Metal Pollution of Low-Mass Population III Stars through Collision of Interstellar Objects

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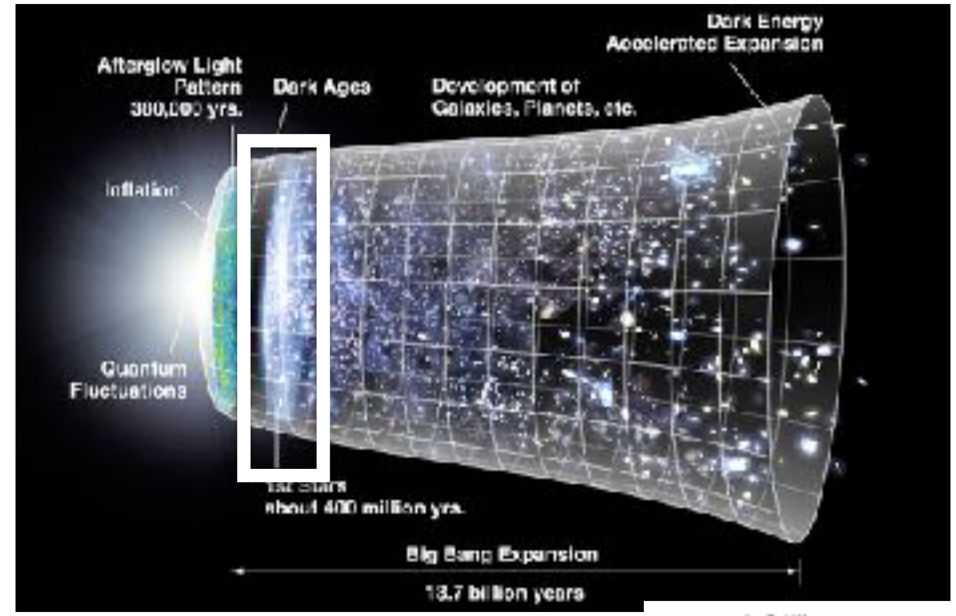
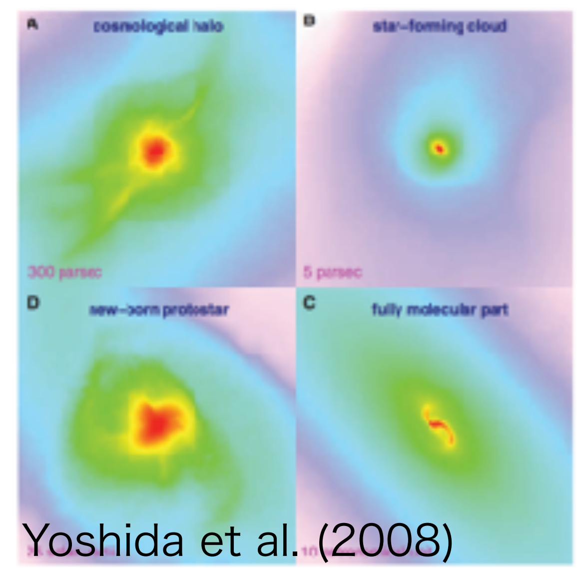
Tanikawa, Suzuki, Doi (2018, PASJ in press, arXiv: 1804.08200)

