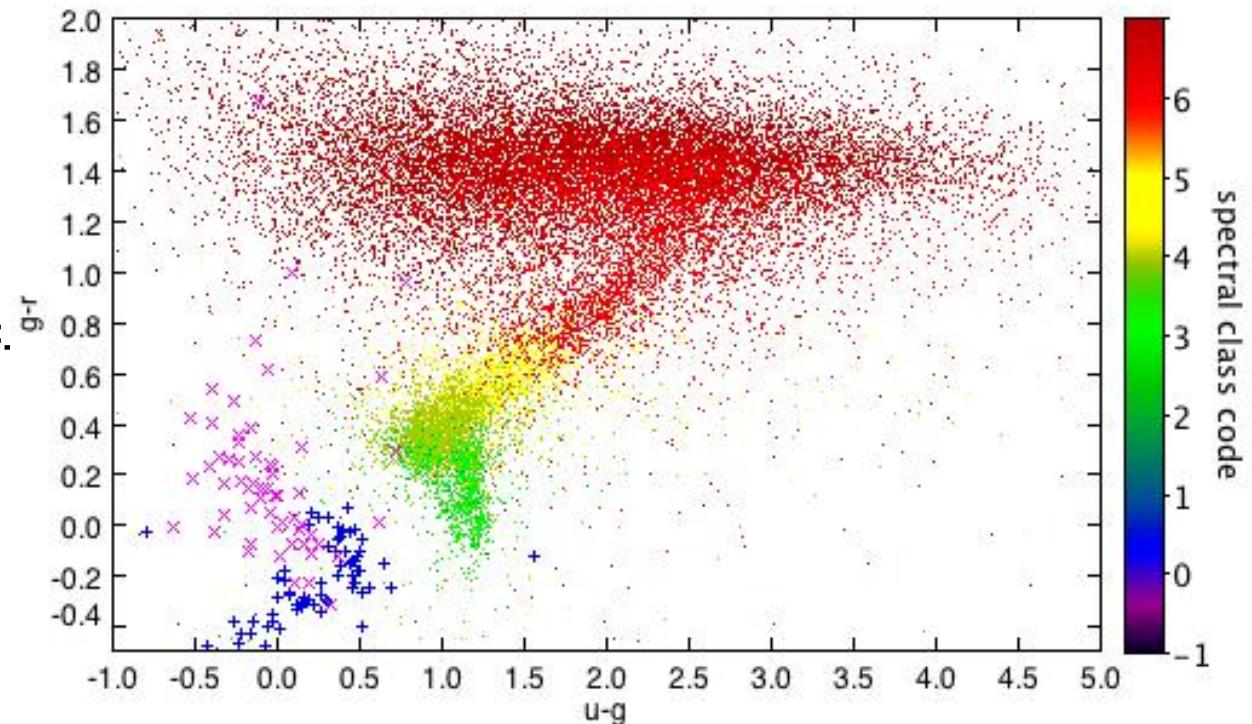
- 10 known QSOs  $\text{deg}^{-2}$   $i < 20.5$ , in  $\sim 1200 \text{deg}^2$  ELG region
- All DR7, DR12 + SDSS-IV QSOs  $i < 19.1$  (+most-variable to  $i < 20.5$ )
- $\sim 16,000$  observed in most recent TDSS files
- RQS+FES provides dozens of new candidate “Changing Look Quasars”  
e.g. LaMassa+2015, Ruan+, Runnoe+, & MacLeod+(all 2016).

