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The quest for metal poor stars with 4MOST:

how to chemically disentangle accreted components in the Galactic Halo

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4MOST Workshop
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how to chemically disentangle accreted components in the Galactic Halo

Which chemical signatures for extremely low metallicity stars?

(within the “4MOST” chemical elements space)

(Fe, Mg, Si, Ca, Ti, Na, Al, V, Cr, Mn, Co, Ni, Y, Ba, Nd, Eu)

Alpha elements?

Iron peak elements?

Neutron capture elements?

(Na/Al?)

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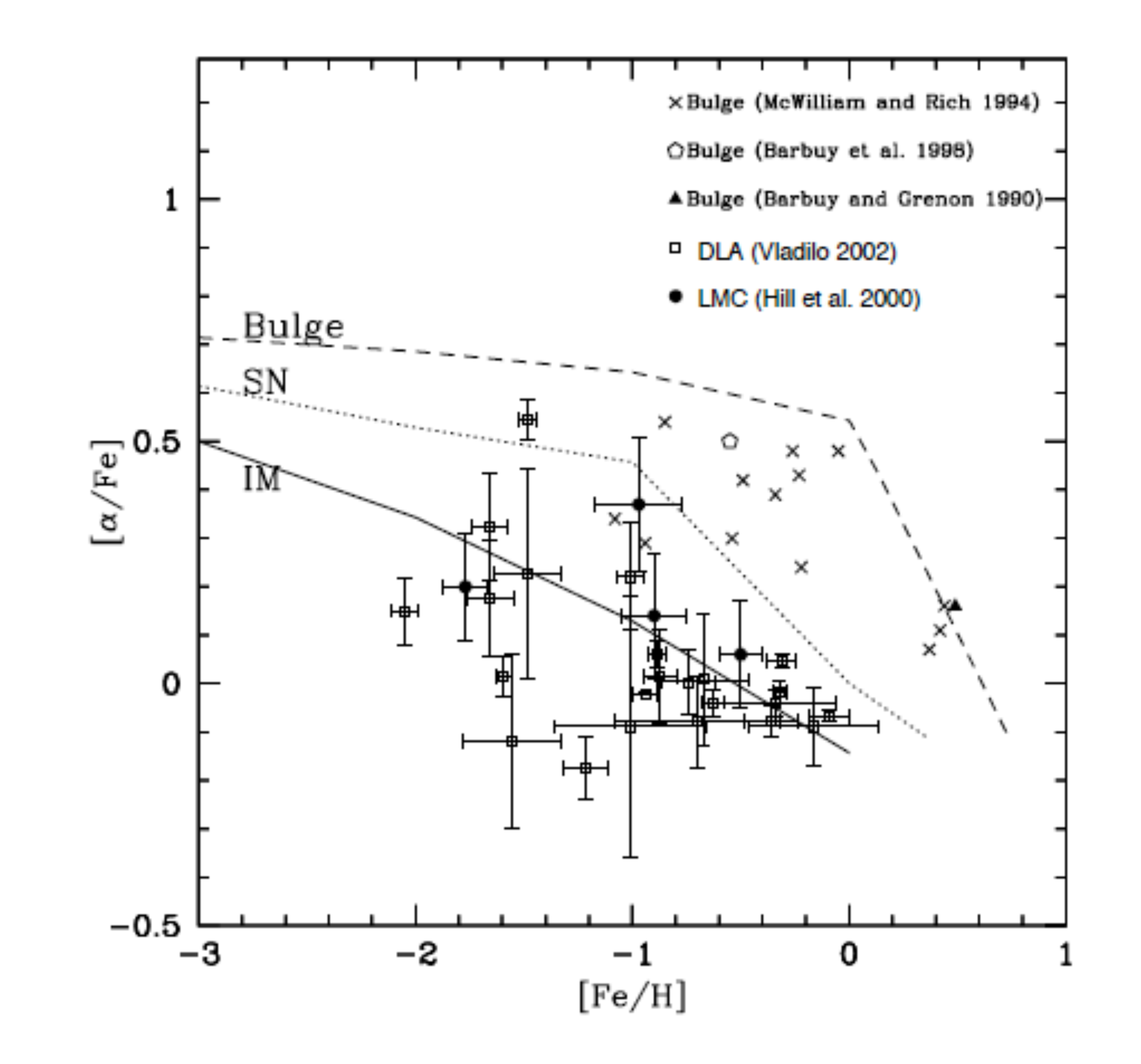
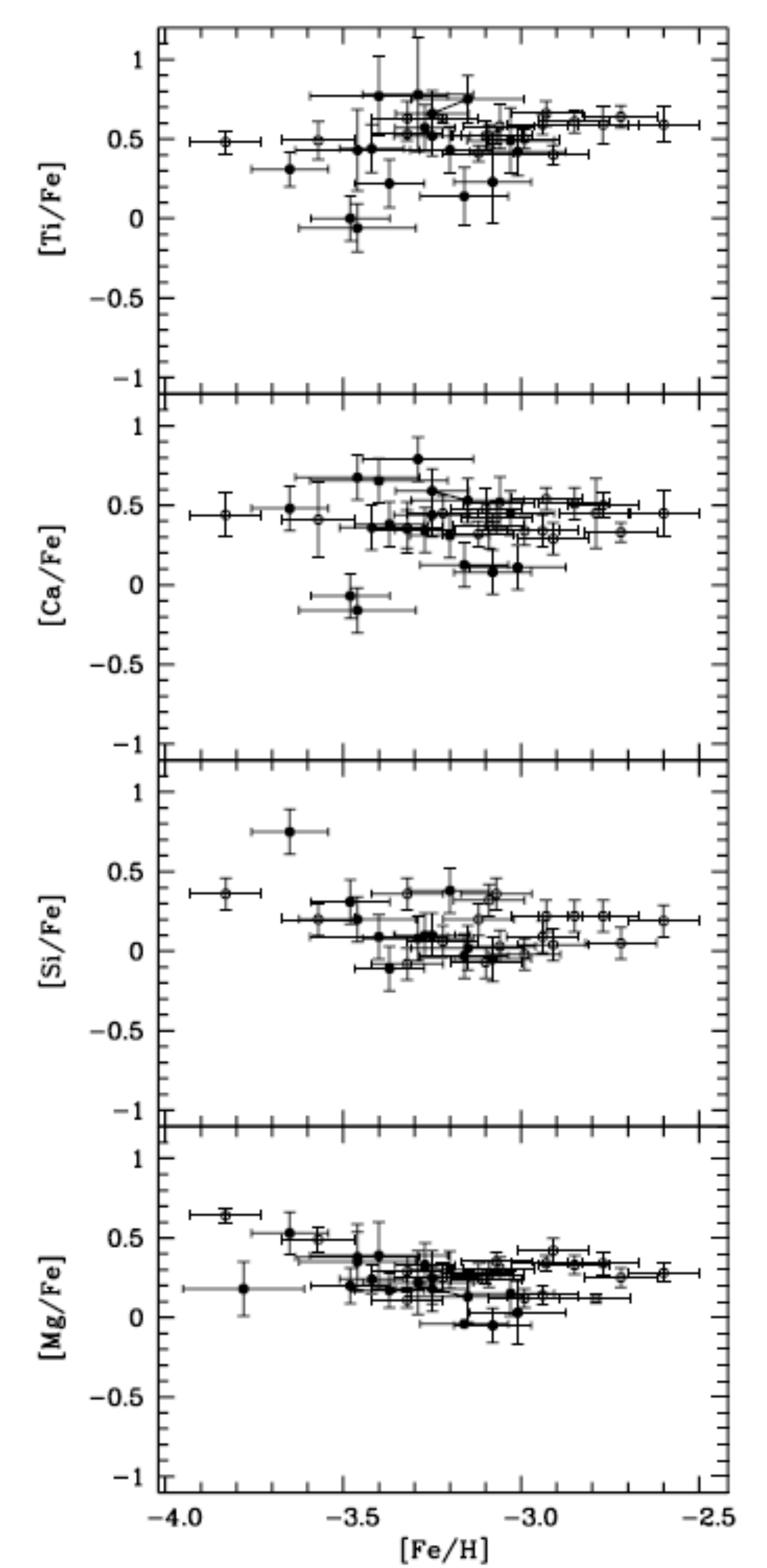
[alpha/Fe] ratio shows a chemical signature: the delayed SNIa enrichment produces a knee (Matteucci & Greggio 1986): this knee can be used as a signature to infer different SF histories.



Timescale for the bulk of production for SNIa is >1Gyr and it is not present in the EMP stars.

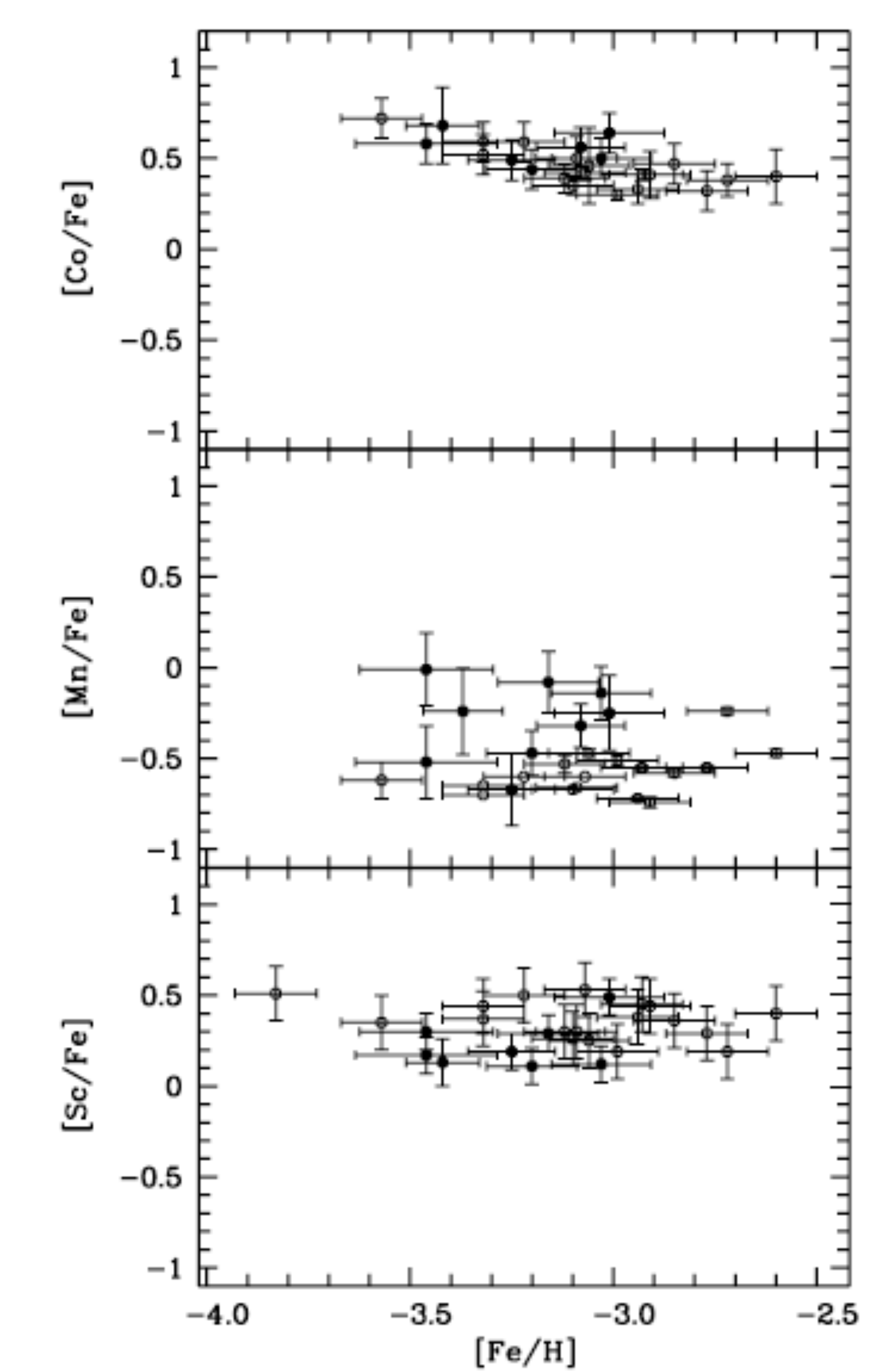
Possible in the Galactic halo at "high metallicity" see Nissen and Schuster (2011)



At Extremely Low Metallicity
α-elements and iron peak elements present an (almost) flat trend.
So, no chemical signatures can be expected (*) and possible differences in the formation histories cannot be chemically disentagle.

Bonifacio et al. (2012)

(*) Without changing the IMF or the nucleosynthesis



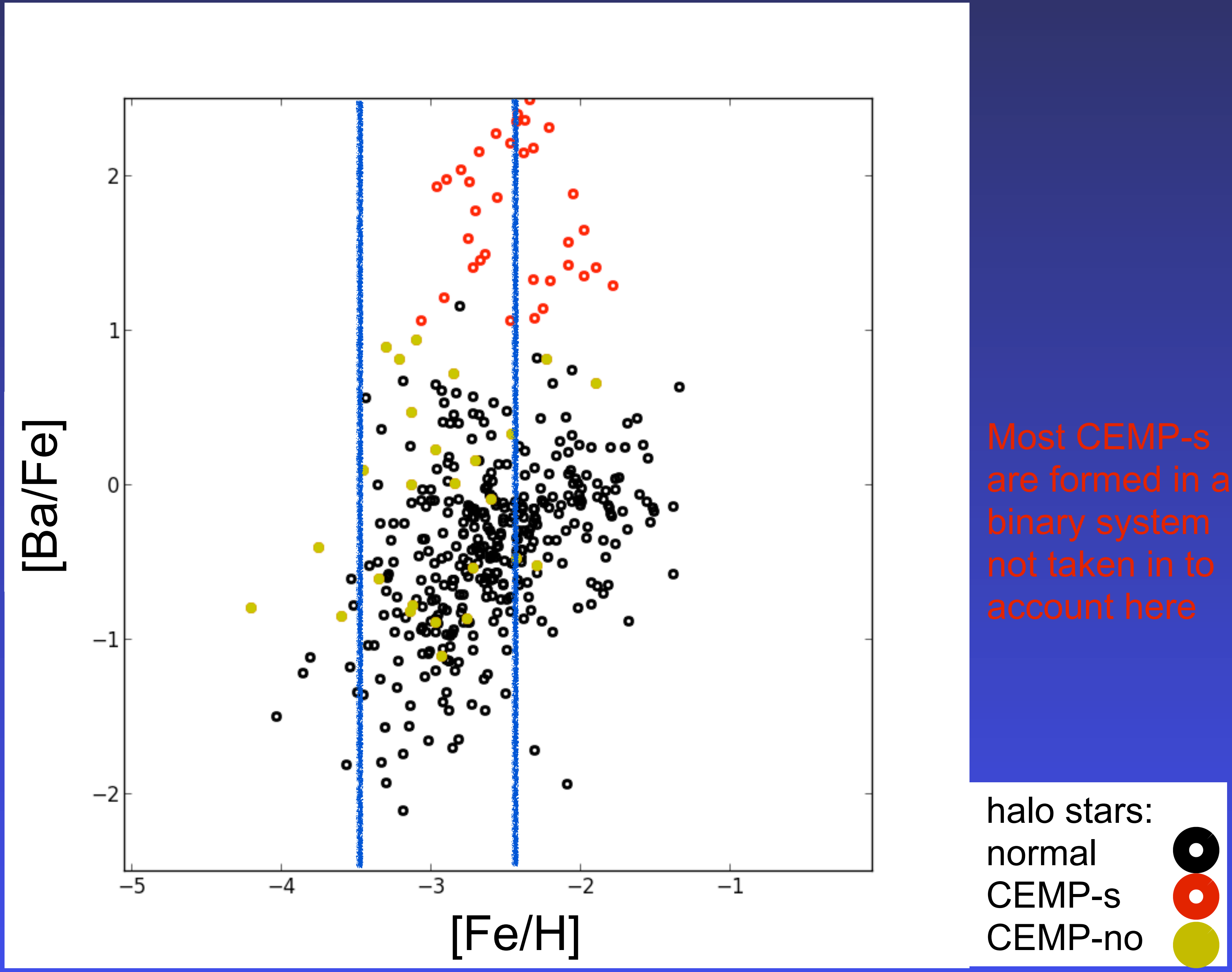
Neutron capture elements show a feature: a large spread at -3.5<[Fe/H]<-2.5

We need a **model** able to follow the chemical evolution for these elements to investigate **(if and) how** this signature can be different in an accreted component.

