２次元輻射流体計算による 低金属度大質量星形成

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1.Introduction

Low-Metallicity Massive Star

- Crucial Roles for Galaxies

  HII region formation, Supernovae,
  re-ionization of universe ..

- Chemical Evolution

  heavy elements are ejected in SN explosion

- Sources of Binary Black Hole

- Maximum mass

  in the Galaxy

  $$\sim 150 M_\odot$$

  in LMC

  $$> 300 M_\odot$$

  (Crowther 2010)

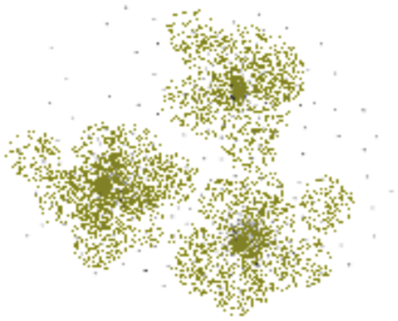
How massive stars are formed?

The Maximum Mass of Stars?

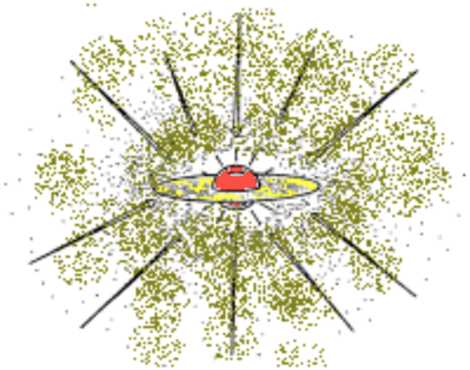
in Low-Metallicity Environment

The Standard Scenario of Star Formation

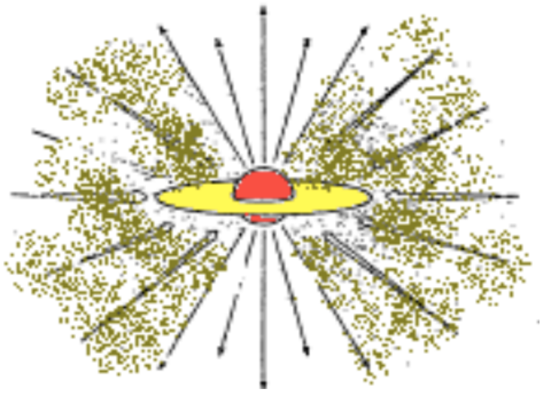
(1) Dense cores forms within molecular clouds.



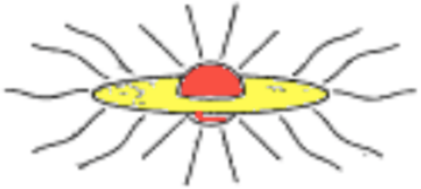
(2) A protostar forms at the center of a core, growing by accretion of ambient matter.



(3)A stellar wind breaks out, creating a bipolar flow



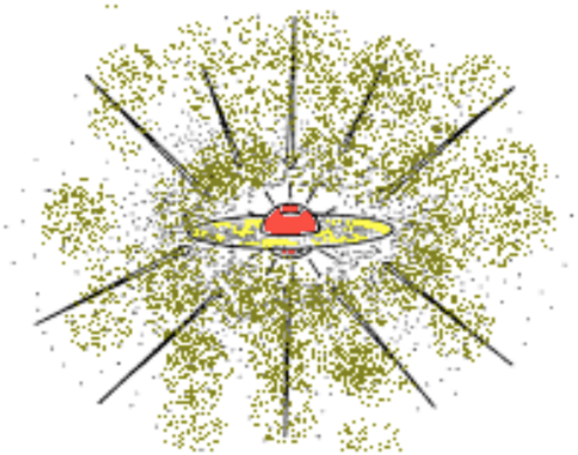
(4) The infall terminates, revealing a newly formed with a disk.



