Chemically peculiar stars

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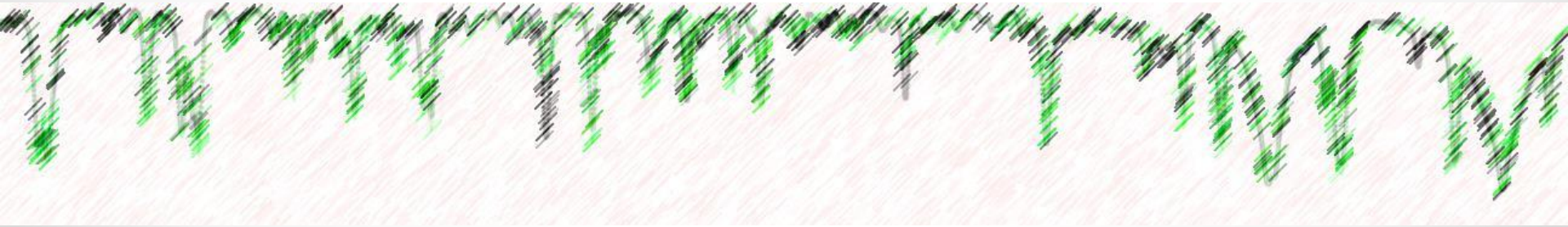
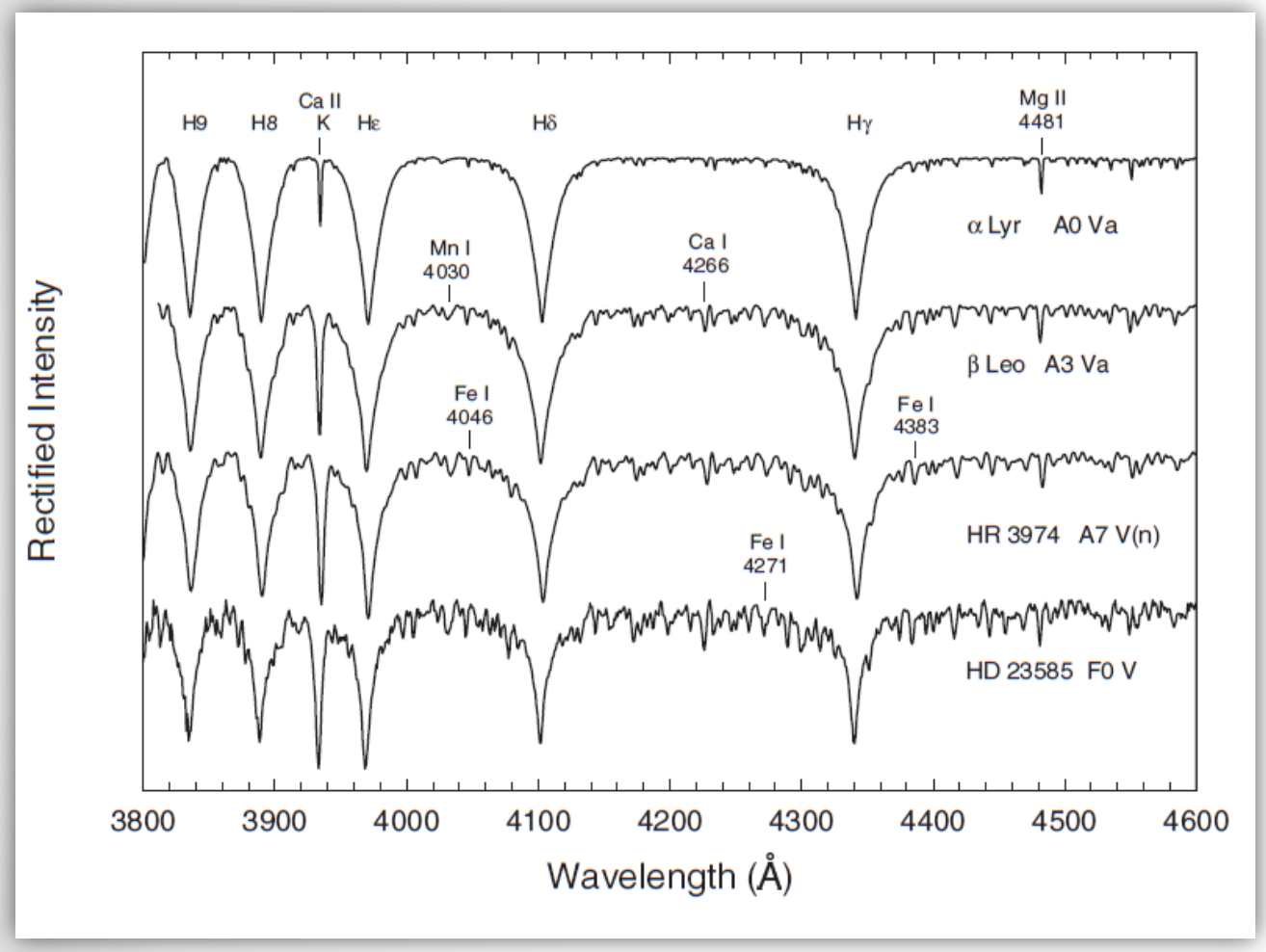
Spectroscopic data analysis with iSpec, Wrocław, June 26-29 2018



What are chemically peculiar (CP) stars?

A star that does not fit into a standard spectral classification.



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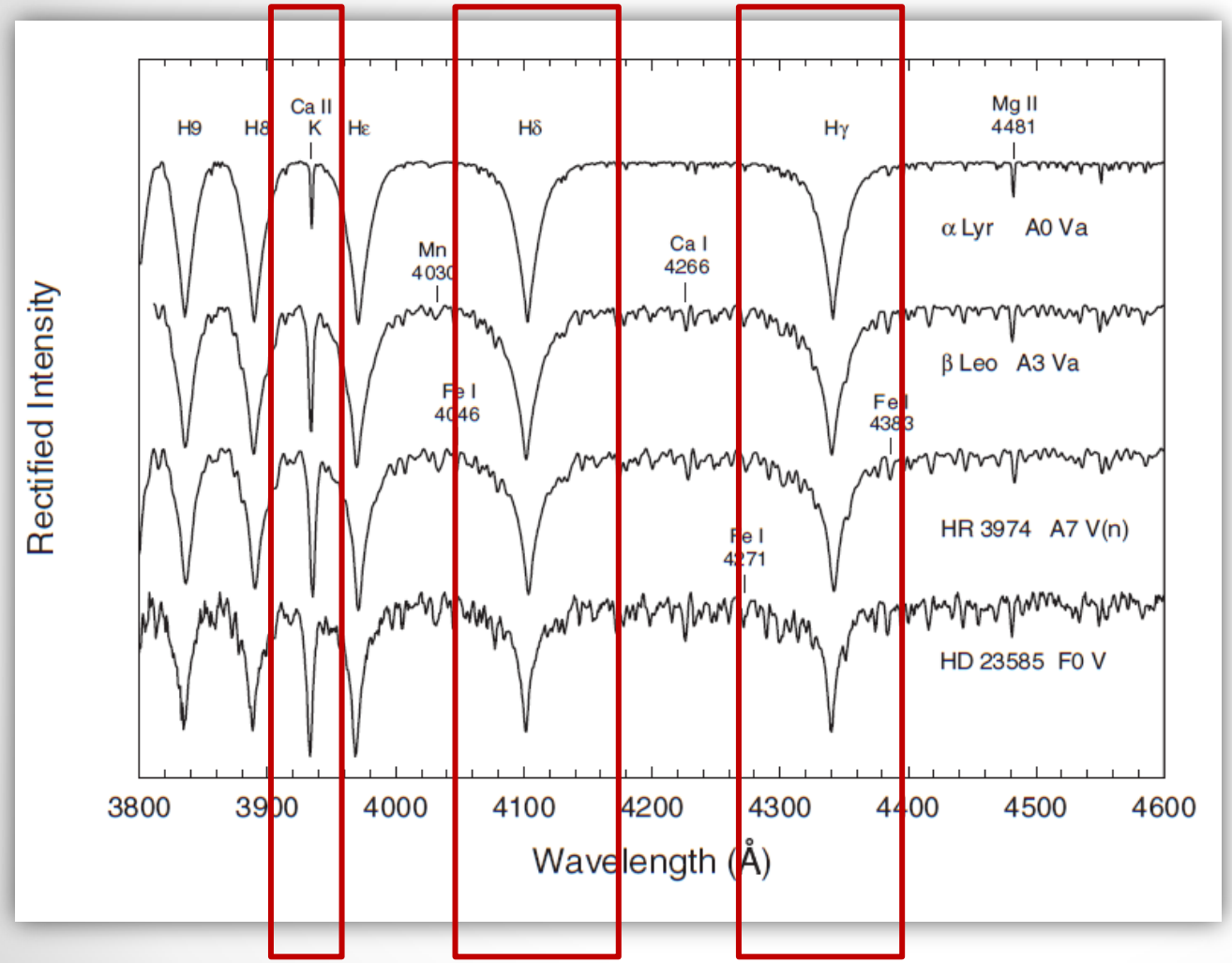


A type stars:

