



Osservatorio Astronomico di Trieste
Astronomical Observatory of Trieste



Revealing the Nature of the First Stars: the role of the chemical signatures in the primordial stars of our Galaxy

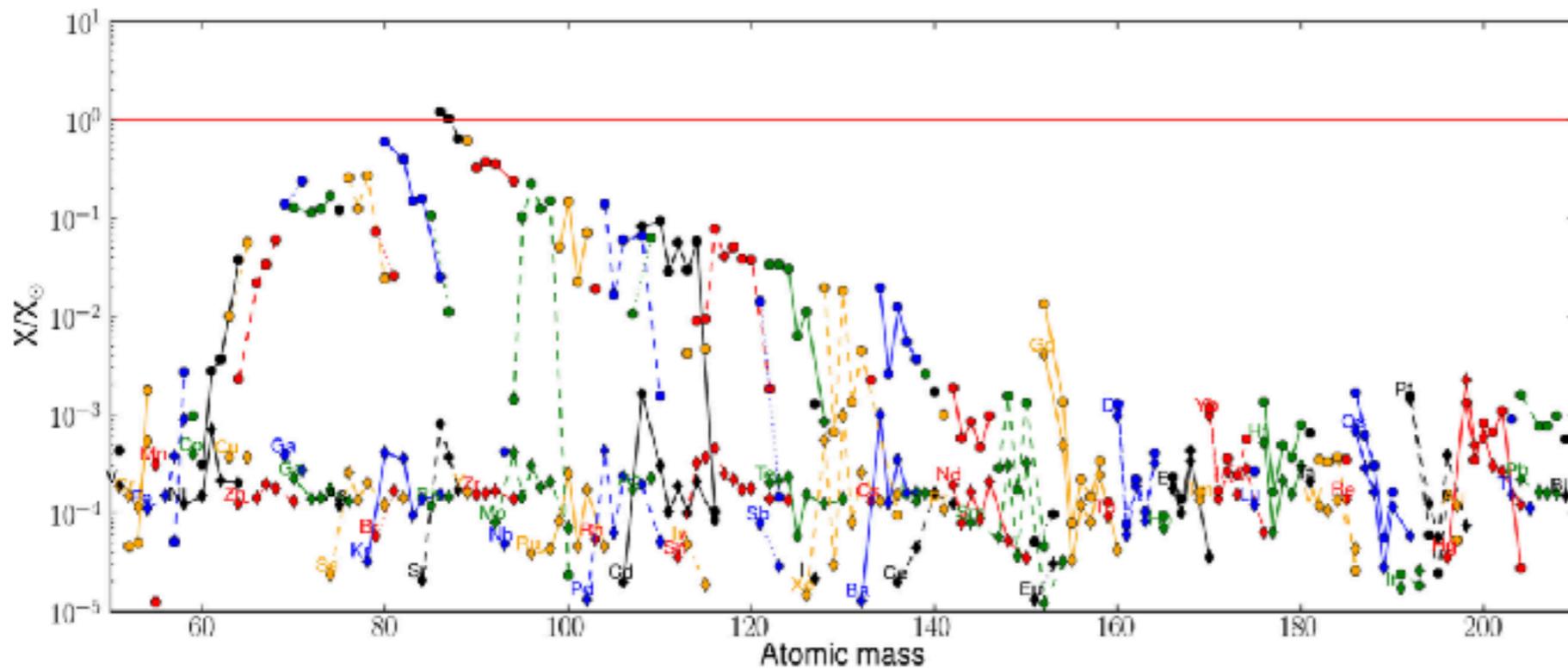
Gabriele Cescutti



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grant agreement No 664931

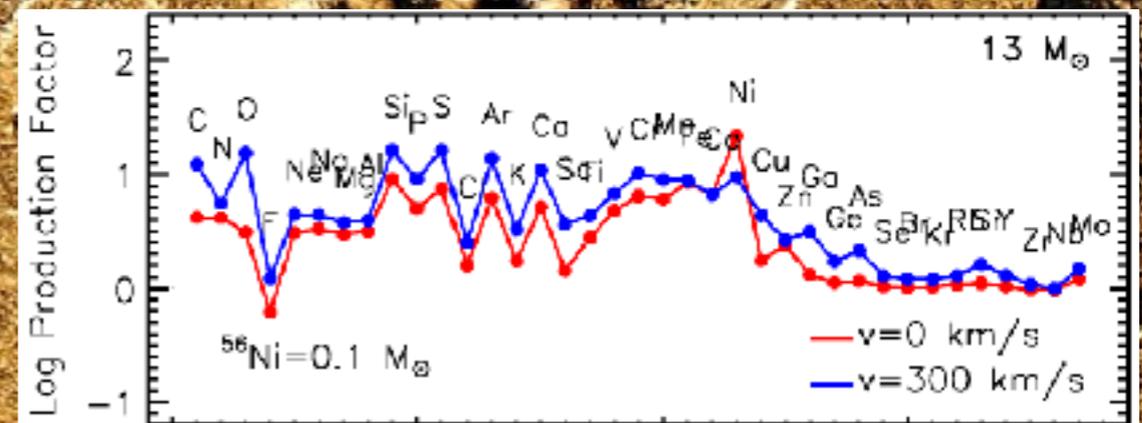
Roma, 23 October 2018

Stellar evolution model with nucleosynthesis



Frischknecht+16

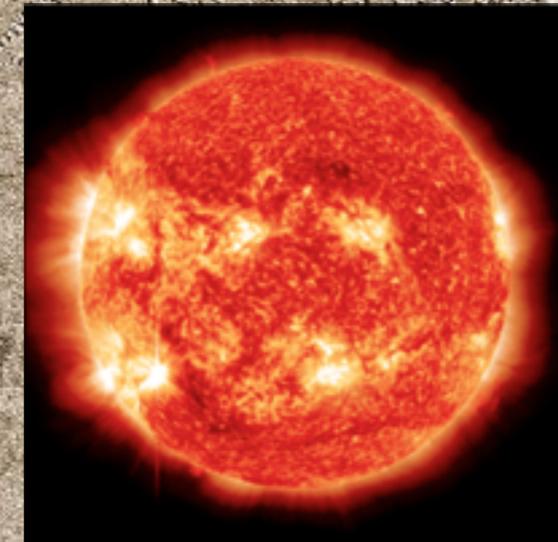
Limongi+12



Chemical abundances in stars

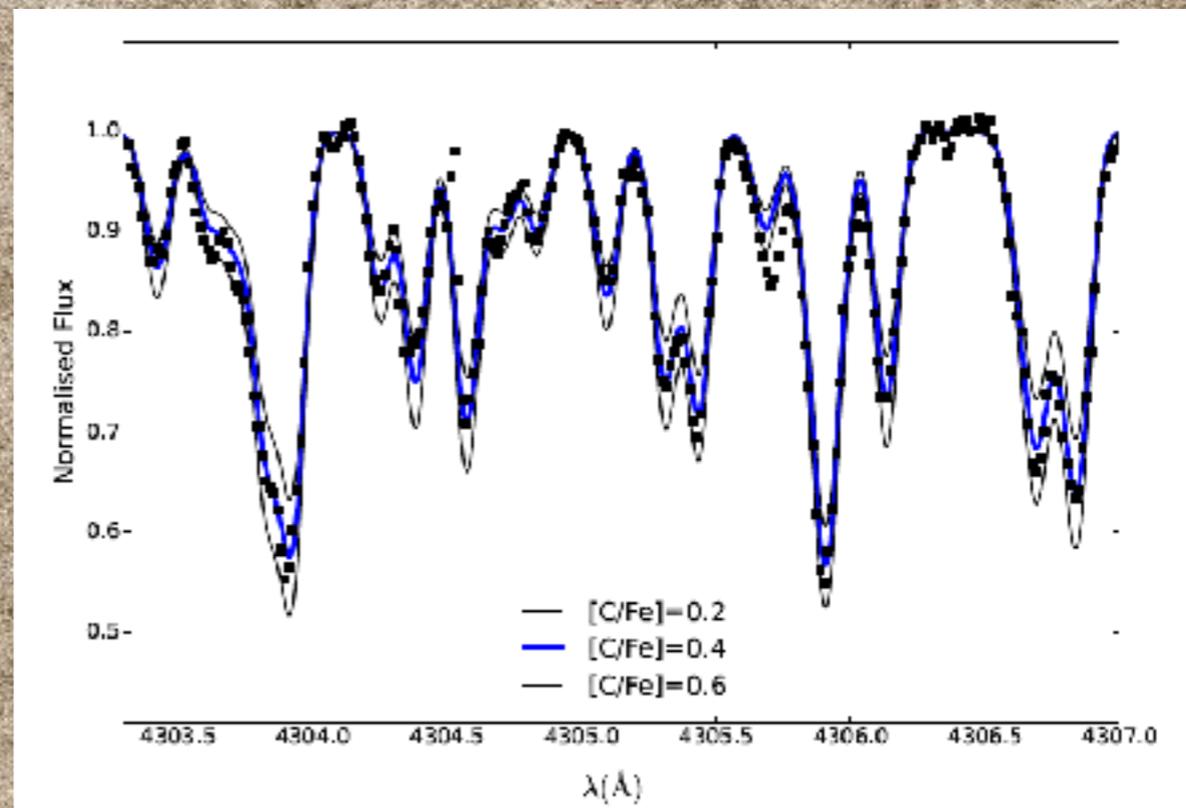


VLT ESO, Paranal, Chile



**High resolution
spectra of stars**

**Abundances of
chemical elements**

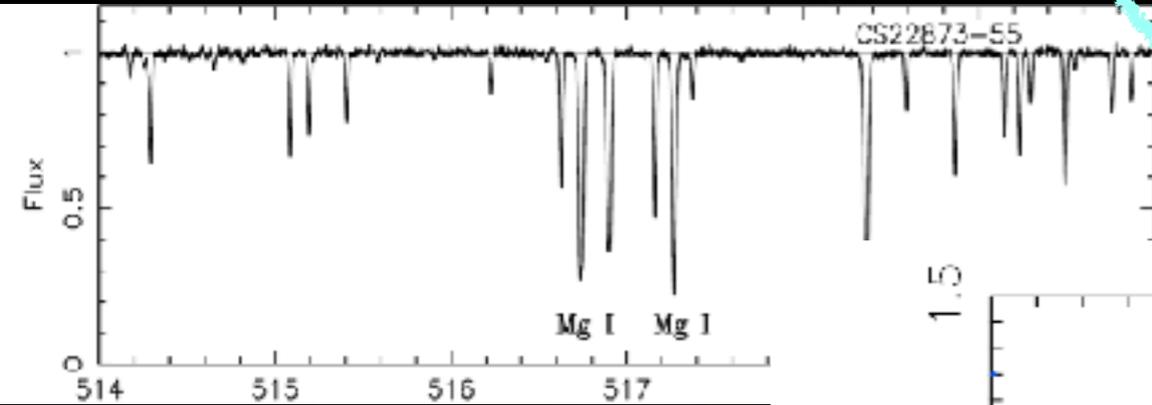


Chemical evolution models

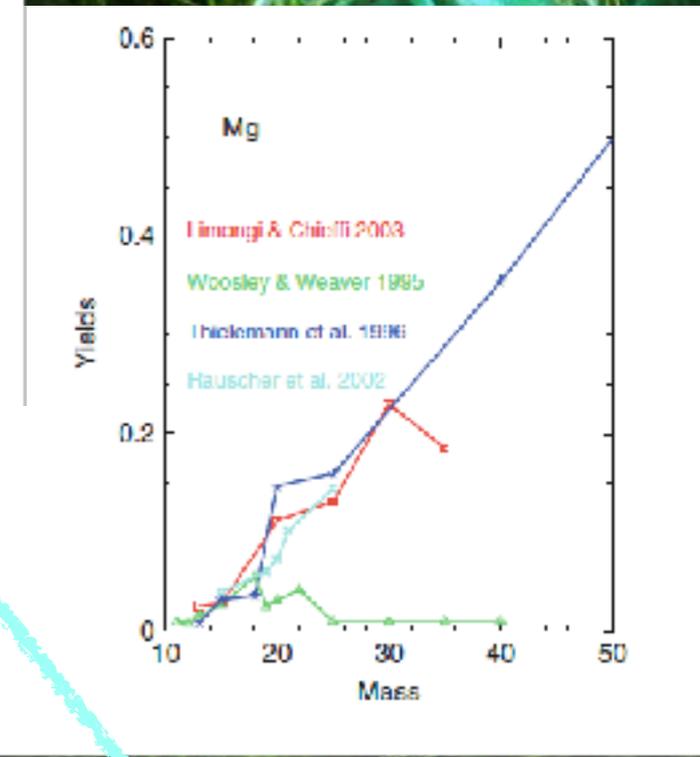
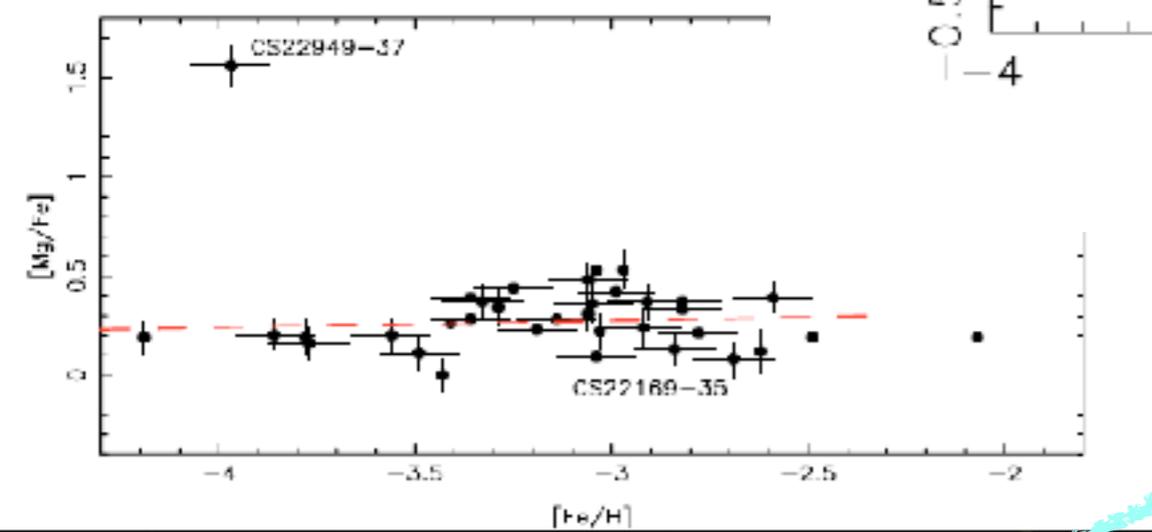
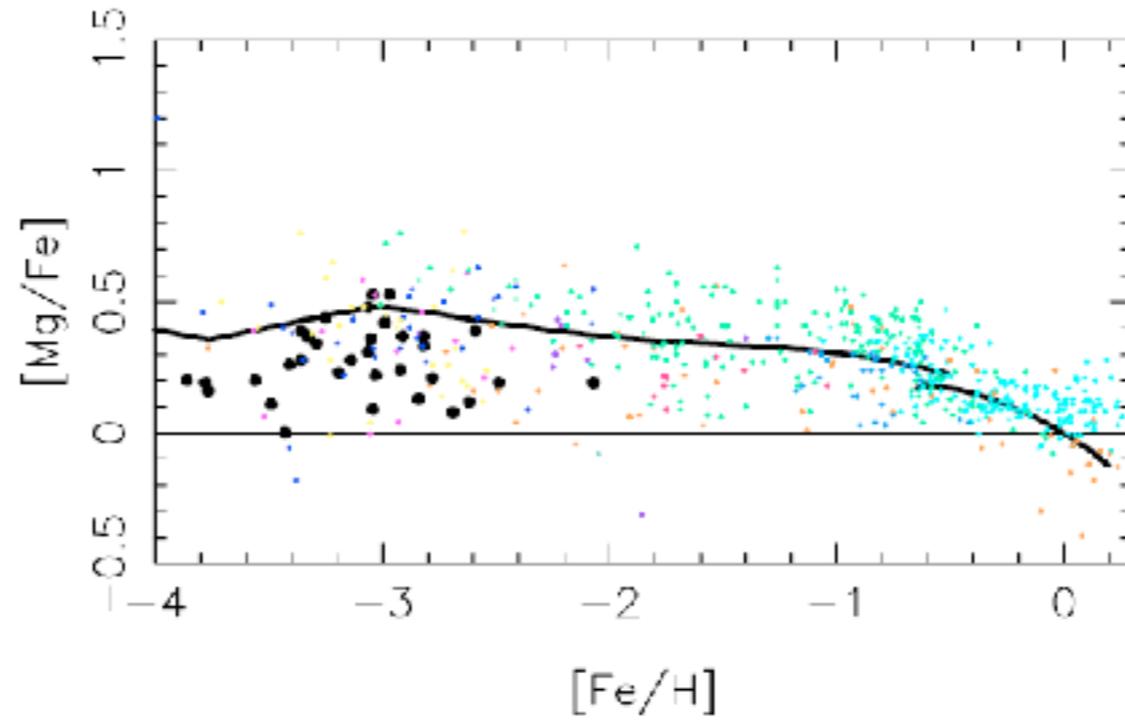
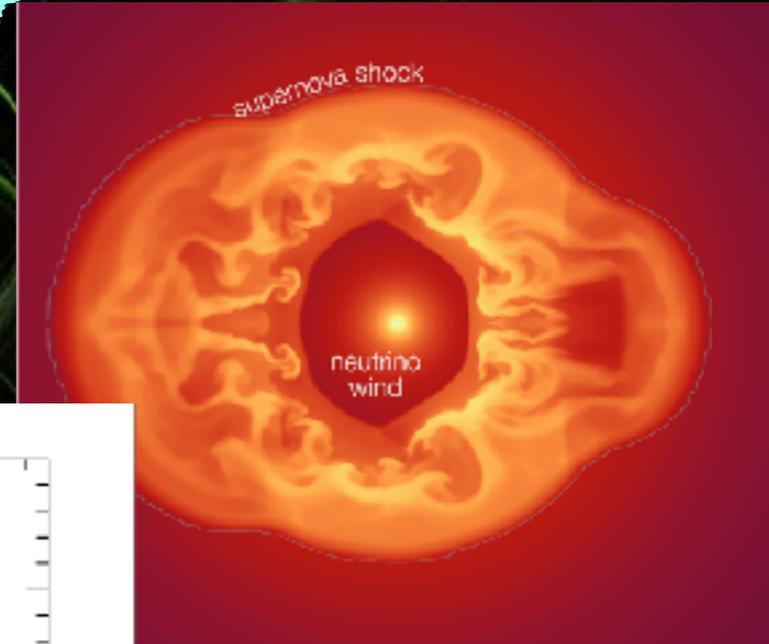


Stellar evolution

Stellar spectra



?



Nucleosynthesis

Chemical abundances



Second year plan:

- Implement in the models nucleosynthesis for the First Stars Hypernovae and Keele group
- Test the statistical code with the results in the halo and its observational data
- Publish first results using the statistical code of multiple stellar nucleosynthesis in the Galactic halo
- **Develop a generic code for satellite dwarf galaxies and adapt the code for a selection of galaxies**

Invited to AAS in Denver for the Meeting in the meeting: Abundance in dwarf spheroidal galaxies



UNIVERSITÀ DEGLI STUDI DI TRIESTE
DIPARTIMENTO DI FISICA
Corsi di Laurea Triennale in Fisica

Nucleosynthesis of Heavy Elements and Chemical Evolution of the Galaxy

