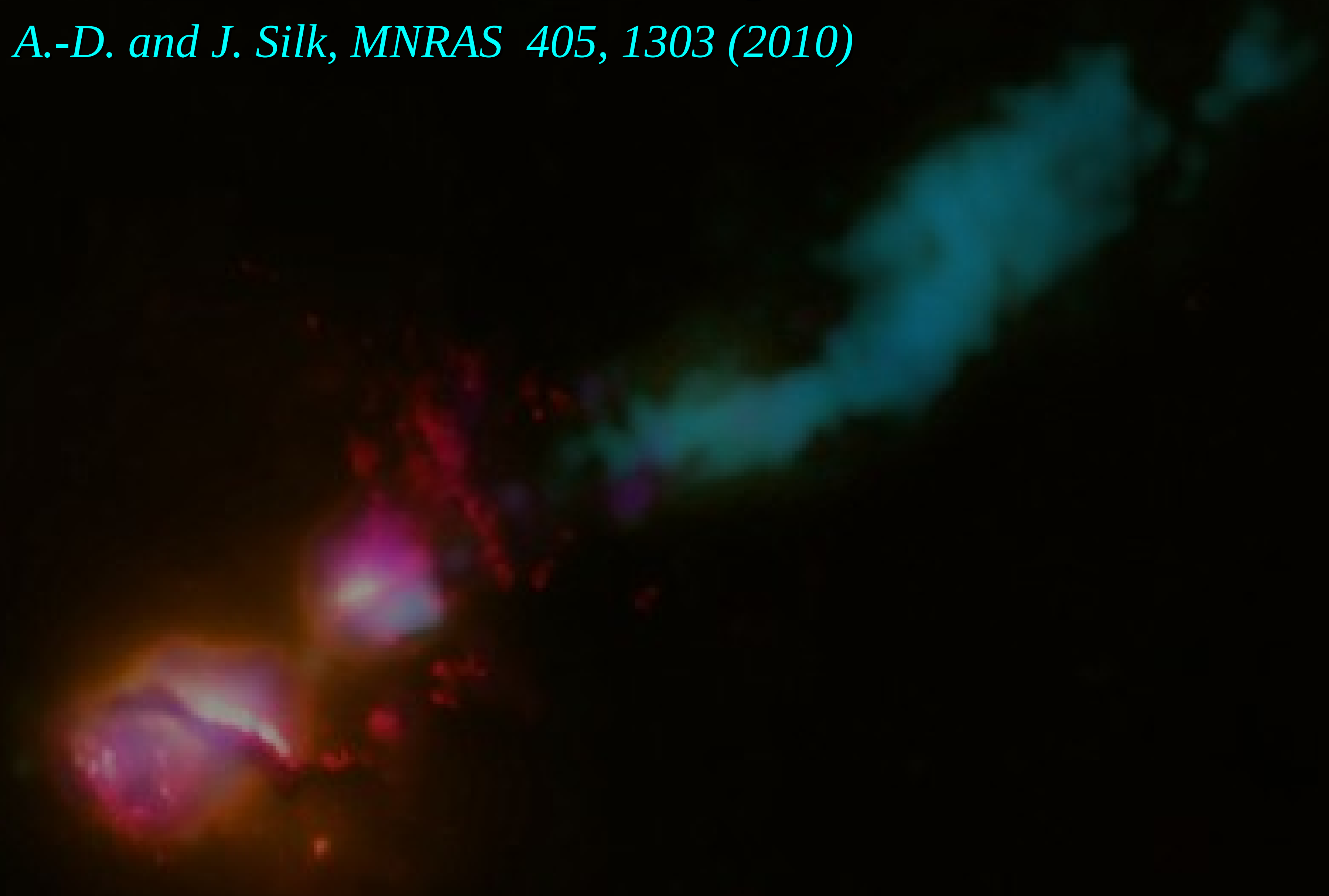
The self-feeding AGN

V. A.-D. and J. Silk, MNRAS 405, 1303 (2010)



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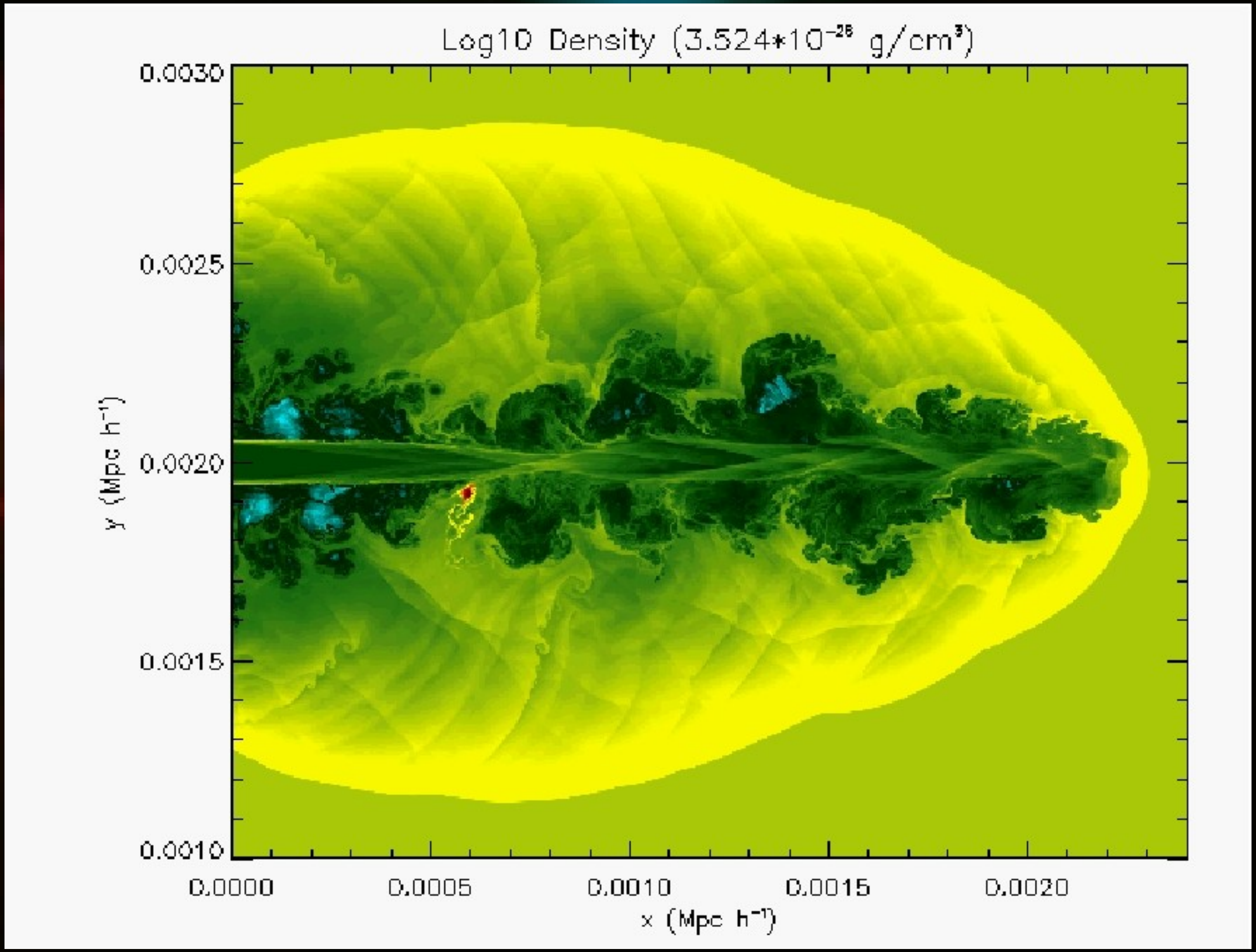

