Highlights from the Tillinghast Reflector Echelle Spectrograph (TRES)

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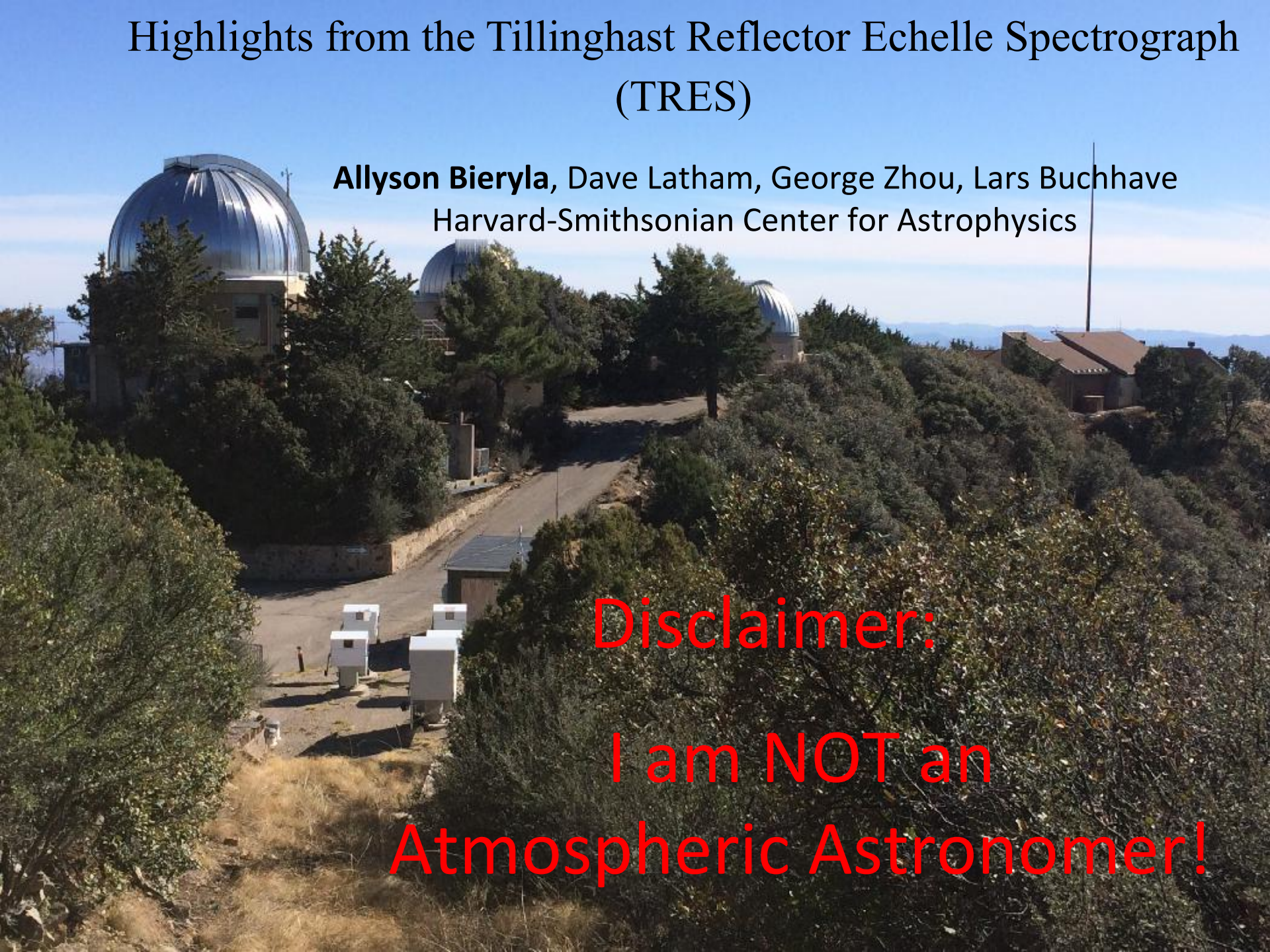
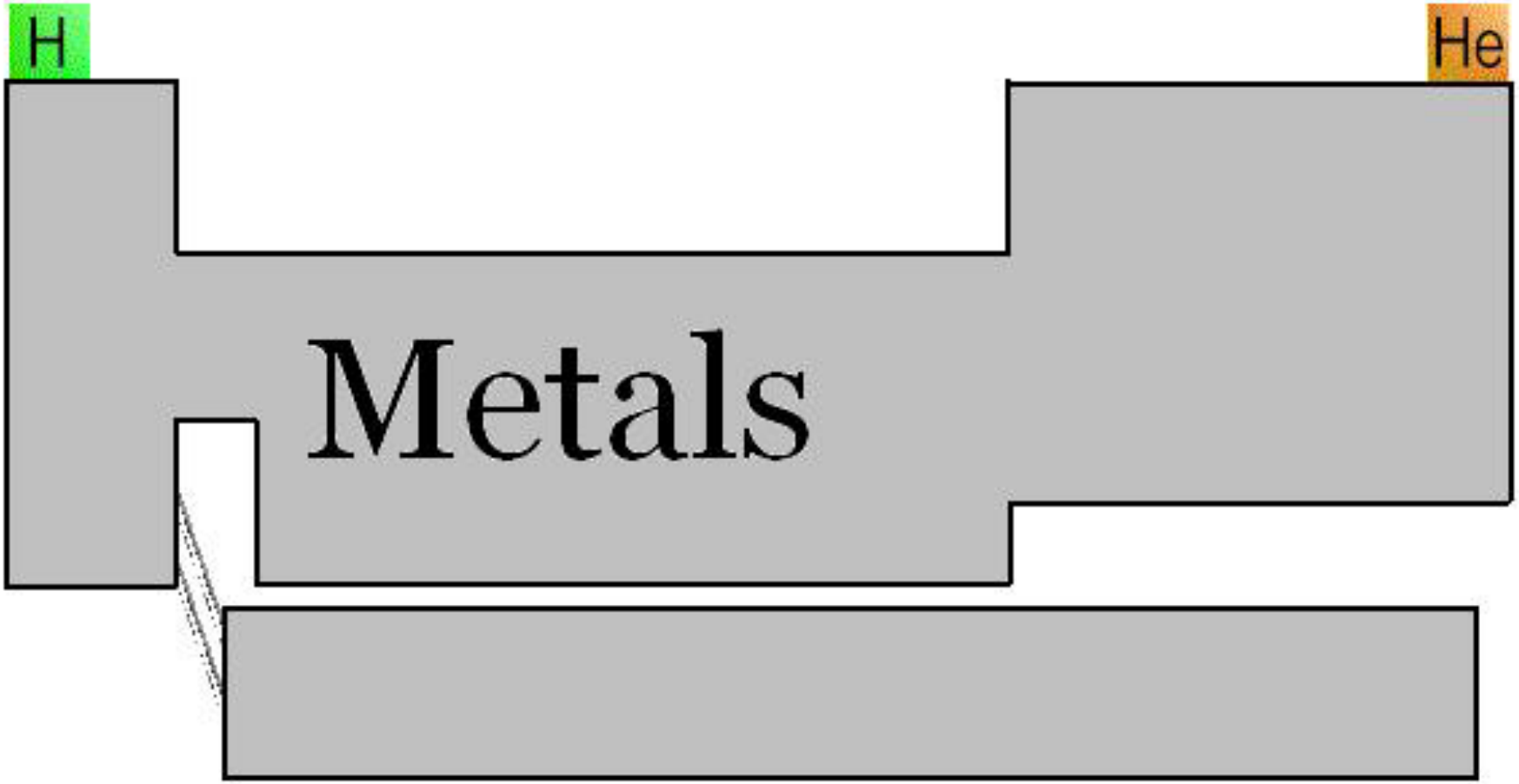
Harvard-Smithsonian Center for Astrophysics

