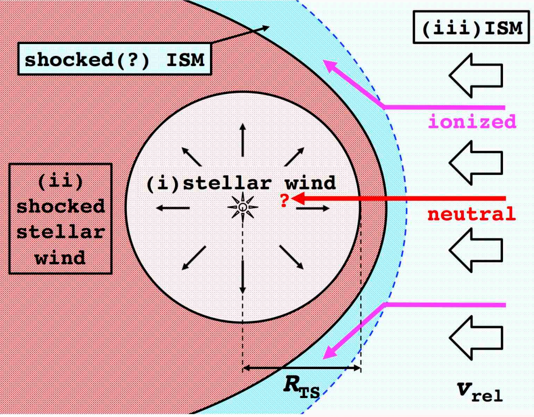


Tanaka, Chiaki, Tominaga, & Susa, ApJ, 844, 137 (2017)

# 恒星風による低質量初代星への星間金属降着の阻害

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with
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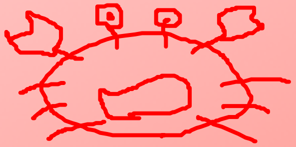


# Introduction

# Low-mass Population III Stars

- Study the initial mass function (IMF) of PopIII stars.
- Top-heavy PopIII IMF has been predicted, while some might have < 1 $M_{\odot}$

Nakamura&Umemura01

- Low-mass PopIII stars < 0.8$M_{\odot}$ are still in Main-sequence phase, if they exist.

Machida+13

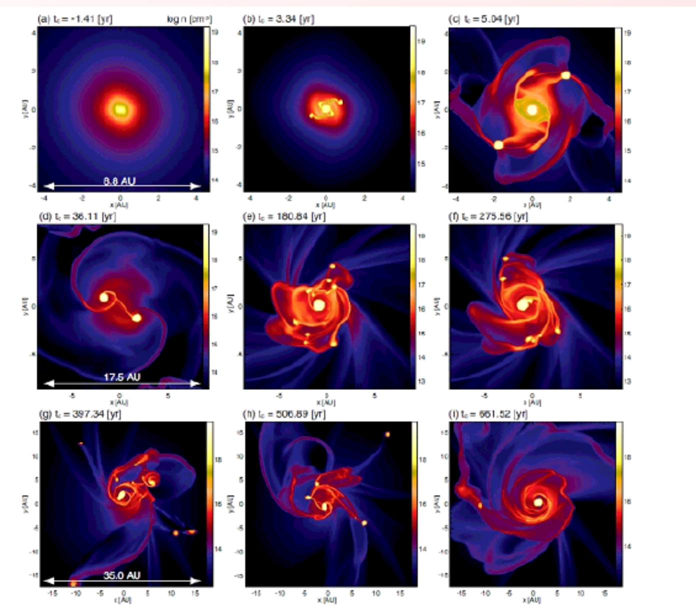
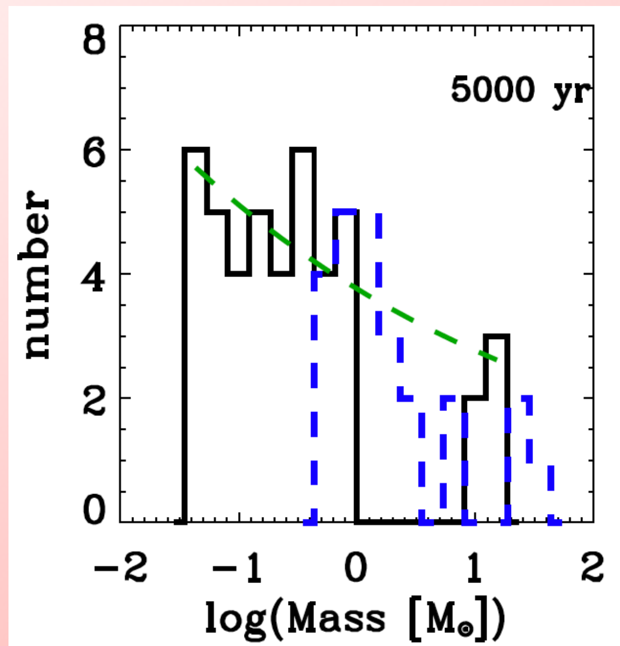
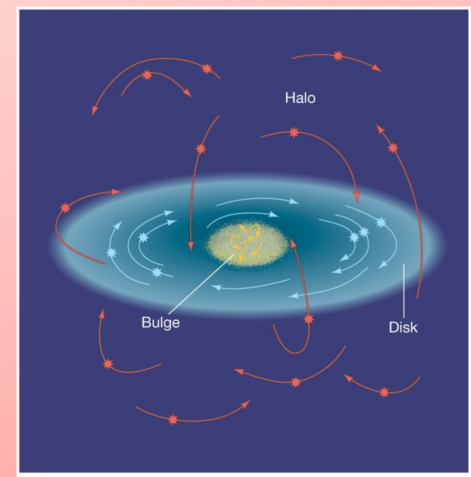


**Figure 6.** Time sequence images around the centre of the cloud for model 2. In each panel, the density (colour) distribution on the $z = 0$ plane is plotted. The box size is different in each row. Elapsed time after protostar formation is given in each panel.

