高赤方偏移銀河の金属量非一様性と初代星初期質量関数への影響

Metallicity inhomogeneity inside high-z galaxies and its effects on Pop-III IMF

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in collaboration with

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Stellar archaeology to IMF

- Direct observation of Pop-III stars is quite difficult.
- -> Can we investigate indirectly?

- Pop-III properties (like IMF) affects…
  - Metal yields
  - Radiation flux

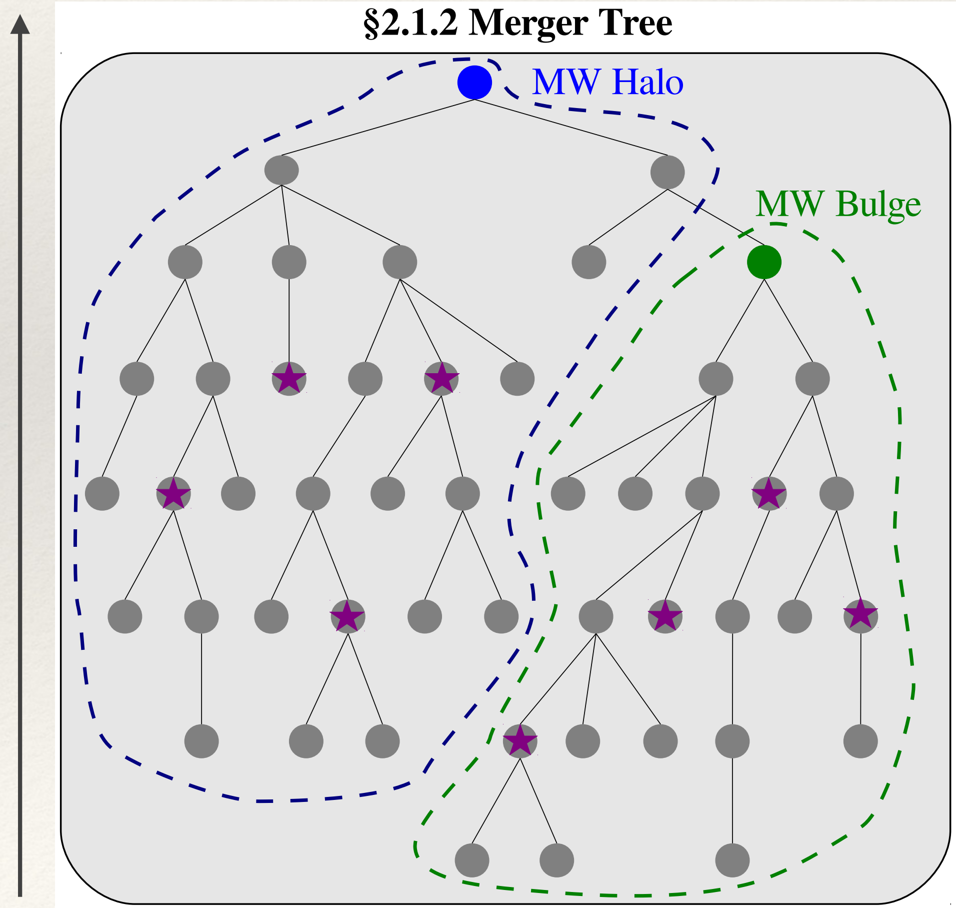
- Using semi-analytical model, we search for pop-III IMF that best reproduces the observation.

What is semi-analytical model(SAM)?

- Simplified simulation of galaxy in each DM halo: **FAST**
- No resolution inside each halo
- → Assume homogeneity

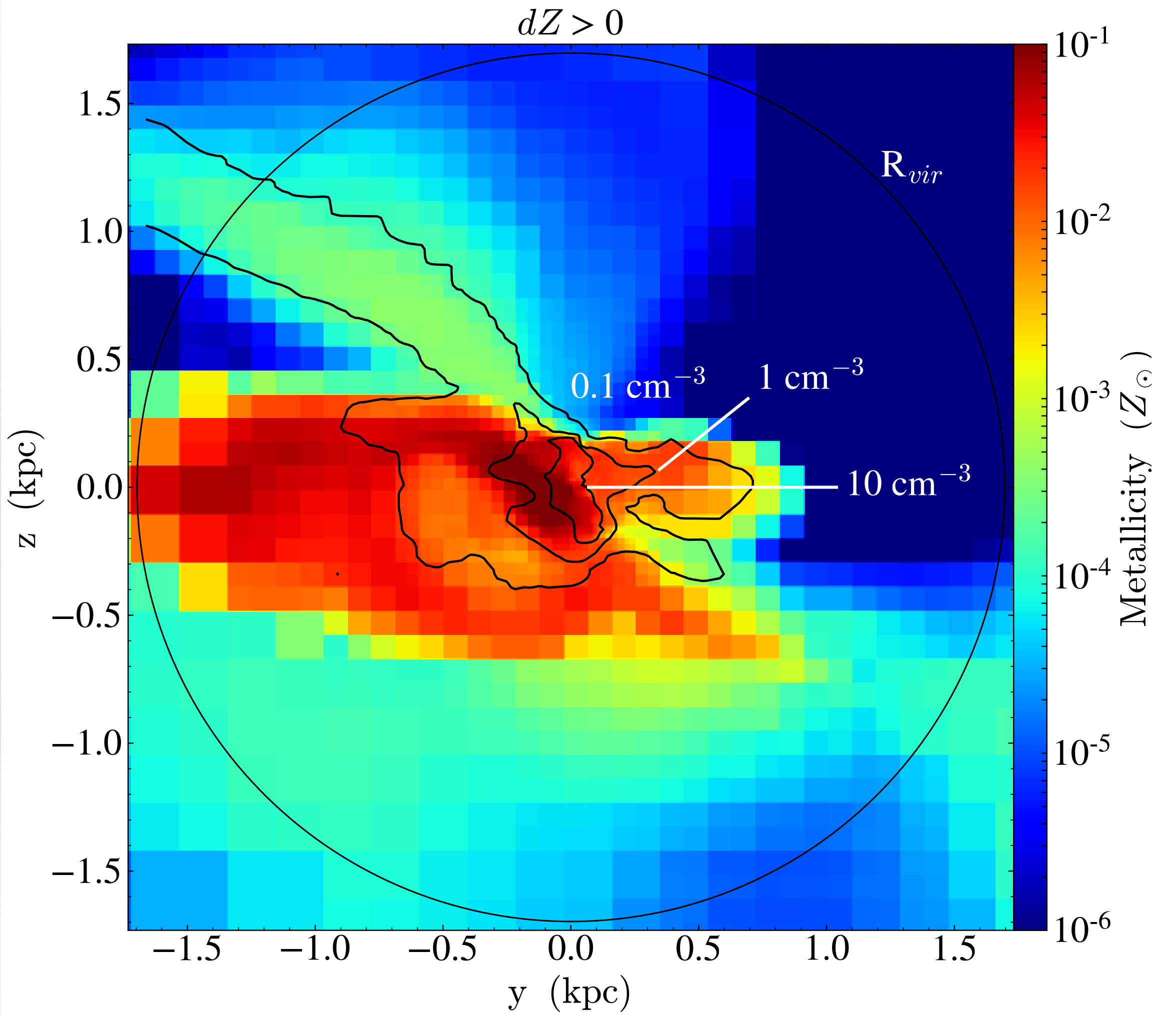
Time

Hartwig+15



How inhomogeneous??

- The metallicity can differ by 5 orders of magnitude (!!!)
- Usually SAM assume homogeneity inside virial radius



→ Inhomogeneity can play an important role !

$$Z \equiv \log_{10}\left[\frac{\text{(metal mass)}}{\text{(total mass)}}\right] - \log_{10}(0.02)$$

