

Galaxy formation and AGN Feedback

Alexander Y. Wagner

*University of Tsukuba, Center for Computational Sciences
Theoretical Astrophysics Group*

Dipanjan Mukherjee

Geoffrey Bicknell

Joe Silk

Raffaella Morganti

Nicole Nesvadba

Masayuki Umemura

Rebekka Bieri

Yohan Dubois

Salvatore Cielo

Ralph Sutherland

Outline

Galaxy formation and AGN Feedback
(Jet feedback)

Simulations of AGN jet feedback in spherical, gas-rich, forming galaxies

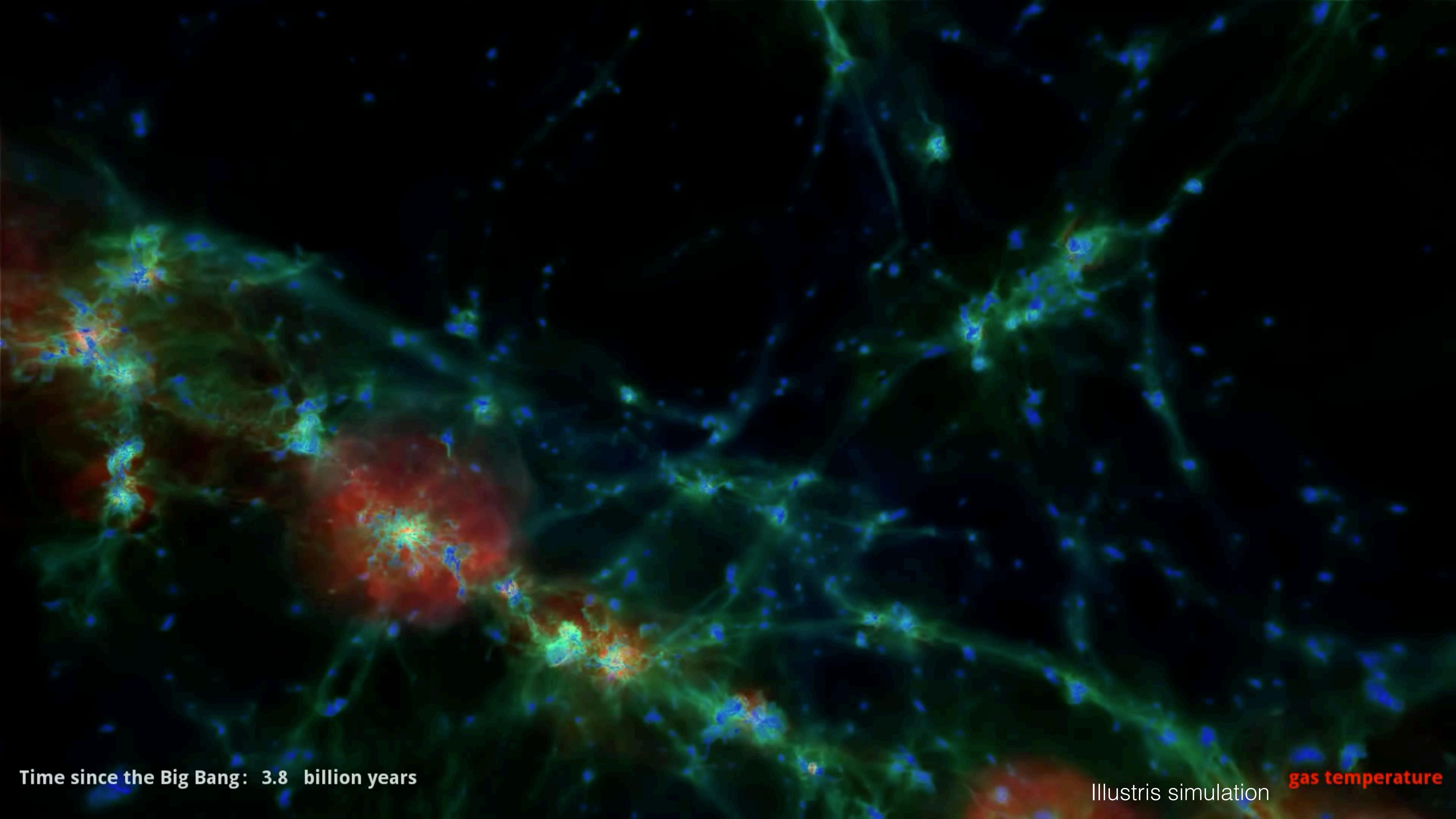
Simulations of AGN jet feedback in gas-rich, disc galaxies

Simulations of AGN radiation feedback in gas-rich, disc galaxies

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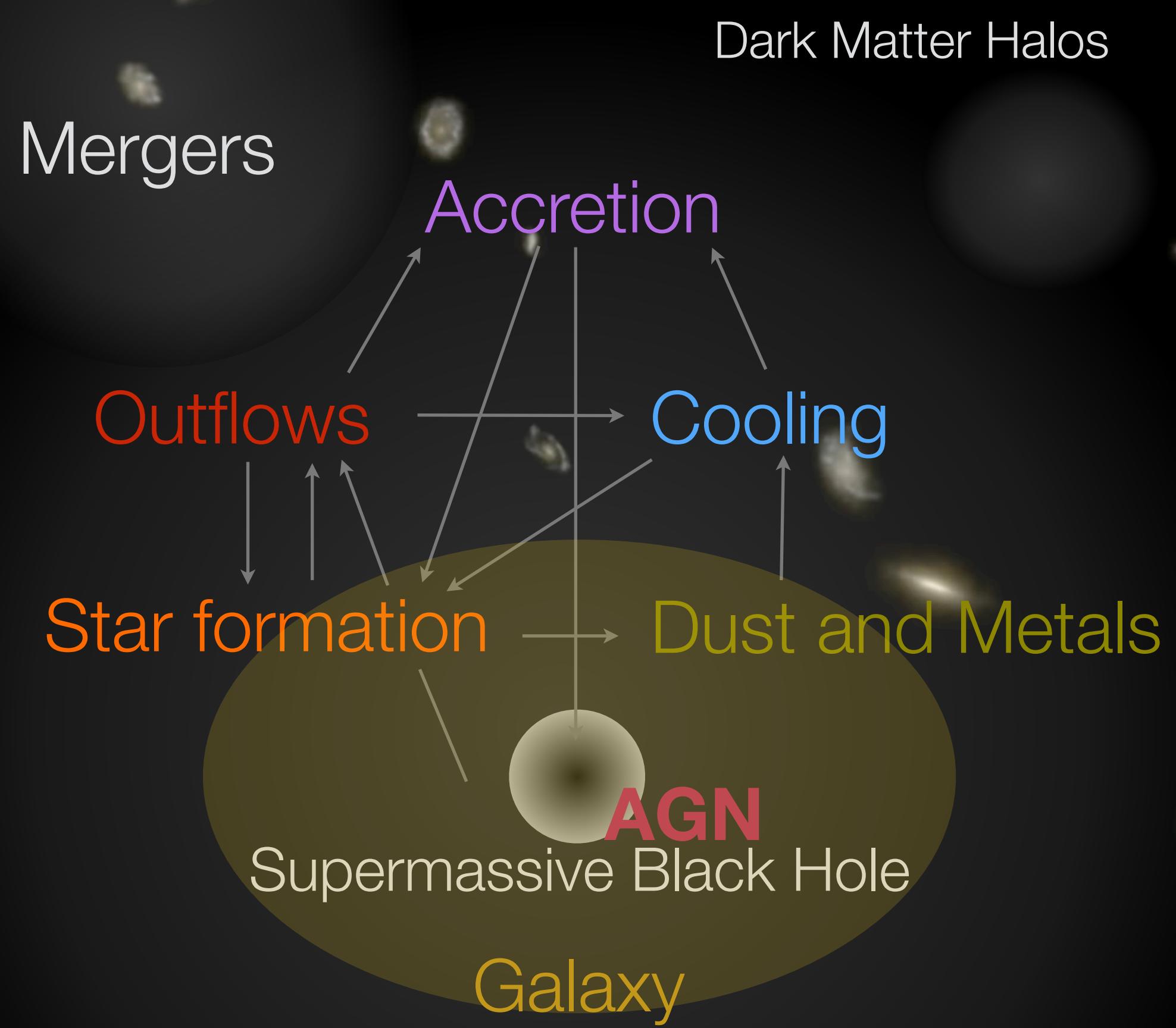


