Chemical evolution of neutron capture elements in the Galactic bulge (and in the dwarf galaxies)

Gabriele Cescutti
Cristina Chiappini
Ugur Ural and Andreas Koch (Landessternwarte)

A possible way to constrain the

Nucleosynthesis:

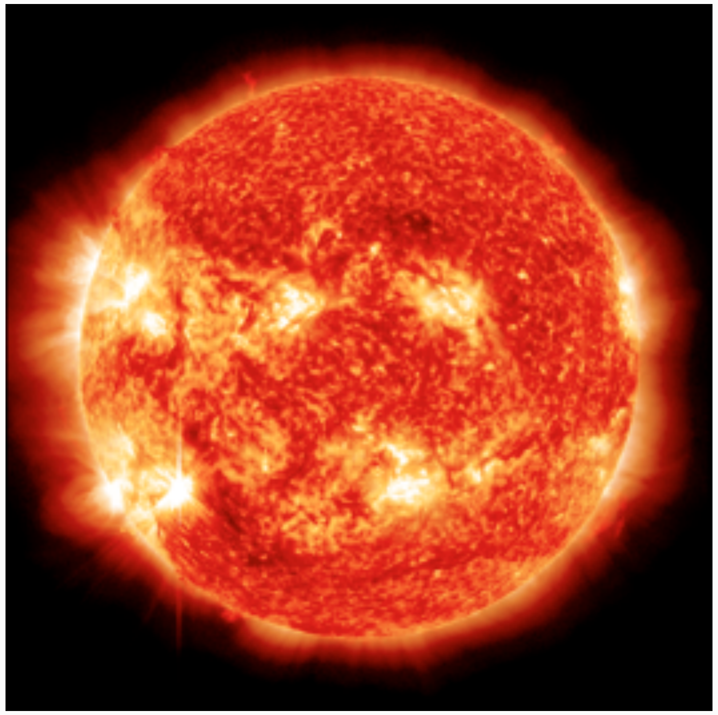
The oldest stars in our Galaxy are formed from the gas ejected by few massive stars
(diluted in the ISM!)

Massive Stars – short lifetimes

Core collapse Supernova

First polluters in the Universe

Low mass stars – long lifetimes

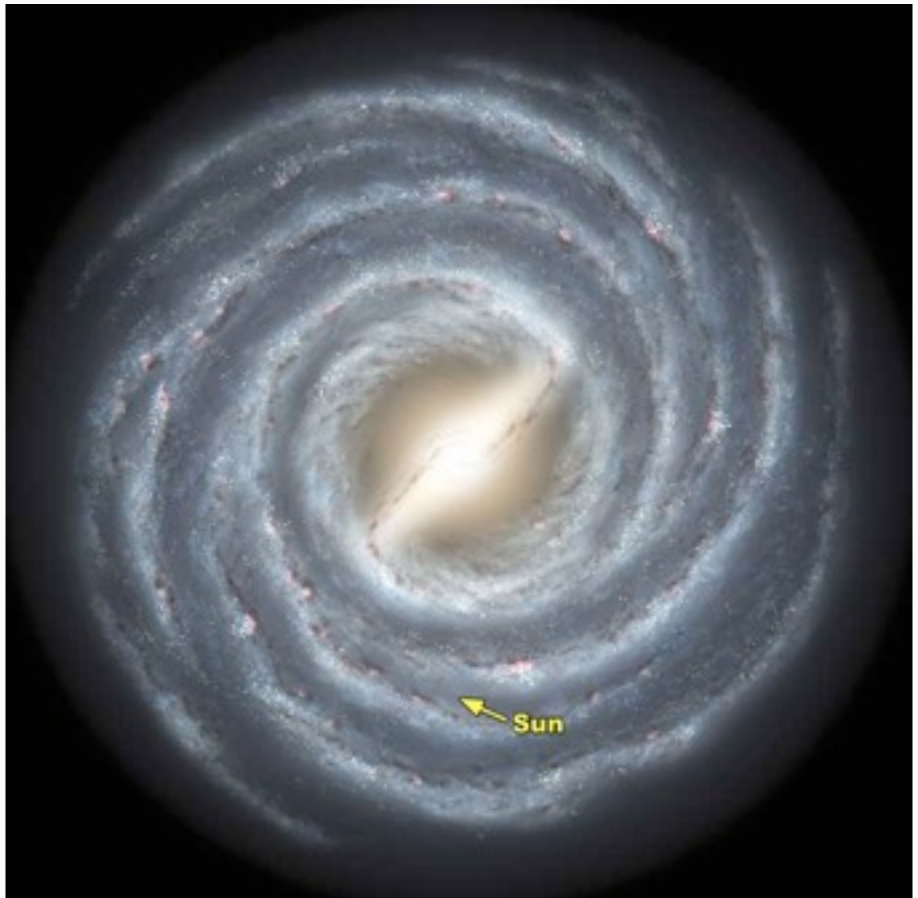


The Sun

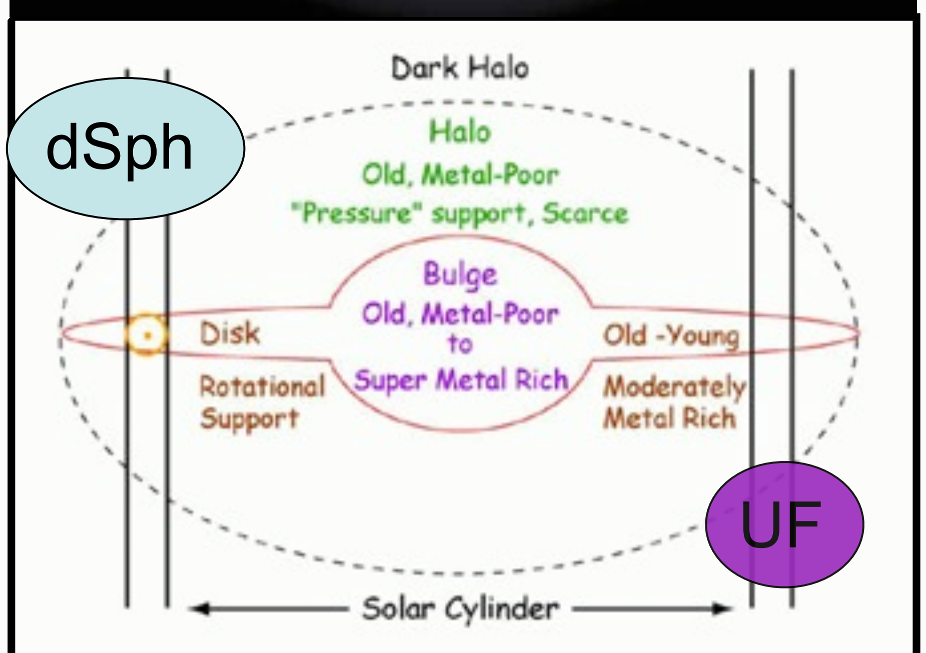
Imprints on the oldest stars

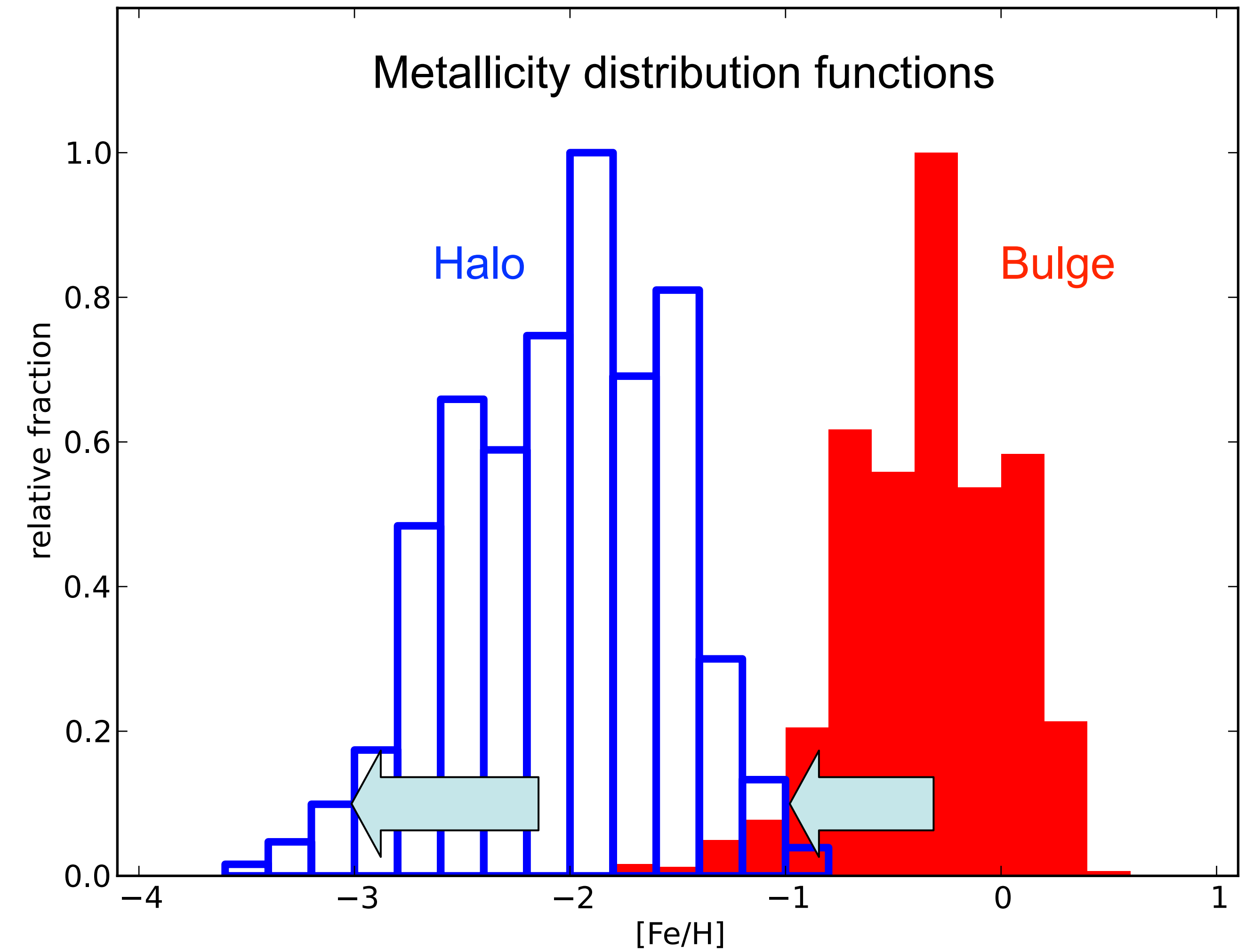
Where are the oldest fossil stars in the MW