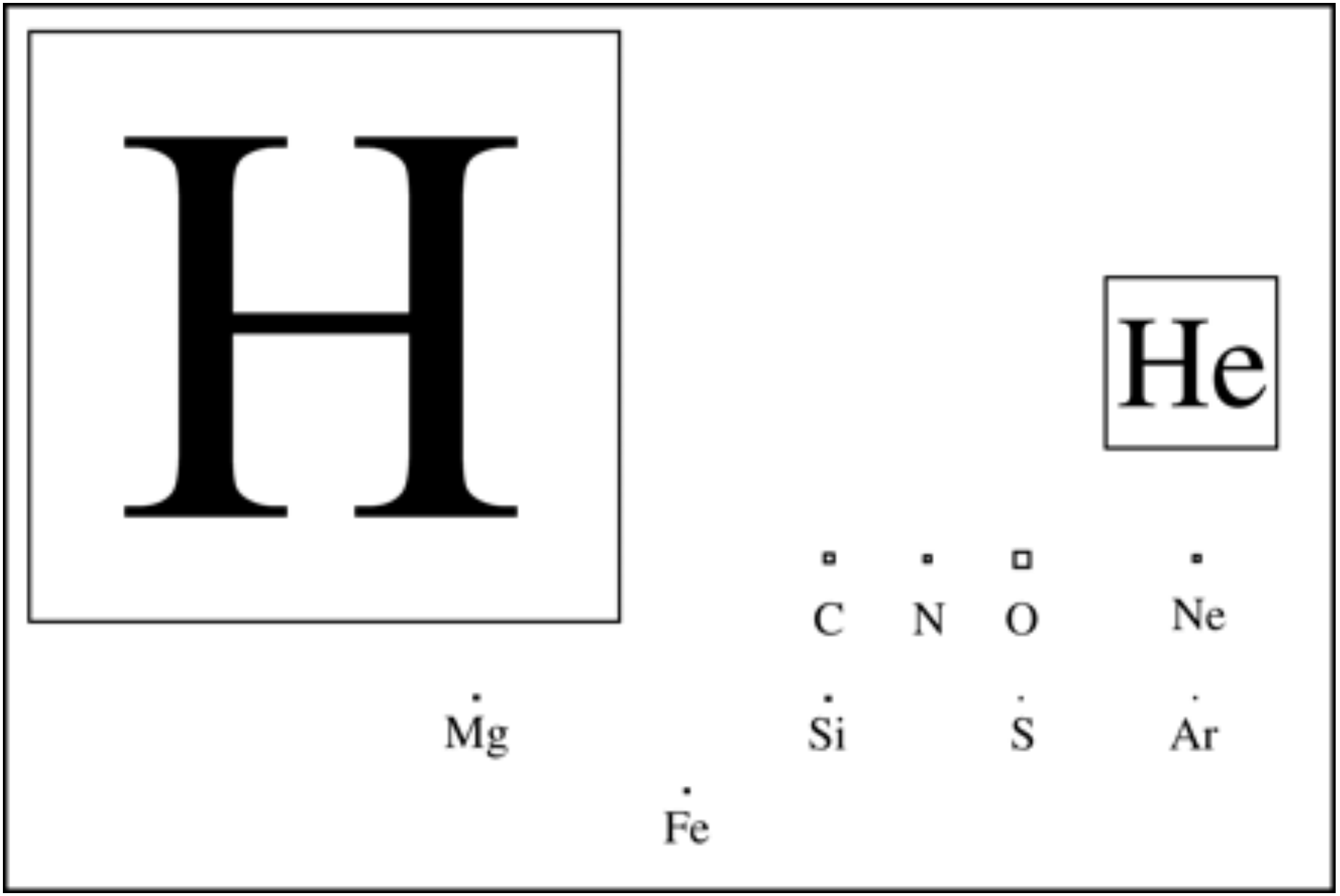


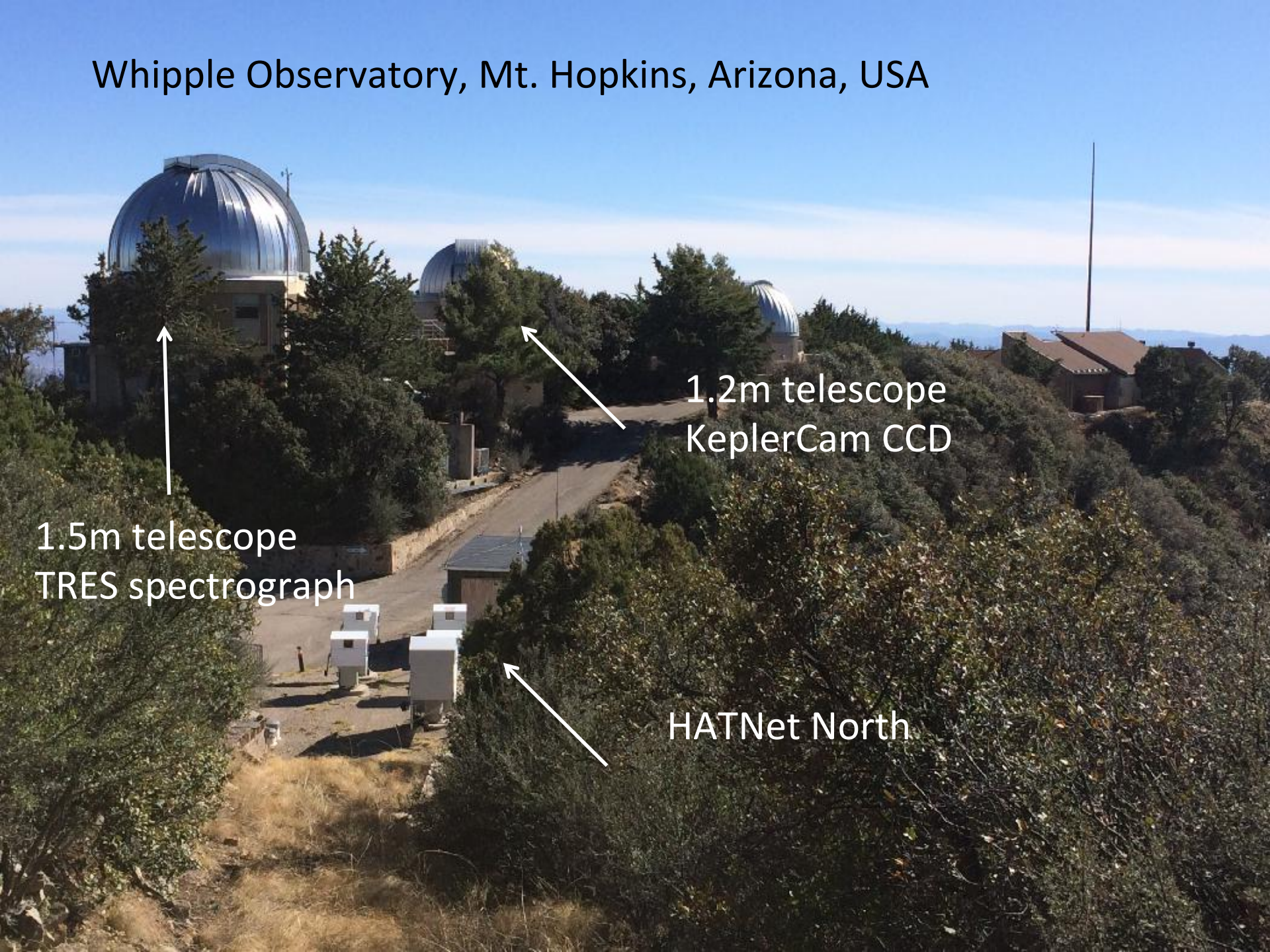
Disclaimer:

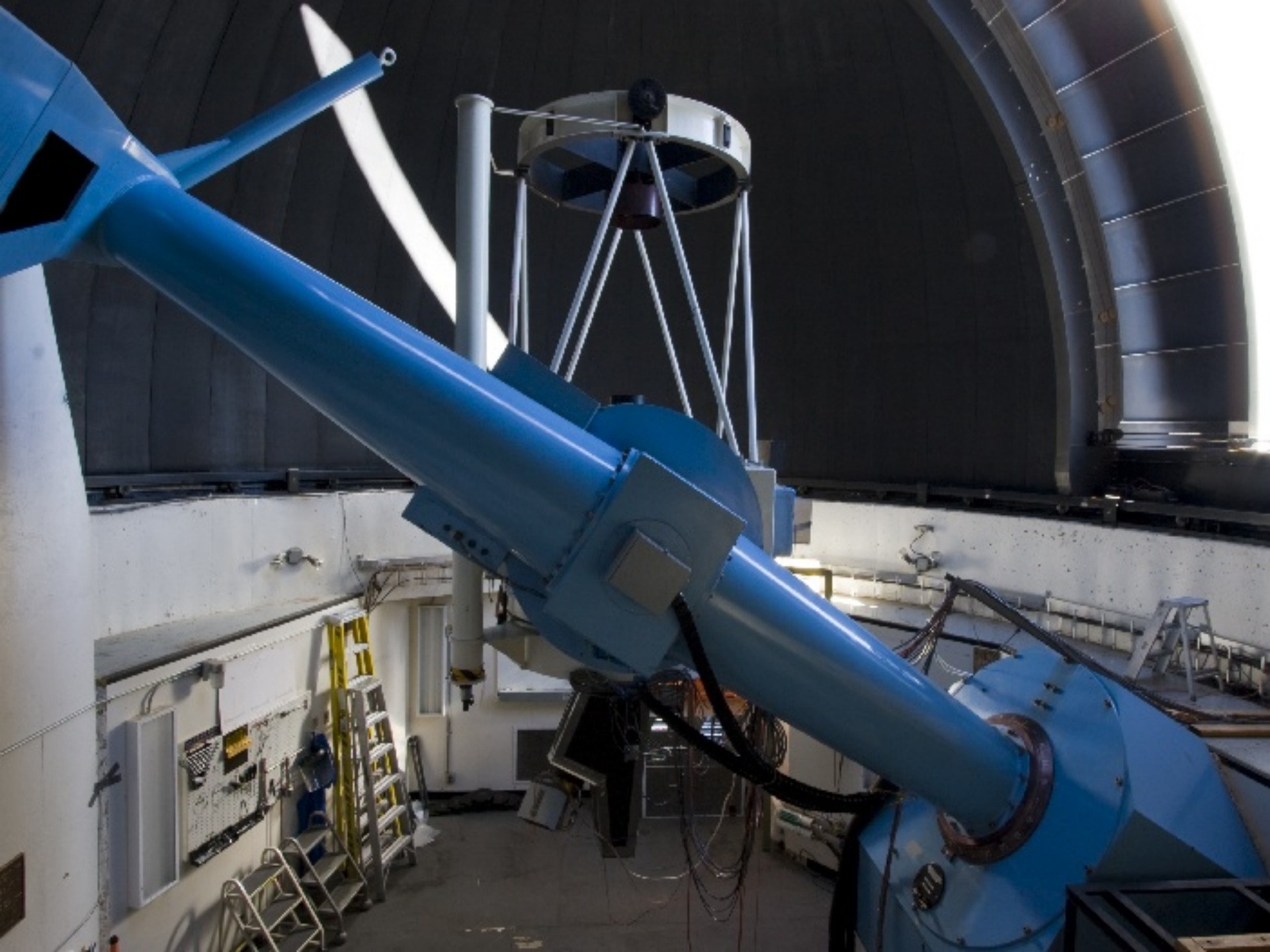
I am NOT an Atmospheric Astronomer!

The Astronomers' Periodic Table of Elements




H
He
C
N
O
Ne
Mg
Si
S
Ar
Fe


Whipple Observatory, Mt. Hopkins, Arizona, USA
1.2m telescope
KeplerCam CCD
1.5m telescope
TRES spectrograph
HATNet North



TRES Specifications

- Tillinghast Reflector Echelle Spectrograph (TRES)
  - 1.5m Tillinghast Reflector at the Whipple Observatory, AZ
  - CCD echelle with wide wavelength coverage (390-910 nm)
  - Resolving Power ~44,000
  - Pipeline developed by Lars Buchhave
    - Radial Velocities and Stellar Parameters
  - Fiber fed, temperature stabilized in Coudé chamber
  - Velocity precision floor ~ 10 m/s, limiting magnitude V~15.0
  - More than 50,000 observations since 2009, queue scheduled

TRES team

- 

Dave Latham

TRES Tools

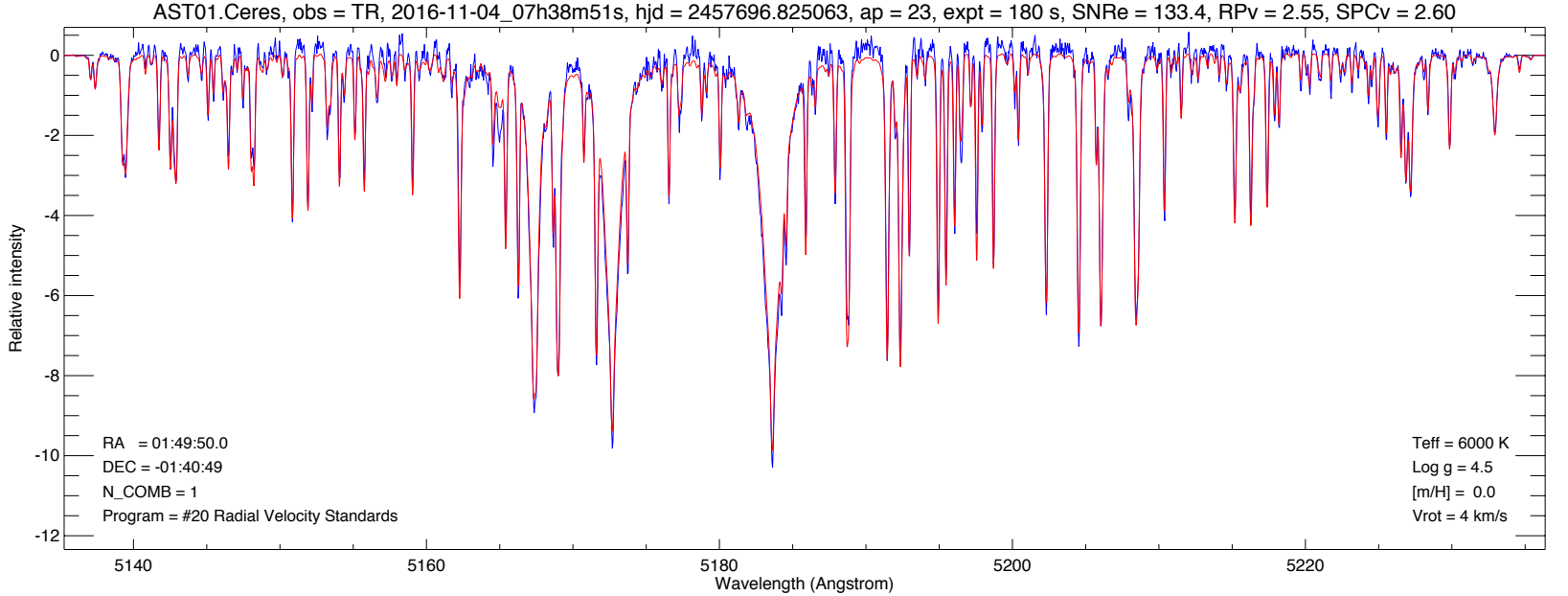
- Standard Pipeline (Buchhave 2010)
  - Single-order (Mgb order) radial velocities
    - Cross-correlated using a best matched synthetic template
  - Quick look classification − Teff, Logg, [m/H], vsini
    - Uses solar metallicity as a default parameter, logg, Teff and Vsini free parameter
- Higher Precision RVs
  - Multi-order analysis
    - Using carefully selected orders for given star
- Stellar Parameter Classification (SPC; Buchhave 2012)
  - Uses a grid of synthetic templates based on Kurucz atmospheric models (Kurucz 1992)