Tesi di Laurea Triennale

Relatore: Prof. Mario Pasquon Martignoli
Candidato: Dott. Gabriele Cescutti

Accompagnato: Federico Bianco, Maurizio Siliquetti

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The oldest stars of the bulge: new information on the ancient Galaxy

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Astronomy Astrophysics

Manganese spread in Ursa Minor as a proof of sub-classes of type Ia supernovae

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Uncertainties in s-process nucleosynthesis in low-mass stars determined from Monte Carlo variations

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ABSTRACT
The s-process is a key element in the chemical evolution of galaxies. However, the impact of nuclear physics uncertainties on the predicted abundances of s-process elements is not well understood. In this paper, we perform a comprehensive Monte Carlo analysis of the s-process nucleosynthesis in low-mass stars, taking into account the uncertainties in the reaction rates of the s-process. We find that the s-process nucleosynthesis in low-mass stars is dominated by the uncertainties in the reaction rates of the s-process, which are in turn dominated by the uncertainties in the reaction rates of the s-process. We also find that the s-process nucleosynthesis in low-mass stars is dominated by the uncertainties in the reaction rates of the s-process, which are in turn dominated by the uncertainties in the reaction rates of the s-process.

Key words: nuclear reactions, nucleosynthesis, abundances – stars: abundances – stars: AGB and post-AGB – stars: evolution – stars: low-mass