Face on



Edge on





In the Halo
[Fe/H] < -3
data by Li et al. 2010

In the Bulge
[Fe/H] ~ -1
data by Ness et al. 2013

Neutron capture elements

from Truran 1981 to ~5 years ago

AIP

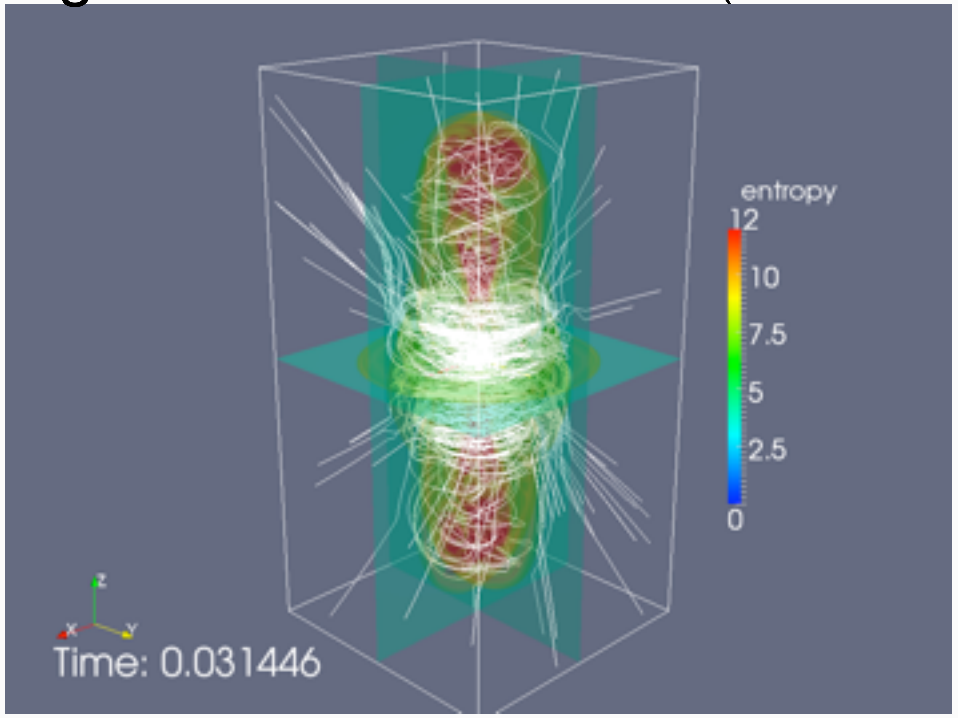
Early Galaxy

	s-process	r-process
site	Low-(intermediate) mass stars	Massive stars (& NS mergers) O-Ne-Mg core explosions? NS stars mergers?Magneto rot. driven SN? many scenarios...
time scale	>300Myr	< 30Myr (excluding NS mergers)
yields	Busso et al. 2001 *Cristallo+ 2011 Karakas+ 2012)*	....

Site(s) of the r-process?

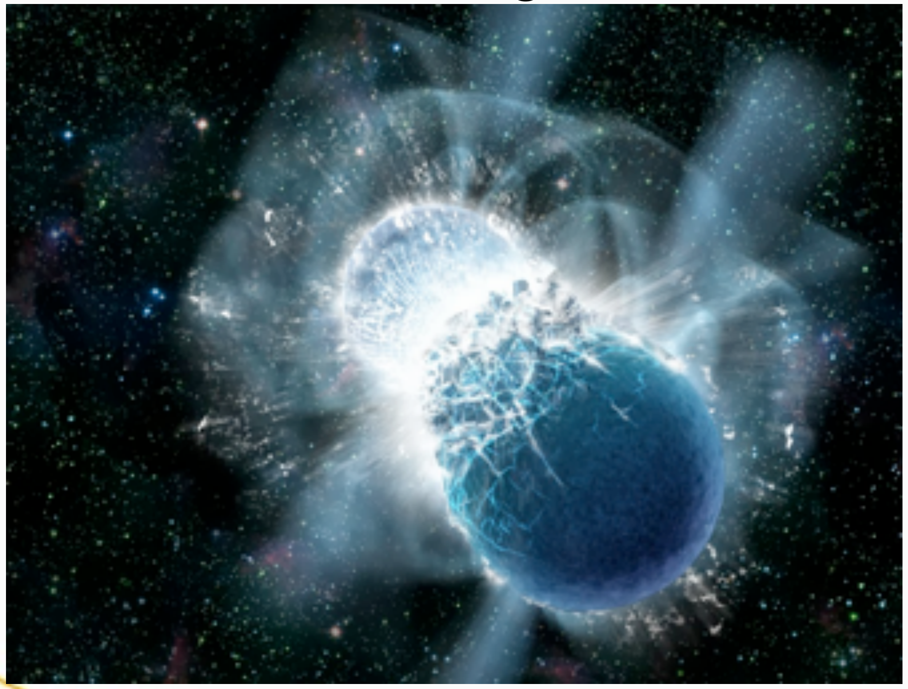
Electron Capture SNe (Wanajo+11)

Magnetorotat. driven SNe (Winteler+12)

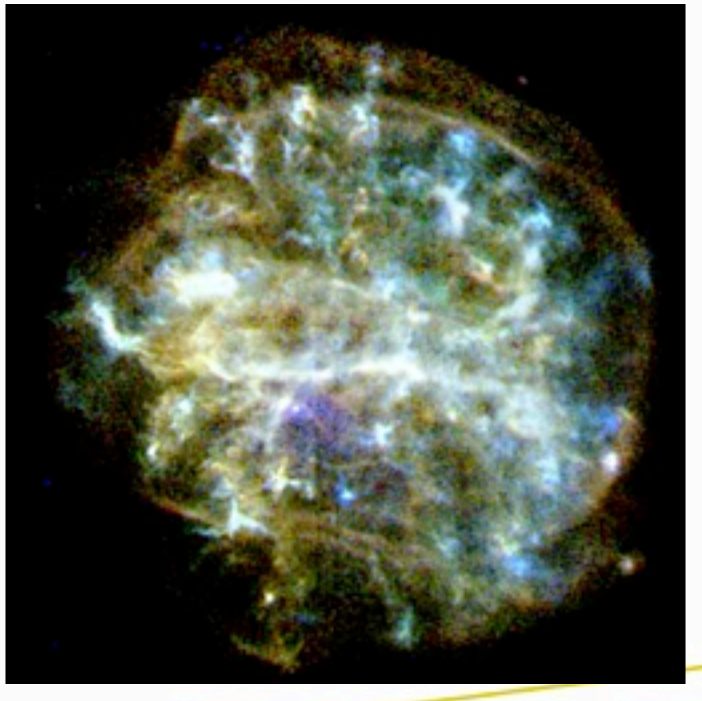


?

Neutron star mergers (Rosswog+13)



Neutrino winds SNe (Arcones+07)

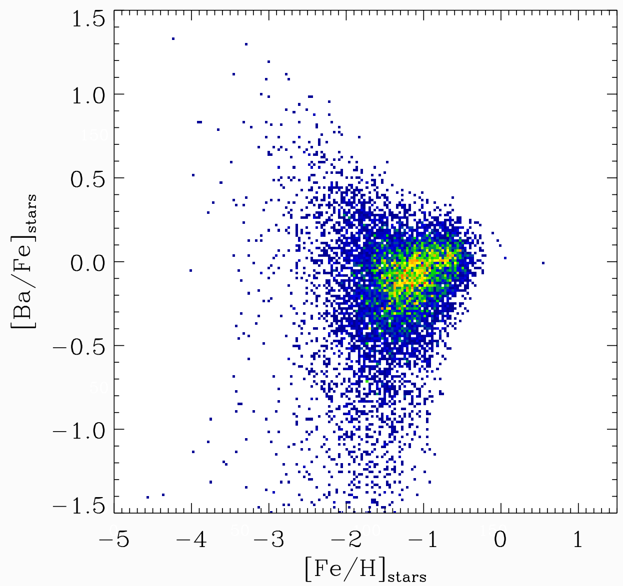


How to predict the chemical enrichment?

Chemical evolution models!

Models for the chemical evolution of galaxies are not self-consistent but they have a predictive power (and are extremely fast). They need to assume the infall of gas, the collapse of gas and metals into stars (*star formation*), the *synthesis of new elements* within these stars, and the subsequent release of metal-enriched gas as stars lose mass and die. An additional feature can be the outflow of gas from the system.

Cosmological simulations with a detailed chemical enrichment treatment are a promising way. Simulations are time demanding and they need anyway a faster tool to check our nucleosynthesis and

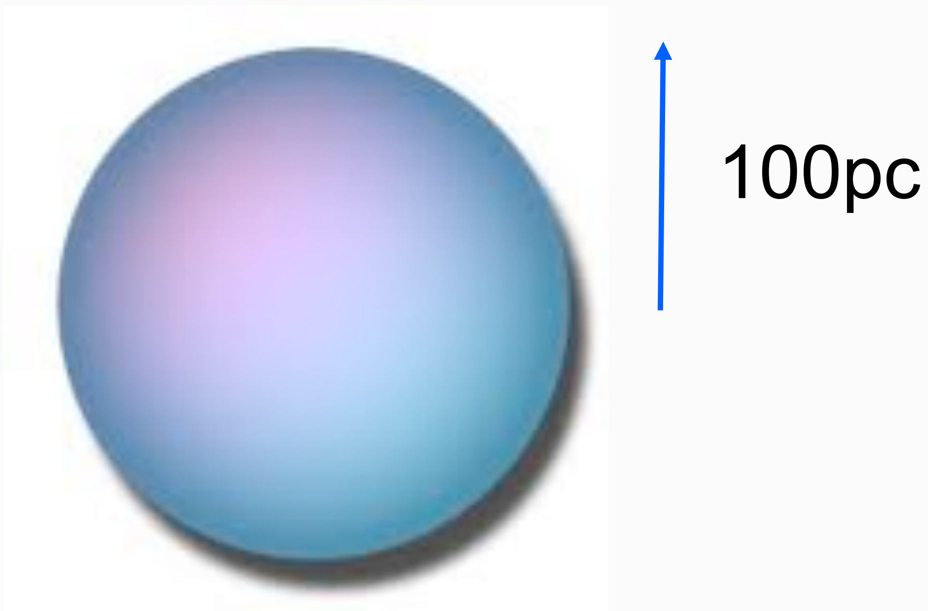


Preliminary results obtained at AIP with C. Scannapieco for a isolated DM halo

Stochastic chemical evolution model for the halo of the Milky Way

AIP

We simulate the halo as formed by many independent volumes each one of the typical dimension of ~ 100 pc (~radius of SN bubble) and we treat each volume as isolate from the others.