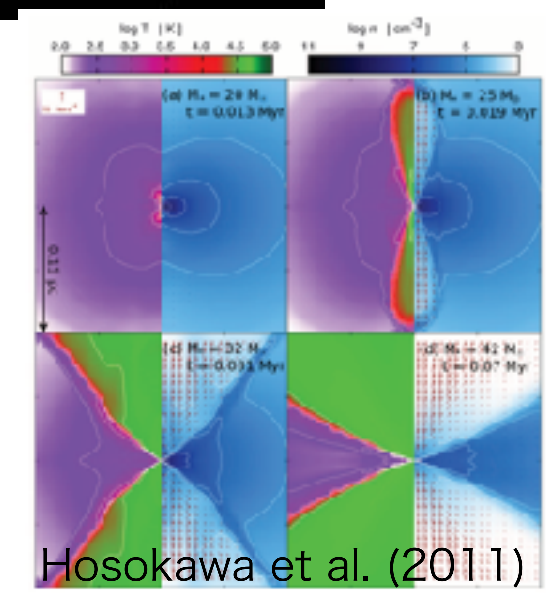
Pop. III stars

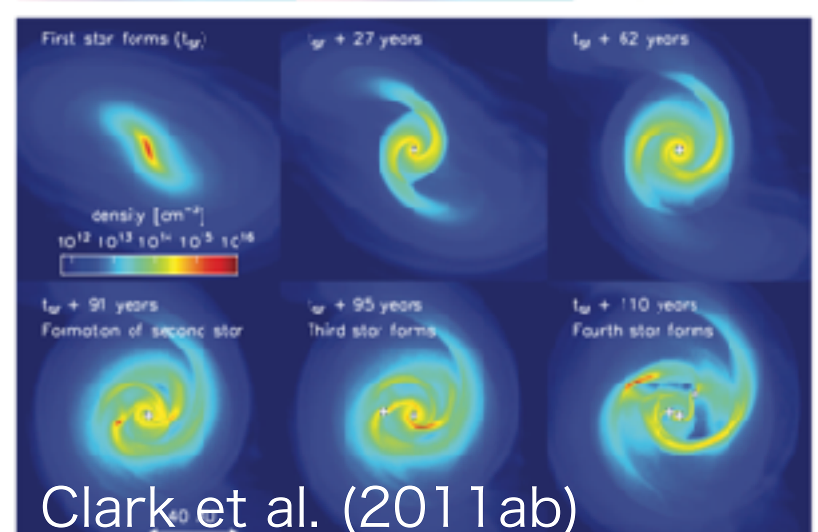
- Importance
  - Reionization
  - Nucleosynthesis
- Mass
  - Massive stars (~100M$_\odot$) formed in the typical mode
  - Low-mass stars (~0.8M$_\odot$) formed around the massive stars
- Low-mass stars (Pop. III survivors)
  - Long lifetime (~ 10Gyr)
  - Should-be observed in the Milky Way galaxy
- No discovery of metal-free stars



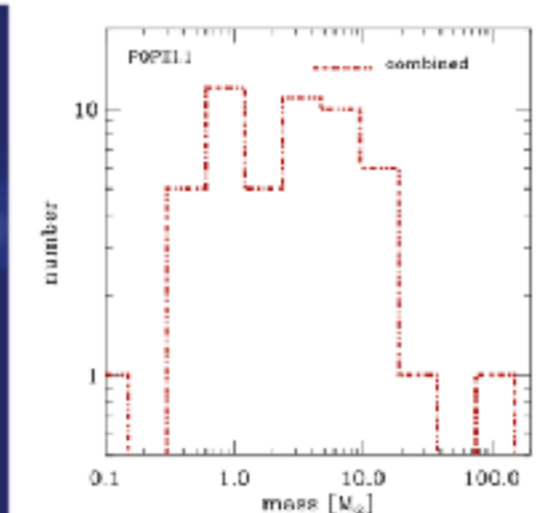


Yoshida et al. (2008)


Hosokawa et al. (2011)