Time since the Big Bang: 3.8 billion years

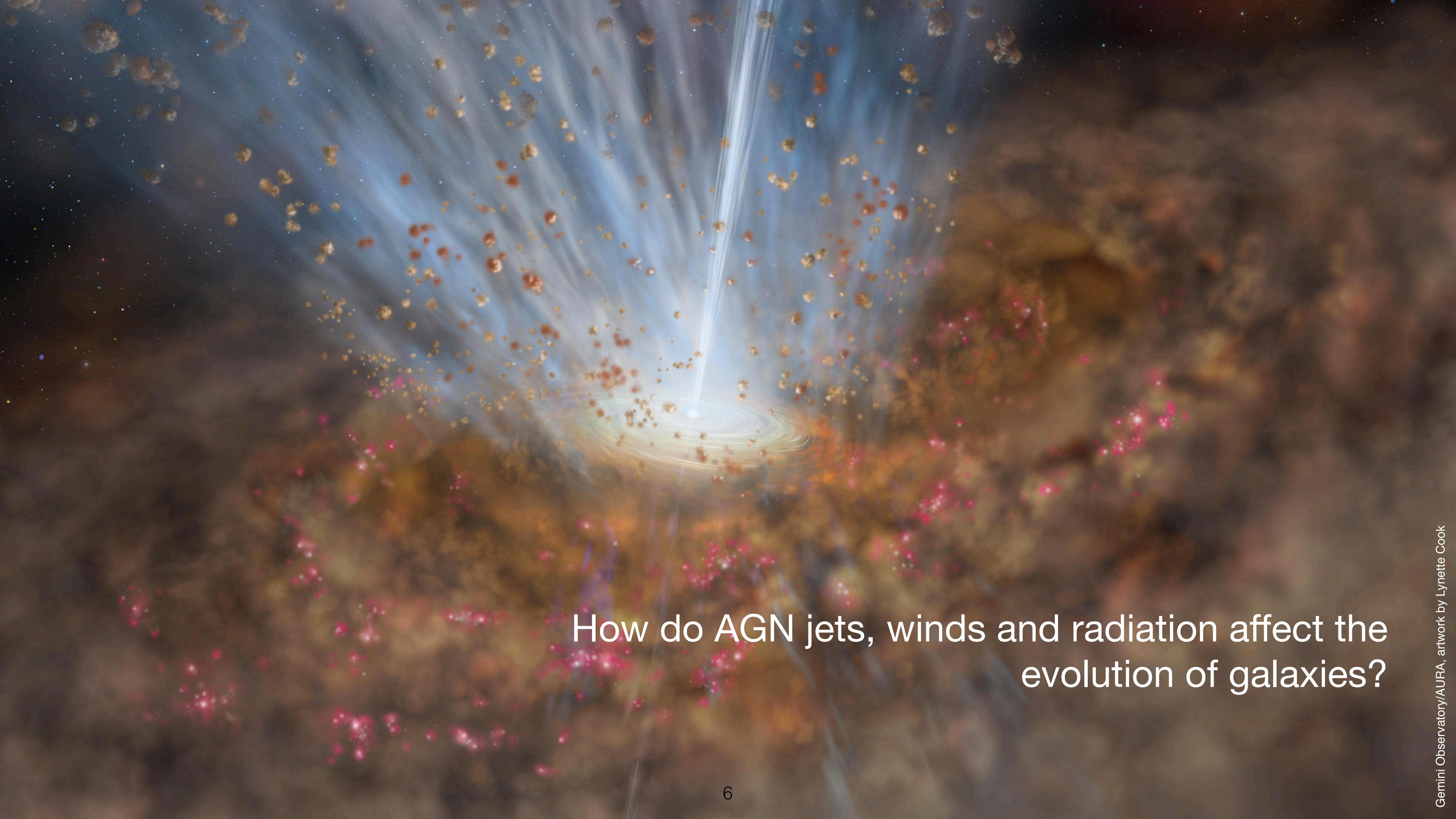
Illustris simulation

gas temperature

Processes in galaxy and BH formation

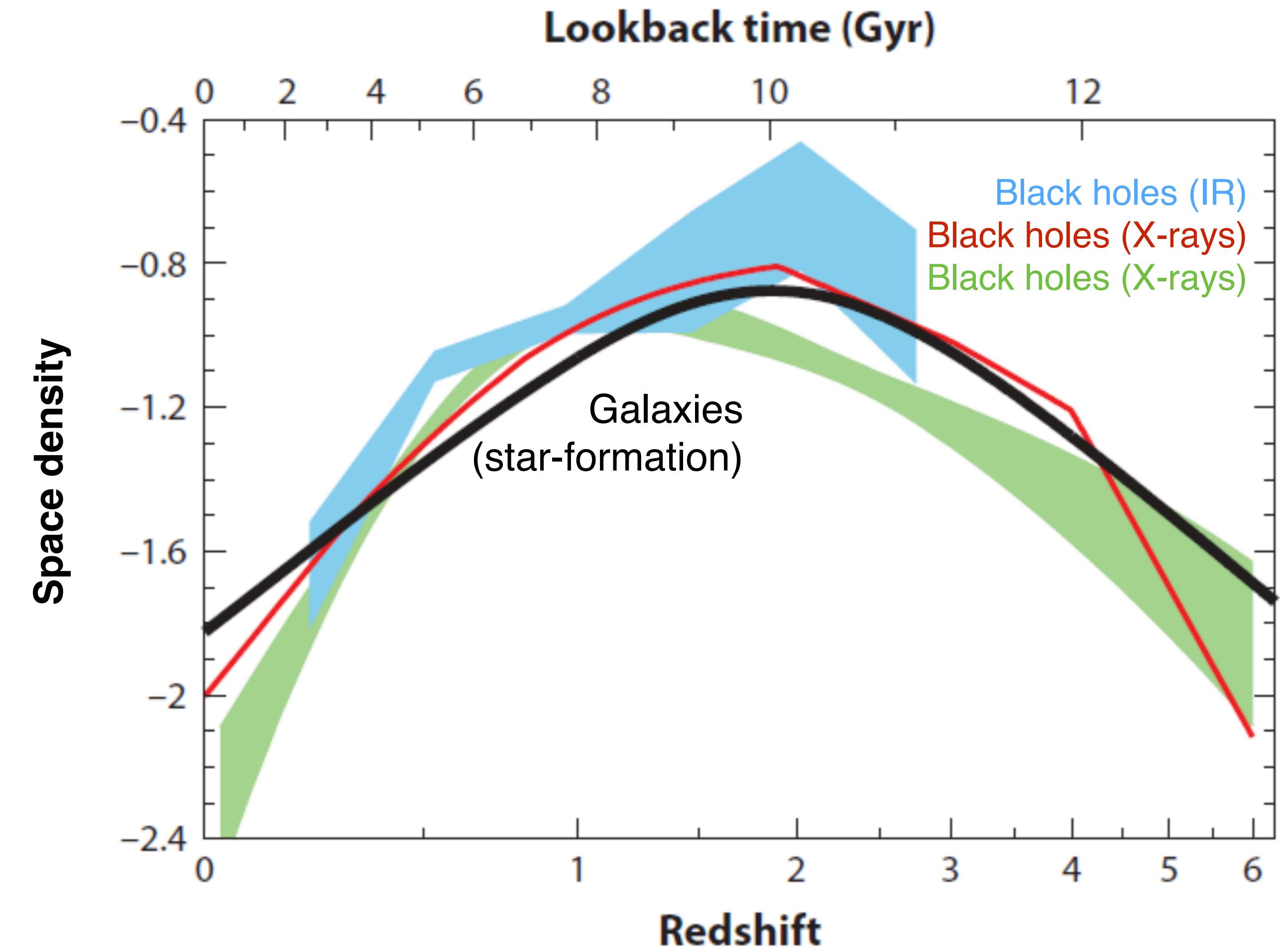
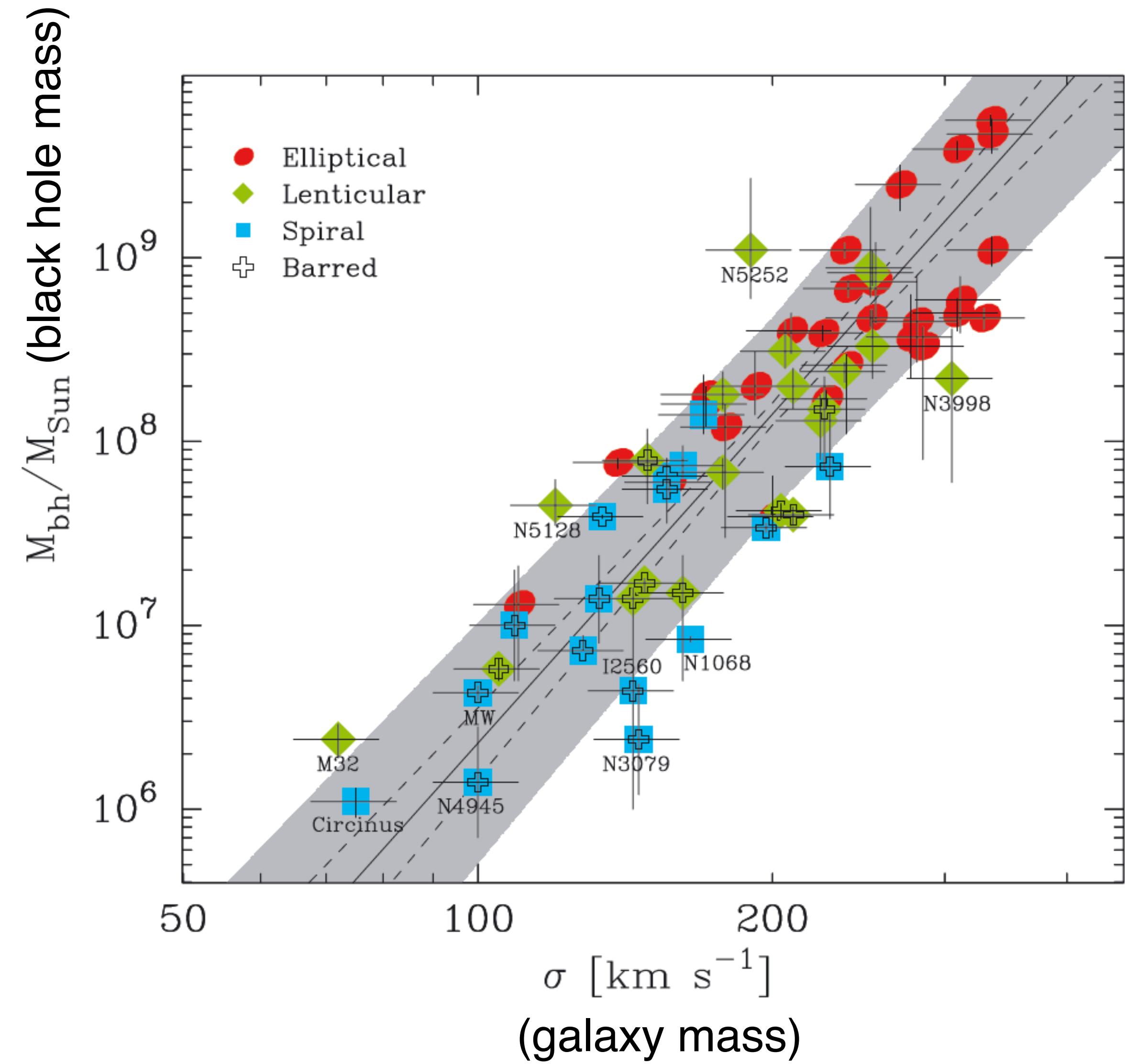


