When binaries keep track of recent nucleosynthesis

Zr-Nb pair in extrinsic stars as a s-process thermometer

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AGB Stars: an introduction

Why are AGB stars important?

- Evolutionary stage
- Heavy element nucleosynthesis (s-process)
- Contribution to galactic chemical evolution

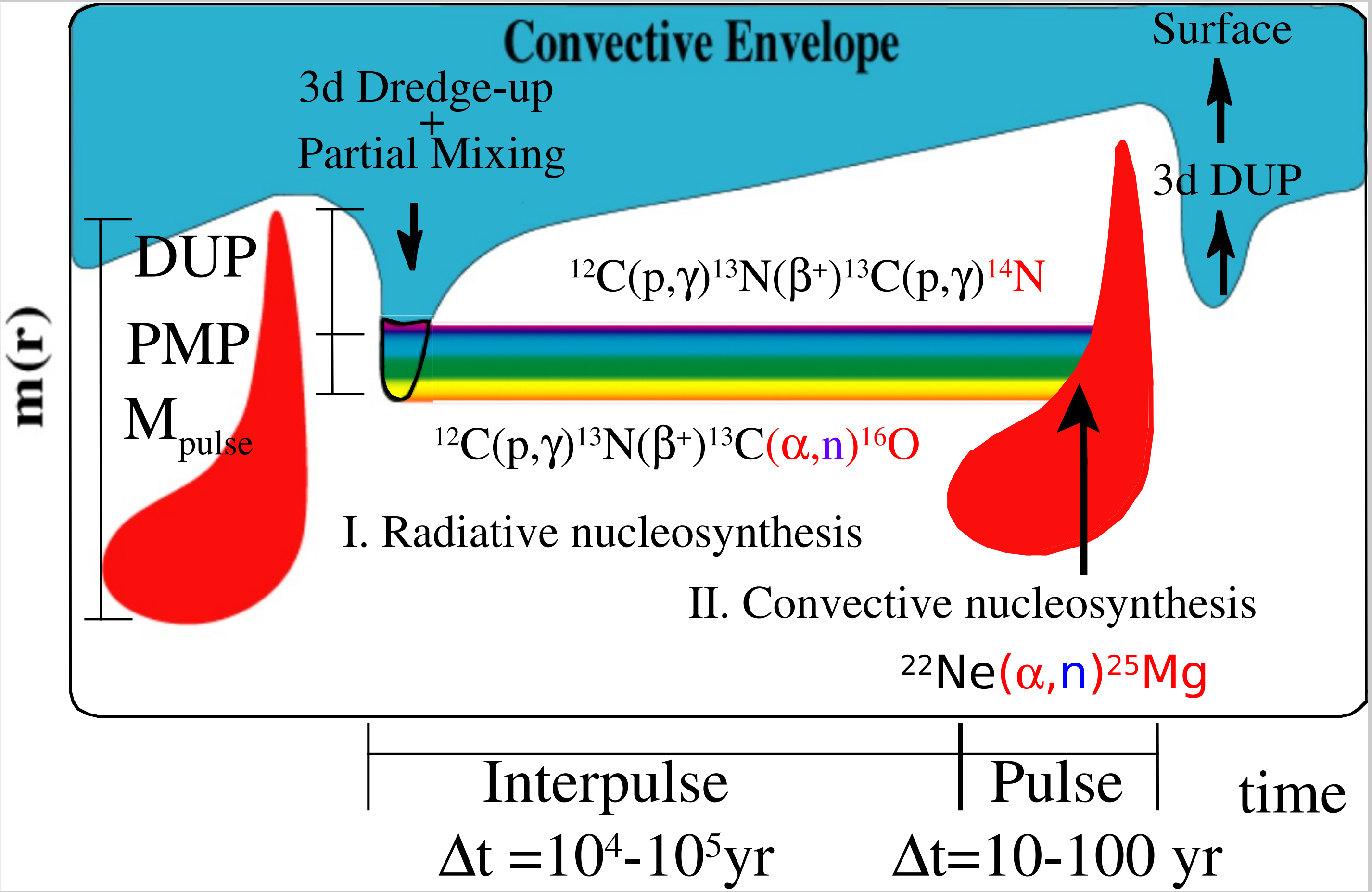
s-process neutron source

- ➔ ^{12}C (p, γ)^{13}N (β)^{13}C(α, n)^{16}O [^{13}C pocket]

  (low mass (1- 3 $M_{\odot}$)AGB stars T = 0.9 x 10^8 K)

- ➔ ^{22}Ne(α, n)^{25}Mg

  (For AGB stars with masses > 4 $M_{\odot}$, T > 3.5 x 10^8 K)



Credit: S . Goriely and S. Van Eck

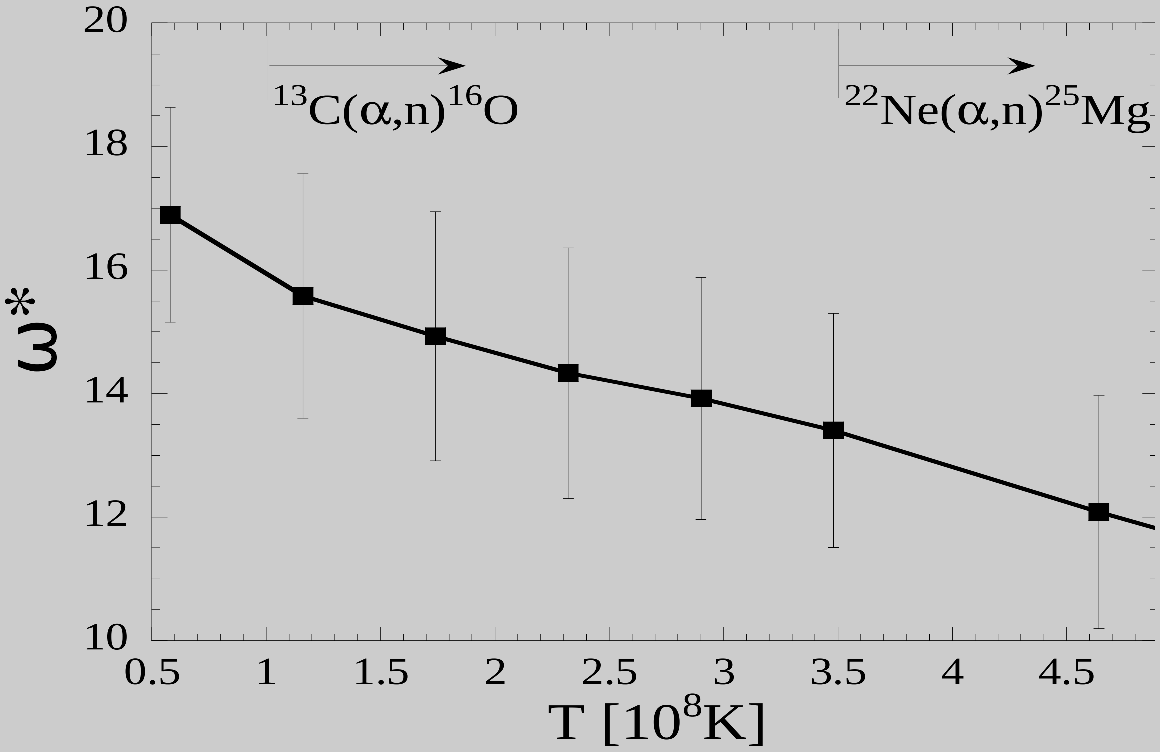
How do we get a thermometer?

$$\omega^* = \langle\sigma_{93}\rangle \times \left[\frac{1}{\langle\sigma_{90}\rangle} + \frac{1}{\langle\sigma_{91}\rangle} + \frac{1}{\langle\sigma_{92}\rangle} + \frac{1}{\langle\sigma_{94}\rangle}\right]$$

From the isotopic abundances of s-only isotopes

$$\omega^* = N_s(Zr)/N_s(^{93}Zr)$$

where ω*, the maxwellian averaged cross section is a sensitive function of temperature