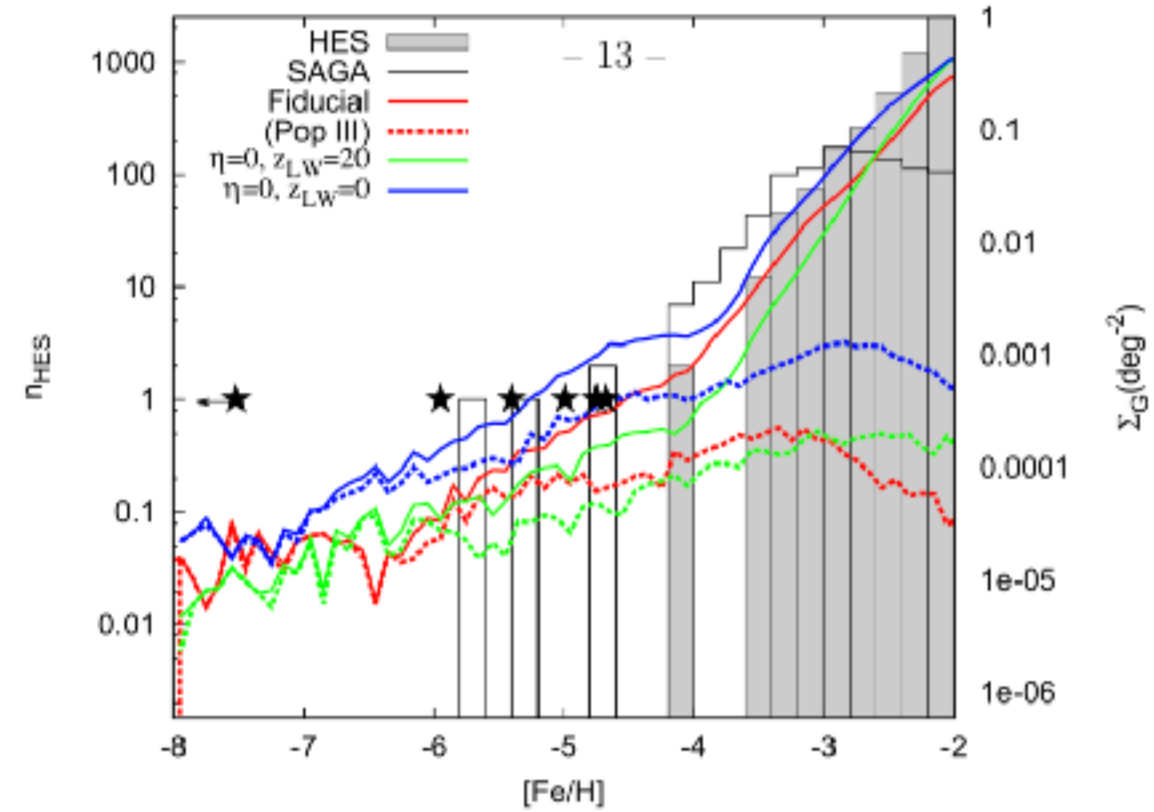


Clark et al. (2011ab)

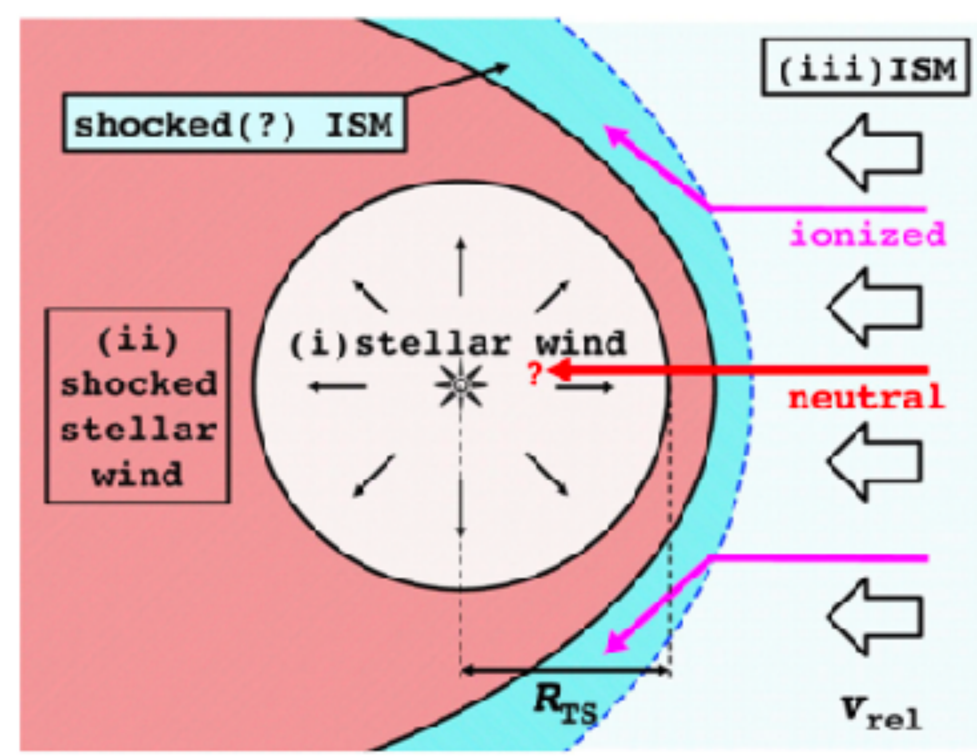


Metal pollution

- 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
  - Blocked by stellar wind