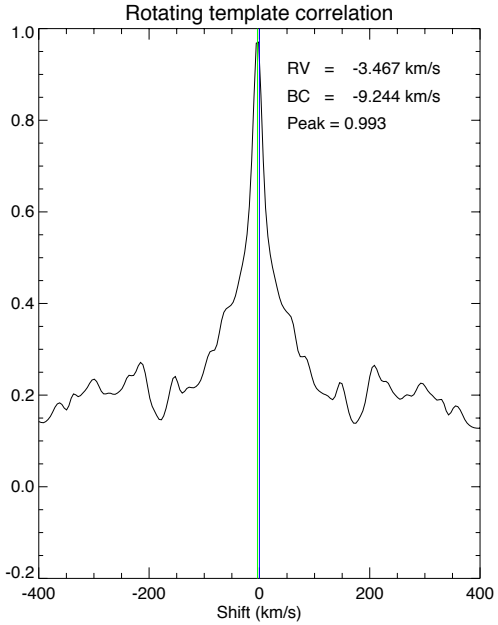
TRES Exoplanet Follow-up

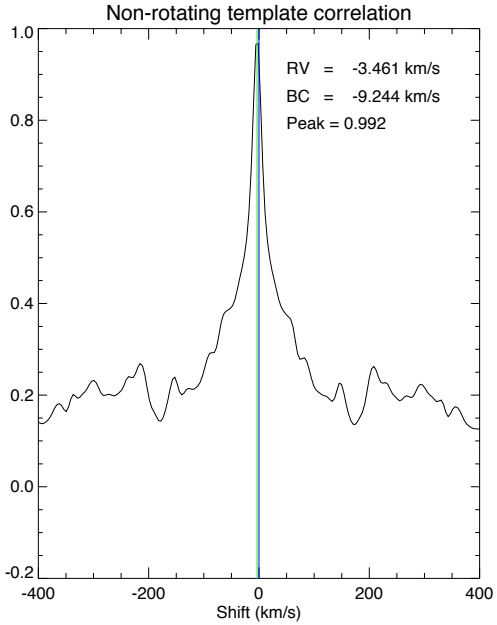
- Ground-based Surveys
  - HATNet, KELT, QES, etc…
- Space-based Surveys
  - All spectra uploaded to ExoFOP (usually within the week)*
  - https://exofop.ipac.caltech.edu
    - Kepler
      - Currently 1051 spectra of 598 unique targets
      - We have more!!
    - K2
      - Currently 1145 spectra of 694 unique targets
    - TESS
      - Soon !!
      - Spectroscopic data
      - Photometric data
      - Direct imaging

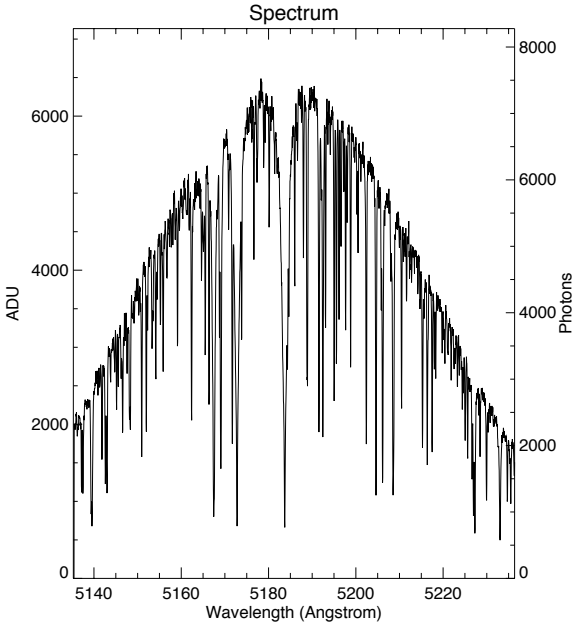
* Unless I am really busy!