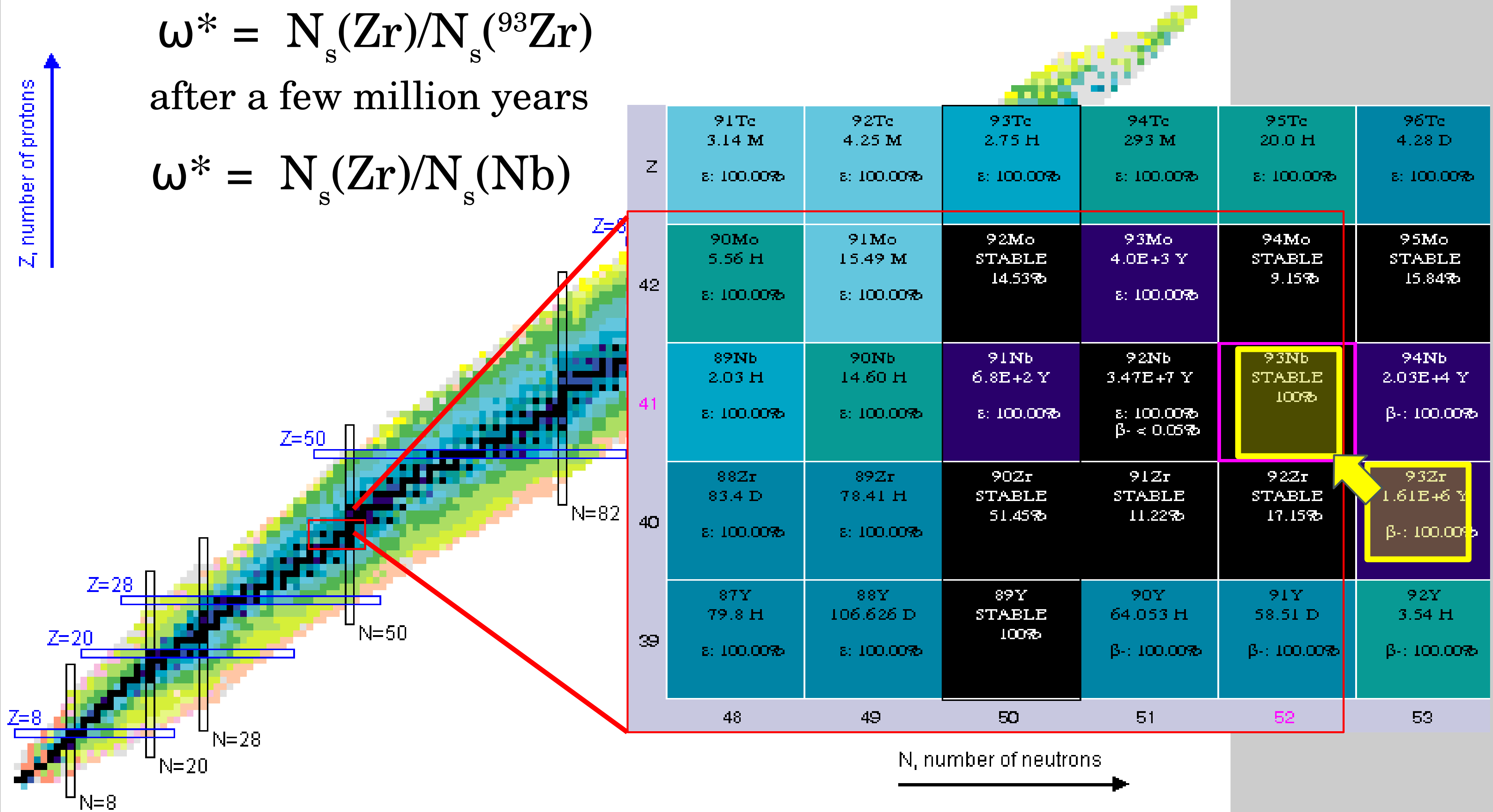


New s-process thermometer

$\omega^* = N_s(Zr)/N_s(^{93}Zr)$

after a few million years

$\omega^* = N_s(Zr)/N_s(Nb)$

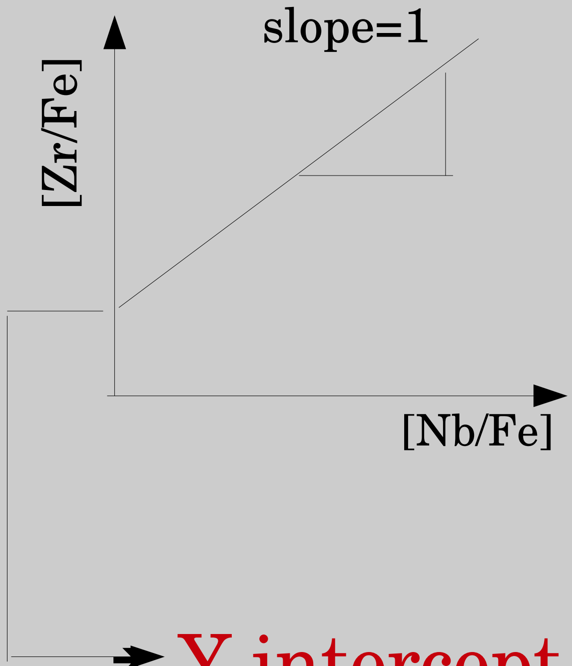


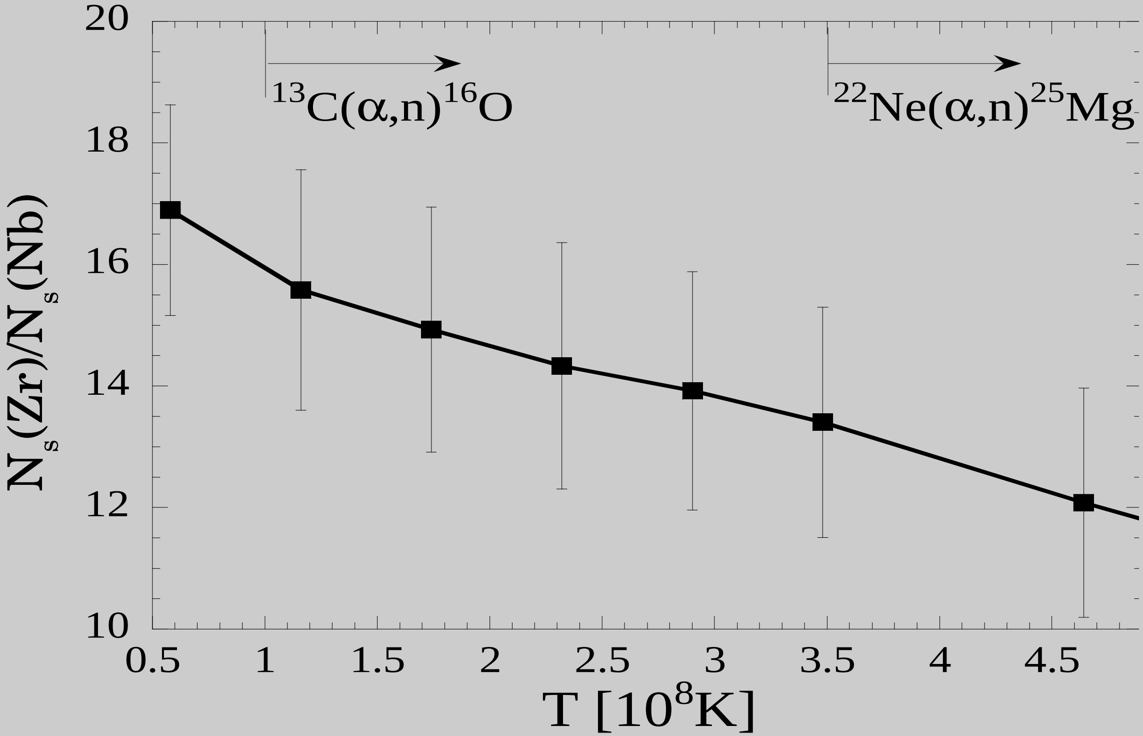
New s-process thermometer

ω^*

$$[Zr/Fe] = [Nb/Fe] + \log (N_s(Zr)/N_s(Nb)) - \log (N_\odot(Zr)/N_\odot(Nb))$$

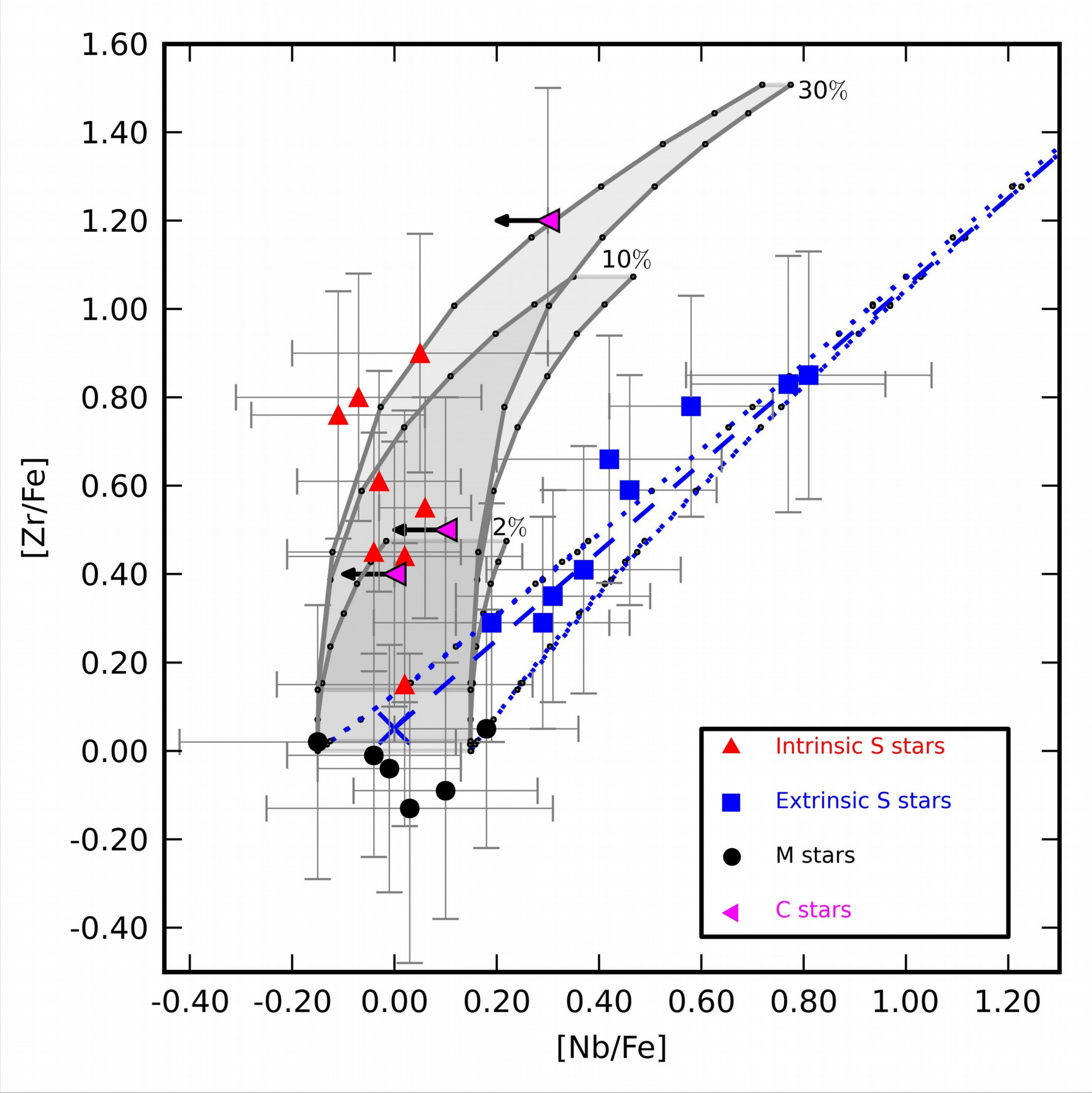
(Neyskens, Van Eck, Jorissen, Goriely, Siess & Plez, Nature, 2015)



