Stellar Archaeology as a Time Machine to the First Stars, 2018 December 5th

METAL MIXING IN THE FIRST GALAXIES

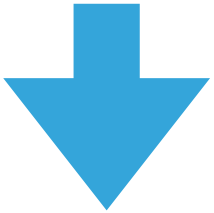
SEMI-ANALYTICAL MODEL IMPROVEMENT AND ITS IMPLICATIONS

Yuta Tarumi (U.Tokyo)

東京大学
THE UNIVERSITY OF TOKYO

OPEN QUESTIONS AND METAL MIXING

Simulations predict metal yields



How metals mix with Hydrogen?

Abundance pattern: observational calibration

- Origin of CEMP stars
- Nature of EMP stars
- Population III properties (IMF, multiplicities, …)

WHY SEMI-ANALYTICAL MODEL ?

- Semi-Analytical Model (Hartwig+15,+18, Magg+18): FAST
  - Good for parameter exploration
  - Can predict various quantities
  - Analytical treatment requires physical understanding

SAM give us insights on early star formation !

But it needs to be calibrated

PARAMETERS WE HAVE

- Poorly constrained quantities
  - recovery time
  - eject/fallback fraction
  - **dilution factor**
  - ...

Parameter	Value
mass threshold for Pop III	Eq. 1
mass threshold with LW feedback	Eq. 3
Pop III SFE	$\eta_{\rm III} = 0.001$
Pop II SFE	$\eta_{\rm II} = 0.01$
fraction of faint SNe	$f_{\rm faint} = 40\%$
metal fallback fraction	$f_{\rm fallback} = 20\%$
metal ejection fraction	$f_{\rm eject} = 80\%$
Pop III SN wind velocity	$v = 10\,{\rm km/s}$
lower IMF limit	$M_{\rm min} = 3\,{\rm M}_\odot$
upper IMF limit	$M_{\rm max} = 150\,{\rm M}_\odot$
recovery time	$t_{\rm recov} = 100\,{\rm Myr}$
mean of dilution distribution	$\mu = 10^{-1.5}$
width of dilution distribution	$\sigma = 0.75\,{\rm dex}$

Table 1. Parameter values in our fiducial model. This set of parameters best reproduces observations at [Fe/H]$\leqslant -3$ as we show below.

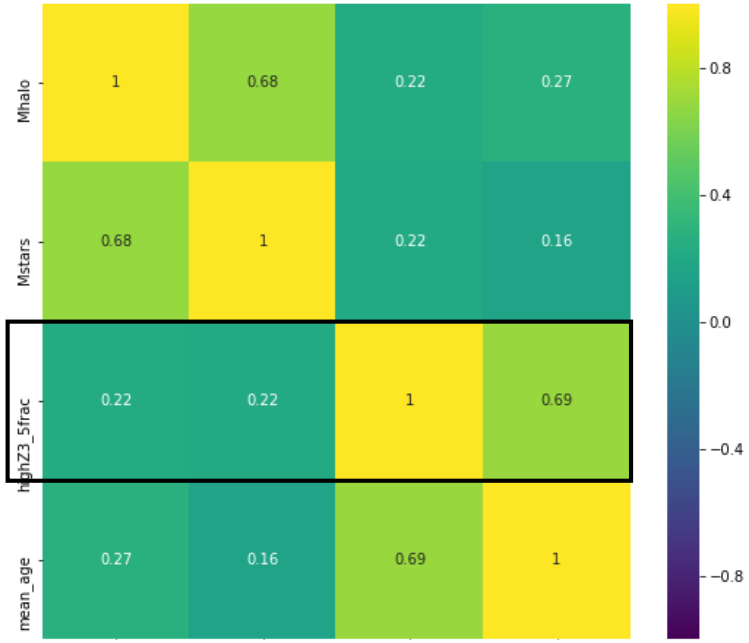
$$\frac{\text{(Hydrogen gas mixed with metals)}}{\text{(Hydrogen gas in the halo)}}$$

