Science with the LAMOST-Kepler spectra based on an analysis with the MKCLASS Code

Richard Gray[1] and Christopher Corbally[2]

[1]Appalachian State University

[2]Vatican Observatory Research Group

LAMOST-Kepler Workshop, Brussels, August 2017

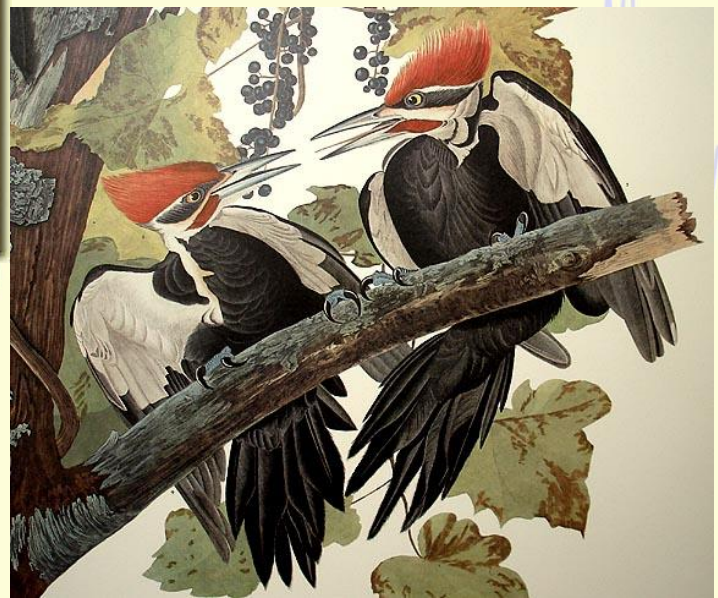
Outline of Talk

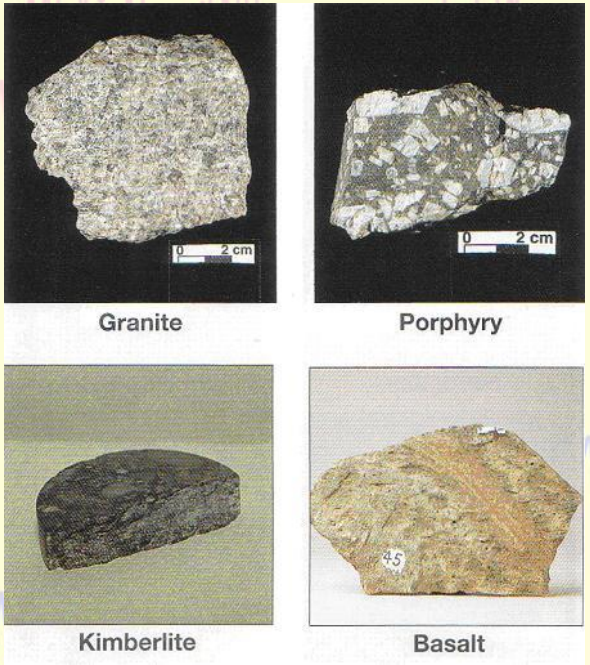
- Why Classify Spectra?
- How do we classify spectra
- The MKCLASS spectral classification code
- Classification of the LAMOST-Kepler Spectra
- Major Results
- Interesting Stars
- Lambda Bootis stars identified in the Kepler field and their pulsation characteristics

Why Classify Spectra?

Classification is an Essential Activity of Science

and serves as the beginning point for deeper analysis





The Two Goals of MK Spectral Classification

1) To locate a star in the context of the broad population of stars – e.g. its location in the HR diagram.

2) To identify peculiar and astrophysically interesting stars.

Spectral Classification and Spectral Analysis

Spectral analysis begins with estimates for the physical parameters of the star – T_{eff}, log(g), [M/H].

Spectral classification helps by:

1) Providing an unbiased determination of interstellar reddening
2) Calibrations of spectral types give good first estimates of T_{eff}, log(g), and [M/H].
3) The spectral type serves as "ground truth" for checking the results of further analysis.

Spectral Classification and Spectral Analysis

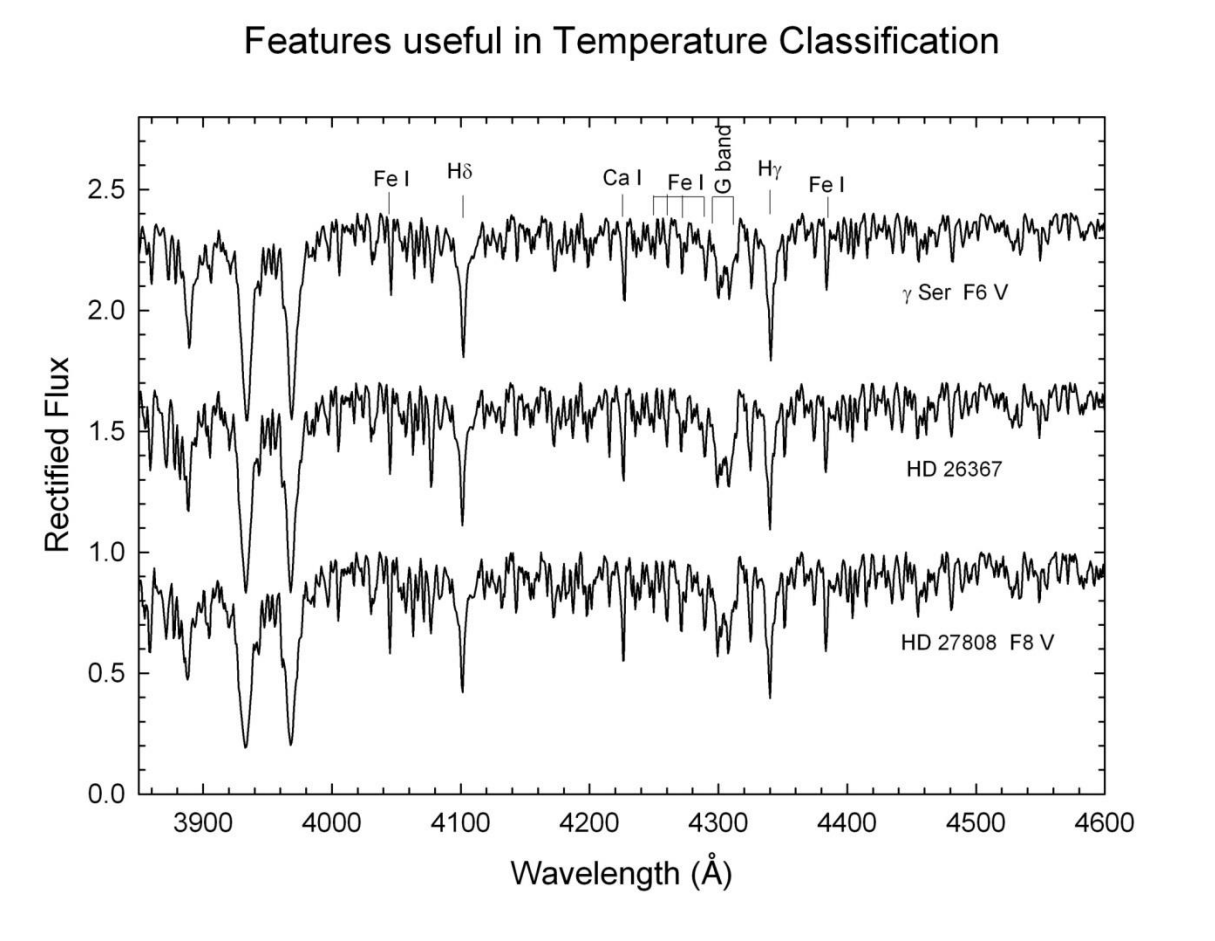
The second goal – identification of peculiarities and astrophysically interesting stars is also important for spectral analysis:

Spectral classification can identify stars worthy of further analysis

Knowledge that a star is peculiar in some way is of vital importance in spectral analysis, as, for some peculiar stars (for instance Ap and Am stars), the atmospheric structure can deviate strongly from standard model atmospheres.

