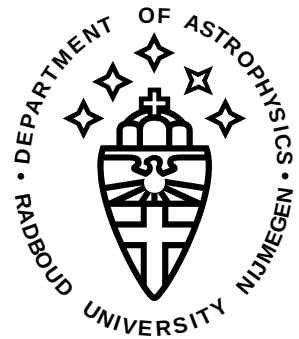
CEMP-s stars

A window to AGB nucleosynthesis at low metallicity

Carlo Abate



with
O.R. Pols, A.I. Karakas, R.G. Izzard

Outline

1. Carbon-enhanced metal-poor(-s) stars
2. Model & Method
3. Results
4. Summary

CEMP-s stars

Carbon and s-elements enhanced metal-poor stars (CEMP-s):

- $-2.8 \leq [\mathrm{Fe/H}] \leq -1.8$
- $[\mathrm{C/Fe}] \geq 1.0$
- $[\mathrm{Ba/Fe}] \geq 0.5$

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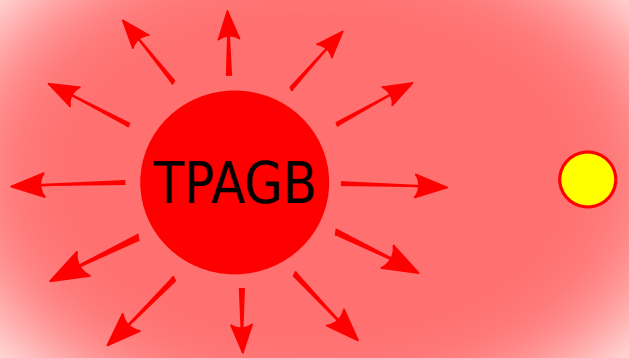
r-elements enhancement:

- $[\mathrm{Eu/Fe}] < 1.0 \longrightarrow$ **CEMP-s-only**
- $[\mathrm{Eu/Fe}] \geq 1.0 \longrightarrow$ **CEMP-s/r**

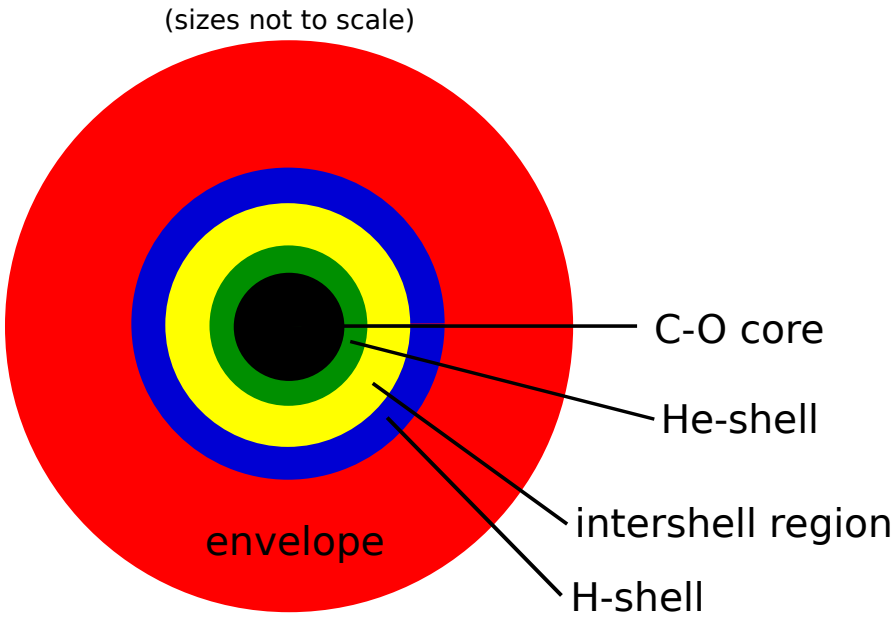
CEMP-*s* stars

1. binary systems
   (Lucatello+2005b, Starkenburg+2014)