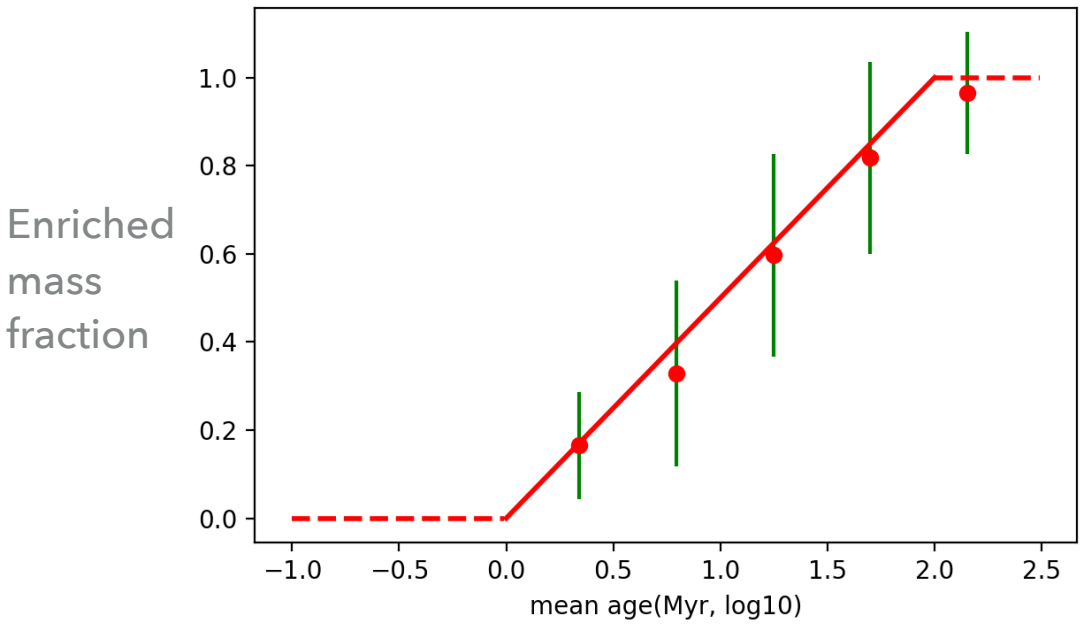
Hartwig+18

- Dilution factor can be inferred from cosmological simulations

COSMOLOGICAL SIMULATION

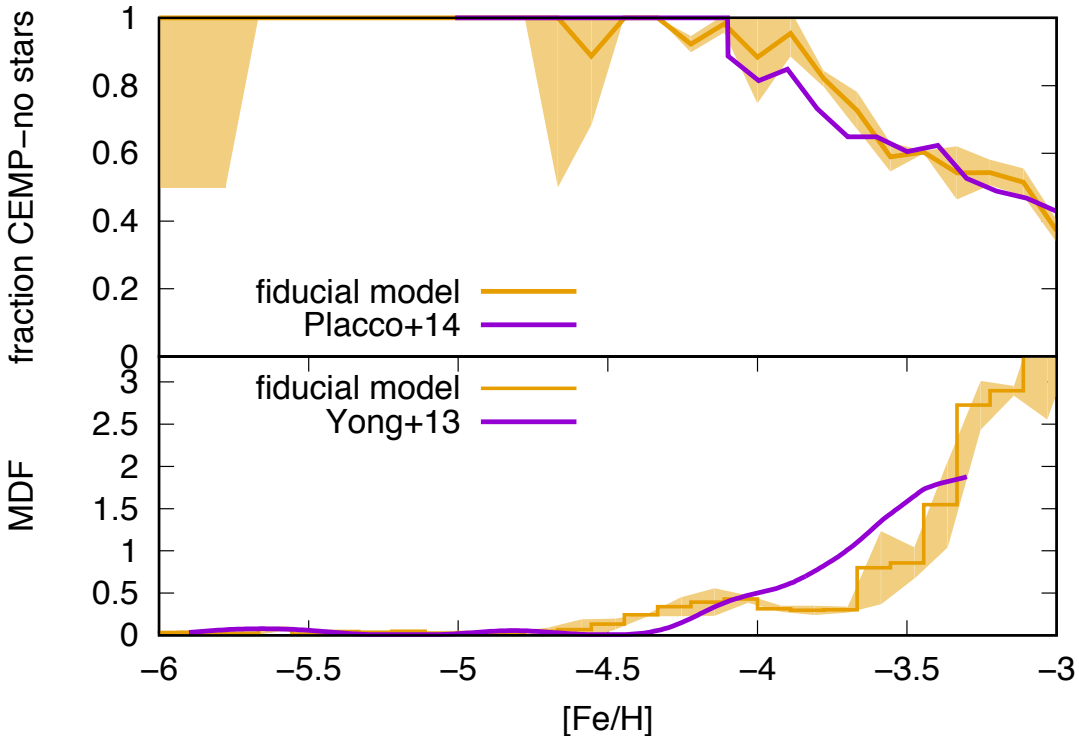
- Enzo outputs at z=11, 13, 15
- "Enriched gas": $Z > 10^{-3.5} Z_{\odot}$
- Enriched mass fraction is correlated with stellar age, rather than stellar mass (≒ E_{SN})
- Determine dilution factor by stellar age