Shu, Adams & Lizano(1987)

Massive Star Formation Scenario

mass accretion phase



Stellar luminosity grows and impacts accretion flow

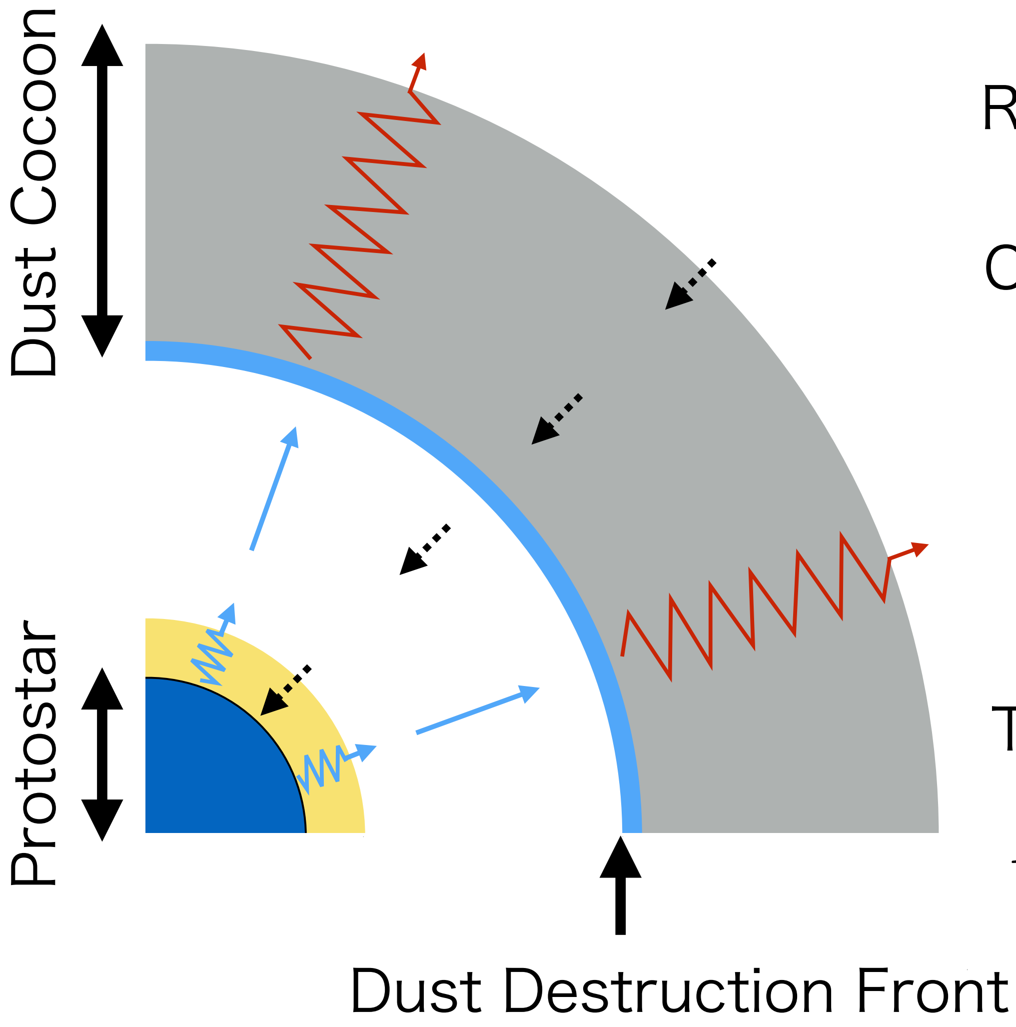
$M_* \nearrow \quad L_* \uparrow$

➡ **Radiation Feedback Limits Stellar Mass ?**

2. Radiation Feedbacks

Radiation Pressure Barrier (Wolfire & Cassinelli 1987)