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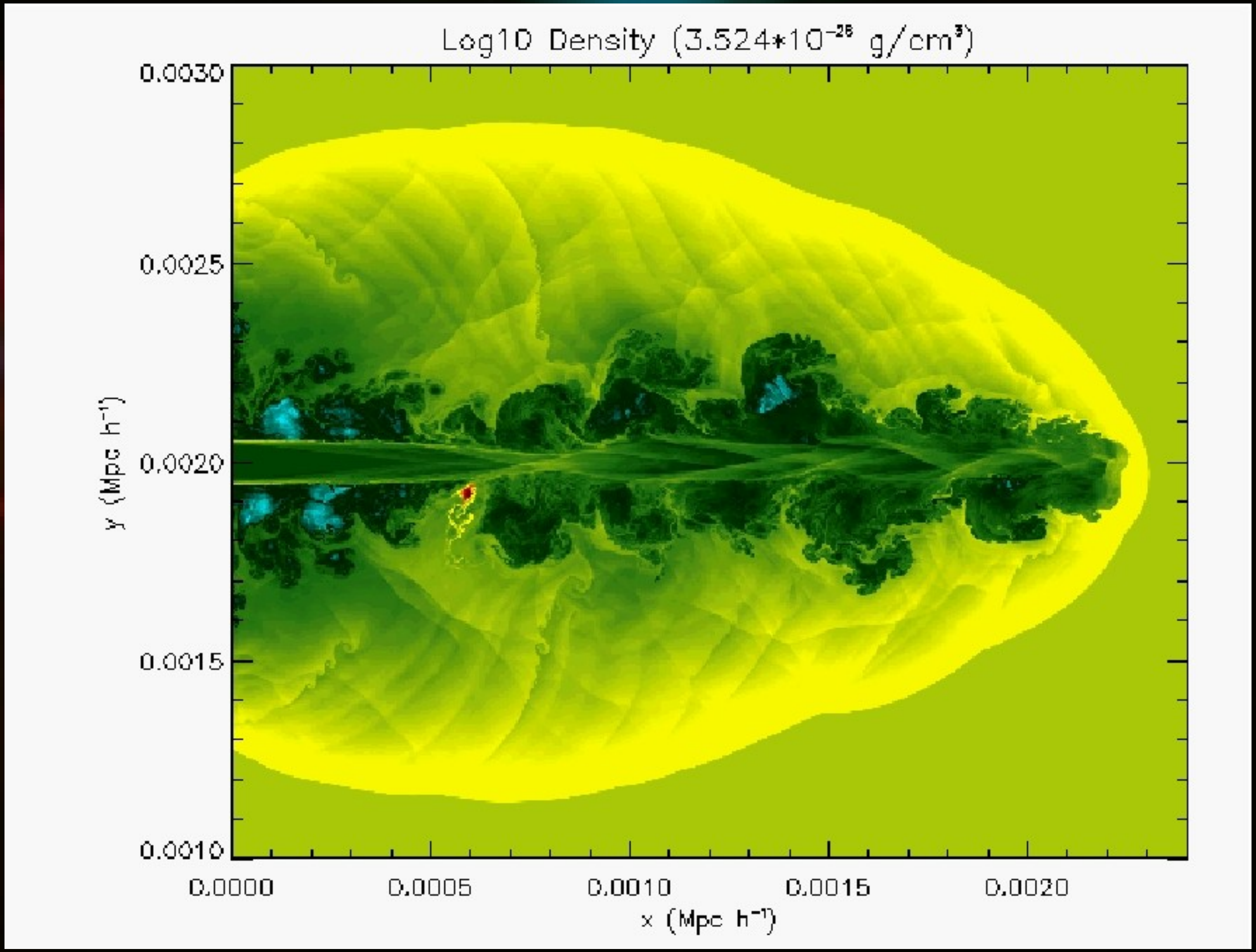
- AMR simulations
FLASH 2.5



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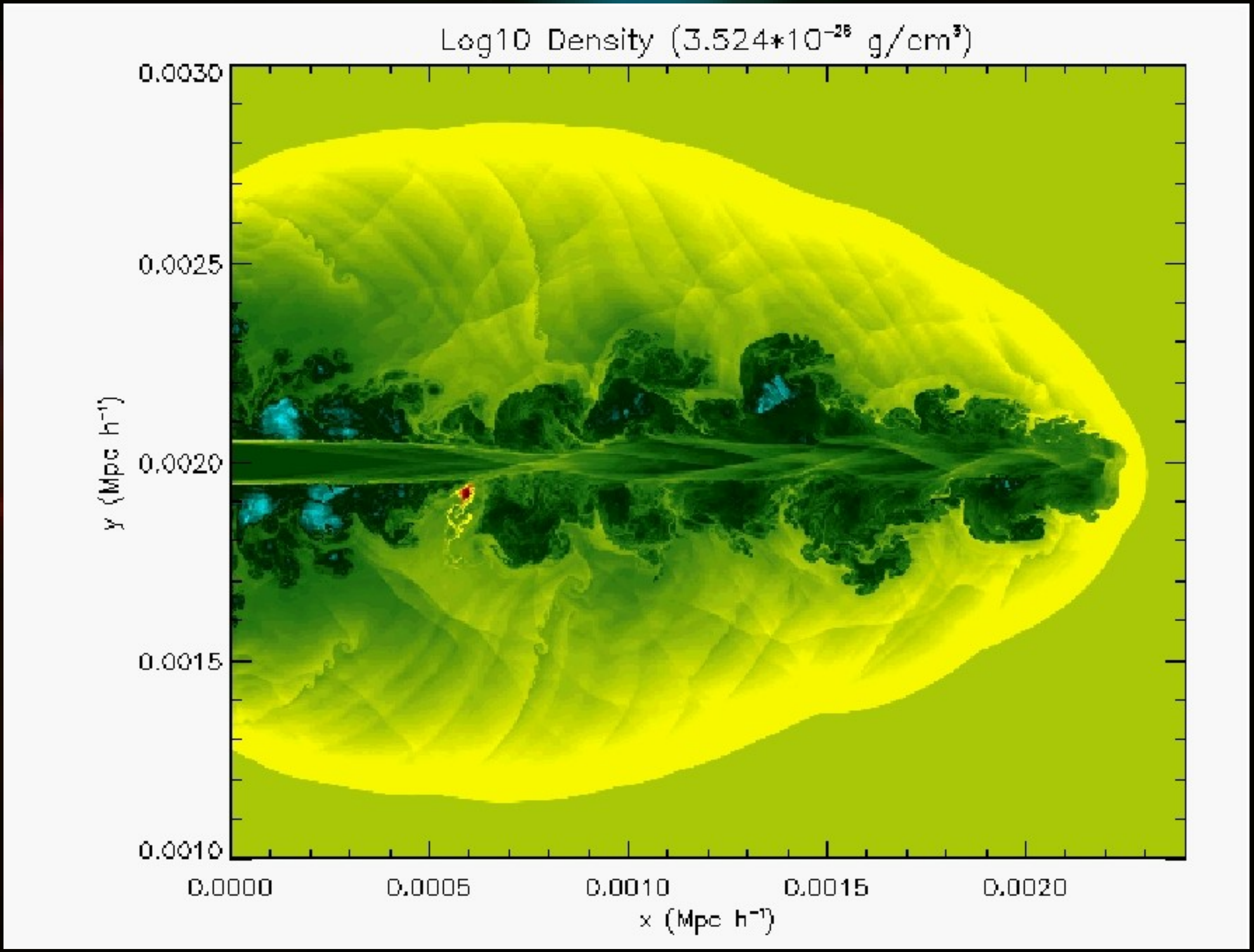
- 6 ref. levels, 20 in. mesh cells, 40 kpc h^{-1} box → l_{min} = 7.85 pc h^{-1}



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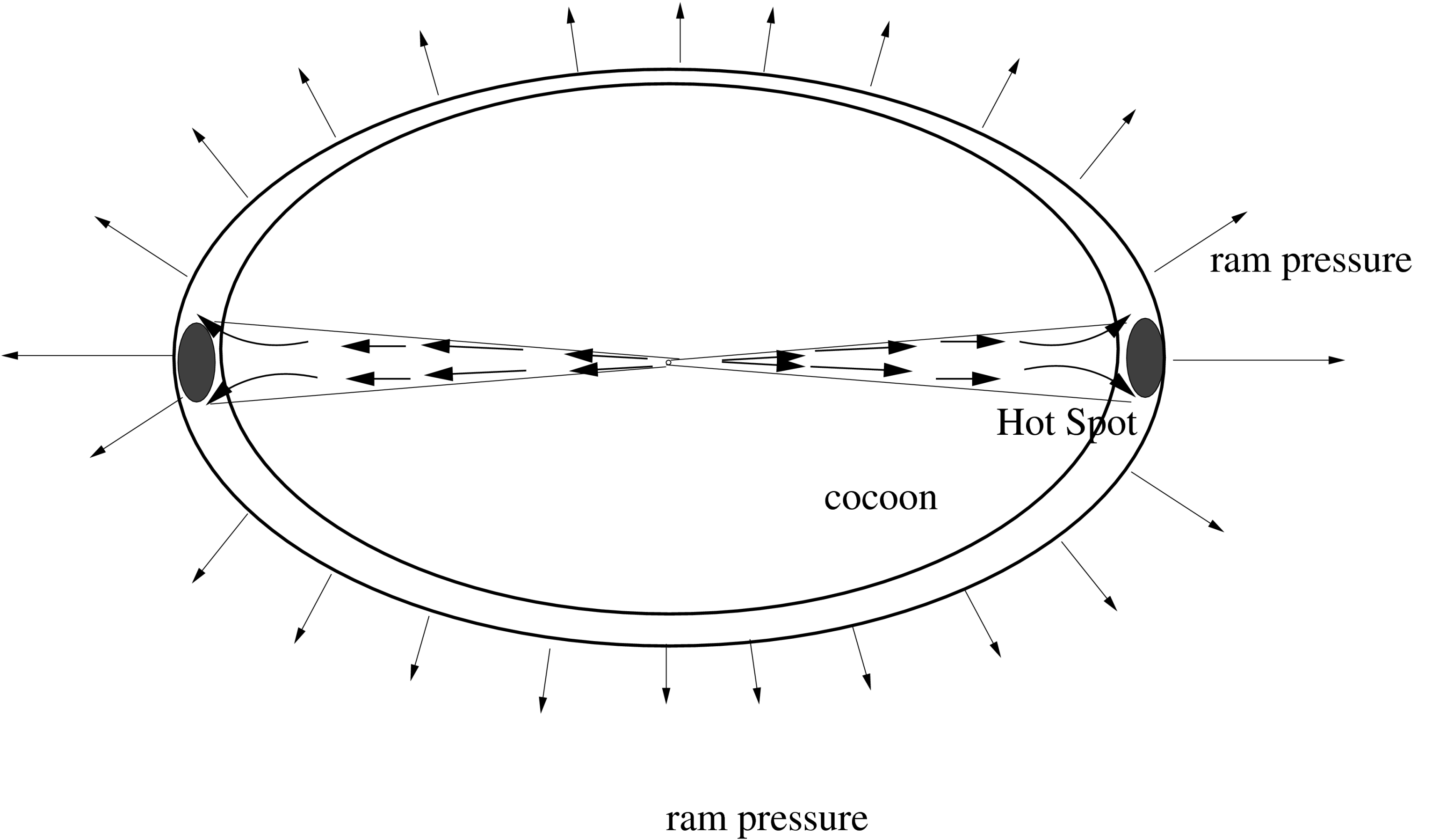
How does the cocoon expand?

