OMEG15
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s-Process Nucleosynthesis in AGB Stars at Low-Metallicity

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in collaboration with

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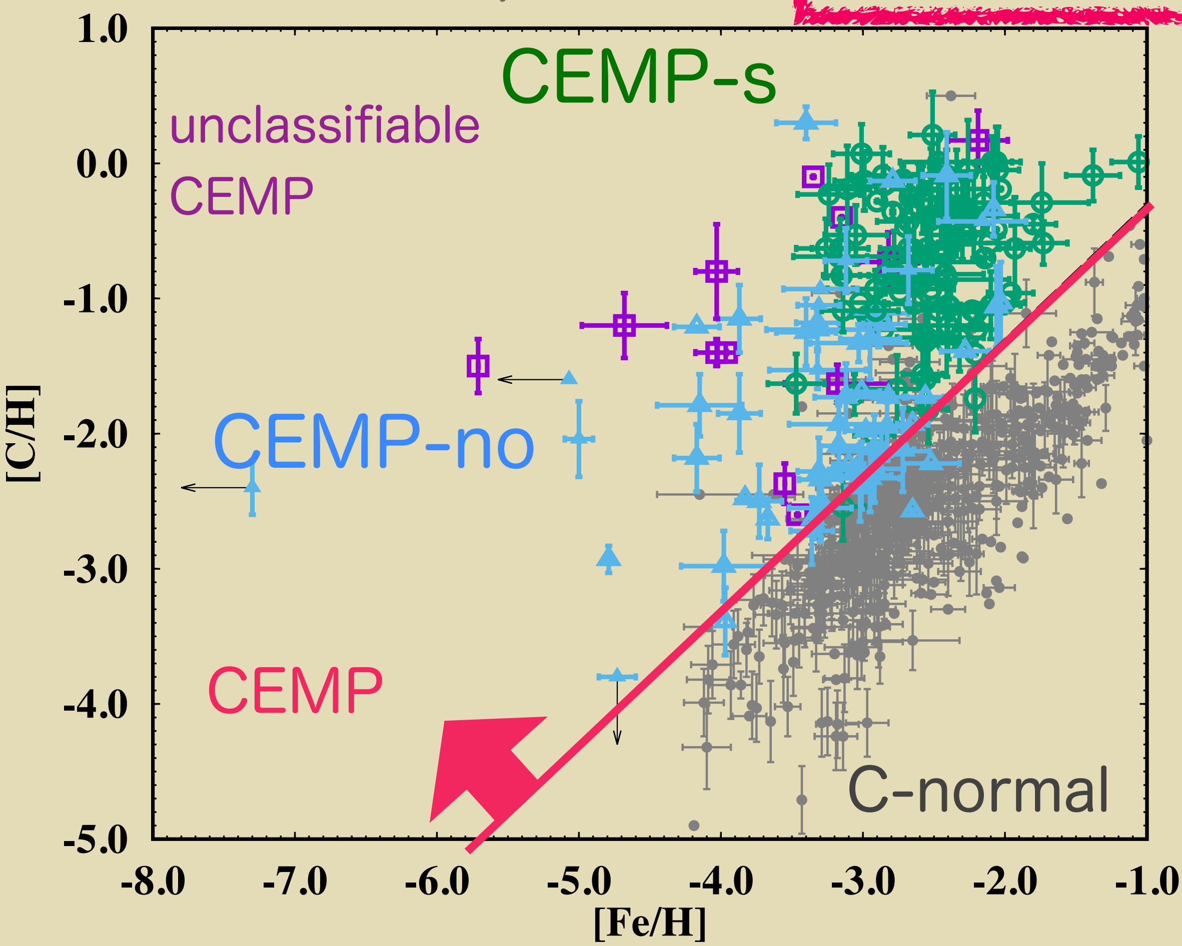
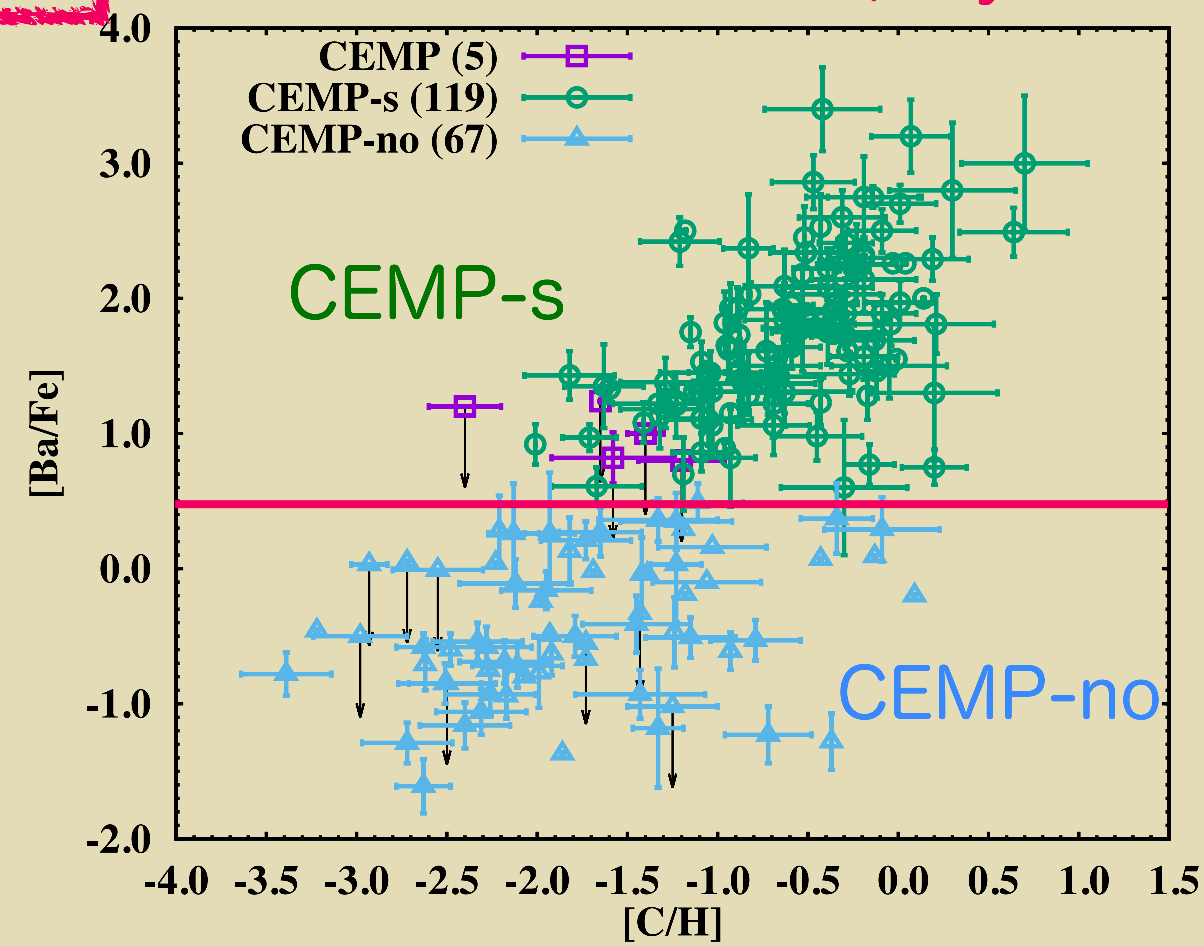
Origin of Extremely Metal-Poor (EMP) Stars

