The Power of Jets

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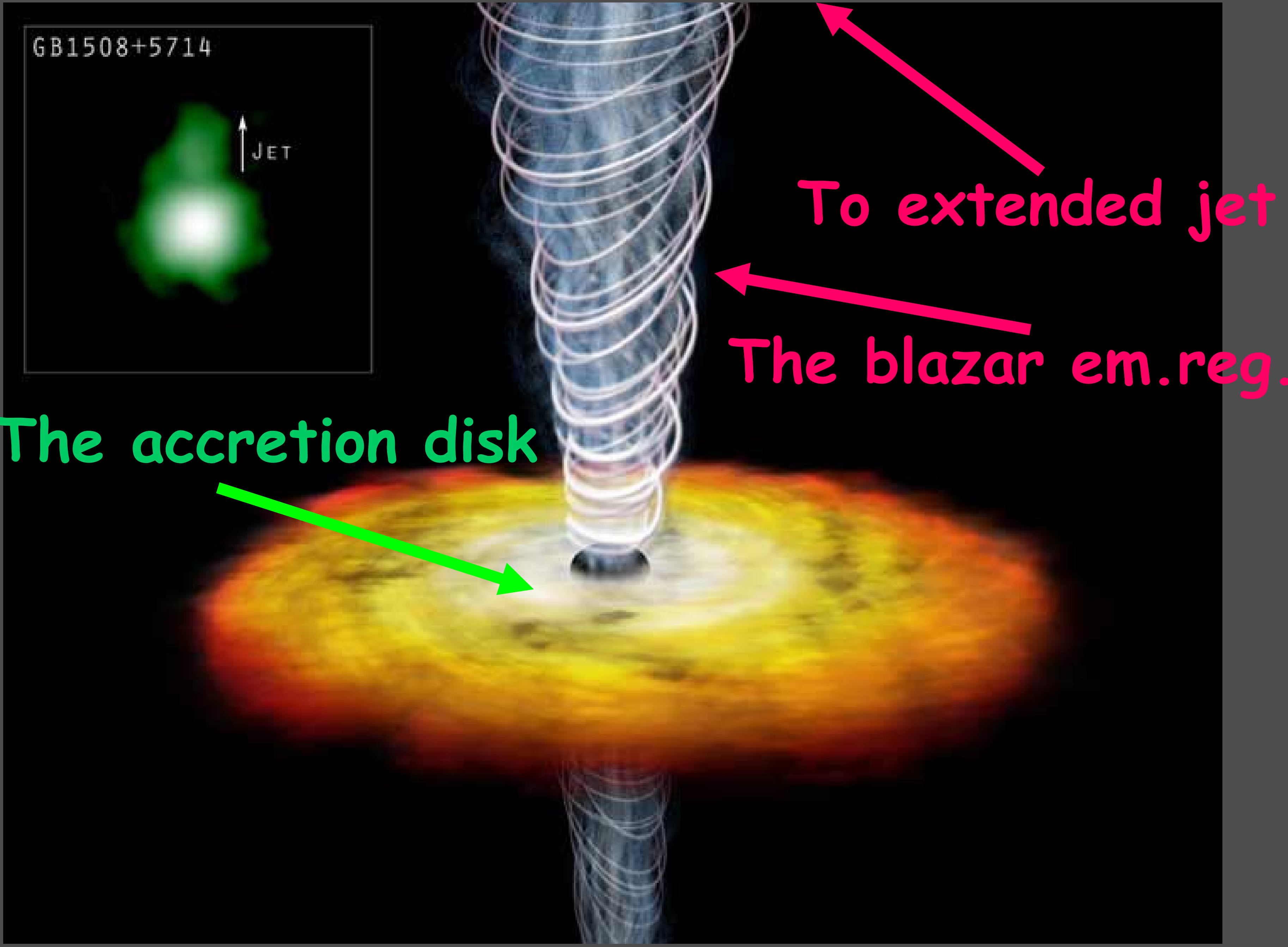
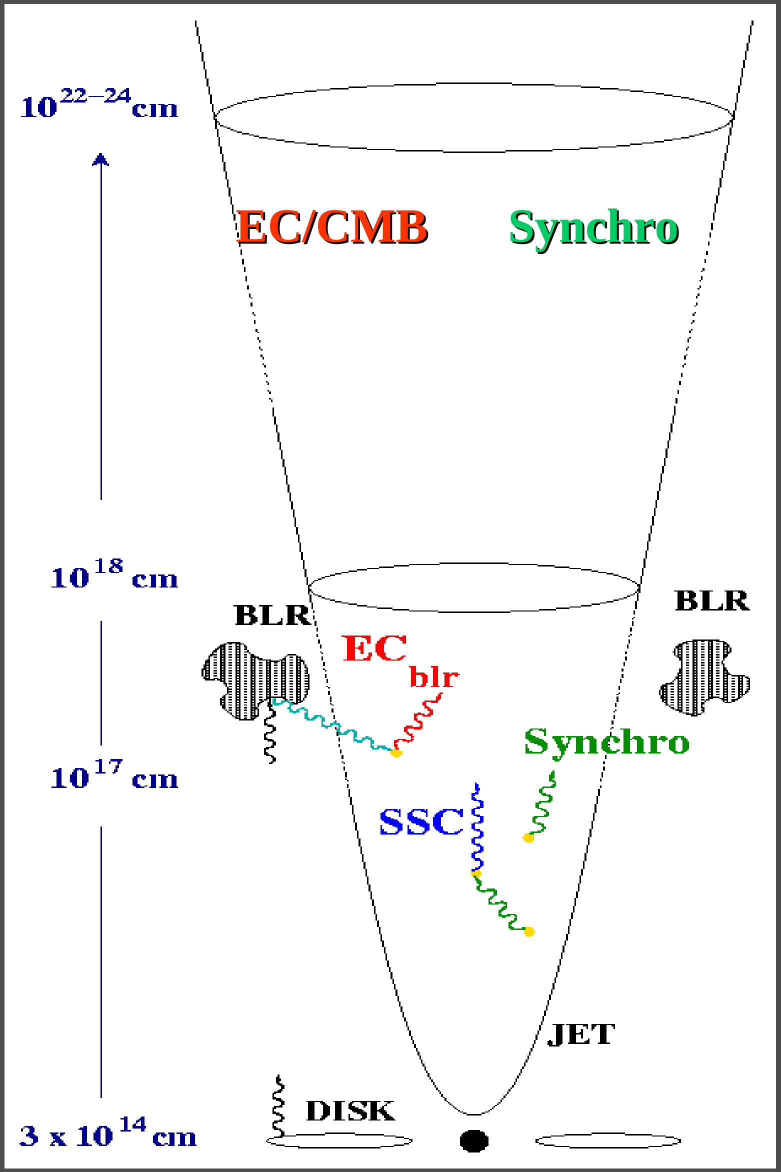

GB1508+5714
JET
To extended jet
The blazar em.reg.
The accretion disk

Jet scales

Resolved X-ray jet
10 - 100 kpc scale

Blazar emission region
sub-pc scale

Accretion region
Jet origin
R_S scale

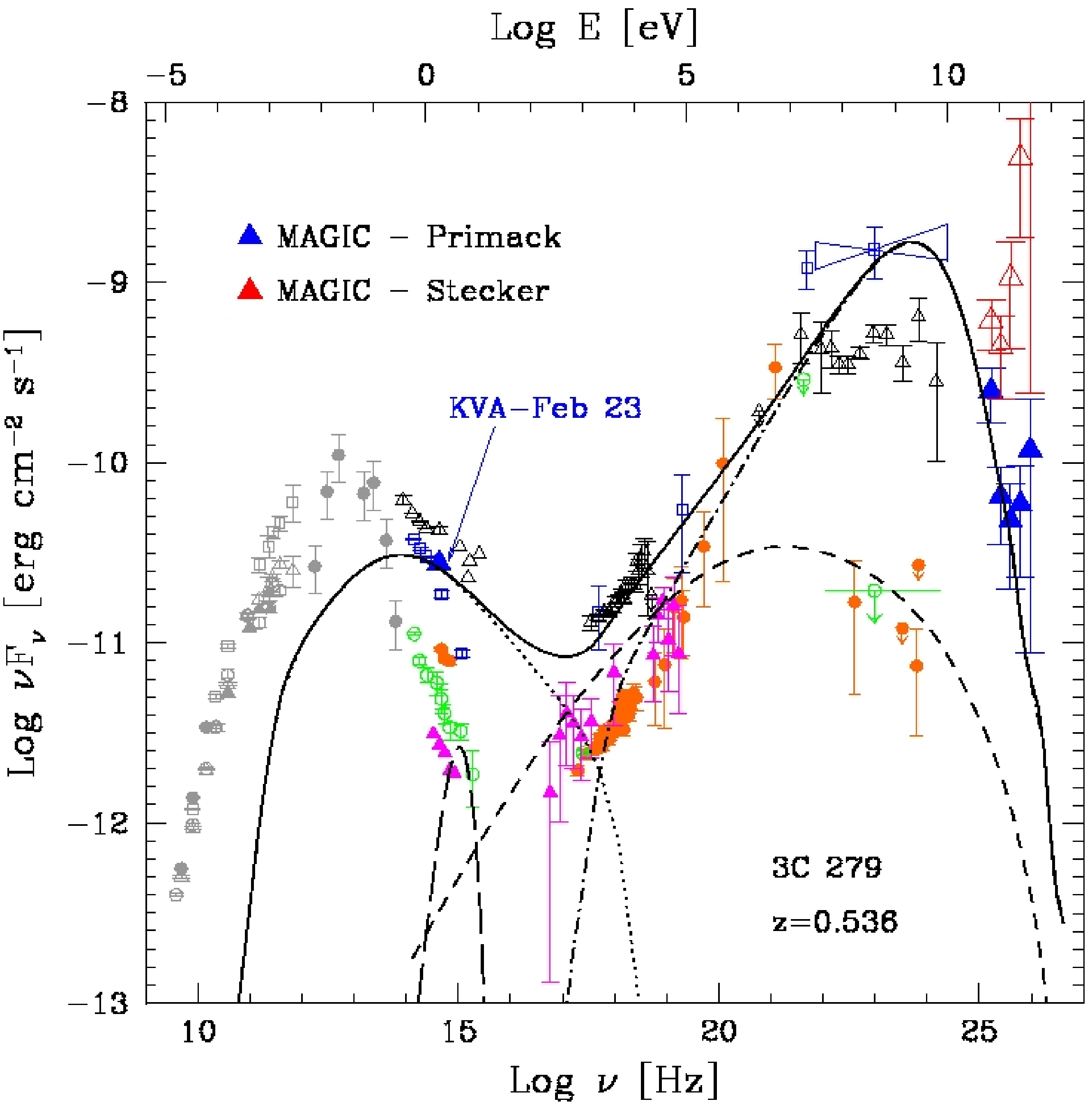


The blazar region

Blazar jets are not unusual jets!

They exist in all radio-sources but can be best probed in blazars due to the help of relativistic beaming, causing strong amplification in the forward direction.

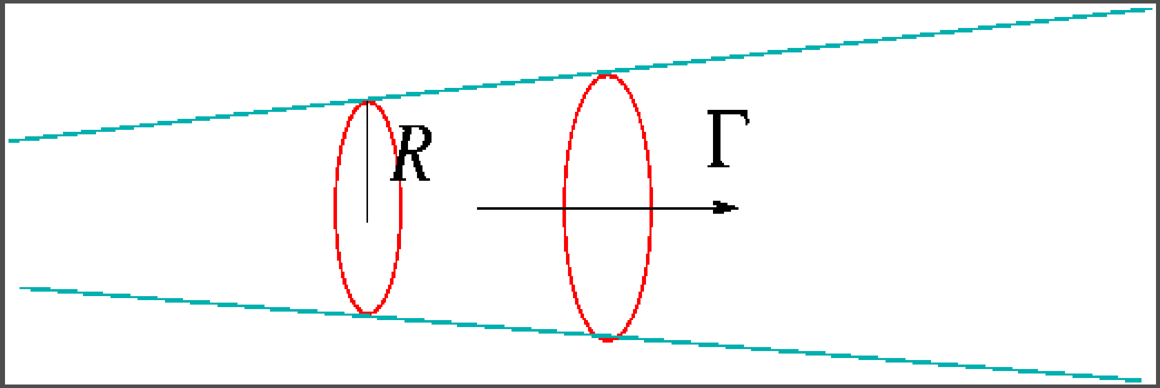
If SYNCHRO AND IC radiation are observed physical parameters within jets can be estimated, as well as the beaming factor/ Bulk Lorentz factor



MAGIC TEV detection

Albert et al.
Science 08

Jet power



$$P_{\rm jet} = \pi R^2 \Gamma^2 \beta c U$$

where

$$U = U_B + U_e + U_p$$

$$U_p + U_e = n m_e c^2 \left(< \gamma > + \frac{m_p}{m_e} \right)$$

Jet power depends on total number of particles

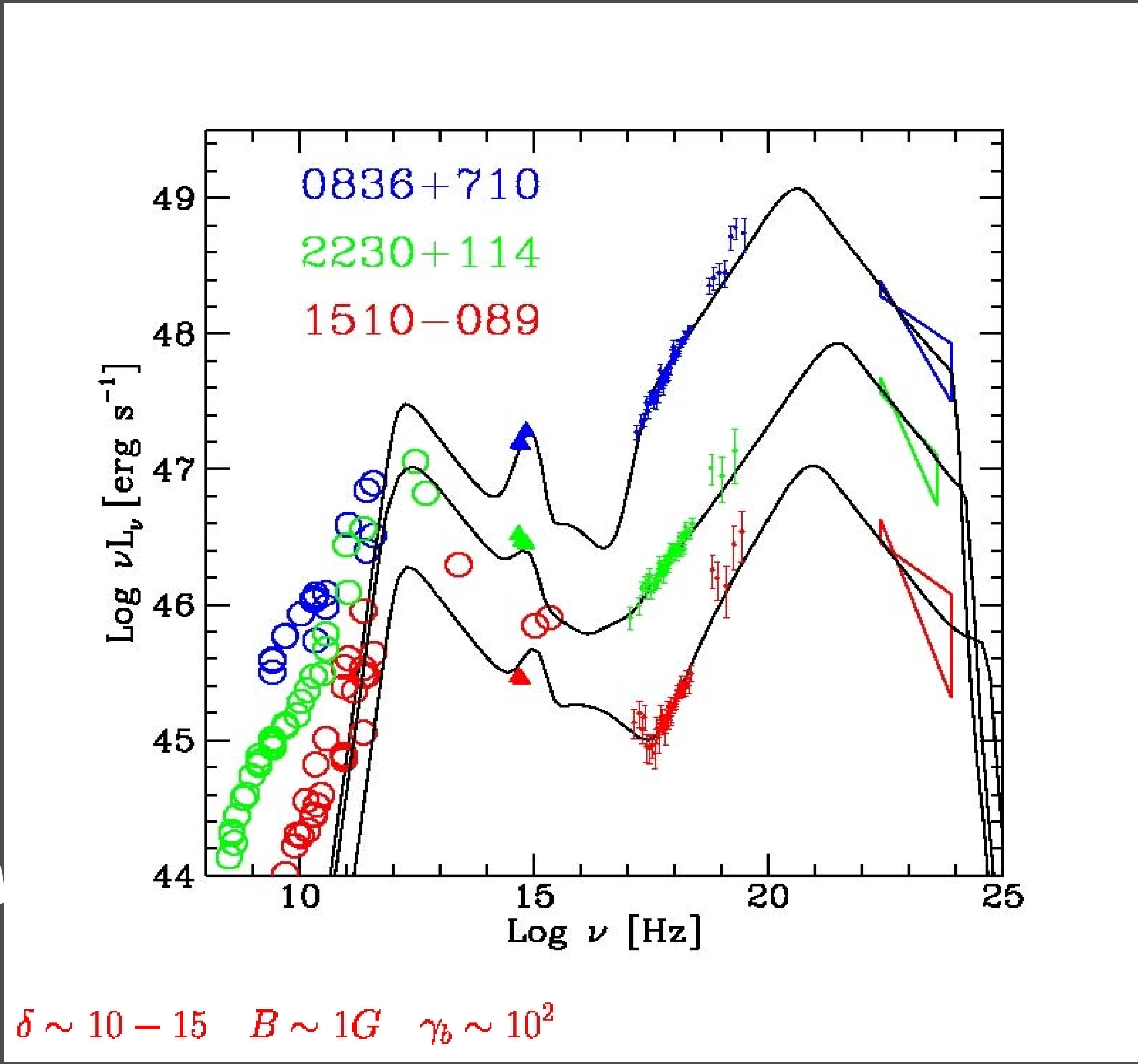
Can be estimated at different scales along the jet