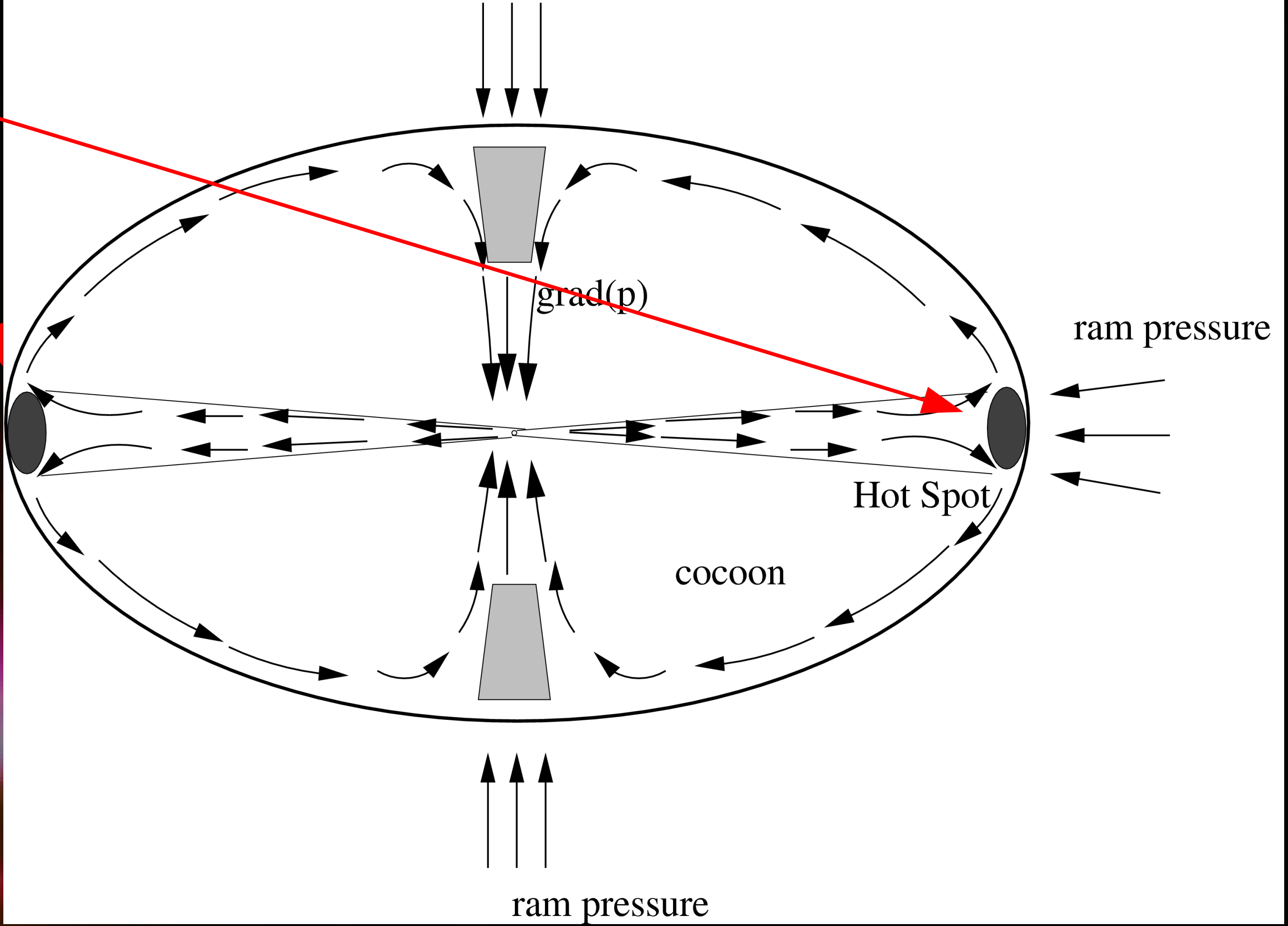


- 3 components: relativistic jet, turbulent cocoon, bow shock (Hot Spot)

- Self-similar model (Falle, 1991): only predicts the *global expansion* of the cocoon (L $\propto t^{3/5}$)

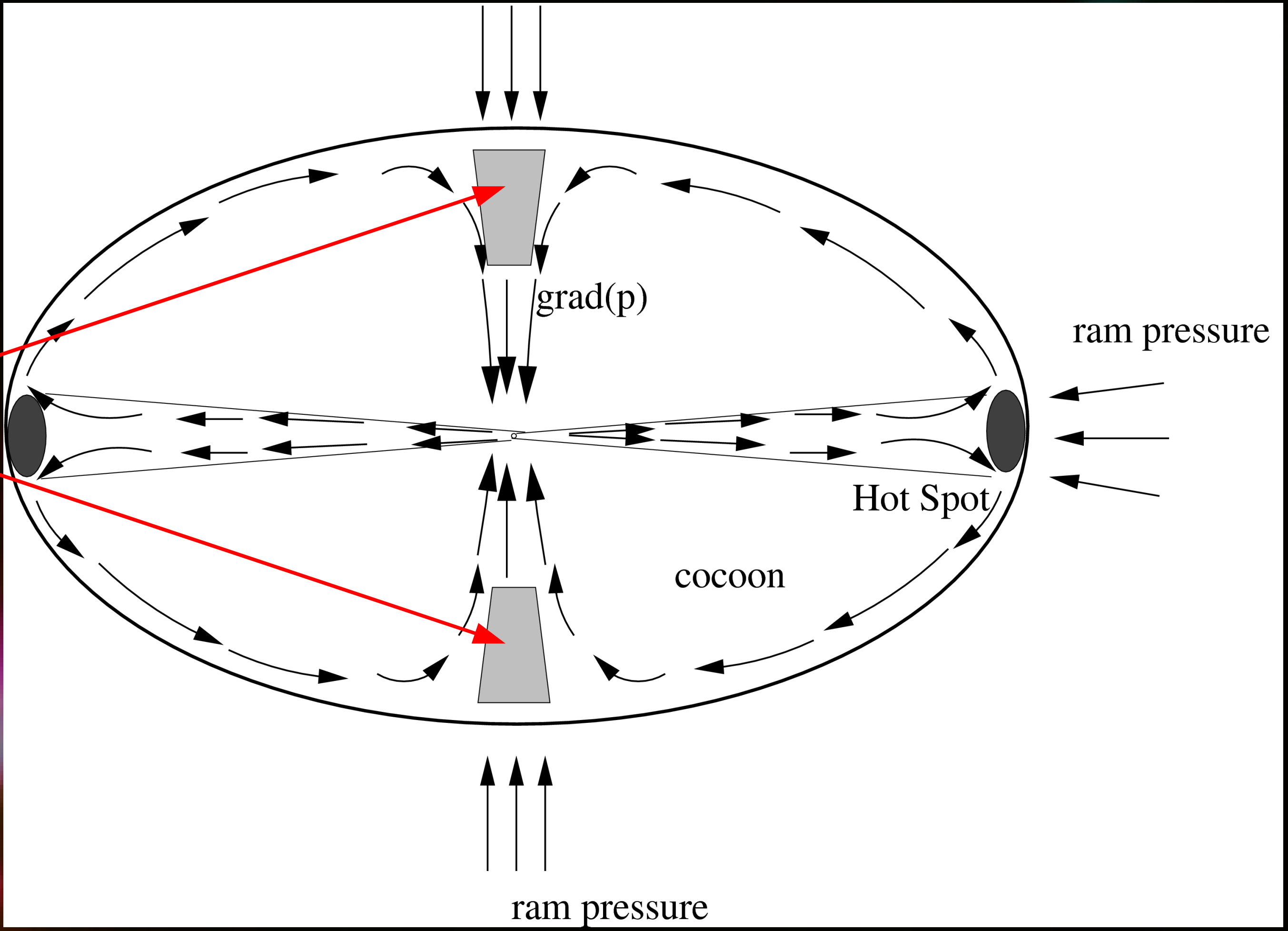
How does the cocoon expand?

