Carbon and heavy elements abundance in the extremely metal-poor carbon-rich stars

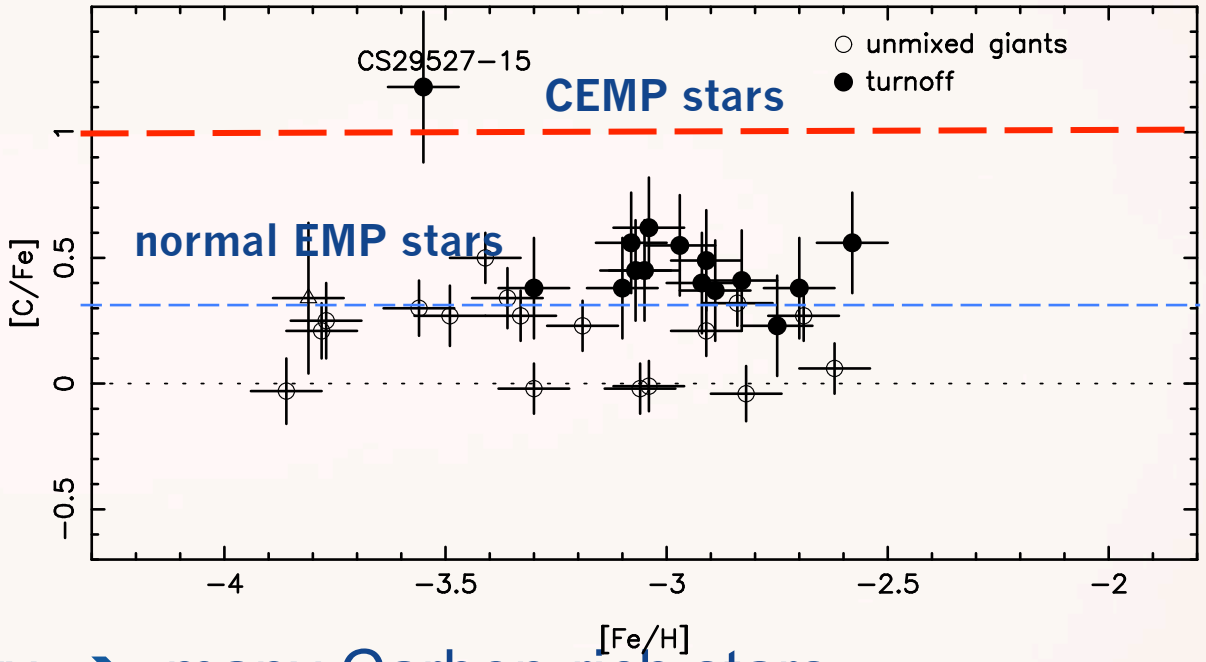
comparison EMP CEMP

field stars [Fe/H]<-2.7

M. Spite

l'Observatoire de Paris — GEPI

definition: C-rich star
CEMP
[C/Fe] > 1.0



Low metallicity ➔ many Carbon-rich stars

e.g.

Marsteller et al. (2005); Beers & Christlieb (2005)
Frebel et al. (2006) ; Lucatello et al. (2006) ...

[Fe/H] < -2 ➔ 20% of C-rich stars

[Fe/H] < -4.5 ➔ 4 stars are known
only 1 has no carbon enrichment...
SDSSJ102915+172927 (Caffau et al. 2012)

The heavy elements (Sr, Y, Ba, Eu…)

formed by neutron capture on iron seeds

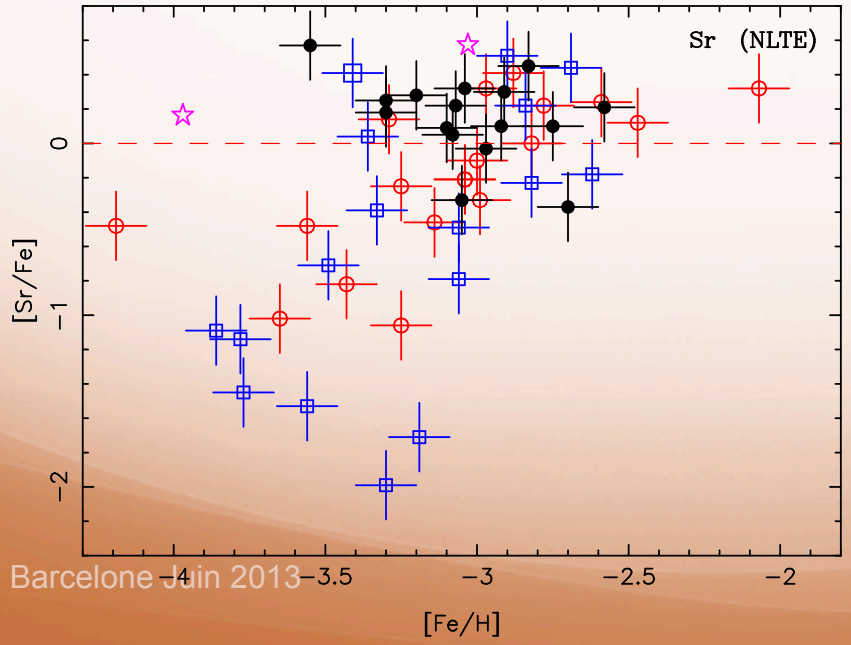
Low metallicity ➟
the matter which formed the stars could be enriched only by the **yields of massive stars** with a very short lifetime:
collapse of SNII, **neutron stars merging**, and also by the winds of **fast rotating massive stars.**

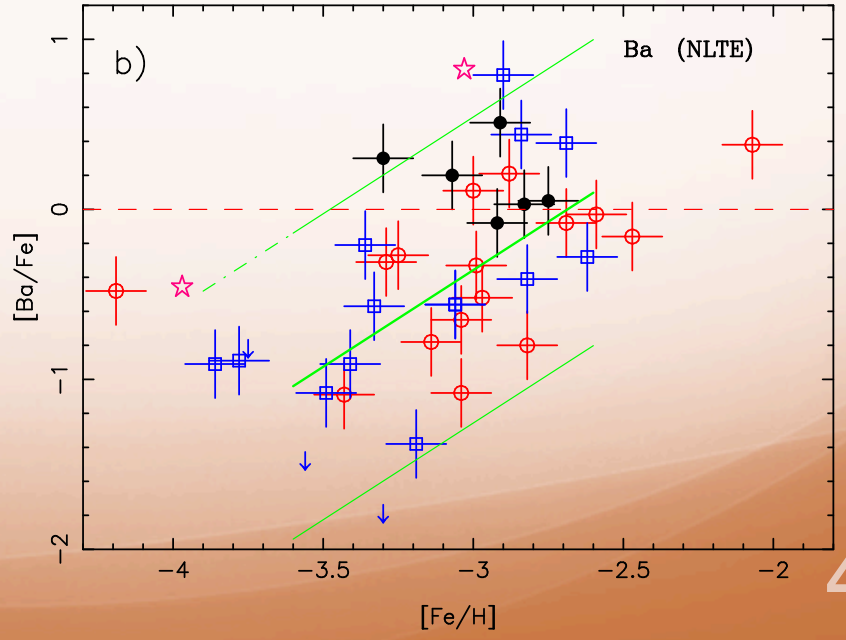
The low mass AGB stars with a long lifetime had no time to enrich the matter with slow neutron capture elements (main s-process)

