Effect of interstellar objects on metallicity of low-mass first stars formed in a cosmological model

Kirihara et al. MNRAS, in press
arXiv: 1905.02974v1

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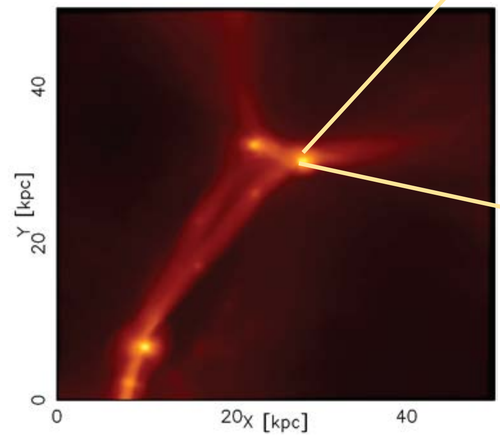
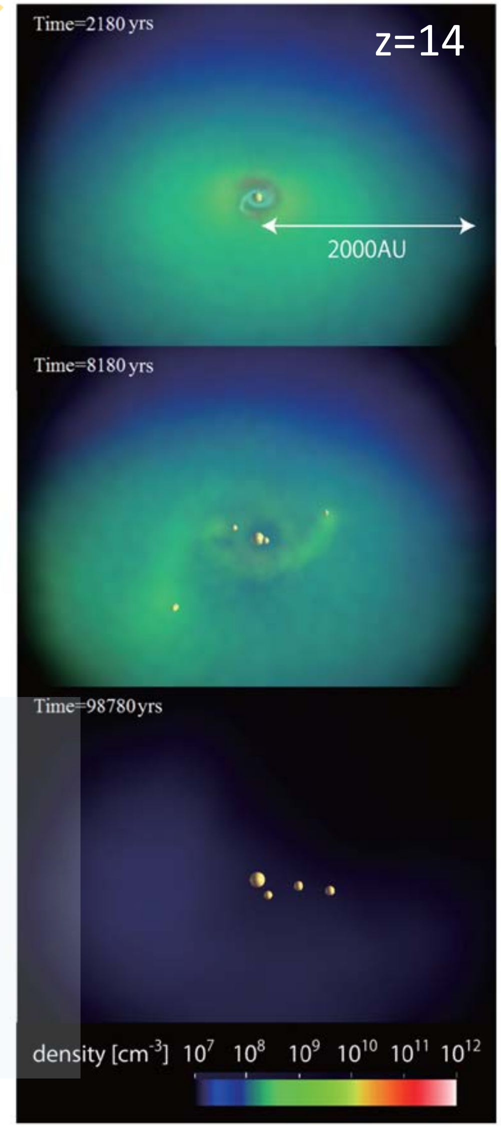
Population III survivors

Susa+14

Pop. III stars
- ✓ formed in pristine gas
- ✓ 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)

Low-mass Population III stars (Pop. III survivors)
- ✓ Born in the disks via fragmentation
  (e.g., Greif et al. 2012)
- ✓ $M_* \lesssim 0.8 M_{\odot}$ (Lifetime ≥ Cosmic age)
- ✓ They should be observed in the MW

No Metal-free stars have been discovered so far.

Metal pollution of Pop.III survivors

Can they get metals from ISM while wandering in the MW?

