Radiative Feedback and Final Stellar Masses in Low-Metallicity Environment

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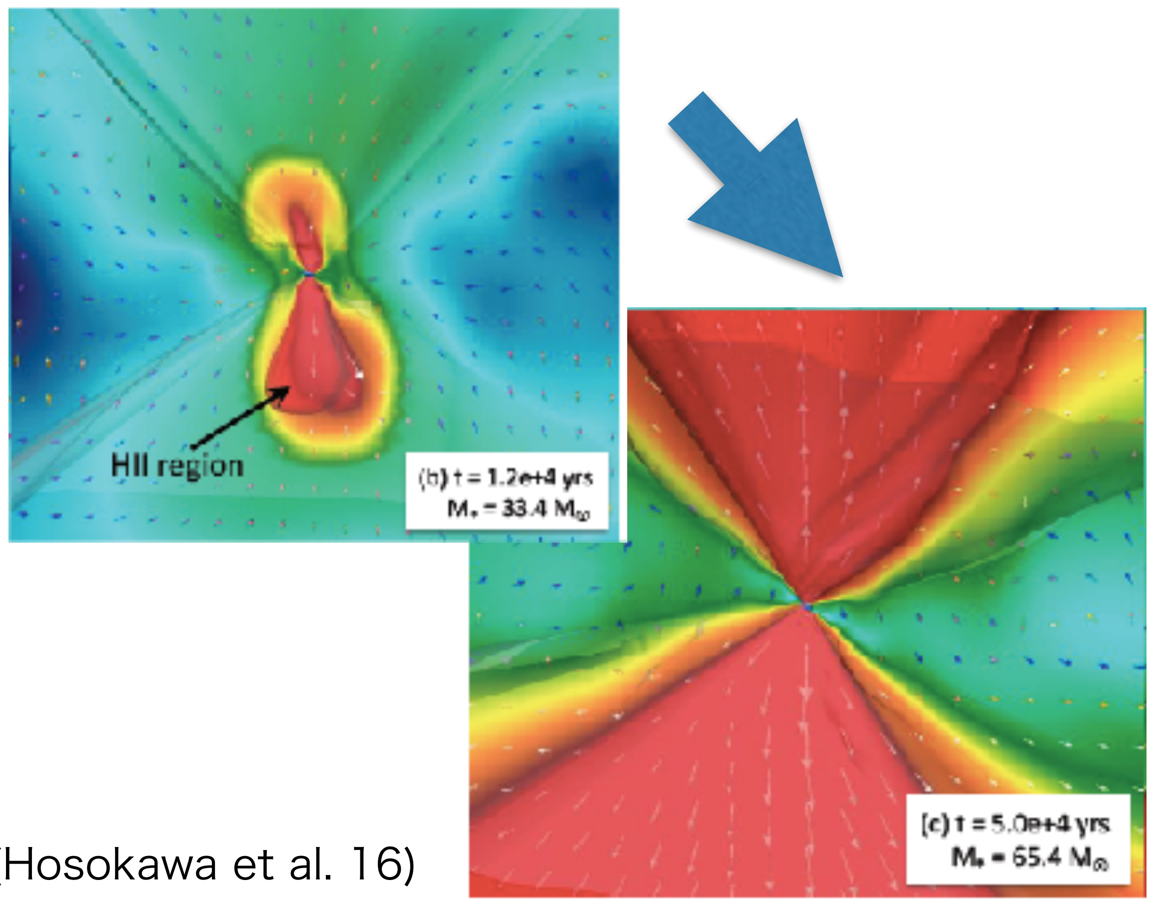
Stellar Archaeology as a Time Machine to the First Stars @IPMU

Radiation Feedback Effects

$Z = 0$ (Primordial stars)

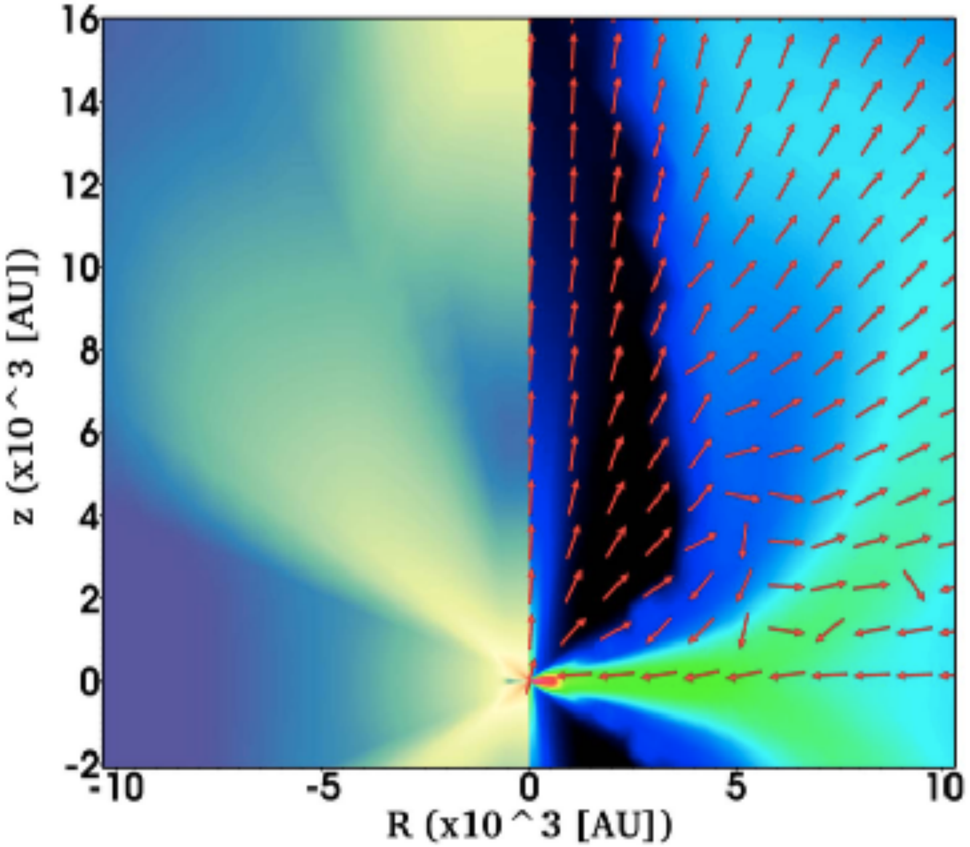
HII region formation



(Hosokawa et al. 16)

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

$1Z_{\odot}$ Radiation Pressure on Dust grains (+ HII region formation)



(Kuiper et al. 16)

