New Initiatives on RR Lyrae Chemical Compositions

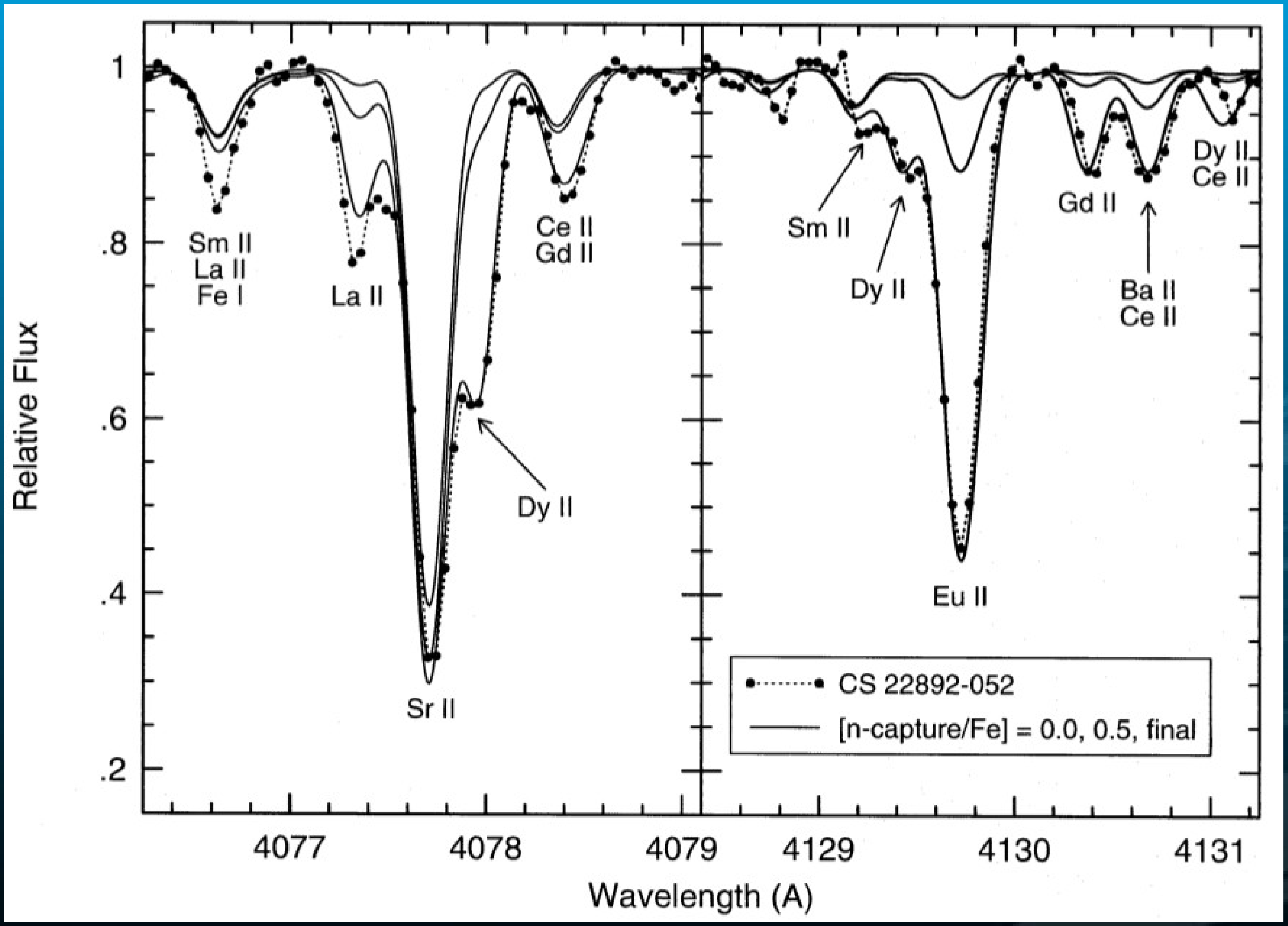
Chris Sneden & BiQing For* (U Texas)

Juna Kollmeier, George Preston, Steve Shectman, Ian Thompson, Jeff Crane (Carnegie Obs)

Andy Gould (Ohio State U)

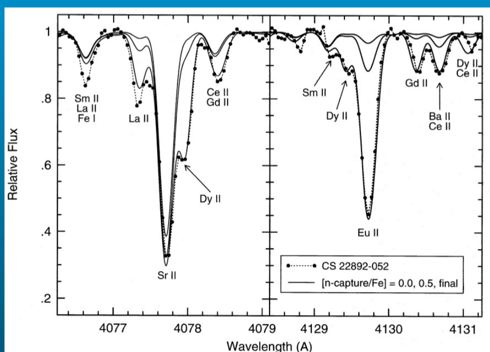
* Now John Stocker Postdoctoral Fellow, U Western Australia

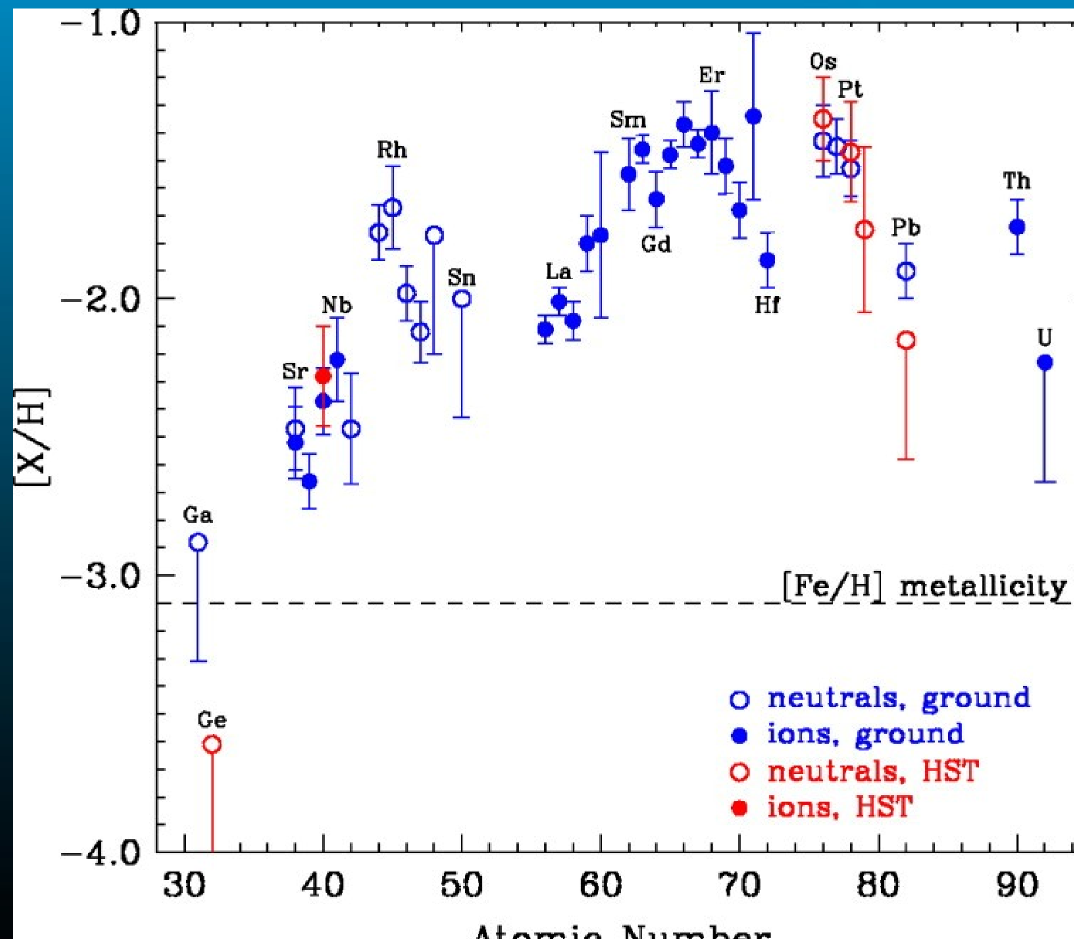
Once upon a time I had a simple research identity



Sneden et al. 1996

Turning metal-poor, exotic heavy-element-rich spectra into neutron-capture abundance distributions





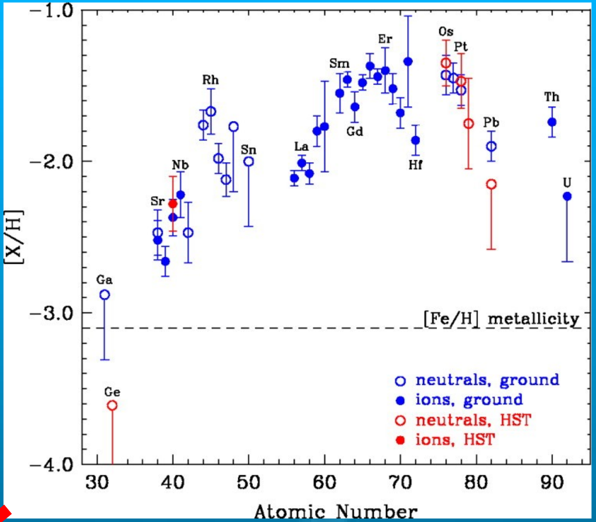
log ε = log(NFe/NH) + 12

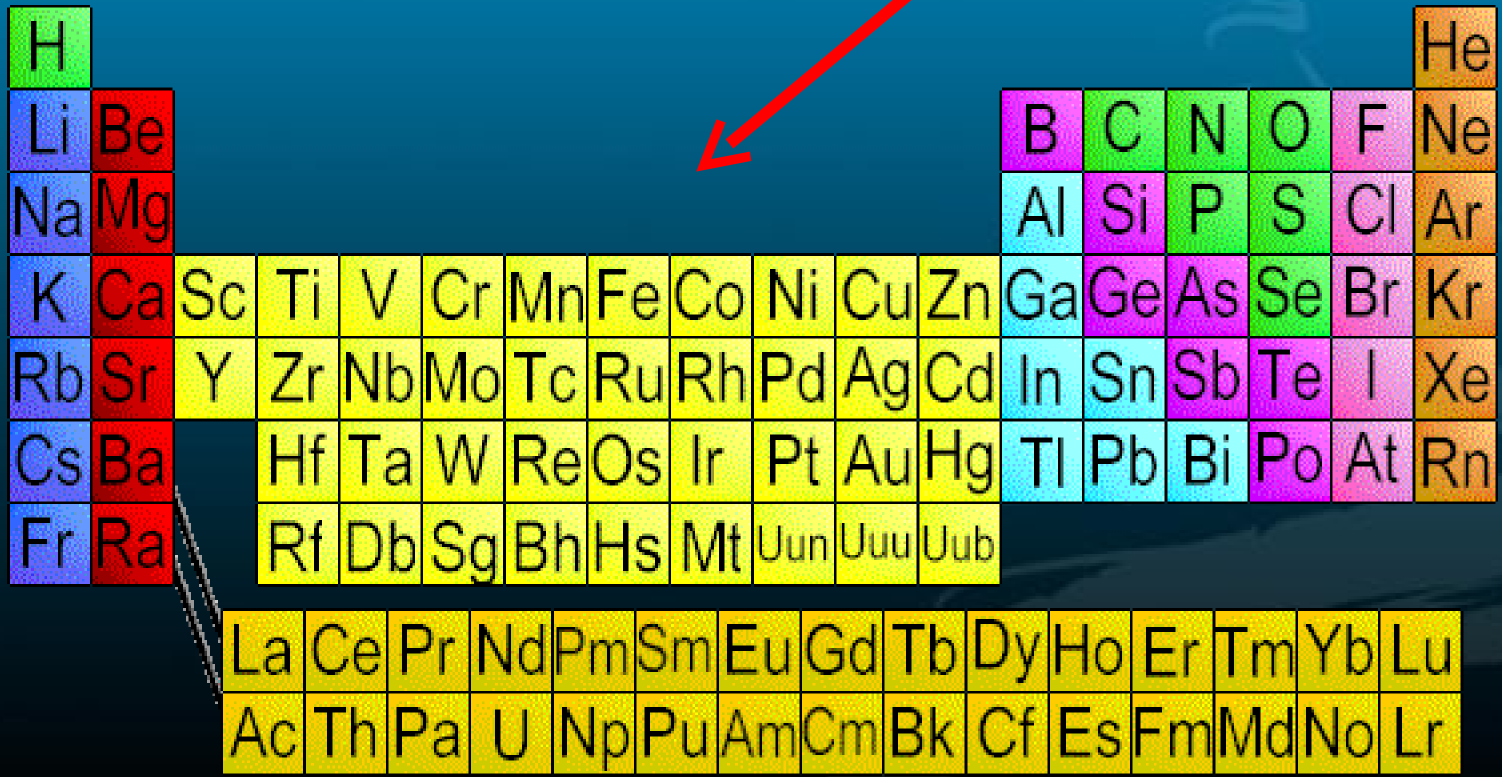
[X/Y] = log(NX/NY)star –

log(NX/NY)Sun

Sneden et al. 1996

Goal: to understand creation of elements (especially the heaviest ones) in the early Galaxy

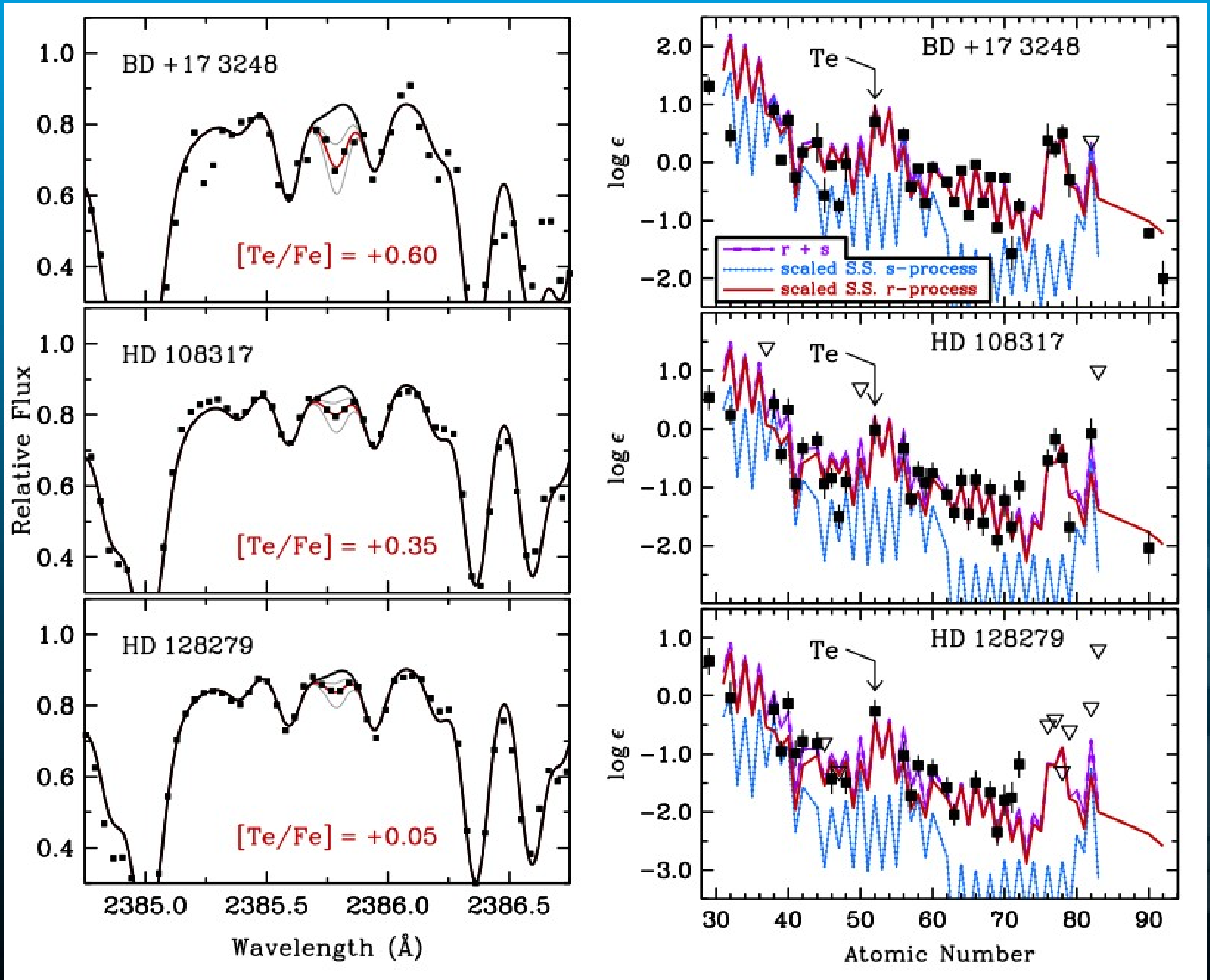




http://www.chemicalelements.com/

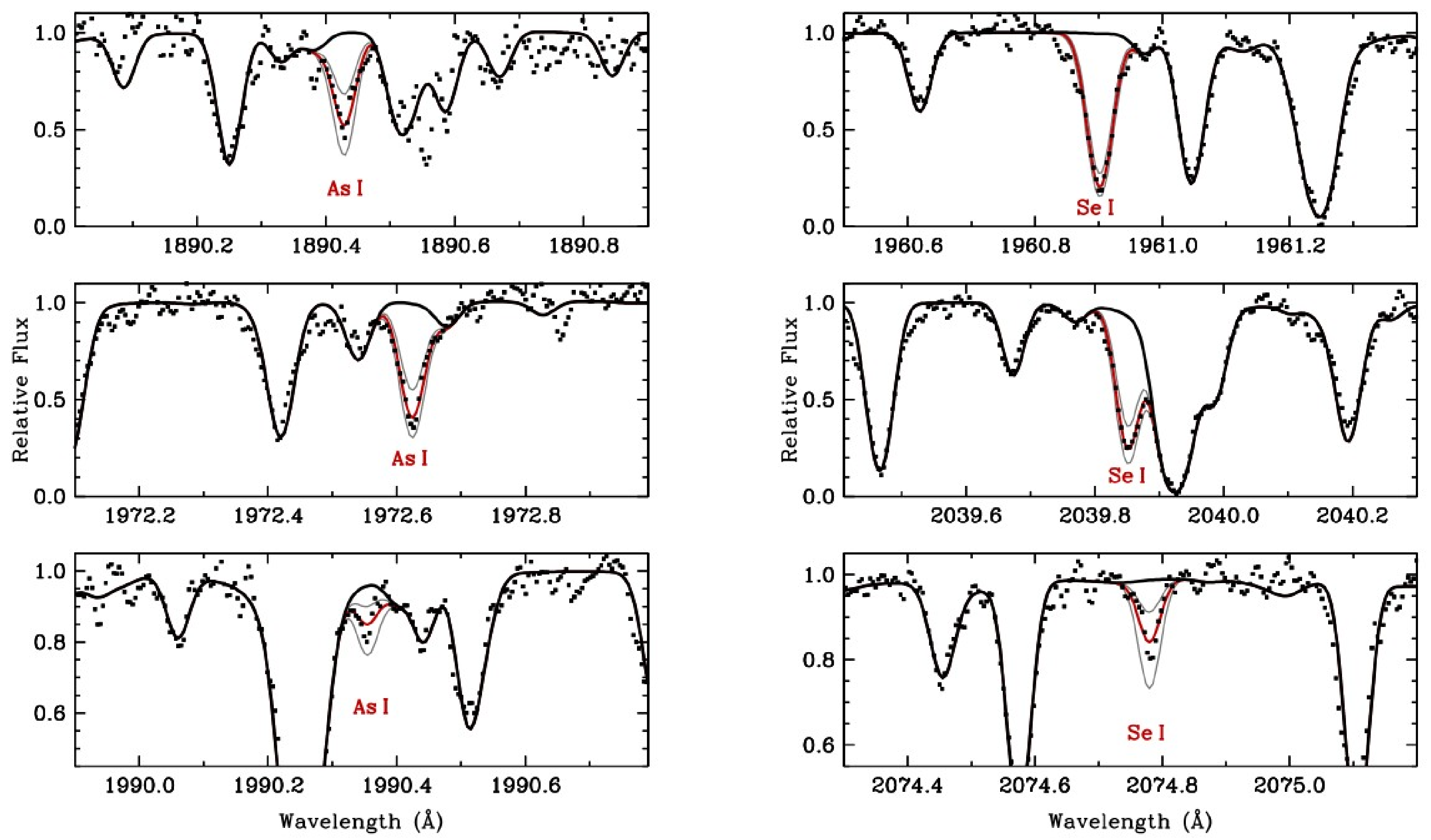
This work continues, now being led by others

Tellurium:
Z = 52



Roederer et al 2012

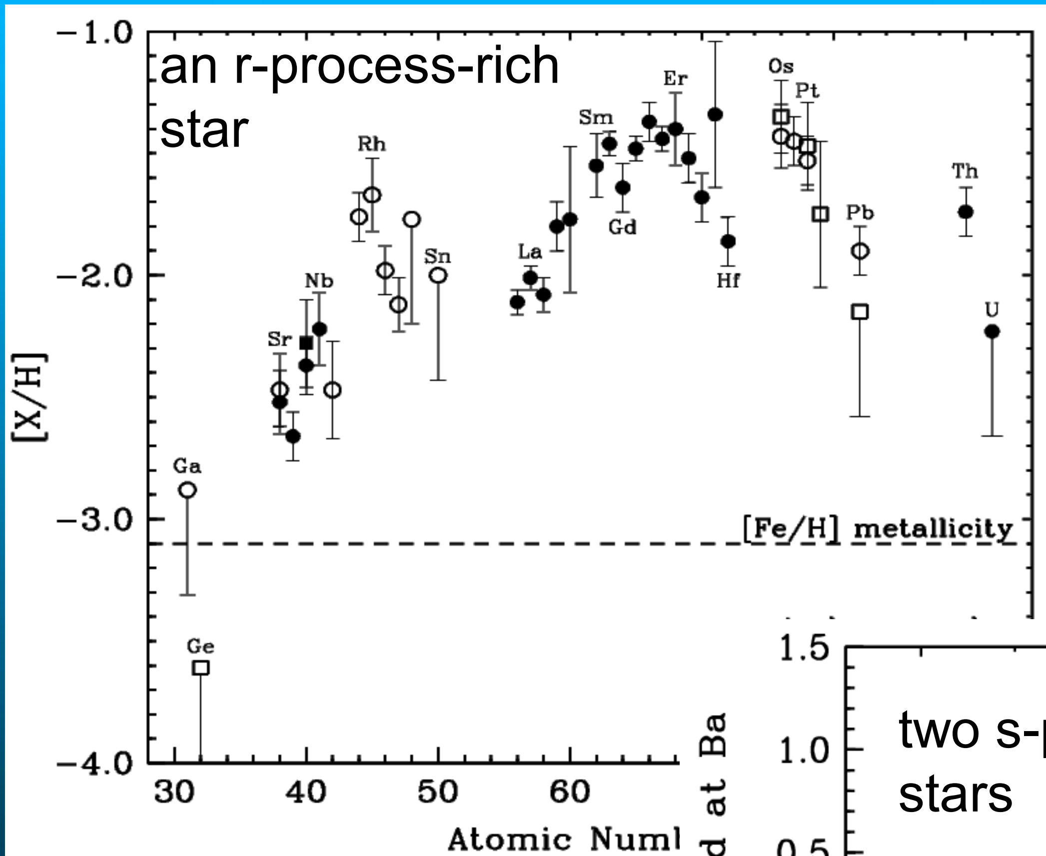
The UV (Hubble STIS) is increasingly important here

