Osservatorio Astronomico di Trieste
Astronomical Observatory of Trieste

# The chemical signature of SNIax in the stars of Ursa minor?

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and Chiaki Kobayashi

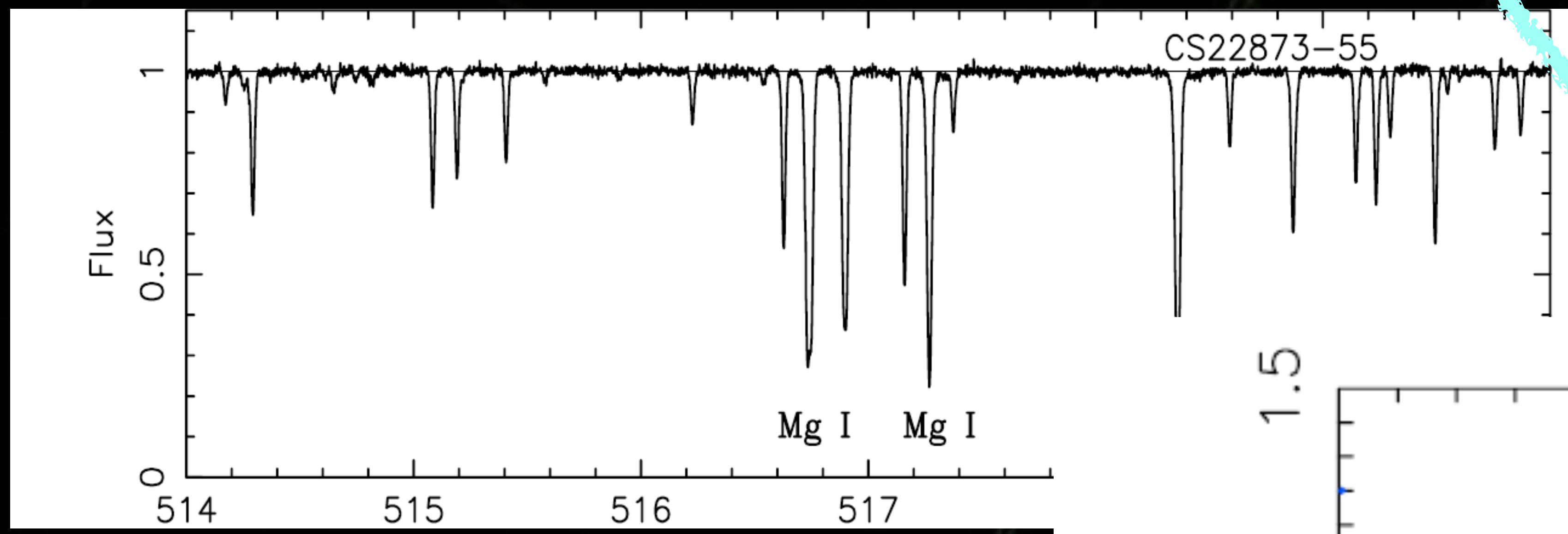
Astro FIt 2
Astronomy Fellowships in Italy

Denver, June 04, 2018

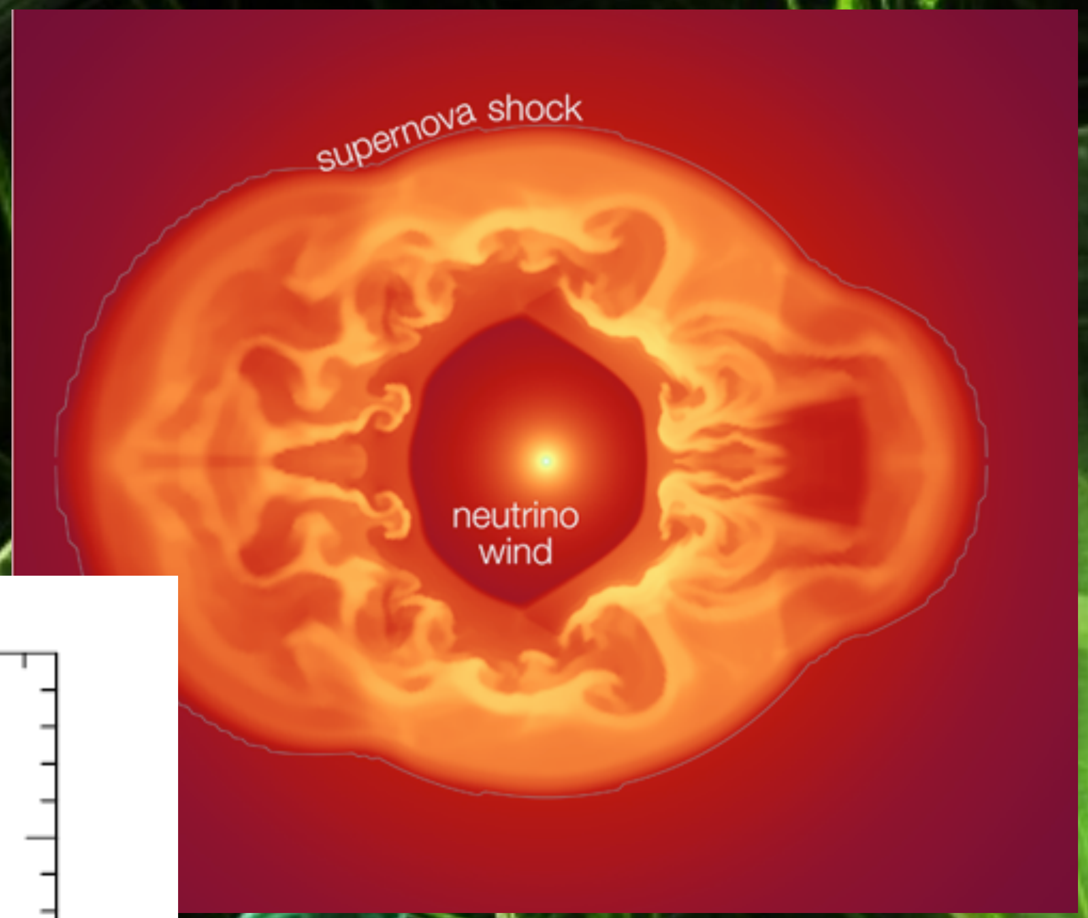
# Chemical evolution models

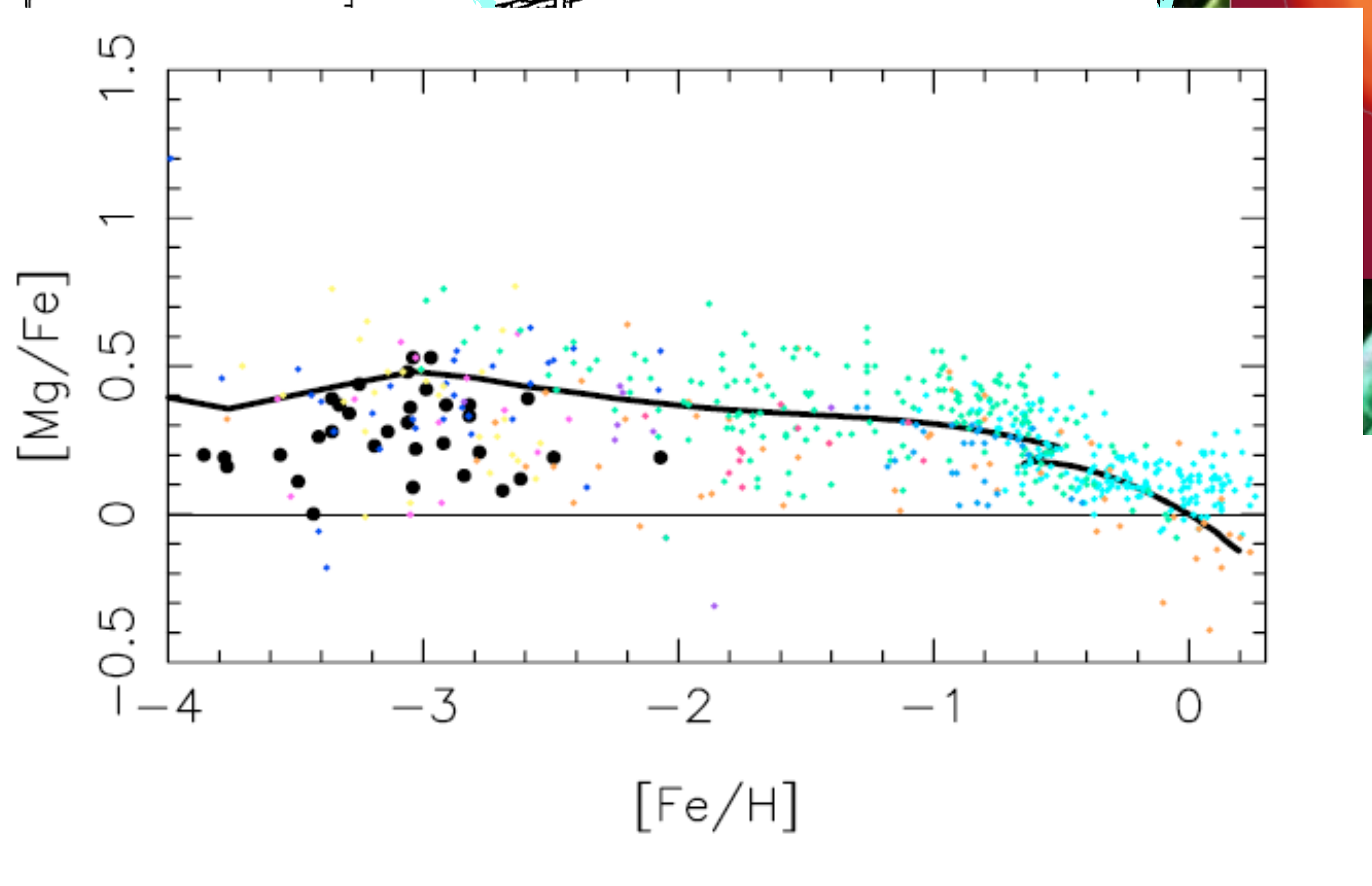
?