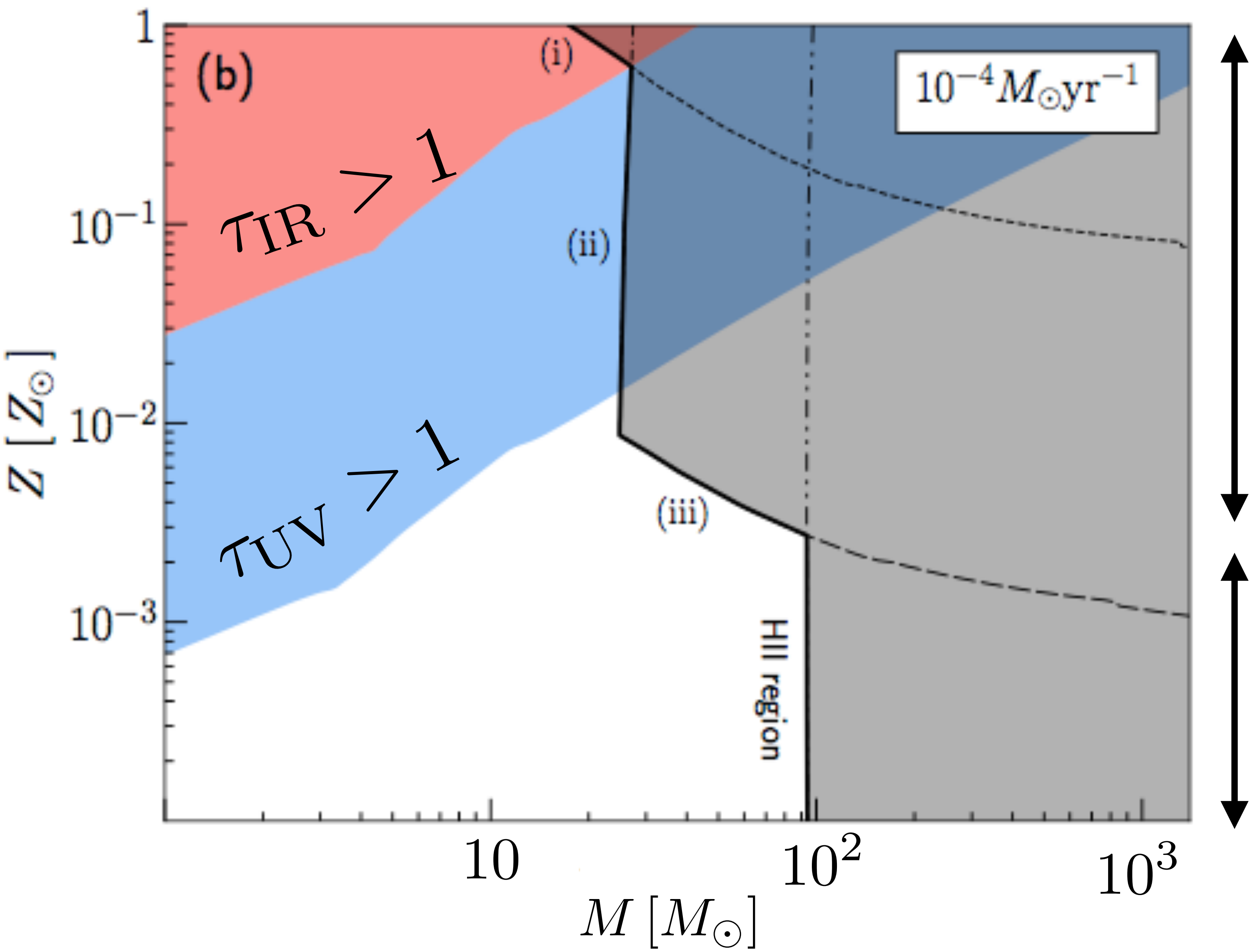
(Yorke & Bodenheimer 99; Krumholz et al. 09; Kuiper et al. 10; Rosen et al. 16)

Which is dominant in low-metallicity environment ?

In spherically symmetric case

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

Solid line: the upper mass limits (1D)



Radiation pressure in the dust cocoon

HII region formation

(HF et. al 2018)

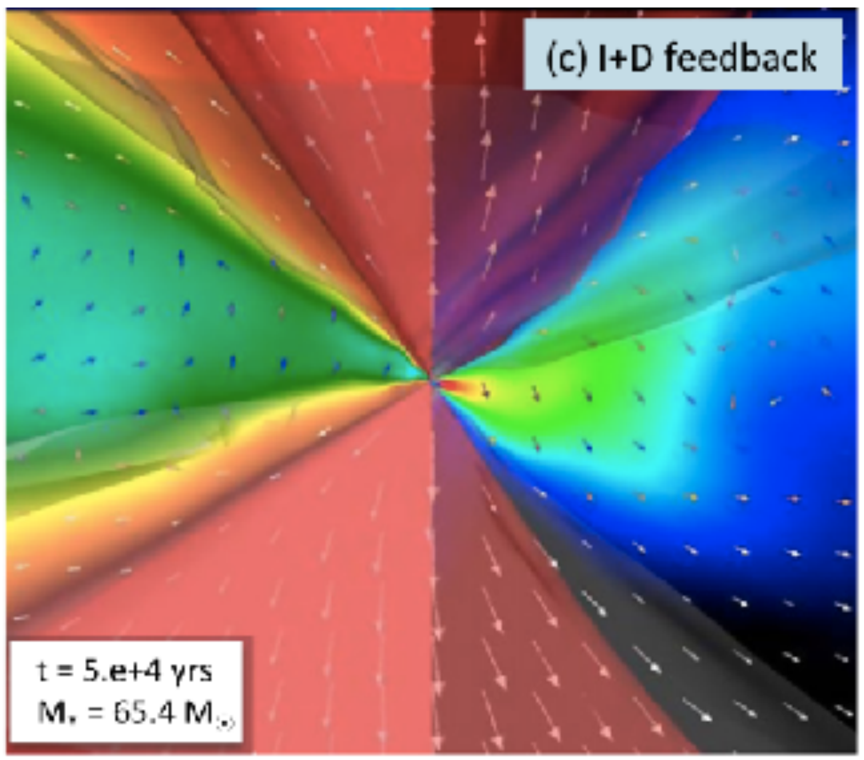
$\tau_{\rm IR}, \tau_{\rm UV}$: optical depth for IR and UV light

In this work, we assume spherically symmetric flow.
Next, we consider multi-dimensional effects.

Method (Modified version of Nakatani et al. 2017 + Sugimura et al. 2017)

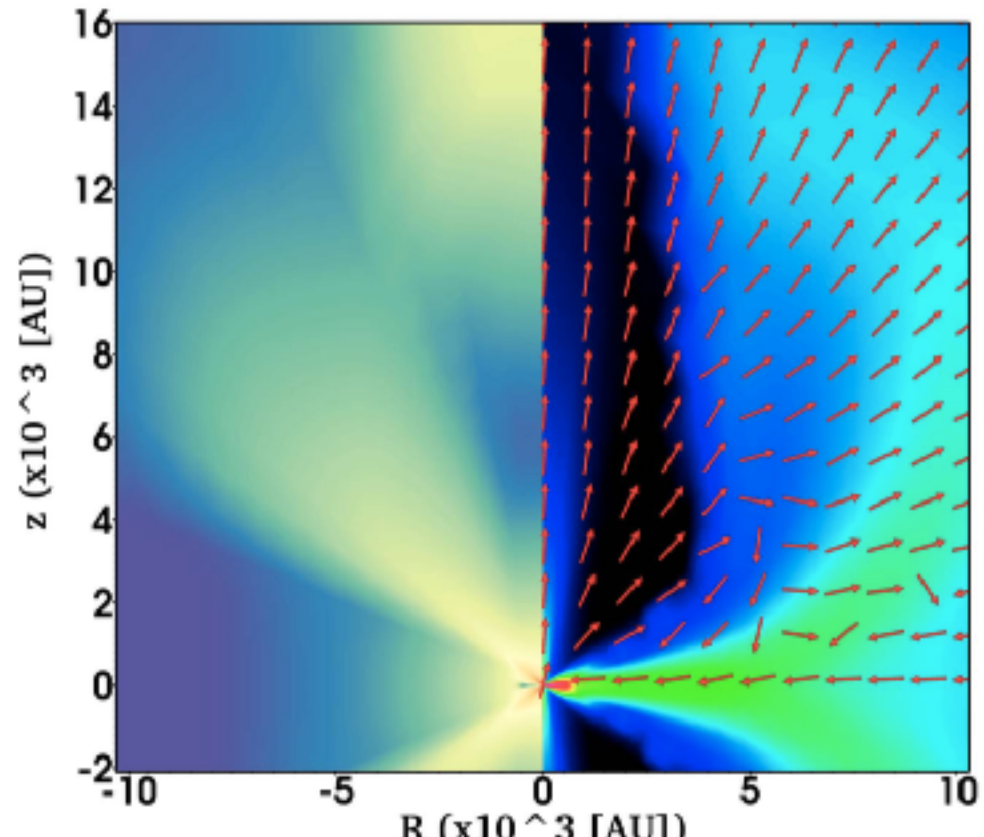
2D Radiational Hydrodynamics Simulations (PLUTO4.1)