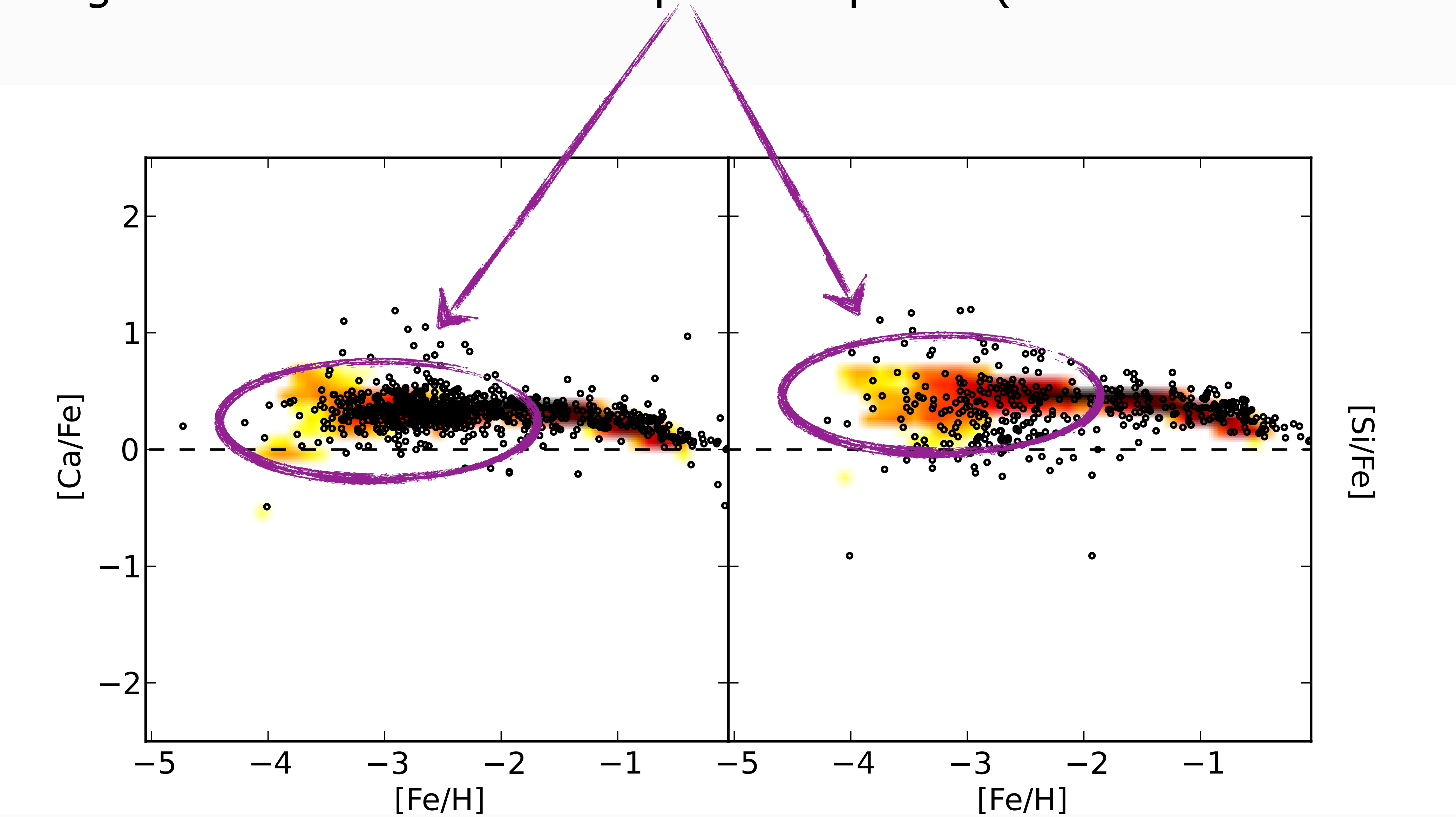


Inside each volume, we simulate for 1 Gyr the chemical enrichment.

The main parameters are the same as those of the homogeneous model but in each isolated volume there is a stochastic formation of new stars subjects to the condition that the cumulative mass distribution follows a given initial mass function; this fact produces different enrichments in the different volumes.

NO spread for alphas in the halo

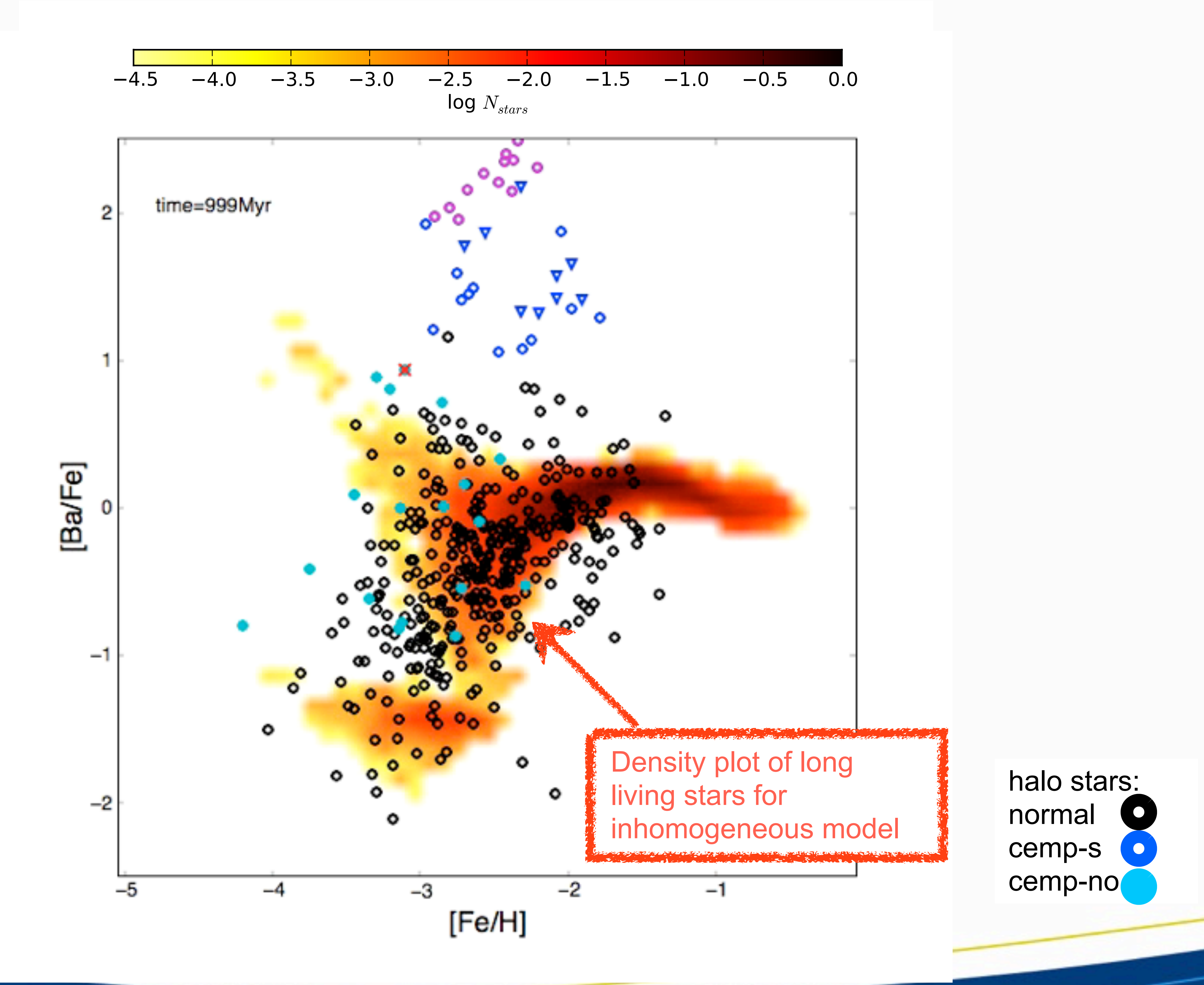
With standard yields for alpha (shallow dependence to the mass) the inhomogeneous model does not predict spread (less than the data!!!)



Spread in the n.c. elements (Ba)

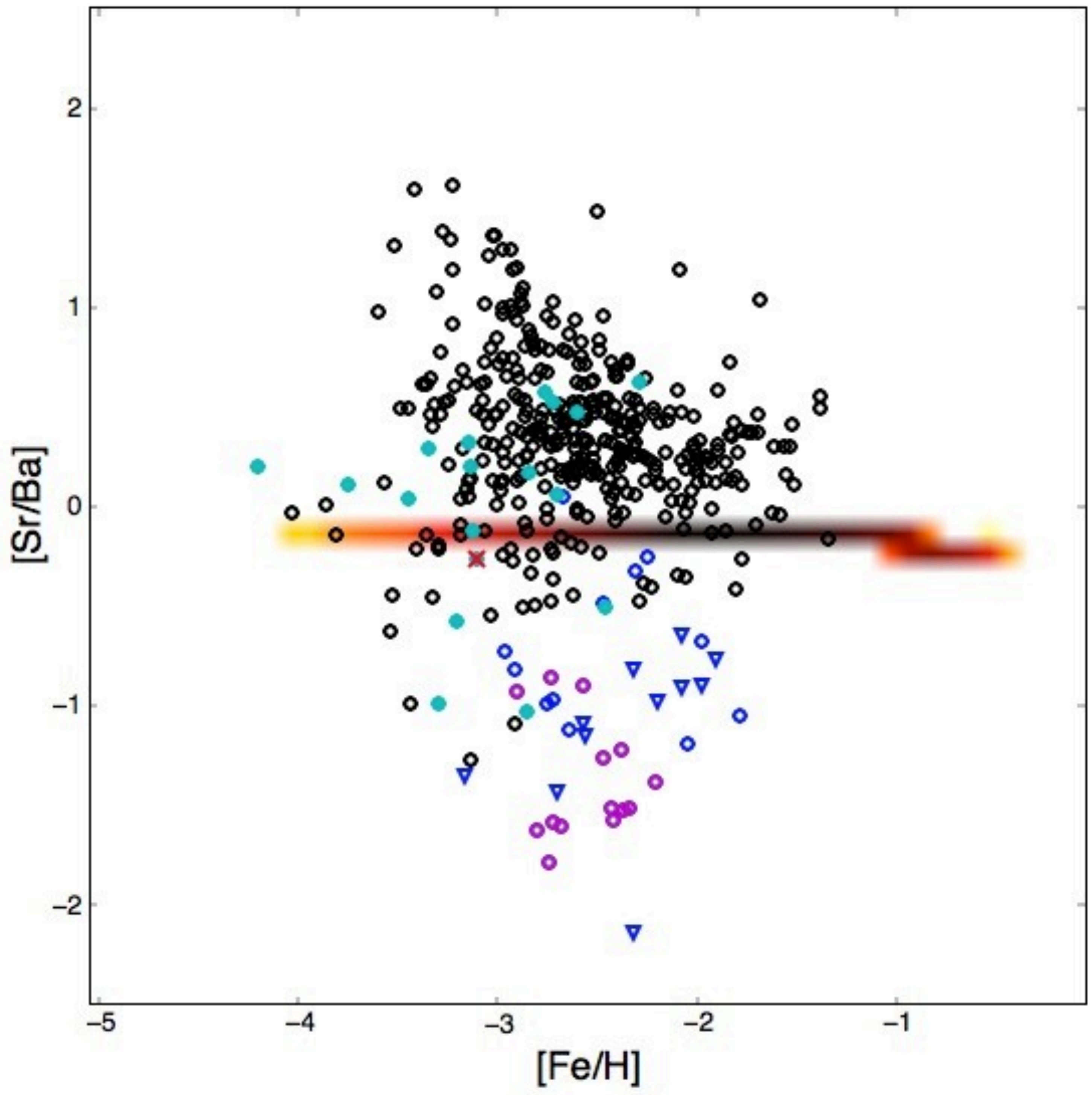
We can reproduce the [Ba/Fe] spread.

The spread in the model is due to the peaked and strong mass dependent (8-10) for nc elements we assume which is connected to the EC scenario.



