Nov. 14, 2017
Monash

Observations of CEMP stars. II.

CEMP-no stars

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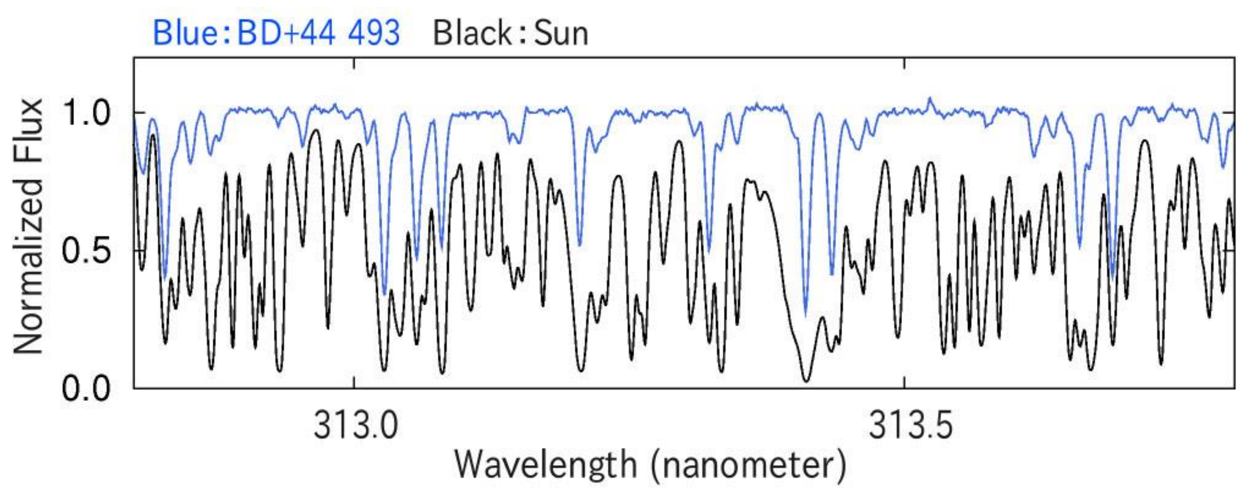


CEMP-no stars

- **Definition and classification**
- **Observational features**
  - **Metallicity and C abundance distribution**
  - **Binarity**
  - **Li abundances**
  - **Abundance patterns**
  - **Neutron-capture elements**

CEMP=Carbon Enhanced Metal-Poor stars

Carbon-enhanced stars in the Galactic halo are known as the spectral class CH stars (Keenan 1942).

A number of carbon-enhanced stars were identified by the HK survey (e.g. *Beers et al. 1992*)

The fraction of CEMP is estimated to be 10-25% in [Fe/H]<-2.

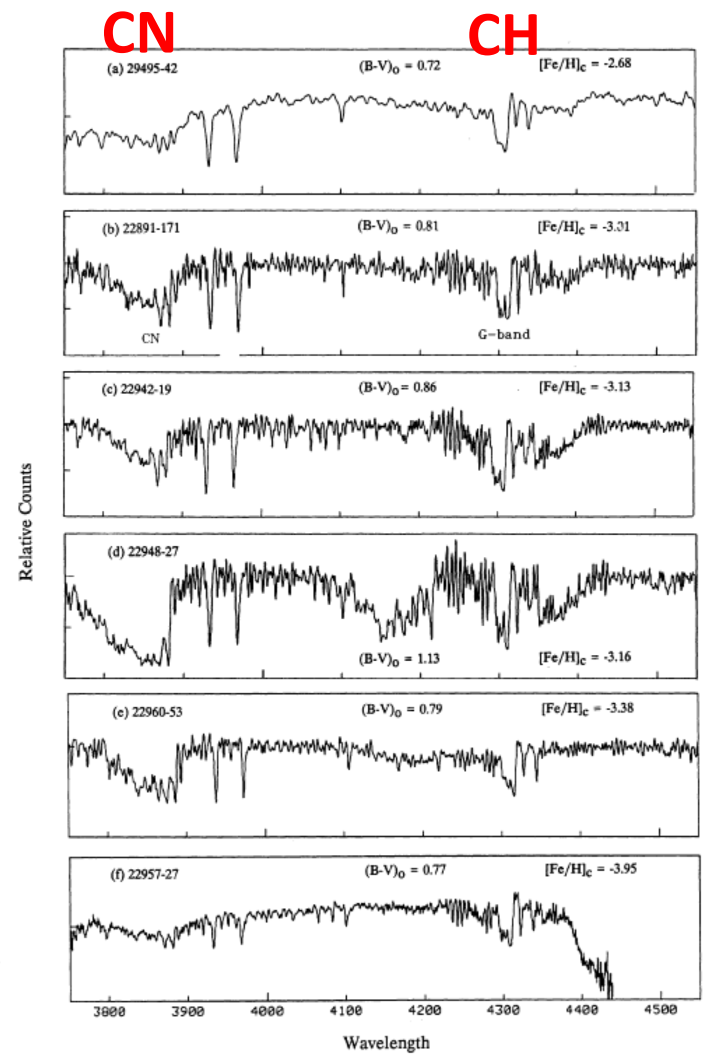


FIG. 13. Type examples of stars in the present sample with moderate to strong CN bandheads at λ3883 Å and/or λ4215 Å, and anomalously large CH (*G*-band) λ4300 Å features. All spectra have been smoothed with a Gaussian of breadth 2.5 Å, and flattened with a boxcar smooth.

Beers et al. (1992)

CEMP definition

Beers & Christlieb (2005, ARAA)

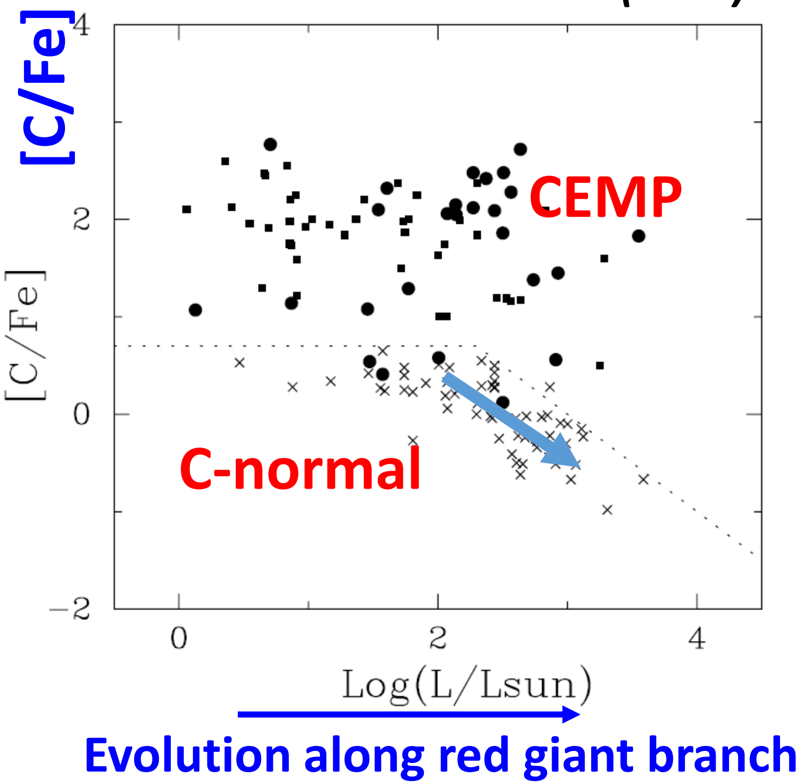
TABLE 2 Definition of subclasses of metal-poor stars

Neutron-capture-rich stars	
r-I	$0.3 \leq [Eu/Fe] \leq +1.0$ and $[Ba/Eu] < 0$
r-II	$[Eu/Fe] > +1.0$ and $[Ba/Eu] < 0$
s	$[Ba/Fe] > +1.0$ and $[Ba/Eu] > +0.5$
r/s	$0.0 < [Ba/Eu] < +0.5$
Carbon-enhanced metal-poor stars	
CEMP	$[C/Fe] > +1.0$
CEMP-r	$[C/Fe] > +1.0$ and $[Eu/Fe] > +1.0$
CEMP-s	$[C/Fe] > +1.0$, $[Ba/Fe] > +1.0$, and $[Ba/Eu] > +0.5$
CEMP-r/s	$[C/Fe] > +1.0$ and $0.0 < [Ba/Eu] < +0.5$
CEMP-no	$[C/Fe] > +1.0$ and $[Ba/Fe] < 0$

CEMP definition

- **CEMP stars are well separated from C-normal stars in general, but CEMP-no stars could be affected by the definition**
- **Highly evolved red giants might be affected by CNO cycle**

Aoki et al. (2007)



Placco et al. (2014)