Dominant EC → FSRQs

Blue Bump evident

ultrahigh jet apparent lum

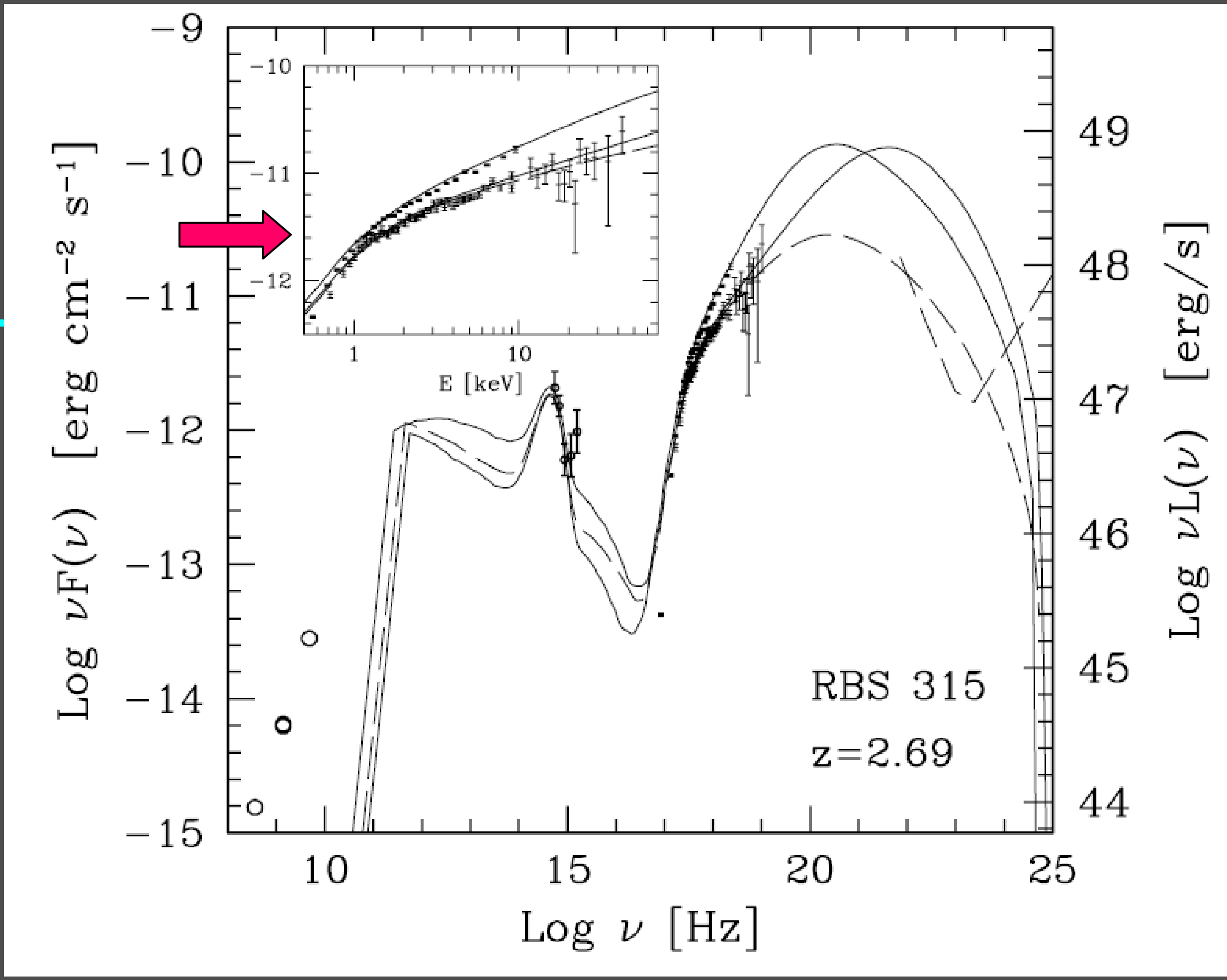
steep gamma ray spectrum



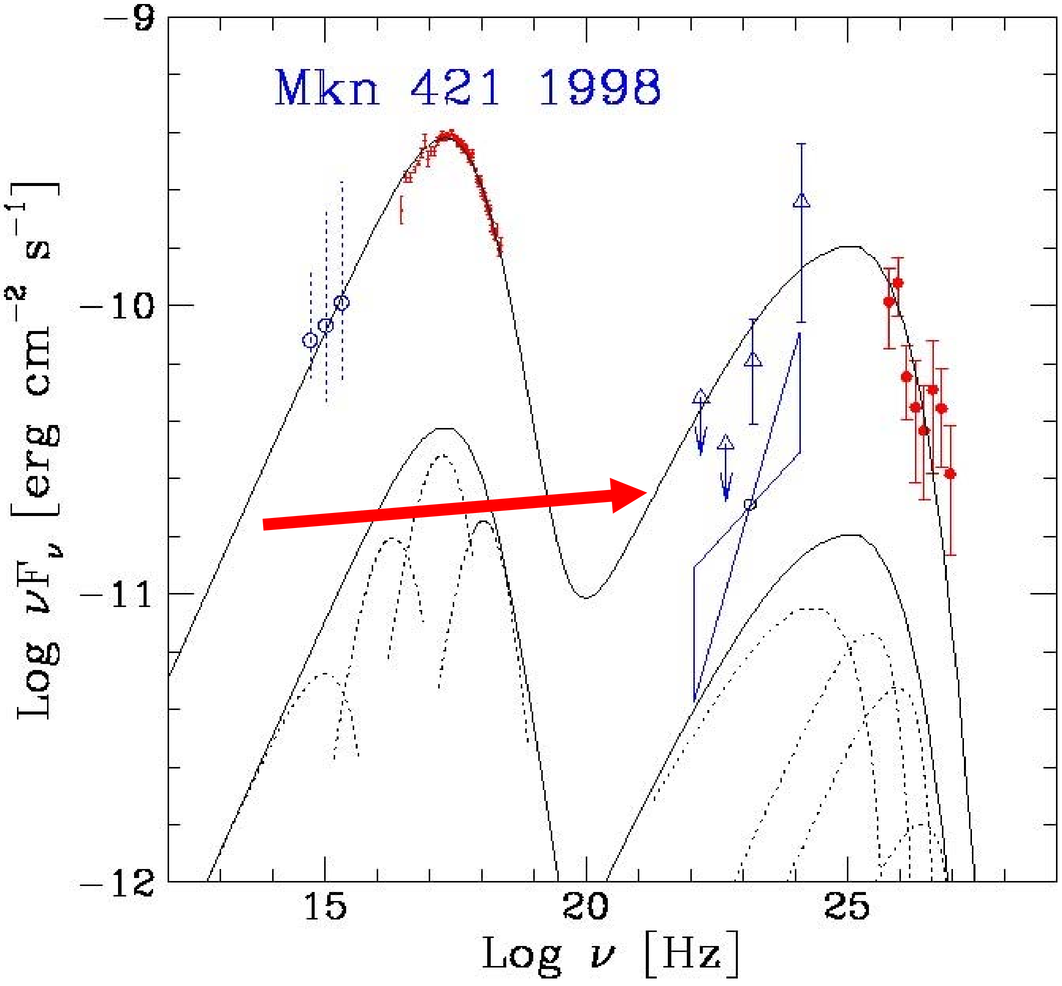
Tavecchio et al. 2000

The minimum energy of the radiating electrons can be traceable at the low end of the X-ray spectrum

Tavecchio et al. 07



"Pure“ SSC → Mkn 421: a nearby BL Lac

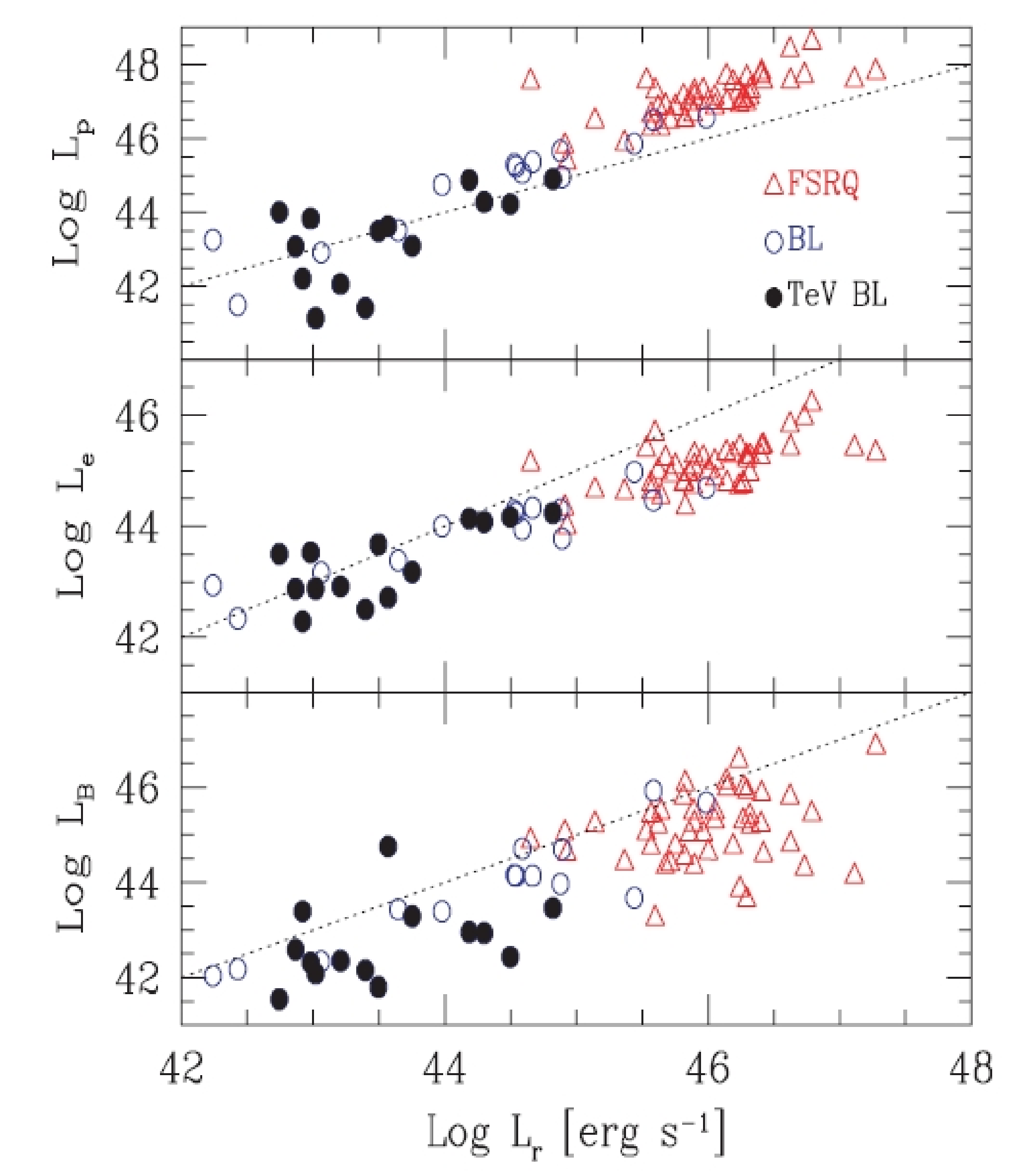


$\delta \sim 10 - 15 \quad B \sim 0.1G \quad \gamma_b \sim 10^5$

The low energy end of the electron distribution is poorly constrained

Maraschi et al. 1999

Jet energy fluxes in particles and B



1 cold proton per electron assumed

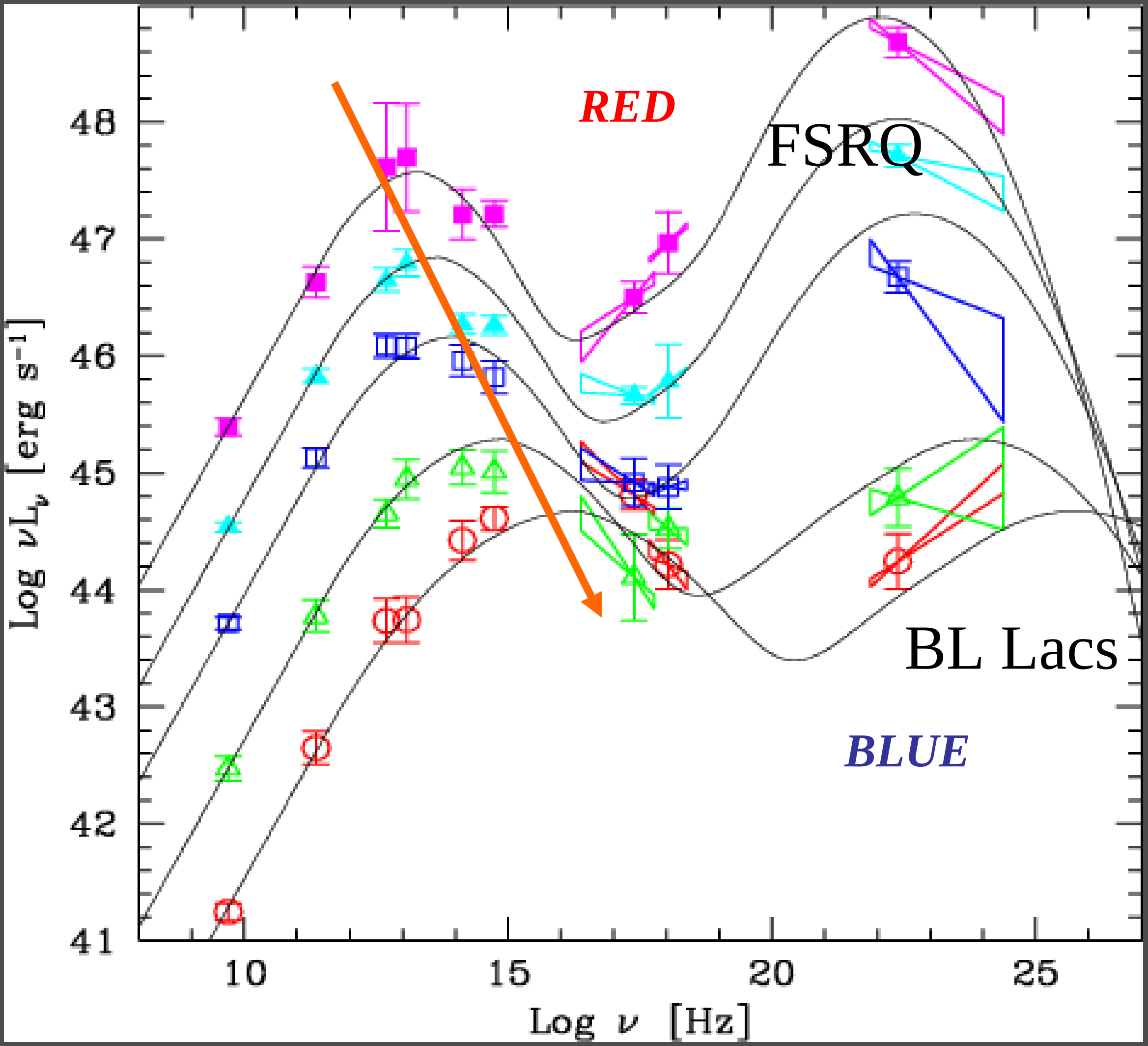
Powers in the form of electrons and magnetic fields are insufficient to account for the emitted radiation

