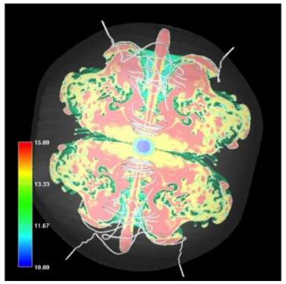
金属欠乏星のrプロセス元素組成

r-process abundance of metal-poor stars



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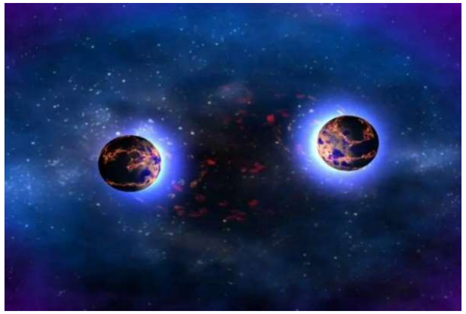

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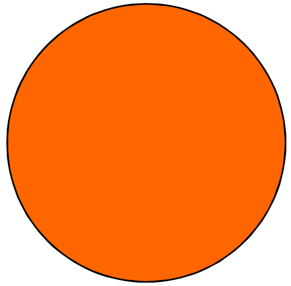
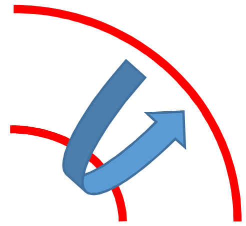
Stellar abundances and evolution

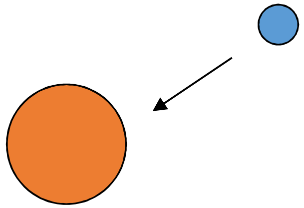
Stellar abundances are invaluable indicators of birth environments.



- Main sequence (e.g., Sun)
  - Keep initial elemental abundance in the atmosphere.

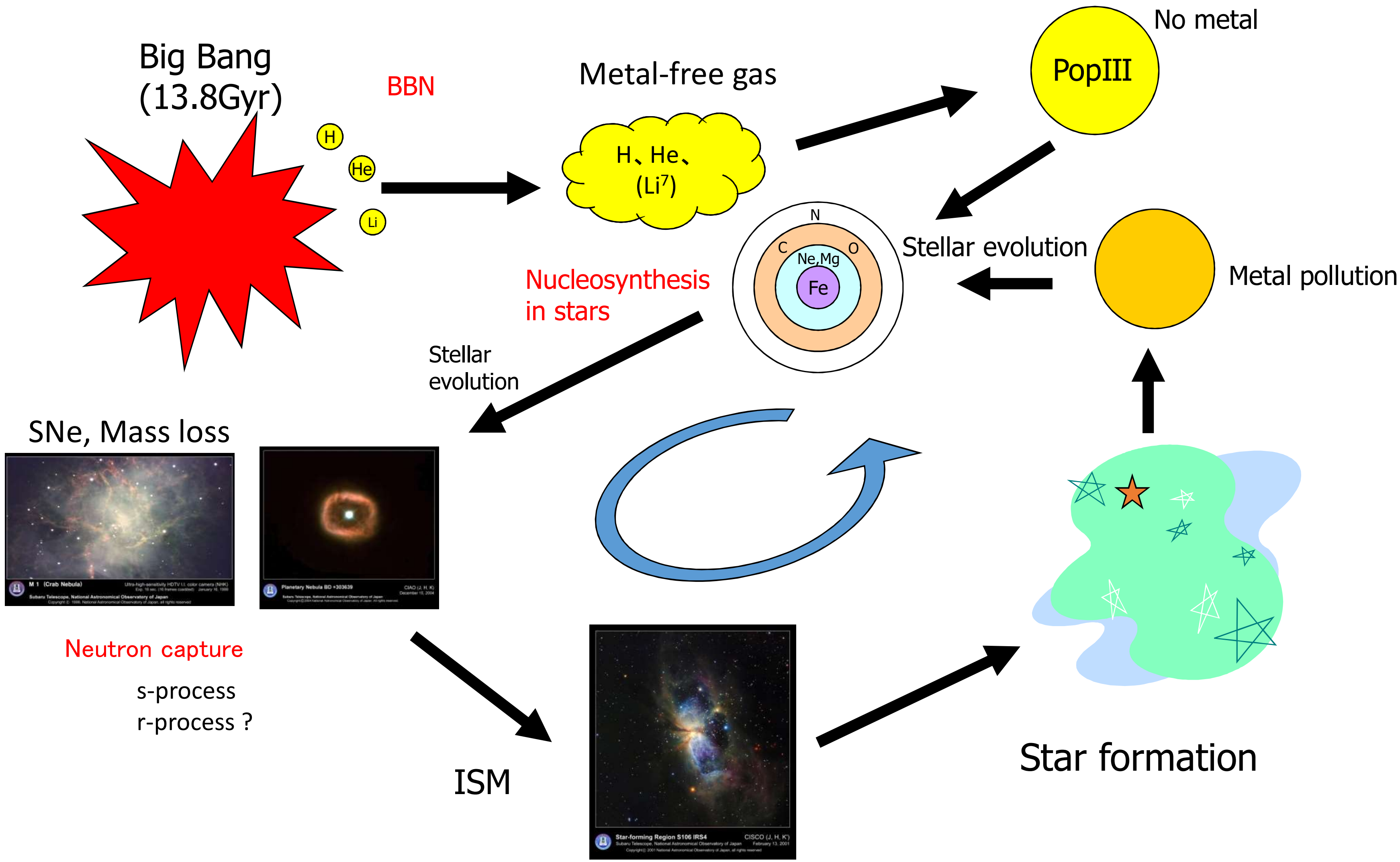


- Evolved stars (e.g., AGB)
  - Synthesized elements (e.g., C) inside the stars are carried to the surface by convection（e.g., Dredge up）.

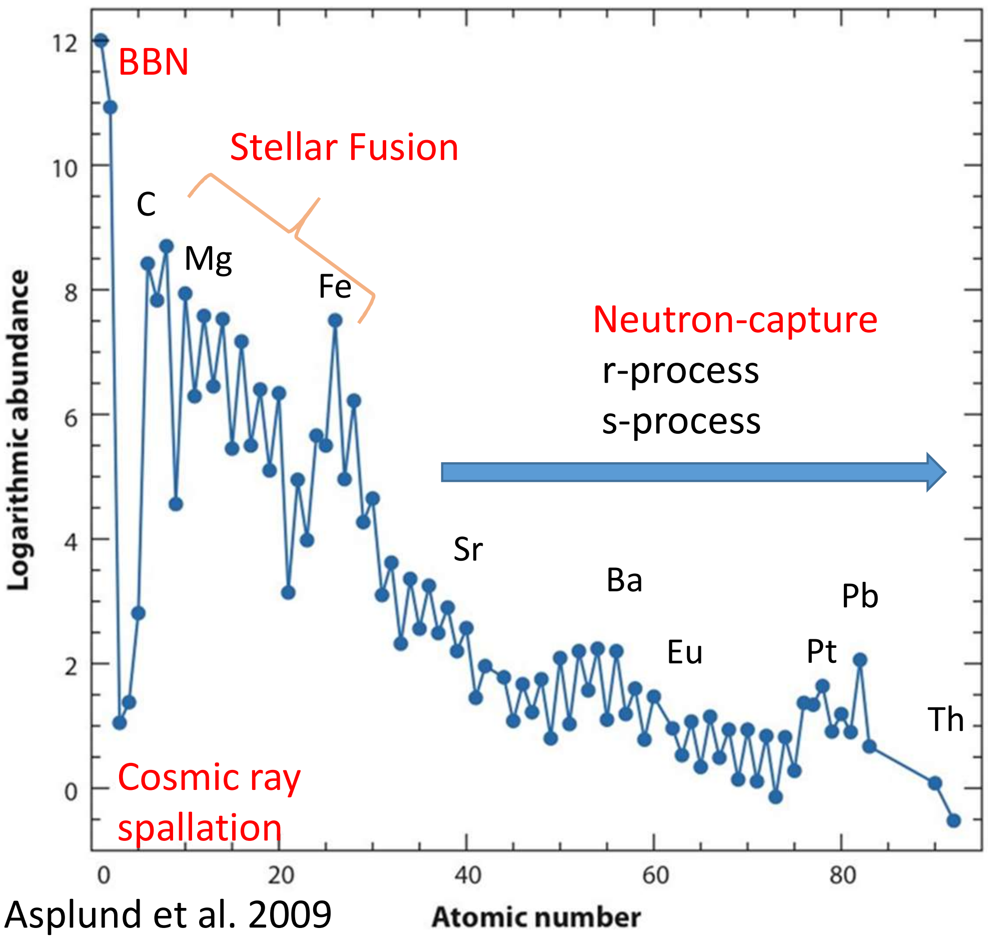


- Binary system
  - Affected by pollution from the binary companion (mass transfer).

Chemical evolution of the Universe



Solar (Cosmic) abundance



Asplund et al. 2009

- Stellar abundance is compared with the Sun.
  - Cosmic abundance ≒ Solar abundance
  - The solar abundances show some evidences for nucleosynthesis processes.

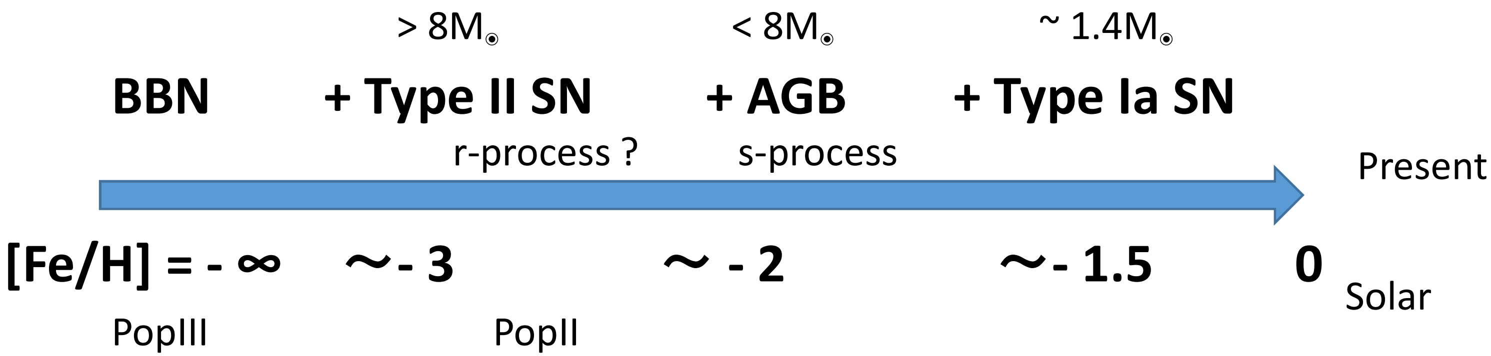
- Neutron-capture process
  - s-process : AGB （Ba, Pb)
  - r-process : NSM and/or SNe ? (Eu, Pt, Th)