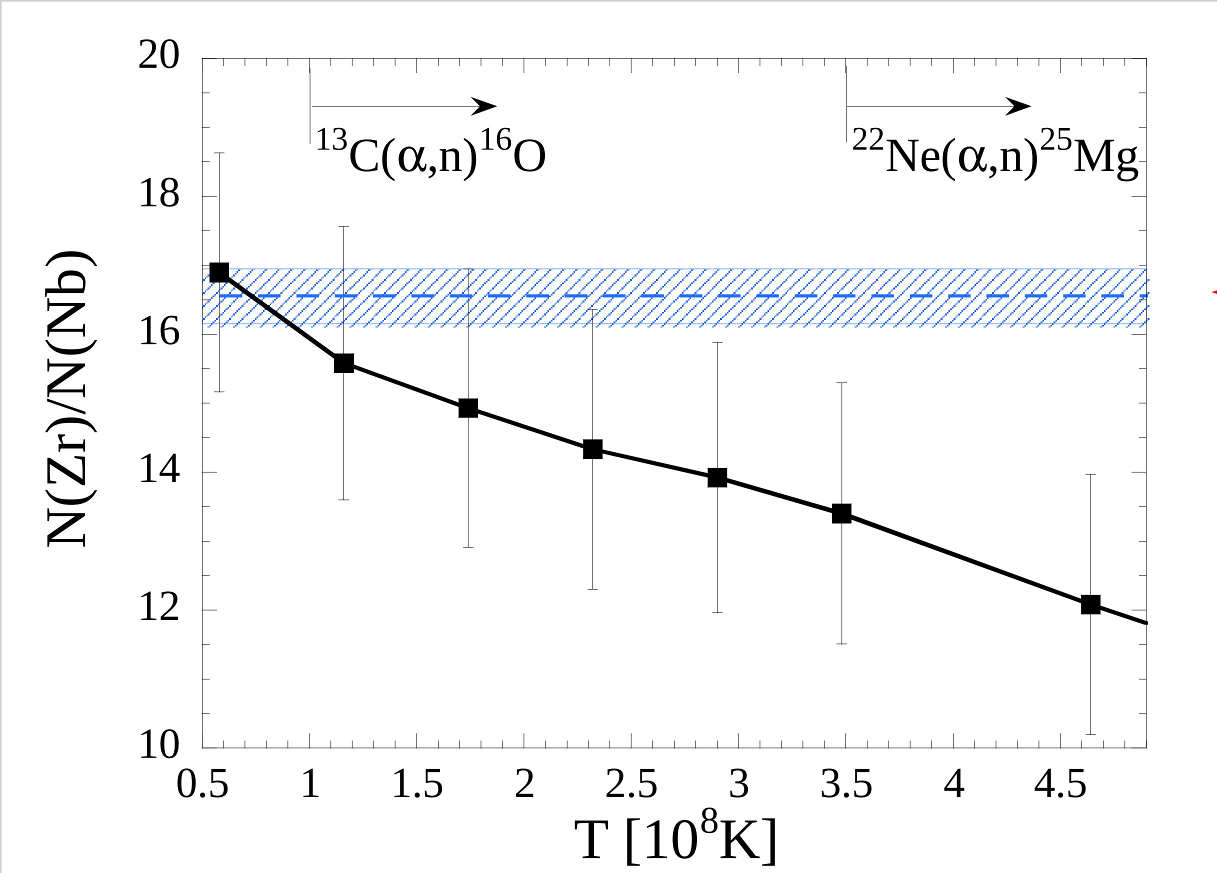


Y intercept of Zr – Nb plot provides ω^*

Application: S- stars



(Neyskens, Van Eck et al. Nature 2015)