Project on nucleosynthesis

⁷Li evolution in the thin and thick disks of the Milky Way

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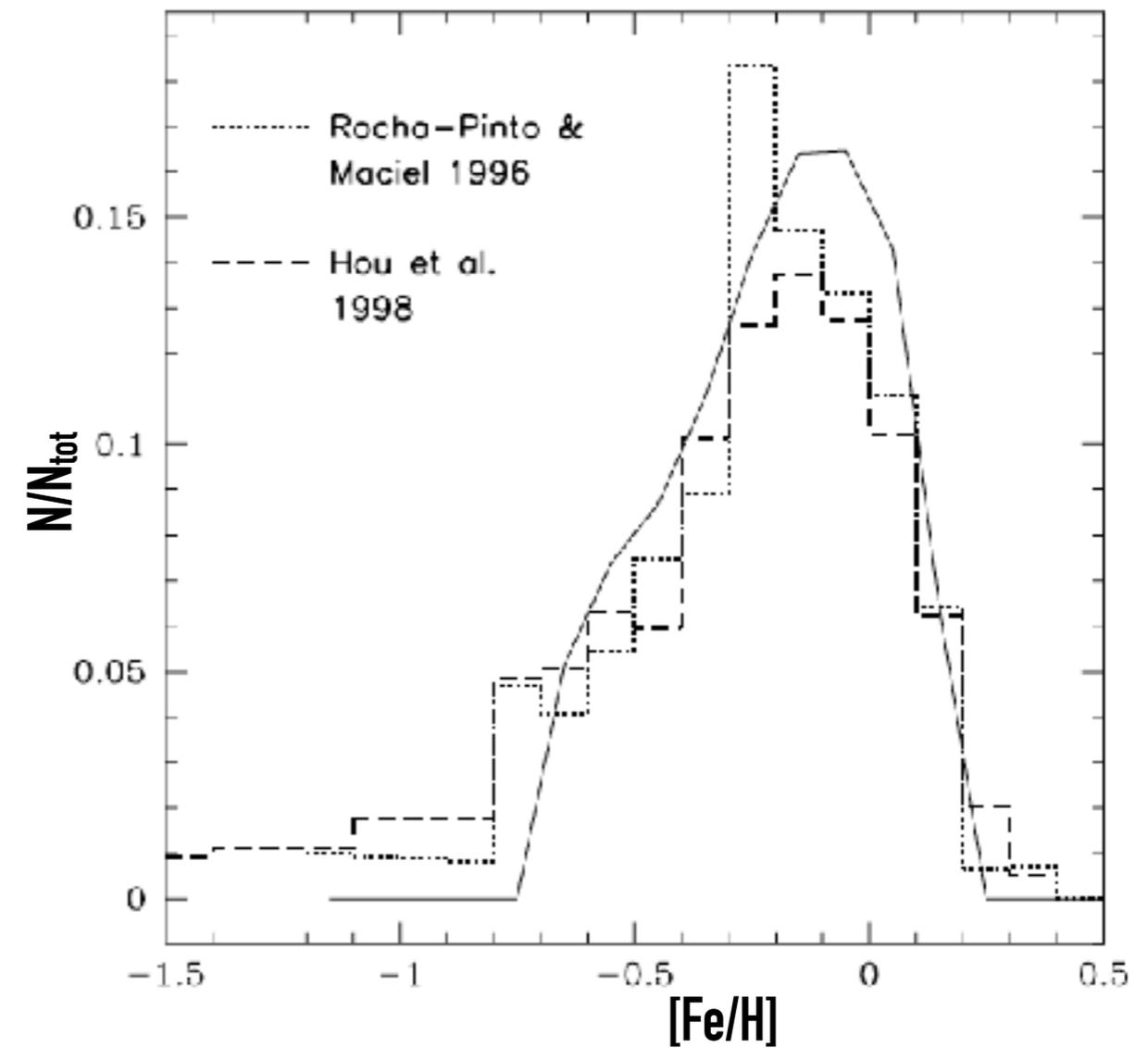
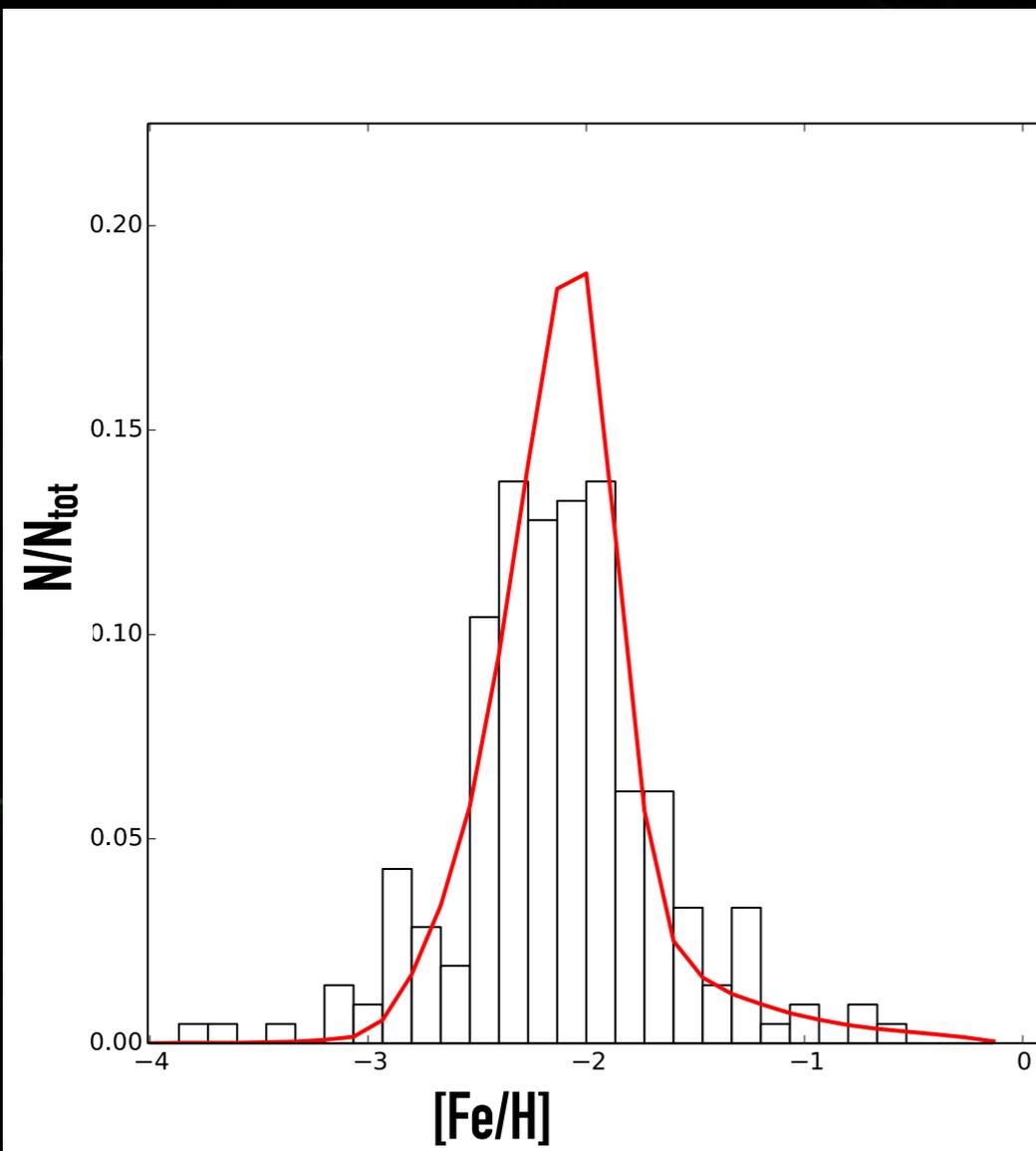
Personal chemical evolution models



Different galaxies have different chemical evolution, typical constrain is the metallicity distribution function. More massive systems have higher efficiency; dSph models present outflows.

Ursa minor MDF

MW solar vicinity MDF



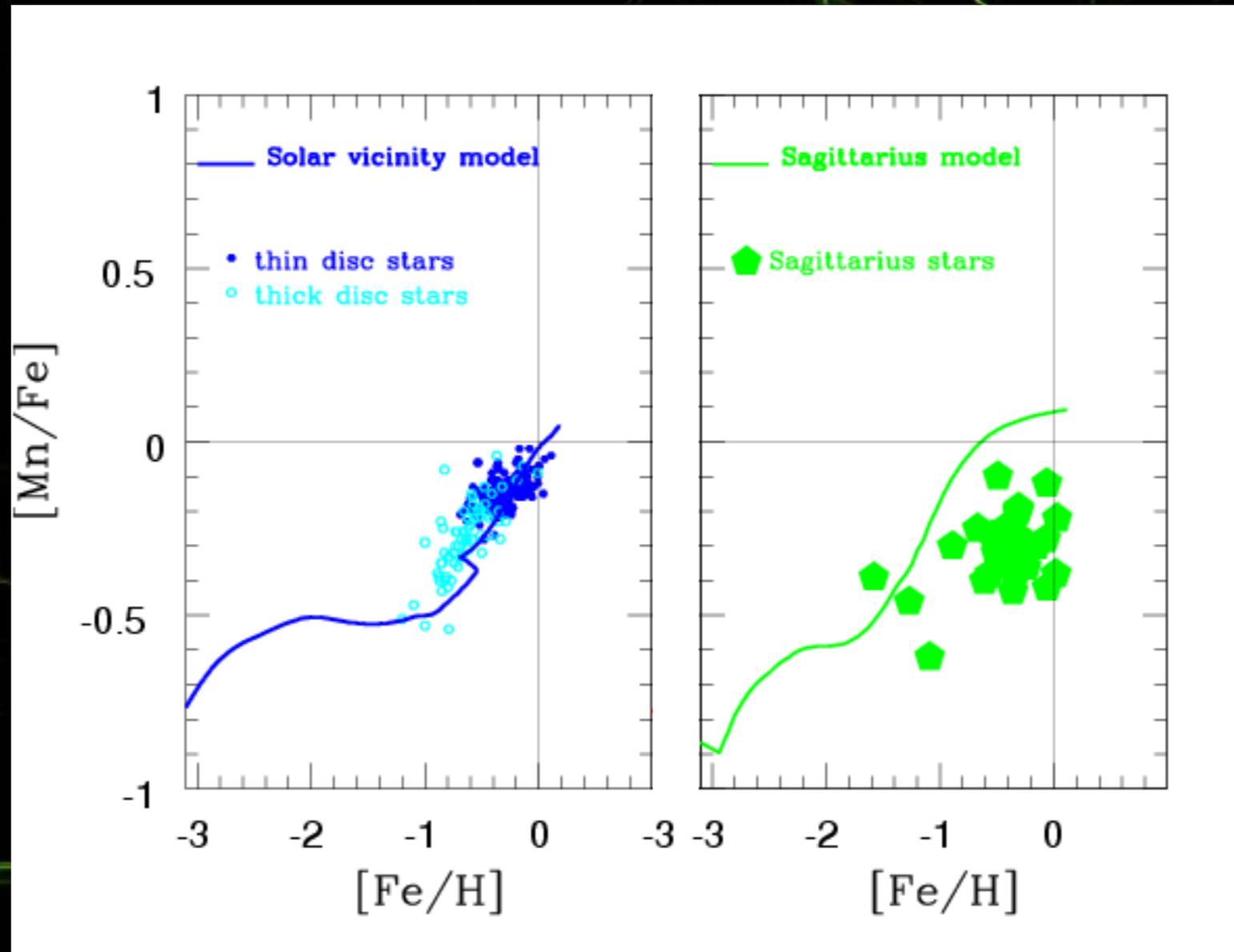
model Ural, GC+15
data Kirby+11

model Chiappini+01

The first issue with Manganese...



Iron peak element and its evolution is driven by SNI and SNIa



Cescutti et al. (2008)

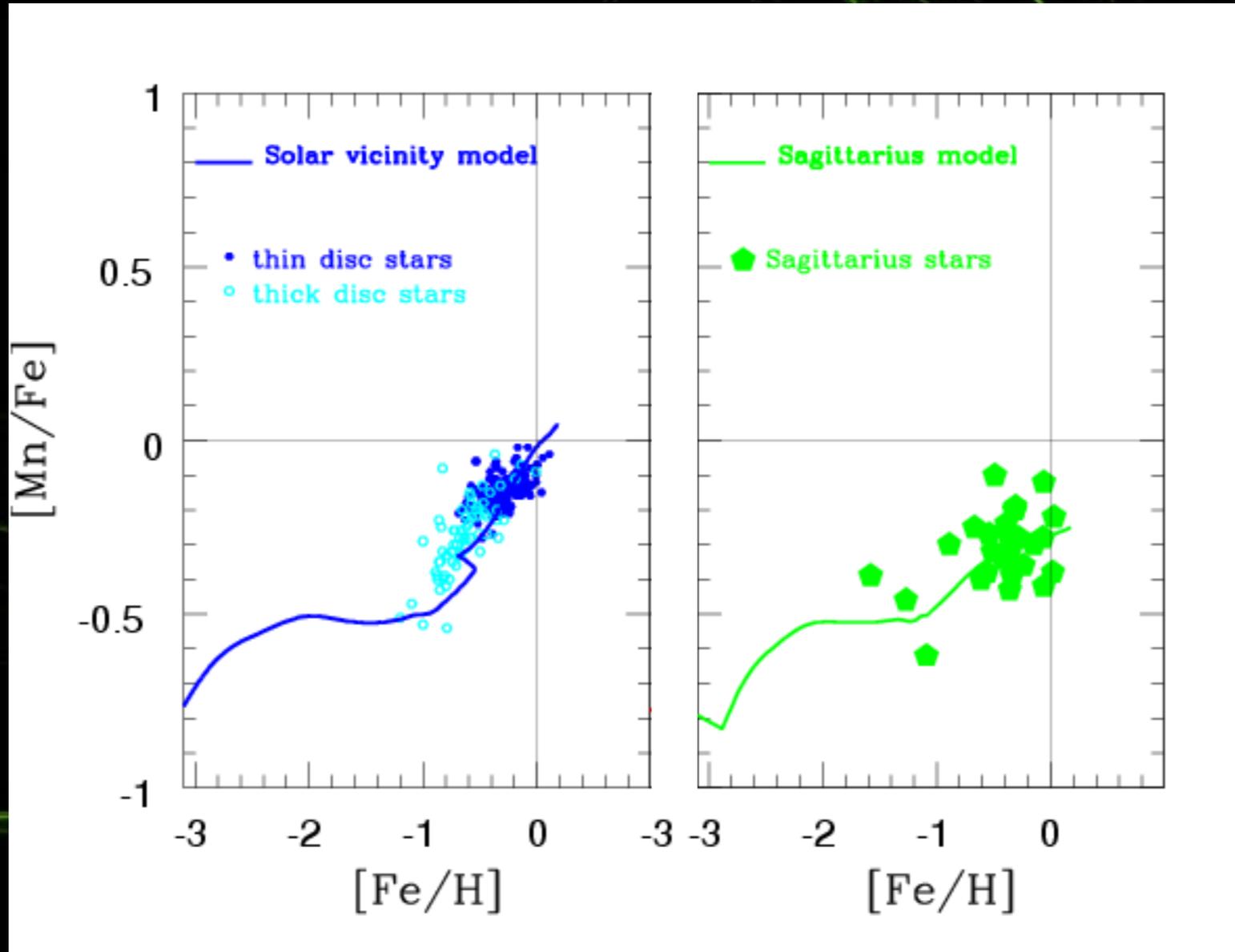
MW:
Reddy et al 2003
Sagittarius:
McWilliam 2003
Sbordone 2007

Results obtained using standard nucleosynthesis for SNe II and SNe Ia with a Ch-mass deflagration (W7 model)

First solution: SNIa yields metal dependent?



