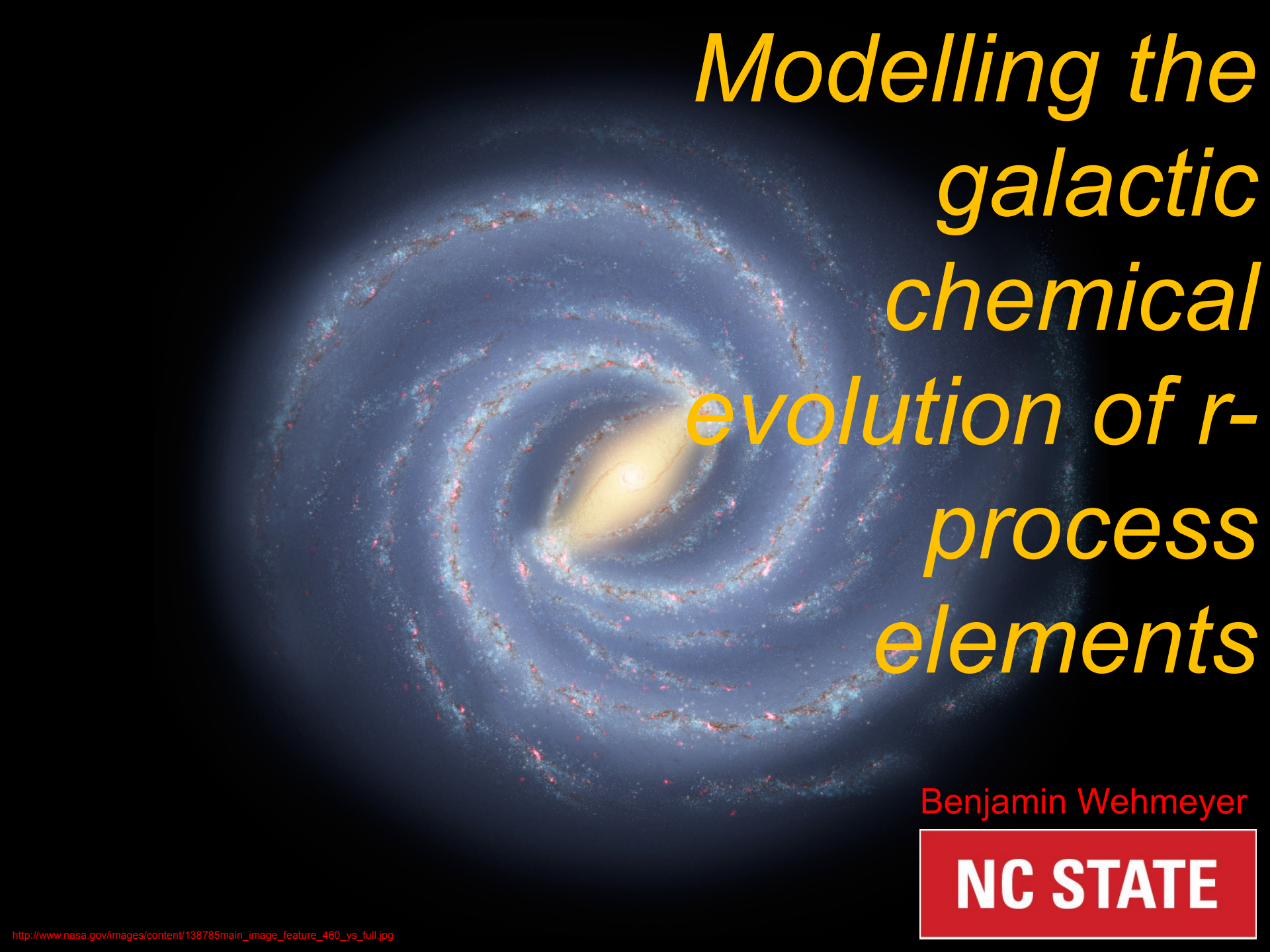


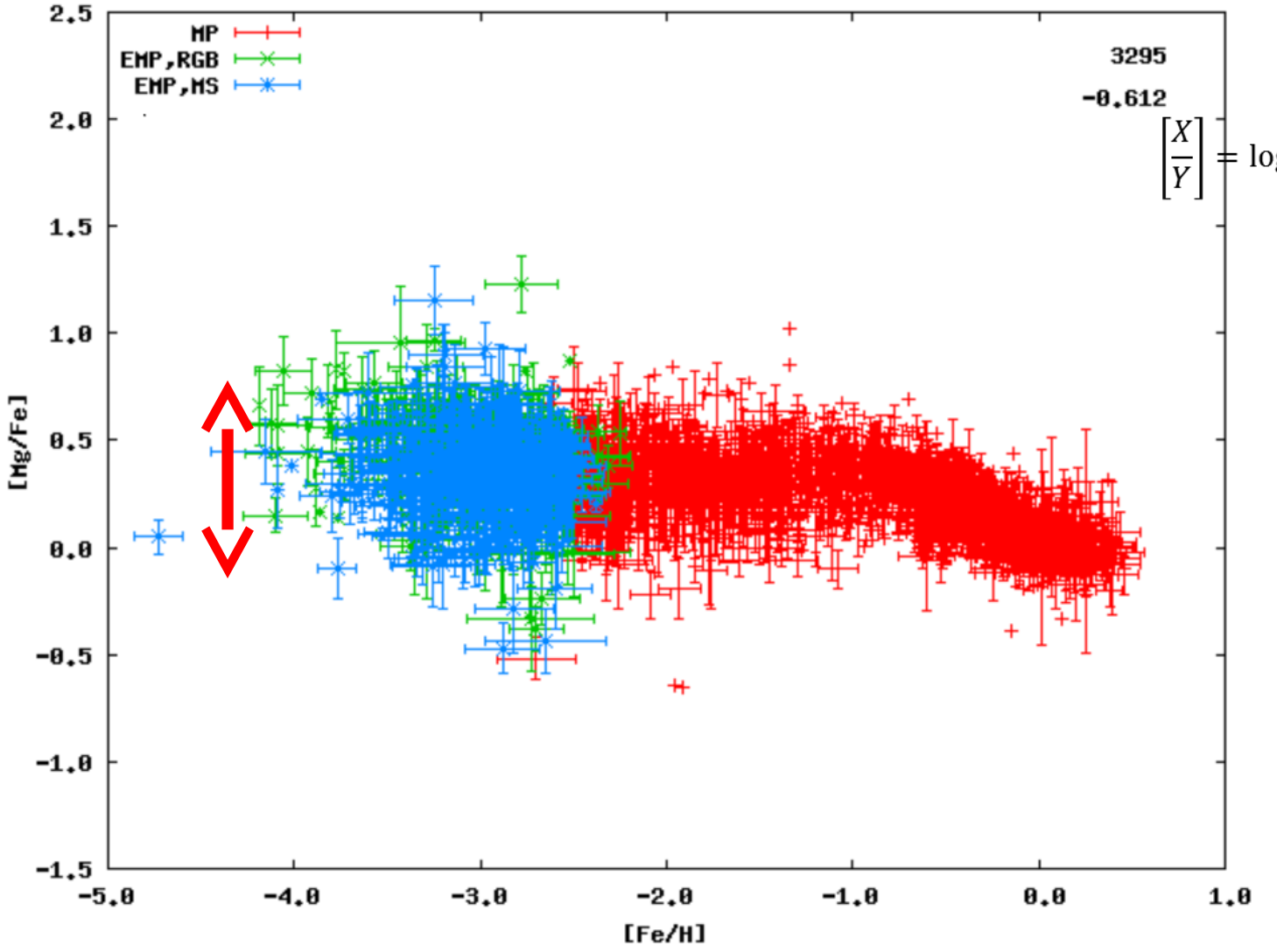
Modelling the galactic chemical evolution of r-process elements