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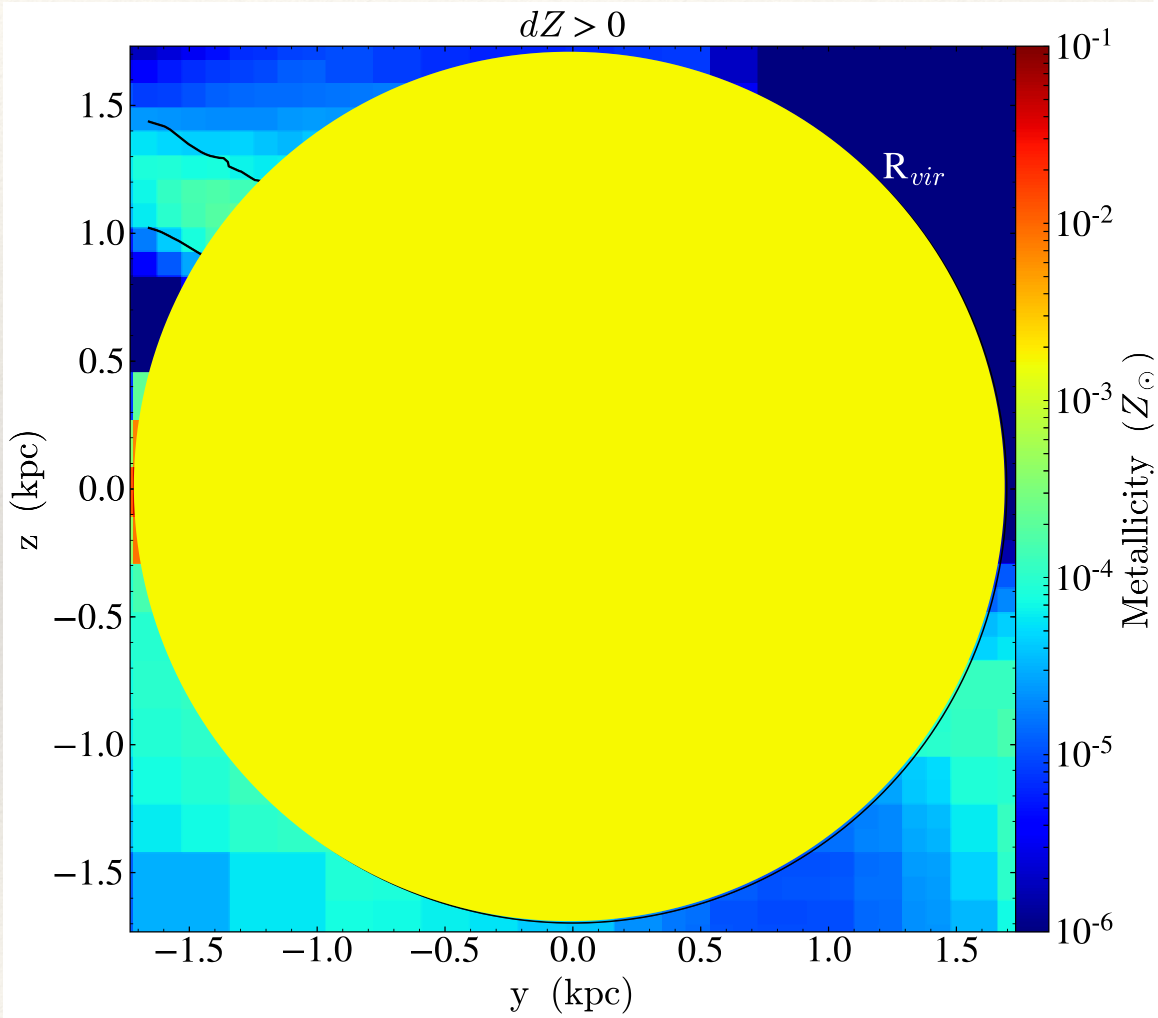

→ We take inhomogeneity into account…

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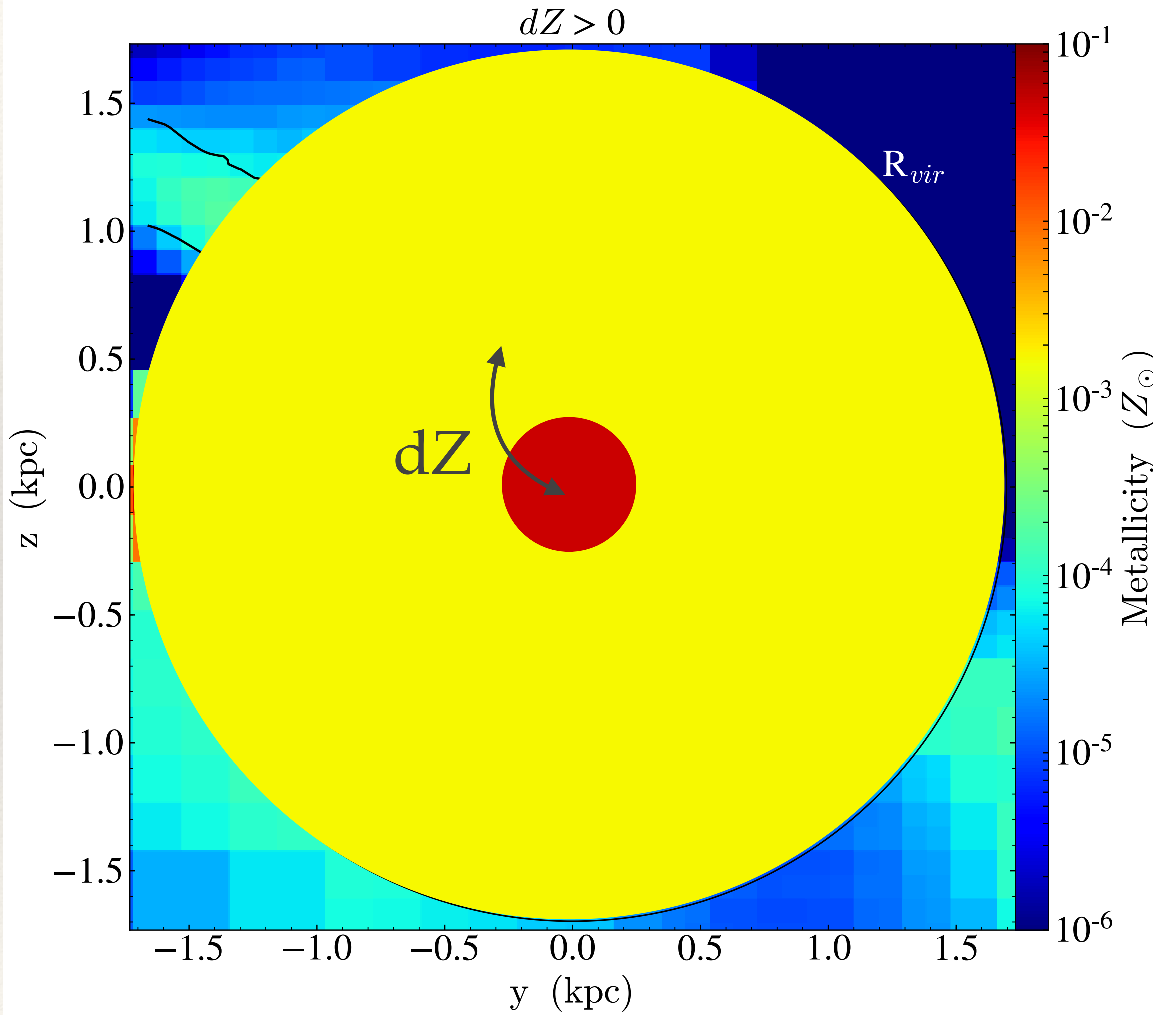
By introducing
a new parameter dZ



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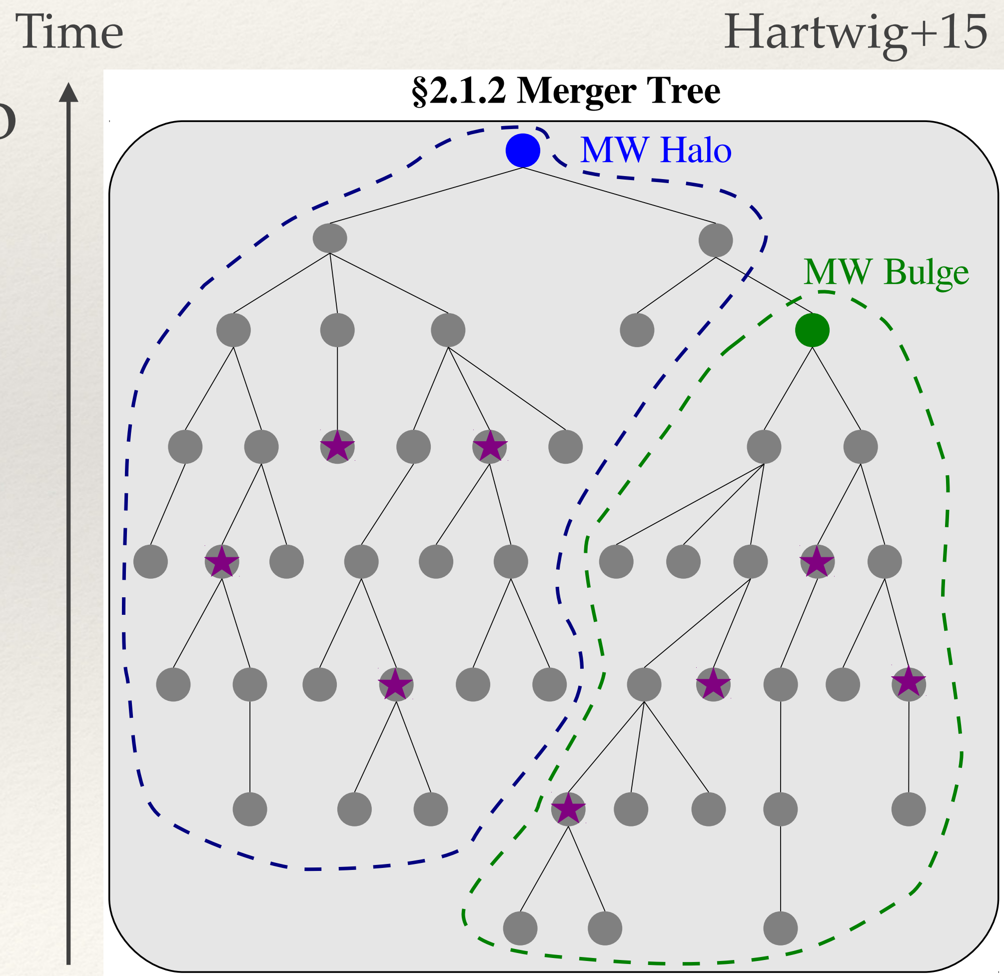


