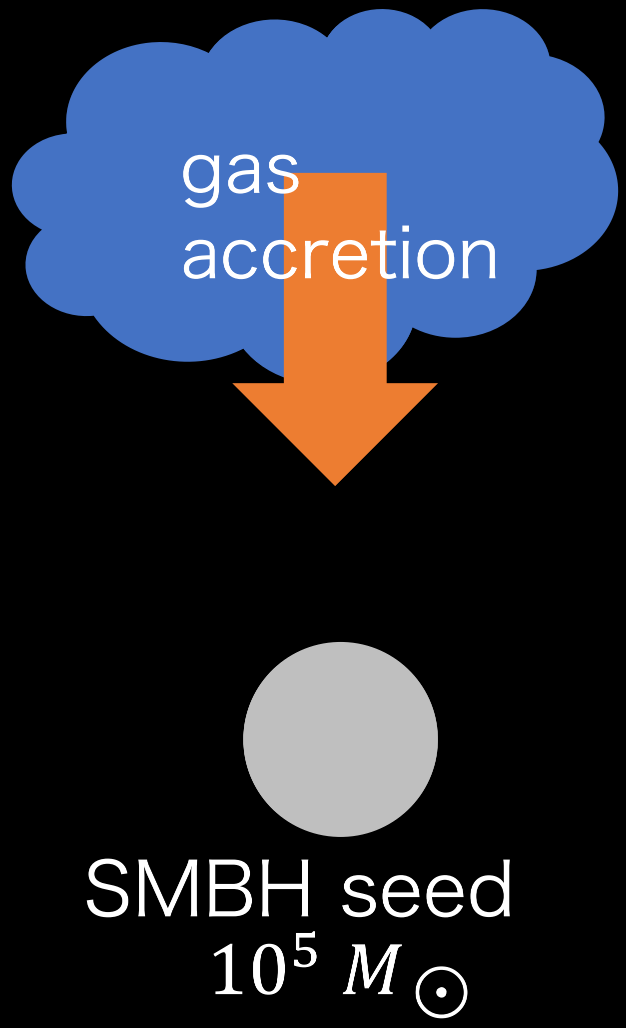
Growth of massive black holes in dusty clouds: impacts of relative velocity between dust and gas

Shohei Ishiki (Hokkaido University),
Takashi Okamoto (Hokkaido University),
Hidemobu Yajima (Tukuba University)

1. Introduction



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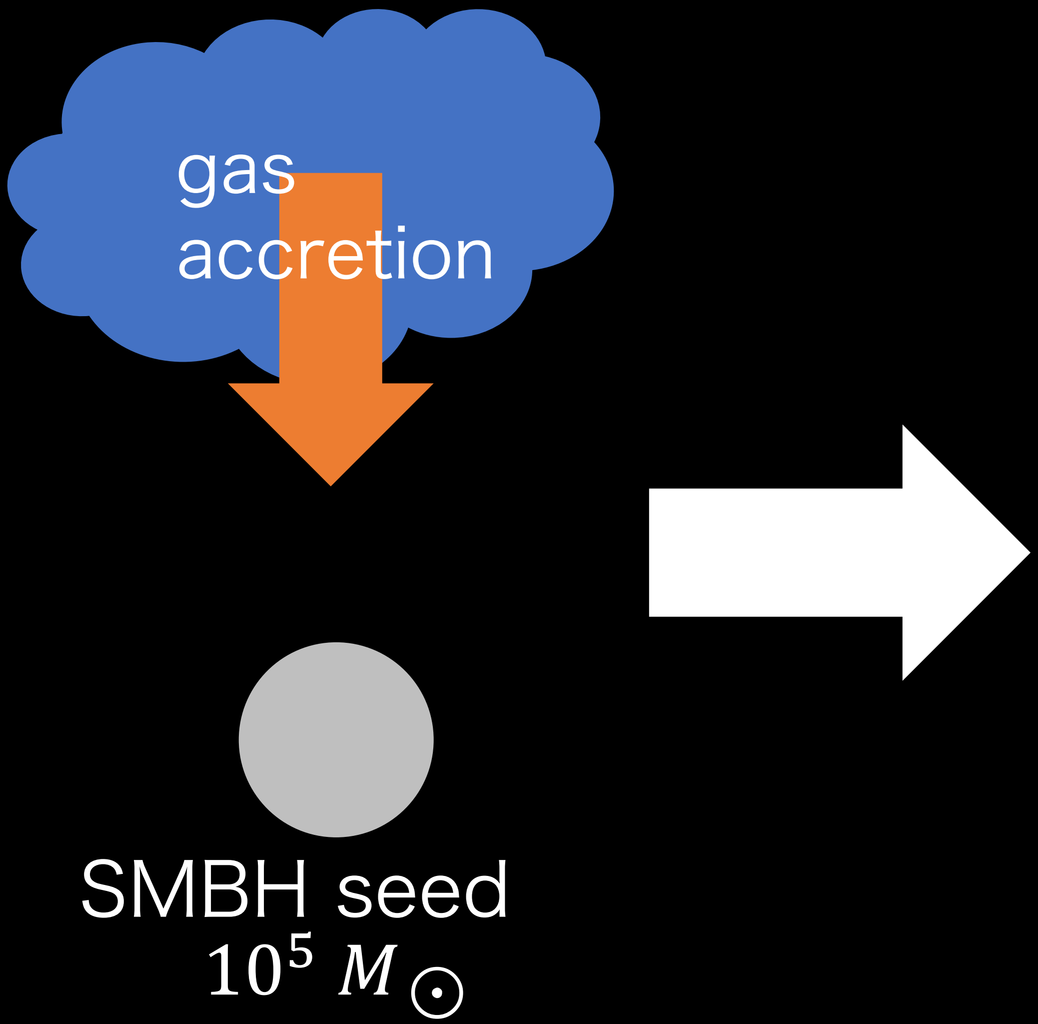

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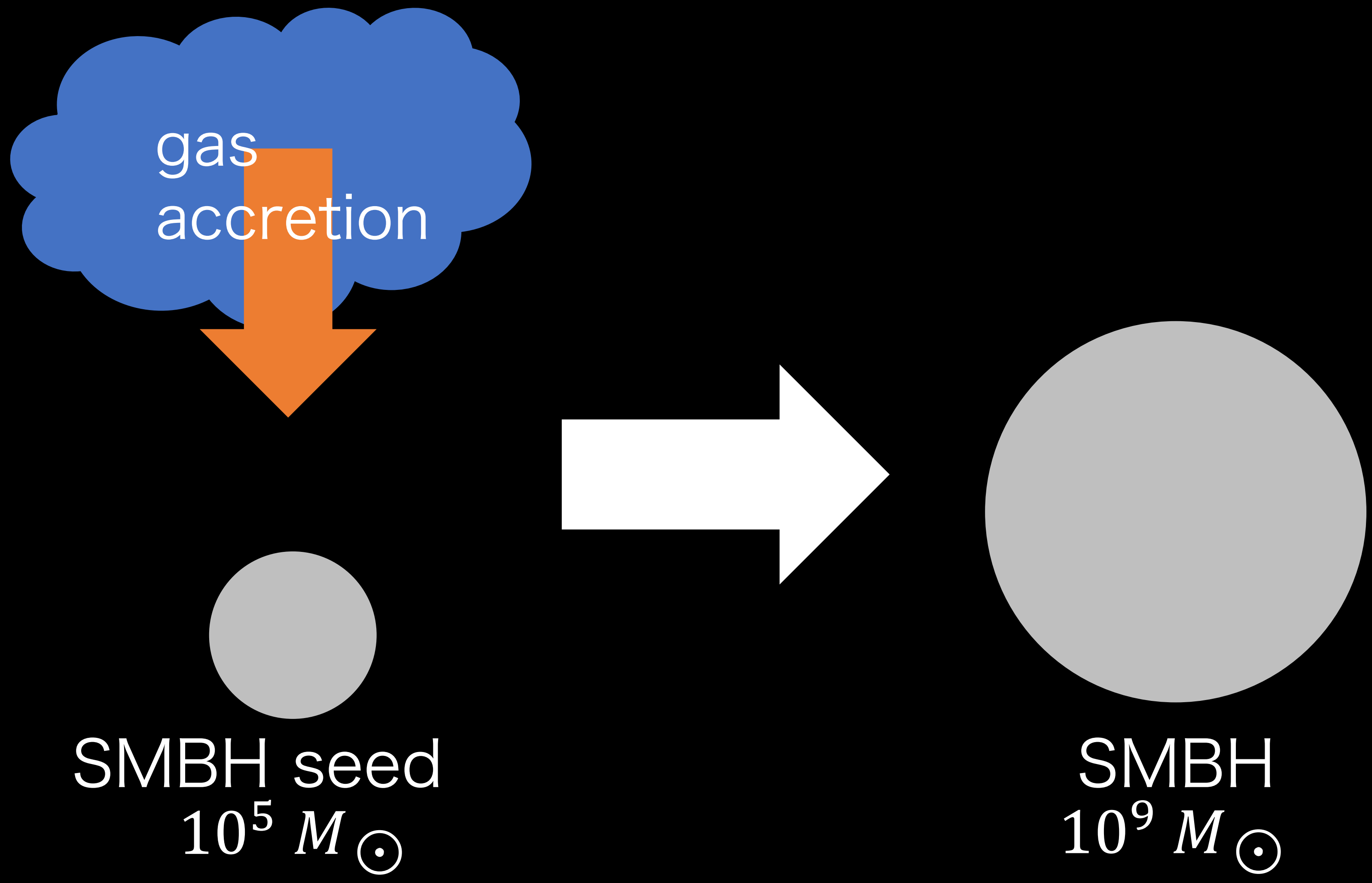

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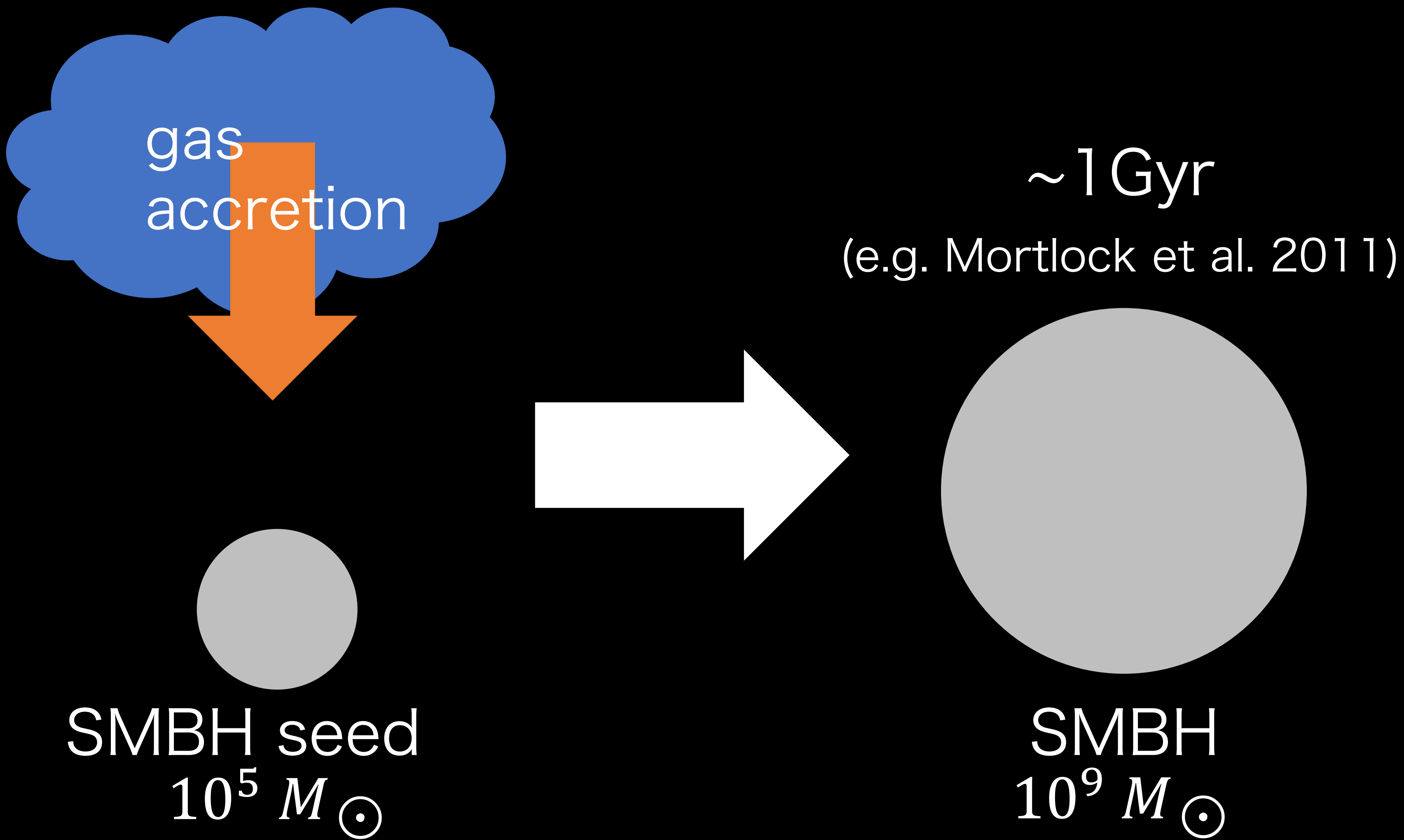

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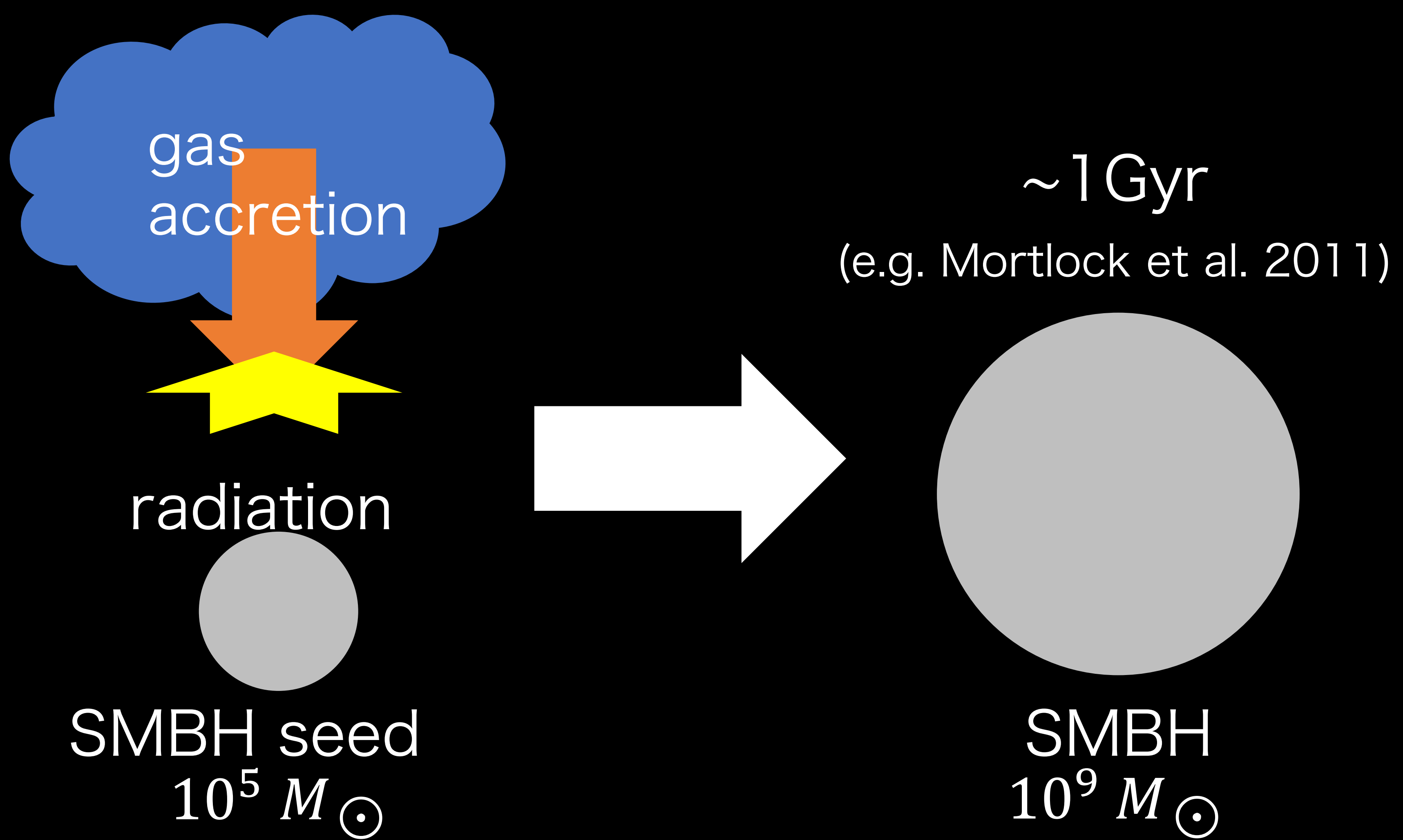