Protons are necessary

Celotti and Ghisellini 08

The spectral sequence of blazar SEDs

Fossati et al. 1998; Donato et al. 2001

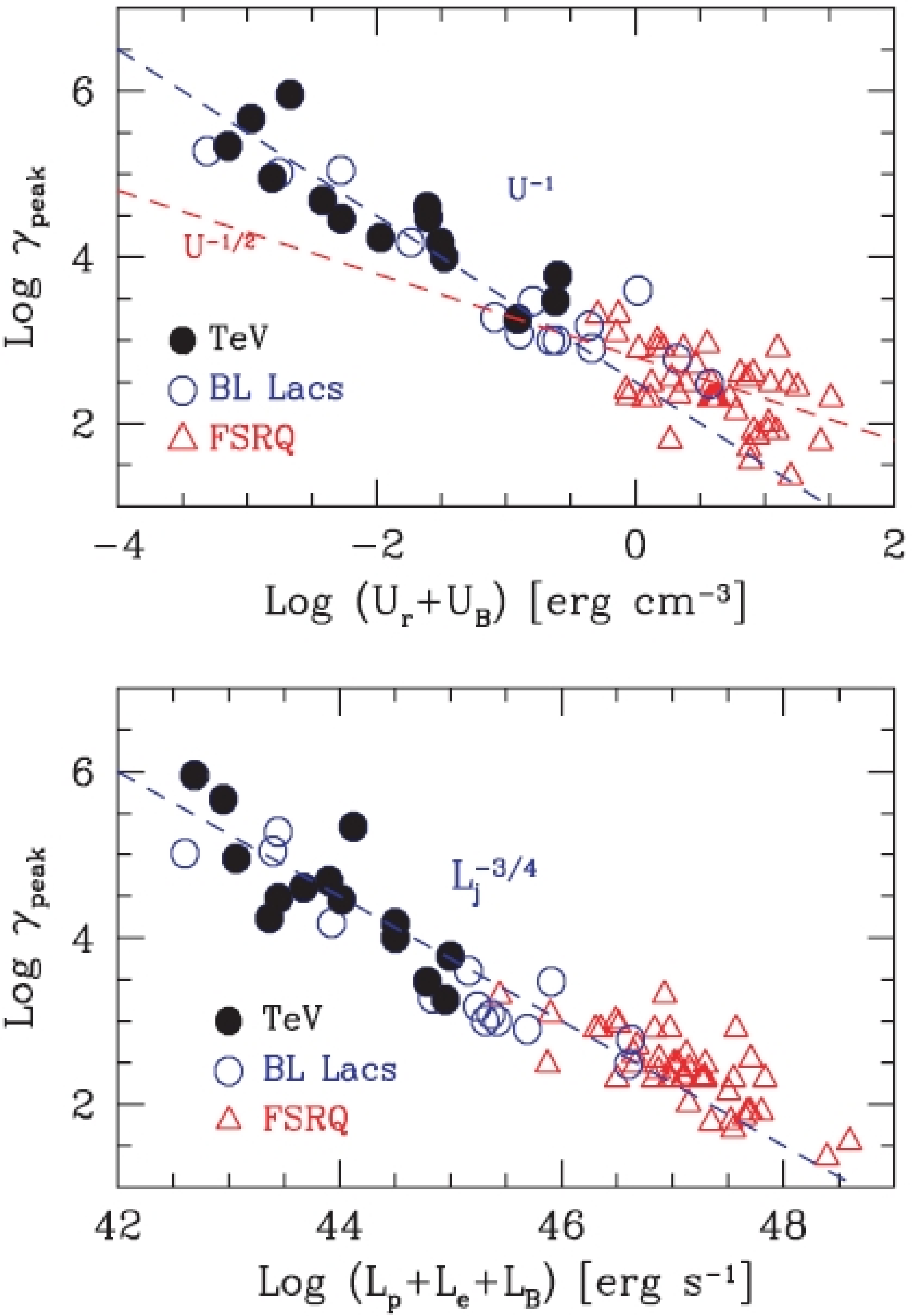


The Spectral Energy Distributions of blazars averaged within radio luminosity classes suggest systematic trends: peaks at higher frequencies with decreasing luminosity

The cooling hypothesis

Model:
electron distributions with similar injection spectra modified by radiative cooling

Result:
Gamma_peak correlates with radiation energy density and jet power

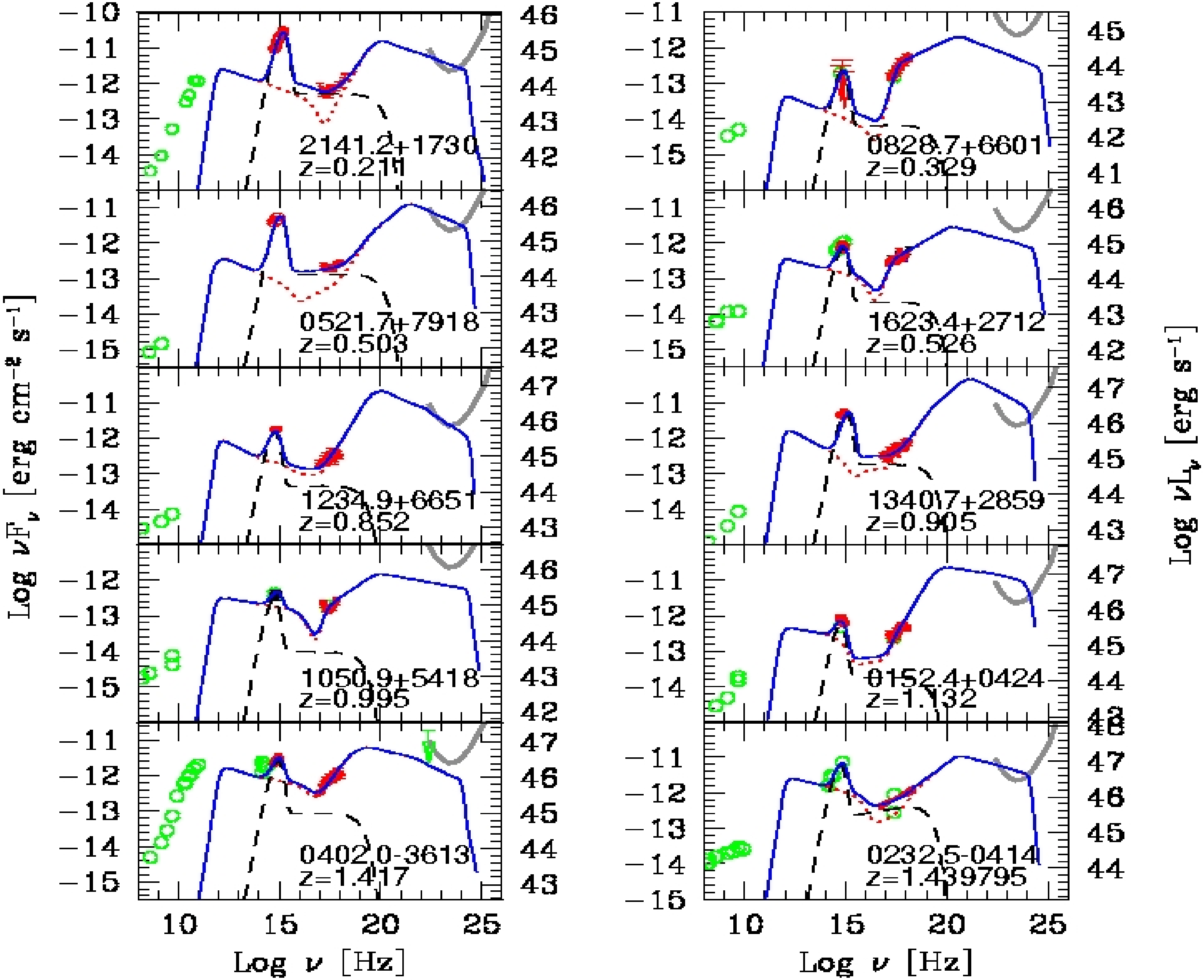


The Fossati “sequence” was based on three bright complete samples (BL Lacs and FSRQs)
In particular it did not include a sample of “X-ray selected” FSRQs

Radio Loud FS AGN selected from the Einstein Med. Sens. Survey by Wolter and Celotti (2001) were observed with SWIFT (filler program) yielding simultaneous X-ray and optical data.

Maraschi et al. to be submitted

Overview of 10 X-ray bright FSQs



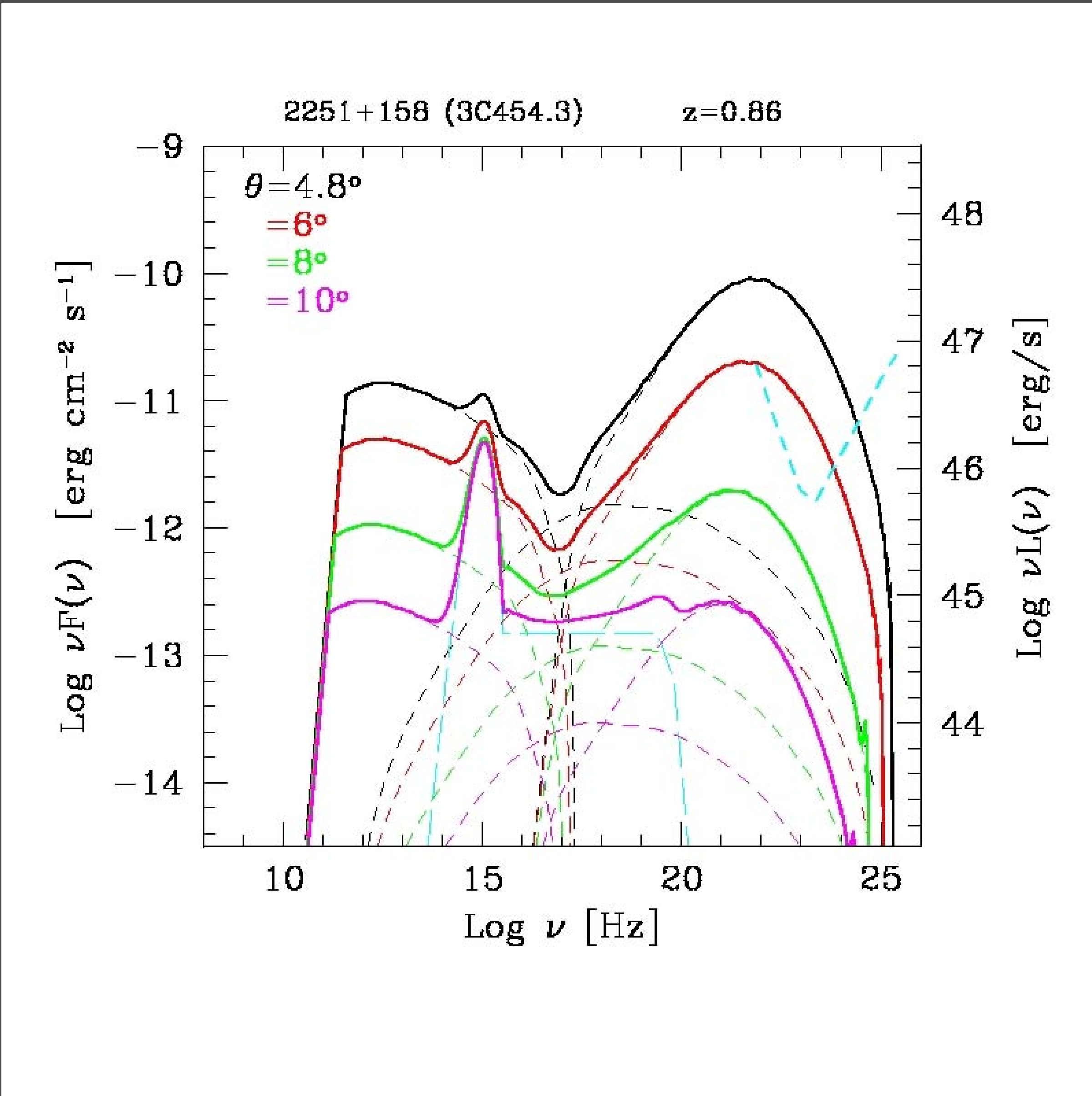
The simultaneous optical and X-ray data from SWIFT clearly suggest that the optical to X-ray SEDs are concave, pointing to an IC origin of X-rays

The different optical to X-ray ratios suggest either jets with different intrinsic luminosity w.r. to the blue bump or with different degrees of beaming: models favor the second

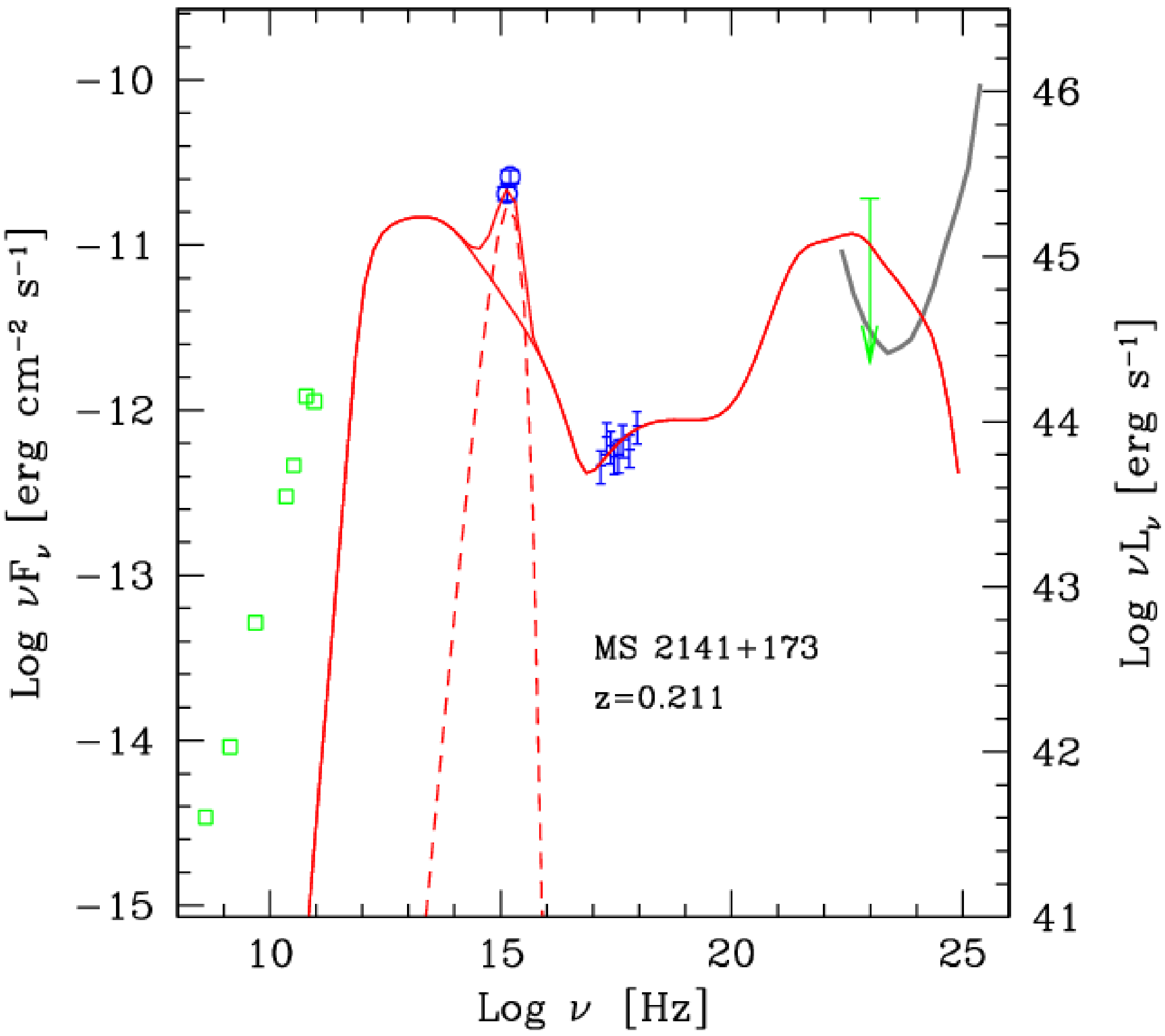
The viewing angle effect:

Small changes in angle cause X-ray and gamma-ray fluxes to decrease dramatically…. The blue bump is constant

This may introduce some confusion in the "sequence" !

