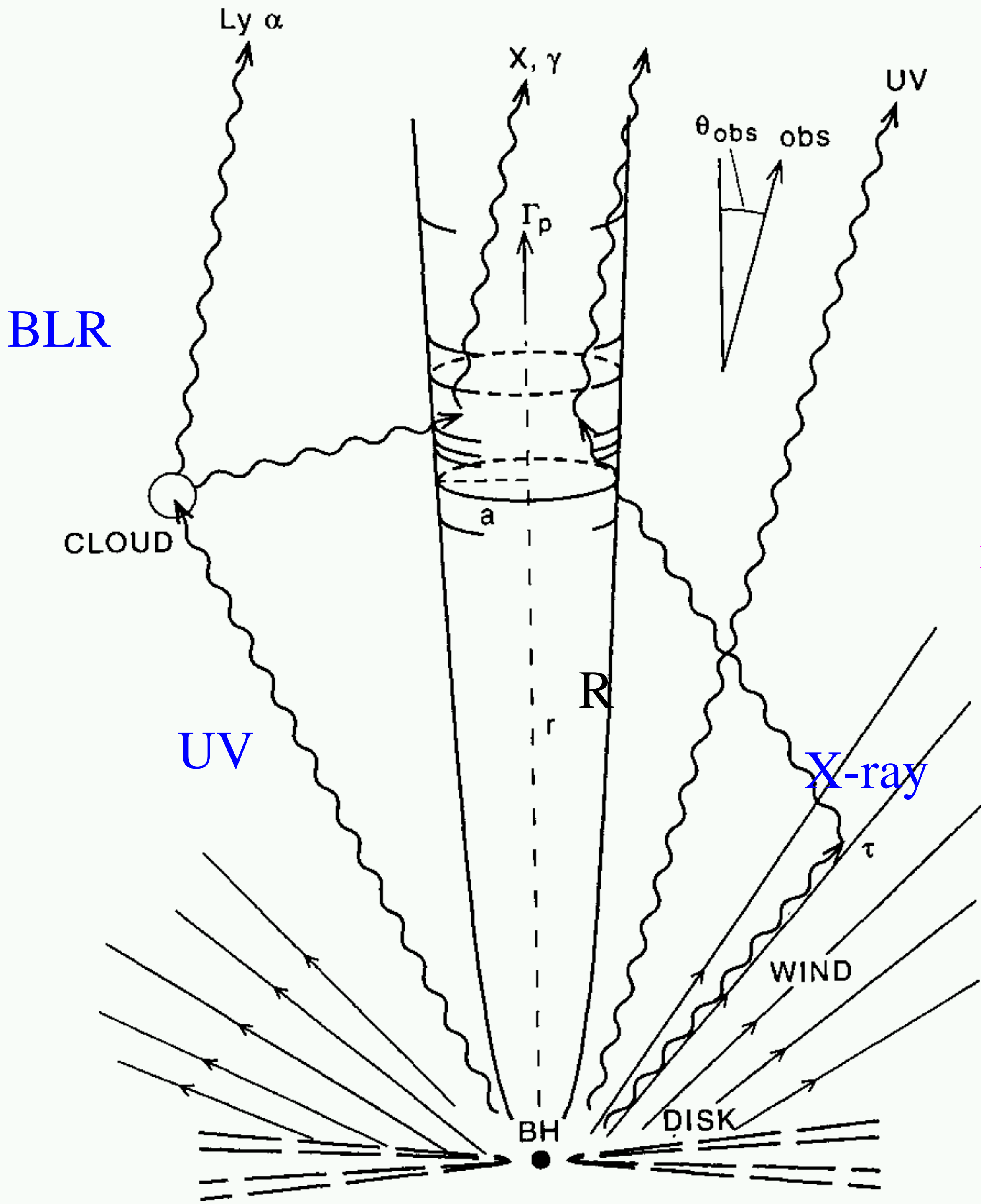
# Blazars as probes of jet sub-parsec regions

*Luigi Costamante, MPI-K Heidelberg*

Jet composition, Jet structure, Jet velocity.
Location of SED-peak emitting region.
Gamma-rays as probes of external fields.
Physics of flares (variability patterns).

Common wisdom developed mostly on FSRQ.
New insights from HBL-TeV Blazars ??

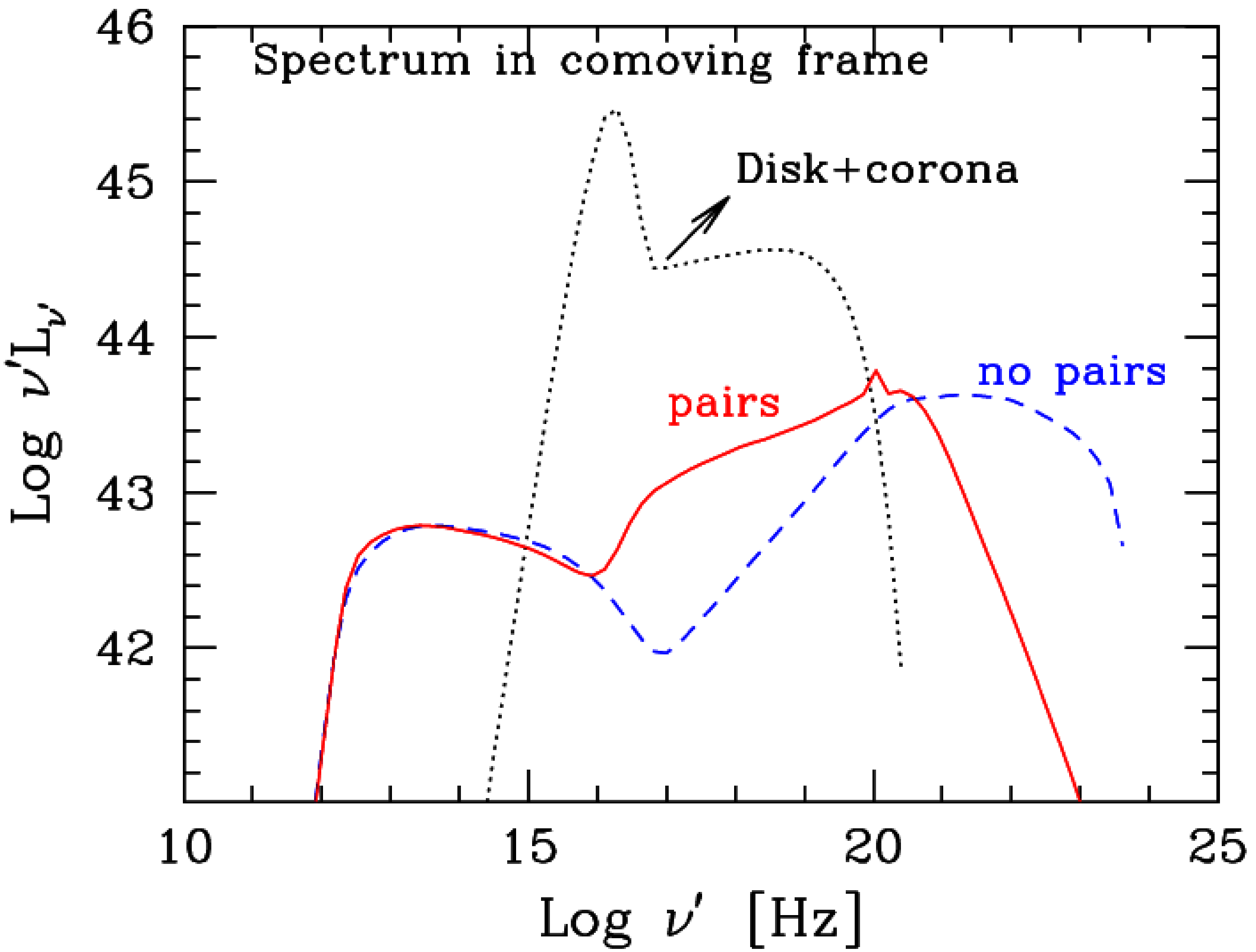



Sikora Begelmann Rees 1994

| dimensions: | FSRQ properties (Egret): |
| --- | --- |
| VLBI e17 – e19 | |
| e17 | EC modelling |
| $r_{blob}$ ~ e16 | Variability (1d) |
| | $L_{lines}$ ~$10^{44\text{-}45}$ |
| | $L_{lines}$ ~ 0.1 $L_{disk}$ |
| e14 - e15 | X-rays ($\gamma\gamma$-> e+e-)<br>UV (coolers)<br>--> soft X spectra |

Ghisellini & Madau 1996

If pair production X-UV is important --> softer X-spectra than observed (for FSRQ)




r ~ e15

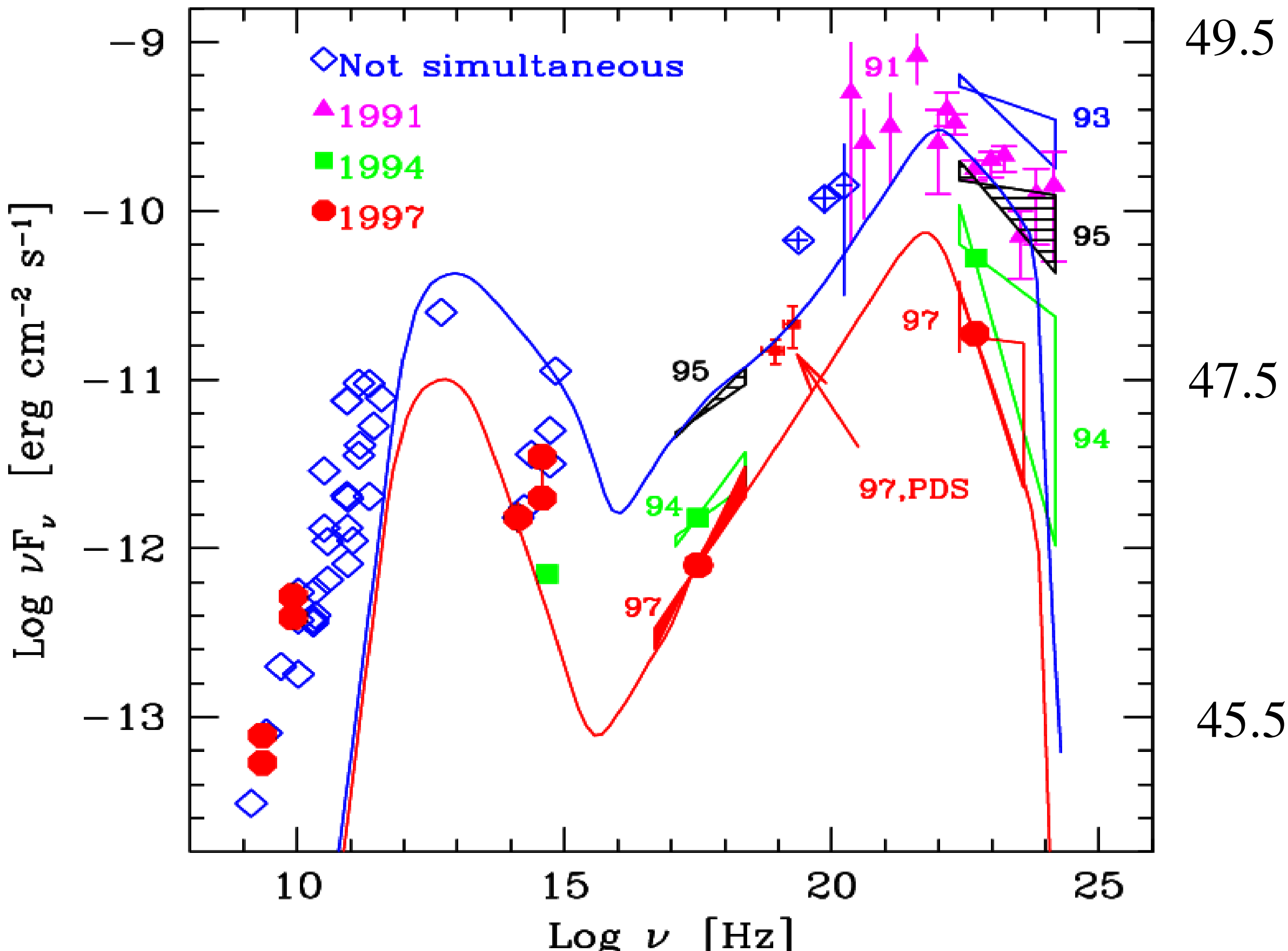
Γ=15

R ~e16

$L_{disk}$ ~$10^{46}$

Ghisellini 2003

# e.g. PKS 0528+134 (z=2.07)
# ...but consider PDS points: why often higher ?




Ghisellini, Costamante et al. 1999

FSRQ

TABLE 3

Apparent Speeds

| Source | Component | $\mu$ (mas yr$^{-1}$) | $\beta_{app}$ | $n$[a] | Quality[b] |
|---|---|---|---|---|---|
| 0235+164 ....... | C1 | 0.51 ± 0.14 | 25.6 ± 7.0 | 2 | P |
| | C2 | 0.18 ± 0.03 | 8.9 ± 1.3 | 4 | G |
| | C3 | 0.16 ± 0.09 | 7.9 ± 4.7 | 4 | P |
| 0827+243 ....... | C2 | 0.51 ± 0.09 | 25.6 ± 4.4 | 3 | E |
| | C3 | 0.38 ± 0.07 | 19.2 ± 3.7 | 3 | E |
| | C4 | 0.24 ± 0.15 | 12.3 ± 7.4 | 2 | F |
| | C5 | 0.24 ± 0.16 | 12.1 ± 8.1 | 2 | P |
| | C6 | 0.06 ± 0.07 | 3.2 ± 3.7 | 4 | F |
| 1406−076 ...... | C1 | 0.22 ± 0.19 | 15.6 ± 13.2 | 1 | P |
| | C2 | 0.40 ± 0.09 | 28.2 ± 6.6 | 2 | F |
| | C3 | 0.32 ± 0.13 | 22.5 ± 8.9 | 2 | F |
| | C4 | 0.23 ± 0.03 | 15.8 ± 2.0 | 4 | G |

[a] Radial error bars are expressed as a fraction $1/2^n$ of the beam.
[b] Quality code: excellent (E), good (G), fair (F), or poor (P).

$$\beta_{app} \le \beta\Gamma$$

$$\Rightarrow \ \Gamma \sim 25\text{-}30 \quad \text{at} \ \sim 8 \text{ pc !}$$

Piner et al 2004, 2006

In FSRQ, direct evidence for high deltas (vlbi)

in TeV-blazars... no!

