



STARS:
CRAZY COMPOSITION,
PUZZLING PULSATION,
AND CHAOTIC KINEMATICS

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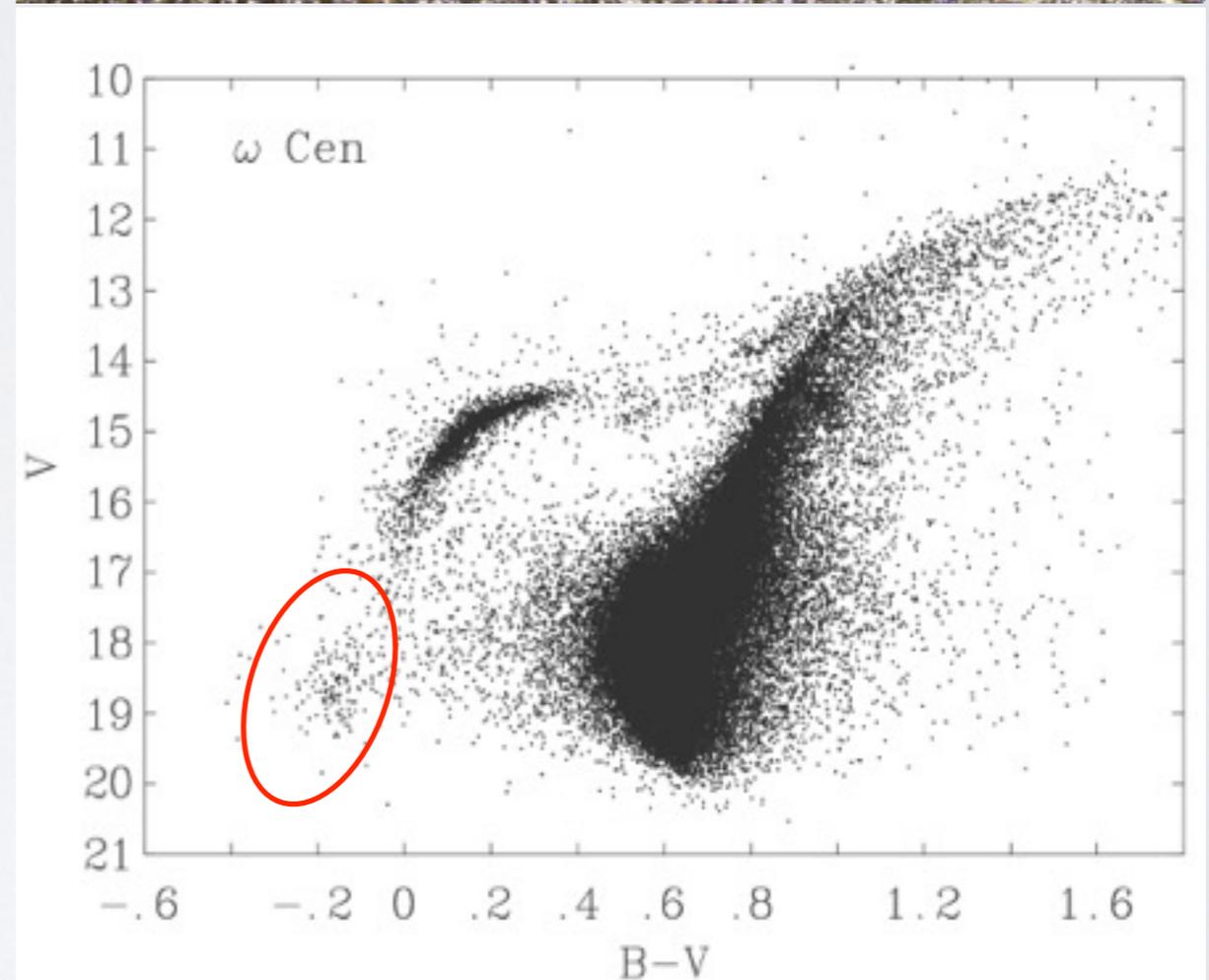


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OUTLINE

- Horizontal-branch stars, hot subdwarfs, and helium-rich hot subdwarfs
- The zirconium subdwarf: LS IV-14 116
- The lead subdwarfs
- Puzzling pulsations
- Chaotic kinematics



ω Cen: Hesser + 1987.

A HORIZONTAL-BRANCH STAR

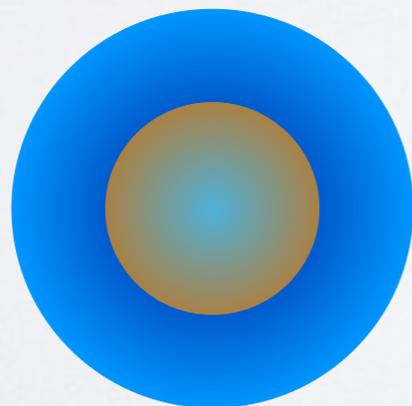
consists of a helium core and a hydrogen envelope. Structure may be defined by four parameters:

M_{core} : core mass

M_{env} : envelope mass

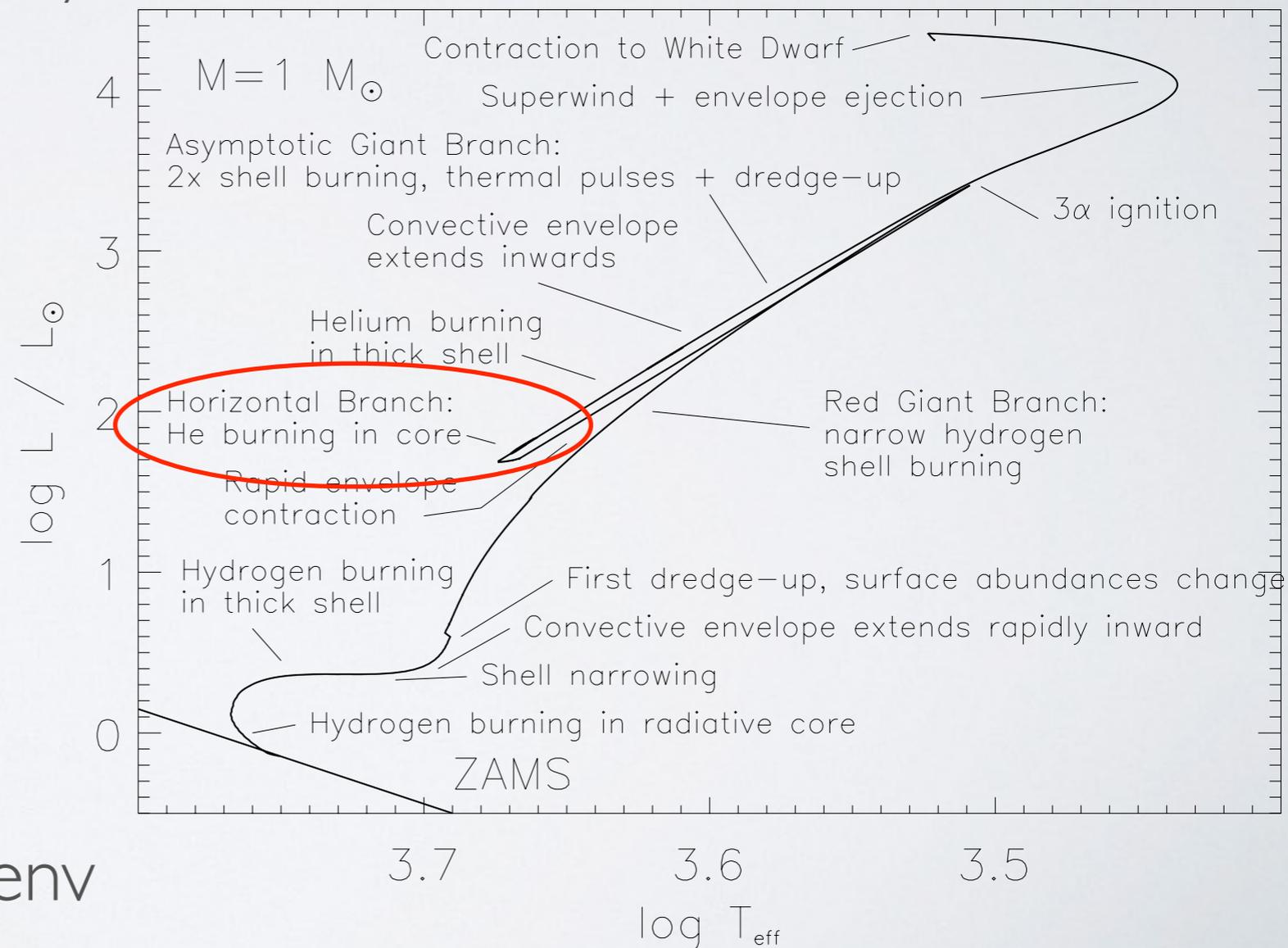
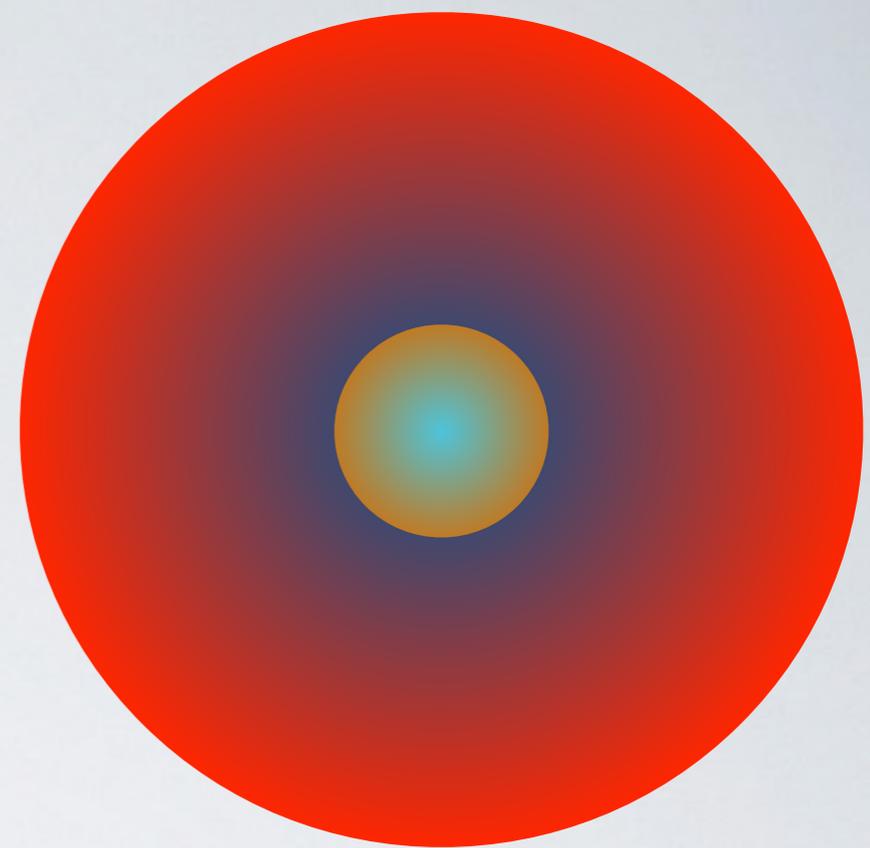
Y_{env} : envelope helium