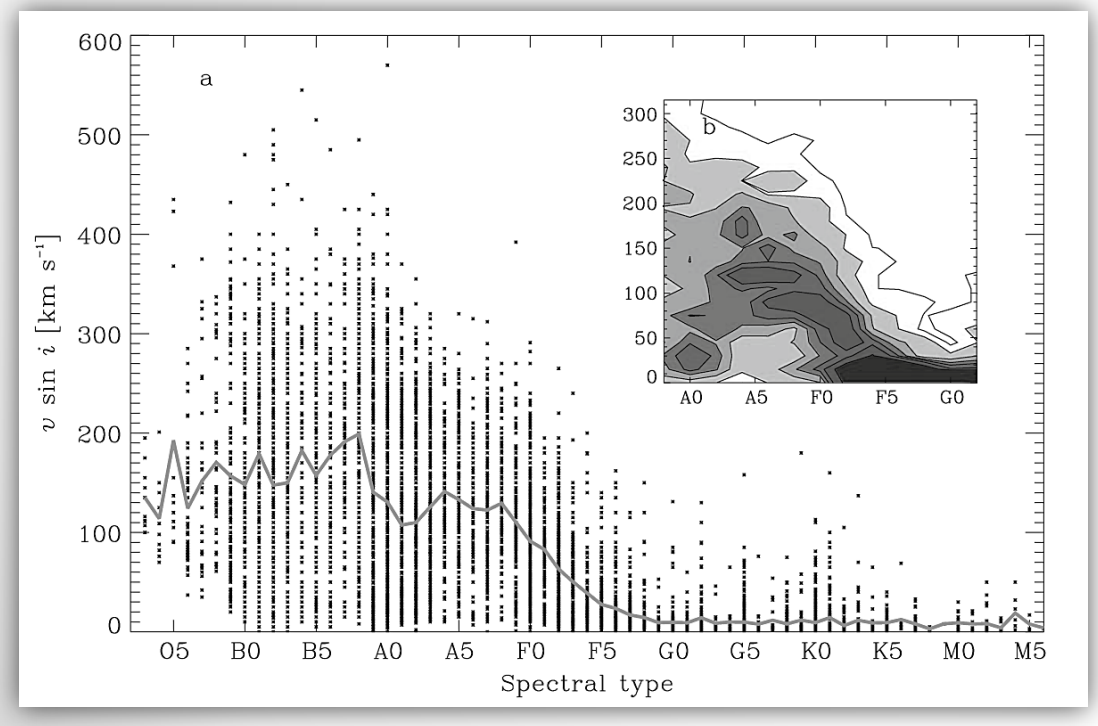
- SpT(Ca II K line) ≠ SpT(Balmer lines) = CP?
- metal lines: unusual abundances of some elements = CP?

What are chemically peculiar (CP) stars?

A star that does not fit into a standard spectral classification.

Identifying CP stars (from the spectrum):

- Spectral classification; peculiar (very strong or weak) absorption lines of certain elements;
- Slow rotation inferred by sharp spectral lines;
- Variable line strengths.



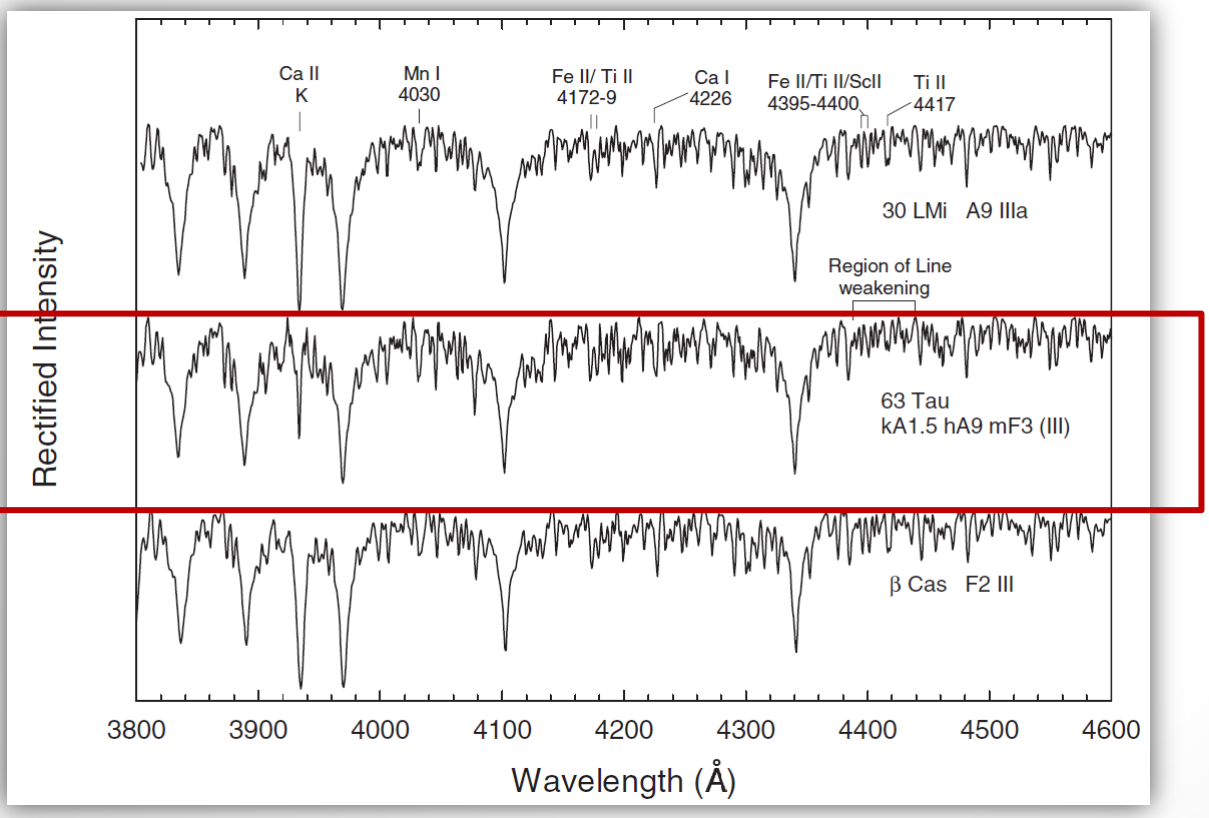
Classification of CP stars

Classical name	Preston group	Discovery criteria	Spectral types	Temperature range [K]
λ Boo		Weak Mg II, weak metals	A0-F0	7500 – 9000
Am-Fm	CP1	Weak Ca II, Sc II, enhanced metals	A0-F4	7000 – 10,000
Bp-Ap	CP2	Enhanced Sr, Cr, Eu, Si	B6-F4	7000 – 16,000
HgMn	CP3	Enhanced Hg II, Mn II	B6-A0	10,500 – 16,000
He-weak	CP4	Weak He I	B2-B8	14,000 – 20,000
He-rich		Enhanced He I	B2	20,000 – 25,000

Chemically peculiar Am stars

Am, metallic-line A-type stars: A- and early F-type stars with Ca II K-line spectral type earlier than the metallic-line spectral type;

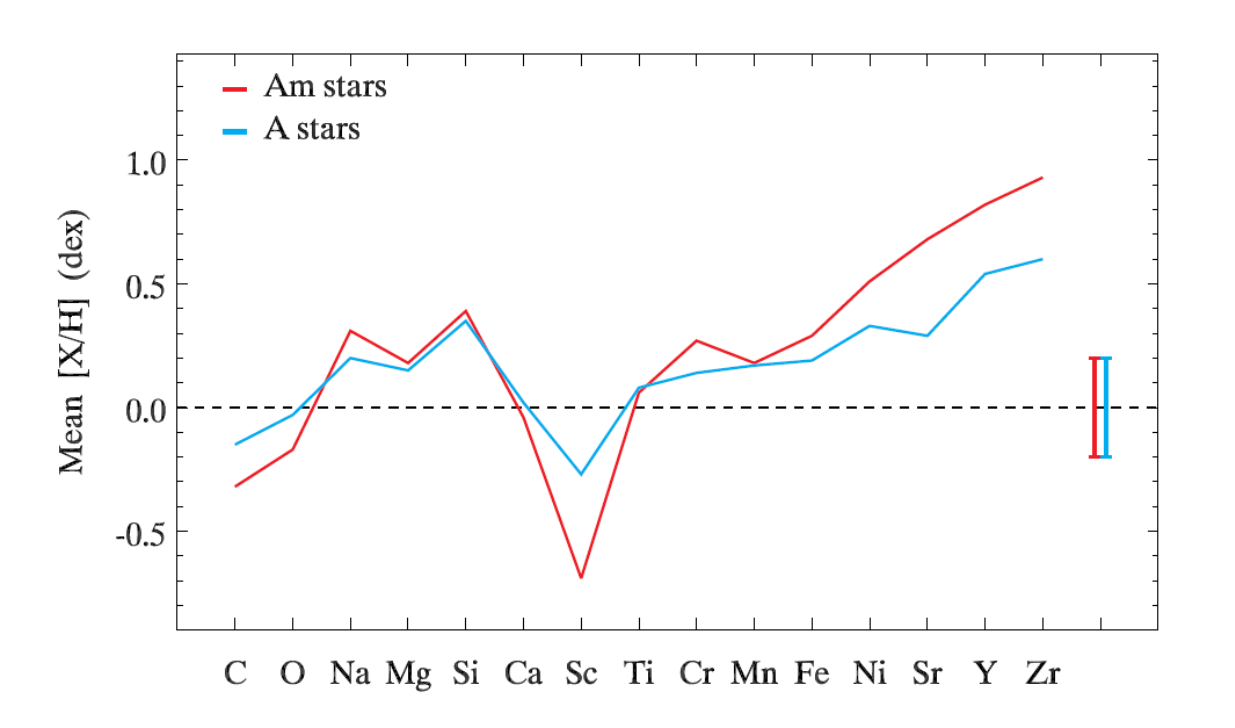
e.g. spectral type of 63 Tau: **kA1.5 hA9 mF3**



Chemically peculiar Am stars

Anomalous luminosity effect (ALE): lines of 4395 –4400 Å and 4417Å – *dwarfs*; Fe II/Ti II 4172–9 Å blend – *giants*.

