The effect of radiation pressure on dust distribution inside HII regions

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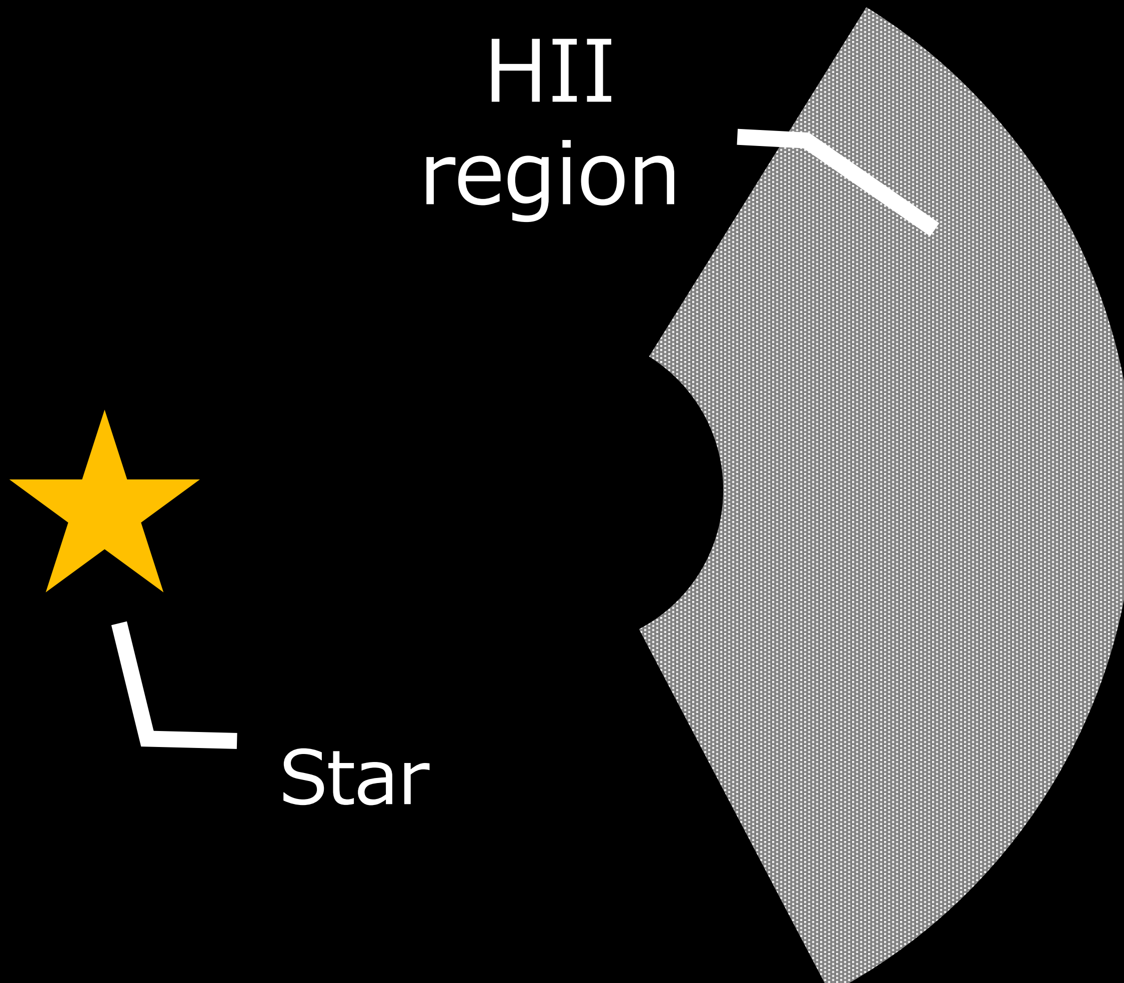
Introduction

1. Introduction

From observational estimates (Inoue 2002),



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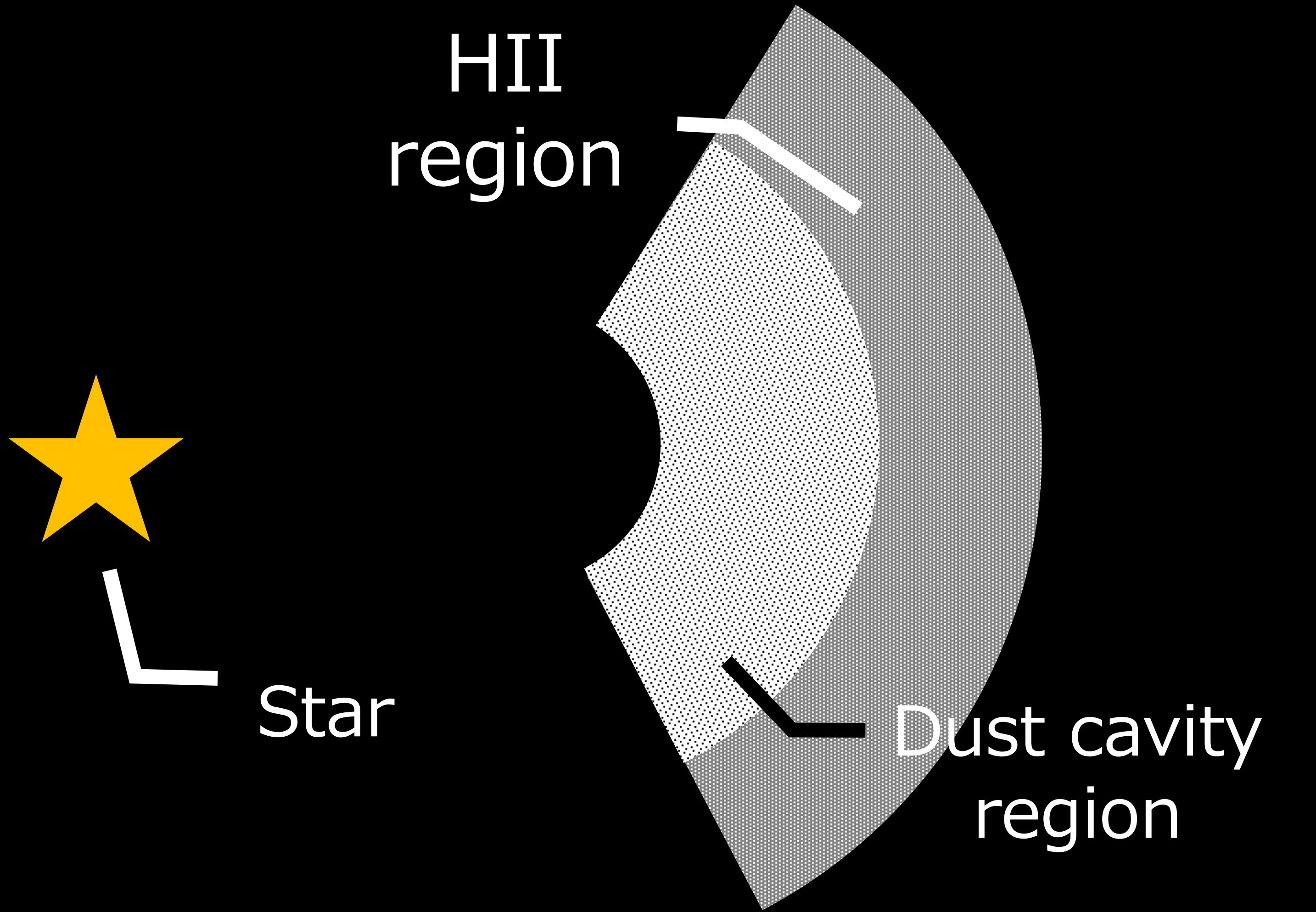