NSM : Neutron-Star Merger

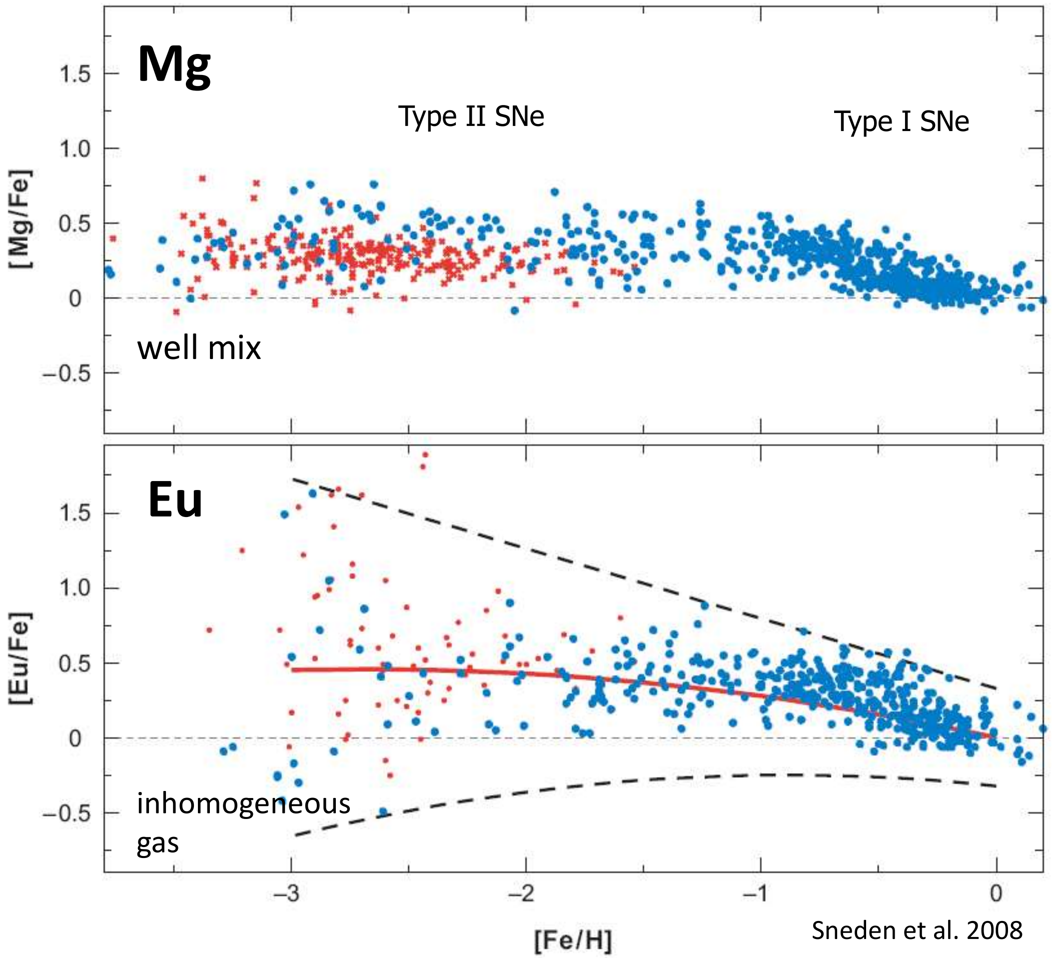
Abundances of metal-poor stars

- The chemical compositions are fossil records of the nucleosynthesis of single (or a few) process.

- They hold the situation of early epochs of galaxy formation.



Observations of metal-poor stars

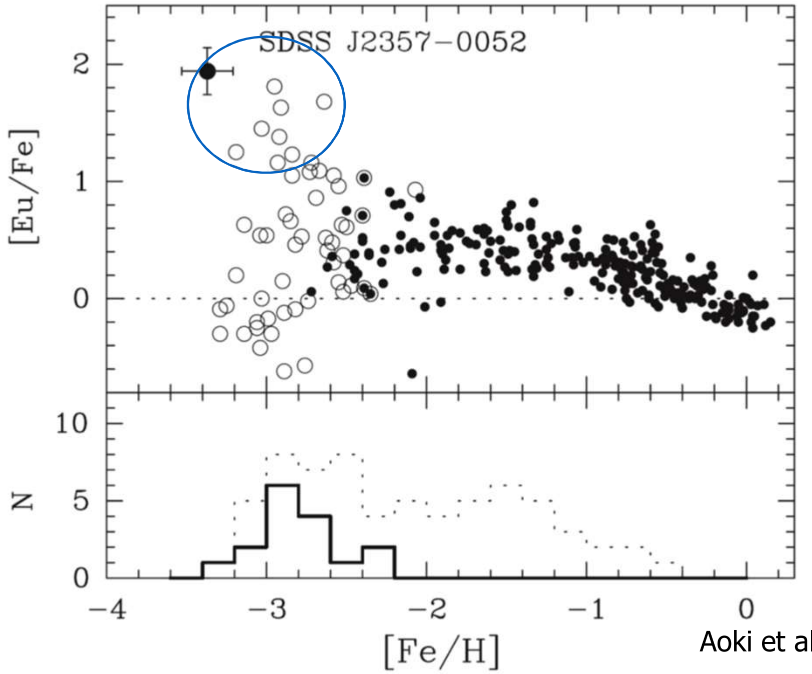


- n-cap. elements show large scatter in [Fe/H] < -2
  - ~ 2 dex (0.5 dex in alpha and iron peak elements)
- This scatter is due to the spatial inhomogeneity of the chemical composition of interstellar matter in the early Galaxy.
  - the r-process is a rare event.
- Some objects show extremely large abundance.

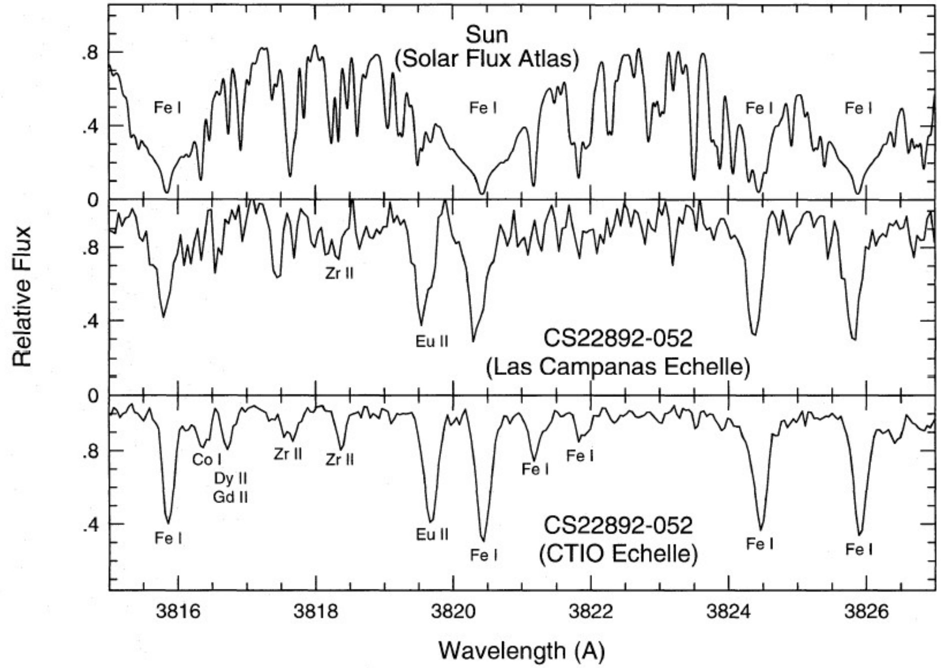
- Comparison with chemical evolution models based on statistics of metal-poor stars.

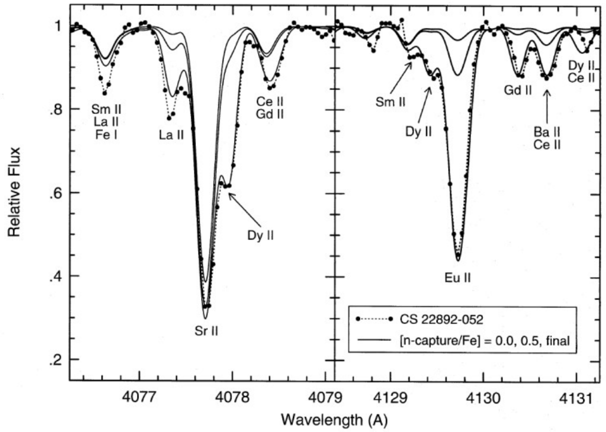
r-process enhanced stars

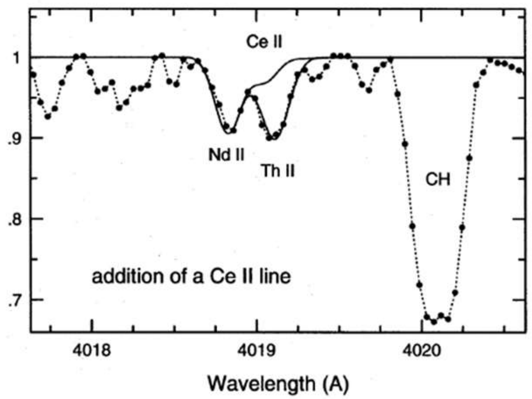
- It will reflect the pure r-process.
- r-II ： +1<[Eu/Fe]　(no s-process)
  - r-II stars exist only in the region of -2.5 > [Fe/H] > -3.4
  - r-I　： +0.3<[Eu/Fe]<+1



Aoki et al. 2010





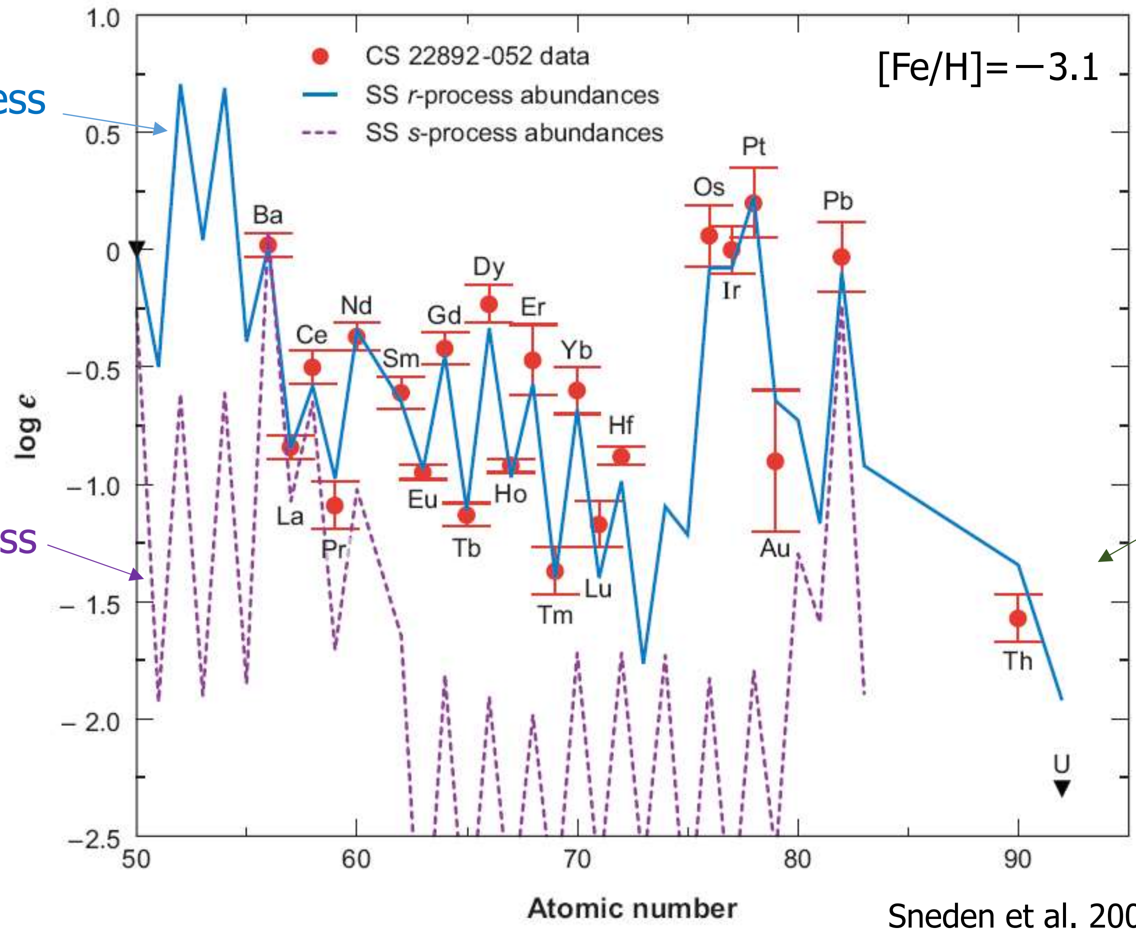


CS 22892-052　Sneden et al. 1996

abundance patterns of n-capture rich stars

r-process

s-process



Sneden et al. 2003

r-II stars show similar abundance pattern of the solar r-process pattern.
(total – s = r)

Th (half life 14Gyr) is detected.
Age estimation by chronometry.