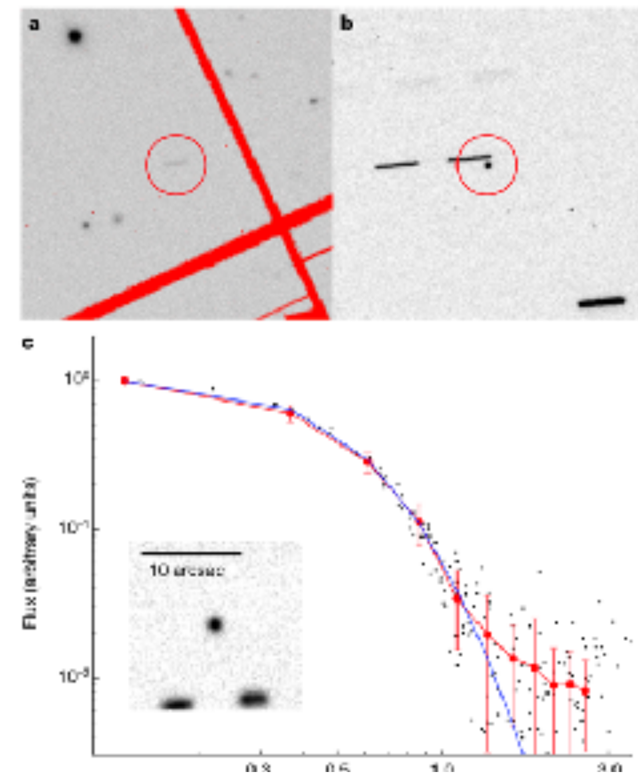
Komiya et al. (2015)



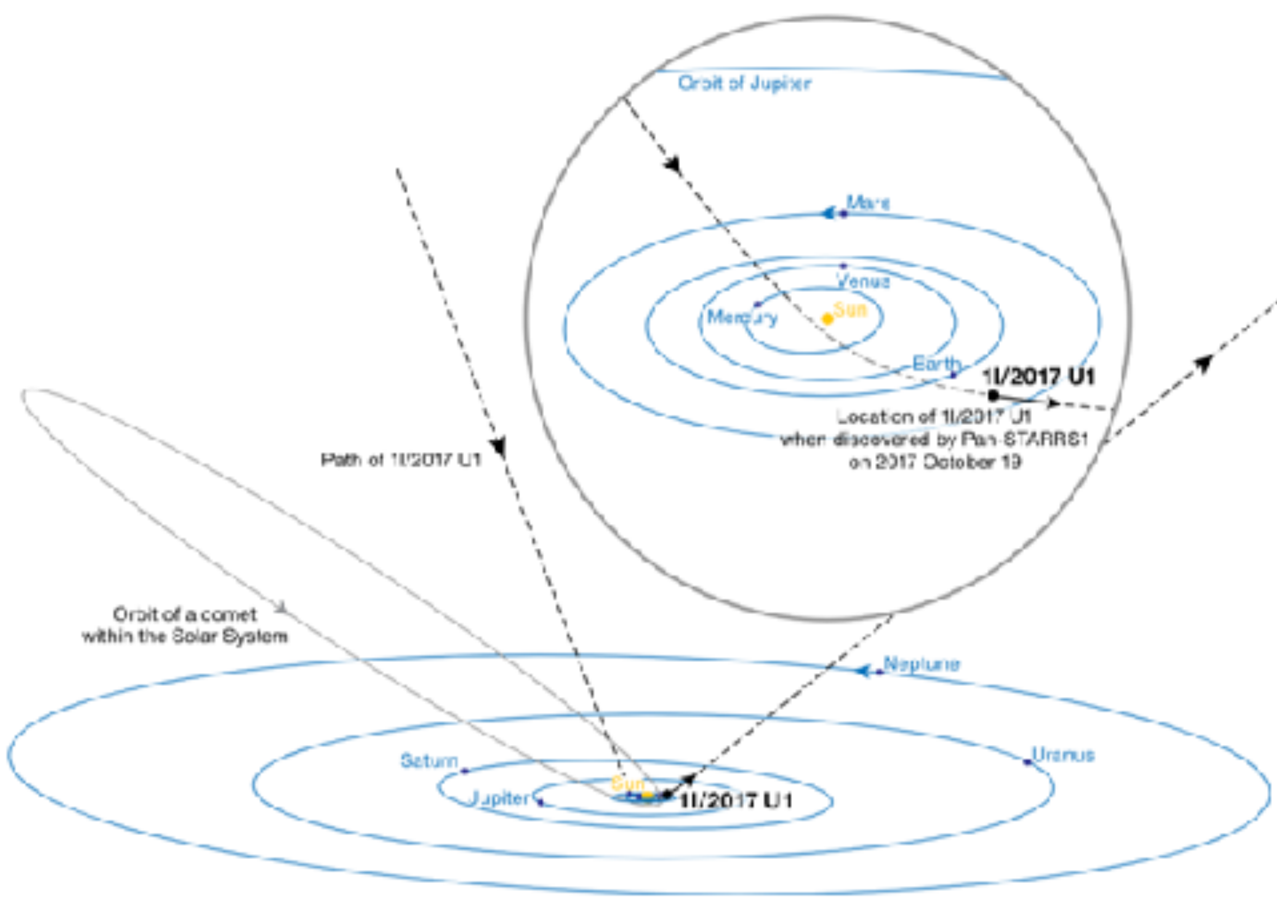
Tanaka et al. (2017), Suzuki (2018)

