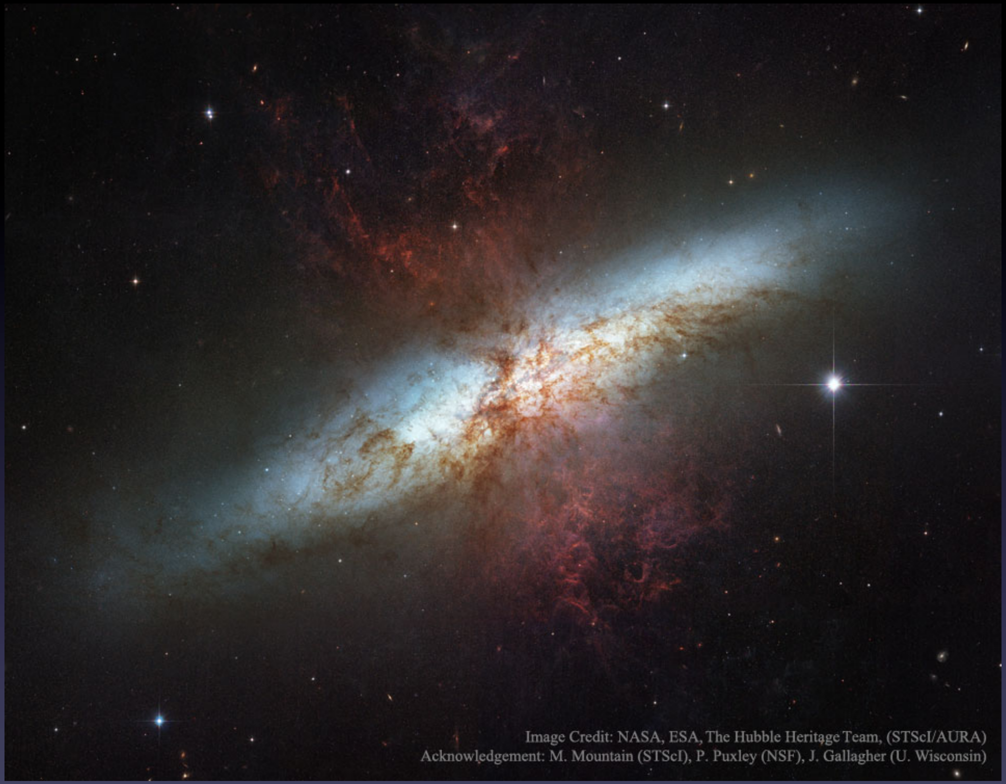
Radiation's Role in Accelerating Galactic Outflow

2019 Athena++ User Meeting | Xiaoshan Huang

(Shane W. Davis, Dong Zhang)

Radiation’s Role in Accelerating Galactic Outflow

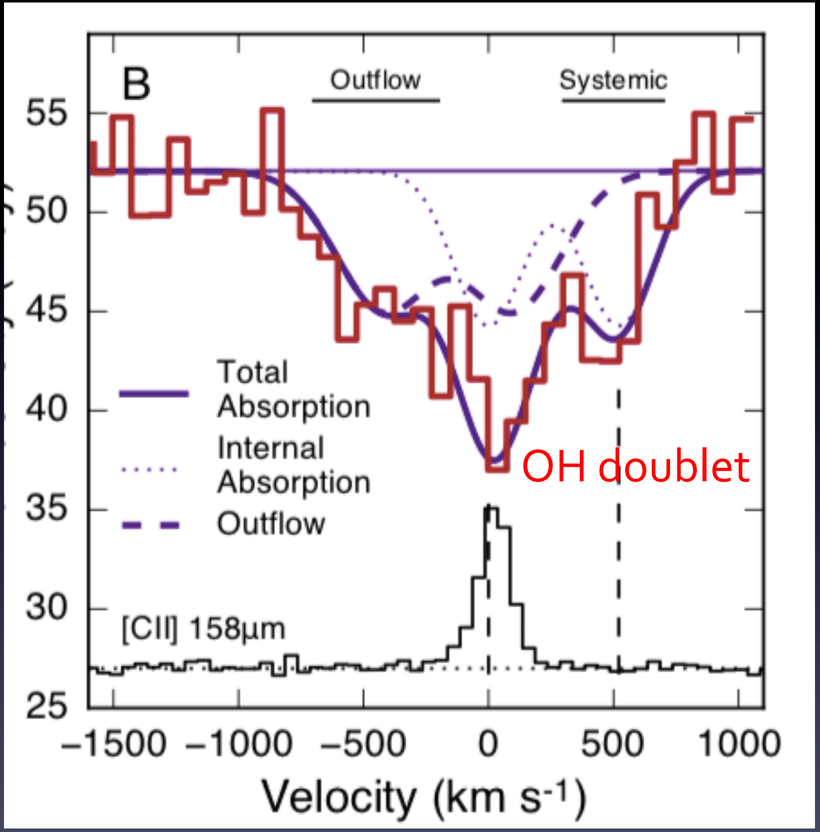
- Galactic Outflow : Importance in Galaxy Evolution



- Galaxy properties: galaxy luminosity function
- Enrichment of IGM
- Star formation feedback

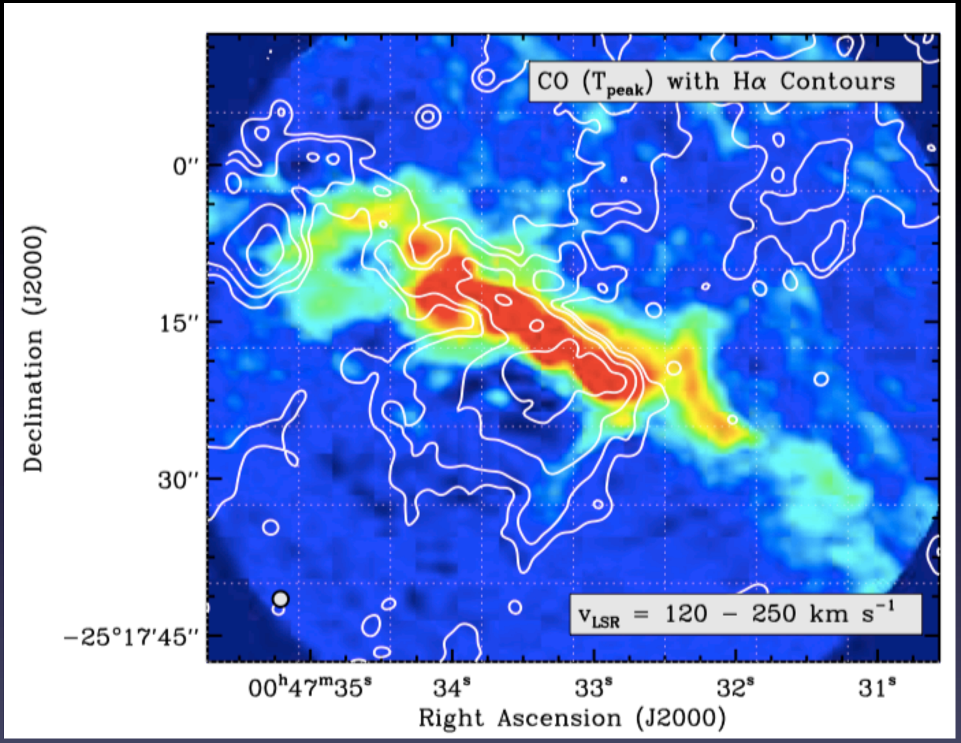
Radiation's Role in Accelerating Galactic Outflow

- Galactic Outflow : Observed Properties



(Spilker et al 2018)