Puzzling result for the "heavy to light" n.c. element ratio

For Sr yields: scaled Ba yields according to the r-process signature of the solar system (Sneden et al '08)



It is impossible to reproduce the data, assuming only the r-process component, enriching at low metallicity.
Well known issue (see Sneden+ 03, François+07, Montes+07)

halo stars:
normal
cemp-s
cemp-no

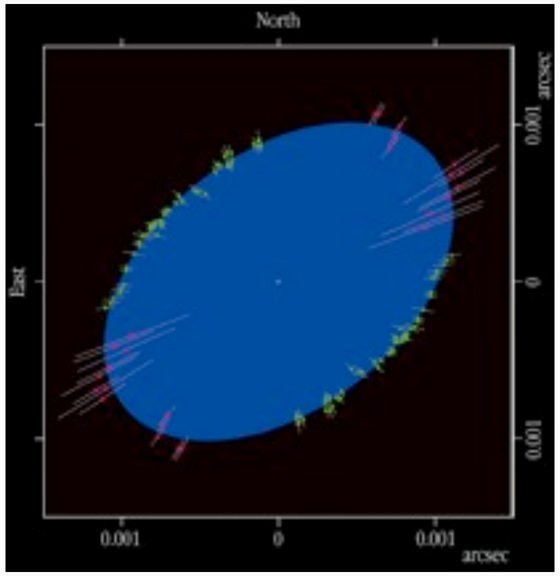
First Stars: fast rotators?

In the Local Universe

Stellar Rotation:

Can explain observed stellar properties that models without rotation/mass-loss cannot
(e.g. departure from spherical form)

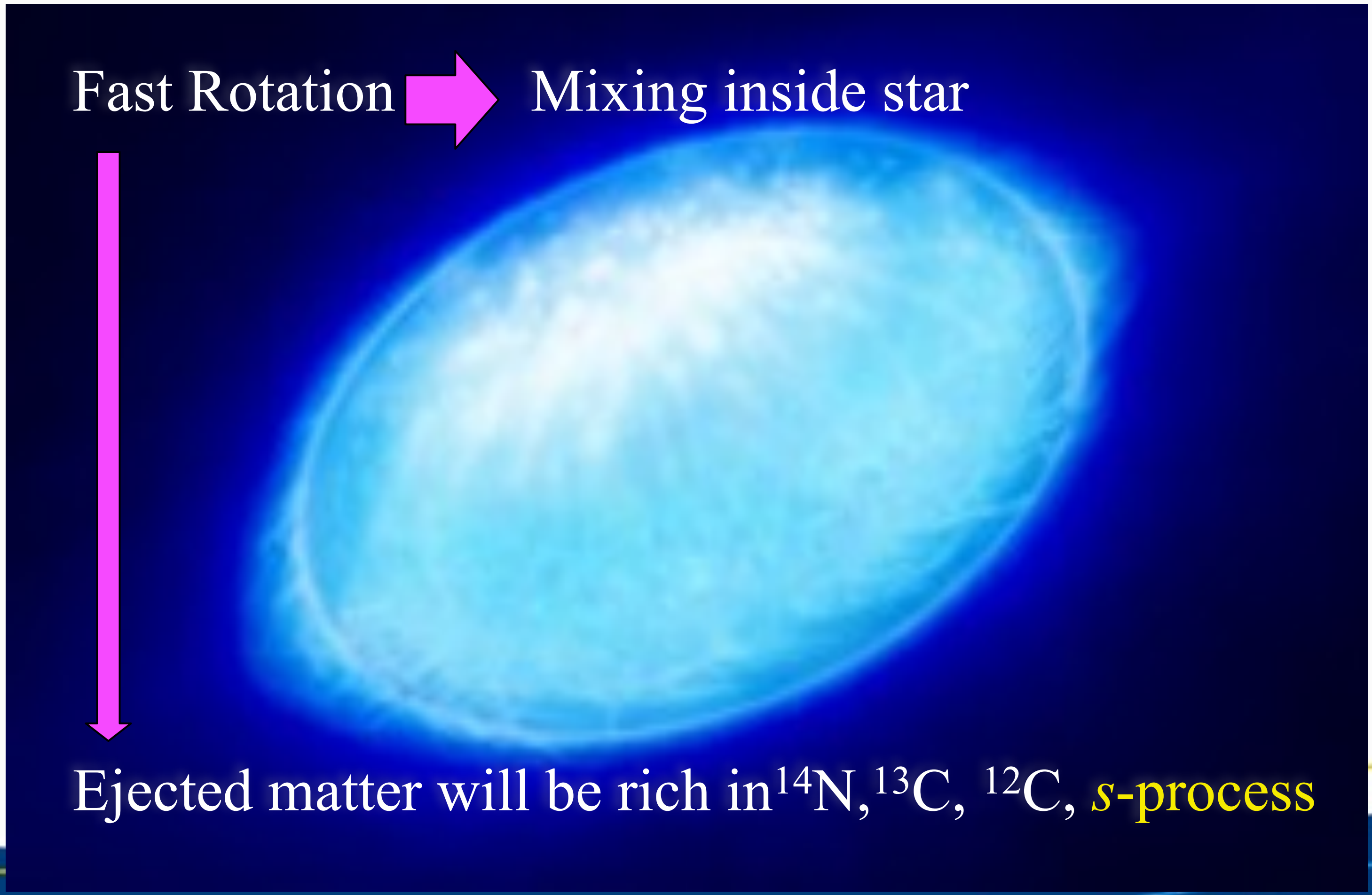
Achernar VLTI



R_e/R_p=1.5

In the Early Universe

Low metals: stars rotate faster (more compact)



Signatures of Fast Rotators found in the Galactic Halo

(1) Large amounts of N in the early Universe (Chiappini et al. 2006 A&A Letters)

(2) Increase in the C/O ratio in the early Universe

(3) Large amounts of ^{13}C in the early Universe (Chiappini et al. 2008 A&A Letters)

(4) Early production of Be and B by cosmic ray spallation (Prantzos 2012)

5 Early production of neutron capture elements through a boosted s-process (Sr,Ba,...)

AIP

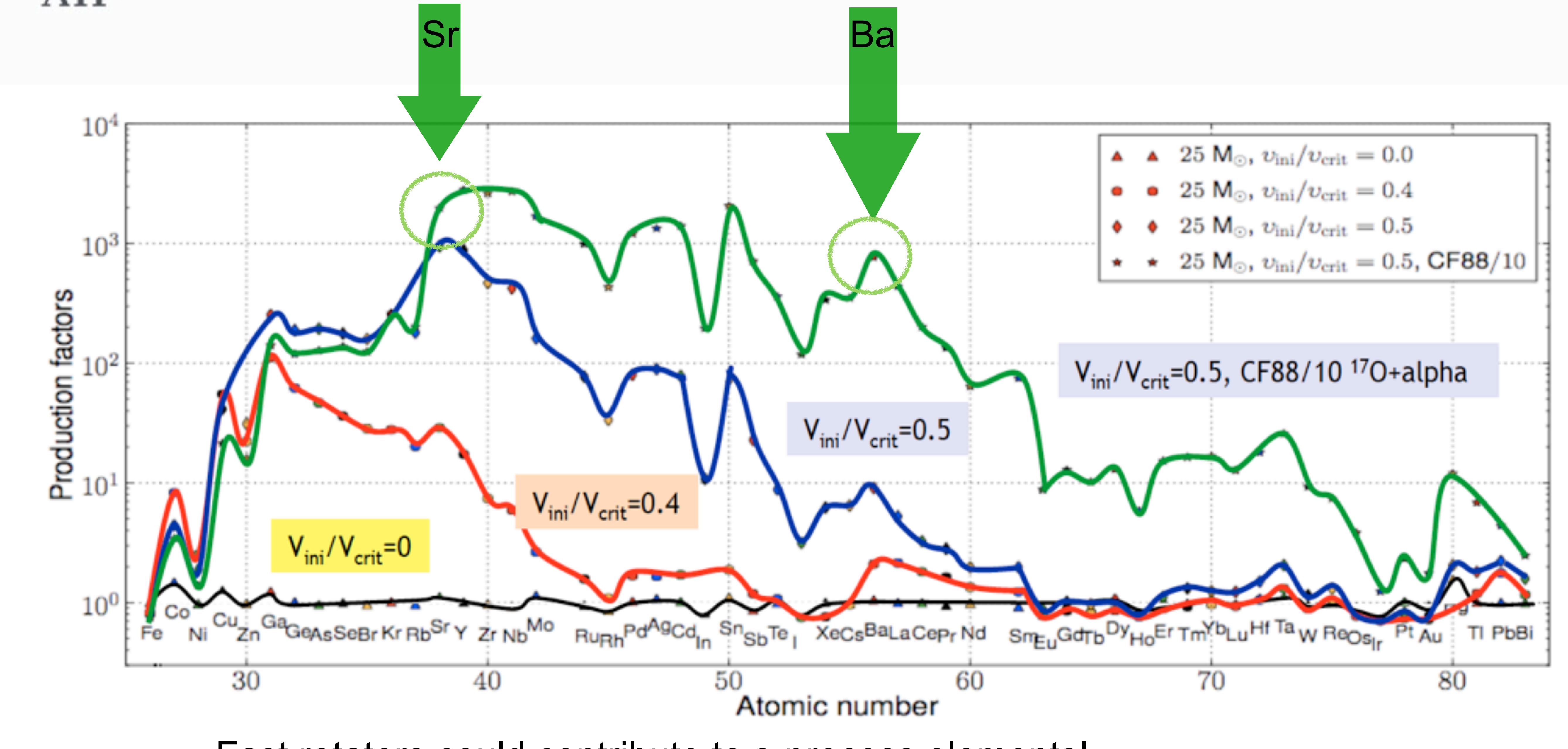
Neutron capture elements

The picture now

s-process		r-process
	Early Galaxy	
Low-(intermediate) mass stars	rotating Massive stars	Massive stars (& NS mergers)
		O-Ne-Mg core explosions? NS stars mergers?Magneto rot. driven SN? many scenarios...
>300Myr	< 30Myr	< 30Myr (excluding NS mergers)
Busso+ 2001	Frischknecht+ 2012	....
Cristallo+ 2011 *Karakas+ 2012)*	*Pignatari+ 2008,* *Limongi+ 2013*	

5th signature:
Fast rotators imprints in s-process elements?

Can they explain the puzzles for Sr and Ba in halo?



Fast rotators could contribute to s-process elements!

