# Energy dissipation in relativistic jets:

How far from the black hole is the $\gamma$-ray emission being produced?

# Collective evidence for external Compton emission in powerful blazars

*Eileen Meyer*[1]
*Giovanni Fossati*[1]
***Markos Georganopoulos***[2,3]
*Matt Lister*[4]

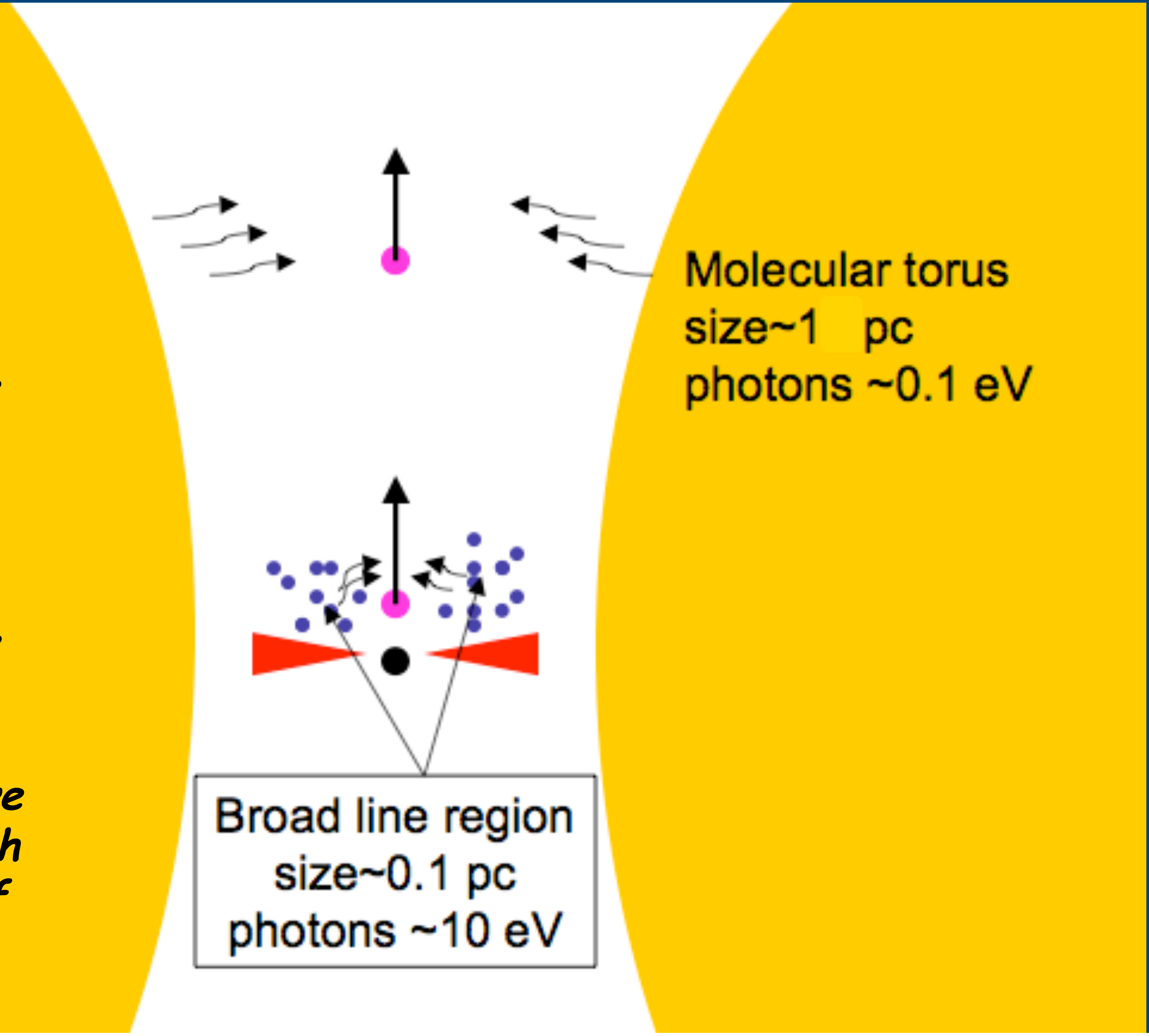
[1]*Rice University*
[2]*University of Maryland Baltimore County*
[3]*NASA/Goddard Space Flight Center*
[4]*Purdue University*

**Meyer et al. 2012 ApJ 740, L98**

# γ-ray emission location?

*For powerful sources with a strong BLR and MT γ-rays are produced by inverse Compton scattering these external photon fields.*

*Further out, where there are no significant external photon fields, γ-rays are produced through synchrotron-self Compton (SSC) scattering.*



# The nature of the γ-ray emission

*Near (<~ 1-few pc):*

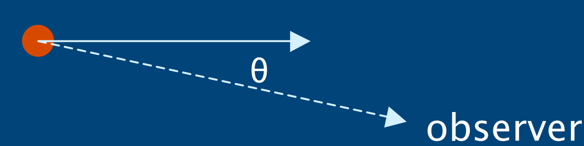
*External Compton (EC) on the BLR or  MT seed photons*

*Far (>~ few pc):*

*Synchrotron Self Compton (SSC)*

***VERY IMPORTANT: THESE EMISSION MECHANISMS HAVE DIFFERENT RELATIVISTIC BEAMING PATTERNS:***

$$L_S, \quad L_{SSC} \propto \delta^4, \qquad L_{EC} \propto \delta^6, \qquad \delta = \frac{1}{\Gamma(1-\beta\cos\theta)}$$

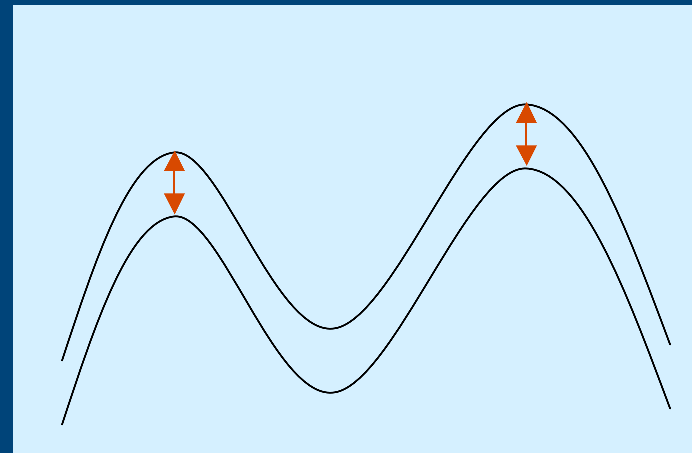


# Aligning a source

Compton Dominance

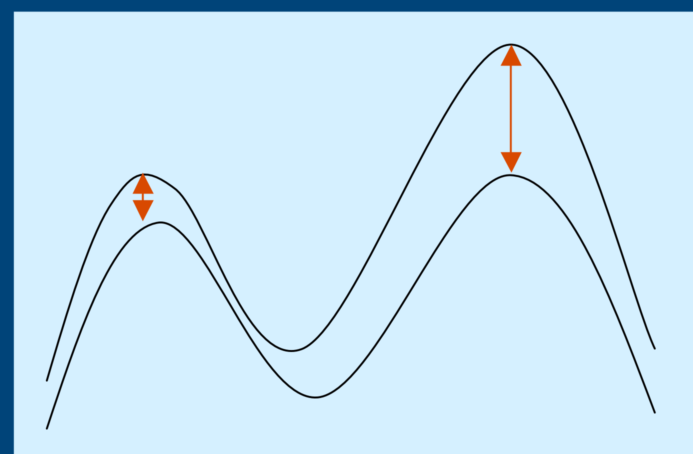
$$\text{For SSC}: \quad \frac{L_{SSC}}{L_s} = const$$