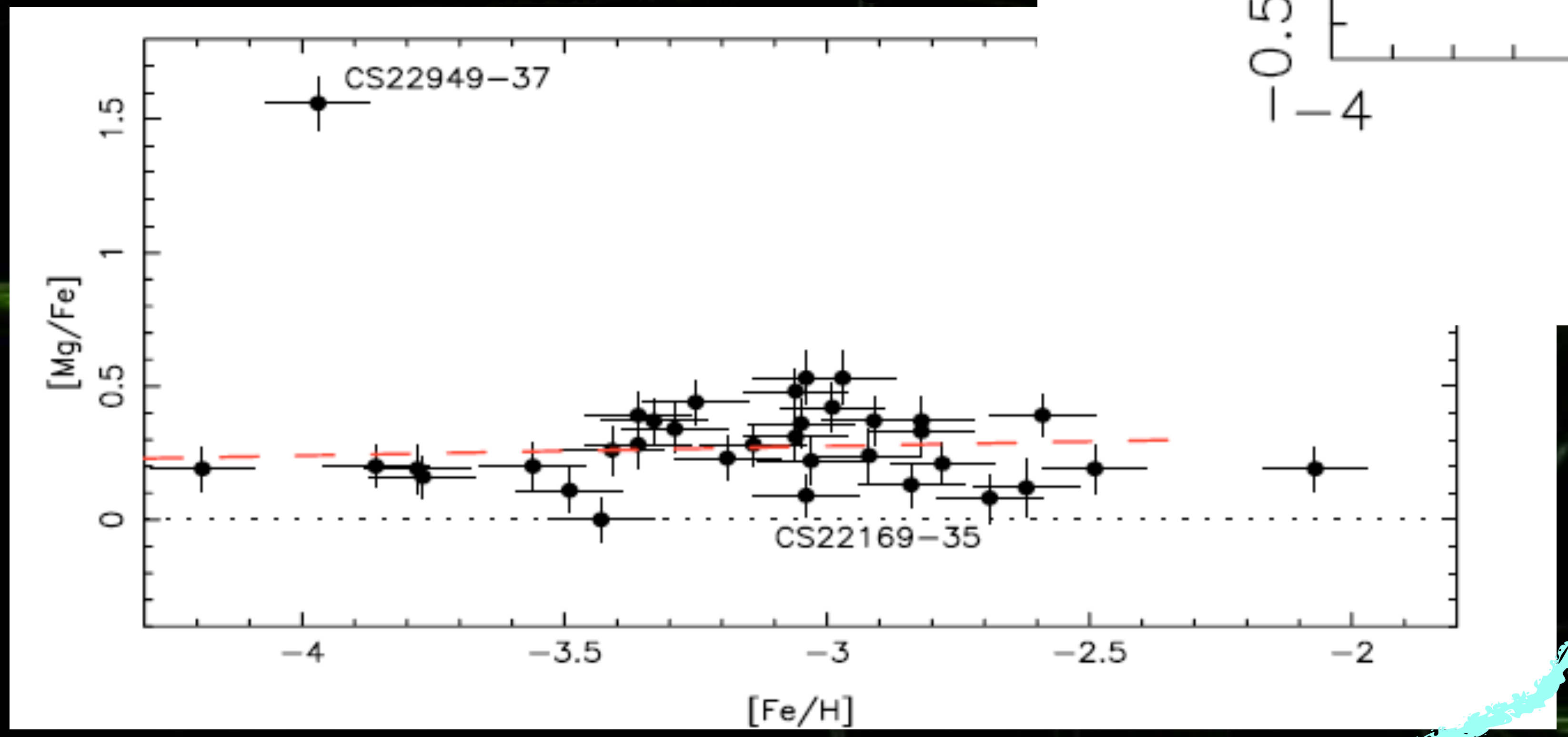
Stellar spectra



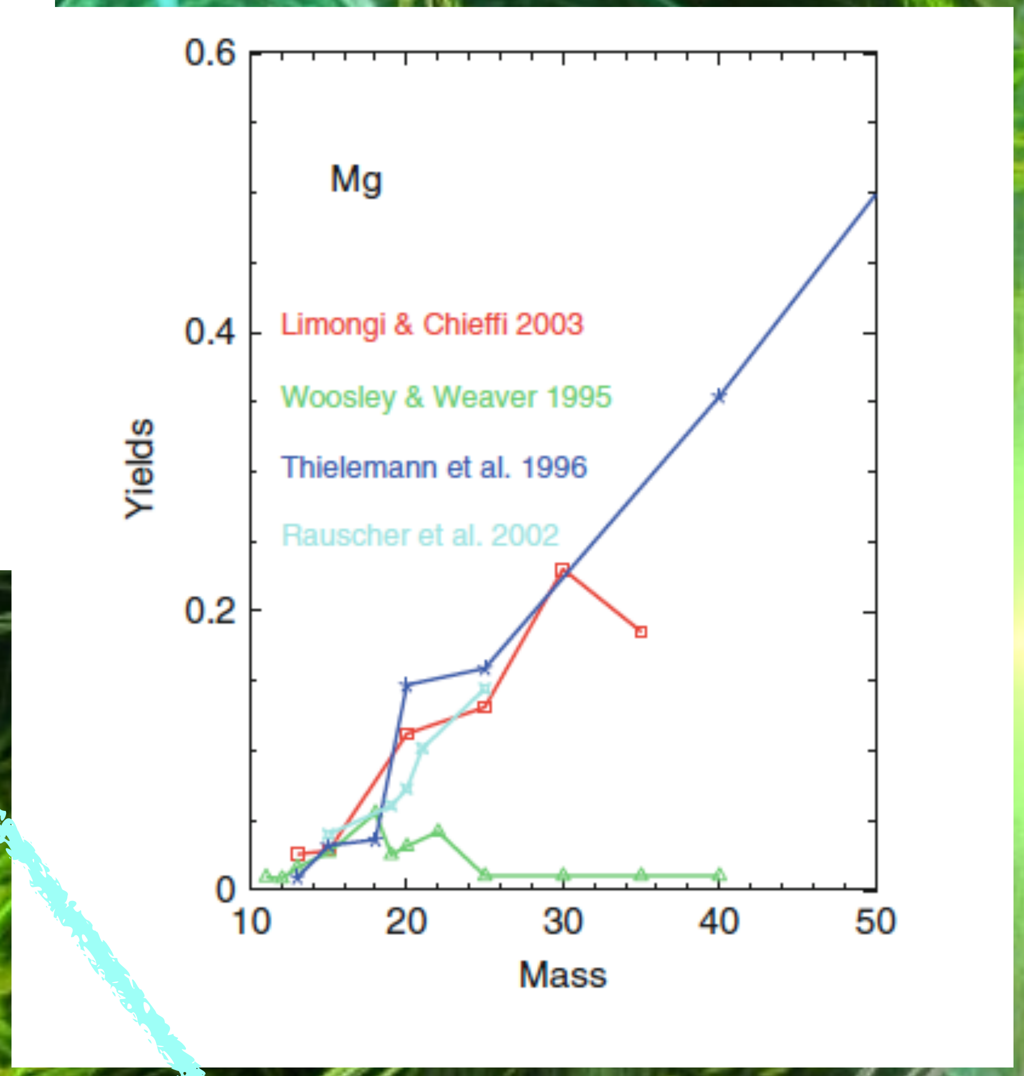

Stellar evolution




Chemical abundances

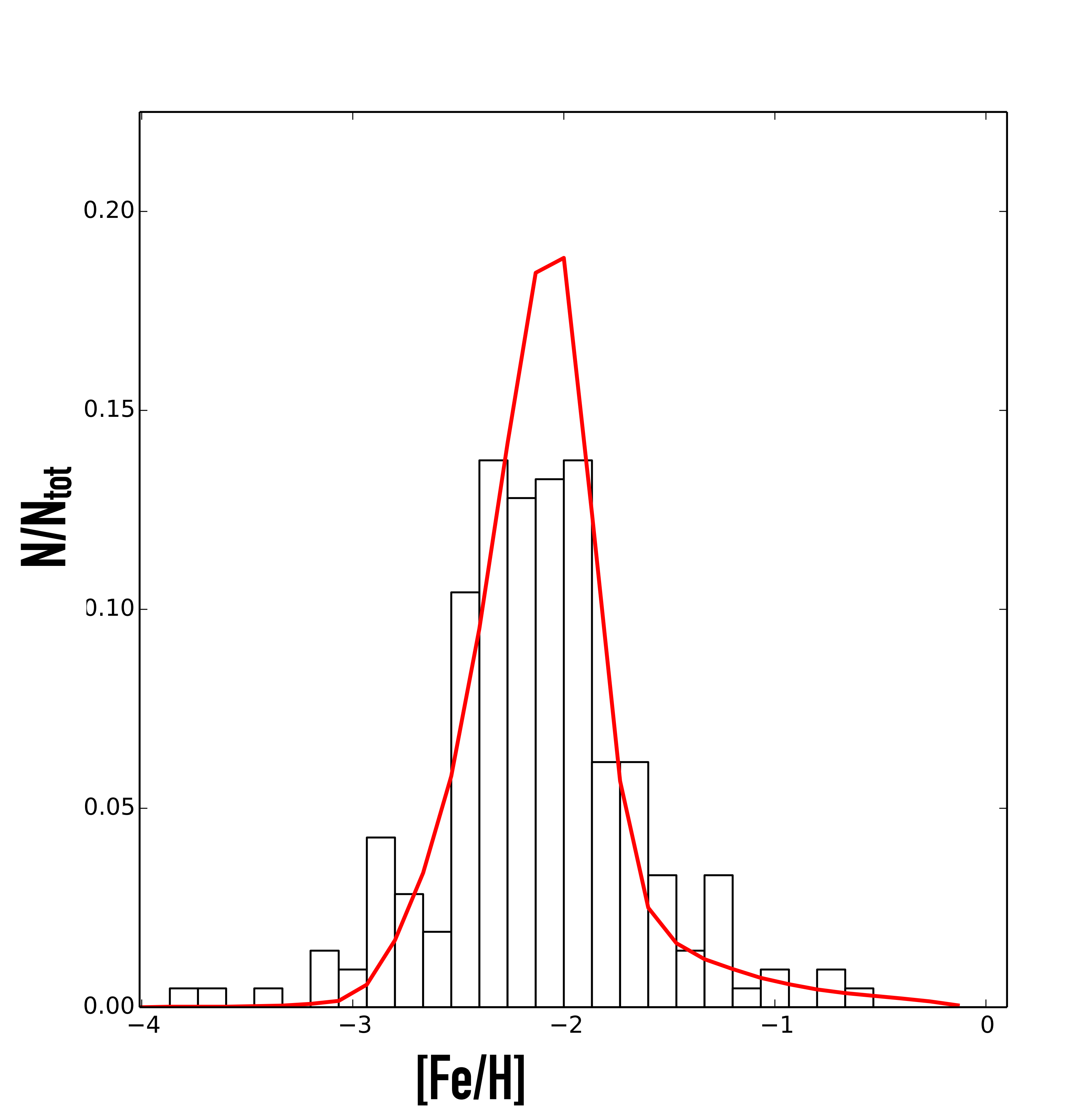



Nucleosynthesis

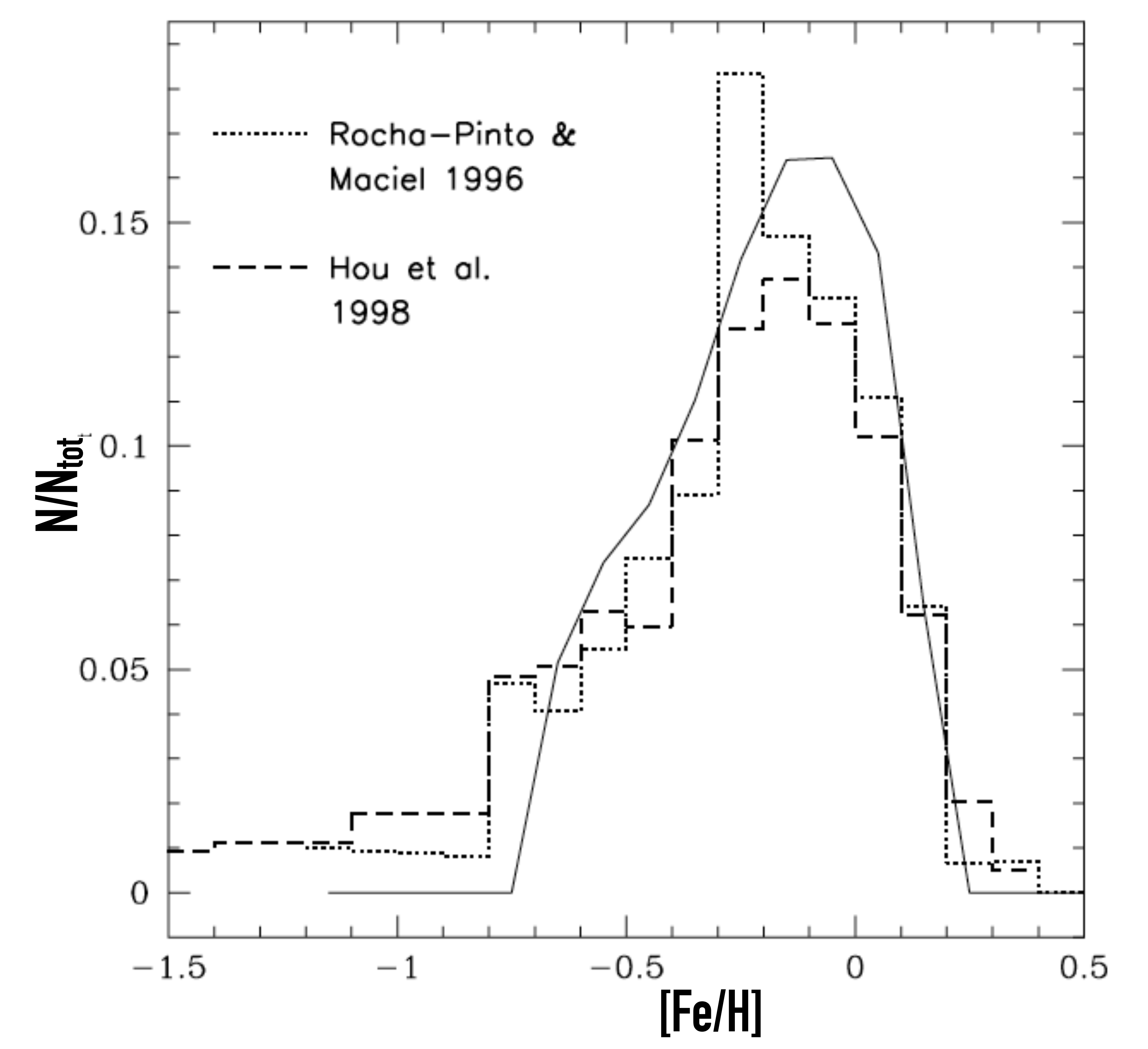
# Personal chemical evolution models

Different galaxies have different chemical evolution, typical constrain is the metallicity distribution function.
Massive systems have high efficiency; dSph models have low SF efficiencies and present outflows.