Abundance pattern of r-process

- Abundance patterns of r-II stars are very similar with the solar r-pattern.

  Universality (56 ≤ Z ≤ 72 ?)

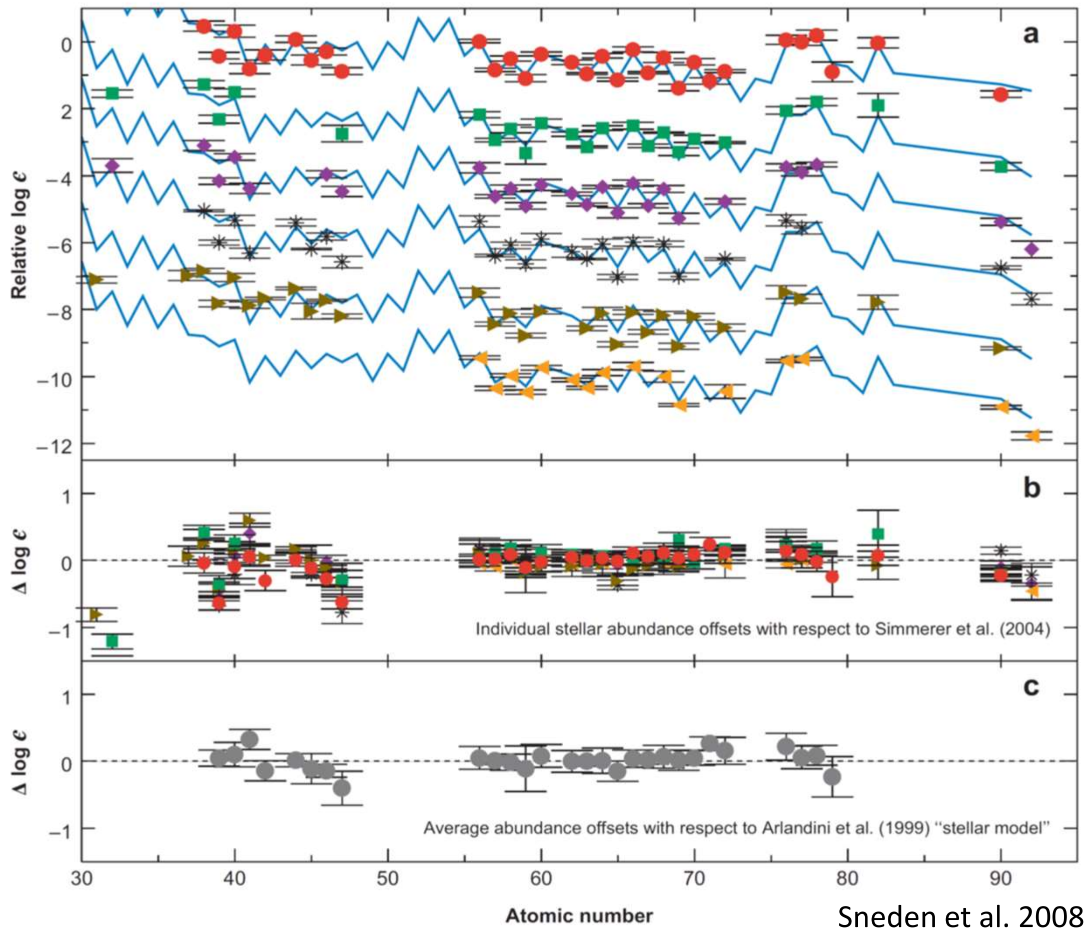
- Observed differences in the patterns of actinides (Th, U) in some r-II stars.

  1/3 of r-II are actinide boost stars ?

  But having a low Pb in CS31082-001.

- weak r-process in r-II star ?

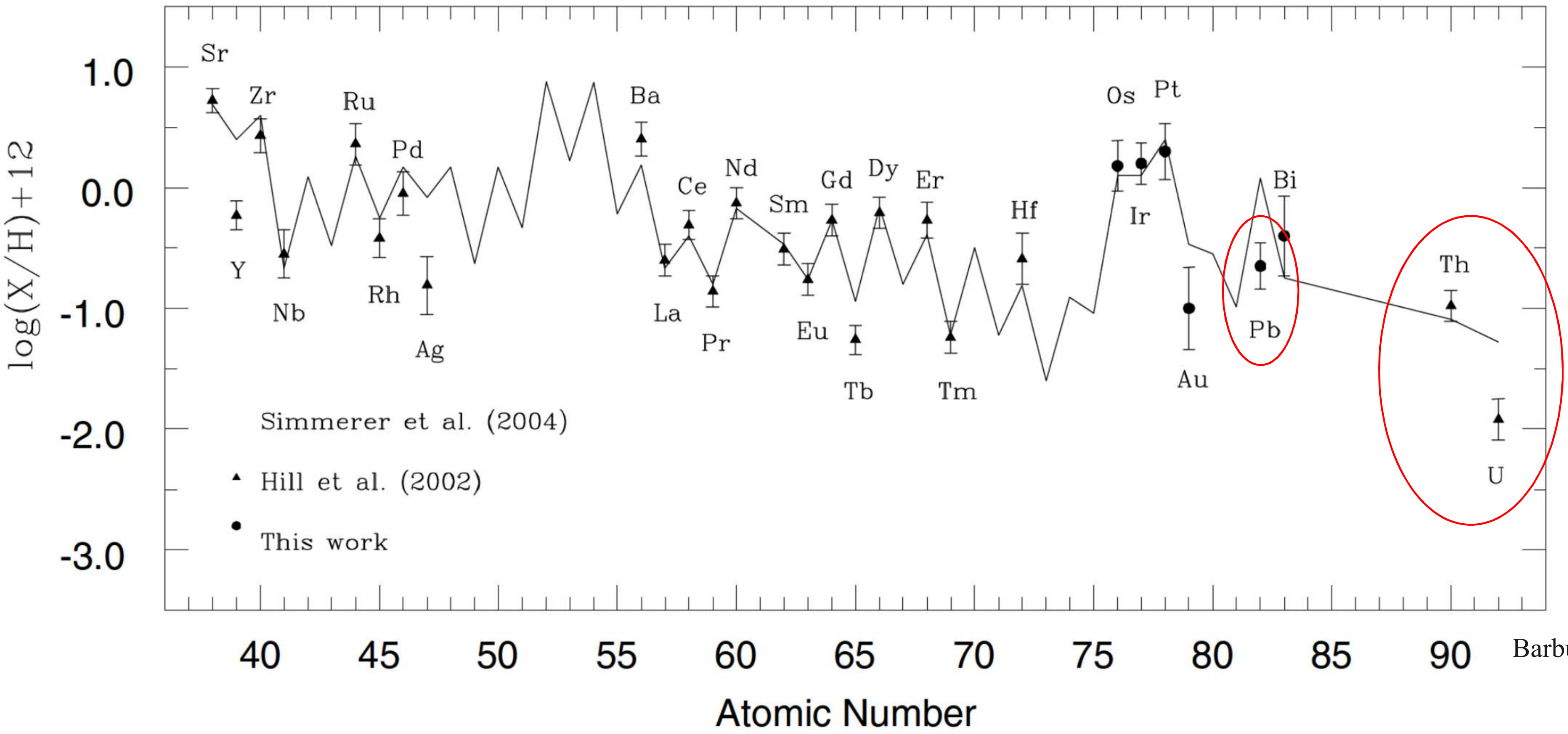
weak r-process ? Universality Pb? Actinide boost ?



Sneden et al. 2008

r-II star CS 31082-001 ([Fe/H] = -2.9)

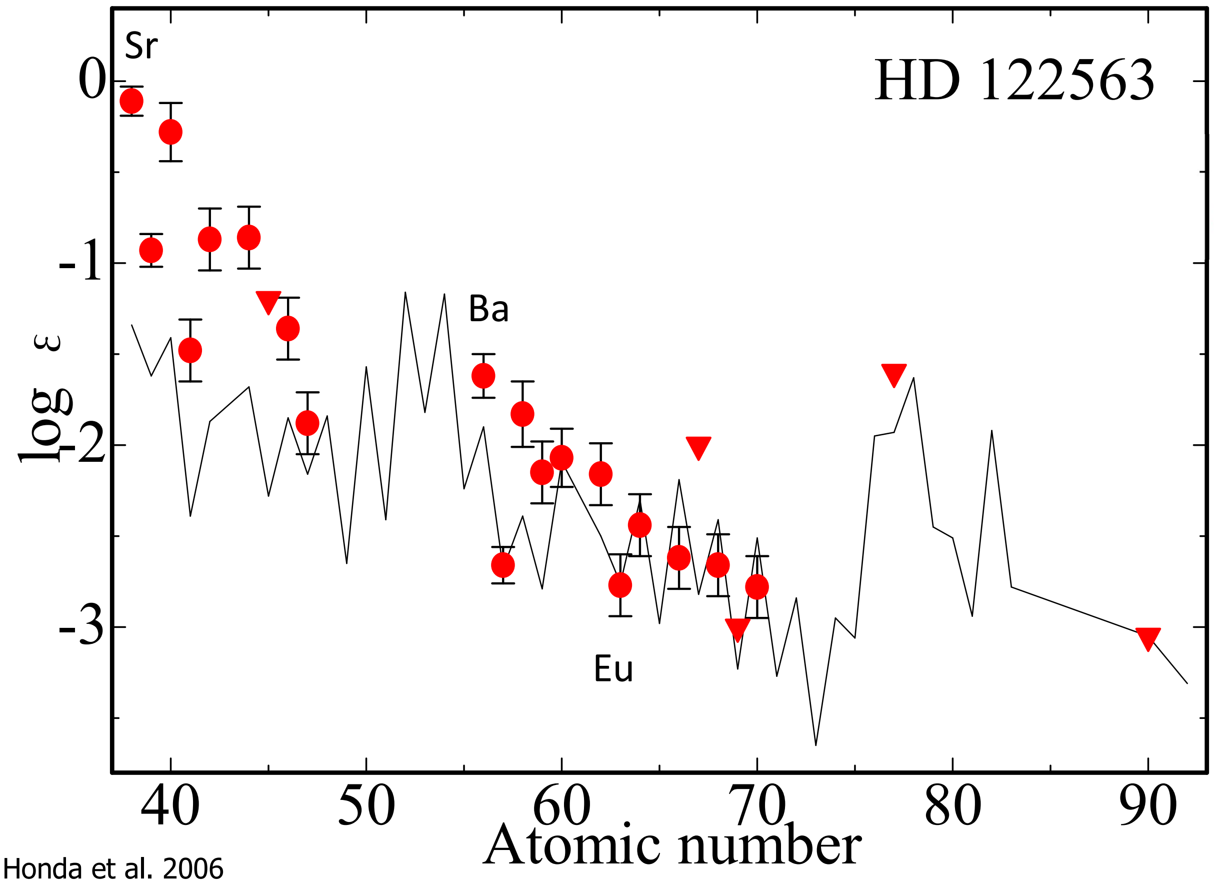
Cayrel et al. 2001
Hill et al. 2002



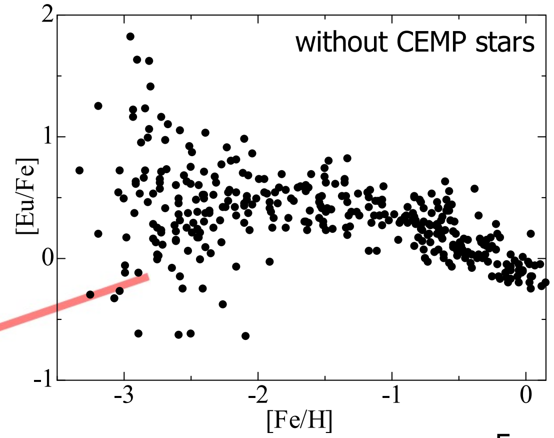
Barbuy et al. 2011

- Compared to other stars CS31082-001 has higher abundances of the actinides, but a very low Pb abundance.
  - estimating the age from U/Th ≠ Th/Eu
  - actinide boost star