Stacy+16




?

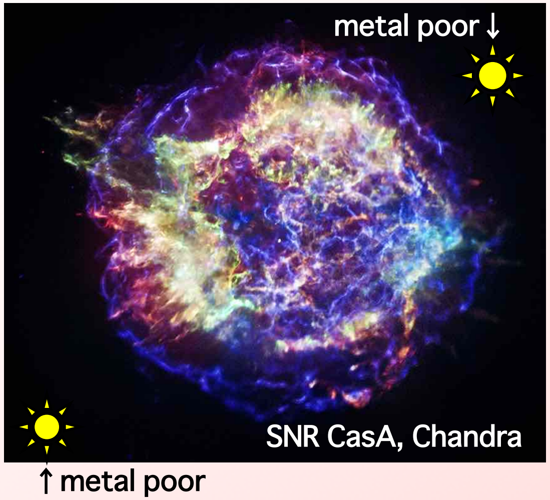



http://pages.uoregon.edu/jimbrau/astr123/

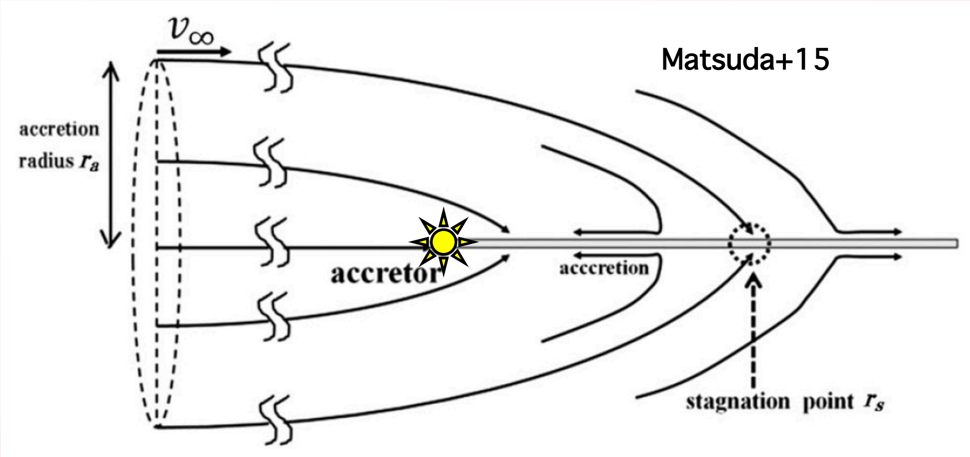
Can we find **low-mass PopIII stars as metal free star** in our Galactic halo?

# Origin of Metal Poor Stars

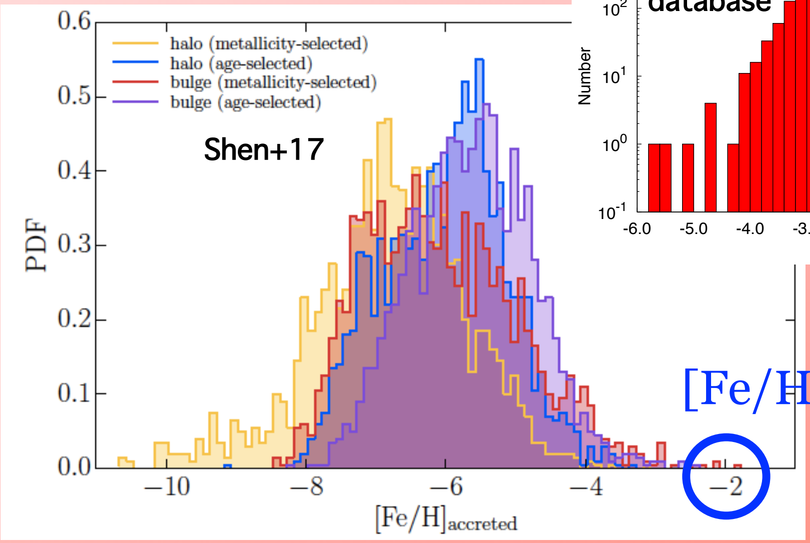
1. Second generation stars?