How are Spectra classified?

On the MK System, spectra are classified by direct comparison with the MK Standards



The MKCLASS Code

The MKCLASS code is an *expert* system designed to classify spectra in the same way humans do:
via direct comparison with the MK Standards

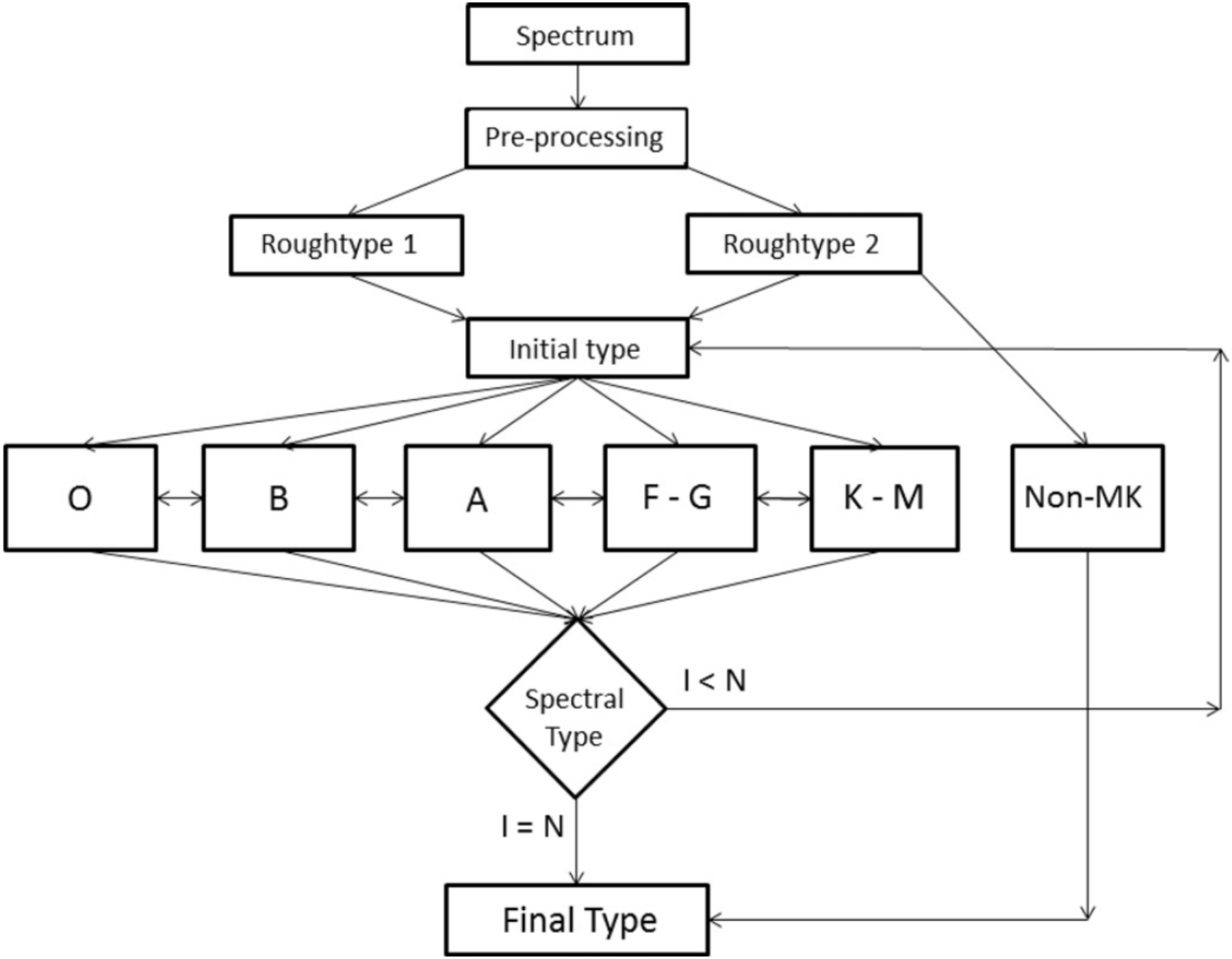
MKCLASS is also designed to detect and classify many of the common spectral peculiarities, fulfilling the second goal of spectral classification.

Open source, freely available to astronomers:

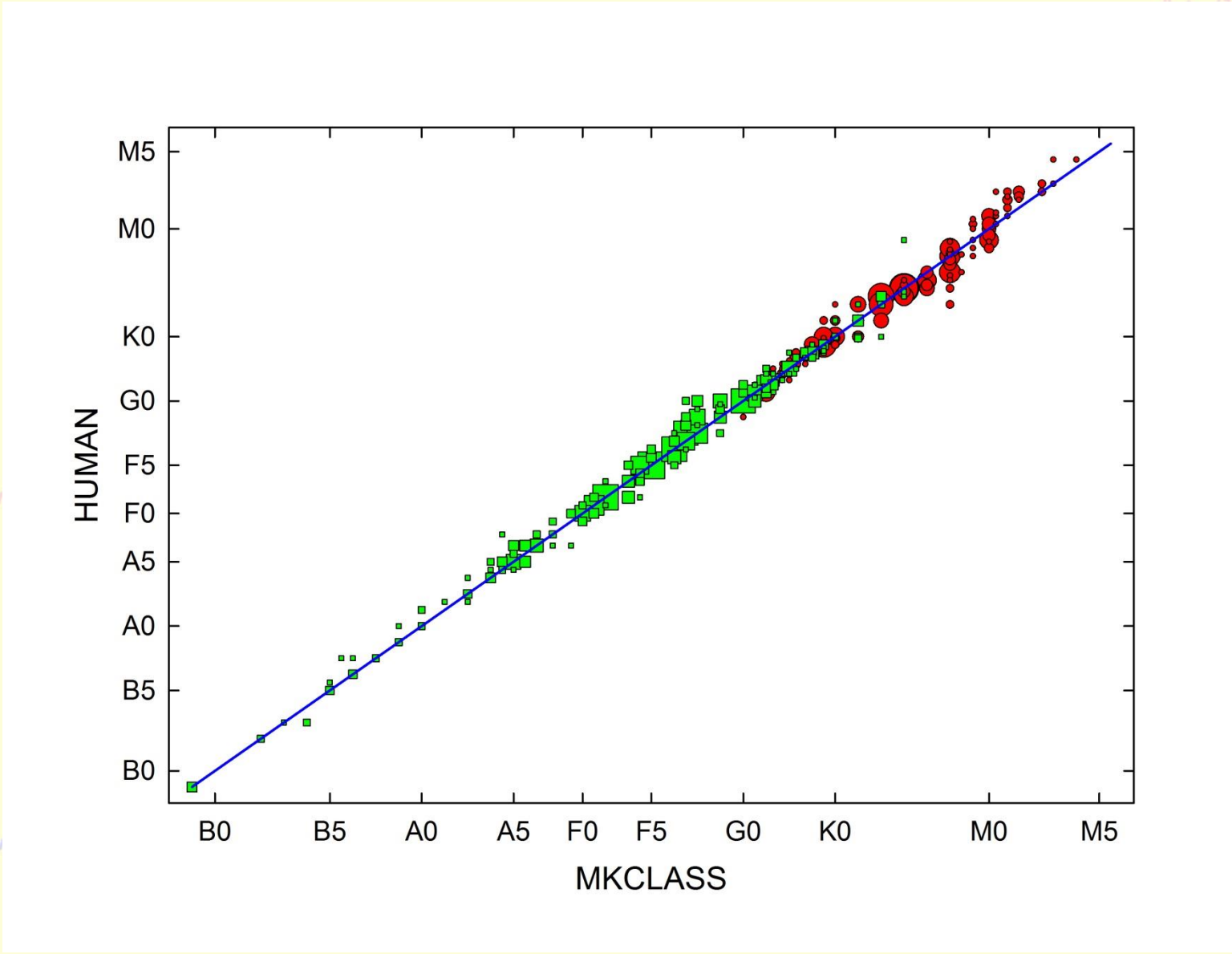
http://www.appstate.edu/~grayro/mkclass/