Peculiar abundance pattern: **calcium and scandium are underabundant; iron-peak elements and heavier elements are overabundant.**



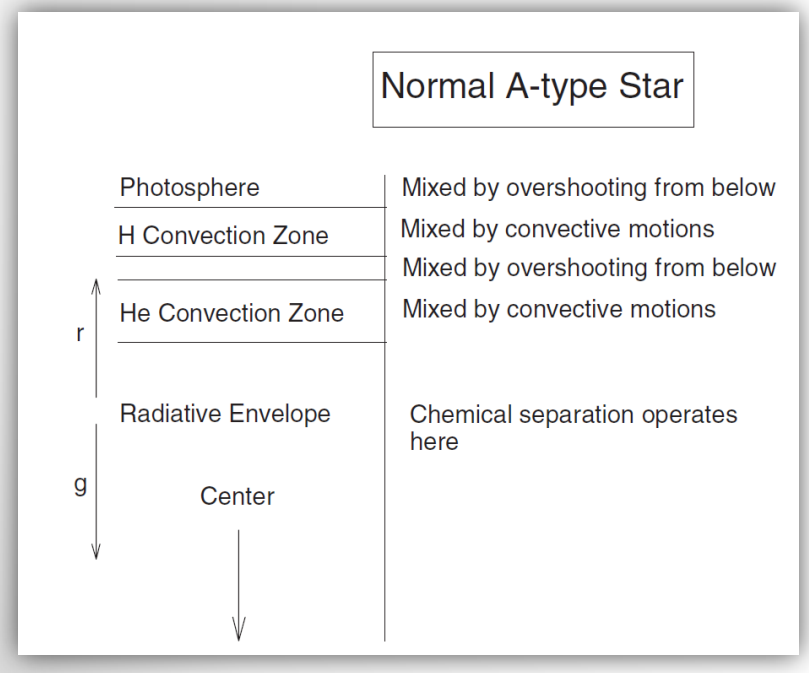
Gebran et al. (2010)

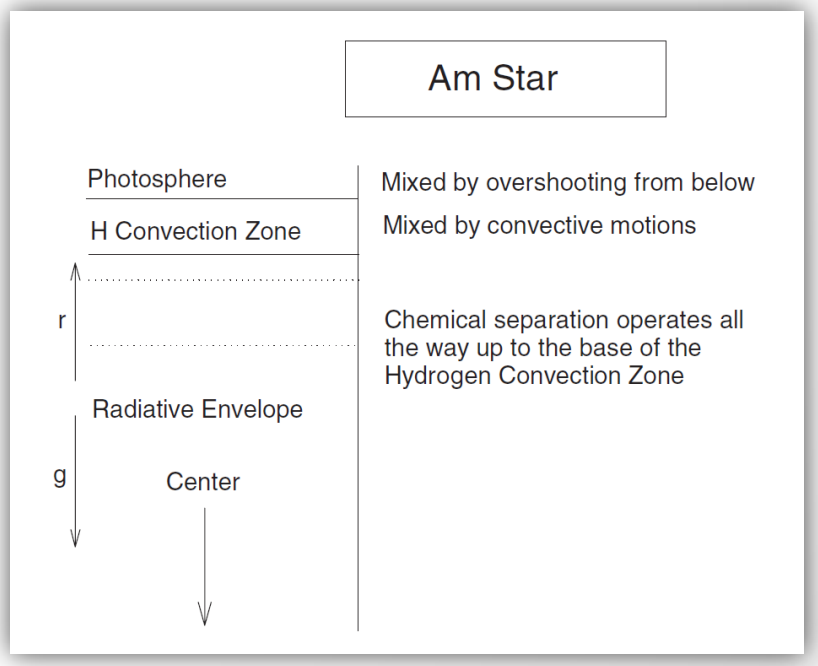
Chemically peculiar Am stars

Am stars mechanism: chemical separation driven by radiative and gravitational acceleration.

Normal A-type stars: chemical separation < effects of rotation (meridional circulation).
Am stars are slow rotators: **chemical separation > mixing by meridional circulation**.

Later spectral types: strong convection.





Chemically peculiar Am stars Summary

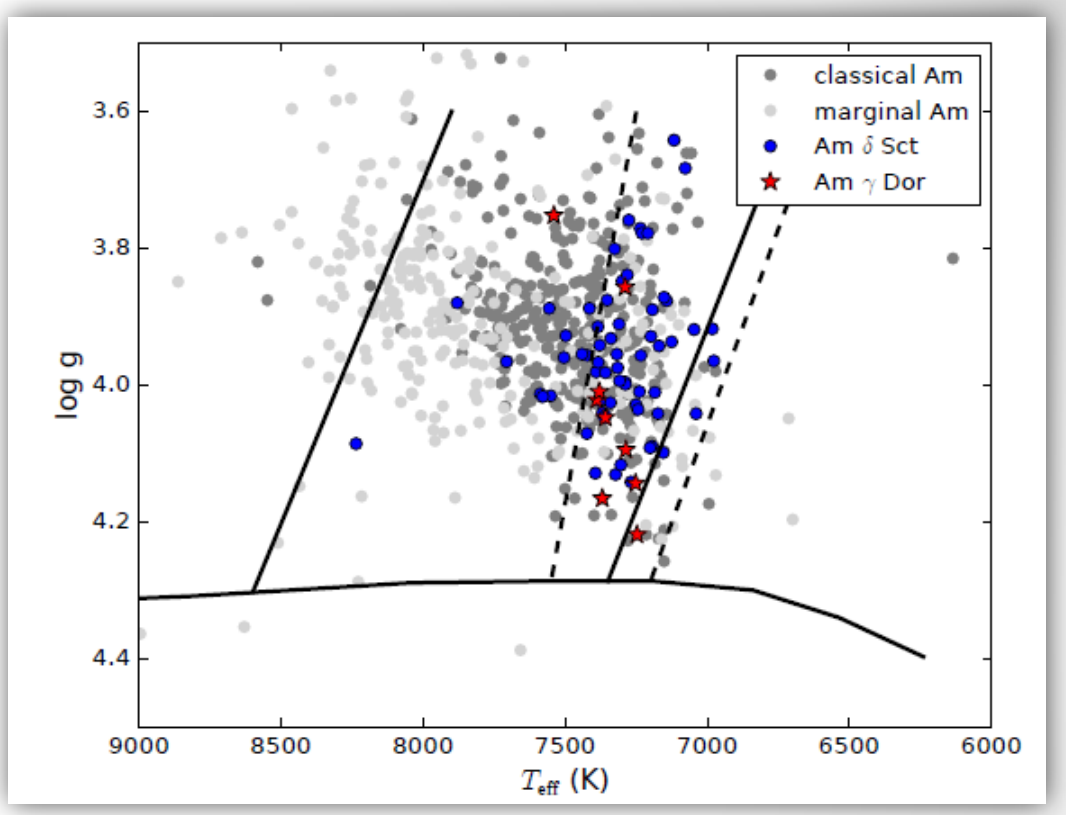
Complicated spectral types; chemical peculiarities, ALE;

Slowly rotators;

Most in binary systems;

Pulsating stars (δ Sct, γ Dor; e.g. Kepler observations);

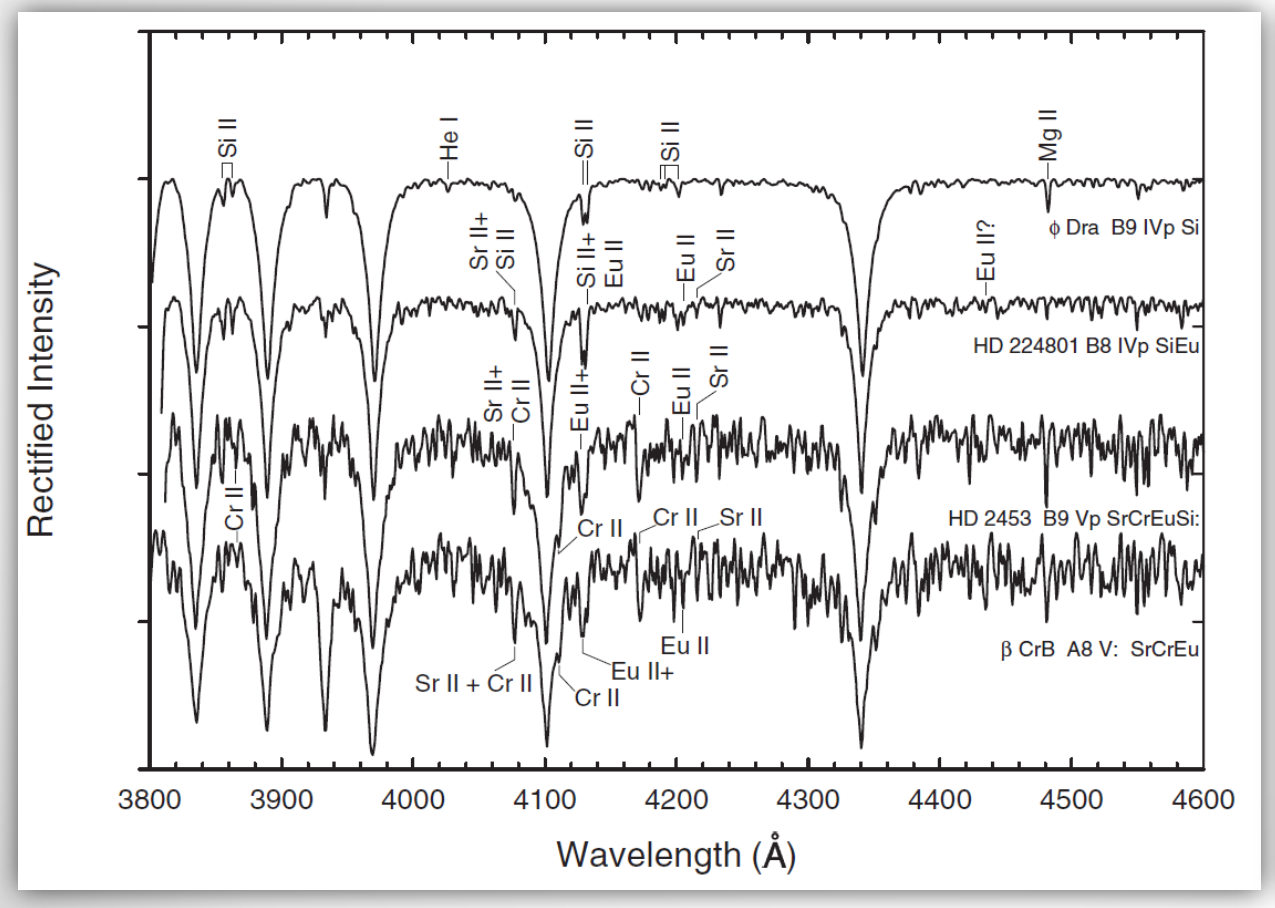
Ultra-weak magnetic fields.