NGC253



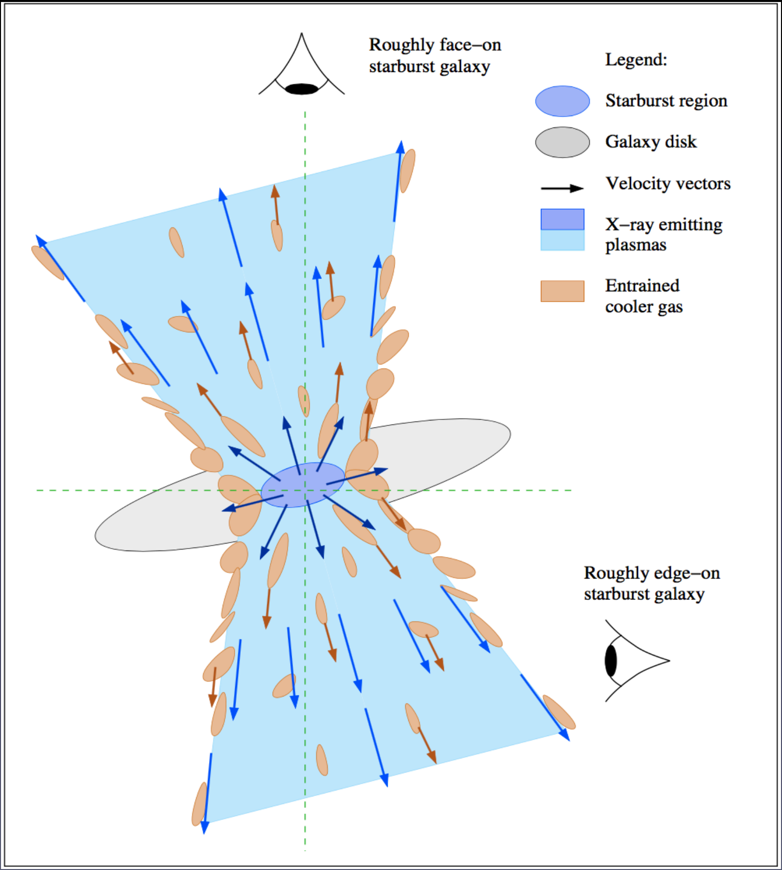
(Walter et al 2017)

- Velocity: $V_{obs} \sim \mathrm{few} 100 \mathrm{km/s}$
- Cold gas: Molecular temperature

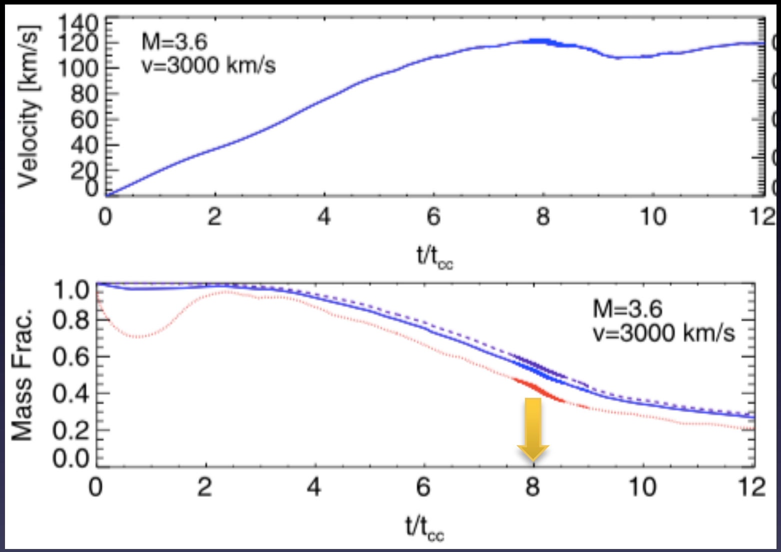
Radiation's Role in Accelerating Galactic Outflow

- Galactic Outflow : Driving Mechanism. Simulation Study

- Schematic Picture



- Entrainment in hot wind



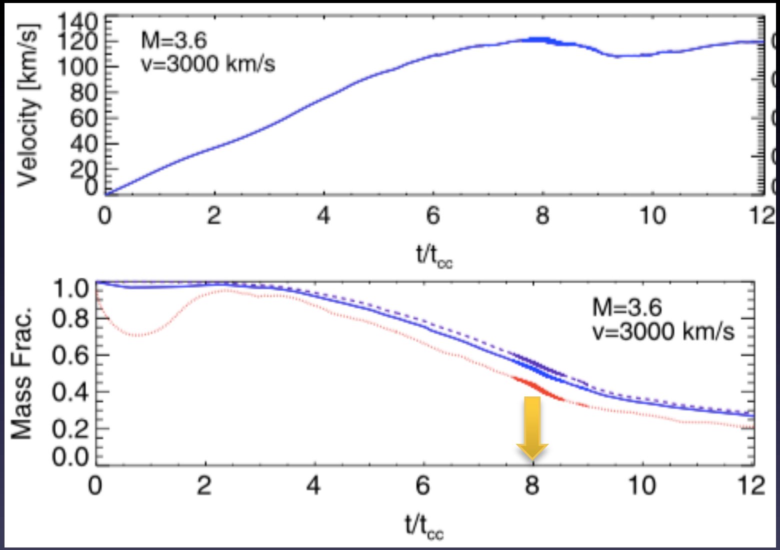
$$t_{cc} = 1.8 Myr$$

(Scannapieco 2015)

Radiation's Role in Accelerating Galactic Outflow

- Galactic Outflow : Driving Mechanism. Simulation Study

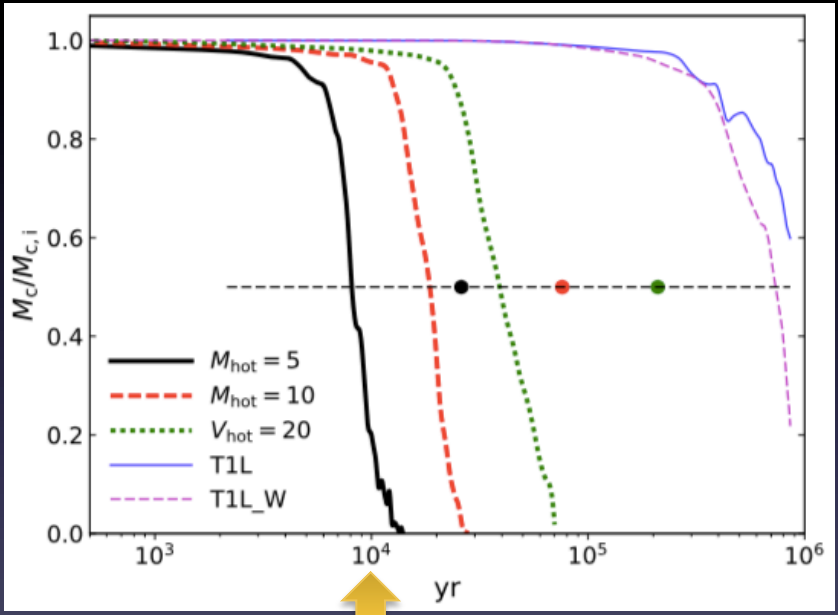
- Entrainment in hot wind



$t_{cc} = 1.8Myr$

(Scannapieco 2015)

- IR Radiation from SF regions



(Zhang et al 2018)

surviving time: when cloud lose half of its initial mass

Athena++ RHD code

- Directly Solve the multi-band RT Equation

$$\frac{\partial I_\nu}{\partial t} + c\mathbf{n} \cdot \nabla I_\nu = s_\nu(\mathbf{n})$$

- Couple with Hydrodynamic Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0,$$

$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla \cdot (\rho \mathbf{v}\mathbf{v} + \mathsf{P}) = -\mathbf{S}_\mathbf{P}, \quad \mathbf{S}_\mathbf{P} \propto \int s_\nu(\mathbf{n})\mathbf{n}\mathbf{d}\boldsymbol{\Omega} d\nu$$

