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Stellar wind prevents the ISM gas from accreting onto the Pop III stars

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Abstract. Hyper Metal Poor (HMP) stars in our Galactic halo are often interpreted as the population III (pop III) stars covered by a slight amount of accreted heavy elements from ISM. However, in the case of the Sun, the solar wind maintains the heliosphere which prevents the ISM gas from accreting. We assess the effects of the stellar wind from main sequence pop III stars on the metal accretion onto the surface of them. As a result, we find the heavy elements are ionized by the stellar radiation to be picked up by the stellar wind, thus they cannot touchdown the stellar surface. This result strongly suggests that the HMP stars were born from the gas with a slight amount of metals, which preserves the information of the progenitor stars.

1. Introduction

Population III (pop III) stars, or zero-metallicity stars have been hunted for decades, but not been found. This fact provides a useful information on the formation theory of those stars. In fact, the analytic assessments and the numerical simulations predict the majority of the pop III stars should be very massive and they cannot survive until today (e.g., Susa et al. 2014). Hence, simple theory and the absence of zero-metallicity stars in observation seems to be consistent with each other. On the other hand, recent high resolution cosmological simulations suggest the possibility of the formation of low mass pop III stars. Thanks to the very high mass accretion rate onto the pop III protostar, a very heavy circumstellar disk around the primary protostar inevitably forms to fragment into several pieces. Some of them are ejected to less dense outer envelope of minihalos. As a result, the mass accretion onto these fragments could be very limited. If these stars do not grow more than $0.82M_{\odot}$, they can survive until present to be found by observations. In fact, theoretical interpretations based on the no-finding of these stars already put rather stringent constraint on the formation of such low mass pop III stars (e.g., Ishiyama et al. 2016). Another possible interpretation of the absence of the zero-metallicity star is that they do exist, but covered by the metals accreted from the ISM. Since the convective layer of such stars is thin ($\sim$ 0.1% in mass), only a small amount of metal accretion can increase the observed metallicity of the stars. On the other hand, when we look at our solar system, strong solar wind prevents the ISM gas from accreting. Considering the theoretical models of solar wind launching (e.g., Suzuki & Inutsuka 2005), it is natural to assume the presence of main sequence stellar wind even in the case of zero-metallicity stars. Thus, it is worth

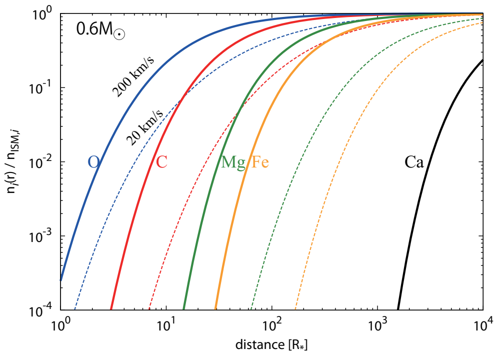

Fig. 1. Fraction of neutral atoms as functions of the distance from an $0.6M_{\odot}$ zero-metallicity star. Solid curves are for the relative velocity of ISM to the star is 200km/s, while the dashed curves are for 20km/s.

studying the metal accretion onto the pop III stars in the presence of stellar wind.

Metal accretion process under the presence of stellar wind can be understood in two different regimes, depending on the density of ISM. In the high density regime, the mass accretion rate is so large that the stellar wind cannot keep launching from the stellar surface. In this case, the gas can accrete from ISM at Bondi-Hoyle-Lyttleton accretion rate.

In the low density regime, stellar wind can push back against the accretion flow forming ionized bubble like heliosphere. The scale of the accretion flow is not so large that the hydrodynamics approximation is not valid for neutral particles. However, the ionized particles are well coupled with the magnetic field, and their gyration radii are very small. Thus, the ionized matter behaves hydrodynamically. In other words, neutral matter in ISM can accrete freely regardless of the presence of stellar wind. The critical density to split the two regimes could be estimated by the balance between the ram pressure of the stellar wind and the accreting matter (Talbot & Newman 1977; Johnson & Khochfar 2011). Assuming the properties of stellar wind as those of the solar wind, and relative velocity of the ISM and the star (200km/s), we obtain the critical density $n_{\rm crit} \sim 10^4 {\rm cm}^{-3}$ (Tanaka et al. 2017), although the actual accretion flow have more complicated configuration (Shima et al. 1985). Rigorous value of $n_{\rm crit}$ should be investigated by future simulations of Bondi-Hoyle accretion with stellar wind. In any case, the critical density is pretty high compared to the averaged density of the galaxy. In addition, the density of the accreting matter in cosmological galaxy formation simulation is less than $\sim 10^2 {\rm cm}^{-2}$ (Shen et al. 2017). Hence we do not consider the metal accretion in high density regime in this paper. In the low density regime, the key is the fraction of neutrals in the accreting matter, which should be calculated by the rate equations regarding the ionization processes, coupled with the infalling motion. Fig. 1 shows the neutral fraction for various species as functions of the distance from the stellar surface in case we consider $0.6M_{\odot}$ star. It is obvious that the iron atom is highly ionized in the vicinity of the star. Thus, very small fraction of accreting matter can touch down the stellar surface. Considering the cosmological mass accretion rate from the simulation and the mixing in the convective layer of the star, we obtain the expected metallicity of these stars. As a result, we find [Fe/H] is less than -10, which is much below the most iron deficient stars. Present results strongly suggests that the pop III stars should be observed as zero-metallicity stars if they exist, and the hyper metal poor stars are formed in the slightly metal enriched but not pristine environments.

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