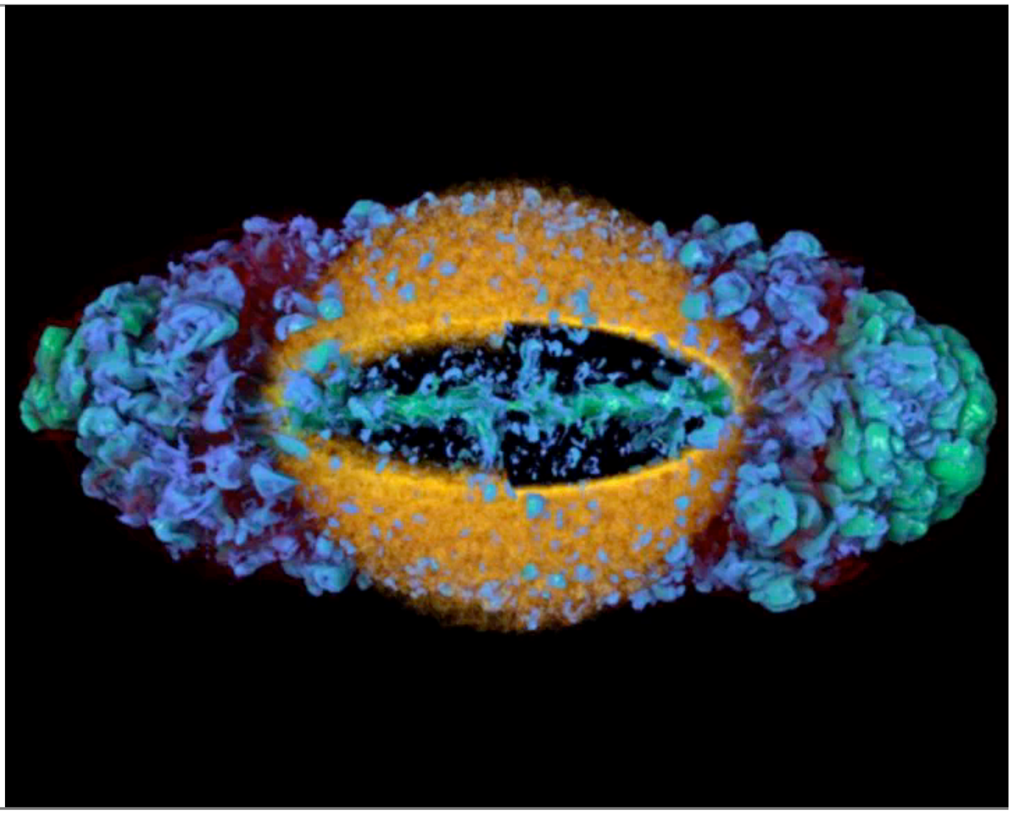
AGN Feedback by Relativistic Jets and Fast Disc Winds

(Wagner, Bicknell, & Umemura 2012; Wagner, Umemura, & Bicknell 2013)

Alex Wagner
CCS postdoctoral fellow
Center for Computational Sciences,
University of Tsukuba

in collaborations with
Masayuki Umemura (CCS)
Geoff Bicknell (ANU)
Ralph Sutherland (ANU)
& Joseph Silk (IAP, Oxford, JHU)



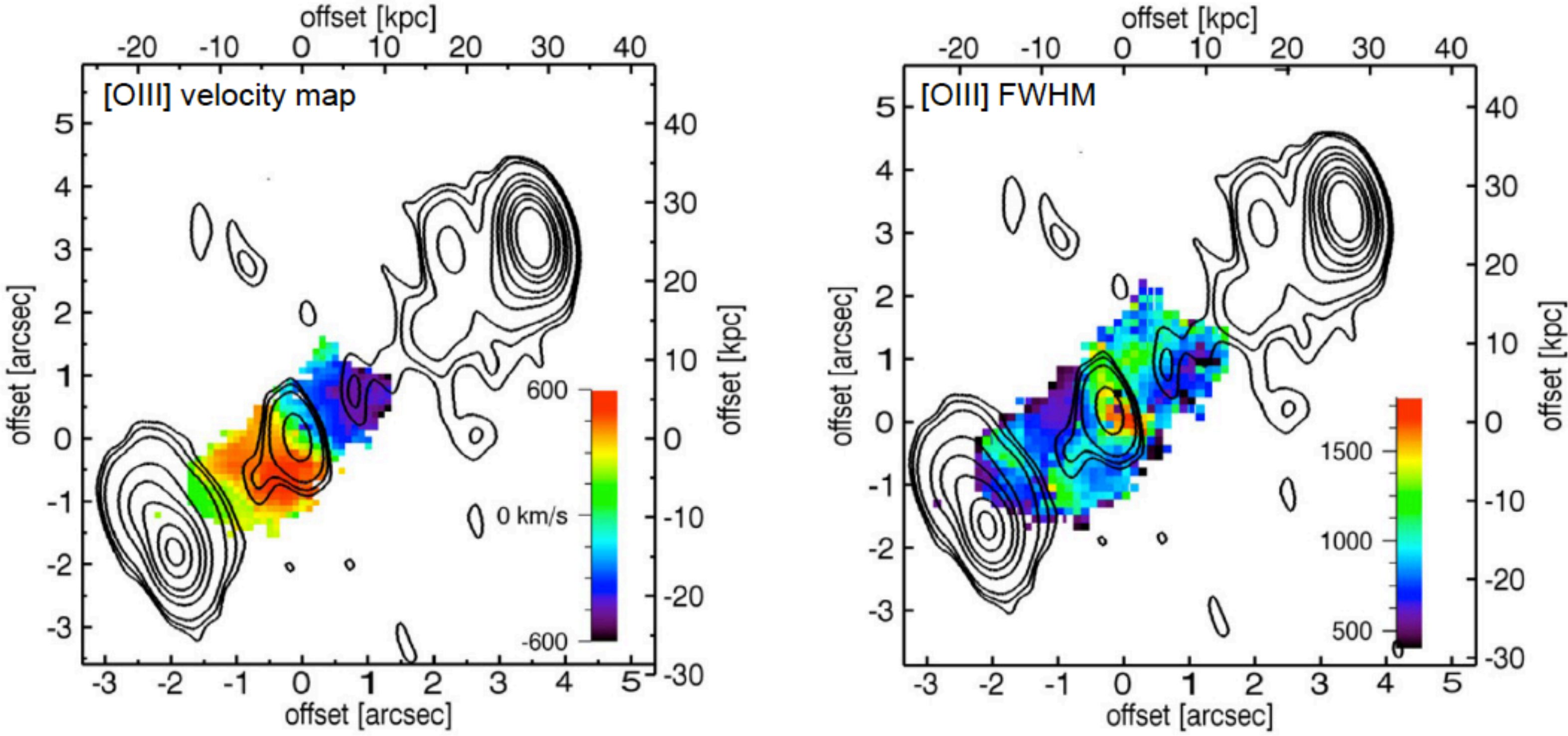
CCS External Review *Feb. 19, 2014*

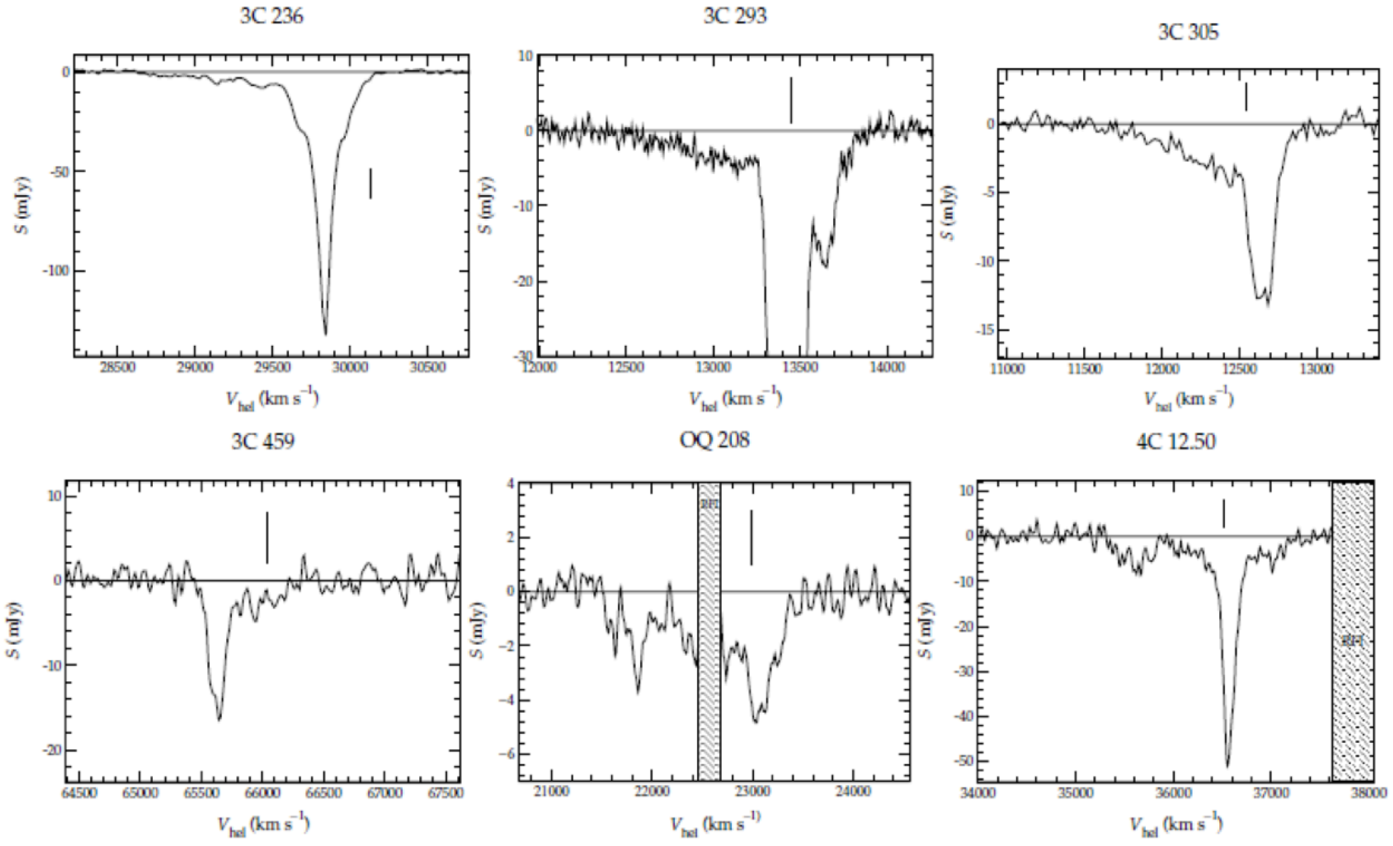
Movies shown in this talk can be found at http://www2.ccs.tsukuba.ac.jp/Astro/Members/ayw/research/agn_feedback/agn_feedback.html

AGN Jet feedback

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.