Interstellar objects (ISOs)

- The discovery of 1I/2017 U1 \`Oumuamua
- The first ISO
- No hint of cometary activity (asteroid or comet nucleus)
- Size ~ 100m
- High number density ~ 0.2 au^{-3} (Do et al. 2018)
- Metal pollution of Pop. III through collision with ISOs



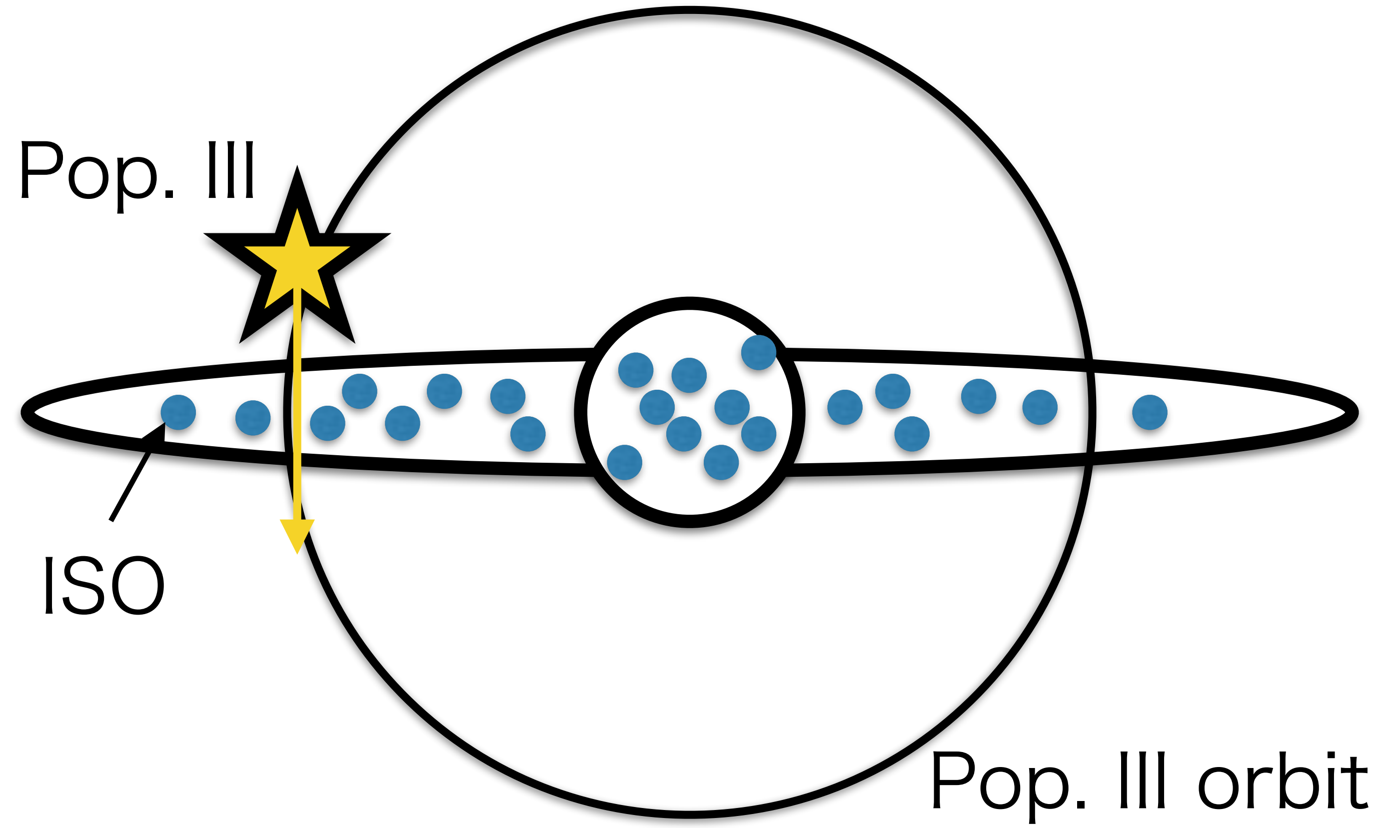
Meech et al. (2017)