BUT (PROBLEM 1) nucleosynthesis for these elements (in massive stars) is very complex:

r-process still under debate the site of production, nuclear details of the reactions not directly measurable ...

s-process production possible if massive stars were fast rotating (see Frischknecht et al. 2012 and Chiappini et al. 2011)



Most CEMP-s are formed in a binary system not taken in to account here

data collected by Frebel '10

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Empirical yields for r-process

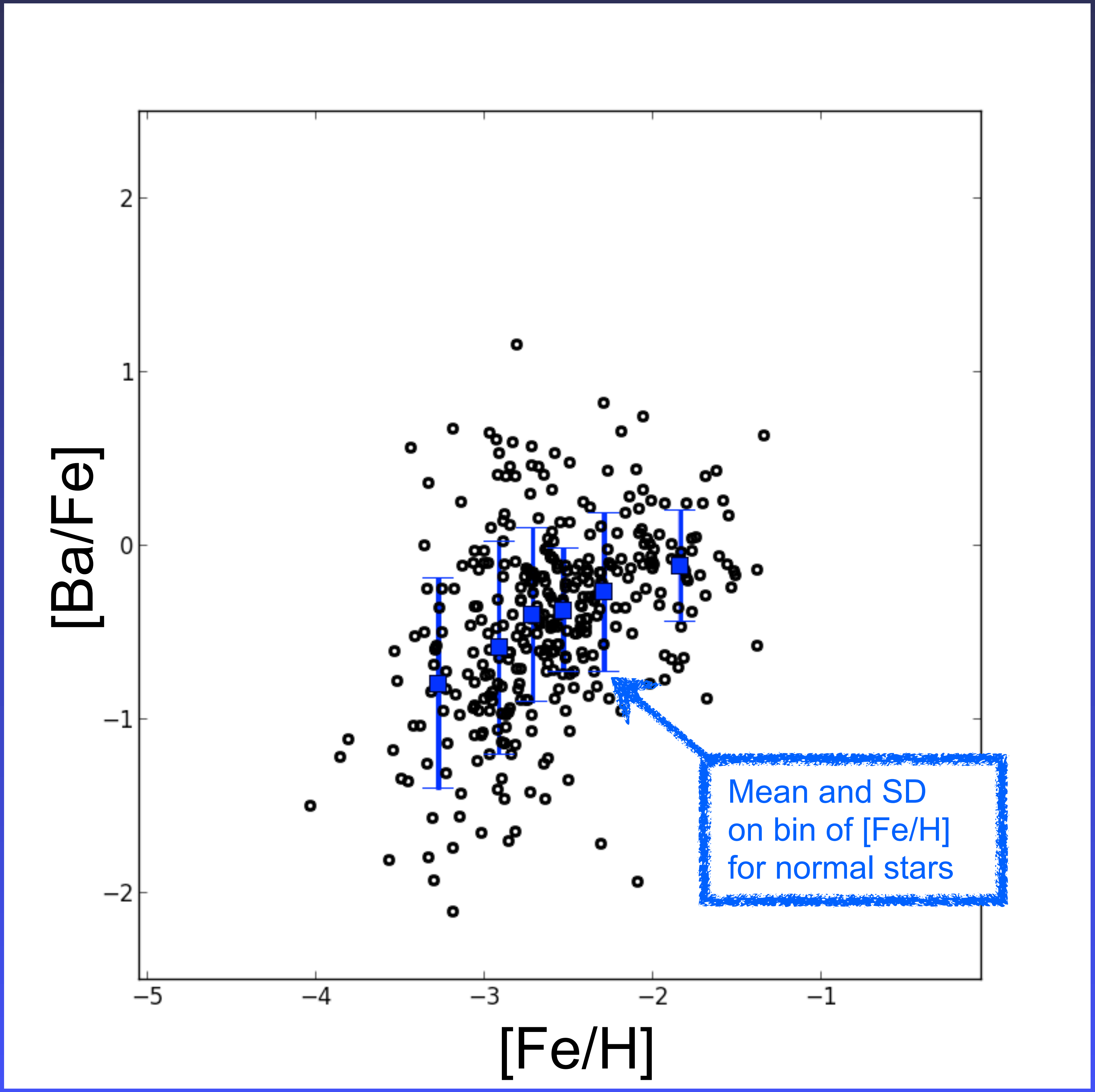
Why empirical?
r-process still not fully understood

Procedure as
Cescutti et al. ’06

BUT
we take into account the s-process from **spinstars**

New model
for the halo
Cescutti & Chiappini ’10
&

New data
collected by Frebel ’10



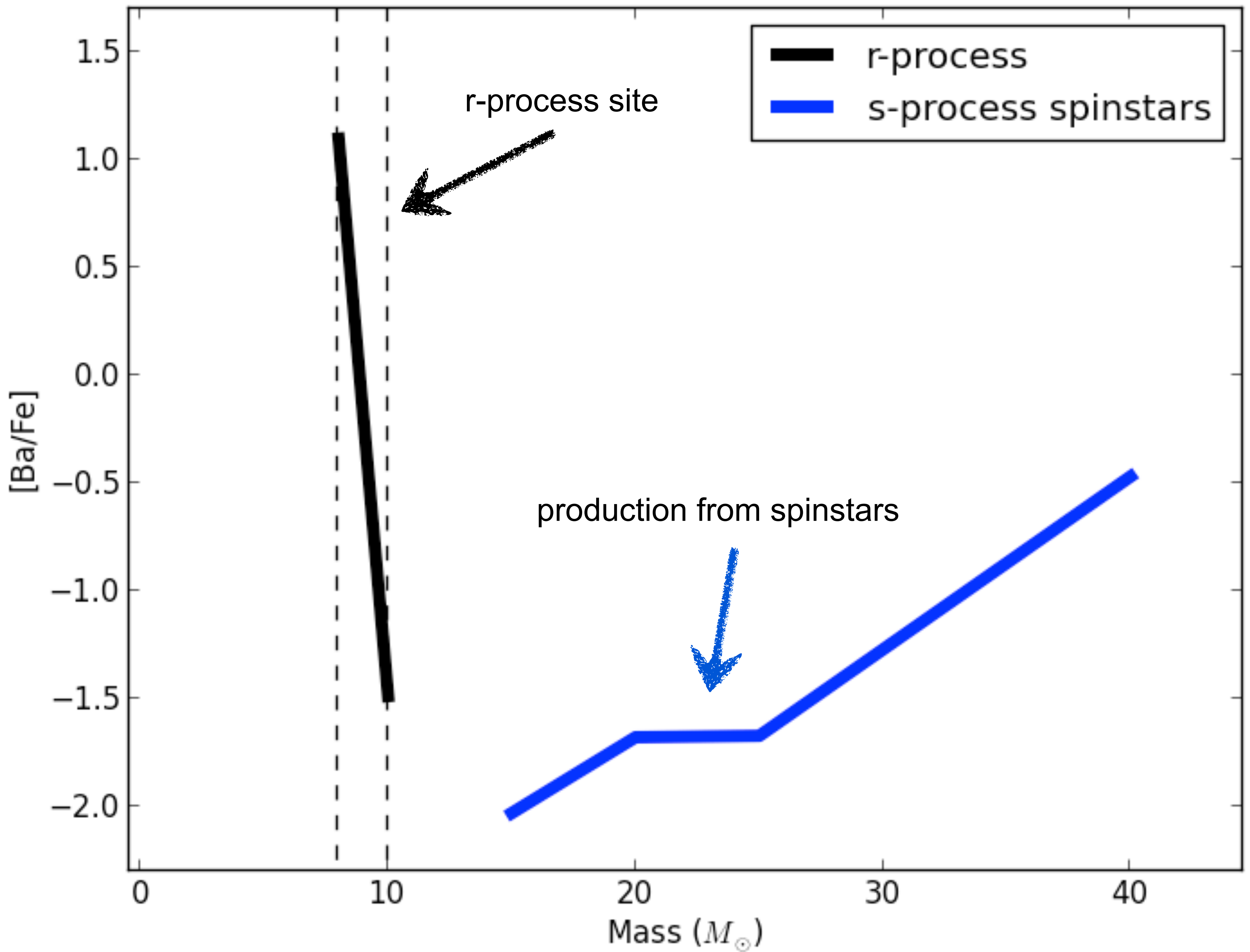
Yields of massive stars for Barium

To fit the data:
2 regimes of production.

1) High level of production in the low tail of massive stars (standard r-process site) RARE EVENTS (magnetorotational CC SN? NS mergers?)

2) Lower level of production coming from spinstars (Frischknecht et al 2012, Chiappini et al 2011)

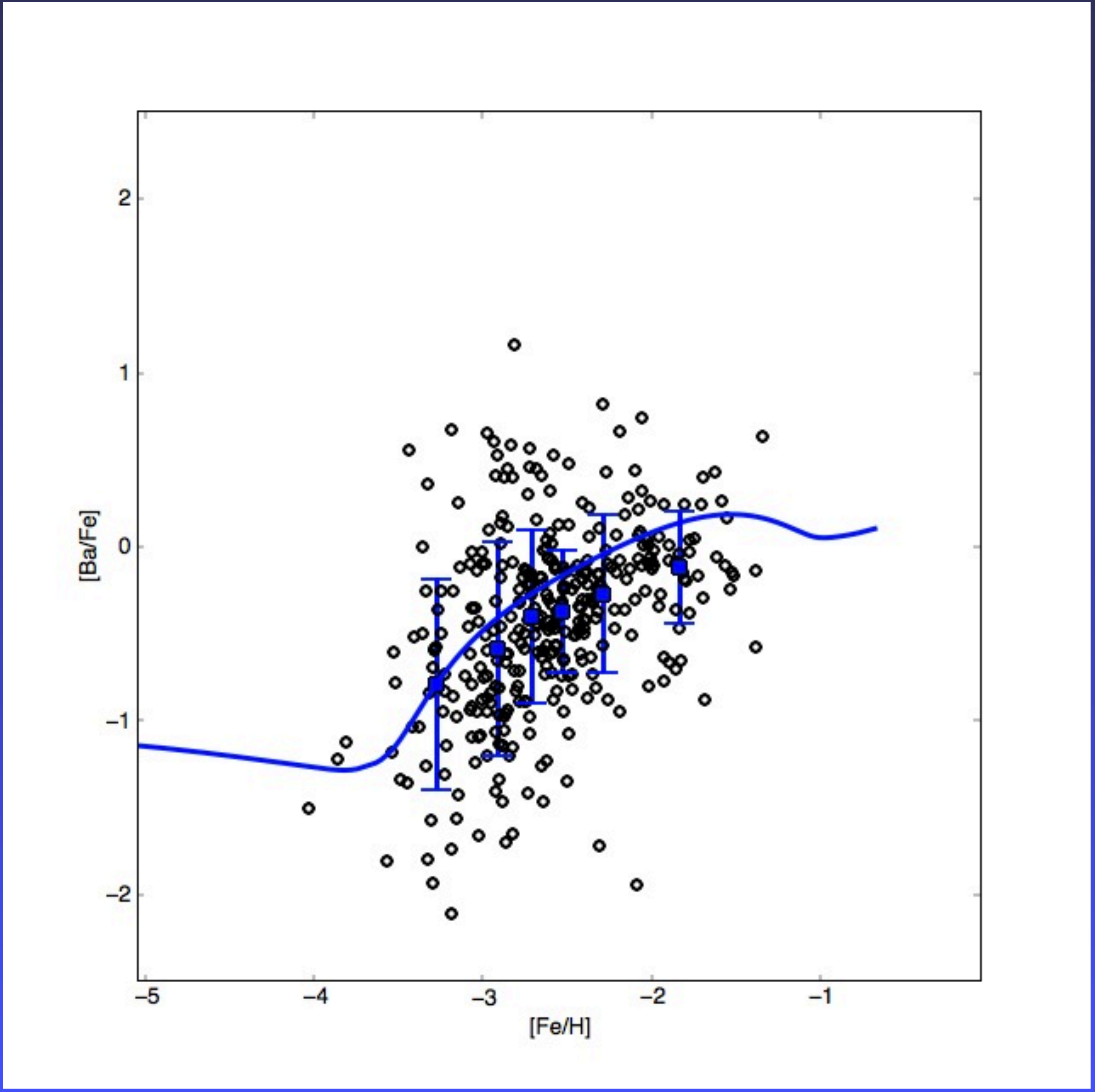
FUNDAMENTAL for the spread in Sr/Ba
(2 extra slide though)



Standard chemical evolution results for Ba

The homogeneous model with:
• empirical yields for r-process
+
• s-process yields from spinstar

does fit the data
but
PROBLEM 2
It cannot explain the spread...



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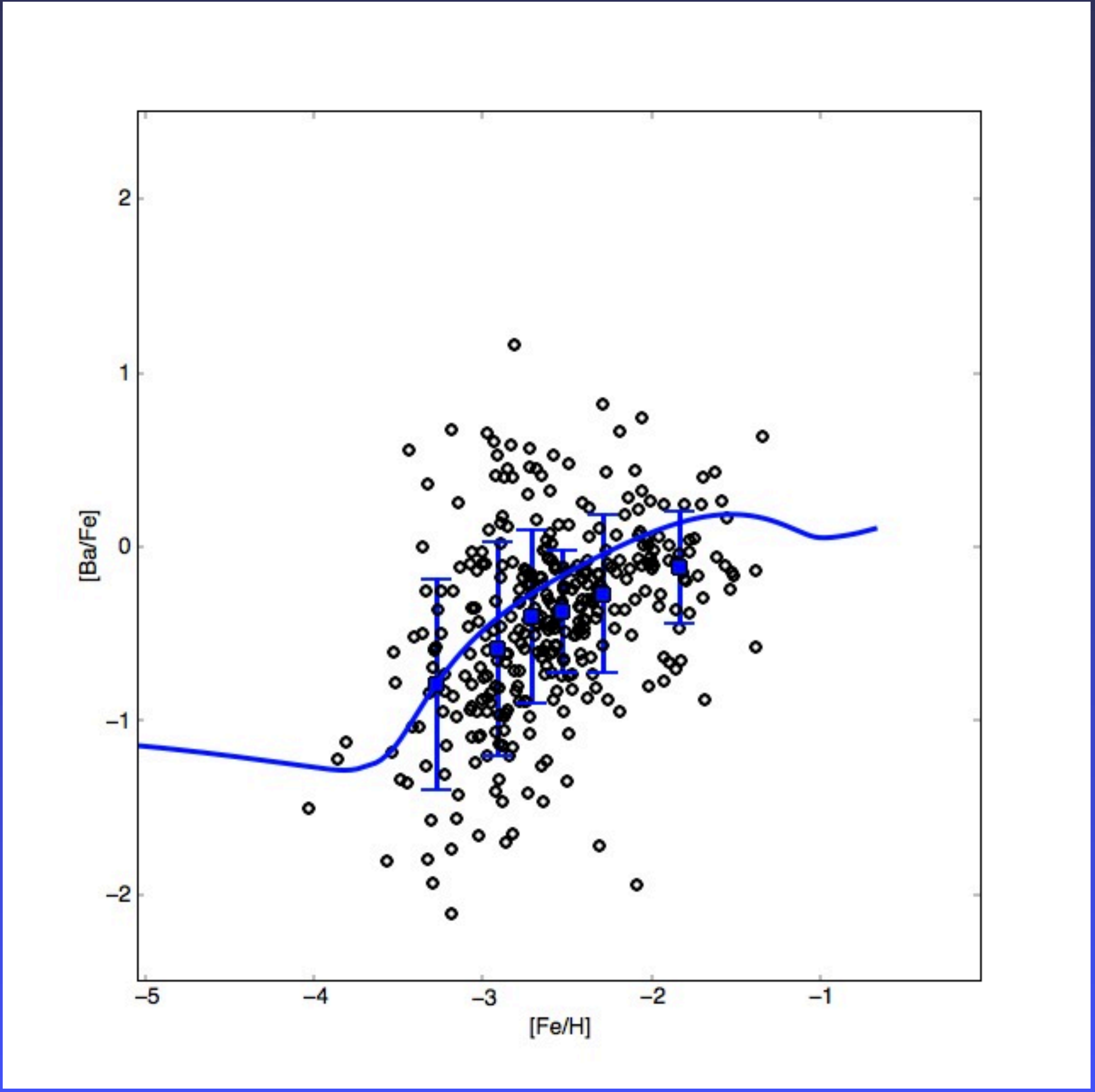
So we adopt the inhomogenous model (Cescutti '08) with the new yields