accretion envelope structure



Radiation Pressure $\frac{L}{4\pi r^2 c}$

Ram Pressure ρu^2

Condition for Mass Accretion

$$\boxed{\rho u^2 > \frac{L}{4\pi r^2 c}}$$

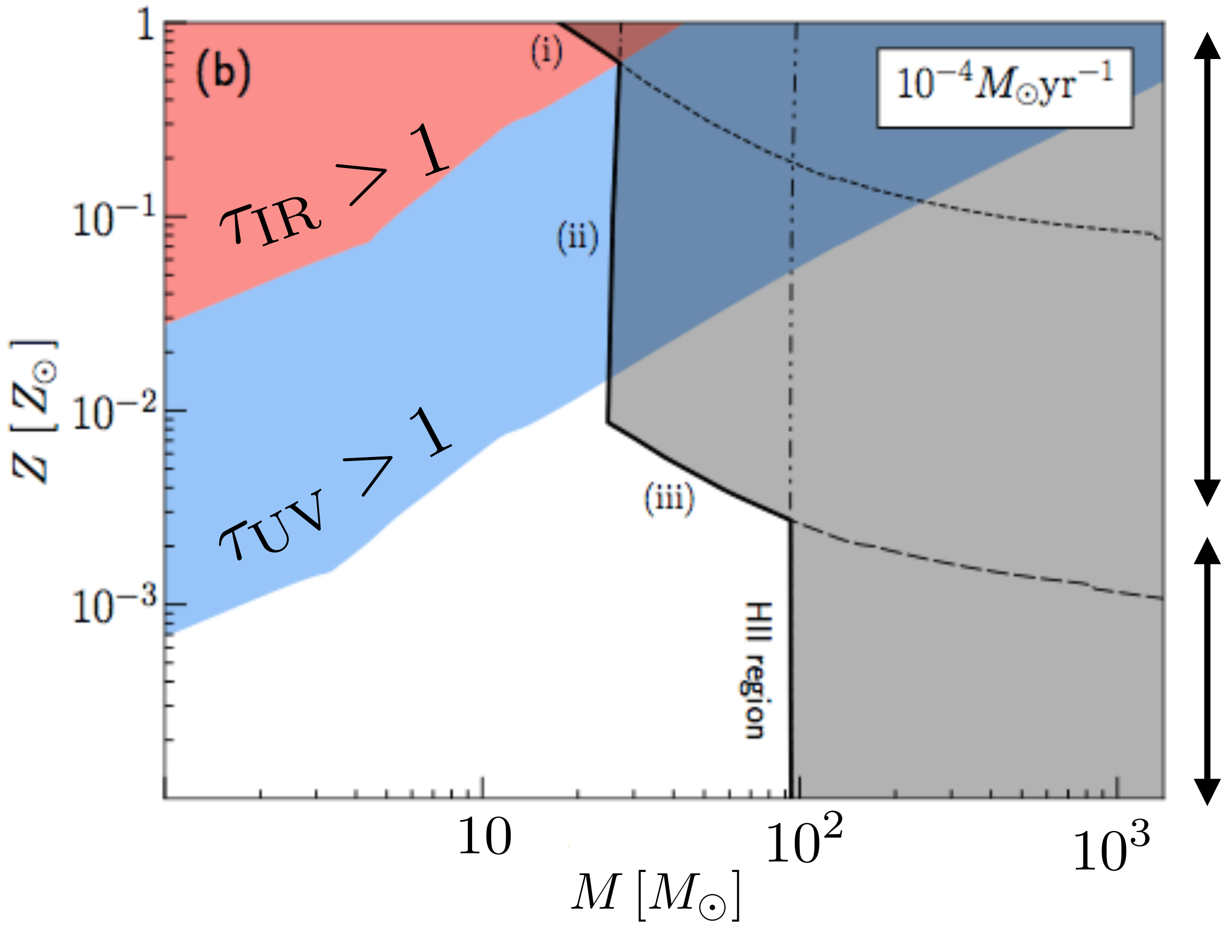
The upper mass limit

$M \sim 20\ M_\odot$

with $\dot{M} = 10^{-4}\ M_\odot \mathrm{yr}^{-1}$

The upper mass limits (1D)

e.g., $10^{-4} M_\odot \mathrm{yr}^{-1}$