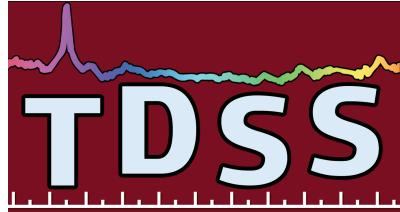




# TDSS/SES update

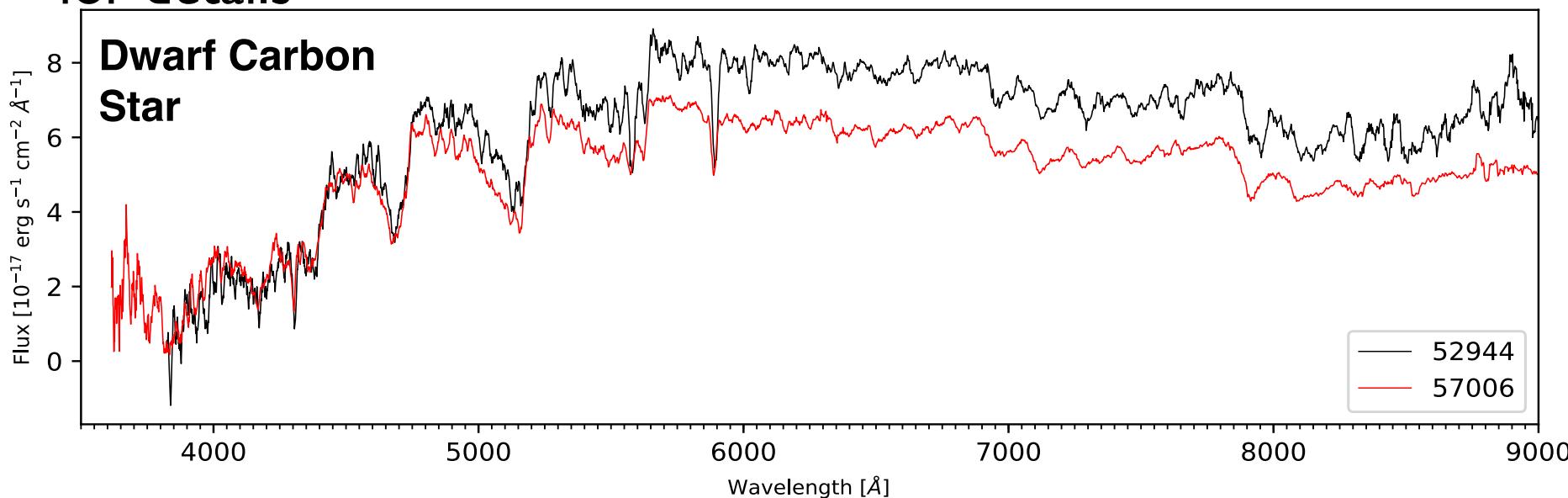
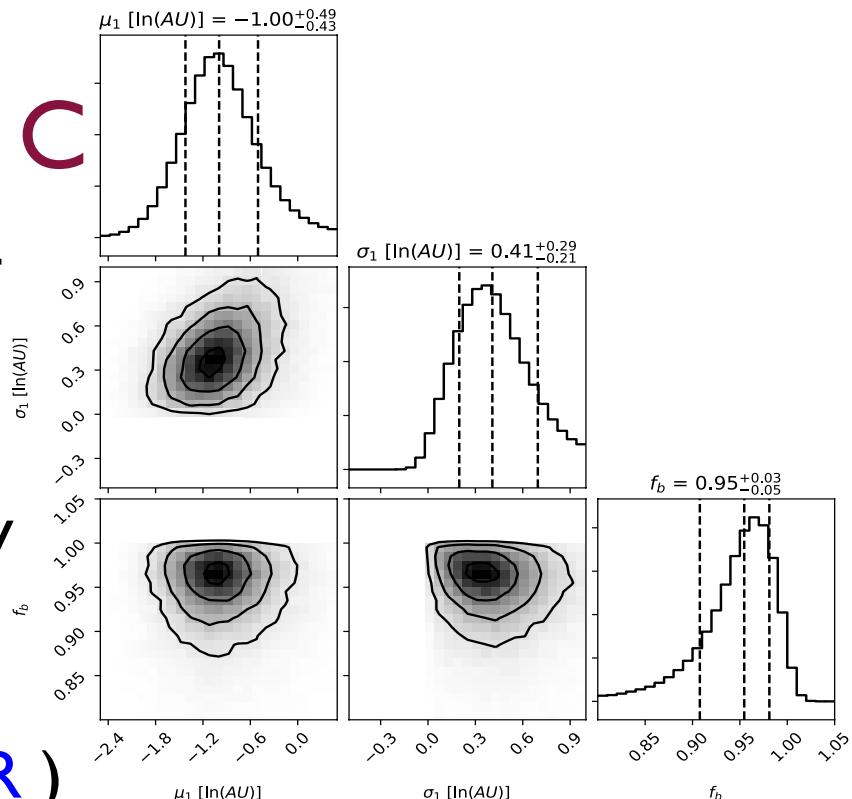
STAR subclasses (pipe) range from O/B, through A/F (green), to K/M (orange/red). Flaring M stars dominate, but thousands are in A/F-star regime that includes pulsating RR Lyrae. >710 have cataloged periodic light curves, e.g., also includes eclipsers. Large symbols highlight ~60 each CVs (purple x's)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

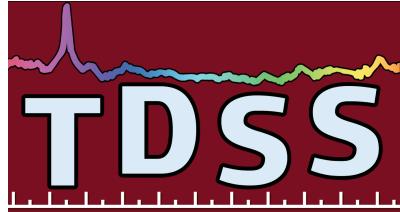




# TDSS-FES DWARF C

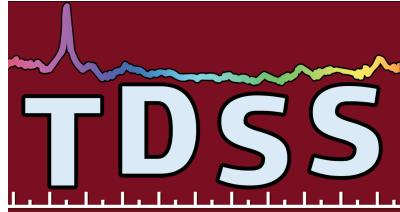
- FES program for repeat spectroscopy of dwarf carbon stars
- MCMC modeling confirms  $\sim 100\%$  binary fraction
- See Roulston+2019 ([2019ApJ...877...44R](#)) for details