2. C and *s*-elements produced by AGB primary



AGB nucleosynthesis in a nut$_{\text{inter}}$shell



$$^{13}\mathrm{C} + \alpha \rightarrow \mathbf{n} + {}^{16}\mathrm{O}$$

$$^{56}\mathrm{Fe} + \mathbf{n} \rightarrow s\text{-elements}$$

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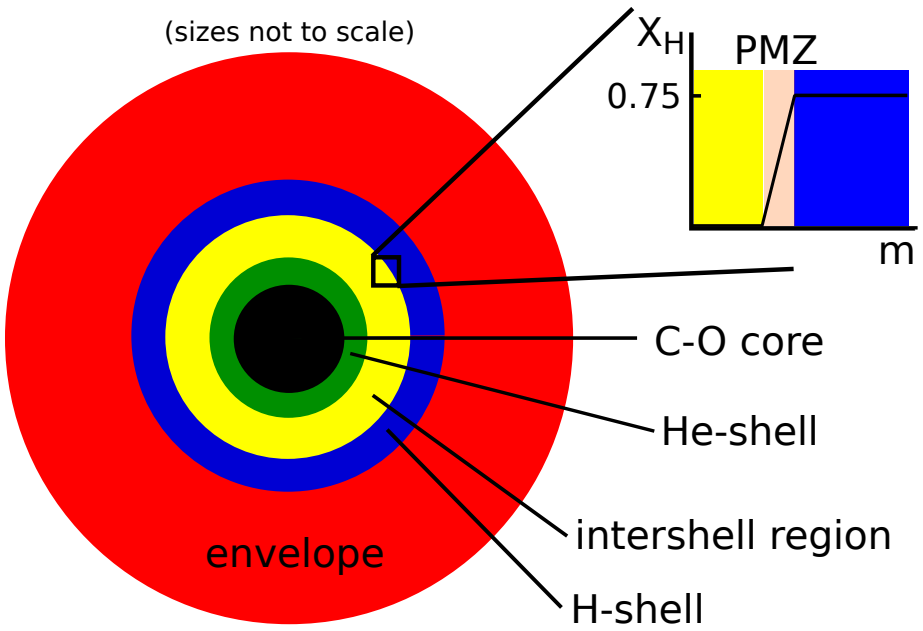

PMZ: partial mixing zone

$(\mathrm{M_{PMZ}} \approx [0,\, 0.004]\,\mathrm{M_\odot})$

$$^{12}\mathrm{C} + {}^{1}\mathrm{H} \rightarrow {}^{13}\mathrm{C}$$

$$\Downarrow$$

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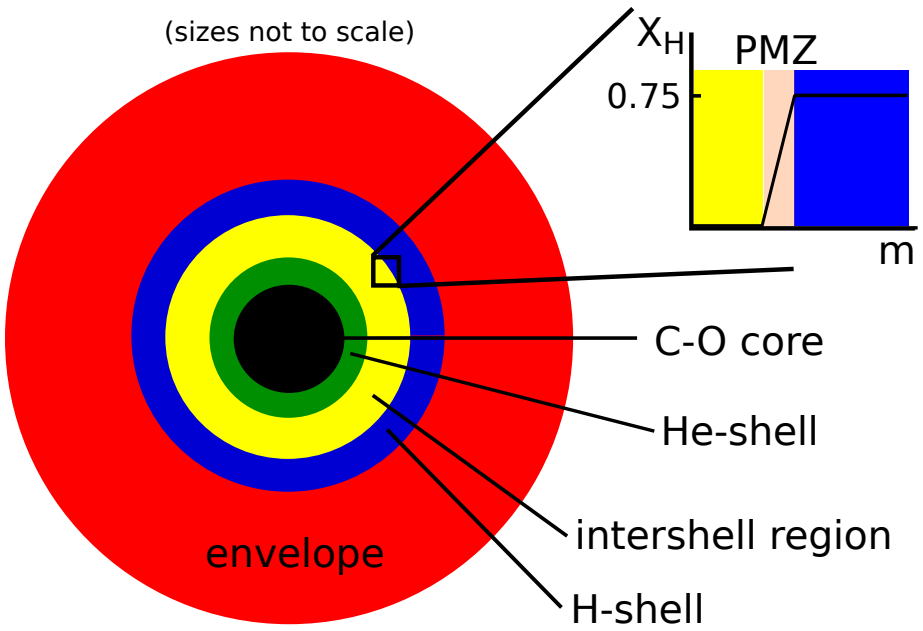

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larger $\mathrm{M_{PMZ}} \Rightarrow$ more $\mathbf{n}$ available for s-process

Goals

1. Model of chemical and dynamical evolution

2. Conditions to reproduce observed abundances

Model ingredients

Our code: `binary_c/nucsyn` *(Izzard+ 2004, 2006, 2009)*

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single/binary star evolution

M_1 , M_2 , a , $\dot{M}_{\rm lost}$, $\dot{M}_{\rm acc}$, $\dot{J}$

AGB nucleosynthesis

tables of intershell abundances

(based on Karakas2010, Lugaro+2012)

