Unlocking with beaming the γ-ray emission process and its location

- The beaming of isotropic emission *(blackboard)*
- The beaming of External Compton emission *(blackboard)*
- A collective signature of External Compton (slides-*blackboard*)
- Superluminal expectations (*blackboard*-slide)

Beaming of isotropically emitted in the comoving frame radiation: Emission coefficient

$$\boxed{J(\epsilon) = J(\epsilon')\left(\frac{\varepsilon}{\varepsilon'}\right)^2}$$

J/ϵ^2 is a Lorentz invariant (Rybicki and Lightman)

$$\varepsilon = \varepsilon'\Delta \quad , \quad \Delta = \frac{1}{\Gamma(1-\beta\cos\theta)}$$

Good for any isotropic emission mechanism

If $J(\epsilon') = \kappa\epsilon'^{-a}$

$$J(\epsilon) = \Delta^2 J(\varepsilon/\Delta) = \Delta^2 \kappa\left(\frac{\epsilon}{\Delta}\right)^{-\alpha} = \Delta^{2+a}\kappa\epsilon^{-\alpha}$$

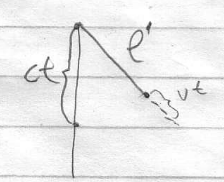
For a moving feature $V = \Delta V'$ *

So $L(\epsilon) = J(\epsilon)\Delta = \Delta^3 J\left(\frac{\epsilon}{\Delta}\right) = \Delta^{3+a}\kappa\epsilon^{-\alpha}$

For the νL_ν peak $a=-1$ $\boxed{L \propto \Delta^4}$

An explanation for $V = \Delta V'$ simplified to $l = \Delta l'$

$$ct = \frac{l'}{\Gamma}\cos\theta + vt\cos\theta$$



$$t(c - v\cos\theta) = \frac{l'\cos\theta}{\Gamma(c - v\cos\theta)} \Rightarrow$$

$$ct = \frac{l\cos\theta}{\Gamma(1-\beta\cos\theta)} \Rightarrow l = \frac{ct}{\cos\theta} = \frac{l}{\Gamma(1-\beta\cos\theta)} = \Delta l'$$

Beaming of External Compton

(see Georgano poulos et al 2001 for a detailed

Start by the invariance of $n(\gamma)/\Delta^2$ for $\gamma \gg 1$

Assume, for simplicity, a monoenergetic electron distribution

$$n'(\gamma') = \frac{K}{4\pi}\,\delta(\gamma' - \gamma_0) \quad \text{, an isotropic distribution}$$

From the Lorentz invariant we have:

$$n(\gamma, \mu) = \frac{K}{4\pi}\,\Delta^2\,\delta\left(\frac{\gamma}{\Delta} - \gamma_0\right) = \frac{K}{4\pi}\,\Delta^3\,\delta(\gamma - \Delta\gamma_0)$$

multiply by ΔV, $N_{eff}(\gamma, \mu) = \frac{KV}{4\pi}\,\Delta^4\,\delta(\gamma - \Delta\gamma_0)$

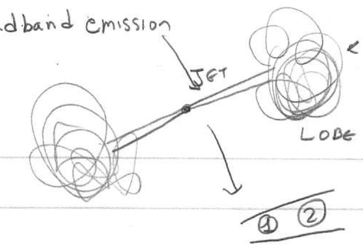
Now calculate the received power:

$$\frac{dL}{d\Omega} \int \frac{4}{3}\,\sigma_T c\,\gamma^2\,U\,\frac{KV}{4\pi}\,\Delta^4\,\delta(\gamma - \Delta\gamma_0)\,d\gamma$$

(U ↑ external photon energy density)

$$= \boxed{\frac{4}{3}\,\sigma_T c\,\gamma_0^2\,U\,\frac{KV}{4\pi}\,\Delta^6}$$

Beamed broadband emission ← Extended, unbeamed emission in the radio



1. plasma producing the peaks in νf_ν of the synchrotron and inverse Compton emission. Lorentz factor Γ_p

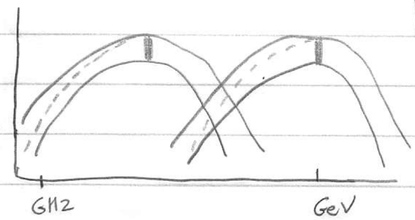
2. plasma producing the core jet radio emission. Lorentz factor Γ_{core}