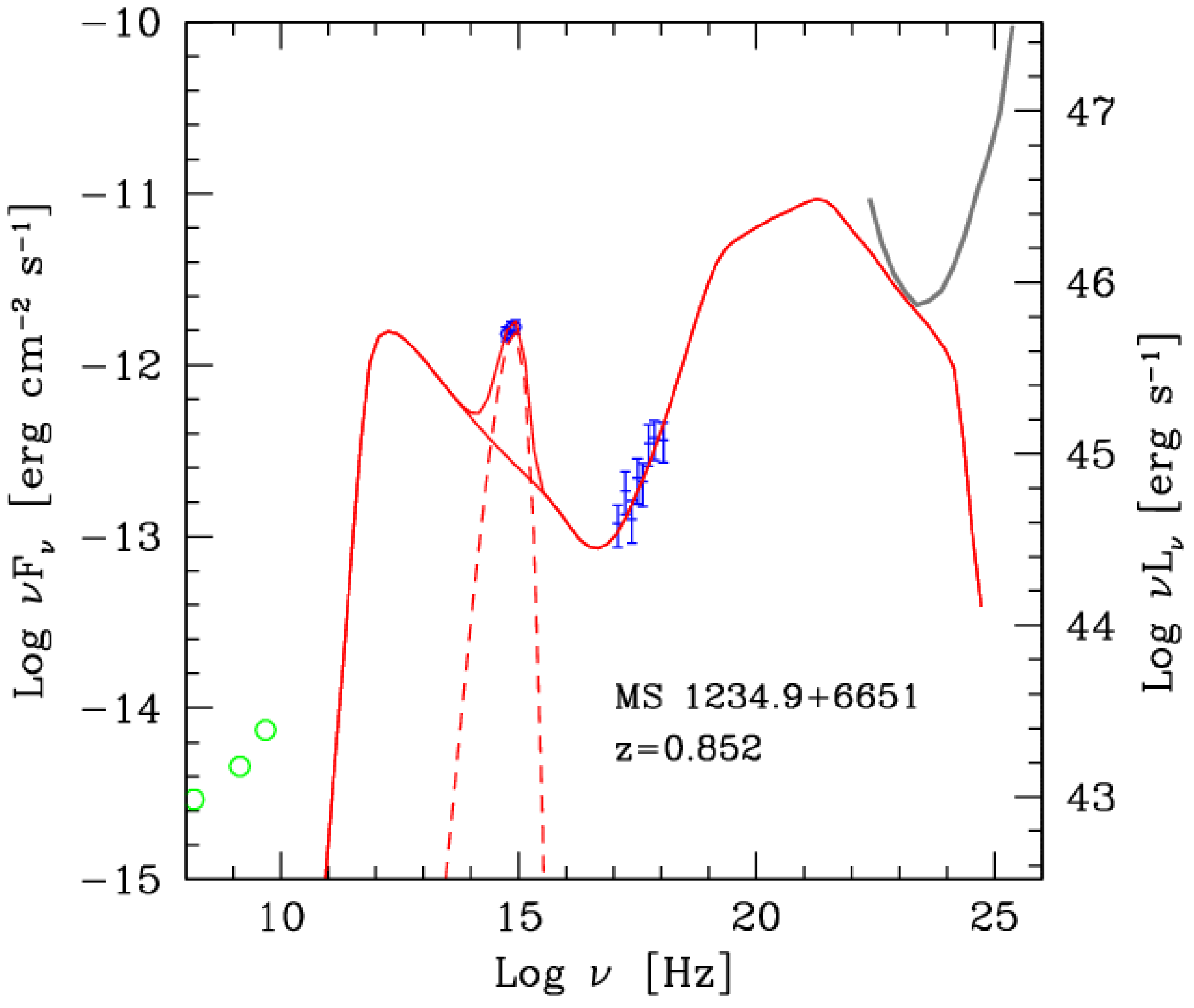


High optical to X-ray ratio: weak jet (relative to disk) but bright, may be detected by GLAST



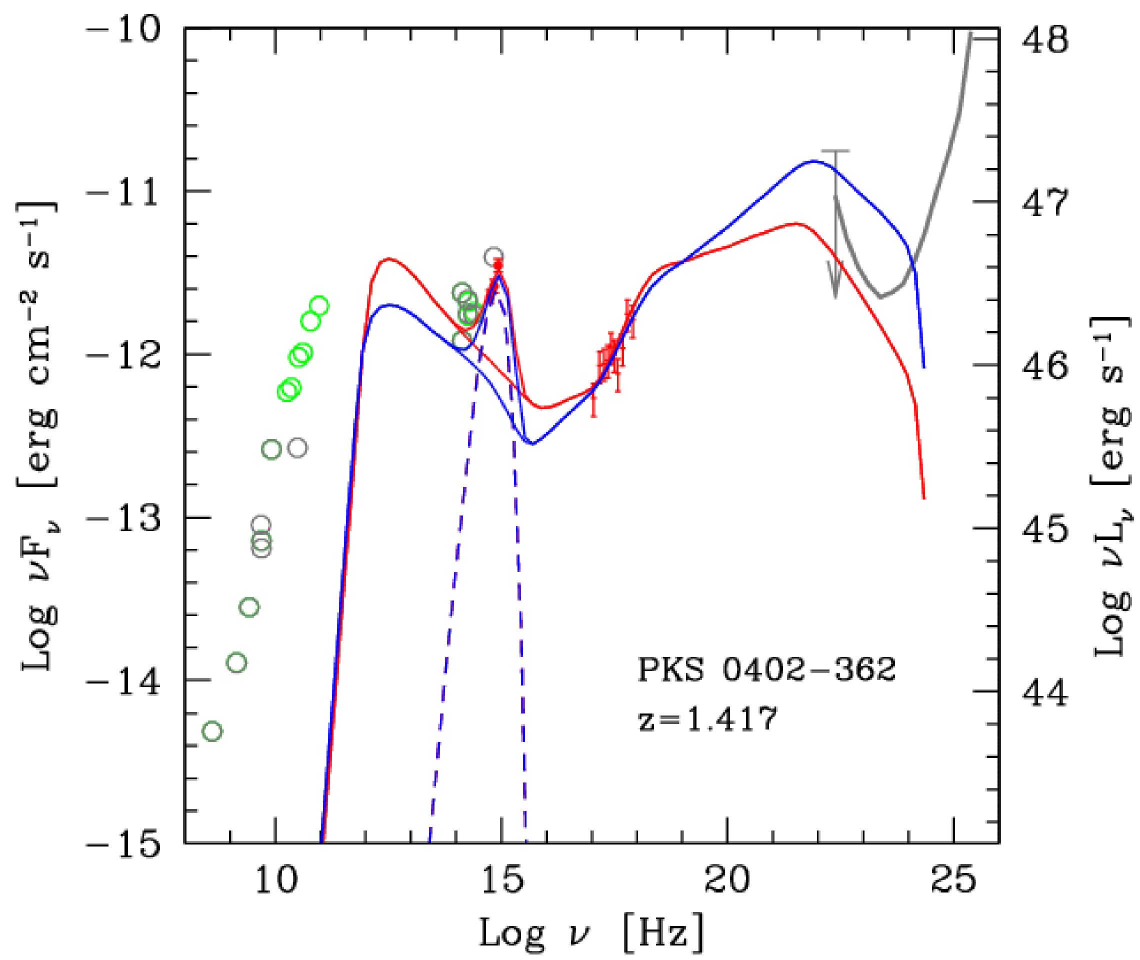
Lower optical to X-ray ratio:

stronger jet (relative to disk) but fainter, may not be detected by GLAST



The farthest object:

The two SEDs indicate the uncertainty of models when data are scarce: waiting for GLAST !!



“Controversial” blazars:

Two ultraluminous high z objects (z=3.9, 3.7), Giommi et al. 07 Bassani et al. 07, one of them selected in hard X-rays (INTEGRAL), were suspected to exhibit a high energy Syncrotron peak…….

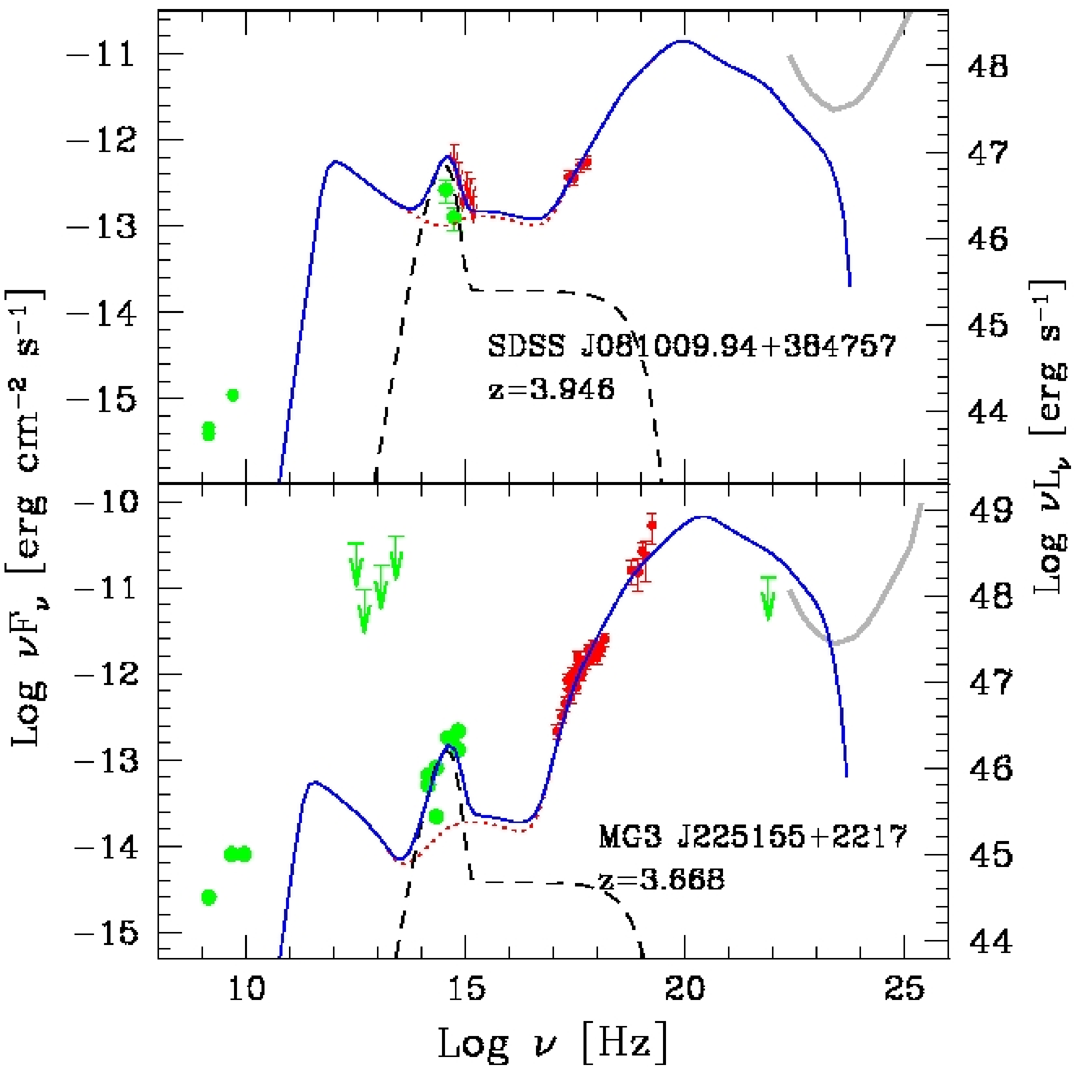
Two more “blue” quasars claimed (Giommi 08, Padovani et al. 02)

Do these objects violate “strongly” the sequence concept ?

Giommi et al 07

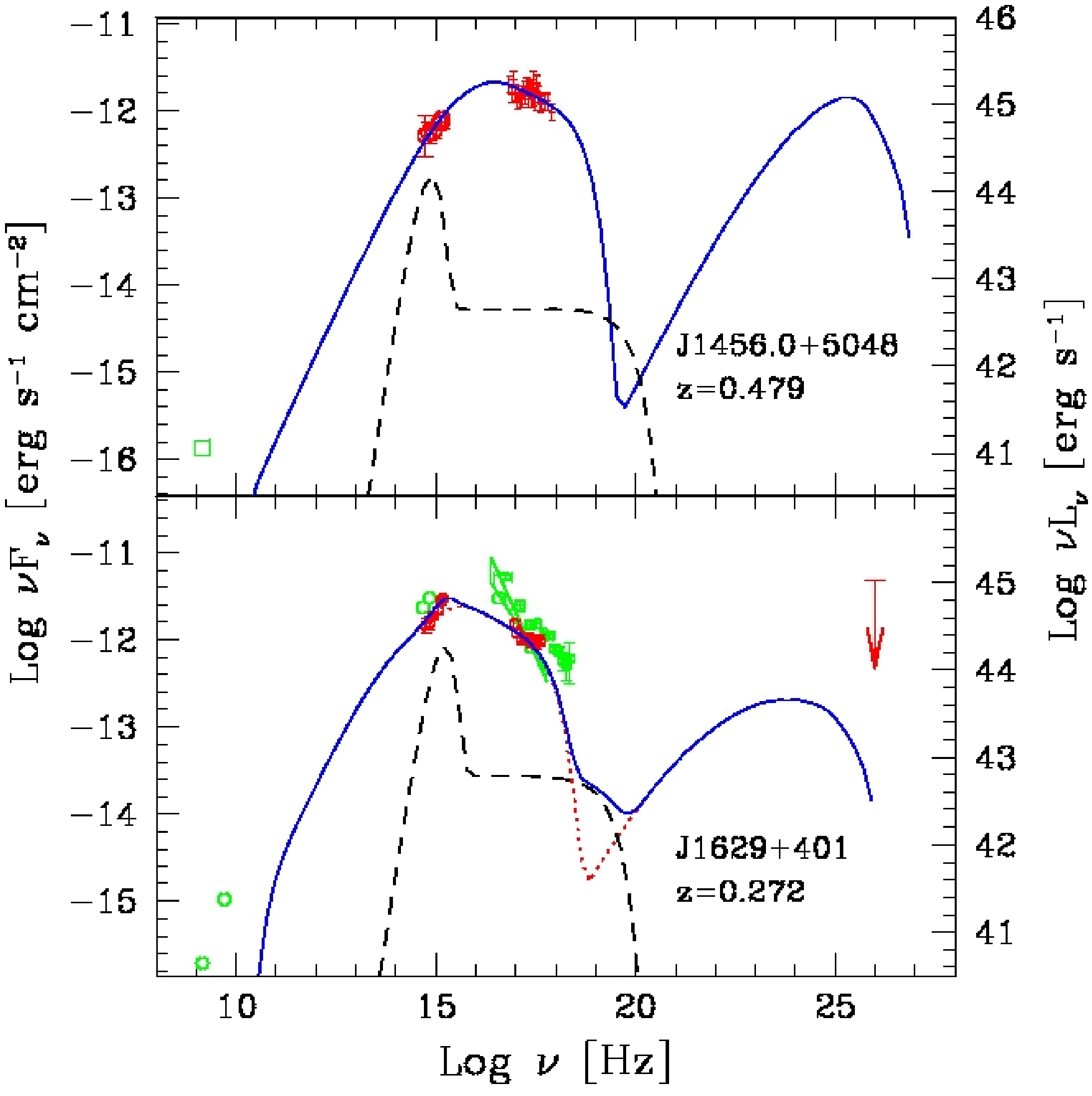
New analysis of Swift and INTEGRAL data suggests instead huge EC component