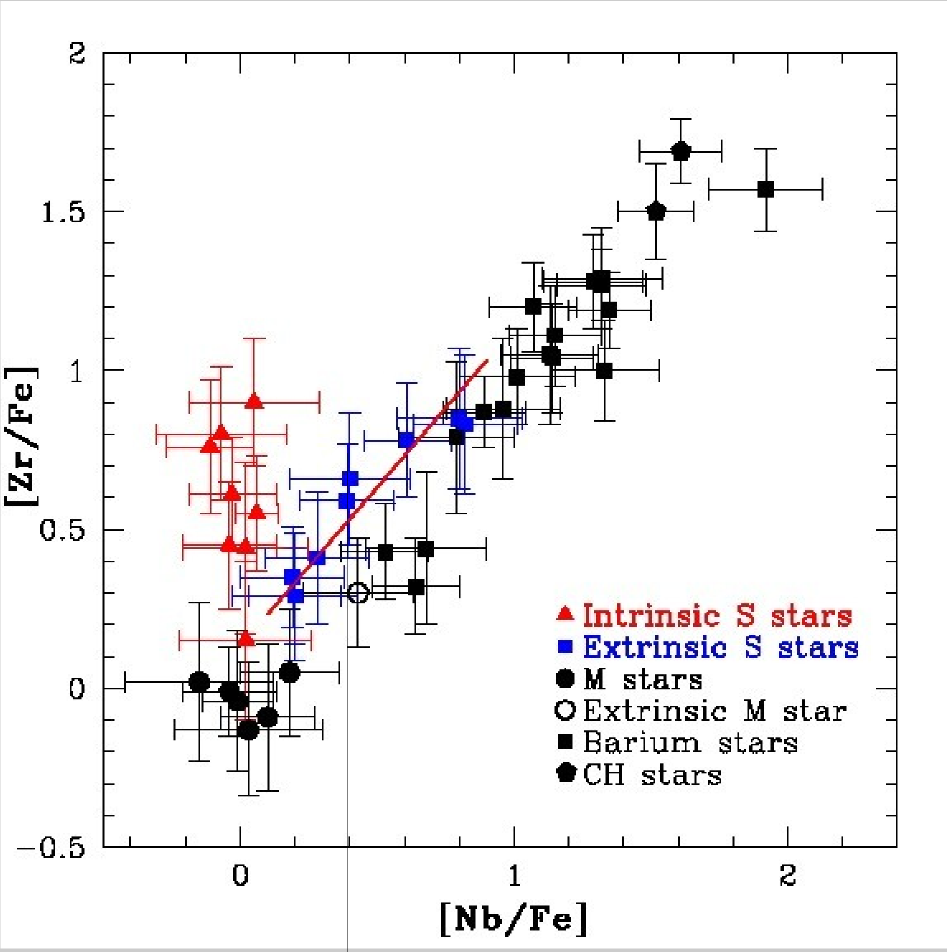
ω* from S stars

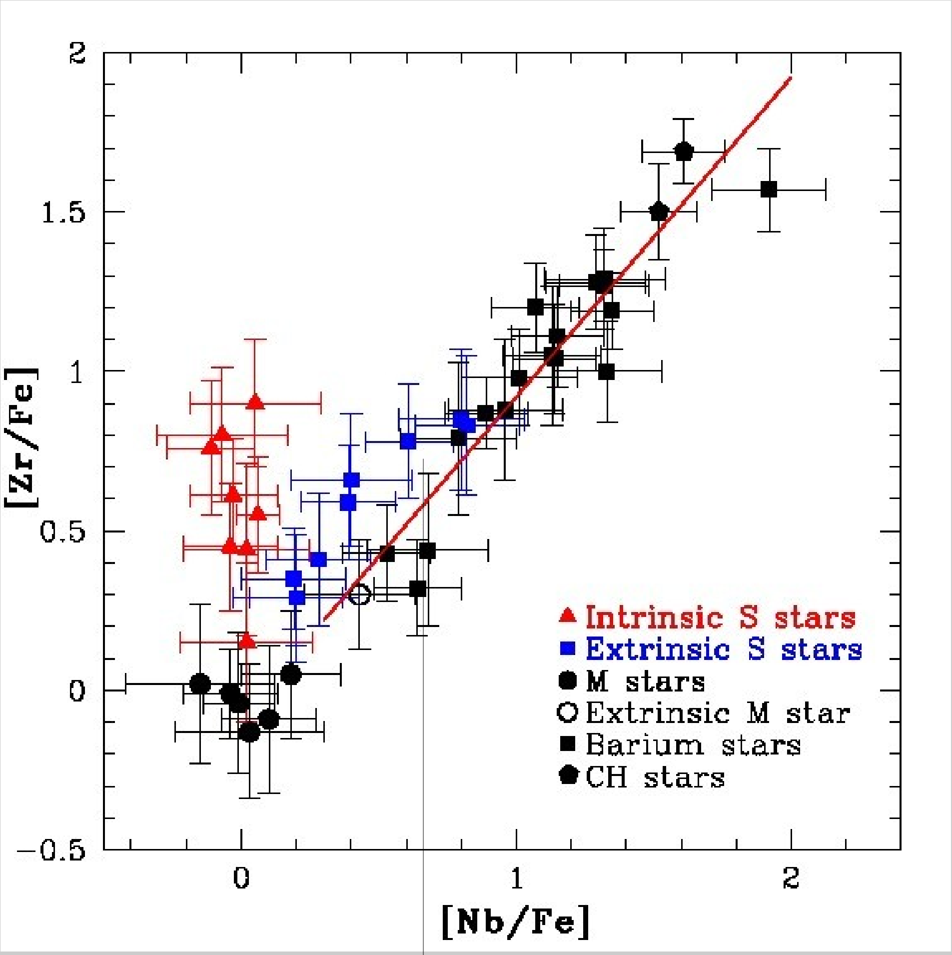
ω* from nuclear computations

Neutron source in S stars identified: $^{13}C(\alpha,n)^{16}O$

Neyskens, Van Eck et al., Nature, 2015

Extending the sample with Barium stars



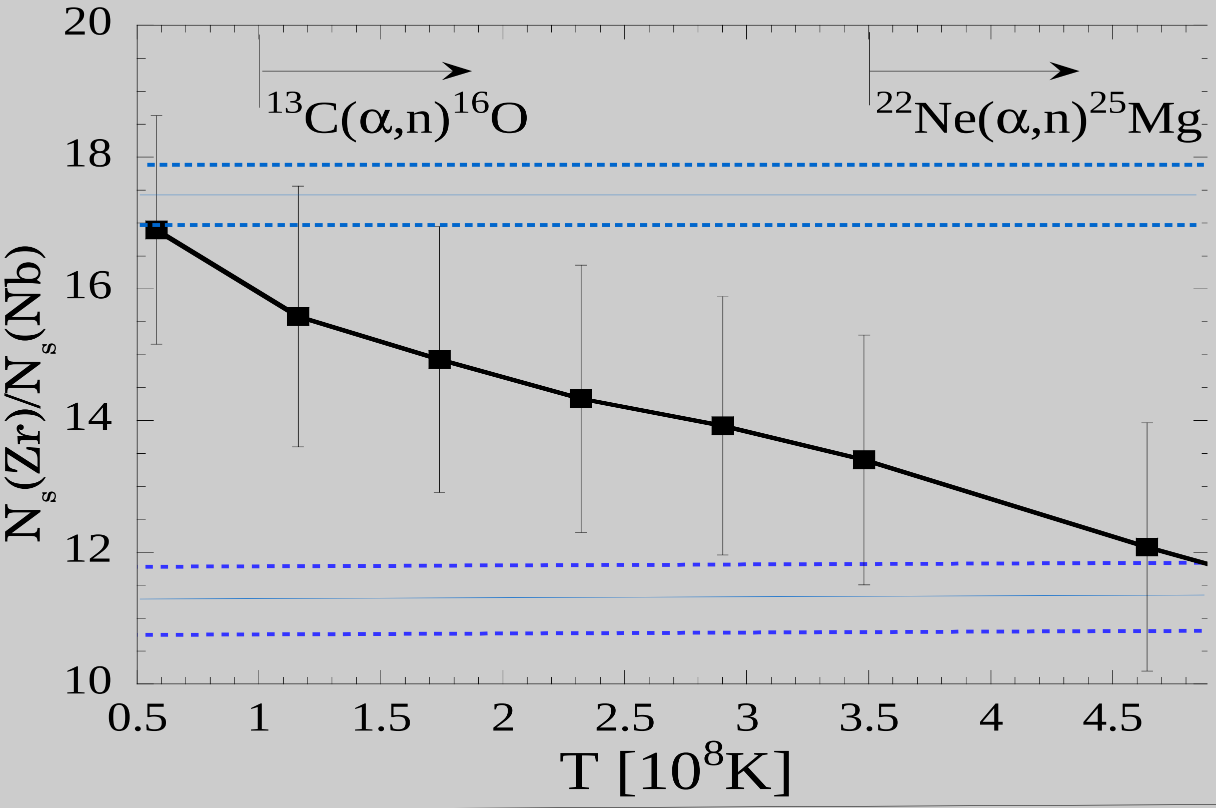


ω* from S stars 17.4

ω* from Ba and CH stars 11.3

Derived s-process operation temperatures

temperature derived from extrinsic S- stars   0.6 x 10^8 K

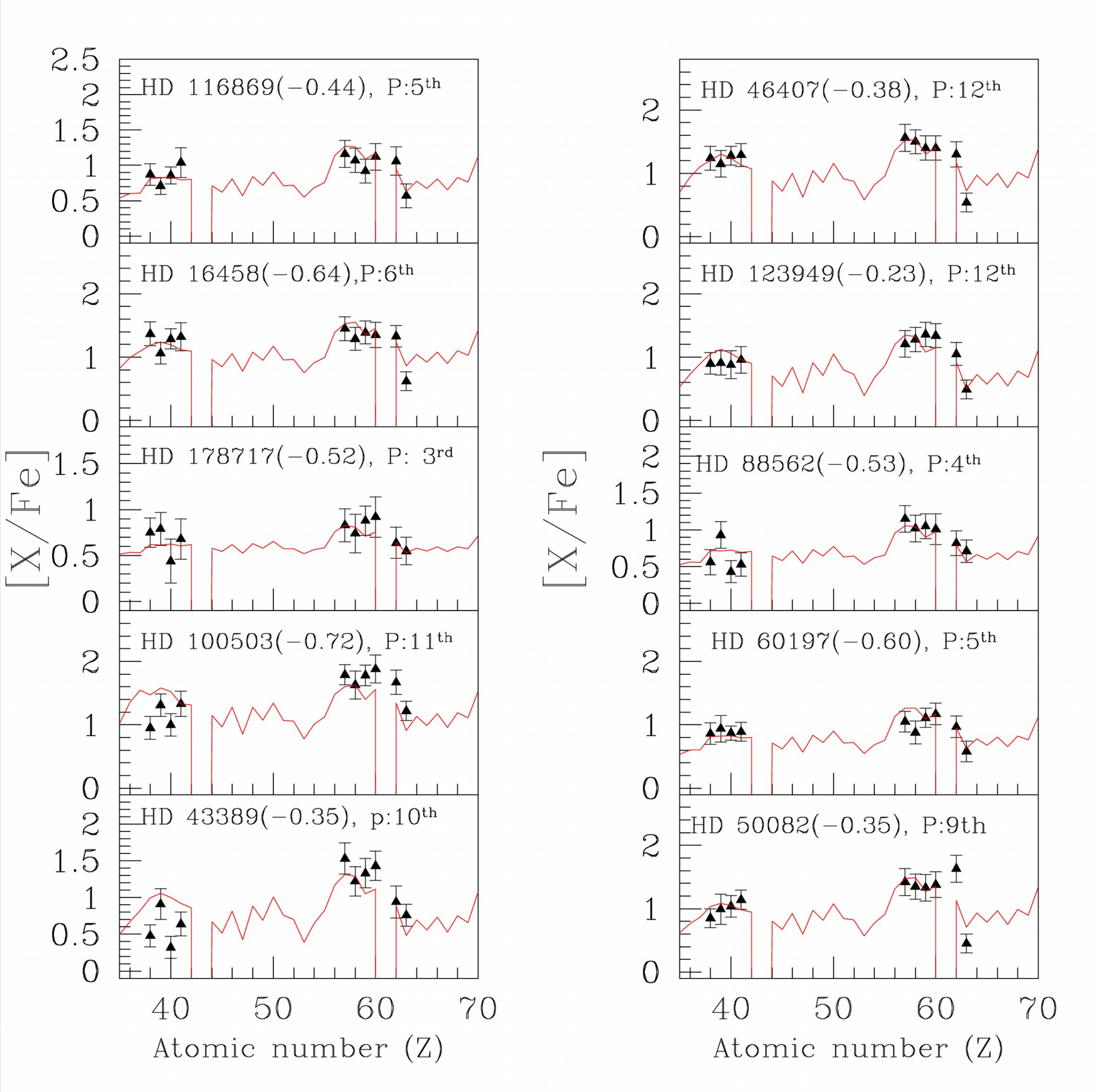


$^{13}C(\alpha, n)^{16}O$

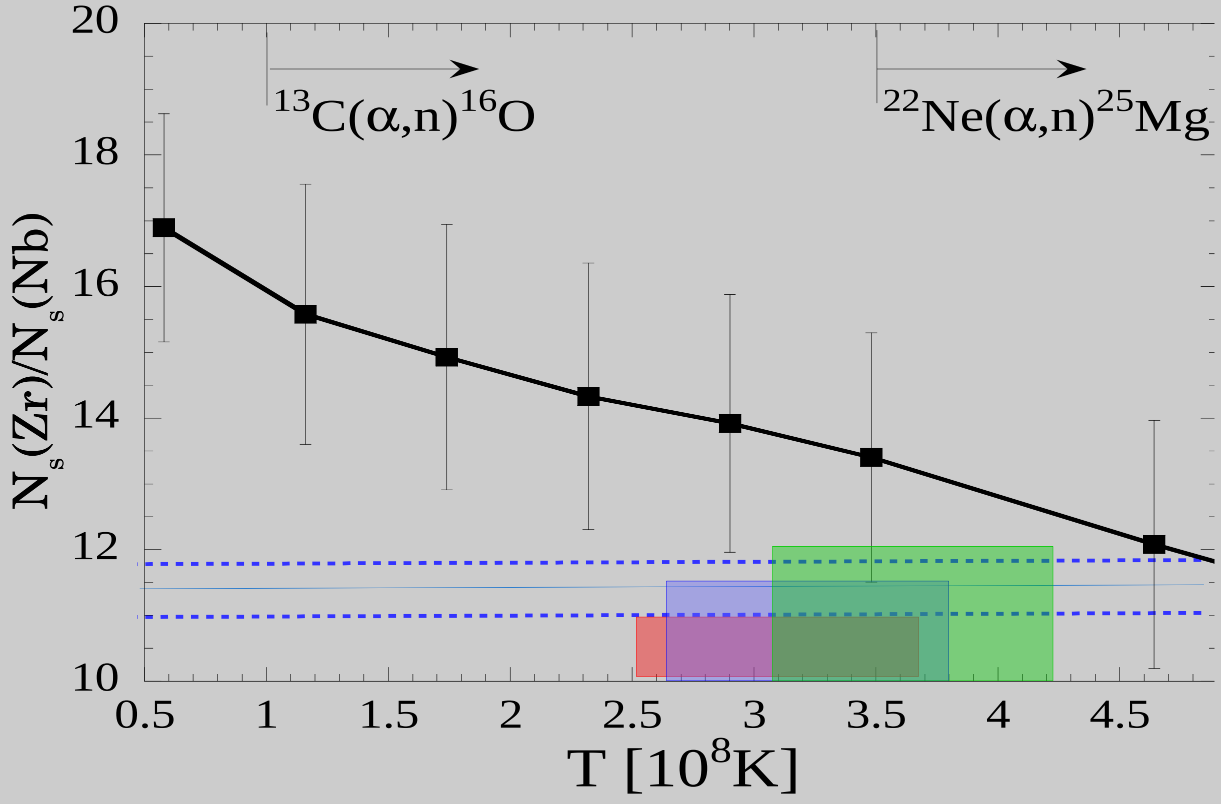
$^{22}Ne(\alpha, n)^{25}Mg$

temperature derived from Ba and CH stars   >3.5 x 10^8 K

s-process abundance pattern (4 $M_\odot$ models)