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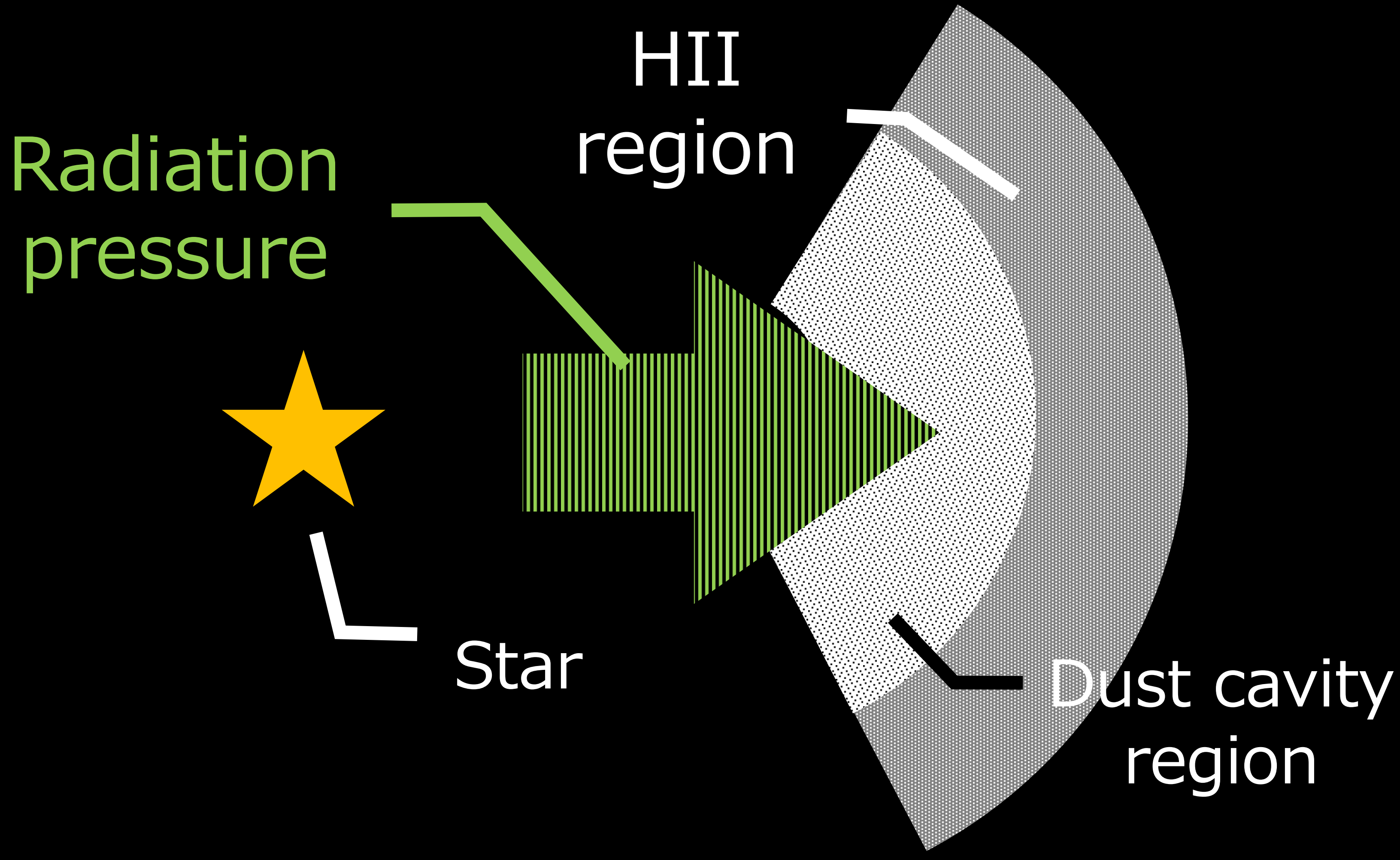

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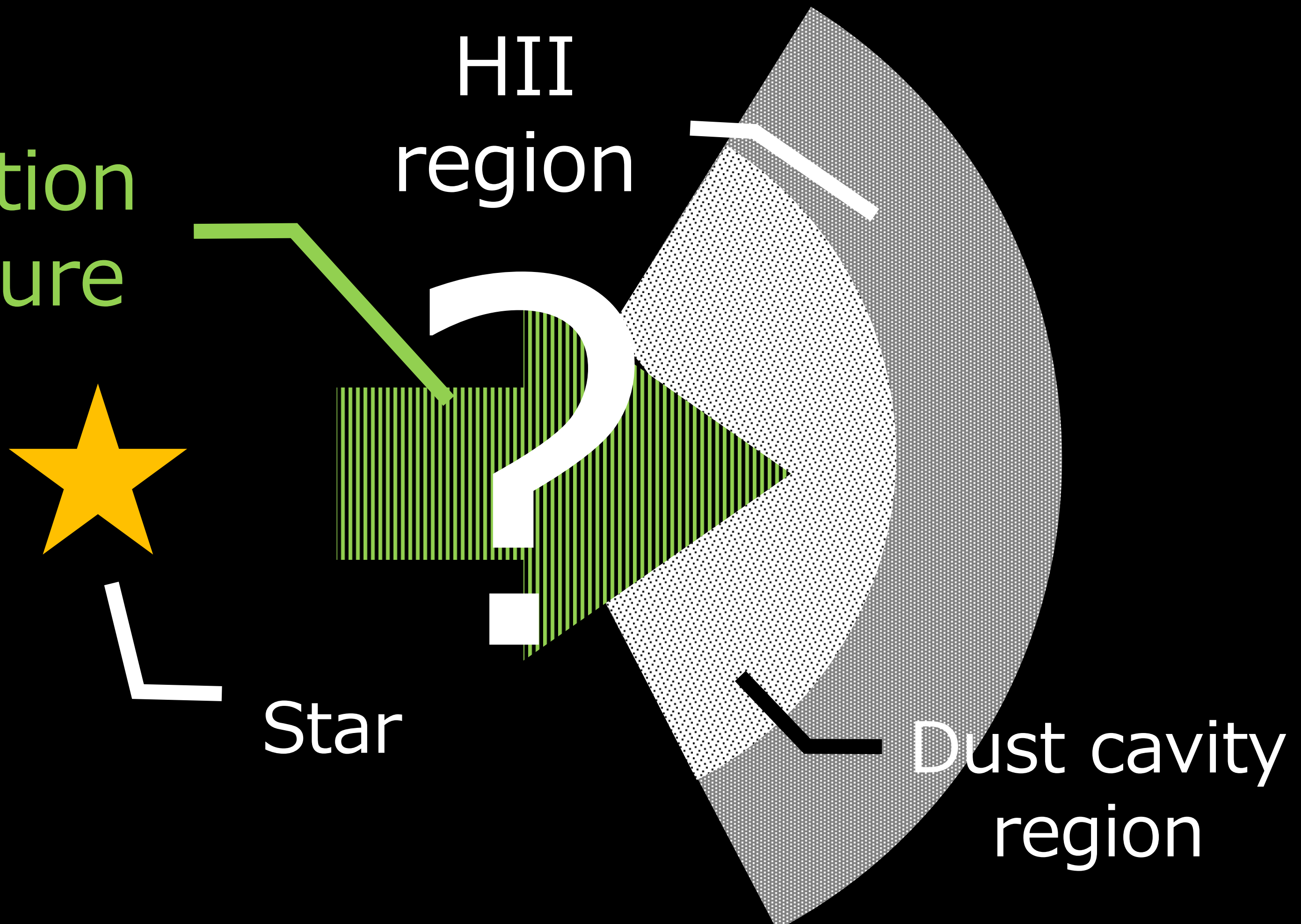


1. Introduction

From observational estimates
(Paladini et al. 2012)

Radiation pressure

1. Introduction

From observational estimates
(Paladini et al. 2012)

Radiation pressure

↓

Spatial variations of
the grain size distribution

1. Introduction

From observational estimates
(Paladini et al. 2012)

Radiation pressure

Spatial variations of
the grain size distribution

1. Introduction

Dust & gas

$$\frac{\partial}{\partial t}\left(\rho_d+\rho_g\right)v+\frac{\partial}{\partial x}\left(\rho_g+\rho_d\right)v^2=F_g+F_d+\left(\rho_d+\rho_g\right)G-\frac{\partial}{\partial x}p$$

$$\frac{\partial}{\partial t}\rho_g v_g+\frac{\partial}{\partial x}\rho_g v_g^2=F_{\mathrm{r,g}}+\rho_g g+K_d\left(v_d-v_g\right)-\frac{\partial}{\partial x}p$$

$$\frac{\partial}{\partial t}\rho_d v_d+\frac{\partial}{\partial x}\rho_d v_d^2=F_{\mathrm{r,d}}+\rho_d g-K_d\left(v_d-v_g\right)$$