Inhomogeneous chemical evolution model of the Galactic Halo

Why inhomogenous?
The neutron capture elements at low metallicities show spread whereas α- and iron peak elements do not.
Solved in Cescutti (2008) in the context of halo formed by non-interacting regions with the **same** SF histories but

a random formation of new stars

(subjects to the condition that the cumulative mass distribution follows a given initial mass function)

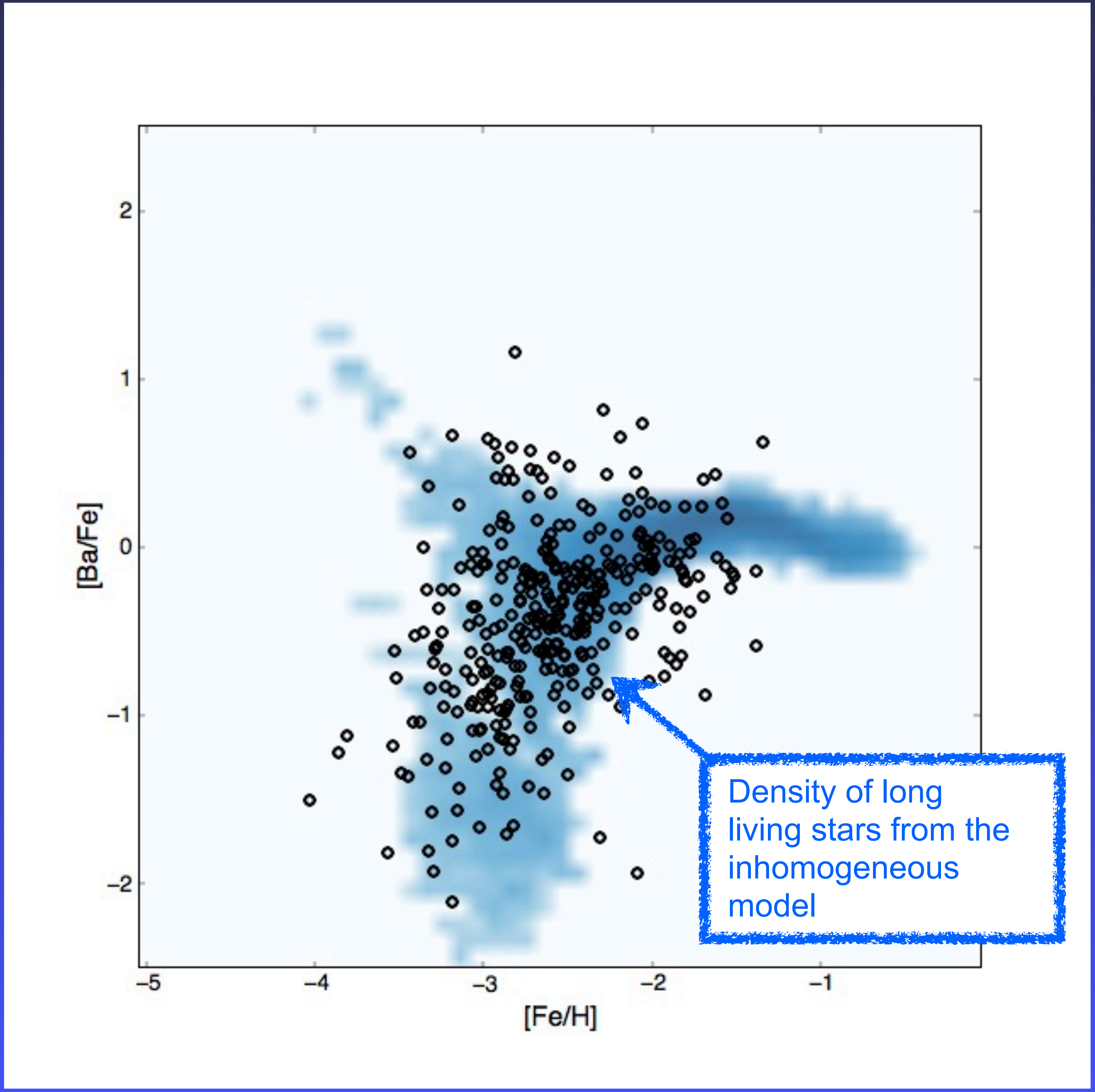
Coupled with

different production mass ranges for α-elements and neutron capture elements

(All the massive stars for α-elements
8-30 M⊙ for neutron capt. elements
(but with a peak at ~8-10Msun)

The same inhomogenous model was used to explain the spread of C/O and N/O in Cescutti & Chiappini (2010), in the framework of fast rotating stars.

Inhomogeneous chemical evolution results for Ba

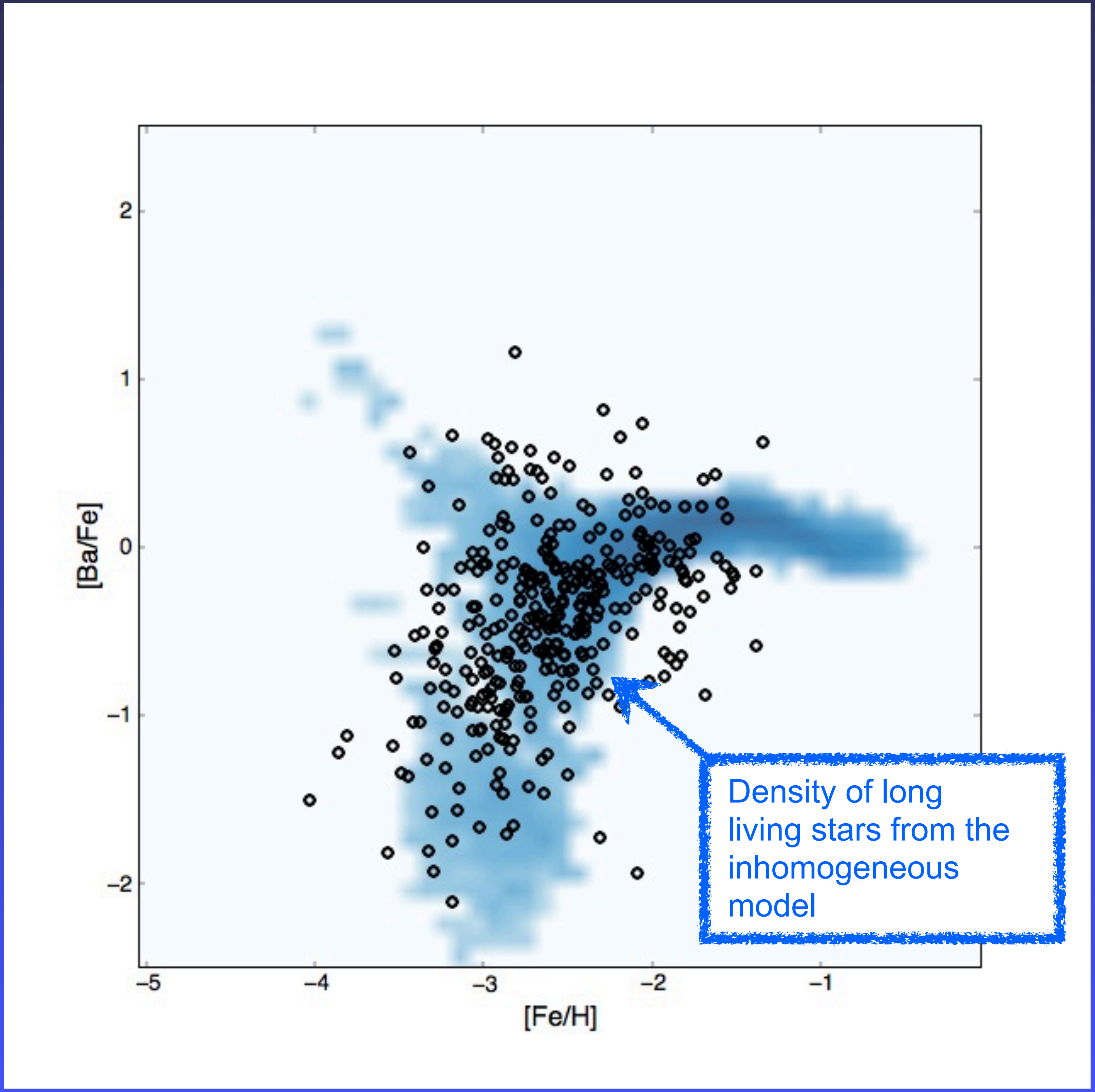


Inhomogeneous chemical evolution results for Ba

Finally we reproduce the chemical evolution of Ba in the Galactic halo (with the future 4MOST data-> better constraints)

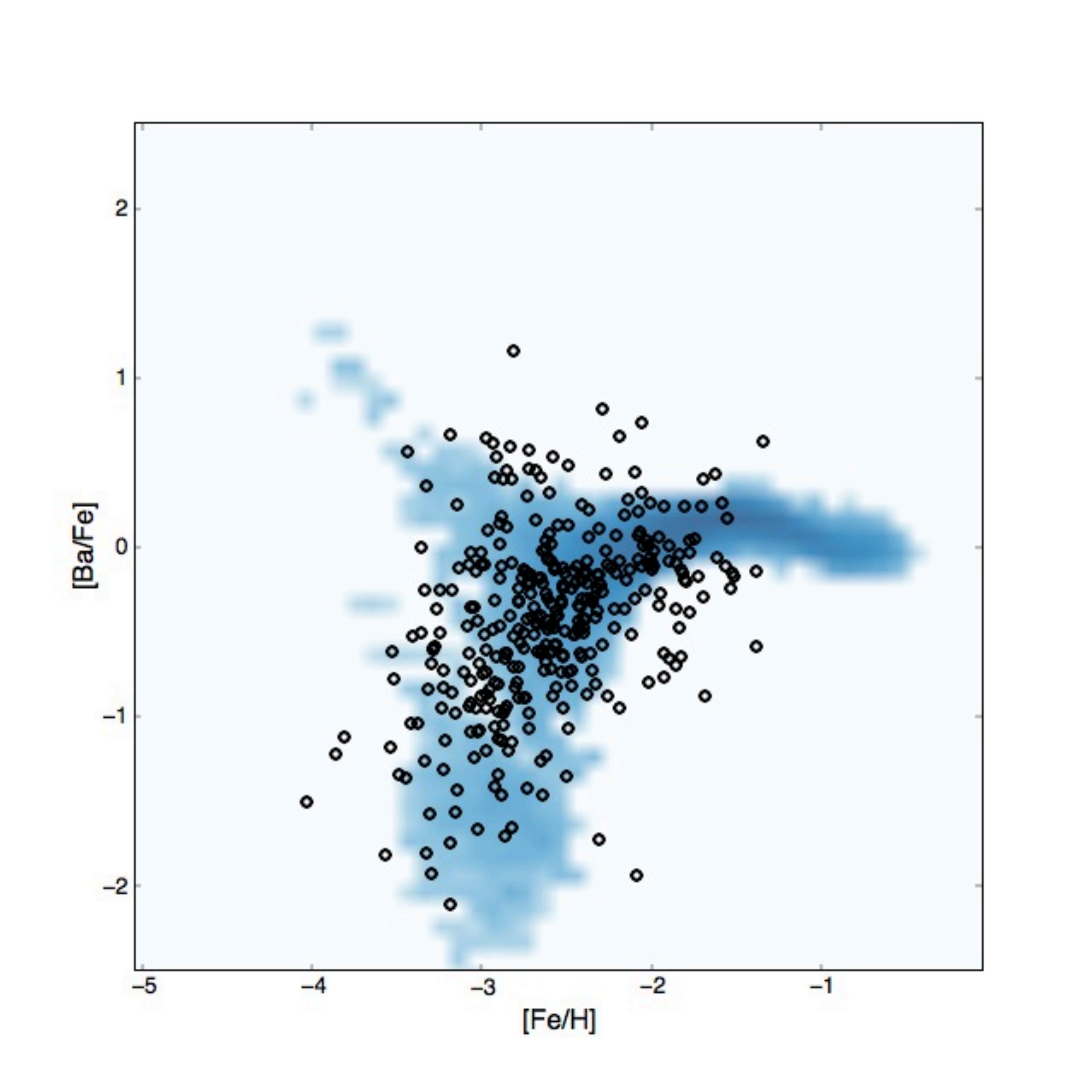
Now, we investigate on how and if we can possibly distinguish debris from accreted components.

The hypothesis is that the accreted components do not share the same history of SF of the halo.



Signature of different SF history for Ba

To modify the SF history we change the SF efficiency in our system.



Signature of different SF history for Ba

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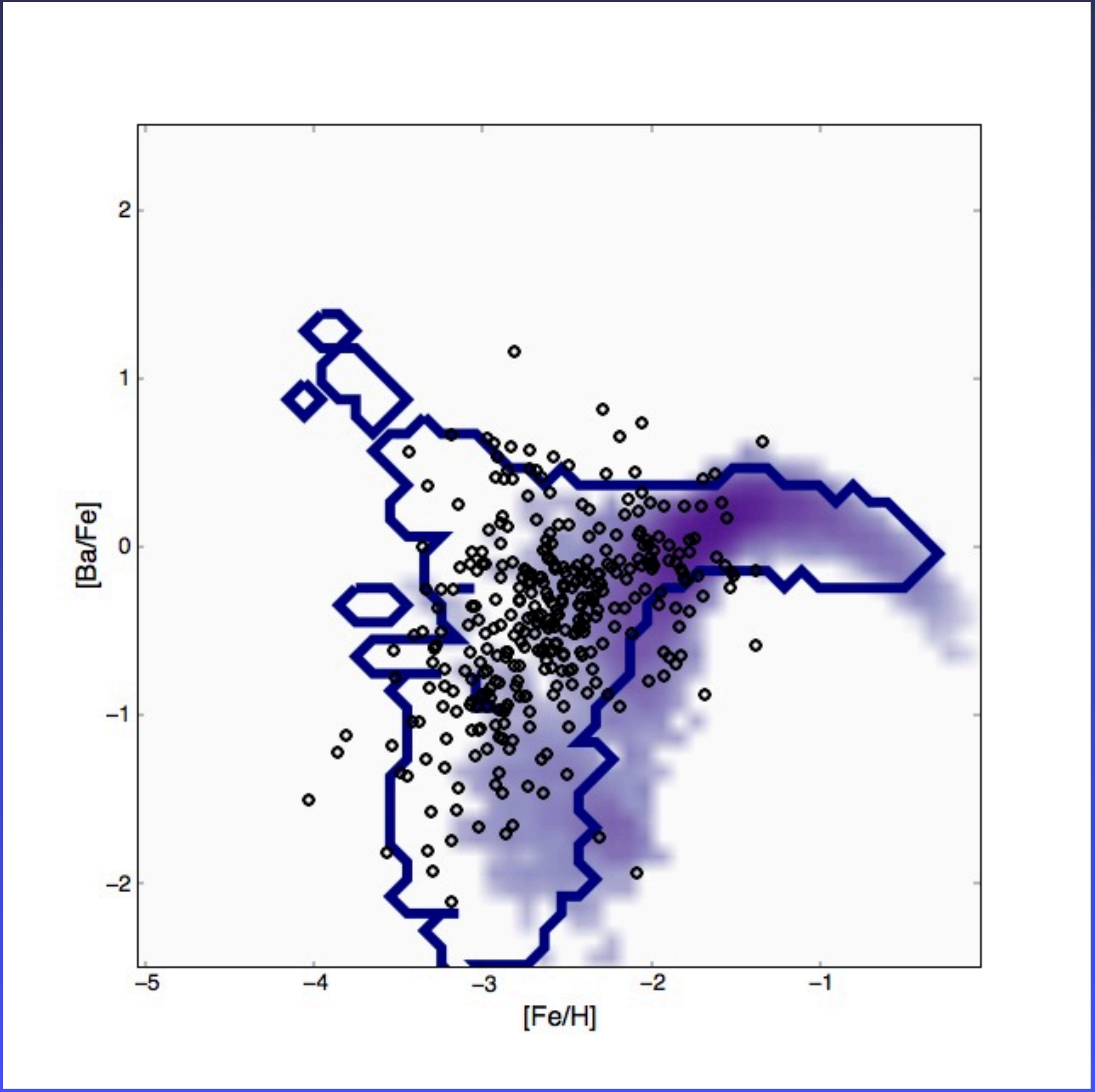
10x