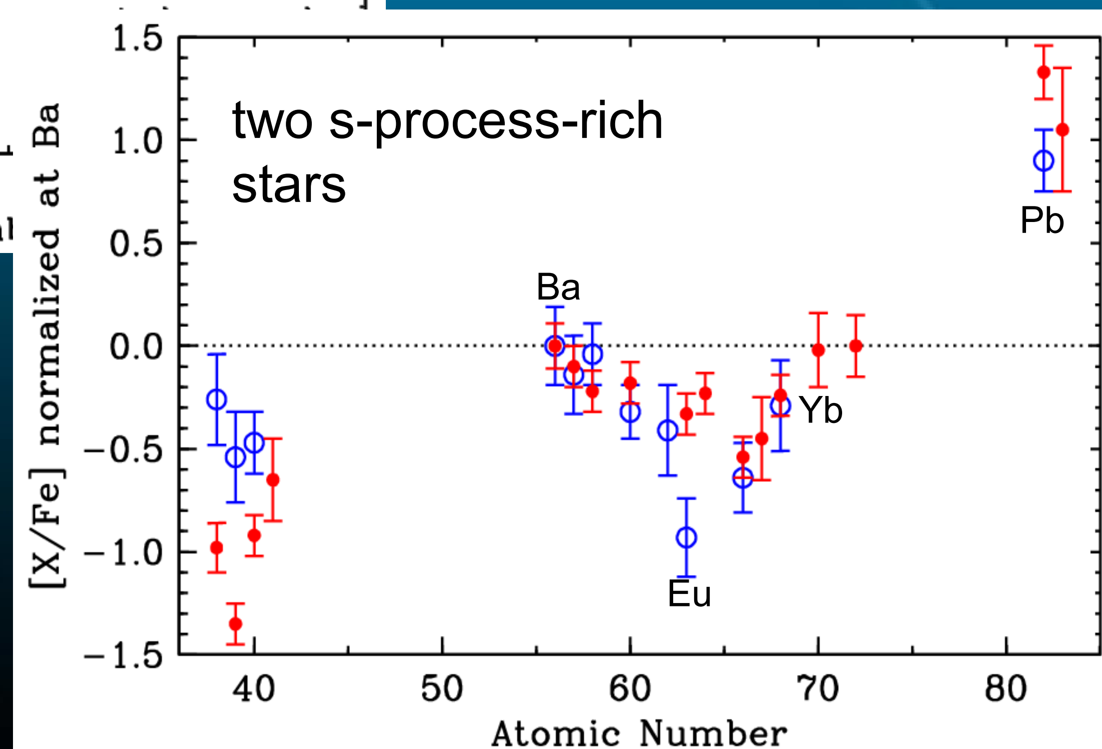


Arsenic (Z=33) & Selenium (Z=34)

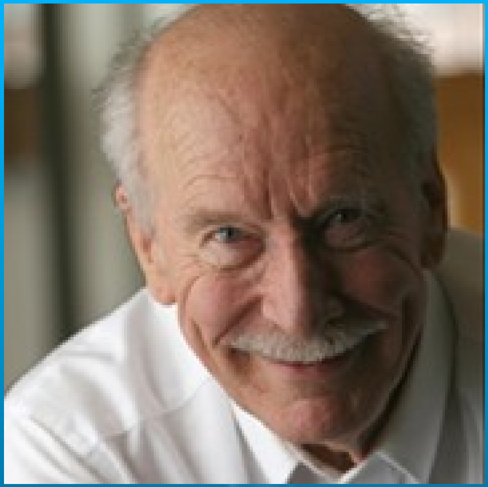
Roederer & Lawler 2012

The complexities in neutron-capture distributions in metal-poor stars continue to fascinate





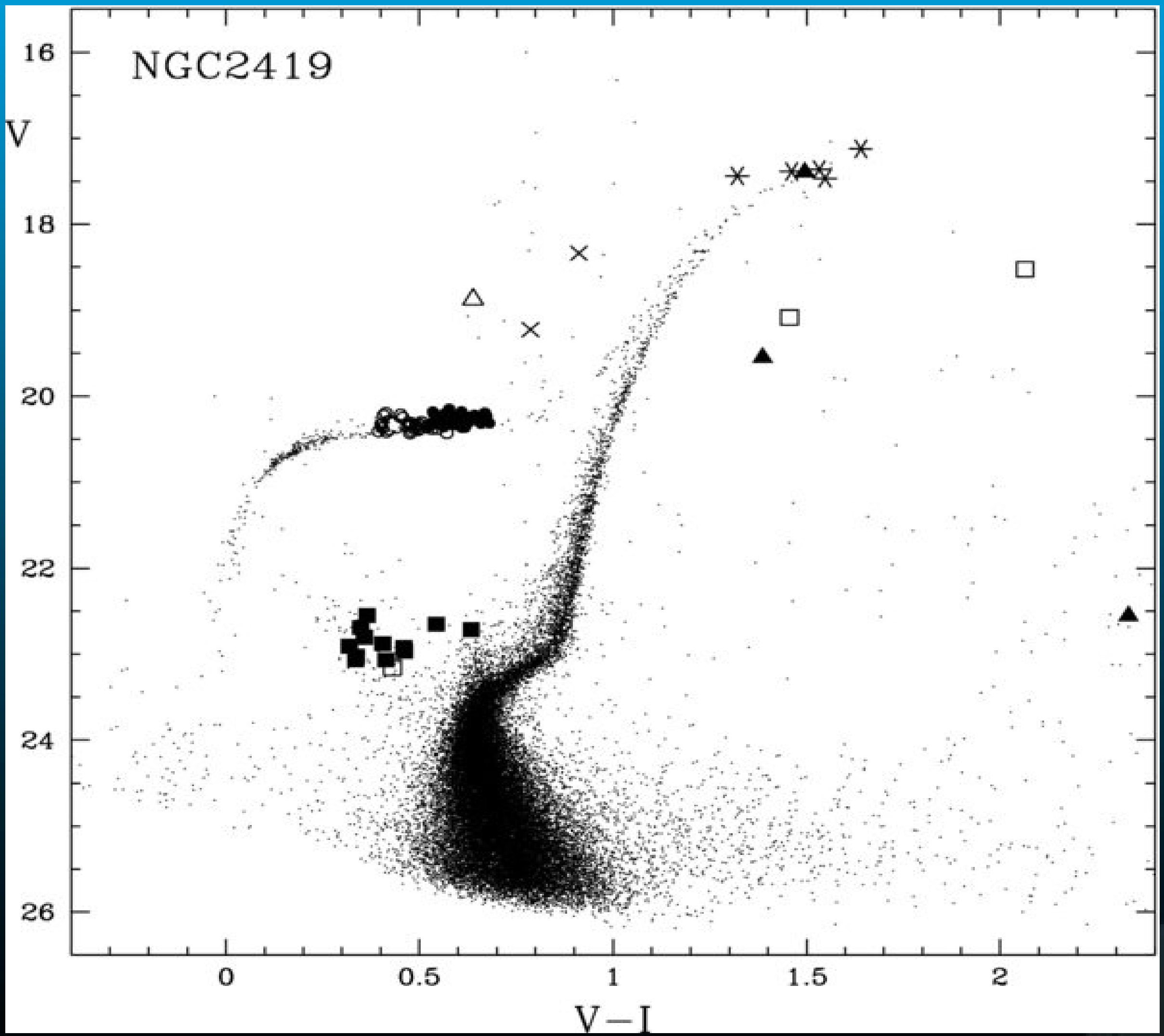
But re-awakening of George Preston to his original research area has pulled me slowly in ….



My adventures in RR Lyrae chemical compositions:

- the accidental discovery: CS 22881-071 = TY Gru
- making sense (?) of TY Gru: a big study of RRab's
- looking at RRc's in different ways:
    - as individuals, around their cycles
    - as a group, for Galactic structure issues

A color-magnitude diagram to remind me …



Rrab are filled circles
RRc are open circles

Di Criscienzo et al. 2011

What started everything in this area: Preston 1959

A SPECTROSCOPIC STUDY OF THE RR LYRAE STARS*

GEORGE W. PRESTON
Lick Observatory, University of California
Received March 12, 1959

ABSTRACT

The possibility that the RR Lyrae stars do not constitute a homogeneous spectroscopic group has been investigated by surveying the spectra of more than one hundred RR Lyrae stars at very low dispersion (430 A/mm at $H\gamma$).

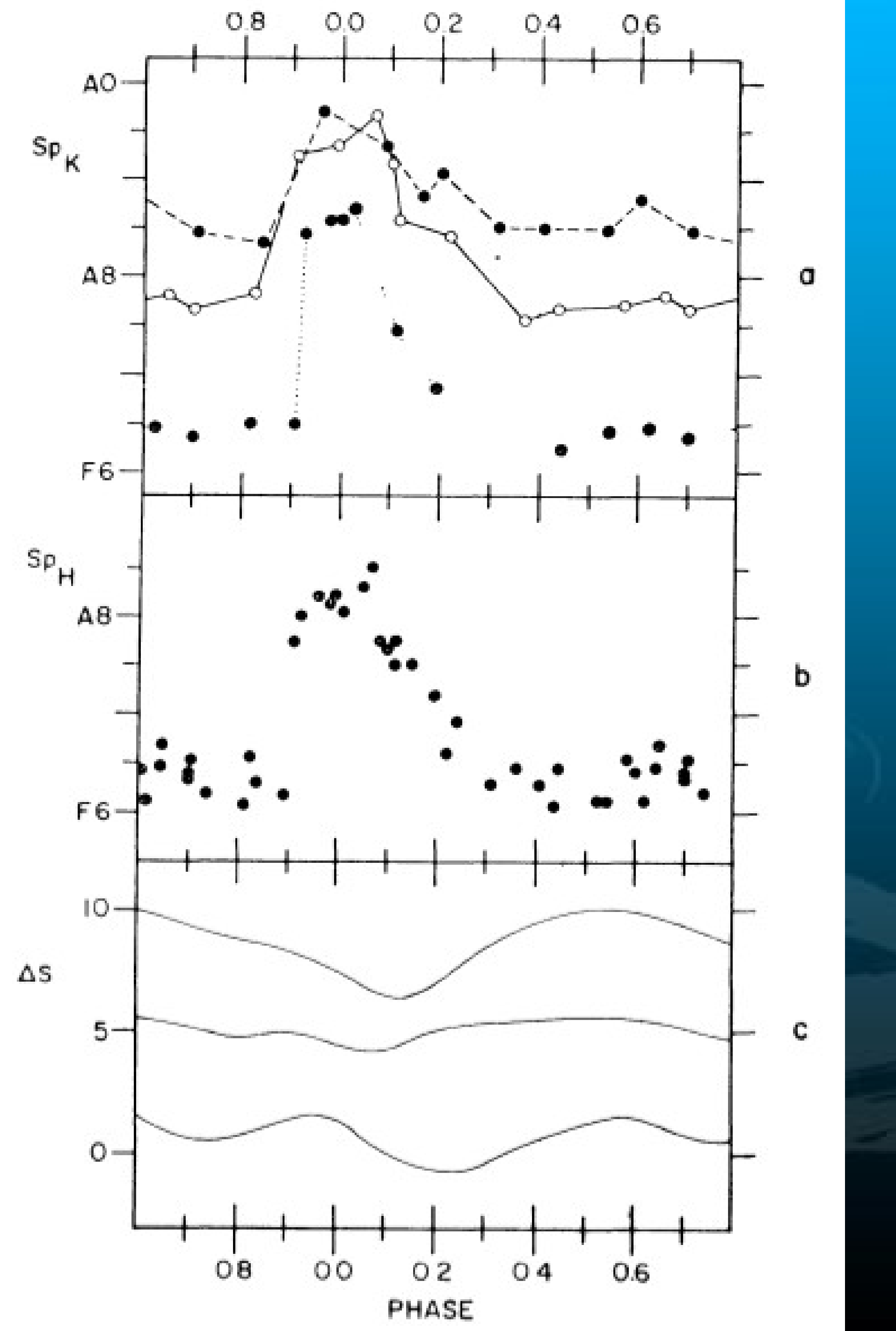
d) A Parameter To Describe the Spectra

The K-line type at minimum light does not by itself provide a satisfactory description of the weak-line characteristic of the RR Lyrae stars. It fails, for example, to provide an adequate comparison between the Bailey type a's and c's, since the latter are systematically earlier in type at minimum light. Even among the type a's there are stars with stronger than average hydrogen lines at minimum, e.g., VX, VZ, and AR Her. To minimize possible temperature effects suggested by these circumstances, we use, instead, the *difference* between the hydrogen- and K-line types reckoned in units of tenths of spectral class. In symbols,

$$\Delta S = 10[\mathrm{Sp(H)} - \mathrm{Sp(Ca\ II)}]$$

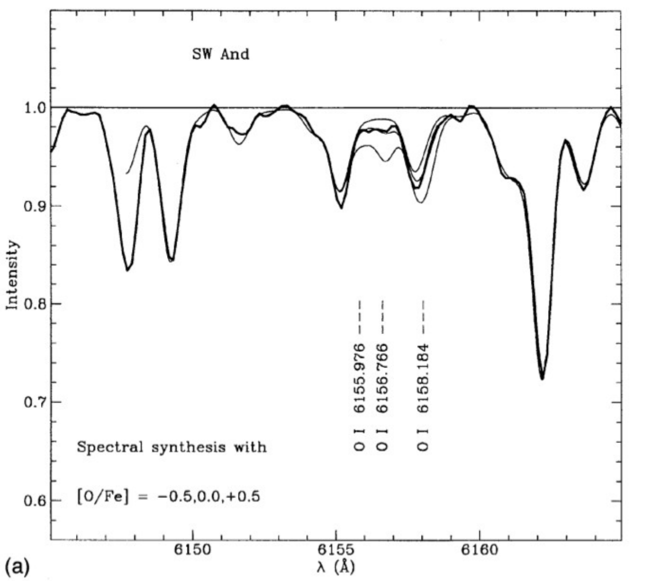
ΔS of course was uncalibrated

$$\Delta S = 10[\mathrm{Sp(H)} - \mathrm{Sp(Ca\ II)}]$$

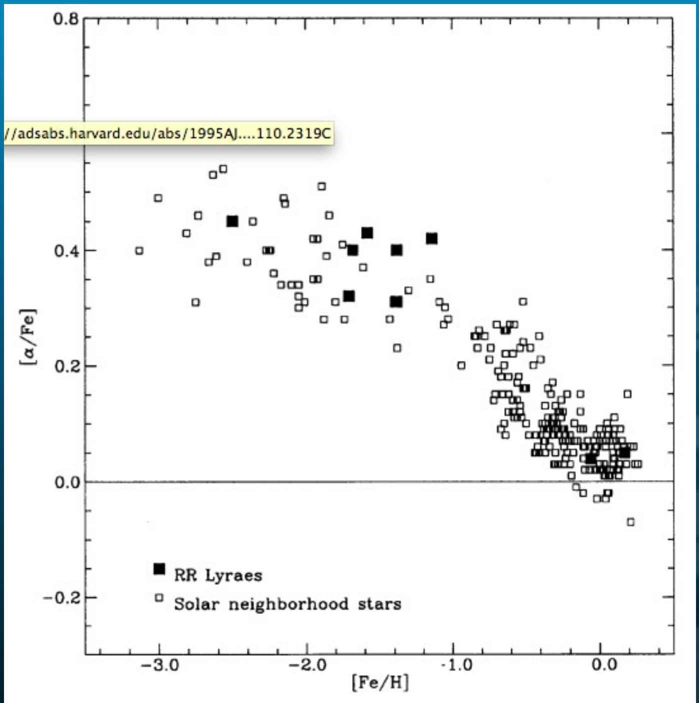


The pioneering "classical" study of RR Lyr metallicities and abundances

Typical spectrum



One main result



You CAN do standard LTE analyses

Phase smearing limits targets

Sensible results from calm phases

Clementini et al. 1995

(see also the good earlier paper by Butler 1975)

My entry was with TY Gru: an accidentally observed star

The Astronomical Journal, 132:85–110, 2006 July

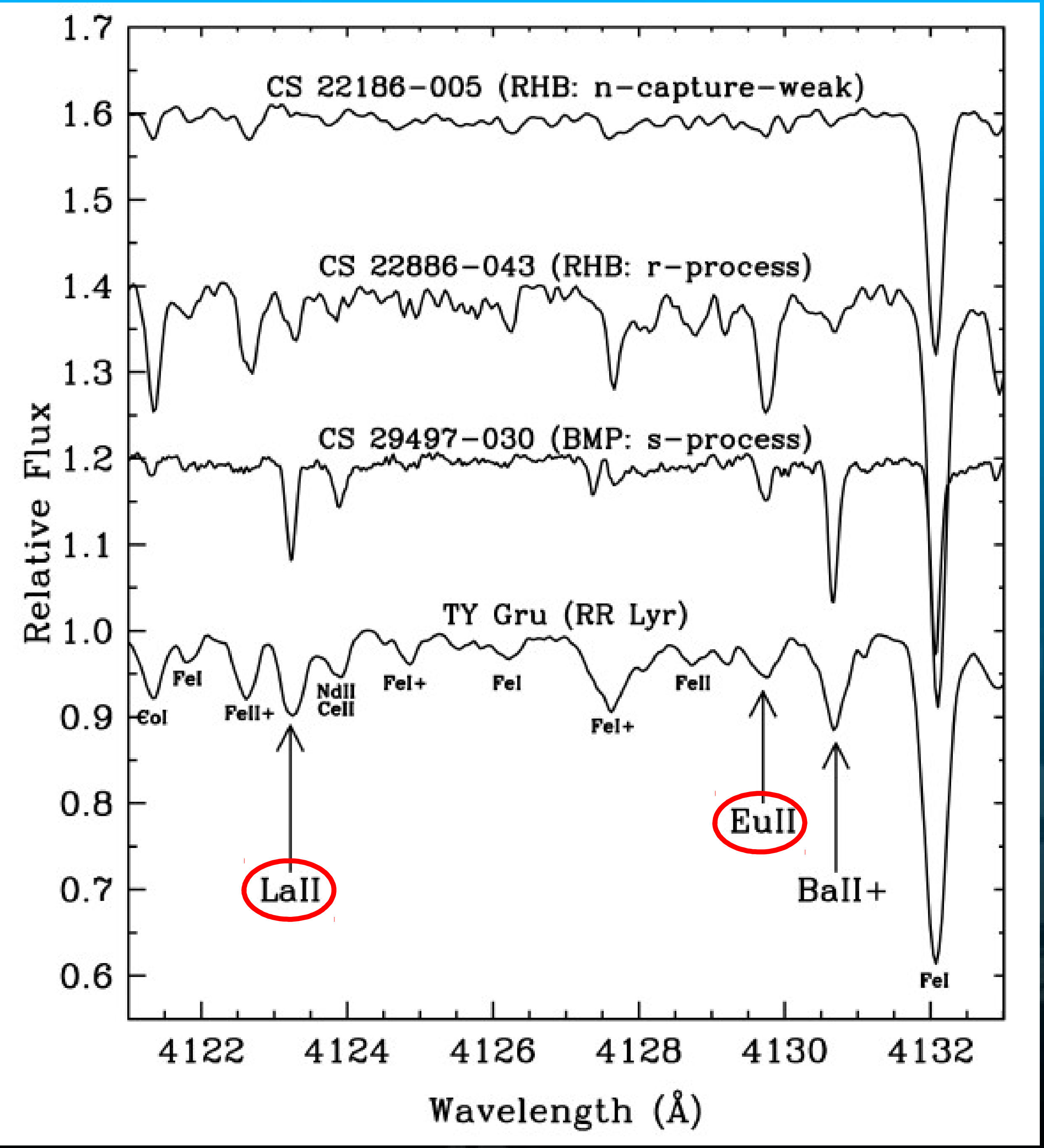
ATMOSPHERES, CHEMICAL COMPOSITIONS, AND EVOLUTIONARY HISTORIES OF VERY METAL-POOR RED HORIZONTAL-BRANCH STARS IN THE GALACTIC FIELD AND IN NGC 7078 (M15)[1]

George W. Preston,[2] Christopher Sneden,[2,3] Ian B. Thompson,[2] Stephen A. Shectman,[2] and Gregory S. Burley[2]
Received 2006 February 3; accepted 2006 March 14

3.2. *Cleansing the Sample*

Several more stars were originally included in our observing program but were eliminated from further discussion in this study for various reasons. CS 22881-071 had RVs of −7, +14, and +10 km s^{-1} on 2003 June 14/15, October 8/9, and October 12/13, respectively. This prompted a SIMBAD search, which revealed it to be an RR Lyrae star of unknown period called TY Gruis. CS 22964-061 is also an RR Lyrae star.

