Chemical evolution of heavy elements in different stellar systems of the Local Group

Cescutti Gabriele
in collaboration with
Francesca Matteucci,
Gustavo Lanfranchi, Andrew McWilliam,
Patrick François, Cristina Chiappini

Astronomy Department
Trieste University

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Outline

- Galactic chemical evolution – introduction
- Studied stellar systems
- The Manganese in the three stellar systems
- The Oxygen in the Galactic bulge and in the Galactic disc
- The neutron capture elements and the comparison between dwarf spheroidal galaxies and the MW
- Description and results of a new inhomogeneous chemical evolution code
- Results for the radial gradients for different chemical elements in the disc of our Galaxy
- Conclusions

Galactic chemical evolution

Stars and interstellar gas in galaxies exhibit diverse chemical element abundance patterns that are shaped by their environment and formation histories.

The aim of Galactic Chemical Evolution is to use the observed abundances in stars and the interstellar medium to reconstruct the chemical history and so try to understand the mechanisms of galaxy formation and evolution, moreover, have an insight into the stellar evolution, giving constraints to the stellar yields.

Models for the chemical evolution of galaxies need to account for 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 are the ongoing accretion of gas from the outside of system and the possible presence of galactic winds.

Galactic chemical evolution

An homogeneous model follows the time evolution of the gas fraction of element A with this equation:

$$\dot{G}_A(R,t) =$$

$$\psi(R,t) = \nu G^k(R,t)$$

$$- X_A(R,t)\Psi(R,t) + X_A^{\inf\, all}\dot{G}_{\inf}(R,t) \quad - X_A(R,t)\dot{W}(R,t)$$

1) Locked in stars
Star formation

2) Infalling in the system
Accretion of gas

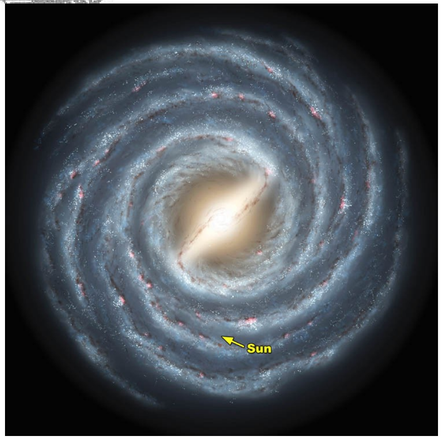
3)Flowing out the system
Galactic winds

$$+\int_M \Psi(R, t-\tau(\tilde{m}))\phi(\tilde{m})Q(\tilde{m}, Z(t-\tau(\tilde{m})))_A d\tilde{m}$$

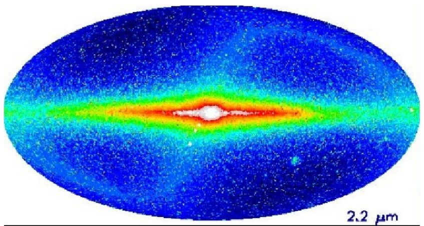
3) Produced by stars
Stellar winds-SNII-SNIa

Stellar nucleosynthesis

Studied stellar systems



Solar vicinity Located at about 8kpc from the centre of our Galaxy, belongs to the galactic disc within the Orion spiral arm.
We can resolve individual stars at all evolutionary phases.



Galactic bulge In the center of the Milky Way, the distribution of stars changes: a sign of a different component of the galaxy - the galactic bulge. It is hard to study the galactic bulge due to dust. But the dust is patchy, and there are holes which we can peek through, such as Baade's window.
Different teams were pursuing the detailed element abundances of bulge giant stars following the pioneering effort by McWilliam & Rich (1994).

Dwarf spheroidal galaxies They are low luminosity, dwarf elliptical galaxies with low surface brightness. The Milky Way has 12 identified dwarf spheroidal galaxies (dSphs) companions.
It is possible the measure the chemical abundances in red giant stars with high resolution spectroscopy.

Studied stellar systems 2

The different stellar systems have had different evolutions.
To account for these, their models present some main differences:

	Solar vicinity	Milky way Bulge	Dwarf spheroidals
ʋ Star formation Efficiency	1	20	<1
Wind	No	Yes	Yes
Infall Law	Two infall model (halo-disc)	One infall (short timescale!)	Depends on the dwarf spheroidal
More recent model	Cescutti et al. (2006)	Ballero et al. (2007)	Lanfranchi et al. (2008)

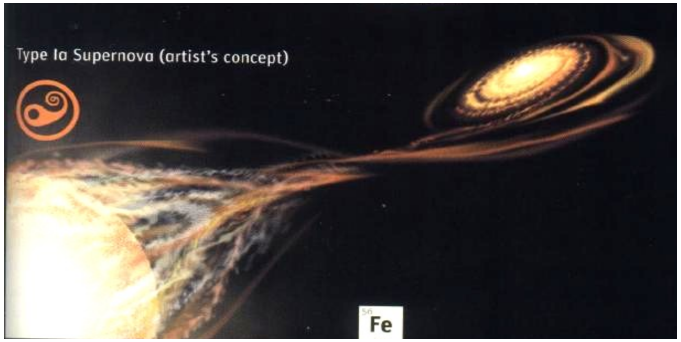
They share the same stellar nucleosynthesis!

Manganese and SNIa

The Mn in the ISM is enriched by two main sources (as iron!):
- Supernovae type II
- Supernovae type Ia (yields by Iwamoto et al.1999)

Important ingredient of GCE, produce ~30% of iron at the solar formation time. The scenario we take in account in the models for SNeIa is the single degenerate: a white dwarf accreting material from a companion giant star up to the Chandrasekhar limit.

Manganese is a gray-white metal, resembling iron. It is a hard metal and is very brittle, fusible with difficulty, but easily oxidized. Manganese metal and its common ions are paramagnetic.

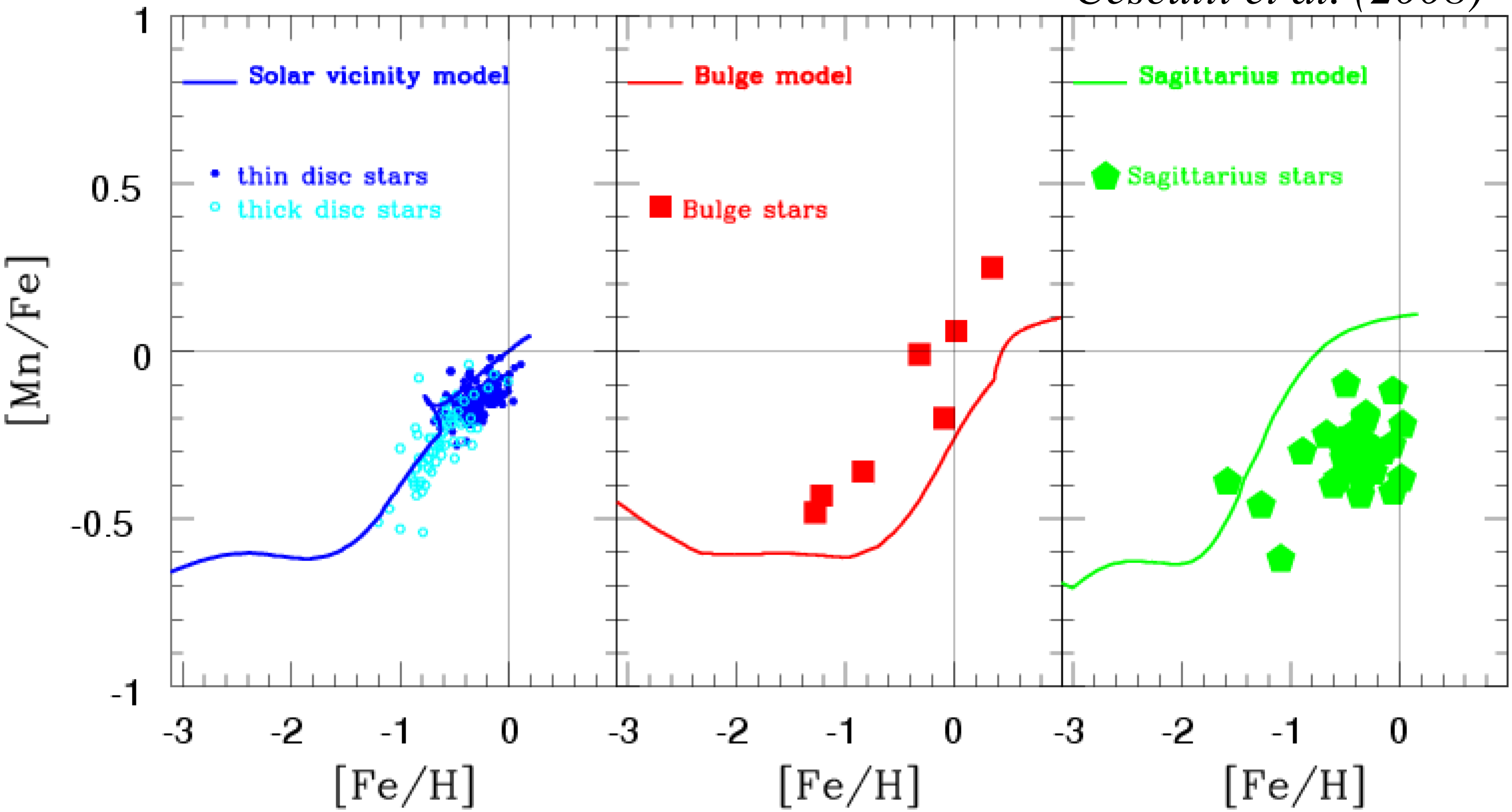


They have a long timescale, in the MW disc they start to be important at [Fe/H]=-1!

Manganese 1

The Mn in the three systems with the yields determined by François et al. (2004), to well fit the data of the MW disc (without metallicity dependence)

Cescutti et al. (2008)



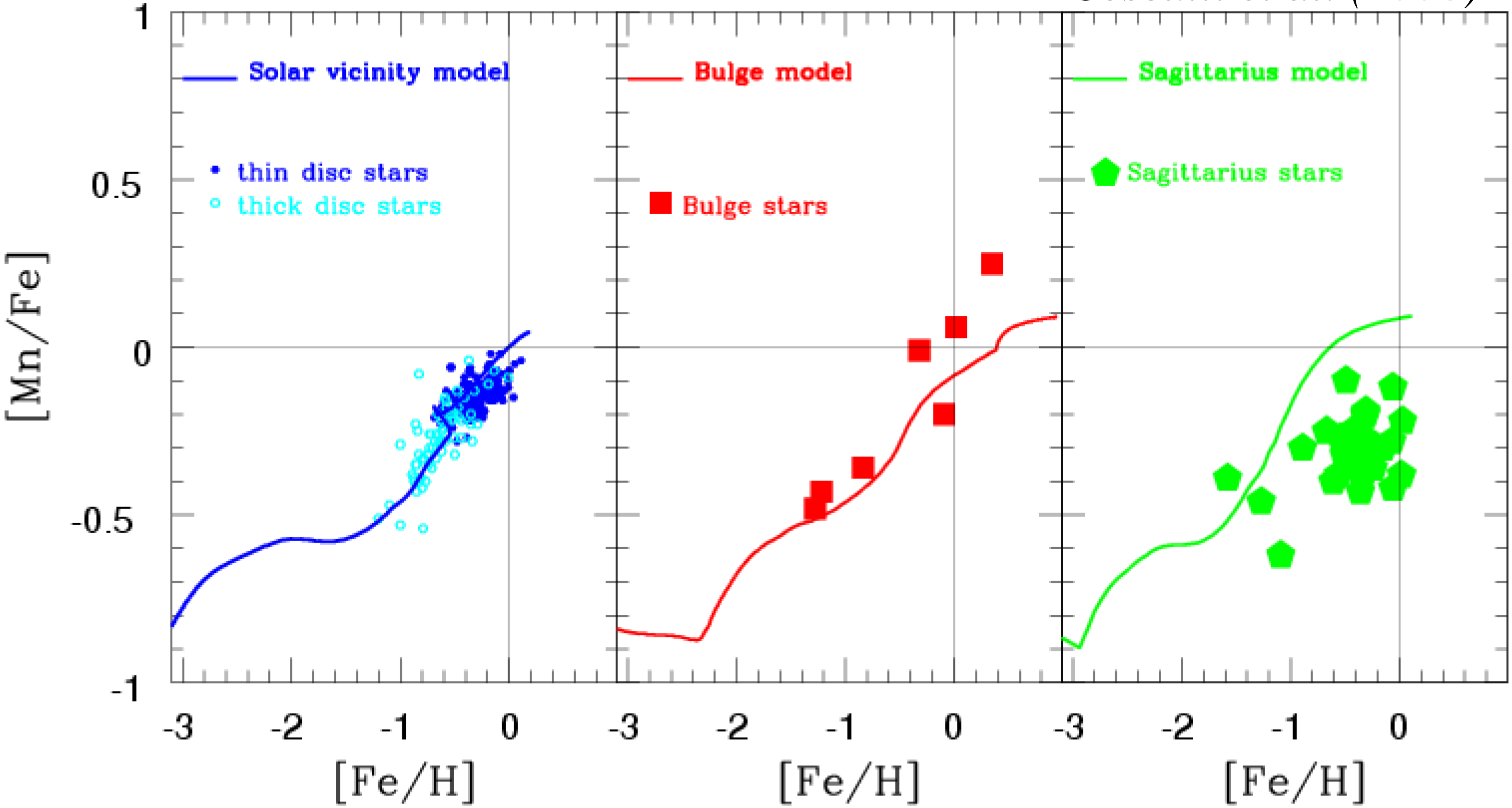
$[A / B]=\log_{10}[N_A / N_B]_{star} - \log_{10}[N_A / N_B]_{sun}$

Adopted solar values: Asplund et al. (2005)

Manganese 2

To improve the results for Mn we use the yields for SNII computed by Woosley & Weaver (1995), with metallicity dependence

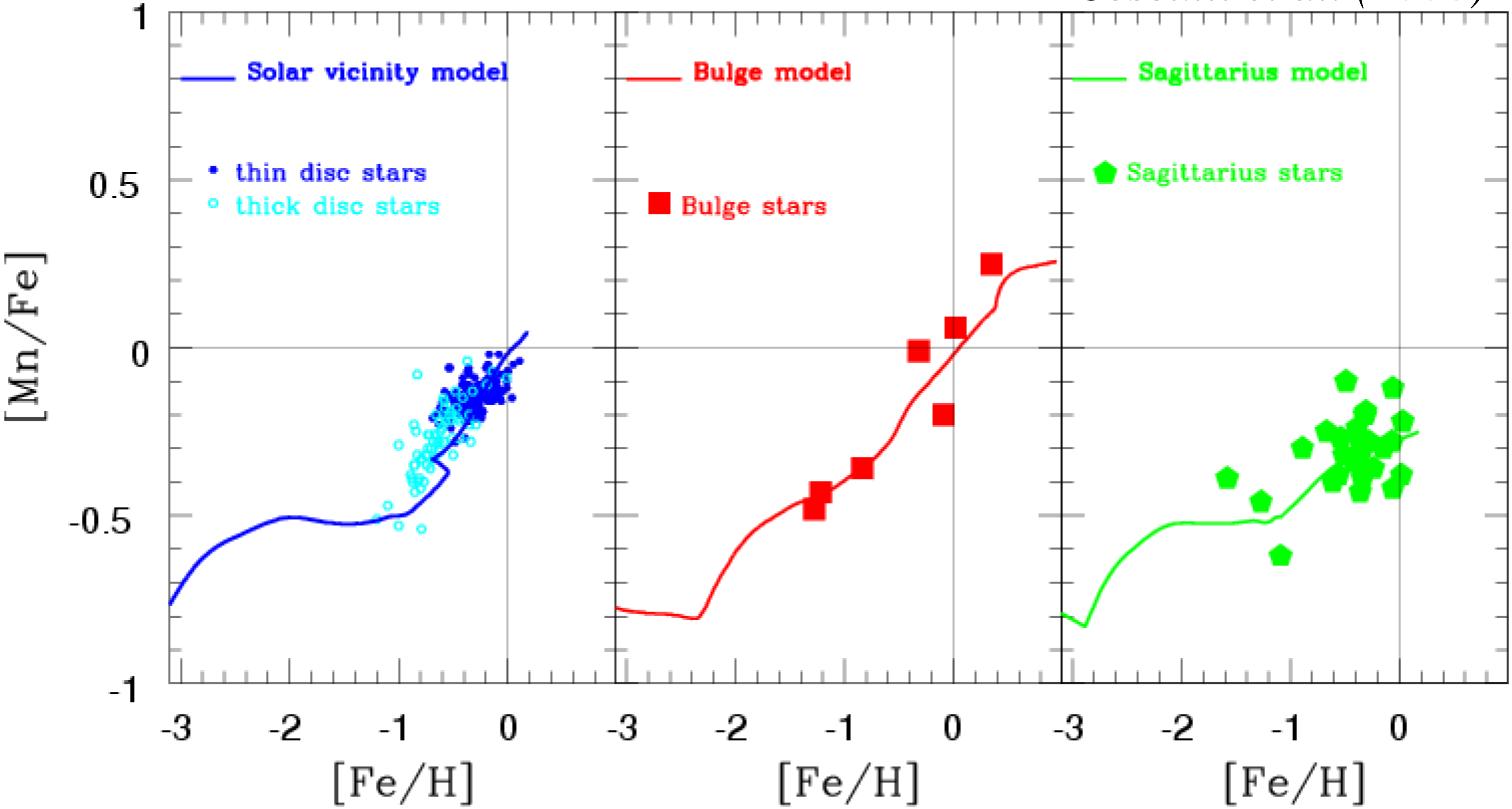
Cescutti et al. (2008)