Z : metallicity

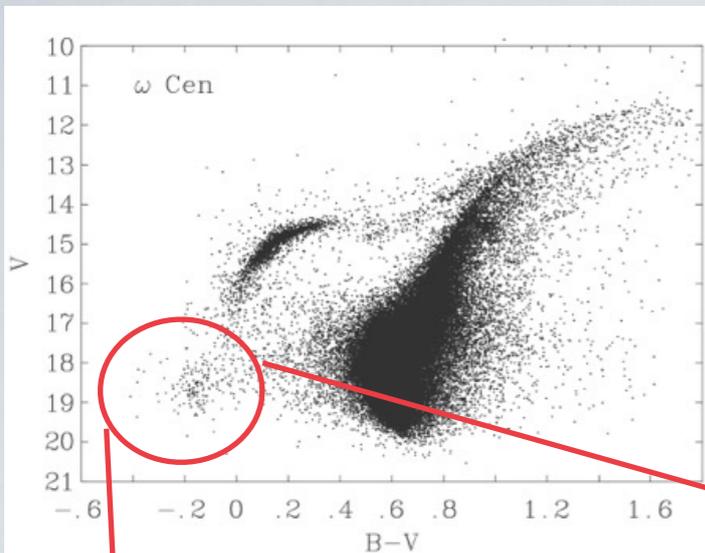


low Z , low M_{env}

high Z ,
high M_{env}



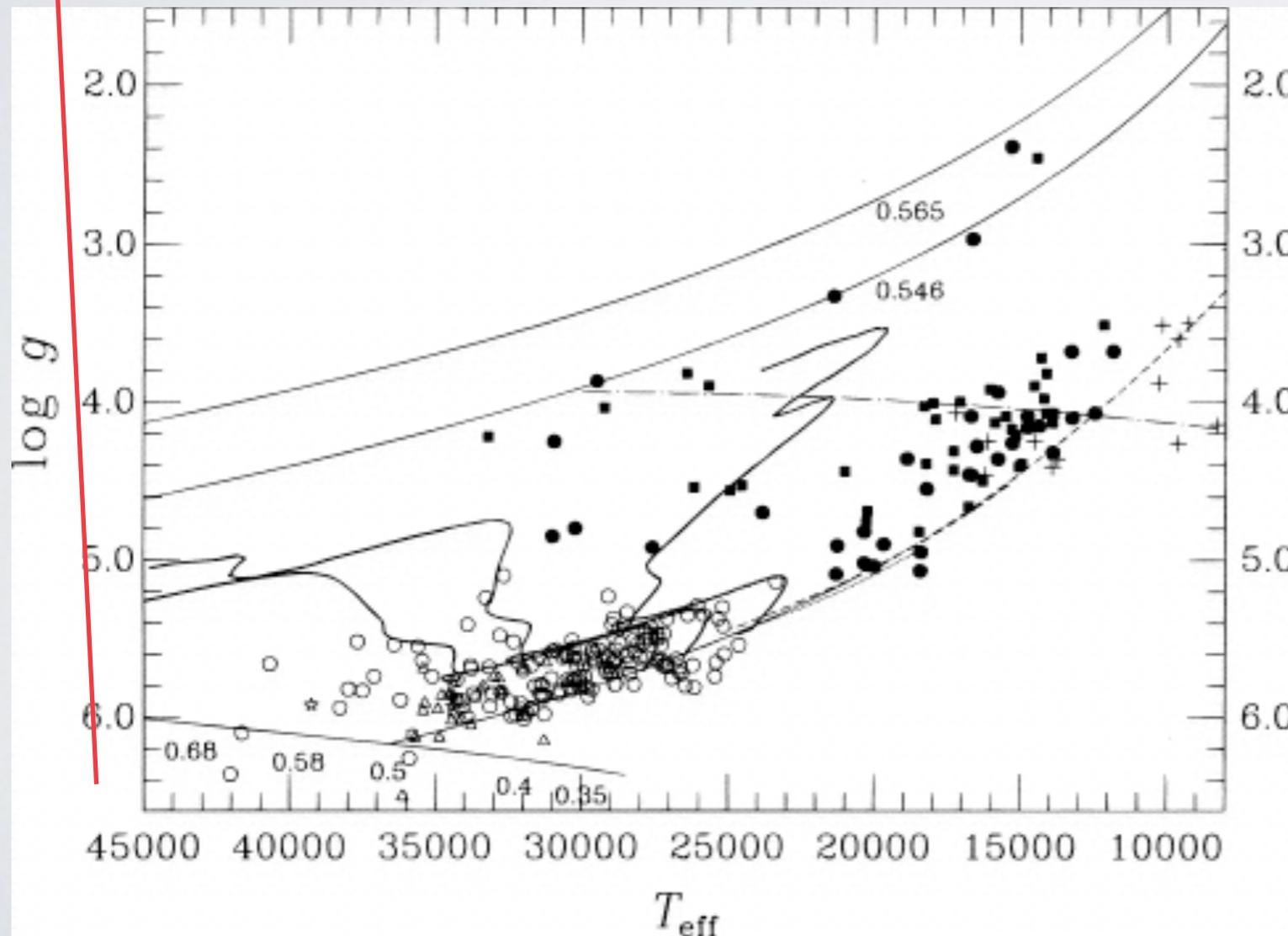
NON-CLASSICAL HB: SUBDWARF B STARS

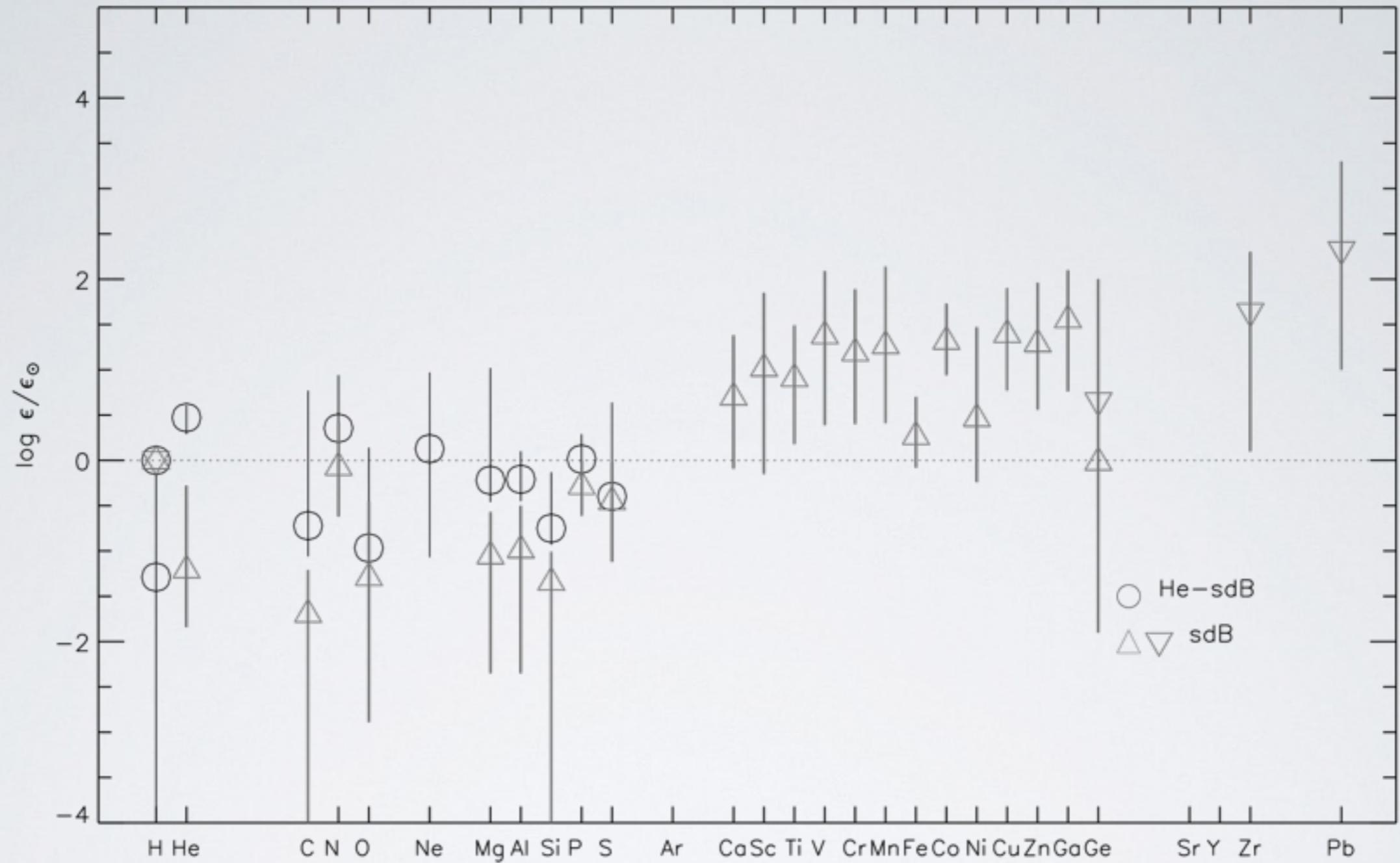


Field subdwarf B stars
(Greenstein & Sargent 1966)

Subdwarf B stars and blue-
horizontal branch stars in
the field, ...

with evolution tracks for
EHB stars with $M_{\text{core}}=0.5$
 M_{sun} (Saffer et al. 1997)





NORMAL SDB STAR SURFACES: Δ

He and C - S: $\odot / 10$

N, Fe, Ni: \odot

Ca - Ga: $\odot \times 10$

HELIUM-RICH SUBDWARFS

Palomar-Green survey of faint-blue objects finds many hot subdwarfs.