- A *hotspot* develops near the jet's termination



How does the cocoon expand?

- A *hotspot* develops near the jet's termination
- A high density region develops in two spots near the meridional plane



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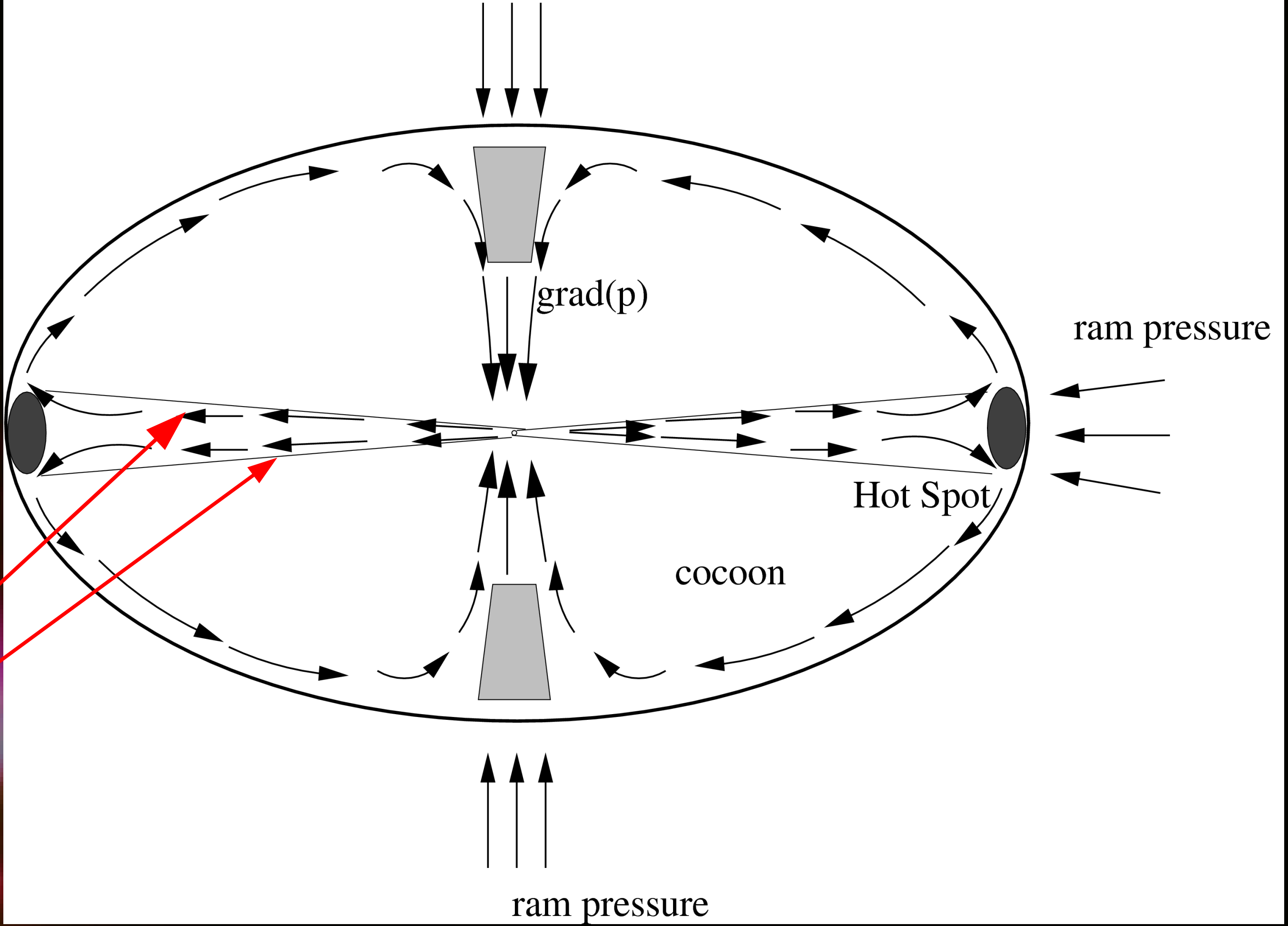
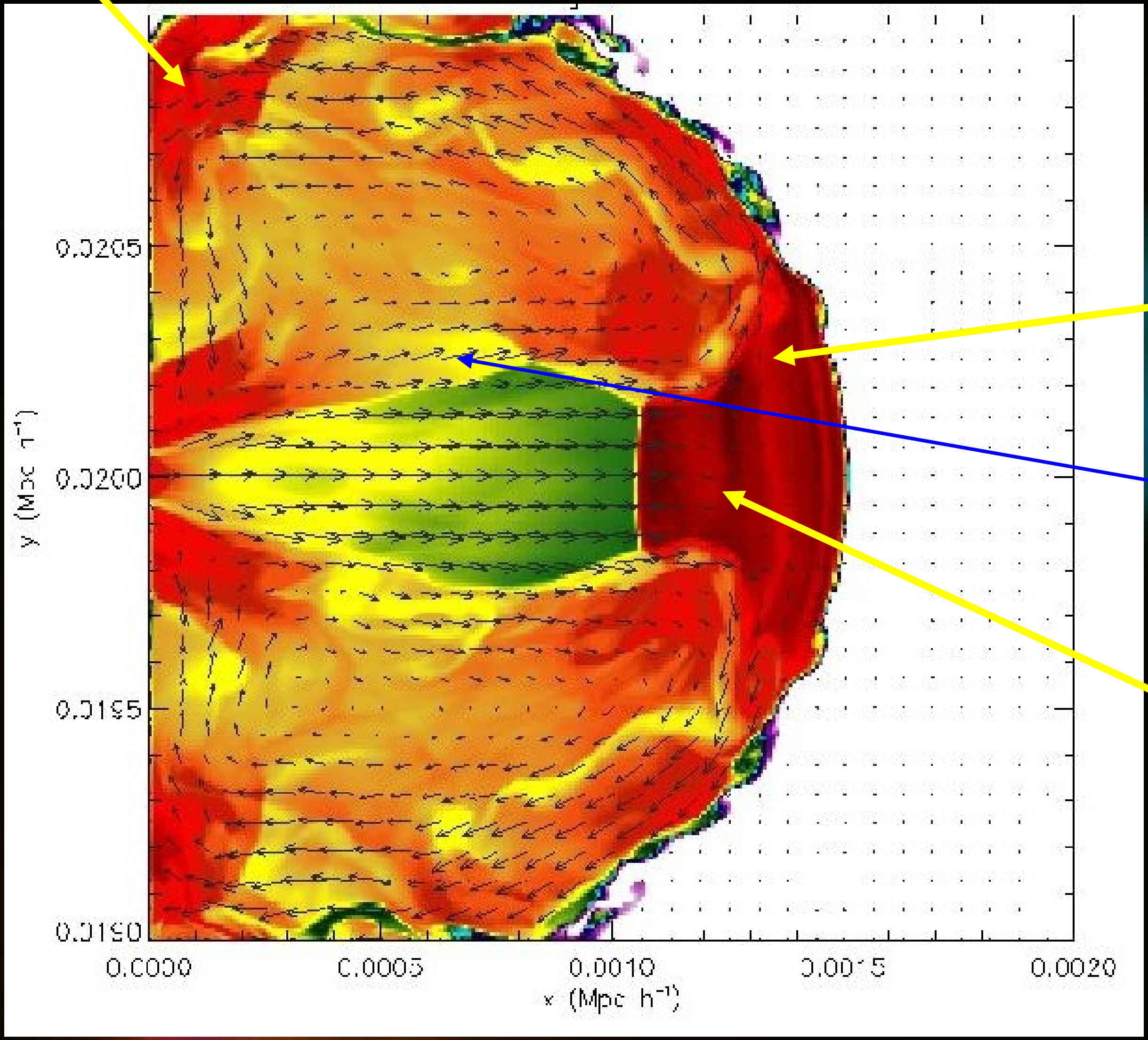