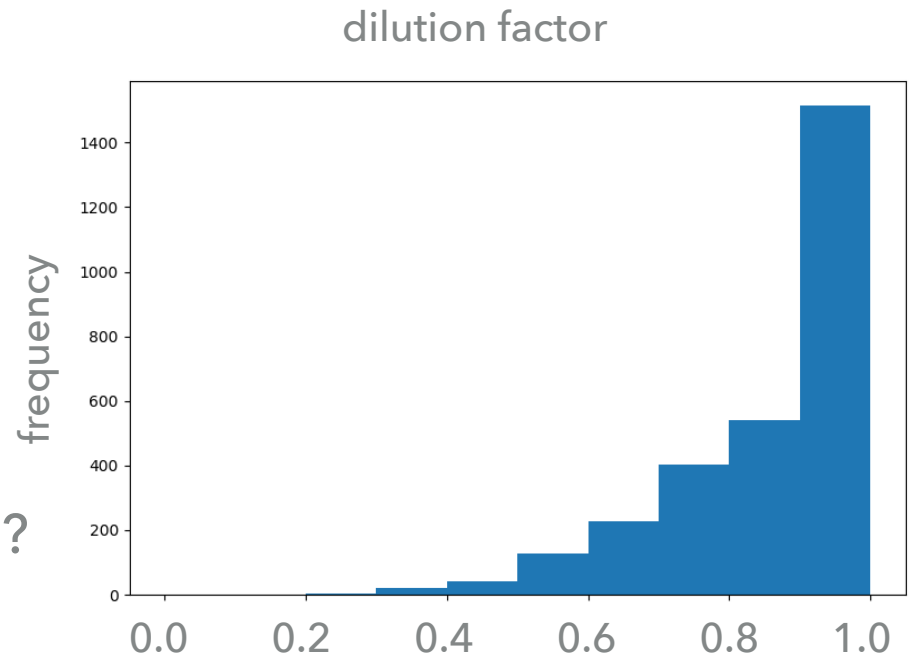
CALIBRATION

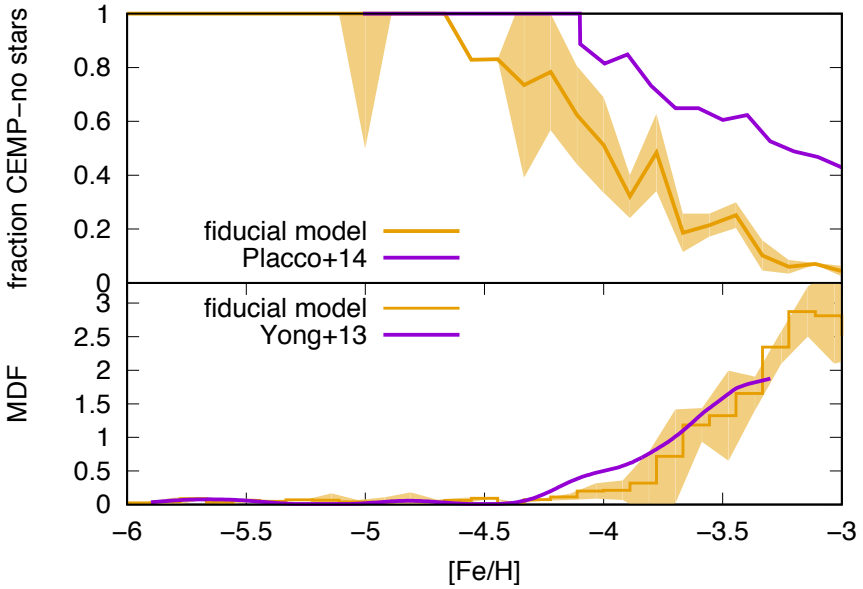
- We fit “CEMP-no fraction” and metallicity distribution function
- Best-fit parameters:
  - popIII IMF slope = 1.0 (linear-flat)
  - IMFmax = 150 Msun
  - faint SNe fraction = 20%
  - Recovery time = 60Myr