Manganese 3

We explore the role of the SNIa yields, adopting yields again depending on the metallicity : $(Z/Z_{\odot})^{0.65}$ (cfr Badenes et al. 2008)

Cescutti et al. (2008)

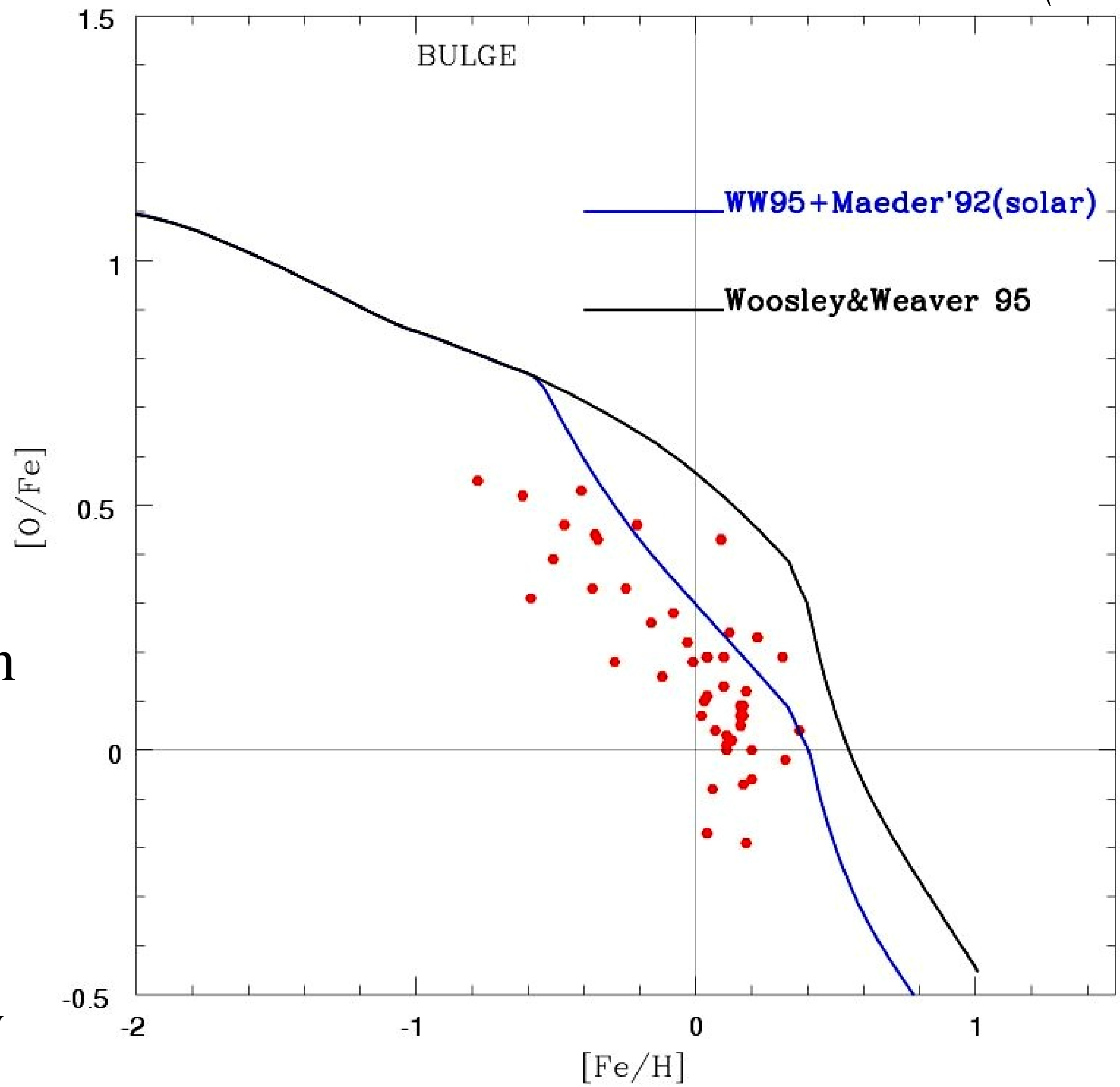


This solution to the Mn problem in Sagittarius was suggested by McWilliam et al. (2003)

Oxygen in the Bulge 1

The model for the Bulge with the oxygen yields of Woosley & Weaver('95) (the best fit for the solar vicinity, see François et al. 2004) does not fit the data for oxygen of this system.
We improve the results if we use the yields by Maeder '92 (which take in account the mass-loss in the massive stars), only for the solar metallicity.

McWilliam et al. (2008)



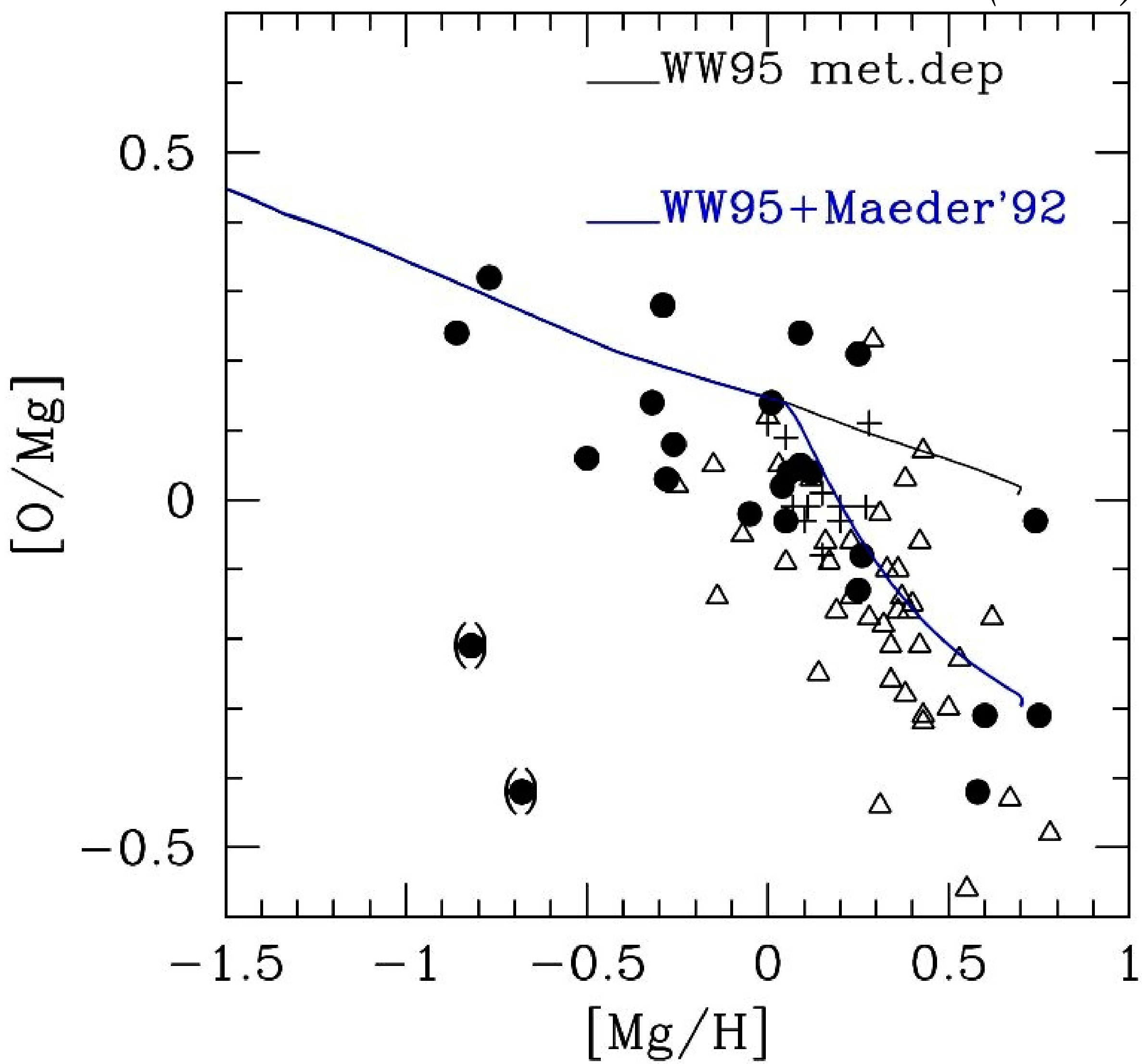
Observational data by Lecureur et al.(2007)

Oxygen in the Bulge 2

The improvement is clearer when we plot [O/Mg] vs [Mg/H].

The chemical evolution of Carbon is work in progress!

McWilliam et al. (2008)

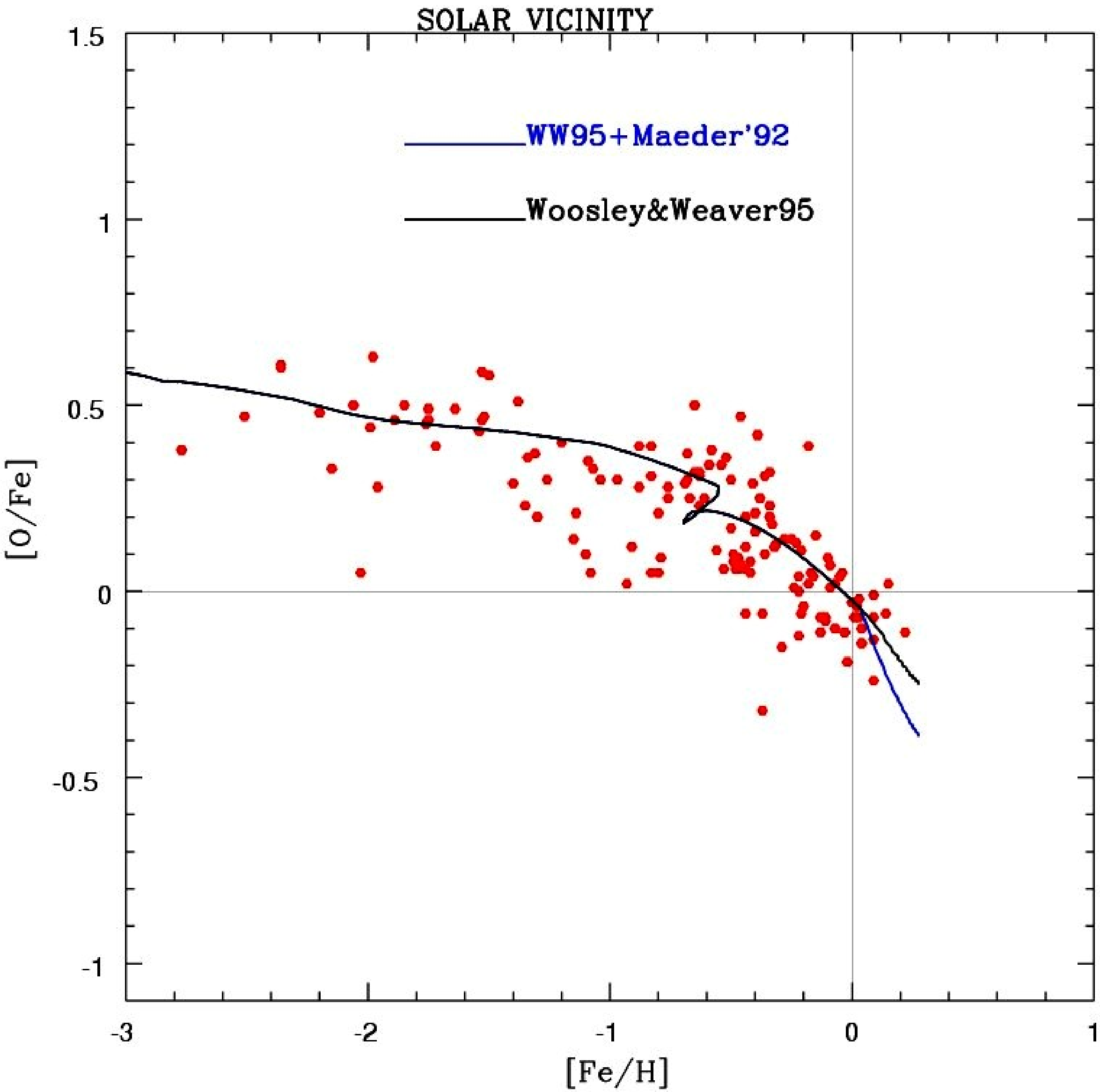


Observational data by
- △ Lecureur et al.(2007)
- ● Fulbright et al.(2007)
- + Origlia et al.(2005)

Oxygen in the solar vicinity

The model for the solar vicinity fits the data with the yields of Woosley &Weaver ('95) (cfr. François et al '04).

However, the model with the yields by Maeder ('92) does not change the results in the solar vicinity up to solar



Neutron capture elements: r-s process

The elements beyond the iron peak (A>60) are formed through neutron capture on seed nuclei (iron and silicon).

Two cases:

s-process

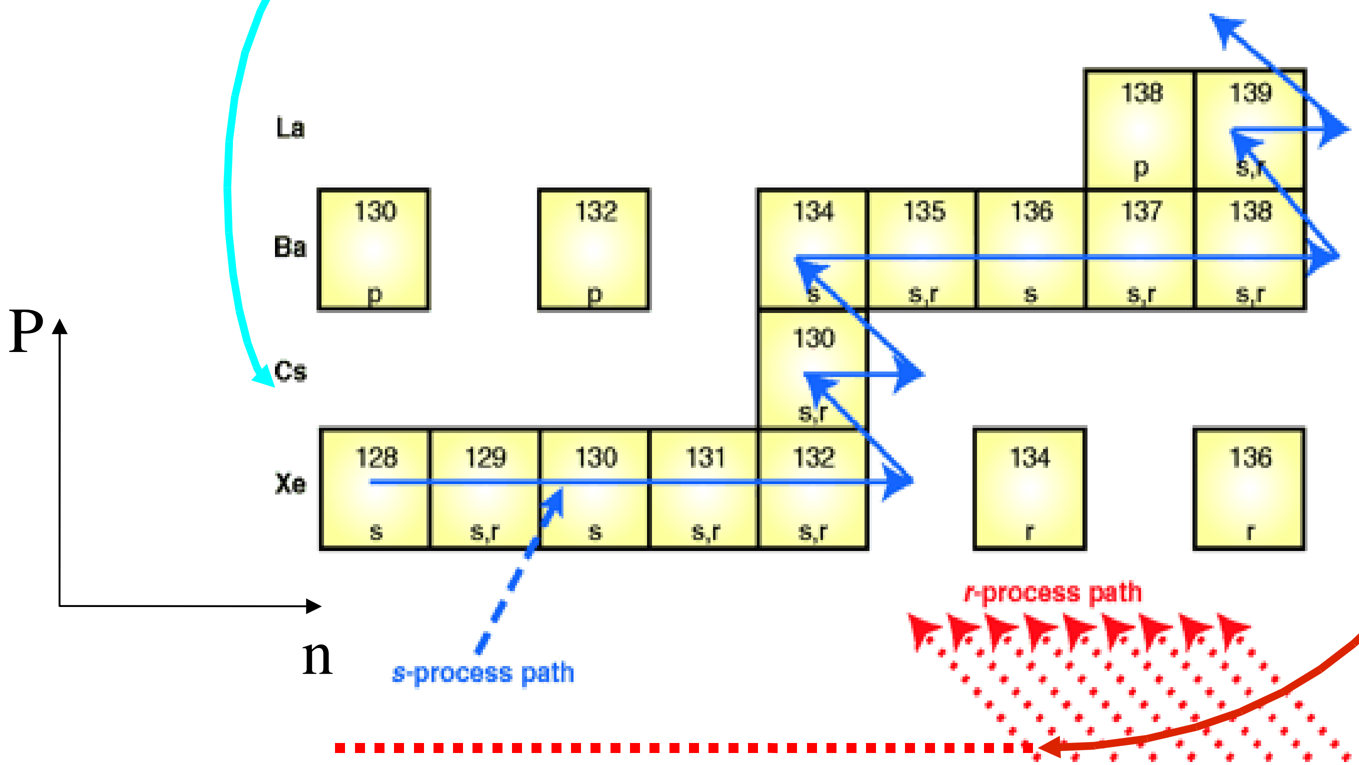
Different Timescale of the neutron capture

r-process

$\tau_{\beta} \ll \tau_{c}$

Different process path

$\tau_{\beta} \gg \tau_{c}$



Yields for neutron capture elements

s-process:

r-process:

where

low mass AGB stars

explosions of SNe II (?)