*The Compton dominance stays constant as the source gets aligned*



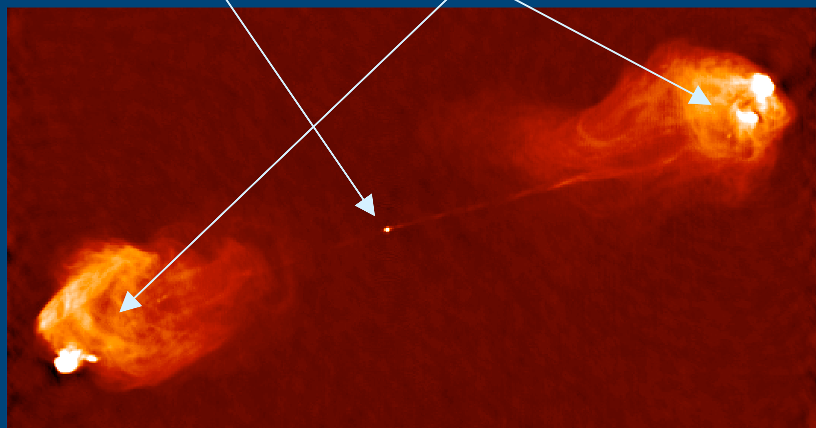
$$\text{For EC}: \quad \frac{L_{EC}}{L_S} \propto \delta^2$$

*The Compton dominance increases as the source gets aligned*



# An orientation proxy

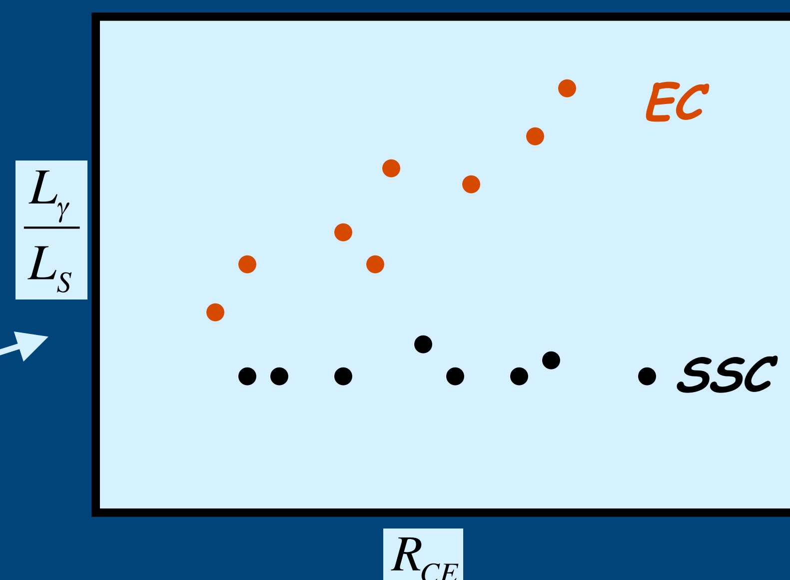
$R_{CE}$, core to extended radio emission



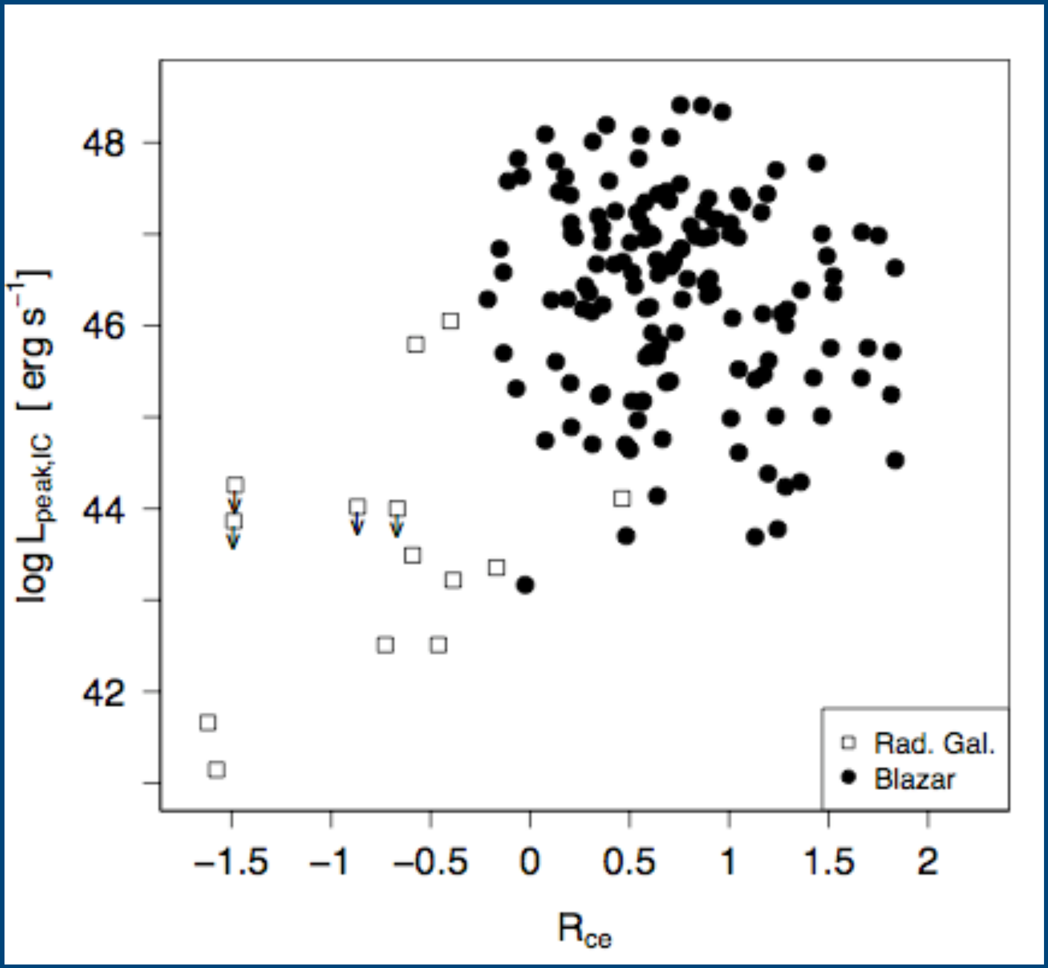
$$R_{CE} = \frac{f_c}{f_E} \propto \delta^{2+a}$$

$$\frac{L_\gamma}{L_s} \propto R_{CE}^{2/(2+a)} = R_{CE} \quad for \quad a = 0 \quad (flat\ radio\ core)$$

For a set of similar jet kinetic power we expect:

