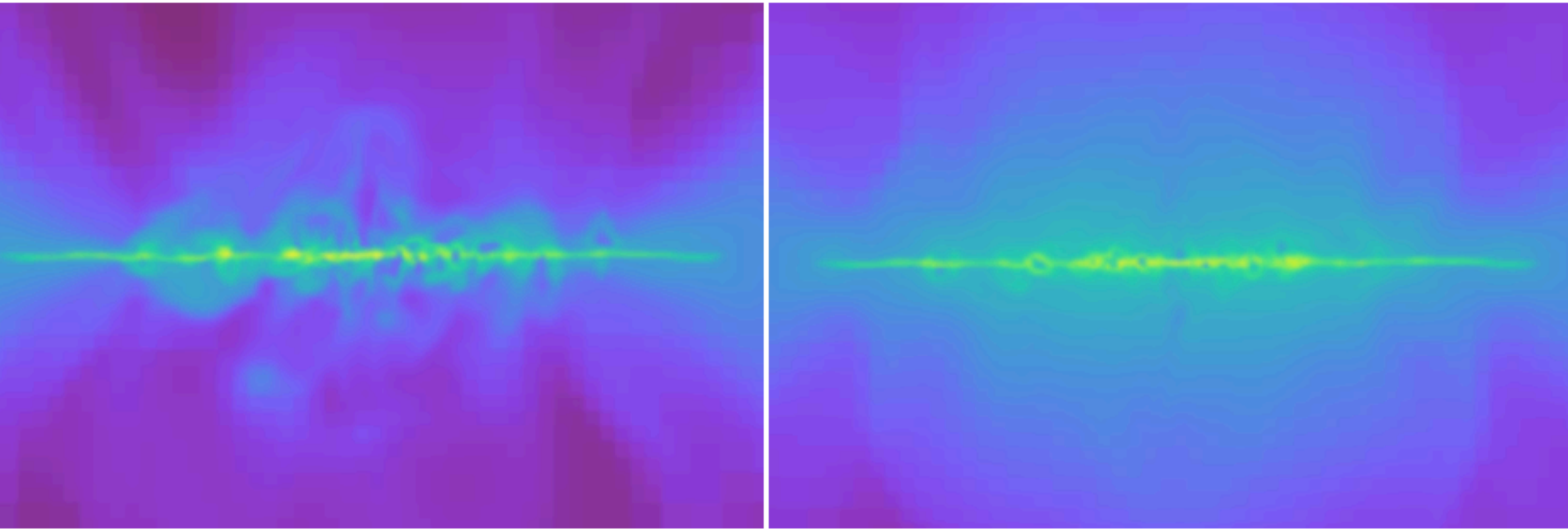
Cosmic ray feedback in dwarf galaxies



Gohar Dashyan, Yohan Dubois

RUM, 17/09/2018

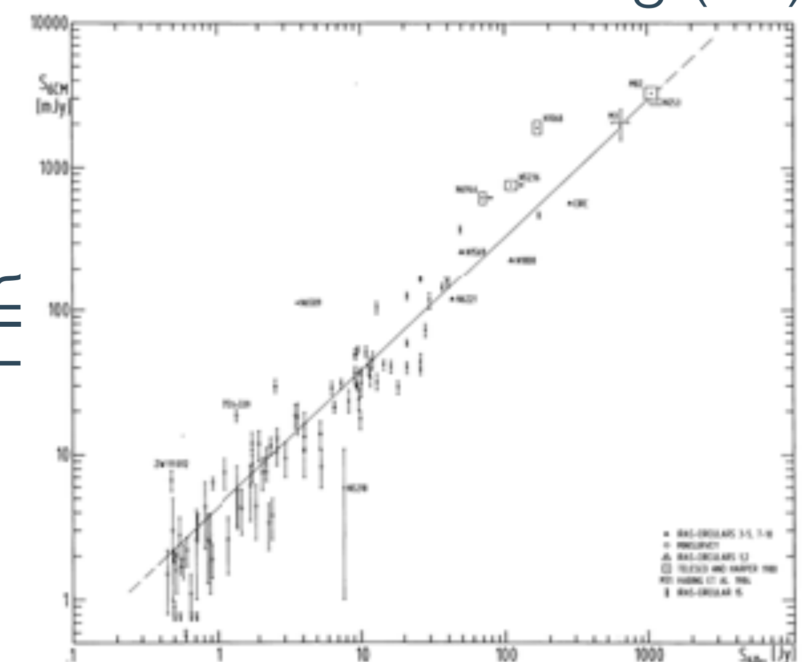
Case for cosmic ray feedback

Sources : supernovae, AGN, accretion shocks

de Jong (85)

- Tight correlation between FIR luminosity and synchrotron emission

FIR



Radio

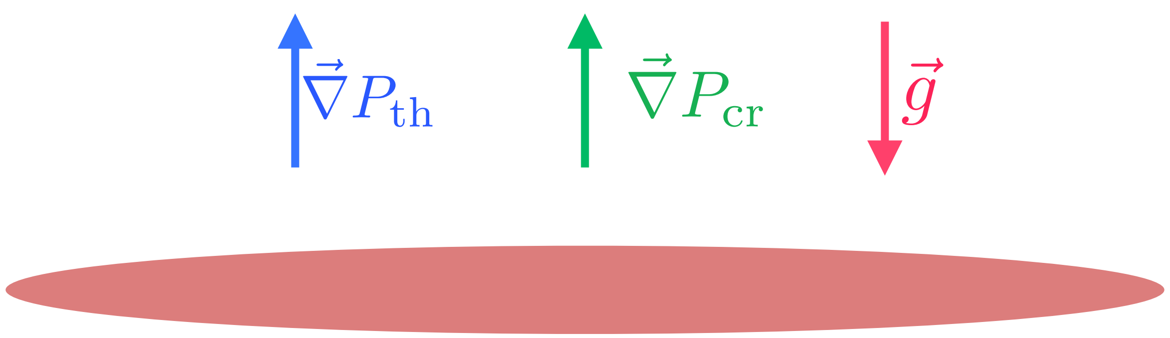
- Observed equipartition of cosmic ray, thermal, turbulent and magnetic energies

→ **Powerful regulation mechanism**

Cosmic ray hydrodynamics

- **Sources :** supernovae, AGN, accretion shocks

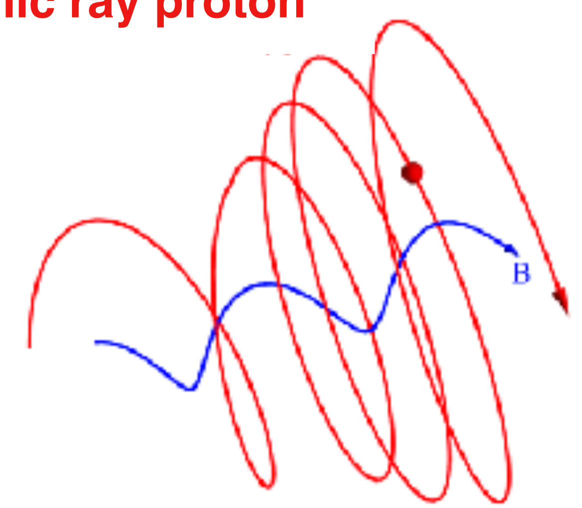
- **Fluid picture** because huge range of dynamical scales



$$P_{\rm cr} = \frac{1}{3} e_{\rm cr}$$

$$P_{\rm th} = \frac{2}{3} e_{\rm th}$$

Cosmic ray proton



- **Transport**

CR **stream** down their pressure gradient

$$\mathbf{v}_{\rm S} = -v_{\rm A} \frac{\mathbf{b}\cdot\nabla P_{\rm cr}}{|\mathbf{b}\cdot\nabla P_{\rm cr}|}$$

CR **diffuse** due do pitch angle scattering by MHD waves

$$\mathbf{v}_{\rm D} = -\kappa \frac{\mathbf{b}\cdot\nabla e_{\rm cr}}{e_{\rm cr}}$$