Ceres 180 s SNRe 133



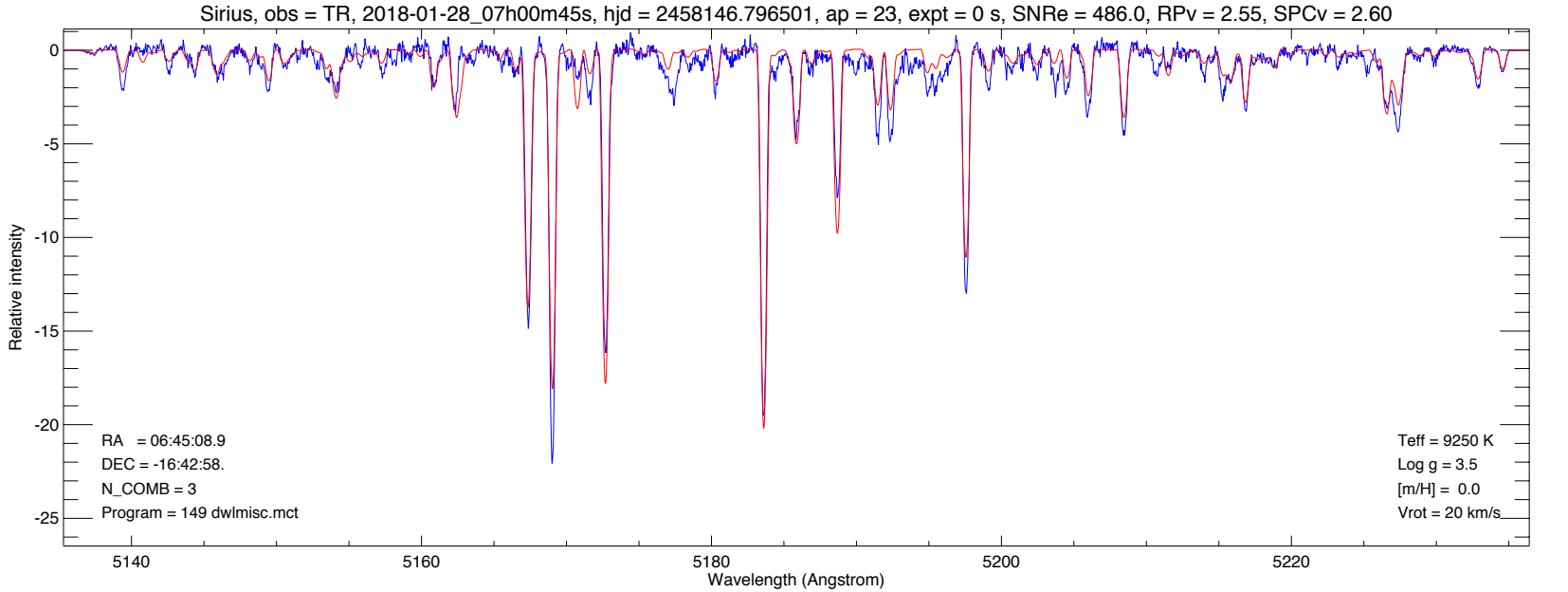


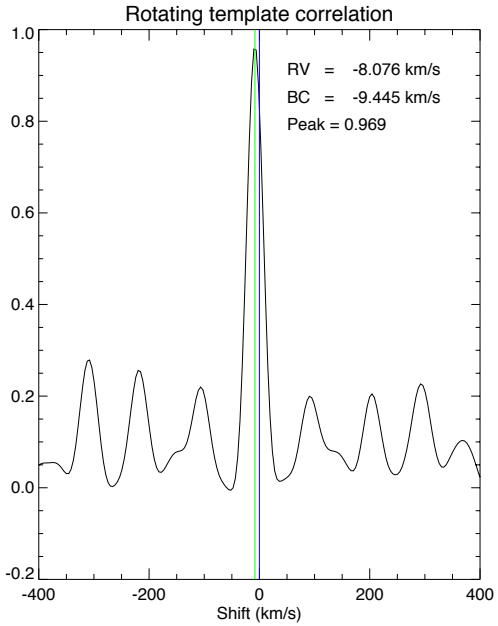


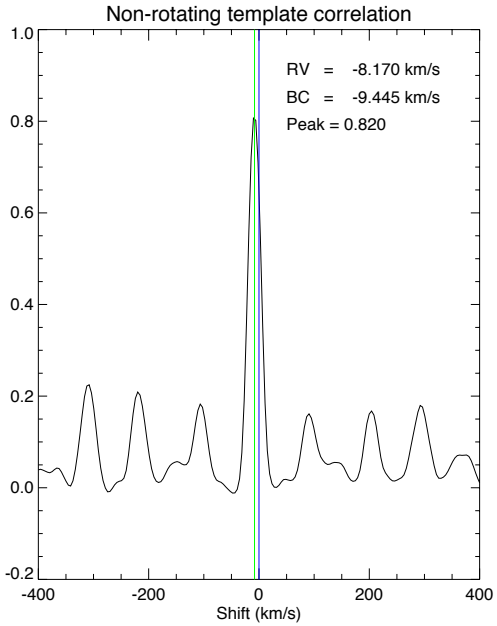


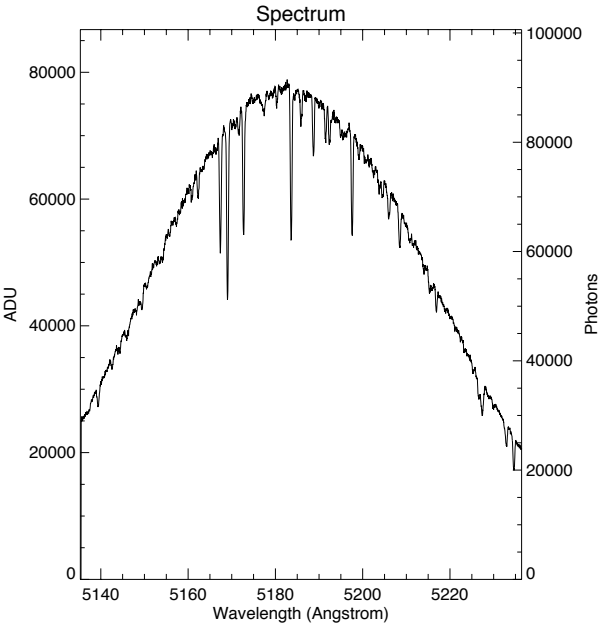
Sirius

0.3 s 486 SNRe

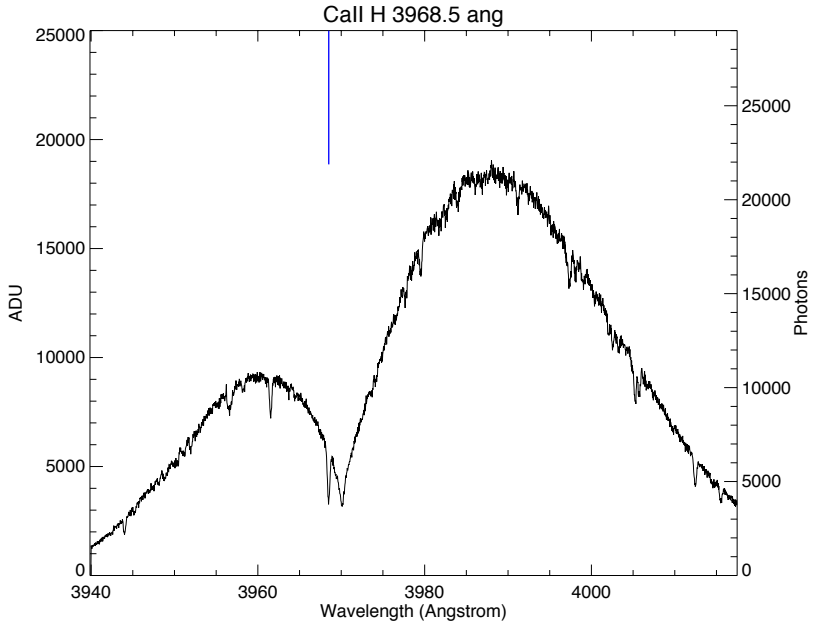


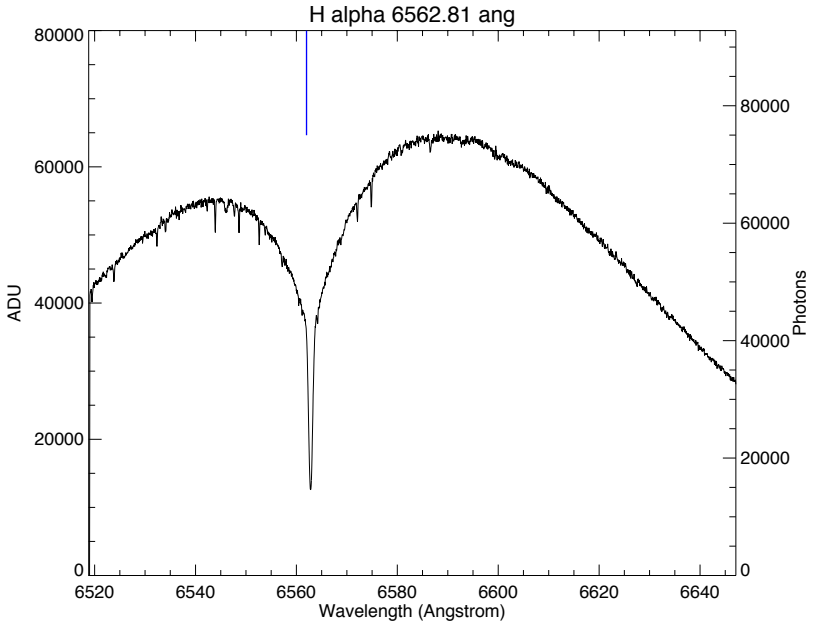


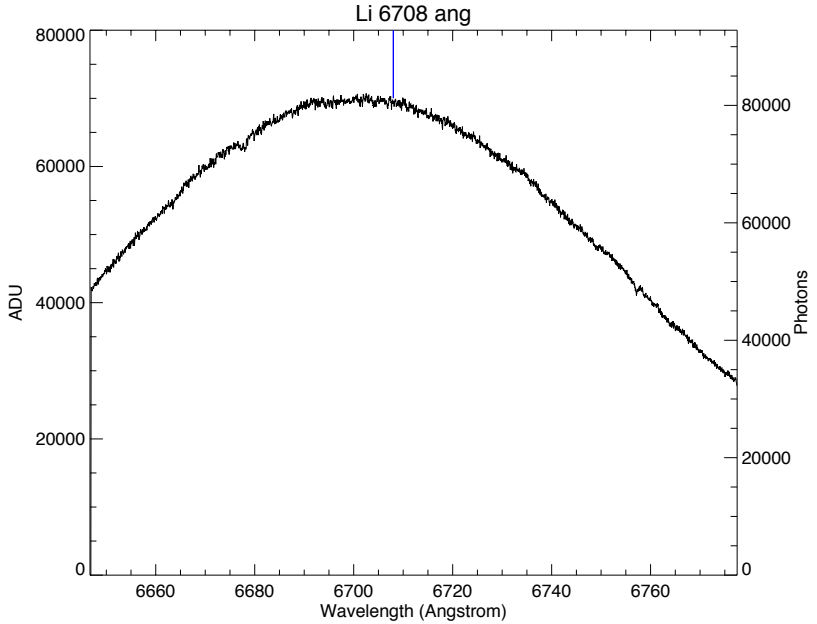


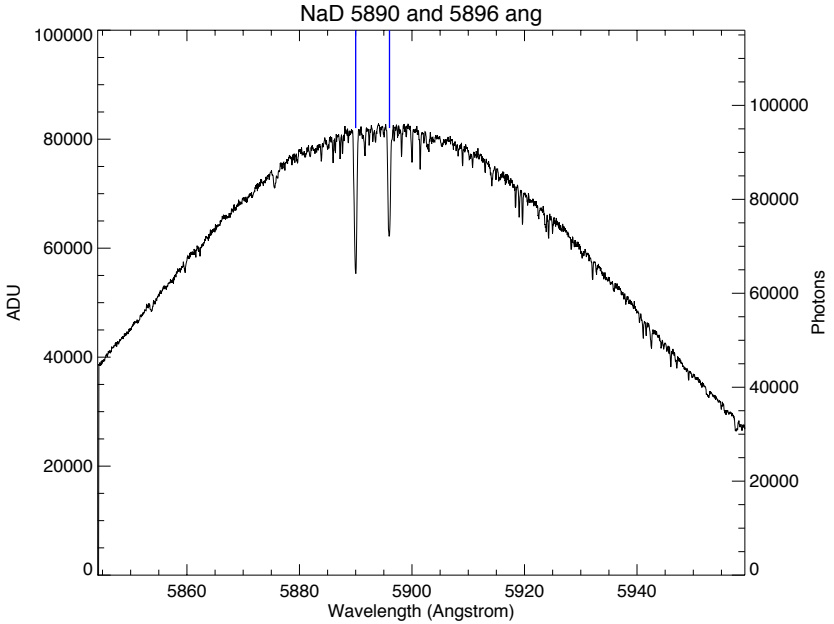


Sirius


CaII H 3968.5 ang
ADU
Photons
Wavelength (Angstrom)
0
5000
10000
15000
20000
25000
3940
3960
3980
4000

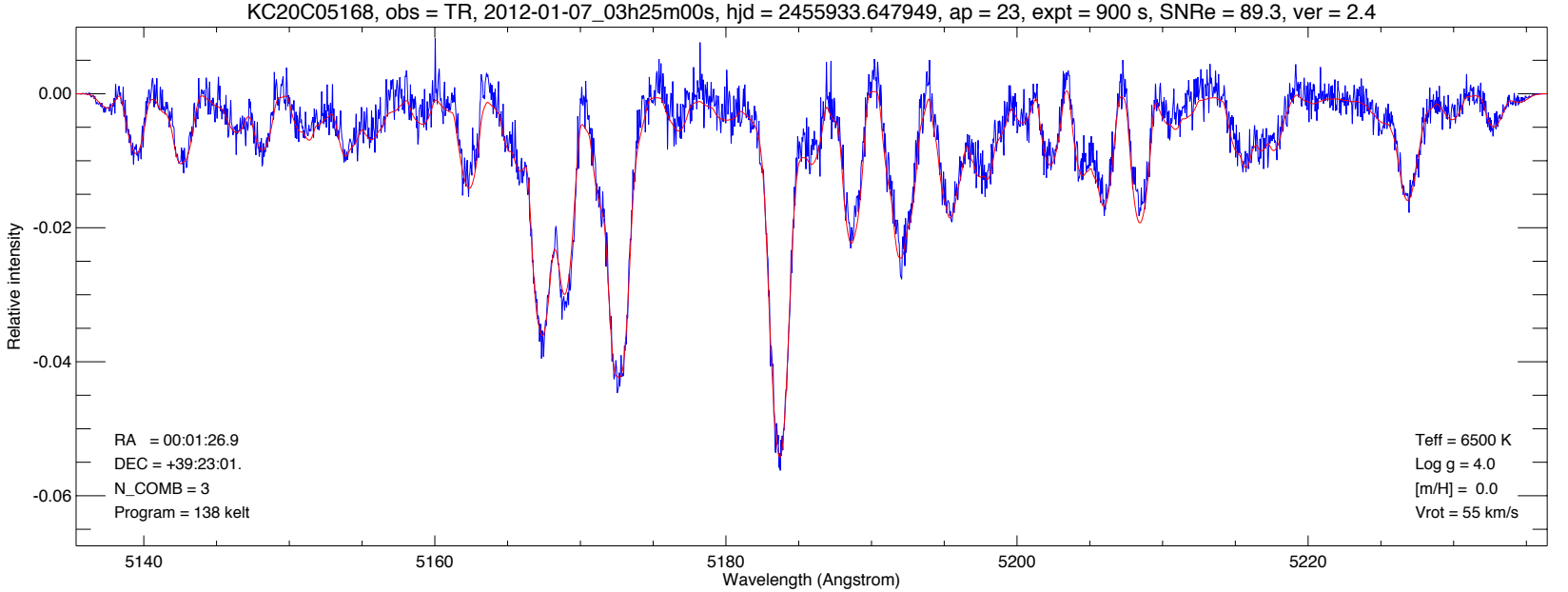

H alpha 6562.81 ang
ADU
Photons
Wavelength (Angstrom)
0
20000
40000
60000
80000
6520
6540
6560
6580
6600
6620
6640

