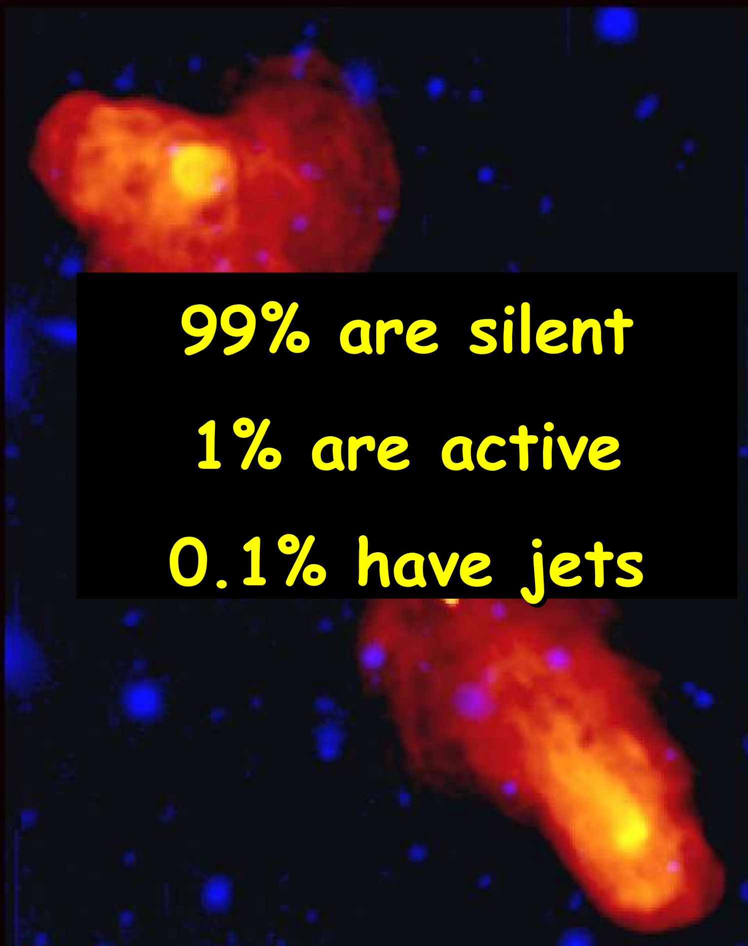
Relativistic extragalatic jets

Gabriele Ghisellini

Radio Galaxy 3C219
Radio/optical

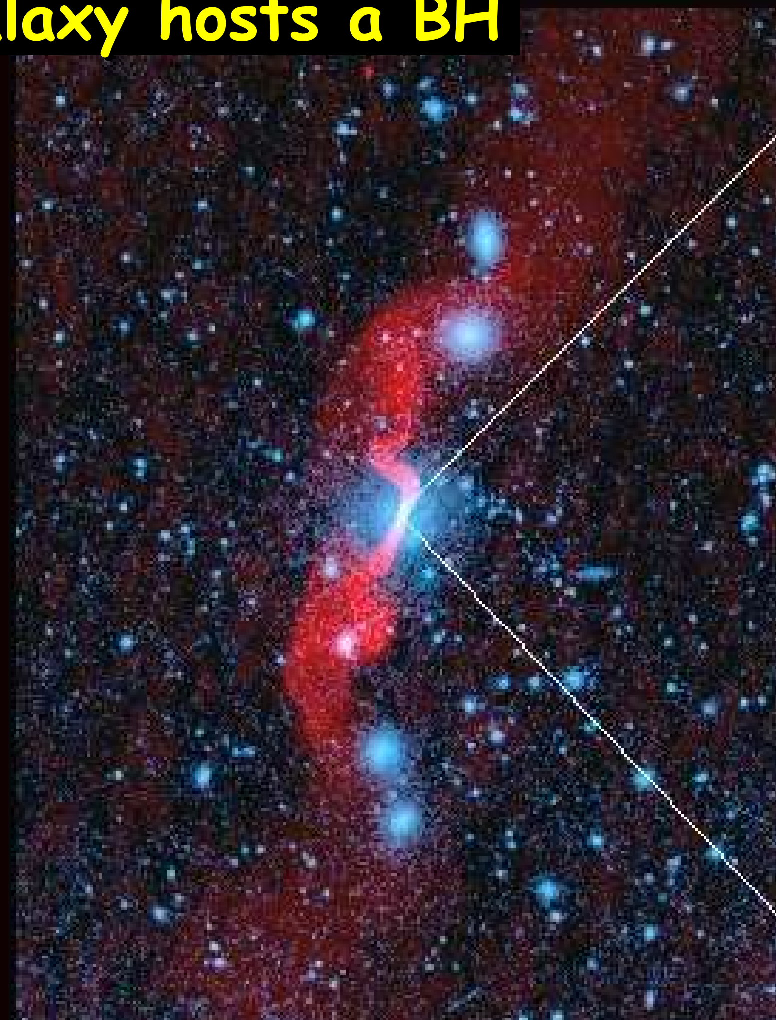
Almost every galaxy hosts a BH



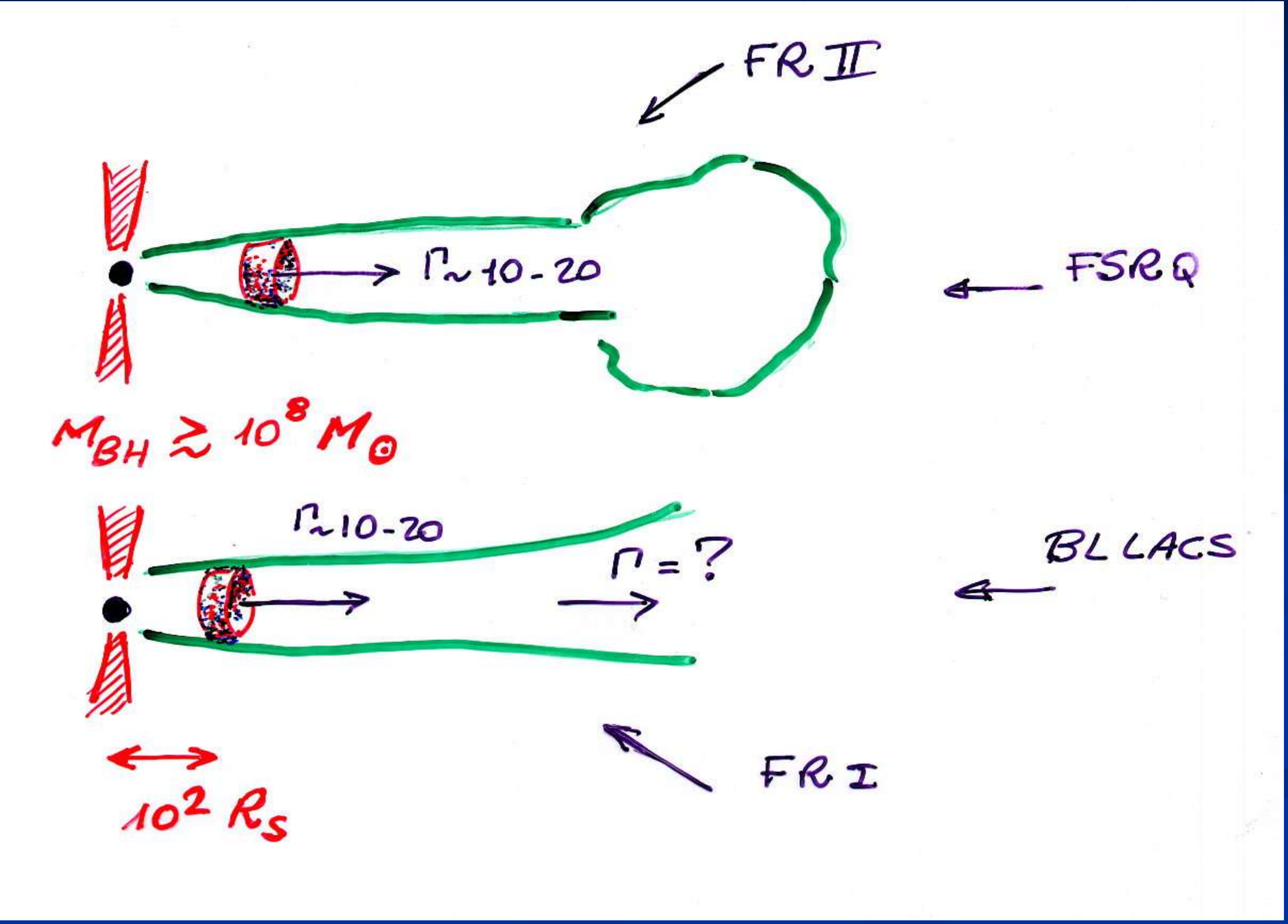
99% are silent

1% are active

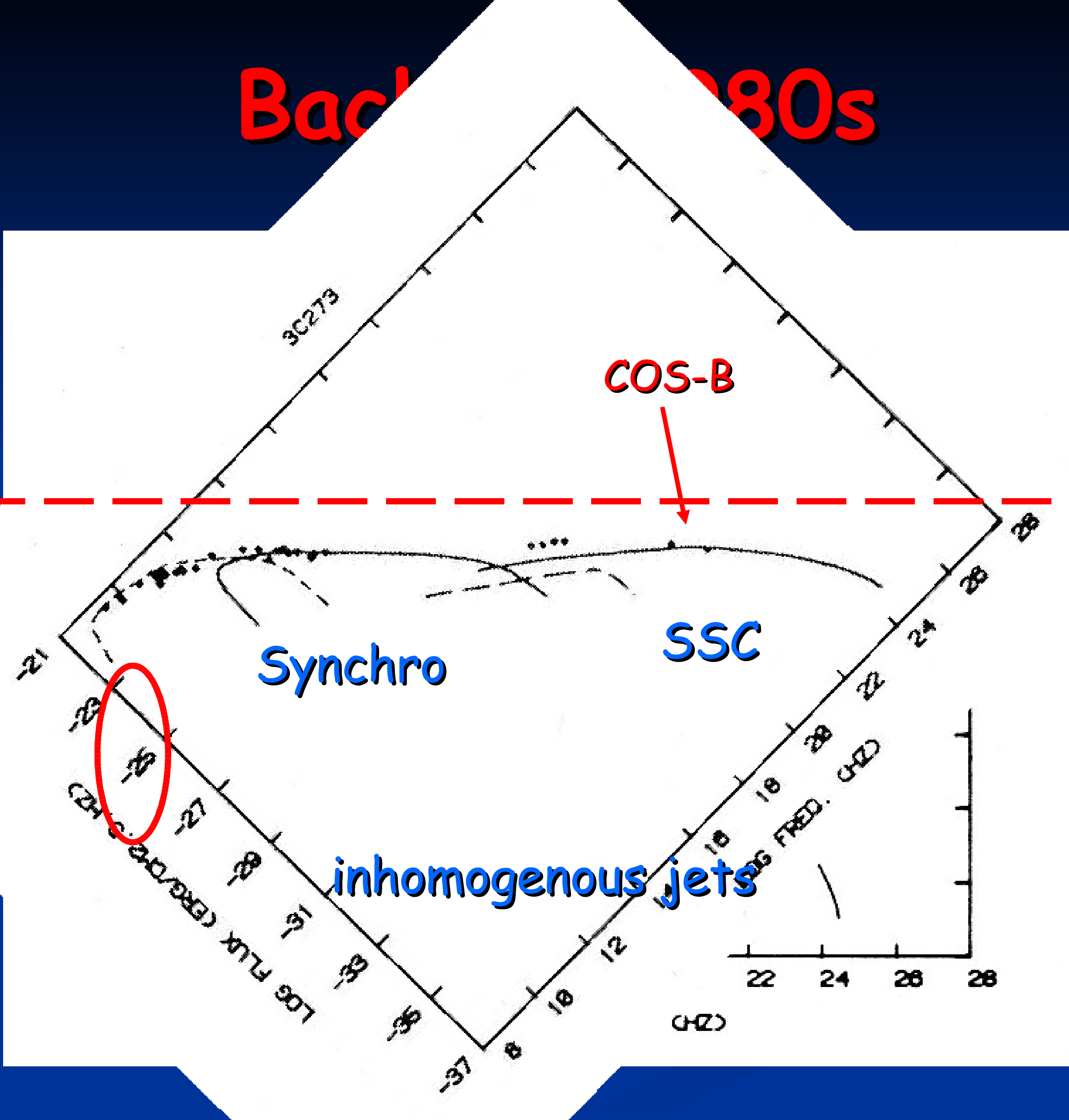
0.1% have jets



FRI-FRII & Blazars

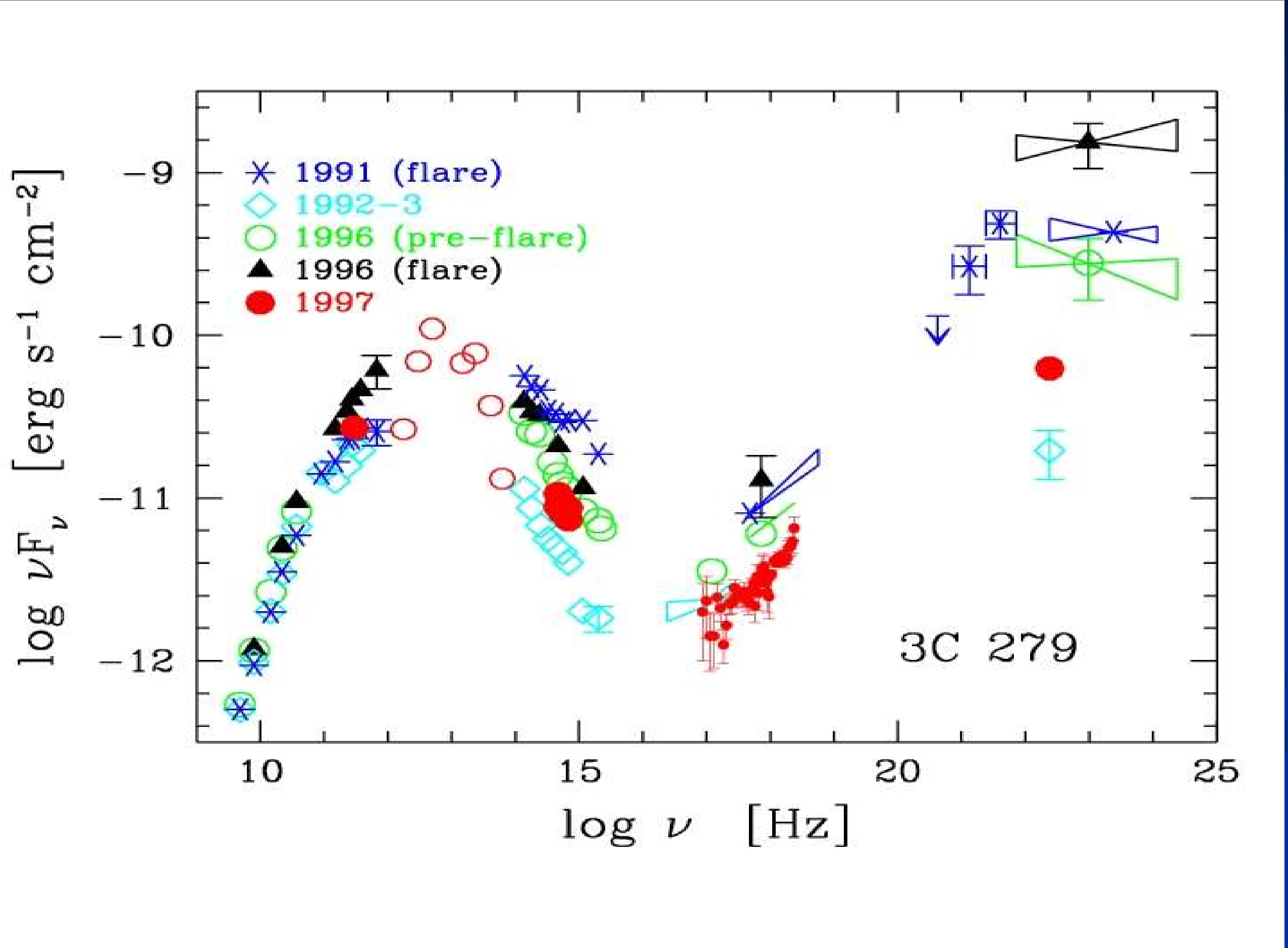


Bac... 80s



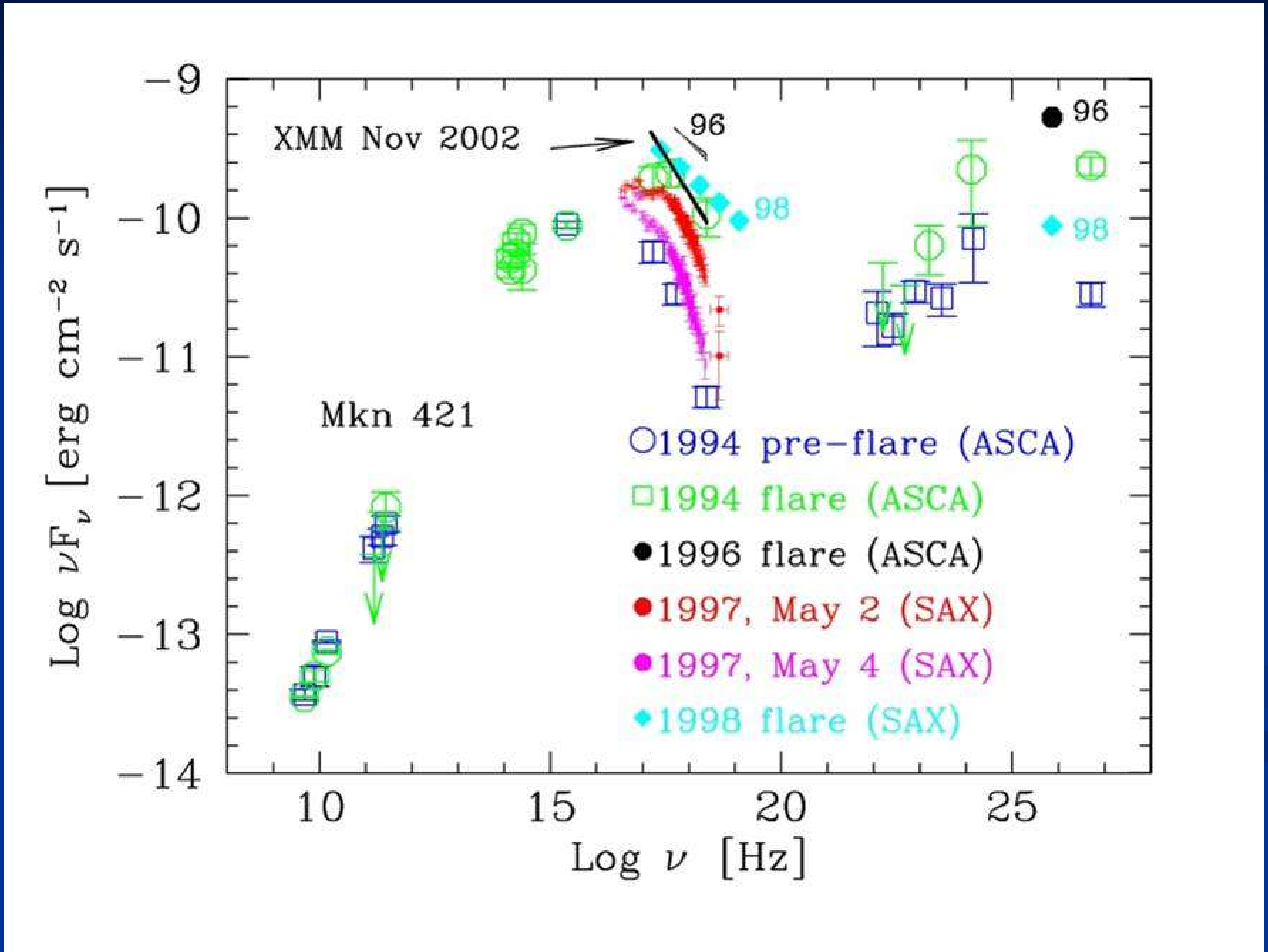
Blandford & Konigl 1979; Marscher 1980;
Konigl 1981; Ghisellini, Maraschi Treves 1985

1990s: EGRET



1991 (flare)
1992-3
1996 (pre-flare)
1996 (flare)
1997
3C 279
log νF_ν [erg s^{-1} cm^{-2}]
log ν [Hz]
-9
-10
-11
-12
10
15
20
25