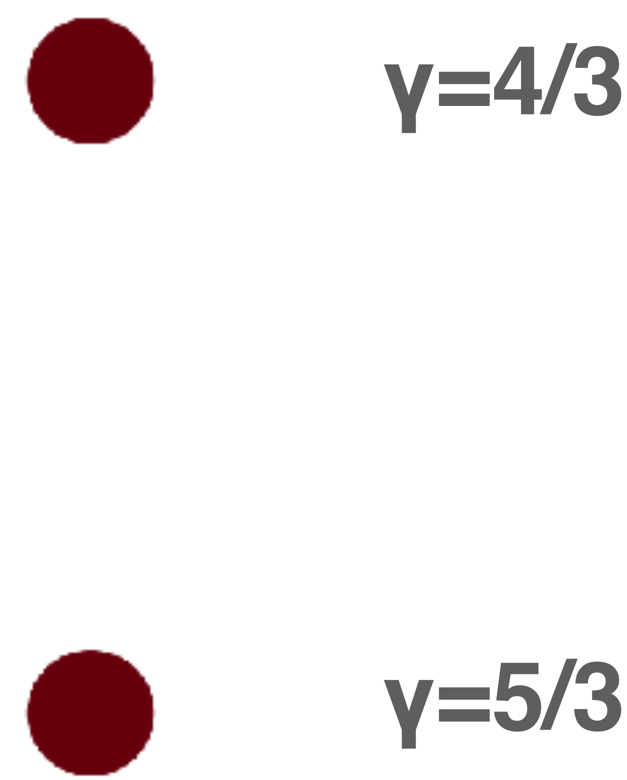
Some interesting features

Lower adiabatic index γ=4/3

Longer cooling timescale

Stream and diffuse relative to the gas

Alfvén wave heating



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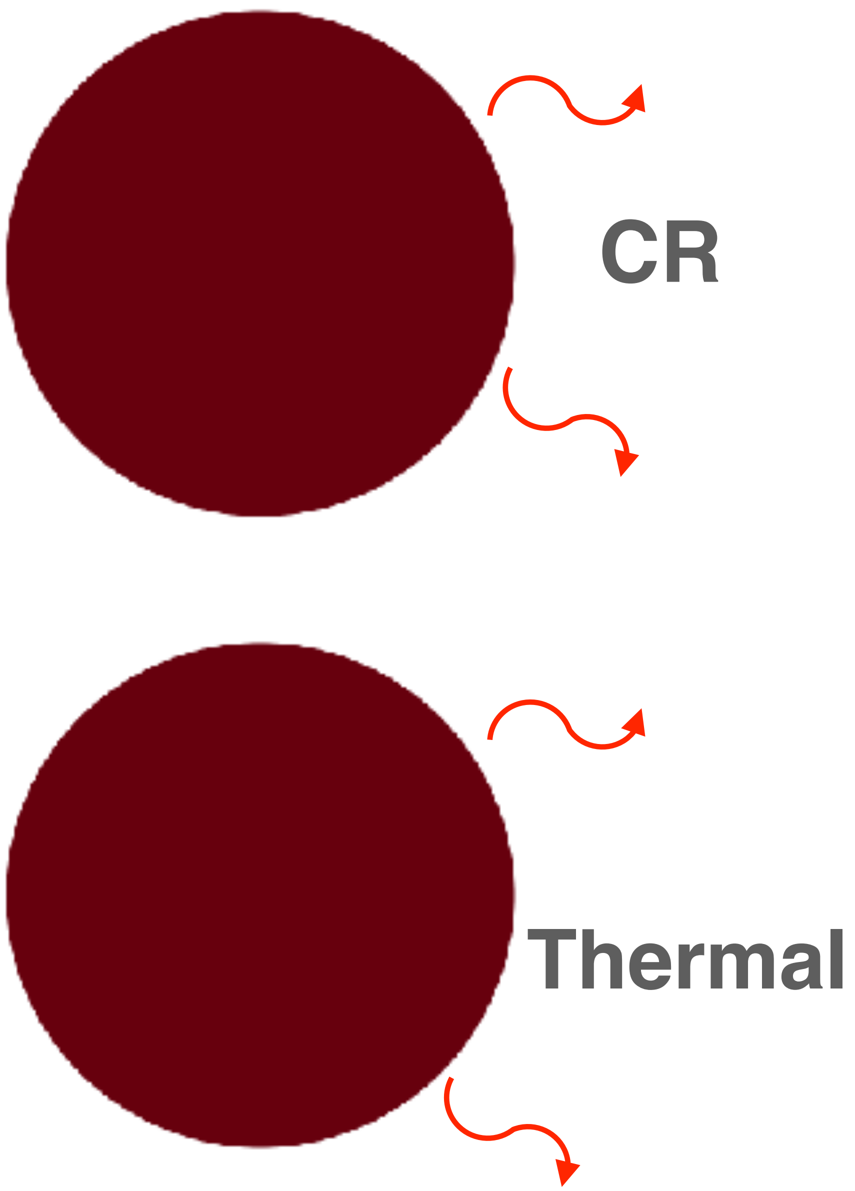


Some interesting features

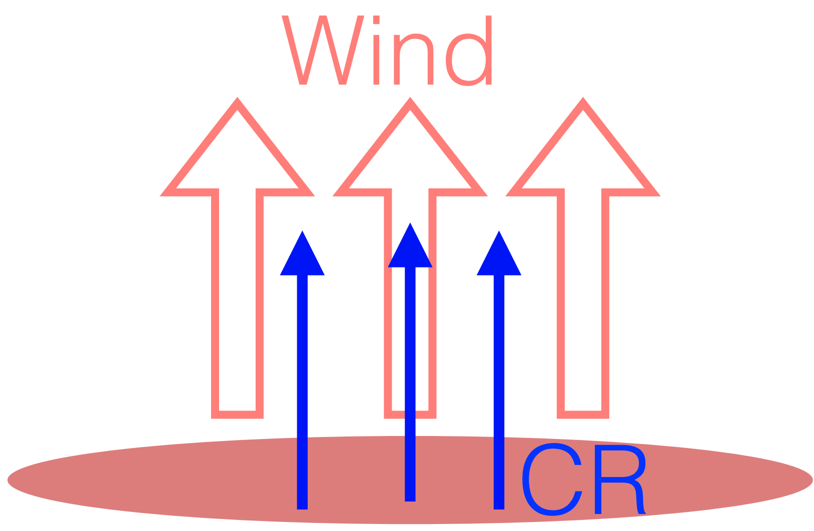
Lower adiabatic index γ=4/3

Longer cooling timescale

Stream and diffuse relative to the gas

Energize the winds

Leave the high cooling rate regions



Alfvén wave heating

Some interesting features

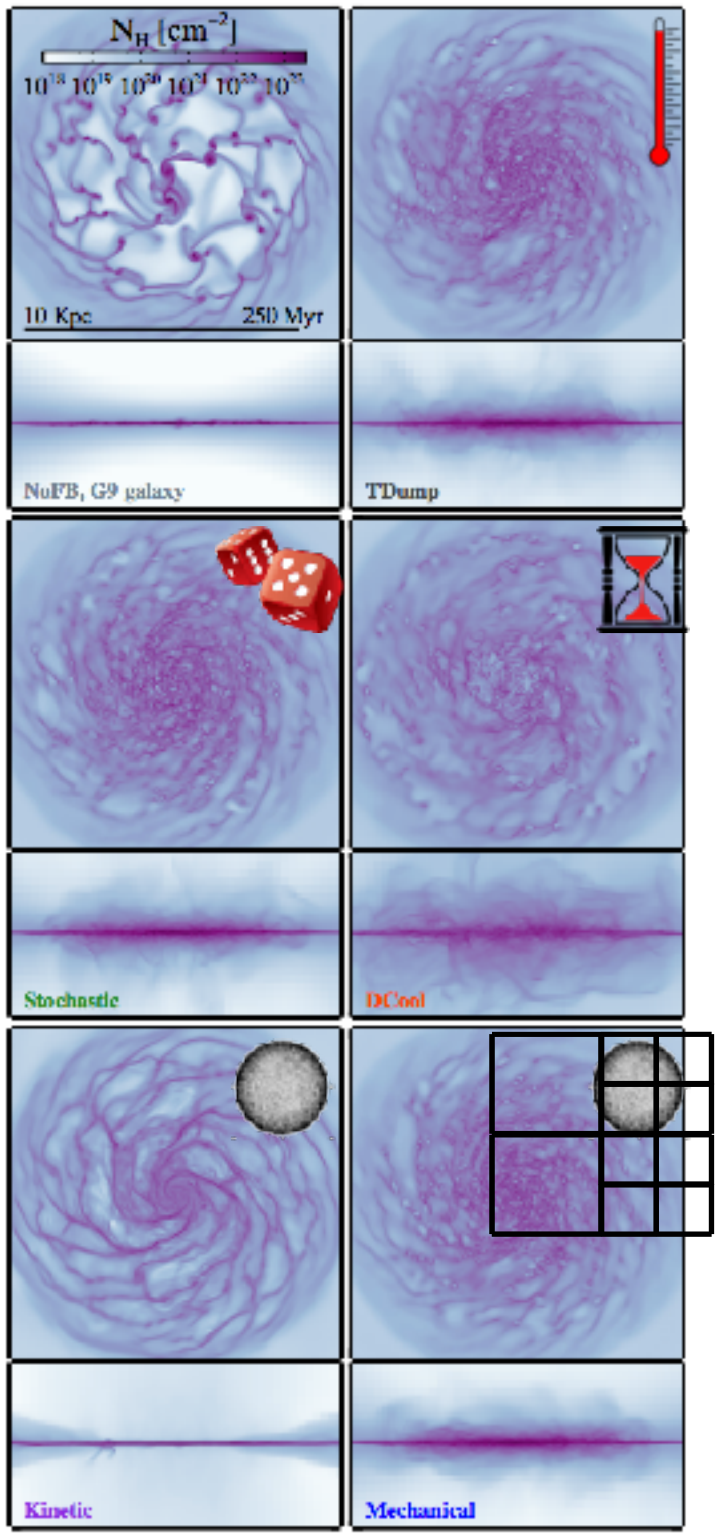
Lower adiabatic index $\gamma=4/3$

Longer cooling timescale

Stream and diffuse relative to the gas

Alfvén wave heating $-\mathbf{u}_{\mathrm{A}} \cdot \nabla p_{\mathrm{c}}$

Our simulations



ICs from Joki's simulations
Rosdhal +17

$$M_{\rm bar} = 3.8 \times 10^9 {\rm M}_\odot$$
$$M_{\rm halo} = 10^{11} {\rm M}_\odot$$
$$f_{\rm gas} = 0.5$$

+Ramses with cosmic rays
from Yohan & Benoît
Dubois & Commerçon 2016

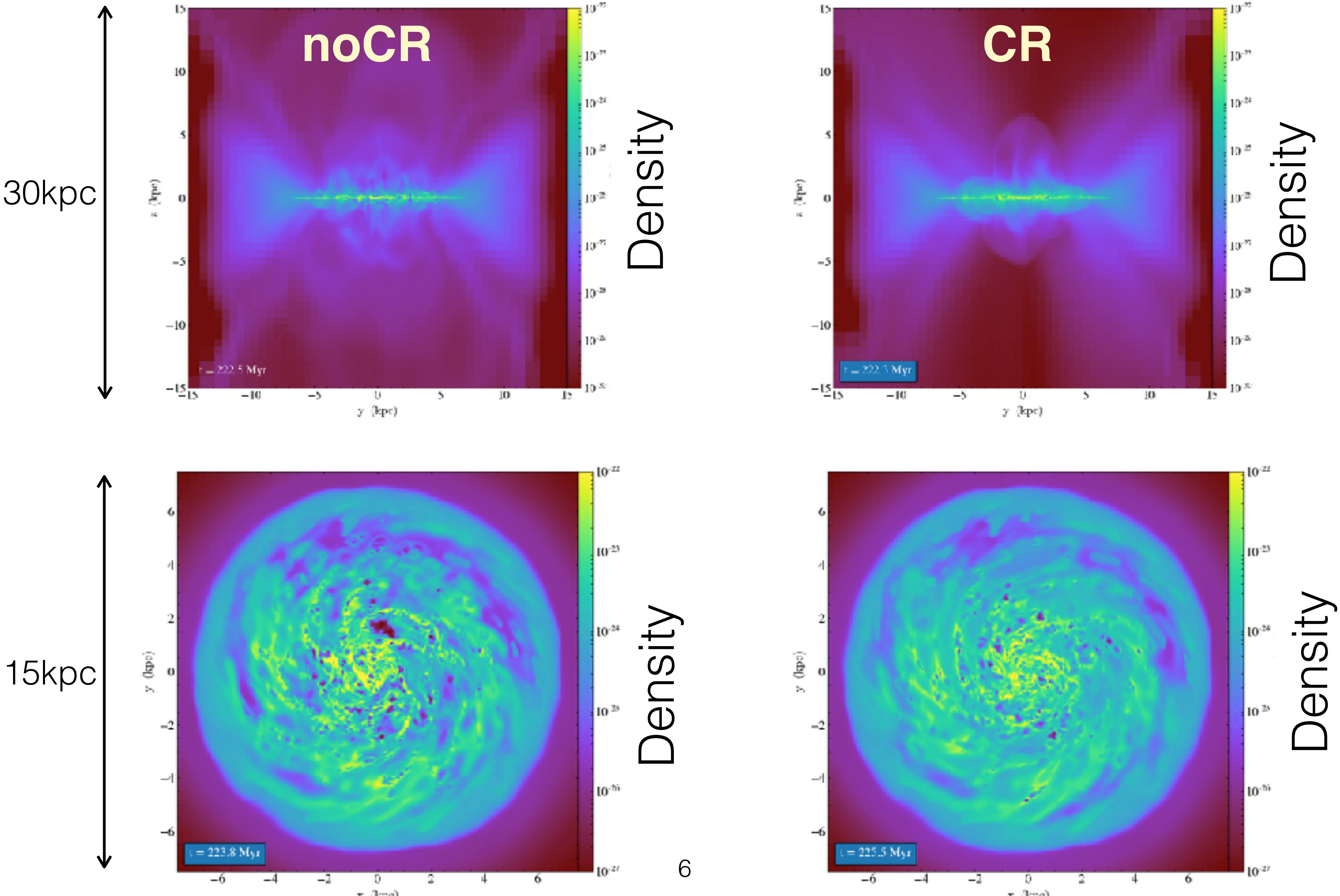
Mechanical feedback from SNe
from Taysun **Kimm +15**