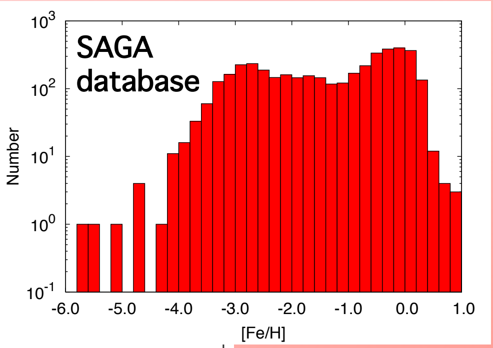



2. Chemically enriched PopIII stars?



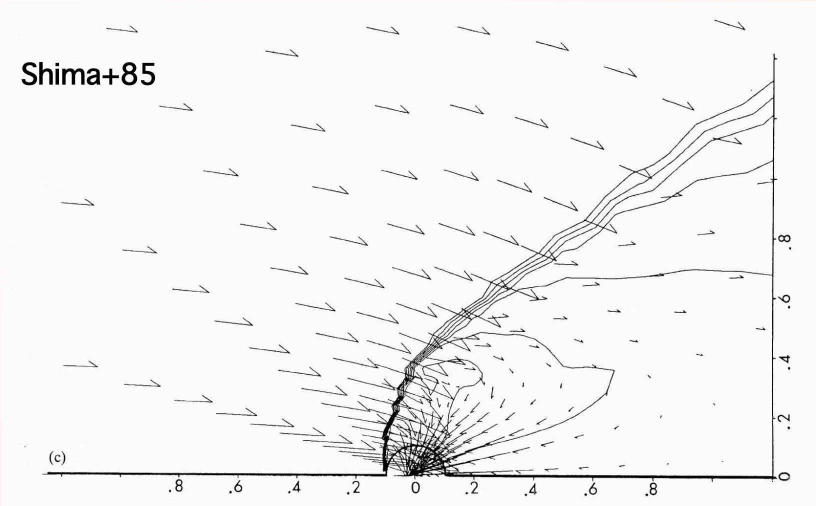

- Forget about scenario 1 (second generation hypothesis) in this study.
- Study of scenario 2 predicts [Fe/H] ~ -2 in an extreme case.



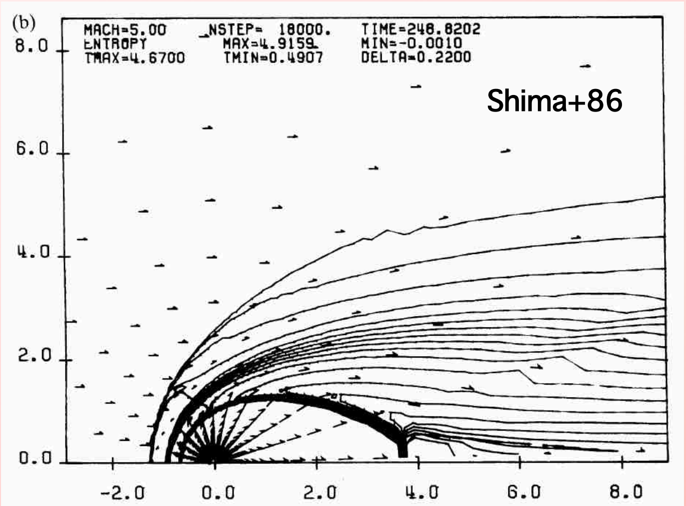
# Accretion or Wind?

Bondi-Hoyle-Lyttleton accretion

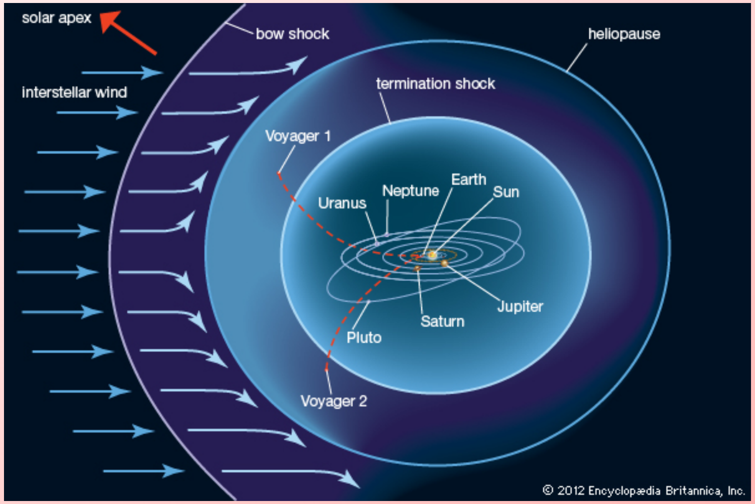


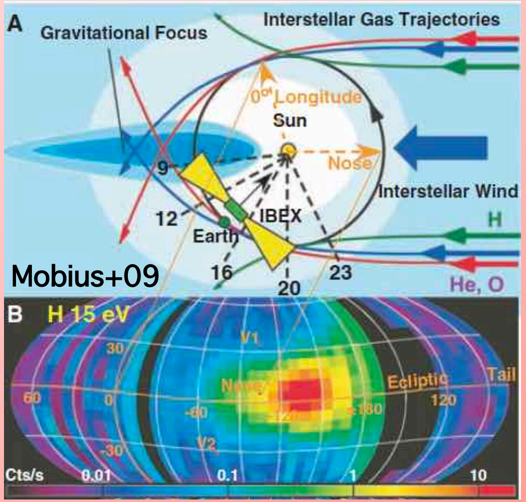

VS.

