METAL MIXING IN THE FIRST GALAXIES

SEMI-ANALYTICAL MODEL IMPROVEMENT AND ITS IMPLICATIONS

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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
- ... (Hydrogen gas mixed with metals)
  (Hydrogen gas in the halo)
- Dilution factor can be inferred from cosmological simulations

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

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 ($\equiv E_{\text{SN}}$)

- 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
**RESULTS**

**IMPLICATION FROM CALIBRATION**

- High dilution factor $\rightarrow$ low $[\text{Fe/H}]$
- More Carbon-rich yield **without** decreasing Fe is required
  - Carbon from PISNe around 150M$_\odot$?
  - 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?
“Dilution factor” can be estimated by stellar mean age

High [C/Fe] SNe is favored by semi-analytical model
PISNe metal yield

- PISNe around 150 Msun produce high C/Fe ratio
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