Bassani et al. 07



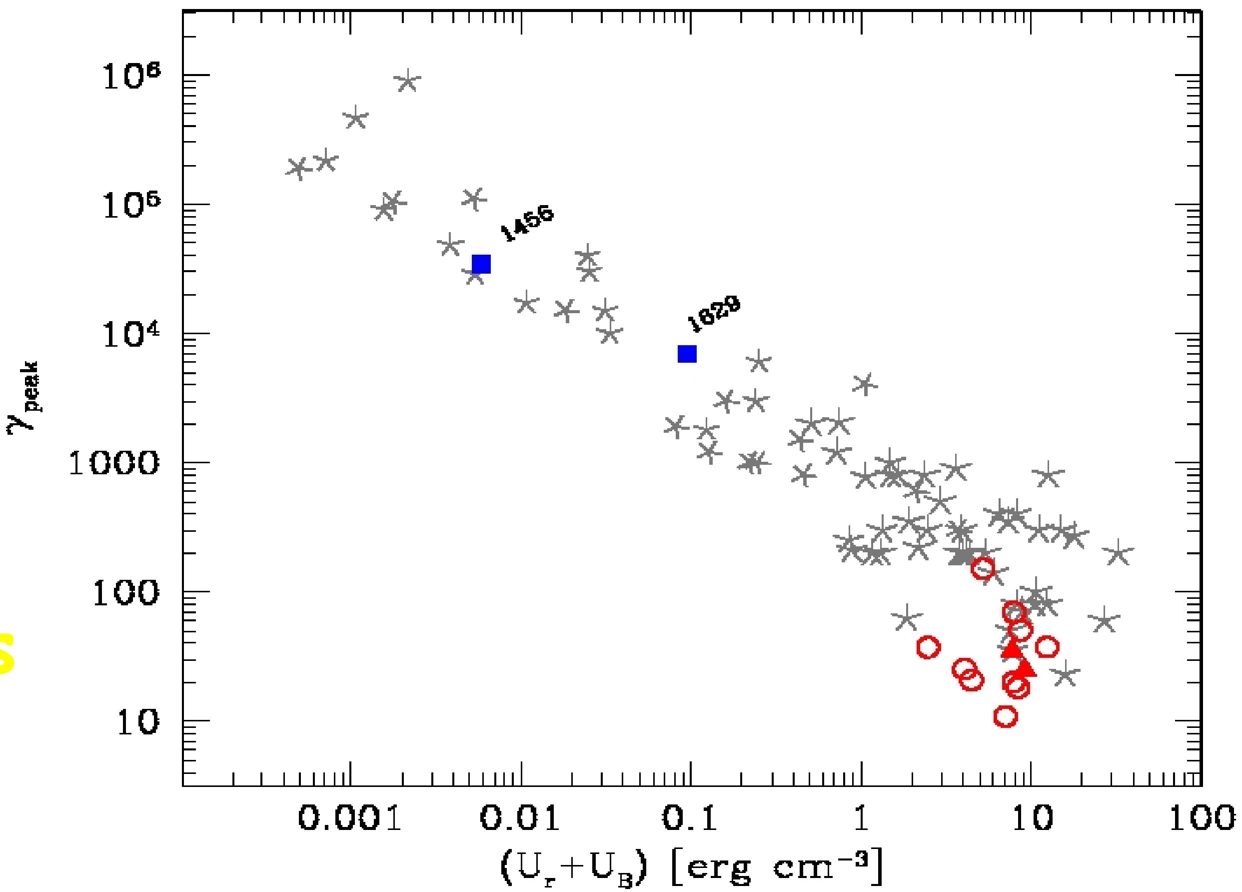
Giommi 2008:
a luminous
high peaked
BL Lac
(comp to 2155)

Padovani et al.
2002:
this is really a
NLSy 1, moder.
radio loud, could
harbor a jet
(see Yuan 2008,
Foschini talk)



Peak energy vs. radiation energy density: new objects and all the objects in Celotti & Ghisellini 2008

The new sources fall on the "parameter sequence"

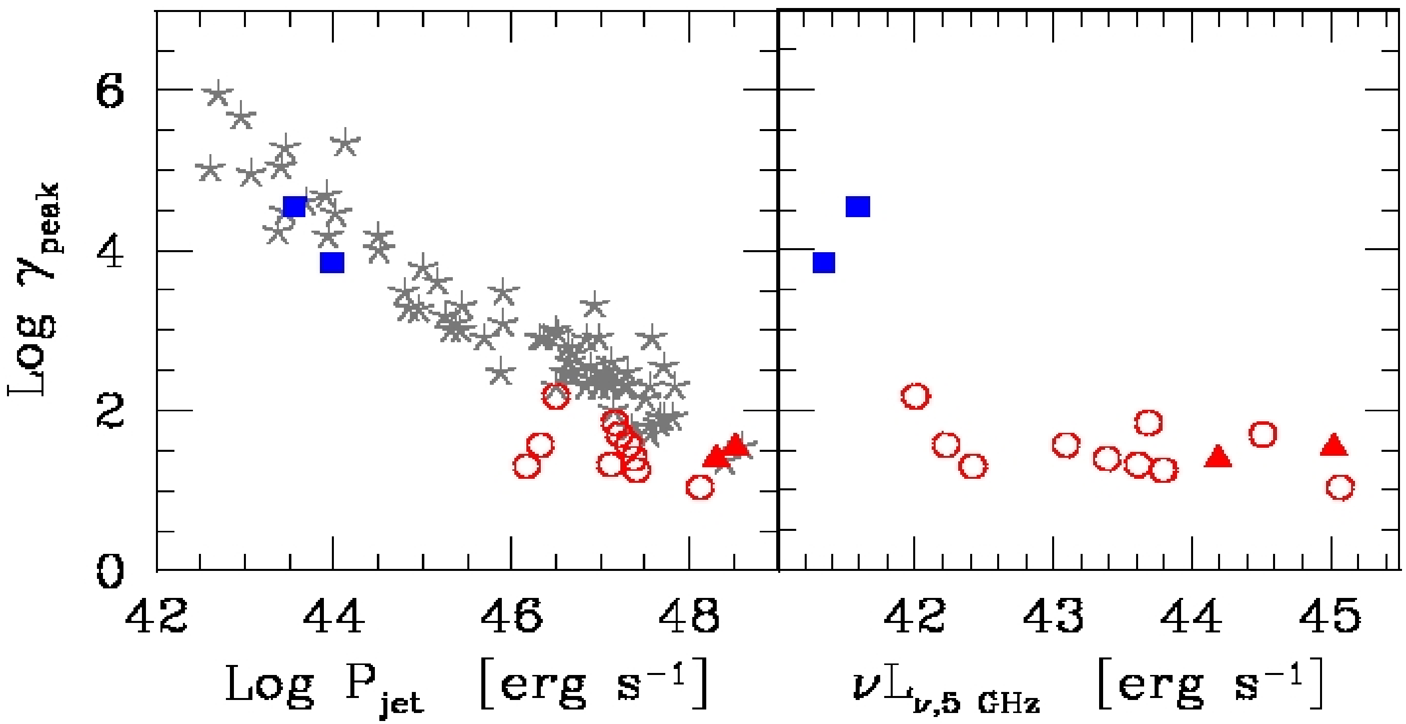


The Sequence holds in parameter space

Since the model takes into account the effect of cooling on the injected electron distributions a correlation between Gamma_peak and U_rad may be partially built in

However the jet power derived from the models is a “global” quantity that combines all the parameters used to fit the SEDs

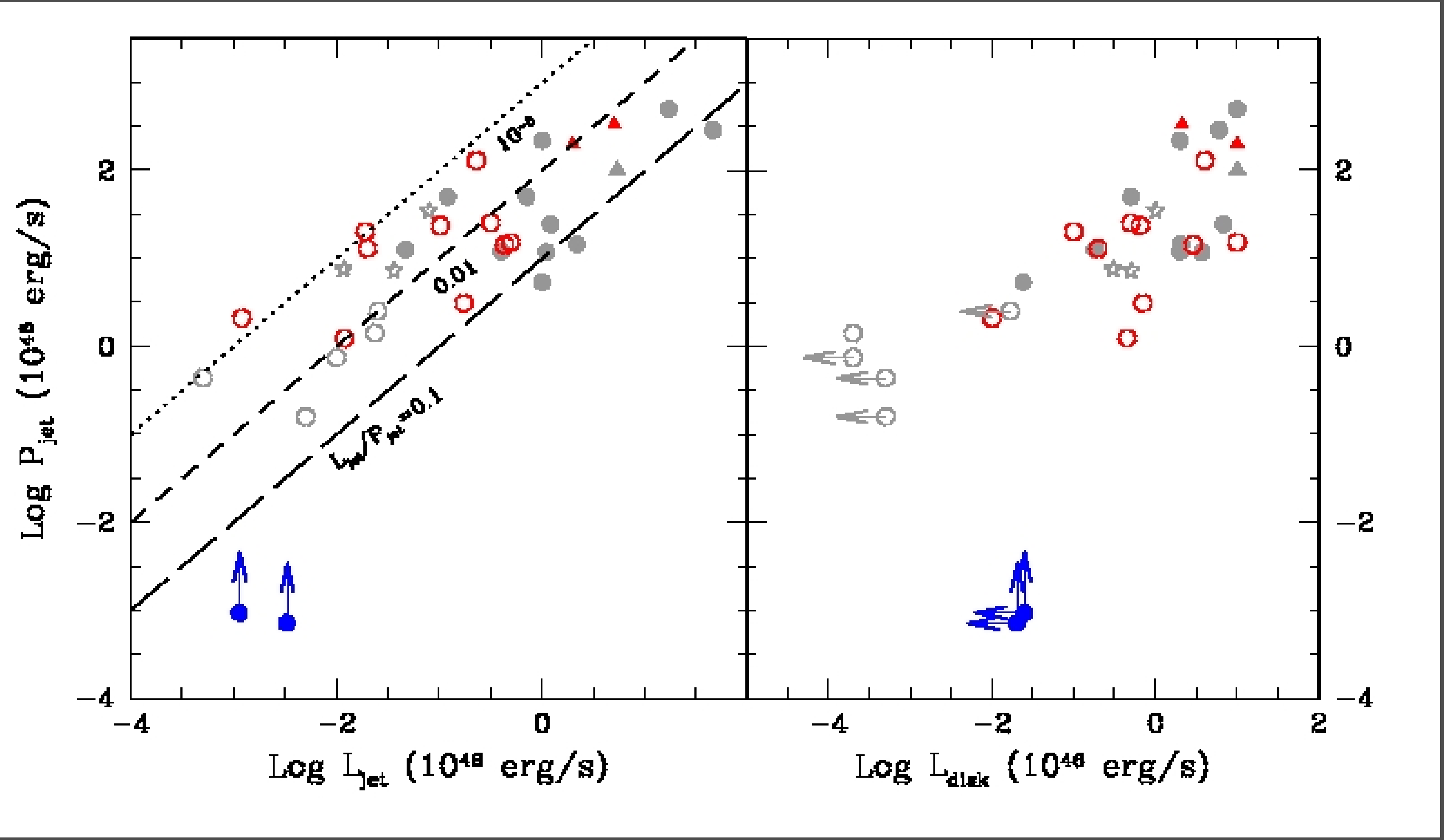
Gamma-peak vs. P-jet and vs. Radio Luminosity



Gamma-peak correlates with P-jet but not with Radio Luminosity

The parameter sequence is related to P-jet more than to L-radio

Jet power vs Jet Lum. and Disk Lum.



For "red" SEDs, Pjet ~ 10 Ldisk ~ Pacc

Grey points from M & Tavecchio 2003

JET POWER AND SEDs

At high power the jet correlates with the accretion disk luminosity and with the accretion power.
The jet's SED is "red" due to the large radiation energy density provided by the accretion disk.

When Mdot/Mbh decreases below some threshold (10-2,10-3) the accretion flow becomes radiatively inefficient: optical disk signatures disappear, the jet propagates in a photon poor ambient and its SED is "blue"

