Metal pollution of low-mass Population III stars through accretion of interstellar objects

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Stellar Archaeology as a Time Machine to the First stars
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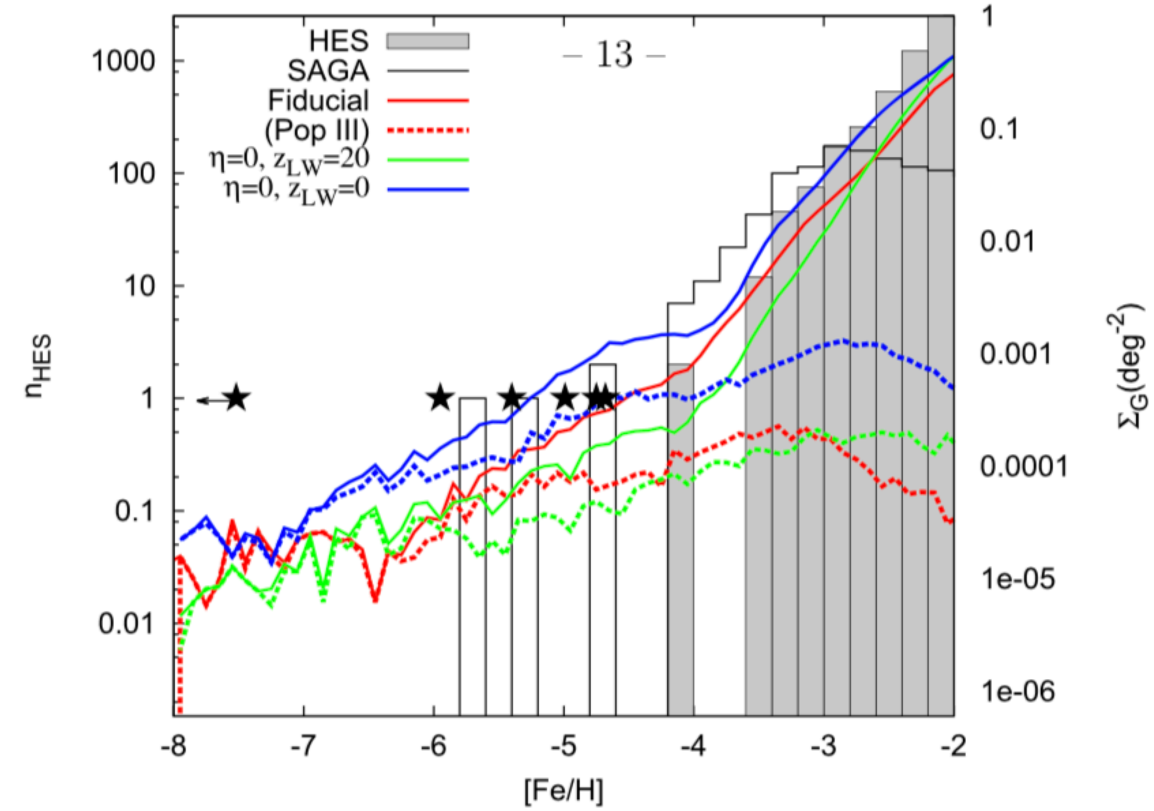
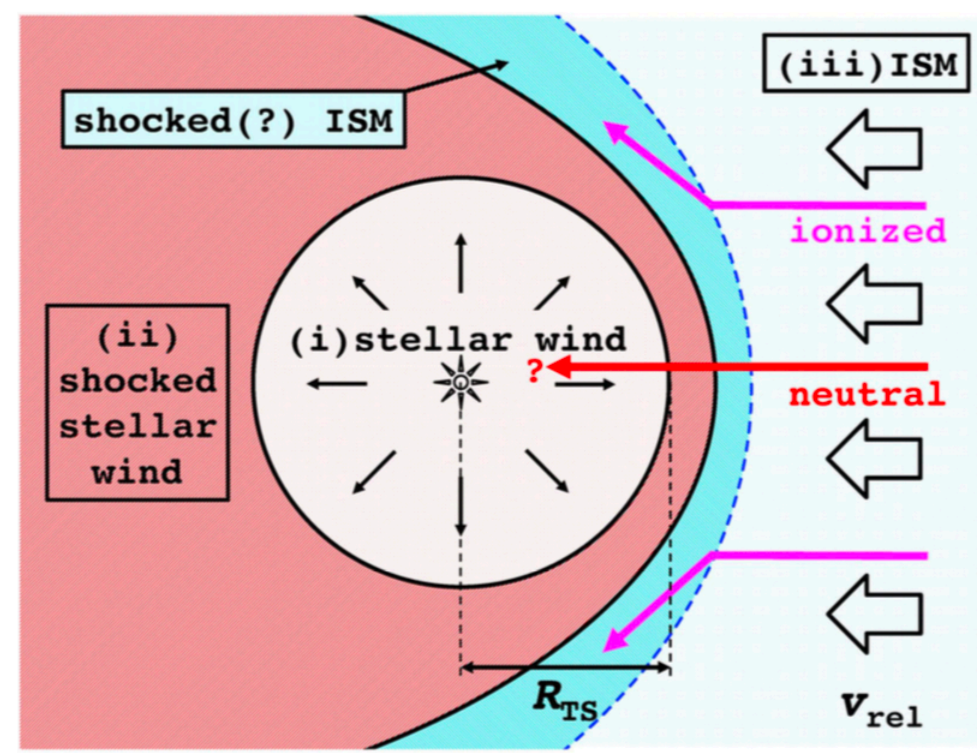
Tanikawa, Suzuki, Doi (2018, PASJ, 70, 80)