s-process operation temperatures from the model



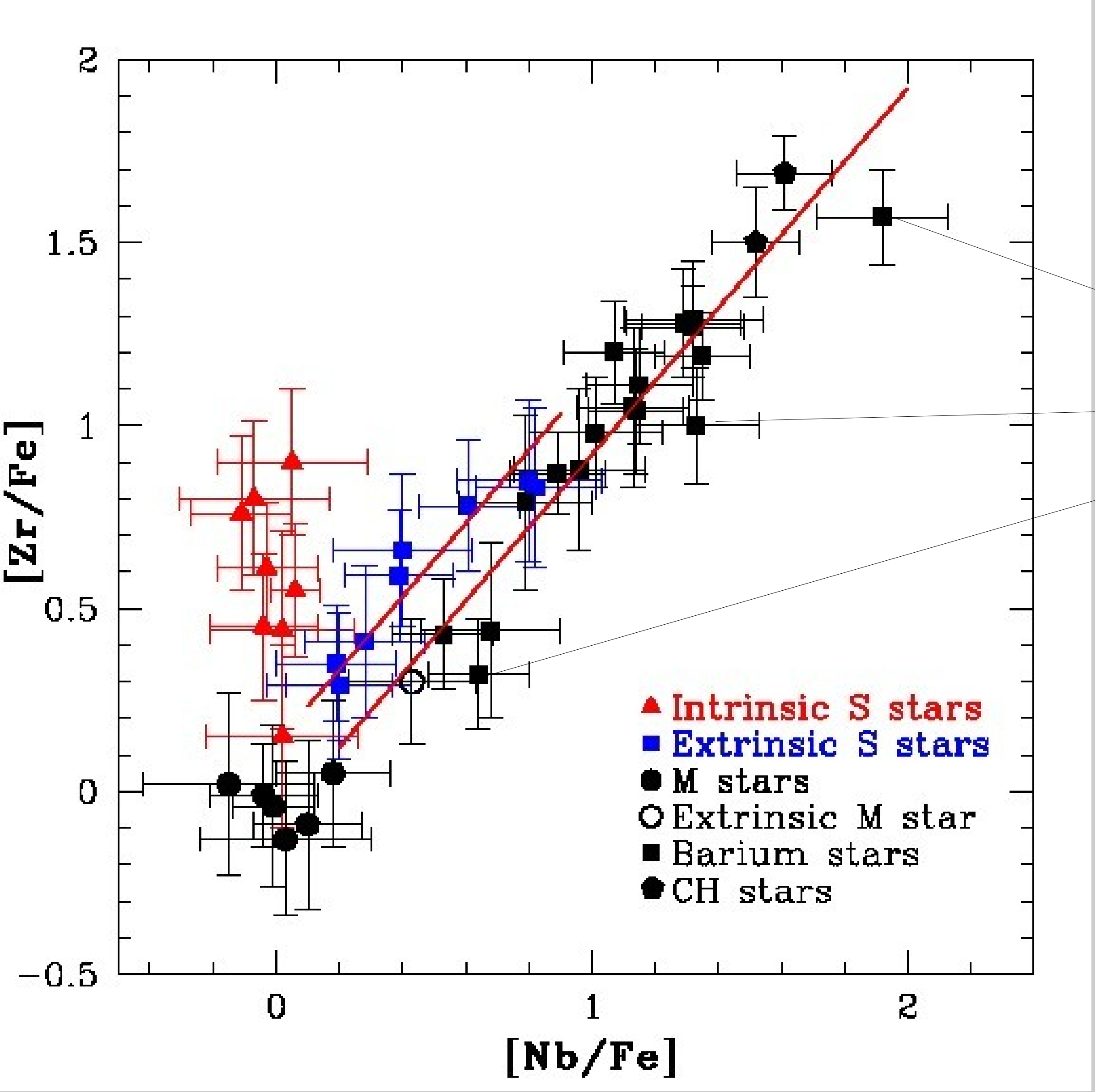
Comparison with temperatures (bottom of the pulse) of STAREVOL models

[Fe/H]=-0.3 (pulse 13)
2.45 - 3.76 x 10^8 K

[Fe/H]=-0.5 (pulse19)
2.45 - 3.85 x 10^8 K

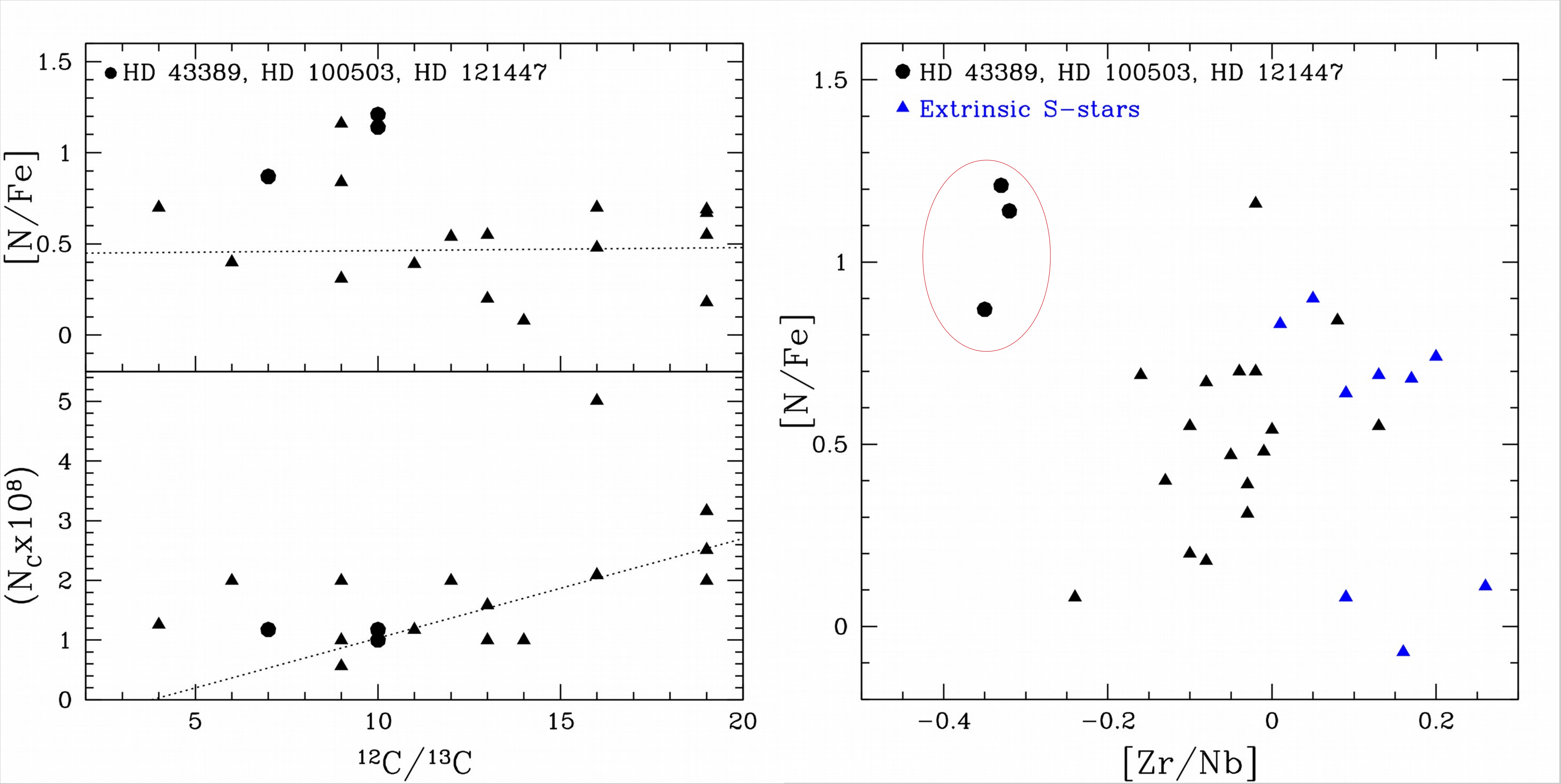
[Fe/H]=-0.7 (pulse 13)
3.15 - 3.89 x 10^8 K

Discussion on peculiar objects



3 outliers

Diagnosis. 1: Nitrogen abundance



Diagnosis 2. The mass

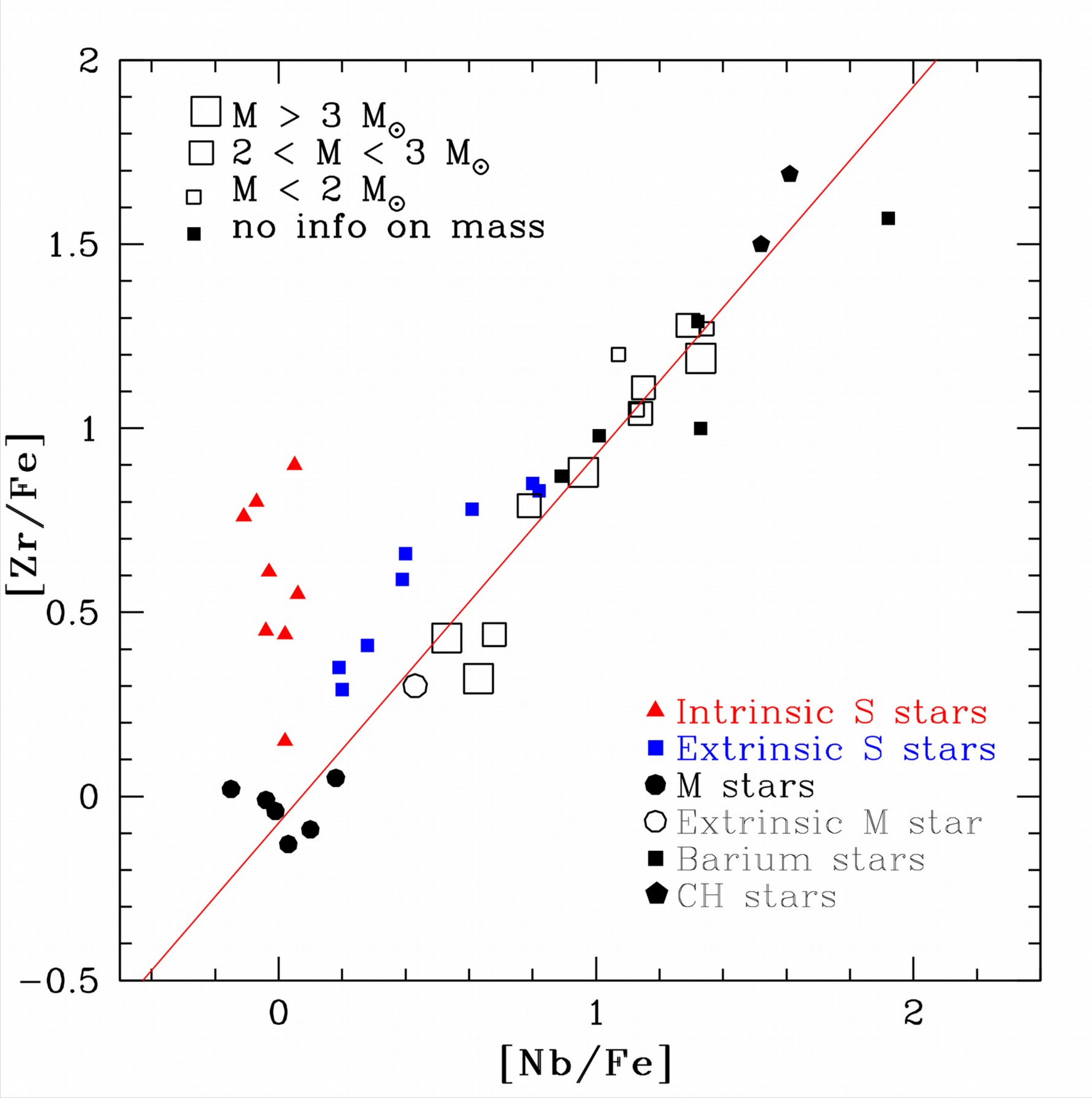
- Lower limit on the donor mass is derived from the HR diagram:

  STAREVOL evol. tracks; GAIA parallaxes; more details in A. Escorza's talk

- Only 3/13 objects have M< 2 $M_\odot$ and their [Zr/Nb] does not indicate high s-process temperatures

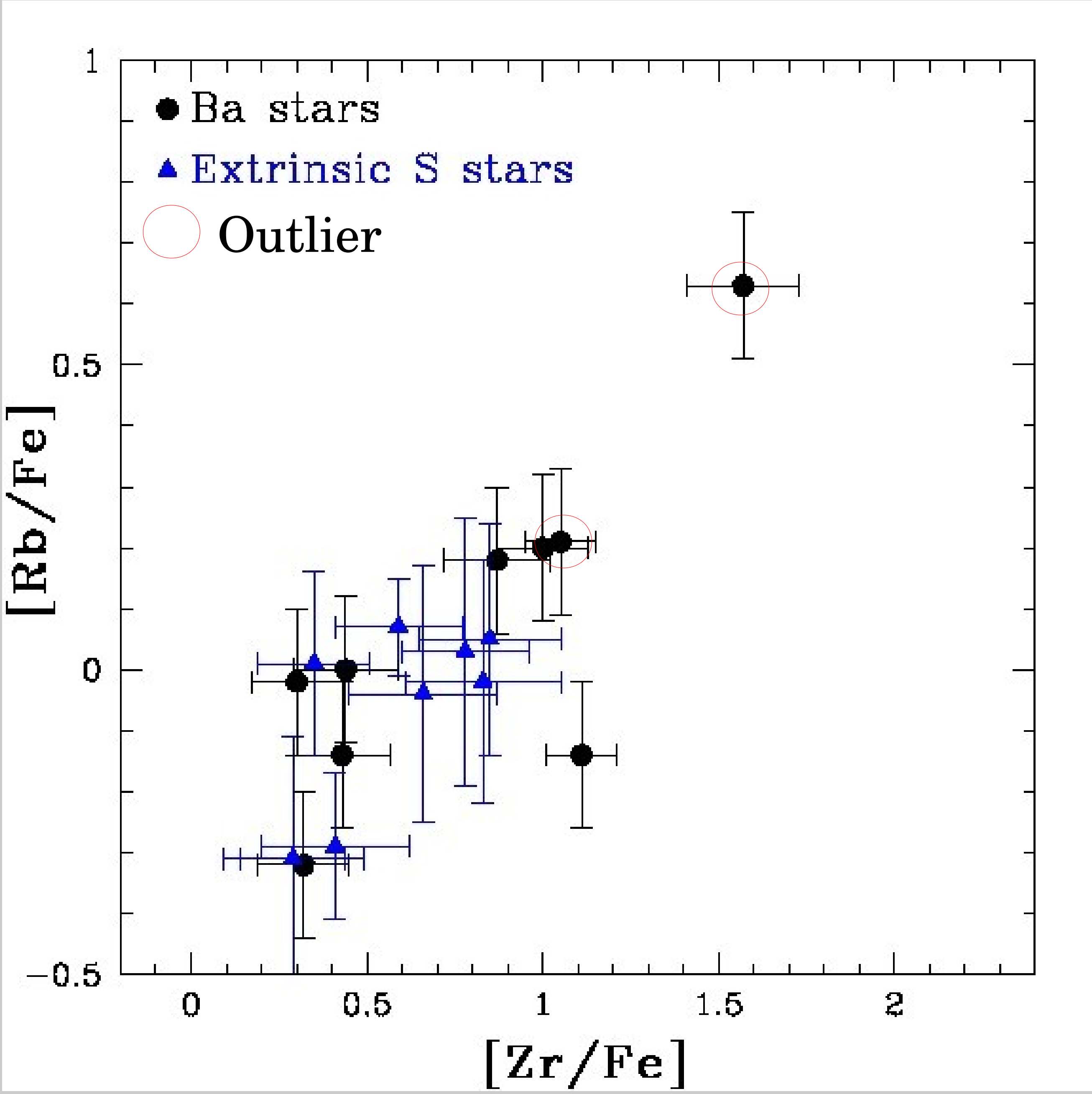
- Among the 3 outliers with large [Zr/Nb], only 1 mass could be determined: M > 3 $M_\odot$

  → consistent with higher s-process temperatures operating in more massive stars



Diagnosis 3: Rb abundance

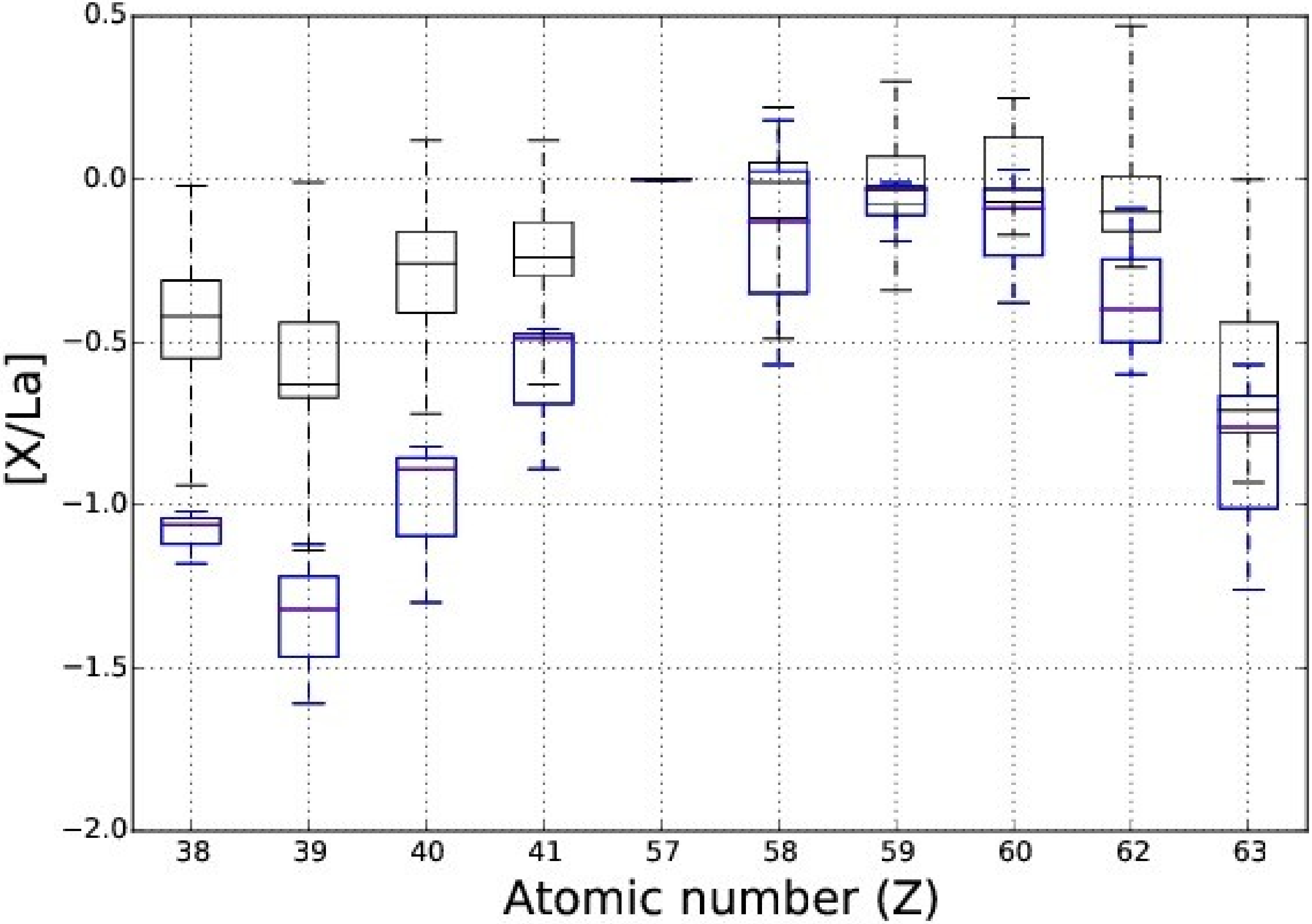
- High [Rb/Fe] observed for high mass stars and it point at ^{22}Ne source.
- [Rb/Fe] larger for Ba stars compared to S stars, but much below model predictions



Conclusion

- Preliminary results indicate high neutron temperatures for the production of s-process elements in barium and CH stars.
- Possibly a difference between extrinsic S stars and barium stars (originating from the mass of the donor?)