Formation of astrosphere




Case of our Sun: interstellar particles are picked up by the solar wind!!

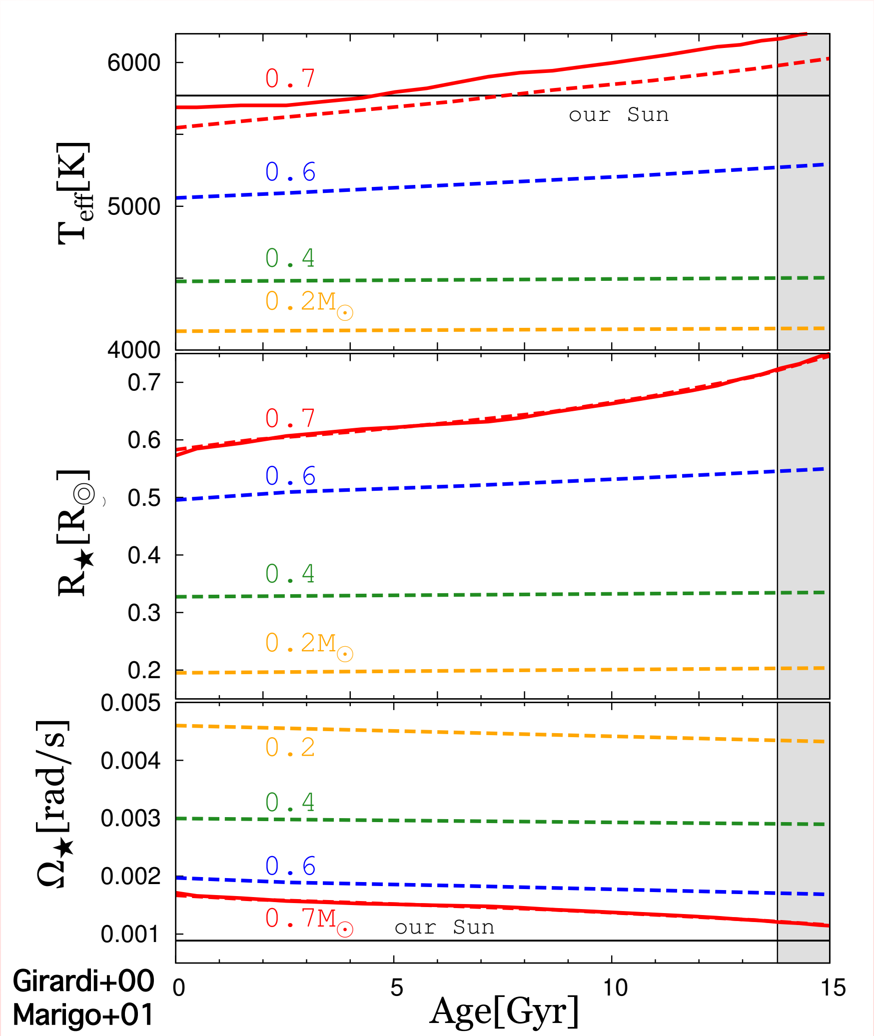



**Can interstellar heavy elements accrete onto low-mass PopIII stars against their wind?**

# Model

# Stellar Model




$$\frac{r_{\mathrm{g,FeII}}(R_\star)}{R_\star} \approx 10^{-5} \left(\frac{B_{\mathrm{sw}\star}}{1\ \mathrm{G}}\right)^{-1} \left(\frac{\Omega_{\mathrm{K}\star}}{10^{-3}\ \mathrm{rad\ s^{-1}}}\right),$$