radiation pressure
in dust cocoon

HII region

(Hosokawa & Omukai 2009,
HF et. al 2018)

Solid line: the upper mass limits

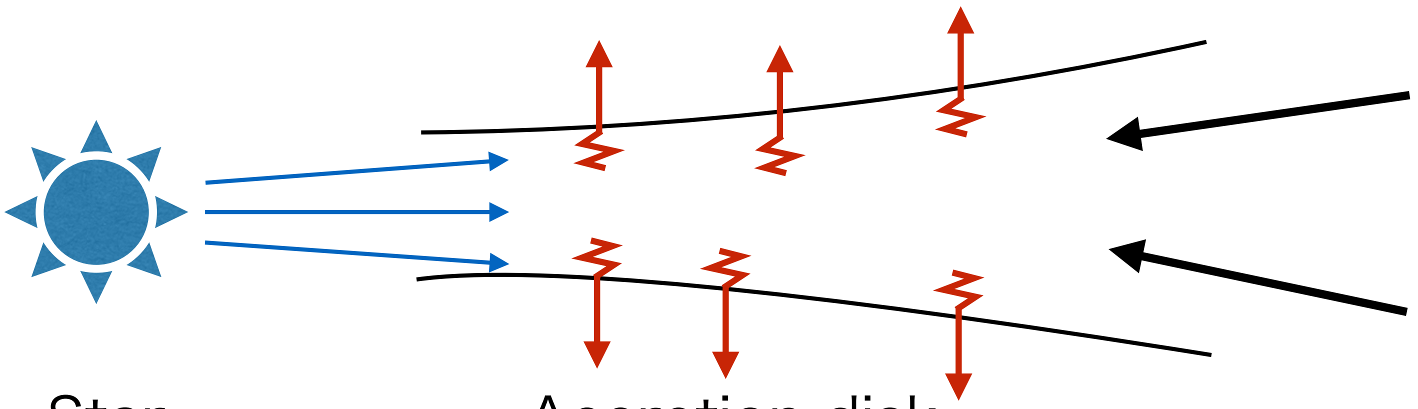
(i) $L_* > L_{\rm Edd} = \dfrac{4\pi c G M}{\kappa_{\rm IR}}$ (ii) $\dfrac{L_*}{4\pi r_{\rm d} c} > \rho u^2$ (iii) $L_* > L_{\rm Edd} = \dfrac{4\pi c G M}{\kappa_{\rm UV}}$