Metal pollution

- Low-mass Pop III stars (<0.8M☉)
  - must survive during this ~10Gyr.
  - do not always remain metal-free, however.
- By ISM
  - Pop. III survivors have wandered in the MW for 10Gyr.
  - They may have accreted ISM through Bondi-Hoyle-Lyttleton accretion.
- ISM gas
  - Blocked by stellar wind
  - [Fe/H] ~ -14 (<< [Fe/H] of EMP stars)
- ISM dust
  - Sublimated by stellar radiation
  - Also blocked by stellar wind



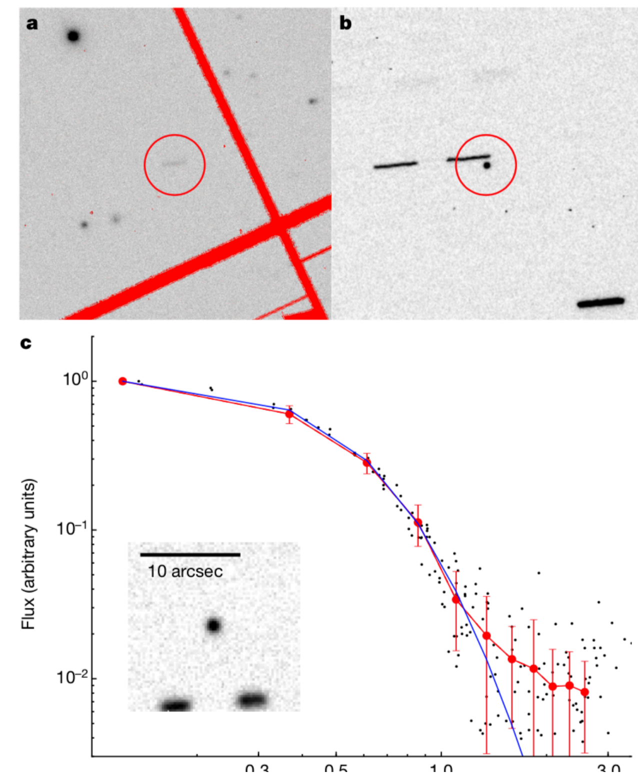
Komiya et al. (2015)

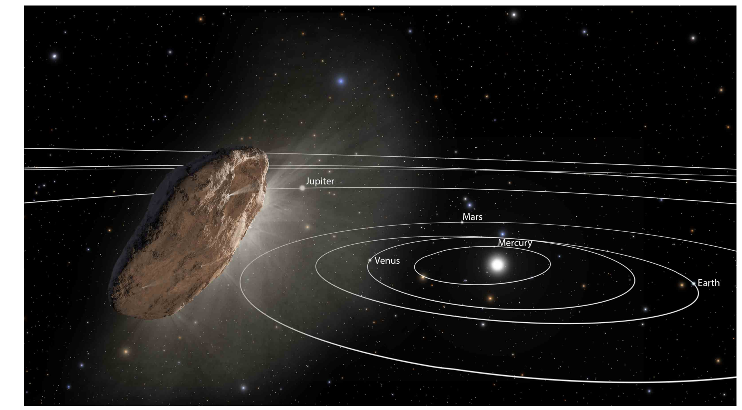


Tanaka et al. (2017), Suzuki (2018)