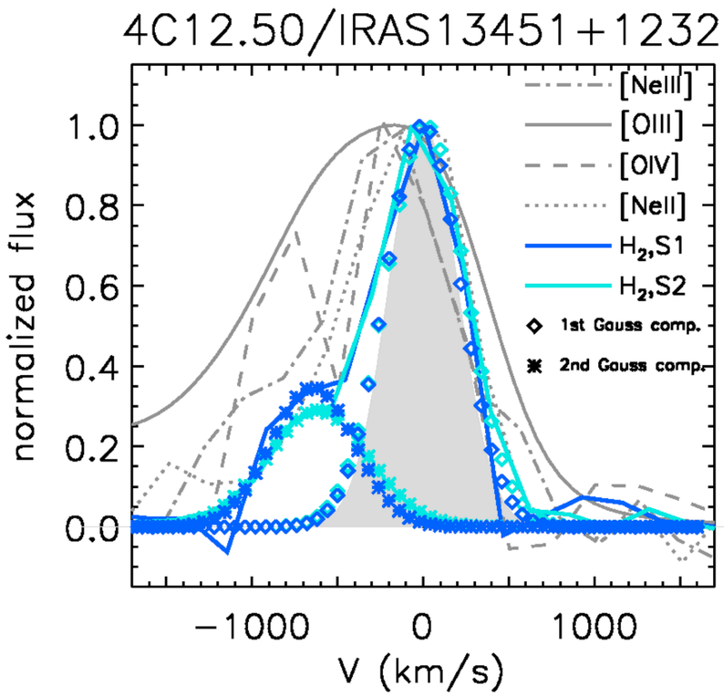
Outflows in radio galaxies
Negative feedback

⇛ suppression of star-formation
⇛ Black hole - galaxy co-evolution

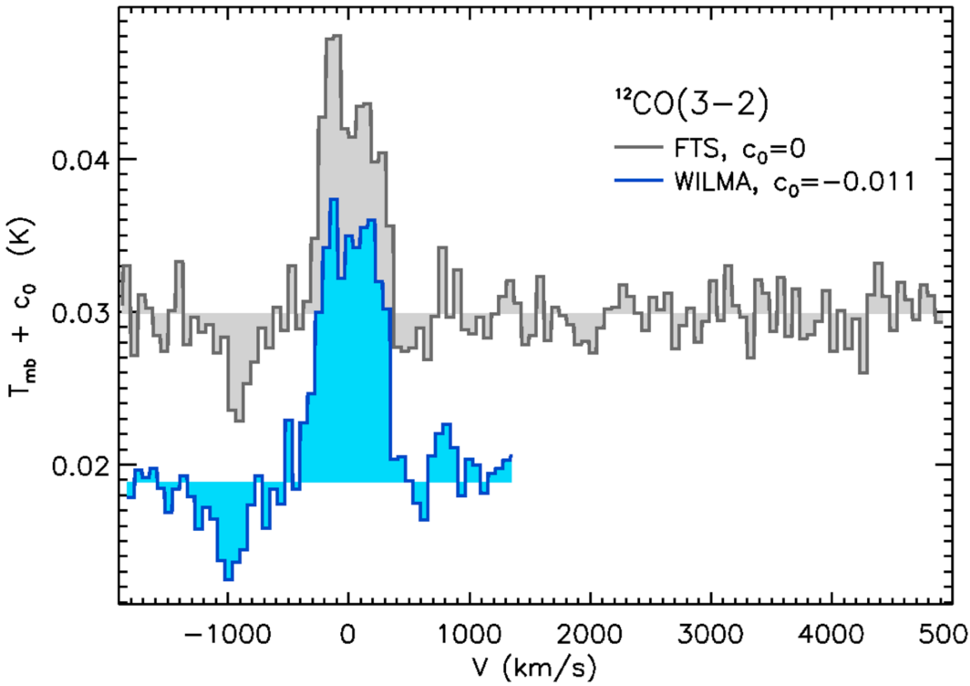
Multiphase outflows
4C 12.50 (z~0.122)

- 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}!)

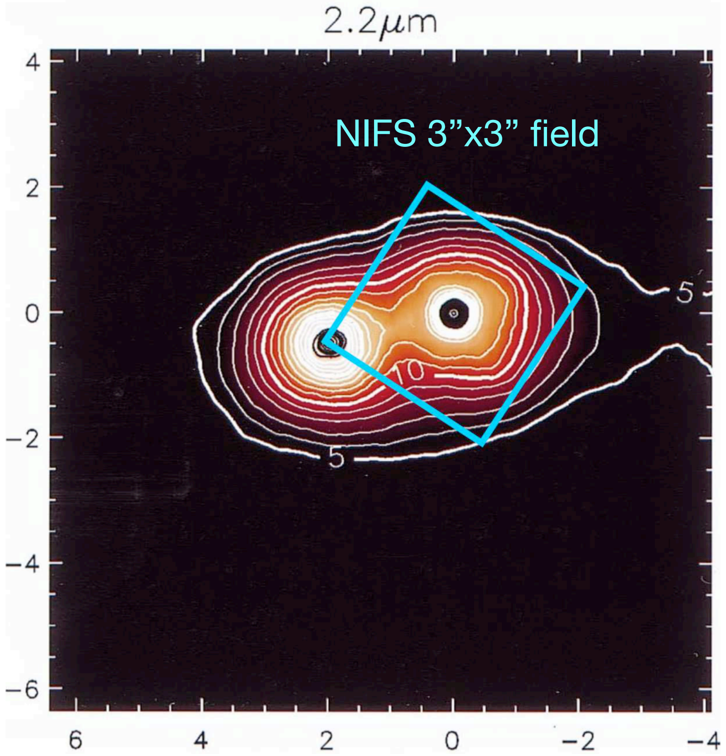
- Molecular phase dominates d*M*/dt. But within molecular phase warm phase dominates mass fraction. 1/4 of entire molecular gas reservoir is outflowing.
- We will probe the warmest (few 1000 K) molecular gas phase via NIR ro-vibrational H_2 lines with NIFS observations (Gemini South, accepted).
- Can 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)

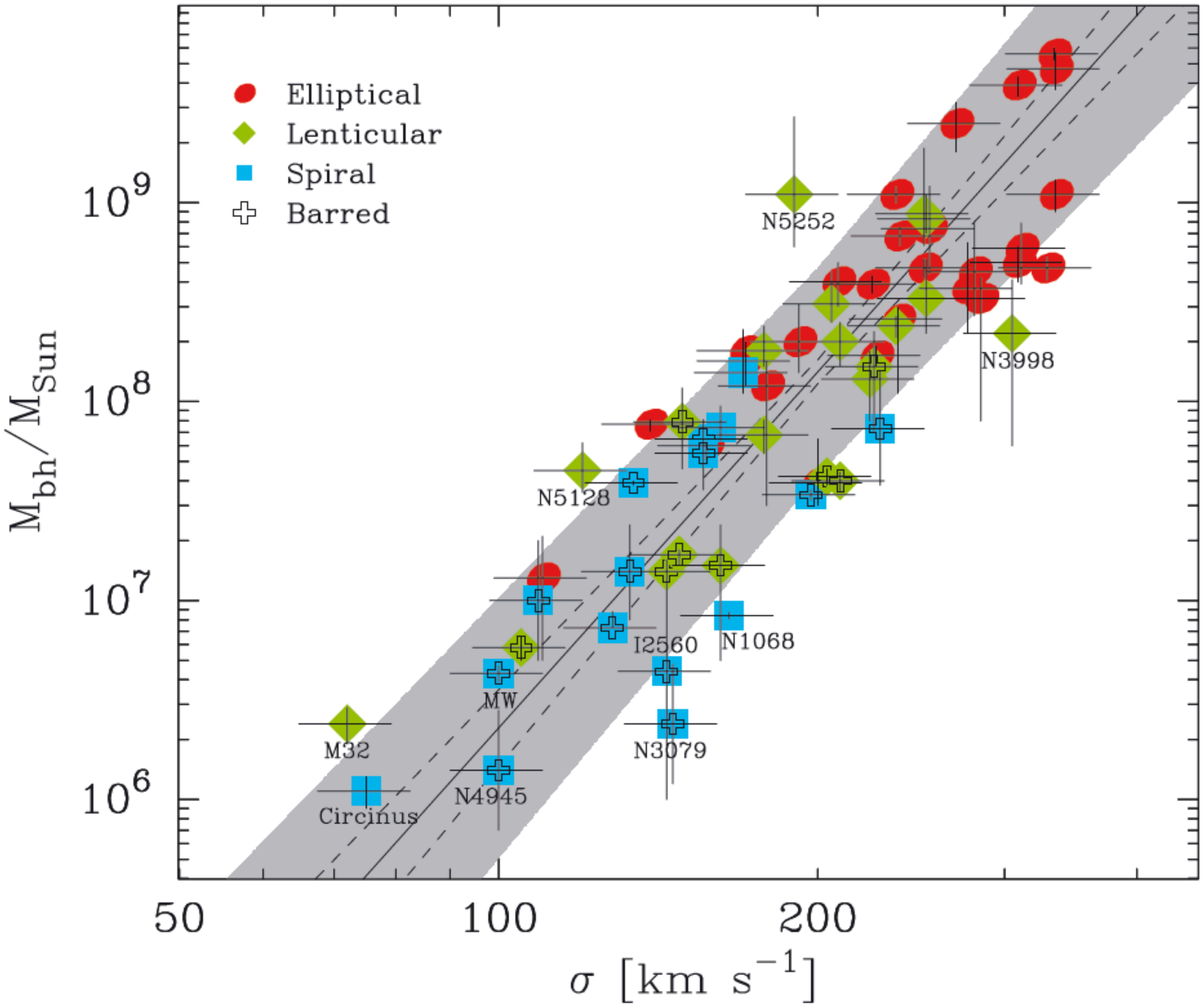


Dasyra & Combes (2012)