Important parameters of low-mass PopIII stars

Effective temperature

- Photoionization of neutrals by blackbody

Stellar radius

- Photoionization of neutrals by EUV component

Kepler frequency @ stellar surface

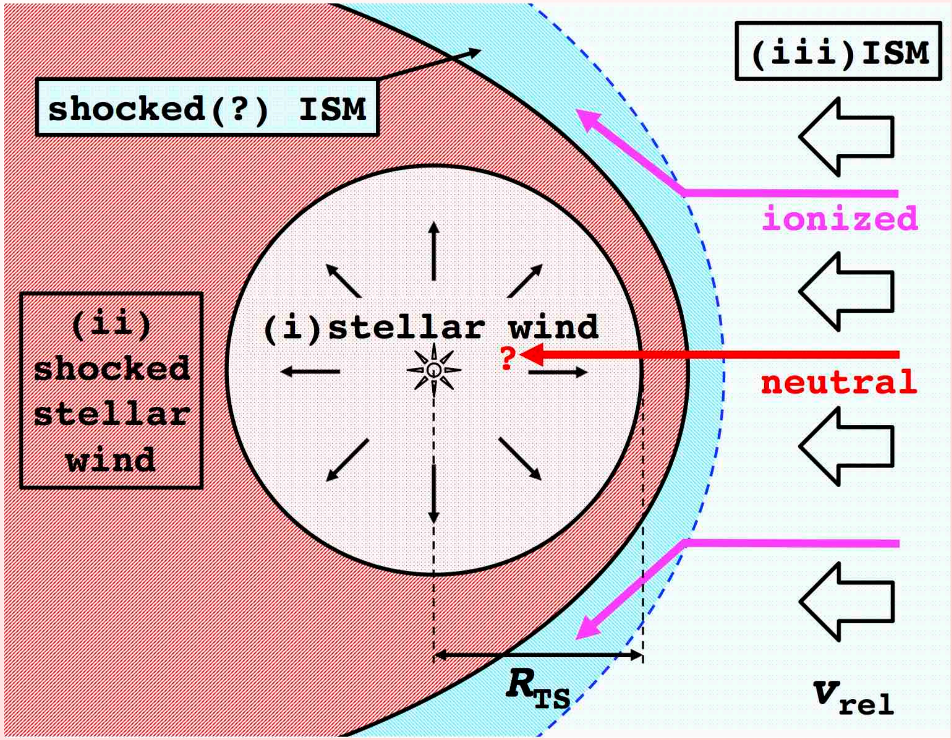
- Rate equation

Magnetic field

- Trapping photoionized neutrals

# Stellar Wind & ISM

The parameters of stellar wind are set to the Solar values.




(i) Thermal driven supersonic flow

$$n_{\rm sw}(r) = n_{\rm sw\star}\left(\frac{r}{R_\star}\right)^{-2}$$

$$v_{\rm sw}(r) = v_{\rm sw\star},$$

(iii) Bondi-Hoyle-Lyttleton accretion flow

$$n_{\rm HL}(r,\theta,\xi) = \frac{n_{\rm ISM}\xi^2}{r\sin\theta(2\xi - r\sin\theta)},$$

$$v_{{\rm HL},r}(r,\theta,\xi) = -\sqrt{v_{\rm rel}^2 + \frac{2GM_\star}{r} - \frac{\xi^2 v_{\rm rel}^2}{r^2}},$$

**Conditions for astrosphere formation around low-mass star?**

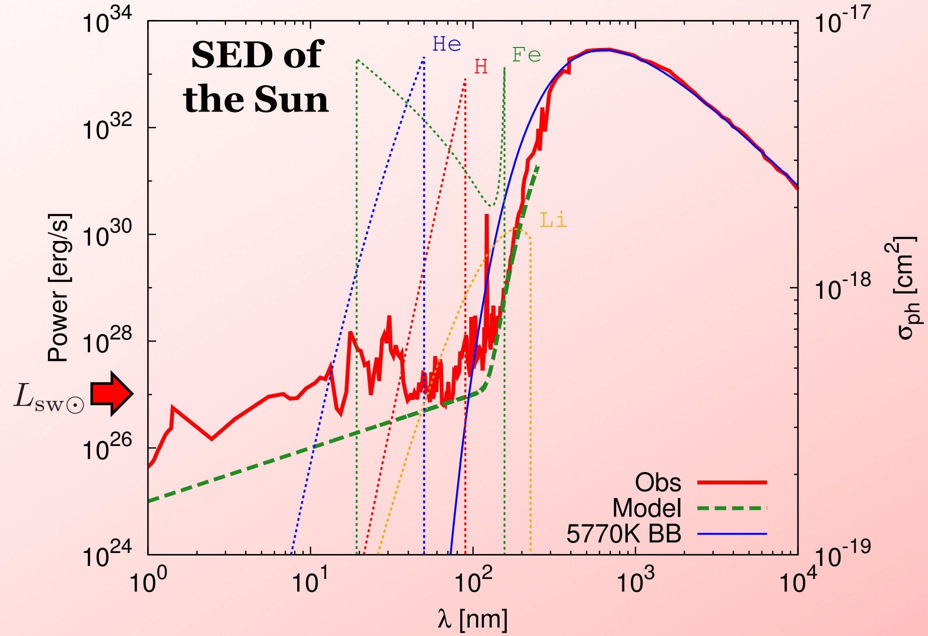
**Neutrals in the ISM behave different from ionized ones!!**

# Stellar Radiation

Photoionization by stellar radiation.
(c.f., charge exchange & electron impact may also work)

Absorbed black body + EUV emission.