Possibly $\Gamma_p > \Gamma_{core}$

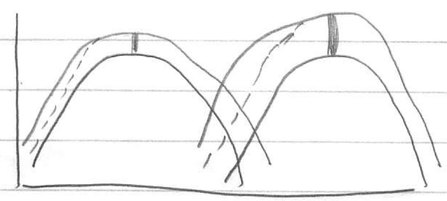
Same source under different angles

A. SSC

--- For $\Gamma_p > \Gamma_{core}$



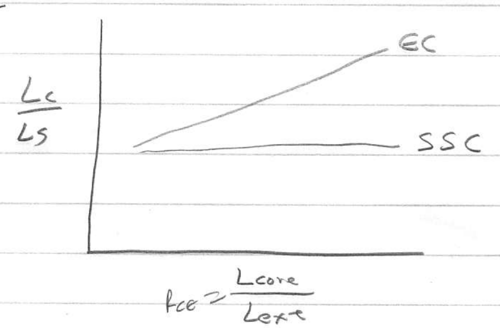
B. EC



$$\frac{L_c}{L_s} \propto \frac{\delta_p^6}{\delta_p^2} \propto \delta_p^2 \qquad \frac{L_{core}}{L_{ext}} \propto \delta_{core}^{2+\alpha}$$

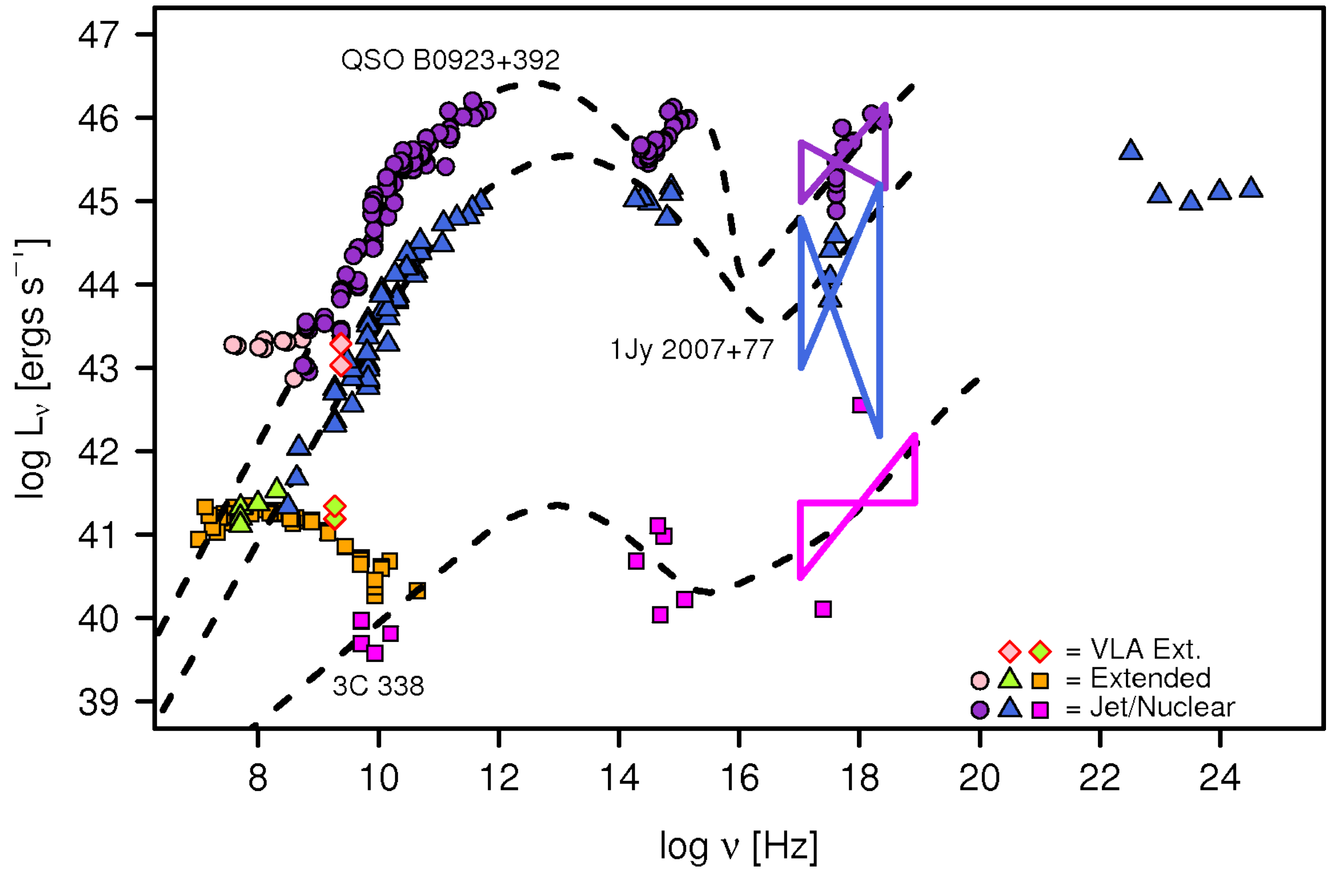
If $\Gamma_p = \Gamma_{core}$ $\quad \frac{L_c}{L_s} \propto \left(\frac{L_{core}}{L_{ext}}\right)^{\frac{2}{2+\alpha}} = \left(\frac{L_{core}}{L_{ext}}\right)^{0.8}$ for $\alpha = 0.5$

How is the Compton dominance expected to vary as a function of core dominance as we change the orientation of the source?