TeV BL Lacs, 0.1-0.4 pc

TABLE 3

Apparent Component Speeds in TeV Blazars

| Source | Component | Apparent Speed[a] (multiples of $c$) | Reference | $\theta$[b] (deg) |
|---|---|---|---|---|
| Mrk 421 ............... | C4 | 0.04 ± 0.06 | 1 | |
| | C5 | 0.20 ± 0.05 | 1 | 0.2 |
| | C6 | 0.18 ± 0.05 | 1 | |
| | C7 | 0.12 ± 0.06 | 1 | |
| | C8 | 0.06 ± 0.03 | 1 | |
| Mrk 501 ............... | C1 | 0.05 ± 0.18 | 2 | |
| | C2 | 0.54 ± 0.14 | 2 | 0.6 |
| | C3 | 0.26 ± 0.11 | 2 | |
| | C4 | −0.02 ± 0.06 | 2 | |
| 1ES 1959+650 ...... | C1 | −0.11 ± 0.79 | 3 | 0.8 |
| | C2 | −0.21 ± 0.61 | 3 | |
| PKS 2155−304..... | C1 | 4.37 ± 2.88 | 3 | 4.2 |
| 1ES 2344+514 ...... | C1 | 1.15 ± 0.46 | 3 | 1.3 |
| | C2 | 0.46 ± 0.43 | 3 | |
| | C3 | −0.19 ± 0.40 | 3 | |

[a] For $H_0 = 71$ km s$^{-1}$ Mpc$^{-1}$, $R_m = 0.27$, and $\Omega_m = 0.73$.
[b] Angle to the line of sight calculated for an assumed Doppler factor of 10, using the highest measured component speed (or speed upper limit) for each source. This is *not* meant to be used as the actual Lorentz factor and angle to the line of sight (see text).

(1) B. G. Piner & P. G. Edwards 2003, in preparation. (2) Edwards & Piner 2002, with modified cosmological parameters. (3) This paper.

# Bulk motion Comptonization: and if Γ=100 ?

Cold plasma, FSRQ:

$$L_{BC} \approx 4*10^{46} \left(\frac{\Gamma}{10}\right) \left(\frac{R}{3*10^{17}}\right) \left(\frac{U_{diff}}{3*10^{-3}}\right) \left(\frac{\nu L_{\nu,\gamma}}{10^{48}}\right) \quad \text{erg/s}$$

$$\epsilon_{BC} \approx \Gamma^2 \epsilon_{UV \approx 10\,eV}$$

L(lines) ~ $10^{44}$

R(blr) ok with reverb. mapp.

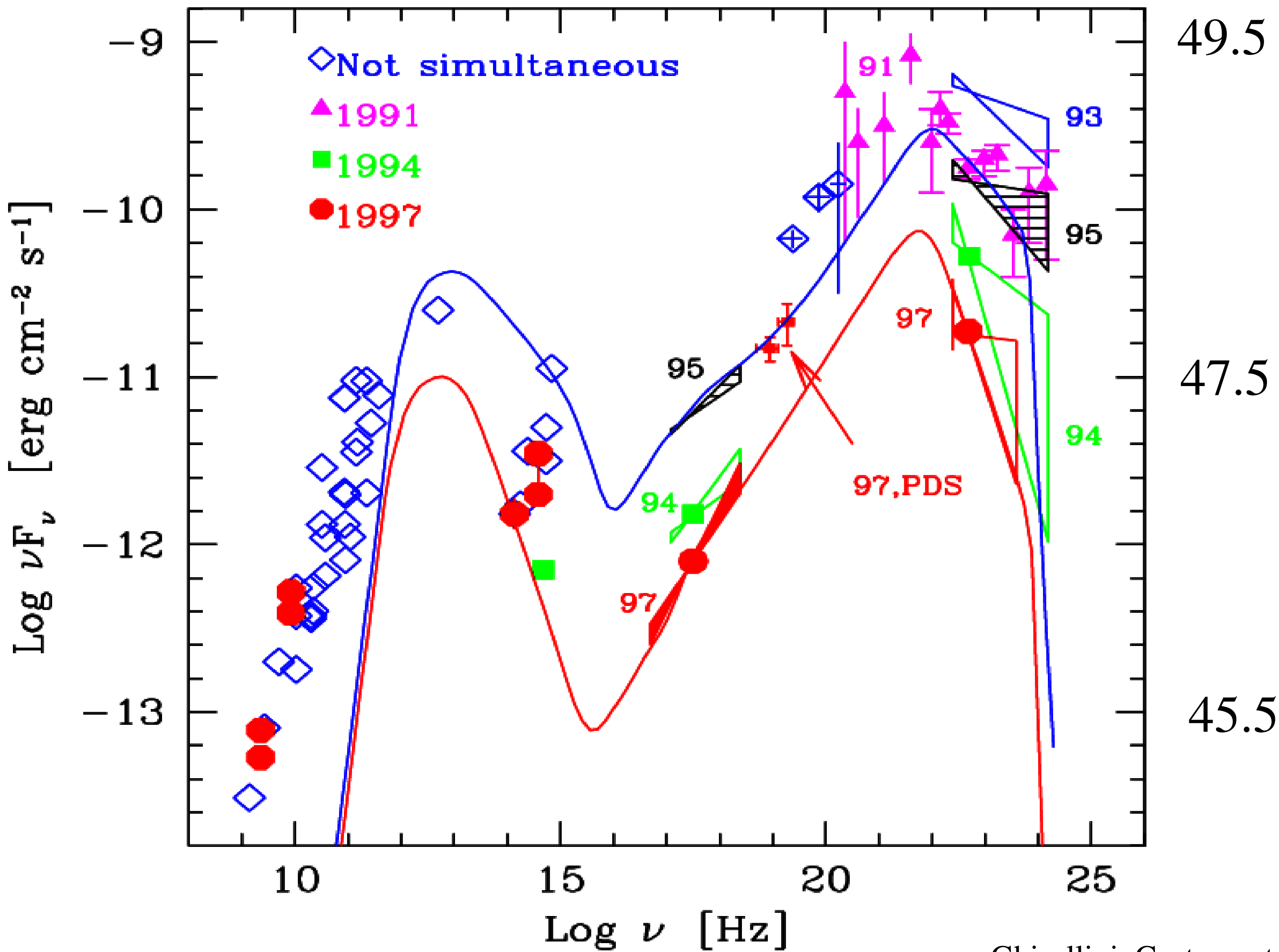
Absence soft X-ray bump / precursor --> Jet R <$10^{17}$ not fully developed

Not pair jet only (Sikora & Madjeski 2000/2)

But suppose higher Gamma: For 0528+134 --> ~$4*10^{47}$ @100 KeV !

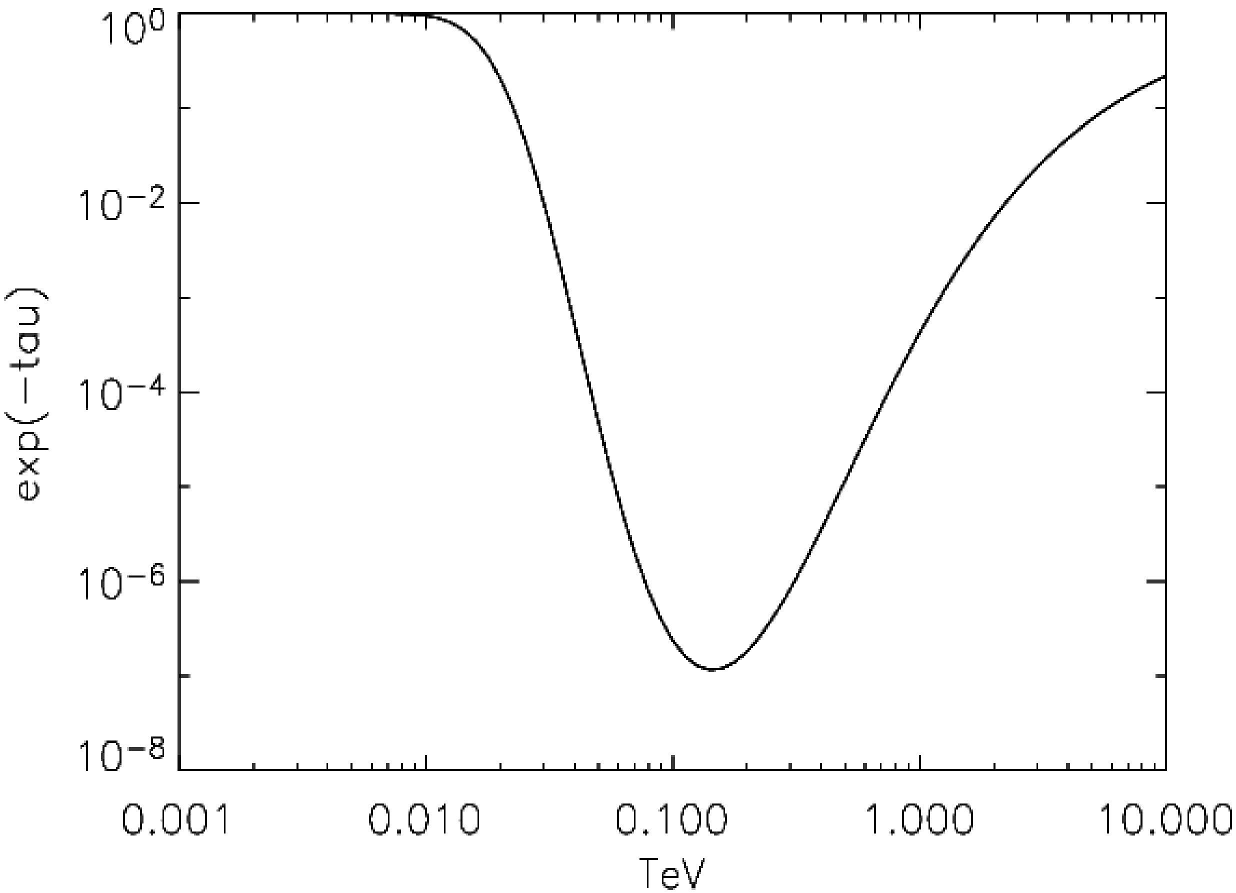
I.e. Exactly where PDS points are higher:

so far have we maybe looked for the 'Sikora-bump'
in wrong energy band ?   (soft-X instead of hard-X ?)




Ghisellini, Costamante  et al. 1999

# External UV radiation L~10$^{44-45}$
# --> strong absorption
# --> cut off gamma-ray emission




$L = 10^{44}$
$R = 10^{17}$
blob @R/2

BBody UV 10eV

Same UV photons yielding EC emission, kill emission above few GeVs. Not much expected anyway (from synchrotron distribution), but in HBLs....