Method

1. **Grid of modelled stars:**

   → $M_{1,\mathrm{i}}$, $M_{2,\mathrm{i}}$, a_{i}, $\mathrm{M_{PMZ}}$

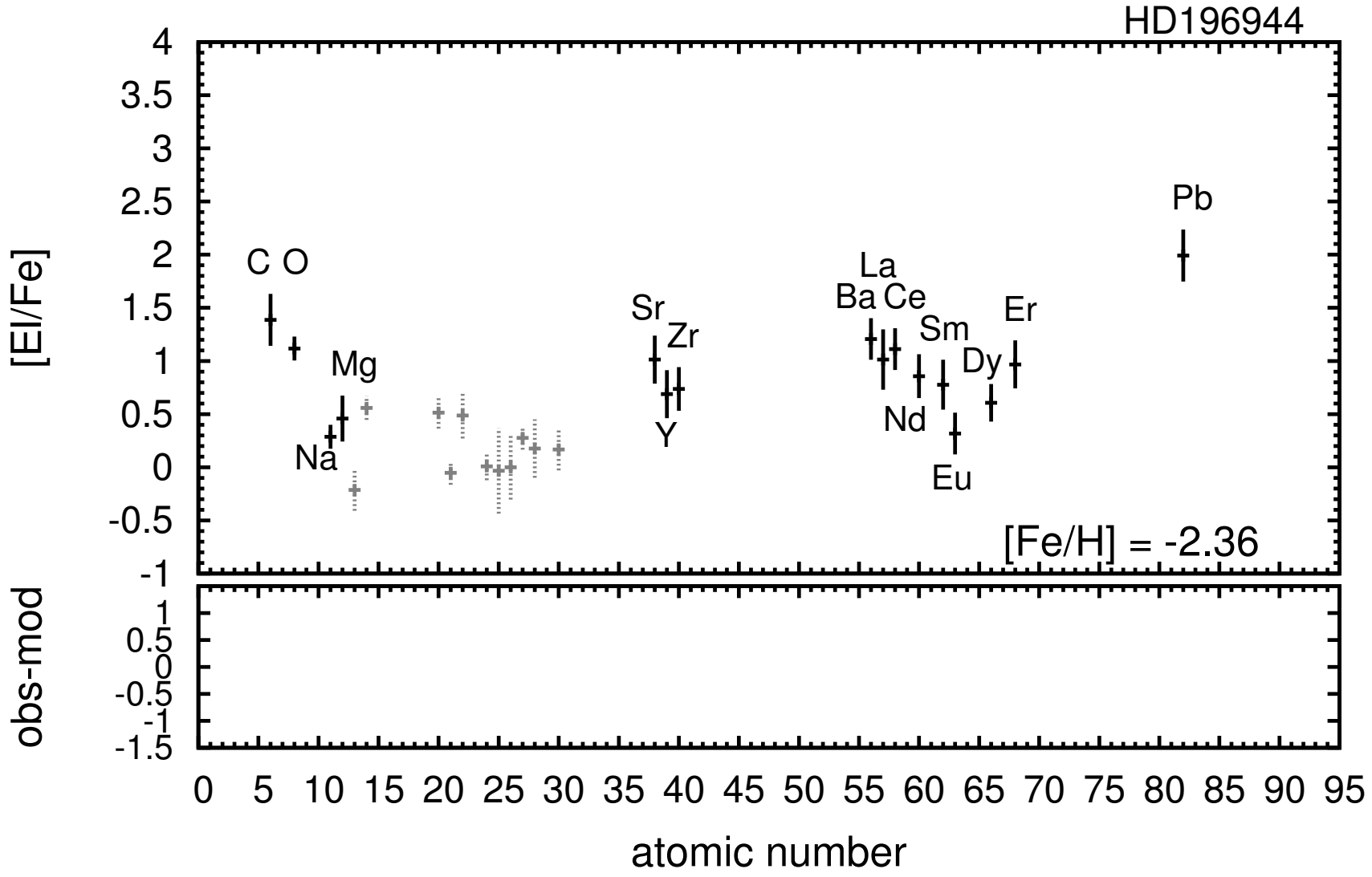
2. **Observed sample:**

   → 62 CEMP-*s* stars *(from SAGA database, Suda+2012)*