Intrinsic jet power by proxy

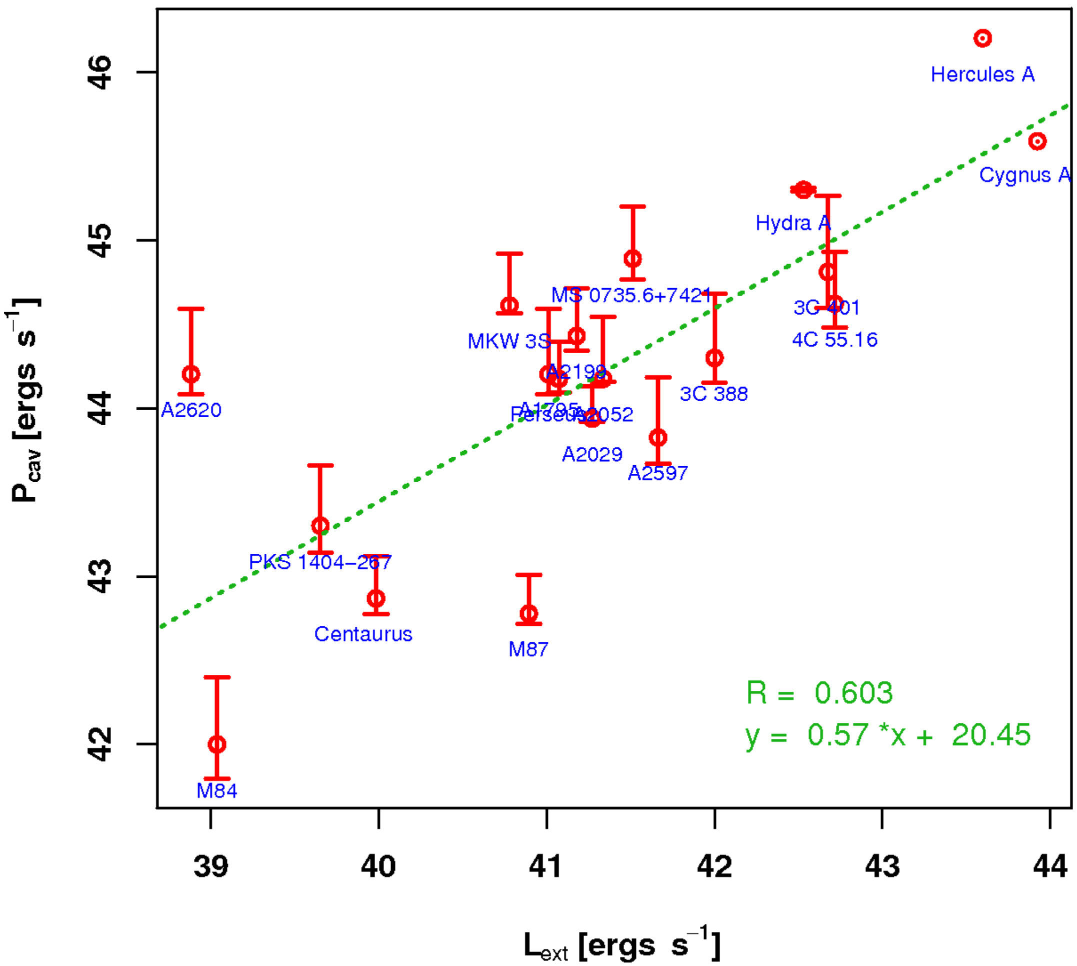
- We need a measure of the **intrinsic** jet power, non altered by the effects of relativistic beaming. The best consensus estimator is the luminosity of the extended radio emission:
  - It is assumed to be emitted isotropically.
  - It represents a long term average of the jet power.
  - It is not variable.



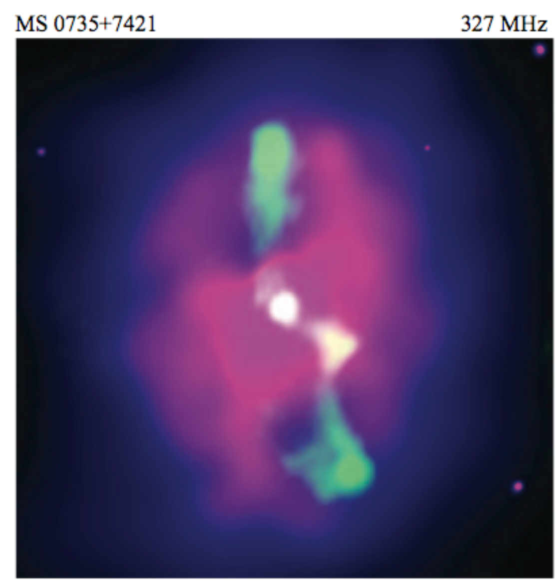
- It typically dominates the spectrum at low frequencies (below the GHz range) because of its different –steep- spectral shape.
  - We combined spectral decomposition to recognize the steep component and
  - imaging radio data allowing a direct estimate of the spatially extended flux.

