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

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Direct observation of Population III stars (Pop. III stars) is important to understand the cosmic dawn era and Pop. III stars themselves. Pop. III stars can be explored in the Galaxy, since theoretical studies have predicted the formation of low-mass Pop. III stars that have their lifetimes of more than the Hubble time. We call such low-mass Pop. III stars "Pop. III survivors". In order to discover Pop. III survivors, we need to know their current metallicity. Pop. III survivors must be originally metal-free, and may be polluted, accreting interstellar medium (ISM). However, it have been shown that radiation pressure prevents the accretion of ISM dust [1], and that stellar wind prevents the accretion of ISM gas [2, 3]. The metallicity of Pop. III survivors polluted by ISM is estimated at [Fe/H] ~ -14 [2]. Pop. III survivors can be little polluted by ISM accretion.

We calculate accretion mass of interstellar objects (ISOs) like 'Oumuamua [4] onto Pop. III survivors, and estimate surface pollution of Pop. III survivors [5]. An ISO number density estimated from the discovery of 'Oumuamua is so high (~ 0.2 au^{-3}) that Pop. III survivors have chances at colliding with ISOs $\gtrsim 10^5$ times per 1 Gyr. In contrast, Pop. III survivors never collide with free floating planets and Pop. I/II stars in the Hubble time. 'Oumuamua itself would be sublimated if it approaches to Pop. III survivors, since it has small size, ~ 100 m. However, ISOs with size $\gtrsim 3$ km would reach the surfaces of Pop. III survivors. Supposing an ISO cumulative number density with size larger than D is $n \propto D^{-\alpha}$, Pop. III survivors can accrete ISO mass $\gtrsim 10^{-16} M_\odot$, or ISO iron mass $\gtrsim 10^{-17} M_\odot$, if $\alpha < 4$. This iron mass is larger than the accretion mass of ISM by several orders of magnitude. Taking into account material mixing in a convection zone of Pop. III survivors, we obtain their surface pollution is typically [Fe/H] $\lesssim -8$ in most cases, however the surface pollution of Pop. III survivors with $0.8 M_\odot$ can be [Fe/H] $\gtrsim -6$ because of the very shallow convective layer, if the ISO cumulative number density is shallow ($\alpha \sim 2.5$) up to $D \sim 10$ km. The dependence of the metal pollution is as follows. If $\alpha > 4$, Pop. III survivors have no chance at colliding with ISOs with $D \gtrsim 3$ km, and keep metal-free. If $3 < \alpha < 4$, Pop. III survivors would be most polluted by ISOs up to [Fe/H] ~ -7. If $\alpha < 3$ up to $D \sim 10$ km, Pop. III survivors could hide in metal-poor stars so far discovered. Although the metal pollution strongly depends on the power α, we first show the importance of ISOs for the metal pollution of Pop. III survivors.

References

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