$$E_{\rm cr} = 0.1 E_{\rm SN}$$

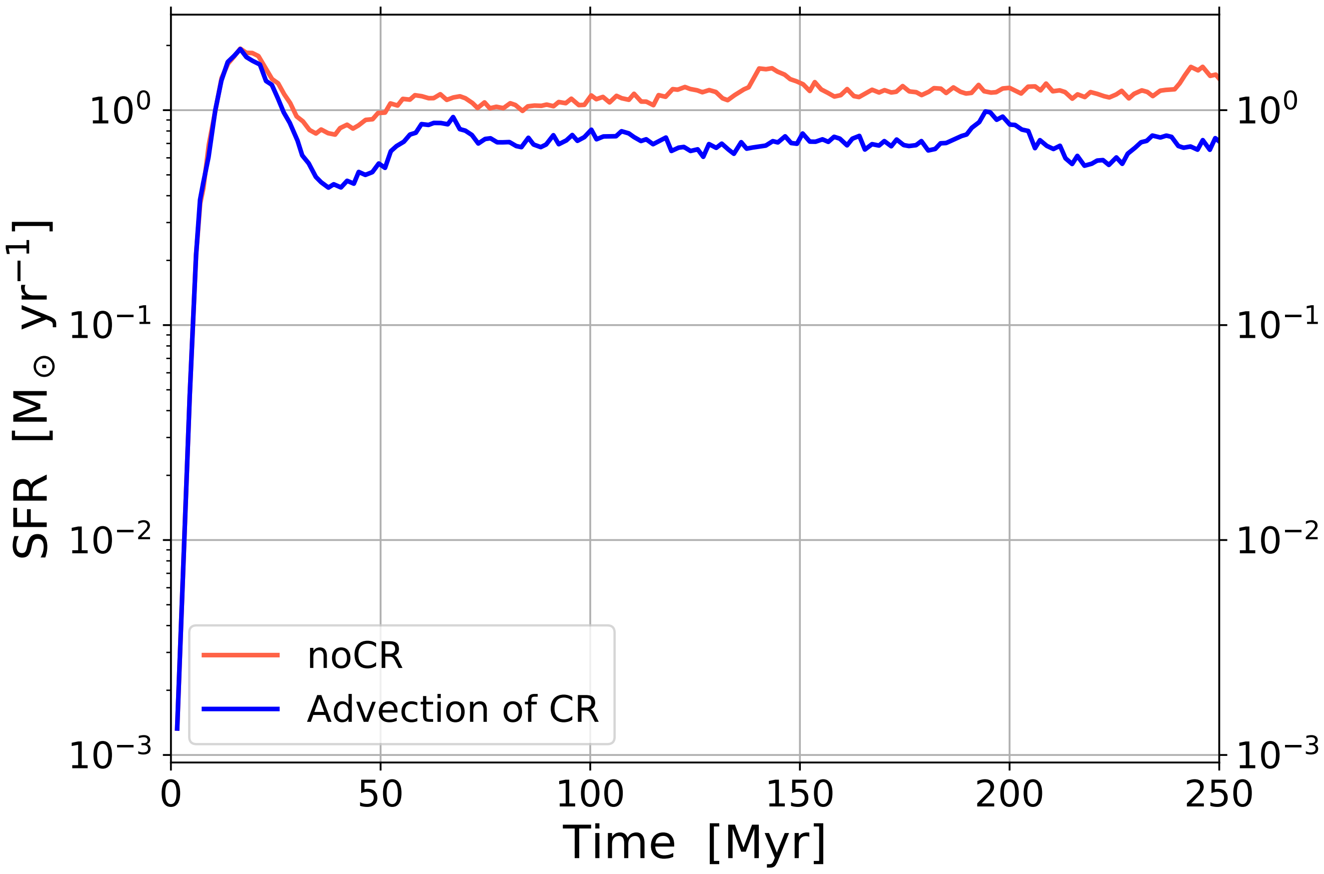
Turning on/off Streaming, Diffusion…

$$\Delta_{\rm xmin} = 18\,{\rm pc}$$

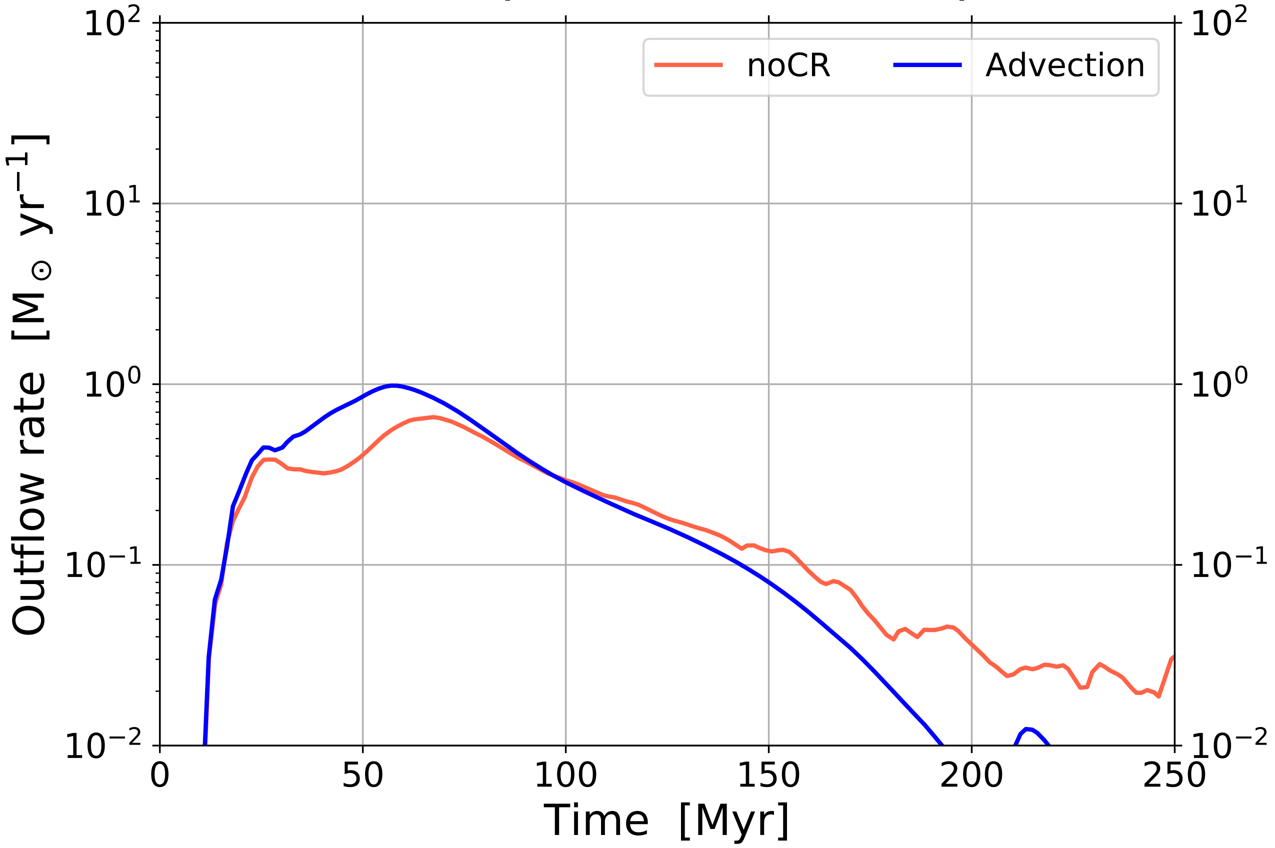
Cosmic ray pressure (advection only)