# In TeV Blazars can be important:

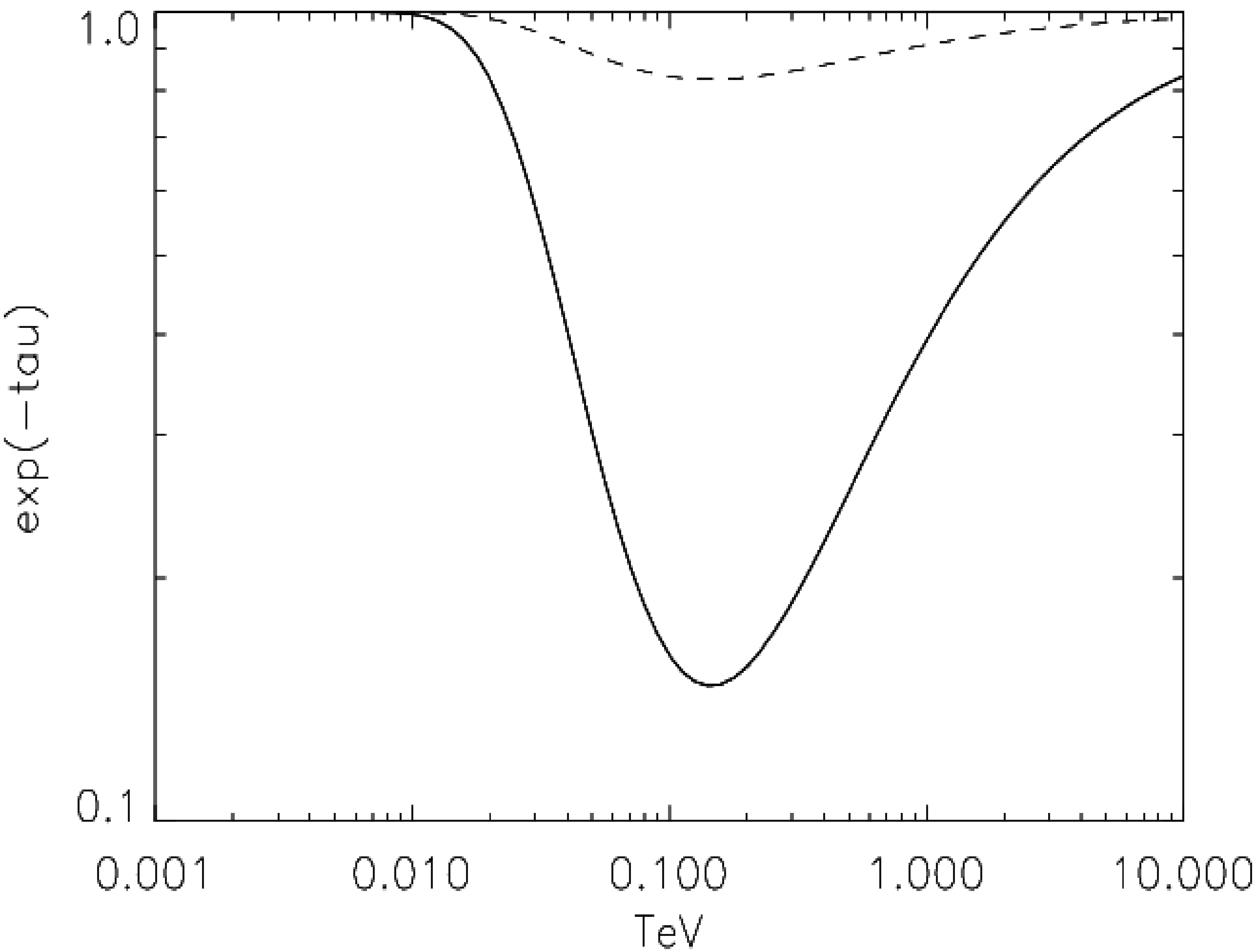
- No radiatively efficient disk ; L(lines) $\leq 10^{40\text{-}41}$
  -----> less ionizing flux, smaller BLR

- Fast variability (15-20 min.) could indicate origin closer to BH

- If so, narrow local radiation fields can imprint absorption features on TeV spectra !

- --> Diagnostic of local fields and accretion modes !

Example: Planckian field close to the BH




Planckian field, 10 eV

R = $10^{15}$
L = $10^{41}$ $10^{40}$

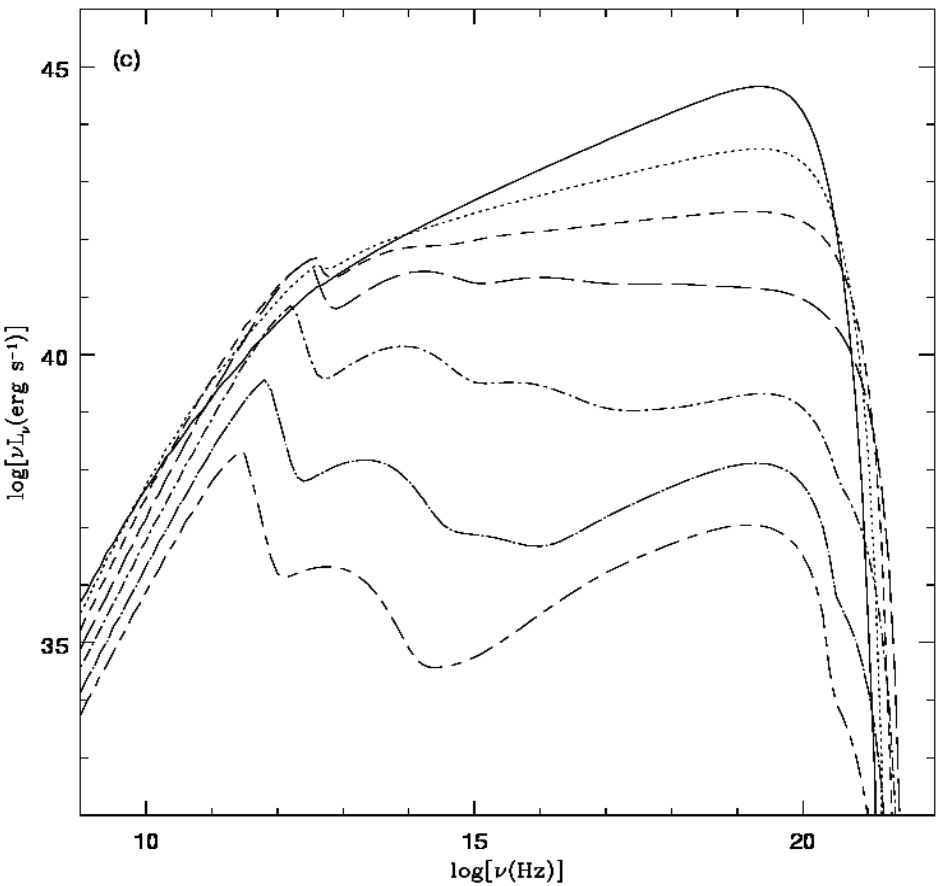
Works only if ambient field is narrow-band --> ADAF / Thin disk diagnostics !

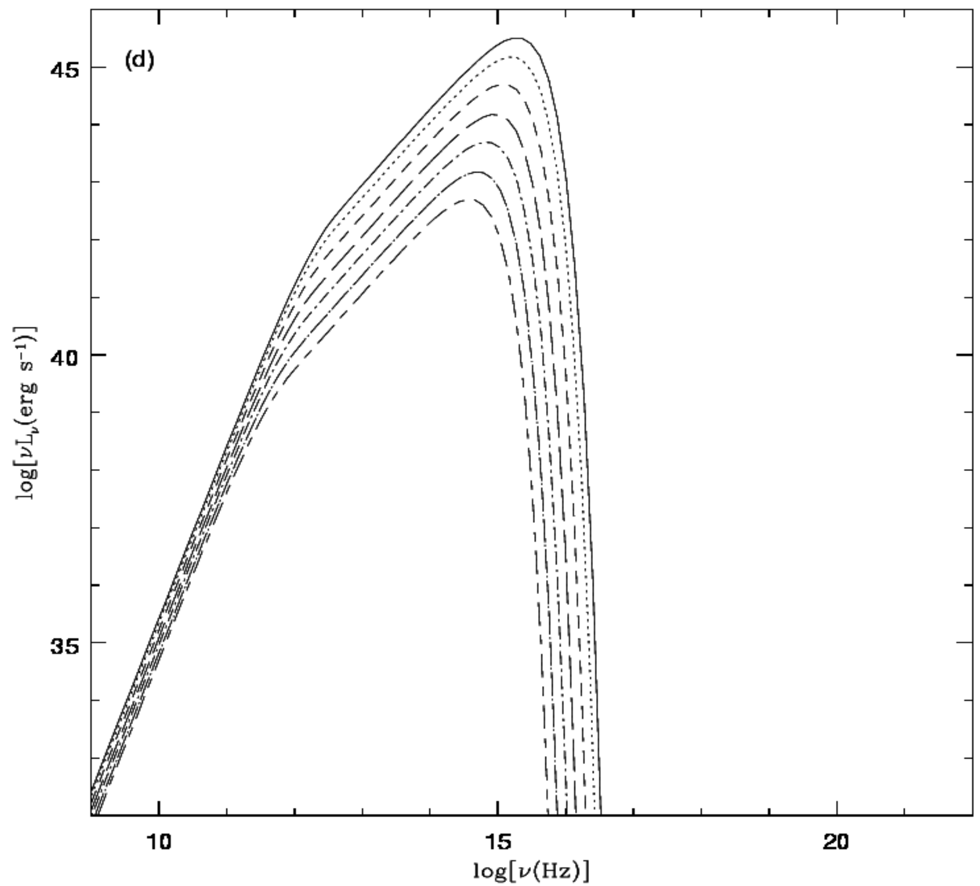
It's a possible way to have/explain hard TeV spectra (e.g. above, $\Delta\Gamma$~1)

Aharonian et al 2006, in preparation)

ADAF: quite broad-band

Pure Thin Disk: narrow band field

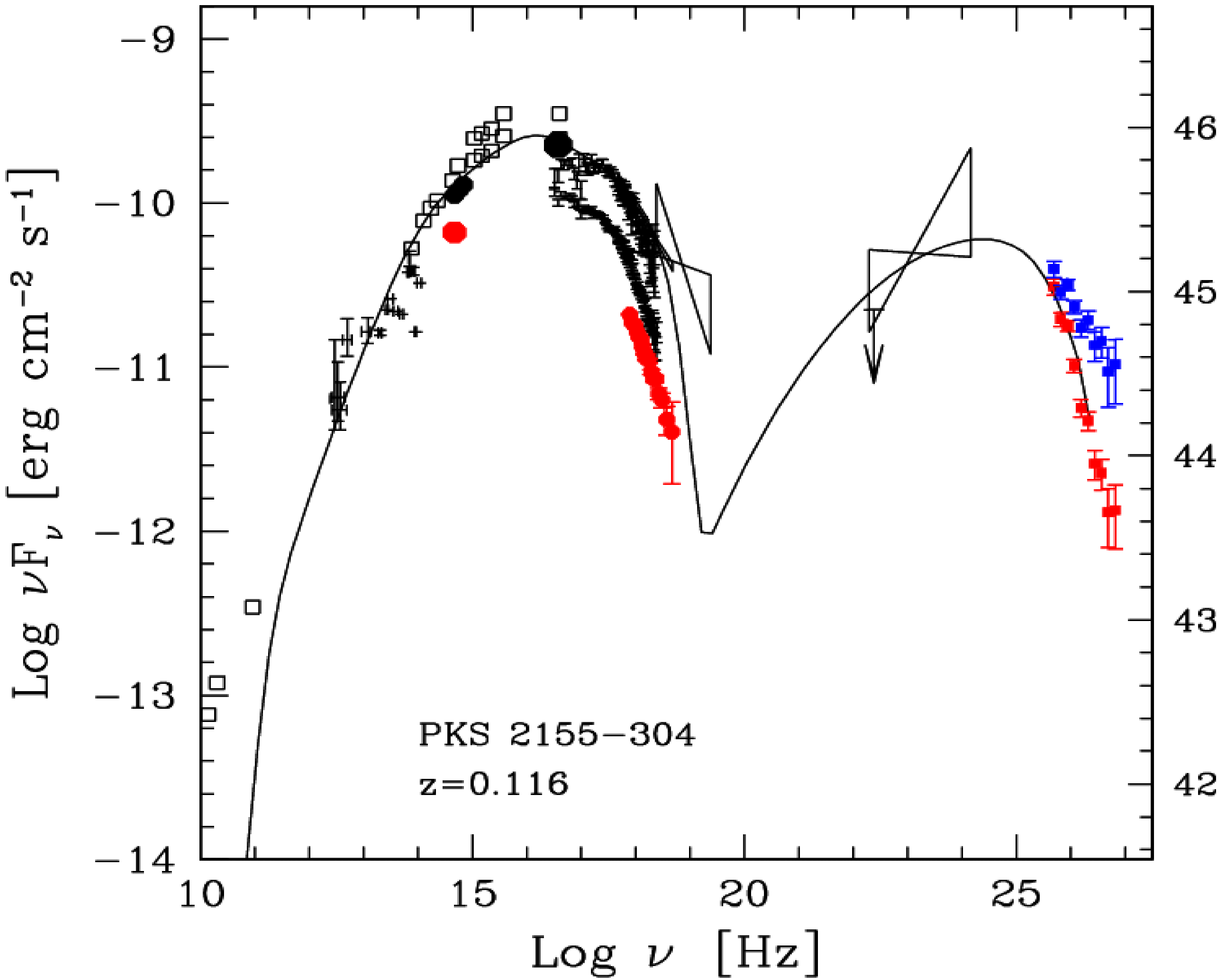



For $10^9$ solar mass BH.