- ☆common in Extremely Metal-Poor (EMP) stars
  - ☆> 20 % for [Fe/H] < -2 with [C/Fe] ≧ 0.7
- ☆divided into subclasses
  - ☆CEMP-s (s-process) [Ba/Fe] ≧ 0.5
  - ☆CEMP-no (no s-proces) [Ba/Fe] < 0.5
    - lower and higher CEMP-no (Bonifacio+15)
  - ☆CEMP-r (r-process), CEMP-r/s (s+r), etc.

- Possible origins
  - I) CEMP-s and no come from binary mass transfer
  - II) CEMP-no from supernova models (Umeda+02)
  - III) CEMP-no from rotating massive stars (Meynet+06)

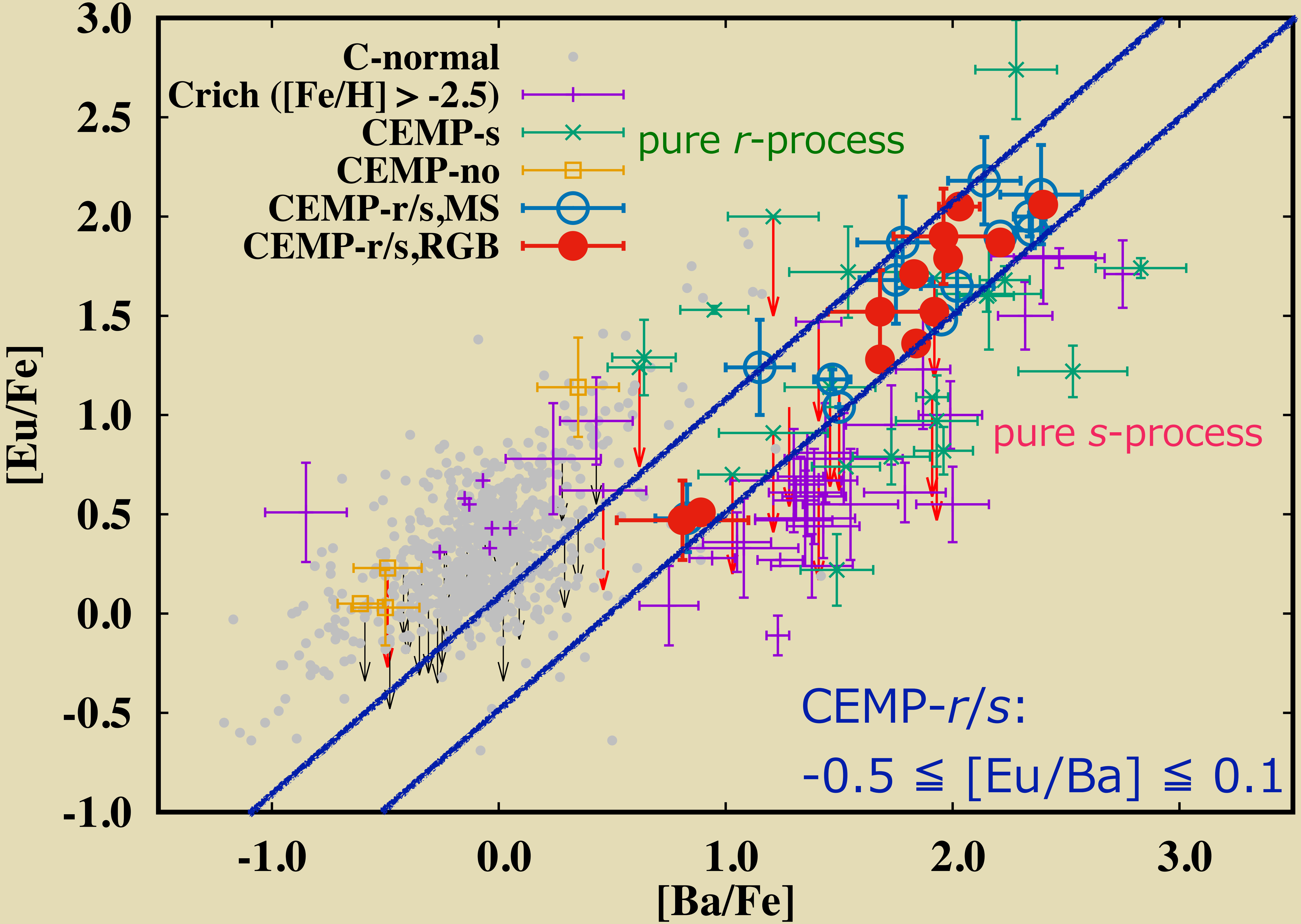




See also discussions by Aoki+07, Bonifacio+15, Yoon+16, Matsuno+17, etc.

Data taken from SAGA database (TS+08,11,17, Yamada+13)

CEMP-r/s stars



How to reproduce the [Eu/Ba] ratio?

I) -0.5 < [Eu/Ba] < 0.1 cannot be achieved by neither pure *s*-process nor pure *r*-process.

II) It is unlikely to be caused by the mixture of *r*-process and *s*-process (pre-enrichment by "*r*" and binary mass transfer by "*s*":

- larger fraction of Eu-enhanced stars in CEMP-*r*/*s* than in r-II stars.

III) Previous studies rely on the "*i*-process", but do we need such high neutron densities?

