



Turbulence and thermodynamics

Powerful Jet from a Supermassive Black Hole in Galaxy System 3C 321



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- Turbulence within the tenuous ($n_e \sim 10^{-3} \text{ cm}^{-3}$), hot ($T_e \sim 10^{8-9} \text{ K}$)





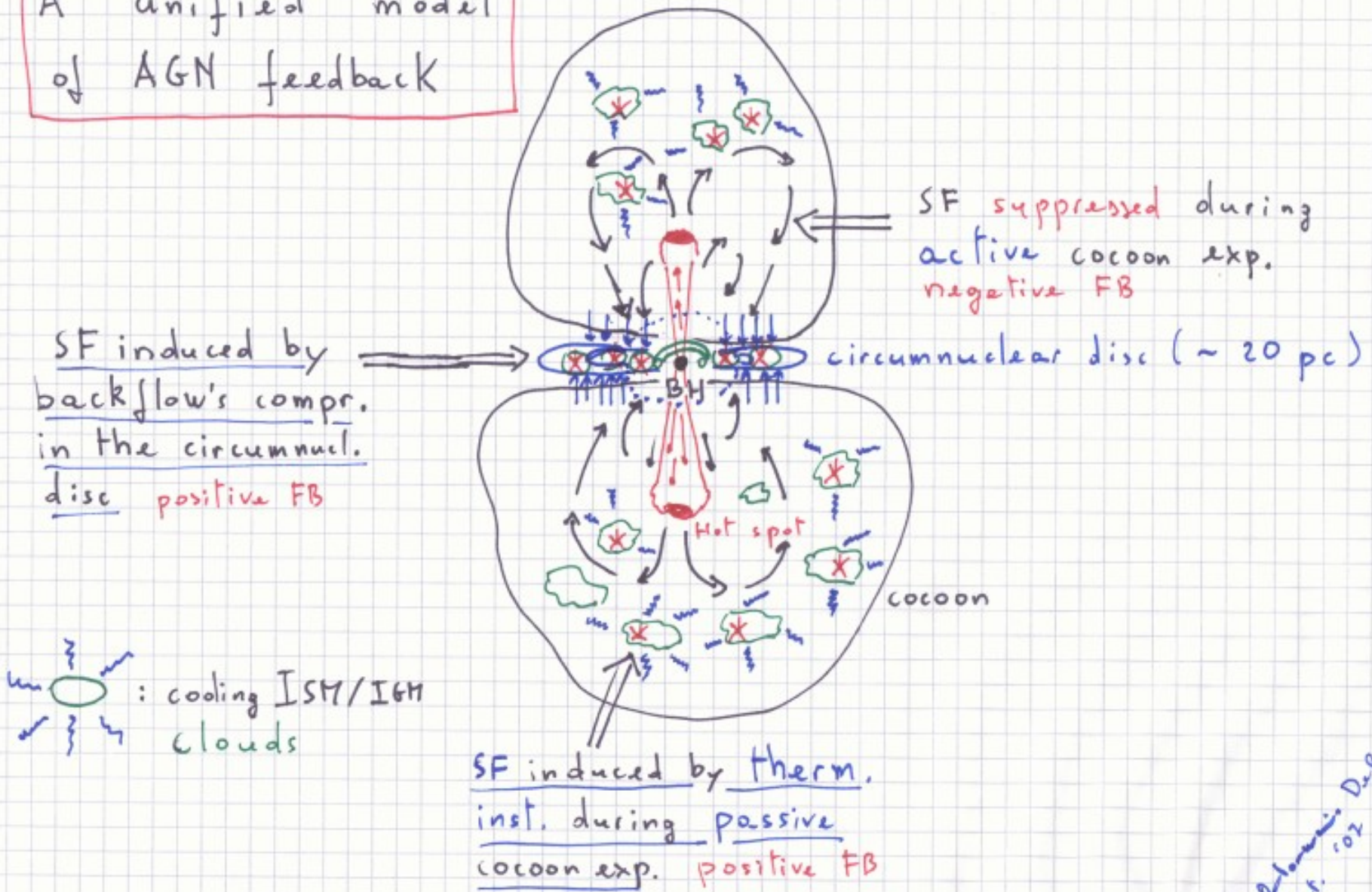
Turbulence and thermodynamics

Two (related) issues:

- Turbulence within the tenuous ($n_e \sim 10^{-3} \text{ cm}^{-3}$), hot ($T_e \sim 10^{8-9} \text{ K}$)
- Relativistic jet's thermodynamics