The Programming of MKCLASS

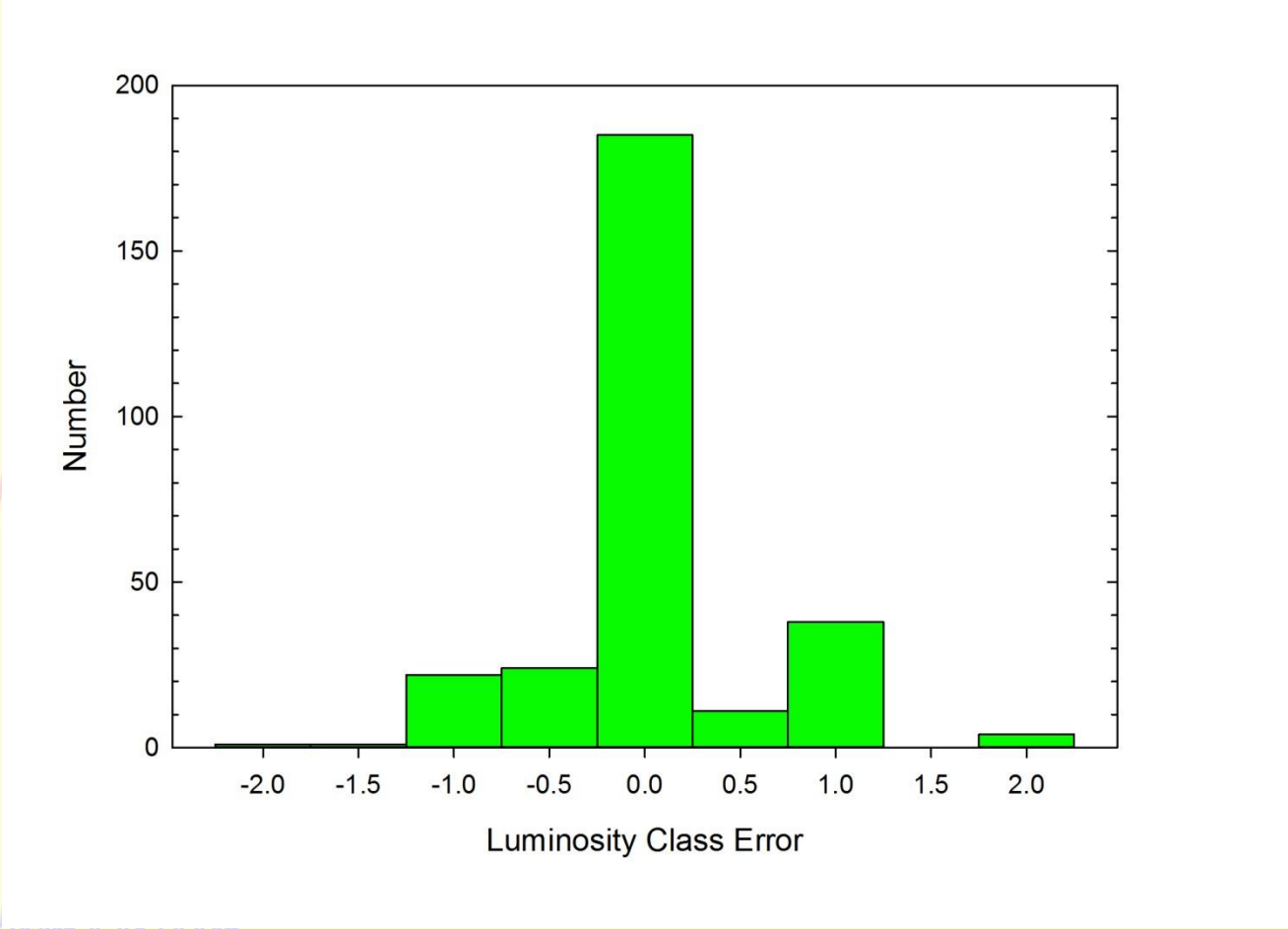
- Motivated by the need to classify > 160,000 LAMOST spectra!
- Conforms to the basic characteristics of an Expert system
- Requires the use of a specially constructed MK standards spectral library – distribution comes with two such libraries.
- A preprocessor manipulates the LAMOST spectra to conform to one of the spectral libraries.


Spectrum
Pre-processing
Roughtype 1
Roughtype 2
Initial type
O
B
A
F - G
K - M
Non-MK
Spectral Type
I < N
I = N
Final Type