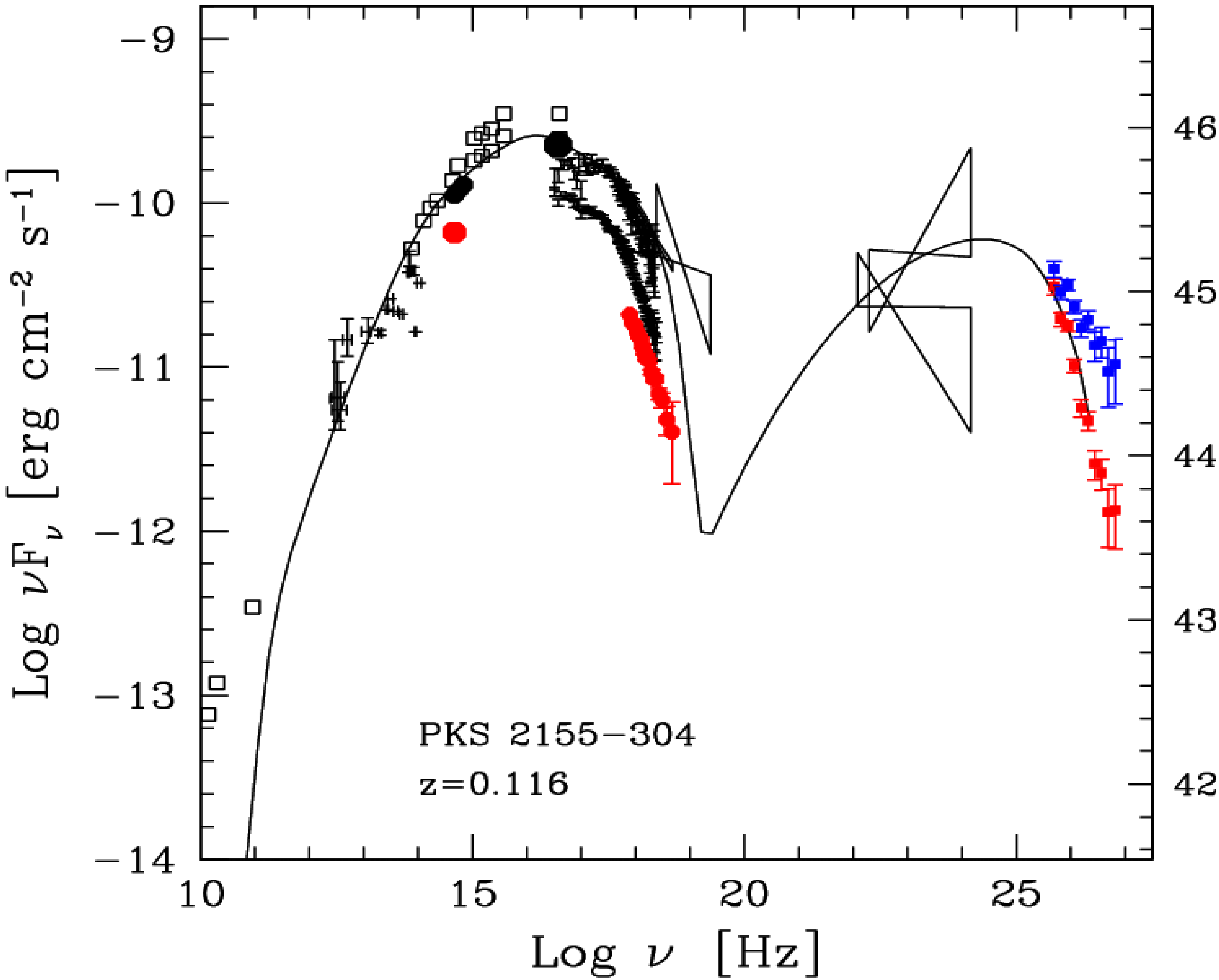
Narayan et al. 98

Just as speculation... but hint:

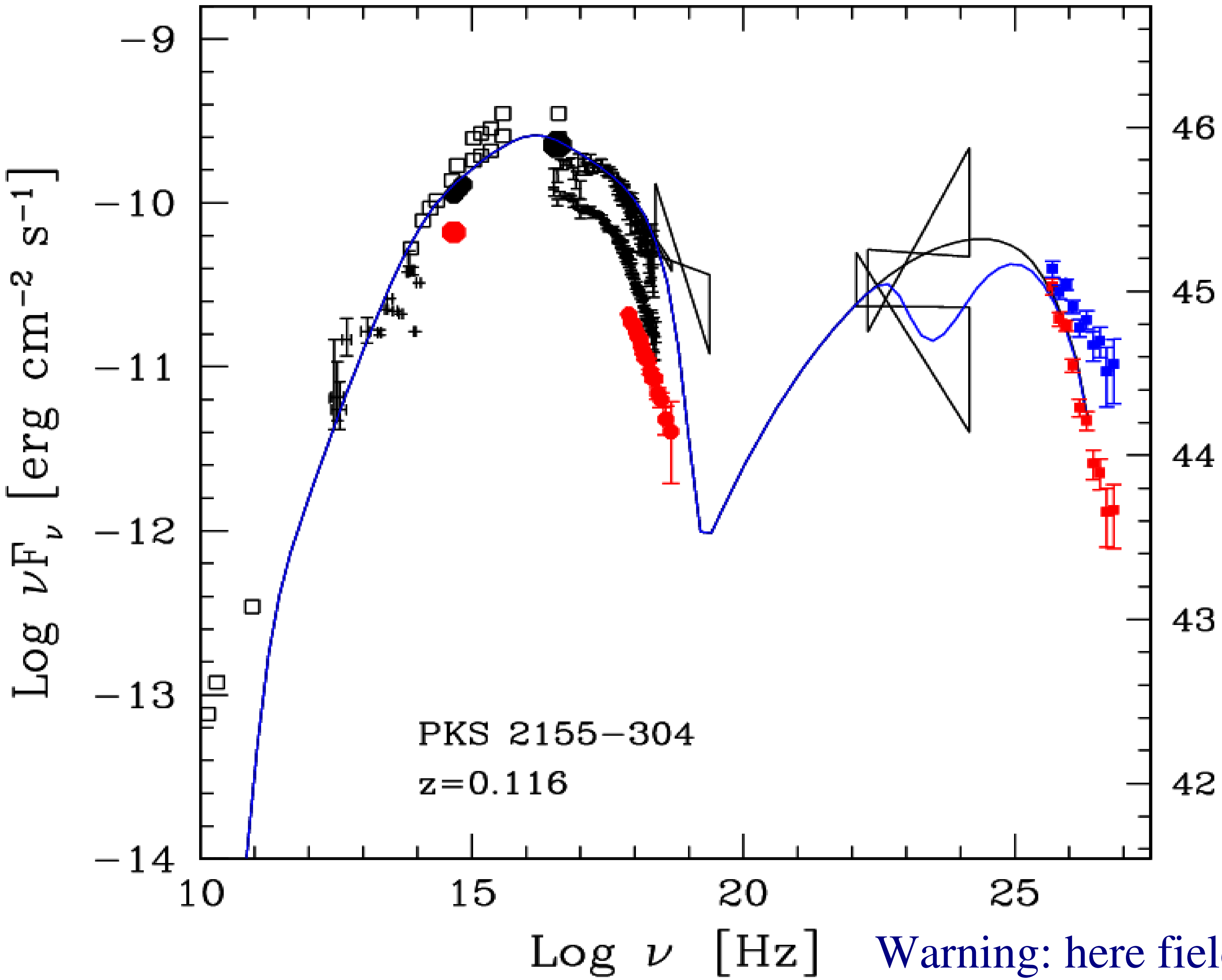



MWL data, see Aharonian et al. 2005

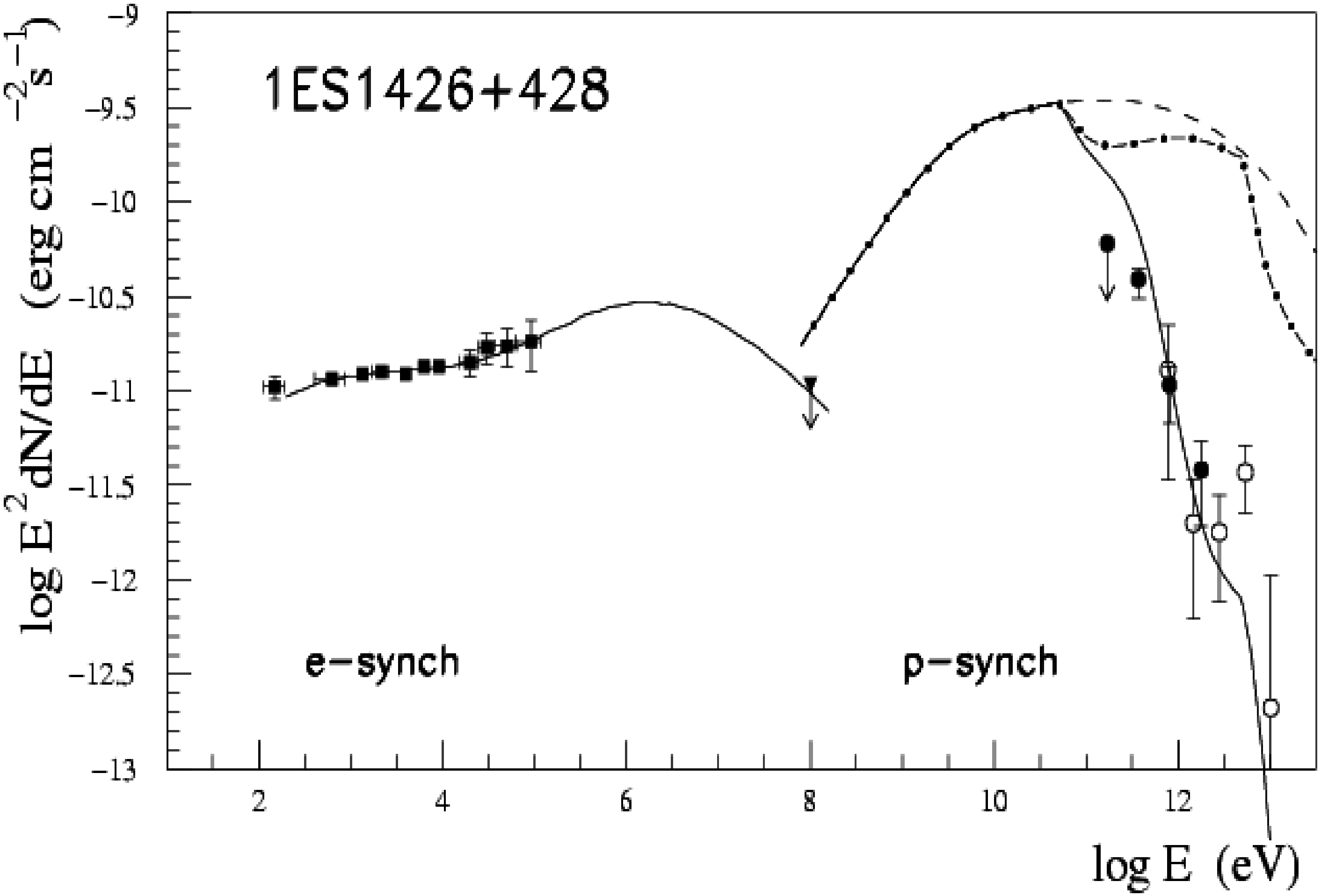
Considering the 4-years 3EG catalogue spectrum.. it's steep !