IMPLICATION FROM CALIBRATION

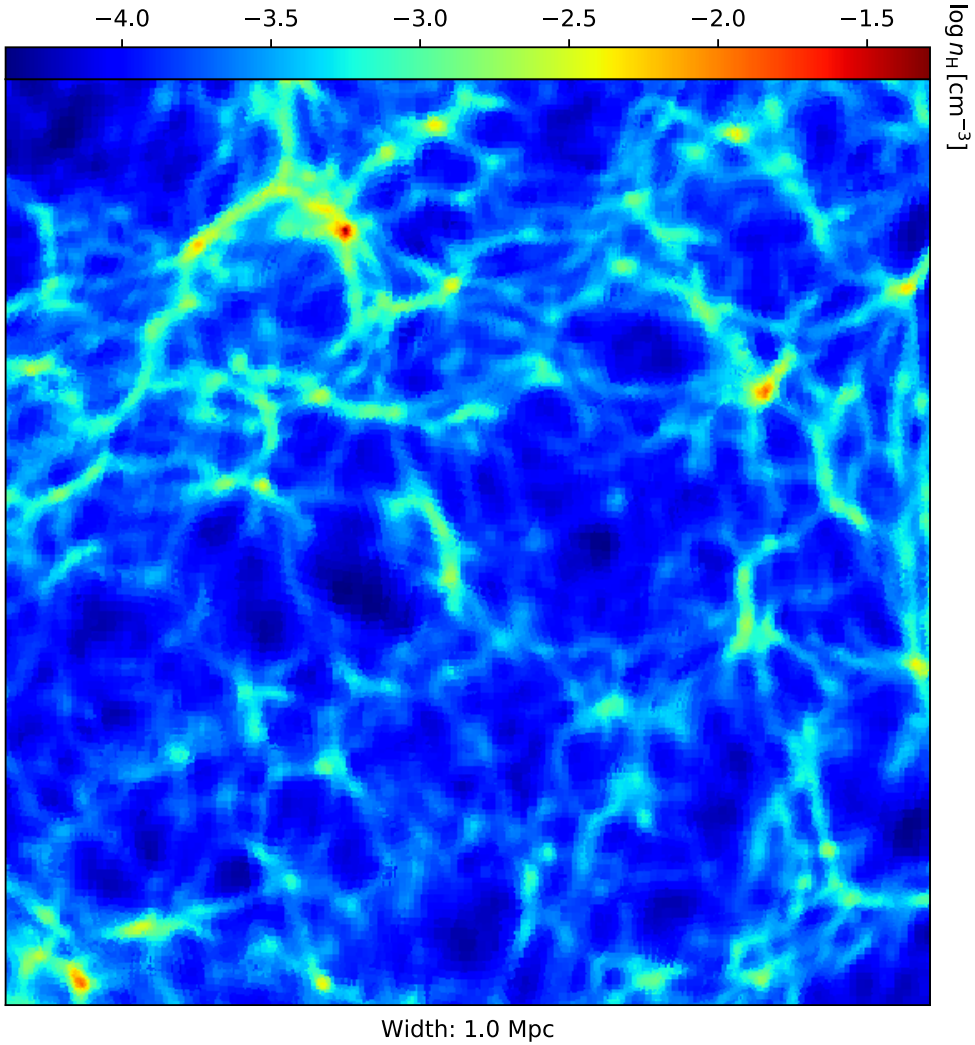
- High dilution factor → low [Fe/H]
- More Carbon-rich yield without decreasing Fe is required
  - Carbon from PISNe around 150Msun ?
    - Top-heavy IMF
  - Other channels ?
    - Binary mass transfer (Arentsen+18)
    - Inhomogeneous mixing (Hartwig & Yoshida, submitted)