r-process poor stars



Honda et al. 2006

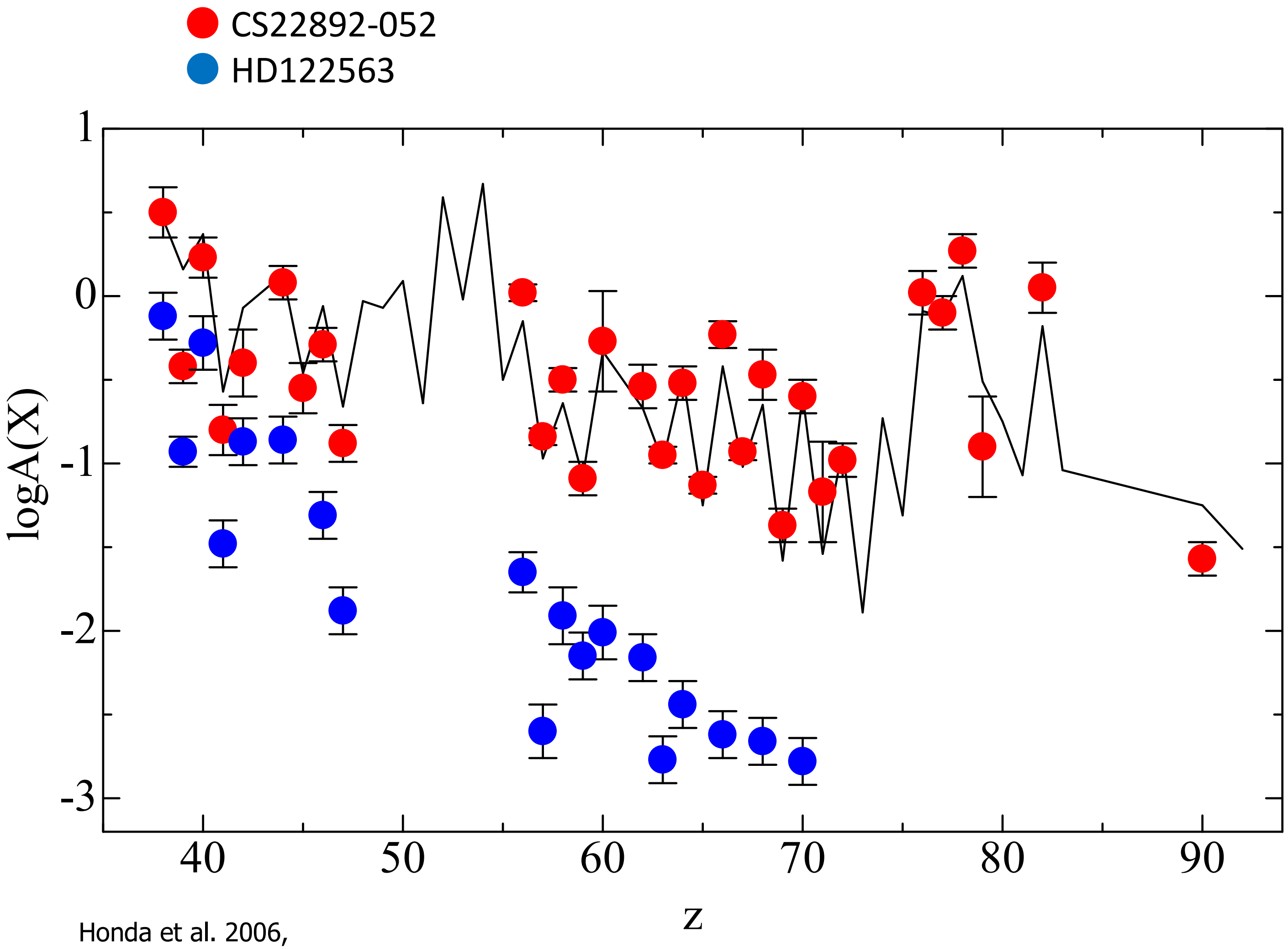


From SAGA DB
Suda et al. (2008)

Light n-capture elements show a large deviation from the solar system r-process abundance pattern in some objects.

→ Existence of another process ?

LEPP (Travaglio et al. 2004)
weak r-process (Wanajo et al. 2006)



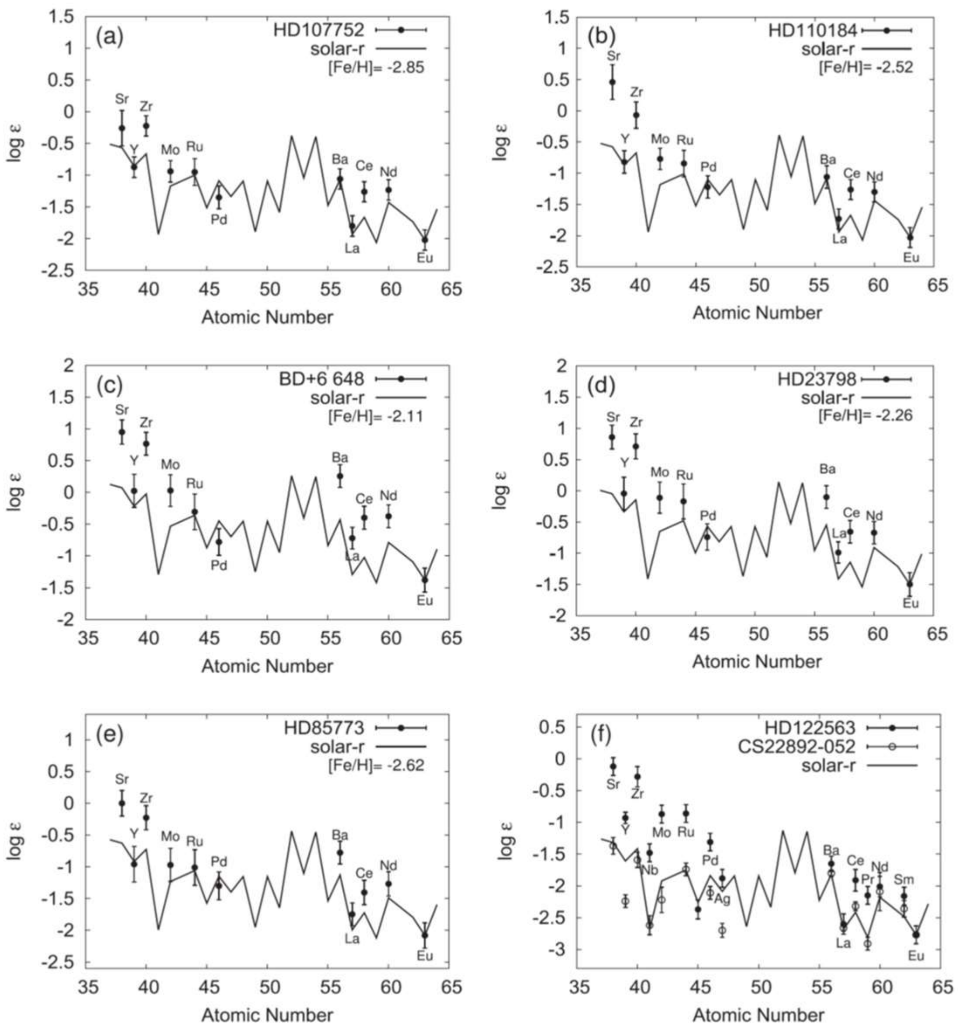
Honda et al. 2006,

HD 122563 has a significantly different abundance pattern from that of the solar system r-process abundance pattern.

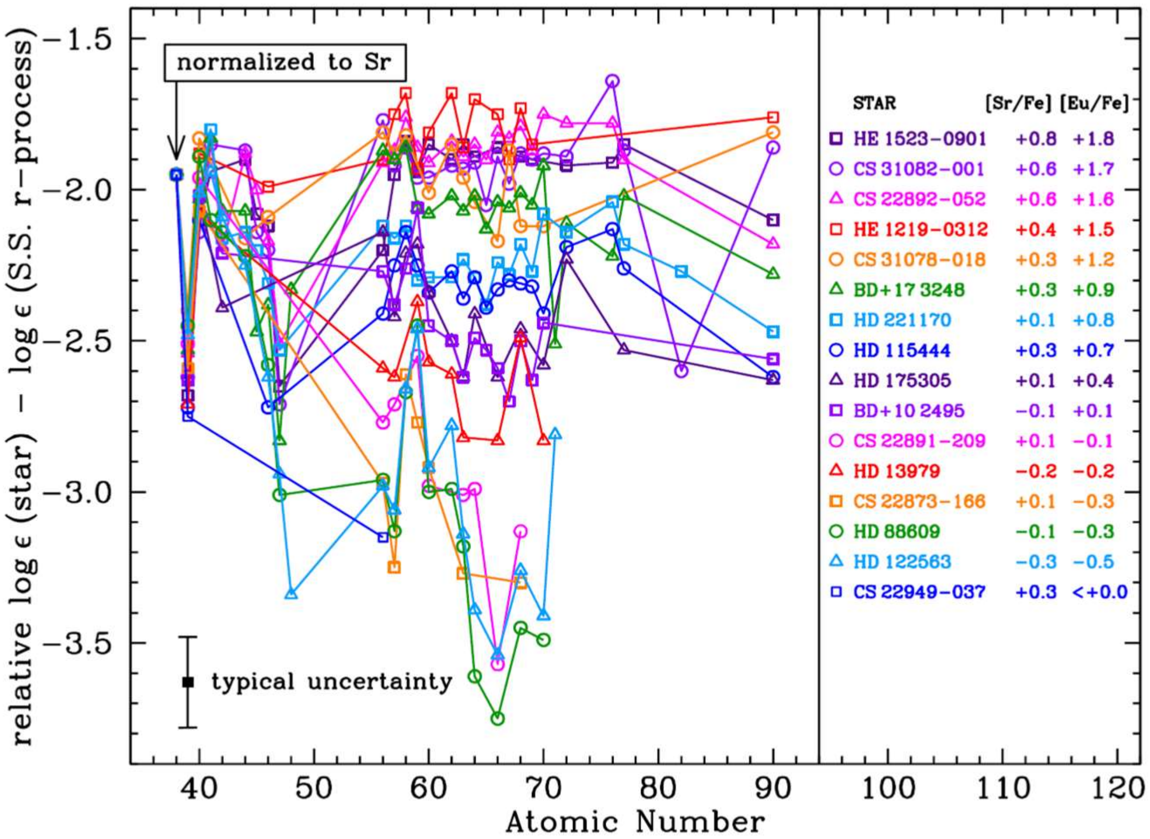
LEPP (lighter element primary process) ?
e.g., Travaglio et al. 2004