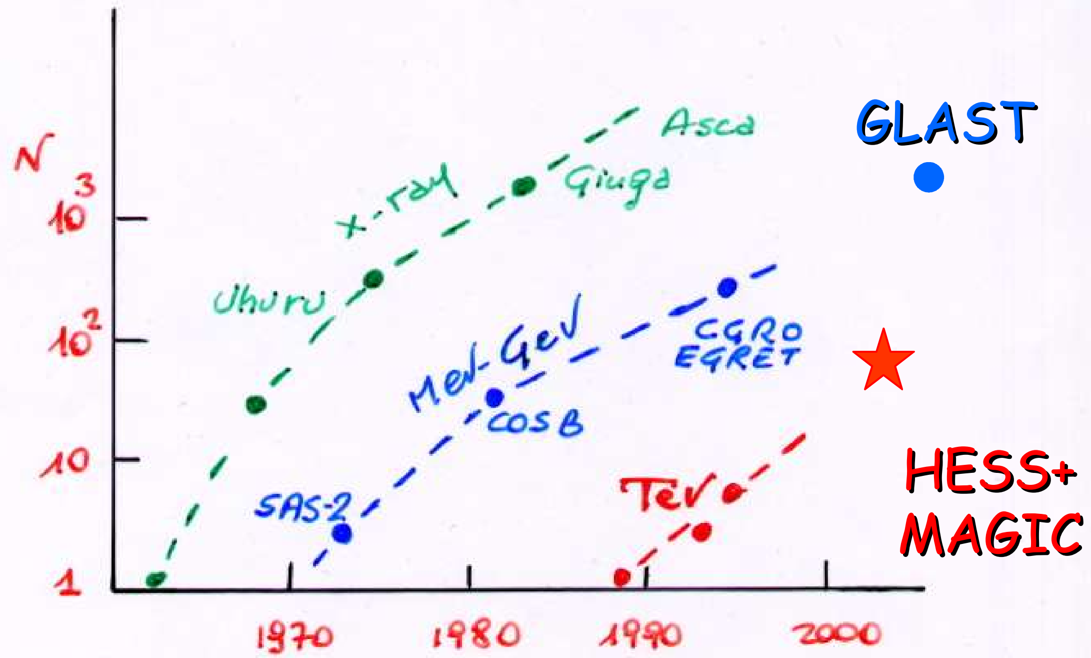
1990s: WHIPPLE



TeV BL Lacs

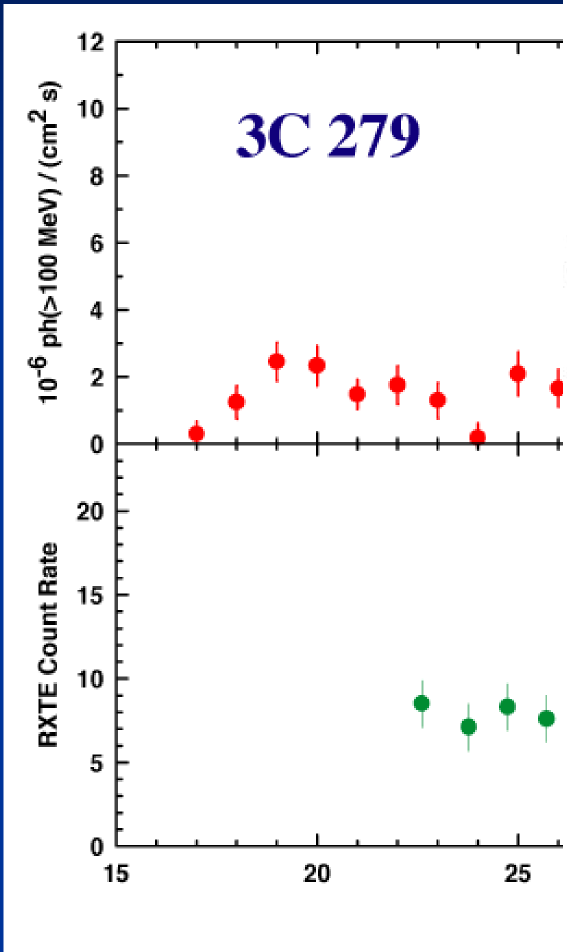
EGRET: ~60 blazars

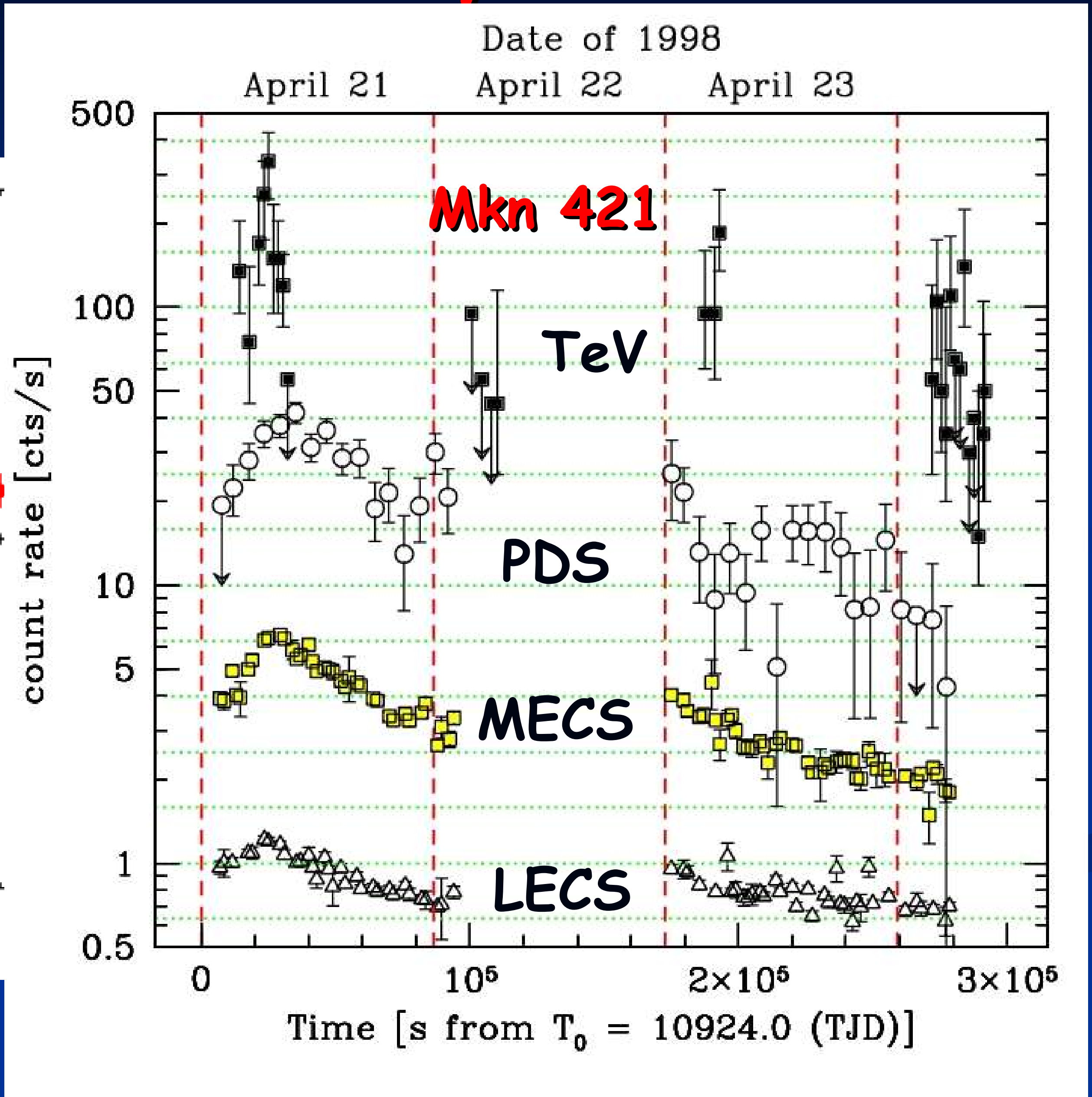
Cherenkov: ~6 BL Lacs

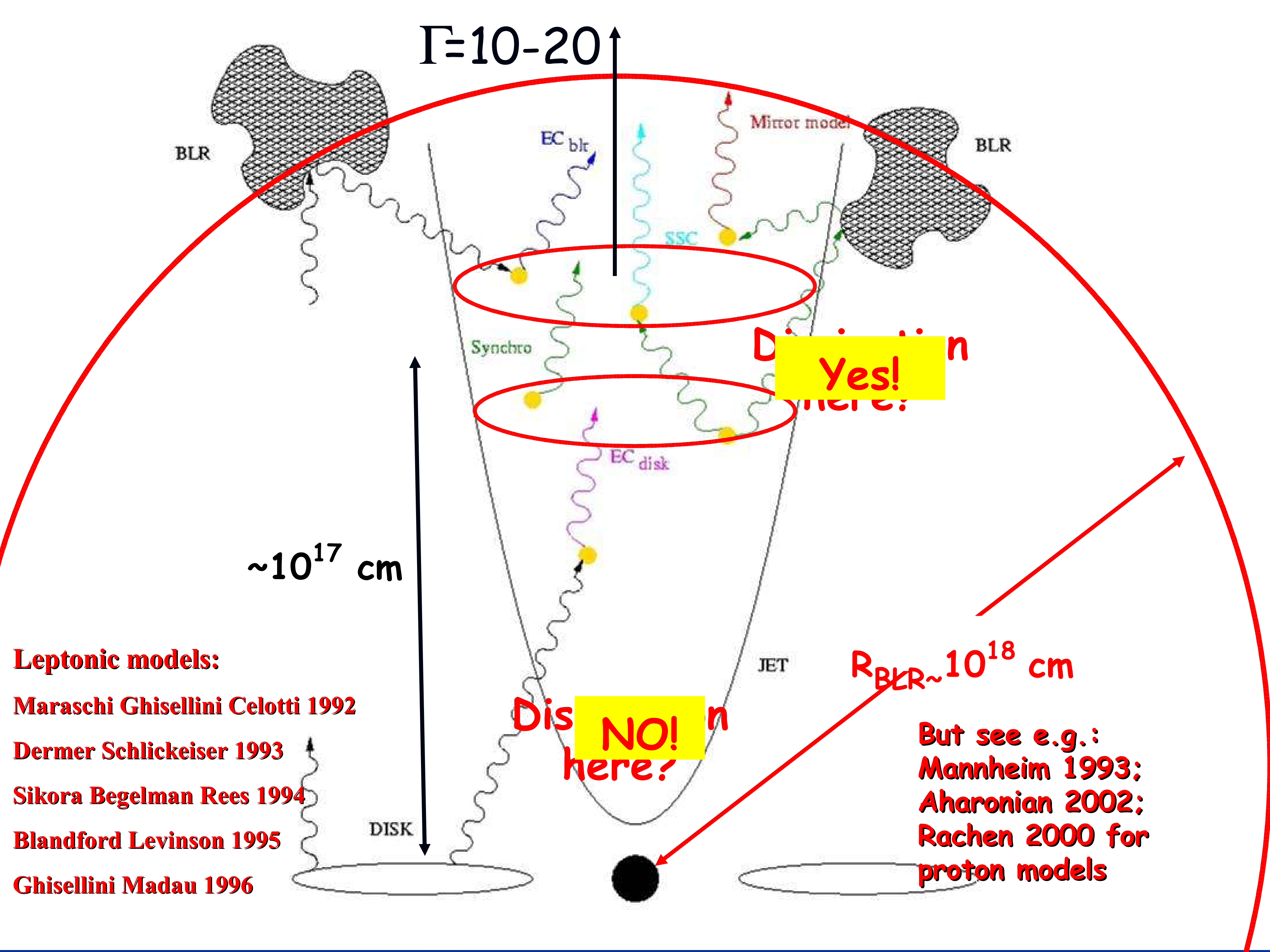


The Universe becomes opacque at z~0.1 at 1TeV at z~2 at 20 GeV

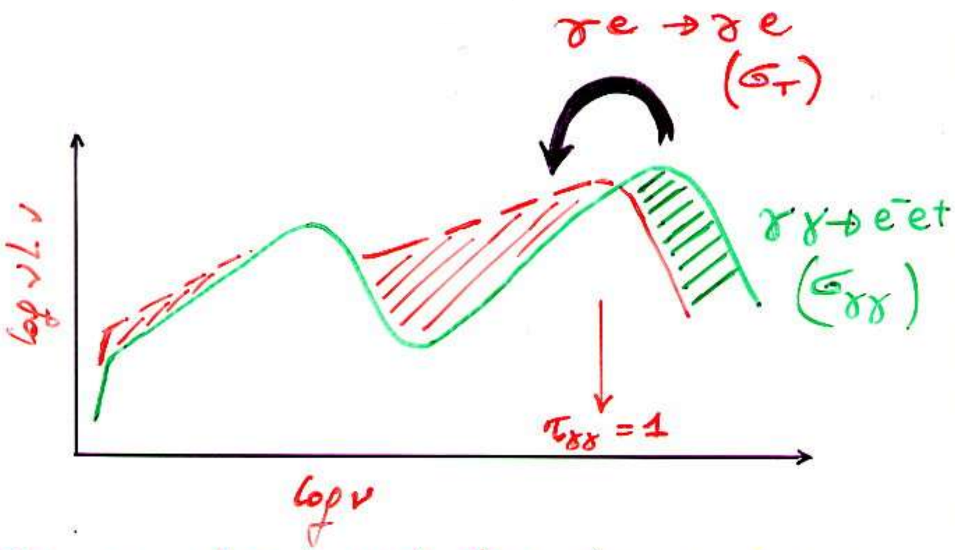
Coordinated variability at different






Γ=10-20
BLR
BLR
Mirror model
EC blr
SSC
Synchro
EC disk
Yes!
~10^17 cm
JET
DISK
NO!
R_BLR~10^18 cm
Leptonic models:
Maraschi Ghisellini Celotti 1992
Dermer Schlickeiser 1993
Sikora Begelman Rees 1994
Blandford Levinson 1995
Ghisellini Madau 1996
But see e.g.:
Mannheim 1993;
Aharonian 2002;
Rachen 2000 for
proton models

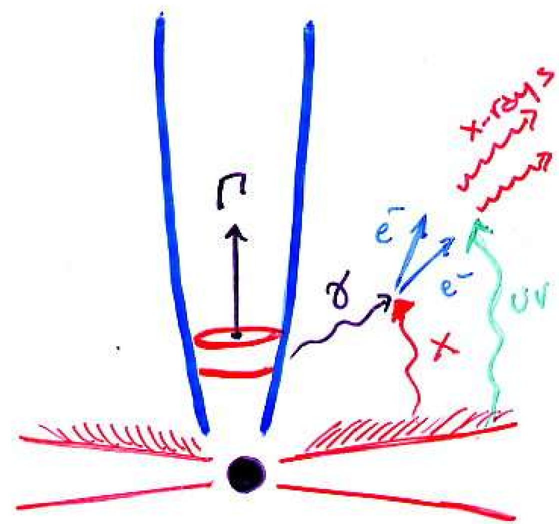
Importance of γ-rays



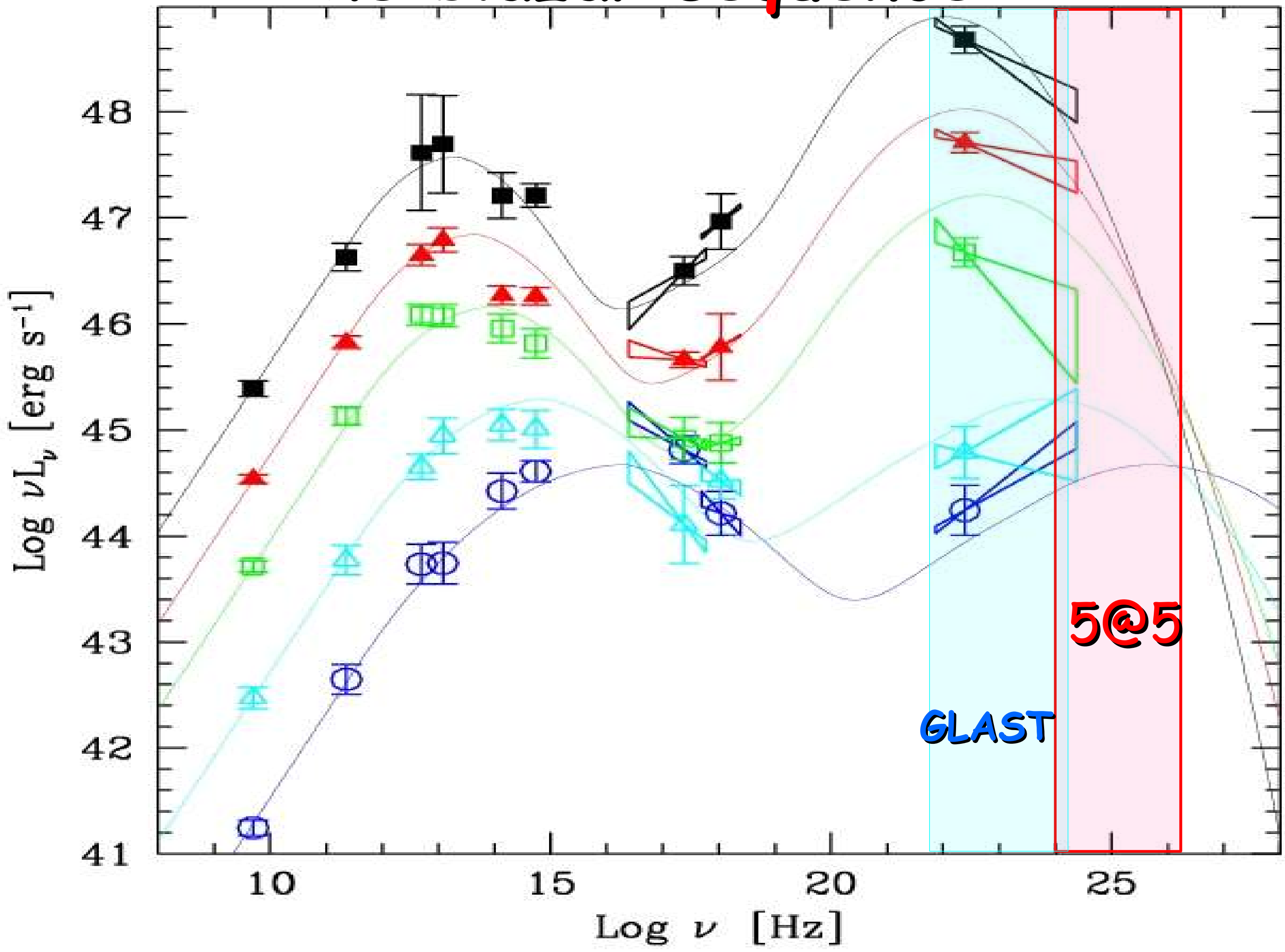
- If γ-γ important → too many X-rays → $\delta_{x,\gamma} > 1$ (>10)
- R_{blob} large enough (>10^{16} cm), but
- $t_{var} < 1$day → $R_{blob} < 2.5 \times 10^{15}\ t_{var} \delta$ cm

