Radio-mode Feedback

Alex Wagner
Geoff Bicknell
(with previous contributions by Ralph Sutherland & Curtis Saxton)

Aims

- Provide "sub-grid" physics for cosmological AGN feedback calculations
- Understand the early stages of evolution of radio galaxies
- Theoretical basis for GMT and SKA observational programs

[OIII] and radio morphology of MRC0406-244

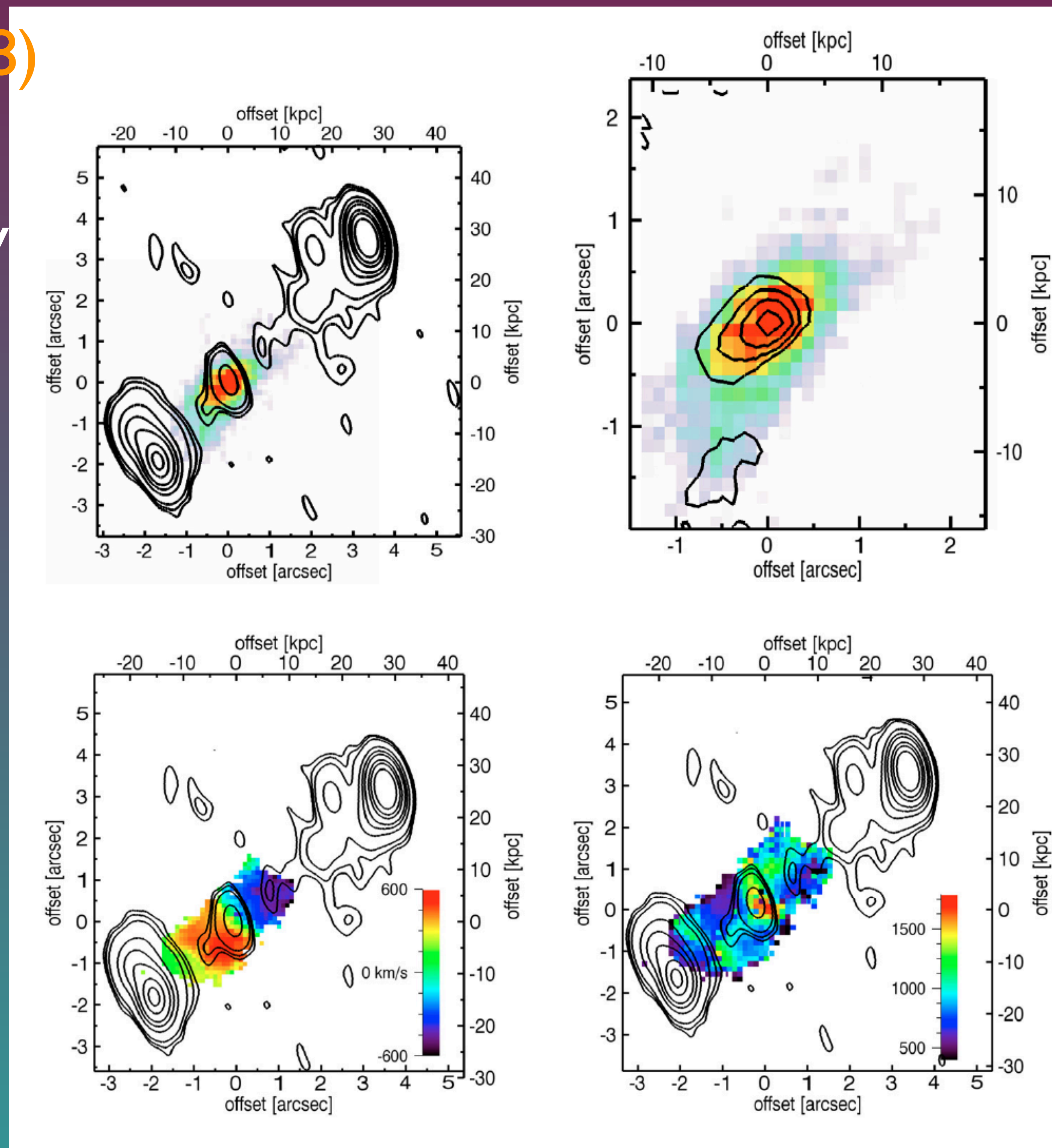
Nesvadba et al. '08)

[OIII] morphology

Contours of line-free continuum

[OIII] velocity

[OIII] velocity dispersion



Effect of an inhomogeneous medium

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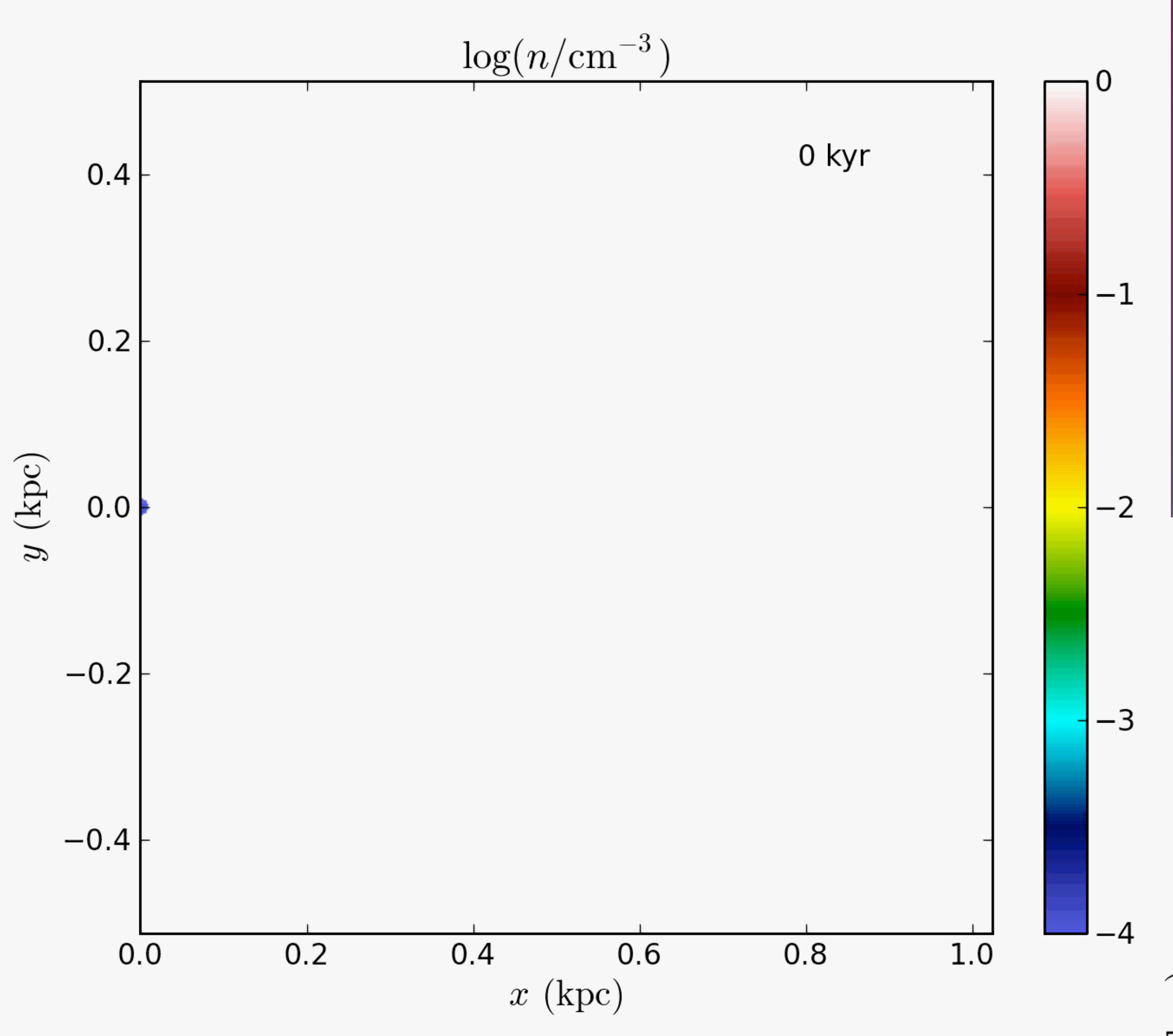