Interstellar objects (ISOs)

- Asteroids or comets wandering interstellar space
- 1I/2017 U1 \`Oumuamua (The first ISO discovered by Meech et al. 2017)
  - Extrasolar asteroids, comet nuclei, or etc.
  - Size ~ 100m
- High number density ~ 0.2 au^{-3} (Do et al. 2018)
- Metal pollution of Pop. III through collision with ISOs





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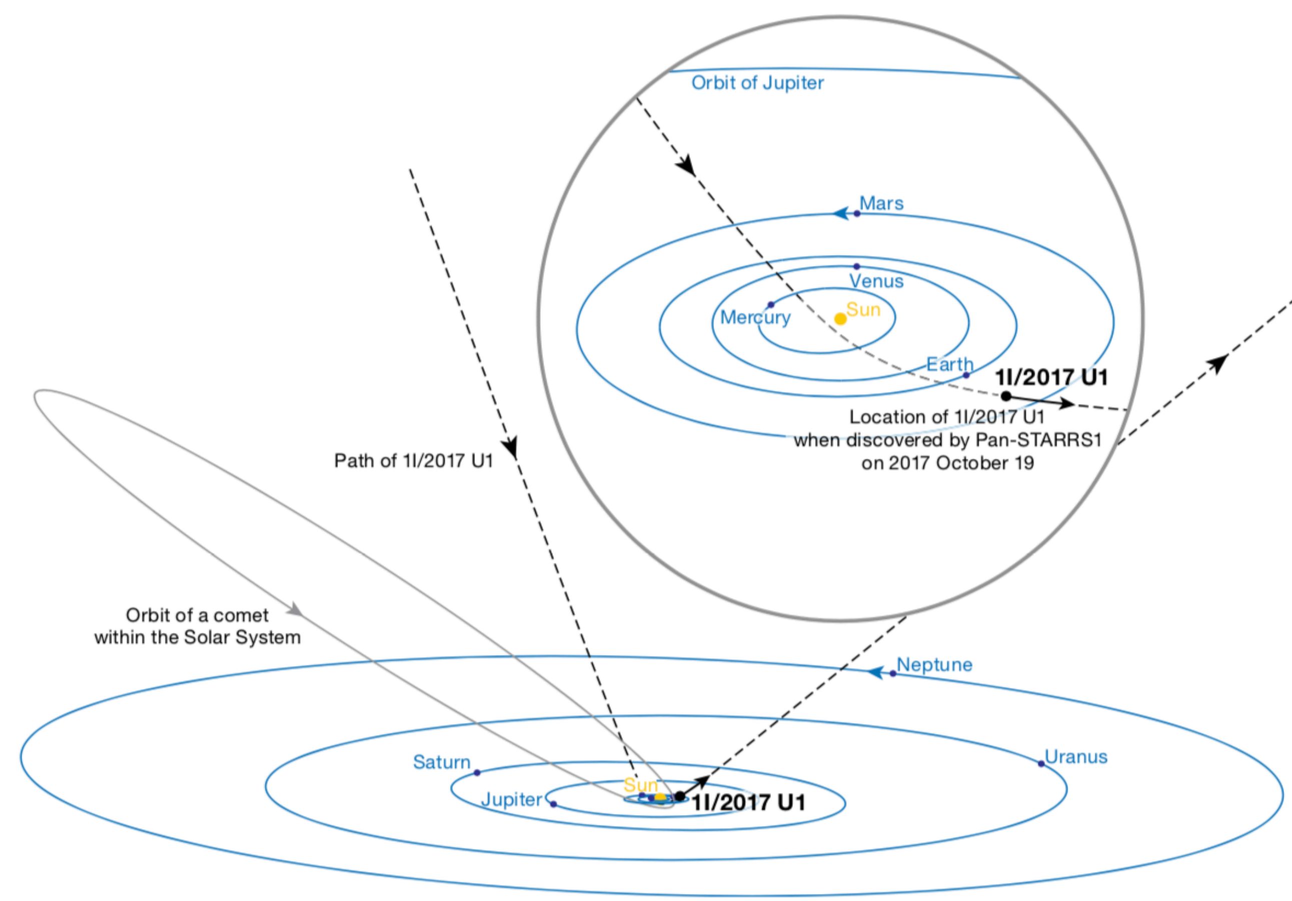
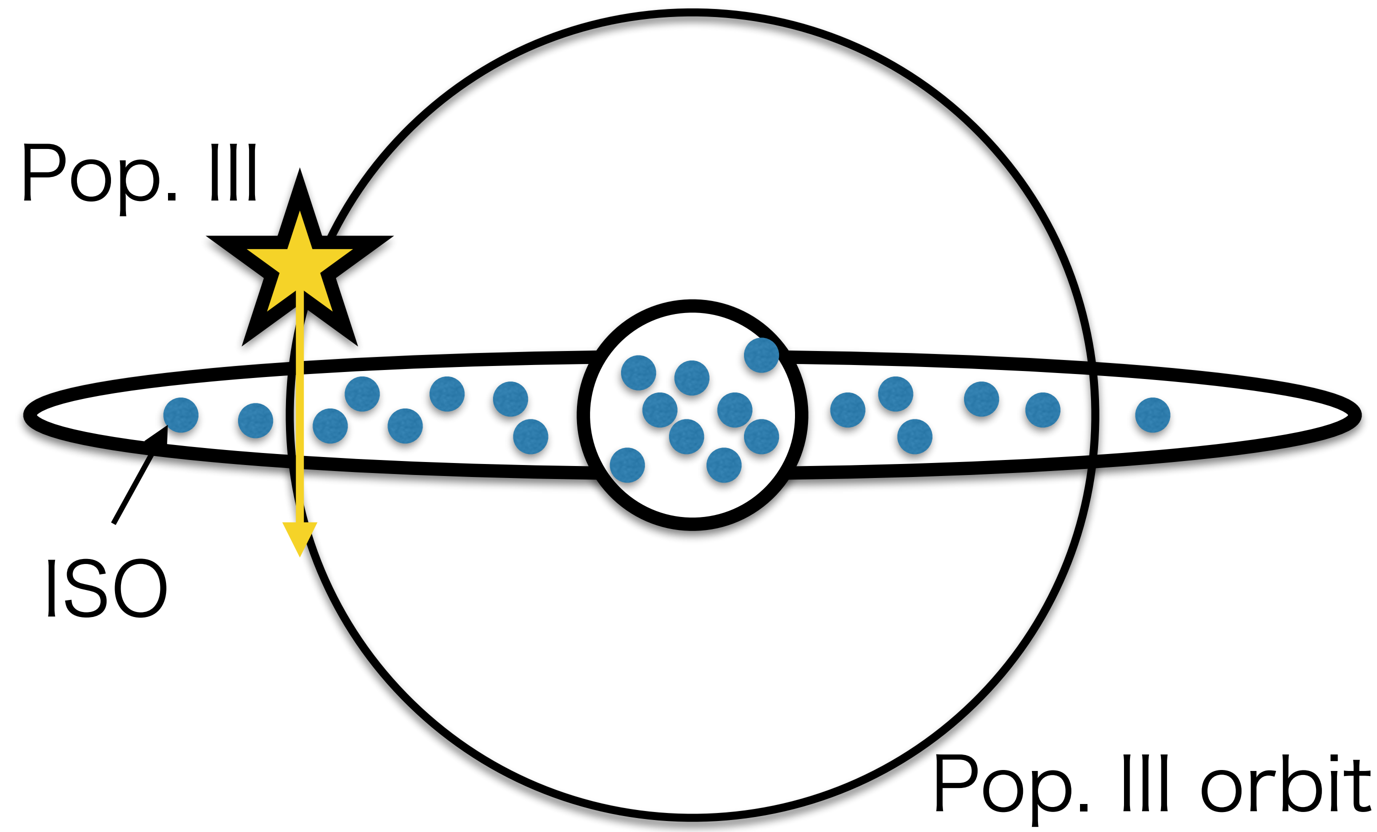
Meech et al. (2017)