Blob away from accretion disk X-ray

Energy transport in inner jet must be dissipationless

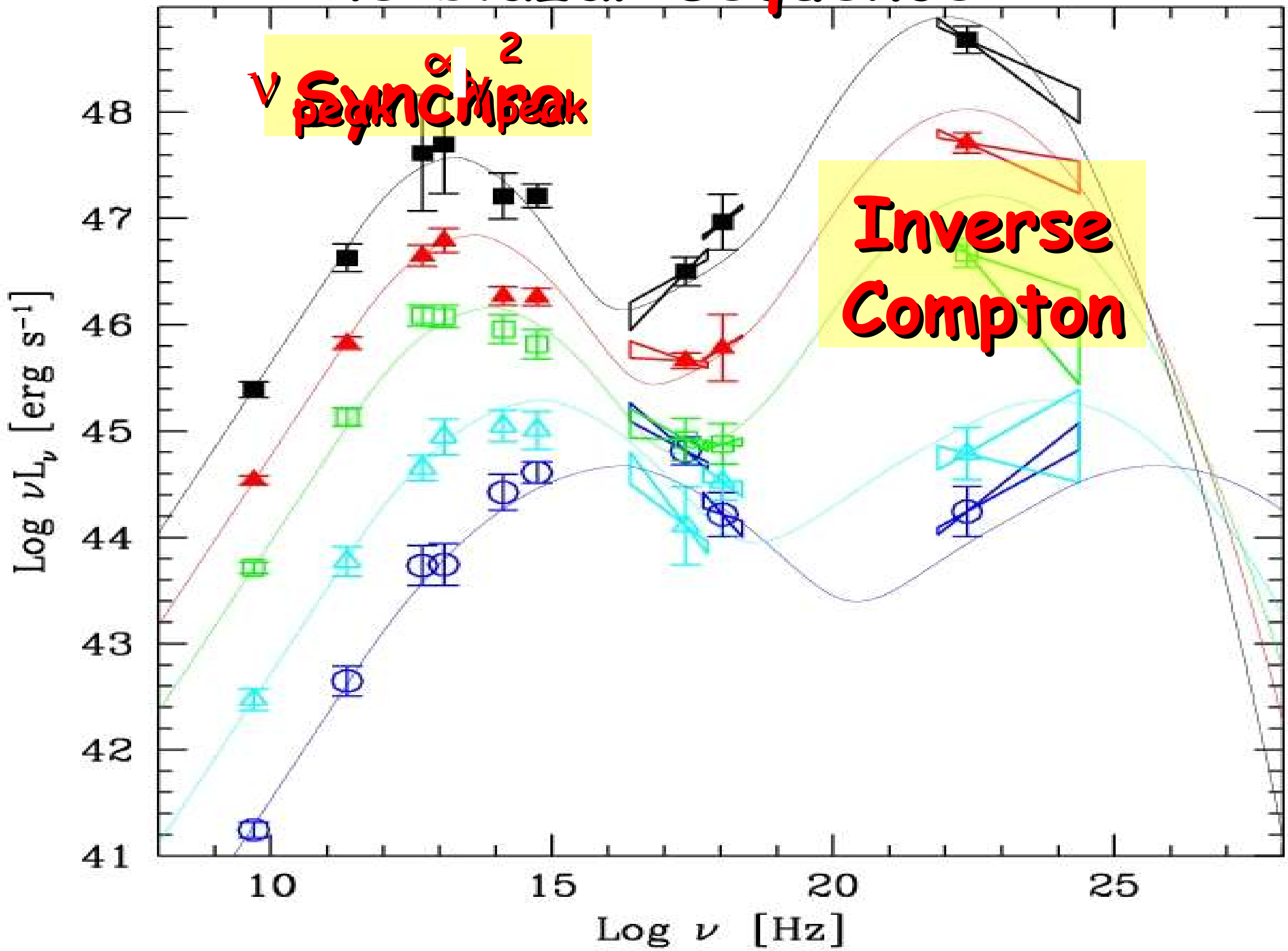


The blazar sequence

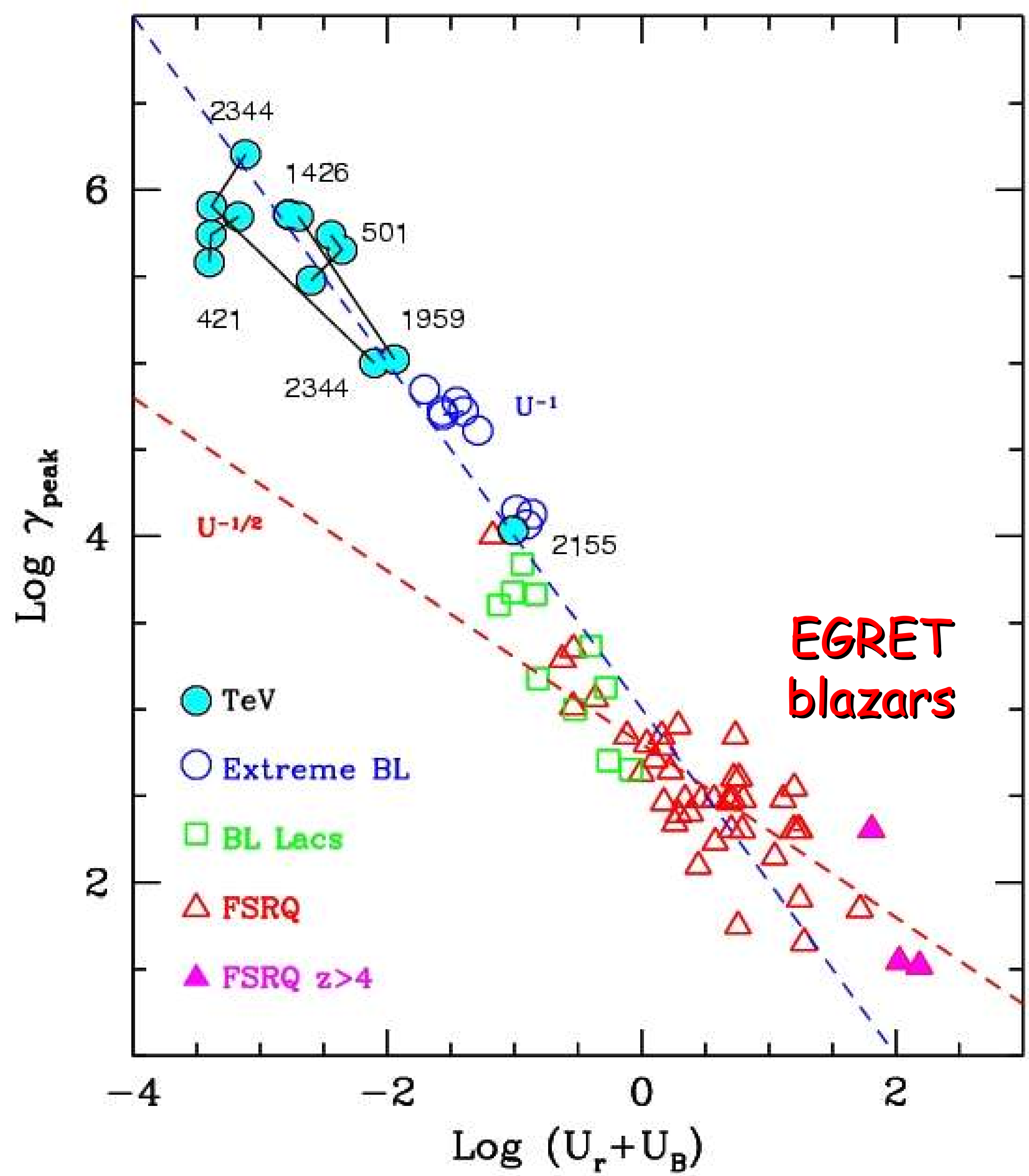


Fossati et al. 1998; Donato et al. 2001

The blazar sequence

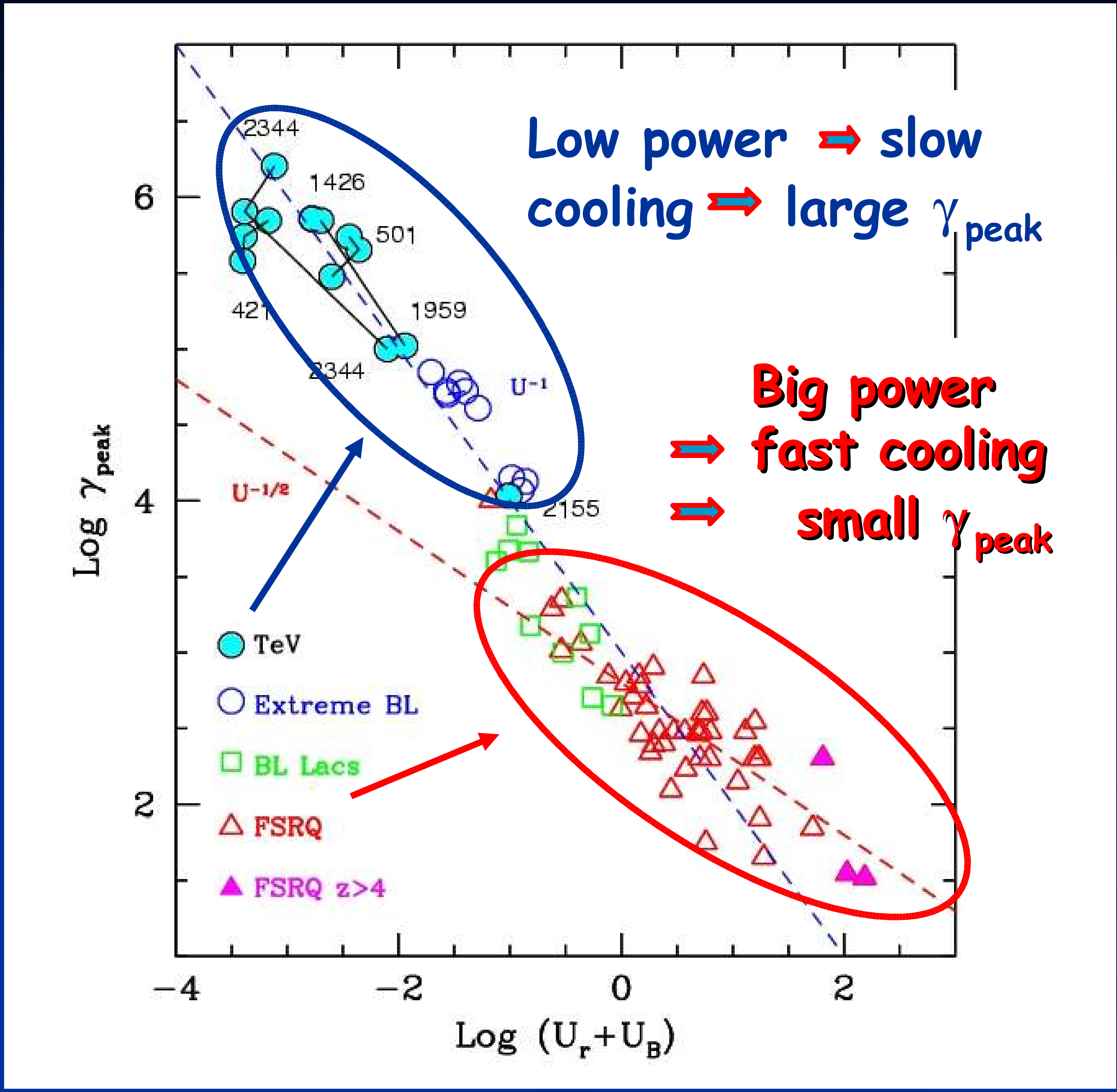


Fossati et al. 1998; Donato et al. 2001

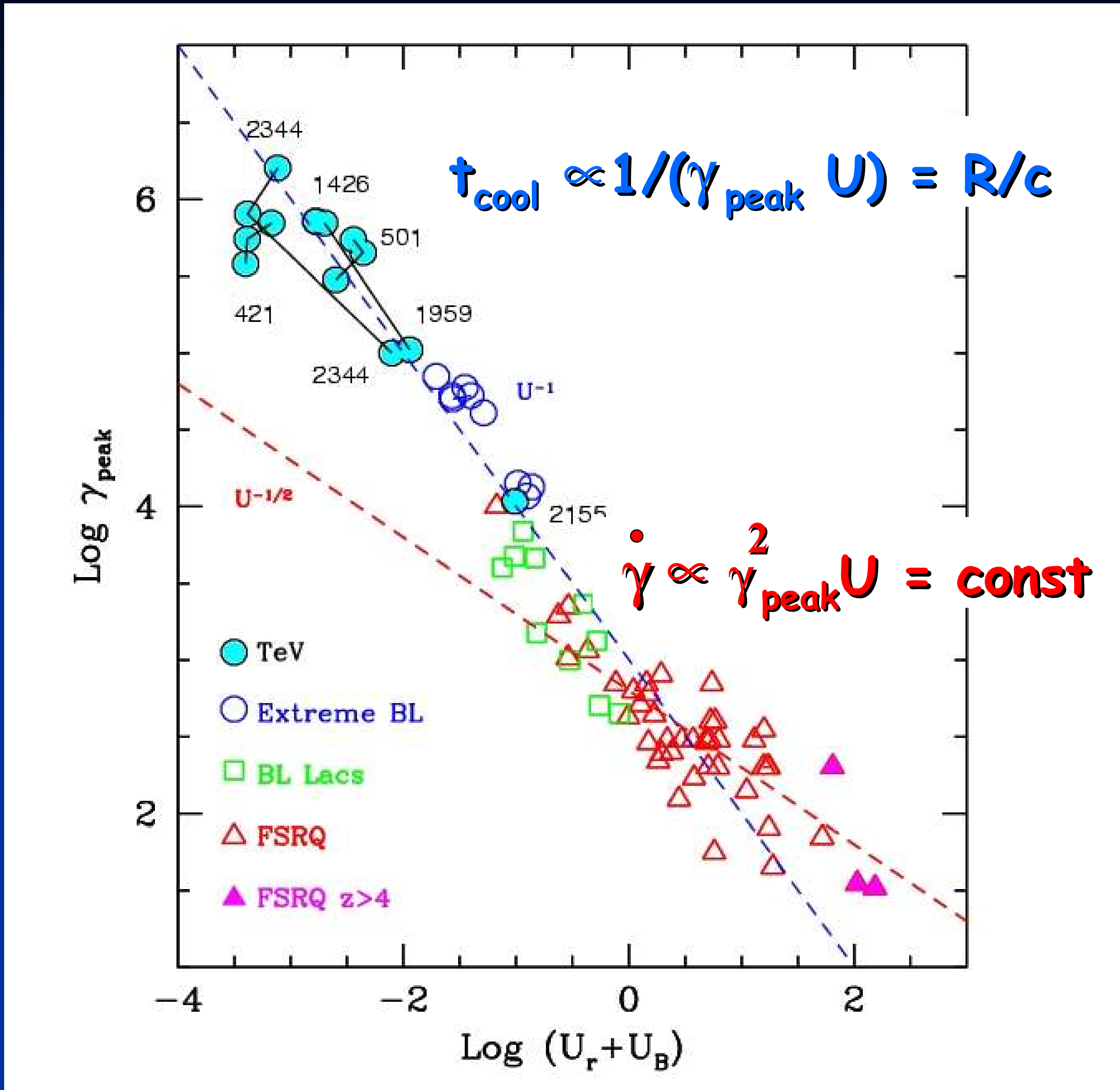


By modeling, we find physical parameters in the comoving frame.

γ_{peak} is the energy of electrons emitting at the peak of the SED

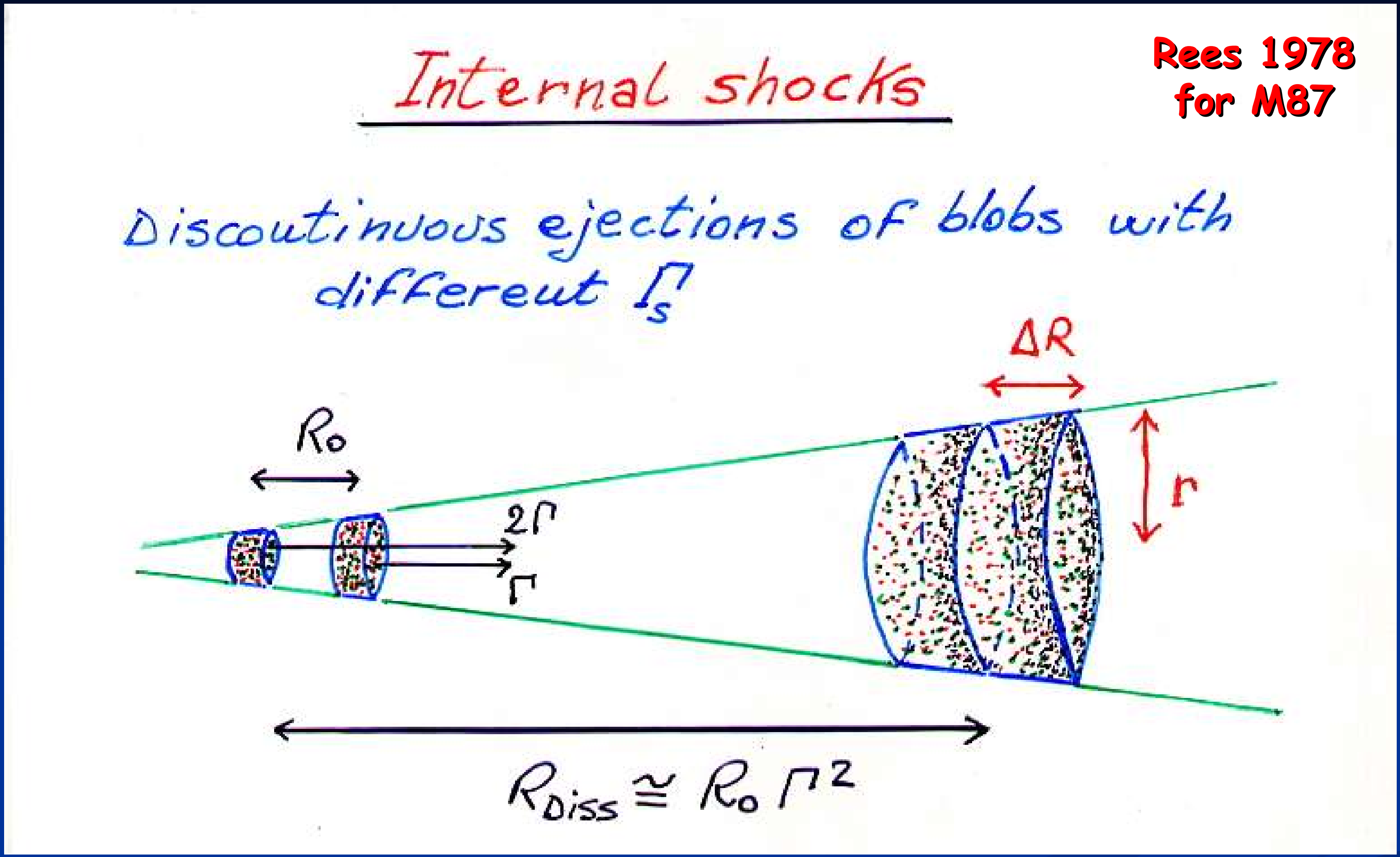


Low power ⇒ slow cooling ⇒ large γ_{peak}
Big power ⇒ fast cooling ⇒ small γ_{peak}
Log γ_{peak}
Log (U_r+U_B)
2344
1426
501
421
1959
2155
U^{-1}
$U^{-1/2}$
TeV
Extreme BL
BL Lacs
FSRQ
FSRQ z>4



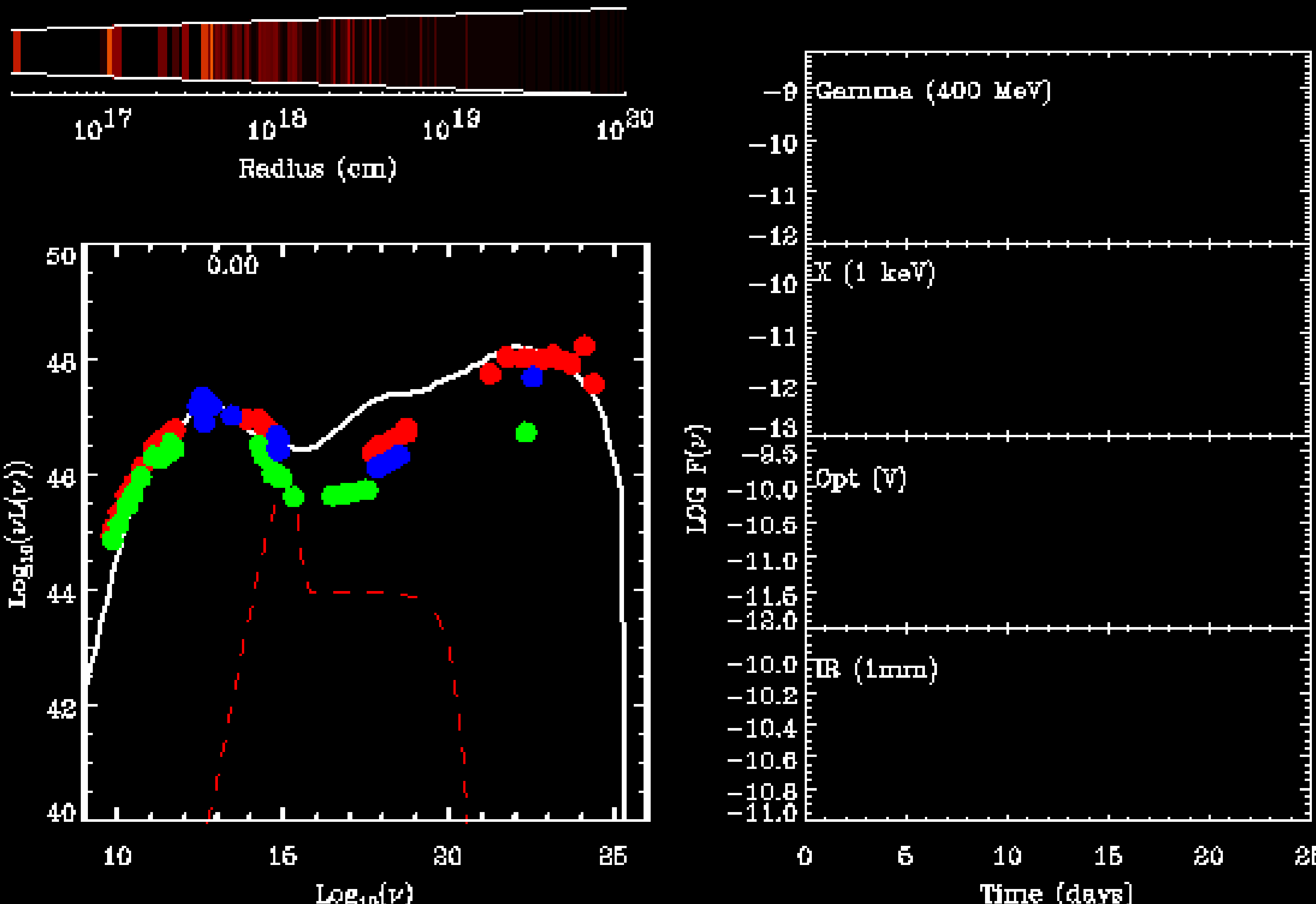
$$t_{cool} \propto 1/(\gamma_{peak}\, U) = R/c$$