➟ **the heavy elements observed in the EMP stars have been formed through rapid neutron capture processes (r-process)**
(Contribution of the weak s-process in fast rotating massive stars has also to be considered)

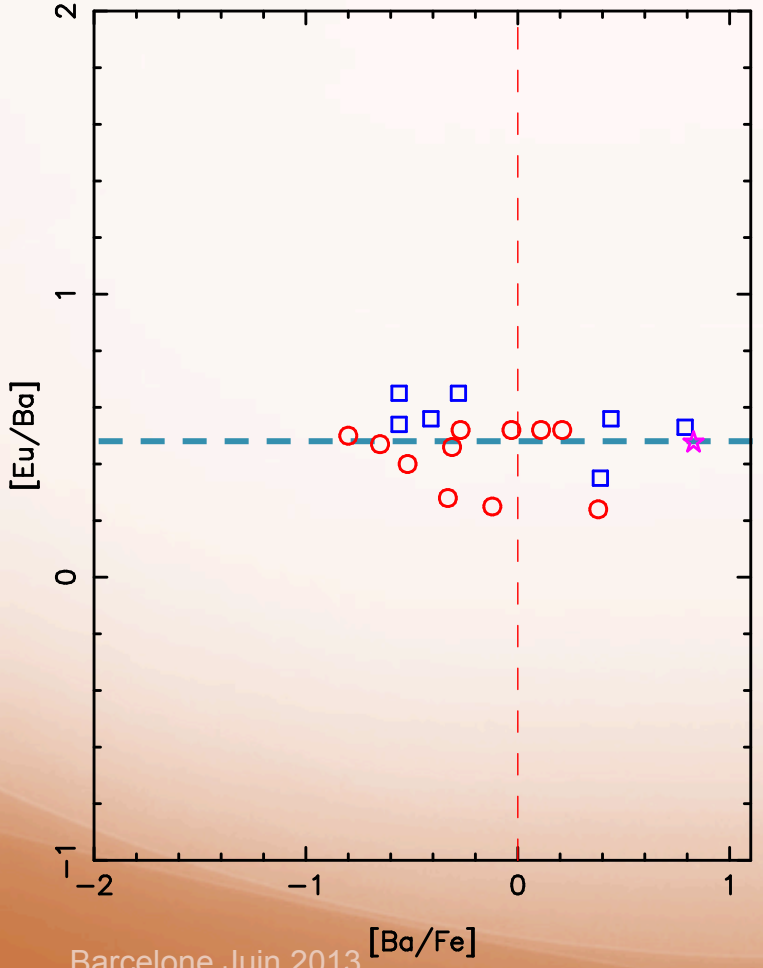
EMP stars

In the frame of the LP-ESO program "First Stars First Nucleosynthesis"
50 field stars observed
without carbon enrichment with [Fe/H]<-2.5
large **scatter** of the relations
[X/Fe] vs [Fe/H]
(where X is an heavy element see François et al. 2007)





EMP stars



Below [Fe/H]=-2.5

in ***normal*** metal-poor stars (not C-rich)

Good correlation between Ba and Eu

François et al. (2007)
Mashonkina et al. (2010)

Ba-rich = Eu-rich

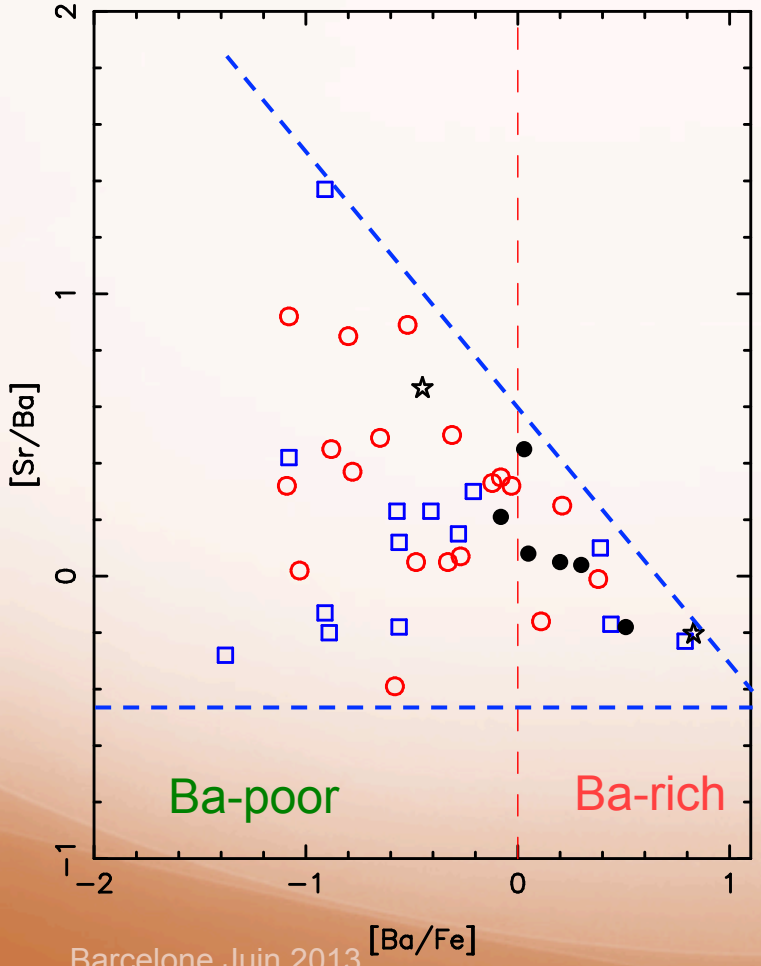
r-rich star: [Eu/Fe]>0.3 (Barklem 2005)