visible light

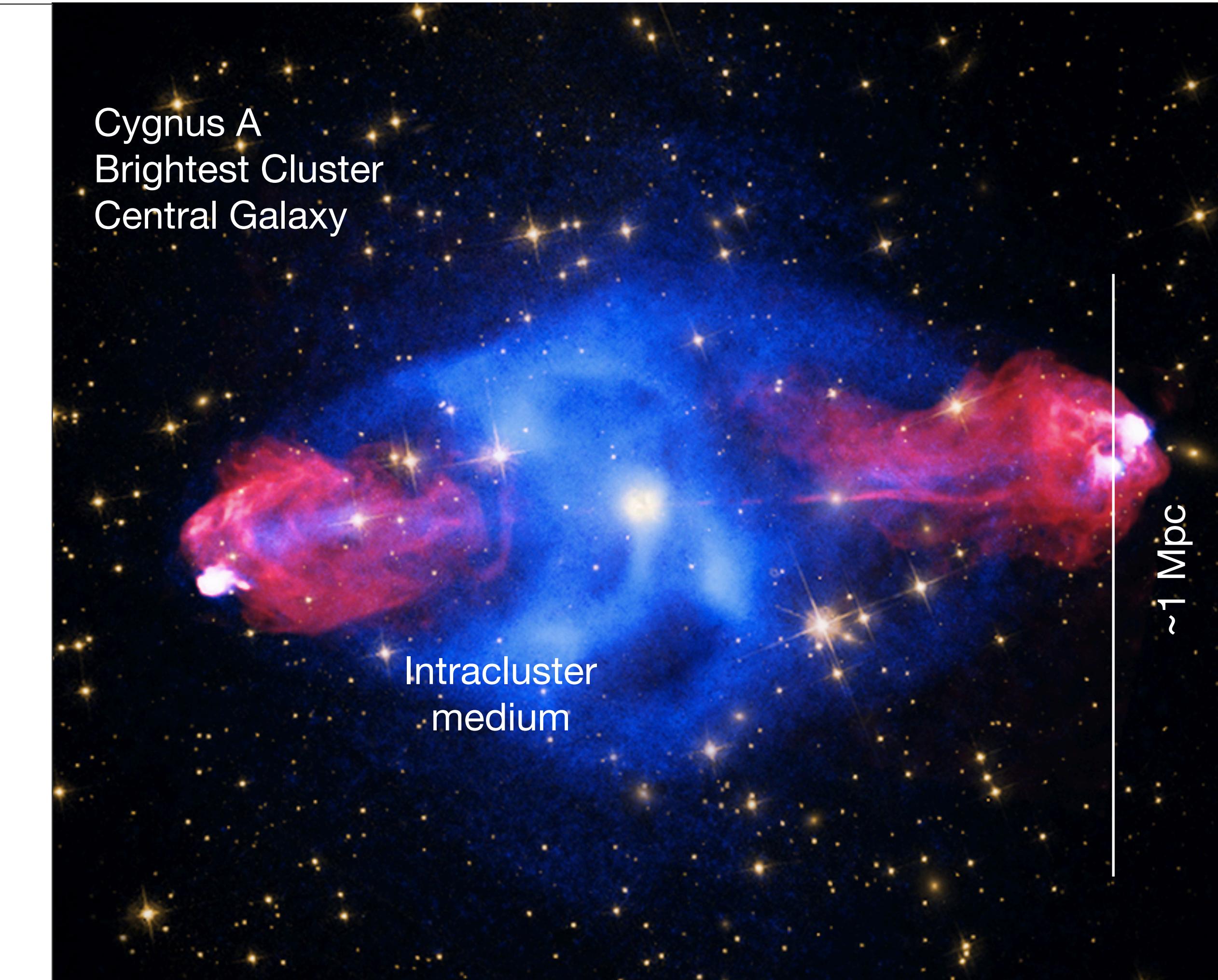
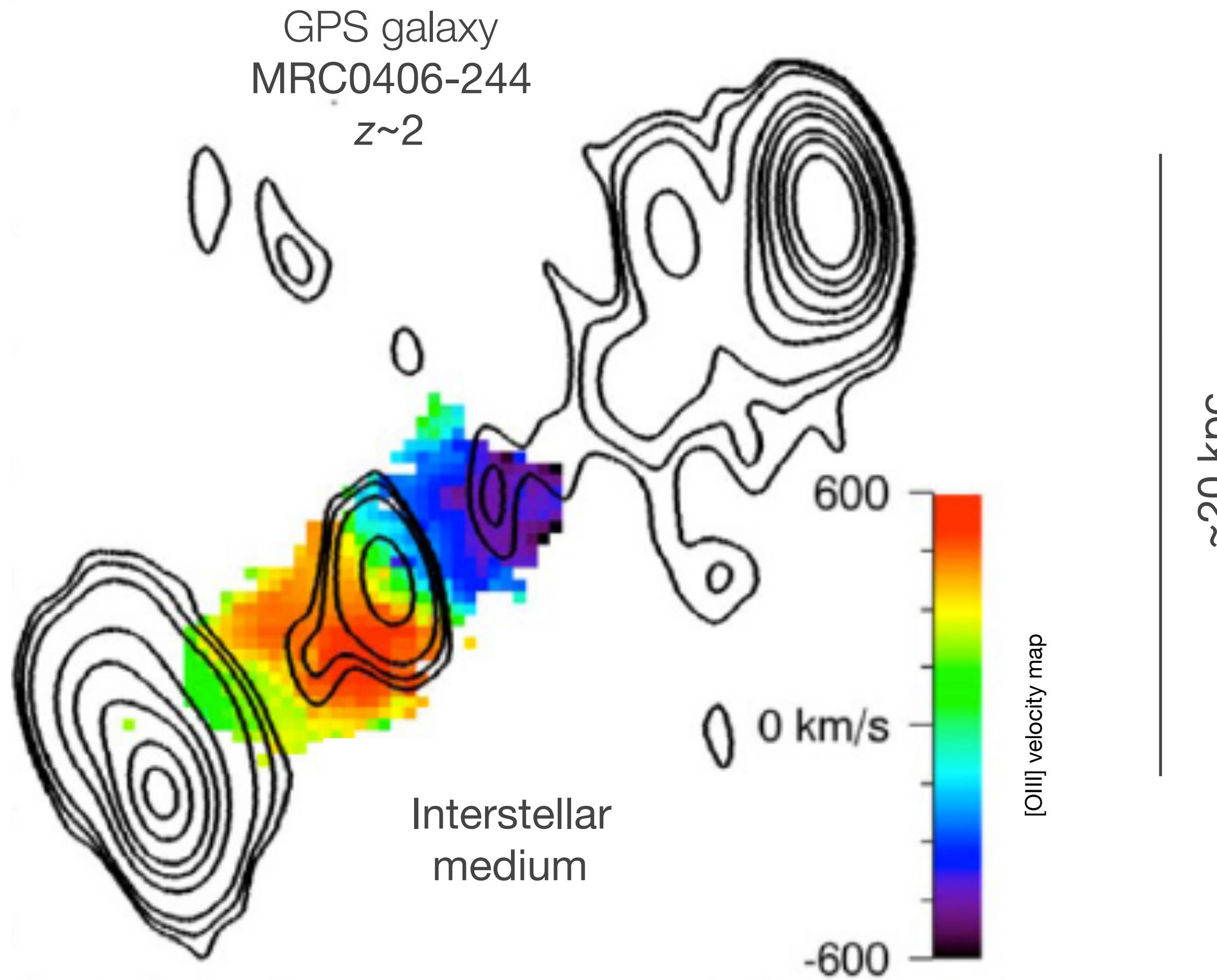


How do AGN jets, winds and radiation affect the evolution of galaxies?

