Gamma rays from AGN: an overview

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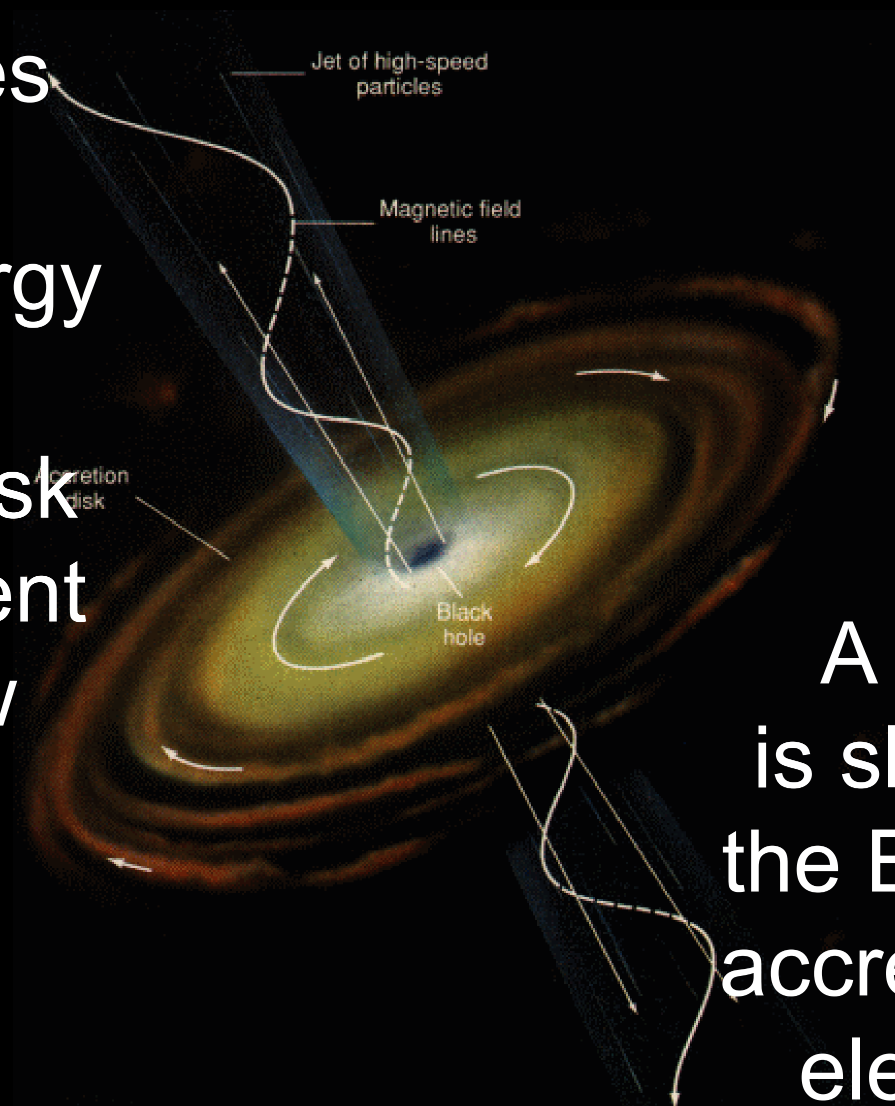
Outline

- The AGN core
- Relativistic jets and blazars
- Population properties of blazars
- First FERMI results
- Fast variability
- HE and VHE spectra

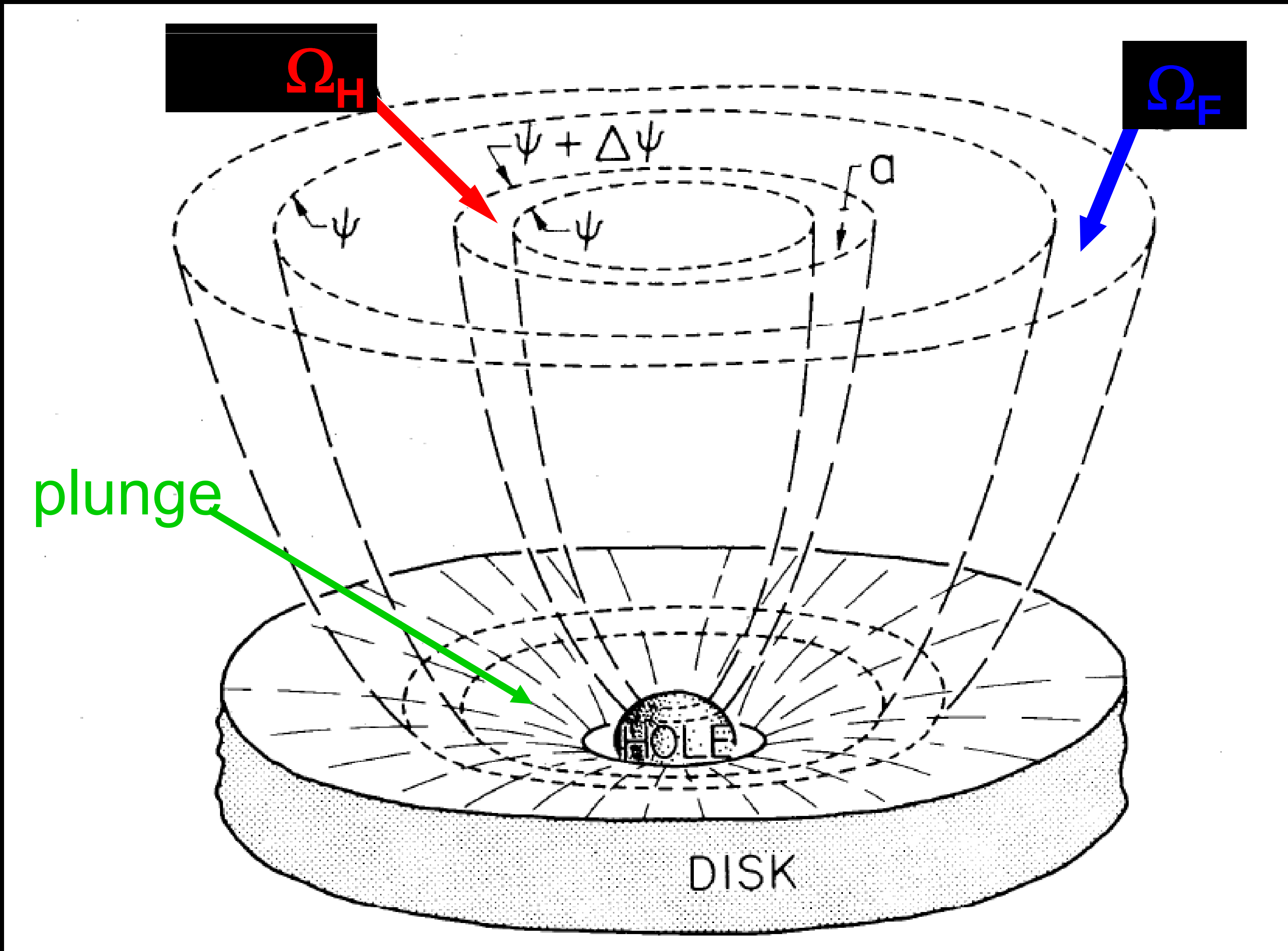
The core of a radio loud AGN

Matter accretes
onto the BH
dissipating energy
in
an accretion disk
or rad. Inefficient
accretion flow



A spinning BH
is slowed down by
the B field carried by
accretion, launching
electromag. jets

The Blandford Znajek mechanism (1977)



illustrated by Macdonald and Thorne (1982)

Particles and radiation processes in the jet

GR-MHD is used to study the evolution of the jet close to the BH (e.g. Mc Kinney 2005)

Matter captured in the jet is accelerated to bulk Lorentz factors of order 10 within 10 - 100 Rs, in a cone of 5 deg, surrounded by a wider cone (20) with slower bulk motion

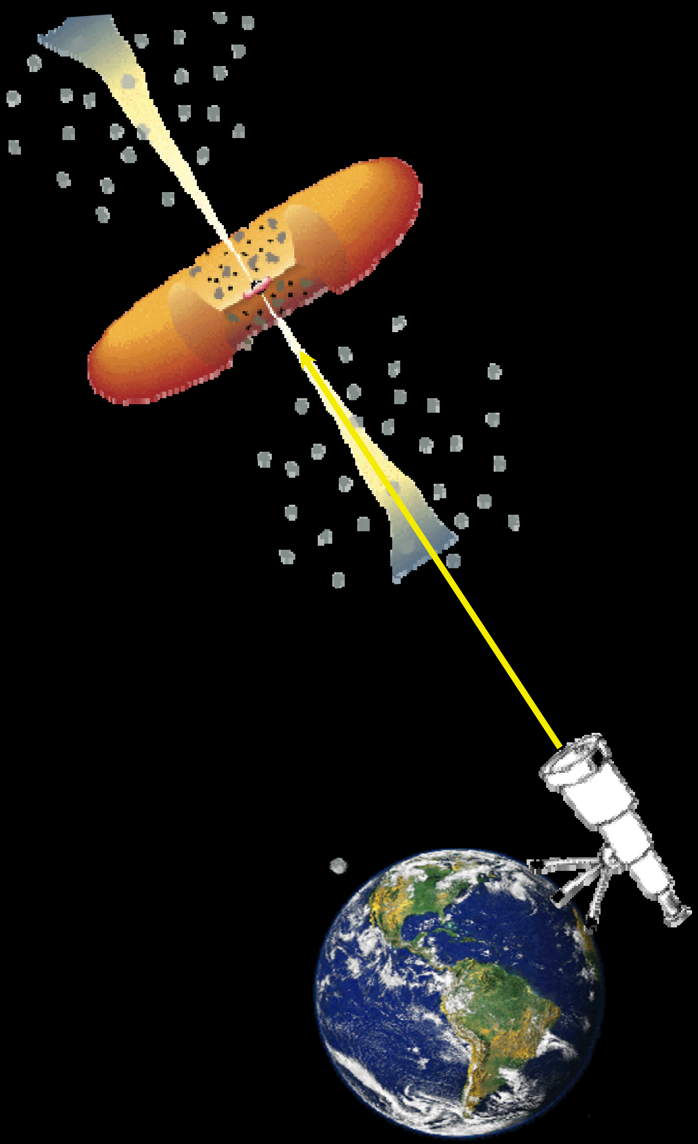
Shocks, internal or external, are needed to accelerate high energy particles which radiate

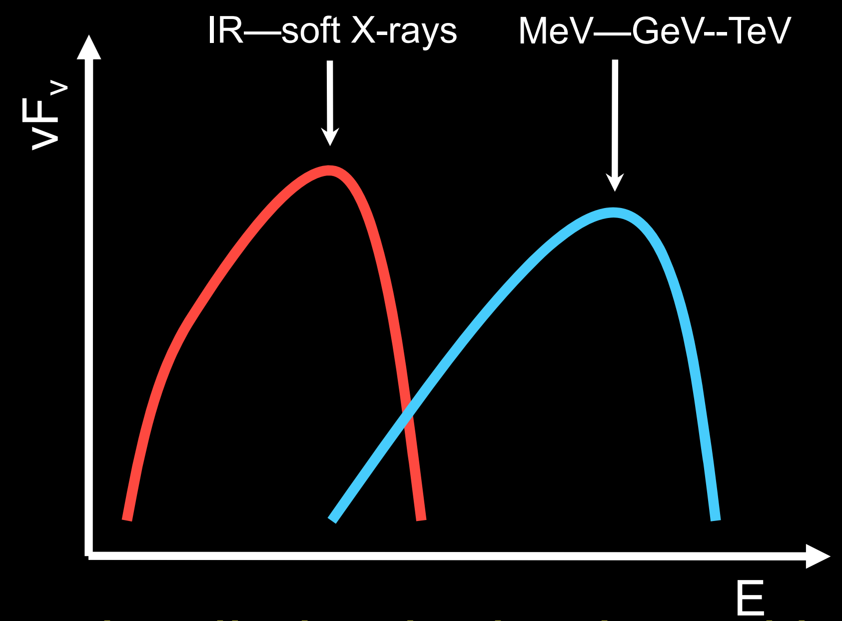
via synchrotron and Inverse Compton

Radio – UV – X X – MeV – GeV- TeV

Due to the bulk motion the radiation is beamed

Blazars





 Observed radiation is dominated by the beamed non-thermal emission of the jet

Two broad humps:

Synchrotron and Inverse Compton in leptonic models.

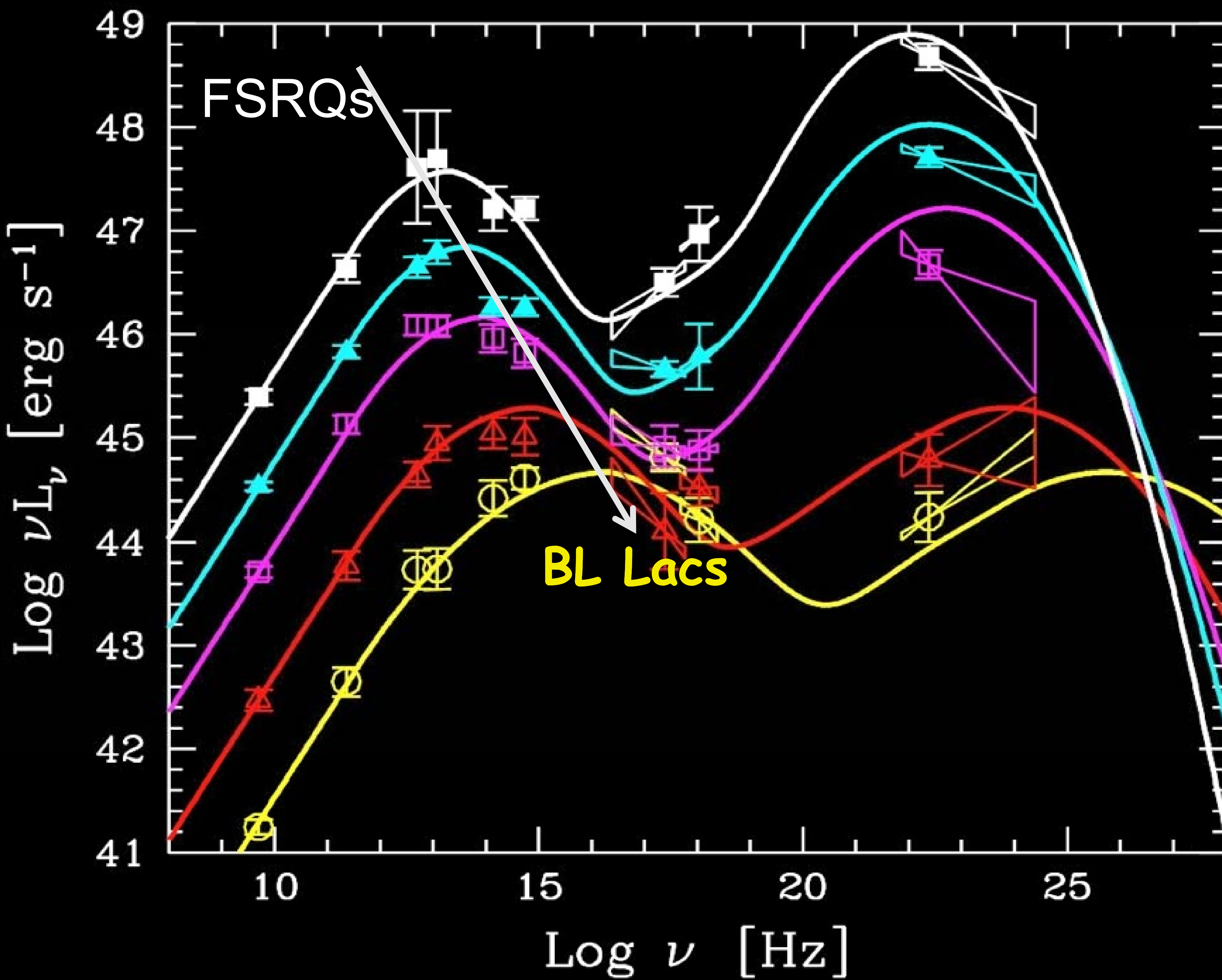
Hadronic scenarios considered (e.g. Mannheim, Boettcher, Reimer).