Dust drag force

1. Introduction

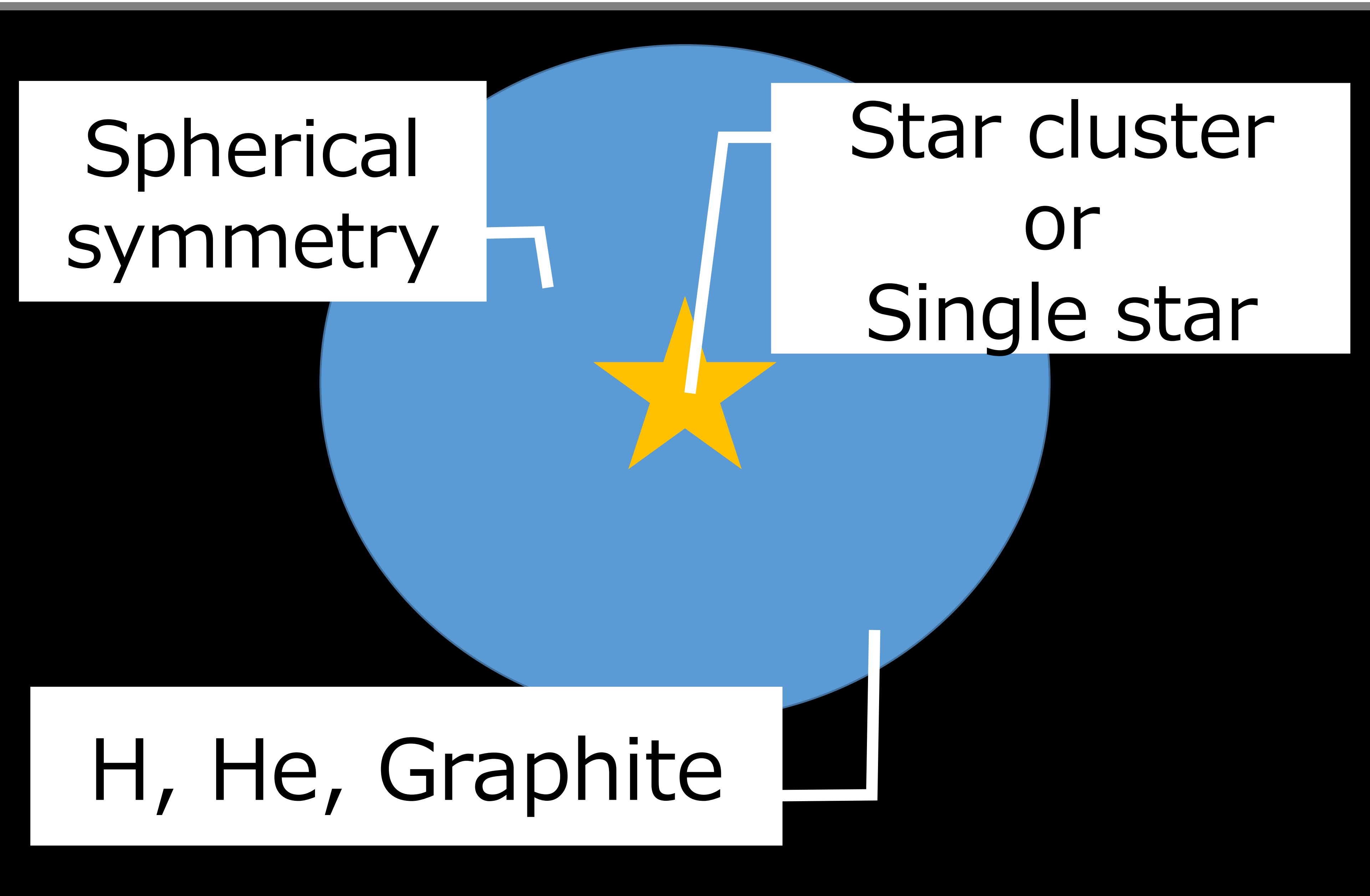
We investigate
the effect of radiation pressure on

1. spatial dust distribution
   - dust cavity size
2. spatial variations of the dust grain size distribution

inside HII regions
by numerical simulations

Method & Model

2. Model


Spherical symmetry
Star cluster
or
Single star
H, He, Graphite

2. Method

1D Radiation transfer

$$\frac{dI}{dx} = -\alpha I + j$$

Hydrodynamics + dust motion

- AUSM+
- Dust drag force
  - Collisional drag force
  - Coulomb drag force ← Dust charge

2. Method

1D Radiation transfer

Radiation intensity

Re-emission

$$\frac{dI}{dx} = -\alpha I + j$$

Absorption

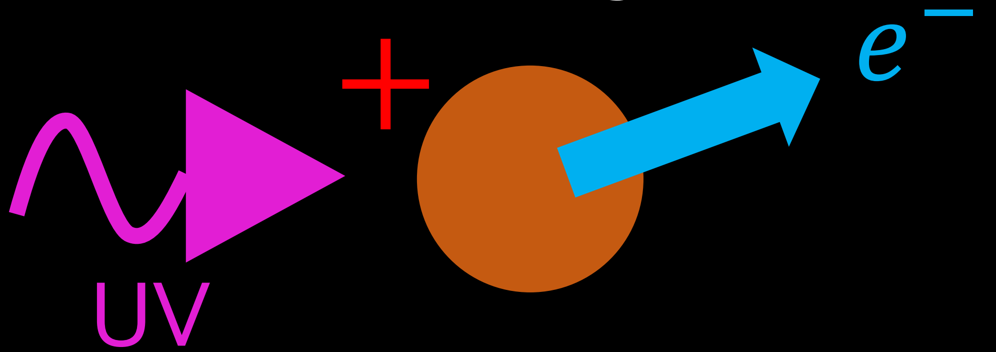
Hydrodynamics + dust motion

- AUSM+
- Dust drag force
  - Collisional drag force
  - Coulomb drag force ← Dust charge

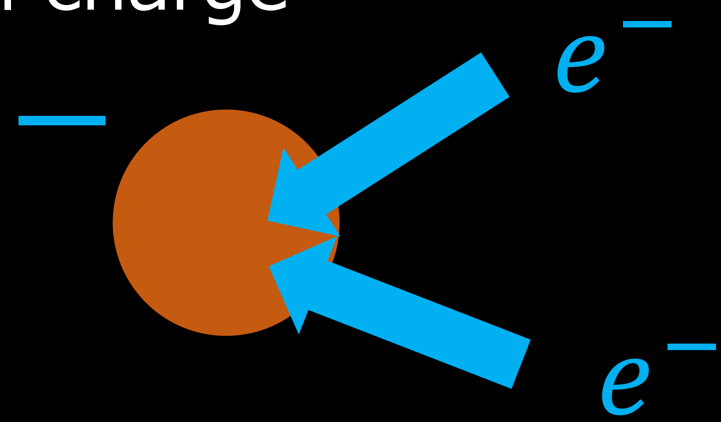
Method

Dust charge

i. Photoelectric charge



ii. Collisional charge



2. Method

Dust

Graphite

size

Case 1: dust cavity

0.1μm

Case 2: spatial dust grain size distribution

0.1, 0.01 μm; $n_{0.1}:n_{0.01} = 1:10^{2.5}$

Temperature

Radiative equilibrium

2. Method

Temperature of gas

Heating

- Gas photoionization heating

Cooling

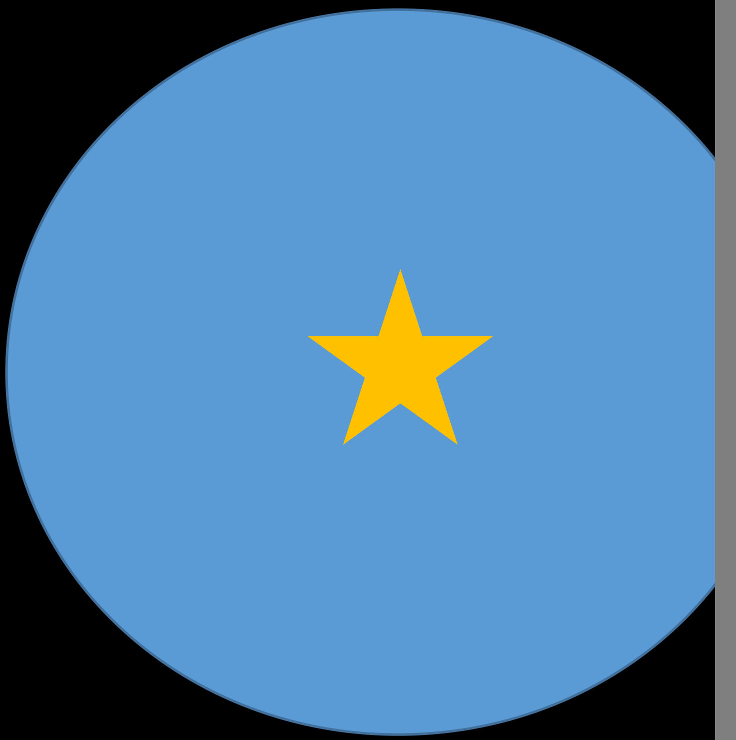
- Recombination
- Collisional ionization
- Collisional excitation
- Bremsstrahlung
- inverse-Compton

Result

1. Spatial dust distribution

- dust cavity size

3. Result



Cloud 0
density: $4.0 \times 10^5\ \mathrm{cm}^{-3}$
radius: 1.2 pc
distribution: constant