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



Cescutti et al. (2008)

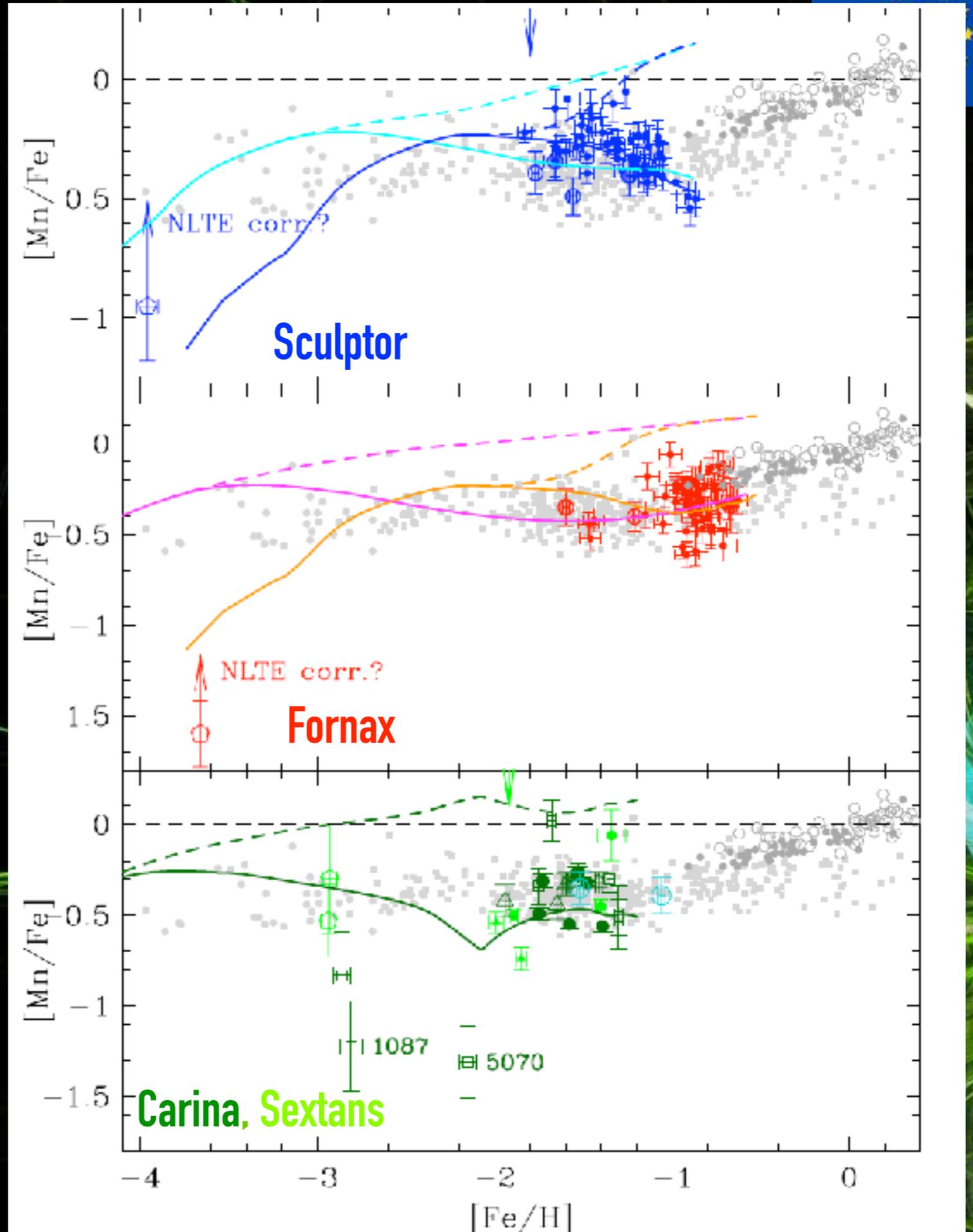
MW:
Reddy et al 2003
Sagittarius:
McWilliam 2003
Sbordone 2007

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

Same prescriptions give excellent results for Sculptor, Fornax, Carina and Sextans

Issues :

- Ch-mass deflagration or delayed-detonation, do not produce Mn with a strong metal dependency
- spread of the measured abundances of Mn in this dSph?



Mn nucleosynthesis in different SNIa explosions/progenitors



Röpke+04

Delayed-detonation models near-CH mass

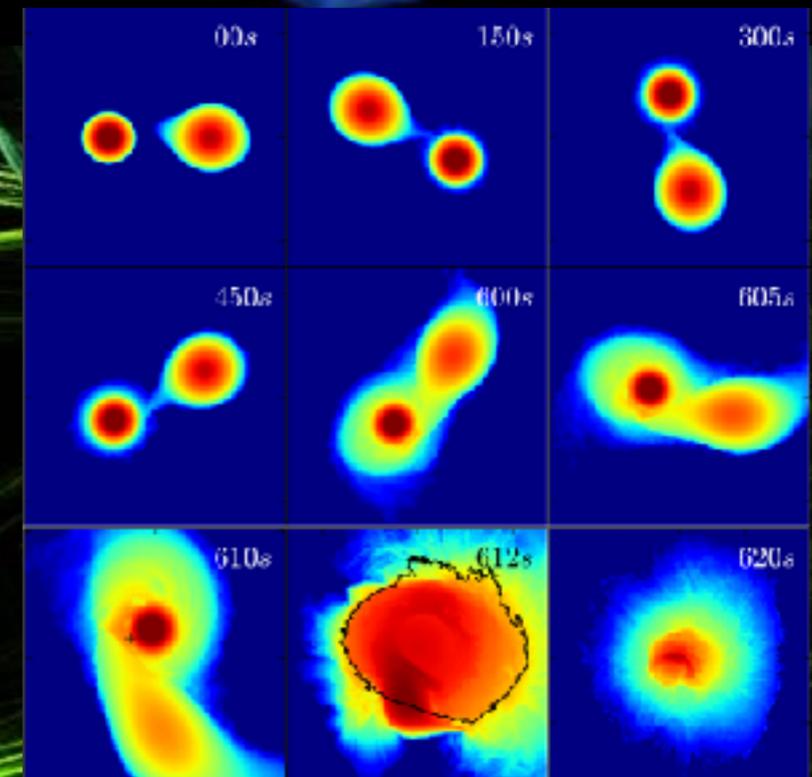
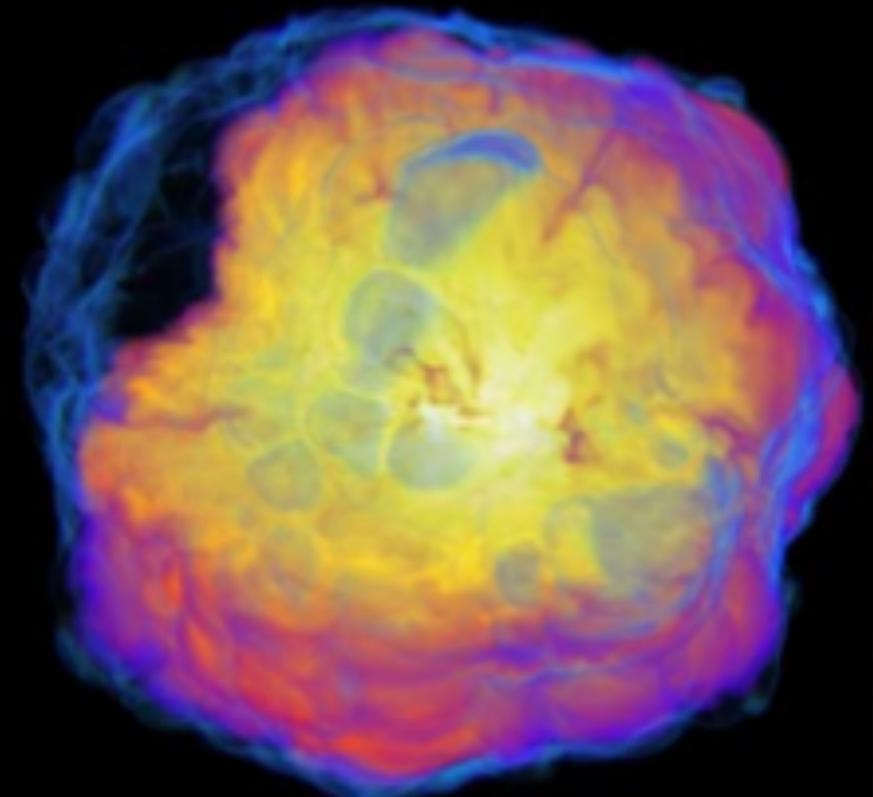
$[Mn/Fe] \sim 0.3$ dex

Theoretically, they do not explode at low metallicity!

Sub-CH mass violent mergers (double detonation)

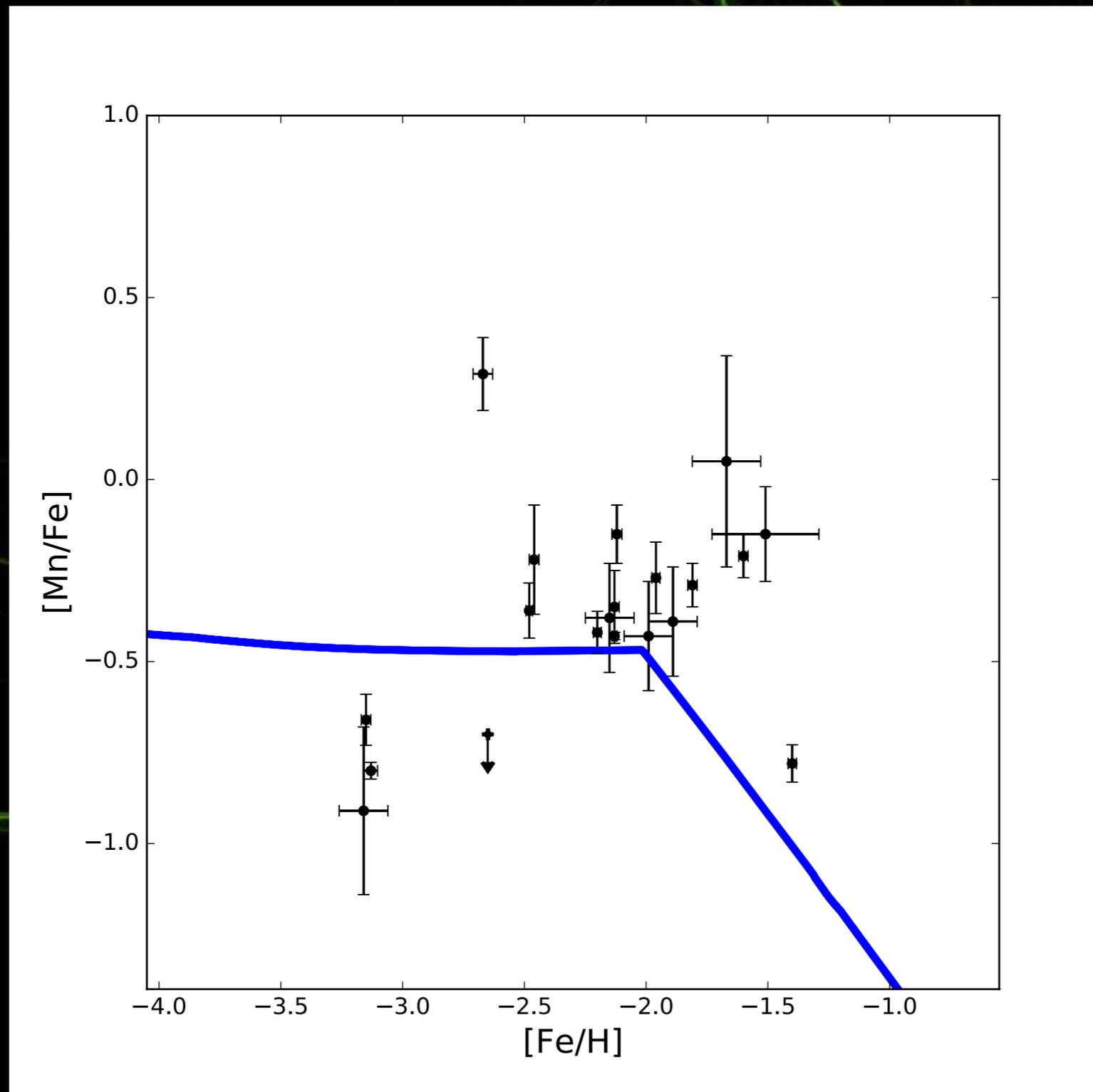
$[Mn/Fe] \sim -0.2$ dex

Delayed-detonation models involve higher densities and they will have an enhanced production of Mn from the contribution of “normal” freeze-out from NSE (as opposed to “alpha-rich”). This is not the case for violent merger or double detonation models.