Blazar jets are special jets
only with regard to orientation

Privileged orientation makes them
brighter and best studied

But their "intrinsic" properties are
representative of the jet population
in AGN at large

The “blazar sequence”



Fossati et al. 1998; Donato et al. 2001

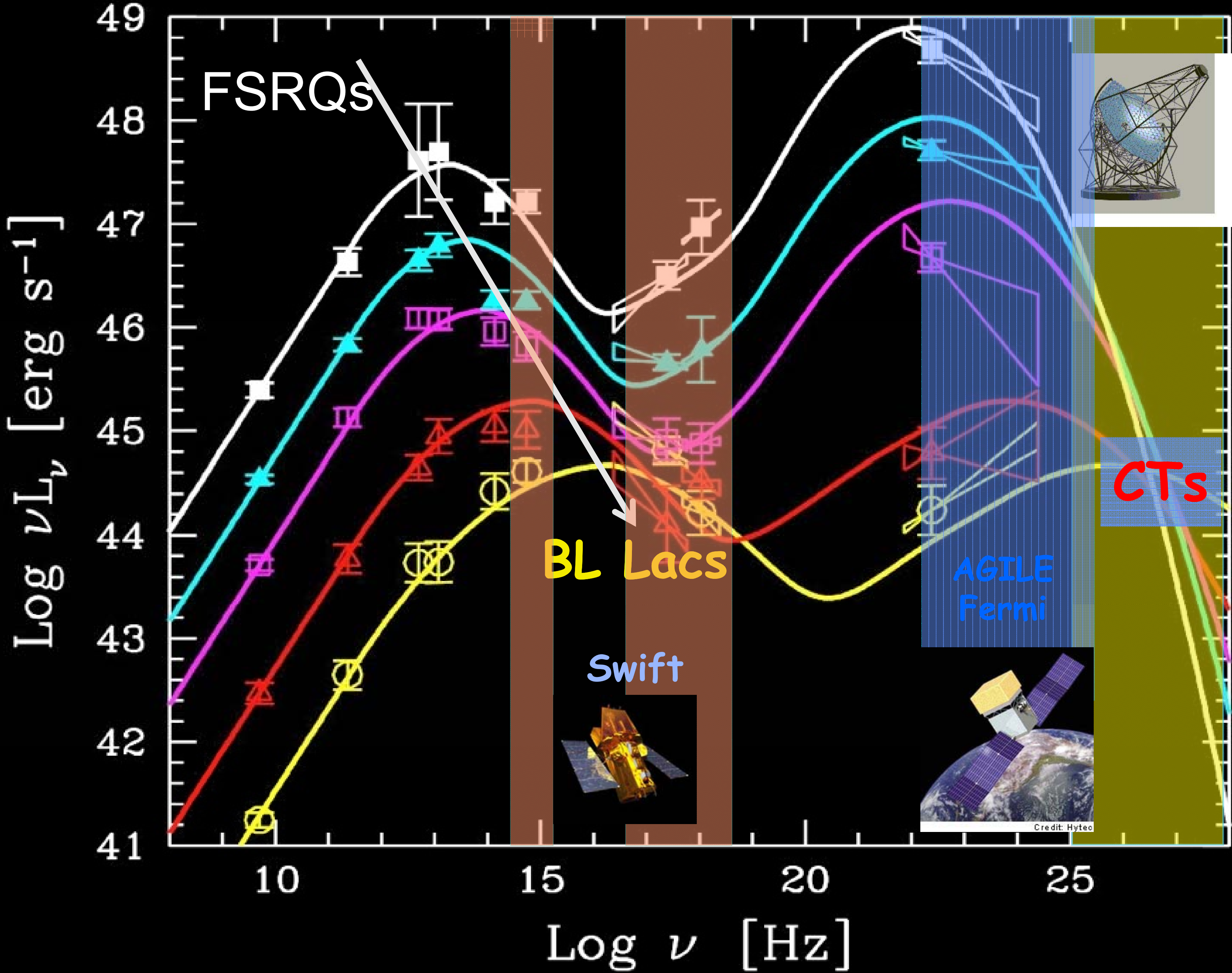
The SEDs of Blazars follow systematic trends:

the peaks shift to lower energies
with increasing luminosity

This result was obtained averaging data on blazars
in fixed radio -- luminosty intervals

The data coverage at high energies was poor

New windows on the "blazar sequence"



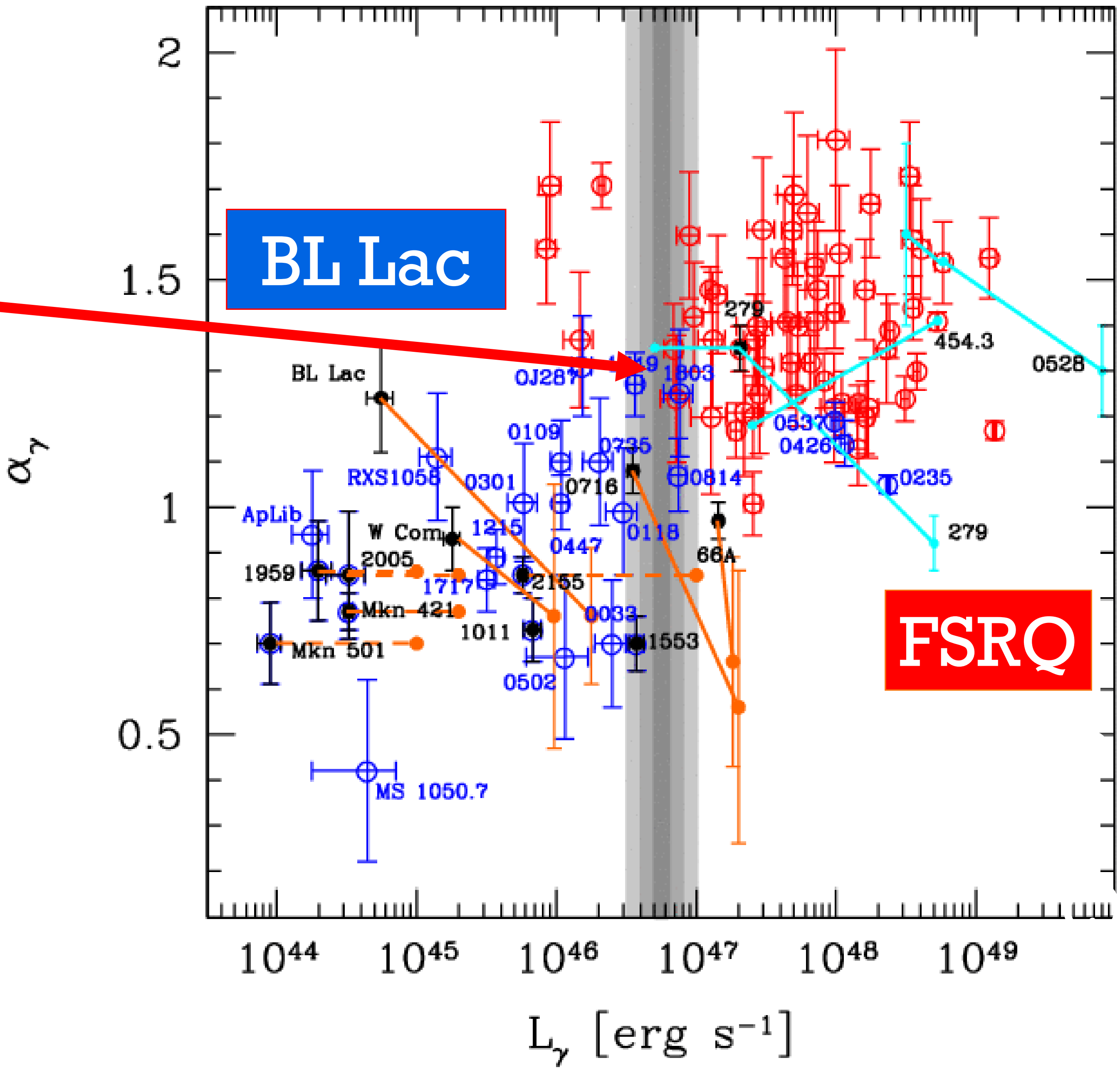
Fossati et al. 1998; Donato et al. 2001

The critical divide:

$L_\gamma \sim 10^{47}$

FERMI first three months

Ghisellini
Maraschi
Tavecchio
09



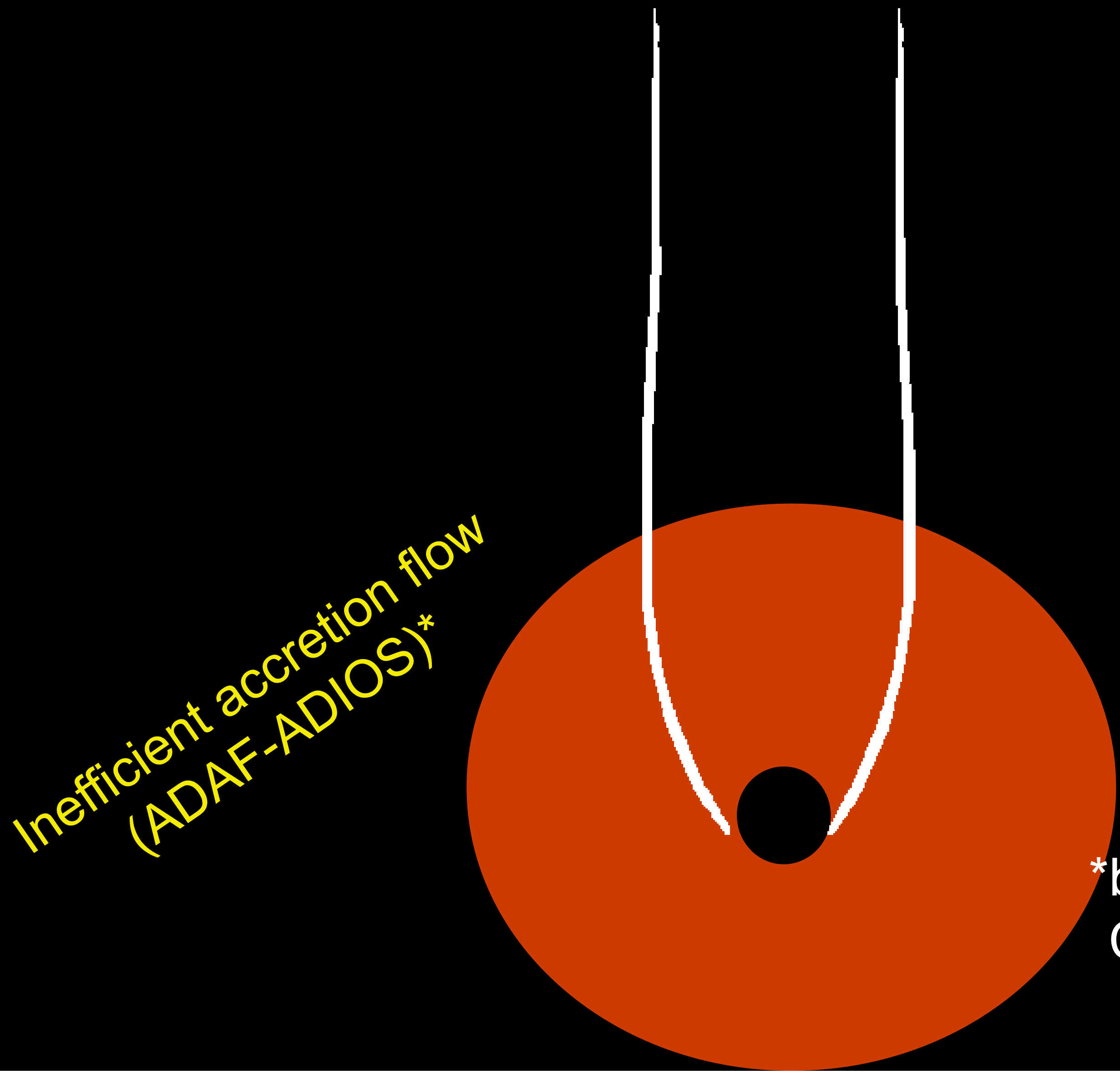
Why do the jet SEDs depend on luminosity ?