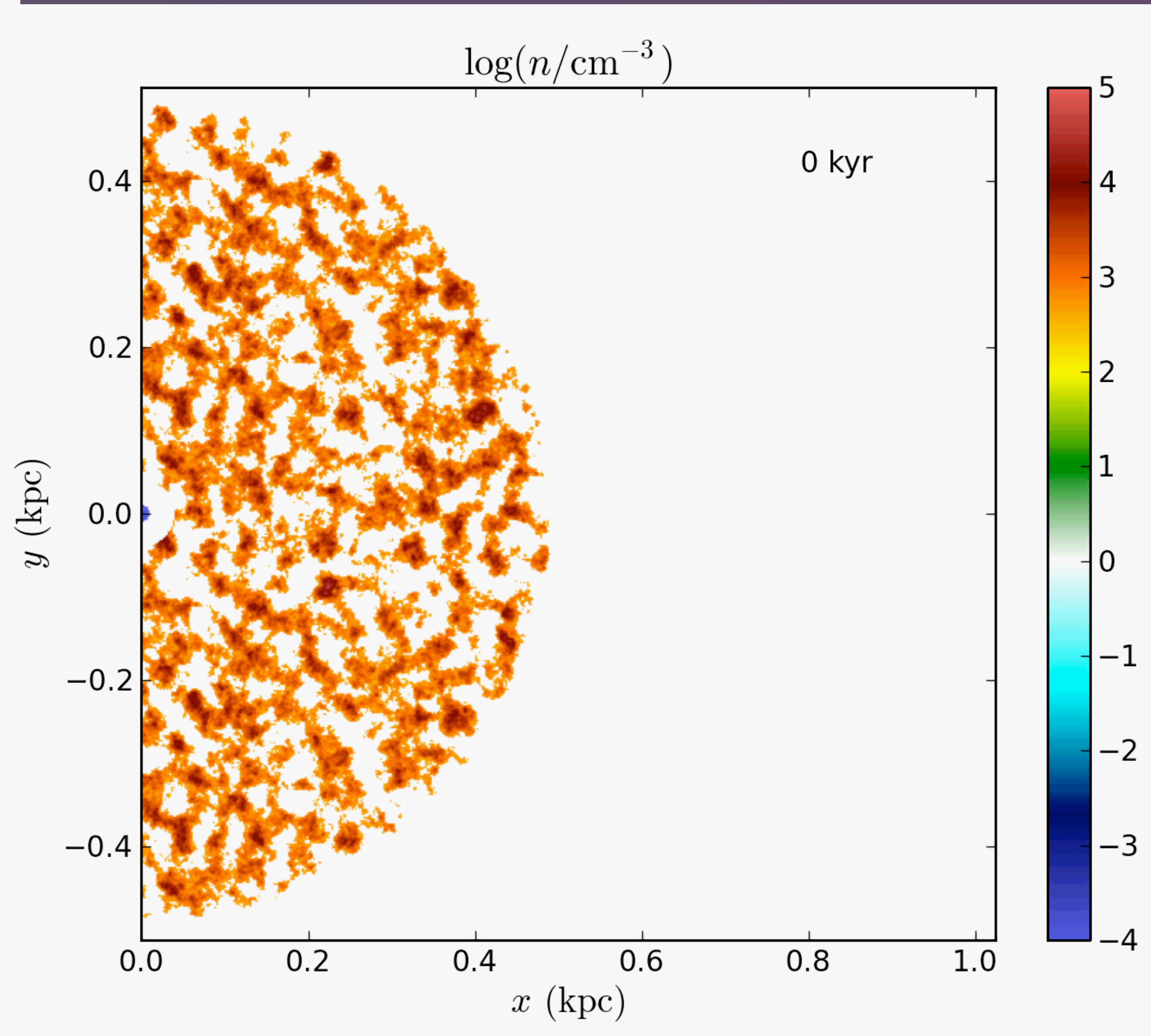

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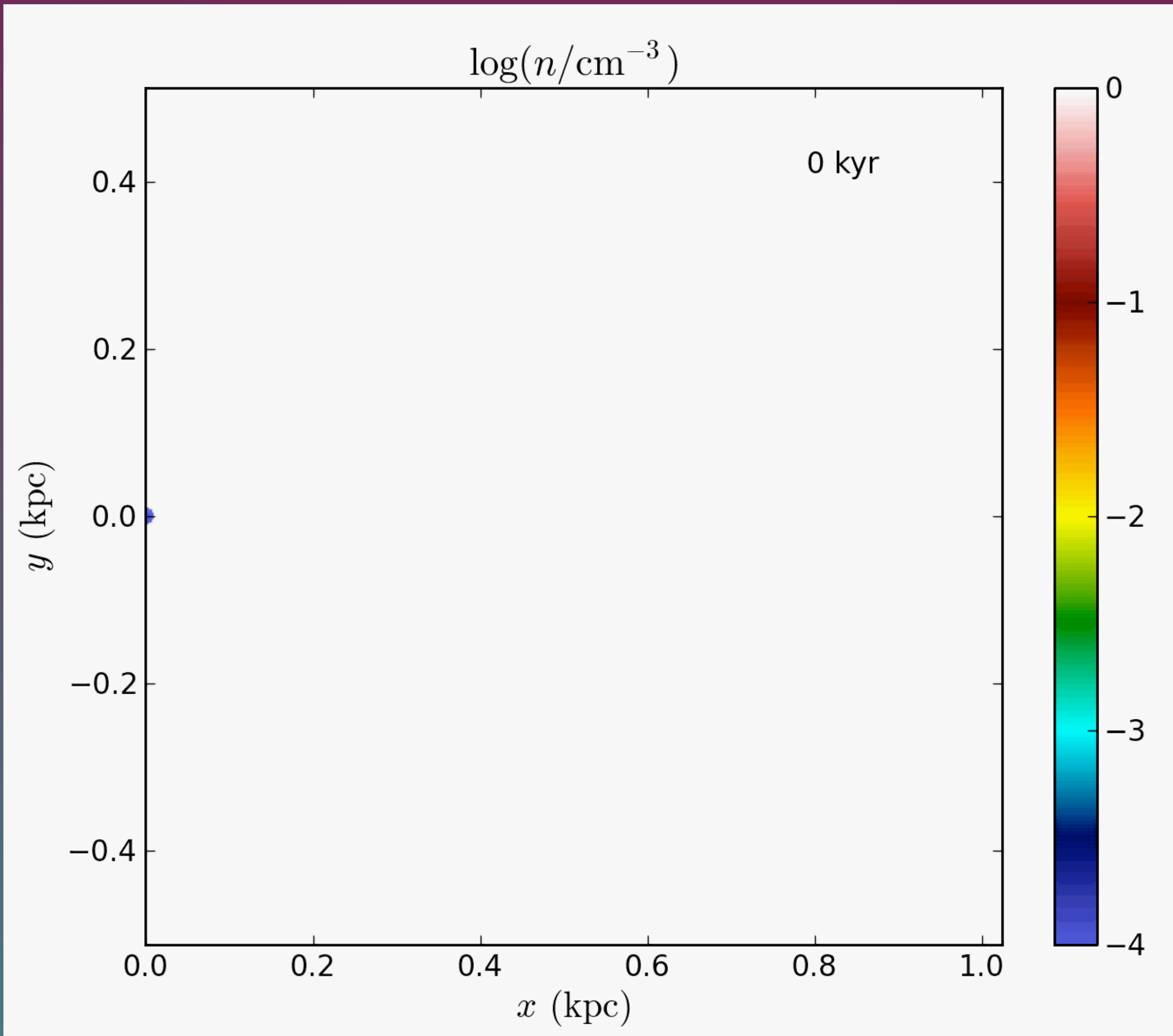
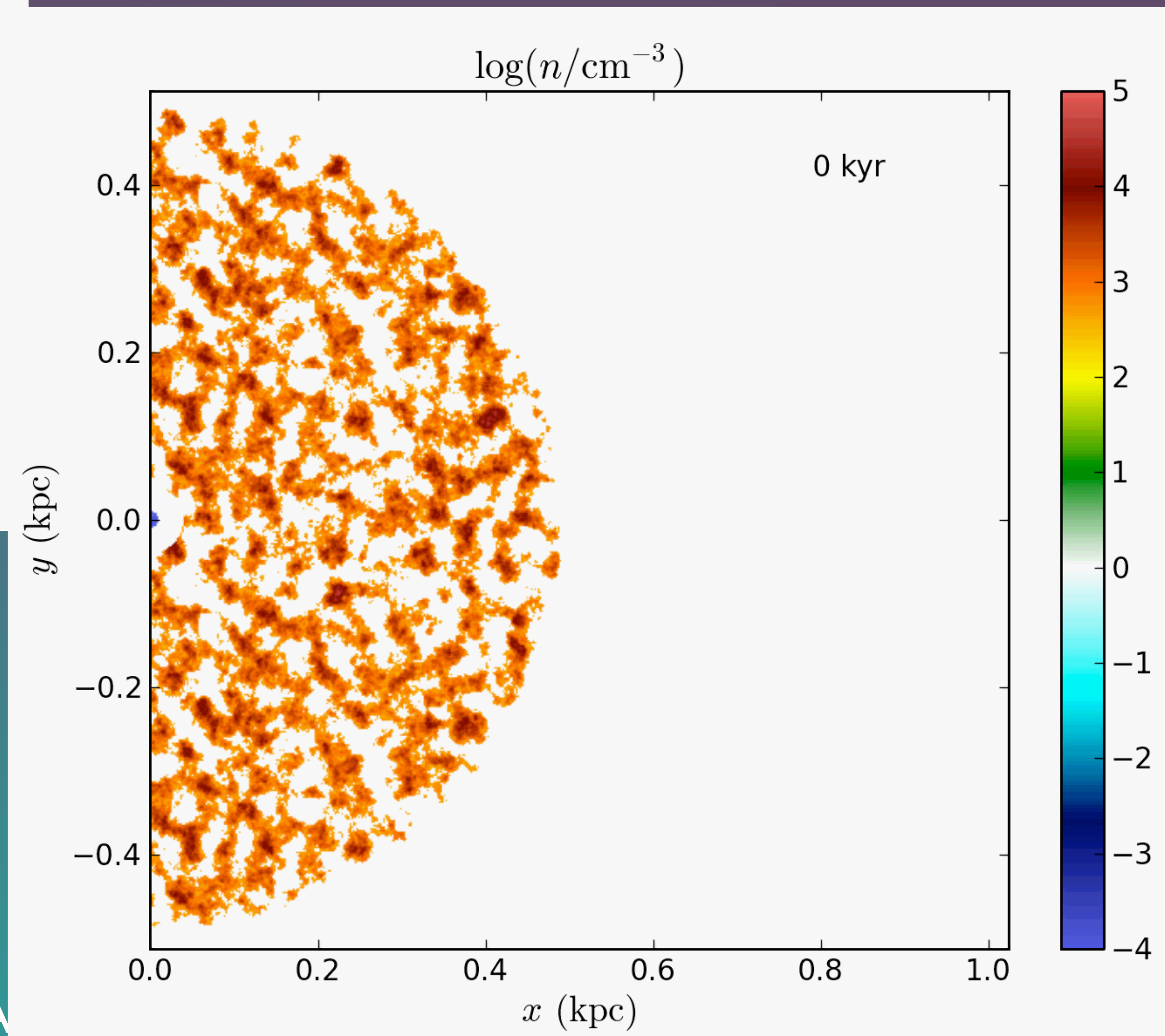
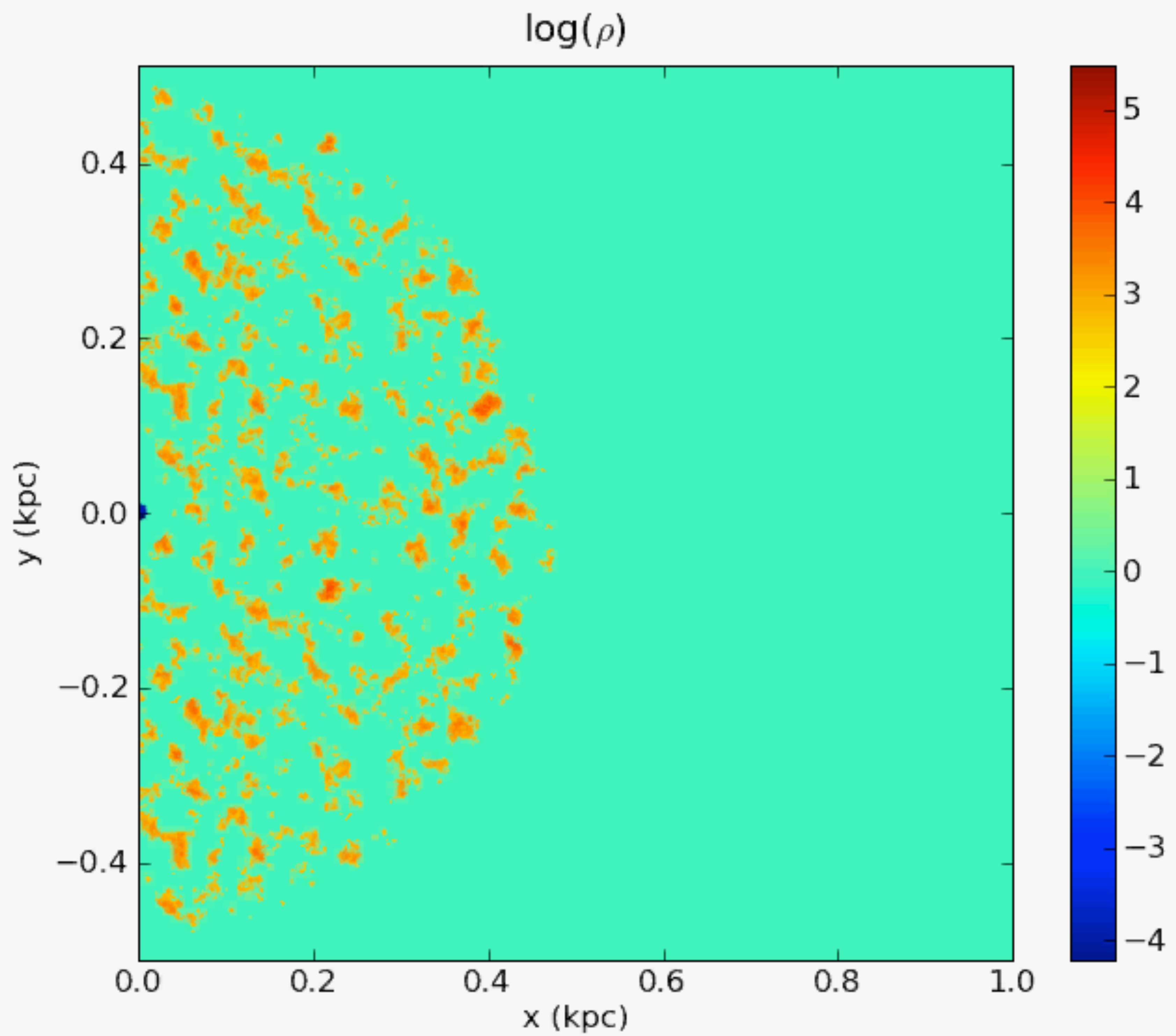