r-II [Eu/Fe]>1.0 r-I 0.3<[Eu/Fe]<1.0

r-poor star: [Eu/Fe]<0.0

Very difficult to measure Eu in EMP and CEMP stars ➔ Ba

EMP stars



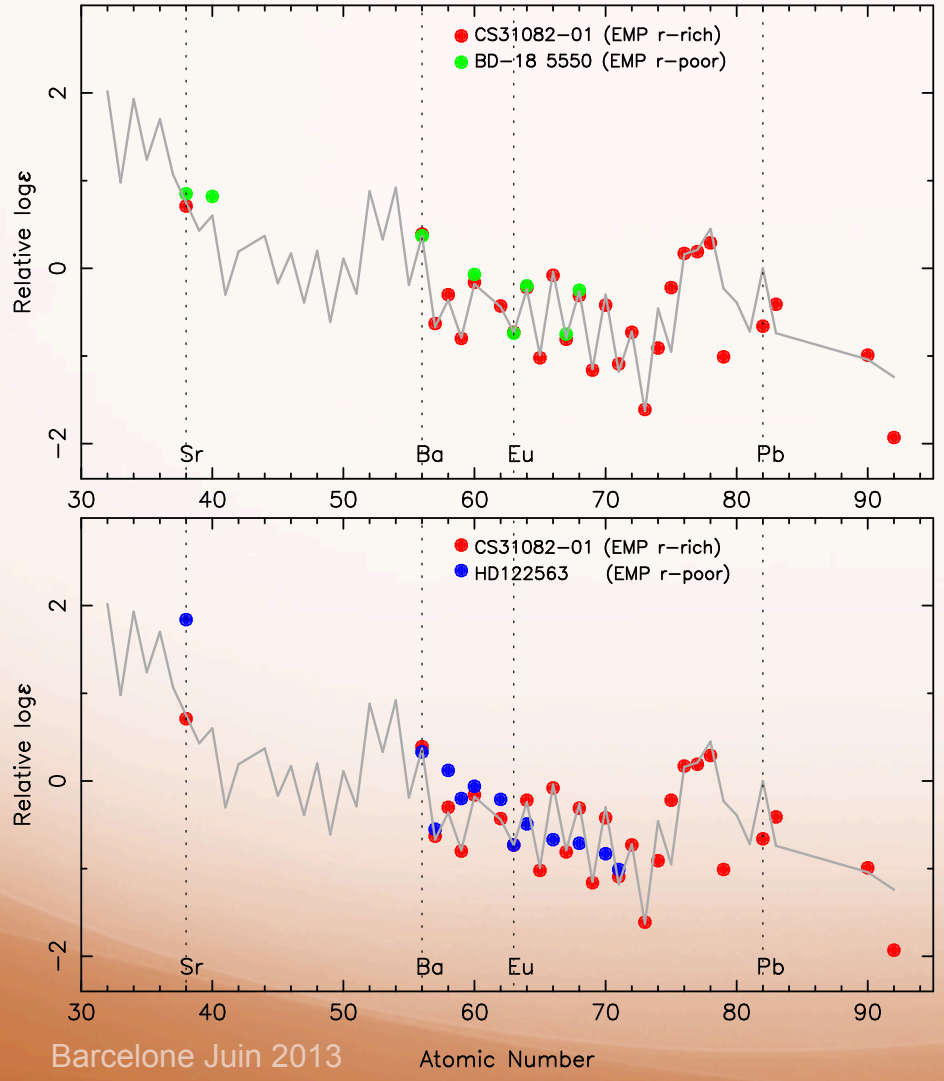
Below [Fe/H]=-2.5

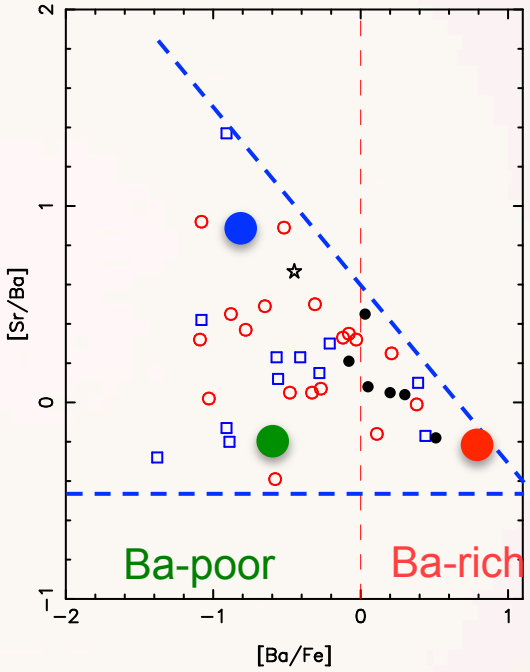
in ***normal*** metal-poor stars (not C-rich)

scatter of [Sr/Ba] ↗ when [Ba/Fe] ↘

and reaches 2.0 dex

EMP stars





The position in the Sr/Ba diagram induces different heavy elements patterns (2nd peak)