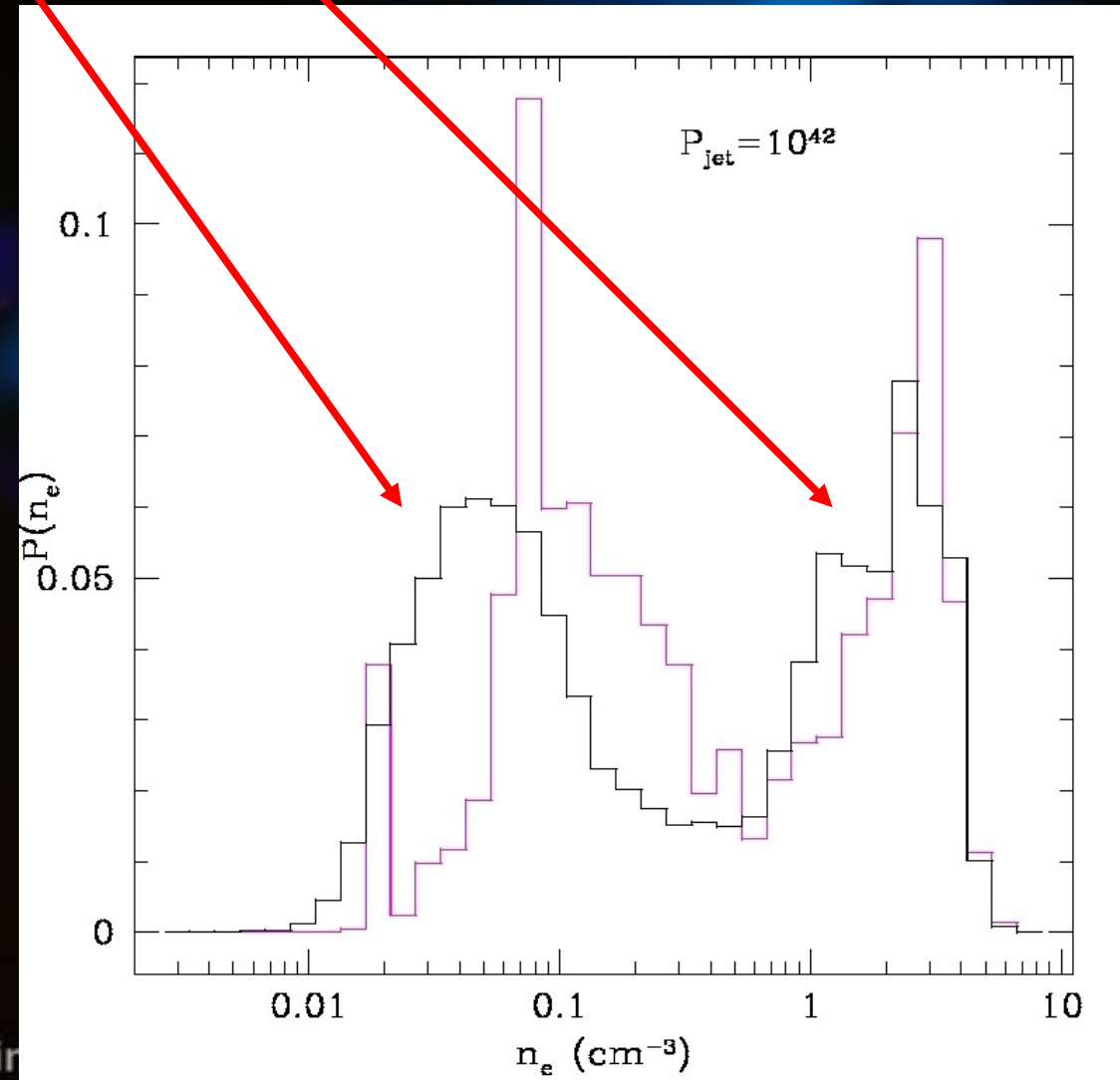
The "unified" model of AGN feedback

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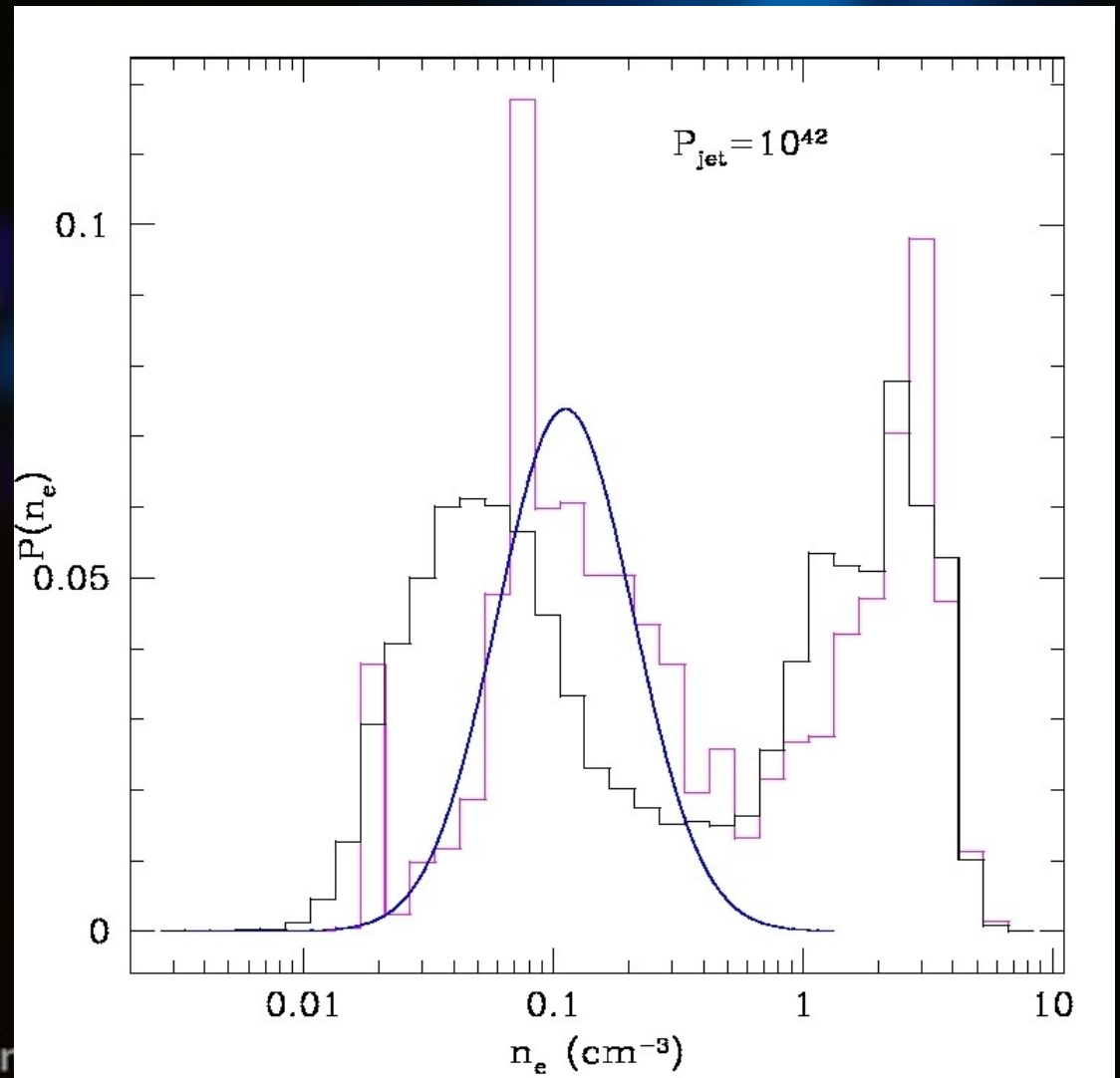