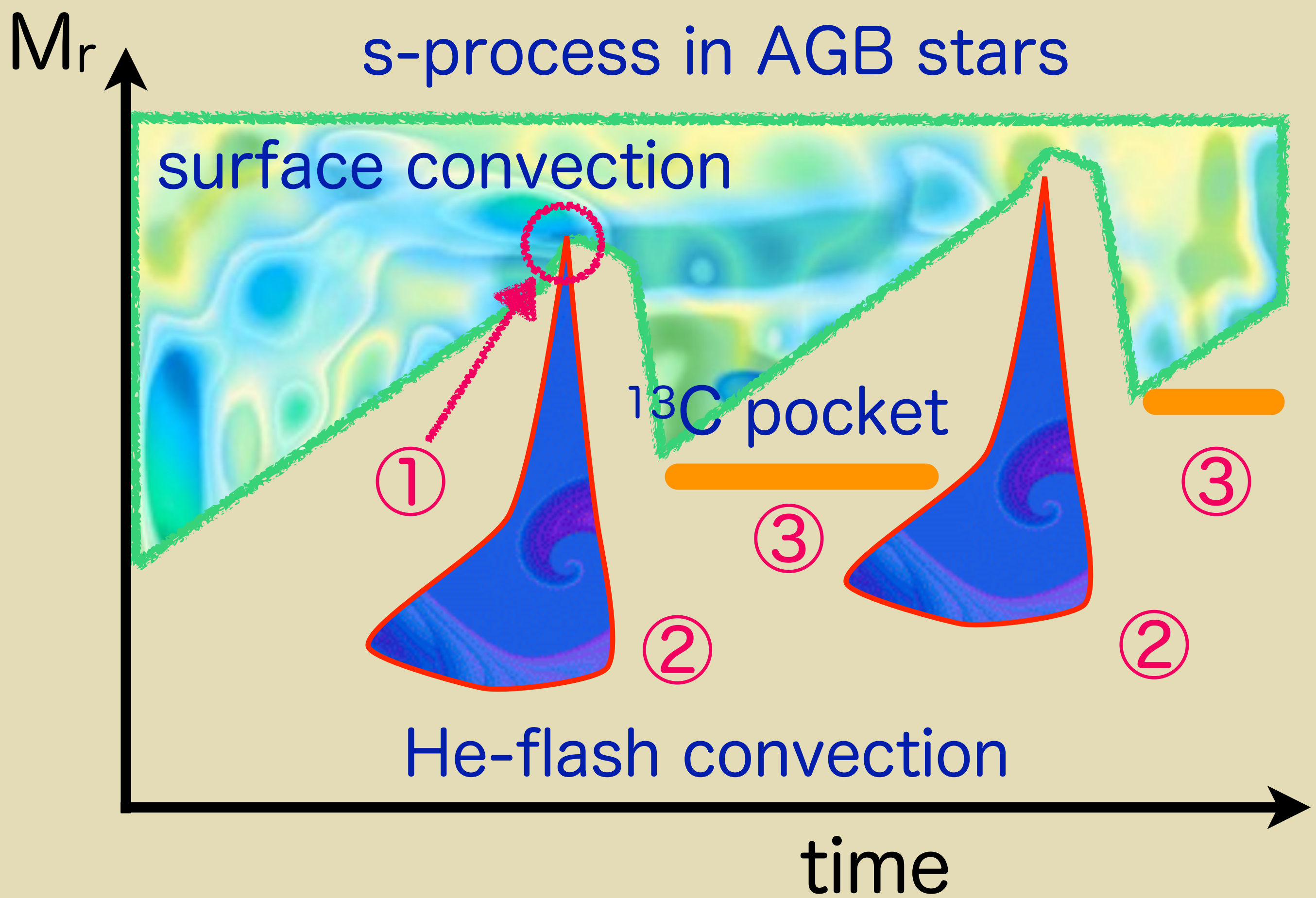
- *i*-process: $n_n = 10^{13-15}$ cm^{-3} compared with normal *s*-process with $n_n = 10^{8-11}$ cm^{-3}. (Cowan+77, Herwig+14, Denissenkov+17,18)

IV) What makes a variation in [Eu/Ba]?

Mixing Mechanisms and Neutron Sources

① Helium-Flash Driven Deep Mixing (He-FDDM) during the AGB phase for [Fe/H] < -2.5 (Fujimoto+90, 00, TS+04, 10)

- $^{13}C(\alpha,n)^{16}O$ in the He-flash convective zones
- ^{13}C abundance as a free parameter
- Wide range of possible neutron densities: **$n_n=10^{8-14}$ cm^{-3}**