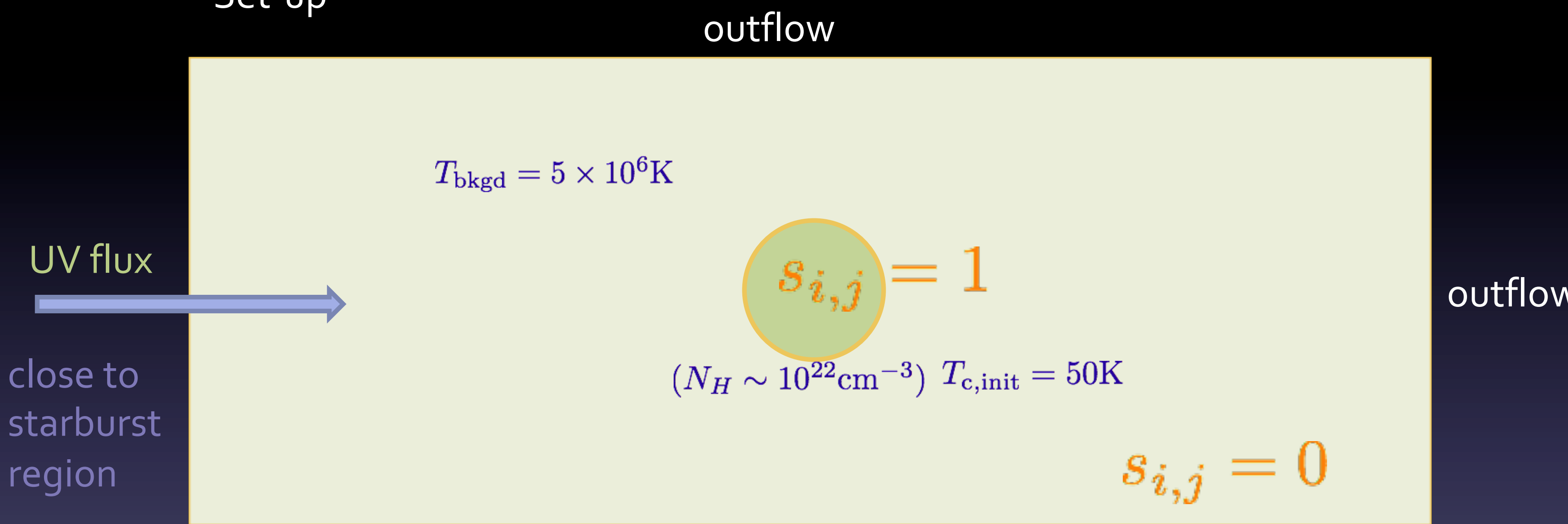
$$\frac{\partial E}{\partial t} + \nabla \cdot [(E + P)]\mathbf{v}] = -cS_E \quad S_E \propto \int s_\nu(\mathbf{n})\mathbf{d}\boldsymbol{\Omega} d\nu$$

- Reduced Speed of Light Approximation

$$\mathbb{R} = \tilde{c}/c$$

Fiducial Run

- Set-up

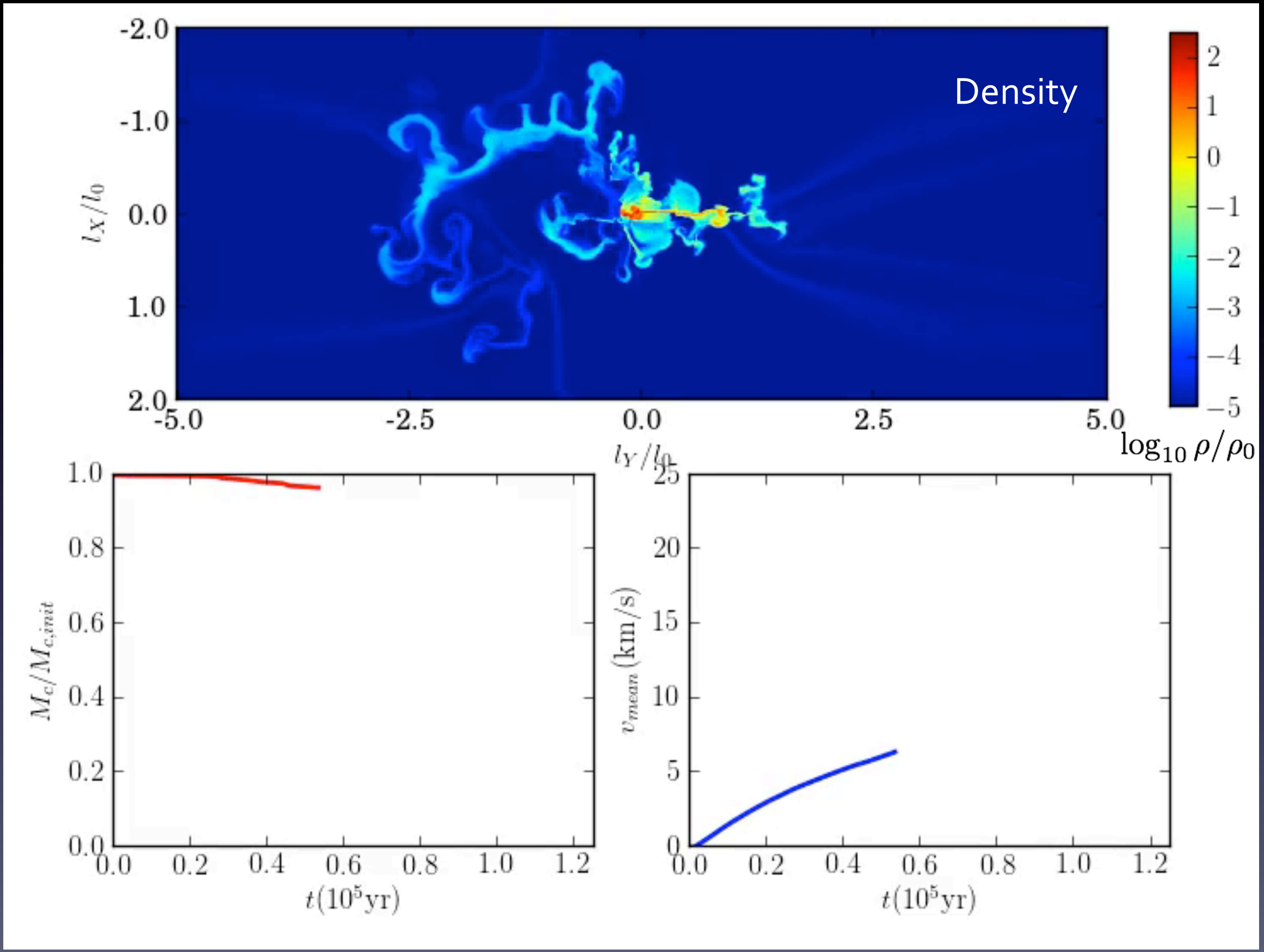


$$M_c \equiv \sum_{i,j} s_{ij} \rho_{ij} V_{ij}$$

- Passive Scalar to track dust
- Cloud-following Frame
- Initial random perturbation on density
- Uniform incoming radiation flux

$$\tau_{IR} \sim 0.1, \ (\kappa_{IR} \propto T^2)$$
$$\tau_{UV} \sim 10$$
$$\text{Dust sublimates} \sim 500\text{K}$$