Possible absoprtion effect



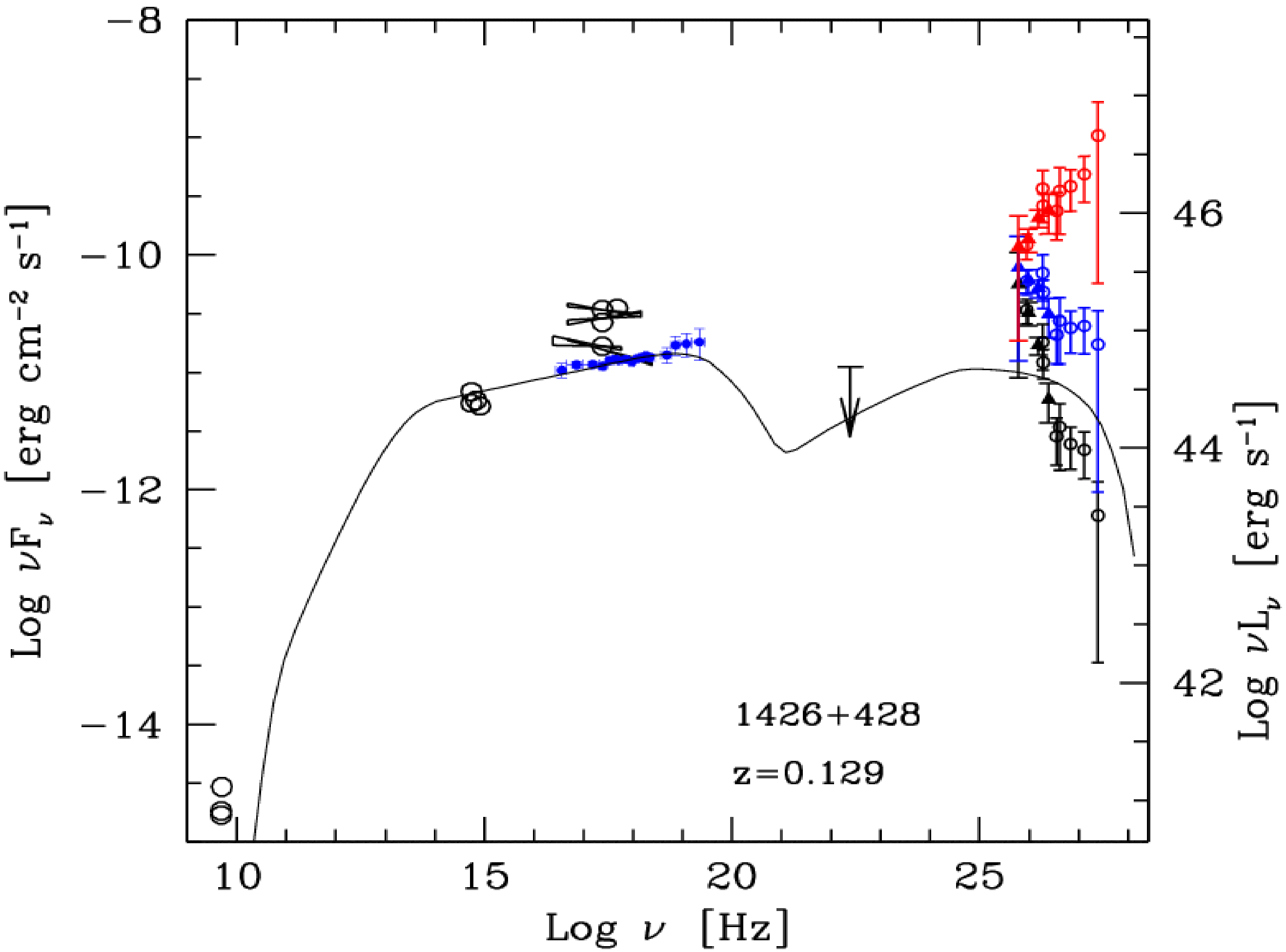

Warning: here field peaks in soft-X !




Absoprtion on external fields (here 1 and 100 eV)
is a viable (even natural) way for proton synchrotron models
(the pairs produced emit X-rays, and can well explain observed spectrum)
B=100G R=3x10$^{15}$ $\delta$=20 p=2

Aharonian et al. 2000, 2005

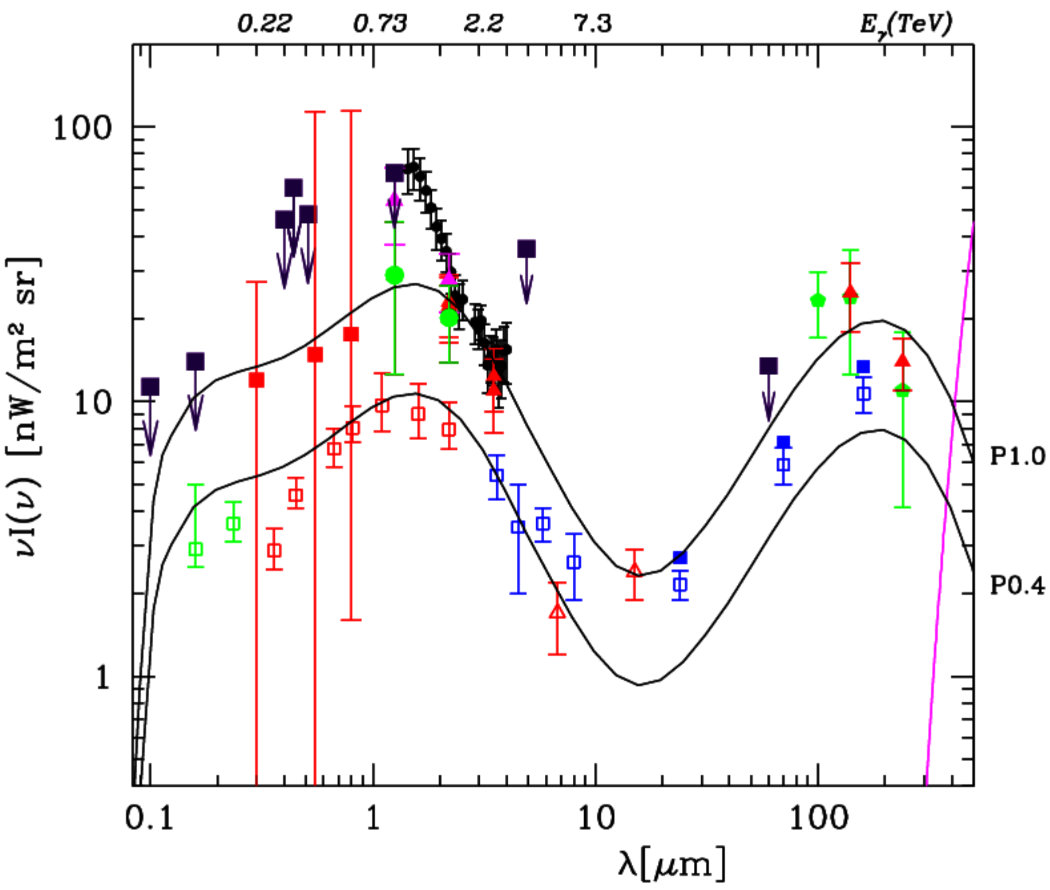
# Problem: intergalactic absorption on opt-IR bkg field

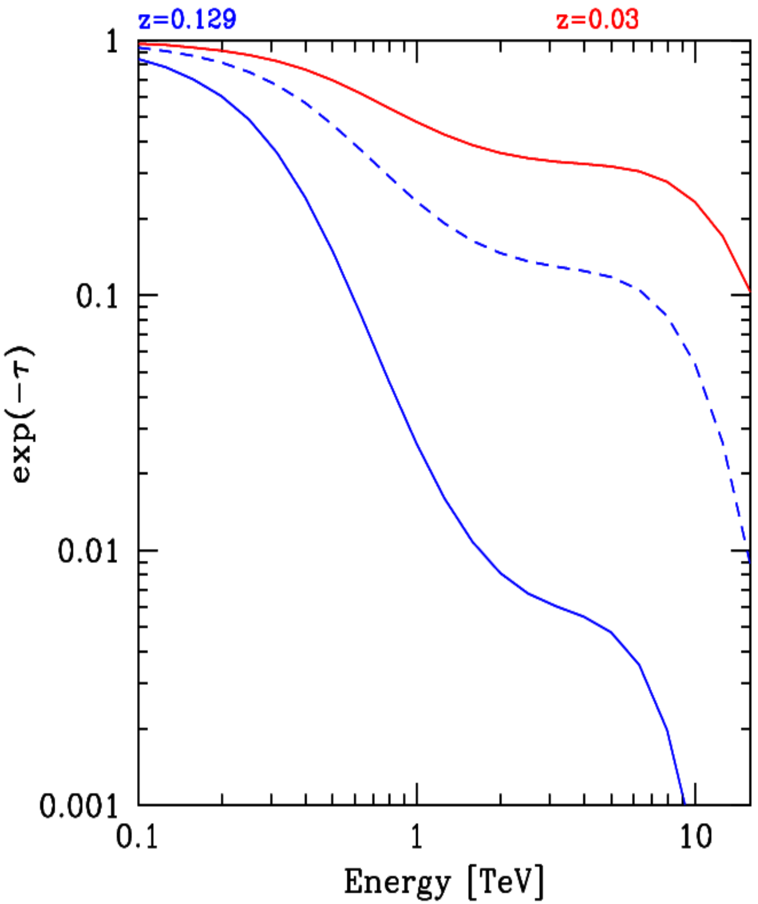



Which one is the real blazar spectrum ? (red or blue ?)

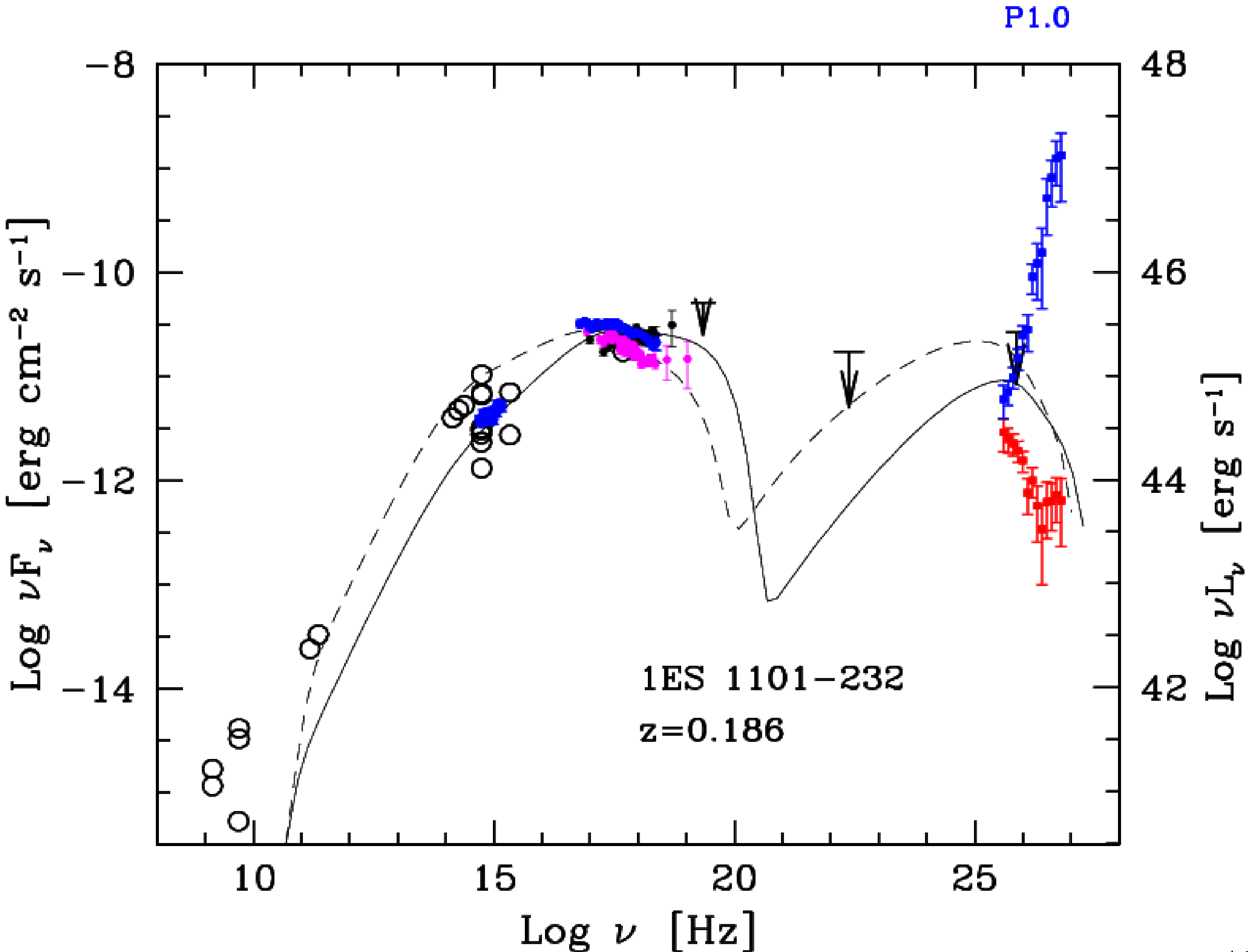
# Extragalactic Background Light:

## SED　　　　　　　　　　absorption effects



# Breakthrough: H.E.S.S. spectra of 1101-232 & 2356-309

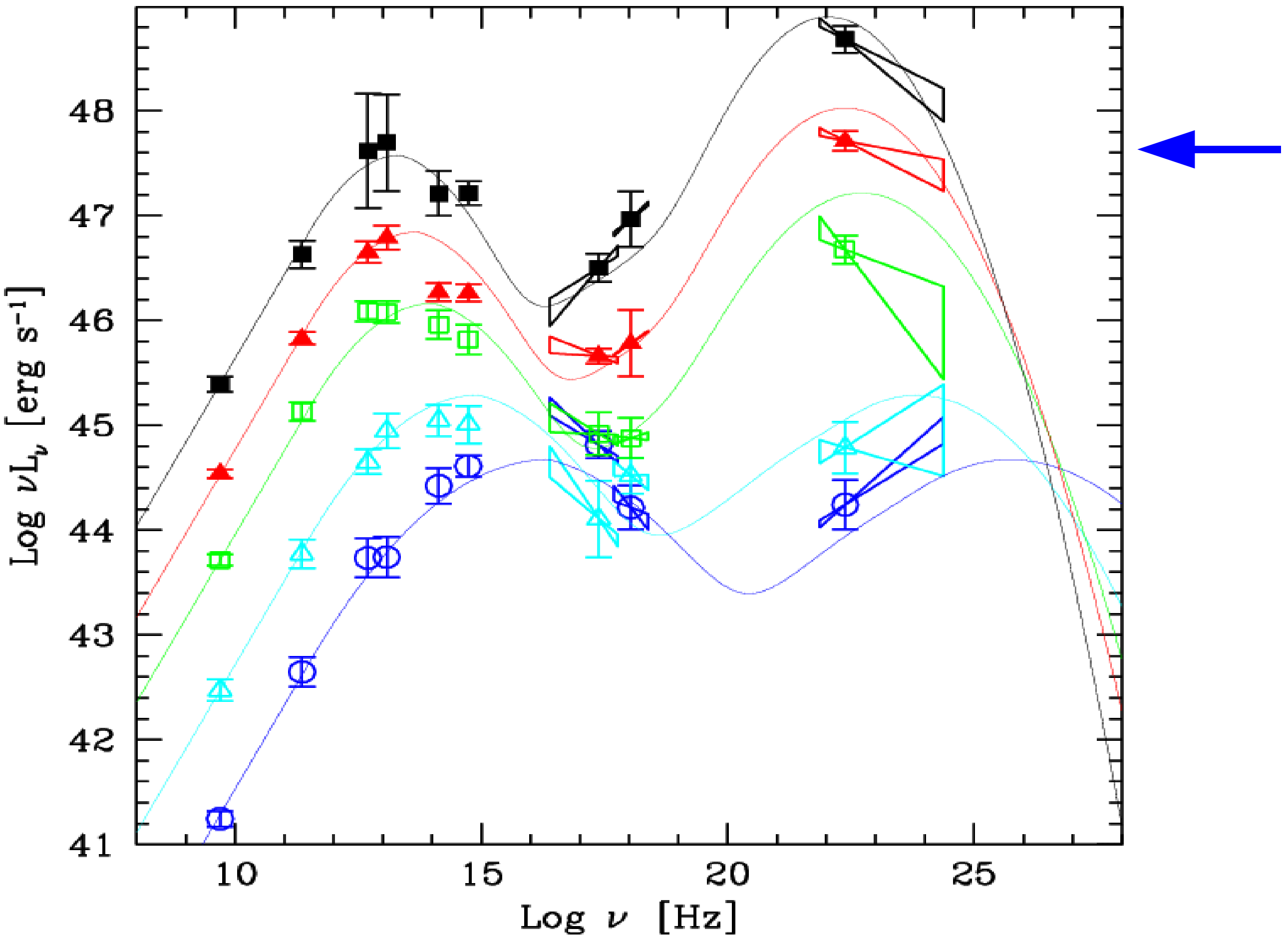



$\Gamma = -0.1$ !

$\Gamma_{obs} = 2.88 \pm 0.17$

Aharonian et al. 2006

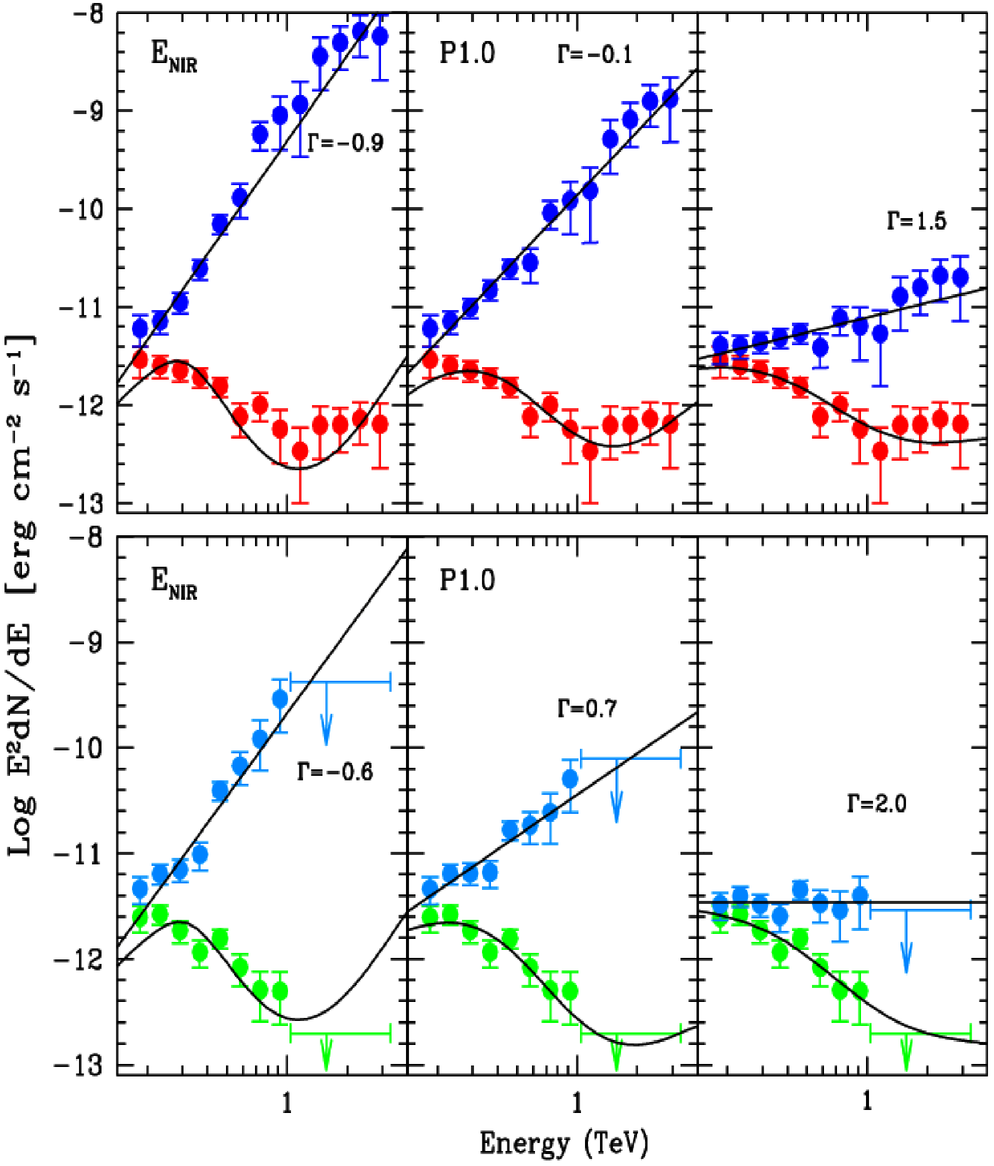
Note: a high EBL or large-z sources might have large luminosities: revision blazar sequence ?



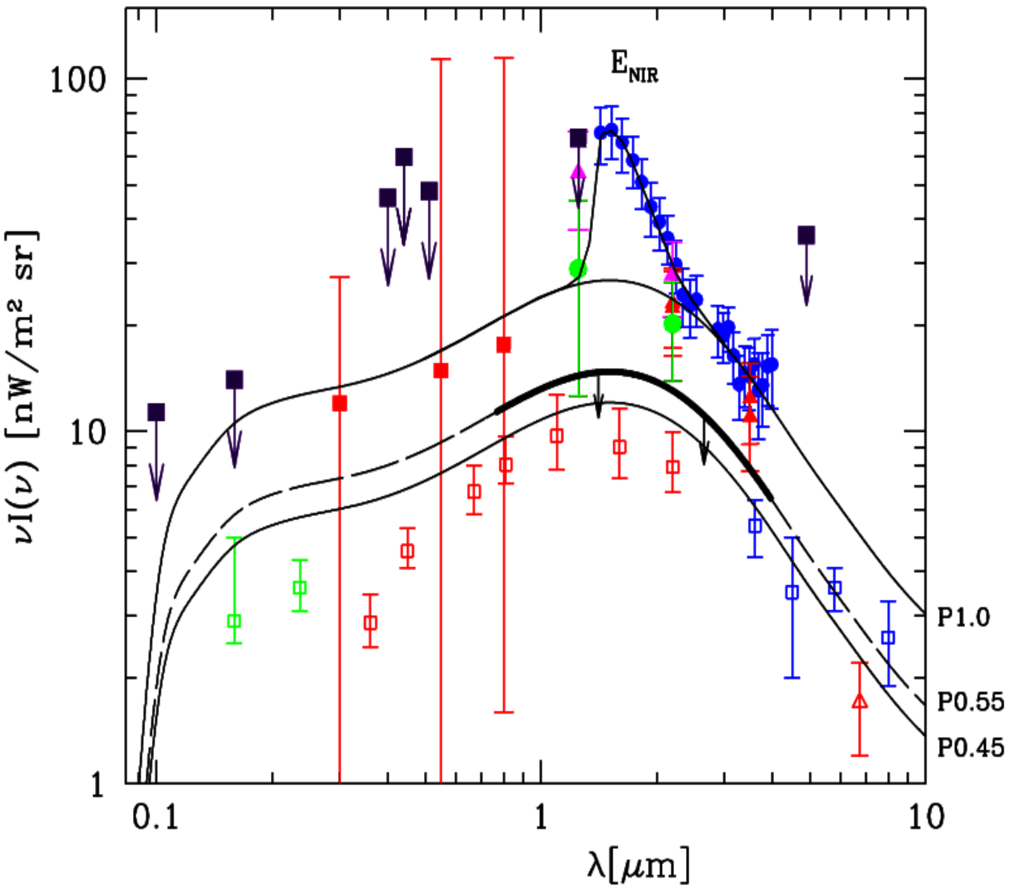

Fossati et al. 98, Donato et al. 02

With normal spectra --> EBL very low, close to galaxy counts limit

1101-232




2356-309




Aharonian et al. 2006 (Nature)