Comparisons between MKCLASS and Human classifiers

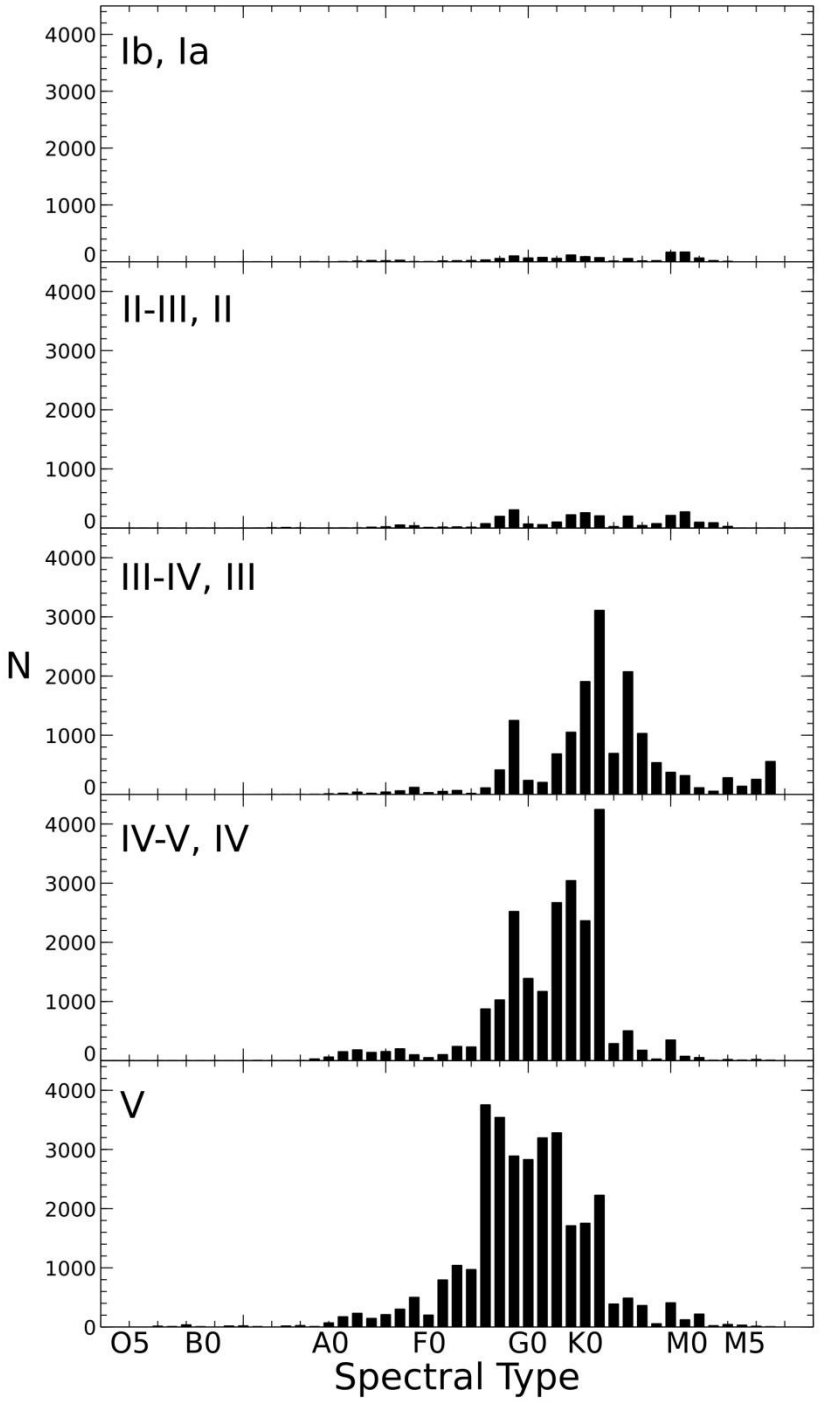


Luminosity Classification Comparison



```
kplr005609930.nor  | F6 V                |  vgood  | \\
kplr005609986.nor  | F8 V                |  vgood  | \\
kplr005610881.nor  | G9 IV-V             |  vgood  | \\
kplr005611160.nor  | F1 III-IV           |  vgood  | \\
kplr005611325.nor  | G0 V                |  vgood  | \\
kplr005612160.nor  | F8 V                |  vgood  | \\
kplr005612549.nor  | G7 III-IV    CH1    |  vgood  | \\
kplr005612877.nor  | F6 V                |  vgood  | \\
kplr005613047.nor  | G3 V                |  vgood  | \\
kplr005613241.nor  | K2 III              |  vgood  | \\
kplr005613330.nor  | F6 IV-V             |  vgood  | \\
kplr005613387.nor  | K2 III              |  vgood  | \\
kplr005613643.nor  | G4 IV               |  vgood  | \\
kplr005613992.nor  | A7 mA0 V metal-weak|         | \\
kplr005614096.nor  | F8 V                |  vgood  | \\
kplr005614247.nor  | F5 V       Fe-0.56 |  vgood  | \\
kplr005614959.nor  | F9 IV-V             |  vgood  | \\
kplr005615202.nor  | F6 V                |  vgood  | \\
kplr005615479.nor  | G1 V                |  vgood  | \\
kplr005615987.nor  | F1 III              |  vgood  | \\
kplr005616033.nor  | kA2hA3mA7  Sr       |         | \\
kplr005616145.nor  | F7 V                |  vgood  | \\
kplr005616432.nor  | G1 V                |  vgood  | \\
kplr005616489.nor  | G8 III-IV           |  vgood  | \\
kplr005616896.nor  | M4 III              |  good   | \\
kplr005617110.nor  | kA0hA2mA6  Sr       |         | \\
kplr005617342.nor  | kA2hA3mA4  Sr       |         | \\
kplr005617601.nor  | M3 III              |  good   | \\
kplr005617730.nor  | F8 V                |  vgood  | \\
kplr005618126.nor  | A5 IV               |  vgood  | \\
kplr005620295.nor  | F8 V                |  vgood  | \\
kplr005695281.nor  | G7 IV-V             |  vgood  | \\
kplr005695396.nor  | G3 V                |  vgood  | \\
-:**-  lamost.out     39% L959   (Fundamental)
```