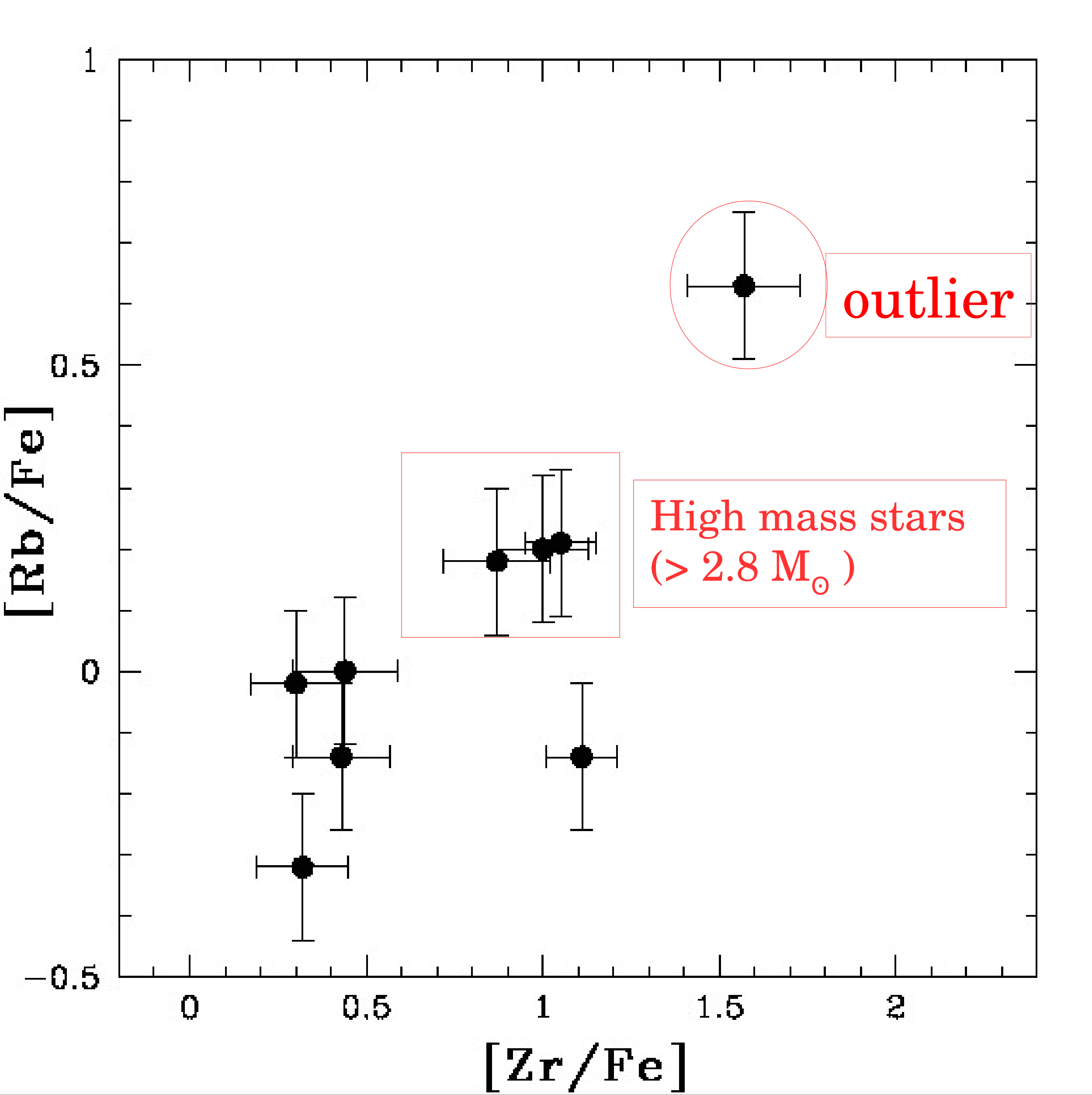
Thank you for your kind attention!!!!!

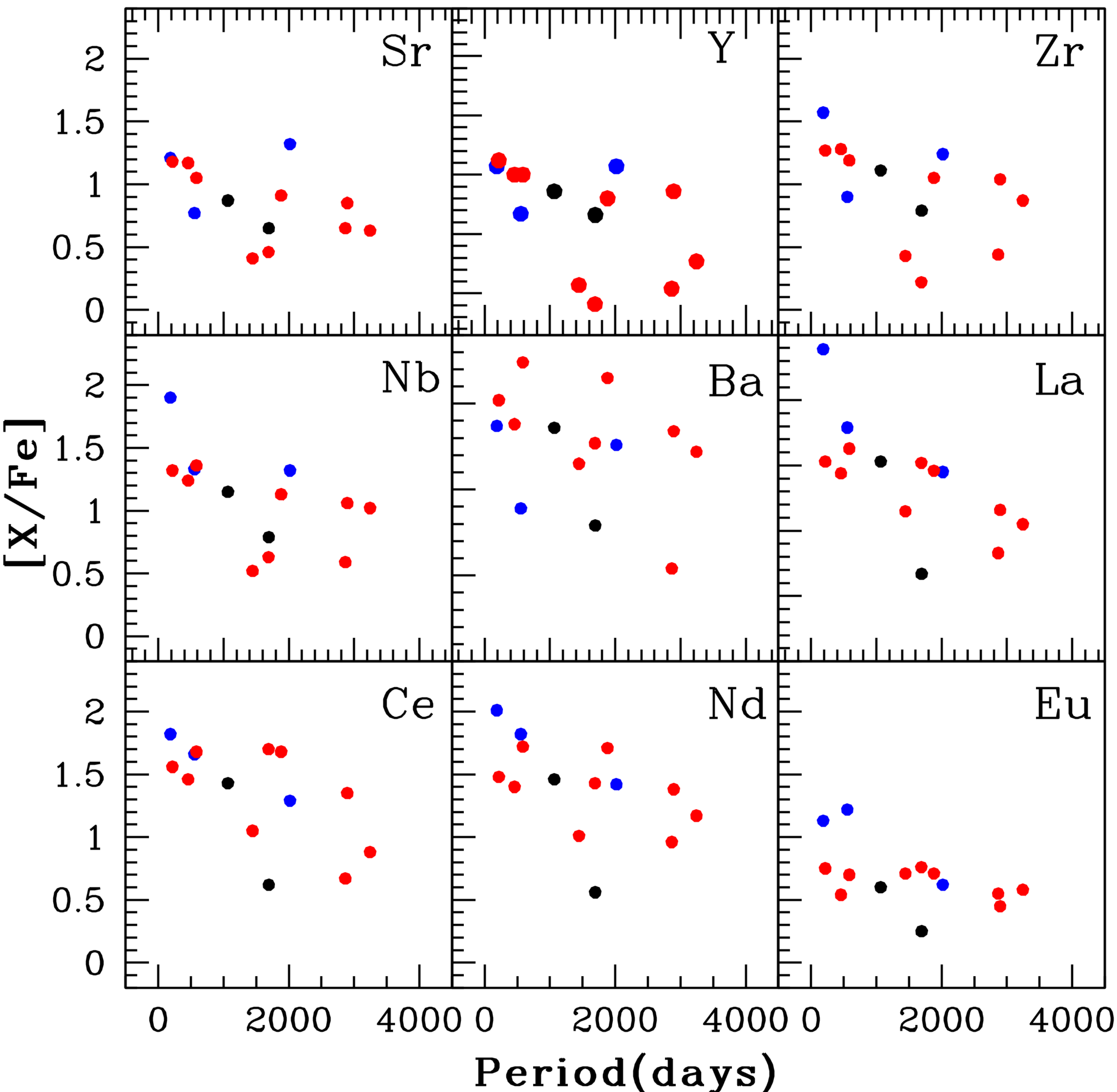


0.5
0.0
−0.5
−1.0
−1.5
−2.0
[X/La]
38
39
40
41
57
58
59
60
62
63
Atomic number (Z)