Ursa minor MDF




MW solar vicinity MDF




model Ural, GC+15
data Kirby+11

model Chiappini+01

# Mn nucleosynthesis in different SNIa explosions/progenitors

Delayed-detonation models near-CH mass

[Mn/Fe]~0.3 dex

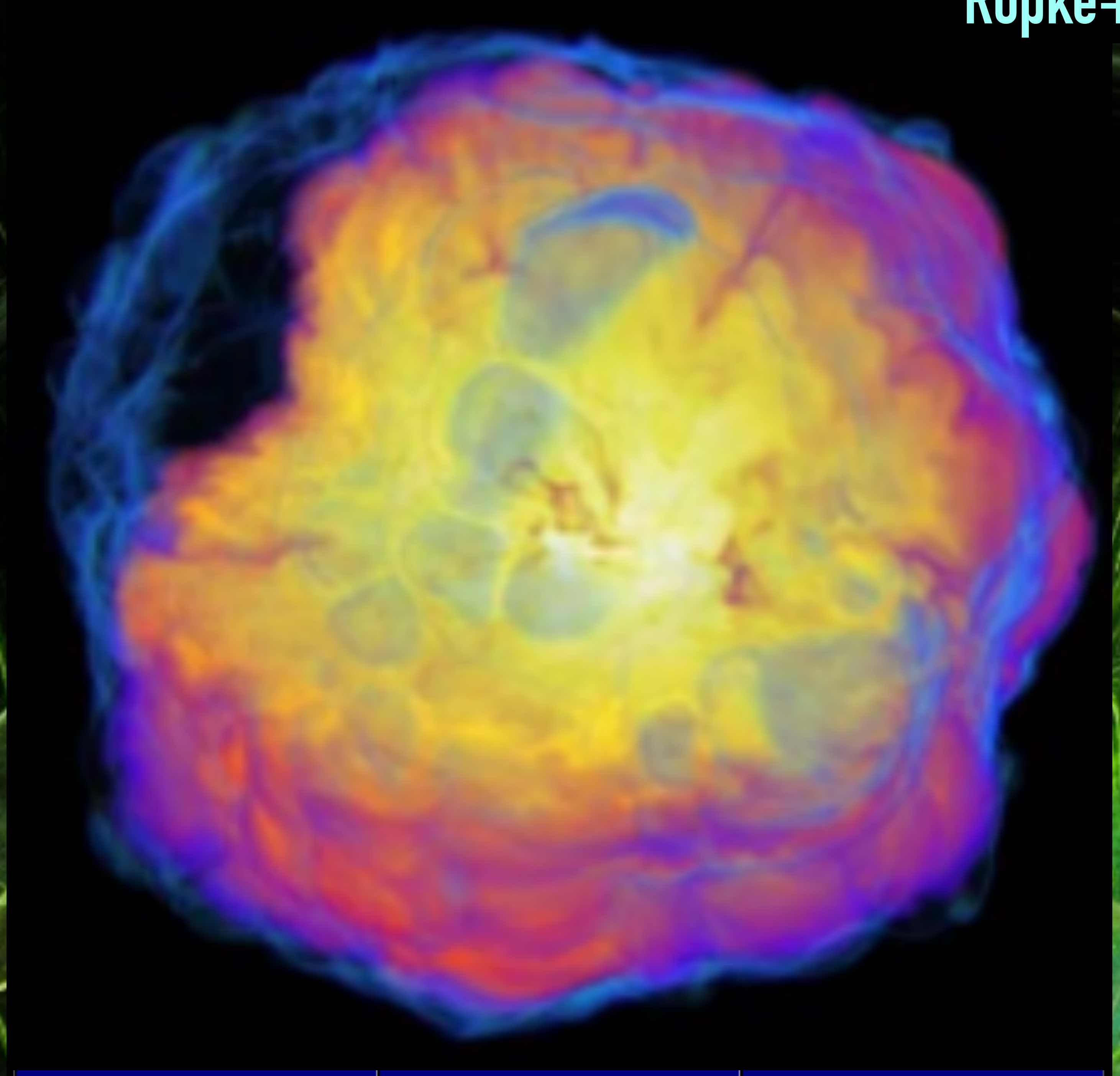
Delayed-detonation models involve higher densities and they will have an enhanced production of Mn from the contribution of "normal" freeze-out from NSE (as opposed to "alpha-rich").

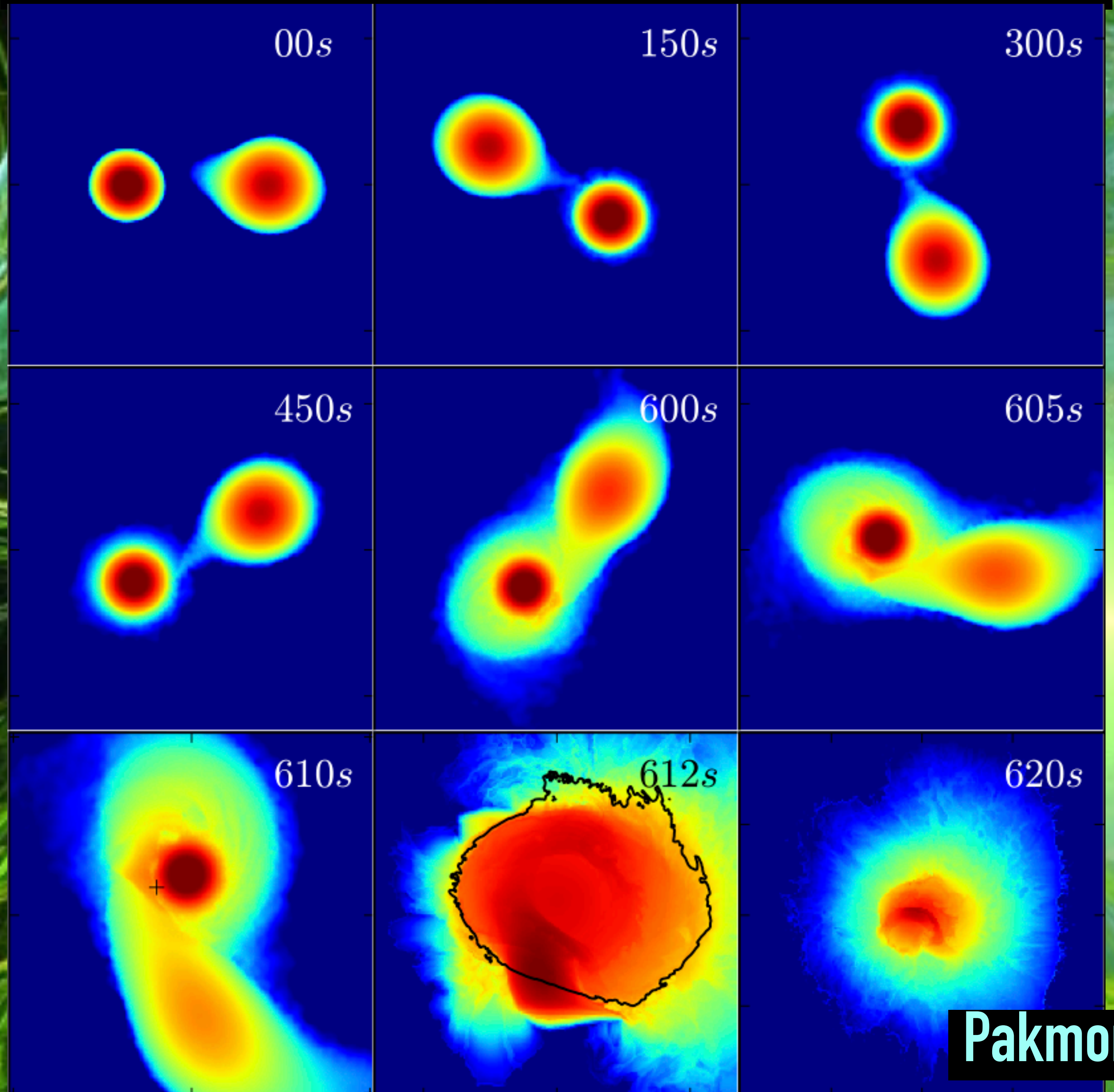
This is not the case for violent merger or double detonation models.

Sub-CH mass violent mergers (double detonation)

[Mn/Fe]~-0.2dex

Röpke+04



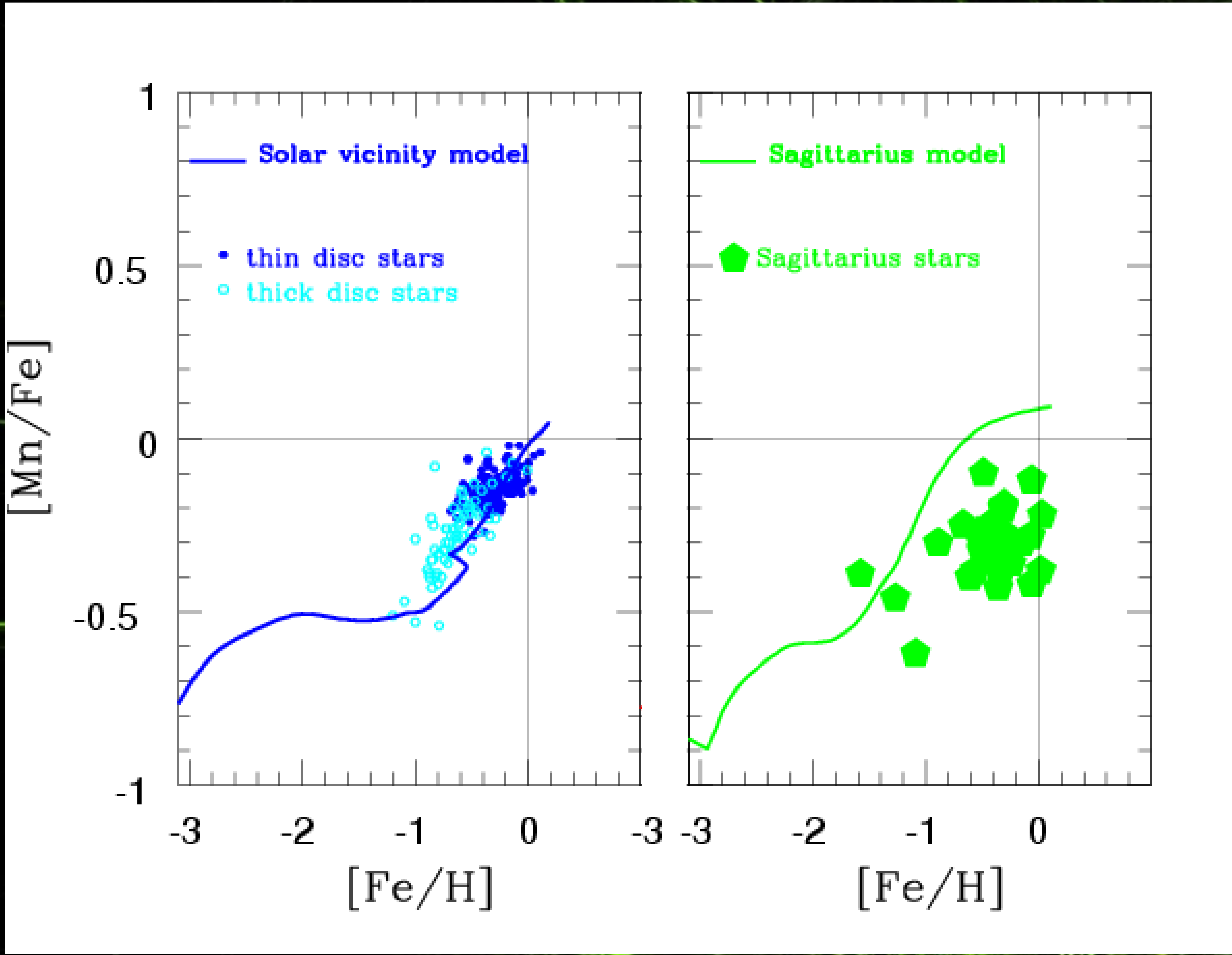



Pakmor+12

# The first issue with Manganese…

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

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



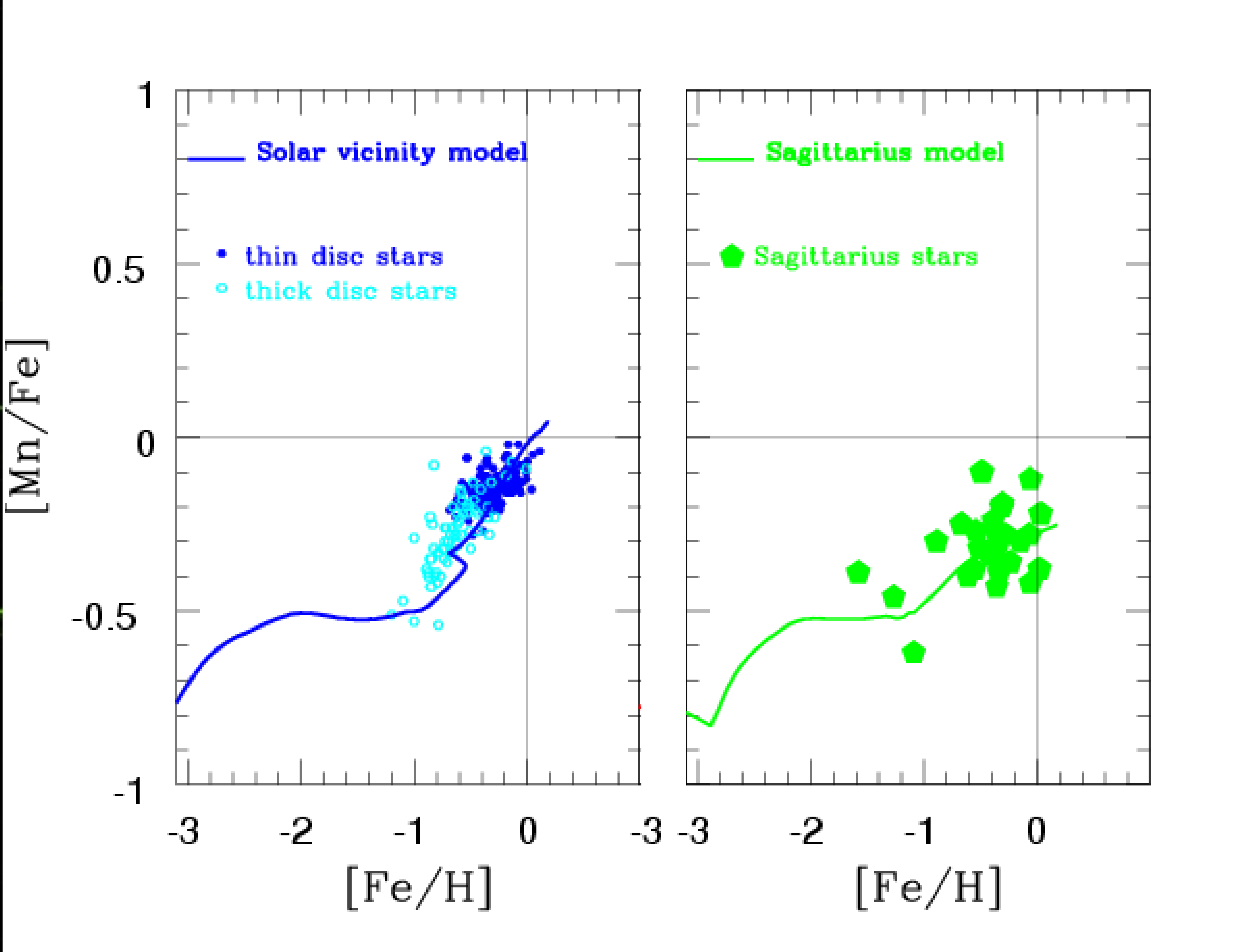

Cescutti et al. (2008)