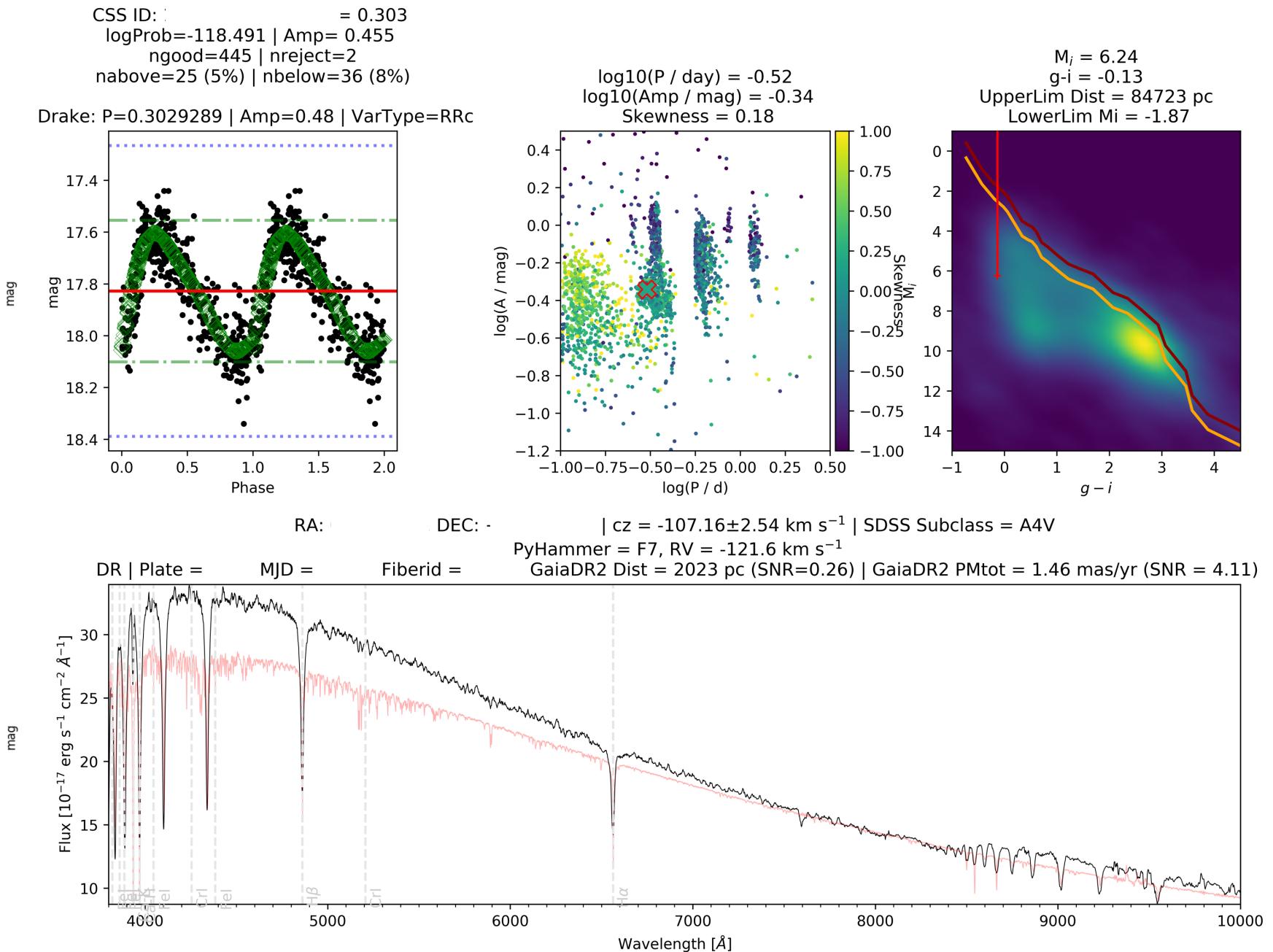
# TDSS Stellar Science Opportunities

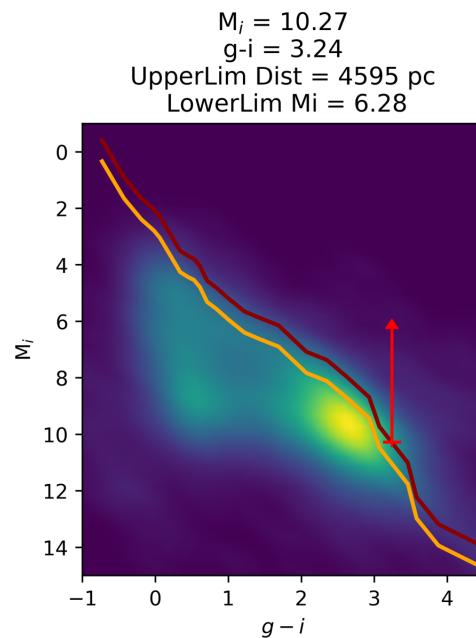
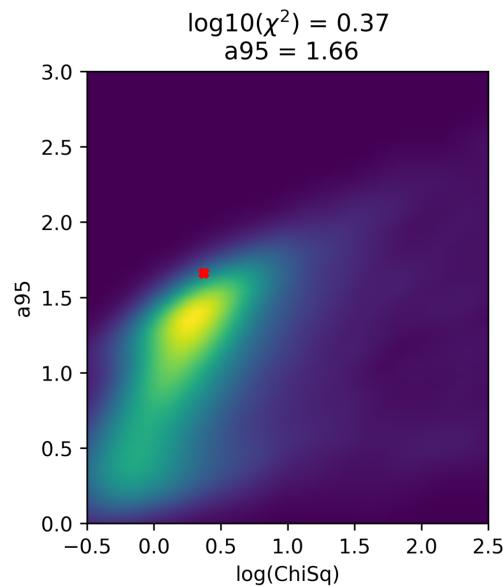
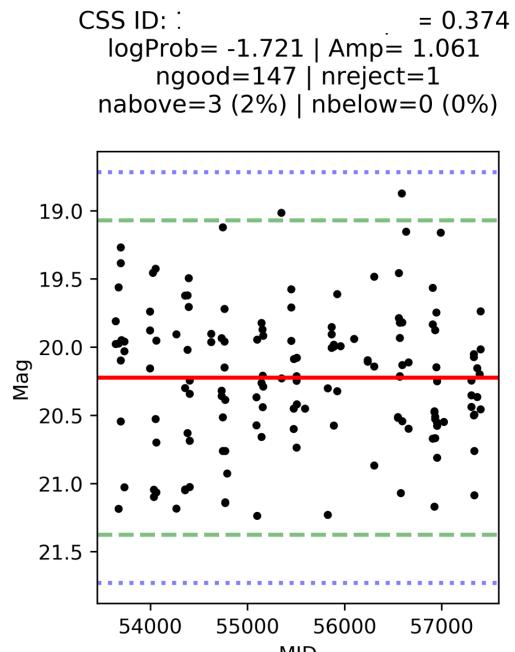
- Expect ~25,000 stellar variables in TDSS (pulsating, eclipsing, accreting, active)
  - ~ 4,000 off the main sequence
  - ~ 1,000 RR Lyr
  - ~ Handful of
    - WDs
    - CVs
    - Carbon stars
- ~10% of variables are periodic ( $\log\text{Prob} < -10$ )