$\tau_{\rm IR}, \tau_{\rm UV}$: optical depth for IR and UV light

Multidimensional effect

Mass accretion continues through the accretion disk

(Flash light effect; Yorke & Bodenheimer 1999; Krumholz et al. 2009; Kuiper et al. 2010; Klaassen et al. 2016; Rosen et al. 2016)

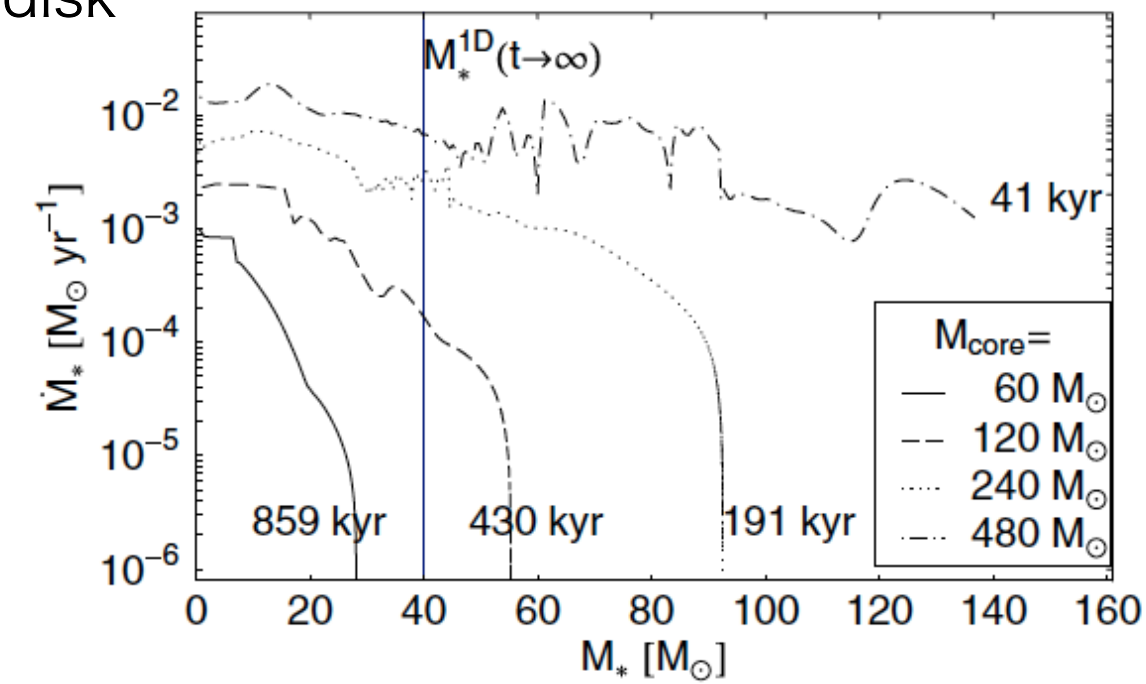


accretion flow

Star

Accretion disk

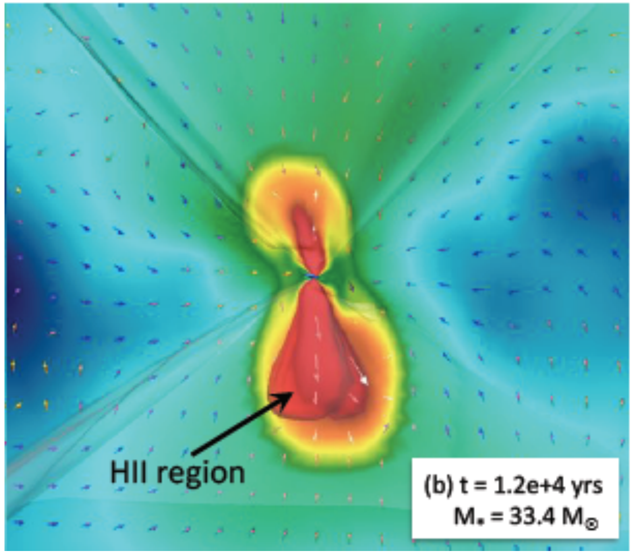
(Kuiper et al. 2010)



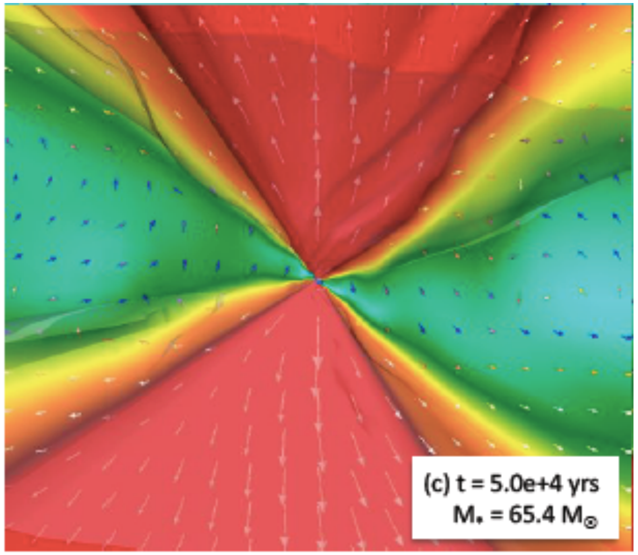
Massive star larger than $20M_\odot$ can form

Formation of HII regions and Photoevaporation of accretion disks

HII region expansion



photoevaporation of accretion disk



(Hosokawa et al. 11, 16, McKee & Tan 2008)