- ISM (interstellar medium) accretion

  → [Fe/H]～－５

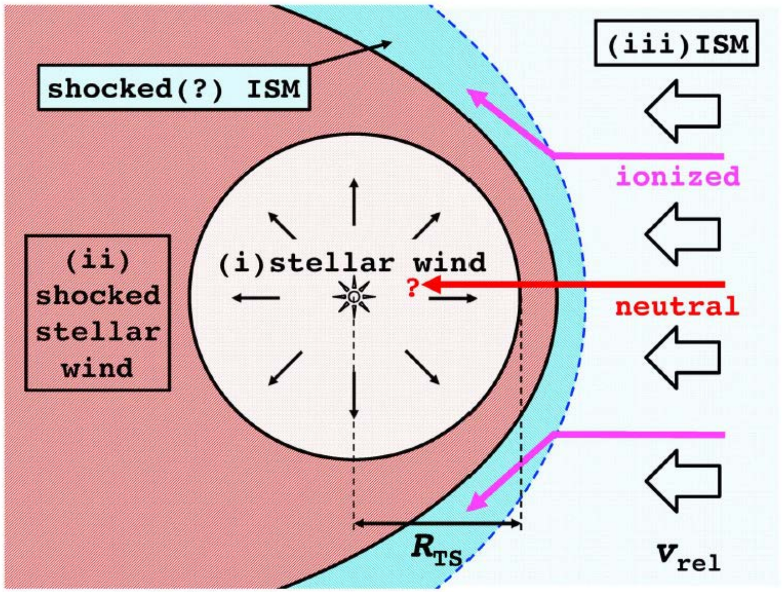
  assuming Bondi-Hoyle accretion

  （Yoshii 1981, Komiya+15, Shen+17）

- Steller wind block the accretion

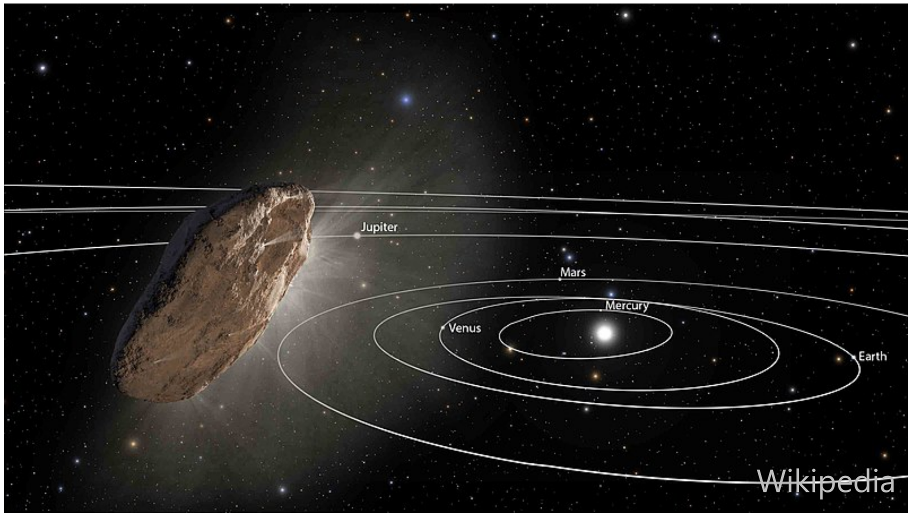
  → [Fe/H]<-14

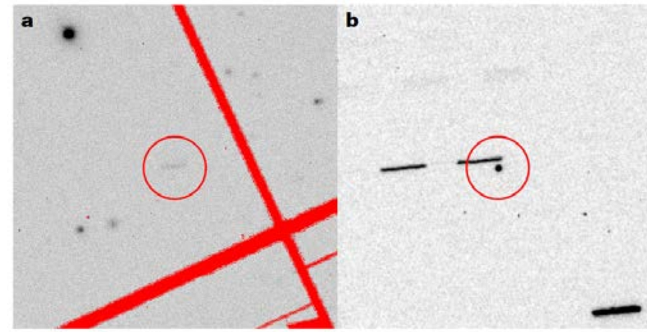
  (Tanaka et al. 2017, Suzuki 2018)



Tanaka+17

Interstellar objects (ISOs)