Pakmor+12

Results for Ursa minor only with sub-Ch SNe



CEM with only sub-Ch mass SNe Ia cannot reproduce the observed abundance in Ursa minor (same applies to others dSph galaxies)

data from Ural, GC+15



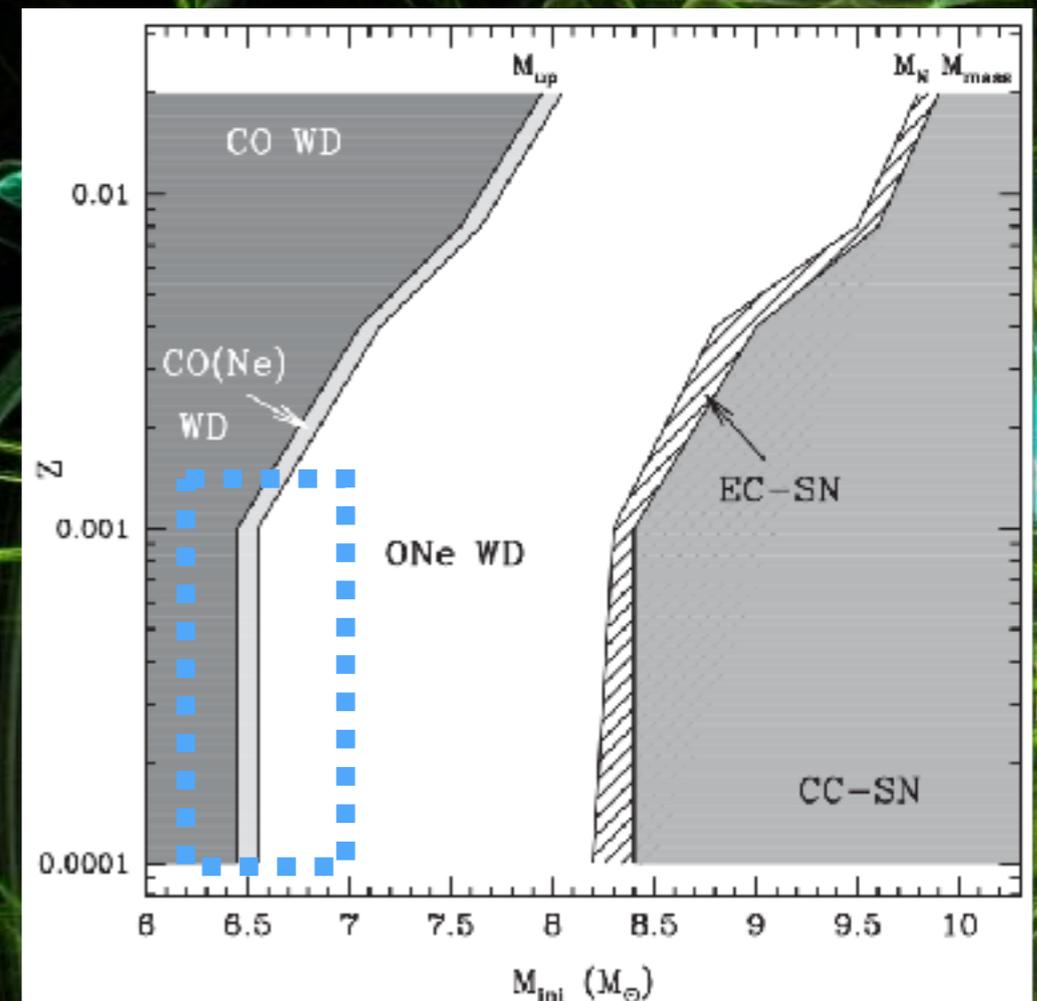
More SN Ia channels: SNe Iax

A near CH CO-WD or hybrid CO(Ne) WD (Denissenkov+13) undergoes central carbon deflagration similar to the one of a normal SNe Ia but the carbon deflagration is quenched when it reaches the outer O+Ne layer.

The progenitor WD is only partially burnt and ejected, The SN Ia produce less Ni and it has a fainter luminosity (yields from N5def, Kromer+13, Fink+14)

SNe Iax

Meng & Podsiadlowski 14, Kobayashi+15, Kromer+13 +15

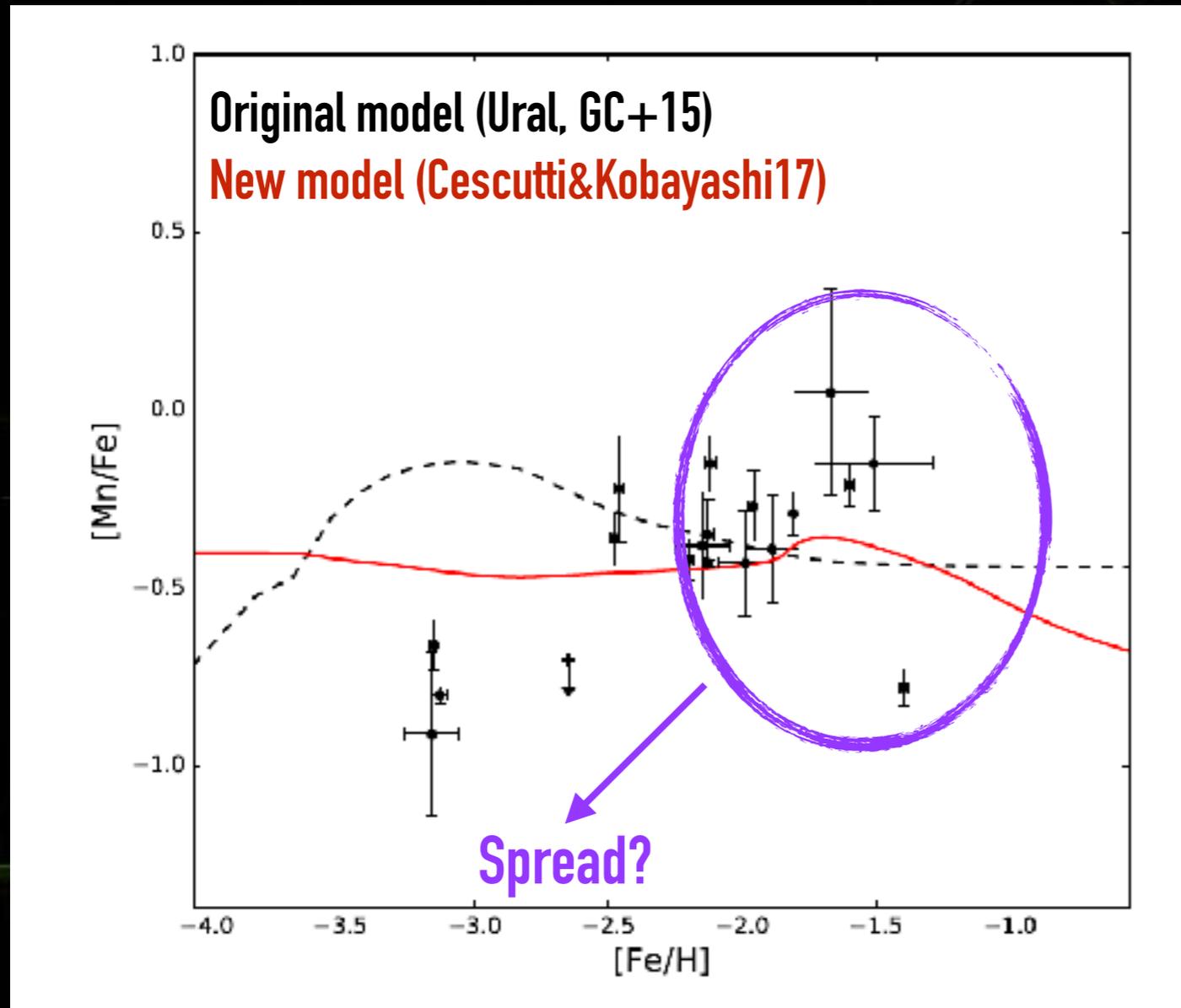


Doherty +15



New channels of SNe Ia in Ursa minor model

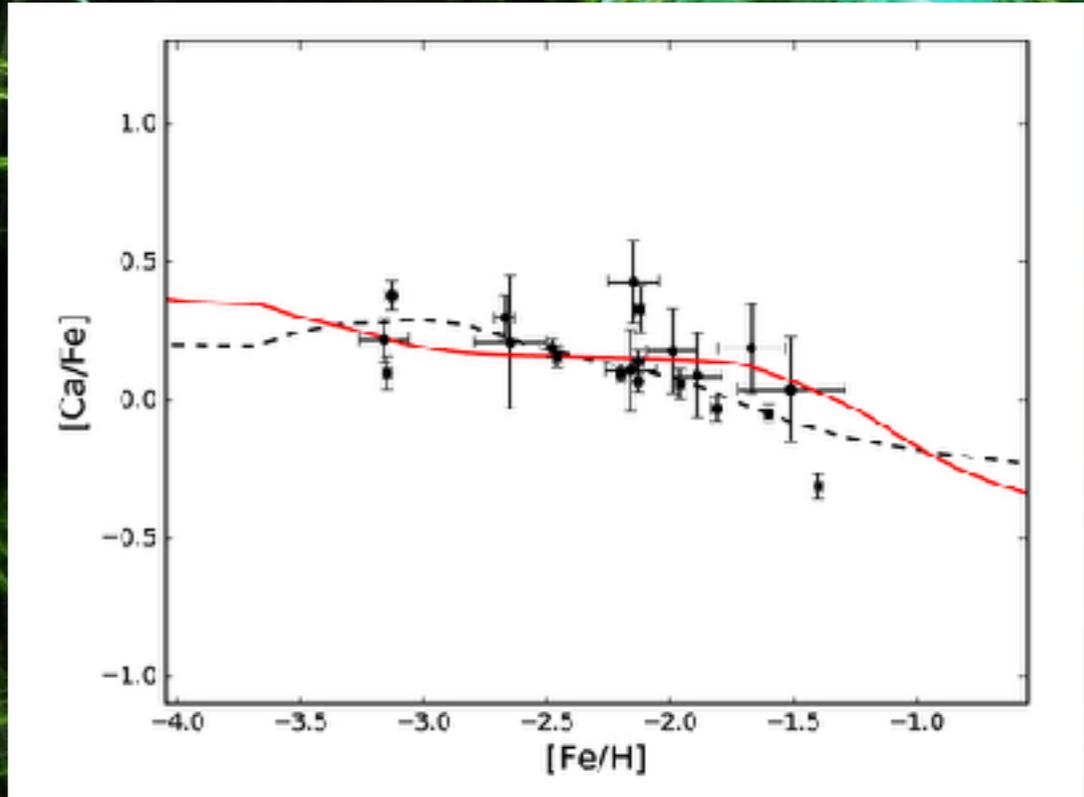
Cescutti & Kobayashi (2017)



Metal dependent deflagration channel reproduces the data of Mn, but also the new model with both SNe Ia and sub-Ch