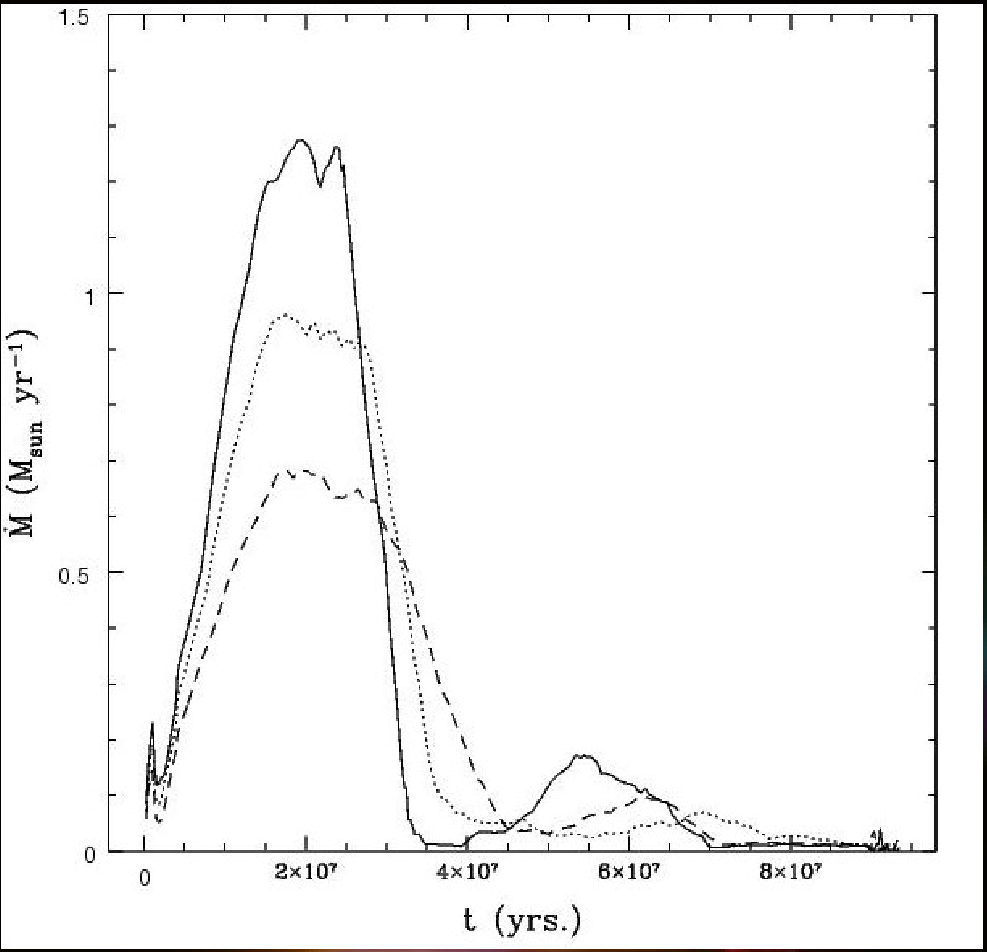
- Shearing gas gains angular momentum when crossing a gradient in h_0 (*stagnation enthalpy*) near the meridional spots and the hotspot (*Crocco theorem*)

$\sigma_v = 100$, $t=6.8\times10^6$ yrs.



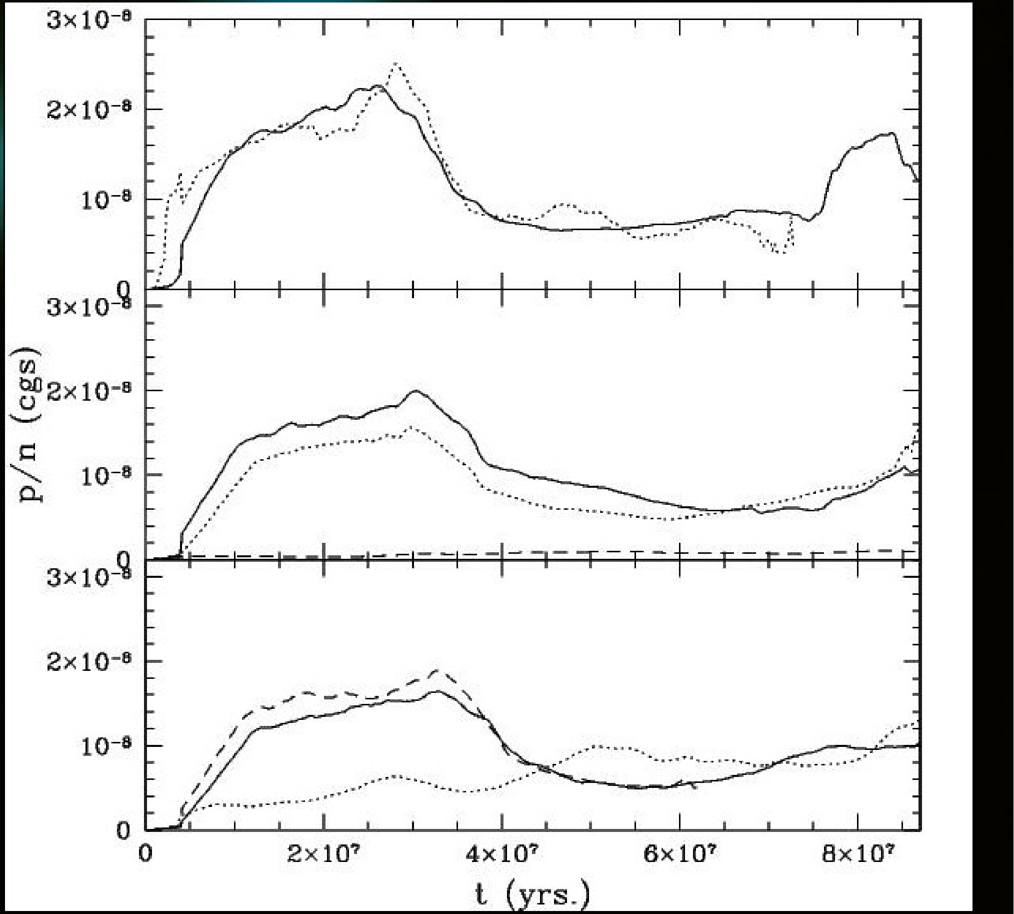
- A *global backflow circulation* develops – a fraction of the gas flows back towards the BH

Mass backflow in a 10 pc circumnuclear region



- dM/dt ~ 0.32 – 0.76 M_{sun} yr^{-1}, peak values ~ 0.6 – 1.3 M_{sun} yr^{-1}

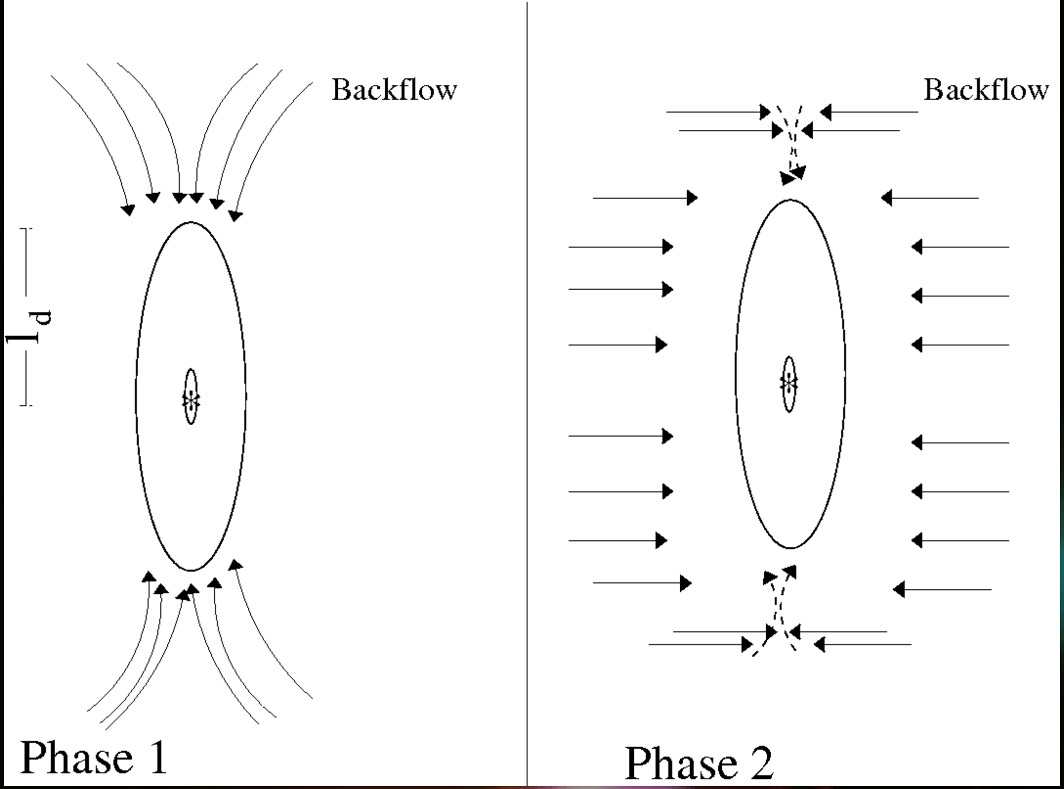
- T ~ 2-4x10^7 yrs.



