First star discrimination in the metal abundance of the z=3 intergalactic medium

(赤方偏移3の銀河間物質における初代星由来の重元素汚染)

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Collaborators

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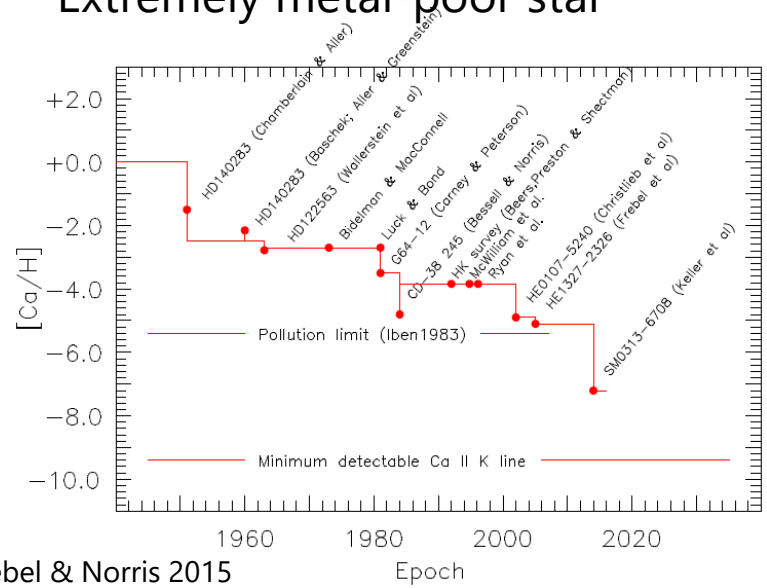
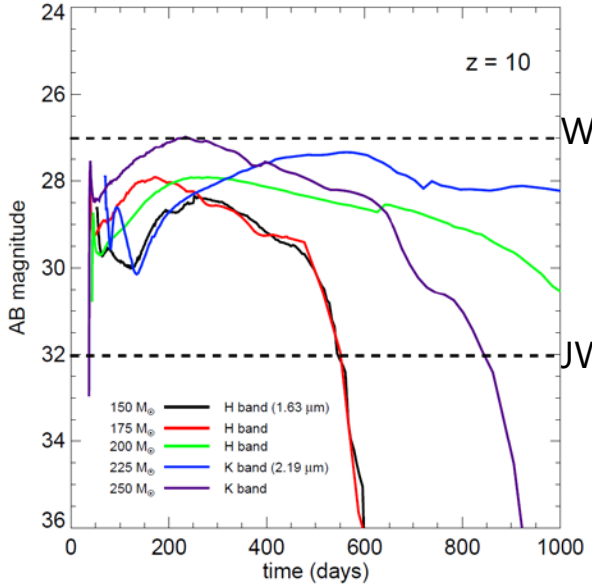
Pop. III search