Frischknecht et al. 2012

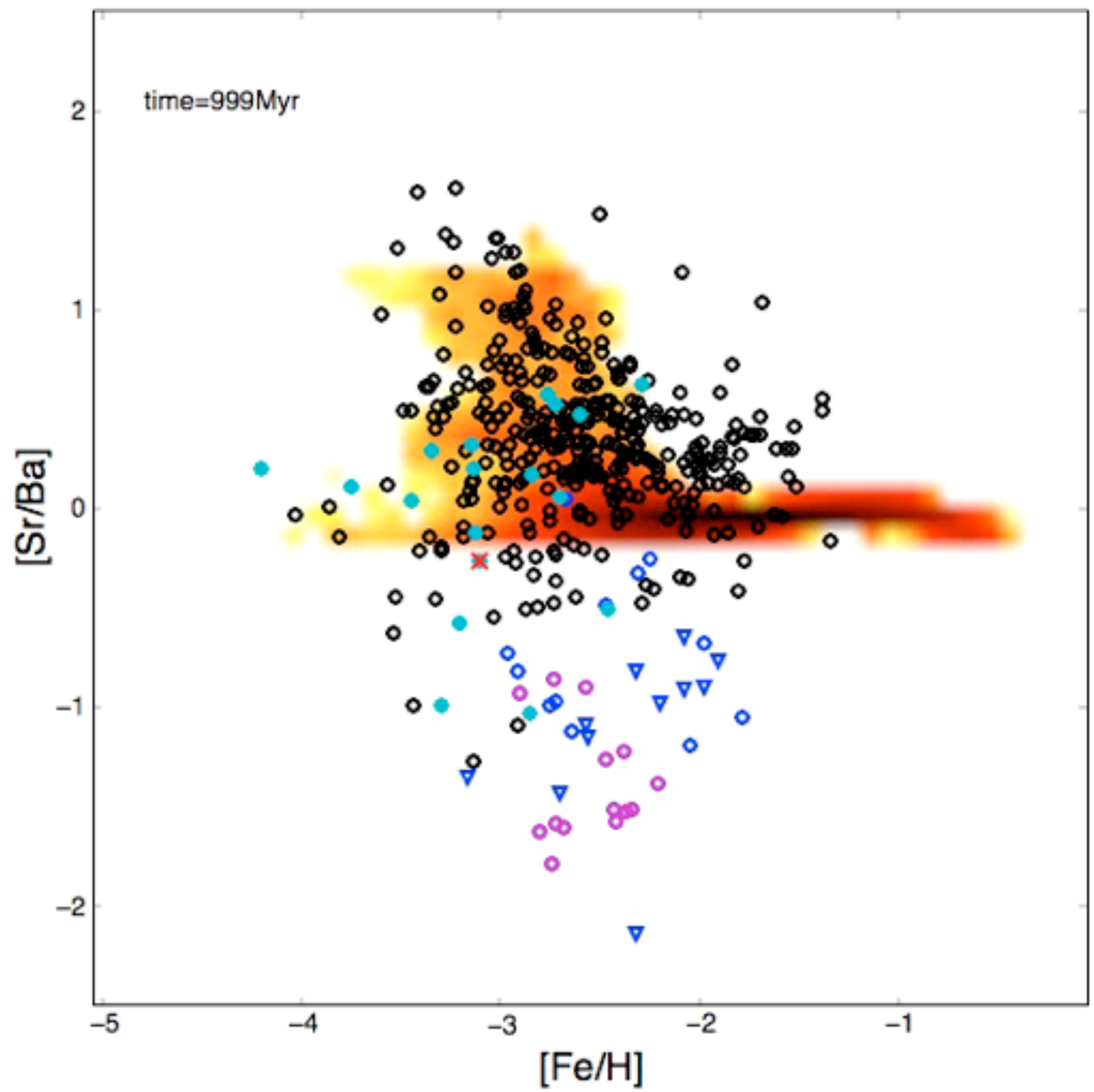
(self-consistent *spinstar* models with reaction network including 613 isotopes up to Bi)

s-Process from fast rotators

+ EC SN as r-process site (the 2 productions are decoupled!)

Cescutti et al. (2013)

Stellar models:
V_{ini}/V_{crit}=0.5
&
0.1
of the reaction rate by Caughlan & Fowler '88 for $^{17}O(\alpha, \gamma)$

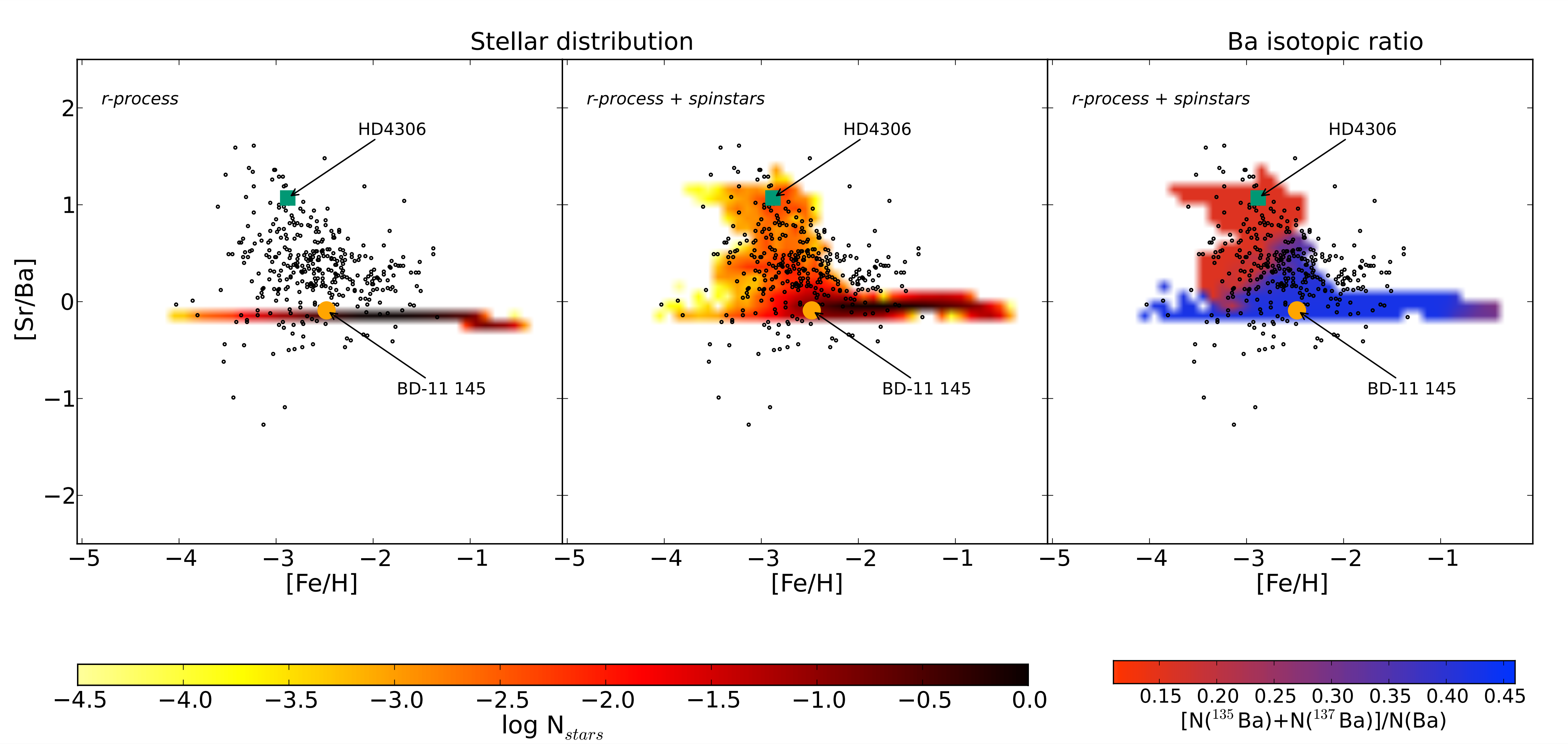


s-process from spinstars provide a solution!

halo stars:
normal
cemp-s
cemp-no

Isotopic ratio for Ba in halo stars

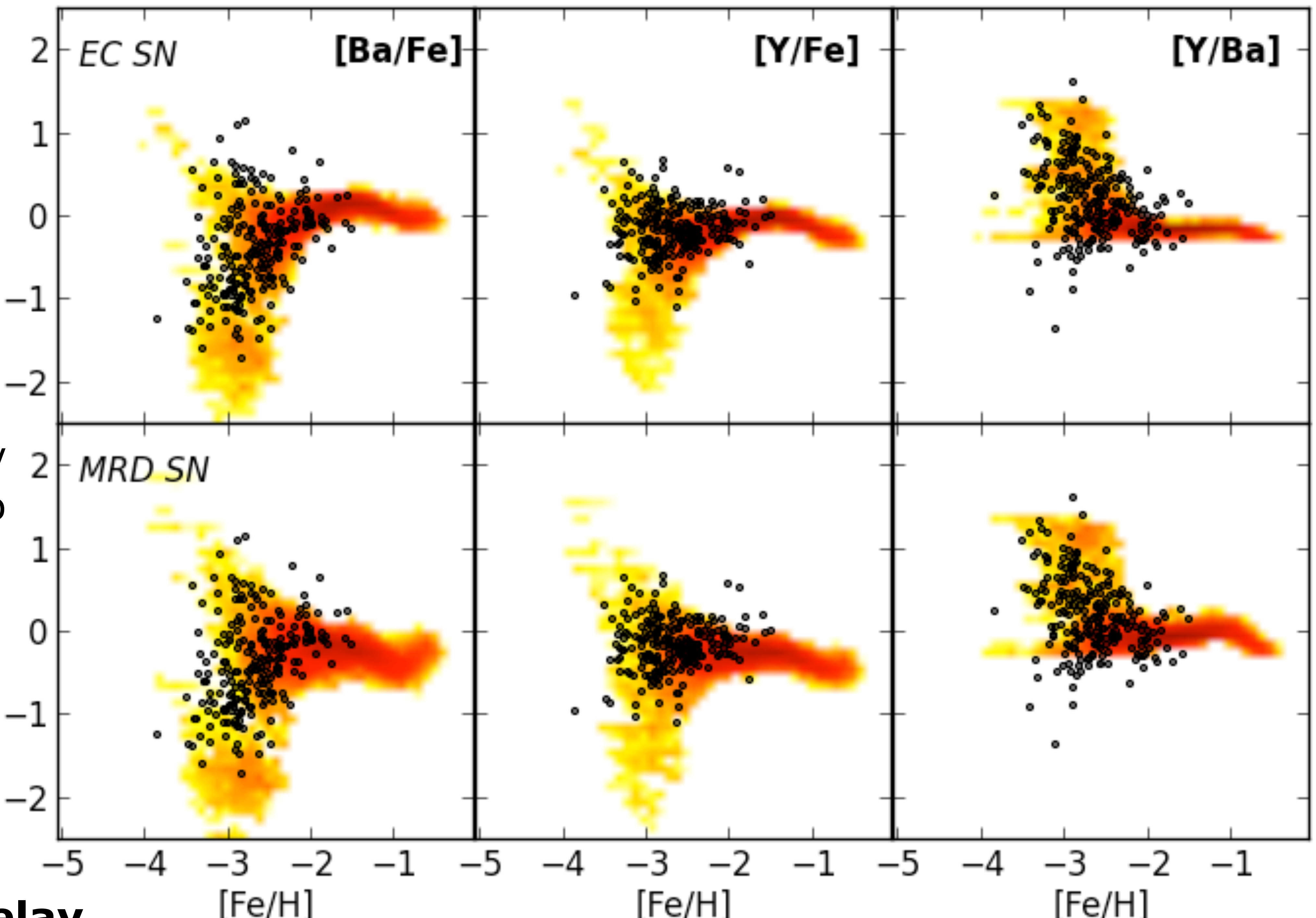
We have a proposal which has been recently accepted by ESO to identify this tiny variation of the Ba line due to the different isotopic ratio.
We plan to measure this in two stars with a R>100000 and with a S/N~900 with UVES at VLT. The run is scheduled for the next October.