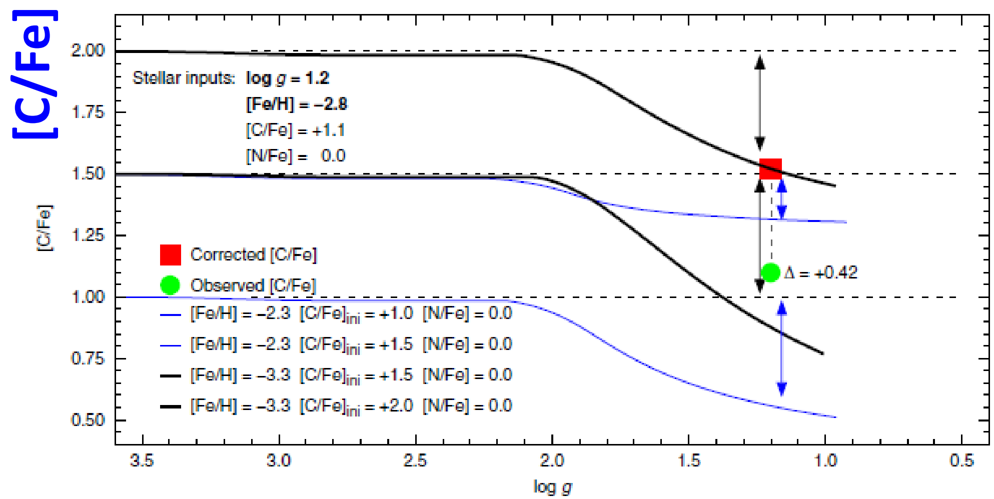


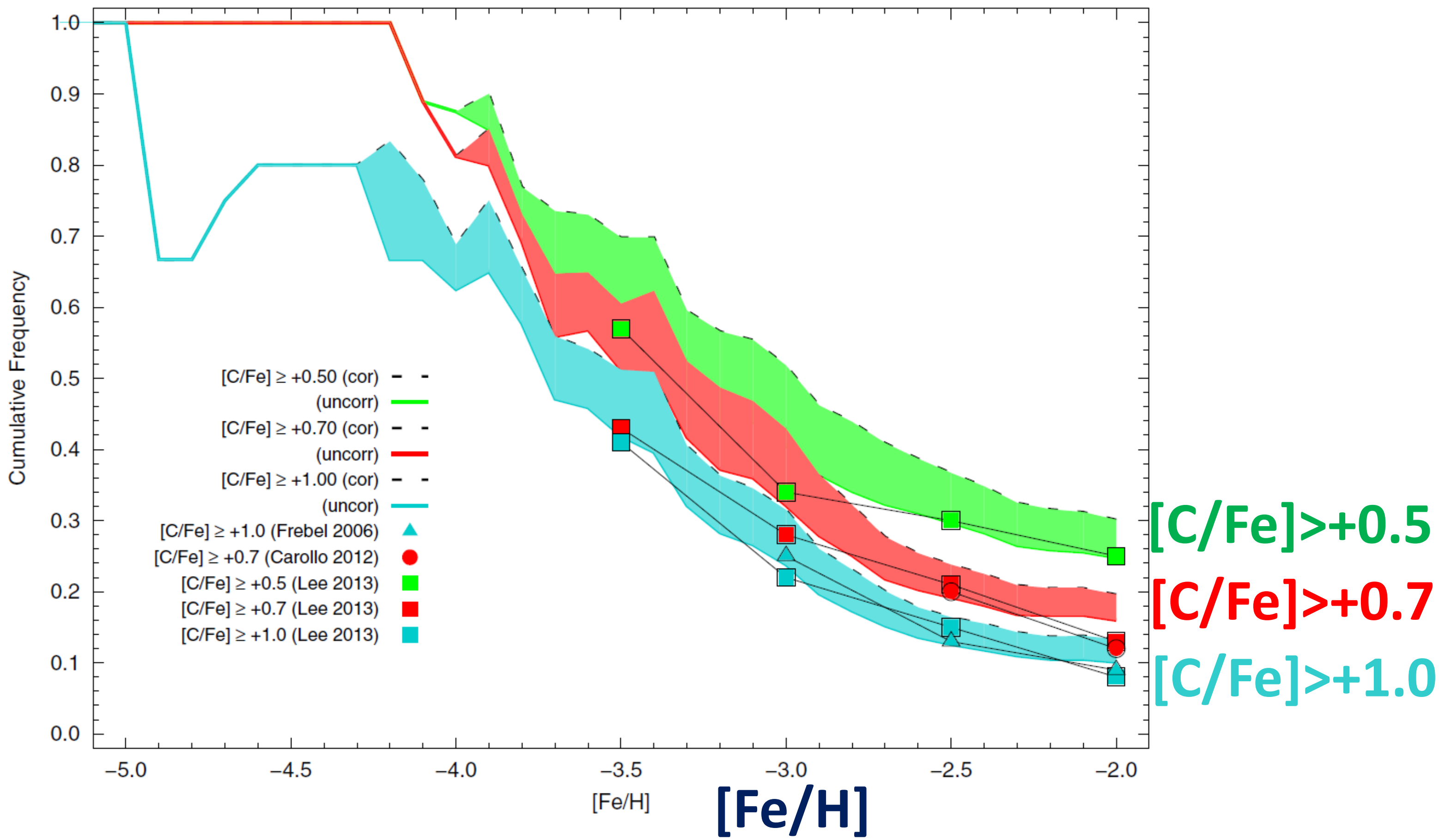
Figure 8. Procedure for the determination of carbon abundance corrections. Top panel: observed (green circles) and corrected (red squares) carbon abundances for four different log g values. The horizontal dashed lines show the initial [C/Fe] model values. The final corrections, Δ, are determined from a linear interpolation of the corrections of each model (vertical arrows). Since the [Fe/H] input value coincides with the model values, no interpolation in [Fe/H] is made. Bottom panel: complete interpolation procedure for log $g = 1.2$, and [Fe/H] $= -2.8$. The four vertical arrows represent the corrections for each model. The final correction is a linear interpolation in both [Fe/H] and log g.

Evolution along red giant branch

CEMP frequency

CEMP frequency increases with decreasing metallicity

Placco et al. (2014)



CEMP classification

Beers & Christlieb (2005, ARAA)

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r-II	[Eu/Fe] $> +1.0$ and [Ba/Eu] < 0
s	[Ba/Fe] $> +1.0$ and [Ba/Eu] $> +0.5$
r/s	$0.0 <$ [Ba/Eu] $< +0.5$
Carbon-enhanced metal-poor stars	
CEMP	[C/Fe] $> +1.0$
CEMP-r	[C/Fe] $> +1.0$ and [Eu/Fe] $> +1.0$
CEMP-s	[C/Fe] $> +1.0$, [Ba/Fe] $> +1.0$, and [Ba/Eu] $> +0.5$
CEMP-r/s	[C/Fe] $> +1.0$ and $0.0 <$ [Ba/Eu] $< +0.5$
CEMP-no	[C/Fe] $> +1.0$ and [Ba/Fe] < 0

CS22957-027: A carbon-enhanced star with no excess of neutron-capture elements

[Fe/H]=-3.38, [C/Fe]=+2.2, [Ba/Fe]=-0.97, [Sr/Fe]=-0.56

Norris et al. (1997)

EXTREMELY METAL-POOR STARS. THE CARBON-RICH, NEUTRON CAPTURE ELEMENT–POOR OBJECT CS 22957−027

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Received 1997 June 23; accepted 1997 September 4; published 1997 October 9

Bonifacio et al. (1998)