Smalley et al. 2017, MNRAS, 465, 2662

Chemically peculiar Ap stars

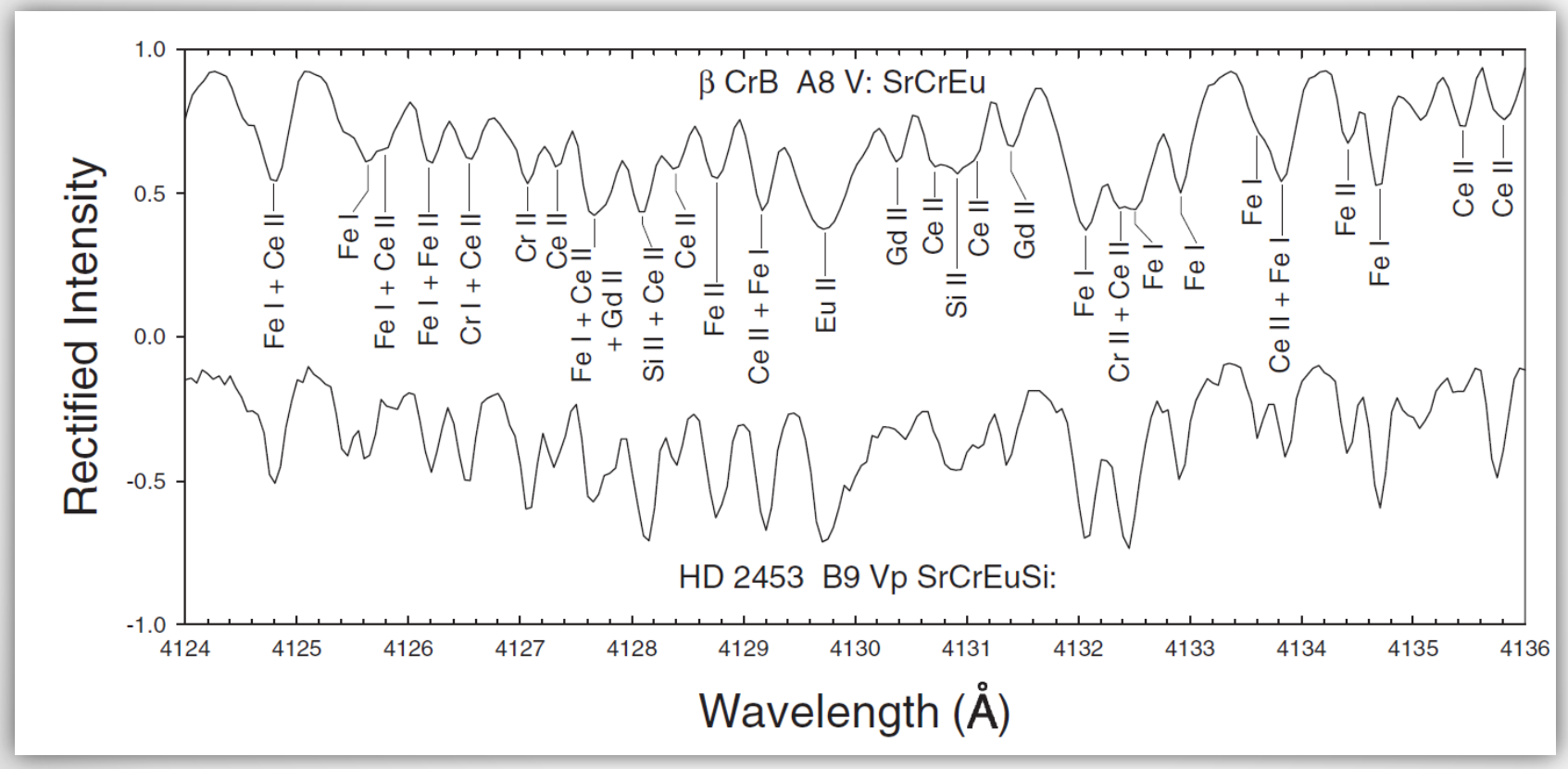
Ap, peculiar A-type stars: only selected elements have greatly enhanced abundances. Most of the Ap stars are B-type stars in terms of effective temperature; but the coolest are early F-type stars.



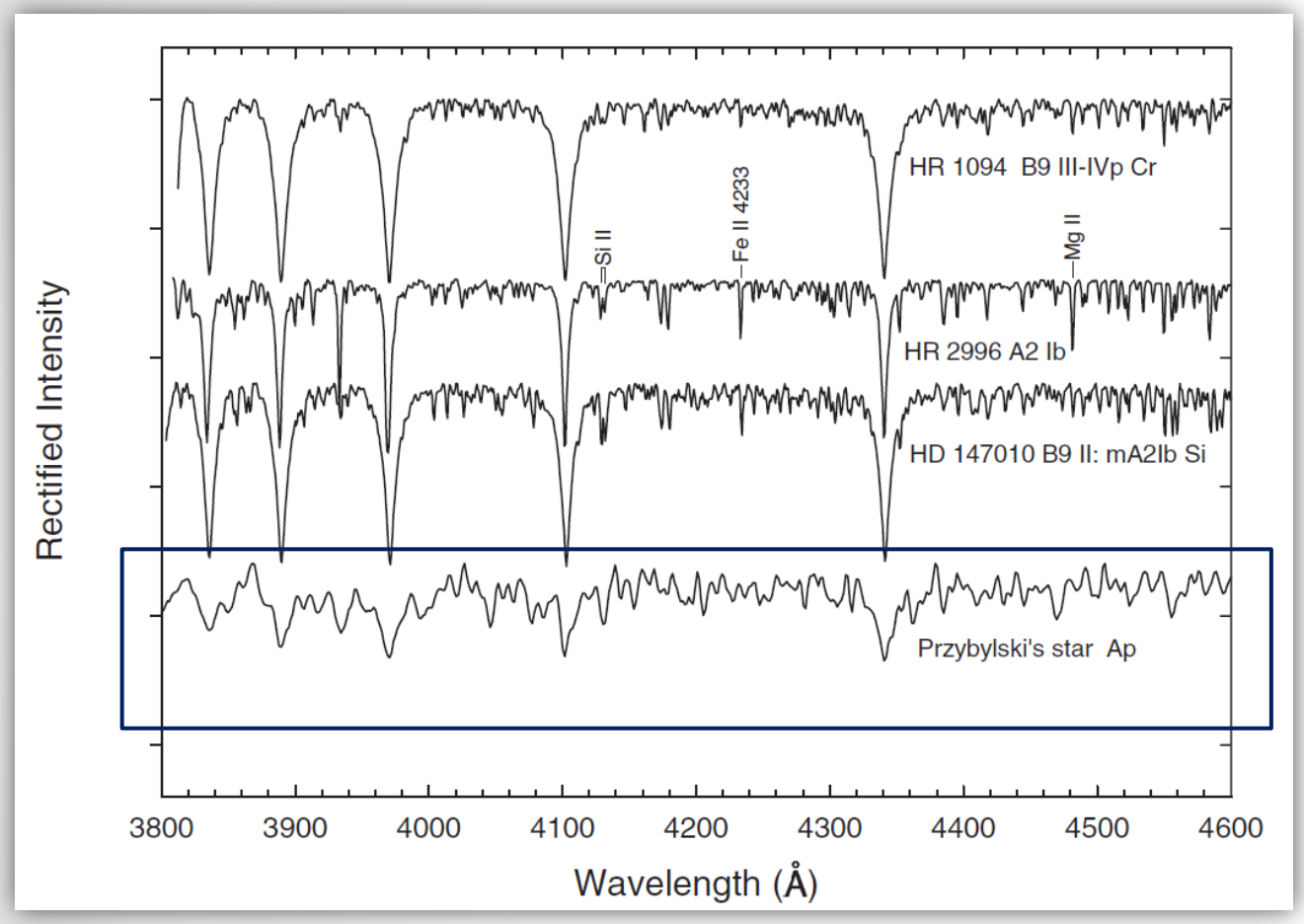
Ion	λ(Å)
Si II	4128 & 4131
	4200
	3856 & 3862
	4002, 28 & 76
Cr II	4172
	4111
	3866
	4077
Sr II	4077
	4216
Eu II	4205
	4130

Chemically peculiar Ap stars

Complex blend in Ap stars: the most important is Eu II, but lines of Fe I and Fe II and rare earths Ce II and Gd II are also involved.



Chemically peculiar Ap stars
Przybylski star, HD101065



Strongest lines:
Singly ionised lanthanides (abundances: 10 000 times solar);

Fe: deficient

Lines of Pm, Tc

Half-life:
Tc: 4.2×10^6 yr
Pm: 17.7 yr
In situ production via nuclear reactions.