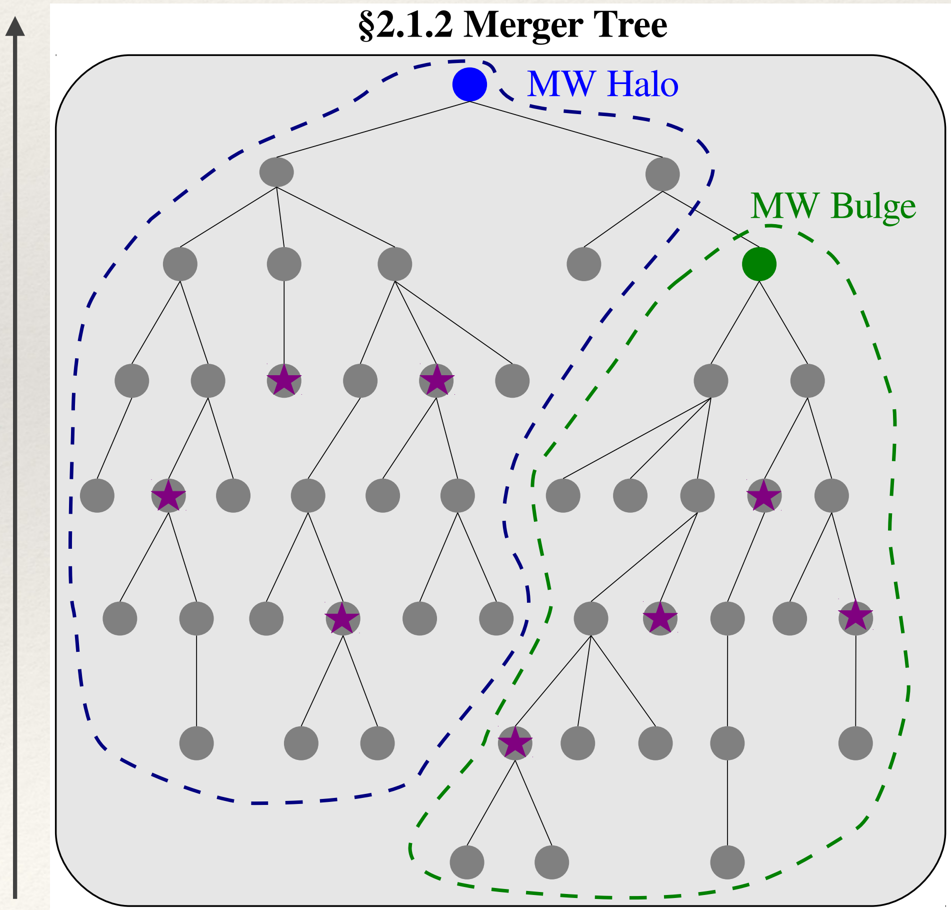
What is semi-analytical model(SAM)?

- Simplified simulation of galaxy in each DM halo: **FAST**
- No resolution inside each halo
- → Assume homogeneity, or introduce a parameter to take inhomogeneity into account

Use cosmological simulation to calibrate this parameter!!

Time

Hartwig+15



Motivation

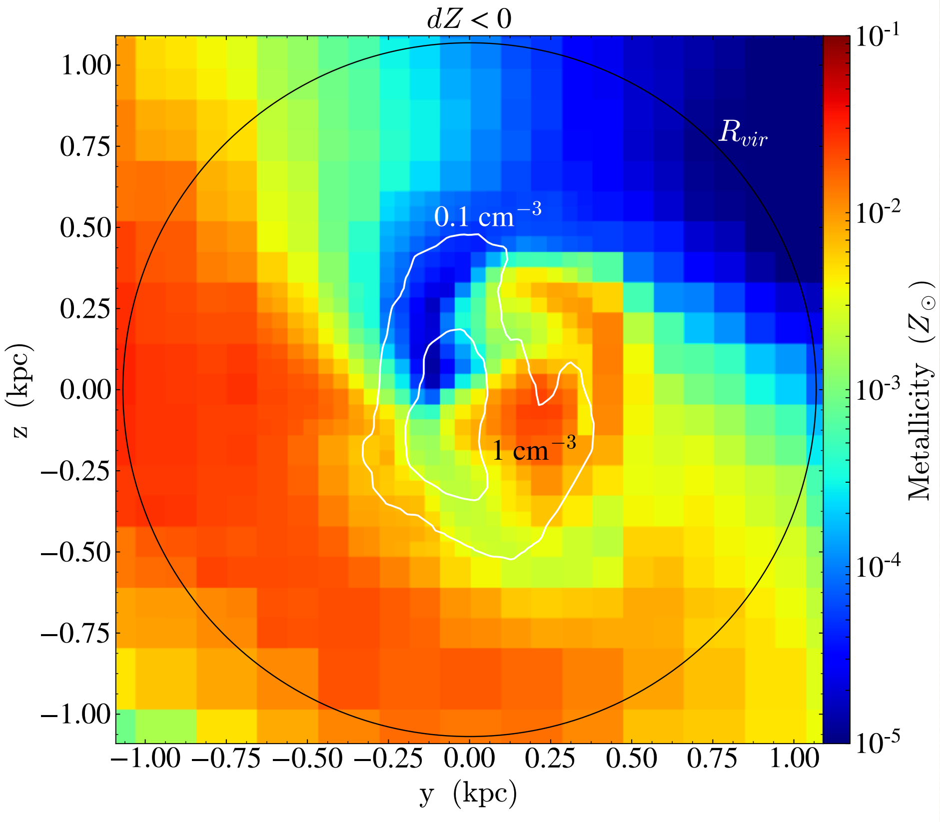
- I want to…
  - predict [Fe/H] of stars in a halo, only by
    - total metal mass
    - total hydrogen mass
- and obtain better prediction on Pop-III IMF through SAM calibration.

Method1: cosmological simulation

- Introduce a parameter “dZ” as: $Z \equiv \log_{10}\left[\frac{\text{(metal mass)}}{\text{(total mass)}}\right] - \log_{10}(0.02)$

$$dZ = Z_{\text{dense}} - Z_{\text{all}}$$

$dZ < 0$



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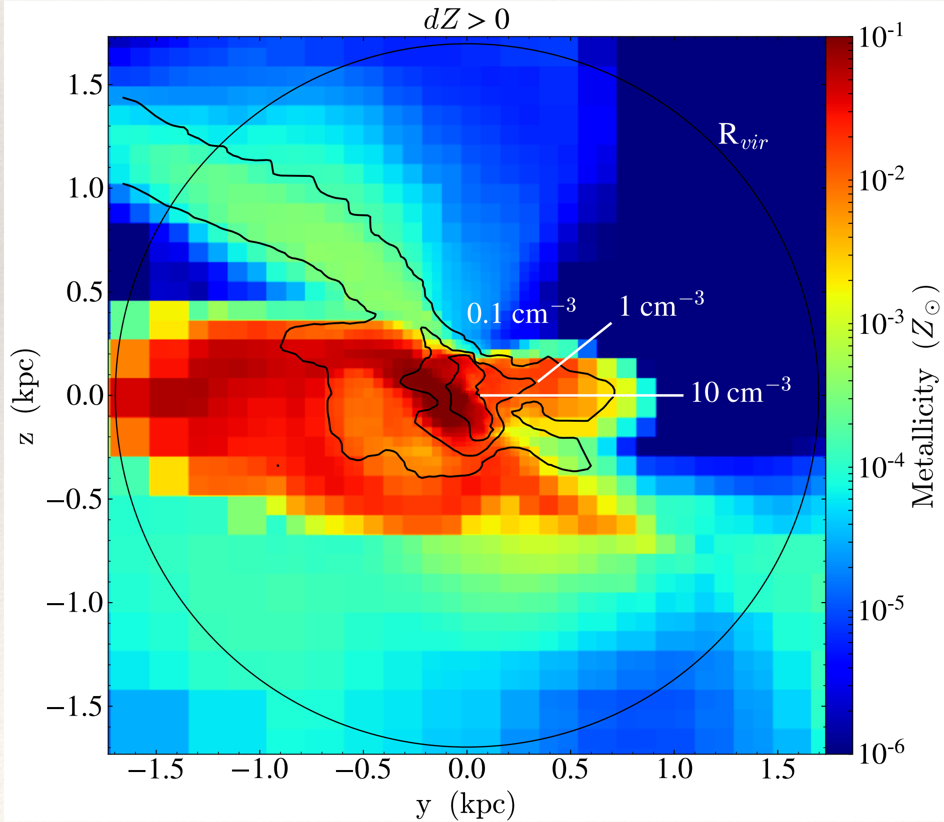
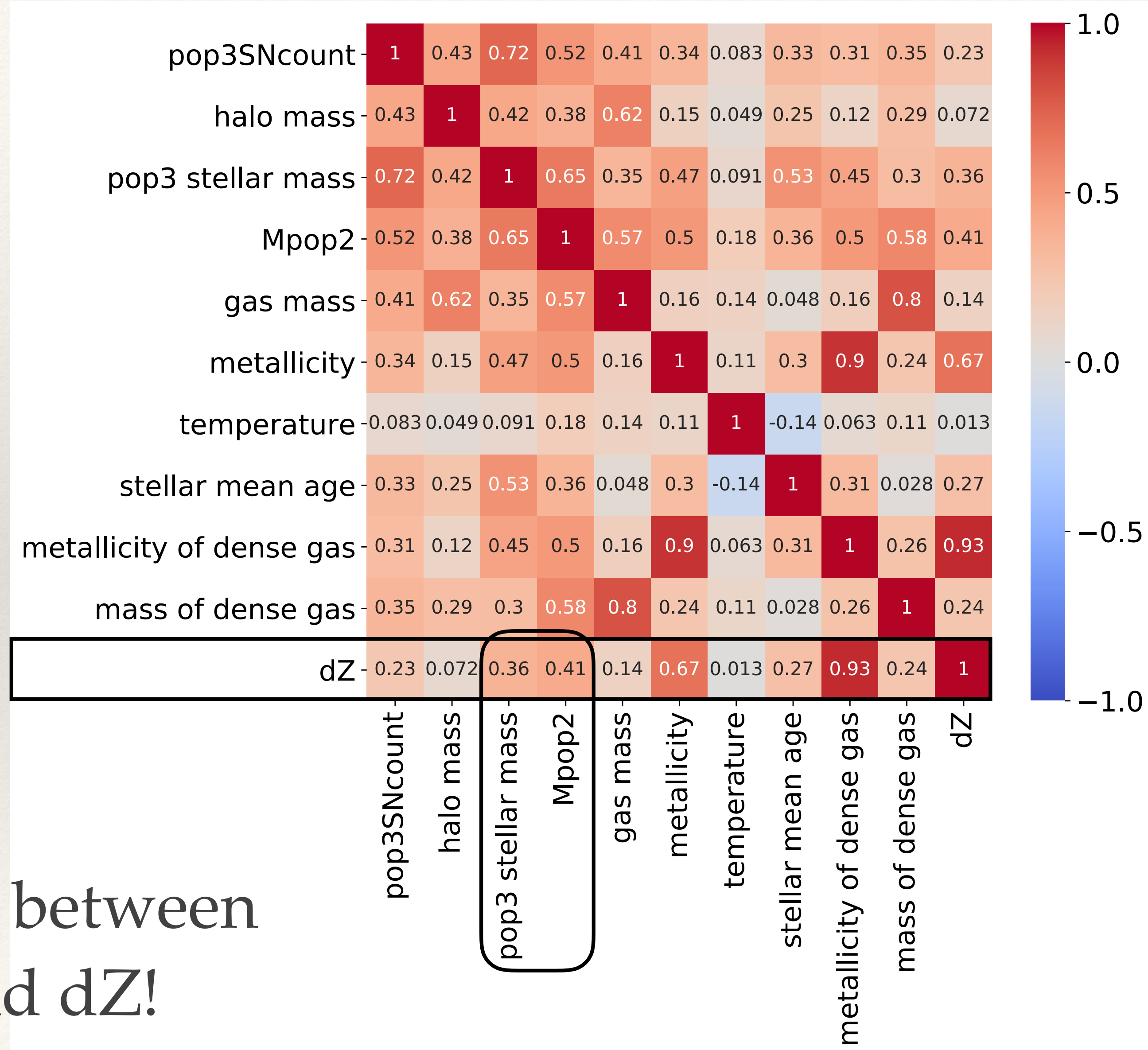