DIfferent SF histories produce a different signature for [Ba/Fe], providing a possible selection criteria to investigate for debris of accreted systems



Signature of different SF history for Ba

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0.1 x

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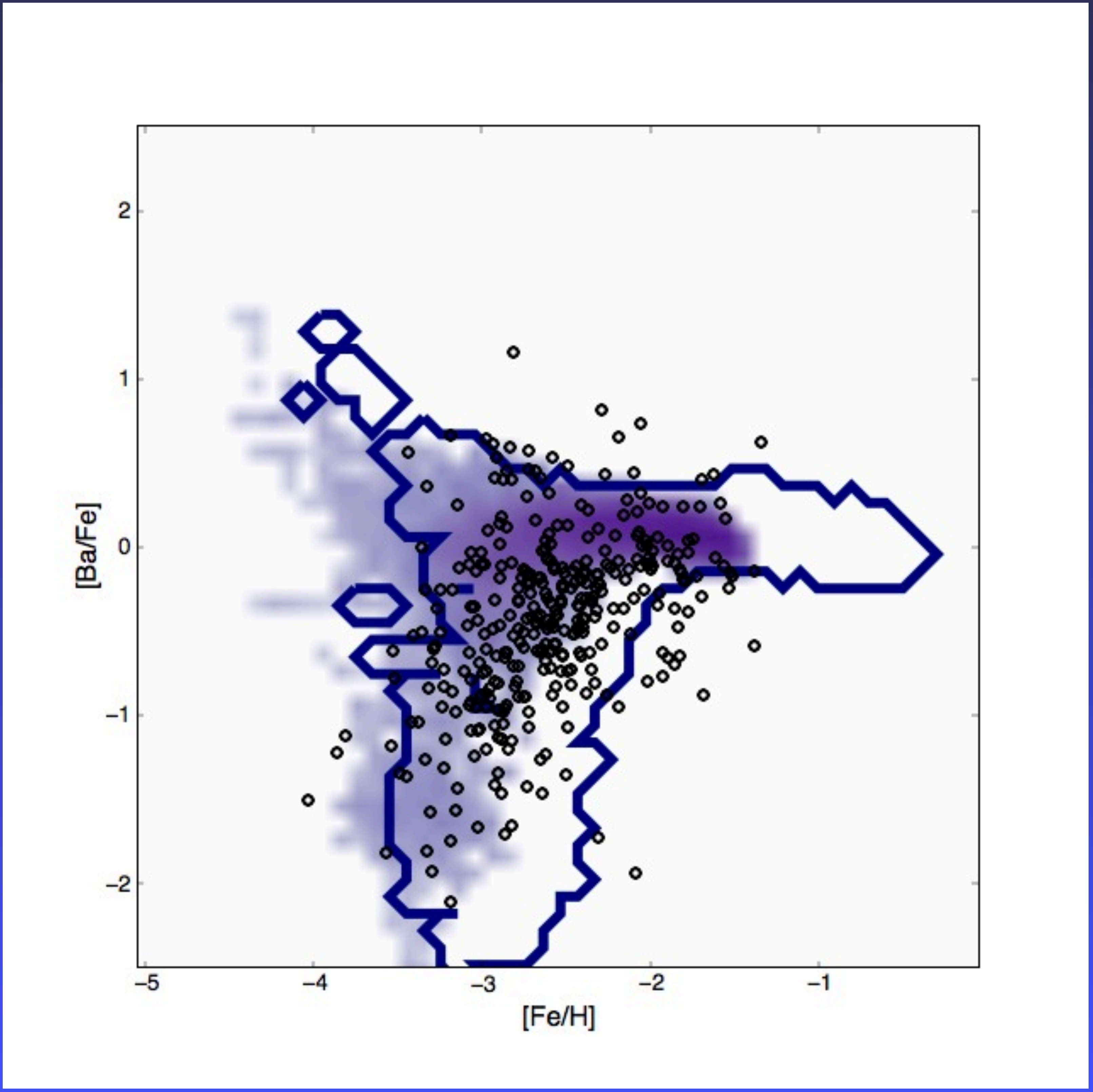
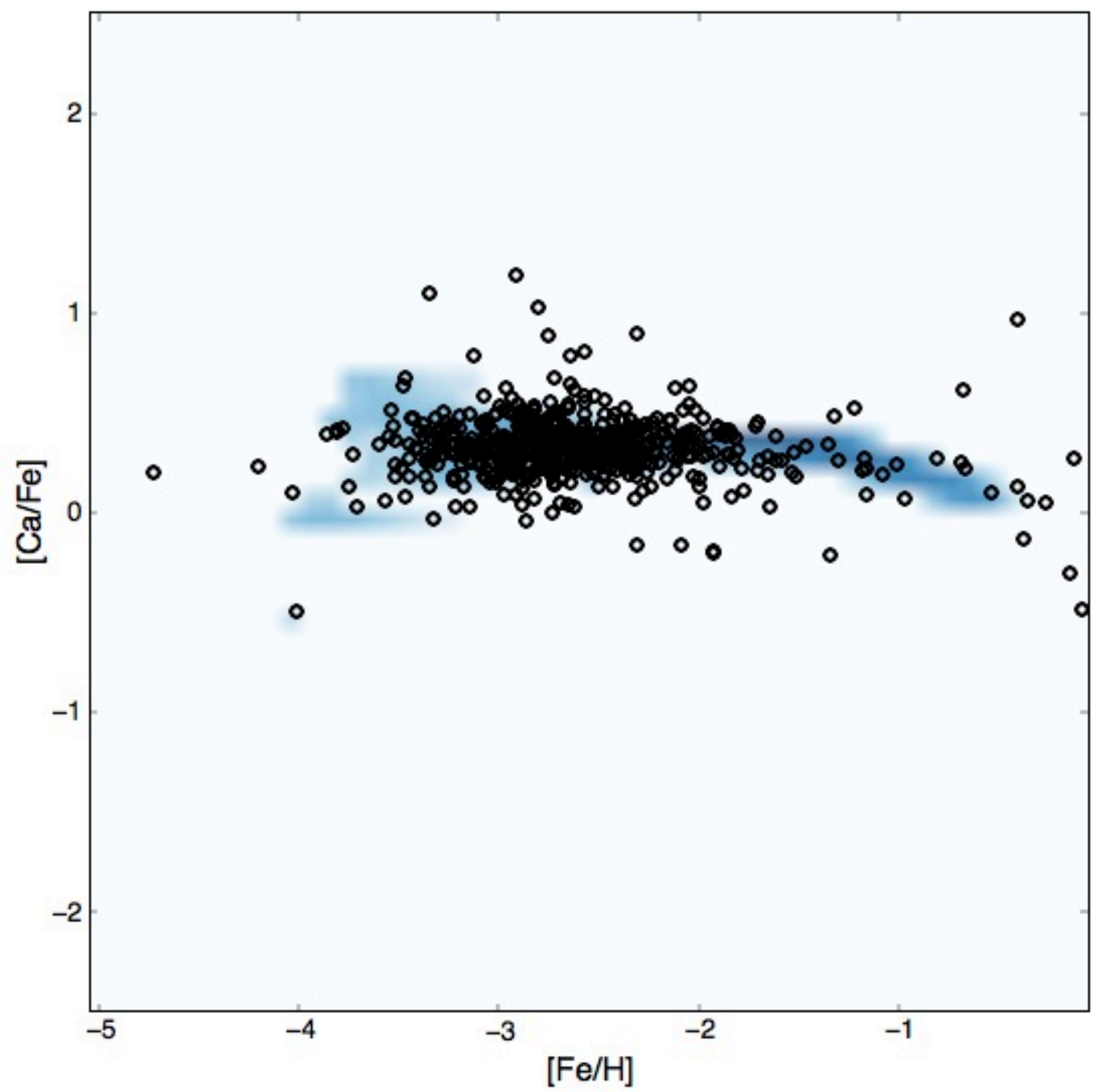


What about α-elements?

(case of Ca)

Results with the SF for the Galactic halo for Ca. (Note how for this element the spread is reduced and some outliers can be explained with single SN enrichment in this scenario)



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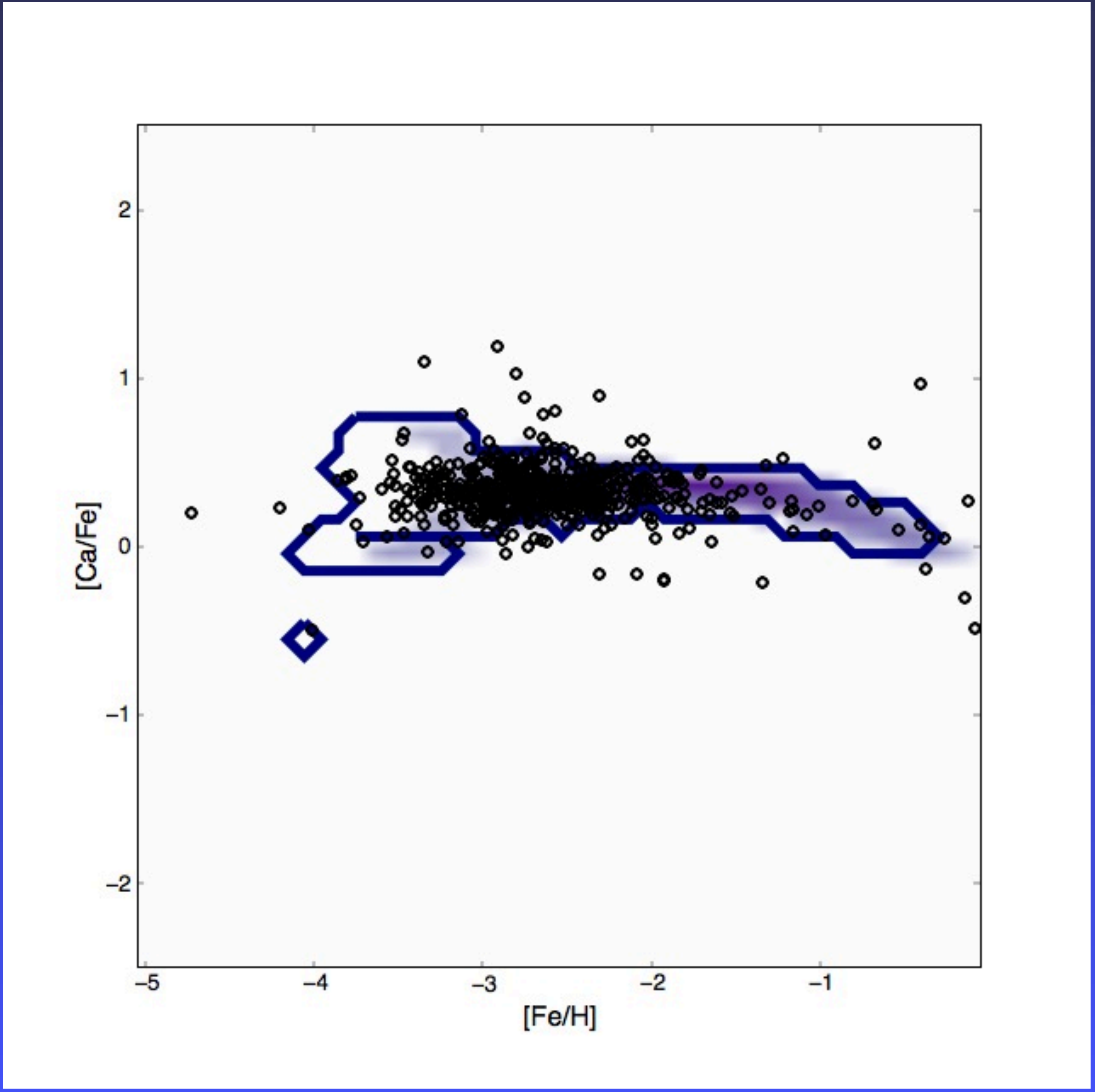
Signature of different SF histories for Ca (?)

To modify the SF history we change the SF efficiency in our system.

10x



DIfferent SF histories overlap for the [Ca/Fe] and do not permit to disentangle different components.

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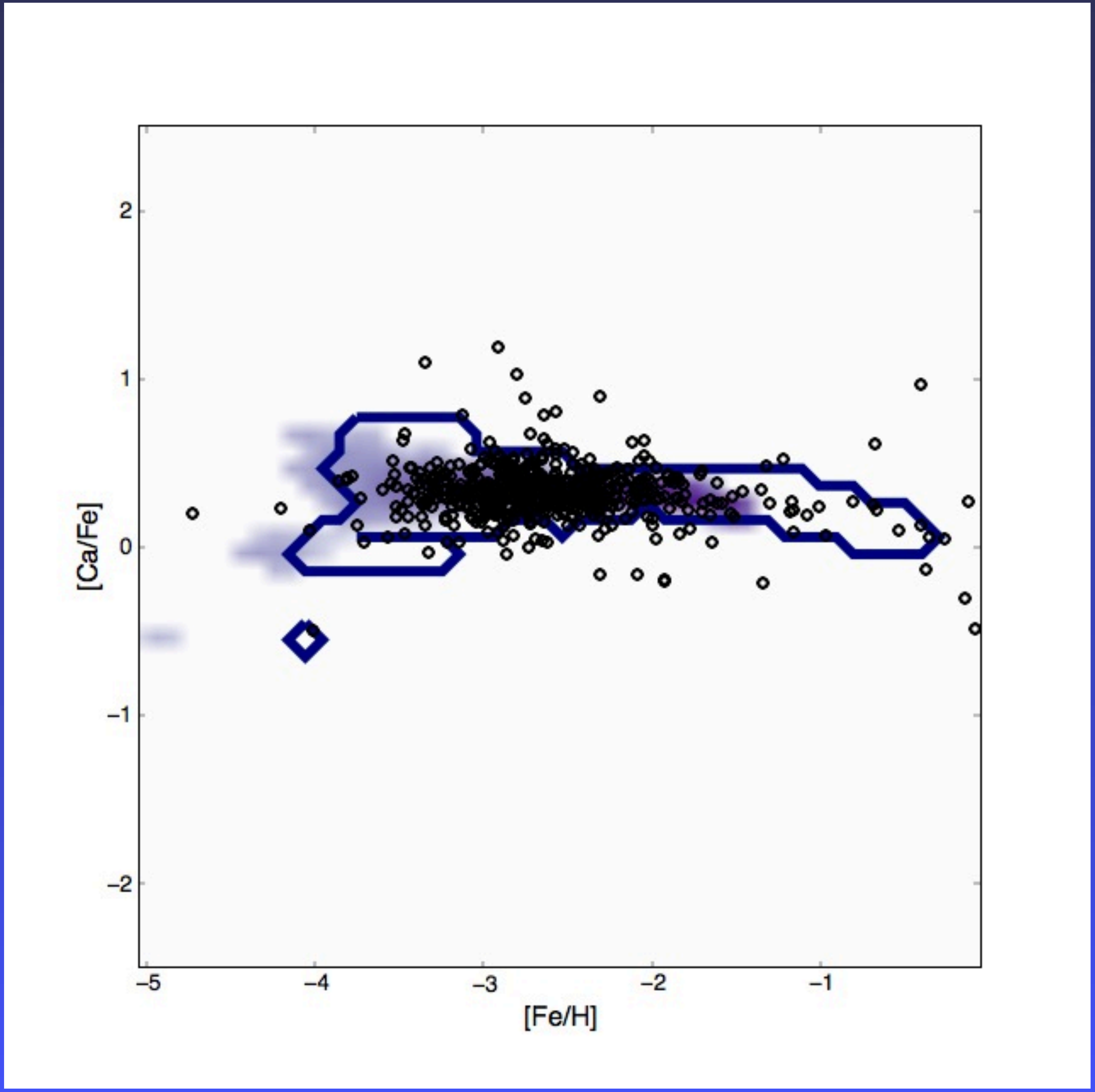

Conclusions

•Accreted stars populate different regions in the [Ba/Fe] vs [Fe/H] space compared to stars of the (inner) Galactic Halo.