# TDSS Stellar Science Opportunities

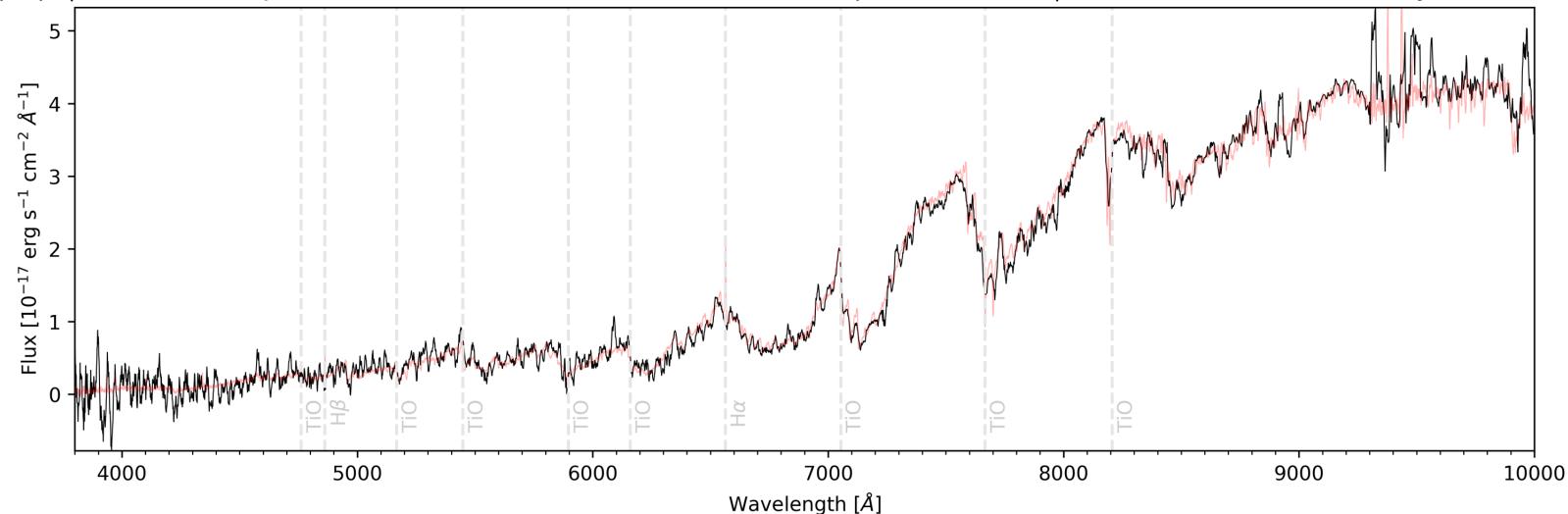
- Identify SB2s within the sample
- RR Lyr (study Galactic Halo, streams?)
- Flare stars
- WD+dM systems
- Classify all variables with RF/Clustering algorithms
  - Light curve features e.g. amplitude, period, skewness...
  - Spectral type and emission line activity
  - parallax and proper motions (Gaia DR2)
  - RV, space motions, kinematic population

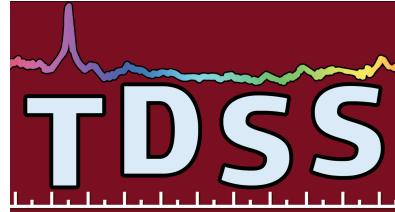




RA: DEC: |  $cz = -3.86 \pm 11.36 \text{ km s}^{-1}$  | SDSS Subclass = M5III  
 PyHammer = M6, RV =  $43.23 \text{ km s}^{-1}$   
 GaiaDR2 Dist = 729 pc (SNR = 1.53) | GaiaDR2 PMtot =  $27.47 \text{ mas/yr}$  (SNR = 21.14)