Radiation source
spectrum: BB
T_{BB}: $5.0 \times 10^4\ \mathrm{K}$

Dust: 0.1 μm

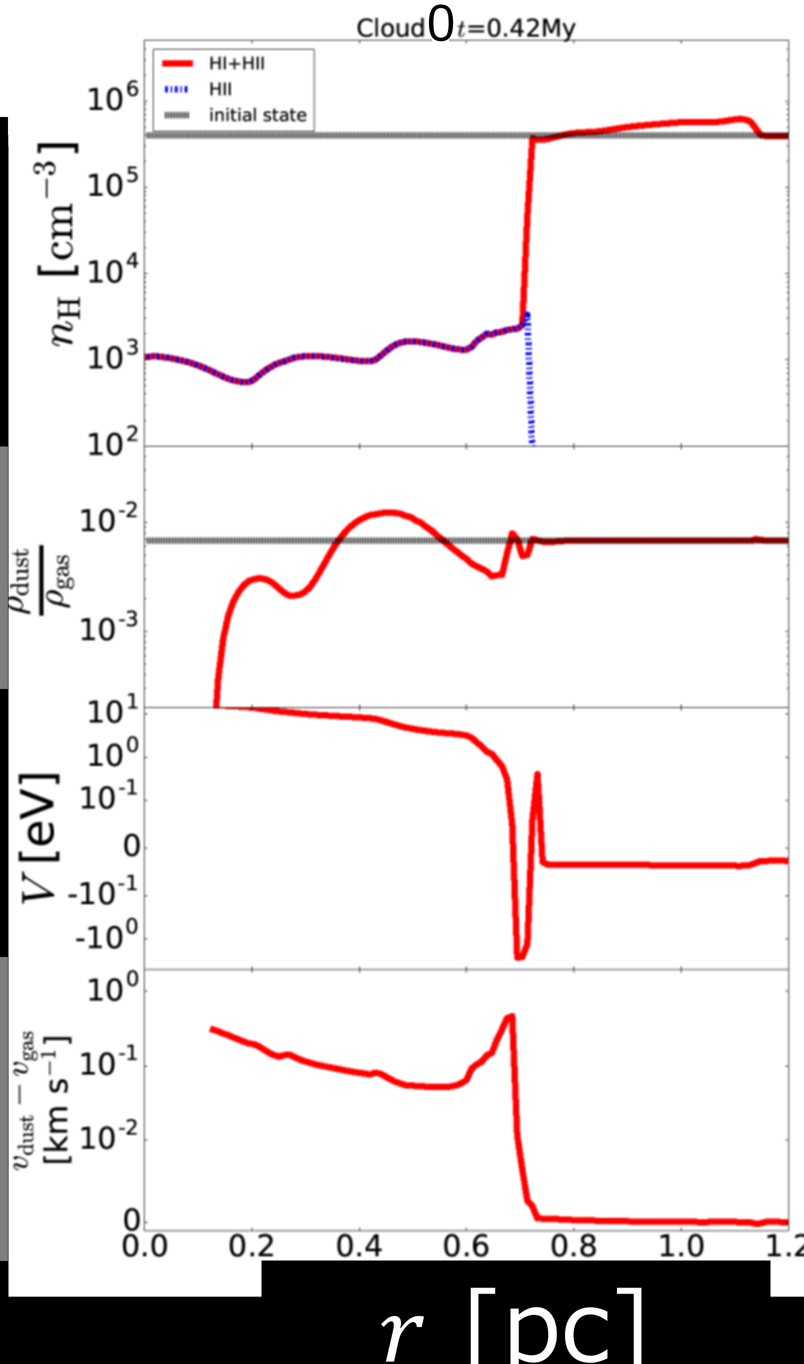
3. Result

Number density of hydrogen

Dust-to-gas mass ratio

Dust charge

Relative velocity between gas and dust



3. Result

Number density of hydrogen

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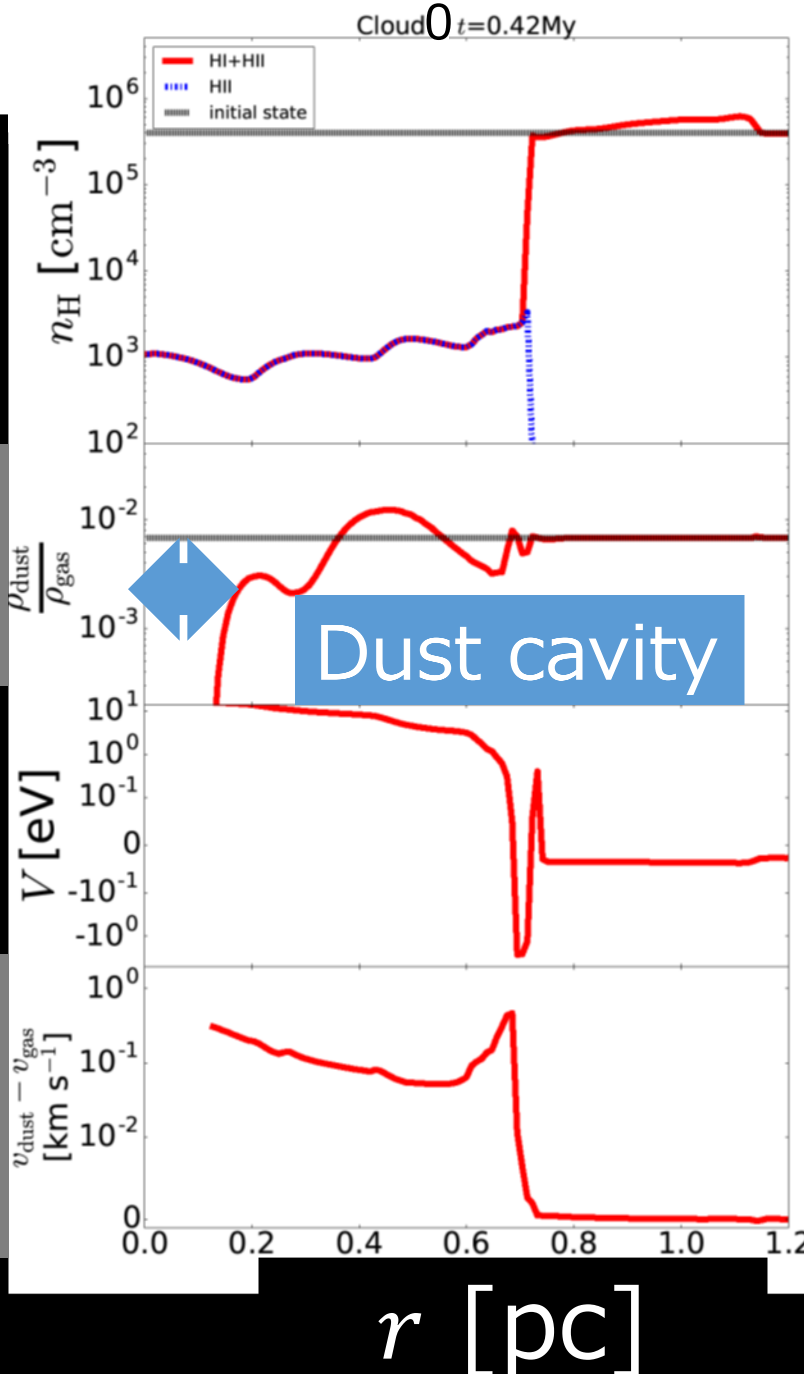
Dust charge

Relative velocity between gas and dust



3. Result

	$\overline{n_{\rm H}}$ (cm^{-3}) inside ionzied region	$r_{\rm i}$ (pc) Ionize radius	$\dot{N}_{\rm ion}$ (10^{49}s^{-1}) Ionized photon	$r_{\rm d}$ (pc) Dust cavity radius
Calculation	1319	0.71	6.2	0.15
Observational estimation (Inoue 2002)	1200±400	0.72	6.8±3.9	0.28±0.13