1) sdB: $\text{He} < 1\%$

However, many are **helium-rich**

2) sdO, sdOB,
sdOC = He-sdO,
sdOD = He-sdB

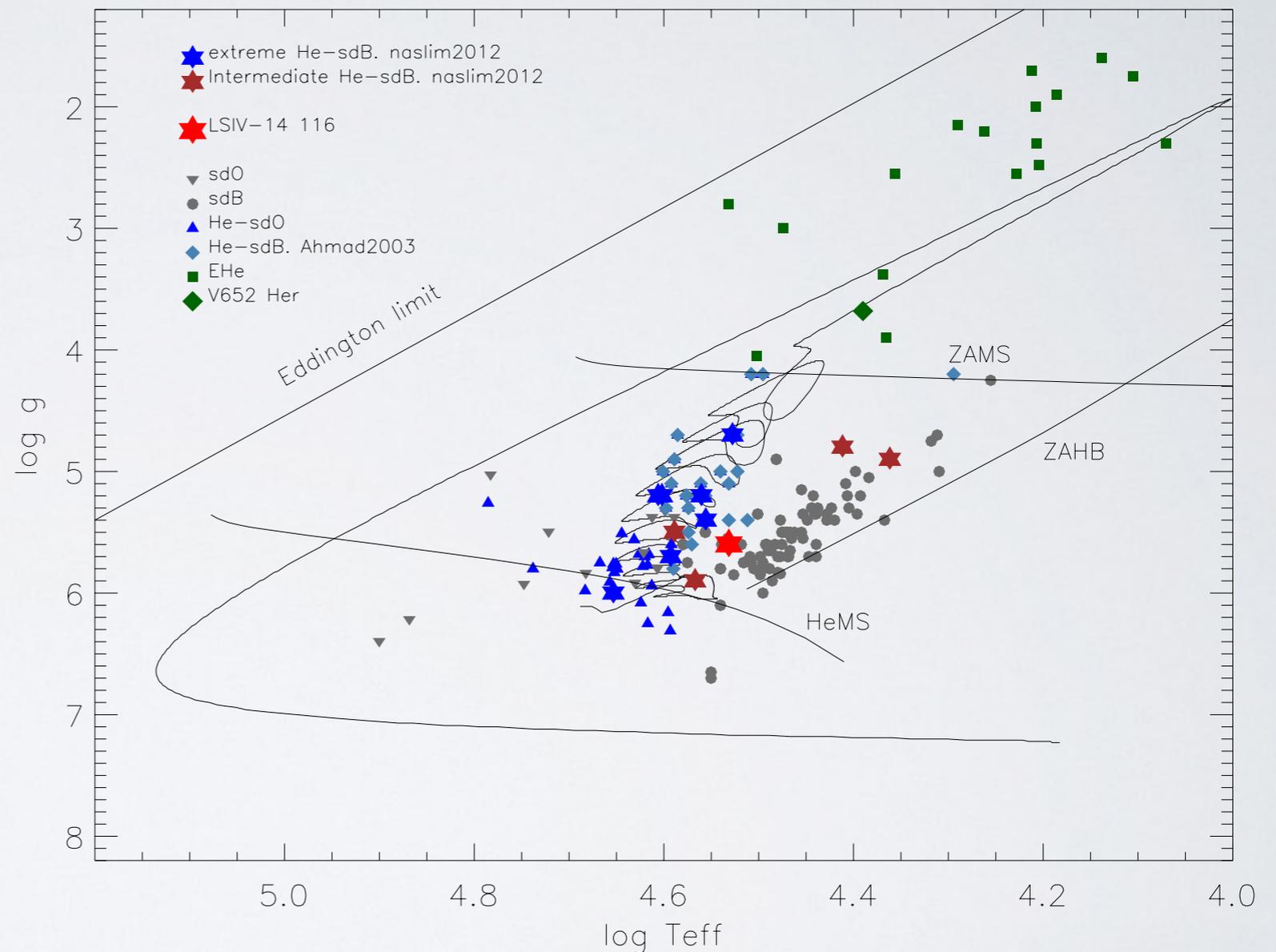
+SDSS+EC+HE+Galex:
> 250 He-sds.

(cf. over 3000 sdBs)

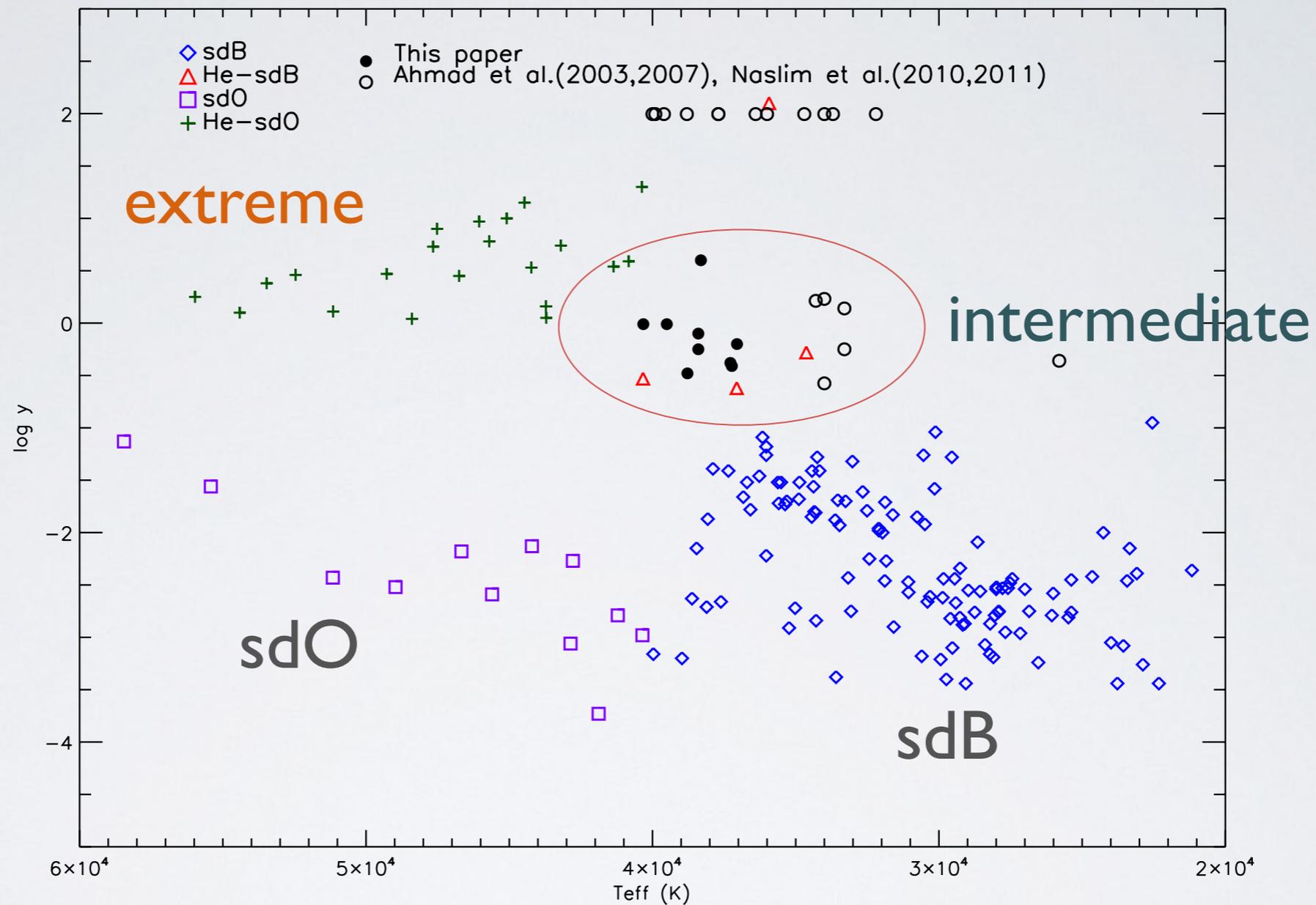
Spectroscopic analysis \rightarrow

extreme: $\text{H} < 10\%$

intermediate: $10\% < \text{H} < 99\%$



HOT SUBDWARFS BY HELIUM ABUNDANCE



Distribution of helium abundance with Teff for the
Galax subdwarf sample, and including IHe subdwarfs.
 $\log y = \log n_{\text{He}}/n_{\text{H}}$ (from Nemeth et al. 2012).

What does surface composition tell us?

LS IV-14°116

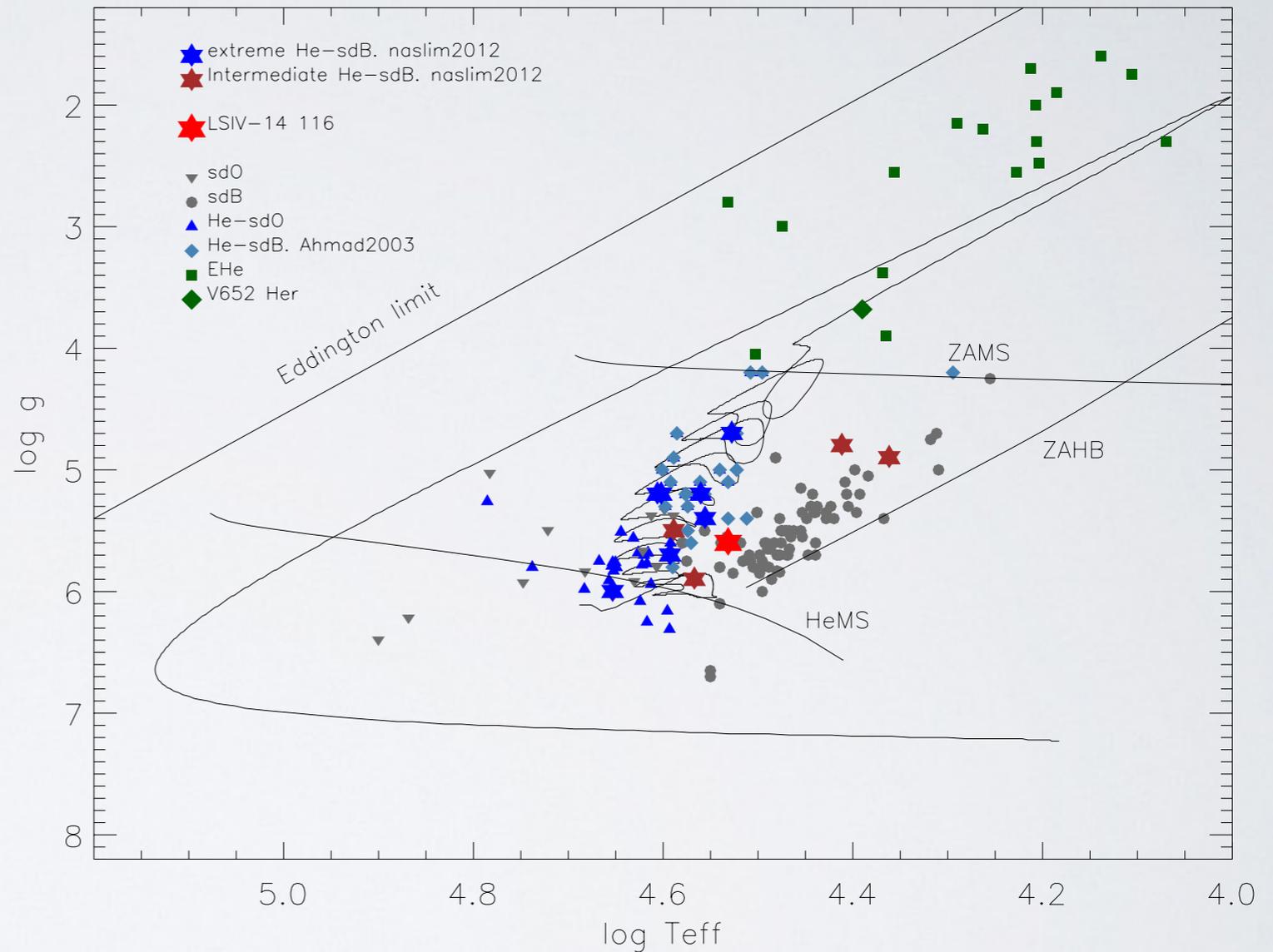
1991:
intermediate helium-rich subdwarf

2003,2004:
basic parameters (Ahmad & Jeffery)