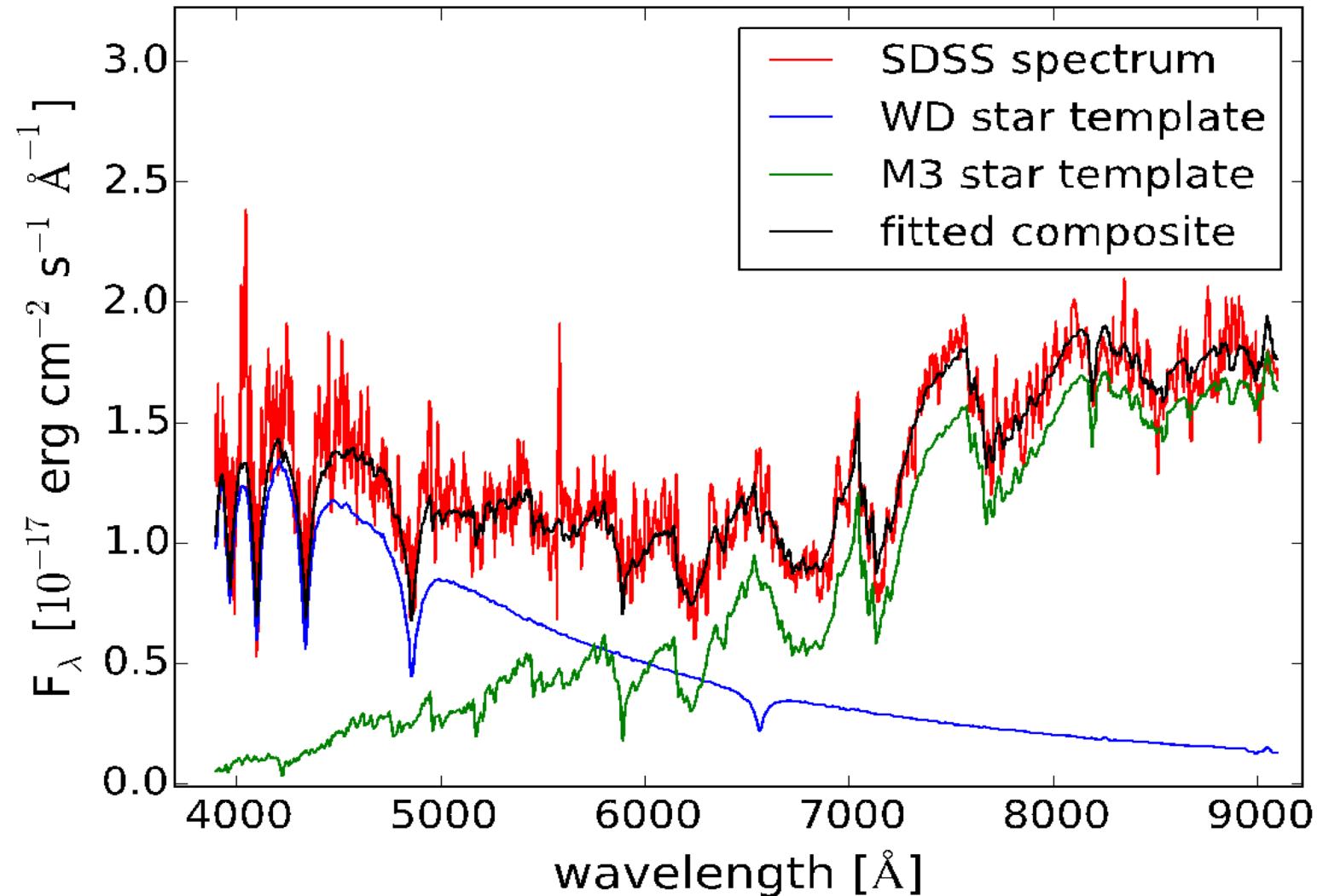
prop. | Plate = MJD = Fiberid =

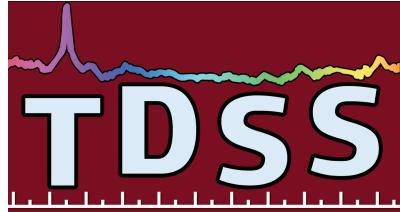




# Composite-spectrum Binaries (a.k.a. SB2)