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

# 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)

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




Cescutti et al. (2008)

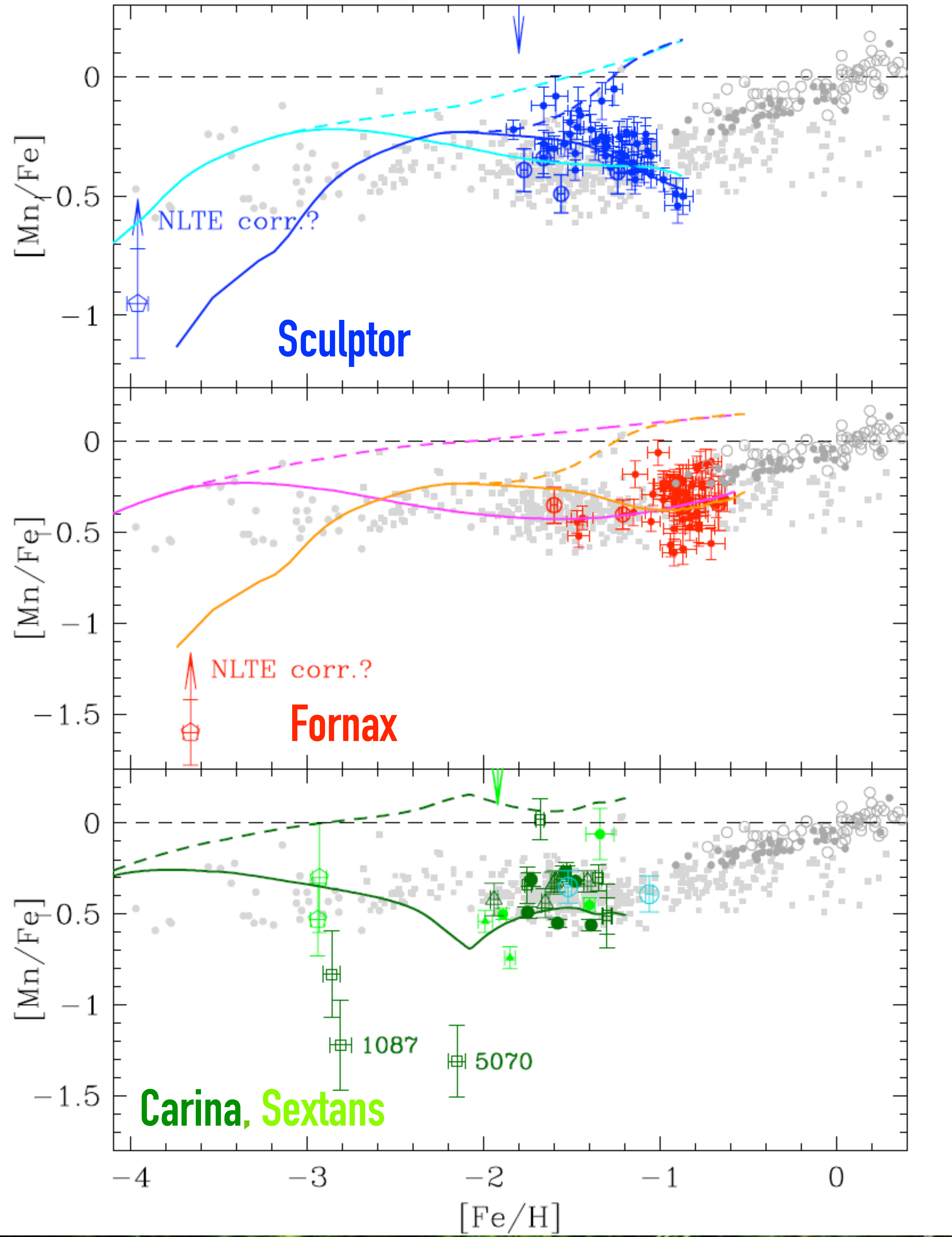
MW:
Reddy et al 2003
Sagittarius:
McWilliam 2003
Sbordone 2007

North, GC+ (2012)

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?

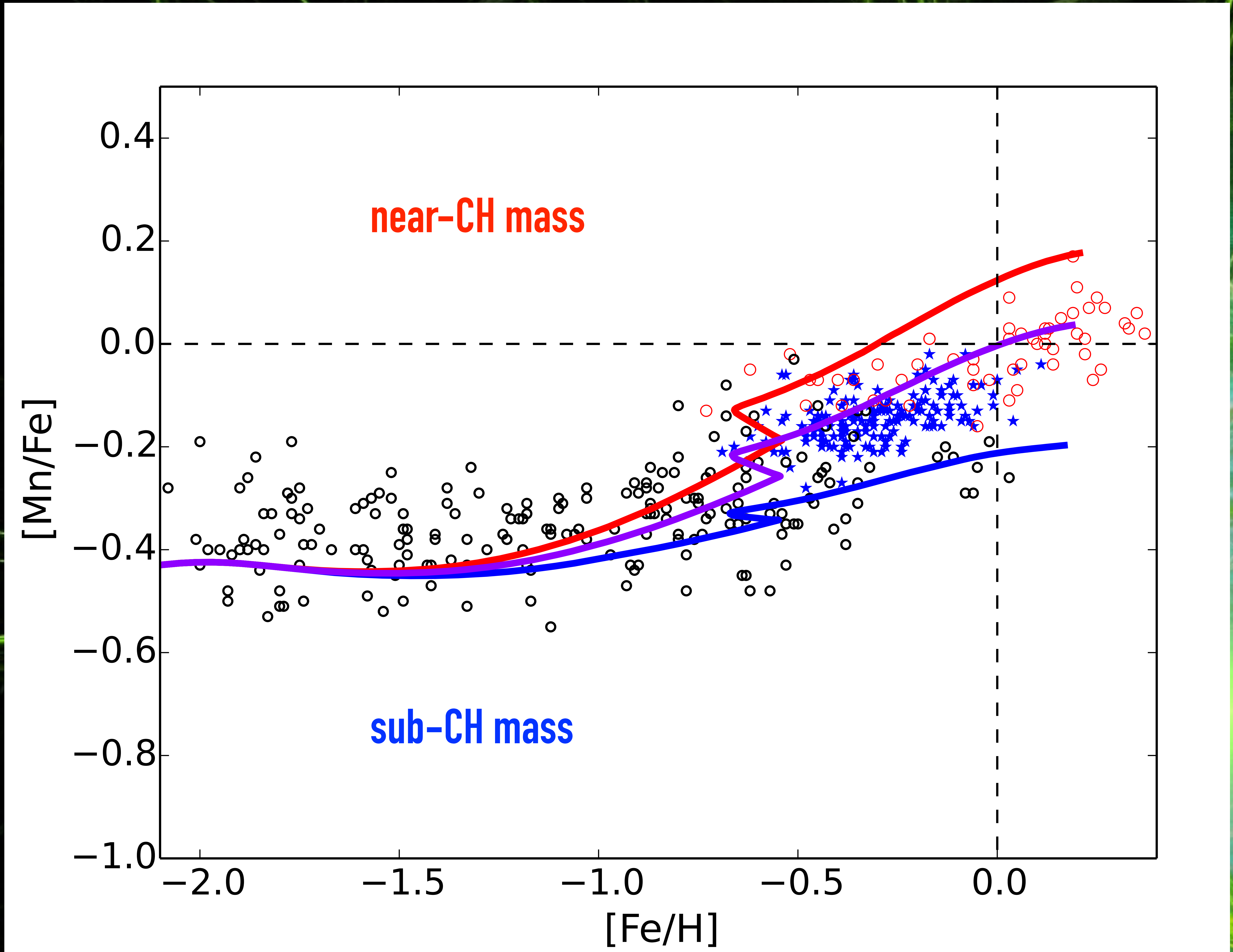


# Two SNe Ia channels to explain the solar manganese

Seitenzahl, GC+ (2013)

Using only the sub CH mass SNe Ia, the model cannot reach the solar value: Both SNIa and SNeII produce sub solar [Mn/Fe] ratio.

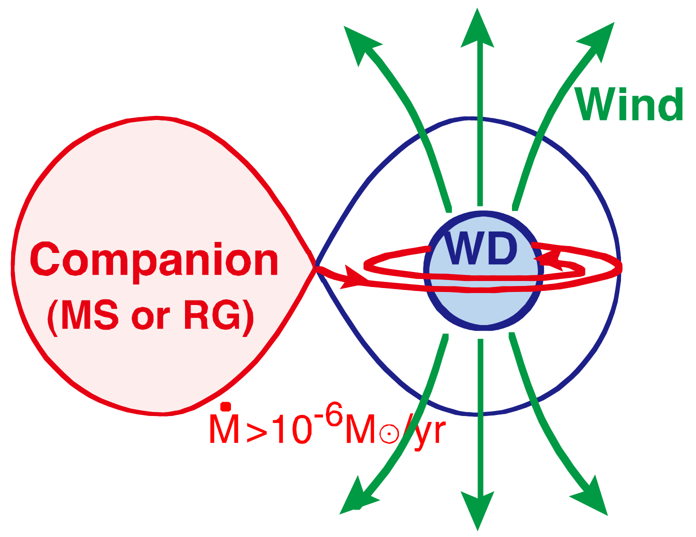
On the other hand only SNIa near-CH produce too high [Mn/Fe] and they are not metal dependent, contrary to sub-CH explosions



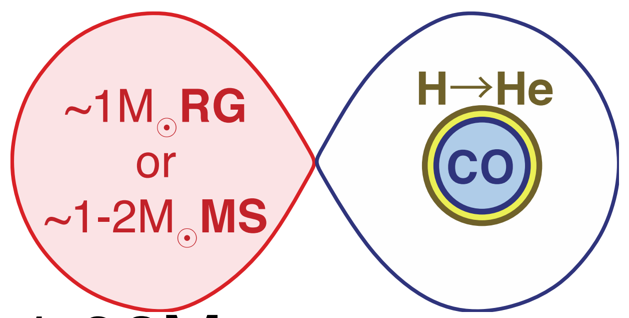
# Mass ranges of primary/secondary stars at low metallicity

Kobayashi+15

| [Fe/H] | -∞ | -2.5 | -2.4 | -2 | -1.1 | -1 | -0.7 | 0. | 0.4 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | normal SN Ia | | | | | |
| $m_{\mathrm{RG},\ell}$ | | - | - | - | 0.9 | 0.9 | 0.9 | 0.9 | 0.8 |
| $m_{\mathrm{RG,u}}$ | | - | - | - | 0.9 | 1.5 | 2.0 | 3.0 | 3.5 |
| $m_{\mathrm{MS},\ell}$ | | - | - | - | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| $m_{\mathrm{MS,u}}$ | | - | - | - | 1.8 | 2.6 | 4.0 | 5.5 | 6.0 |
| $m_{\mathrm{WD},\ell}$ | | - | - | - | 2.4 | 2.5 | 2.8 | 3.5 | 3.9 |
| $m_{\mathrm{WD,u}}$ | | | - | - | 6.9 | 7.0 | 7.3 | 8.0 | 8.4 |
| | | | | sub-Ch SN Ia | | | | | |
| $m_{\mathrm{subCh,RG},\ell}$ | - | - | - | - | 0.835 | 0.835 | 0.835 | 0.835 | |
| $m_{\mathrm{subCh,RG,u}}$ | | - | - | - | 0.835 | 1.0 | 1.3 | 1.9 | |
| $m_{\mathrm{subCh,MS},\ell}$ | 0.835 | | | | 0.835 | 1.05 | 1.05 | 1.05 | |
| $m_{\mathrm{subCh,MS,u}}$ | 1.35 | | | | 1.35 | 1.9 | 1.9 | 1.9 | |
| $m_{\mathrm{WD},\ell}$ | 5.9 | | | | 5.9 | 6.0 | 6.3 | 7.0 | |
| $m_{\mathrm{WD,u}}$ | 6.9 | | | | 6.9 | 7.0 | 7.3 | 8.0 | |