Different r-process scenario + spinstars

Model based on the:
Electron **C**apture SN.

rare because they are produce only in a narrow range of masses
Theoretical predictions do not confirm the production of Ba and Eu (Wanajo+ 2011)



Magneto**R**otationally **D**riven SN scenario

(Winteler+ 2012):
rare because only a small percentage of the massive stars (~1-5%)
We use a higher value (10%) however this percentage is not well constrained, in particular in the early Universe.

NSM with short delay

Distribution functions

A more detailed comparison between model and observational data.

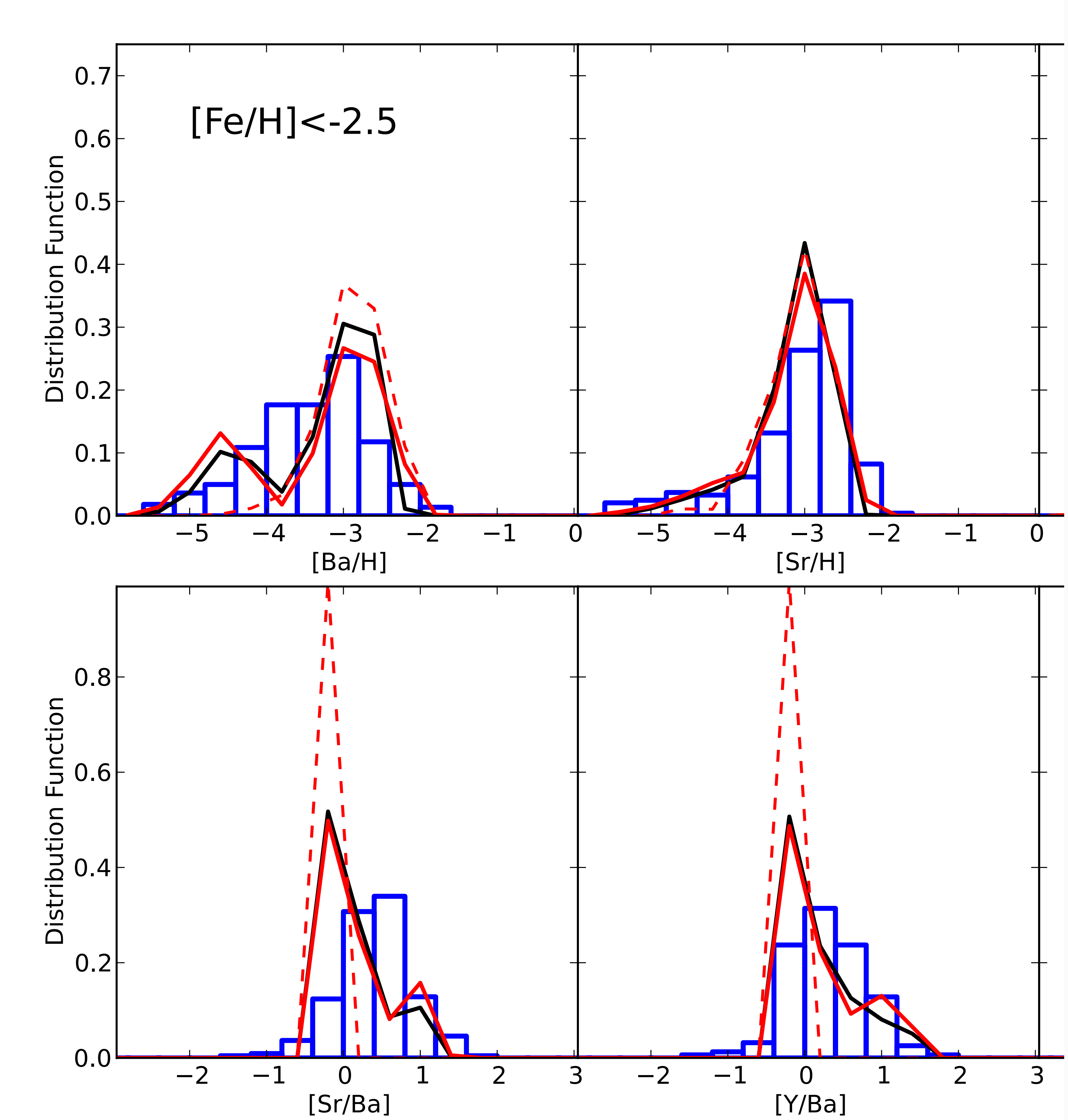
Still some problems (possible biases) but future data can help to improve the comparison (at the moment large bins to have a significant number of stars in each bin).

Both models are acceptable.

EC SNe +s

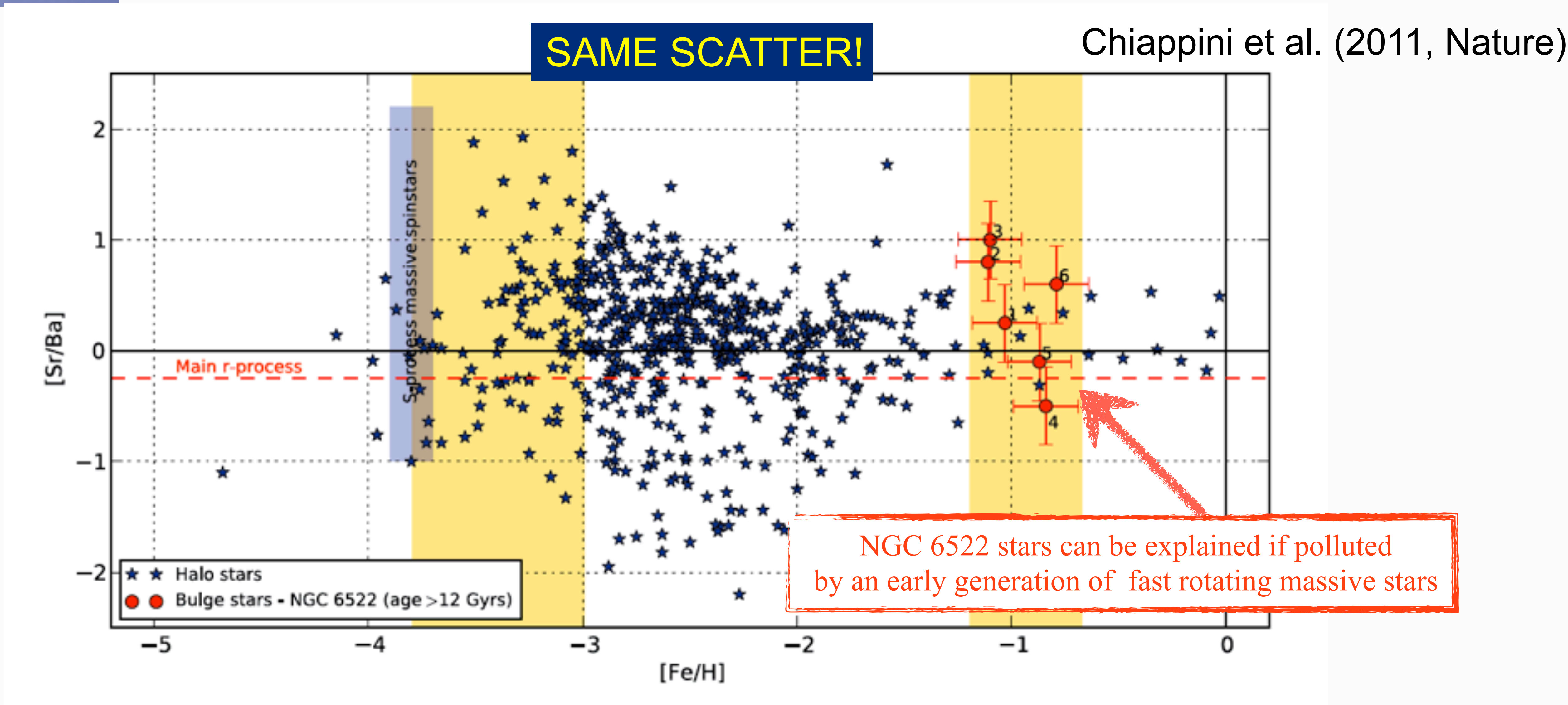
MRD SNe +s

MRD SNe -s



What's going on in the other fossil early Universe - the Bulge?

EARLY UNIVERSE EARLY UNIVERSE



Fast rotating massive stars can also solve this spread?

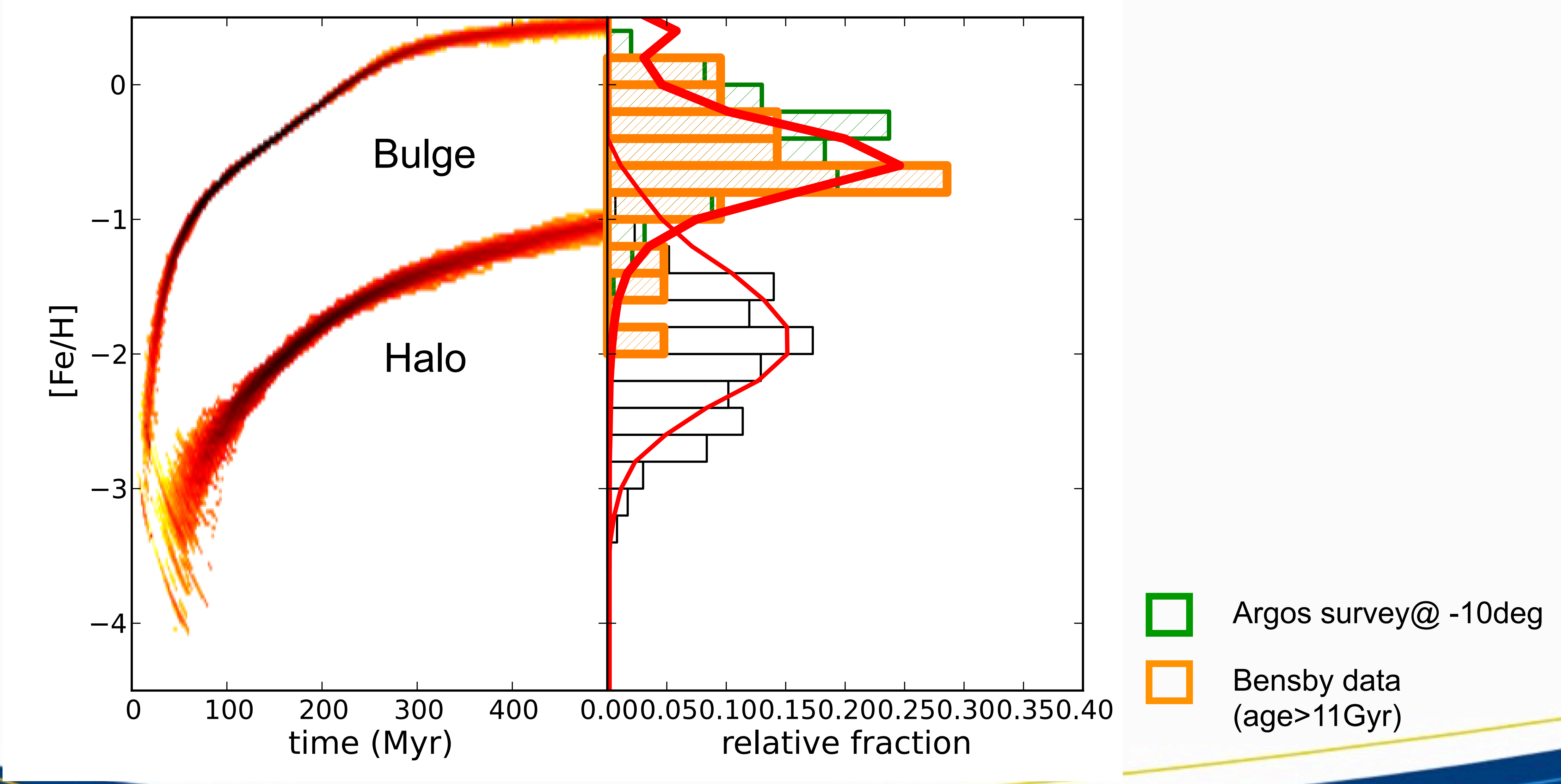
(is it real?)