Sample output of MKCLASS



Classification of LAMOST-Kepler Spectra

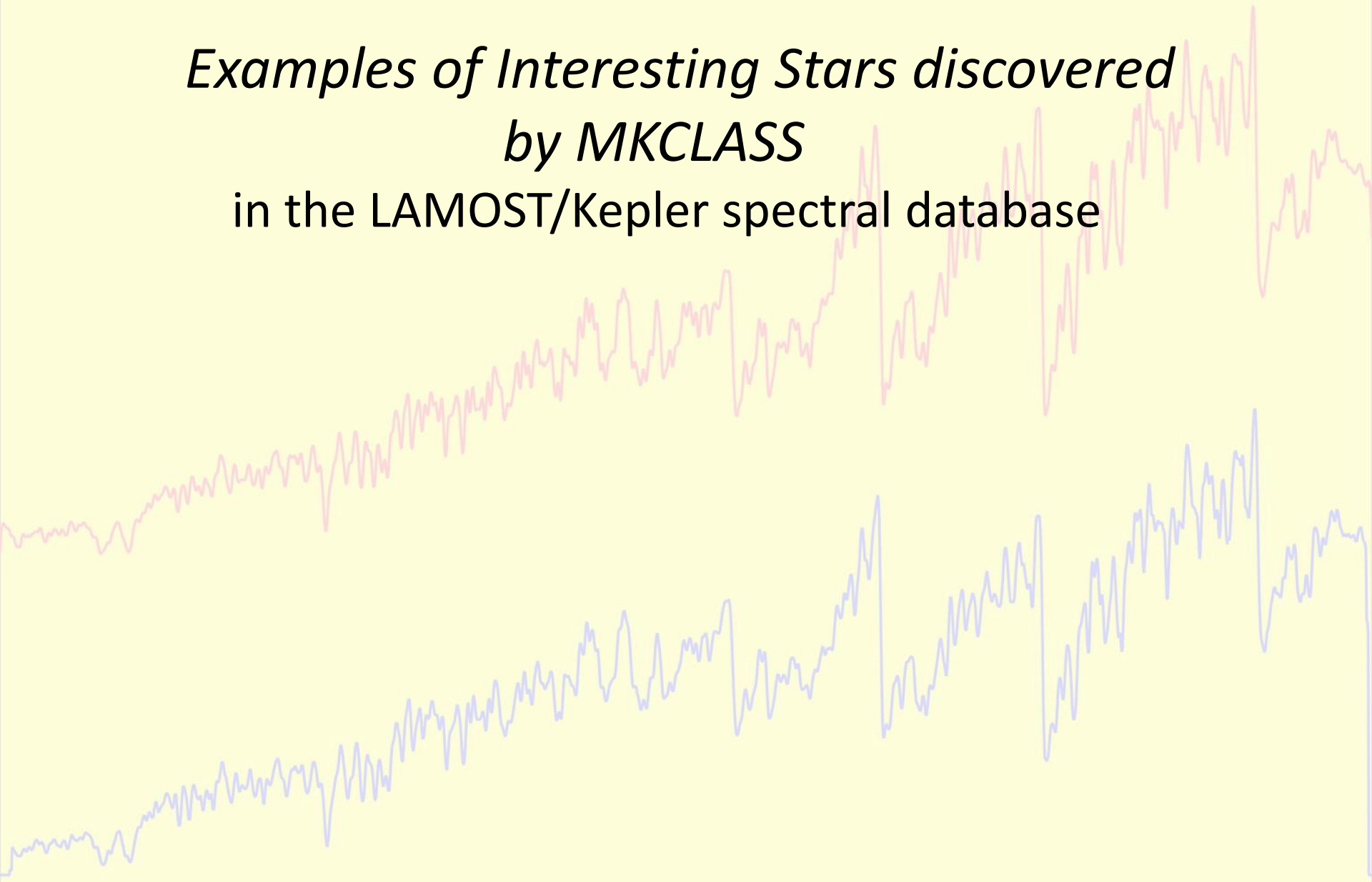
2011-2014: 81,171 classifiable spectra.