In low luminosity AGN the accretion flow is radiatively inefficient, therefore the ambient surrounding the jet is clean:

Weak energy losses → high particle energies

In high luminosity AGN the ambient where the jet propagates is crouded with photons produced be the accretion disk and BLR

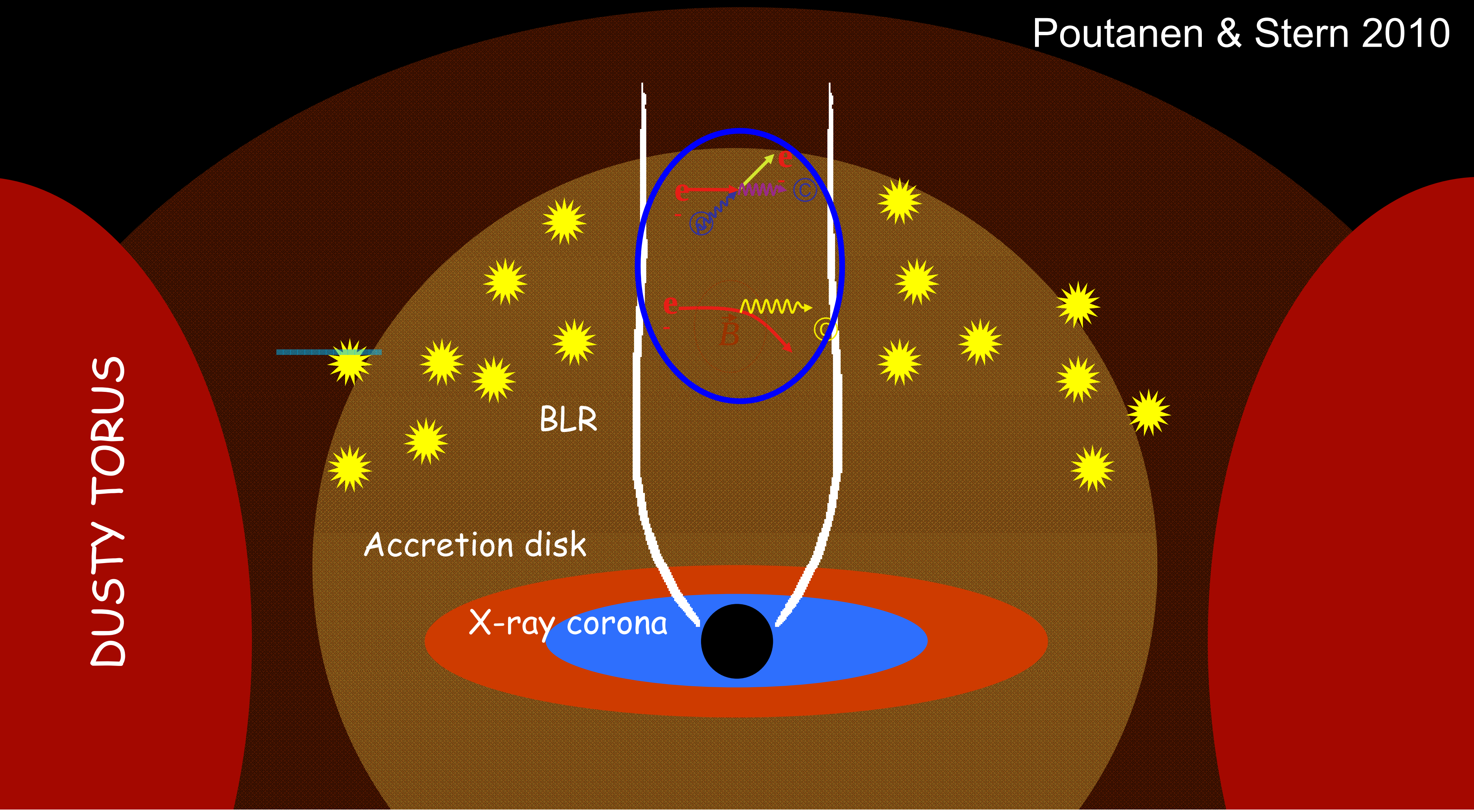
BL Lacs: “clean” jets



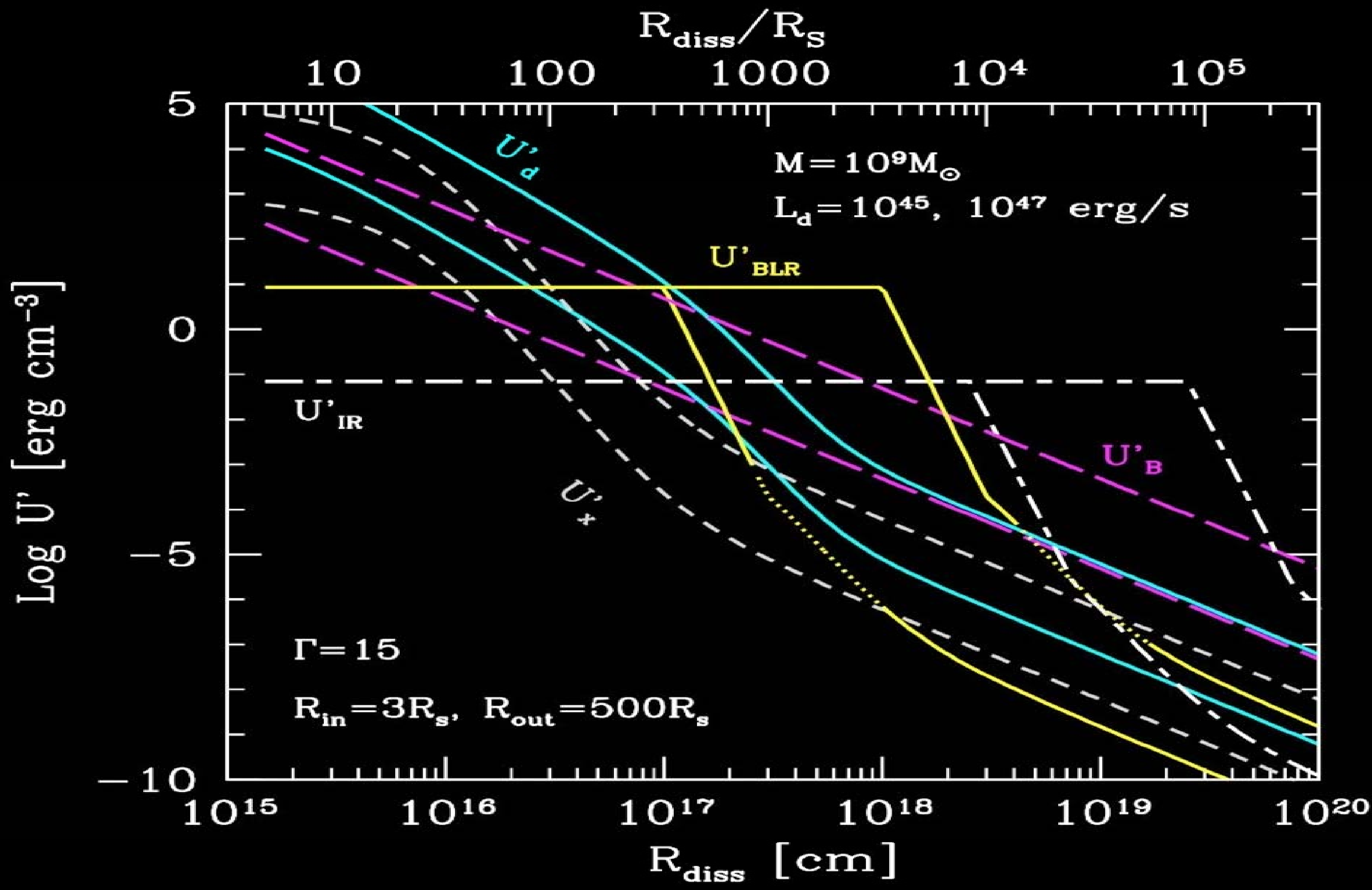
*but see Raiteri et al. 2009 Capetti et al. 2010 for BL Lac itself

FSRQs: a polluted “ambient”

Dermer et al. 2009
Ghisellini, FT 2009
Sikora et al. 2009
Poutanen & Stern 2010



Radiation energy density at different distances from the BH

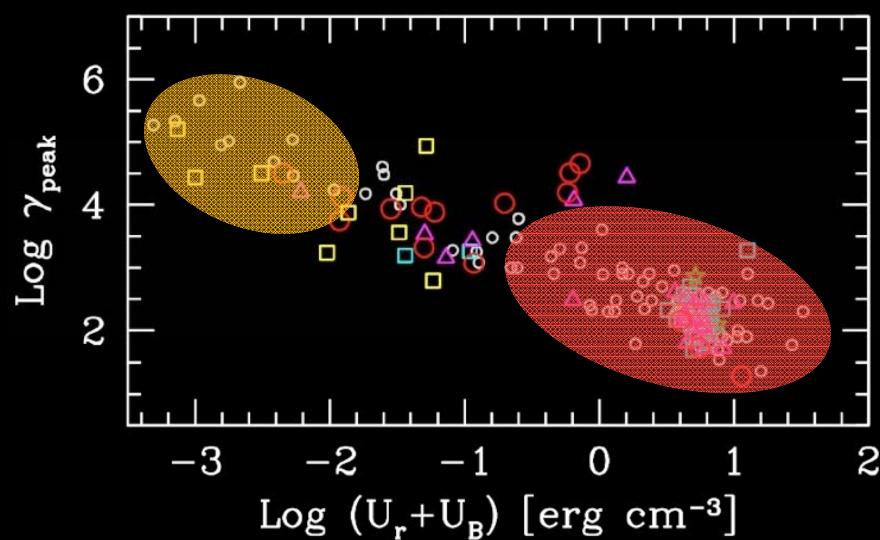


The “cooling” hypothesis

FSRQs: strong cooling → low el. energy

BL Lacs: weak cooling → high el. energy

Energy of electrons emitting at the peak



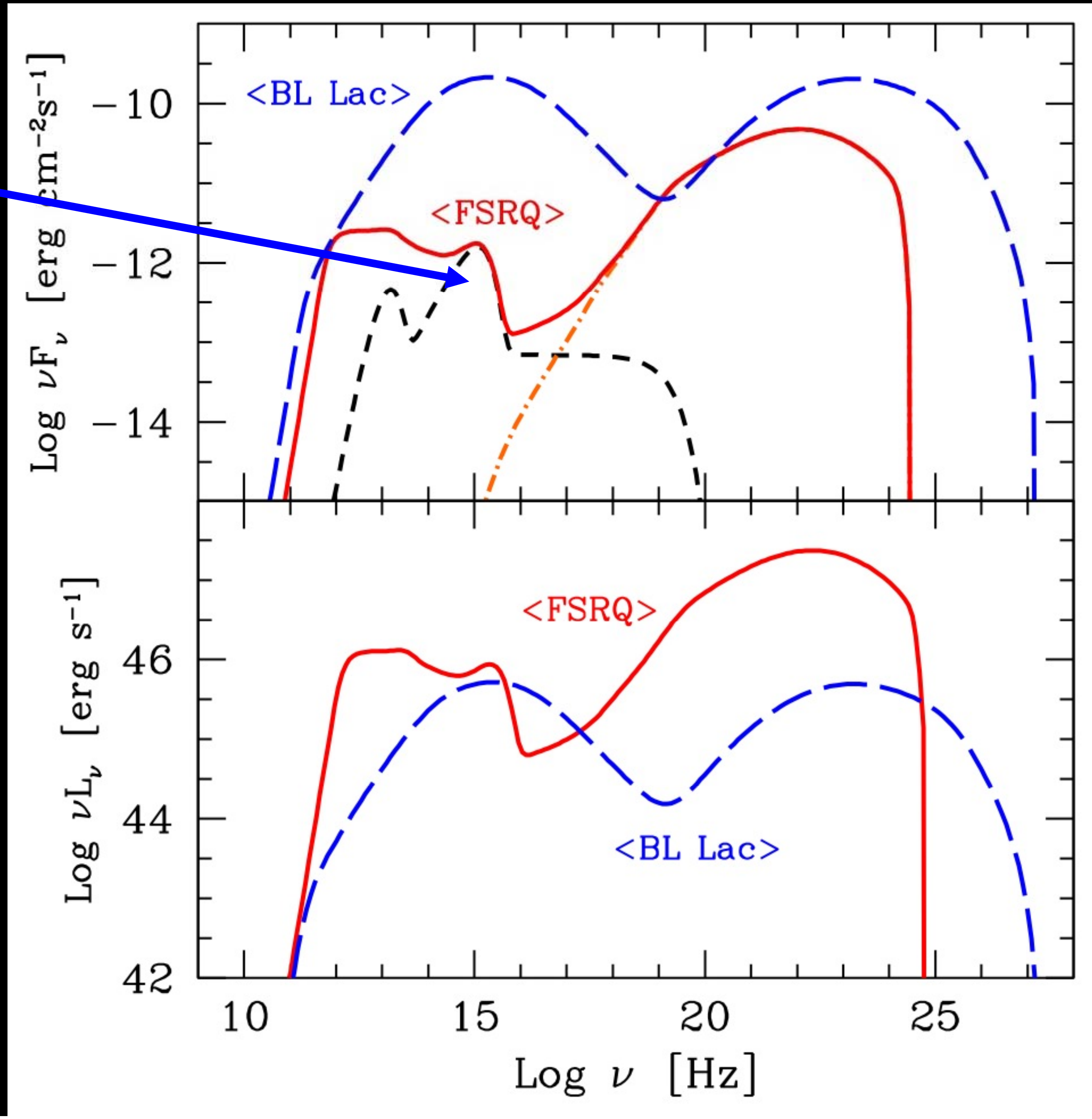
Ghisellini et al. 2010

Total en. density ≈ cooling rate

Average SED models of the FSRQs and BLLacs in the 3 months Fermi Blazar sample

The blue bump is directly observed in FSRQs
→the accretion disk lumnosity can be derived

For BL Lacs upper limits can be derived



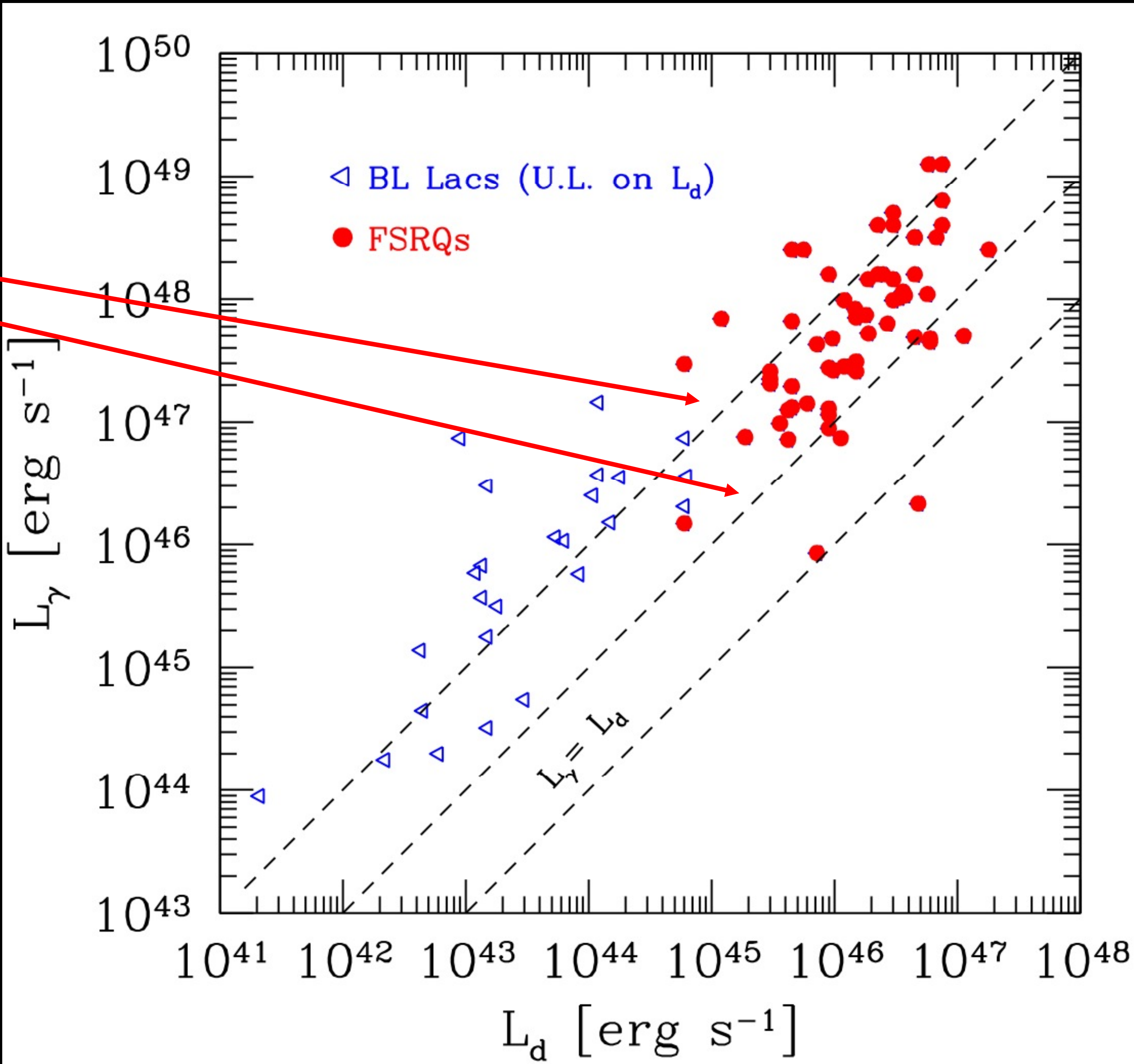
Gamma-ray luminosity vs disk luminosity

(2 observables)