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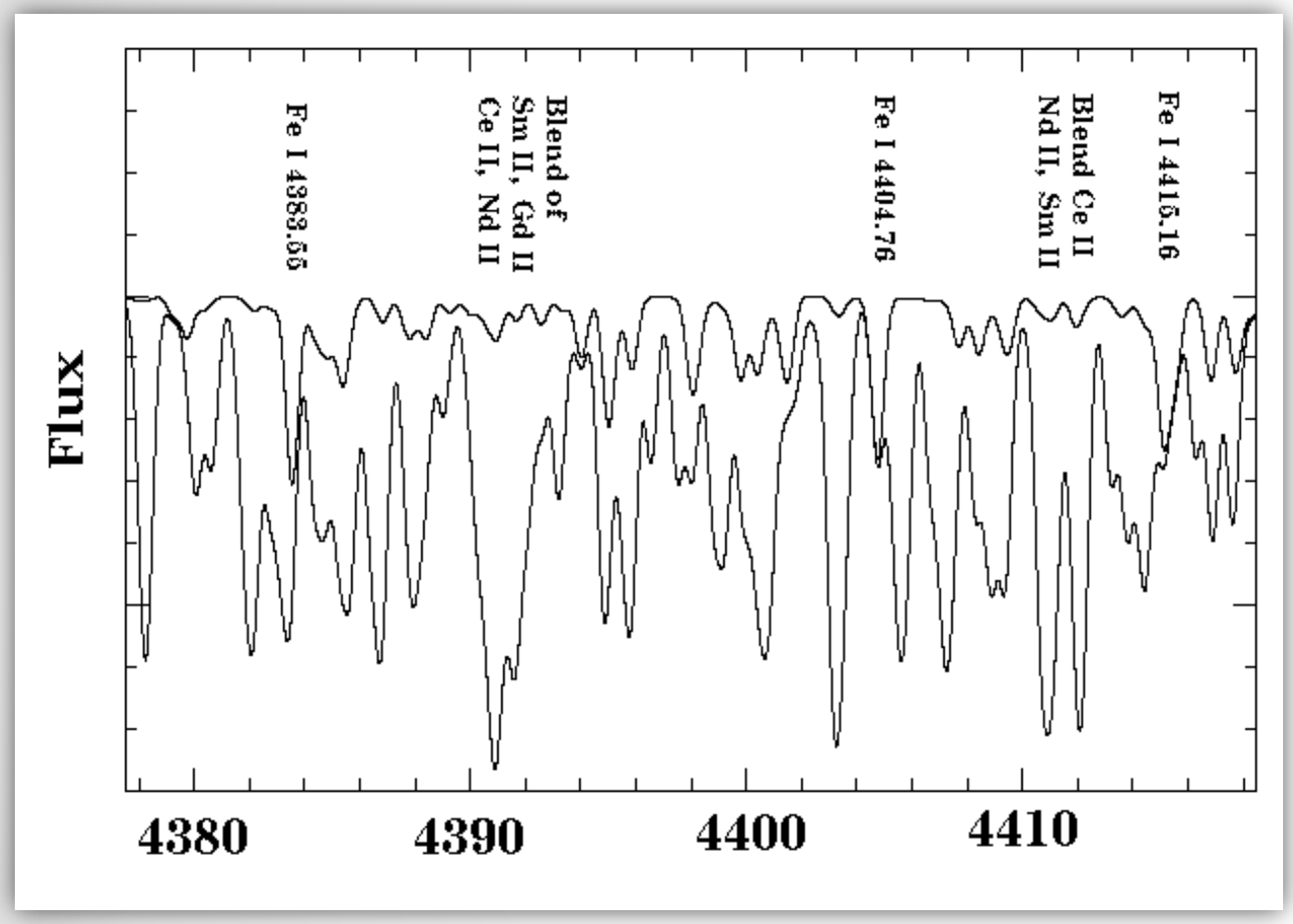

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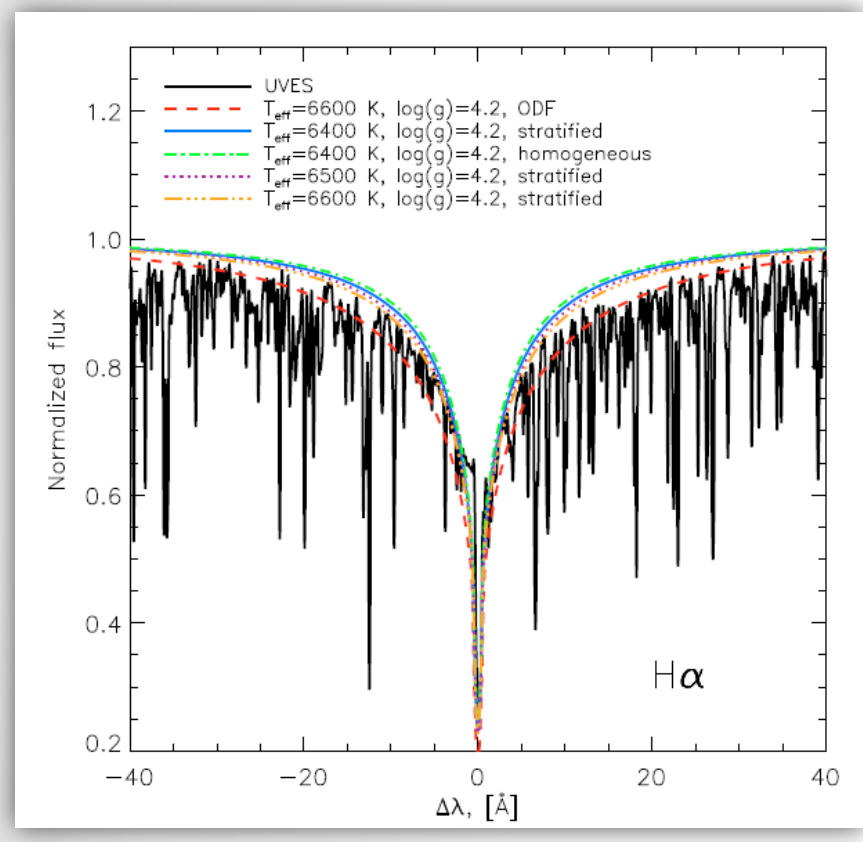
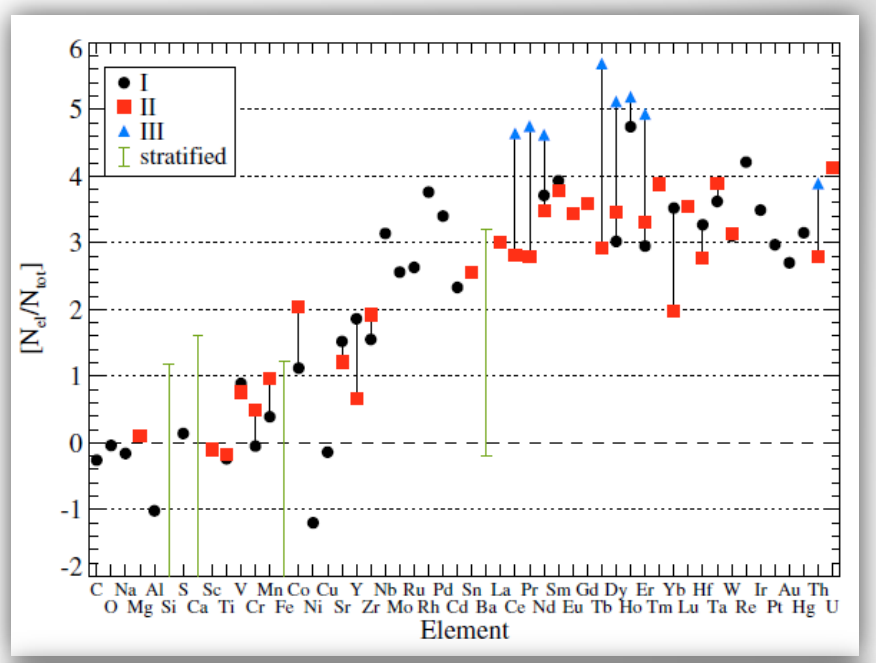
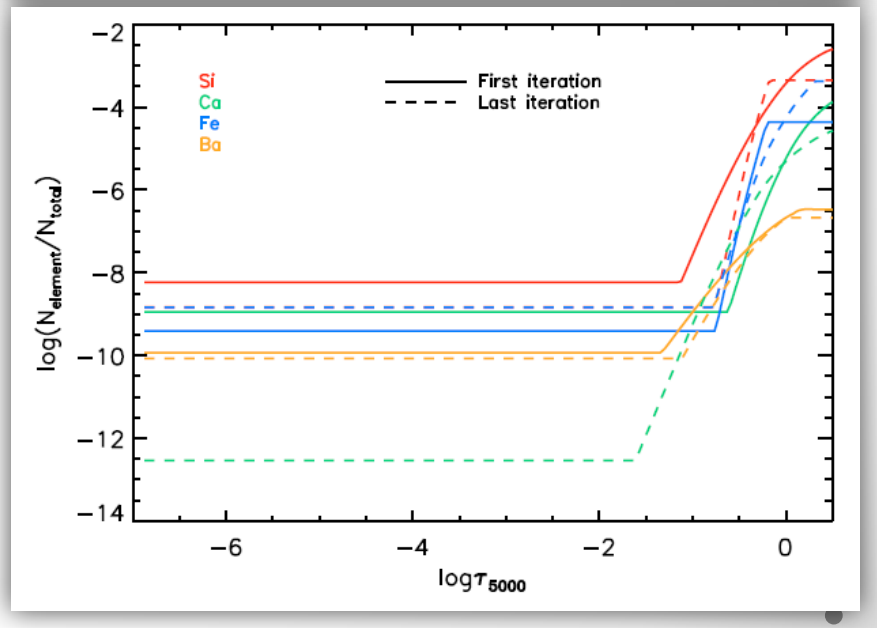