Benjamin Wehmeyer

NC STATE

http://www.nasa.gov/images/content/138785main_image_feature_460_ys_full.jpg

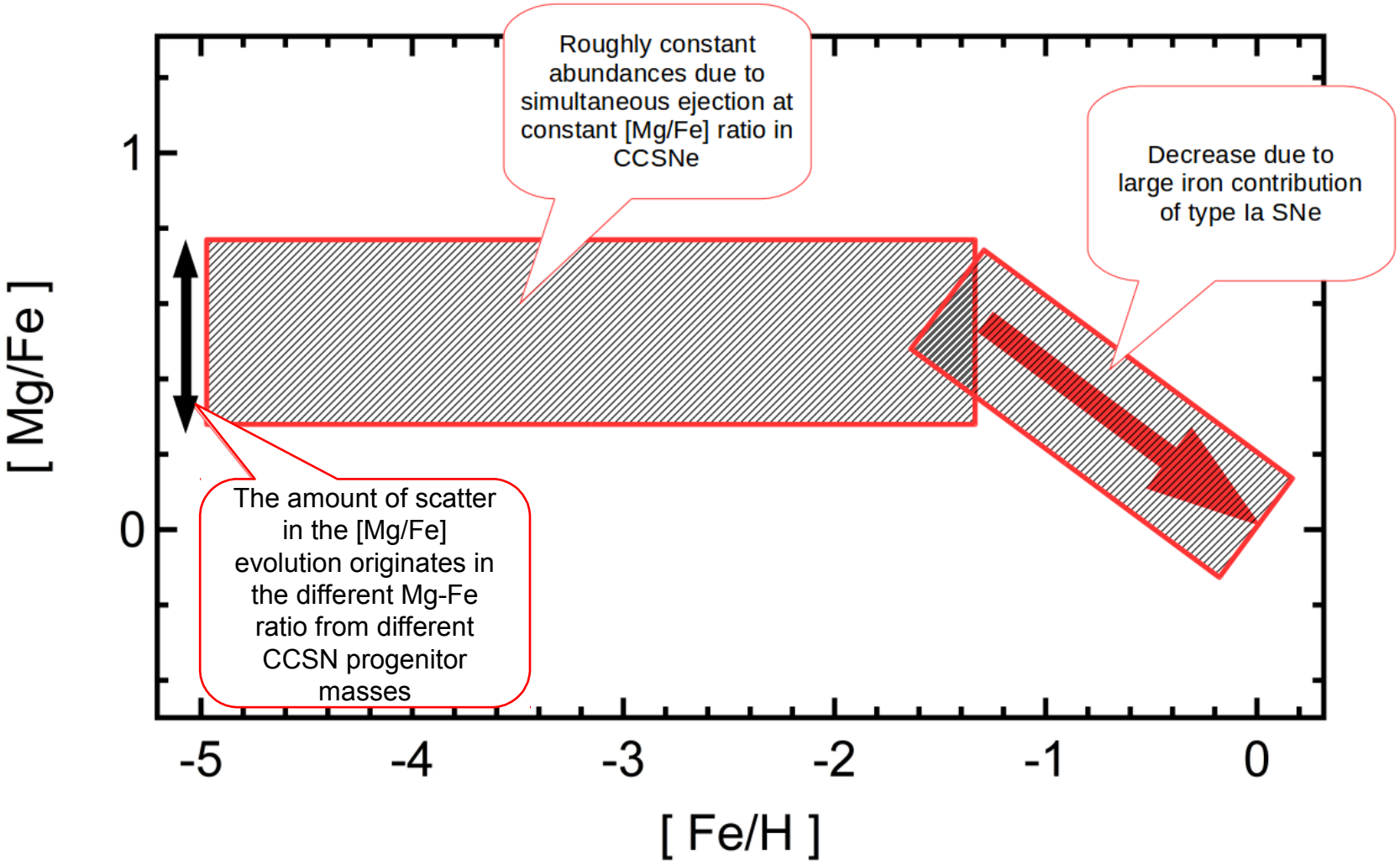
Abundance of α-elements vs. „metallicity“



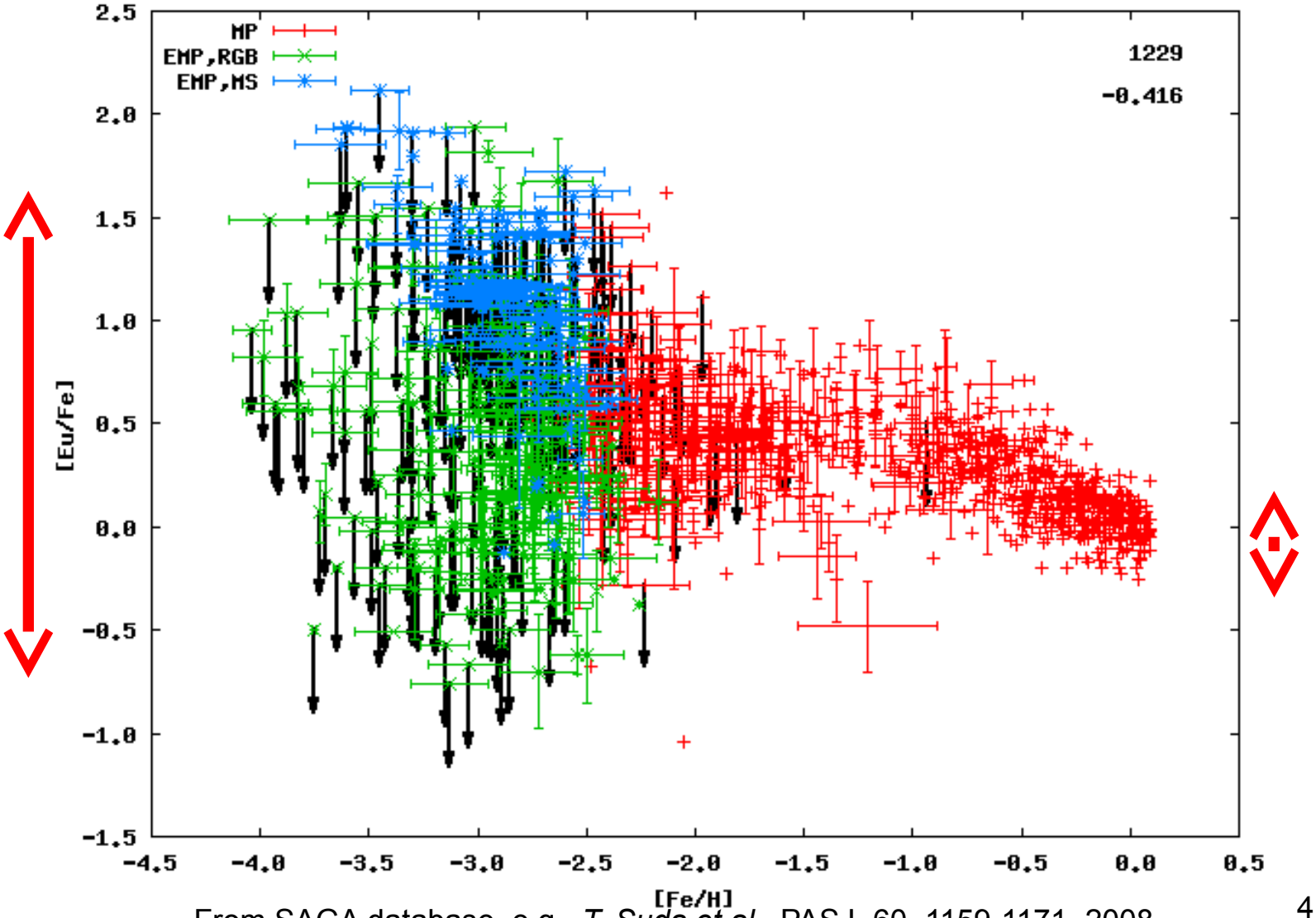
$$\left[\frac{X}{Y}\right] = \log \frac{X_{Star}/Y_{Star}}{X_{Sol}/Y_{Sol}}$$

From SAGA database, e.g., *T. Suda et al.*, PASJ, 60, 1159-1171, 2008.

How can this evolution be explained?