## Can sometimes be obvious!

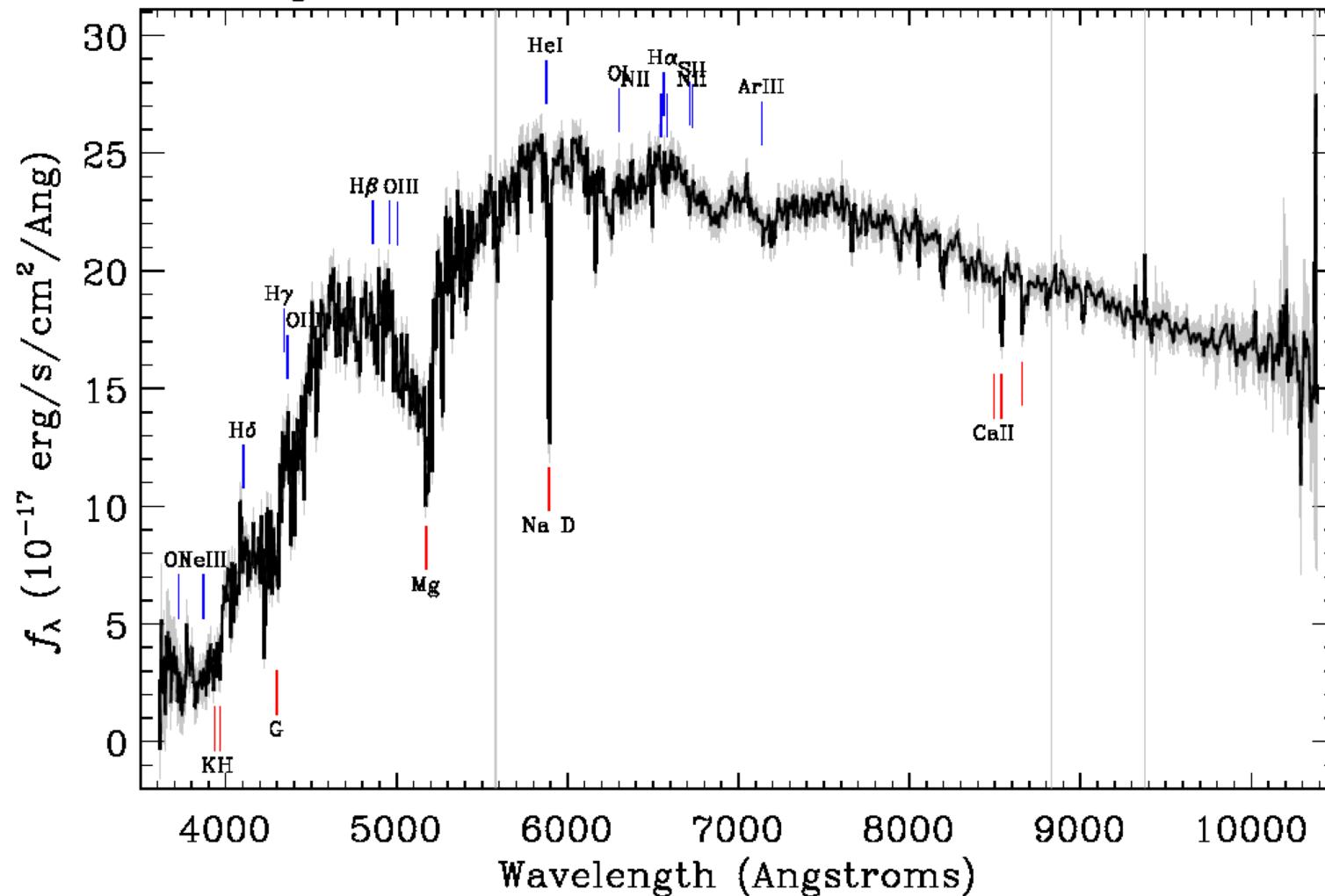


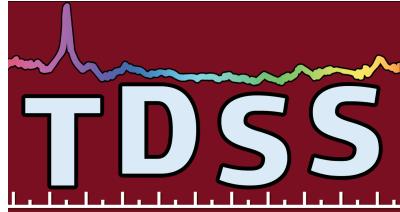


# More Typical Composite-Spectrum