Nucleosynthesis prescriptions

Busso et al. (2001)

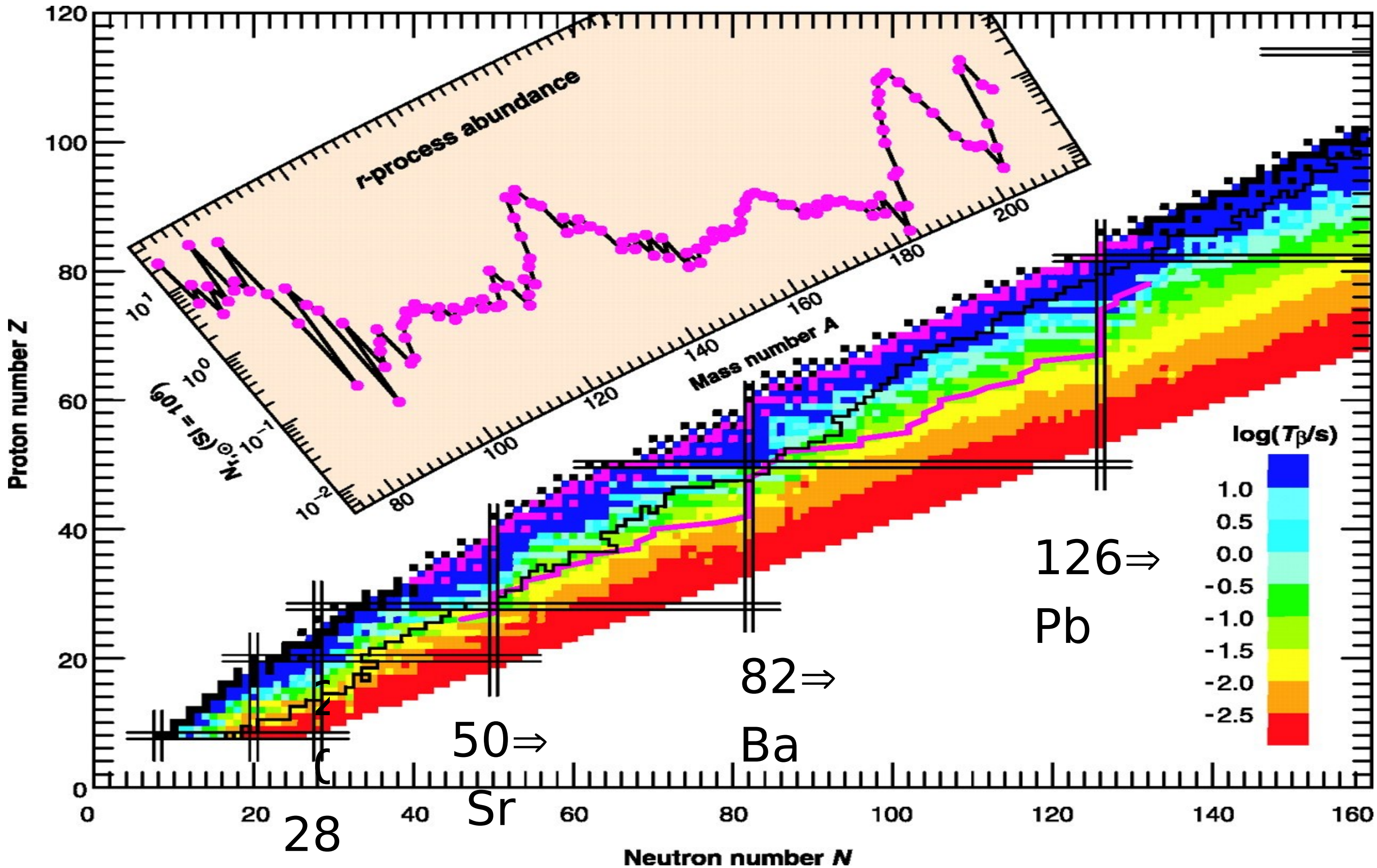
for Ba, La, Sr, Y & Zr

No theoretical computations

(see Travaglio et al. 2004)

We use these which best fit the data:

M_{star}	Q_{Sr}	Q_Y	Q_{Zr}	Q_{Ba}	Q_{La}	Q_{Eu}
$10M_{sun}$	$1.62\ 10^{-6}$	$8.60\ 10^{-7}$	$1.80\ 10^{-6}$	$9.00\ 10^{-7}$	$9.00\ 10^{-8}$	$4.50\ 10^{-8}$
$15M_{sun}$	$5.40\ 10^{-8}$	$1.20\ 10^{-8}$	$1.80\ 10^{-7}$	$3.00\ 10^{-8}$	$3.00\ 10^{-9}$	$3.00\ 10^{-8}$
$30M_{sun}$	$3.25\ 10^{-9}$	$1.00\ 10^{-9}$	$5.00\ 10^{-9}$	$1.00\ 10^{-9}$	$1.00\ 10^{-10}$	$5.00\ 10^{-10}$



The stable nuclides are marked by black boxes; n-capture in s-process synthesis occurs near these nuclei. The jagged diagonal black line represents the limit of experimentally determined properties of nuclei, and the magenta line represents the r-process "path." Vertical and horizontal black lines represent closed neutron or proton shells. Color shading denotes the different (log) time scales for β -decay.

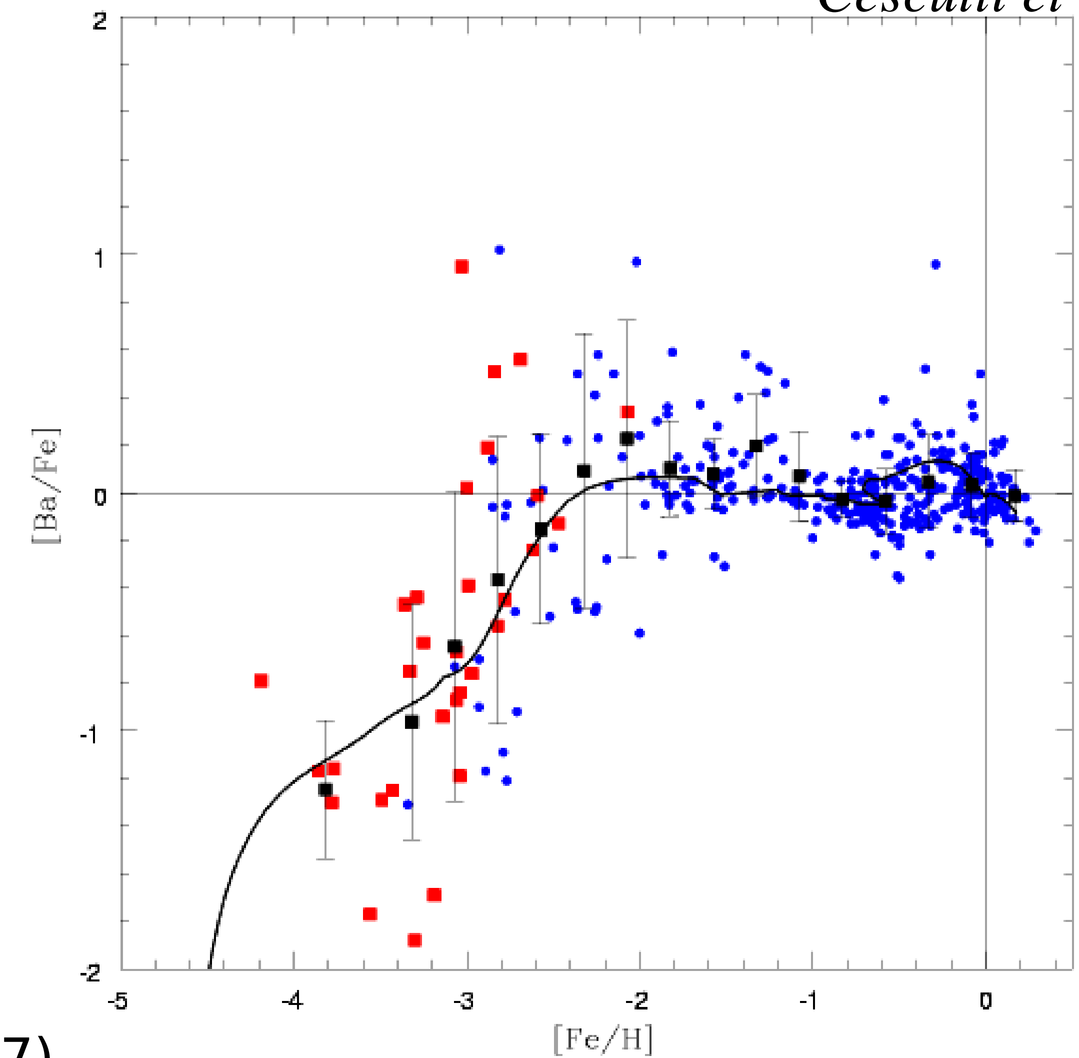
Barium

s-process
low mass stars
1-3M$_{sun}$
Busso et al.

+

r-process
massive star
10-30M$_{sun}$
(previous table)

Cescutti et al. (2006)

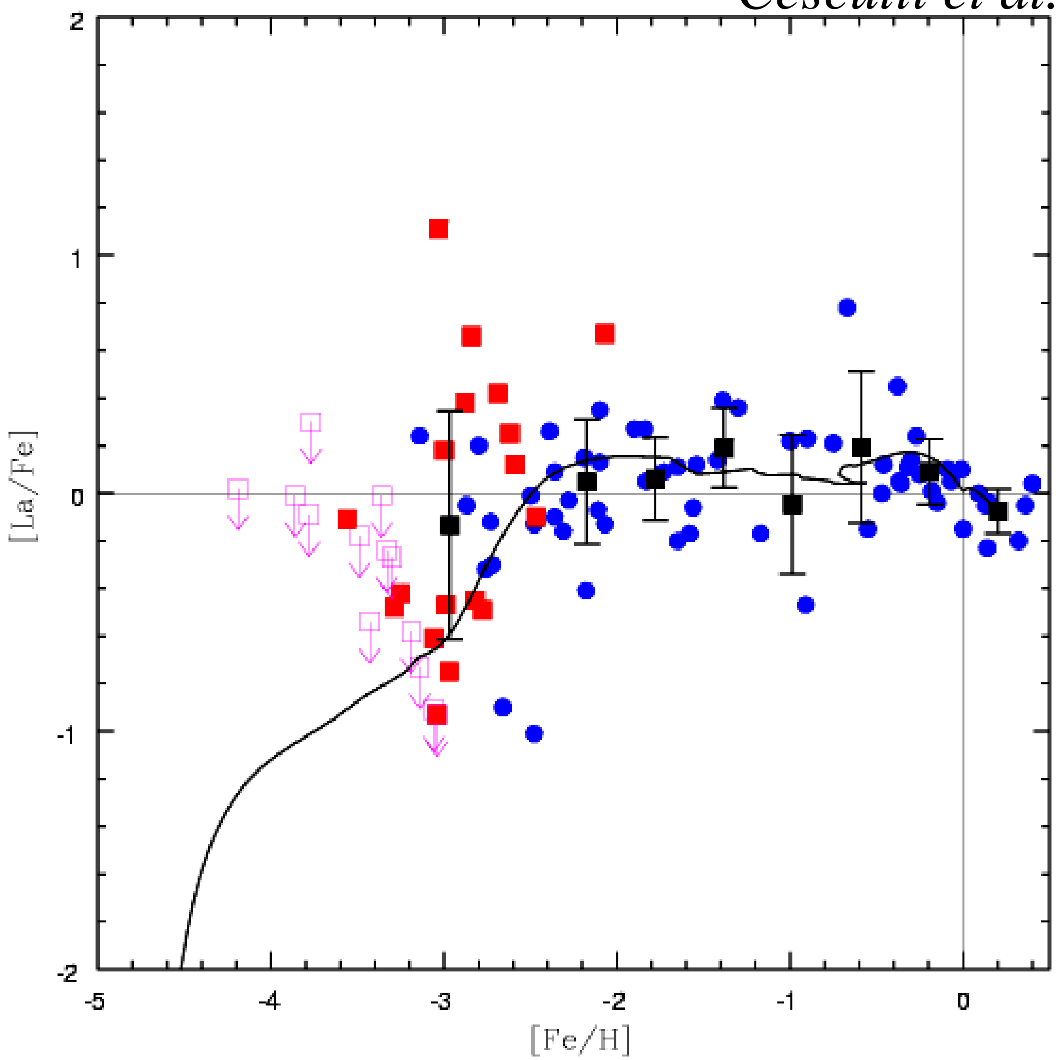


Observational data:

- François et al.(2007)
- Honda et al (2004) & other authors

Lanthanum

Cescutti et al. (2007)



s-process
low mass stars
1-3M_{sun}
Busso et al.

+

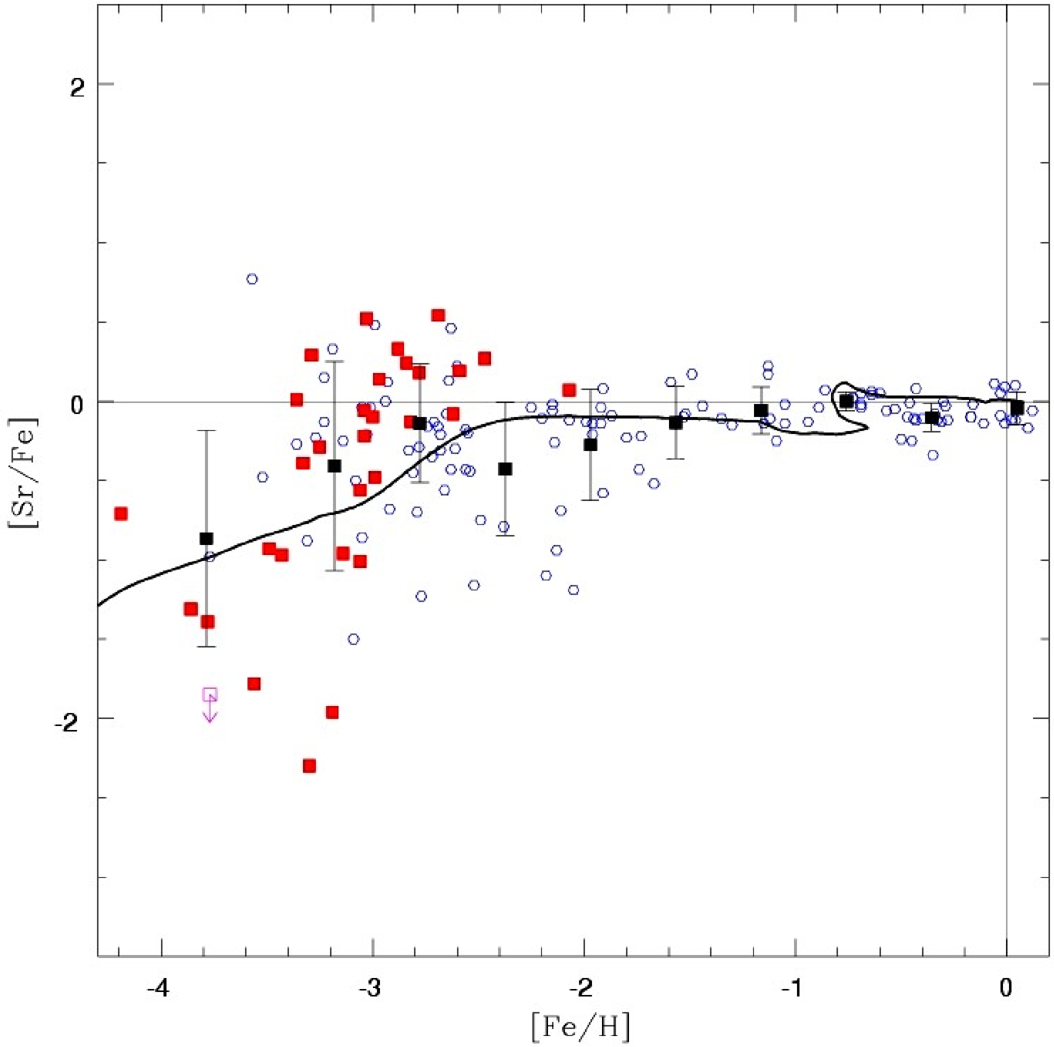
r-process
massive star
10-30M_{sun}
(this work)

Observational data:

- François et al.(2007)
- upper limits
- Honda et al (2004) & other authors

Strontium

Cescutti PhD thesis



s-process
low mass stars
1-3M$_{sun}$
Busso et al.