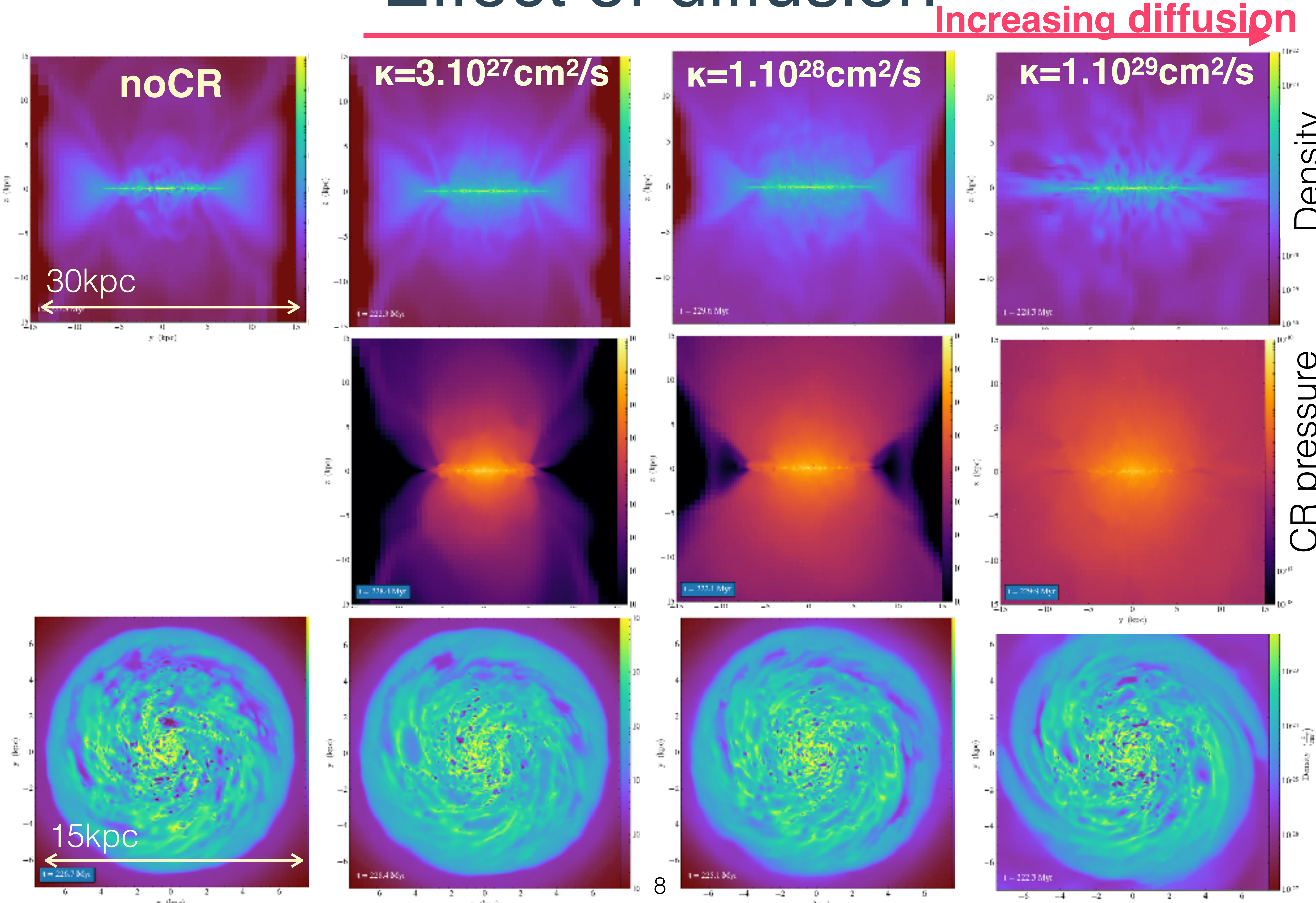
Cosmic ray pressure (advection only)