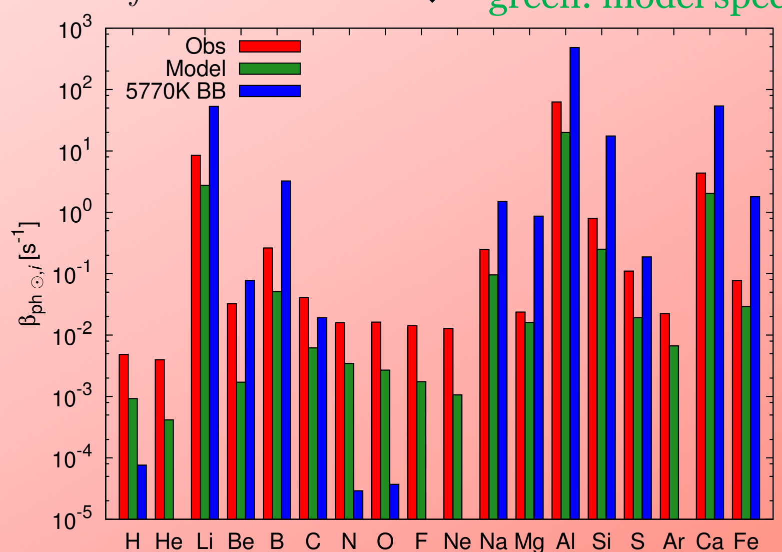
Lines from heavy elements    Related with the wind (?)




**Photoionization rate**

$$\beta_{\mathrm{ph},i}(r) = \int d\lambda \dot{N}_\lambda(r)\sigma_{\mathrm{ph},i}(\lambda)$$

Case for the Sun
red: observed spectrum
green: model spectrum




Assumption:
PopIII stars have unabsorbed blackbody spectrum & also have the EUV component of the similar power to the Sun.

$$\pi J_{\lambda\star} = \pi B_\lambda(T_{\mathrm{eff}}) + \frac{L_{\mathrm{EUV}}}{4\pi R_\star^2}$$

Taken from model of zero or low-metallicity stars

Girardi+00, Marigo+01

# Rate Equation

Ionization of interstellar neutrals

$$v(r)\frac{dn_i(r)}{dr} = -\beta_{\mathrm{ph},i}(r)n_i(r) + \alpha_{\mathrm{rec},i}n_{\mathrm{e}}n_i(r)$$

Recombination processes can be neglected.

$$v(r) = -\sqrt{v_{\mathrm{rel}}^2 + \frac{2GM_\star}{r}}$$

Motion of neutrals in gravitation field

$$\beta_{\mathrm{ph},i} \propto r^{-2}$$

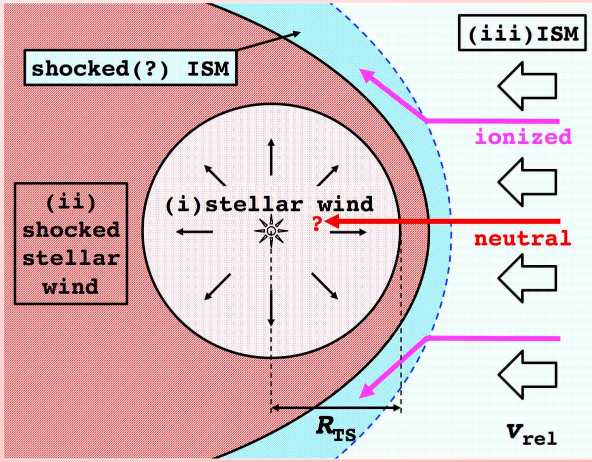
$$\frac{n_i(r)}{n_{\mathrm{ISM},i}} = \exp\left[-\frac{\sqrt{2}\beta_{\mathrm{ph}\star,i}}{\Omega_{\mathrm{K}\star}}\left(\sqrt{\frac{v_{\mathrm{rel}}^2}{v_{\mathrm{esc}\star}^2} + \frac{R_\star}{r}} - \frac{v_{\mathrm{rel}}}{v_{\mathrm{esc}\star}}\right)\right]$$

# Results

# Formation of Magnetosphere

Pressure balance between accretion and wind flows.

$$n_{\mathrm{sw}\star} v_{\mathrm{sw}\star}^2 \left(\frac{R_\star}{R_{\mathrm{TS}}}\right)^2 \approx n_{\mathrm{ISM}} \left(v_{\mathrm{rel}}^2 + v_{\mathrm{esc}\star}^2 \frac{R_\star}{R_{\mathrm{TS}}}\right) .$$




For ($R_\star <$) $\xi_{\mathrm{BHL}} < R_{\mathrm{TS}}$

c.f., Talbot&Newman77

$$\xi_{\mathrm{BHL}} = \frac{2GM_\star}{v_{\mathrm{rel}}^2} = R_\star \frac{v_{\mathrm{esc}}^2}{v_{\mathrm{rel}}^2}$$

$$n_{\mathrm{crit}} \equiv \frac{n_{\mathrm{sw}\star}}{2} \frac{v_{\mathrm{sw}\star}^2 v_{\mathrm{rel}}^2}{v_{\mathrm{esc}\star}^4}$$

$$\approx 10^4 \ \mathrm{cm}^{-3} \left(\frac{n_{\mathrm{sw}\star}}{7.0\times10^5 \ \mathrm{cm}^{-3}}\right) \left(\frac{v_{\mathrm{sw}\star}}{400 \ \mathrm{km \ s}^{-1}}\right)^2 \left(\frac{v_{\mathrm{rel}}}{200 \ \mathrm{km \ s}^{-1}}\right)^2 \left(\frac{v_{\mathrm{esc}\star}}{680 \ \mathrm{km \ s}^{-1}}\right)^{-4}$$