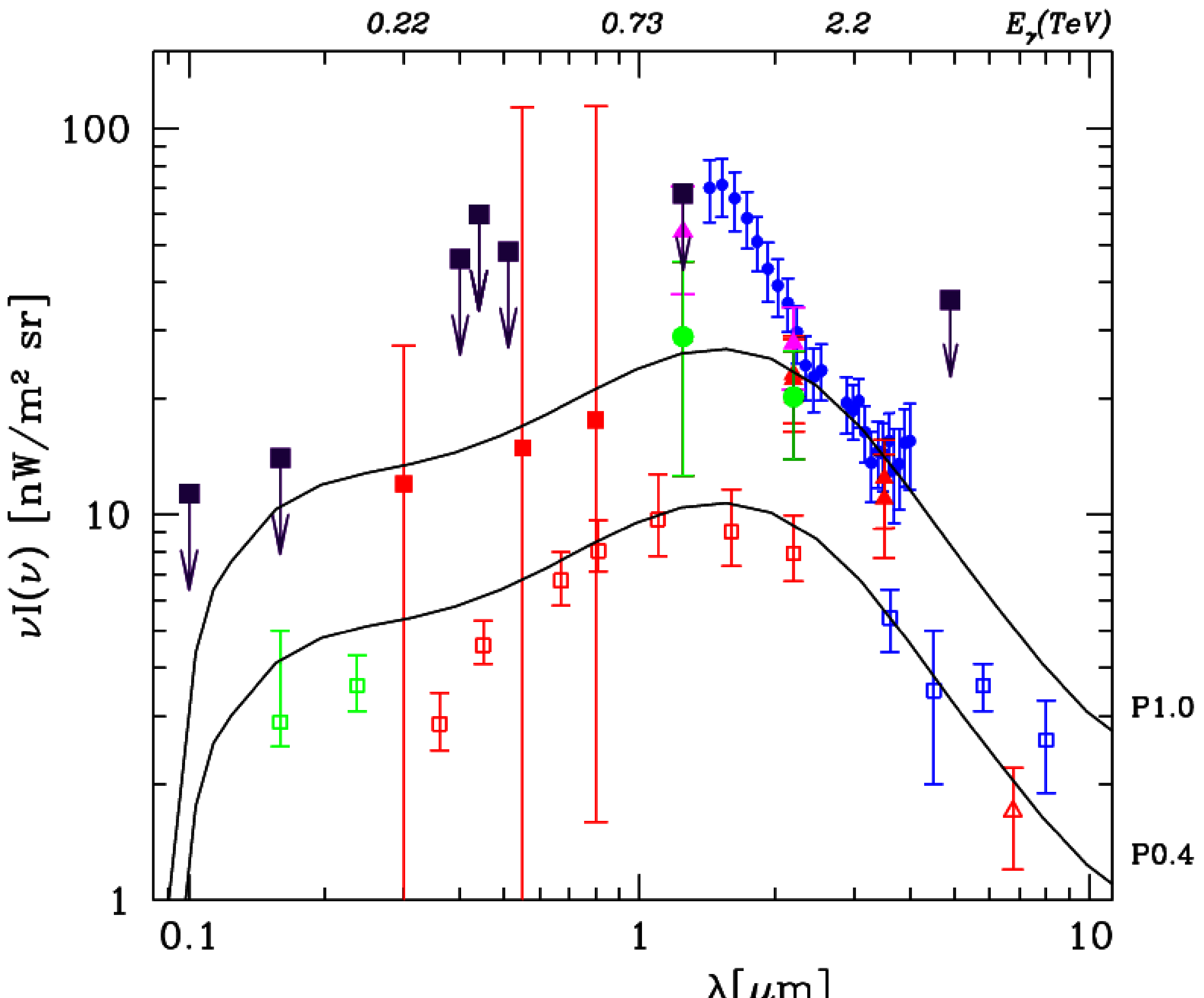
# The alternative: such hard spectra/SED could be real

- Bulk motion Comptonization in deep KN regime of a narrow (BB) photon distribution ---> sharp pile-ups (Aharonian 2001)

- Pile-up /maxwellian e- distributions seem natural outcome from turbulent acceleration
- (Henri & Sauge` 2004, Schlickeiser 98, Henri & Pellettier 91, Petrosian et al 94-04)

- Sharp "low" energy (g~2e5) cut-off (Katarzynski et al. 2005)

But.... this seems not the case:

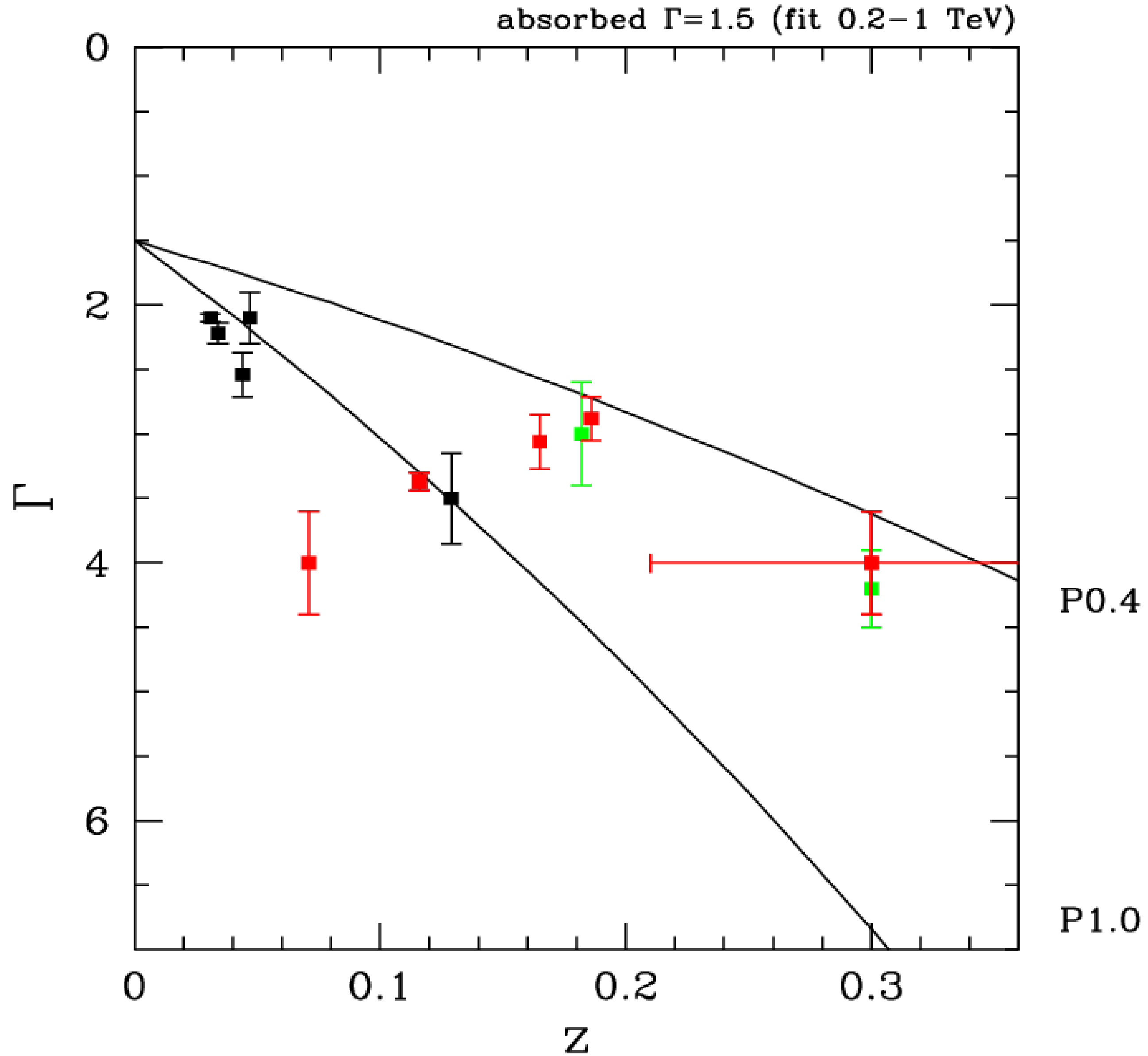


0.22
0.73
2.2
$E_\gamma$(TeV)
100
10
1
$\nu I(\nu)$ [nW/m$^2$ sr]
0.1
1
10
$\lambda[\mu m]$
P1.0
P0.4

Two situations:

Either the EBL is high, or is low.

High EBL
--> blazars at z<0.1 are different from blazars at z=0.2



# However, a low EBL reduces but does not solve the need for high Delta and low B

Mkn 421 SED still peak at 1-2 TeV... Other observational facts:

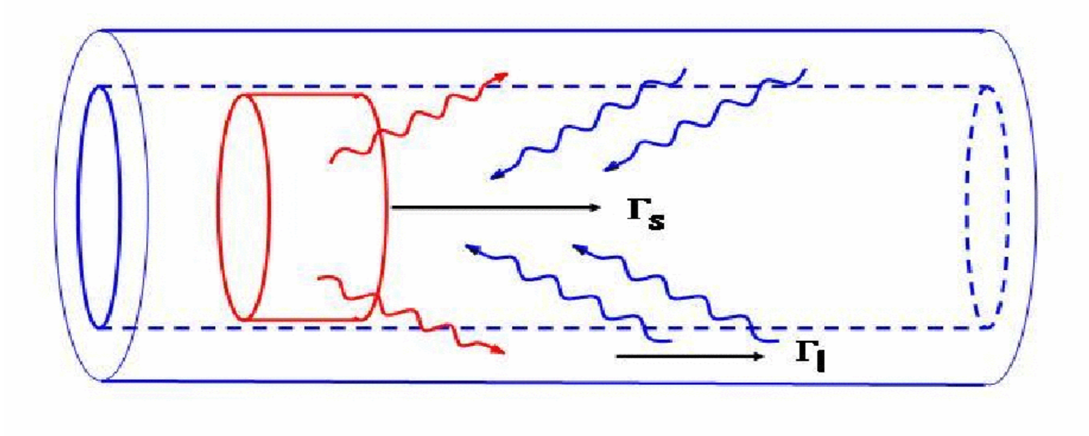
- Jet stops down to Delta~ 3-4 from 15-20 , at $>10^{17}$ cm (no / slow superluminal motion VLBI scale)
- Limb brightening of mas radio emission MKN 421 and 501
- Unification FR1 – BLLacs (debeaming paths)

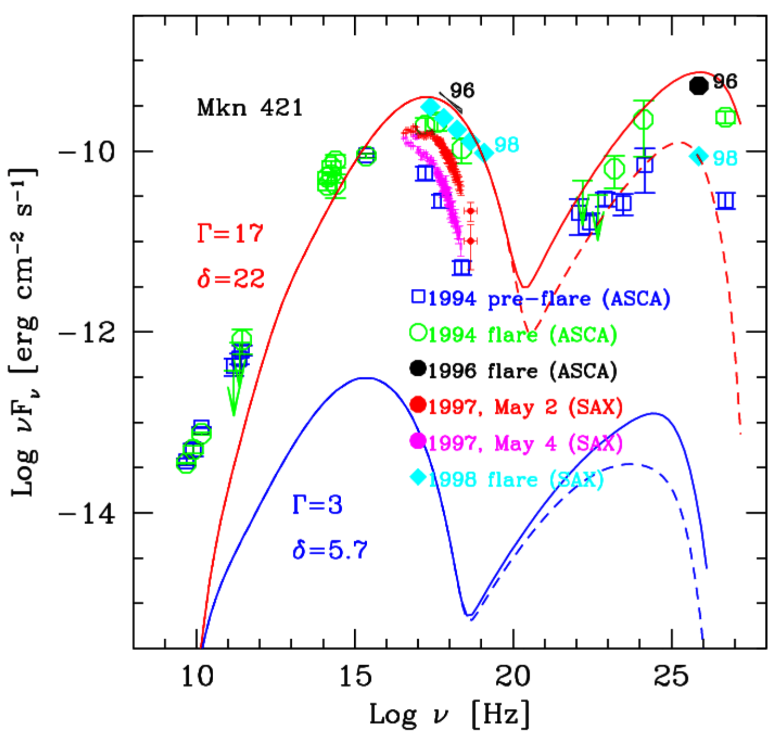
⇒ Jet structured: spine-layer (e.g. Ghisellini et al. 2005)

decelerating flow

(Georganopoulos & Kazanas 2004)