•This chemical signature can be used to disentangle debris of accreted systems in the 4MOST data.

•The same does not hold for α-elements (& iron peak elements).

•*4MOST data can be also used to better constrain the nucleosynthesis of neutron capture elements.*

•*SPH simulations can provide more realistic SF histories for this systems, or they can be directly used implementing the nucleosynthesis of these elements.*

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EXTRA

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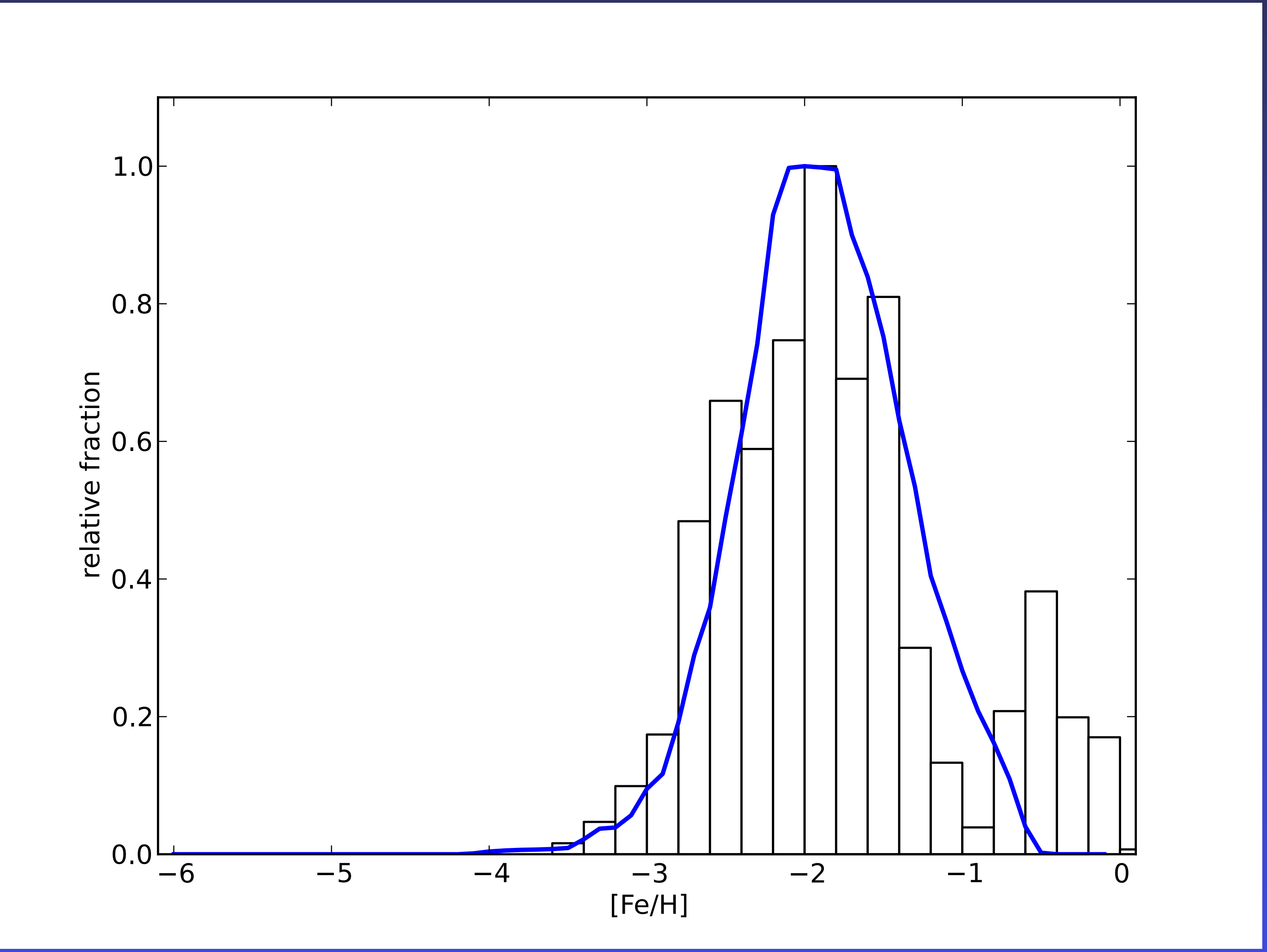
Comparison between the model MDF in blue line and the observed MDF by Li et al. (2010): main-sequence turnoff stars in the HESS (Hamburg ESO)



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AIP

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)

[Sr/Ba]

halo stars:
normal
cemp-s
cemp-no

[Fe/H]

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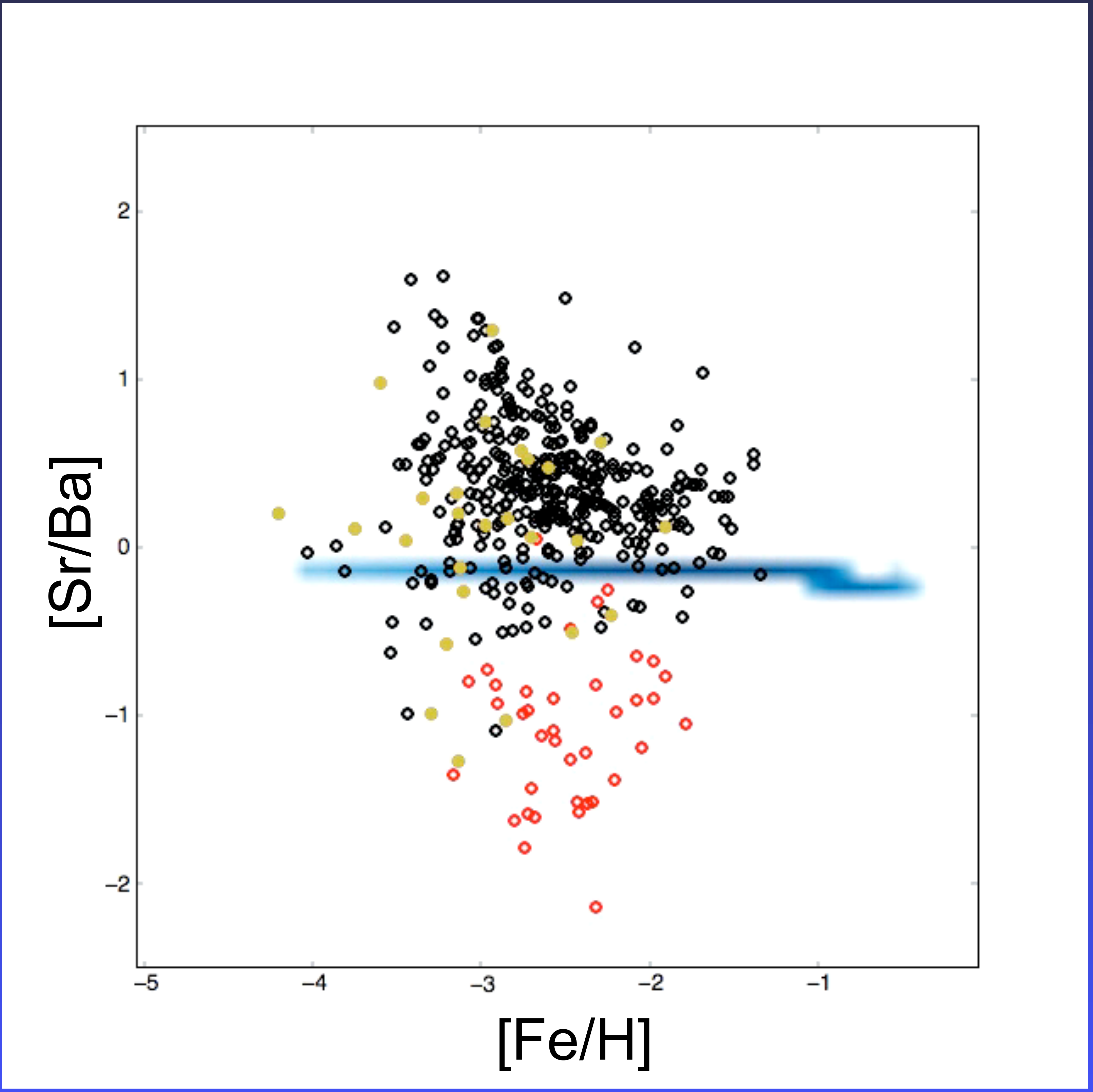

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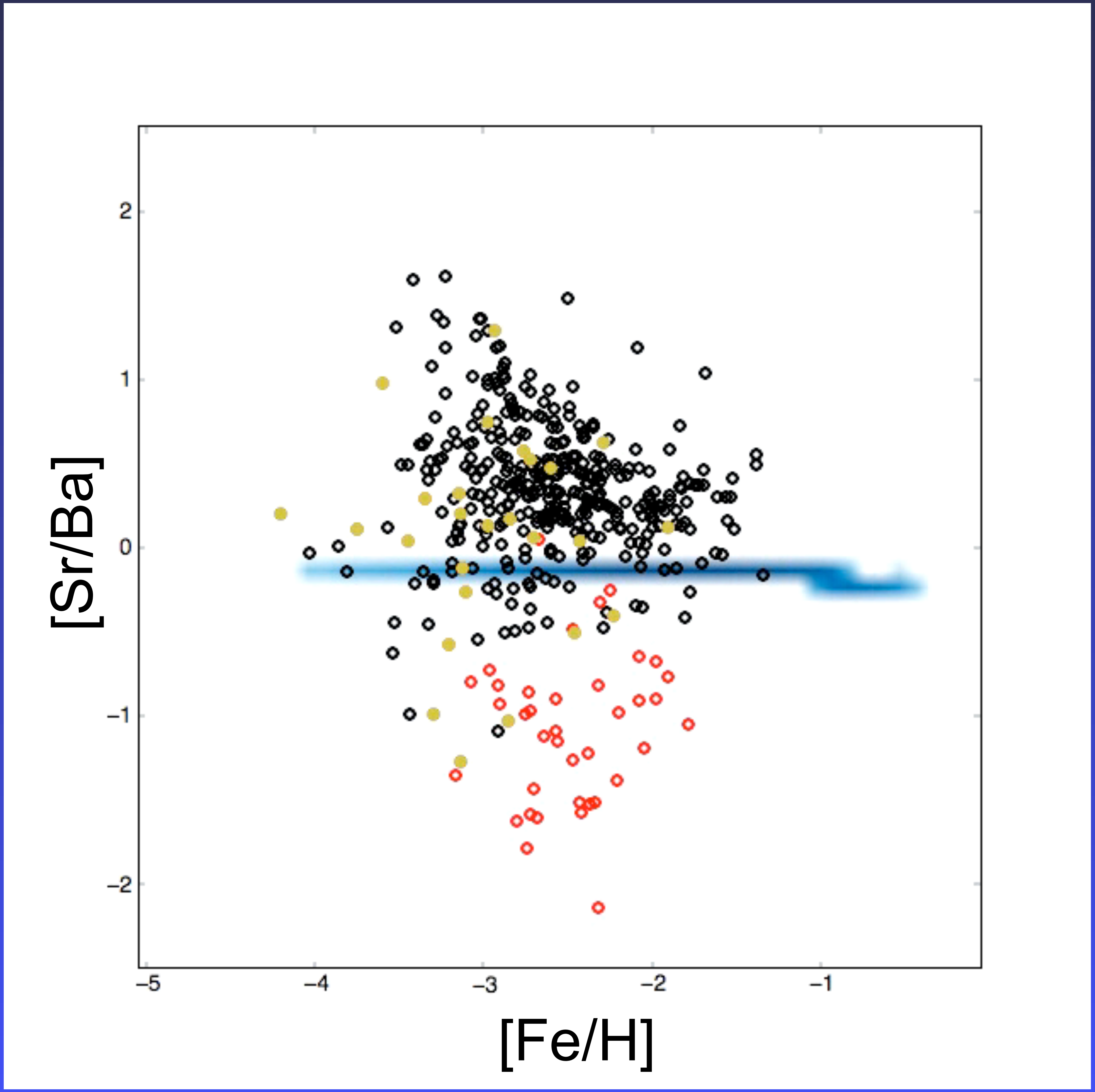

It is impossible to reproduce the data, assuming only the r-process component, enriching at low metallicity.
Well known issue
(talk Arcones, Hansen, Aoki)

halo stars:
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cemp-no

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

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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)

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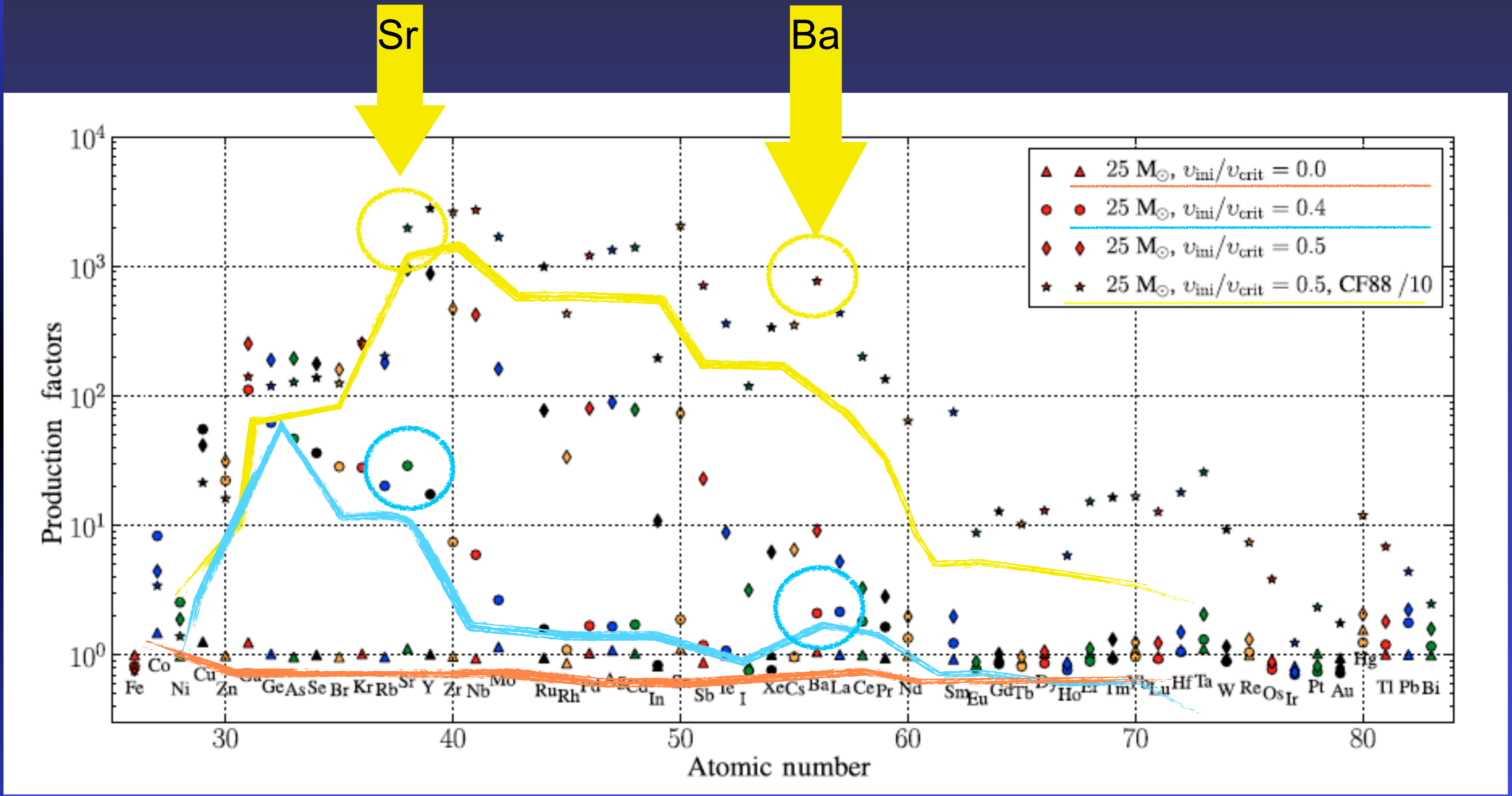
5^{th} signature: Fast rotators imprints in s-process elements?