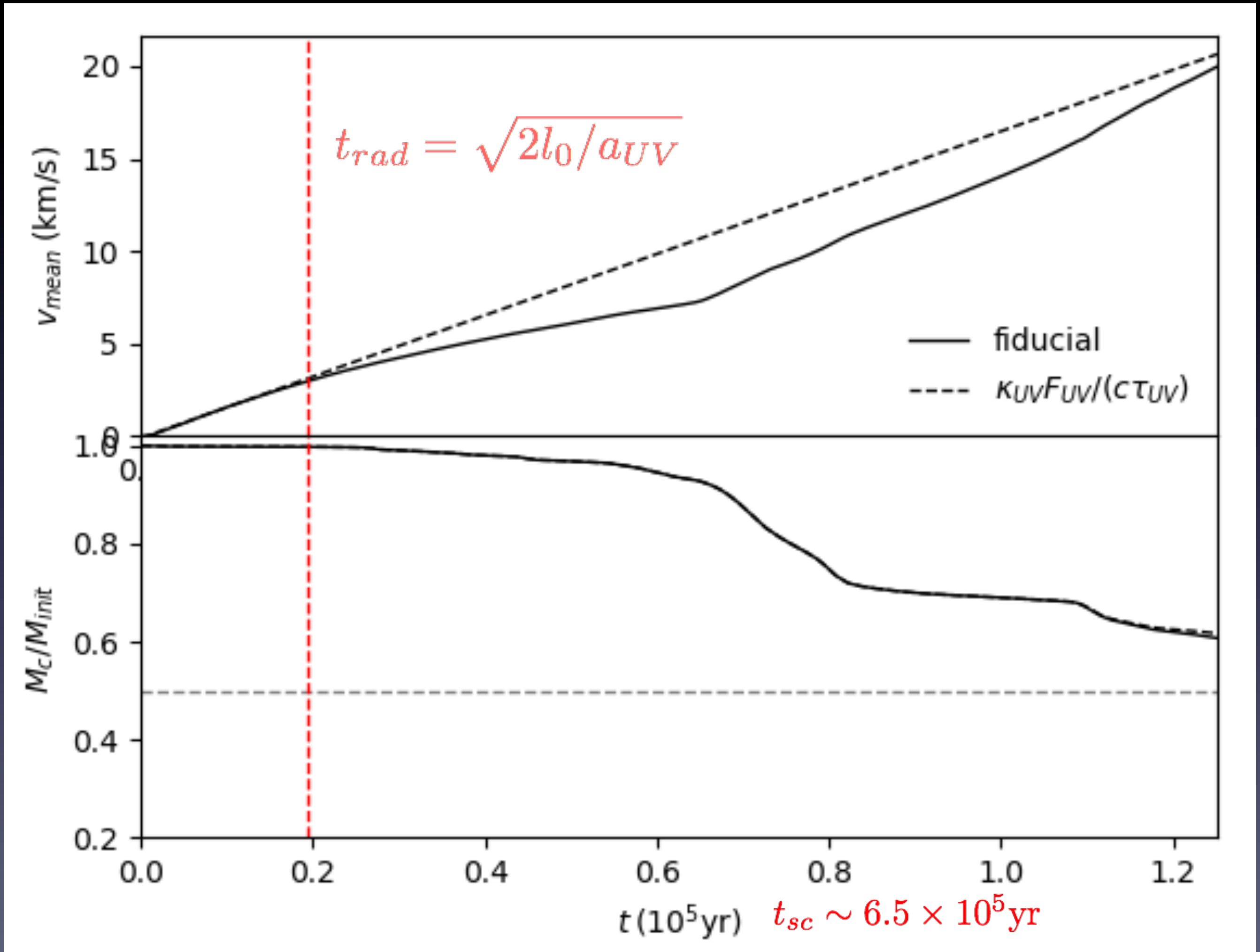
Radiation's Role in Accelerating Galactic Outflow

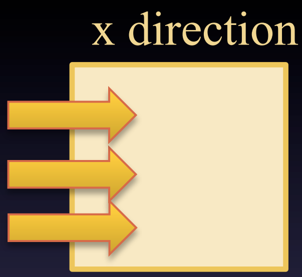


Compression by radiation pressure → volume minimum → Re-expand by gas pressure

Radiation's Role in Accelerating Galactic Outflow

- Cloud surviving time: $$M_c \equiv \sum_{i,j} s_{ij}\rho_{ij}V_{ij}$$ passive scalar: dust fraction of cell





Radiation Flux

$$F_{\rm rad}(x) = F_0 e^{-\tau_x}$$

$$a \approx \frac{\kappa F_0}{c\tau_x}$$

$$a_{UV} \equiv \frac{\kappa_{UV}F_{UV}}{c\tau_{UV}}$$

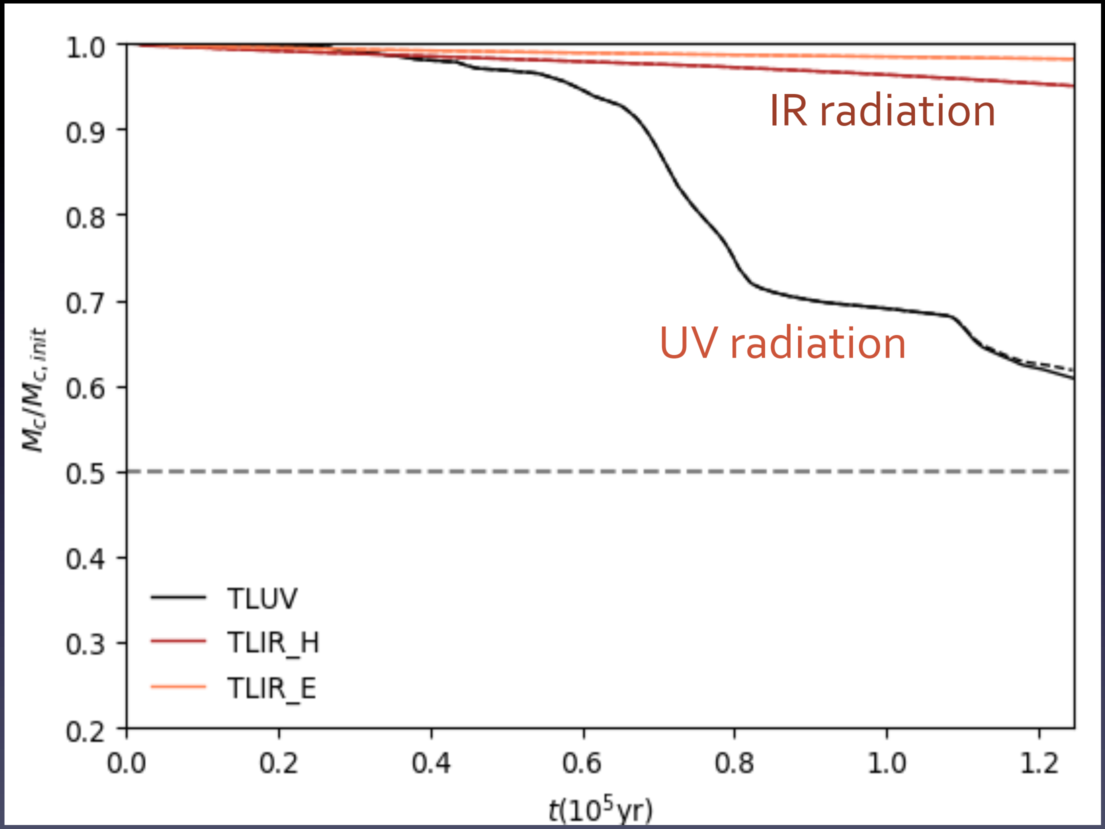
Radiation's Role in Accelerating Galactic Outflow