Result1: correlation matrix

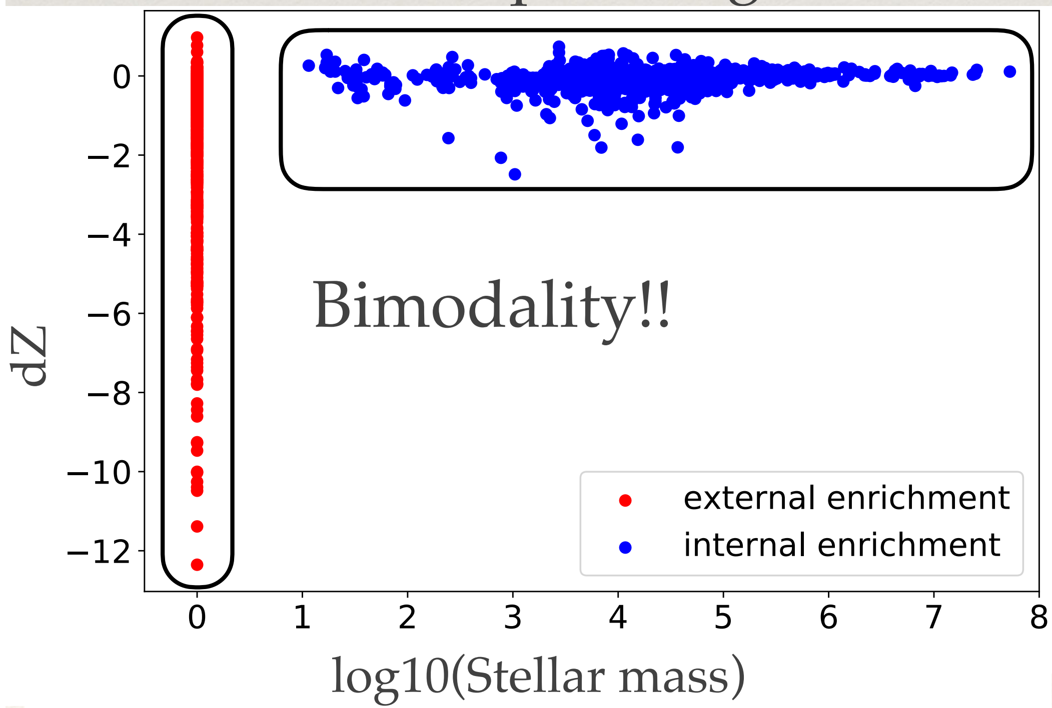
- $dZ = Z_{\mathrm{dense}} - Z_{\mathrm{all}}$ is correlated with:
  - Z_{dense}
  - Z_{all}
  - M_{pop2}
  - M_{pop3}



There's something between stellar mass and dZ!

Result1: distribution of dZ

- dZ distribution is different between internal and external enrichment.
- In internal enrichment, dZ distributes around 0: well mixed
- In external enrichment, dZ is mostly negative, and the absolute value can be quite large (~ -5 or more)