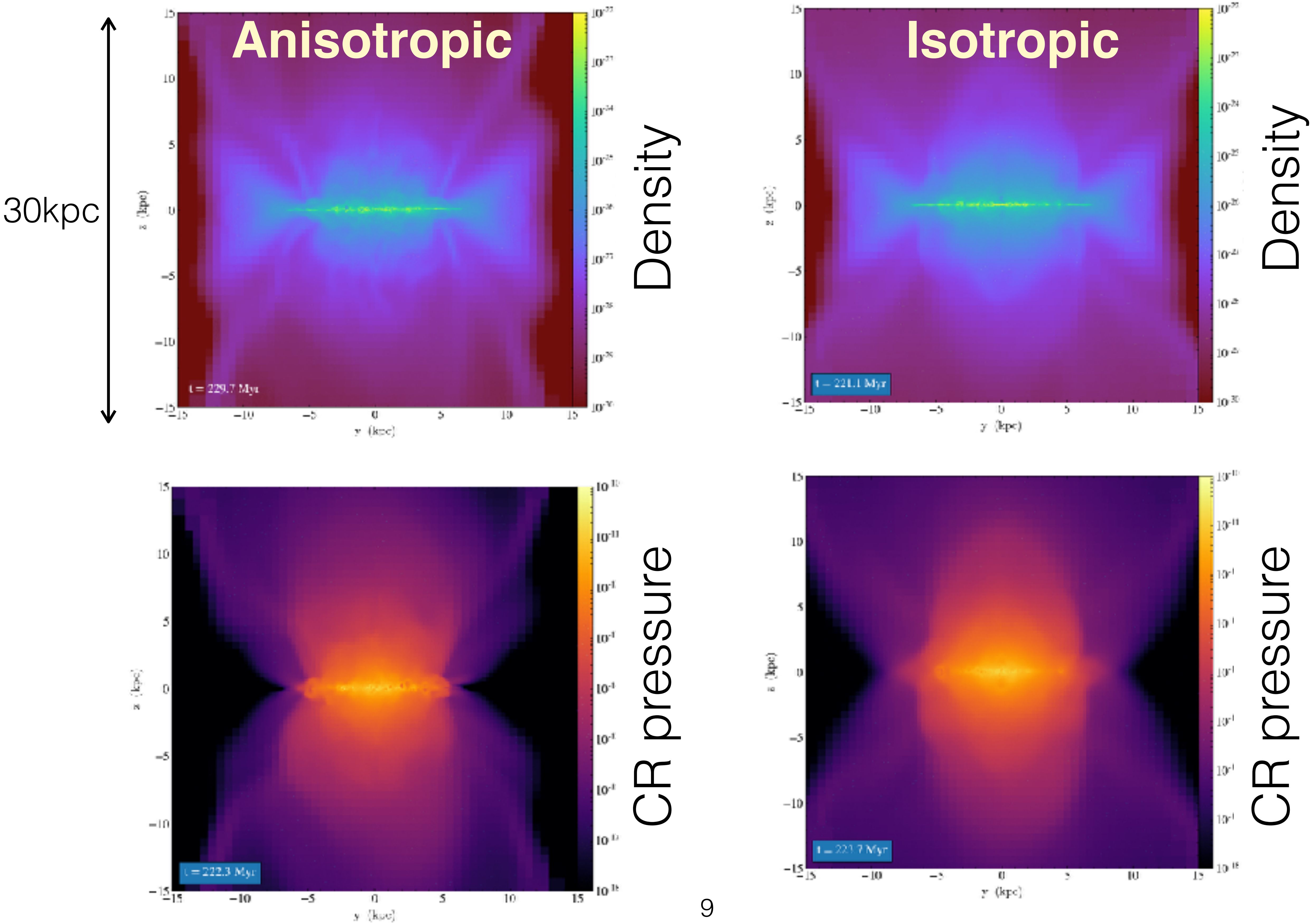
2kpc from disc plane



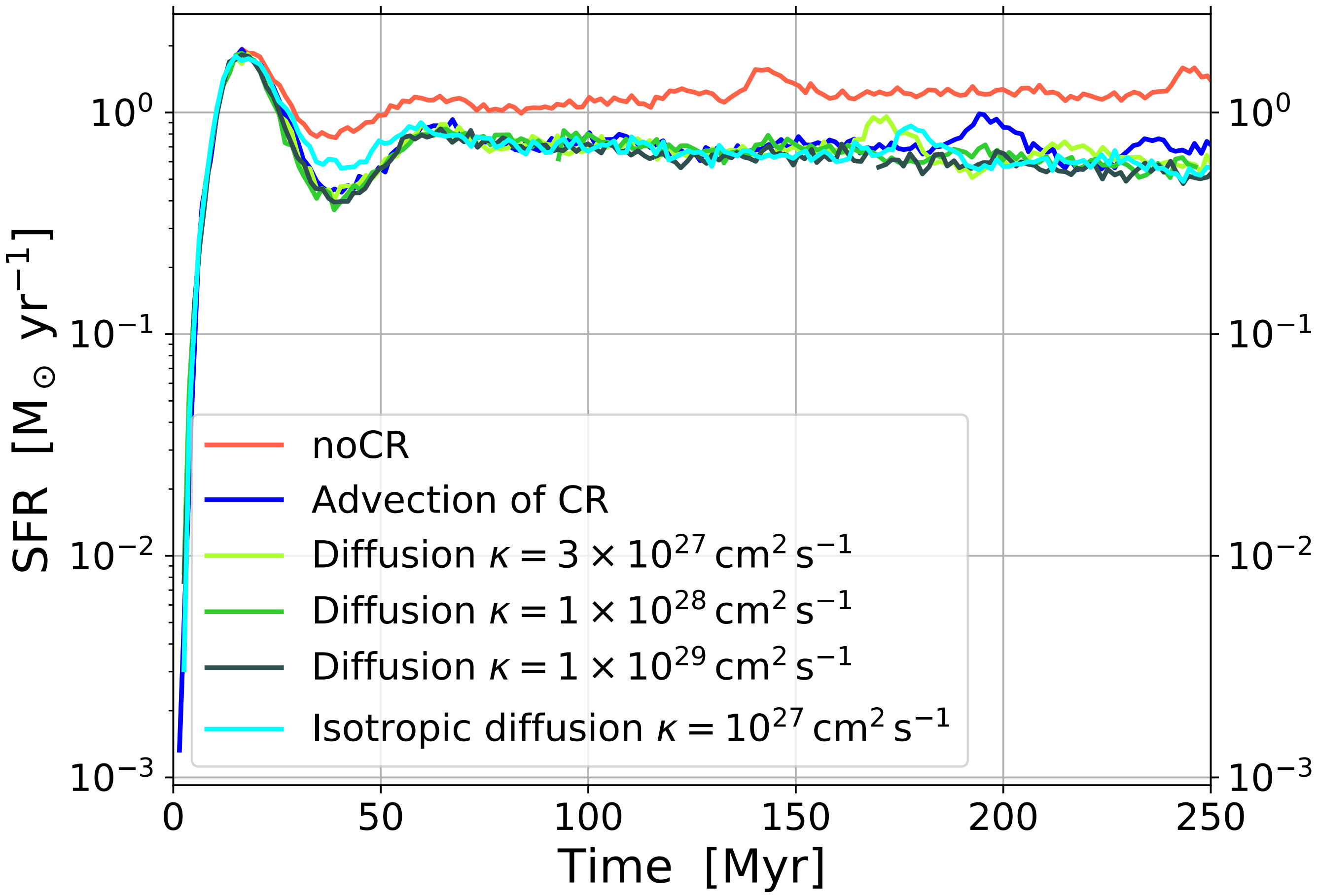
Effect of diffusion



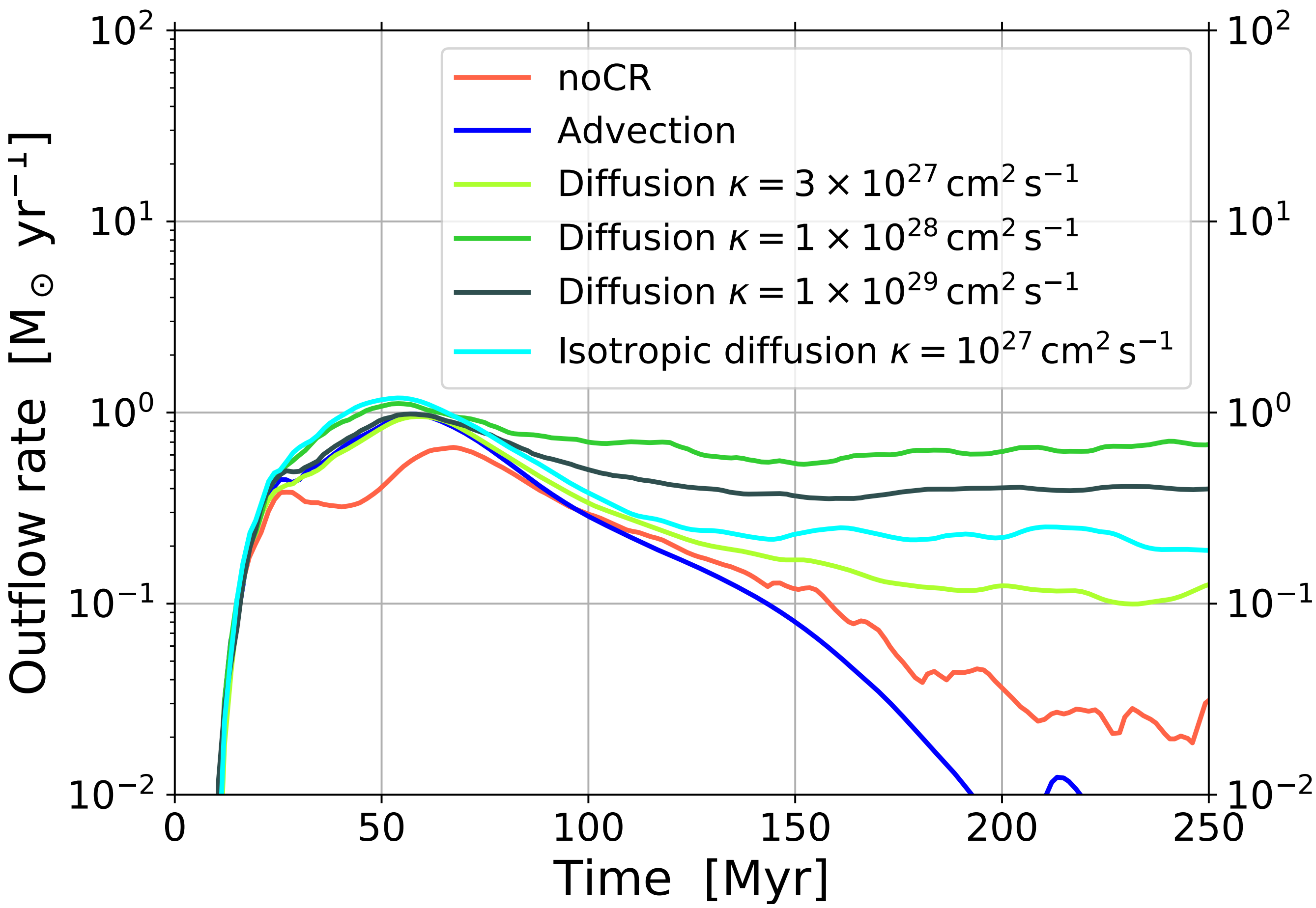
Anisotropic versus isotropic diffusion



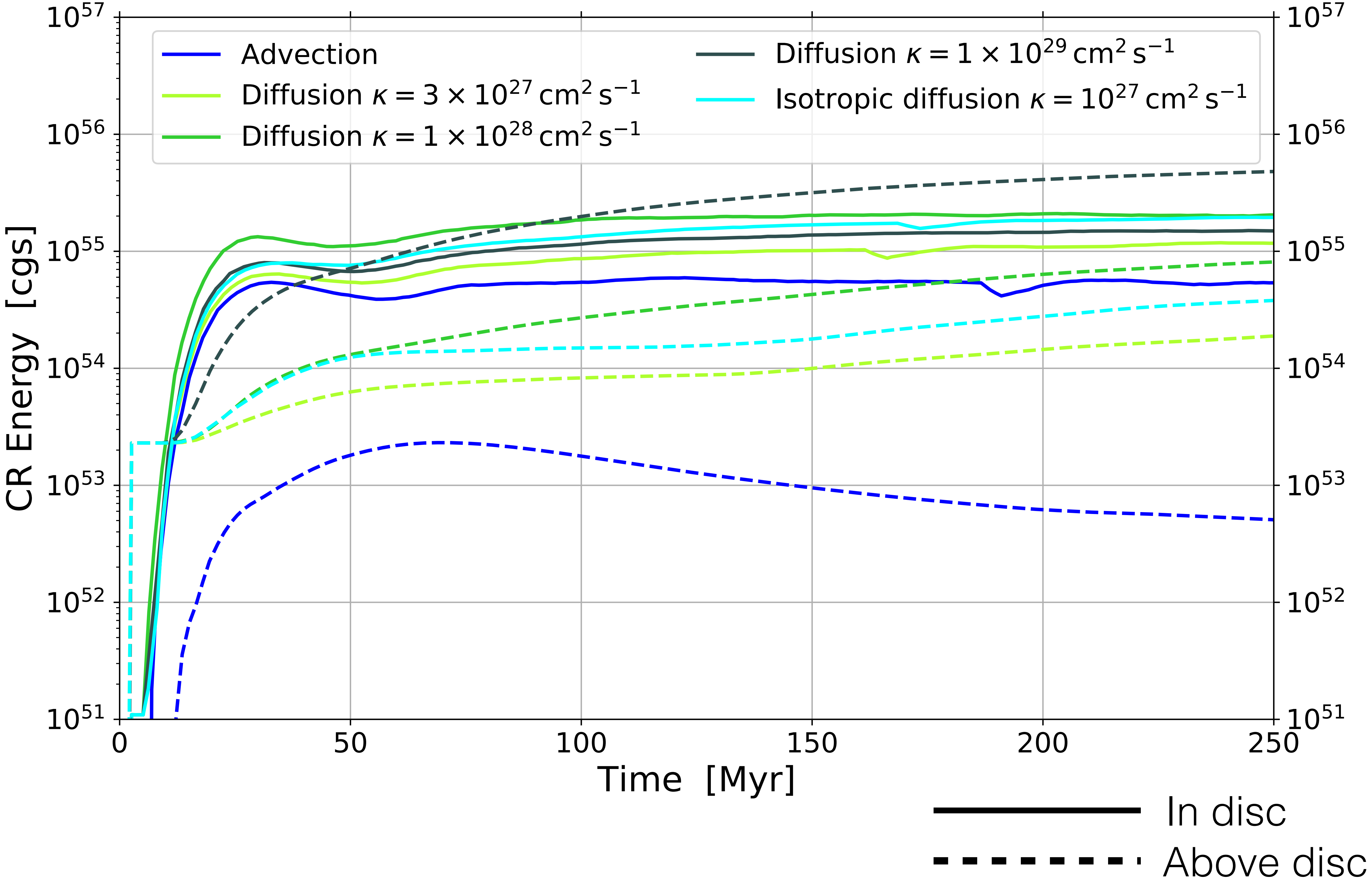
