Galaxy-scale Feedback by AGN Jets and Winds

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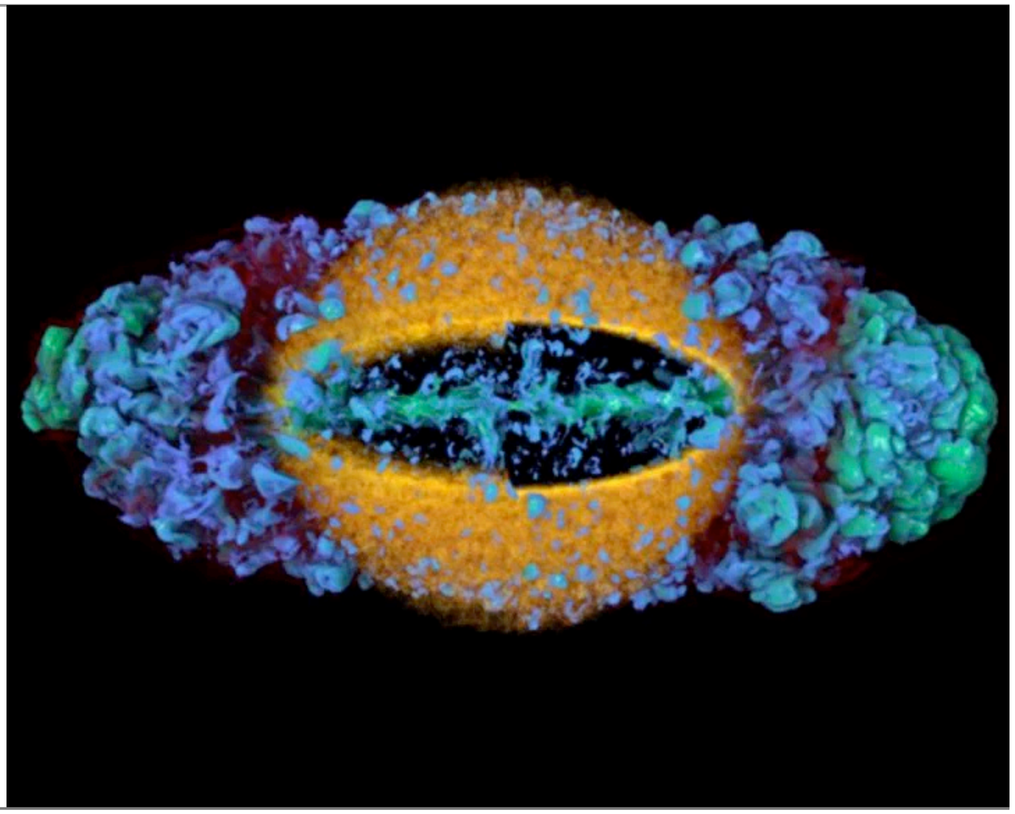
in collaborations with
Geoff Bicknell, Masayuki Umemura & Joseph Silk



AGN workshop *Nov. 20, 2013*

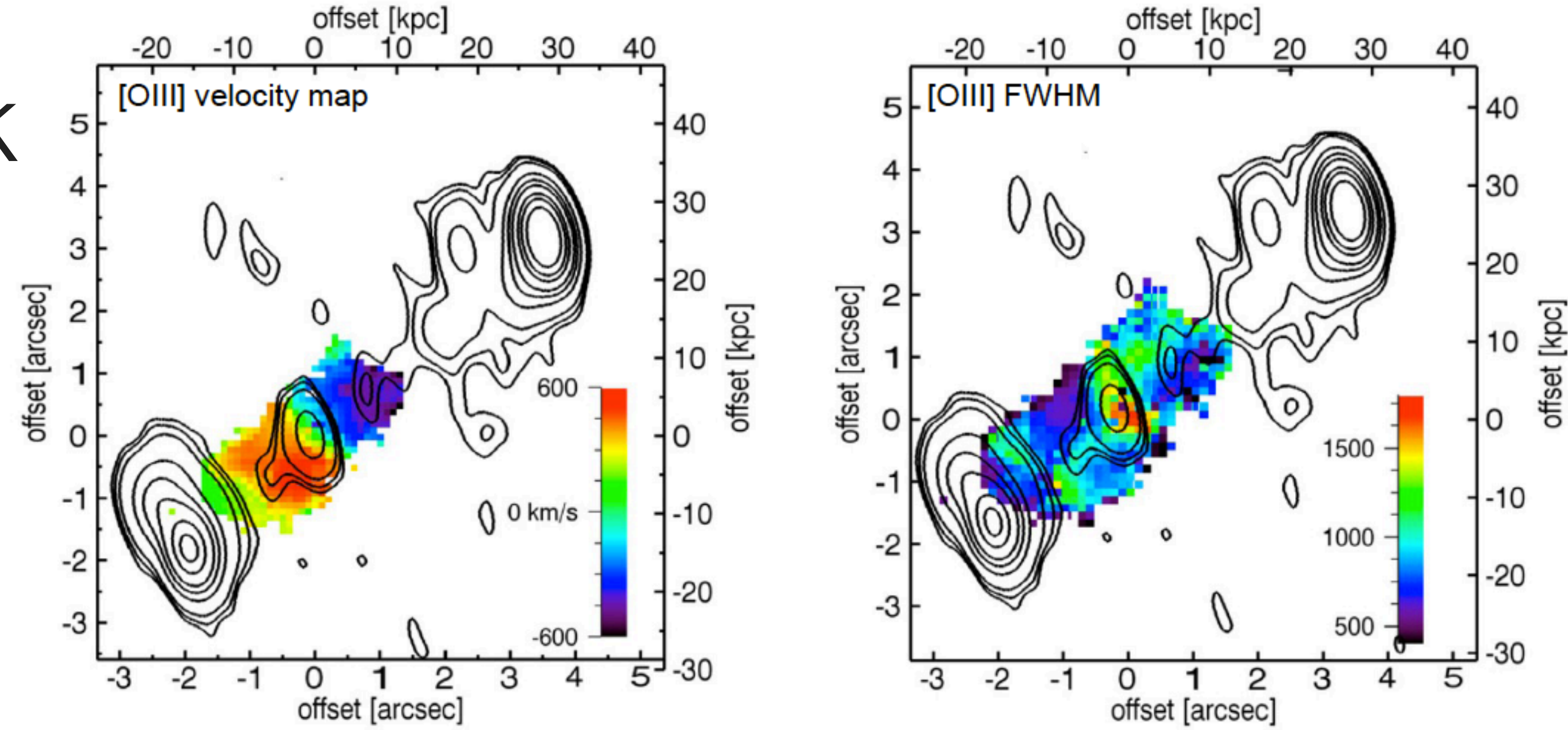
Movies shown in this talk can be found in this youtube playlist:
https://www.youtube.com/watch?v=28zI3ItGX08&list=PL70IGmZkmmyqFijTsoYxTWXgcya_ummZe

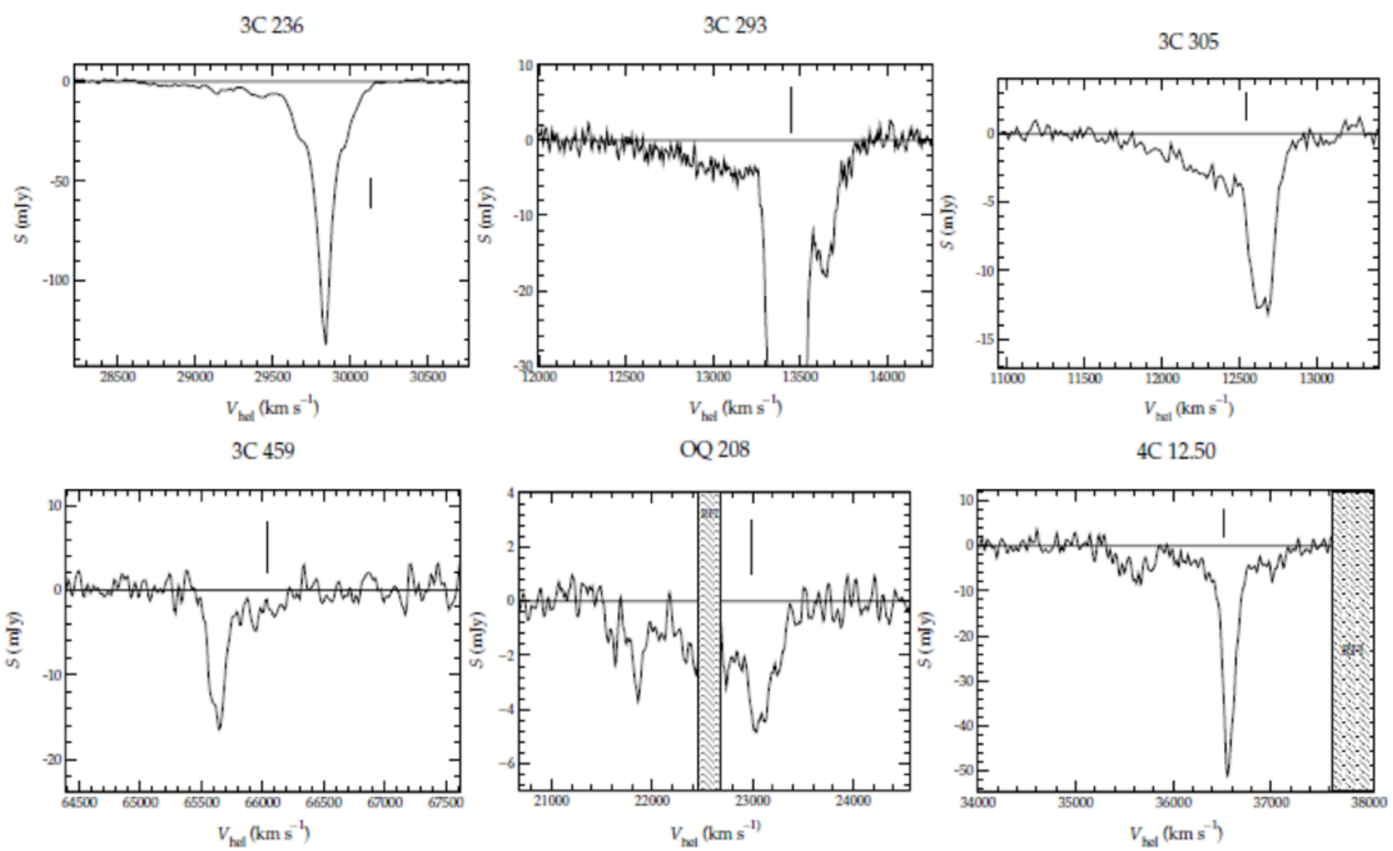
Radio-mode feedback

in action at high redshift

Ionised Gas v >1000 km s^{-1}

(Nesvadba et al 2006-2010)





Neutral gas (HI)

v ~ several 100 km s^{-1}

(Morganti et al 2005-2010, Mahony et al 2013)

~10% of Jet energy "goes into" outflow kinetic energy.

Outflows in radio galaxies

Negative feedback

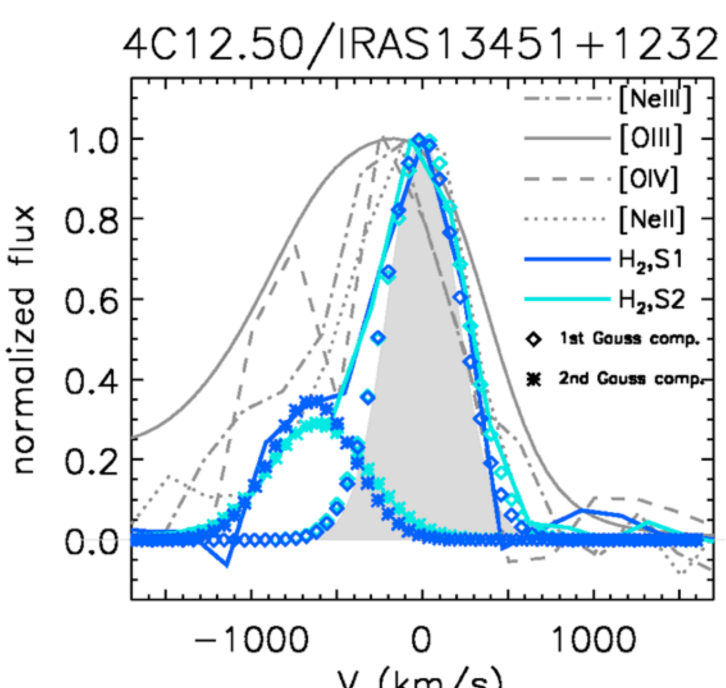
⇛ suppression of star-formation

⇛ Black hole - galaxy co-evolution

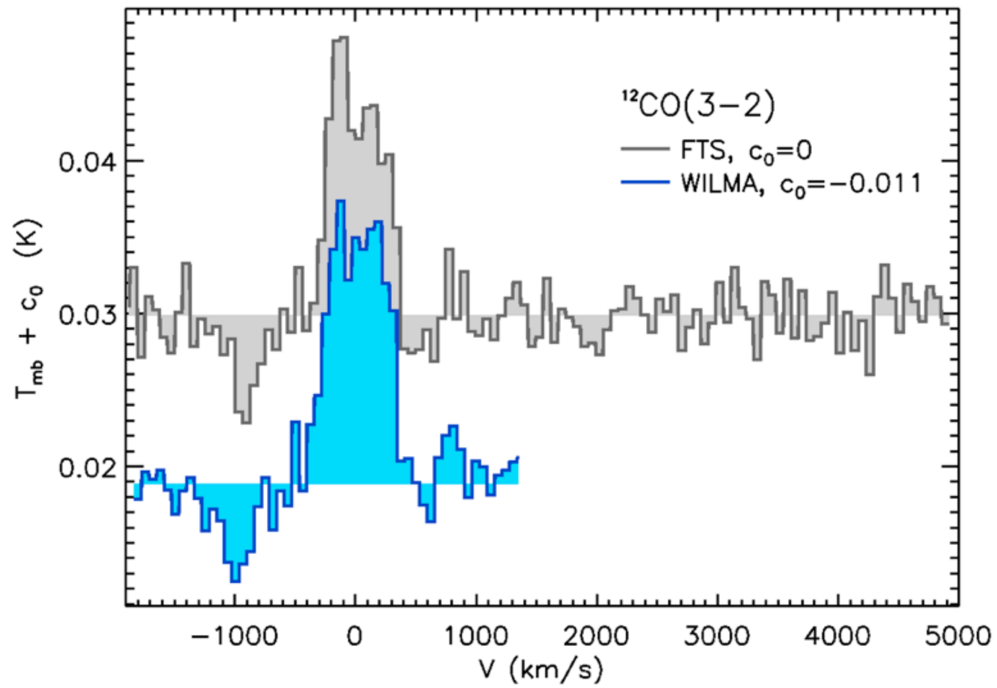
Multiphase outflows 4C 12.50 (z~0.122)

- Radio galaxy with the widest waveband coverage of the outflow:
  - Ionized gas (Holt et al 2003, 2008)
  - Neutral gas (HI absorption Morganti et al. 2004, NaI absorption Rupke et al 2005)
  - Cold and warm molecular phase. (~900 km s^{-1}!)