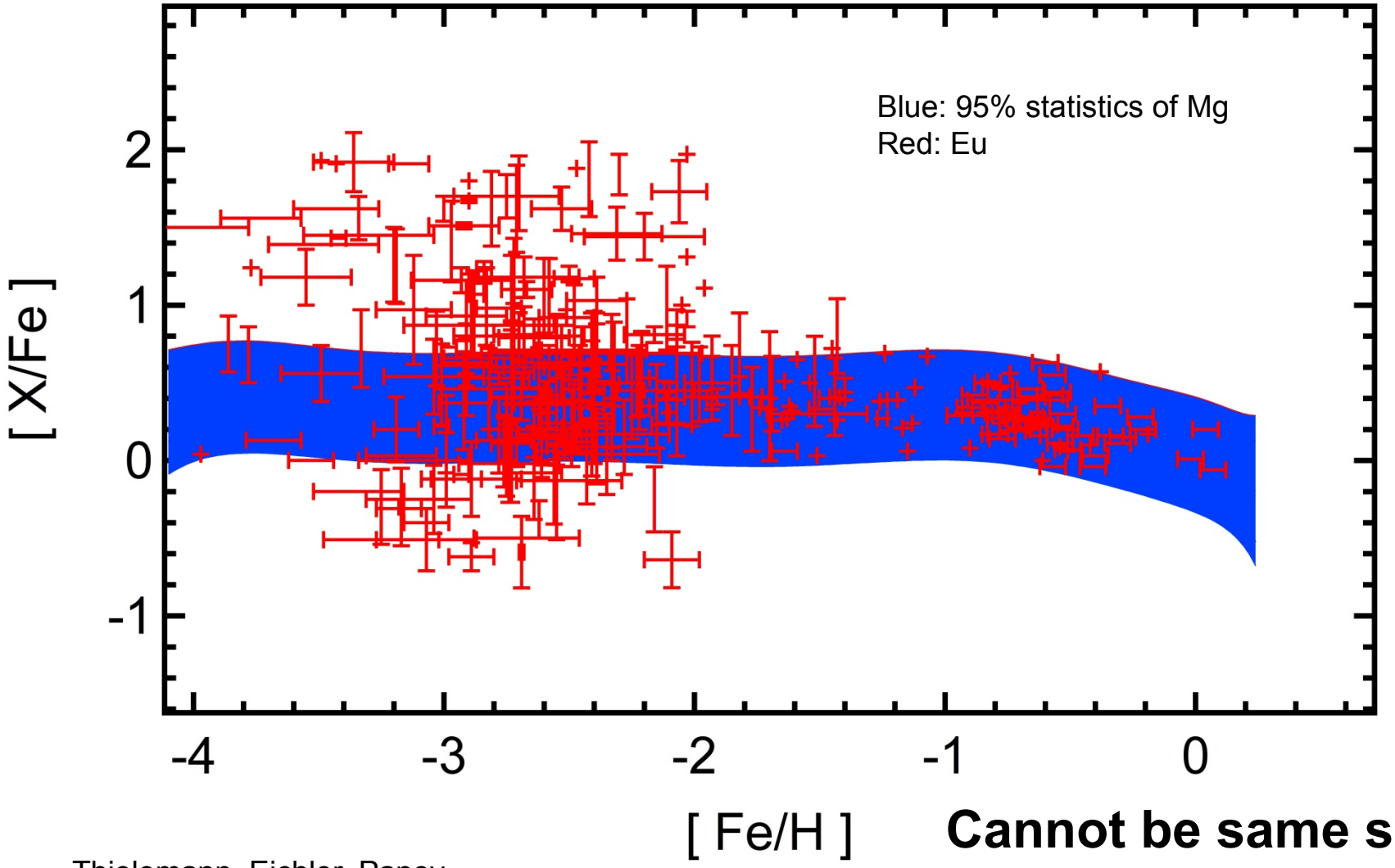


But what about r-process elements?



From SAGA database, e.g., *T. Suda et al.*, PASJ, 60, 1159-1171, 2008.

Both together

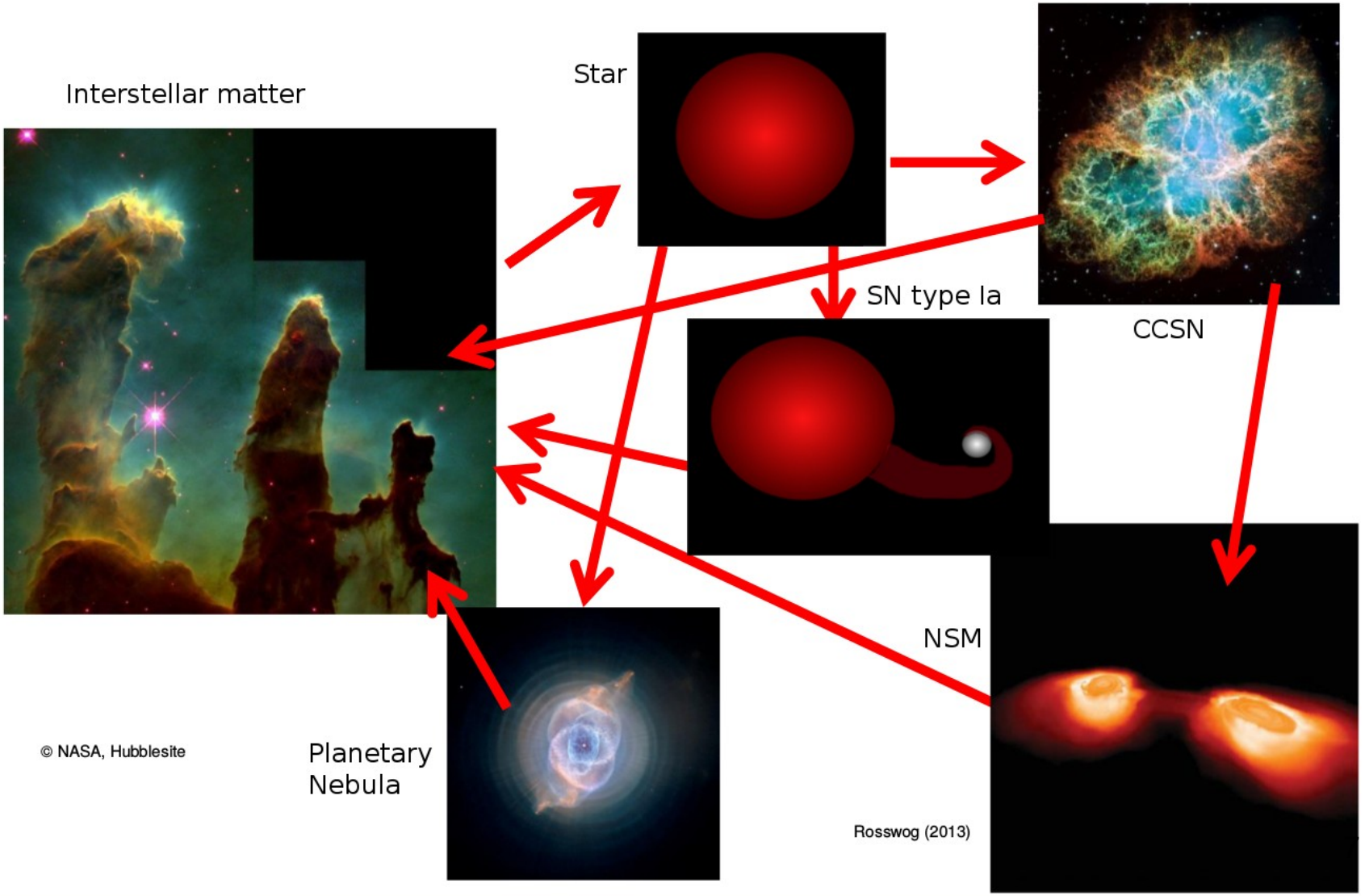


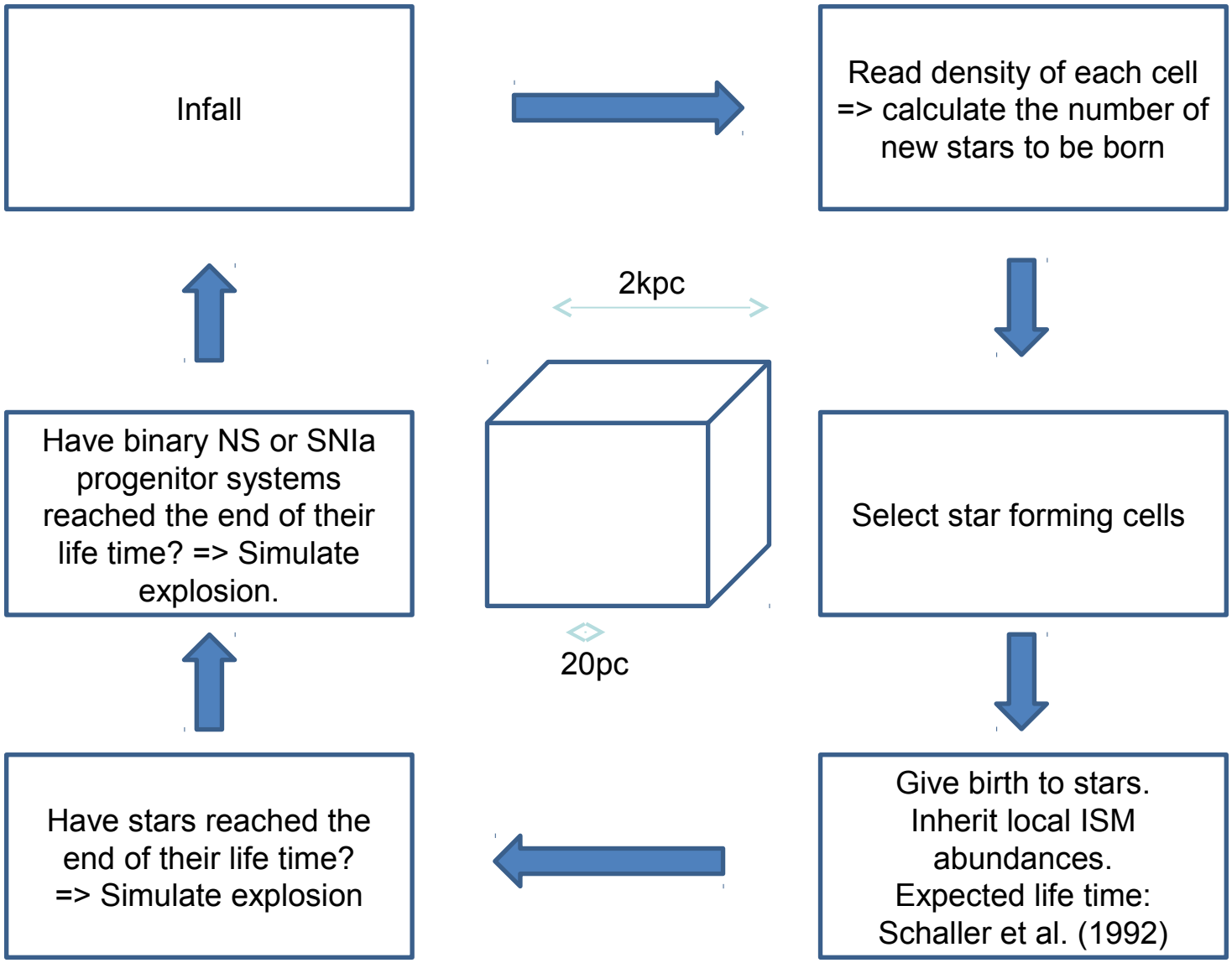
Cannot be same site!