Can we distinguish between the 2 site of r-process?

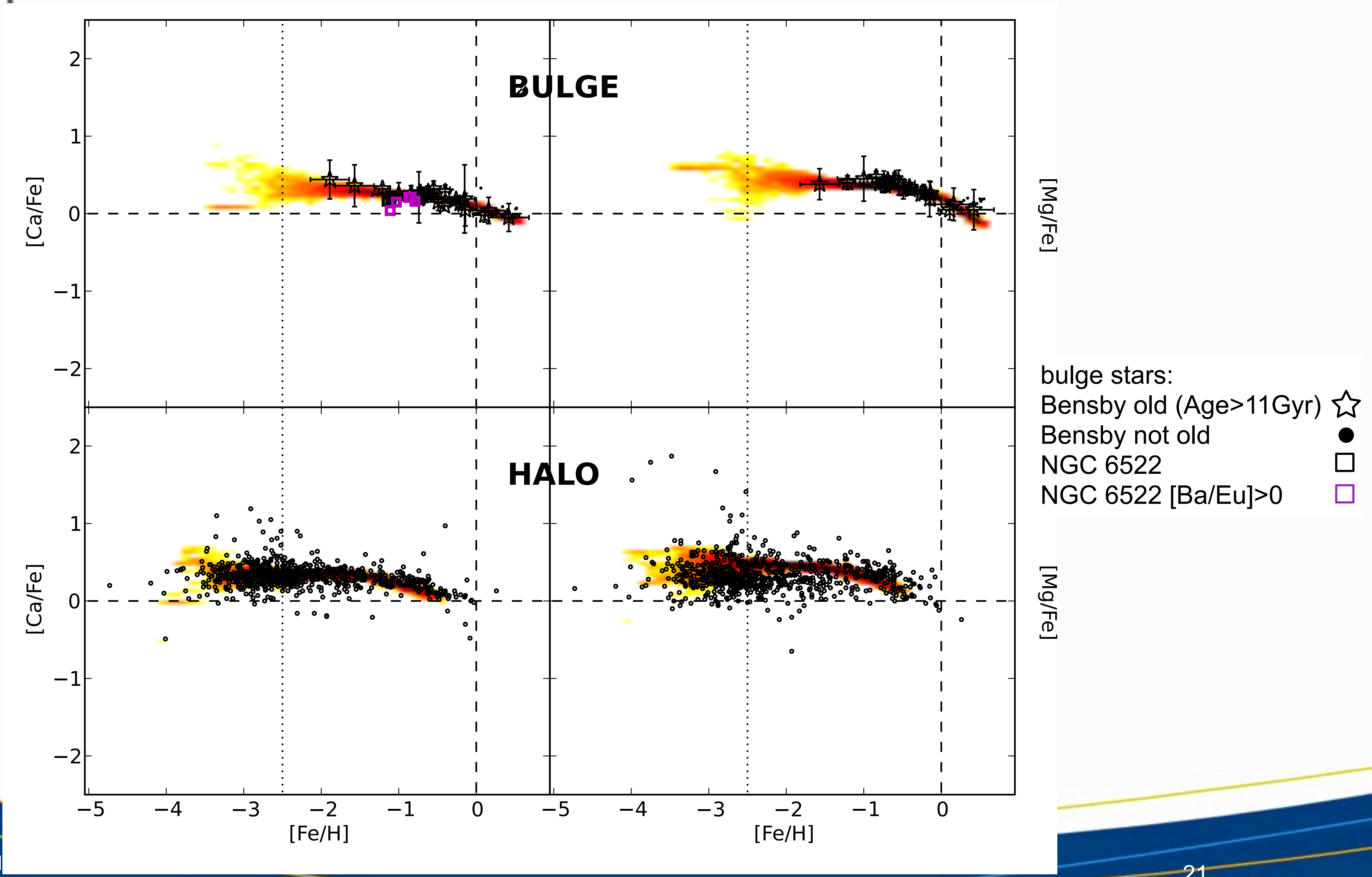
Stochastic C.E. model for the bulge

Gaussian infall law with an high final density which promotes a **fast** chemical evolution.
We aim to reproduce only the tail of the most metal poor and old stars of the bulge

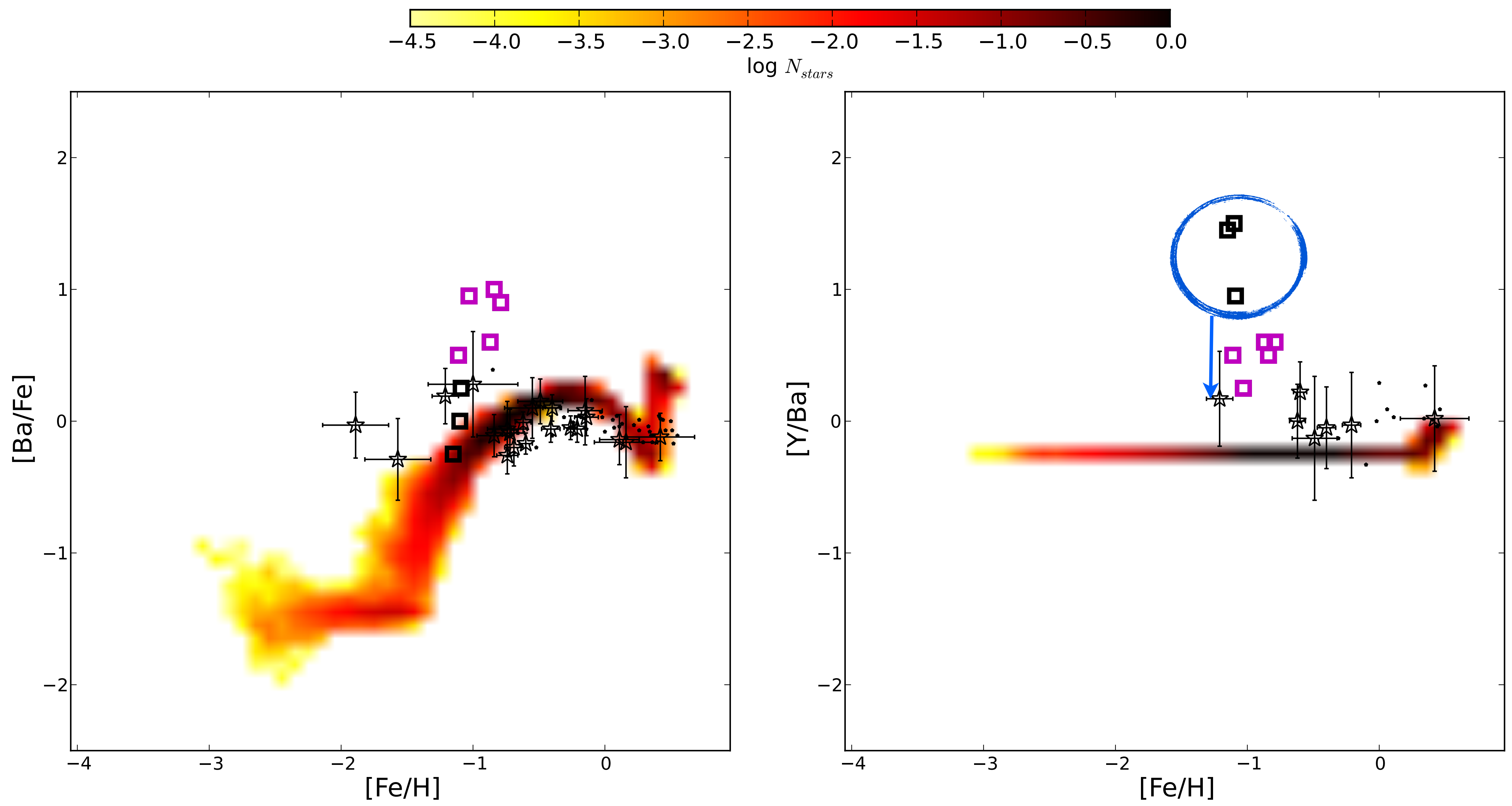
The SN bubble is dependent to the density ($\sim\rho^{-0.4}$), so the dimension of the volumes are decreased.