CS 22957-027: a carbon-rich extremely-metal-poor star*

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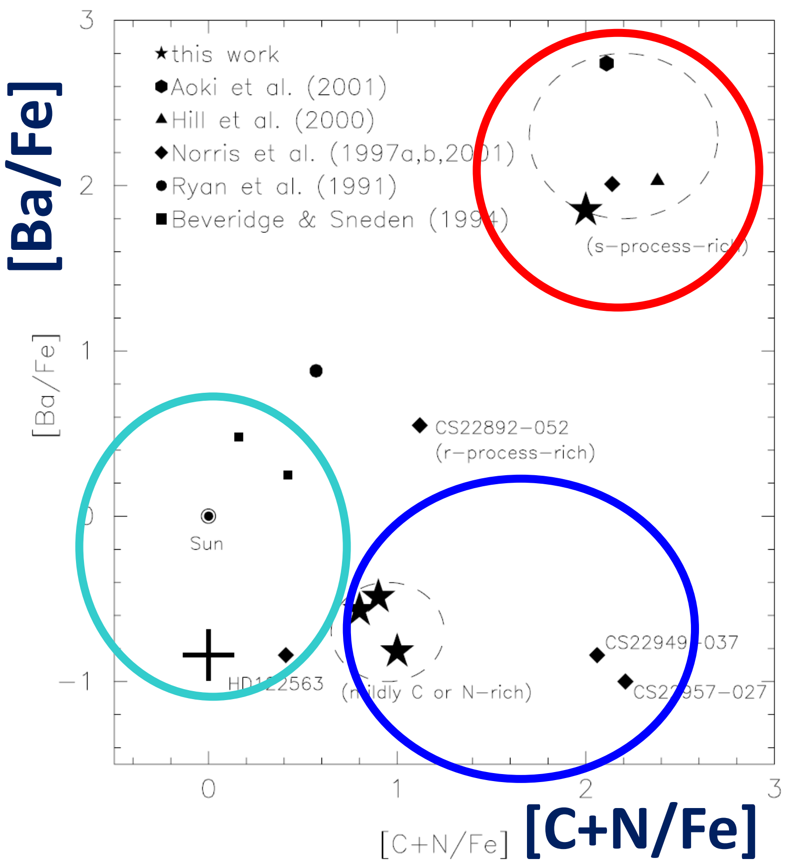
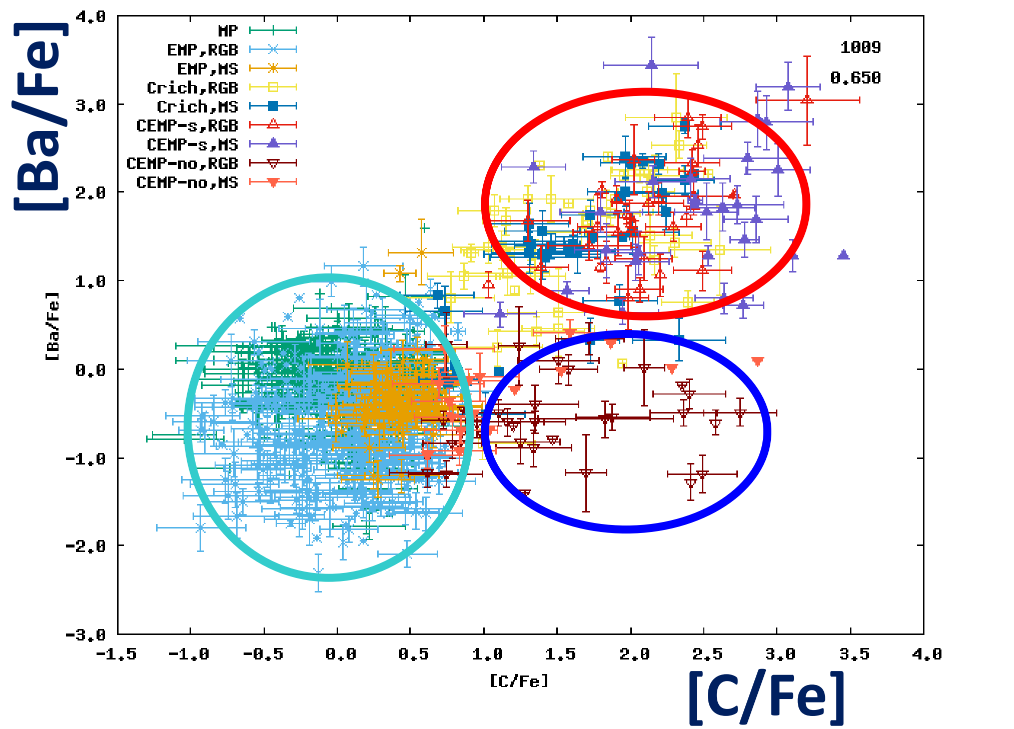
CEMP classification

CEMP-s : Ba-rich stars (due to s-process)
CEMP-no : Ba-normal stars

Aoki et al. (2002)



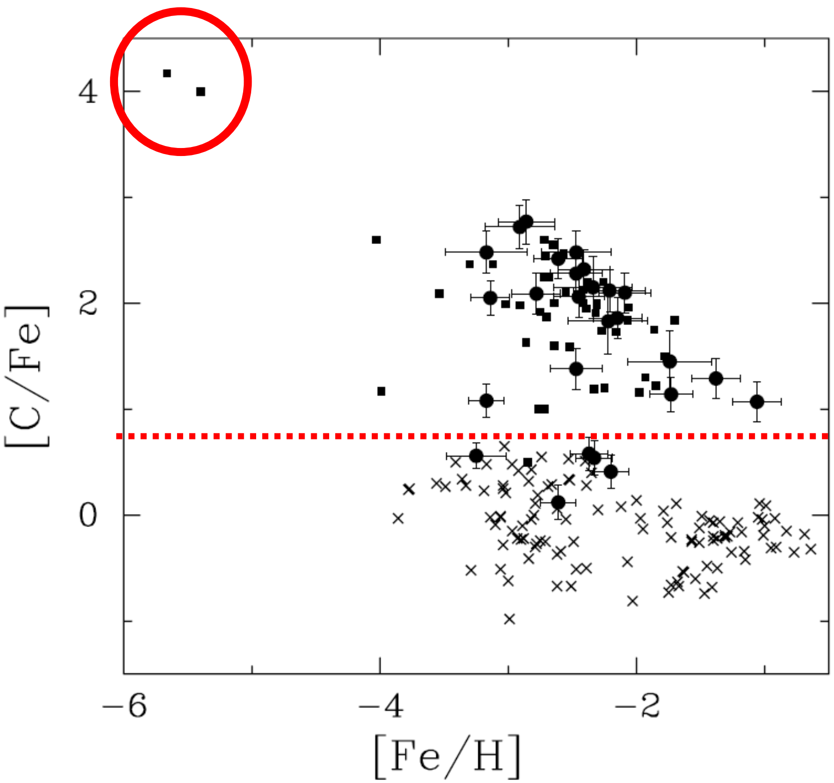
SAGA database (Suda et al. 2017)

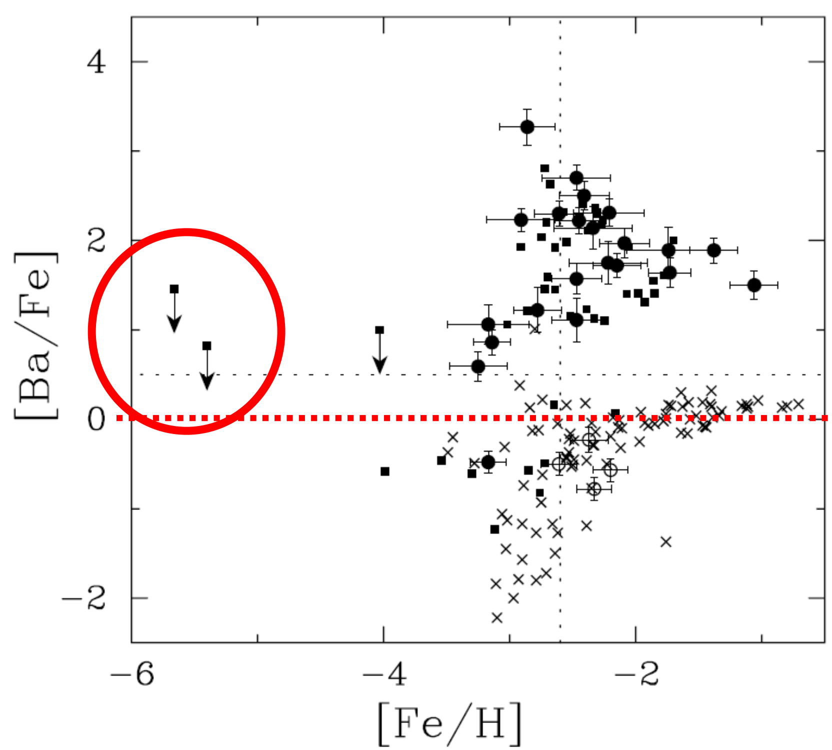


“Hyper metal-poor” stars as extreme cases of CEMP-no

HE0107-5240 [Fe/H]=-5.4, [C/Fe]=+4.0, [Ba/Fe]<+0.8
HE1327-2326 [Fe/H]=-5.6, [C/Fe]=+4.3, [Ba/Fe]<+1.5

Aoki et al. (2007)