- r-rich low Sr/Ba
- r-poor low Sr/Ba

} = pattern

- r-poor high Sr/Ba ≠ pattern

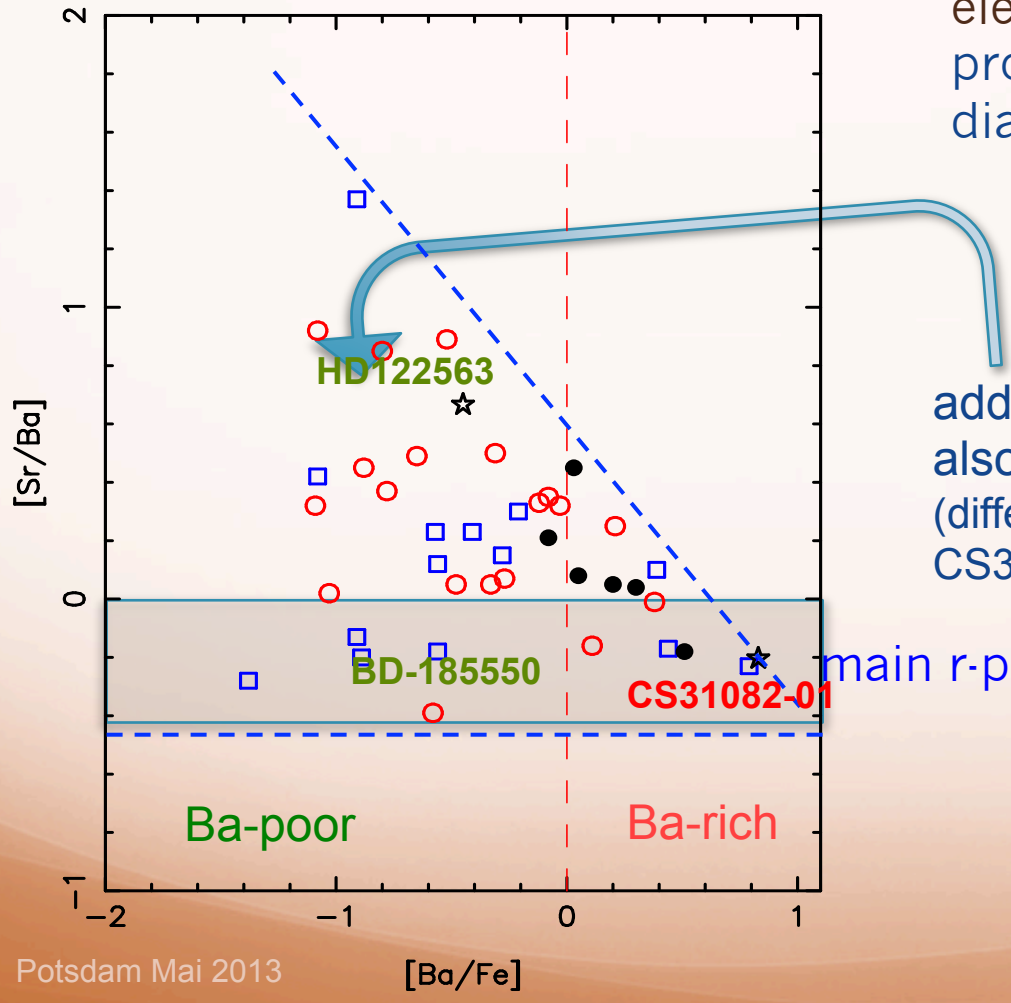
all the stars are scaled to Eu

CS 31082-01 Siqueira-Mello et al.(2013)
HD 122563 Honda et al. (2006)
BD -18 5550 Francois et al. (2007)

Interpretation ??

EMP stars [Fe/H]≈ -3.0

We need to explain this **figure** +



the different **patterns** of the heavy elements (odd even effect less pronounced at the top of the diagram)

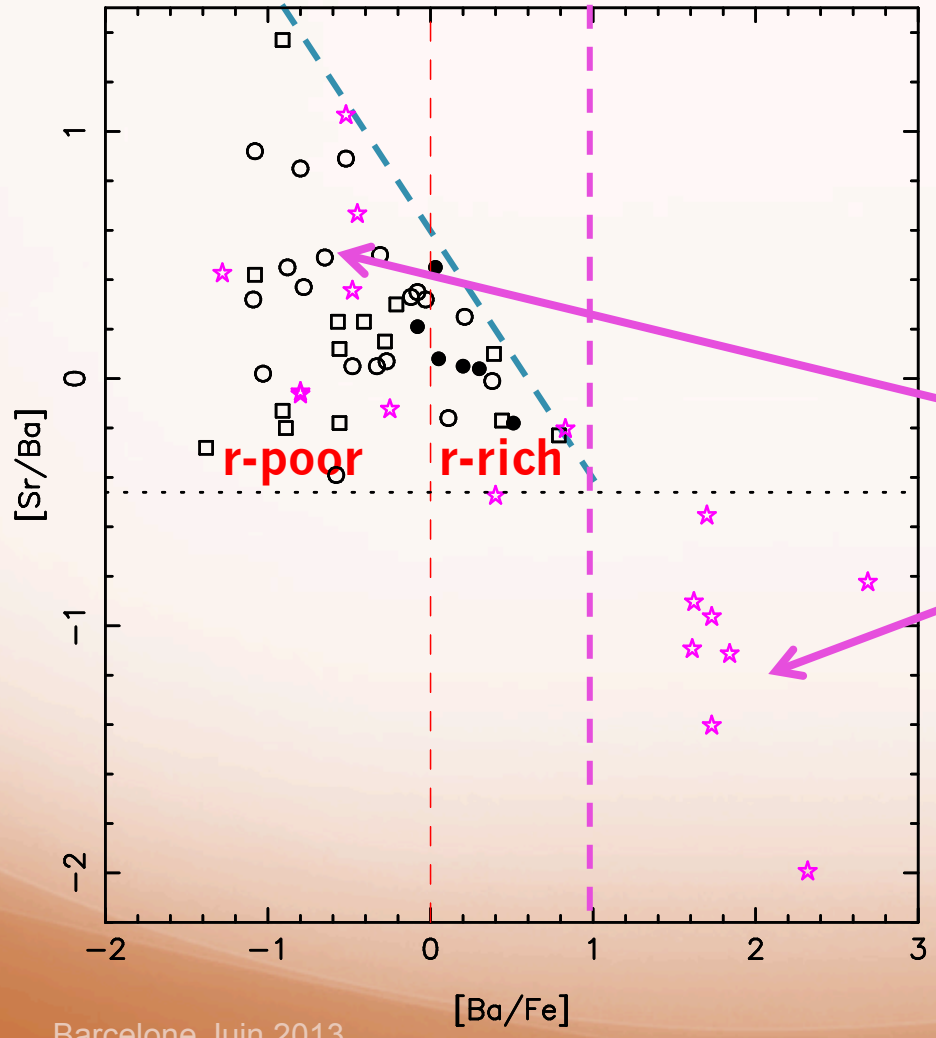
addition of **Sr Y Zr**...
also some heavier elements
(different odd even effect in HD122563 and CS31082-01)

Weak-r process ?