LUMINOUS BLAZARS WITH BLUE SEDs MUST HAVE LARGE MASSES

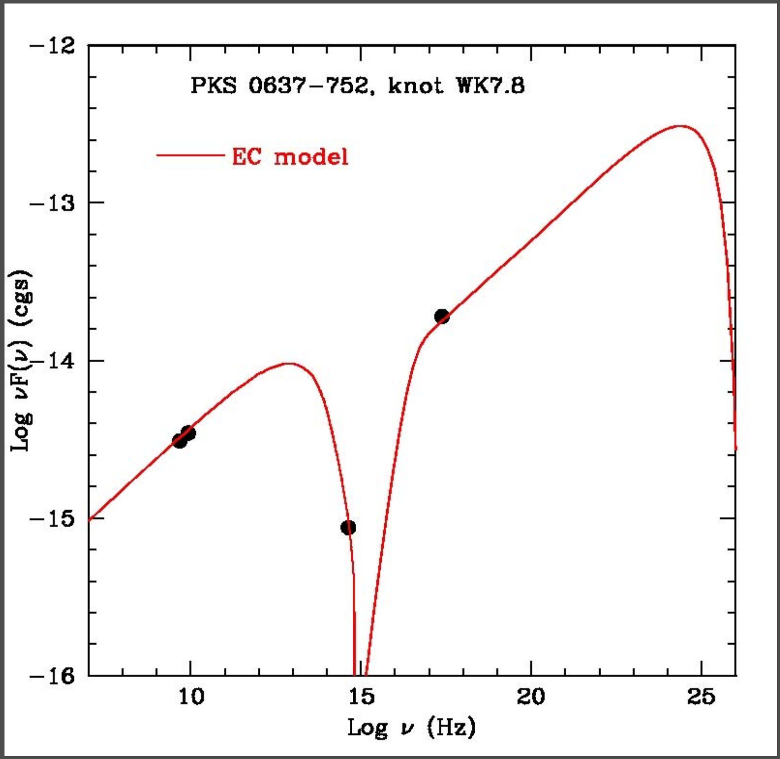
Ghisellini & Tavecchio 08

Chandra: probing large-scale jets

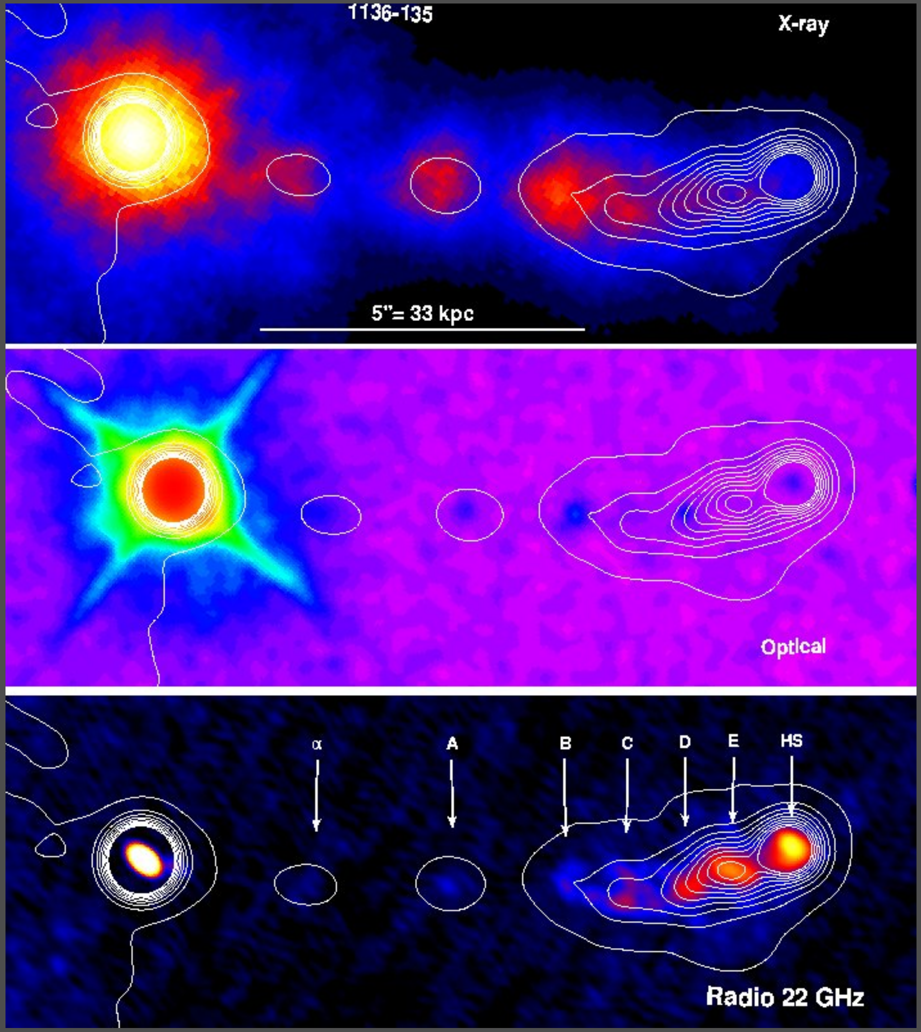
PKS 0637-752: the first *Chandra* jet
Schwartz et al. 1999

Interpretation: IC from CMB implies relativistic bulk motion

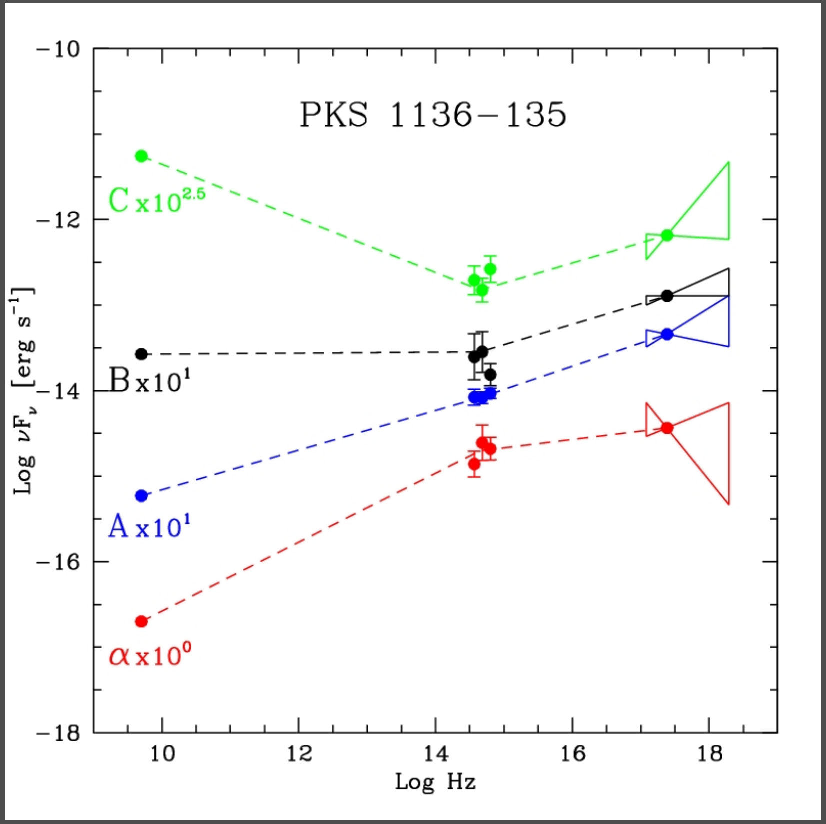
Tavecchio et al. 2000; Celotti et al. 2001



SED evolution along the jet

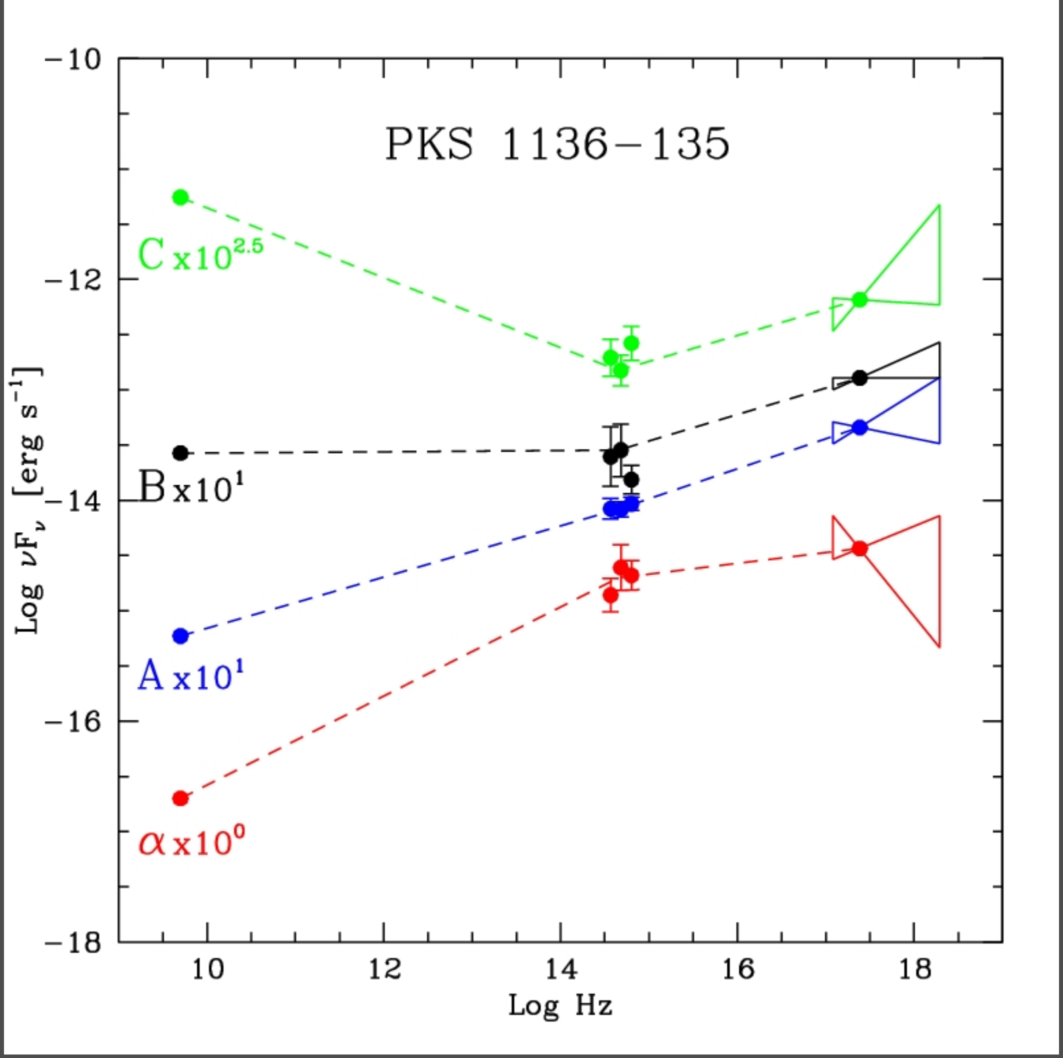


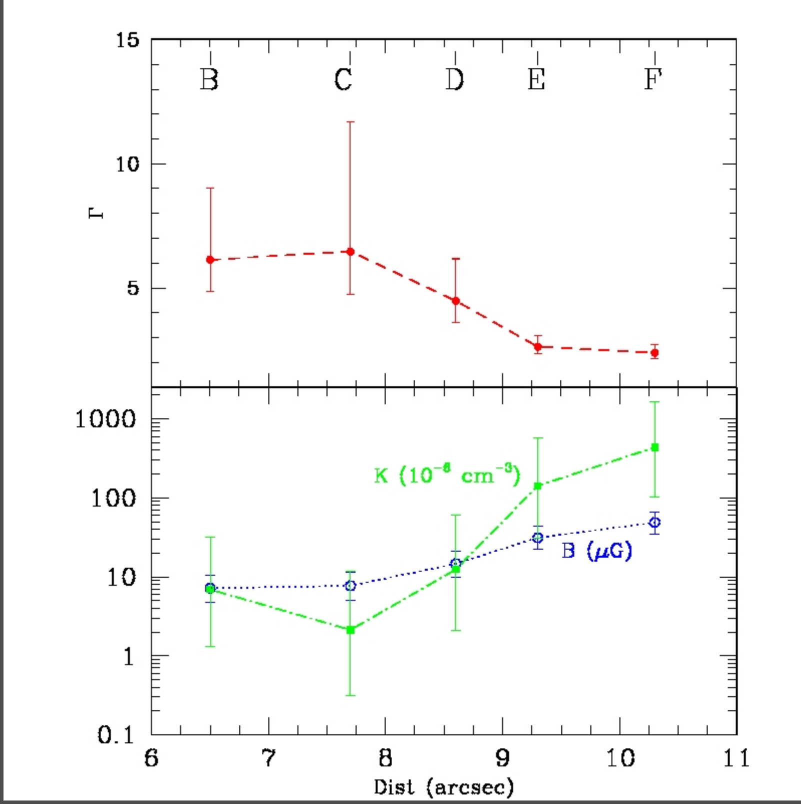
1136-135, z=0.554



Sambruna et al. 2006

Deceleration ?





Consistent with entrainment

Tavecchio et al. 2006

Powers

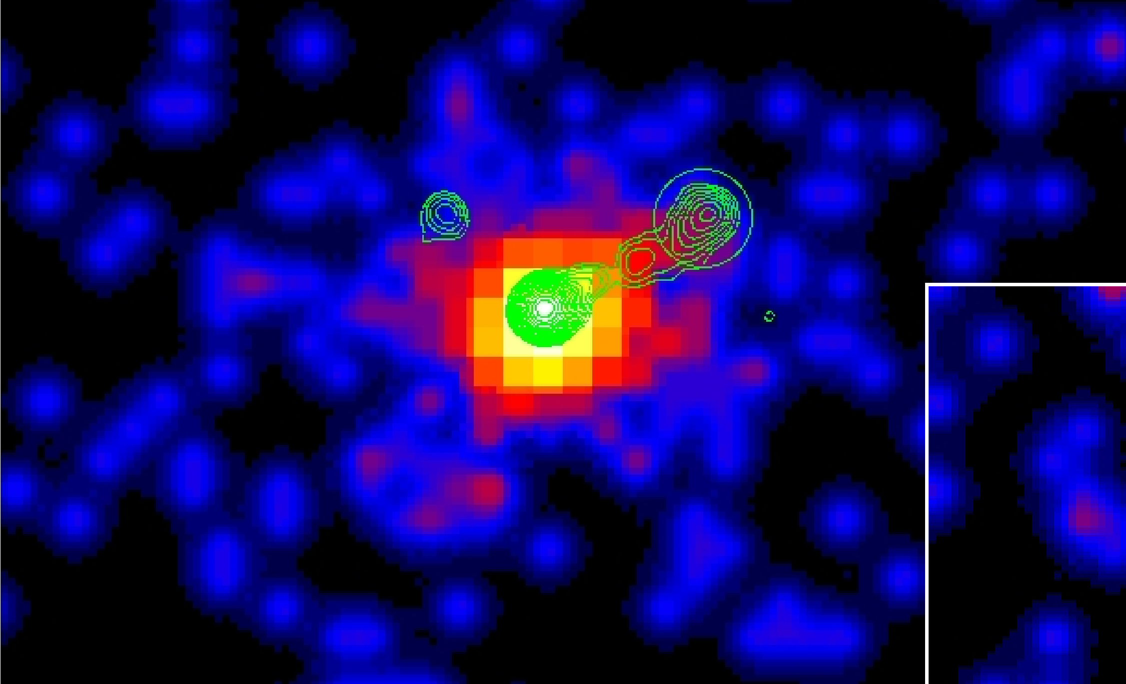
From IC/CMB parameters, assuming 1 proton/electron:

- Kinetic power ~ $10^{46\text{-}47}$ erg/s – similar to pc scales and lobes
- Radiated power ~ $10^{43\text{-}44}$ erg/s
- Radiative efficiency ~ 0.1 %

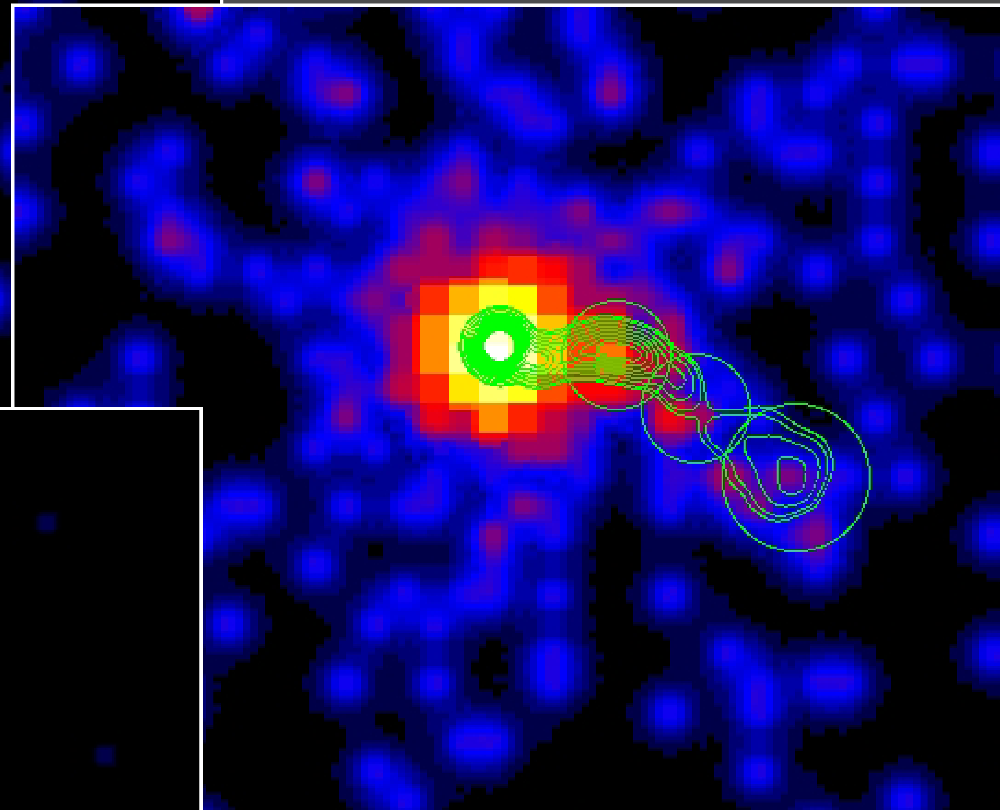
- For Blazar nuclei with large scale X-ray jets we can
- estimate small scale and large scale power in the same object