Solar wind value | Average of halo stars (e.g., Chiba&Beers00) | 0.7 $M_\odot$ PopIII star

$$\dot{M}_{\mathrm{BHL}} = \frac{2\pi G^2 M_\star^2 \rho_{\mathrm{ISM}}}{(c_s^2 + v_{\mathrm{rel}}^2)^{3/2}}$$

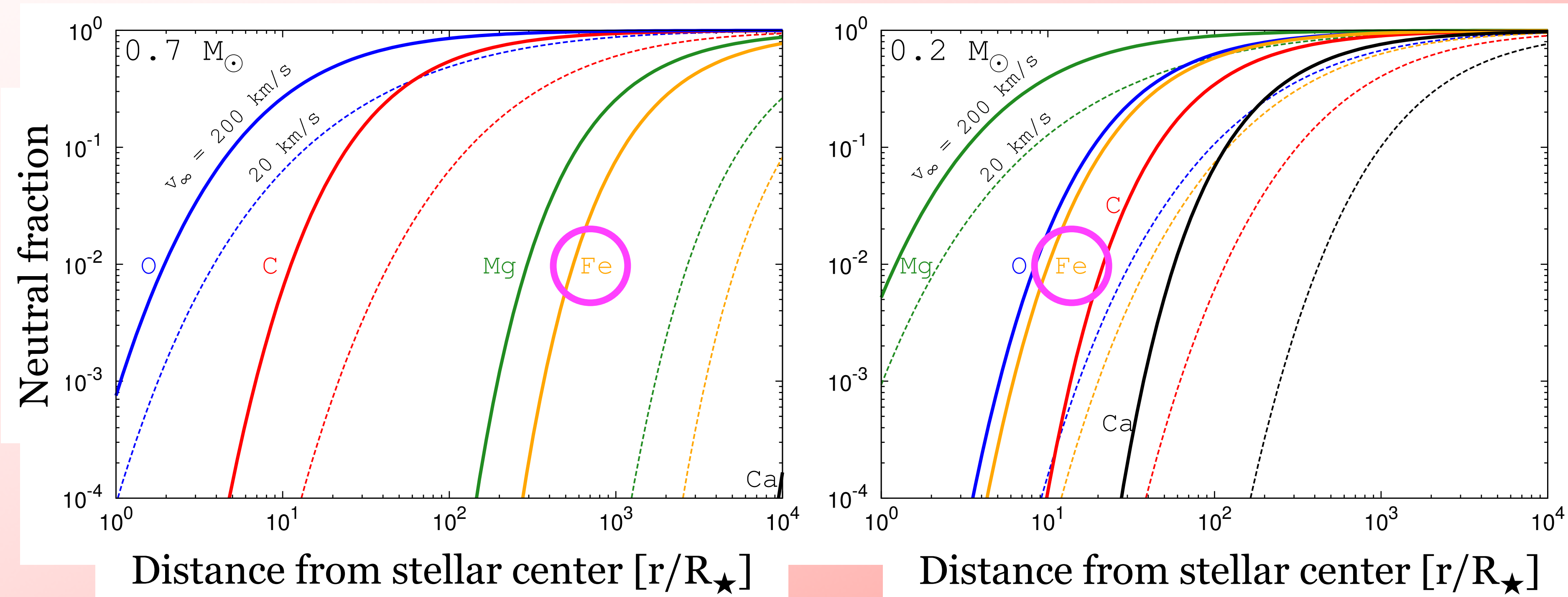
Volume fraction of $n_{\mathrm{ISM}} > n_{\mathrm{crit}}$ is very small even at Gal. disk.

=> **Magnetosphere is sustained!!**

# Survival Probability

Neutral fraction at given radius.

$$\frac{n_i(r)}{n_{\mathrm{ISM},i}} = \exp\left[-\frac{\sqrt{2}\beta_{\mathrm{ph}\star,i}}{\Omega_{\mathrm{K}\star}}\left(\sqrt{\frac{v_{\mathrm{rel}}^2}{v_{\mathrm{esc}\star}^2}+\frac{R_\star}{r}}-\frac{v_{\mathrm{rel}}}{v_{\mathrm{esc}\star}}\right)\right]$$