Binaries

Survey: *eboss* Program: *eboss* Target:

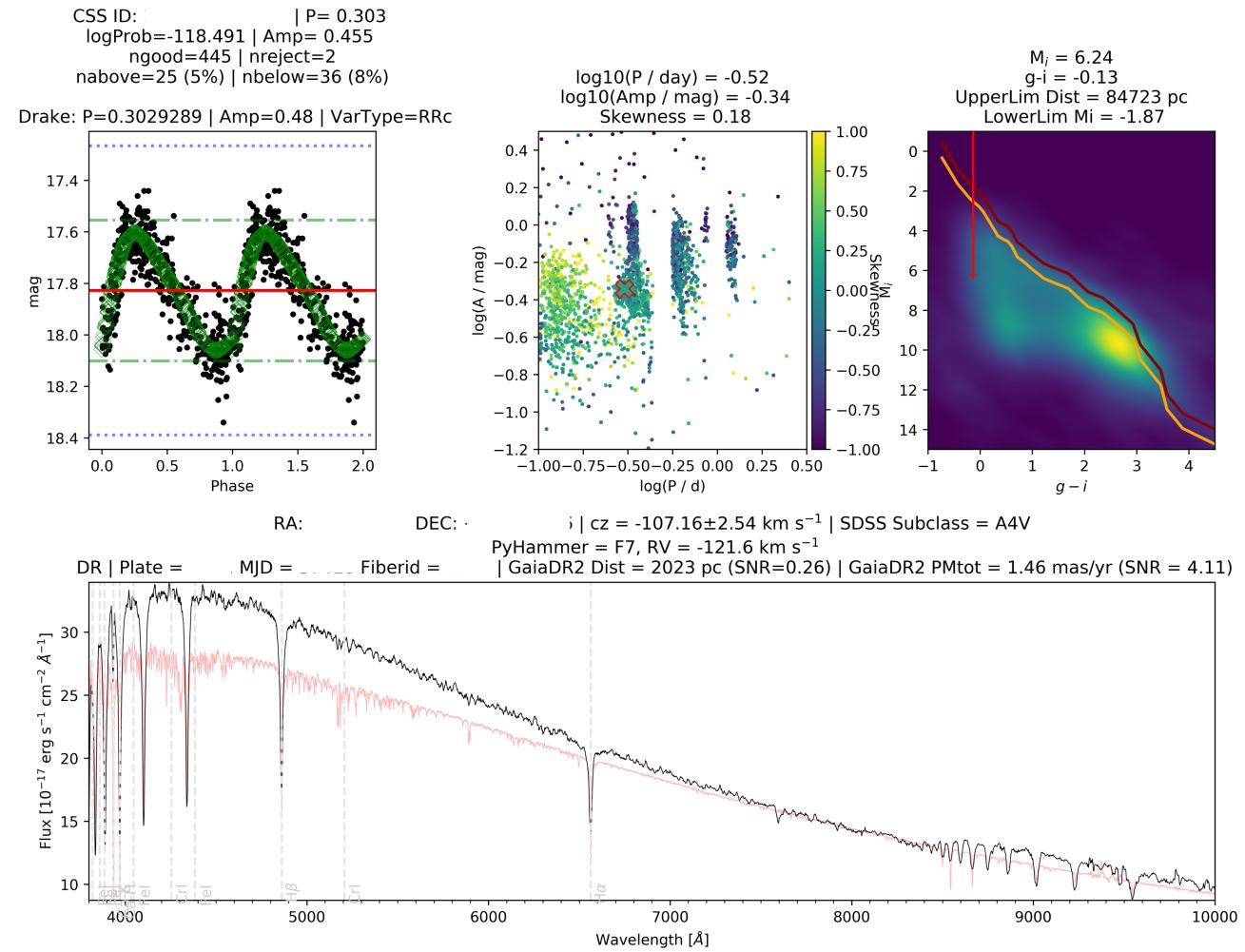
$cz = -88 \pm 3$  km/s Class=STAR K5Ve (118100)  
No warnings.