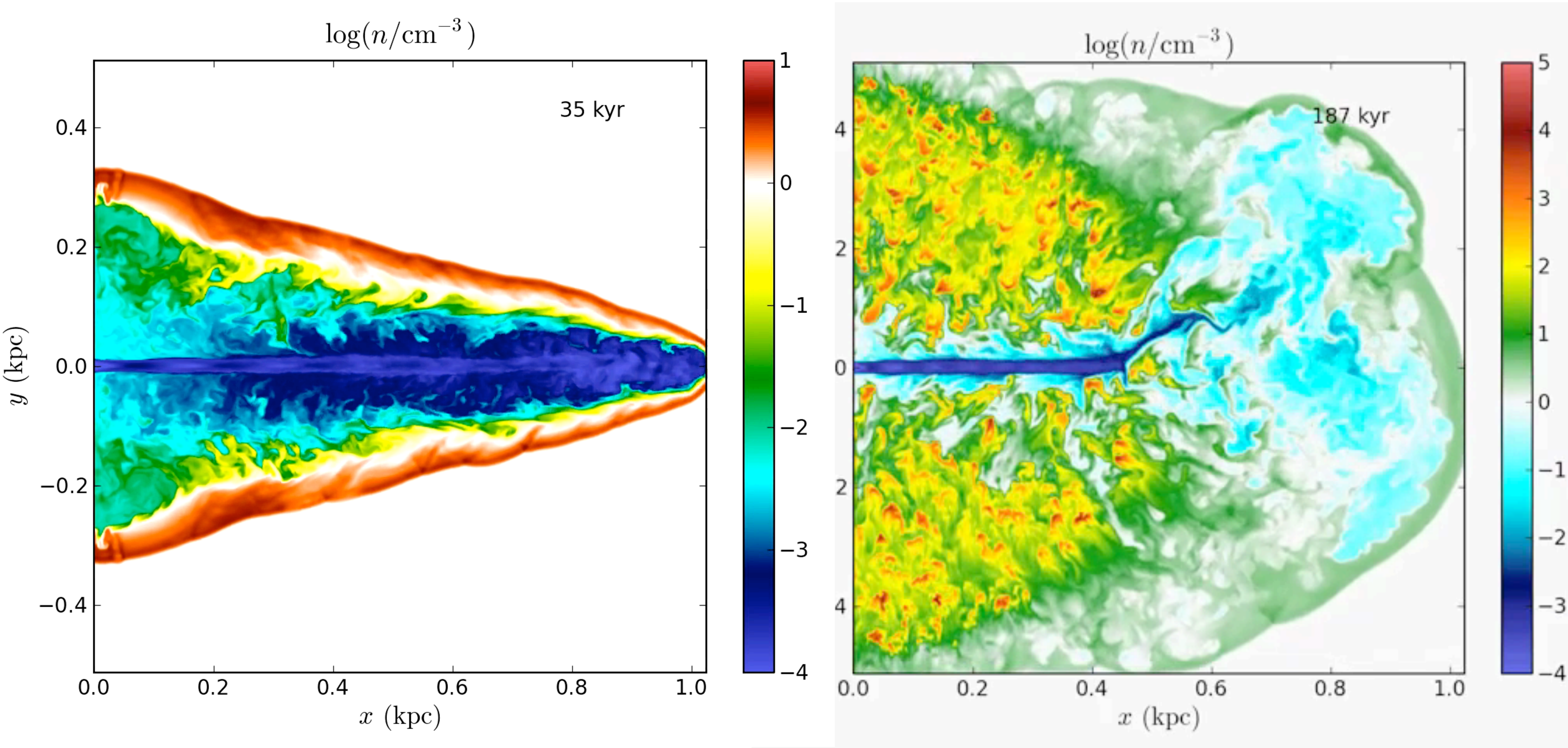
Scoville (2000, NICMOS)

M-sigma relation *Black hole - Bulge coevolution*



Graham et al (2011)

$$\log(M_{BH}/M_\odot) = (8.13 \pm 0.05) + (5.13 \pm 0.34) \log(\sigma / 200\ \mathrm{km\ s^{-1}})$$