Both are able to reproduce the knee in alpha elements

data from Ural, GC+15

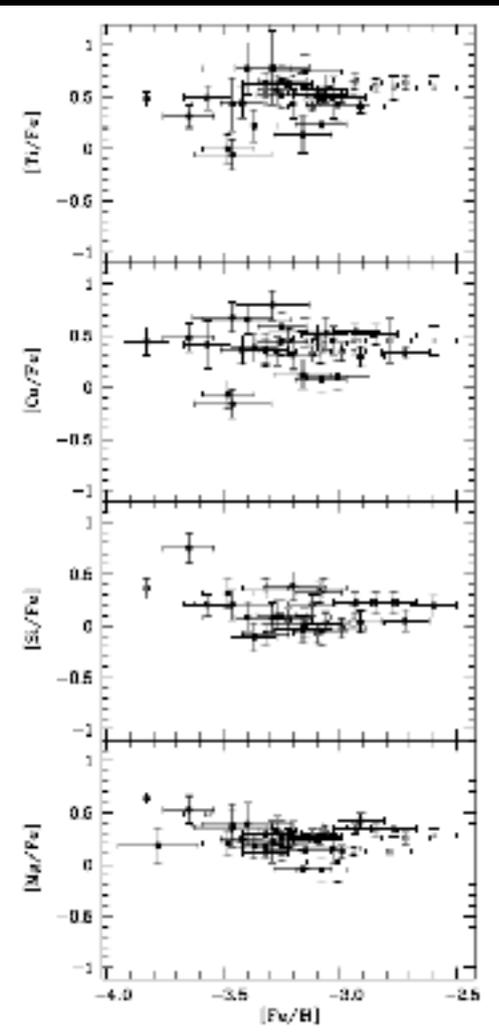


Stochastic chemical evolution models

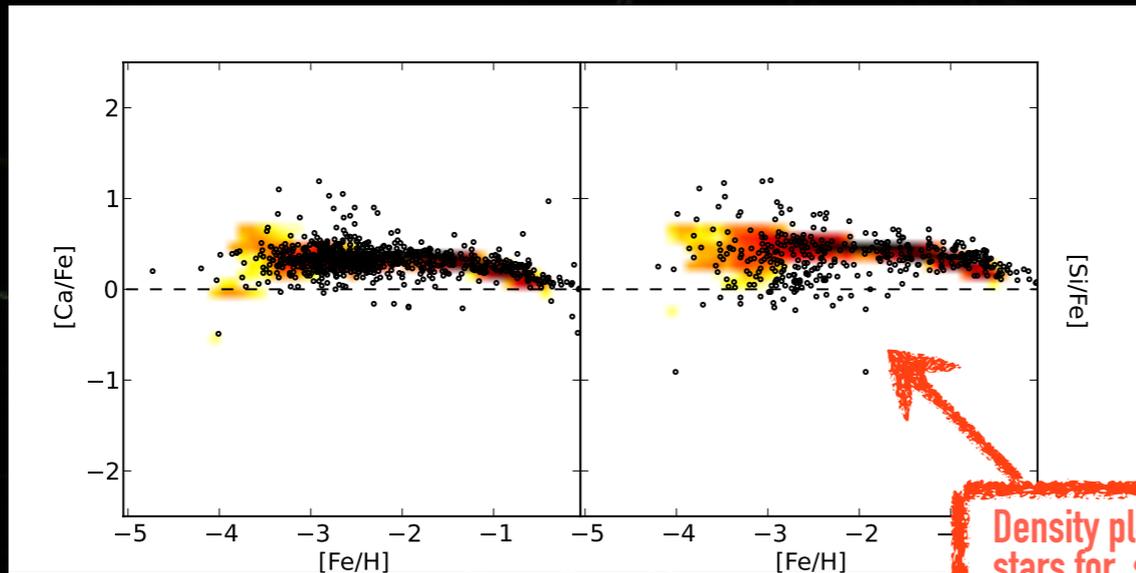
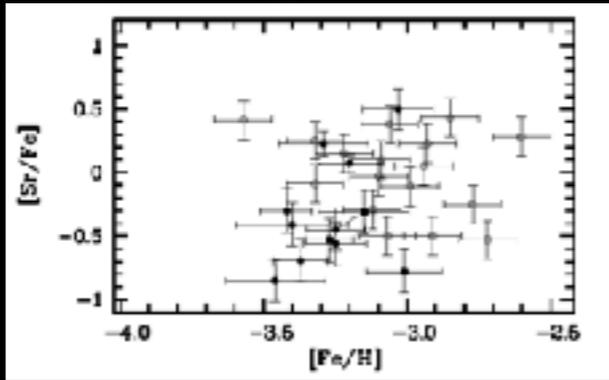


Problem:
Neutron capture elements present a spread alpha elements do not

Solution:
The volumes in which the ISM is well mixed are discrete. Assuming a SNe bubble as typical volume with a low regime of star formation the IMF is not fully sampled. This promotes spread among different volumes if nucleosynthesis of the element is different among different SNe,

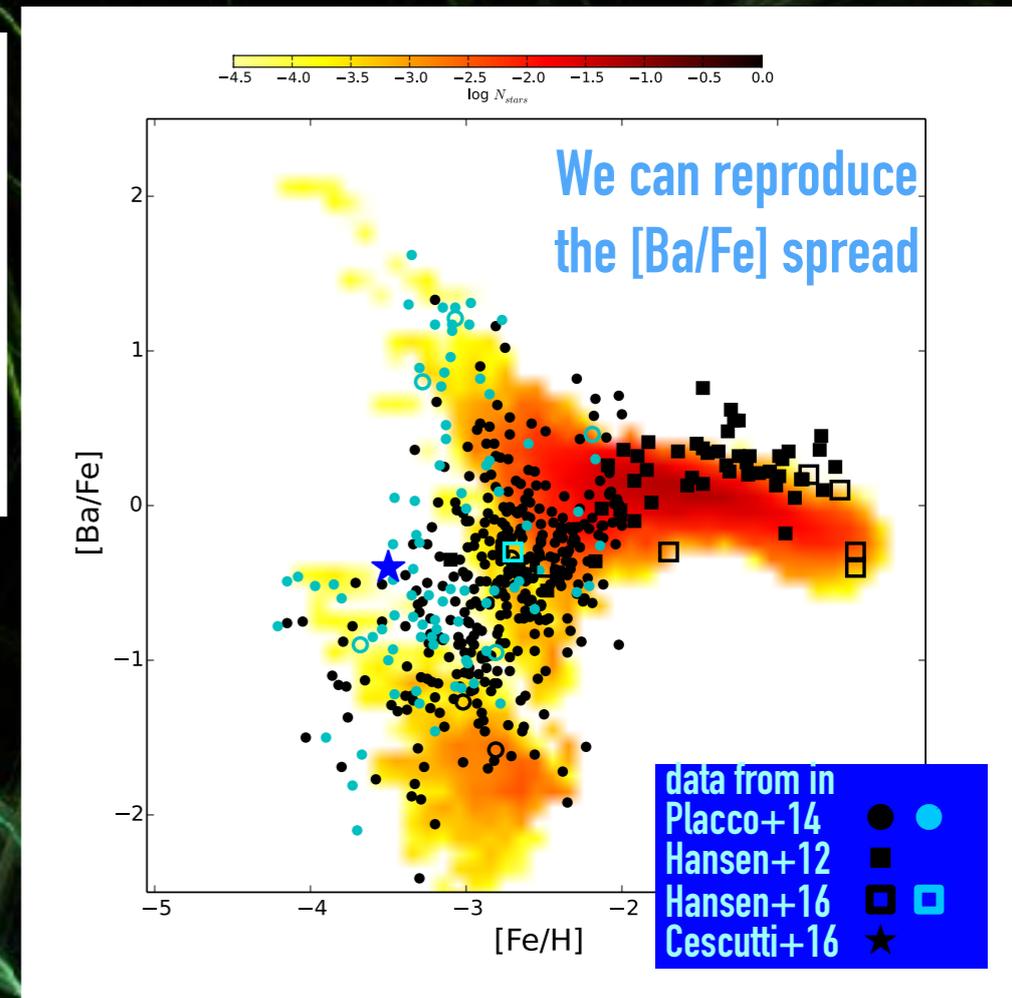


Bonifacio+09



data collected in Frebel 2010

Density plot of long living stars for stochastic model



We can reproduce the [Ba/Fe] spread

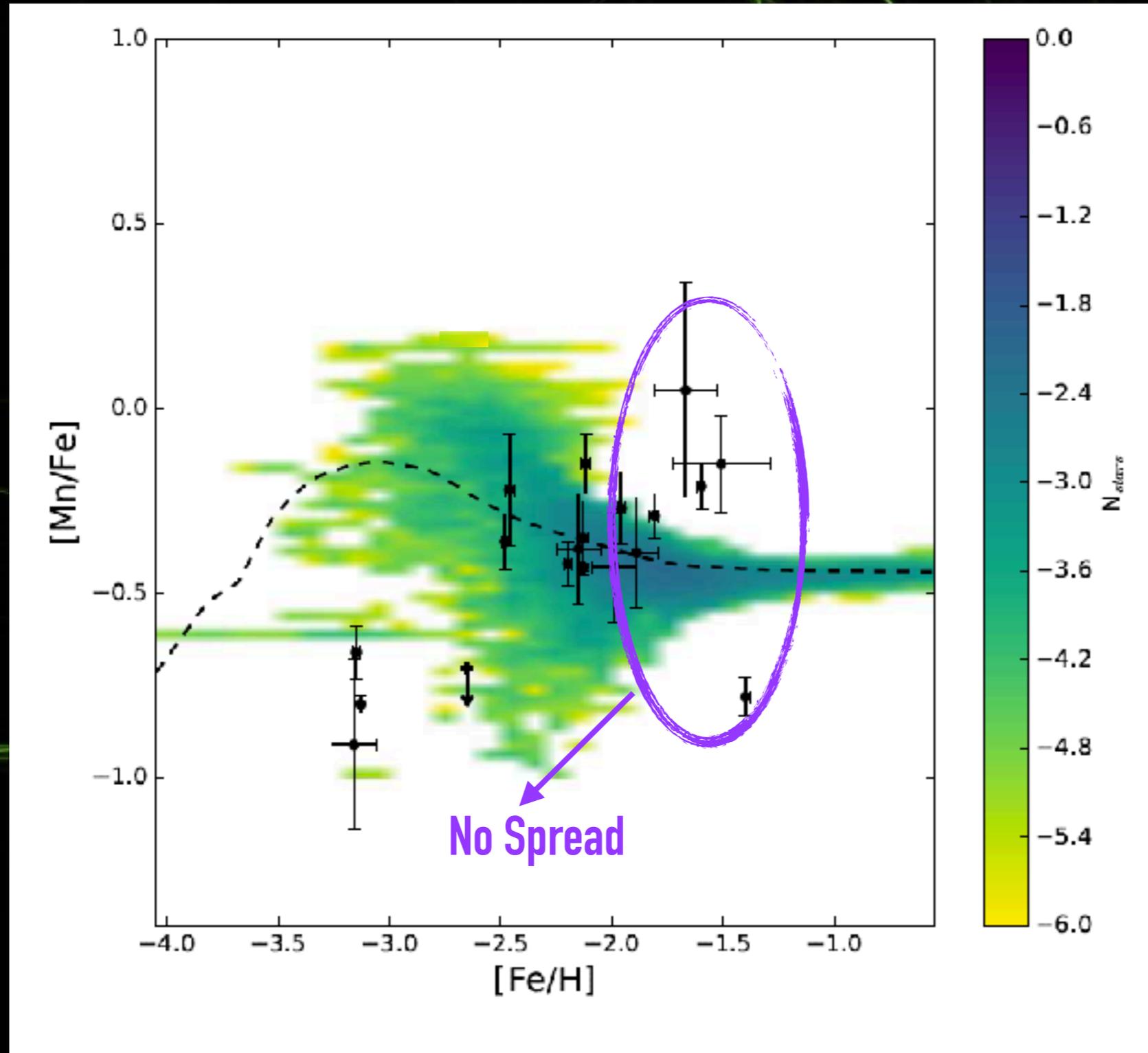
- data from in
- Placco+14 ● ●
- Hansen+12 ■ ■
- Hansen+16 ◻ ◻
- Cescutti+16 ★