(i) Primordial Star Formation



(Hosokawa et al. 16)

(ii) Present-day Star Formation



(Kuiper et al. 16)

Initial Conditions (Kuiper & Hosokawa 2018)

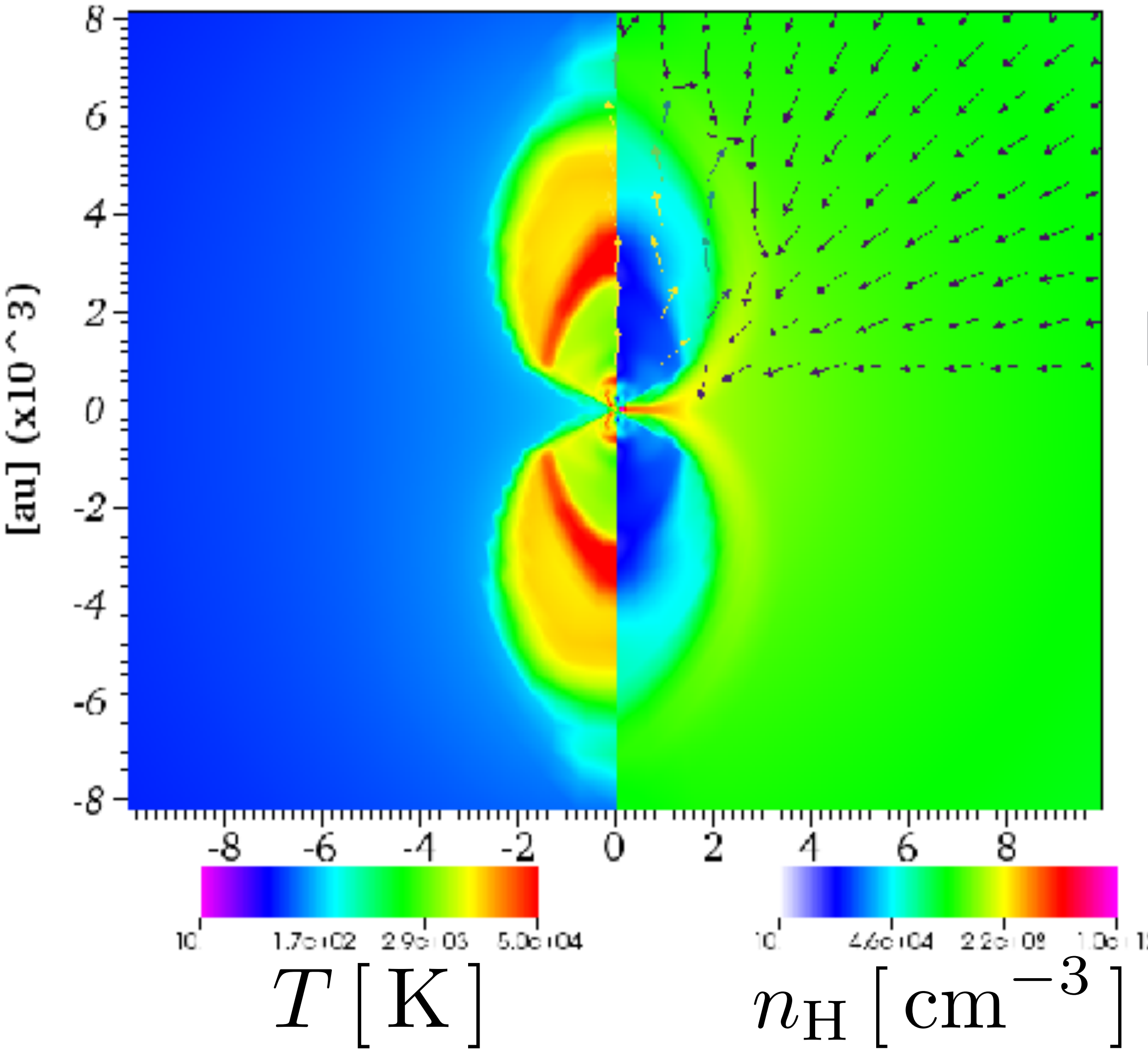
Cloud Mass: $M_{\rm core} = 250, 10^3\ M_\odot$

Metallicity : $1, 10^{-2} Z_\odot$

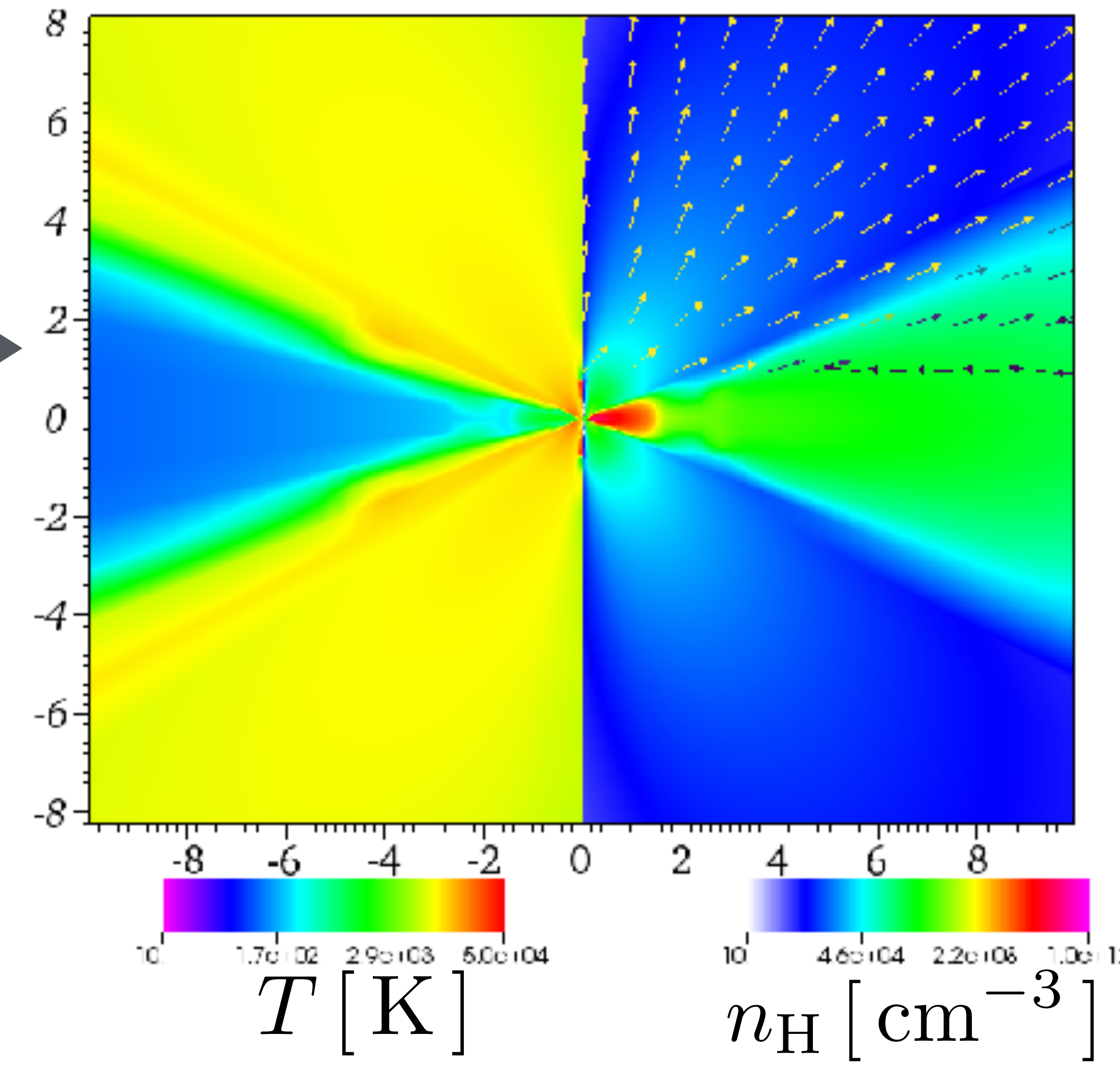
Results: $1Z_\odot$, Cloud Mass = $250\ M_\odot$