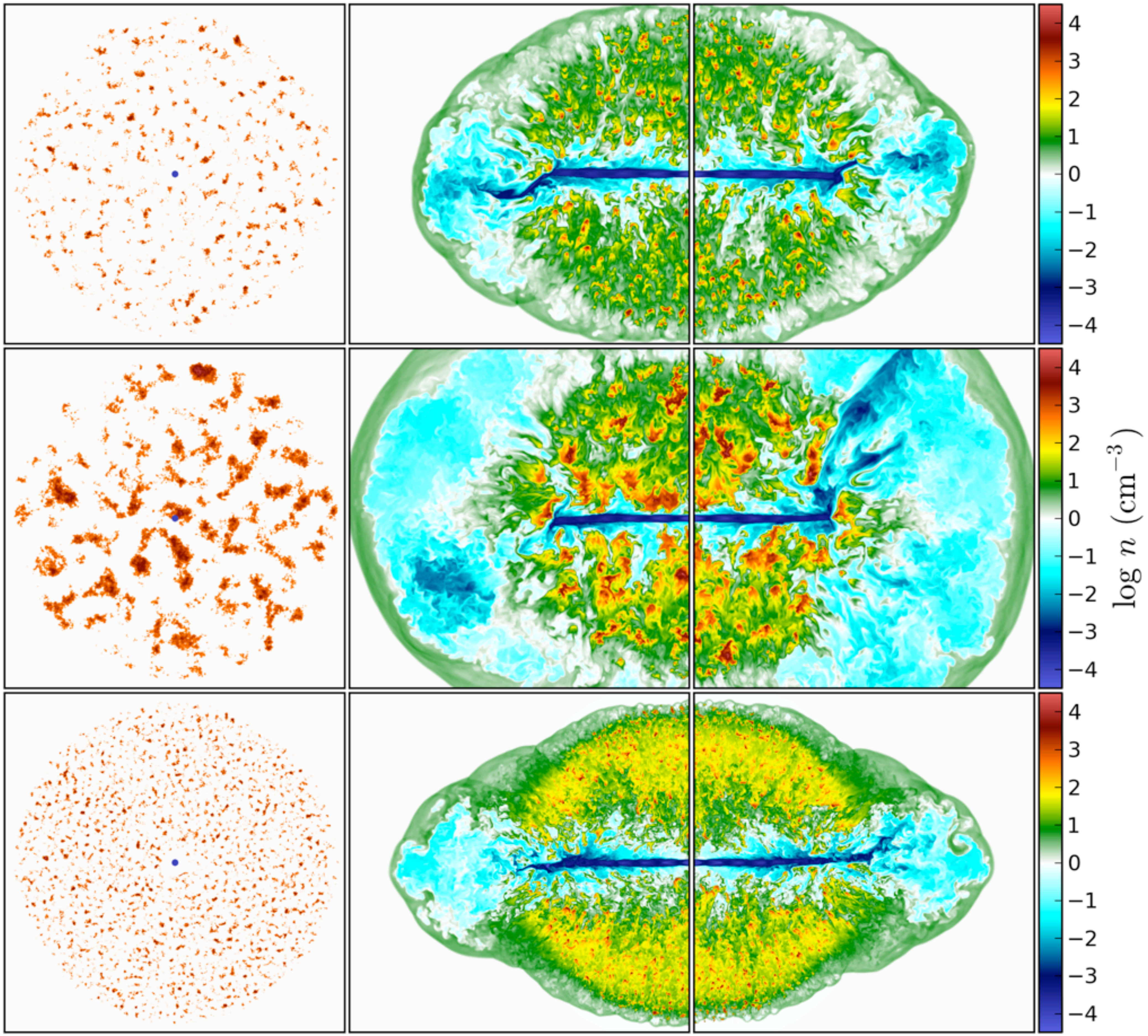


$\Gamma=10$, $P=10^{45}$ erg $^{s-1}$, $\chi = mc^2/4p = 1$

AGN Jet Feedback

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

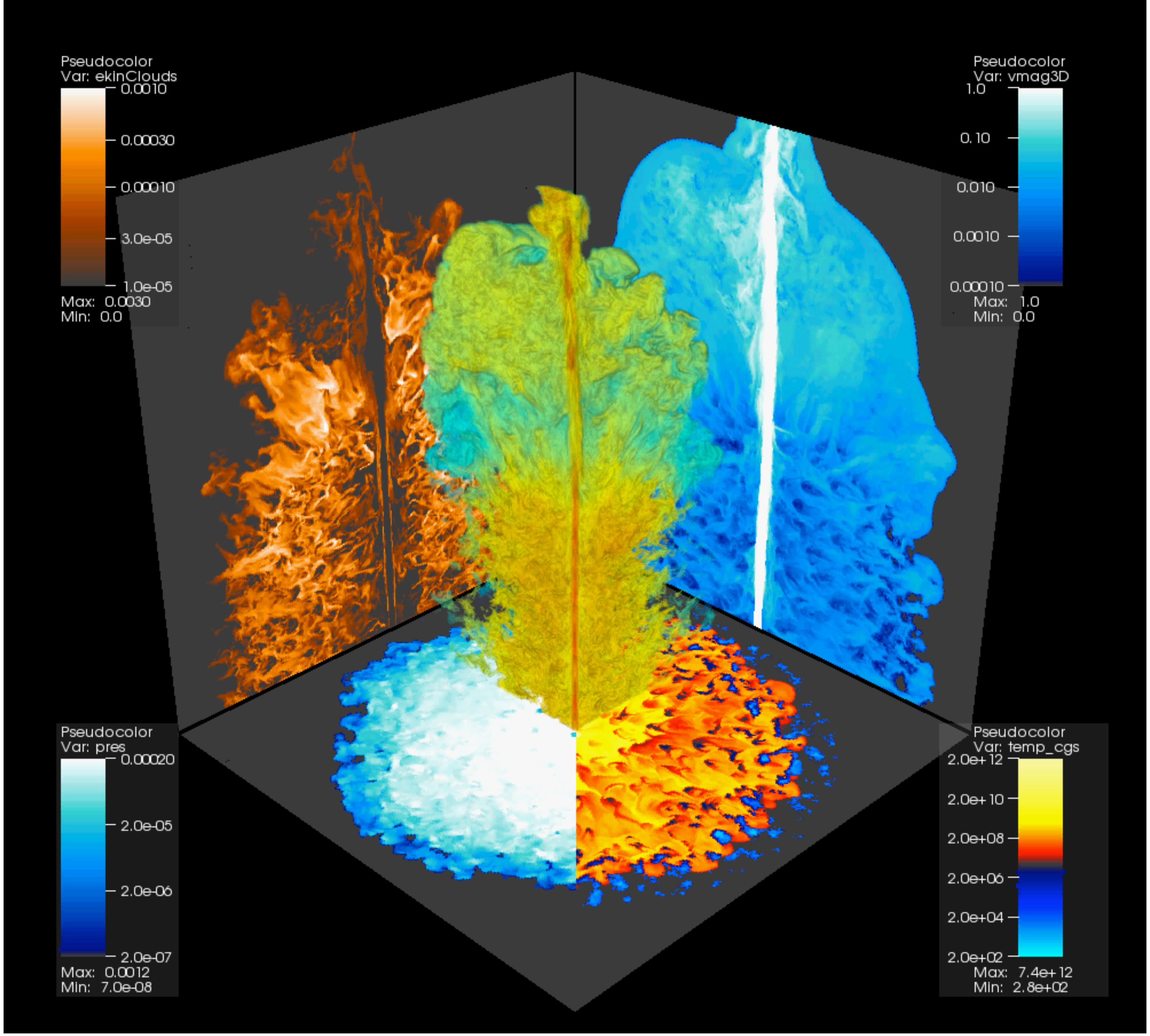
Filling factor and cloud sizes



$f_V = 0.027$
$R_{\mathrm{c,max}} \sim 25$ pc

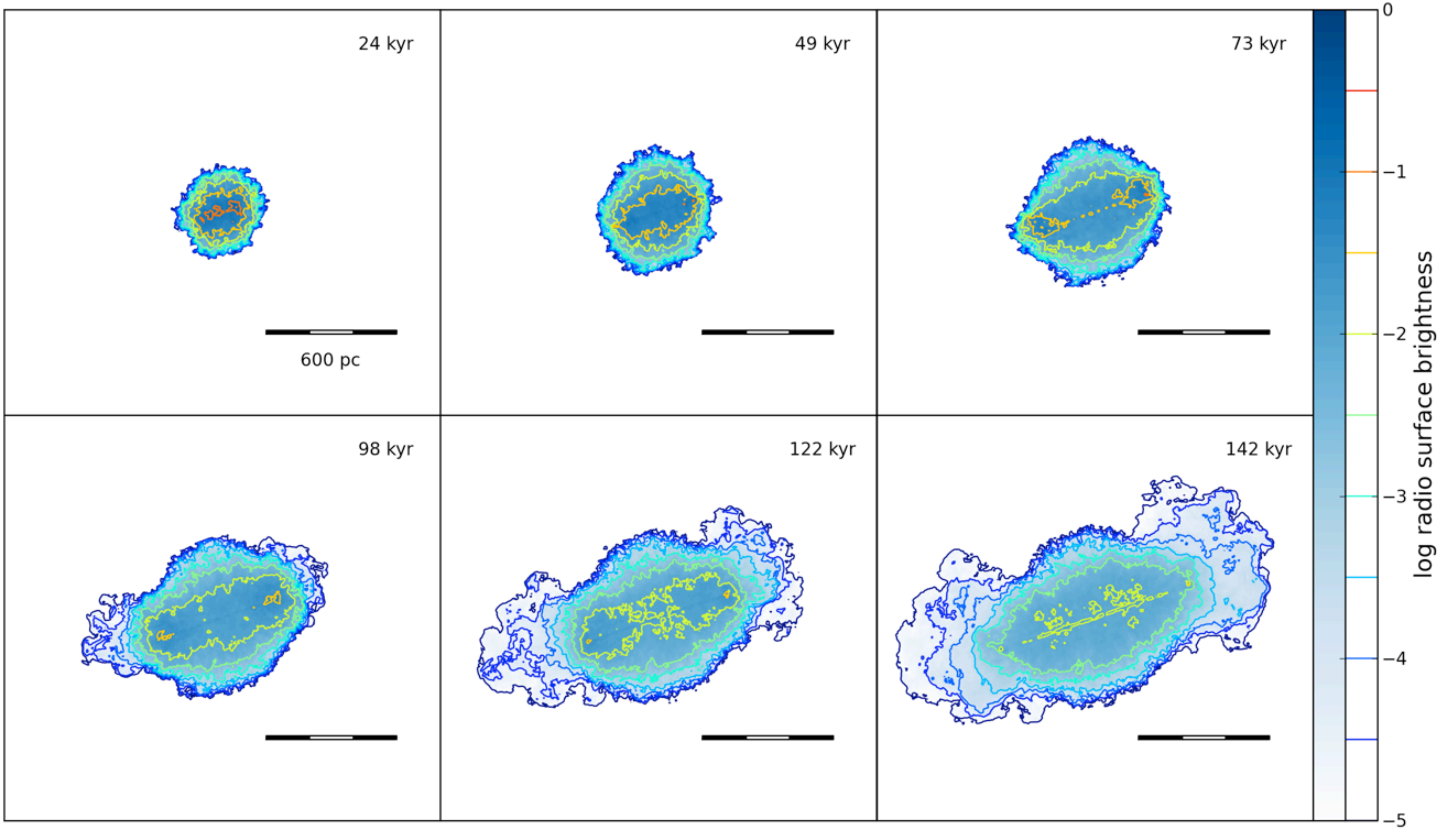
$f_V = 0.053$
$R_{\mathrm{c,max}} \sim 10$ pc

$f_V = 0.053$
$R_{\mathrm{c,max}} \sim 51$ pc



AGN Jet Feedback

Jet propagation
Energy deposition

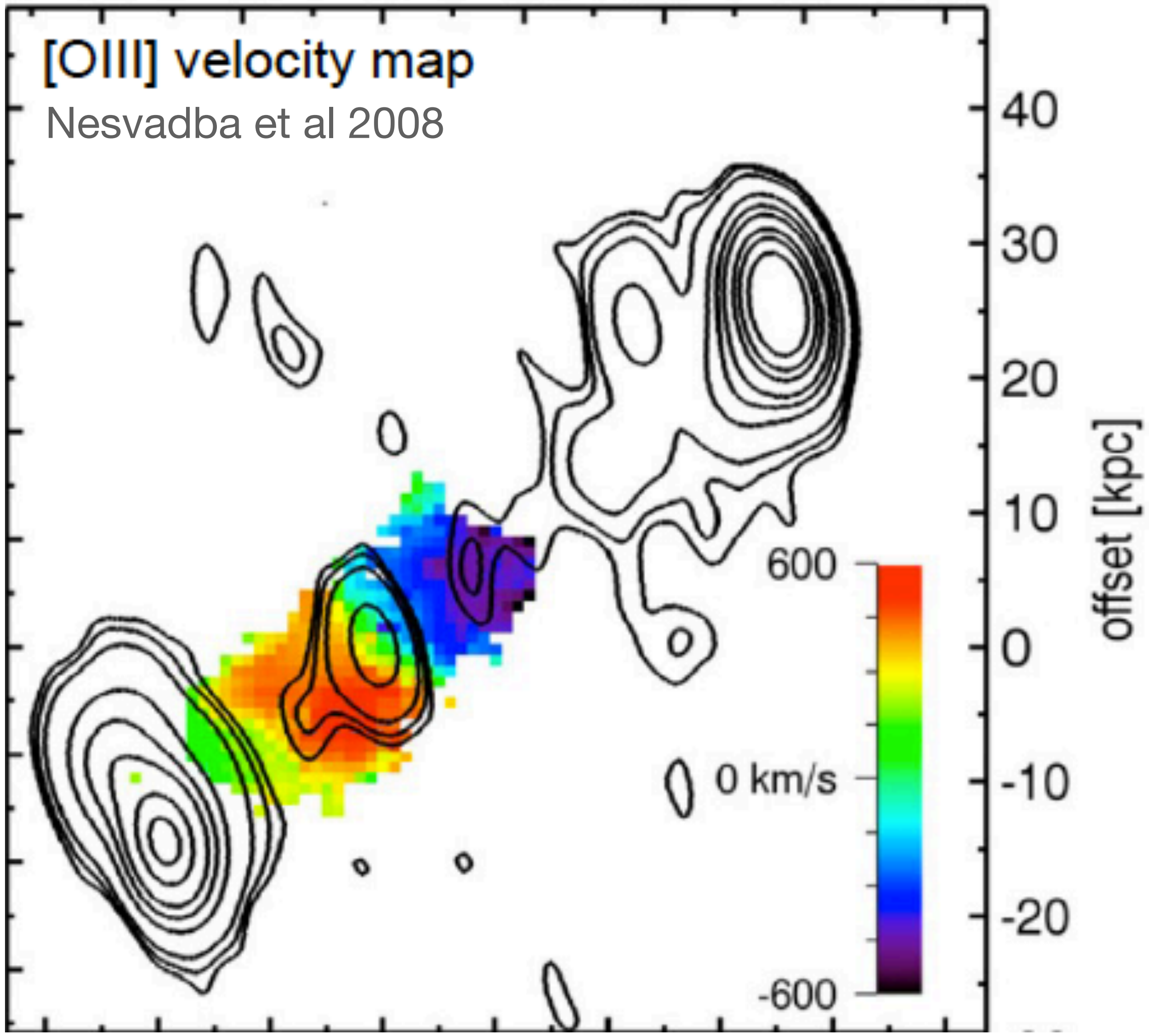


Synthetic radio images

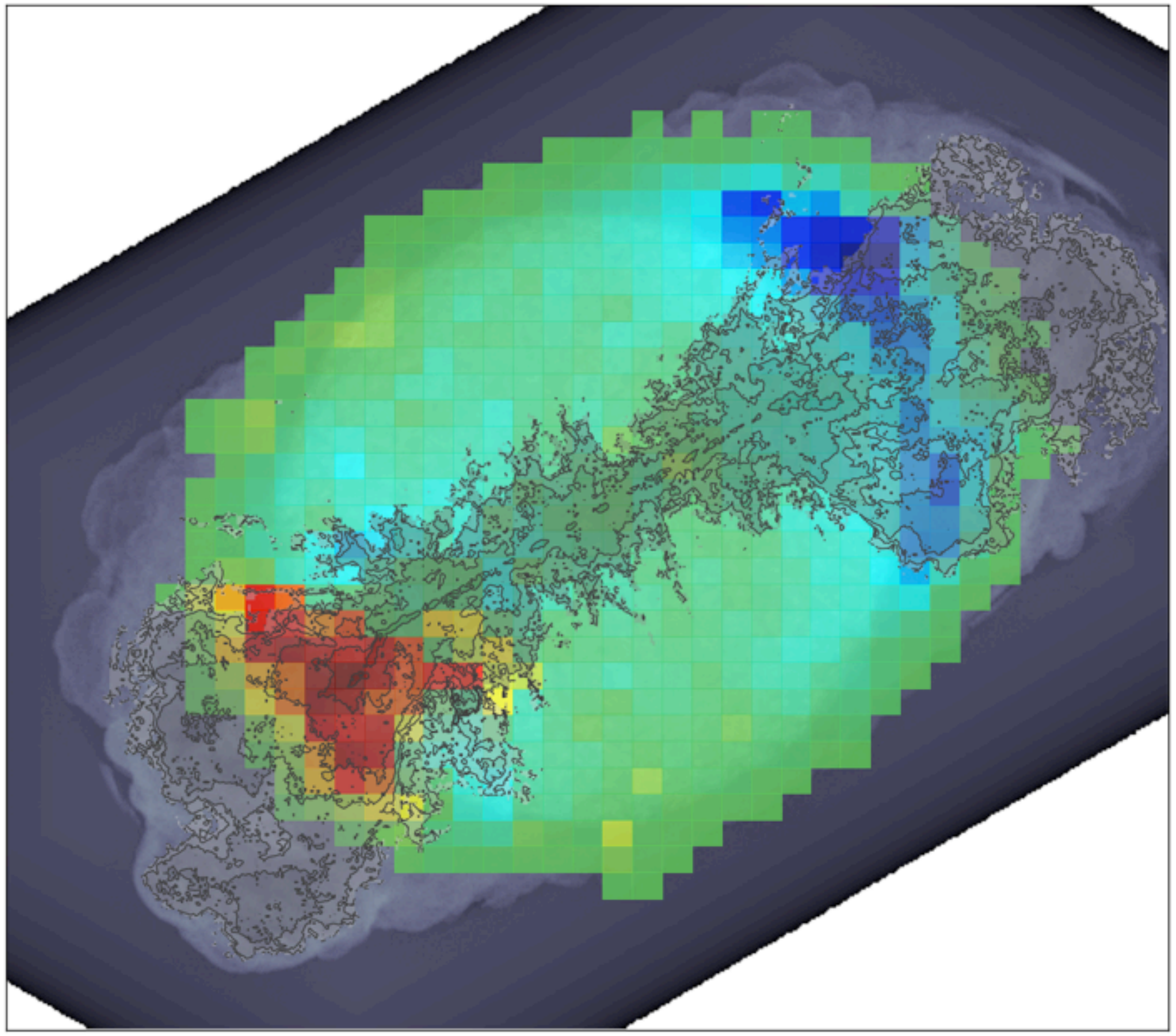
Useful in comparisons to HzRG (e.g. GPS and CSS sources).