$$\dot{\gamma} \propto \gamma^2_{peak} U = const$$

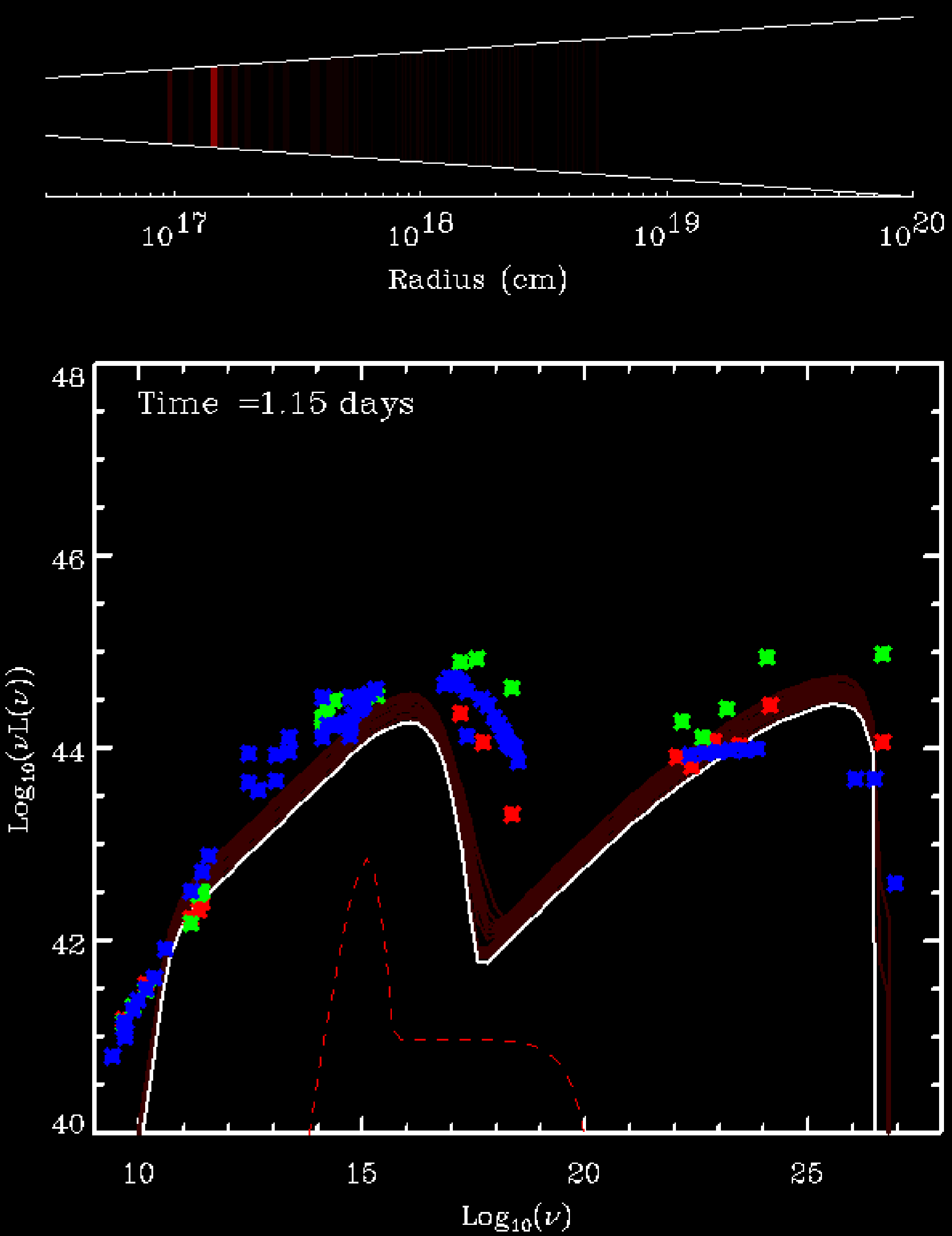


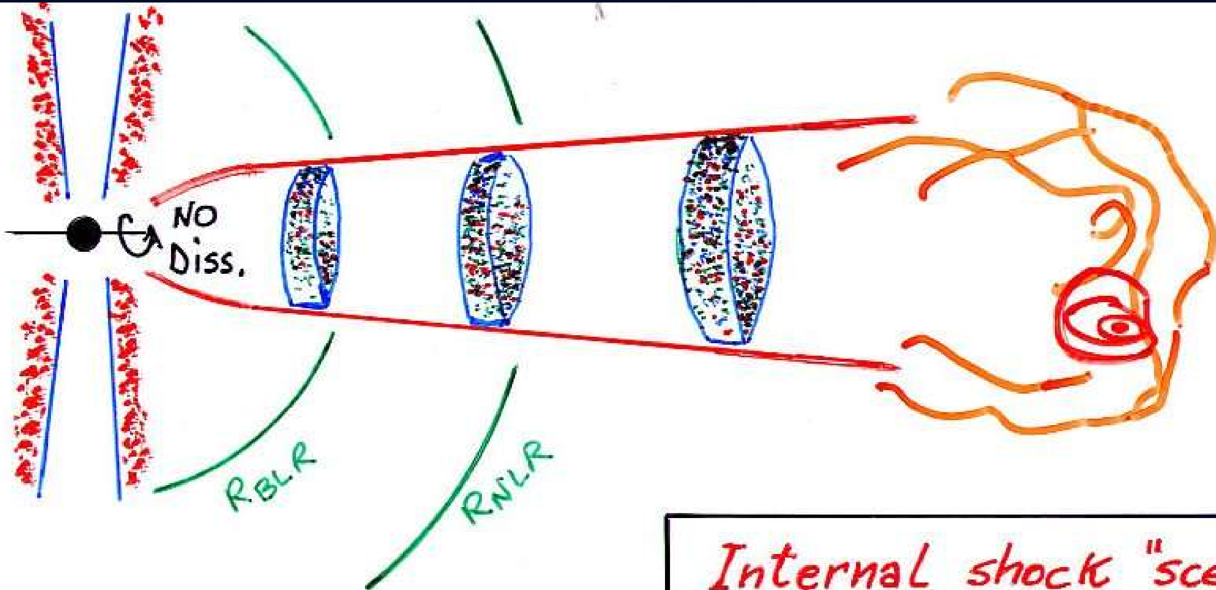
Observed time: $(R_0/c)\Gamma^2(1-\beta\cos\theta) \sim R_0/c$!

3C 279 Spada et al. 2001



Mkn 421 Guetta et al. 2004



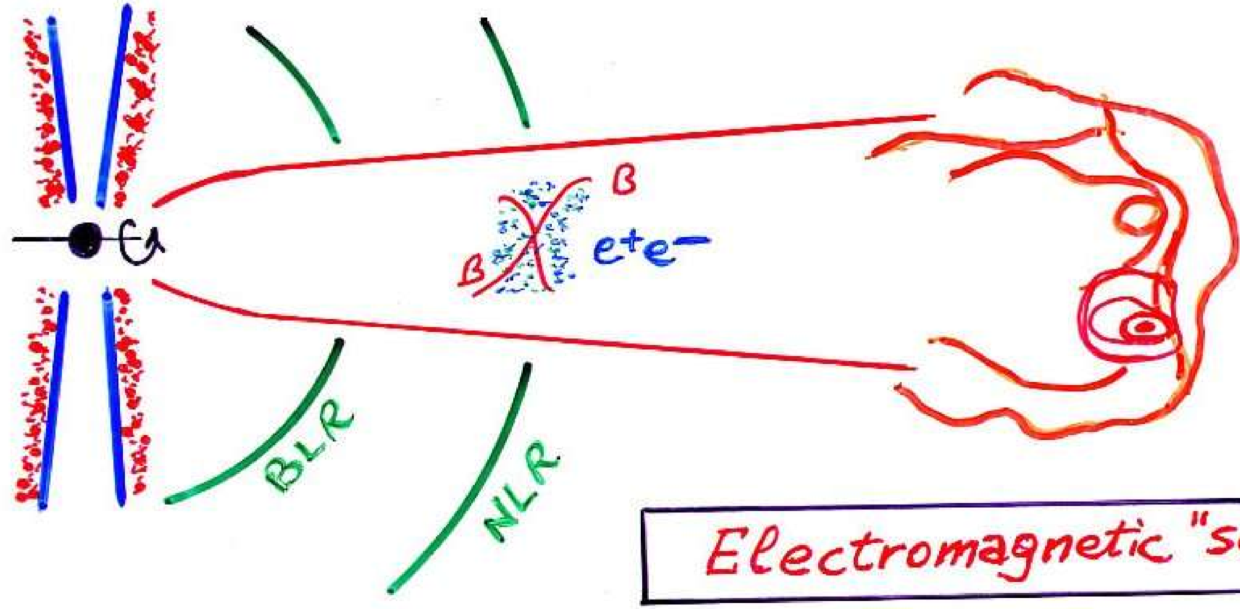


Internal shock "scenario"

- $R_\gamma \sim R_0 \Gamma^2 \sim 100\ R_s$
- Dissipation : $\eta \downarrow$ $R \uparrow$
- Variability
- Can explain SED

- Requires matter
- $L_K > L_B$ in γ-zone and beyond

Ghisellini 1999, Spada et al. 2001; Guetta et al. 2004



Electromagnetic "scenario"

- Almost matter (bariou) free
- $L_B > L_K$ everywhere
- Dissipatiou ↔ Recouuectiou

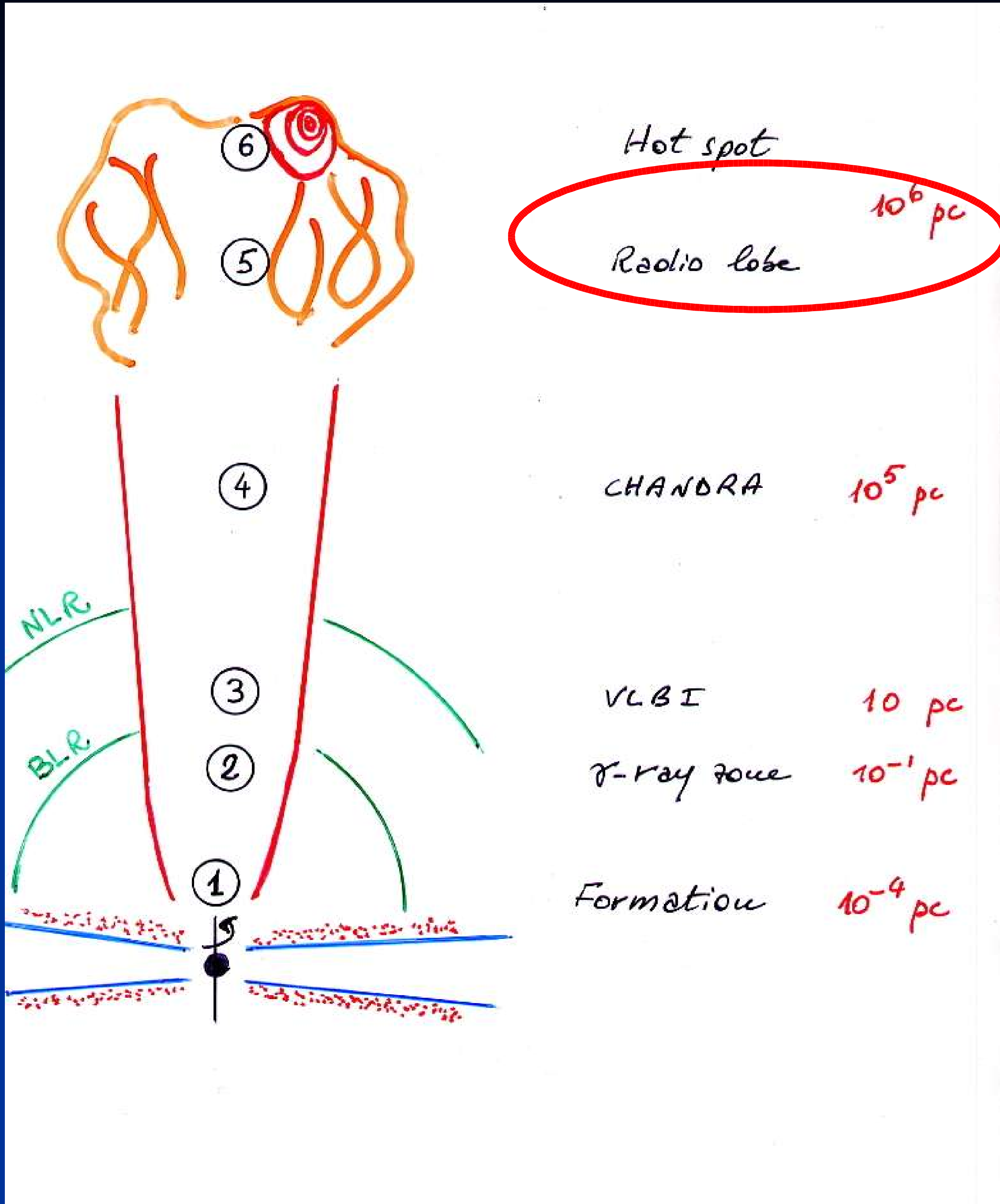
Blandford 2002, 2003, Lyutikov 2003

What carries the energy?

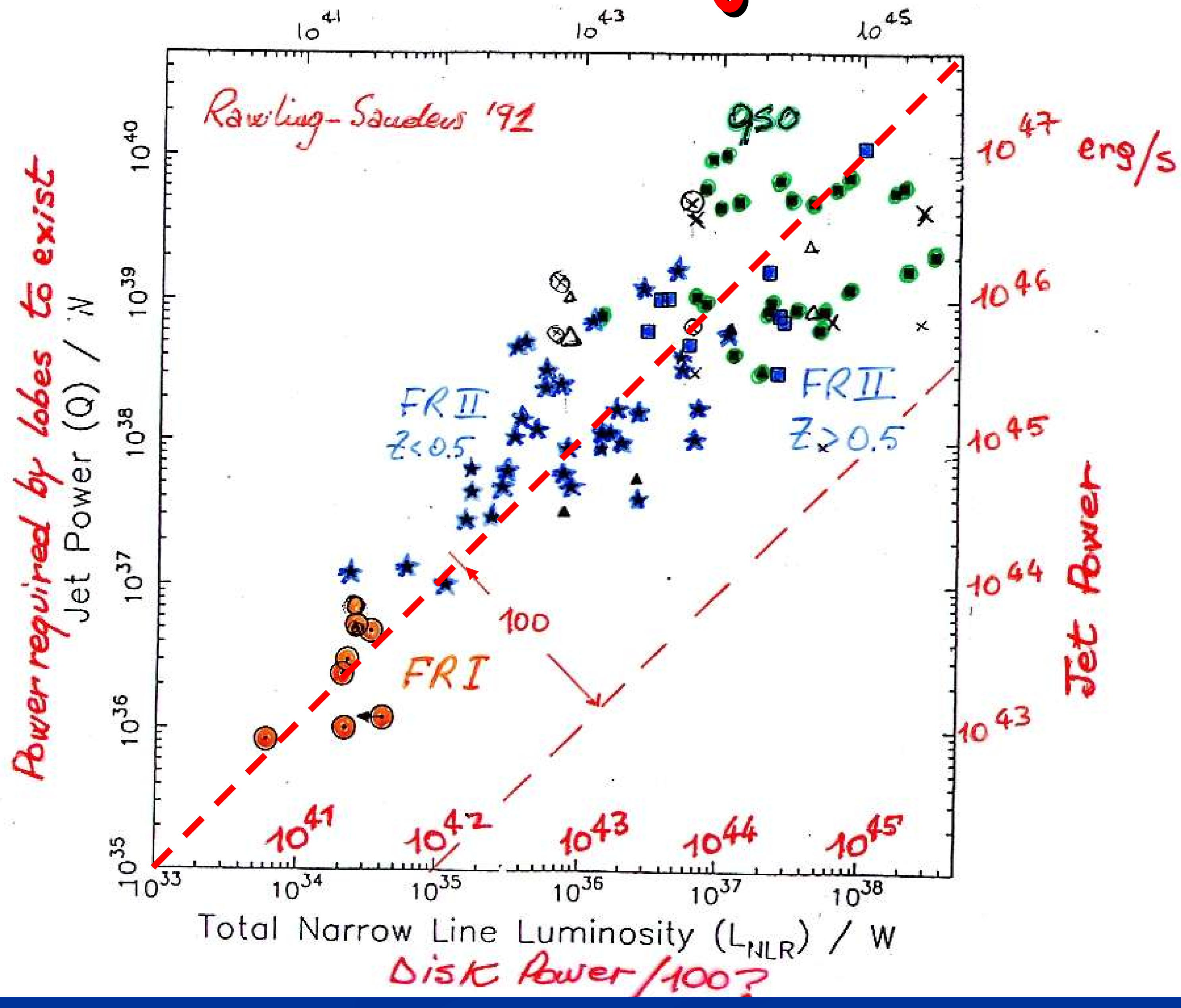
e-p or e+e- or B?