Collision rate

$$\dot{N}_{\rm coll} = n\sigma v f$$

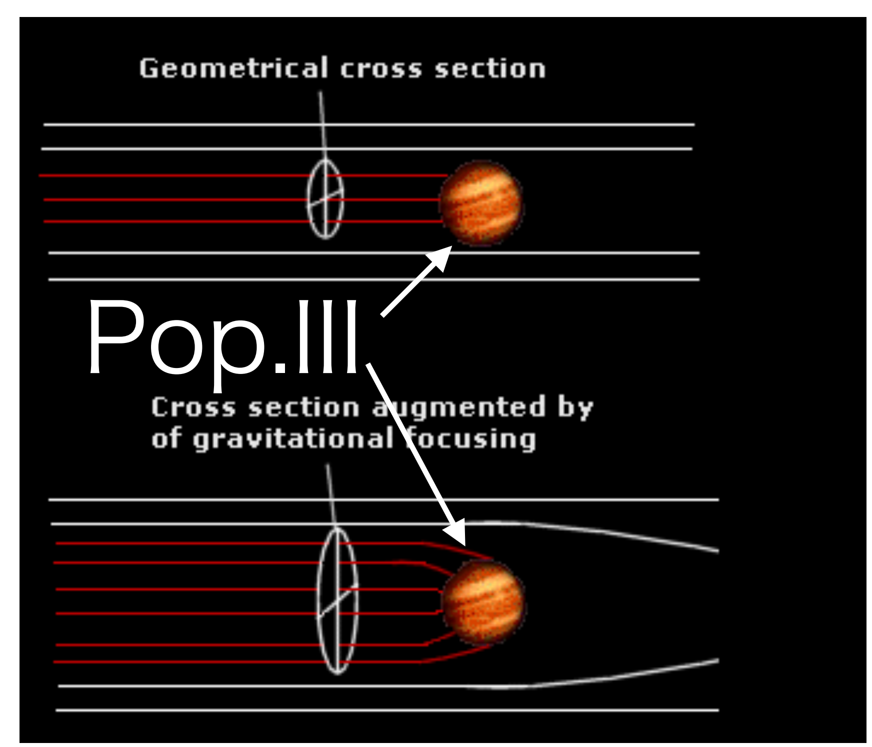
- n: ISO number density (~0.2 au^{-3})
- σ: cross section (~5 x cross section of the sun)
- v: relative velocity between Pop. III and ISOs (~300km/s)
- f: fraction of ISO-rich regions in a Pop. III orbit (~0.03)



ISO $\dot{N}_{\rm coll,iso} \sim 10^5 \left(\frac{n}{0.2{\rm au}^{-3}}\right)[{\rm Gyr}^{-1}]$

Pop. I stars $\dot{N}_{\rm coll,star} \sim 10^{-11} \left(\frac{n}{0.1{\rm pc}^{-3}}\right)[{\rm Gyr}^{-1}]$

Free floating planets $\dot{N}_{\rm coll,ffp} \sim 10^{-8} \left(\frac{n}{200{\rm pc}^{-3}}\right)[{\rm Gyr}^{-1}]$



Sublimation of ISOs

Distance to start sublimated
$$R = \left(\frac{L_*}{4\pi\sigma_s T^4}\right) \sim 6.9 \cdot 10^{-2} \left(\frac{L_*}{L_\odot}\right)^{1/2} \left(\frac{T}{1500\mathrm{K}}\right) \text{ [au]}$$

Velocity at the distance
$$v_R = \left(v^2 + \frac{2GM_*}{R}\right) \sim 3.5 \cdot 10^2 \text{ [km s}^{-1}\text{]}$$

Time to reach a Pop. III survivor
$$t_{orbit} \sim 3.0 \cdot 10^4 \text{ [s]}$$

Conduction time
$$t_{cond} \sim \frac{D^2}{\kappa}$$
(D: ISO size, κ : Thermal conductivity)

$$t_{cond} > t_{orbit} \Rightarrow D_{min} \sim 3.0 \left(\frac{\kappa}{3 \cdot 10^6 \text{ erg cm}^{-1}\text{ K}^{-1}}\right)^{1/2} \text{ [km]}$$

Cumulative size distribution of ISOs

$$n = n_0 \left(\frac{D}{D_0} \right)^{-\alpha} \quad (n_0 = 0.2\ \mathrm{au}^{-3},\ D_0 = 100\ \mathrm{m})$$