FUTURE WORK

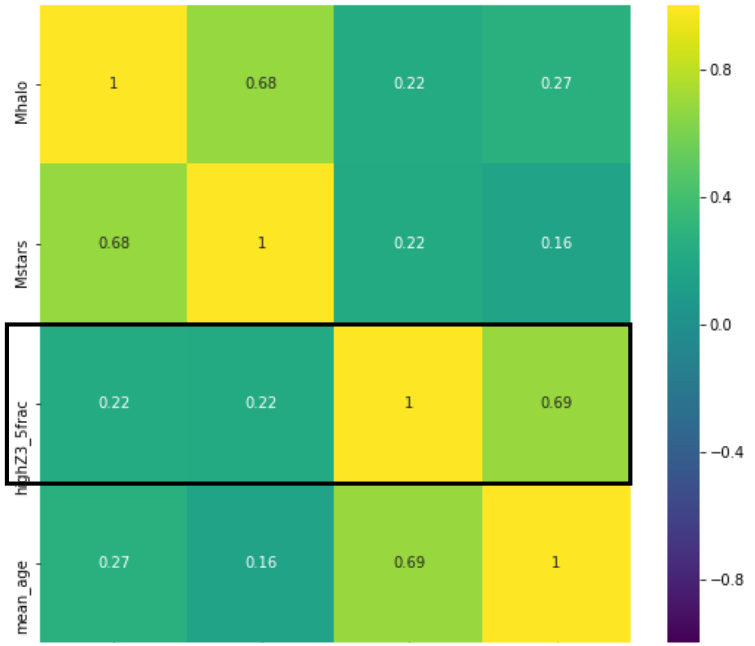
- Confirm age-dilution factor relation with a new simulation - mass range, time resolution
- Other model improvements with hydro-simulation AREPO
- Applications to other galaxy physics ?

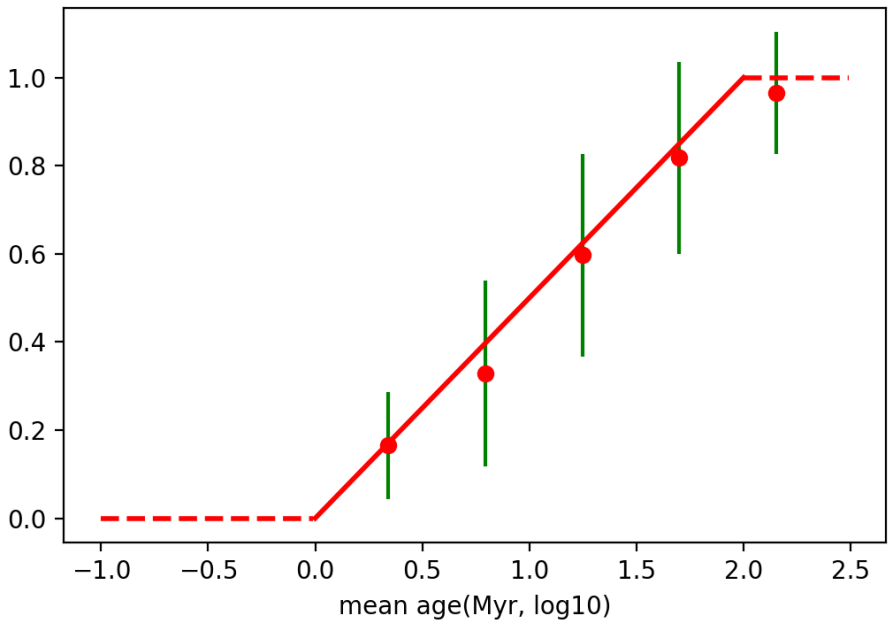


SUMMARY

- "Dilution factor" can be estimated by stellar mean age
- High [C/Fe] SNe is favored by semi-analytical model