Collision rate

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

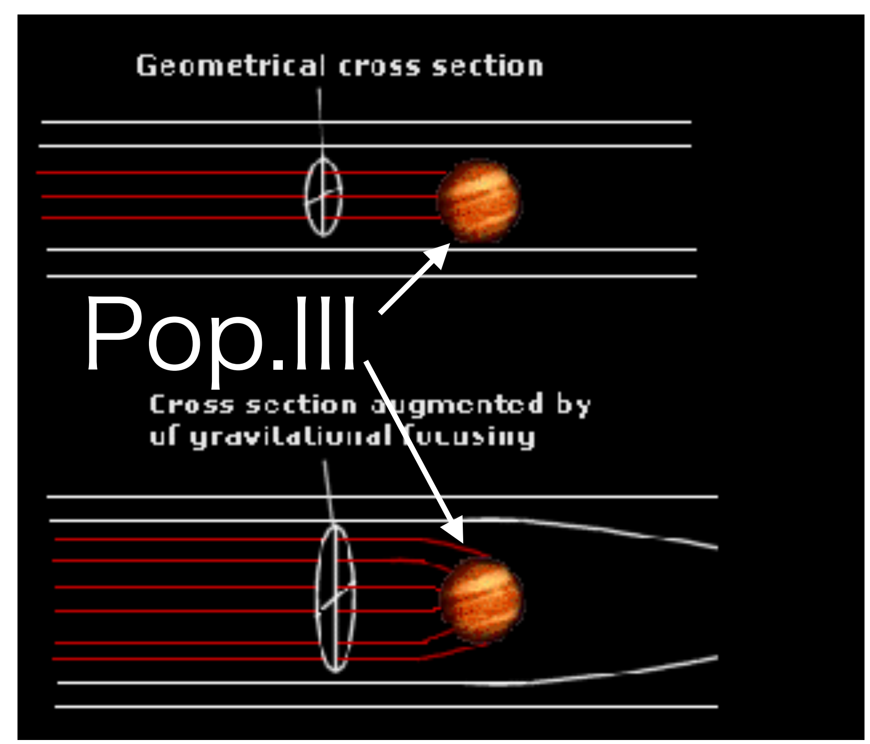
- f: fraction of ISO-rich regions in a Pop. III orbit
- n: ISO number density
- σ : cross section
- v: relative velocity between Pop. III and ISOs



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

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

Velocity at the distance

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

Time to reach a Pop. III survivor

$$t_\mathrm{orbit} \sim 3.0 \cdot 10^4 \text{ [s]}$$

Conduction time

$$t_\mathrm{cond} \sim \frac{D^2}{\kappa}$$

(D: ISO size, κ : Thermal conductivity)