Effect of diffusion



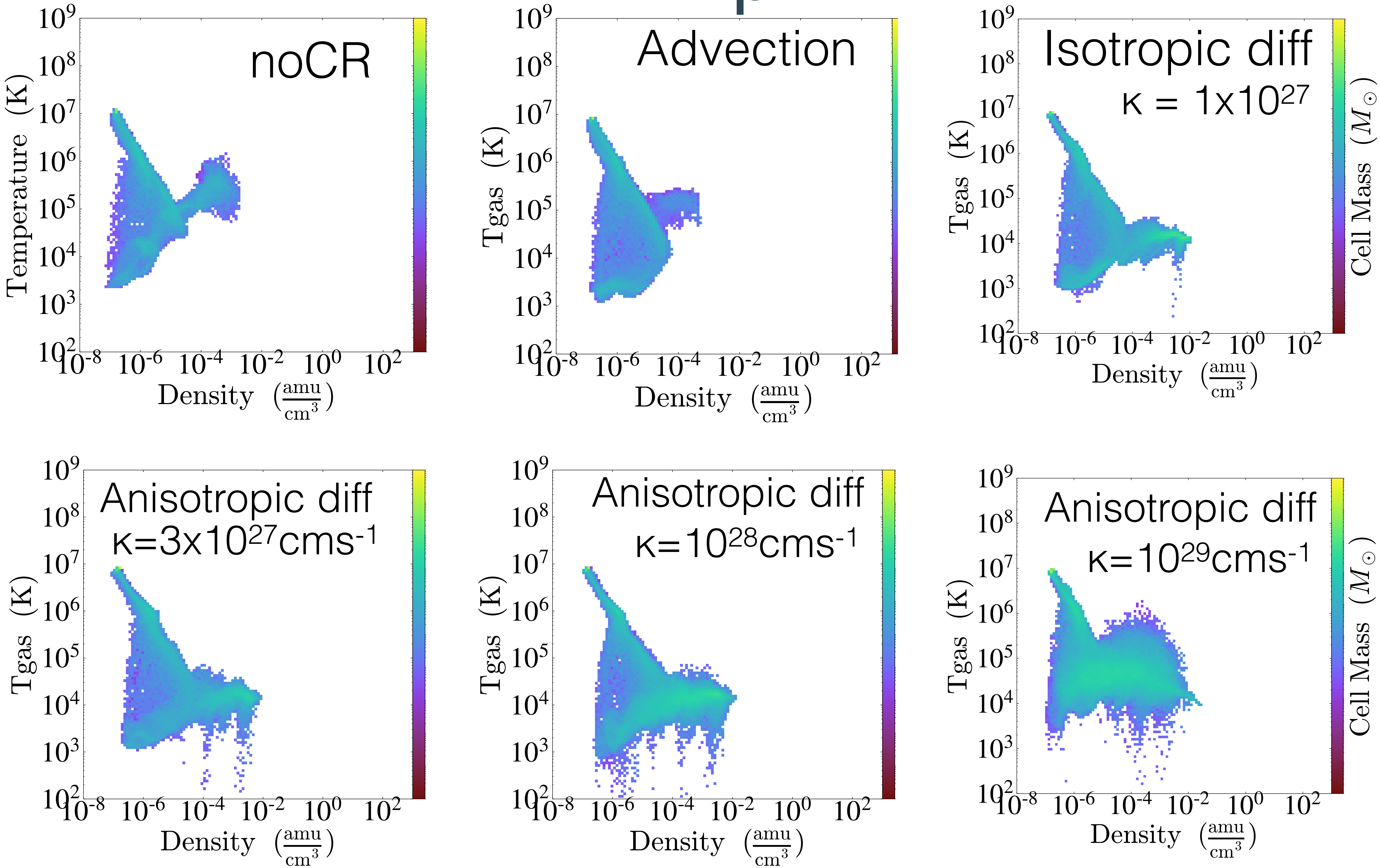
2kpc from disc plane



Cosmic ray energy



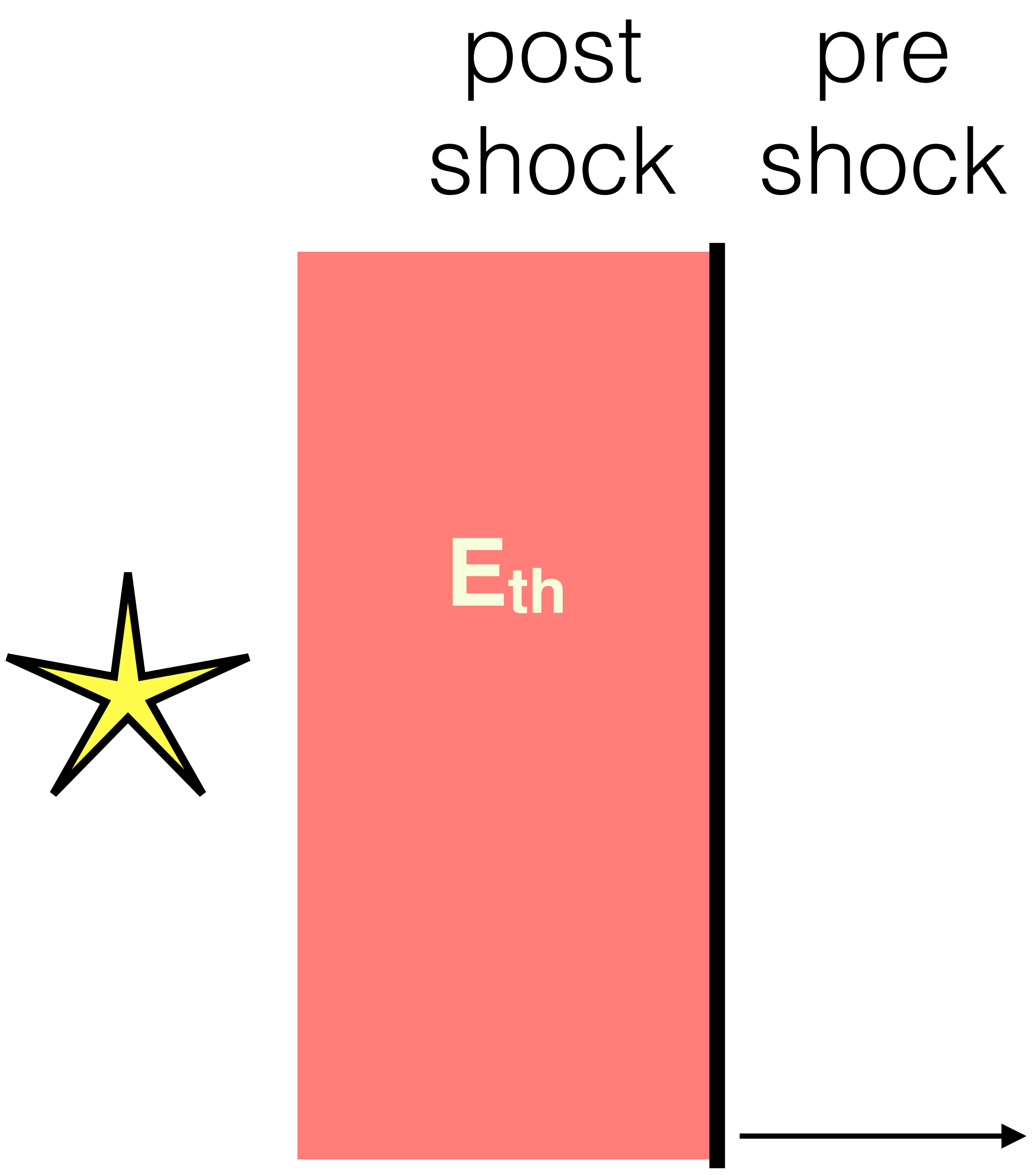
T - ρ



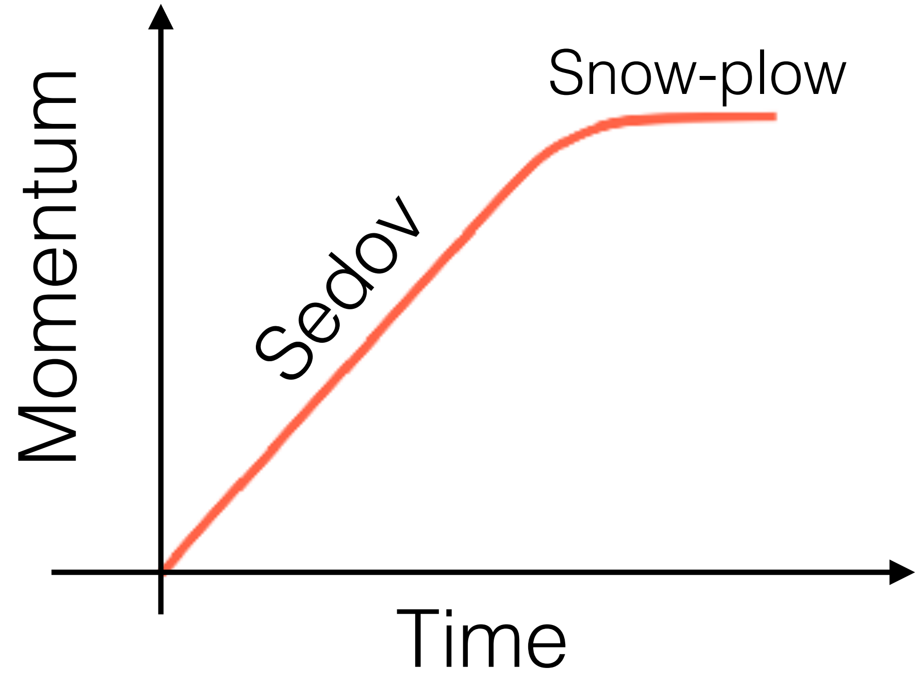
Streaming coming soon…

What about SN explosions with CRs?