weak r-process ?
e.g., Wanajo & Ishimaru 2006

Faild r-process？
Wanajo et al. 2007

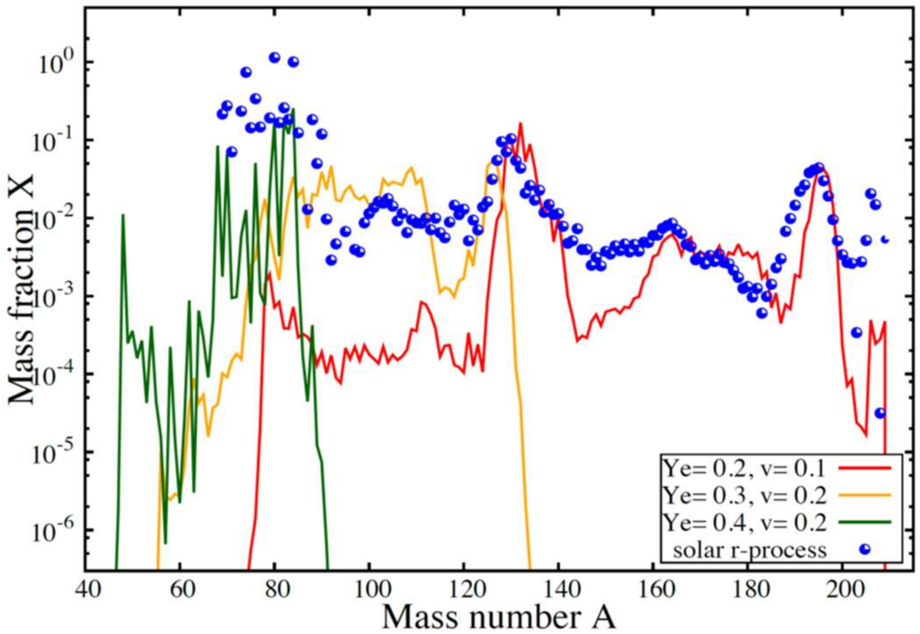


M.Aoki et al. 2017

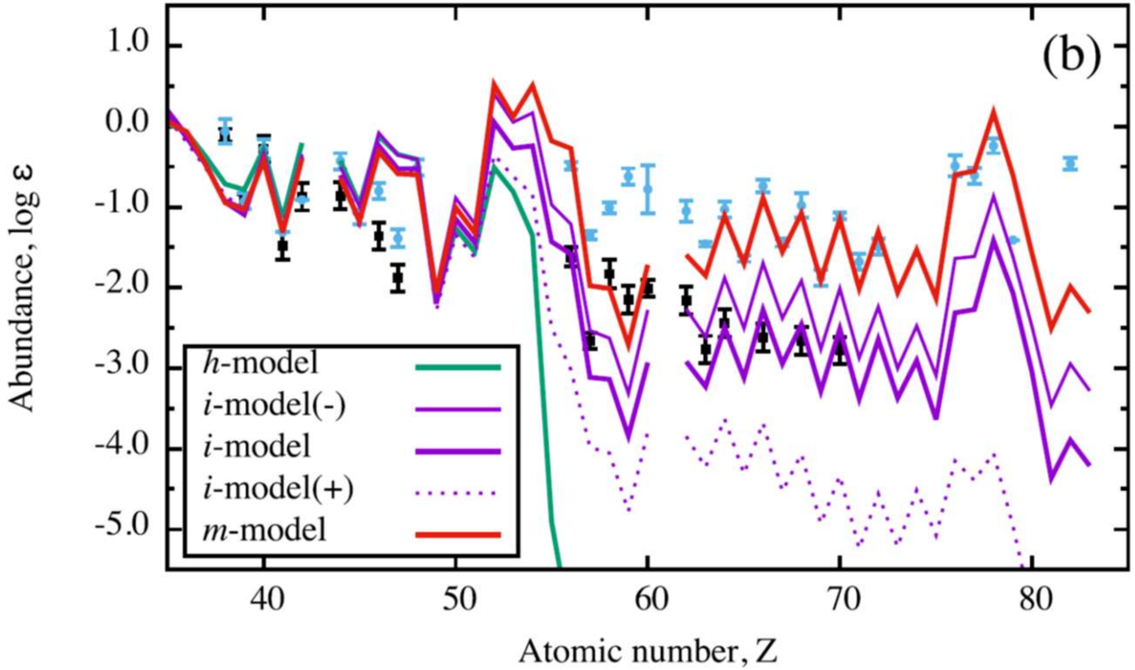


Roederer et al. 2010

r-process models compared with the abundance pattern of the r-process of solar system and metal-poor stars.

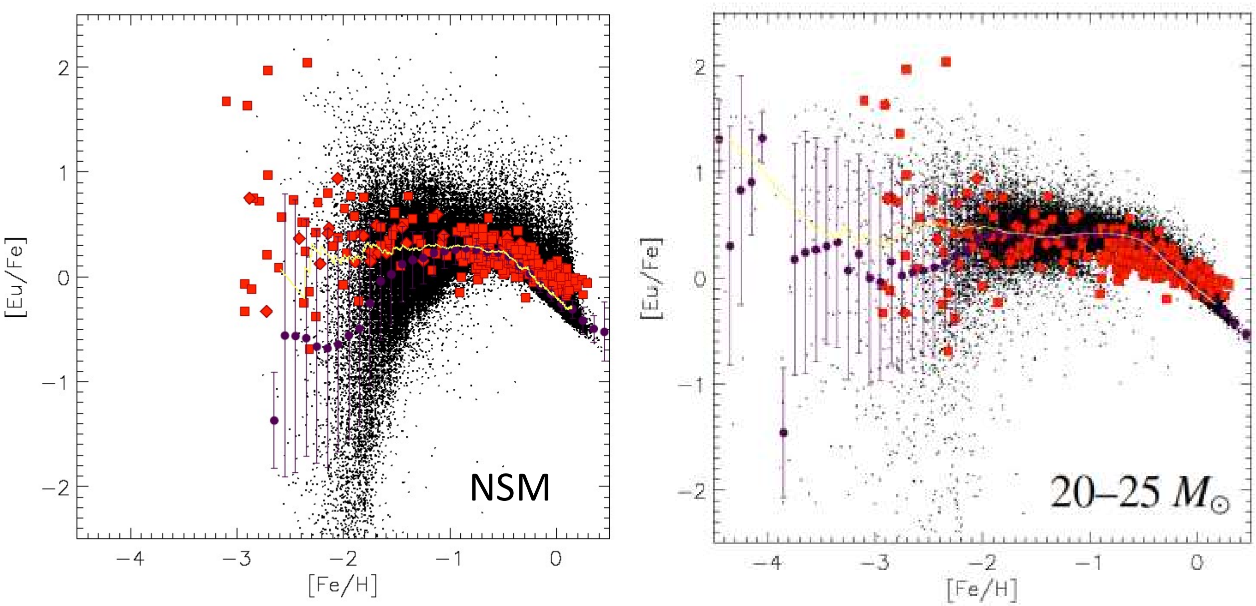


Neutron star mergers (NSM)
Rosswog et al. 2017

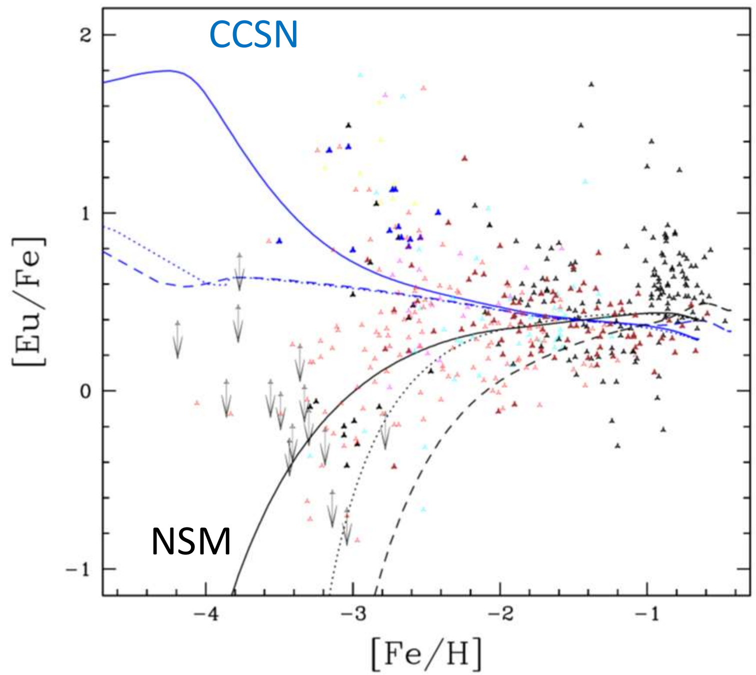


Core-collapse SNe (CCSN)
driven by the magneto-rotational instability
Nishimura et al. 2016

Models of galactic chemical evolution



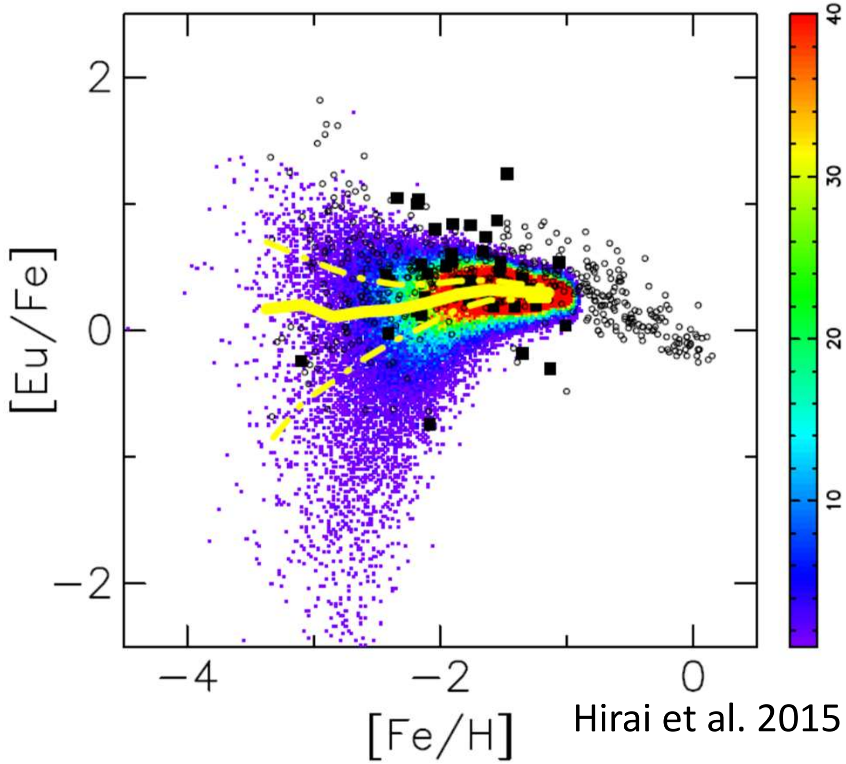
Argast et al. 2004



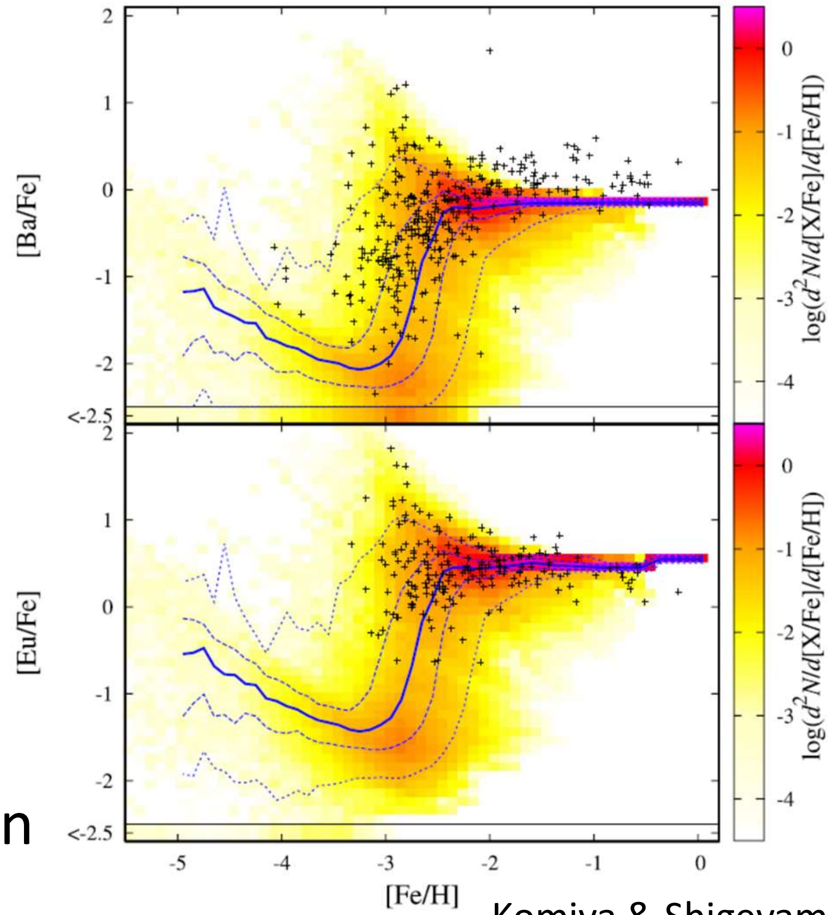
Vangioni et al. 2017

NSM could not reproduce large dispersion of Eu in very low metal stars.
Very short merger time of NSM are needed.