Extremely metal-poor star



Frebel & Norris 2015

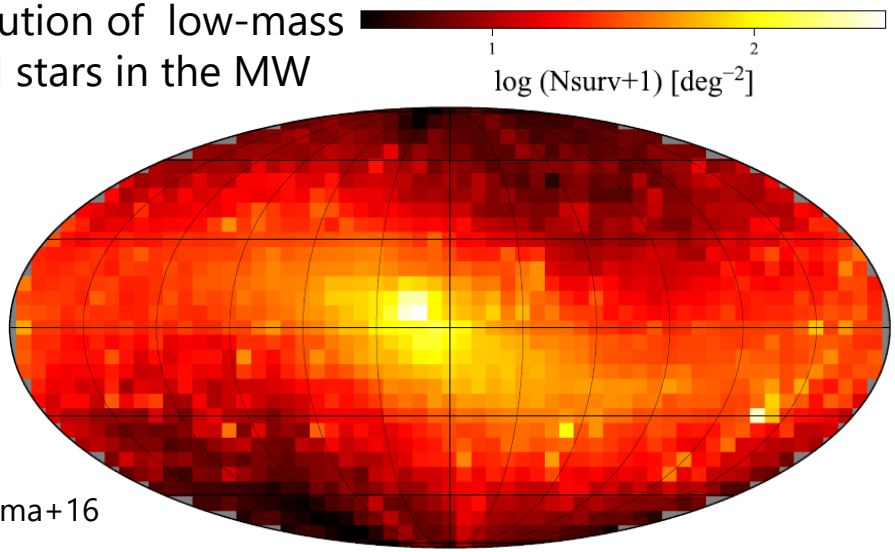
Direct observation of SN at high-z



Whalen +18

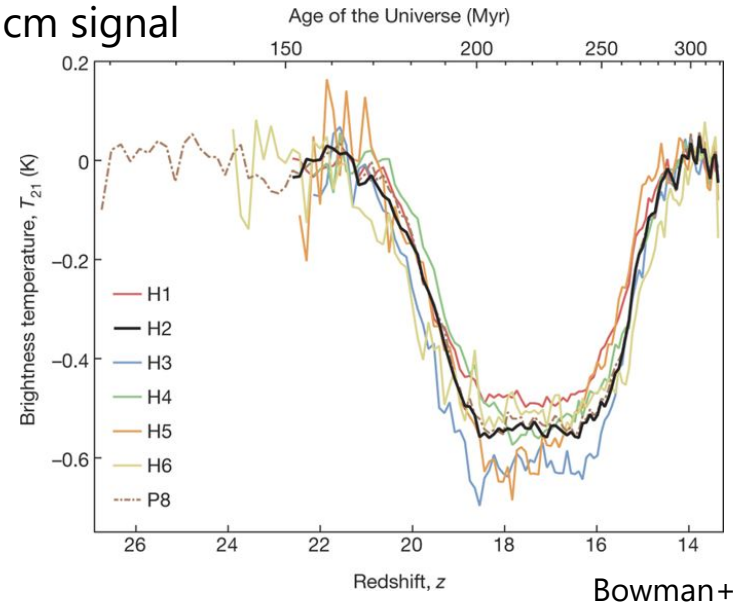
see also TK+19

Distribution of low-mass pop. III stars in the MW



Ishiyama+16

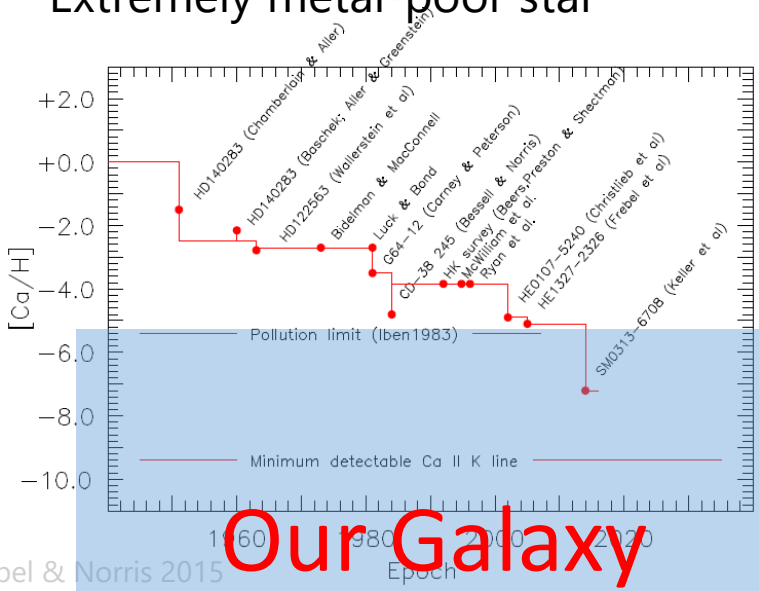
21 cm signal



Bowman+18

Pop. III search

Extremely metal-poor star



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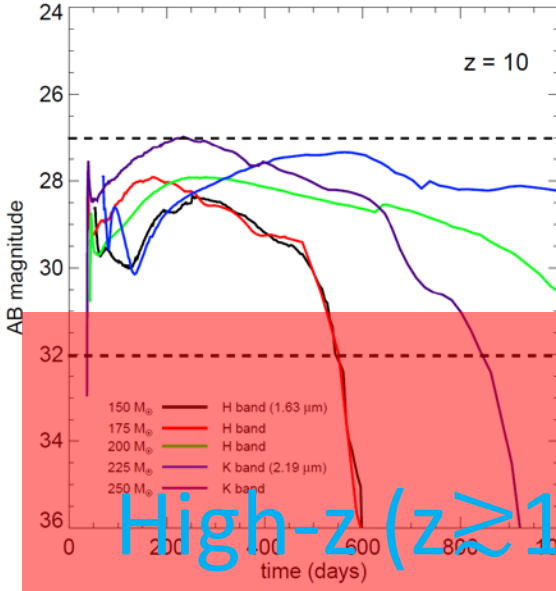


Whalen +18

Our Galaxy

High-z (z≳10)

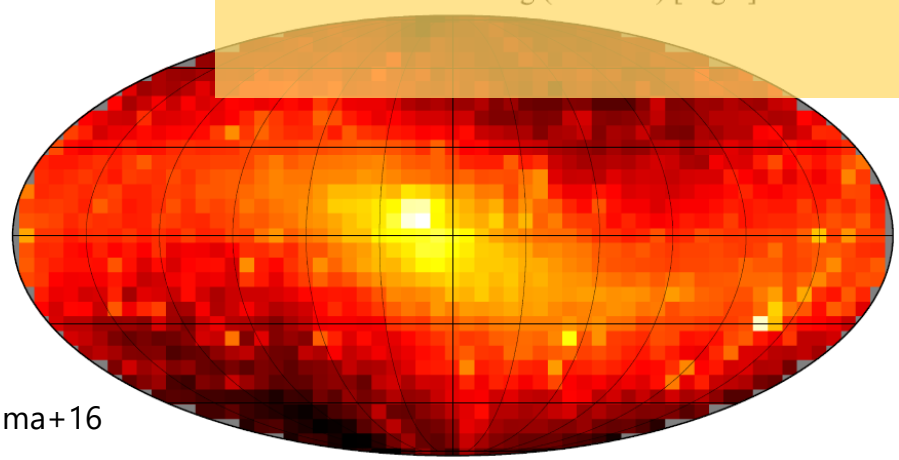
see also TK+19

21 cm signal

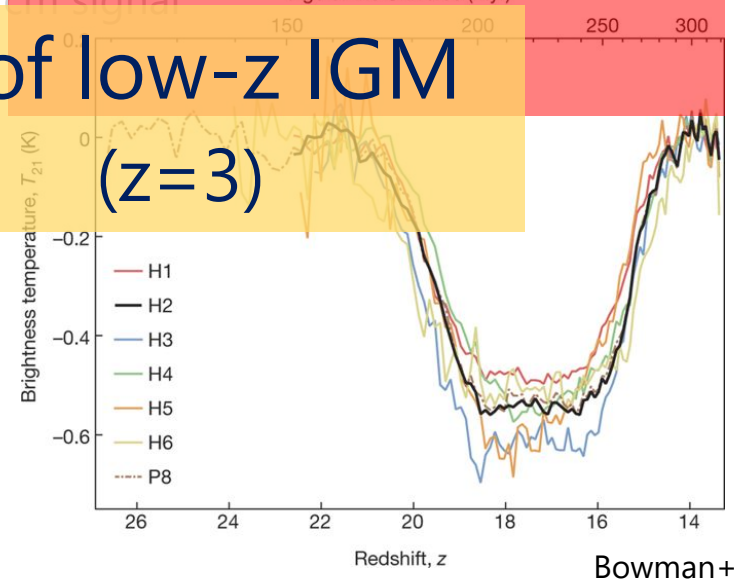
Distribution of low-m
pop. III stars in the MW