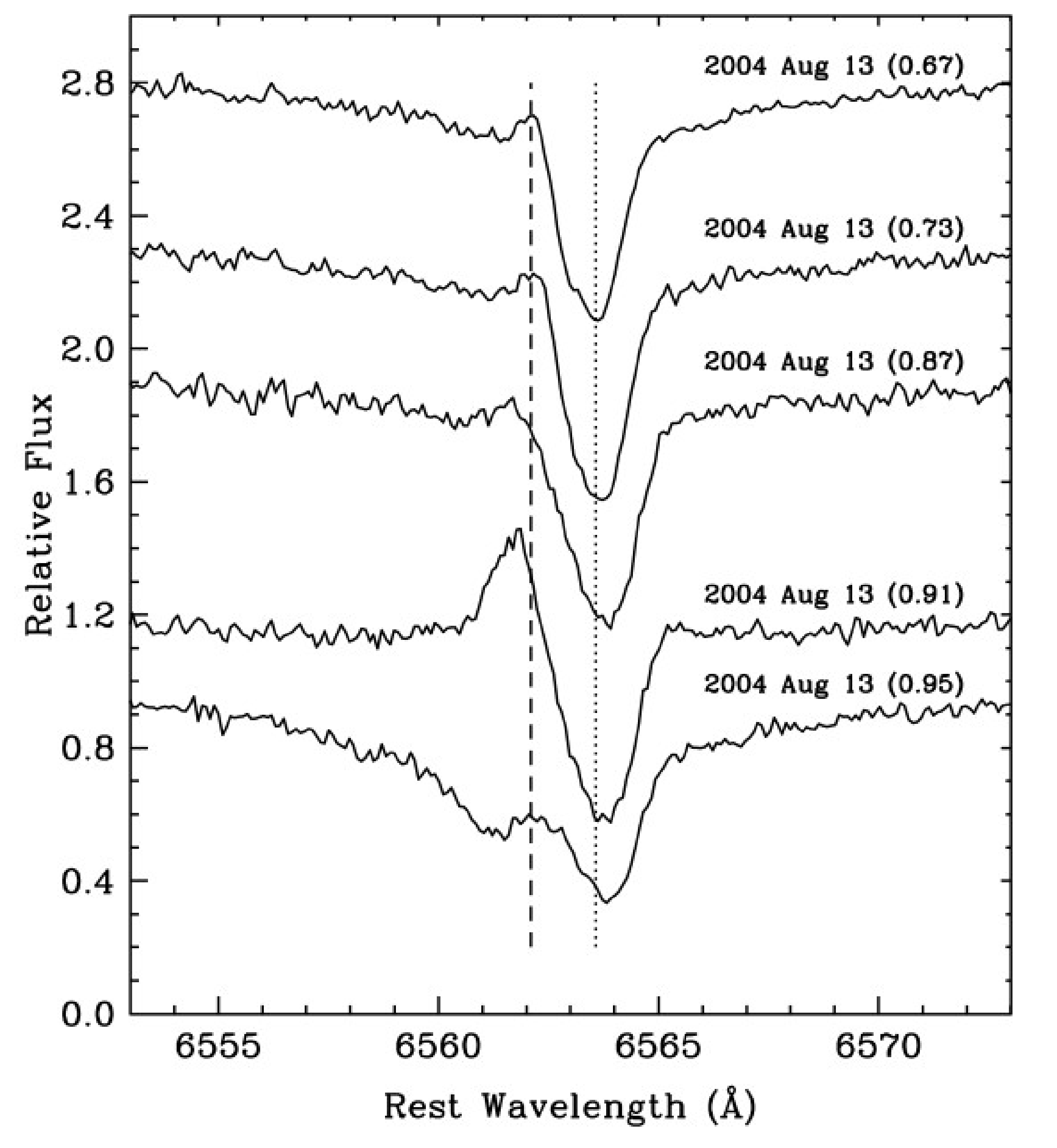
Surprise! TY Gru is a carbon-rich, s-process-rich RR Lyr



A glance at the spectra reveals the s-process enhancements

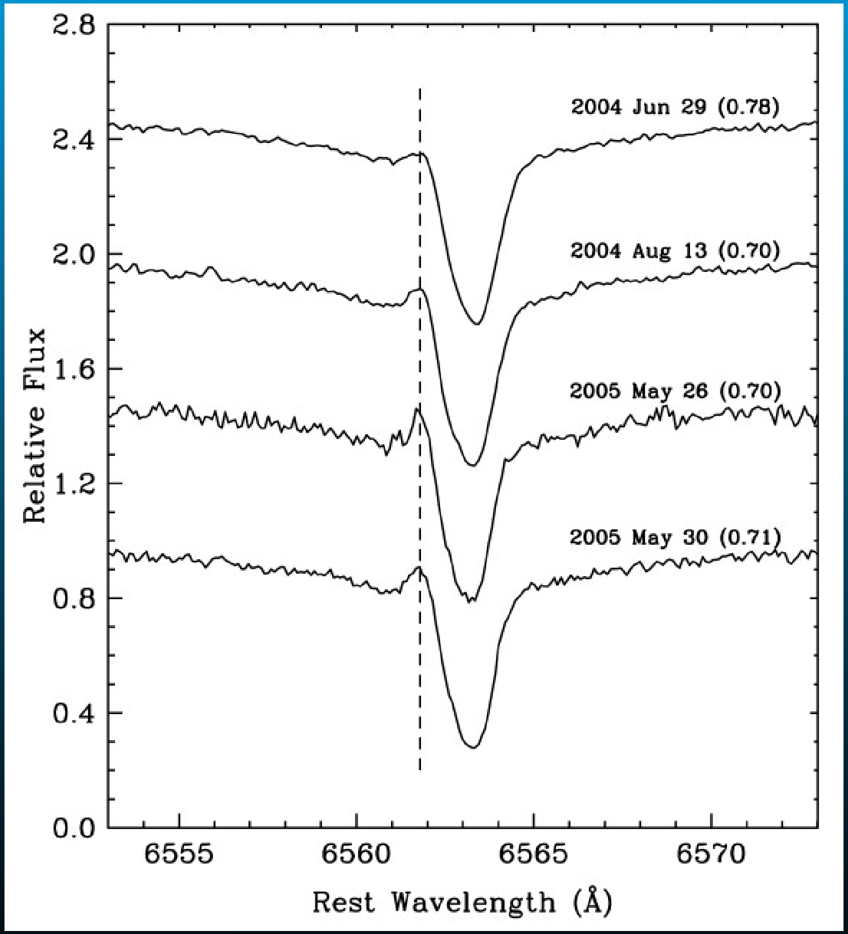
Preston et al. 2006

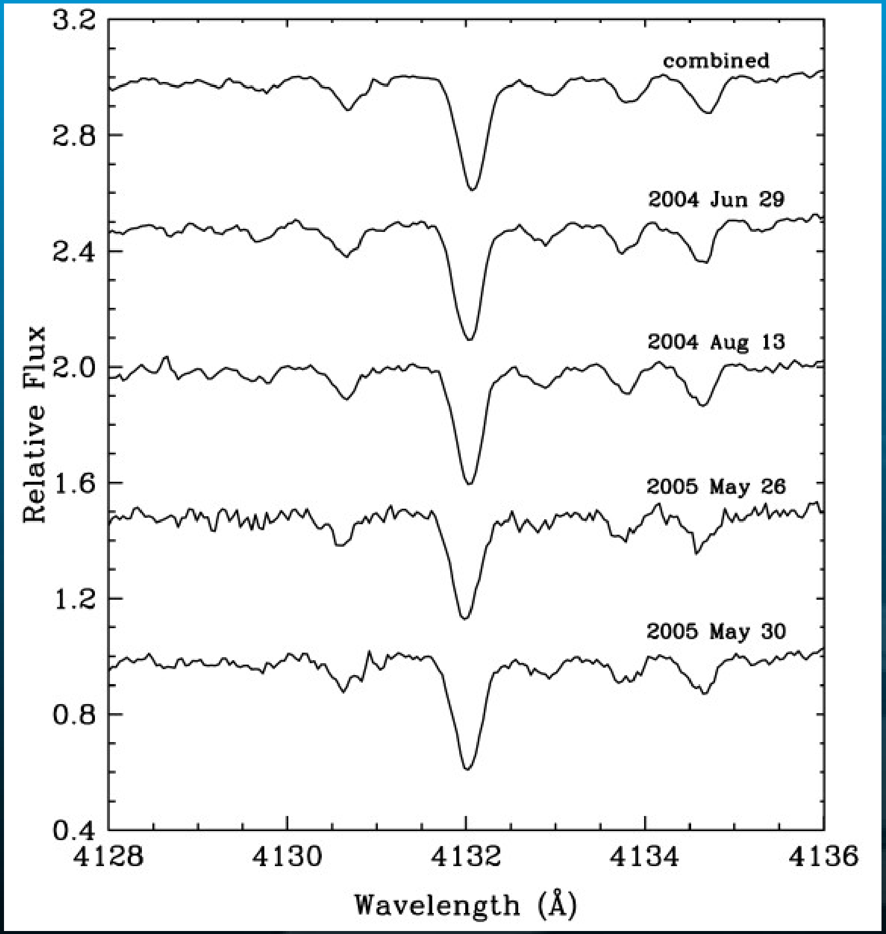
The spectrum analysis challenges are evident in the ever-changing Hα profiles



Preston et al. 2006

But same-phase spectra can be co-added



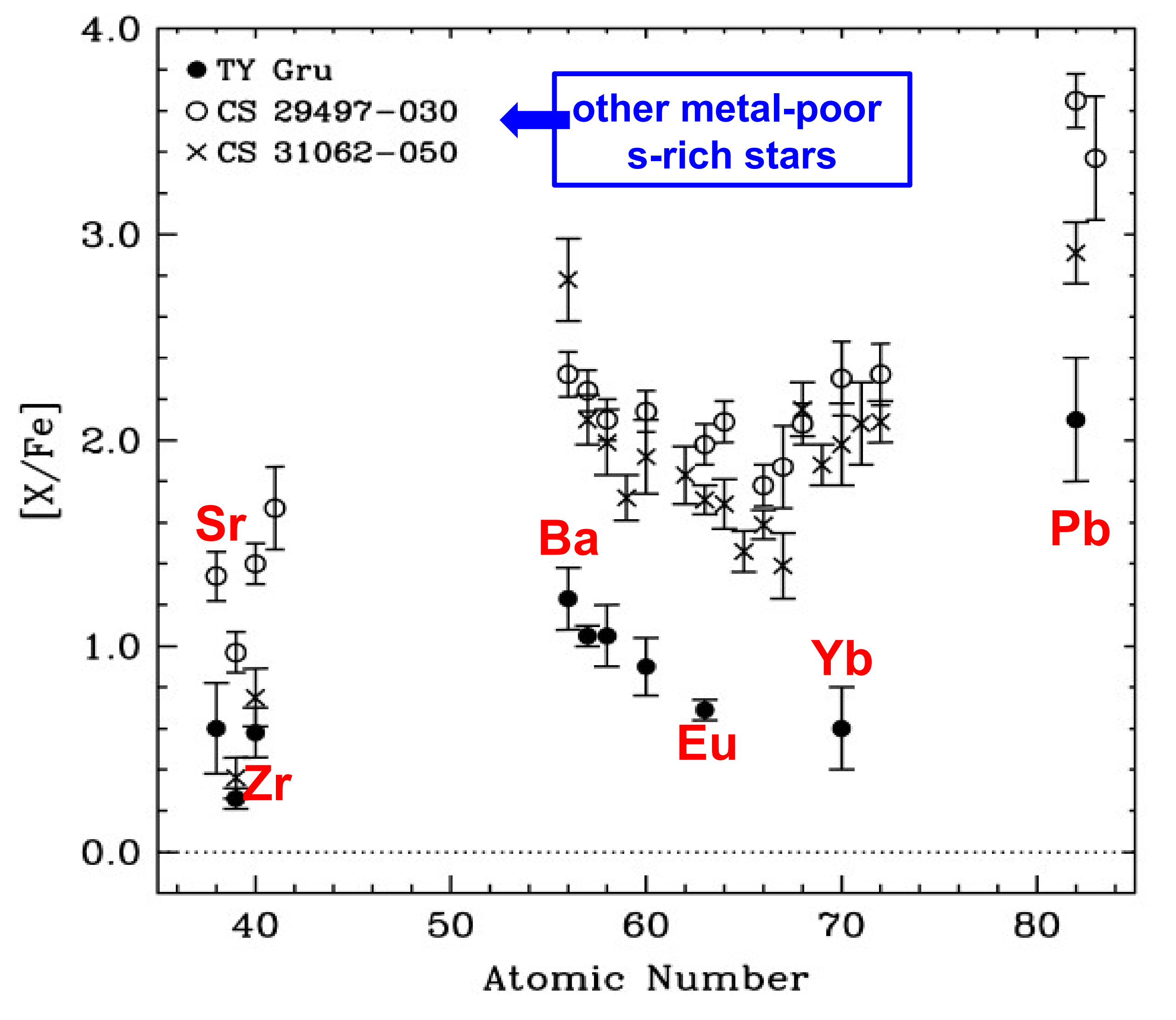


Preston et al. 2006

This is a key point in our approach in detailed studies

The details of the s-enrichment are revealed in the co-added spectrum

Preston et al. 2006



Note:

Large [X/Fe] values of all n-capture elements

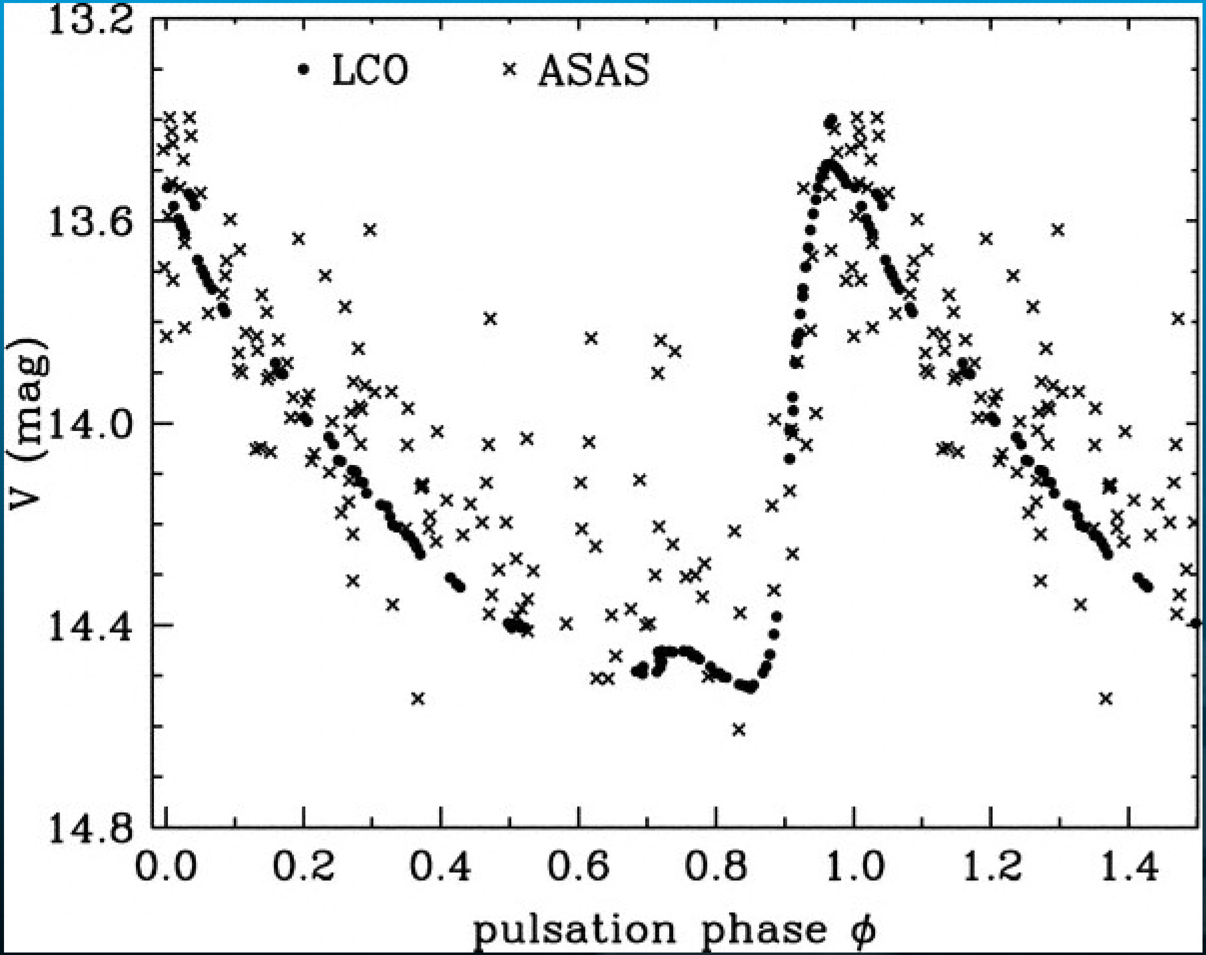
Classical s-process signature: [Ba/Eu] > +0.6

Standard chemical composition analysis; details on request

The TY Gru light curve looks ordinary

LCO = Las Campanas

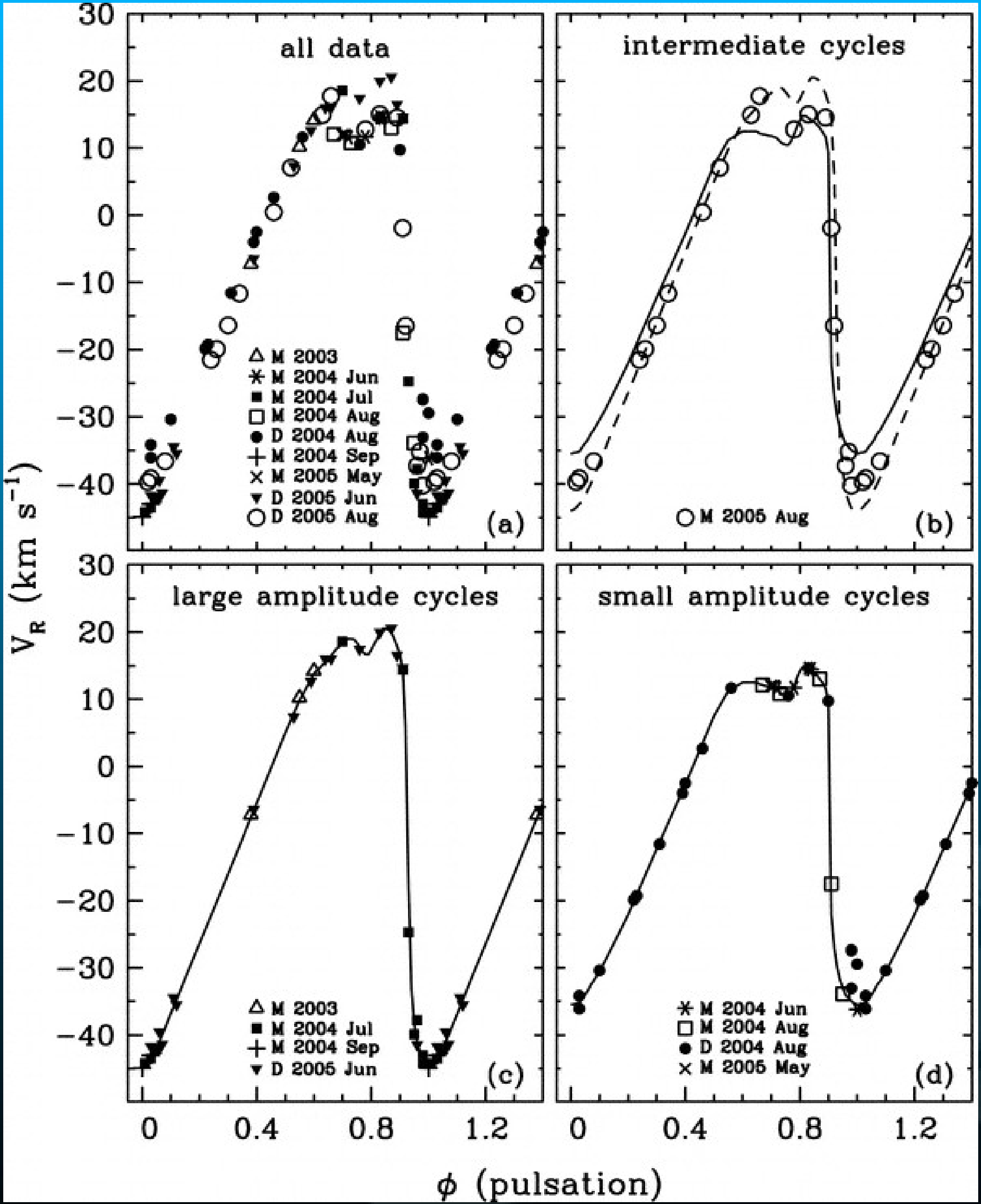
ASAS = All Sky Automated Survey (more on this later)



Preston et al. 1996

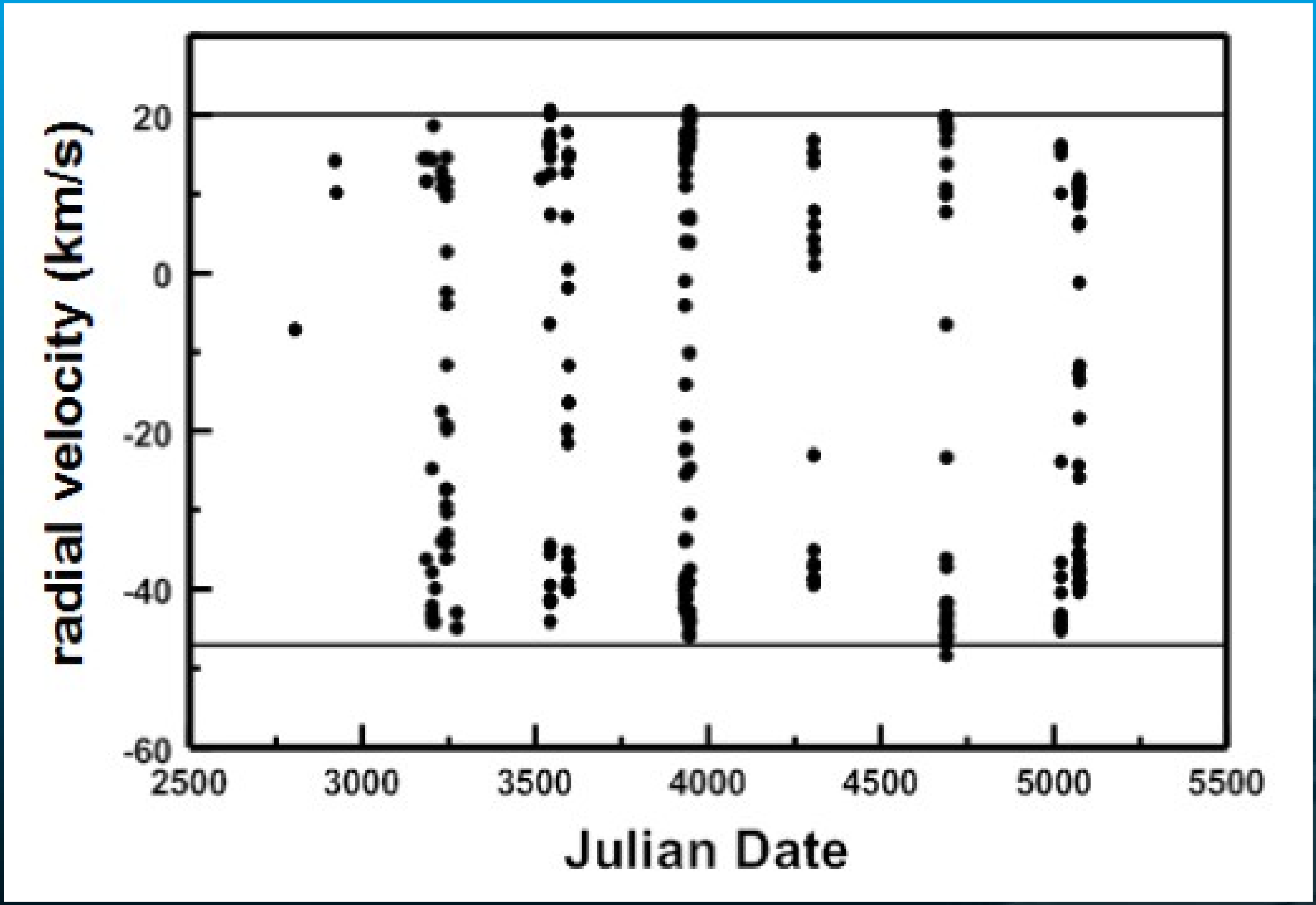
But (grrrrrr…) it is a Blazhko effect variable

nearly impossible to check for a companion star that might have donated the carbon and s-process elements to TY Gru