main r-process

Comparison EMP / CEMP

CEMP stars



Black symbols:
Normal EMP stars [Fe/H]<-2.7

pink stars symbols:
CEMP stars with [Fe/H]<-2.7

CEMP-no [Ba/Fe] < 1.0

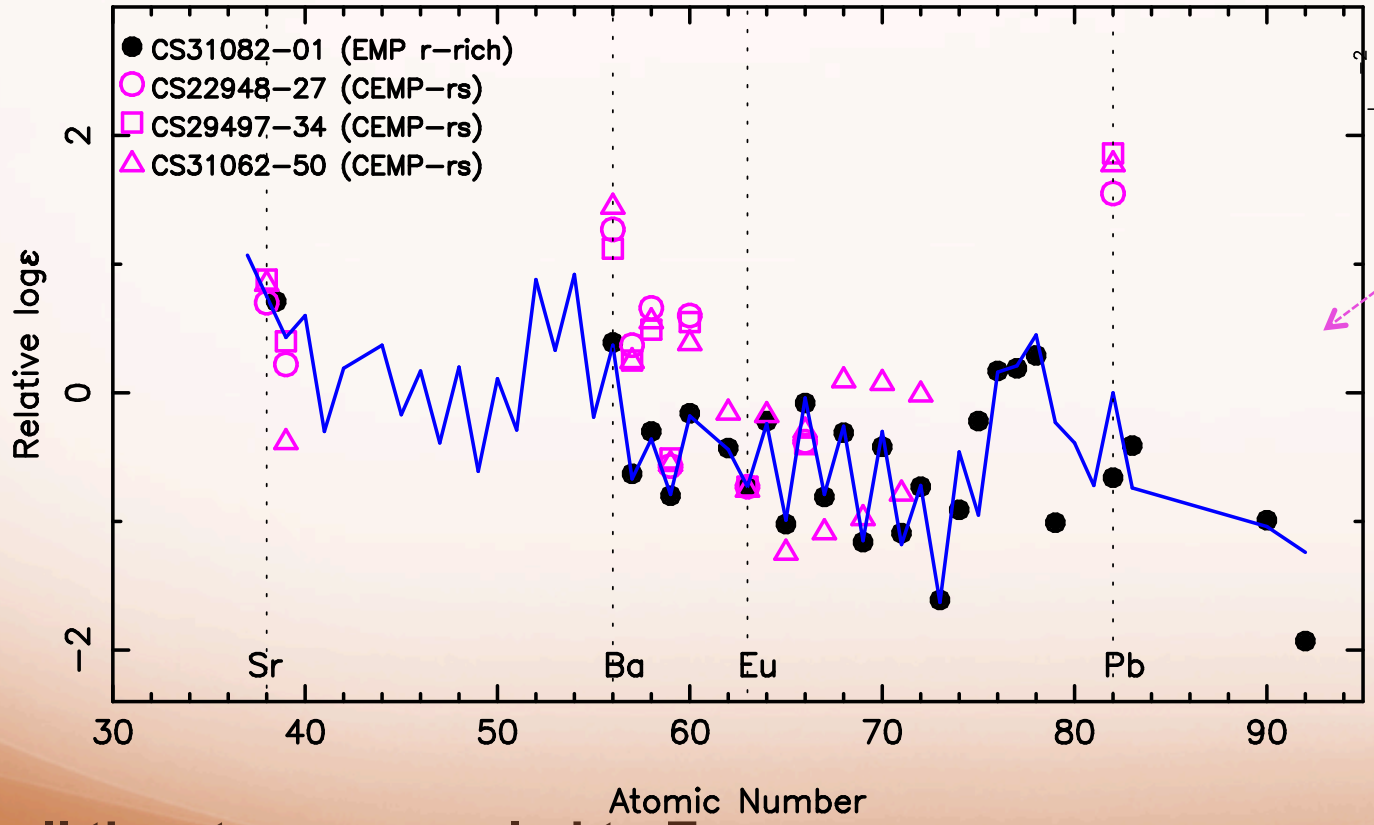
CEMP-rs
[Ba/Fe] > 1.0 and [Eu/Fe]>1.0

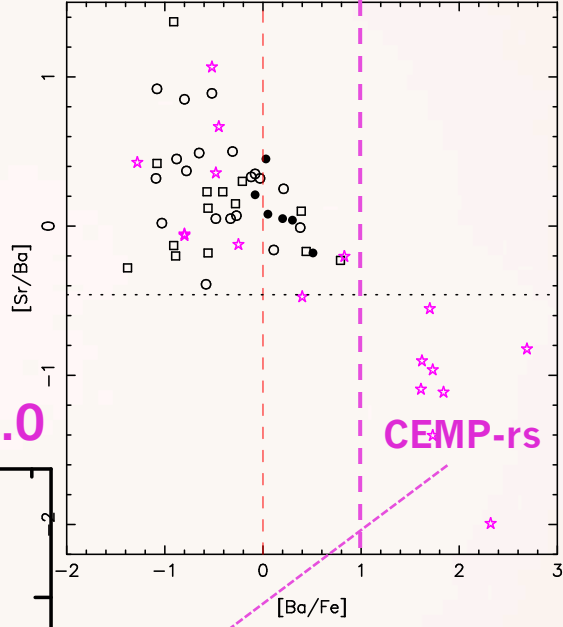
*no **CEMP-s** with [Fe/H]<-2.7 ???*
HE 0024-2523: [Eu/Fe] < 1.1
(Lucatello et al. 2003)

Comparison EMP / CEMP

CEMP-rs

- **EMP r-rich** **CEMP-rs : [Ba/Fe] > 1.0 [Eu/Fe] > 1.0**





$[Ba/Eu]_{CEMP\text{-}rs} \gg [Ba/Eu]_{EMP}$

all the stars are scaled to Eu

CS 31082-01 Siqueira-Mello et al.(2013)
CS22948-27 CS29497-34 Barbuy et al. (2005) CS31062-50 Johnson&Bolte (2004)

Comparison EMP / CEMP

CEMP-rs

CEMP-rs stars are **binaries**
Ba La Ce Nd -rich and **Pb-rich** but
[Sr/Eu] ≈ Cst ≈ to the value in the EMP r-rich
odd even effect more pronounced than in the EMP r-rich

➔ transfer of matter from a companion in its AGB phase

1/ enrichment of C, N
2/ enrichment of s elements

However difficult to represent the pattern of the elements (see e.g. Masseron et al. 2010)
more complete distribution of the elements needed ?...