Consistent with observational estimation

2. Spatial variations of the grain size distribution

3. Result

Cloud 1

density: $790\ \mathrm{cm}^{-3}$

radius: 17 pc

distribution: BE

Radiation source of Cloud 1: BB

T_{BB}: $3.9 \times 10^{4}\ \mathrm{K}$

$\dot{N}_{\mathrm{ion}}$: $7.2 \times 10^{48}\ \mathrm{s}^{-1}$

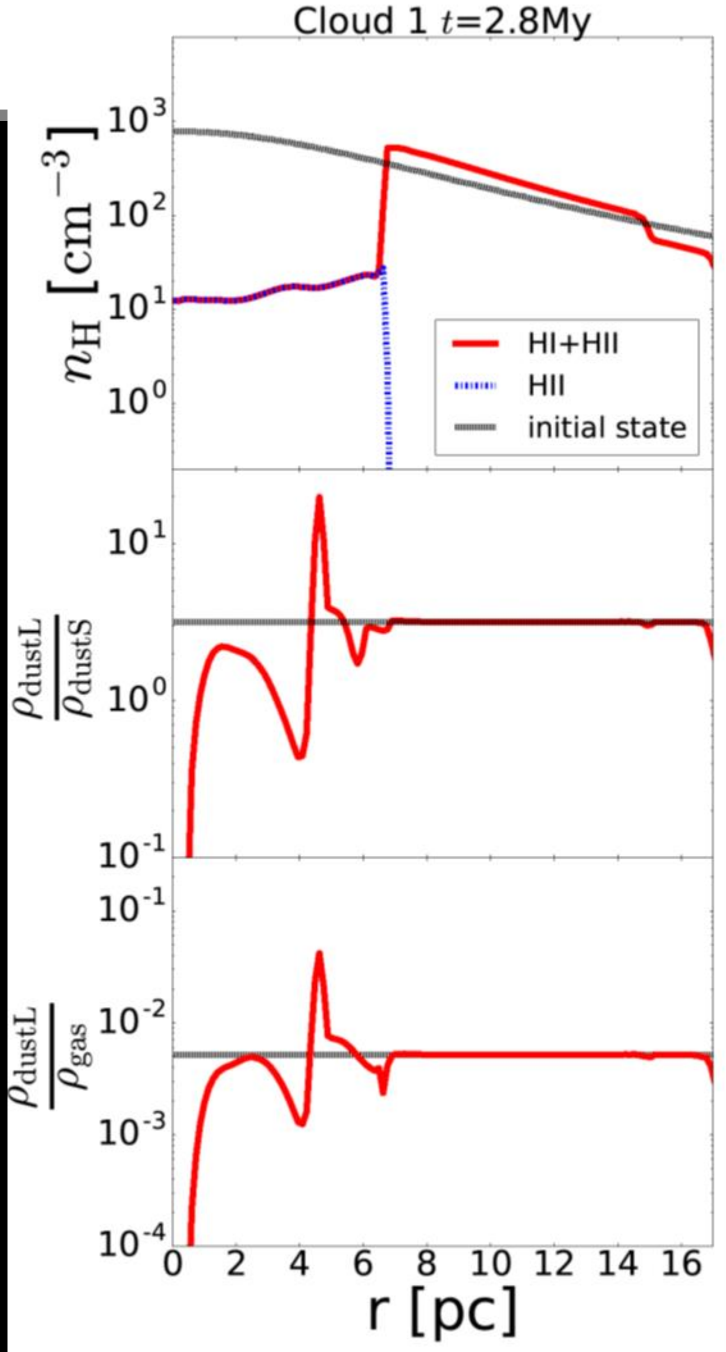
Dust: 0.01 ,0.1 μm

3. Result

Gas density

0.1μm dust mass density/ 0.01μm dust mass density

0.1μm dust mass density/ gas mass density

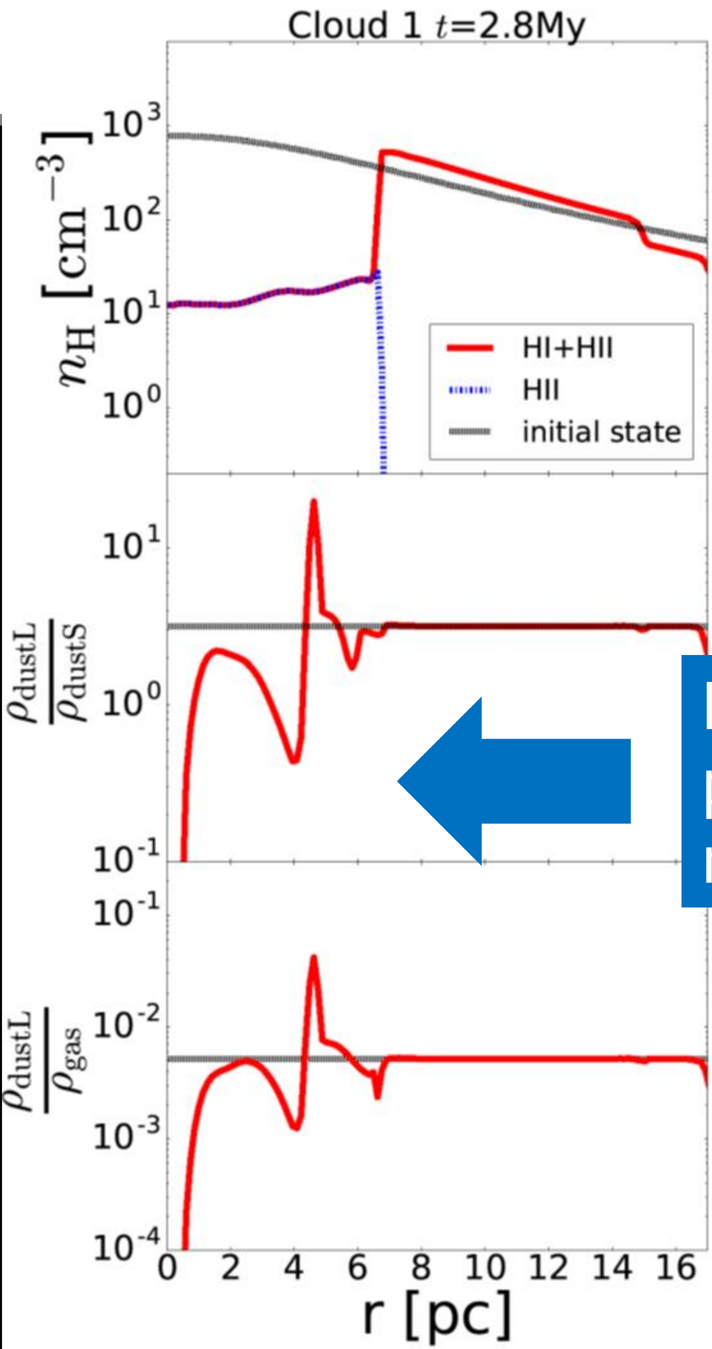


3. Result

Gas density

0.1μm dust mass density/ 0.01μm dust mass density

0.1μm dust mass density/ gas mass density



Large dust is preferentially removed

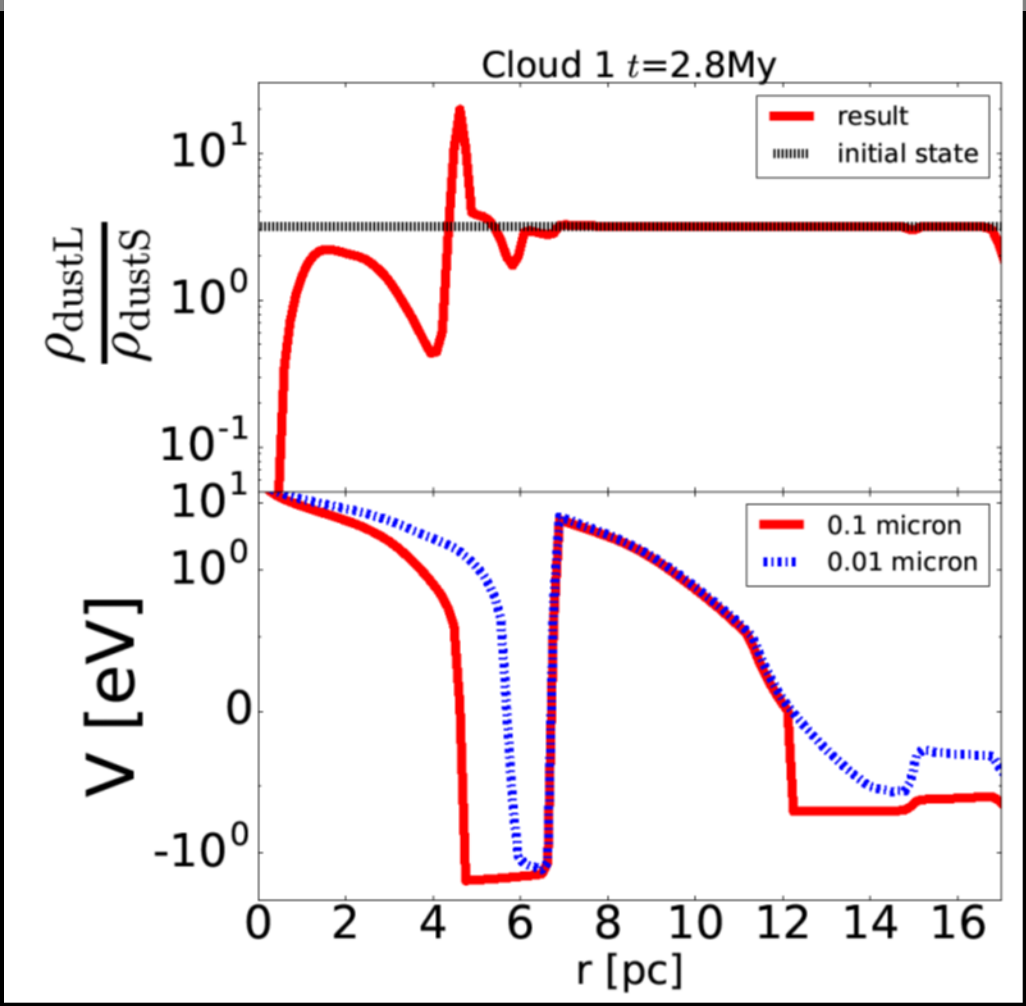
3. Result

Why is the large dust removed?