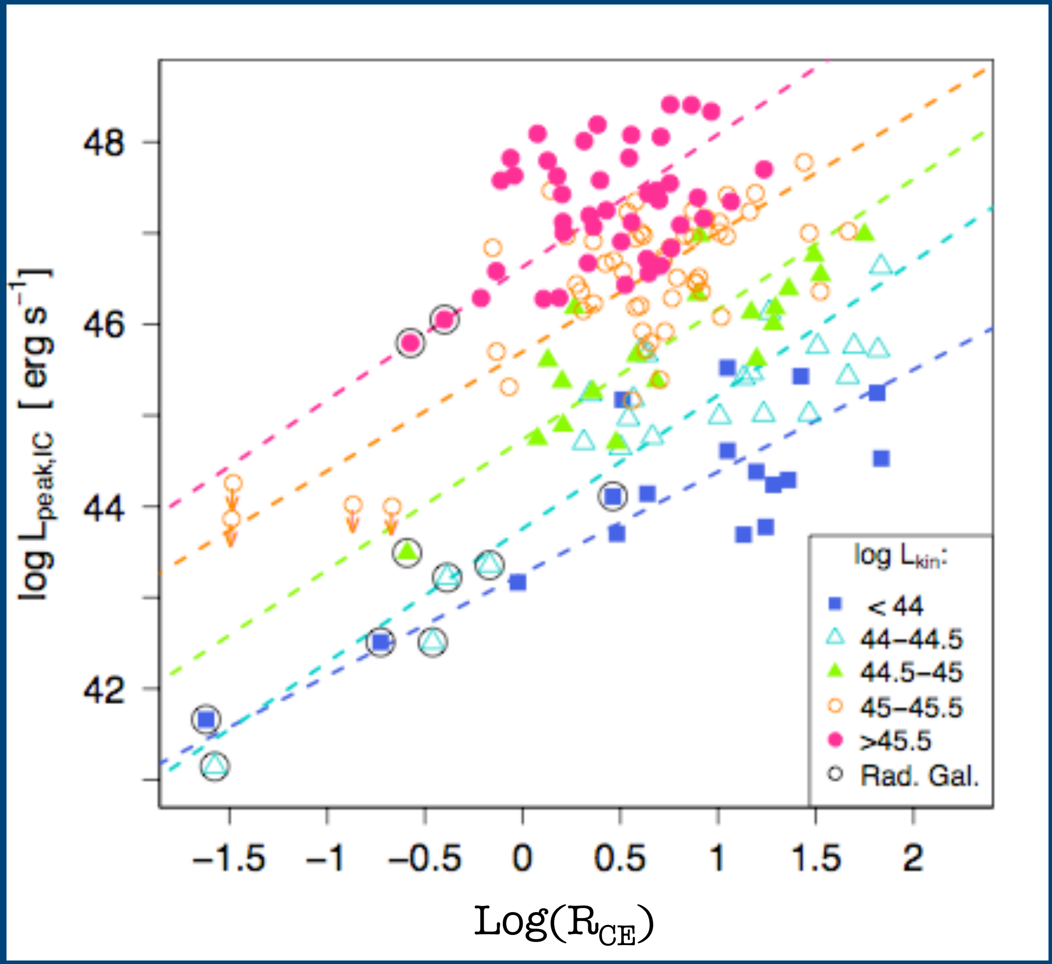


# Fermi Luminosity vs core dominance




- Meyer et al. 2012

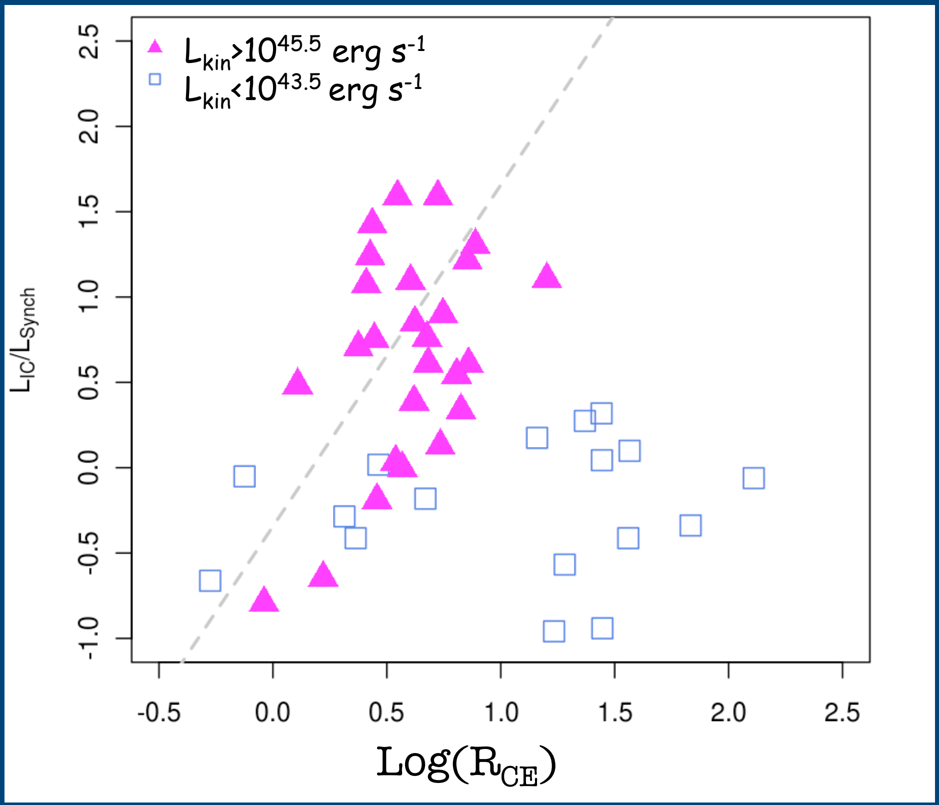
# Fermi Luminosity vs core dominance




- Meyer et al. 2012

# SSC for weak jets
# EC for powerful jets

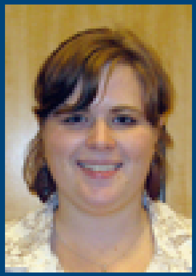
The ratio between the peak luminosities of the γ-ray (IC) and synchrotron components behaves differently as a function of radio core dominance for high and low jet power sources.




- Powerful sources are EC emitters
- Weak jets are SSC emitters

*See poster by Eileen Meyer*

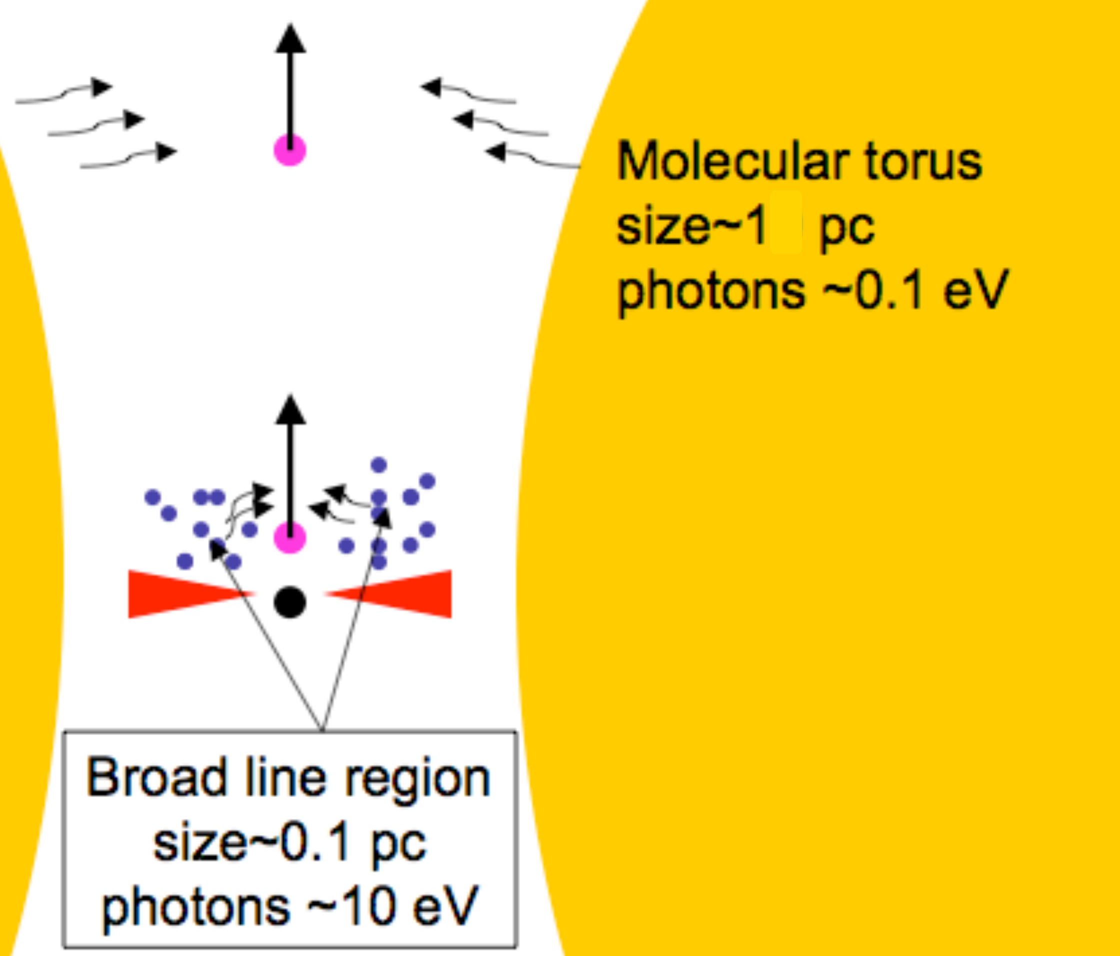
# GeV emission of powerful jets: coming from the BLR or the MT?



*Amanda Dotson*[1]
***Markos Georganopoulos*[1,2]**
*Demosthenes Kazanas*[2]
*Eric Perlman*[3]

[1]*University of Maryland Baltimore County*
[2]*NASA/Goddard Space Flight Center*
[3]*Florida Institute of Technology*

# BLR or MT?




VERY IMPORTANT:

The BLR photons are ~100 times more energetic than the MT photons.

# Cooling in the Klein-Nishima regime

VERY IMPORTANT:

The BLR photons are ~100 times more energetic than the MT photons.