Metal abundance of low-z IGM

(z=3)



Ishiyama+16

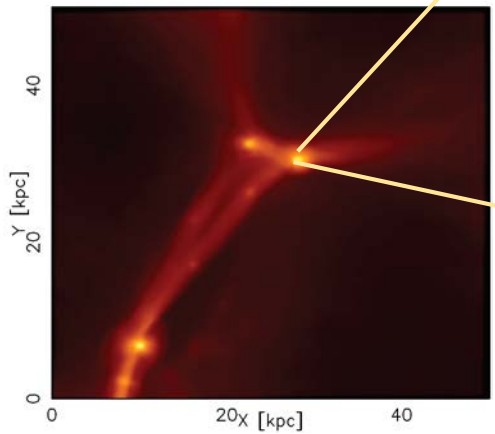


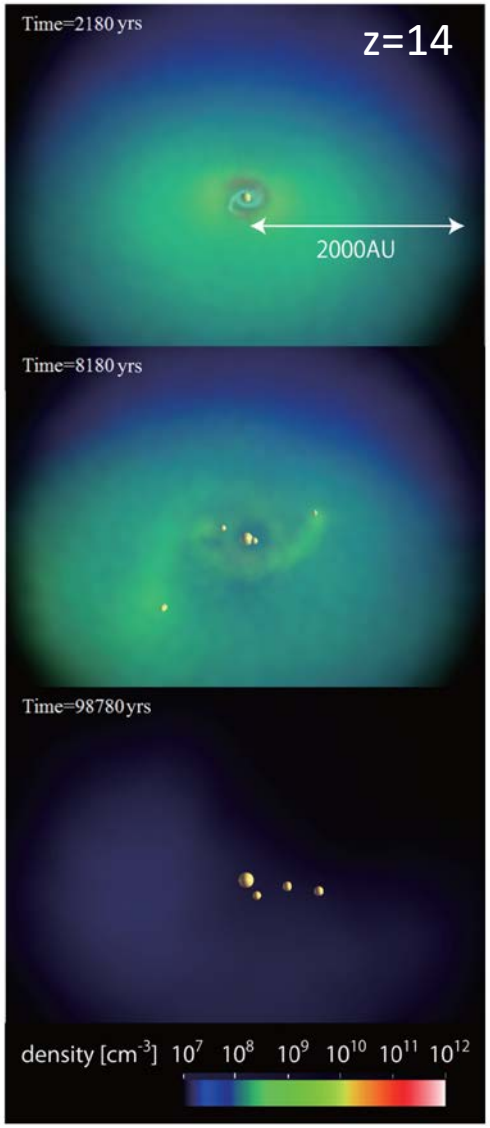
Bowman+18

Population III star formation

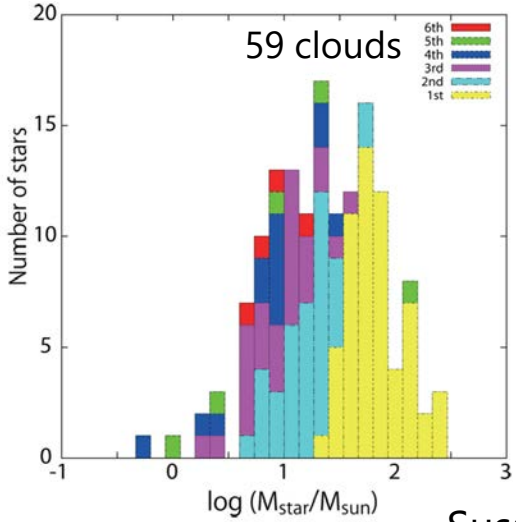
Susa+14

Pop. III stars
- ✓ formed in pristine gas
- ✓ H_2 cooling
- ✓ typically very massive $10 - 1000 M_\odot$
- ✓ SN explosions at high-z

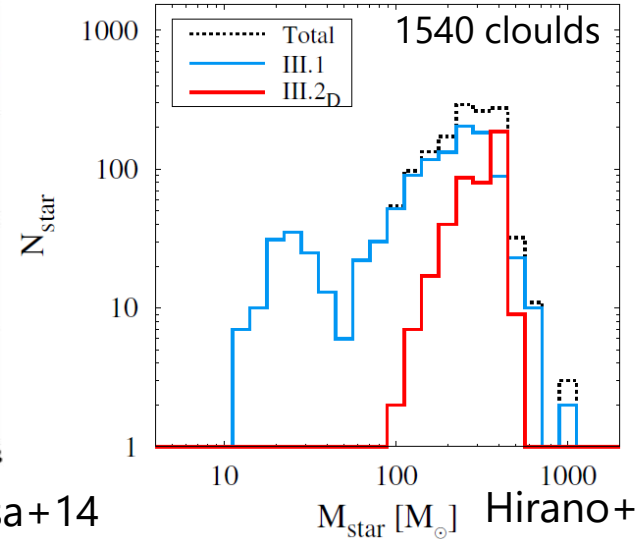




(e.g., Tegmark +97; Omukai & Nishi +98; Nakamura & Umemura +01; Abel+02; Bromm+02; Hosokawa +11; Stacy+12)