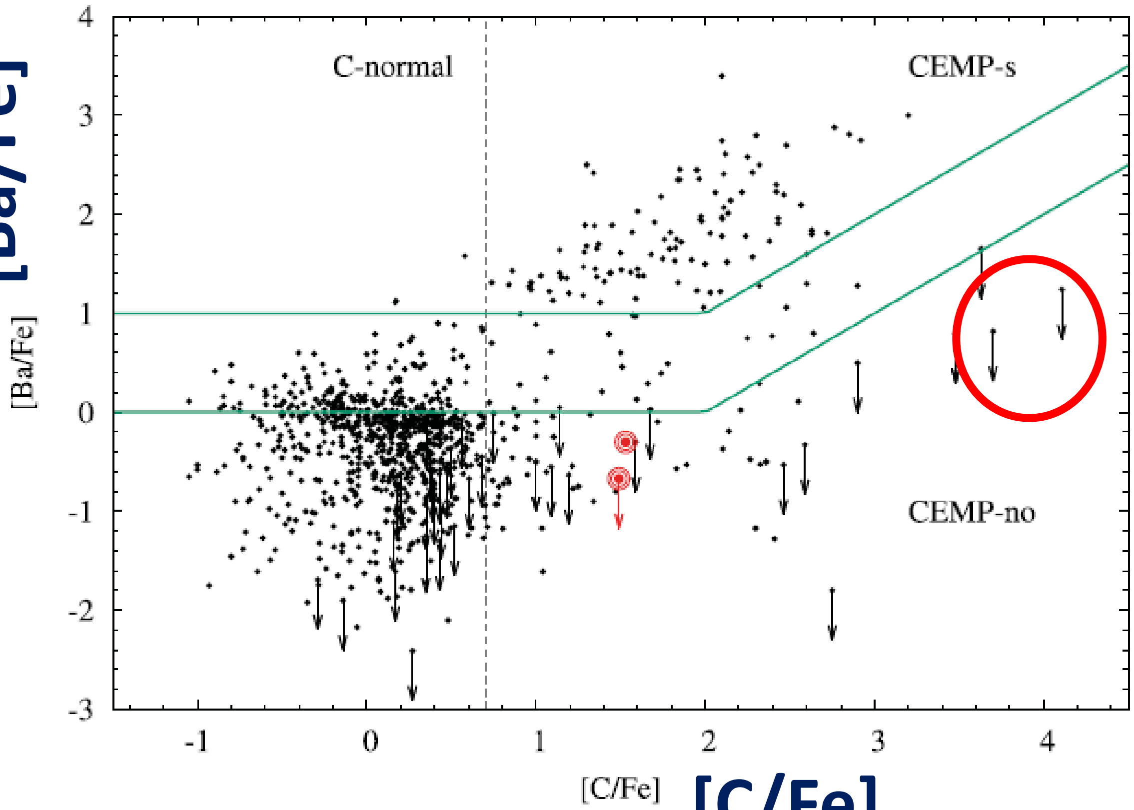




New definition of CEMP-no

[Ba/Fe] < +1.0 (or 0.0) for [C/Fe] < +2.0
[Ba/Fe] < [C/Fe]-1.0 (or -2.0) for [C/Fe]>+2.0

Matsuno et al. (2017)



[Ba/Fe]

[C/Fe]

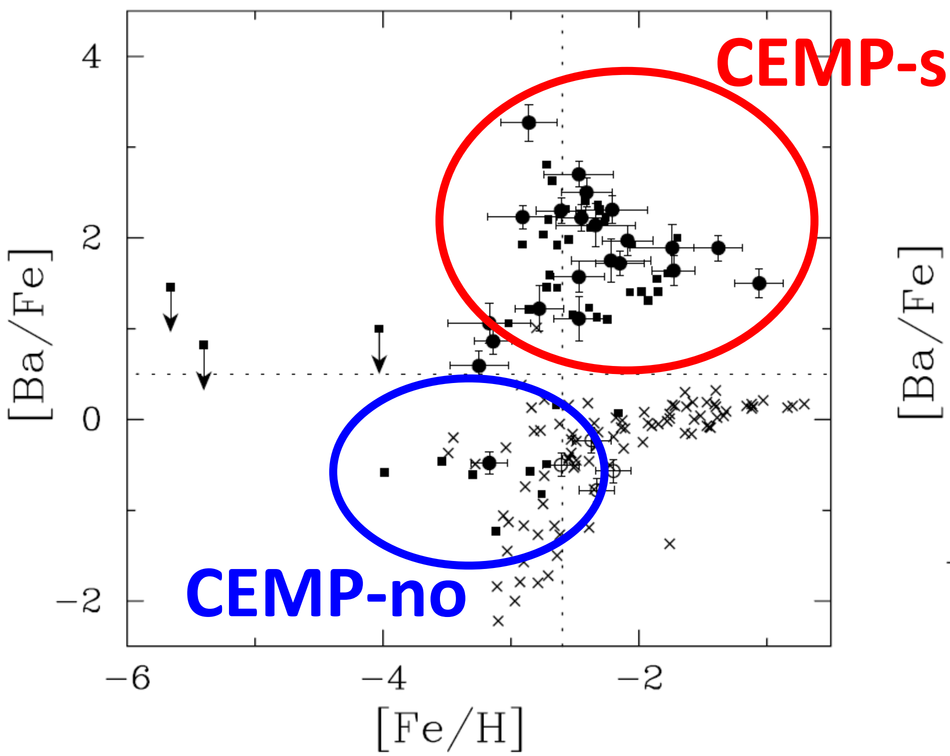
Observational features

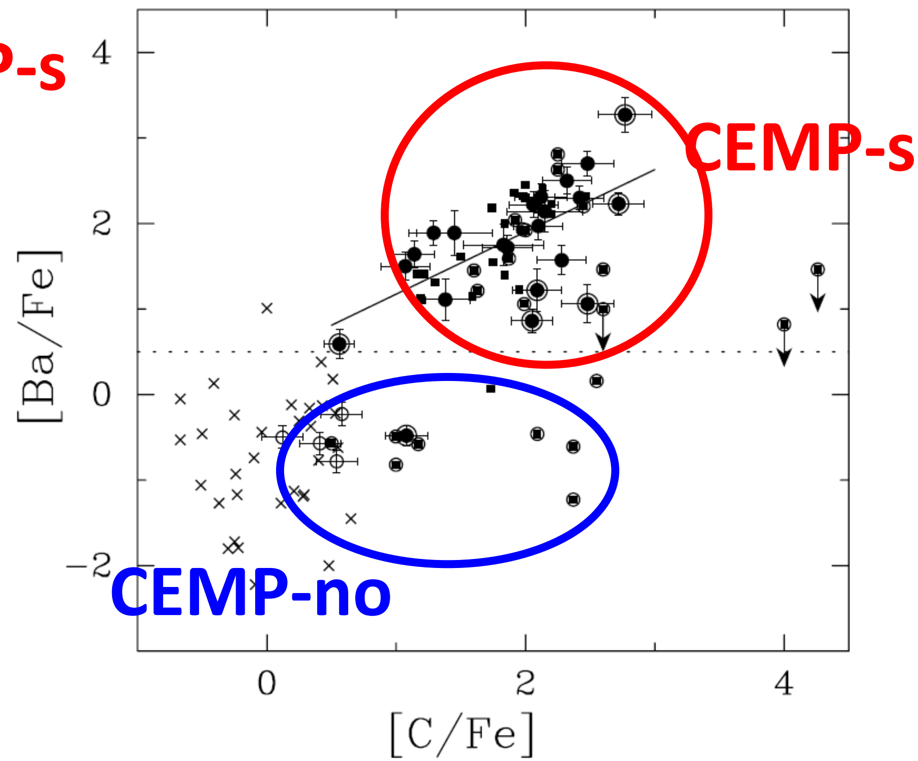
1. Metallicity and C abundance distribution
2. Binarity
3. Li abundances
4. Abundance patterns
5. Neutron-capture elements

CEMP-no stars (1)
Metallicity and C abundance distribution

CEMP-s : found in [Fe/H]>-3, having high [C/H]
CEMP-no : mostly found in [Fe/H]<-2.5, having moderate [C/H]

Aoki et al. (2007)