Yields: W7

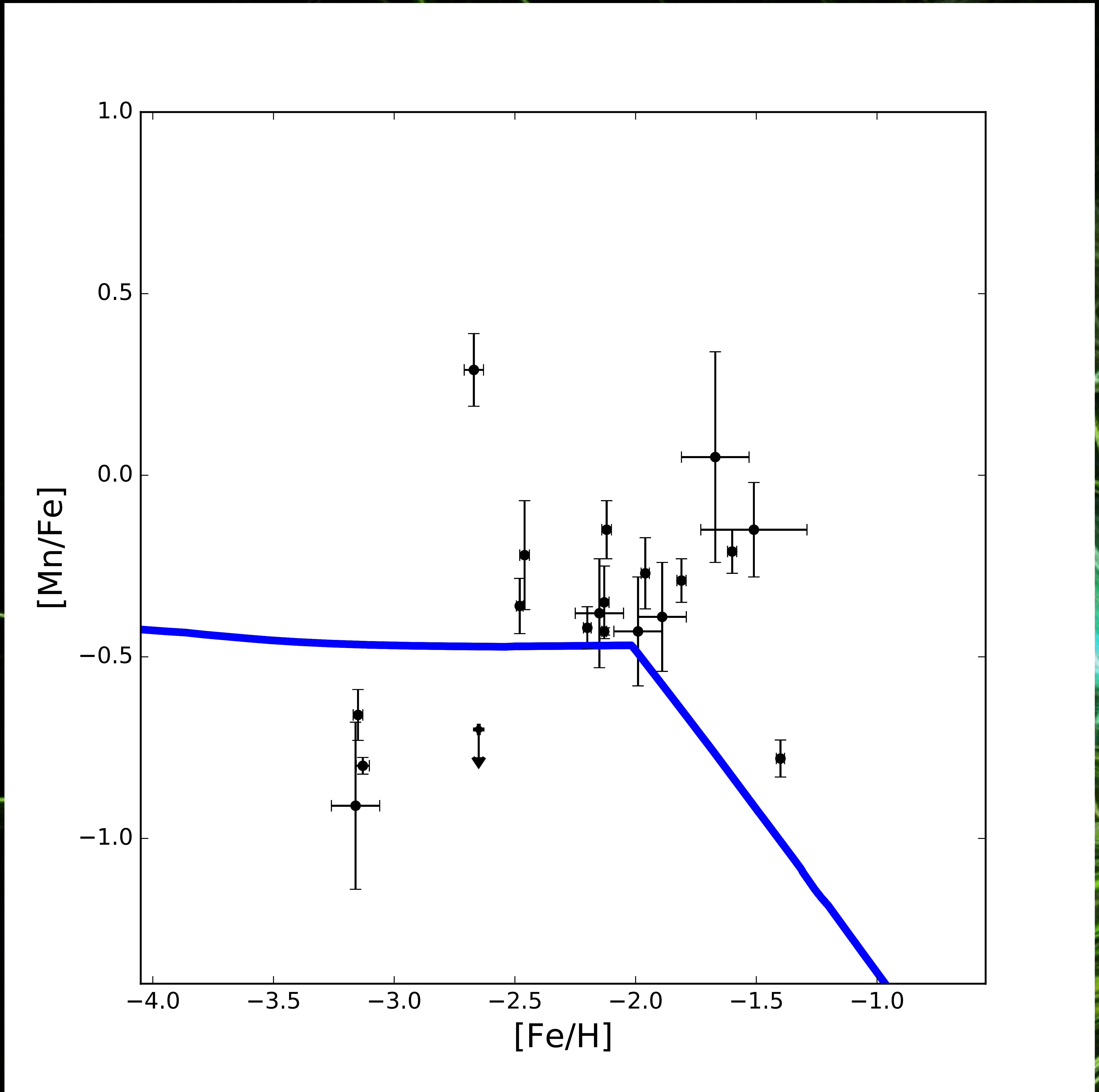



1.06M$_\odot$

Shigeyama+92

# 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

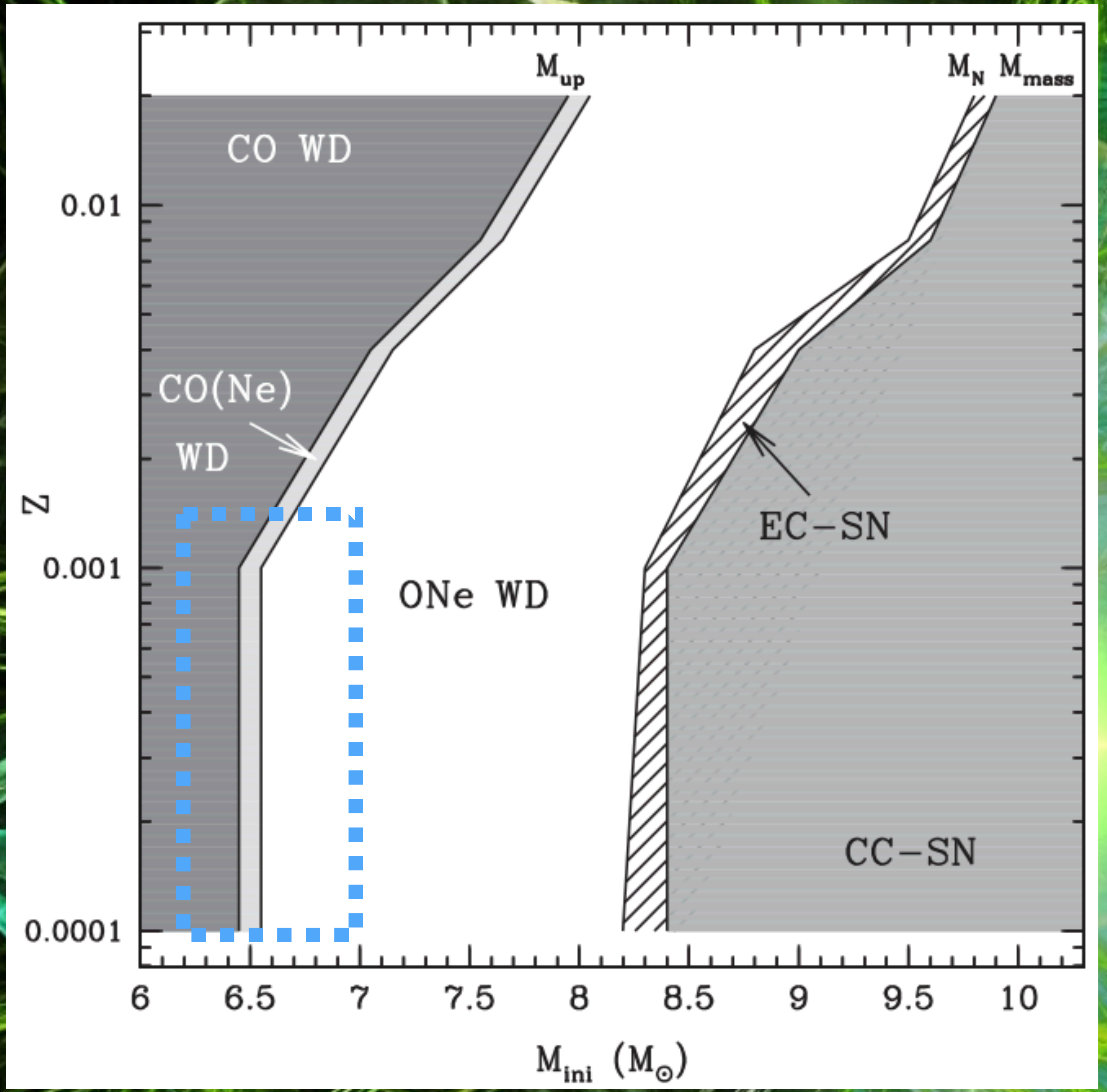
# More SN Ia channels: SNe I ax

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

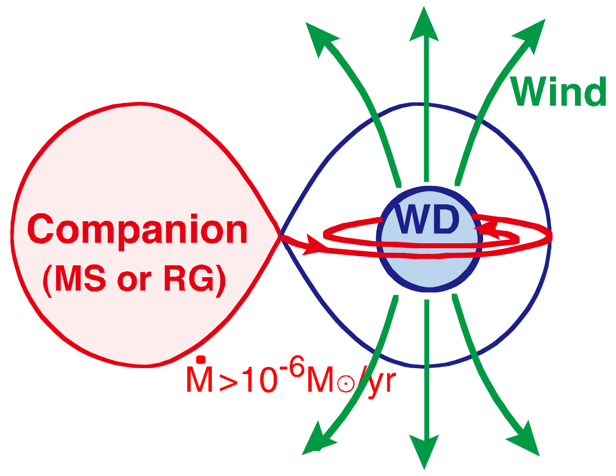




Doherty +15

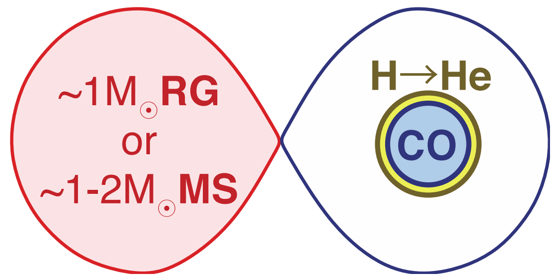
# Mass ranges of primary/secondary stars at low metallicity

Kobayashi+15

| [Fe/H] | -∞ | -2.5 | -2.4 | -2 | -1.1 | -1 | -0.7 | 0. | 0.4 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | normal SN Ia | | | | | |
| $m_{\mathrm{RG},\ell}$ | - | - | - | - | 0.9 | 0.9 | 0.9 | 0.9 | 0.8 |
| $m_{\mathrm{RG,u}}$ | - | - | - | - | 0.9 | 1.5 | 2.0 | 3.0 | 3.5 |
| $m_{\mathrm{MS},\ell}$ | - | - | - | - | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| $m_{\mathrm{MS,u}}$ | - | - | - | - | 1.8 | 2.6 | 4.0 | 5.5 | 6.0 |
| $m_{\mathrm{WD},\ell}$ | - | - | - | - | 2.4 | 2.5 | 2.8 | 3.5 | 3.9 |
| $m_{\mathrm{WD,u}}$ | - | - | - | - | 6.9 | 7.0 | 7.3 | 8.0 | 8.4 |
| | | | | sub-Ch SN Ia | | | | | |
| $m_{\mathrm{subCh,RG},\ell}$ | - | - | - | - | 0.835 | 0.835 | 0.835 | 0.835 | |
| $m_{\mathrm{subCh,RG,u}}$ | [illegible] | - | - | - | 0.835 | 1.0 | 1.3 | 1.9 | |
| $m_{\mathrm{subCh,MS},\ell}$ | 0.835 | | | | 0.835 | 1.05 | 1.05 | 1.05 | |
| $m_{\mathrm{subCh,MS,u}}$ | 1.35 | | | | 1.35 | 1.9 | 1.9 | 1.9 | |
| $m_{\mathrm{WD},\ell}$ | 5.9 | | | | 5.9 | 6.0 | 6.3 | 7.0 | |
| $m_{\mathrm{WD,u}}$ | 6.9 | | | | 6.9 | 7.0 | 7.3 | 8.0 | |
| | | | | SN Iax | | | | | |
| $m_{\mathrm{Iax,RG},\ell}$ | - | [illegible] | 0.8 | [illegible] | | 0.8 | | 0.8 | |
| $m_{\mathrm{Iax,RG,u}}$ | - | [illegible] | 1.5 | [illegible] | | 3.0 | | 3.0 | |
| $m_{\mathrm{Iax,MS},\ell}$ | - | [illegible] | 1.6 | [illegible] | | 1.6 | | 1.6 | |
| $m_{\mathrm{Iax,MS,u}}$ | - | [illegible] | 2.9 | [illegible] | | 6.5 | | 6.5 | |
| $m_{\mathrm{WD},\ell}$ | - | [illegible] | 6.34 | [illegible] | | 7.0 | | 8.0 | |
| $m_{\mathrm{WD,u}}$ | - | [illegible] | 7.34 | [illegible] | | 8.0 | | 9.0 | |