Large scale jets from gamma-ray blazars

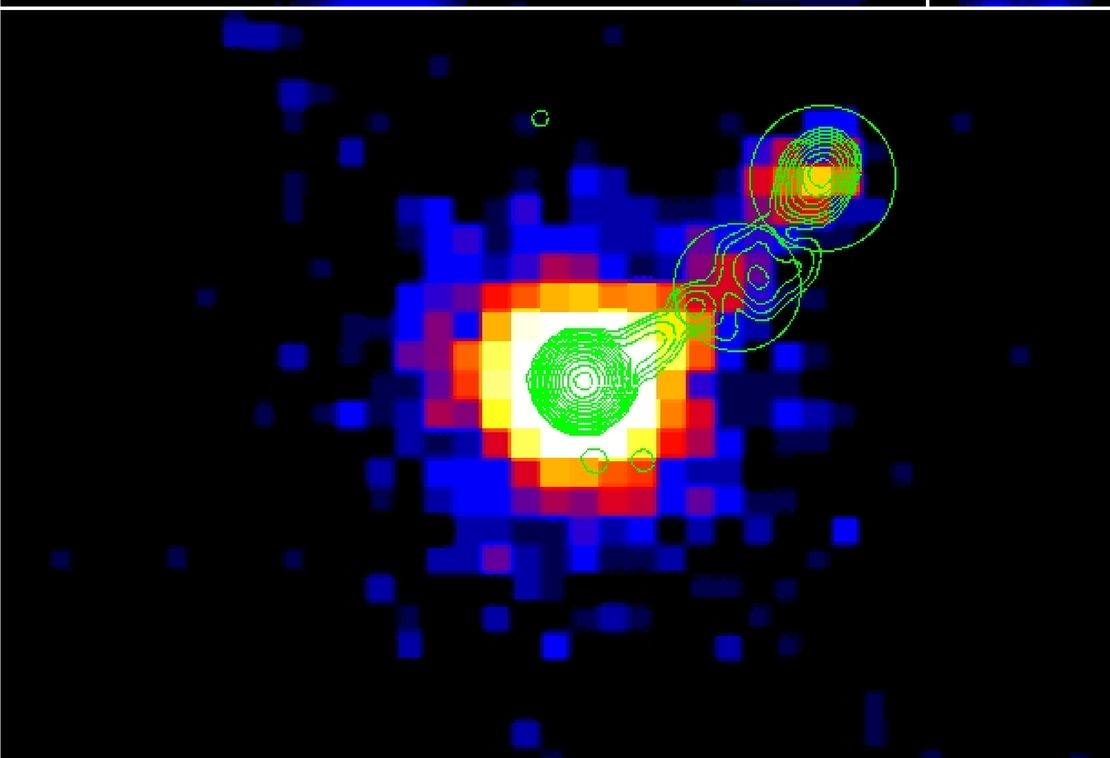
0954



1229

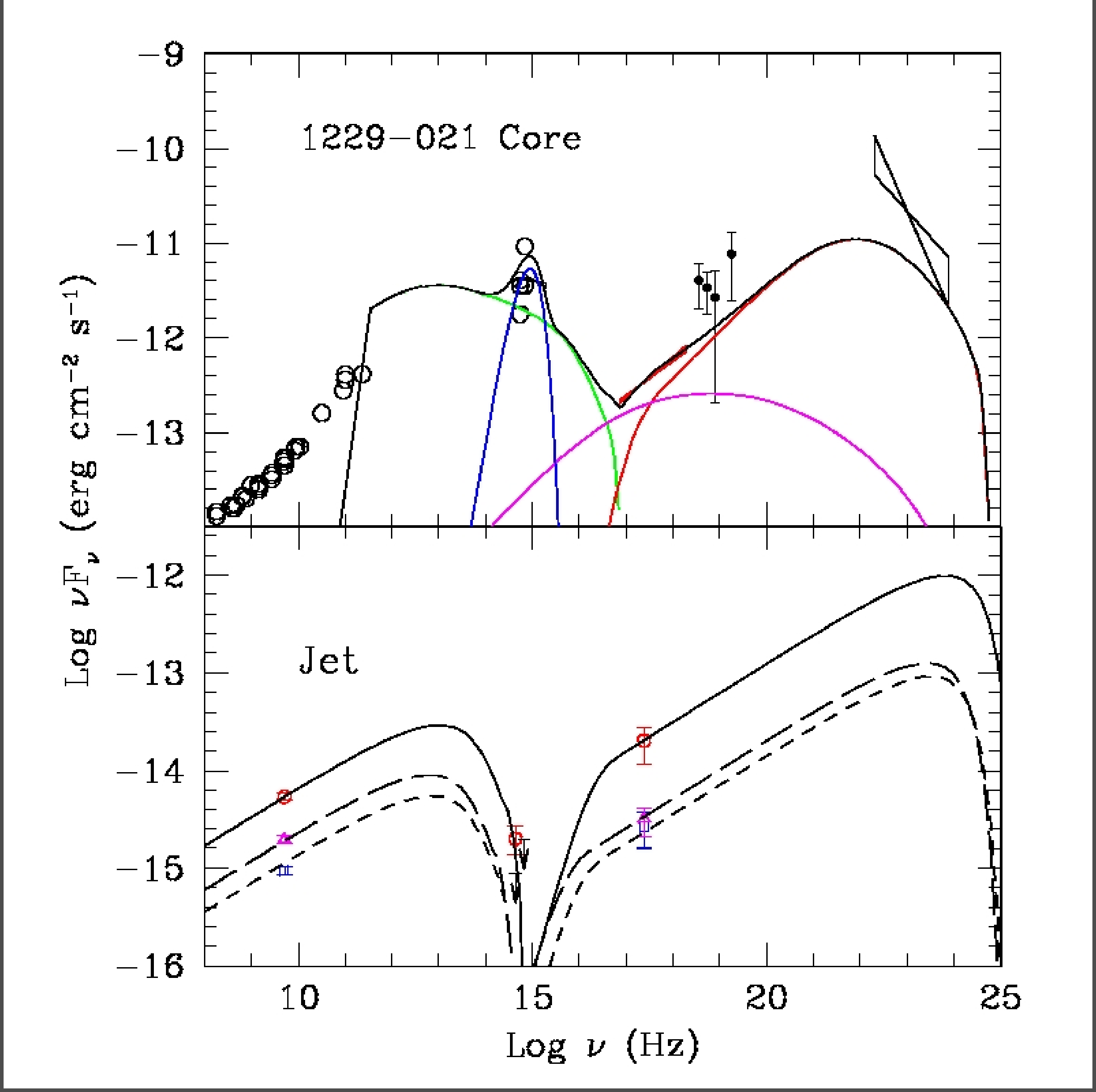


2251



SED: blazar jet + acc.disk

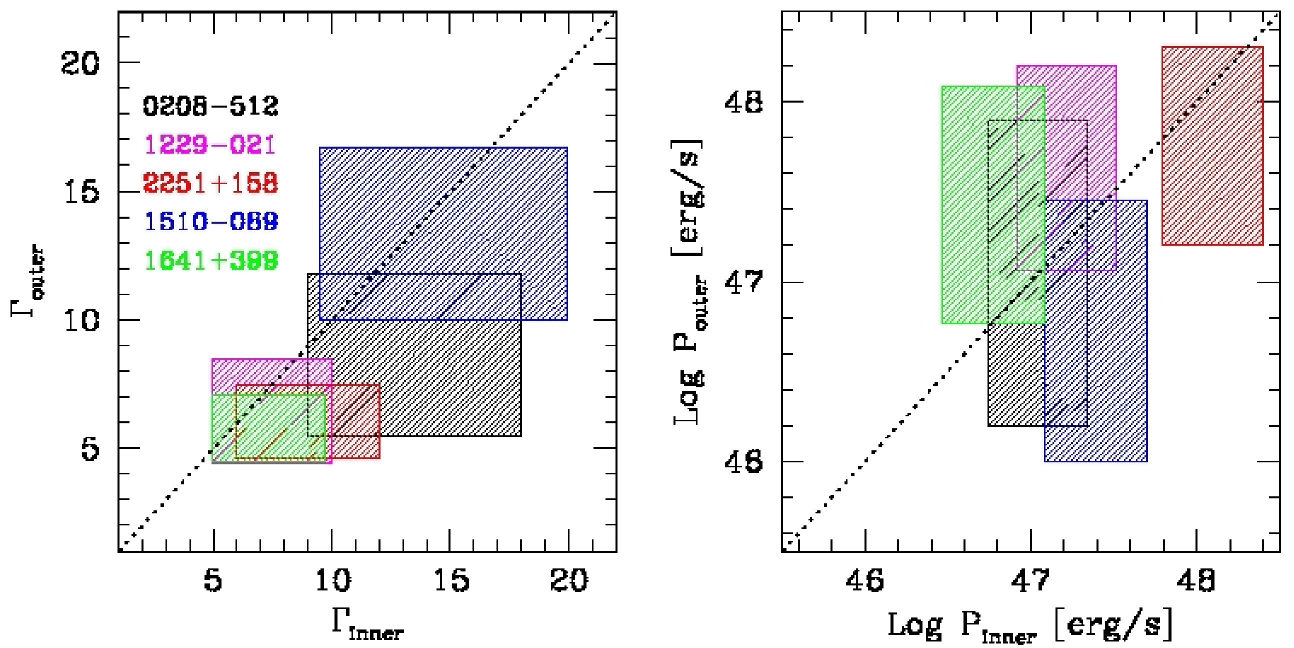
SED: Large scale jet



Power estimates coherent

Powerful jets are not decelerated (before reaching hot spots)

Comparison of Lorentz factors and Powers estimated for the same jets at small (subpc) and large (100 kpc) scales



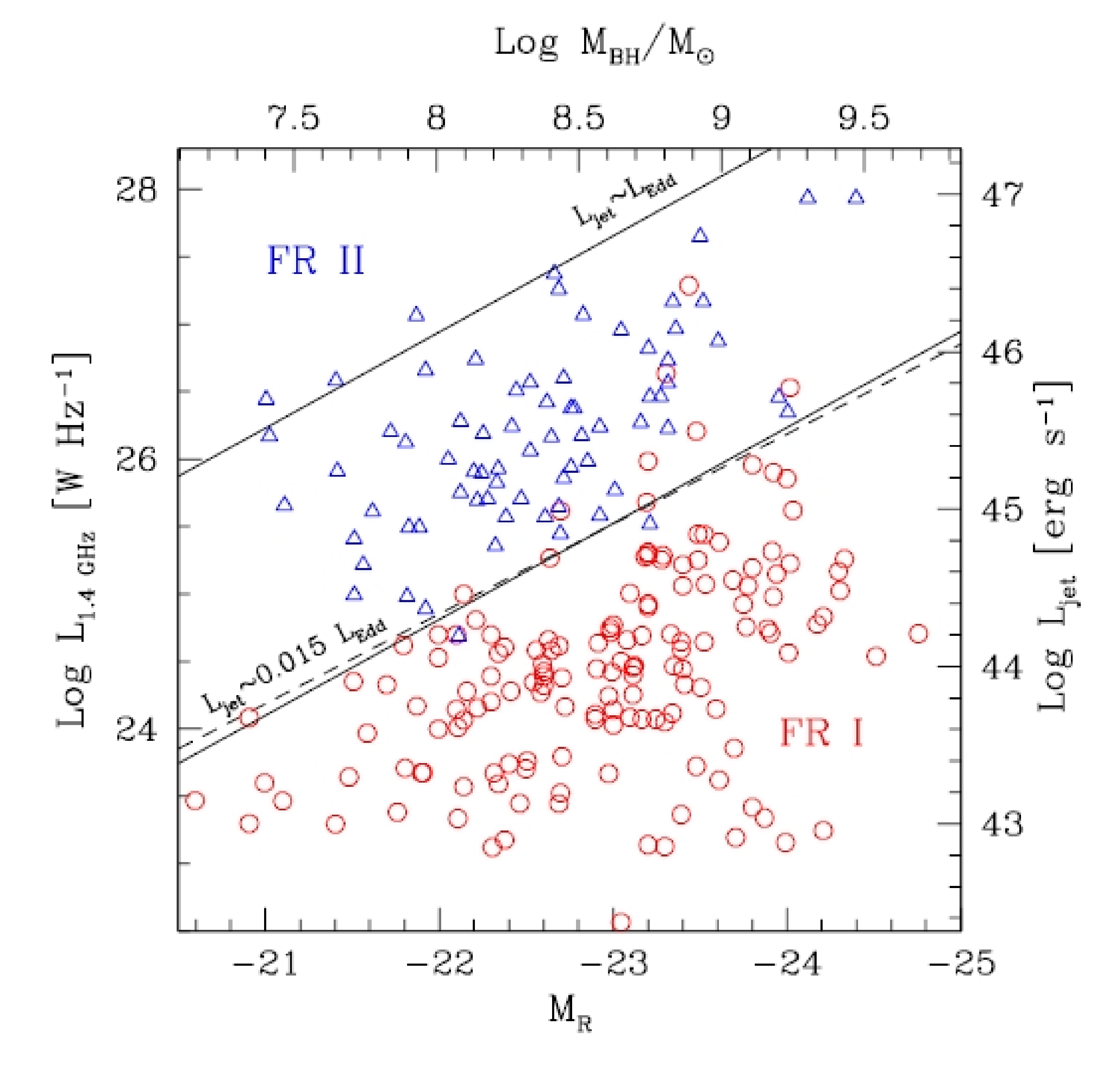
Tavecchio et al. 2007

The view

- FSRQs/FRIIs: near critical accretion, jet power ~ accretion power: opt.thick accretion disk,“red” SEDs, jet continues unperturbed to hot spots

- BL Lacs/FRIs: sub-critical accretion, jet power ~ accretion power , Rad. Ineff.Accr. Flow , “blue” SEDs, deceleration on medium scales