Typical run (D')



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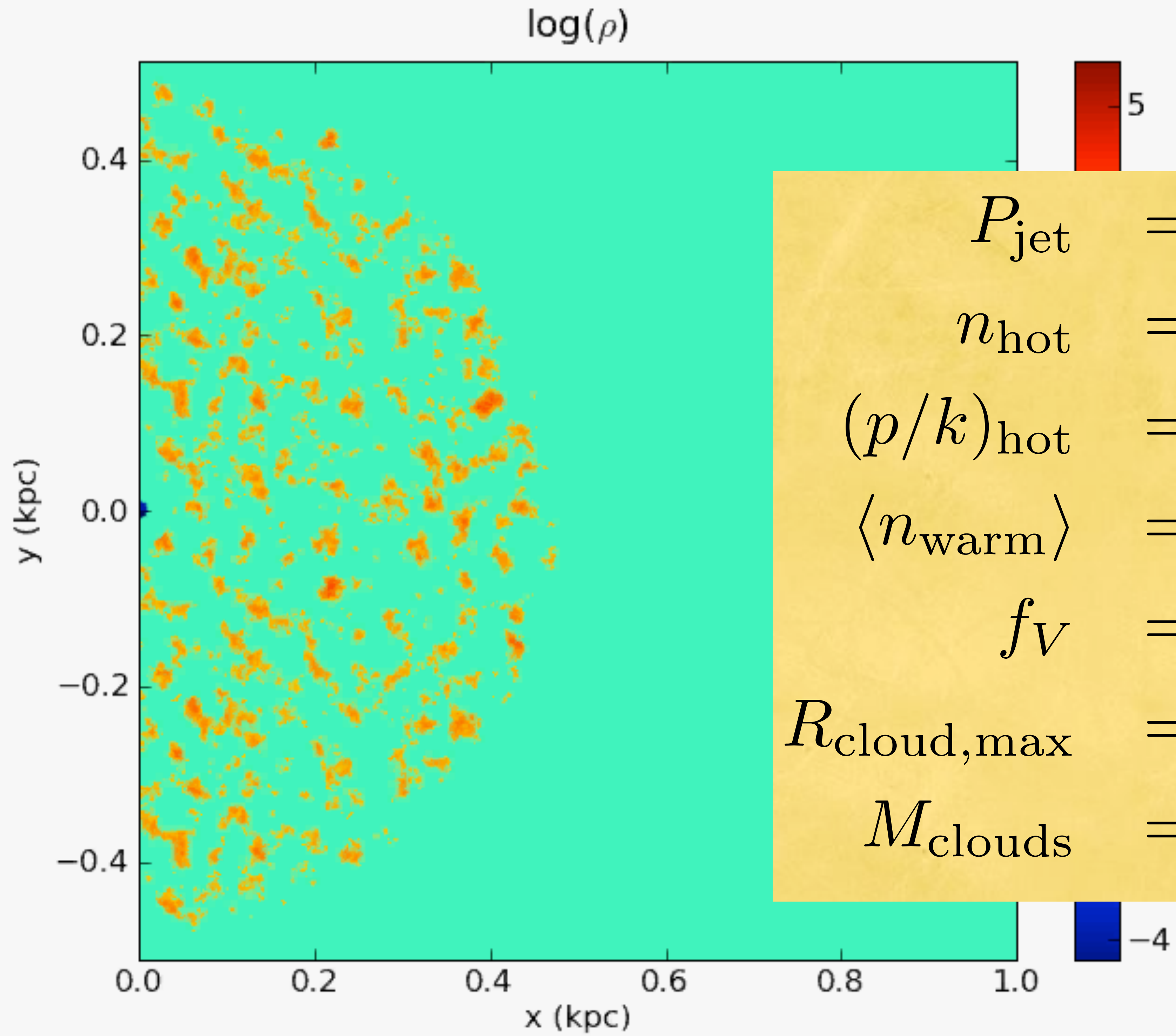
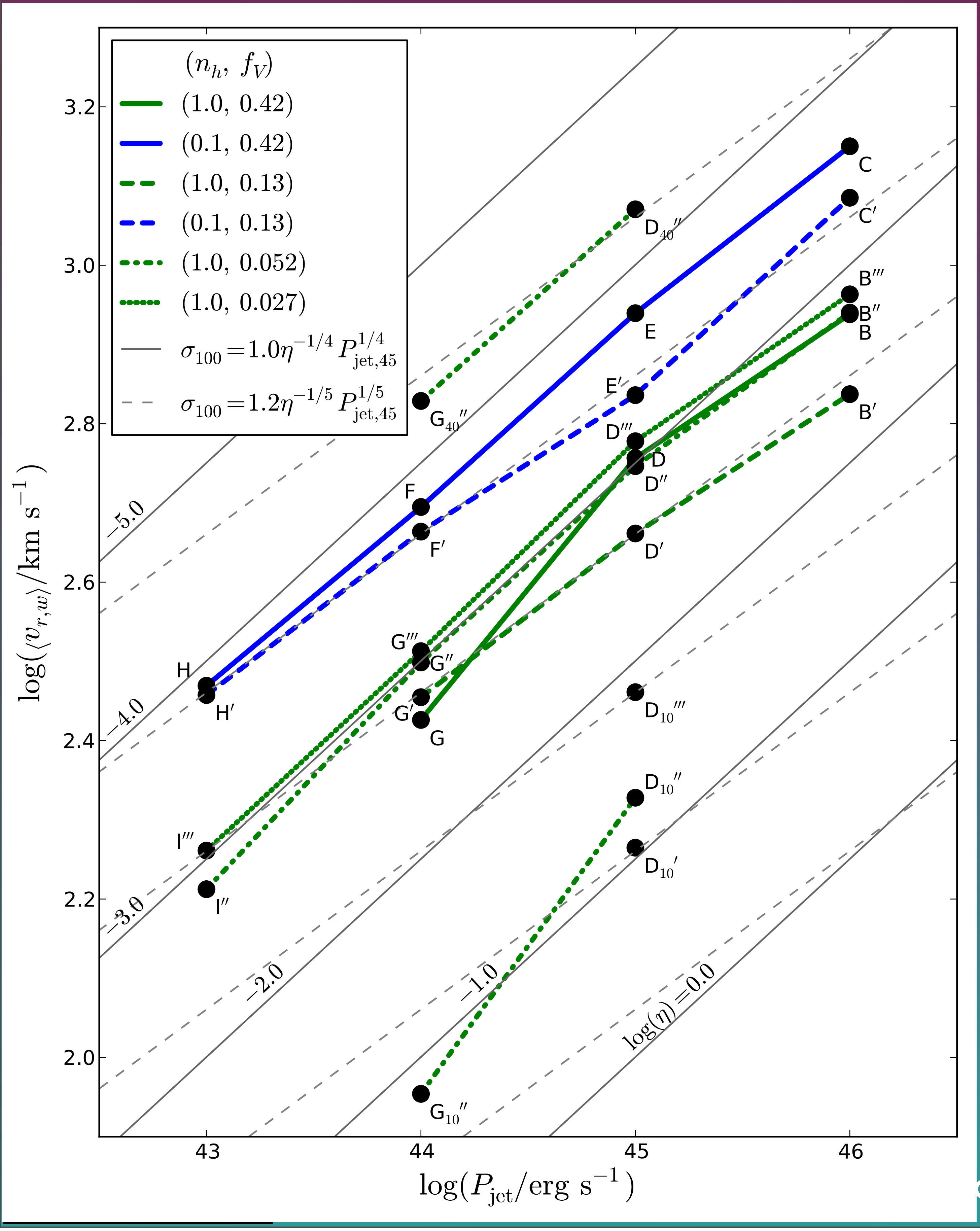


$$
\begin{aligned}
P_{\rm jet} &= 10^{45}\ {\rm ergs\ s^{-1}} \\
n_{\rm hot} &= 1.0\ {\rm cm^{-3}} \\
(p/k)_{\rm hot} &= 10^{7} \\
\langle n_{\rm warm} \rangle &= 300\ {\rm cm^{-3}} \\
f_V &= 0.13 \\
R_{\rm cloud,max} &= 25\ {\rm pc} \\
M_{\rm clouds} &= 3.2 \times 10^{9}\ M_{\odot}
\end{aligned}
$$