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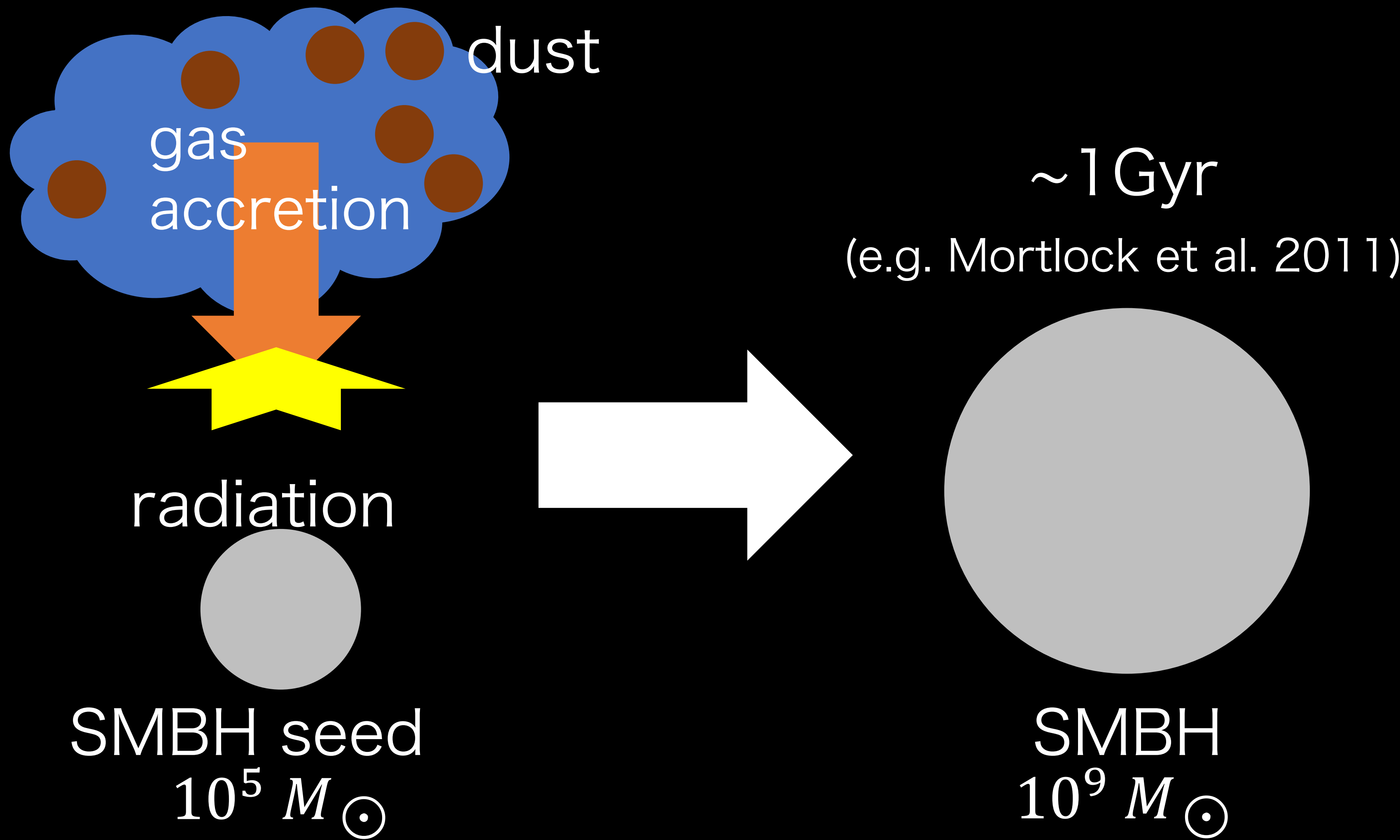

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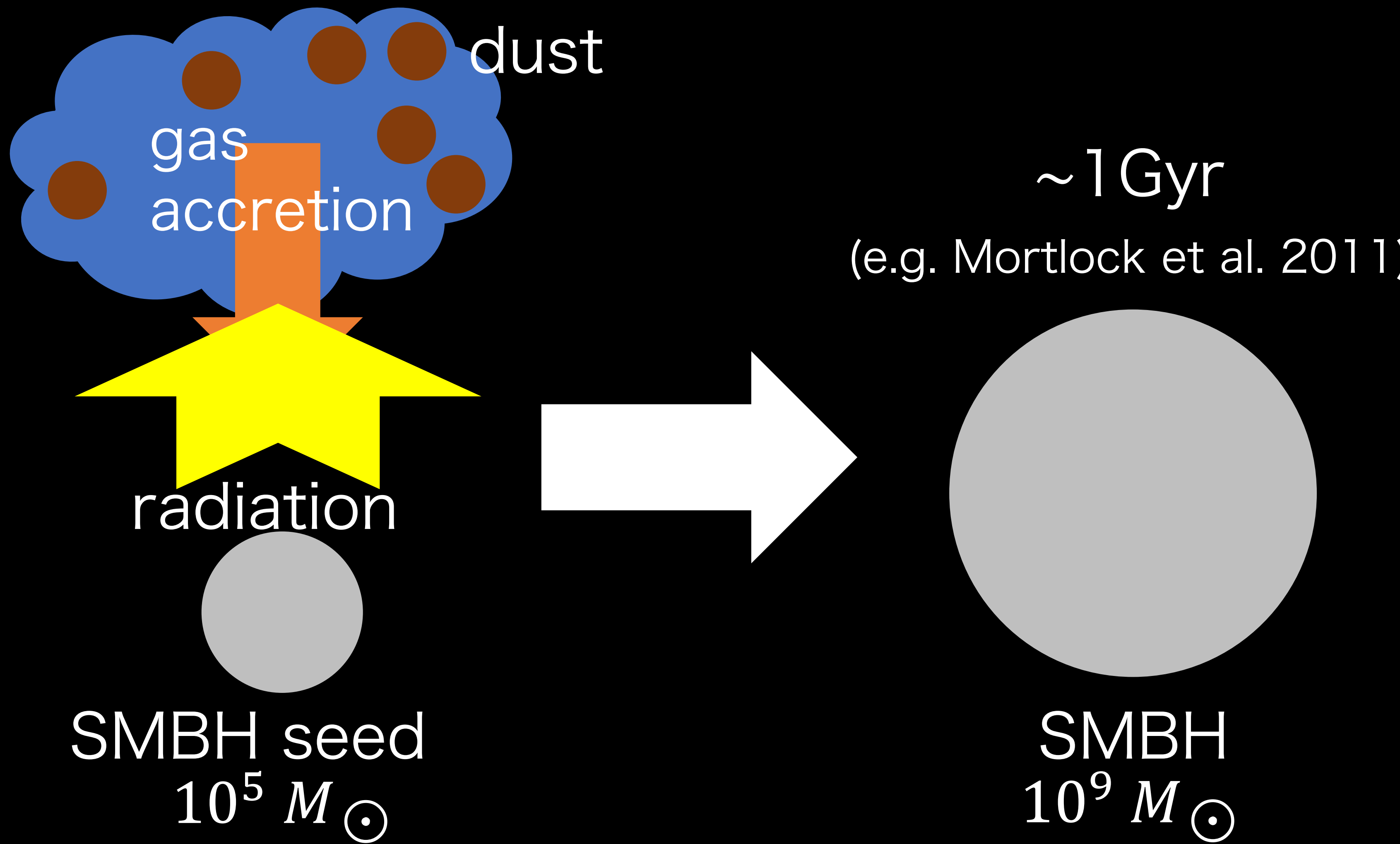
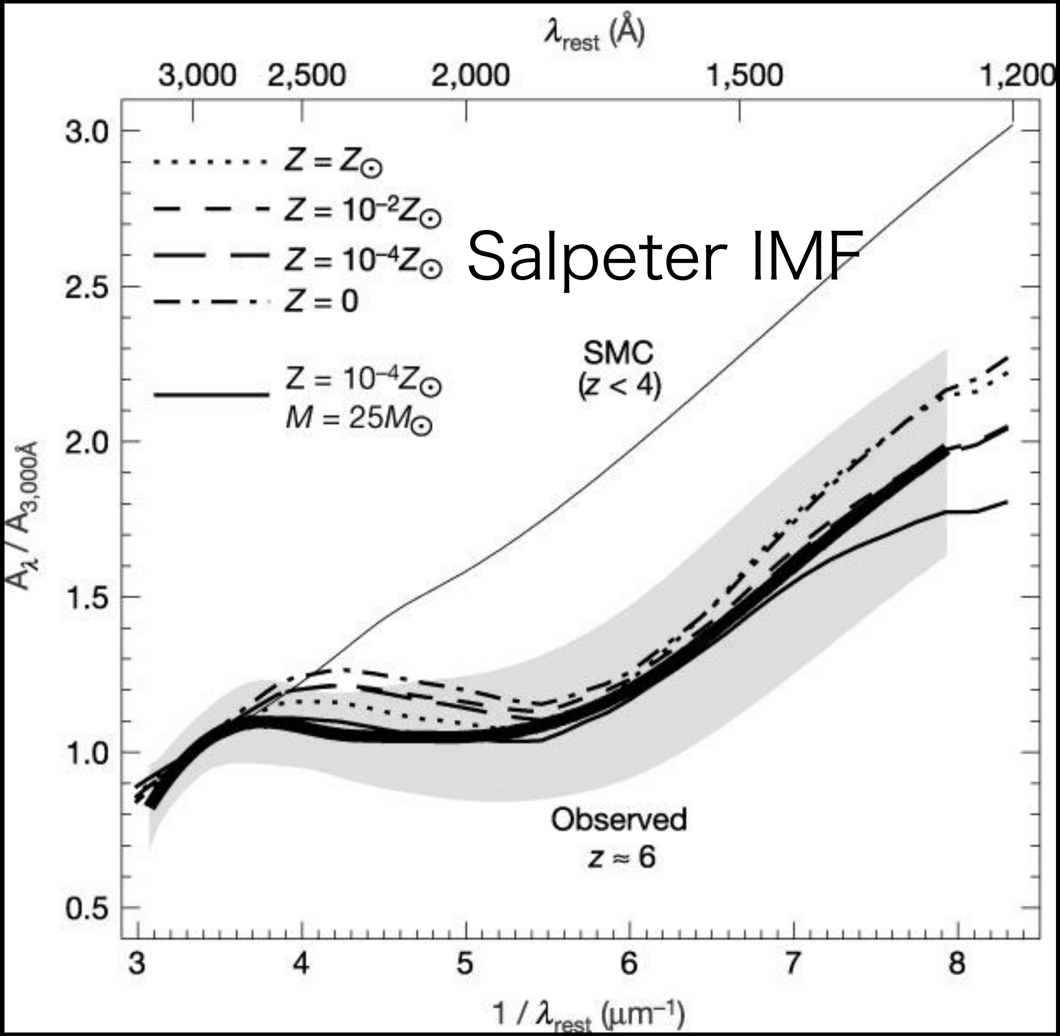


1. Introduction

Extinction curve of quasar at z=6.2



Maiolino et al. (2004)

1. Introduction

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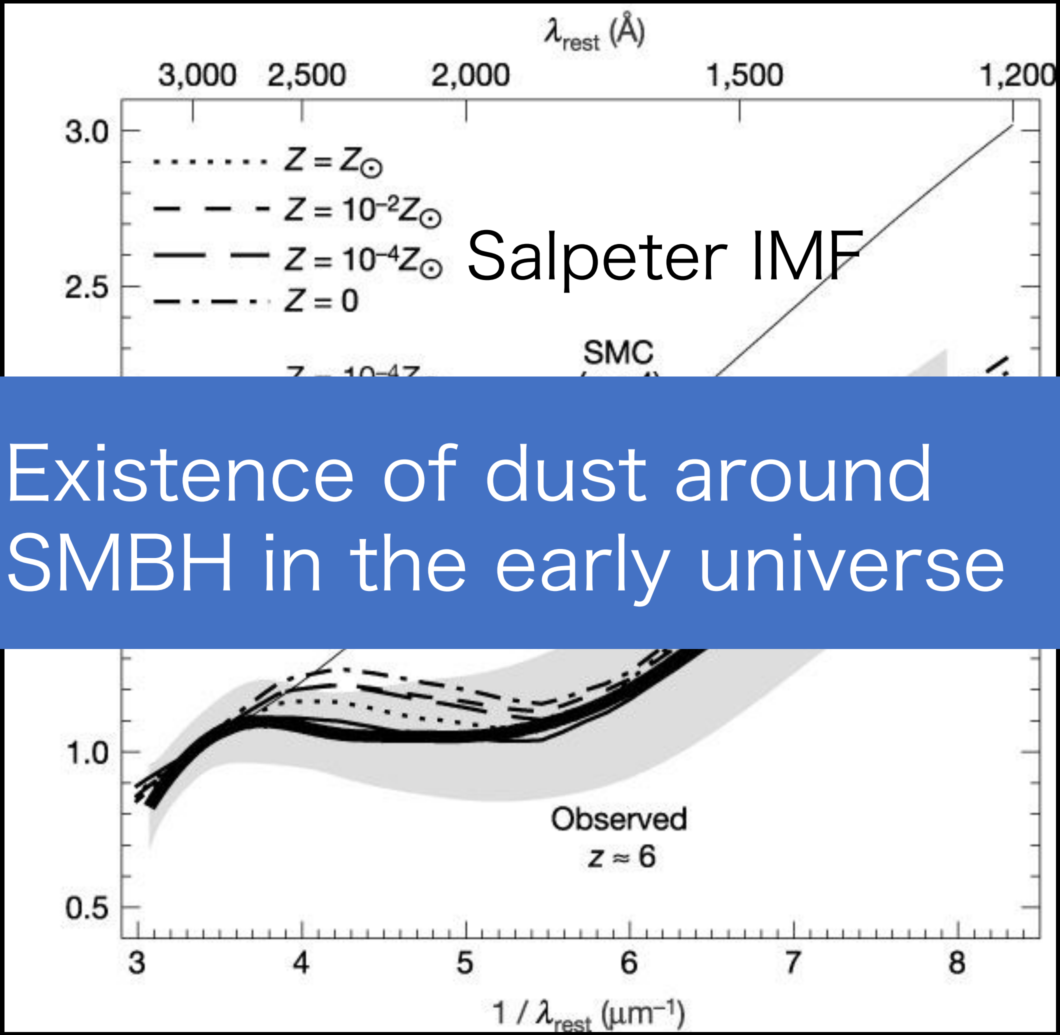
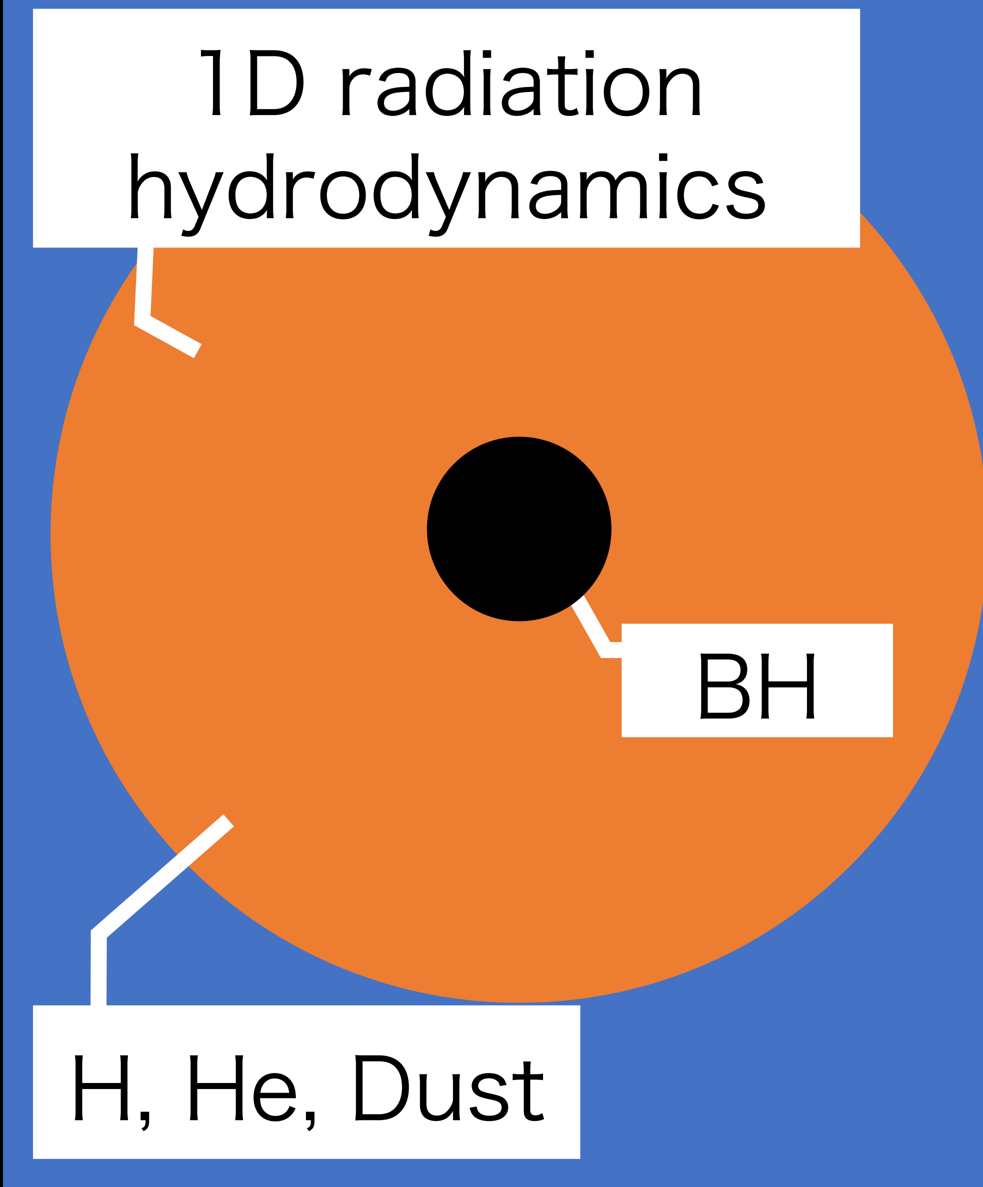