Shulyak et al. 2010, A&A 520, A88





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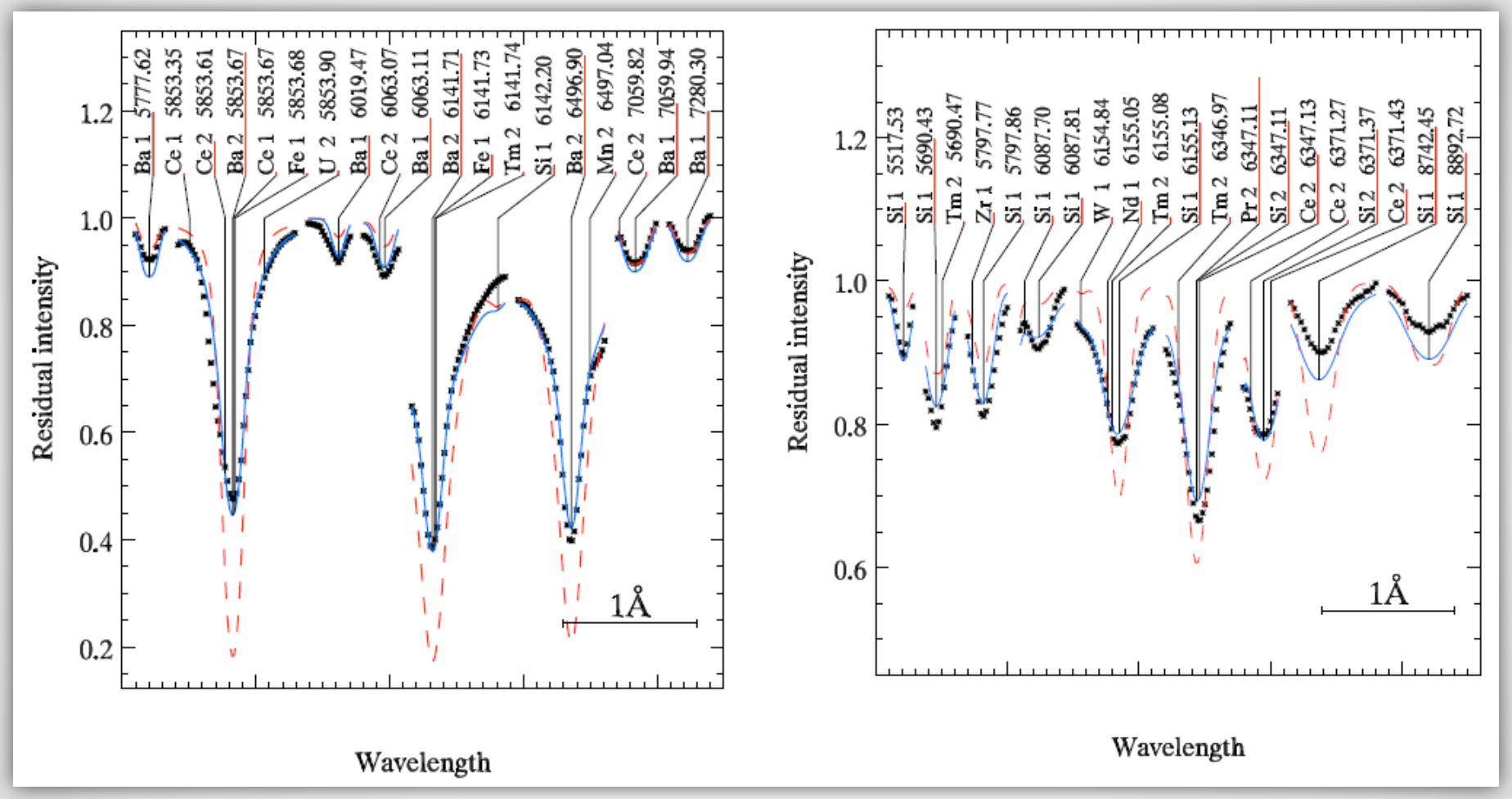

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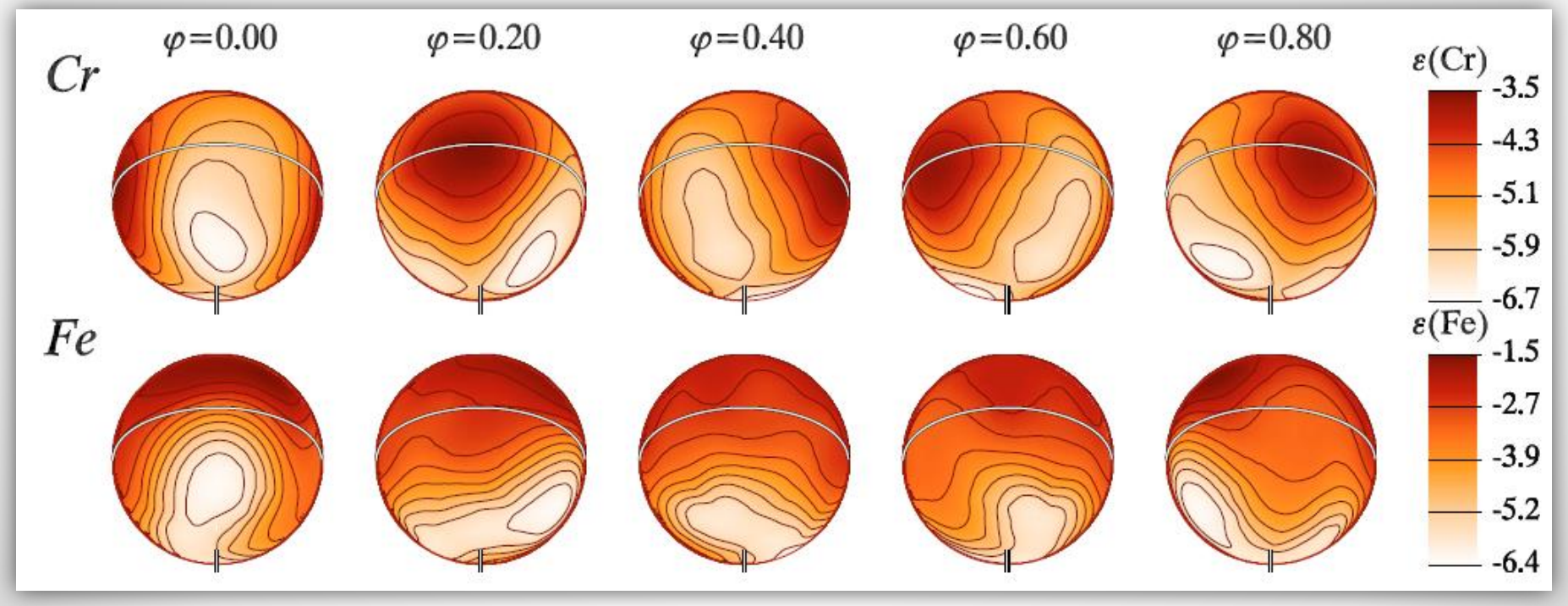
Chemically peculiar Ap stars
Summary

Chemically peculiar stars; most are slow rotators;
Stratification of the elements in the atmosphere;
roAp – rapidly oscillating Ap stars (e.g. Przybylski star);
Spots on the surface (variability of spectral lines); magnetic field (oblique rotation model).



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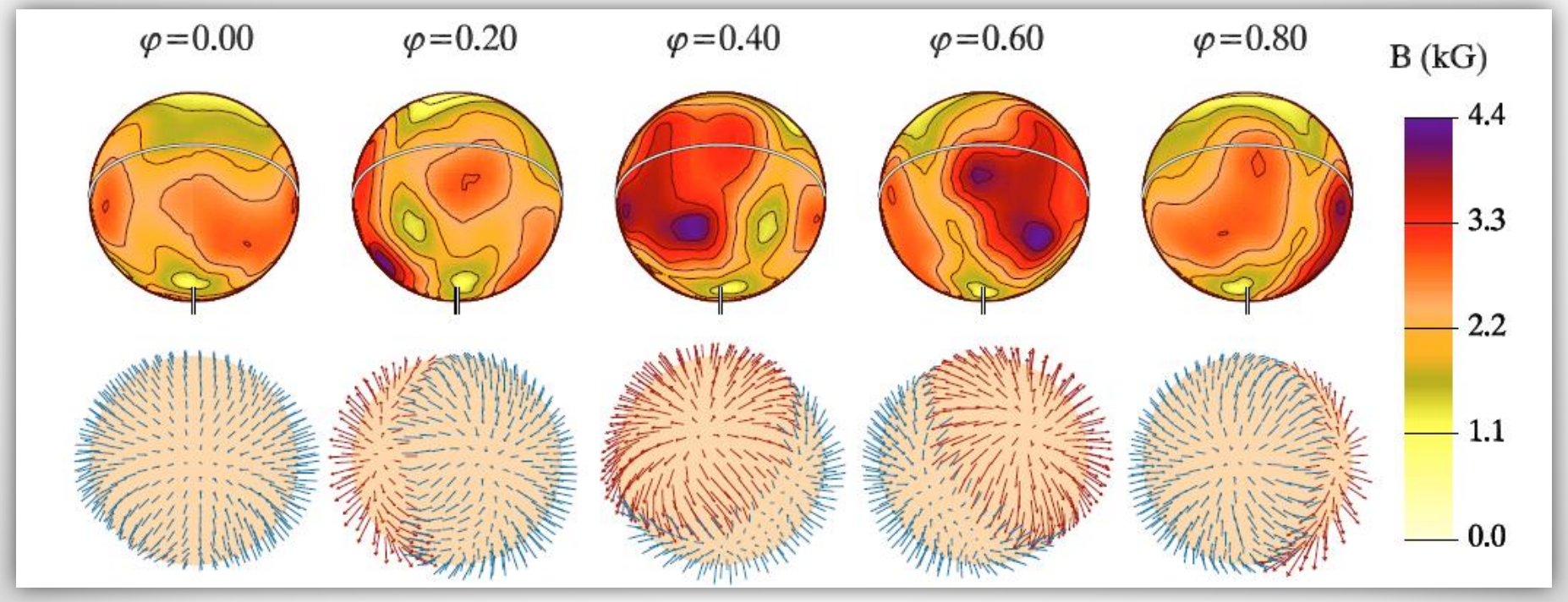
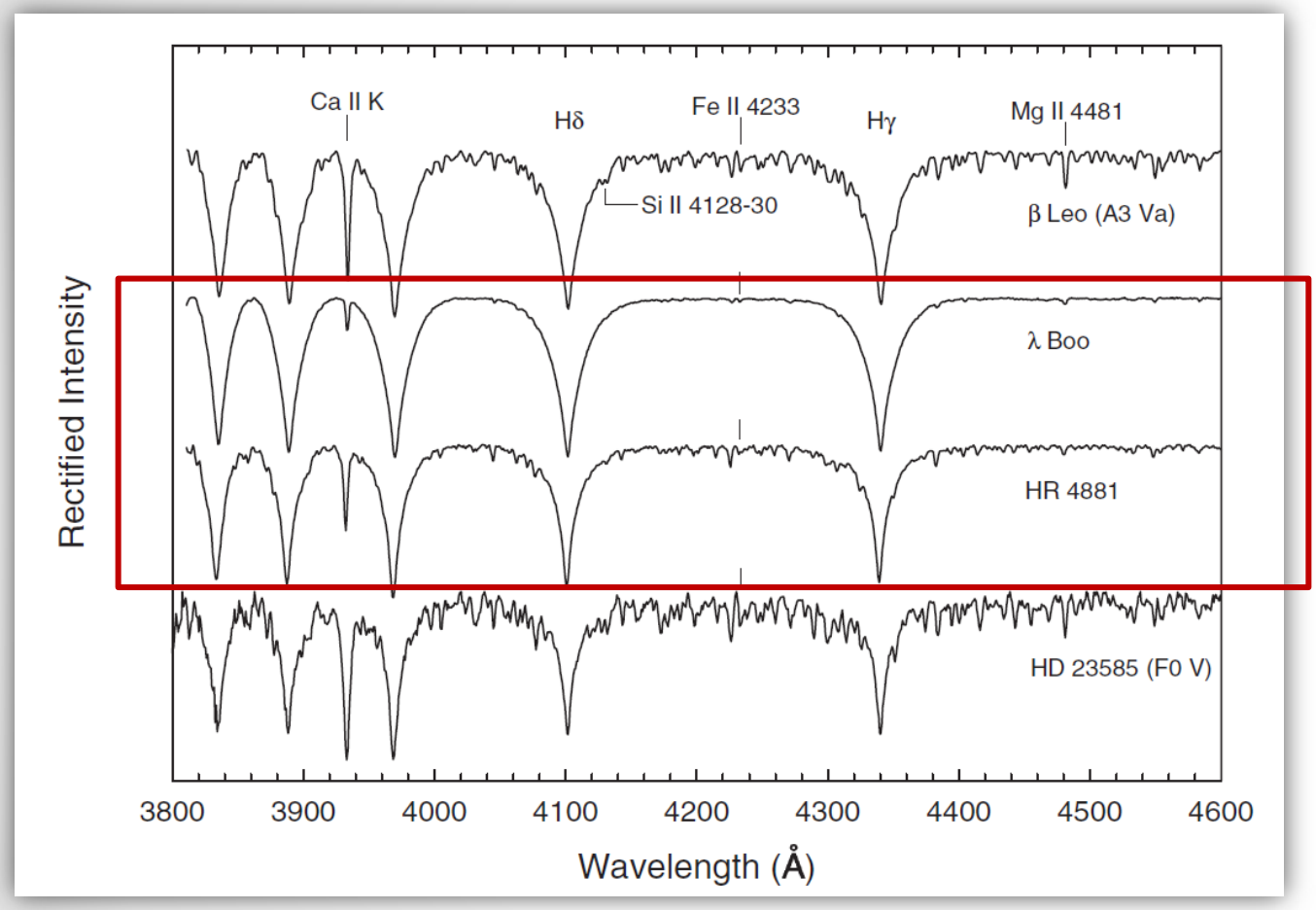