Extended luminosity and intrinsic jet power

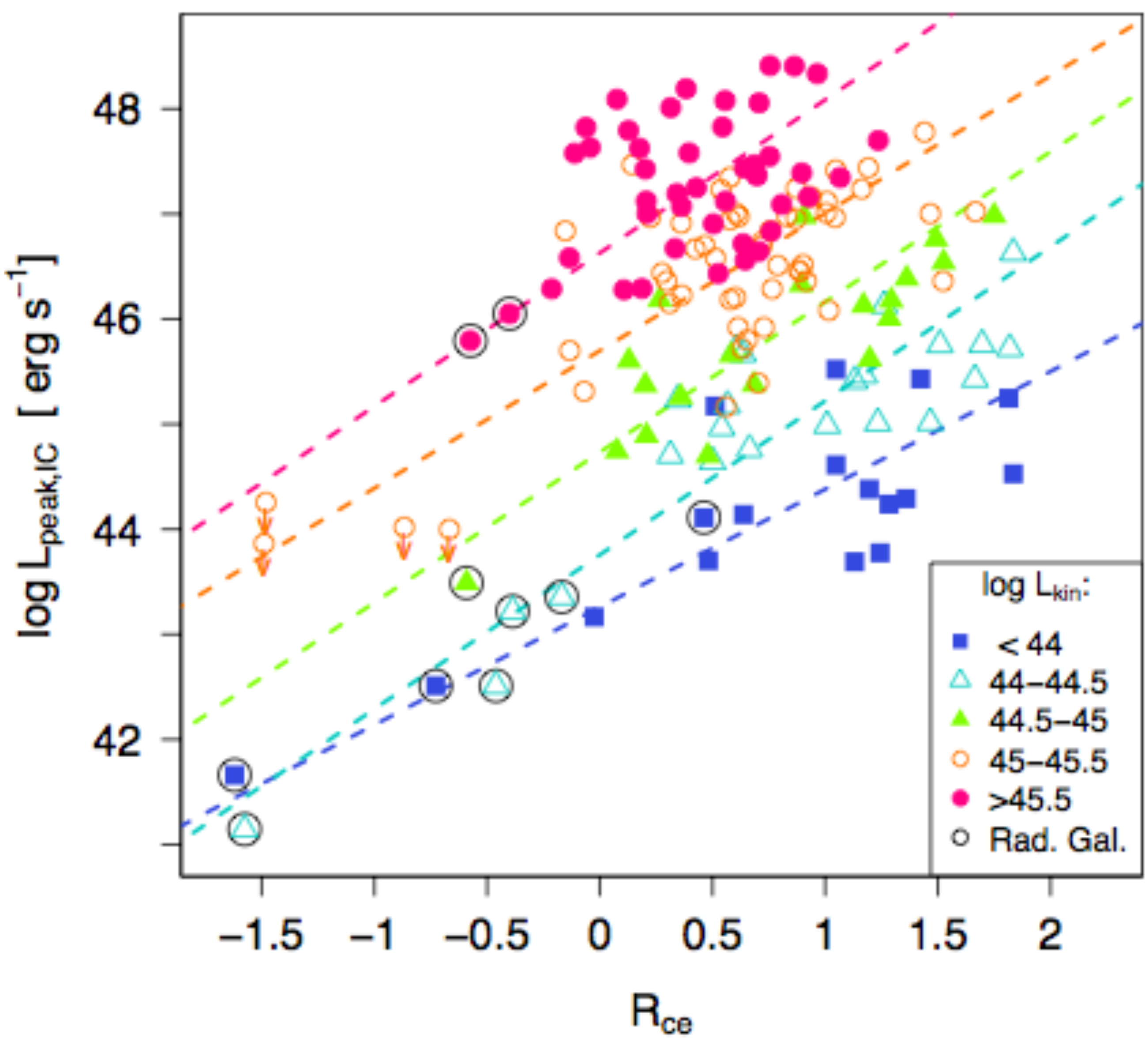
Cavity Power versus Extended Luminosity at 300 MHz for 20 sources in McNamara et al. 2009



- For a sample of radio-galaxies found in clusters of galaxies the intrinsic jet power can be estimated by the study of the cavities that their jets inflated in the intracluster medium.
- This accurate and physically well defined measure of jet power correlates well with our best estimate of the extended radio luminosity.