- For given P_j, n_{ism} strongly affects mass flow rates and backflow energetics

compression → starburst

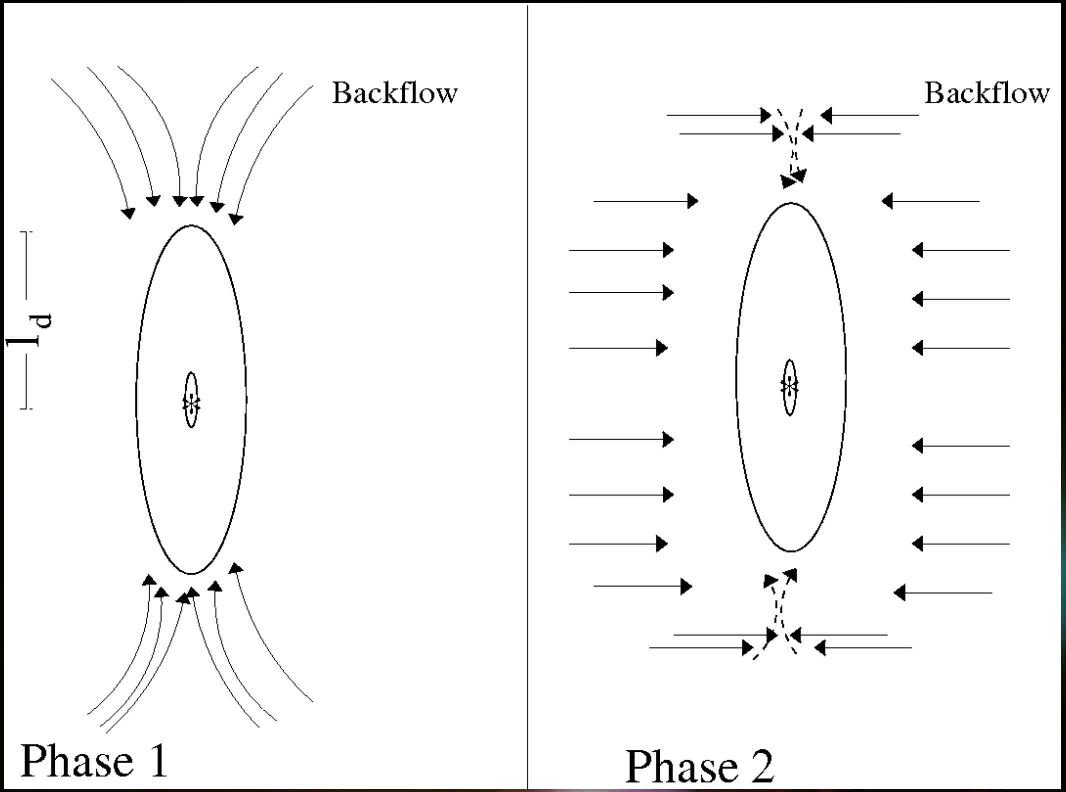
Feedback of the backflow ON the circumnuclear disk



Effects of feedback from backflow:

- Stores more $L_z \sim 0$ gas into the accr. disc → higher P_j
- Suppr. SF → *older* starbursts

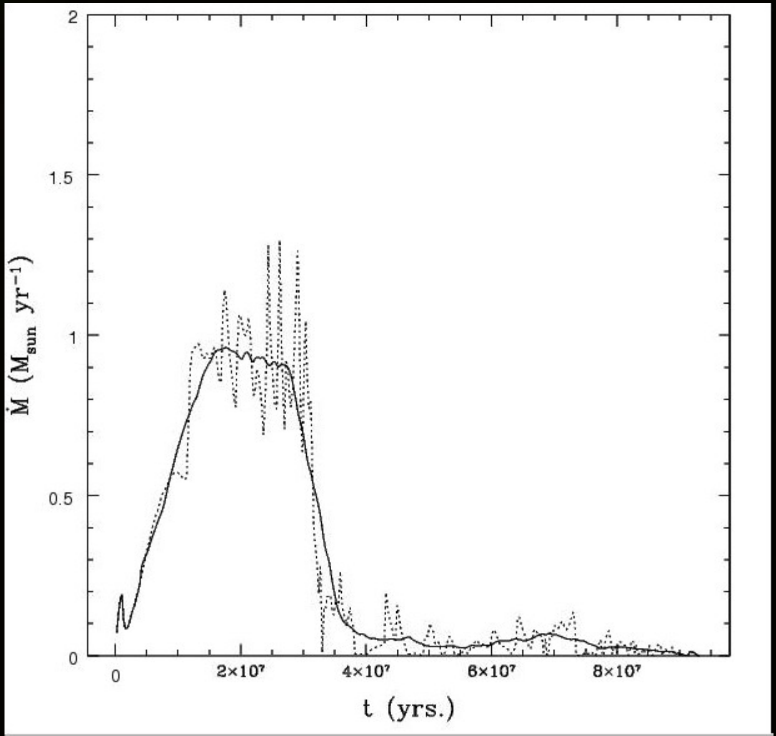
Feedback of the backflow ON the circumnuclear disk



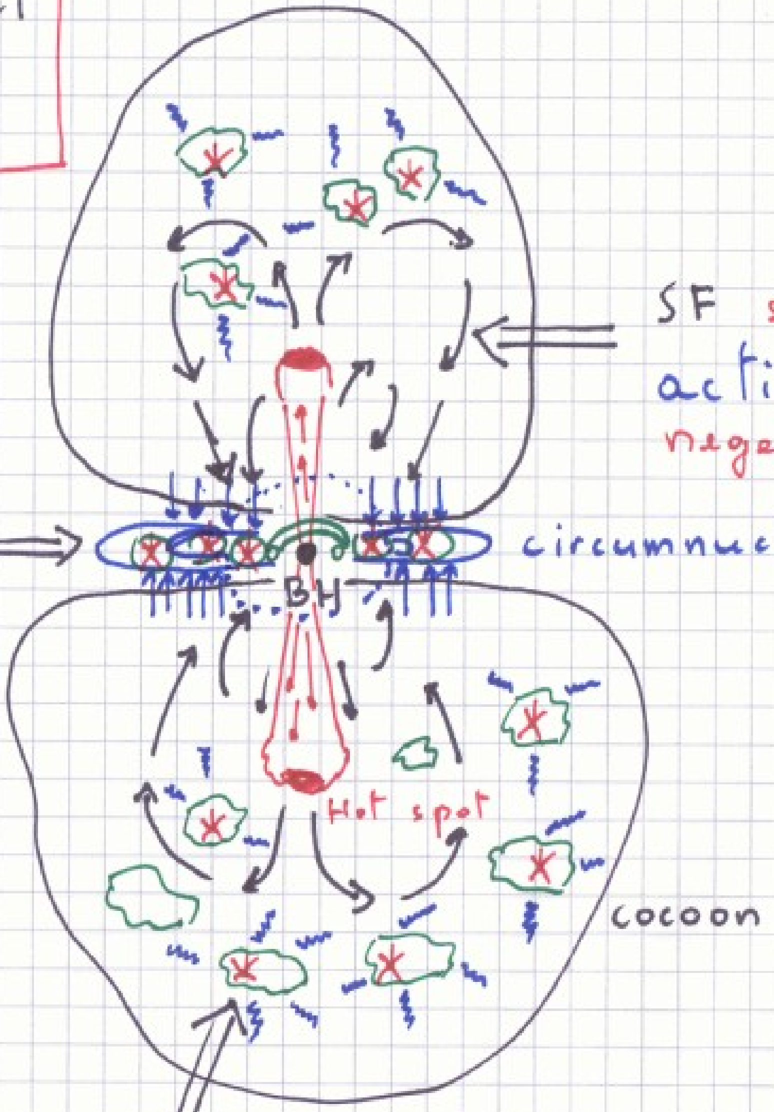
Effects of feedback from backflow:

- Stores more $L_z \sim 0$ gas into the accr. disc → higher P_j
- Line indices: shocks + starbursts (*Mazzuca et al., 2006; Sarzi et al., 2007*)