- Molecular phase dominates d*M*/d*t*. But within molecular phase warm phase dominates mass fraction. 1/4 of entire molecular gas reservoir is outflowing.
- We will probe the warmest (few 1000 K) molecular gas phase, probed via NIR ro-vibrational H_2 lines with NIFS observations (Gemini South, accepted).
- Can we model the outflows with hydrodynamic simulations and predict the outflow composition and whether it is a wind or jet that drives the outflows?



Dasyra & Combes (2011)



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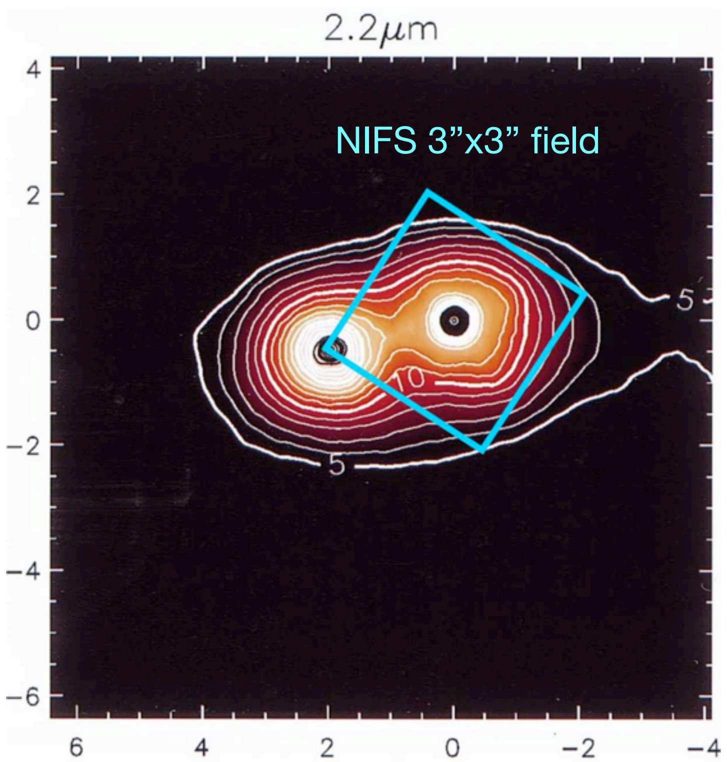
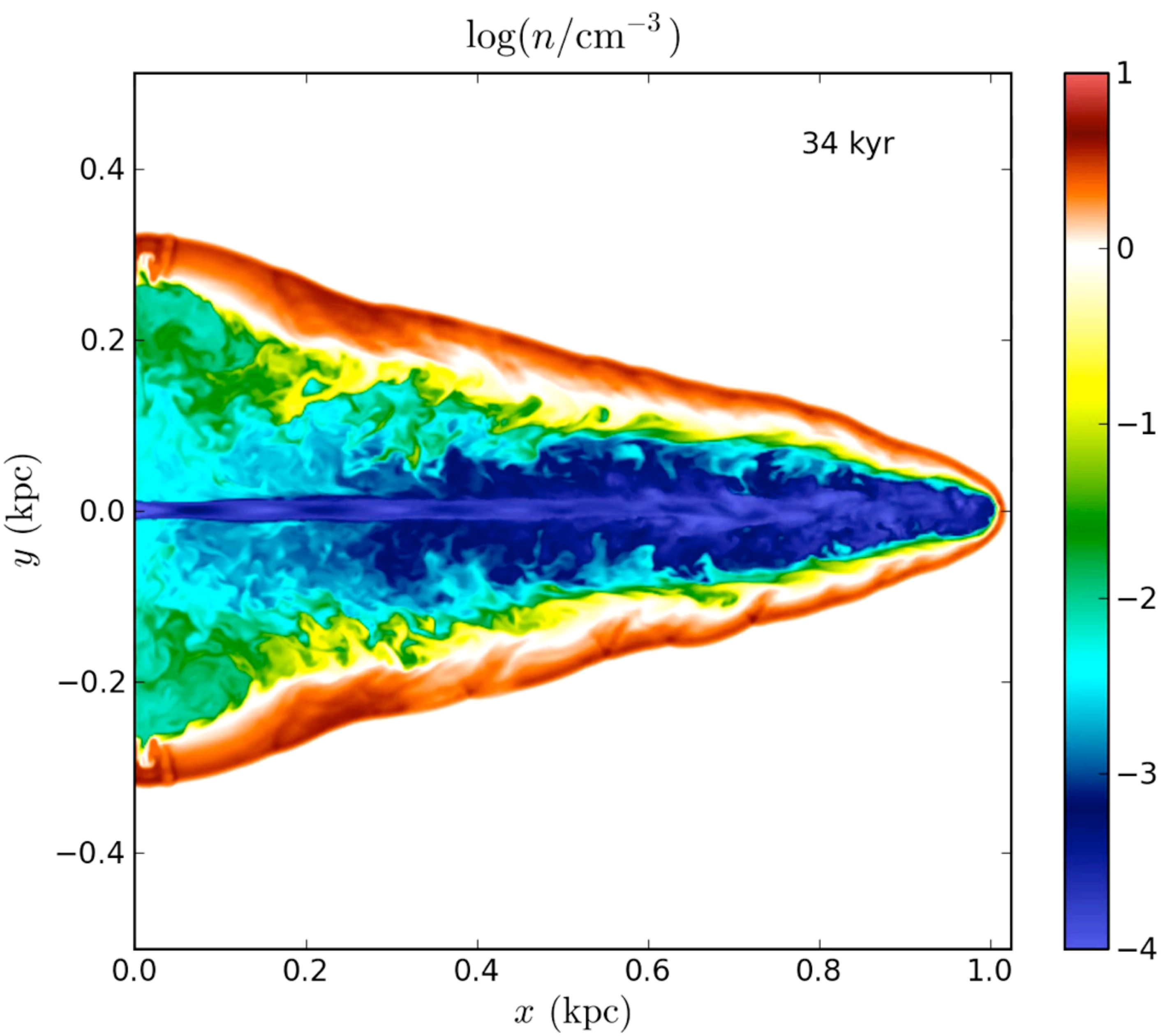
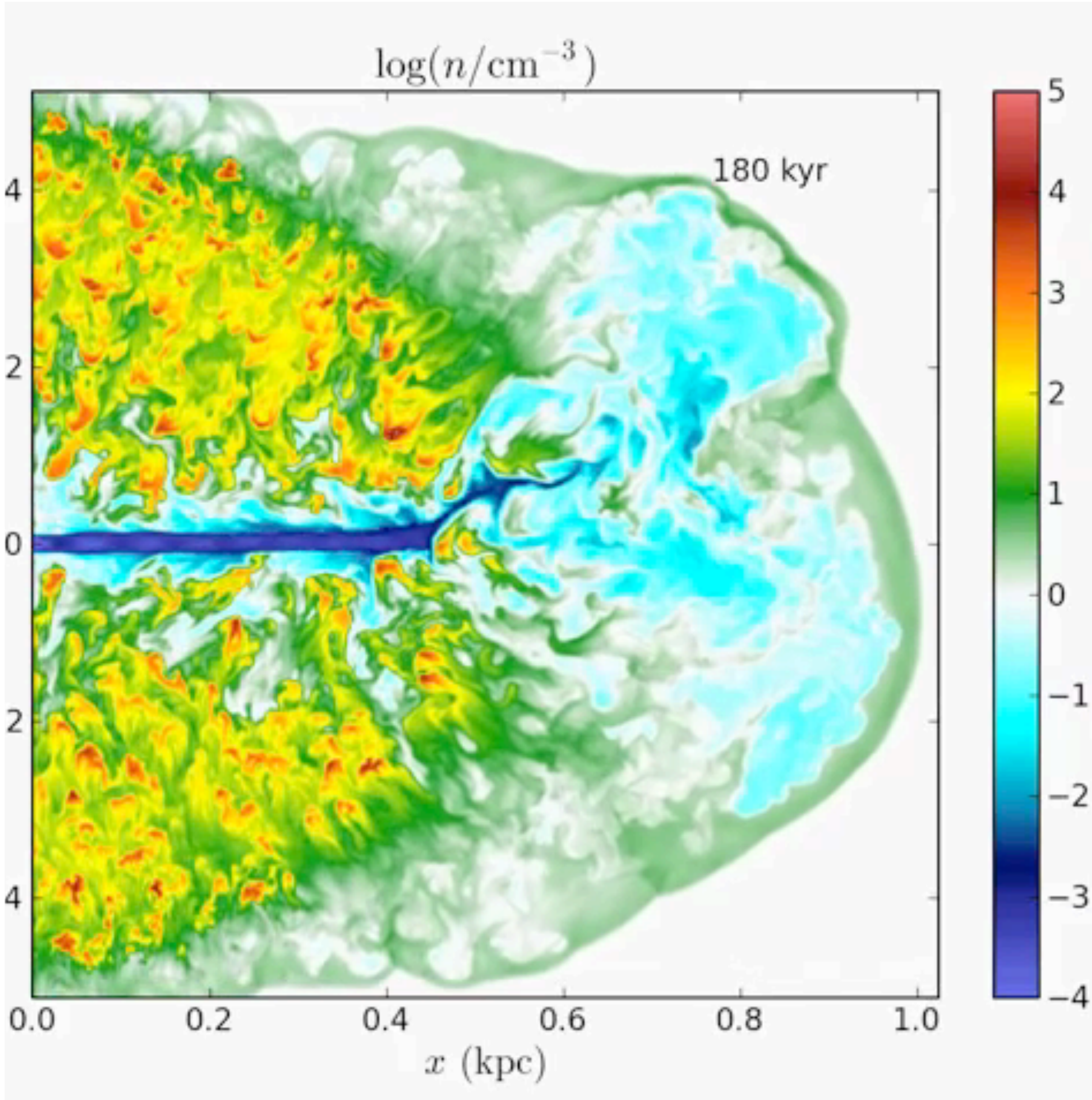


Scoville (2000, NICMOS)