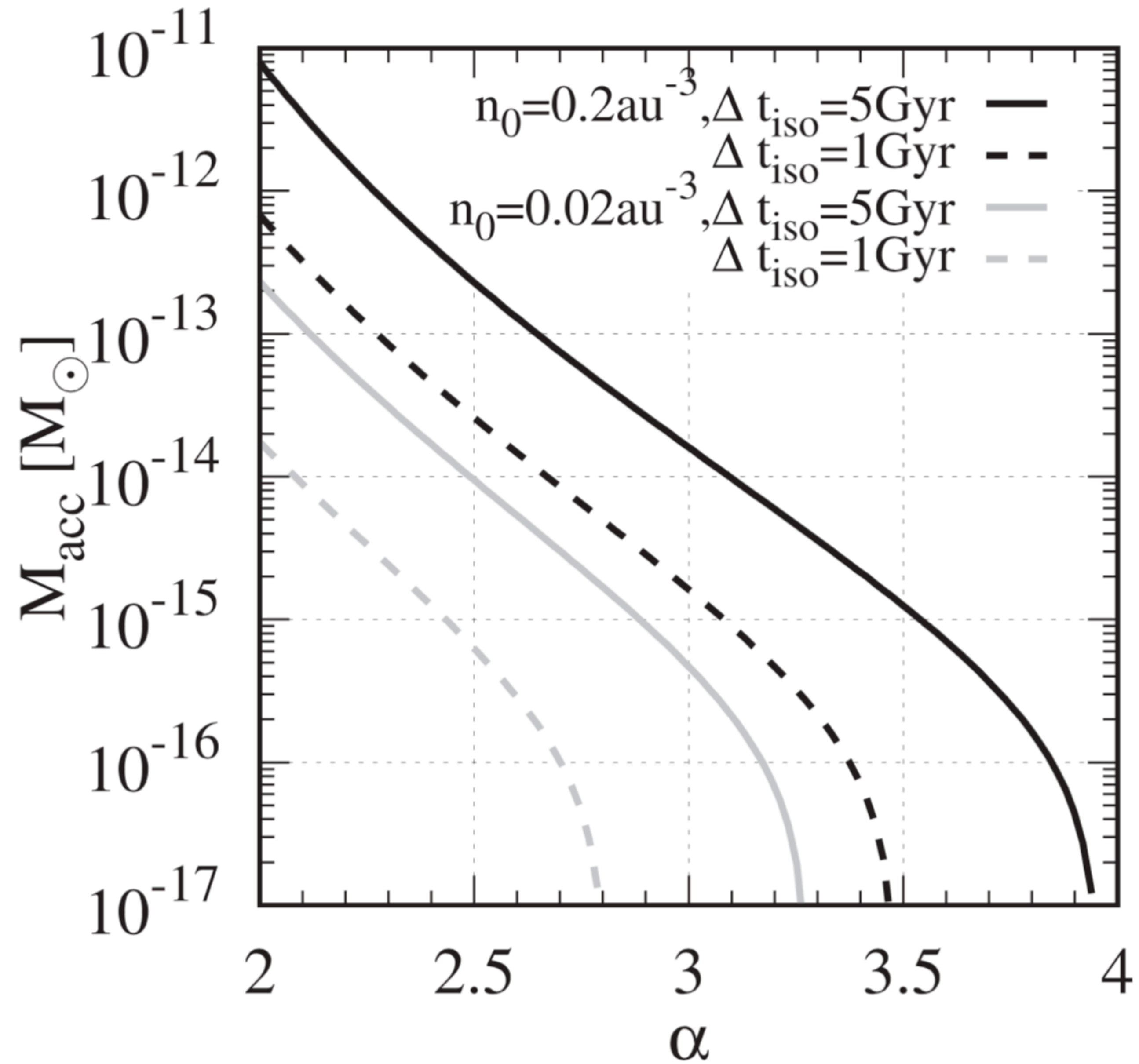
- The main belt: α~1.5 for D>200m (Gladman et al. (2009)
- Long-period comet: α~3 for 0.1-10km (Fernandez et al. 2012)
- The Edgeworth-Kuiper belt: α~2.5-3.5 for 0.1-100km (Kenyon et al. 2004)