Preston et al. 1996

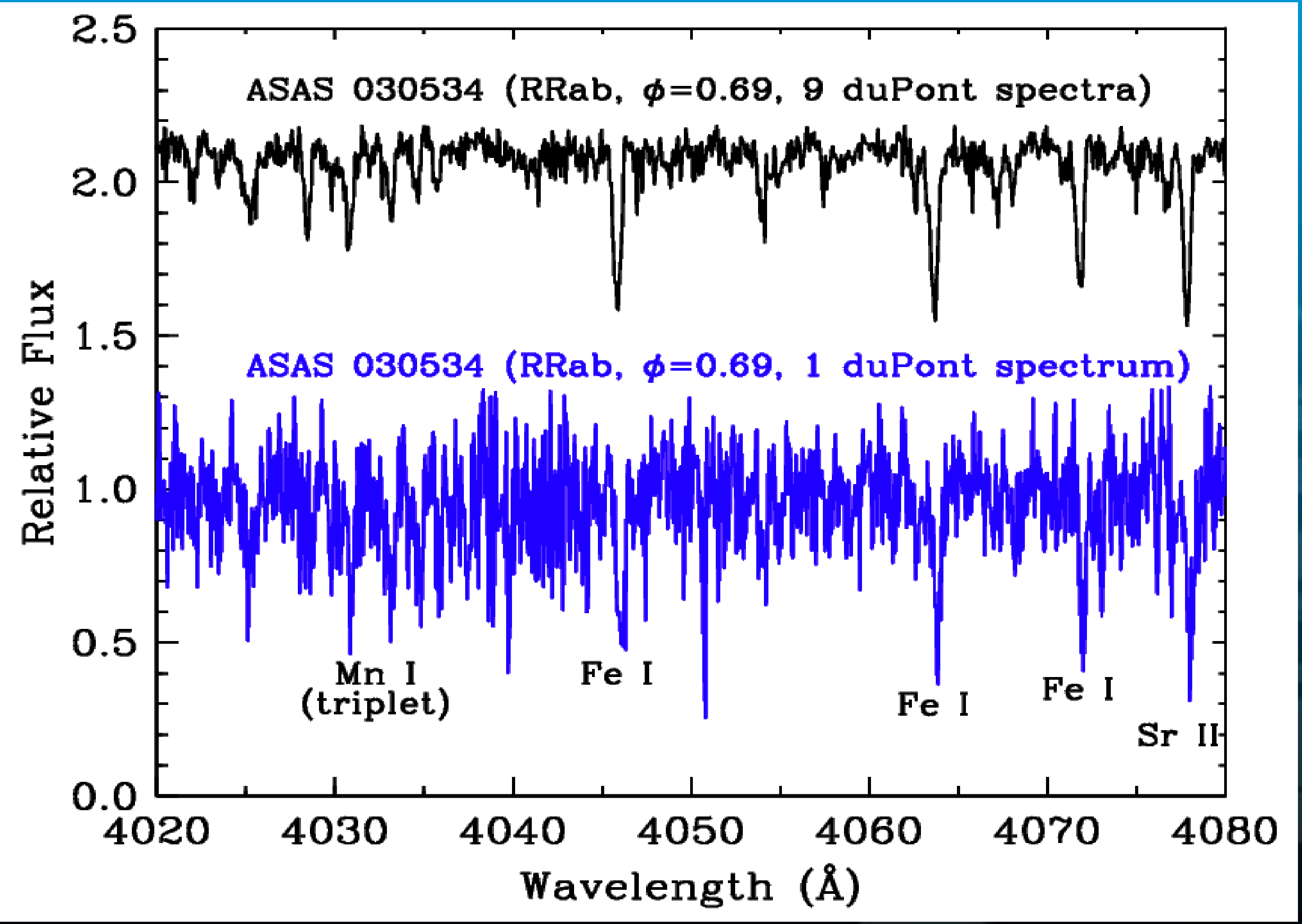
Here is what we can say so far about a companion:



Preston 2009

NOTHING! There are no obvious secular RV trends over 6 years

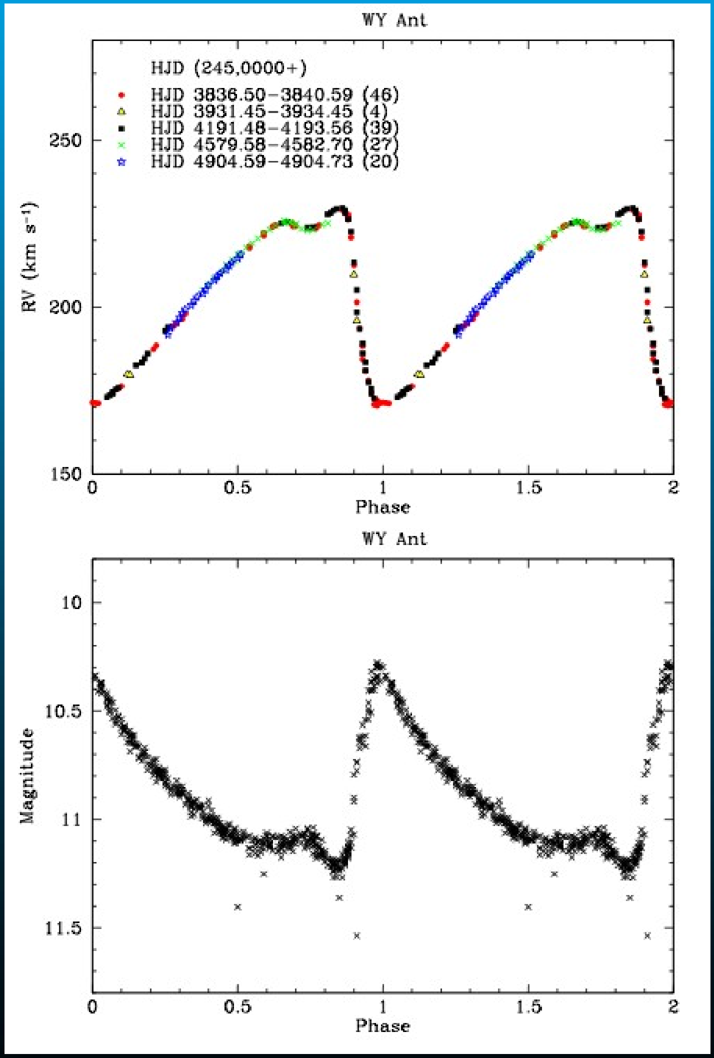
RR Lyr stars vary rapidly so spectra are often noisy
But their regularity means that co-addition works well

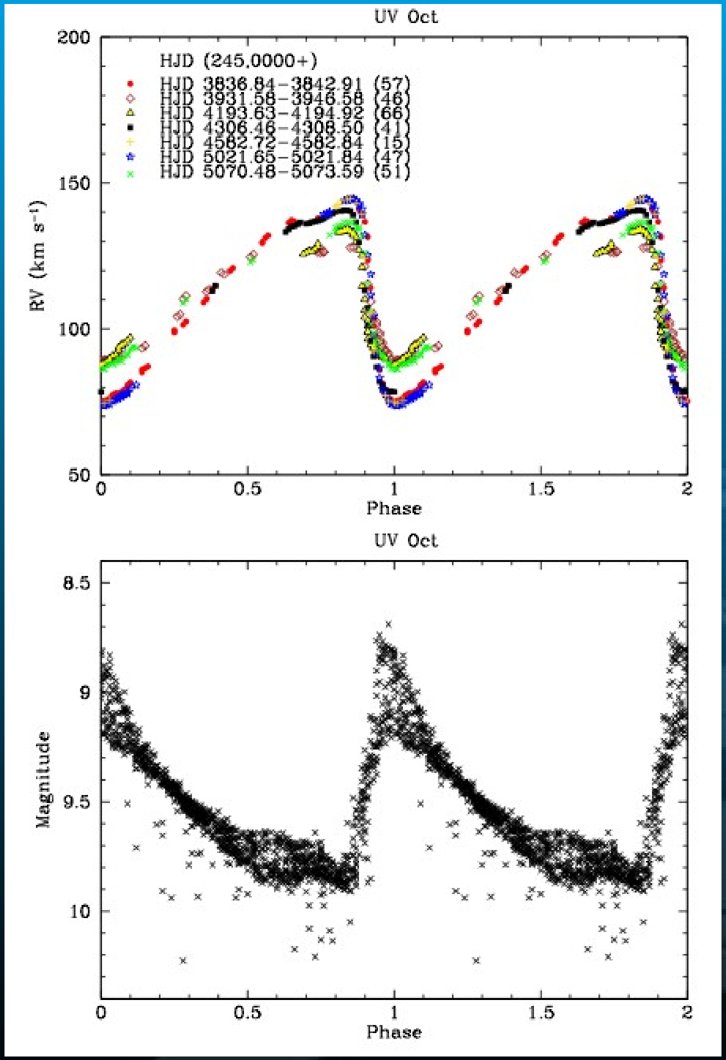


multi-star, multi-phase, multi-epoch atmosphere & chemical composition analysis; dissertation work of BiQing For (U Texas)

- new radial velocities, improved pulsation periods and reference epoch s of 11 field RR Lyrae ab-type variables
- AS Vir, BS Aps, CD Vel, DT Hya, RV Oct, TY Gru, UV Oct, V1645 Sgr, WY Ant, XZ Aps and Z Mic
- based on high resolution spectra from the Las Campanas 2.5-m du Pont telescope and echelle
- obtained ~200 spectra per star (i.e, total of ~2300 spectra)
- spectra distributed more or less uniformly throughout their pulsation cycles
- Preston did all the observing!

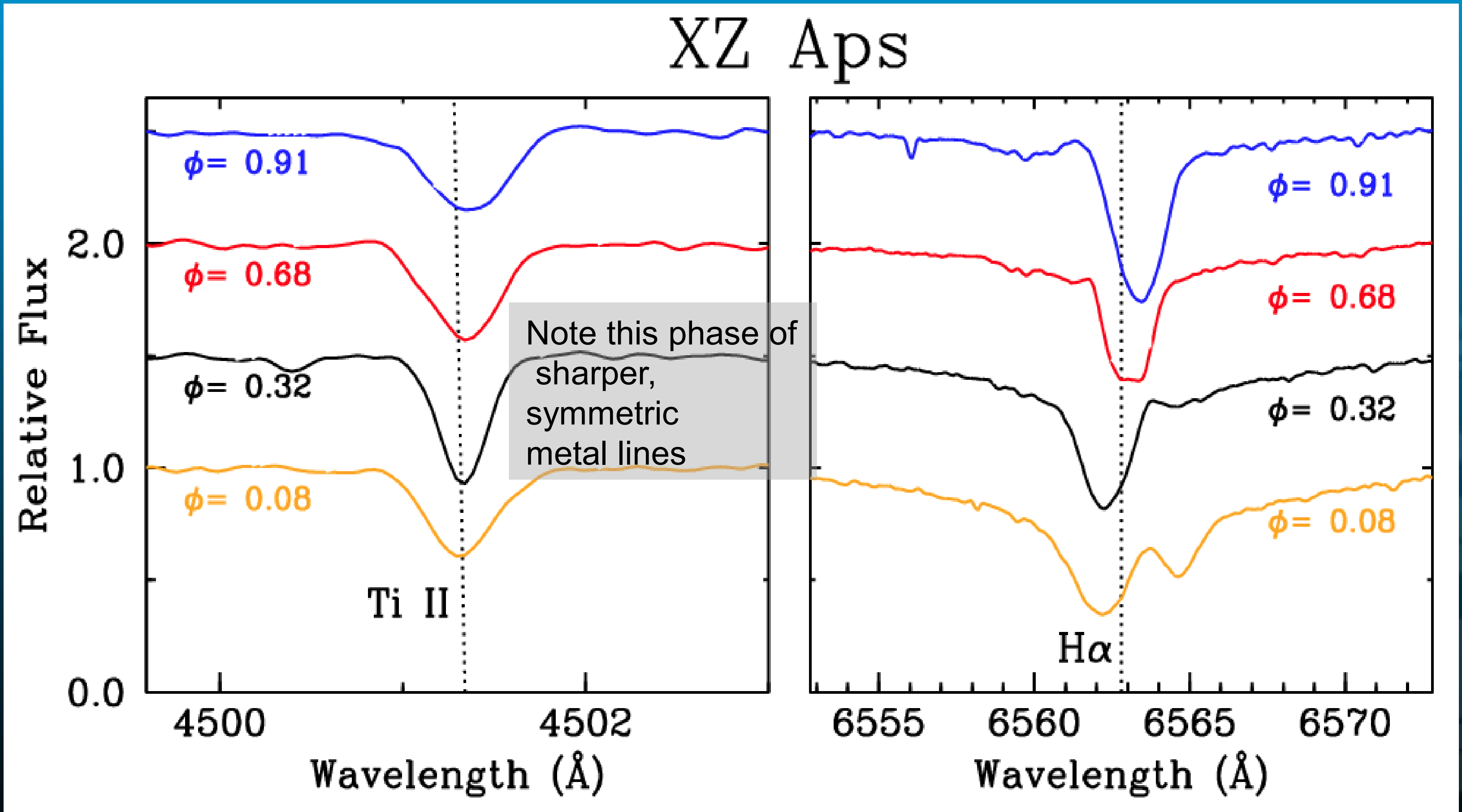
First task: refining the pulsational elements





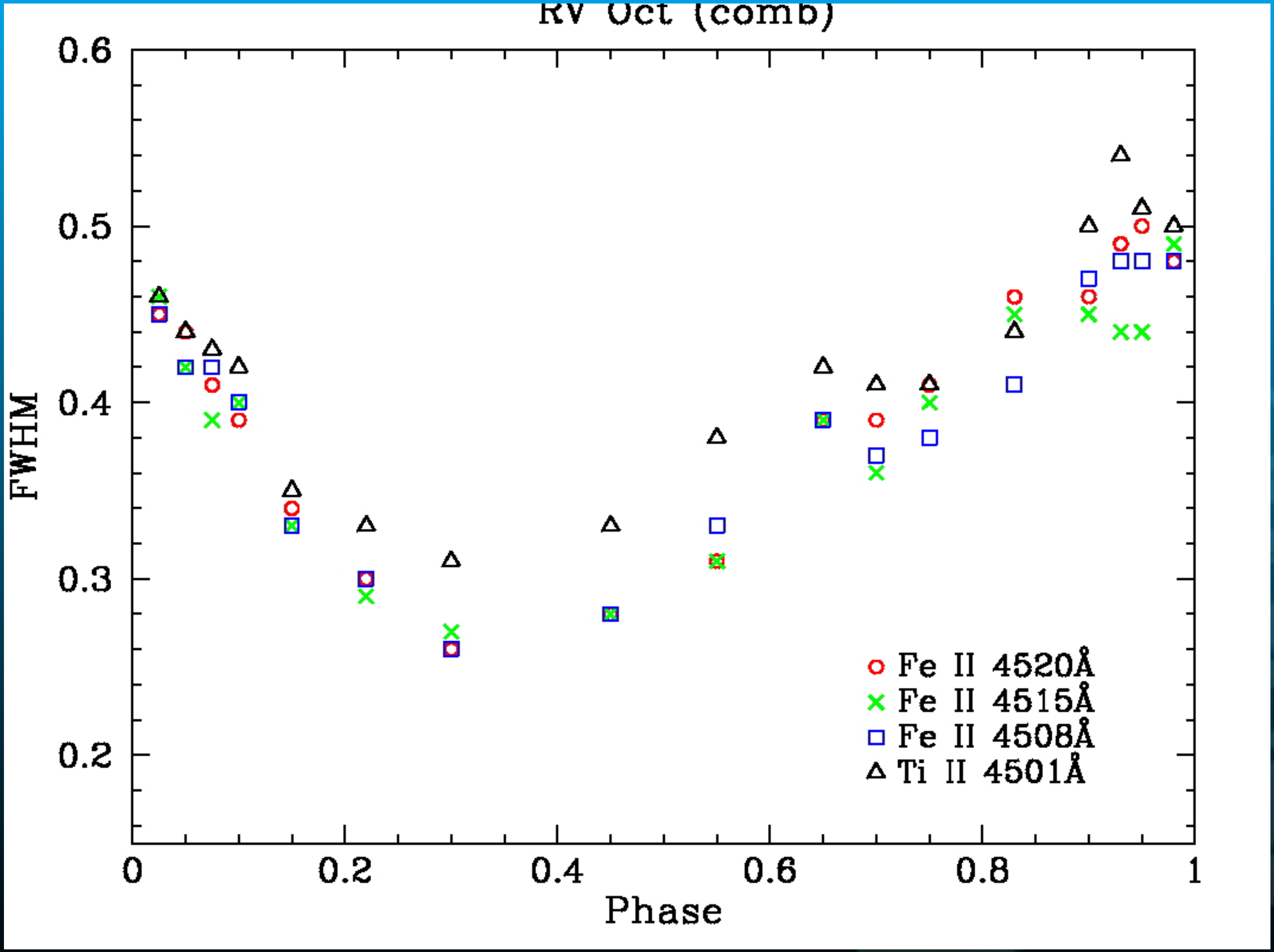
For et al 2011, ApJS, 194, 38

Second task: multi-phase atmosphere & chemical composition analysis



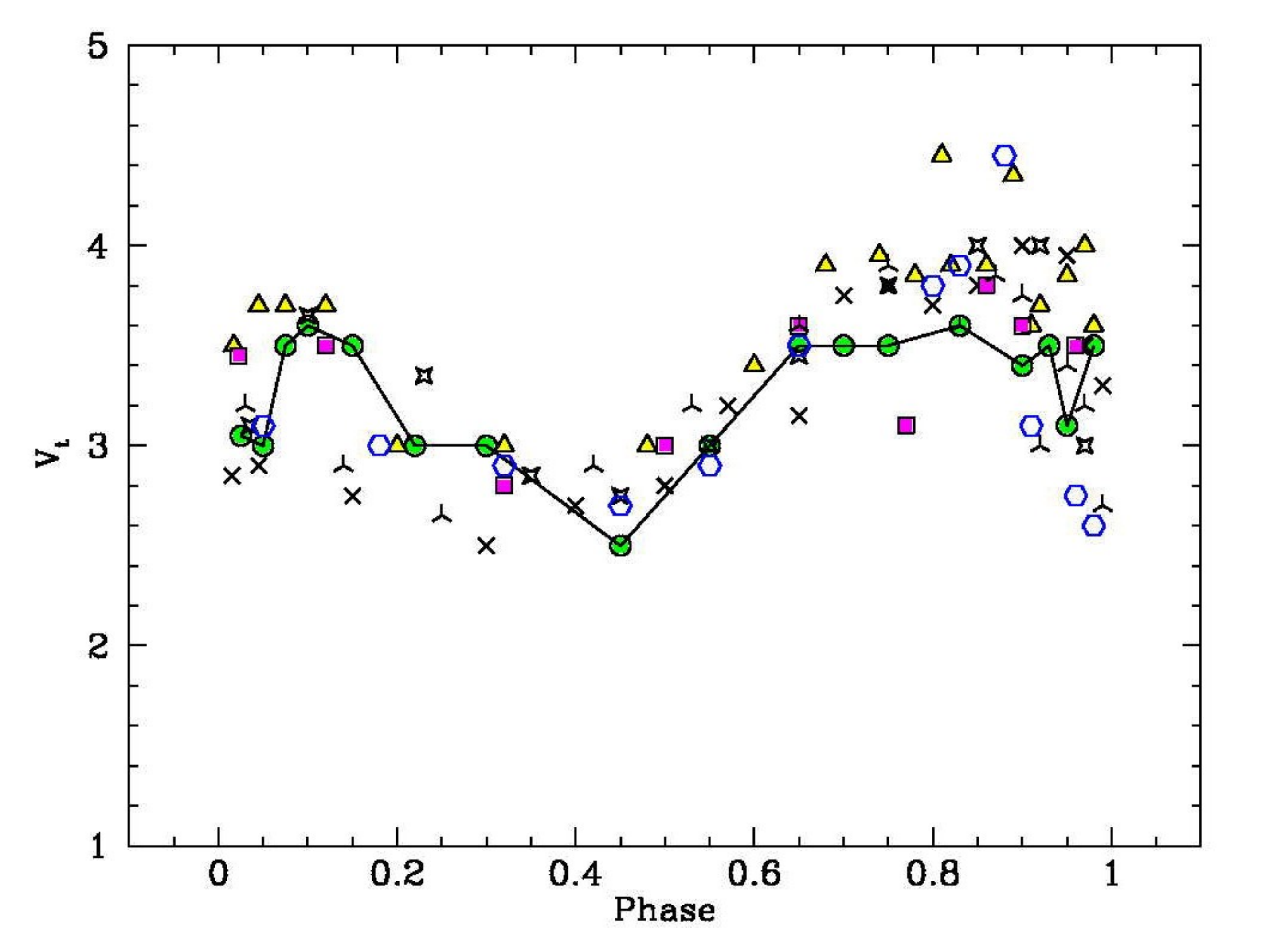
For et al. 2011, ApJS, 197, 29

sharpest, most symmetric lines occur at ϕ = 0.3-0.5



B-Q For et al. 2011

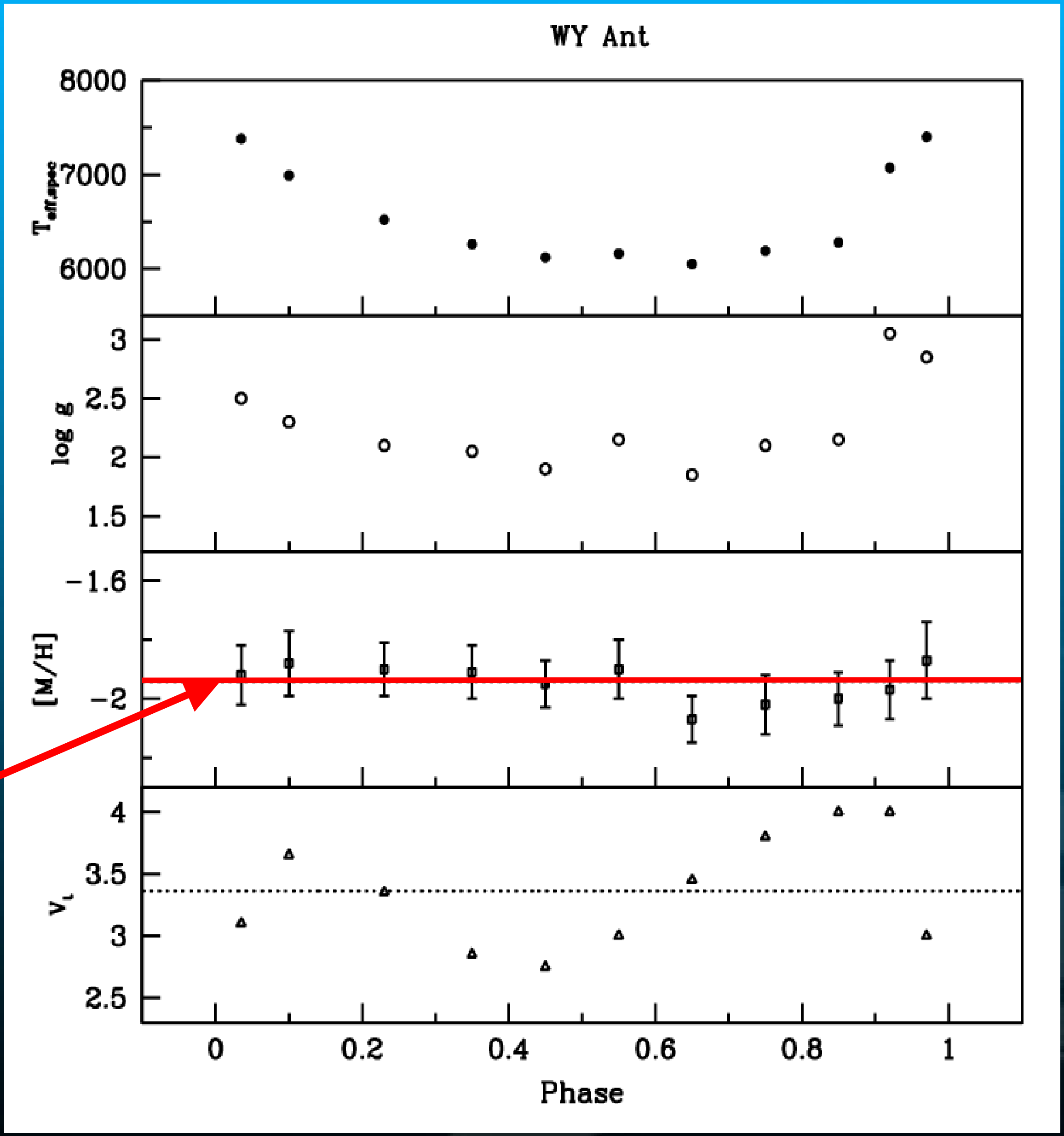
Repeats cycle after cycle for individual stars