② Third dredge-up + $^{22}Ne(\alpha,n)^{25}Mg$

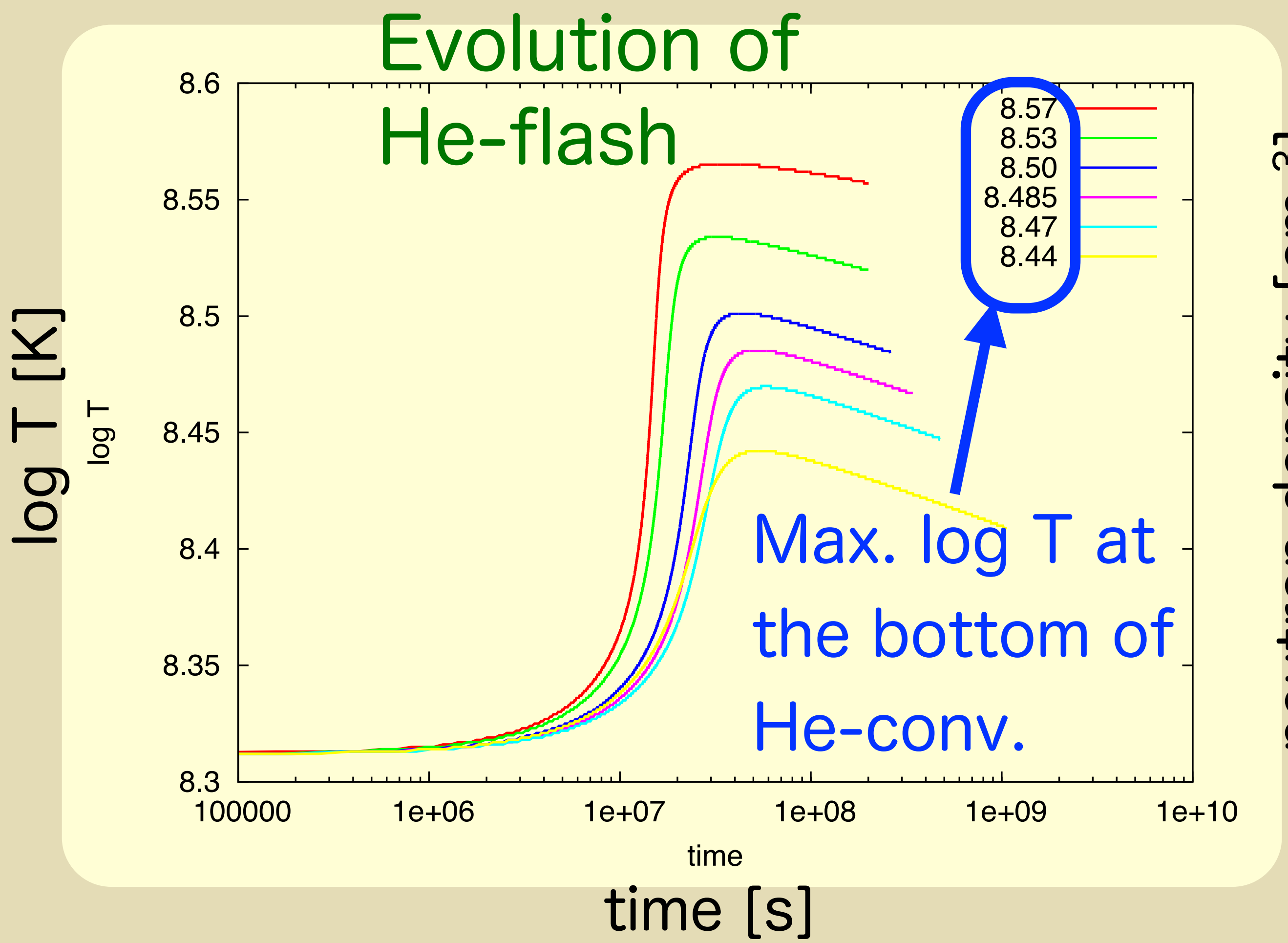
- T > 3x10^8 K at the He-conv. (M > 3.5 M$_\odot$)