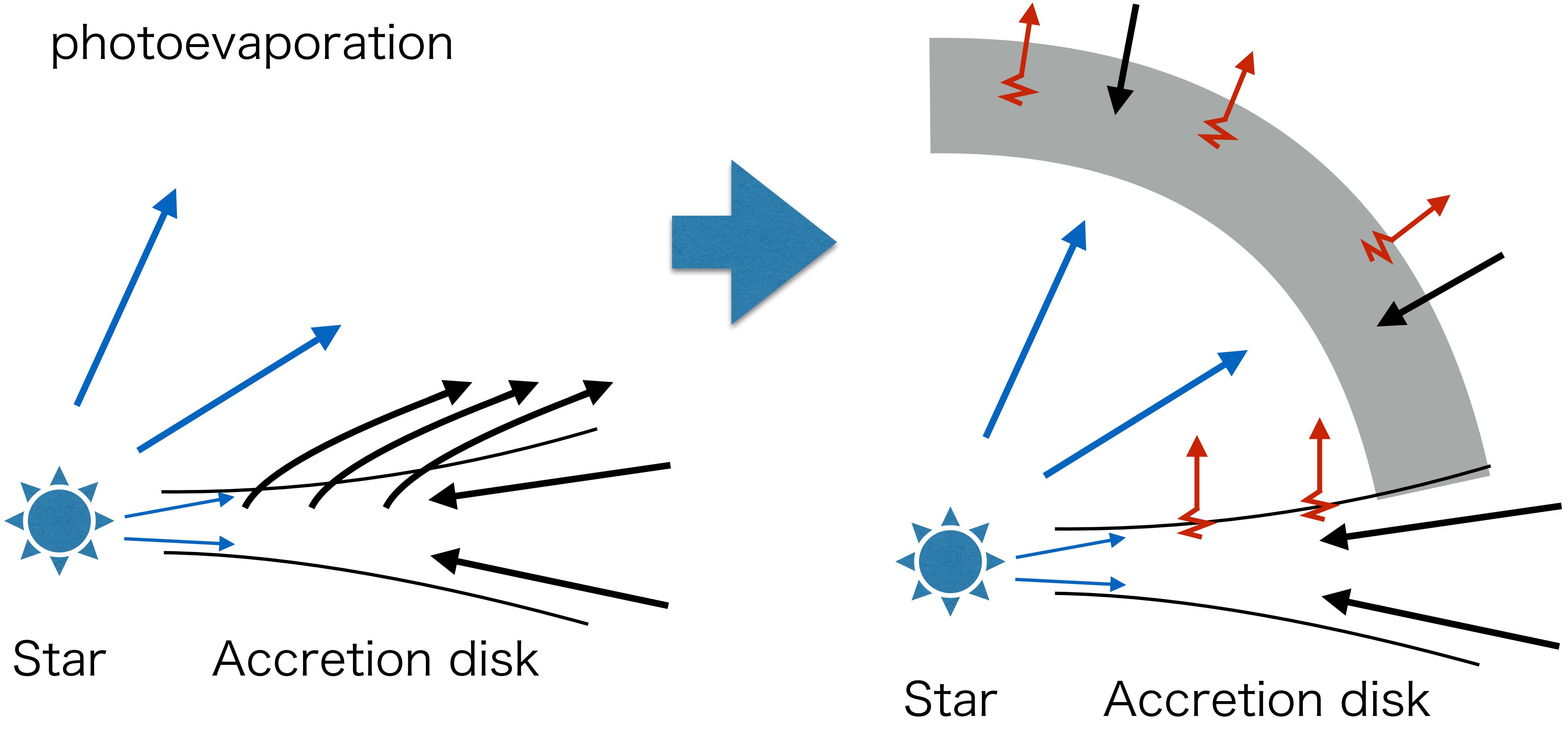
- photoevaporation rate

$$\dot{M}_{\rm evap} = 2 m_{\rm H} c_{\rm s} \int_{r_{\rm g}}^{\infty} 2\pi n(r) r dr$$

gravitational radius

$$r_{\rm g} = \frac{GM}{c_{\rm HII}^2}$$

What radiation feedback dominates in low metallicity environment ?



$Z = 0$

HII region formation &
photoevaporation

$1Z_{\odot}$

Radiation pressure
on dust grains?

3. Method and Calculations

Method (Modified version of Nakatani et al. 2017)

Hydrodynamics (2D, PLUTO 4.1)

+ Self Gravity , alpha viscosity (Kuiper et al. 2010)