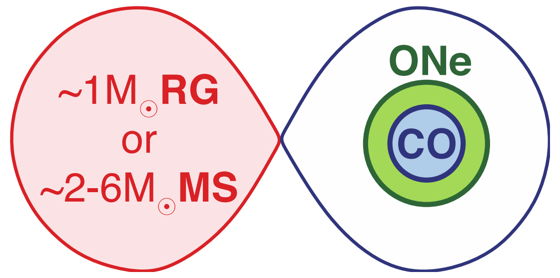



Yields: W7




1.06M⊙

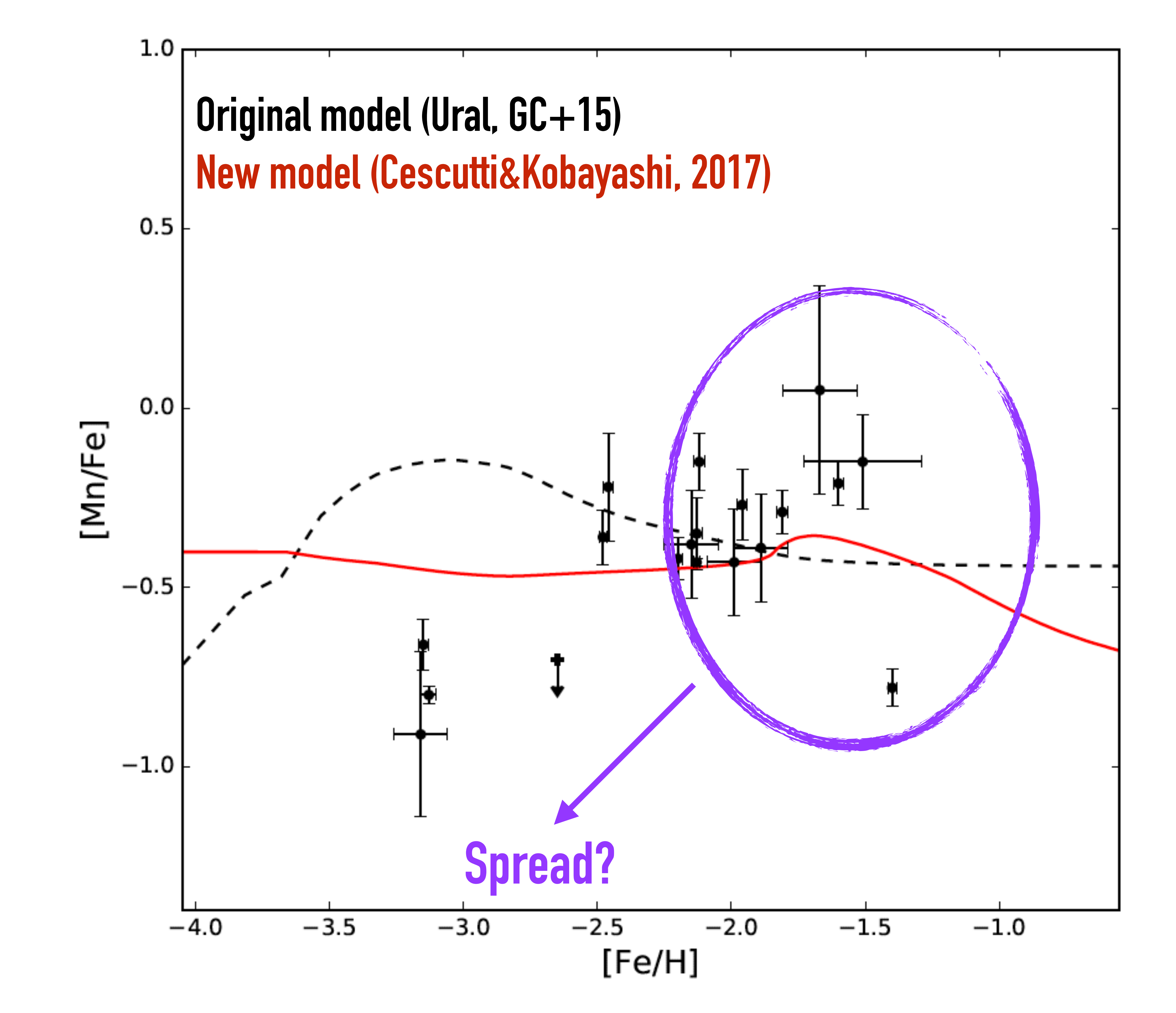
Shigeyama+92




N5def

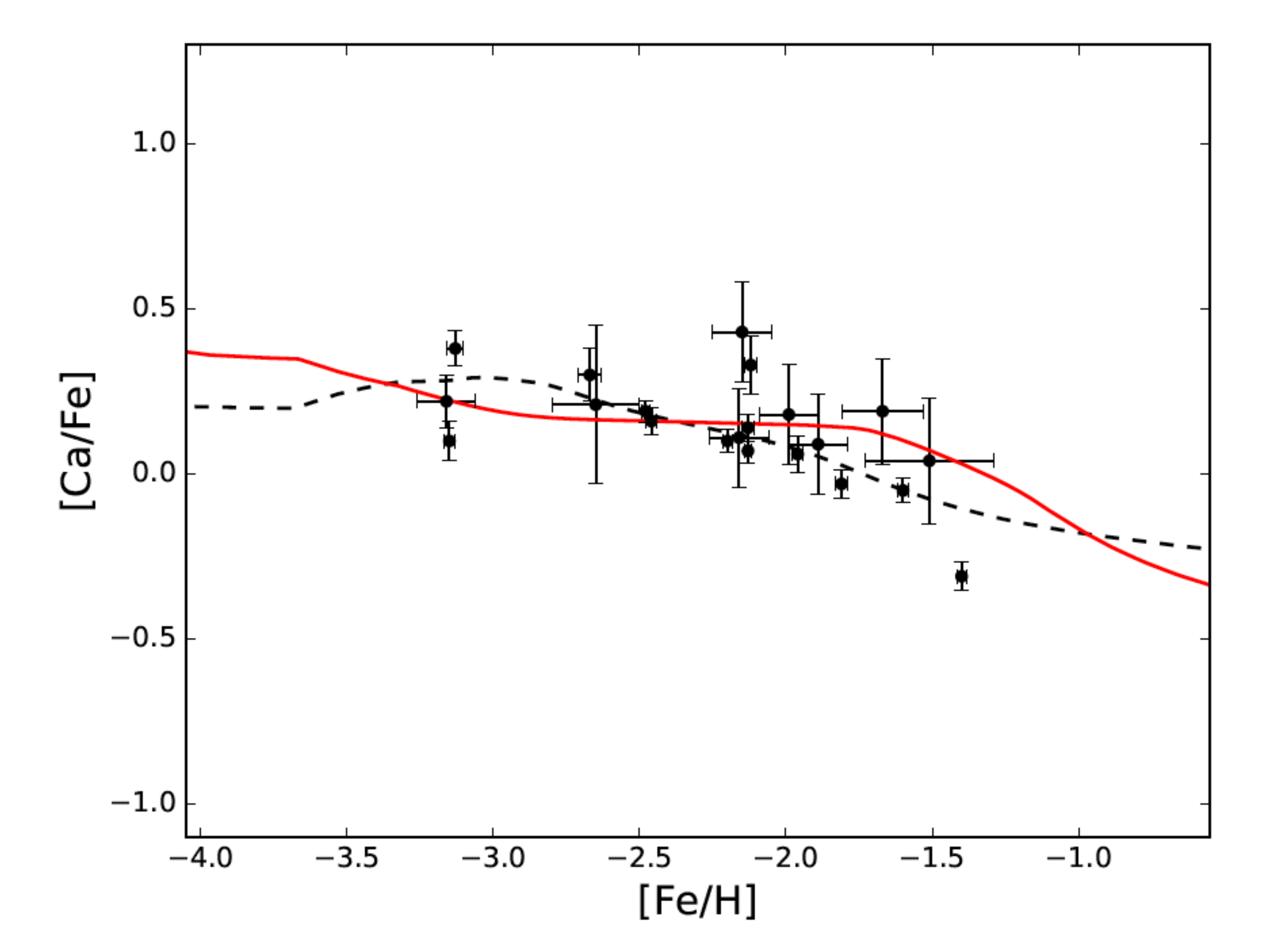
Fink+ 14

# New channels of SNe Ia in Ursa minor model




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

Both are able to reproduce the knee in alpha elements

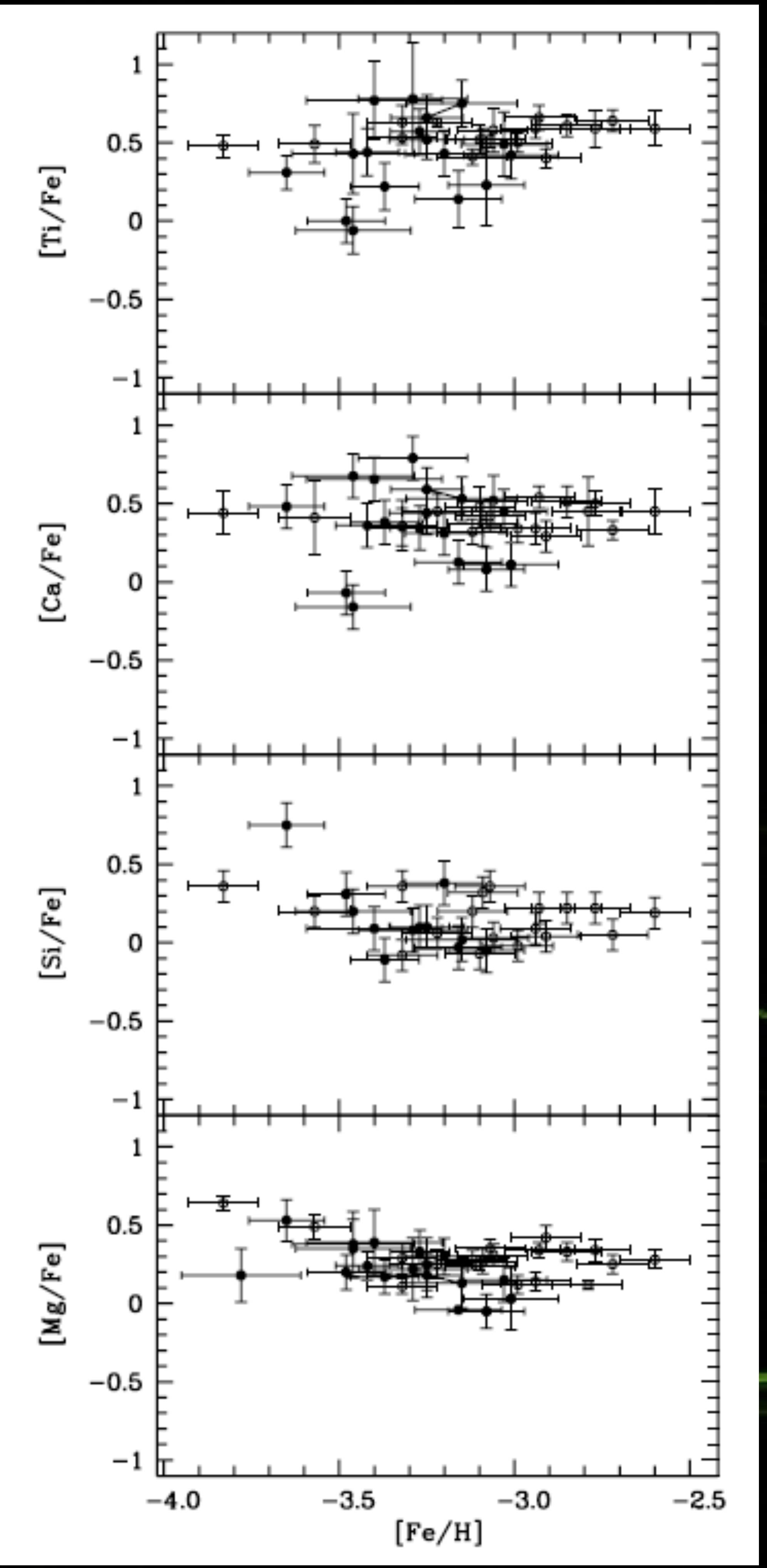



data from Ural,GC+15

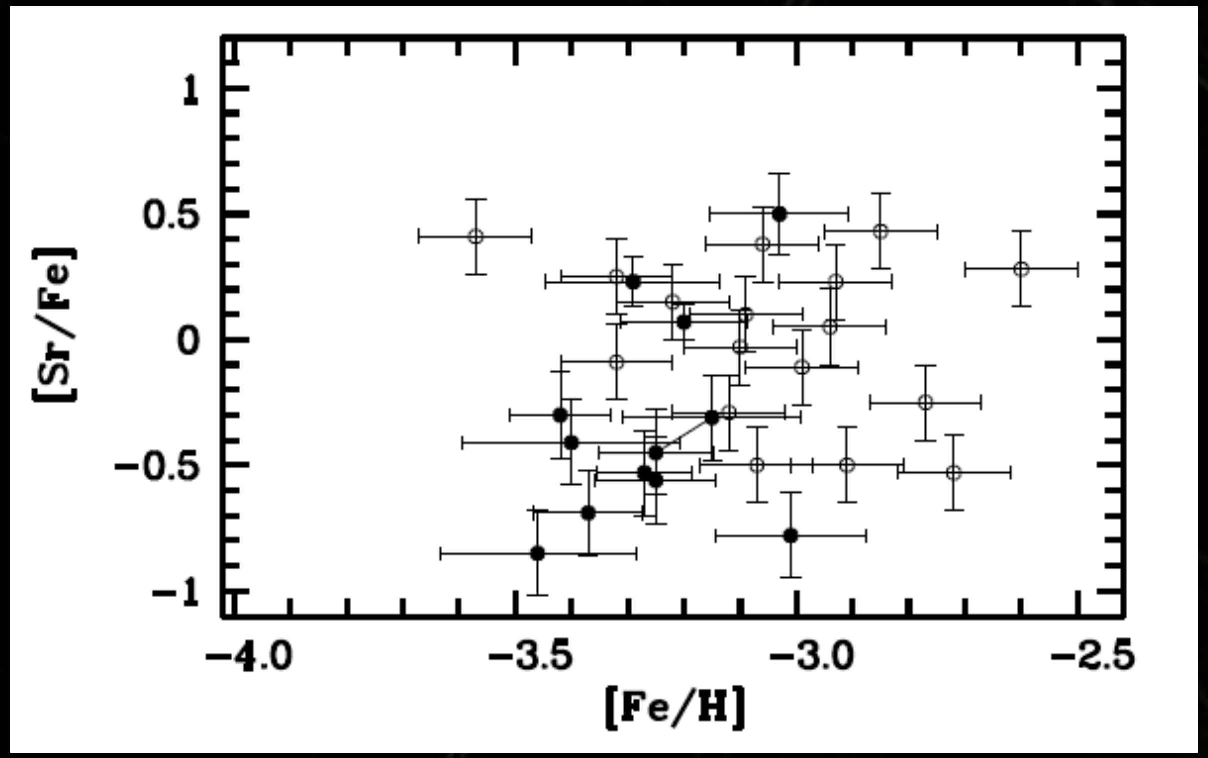
# Stochastic chemical evolution models

Problem:

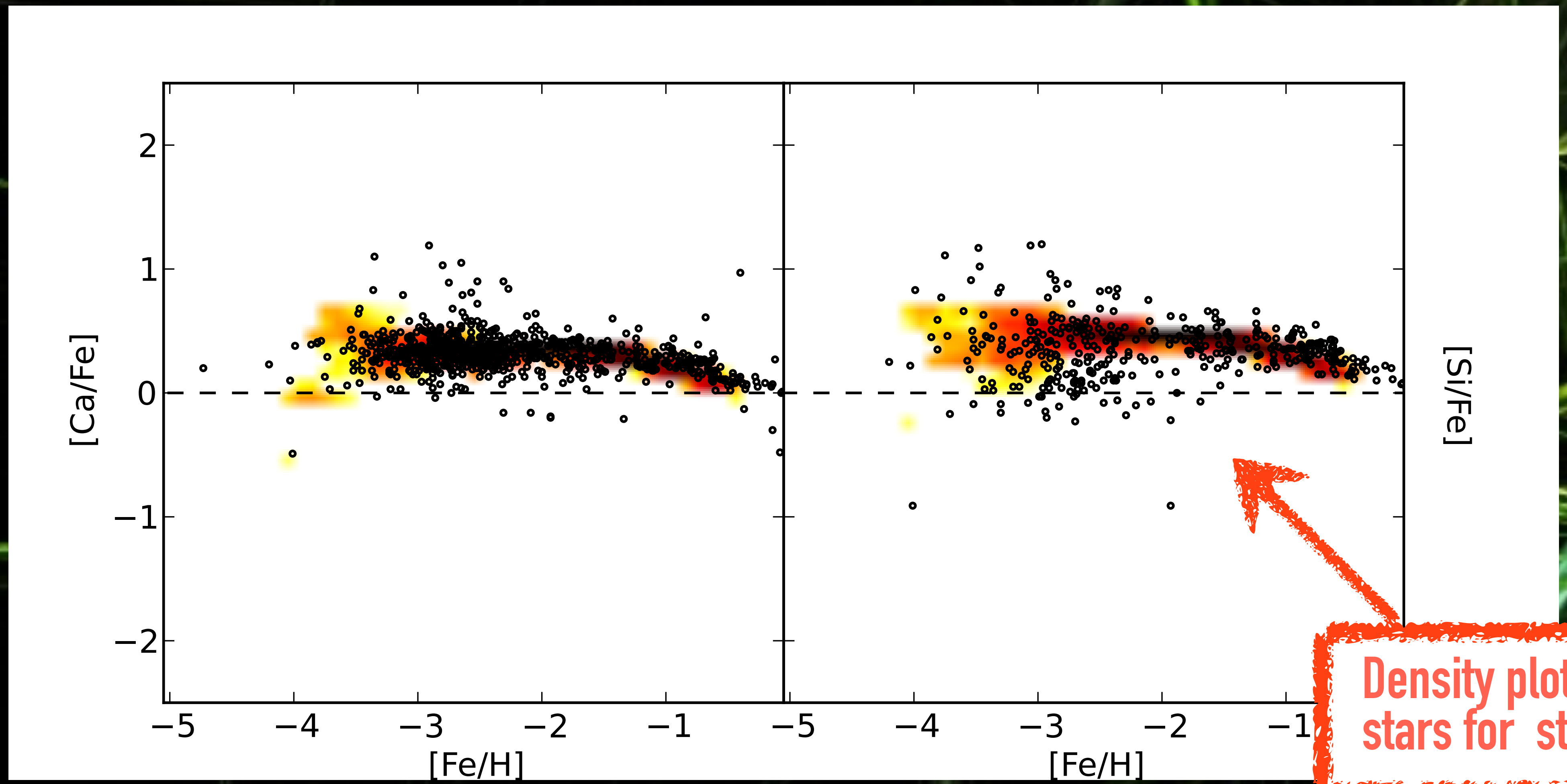
Neutron capture elements present a spread alpha elements do not




Bonifacio+09

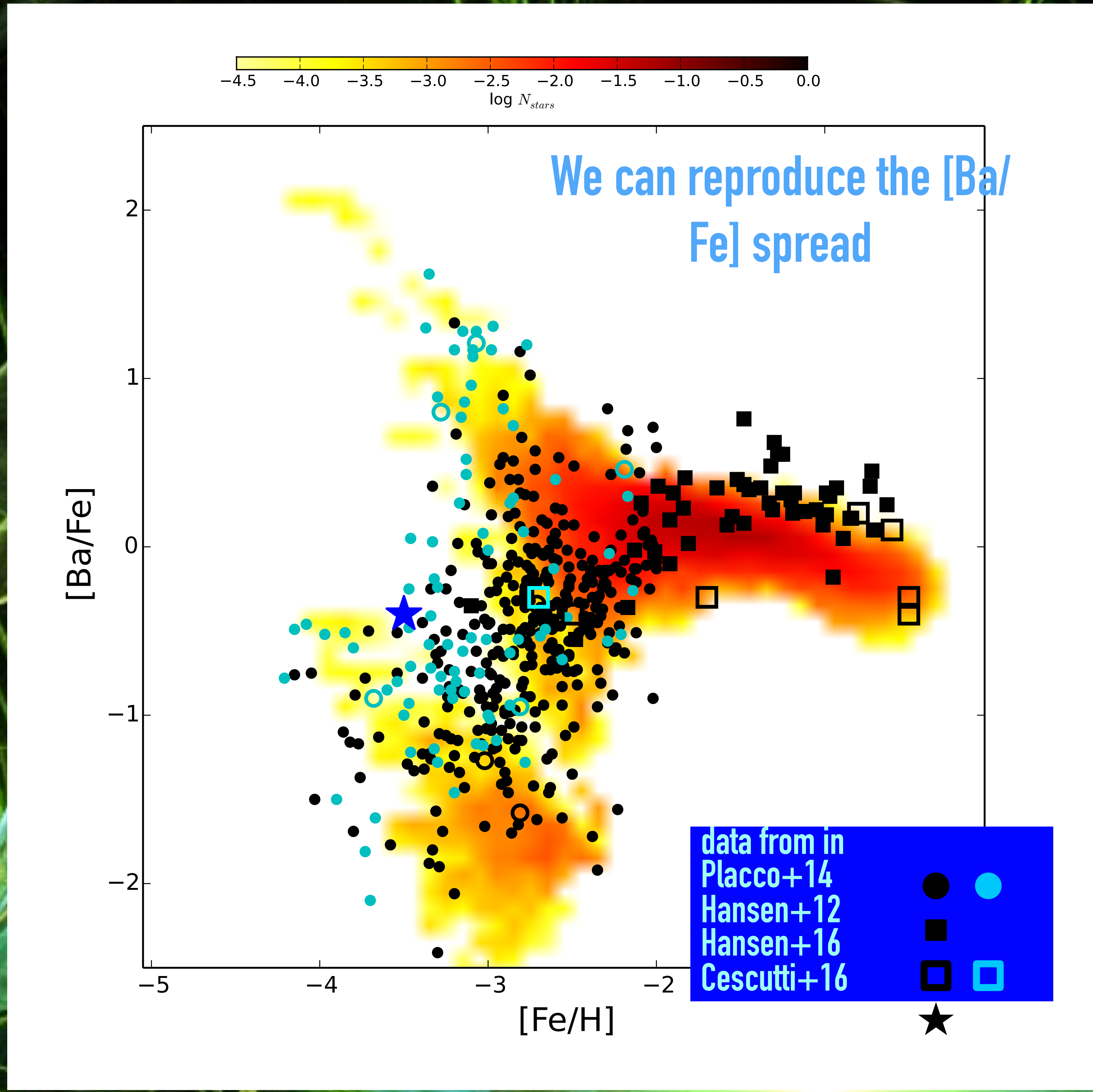



Solution:
The volumes in which the ISM is well mixed are discrete. Assuming a SNe bubble as typical volume with a low regime of star formation the IMF is not fully sampled.
This promotes spread among different volumes if nucleosynthesis of the element is is different among different SNe.




Density plot of long living stars for stochastic model

data collected in Frebel 2010




Cescutti 08 +13,+16

## Same concept applied to Ursa minor model

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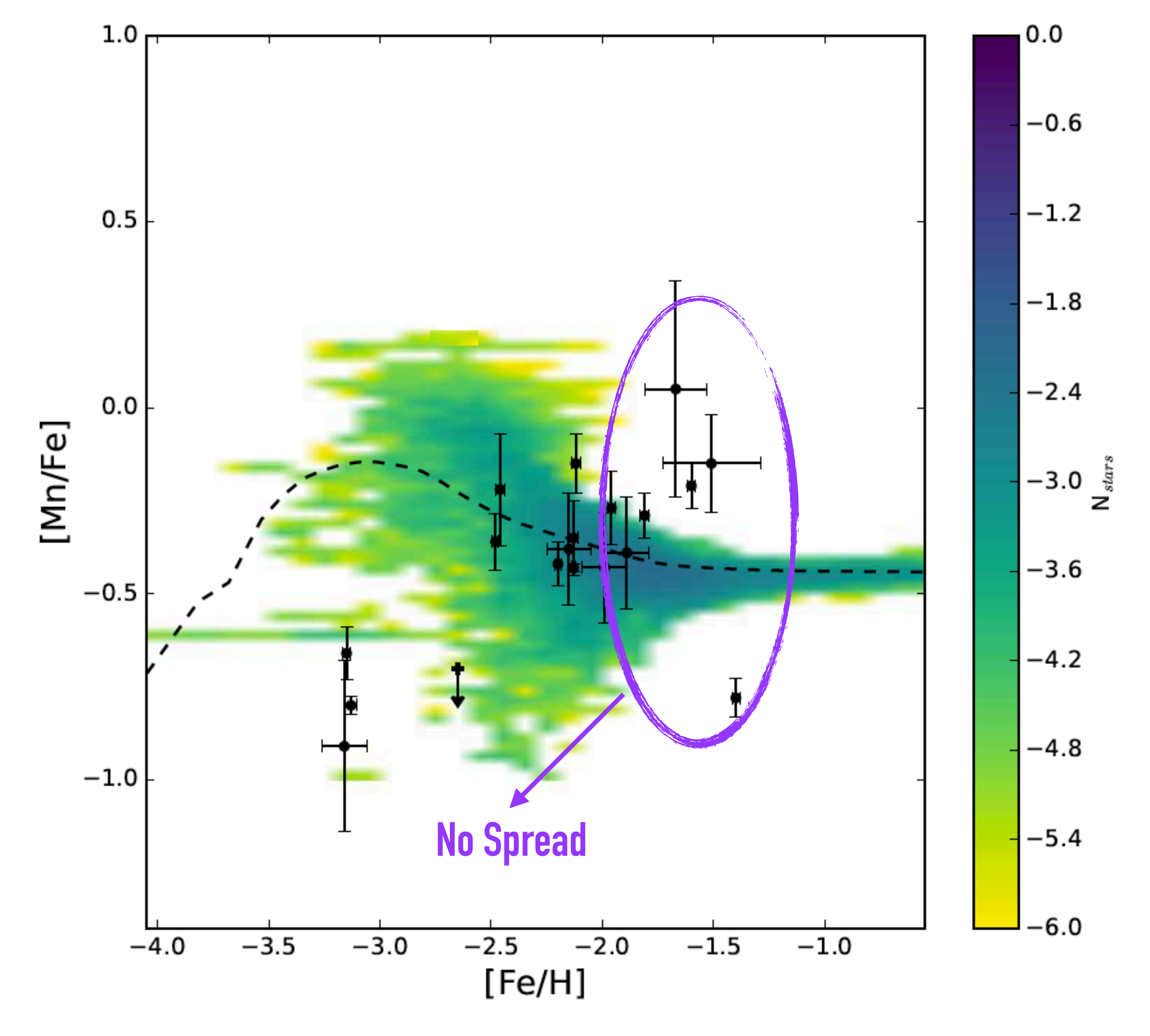
# Stochastic model for Ursa minor 1