Black-hole galaxy co-evolution



AGN jet feedback and galaxy formation



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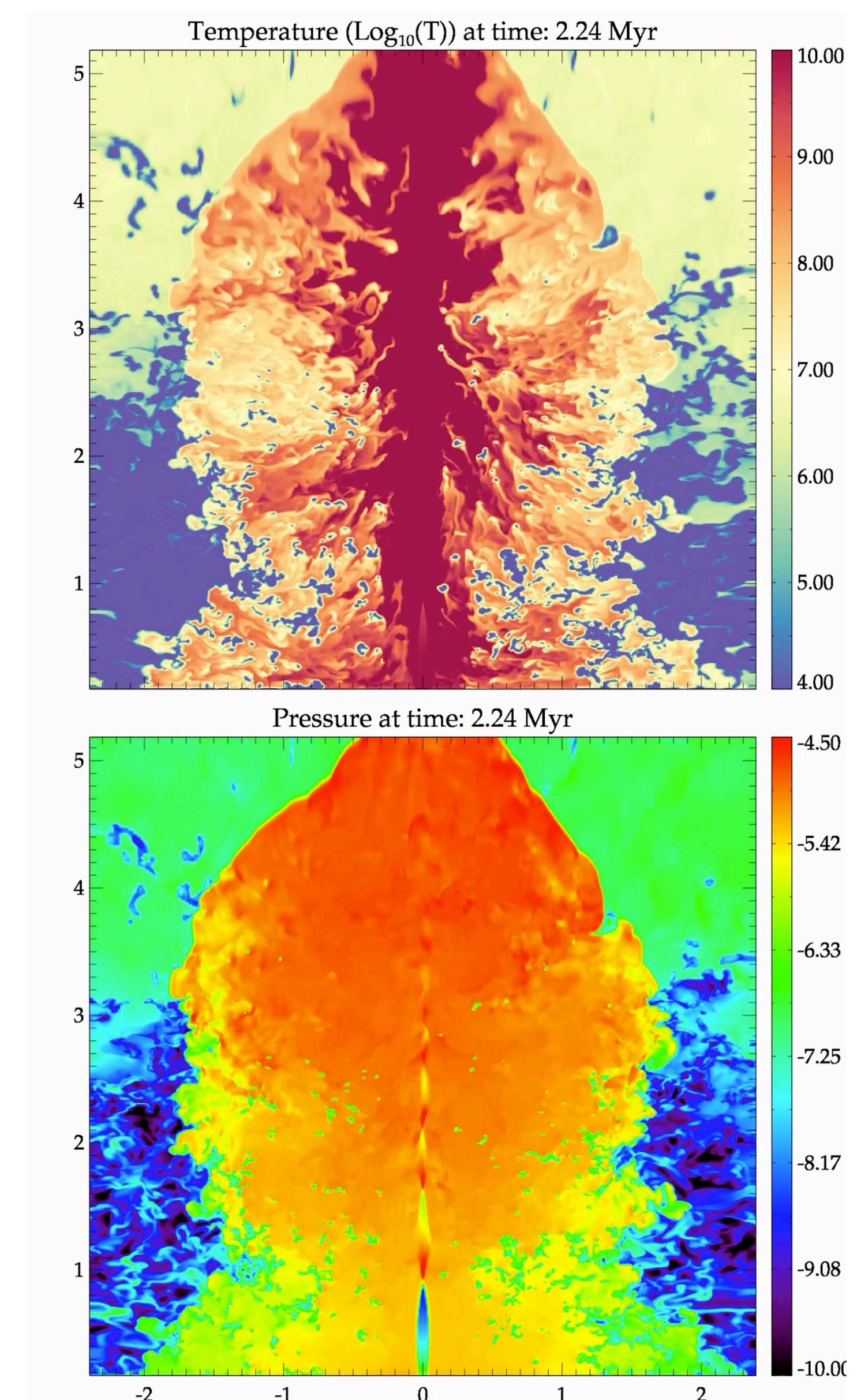
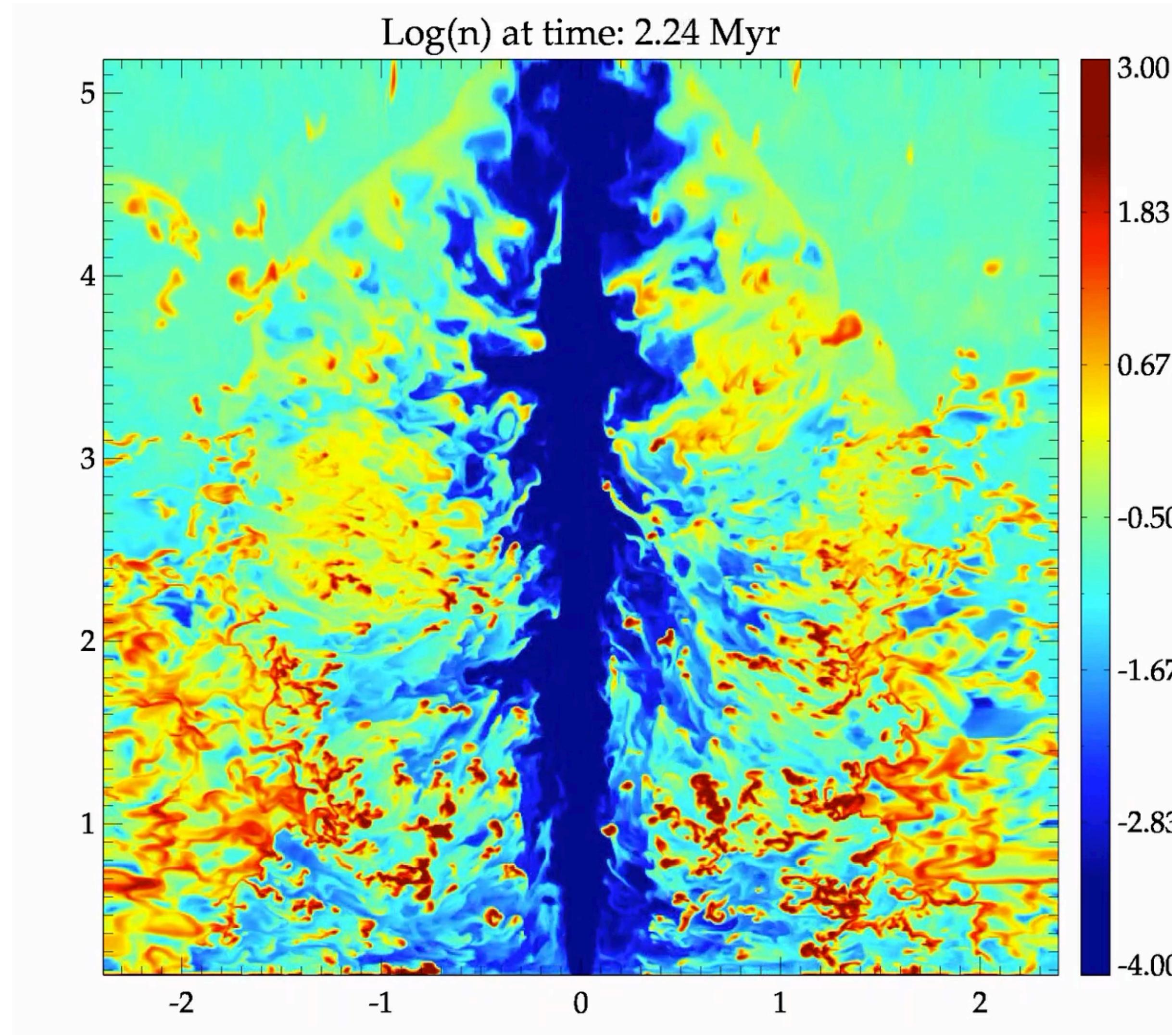
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AGN Jet Feedback in spherical, gas-rich forming galaxies

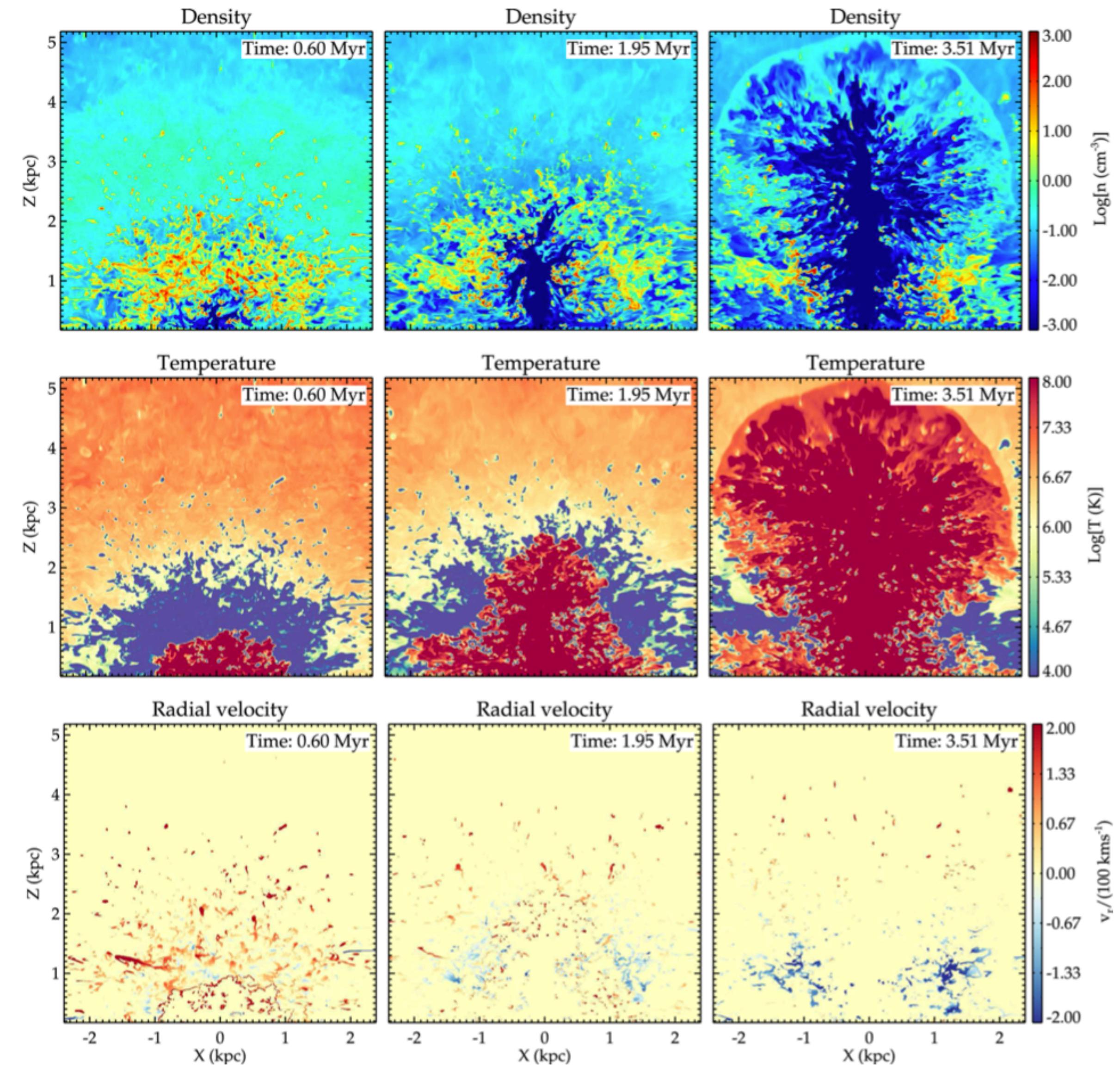
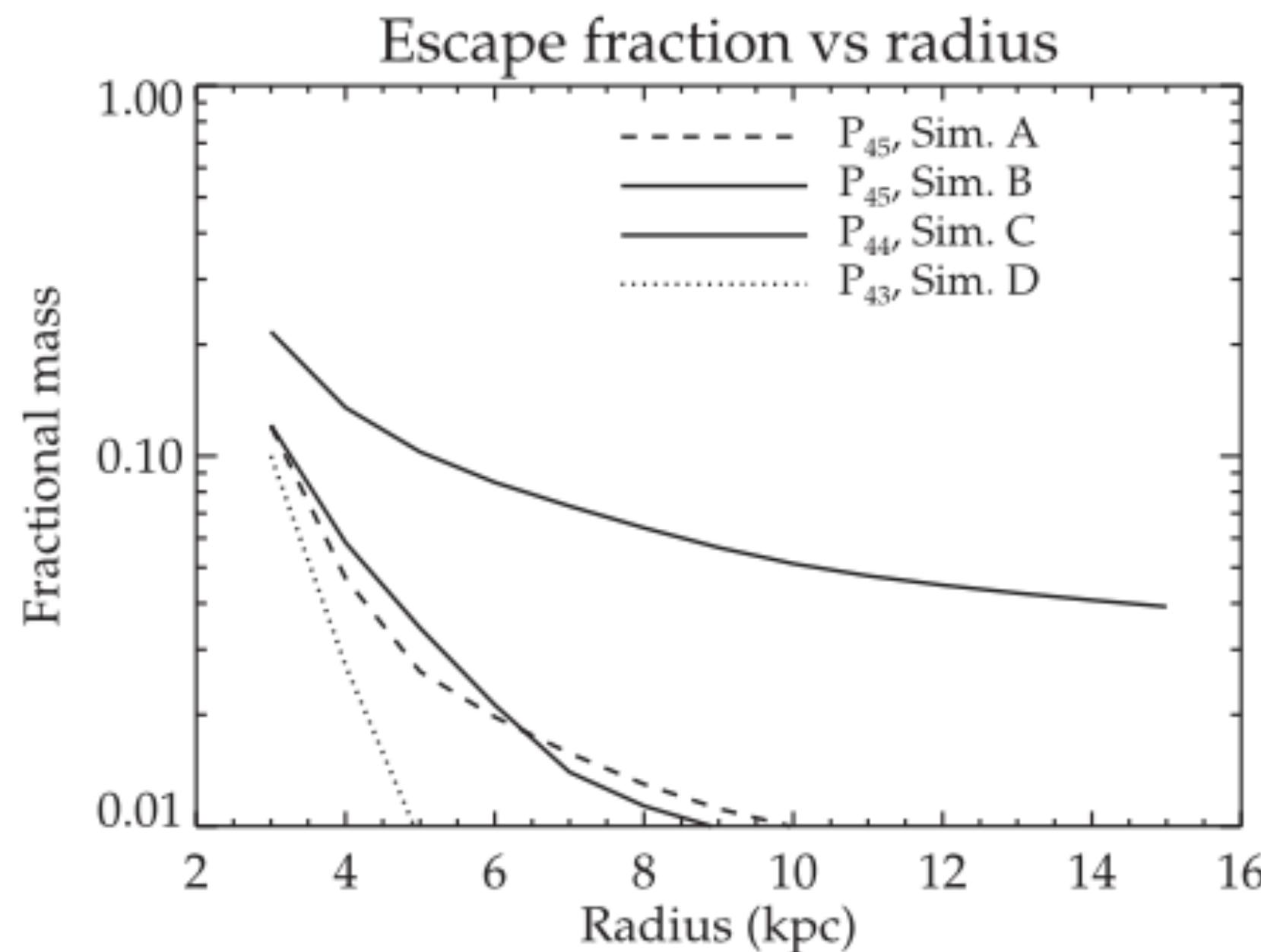
Mukherjee, Bicknell, AYW, MNRAS, 2016