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



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Boosted s-process from fast rotators

+ standard r-process site (the 2 productions are decoupled!)

Boosted models:
V_{ini}/V_{crit}=0.5
&
0.1
of the reaction rate suggested by Caughlan & Fowler '88 for ^{17}O (α, γ)

Boosted s-process from fast rotators assumed only for [Fe/H]<-3

Warning: this is a "rough" approach to reaction rate

[Sr/Ba]

[Fe/H]

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yields by Frischknecht et al. '12 + Frischknecht et al. in prep

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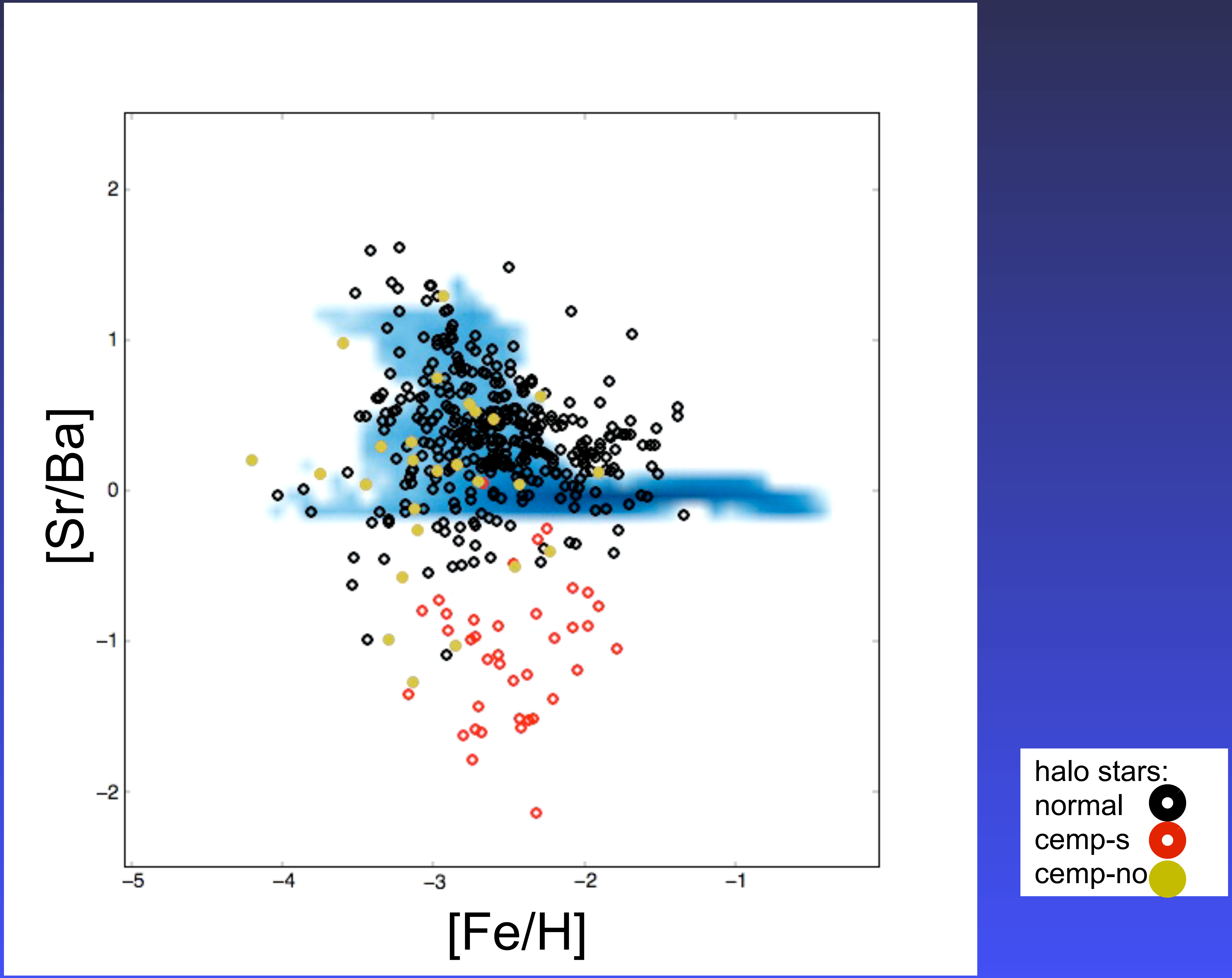

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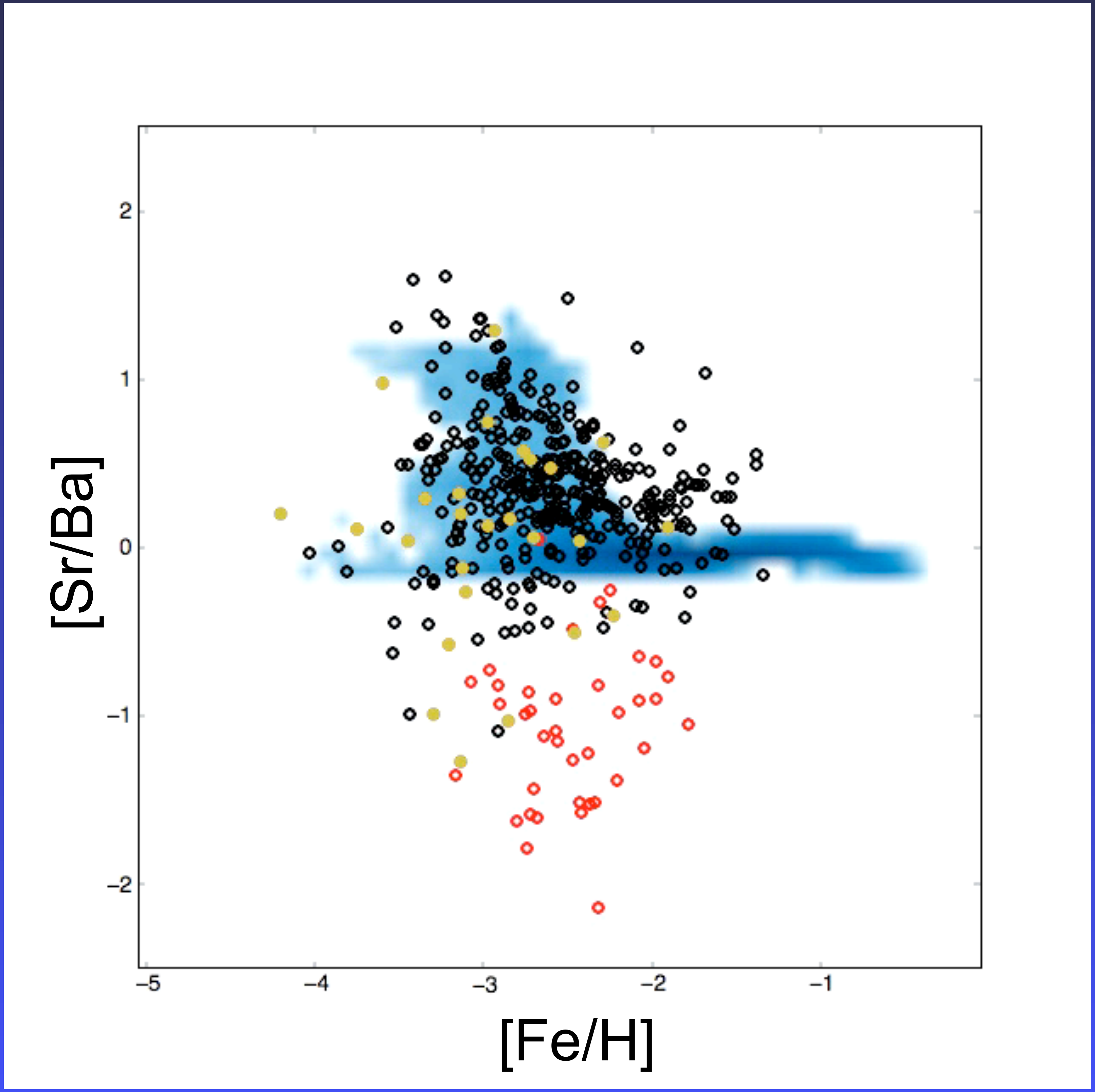

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Boosted s-process provide a solution!

halo stars:
normal
cemp-s
cemp-no

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Another puzzling correlation in halo stars

(see Montes et al. 2007, François et al 2007)

[Sr/Ba]

[Ba/Fe]

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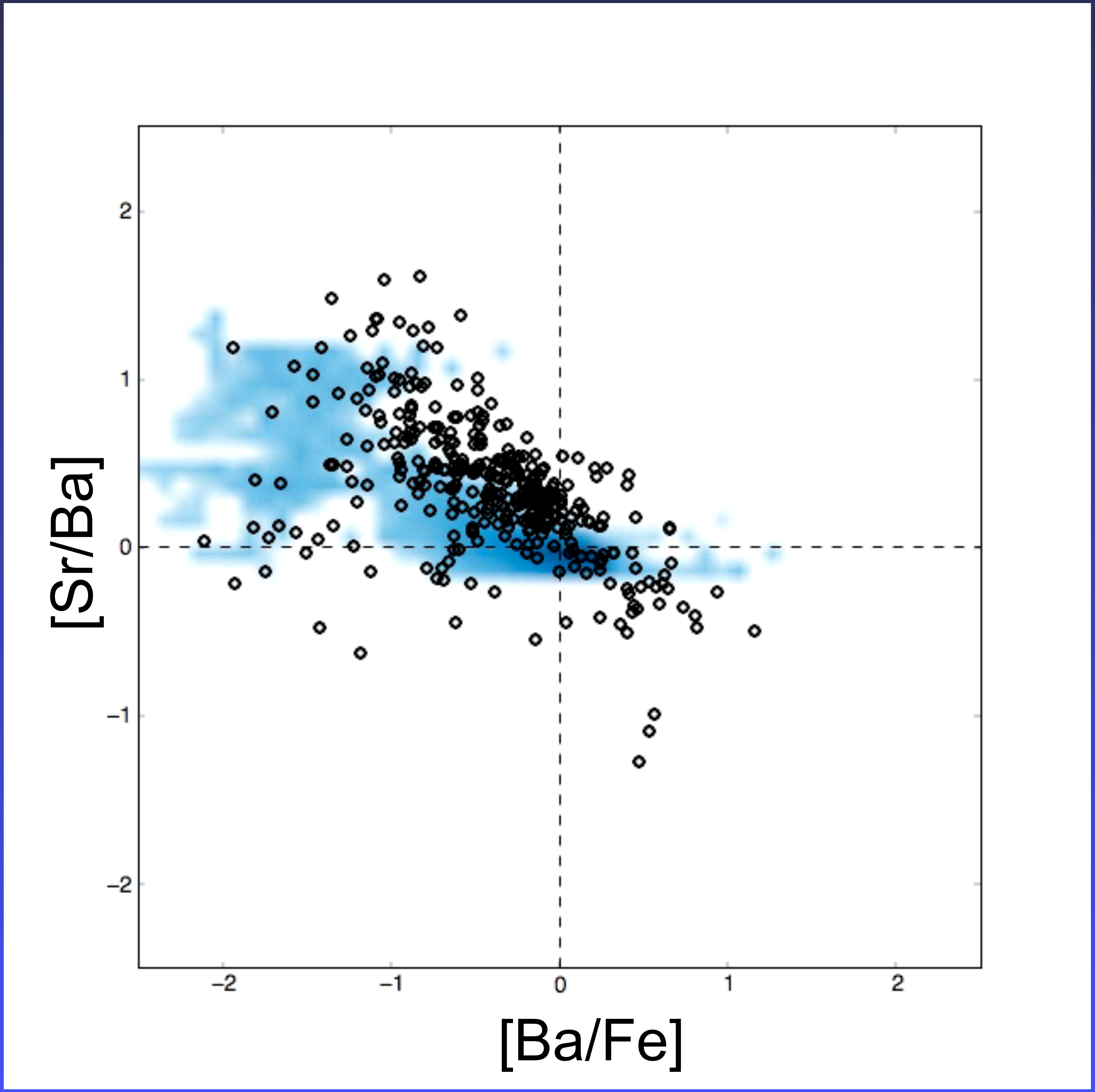

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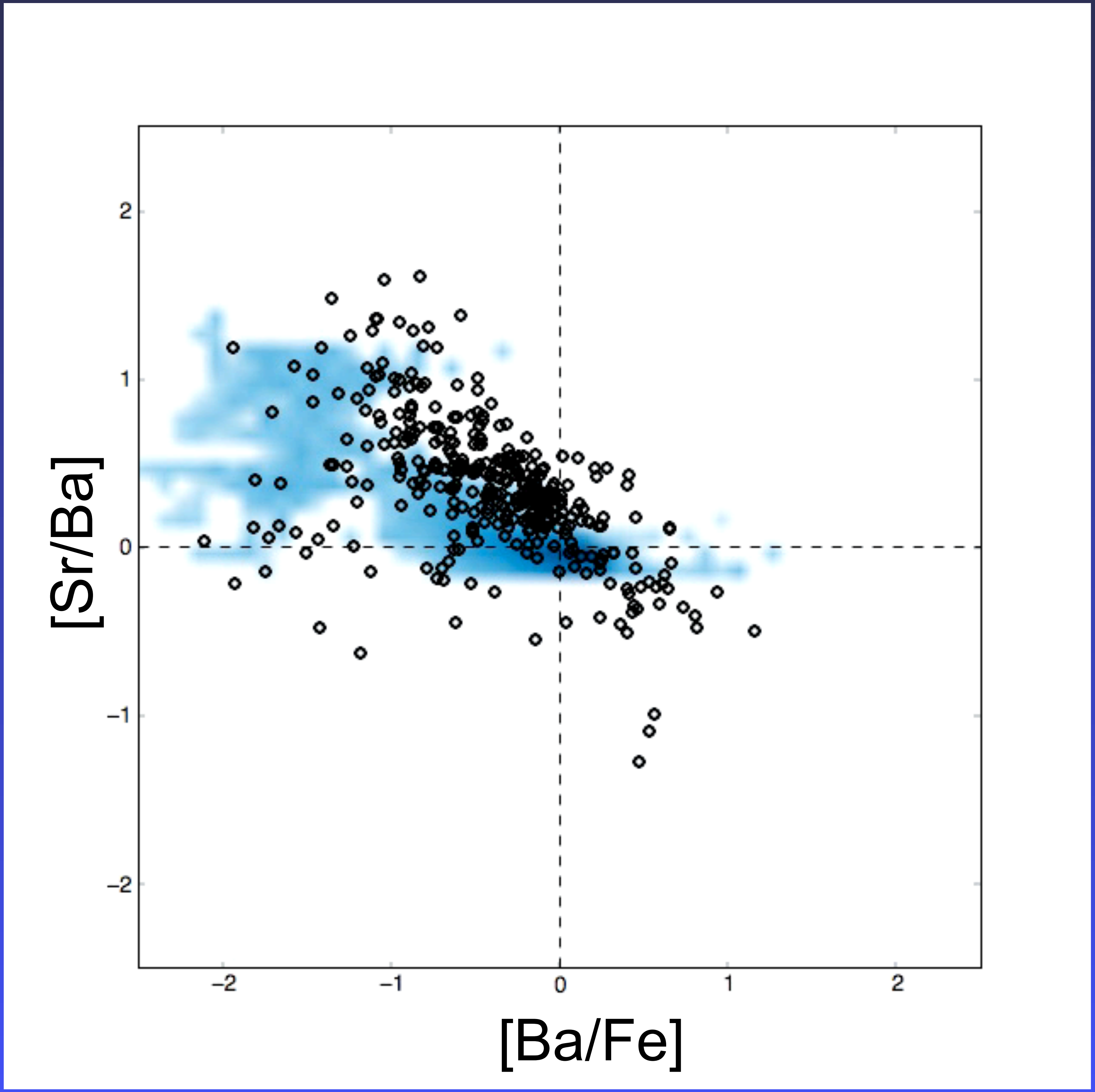
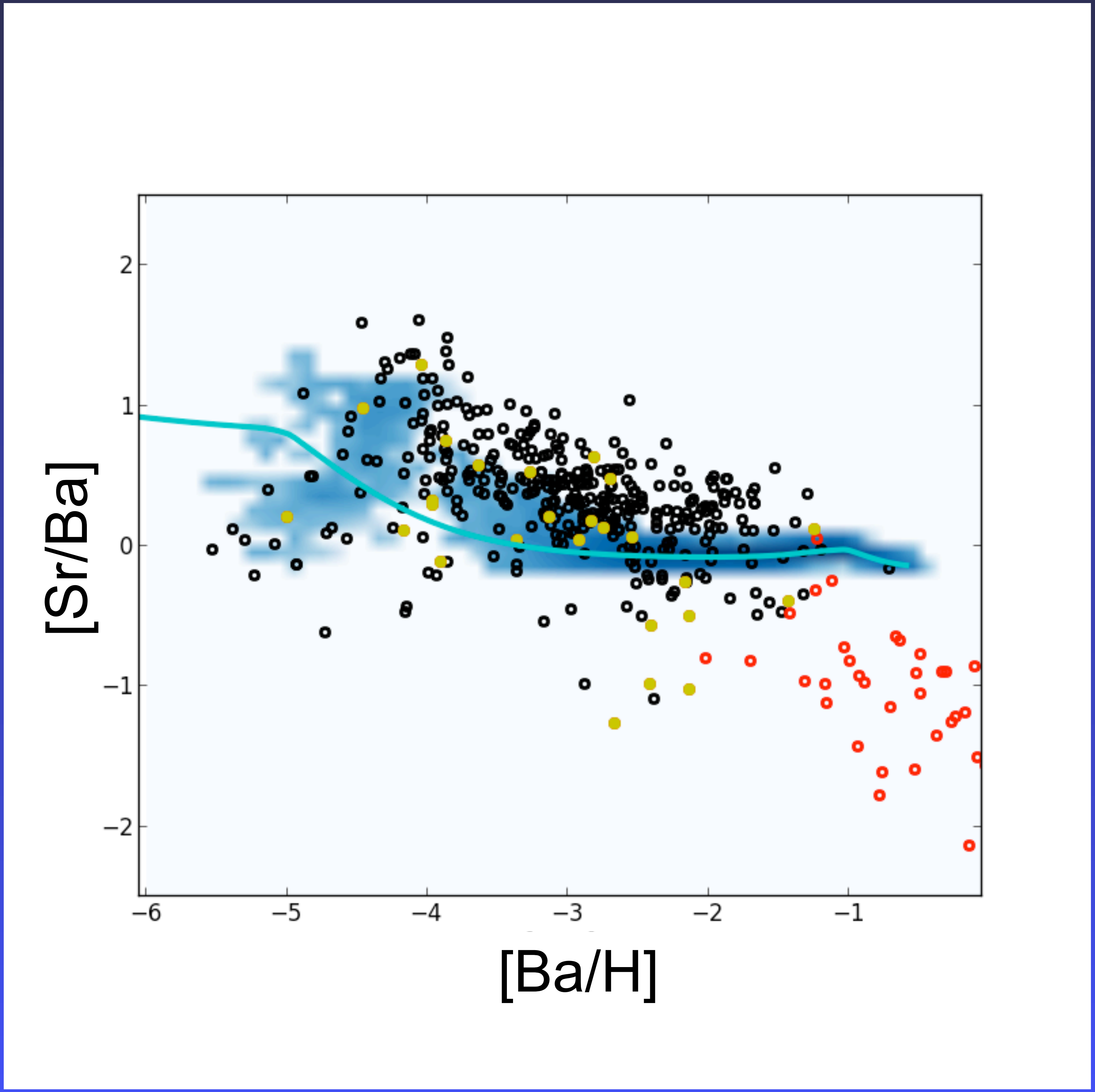