Gray et al. 2016 AJ 151, 13

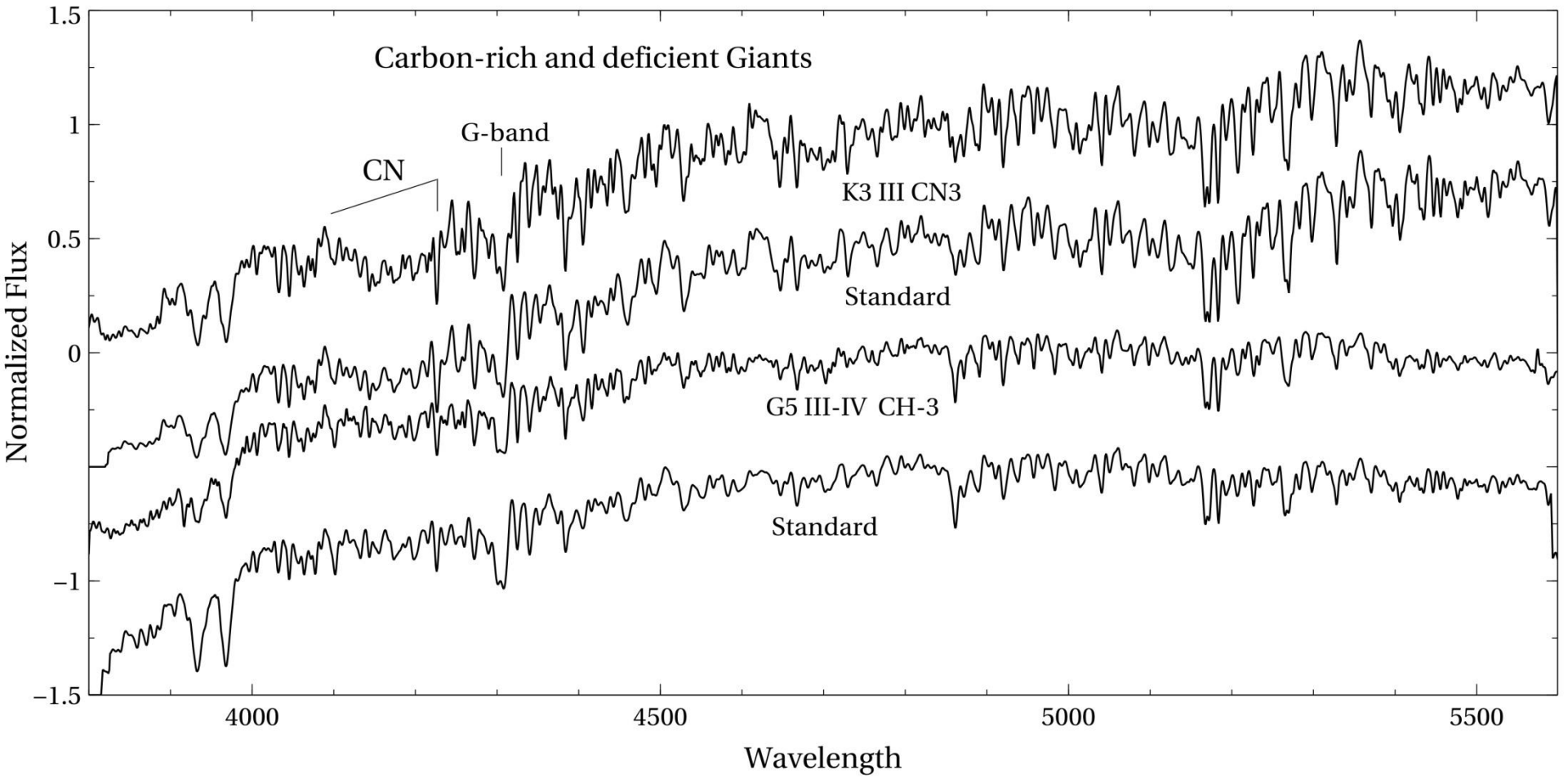
2015: 88,854 classifiable spectra

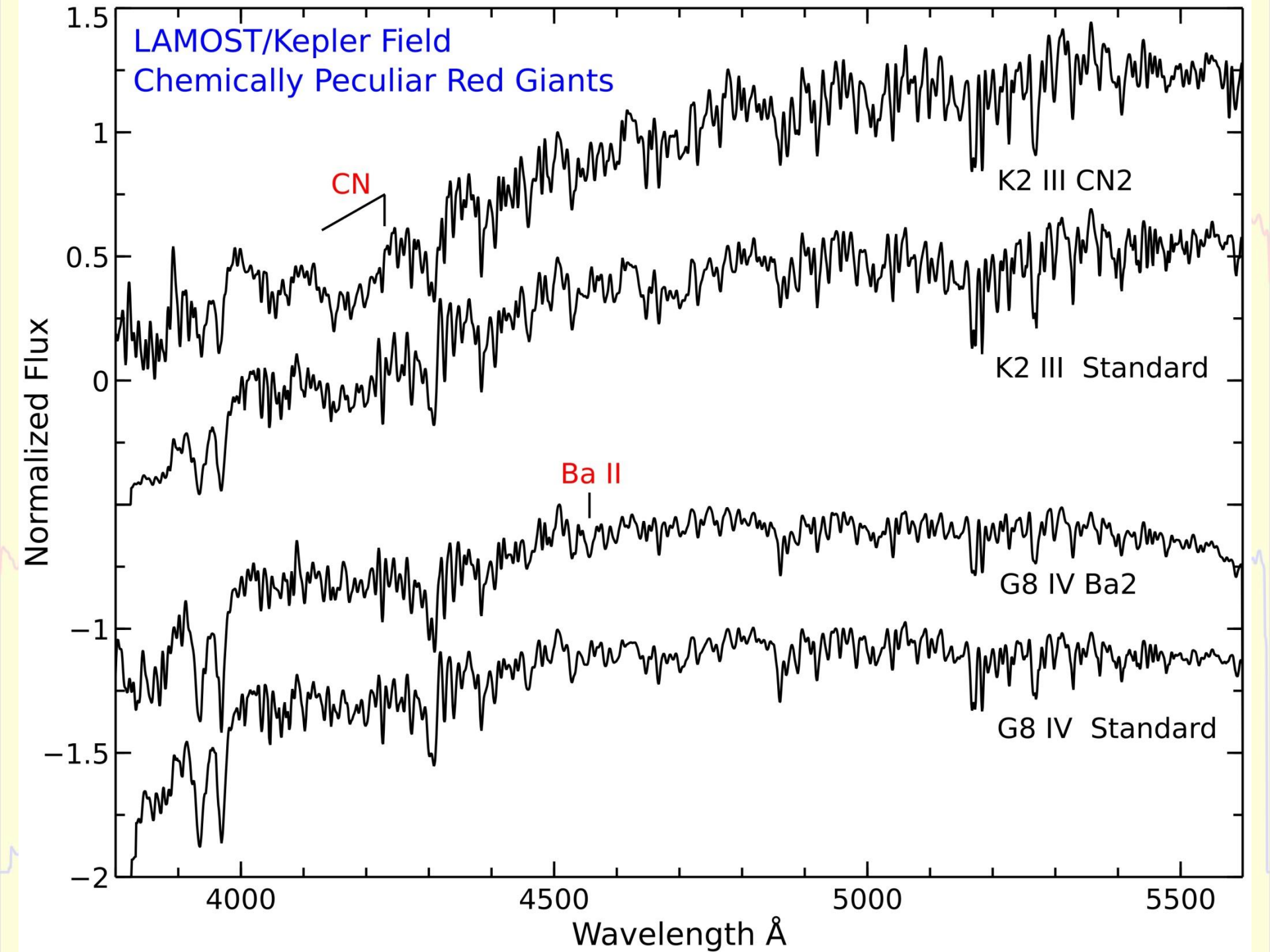
Examples of Interesting Stars discovered by MKCLASS