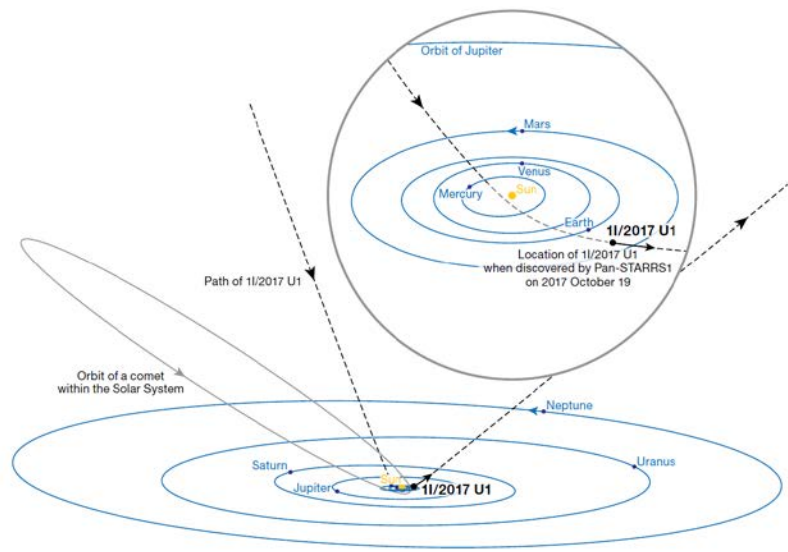


’Oumuamua

- The first ISO observed passing through the Solar System (Meech et al. 2017).
- Size: ~100 m

Estimated cumulative number density of such ISOs (>100 m) is $n_0 = 0.2\ \mathrm{au}^{-3}$

(Do +18)



Meech+17, Nature

Pop. III survivors polluted by ISOs

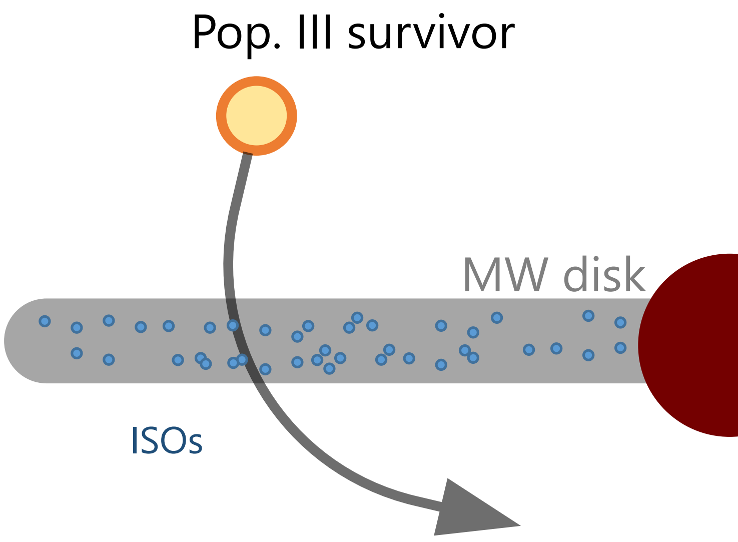
By Tanikawa et al. 2018

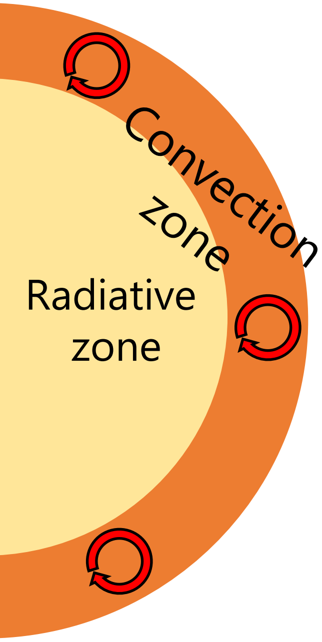
ISOs (>100 m) accretion rate

$$\dot{N}_{\mathrm{acc},0} \sim 1.4 \times 10^{-4} \left(\frac{n_0}{0.2\mathrm{au}^{-3}} \right) [\mathrm{yr}^{-1}]$$