V. Belarovich Dulya
Oct. '07

- PDF, 2 components: *low / high-density (cocoon/bow shock)*

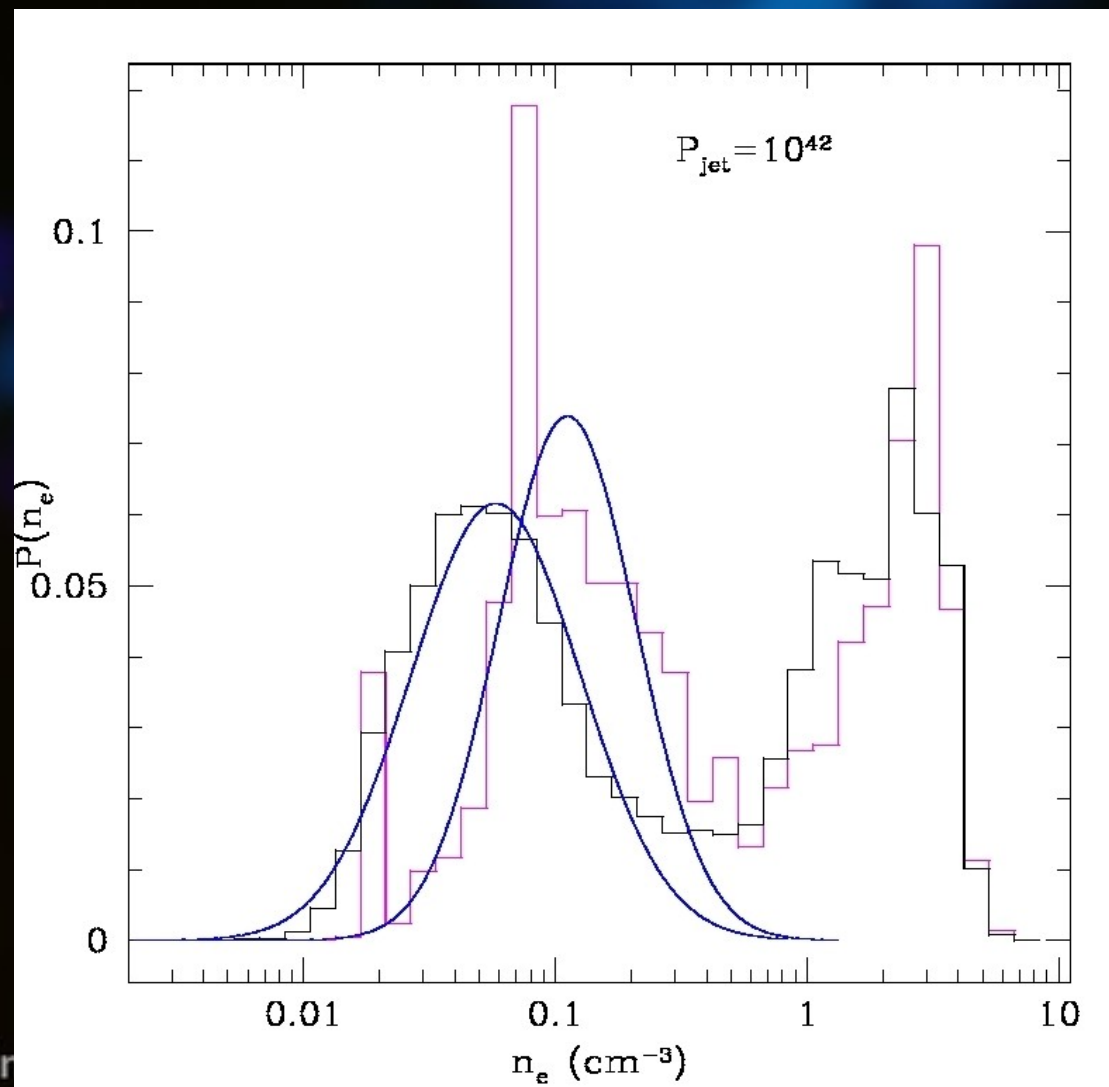


Lognormal fit for low density component



Powerful Jet from a Supermassive Black Hole in

Lognormal fit for low density component



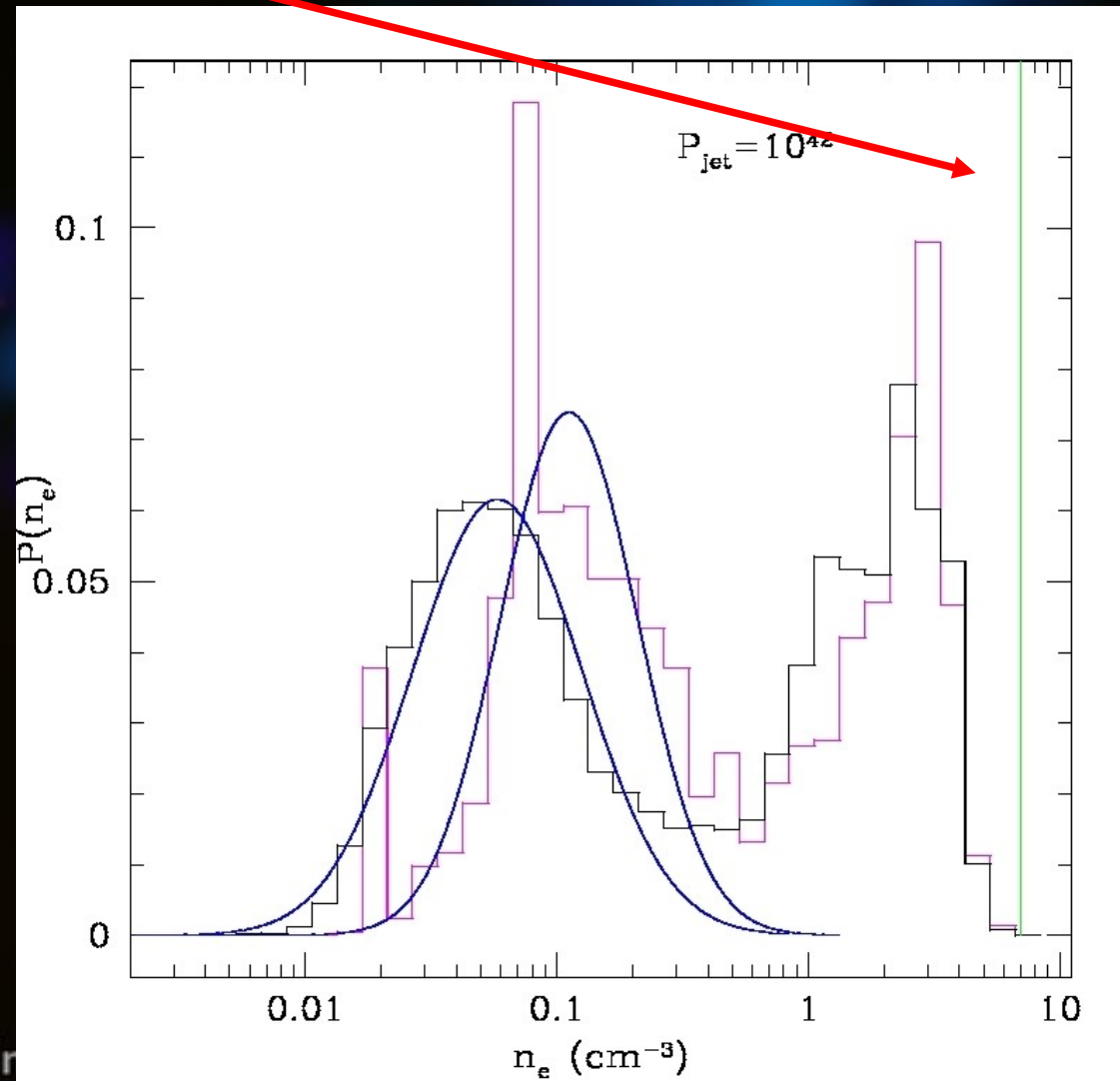
Powerful Jet from a Supermassive Black Hole in

$$\rho_{\text{down}} / \rho_{\text{up}} = 7 \quad (\text{Bouquet, Teyssier and Chieze, 2000})$$

Valid for **optically thick** media (and/OR for $\gamma \approx 4/3$)

Radiative shock

→ Most cells are strongly shocked only once!

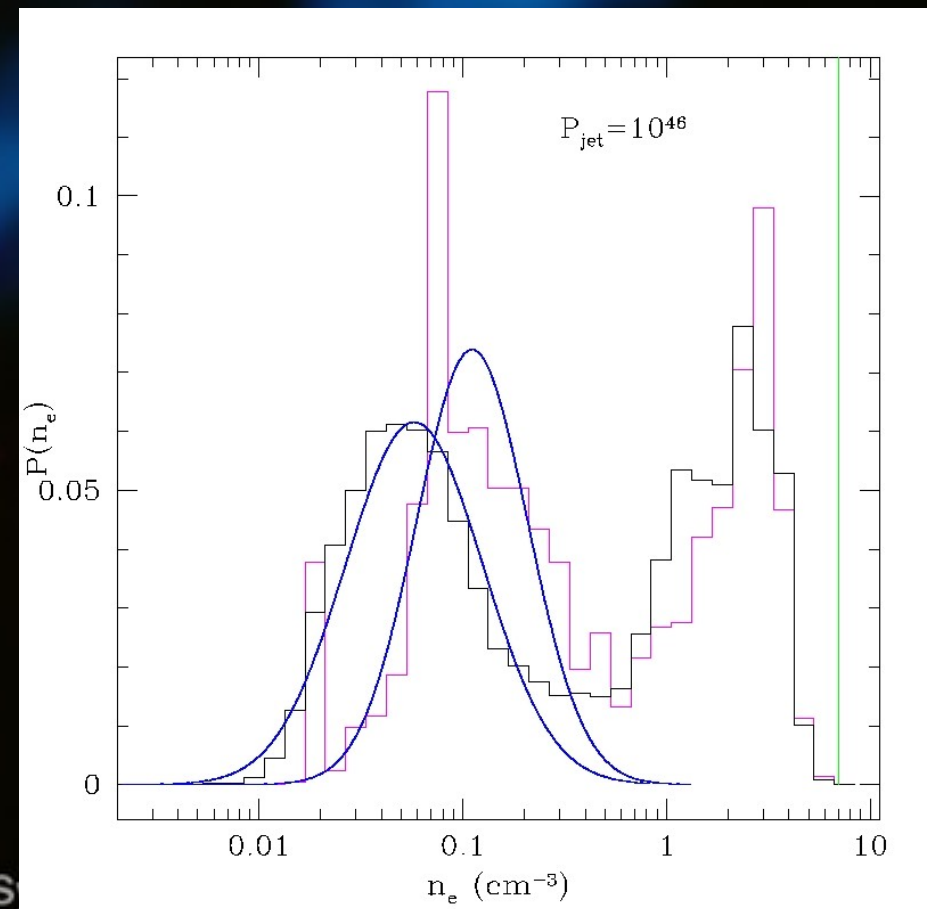
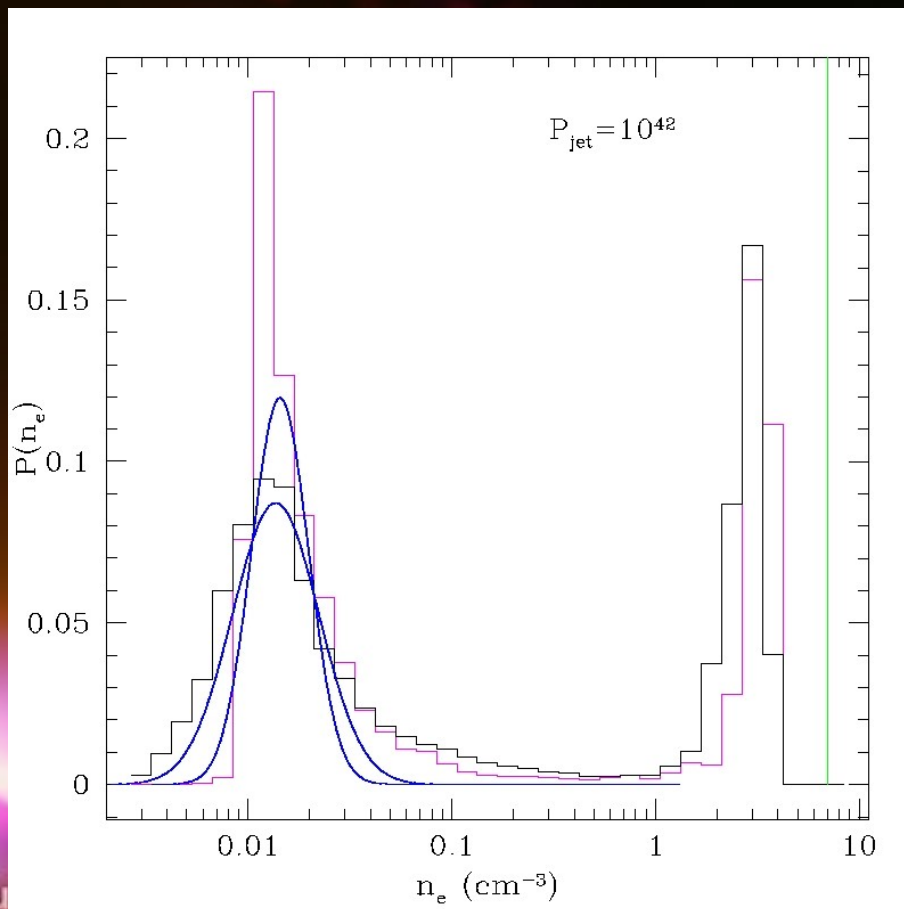


Powerful Jet from a Supermassive Black Hole in

- Lognormal fit for low density component

A universal density PDF

- Turbulence driver: mechanical energy \rightarrow shear \rightarrow KH inst.
- Expanding cocoon \rightarrow stationary, externally driven turbulence



A (universal) density Probability Distribution Function

$$P(s; \gamma) ds = C(\gamma) \exp \left[\frac{-s^2 e^{(\gamma-1)s}}{2M^2} - \alpha(\gamma)s \right] ds.$$

$$S = \ln(\rho - \langle \rho \rangle_{vol})$$

$$M: \langle \text{Mach} \rangle_{vol}$$

γ : effective adiabatic index (from fit, $1.11 \leq \gamma \leq 1.27$)