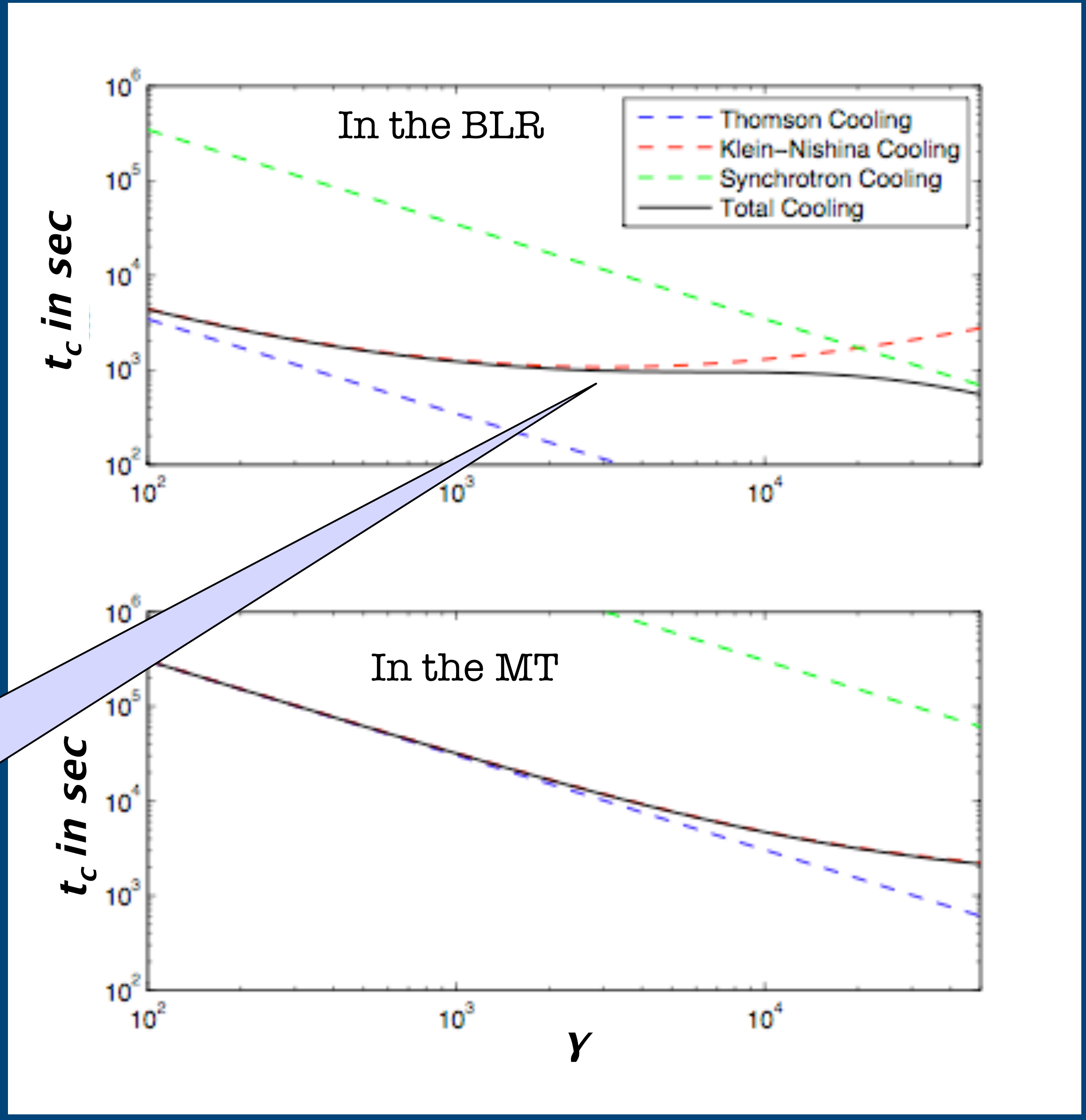
*IC cooling* :

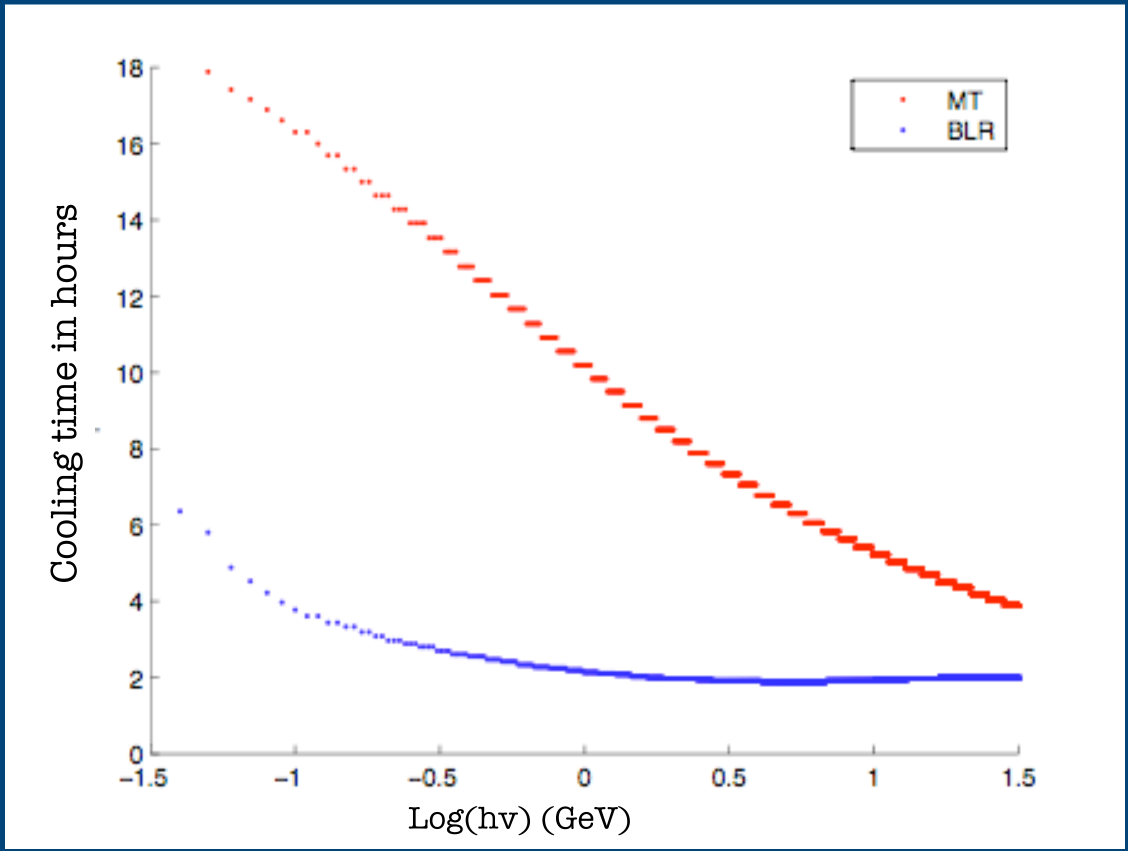
$$t_c \propto \gamma^{-1} \quad for\ \varepsilon\gamma << 1$$