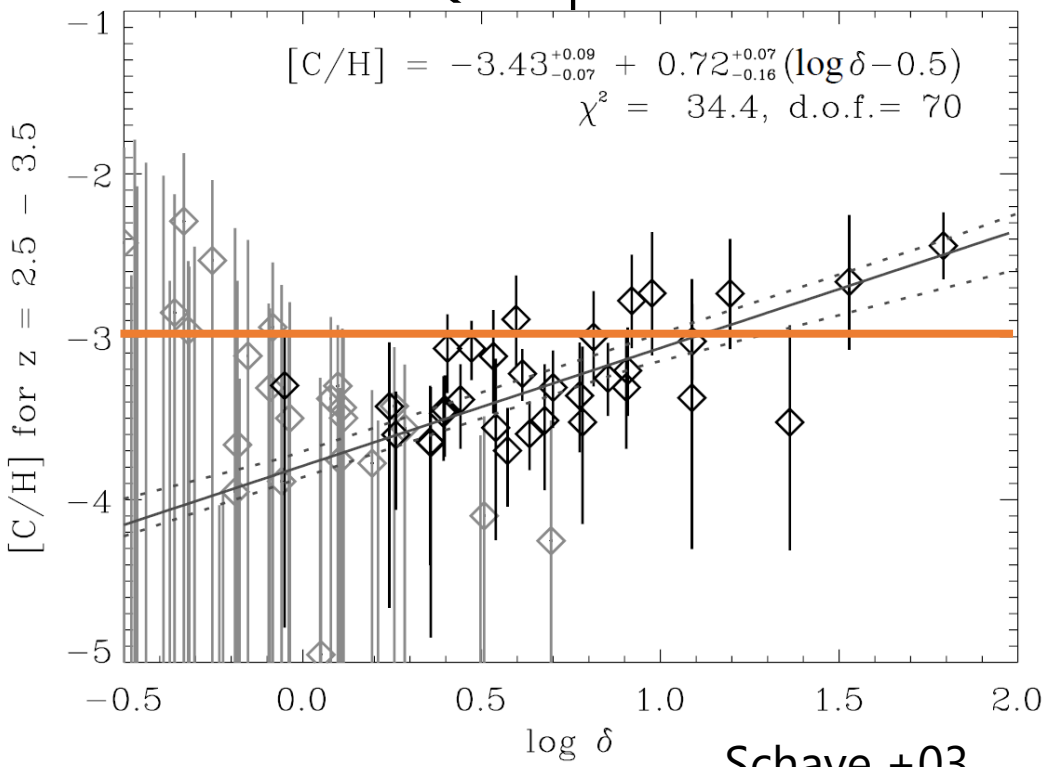
Susa+14



Hirano+15

IGM metal observations

Metallicity of IGM @z=3
19 QSO spectrum



Schaye +03

- ◆ A universal metallicity floor?
  $Z=10^{-3}Z_{\odot}$ at z～3 (Songaila 1997)
- ◆ Can Pop. III stars explain the floor?
  (e.g., Yoshida+04)
- ◆ No such floor at z～3 (Simcoe+04)

- Roughly 30% of lines in the Lyα forest in QSO spectrum are [C, O/H]<−3.5 (Simcoe+04)
- ～40% of HI lines with 14.0< log N_{HI} <14.8 show an associated C_{IV} absorption. (D'Odorico +16)

We investigate where heavy elements originating from Pop. III stars dominate in the cosmic volume using cosmological simulations.

Cosmological simulation + Pop. III model

N-body simulation (Ishiyama +16)

+ Pop. III formation model

- ✓ N=2048^3
- ✓ Boxsize: 8 h^{-1}cMpc
- ✓ Minimum halo mass: 2.4× 10^5 $M_\odot$

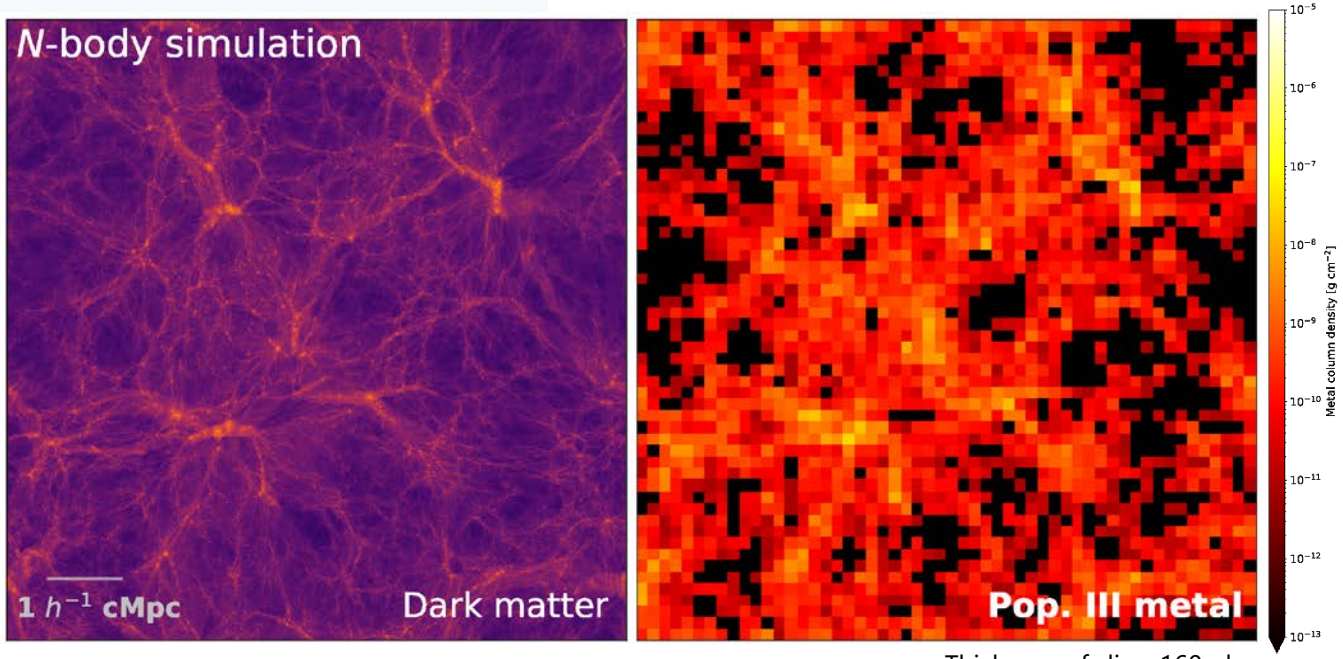
Metal injection

(a) PISN yield (200 $M_\odot$)
(b) reduced SFRD by 90%

(c) CCSN yield(30 $M_\odot$)
(d) reduced SFRD by 90%

Model (a)