$C(\gamma)$: from $\int P(s; \gamma) ds = 1$

$\alpha(\gamma)$: from mass normalisation $\int e^s P(s; \gamma) ds = 1$

- Scalo, Passot, Vázquez-Semadeni (1997, 1998):

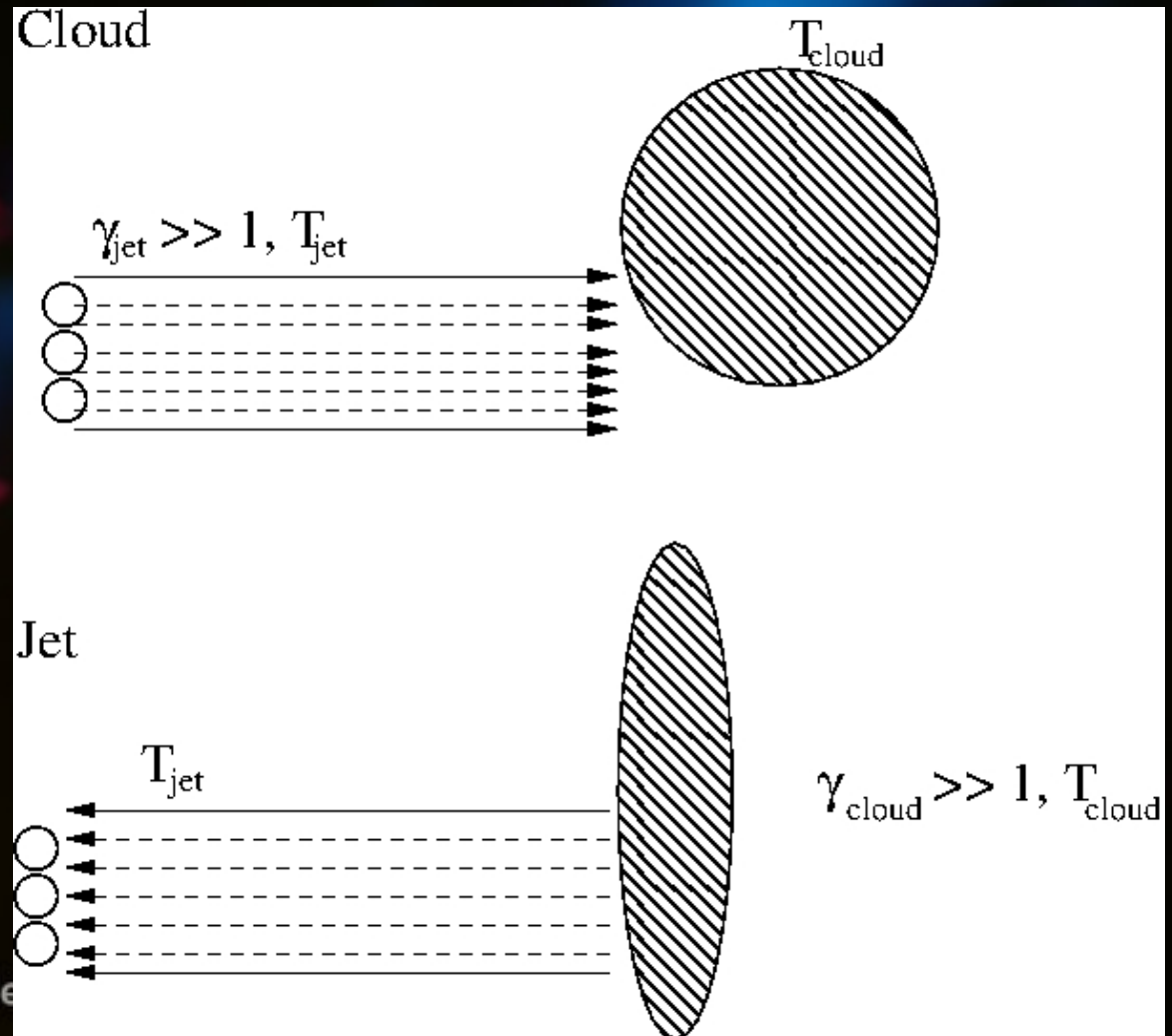
$P(s; \gamma)$ lognormal for $M \approx 1$, $\gamma \approx 1$, $\propto \rho^{-1.7}$ for $\gamma < 1$ (applies to ISM)

- Norman, Padoan, Kritsuk (1997, 1999, 2007):

$P(s; \gamma)$ lognormal with disp: $\sigma^2 = 2 \ln(1 + b^2 M^2)$, $b = 0.26 \pm 0.001$

How *HOT* is a relativistic jet?

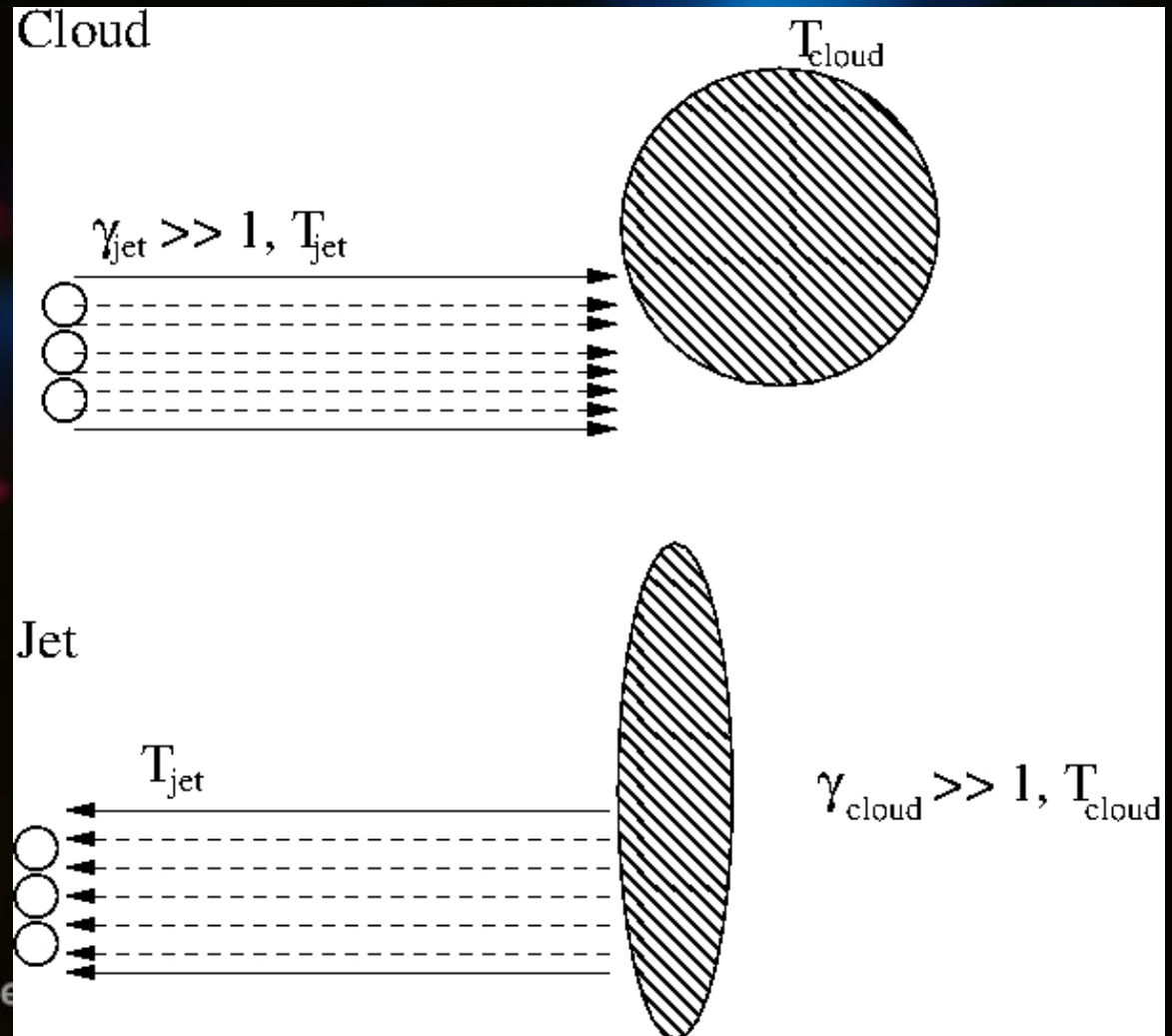
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The jet hits a cloud:
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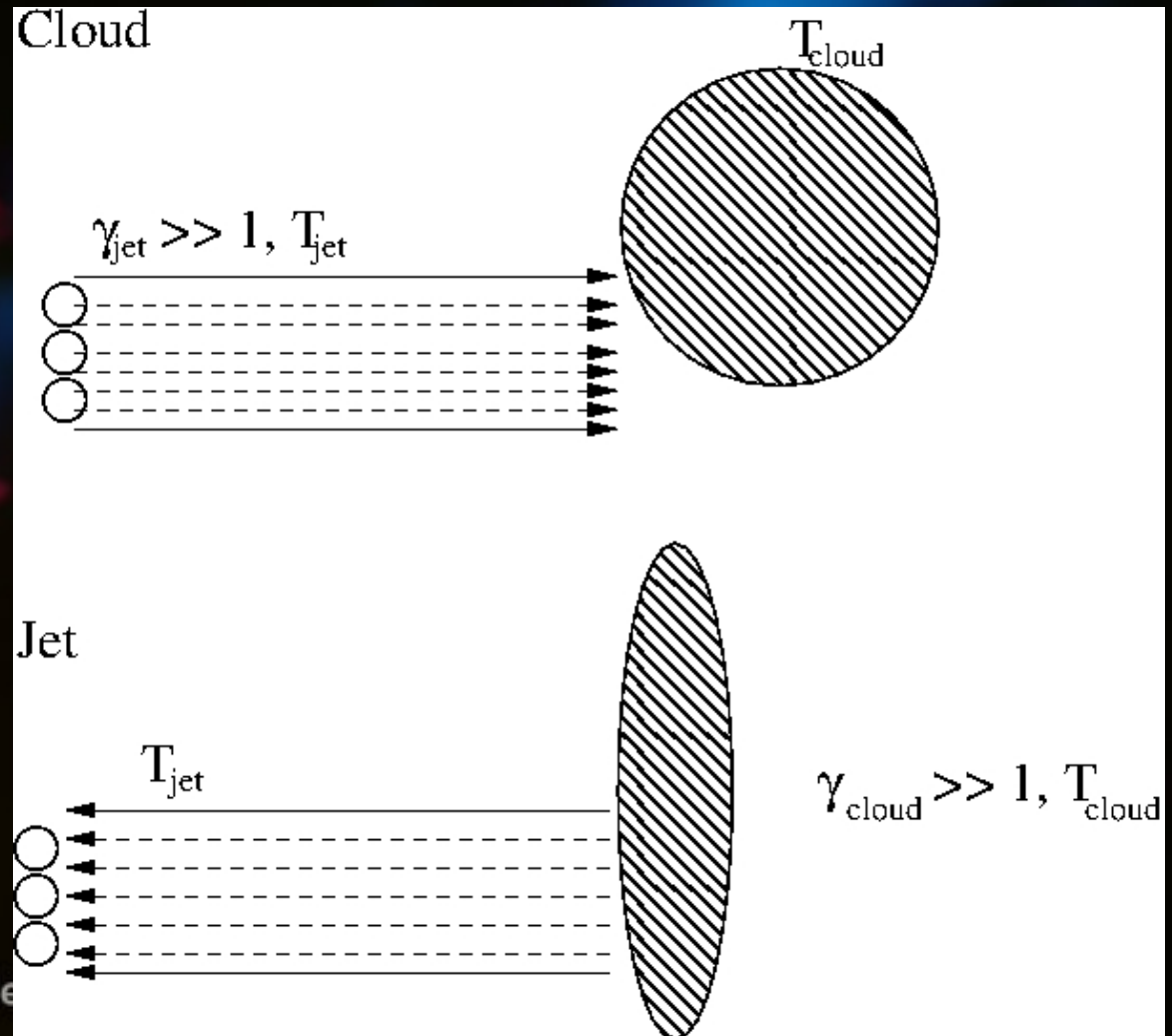