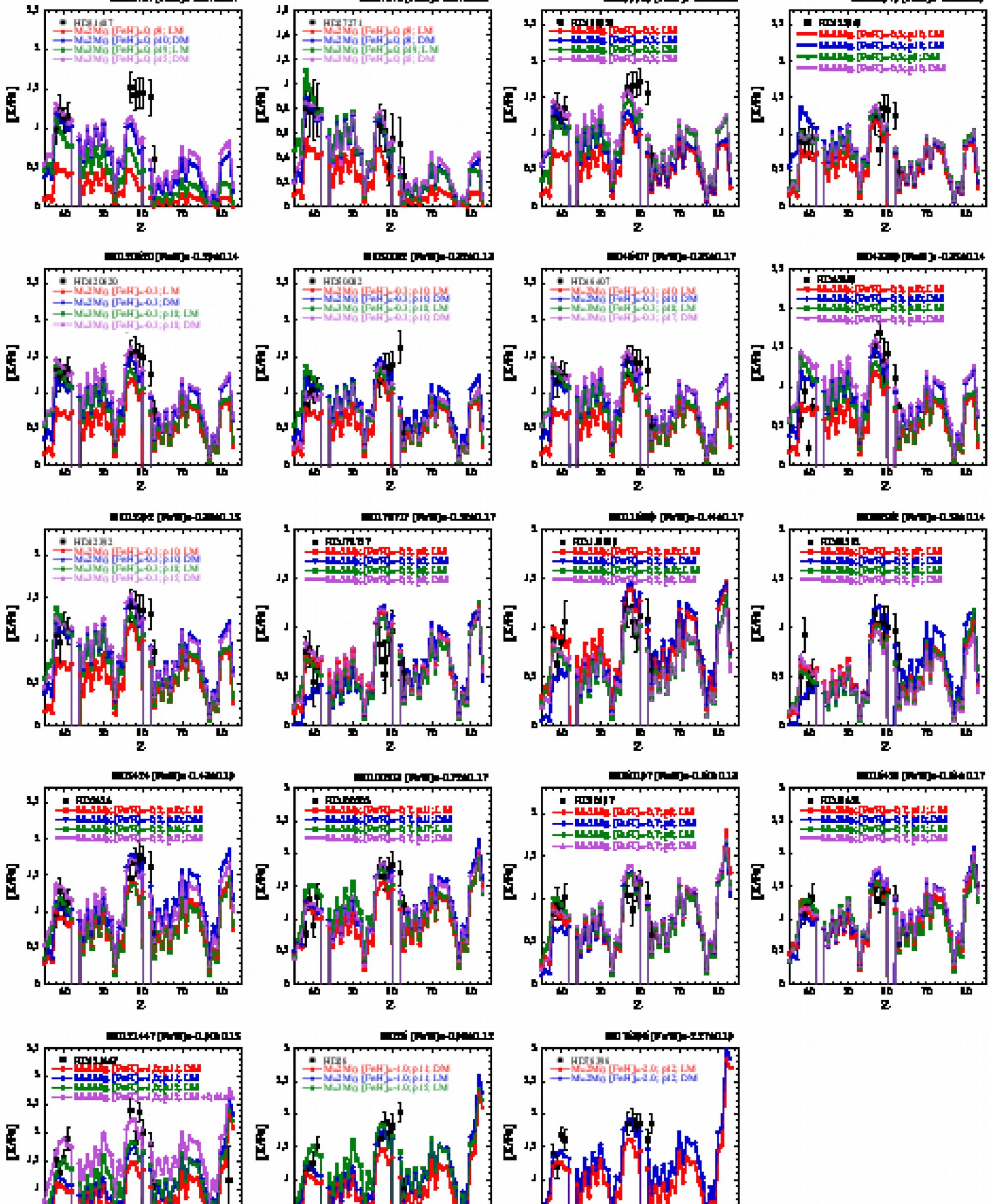
Diagnosis 3: Rb abundance

- High [Rb/Fe] observed for high mass stars and it point at ^{22}Ne source





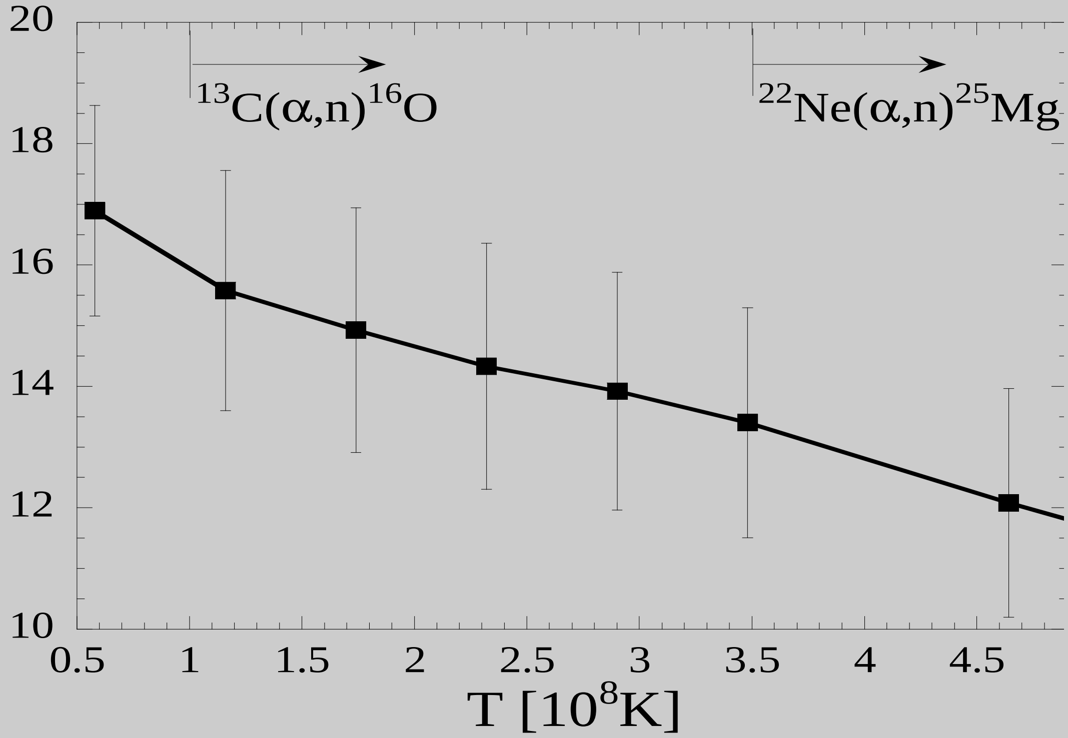
Sr
Y
Zr
Nb
Ba
La
Ce
Nd
Eu
[X/Fe]
Period(days)
0
0.5
1
1.5
2
0
2000
4000



Objectives: To derive s-process operation temperature and thereby to understand the neutron sources for a group of extrinsic stars independent of stellar evolutionary models.

$$\omega^* = \langle\sigma_{93}\rangle \times \left[\frac{1}{\langle\sigma_{90}\rangle} + \frac{1}{\langle\sigma_{91}\rangle} + \frac{1}{\langle\sigma_{92}\rangle} + \frac{1}{\langle\sigma_{94}\rangle}\right]$$

where ω* is a sensitive function of temperature (neutron capture cross sections of Zr is a sensitive function of temperature)



Y intercept of Zr-Nb plot provides ω*

The sample: Extrinsic stars

An extended sample of extrinsic stars:

highly enriched Barium and CH stars

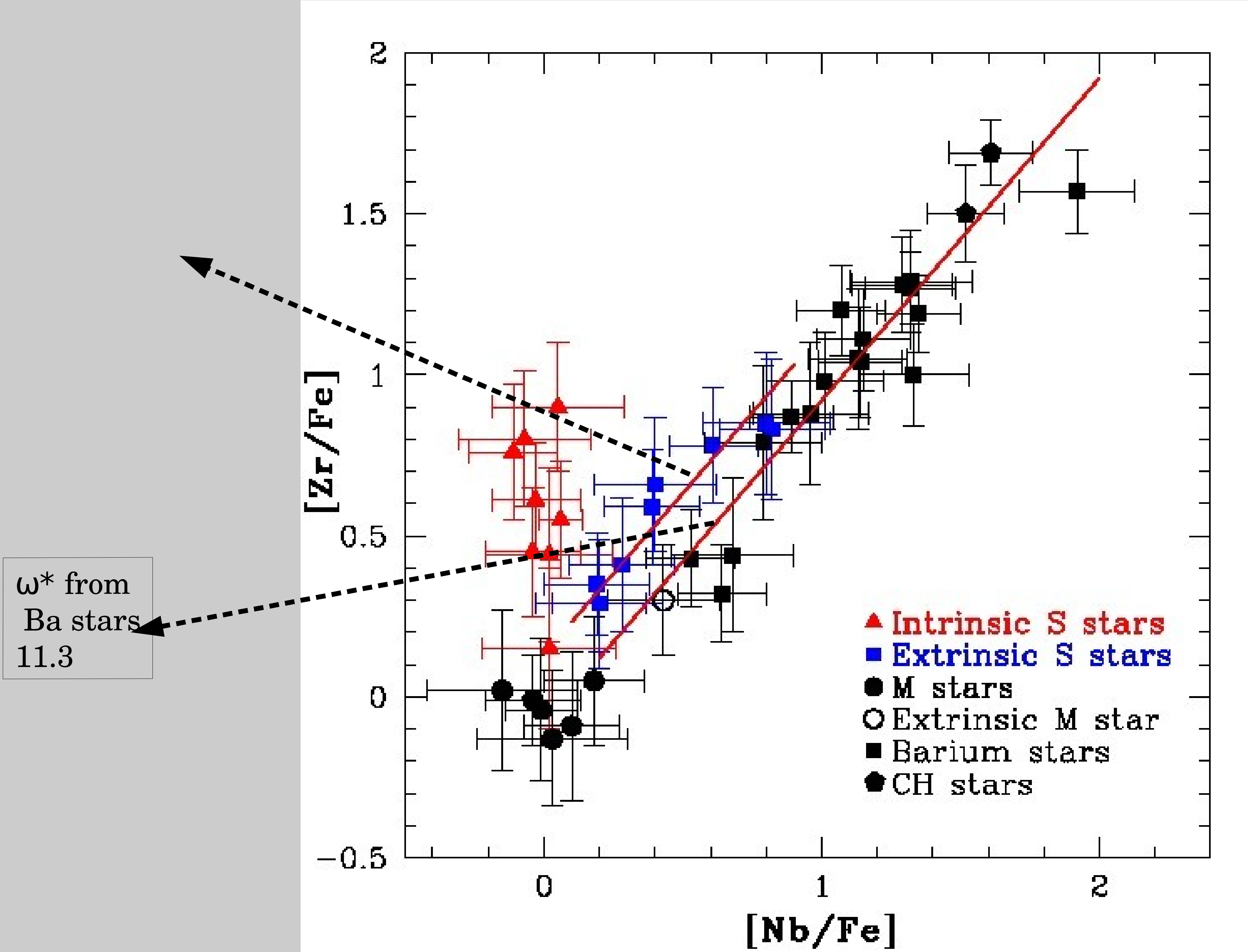
observed using HERMES spectrograph, Resolution (~85000), Wavelength coverage 3750 – 9000 Å.

Parameters and abundance determinations

- Stellar parameters and elemental abundances : using TURBOSPECTRUM spectral synthesis code
- MARCS model atmospheres
- Linelist: VALD database

Results

- T_{eff} ranges from 3800 – 5150 K
- log g between 1 and 3.4
- Derived abundances for nine s-process elements :
  - Careful line selection from comparison with benchmark stars:
    - V762 Cas, (Teff – 3800 K, log g =1)
    - Arcturus (Teff - 4258 K, log g =1.6)
    - Sun



[Zr/Fe]
[Nb/Fe]
2
1.5
1
0.5
0
−0.5
0
1
2
Intrinsic S stars
Extrinsic S stars
M stars
Extrinsic M star
Barium stars
CH stars
ω* from
Ba stars
11.3