Power of jets first

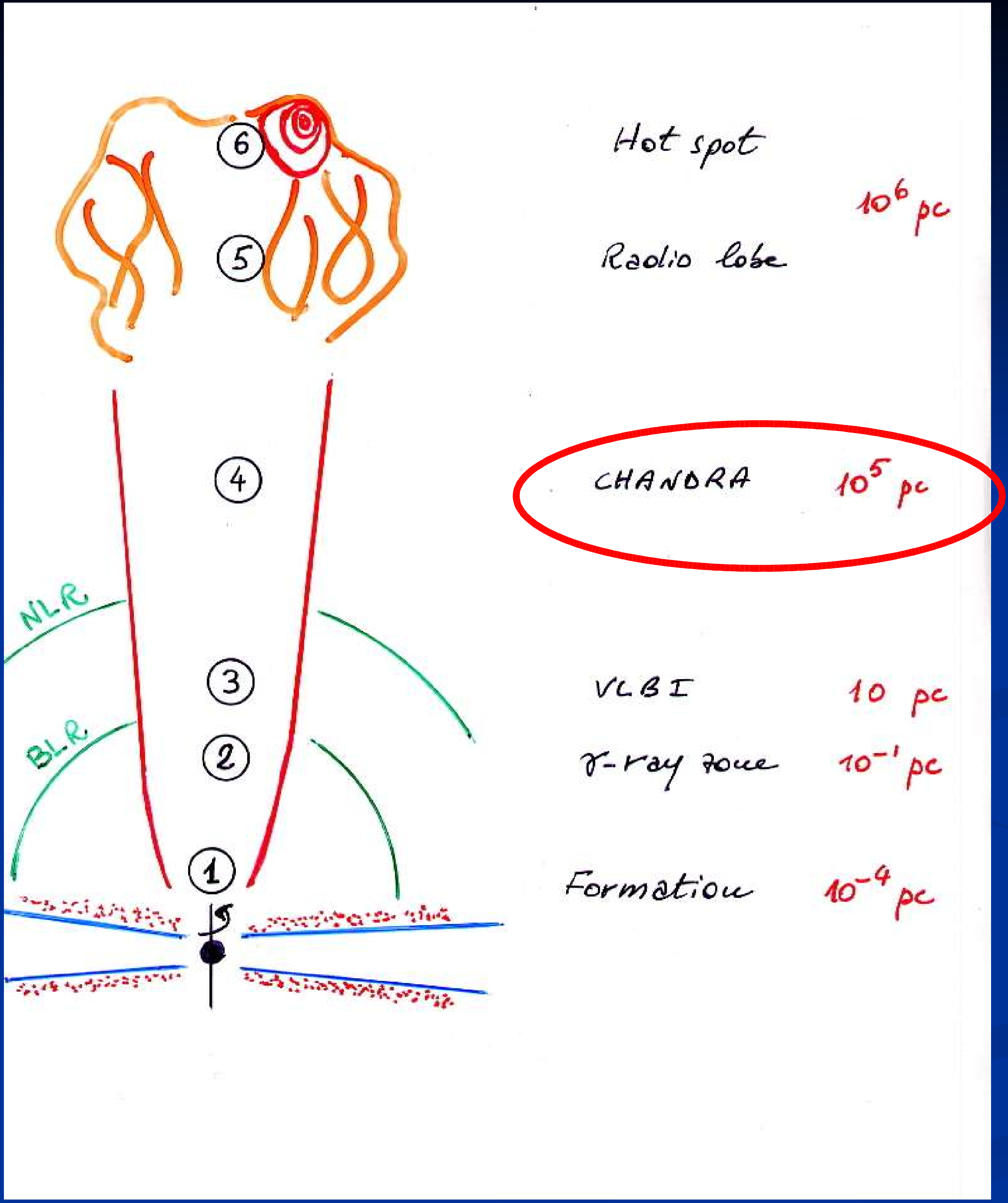
Power of jets in blazars



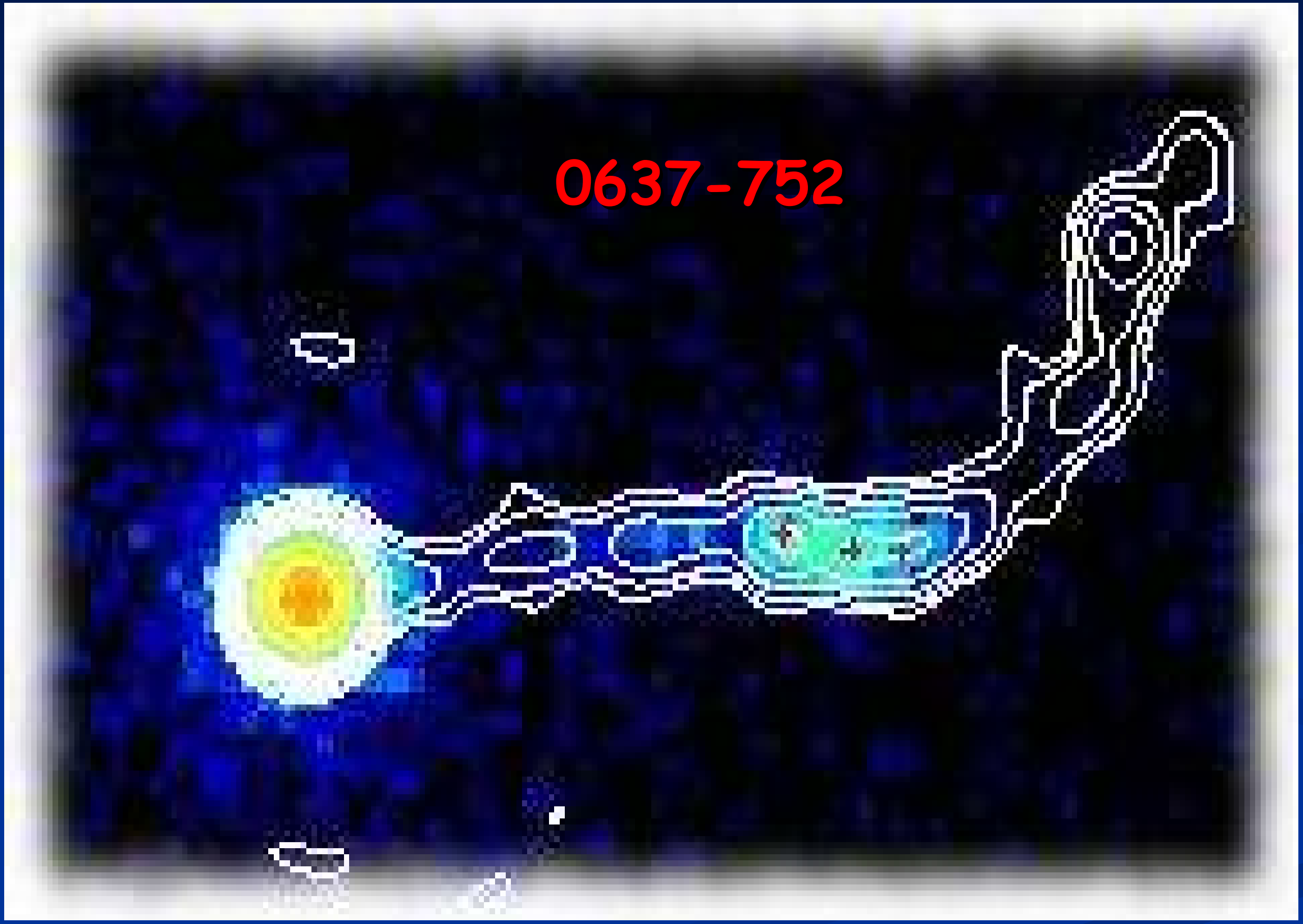
Power of jets

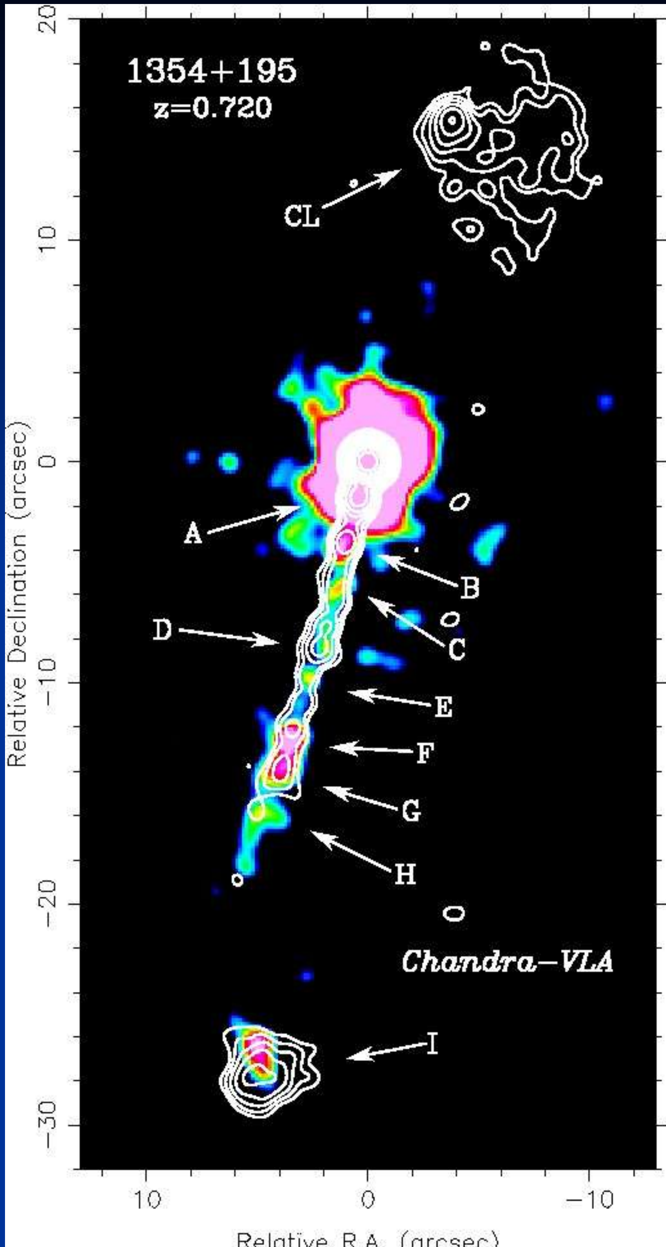


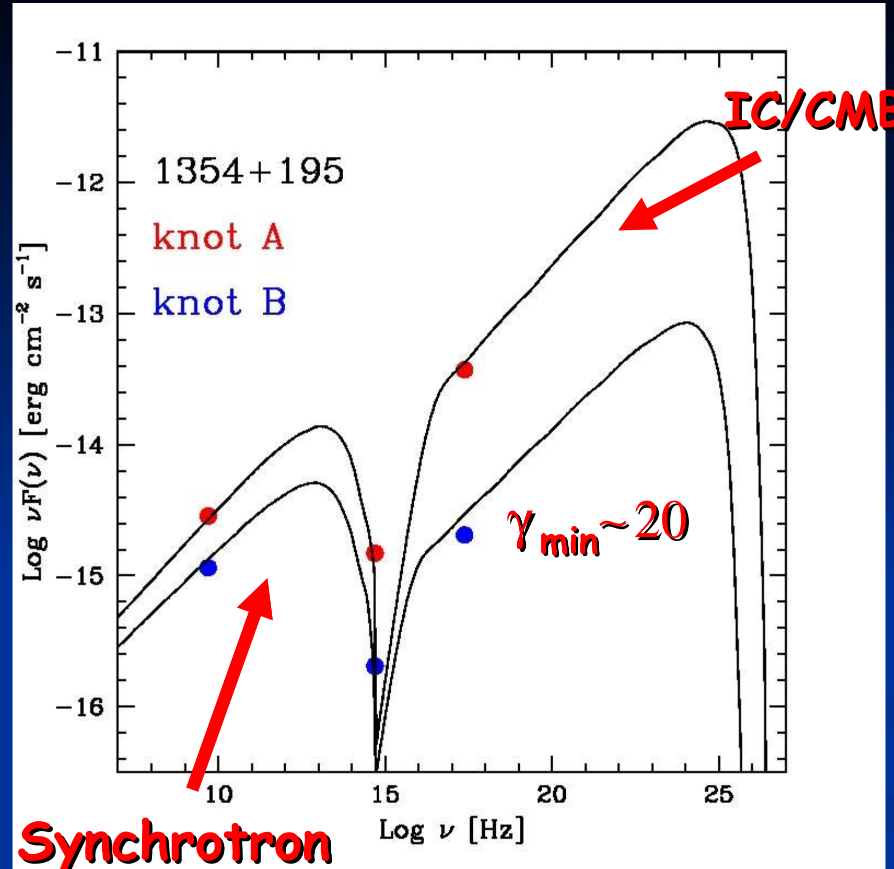
Power of jets in blazars



Chandra jets







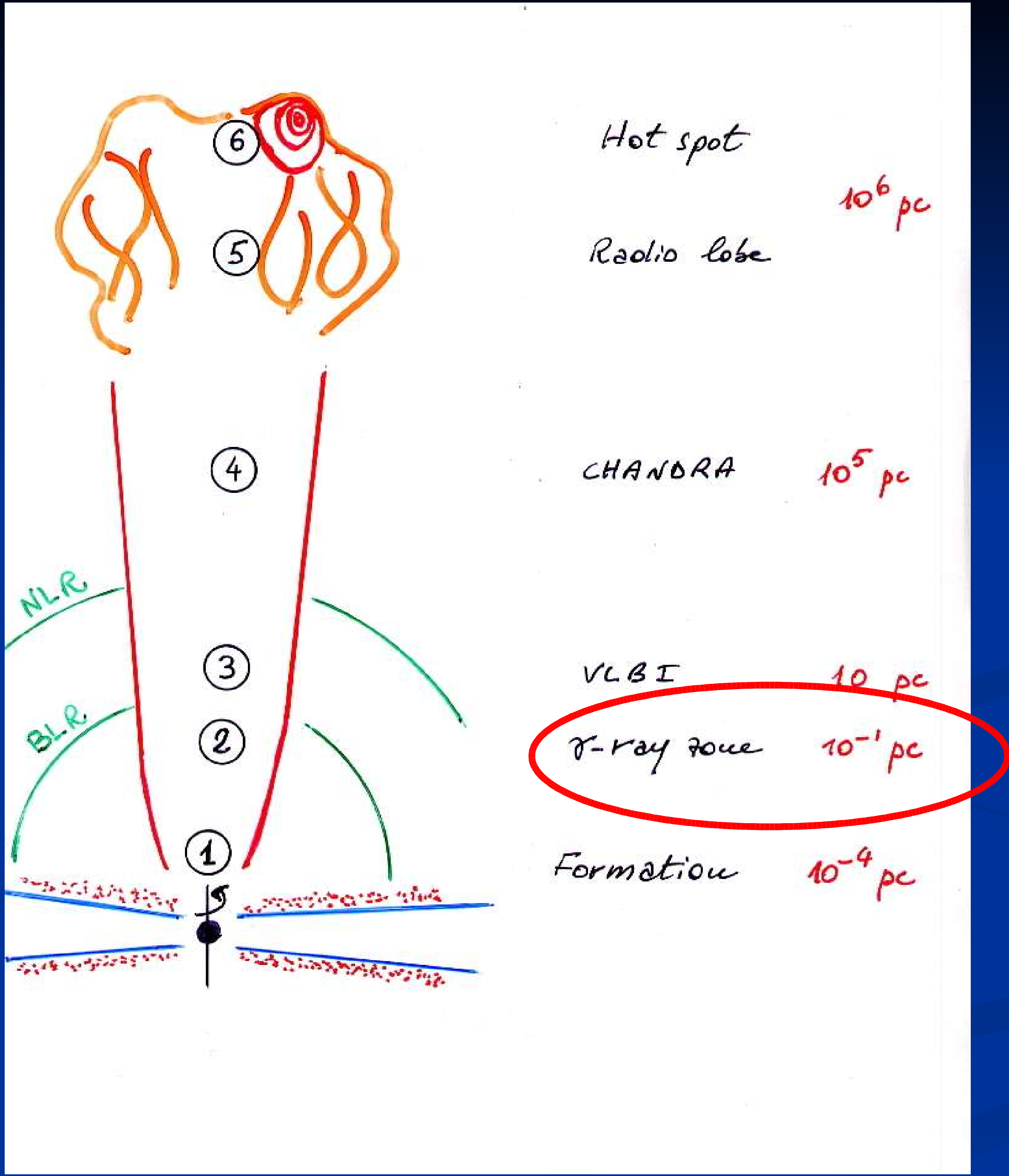
Γ~10

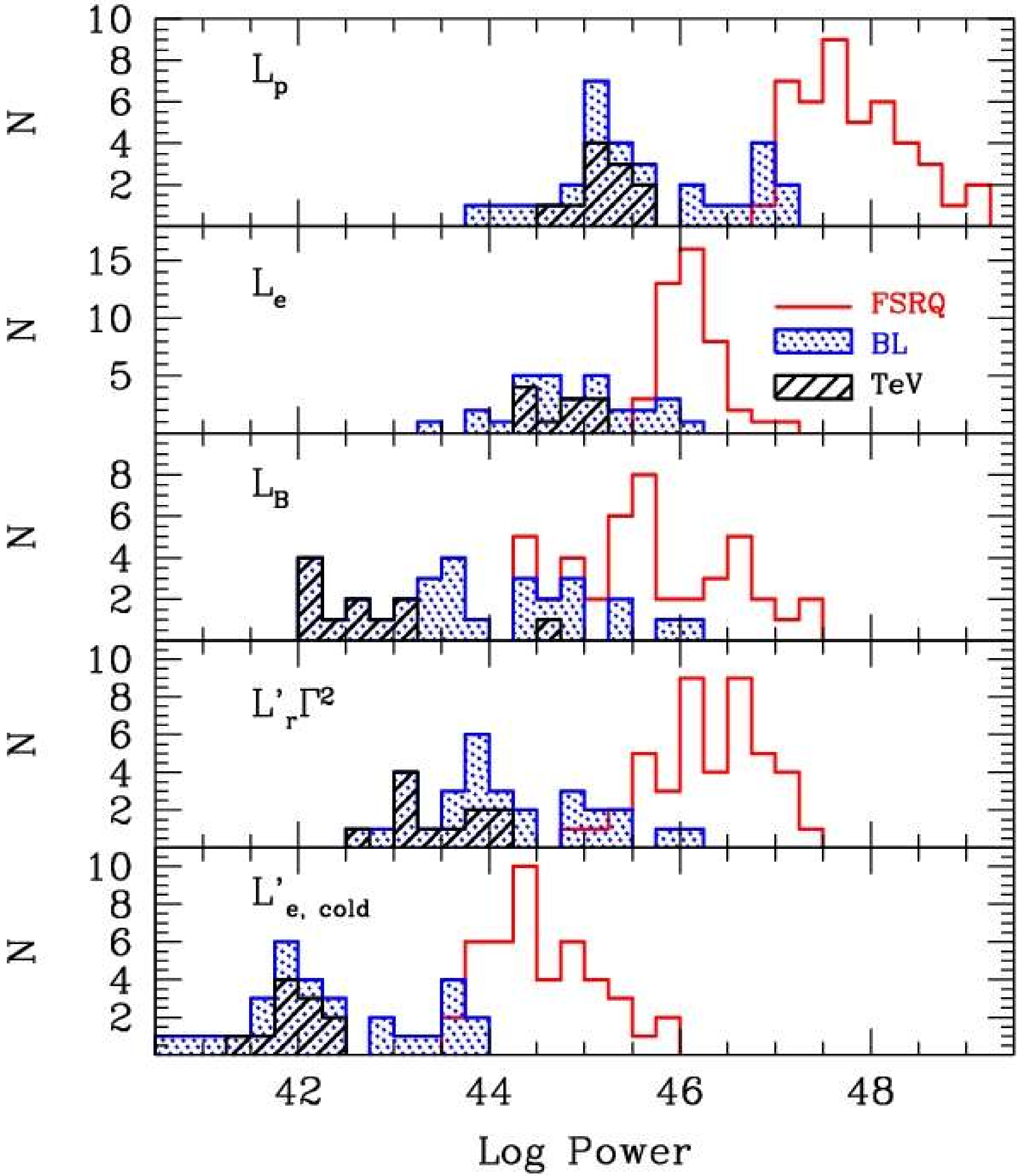
P~10^{47}-10^{48} erg/s

Alternatives: Dermer & Atoyan 2002; Aharonian 2002; Stawarz et al. 2004; Harris et al. 2004

Sambruna et al.2002,2004, Tavecchio et al. 2000, 2004, Celotti et al. 2001; Schwartz

Power of jets in blazars





Celotti & GG in prep

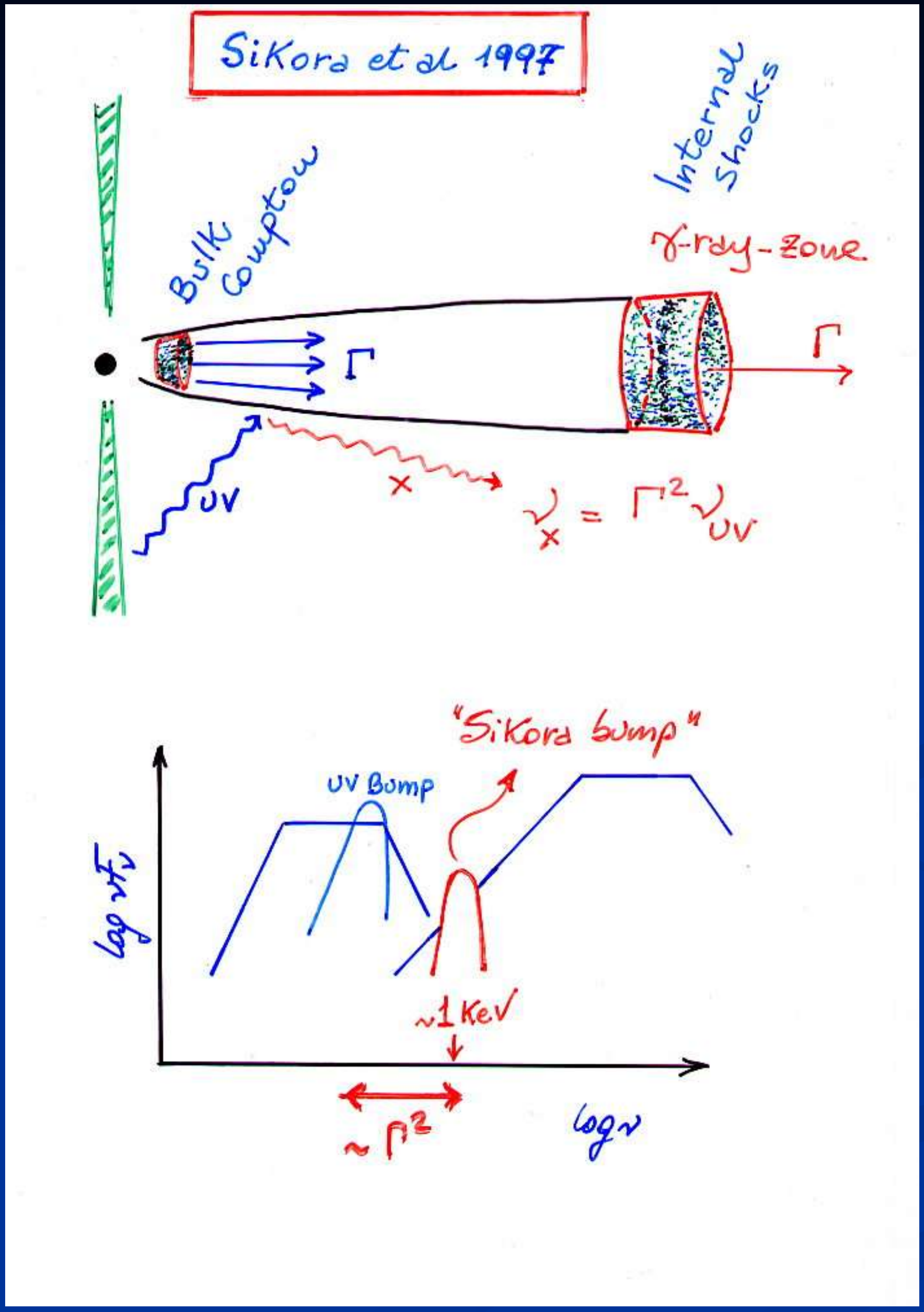
Protons (1 proton per emitting e-)

Relat. Electrons

B-field

Radiation

Cold elecrons

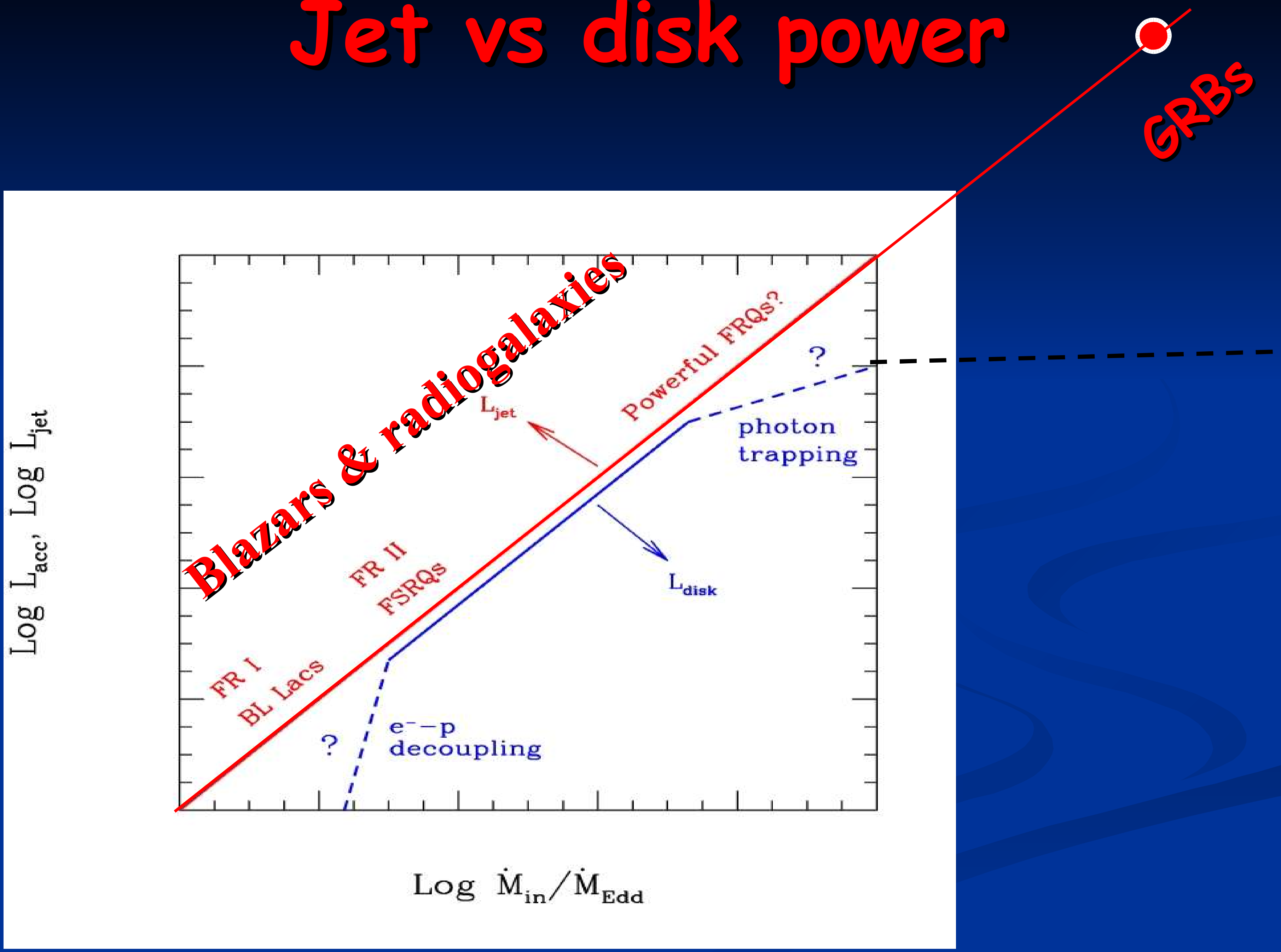


If jet is matter dominated **and fast** from the beginning, it Comptonizes the radiation from the accretion disk...