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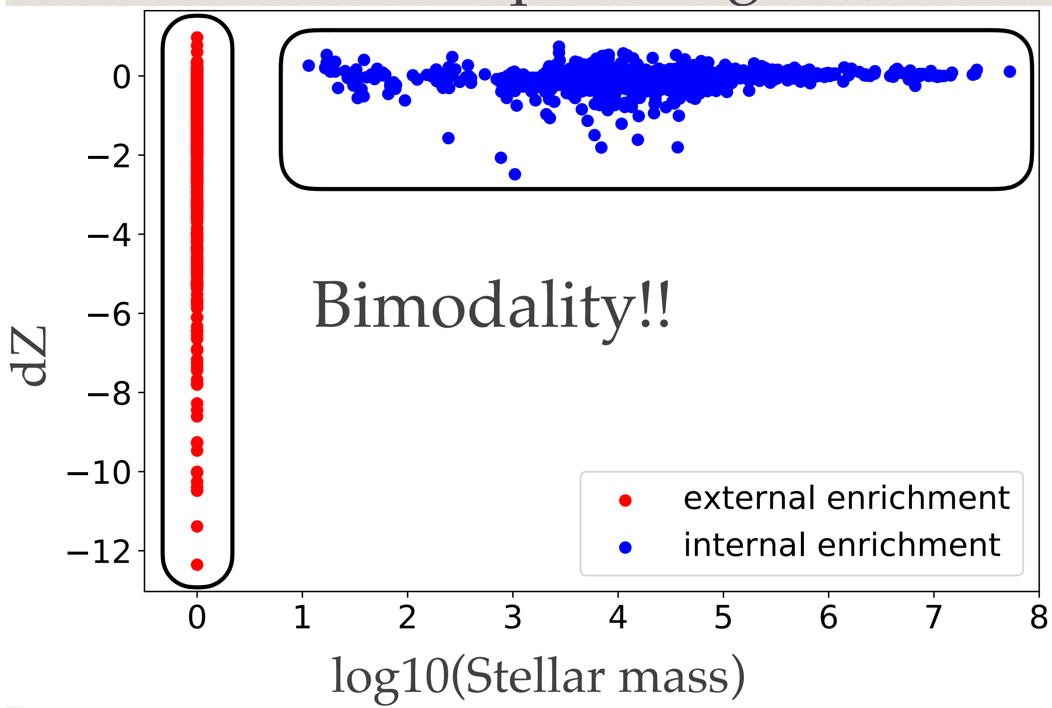
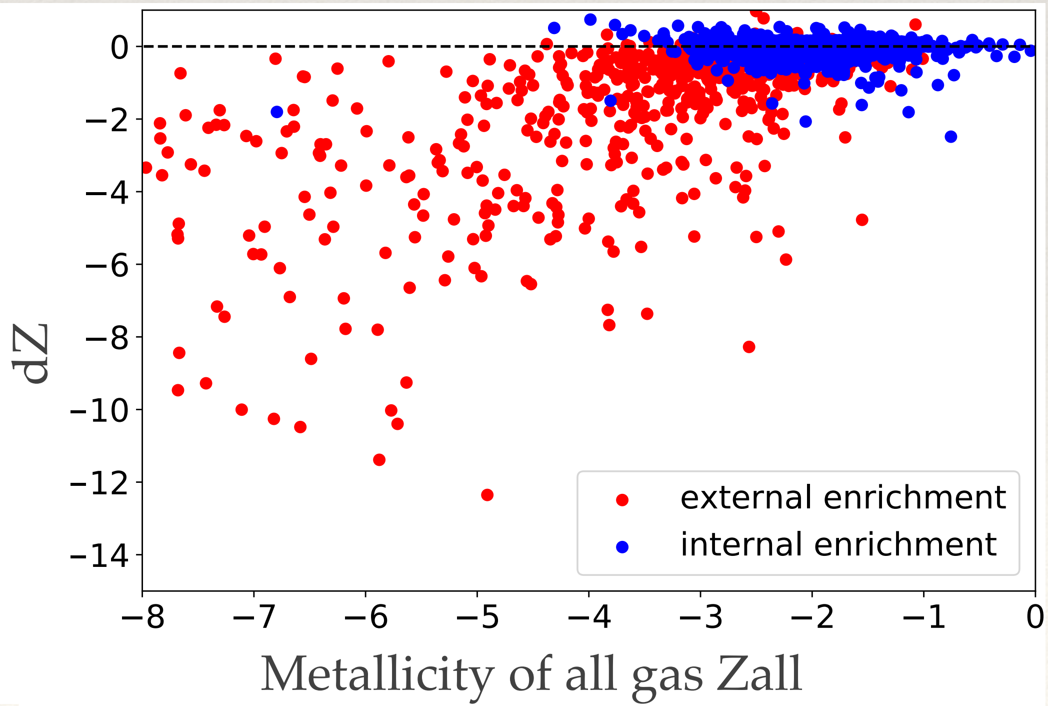
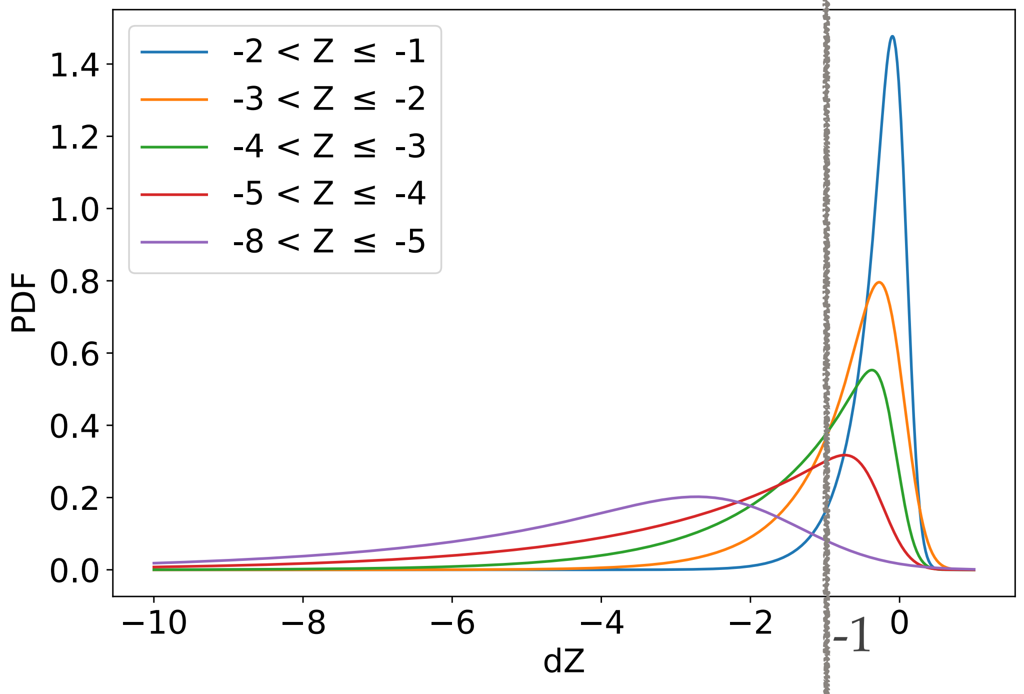




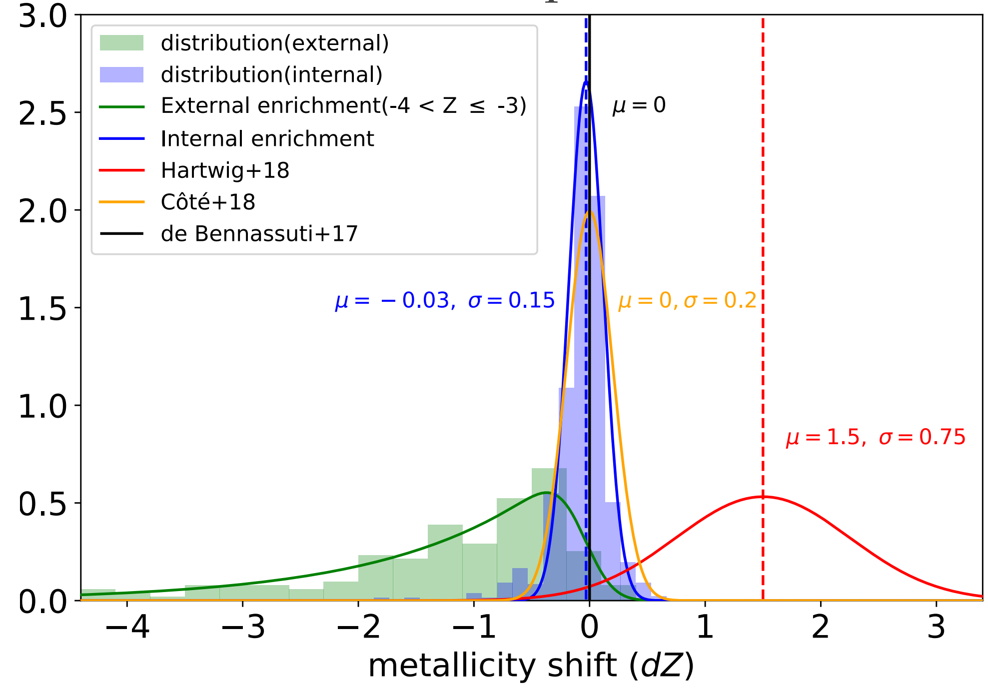
Result1: distribution of dZ

- In external enriched haloes, typically dZ ~ -1
- Previous works assume good dZ distribution for internal enrichment.