A very favorable acceleration condition

$$N_H \sim 10^{22}\text{cm}^{-3}$$

$$F_{UV} \sim 10^{12} L_\odot \text{kpc}^{-2}$$

$$\tau_{UV} \sim 10, \tau_{IR} \sim 0.1$$



surviving time: UV radiation << IR radiation

Radiation's Role in Accelerating Galactic Outflow

- Take-away

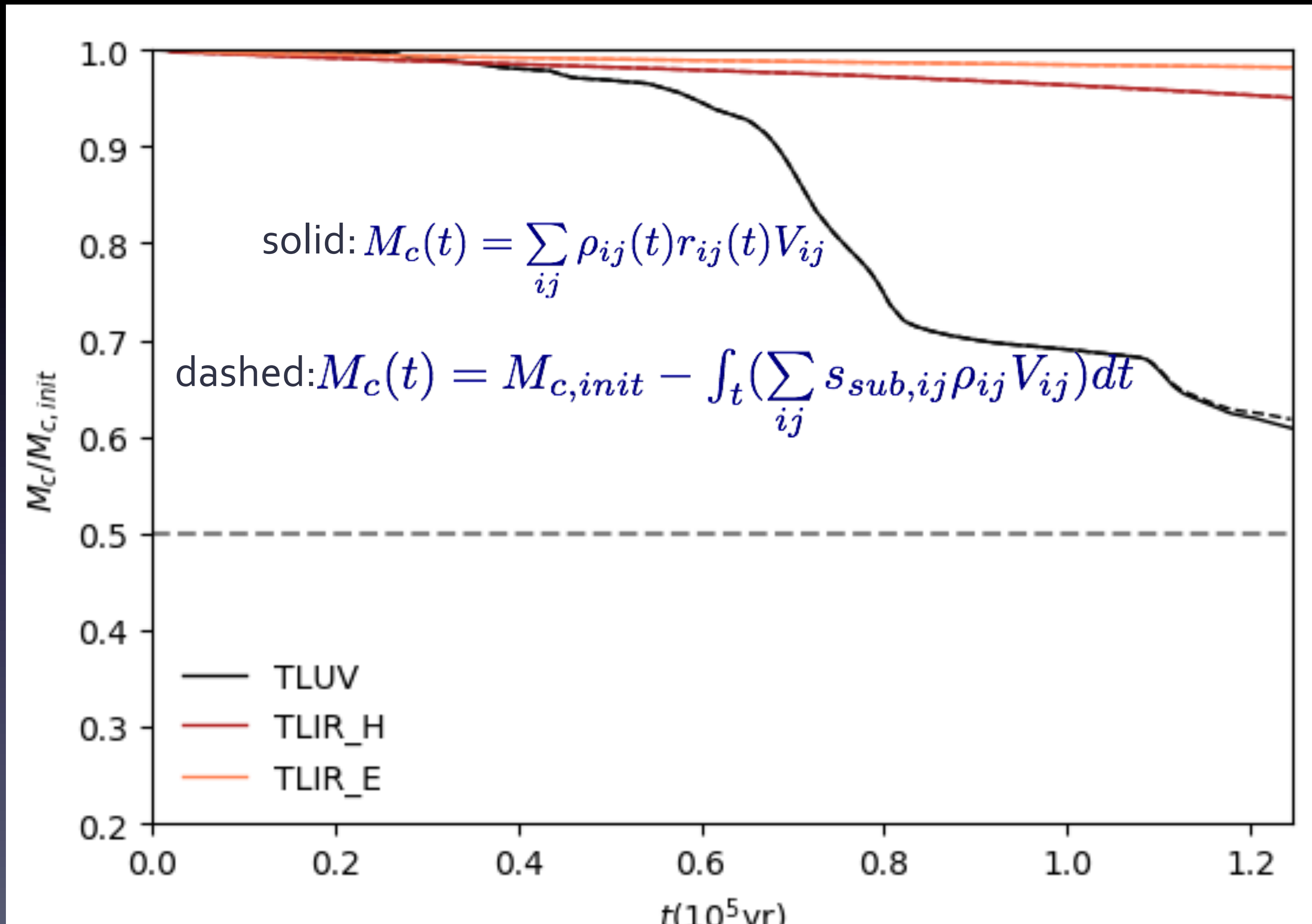
\- Cold cloud being accelerated by UV radiation has significant shorter surviving time compared to IR radiation

- Future Work:

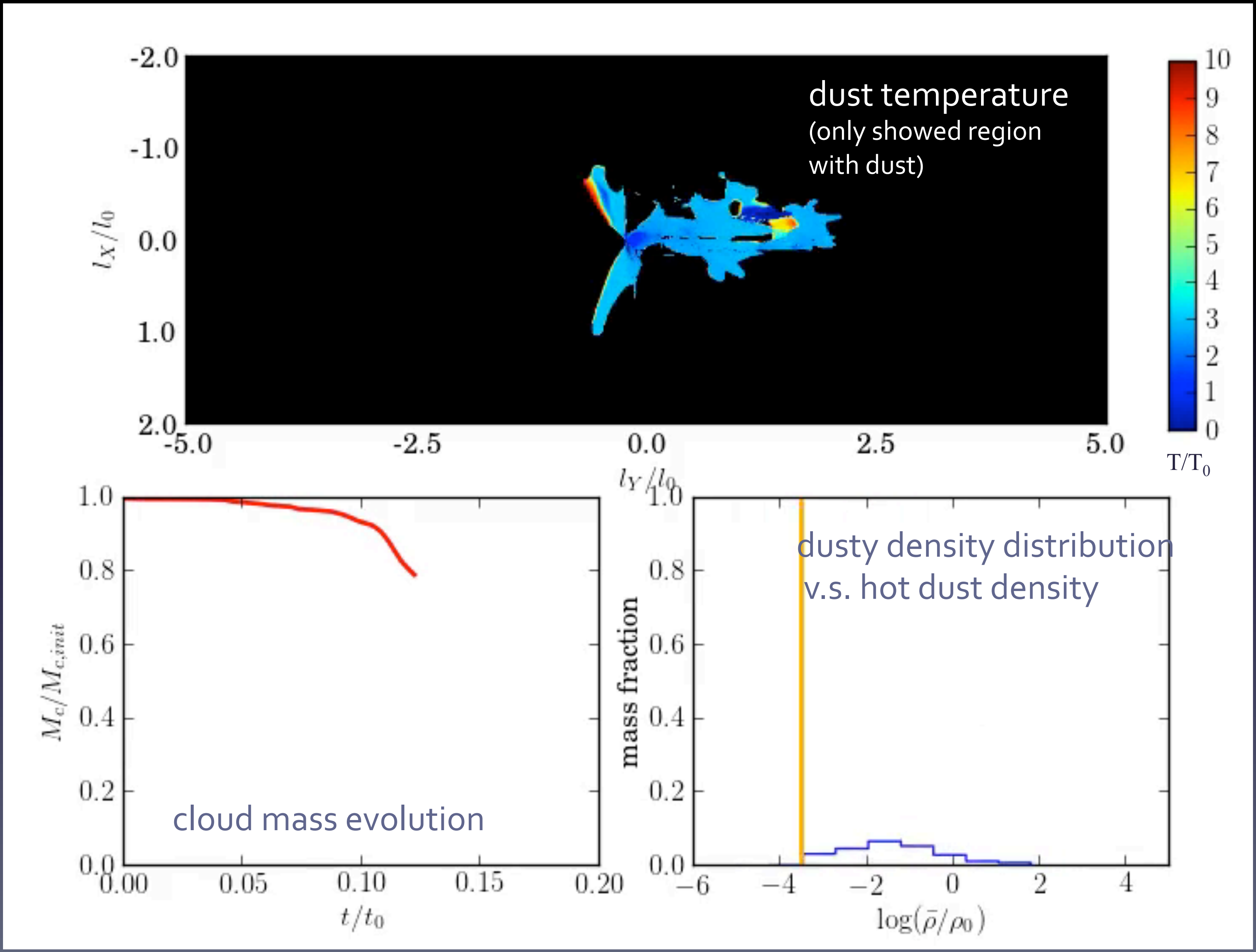
\- Background condition?
\- What fraction of UV radiation in a mixing flux will destroy the cloud?
\- Cosmic Rays?

Radiation's Role in Accelerating Galactic Outflow

- Dust escape from boundary?