ISO size distribution

$$n = n_0 \left(\frac{D}{D_0} \right)^{-\alpha}$$





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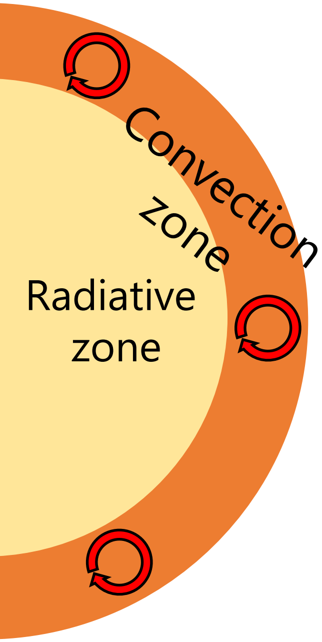
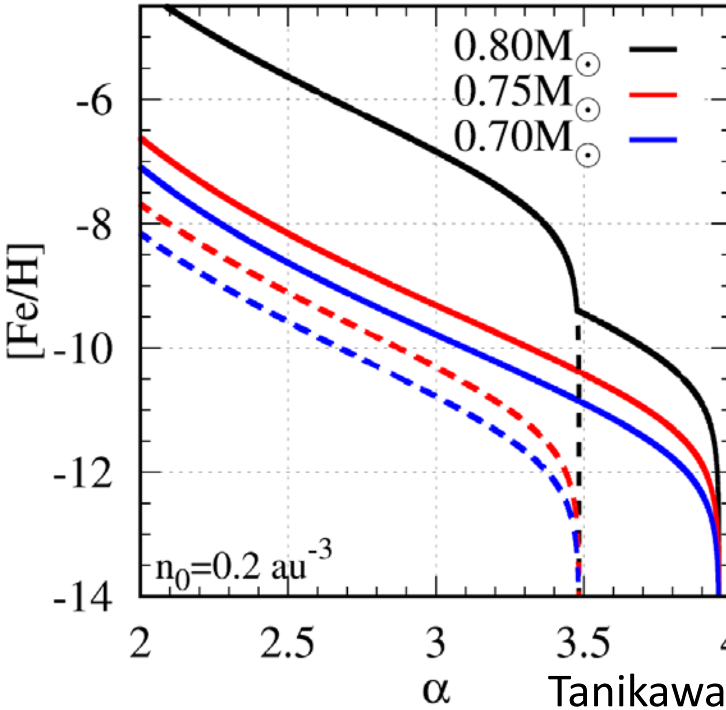
$$[{\rm Fe/H}] \sim \log_{10} \left(\frac{1}{f_{\rm conv}} \frac{\dot{M}_{\rm acc} \Delta t_{\rm pol}}{M_* Z_\odot} \right)$$

$\Delta t_{\rm pol}$ =5 Gyr



Surface metallicity of a survivor



Tanikawa+18

ISOs are the most dominant contributor of metal enrichment.

They assumed one modelled orbit for the analytical estimation.

Cosmological *N*-body simulation

We consider more realistic orbits of Pop. III survivors.

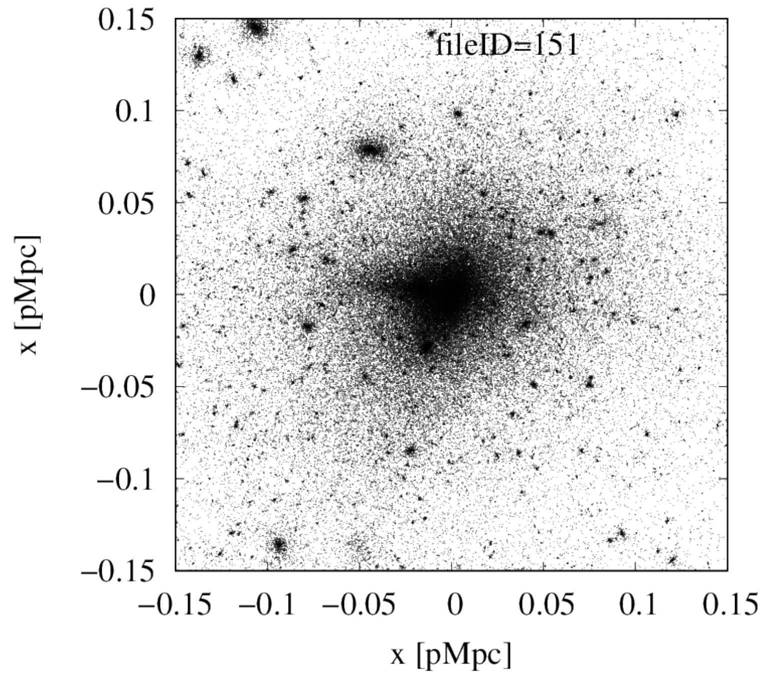
N-body simulation

+ Pop. III formation model

✓ N=2048^3 (Ishiyama +16)