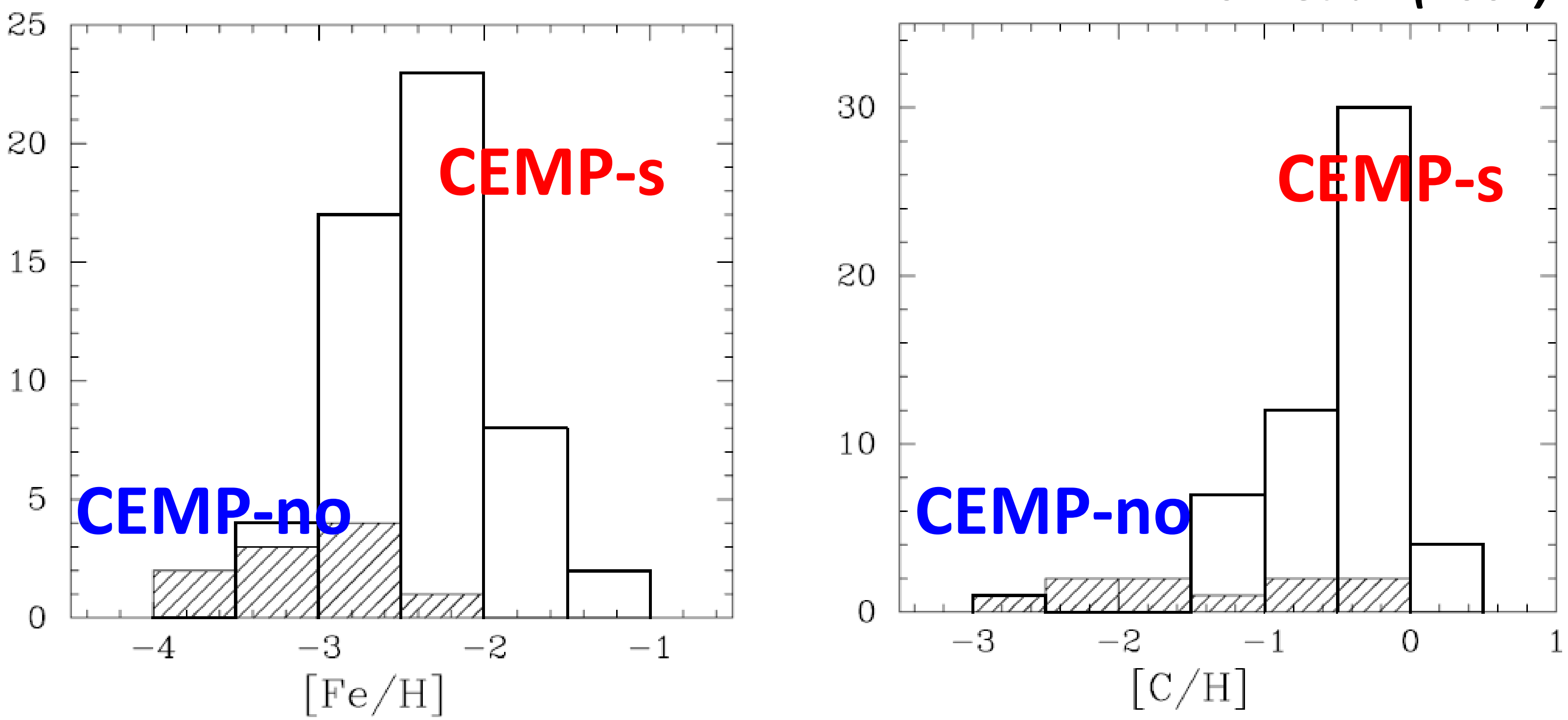




CEMP-no stars (1)
Metallicity and C abundance distribution

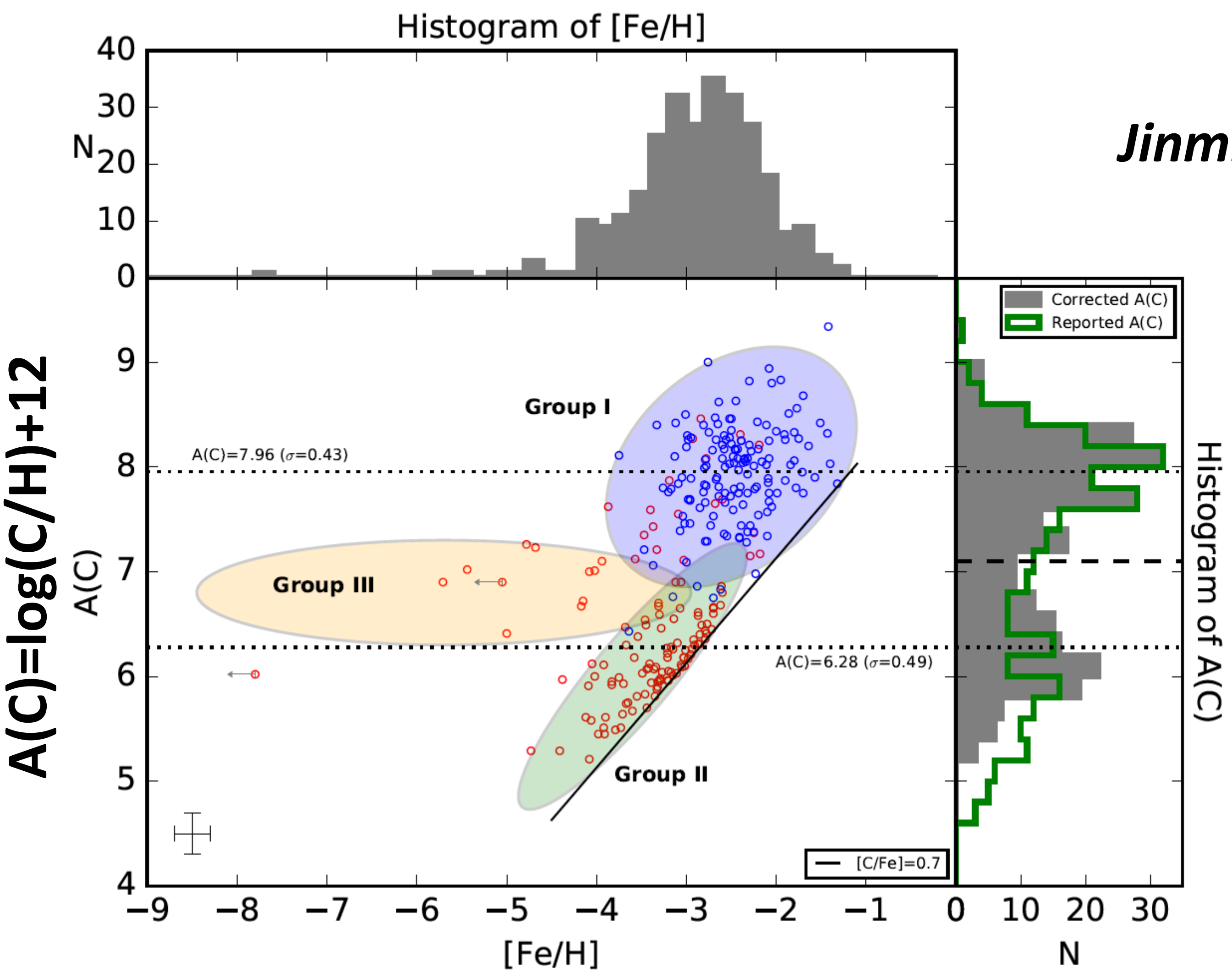
CEMP-s : found in [Fe/H]>-3, having high [C/H]
CEMP-no : mostly found in [Fe/H]<-2.5, having moderate [C/H]

Aoki et al. (2007)



CEMP-no stars (1)
Metallicity and C abundance distribution

Jinmi et al. (2017)

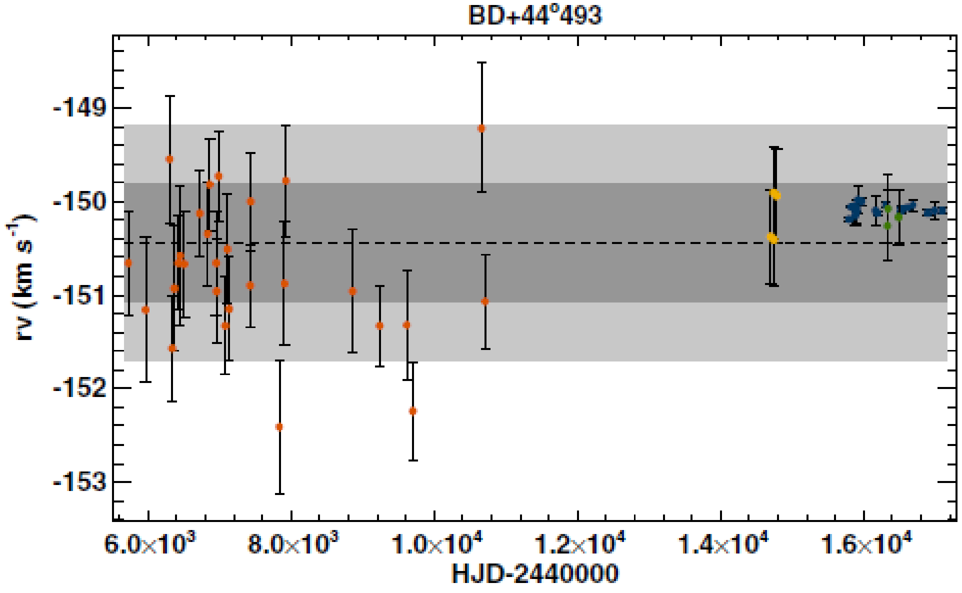


CEMP-no stars (2) binarity

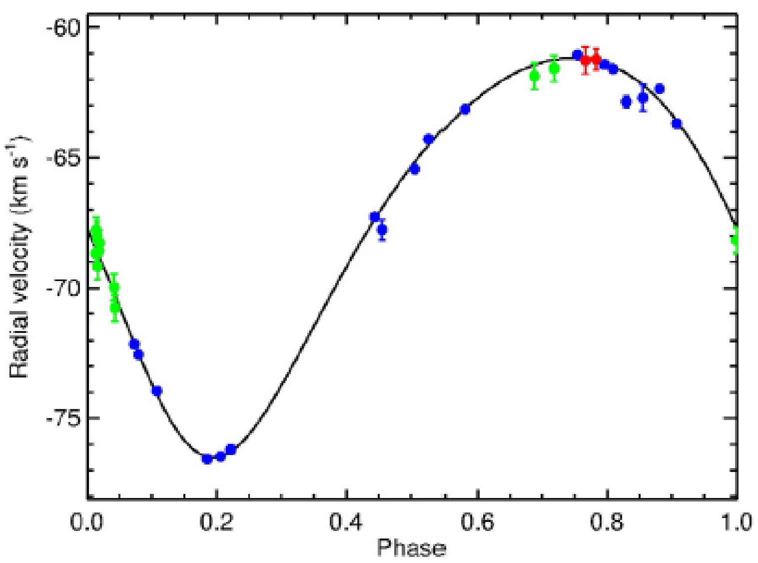
No signature of high binary frequency

Hansen et al. (2016)