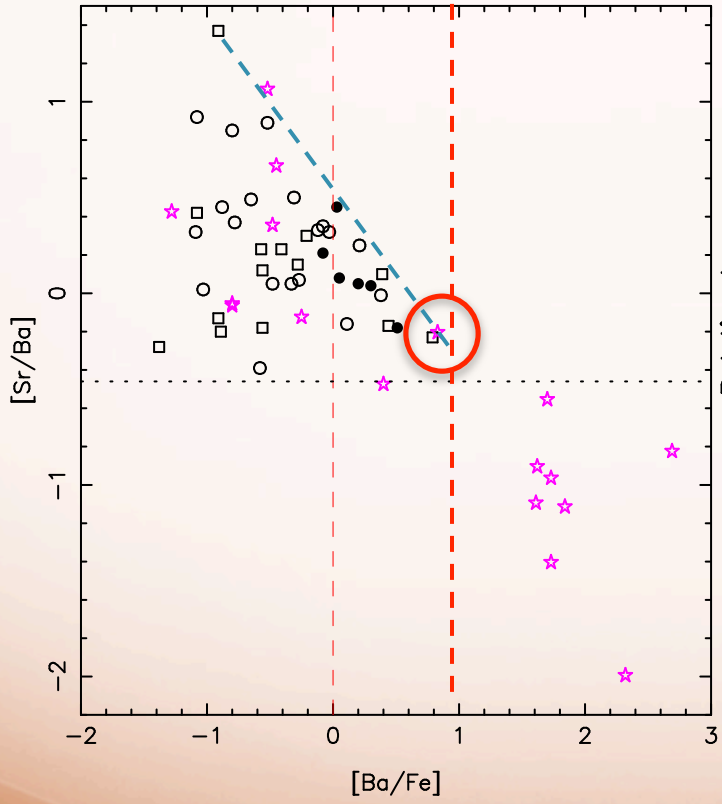
Comparison EMP / CEMP

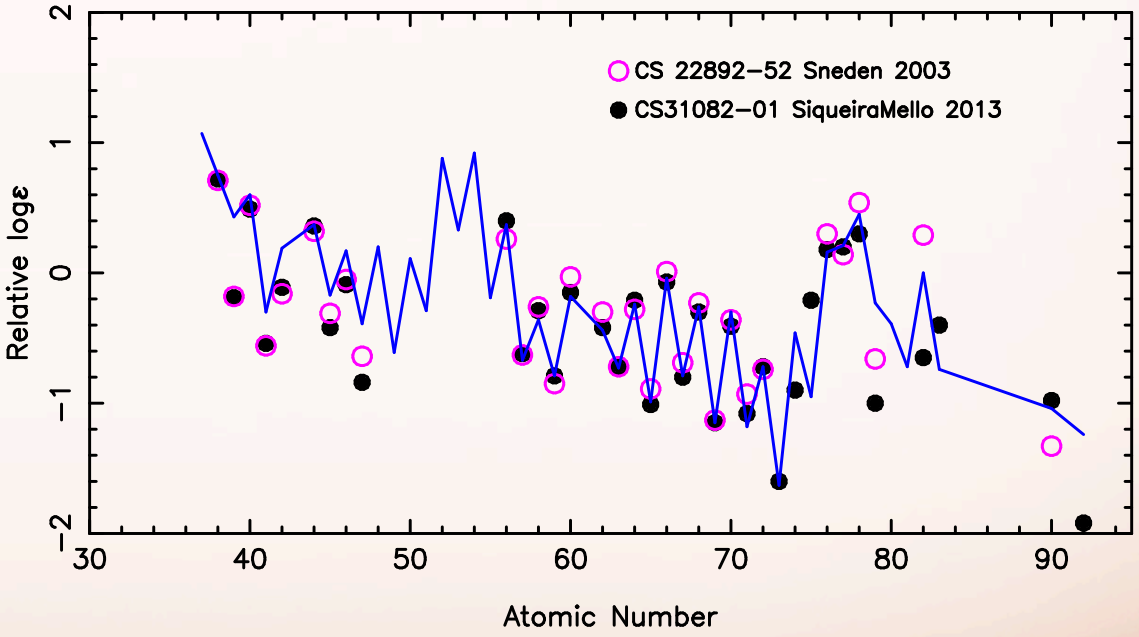
CEMP-no

region r-rich

same distribution in the [Sr/Ba] diagram as the "normal" EMP stars

Same abundance pattern ?