Cescutti 08 +13,+16

Same concept applied to Ursa minor model

Stochastic model for Ursa minor 1

Mn metal dependent from a single degenerate Ch-mass SNe Ia

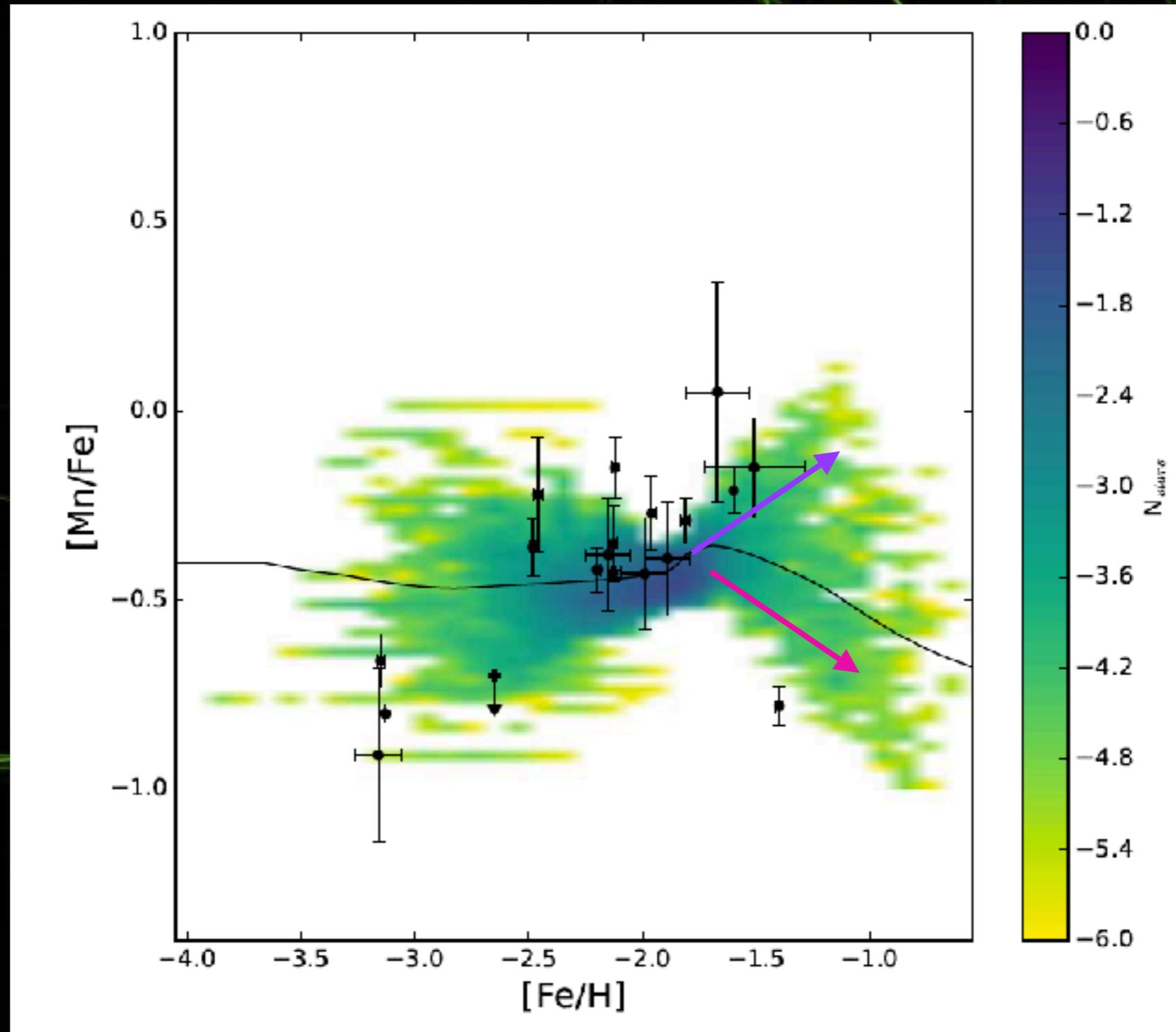


Cescutti & Kobayashi (2017)

Stochastic model for Ursa minor 2



New model with Ch-mass (SNe Iax) & sub-CH mass



The manganese butterfly

Cescutti & Kobayashi (2017)

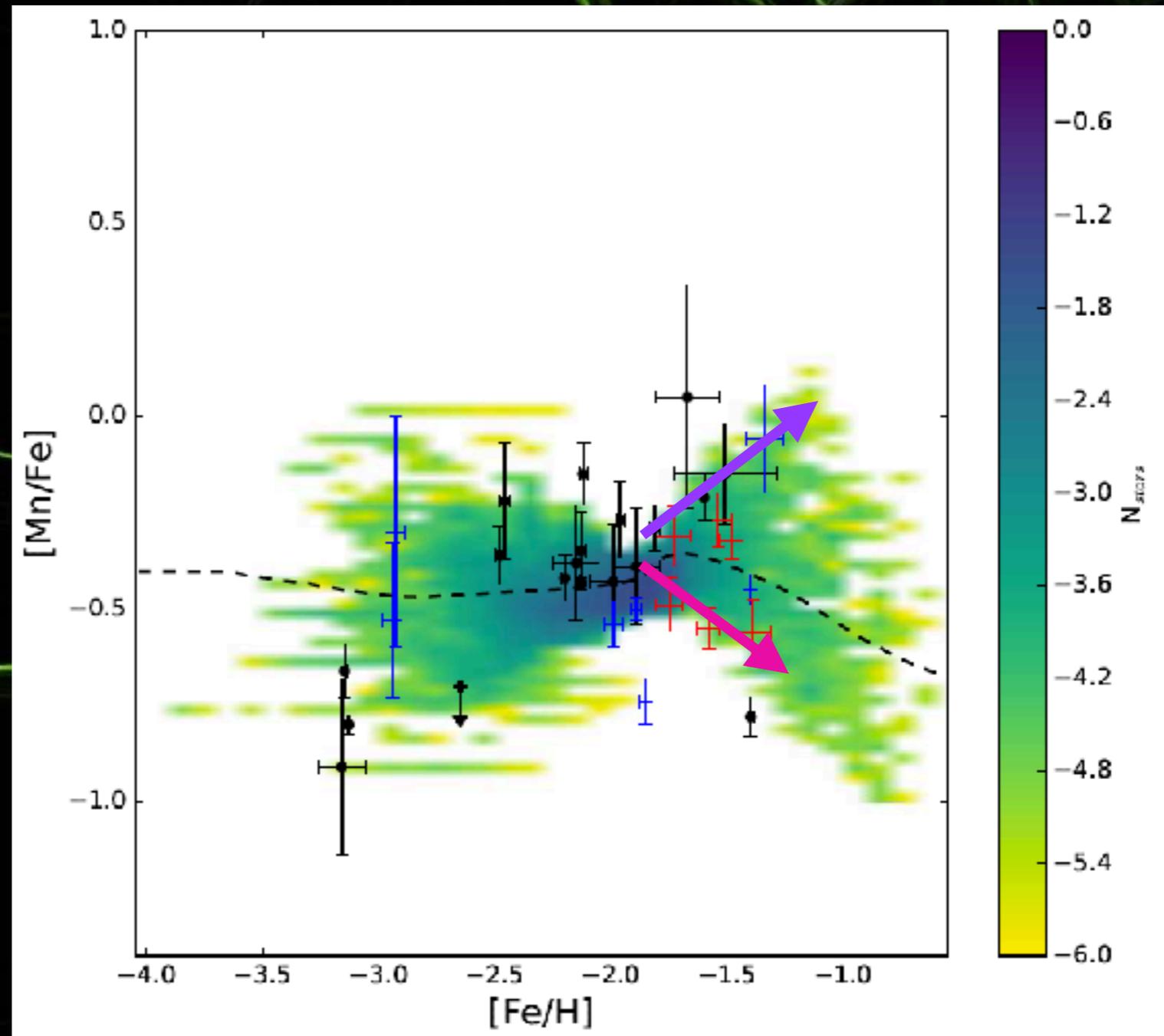
Stochastic chemical evolution models



More data from **Carina** and **Sextans**, dSph with similar mass compared to Ursa minor

We can study the origin of the spread in chemical abundance space. In this case it is originated by two possible SNe Ia progenitors:

Chandrasekhar-mass & sub-Chandrasekhar mass



Neutron capture elements



GALACTIC HALO

s-process

r-process

site

Low-(intermediate) mass stars

fast rotating
Massive stars

Massive stars
(& NS mergers)

time scale

>300Myr

< 30Myr

< 30Myr
(excluding NS mergers)

O-Ne-Mg core explosions? NS
stars mergers? Magneto rot.
driven SN? many scenarios...

yields

Busso+ 2001

Frischknecht+ 2016

....

Cristallo+ 2011
Karakas+ 2012

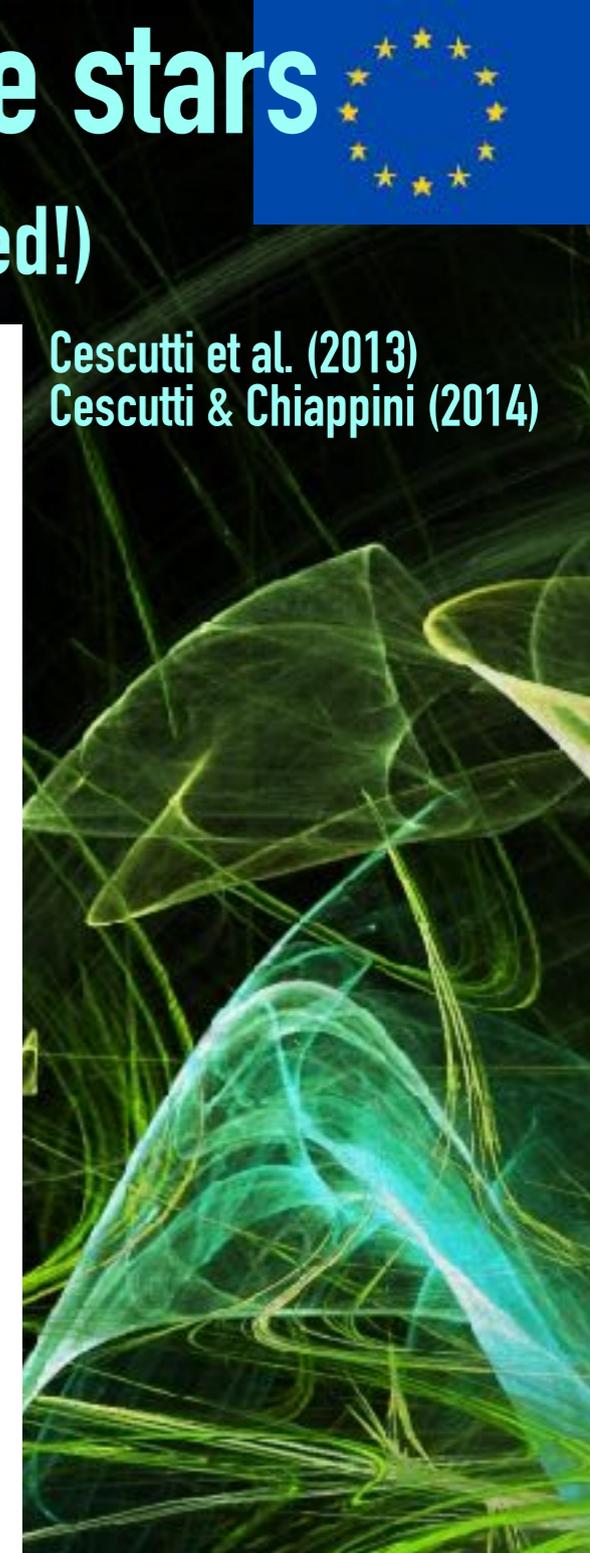
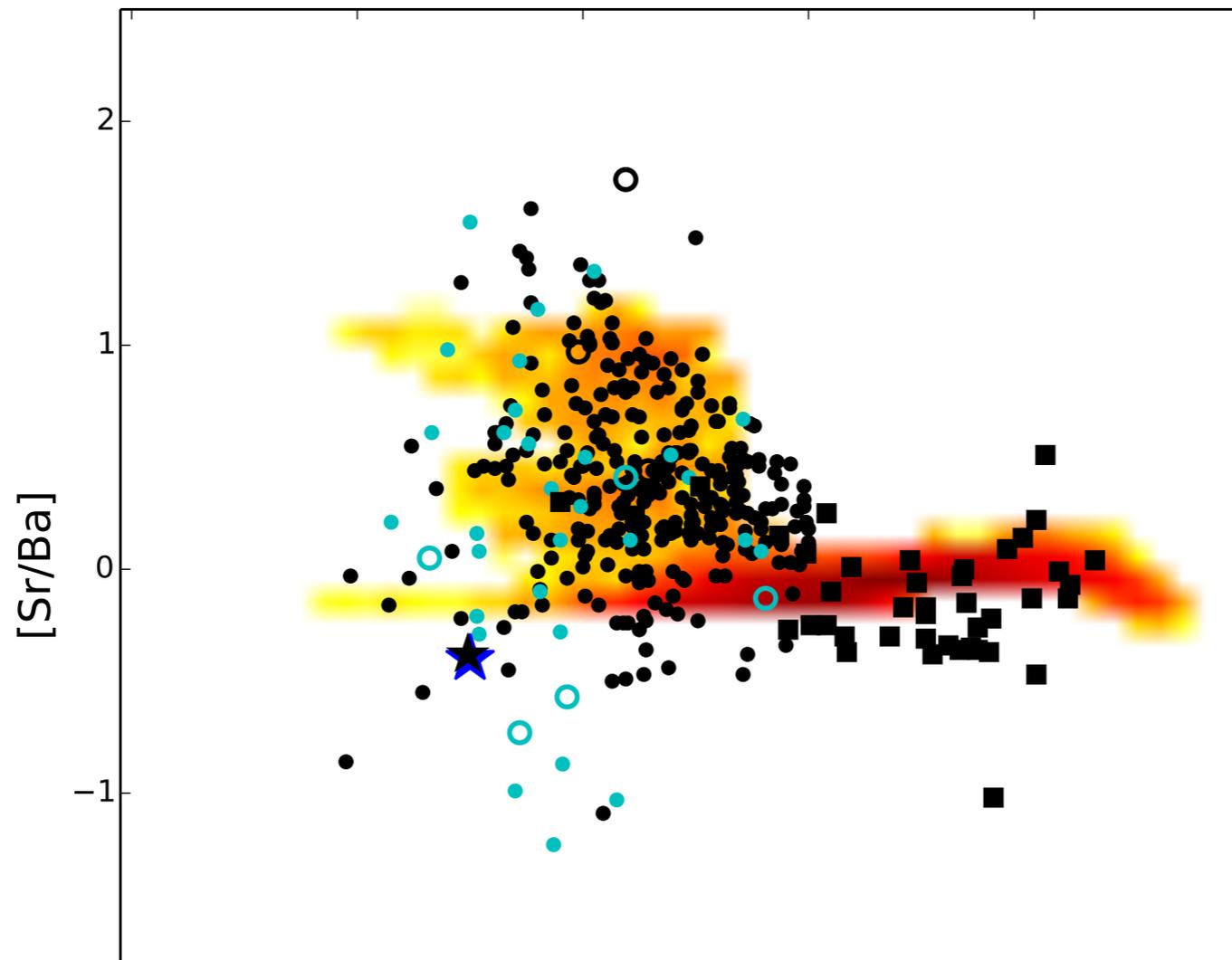
Chieffi & Limongi
yields available