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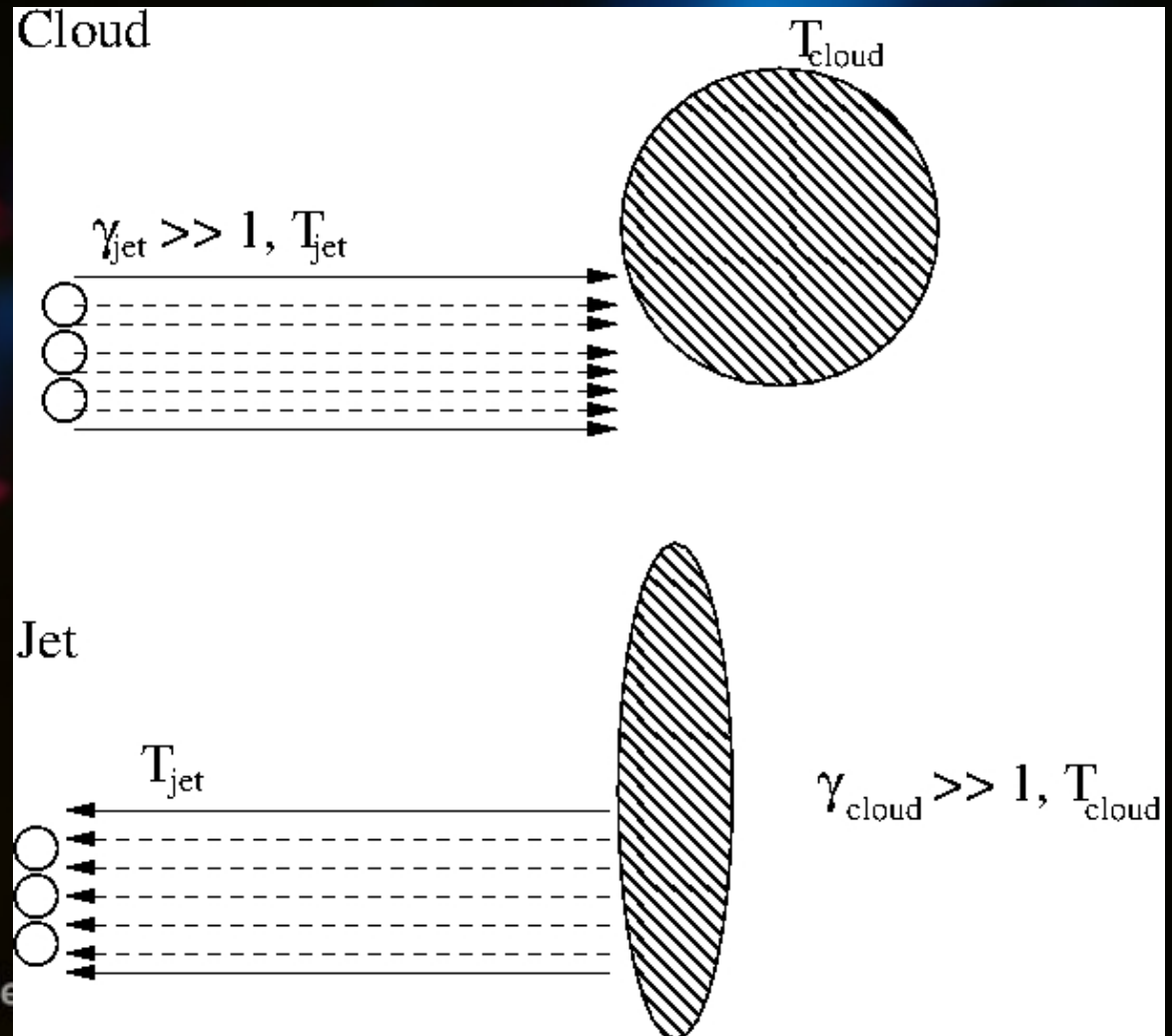
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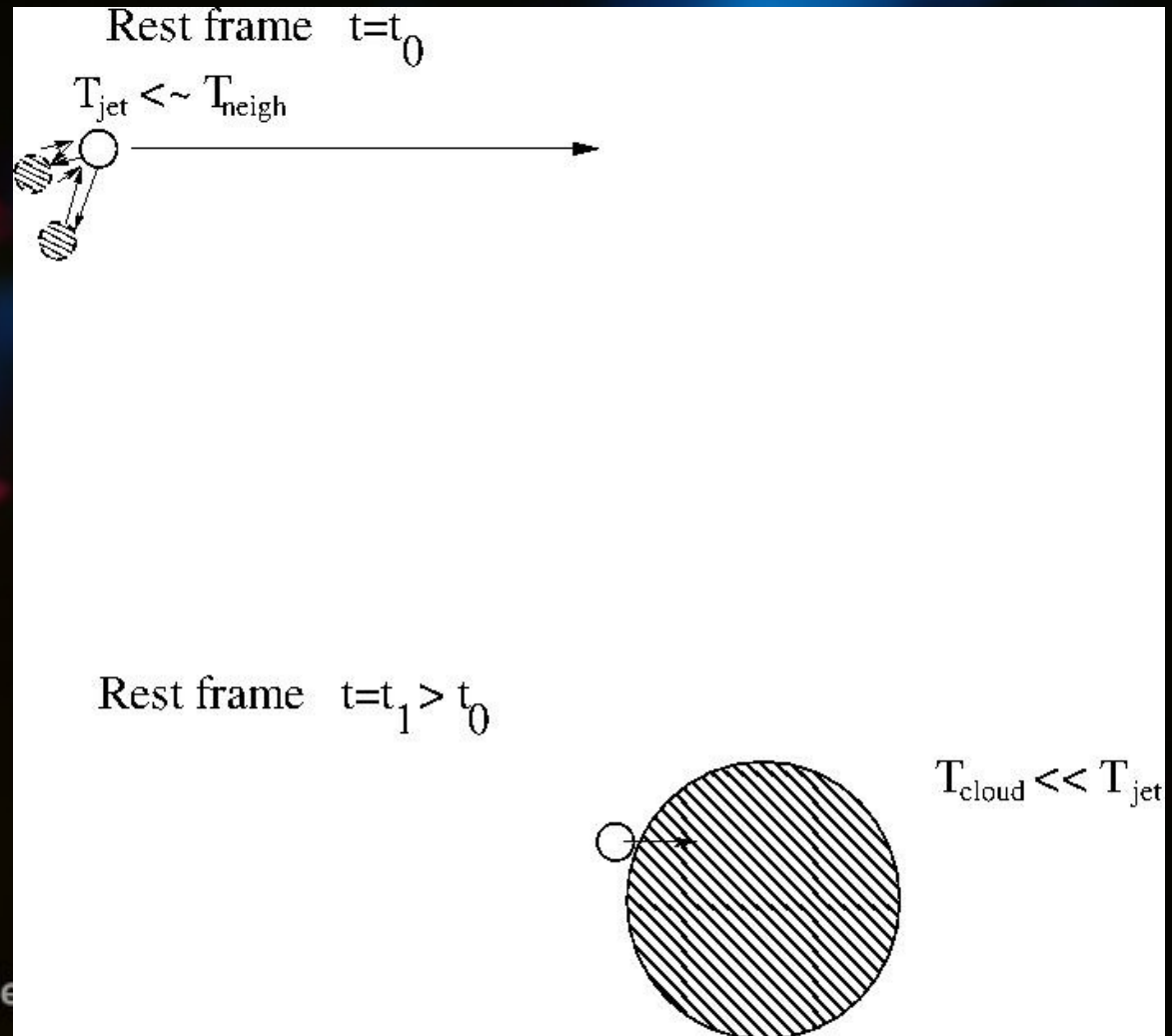
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Astrophysicists implicitly assume $T_1 = T_0$ but only p and S are scalars in SR