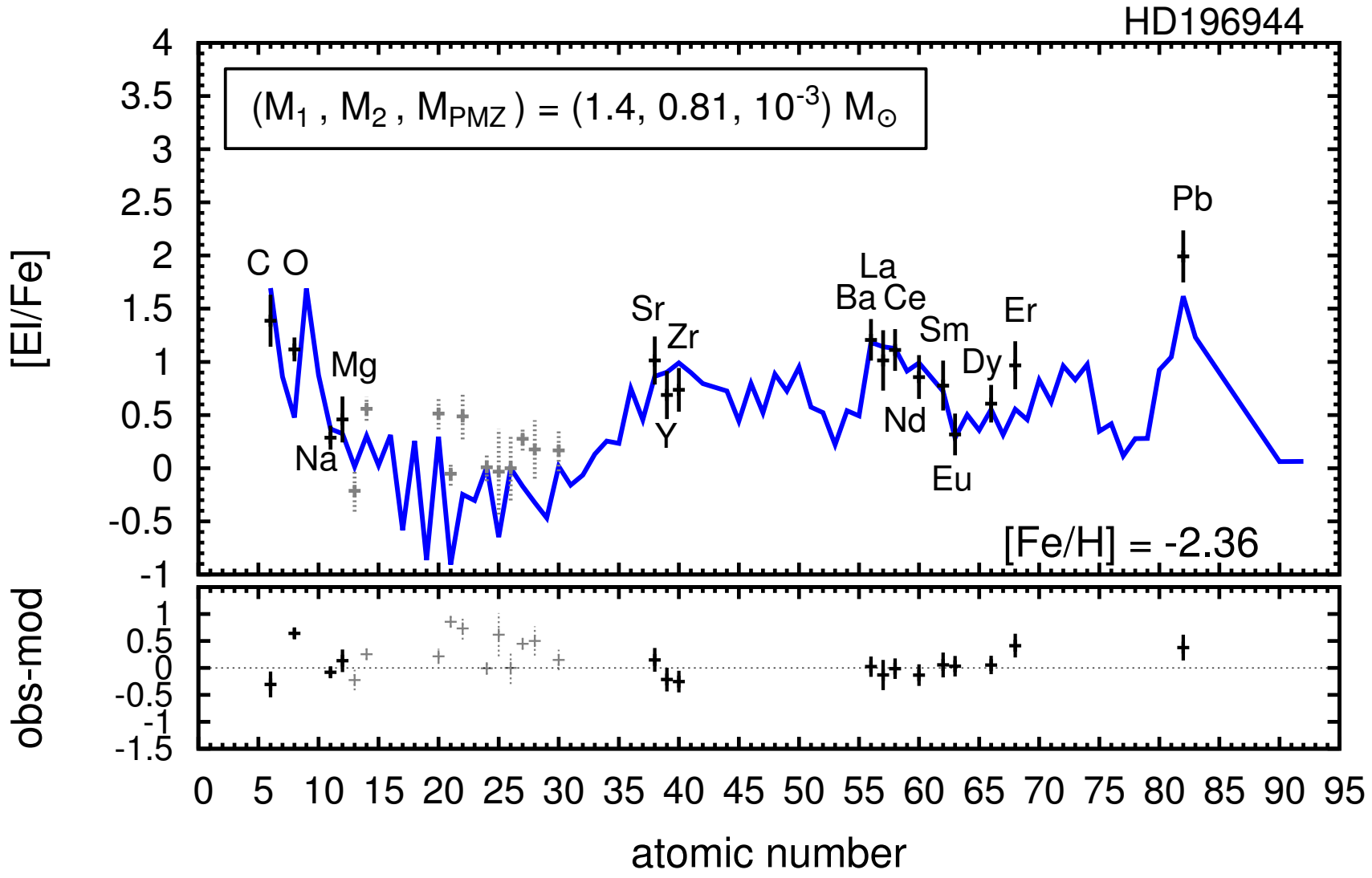
3. **Best model:**

   → $\log(g)$ and χ^2_{min}, where $\chi^2 = \sum_i \frac{(A_{i,\mathrm{obs}} - A_{i,\mathrm{mod}})^2}{\sigma^2_{i,\mathrm{obs}}}$

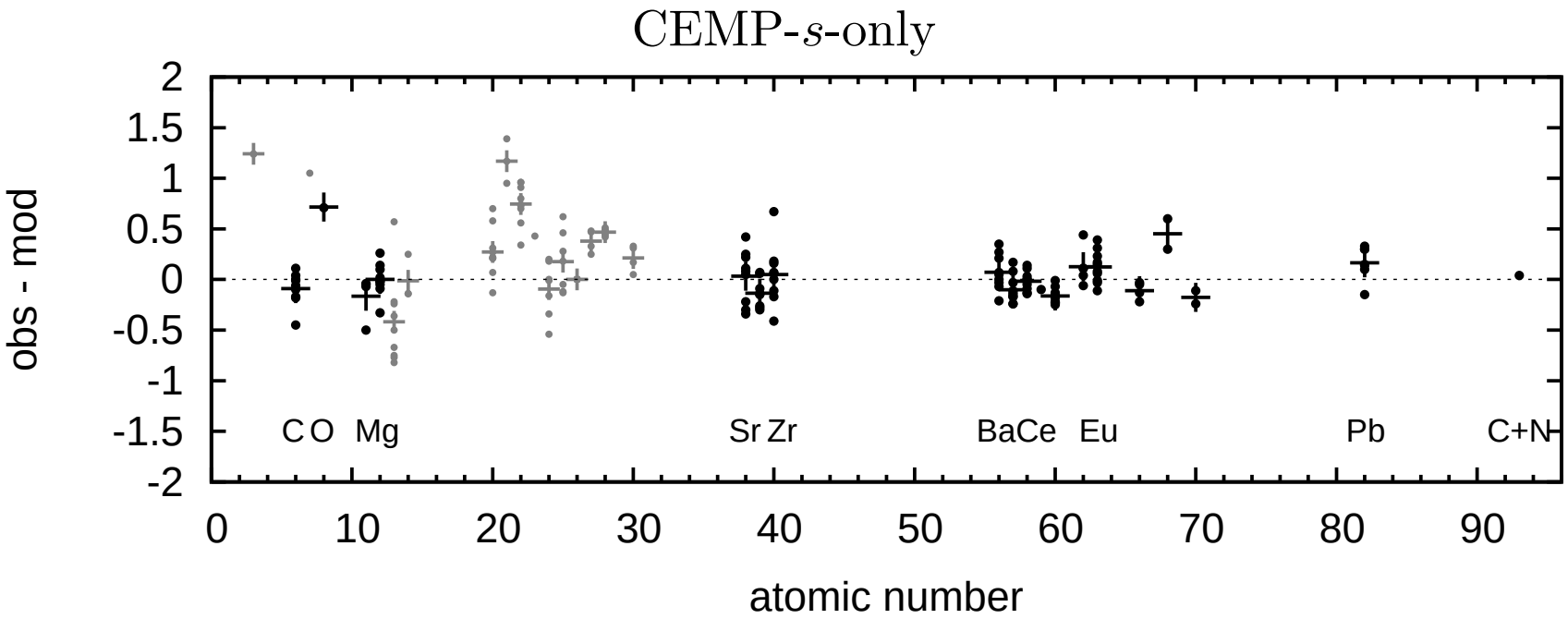
Example (I)