Velocity-power diagram



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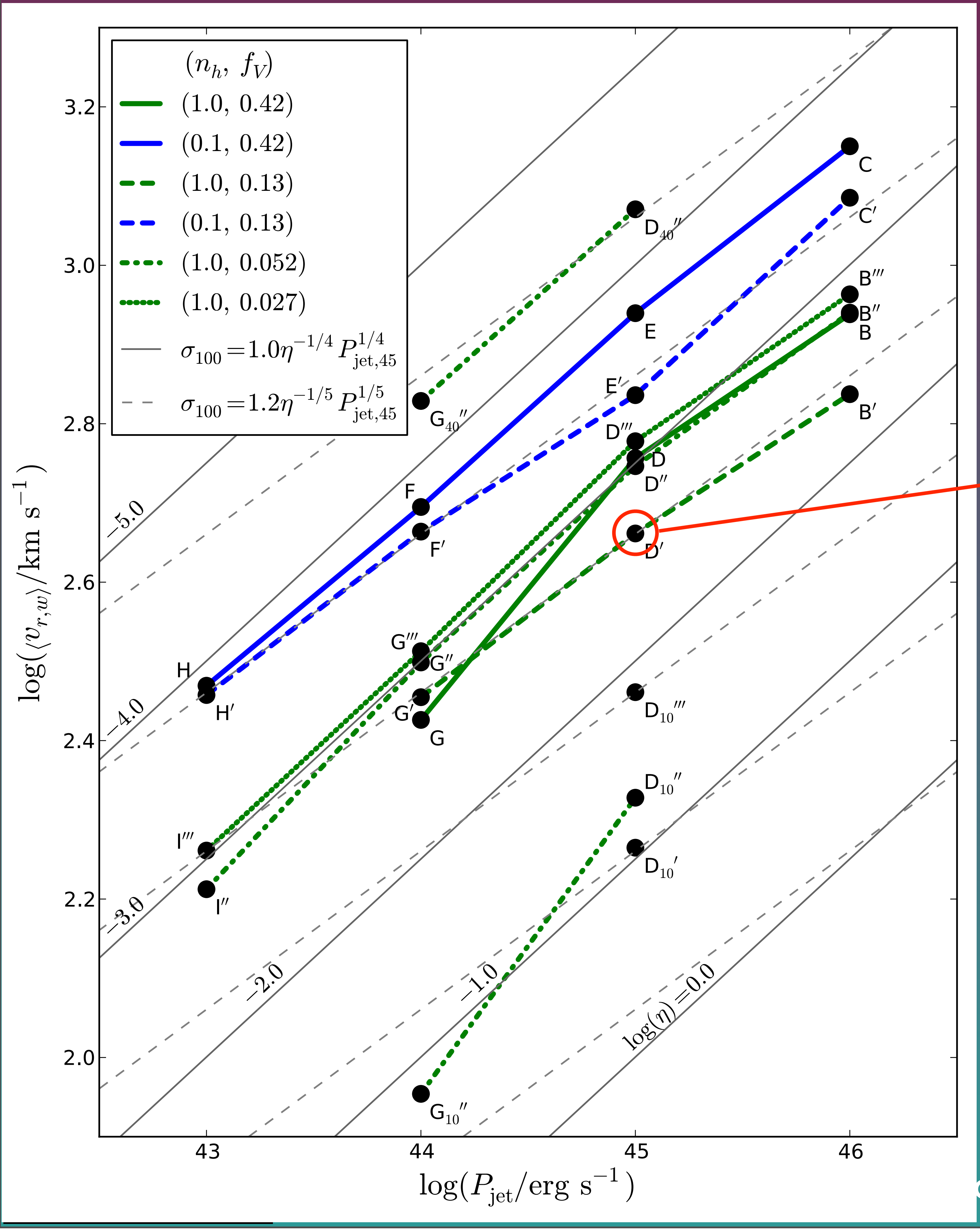
Velocity-power diagram



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$$R_{\rm cloud,max} = 25\ {\rm pc}$$
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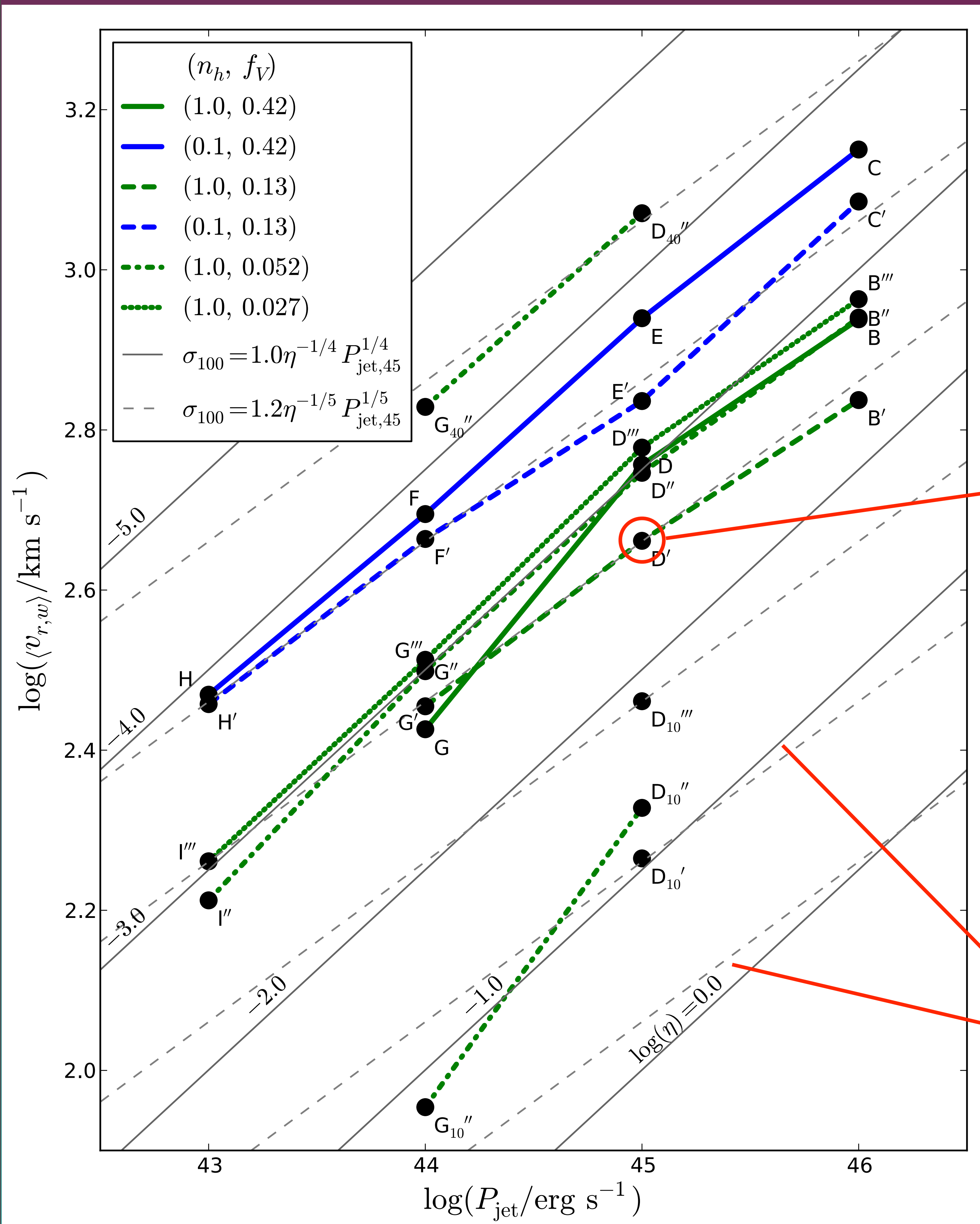
Velocity-power diagram



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$$R_{\mathrm{cloud,max}} = 25\ \mathrm{pc}$$
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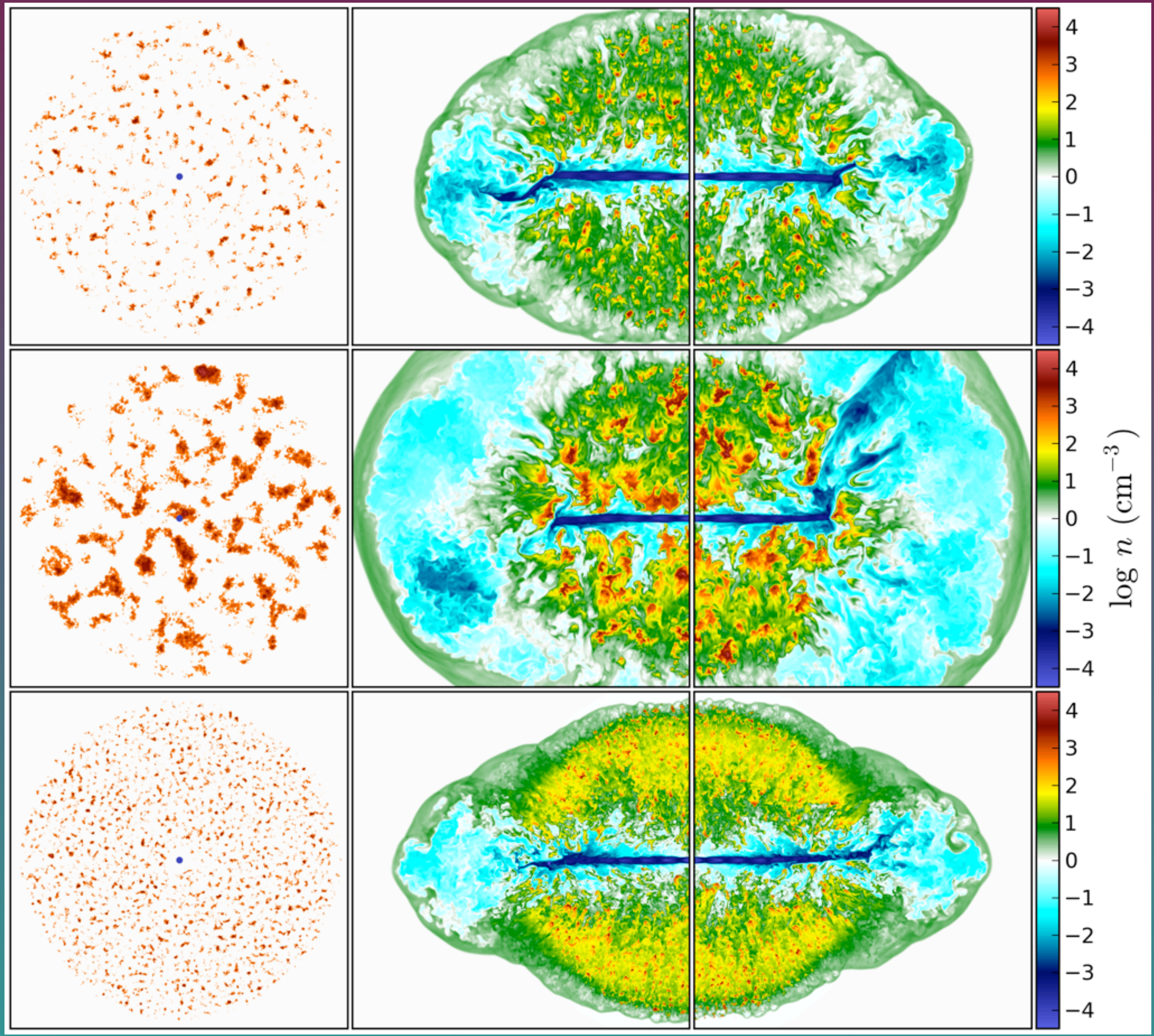
Loci of constant $\eta = \dfrac{P_{\mathrm{jet}}}{L_{\mathrm{Edd}}}$