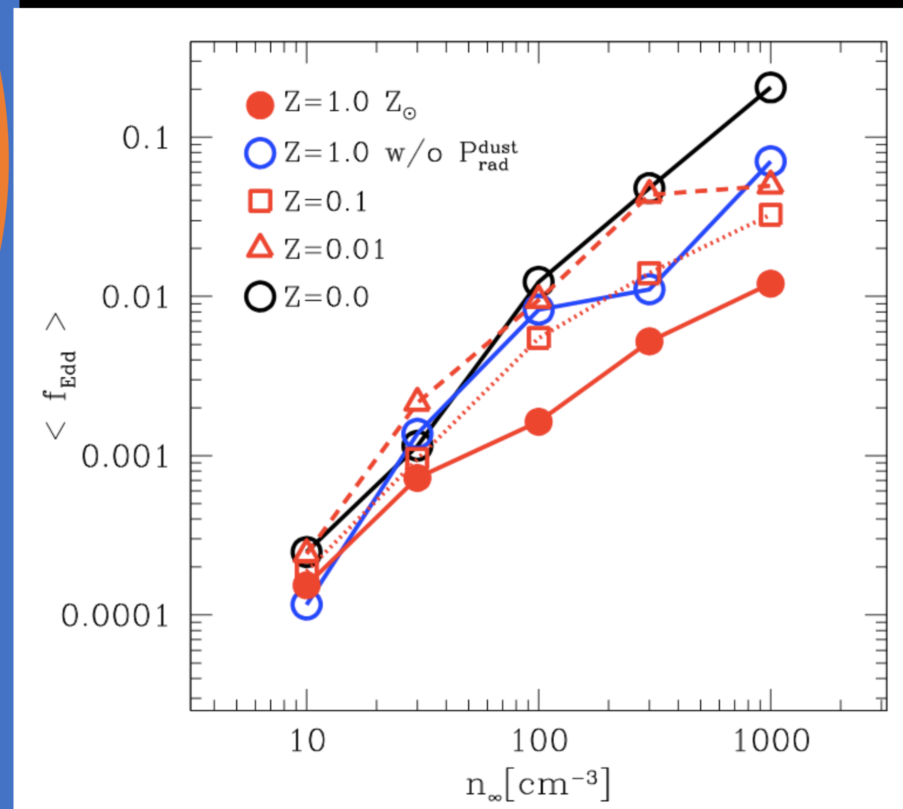
Existence of dust around SMBH in the early universe

Maiolino et al. (2004)

1. Introduction



Yajima et al. (2017) shows that radiation pressure suppress the dusty gas accretion onto BH.



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The effect of relative velocity between dust and gas ?

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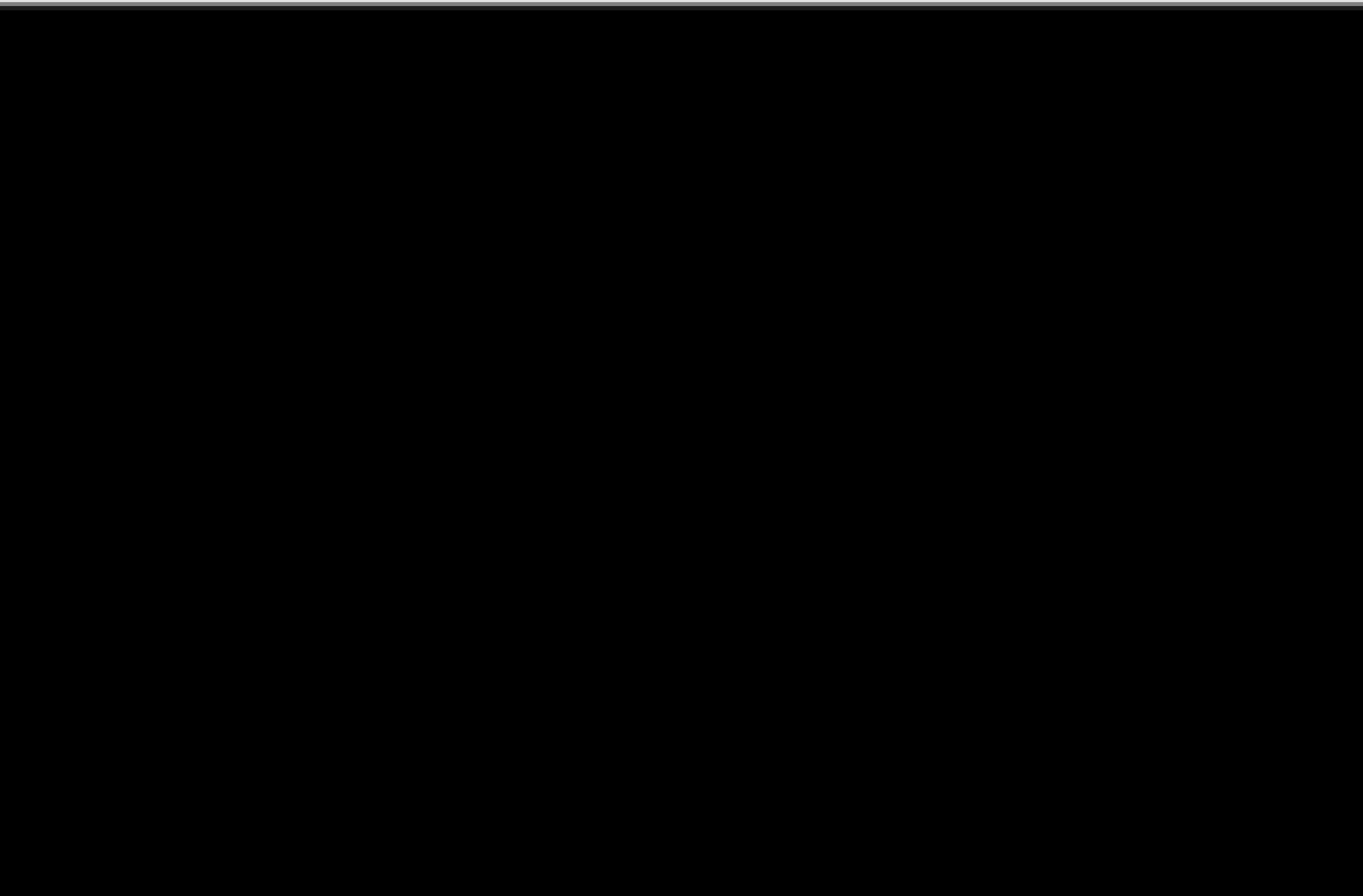
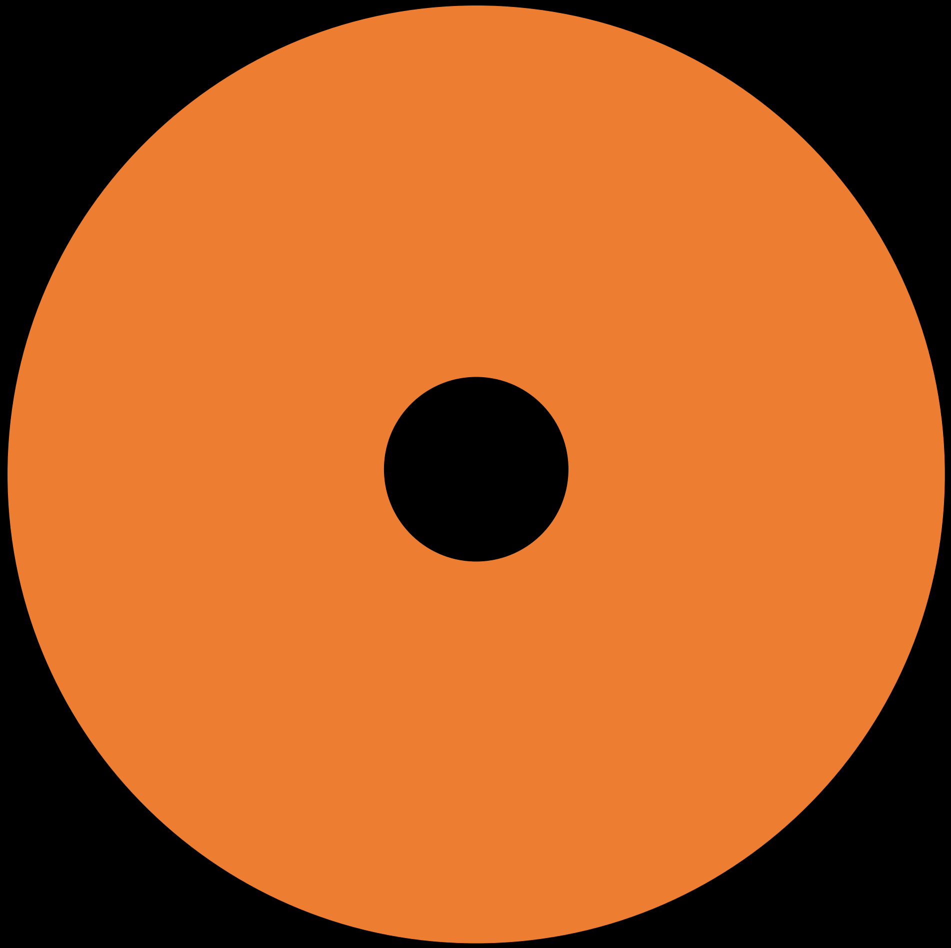


1. Introduction

We investigate
the impacts of relative motion
of dust and gas on the
accretion rate onto BH

2. Method & Model



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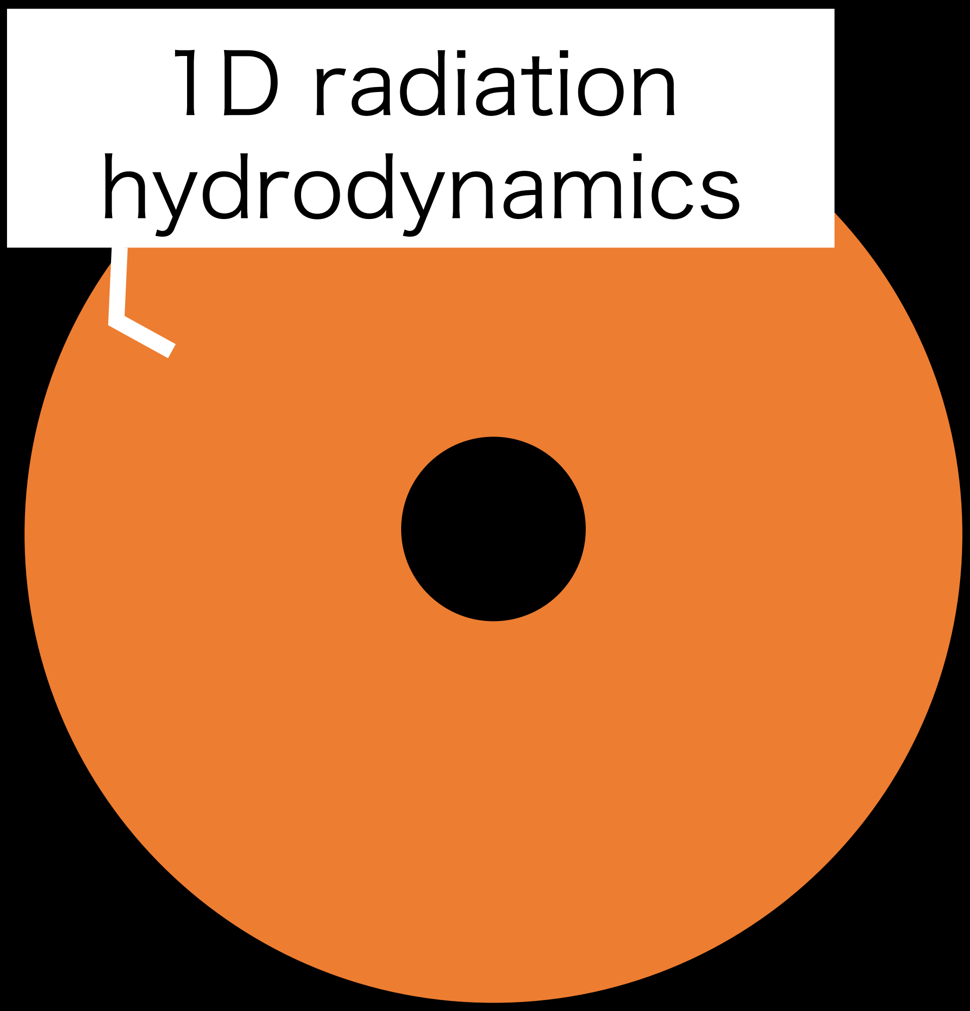