B-Q For et al. 2011

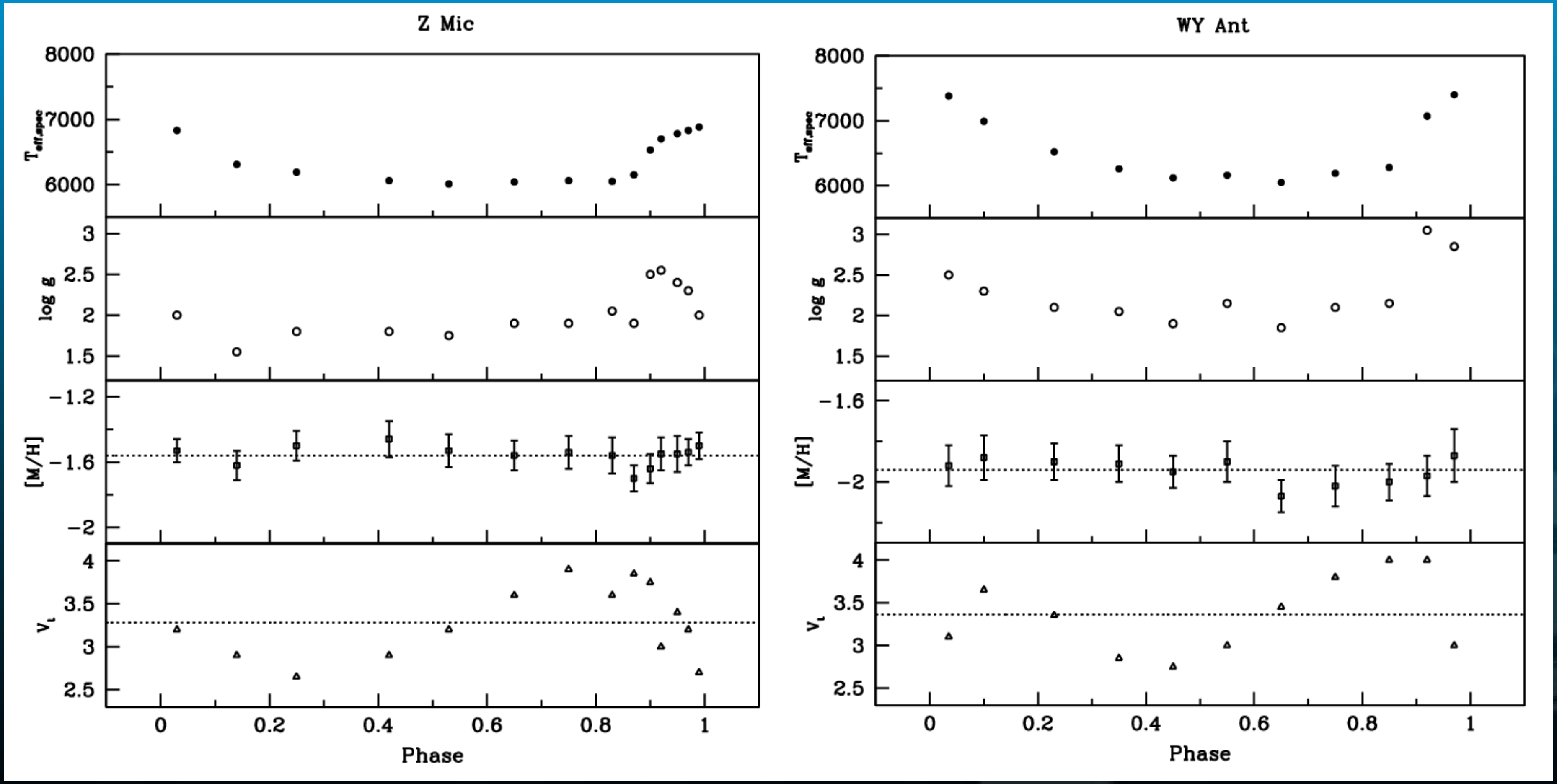
Teff, log *g*, vt variations with phase are regular

But [M/H] is insensitive to phase



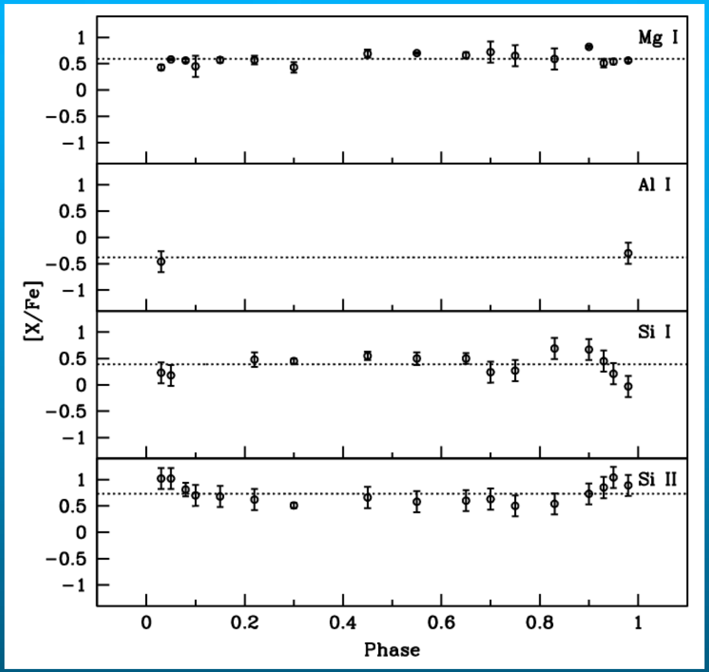
B-Q For et al. 2011

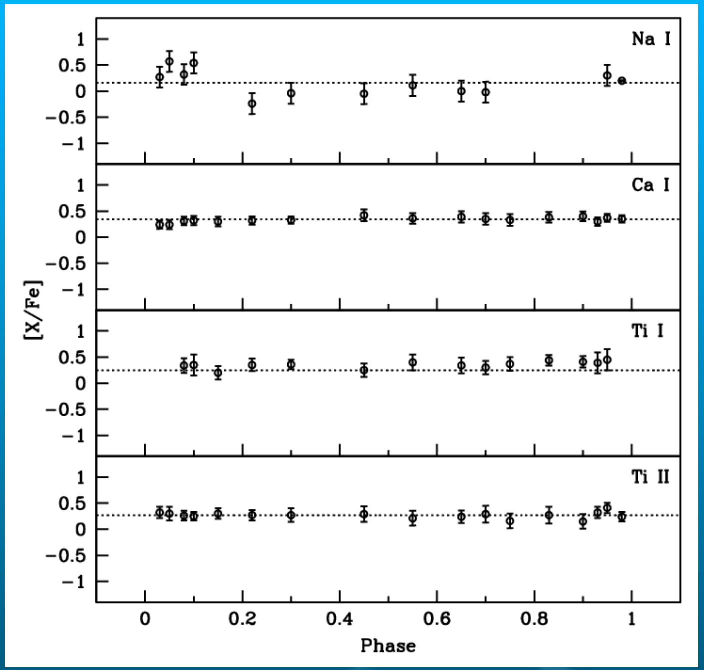
The patterns essentially repeat in all stars

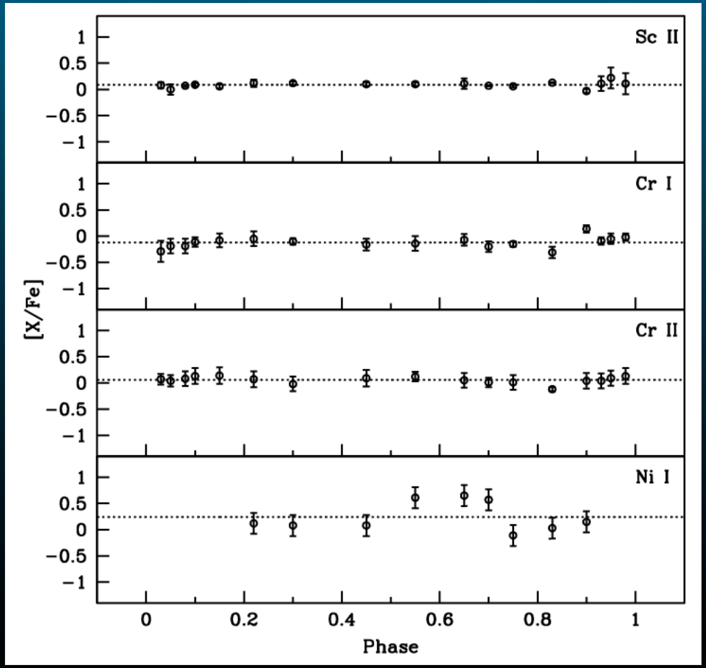


B-Q For et al. 2011

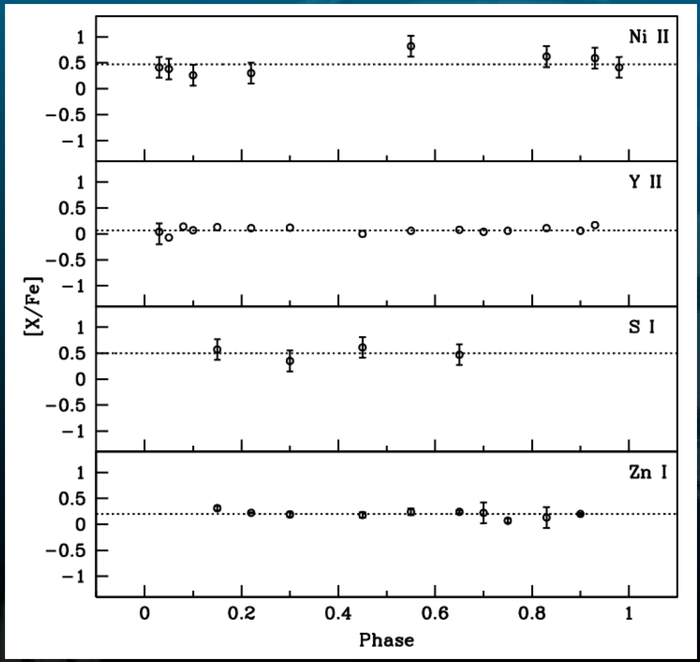
Abundance ratios are mostly insensitive to phase





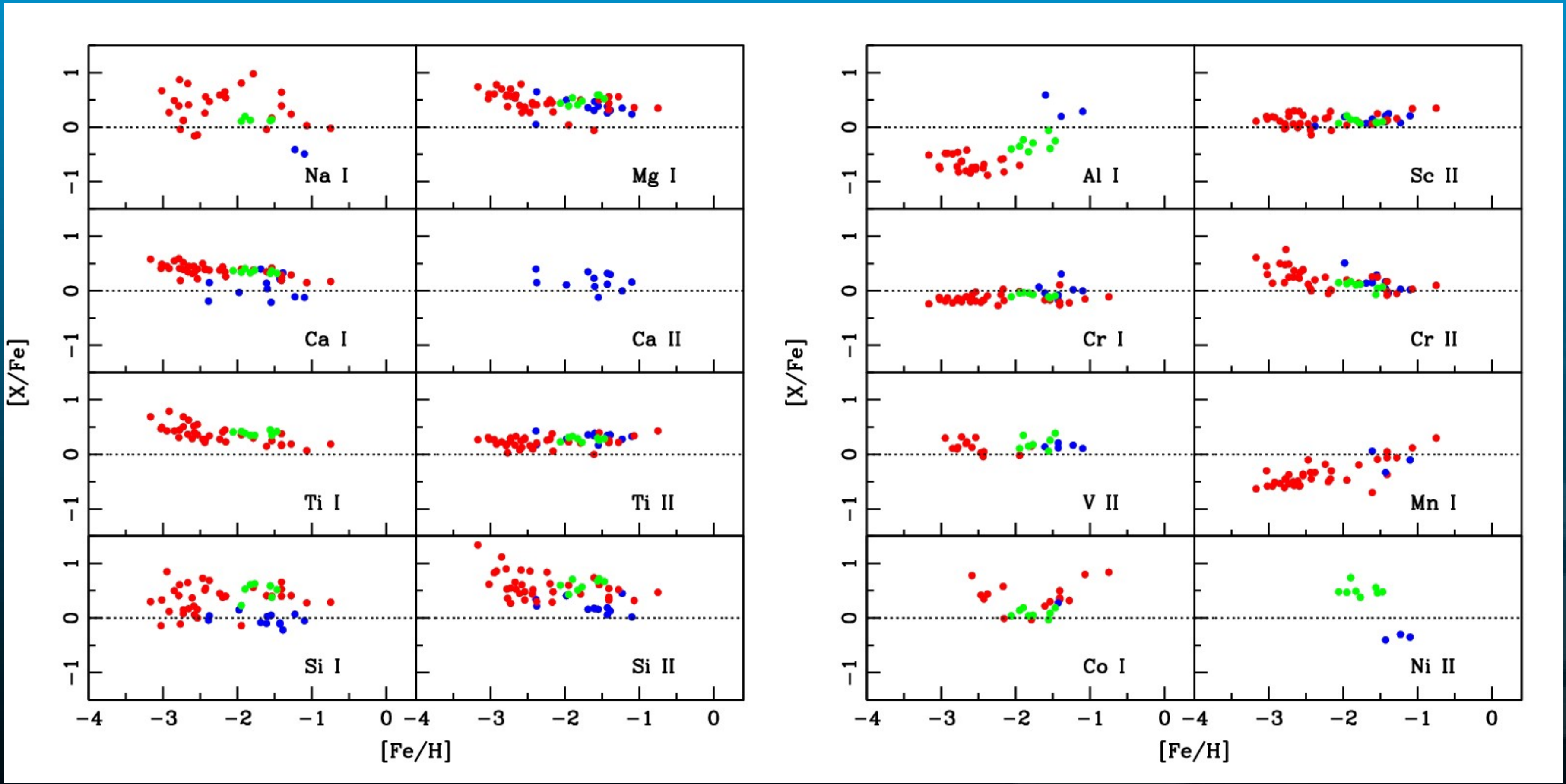


RV Oct



B-Q For et al. 2011

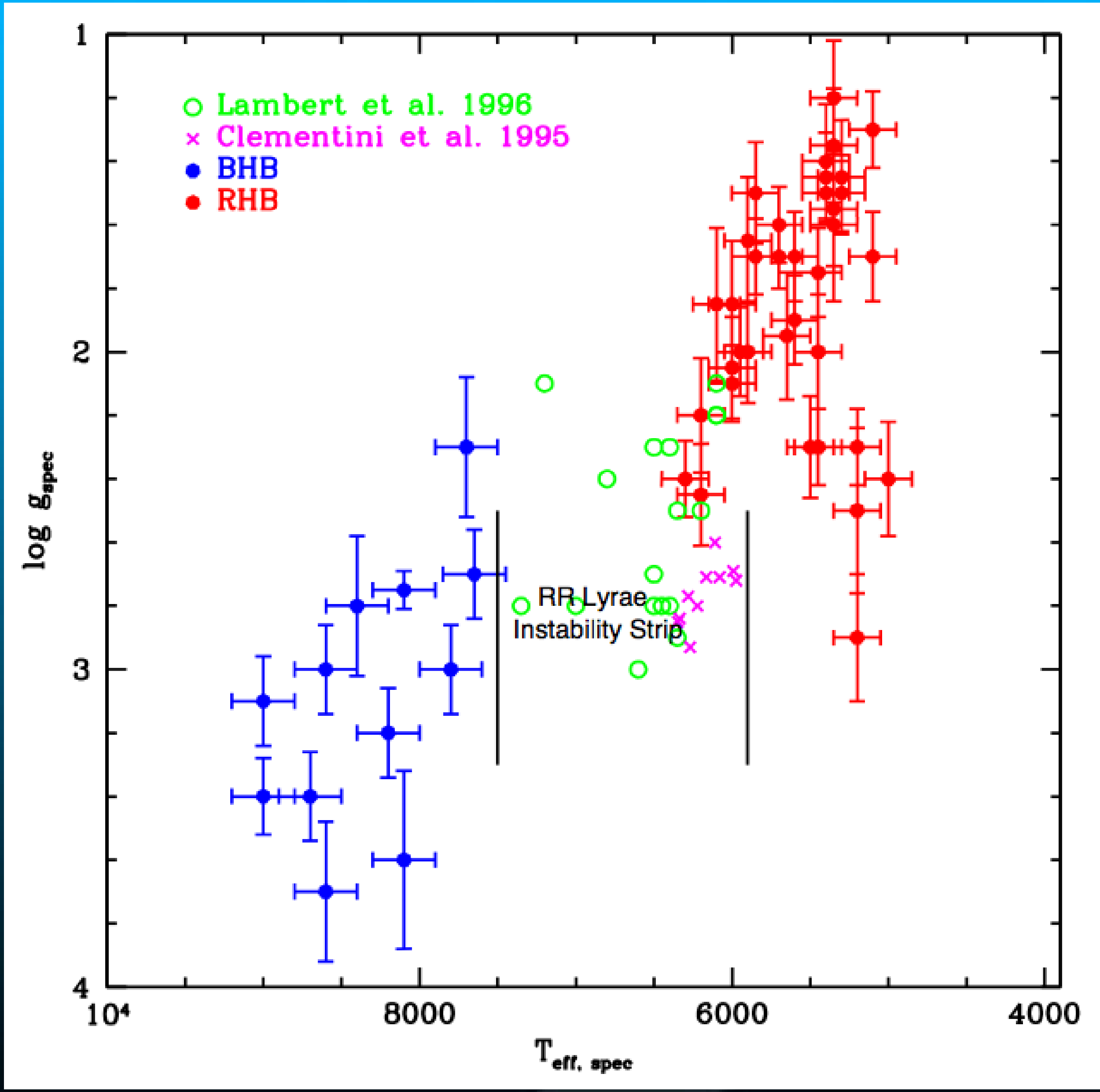
Abundance ratios are mostly in accord with other HB stars