Chemical evolution models of r-process by NSM



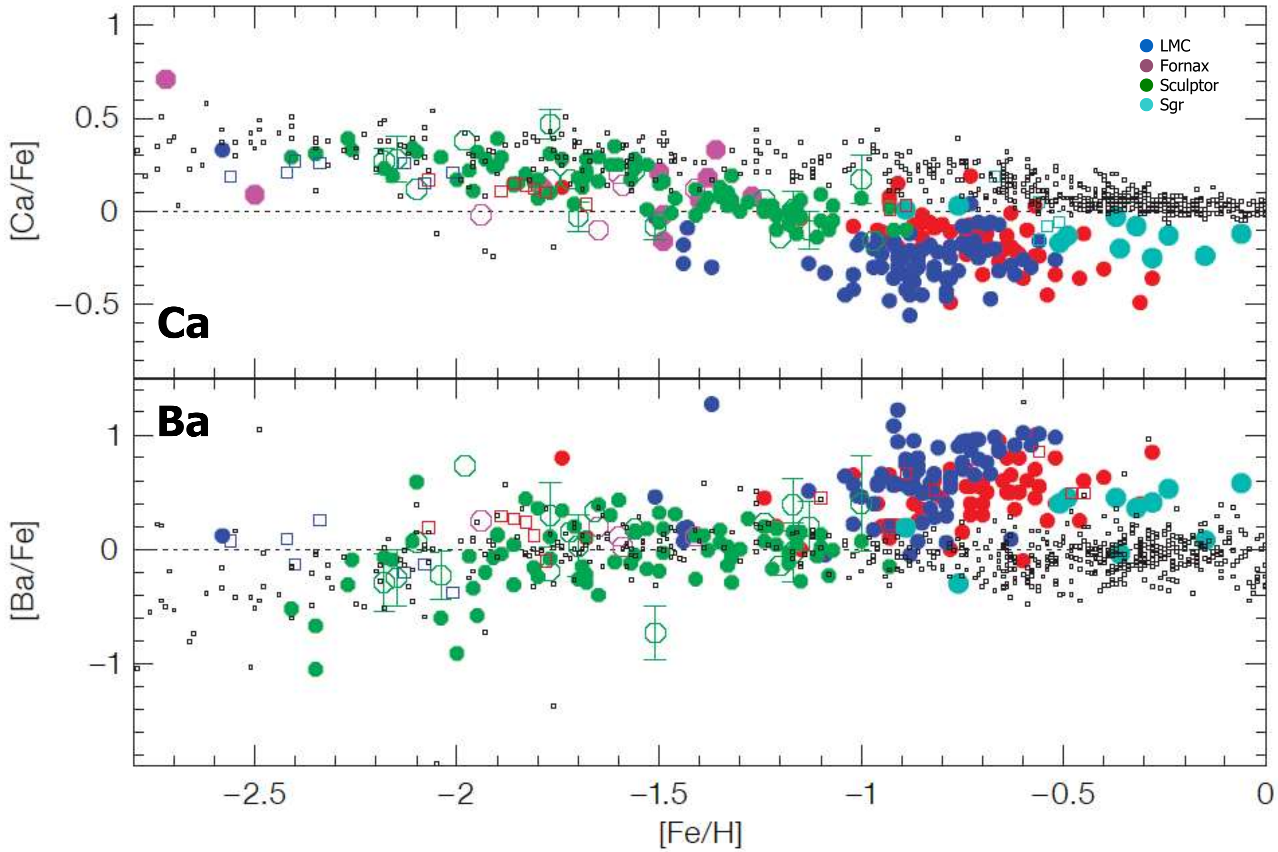
Hirai et al. 2015



Komiya & Shigeyama 2016

Considering hierarchical structure formation solves the problem.

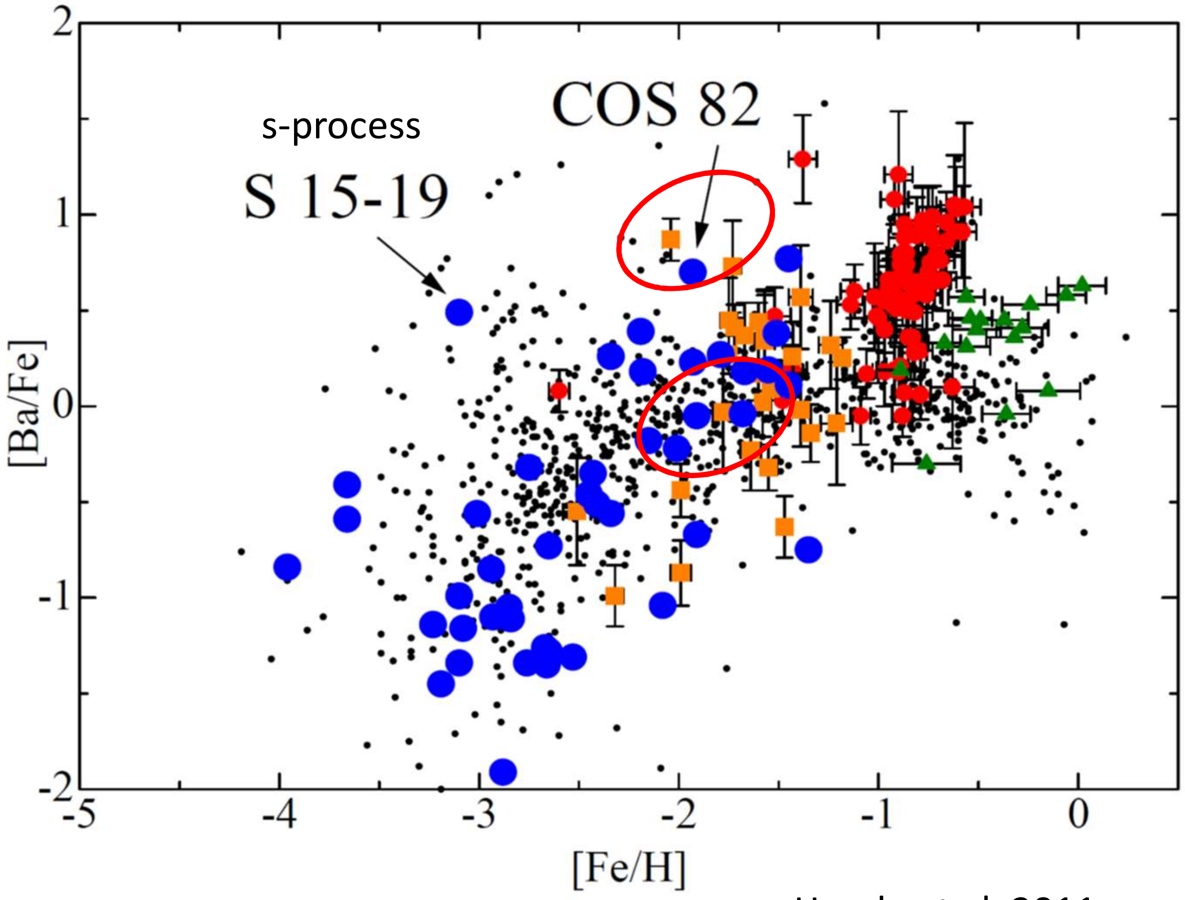
Chemical composition of the star in the dwarf galaxies



Venn & Hill (2007)

- Chemical abundance trend of “luminous” (“metal-rich”) dwarf spheroidal galaxies is different from MW halo.

Neutron-capture elements in EMP stars in faint dwarf galaxies



Honda et al. 2011

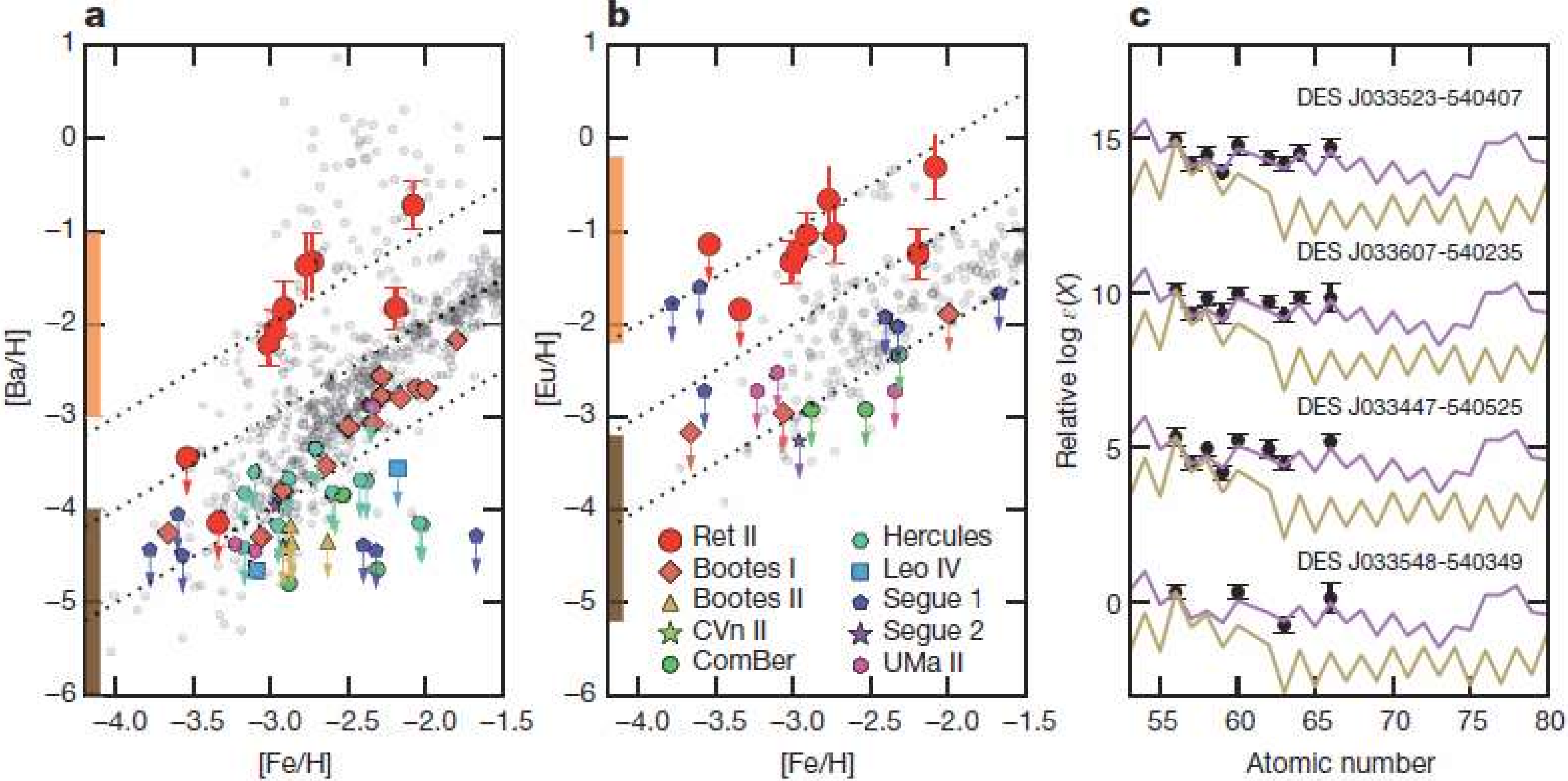
No r-process enhanced EMP star was found in dwarf galaxies and ultra-faint dwarf galaxies.