External

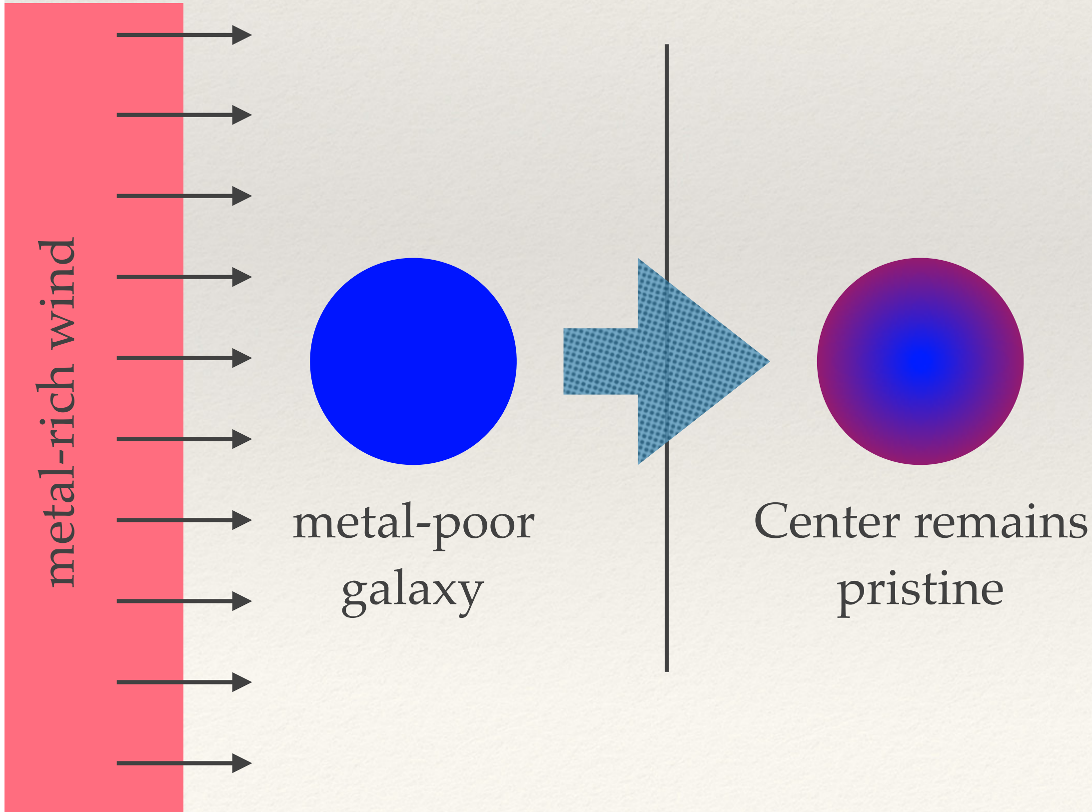


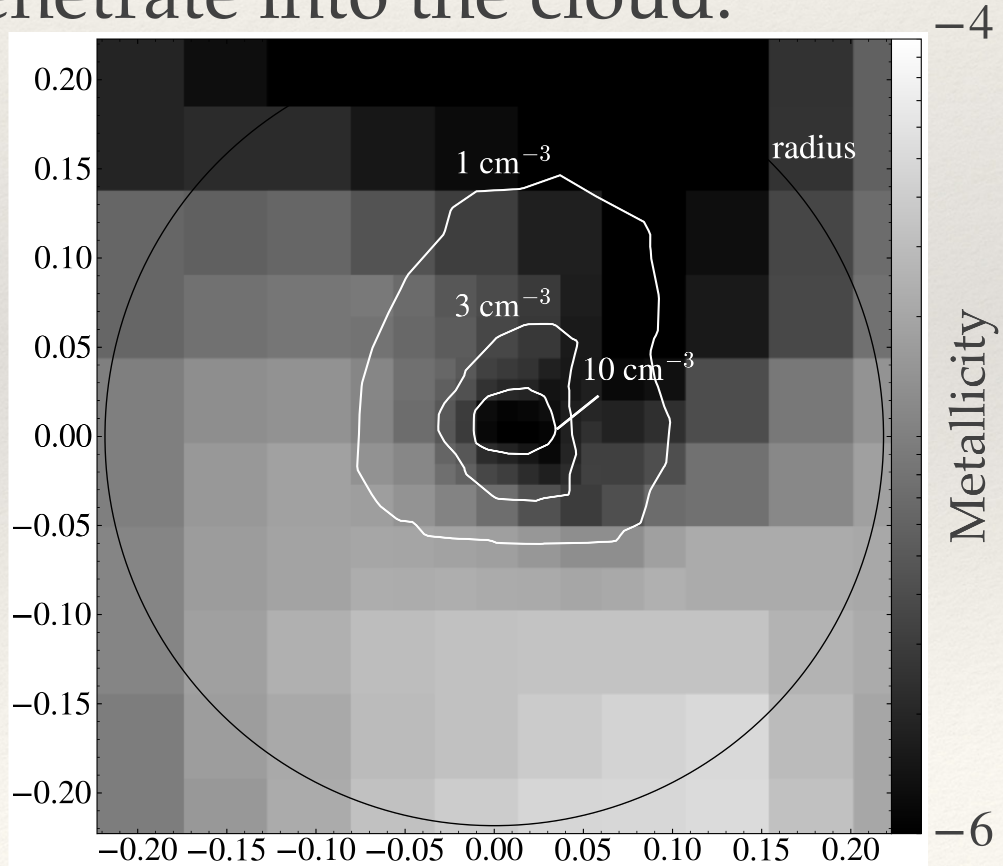
Comparison



Result1: distribution of dZ

- Why the externally enriched halos have negative dZ?
  - Pristine gas collapse happens earlier, and then enrichment wind cannot penetrate into the cloud.





Method2: the semi-analytical model

- SAM has many parameters.

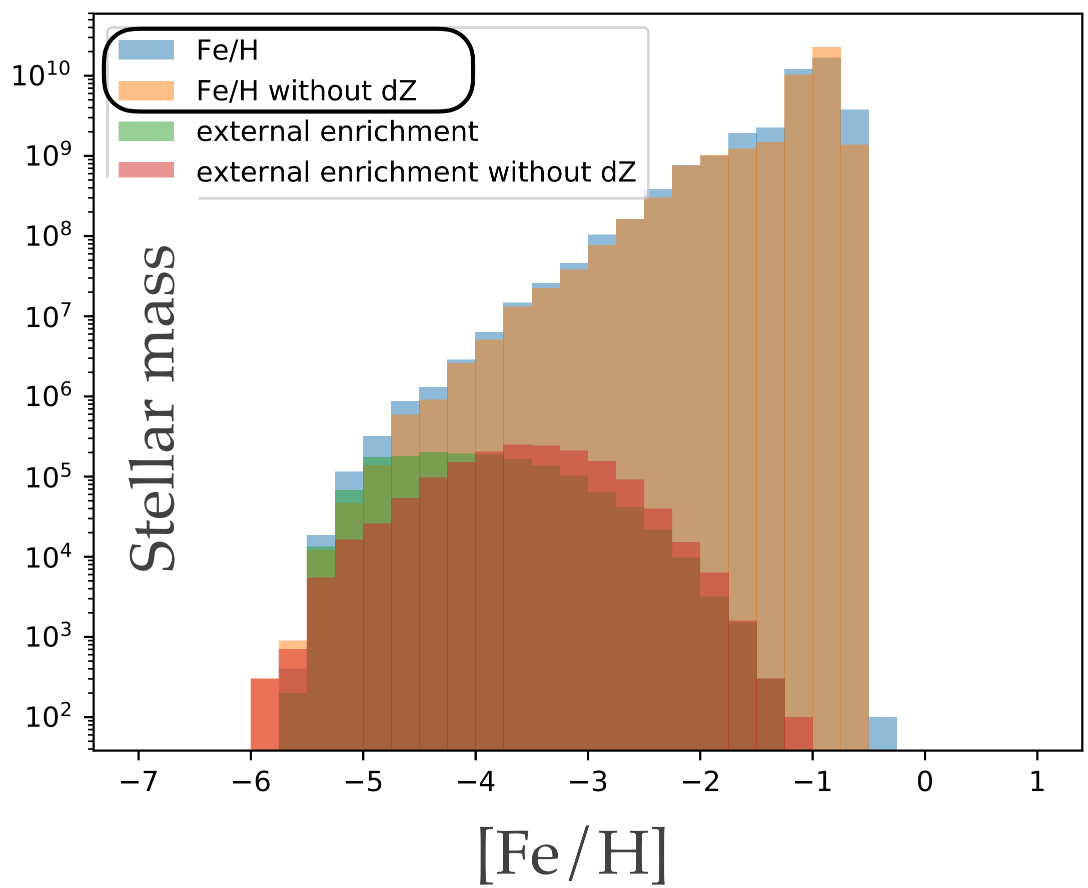
Parameter	Value
Pop III SFE	$\eta_{\rm III} = 10^{-1} \sim 10^{-6}$
fraction of faint SNe	$f_{\rm faint} = 0.0 \sim 1.0$
metal fallback fraction	$f_{\rm fallback} = 0\% \sim 100\%$
metal ejection fraction	$f_{\rm eject} = 100\% \sim 0\%$
lower IMF limit	$M_{\rm min} = 1 \sim 10 {\rm M}_\odot$
upper IMF limit	$M_{\rm max} = 100 \sim 1000 {\rm M}_\odot$
IMF slope α	1.0(flat) ~ -1.35(Salpeter)

- SAM is mainly calibrated by:
  - the SMHM relation $M_*(M_{halo})$ (to Renaissance, abundance matching)
    Behroozi+13, Garrison-Kimmel+14
  - Internal enrichment fraction (to Renaissance)
  - metallicity distribution function (to observation)

Result2: MDF and IMF

- Overall MDF looks similar.