AGN Jet Feedback in spherical, gas-rich forming galaxies

Mukherjee, Bicknell, AYW, MNRAS, 2016

- 20 simulations with **turbulent** interstellar gas, over a 5 kpc volume.
- Strong negative feedback for $P_{\text{jet}} > 10^{44} \text{ erg s}^{-1}$.
- Galactic fountains, stifled jets.
- **Mass ejection** is very inefficient.



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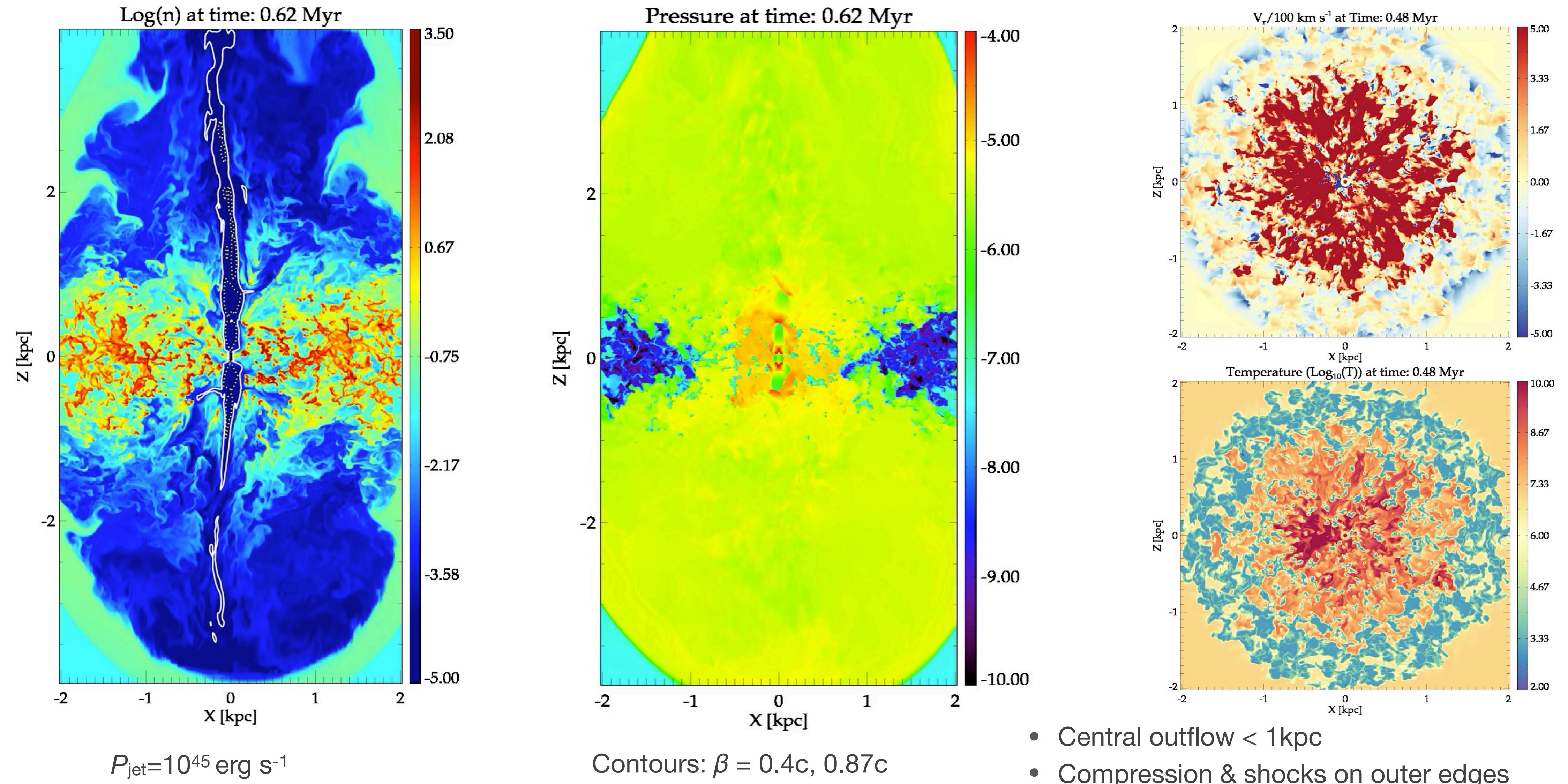
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Jet feedback in disk galaxies

(Mukherjee et al 2018)