+

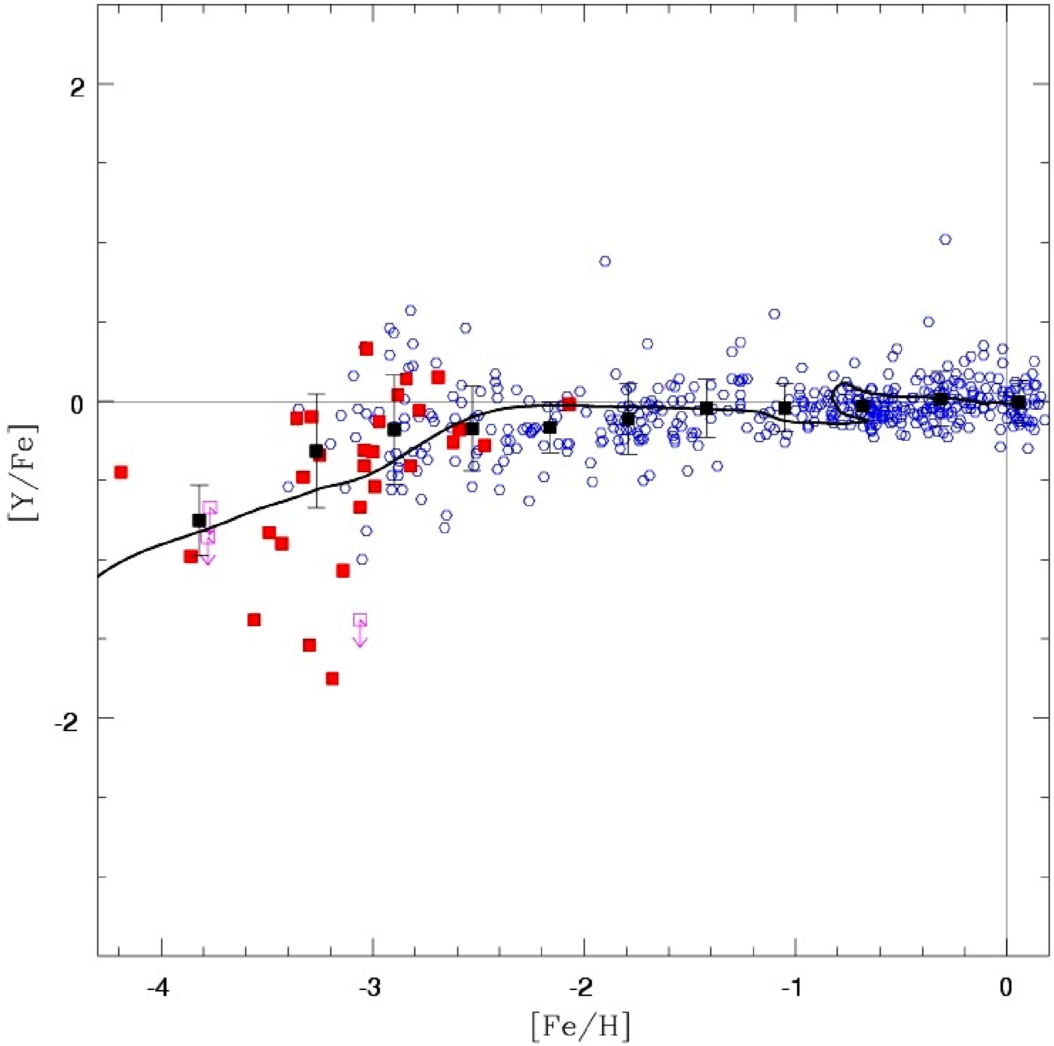
r-process
massive star
10-30M$_{sun}$
(this work)

Observational data:

- François et al.(2007)
- upper limits
- Honda et al (2004) & other authors

Yttrium

Cescutti PhD thesis



s-process
low mass stars
1-3Msun
Busso et al.

+

r-process
massive star
10-30Msun
(this work)

Observational data:

- François et al.(2007)
- upper limits
- Honda et al (2004) & other authors

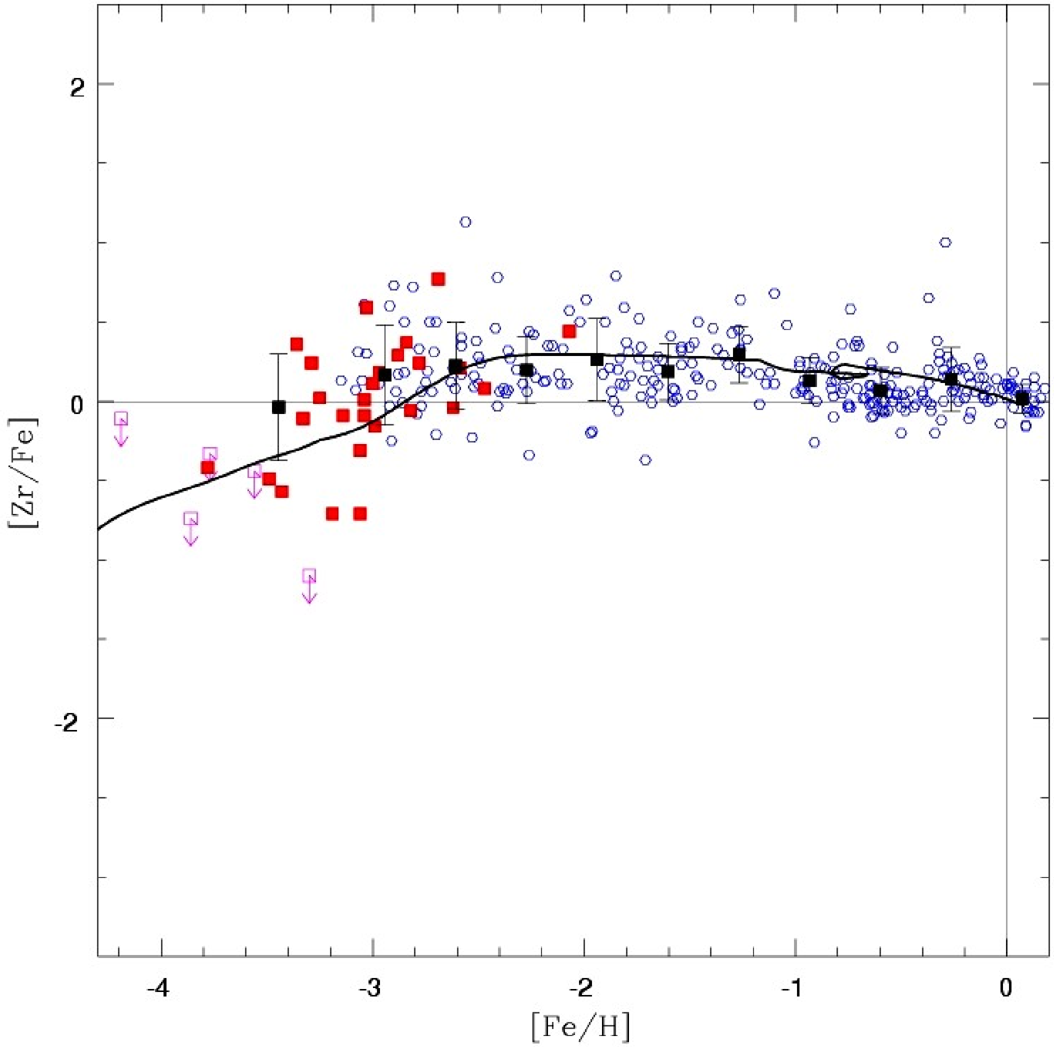
Zirconium

s-process
low mass stars
1-3M_{sun}
Busso et al.

+

r-process
massive star
10-30M_{sun}
(this work)

Cescutti PhD thesis

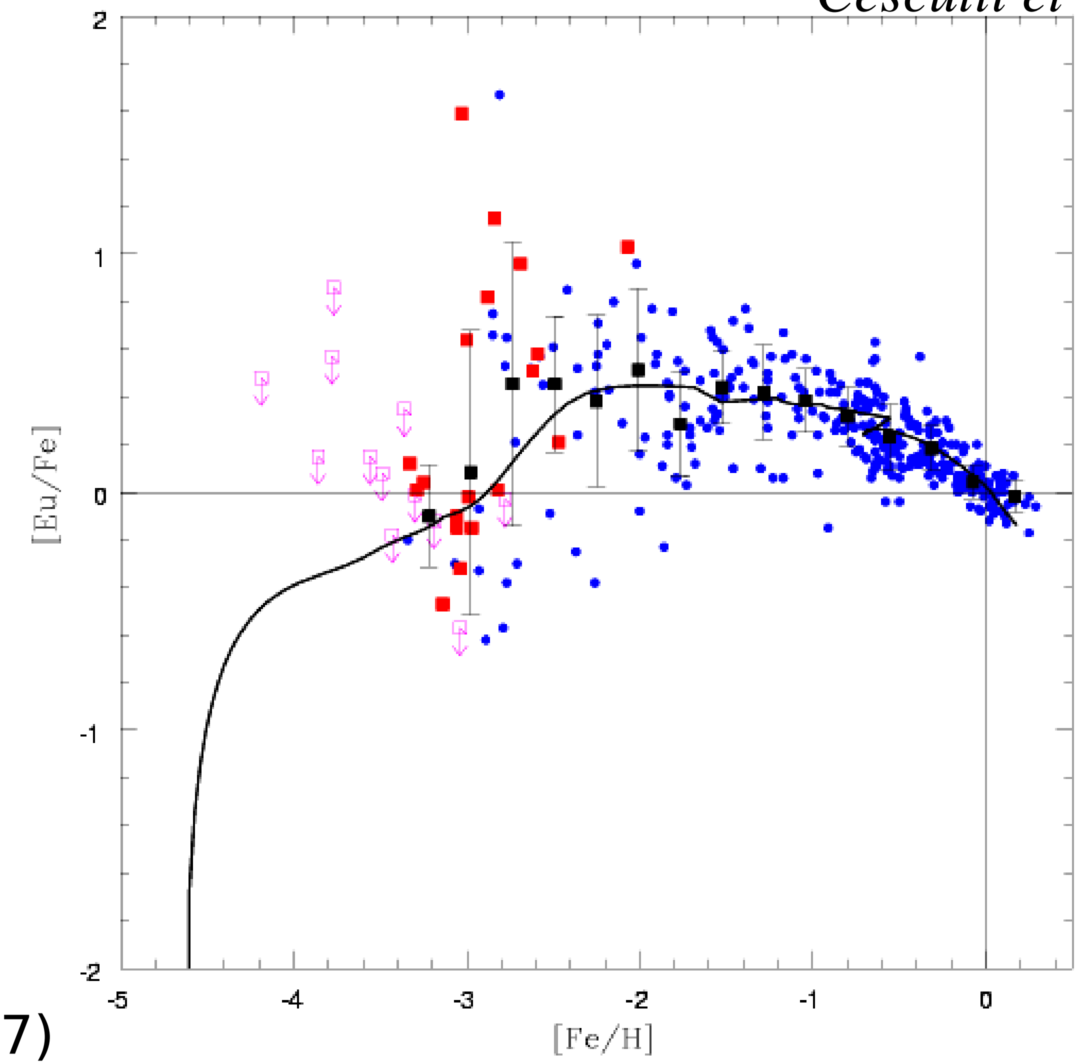


Observational data:

- François et al.(2007)
- upper limits
- Honda et al (2004) & other authors

Europium

Cescutti et al. (2006)



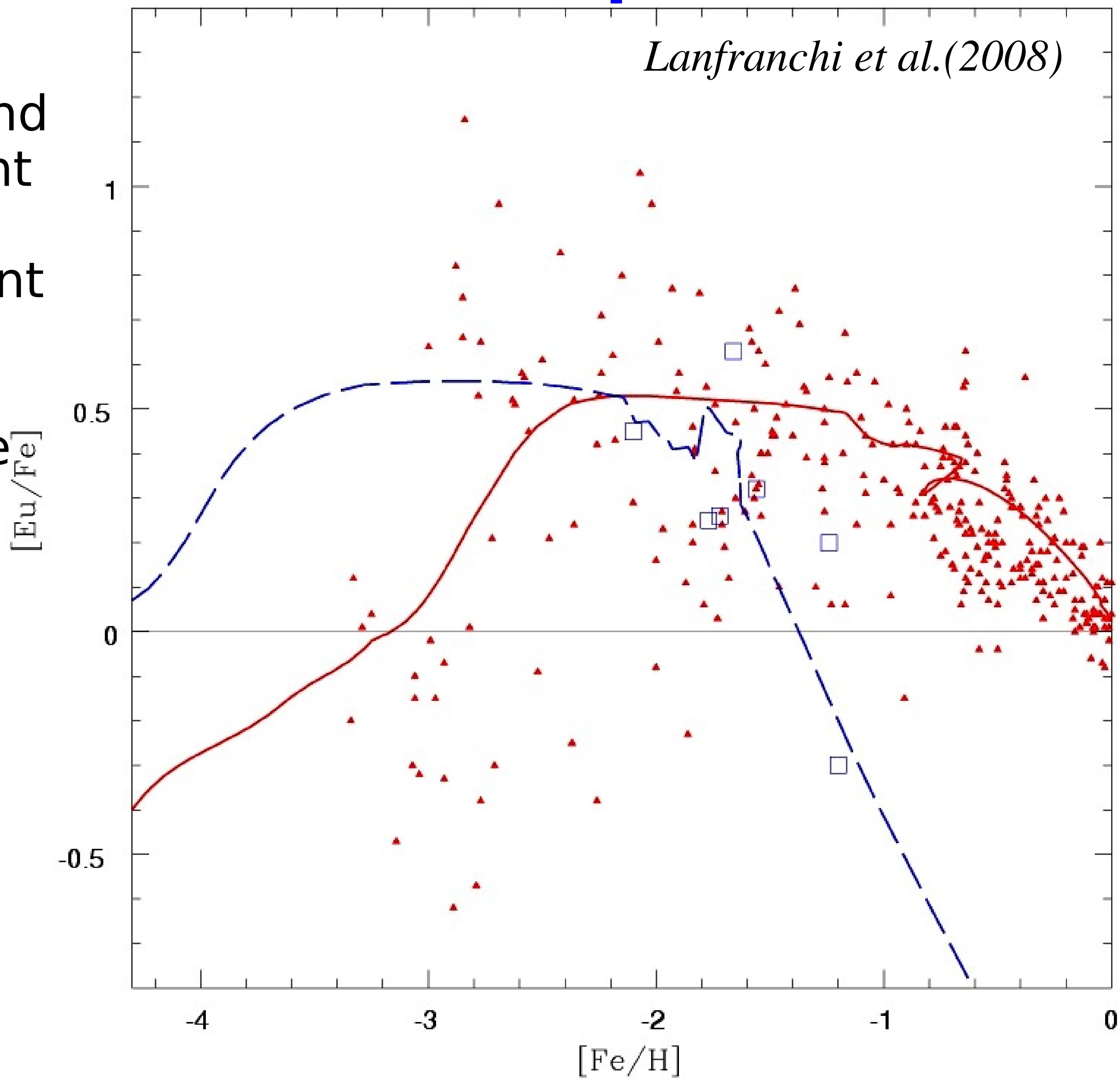
r-process
massive star
10-30M$_{sun}$
(this work)

Observational data:

- François et al.(2007)
- upper limits
- Honda et al (2004) & other authors

Neutron Capture elements in dSphs (vs MW)