Lg ~10-100Ld

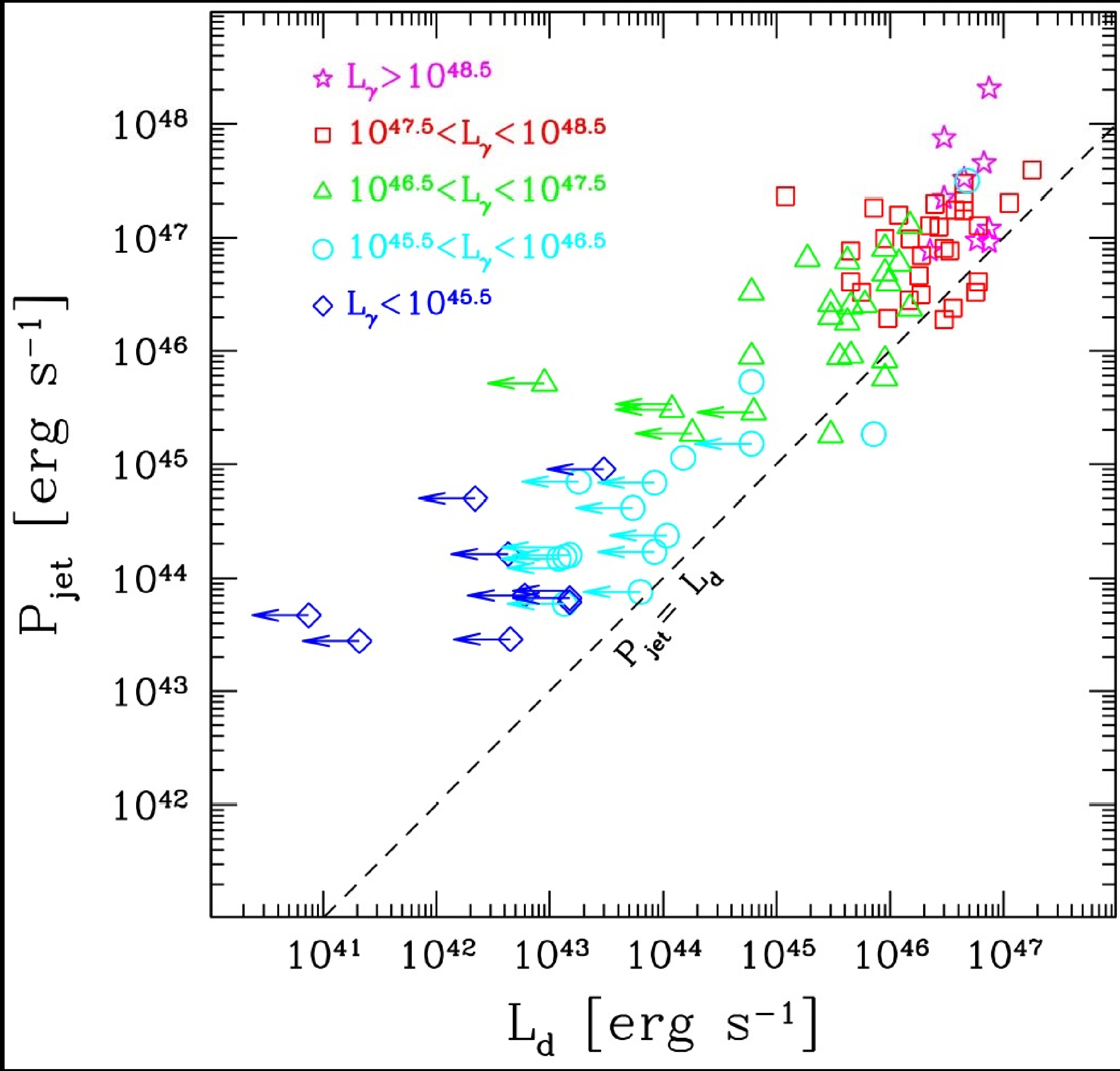
(model independent but Lg is beamed, Ld is not)

modelling needed



Jet power vs. accretion disk luminosity

For FSRQs the correlation is signficant (subtracting z dependence)



Pjet > Ldisk
Ldisk~0.1 Pacc
Pjet ~ Pacc

Ghisellini et al. 2009

The Blandford Znajek formula (1977)

$$L_{BZ} \approx \frac{1}{32} \frac{\Omega_F \left(\Omega_H - \Omega_F \right)}{\Omega_H^2} B_H^2 r_H^2 a^2 c$$

Omega $_H$ BH rotation frequency

Omega $_F$ Field line rotation frequency

B must be carried by infalling matter

If BZ works, the correlation found between jet power and accretion power can be "naturally" explained:

Assuming equipartition and spherical infall in the plunging region

$$B^2\, r_H^2\, c \sim 2\, M^{dot}\, c^2$$

We have a basic understanding of the average stationary properties of blazar SEDs and some clues about the jet formation process

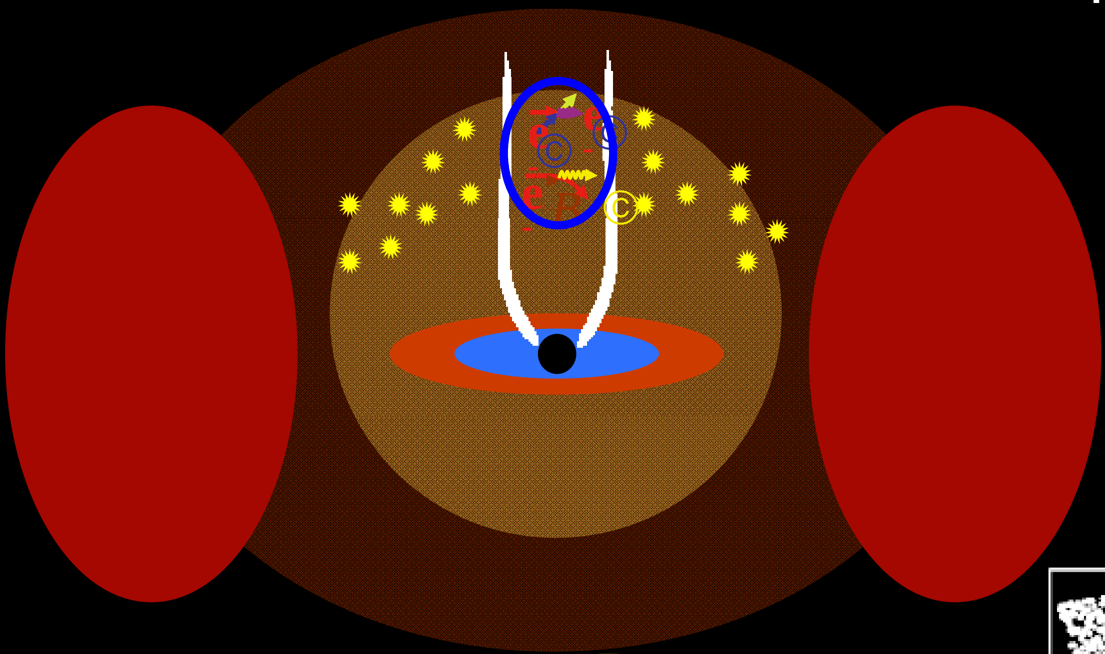
Need deeper knowledge of acceleration and radiation processes within the jets

Fast variability can “resolve” the emitting region size and location

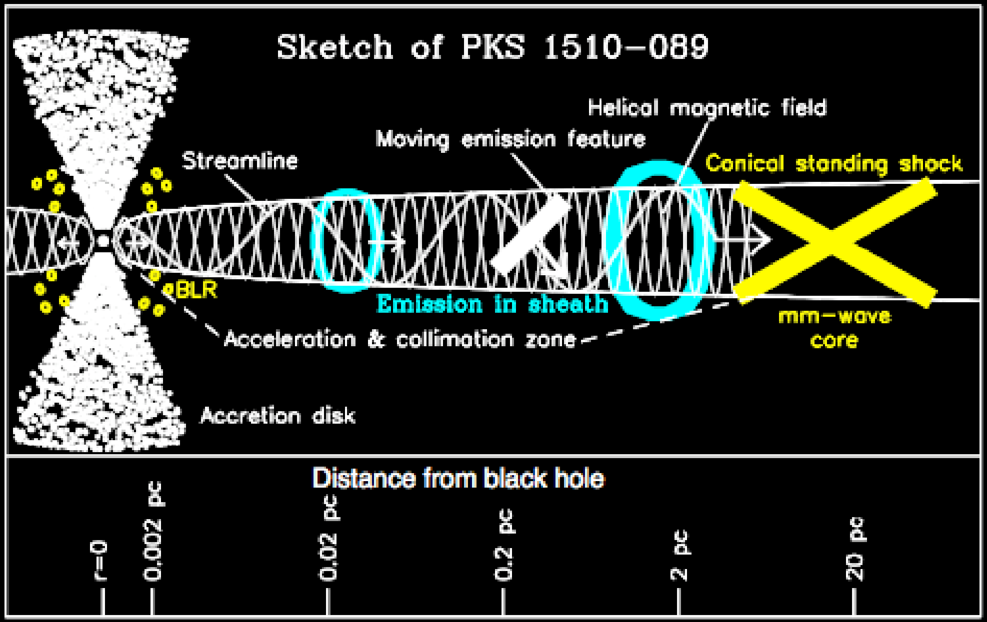
High energy spectra and spectral variability can tell us about particle aceleration and evolution

Localizing the emission region

If GeV photons are produced in the BLR
assumed distances < 0.1-0.3 pc



Marscher et al. 2010

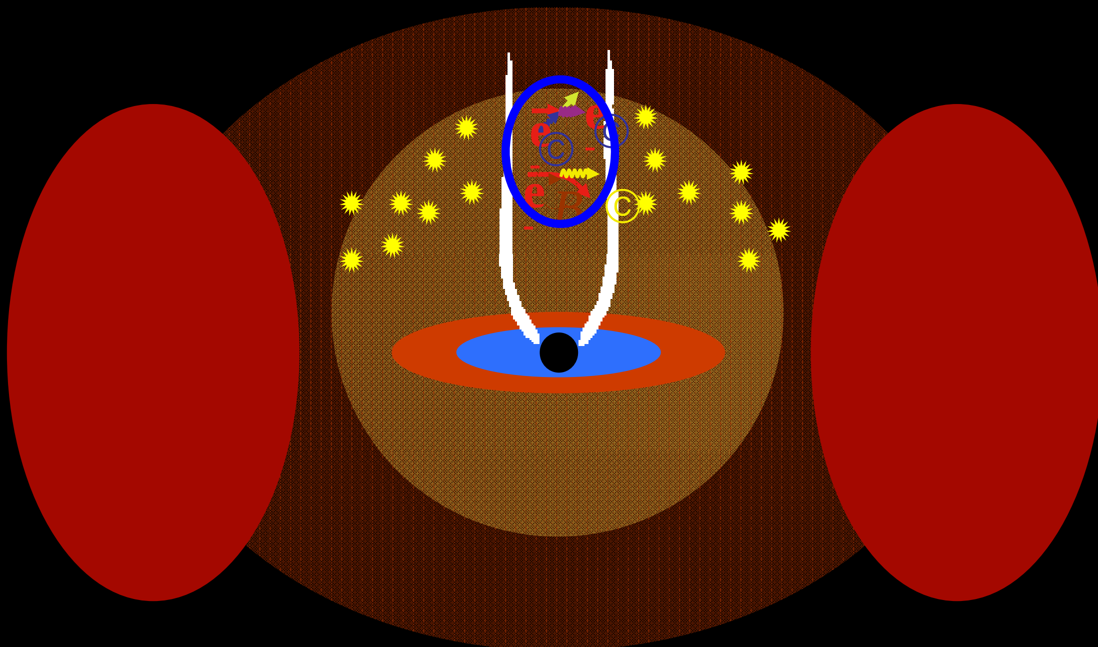


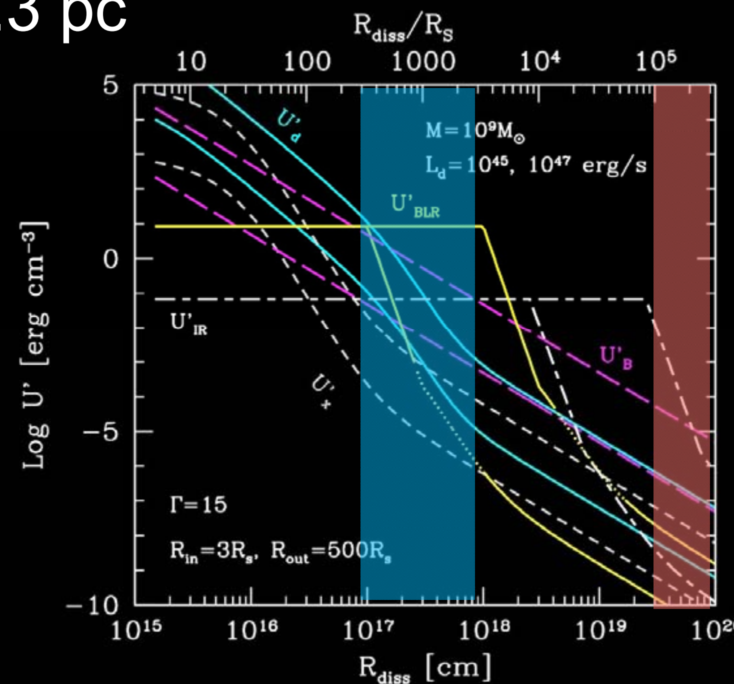
But:
Sikora et al. 2009
Marscher et al. 2009, 2010
Lat Coll. 2010

~10-20 pc!