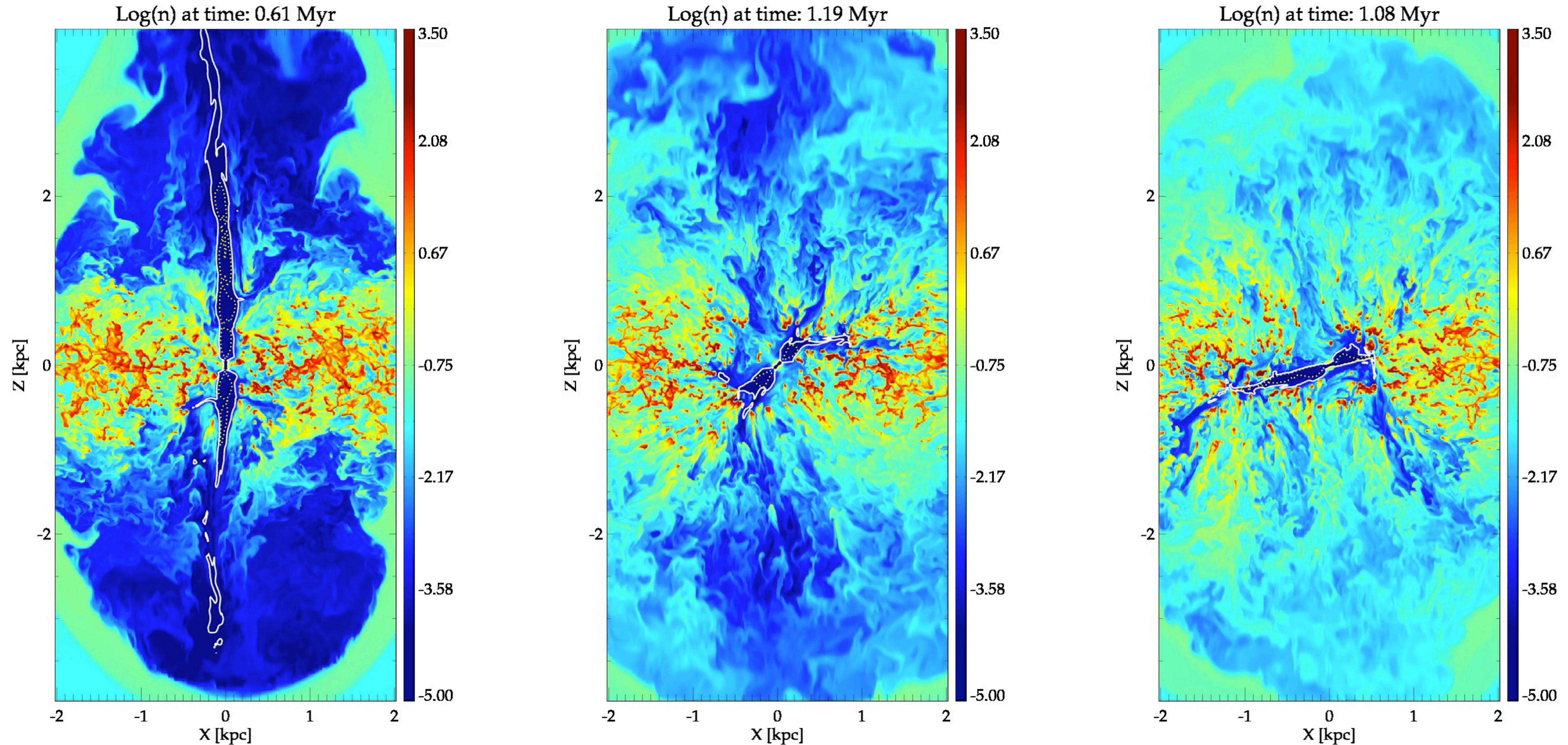
Relativistic-hydrodynamical simulations



Jet feedback in disk galaxies

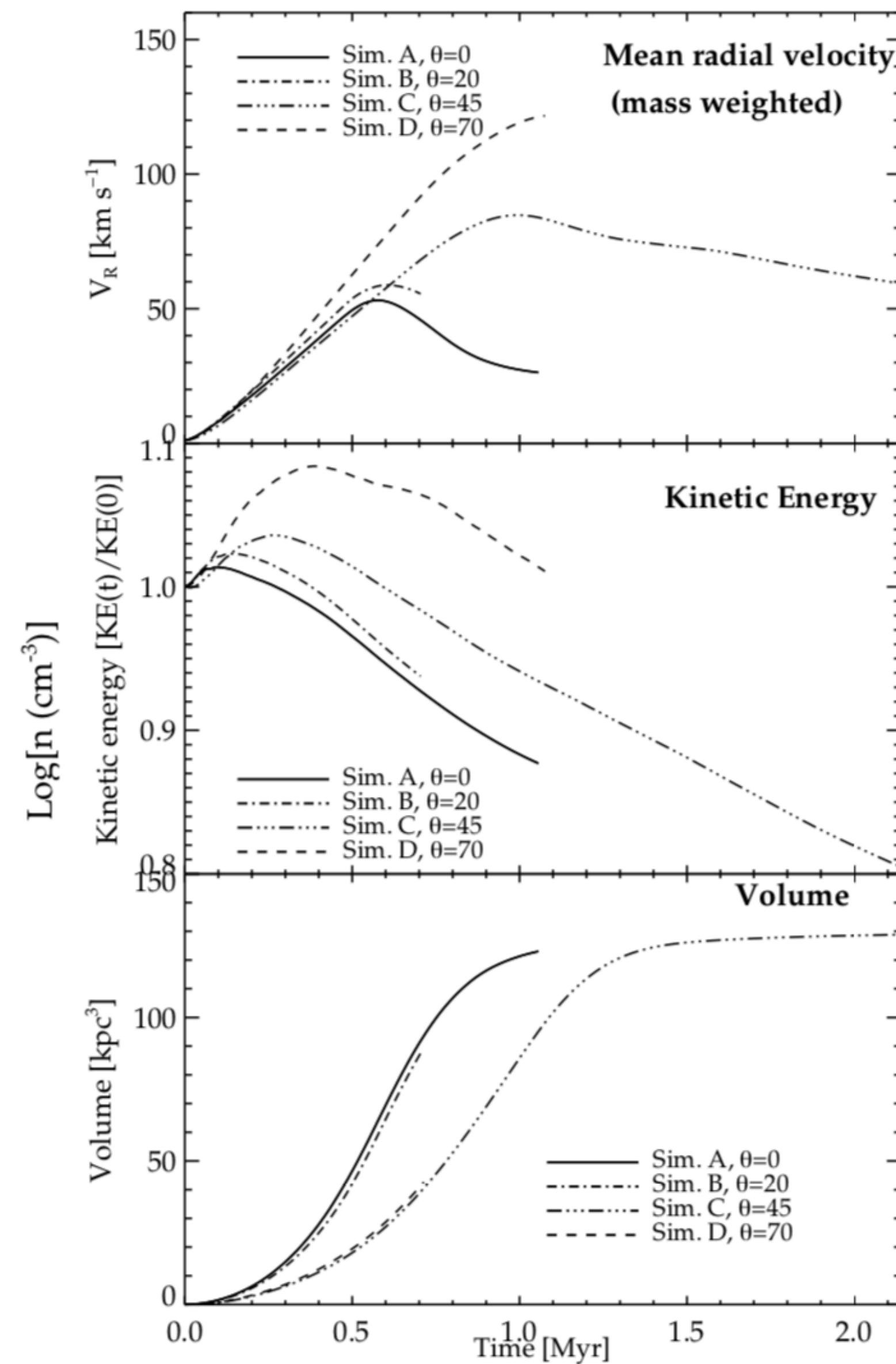
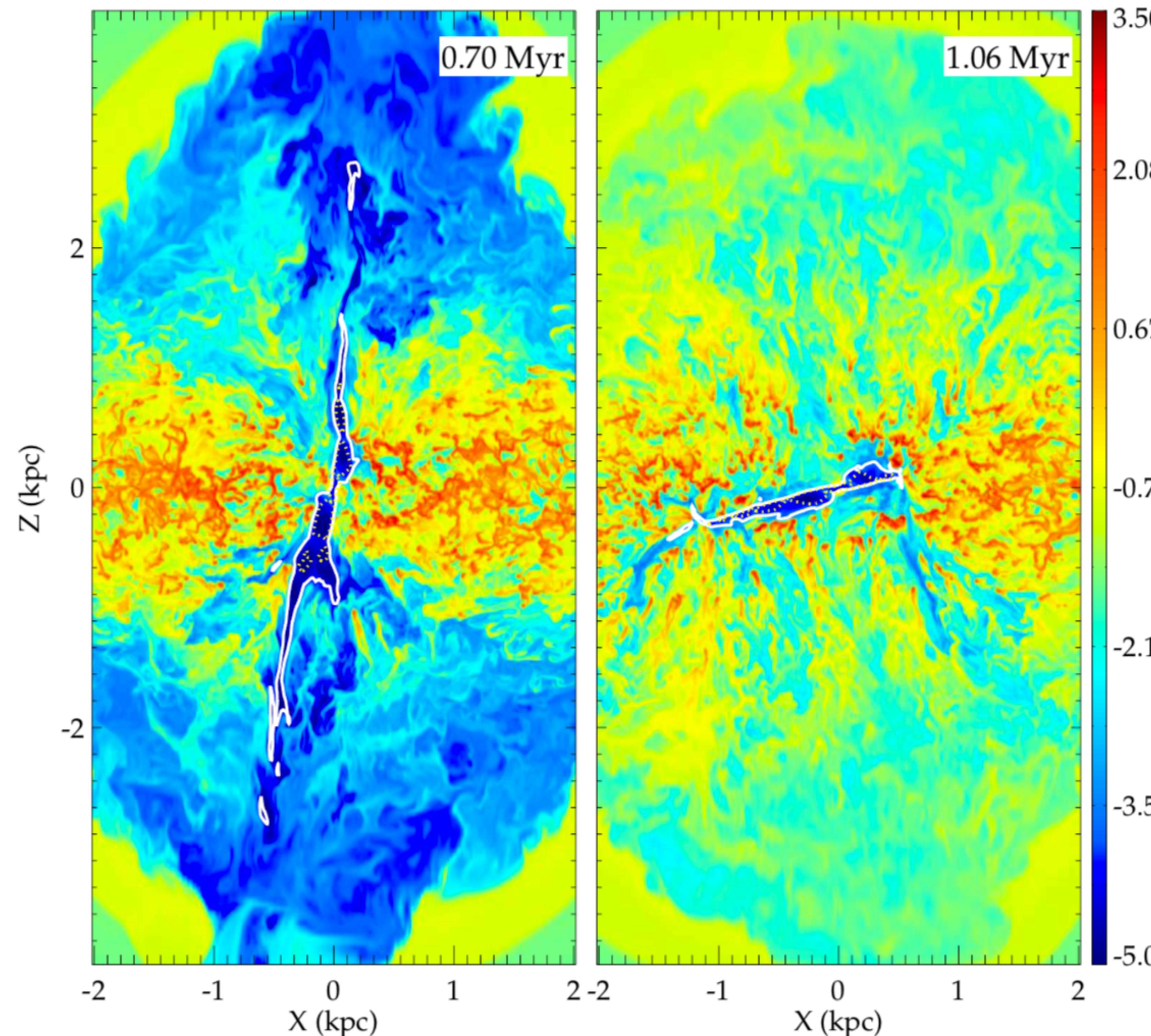
Dependence on inclination angle