Filling factor and cloud size

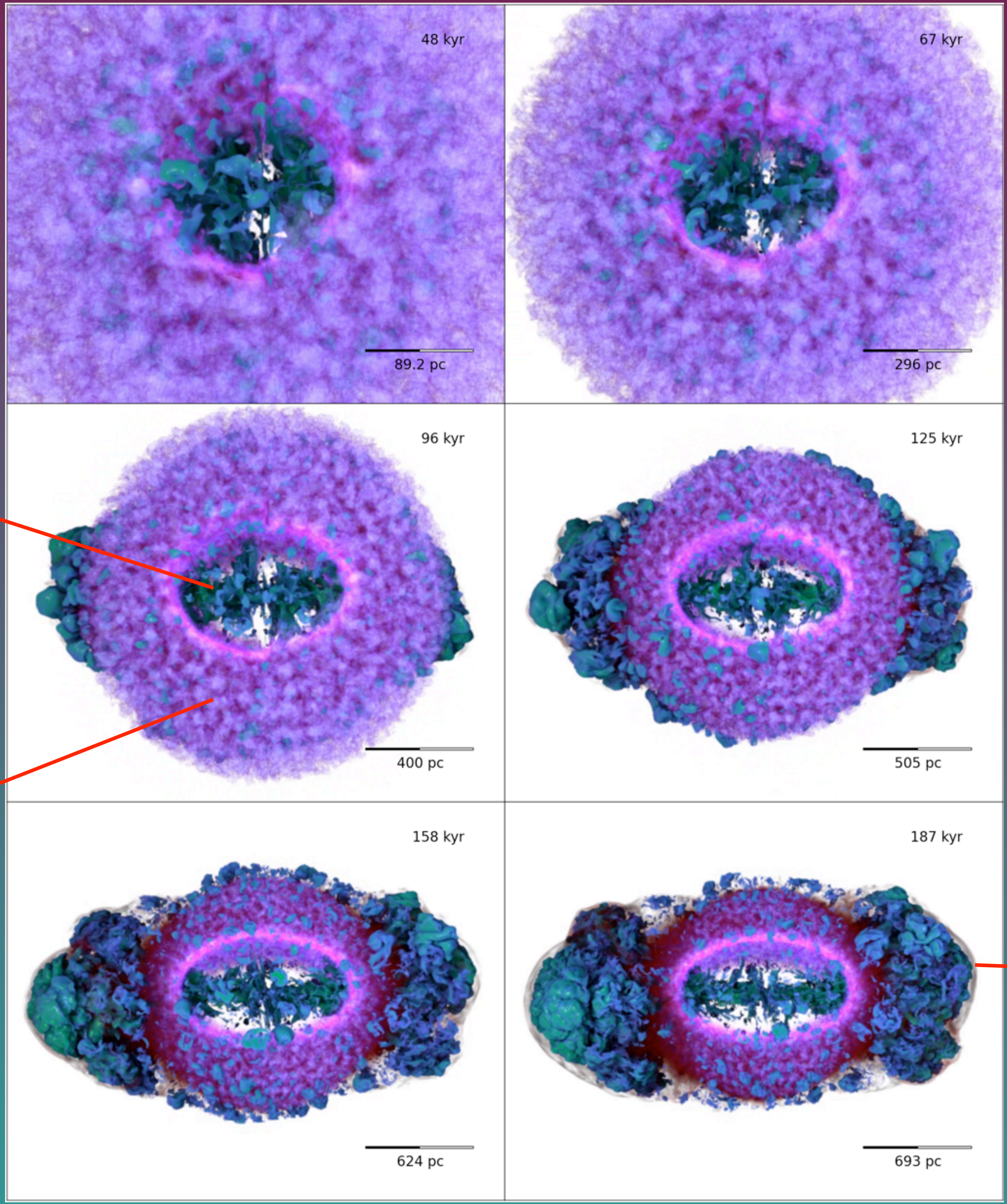
Low filling factor

$R_{cloud,max}$=50 pc

$R_{cloud,max}$=10 pc



3D view of Run 3D’