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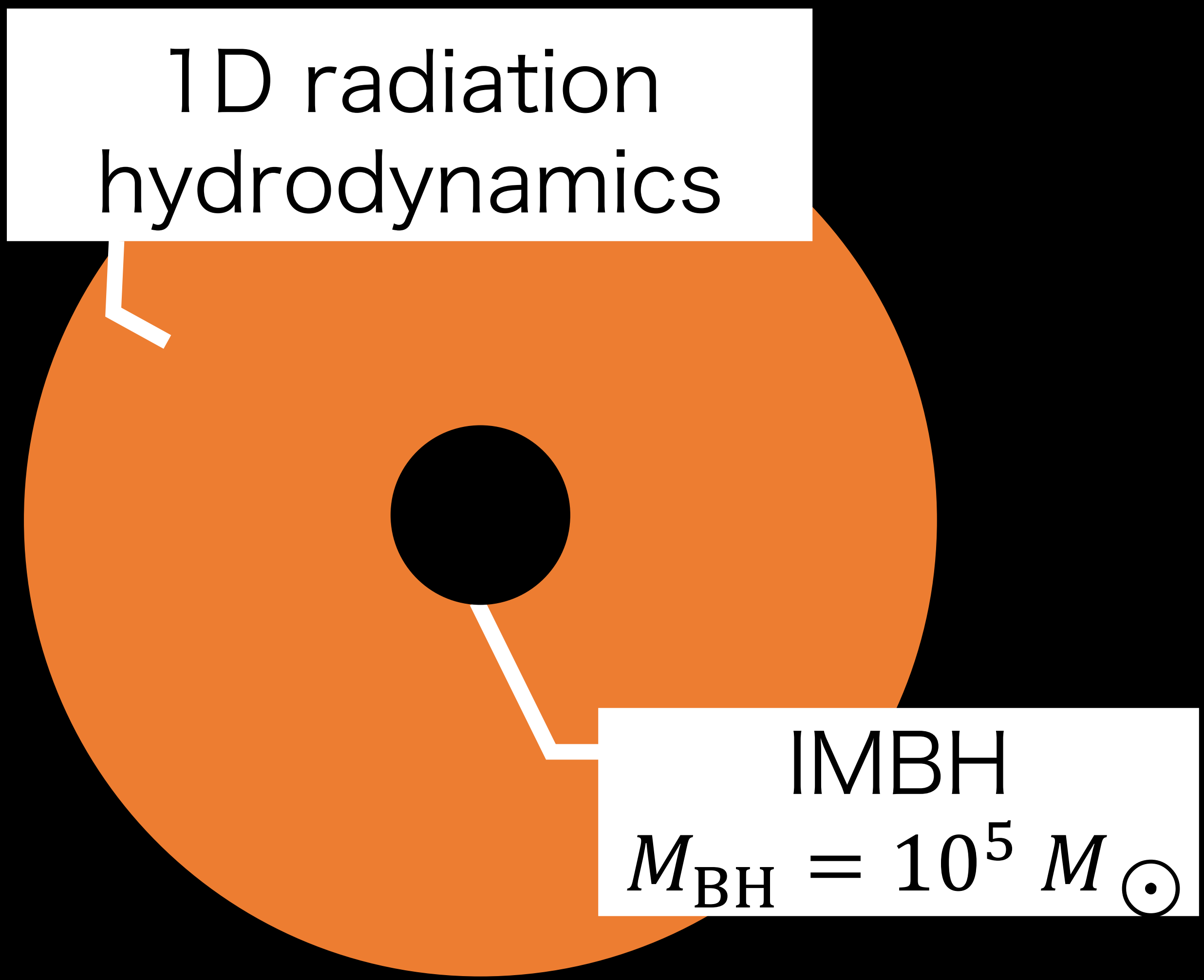

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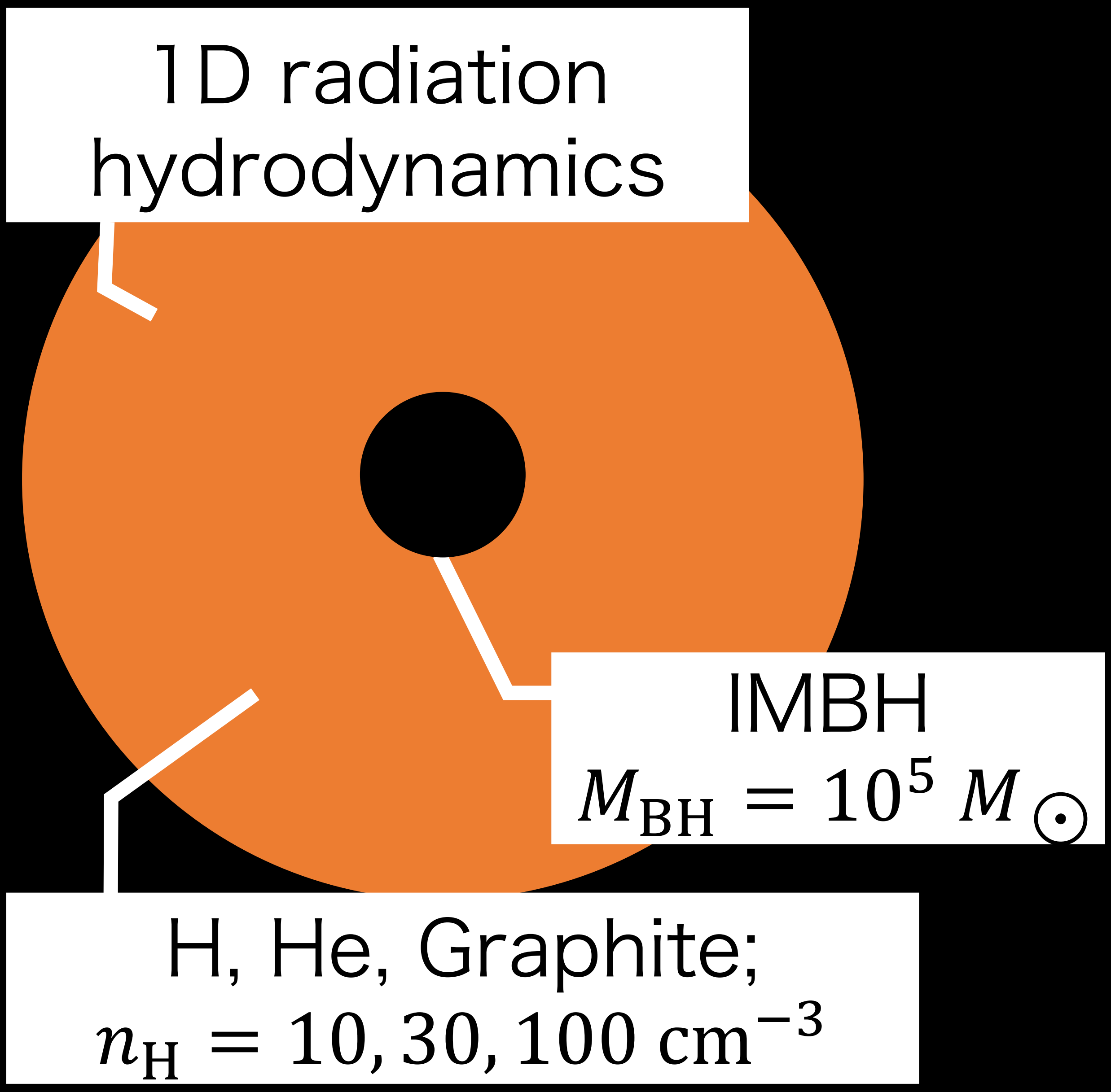

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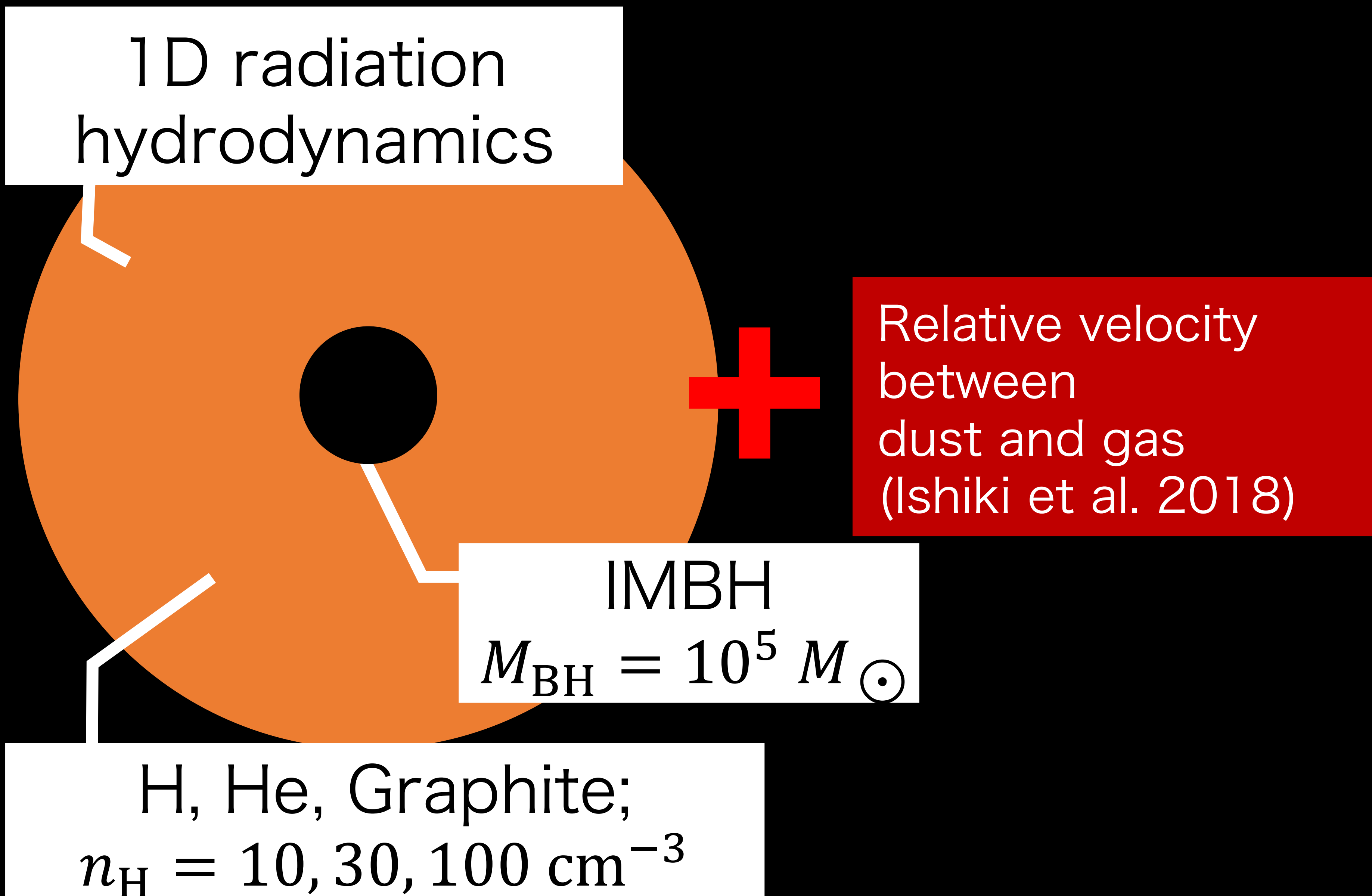

2. Method

2. Method

1D radiation transfer

2. Method

1D radiation transfer

1D Hydrodynamics (Ishiki et al. 2018)

scheme:	SLAU2 (Kitayama & Shima 2013)
dust drag force:	Coulomb drag force Collisional drag force (Draine & Salpeter 1979)
dust charge:	primary electron emission Augar electron emission secondary electron emission electron and ion collision (Weingartner & Draine 2001), (Weingartner et al. 2006)

2. Method

Dust

2. Method

- Dust
  - Graphite

2. Method

Dust

Graphite

size	0.1, 0.01 micron
ratio	$n_{0.1}: n_{0.01} = 1:10^{2.5}$

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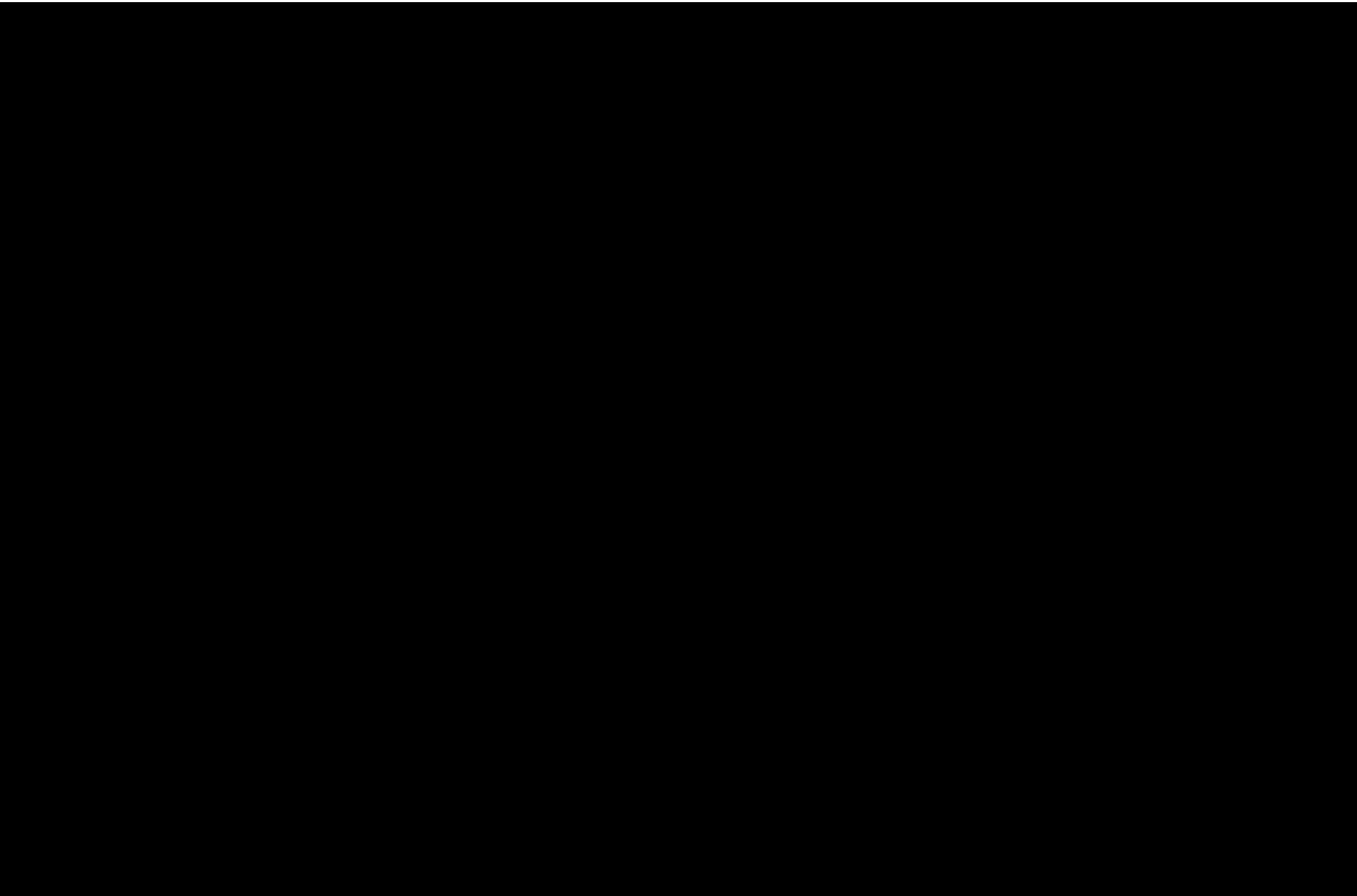

2. Method

Chemical reactions

Collisional ionization
Recombination
Dielectronic recombination

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Chemical reactions

- Collisional ionization
- Recombination
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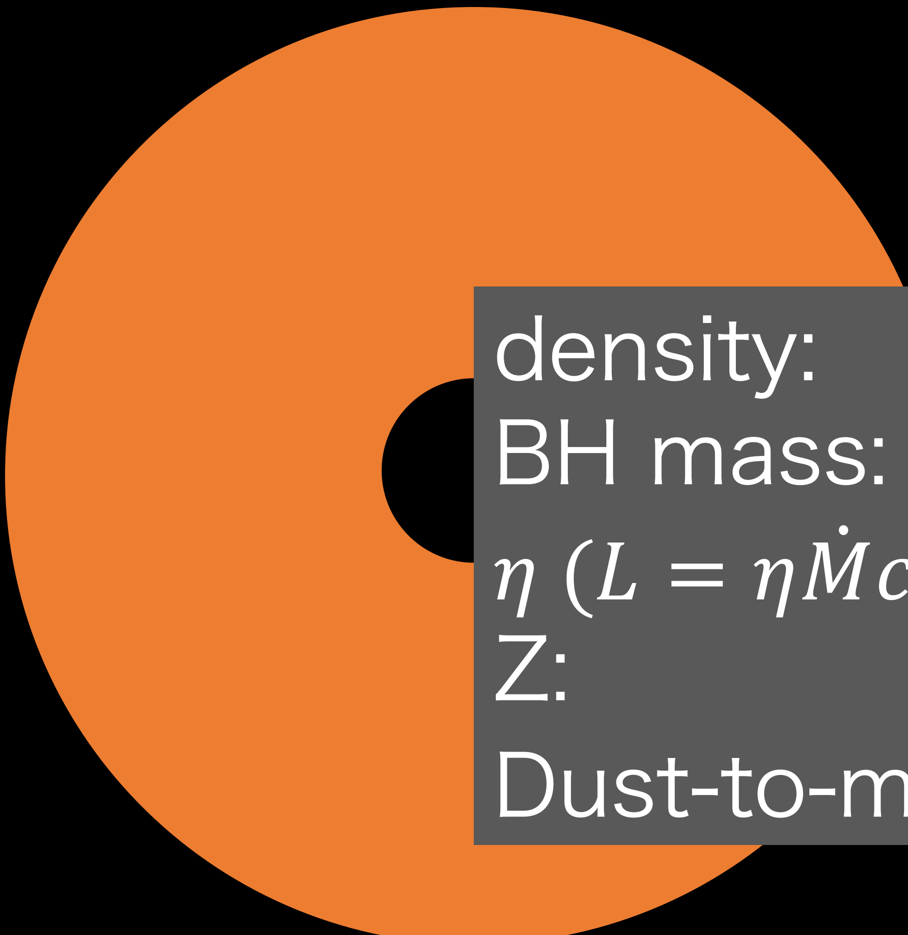
Heating and cooling