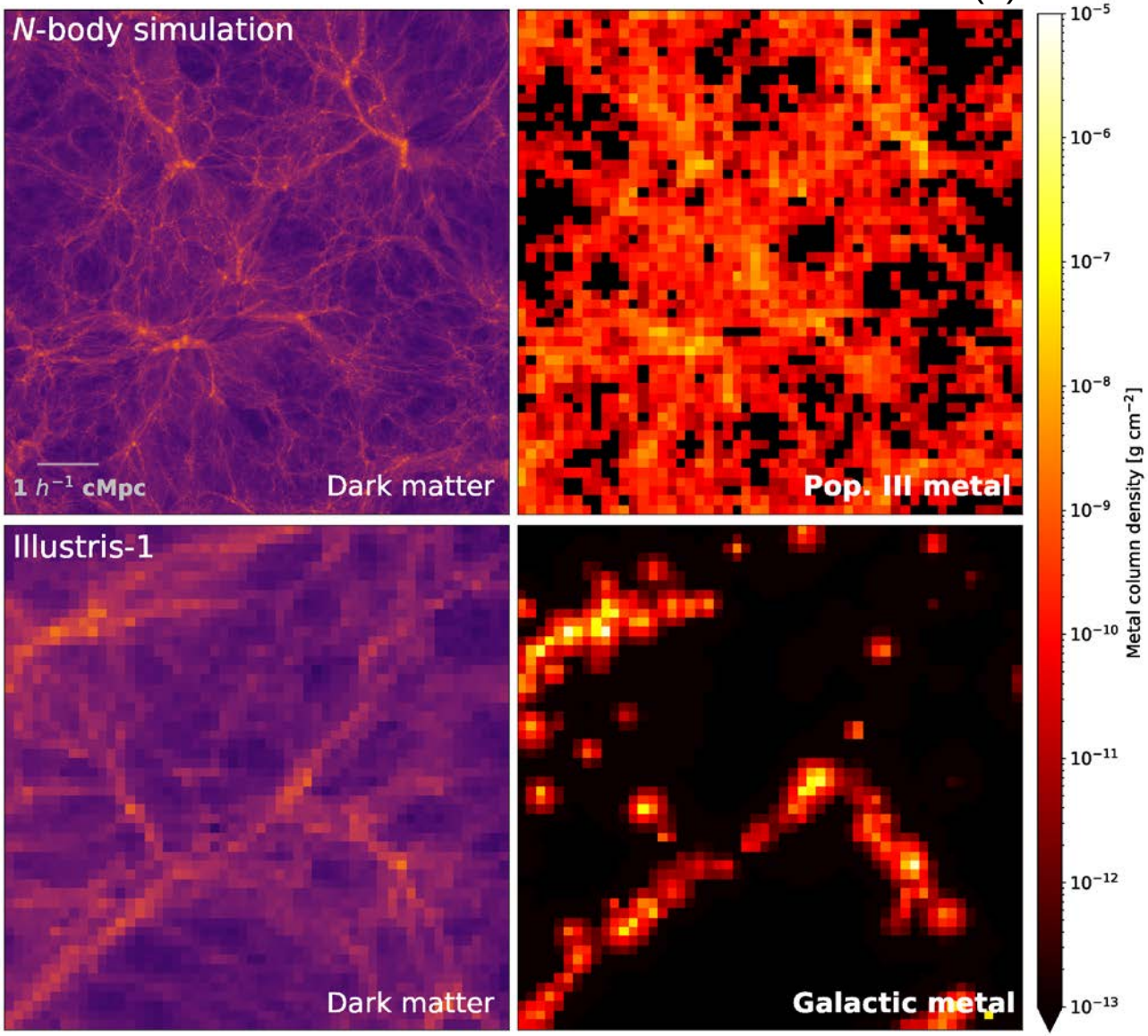
z=3



Thickness of slice: 160 pkpc

Spatial distribution of metals

Model (a)