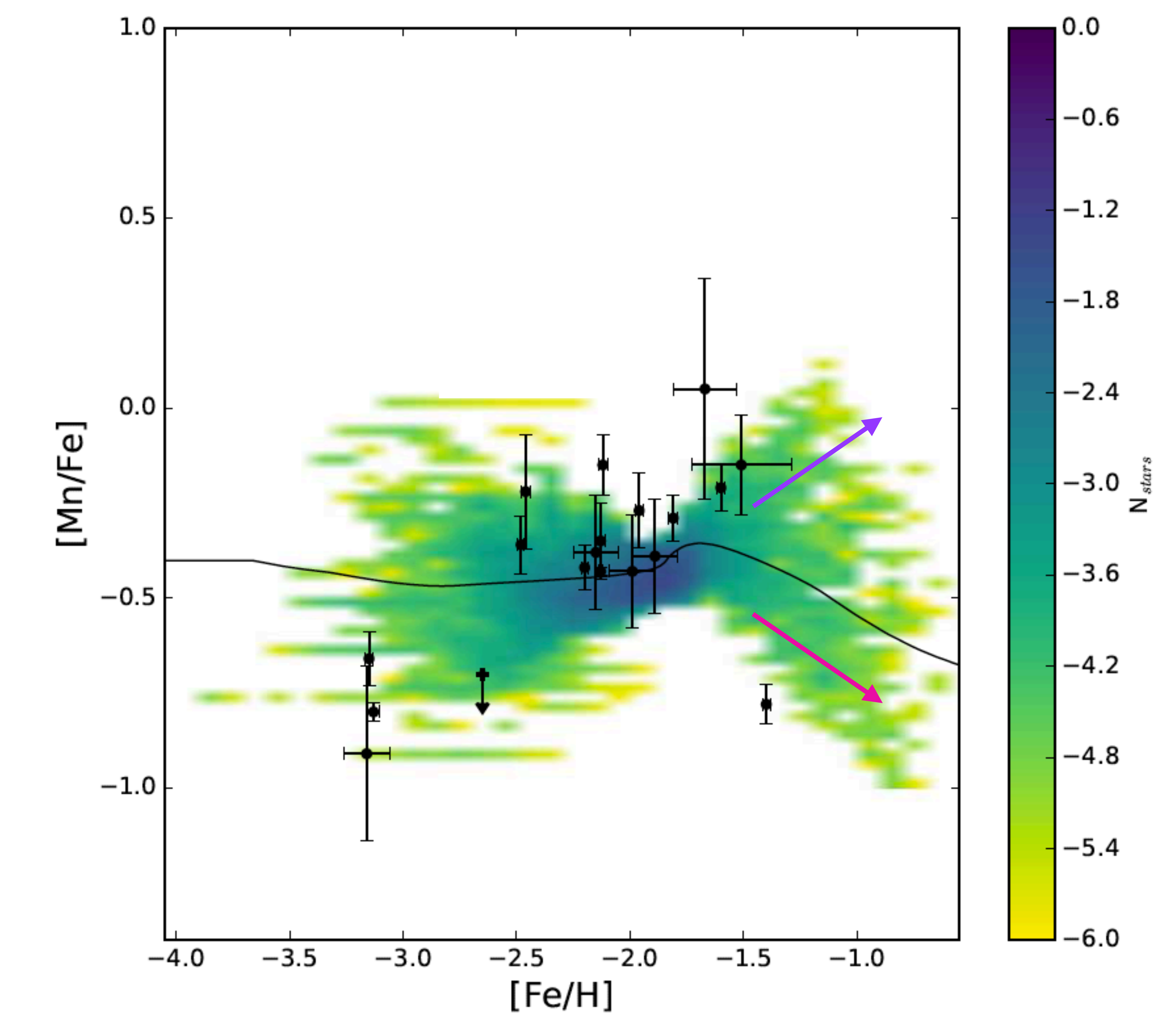
## Mn metal dependent from a single degenerate Ch-mass SNe Ia




data from Ural,GC+15

# Stochastic model for Ursa minor 2

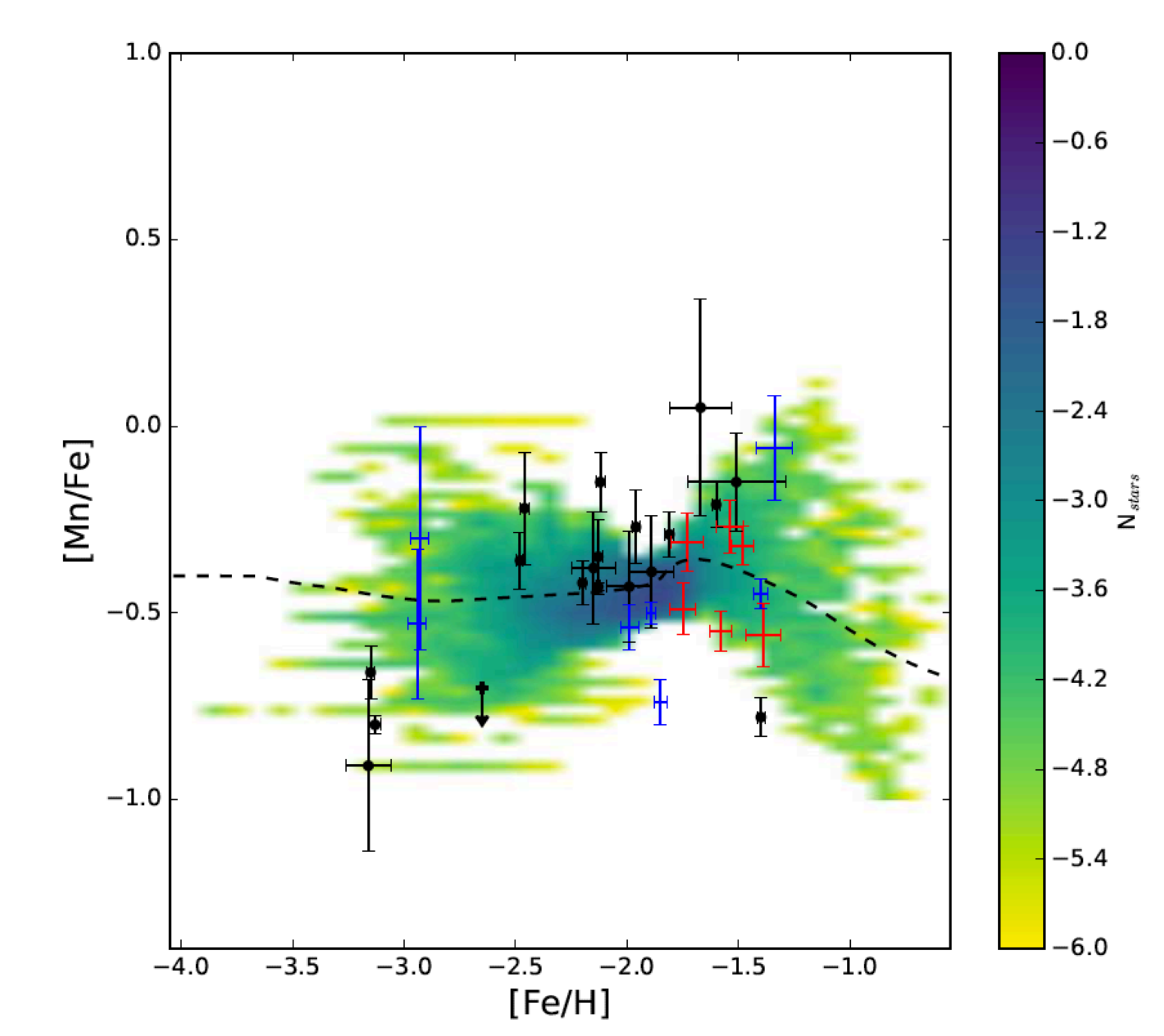
New model with Ch-mass (SNe Iax) & sub-CH mass




The manganese butterfly

# Stochastic model for Ursa minor 3

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

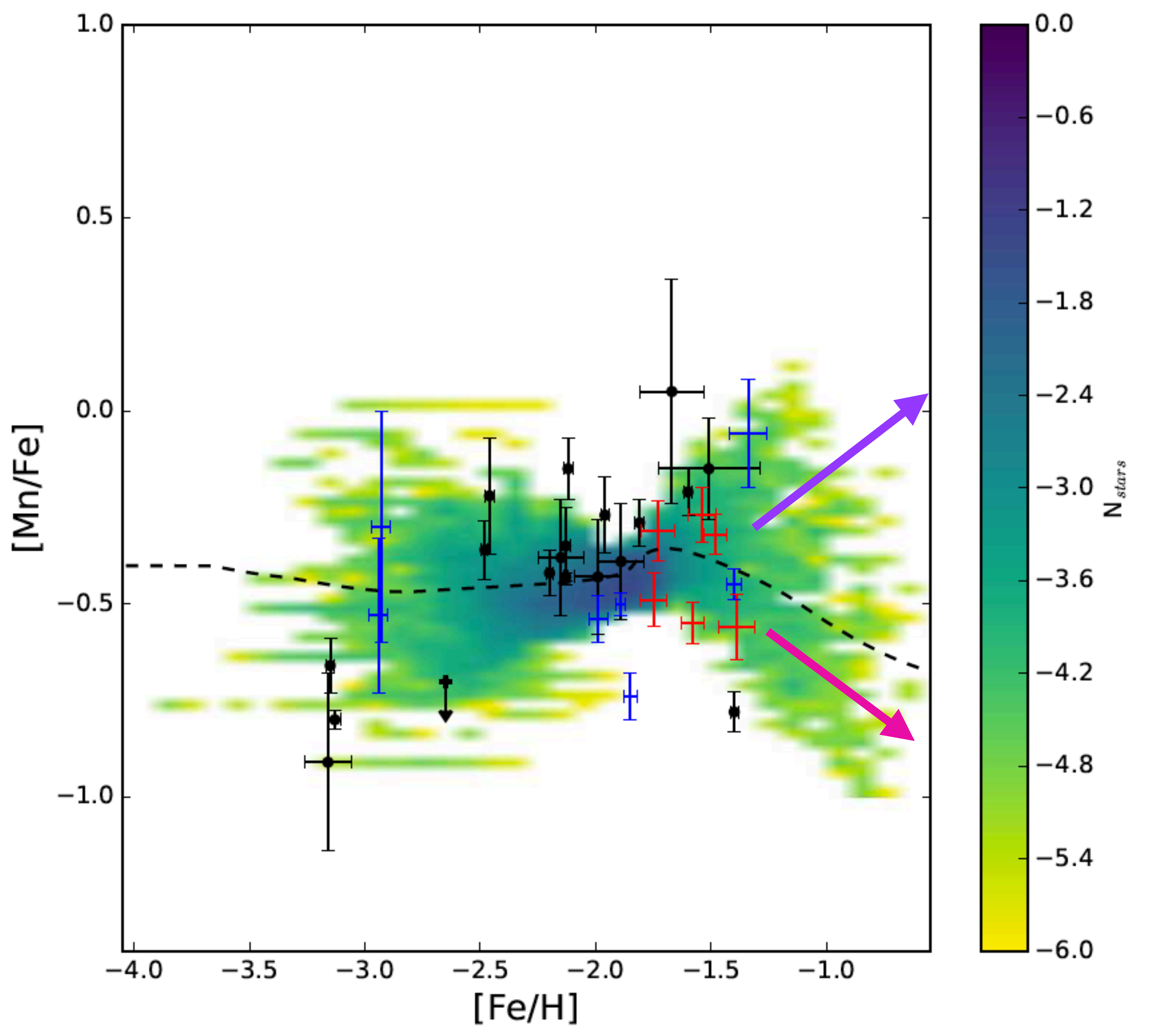



data from Ural,GC+15
and North,GC+12

Denver, June 04, 2018

# Stochastic chemical evolution models

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



# Conclusions

Chemical evolution models indicate that at least two SNe Ia channels should be active to reproduce the Mn/Fe ratio on the Sun.
Seitenzahl, GC+13

Two different channels in the dSph environments can also be a way to reproduce the observation in Mn and also alpha-elements.
Kobayashi+15

In a stochastic chemical evolution model, the presence of two different channels leads to a spread in the [Mn/Fe] vs [Fe/H] space, compatible with the abundance measured in Ursa minor and other dSphs with similar mass.
Cescutti&Kobayashi 17