HD196944
[El/Fe]
obs-mod
[Fe/H] = -2.36
C
O
Na
Mg
Sr
Zr
Y
La
Ba
Ce
Nd
Sm
Eu
Dy
Er
Pb
atomic number

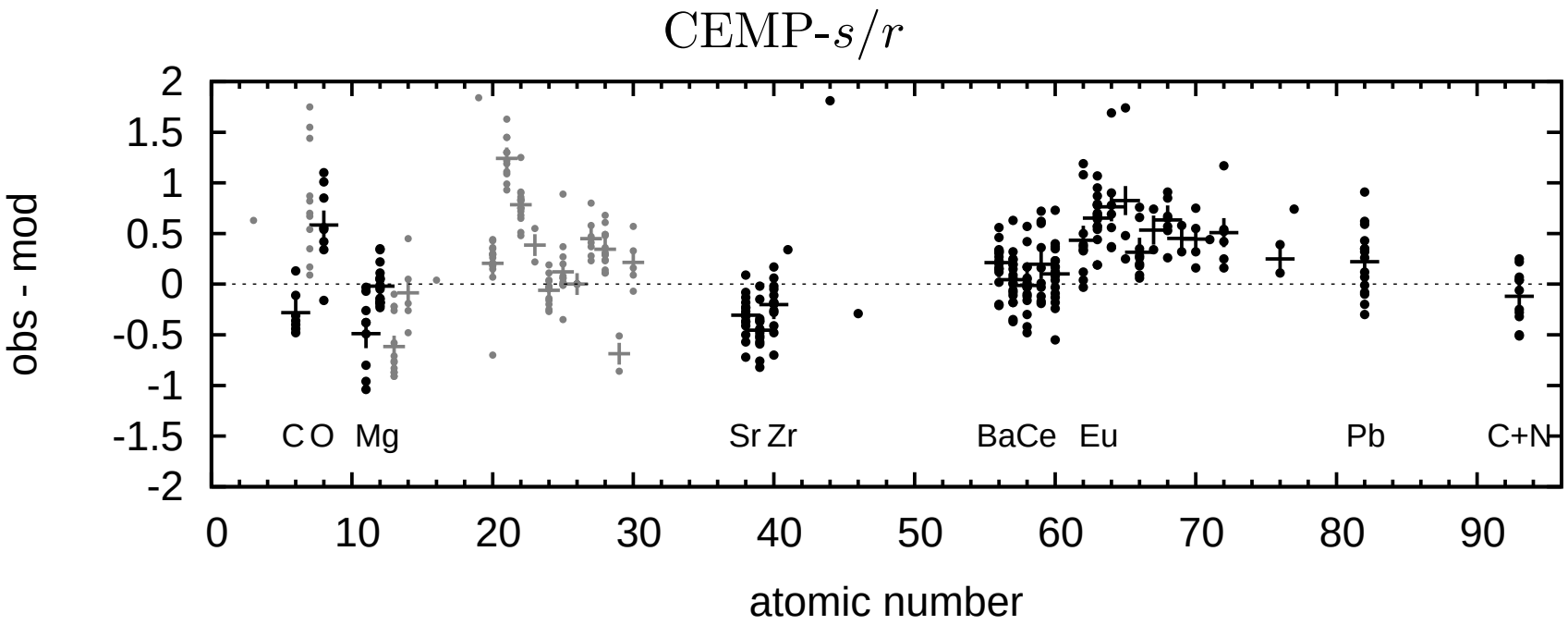
Example (I)


HD196944
(M1 , M2 , MPMZ) = (1.4, 0.81, 10-3) M⊙
[Fe/H] = -2.36
[El/Fe]
obs-mod
atomic number
C
O
Na
Mg
Sr
Y
Zr
La
Ba
Ce
Nd
Eu
Sm
Dy
Er
Pb