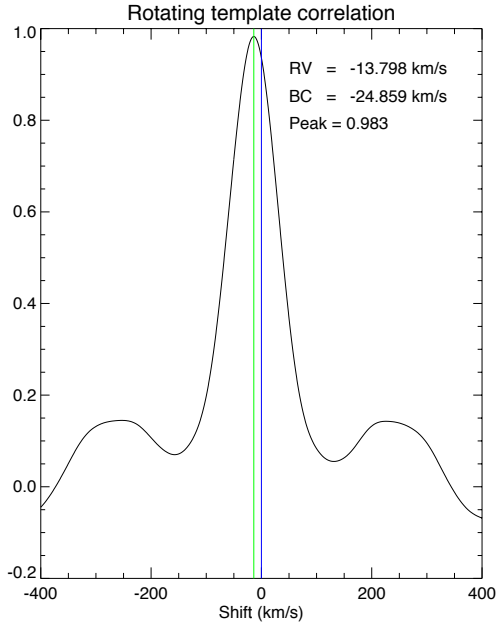

Li 6708 ang
ADU
Photons
Wavelength (Angstrom)
0
20000
40000
60000
80000
6660
6680
6700
6720
6740
6760

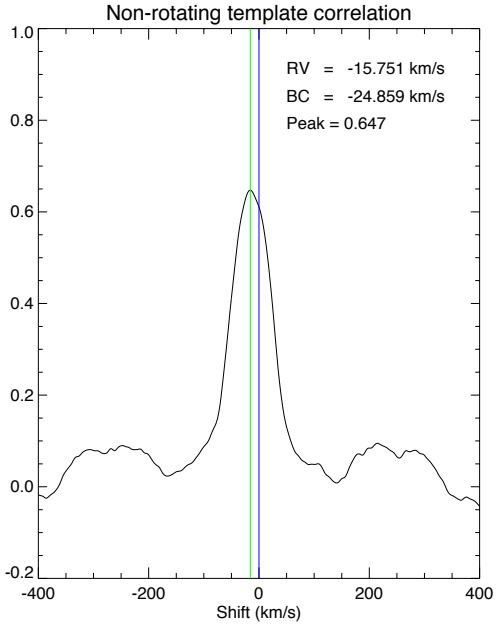

NaD 5890 and 5896 ang
ADU
Photons
Wavelength (Angstrom)
0
20000
40000
60000
80000
100000
5860
5880
5900
5920
5940

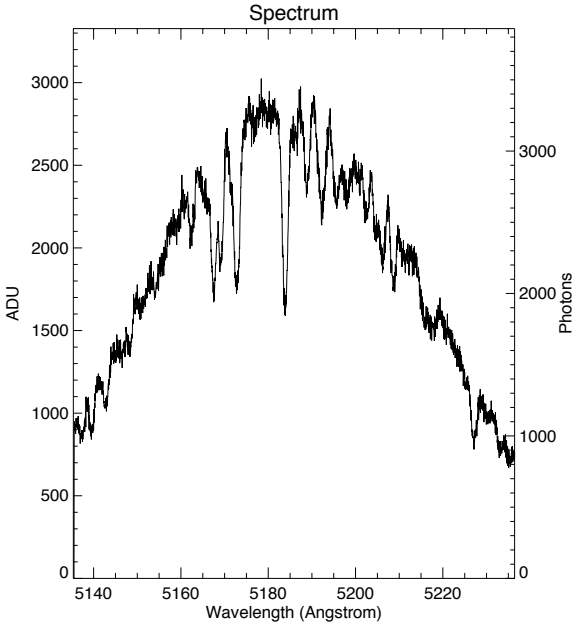
KELT-1

900 s 89.3 SNRe 55 km/s

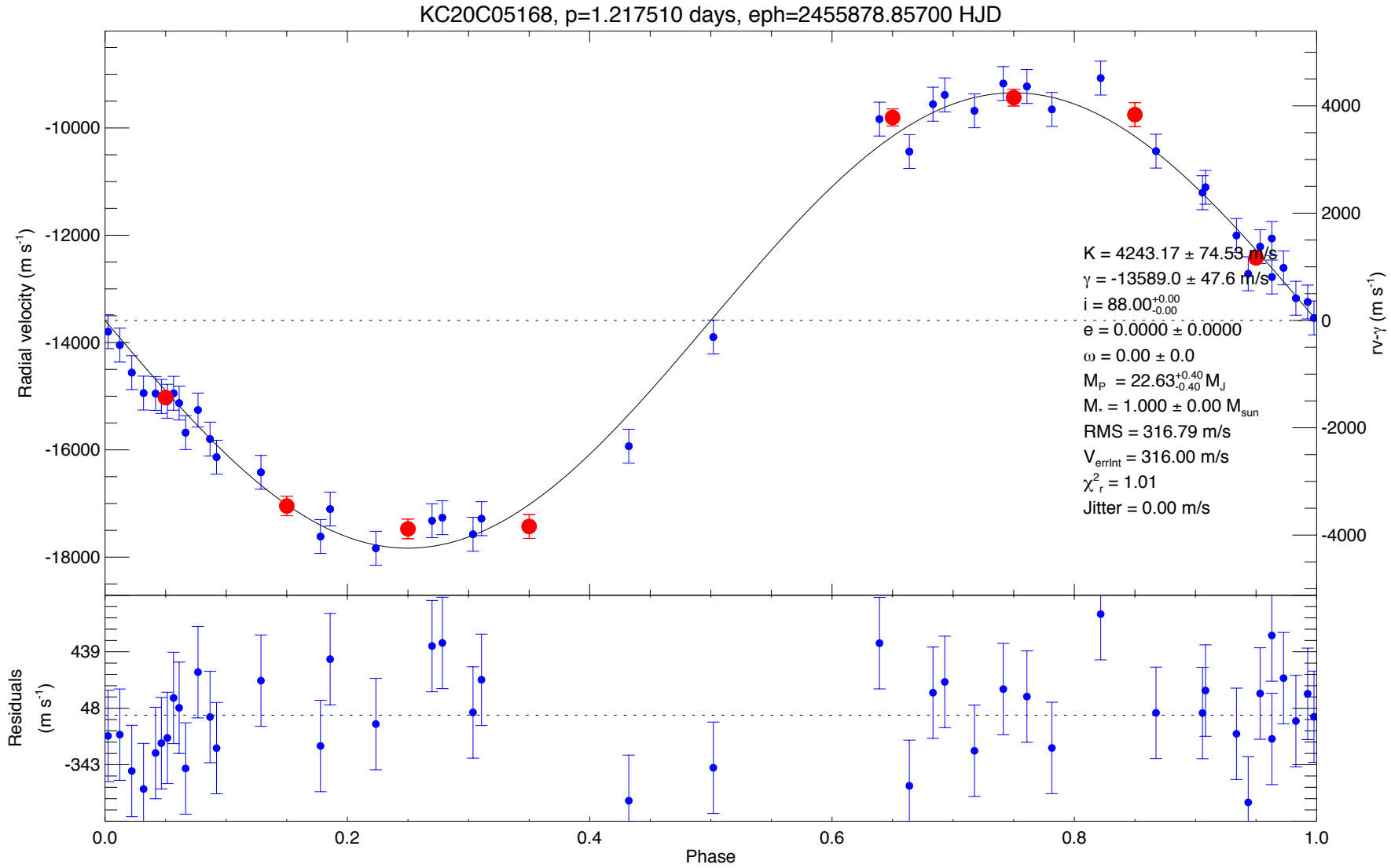








Phased KELT-1 Single-order TRES velocities



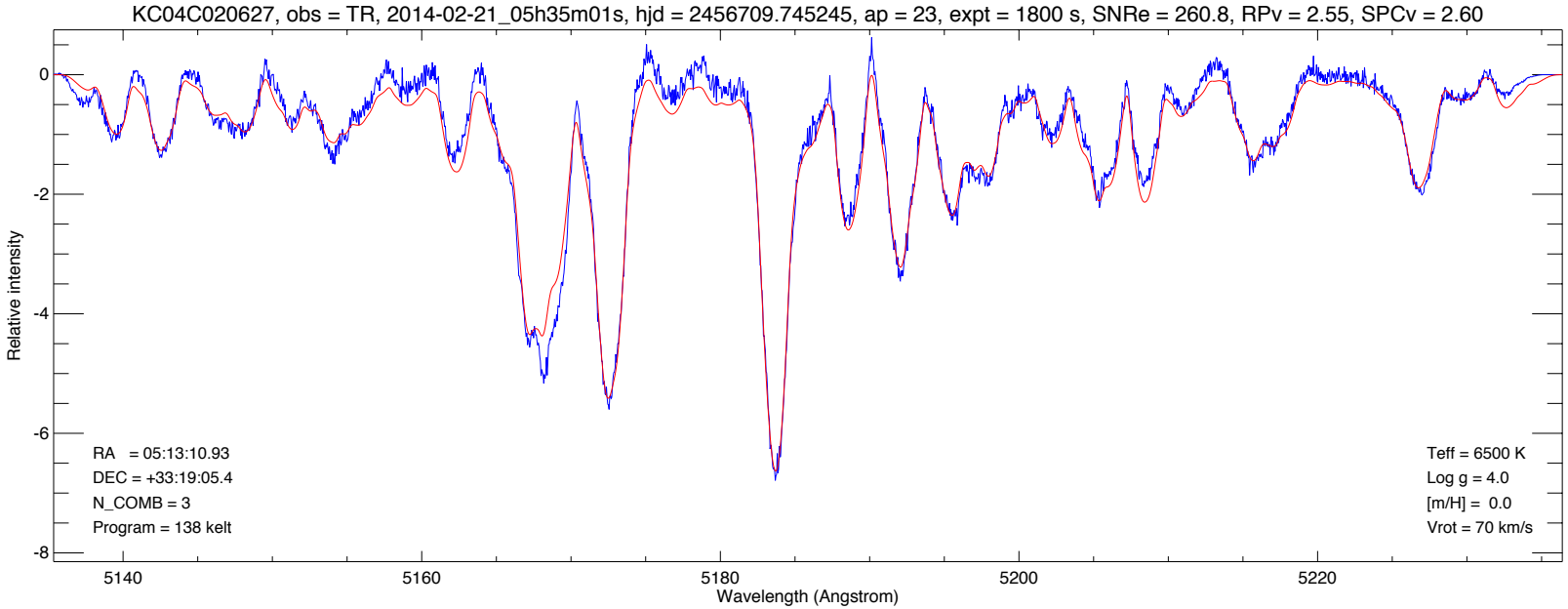
Velocities for Hot Stars

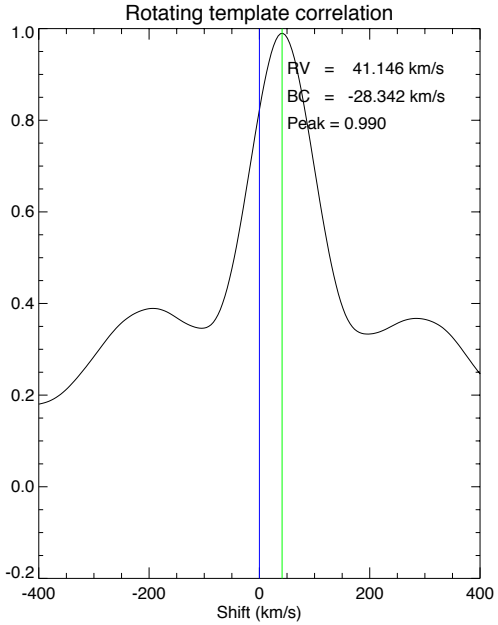
- The challenge: rapid rotation
  - Fewer spectral lines
  - Less precise velocities