BHB RR Lyr RHB

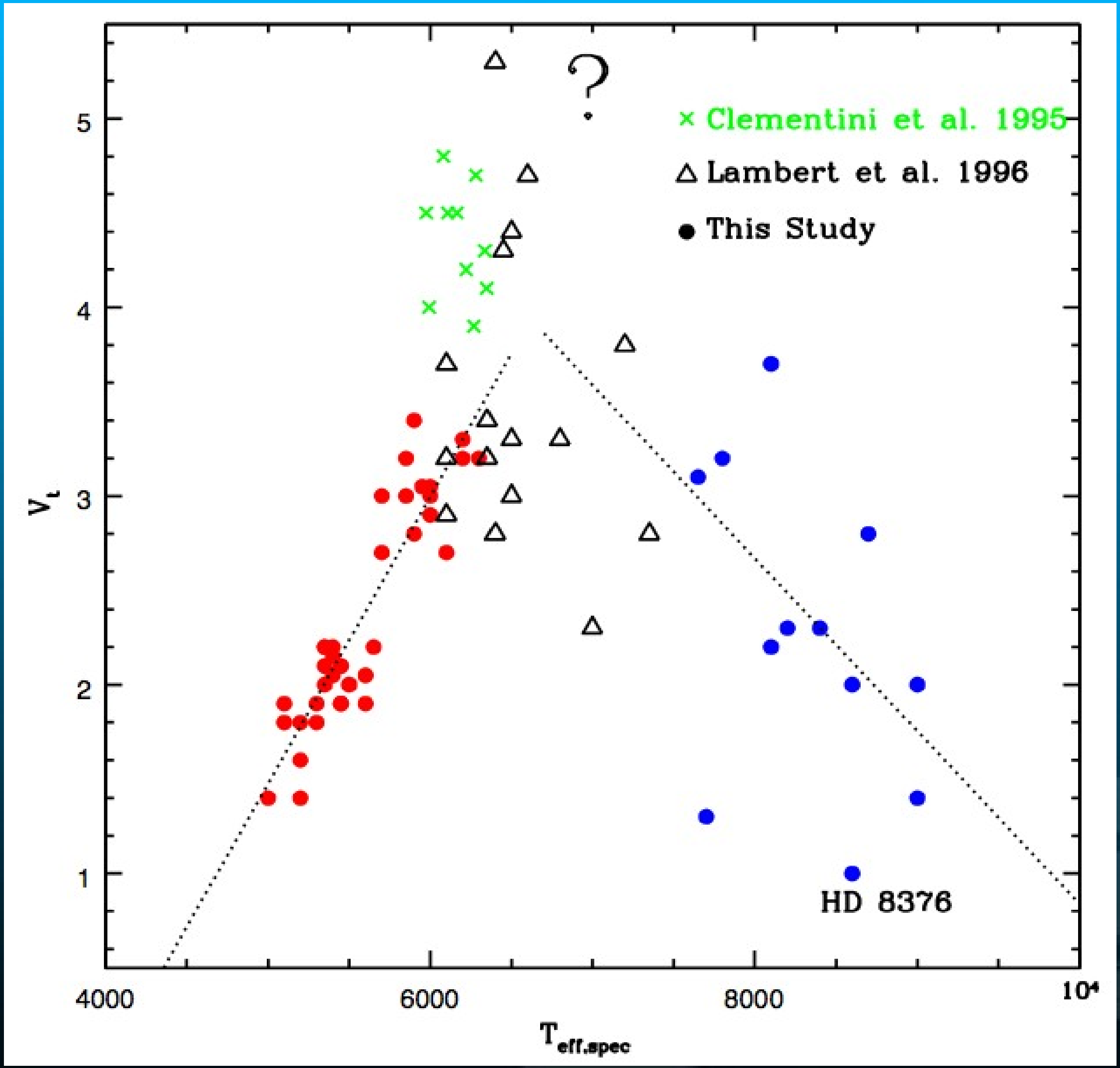
B-Q For et al. 2011

This study is a follow-on to BiQing's work on BHB, RHB non-variables



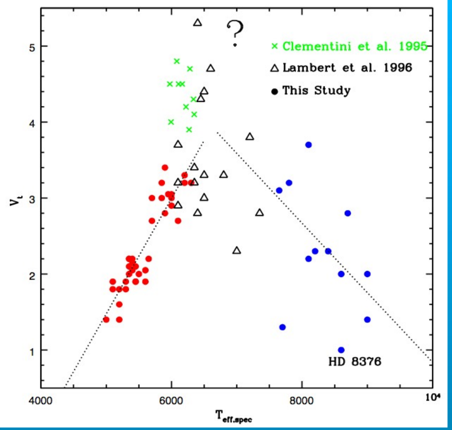
B-Q For et al. 2010

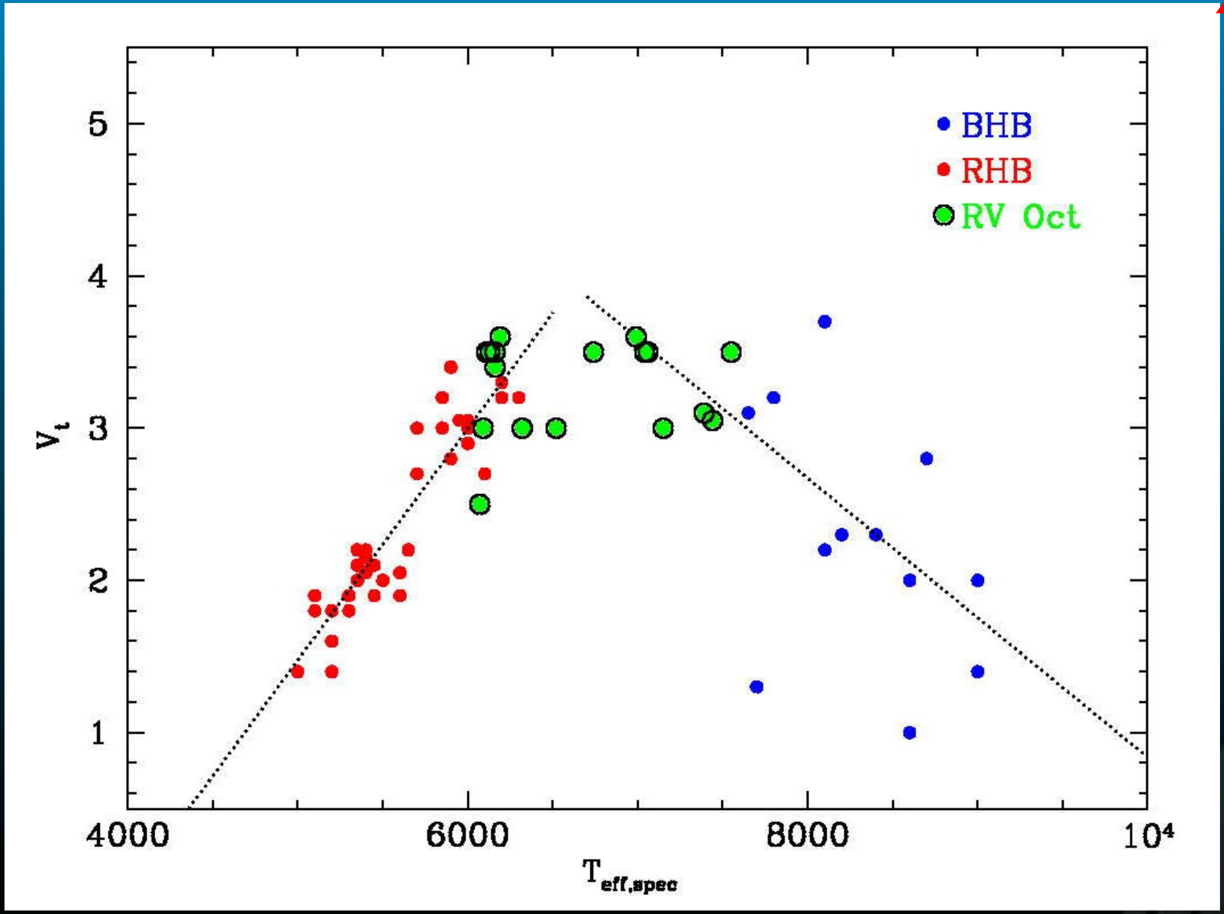
prior to the new RRab study, atmospheric parameters were not secure



B-Q For et al. 2010

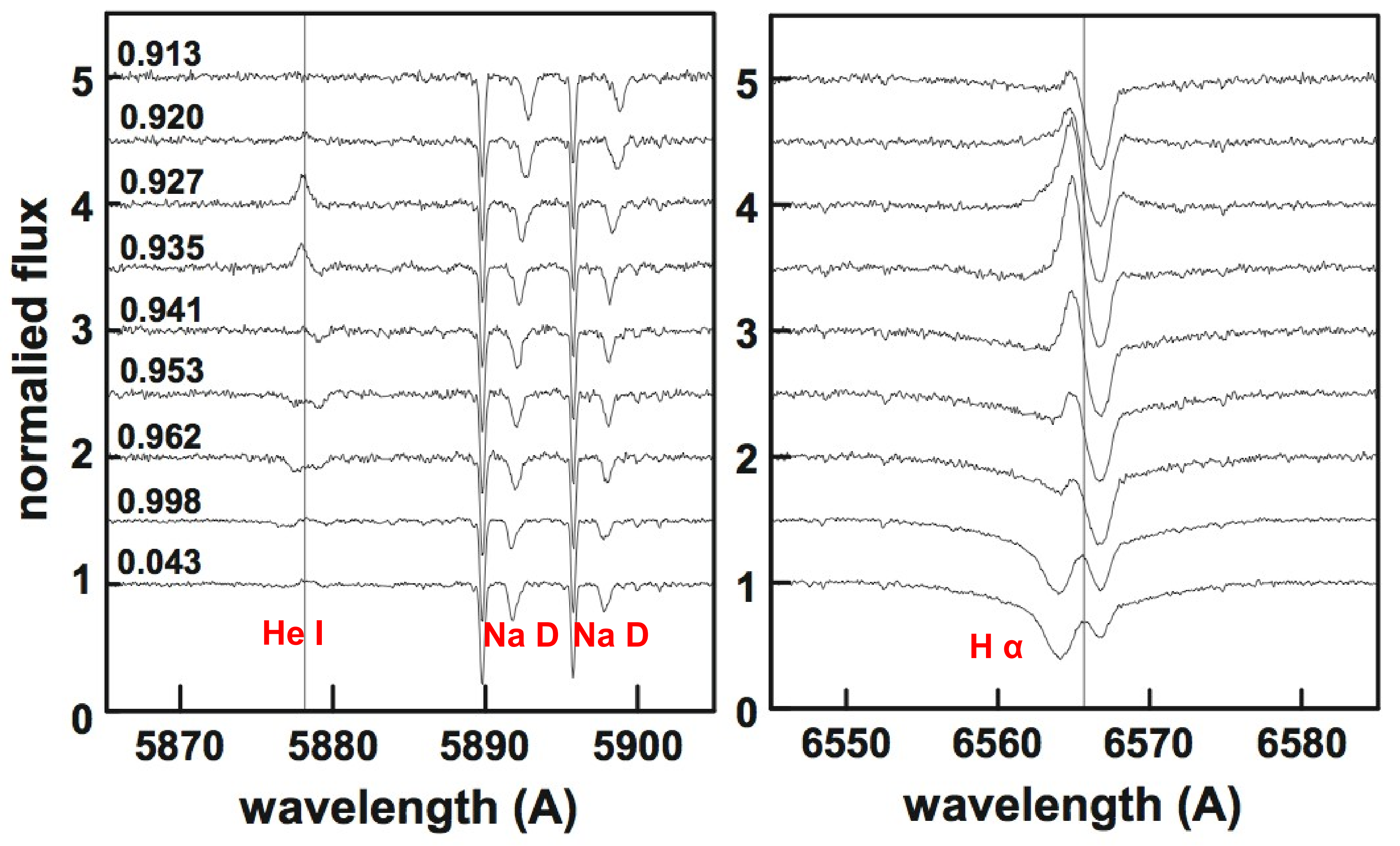
The microturbulence extremes reported previously are probably not real





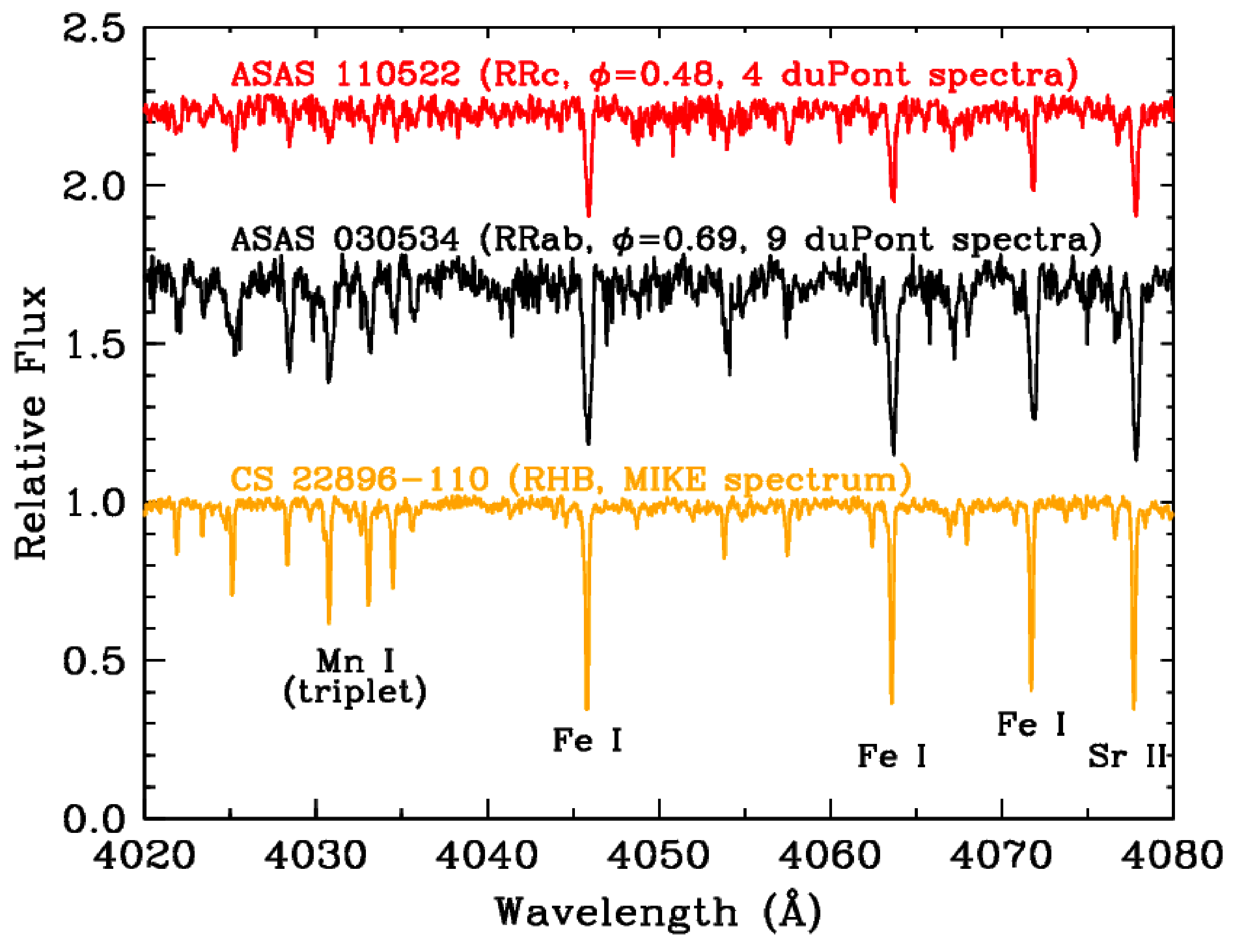
B-Q For et al. 2011

These spectra present many other opportunities

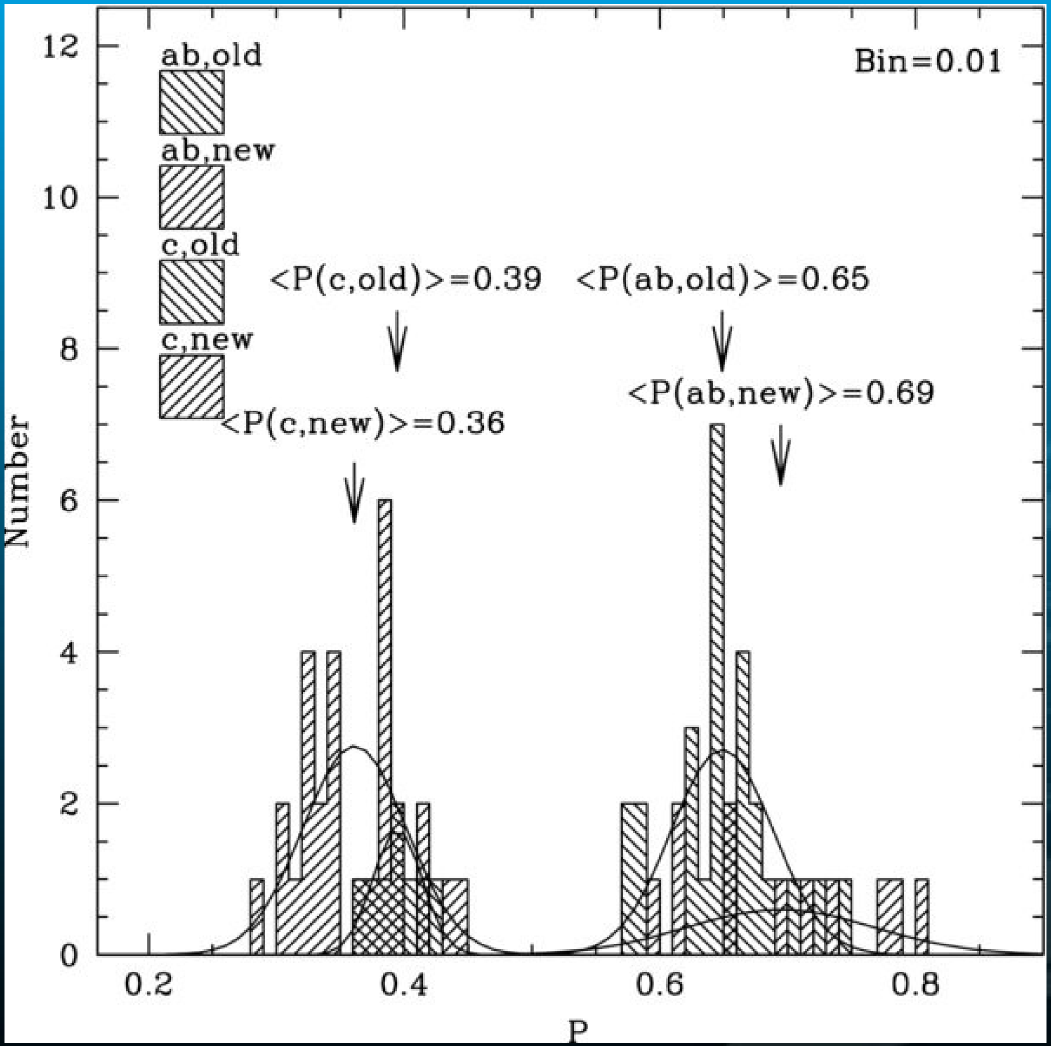


Preston 2009

But, onward to the RRc stars! they have received much less attention



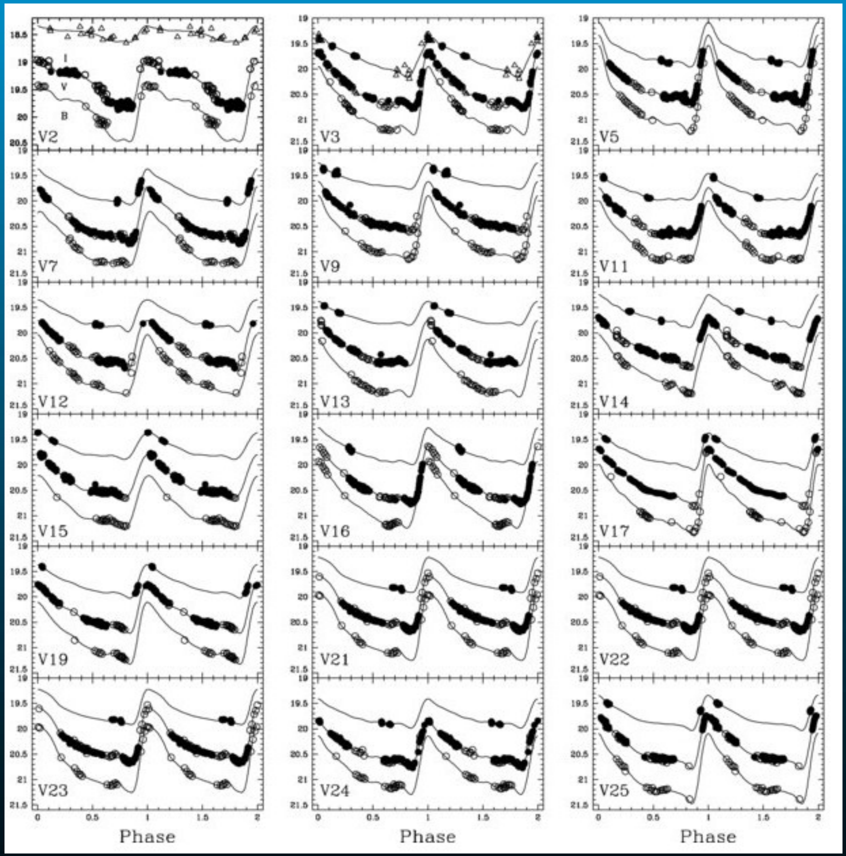
RRc's not difficult to pick out: lightcurves & ***periods***



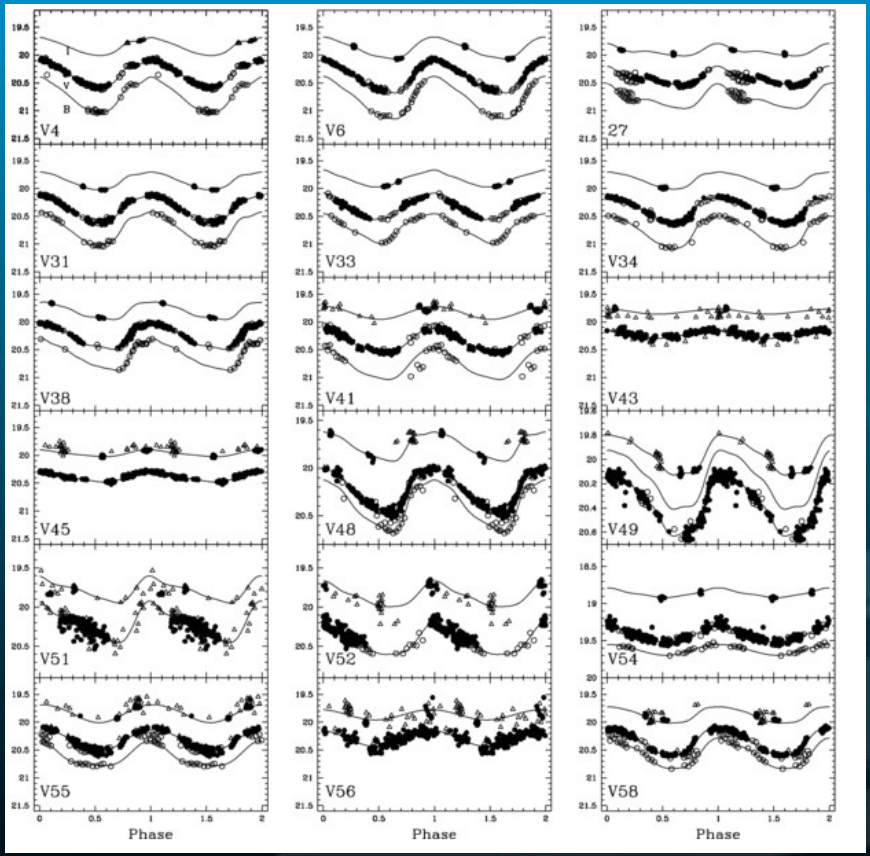
Di Criscienzo et al. 2011

RRc's are easy to pick out: ***lightcurves*** & periods

RRab



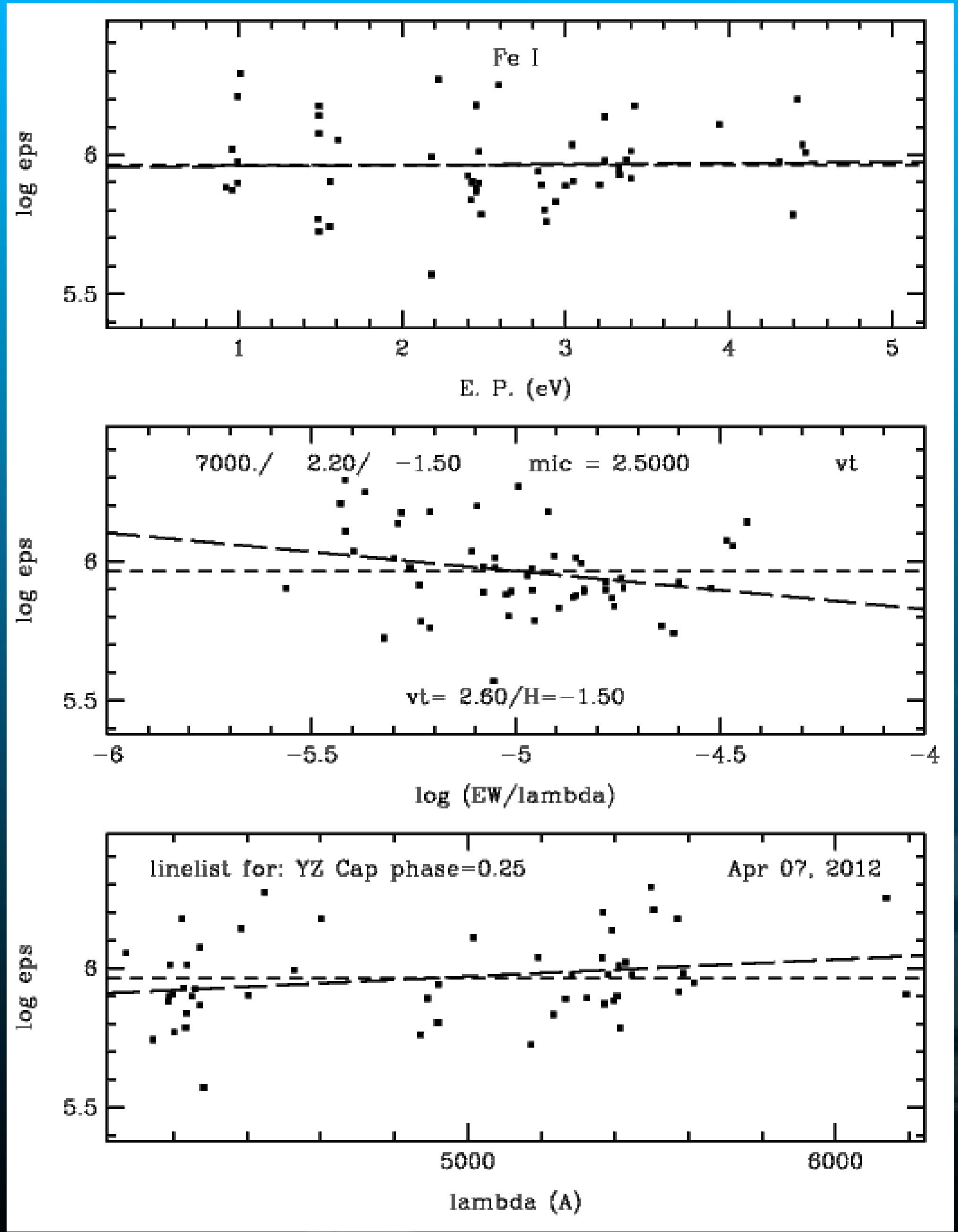
RRc



Di Criscienzo et al. 2011

Try first YZ Cap, a well-observed RRc: for an individual phase (0.25) we have this line-by-line result