$$t_c \propto \gamma \quad for\ \varepsilon\gamma >> 1$$

$$t_c \approx const \quad for\ \ \varepsilon\gamma \sim 1$$

***Practically energy-independent cooling time!***



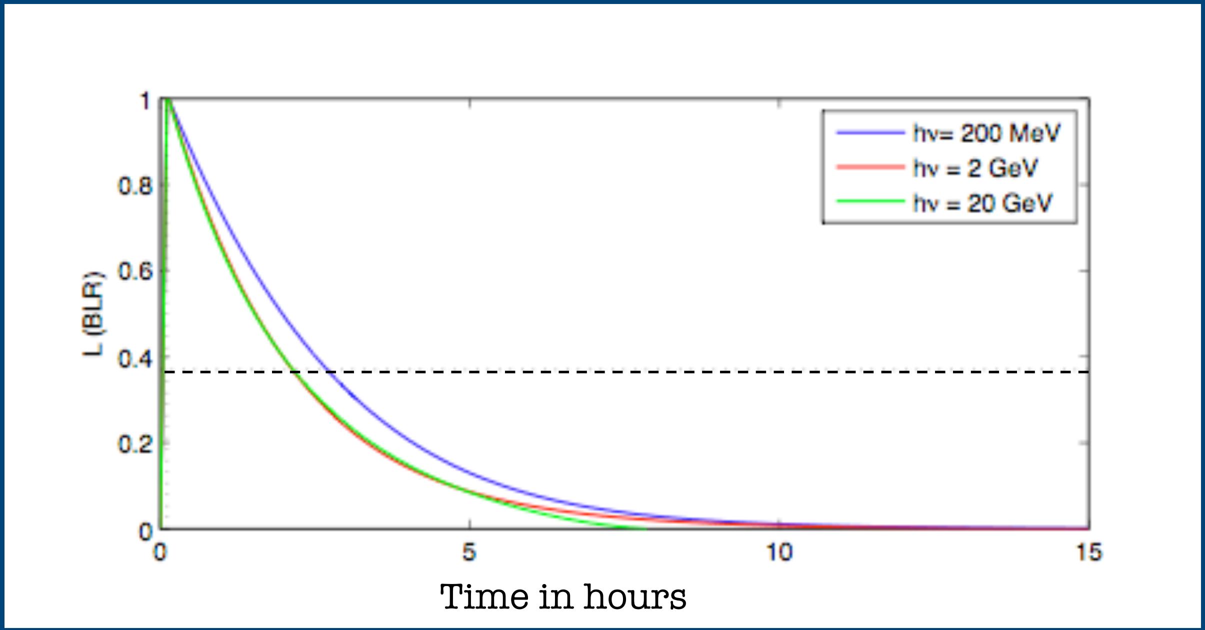



Cooling times as a function of observed energy for cooling in the BLR and MT.

BLR: cooling is faster and almost achromatic.

MT: cooling is slower with shorter cooling times at higher energies.

# A. Blazar inside the BLR

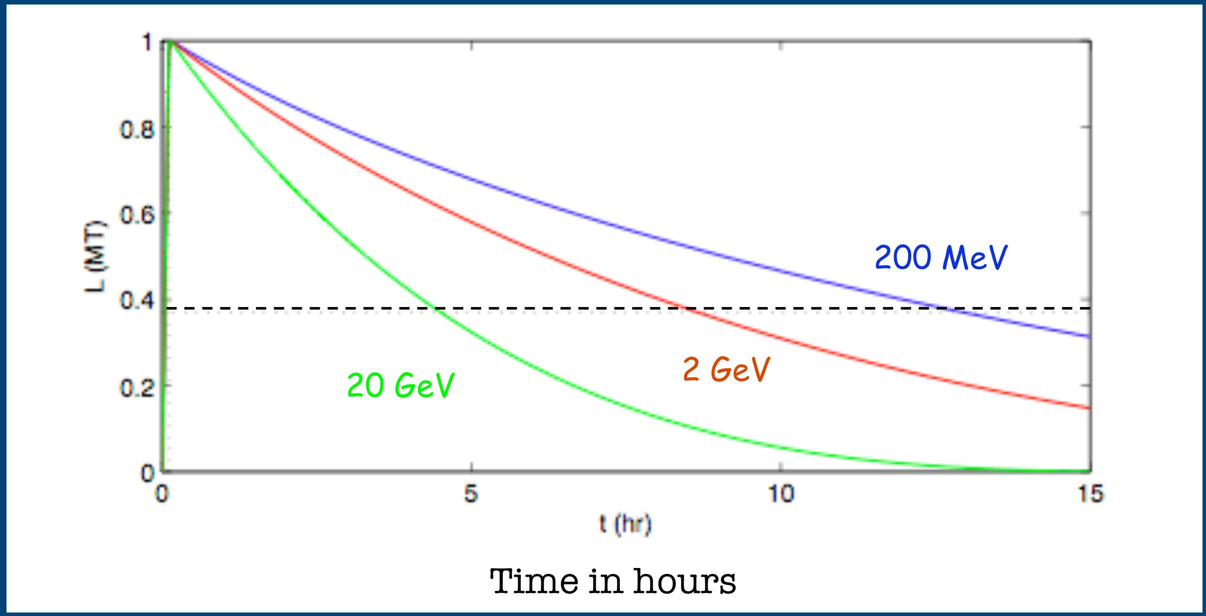



Seed photons for GeV emission: UV BLR photons
Scattering takes place at the onset of the Klein-Nishina regime =>

electron cooling time becomes ~ energy independent =>

energy-independent flare decay time

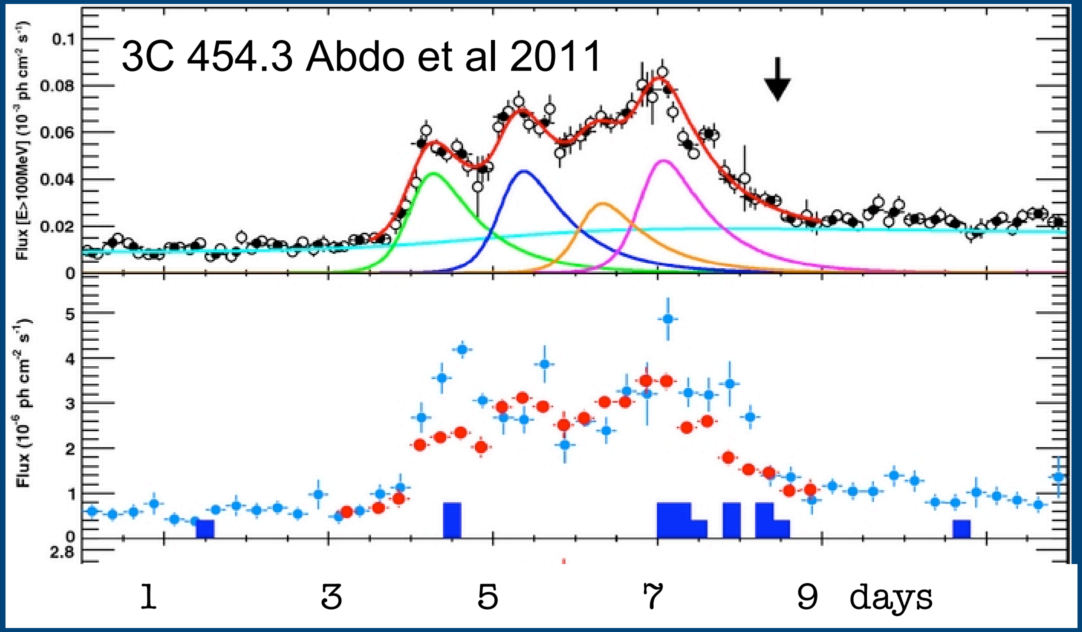
# B. Blazar outside the BLR




Seed photons for GeV emission: IR dust photons scattering takes place in the Thomson regime =>

electron cooling time is ~ energy dependent ~ $1/\gamma$ =>

<u>energy-dependent flare decay time</u>




We need bright fast flares like this, the brightest observed so far. Our diagnostic will be applied on a small number of bright flares.

## What if we can only put upper limits to the decay time difference in different energies ?

- If the time delay between the 100 MeV and the 1 GeV light curves is smaller than $\Delta_{tmax}$ then the emission is at

$$R < 2.3 \times 10^{18}\, \Gamma_{10} [\Delta_{t\,\max,h} L_{MT} /(1+z)]^{1/2} \quad cm$$