in the LAMOST/Kepler spectral database

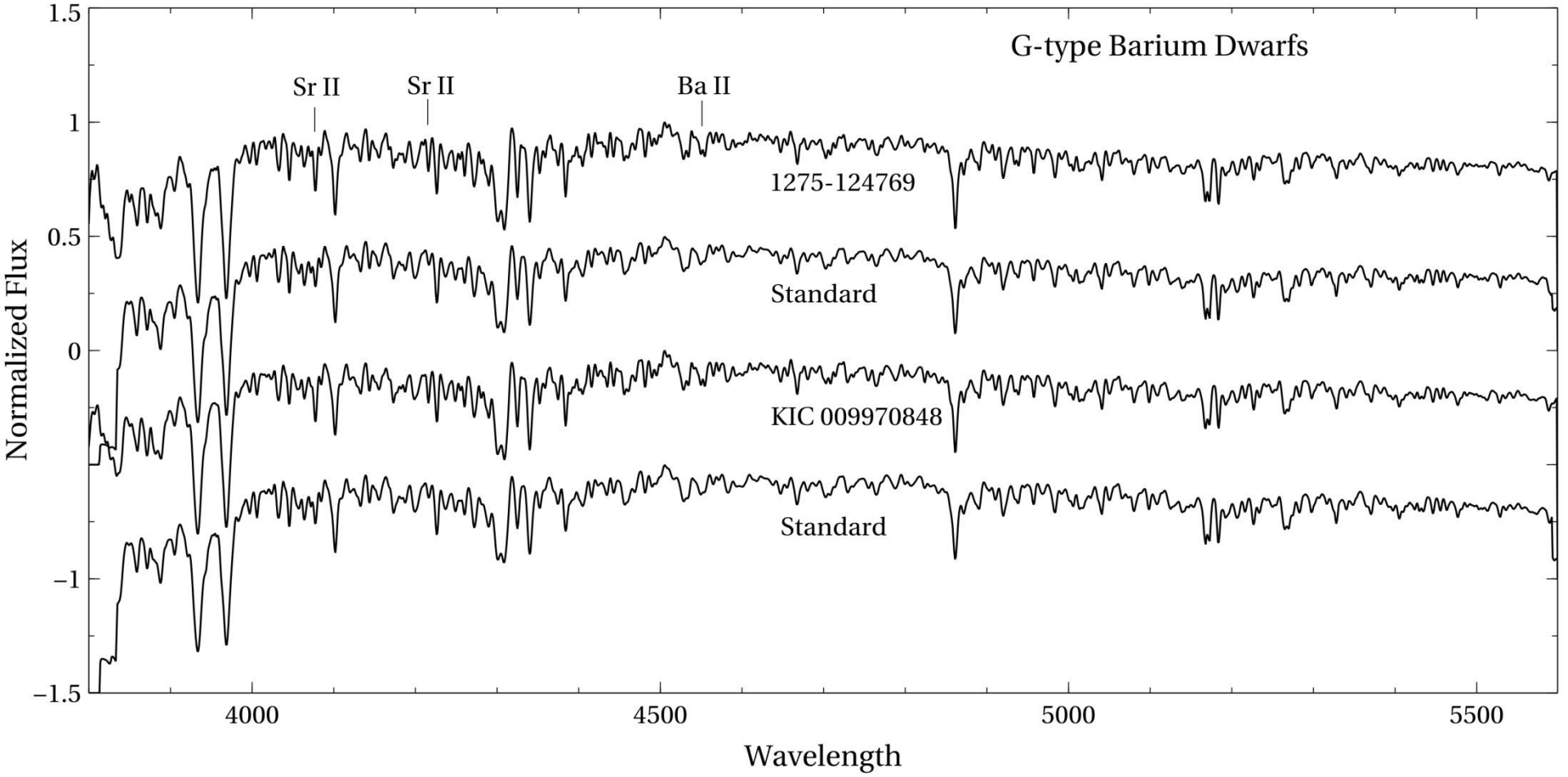


Carbon-peculiar Giants

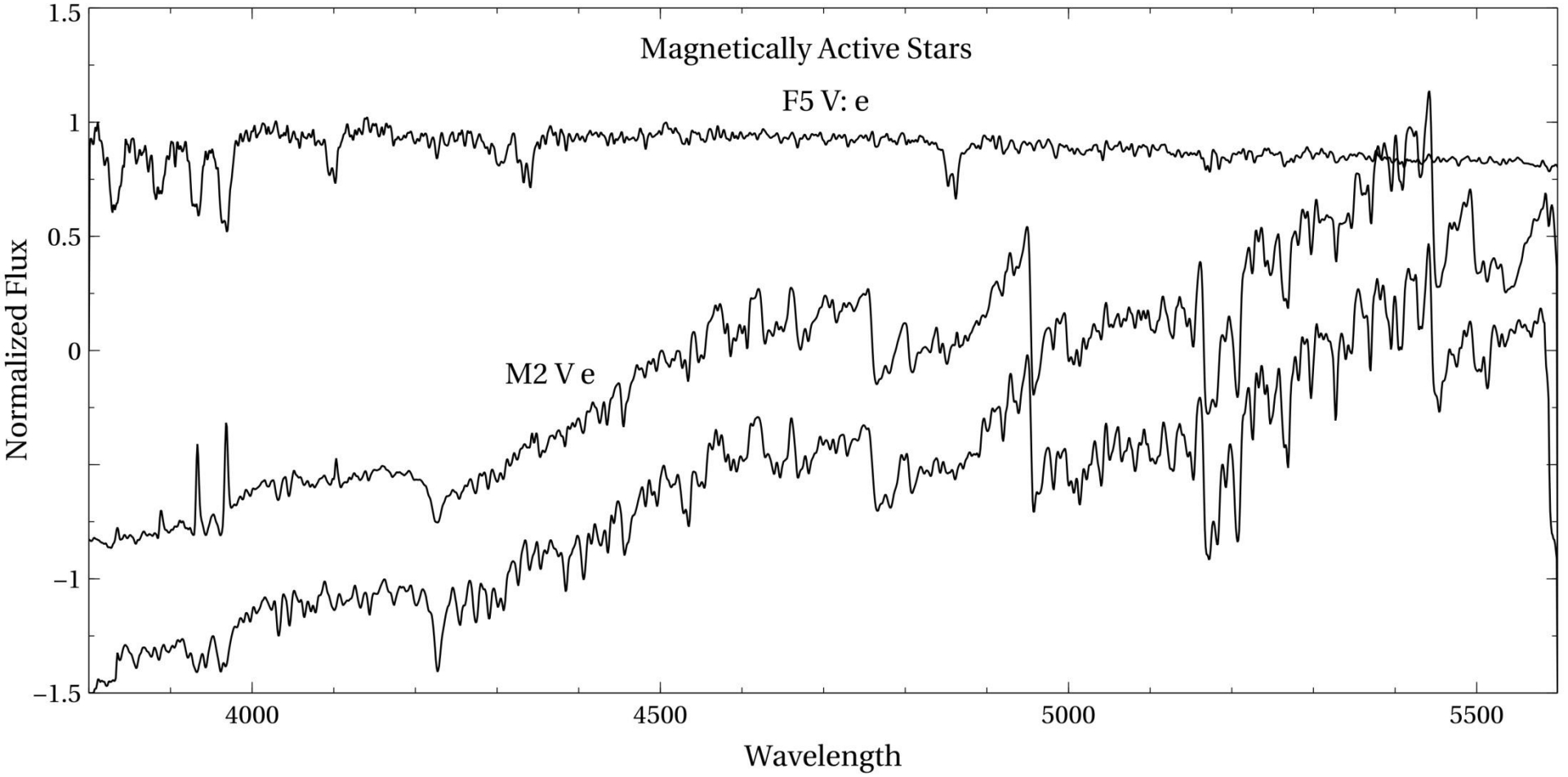


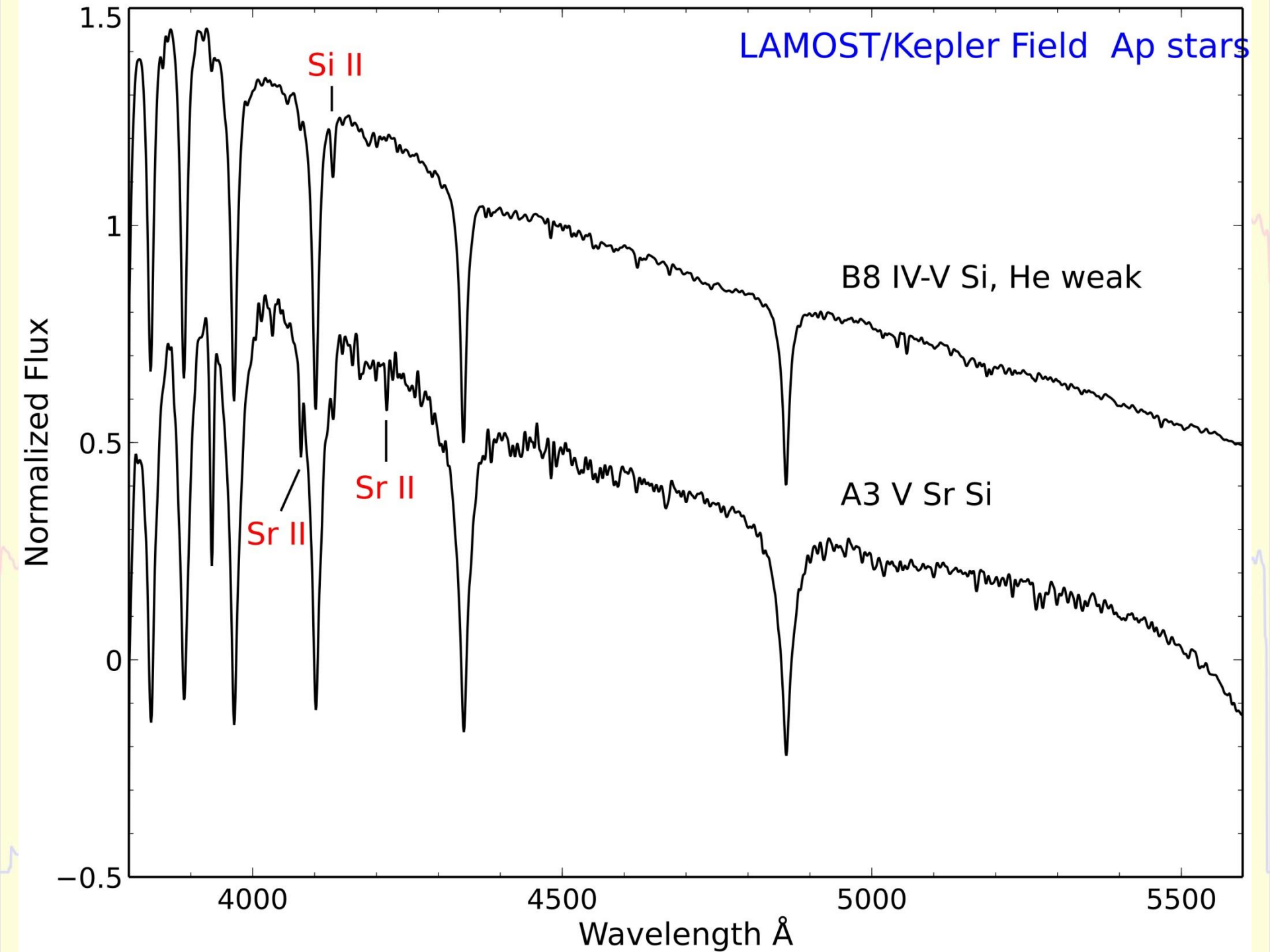

LAMOST/Kepler Field
Chemically Peculiar Red Giants
CN
Ba II
K2 III CN2
K2 III Standard
G8 IV Ba2
G8 IV Standard
Normalized Flux
Wavelength Å
1.5
1
0.5
0
−1
−1.5
−2
4000
4500
5000
5500