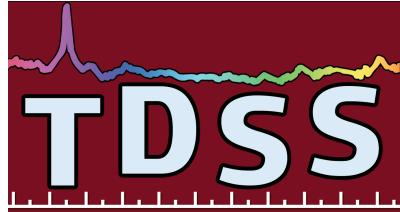




# TDSS Stellar Variables

If you're interested in more information on the TDSS Stellar Variables, see my talk Thursday (27<sup>th</sup>) during the Stellar Templates Parallel V Session L, at 4:45pm.





# TDSS Publications/Recent MoU Files

Published:

Morganson+2015

Ruan+2016

Grier+2016

Ruan+2016

Runnoe+2016

Wang+2016

McGraw+2017

MacLeod+2018

Roulston+2019

SES Target selection

SEQUELS (TDSS pilot)

BAL acceleration

CLQs

CLQs

Binary SMBH

BAL re-emergence/disappearance

RQS/FES Target selection

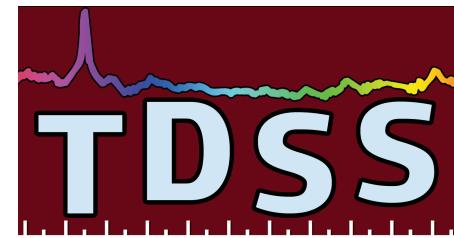
Radial velocity variations in dwarf carbon stars

\*spTDSS-PSI file (PSI/SDSS-IV MoU data-sharing; spAll+PSI and SDSS imaging parameters) file on wiki and delivered to PSI

[spTDSS-PSI-v5\\_10\\_0-21Dec2016\\_DR14v0.txt.gz](#)

\*And see K. Stassun's Filtergraph interface to latter

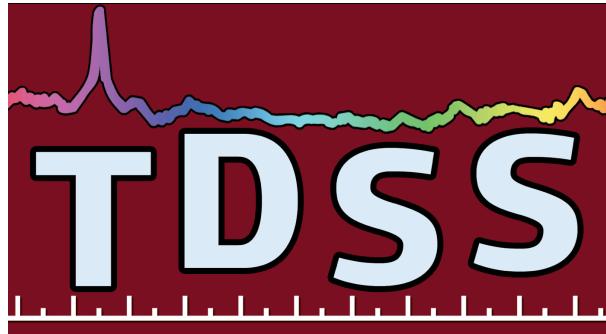
<https://filtergraph.com/tdss>



# 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\_01Jul2018\_v0.txt**
- PS1/SDSS-IV data-sharing file



## TEAM

S. Anderson (Uwa), C. Badenes (UPitt), M. Bershadsky (UWi), M. Blanton (NYU), N. Brandt (PSU), K. Chambers (IfA), J. Davenport (UW), K. Dawson (Utah), M. Eracleous (PSU), N. Filiz Ak (Erciyes), P. Garnavich (Notre Dame), A. Georgakakis (MPE), P. Green (CfA), J. Greene (Princeton), C. Grier (PSU), P. Hall (York), S. Hawley (UW), N. Kaiser (IfA), J.-P. Kneib (EPFL), C. MacLeod (CfA), Vivek Mariappan (Utah), I. McGreer (UA), A. Merloni (MPE), E. Morganson (UIUC), A. Myers (UWy), I. Paris (IAP), B. Roulston (SAO/BU), J. Ruan (UW), J. Runnoe (UMich), M. Salvato (MPE), E. Schlaufly (MPIA), D. Schlegel (LBNL), S. Schmidt (OSU), D. Schneider (PSU), Axel Schwope (AIP), B. Sesar (Caltech), T. Shanks (Durham), Y. Shen (UIUC), S. Smartt (Queen's U. Belfast), K. Stassun (Vander.), P. Szkody (UWa), J. Tonry (IfA), F. Walter (MPIA), D. York (UC), ... YOUR NAME  
HERE