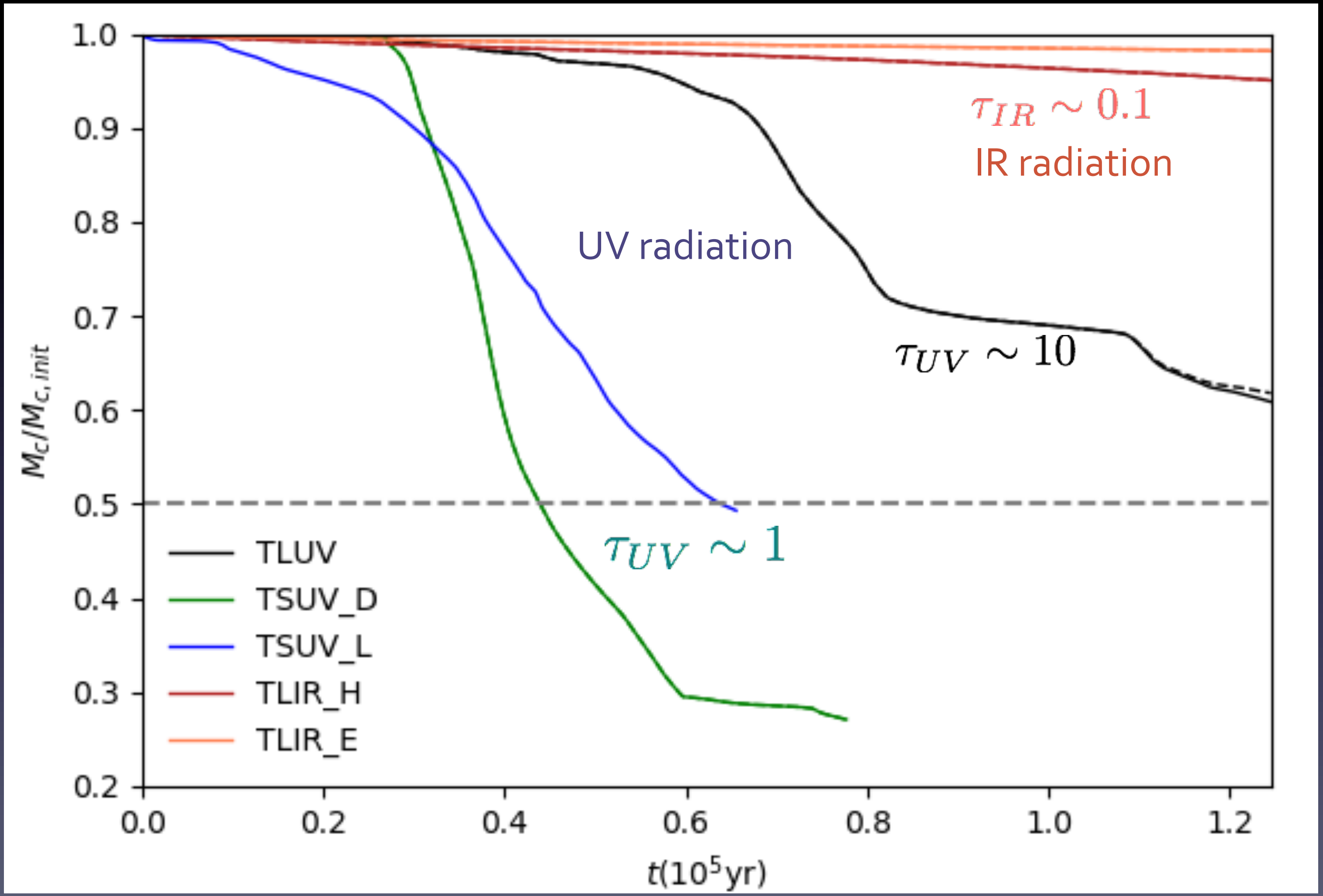


Dust sublimation happens when mixing with background



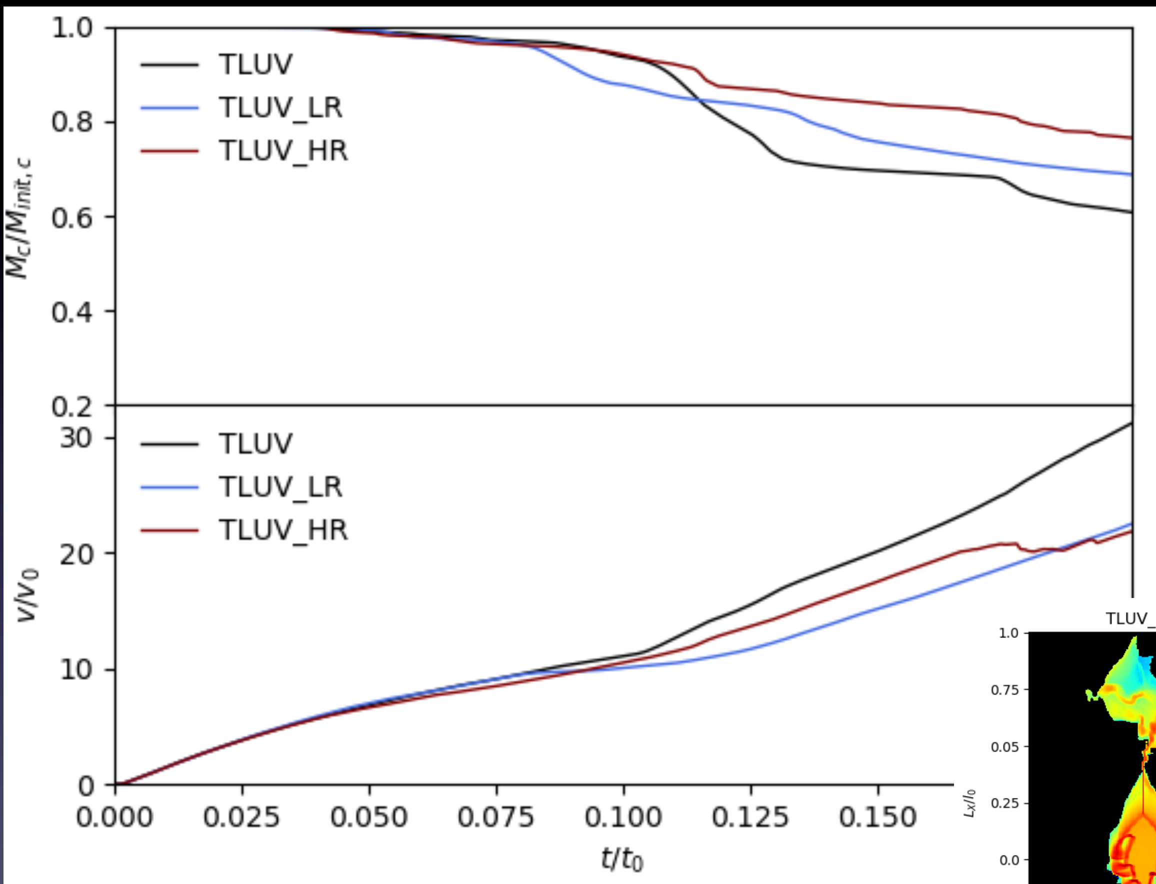
Radiation's Role in Accelerating Galactic Outflow