Thielemann, Eichler, Panov, Pignatari, BW, 2016

Let‘s model GCE of r-process elements!

The cosmic life cycle




Infall
Read density of each cell => calculate the number of new stars to be born
2kpc
Have binary NS or SNIa progenitor systems reached the end of their life time? => Simulate explosion.
Select star forming cells
20pc
Have stars reached the end of their life time? => Simulate explosion
Give birth to stars. Inherit local ISM abundances. Expected life time: Schaller et al. (1992)

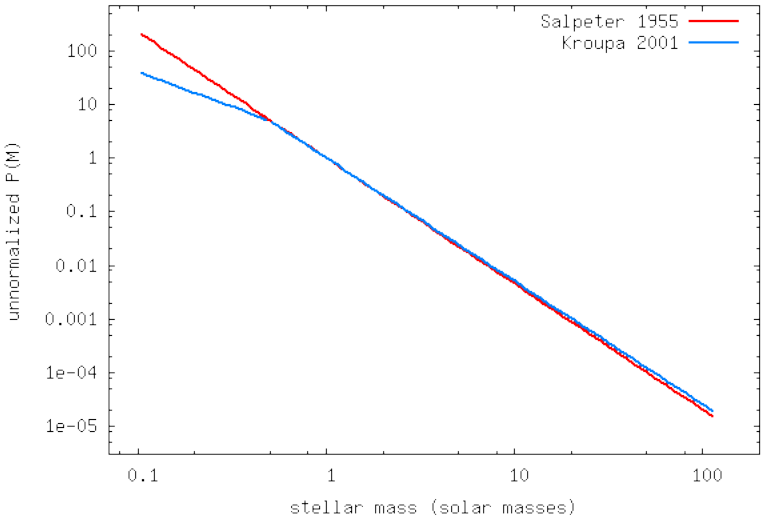
Stars

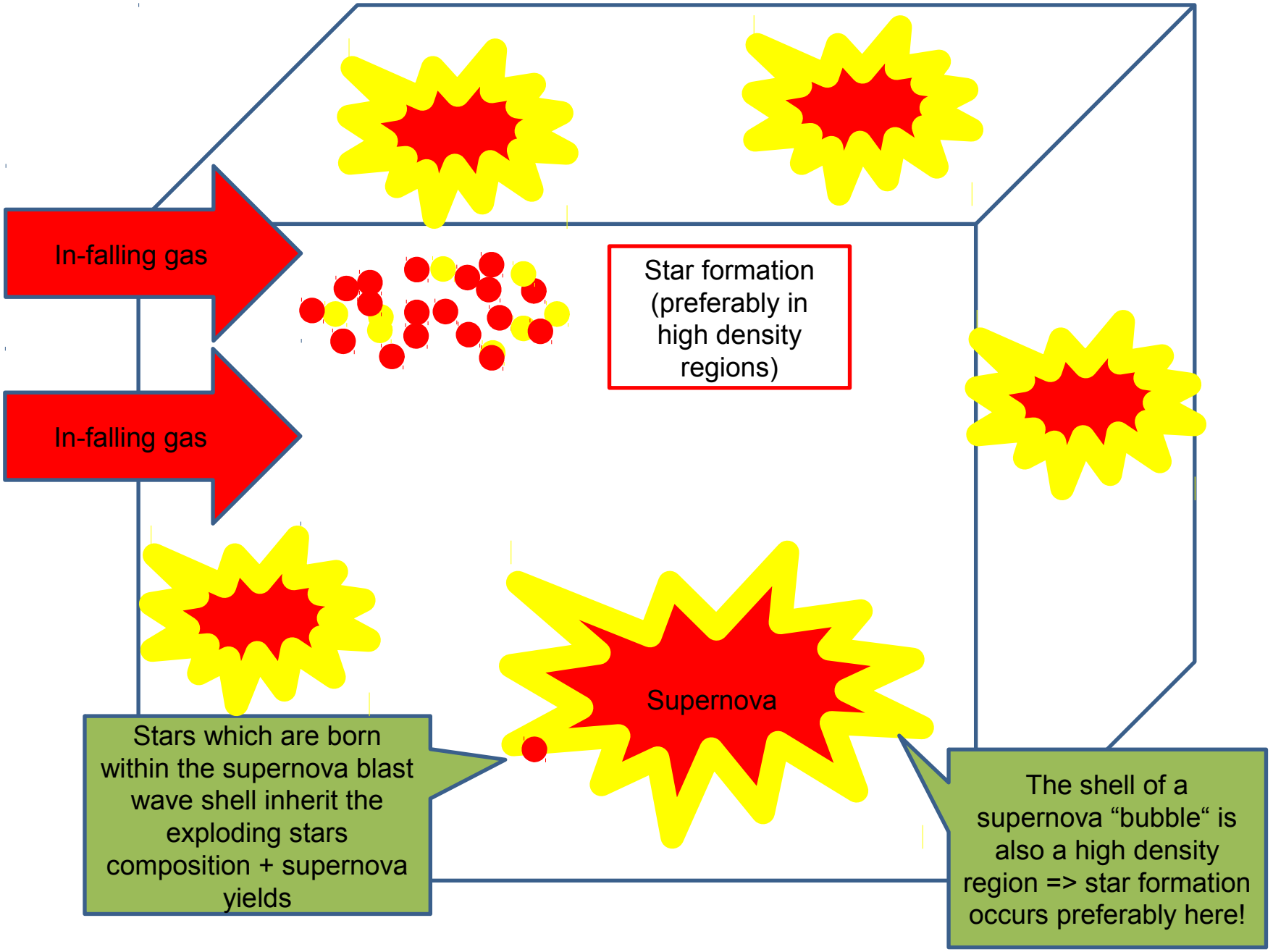
- The mass of a newly born star is randomly determined so that all newly born stars obey the initial mass function (IMF)
- The life time expectancy for a star:

log(T)= (3,79+0,24 Z)-(3,10+0,35 Z)
log (M)+(0,74+0,11 Z) log (M)^2

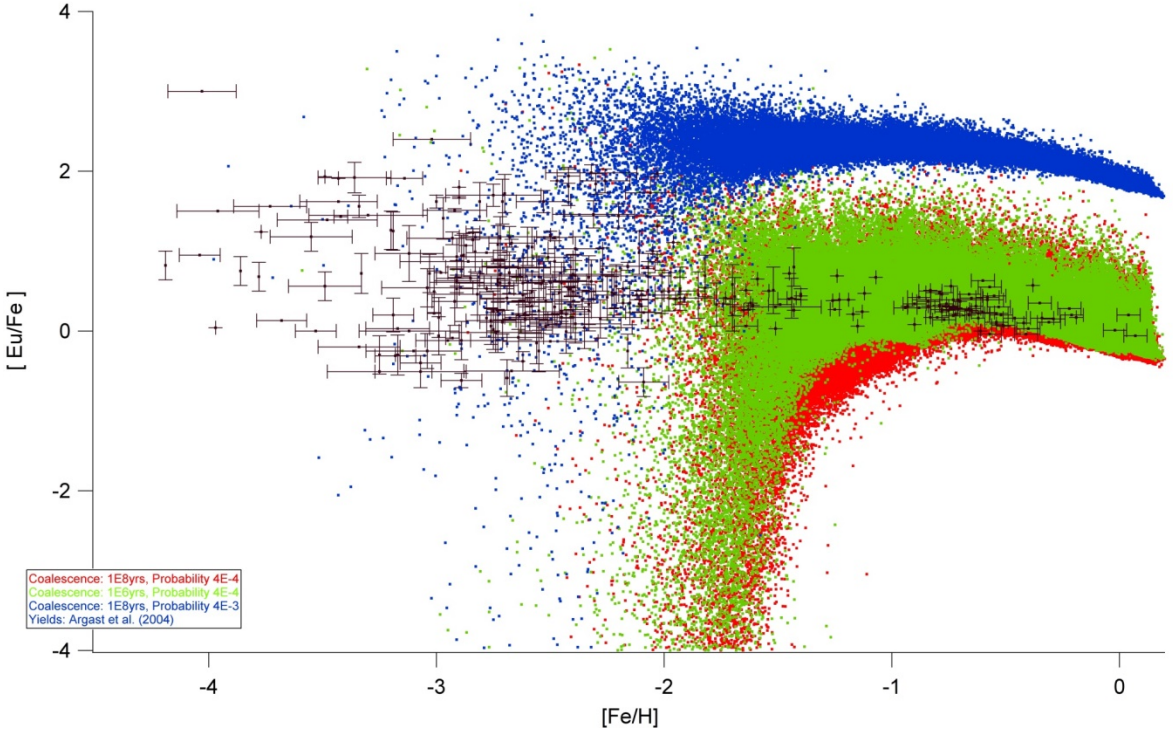
(Schaller+, Maeder+)