Time evolution:

(1) $M_* = 30\ M_\odot$



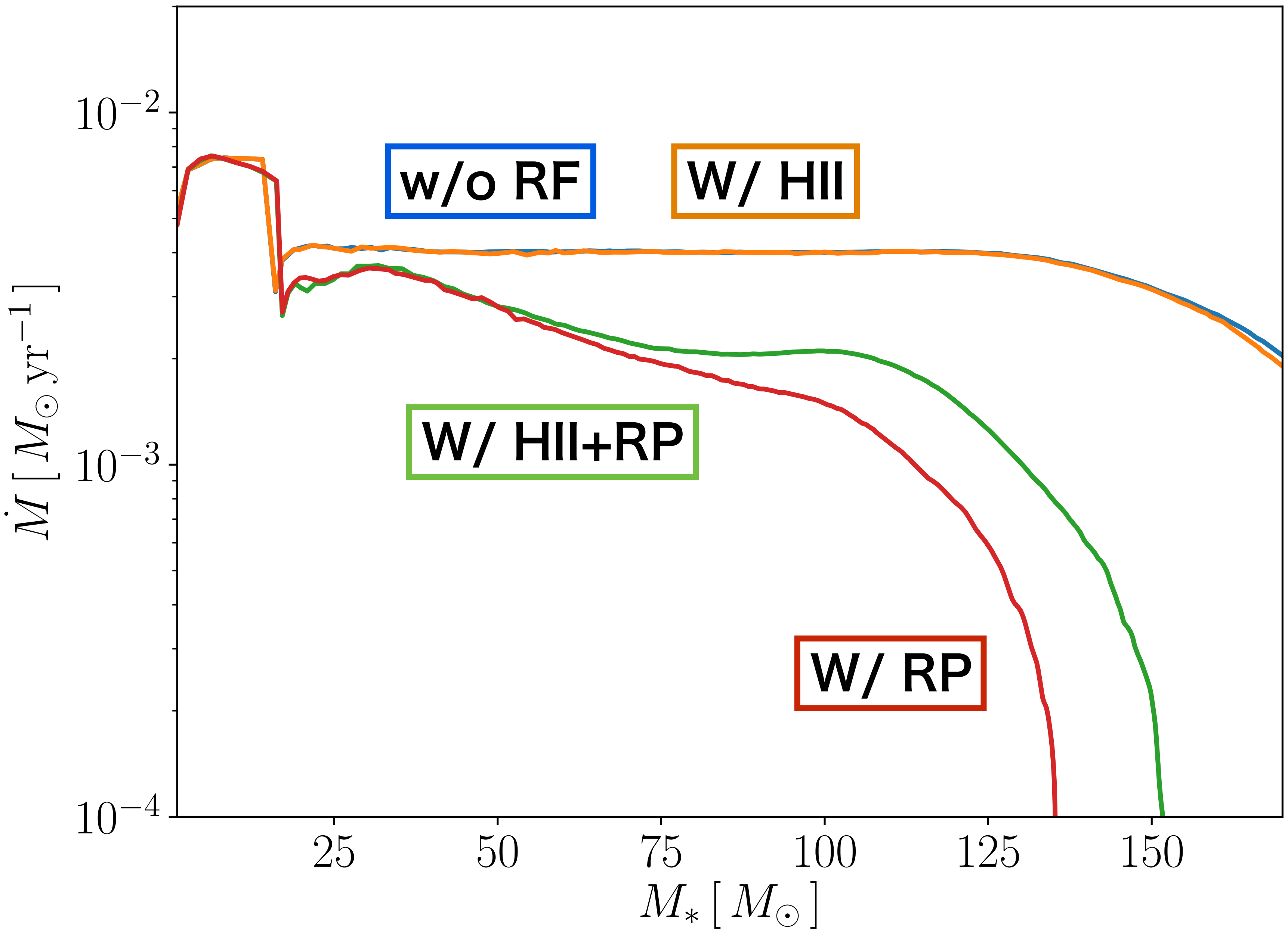
(2) $M_* = 120\ M_\odot$



- Radiation pressure becomes effective in the polar direction.
- Mass accretion continues though the accretion disk

Results: $1Z_{\odot}$, Cloud Mass = $250\ M_{\odot}$

Accretion rates



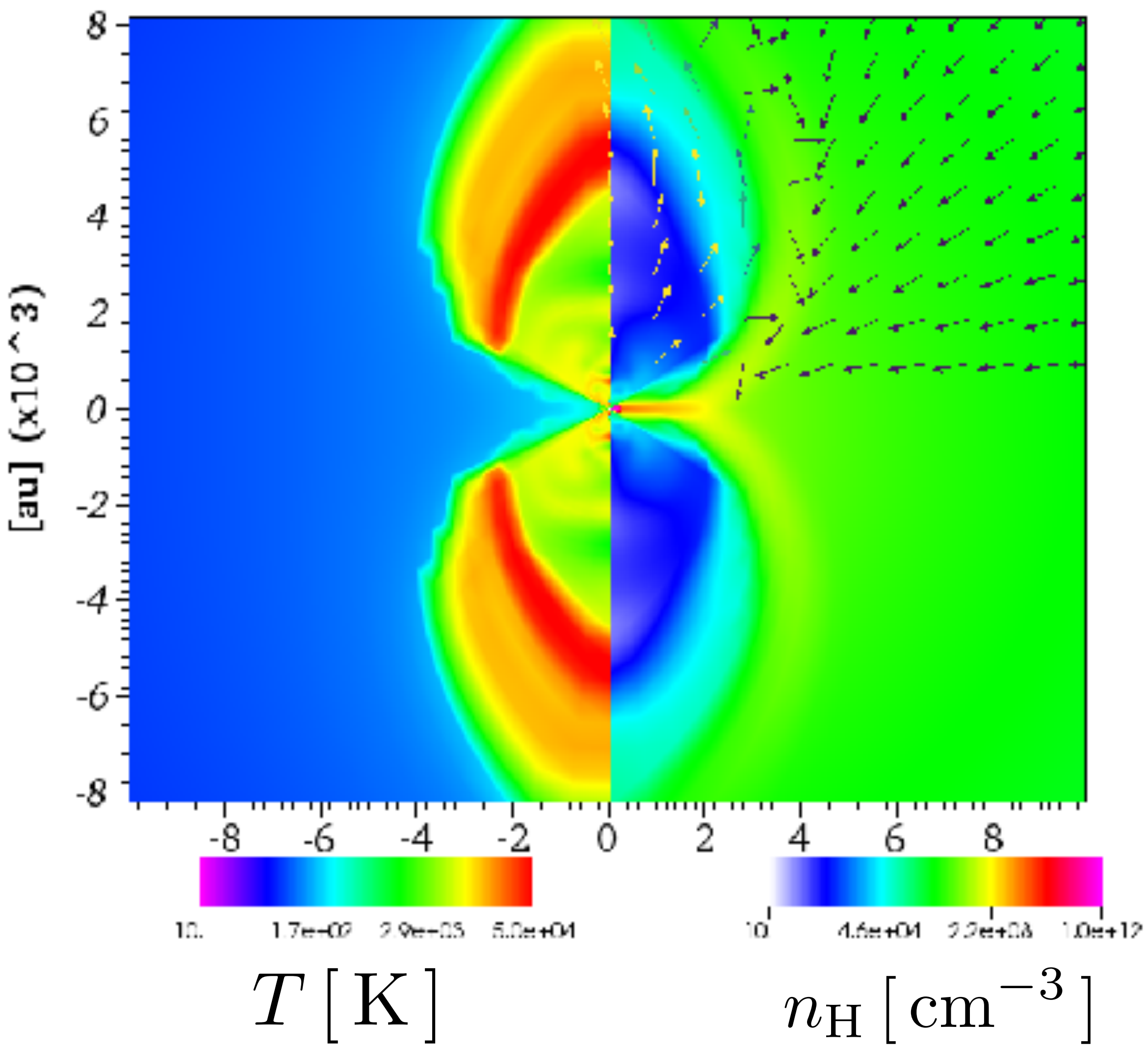
RF: Radiative Feedback
HII: HII region formation
RP: Radiation Pressure