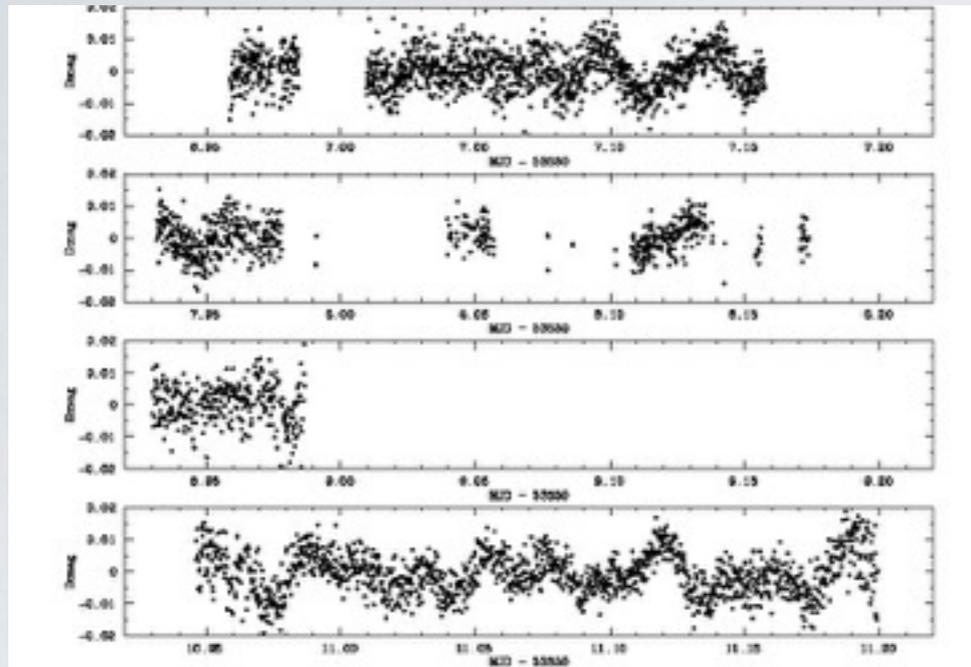
2005:
variability detected in photometry
(Ahmad & Jeffery)

2011:
g-mode pulsations confirmed
(Jeffery II, Green + II)

2010:
extraordinary surface chemistry
(Naslim + 10)



LS IV-14°116: PULSATIONS



THE ASTROPHYSICAL JOURNAL, 734:59 (8pp), 2011 June 10

Table 2
Harmonic Oscillations Detected in the Light Curve of LS IV-14°116

Period (s)	Frequency (mHz)	Amplitude (%)	Phase (s)	S/N
1953.74 ± 0.04	0.51184 ± 0.00001	0.27 ± 0.02	87 ± 17	14.9
2620.27 ± 0.21	0.38164 ± 0.00003	0.11 ± 0.02	114 ± 57	5.8
2872.33 ± 0.18	0.34815 ± 0.00002	0.14 ± 0.02	1645 ± 46	8.0
3581.79 ± 0.27	0.27919 ± 0.00002	0.15 ± 0.02	969 ± 55	8.3
4259.85 ± 0.57	0.23475 ± 0.00003	0.10 ± 0.02	2714 ± 96	5.7
5083.63 ± 0.55	0.19671 ± 0.00002	0.15 ± 0.02	3561 ± 78	8.3

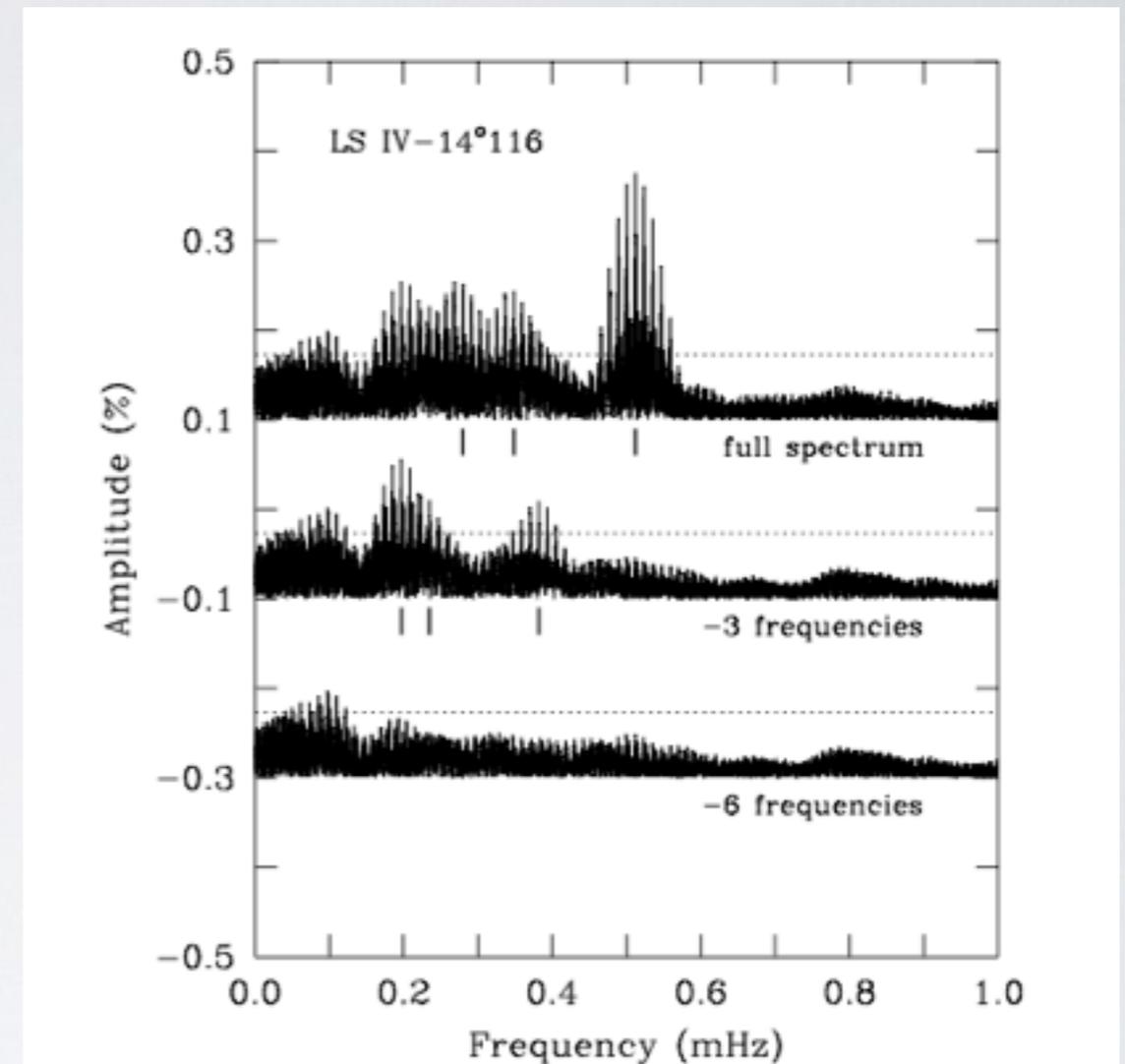
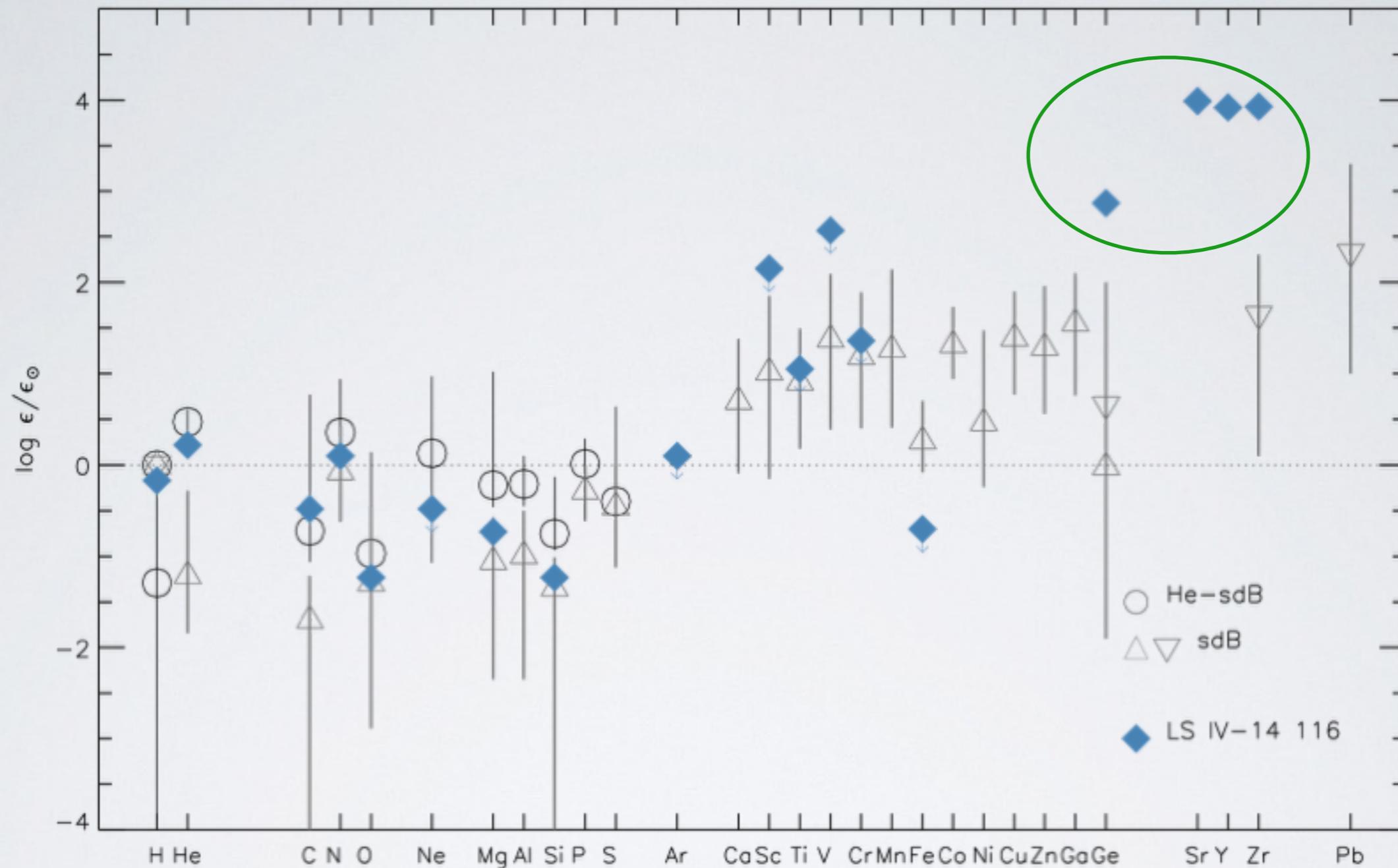