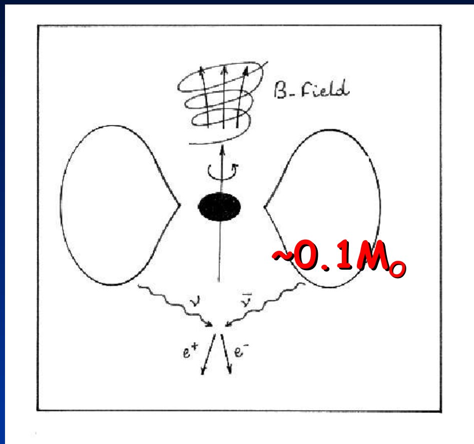
Protons or Poynting?

- Pairs can outnumber protons, but are not dynamically important (Sikora et al. 2005)
- Large L_{ic}/L_{syn} seems to favor protons
- But no signs of bulk Compton…
- Constraints are more severe for powerful jets

Jet vs disk power



Outflowing/inflowing mass rate



$$L_{out} = \dot{M}_{out} \Gamma c^2$$

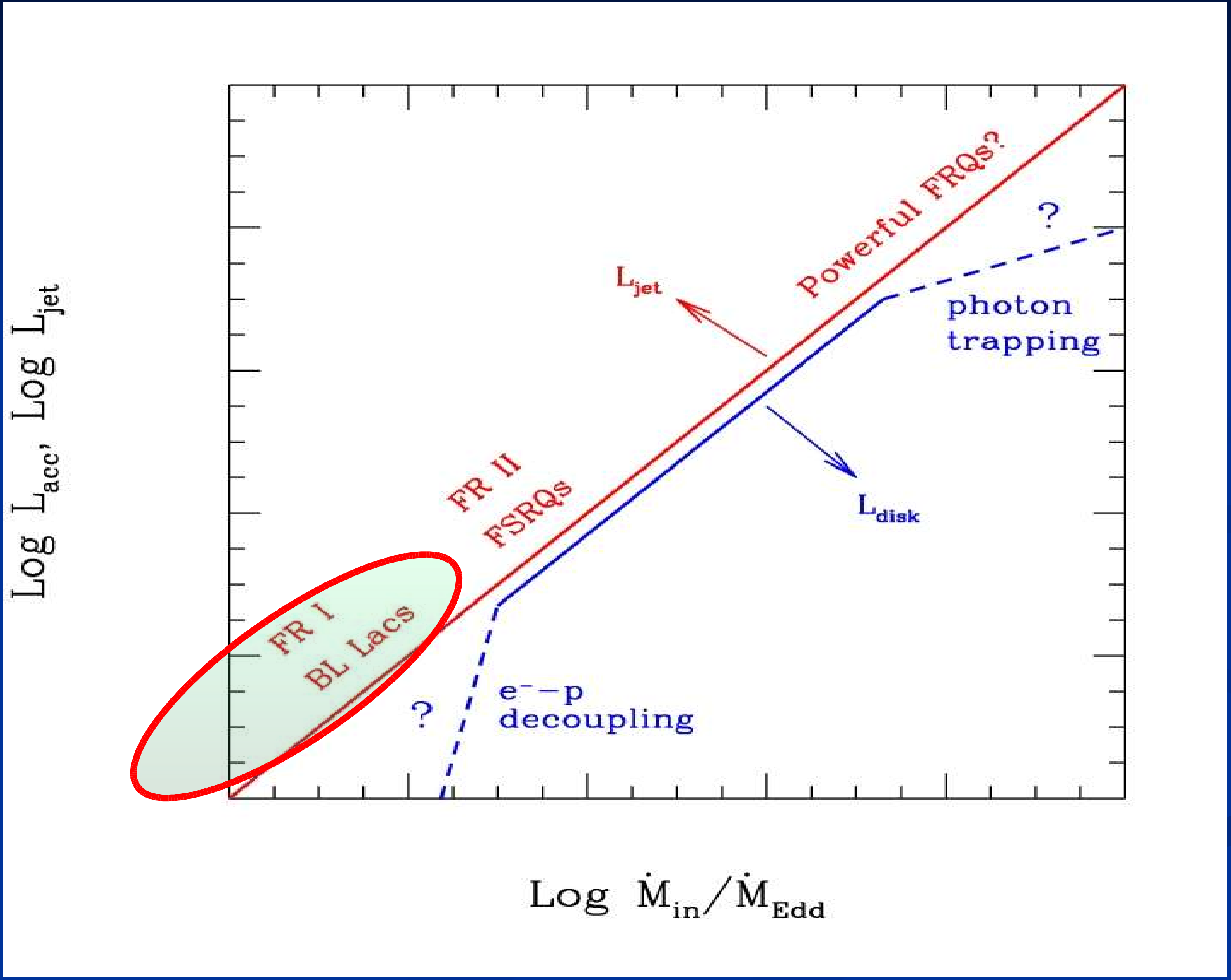
$$\dot{M}_{in} \sim M_{Torus}/t_{burst}$$

$$\frac{\dot{M}_{out}}{\dot{M}_{in}} \sim \frac{L_{out}\ t_{burst}}{\Gamma M_{Torus} c^2} \sim 0.005 \frac{E_{burst,52}}{\Gamma_2 M_{Torus,-1}}$$

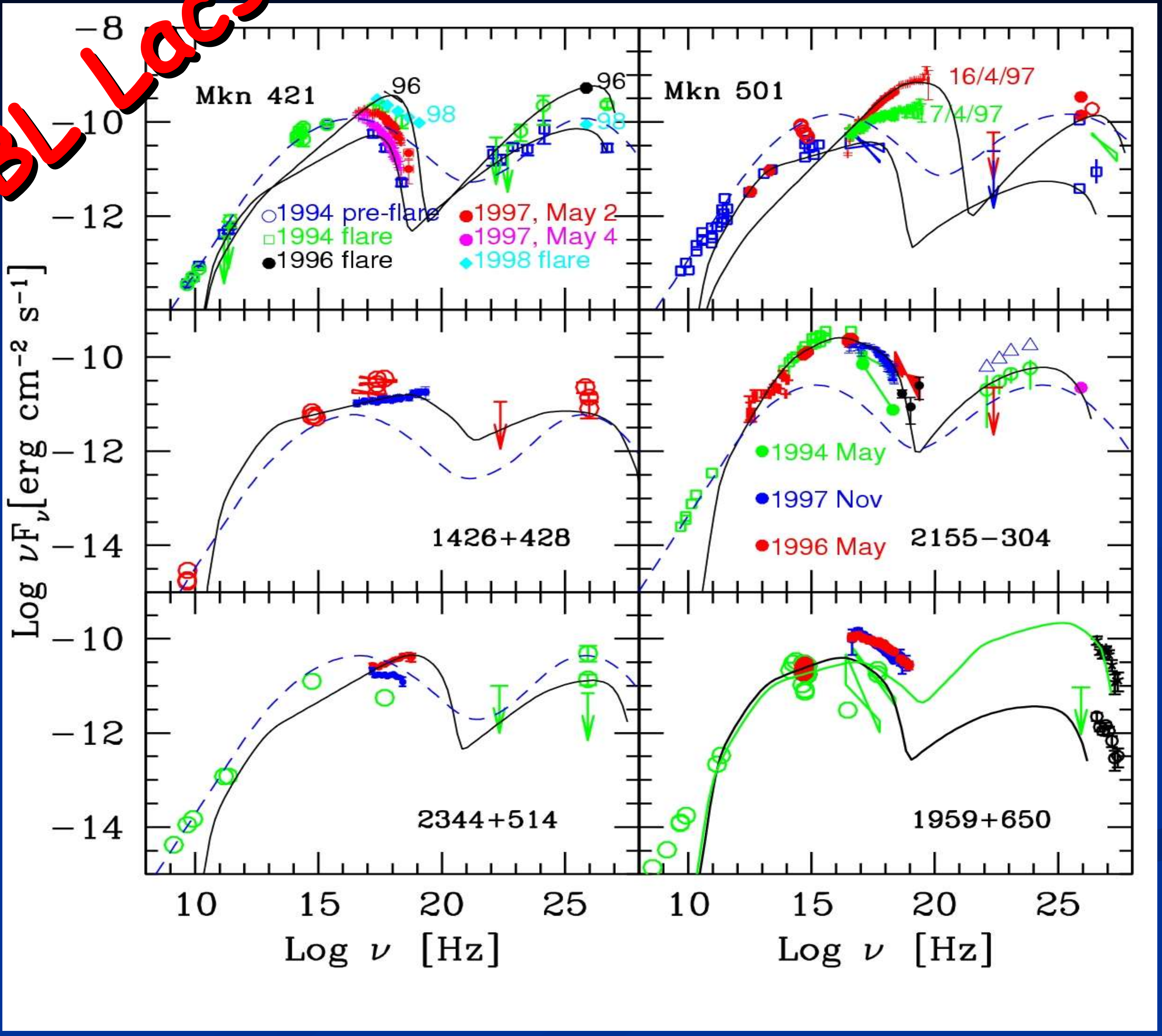
For blazars: $L_{disk} = \eta \dot{M}_{in} c^2$

$$\frac{\dot{M}_{out}}{\dot{M}_{in}} \sim 0.01 \frac{\eta_{-1} L_{out}}{\Gamma_1 L_{disk}}$$

Jet vs disk power



TeV BL Lacs


Mkn 421
96
96
98
98
1994 pre-flare
1994 flare
1996 flare
1997, May 2
1997, May 4
1998 flare
Mkn 501
16/4/97
7/4/97
1426+428
1994 May
1997 Nov
1996 May
2155−304
2344+514
1959+650
Log νF_ν [erg cm^{-2} s^{-1}]
Log ν [Hz]
Log ν [Hz]

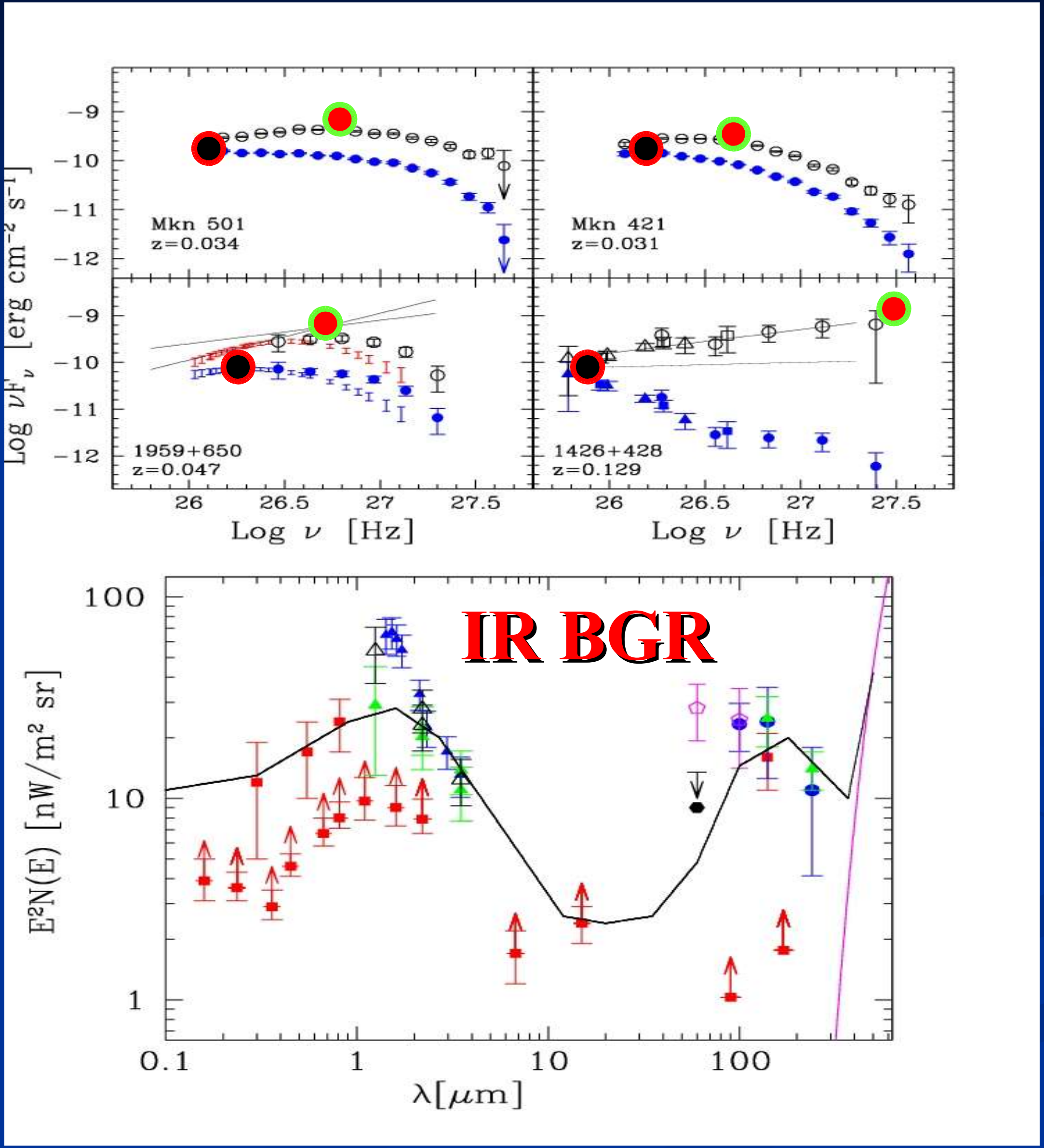
High energy peak is getting large

Mkn 501

1959

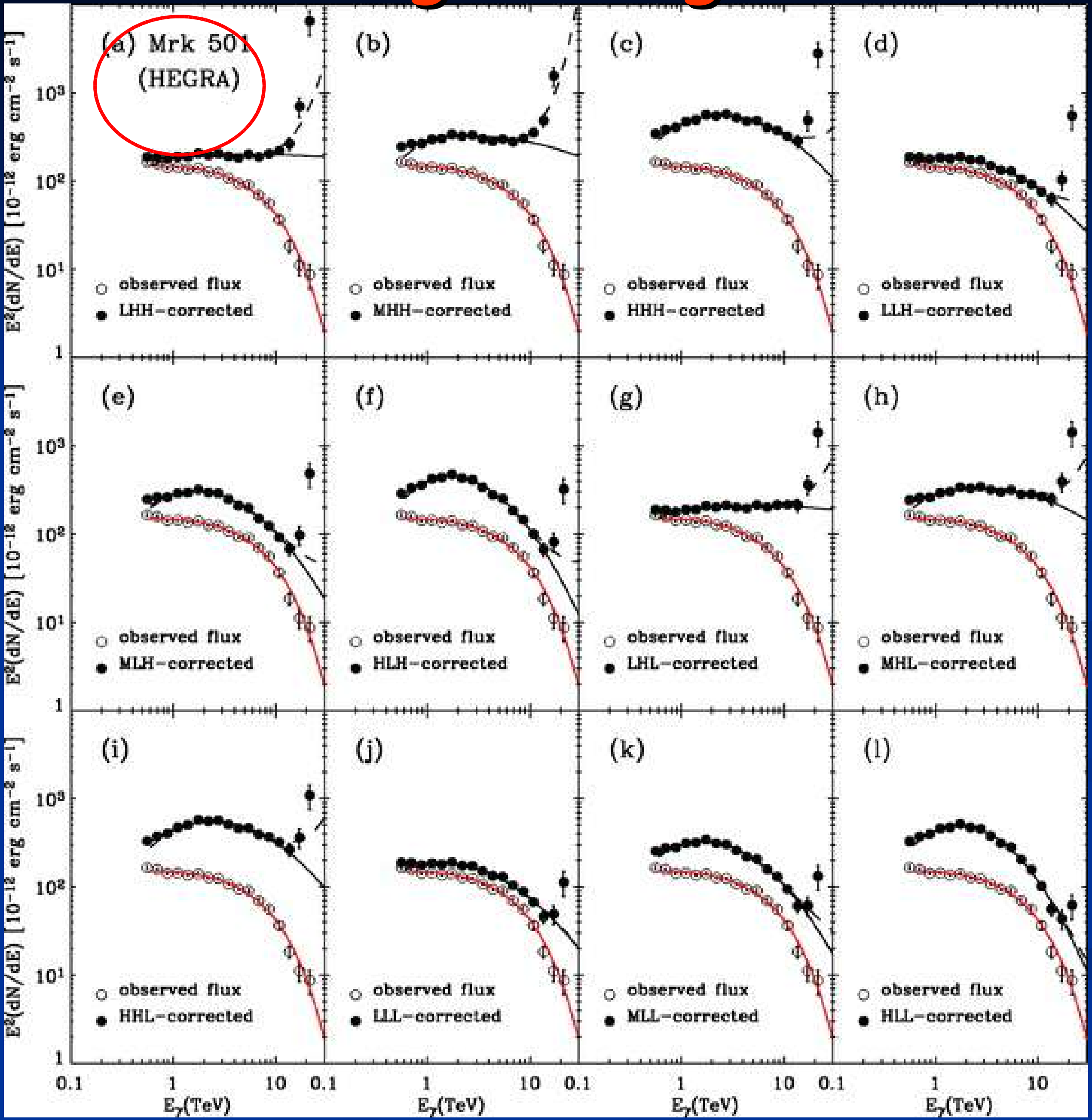
Mkn 421

1426



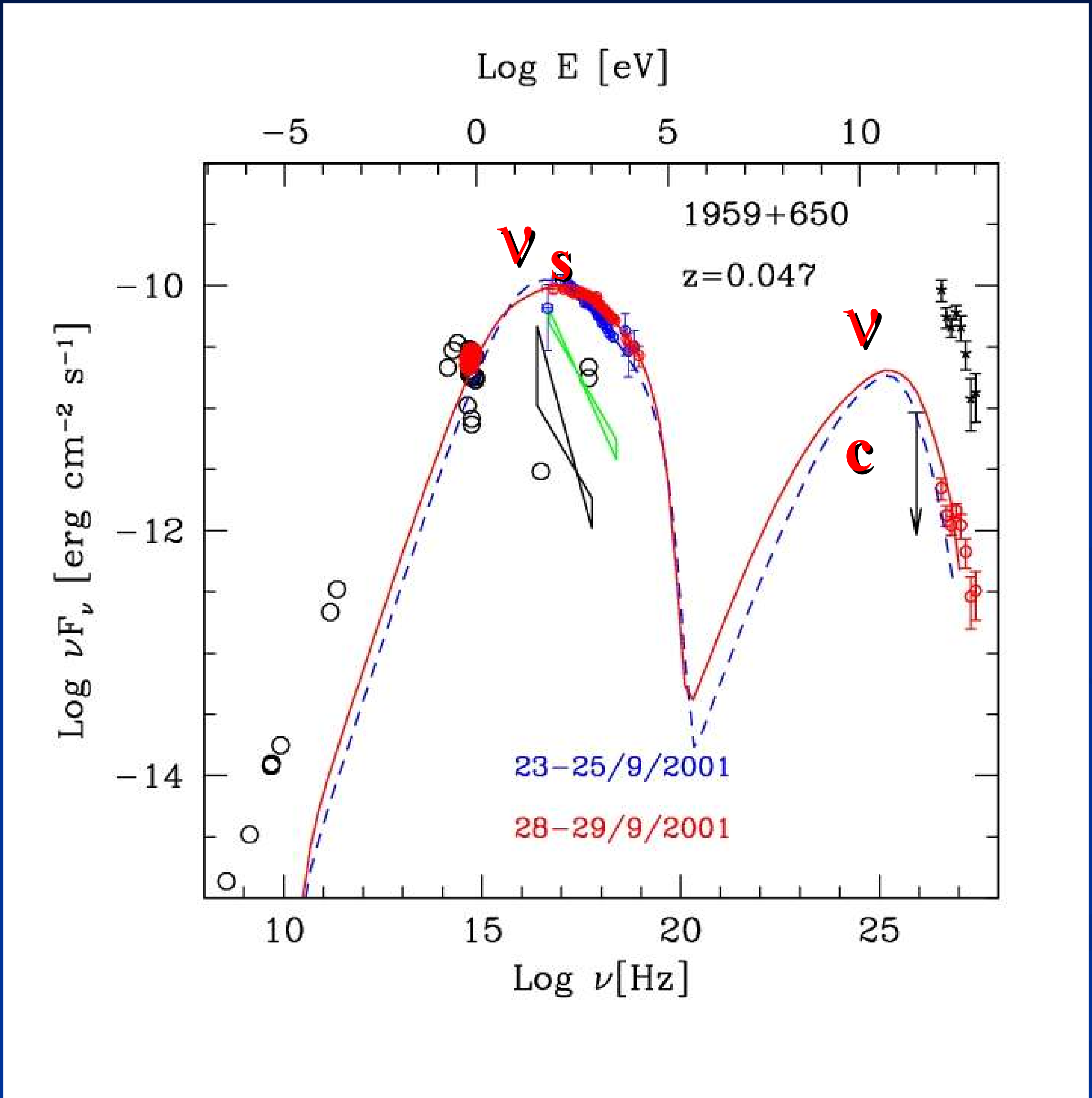
Costamante et al. 2003

Testing IR bkg models



Dwek & Krennrich 2005

Why δ >20?