How *HOT* is a relativistic jet (contd.)?

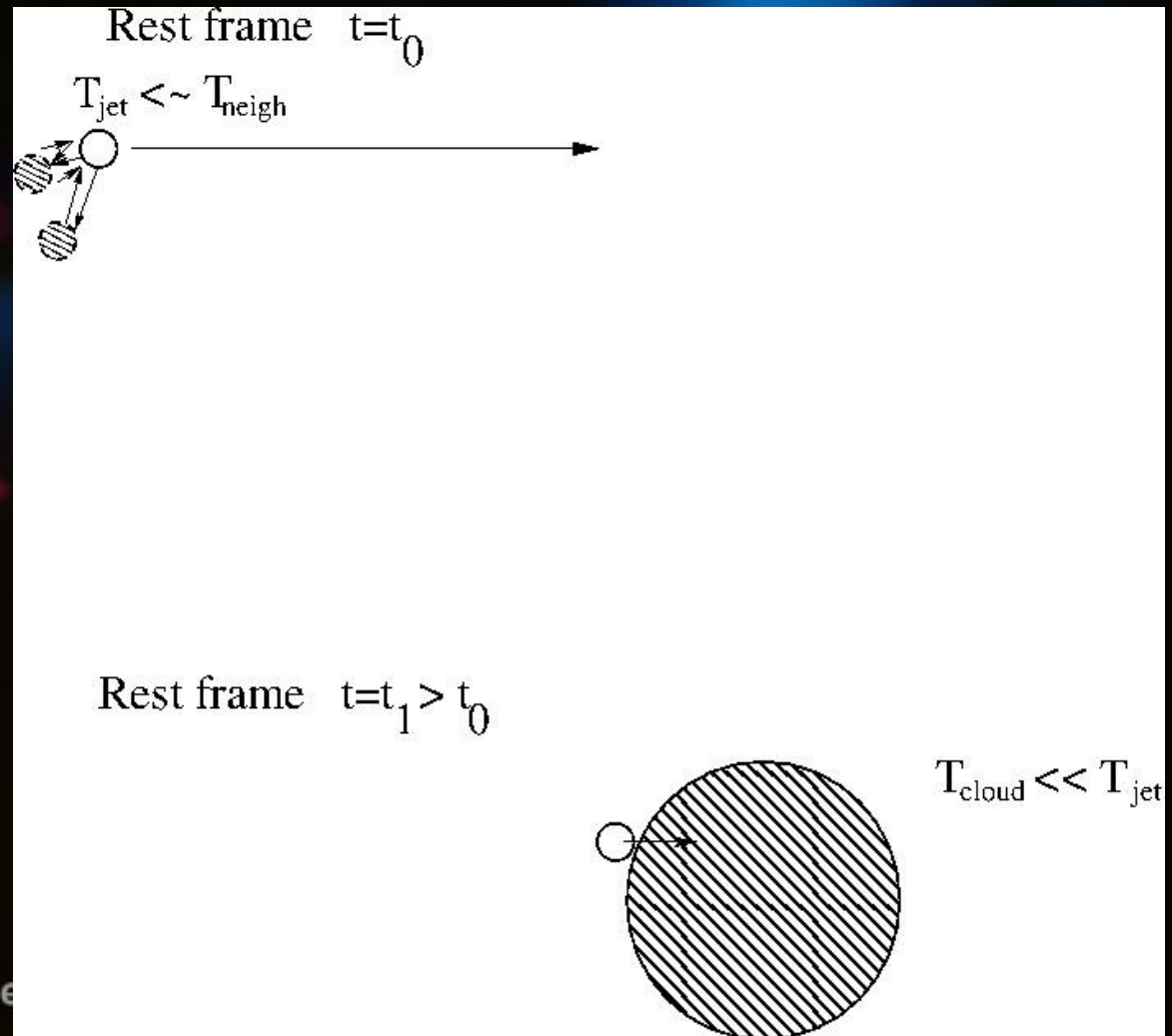
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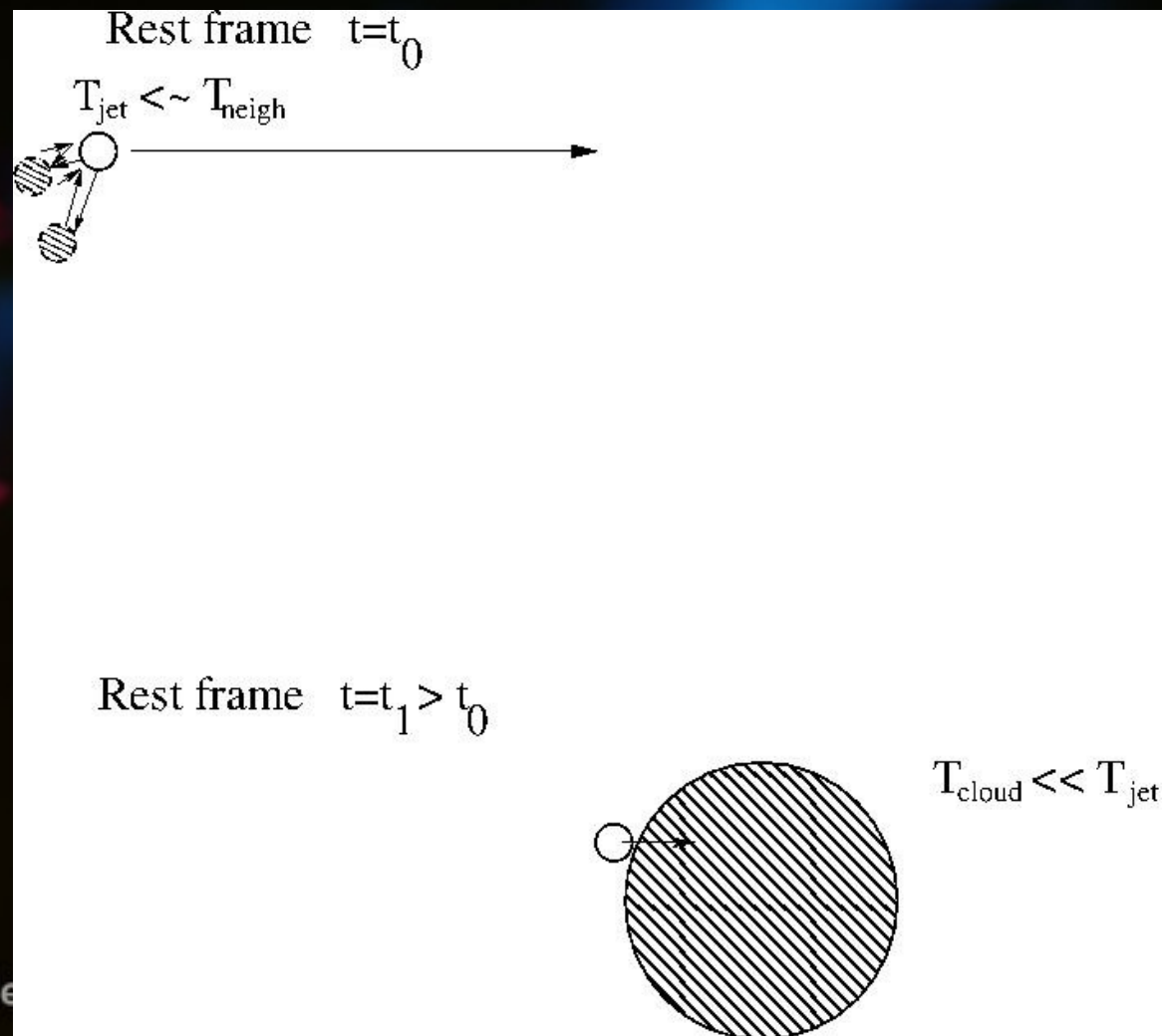