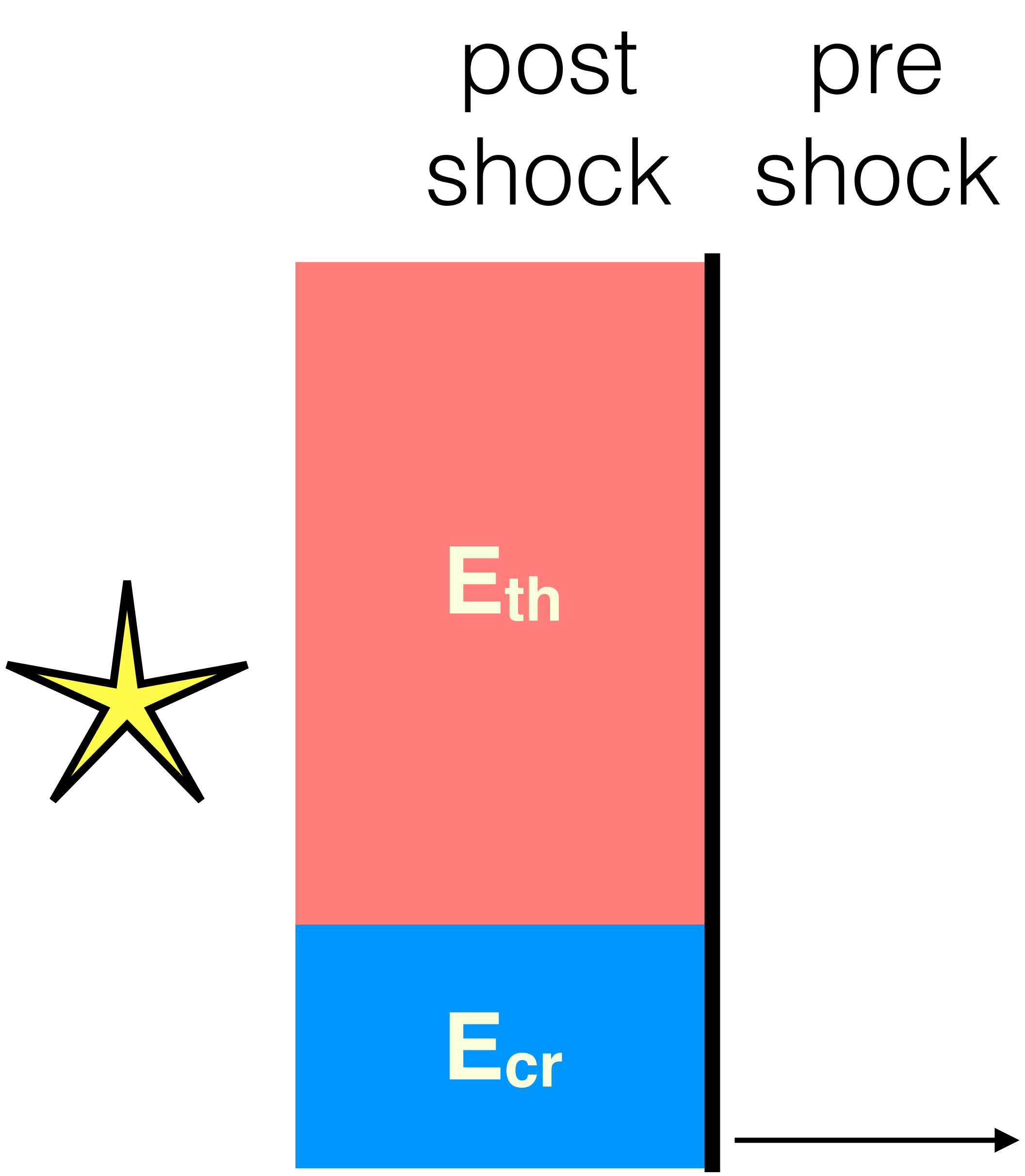
Cosmic ray injection



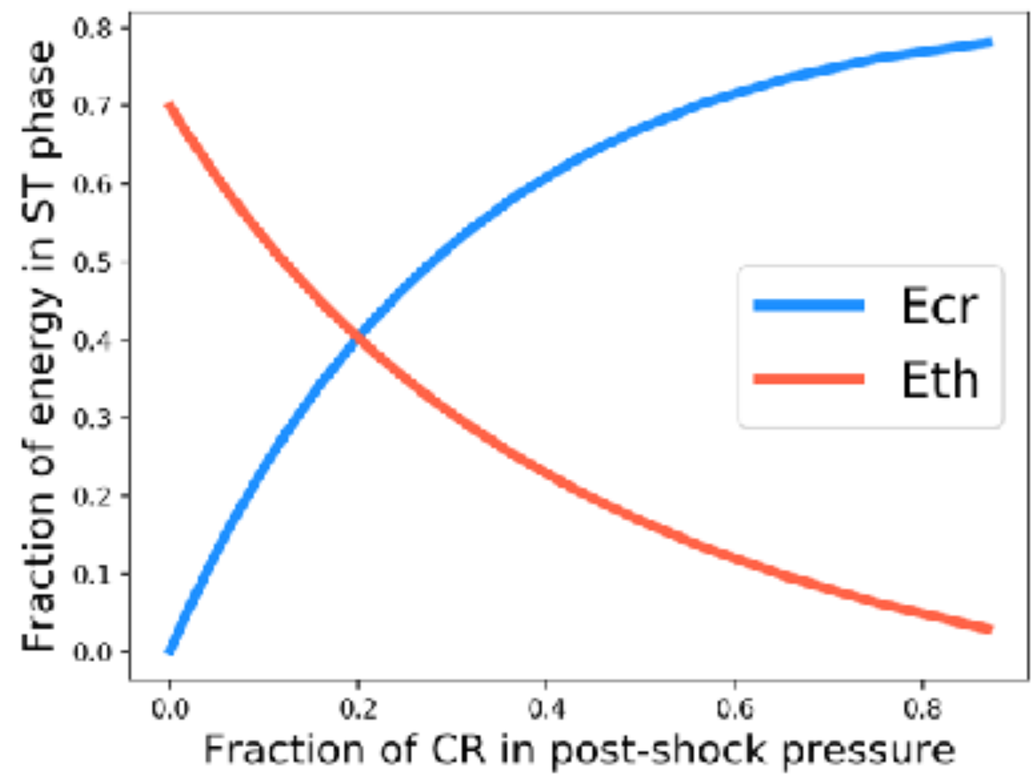
Ecin ~ 30%
Ethermal ~70%

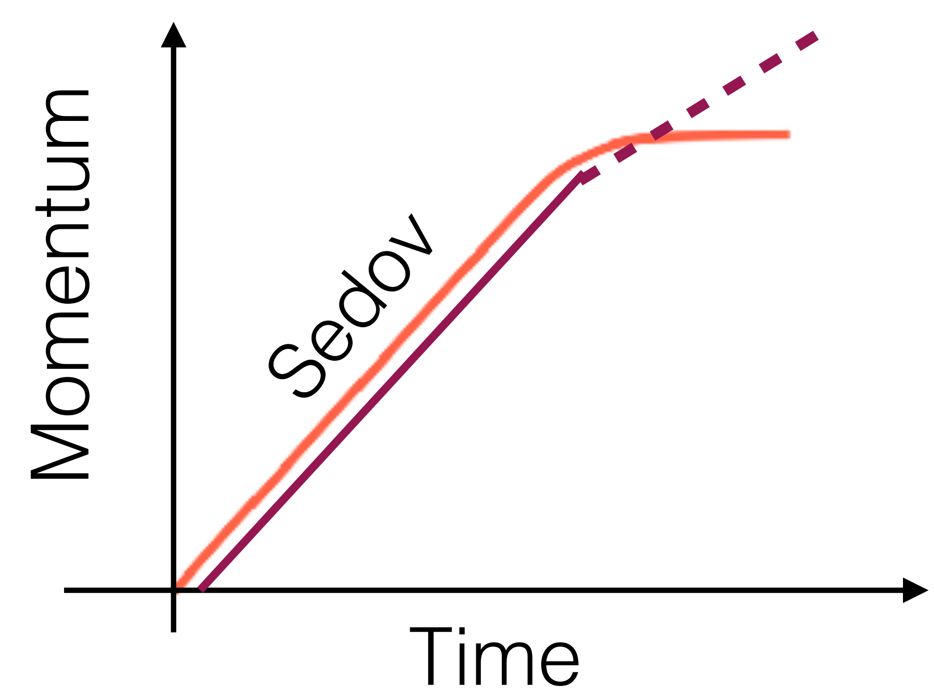


Cosmic ray injection

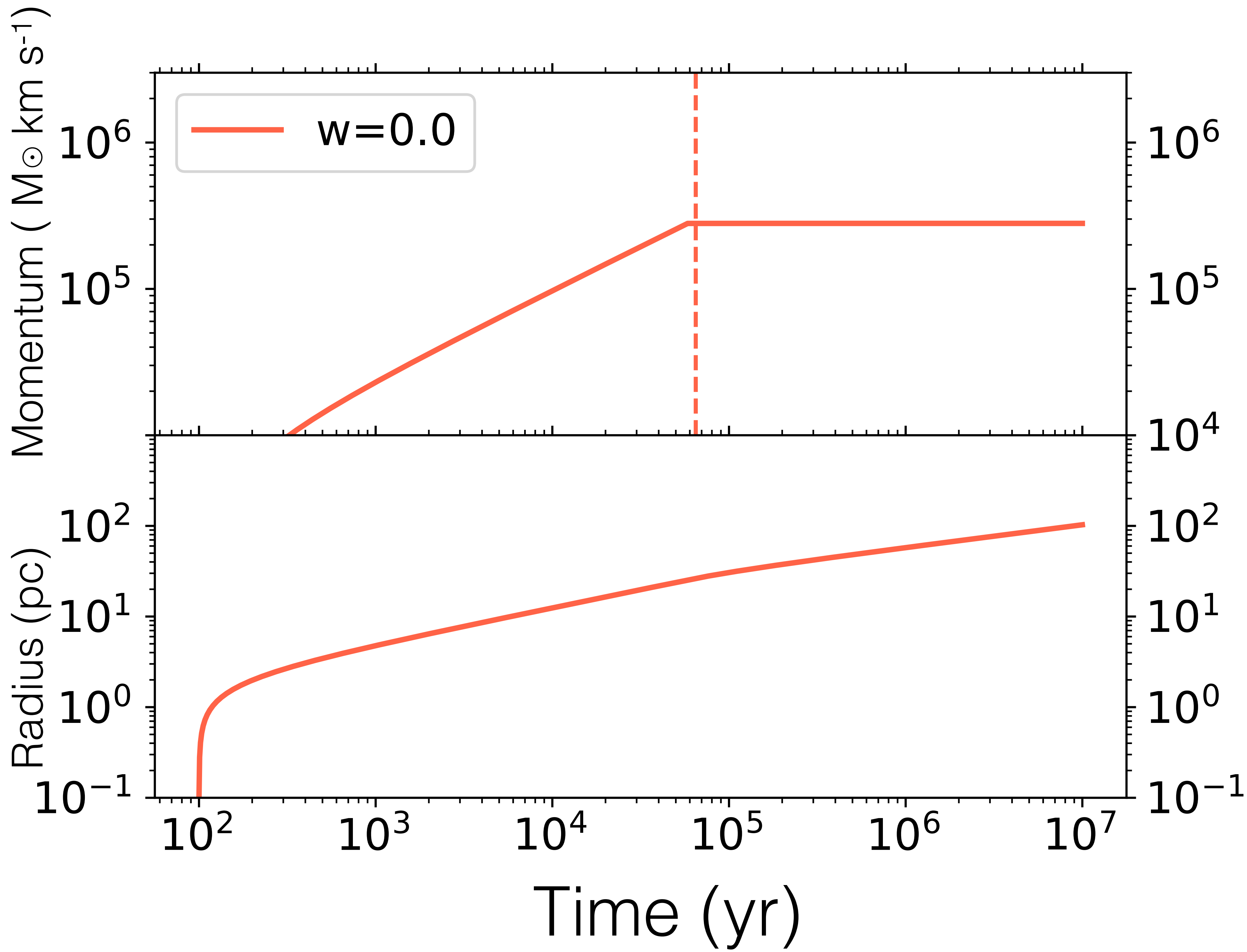


even a small fraction matters





Cosmic ray injection



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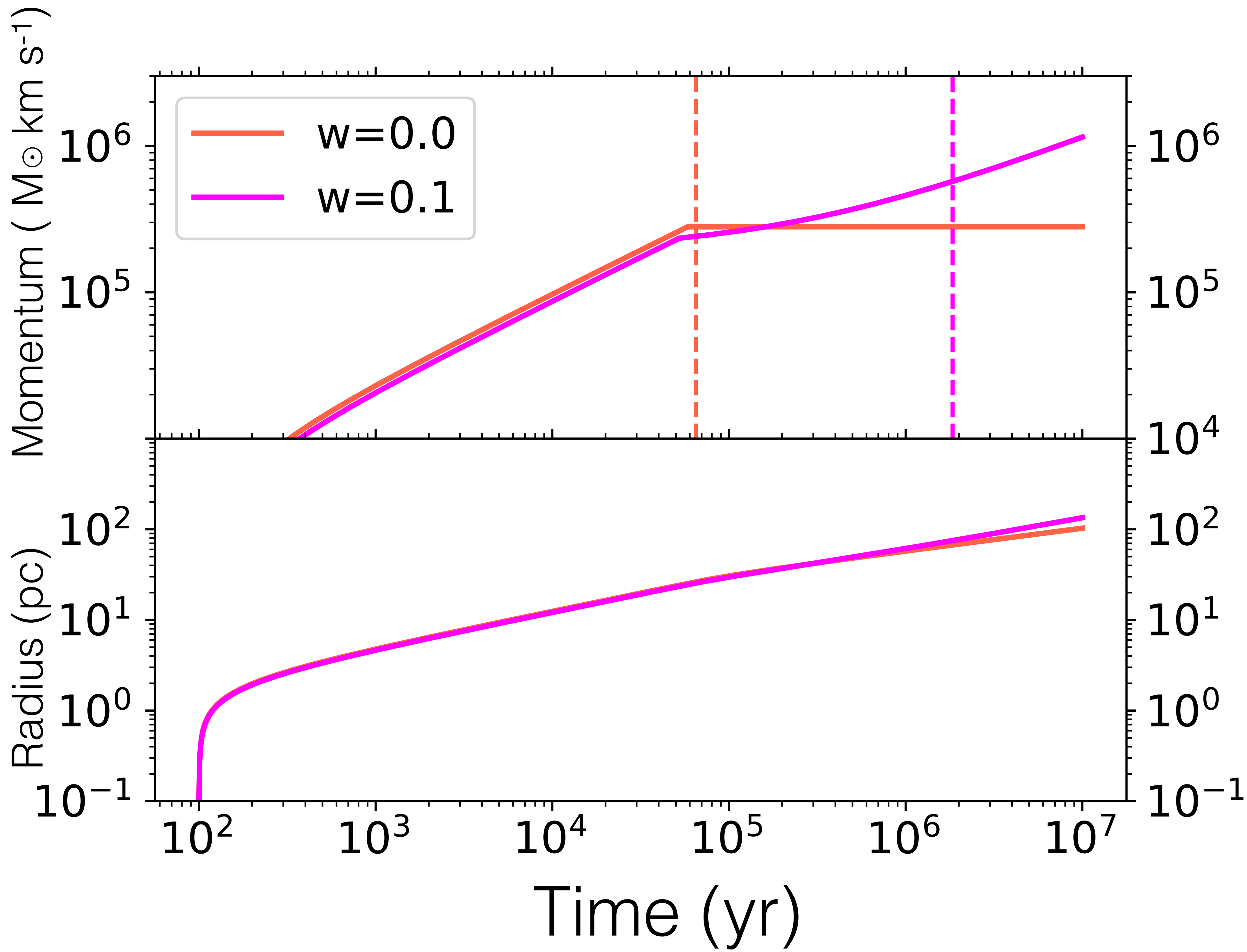