The FRI—FRII division



G&C 2001

The accretion rate in Eddington units, $\dot{m}$ is a fundamental parameter

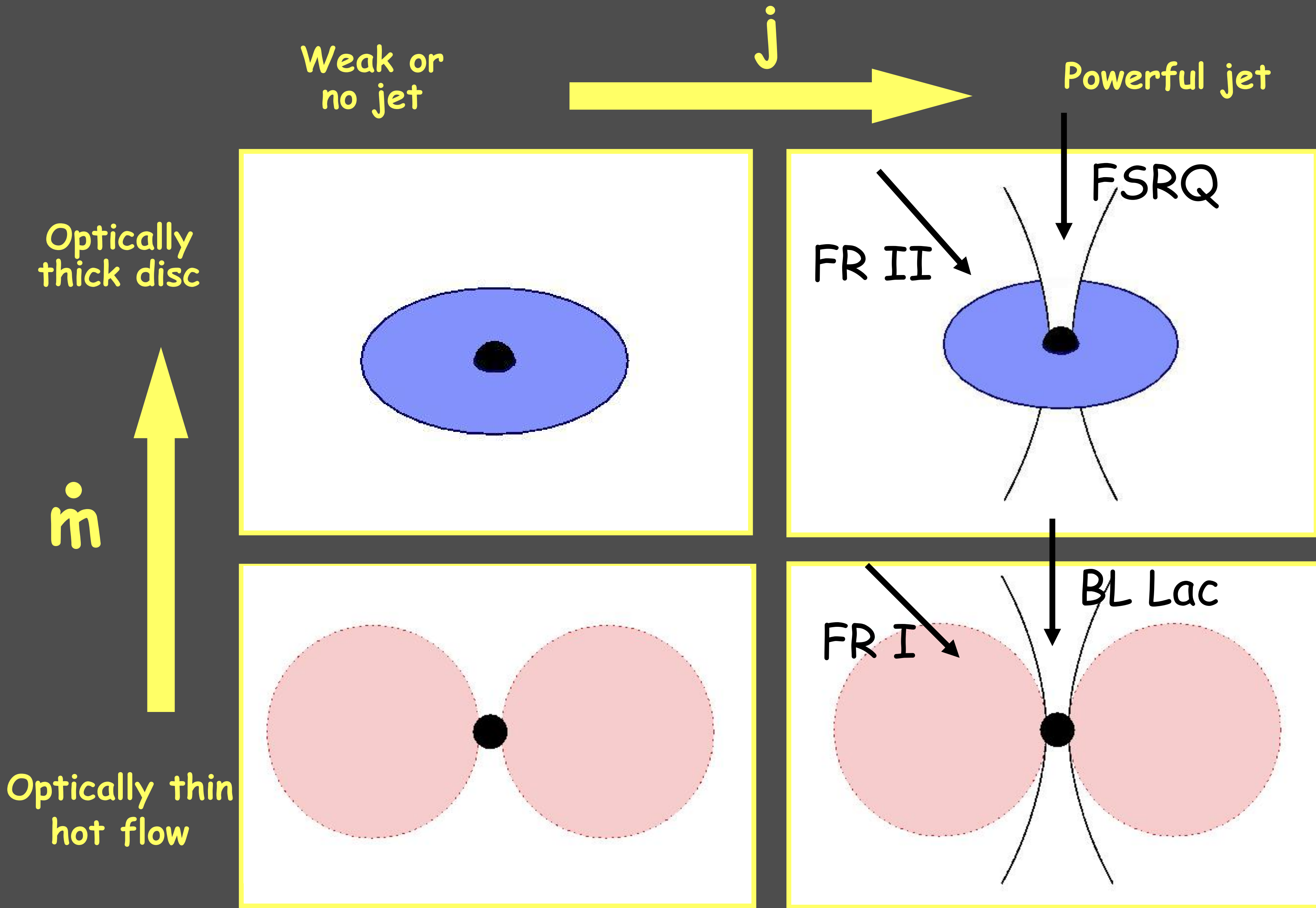
Determining

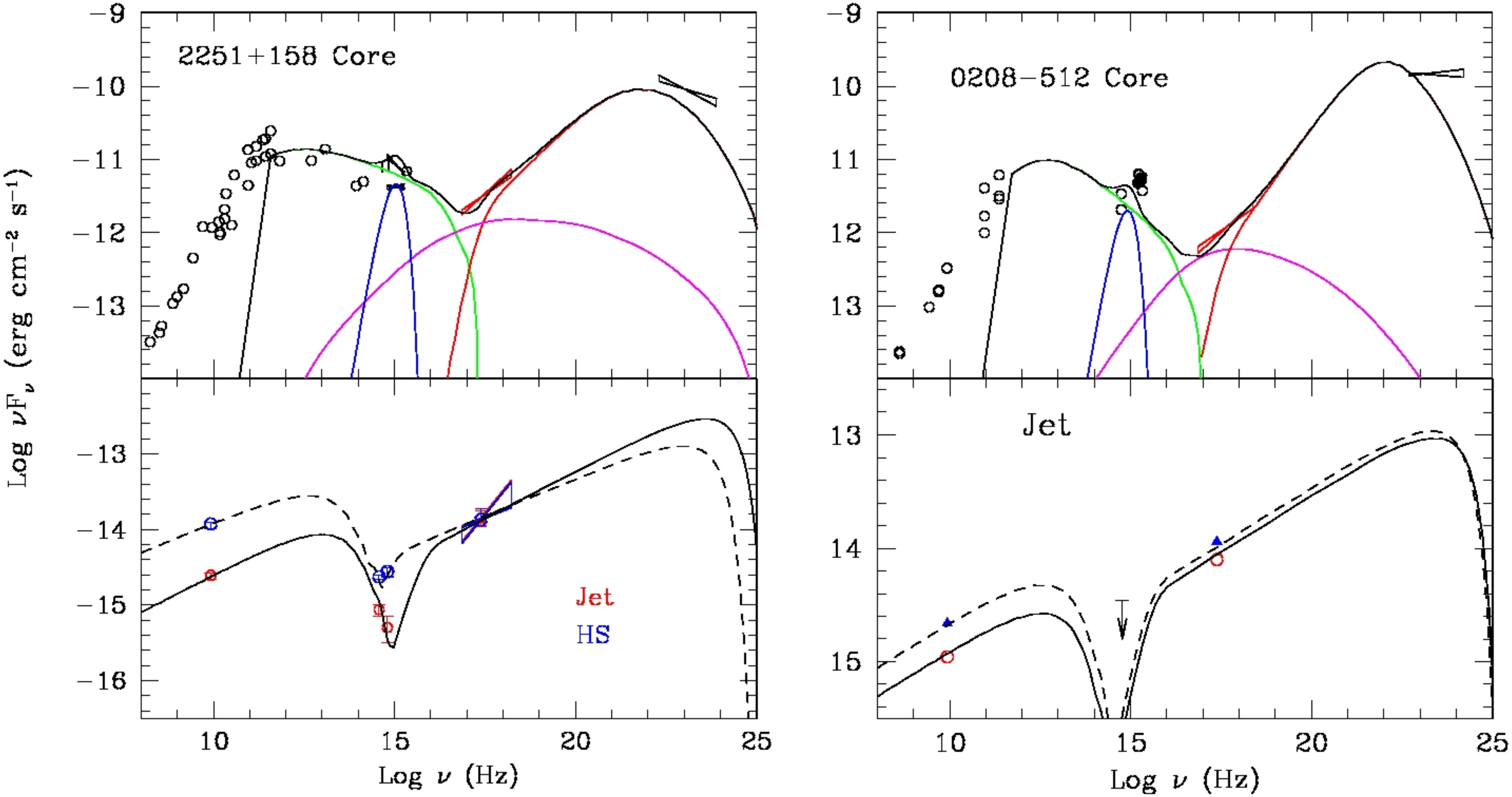
- **The radiative properties of the accretion flows associated with the jets (bright disk or RIAF)**

- **The shape of the SEDs through the intensity of the radiation field surrounding the jet**

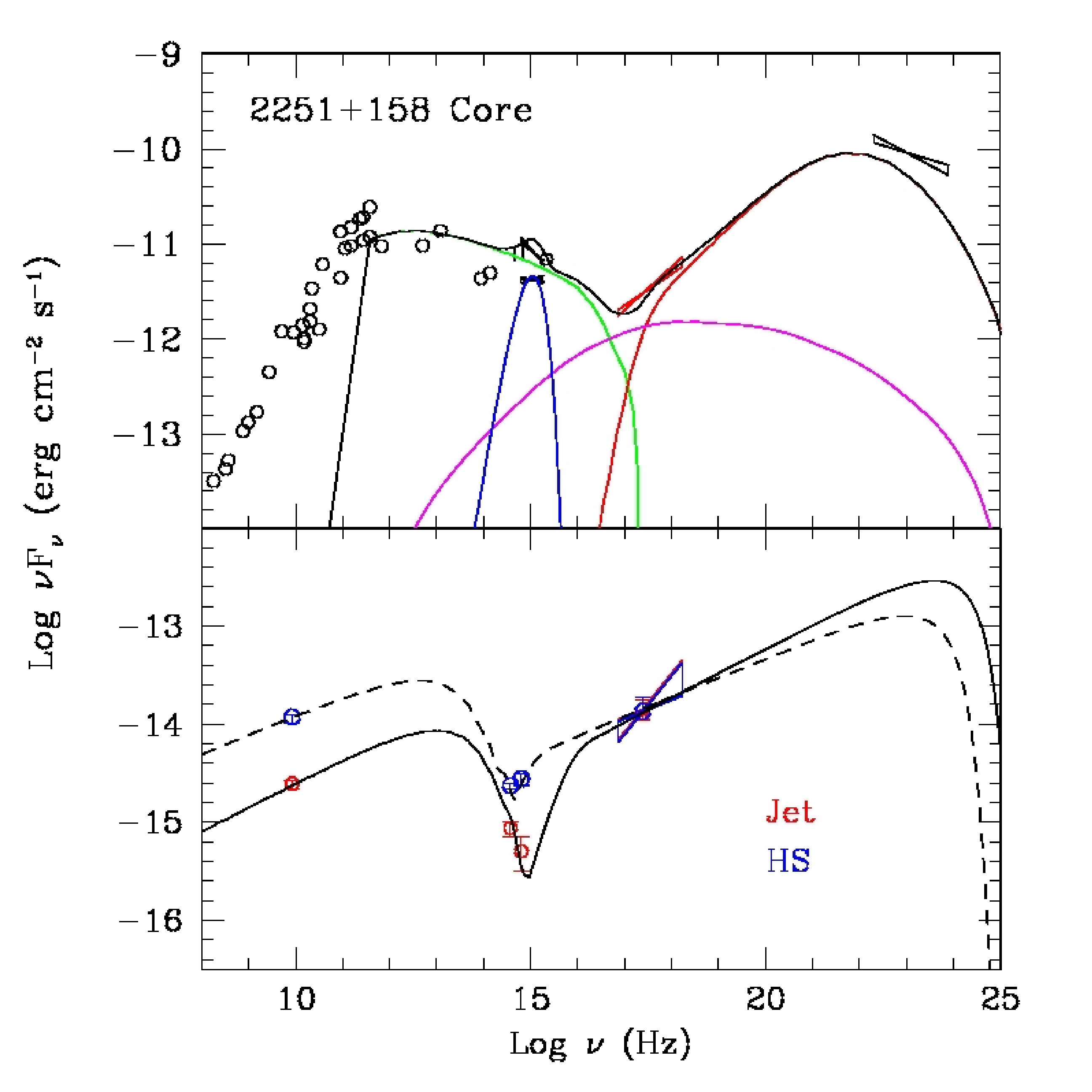
- **The jet power and its survival to large scales, that is the main morphological difference between FRI and FRII radio sources (Celotti and Ghisellini 2001)**

The fundamental AGN plane





2251+158 Core
0208−512 Core
Jet
Jet
HS
Log νF_ν (erg cm⁻² s⁻¹)
Log ν (Hz)
Log ν (Hz)



2251+158 Core
Jet
HS
Log νF_ν (erg cm⁻² s⁻¹)
Log ν (Hz)
−9
−10
−11
−12
−13
−14
−15
−16
10
15
20
25

Results

- From eqs for momentum and energy conservation:

$$m_{dec} \sim M\,\Gamma^{-1}$$

- m_{dec} = entrained mass needed for significant deceleration to set in

- Confirmed by hydrodynamical calculations

Tavecchio et al. 2006

Implications

- Large mass flux: jet reaches hotspots ~ unperturbed
- Small mass flux: jet decelerated sooner
- Low- vs high-power X-ray jets: different mass fluxes/deceleration scales (assuming similar entrainment efficiencies)

SEDs

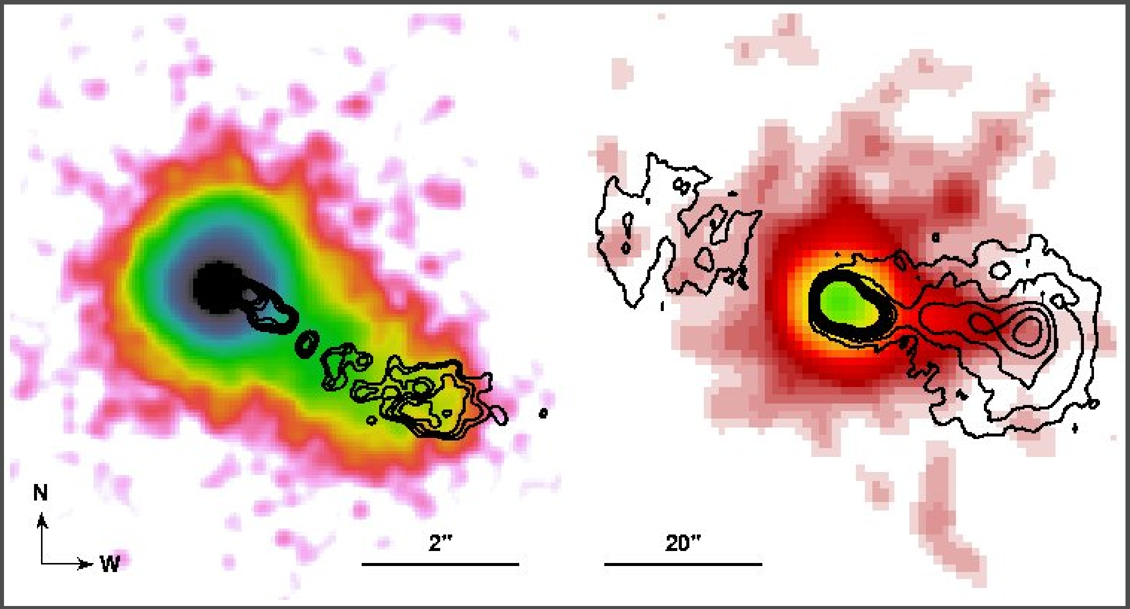
- <u>Chandra jets at low power</u>: strong deceleration near core, high magnetic field B: synchro particles, steep X-ray spectrum

---> "convex" SEDs

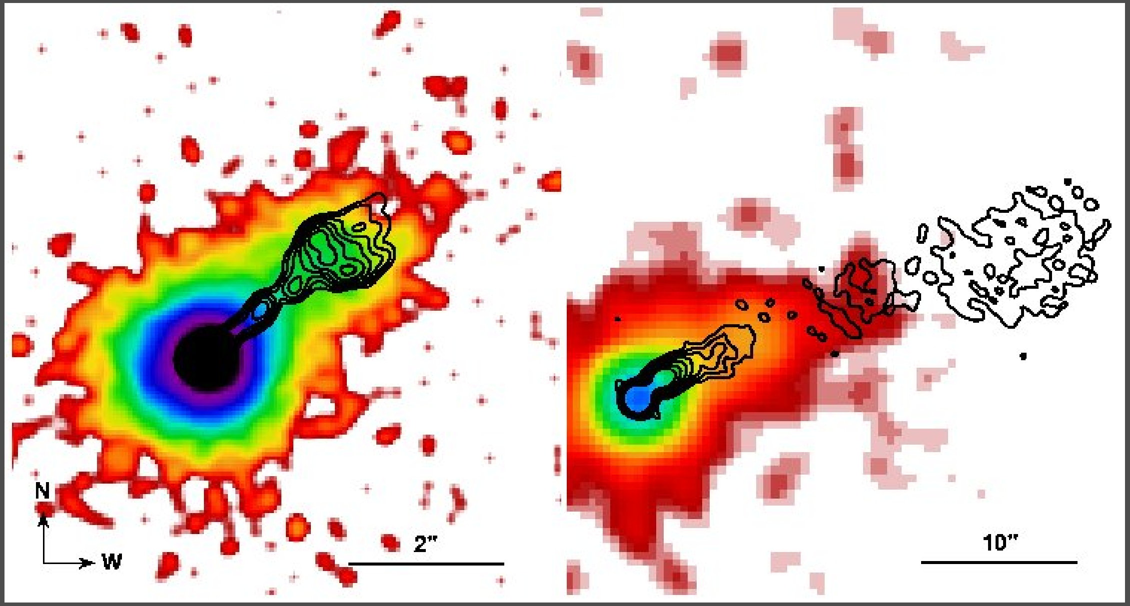
- <u>Chandra jets at high power</u>: jet travels longer, B decreases: lower energy synchro "peaks"; if Γ still ~ high, IC/CMB dominates, or synch from other population

---> "concave" SEDs

Chandra jets at intermediate powers



3C371
z=0.03
1"=0.9 kpc



PKS 2201+044
z=0.027
1"=0.54 kpc

RMS et al. 2007