$\nu_c/\nu_s \sim \gamma^2$

$\nu_s \sim \gamma^2 B\delta$

⇒ $B\delta \sim \gamma^{-2}$

$L_c/L_s \sim L_s/(B^2\delta^6)$

$\sim L_s\gamma^4/\delta^4$

⇒ $\delta \propto \nu_c^{1/2}$

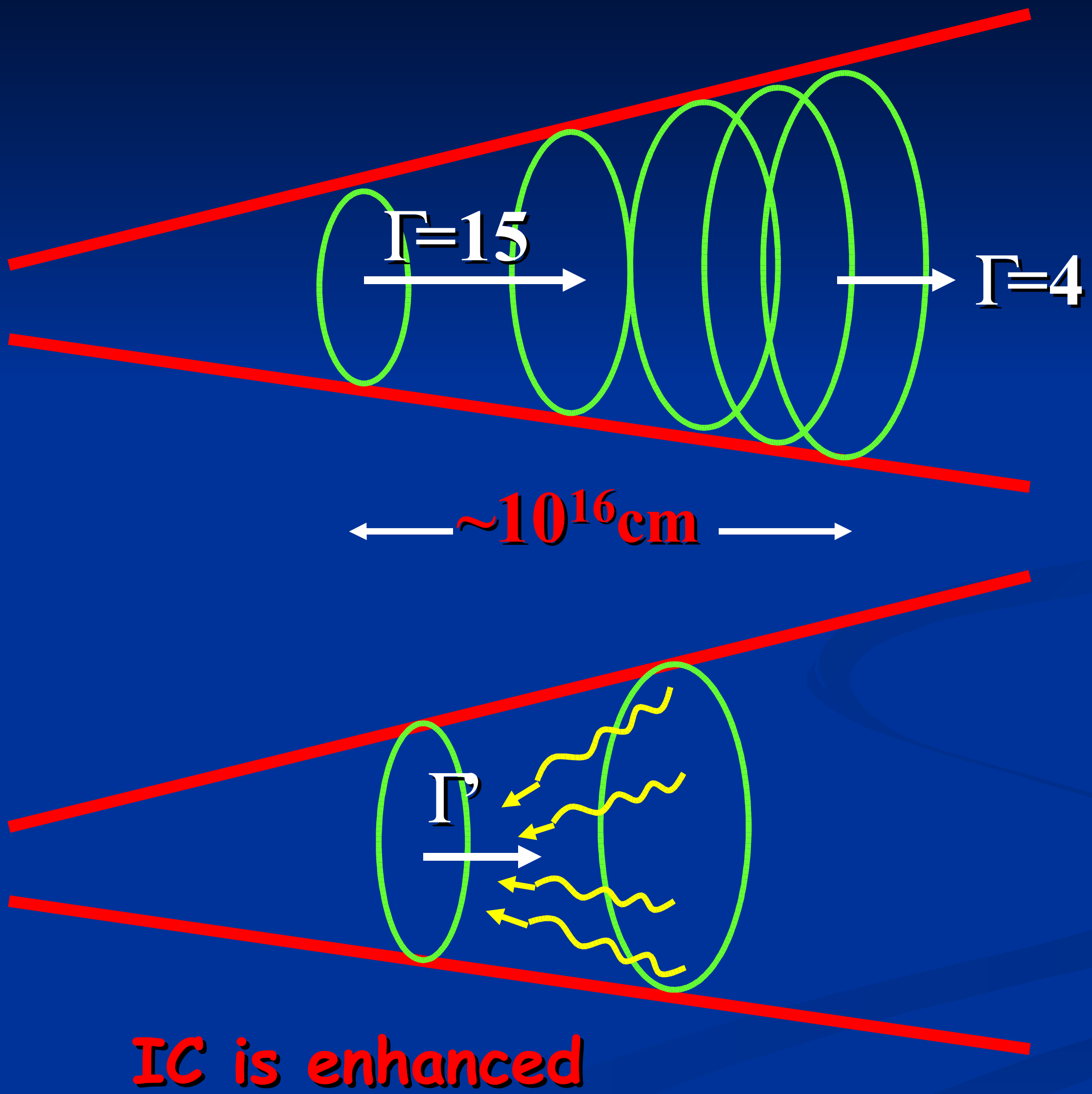
K-N: the same

Subluminal motion for all TeV sources?

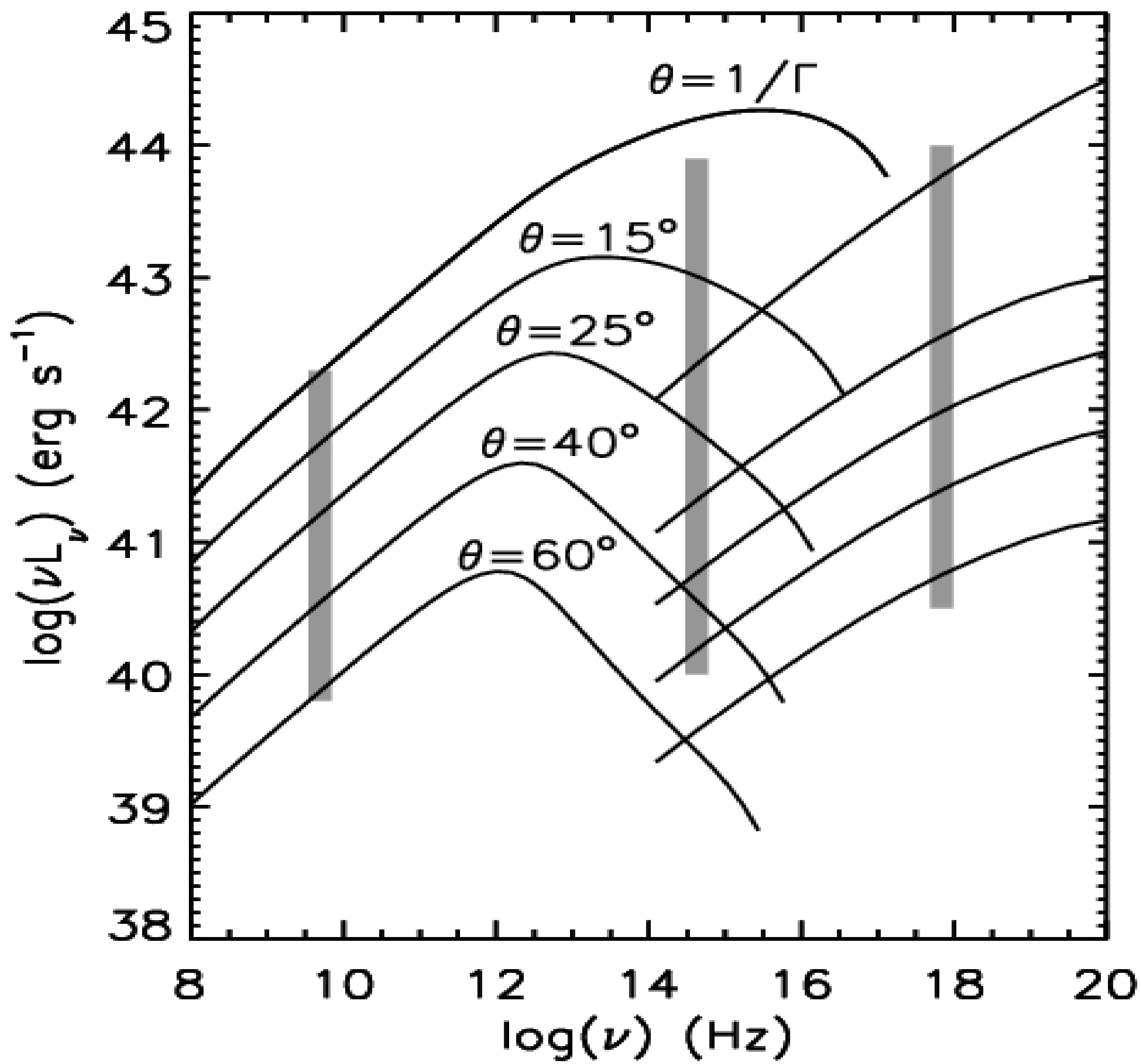
Piner & Edwards, 2004

Mkn 421	$\beta_{app} \sim 0.04 - 0.18$
Mkn 501	$\beta_{app} \sim 0.05 - 0.54$
1959+650	$\beta_{app} \sim 0$
2155-304	$\beta_{app} \sim 4.4$ (+-2.9)
2344+514	$\beta_{app} \sim 0 - 0.5$ (+-0.5)

Decelerating the entire jet



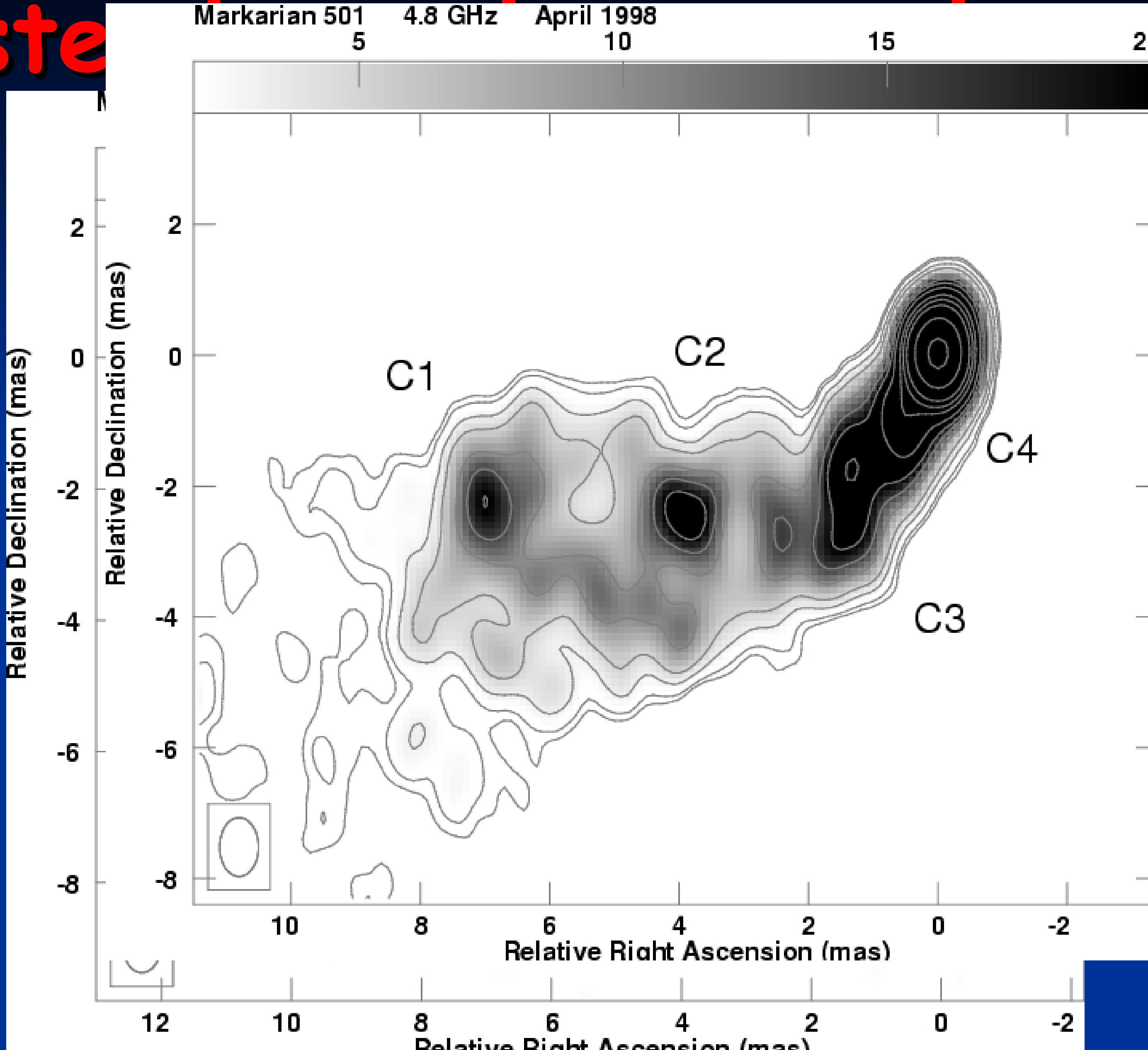
Georganopoulos & Kazanas 2003



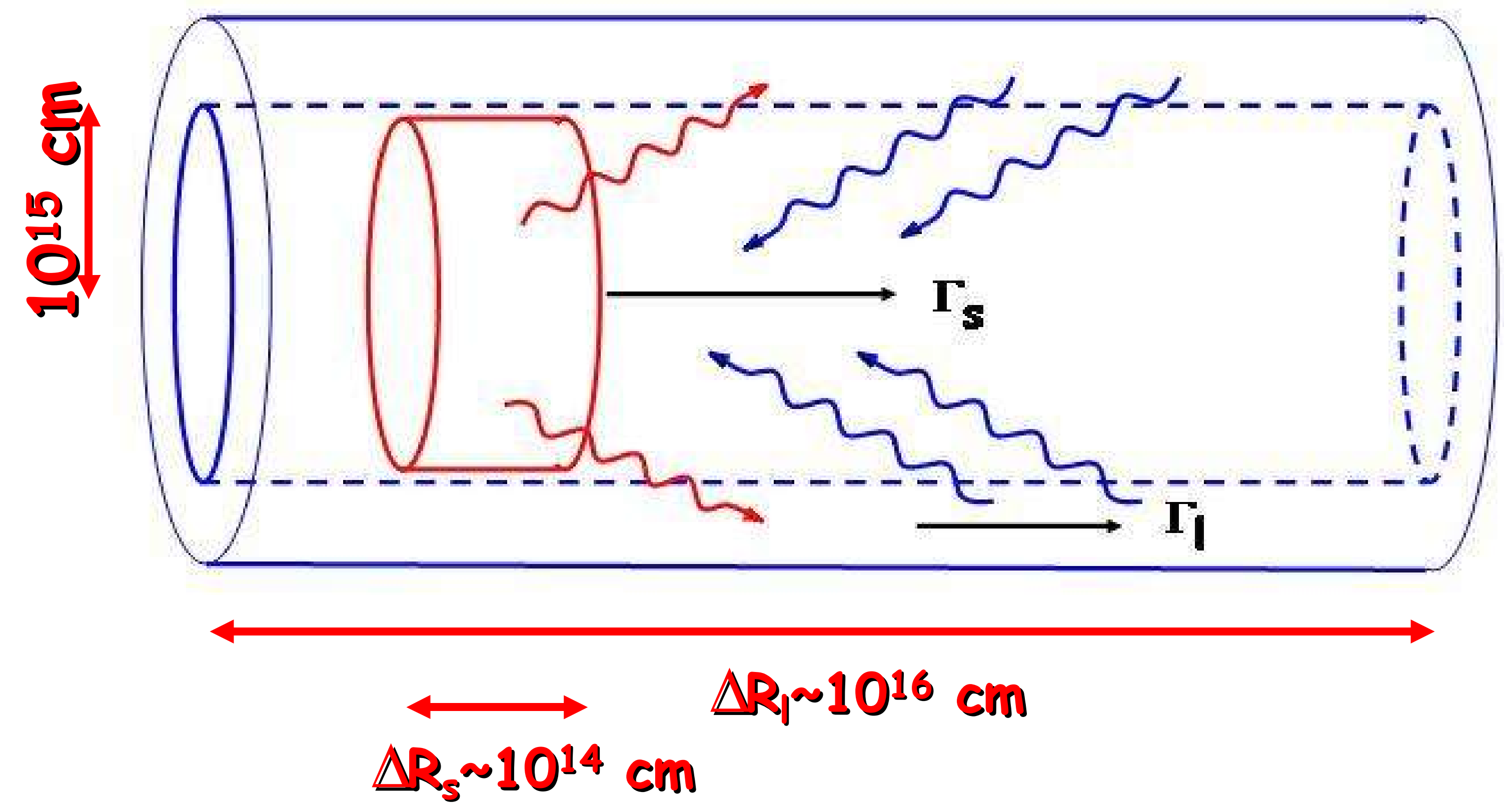
Georganopoulos & Kazanas 2003

Inste

Giroletti et al. 2004

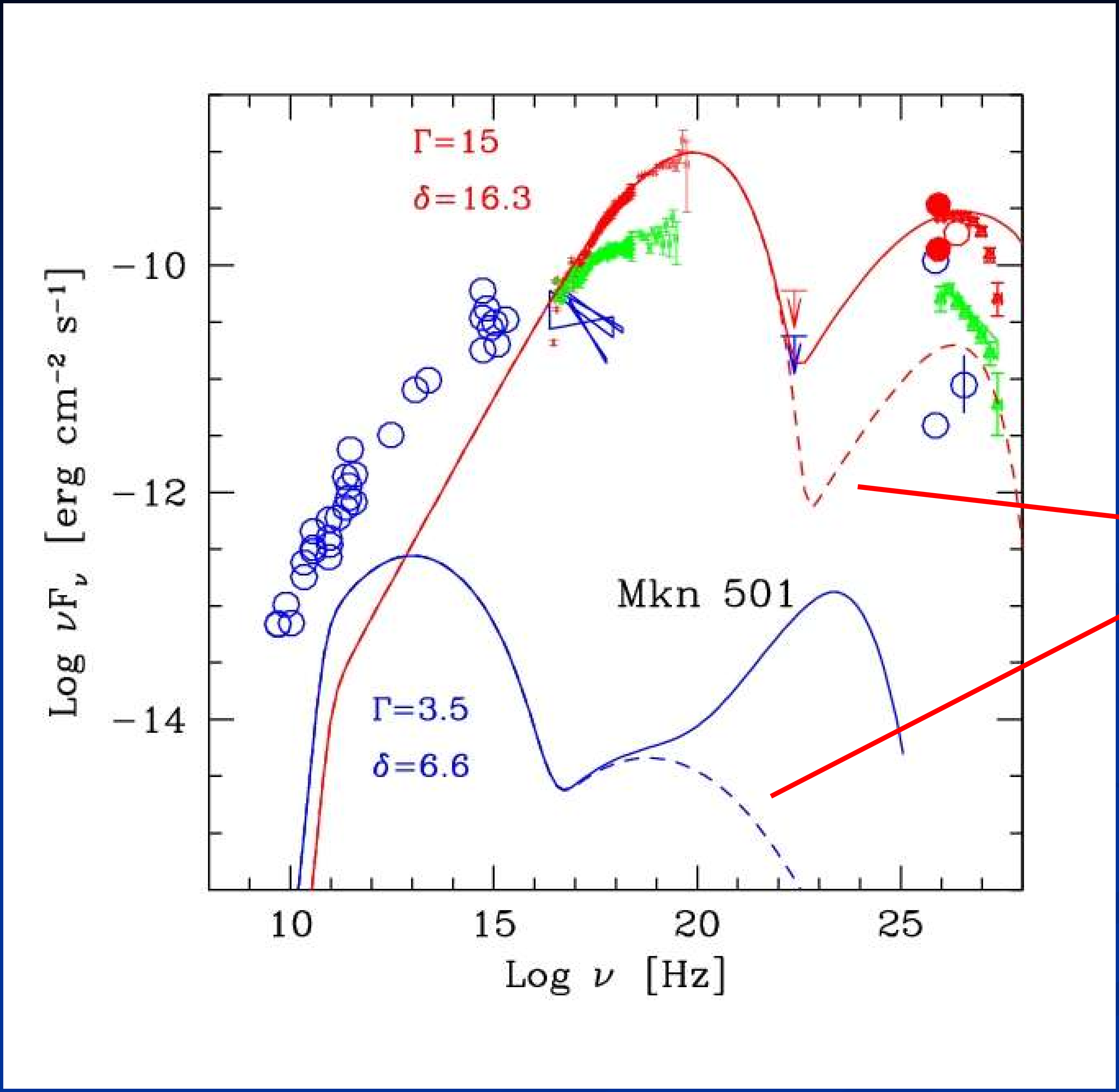


Cospatial fast spine & slow layer



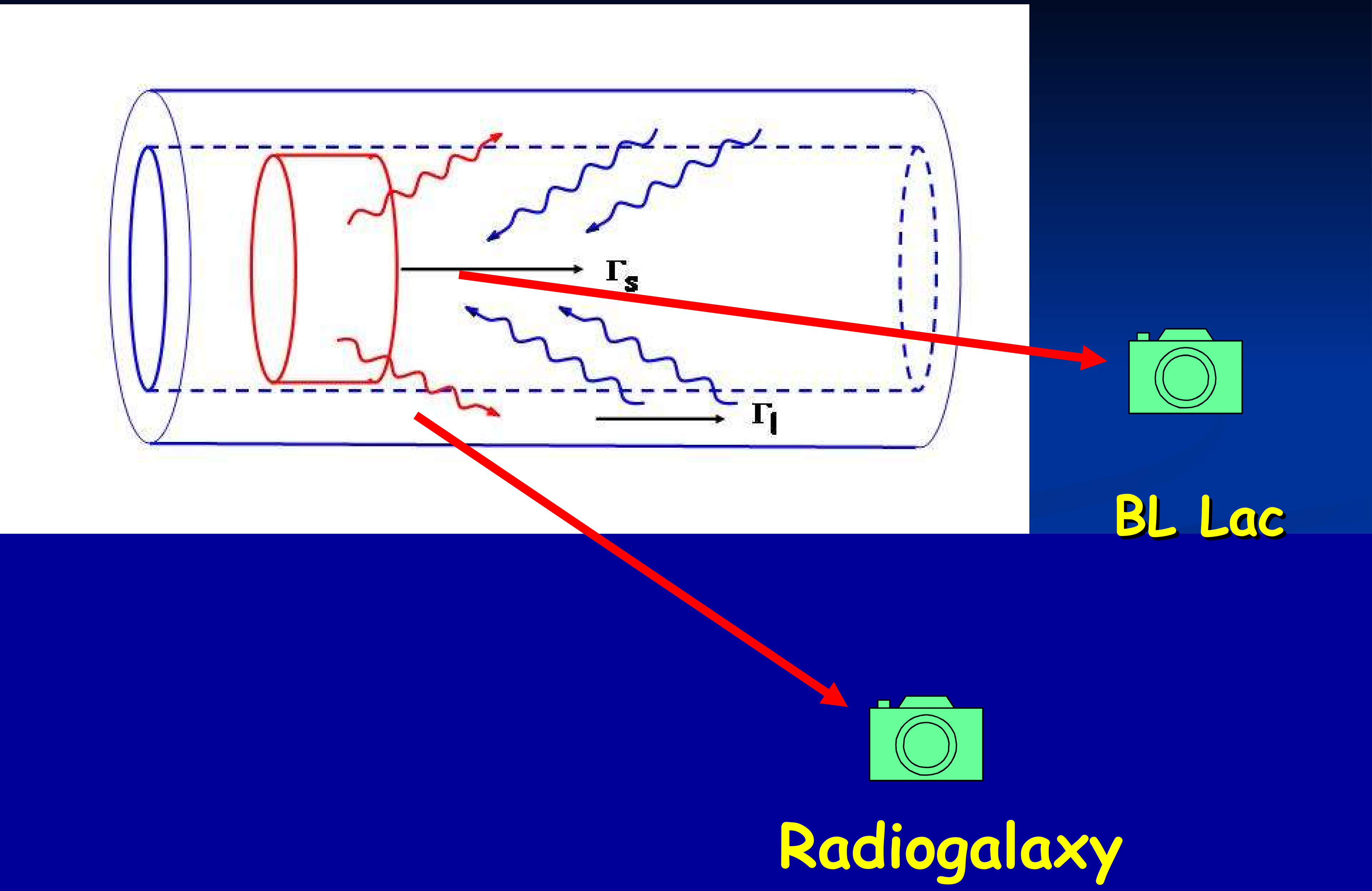
Strong feedback between spine and layer
For both: enhanced IC emission