3. Result

0.1μm dust mass density/ 0.01μm dust mass density

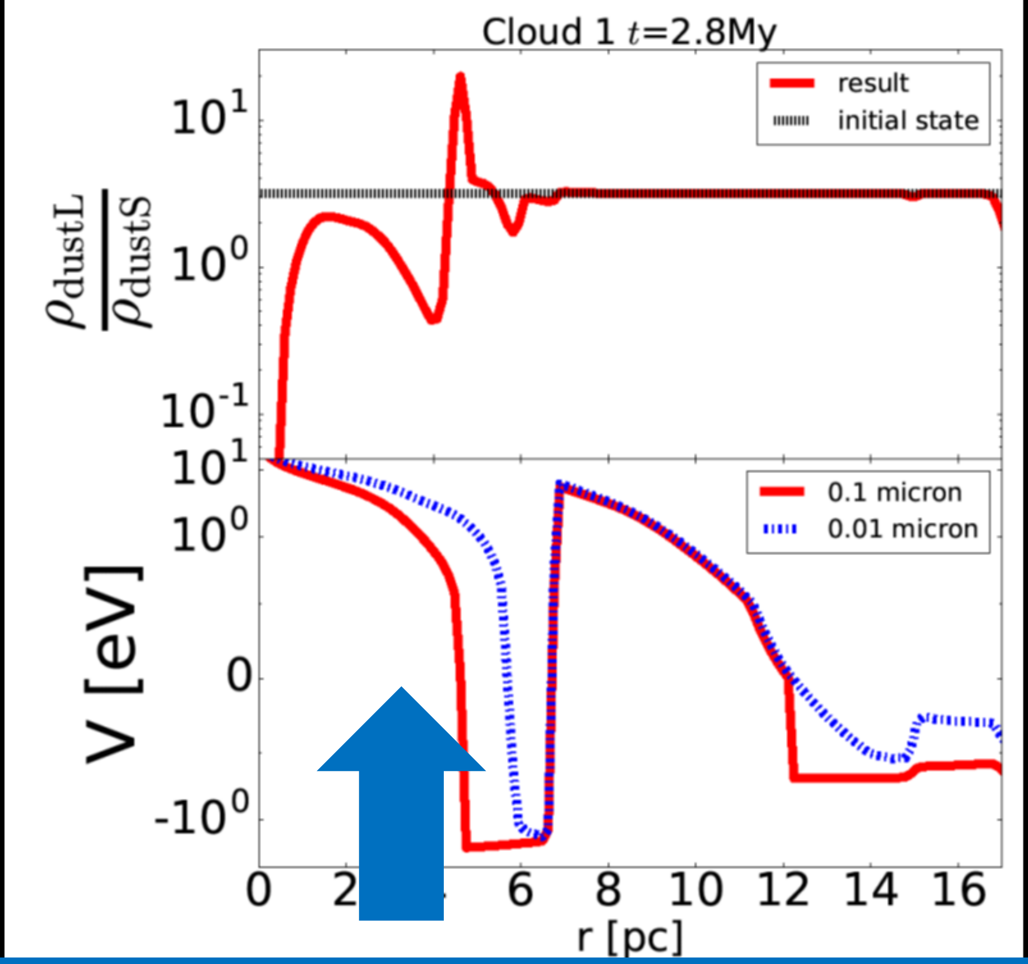
Dust charge



3. Result

0.1μm dust mass density/ 0.01μm dust mass density

Dust charge



Dust charge of large dust is small than that of small dust

3. Result

Dust charge

$$\left|e\Phi_{\text{large dust}}\right| < \left|\mathrm{e}\Phi_{\text{small dust}}\right|$$

Drag force
between dust and gas

$$\left|K_{\text{d; large dust}}\right| < \left|K_{\text{d; small dust}}\right|$$

Relative velocity
between dust and gas

$$\left|v_{\text{large dust}} - v_{\text{gas}}\right| > \left|v_{\text{small dust}} - v_{\text{gas}}\right|$$