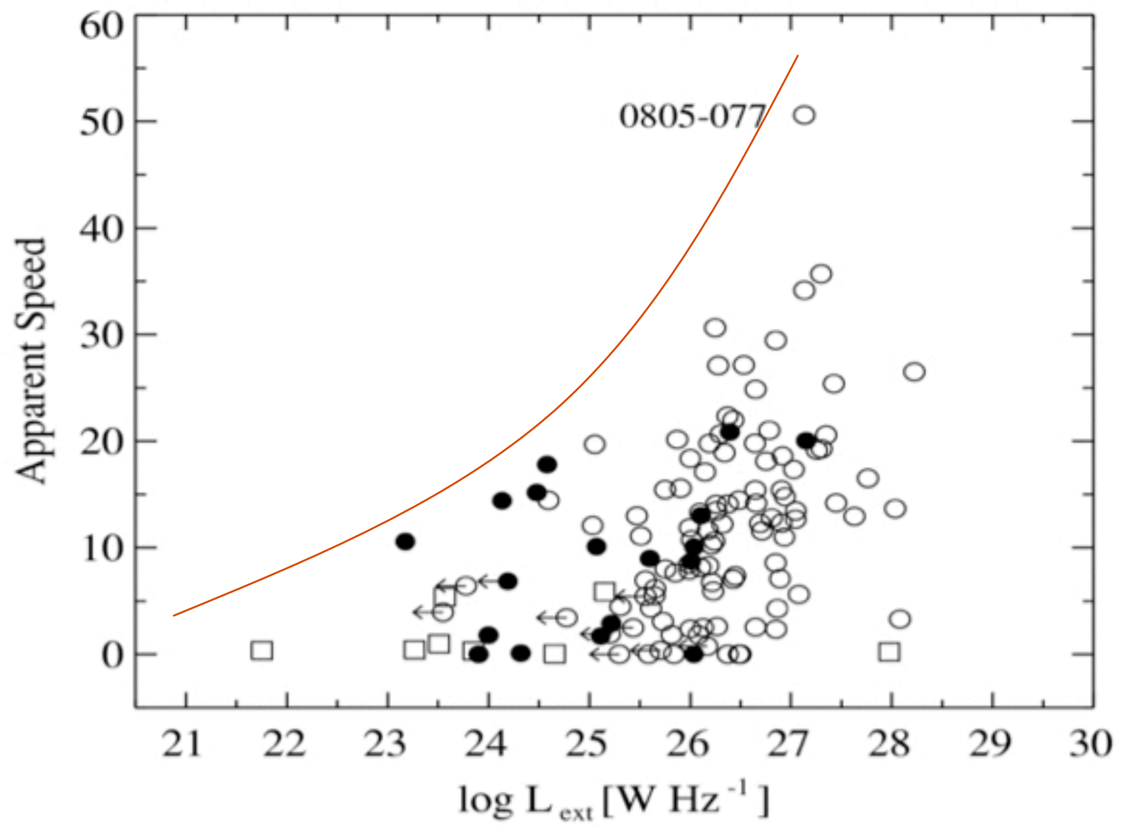
# Conclusions

We present the first collective evidence that the GeV emission of powerful blazars comes form external Compton scattering.

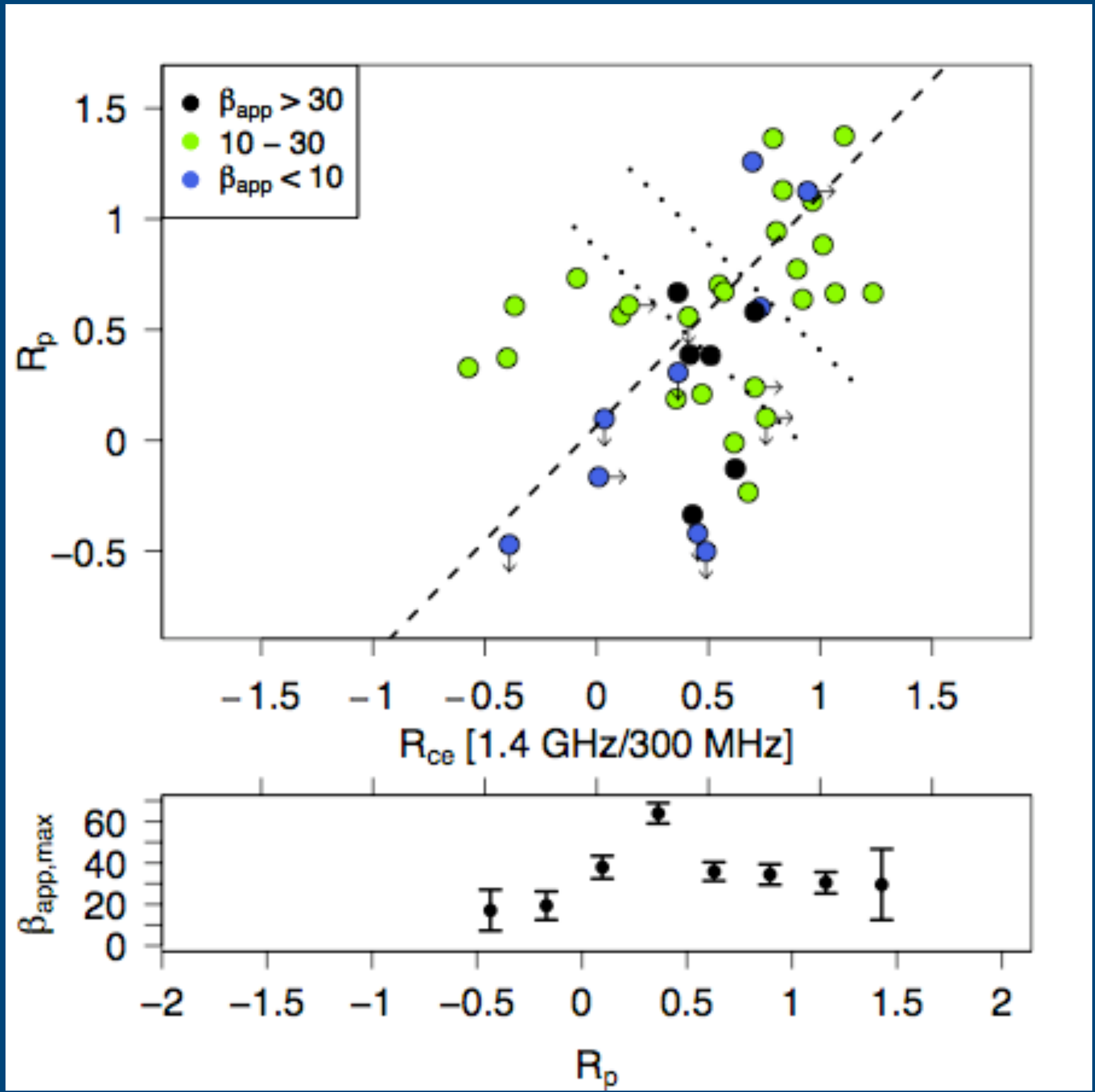
We show that the energy dependence of Fermi variability can determine the nature of the seed photons (UV from the BLR or IR from the MT) and therefore the location of dissipation.

# 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



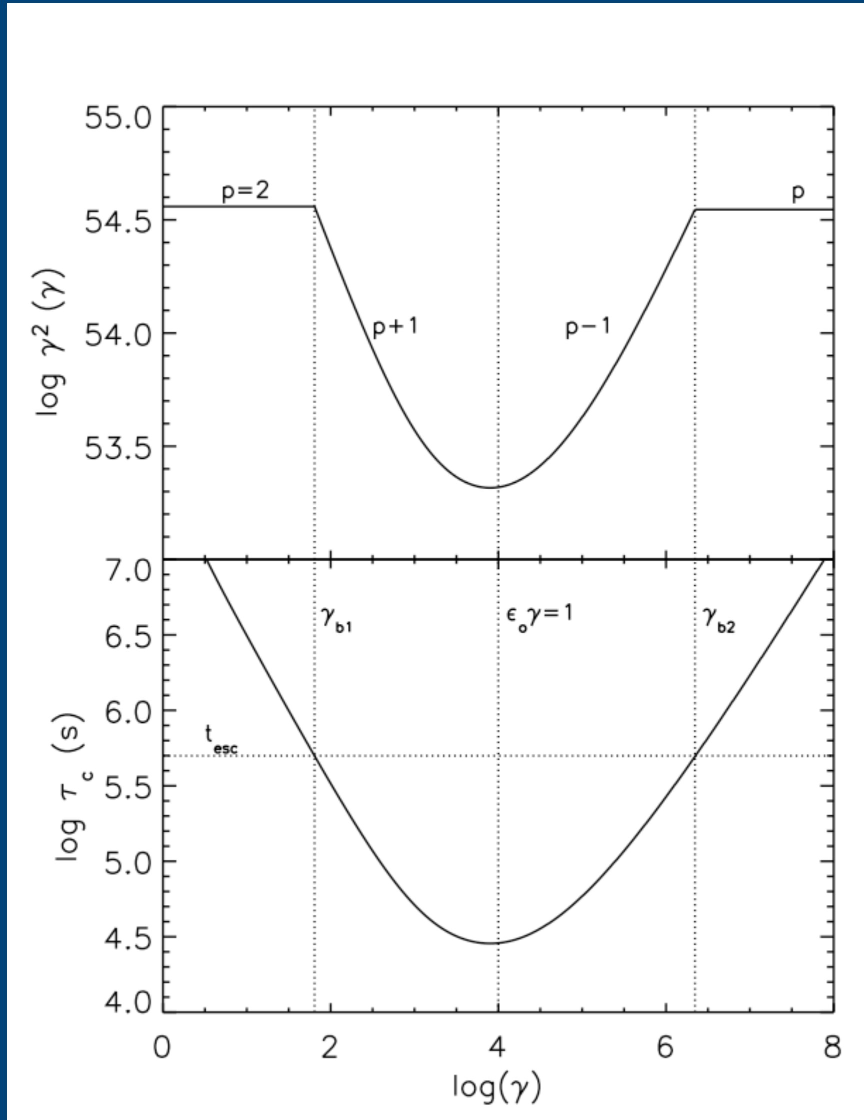
# A nice confirmation of the picture: Superluminal speeds as a function of orientation