✓ Boxsize: 8 h^{-1}cMpc

✓ Minimum halo mass: 2.4× 10^5M$_\odot$

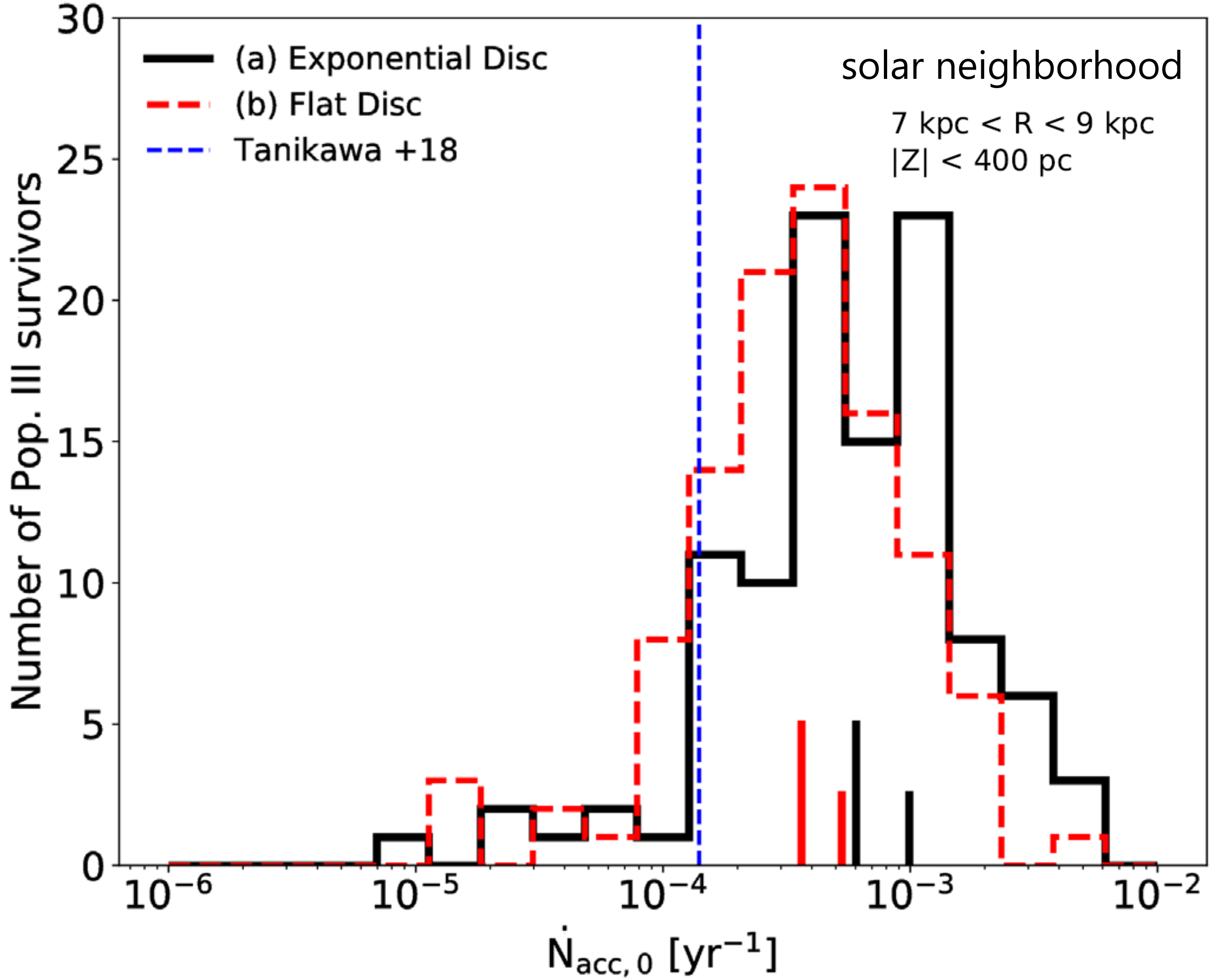


We calculate

$$\dot{N}_{\rm acc,0} = \frac{1}{\Delta t_{\rm ISO}} \int_{\Delta t_{\rm ISO}} f n_0(R(t)) \sigma |v(t) - V_{\rm circ}(R(t))| dt \qquad (\Delta t_{\rm ISO} \equiv 5{\rm Gyr})$$

We set the number density of ISOs $\propto \rho_*$ of the Galactic thin disk.