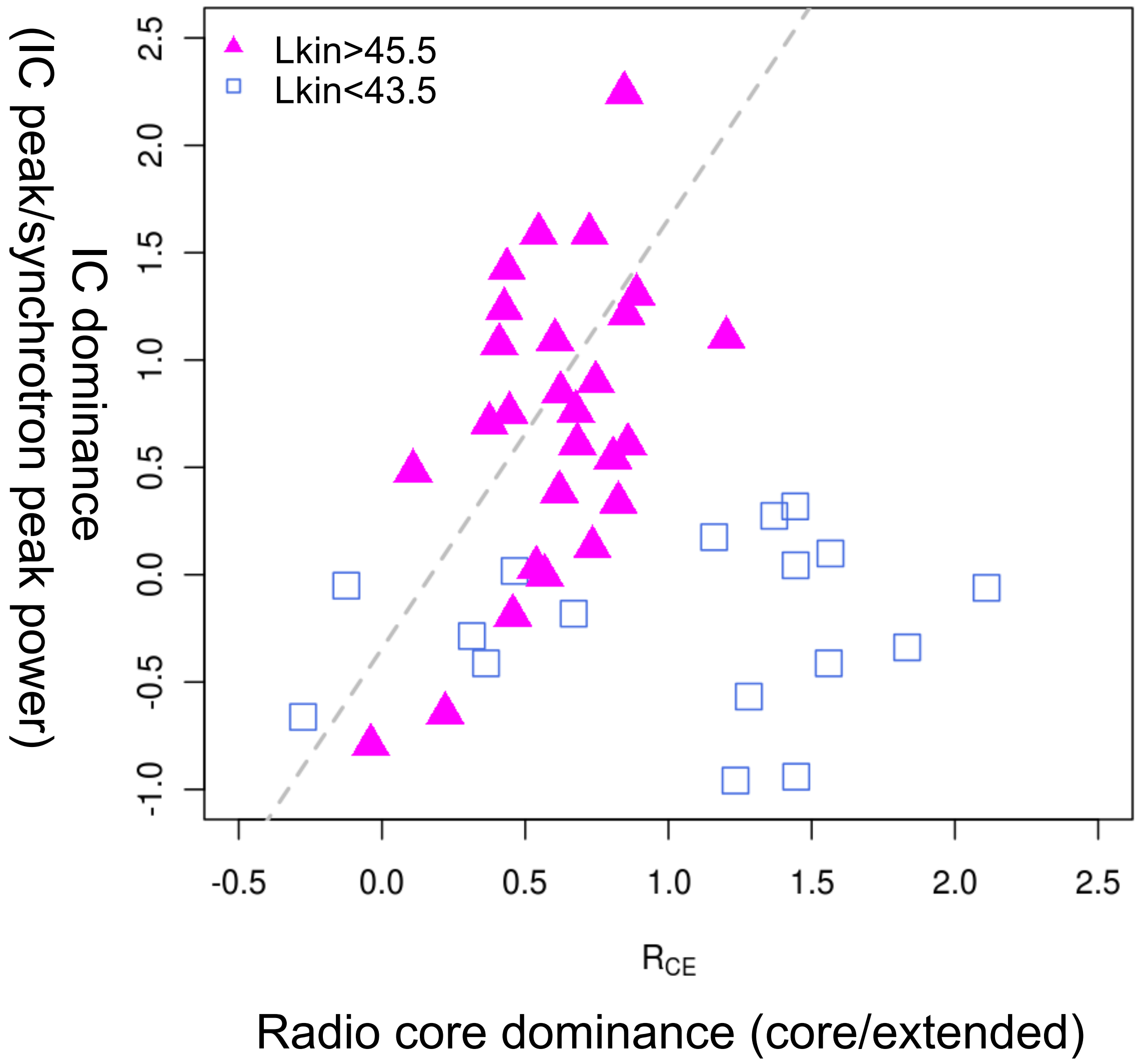
Fermi Luminosity vs core dominance



Meyer et al. 2012 ApJ 725 L4

SSC for weak jets
EC for powerful jets

- The ratio between the peak luminosities of the γ-ray (IC) and synchrotron components behaves differently as a function of radio core dominance for high and low jet power sources.



- Radio core-dominance is sensitive to beaming.
- The trend between these two quantities is sensitive to differences in beaming between the IC and synchrotron components.
- **Powerful sources are EC emitters weak jets are SSC emitters**

Meyer et al. 2012

Q: Do we expect to see many sources within the $\theta = 1/\Gamma$ angle?

Consider jets of the same jet power and Lorentz factor Γ with a comoving density N in a Euclidian Universe. Assuming a survey with flux limit f_c what is the distribution $\frac{dn}{d\theta}$ (where θ is the jet angle to the line of sight)? Compare its peak to $\theta = \frac{1}{\Gamma}$ that maximizes the superluminal speeds.