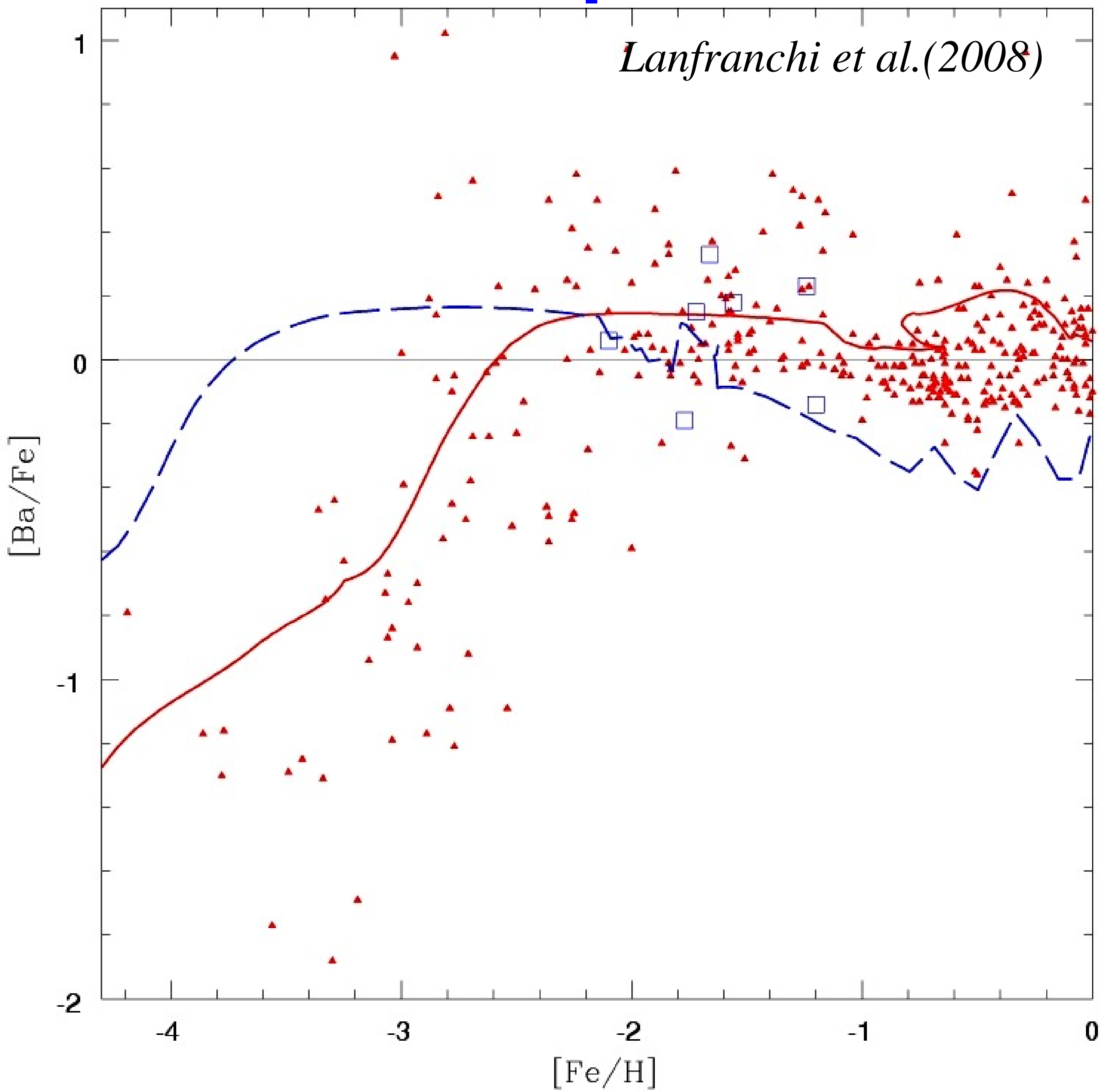
The galactic wind and the different star formation, produce different chemical evolution, in particular in the case of ratio of [Eu/Fe]



Sculptor's data

MW's data

Neutron Capture elements in dSphs (vs MW)

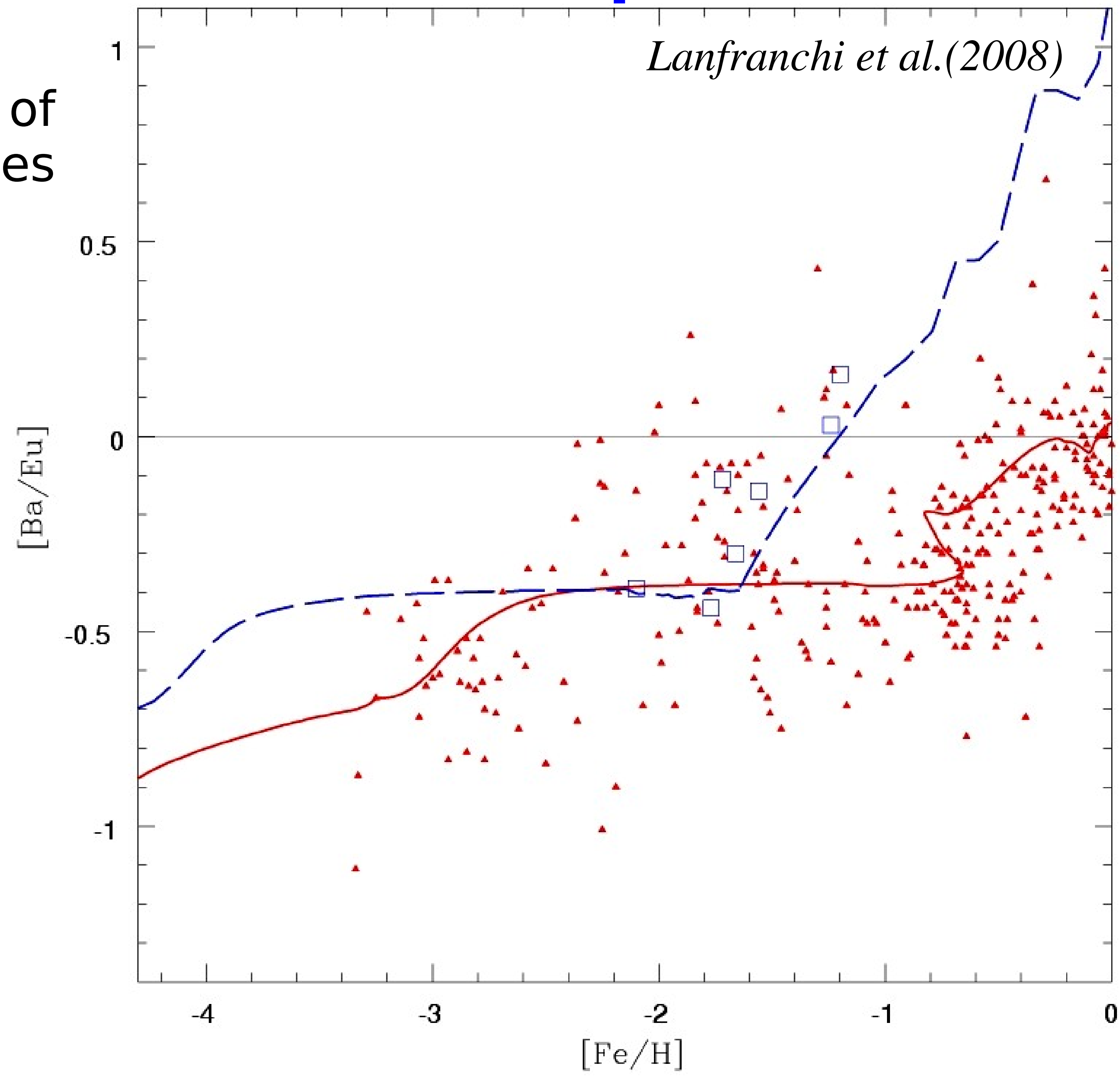


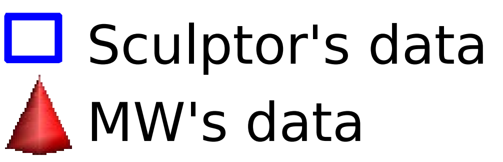
Sculptor's data

MW's data

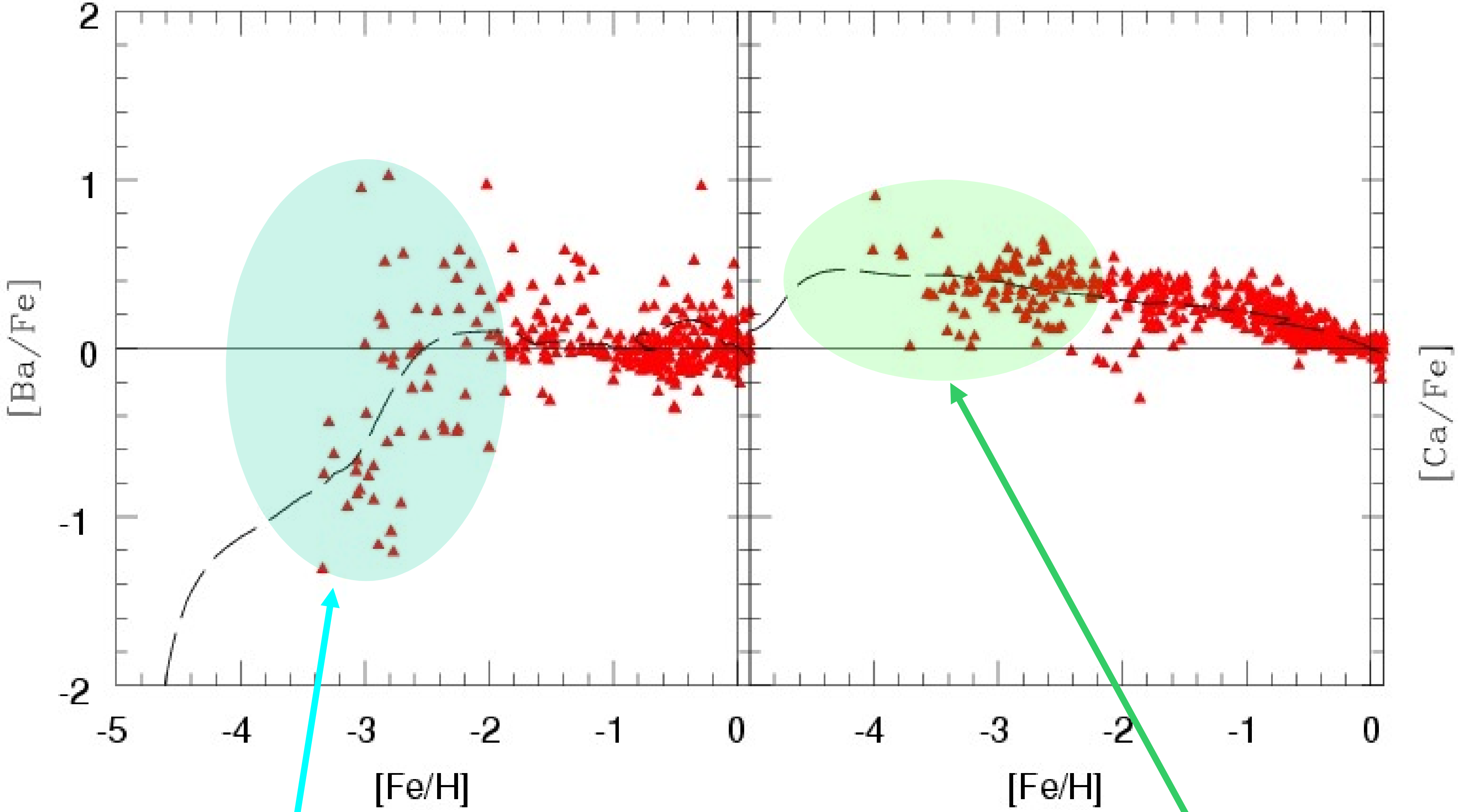
Neutron Capture elements in dSphs (vs MW)

Building blocks of the spiral galaxies as the MW?





The problem of the spread



spread!

No spread!

Inhomogeneous chemical evolution model for the halo of the Milky Way

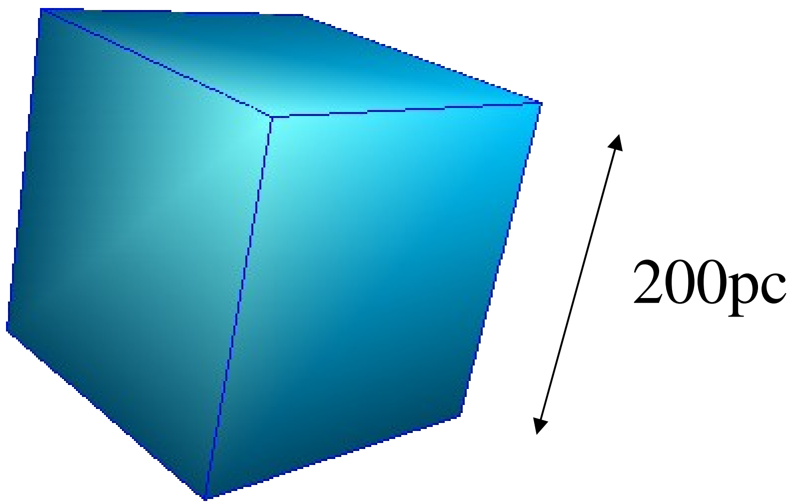
Problem to solve:
The neutron capture elements at low metallicities show spread whereas α-elements (O, Ca, Si, Mg) do not.
Main assumptions:

- A random formation of new stars subjects to the condition that the cumulative mass distribution follows a given initial mass function;

- α-elements and neutron capture elements are produced in different mass ranges:
-All the massive stars for α-elements
-From 10 to 30 M_{sun} for neutron capture elements

Inhomogeneous chemical evolution model for the halo of the Milky Way

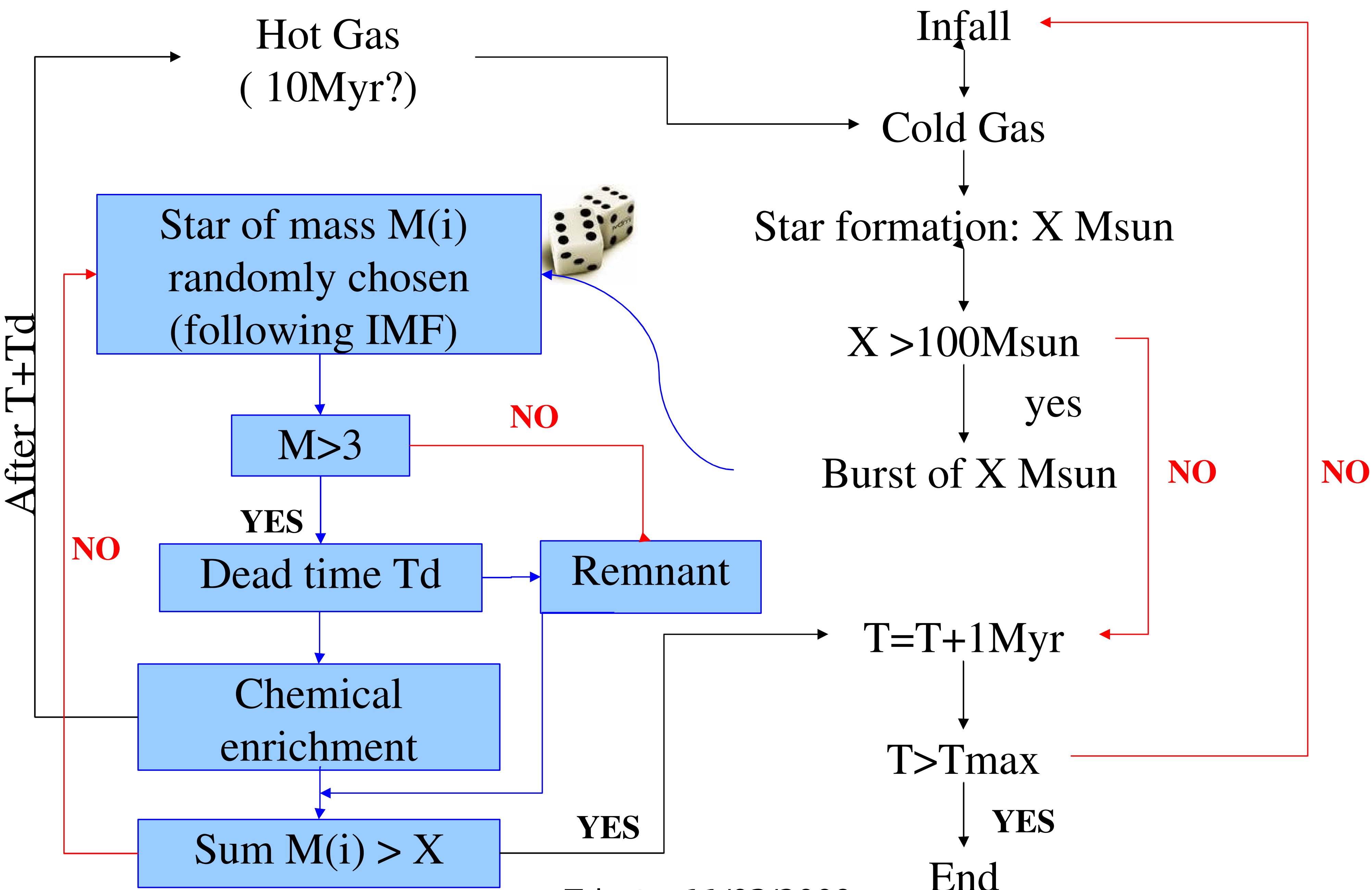
We divide the halo in boxes each one of the typical size of 200 pc and we treat each box as isolate from the other boxes.