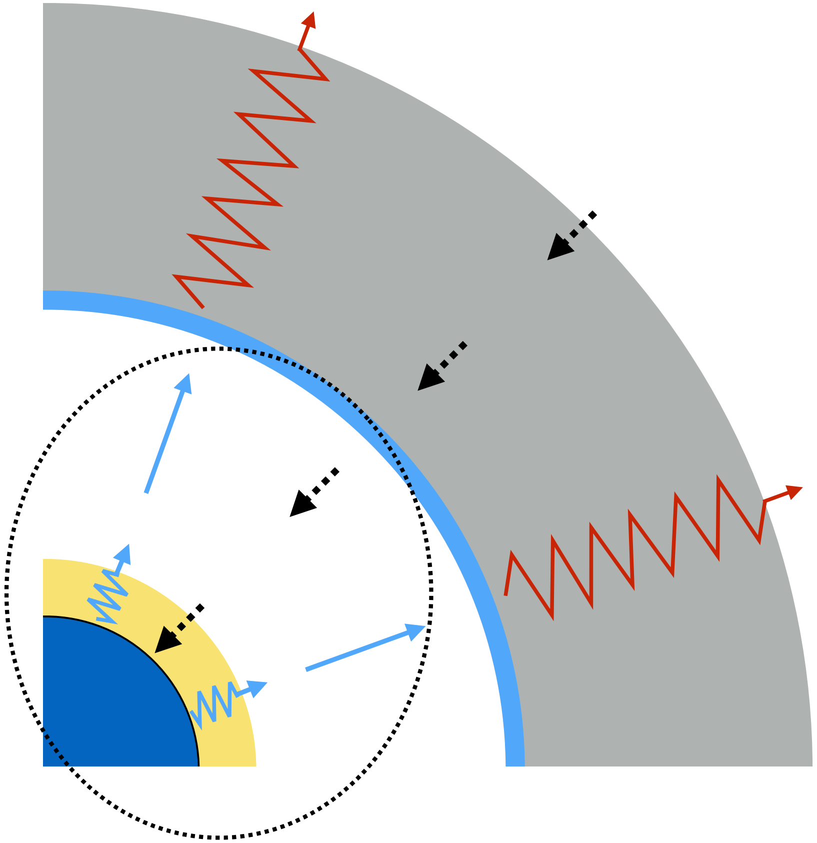
+ non equilibrium Chemistry

+ Radiation Transfer of Direct stellar light

not included

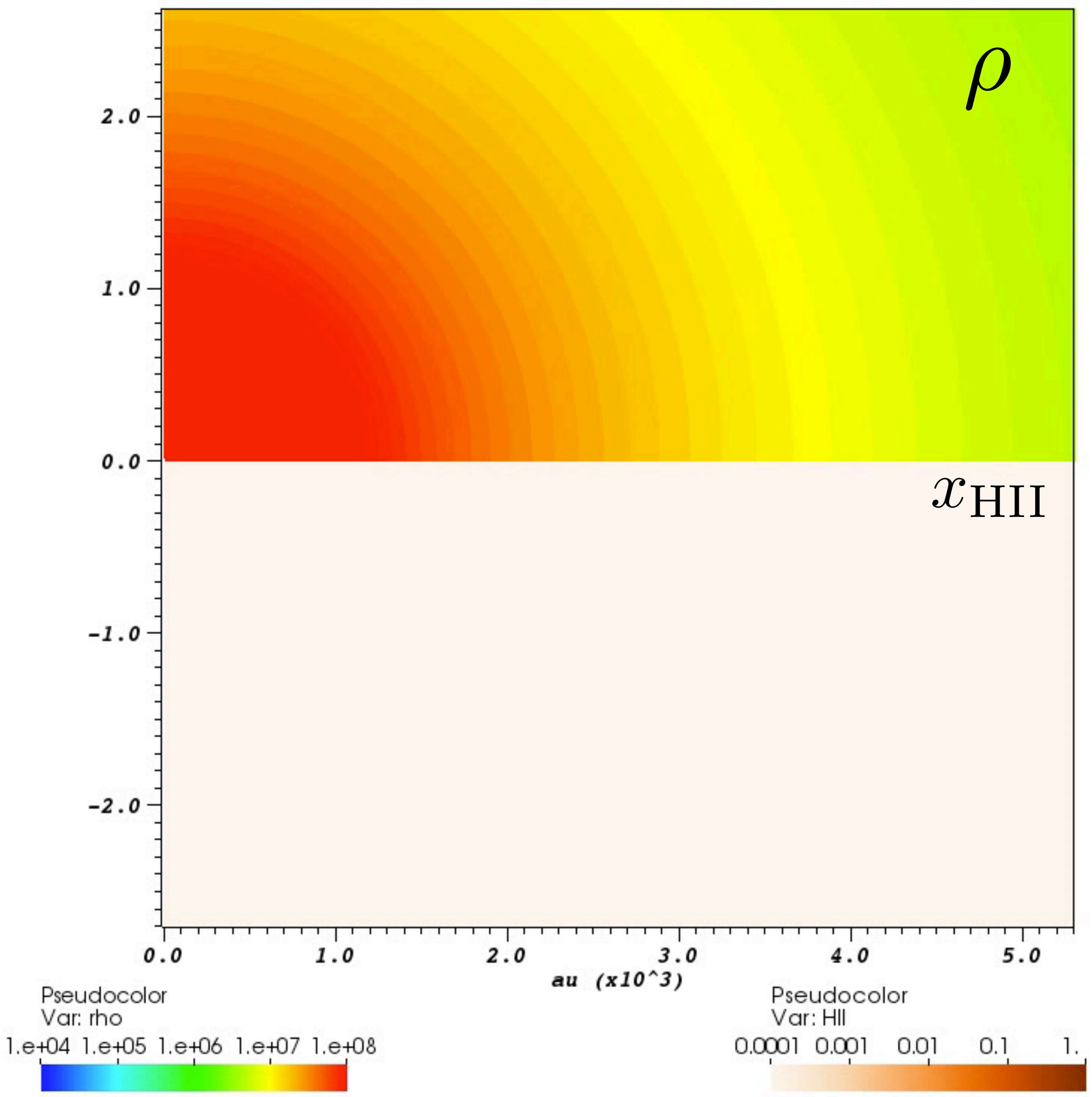
+ FLD (Kuiper et al. 2010)