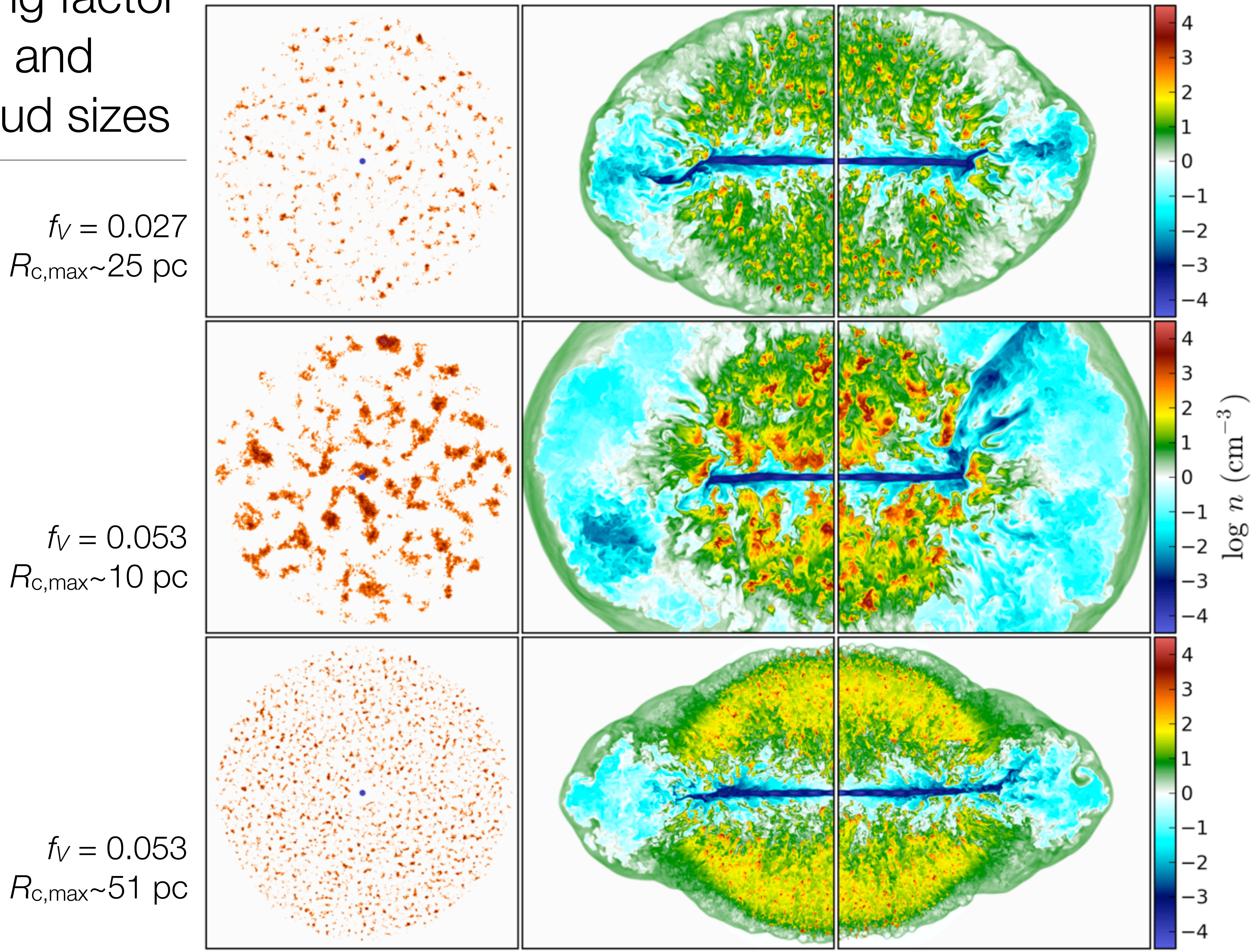


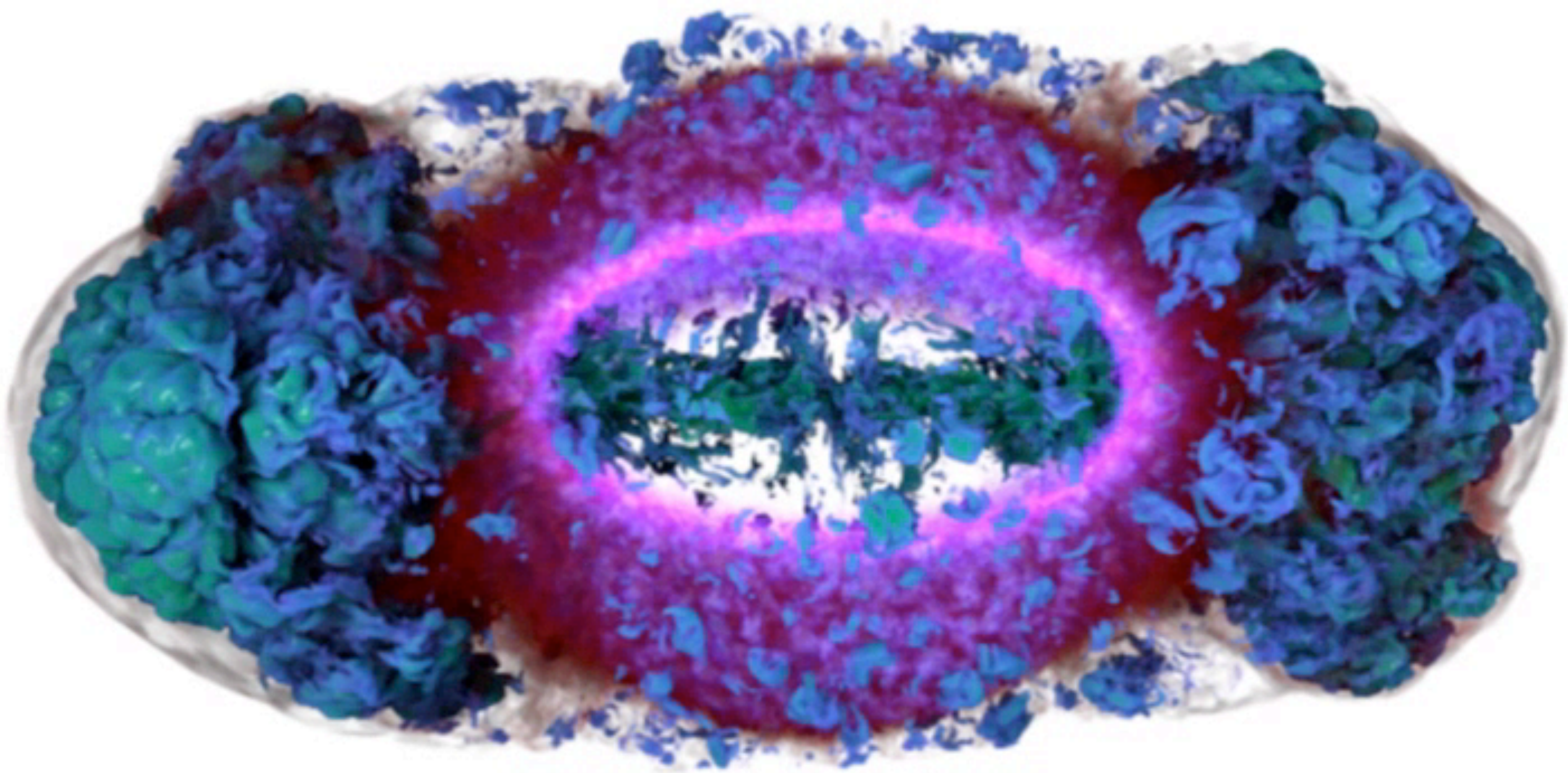
Γ=10, P=10^{45} erg $^{\text{s-1}}$, χ = mc^2/4p = 1

AGN Jet Feedback

The difference between a uniform medium and a two-phase medium.

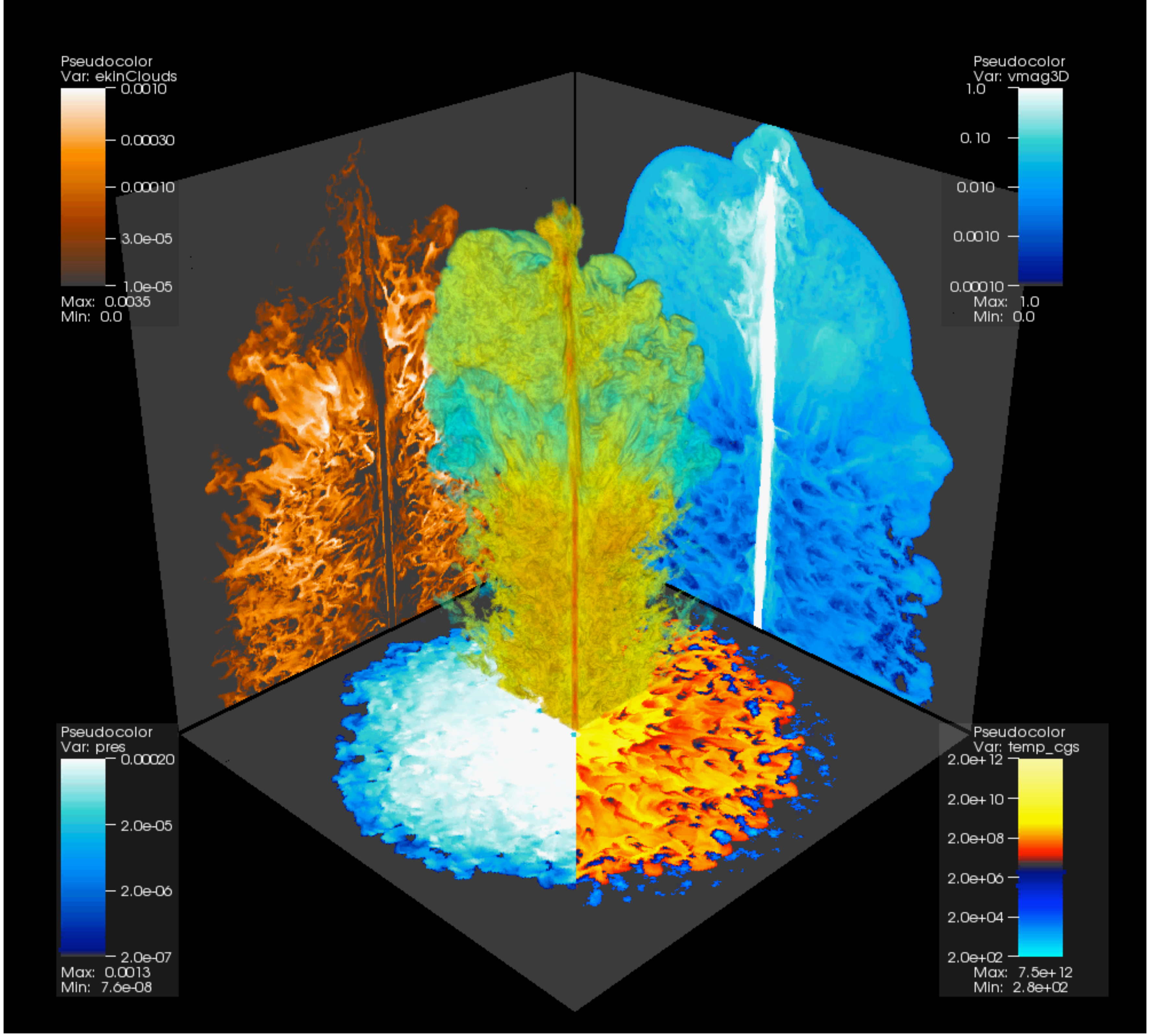
Filling factor and cloud sizes





AGN Jet Feedback

Flood and channel of the jet plasma through fractal ISM clouds



AGN Jet Feedback

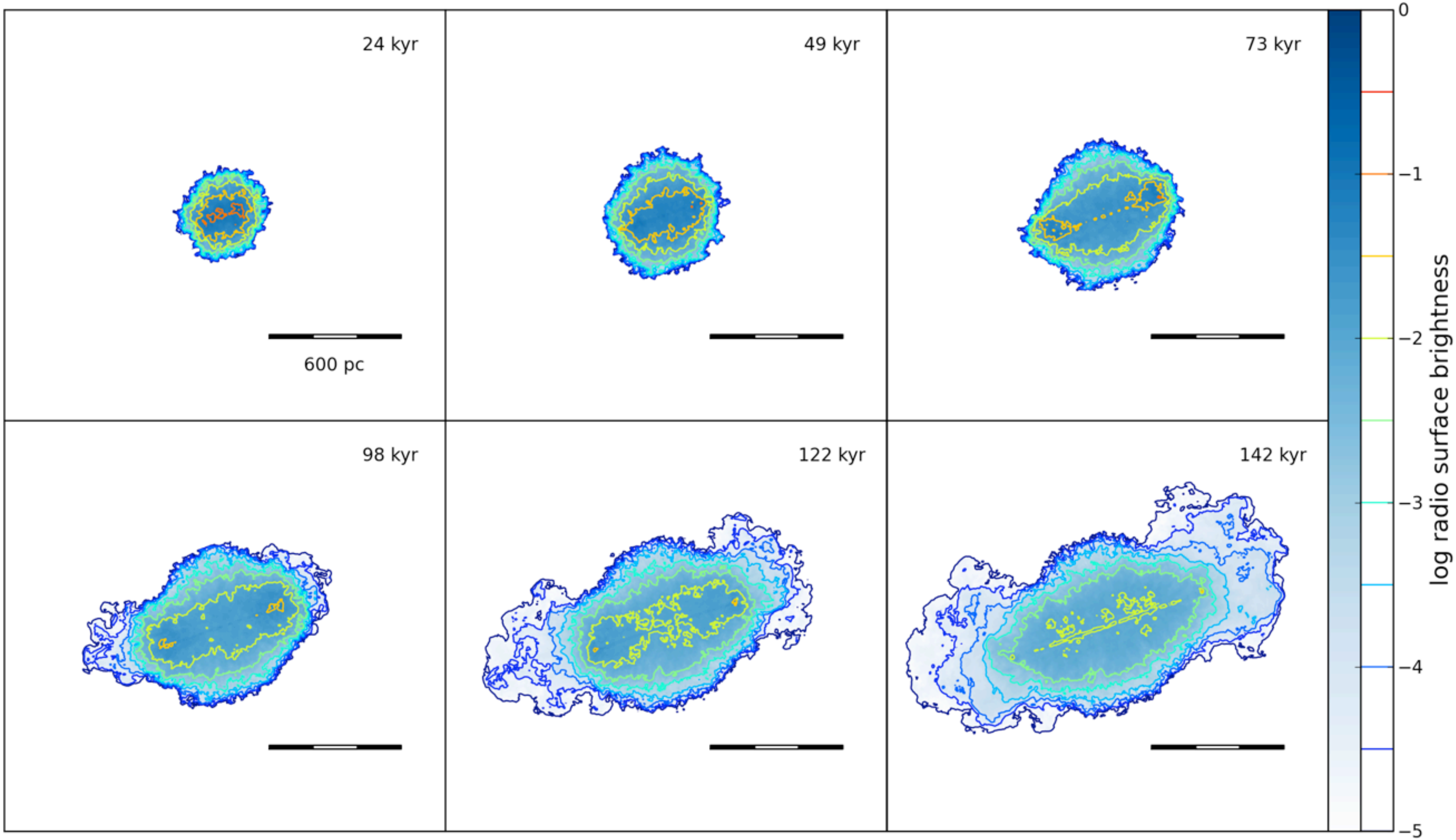
Jet
Ene

eye candy

halo heating, pressurization

-> Star-formation marginally induced.