$L_c = \epsilon \frac{P_{jet}}{\Gamma^2}$ is the comoving luminosity of the jet and ϵ is the efficiency of converting jet power to radiation

For a beaming pattern δ^p ($p = 6$ or 5 for EC, 3-4 for SSC and $2+a$ or $3+a$ for radio spectrum) the observed flux is $f = \frac{L_c \delta^p}{4\pi d^2}$.

The maximum distance that such a source can be detected is $d_{max} = \left(\frac{L_c \delta^p}{4\pi f_c}\right)^{1/2} \propto \delta^{p/2} \propto (1 - \beta\cos\theta)^{-\frac{p}{2}}$

The number of sources $\frac{dn}{d\theta}$, where θ is the orientation angle of the jet is

$$\frac{dn}{d\theta} = 2\pi \frac{N}{4\pi} \frac{4\pi d_{max}^3}{3} \sin\theta \propto \frac{\sin\theta}{(1-\beta\cos\theta)^{3p/2}}$$

For radio observations of flat $(\alpha = 0)$ sources $p=2$ and

$\frac{dn}{d\theta}$ peaks at $\cos\theta \approx \frac{0.45}{\Gamma}$

For $p=6$ (EC) $\cos\theta = \frac{0.24}{\Gamma}$

In general, we do expect the peak of the distribution to be within $1/\Gamma$ and these sources would exhibit slower β_{app}.

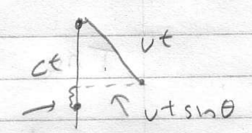
Refresh Superluminal motion

$$v_{app} = \frac{v t \sin\theta}{\Delta t}$$

$$= \frac{v t \sin\theta}{t - \beta t \cos\theta} = \frac{v \sin\theta}{1 - \beta\cos\theta}$$