- M<10M_{Sol}: Not producing SN elements, but lock up ISM for the duration of their life time
- M>10M_{Sol}: Star will undergo CCSN
- NSM: Possibility P_{NSM} for a binary HMS system to also do NSM-Event (after coalescence time)
- Ia: Possibility P_{SNIa} for a binary IMS system to do SNIa event




In-falling gas
In-falling gas
Star formation (preferably in high density regions)
Supernova
Stars which are born within the supernova blast wave shell inherit the exploding stars composition + supernova yields
The shell of a supernova “bubble“ is also a high density region => star formation occurs preferably here!

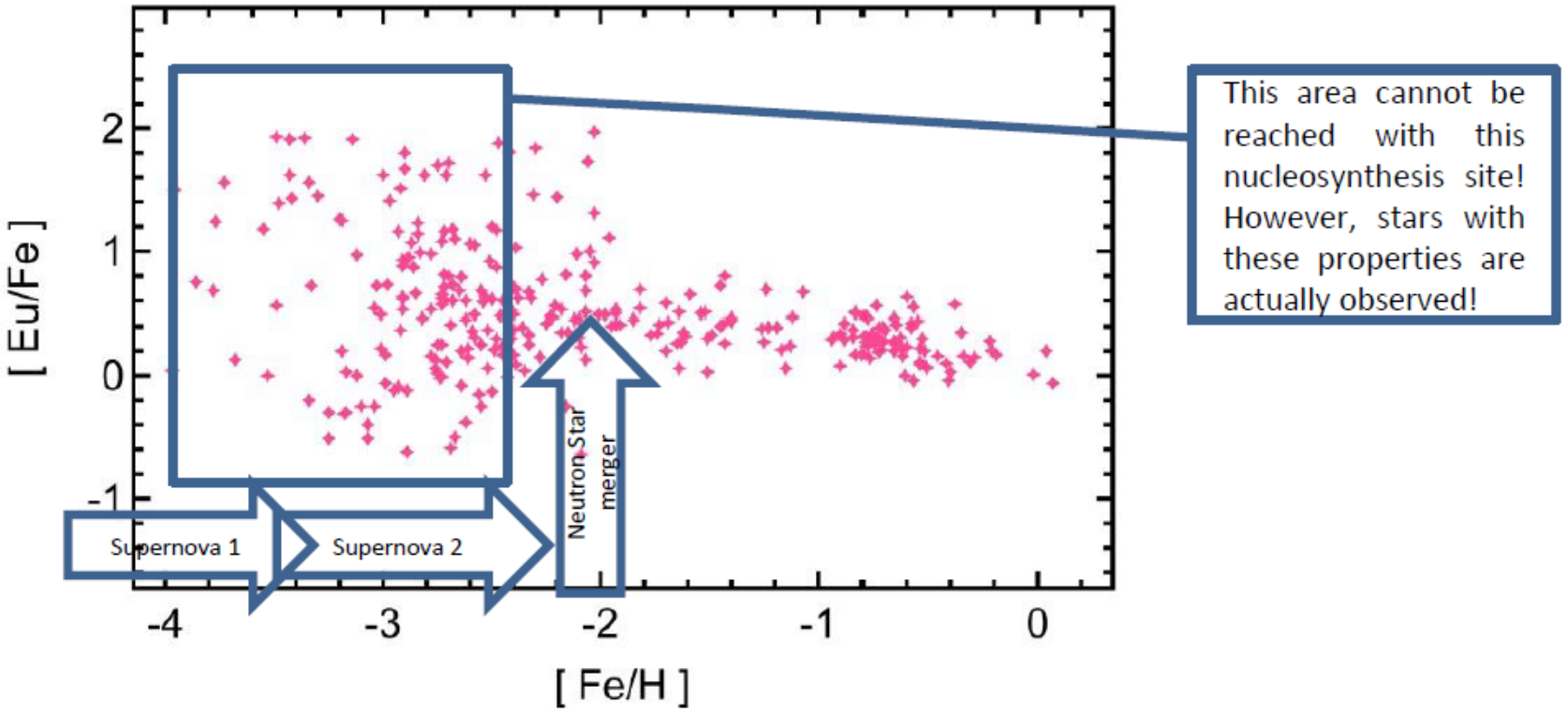
Compare GCE model predictions with observations: NSMs as exlusive r-process site



Wehmeyer, Pignatari, Thielemann (2015/2016a)

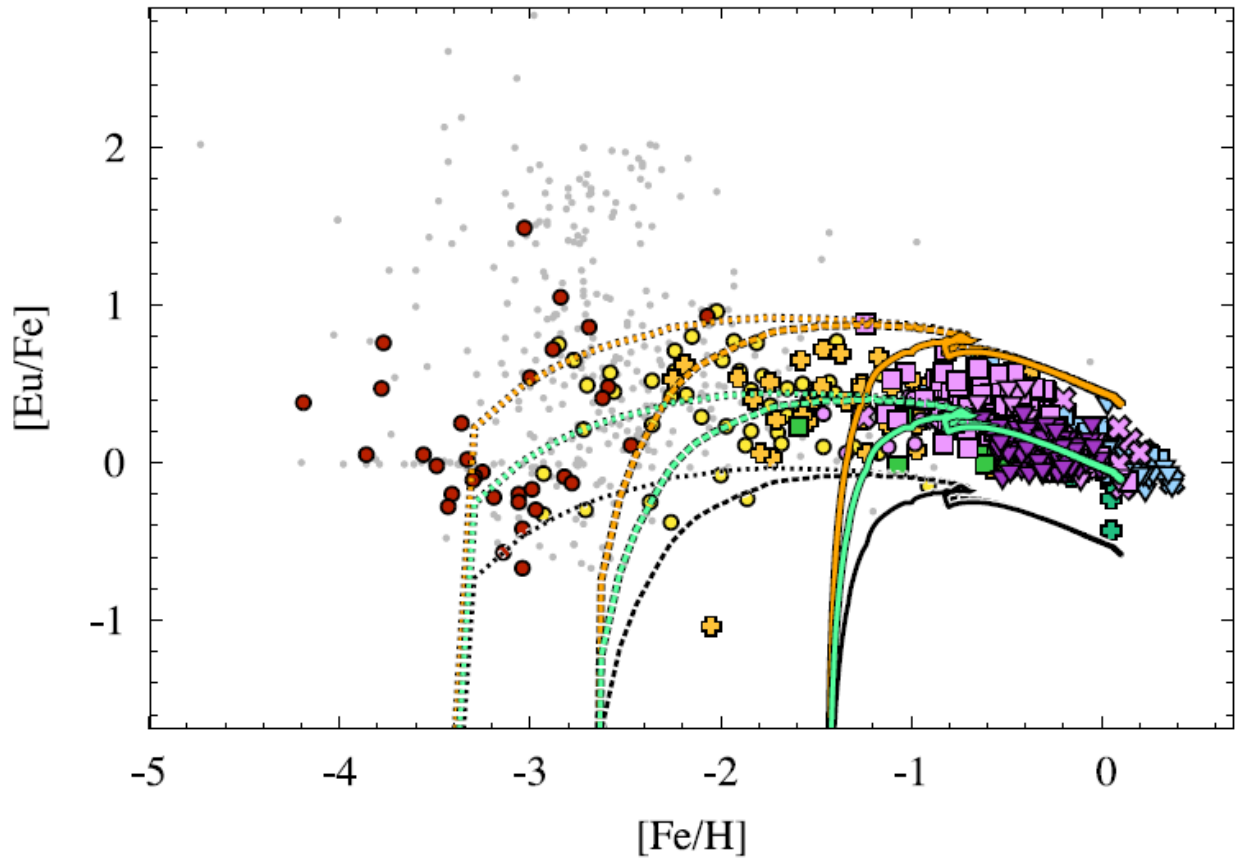
- No matter which parameter is altered, it is difficult to match the observed abundances (black error bars)
- Red dots represent model stars with the canonical parameters
- Green dots are model stars in a model with extremely low coalescence time scales for NSM => The shift is marginal
- Blue dots are model stars with increased NSM probability

Simple explanation:



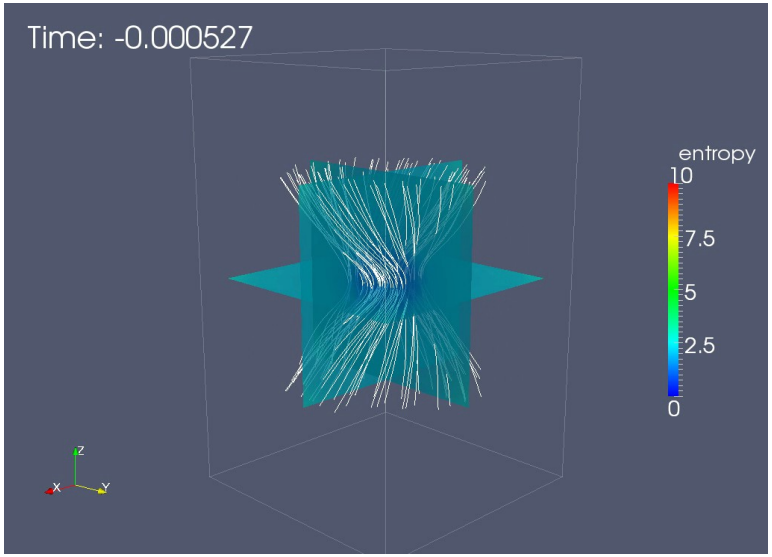
PRELIMINARY!