The bulge model
alpha elements
and the comparison with the halo model



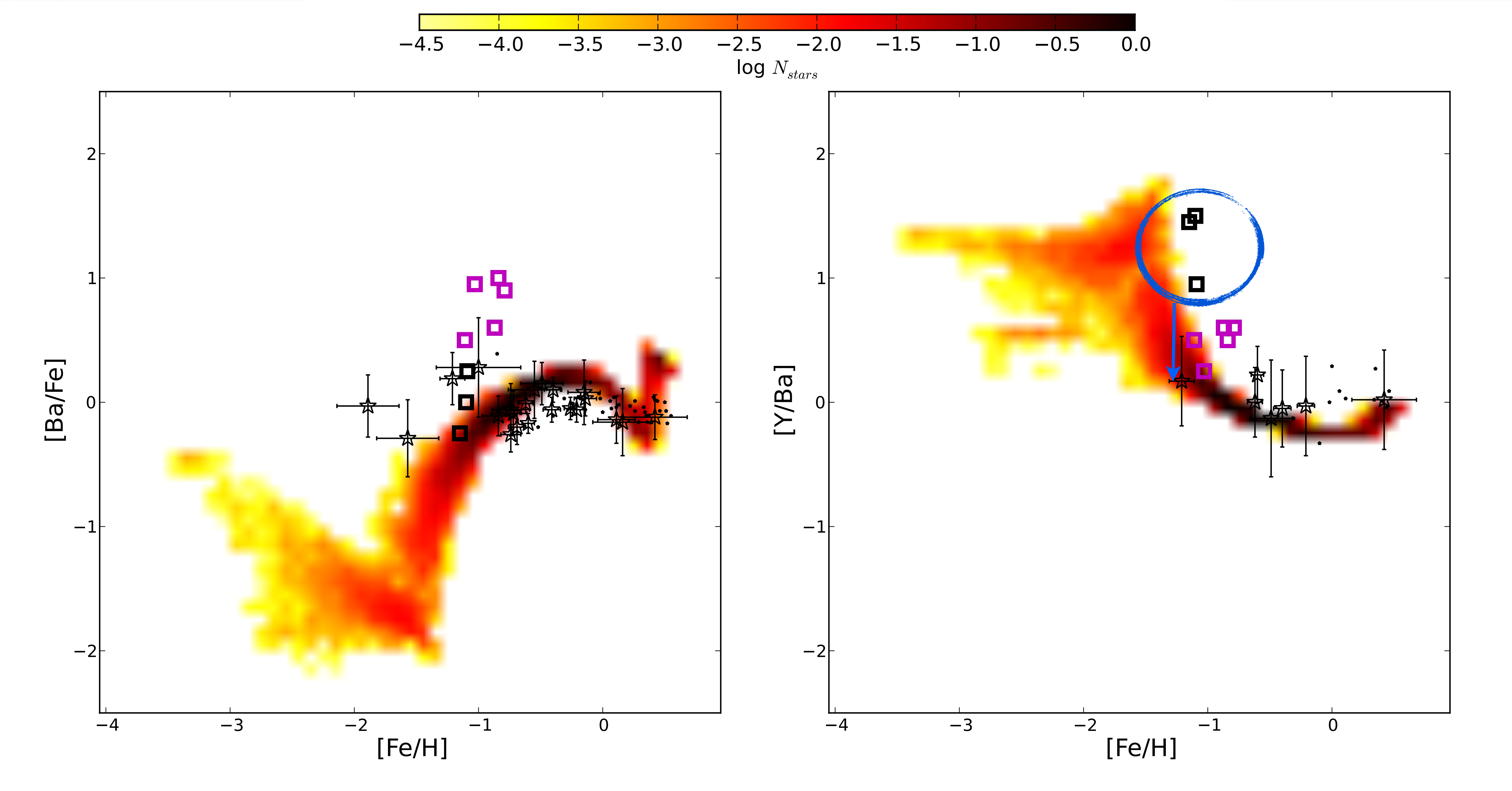
Only r-process
with the EC-scenario



bulge stars:
Bensby old (Age>11Gyr) ☆
Bensby not old ●
NGC 6522 □
NGC 6522 [Ba/Eu]>0 □

spinstars + r-process

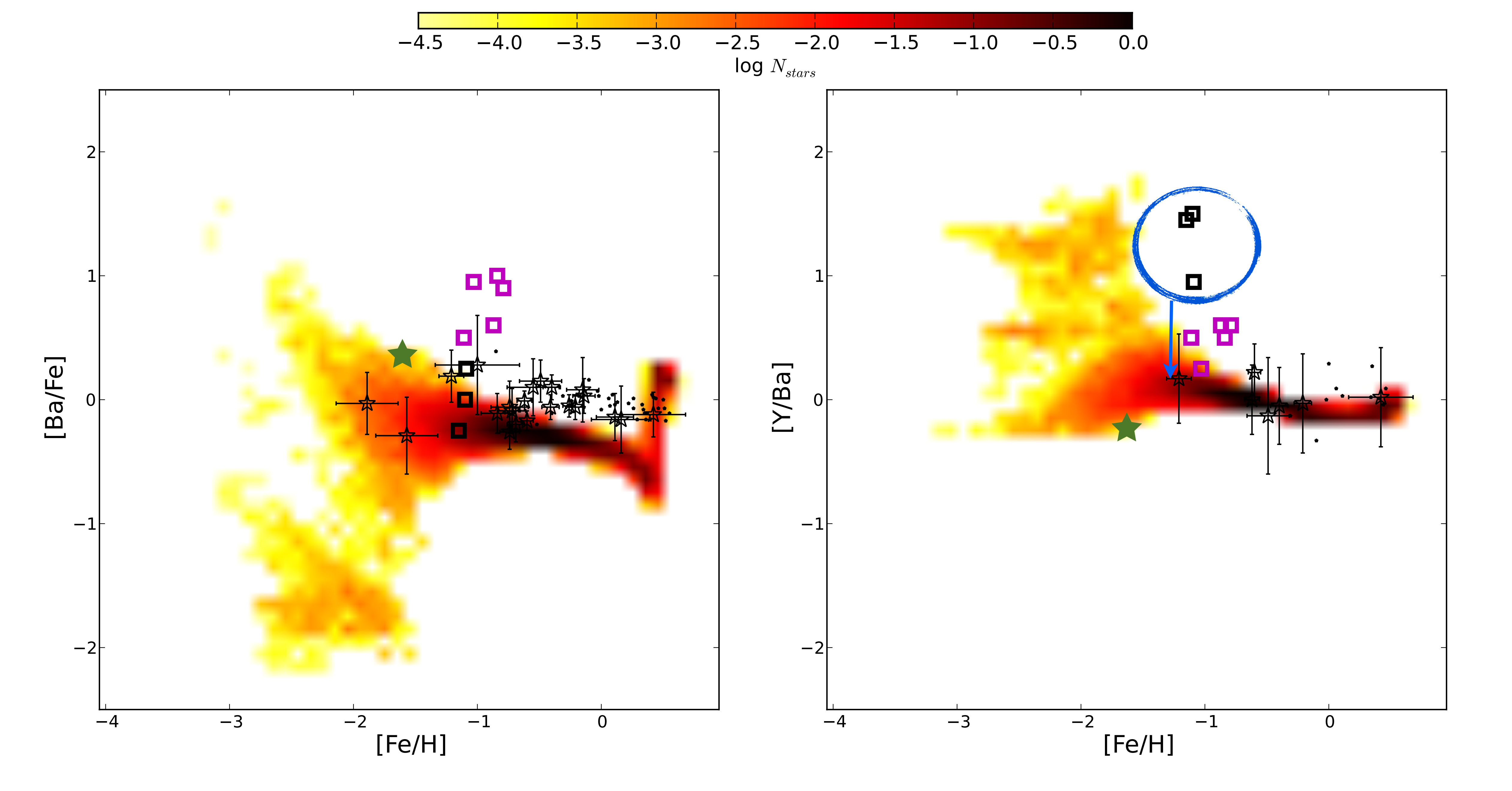
with the EC-scenario (lifetime ~30Myr)



bulge stars:
Bensby old (Age>11Gyr) ☆
Bensby not old ●
NGC 6522 □
NGC 6522 [Ba/Eu]>0 □

spinstars + r-process

with the MRD-scenario (lifetime ~4Myr)

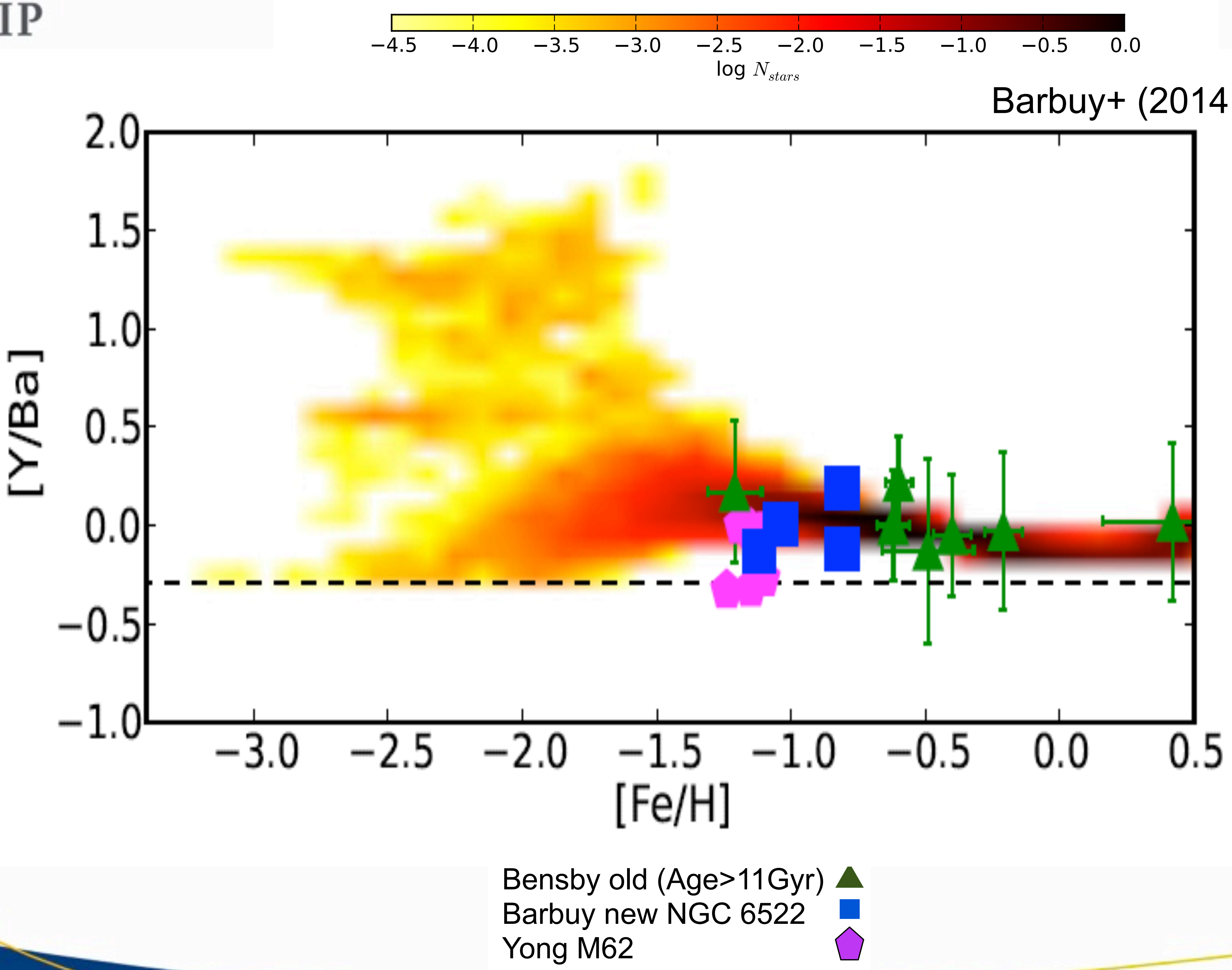


bulge stars:
Bensby old (Age>11Gyr) ☆
Bensby not old ●
NGC 6522 □
NGC 6522 [Ba/Eu]>0 □

★ C.Johnson, McWilliam and Rich 2013

spinstars + r-process
with the MRD-scenario (lifetime ~4Myr)

Barbuy+ (2014, A&A, just accepted)



Conclusions

We model for the first time a chemical stochastic model for the Galactic bulge.

If in the halo the spinstars are a very promising way to explain the scatter in the [Y/Ba] ([ls/hs]).
At the moment in the bulge there are not enough data.
(... but the plateau seems to indicate the necessity of an extra production).

There are hints of a spread in [Ba/Fe] at low metallicity in bulge stars. We can reproduce this spread if the site of production of the r-process elements has a very short time scale, in better agreement to the magneto-rotational driven SNe scenario (compared to electron-capture SNe scenario).