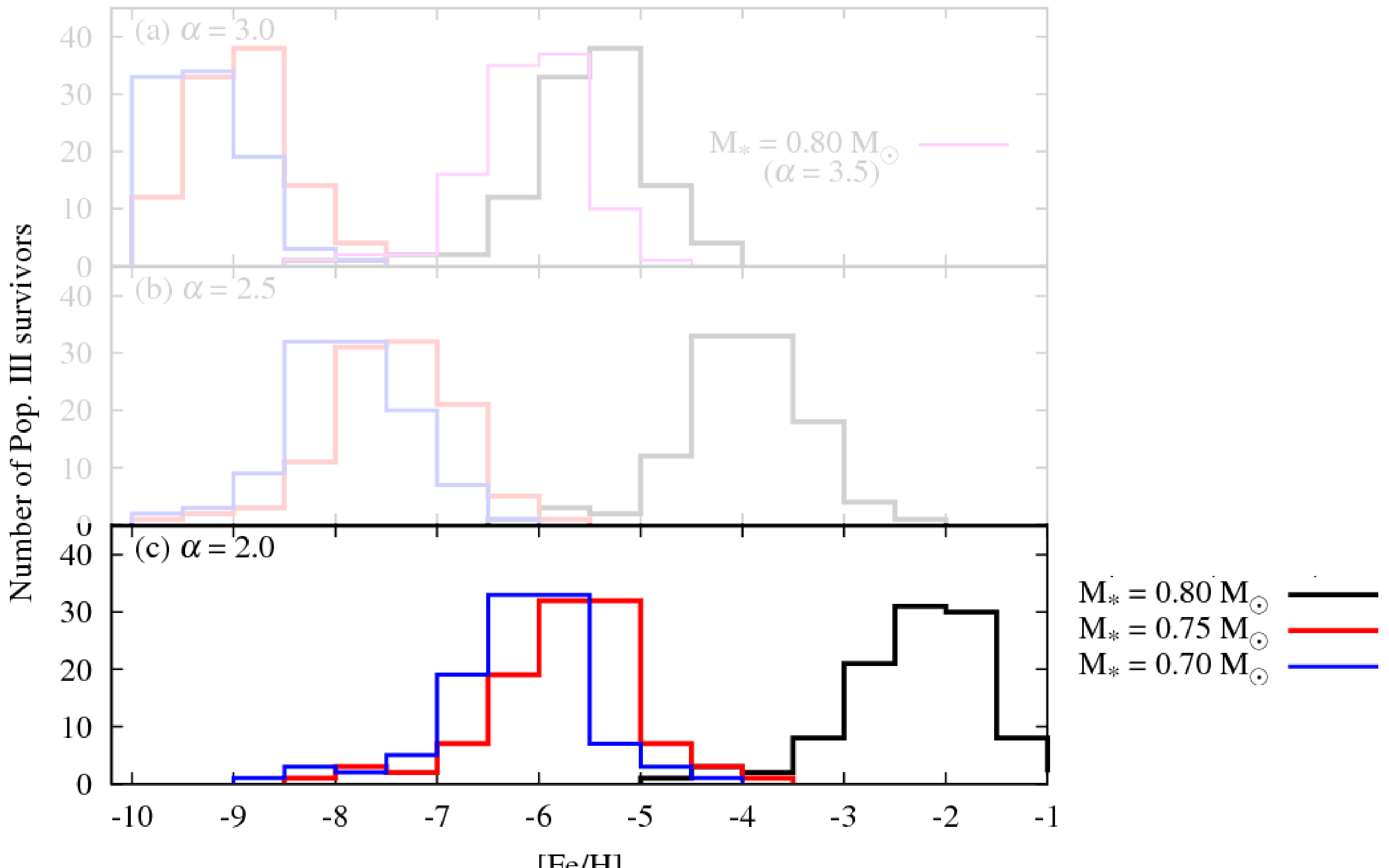
Accretion rate



Pop. III survivors have experienced typically 5M times of ISO(> 100 m) collisions in the last 5 Gyr. The value is one order of magnitude greater than estimated in Tanikawa+18.