Velocity map (km s^{-1})

Observed high-redshift galaxies



Synthetic maps from simulations

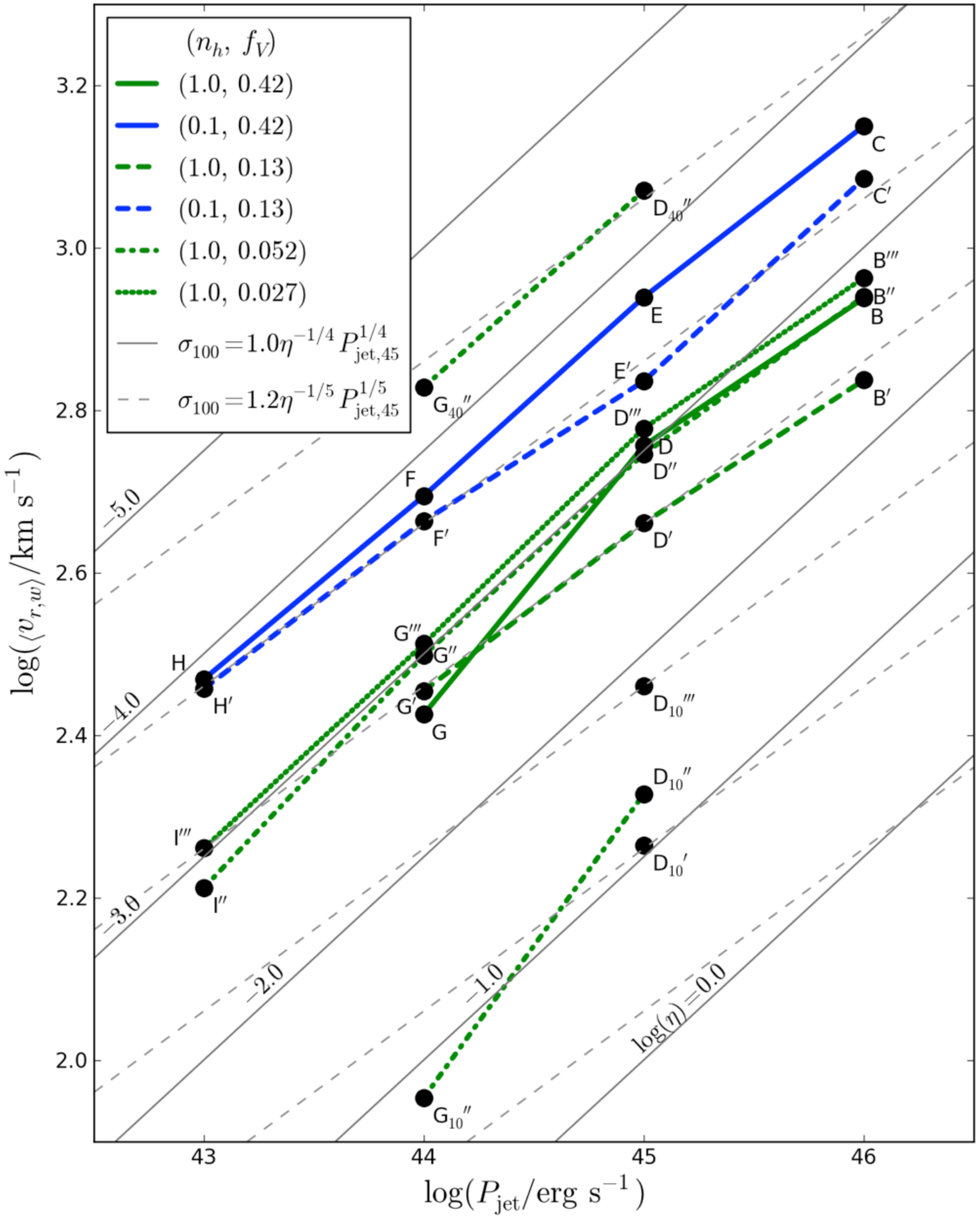


Synthetic IFU data

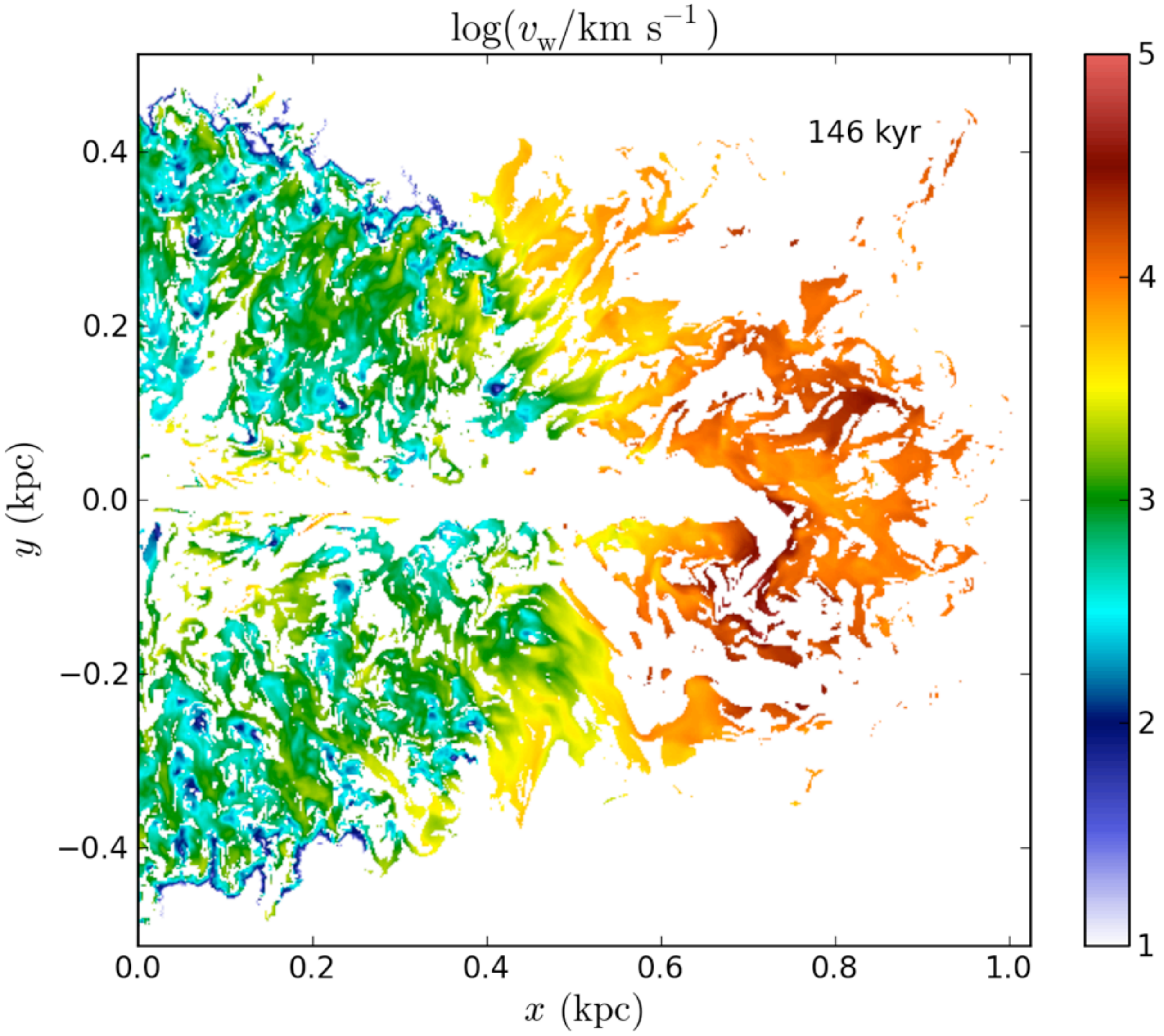
[OIII]

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).



AGN Jet Feedback

Efficiencies

Reason for strong dependence of feedback efficiency on cloud size:

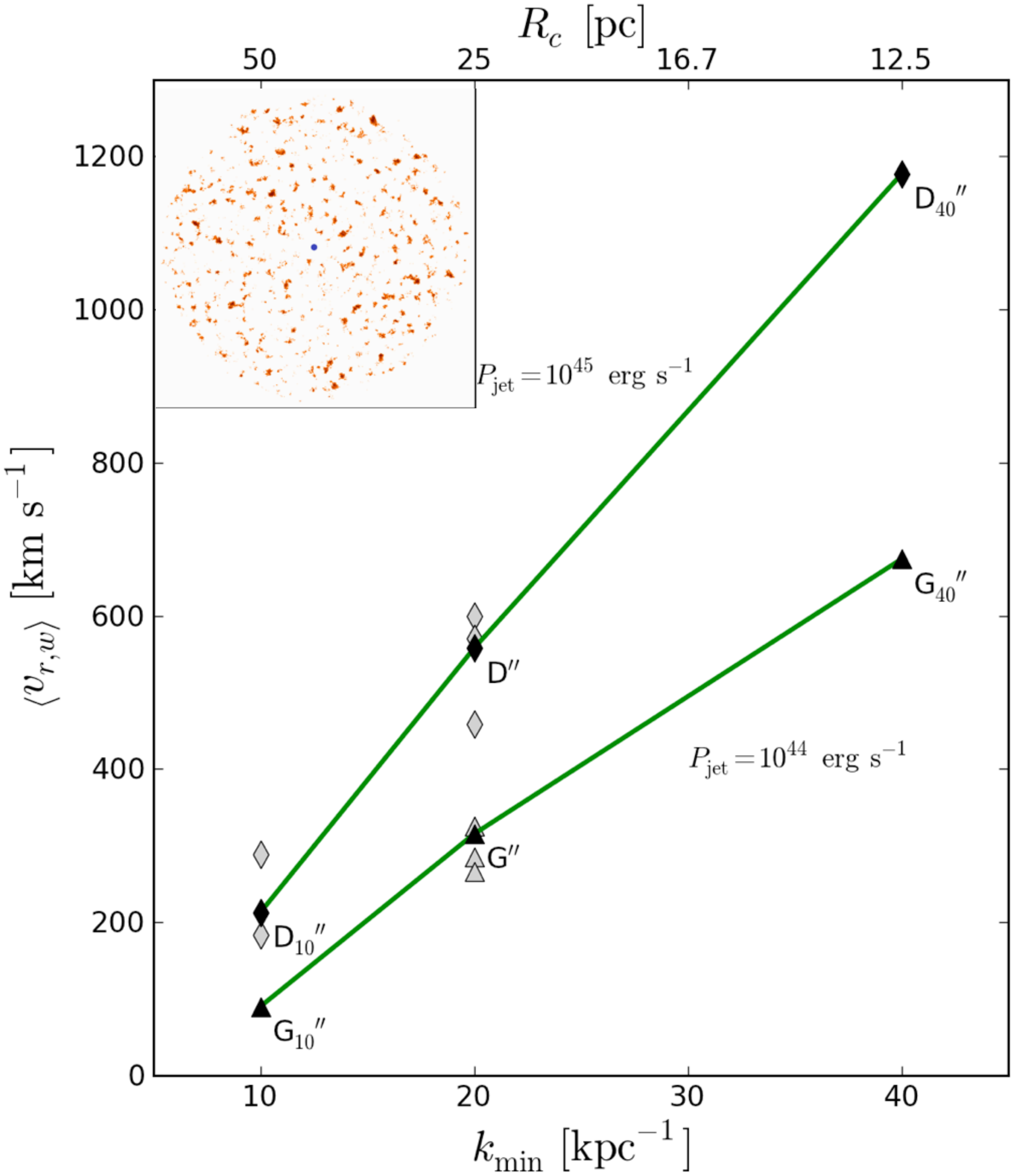
- View problem of jet propagation through galaxy as a (self-avoiding) random-walk/diffusion problem.
- We define an interaction depth:

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

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

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

Dependence on cloud sizes



AGN Jet Feedback

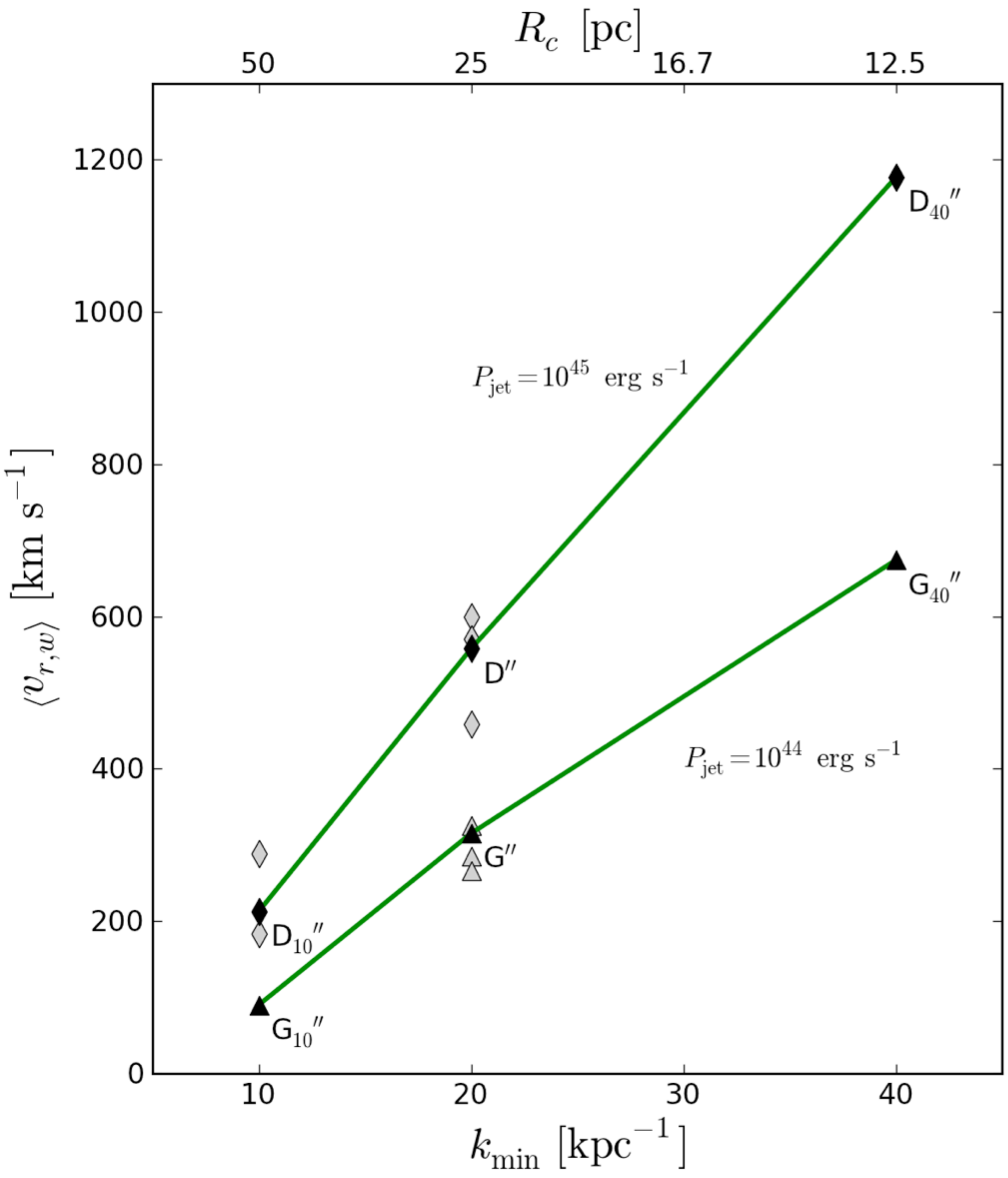
Efficiencies

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.