+ stellar evolution



Now, we can treat radiation transfer inside the dust destruction front

Accretion Phase



$$Z = 10^{-2} Z_\odot$$

Initial Condition

$$M_{\mathrm{core}} = 100\ M_\odot$$

$$R_{\mathrm{core}} = 0.1\ \mathrm{pc}$$

$$\rho \propto r^{-2} \quad \Omega \propto r^{-1}$$

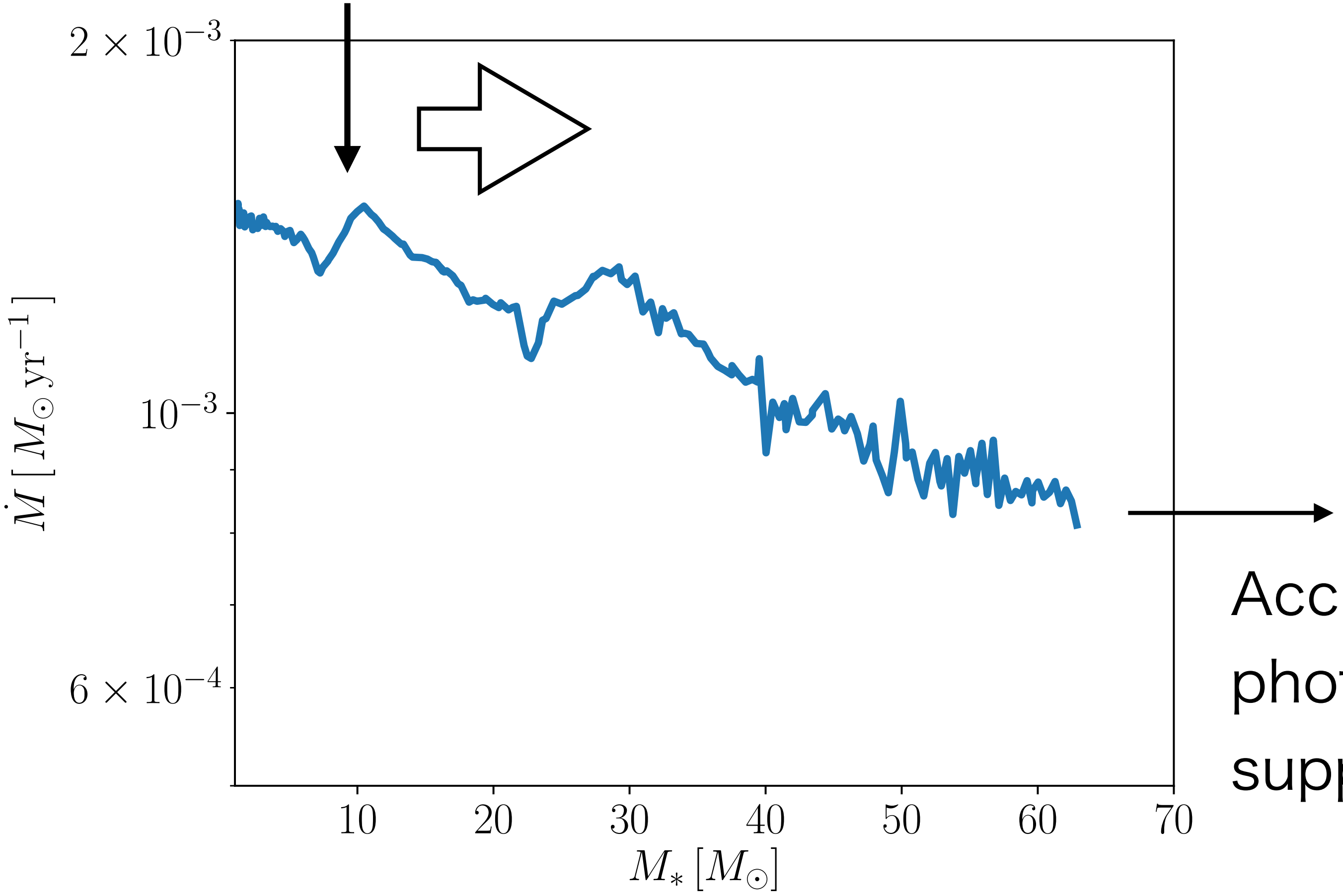
(Kuiper & Hosokawa 2018)

+ protostar evolution

(Hosokawa & Omukai 2010)

Accretion rate

Radiation pressure barrier



Accretion continues until photoevaporation suppresses mass accretion

Summary

- We make the 2-D radiation hydrodynamics code for formation of low-metallicity massive stars

- HII region and the radiation pressure simultaneously affect mass accretion