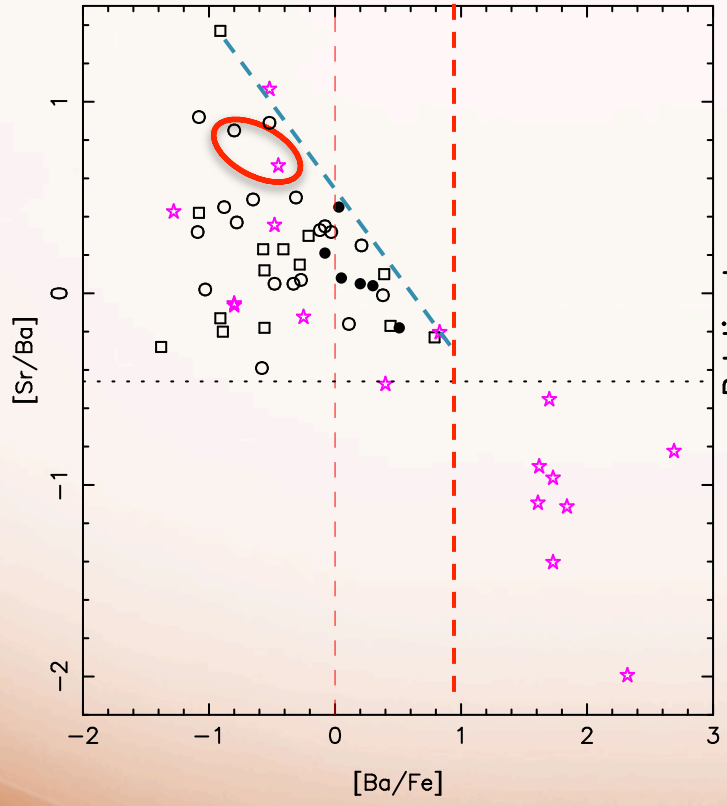


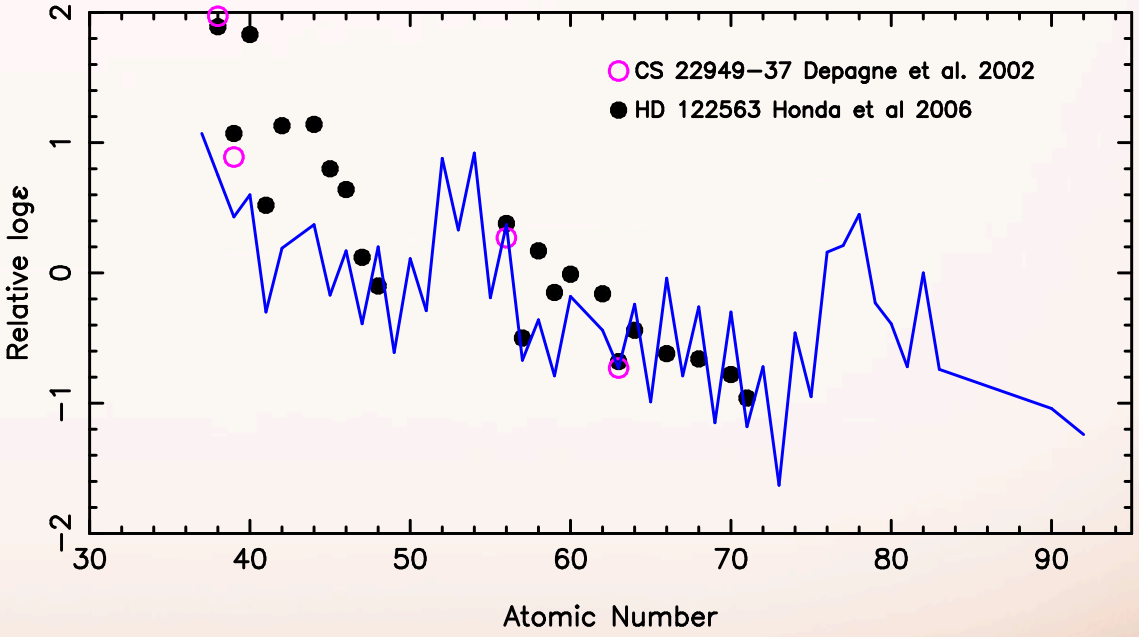


Comparison EMP / CEMP

CEMP-no

region r-poor **high Sr/Ba**





agreement but a more complete pattern useful !

Comparison EMP / CEMP

CEMP-no

-they have undergone a transfer of mass from an AGB companion without enrichment of heavy elements

but: no indication of binarity...

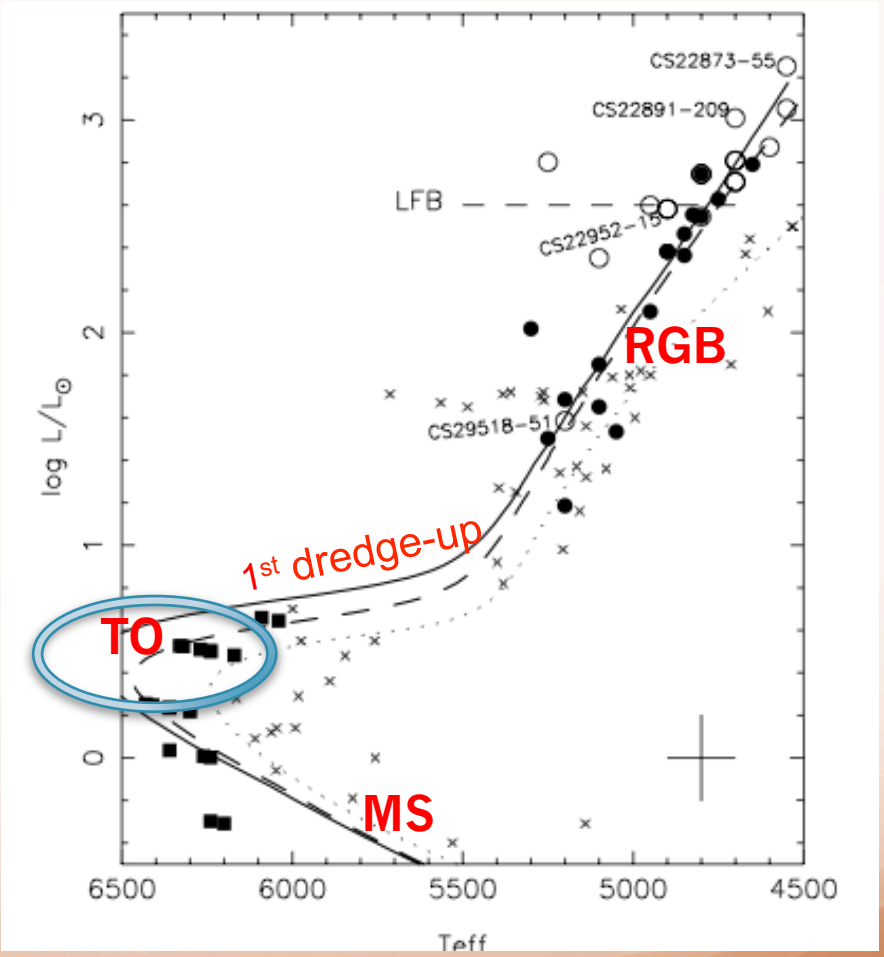
or

-they are EMP stars born from a C rich matter ?