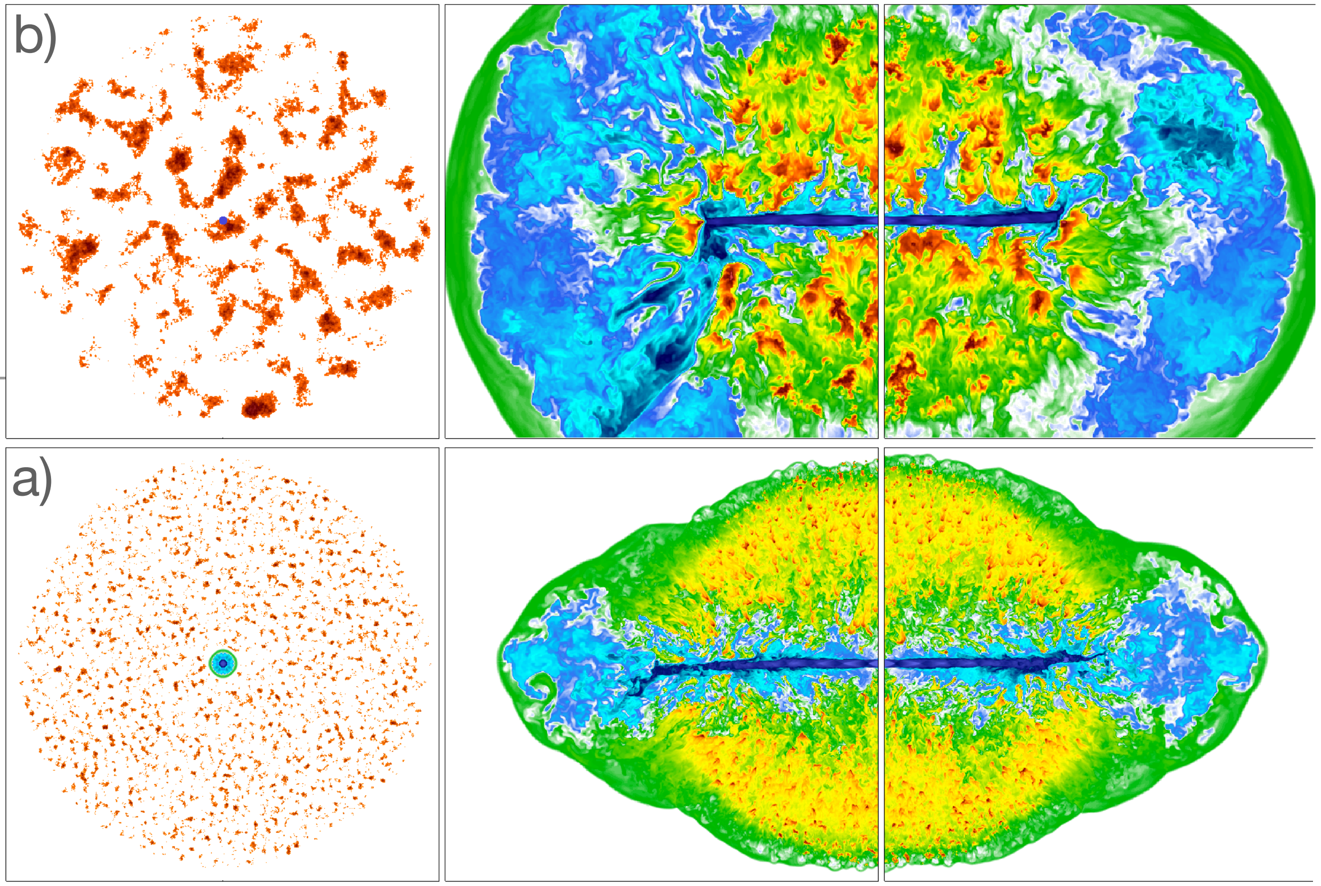
Dependence on cloud sizes



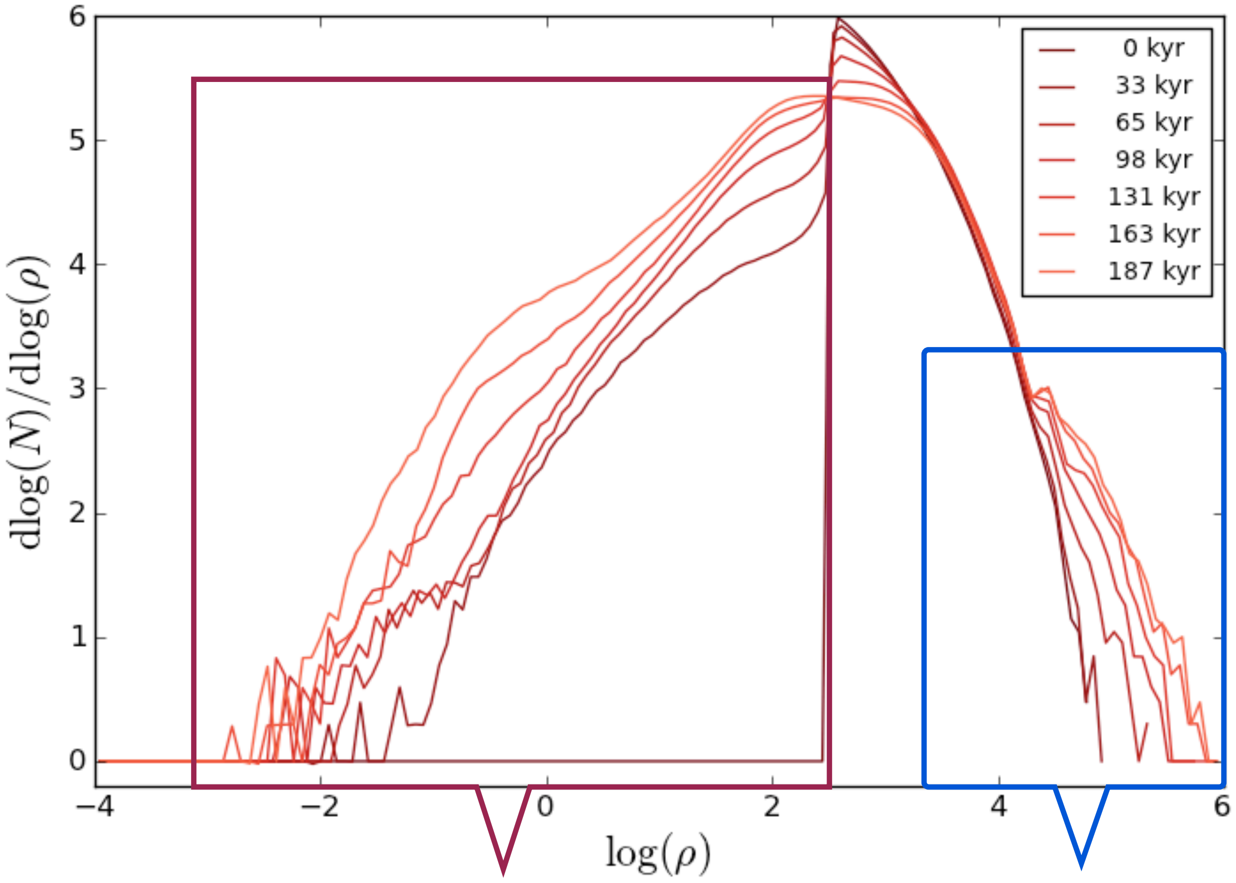
Positive feedback

Star formation

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

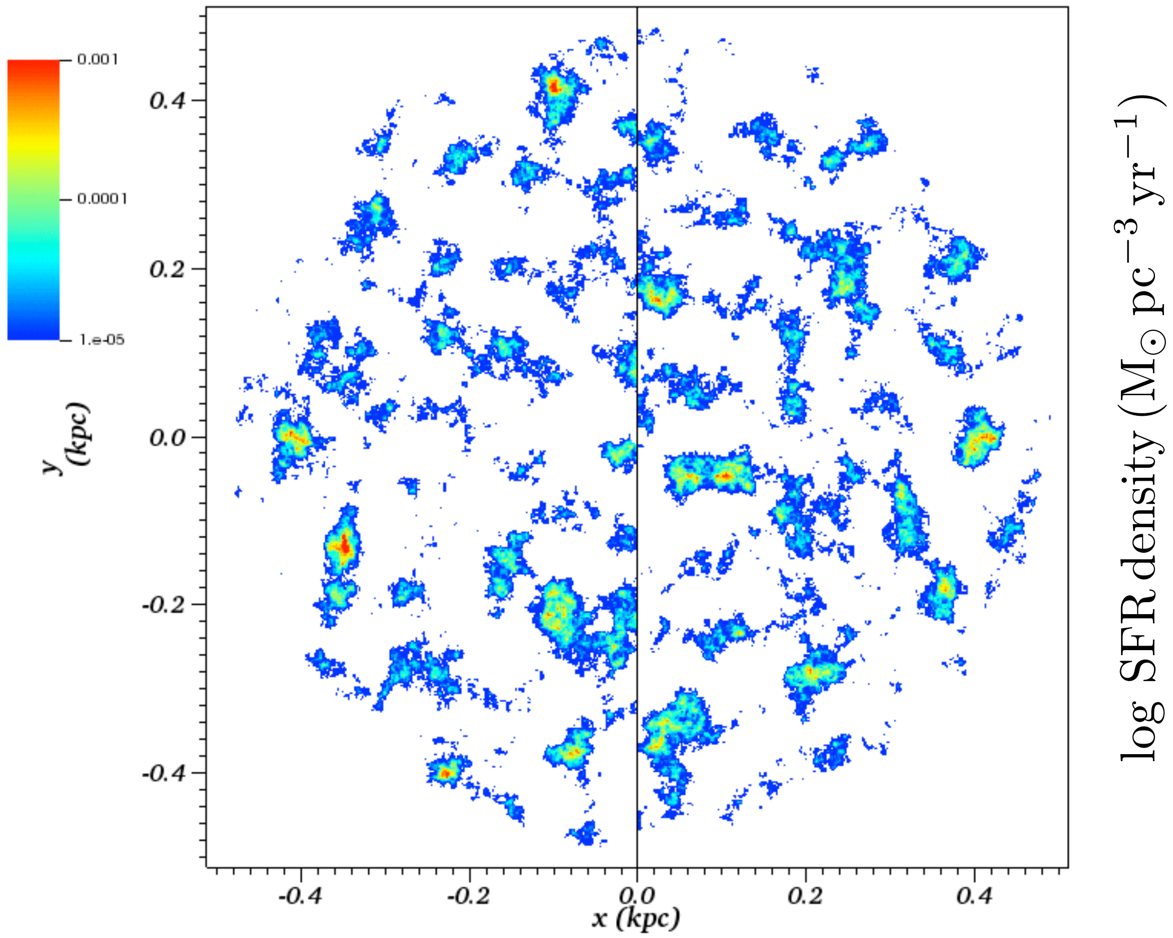


Evolution of density distribution



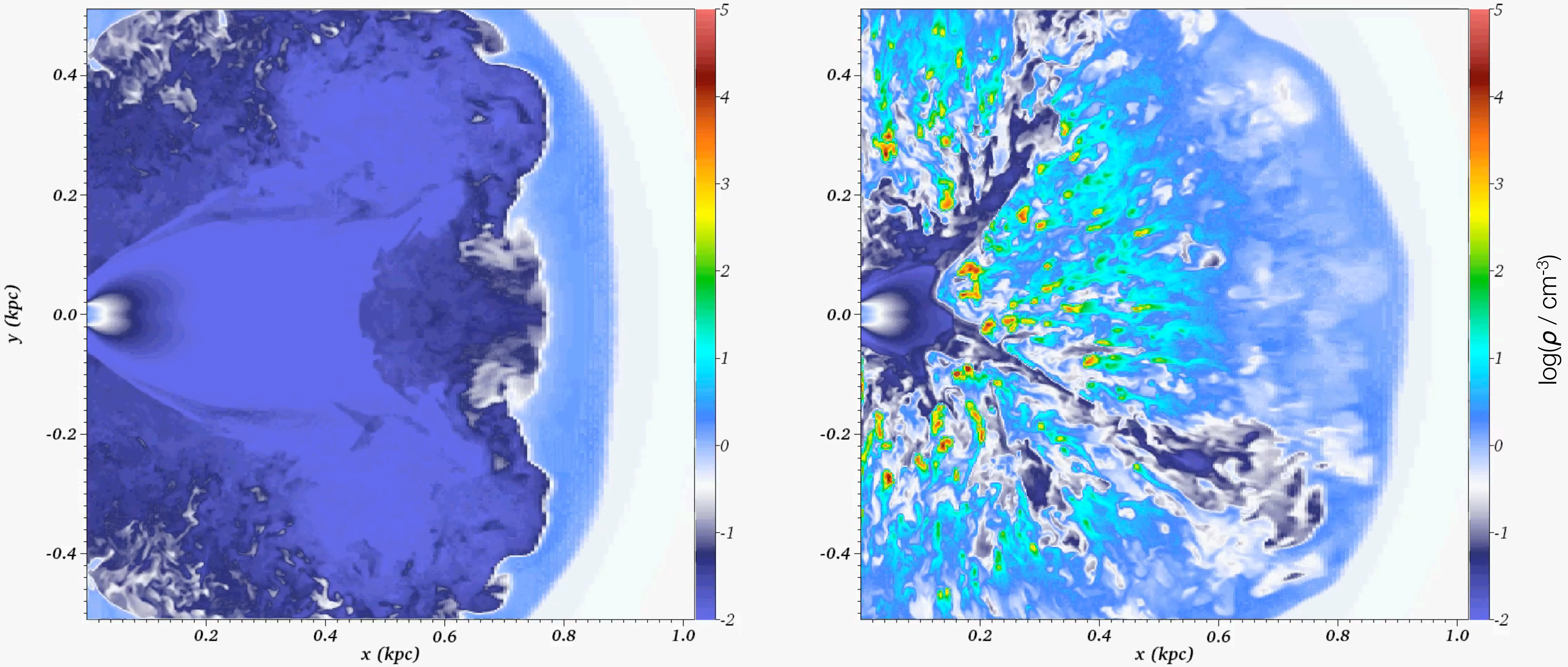
Negative Feedback

Positive Feedback



Simulations of feedback by UFOs

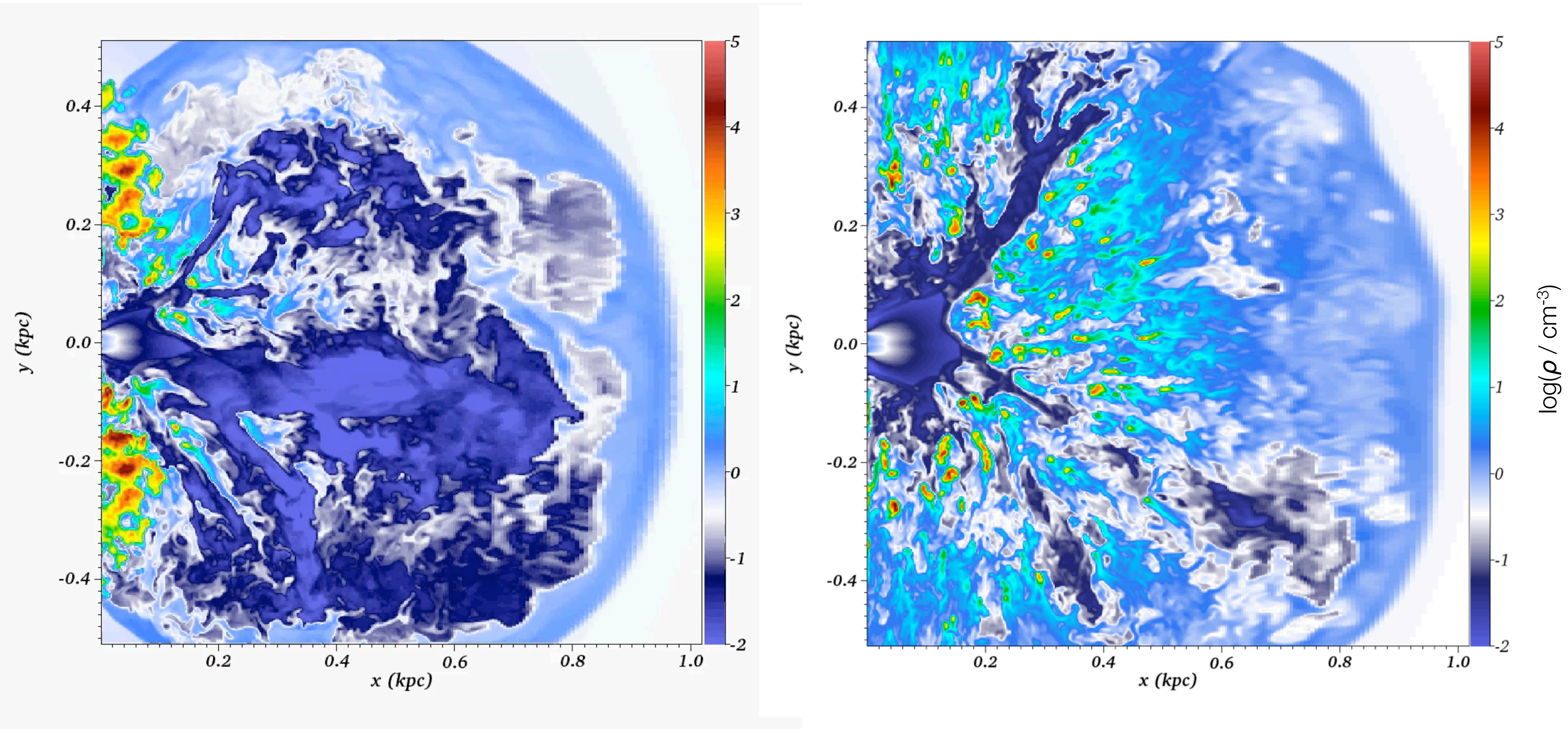
The case of spherically distributed clouds



- 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

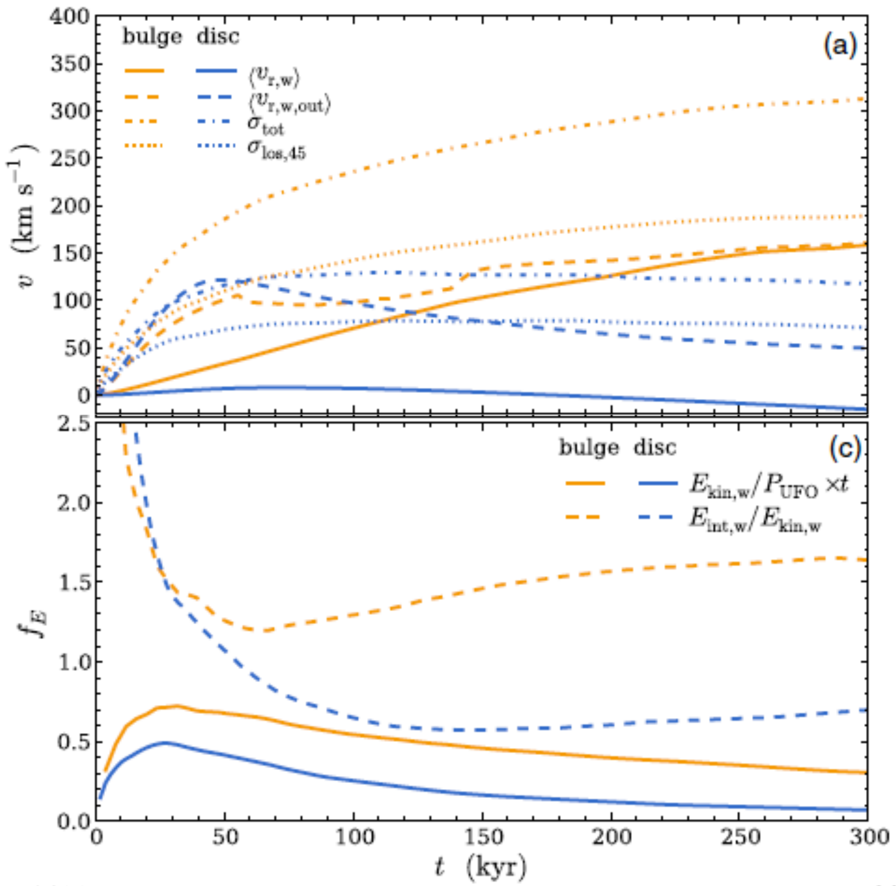