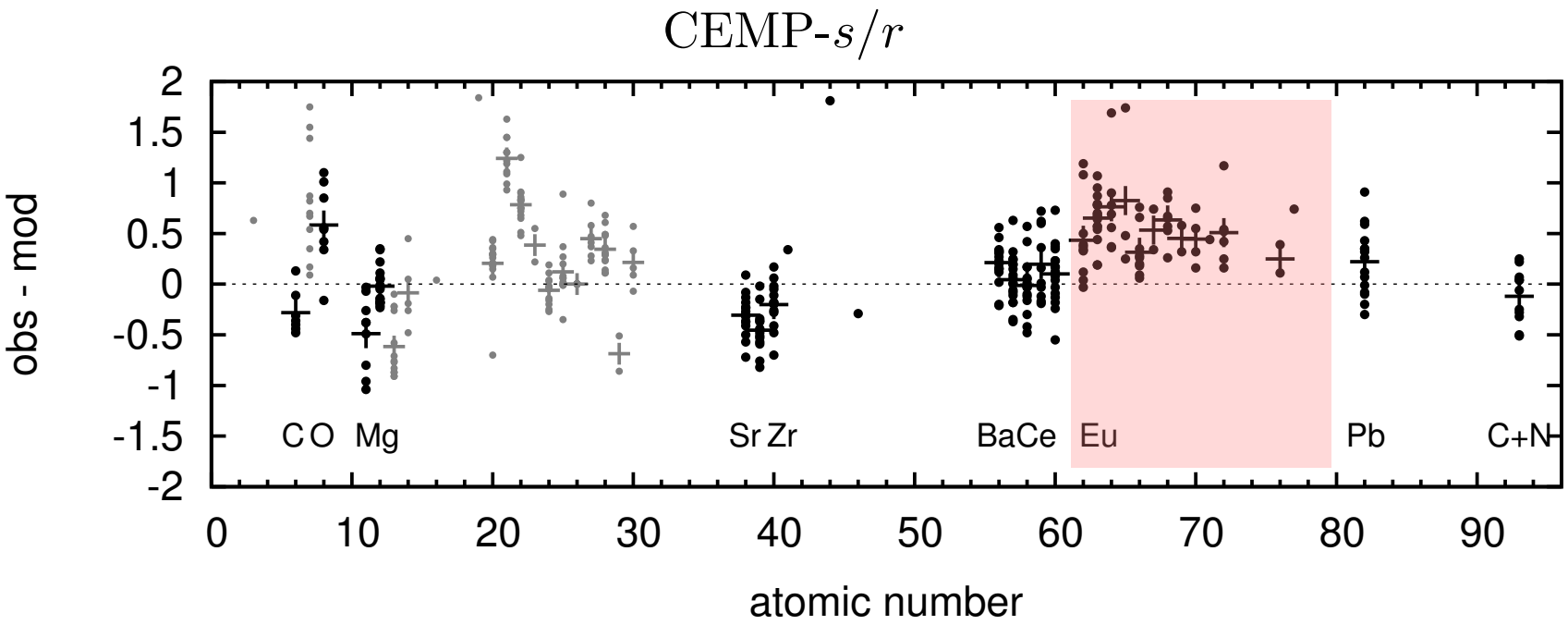
Residuals: CEMP-*s*-only stars



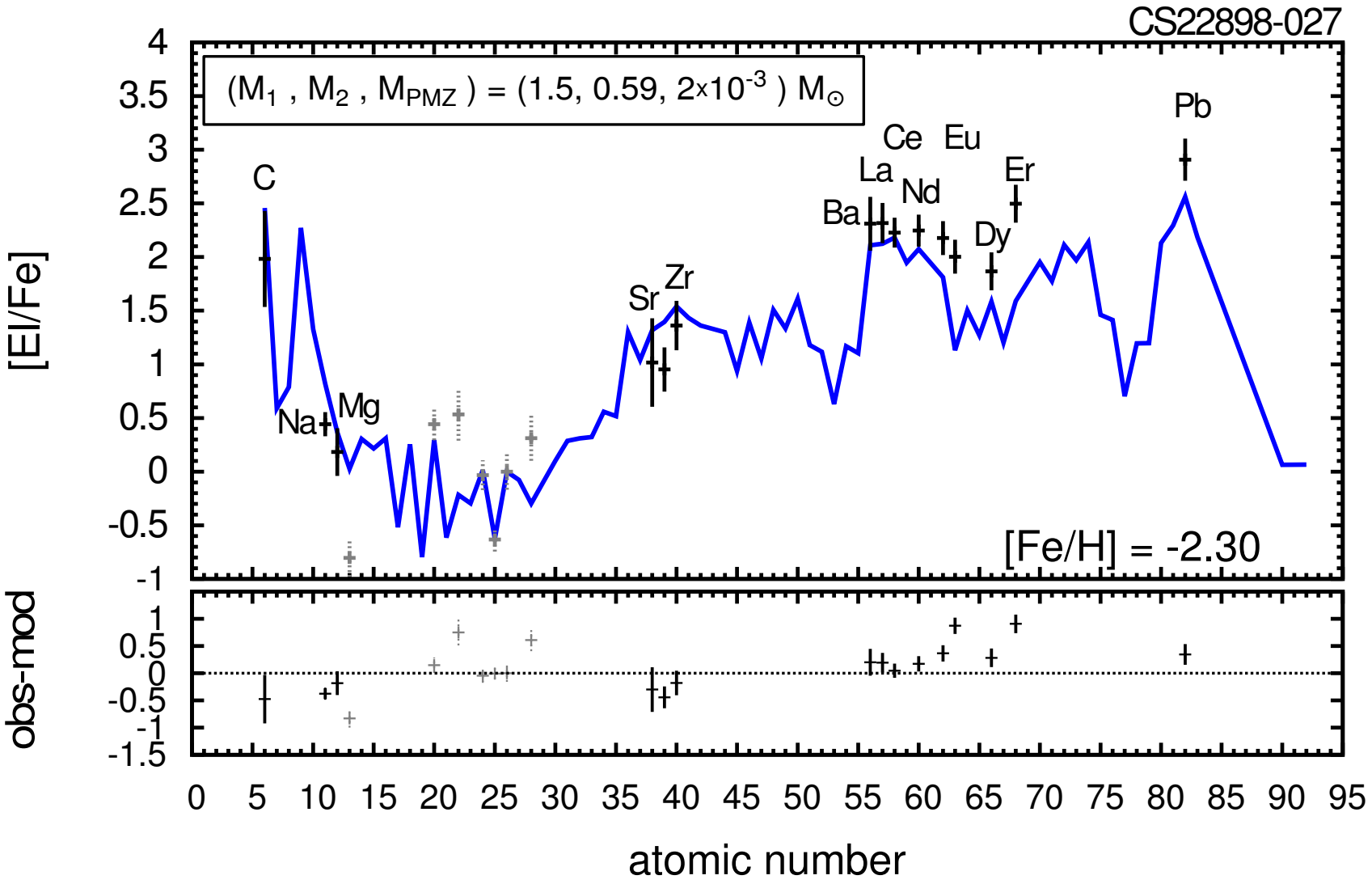
Residuals: CEMP-s/r stars



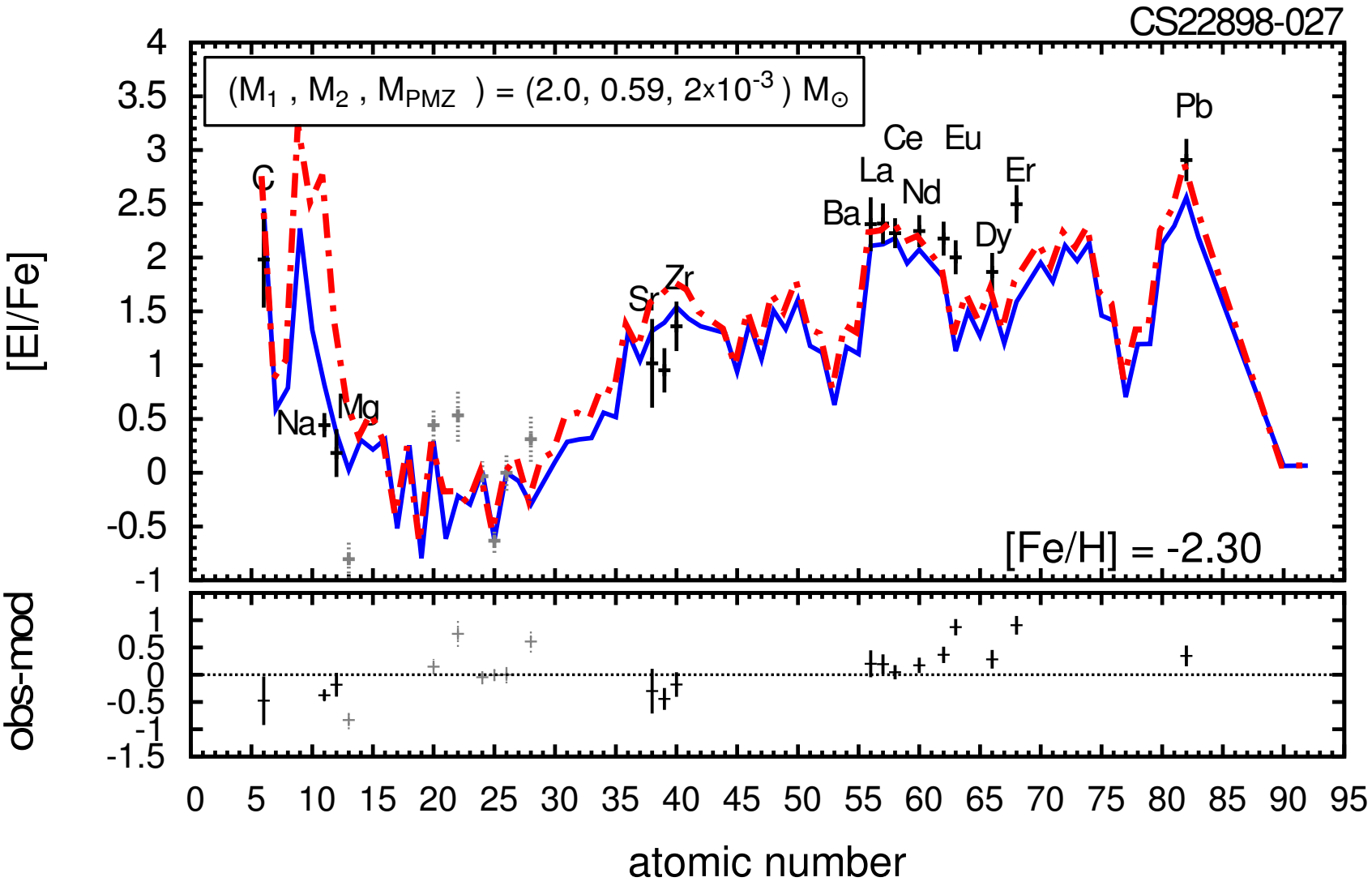
Residuals: CEMP-s/r stars



Example (II): a CEMP-s/r star