(5 spectra co-added)

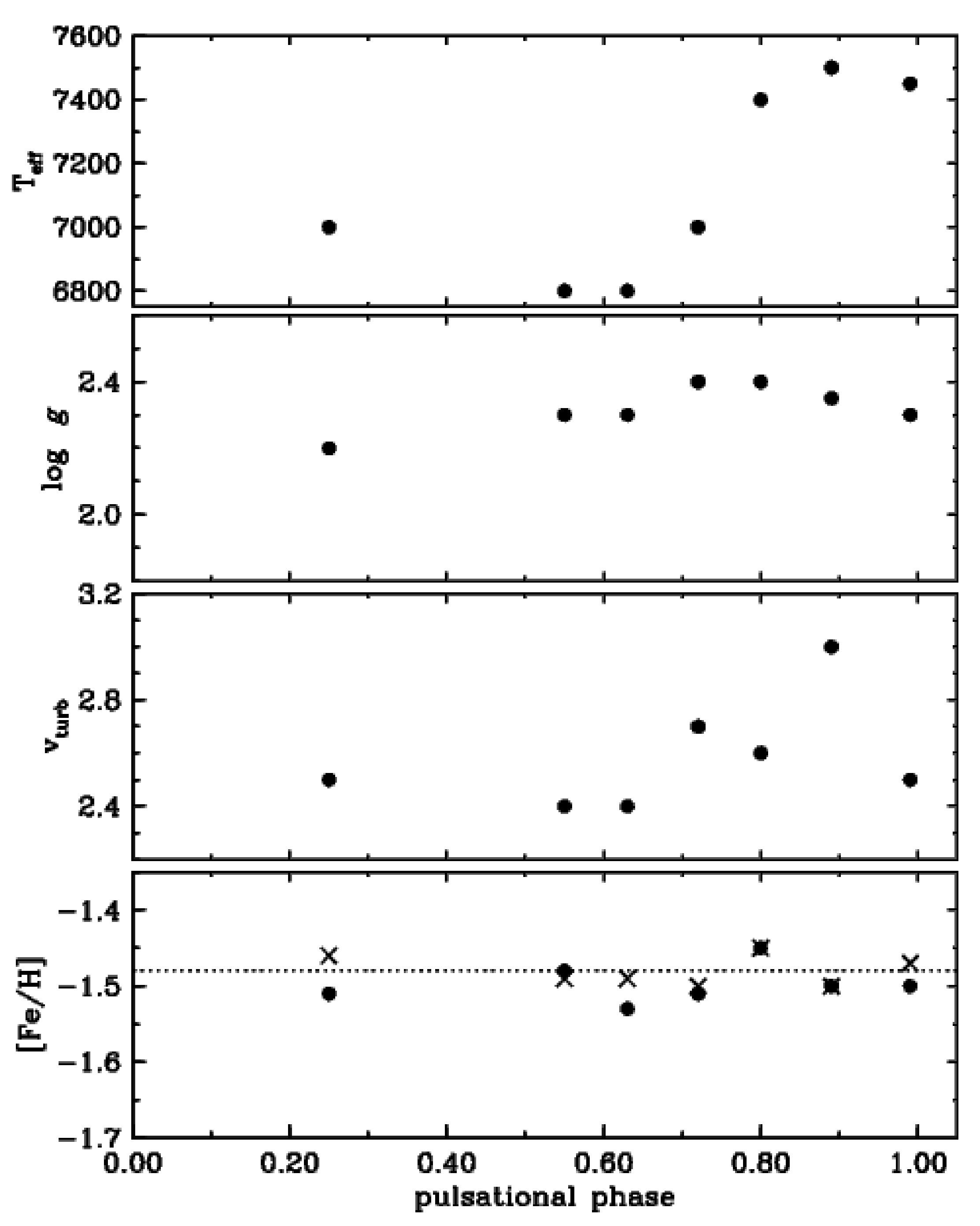


log ε = log(NFe/NH) + 12

 [Fe/H] ~ -1.5

Doing a multi-phase analysis of YZ Cap (RRc)

note the lower microturbulenc e



For a large survey: the All Sky Automated Survey (ASAS)

ASAS is a low cost project dedicated to constant photometric monitoring of the whole available sky, which is approximately 107 stars brighter than V =14. The project's ultimate goal is detection and investigation of of any kind of the photometric variability.

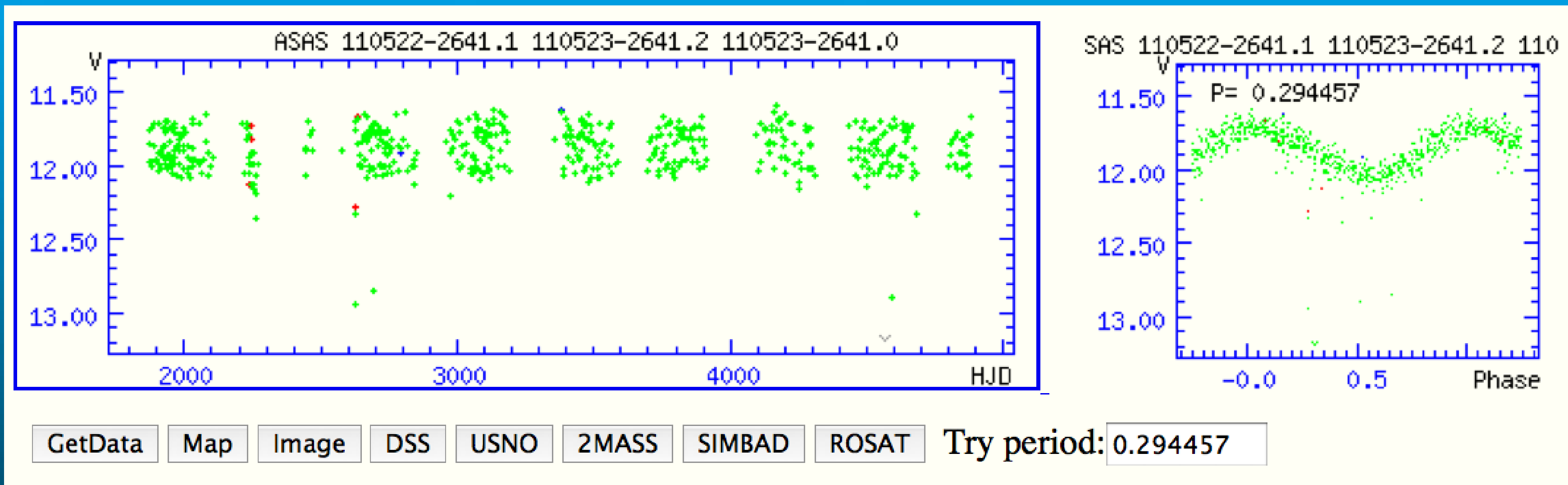
ASAS consists of two observing stations, one in LCO, Chile (since 1997) and the other on Haleakala, Maui (since 2006). Both are equipped with two wide-field instruments, observing simultaneously in ***V*** and ***I*** band. ASAS system is fully automated

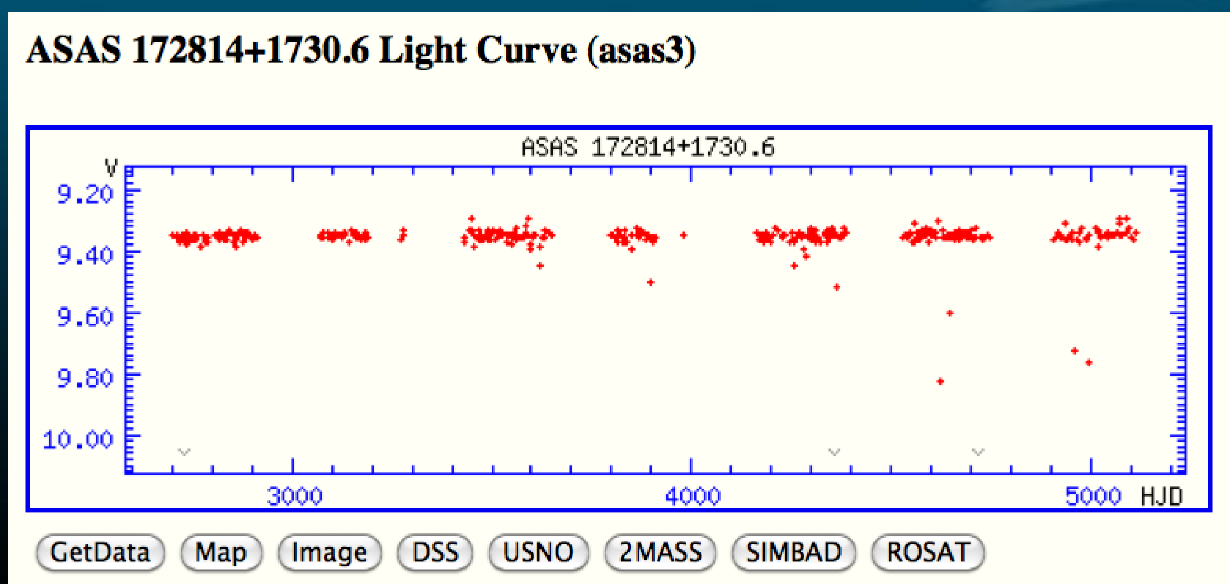
http://www.astrouw.edu.pl/asas/?page=main

Consider ASAS 110522-2641.0 here are "the facts"

Field	Value	Units	Description
ID	110522-2641.0		ASAS identification (RA and DEC in the format: hhmmss+ddmm.m)
RA (2000)	11:05:21.9	[h:m:s.s]	Right ascension (FK5) Equinox=J2000
DEC (2000)	-26:40:59.9	[d:m:s.s]	Declination (FK5) Equinox=J2000
Period	0.294457	[days]	Period (or characteristic time scale of variation for irregular objects)
T_0	2451870.5	[days]	Epoch of minimum (for eclipsing) or maximum (for pulsating) brightness
V max	11.66	[mag]	Magnitude in V at maximum brightness
V amp	0.39	[mag]	Amplitude of variation in V
I max	-	[mag]	Magnitude in I at maximum brightness
I amp	-	[mag]	Amplitude of variation in I
Class	RRC		Type of variability in ASAS classification
Other ID	-		Other identification (mainly from GCVS)
Other Class	-		Type of variability in GCVS classification
IR_12	-	[mag]	-2.5 log (IRAS flux density at 12 μm)
IR_25	-	[mag]	-2.5 log (IRAS flux density at 25 μm)
IR_60	-	[mag]	-2.5 log (IRAS flux density at 60 μm)
IR_100	-	[mag]	-2.5 log (IRAS flux density at 100 μm)
J	11.18	[mag]	J magnitude from 2MASS
H	11.03	[mag]	H magnitude from 2MASS
K	11.01	[mag]	K magnitude from 2MASS
Check	✗	-	If set: this star is to be checked.
New	✗	-	If set: this star is new in the catalogue.
V-IR_12	-	[mag]	Color index
V-J	0.480	[mag]	Color index
V-H	0.630	[mag]	Color index
V-K	0.650	[mag]	Color index
J-H	0.15	[mag]	Color index
H-K	0.02	[mag]	Color index

Comparing ASAS 110522-2641 to a non-variable





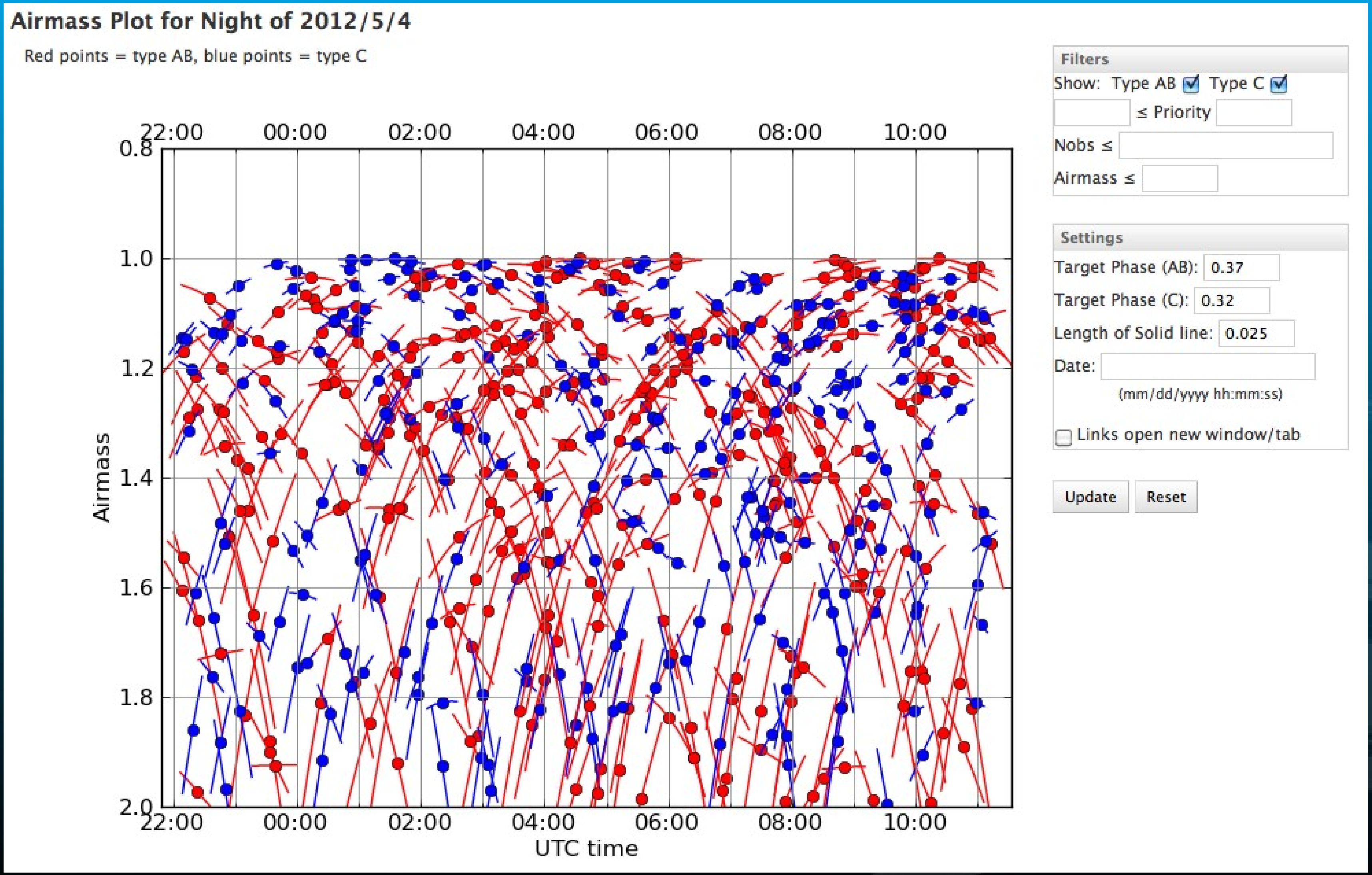
A large RRab and RRc kinematic/metallicity survey

- **Leader: Juna Kollmeier (Carnegie)**
- Observers: George Preston, Ian Thompson et al.
- ASAS selection of targets
- V <~ 15
- Du Pont echelle spectra (R~30K)
- Snapshot spectra at one phase (~0.35)
- Low S/N: ~5-30
- My task: metallicities reliable to ~0.2 dex
- A grid spectrum matching approach

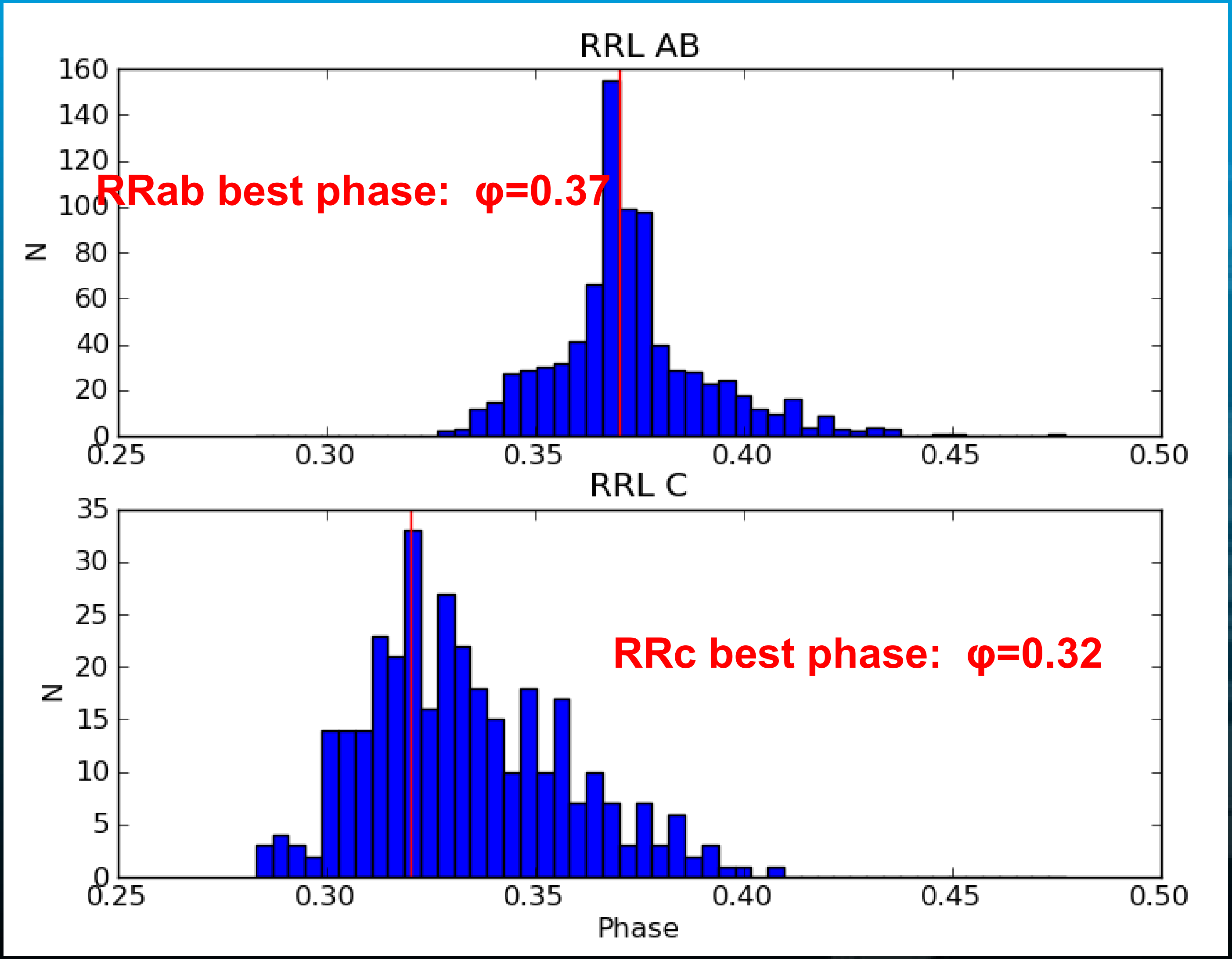
Survey Goals

- spectroscopic Echelle observations of ≈1400 RR Lyrae stars
  - 1000 RRab, 400 RRc from the All Sky Automated Survey.
- state-of-the-art RR Lyrae absolute magnitude scale
  - statistical parallaxes scale as the inverse square of the sample size
  - So this could be most precise before GAIA
- Provide high-resolution, broad-band spectra for these objects
- first estimate of RR Lyrae absolute magnitude scale for RRc's
  - new distance scale measurement