$M_{BE} \sim T^2 \, p_0^{-1/2}$

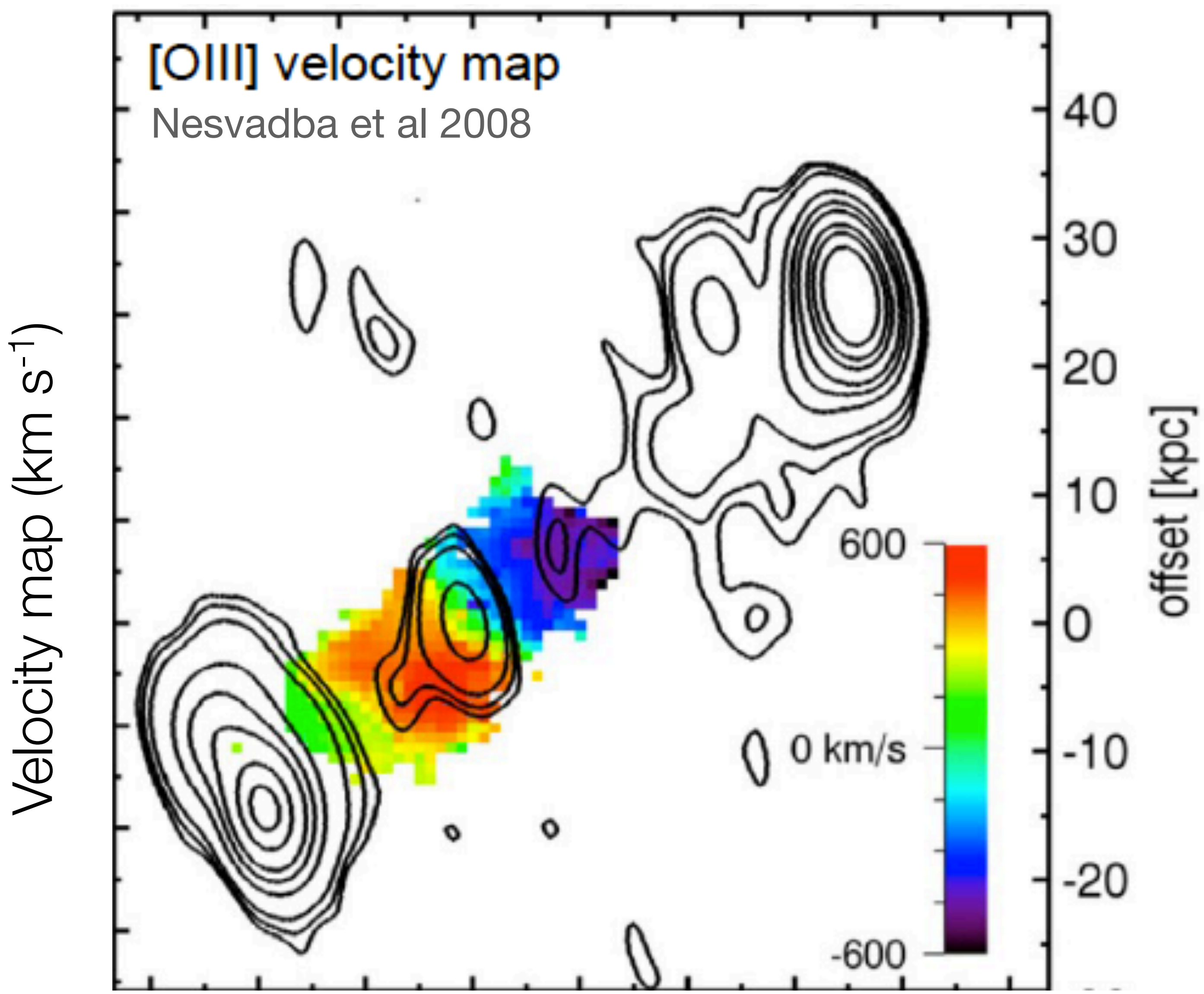


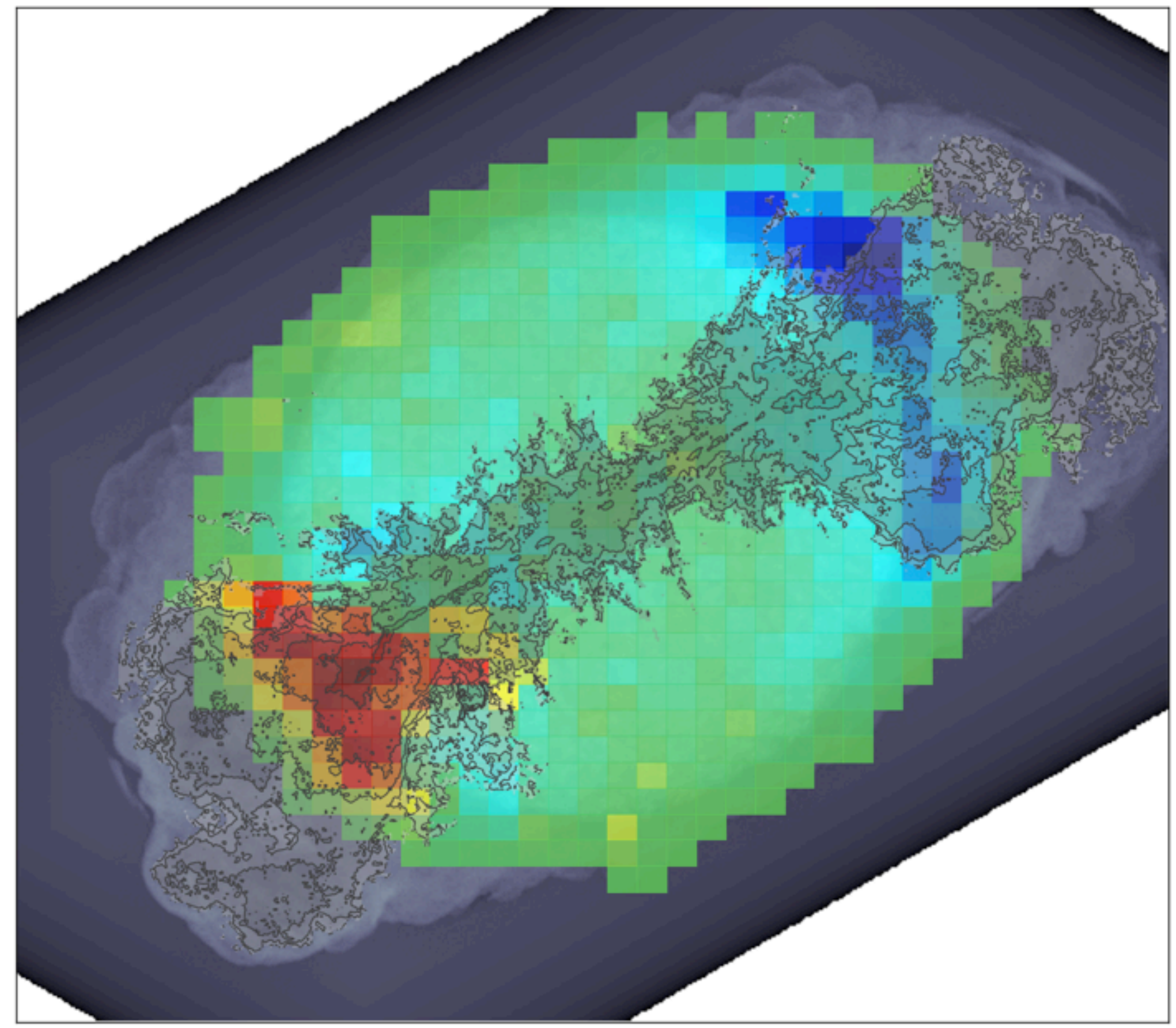
Synthetic radio images

Useful in comparisons to HzRG (e.g. GPS and CSS sources).

Observed high-redshift galaxies

Synthetic maps from simulations

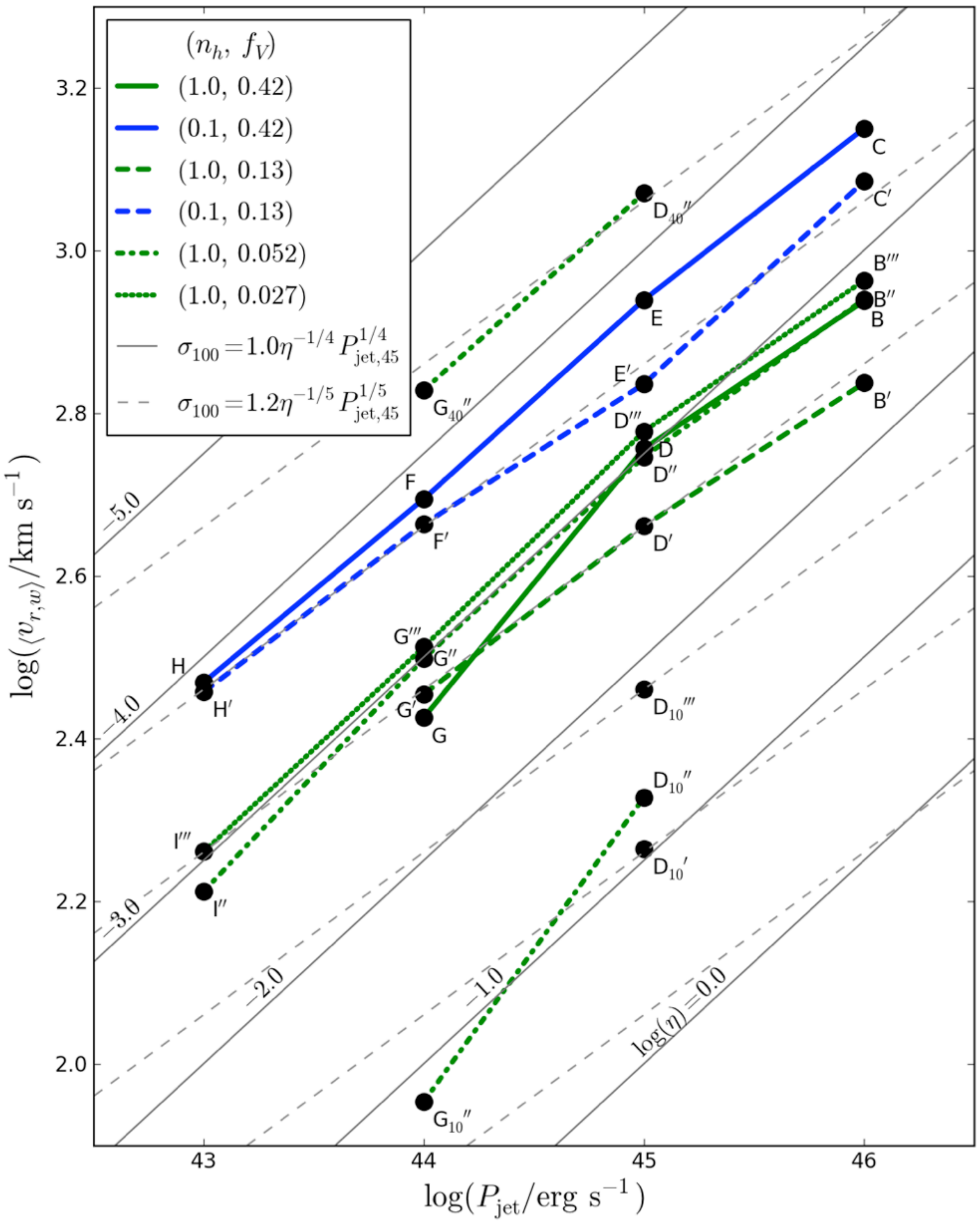




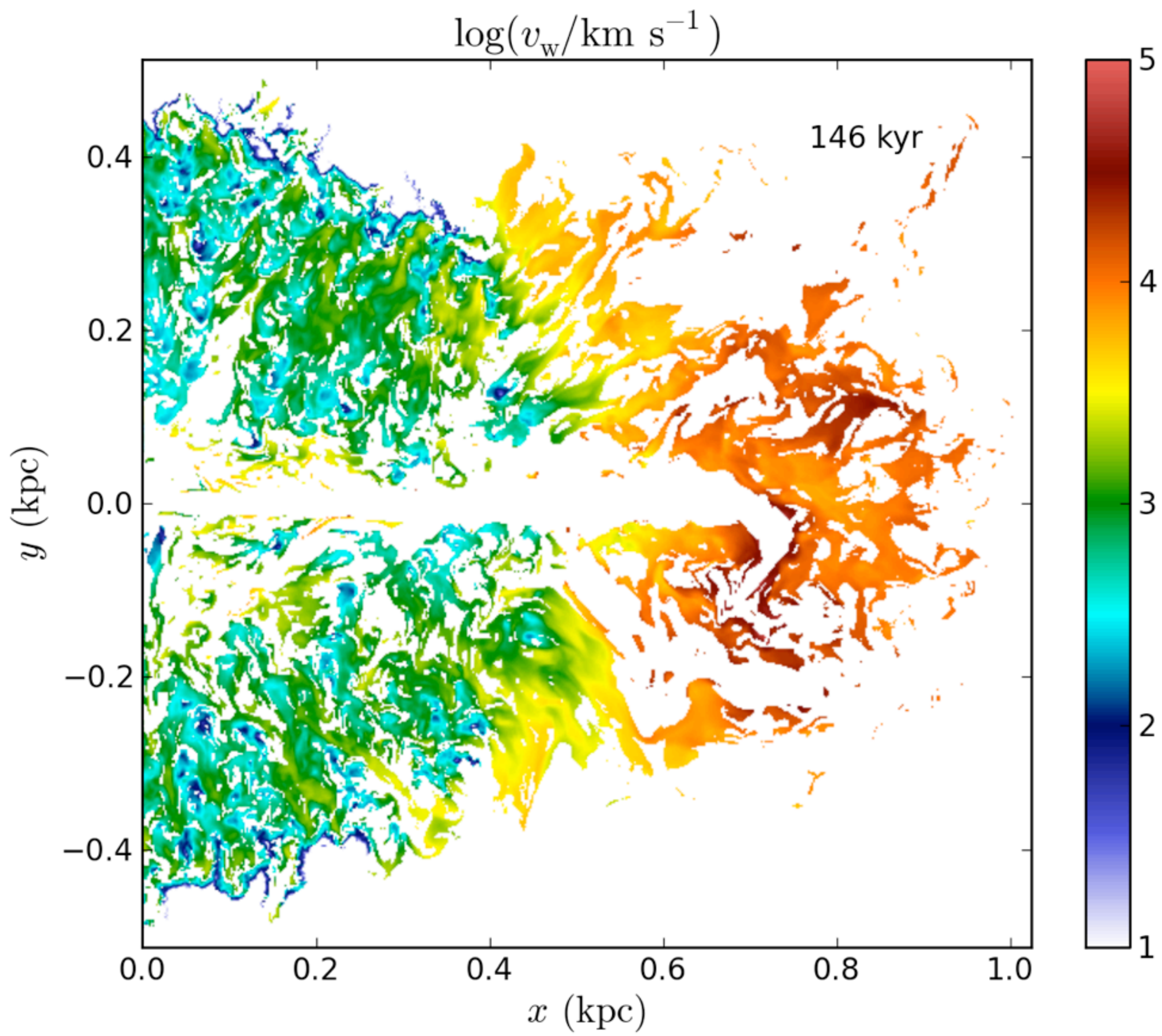
Synthetic IFU data | [OIII]

Negative Feedback

Outflow speeds and M-σ



- In agreement with observations, dense clumps move at ~few 100 km s^{-1}, diffuse ablated cloud material is accelerated to ~few 1000 km s^{-1}.
- The denser the ISM, the lower the dispersion velocities
- The more powerful the jet, the faster the outflows. ➡ *M-σ* scaling (Silk & Rees 1998).