The case a disk-like distribution of clouds

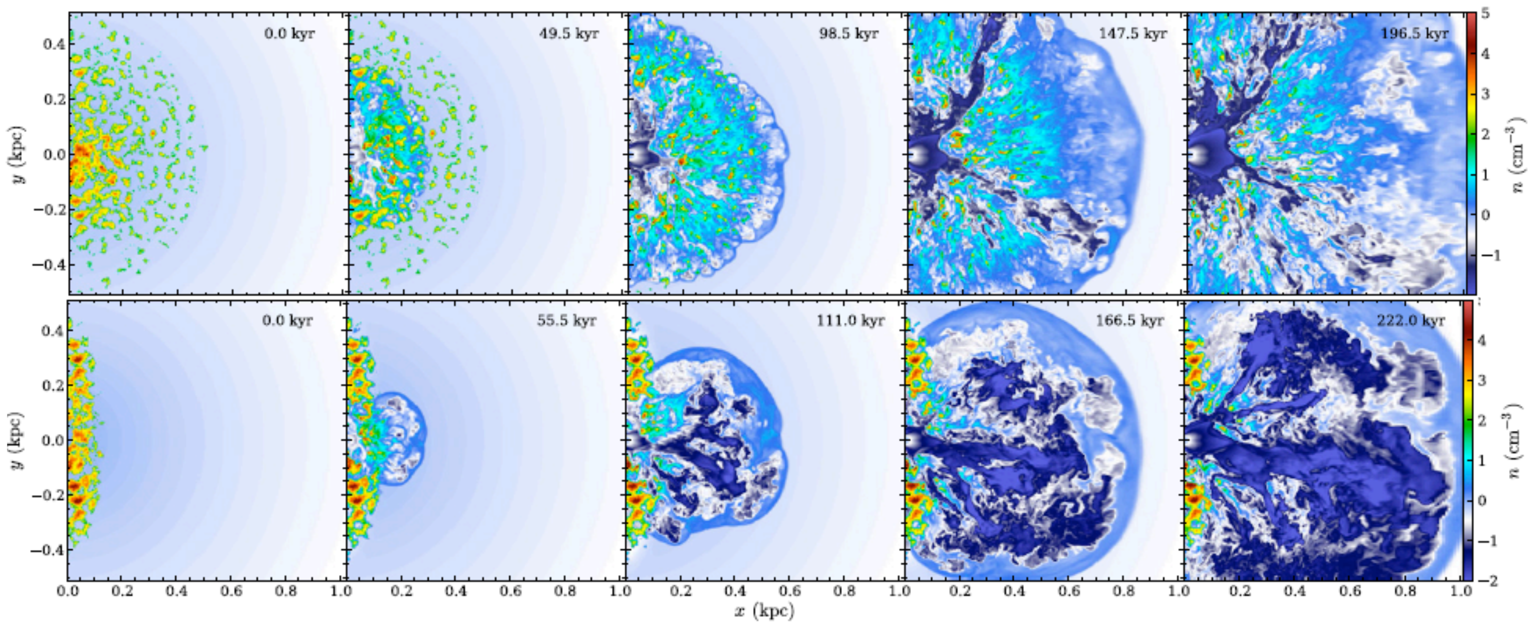


- Comparison between winds in a disc-like gas distribution and a spherical gas distribution.
- Gas at large disc-radii is compressed, while near the wind is blown out.

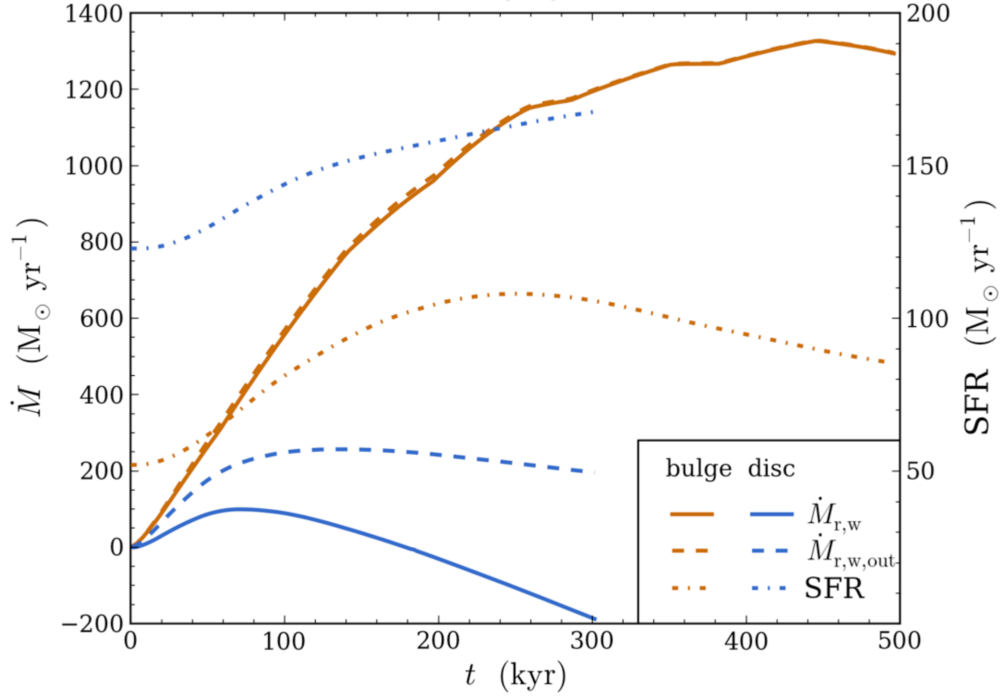
The efficiency of UFO feedback

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

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 efficiencies 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. Positive feedback may be significant in gas rich disc galaxies.

Summary in images