Figure 3. Zoomed-in view of the Fourier transform of the entire data set in the 0–1.0 mHz range where significant signals are found. The lower transforms show the successive steps of prewhitening by three frequencies, and finally by all six frequencies with statistically significant amplitudes. The dotted horizontal lines indicate the 4σ noise level.

Ahmad & Jeffery 2005
 Jeffery 2011
 Green + 2011



LS IV-14° 116: SURFACE ABUNDANCES: ❖

He and C - S: $\odot / 10$
 N, Fe: \odot
 Ca - Ga: $\odot \times 10$

Ge, $\odot \times 10^3$
 Sr, Y, Zr $\odot \times 10^4$

CITIES > THIRUVANANTHAPURAM

THIRUVANANTHAPURAM, December 28, 2012

Updated: December 28, 2012 15:41 IST

She reached for the stars, discovered one

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Speaker G. Karthikeyan presenting a memento to Naslim Neelamkodan, who discovered a star, at a function organised by the Kerala State Higher Education Council in Thiruvananthapuram on Thursday. Photo: S. Mahinsha

The Hindu

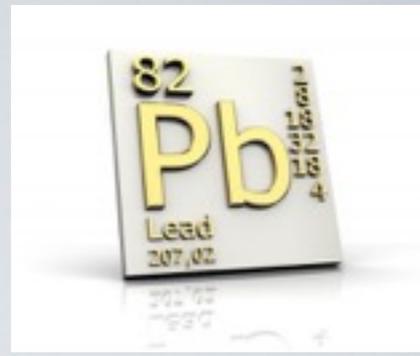
TOPICS

[Kerala](#)[Thiruvananthapuram](#)

Naslim Neelamkodan was honoured during a special function organised by the Kerala State Higher Education Council

'Star' may now be an overused tag for Naslim Neelamkodan, but it is her discovery of a real star shrouded in glittering zirconium metal, 2,000 light years away, that has earned this most befitting title for the 27-year-old Ph.D. holder.

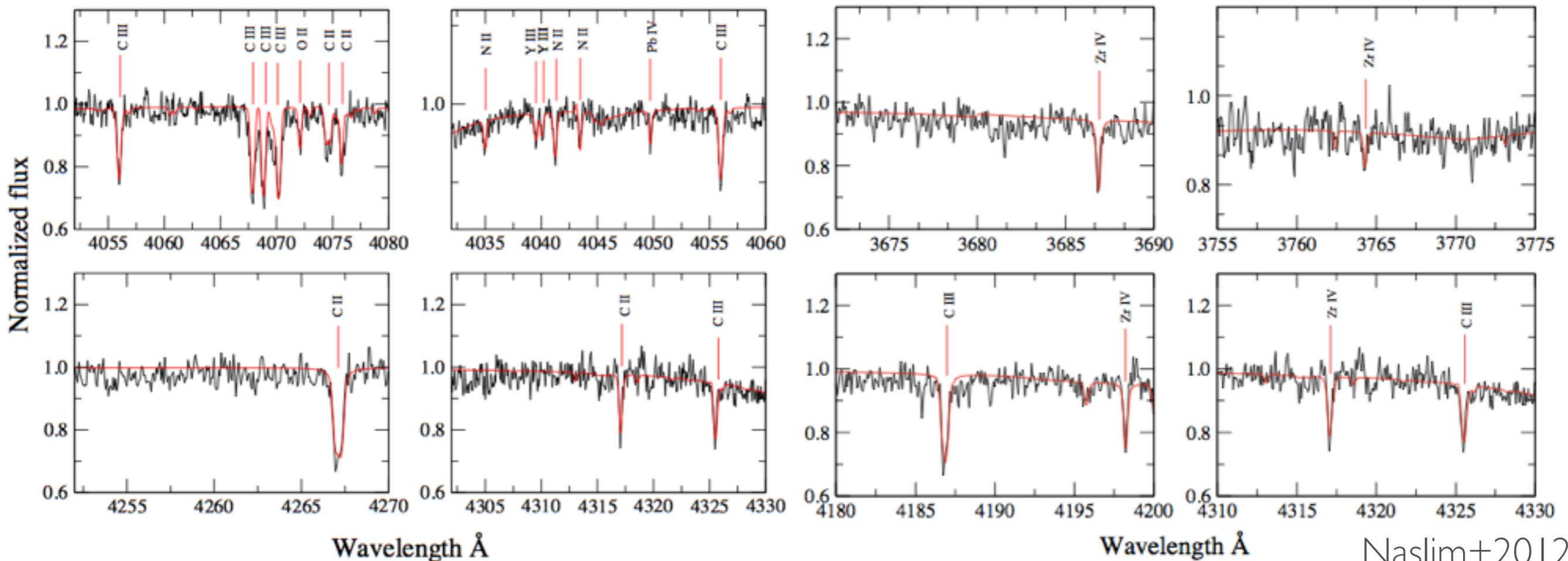
LEAD!



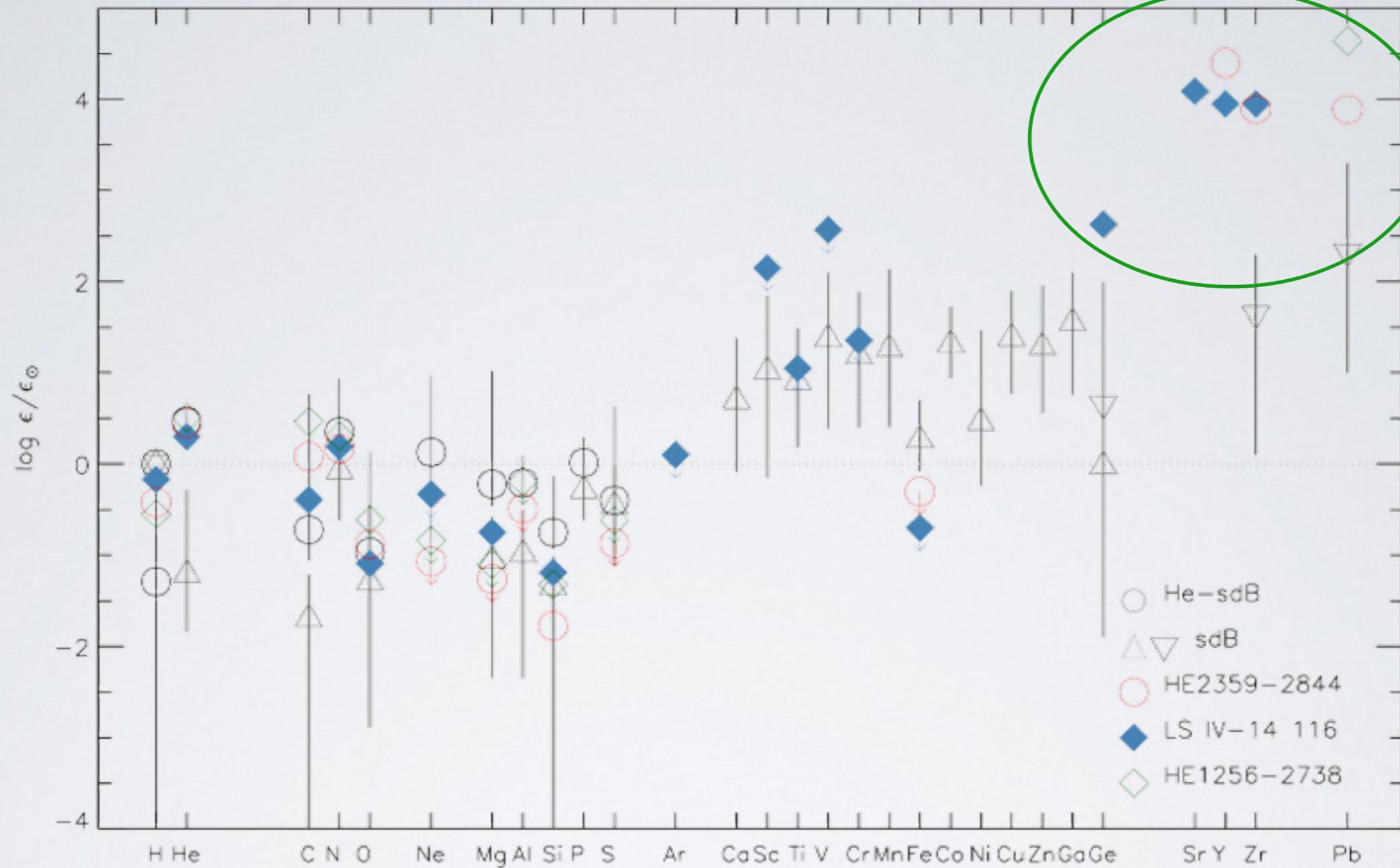
WiFES, FEROS, VLT/UVES spectroscopy of IHe and EHe sdBs.