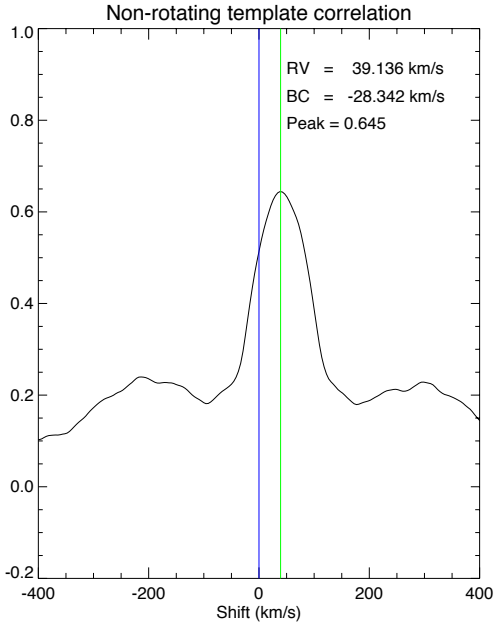
- Need new ways to confirm planets
  - Rossiter-McLaughlin (RM) Effect
  - Doppler Tomography (DT)

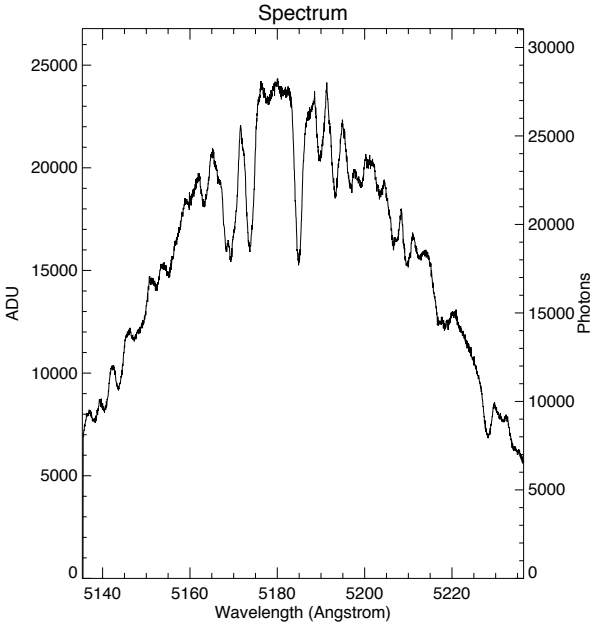
KELT-7

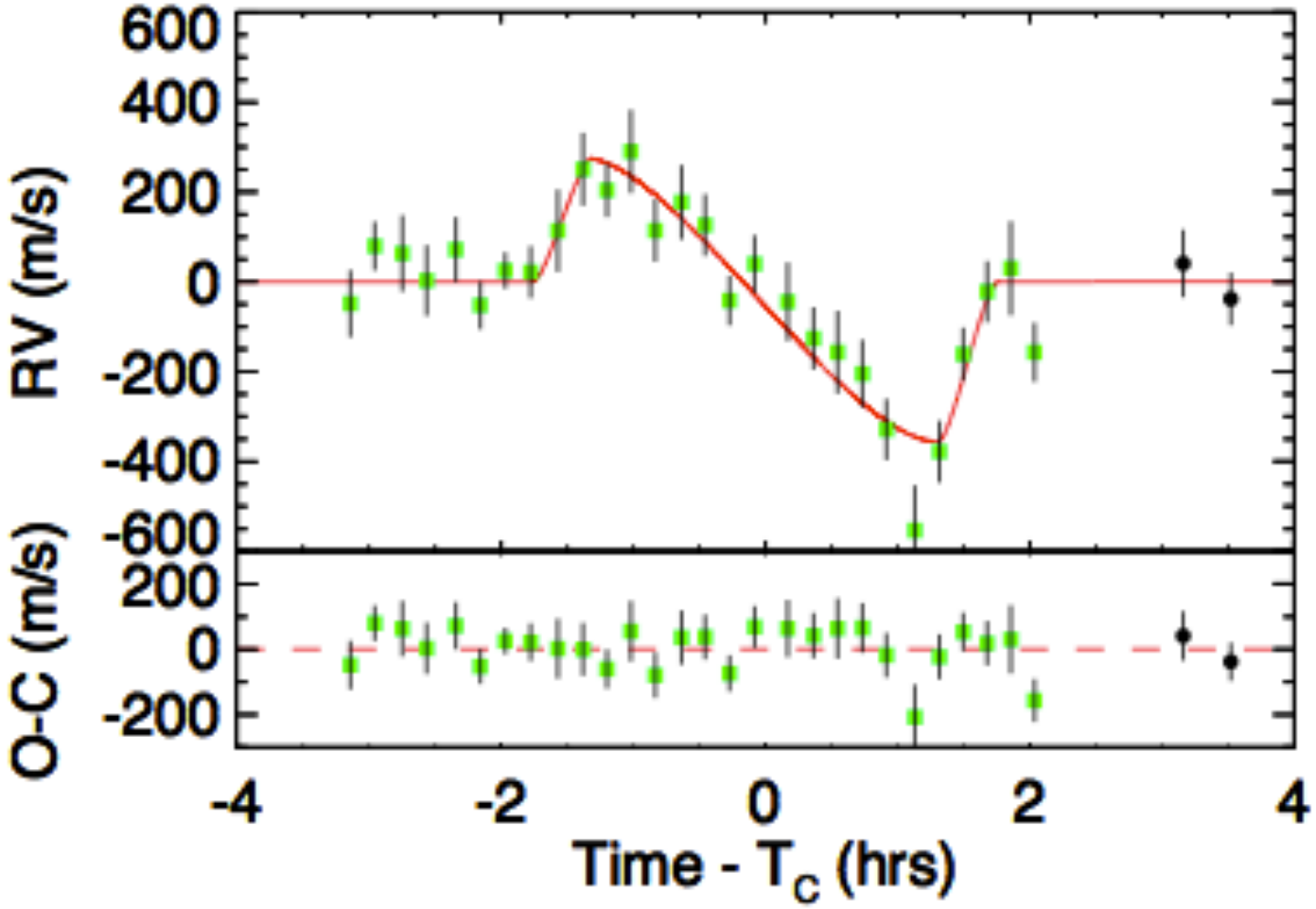
1800 s 260 SNRe 70 km/s







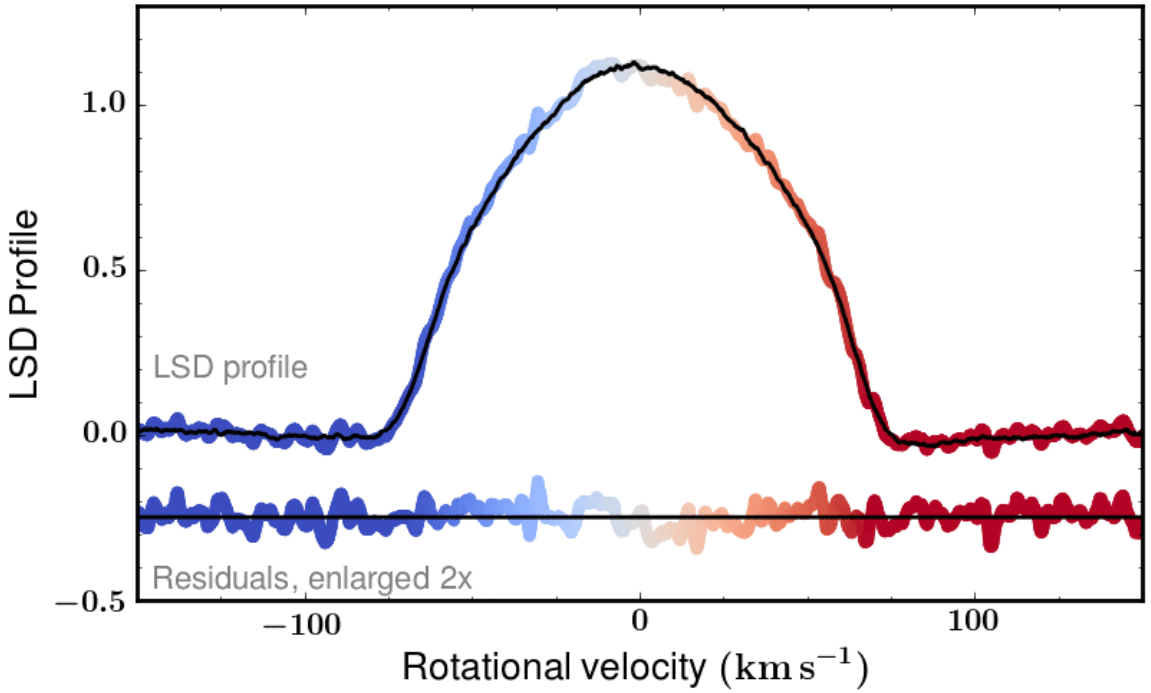


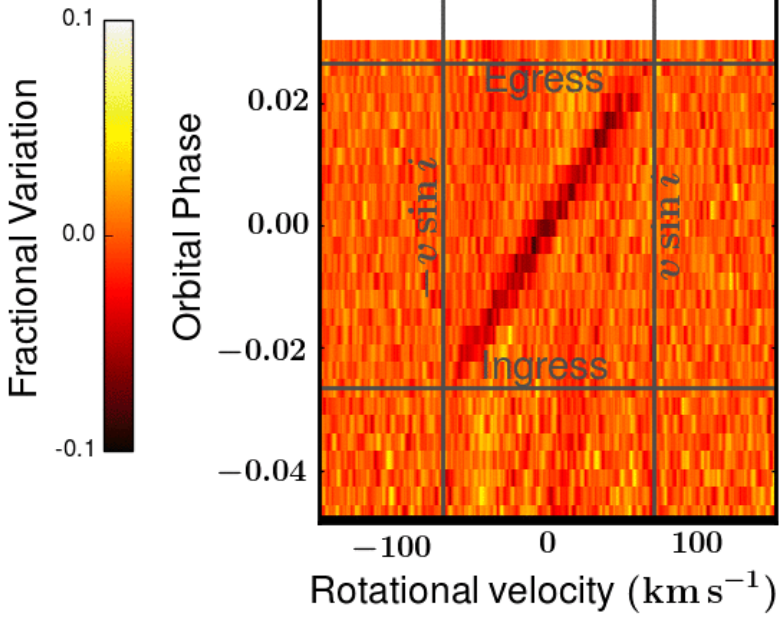


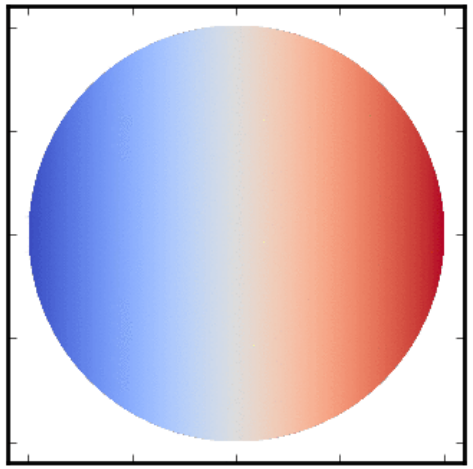
KELT-7 Rossiter-McLaughlin

Bieryla et. al 2015

KELT-7
Doppler Tomography
by George Zhou
V_{rot}=70 km/s

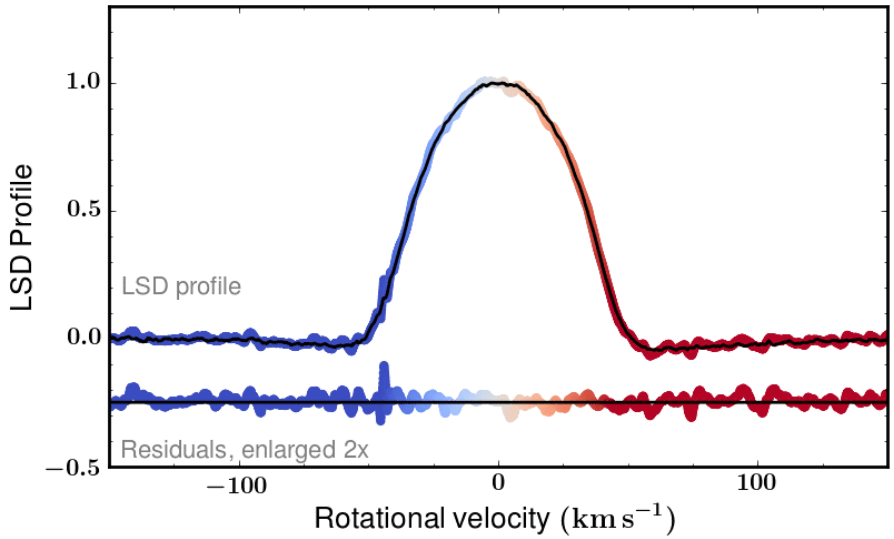