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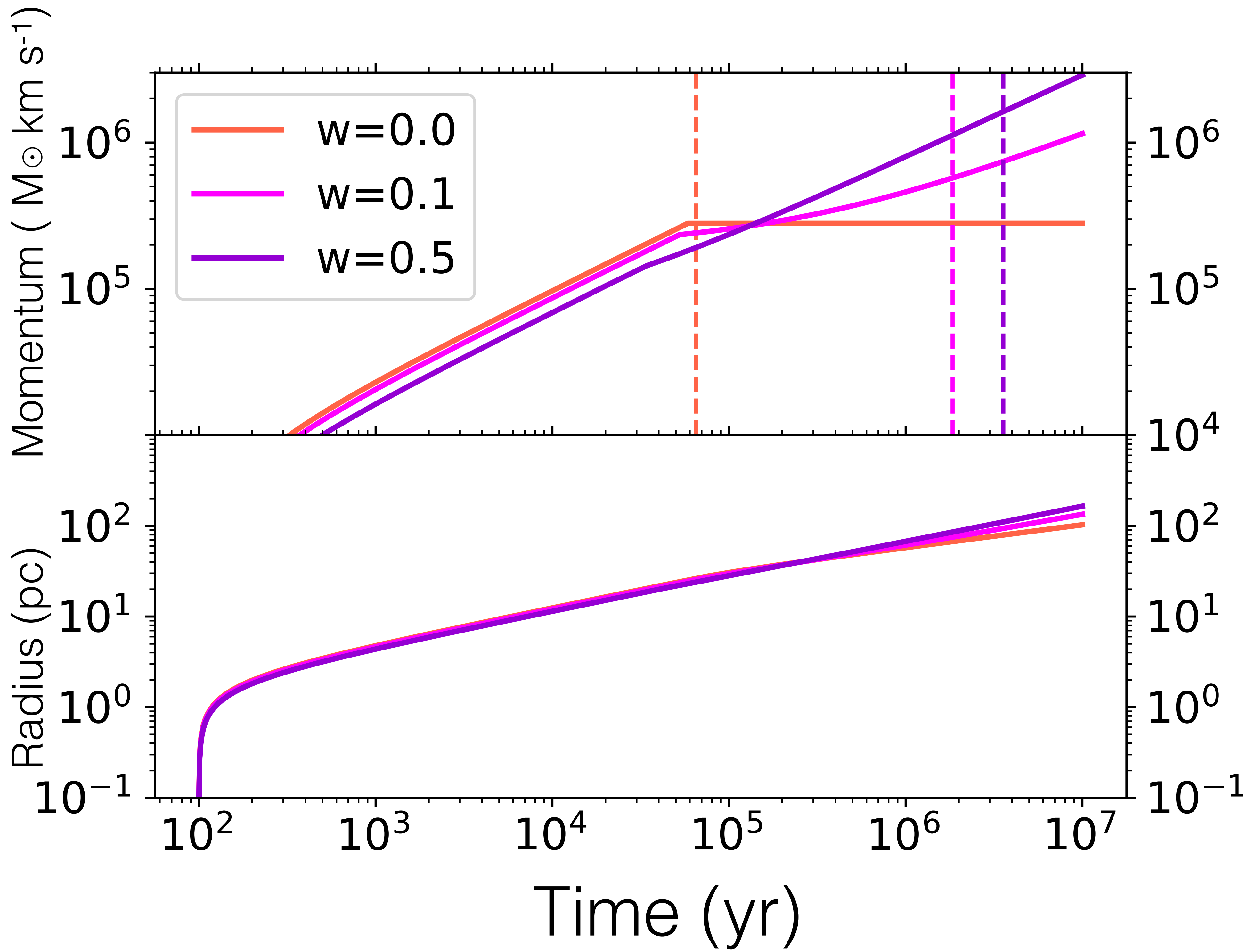
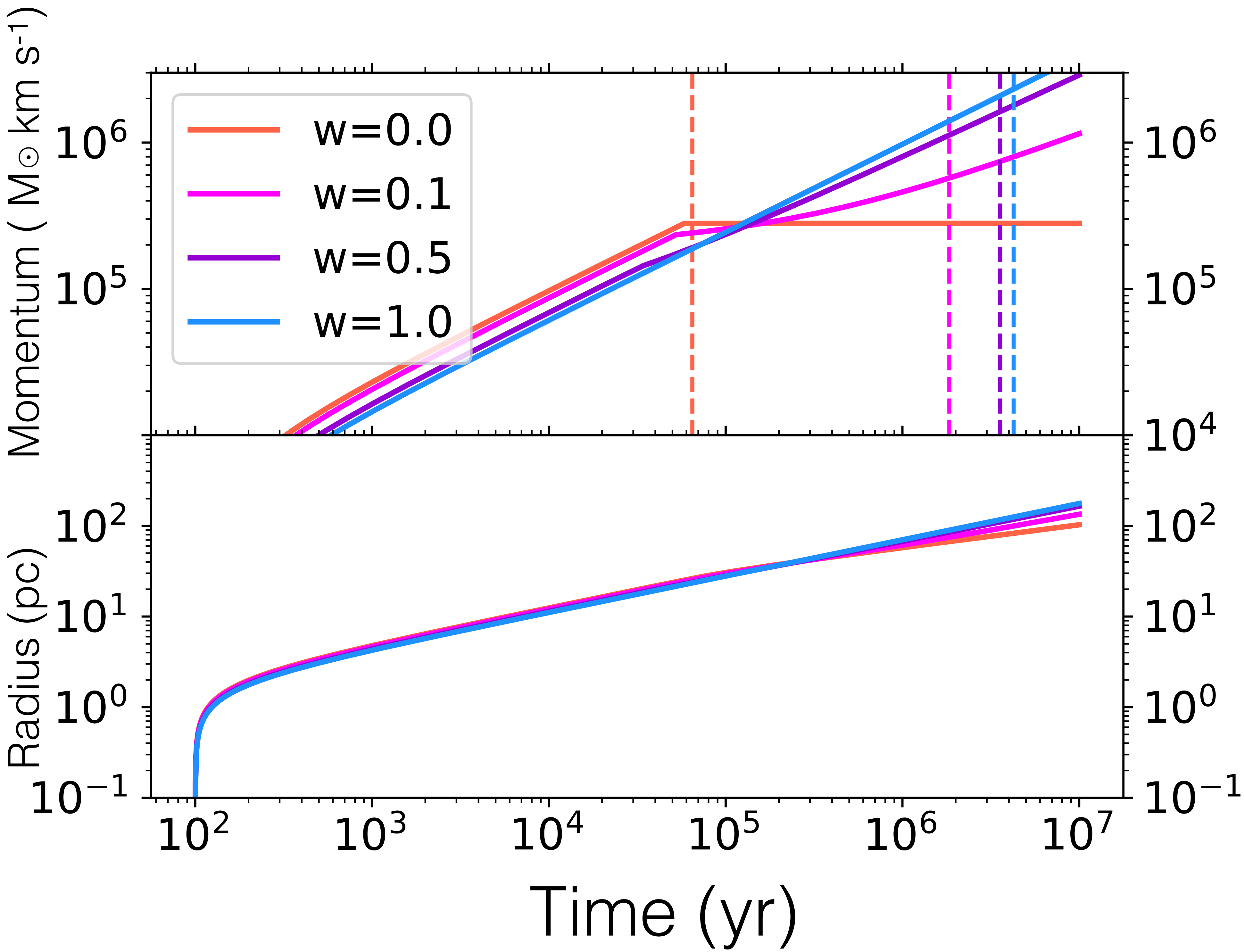


Cosmic ray injection



Summary

- Cosmic ray treatment produces **denser** and **cooler** winds with higher mass loading factors
- Cosmic ray pressure alone does not do the job: **need transport mechanisms**
- Need anisotropic treatment of diffusion with MHD

- Cosmic ray injection in SNe **increases the final momentum** deposited by a supernovae