Pb IV never seen in optical spectra, but seen in UV for sdB stars.

Very **narrow lines**: $v_{\text{rot}} \sin i < 5 \text{ km/s}$



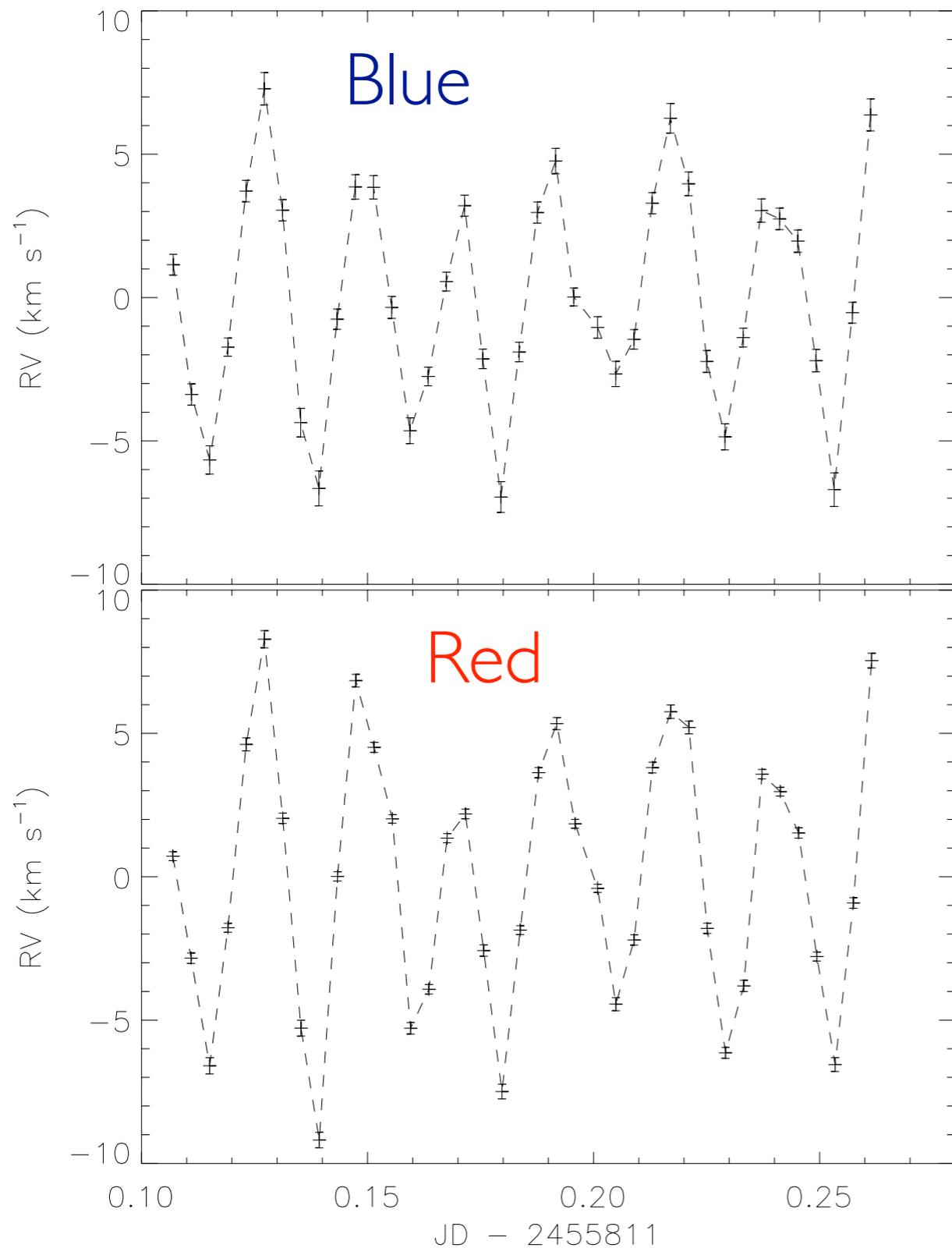
Naslim+2012



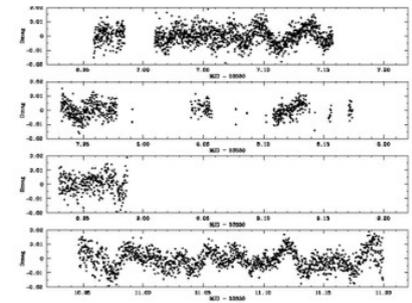
THE HEAVY METAL STARS

He and C - S:	○ / 10	Ge,	○ × 10 ³ ₄
N, Fe:	○	Sr, Y, Zr	○ × 10 ⁴ ₄
Ca - Ga:	○ × 10	Pb	○ × 10

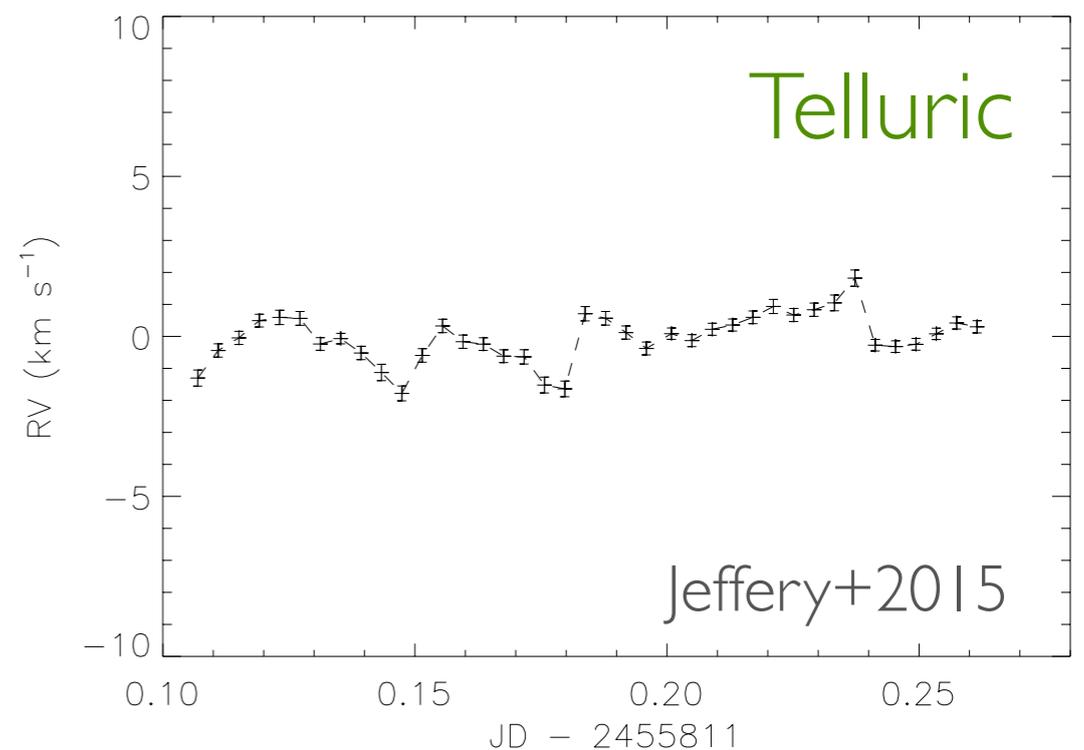
LS IV-14°116: RADIAL VELOCITIES



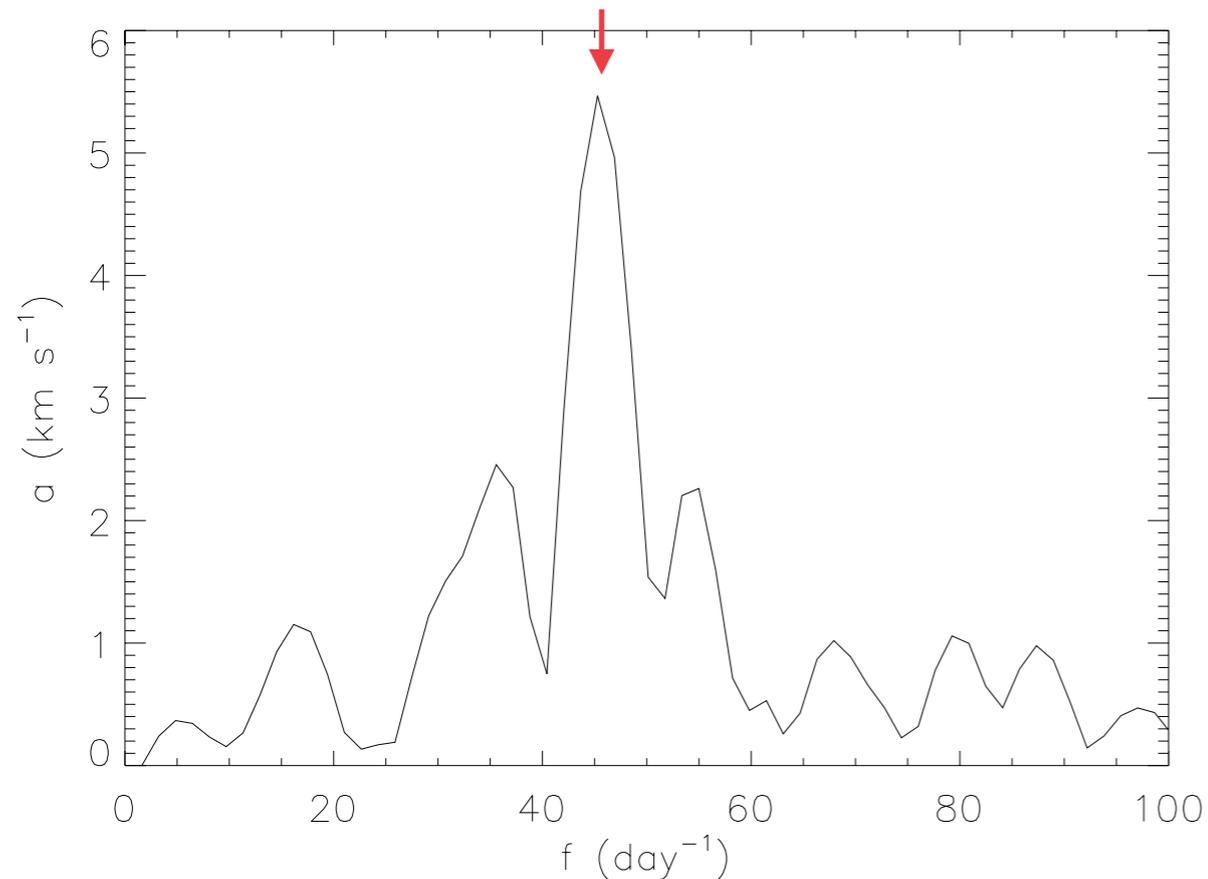
2011: VLT/UVES
4h service: 39x300s



Cross-correlation relative to median spectrum, repeated over three CCDs and for isolated wavelength ranges, including telluric lines (below).