Relativistic-hydrodynamical simulations



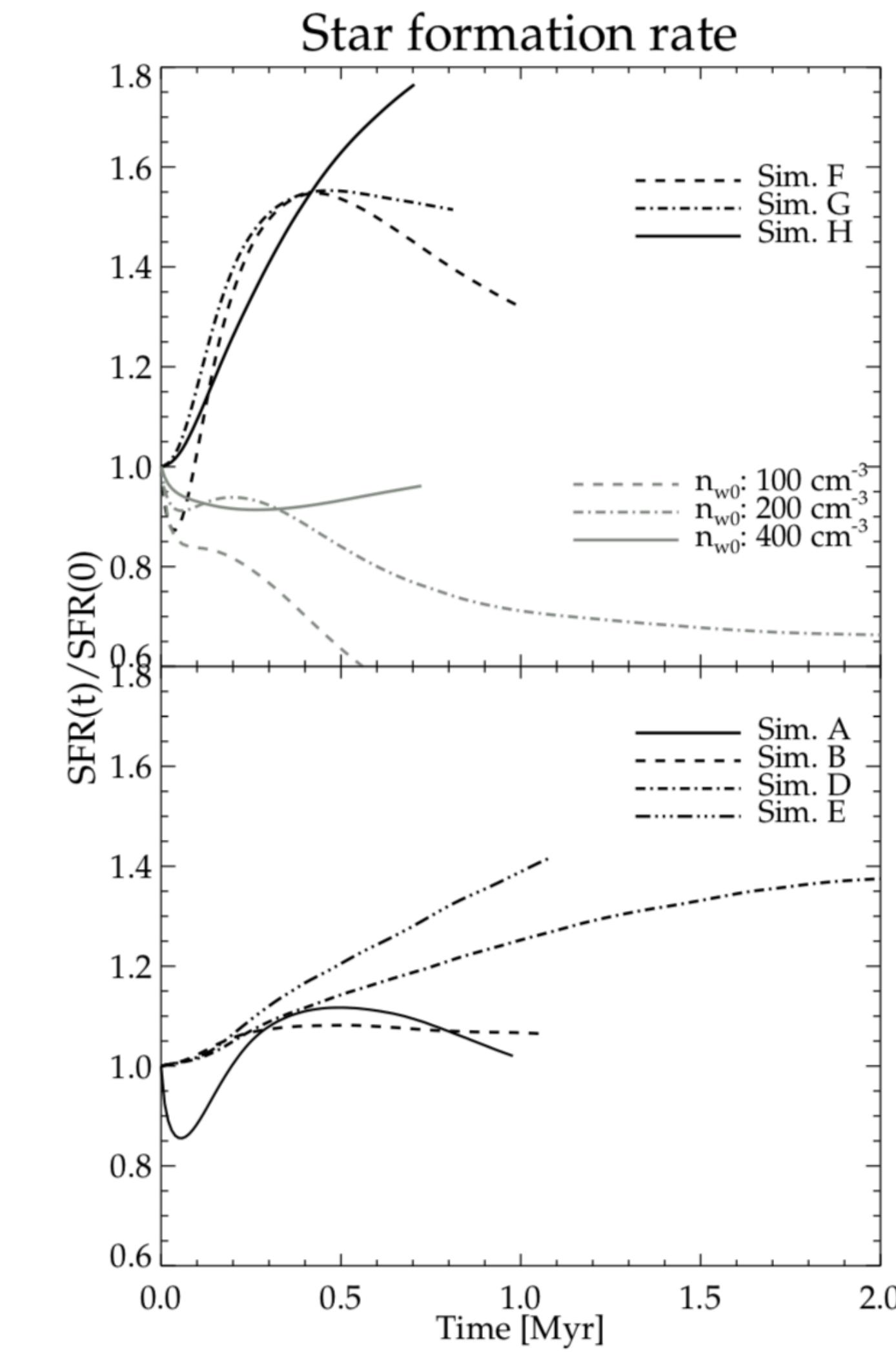
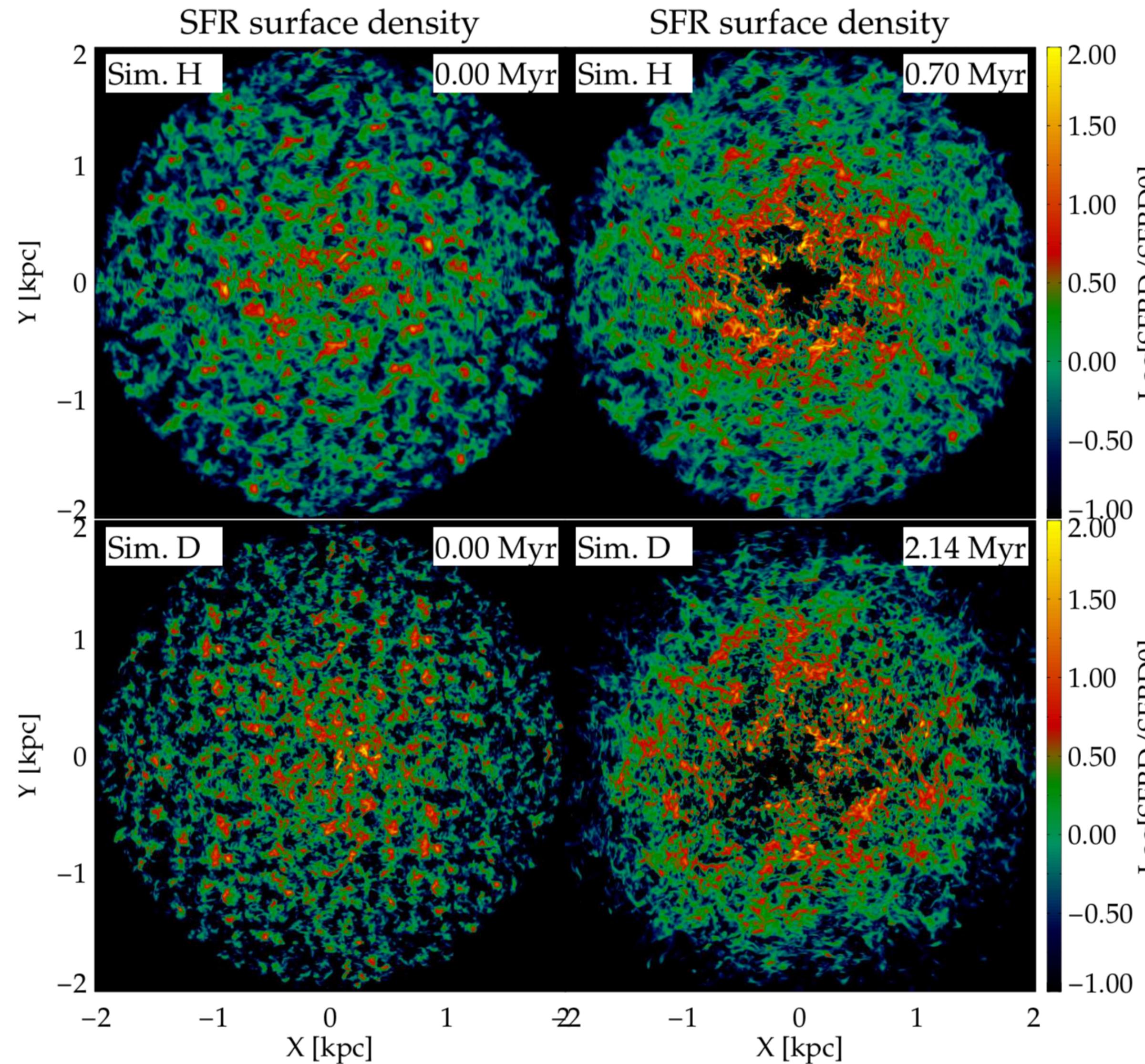
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Dependence on inclination angle



Jet feedback in disk galaxies

Jet-induced star-formation



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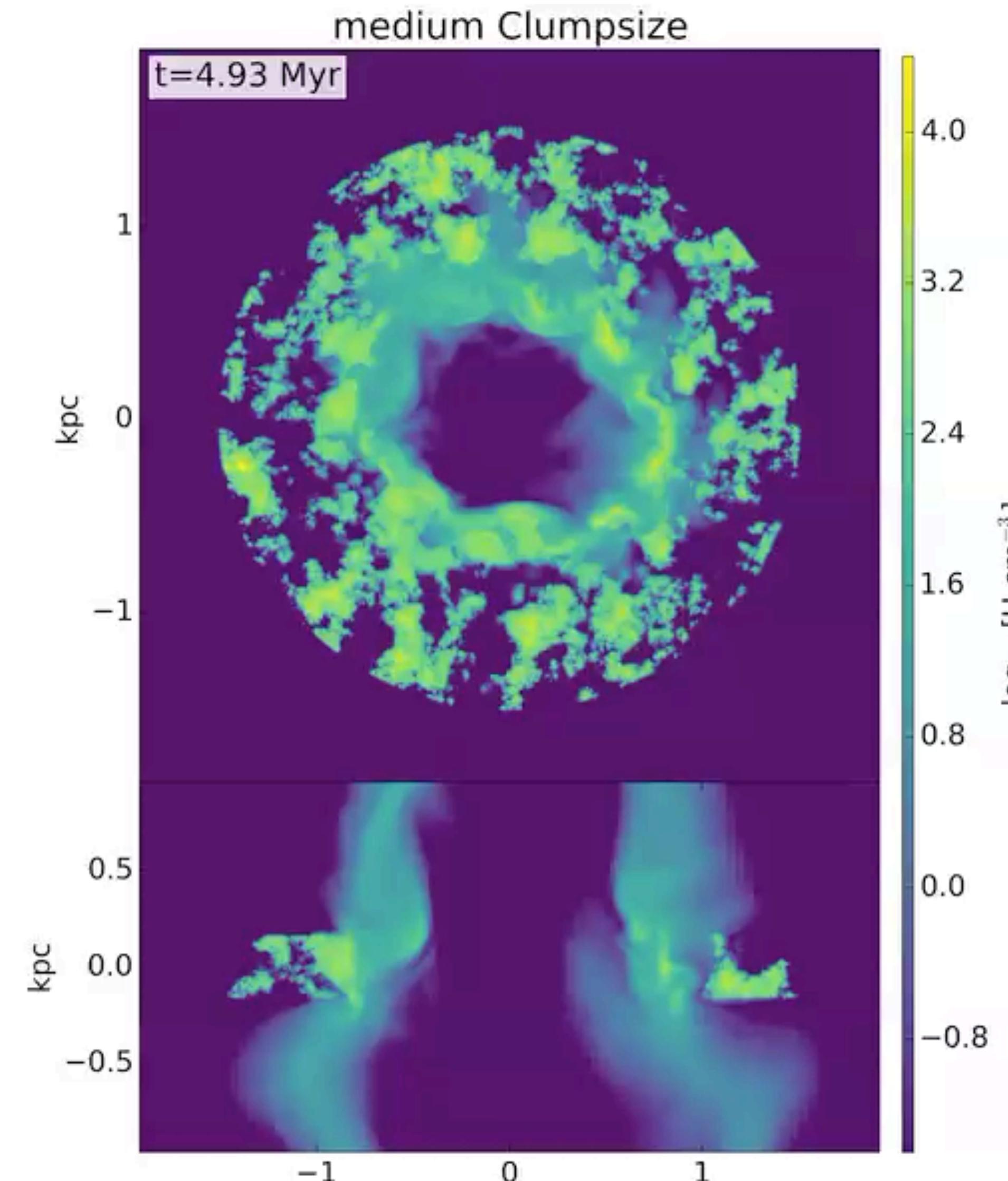
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Radiation-hydrodynamic simulations of AGN quasar Feedback