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

The main parameters are the same as those of the homogeneous model.

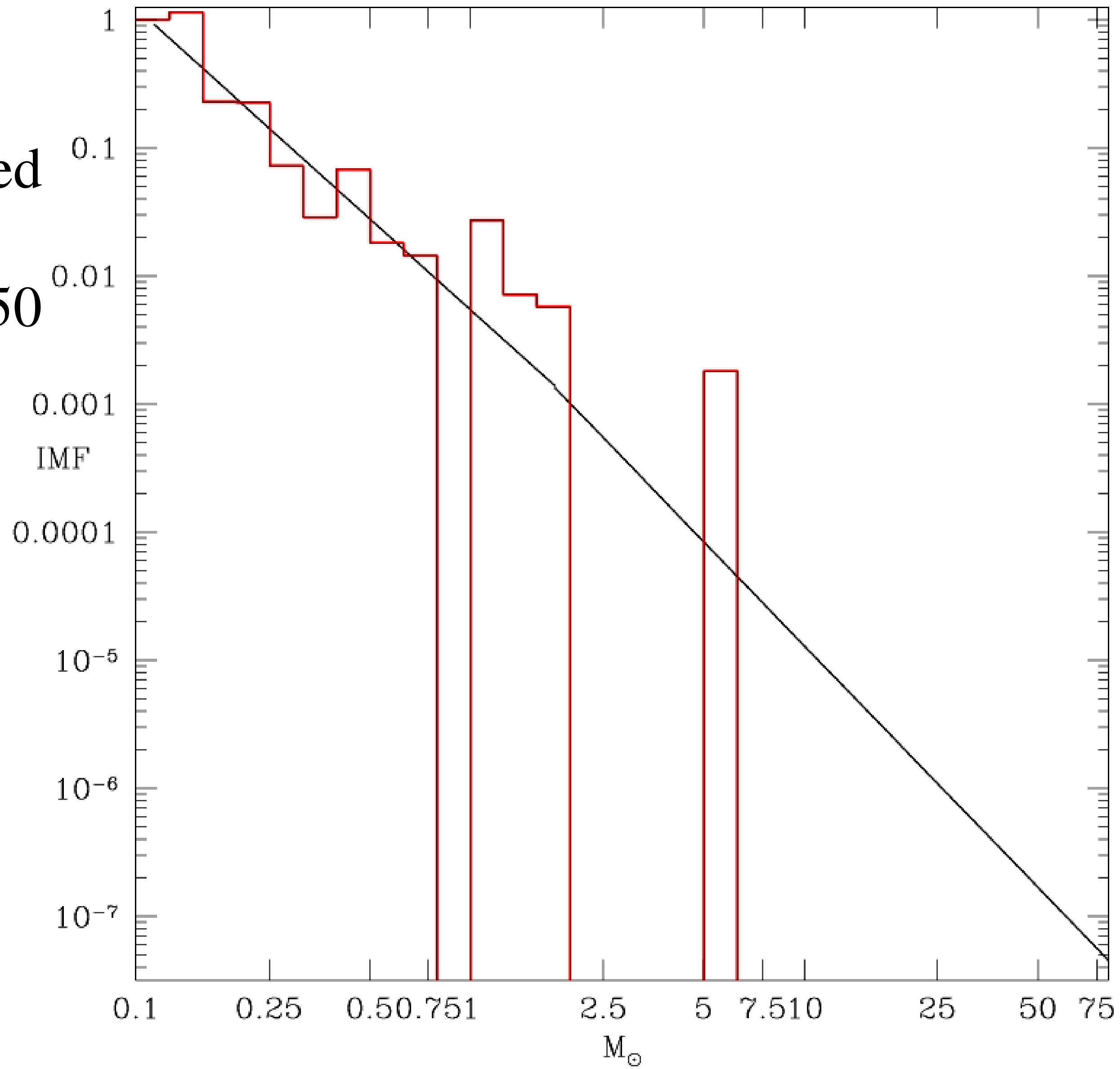
Inhomogeneous chemical evolution model for the halo of the Milky Way



Inhomogeneous chemical evolution model for the halo of the Milky Way

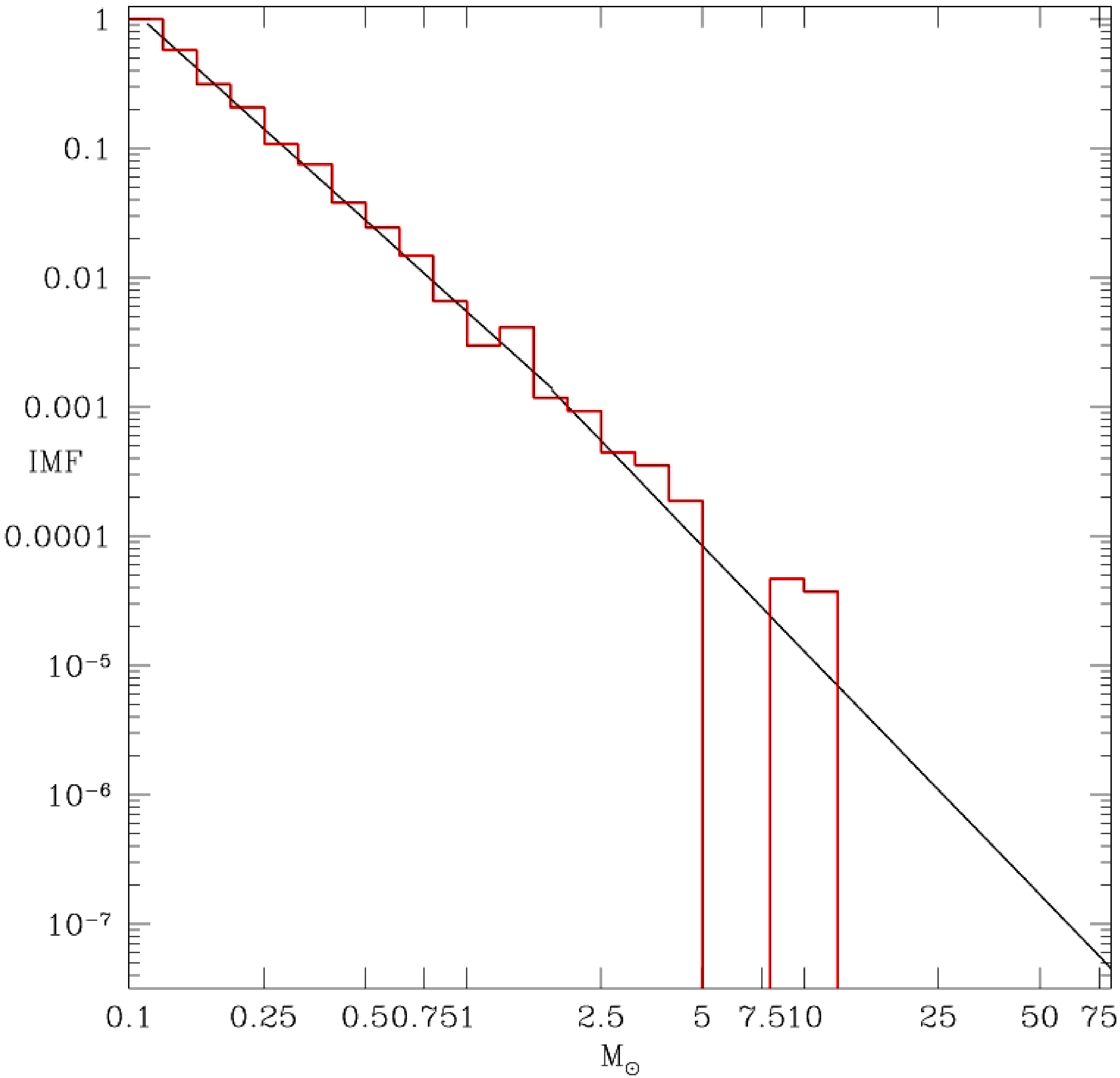
Results obtained if we “extract” the masses of 50 stars

the IMF used



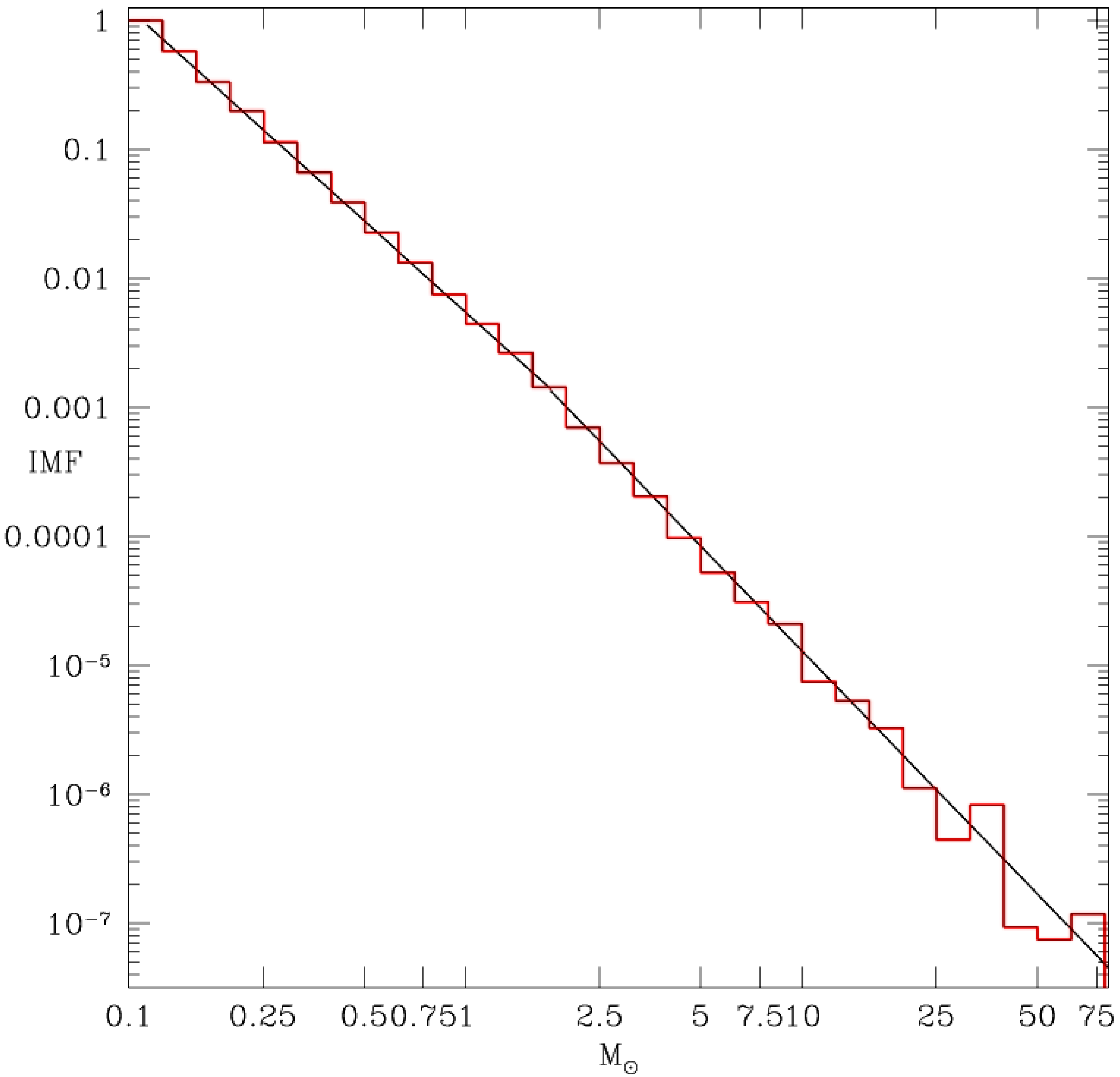
Inhomogeneous chemical evolution model for the halo of the Milky Way

1000 stars



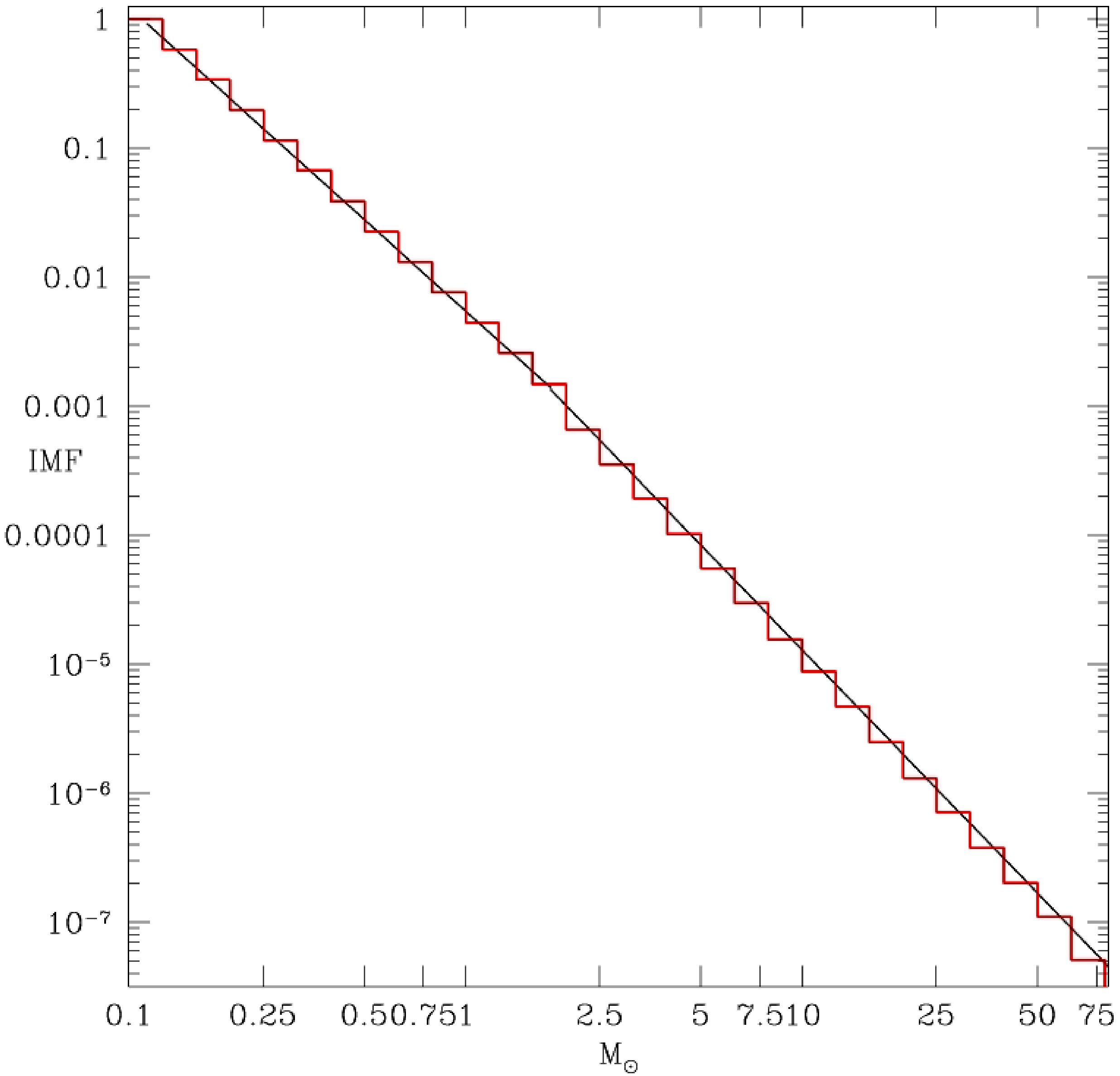
Inhomogeneous chemical evolution model for the halo of the Milky Way