LS IV-14°116: RADIAL VELOCITIES



2011:VLT/UVES

Classical power spectrum,
peak corresponds to $f_1 = 1953\text{s}$.

Phased velocities OK.

Residuals $>$ errors \Rightarrow additional frequencies

THE ASTROPHYSICAL JOURNAL, 734:59 (8pp), 2011 June 10

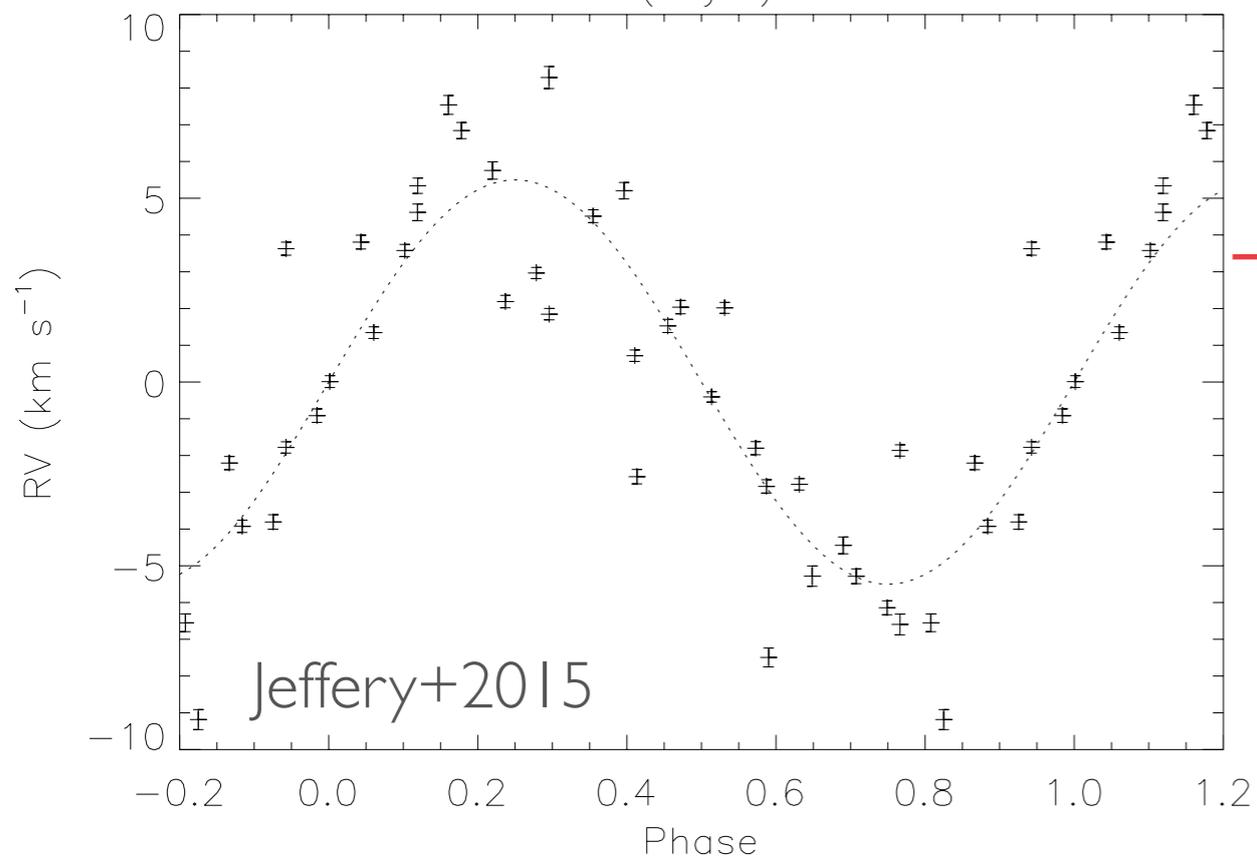
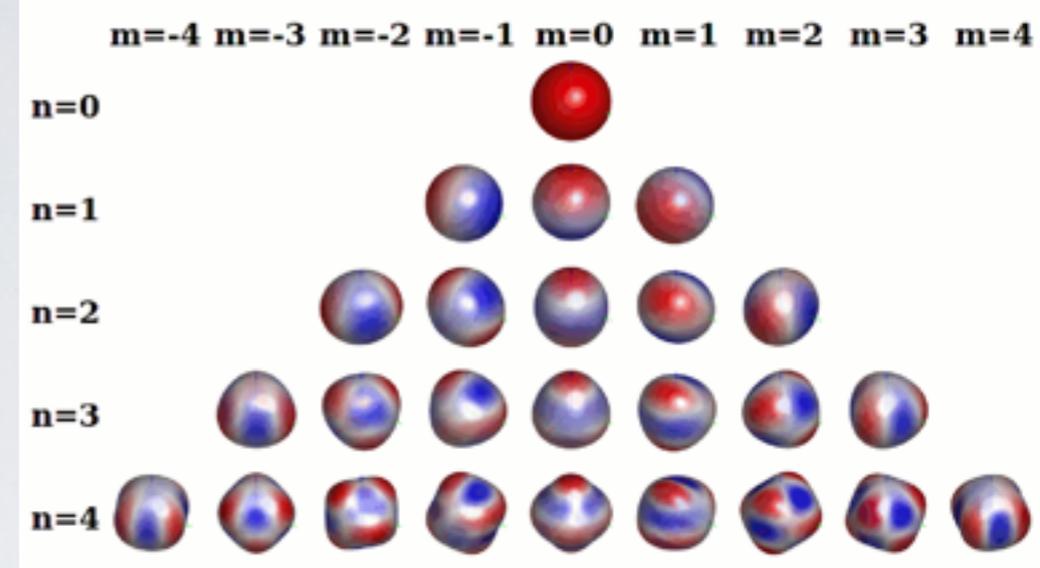


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Green + 2011

LS IV-14°116: PULSATIONS



Detected oscillations at $f = 43.8 \text{ d}^{-1}$ ($\sim 1950 \text{ s}$)

Velocity amplitude $a \sim 5 - 6 \text{ km s}^{-1}$

Amplitude a function of line strength, hence of **optical depth**.

Light / velocity amplitude ratio: $\delta V / \delta v \sim 0.5 \text{ mmag km}^{-1} \text{ s}$

From models: for $l=0, 1, 2$: $\delta V / \delta v \sim 2, 0.5, 0.5 \text{ mmag km}^{-1} \text{ s}$, hence
1950 s mode **cannot** be radial ($l=0$).