[Fe/H] distribution function



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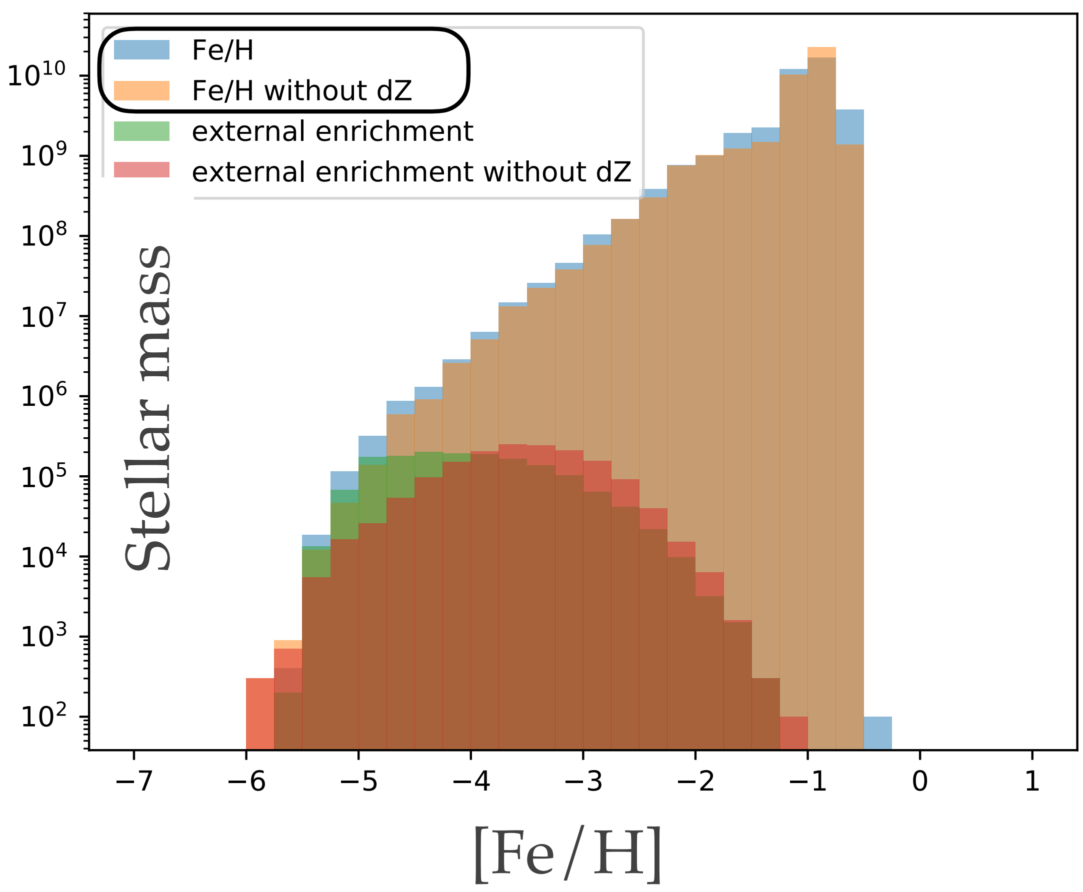
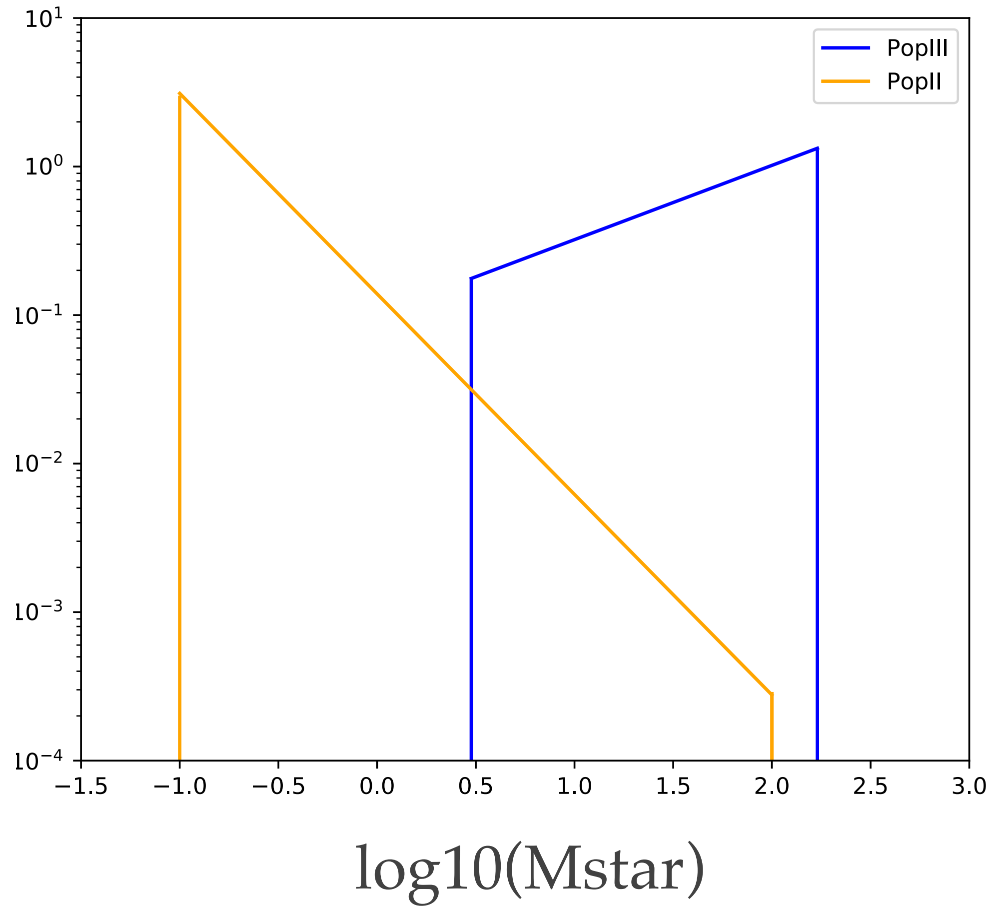
[Fe/H] distribution function

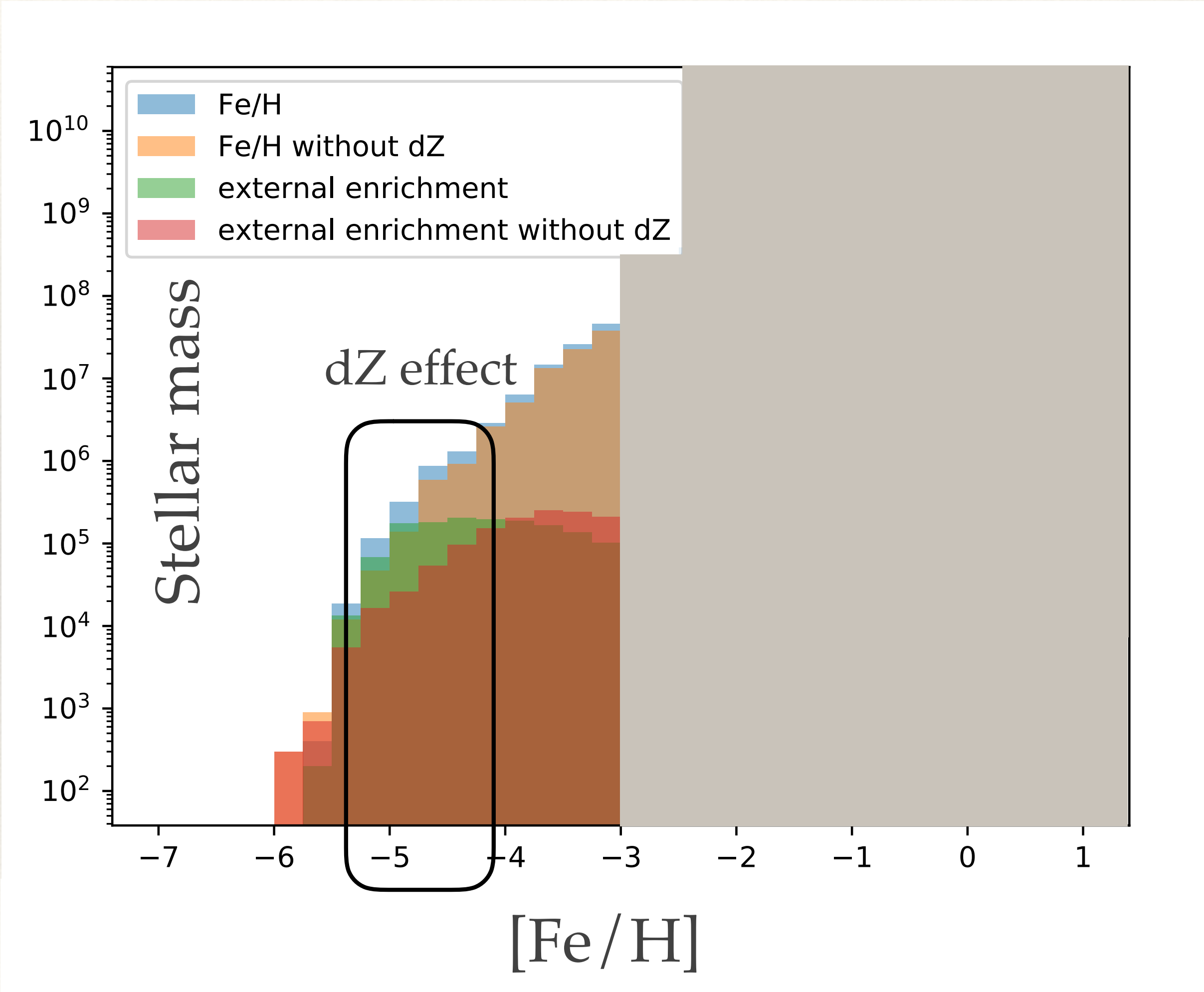


IMF comparison



Result2: The effects of dZ

- Increase # of stars in -5 < [Fe/H] < -4.
- Stars with [Fe/H] < -5 are mostly from external enrichment.
- However, the effect on IMF seems small: **IMF prediction is not much affected by the inhomogeneity.**