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

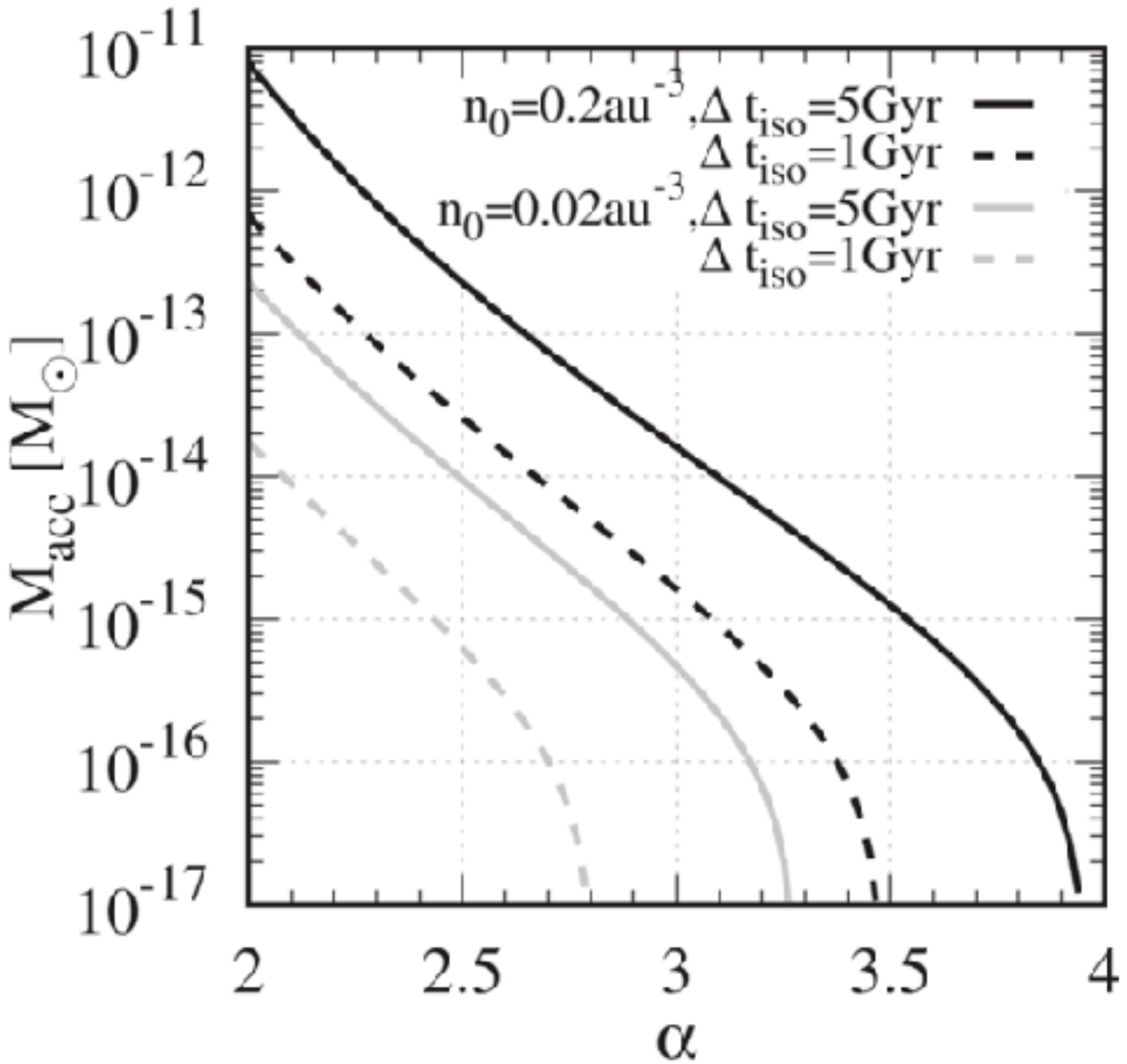
Cumulative size distribution of ISOs

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

- 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)