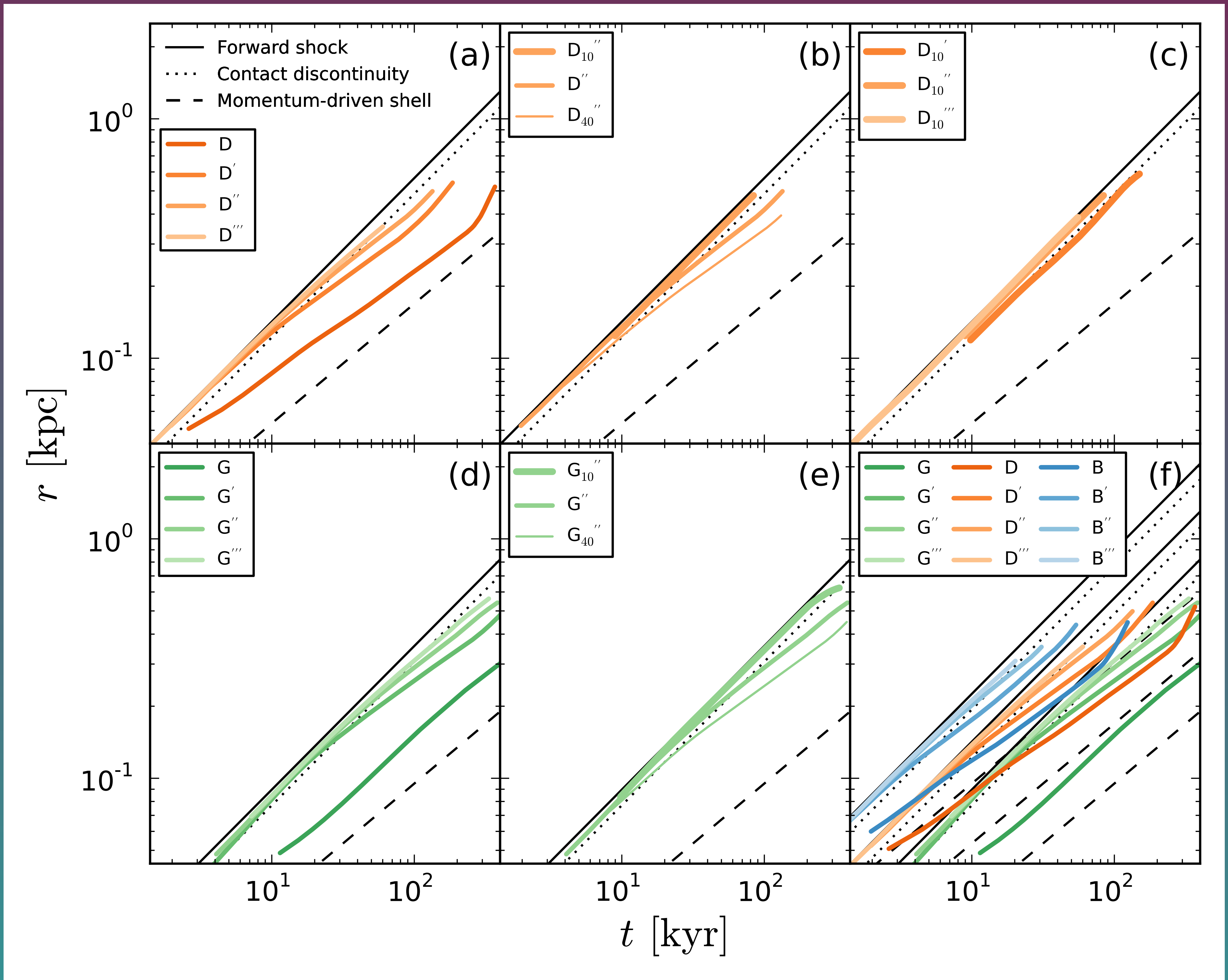


Blue-green jet plasma

Purple clouds

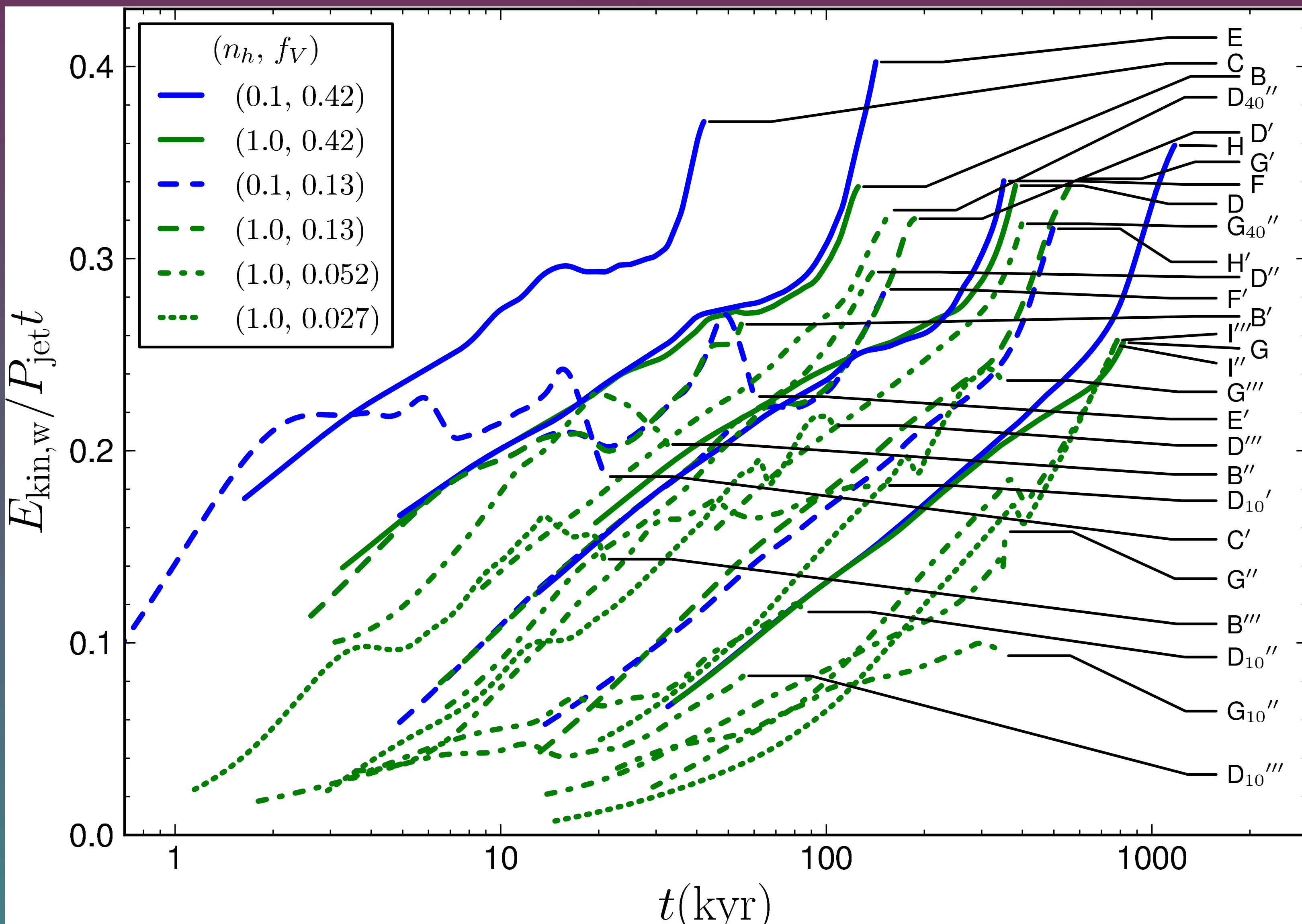
Forward shock of energy-driven bubble

Comparison of R-t relation with analytic energy-driven bubble



Analytic solution approached as filling factor decreases

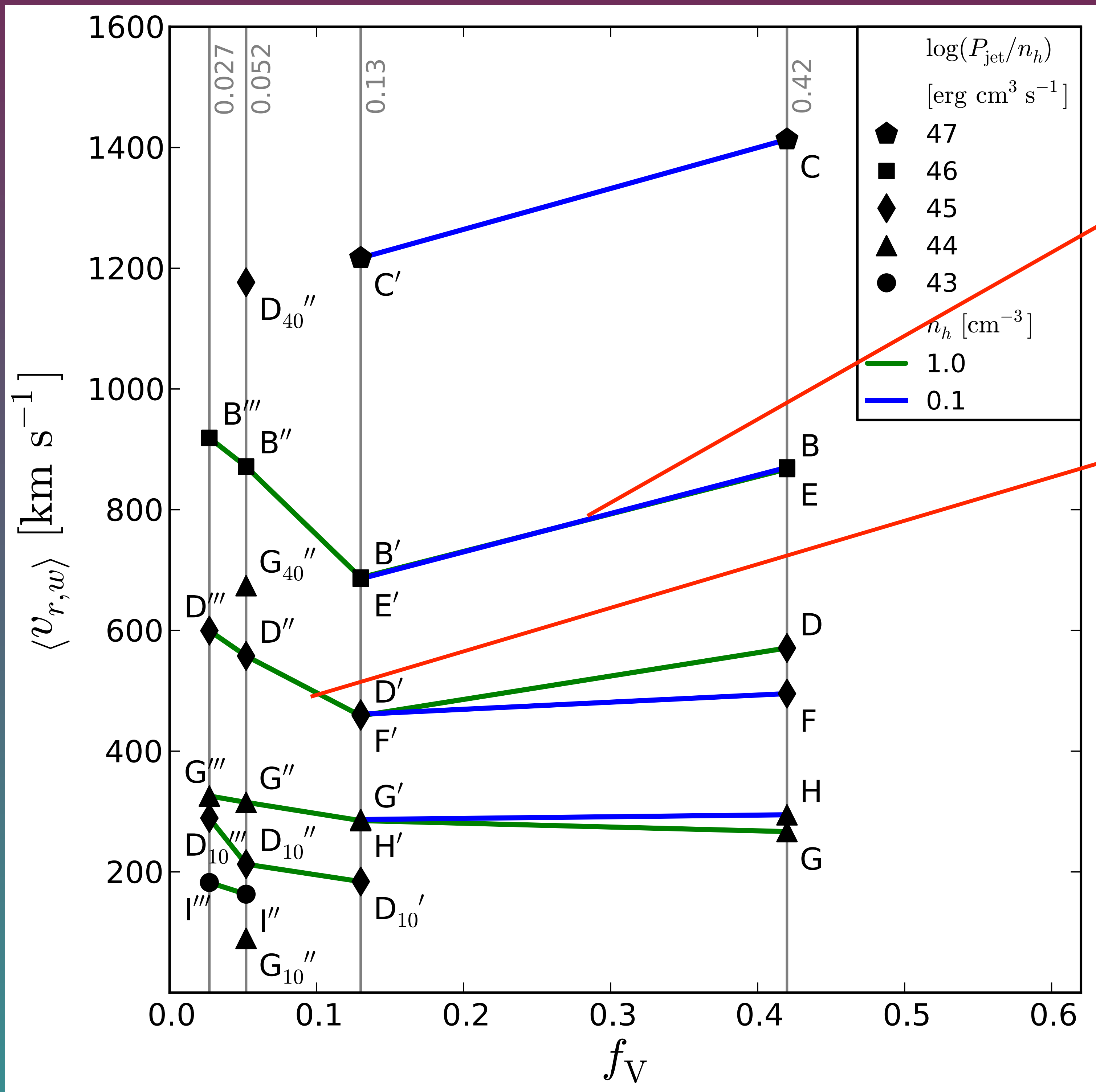
Energy imparted to clouds



Substantial fraction of jet energy ends up in warm clouds

$$0.1 < \frac{E_{\rm clouds}}{P_{\rm jet} \times t} < 0.4$$

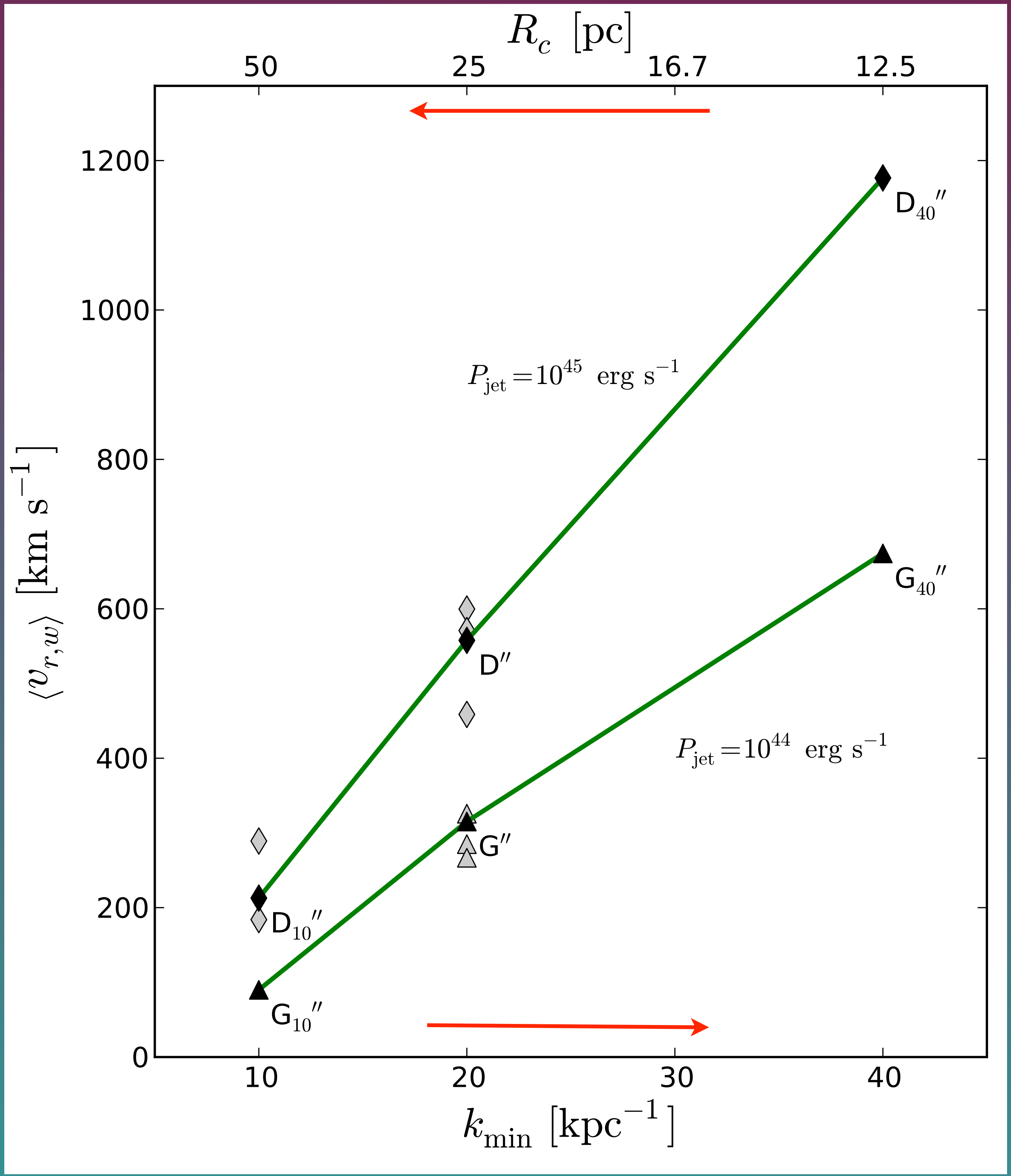
Effect of filling factor



Initial decrease of filling factor increases volume of flood channels for jet plasma