- (Boothroyd+Sackmann98, Busso+88, Blocker95)

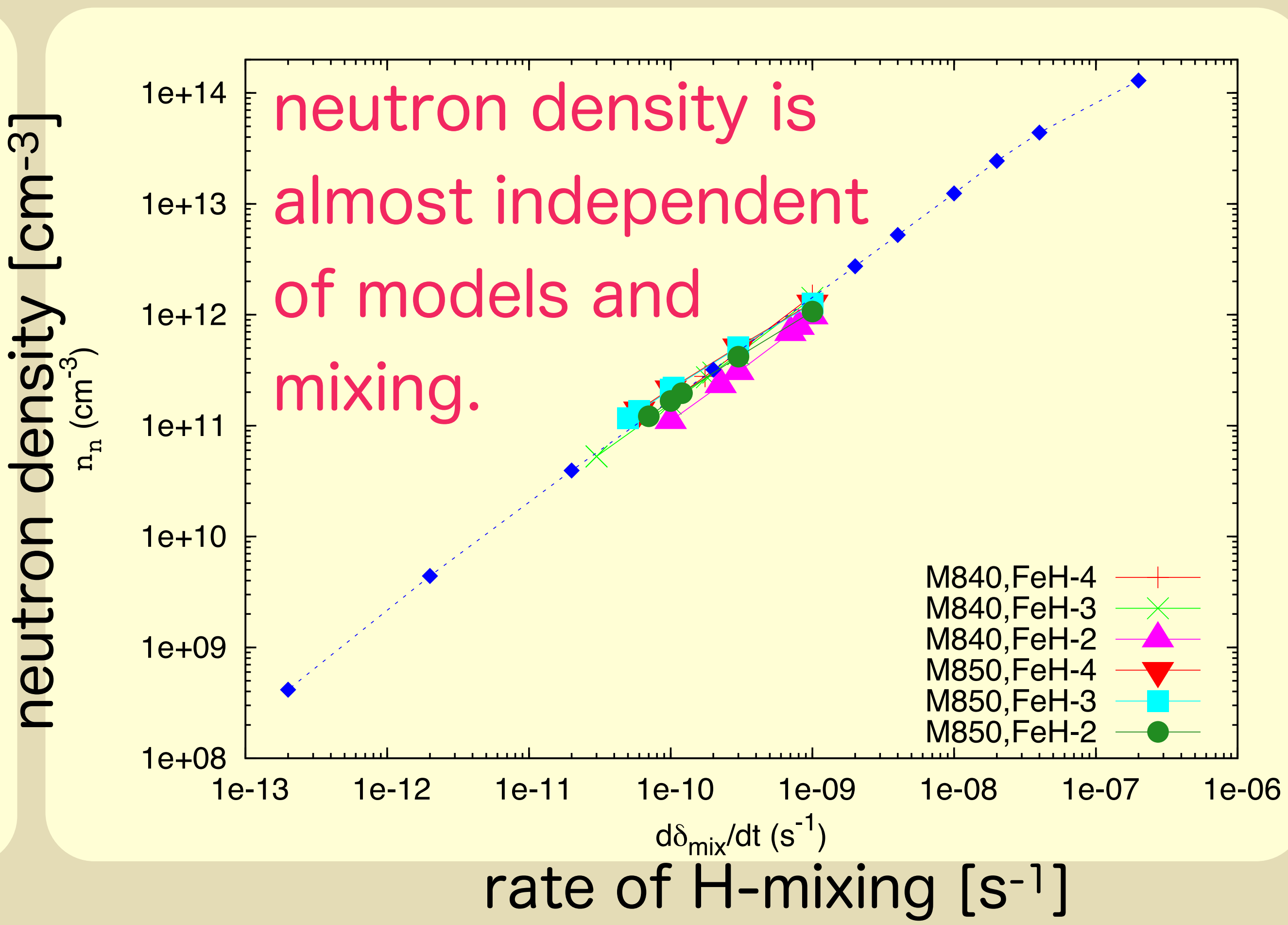
③ Third dredge-up + radiative ^{13}C mixing