- photoionization heating
- collisional ionization cooling
- dielectronic recombination cooling
- collisional excitation cooling
- bremsstrahlung cooling
- inverse Compton cooling

3. Result



density: 10, 30, 100 $\mathrm{cm^{-3}}$

BH mass: $10^5\ \mathrm{M_\odot}$

$\eta\ (L = \eta \dot{M} c^2)$: 0.1, 0.3

Z: 0.1, 1.0 $\mathrm{Z_\odot}$

Dust-to-metal: solar

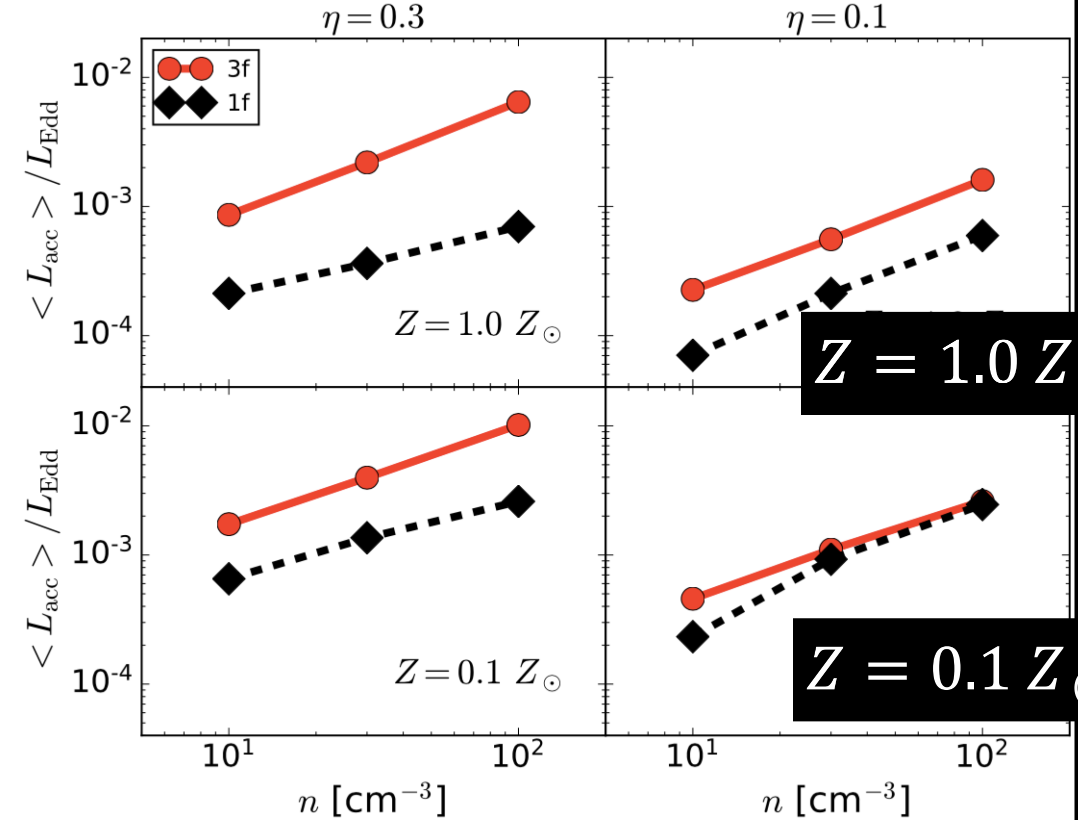
3. Result Time averaged BH luminosity

Red: relative velocity
Black: completely coupled

$$L = \eta \dot{M} c^2$$

$\eta = 0.3$ $\eta = 0.1$

$$\frac{\text{Time averaged BH Luminosity}}{\text{Eddington Luminosity}}$$



$Z = 1.0\, Z_\odot$

$Z = 0.1\, Z_\odot$

Number density of gas

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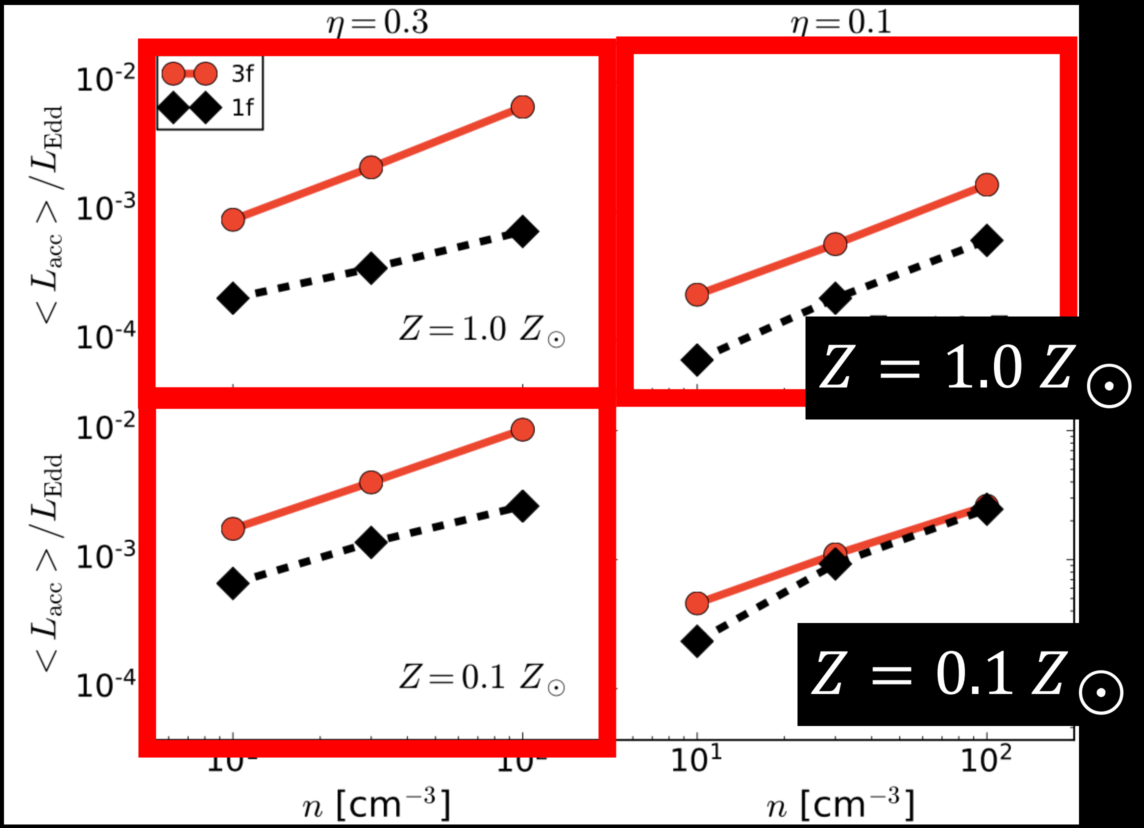

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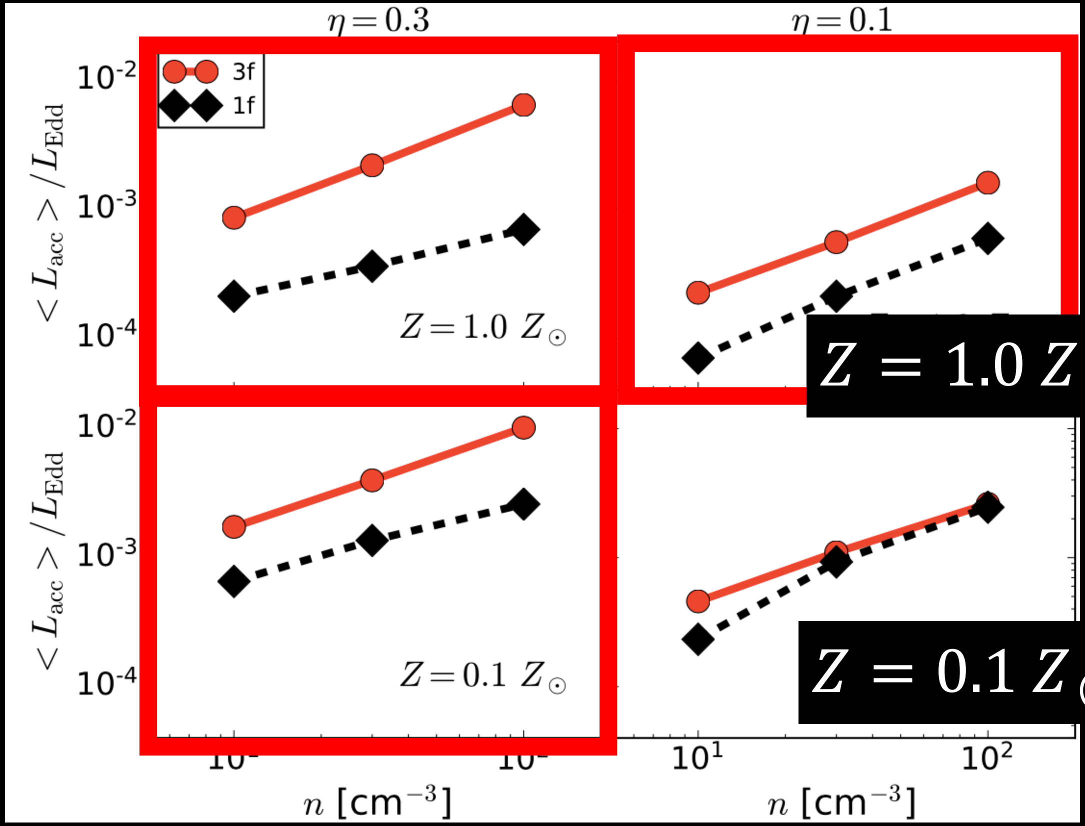
The decoupling of dust from gas promotes the gas accretion onto BH.



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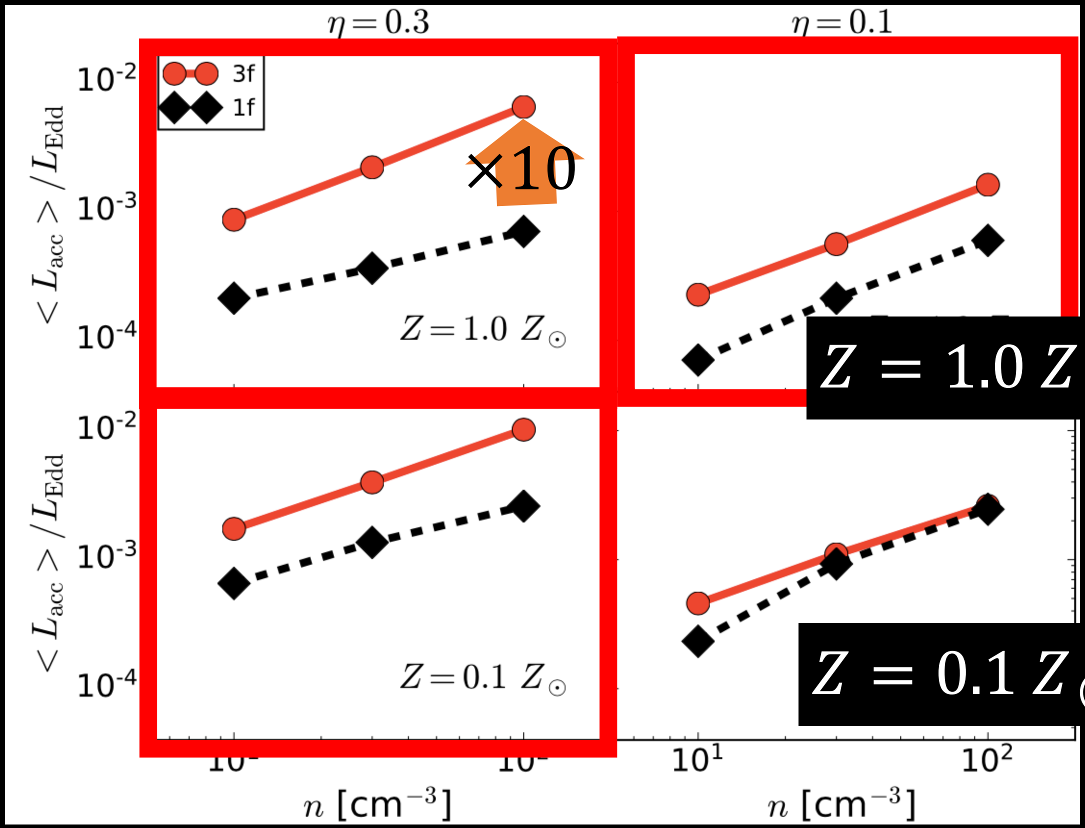

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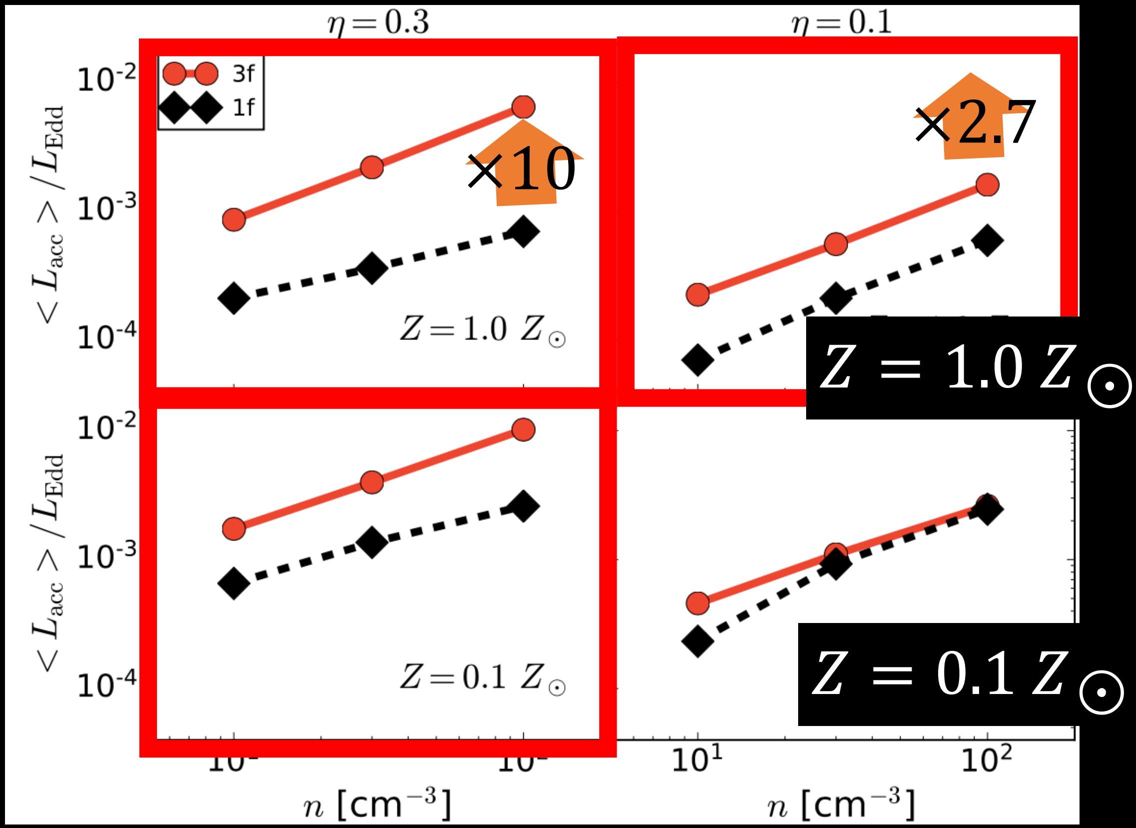

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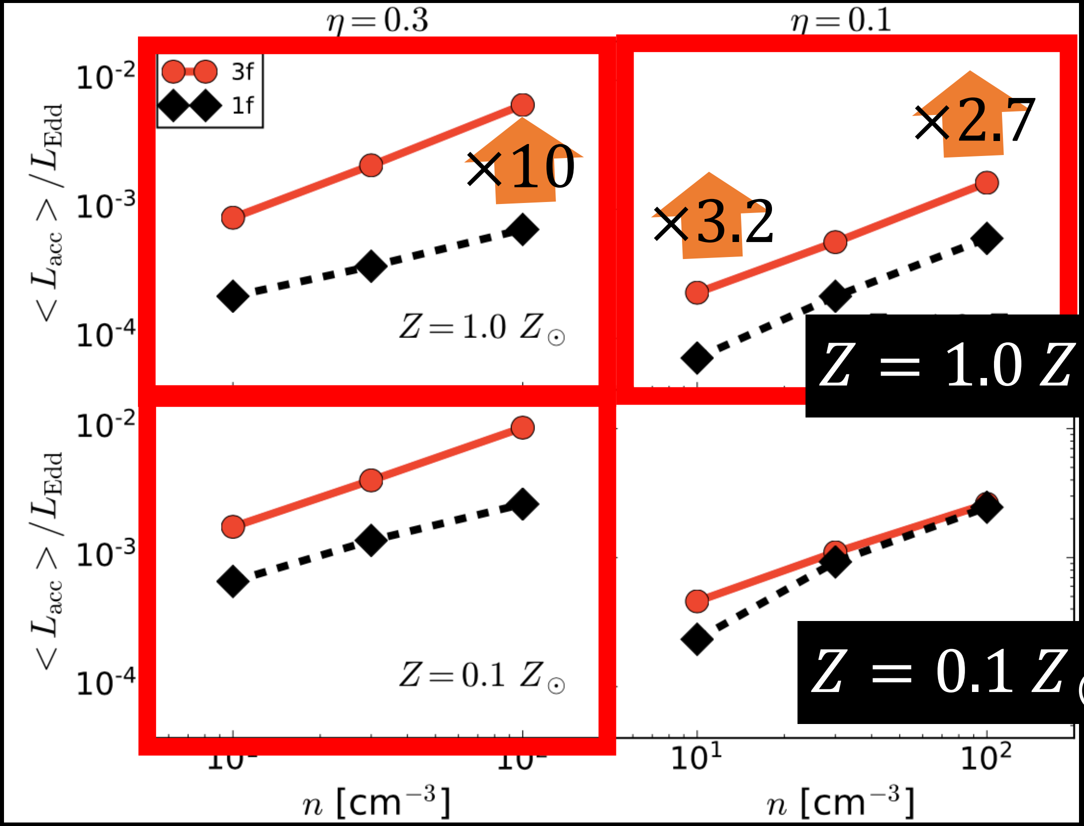

Number density of gas

The decoupling of dust from gas promotes the gas accretion onto BH.