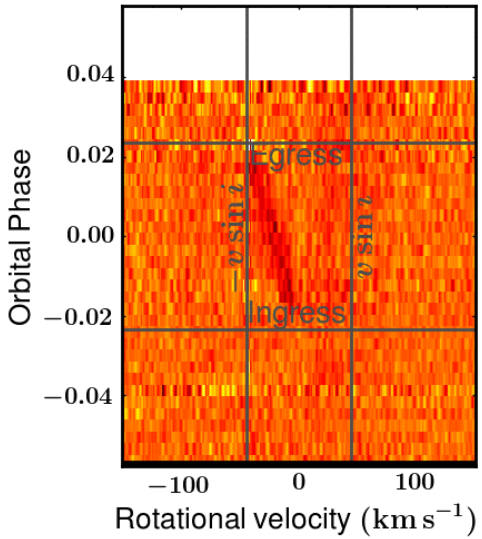


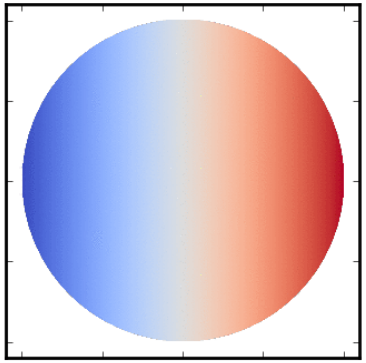


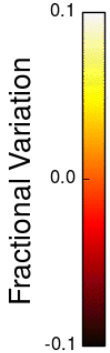
KELT-17

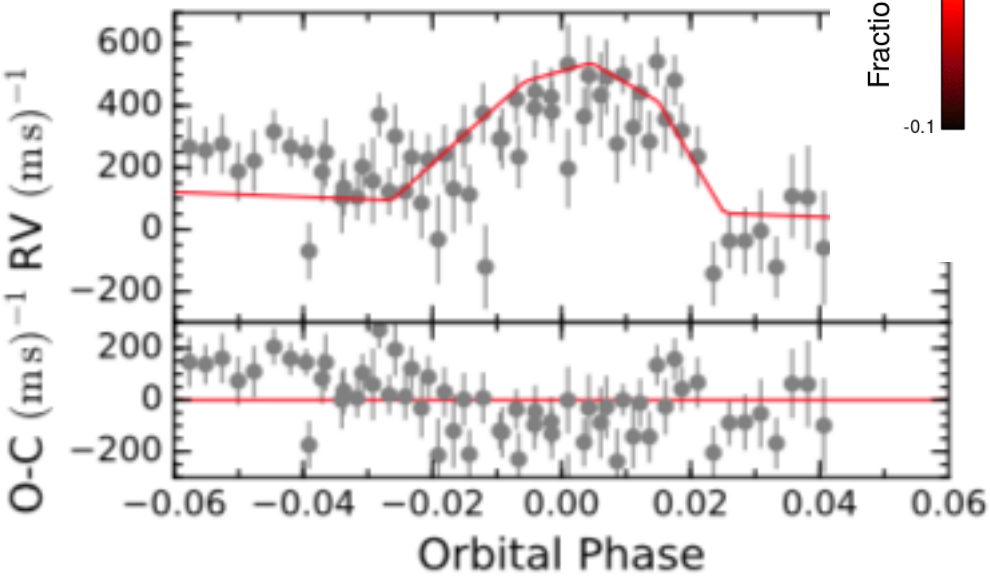
V_{Rot}=44 km/s









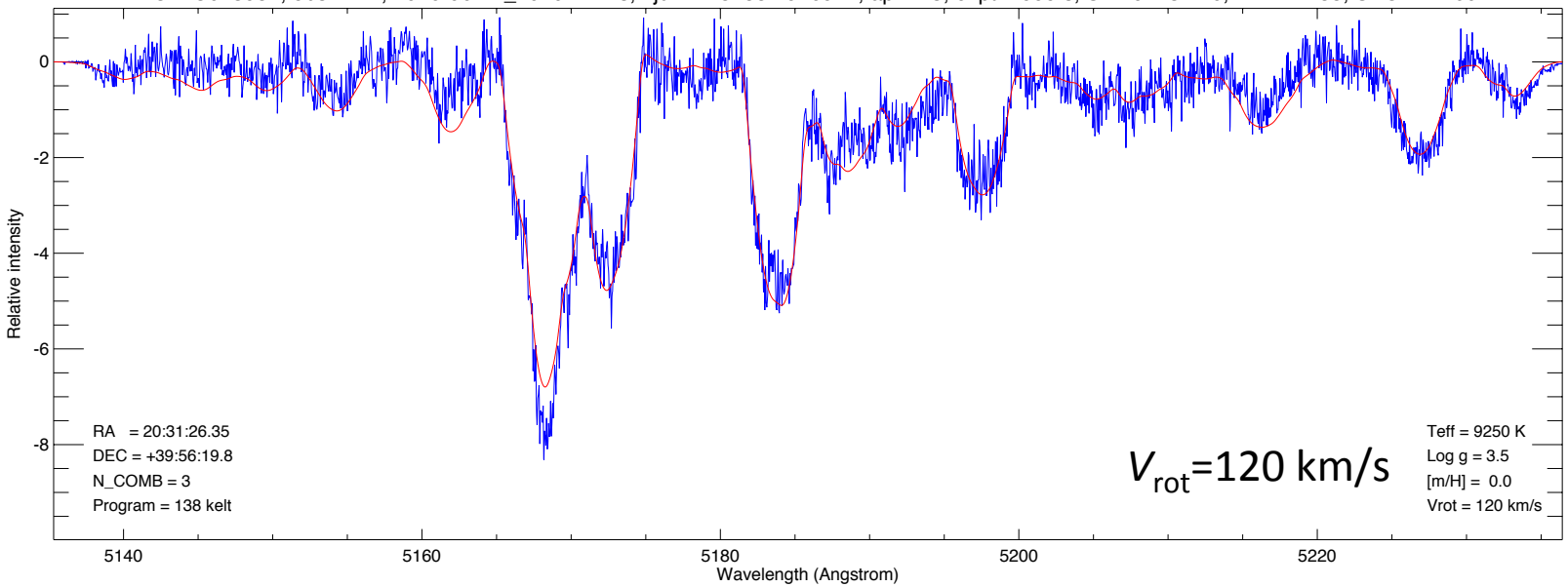


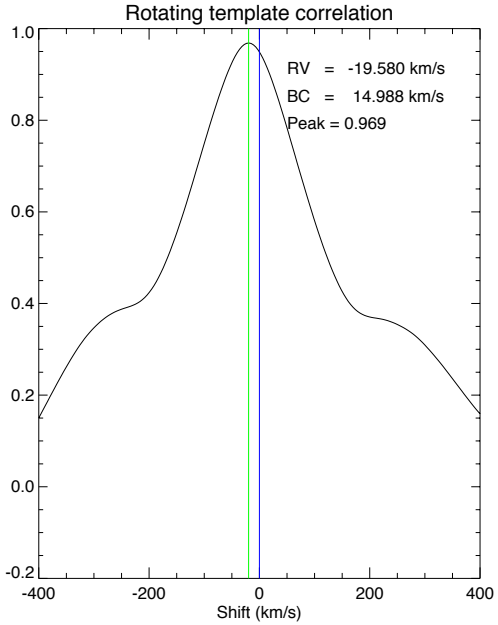
Zhou et al. 2016

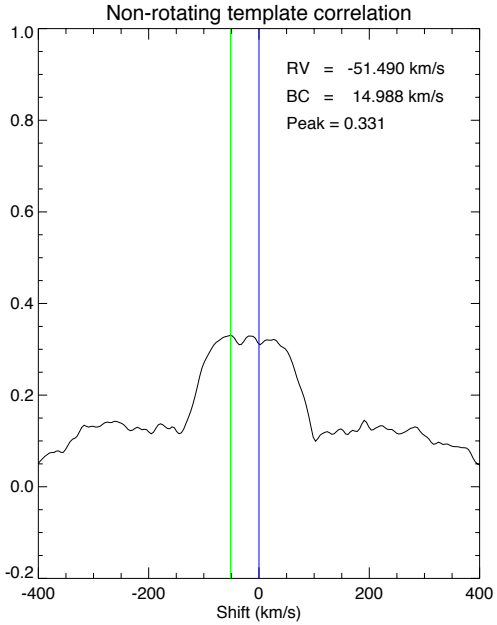
KELT-9

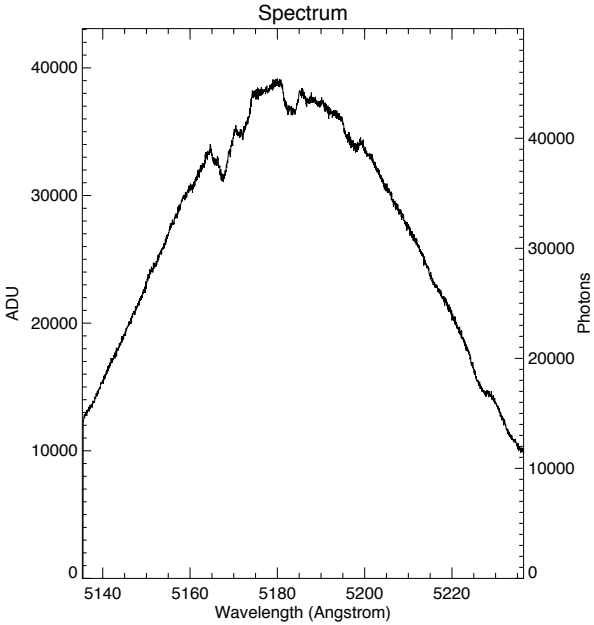
999 s 341 SNRe

KC11C043952, obs = TR, 2016-06-12_10h04m12s, hjd = 2457551.926924, ap = 23, expt = 999 s, SNRe = 341.6, RPv = 2.55, SPCv = 2.60