3. Result

Change the luminosity of the radiation source

3. Result

Cloud

density: $790\ \mathrm{cm}^{-3}$

radius: 17 pc

distribution: BE

Radiation source

Cloud 1; BB

T_{BB}: $3.9 \times 10^{4}\ \mathrm{K}$

$\dot{N}_{\mathrm{ion}}$: $1.0 \times 10^{49}\ \mathrm{s}^{-1}$

Radiation source

Cloud 2, 3: Star cluster

mass C2: $2.0 \times 10^{3} M_{\odot}$

mass C3: $2.0 \times 10^{4} M_{\odot}$

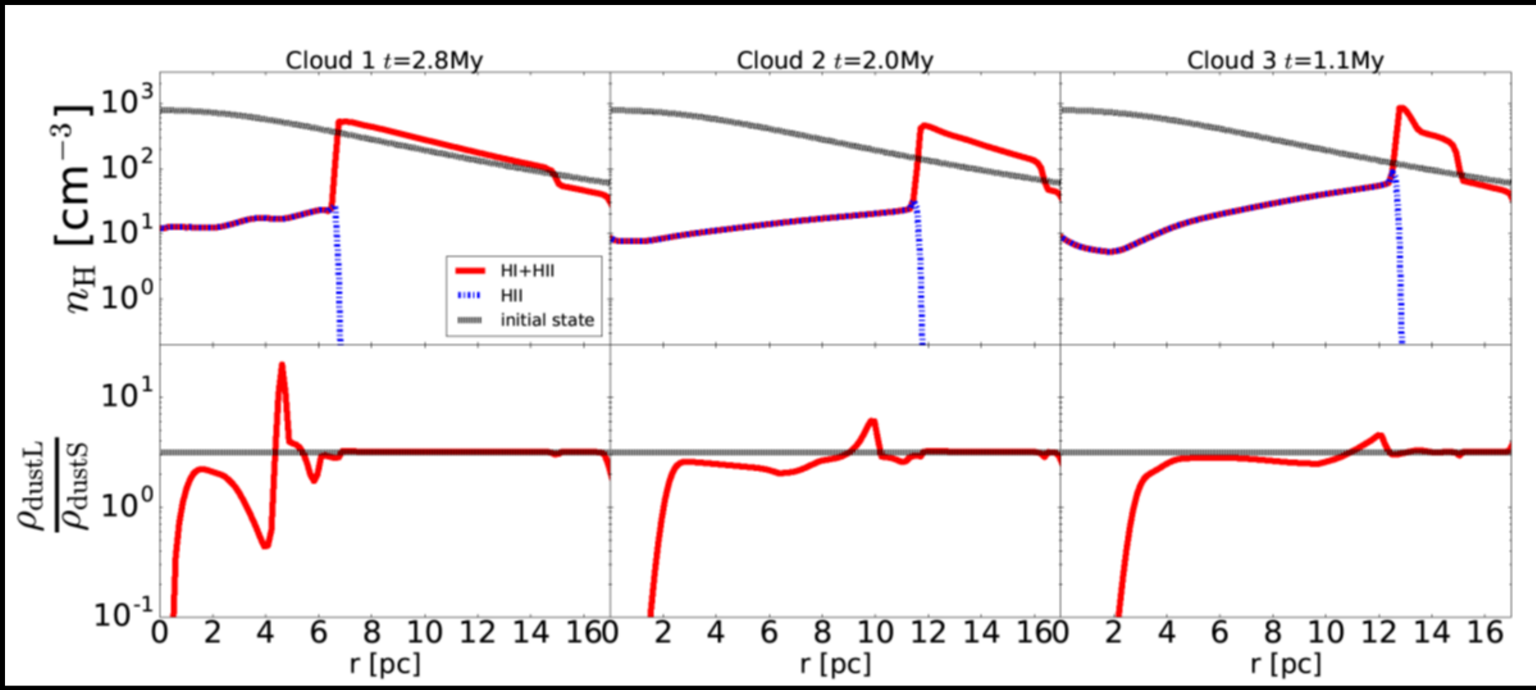
IMF: Salpeter

3. Result

Stronger radiation source

Gas density

0.1μm dust mass density/ 0.01μm dust mass density

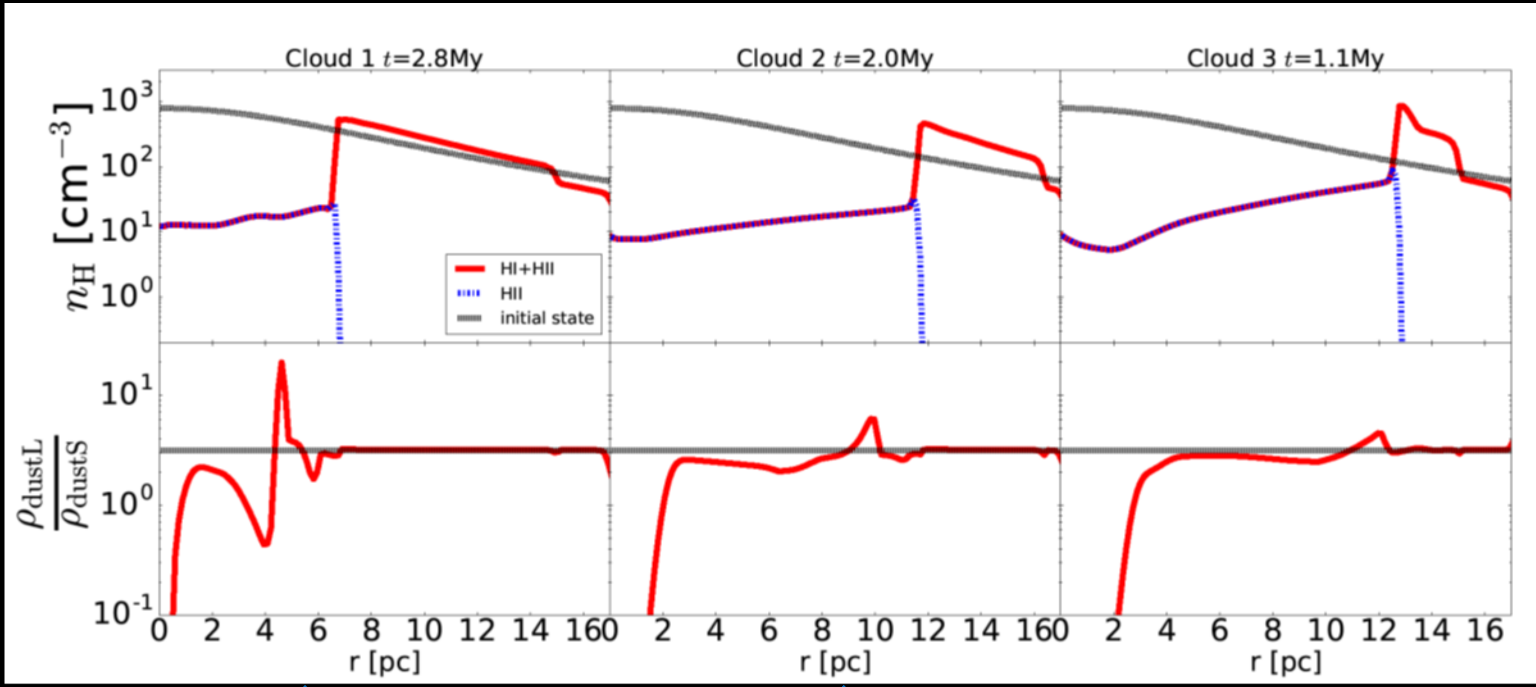


3. Result

Stronger radiation source

Gas density

0.1μm dust mass density/ 0.01μm dust mass density



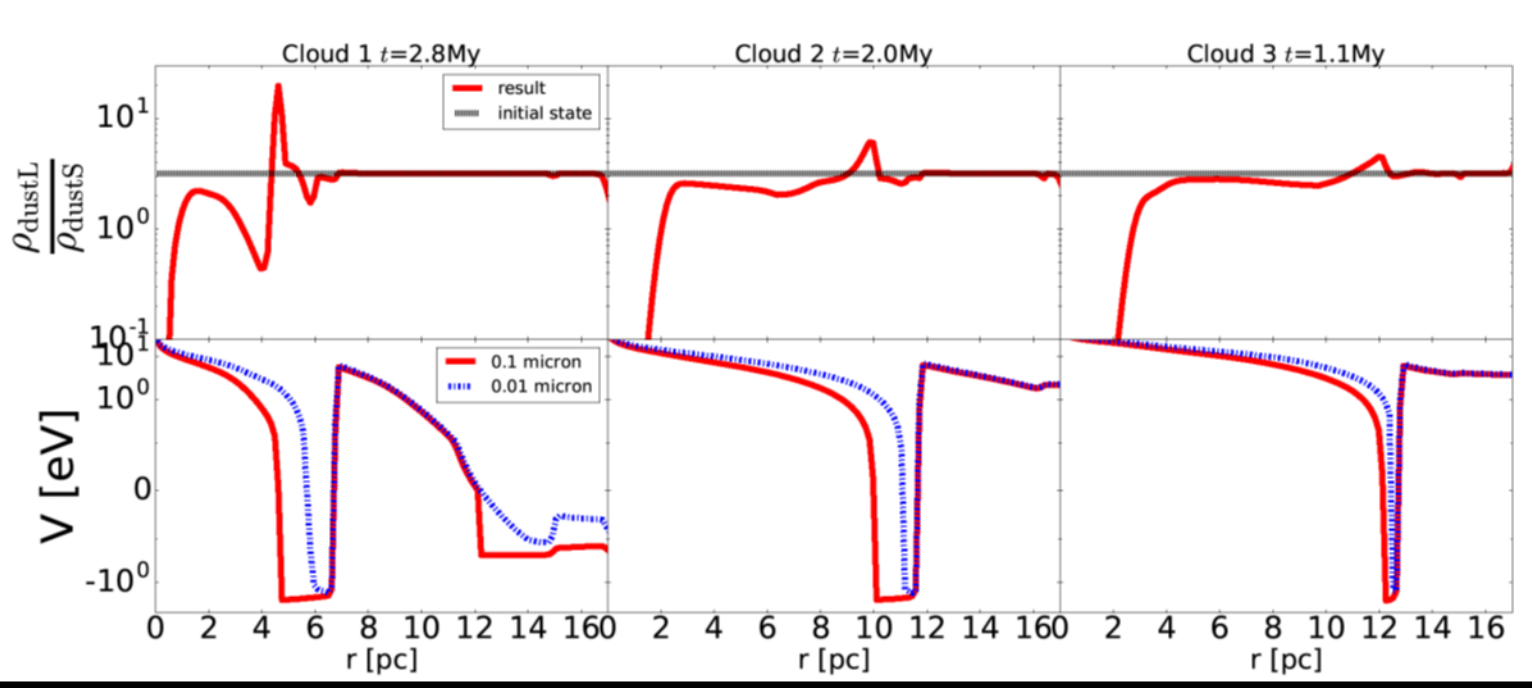
Dust size distribution is less affected when the luminosity is large.