$ct - vt\cos\theta \rightarrow$

$\Delta t = t - \beta t \cos\theta$

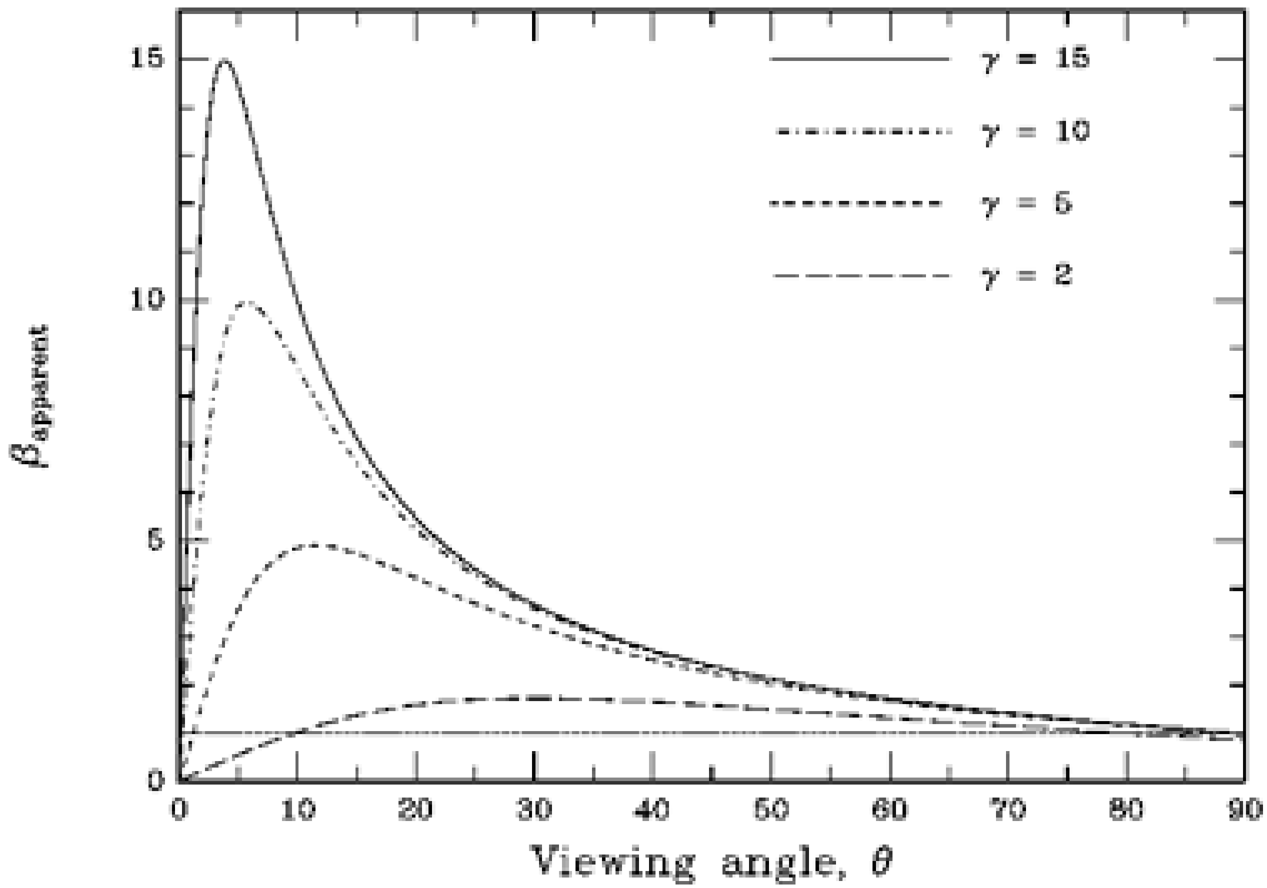


$$\beta_{app} = \frac{\beta \sin\theta}{1 - \beta\cos\theta}$$

Gets its maximum value $\beta\Gamma$

at $\theta \sim \frac{1}{\Gamma}$

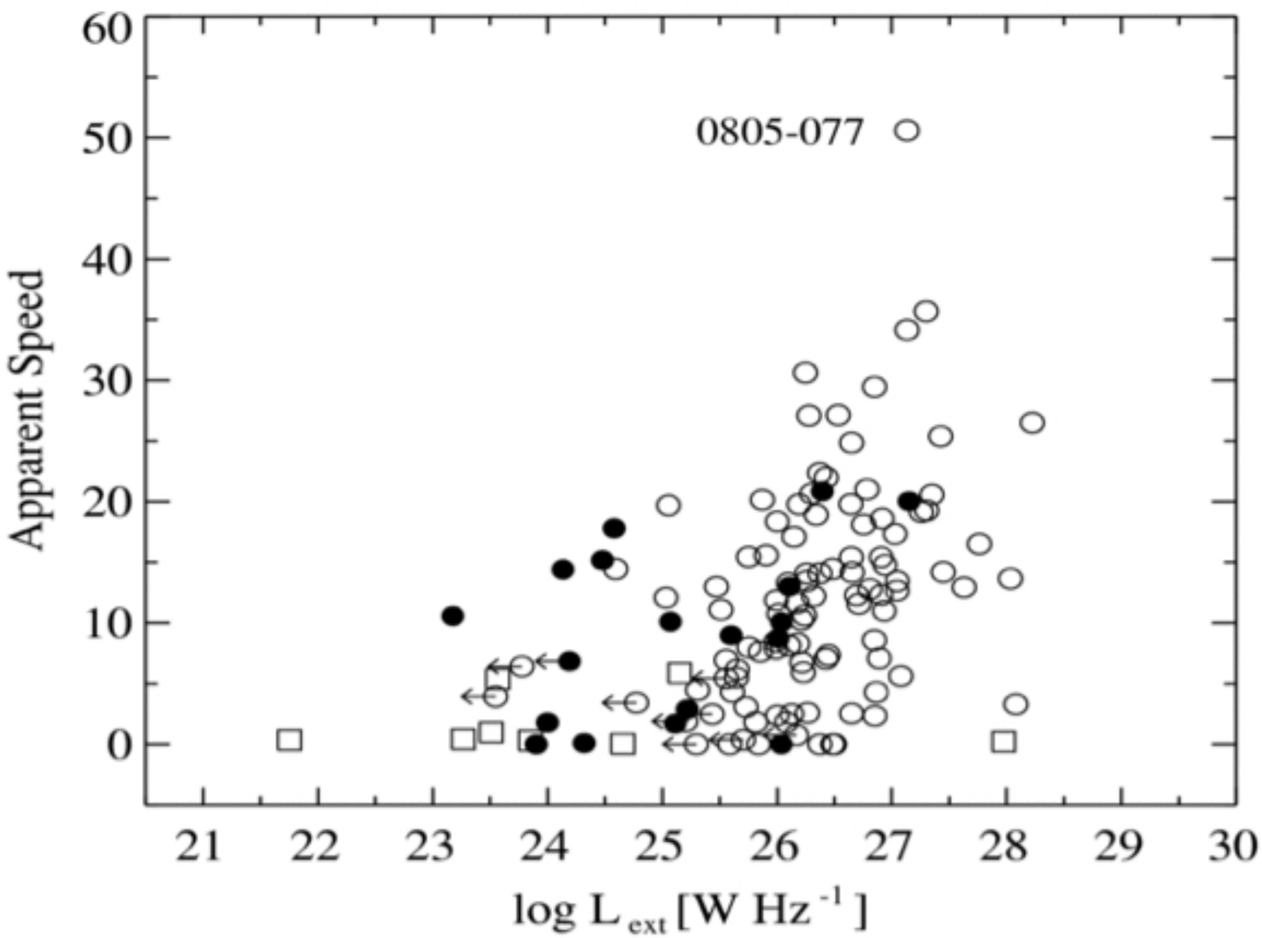
Superluminal speeds: more powerful jets are faster.