- ^{13}C pocket: $^{13}C(\alpha,n)^{16}O$
  - X(^{13}C) = 5 x 10^{-3}, X(^{14}N) = 1.7 x 10^{-4} (Bisterzo+10)

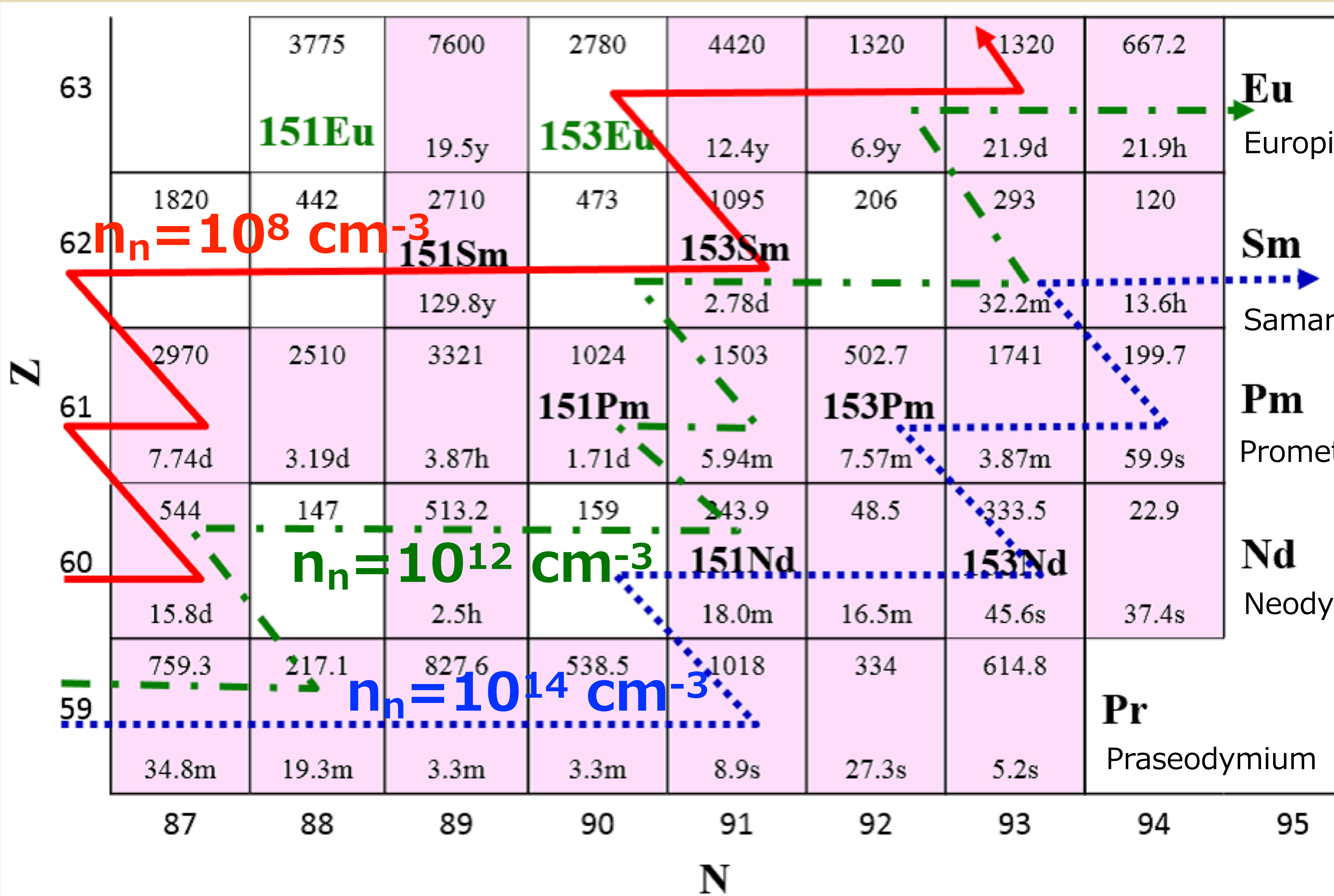
Nucleosynthetic Models

- ☆Nuclear network models (Nishimura+08, Yamada+):
  - ☆One-zone approximation (Sugimoto+Fujimoto78, Fujimoto82)
  - ☆318 isotopes of 84 elements: ^{1}H to ^{210}Po
  - ☆p-, α-, n-captures and β-decays.
    - NACRE, Caughlan+Fowler88, and Bao+00 rates