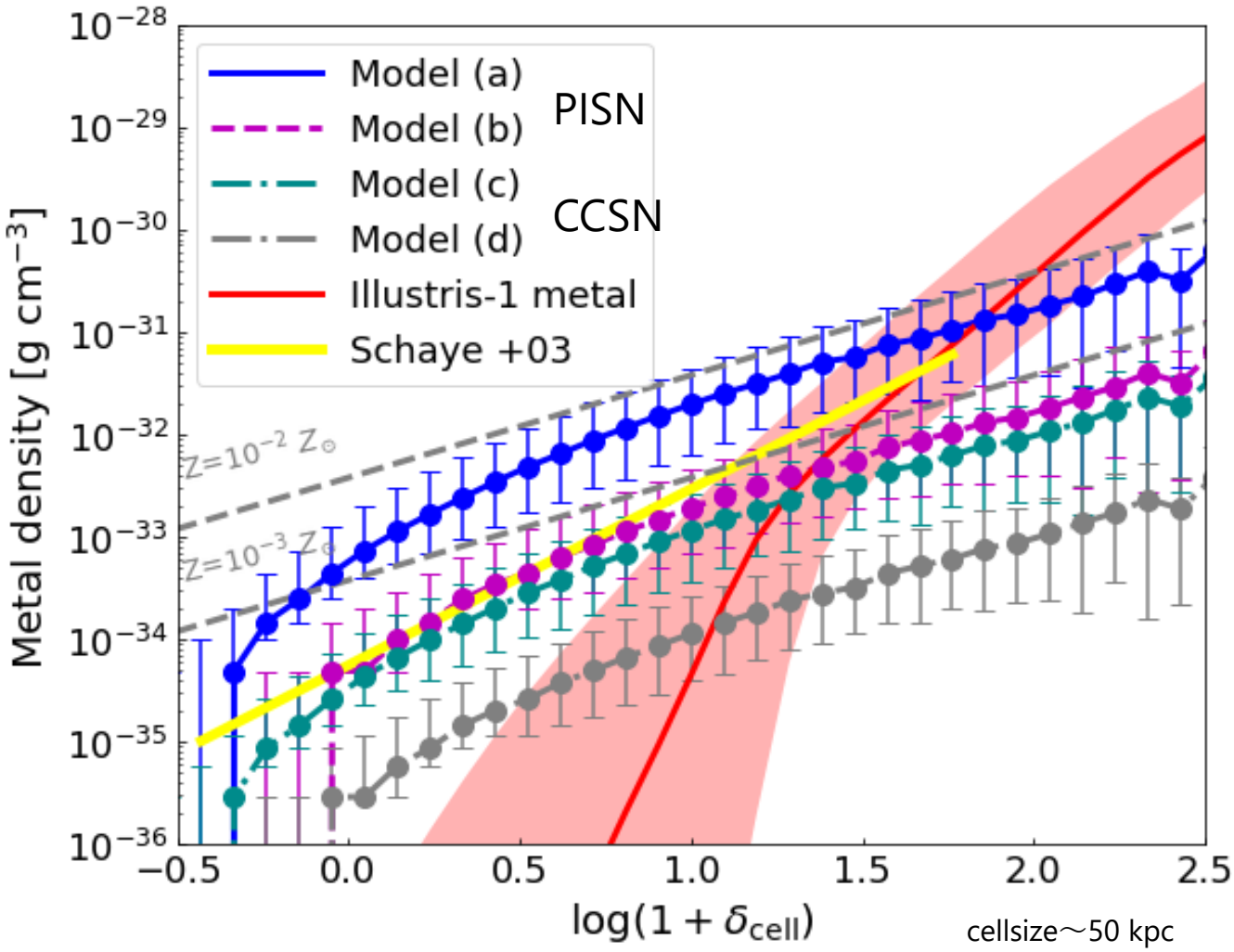


Galactic metal
: Illustris-1 simulation
(Vogelsberger+14)

AREPO (moving-mesh)
75 cMpc/h box
coarse-grained to 512^3

Thickness of slice: 160 pkpc

Metal density distribution



ρ_Z originated in Pop. III SN is a dominant contributor in

log(1 + δcell)<1.8 (Model (a))

log(1+δcell)< 1.3 (Model (b) and (c))

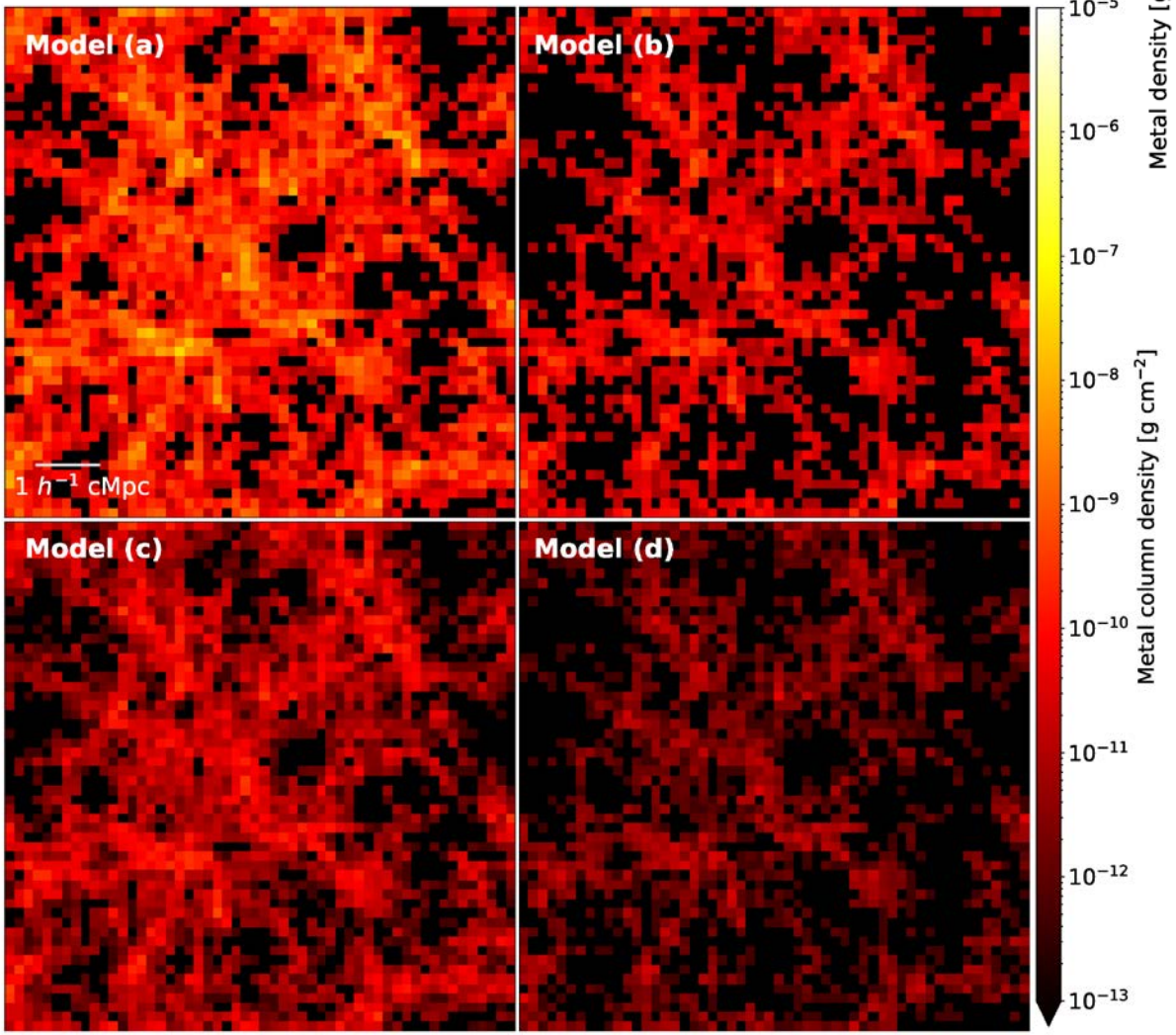
log(1+δcell)< 1.1 (Model (d))