Urry and Padovani 1995

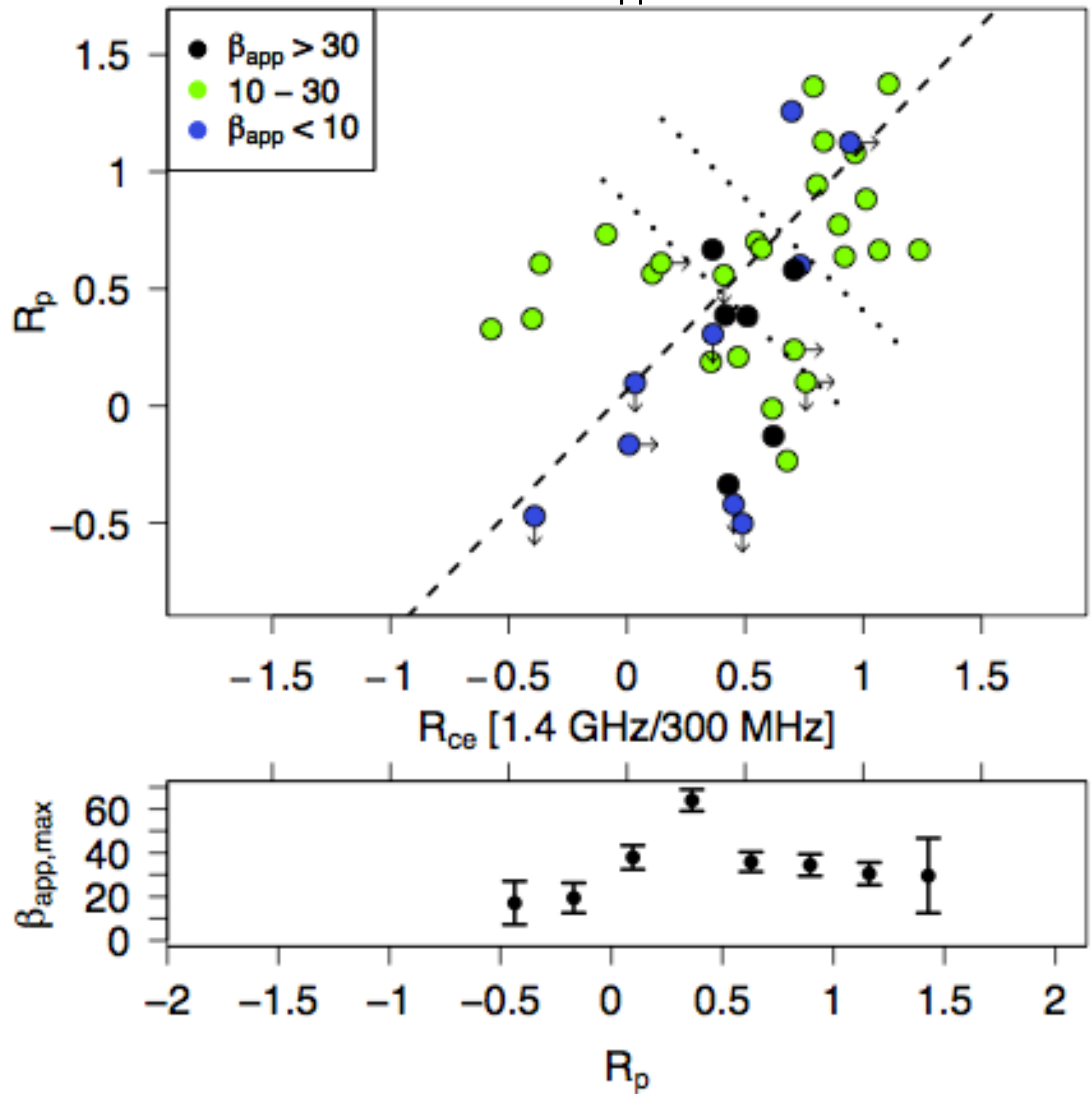
Superluminal speeds: more powerful jets are faster.

Figure 5 from Extended Radio Emission in MOJAVE Blazars: Challenges to Unification
P. Kharb et al. 2010 ApJ 710 764 doi:10.1088/0004-637X/710/1/764



A nice confirmation of the picture

As the jet becomes more aligned, β_{app} first increases, then decreases. This is expected, because as we discussed, we do expect to see sources well within the $1/\Gamma$ angle that maximizes β_{app}.



Meyer et al. 2012