Negative Feedback

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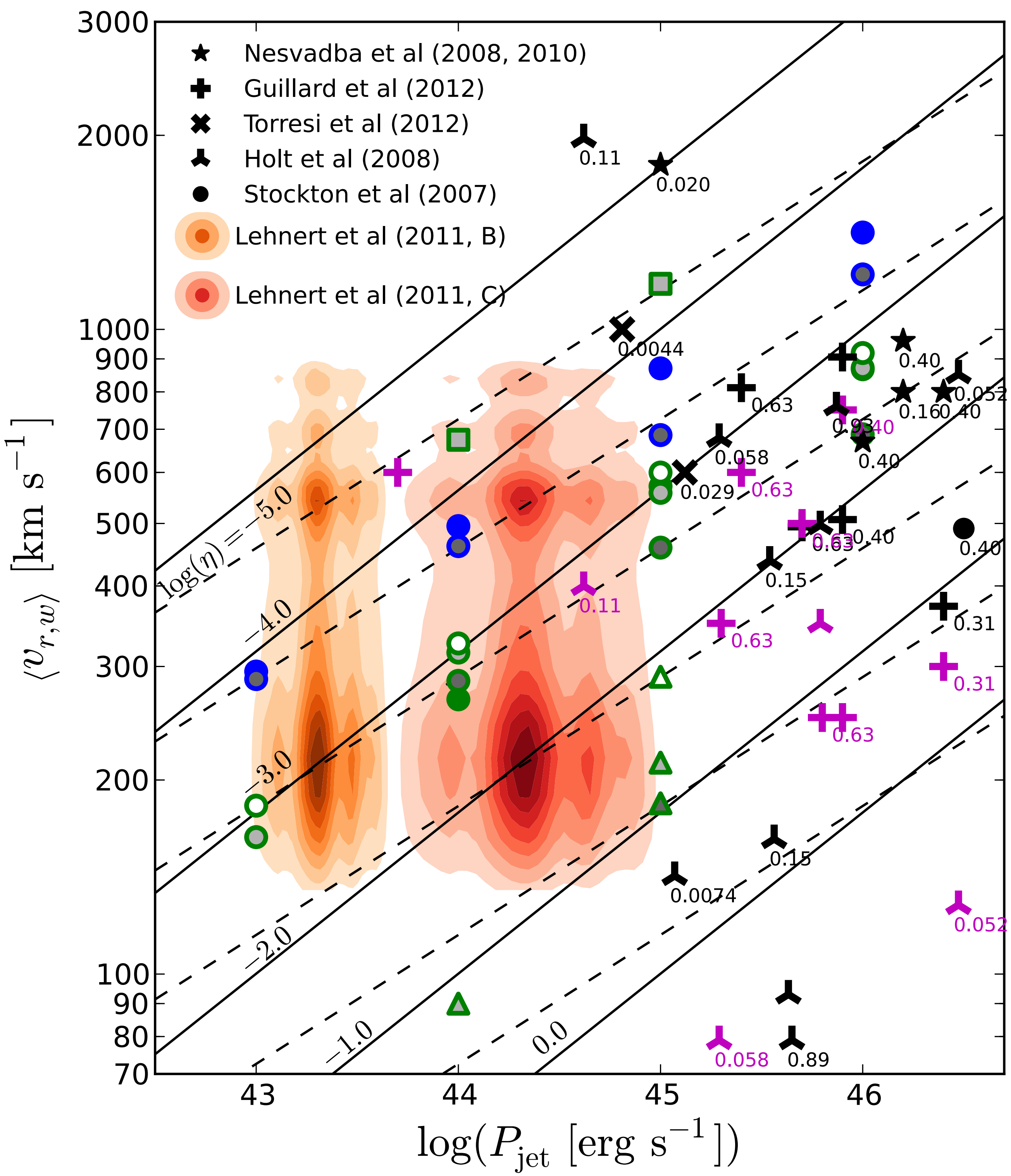

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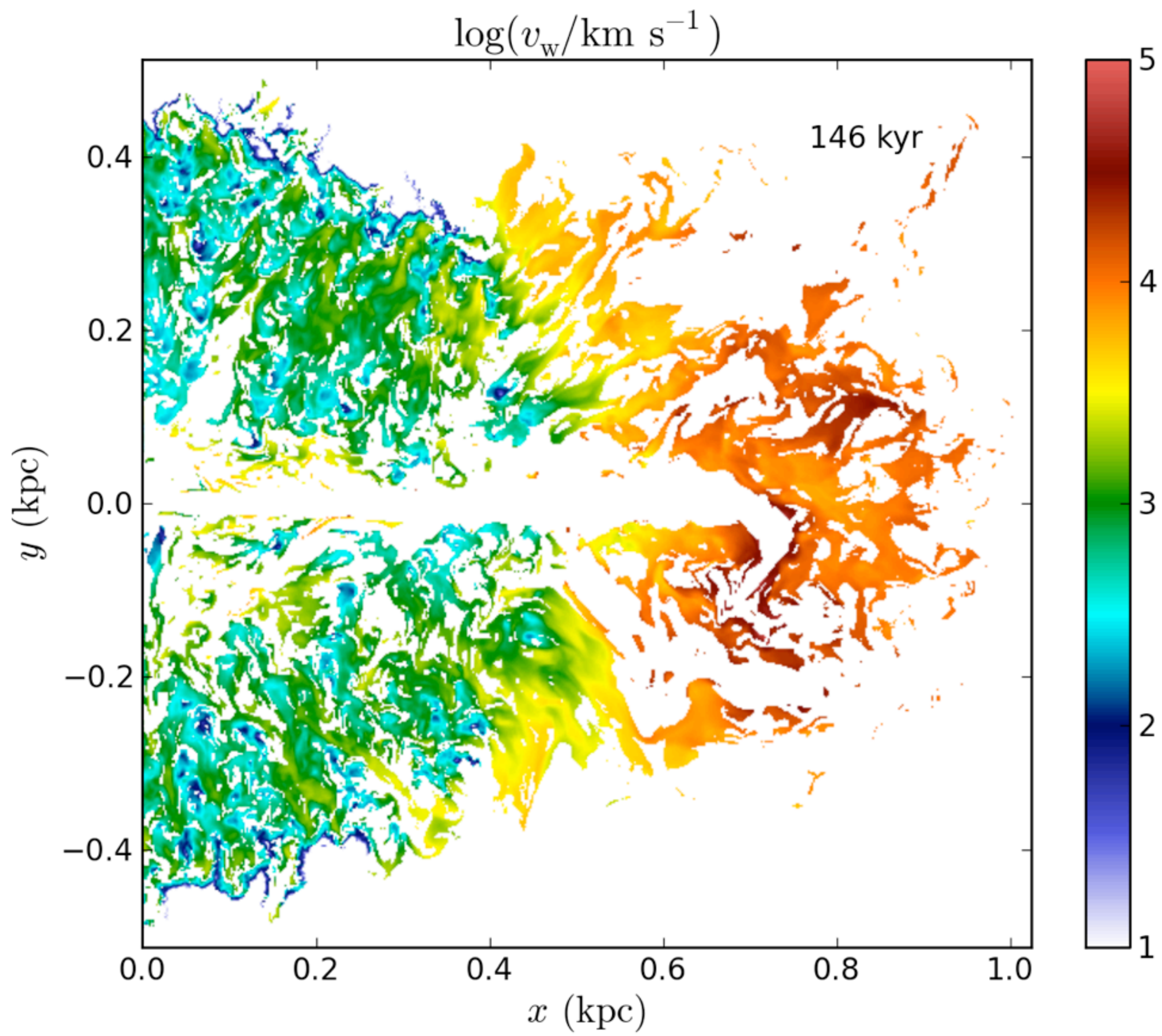
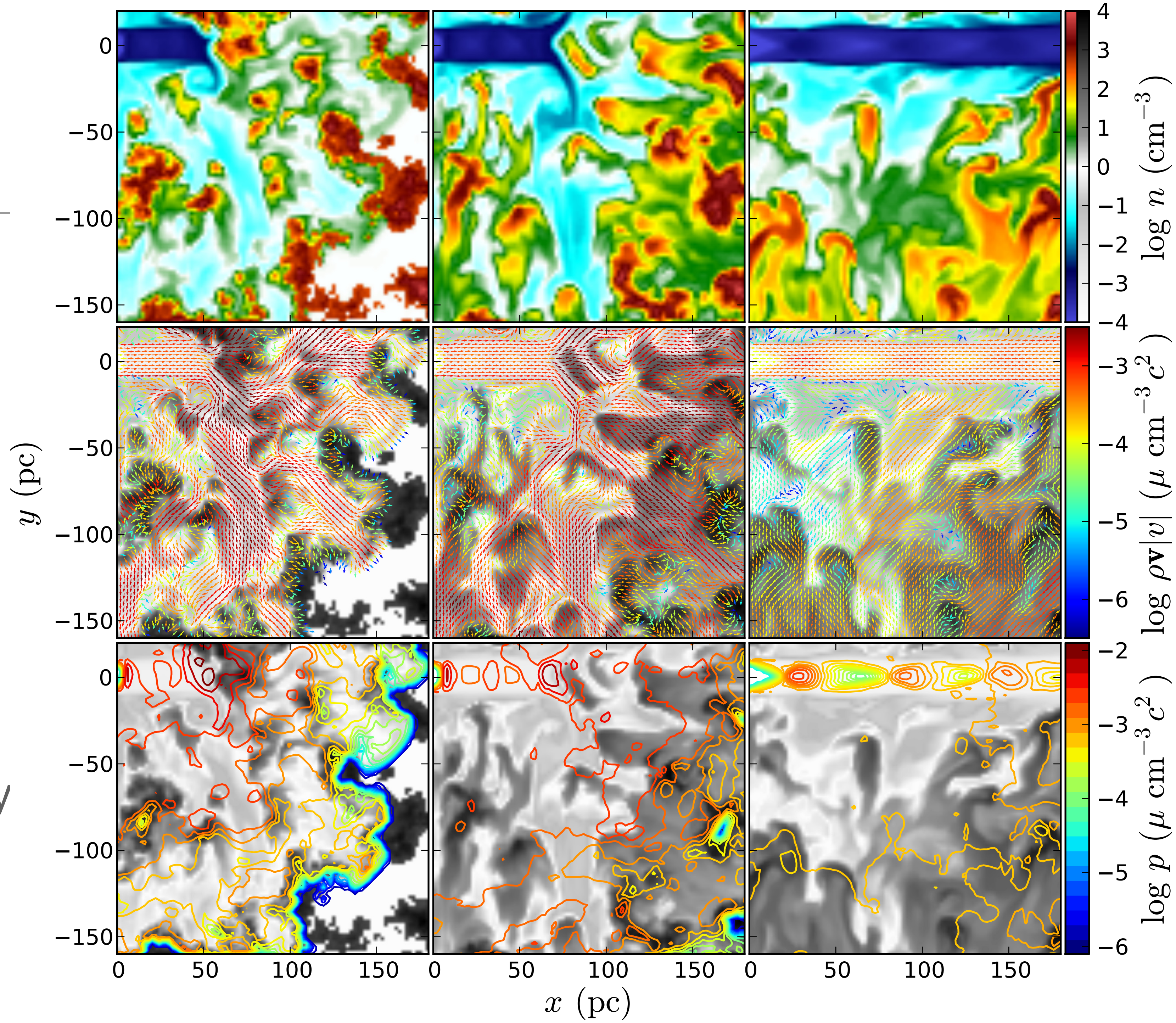


Thermal vs ram-pressure gradients

The channel flow remains at β > 0.01 within the kpc simulation domain.

All channel flows have high densities
$n > 0.1$ cm^{-3} due to turbulently entrained hot-phase material.

Some channel flows are heavily mass loaded by cloud material ($n \gtrsim 10$ cm^{-3}).