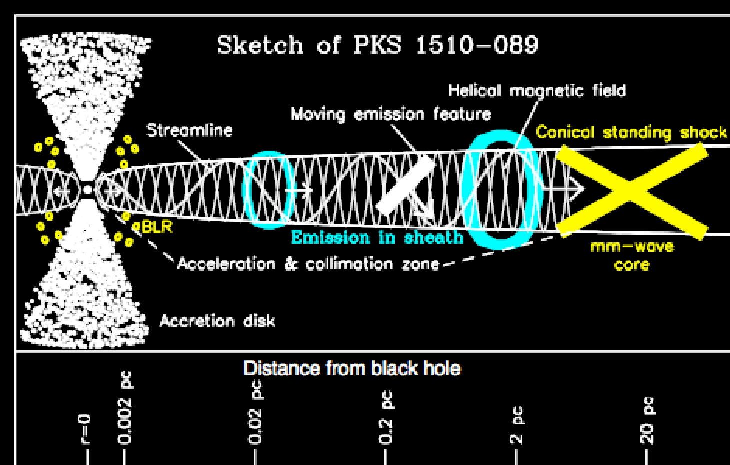
Localizing the emission region

Previous results assume distances < 0.1-0.3 pc





Marscher et al. 2010



But:

Sikora et al. 2009

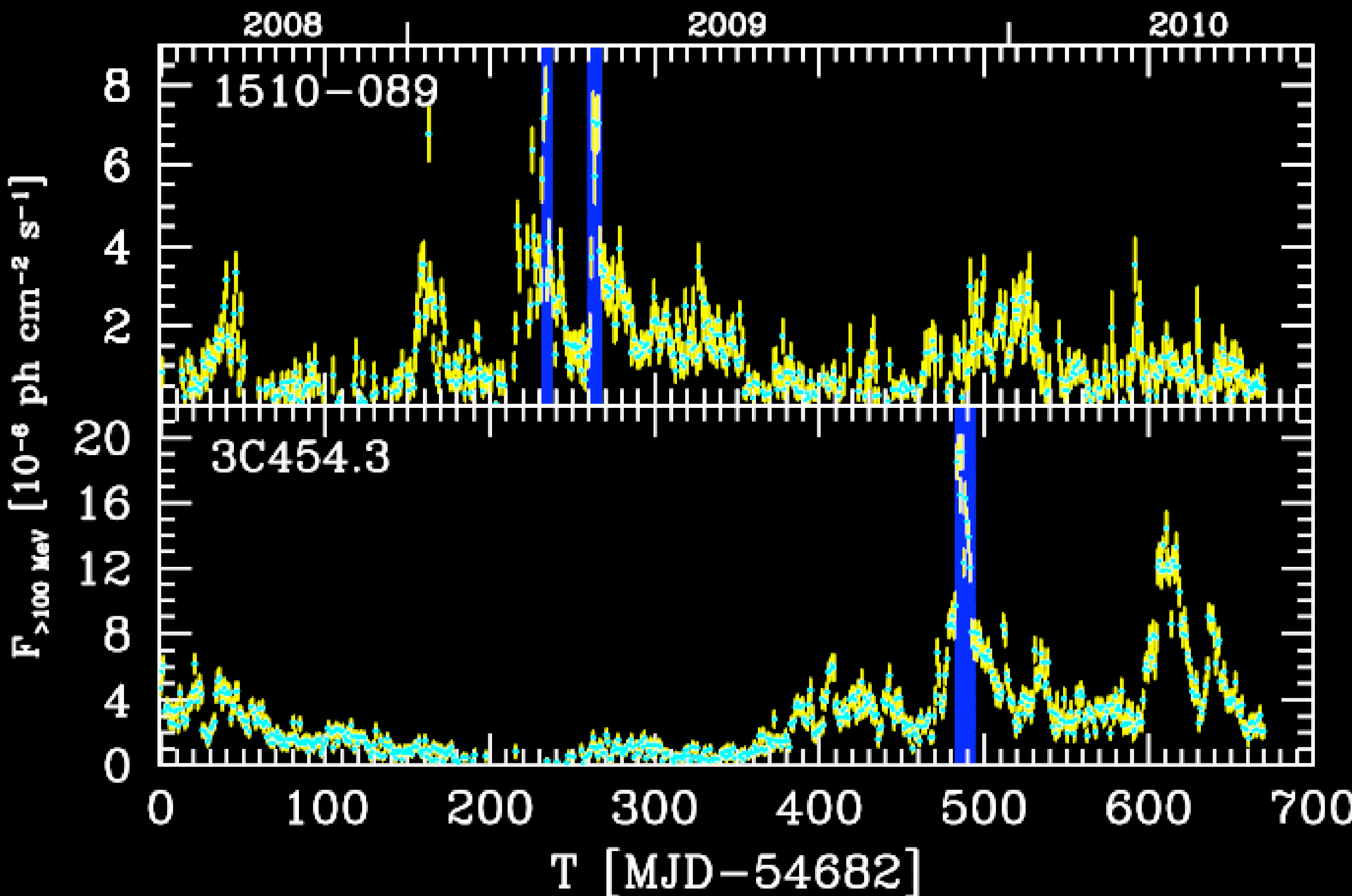
Marscher et al. 2009, 2010

Lat Coll. 2010

IC on IR phot

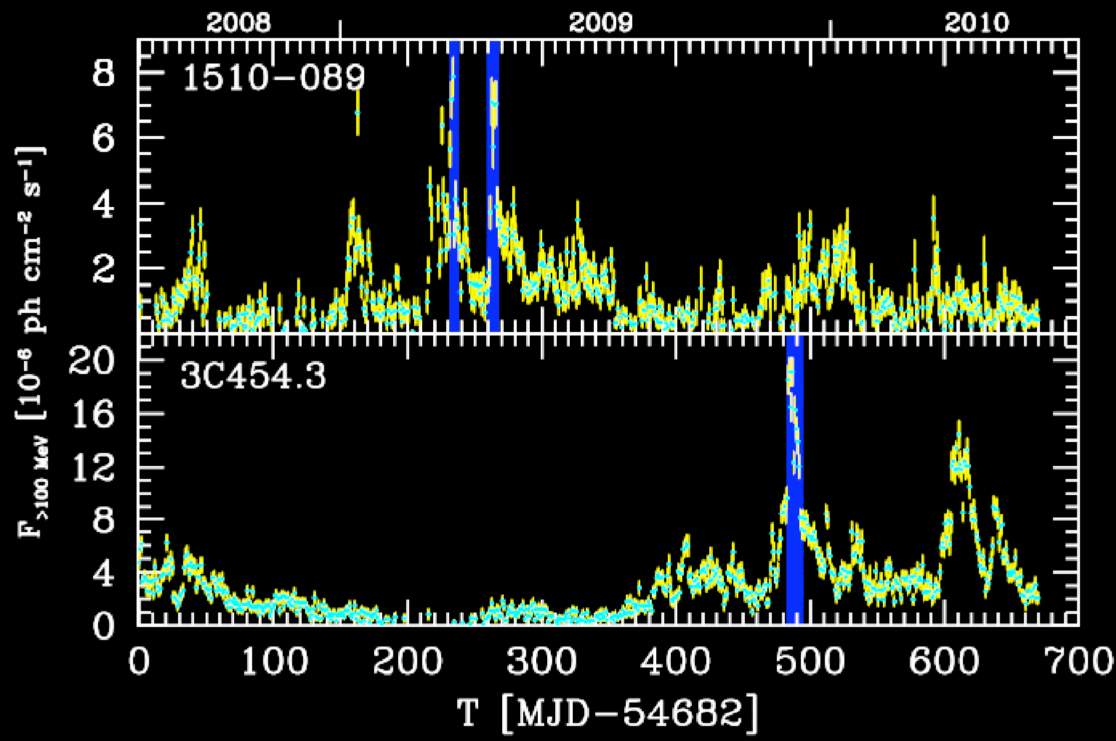
~10-20 pc!

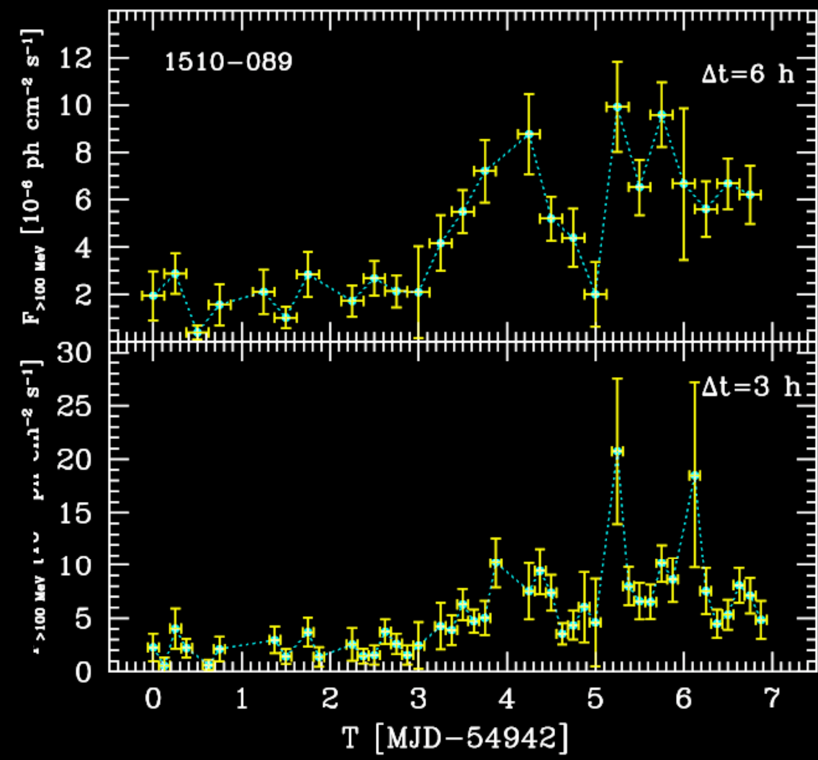
LAT light curves show very rapid gamma-ray variability!

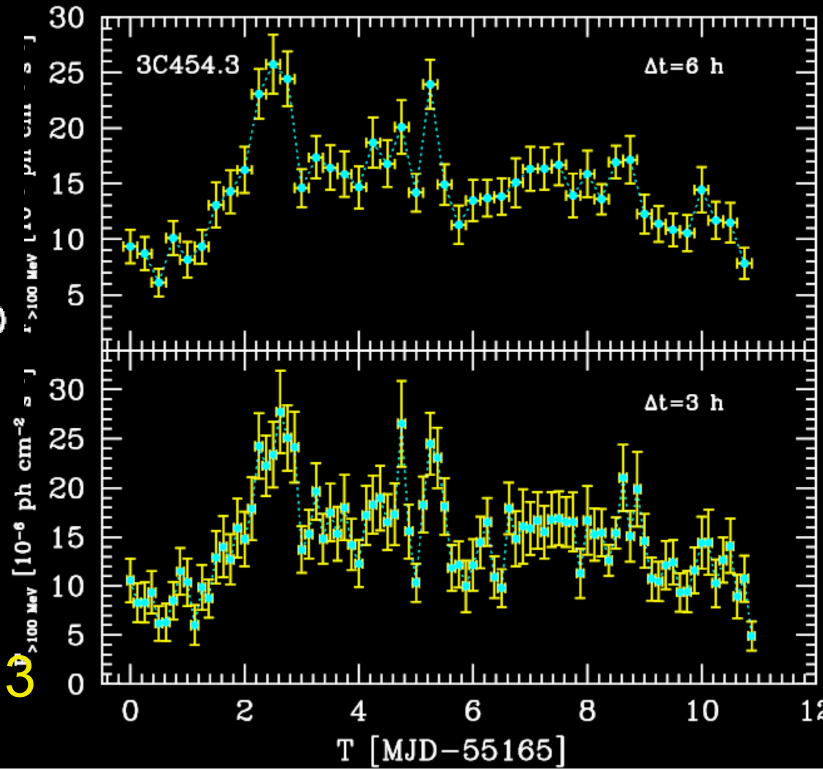


In more detail!

LAT lightcurves







Tavecchio et al. 2010

See also Foschini et al. 2010

Abdo et al. 2010, arXiv:1007.0483 for 3C454.3

Rapid gamma-ray variability requires

$$R < ct_{\rm var}\frac{\delta}{1+z} \simeq \frac{6.5\times 10^{15}}{1+z}\left(\frac{t_{\rm var}}{6\,{\rm h}}\right)\left(\frac{\delta}{10}\right)\ {\rm cm}$$

IF $d \simeq \frac{R}{\theta_{\rm j}}$ Conical geometry

$$\boxed{d < ct_{\rm var}\frac{\delta}{1+z}\theta_{\rm j}^{-1} \simeq \frac{6.5\times 10^{16}}{1+z}\left(\frac{t_{\rm var}}{6\,{\rm h}}\right)\left(\frac{\delta}{10}\right)\left(\frac{\theta_{\rm j}}{0.1}\right)^{-1}\ {\rm cm}}$$ i.e. inside the BLR

Doppler factor is not expected to be >> 30 (e.g. Abdo et al. 2010)

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Very small collimation angle?
If d=20 pc

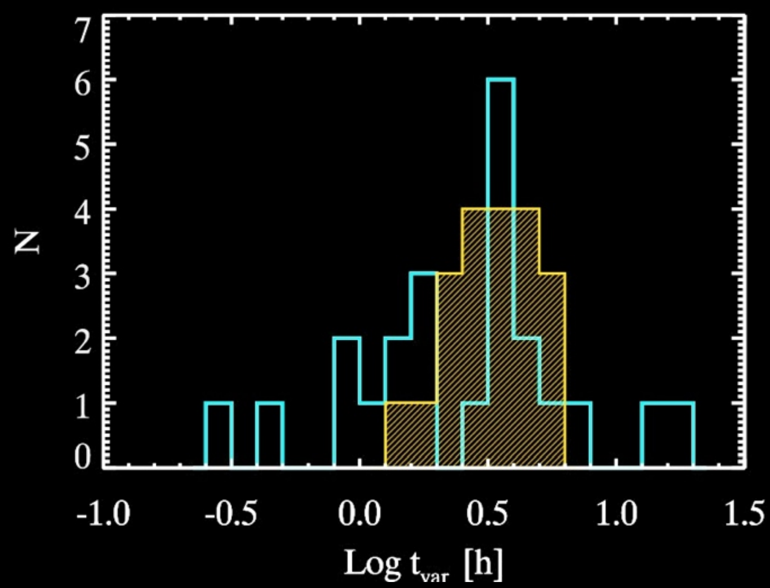
$$\boxed{\theta_{\rm j} \simeq \frac{10^{-4}}{1+z}\left(\frac{t_{\rm var}}{6\,{\rm h}}\right)\left(\frac{\delta}{10}\right)}$$

Geometry may be parabolic in the accel. reg.

A similar problem: too rapid TeV variability in HBLs

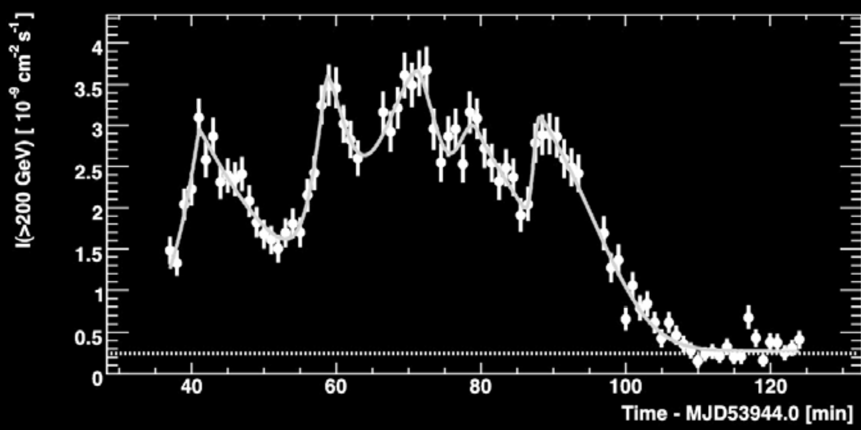
BL Lac Detected in TeV

BL Lac not detected in TeV



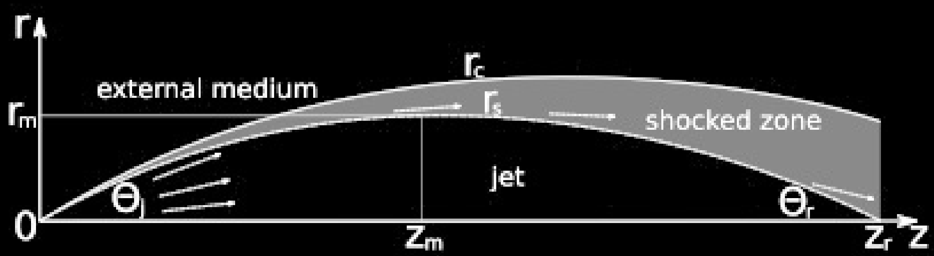
FT et al. 2010

PKS 2155-304 - HESS



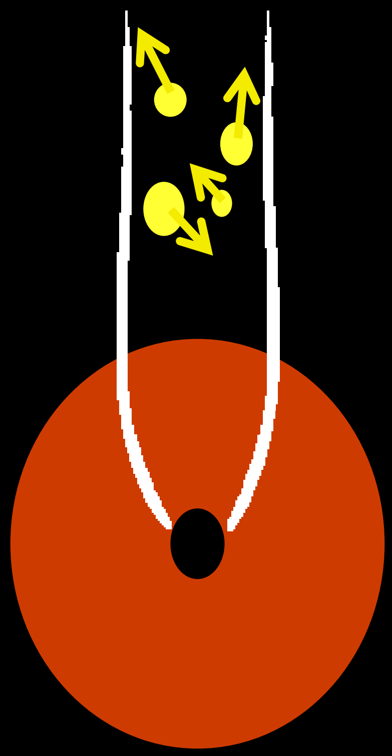
Ultrafast (~200 s) variability (Aharonian et al. 2007, Albert et al. 2007) needs major changes (e.g. Ghisellini et al. 2008, 2009, Giannios et al 2009, Neronov et al. 2008)

Possibilities to reconcile large d and rapid variability in BL Lacs (and FSRQs?)