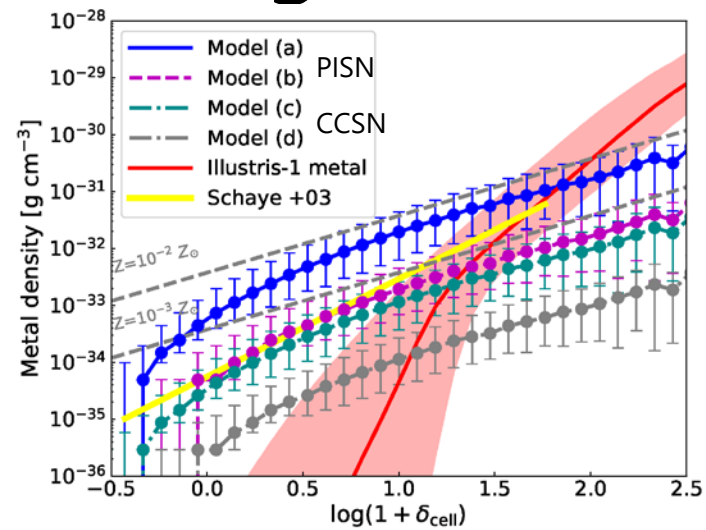
Volume fraction is large at lower density region

0 < log(1 + δcell) <1.8 :15 % of the whole volume

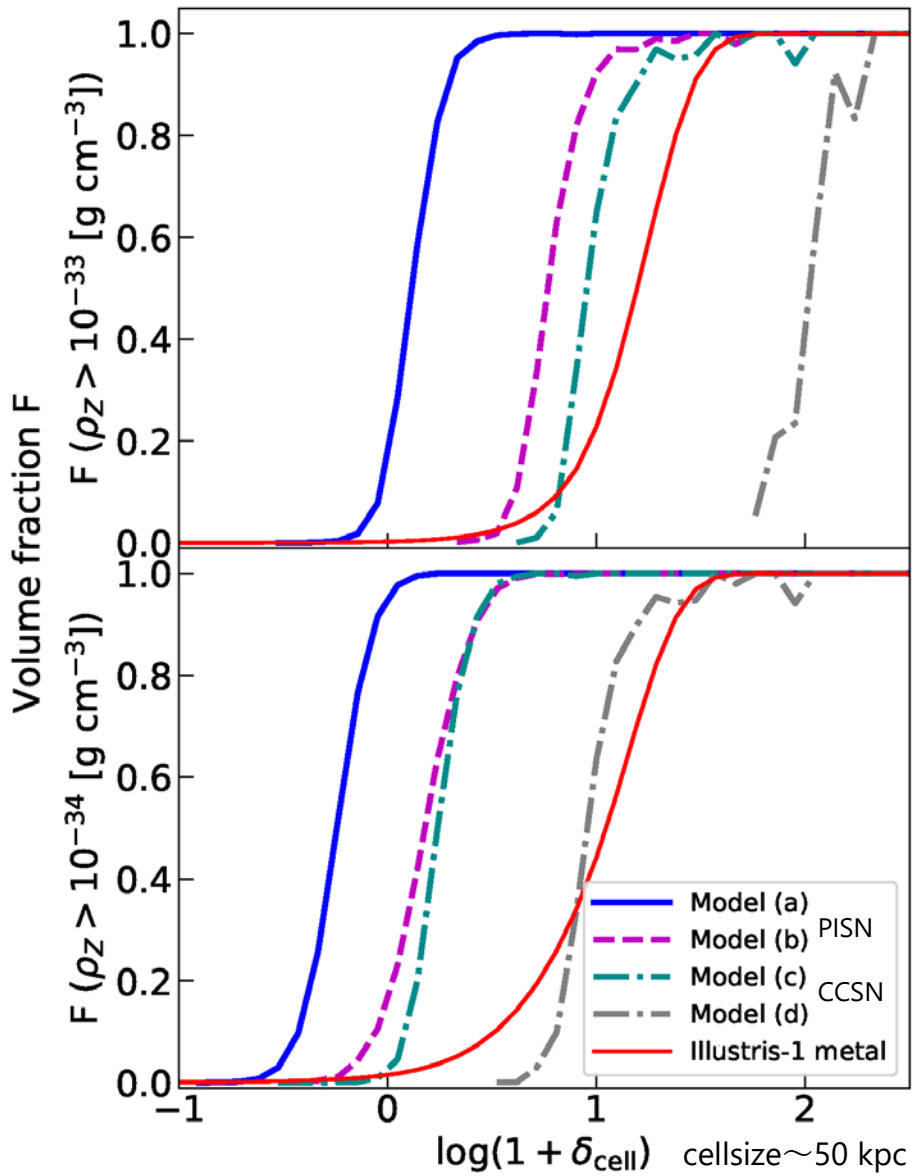
Pop. III metal dominated region

The colored region is dominated by Pop. III originated metals.