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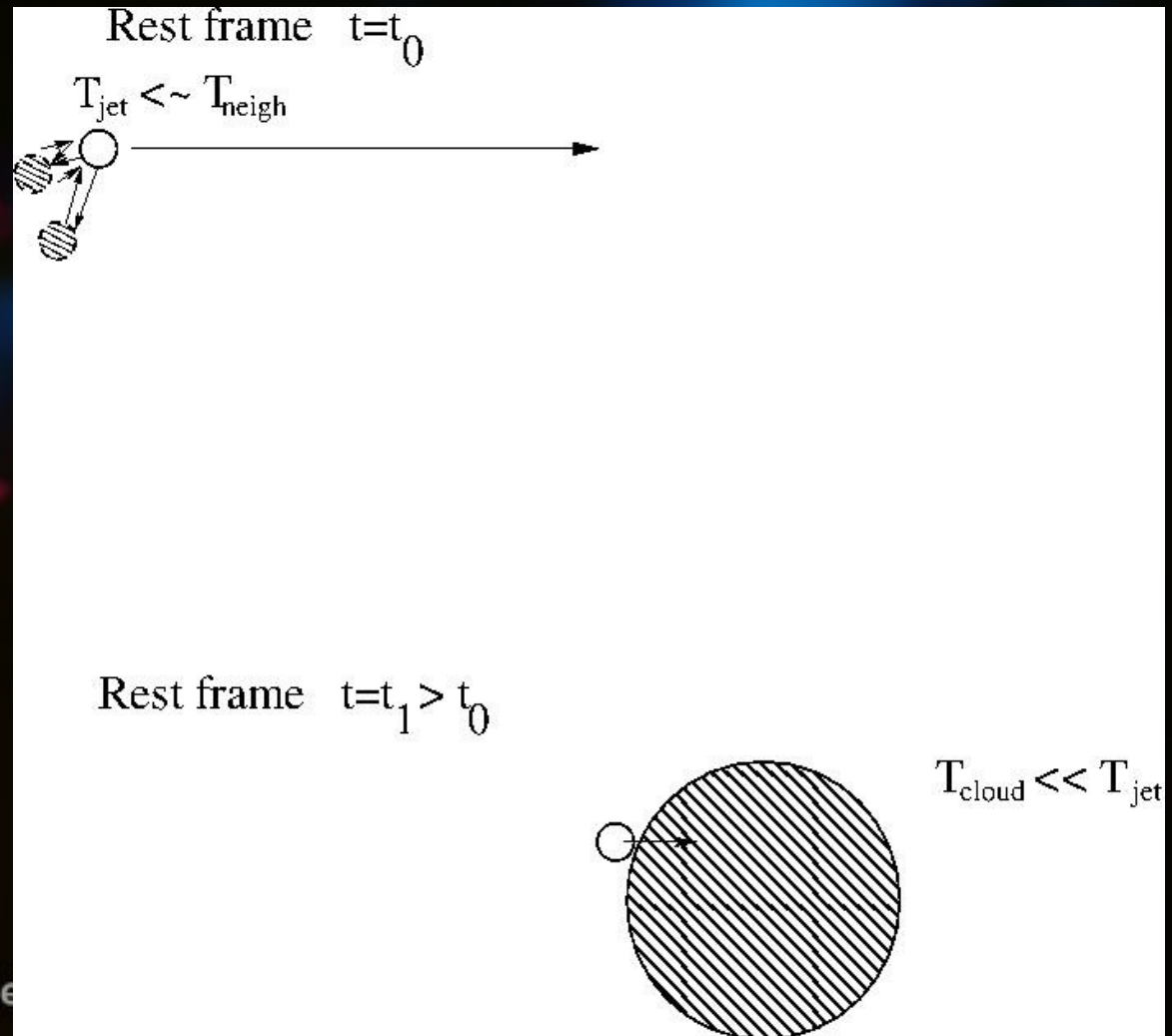
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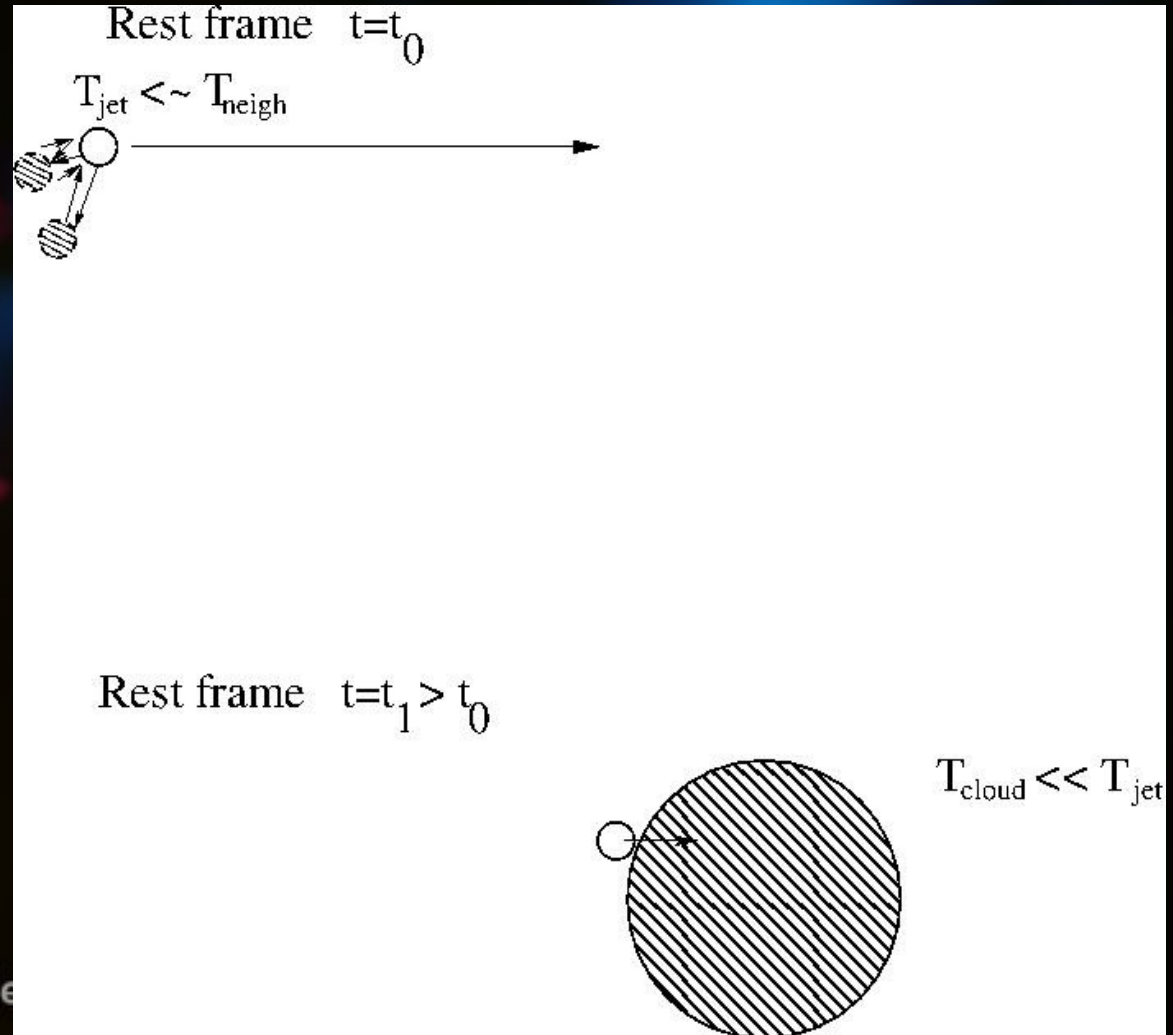
The parcel hits a cloud ($T_{\text{cloud}} \ll T_{\text{jet}}$) and slowed down. It then releases some heat $\delta Q' = \gamma \delta Q$



How *HOT* is a relativistic jet (contd.)?