3. Result

Why does the decoupling of dust from gas promote the gas accretion onto BH?

3. Result Spatial distribution of dust grains

$n_{\mathrm{H}} = 100\ \mathrm{cm}^{-3}$, $\mathrm{Z} = 1.0\ \mathrm{Z}_{\odot}, \eta = 0.1$

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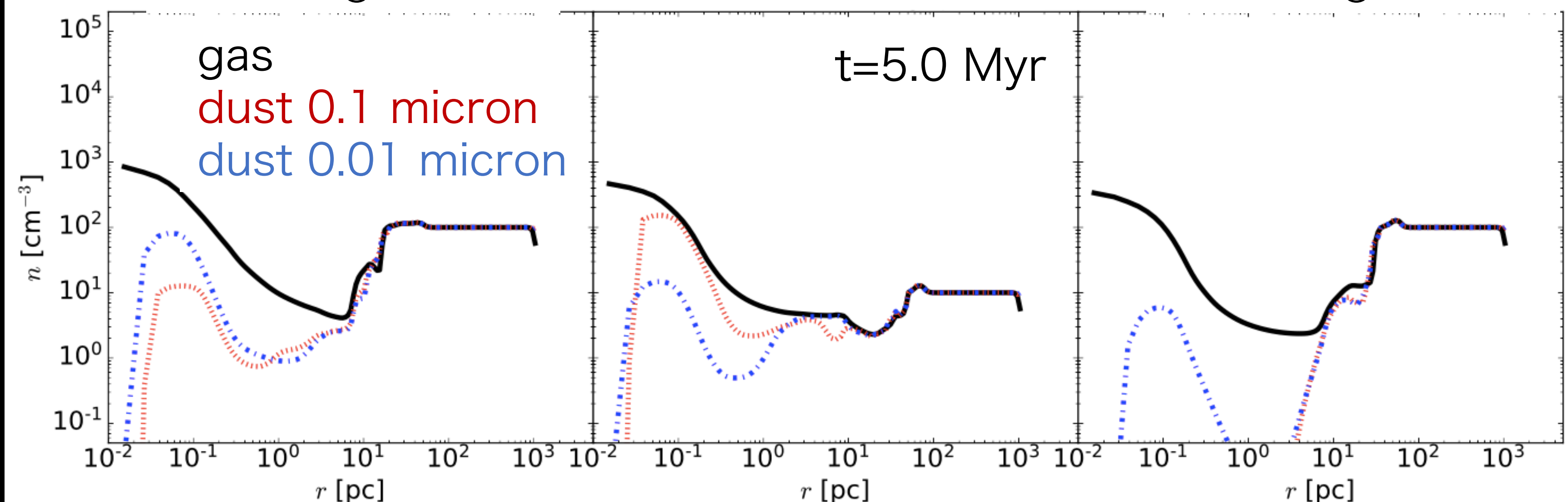
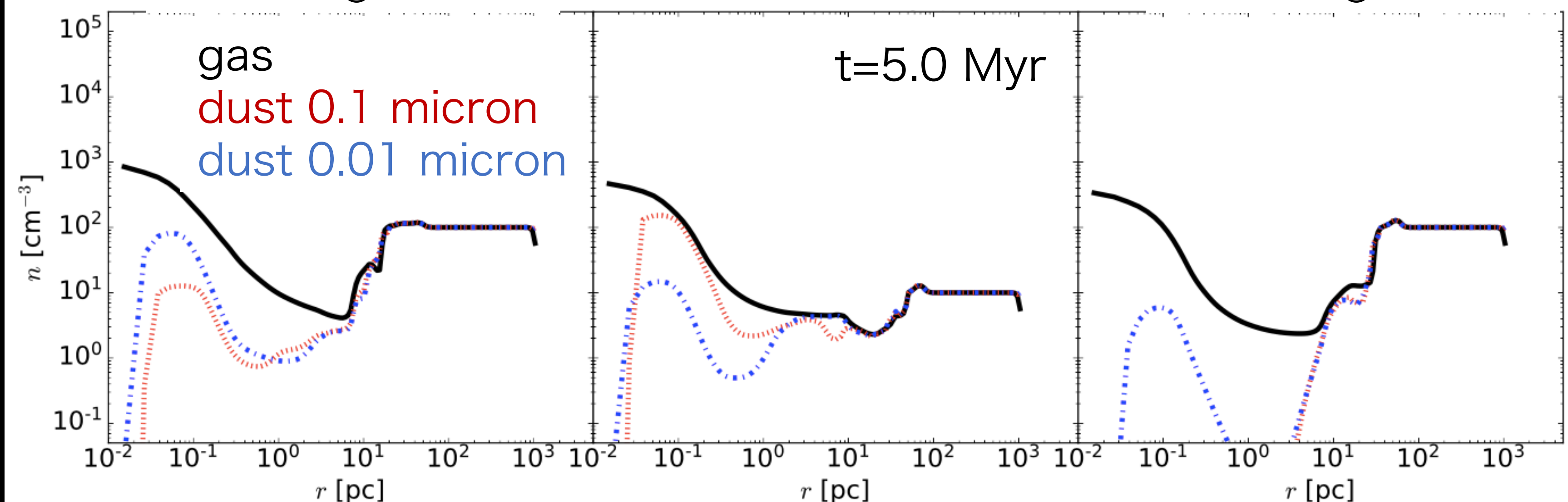


3. Result Spatial distribution of dust grains

$n_H = 100\ \mathrm{cm^{-3}}$, $Z = 1.0\ Z_\odot, \eta = 0.1$ | $n_H = 10\ \mathrm{cm^{-3}}$, $Z = 1.0\ Z_\odot, \eta = 0.1$ | $n_H = 100\ \mathrm{cm^{-3}}$, $Z = 1.0\ Z_\odot, \eta = 0.3$



Dust-to-gas mass ratio near BH becomes small.

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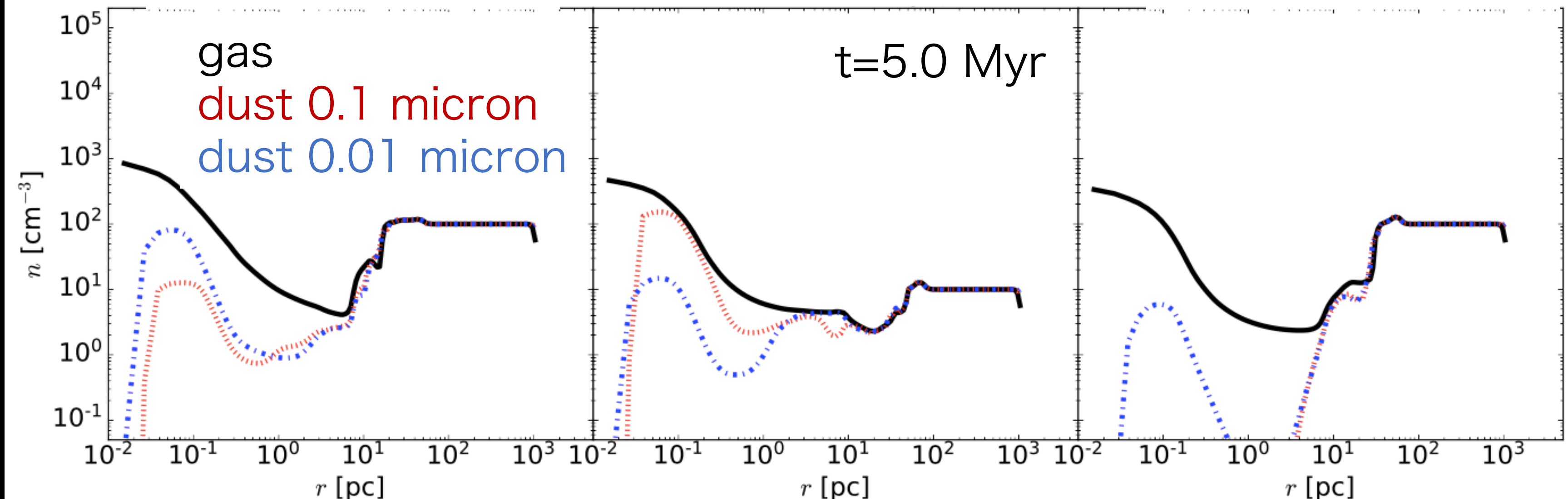

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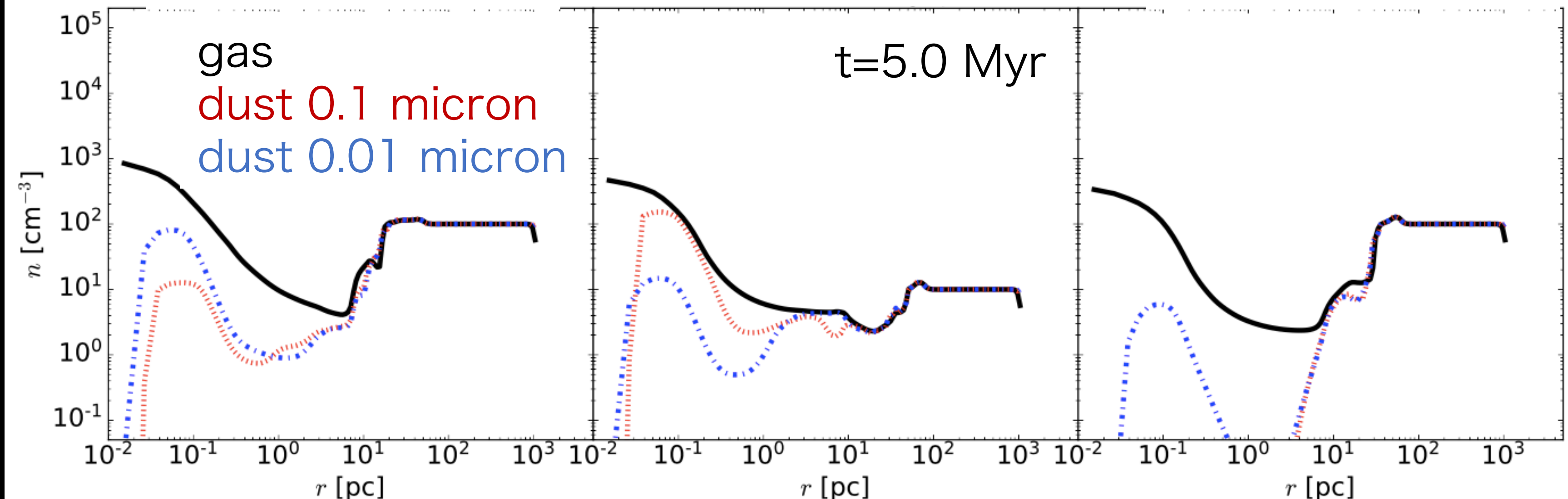

Dust-to-gas mass ratio near BH becomes small.

The effect of radiation pressure on dusty gas accretion becomes weaker.

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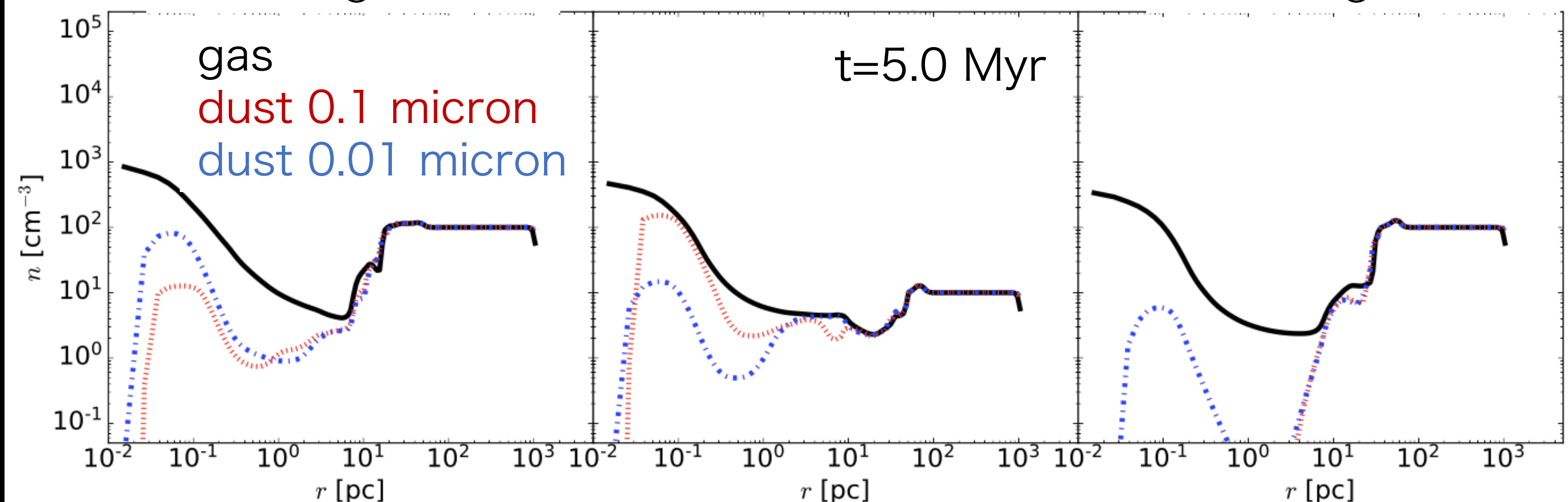

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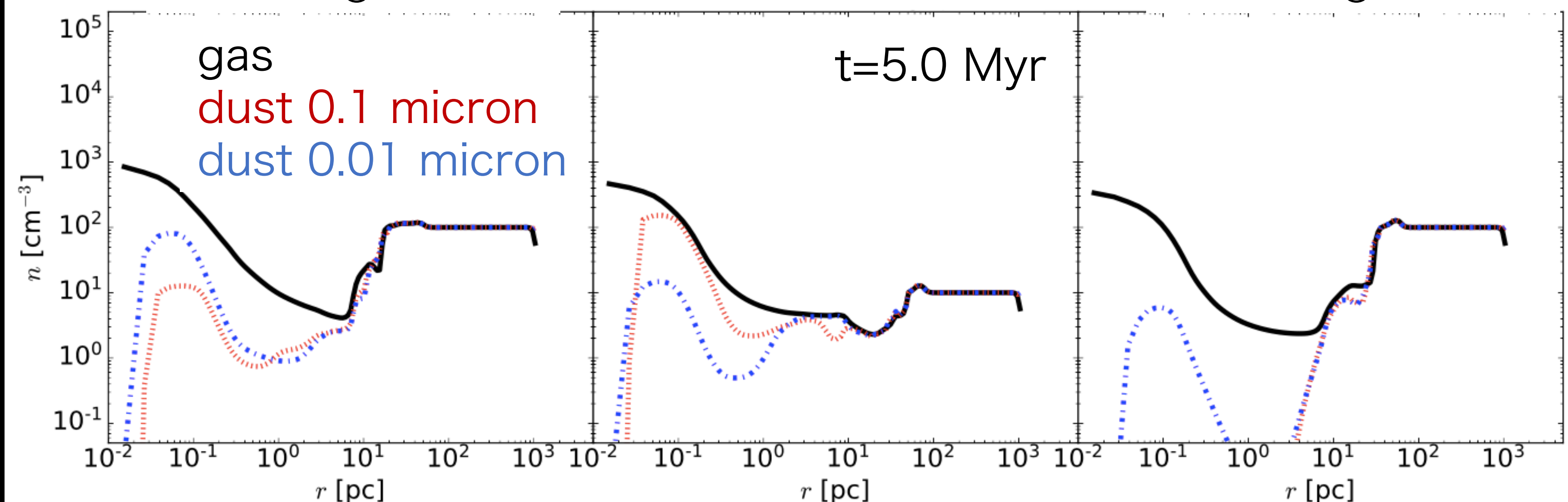

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The decoupling of dust from gas promotes the gas accretion onto BH.