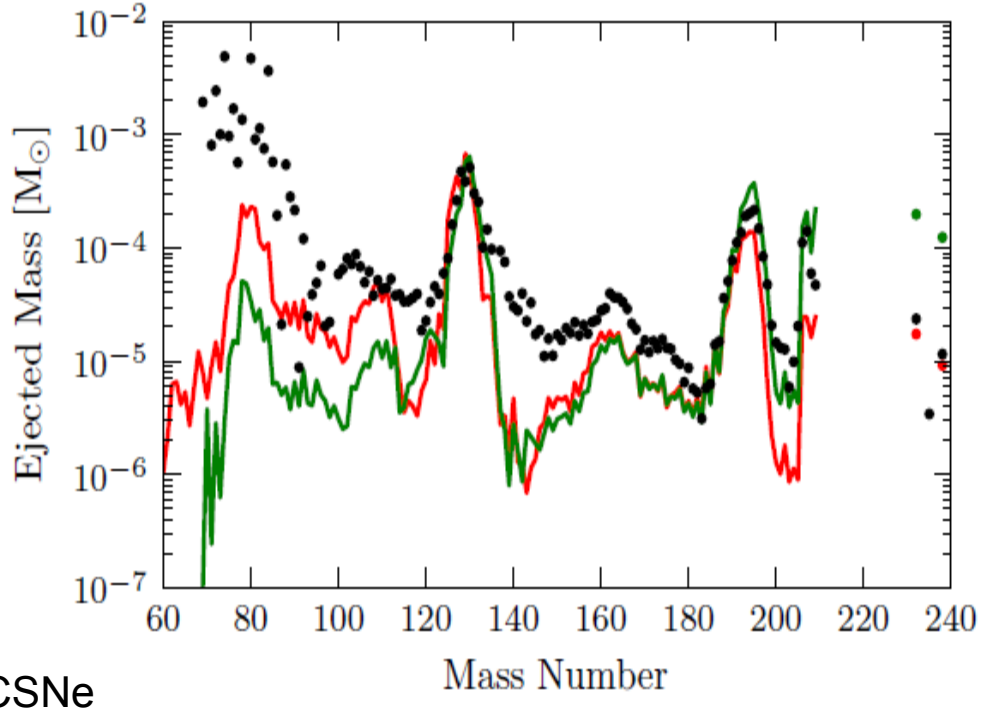
Similar conclusions



- Matteucci et al. (2014) use a homogeneous mixing model to examine the effects of CBMs as exclusive r-process site
- The Galaxy then consists of an overlap of these models
- Conclusion: It is difficult to explain all observations with CBM alone! (only if they all merge within 1 My!)

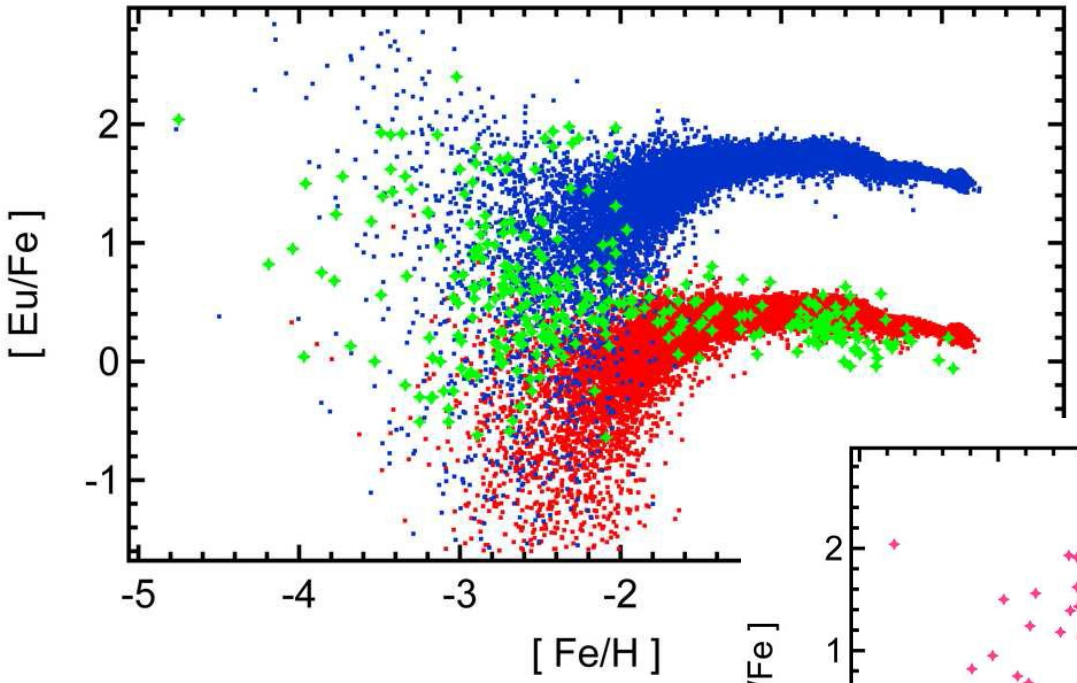
Let‘s consider a second r-process site: MHD-SNe!



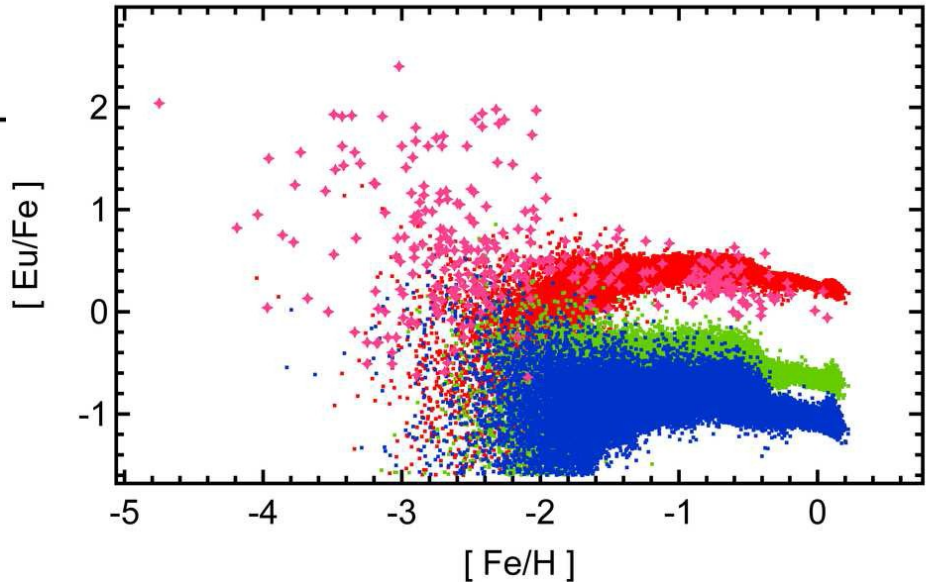


- MHD-SNe are a very rare sub-class of CCSNe
- Their progenitors are extremely fast rotating and highly magnetized
- During explosion, the magnetic field lines force the emergence of polar jets
- In the jets, requirements for an r-process are met (Winteler+12, Nishimura+15)
- Advantage: r-process contribution already at low metallicities!!