BD+44 493



CS22957-027

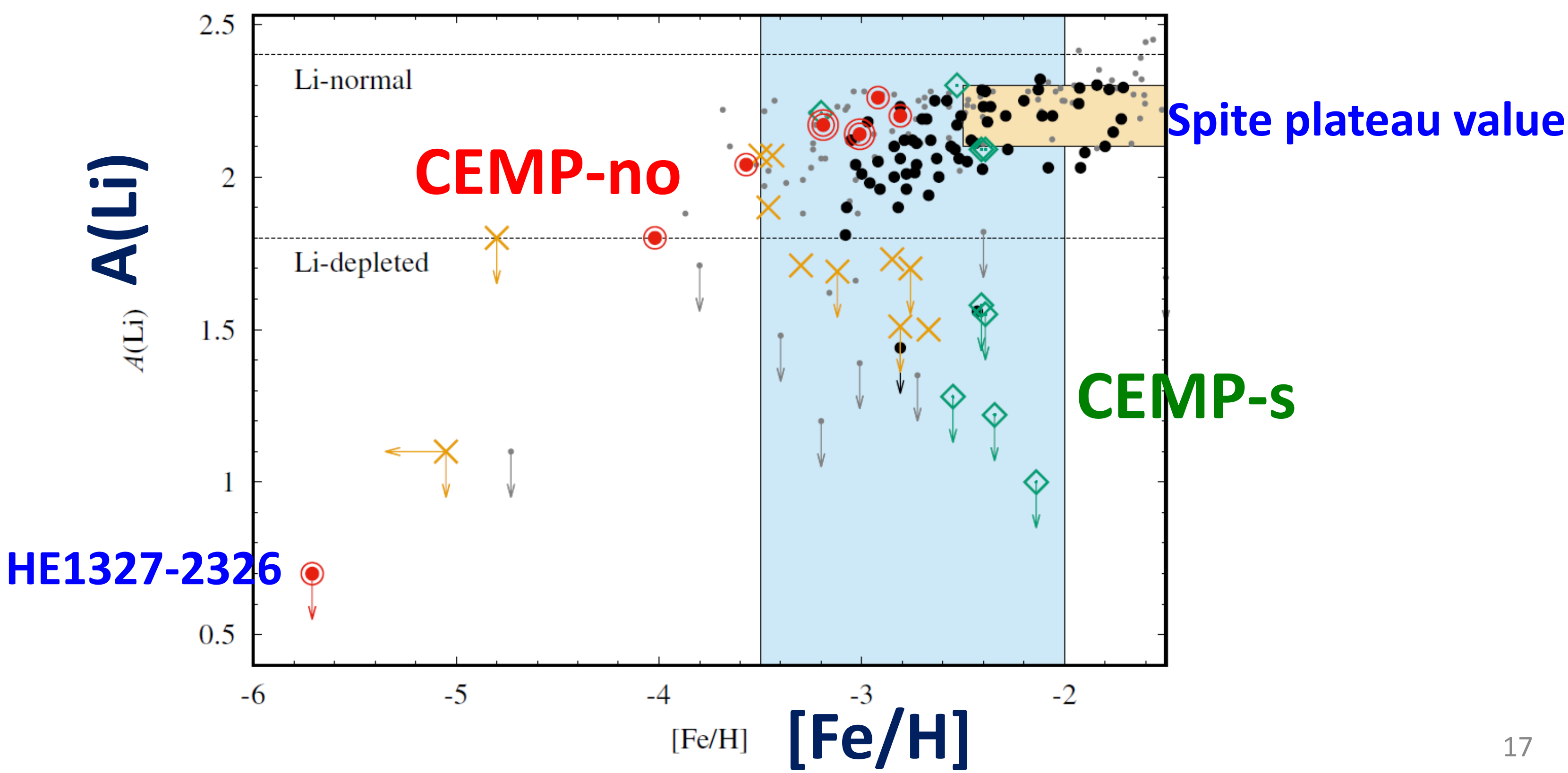


10,000 days!

CEMP-no stars (3) Li in warm stars

- CEMP-no stars with -4<[Fe/H]<-3 have *normal* Li abundance
  cf. Li in CEMP-s stars is depleted
- Li in Ultra/Hyper metal-poor stars (only two!) is depleted

Matsuno et al. (2017)



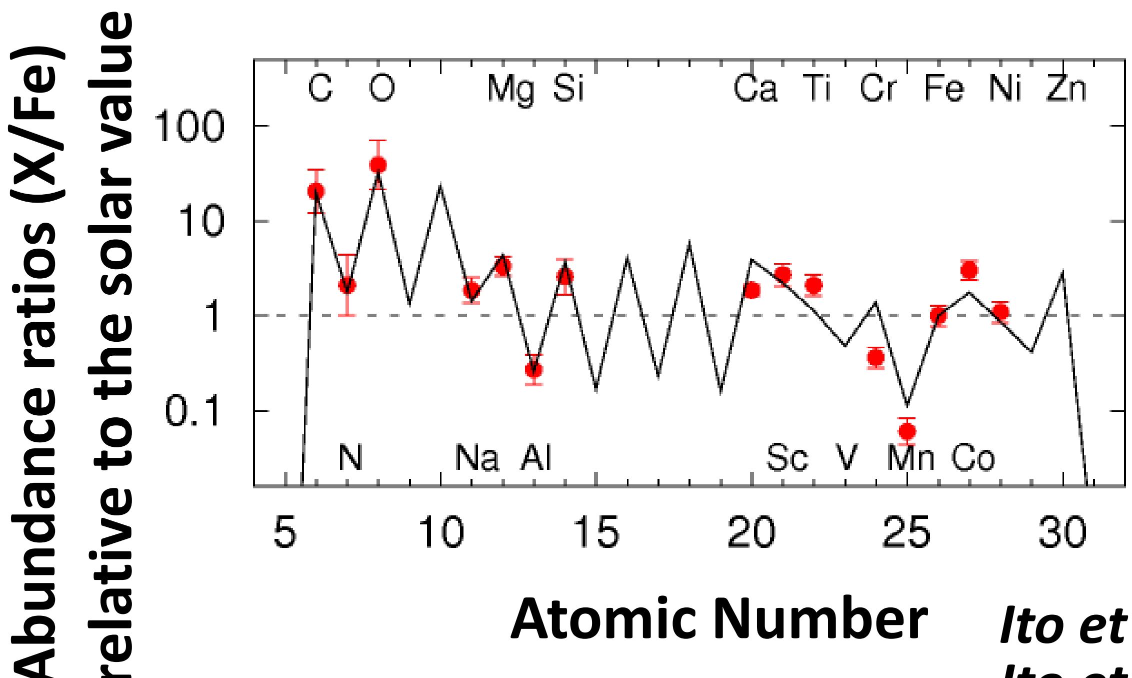
CEMP-no stars (4) abundance pattern

The carbon-enhanced star BD+44 493

[Fe/H]=-3.7, [C/H]～[O/H]～-2.5

The normal Ba abundance, the high O/C, and the low N/C exclude the AGB and massive rotating stars as the progenitor

→ Faint supernova scenario is the remaining possibility.

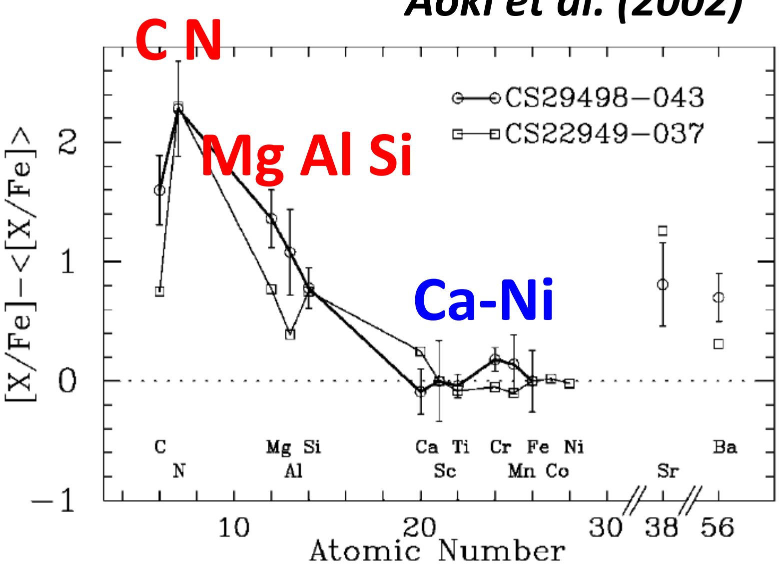


Ito et al. (2009)
Ito et al. (2013)

CEMP-no stars (4) abundance pattern "CEMP-α"