3. Result

Stronger radiation source

0.1μm dust mass density/ 0.01μm dust mass density

Dust charge

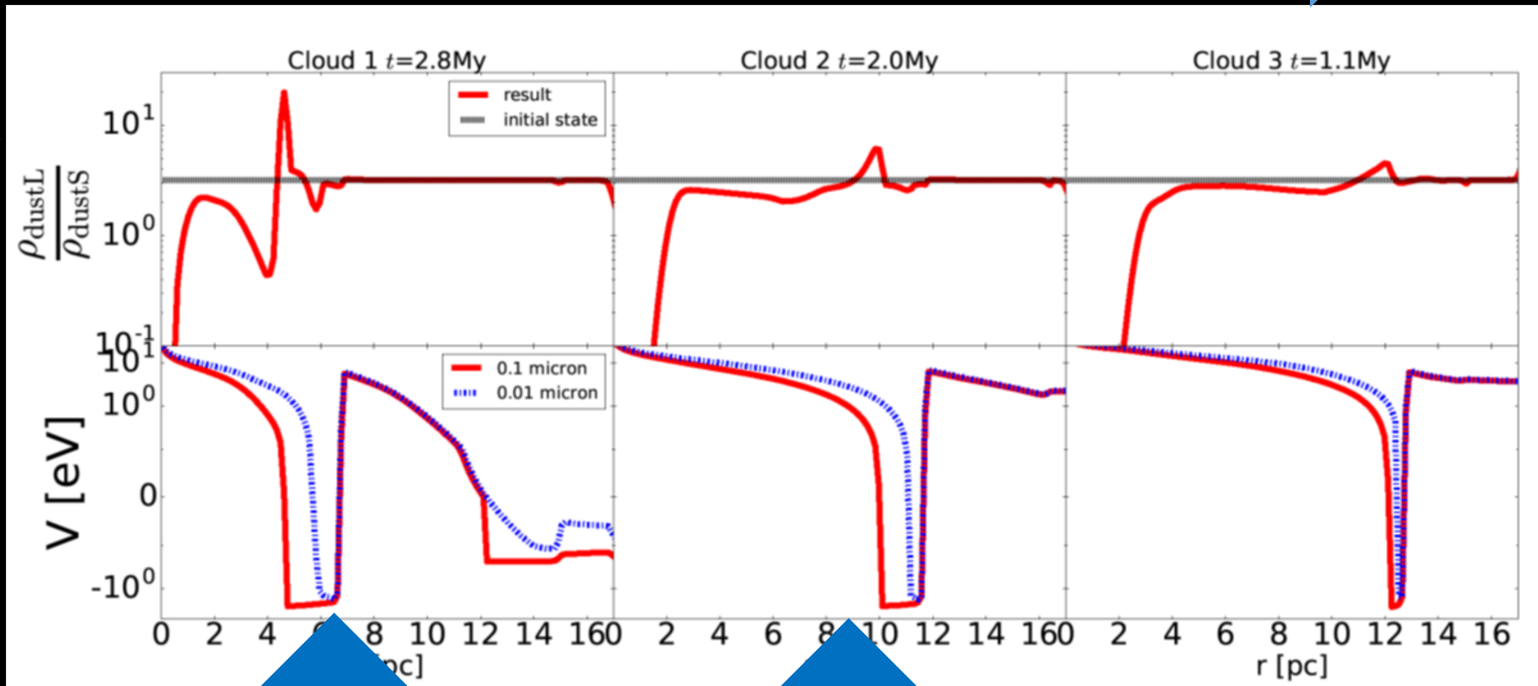


3. Result

Stronger radiation source

0.1μm dust mass density/ 0.01μm dust mass density

Dust charge



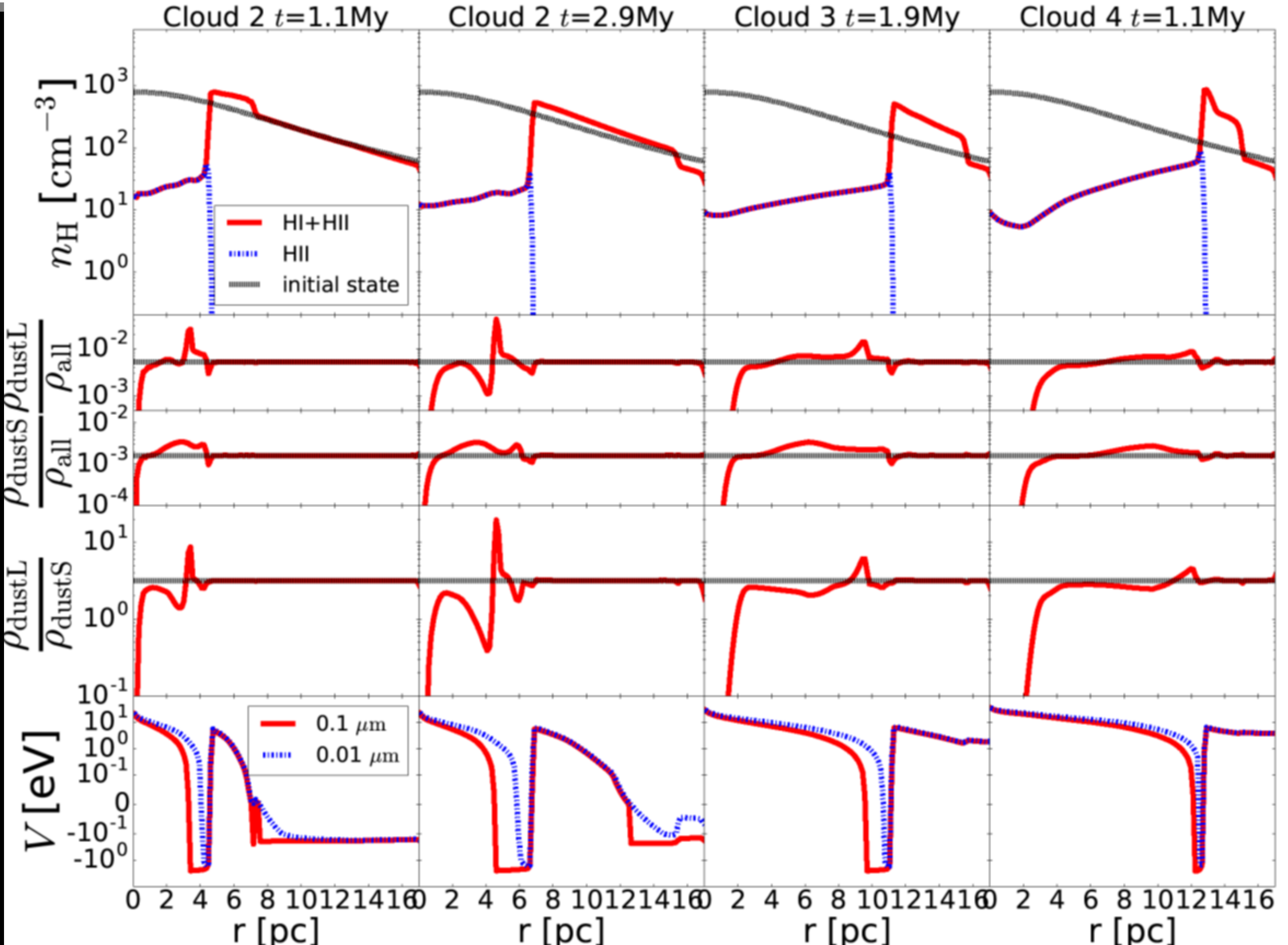
Strongest radiation source makes dust charge strongest

Summary

4. Summary

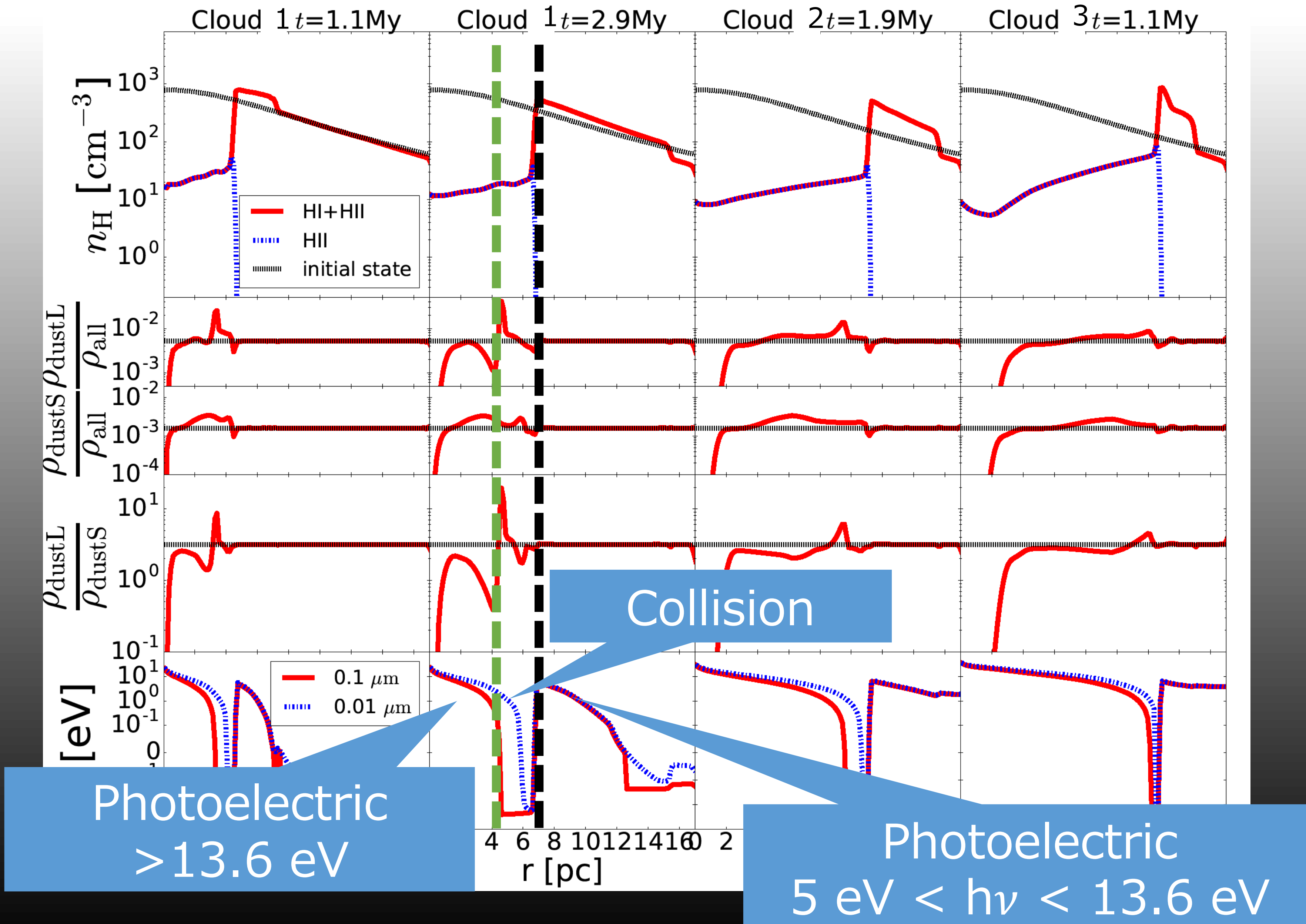
- Radiation pressure affects the dust distribution
- Dust cavity size is almost consistent with the observational estimation
- Large dust is preferentially removed
  - Dust charge of large dust is small
- Dust size distribution is less affected when the luminosity is large.

Result



Cloud 2 t=1.1My
Cloud 2 t=2.9My
Cloud 3 t=1.9My
Cloud 4 t=1.1My
n_{H} [cm^{-3}]
HI+HII
HII
initial state
$\frac{\rho_{\mathrm{dustL}}}{\rho_{\mathrm{all}}}$
$\frac{\rho_{\mathrm{dustS}}}{\rho_{\mathrm{all}}}$
$\frac{\rho_{\mathrm{dustL}}}{\rho_{\mathrm{dustS}}}$
V [eV]
0.1 μm
0.01 μm
r [pc]

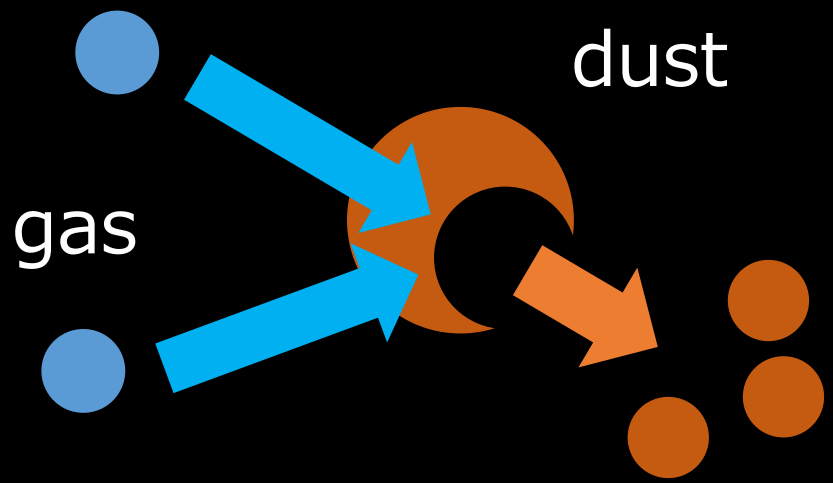
Discussion



Cloud 1 t=1.1My
Cloud 1 t=2.9My
Cloud 2 t=1.9My
Cloud 3 t=1.1My
HI+HII
HII
initial state
0.1 μm
0.01 μm
r [pc]
Collision
Photoelectric
>13.6 eV
Photoelectric
5 eV < hν < 13.6 eV

Discussion

Effect of sputtering



$$\frac{1}{n_{\mathrm{H}}}\frac{da_{\mathrm{dust}}}{dt} < 10^{-5}\ \mu\mathrm{m\ Myr^{-1}cm^{3}}$$

Negligible !

Discussion

The effect of differential velocity on cloud expansion

$$v_{\mathrm{expand}} \approx 10\ \mathrm{km\ s^{-1}}$$
$$|v_{\mathrm{g}} - v_{\mathrm{d}}| \approx 0.5\ \mathrm{km\ s^{-1}}$$

Negligible !

Method Test calculation