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$\eta = 0.3$ $\eta = 0.1$

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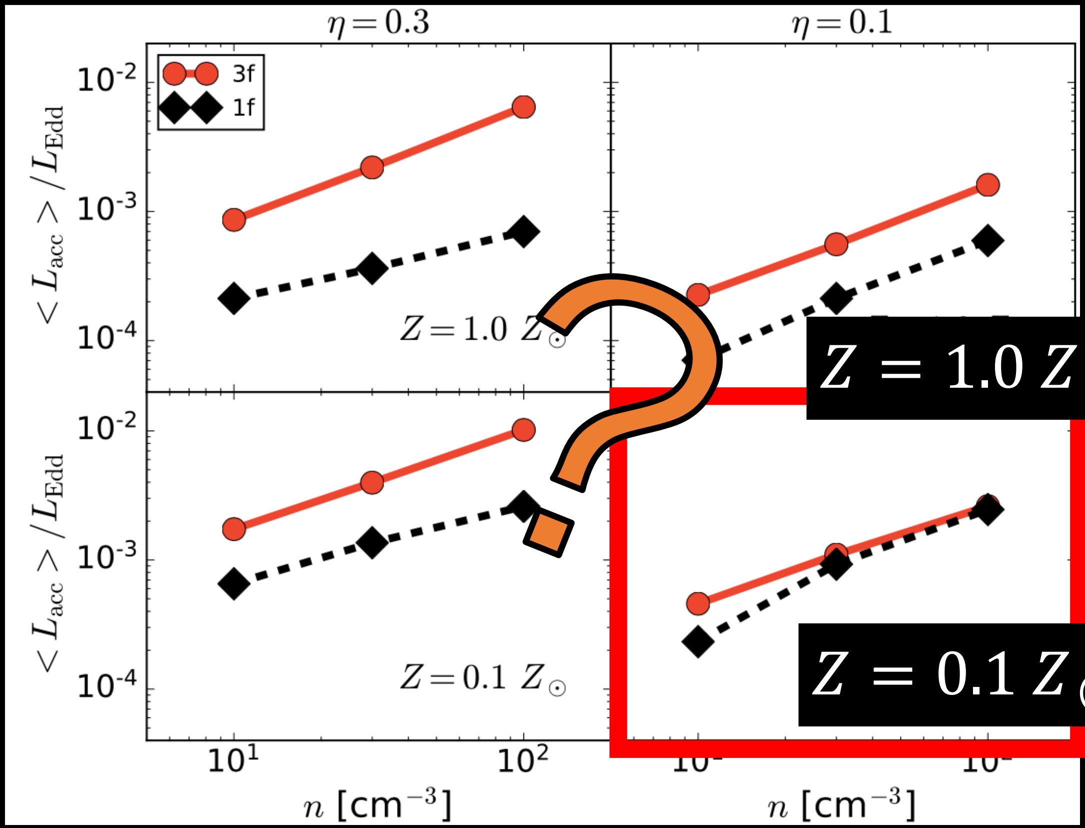

Number density of gas

3. Result Time averaged BH luminosity

Red: relative velocity
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Blue: analytical estimate Z=1.0 $Z_\odot$
Green: analytical estimate Z=0.1 $Z_\odot$
Gray: analytical estimate Z=0.0 $Z_\odot$

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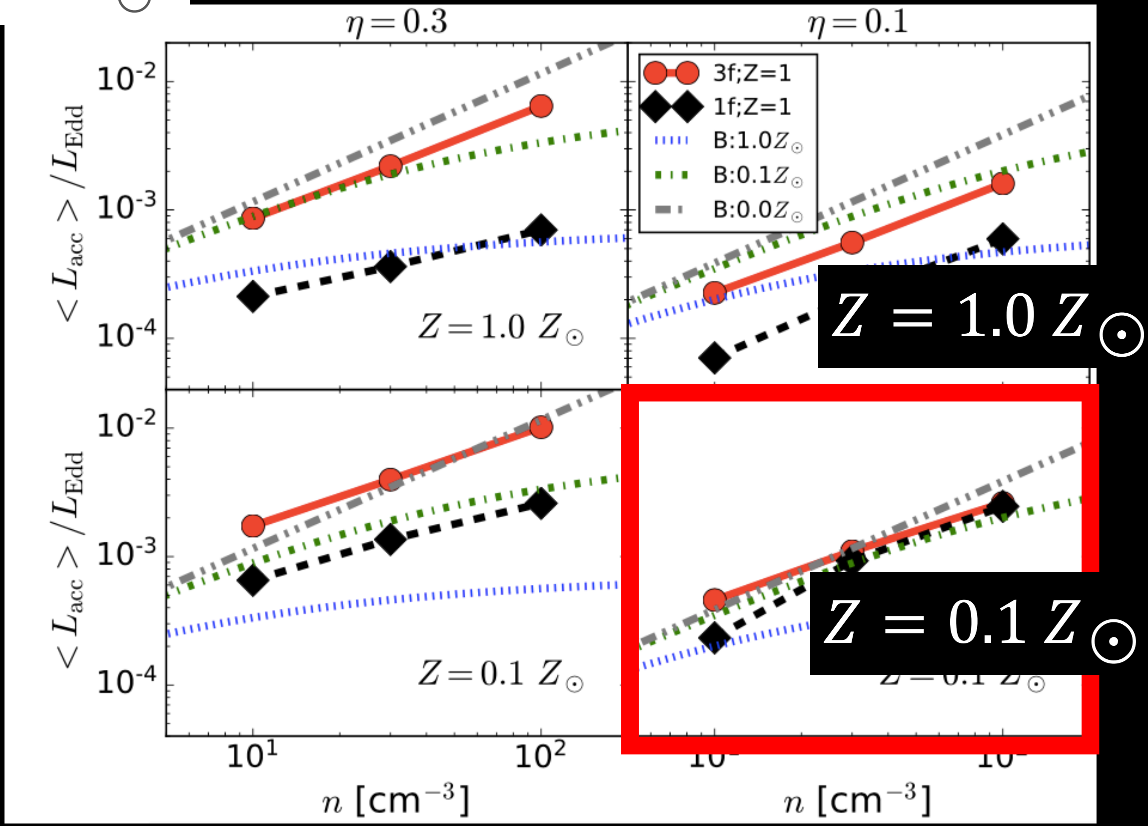

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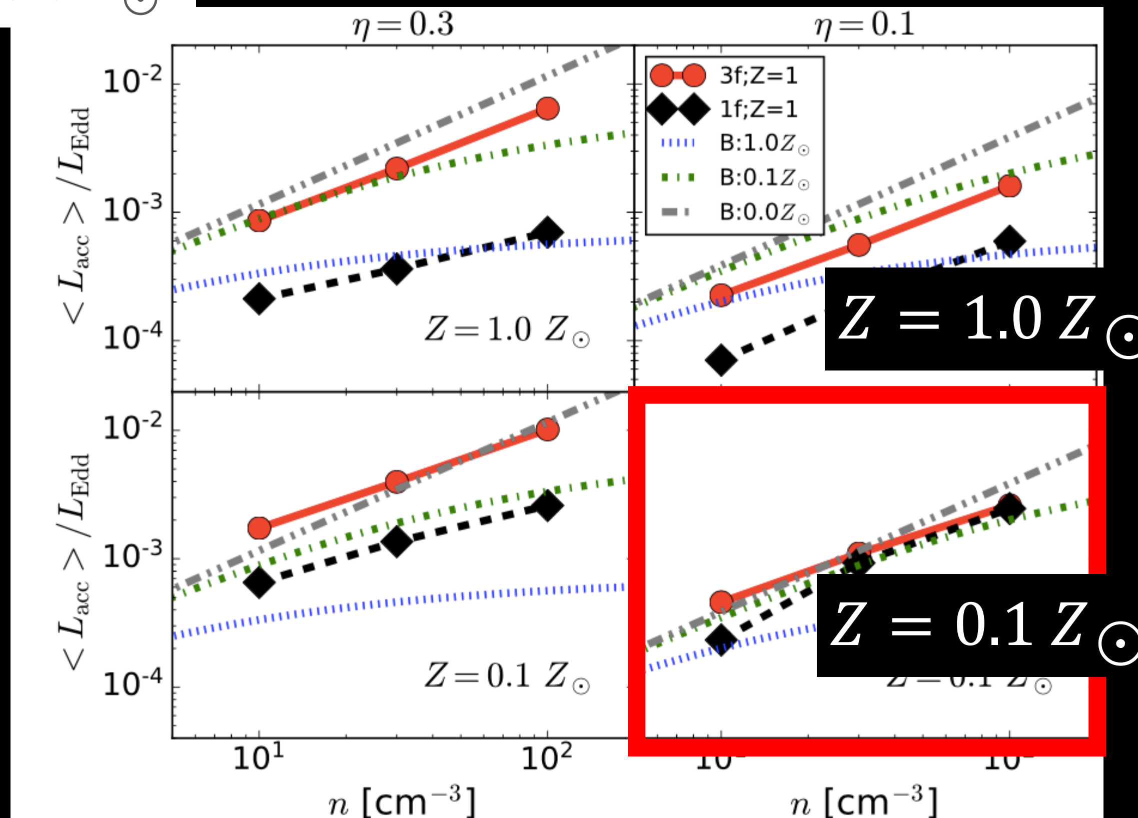


Analytical estimate shows almost same accretion rate between $\eta = 0.1, Z = 0.1\ Z_\odot$ and $\eta = 0.1, Z = 0.0\ Z_\odot$.

Number density of gas

3. Result

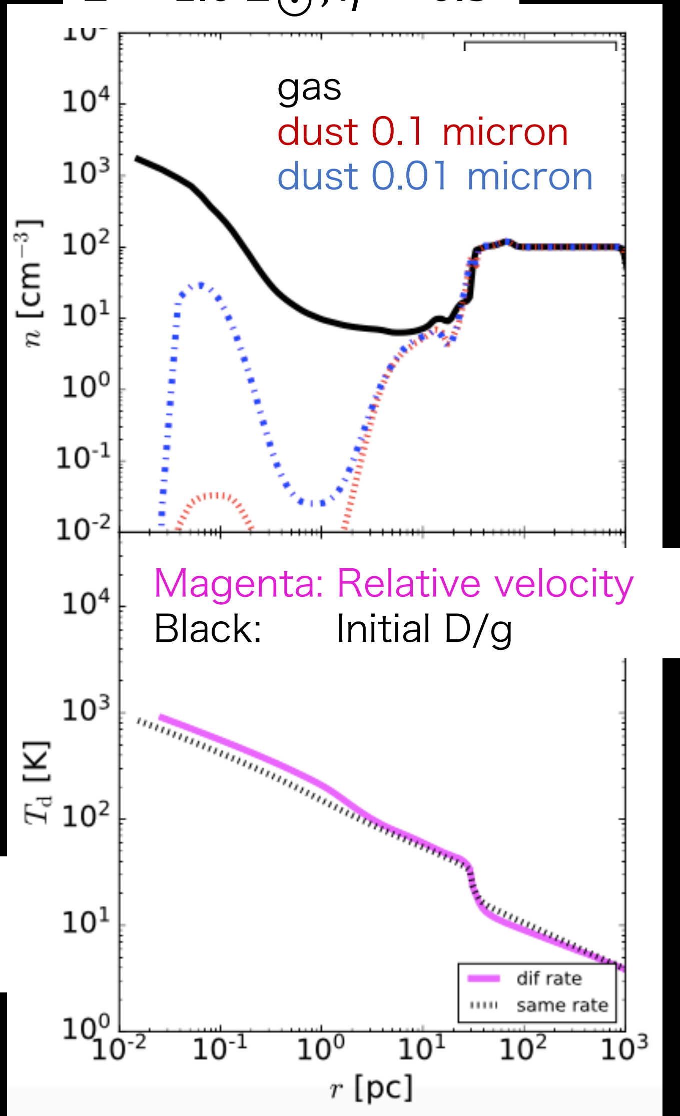
How about Spectral Energy Distribution (SED) at IR wavelengths?