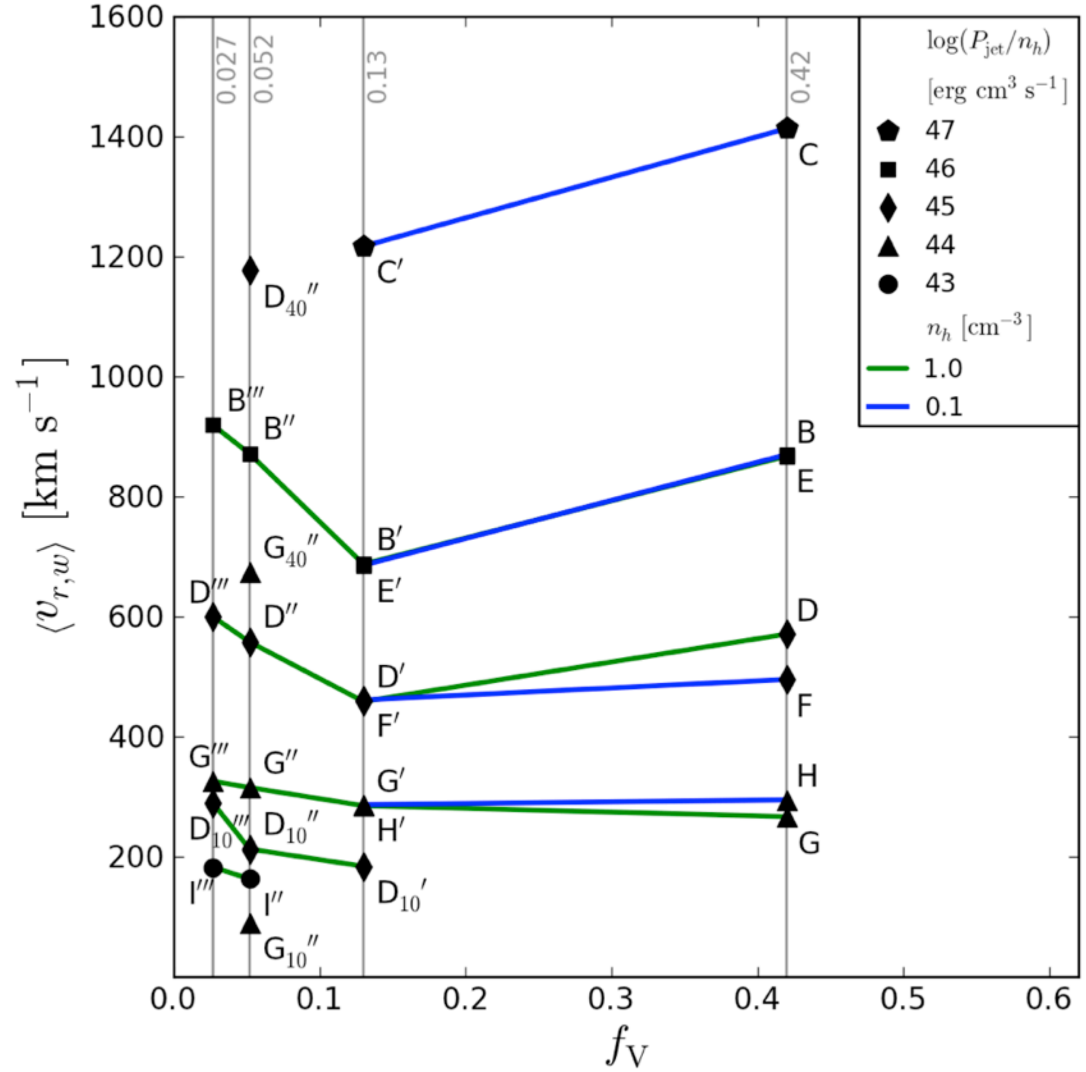


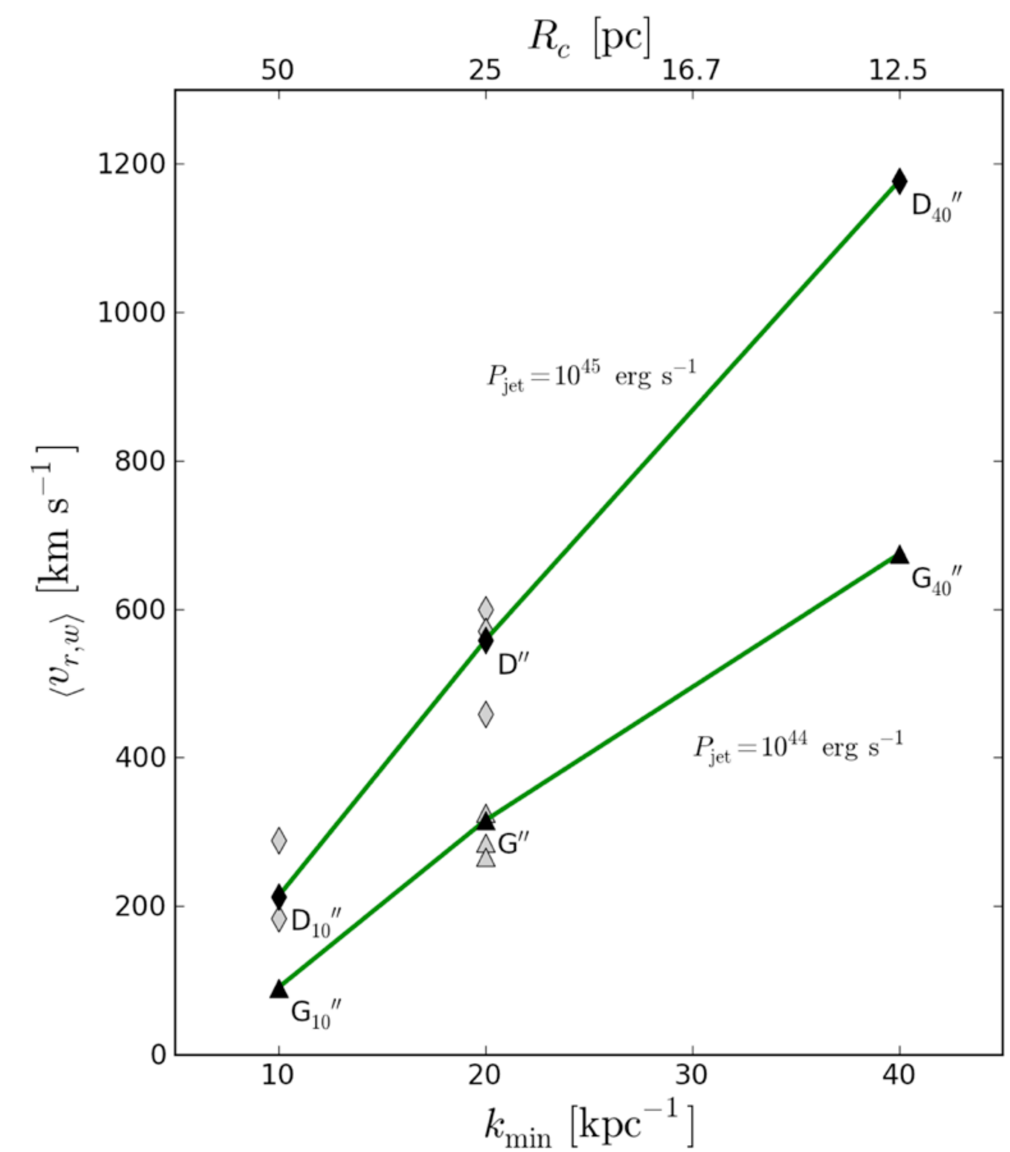
⇒ Pressure gradients at cloud interfaces are maintained mainly through high ram pressure channel flows.

⇒ Estimates of cloud acceleration timescales are less than bubble dynamical time.

AGN Feedback efficiencies

Dependence on filling factor and cloud sizes





- Surface area per unit mass exposed to ablation scales inversely with cloud radius.
- Confinement time of jet, and therefore, the time available for energy and momentum transfer is shorter in lower filling factor environments.

AGN Jet Feedback

Efficiencies

Reason for strong dependence of feedback efficiency on cloud size:

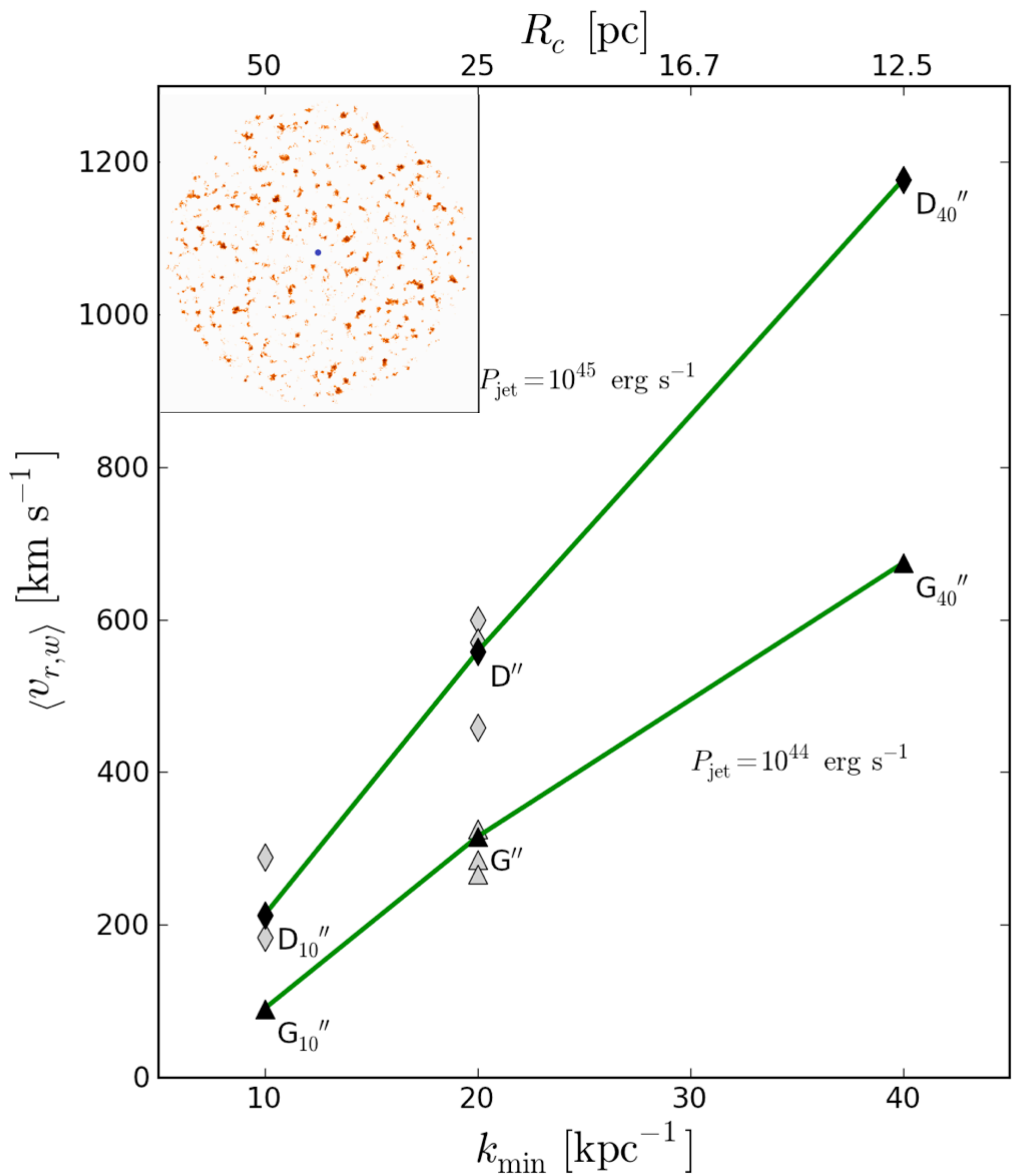
- View problem of jet propagation through galaxy as a (self-avoiding) random-walk/diffusion problem.
- We define an interaction depth:

$$\tau_{\rm jc} = (n_c R^2_{\rm c,max}) R_{\rm bulge}$$

$$N = f_V R^3_{\rm bulge} / R^3_{\rm c,max} = n_c R^3_{\rm bulge}$$

$$\tau_{\rm jc} = f_V (R_{\rm bulge} / R_{\rm c,max}) = f_V k_{\rm min}$$

Dependence on cloud sizes



AGN Jet Feedback

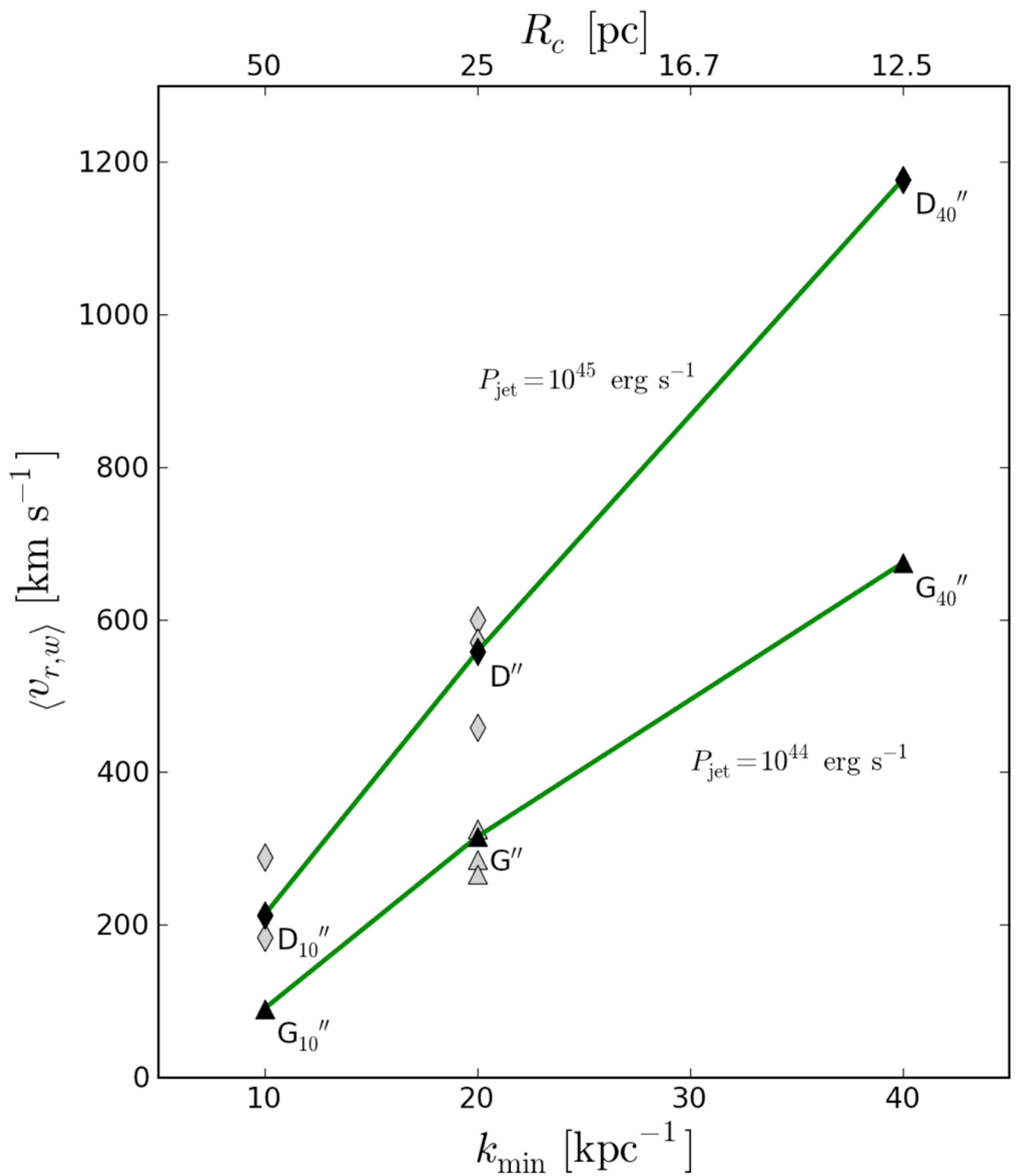
Efficiencies

Feedback efficiencies depend stronger on maximum cloud sizes than on filling factor

A galaxy with many small isolated clouds experiences efficient cloud dispersion compared to a galaxy with fewer but bigger cloud complexes.

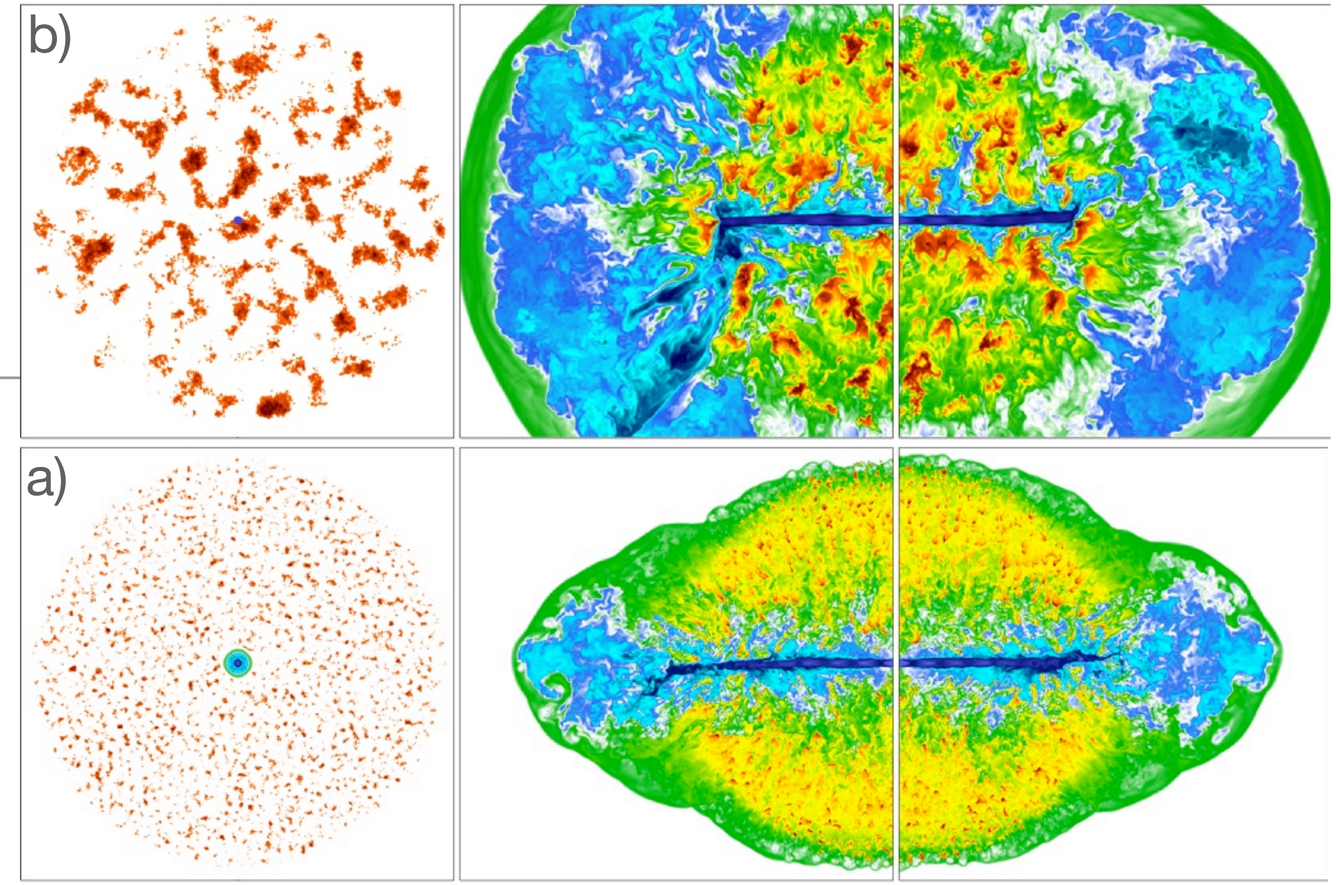
Bigger cloud complexes may be more easily triggered to collapse.