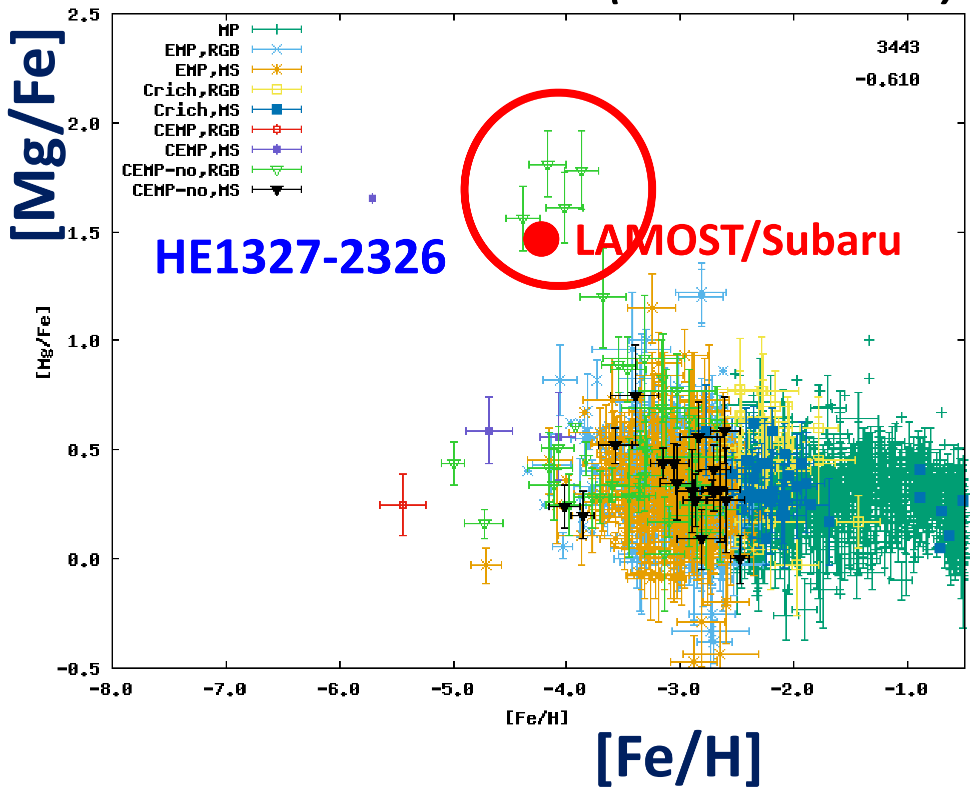
Large excess of C,N,O. and alpha elements with [Fe/H]~-4 … "iron deficient" *(Tsujimoto & Shigeyama 2003, Umeda & Nomoto 2003)*

Aoki et al. (2002)



CS22949-037 ([Fe/H]=-4.0)
Depagne et al. (2002)
CS29498-043 ([Fe/H]=-3.5)
Aoki et al. (2002)

SAGA database (Suda et al. 2017)

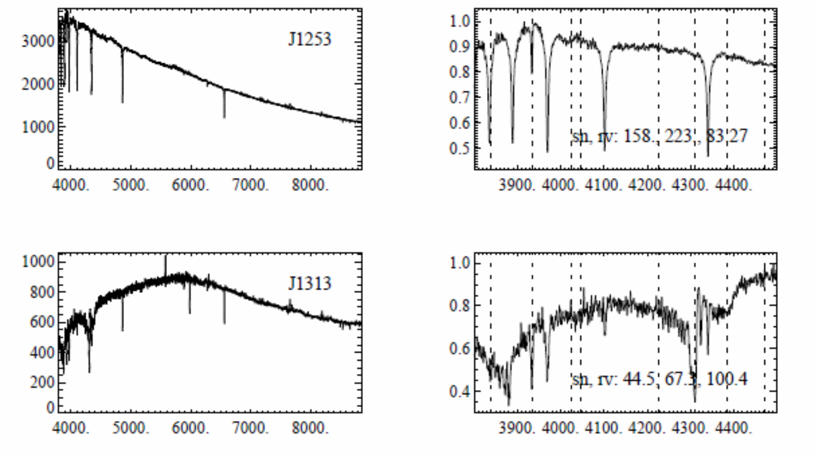


Exploring the early chemical evolution of the Milky Way with LAMOST and Subaru

W. Aoki, T. Suda, S. Honda, M. Ishigaki, M. Aoki, T. Matsuno
G. Zhao, H.-N. Lee, Zhao, J. Xing, Q., Shi, J., Zhang, S., Tan, K., Chen, Y. N. Christlieb