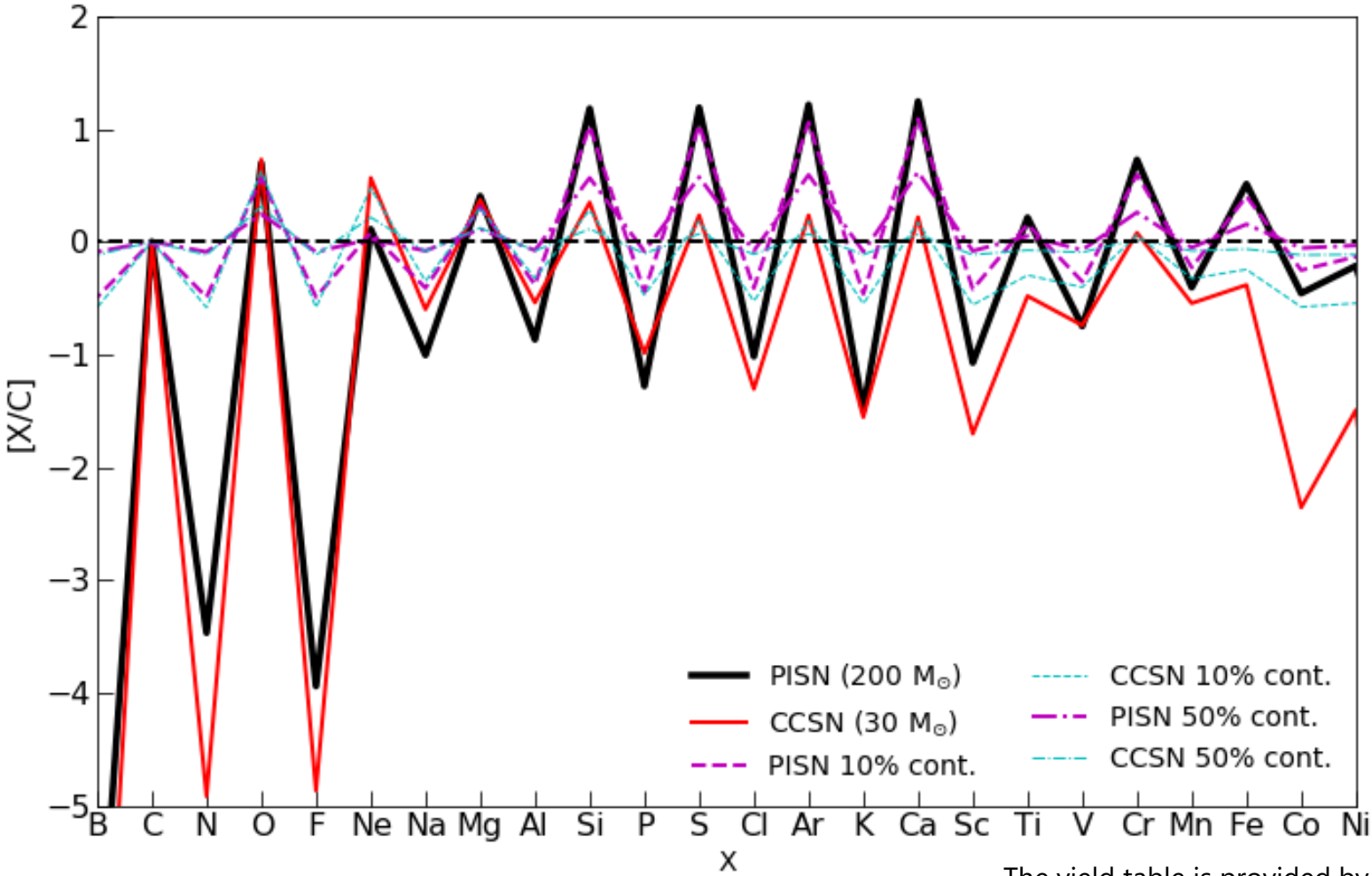
Volume fraction of the metal enriched region



If observations reach $\rho_Z > 10^{-34}\mathrm{g\ cm^{-3}}$, the volume fraction of Pop. III metals dominated region is 0.32 in Model (a).
As for Models (b): 0.11
(c): 0.08
(d) 0.0017

The average number of cells:
Model (a): 18
Model (b): 5.8
Model (c): 4.4
Model (d): 0.093
in the line-of-sight with Δz = 0.012 at z = 3 per QSO spectrum.

Elemental abundance pattern



The yield table is provided by Nomoto+13.

- ✓ Abundance ratios between C, N and O are useful to distinguish the origin.
- ✓ If PISN-originated metal is dominated, the gas would be Si-rich and S-rich even in the contaminated cases.

Summary

- We investigated the Pop. III metal distribution in the cosmological volume at z=3
- We compare the distribution of metals with galactic originated metals (Illustris-1 simulation)
- Pop. III metals have substantial enhancement at lower-density regions $0<\log(1+\delta_{cell})<1.3$
- The median value of the volume averaged metallicity is $Z \sim 10^{-4.5 \sim -2} Z_{\odot}$
- Relics of Pop. III stars should be discriminated by absorption lines in the QSO spectrum that have passed through a lower-density region