**Iron hardly attains stellar surface**

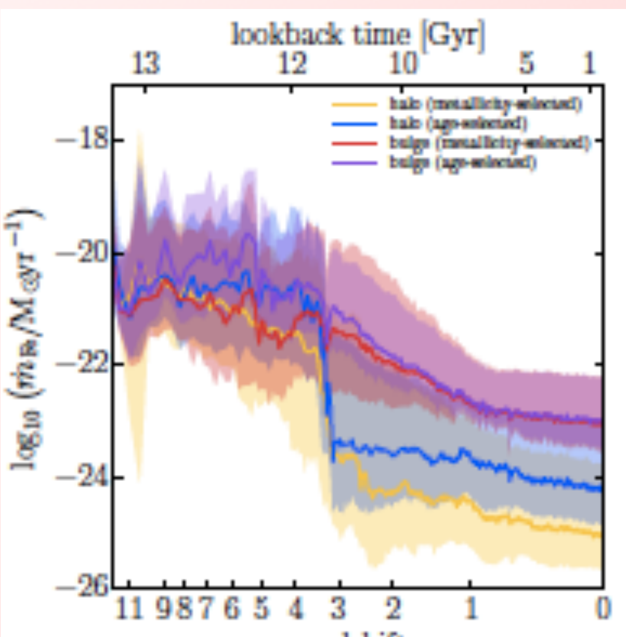
# Discussion & Conclusions

# Accretion from $n > n_{\mathrm{crit}}$

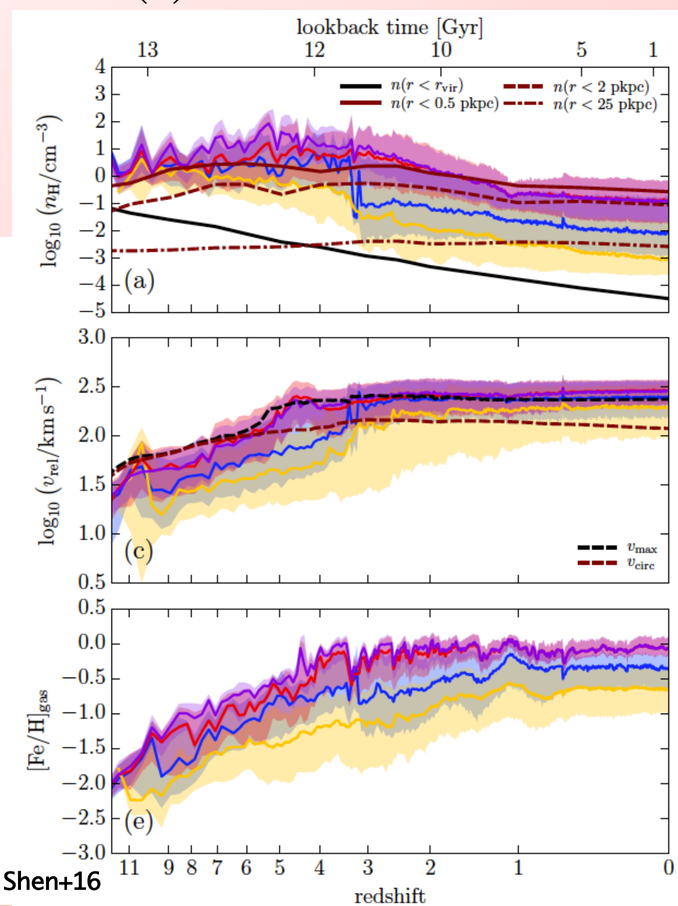
Density probability distribution *P(n, t)* and metallicity distribution *Z(n, t)*

$$M_{Z,\mathrm{acc}} = \int dt \int_{n_{\mathrm{crit}}(t)}^{\infty} dn P(n,t) Z(n,t) \dot{M}_{\mathrm{BHL}}(n,t).$$

Accretion @ high-z is dominant because $\dot{M}_{\mathrm{BHL}} \propto (v_{\mathrm{rel}})^{-3}$



Shen+17



Shen+16

Shen+16 set $n_{\mathrm{crit}} = 0$, i.e., no wind and always $n < 10^2$ cc$^{-1}$! (difficult to resolve $n > 10^2$ cc$^{-1}$ numerically.)

Johnson & Khochfar11 estimated that the probability of encounter of a star and a cloud at high-z is less than 0.1. [Fe/H]~-6 for one encounter.

# Conclusions & Further Studies

Conclusions

- [Fe/H] is reduced by photoionization ([Fe/H] < -14 even for extreme case).
- Currently observed metal poor stars are not low-mass PopIII stars.
- Low-mass PopIII stars will be found as metal free stars or current observations have already constrained PopIII IMF.
- Metal poor stars preserve their initial metallicity.

Further Studies

- Metal accretion in dust phase (however, Johnson2015).
- Binary case.
- Stellar wind from low-mass PopIII stars (Suzuki17)
- Bondi-Hoyle-Lyttleton accretion with stellar wind
  - Used $n_{\mathrm{crit}}$ may be over-simplified because we consider 1D trajectory.