What a survey observer sees in planning a night

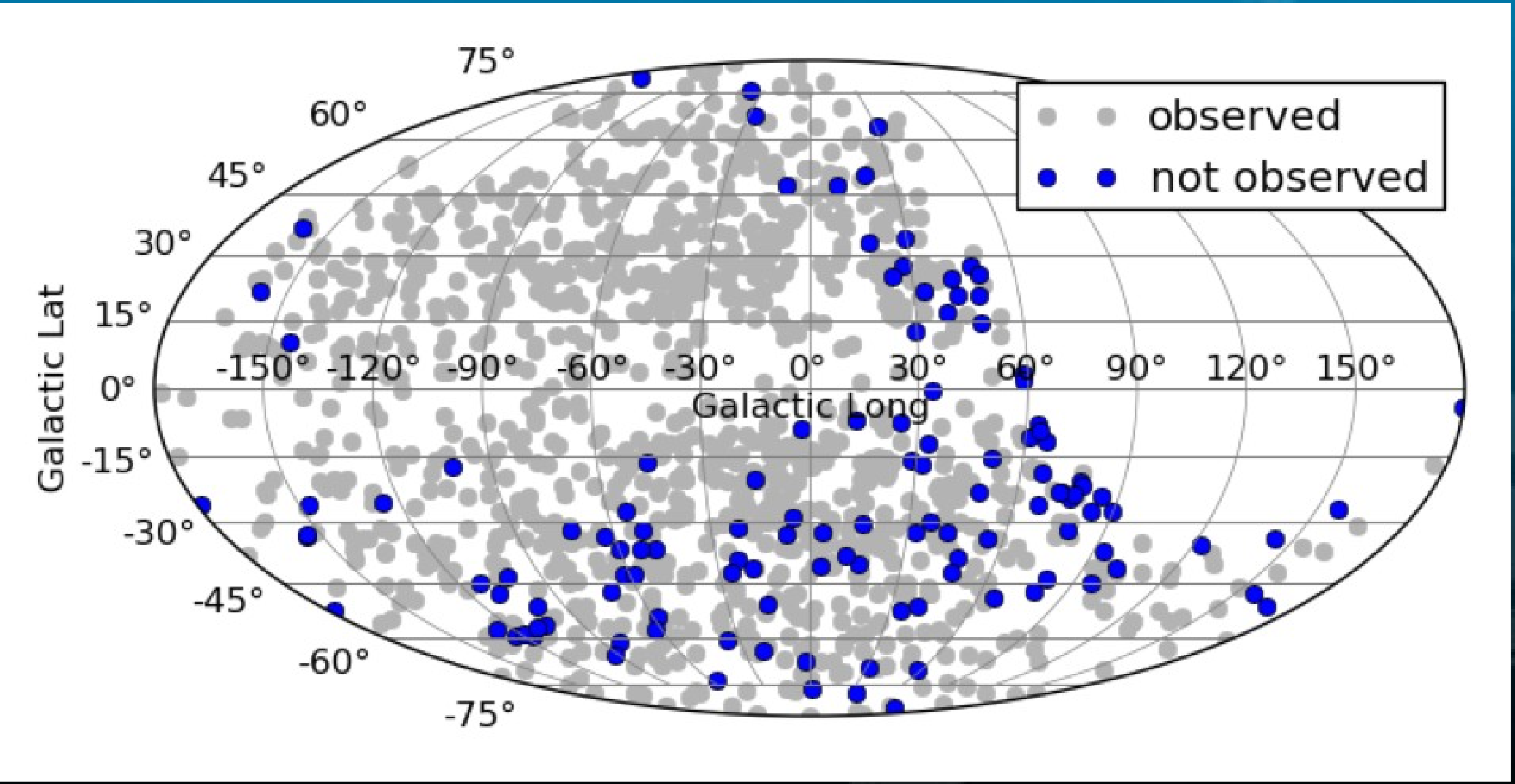


Mostly done a good job at hitting the right phases

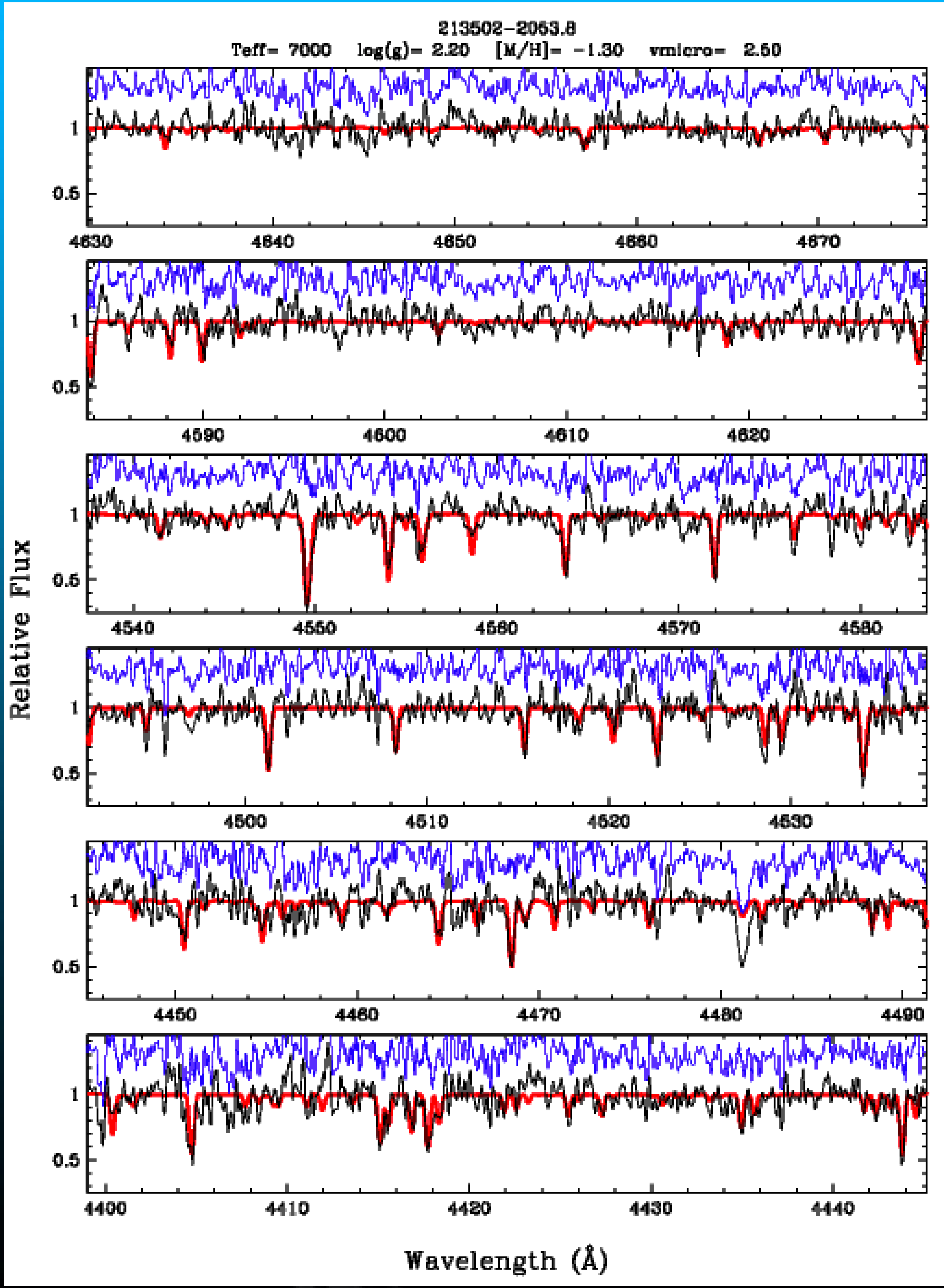


Observation Stats

Number of nights with observations:	53
Average number of objects per night	43.2
Number of Objects Observed:	764 type AB 314 typeC



Two spectral regions chosen for metallicity determinations



4400-4675A:

(1) Dominated by ionized species; might be a gravity check

(2) 4500-4530A

(3) S/N degrading toward blue end

(4) Ba II 4554A can give neutron-capture hints

Two spectral regions chosen

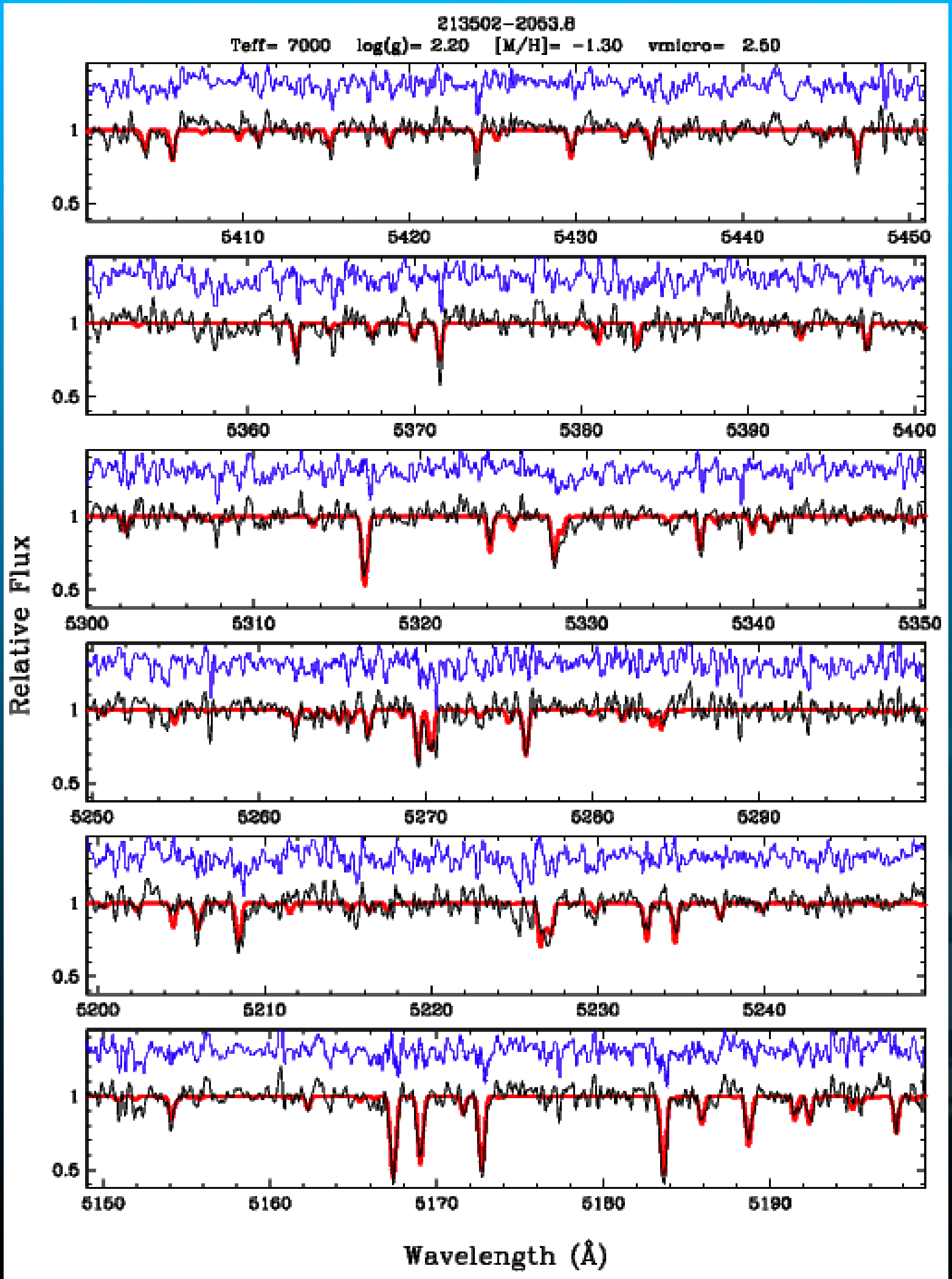
5150-5450A:

(1) Dominated by neutral species

(2) Mg I b triplet is prominent

(3) S/N relatively good

(4) Metallicities from whole region or just the Mg lines



Simple χ2 metallicity estimates

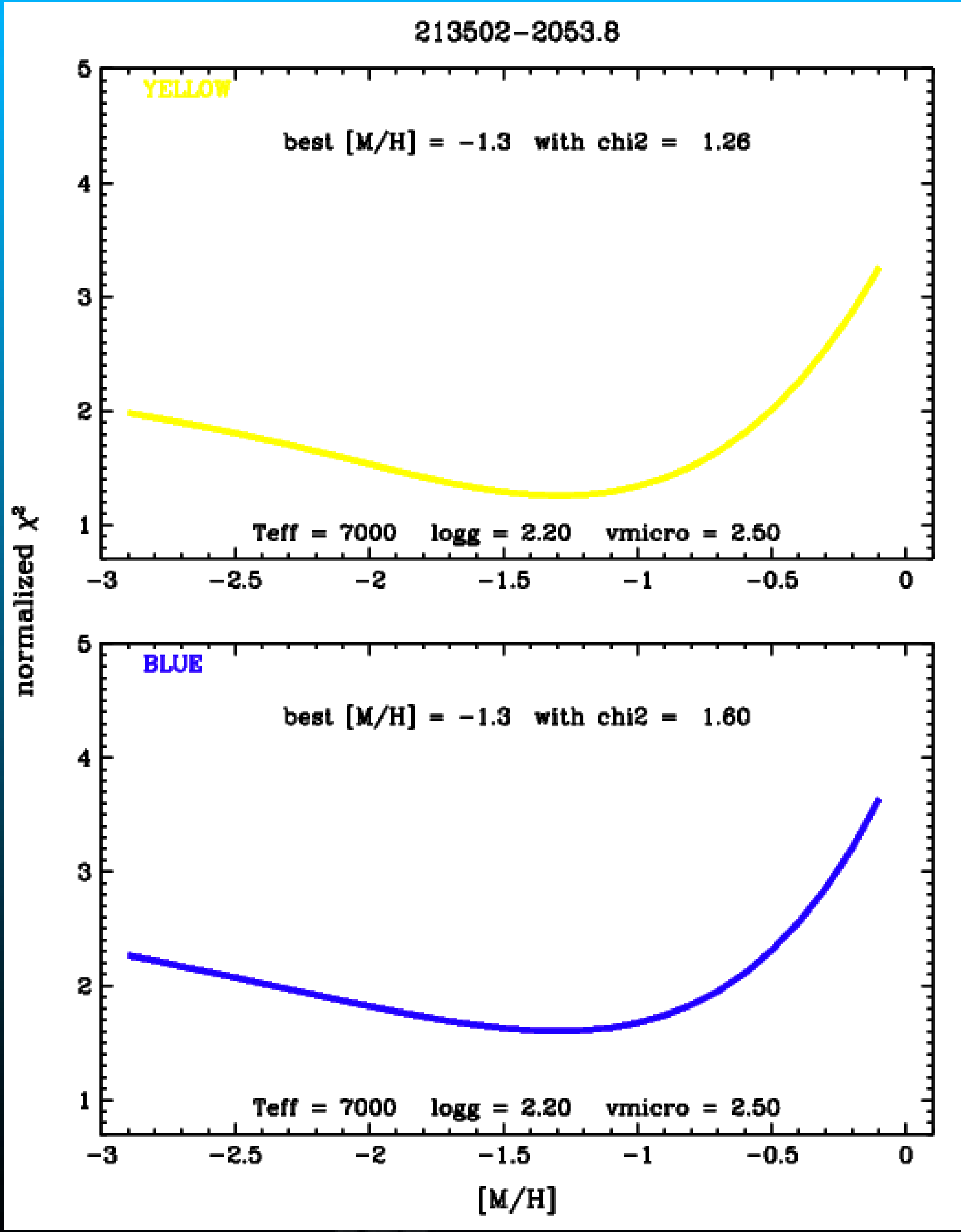
COMMENTS:

(1) Obviously best for higher S/N

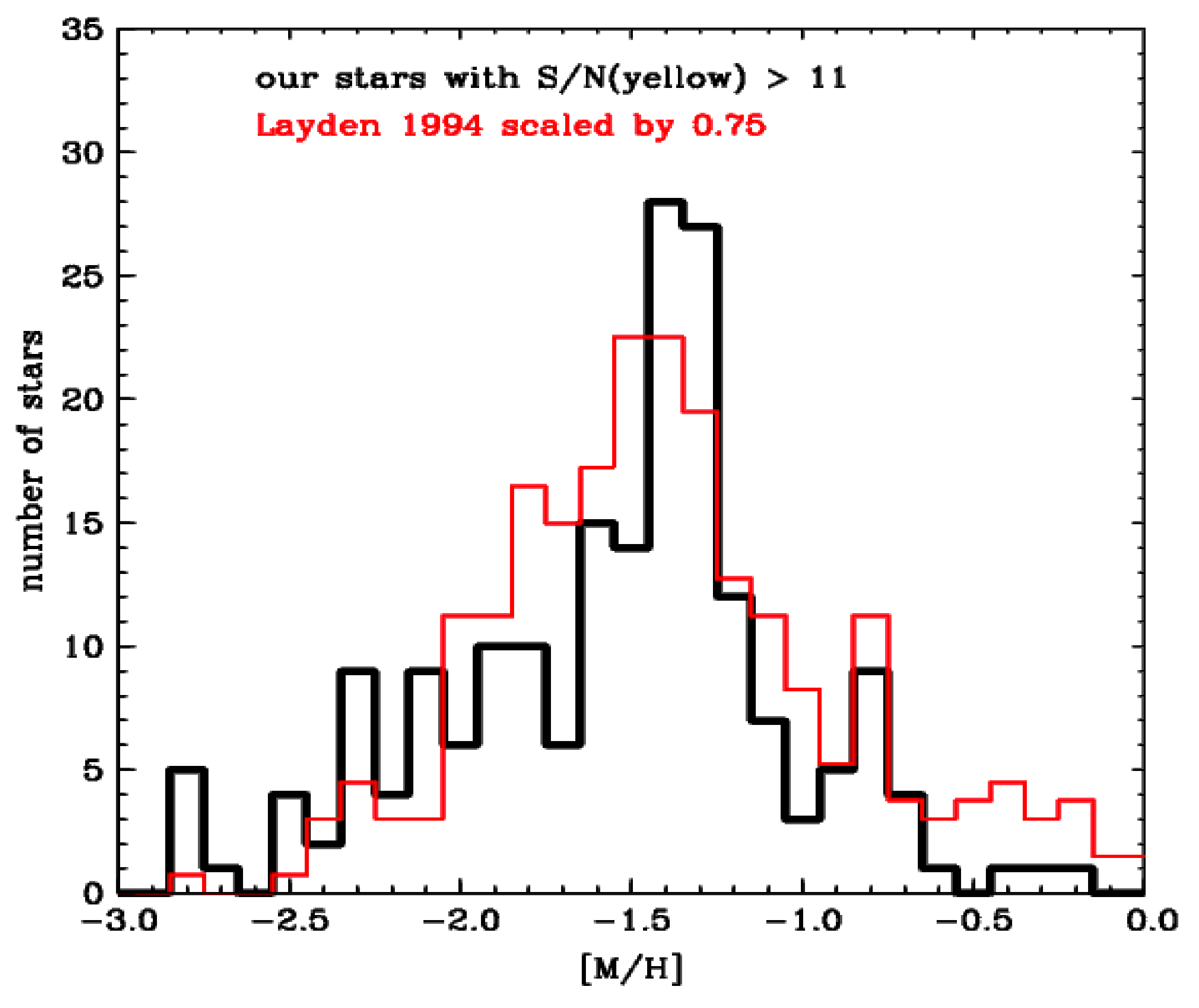
(2) Asymmetry of curves are real

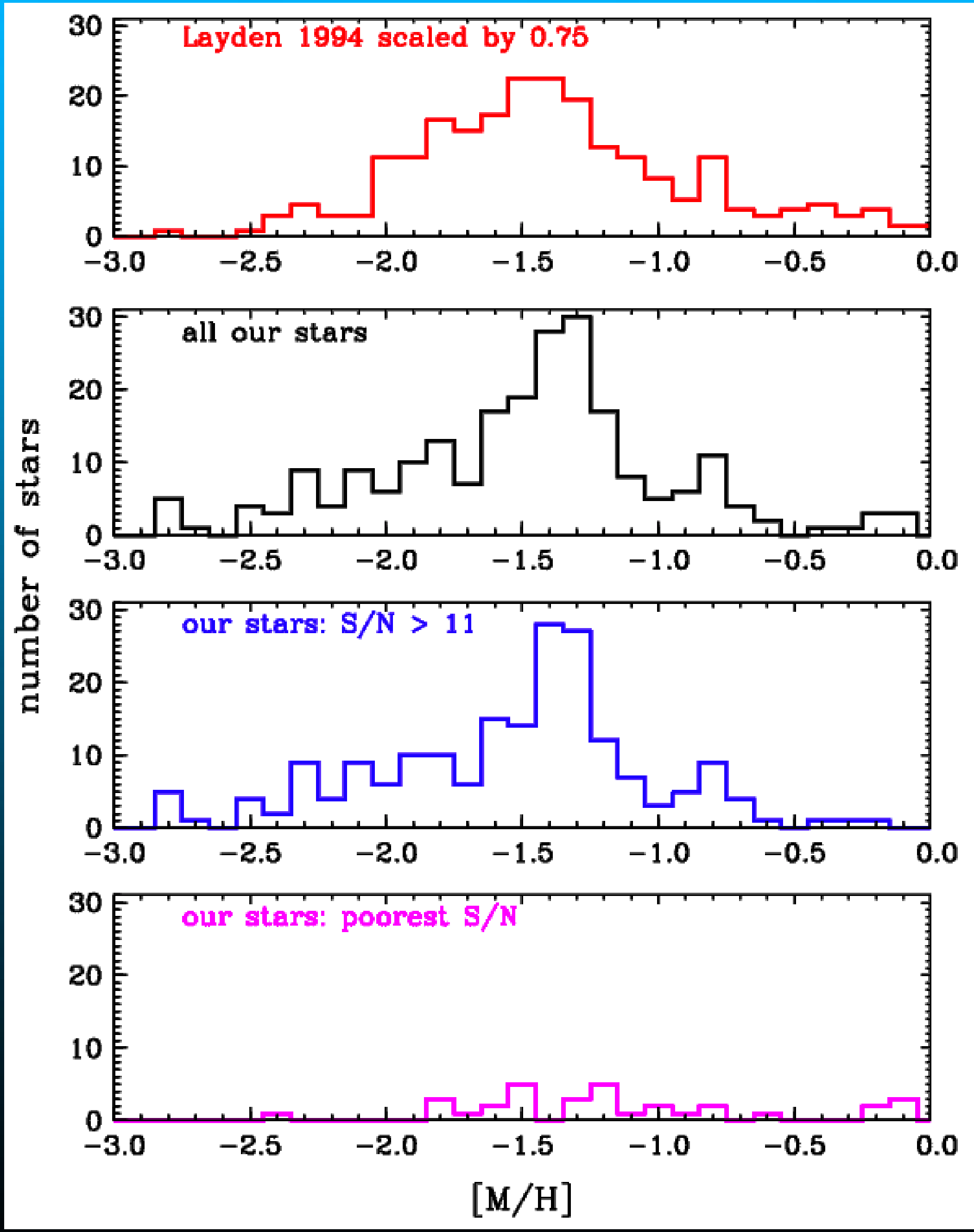
(3) Sensitivity to metallicity weakens at low [M/H]

(4) next: extending estimates to smaller spectral intervals (e.g. Mg I b lines)



Preliminary results are encouraging





We don't have the algorithms tuned perfectly; there is a S/N dependency

Some immediate futures:

- Tune the metallicity algorithms
- Understand how to handle lowest & highest S/N stars
- Home in on indivividual transitions
- Extend to RRab stars
- Atmospheric parameter sensitivities
- Mate with kinematics to discriminate between thick disk & halo stars
- Enough to keep us very busy!