Dependence on cloud sizes

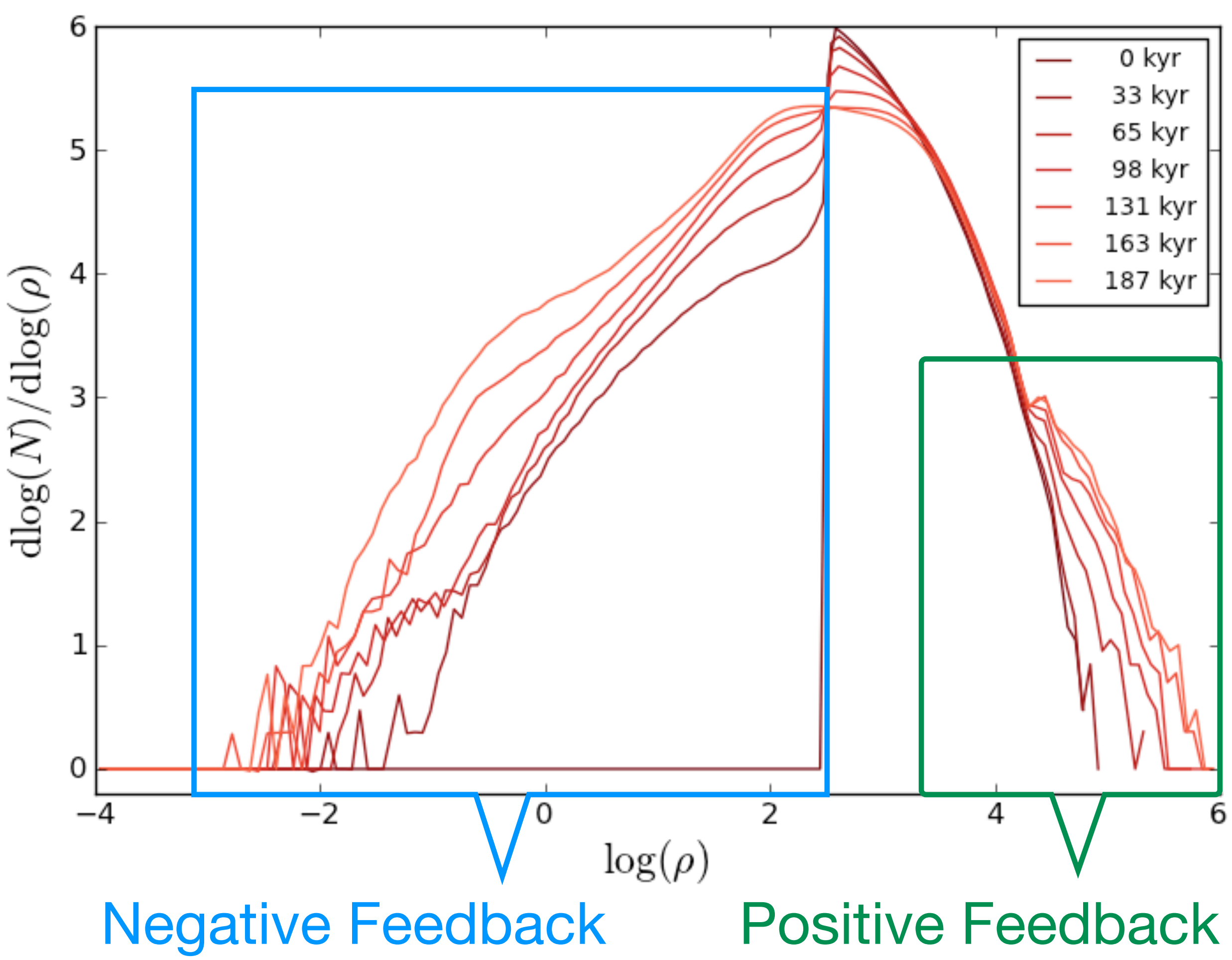


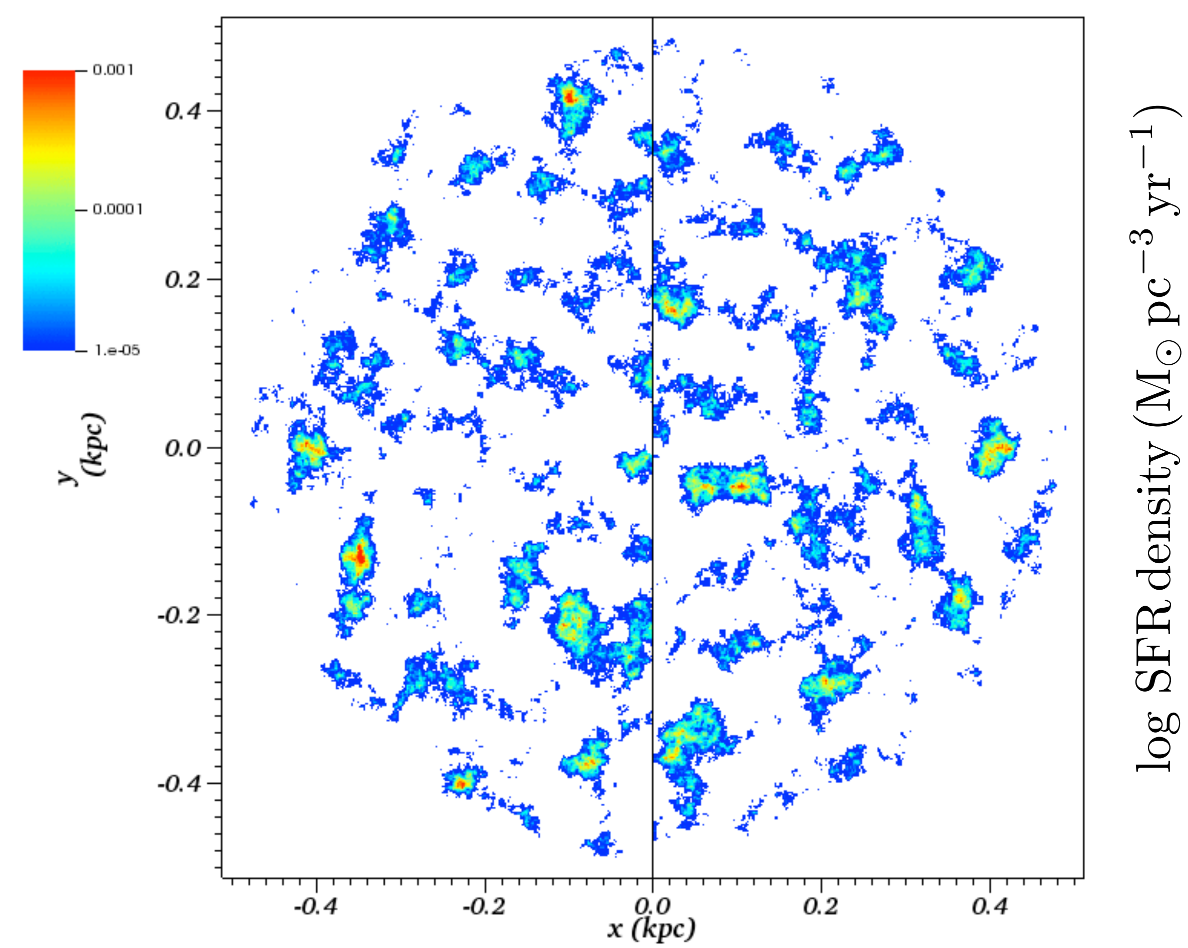
Positive feedback
Star formation

- Competing effects:
  - a) Cloud ablation
  - b) Pressure-triggered collapse



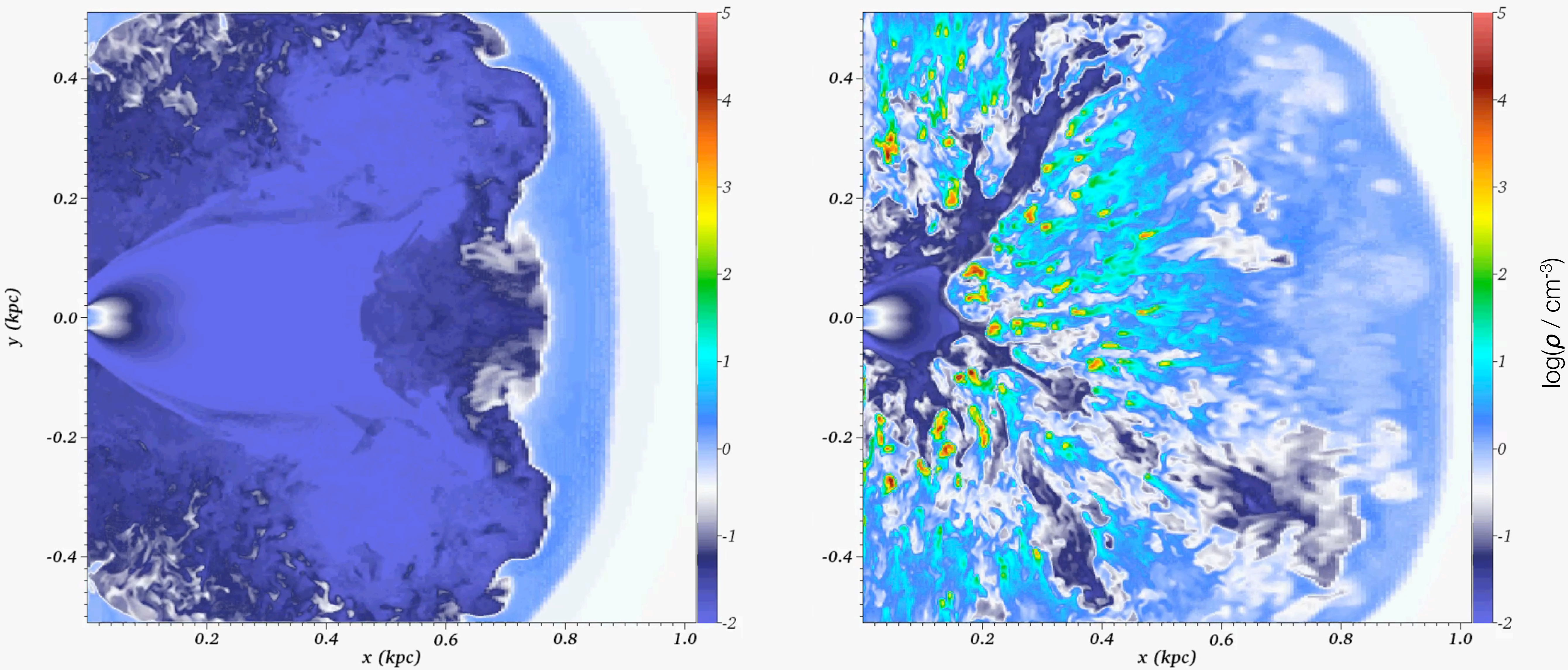
Evolution of density distribution





Simulations of feedback by UFOs

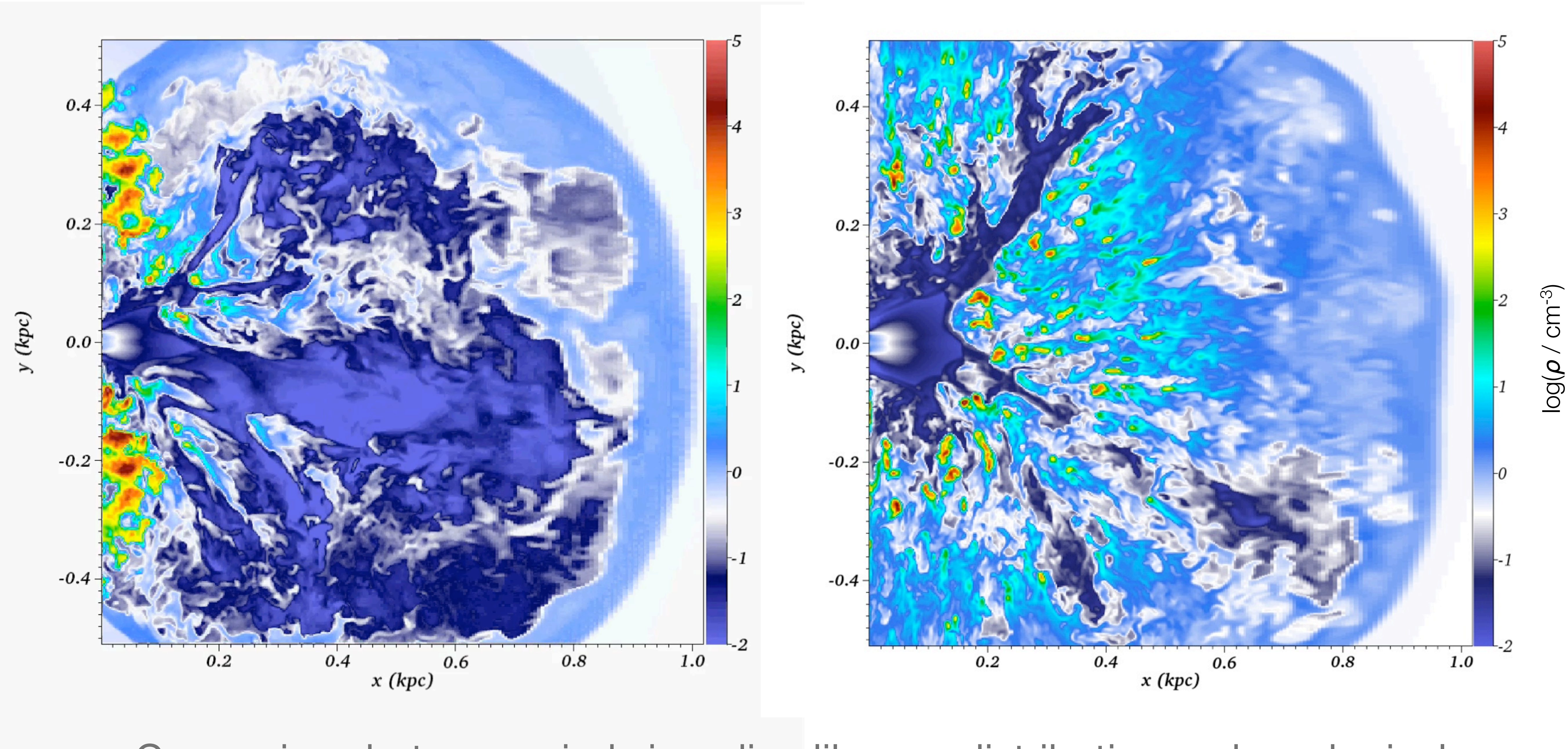
The case of spherically distributed clouds



- 10^{44} erg s^{-1} wind with half opening angle of 30 degrees
- $v = 0.1c$, $dM/dt = 0.1\ M_\odot\ yr^{-1}$.