Strong recollimation

e.g. Nalewajko & Sikora 2009
Bromberg & Levinson 2009

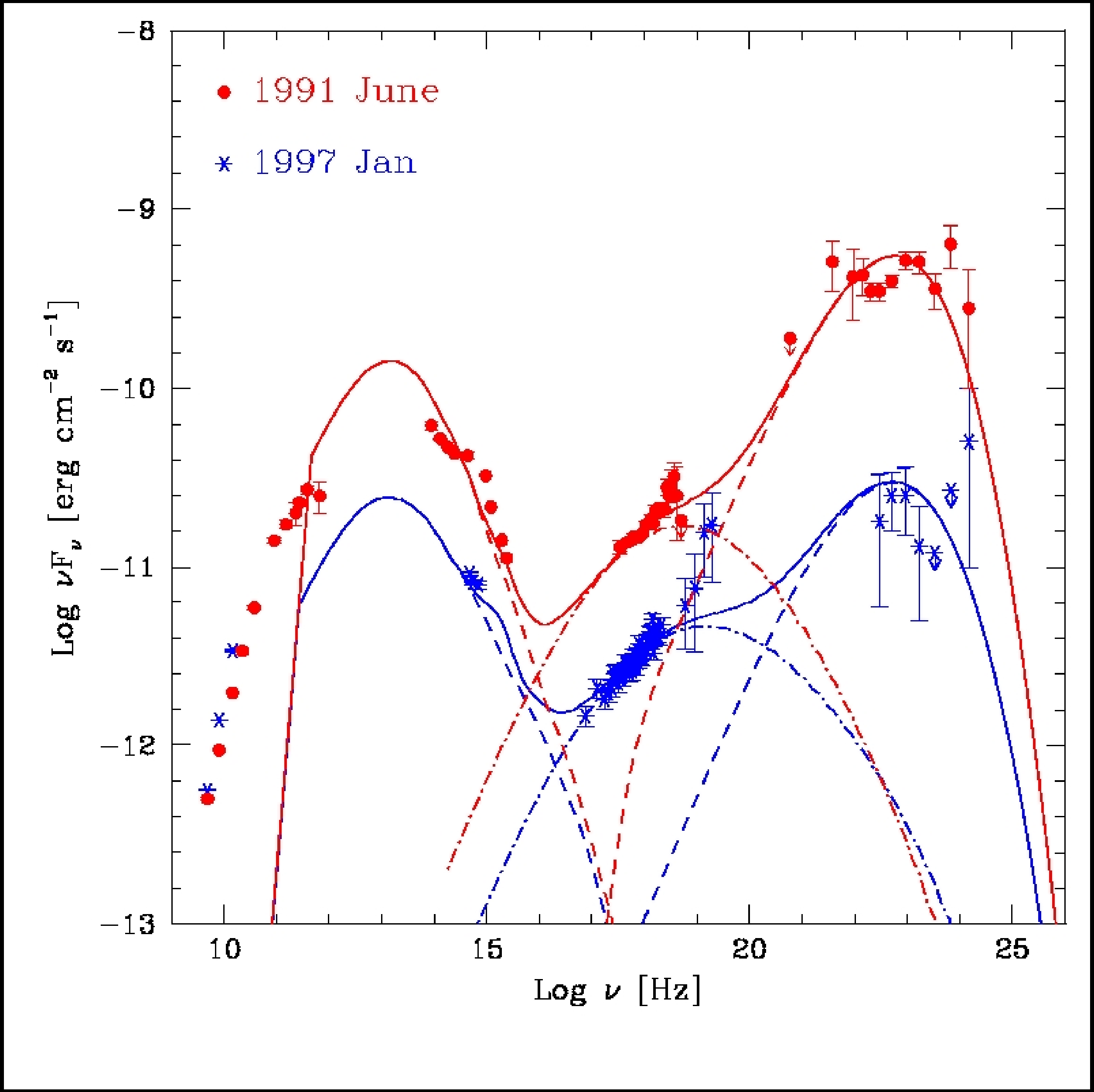


“Needles”within jets

e.g. Ghisellini et al. 2008, 2009
Giannios et al 2009
Marscher & Jorstad 2010

EGRET ERA → 3C279 SSC + EC

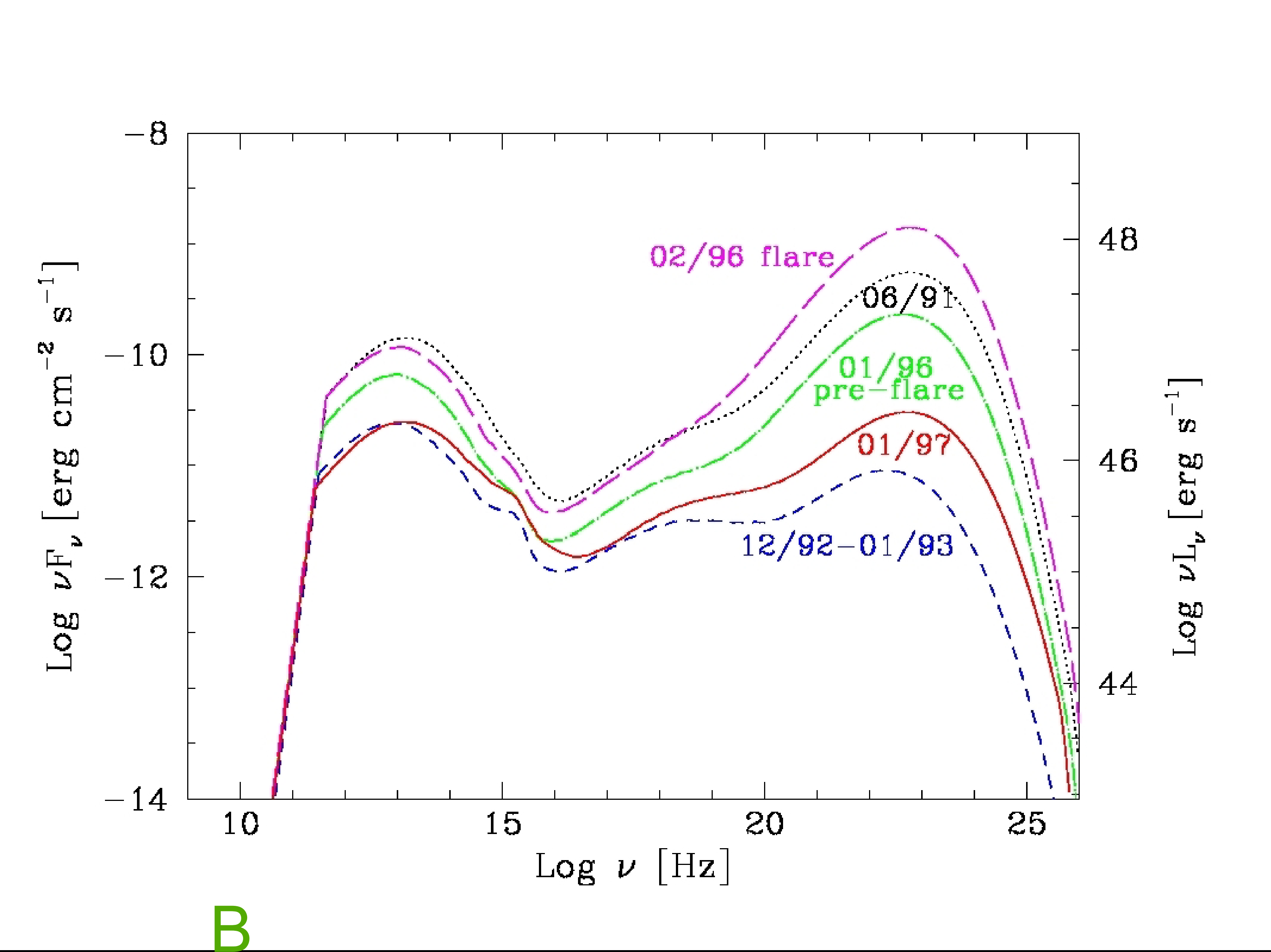
Two states modelled with similar parameters: main difference beaming factor



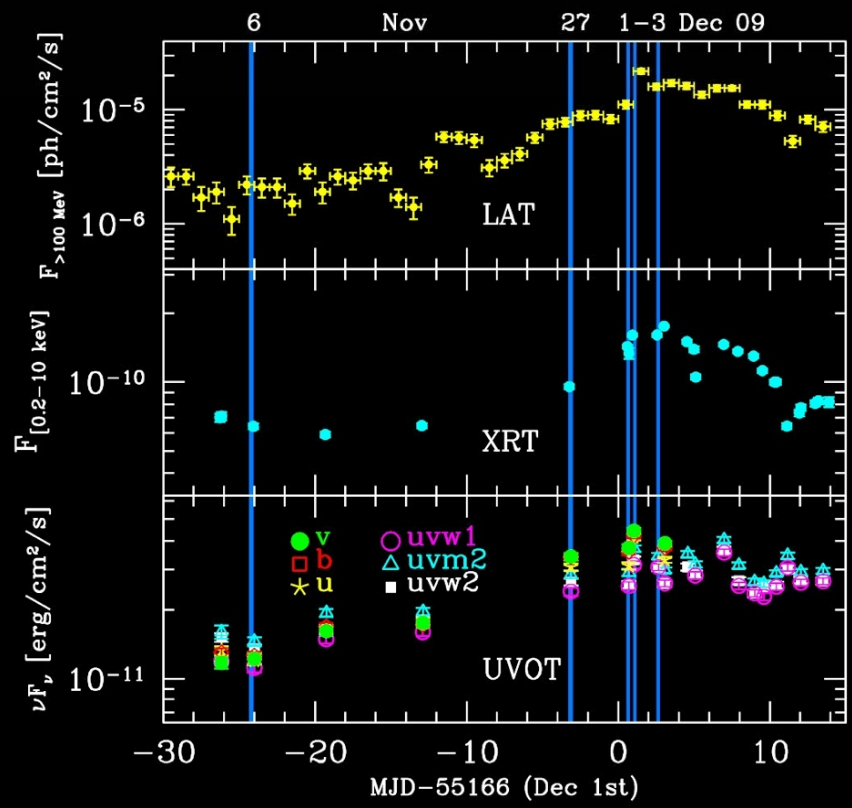
B = 0.6 - 0.5 δ = 17.8 - 12.3 γ_b = 550 - 600

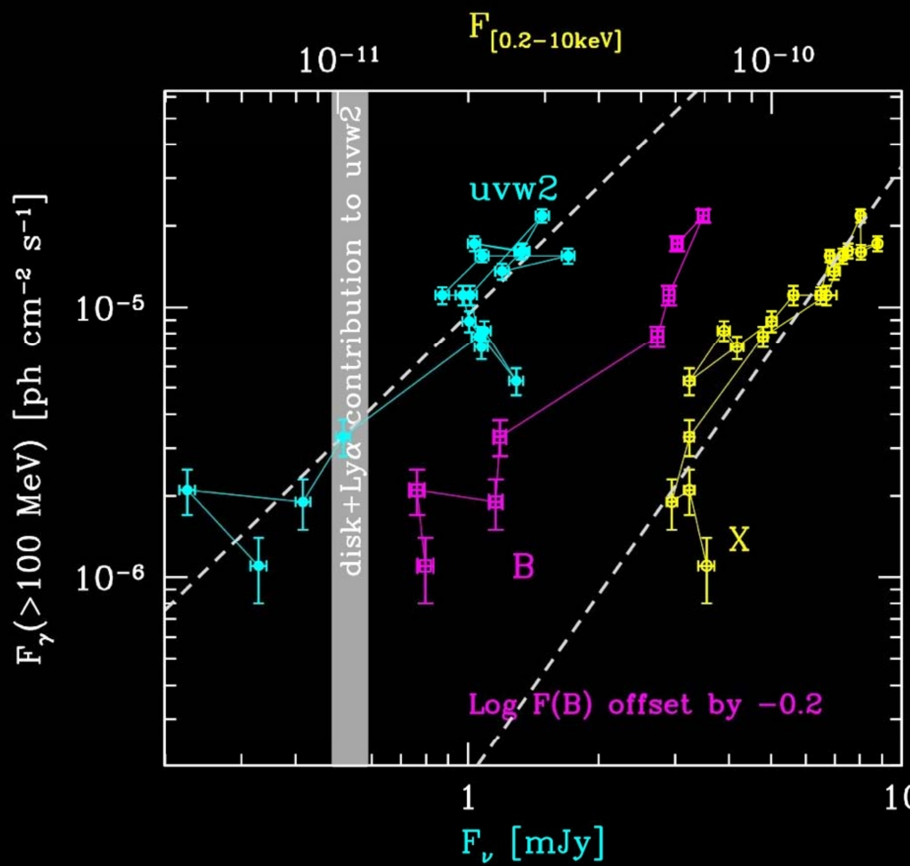
Ballo et al. 2002

For 3C 279 all the different states observed with EGRET could be explained varying only Γ bulk