Surface metallicity of Pop.III survivors

solar neighborhood



(α=2.0)

0.80 $M_\odot$: typically polluted to [Fe/H]~ -2.

0.70 and 0.75 $M_\odot$ stars: the typical surface metallicity are around [Fe/H]= $-6 \sim -5$.

Surface metallicity of Pop.III survivors

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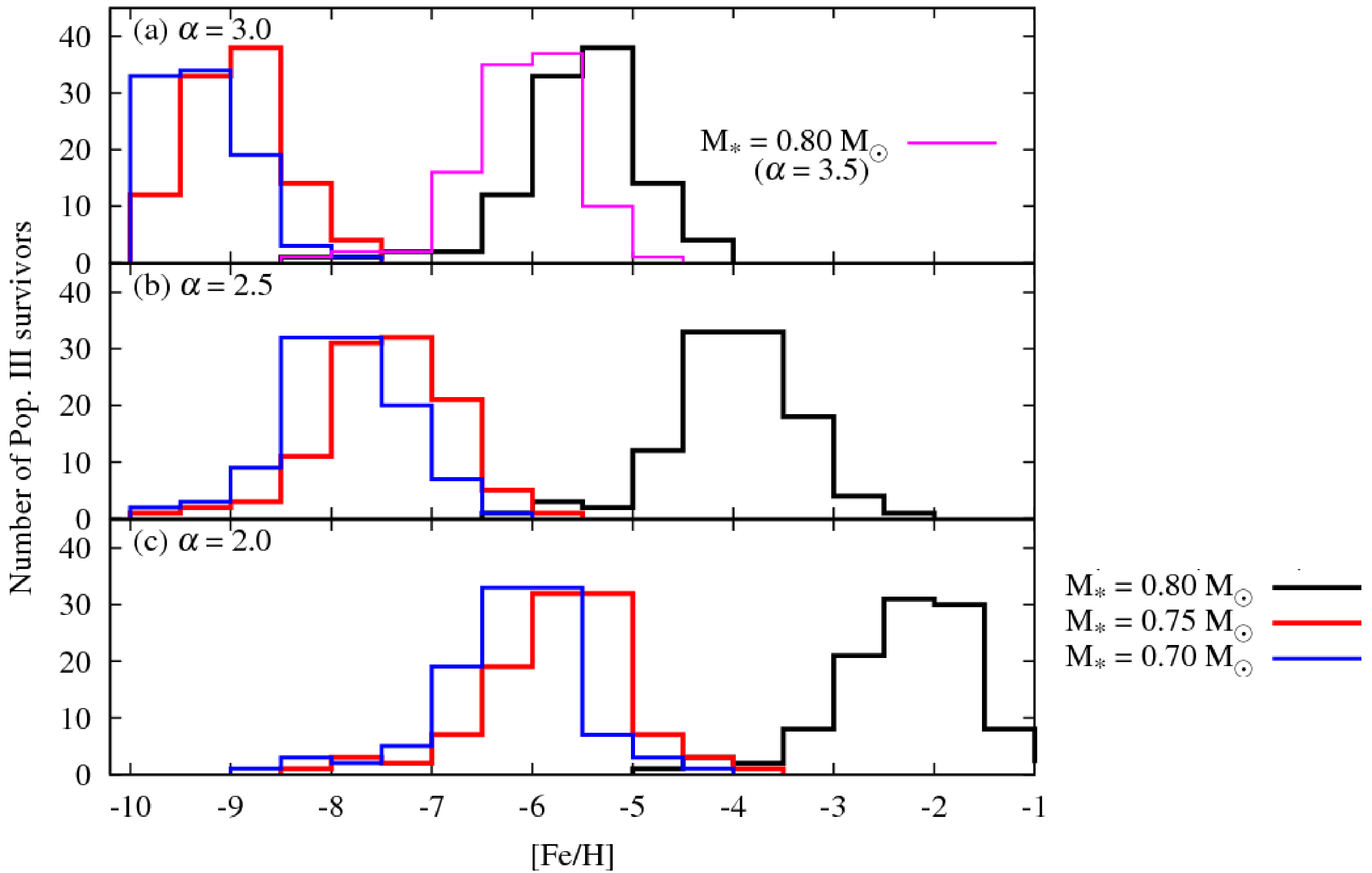