Ghisellini, Tavecchio, Chiaberge 2005

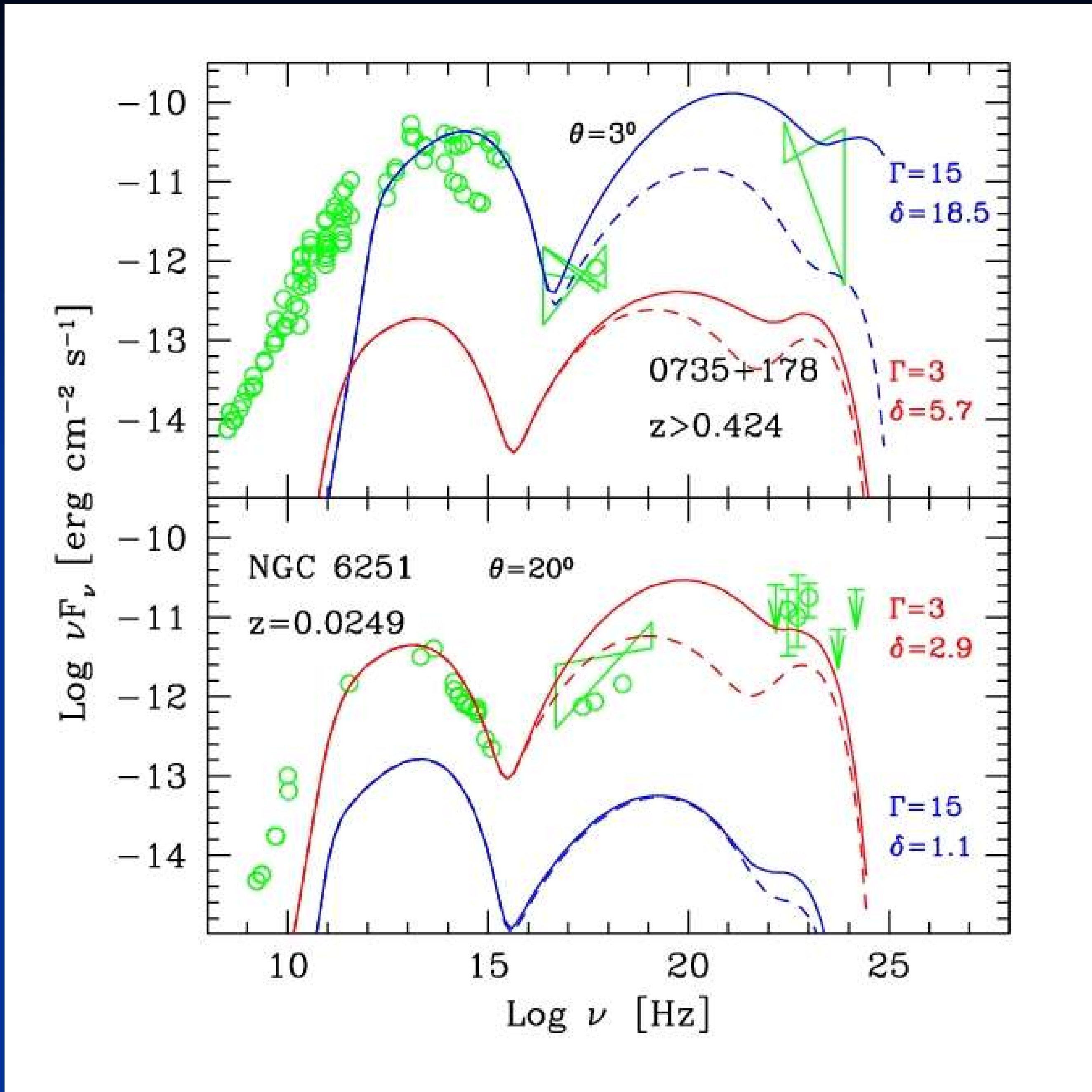


$B = 1.3$ G
$L_e = 4 \times 10^{42}$
$L_B = 1 \times 10^{43}$
$L_p = 2 \times 10^{43}$

No feedback



Γs
Γl
BL Lac
Radiogalaxy



Spine-layer feedback

0735+178

B=5 G

U_B~U_e

L_B~L_e~6x10^{44}

L_p~7x10^{45}

NGC 6251

B=1.8 G

L_B=4x10^{41}

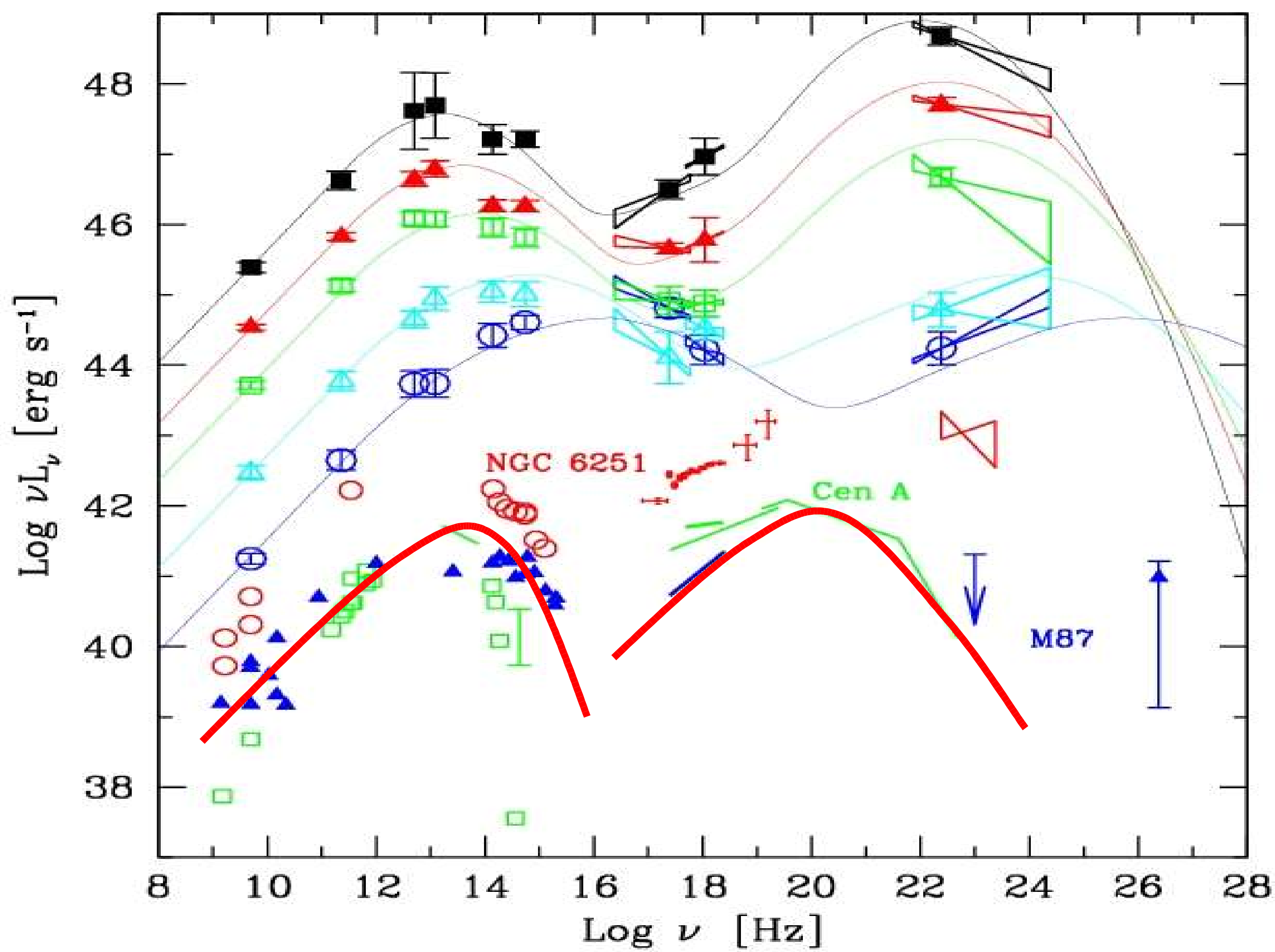
FR1

L_e=2x10^{42}

L_p=2x10^{43}

BL Lac

Fossati et al. 1998



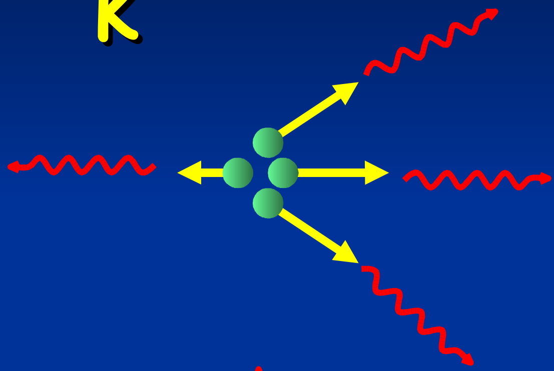
Having increased the B-field, we need fewer electrons to do the radiation we see

The jet is lighter

It is easier to make it decelerate

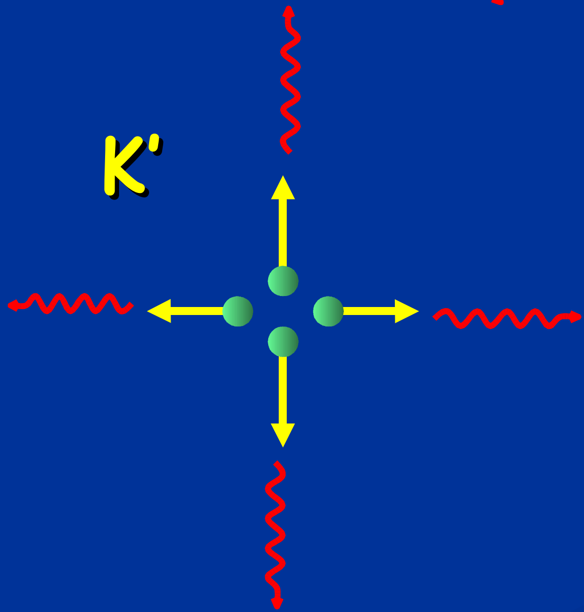
Synchro and SSC

K



In K there is a loss of momentum…

K'

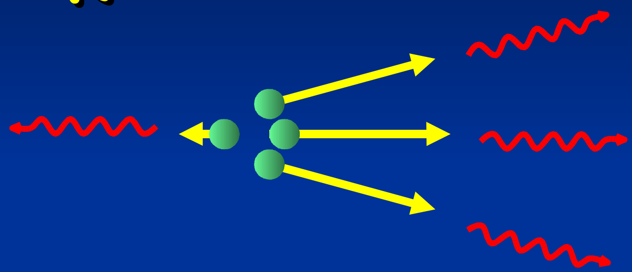


And in K'? no, but the mass $\langle \gamma \rangle m_e$ decreases.

Γ_{bulk} remains the same

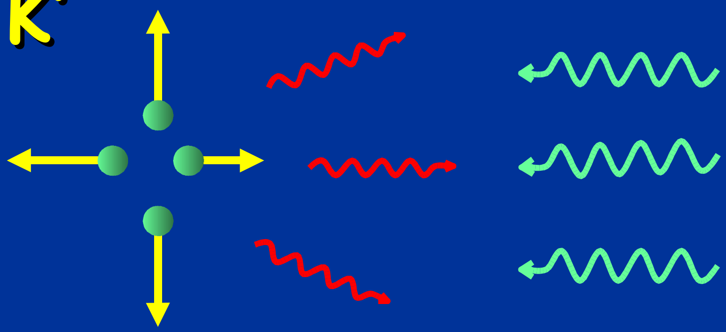
External Compton: the rocket

K



more collimated than before
(Dermer 1995)

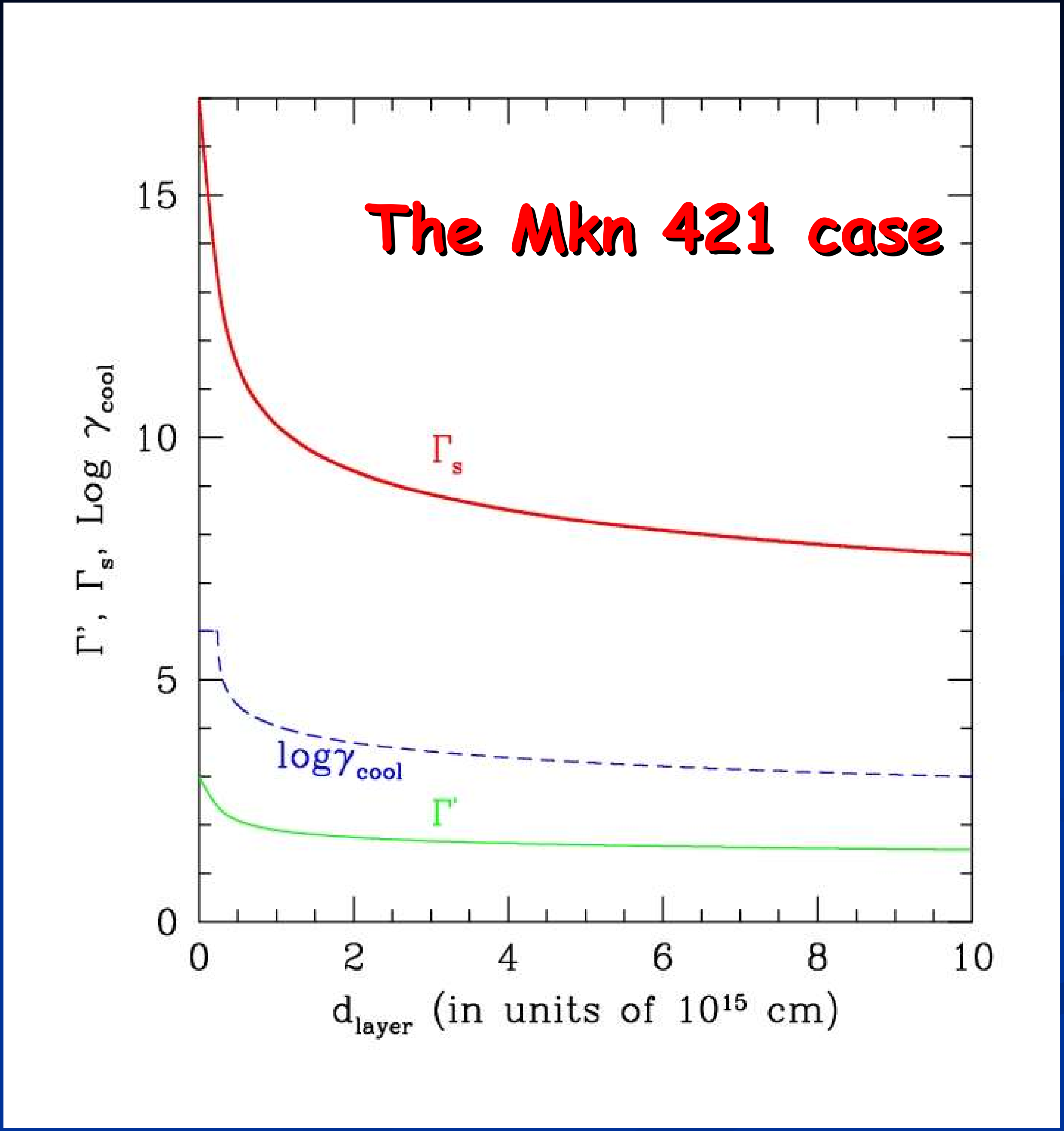
K'



Anisotropic! Loss of momentum ⇒ recoil

Important when $<\gamma> m_e \sim m_p$

Γ_{bulk} decreases



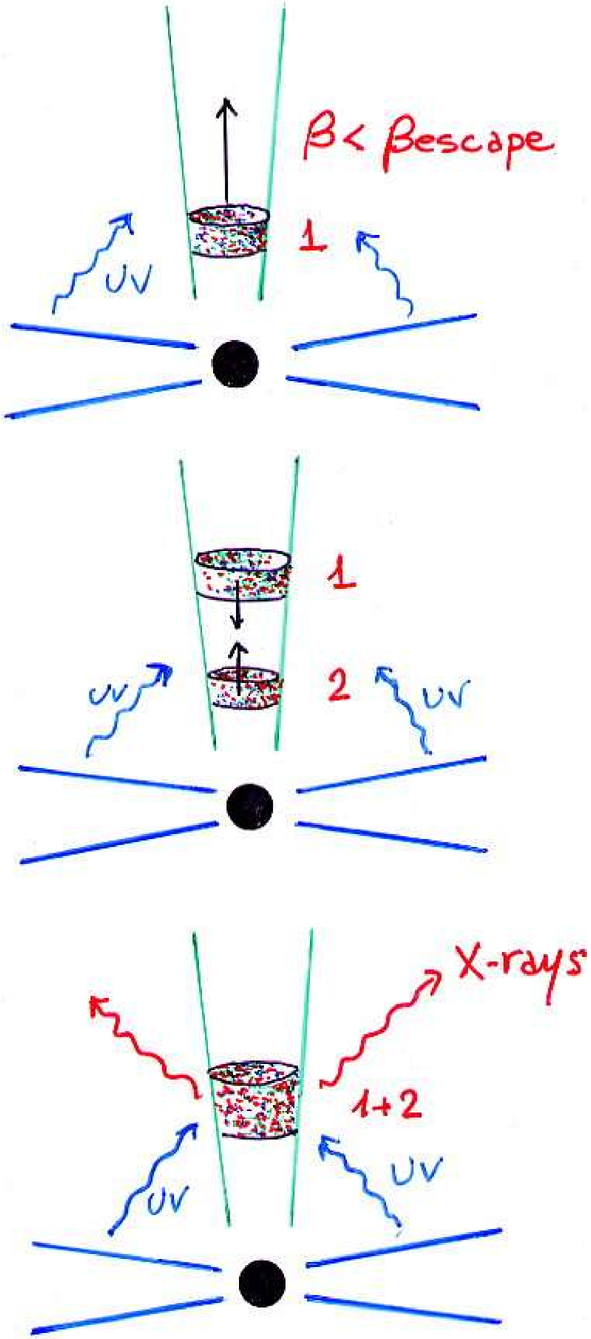
The Mkn 421 case
Γ_s
$\log\gamma_{cool}$
Γ'
Γ', Γ_s, Log γ_{cool}
d_{layer} (in units of 10^{15} cm)
0
5
10
15
0
2
4
6
8
10

Consequences

Low power jets decelerate more?

Extended emission smaller for TeV BL Lacs?

Large angles? Layer. Also GeV-TeV for radio-galaxies (GLAST)



Aborted Jets

$\dot{M}_{out}=\dot{M}_{in}$; $P_{jet}=P_{disk}$

Relative kinetic energy ⇒ heating

UV radiation field ⇒ cooling

⇒ Thermal plasma (T_e~50-100 keV)

⇒ Comptonization

If P_{jet}~P_{di}

Ghisellini, Haardt & Matt 2004

Open issues

- We "know" the radiated power. We "guess" the kinetic power (AGILE-GLAST-Cherenkov)
- We must find the energy carriers. Matter or Poynting flux? (Compt. bump – theory)
- Similarities with GRBs are intriguing, do they mean something, or coincidence? (continue…)
- P_{jet} can be > $P_{accretion}$ (ADAF for FR I?)
- Radio-loud vs quiet (a matter of M_{out}/M_{in}? or M_{BH}, or BH spin?)