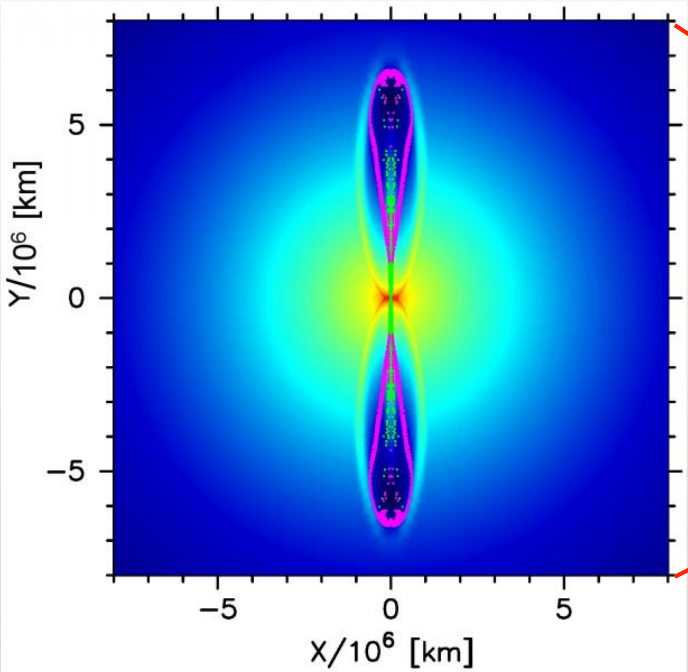


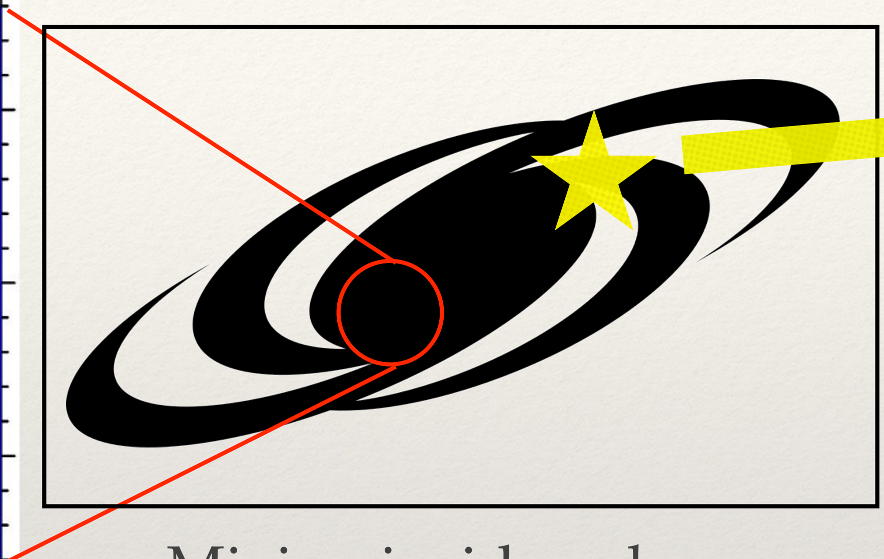
Summary

- (high-z) galaxy is inhomogeneous. **The inhomogeneity is prominent in externally enriched halos**. Dense gas is metal-poor, because metal-rich wind cannot penetrate into gas cloud.
- We may observe [Fe/H] < -4 stars more often than previously we have imagined.
- metallicity inhomogeneity only plays a minor role on MDF and consequently on IMF.

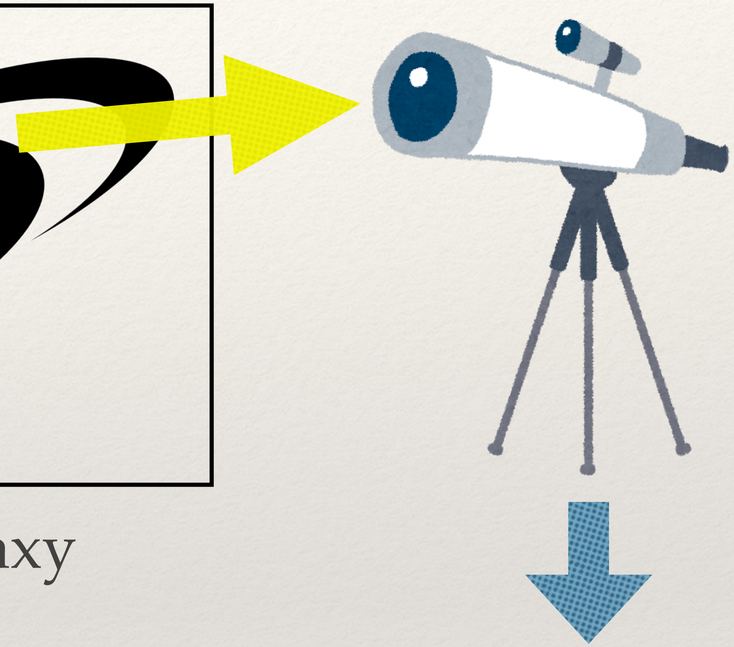
Importance of mixing

https://www.ipmu.jp/ja/20190524-FirstStars

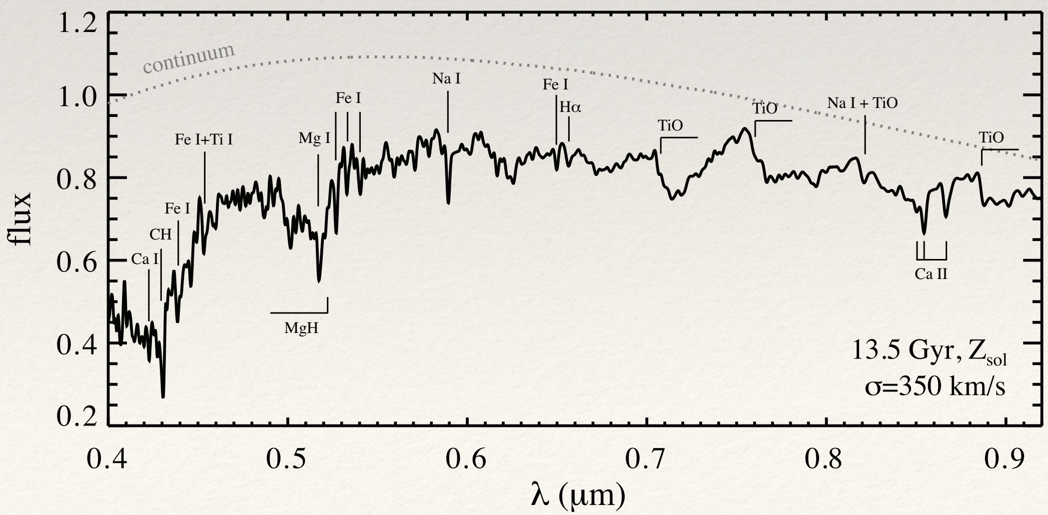




Mixing inside galaxy



- Mixing connects source event and current observations.



Method2: Star formation in the SAM

- Initially halos are “pristine”.
- If each halo satisfies all the criteria, it forms PopIII/II stars and enrich the halo.
- star formation can also enrich neighboring halos

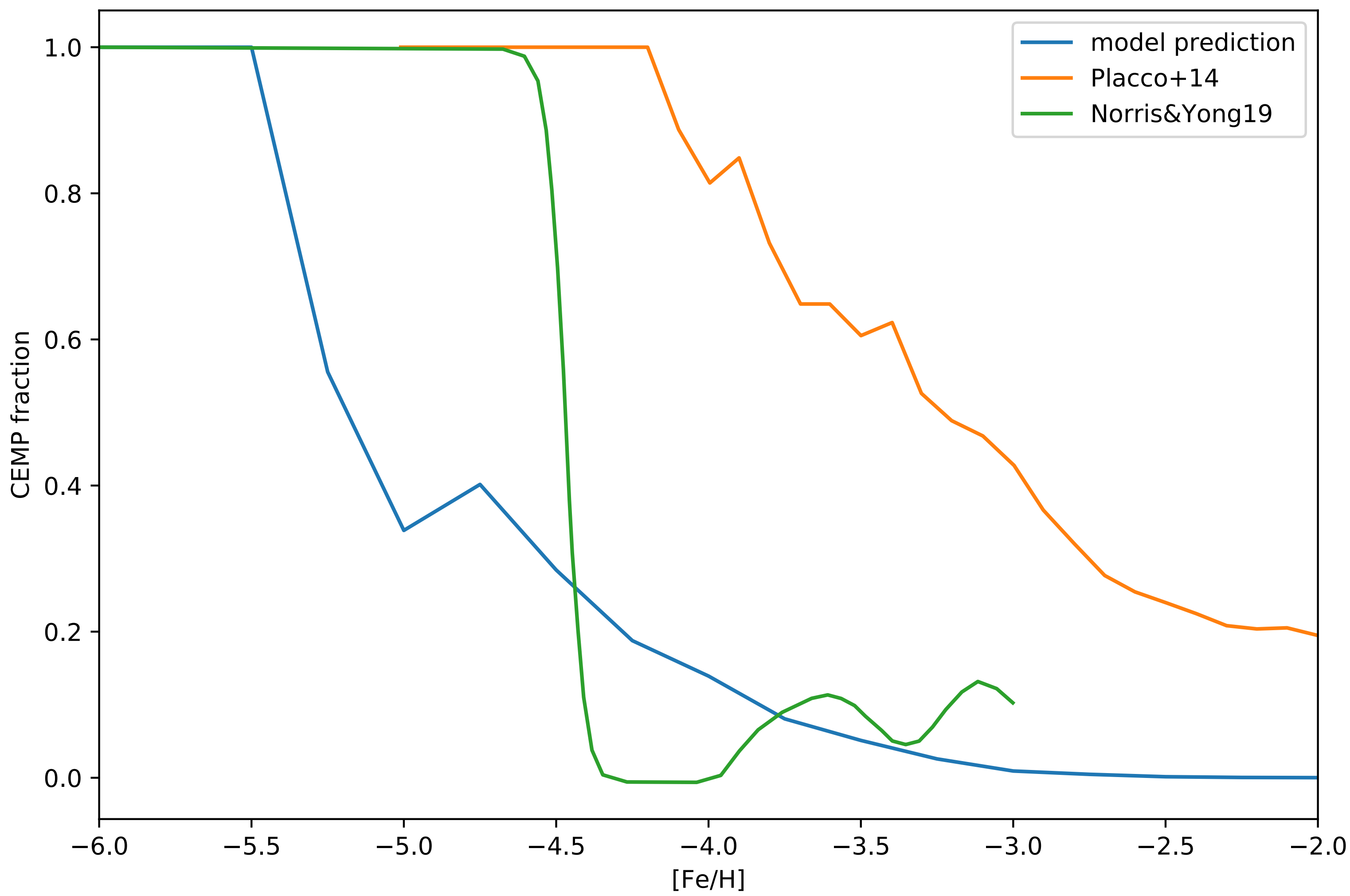
PopIII criteria:

- The halo is massive enough
- The halo is pristine
- The Lyman-Werner feedback is not too strong

PopII criteria:

- The halo is massive enough
- The halo contains enough coolants

CEMP fraction



Method1: cosmological simulation

- "Renaissance simulation": **Large volume, Good resolution**

https://rensimlab.github.io/showcase.html