- Enhanced SF from compression
- Intermittency→ Series of SF episodes



A "unified" model of AGN feedback



SF induced by backflow's compr. in the circumnucl. disc positive FB

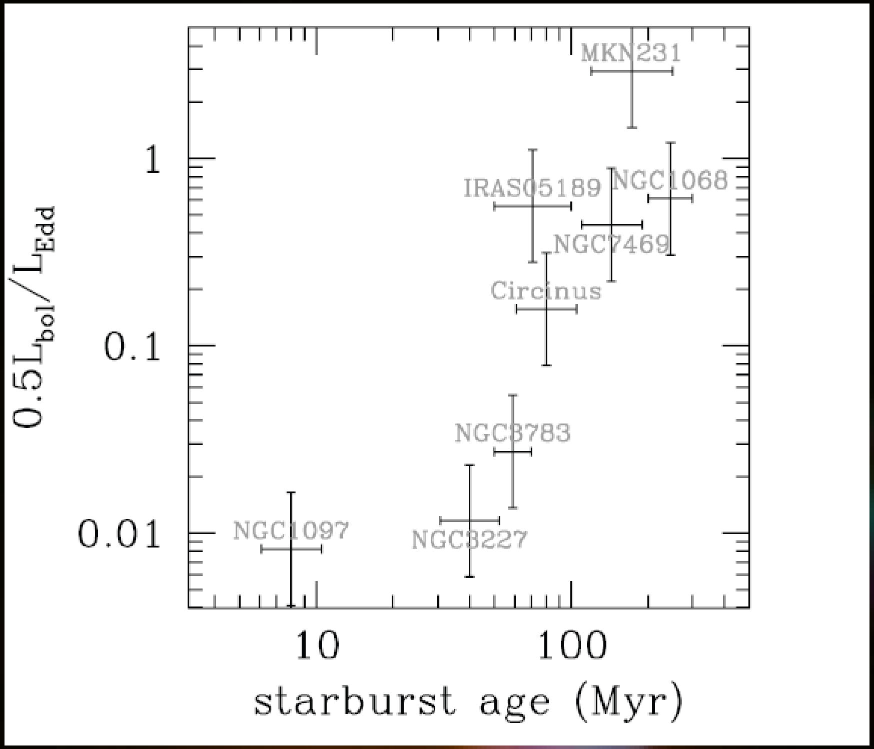
SF suppressed during active cocoon exp. negative FB

SF induced by therm. inst. during passive cocoon exp. positive FB

 : cooling ISM/IGM clouds

V. [illegible] Delog
Oct. '07

A possible explanation of the L_{bol}/L_{Edd} – age connection



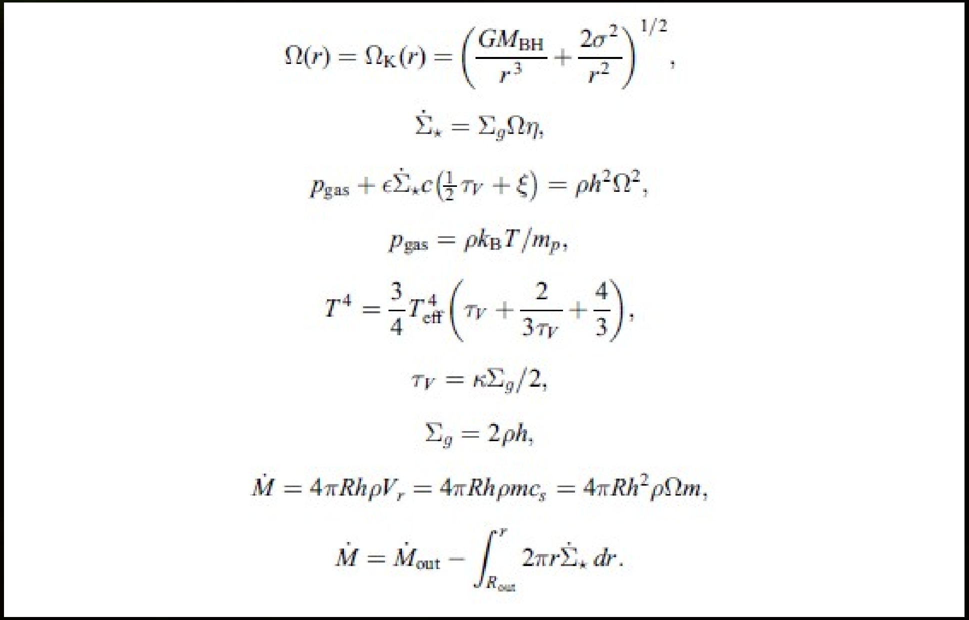
Davies et al. (2007): older starburst are associated with brighter AGNs

- Model: high $P_j \rightarrow$ higher $p_{bck} \rightarrow$

faster suppression of SF in the disc

AND higher $T_{disc} \rightarrow$ higher L_{bol}

- Detailed modelling of gas+stellar discs with external backflow (*V.A.-D. & Silk, MNRAS, subm.*)



$$\Omega(r) = \Omega_{\mathrm{K}}(r) = \left(\frac{GM_{\mathrm{BH}}}{r^3} + \frac{2\sigma^2}{r^2}\right)^{1/2},$$

$$\dot{\Sigma}_\star = \Sigma_g \Omega \eta,$$

$$p_{\mathrm{gas}} + \epsilon \dot{\Sigma}_\star c\left(\tfrac{1}{2}\tau_V + \xi\right) = \rho h^2 \Omega^2,$$

$$p_{\mathrm{gas}} = \rho k_{\mathrm{B}} T / m_p,$$

$$T^4 = \frac{3}{4} T_{\mathrm{eff}}^4 \left(\tau_V + \frac{2}{3\tau_V} + \frac{4}{3}\right),$$

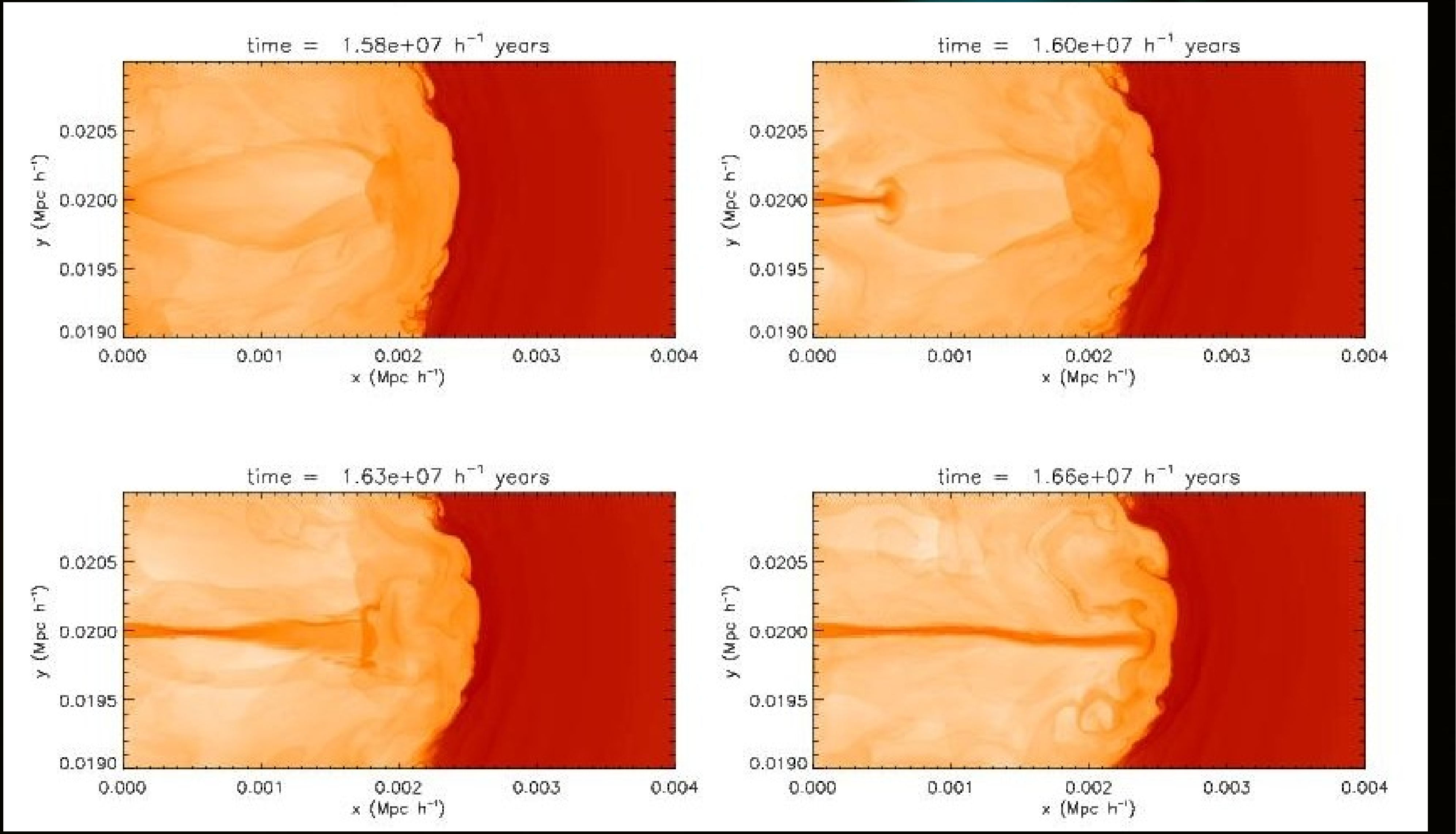
$$\tau_V = \kappa \Sigma_g / 2,$$

$$\Sigma_g = 2\rho h,$$

$$\dot{M} = 4\pi R h \rho V_r = 4\pi R h \rho m c_s = 4\pi R h^2 \rho \Omega m,$$

$$\dot{M} = \dot{M}_{\mathrm{out}} - \int_{R_{\mathrm{out}}}^{r} 2\pi r \dot{\Sigma}_\star \, dr.$$