Accreting mass of ISOs

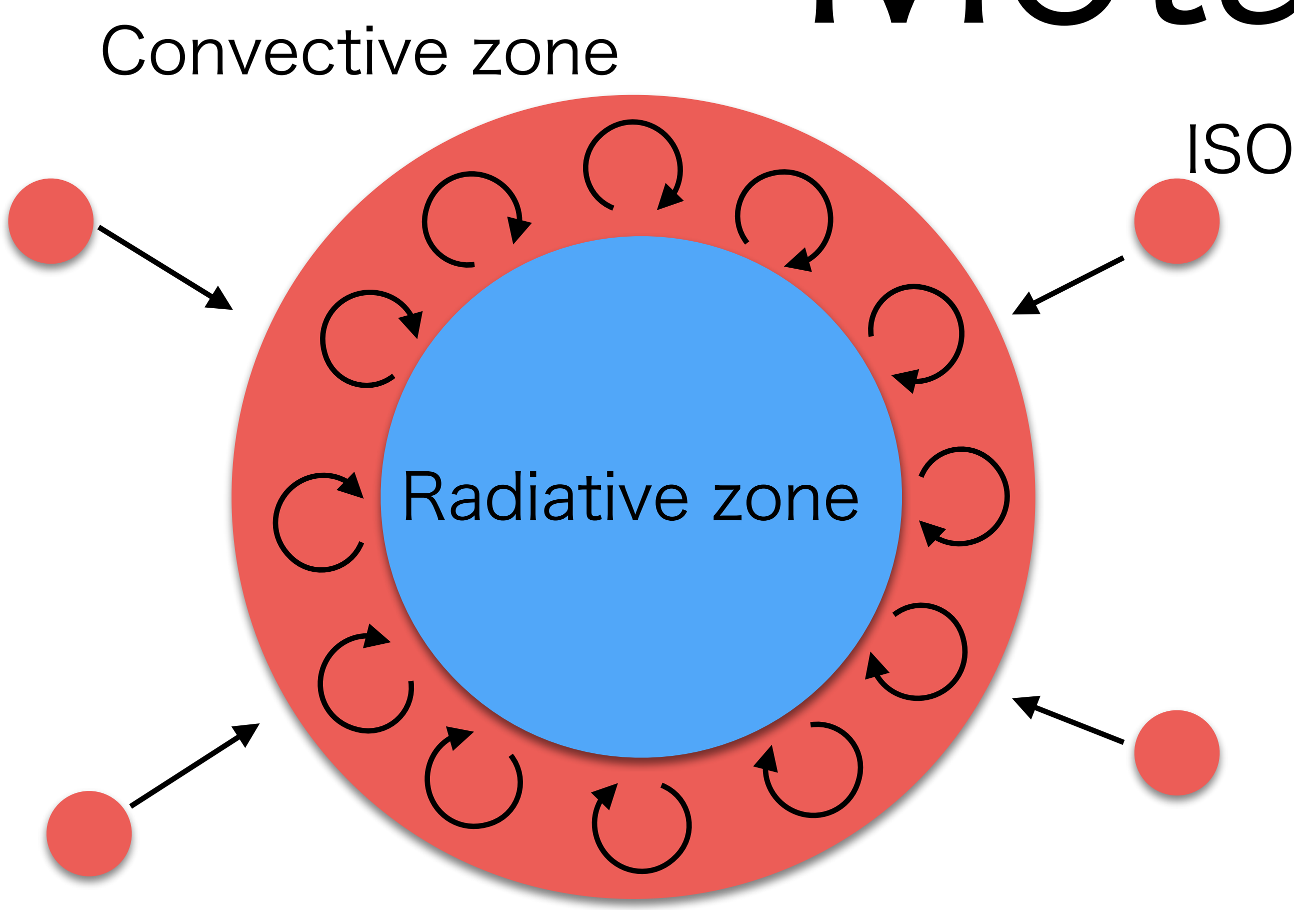
- The total accreting mass of ISOs is 10^{-15}-$10^{-13}M_\odot$ much more than that of ISM ~ $10^{-19}M_\odot$.