Simulations of feedback by UFOs

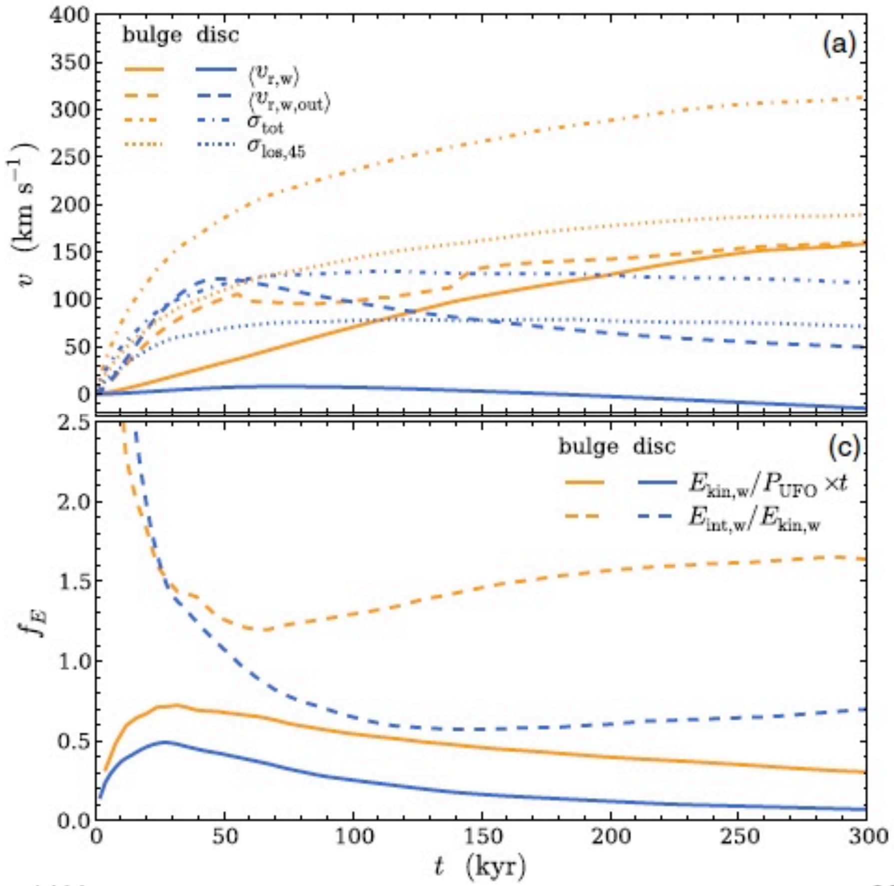
The case a disk-like distribution of clouds

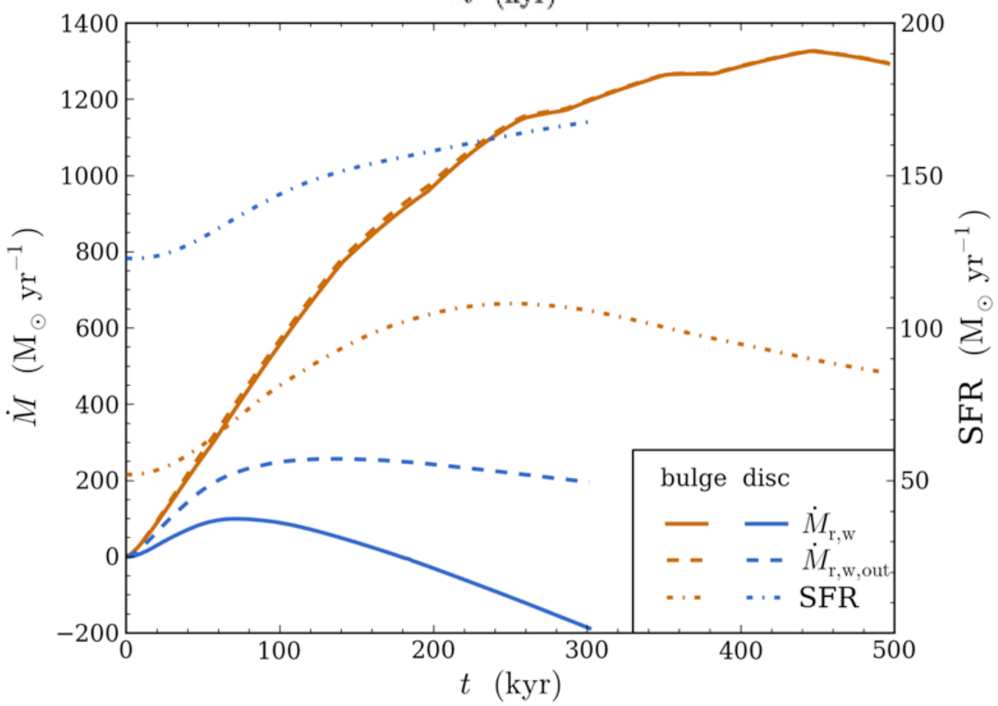


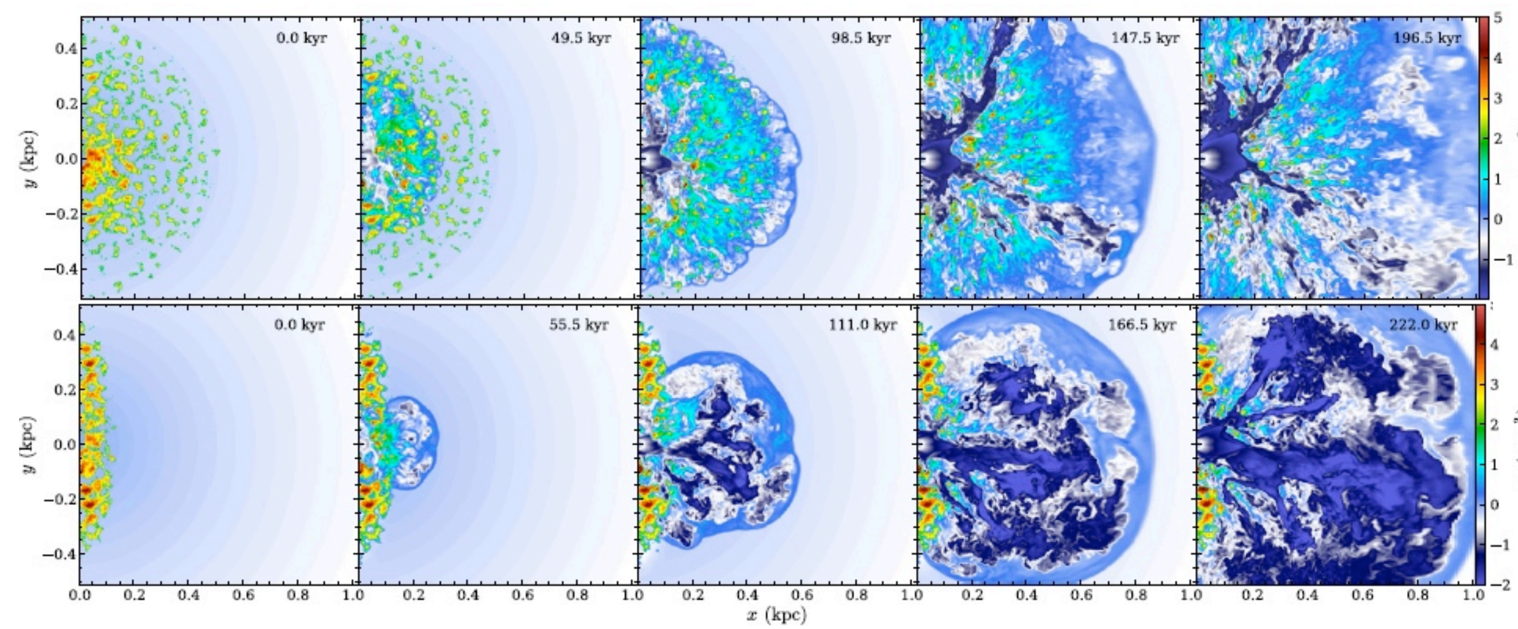
- Comparison between winds in a disc-like gas distribution and a spherical gas distribution.
- Gas at large disc-radii is compressed, while near the wind is blown out.

The efficiency of UFO feedback

Disk-like and spherical gas distributions



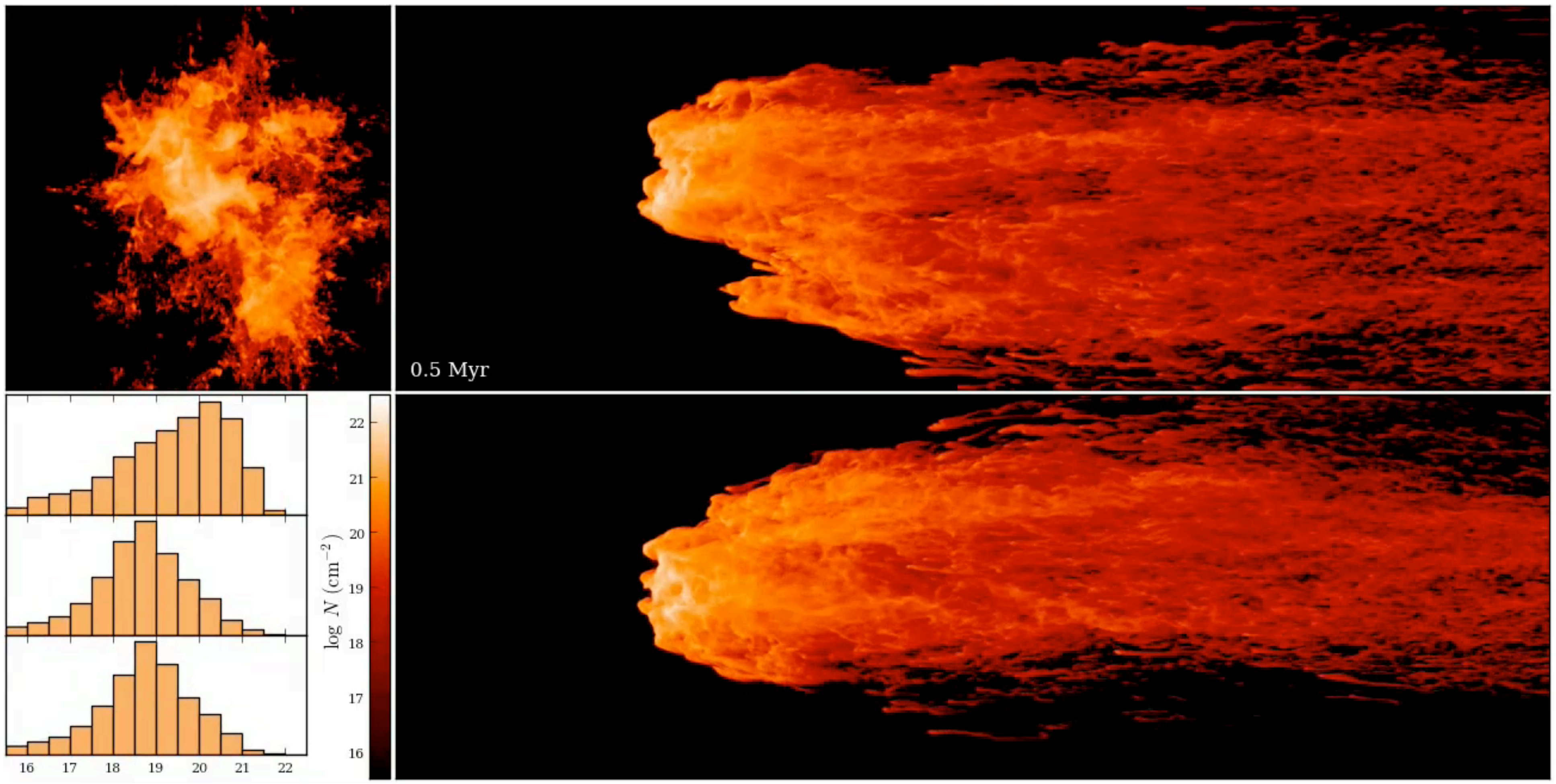




- Negative feedback for spherically distributed clouds, positive feedback for clouds distributed in a disc.
- Radial outflow velocities and velocity dispersions reached in galaxy are high, though not as high as for jet-mediated feedback.The curves also rise slower.
- The dependence of feedback efficiency on opening angle disappears after the interaction with first cloud.
- The momentum transport to clouds and occurs through fast, entrained channel flow.

➡ AGN jet and UFO feedback on kpc scales is similar

Filamentation and acceleration of a fractal cloud



Cooper et al. (2009)

- KH instabilities → cloud ablation → ram pressure driven acceleration
- Radiative cooling enhances lifetime of clouds and formation of filaments
- Still missing: AMR, molecule formation and cooling, self-gravity (and optionally sub-grid (*k*-*ε*) turbulence to aid convergence).

Summary in words

- Hydrodynamic grid-based simulations demonstrate that AGN jets and winds can accelerate ionized, neutral and molecular gas to 100s~1000s km s^{-1}, as seen in observations. ➜ *Negative Feedback*
- The bubble evolves between the energy-driven and momentum-driven regimes and is characterized by diffusive propagation of channel jet streams.
- The ram-pressure in the jet streams reaches clouds everywhere and accelerates them up to the bubble expansion speed within the bubble dynamical time.
- Pressurization of clouds or the entire galactic disc by the AGN blown bubble can lead to enhanced star-formation in the galaxy. ➜ *Positive Feedback*
- The efficiency of positive and negative feedback depend strongly on the properties of the ISM like, e.g. the size-distribution of clouds as well as the column density of the system.

Summary in images