Compare GCE model predictions with observations: MHD-SNe as exlusive r-process site



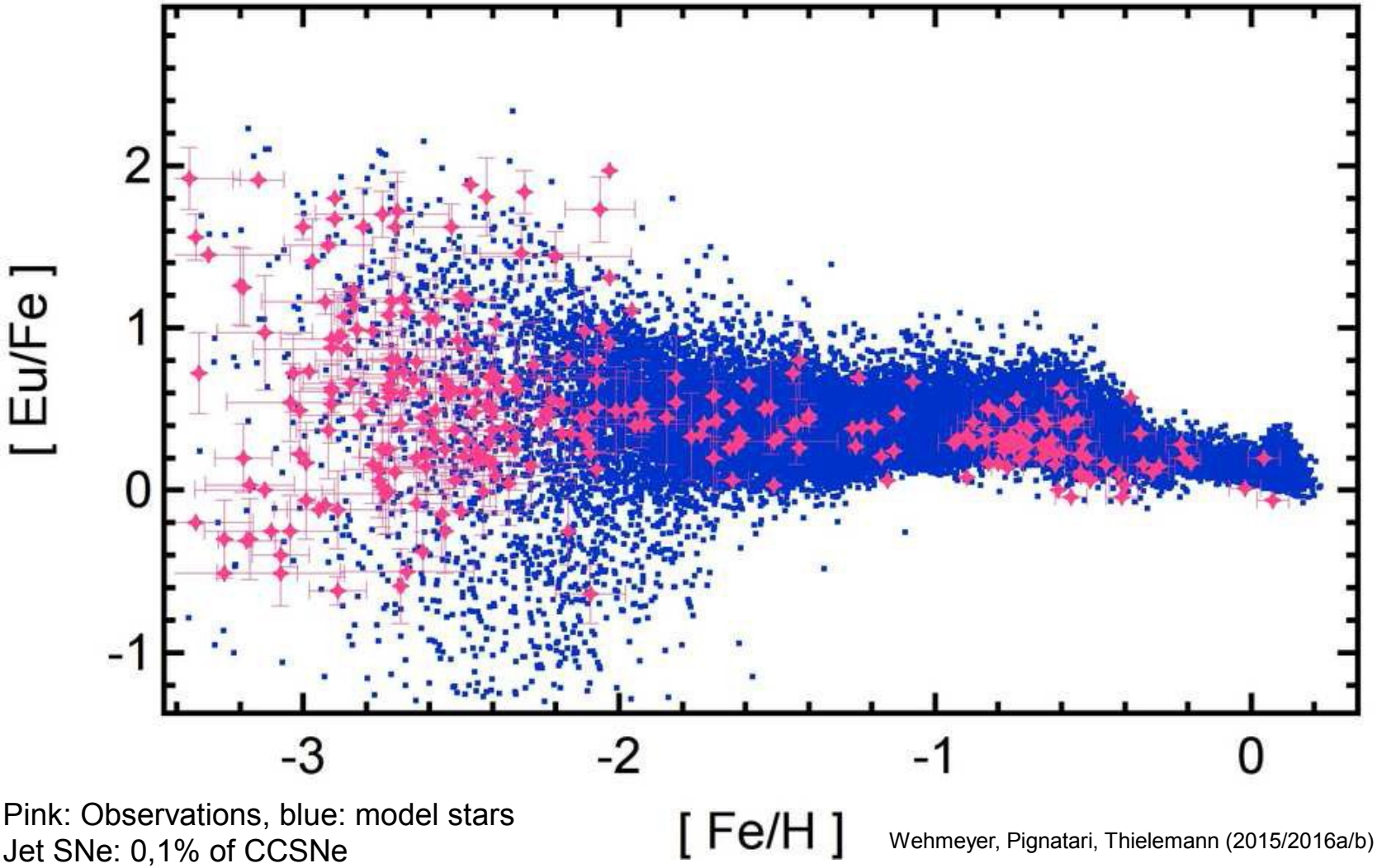
- Left: Observations (green)
- Model stars fitting r-process abundances down to [Fe/H]>-1.8 (red)
- Increased MHD-SN probability (blue)



- Right: Observations (pink)
- Model stars fitting r-process abundances down to [Fe/H]>-1.8 (red)
- Decreased MHD-SN probability (green/blue)

Wehmeyer, Pignatari, Thielemann (2015)

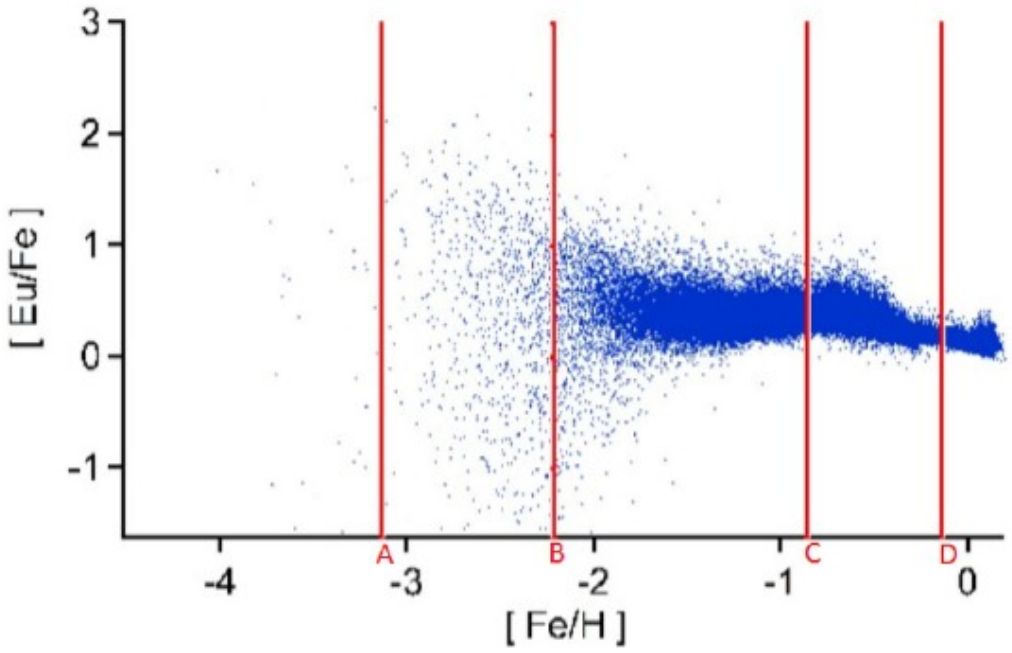
Combined environment with **both NSM and MHD-SNe!**

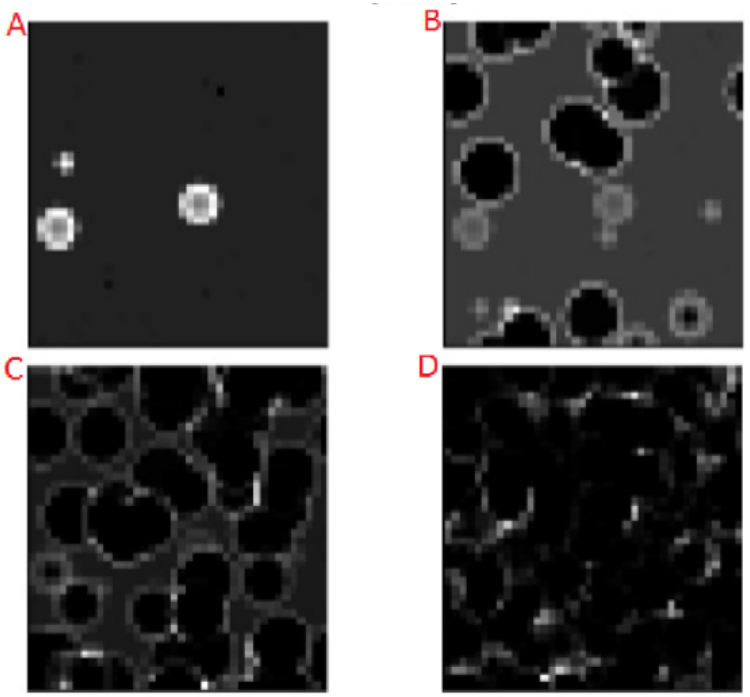


Pink: Observations, blue: model stars
Jet SNe: 0,1% of CCSNe

Wehmeyer, Pignatari, Thielemann (2015/2016a/b)