Chemically peculiar λ Boo stars

λ Boötis stars: metal-weak, population I A-type stars



Chemically peculiar λ Boo stars

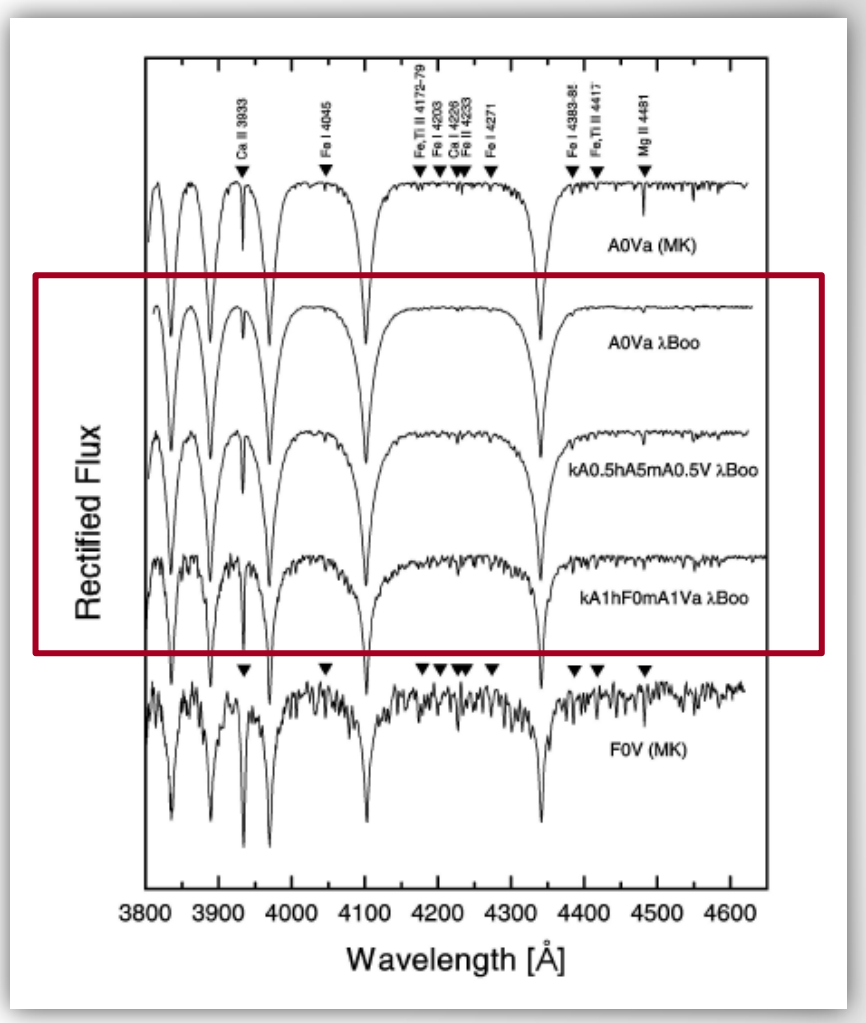
Spectral type deduced from the Ca IIK line is the same as from the overall metallic lines but the hydrogen lines indicate a later one, or in the Yerkes notation:
Sp(k)=Sp(m)<Sp(h); **F0V kA1 mA1.5 λBoo**

Spectral type from the hydrogen lines: from B9.5 to F0 with possible members as late as F3;

Broad hydrogen lines (stars on or near the main-sequence); luminosity class V;

Weak Mg II λ4481 lines;

General metal-weak character.



Paunzen & Heiter 2014, Serb. Astron. J., 188, 75

Chemically peculiar λ Boo stars

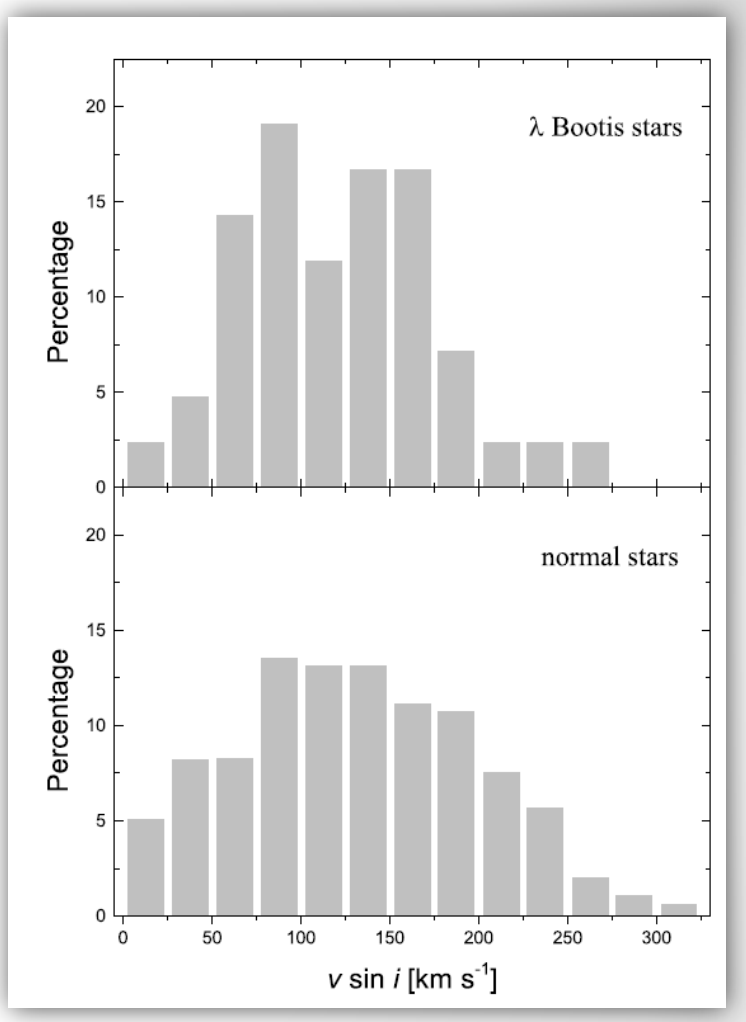
Rotation velocities typical for A stars; circumstellar disc (not all λ Boo stars);

Explanation of CP character: **selective accretion/diffusion theory** (metal-depleted gas from IS is accreted by the star; required accretion rate: 10-14 $M_{\odot}$ yr^{-1}; gas can be associated from IS, circumstellar disc or cometary bodies);

No magnetic fields?

Pulsating stars (γ Dor);

Rare objects.