FERMI: 3C454.3: a benchmark case





Correlation → one zone

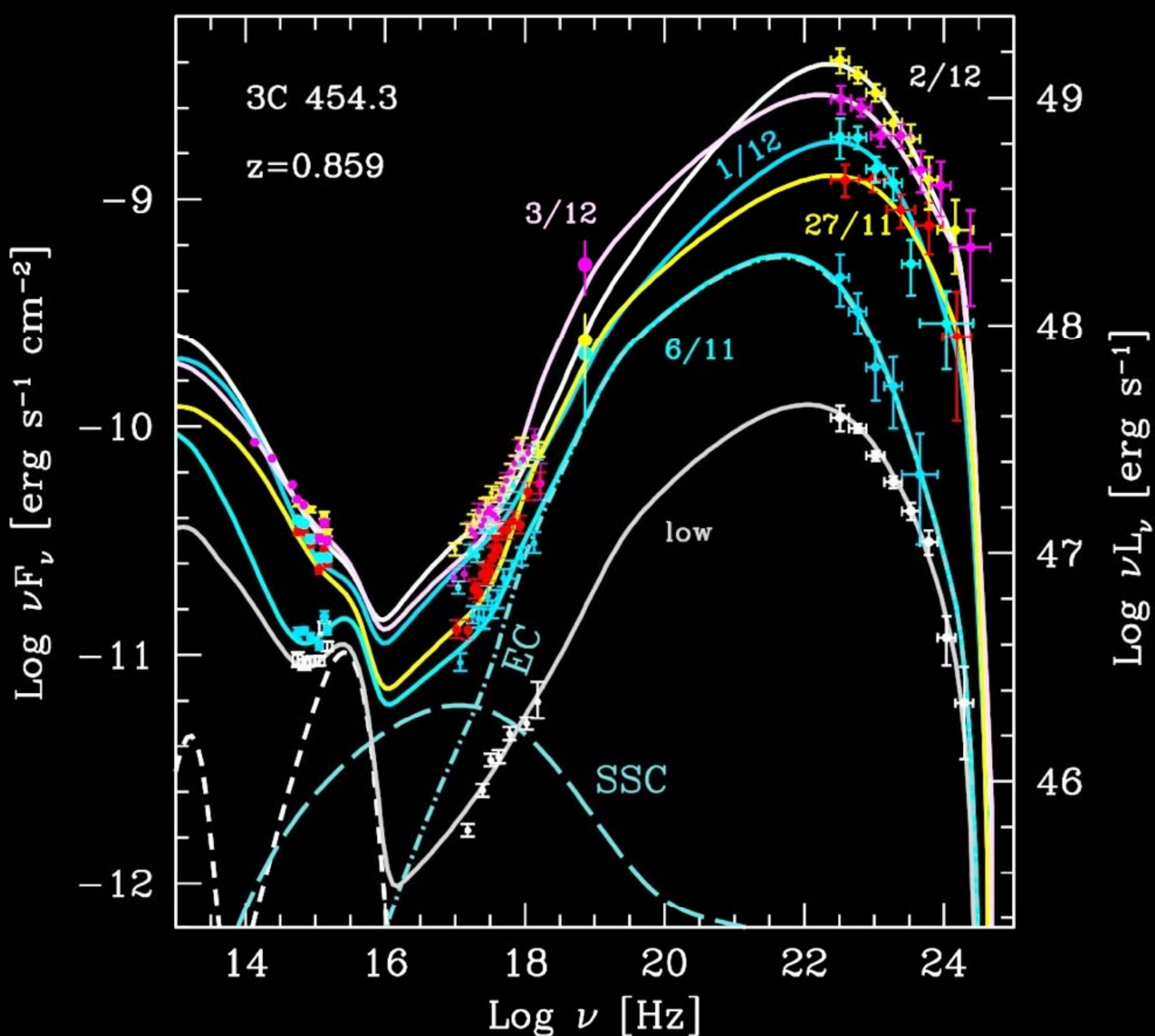
F_{gamma} more than linear in F_{opt} and F_x

as in 3C 279 (Maraschi et al 1994)

Also in PKS 1502+106 (Abdo et al. 2010)

Bonnoli et al. 2010

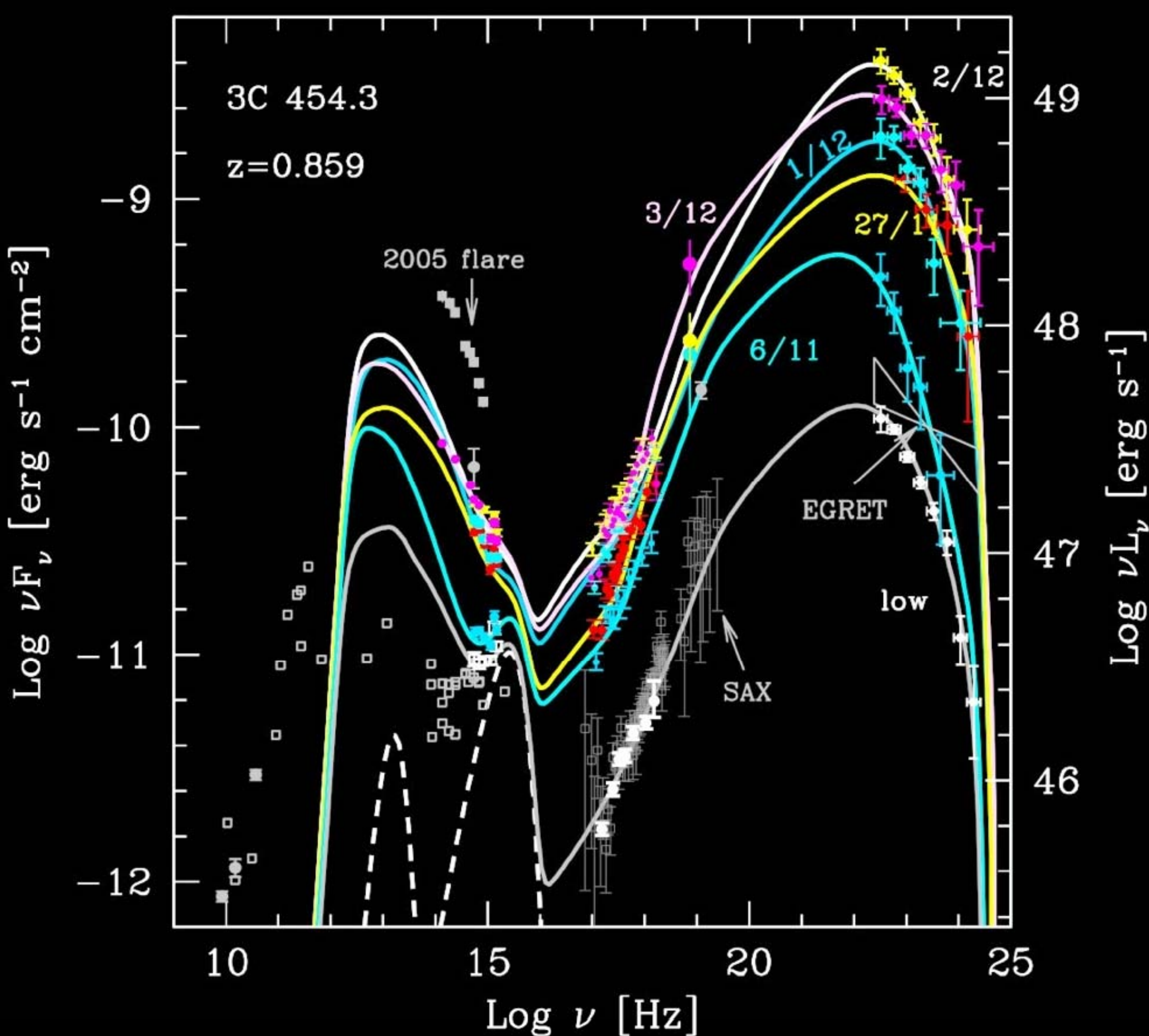
See also Abdo et al. 2010, arXiv:1007.0483



Large flux variations, spectrum rather stable:

electron spectrum stable
similar physical conditions

Modeling of the SED with the “canonical” model



Bonnoli et al. 2010

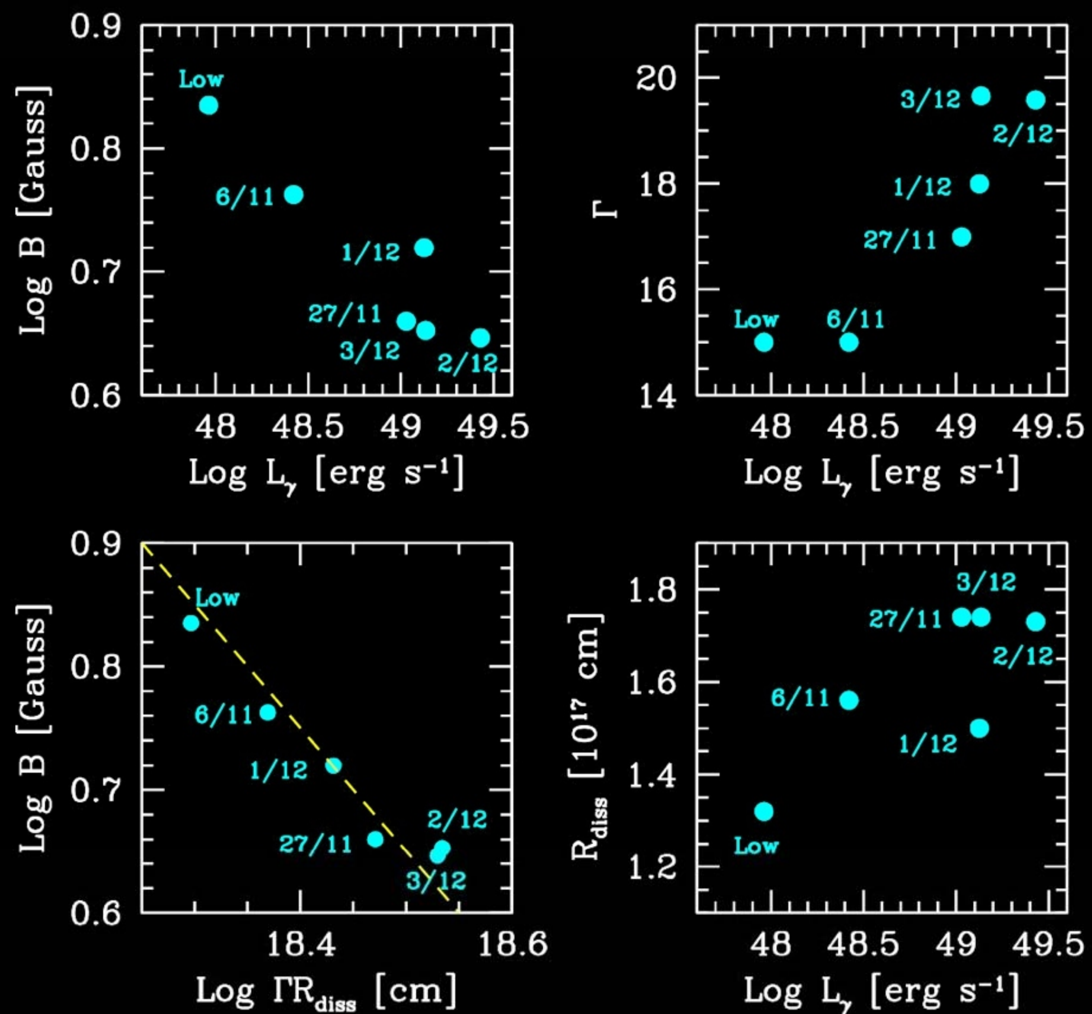
In syncro + EC frame :

- B must vary inversely to bolometric power

- Γ, R_{diss} correlate positively with L_γ

- $B \propto (\Gamma \cdot R_{diss})^{-1}$

- $P_B \propto (R_{diss} \cdot \Gamma \cdot B)^2$ (Poynting flux approx. constant at R_{diss})

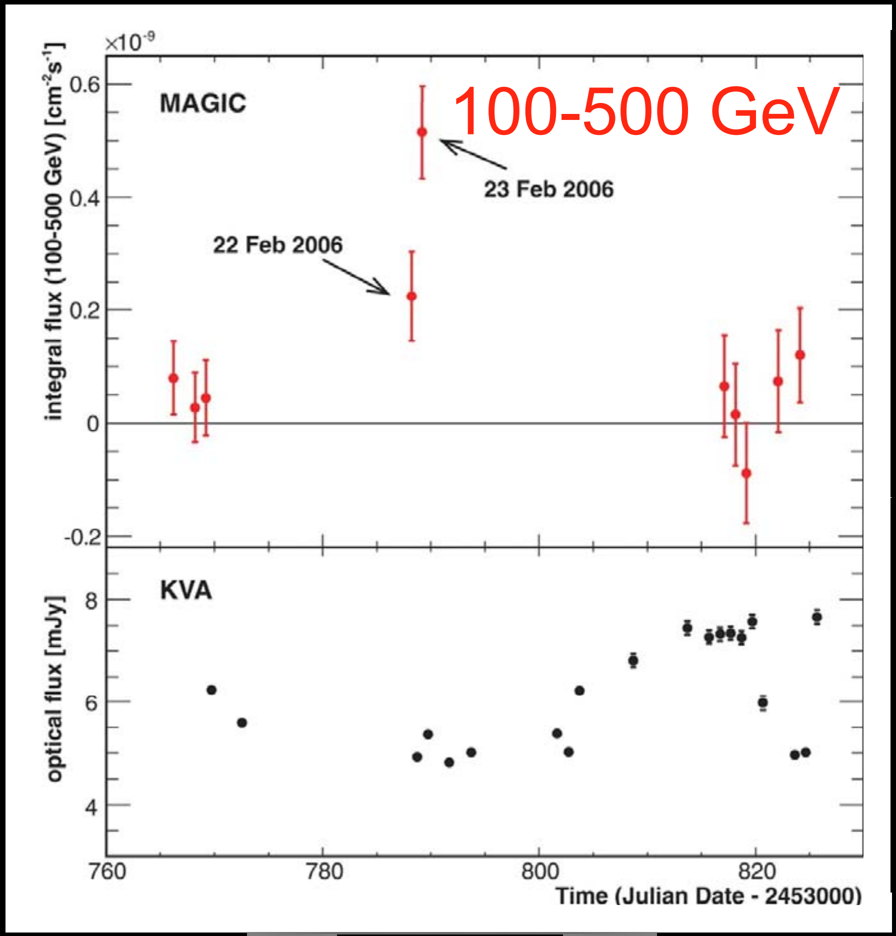


In higher states, the emitting plasma at larger distance from the BH, with lower B and higher Γ