# Cooling in the Klein-Nishima regime

$$\dot{\gamma} \propto \gamma^2 \quad for\ \varepsilon\gamma << 1$$
$$\dot{\gamma} \propto \ln\gamma \quad for\ \varepsilon\gamma >> 1$$

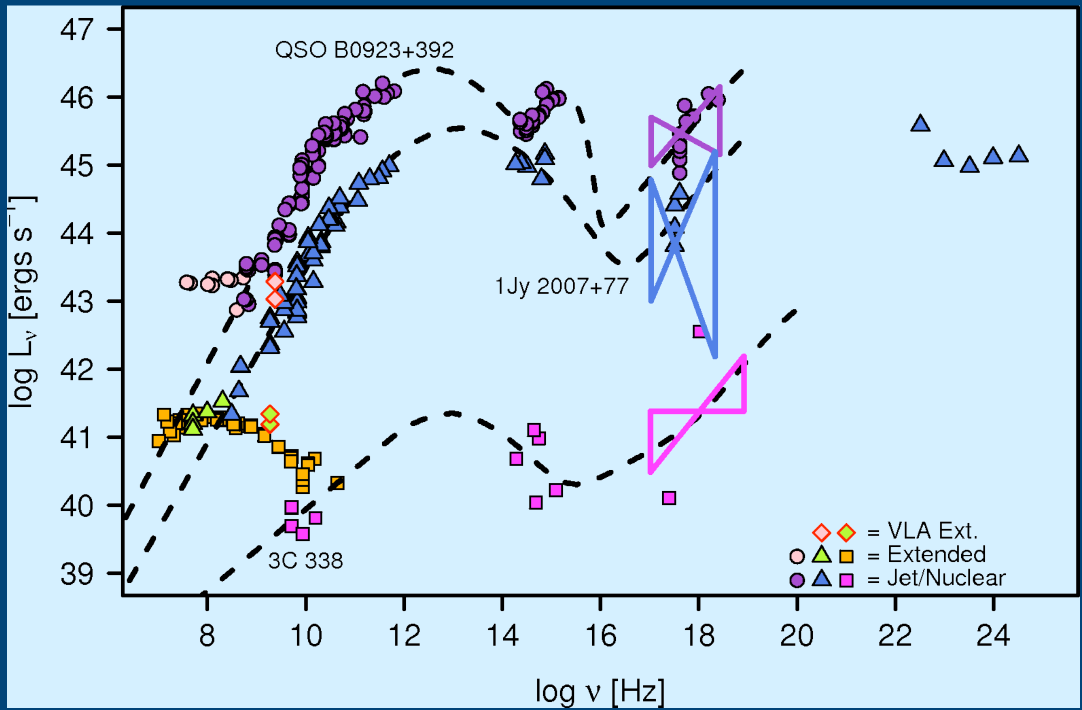
$$n(\gamma) \propto \frac{\int \gamma^{-p} d\gamma}{\dot{\gamma}}$$



# Intrinsic jet power by proxy

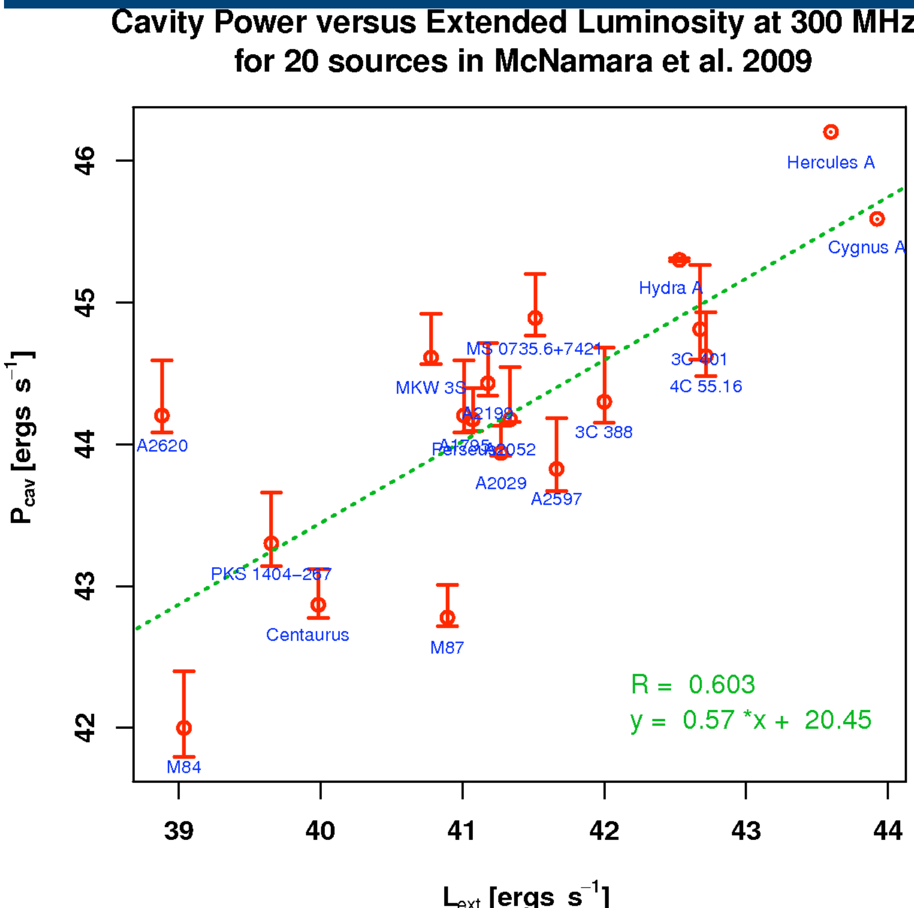
- We need a measure of the **intrinsic** jet power, non altered by the effects of relativistic beaming. The best estimator is the luminosity of the extended radio emission:

  - It is isotropic.
  - It represents a long term average of the jet power.
  - It is not variable.

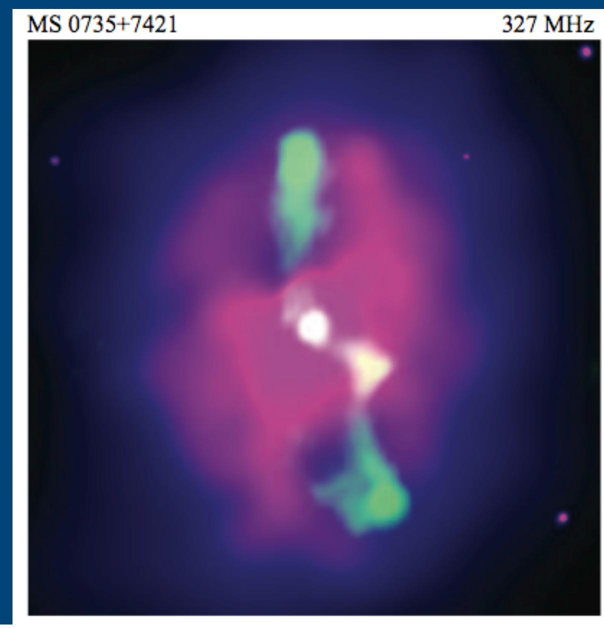



- It typically dominates the spectrum at low frequencies (below the GHz range) because of its different –steep- spectral shape.