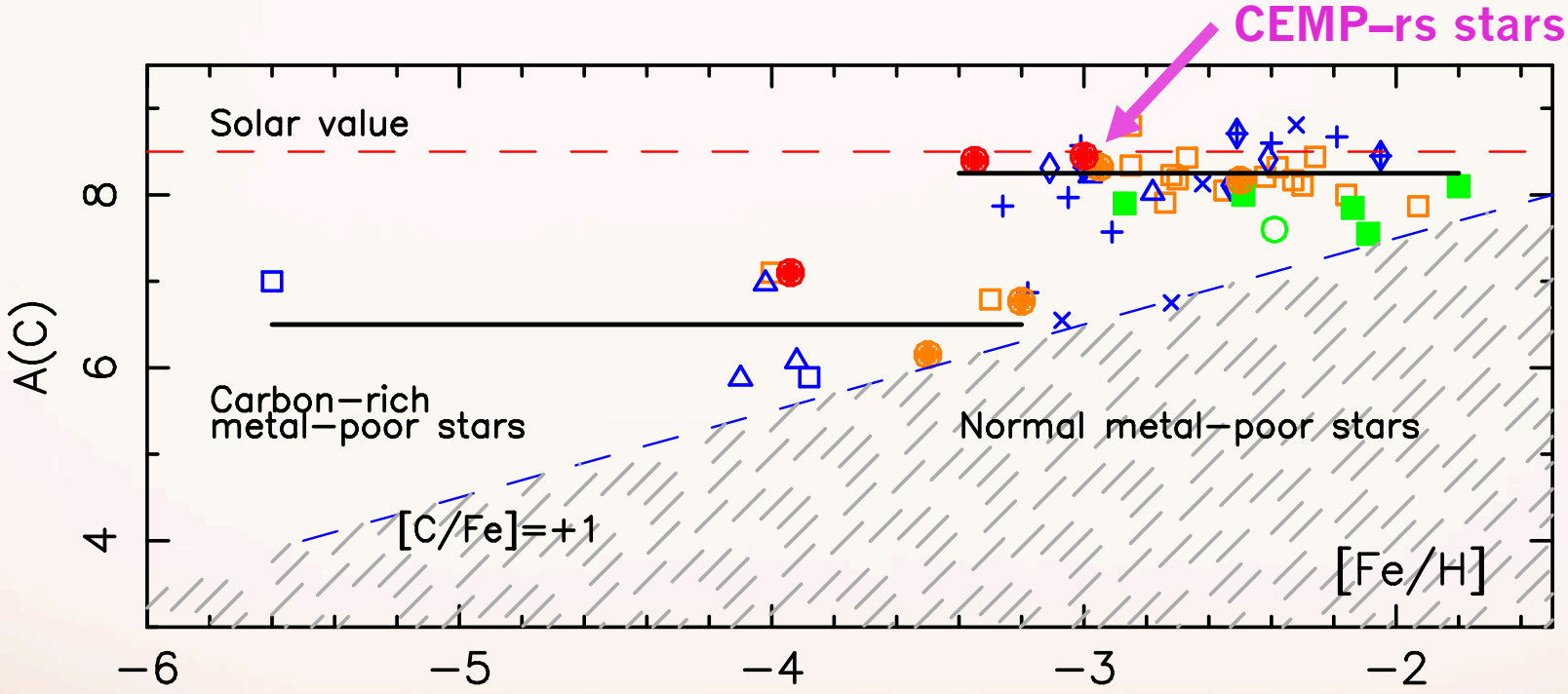
Question: What is the behaviour of C in CEMP stars ?

Abundance of C in CEMP turnoff stars
(or MS stars)

when a star leaves the main sequence and before it ascends the giant branch it undergoes the first dredge-up : material processed by the CN cycle during the MS (C-poor and N-rich) is brought to the surface



Abundance of C in CEMP turnoff stars
(or MS stars)

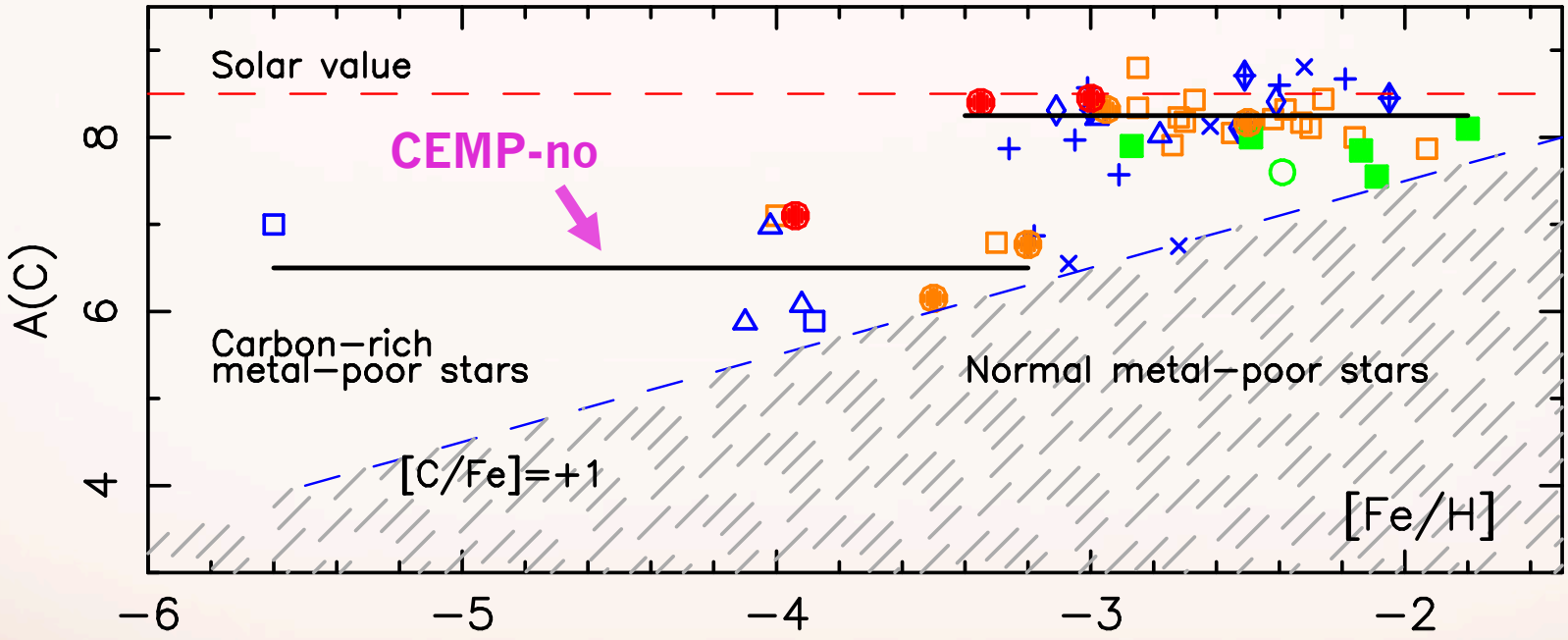


-plateau of the CEMP-rs stars (binaries) A(C)=8.2

the carbon quantity transferred by the defunct AGB to the observed CEMP star has been such as to reach the same amount in all stars whatever the metallicity

What is the most metal poor CEMP rs star ??? [Fe/H]=-3.4 ?

Abundance of C in CEMP turnoff stars
(or MS stars)



-plateau of the CEMP-no stars (not binaries)

A(C)≃6.8

WHY ? true "plateau" or upper limit ???

Metal Production and distribution in a Hierarchical Universe

Les Rencontres de l'Observatoire 2013

"Metal Production and Distribution in a Hierarchical Universe"

ESO Workshop

October 21-25, 2013 Meudon

Metal Production and Distribution in a Hierarchical Universe

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The main objective of this meeting is to bring together observers measuring elemental abundances in different environments: the Milky Way (stars, interstellar medium), the external galaxies (dwarf galaxies in the Local group, spirals), the high redshift clouds, and to connect the recent observations in these different fields to constrain the hierarchical building of the Universe.

Location: Meudon - CNRS - Salle Isadora Duncan - from Oct. 21 to 25, 2013.

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