5% ~ r-II star in MW
Barklem et al. 2005

This trend supports the NSM.

c.f. Tsujimoto & Shigeyama 2014

Discovery of the r-process-rich dwarf galaxy Reticulum II

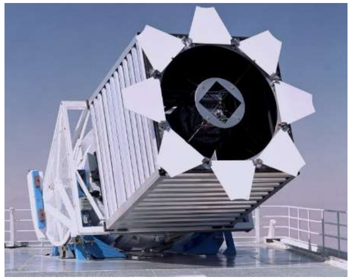


Ji et al. 2016, Roederer et al. 2016

Survey of ultra metal-poor stars ([Fe/H] < -4)

- Survey projects
  - HK survey and Hamburg/ESO Survey
  - SDSS/SEGUE, APOGEE, RAVE
  - Photometric survey with SkyMapper
  - GAIA/ESO
  - LAMOST
  - etc.
- Follow-up with high-resolution spectroscopy
  - 8-10m class telescopes
  - Next generation large telescopes
    - 2025～
    - TMT, GMT, E-ELT

Skymapper



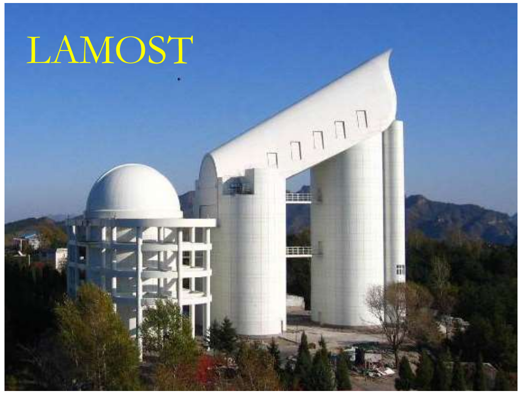
SDSS

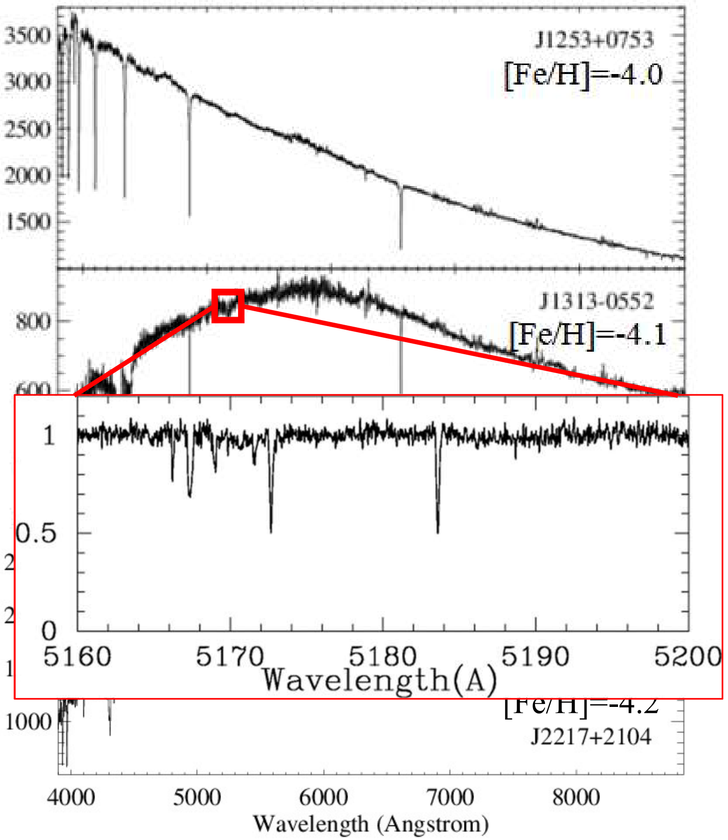
refining the target by 2-4m telescope

Subaru, Keck, GMT etc.

TMT

Subaru/HDS follow-up spectroscopy for a large sample of candidate EMP stars found with LAMOST





- More than 500 metal-poor candidates have been selected from LAMOST

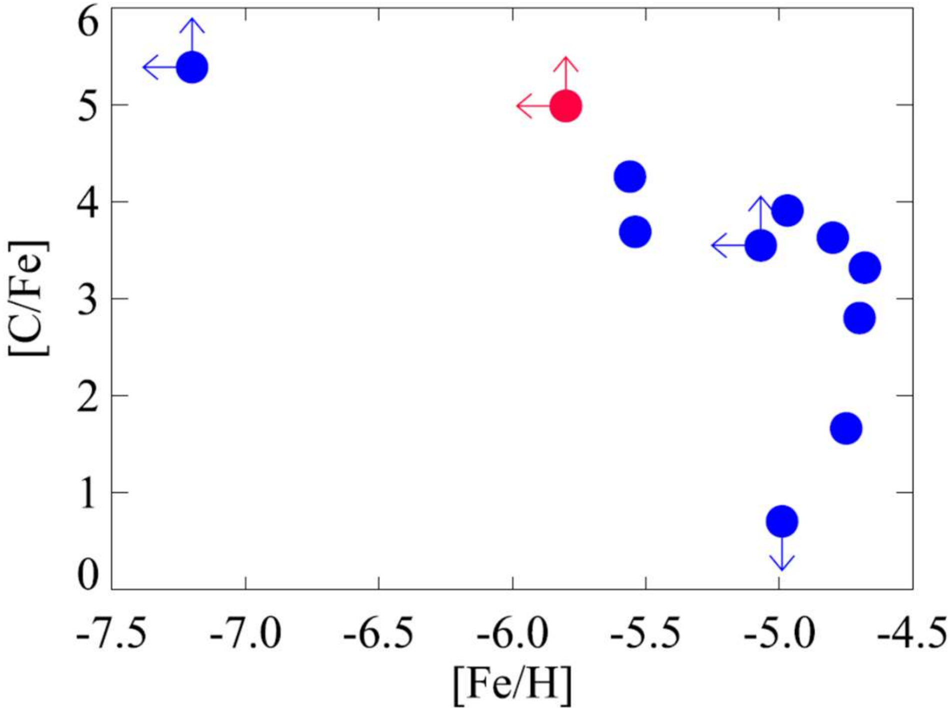
medium resolution spectra

high-resolution spectroscopy

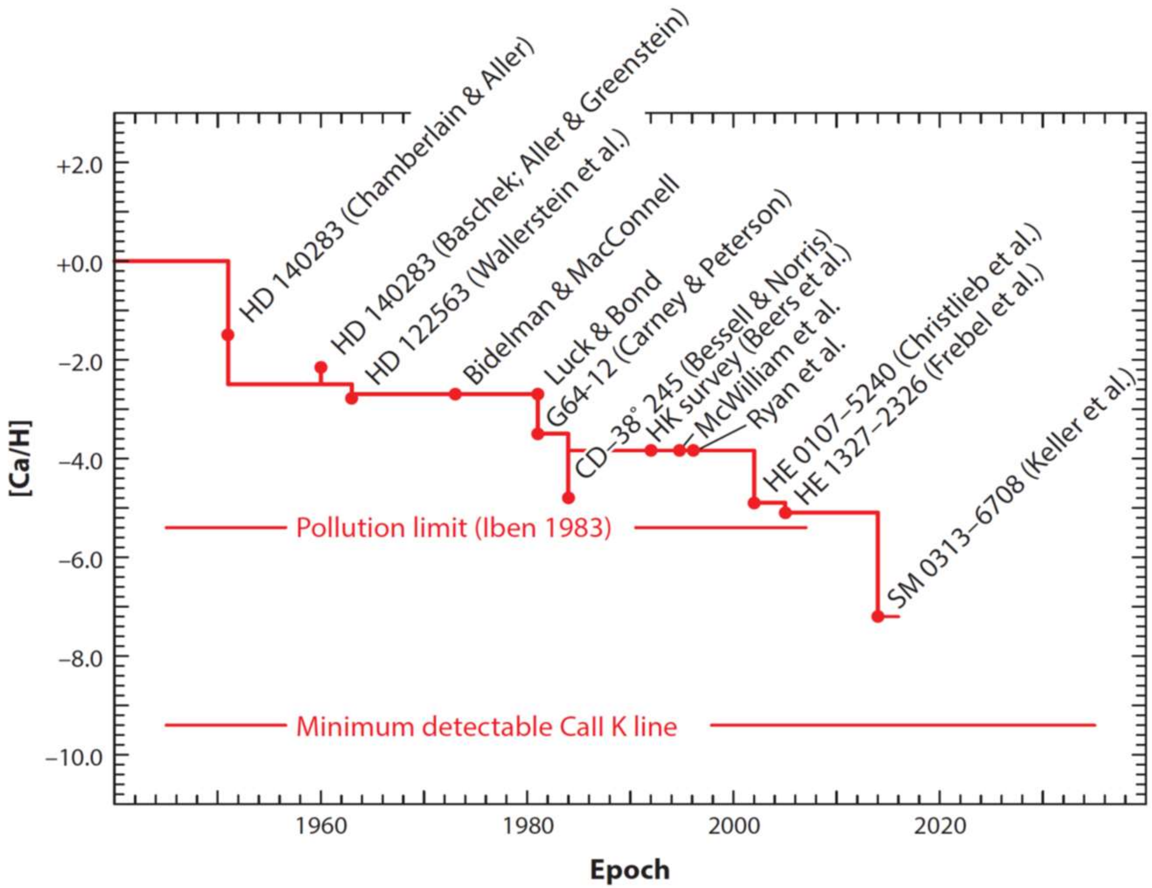
- Follow-up for ~200 stars with three Subaru/HDS runs.

Target selection random selection for a given magnitude/temperature range.

Discovery of hyper metal-poor stars ([Fe/H] < -5)