Example (II): a CEMP-s/r star



Summary

1. **CEMP-s-only :** almost all elements on average reproduced within observational uncertainty.

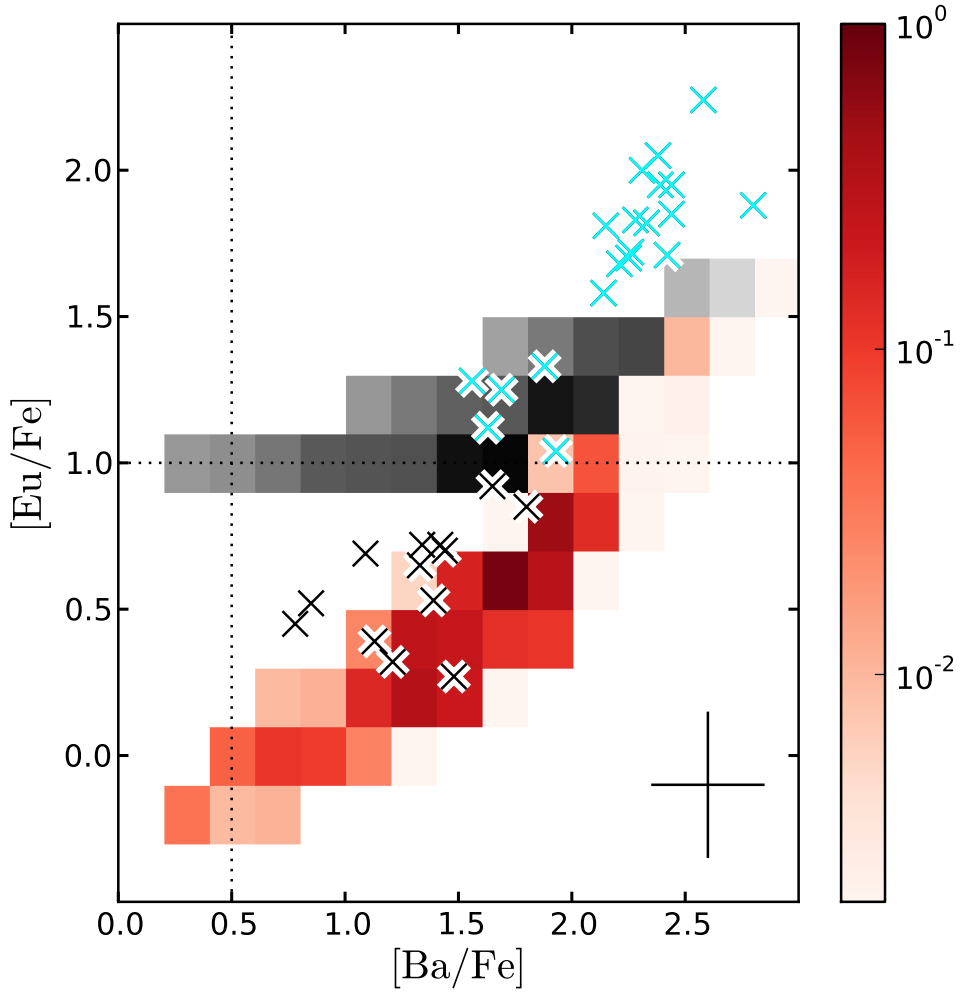
   CEMP-s/r : problems not only with r-elements, also s-elements
   $\Rightarrow$ "s/r"-process?

2. **[hs/ls] threshold:**

$$[\text{hs/ls}]_{\text{obs}} > [\text{hs/ls}]_{\text{mod,max}} \Rightarrow \text{ls-peak overestimated}$$
$$\text{hs-peak underestimated}$$

Appendix

[Ba/Fe] vs [Eu/Fe]



Best fits: $M_{1,\mathrm{i}}$ and $\mathrm{M_{PMZ}}$