- **Radiation Pressure is the dominant feedback effect**
- **The final stellar mass with HII+RP is larger than only with RP (Scissors handle effect)**

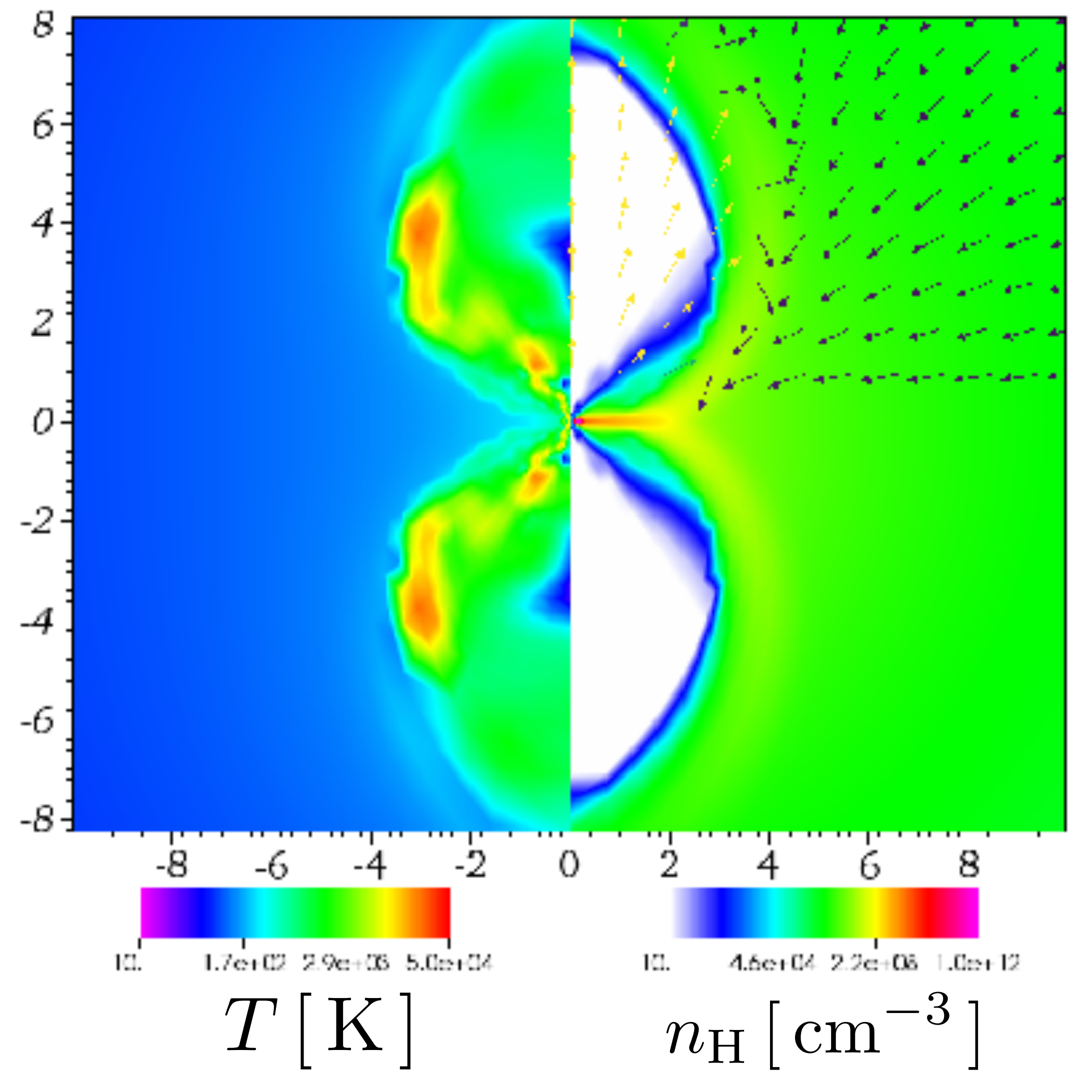
Scissors handle effect (Kuiper & Hosokawa 2018)

Dynamical effect of each radiative feedback:

w/ RP+HII



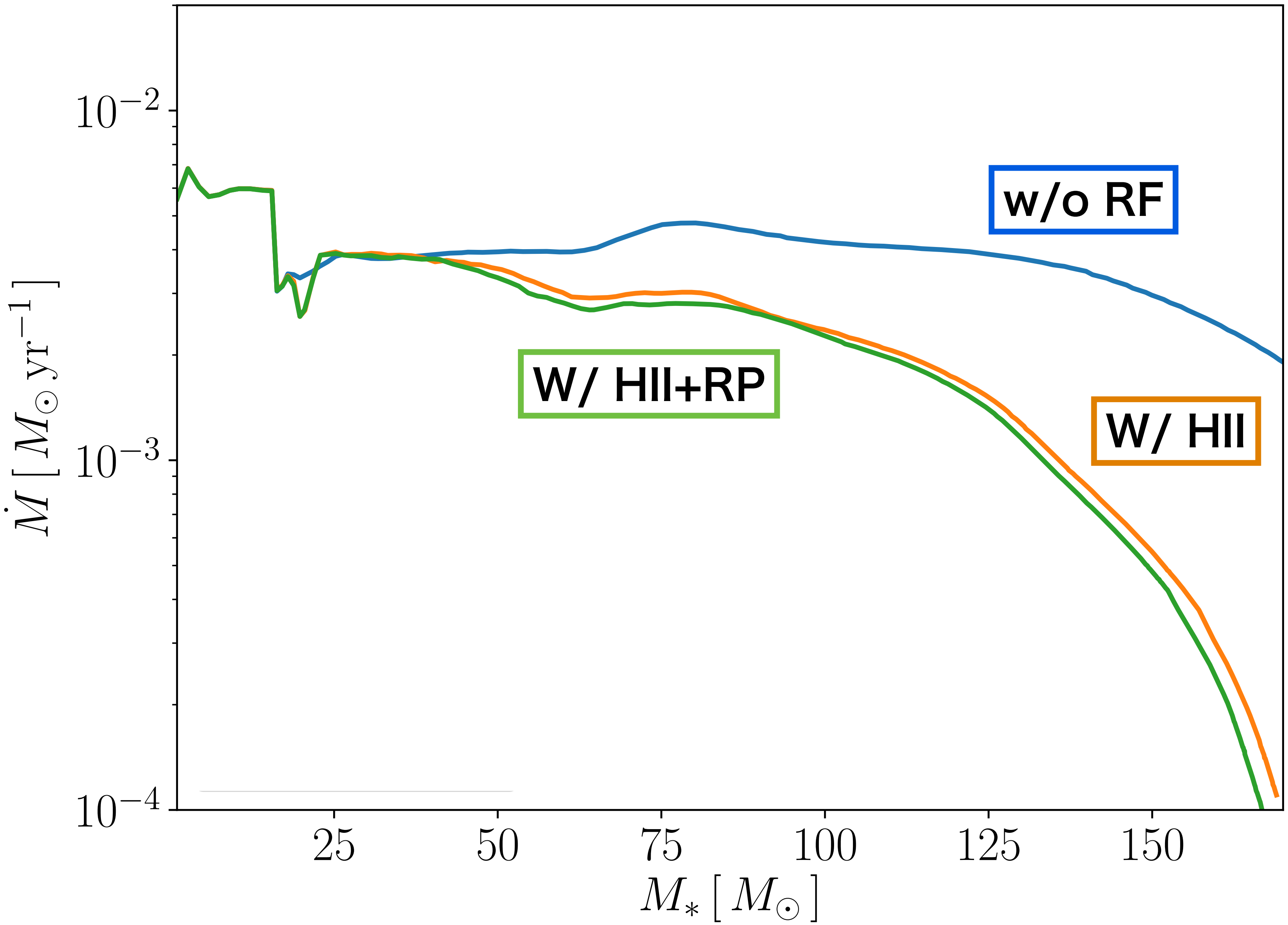
w/ RP



- Pressure excess of the HII region pushes the gas in the envelope into the shade of the disk.
- The final mass increases with scissors handle effect because radiation pressure becomes weaker behind the accretion disk

Results: $10^{-2} Z_{\odot}$, Cloud Mass = $250\ M_{\odot}$

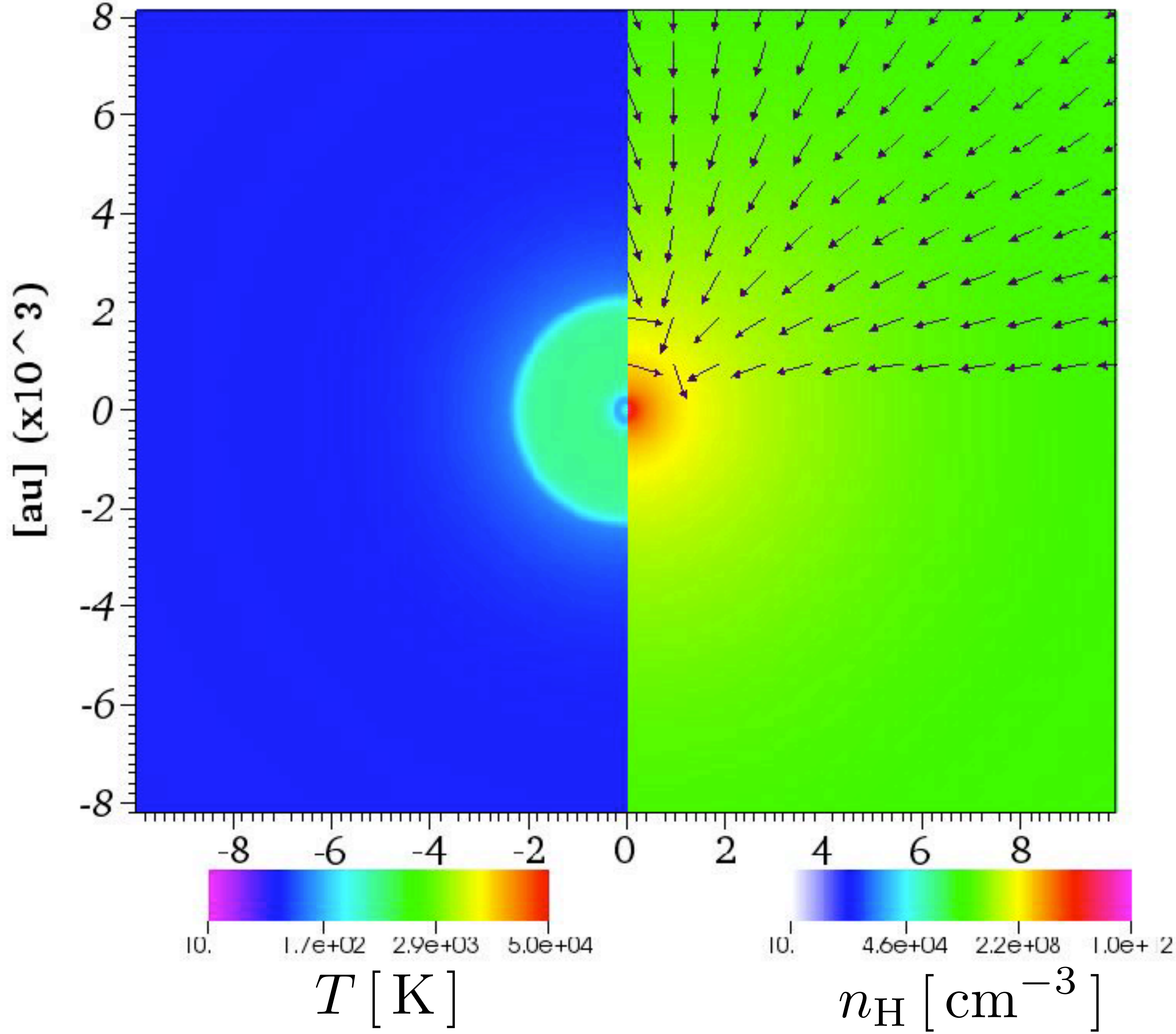
Accretion rates



RF: Radiative Feedback
HII: HII region formation
RP: Radiation Pressure

- The final stellar mass dose not change significantly
- **Radiation pressure becomes ineffective**
- **HII region formation is the dominant feedback effect**

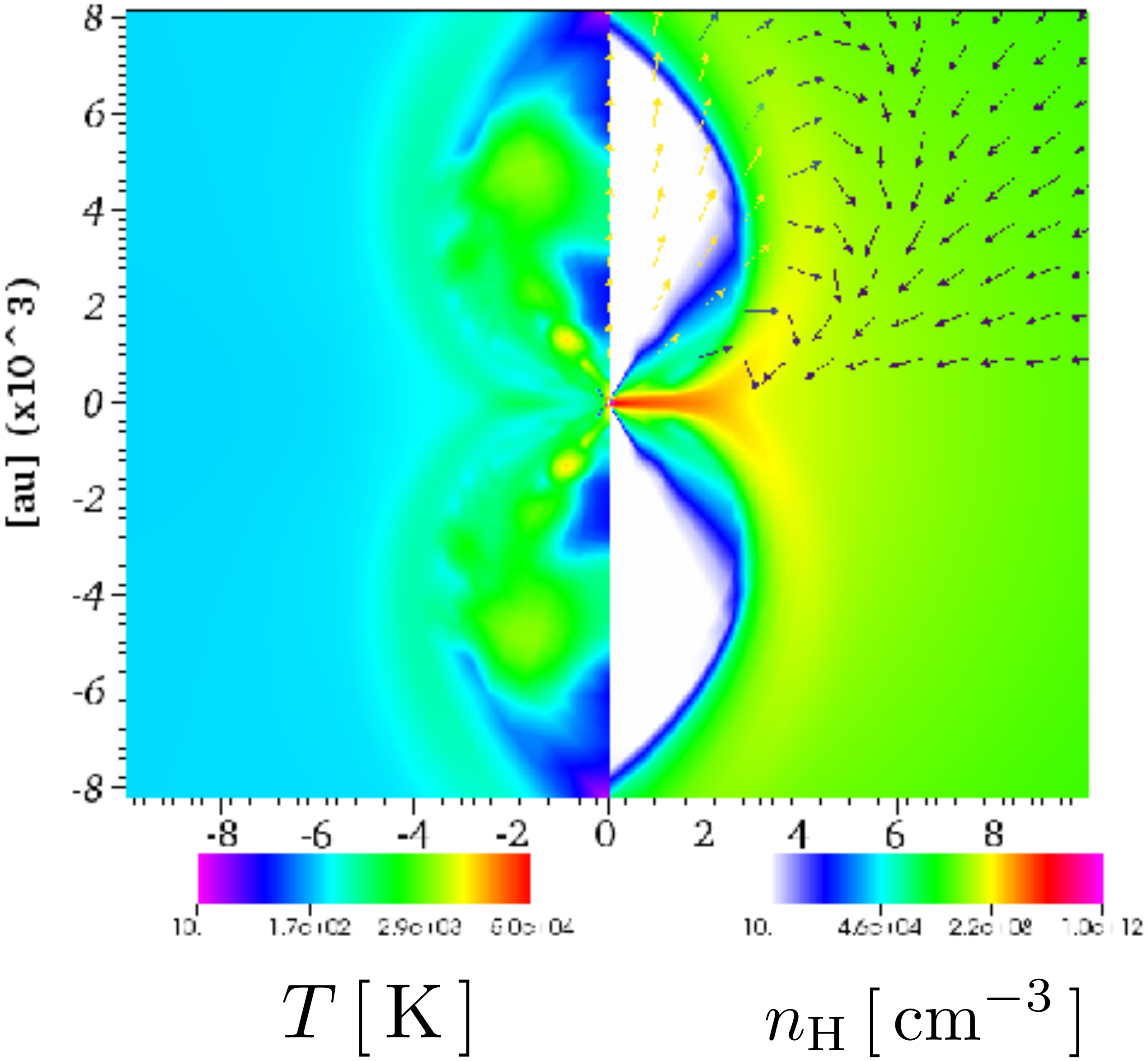
Results: $10^{-2} Z_{\odot}$, Cloud Mass = $250\ M_{\odot}$ w/ RP + HII