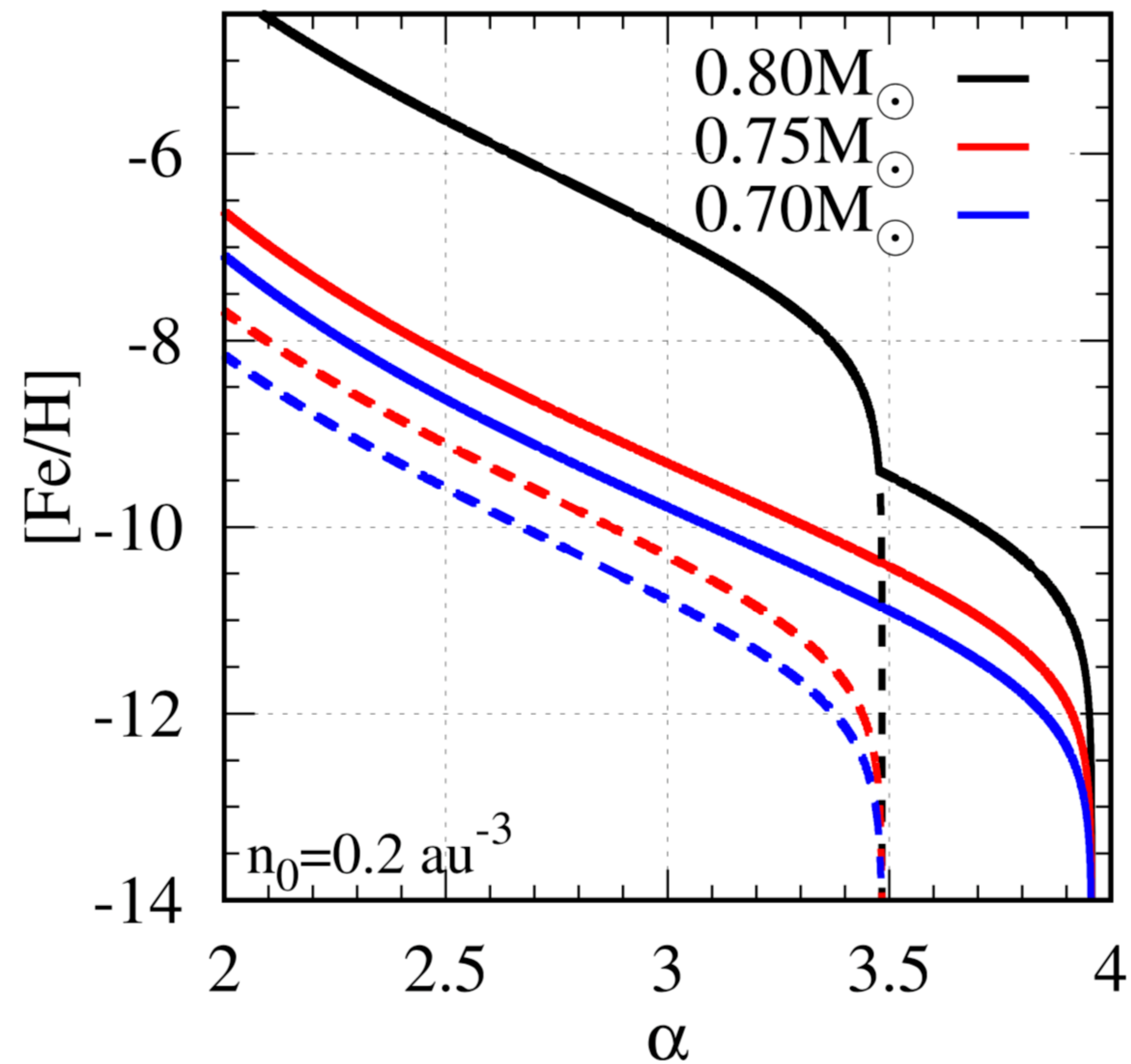
- This is true even if the number density of ISOs is one-tenth of the estimated one.

- ISOs are the most dominant polluter of Pop. III survivors.



Metallicity





- ISO materials spread only in a surface convective zone.
- The mass fractions of the zones are $10^{-6.0}$ for 0.80$M_\odot$, $10^{-2.5}$ for 0.75$M_\odot$, and $10^{-2.0}$ for 0.70$M_\odot$ (Richard et al. 2002).
- [Fe/H] is -9 to -8 in a typical case.
- [Fe/H] is comparable to EMP stars for the extreme case.

Expected abundance pattern

- Not different from the solar abundance pattern
    - Since many ISOs ($\sim 10^5$) collide with a Pop III survivor, personalities of ISOs would be cancelled.
    - In total, asteroids and comets are not different from the solar abundance pattern in the solar system.

Summary

- We have estimated metal pollution of Pop. III survivors by ISOs, or interstellar asteroids.
- We have found ISOs can be the most dominant polluters of Pop. III survivors.
- The abundance pattern would not be different from the solar abundance.
- These results are published in Tanikawa, Suzuki, Doi (2018, PASJ, 70, 80)