Again boosted s-process provides naturally a solution

EXTRA:

[Ba/Fe] with yields boosted s-process production
with 0.5 Vrot/Vcrit and change in the nuclear reaction rate



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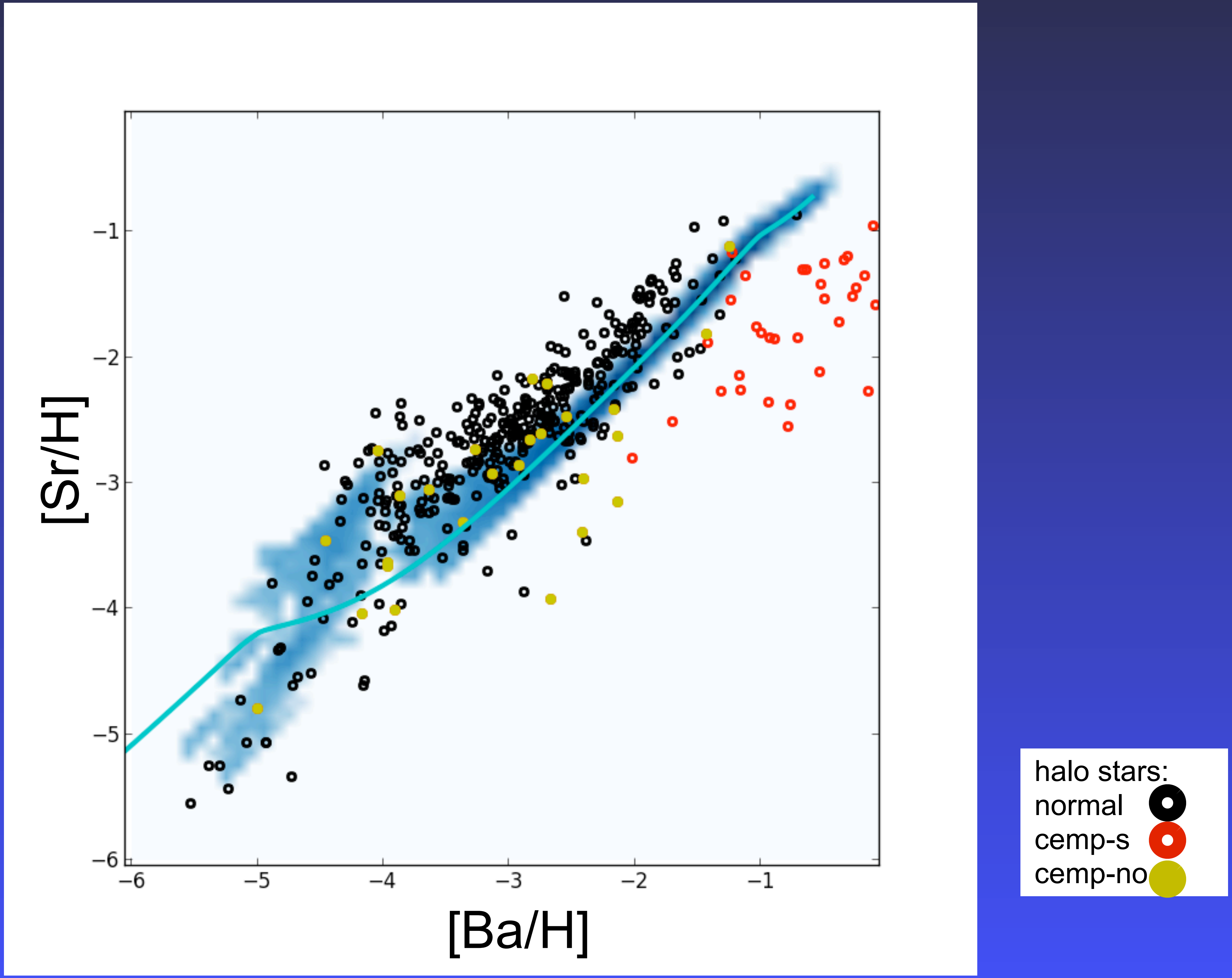

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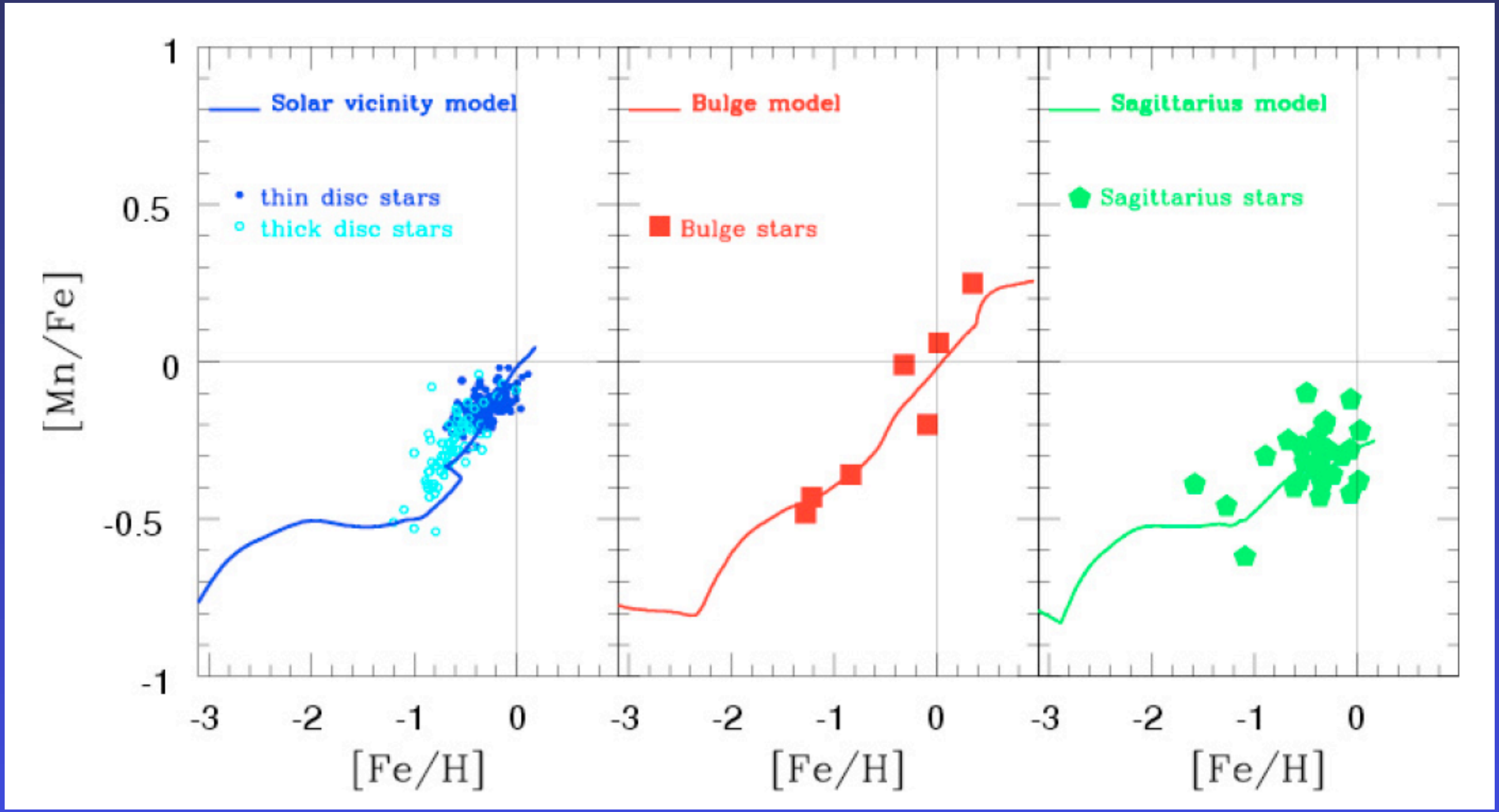
Also [Mn/Fe] ratio shows a chemical signature:
the SNIa enrichment metal dependent (see Cescutti et al. 2008)
produces different slopes that can be used as a signatures to infer different SF histories.



Again this is mostly seen in stars more “metal rich”

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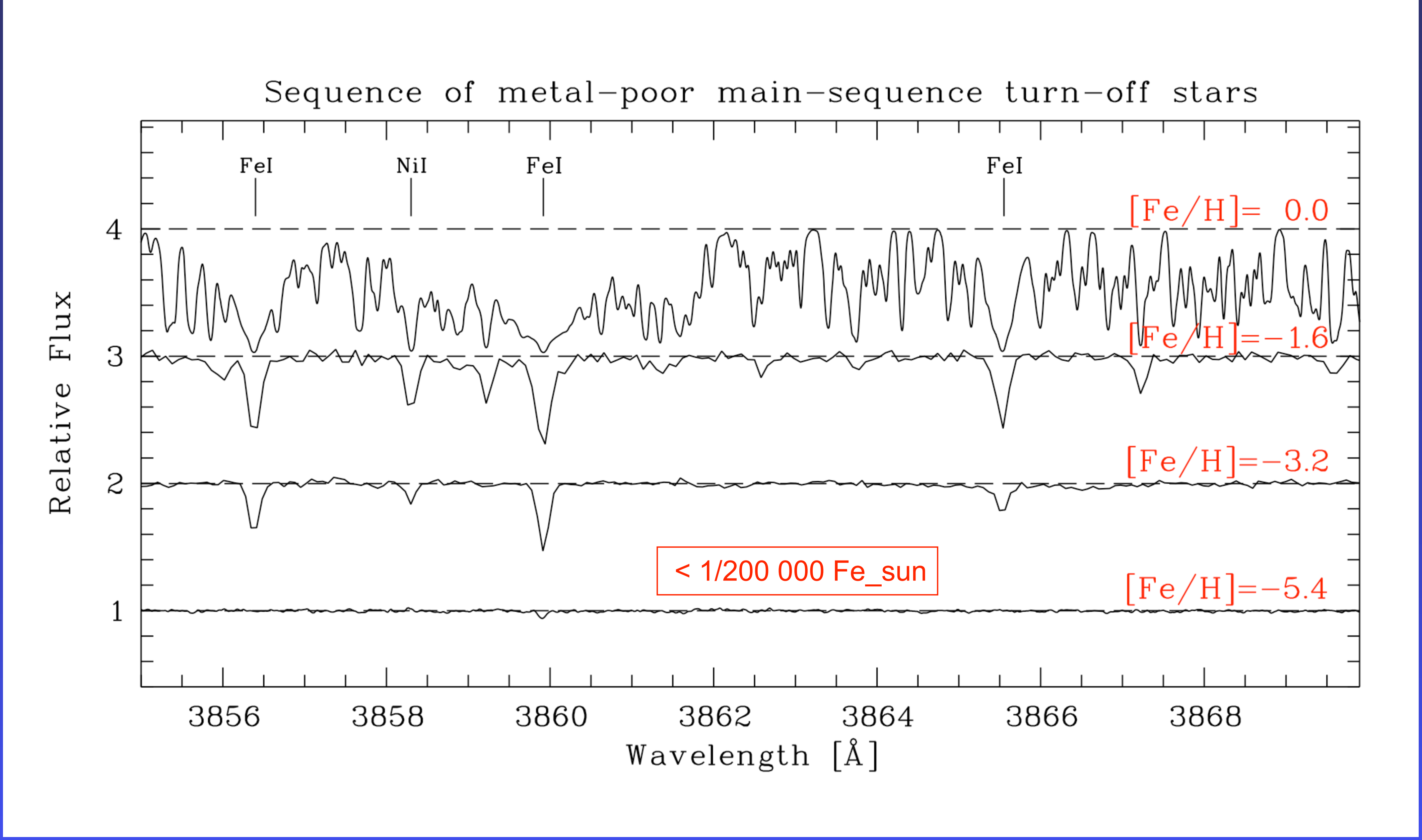
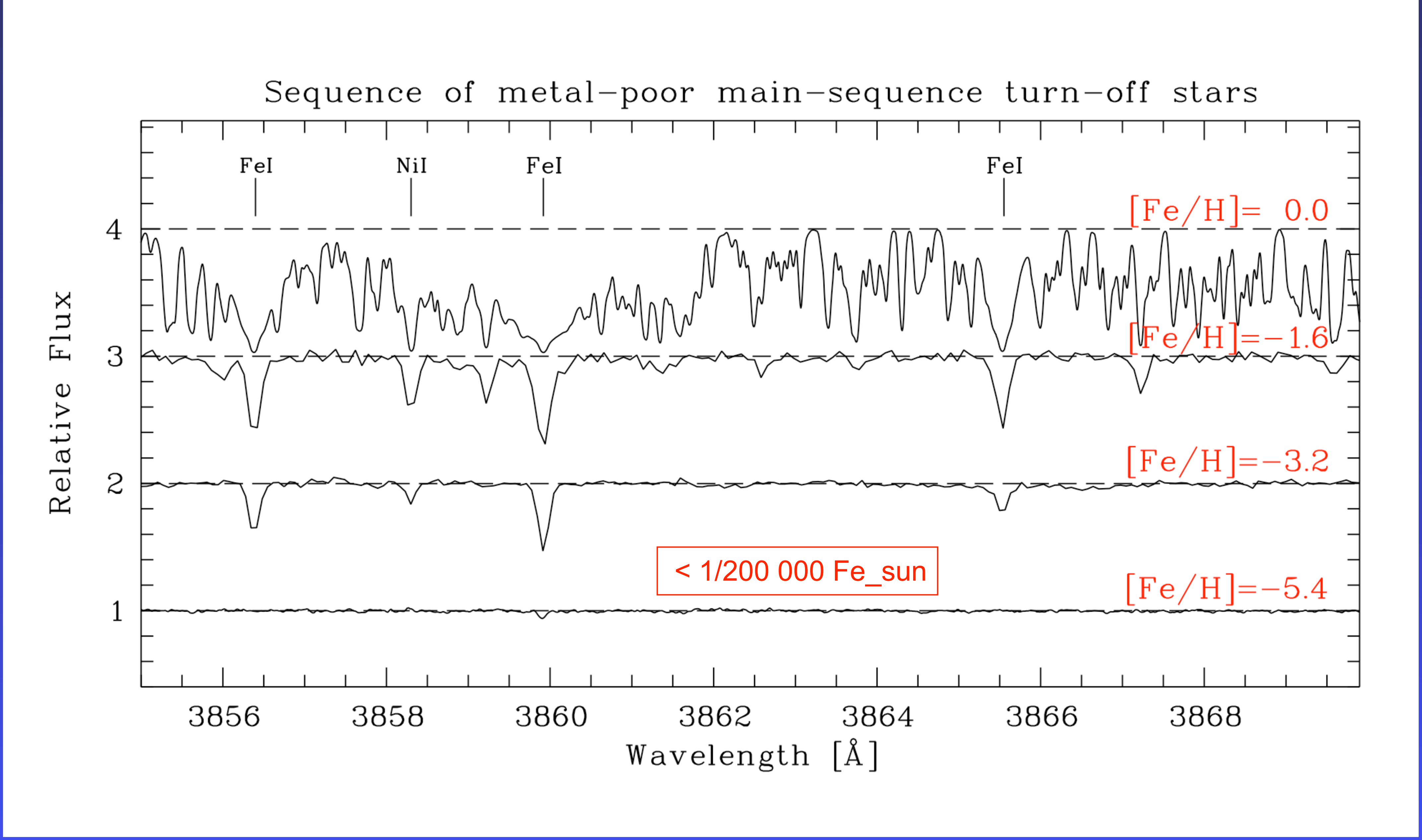