10^5 stars



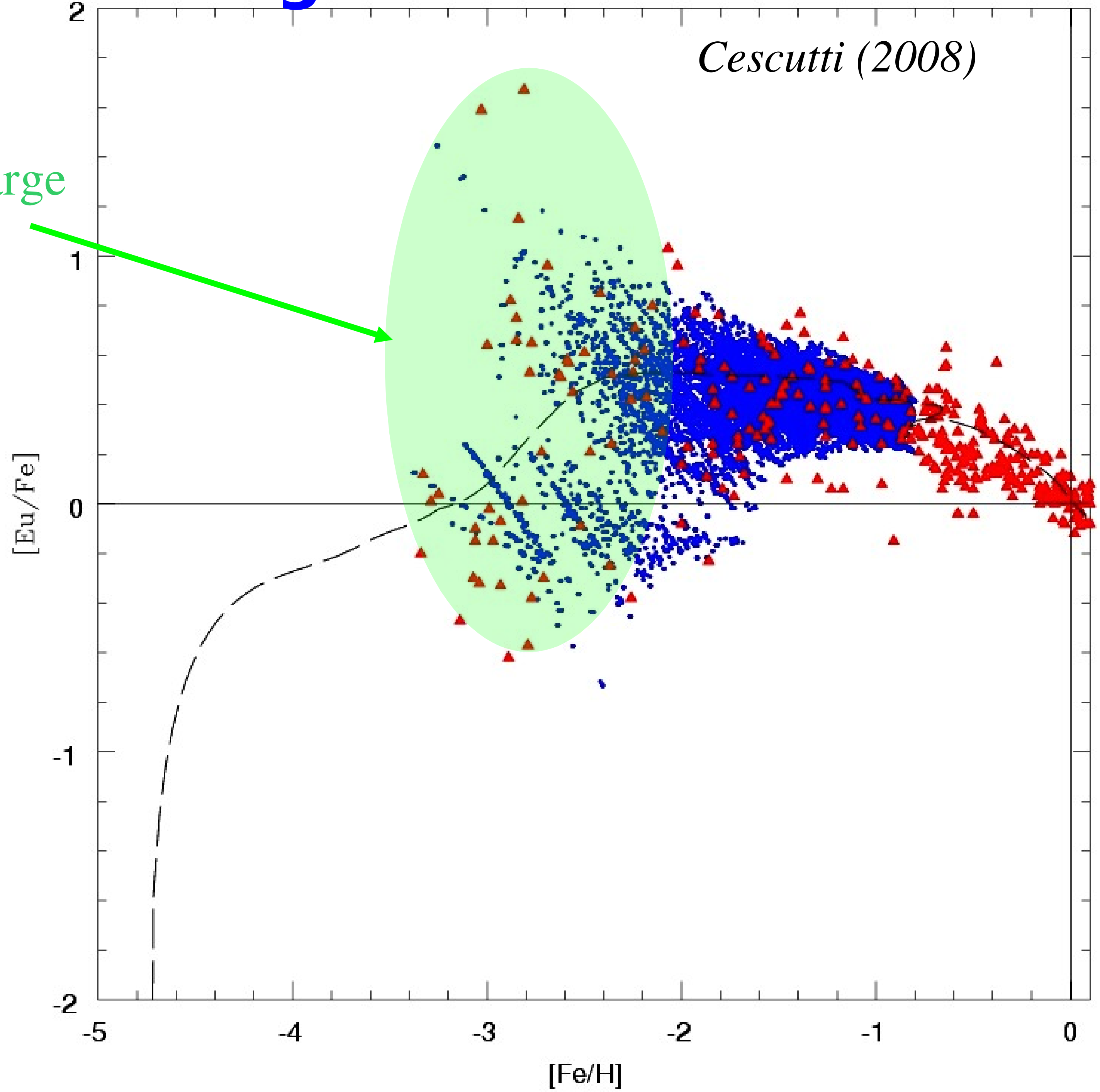
Inhomogeneous chemical evolution model for the halo of the Milky Way

10^7 stars



Inhomogeneous model

Neutron capture: large dispersion

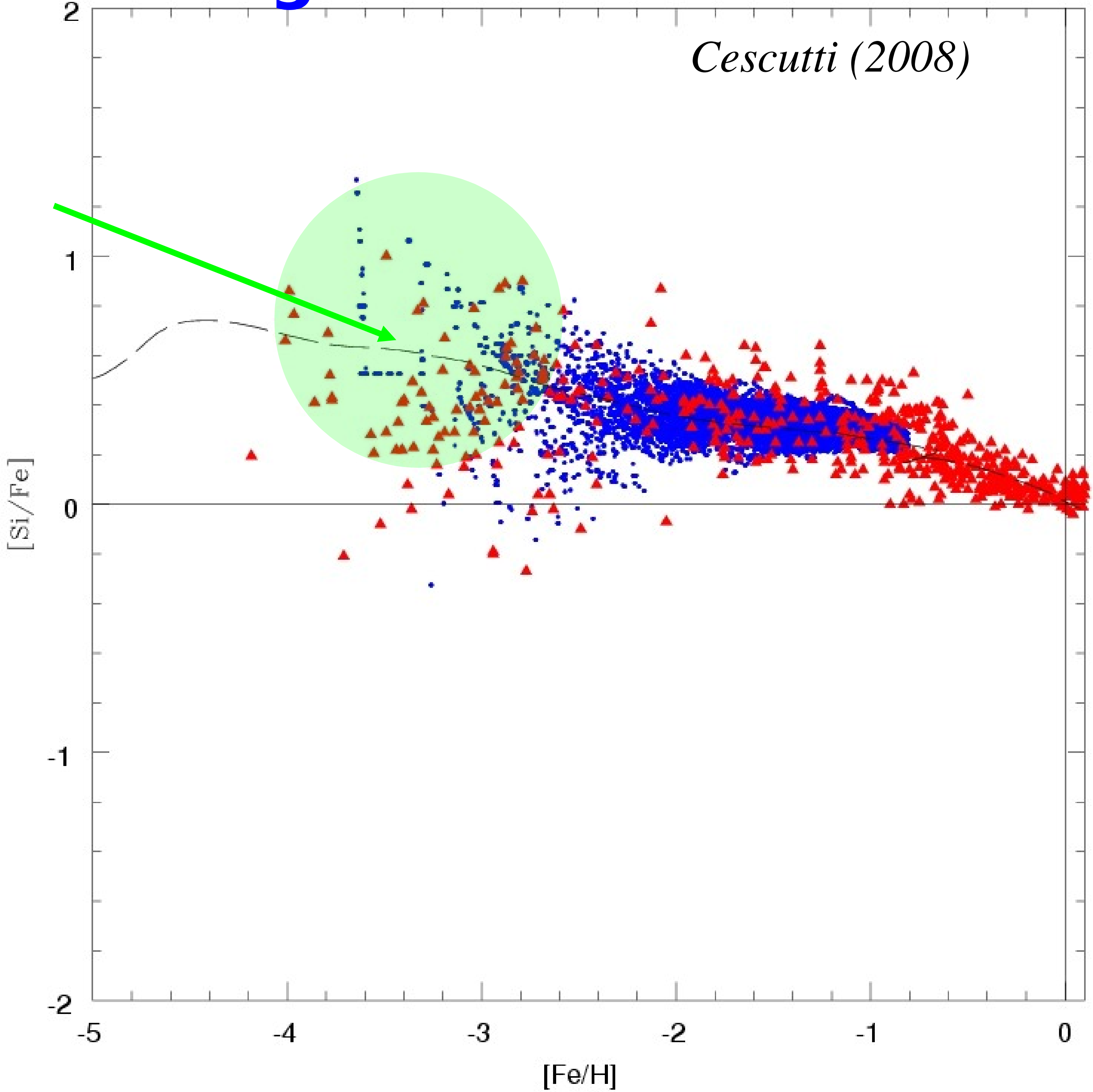


Observational data

Model results

Inhomogeneous model

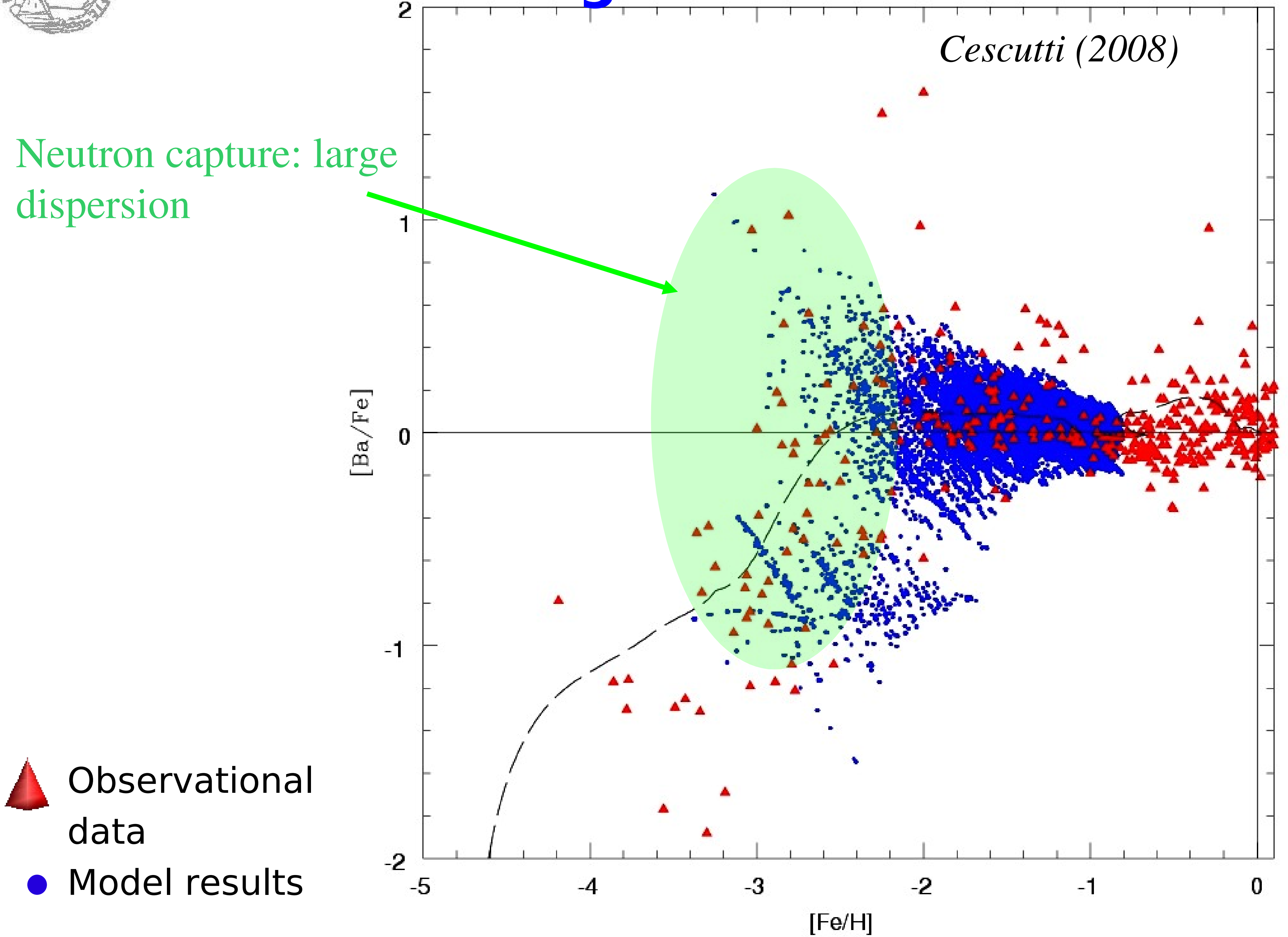
α – elements:
small dispersion



Observational data

Model results

Inhomogeneous model

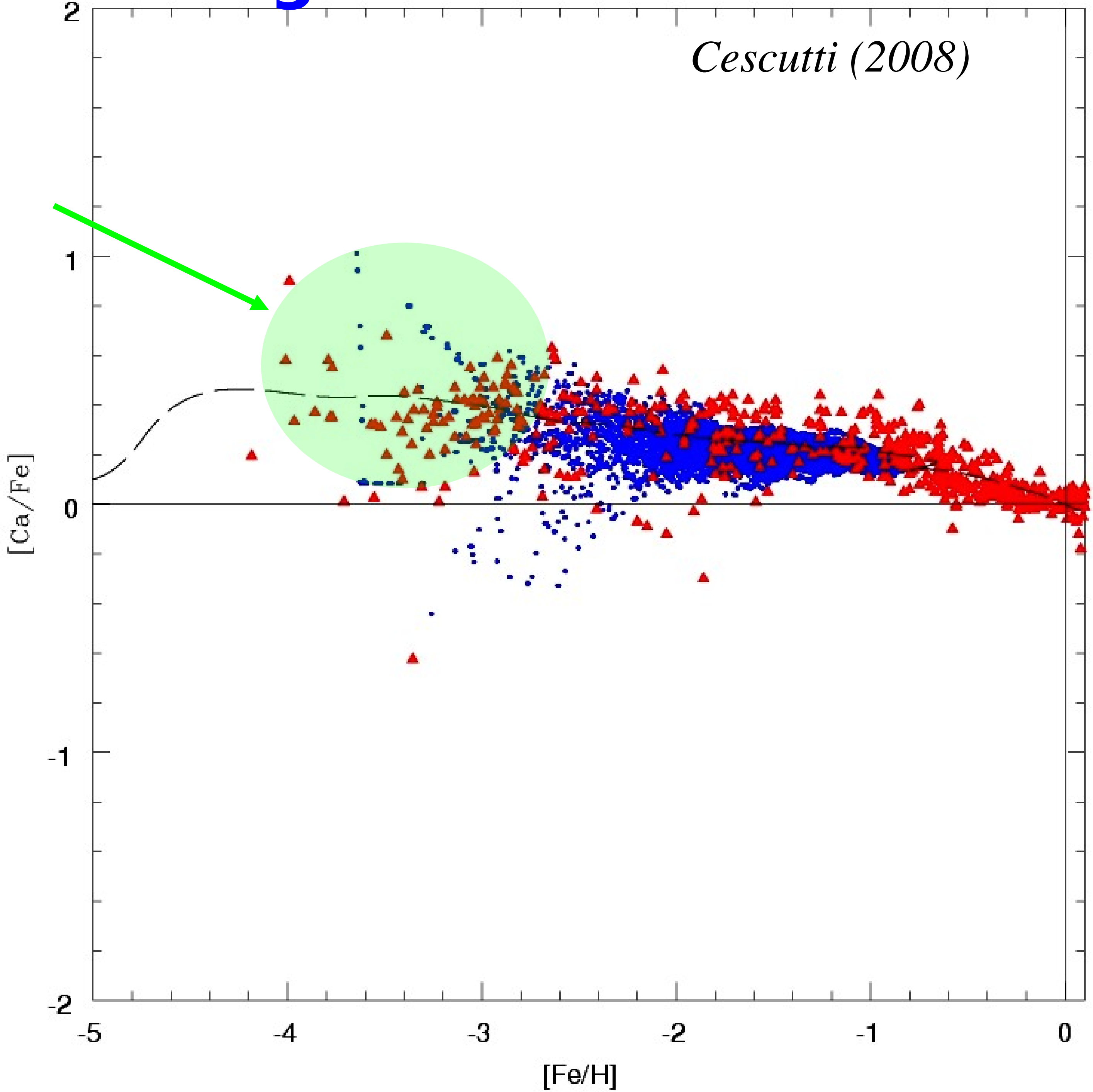


Observational data

Model results

Inhomogeneous model

α – elements:
small dispersion



Observational data

Model results

Radial gradients in the MW

In our chemical homogeneous model, we can mymic a inside-out scenario (the disc starts to form from the center to the outskirts) with a different time scale for the infall rate as a function of the galactocentric distance.

This scenario produces radial gradients for the chemical elements.

It is difficult to measure these gradients, mainly because of the uncertainties in the measurements of the distances.