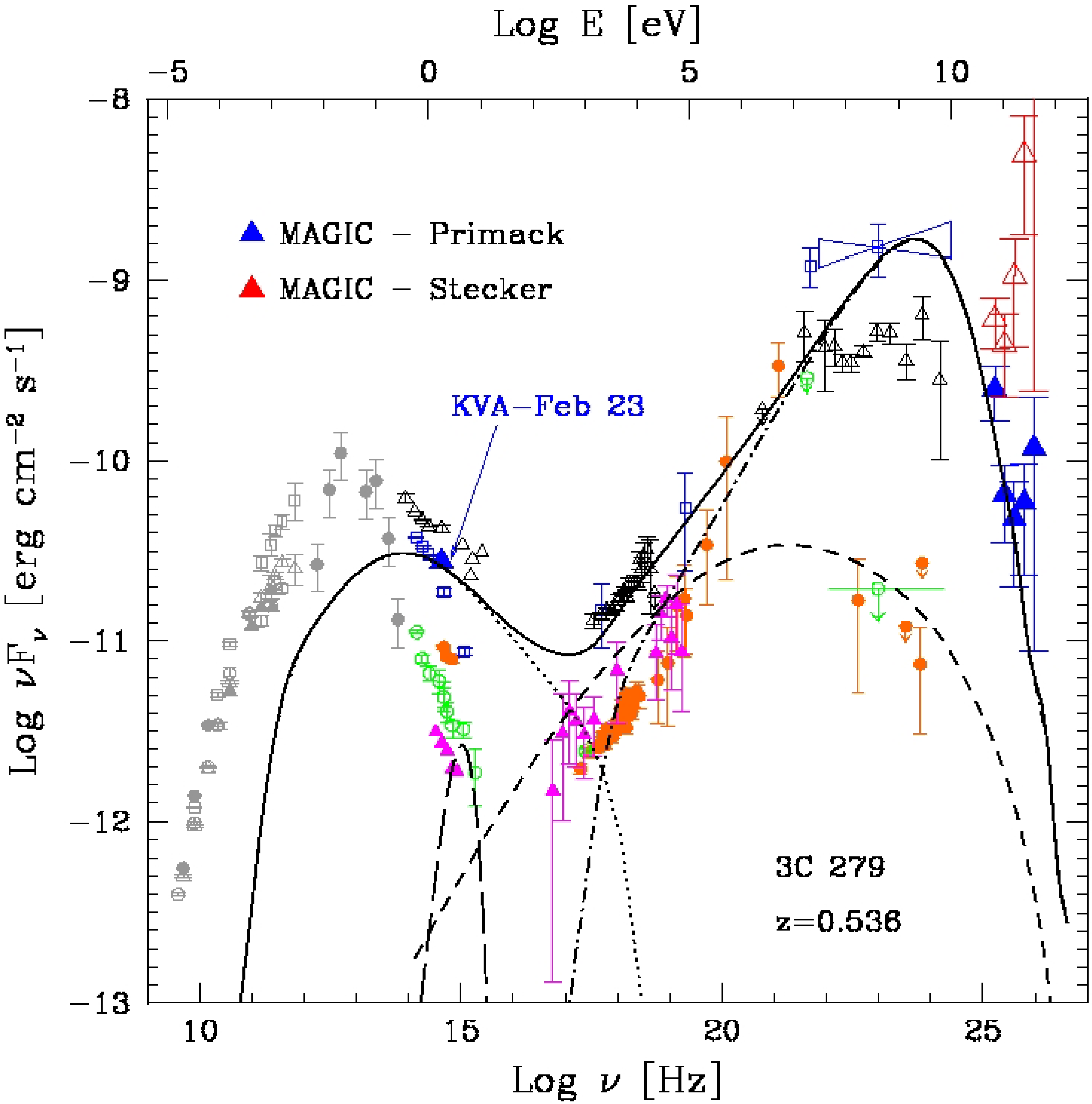
VHE emission from FSRQs

3C279

Albert et al. 2008



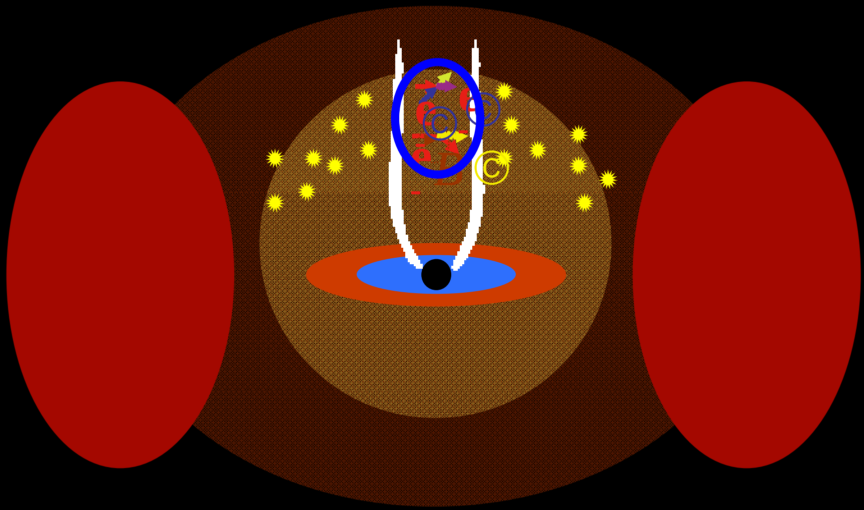
also :
Wagner 2010 for 1510-089 (HESS)
Mariotti 2010 for 1222+216 (MAGIC)



MAGIC TEV
detection

model
rather
extreme !

VHE emission from FSRQs? Difficult inside BLR!



Strong absorption

(E>30 GeV within BLR, E>1 TeV outside)

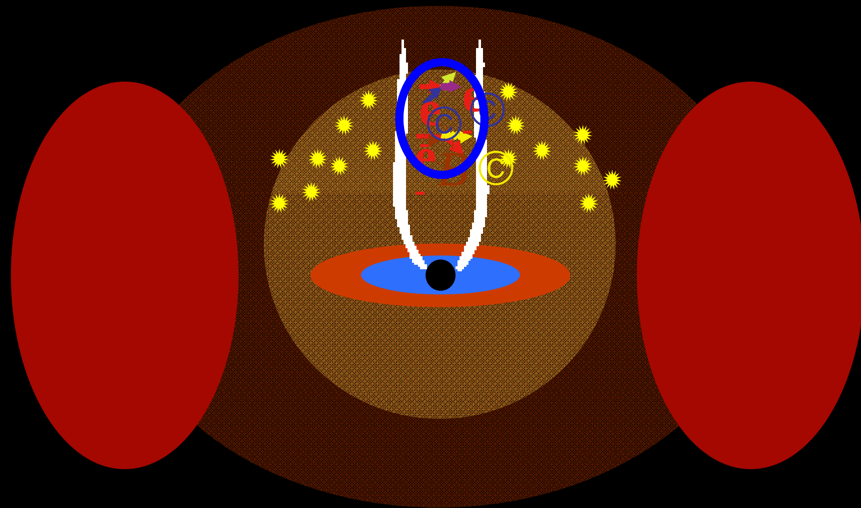
(e.g. Liu et al. 2008, Reimer 2007, FT & Mazin 2009)

Decline of the scattering efficiency

(e.g. Albert et al. 2008, FT & Ghisellini 2008)

Both problems alleviated in the IR region

VHE emission from FSRQs? Difficult inside BLR!



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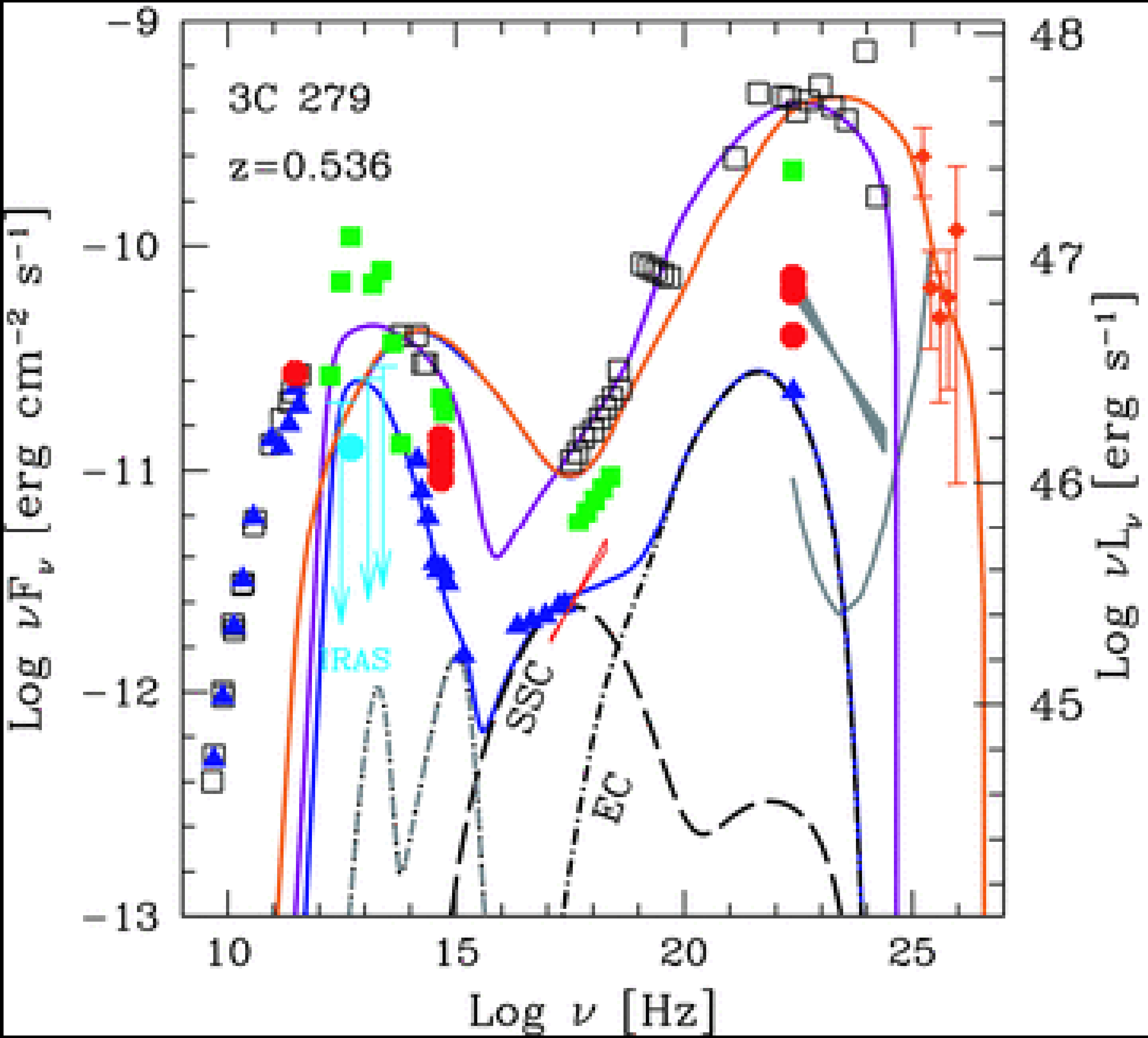
(e.g. Liu et al. 2008, Reimer 2007, FT & Mazin 2009)

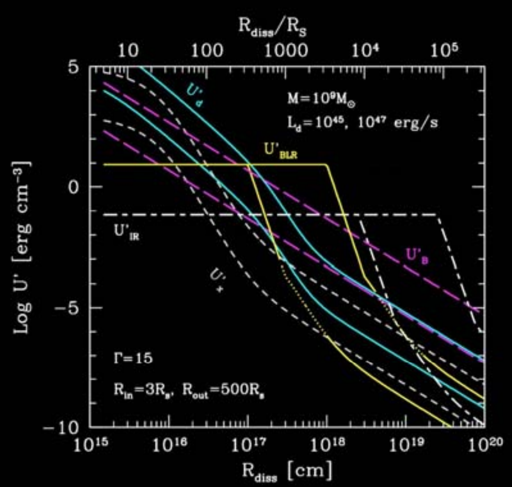
Decline of the scattering efficiency
(e.g. Albert et al. 2008, FT & Ghisellini 2008)

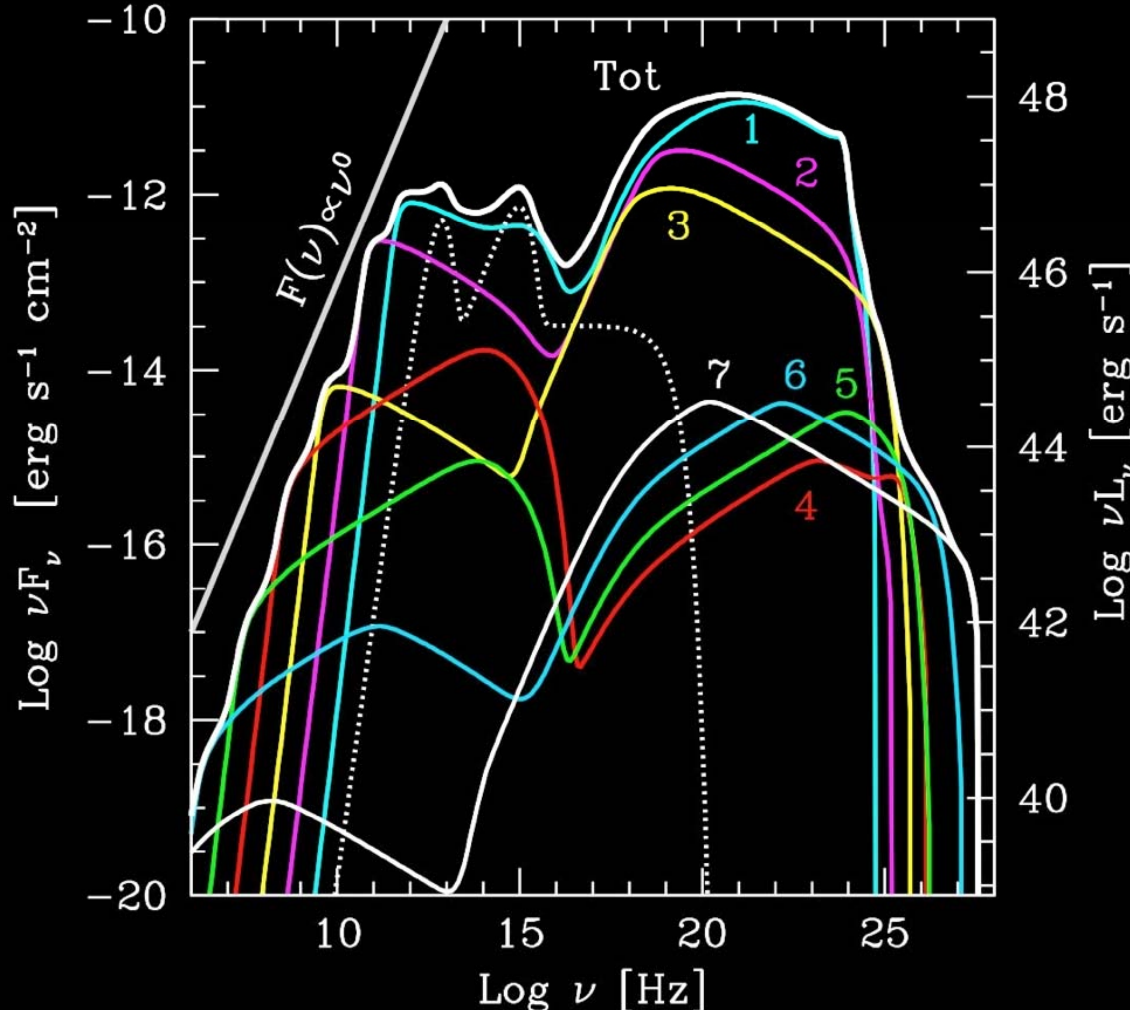
Both problems alleviated outside BLR (IR torus)

New model for 3C 279



More than one region?





Tavecchio 2010

Different variability time-scales
at different energies (GeV: fast - TeV: slow)

No fast TeV variability (unless “needles”)

PKS 1222 detected by MAGIC on June 17

Mariotti 2010

Third detection of a FSRQ at TeV energies

More problems, more fun!!

Summary

Systematic trends of the "Blazar Spectral Sequence"
and
close correlation between jet power and accretion
confirmed by FERMI

"Standard" model for FSRQ: gamma-rays produced
by EC inside BLR consistent with fast variab.
or special geometries if gamma rays produced outside

3C454.3: tracing the dynamics of the emission zone

TeV emission from FSRQ critical : GeV-TeV correlation
important test