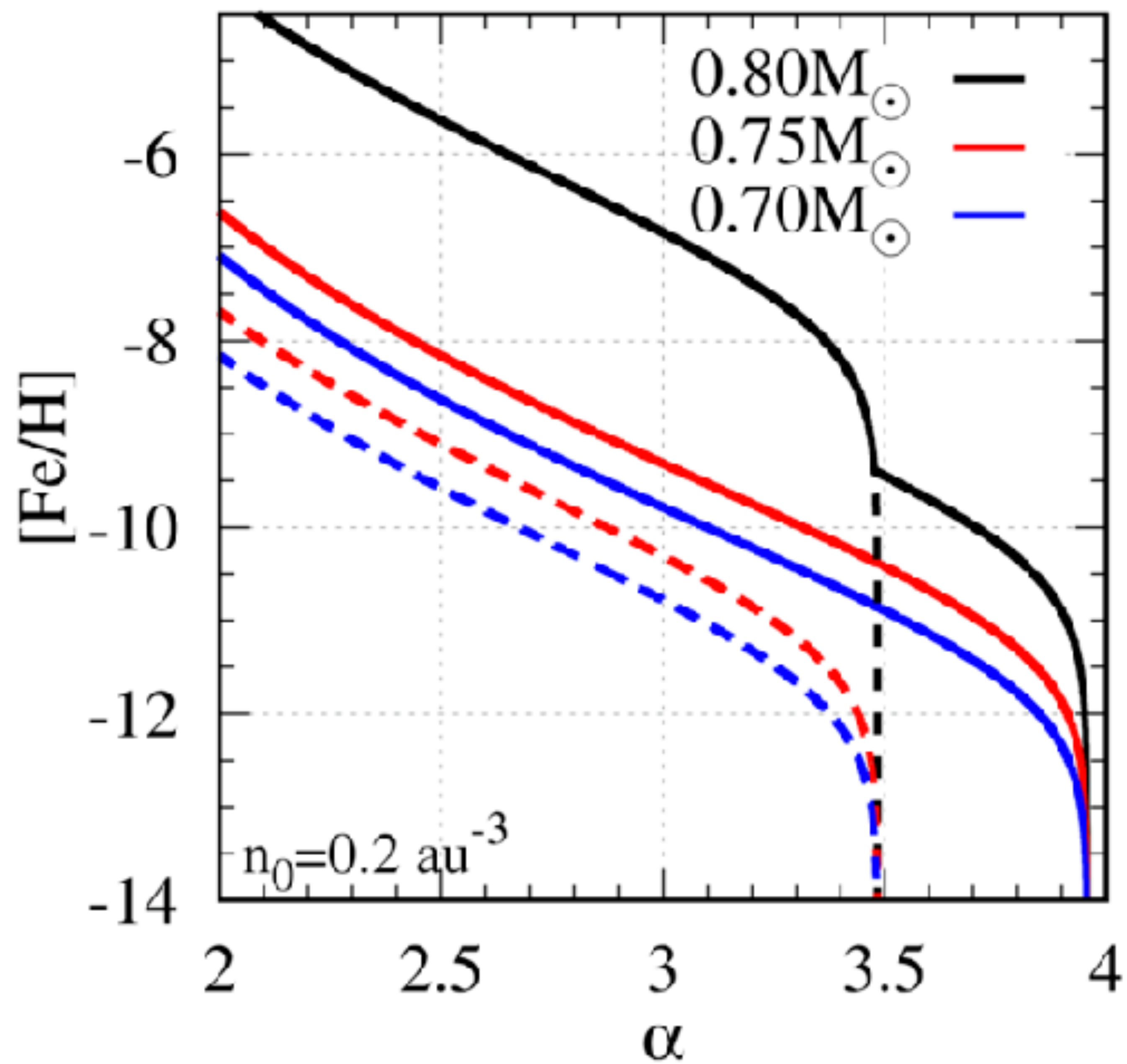
Accreting mass of ISOs

- Total accreting mass is 10^{-15}-$10^{-13}M_\odot$ in the fiducial model.
- ISM accreting mass is $10^{-19}M_\odot$, much smaller than ISO accreting mass.
- Even if ISO number density is smaller than estimated by an order of magnitude, ISO mass is much larger than ISM mass.
- ISOs are the most dominant polluter of Pop. III survivors.



Metallicity

- We assume the mass fraction of a surface convection zone as follows:
  - $0.80M_{\odot}$: $10^{-6.0}$
  - $0.75M_{\odot}$: $10^{-2.5}$
  - $0.70M_{\odot}$: $10^{-2.0}$
- Metallicity is comparable to EMP stars ([Fe/H] > -7) in the extreme case.
- Metallicity is less than EMP stars by several orders of magnitude in non-extreme cases.



Future work

- We re-estimate metallicity of Pop. III survivors polluted by interstellar cometary nuclei (interstellar asteroids in this talk).
- We investigate abundance pattern of polluted Pop. III survivors.
    - ISO size distribution
    - ISO abundance pattern
    - etc.

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.
- In the extreme case, Pop. III survivors could hide in EMP stars so far discovered.
- These results are published in Tanikawa, Suzuki, Doi (2018, PASJ, arXiv:1804.08200)
- In future work, we will derive the abundance pattern of Pop. III survivors polluted by ISOs.