Enriched mass fraction

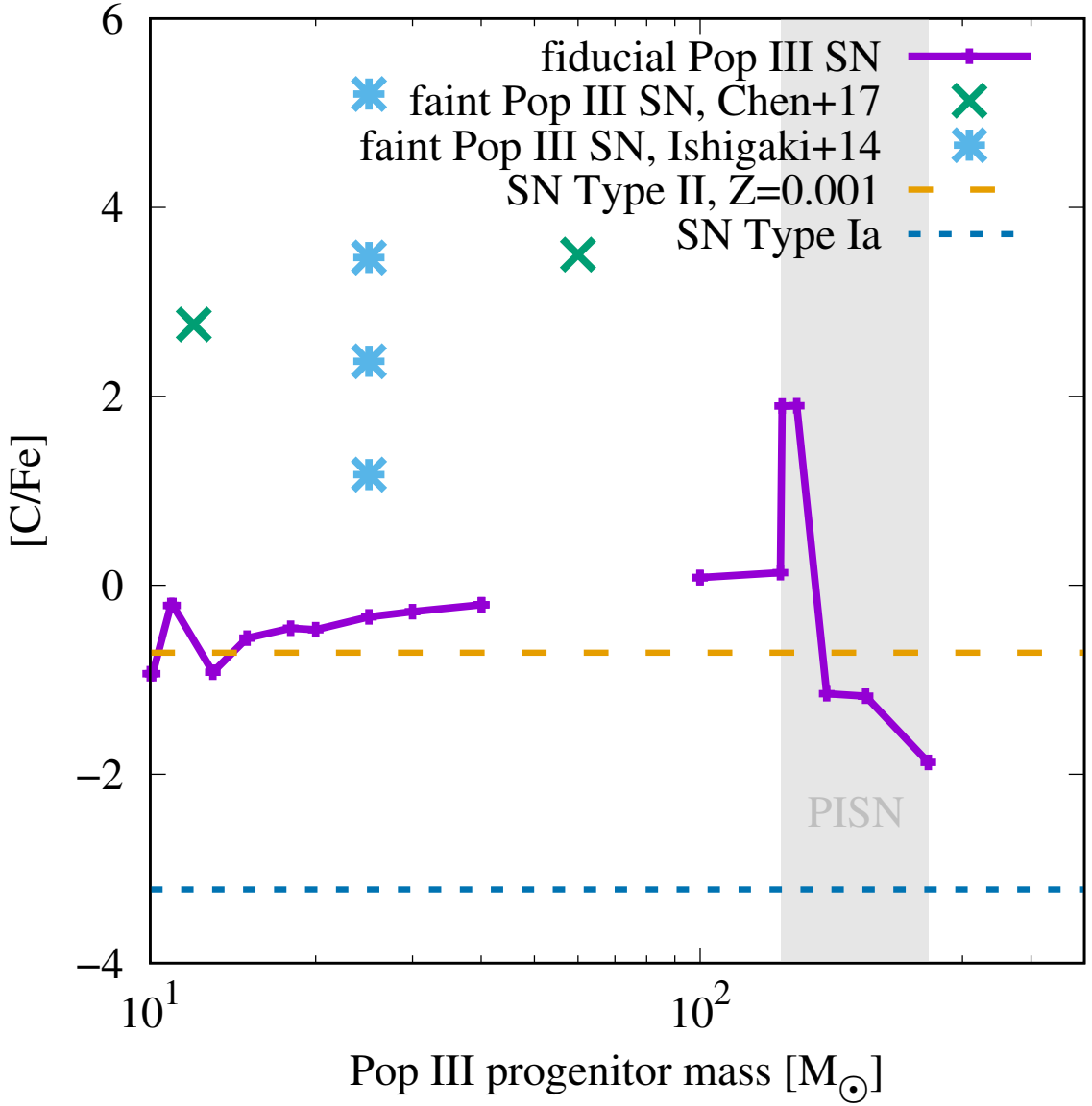




PISNE METAL YIELD

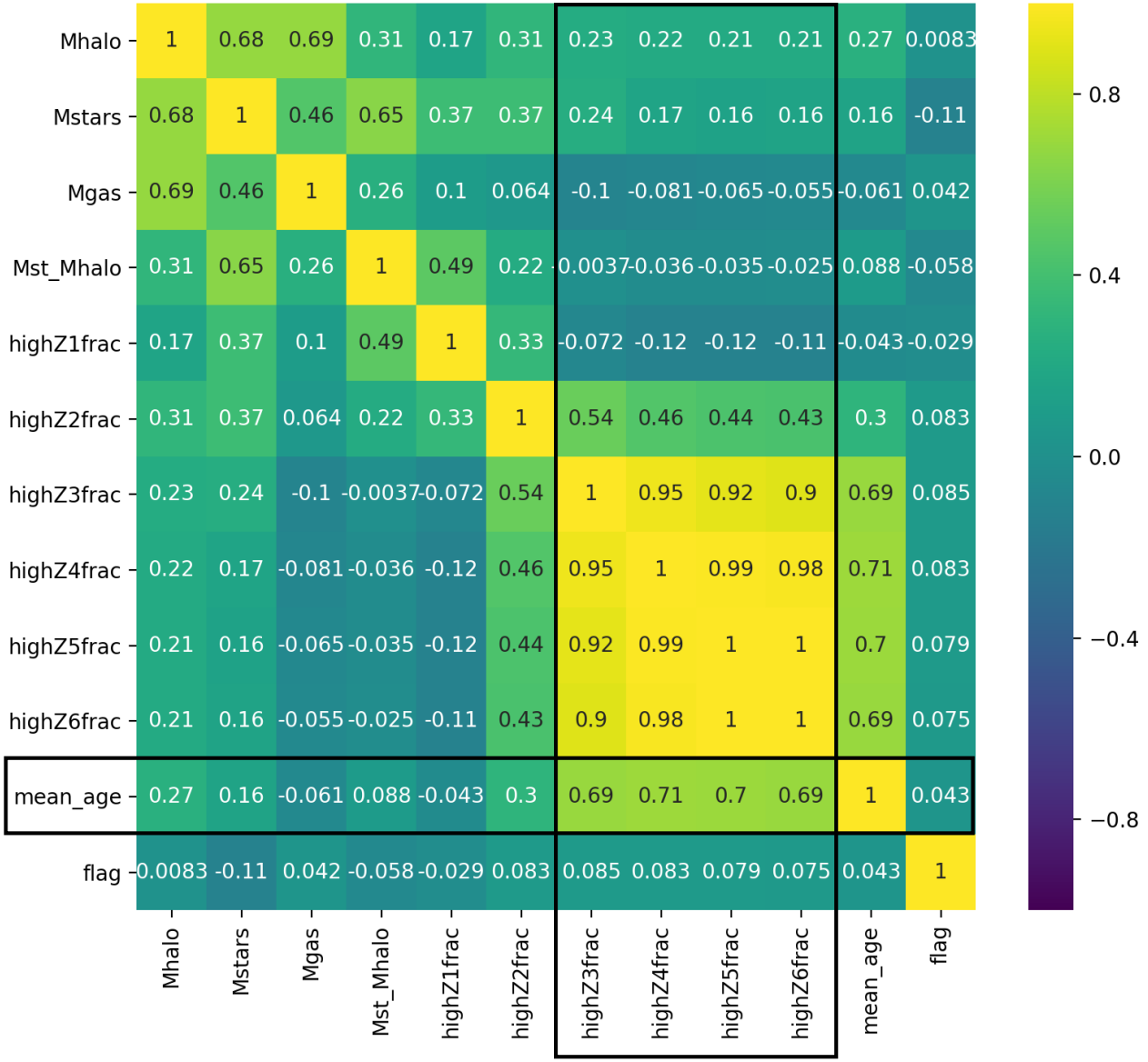
Hartwig+18

- PISNe around 150Msun produce high C/Fe ratio



CORRELATION

- Changing criterion has little effect in the range [-3, -6]



HIGH-CARBON, LOW-IRON YIELD

- Ffaint = 100% figure
- MDF moves to the left: Not enough iron