Bieri, Dubois, AYW, Silk et al, MNRAS, 2017

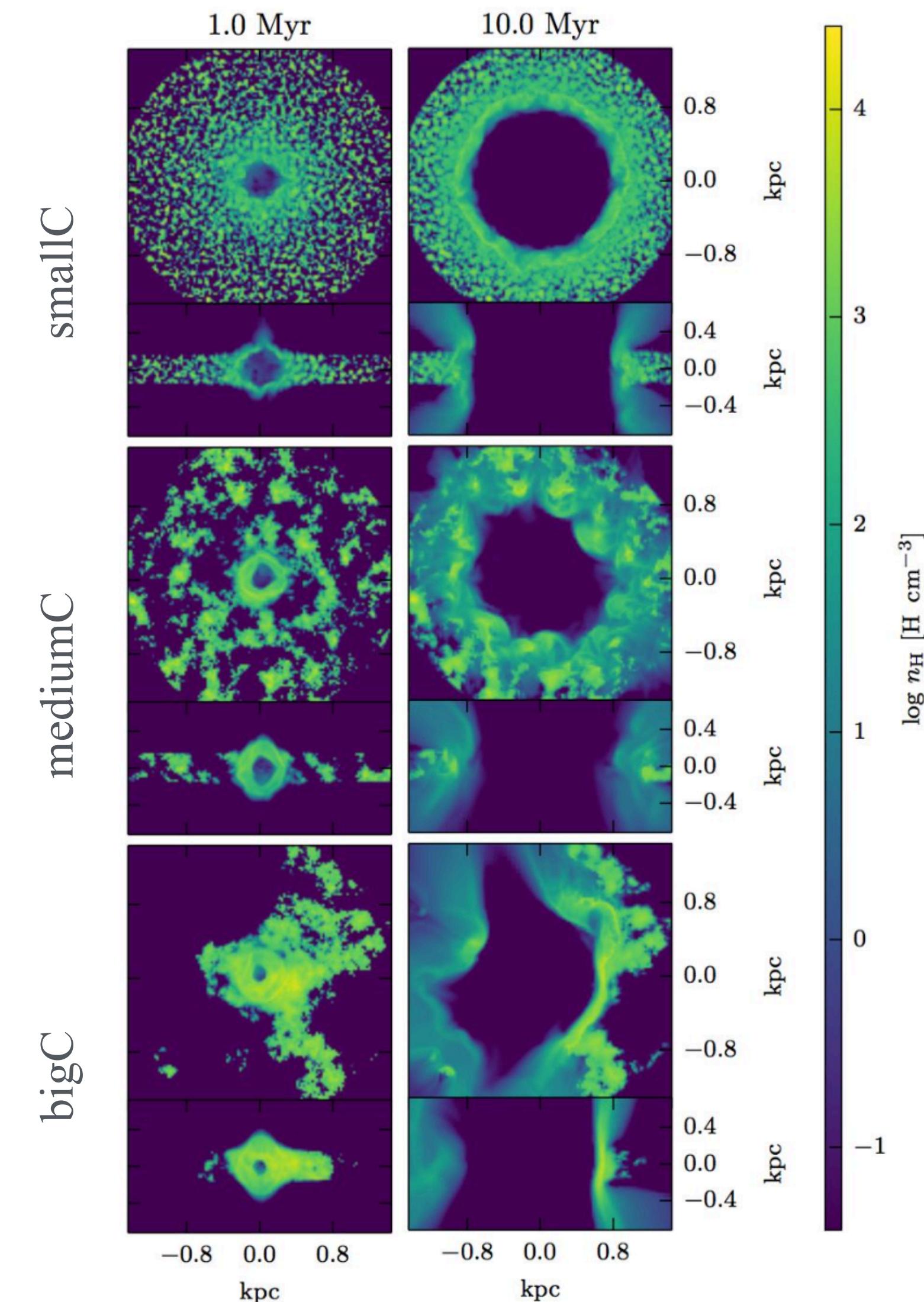
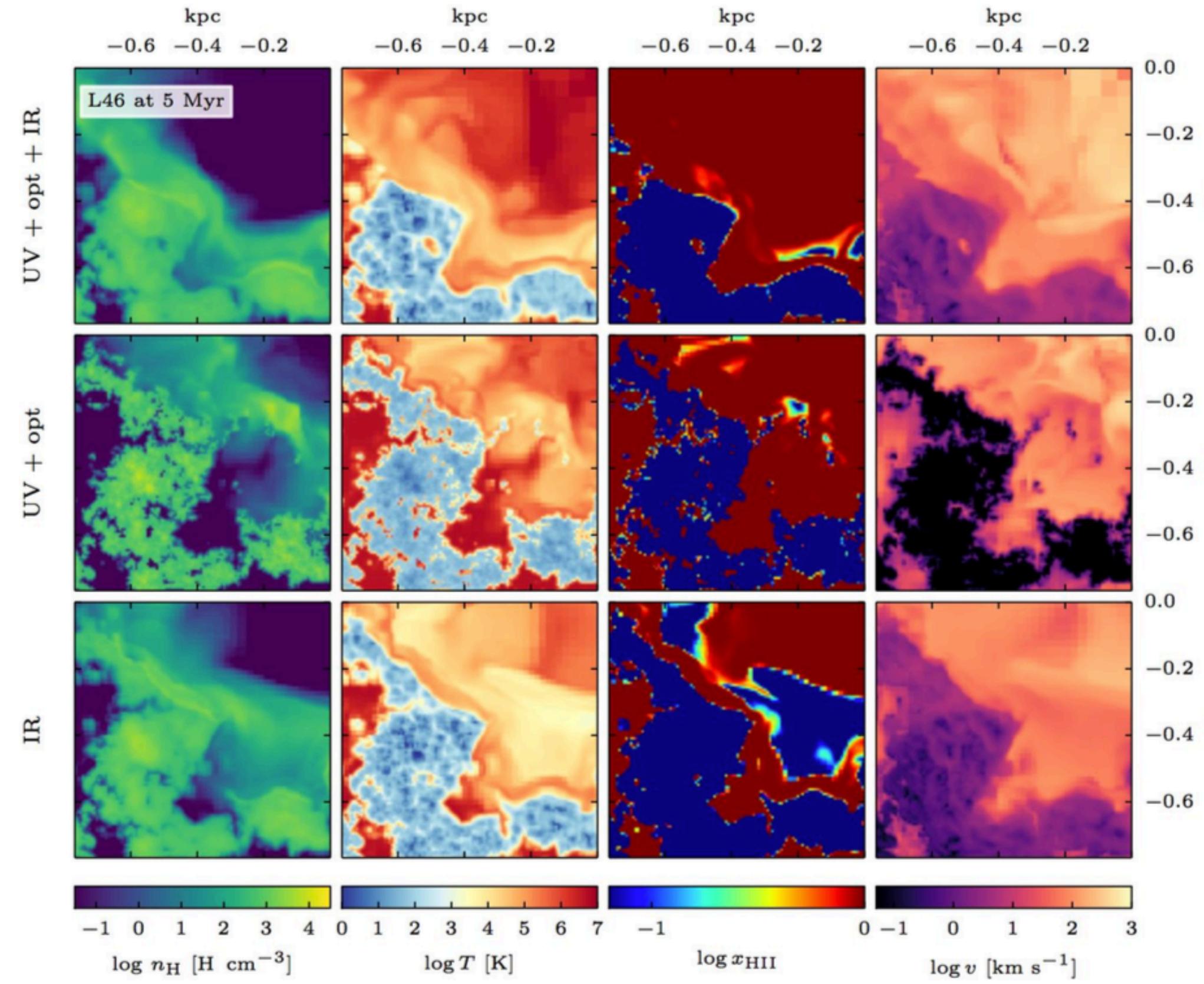


- *First radiation hydrodynamic simulations of AGN quasar feedback in a multiphase medium.*
- Radiative transfer was solved with the M1 scheme for **infrared to UV photons**.
- Sub-grid treatment for **infrared scattering** on dust. (Trapped / free-streaming photons.)

Radiation-hydrodynamic simulations of AGN quasar Feedback

Bieri, Dubois, AYW, Silk et al, MNRAS, 2017

- Identified roles of **ISM properties** and **photon groups**.
The **momentum boost** of the outflow
 $\rho_{\text{outflow}} / (L_{\text{AGN}} / c) \sim 20$



Summary

- AGN jets interact strongly with the interstellar medium because
 - ▶ jets are **light and easily deflected**
 - ▶ jets engulf clouds in **thermal (over)pressure** (100×) that cause *cloud compression and star-formation*
 - ▶ jets carry **ram pressure** that *disperses and accelerates clouds*
 - ▶ jets can be highly **inclined w.r.t. disc**. The more inclined they are the more “damage”.
- AGN jets induce a lot of **turbulence** in this disc.
 - ➡ Unexplored mode of negative and positive feedback
- AGN jets in discs can **induce star-formation**, in particular in the first few Myrs
- AGN radiation is efficient in **heating and dispersing** the interstellar medium through multiply-scattering **infrared photons**.