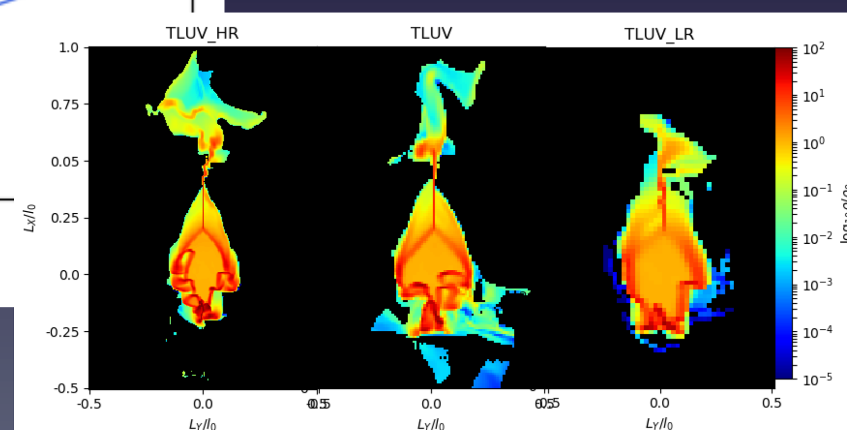
- Optical depth



Radiation's Role in Accelerating Galactic Outflow

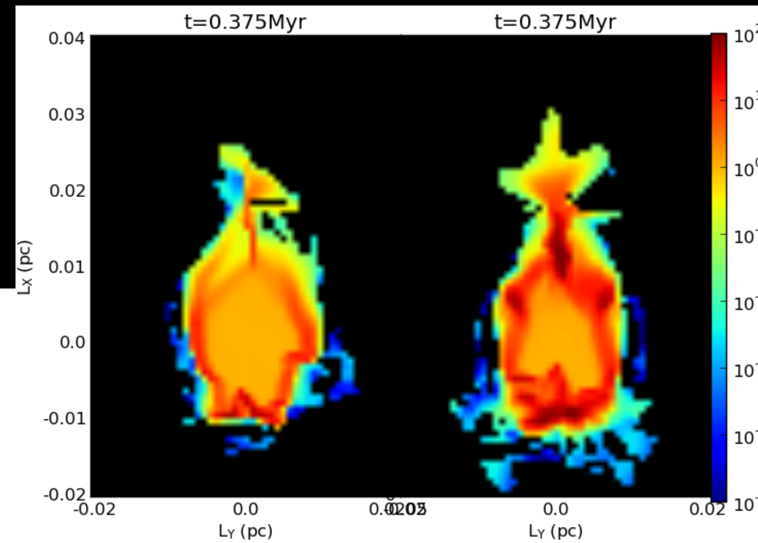
- Resolution

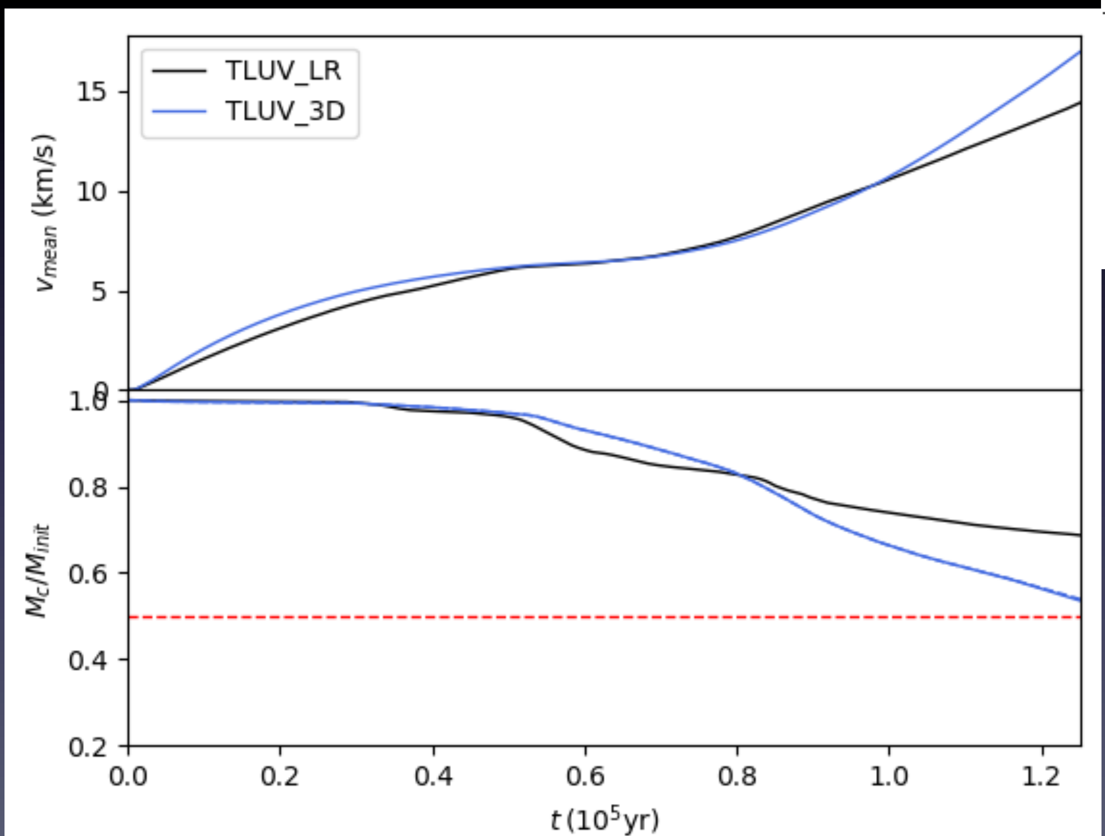


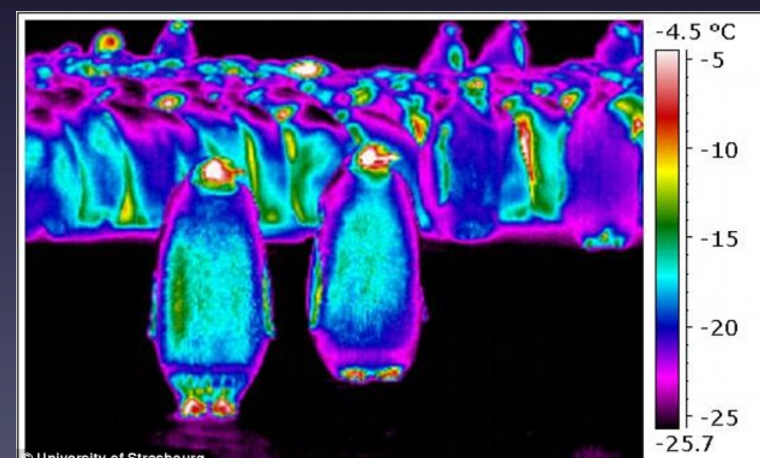


Radiation's Role in Accelerating Galactic Outflow

- Dimension

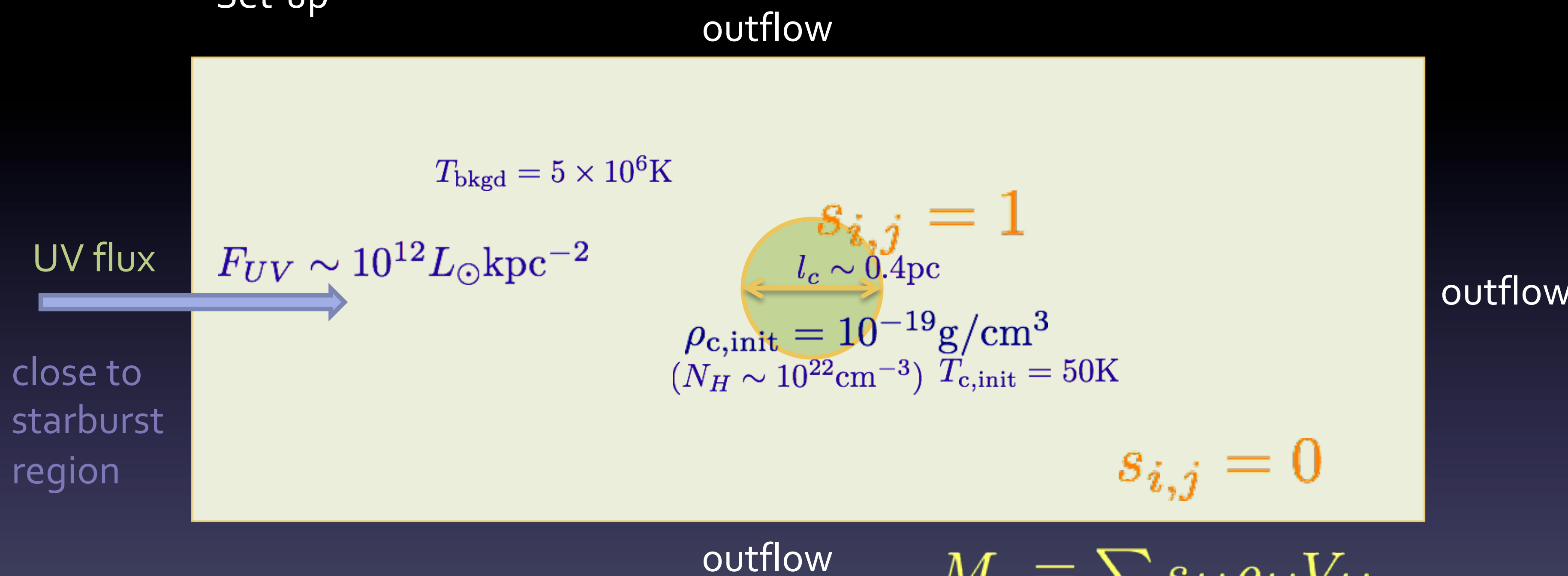






Fiducial Run

- Set-up



$$M_c \equiv \sum_{i,j} s_{ij} \rho_{ij} V_{ij}$$

- Passive Scalar field to track dust
- Cloud-following Frame
- Initial random perturbation on density
- Uniform incoming radiation flux