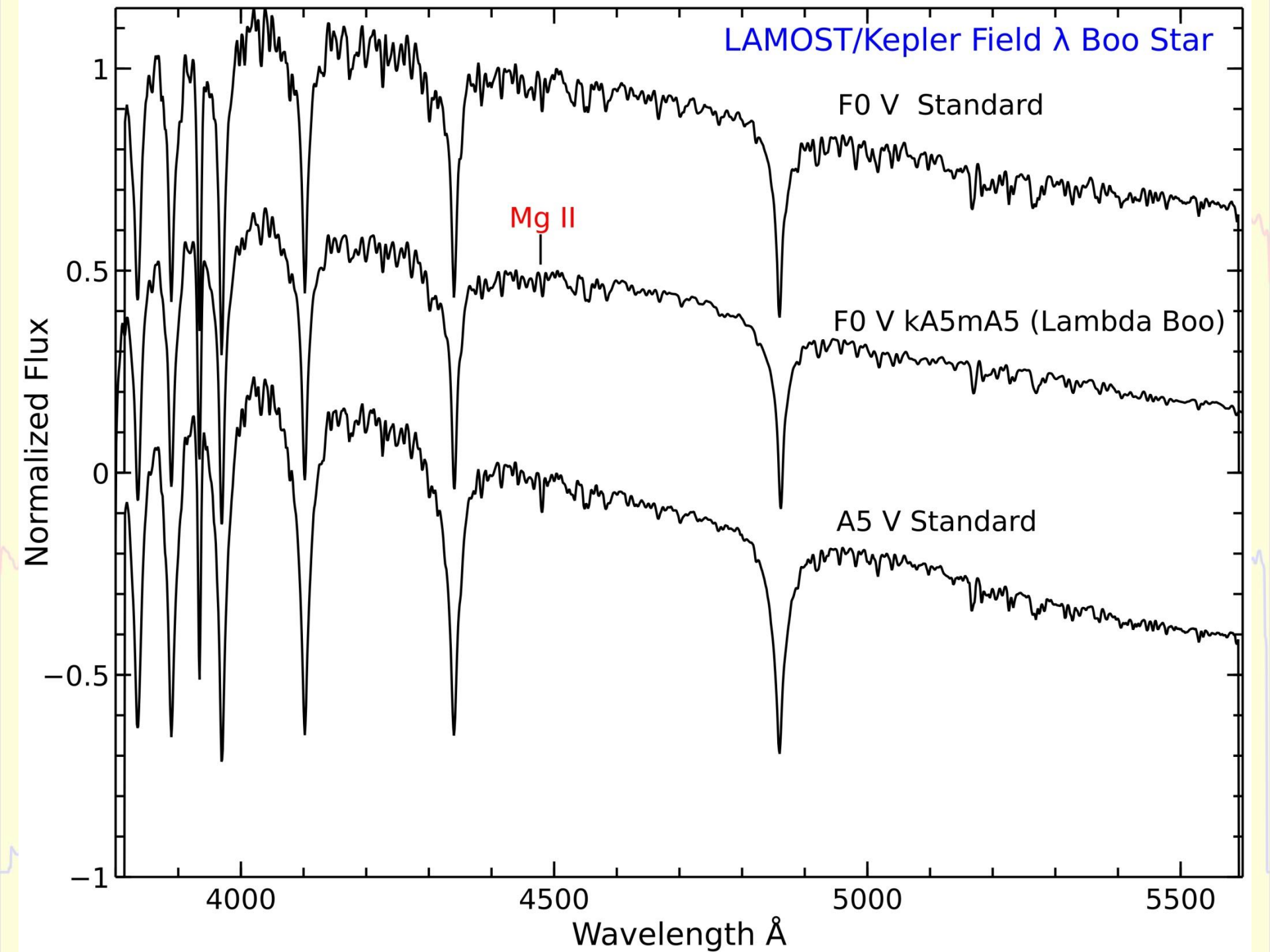
s-process enhanced G-type dwarfs (Barium Dwarfs)



Magnetically Active Stars




LAMOST/Kepler Field Ap stars
Si II
Sr II
Sr II
B8 IV-V Si, He weak
A3 V Sr Si
Normalized Flux
Wavelength Å
1.5
1
0.5
0
−0.5
4000
4500
5000
5500


LAMOST/Kepler Field λ Boo Star
F0 V Standard
Mg II
F0 V kA5mA5 (Lambda Boo)
A5 V Standard
Normalized Flux
1
0.5
0
−0.5
−1
4000
4500
5000
5500
Wavelength Å

- λ Boo stars (late-B to early-F) are a 74 year puzzle over their peculiar abundances: volatiles=solar; refractory=deficient.
- 200 LAMOST-Kepler λ Boo candidates found with MKCLASS.
- VATT spectra of 34 of these candidates show 15 to be λ Boo stars.
- 8 out of 11 with Kepler data pulsate. 4 of these are hybrid δ Sct/γ Dor,
  → important for testing λ Boo hypotheses.

KIC number	Spectral type (CC, SJM)	Kepler photometry analysis (SJM)
KIC04840675	F0 Vn kA6mA6 lam Boo	δSct, & 2 faint solar-type companions
KIC06280902	F1 Vn kF0mA8 (lam Boo)	low-amp δSct (0.1 mmag peaks)
KIC06463047	A6 V kA1mA1 (lam Boo)	δSct-γDor hybrid.
KIC08246833	F0 V kA6mA6 lam Boo	δSct
KIC08560996	A9 V kA3mA4 lam Boo	PM binary with ~1700-d period.
KIC09289960	F0 V kA6mA6 lam Boo	δSct, high amps., > 10 mmag.
KIC09656348	A9 V kA3mA4 lam Boo	δSct-γDor hybrid.
KIC09828226	A1 V kB9.5mB8 lam Boo	δSct-γDor hybrid, well outside instability strip.
KIC10226388	F1 V kA6mA6 (lam Boo)	1.5-d ellipsoidal variable. PM triple system.
KIC10394576	A7 V kA3mA5 lam Boo	non-pulsating. No g modes or p modes.
KIC11973705	F0 V kA2mA2 lam Boo	δSct-γDor hybrid.

Continuing work on λ Boo stars

- Follow up high resolution spectroscopy under way (using APO, Rozhen Obs., …) to provide input parameters for asteroseismology.

- All-sky survey for λ Boo stars continues in view of TESS mission.
  This includes new southern λ Boo stars and high res spectroscopy (SALT, …)

Conclusions

- MKCLASS is a competent spectral classifier with near-human accuracies.
- MKCLASS can classify stars approximately 100X faster than humans.
- MKCLASS is capable of detecting astrophysically interesting stars in large datasets.
- MKCLASS has identified λ Boo stars in the Kepler field with critical dual-mode pulsation.