- At t~1.6x10^7 yrs. the recoll. shock is destroyed → the meridional circulation disappears



FLASH: AMR CFD (Frixell et al. 2000)

Eulerian, shock capturing (Godunov 3rd order)

Euler equations:

$$\begin{aligned} \frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\mathbf{v}) &= 0 \\ \frac{\partial\rho\mathbf{v}}{\partial t} + \nabla\cdot(\rho\mathbf{v}\mathbf{v}) + \nabla P &= \rho\mathbf{g} \\ \frac{\partial\rho E}{\partial t} + \nabla\cdot\left[(\rho E + P)\,\mathbf{v}\right] &= \rho\mathbf{v}\cdot\mathbf{g}\,, \end{aligned}$$

Thermal diffusion:

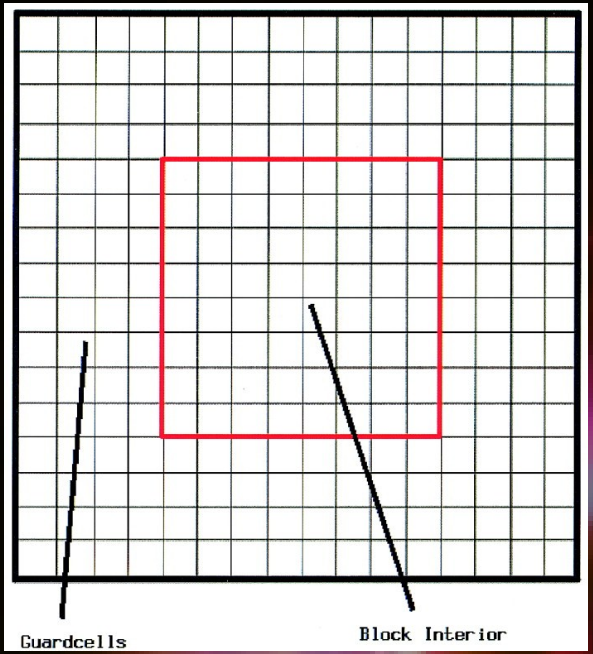
$$F_{heat} = -\sigma(X_i, \rho, T)\nabla T$$

Multiple species (phases):

$$\frac{\partial\rho X_i}{\partial t} + \nabla\cdot(\rho X_i\mathbf{v}) = \nabla\cdot(D\nabla\rho X_i)$$

Simulation setup

- Spatial resolution : $l_{res} = L_{block}/N_{x\text{-cells}}$, $N_{x\text{-cells}} = 8$



$L_{block} = L_{box}/2^r$, $r_{max} = 6$

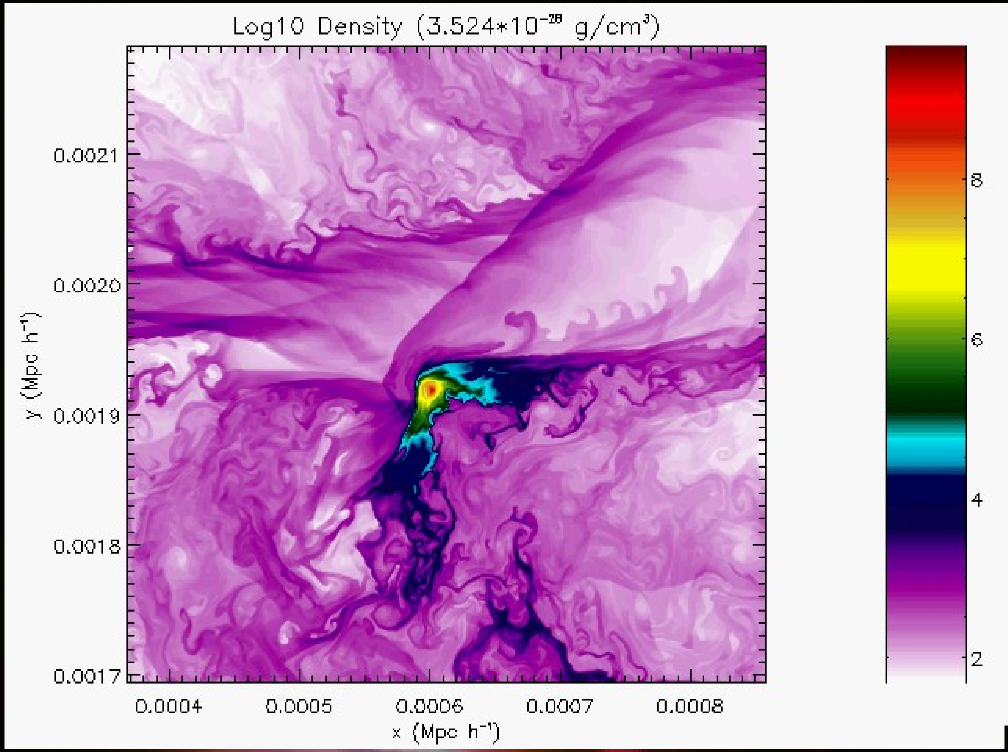
$L_{box} = 4\ h^{-1}$ kpc $\Rightarrow$ $\max(L_{block}) = 0.0625\ h^{-1}$ kpc

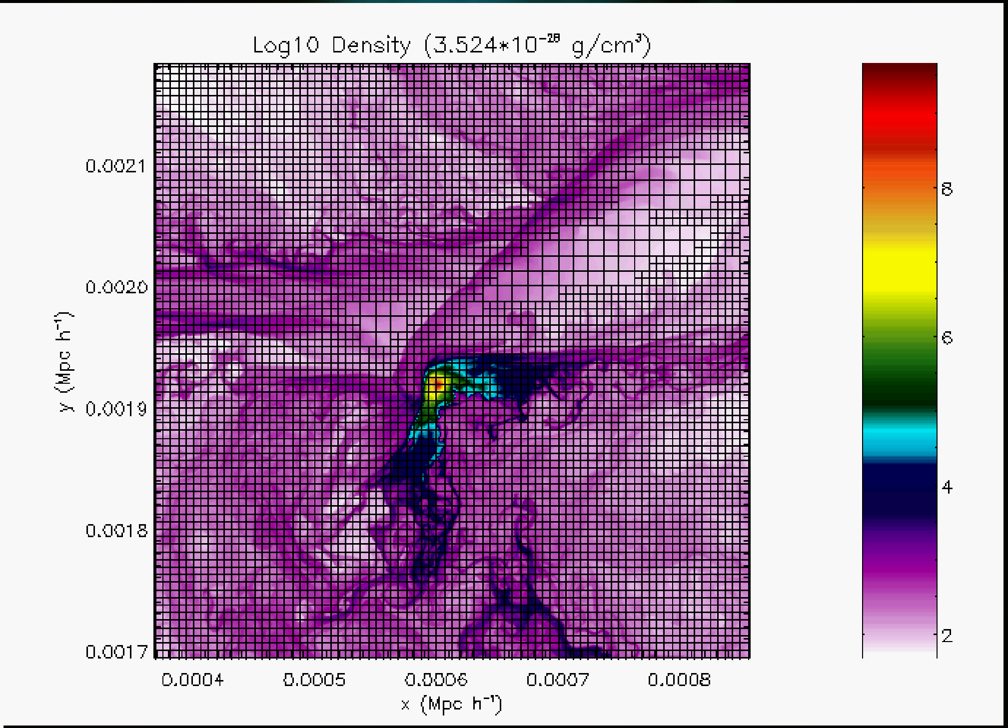
$l_{res} = 7.8125\ h^{-1}$ pc (effective resolution)

- Gravity: switched on for $n > 10\ \text{cm}^{-3}$

- *Effective viscosity* controls *vorticity* (Falle, 1991) – $l_c \ll l_{KH}$ near cloud

Why $r_{max} = 6$?





Block distribution

- KH instability 4 blocks (256 cells) to resolve $l \sim 2l_{res}$ eddies
- Cloud's compression by multiply resolved shocks