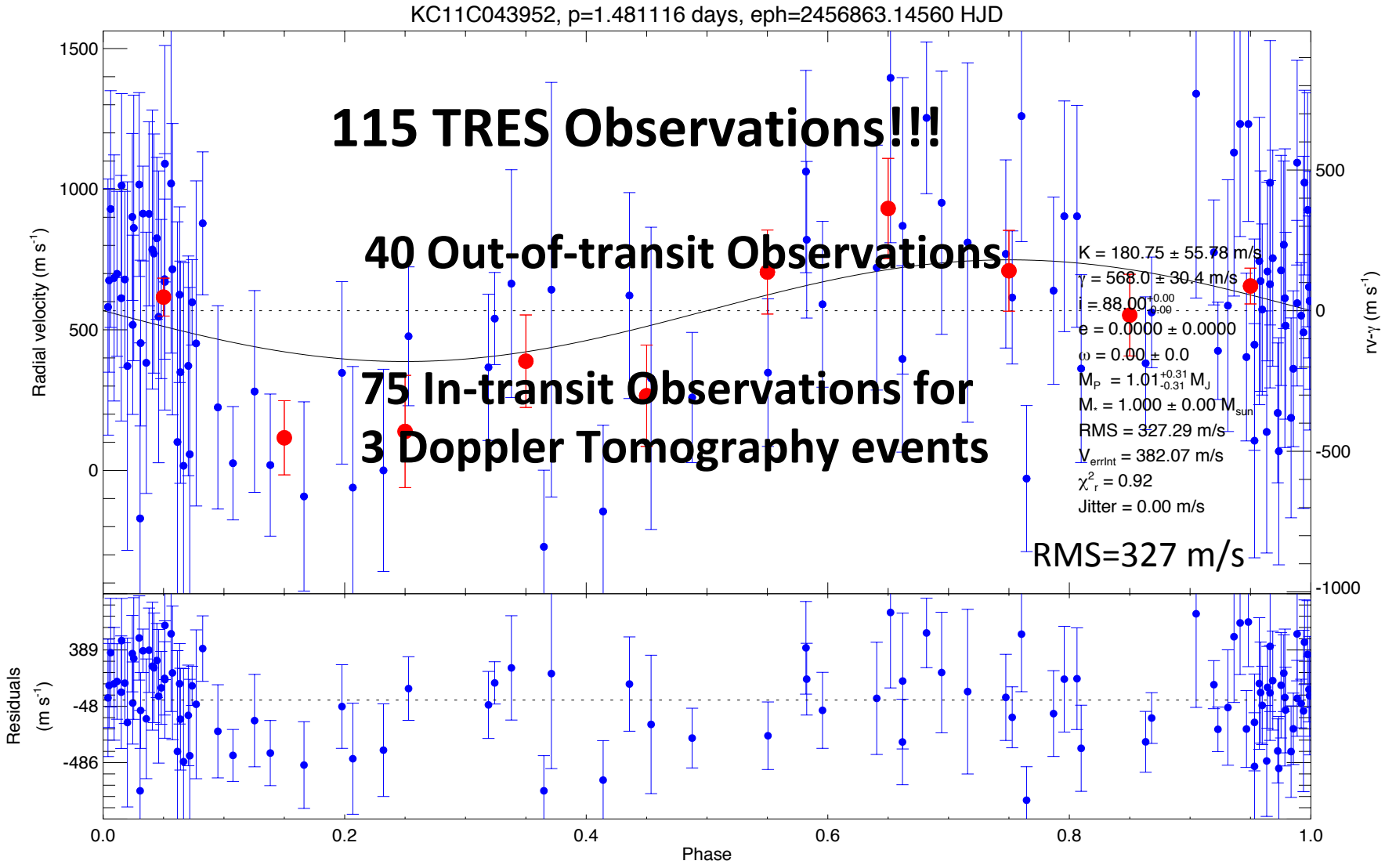








Phased KELT-9 multi-order TRES velocities



KELT-9b TRES Doppler Tomography

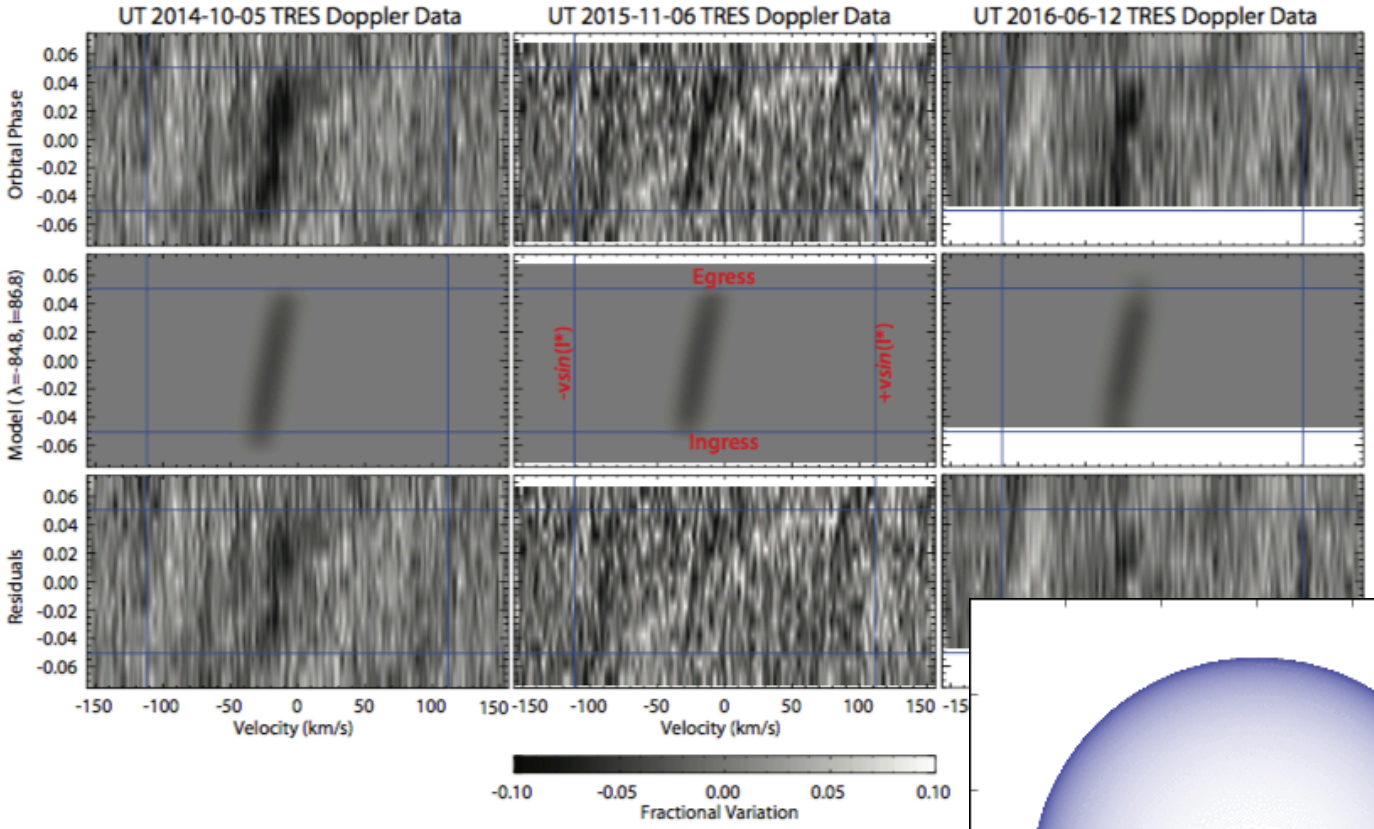
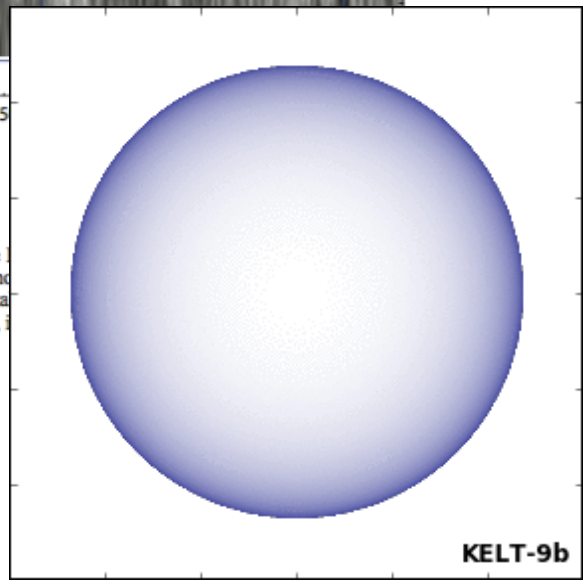


FIG. 4.— Doppler tomographic line profile plots. The data, models, and residuals from all three nights where
in three columns. In each case, the top plot shows the spectroscopic data, the middle panels show the derived mo
In each panel, the vertical blue lines denote the width of the convolution kernel (i.e., $v \sin I_*$), and the horizonta
Time increases vertically for each panel. Note the transit is nearly coincident with the projected stellar spin axis,

Polar Aligned!!!



Gaudi et al. Nature 2017

Animation credit: George Zhou

TRES Exoplanet Spectra Since 2011

Project	Observations	Targets
HATNet	3,400	1,455
KELT	2,168	568
QES	1,868	739
Kepler	1,932	1,342
K2	1,145	598
Total	10,402	4,702
TESS	3,000?	1,500

Orbits, Rossiter-McLaughlin, Doppler Tomography
PRV follow-up for Kepler/K2 masses with HARPS-N