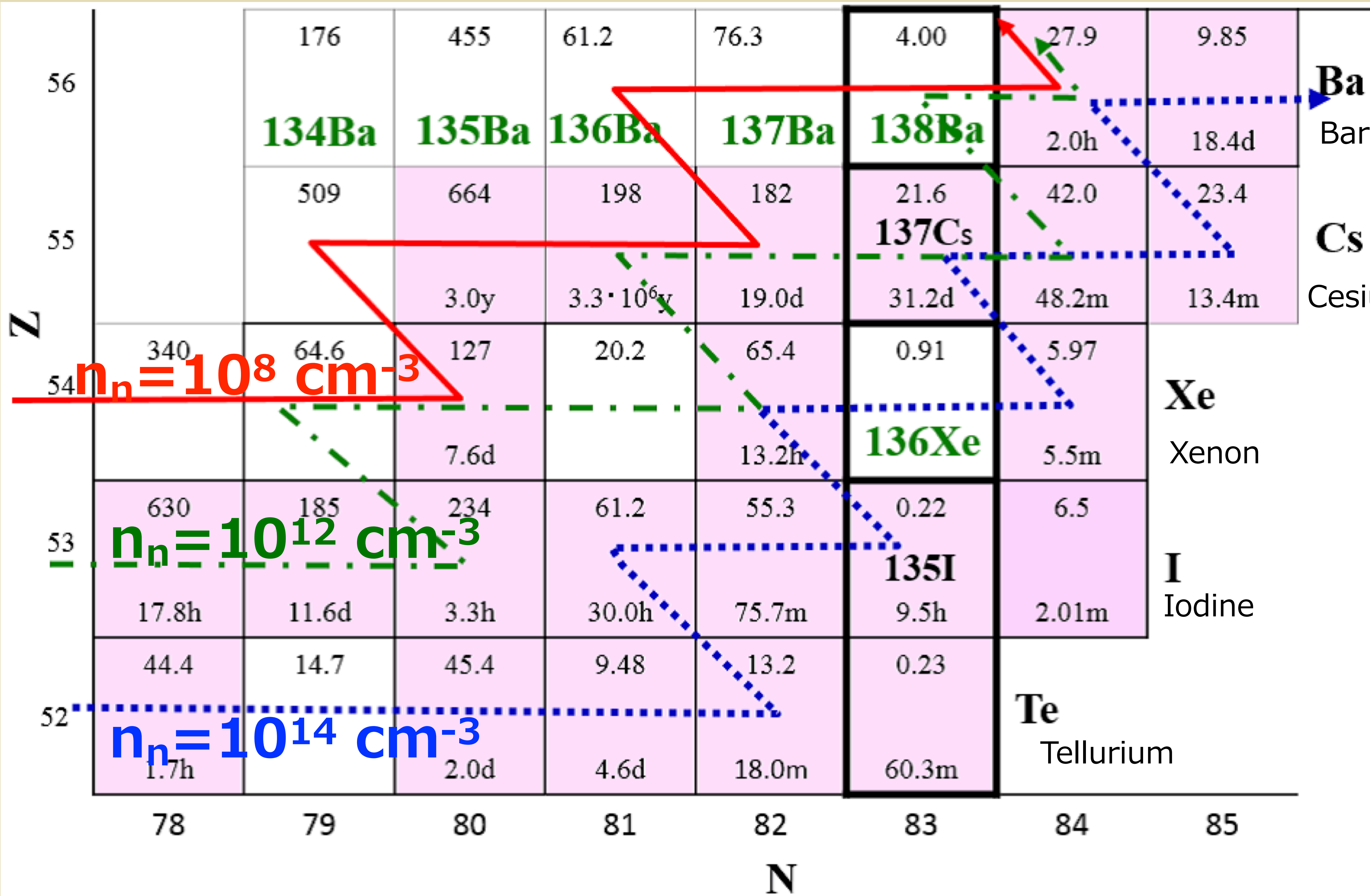




Formation paths around 153Eu

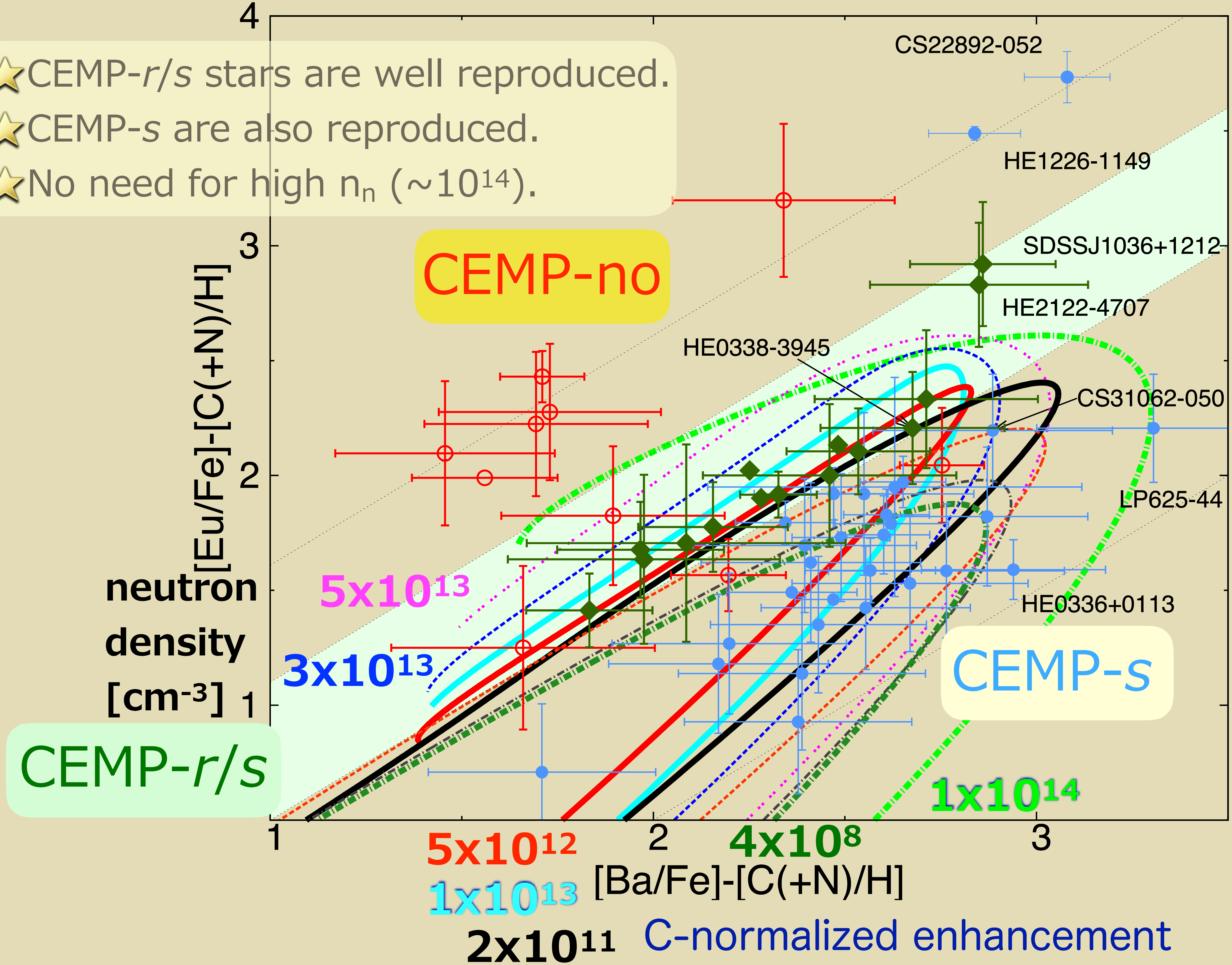


Formation paths around 138Ba



Comparison with the observations

- ⭐CEMP-*r/s* stars are well reproduced.
- ⭐CEMP-*s* are also reproduced.
- ⭐No need for high n_n (~10^{14}).



Summary

I) CEMP-r/s stars are interesting objects showing both *r*- and *s*-process enrichment.

II) Observed [Eu/Ba] can be explained by the efficient hydrogen mixing ($n_n=10^{11-13}$ cm^{-3}) into the He-flash convective zones in low-metallicity AGB stars.

III) Too larger amount of mixing ($n_n>10^{14}$ cm^{-3}) results in the decrease of [Eu/Ba] due to a bypass with Pr with Nd and Sm.

- CEMP-*s* counterparts with characteristic isotope ratios for Ba.