3. Result

Temperature of dust:
Radiative equilibrium

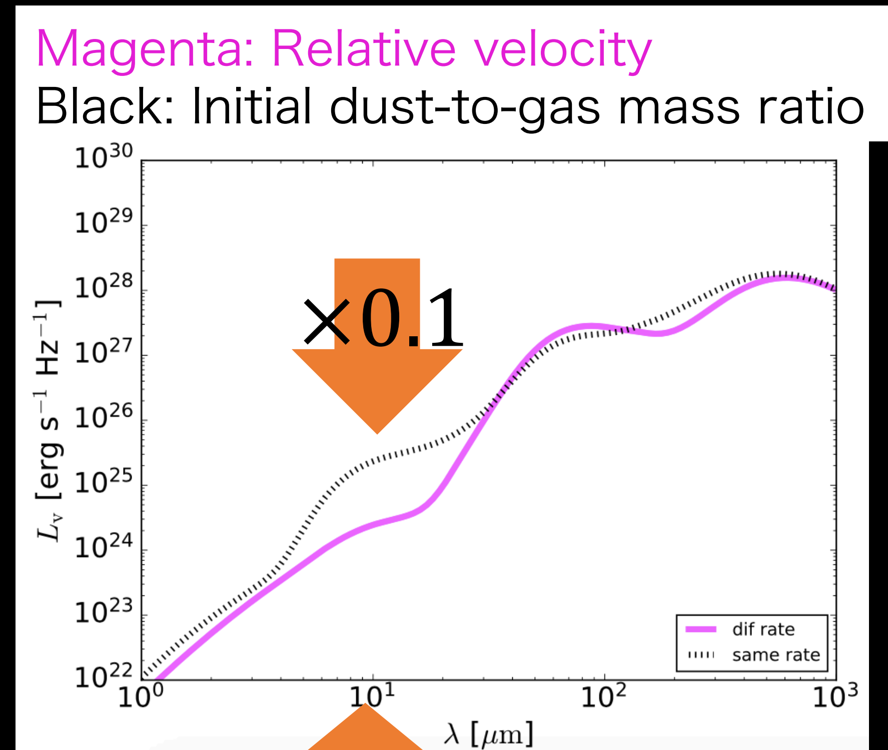
3. Result SED: IR re-emission from dust

$n_{\rm H} = 100\ {\rm cm^{-3}}$,
$Z = 1.0\ Z_{\odot}, \eta = 0.3$



Dust Temperature

SED



$\sim 10^3$ K

3. Result SED: IR re-emission from dust

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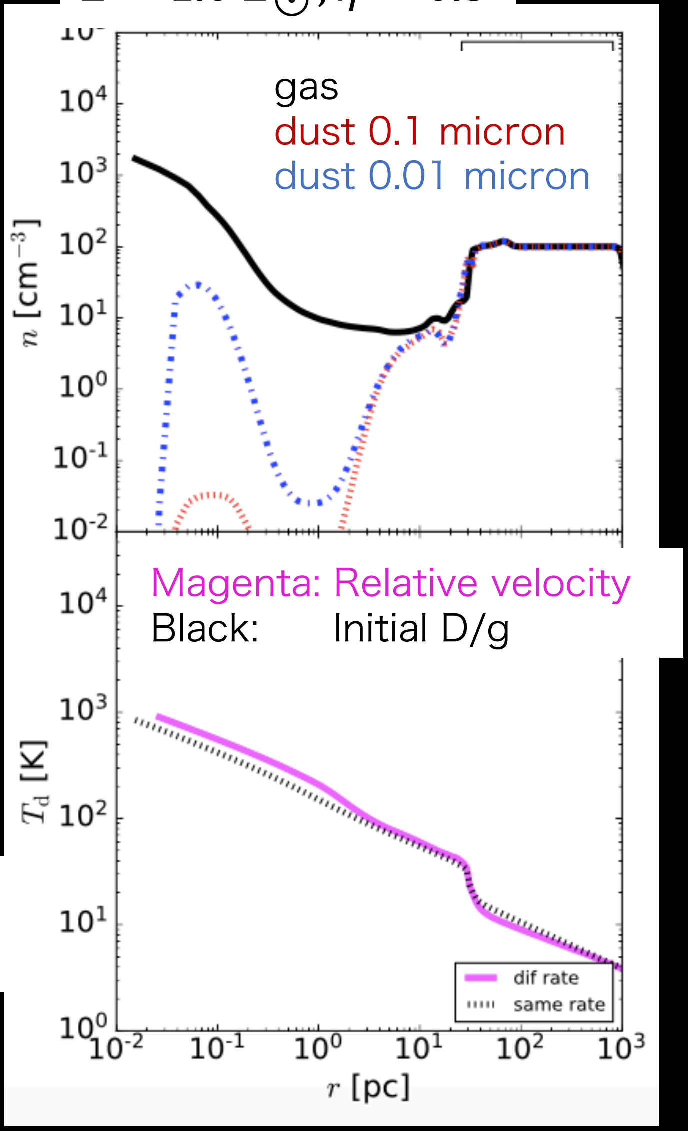
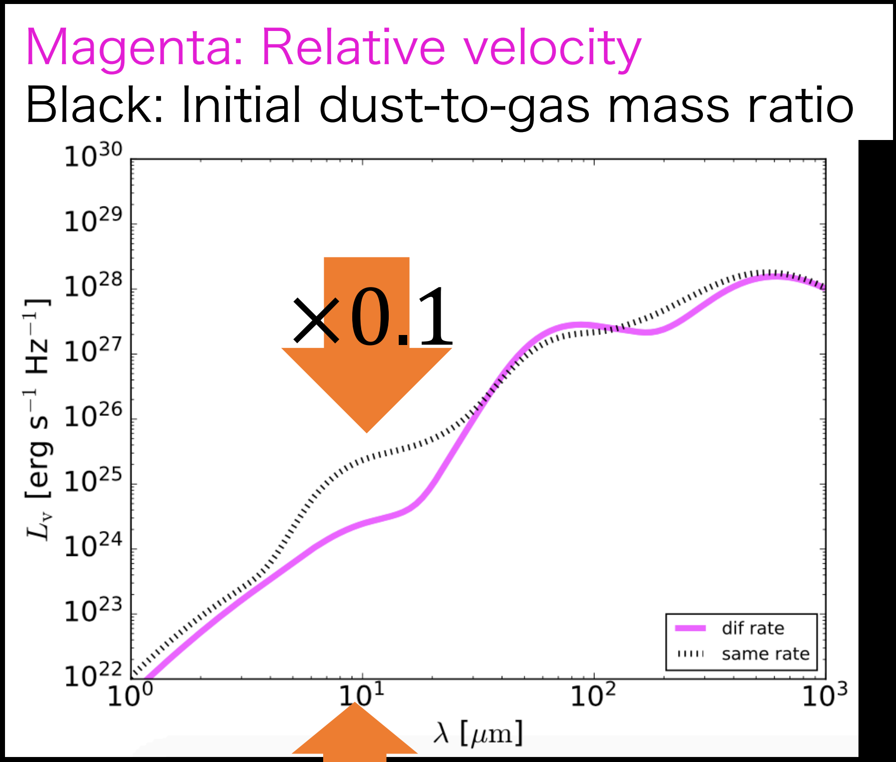


Dust Temperature

SED

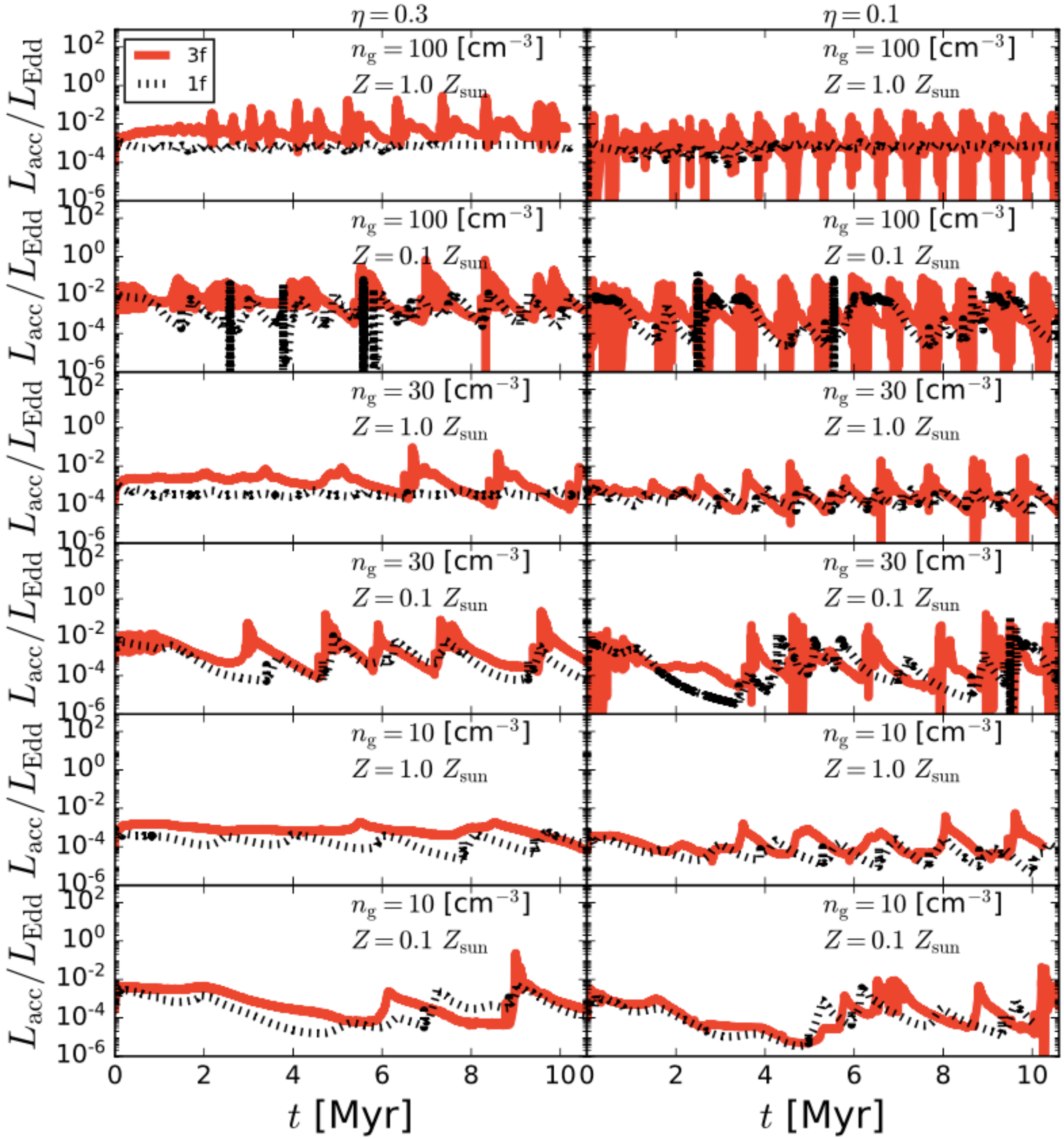


$\sim 10^3$ K

Radiation pressure removes high temperature dust.

4. Summary

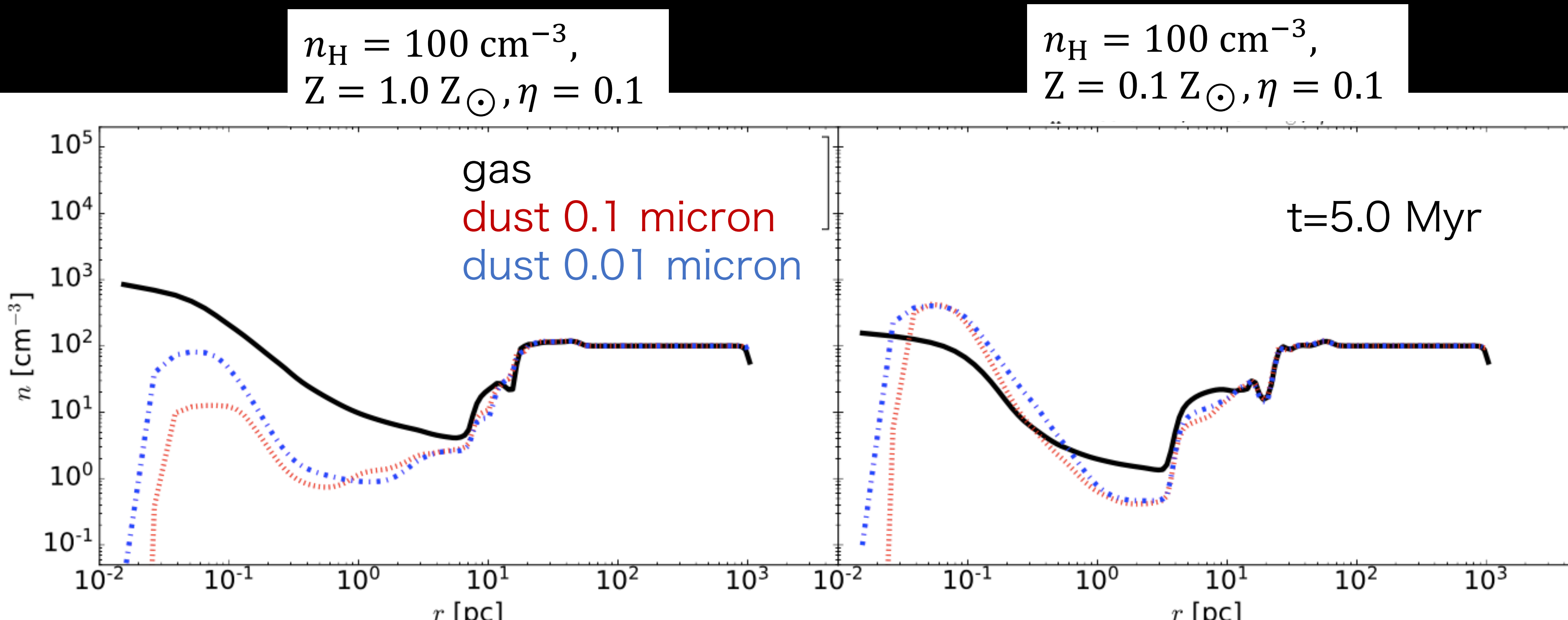
- The decoupling of dust from gas promote the gas accretion onto BH.
- The dust-to-gas mass ratio significantly changes in HII regions because of the strong radiation pressure.
- The decoupling of dust from gas affects SED at IR wavelengths.



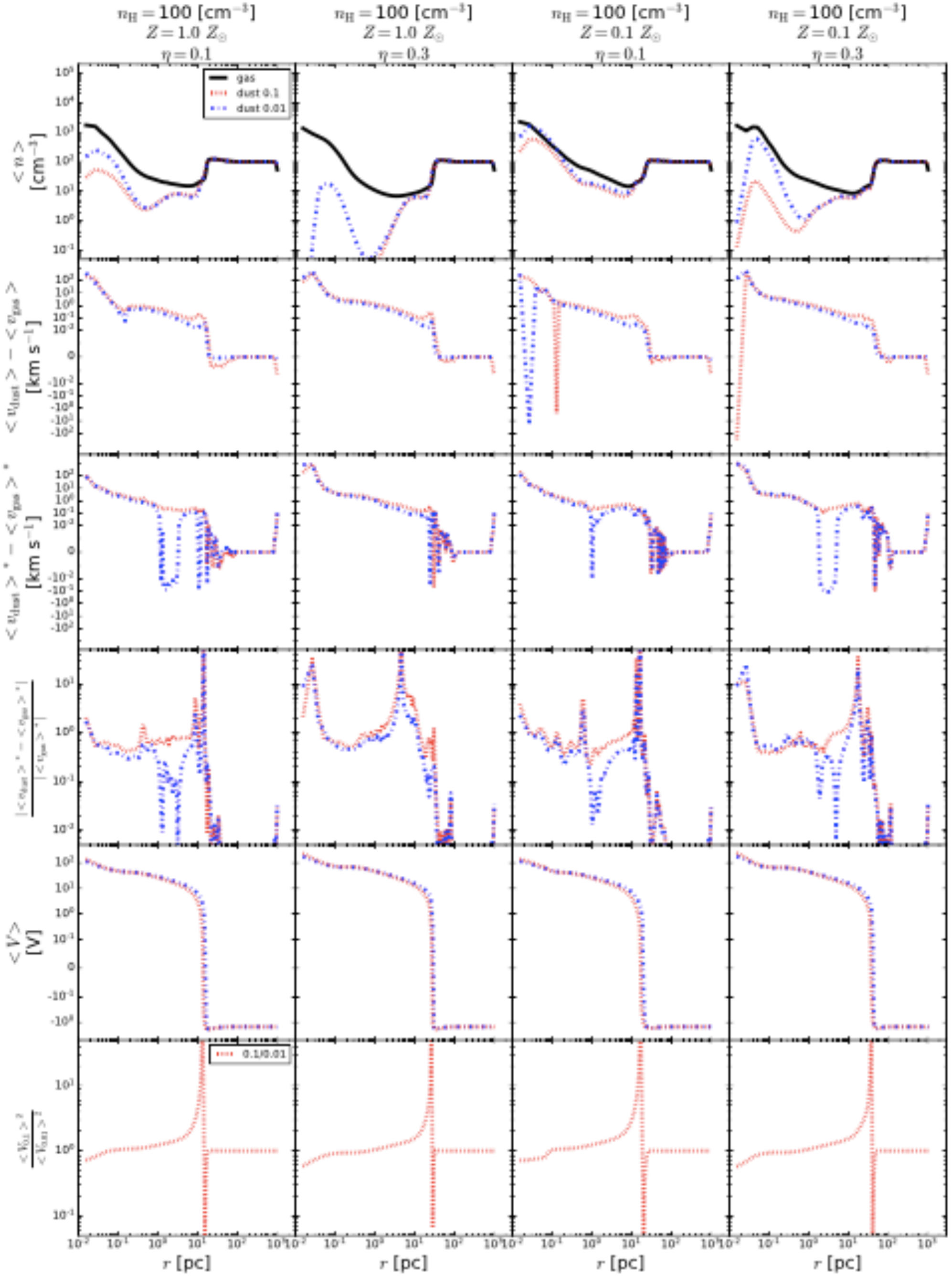
$\eta = 0.3$
$\eta = 0.1$
3f
1f
$n_{\rm g} = 100$ [cm^{-3}]
$Z = 1.0\ Z_{\rm sun}$
$Z = 0.1\ Z_{\rm sun}$
$n_{\rm g} = 30$ [cm^{-3}]
$n_{\rm g} = 10$ [cm^{-3}]
$L_{\rm acc}/L_{\rm Edd}$
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
0
2
4
6
8
10
t [Myr]

3. Result Spatial distribution of dust grains

[redacted]



[redacted]



$n_{\rm H} = 100$ [cm^{-3}]
$Z = 1.0\ Z_{\odot}$
$\eta = 0.1$
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$Z = 0.1\ Z_{\odot}$
$\eta = 0.3$
gas
dust 0.1
dust 0.01
$< n >$ [cm^{-3}]
$< v_{\rm dust} > - < v_{\rm gas} >$ [km s^{-1}]
$< v_{\rm dust} >^* - < v_{\rm gas} >^*$ [km s^{-1}]
$< V >$ [V]
0.1/0.01
r [pc]
r [pc]
r [pc]
r [pc]