sdB stars pulsate in p- and in g- modes, depending on T_{eff}

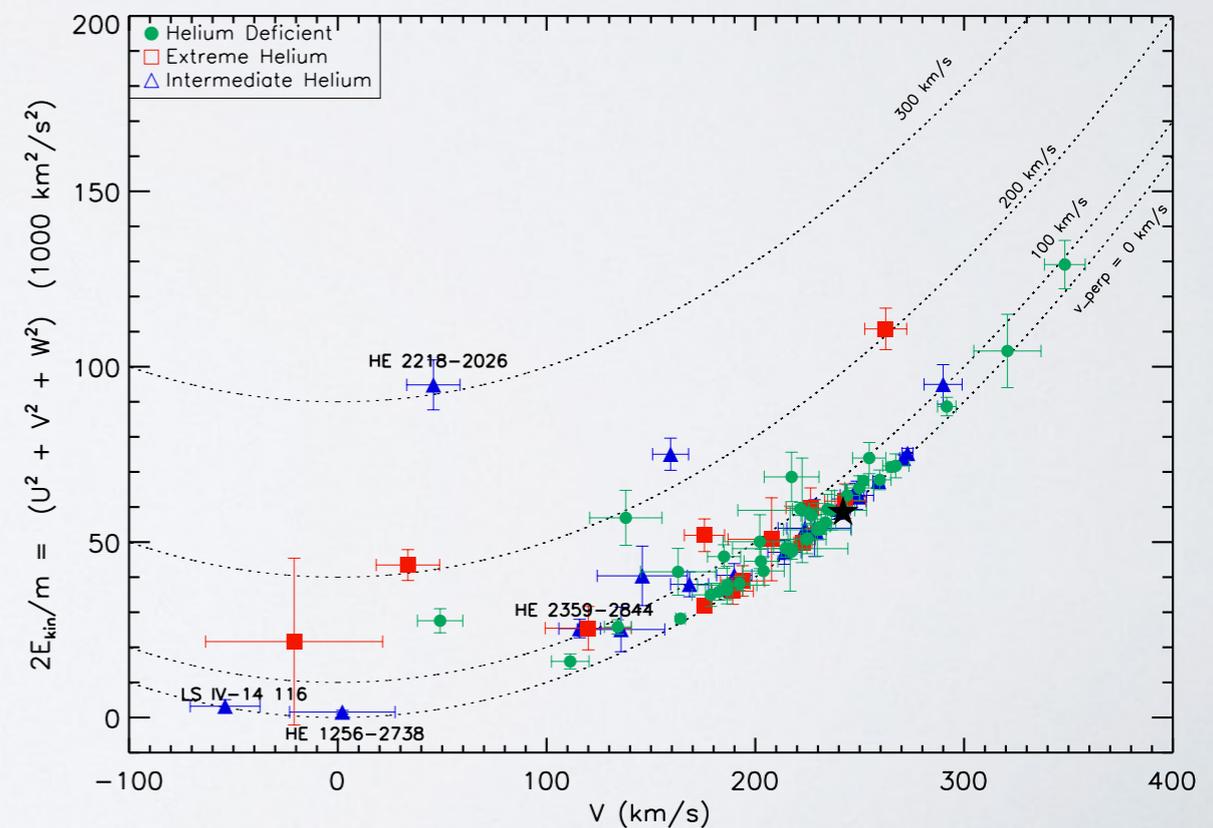
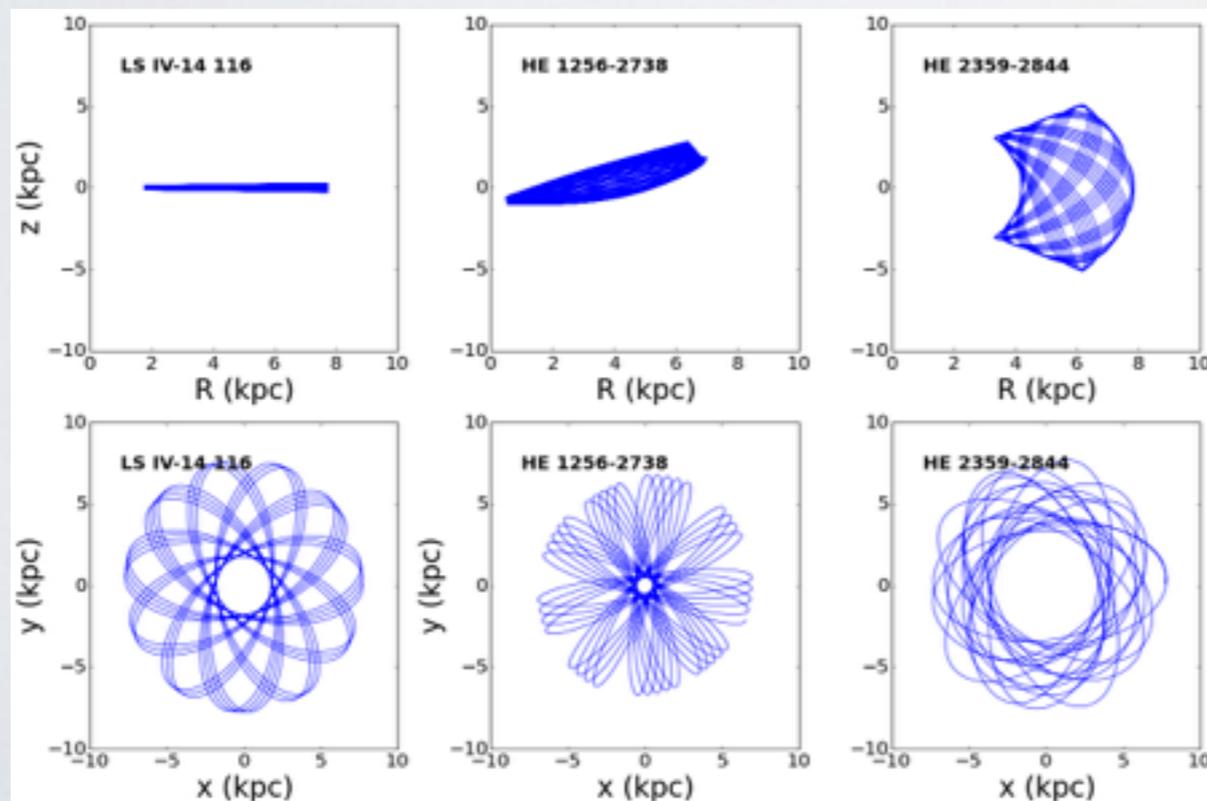
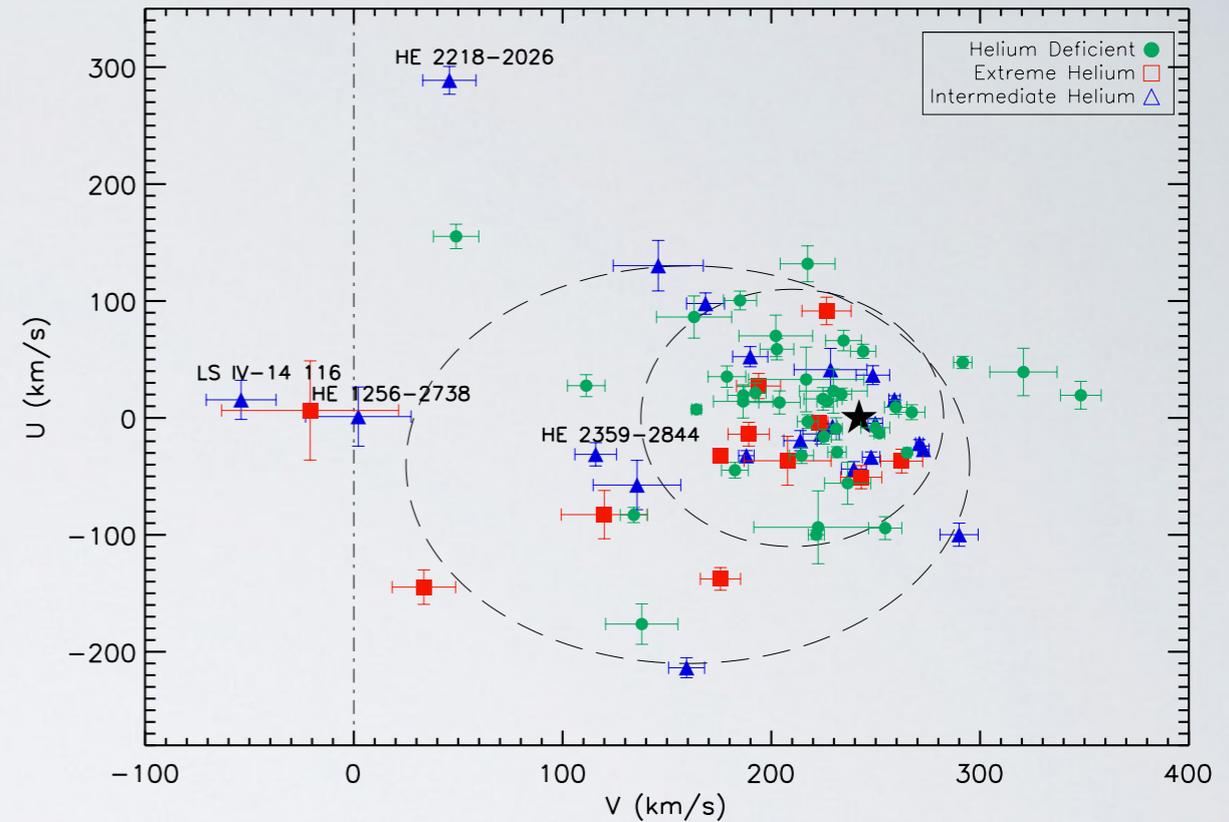
BUT: *LS IV-14 116 is TOO HOT to pulsate in g-modes*

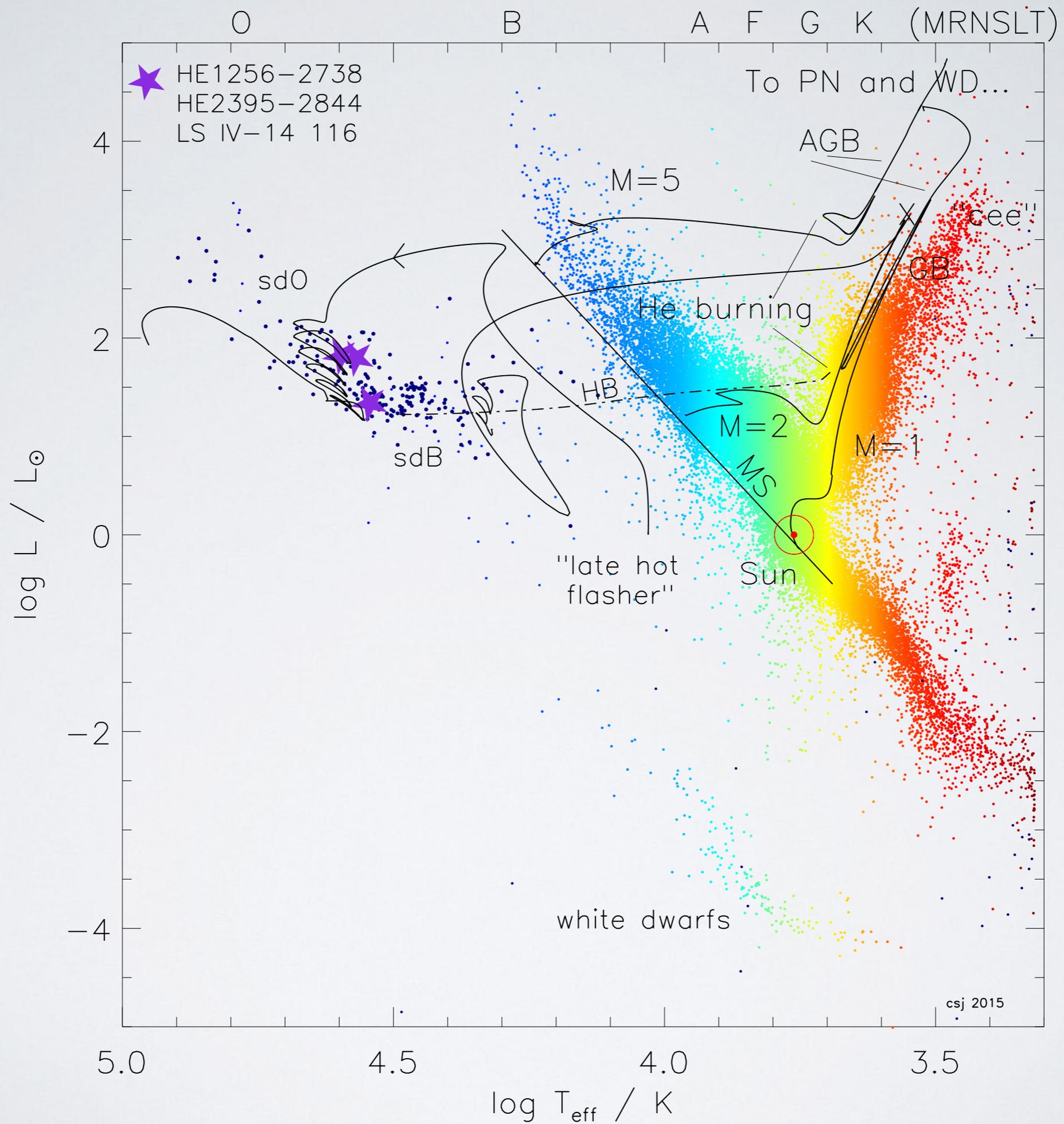
KINEMATICS

Randall+14 noted peculiar RV of LS IV-14 116. We checked RV for other intermediate and extreme helium subdwarfs.

Normal subdwarf kinematics consistent with disk.

Heavy-metal and other intermediate and extreme helium subdwarfs have halo-like orbits.





HEAVY METAL STAR CHALLENGES



What are the masses and luminosities ?

Why such peculiar surface chemistries ?
(mixing, mass transfer, diffusion, ...)

Why do they rotate so slowly ?

What is their origin ?
(merger, common-envelope, pre- or post He-MS,)

Are high velocities a result of halo kinematics or binary kicks ?

What drives pulsations in LS IV-14°116 ?

HST/STIS and VLT/UVES time for LS IV-14 116 approaching fast