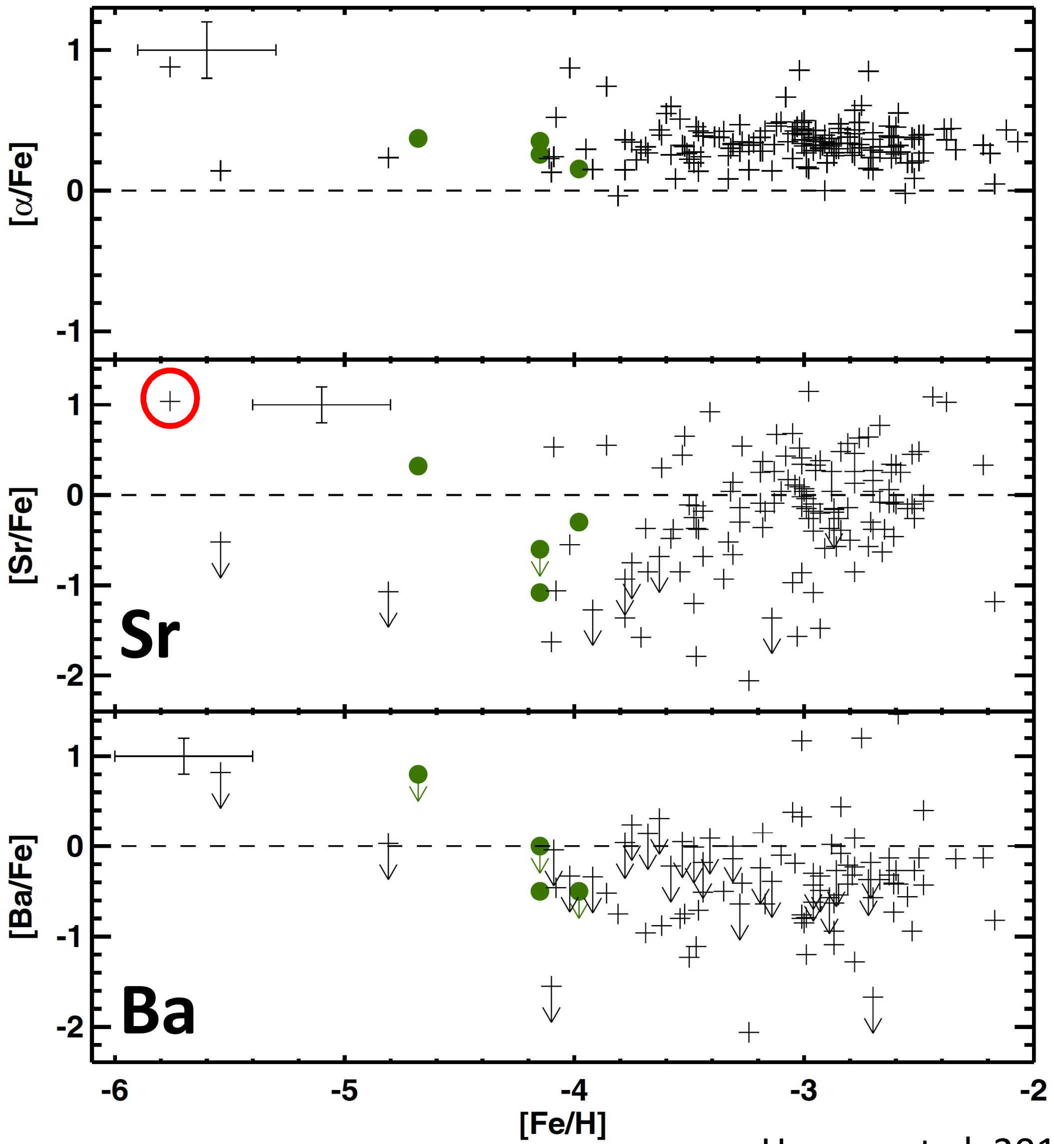
Aguado et al. 2018



Frebel & Norris 2015

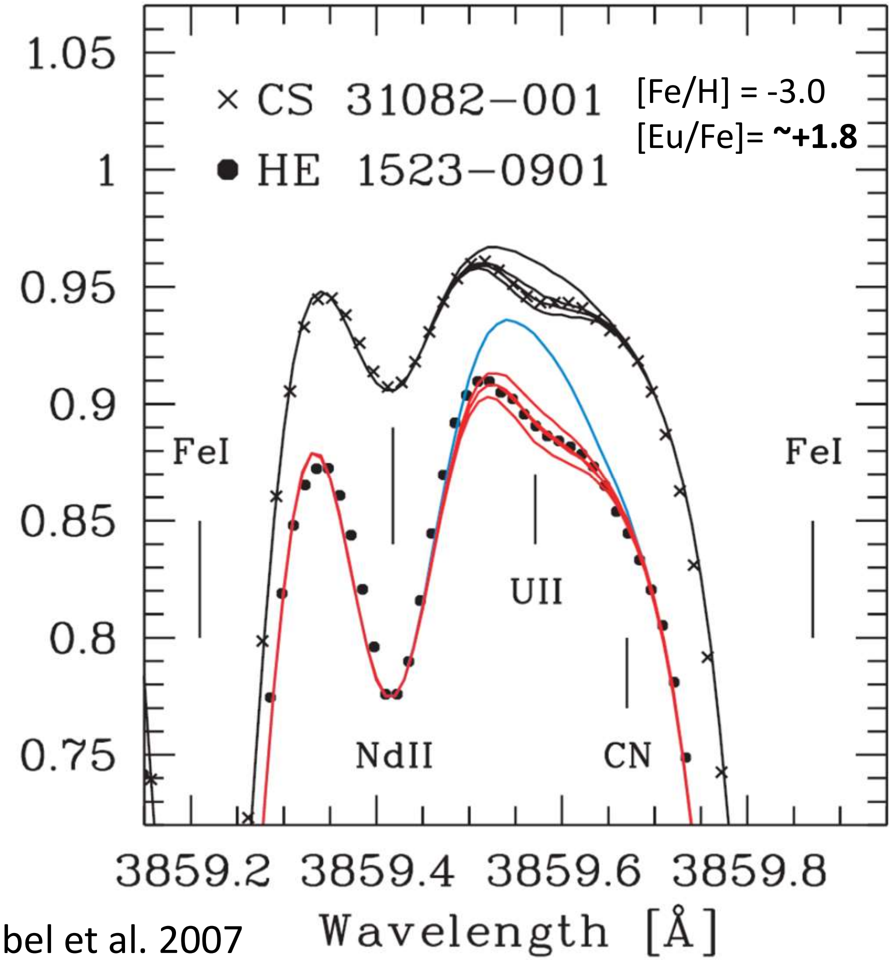
Insufficient sample size for statistical discussion

Neutron-capture elements



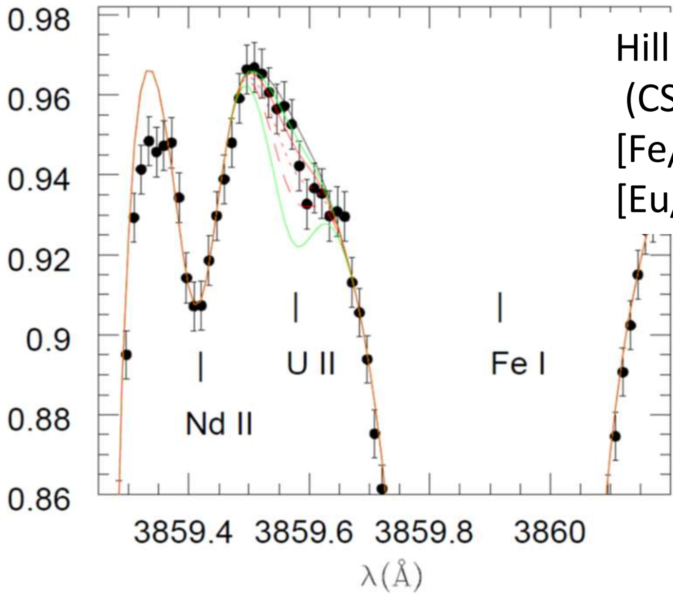
Hansen et al. 2015

- Sr and Ba are the most detectable elements.
- no stars with high Ba in [Fe/H] < ~-4
- Sr was detected in HE 1327-2326 ([Fe/H] = - 5.7)
- weak r-process is primary process ?
- Support NSM scenario.

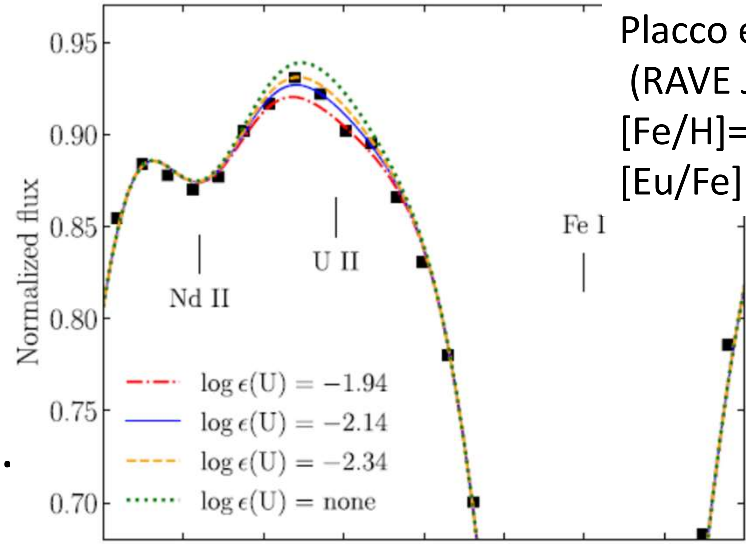


[Fe/H] = -3.0
[Eu/Fe]= **~+1.8**

Frebel et al. 2007



Hill et al. 2016
(CS 29497-004)
[Fe/H]= -2.85
[Eu/Fe]= **+1.6**

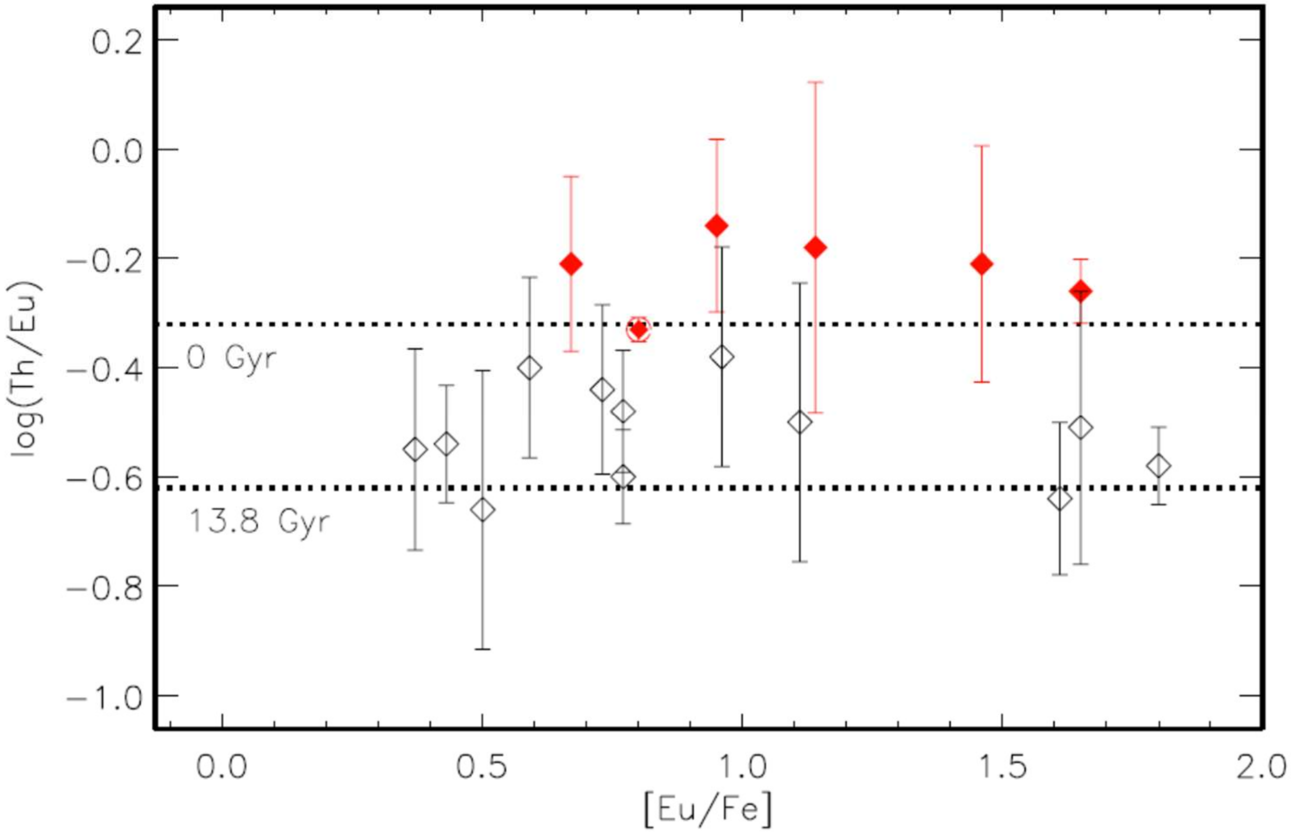


Placco et al. 2016
(RAVE J2038-0023)
[Fe/H]= -2.91,
[Eu/Fe] = **+1.64**

Large survey for r-process enhanced star is ongoing.

c.f., Sakari et al. 2018

Actinide boost stars are common ?



What does this population difference mean?

Mashonkina et al. 2014

Dispersion is not so large

Summary

- The origin of r-process is likely to be neutron star mergers.
- CCSNe may also be the origin of r-process.
- Eu (r-process element) detections in EMP ([Fe/H] < -3.5) stars are important.
- The origin of actinide boost stars is still unknown.
- The origin of r-process will be clarified by survey of metal-poor stars and follow-up high-dispersion spectroscopy.