Increased cloud ablation

Effect of cloud size



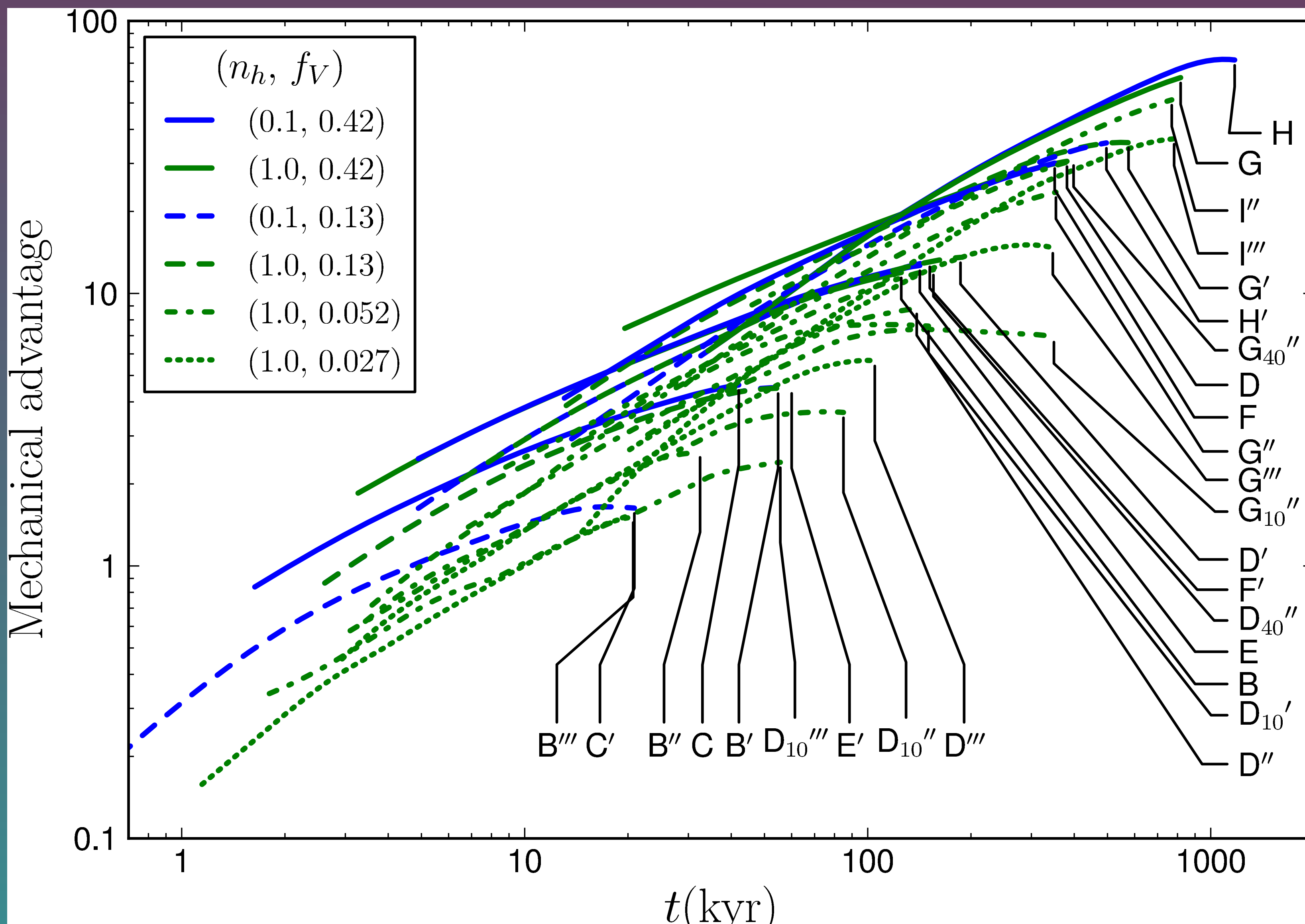
Clouds generated using Fourier code (Ralph) with a minimum wave number k_{min}

Maximum cloud radius $R_{cloud,max} = 1/(2\ k_{min})$

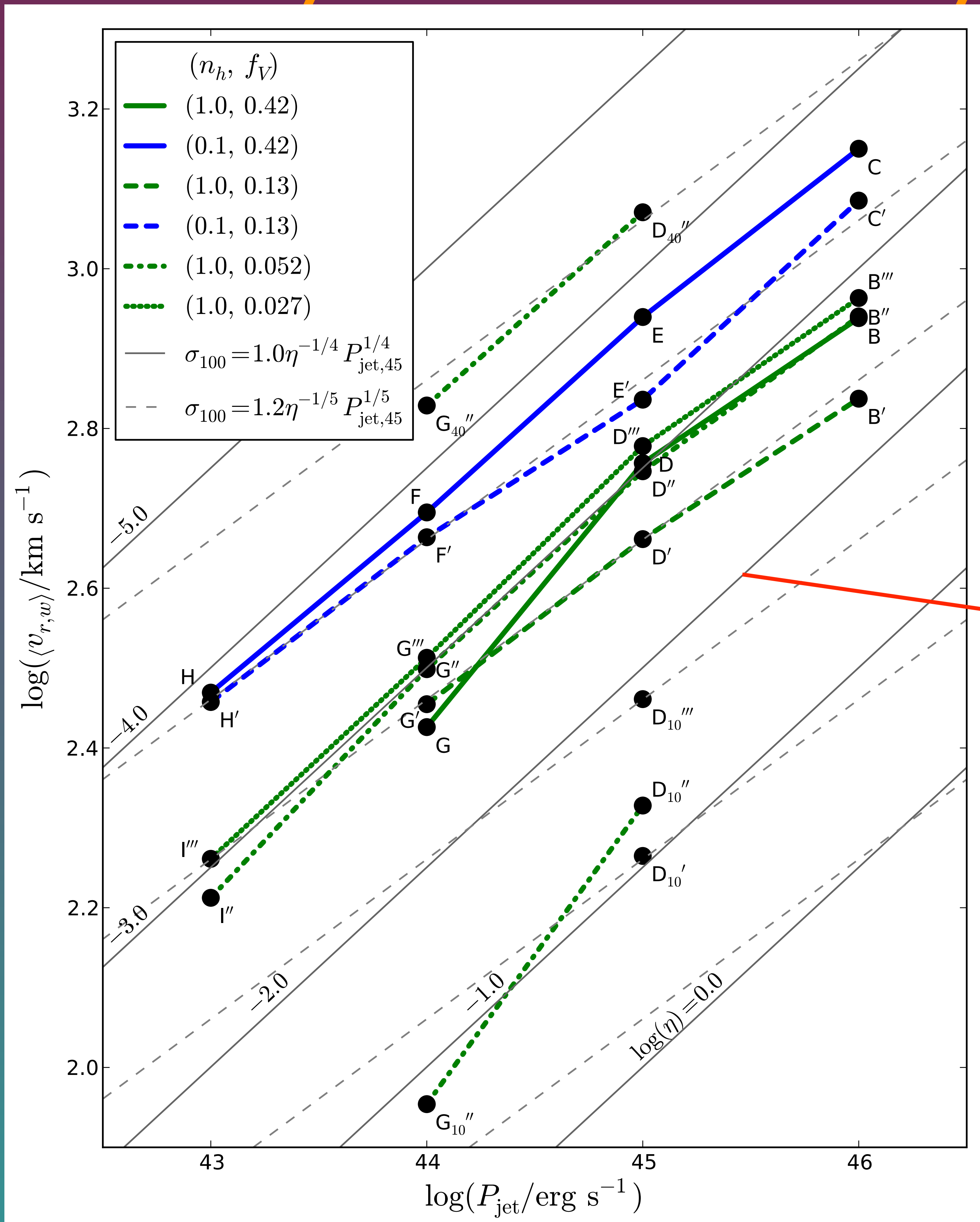
Unsurprisingly larger clouds are harder to accelerate

Mechanical advantage

$$\text{Mechanical Advantage} = \frac{\text{Total momentum in clouds}}{\text{Momentum flux of jet} \times t}$$