In relativistic fluids the T transformation depends on the *thermodynamic process*

This is a Carnot cycle similar to Ott (1983).
All transf. Are reversible, thus:
$$\delta S = \delta Q'/T_{\text{jet}} + \delta Q/T_0 = 0$$



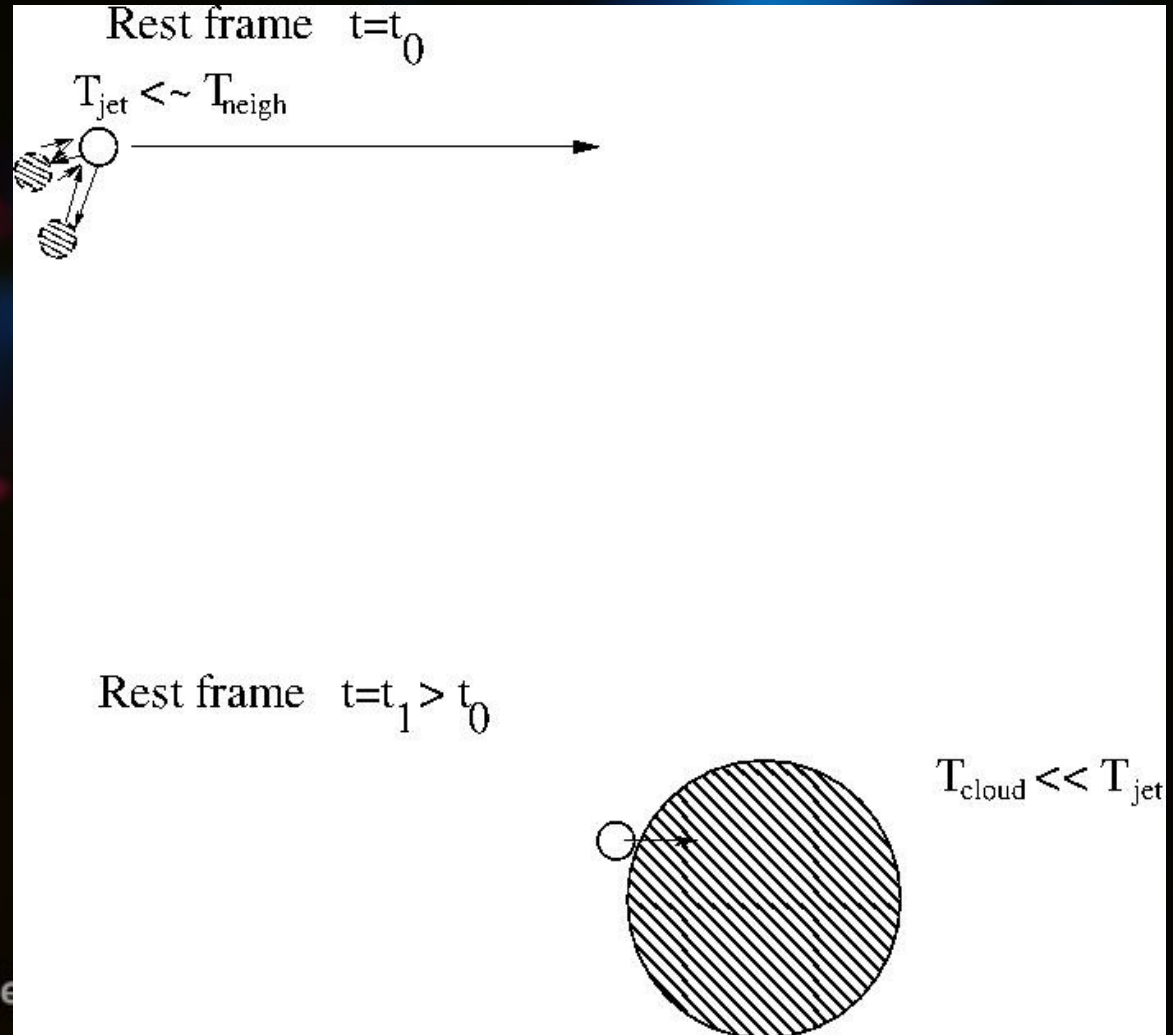
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The jet appears **hotter** to the cloud



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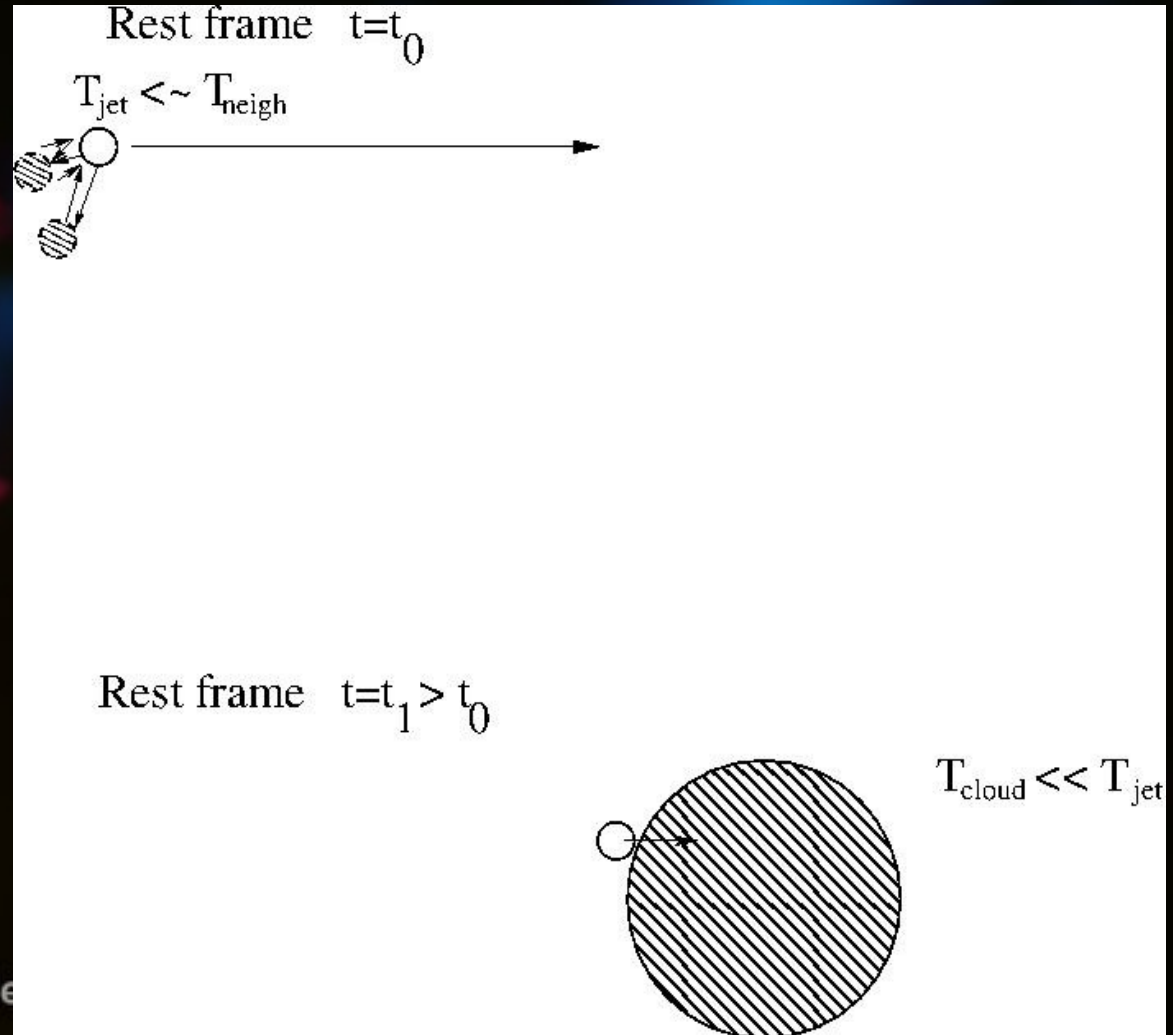
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Spectral signature





$M_{\text{BH}} - M_*$ predictions from Yohan's sims is similar to Booth & Schaye 2013 : M_{BH} only depends on *global* DM halo properties

MV: To fit the $M_{\text{bh}} - \text{MDM}$ relation at high z need *selective accretion*





Open issues

- > Backflows: always present before $t < 10\text{-}20$ Myrs
Go to $\sim 10\text{-}10^3$ pc simulations, BH+disc dominate
- > Get ϵ_f for cosmological simulations (Yohan) from actual jet simuls. within inhomogeneous galaxies (cold, SF clouds)
- > ?