$\tau_{IR} \sim 0.1, \ (\kappa_{IR} \propto T^2)$

$\tau_{UV} \sim 10$

Dust sublimates $\sim 500\mathrm{K}$

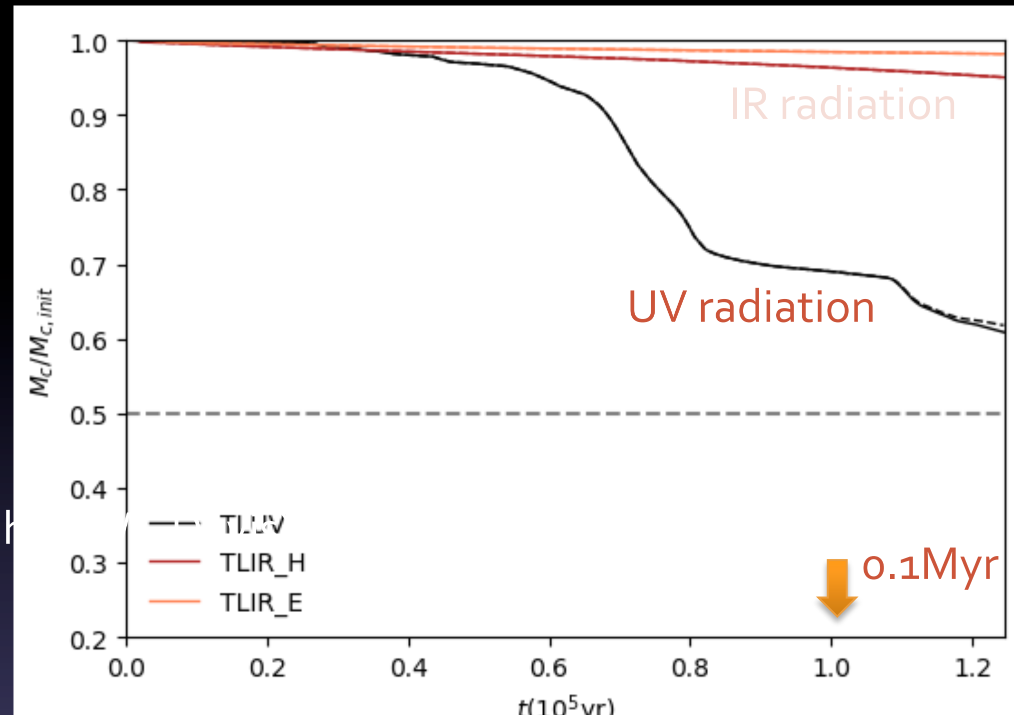
Radiation's Role in Accelerating Galactic Outflow

A very favorable acceleration condition

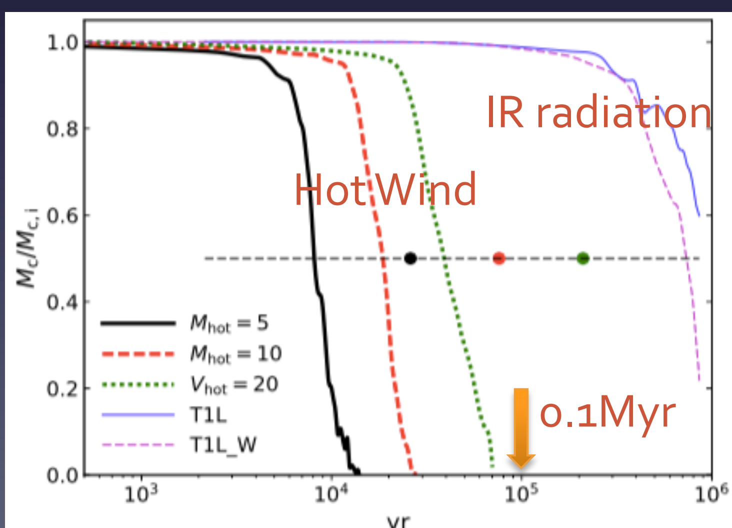
$$N_H \sim 10^{22}\text{cm}^{-3}$$

$$F_{UV} \sim 10^{12} L_{\odot}\text{kpc}^{-2}$$

$$\tau_{UV} \sim 10, \tau_{IR} \sim 0.1$$



, Sh



(Zhang et al 2018)

$$F_{IR} \sim 10^{13} L_{\odot}\text{kpc}^{-2}$$

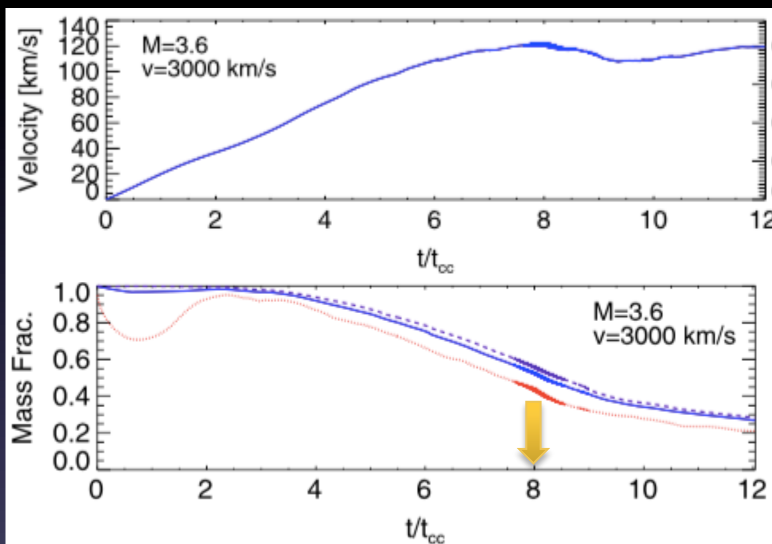
$$\tau_{IR} = 1$$

surviving time: UV radiation << IR radiation

Radiation's Role in Accelerating Galactic Outflow

- Galactic Outflow : Driving Mechanism. Simulation Study

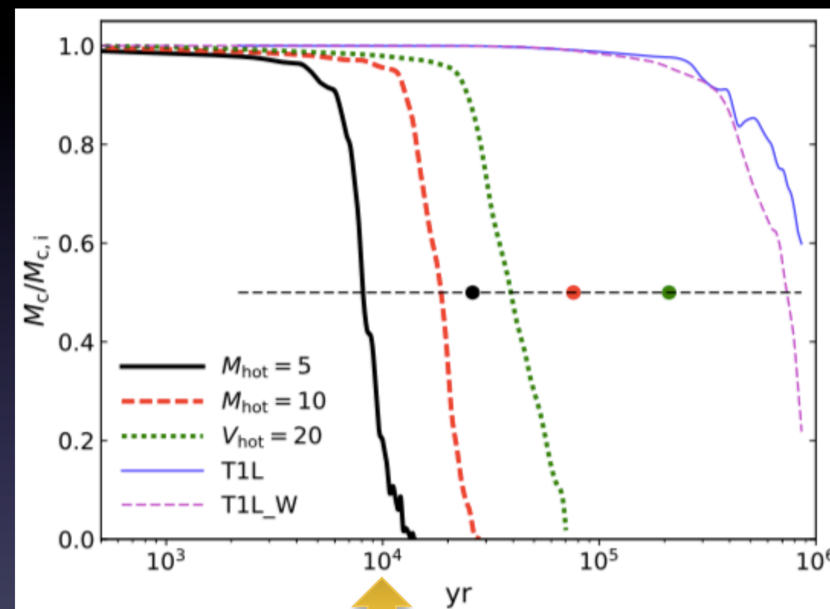
- Entrainment in hot wind



$$t_{cc} = 1.8 Myr$$

(Scannapieco 2015)

- IR Radiation from SF regions



(Zhang et al 2018)

surviving time: when cloud lose half of its initial mass