Summary of cloud velocity vs Jet power



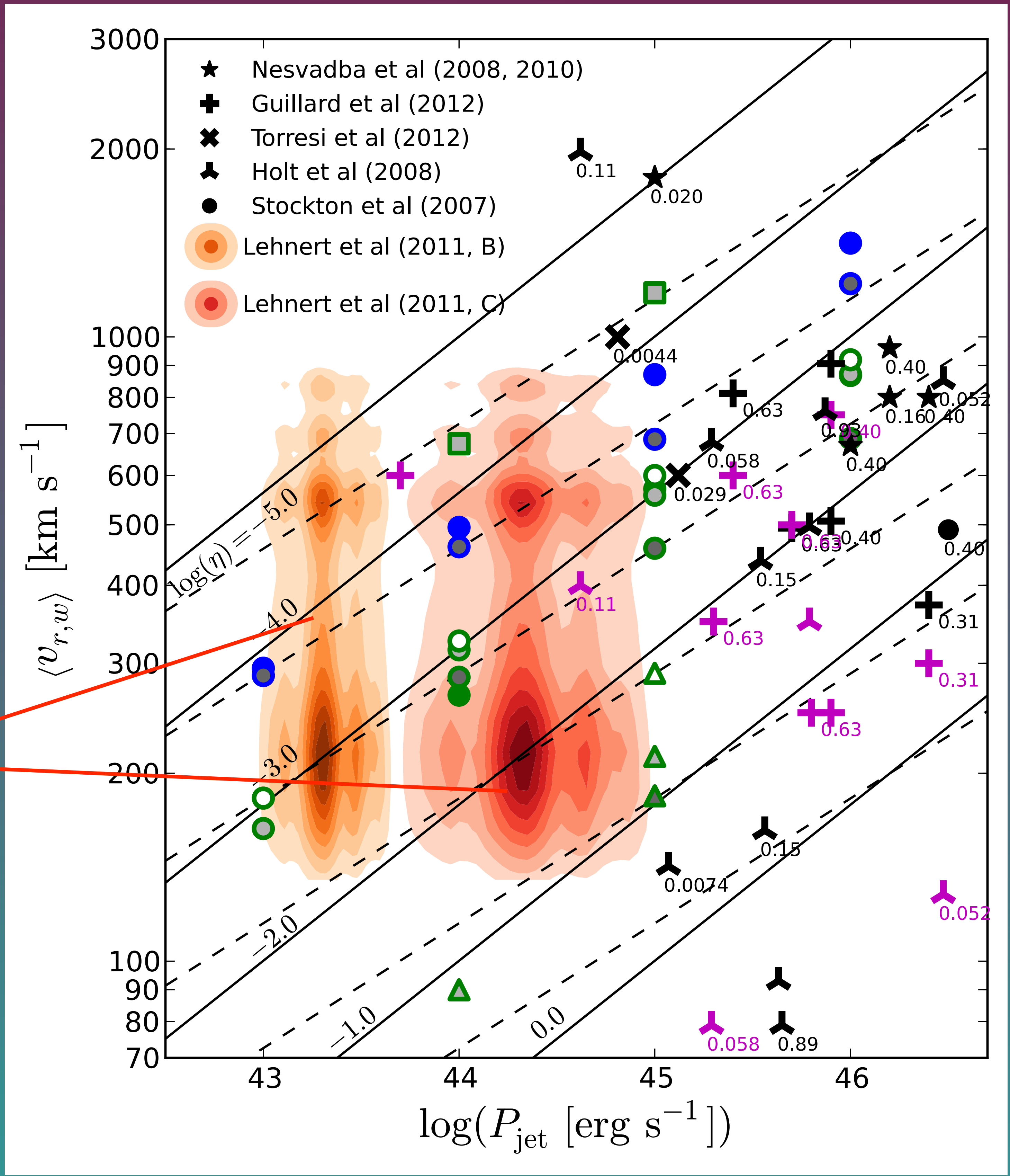
$$\eta = \frac{P_{\rm jet}}{L_{\rm Edd}}$$

$$\frac{\sigma}{100\ \mathrm{km\ s^{-1}}} = 1.0\,\eta^{-1/4}\left(\frac{P_{\rm jet}}{10^{45}\ \mathrm{ergs\ s^{-1}}}\right)^{1/4}$$

Comparison with observations

Lehnert et al. (2011)
691 radio galaxies

(Different estimates of P_{jet} from 1.4 GHz radio power)



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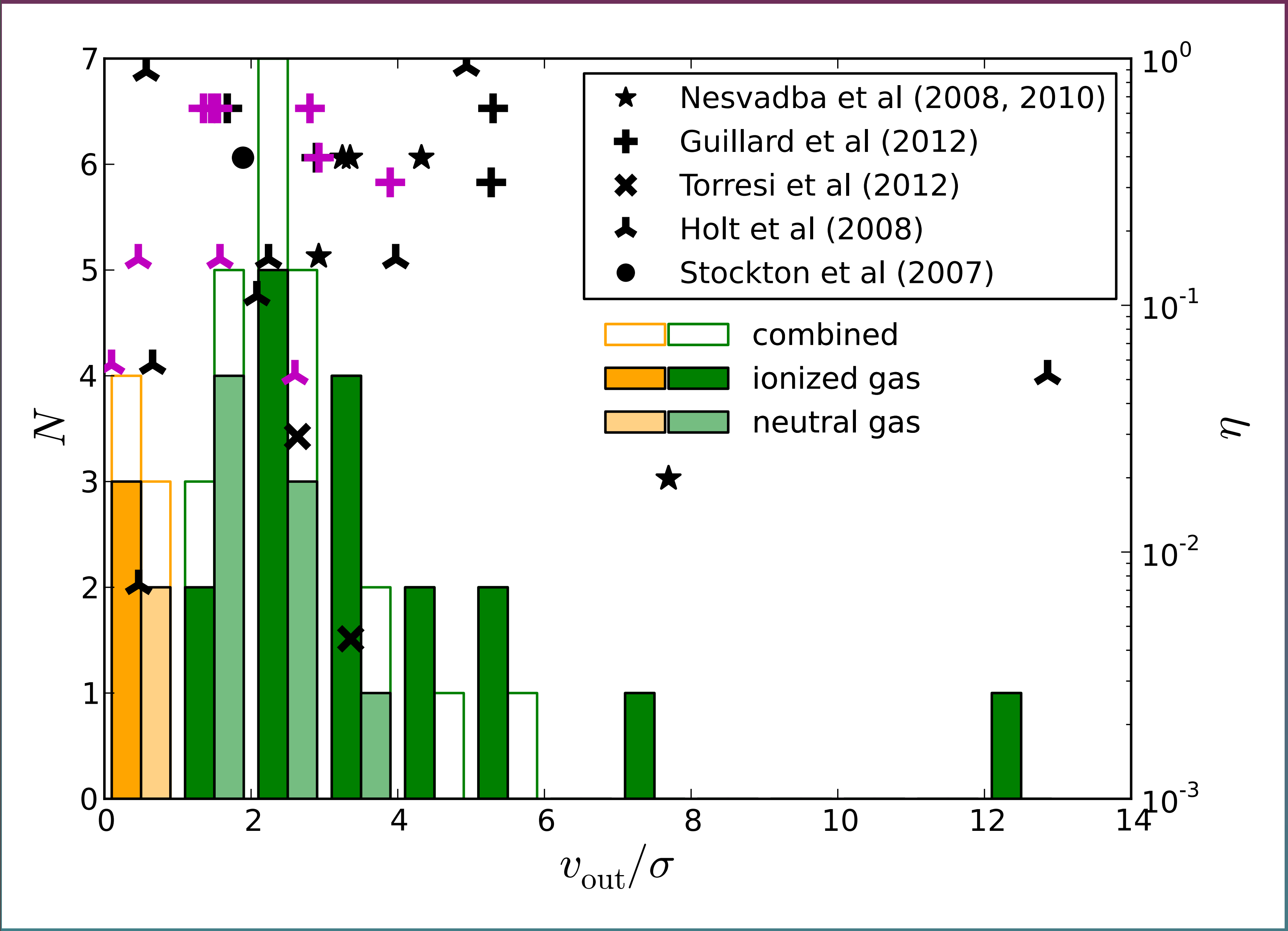
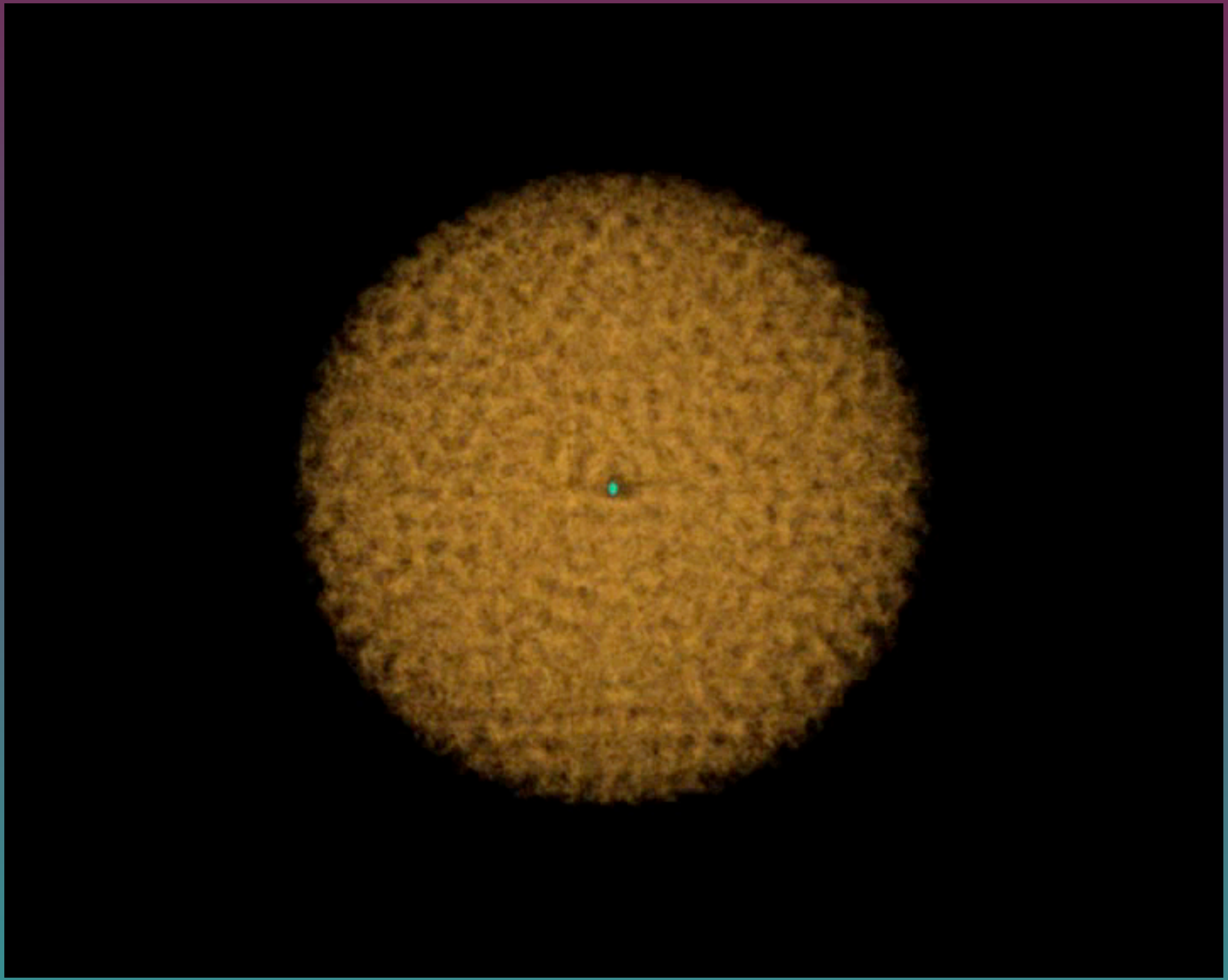
Distribution of velocities



Most of the galaxies with outflows have v > velocity dispersion

3D jet plasma visualization - Ajay Limaye



3D density visualization