# Extended luminosity and intrinsic jet power




- The intrinsic jet power can be measured by the study of the cavities that their jets inflated in the intra-cluster medium.
- This jet power correlates well with the extended radio luminosity.



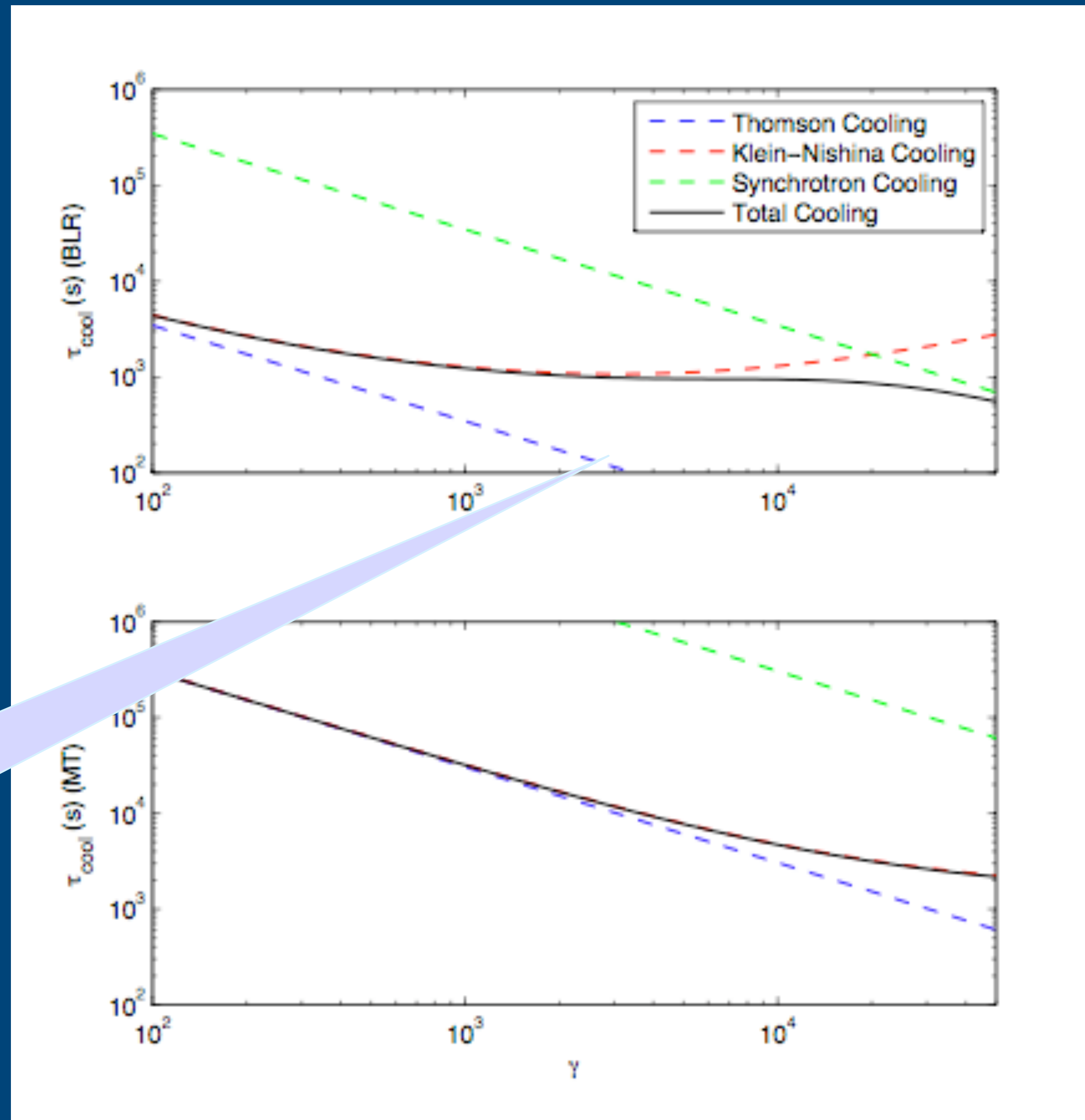
# Cooling in the Klein-Nishima regime

<u>VERY IMPORTANT:</u>

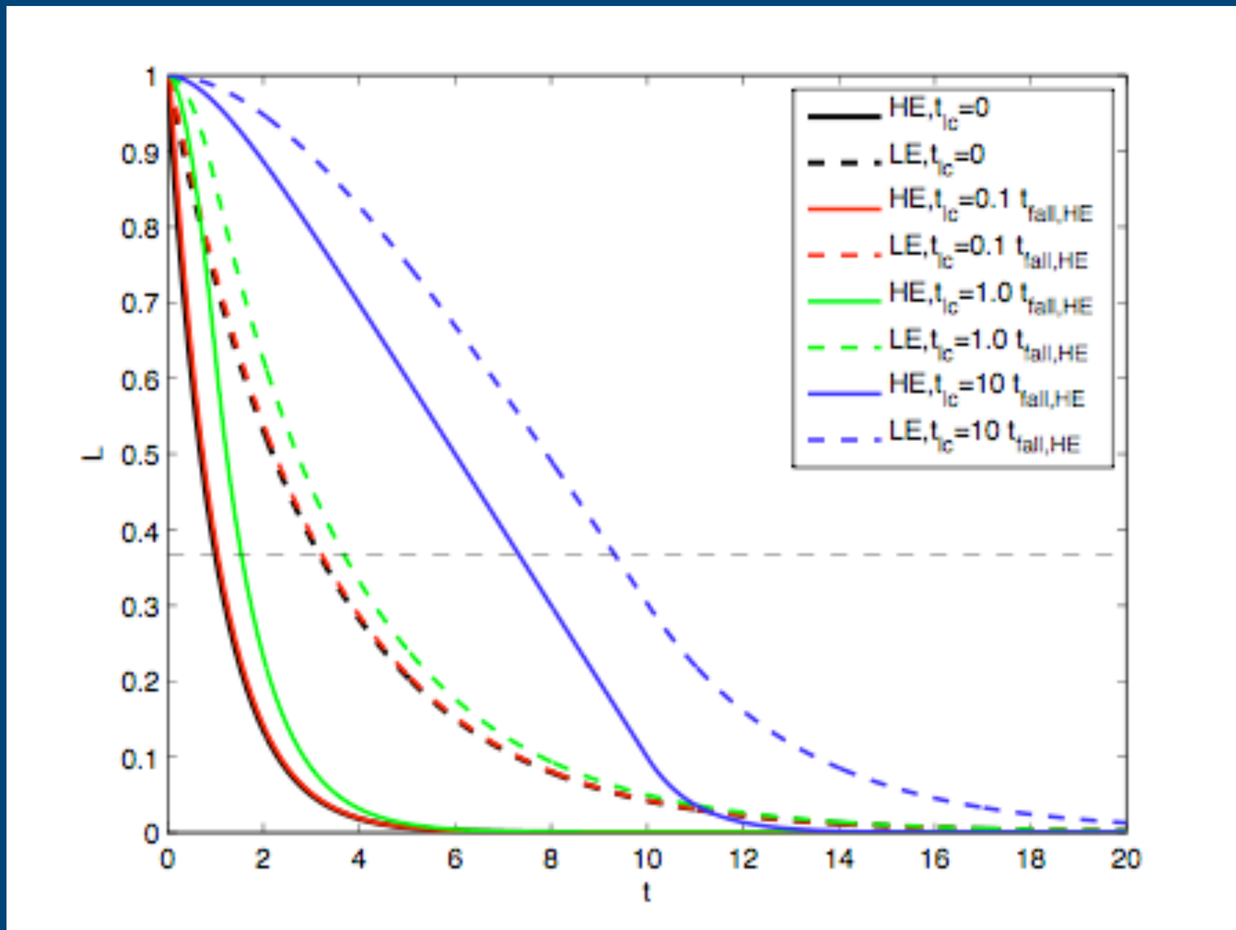
**The BLR photons are ~100 times more energetic than the photons from the molecular torus.**

$$IC\ cooling:$$
$$t_c \propto \gamma^{-1} \quad for\ \varepsilon\gamma << 1$$
$$t_c \propto \gamma \quad for\ \varepsilon\gamma >> 1$$

***Practically energy-independent cooling time!***



# Light travel effects, achromatic timescales?




***Time delays persevere the convolution with the achromatic timescale***