s-process from fast rotating massive stars



+ an r-process site (the 2 productions are not coupled!)

Cescutti et al. (2013)
Cescutti & Chiappini (2014)



A s-process (from fast rotating massive stars)
and an r-process (from rare events)
can reproduce the neutron capture elements in the Early Universe



The model for an ultra faint galaxies: Hercules

- short SF history (<200Myr)
- strong winds

We constrain the model to match the MDF (and the total stellar mass)

The nucleosynthesis is exactly the same as the halo.

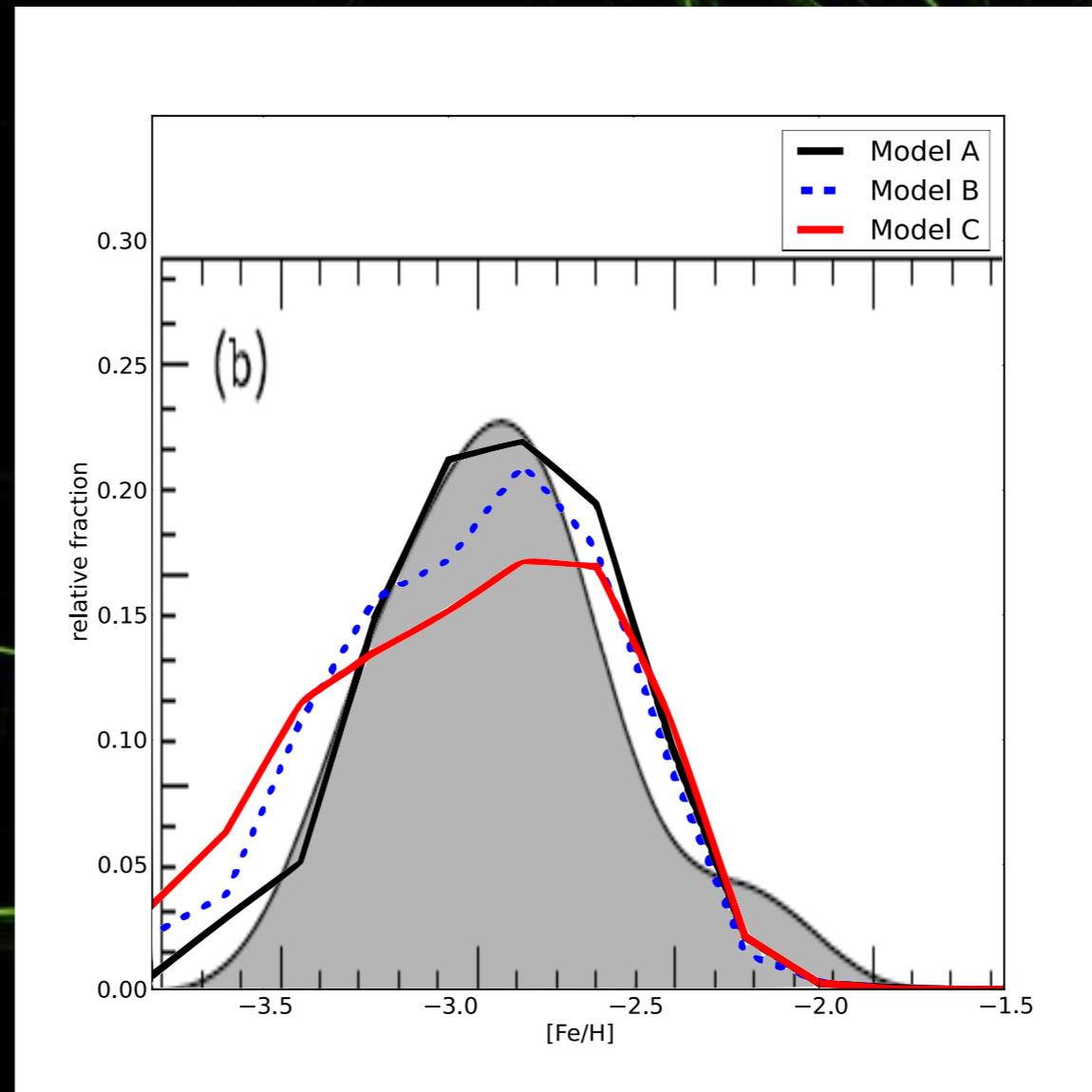
Tested three different (initial) total mass of gas.

A : $1 \cdot 10^5 \text{ Msun}$

B: $2 \cdot 10^5 \text{ Msun}$

(C : $5 \cdot 10^5 \text{ Msun}$)

Aden+11



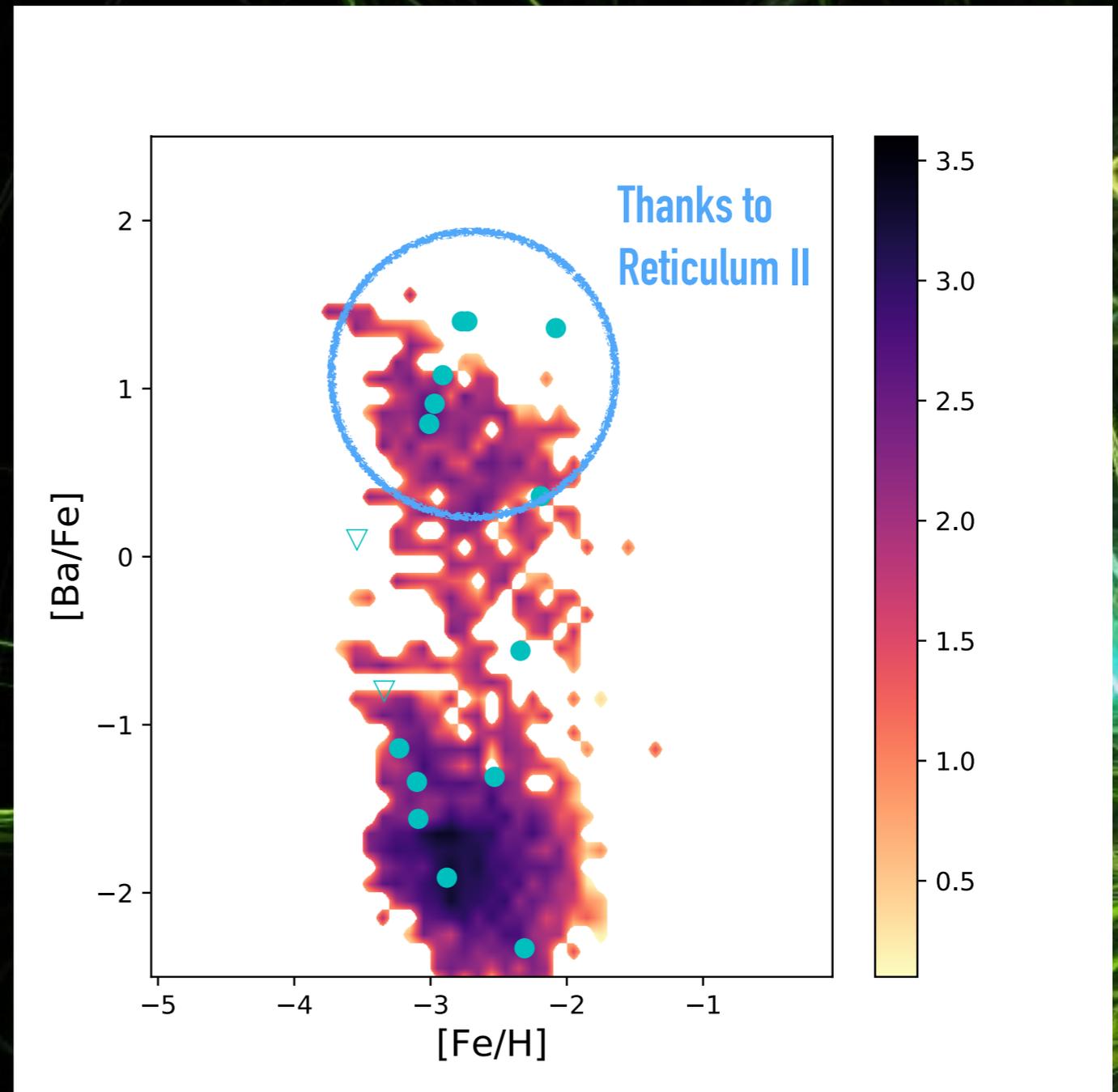
0.04 Msun/pc^2
 0.08 Msun/pc^2
 $1 \cdot 10^5 \text{ Msun gas}$
 $2 \cdot 10^2 \text{ Msun stelle}$
 0.002

$0.037 \cdot 10^6 \text{ Msun}$
 $2.6 \cdot 10^6 \text{ Msun}$
 ~ 0.01



Results in Ultra Faint Galaxies: Ba

Data support the model:
some UF galaxies are indeed
enriched by r-process
elements...



- Ji+16
- Frebel+10
- Roederer+16
- ▽ upper limits



Results in Ultra Faint Galaxies: Eu

All the stars with low Ba do not show any Eu.

It is connected to problem in measuring Eu, but possibly also in a pristine environment, such as in a UF galaxy, maybe we can find Eu-free stars(?)