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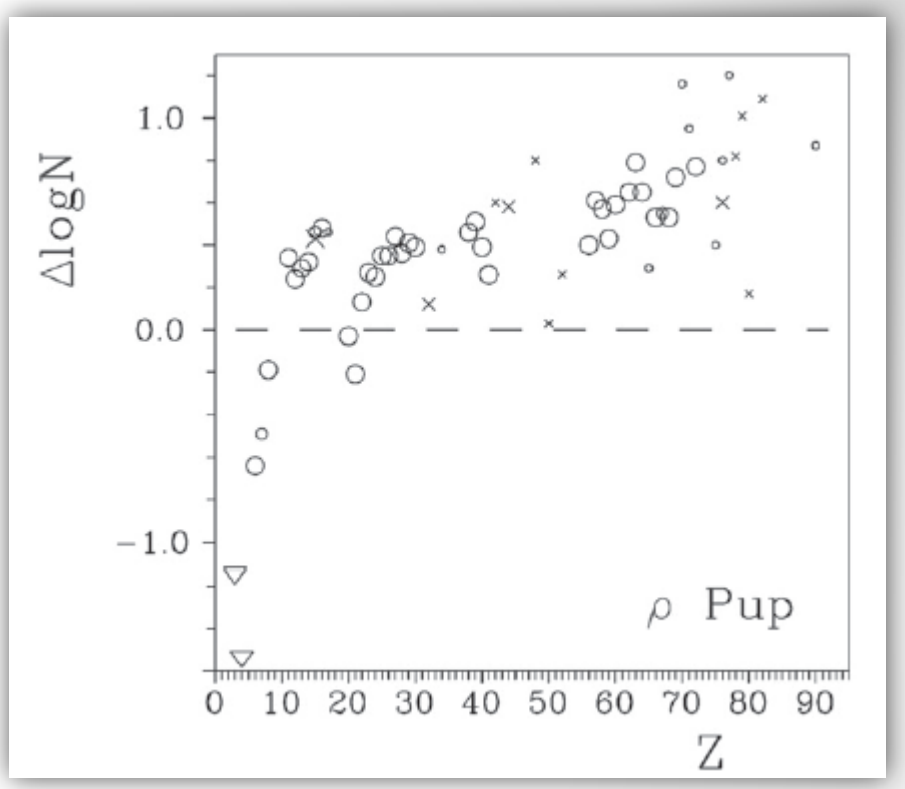
Chemically peculiar ρ Pup stars

Prototypes: **ρ Pup** (the brightest), **θ Gru**, **HD 103877**

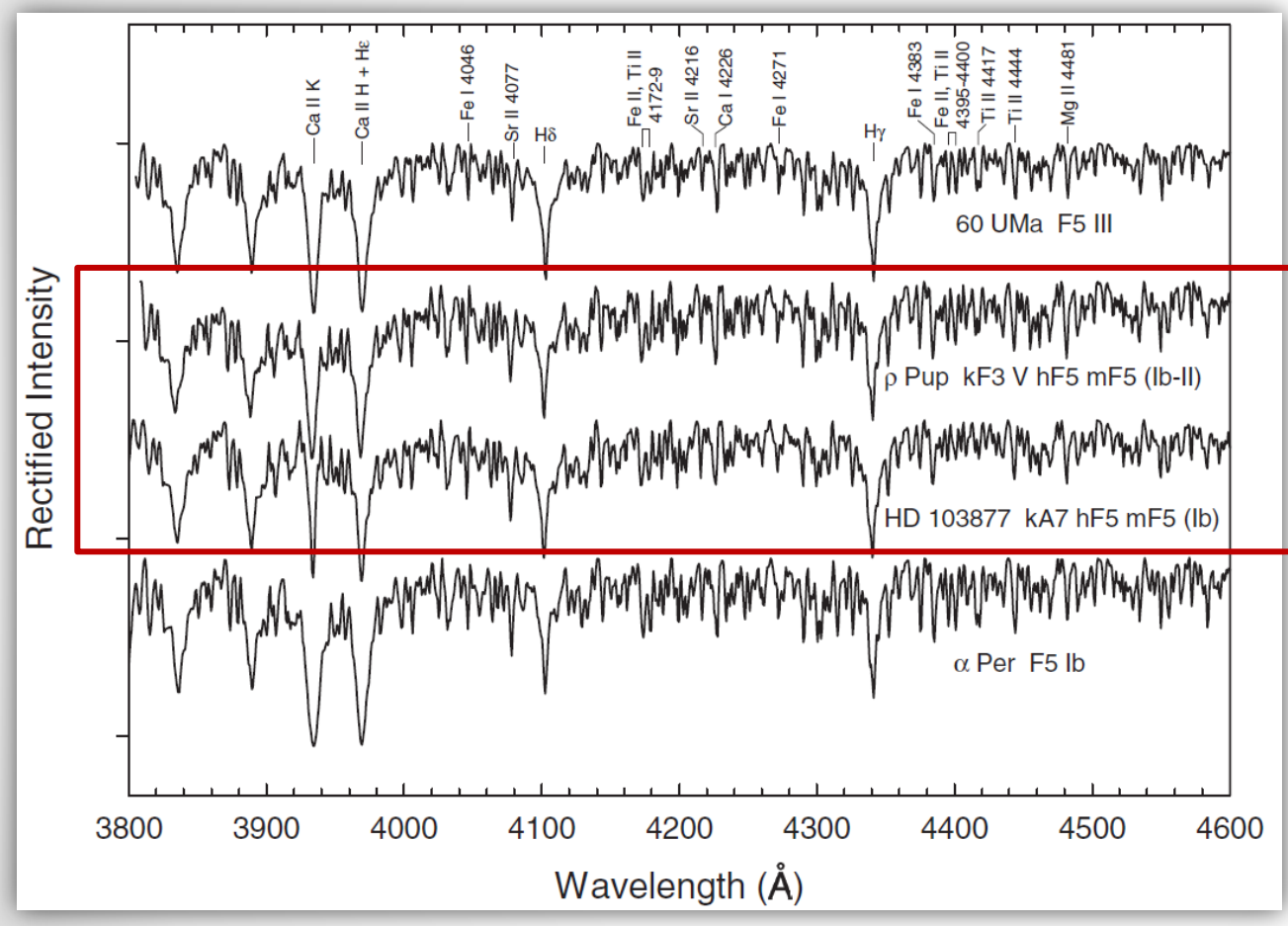
Late Am stars (all show ALE)

- hydrogen-line types: F5 (late for Am stars);
- **luminosity types** (from the Fe II, Ti II λλ4172-9 blend, Sr II λλ4077, 4216 lines) **from II-III to Ib** (but ALE; stars located above the main sequence).



Chemically peculiar ρ Pup stars

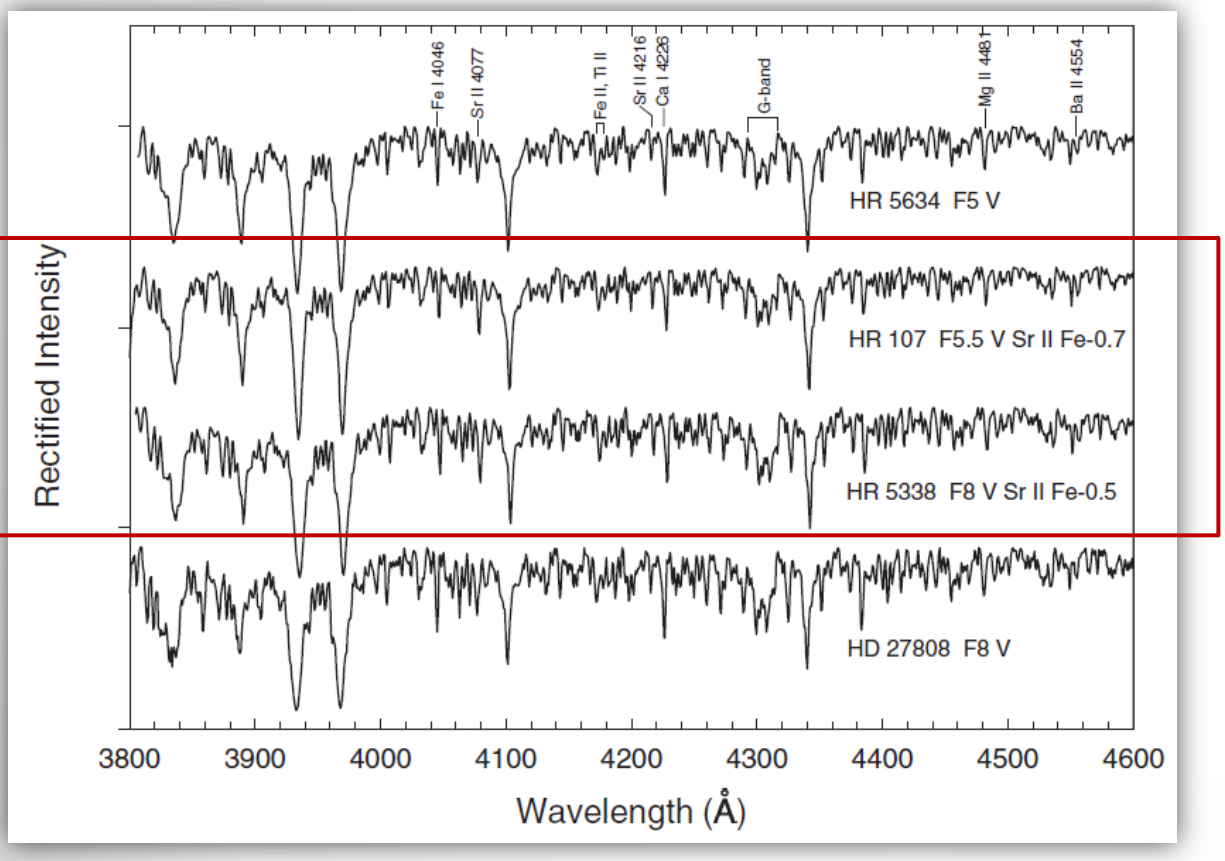
Evolved Am stars



Stars with strong Sr λ4077 line and Ba stars

Sr II λ4077 stars: spectral types F5 – early G; (some are late Am stars);

Barium dwarfs: spectral types F-G-K, **show overabundances of other *s-process* elements including barium**; contamination by an AGB companion (now a white dwarf).



Conclusions

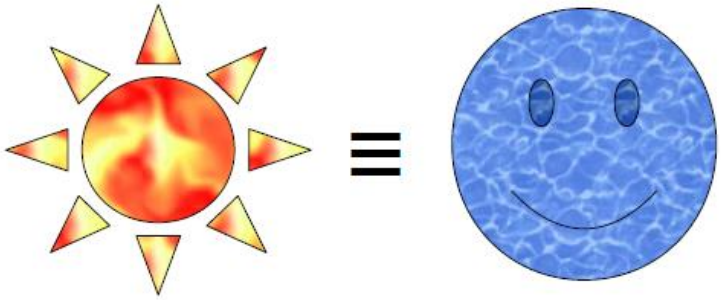
Do spectral classification before the proper spectral analysis;

Peculiar stars:

- atmosphere parameters determination is more complicated;
- take care of atomic data;
- If necessary, take into account stratification and/or stellar spots (so you need time-resolved spectroscopy).

"Normal A stars are rather like normal people. If you don't look too hard, there seem to be quite a few of them. After you get to know them well, most seem a little crazy."

Cowley, 1991, IAU Symposium 145, p.183



Mostly hydrogen (by number)