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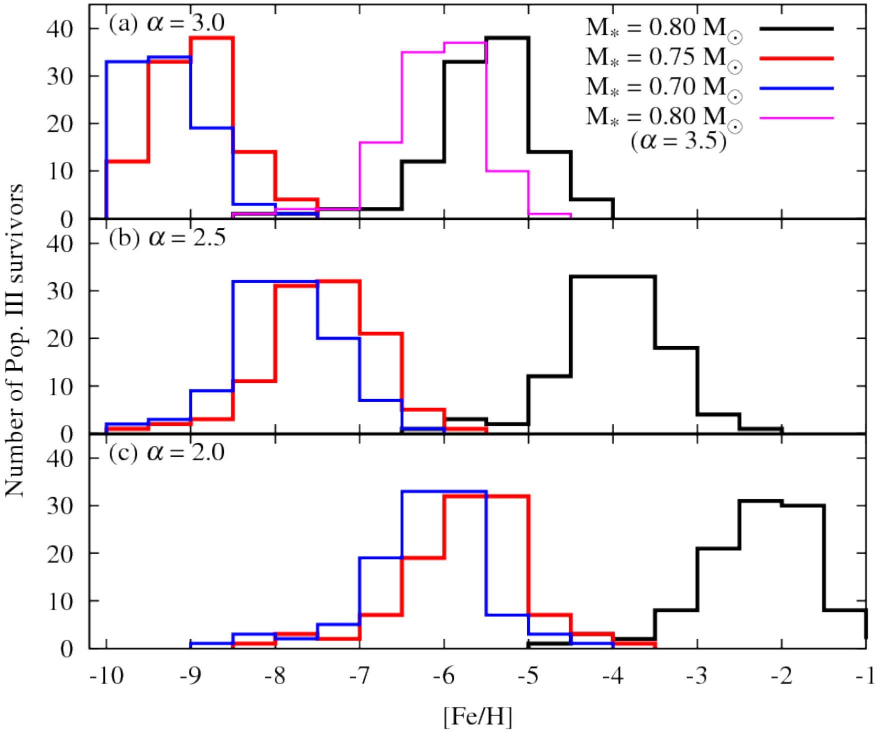
Metal-poor stars as candidates of Pop.III



We choose non- C-enhanced metal poor (non-CEMP) and main-sequence stars in the MW.

Most metal-poor stars with 0.8 $M_\odot$
6 stars with −3.8 < [Fe/H] < −3.6
SAGA database (Suda +08)

α=3.0: there is no Pop. III candidate.

α=2.5: 6 stars with 0.80 $M_\odot$ are the most promising candidates of Pop. III survivors.

α〜2.0: non-CEMP and main-sequence stars with Teff ~ 6500 K (0.80 $M_\odot$) and [Fe/H]≲−3 are candidates of Pop. III survivors.

1 star with 0.75 $M_\odot$

SDSS J164234+443004 (Teff = 6280 K and [Fe I/H]= −4.05), which as small perigalacticon (〜2 kpc) by Gaia (Sestito et al. 2019)

Summary

- We investigated metal pollution onto the surface of Pop. III survivors by ISOs floating in the Galactic disk.
- ISOs are the most dominant contributor of metal pollution.
- Metal-poor stars so far discovered at solar neighborhood are possible to be metal-free Pop. III stars on birth.
- Pop. III survivors could hide in extremely metal-poor stars so far discovered.