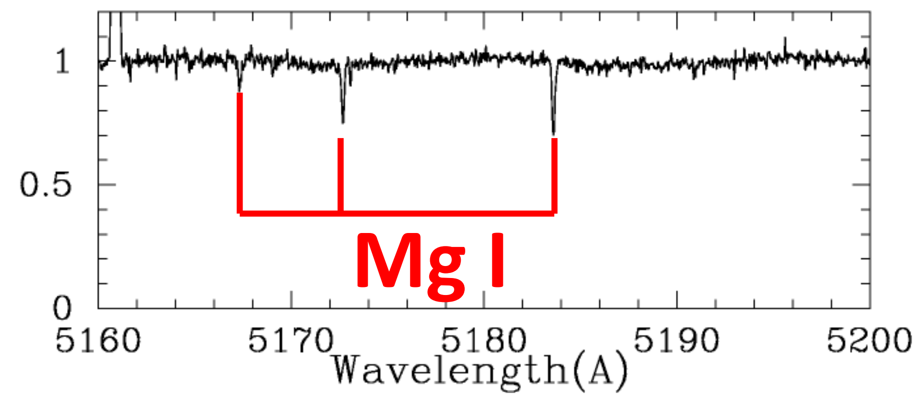
LAMOST

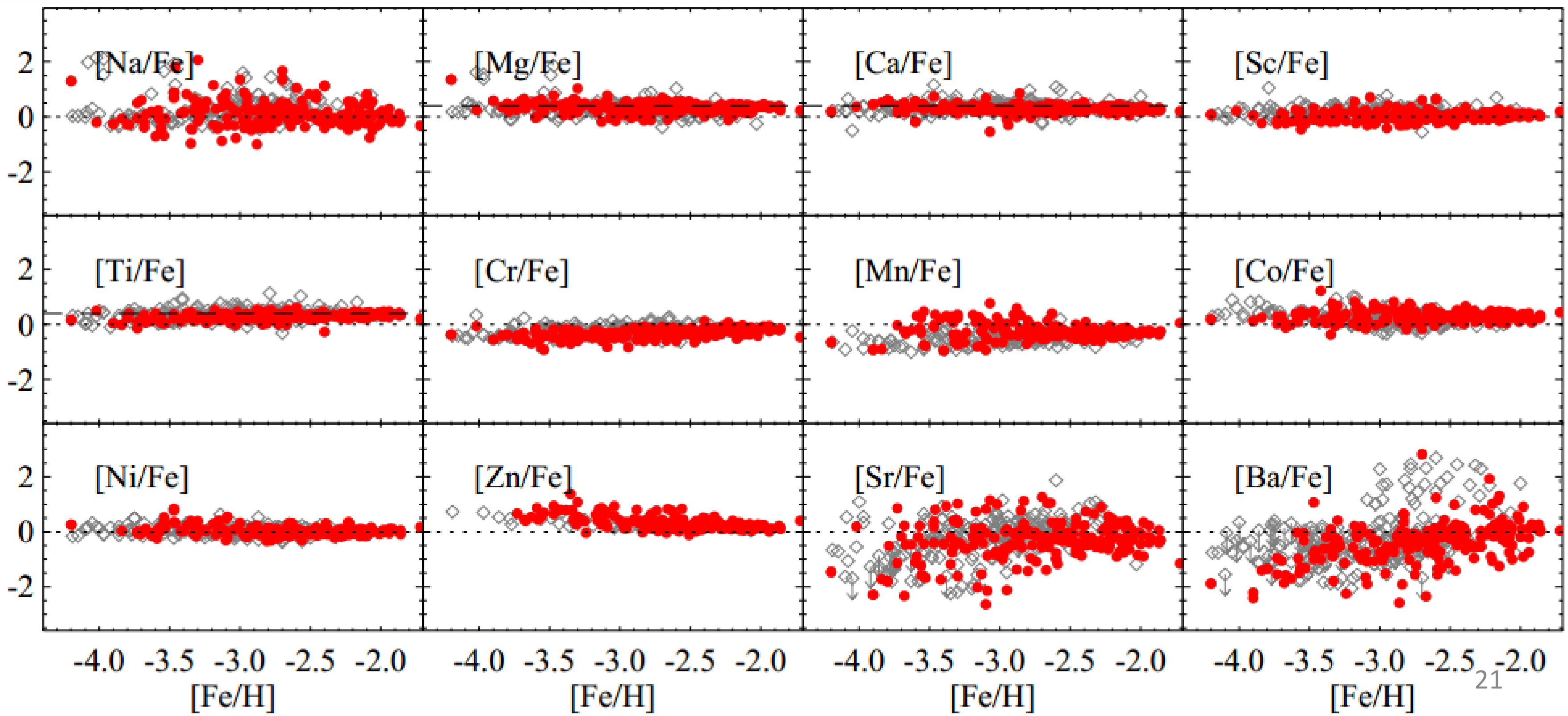
***R*=1800**



Subaru

***R*=45000**

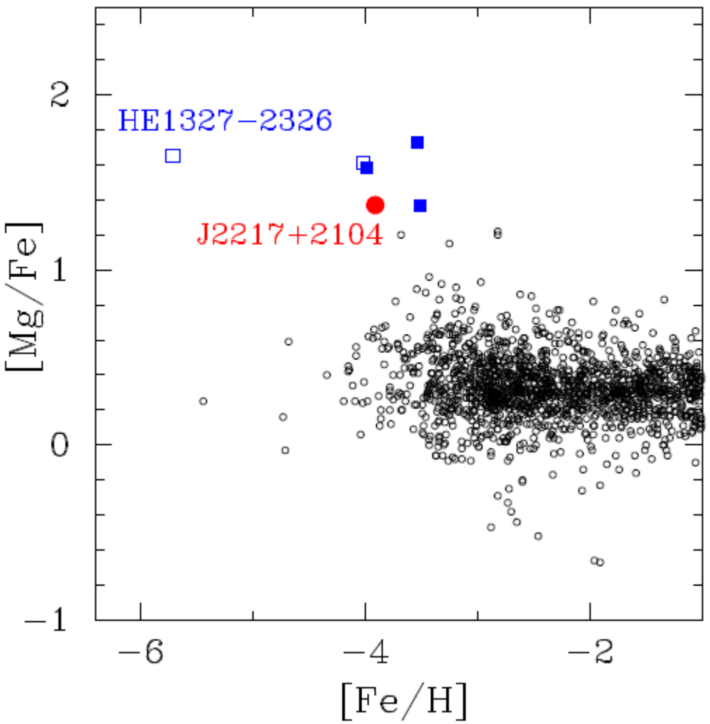


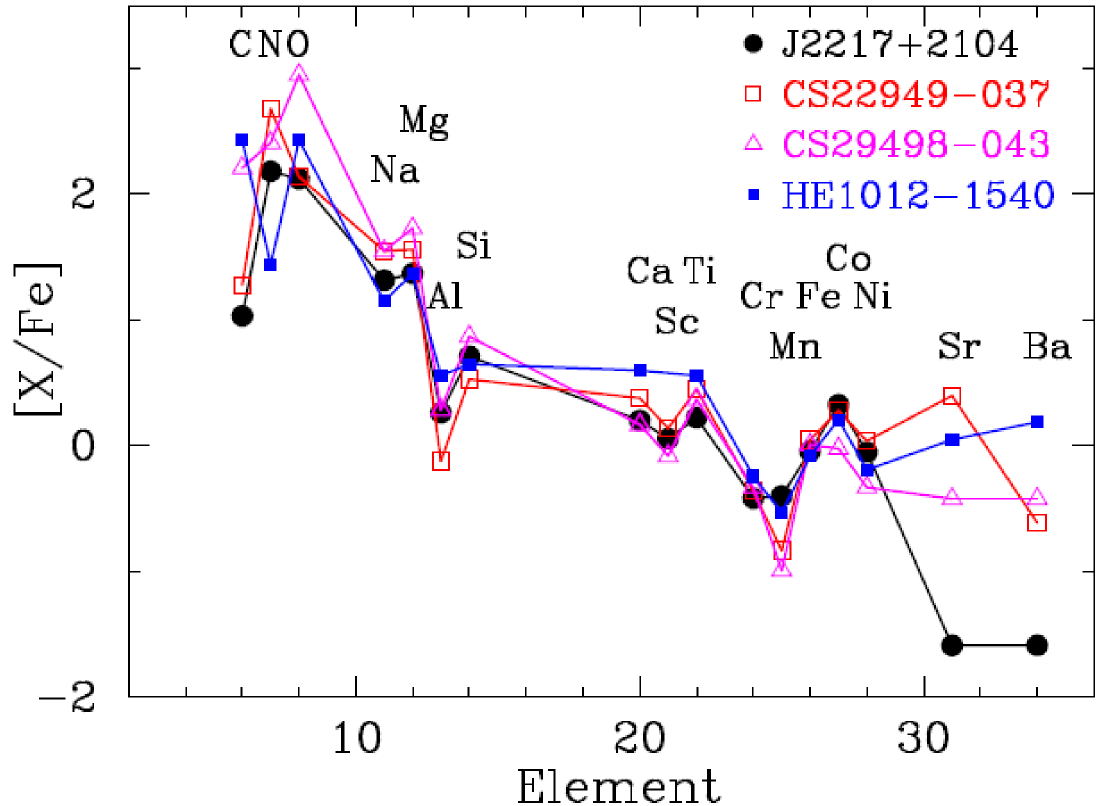


CEMP-no stars (4) abundance pattern "CEMP-α"

- **Very similar pattern between C and Ni**
- **Scatter in neutron-capture elements**

Aoki et al. (in prep)

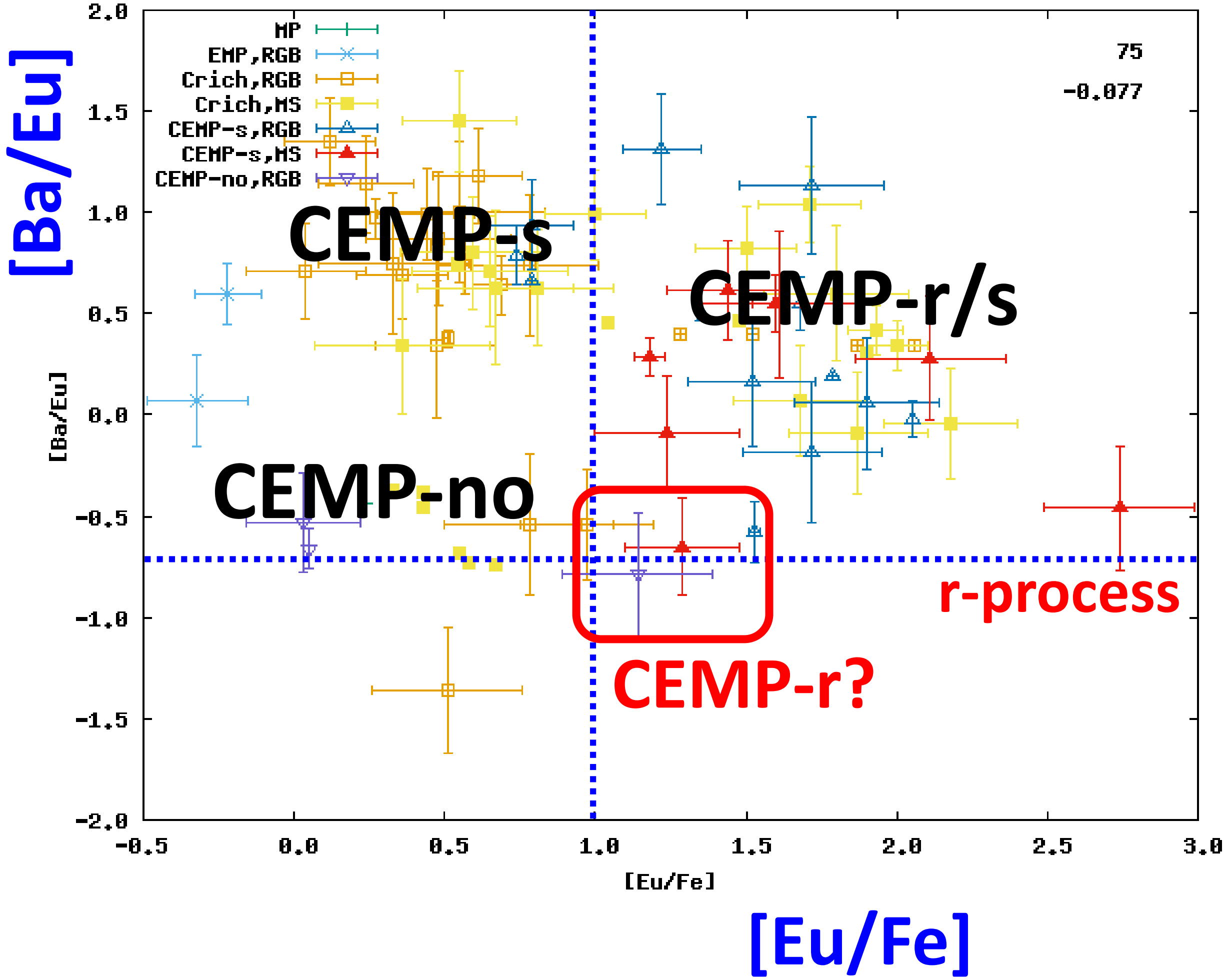




CEMP-no stars (5) neutron-capture elements: “CEMP-r stars”

How many CEMP-r stars do we know?

Carbon-enhanced stars ([C/Fe]>+0.7)



CS22892-052
Sneden et al. (1996)

CS22945-017
Roederer et al. (2014)

BS16929-005?
Allen et al. (2012); but *Lai et al. (2008)* report lower Eu upper limit

BS16543-097?
Allen et al. (2012); but *Honda et al. (2004)* and *Aoki et al. (2005)* report normal C abundance

CS31070-093?
Allen et al. (2012) CEMP-r/s star?

Classification and origins of CEMP stars

- **CEMP-s and CEMP-r/s stars:**

  s-process, high binary frequency, Li depletion

  → mass transfer from AGB stars in binary systems

- **CEMP-no stars:**

  Common feature with C-normal stars: binary frequency, Li, heavy neutron-capture elements, etc.

  a small fraction of CEMP-no stars show excess of alpha elements … similar to some Hyper Metal-Poor stars?

  → Faint supernovae, and other origins?