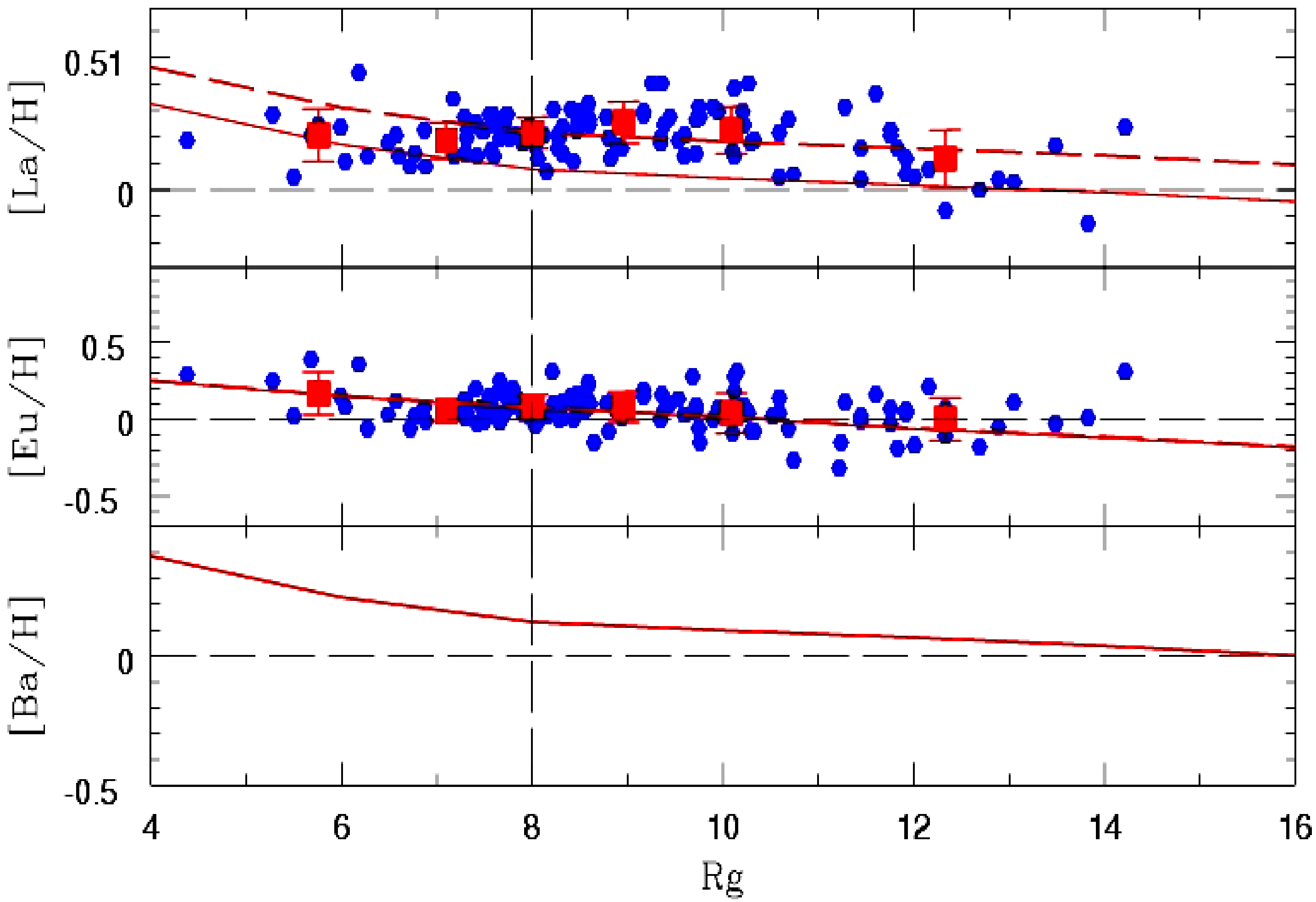
With the new data on Cepheids by Andrievsky et al.(2005), for the first time we have observational data for the gradients of heavy elements as neutron capture elements.

$$\dot{G}_A(R,t) = -X_A(R,t)\Psi(R,t) + X_A^{\inf\, all}\dot{G}_{\inf}(R,t)$$
$$+\int_M \Psi(R, t-\tau(\tilde{m}))\phi(\tilde{m})Q(\tilde{m}, Z(t-\tau(\tilde{m})))_A d\tilde{m}$$

Radial gradients in the MW

Radial gradients are produced by the inside-out formation of the Galactic disc

Cescutti et al. (2007)



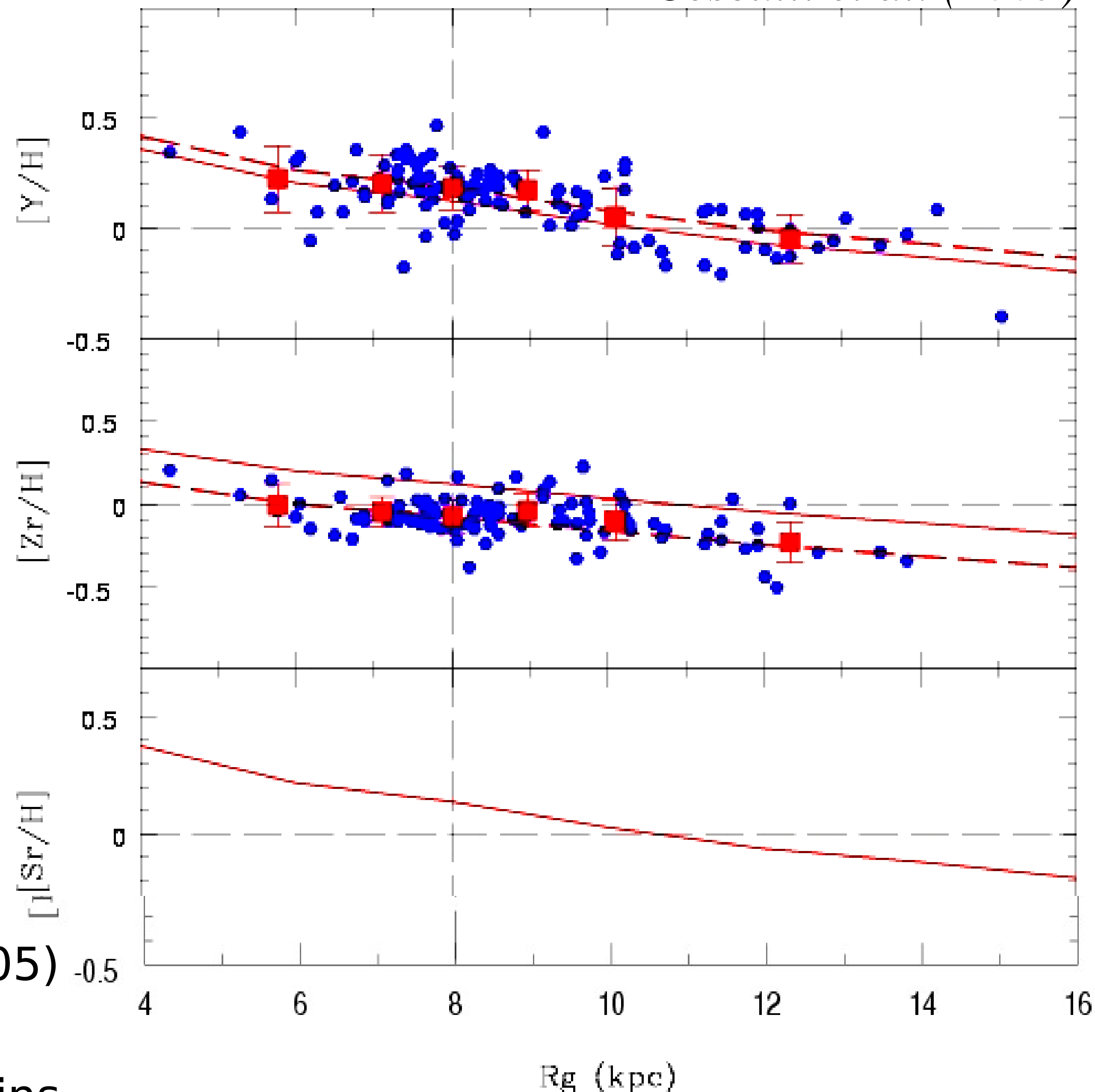
Andrievski et al. (2005)

Mean and standard deviation on radial bins

Radial gradients in the MW

Cescutti et al. (2007)

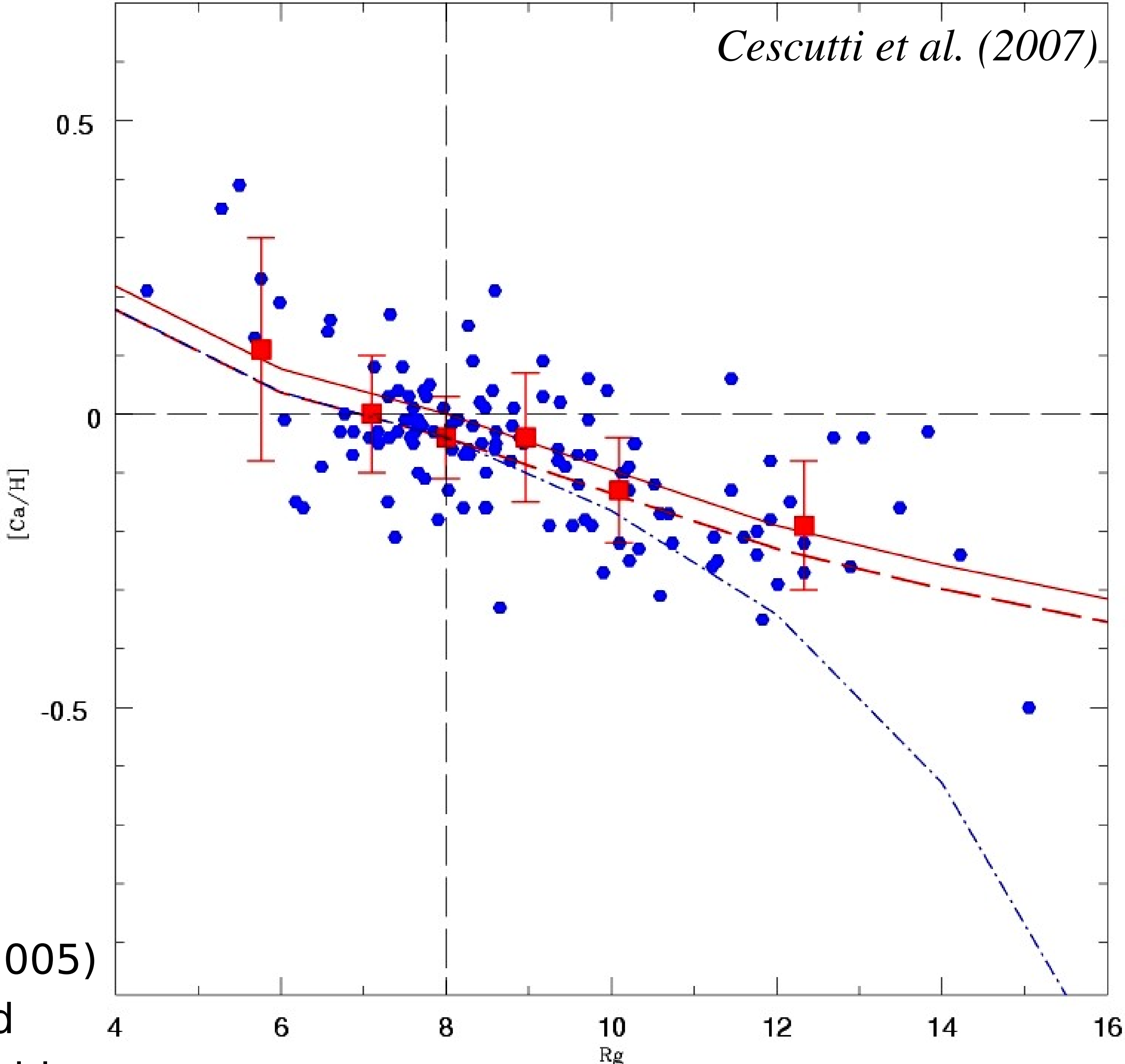
Radial gradients are produced by the inside-out formation of the Galactic disc



Andrievski et al. (2005)

Mean and standard deviation on radial bins

Radial gradients in the MW

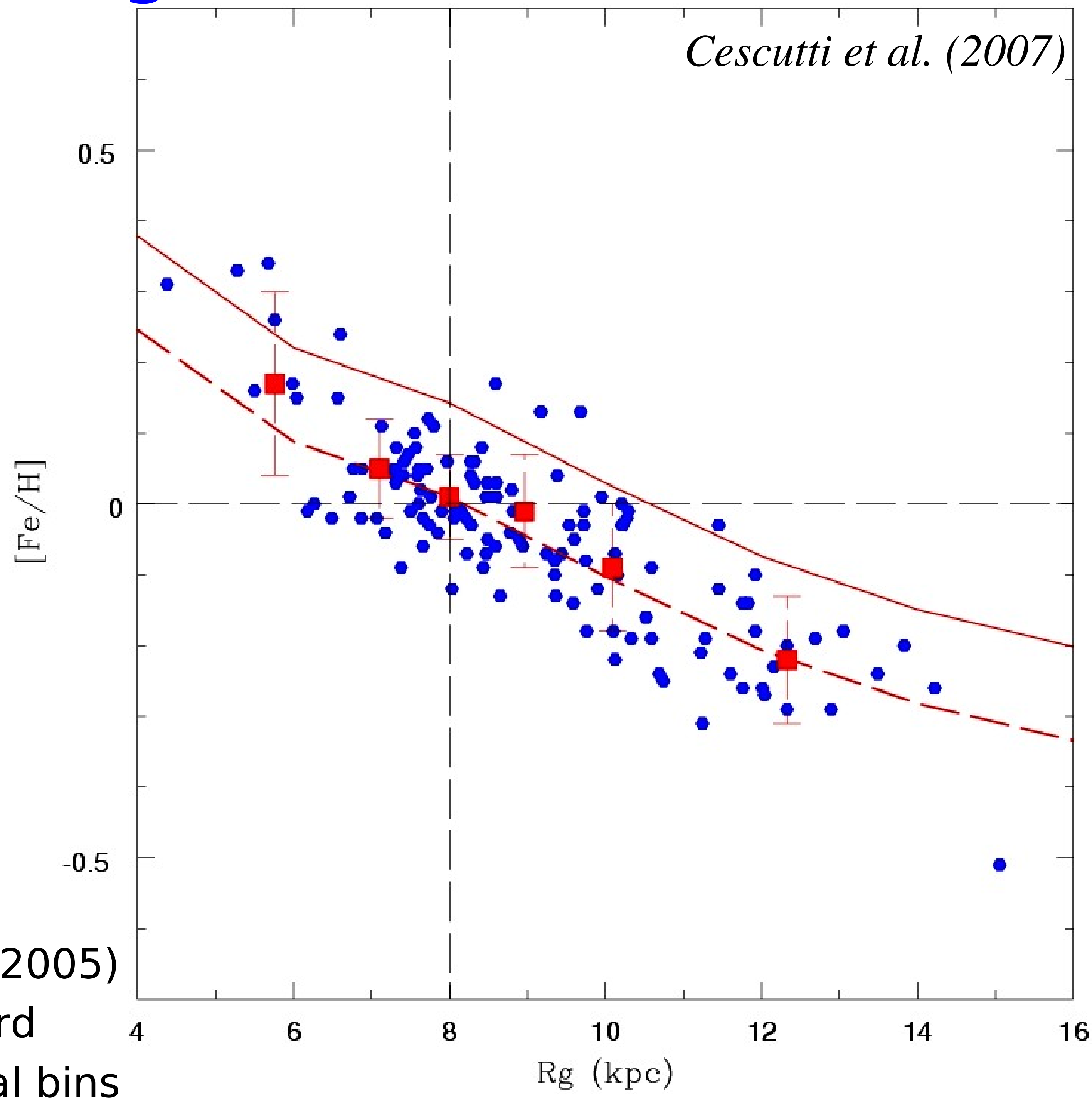


Radial gradients are produced by the inside-out formation of the Galactic disc

- Andrievski et al. (2005)
- Mean and standard deviation on radial bins

Radial gradients in the MW

Radial gradients are produced by the inside-out formation of the Galactic disc



Andrievski et al. (2005)

Mean and standard deviation on radial bins

Conclusions

Modelling different histories of star formation in the three systems (Solar neighborhood, MW bulge and Sagittarius dwarf spheroidal) are insufficient to reproduce the different behaviour of the [Mn/Fe] ratio; rather, it is necessary to invoke metallicity-dependent type Ia SN Mn yields.

The inclusion of metallicity-dependent oxygen yields improve significantly the agreement between our predictions for the Galactic bulge and the observed [O/Mg]; moreover our results confirms the conclusion that the bulge formed more rapidly than the disk, based on the overabundances of elements produced by massive stars.

By means of the comparison between the models and the new data at low metallicity we conclude that:

· Sr, Y, Zr, Ba and La are produced by both r and s-process:

  by s-process in low mass stars (1-3M_{sun})

  by r-process in massive stars (10-30M_{sun})

· Europium is produced by r-process in massive stars (10-30M_{sun})

Conclusions

The same nucleosynthesis prescriptions adopted to well fit the data in the Milky Way reproduce a good fit to the data of dwarf spheroidal galaxies. Moreover, the chemical evolution excludes that the dwarf spheroidal galaxies (that we see nowadays) are the building blocks of the Milky Way.

We have developed a model which is able to reproduce the spread of neutron capture elements and, at the same time, the small star to star scatter of the alpha-elements.

Our model for the galactic disc with our nucleosynthesis prescriptions well fits the radial abundance gradients measured in the Cepheids for several elements and confirm the inside-out scenario for the formation of the MW disc

Future prospectives

- Improve the inhomogeneous model and extend it to the dwarf spheroidal systems.
- Reproduce the chemical evolution in the disc of the Milky Way for Carbon using a nucleosynthesis which reproduces to observational data of the MW bulge.
- Try to predict the chemical evolution of the dwarf spheroidal galaxies for iron peak elements with a nucleosynthsis consistently with the MW results.