The role of inhomogeneities





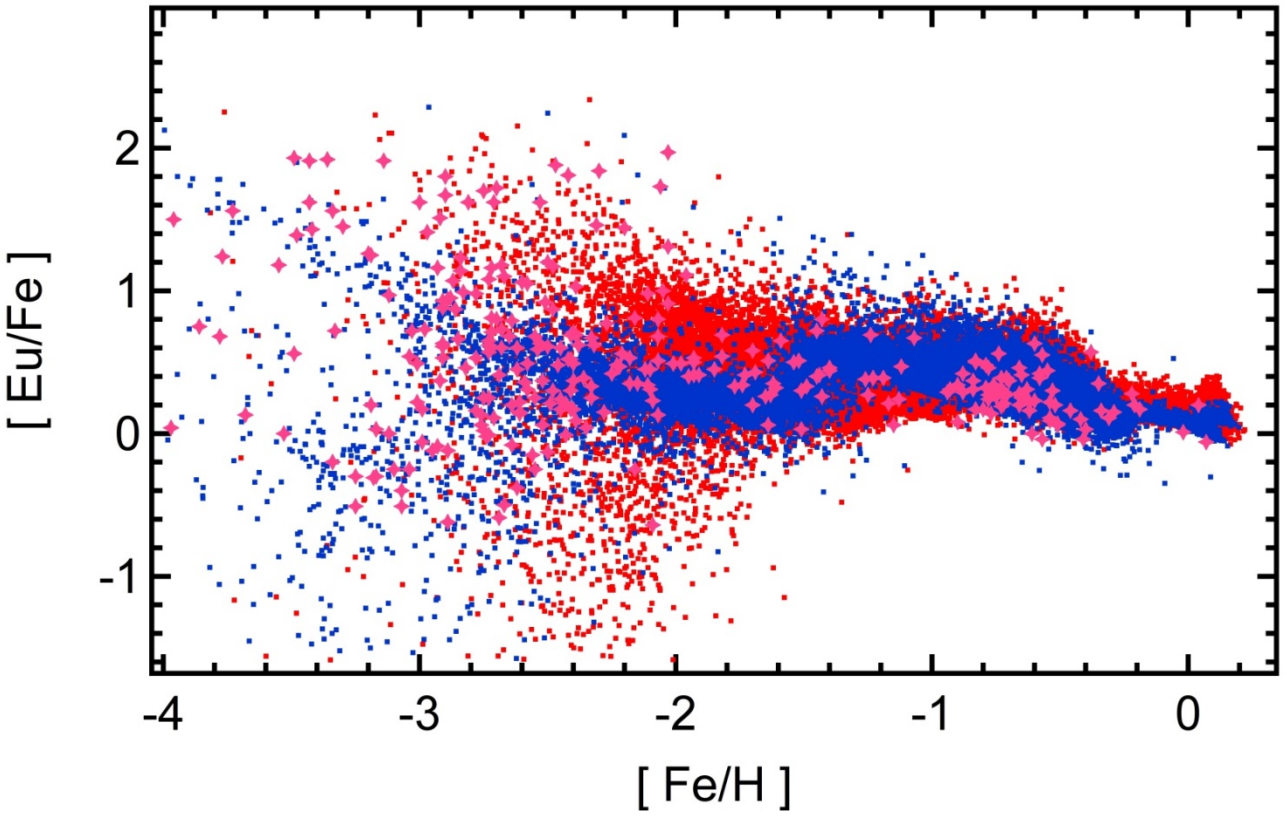
Extreme inhomogeneities together with the rare site(s) in the early Galaxy explain the scatter…

Wehmeyer, Pignatari, Thielemann (2015)

How much interstellar medium is polluted by a SN?

- Ryan et al. (1996); Shigeyama & Tsujimoto (1998) studied a Sedov-Taylor blast wave of a single SN (of 10^{51} erg) in a gas filled volume and estimated the amount of gas which is swept up by the explosion:
- $M_{Pol} = 5.1 \cdot 10^4 \mathrm{M_{Sol}} \left(\frac{E_0}{10^{51} erg}\right)^{0.97} \cdot n^{-0.062} \cdot \left(\frac{c_s}{10 \frac{km}{s}}\right)^{-\frac{9}{7}}$
- The SN produces a “bubble” with high density shells and low density interior

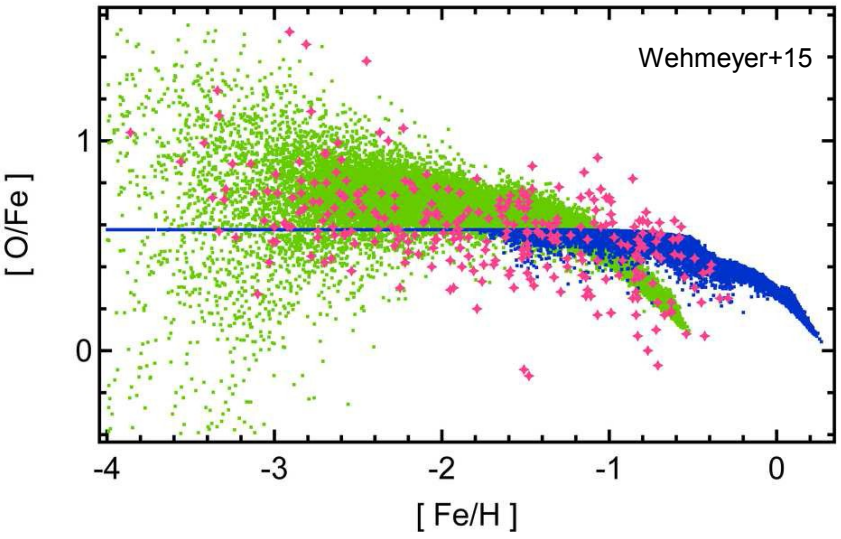
The role of the „sweep up mass“

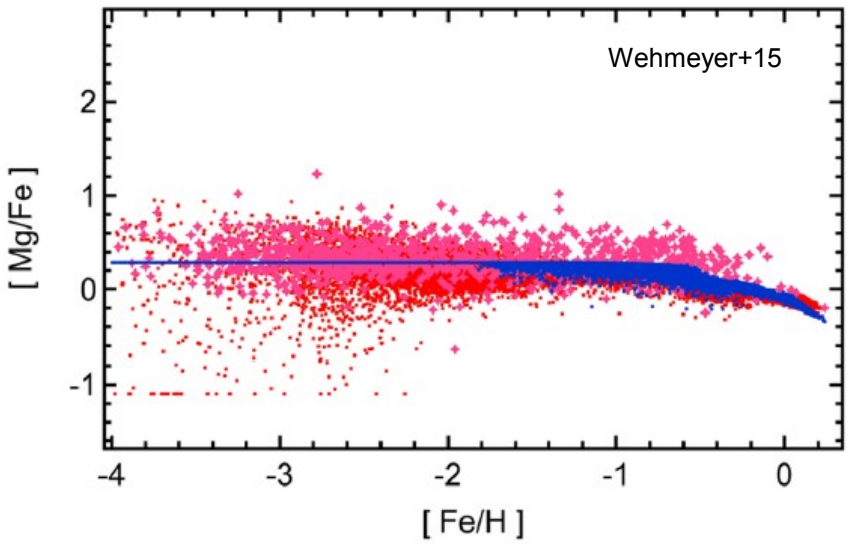


Wehmeyer, Pignatari & Thielemann (2015)

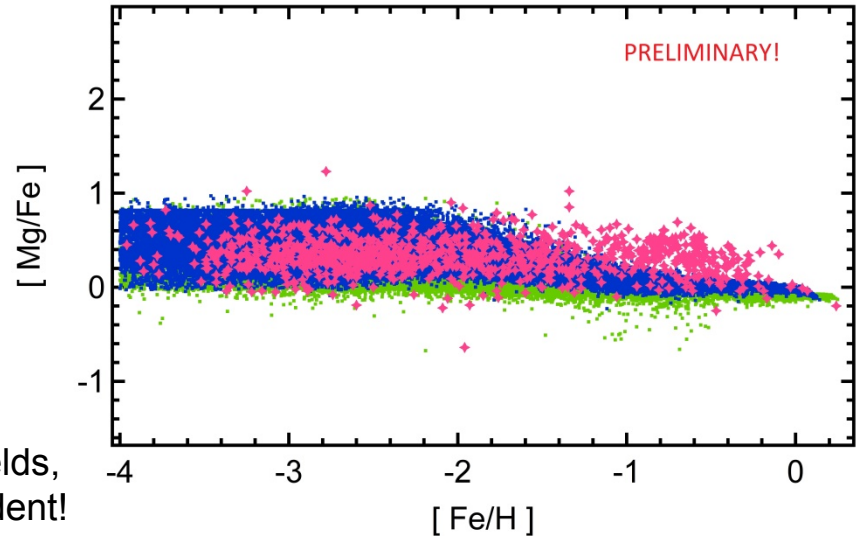
- Red dots represent model stars of the reference model with 5E4 solar masses of ISM swept up per SN
- Blue dots represent model stars where the swept-up mass is increased to 2E5 solar masses of ISM
- GCE path is shifted towards homogeneous case: smaller spread, faster increase in metallicity

Problem(?) with ccSN yields





Green and red dots from Thielemann+96
or Nomoto+97 CCSN yields,
Blue dots represent
ad-hoc yields, e.g., Y(Fe)=0.5 Y(alpha)



Kobayashi+06 /
Kobayashi+12 yields,
Metallicity dependent!

Conclusions

- NSM alone have difficulties to explain abundances at low metallicities => earlier site cures this (e.g., MHD-SNe)
- The spread in the [r/Fe]-ratio at low-metallicities can be explained by inhomogeneities (and the rarity of sites)
- Yields from SNe still have to be improved (=>have huge impact on GCE)
- Explosion energies for whole spectrum of progenitors highly needed for GCE!

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