Frebel 2010 AN

The observational challenge:

Finding stars with [Fe/H] < -3 (large volume surveys) & Getting abundances



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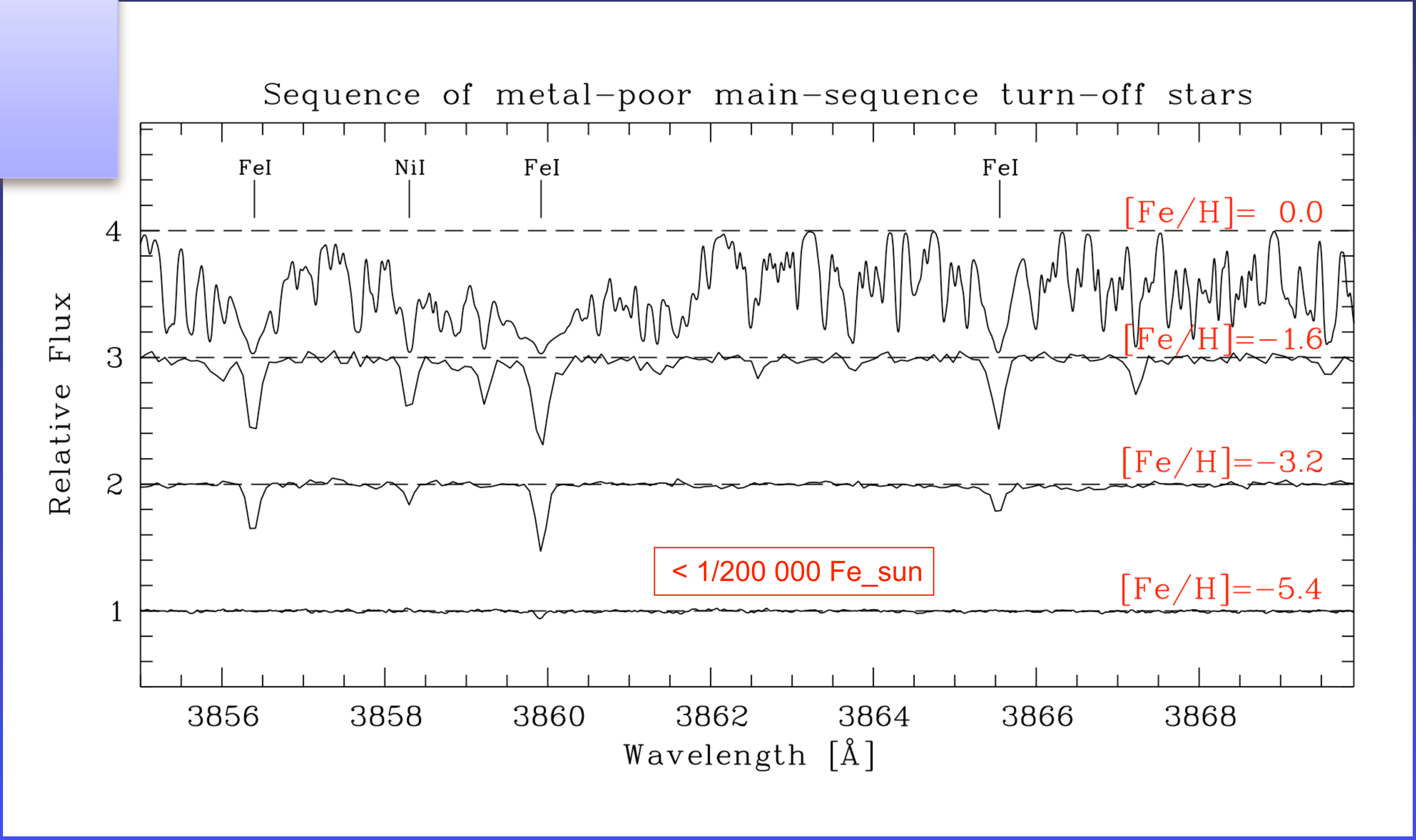
Confirmed fossil stars:

130 stars [Fe/H] < -3
14 stars [Fe/H] < -3.6
4 stars [Fe/H] < -4
2 stars [Fe/H] < -5



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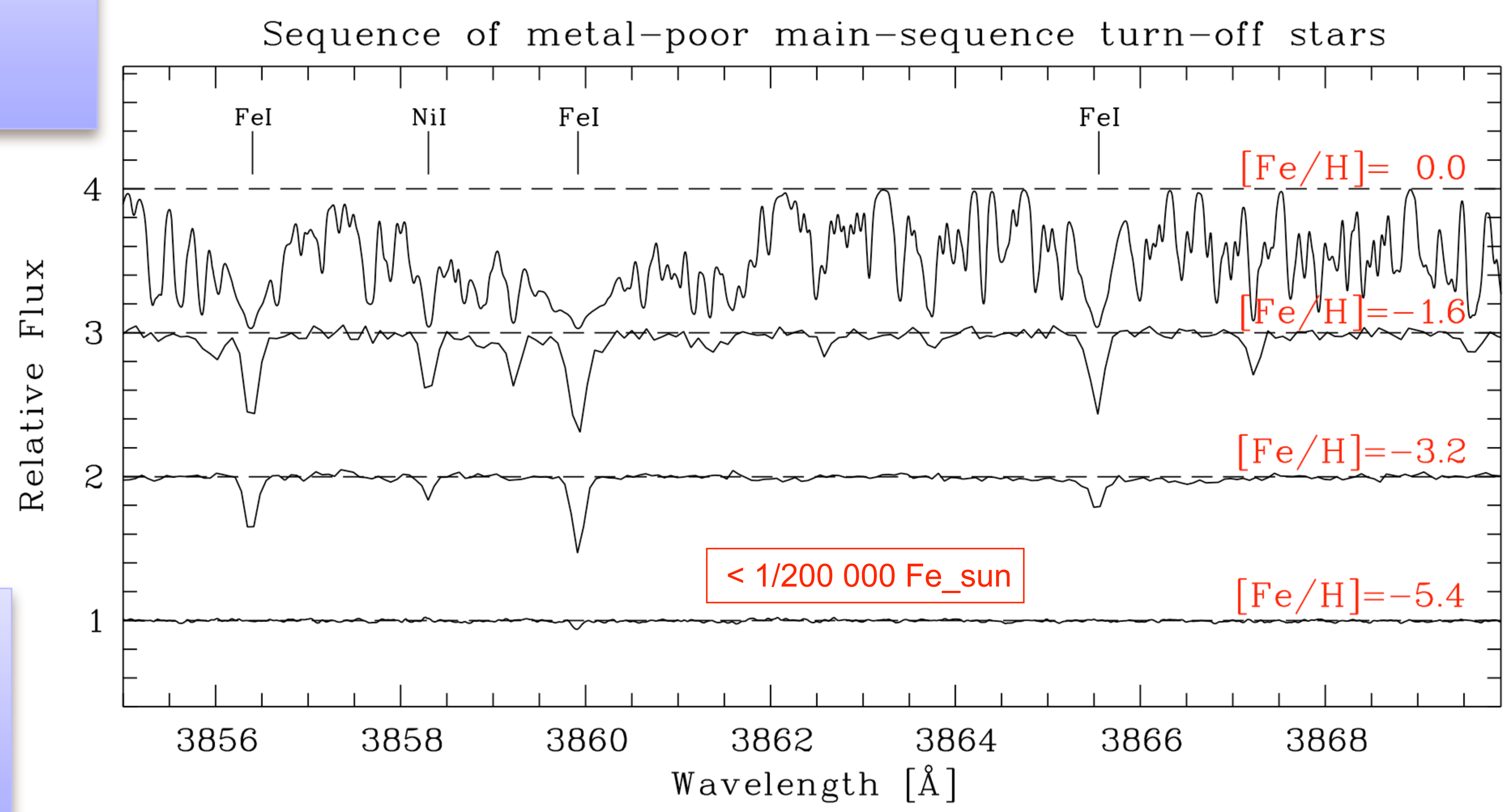

Typically "bright"

Outer halo still unexplored!

Bulge mostly unexplored!
High extinction

Frebel 2010 AN

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Signatures of Fast Rotators in the Early Universe 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)

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Naturally accounted for if the first stellar generations in the Universe were fast rotators

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

Fast rotating massive stars

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Solution for 4 signatures in the early Universe

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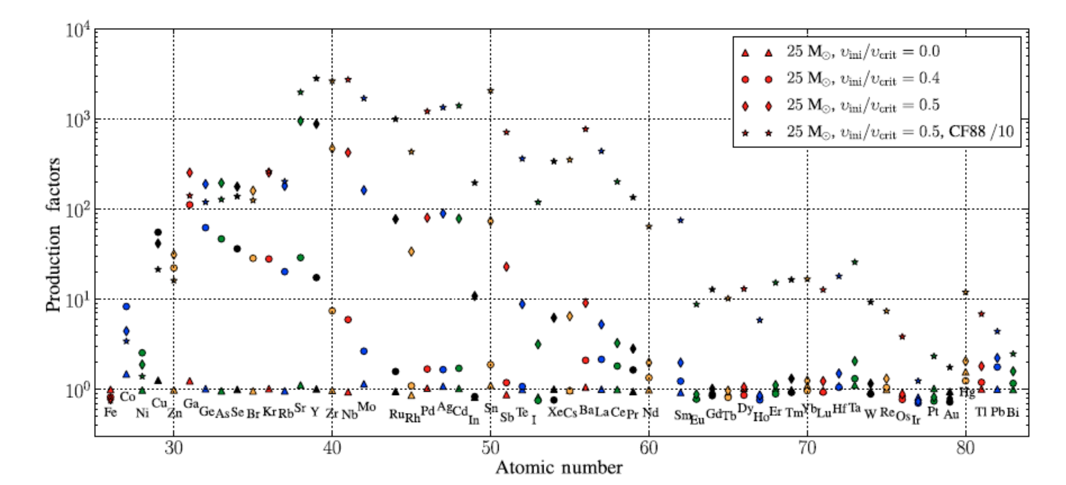

Models predict a boosted s-process

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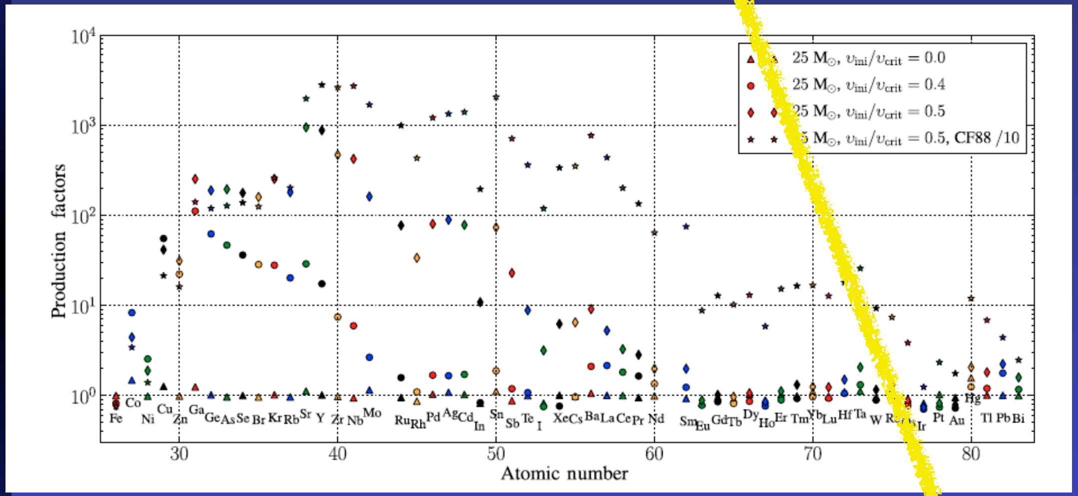

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<u>5th signature</u>: The boosted s-process can solve the puzzle of Sr/Ba

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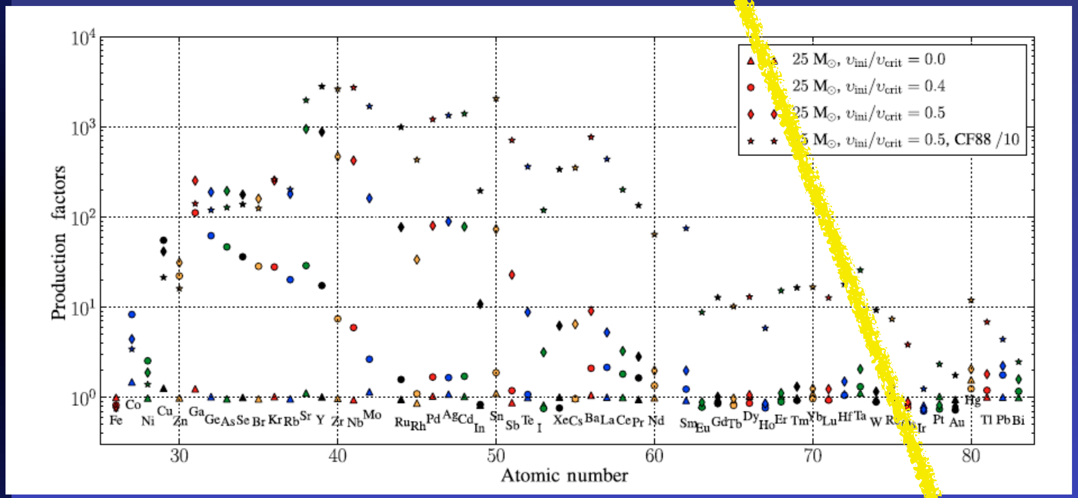

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In the Early Universe the stars were fast rotators