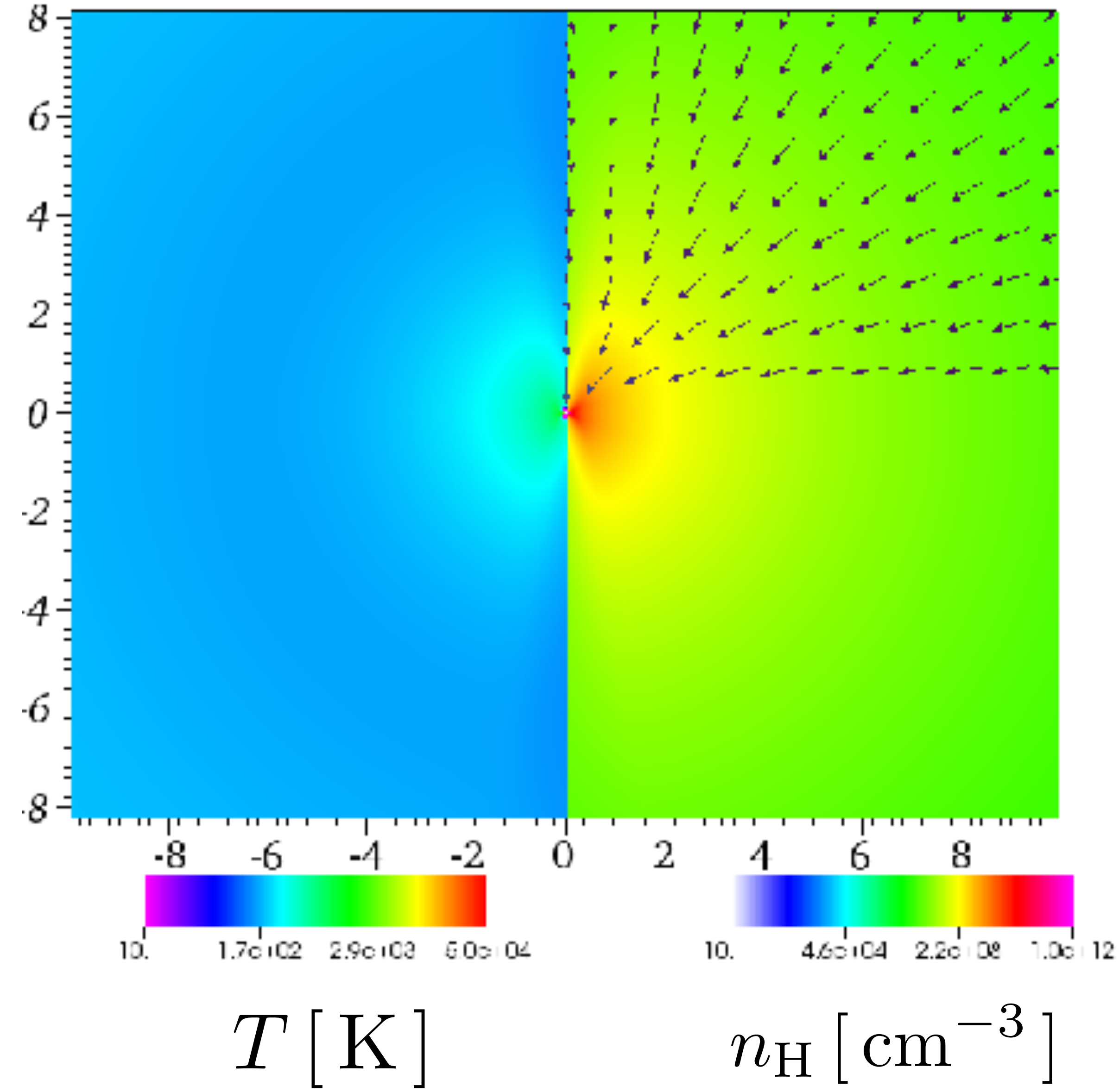
Results: Cloud Mass = $10^3 M_\odot$

Metallicity dependence of radiative feedback effects:

$1Z_\odot, 100M_\odot$, W/ HII + RP

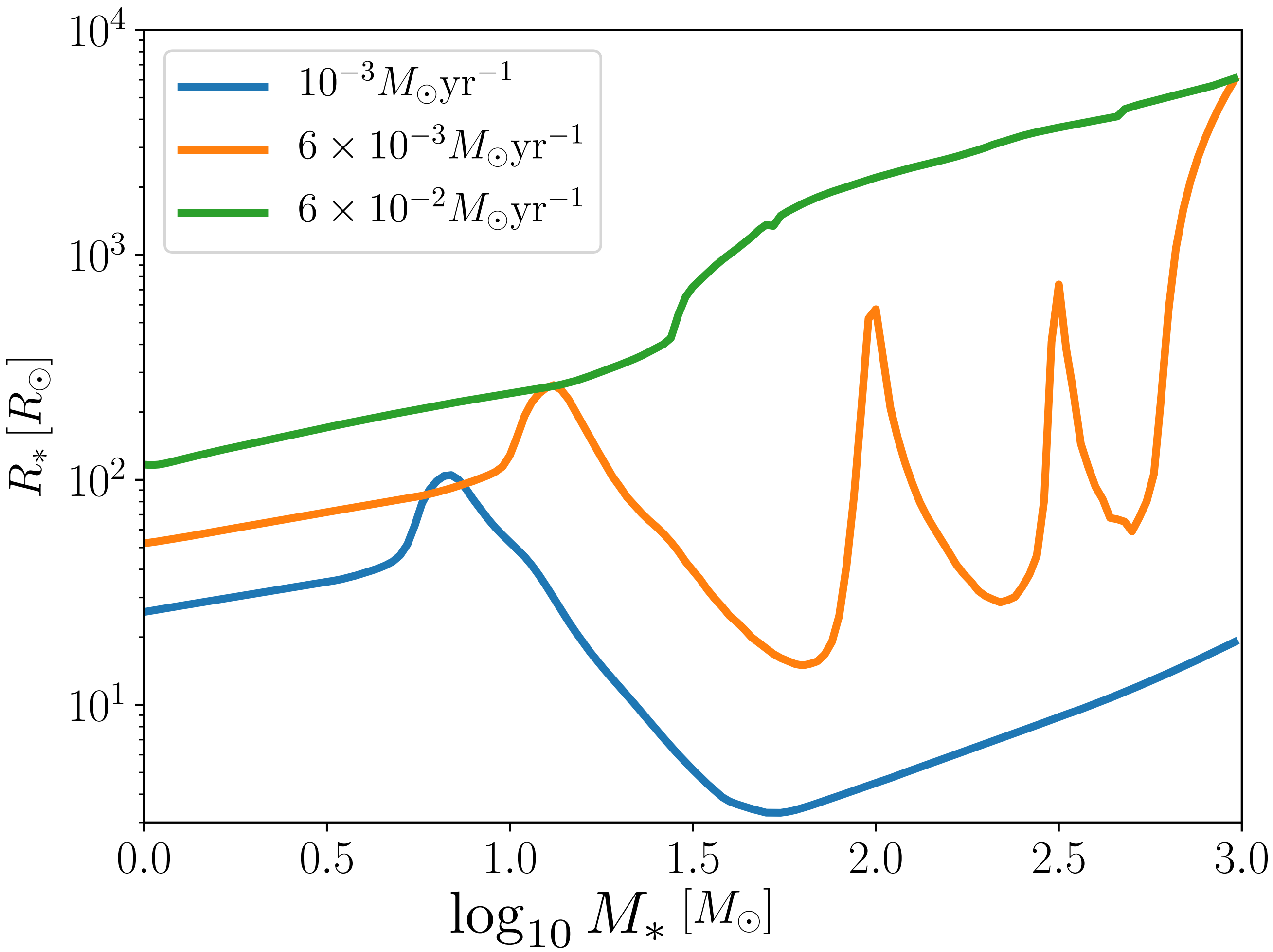


$10^{-2}Z_\odot, 100M_\odot$, W/ HII + RP



- Radiation pressure only becomes effective with 1Zsun
- Both radiation pressure and HII region formation becomes ineffective with 0.01 Zsun

Protostar evolution



(Omukai & Palla 2003; Hosokawa et al. 2012)

(1)KH contracting protostar

$\dot{M} < 4 \times 10^{-3} M_\odot \mathrm{yr}^{-1}$

The protostar becomes main-sequence star.

(2)Oscillating protostar

$\dot{M} > 4 \times 10^{-3} M_\odot \mathrm{yr}^{-1}$

(3)supergiant protostar

$\dot{M} > 4 \times 10^{-2} M_\odot \mathrm{yr}^{-1}$

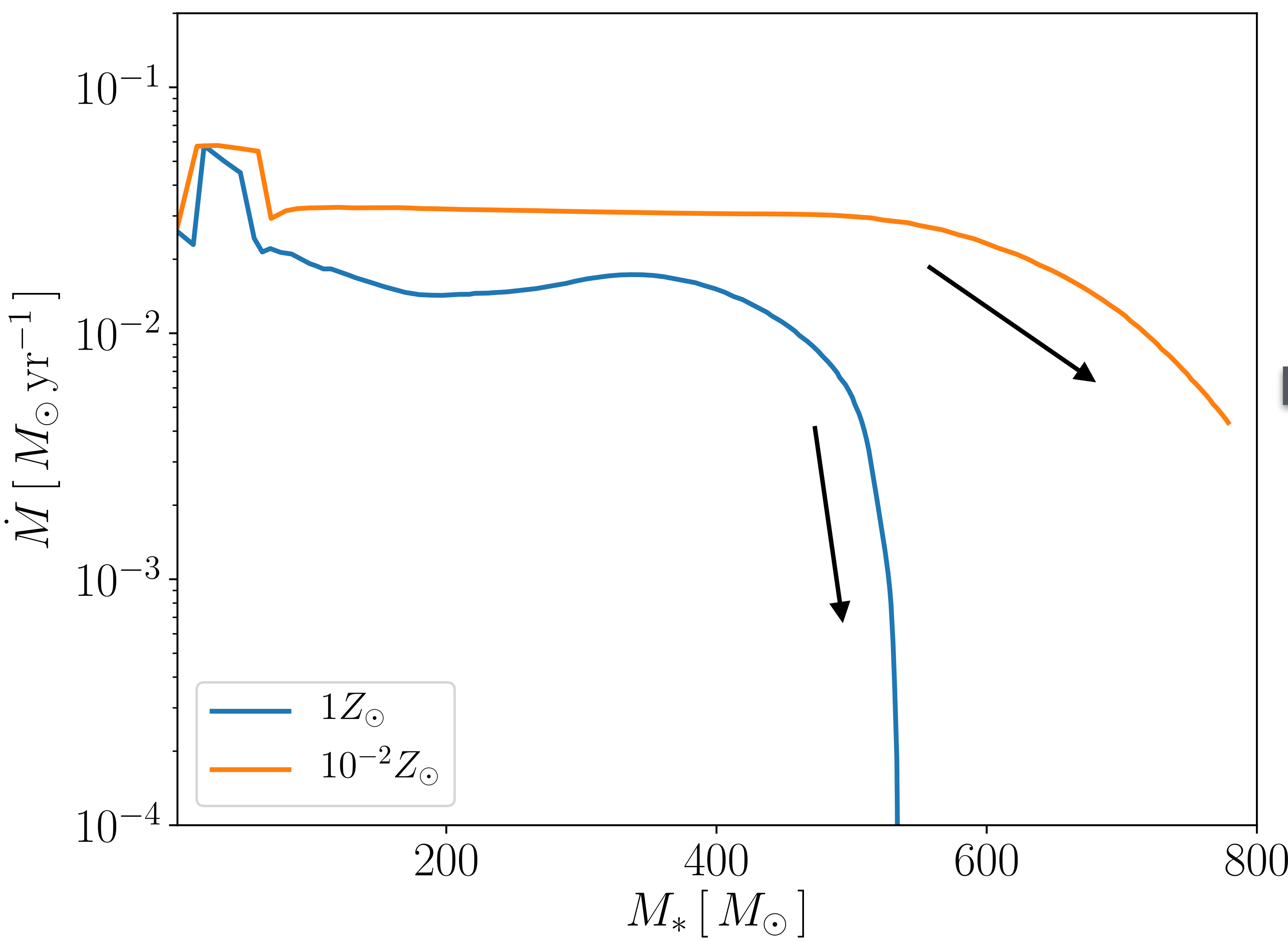
The stellar radius expands.

$T_{\mathrm{eff}} \simeq 5000\mathrm{K}$

- **Supergiant protostar cannot emit UV photos due to low effective temperature.**

➡ **HII region formation dose not occur around the supergiant protostar.**

Results: $M_{\rm core} = 10^3 M_\odot$ **(Preliminary results)**



$\dot{M} \simeq 4 \times 10^{-2} M_\odot {\rm yr}^{-1}$

Supergiant protostar !

$1Z_\odot$: Radiation pressure suppresses mass accretion, and accretion rate decreases.

$10^{-2}Z_\odot$: HII region formation becomes ineffective, mass accretion continues until most of gases in the core fall.

Summary & Discussion

・We follow the formation of massive star with 2D radiation-hydrodynamics simulations.

・In the star formation of -150Msun, the strength of radiative feedback dose not significantly change.

・When cloud mass is equal to 1000Msun, radiative feedback becomes ineffective in the low-metallicity environments.

Future (current) work

・To investigate the initial condition dependence (Core masses, etc.)

・To simulate with more realistic initial conditions