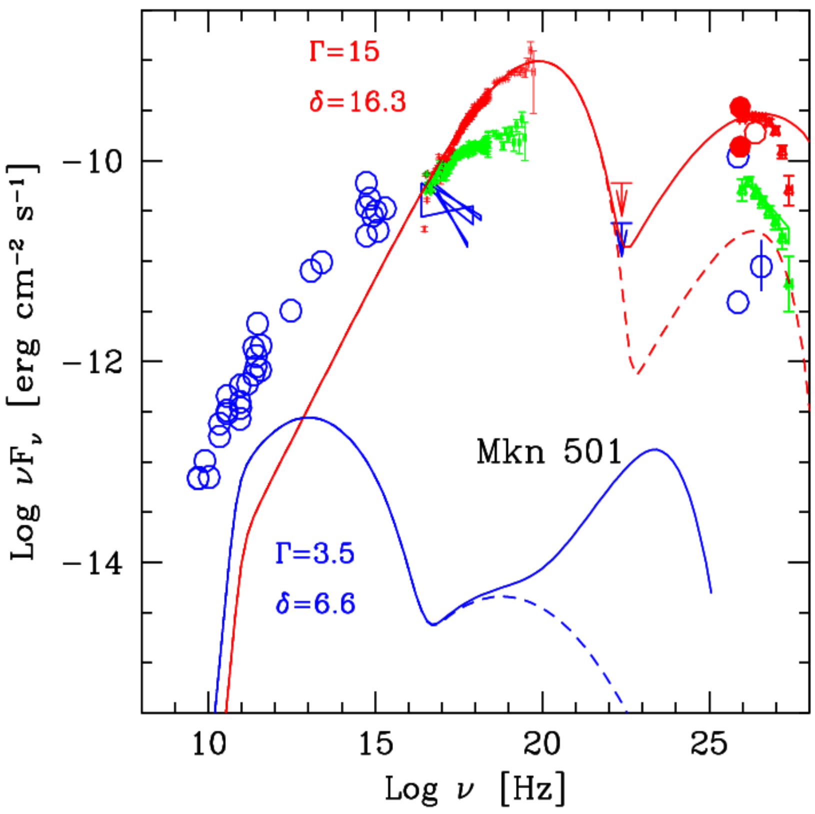
# Spine-layer scenario

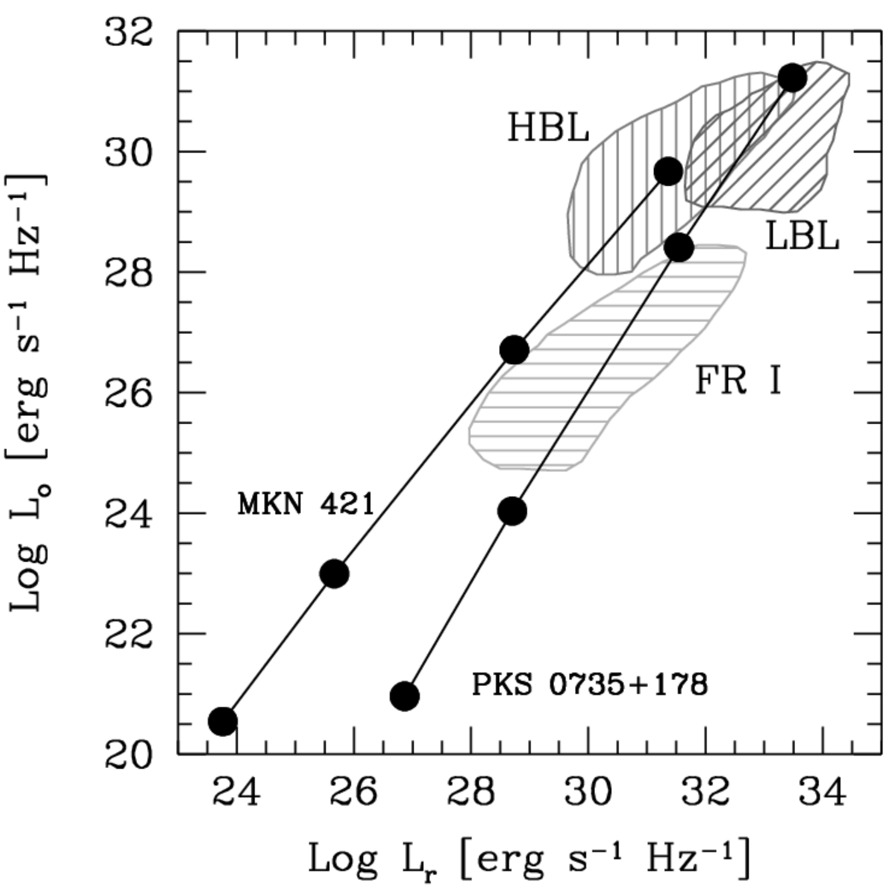



Many advantages:

- IC emission naturally enhanced
- B can be larger (~equipartition)
- the recoil of the spine can explain why jet stops/ is disrupted (when Lc ~ kinetic power)
- ok FR1 - BLLacs
- predict/explain radio-galaxy gamma emission
- BUT: still need to stop the jet




Chiaberge et al 2000

# Still... many various hints for $\delta$=100 ... why not ?

Main CONTRA arguments:

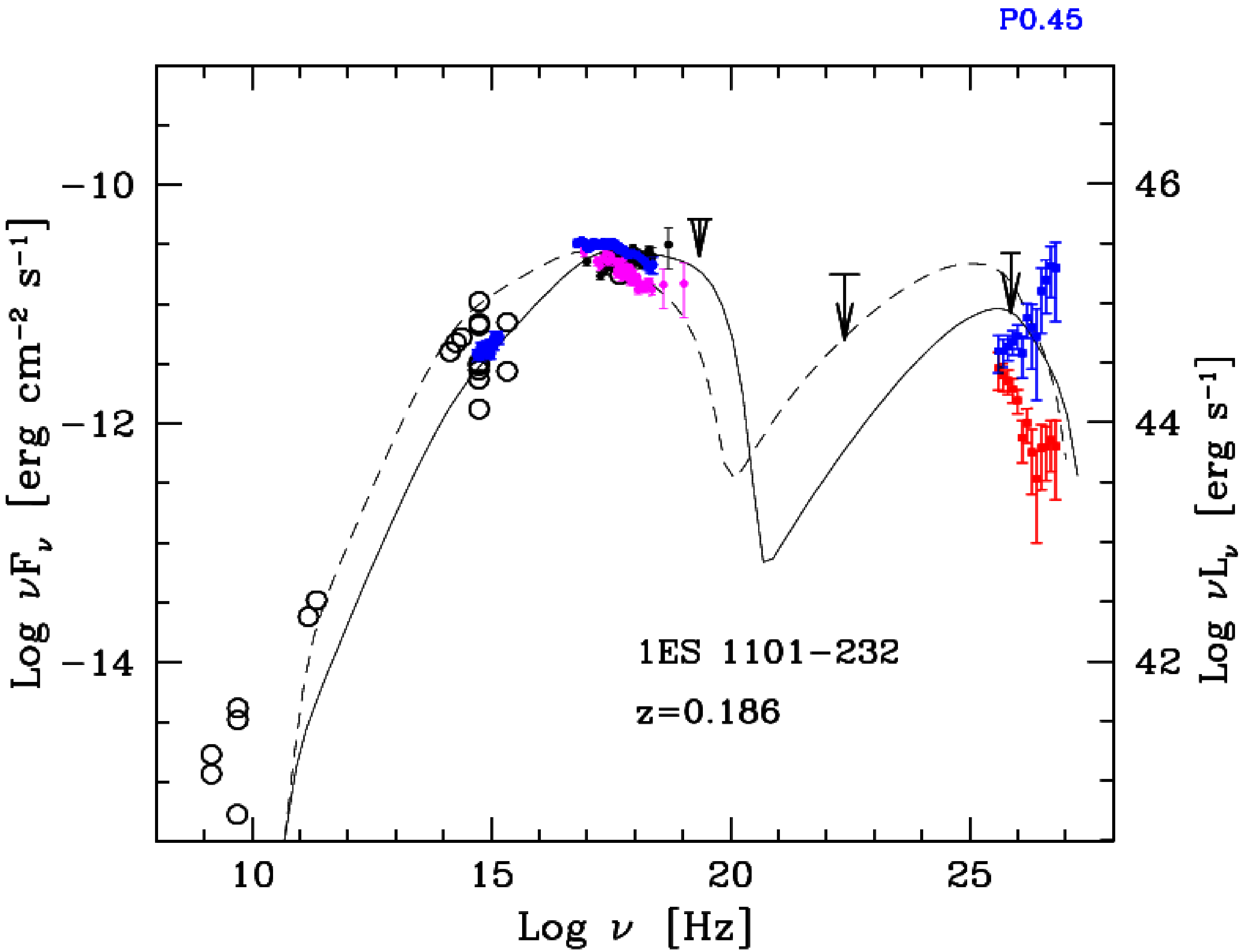
- no superluminal motion VLBI --> (but same problem for $\delta$=15)

- wrong number of beamed/unbeamed sources ($1/2\Gamma^2$)
  ---> "sprayed jet" ? (see e.g. 'wide'jet, Celotti et al. 1993)

- de-beaming trail (FR1-BLLac problem) --> spine – layer

- any other fundamental/strong issue ??
  Why not considering high Doppler factors ??

Other example solved by high $\Gamma$:

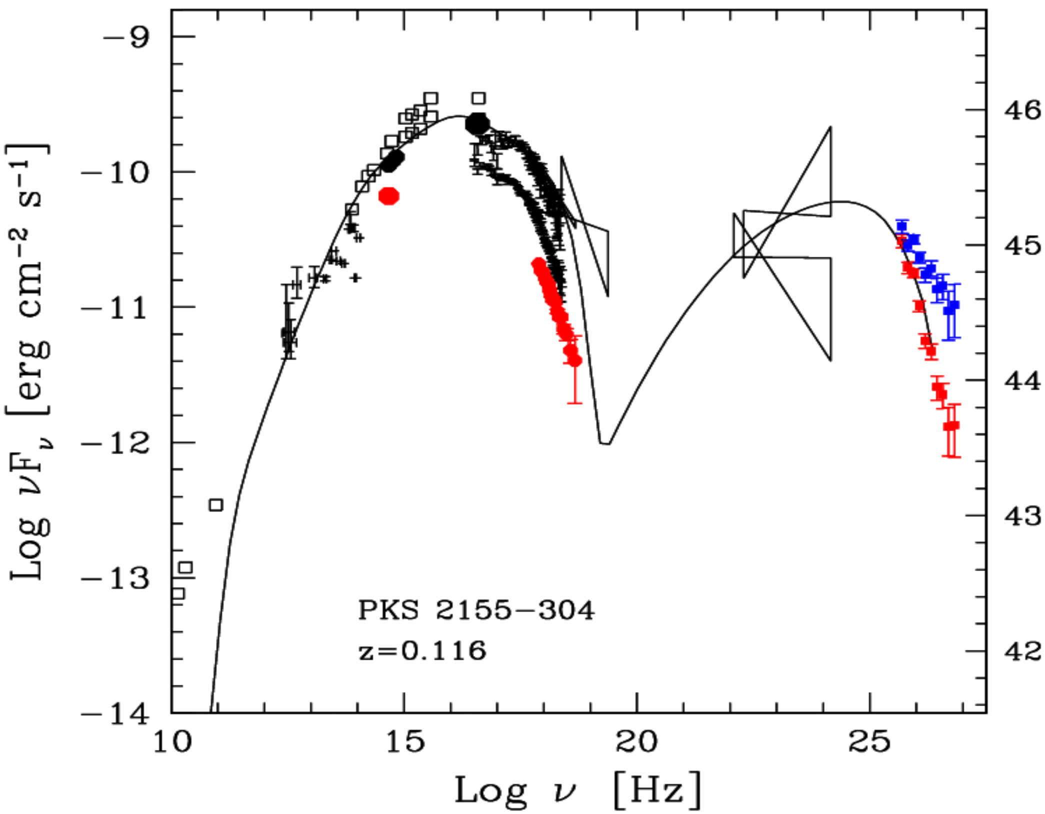


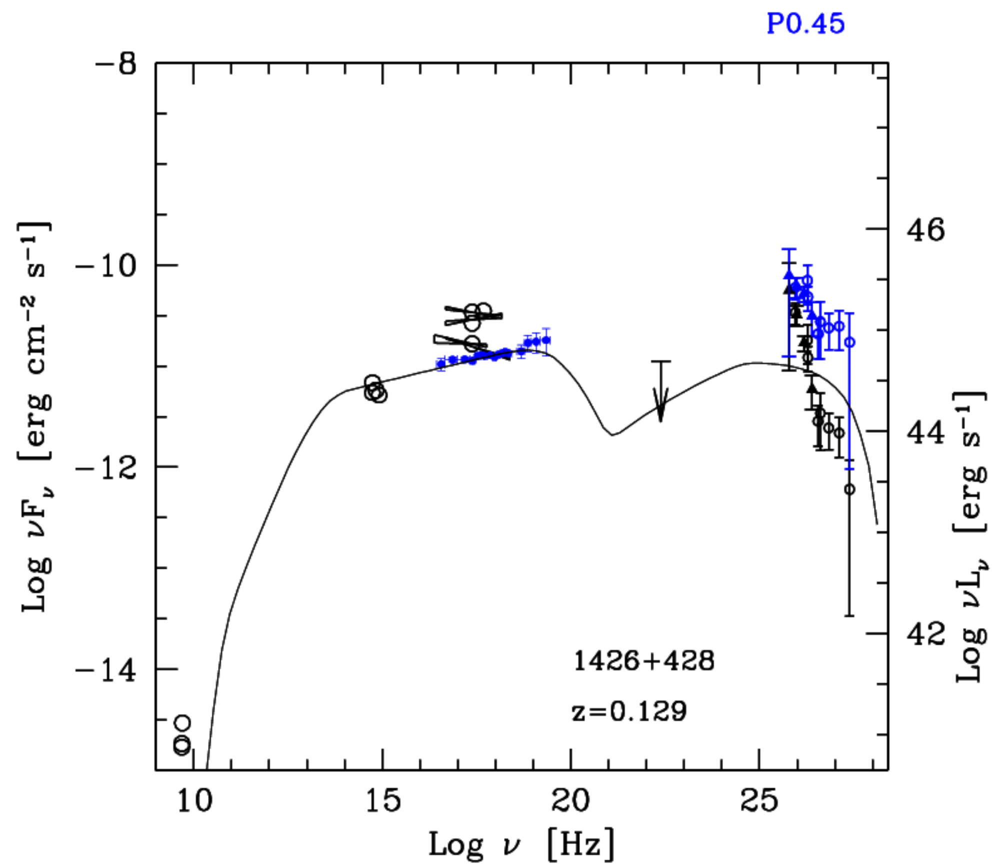

Intrinsic TeV spectrum: always hard ! (EBL-independent) $\Gamma$=1.5 (1.8)

Where is the TeV-electrons synchrotron emission ??

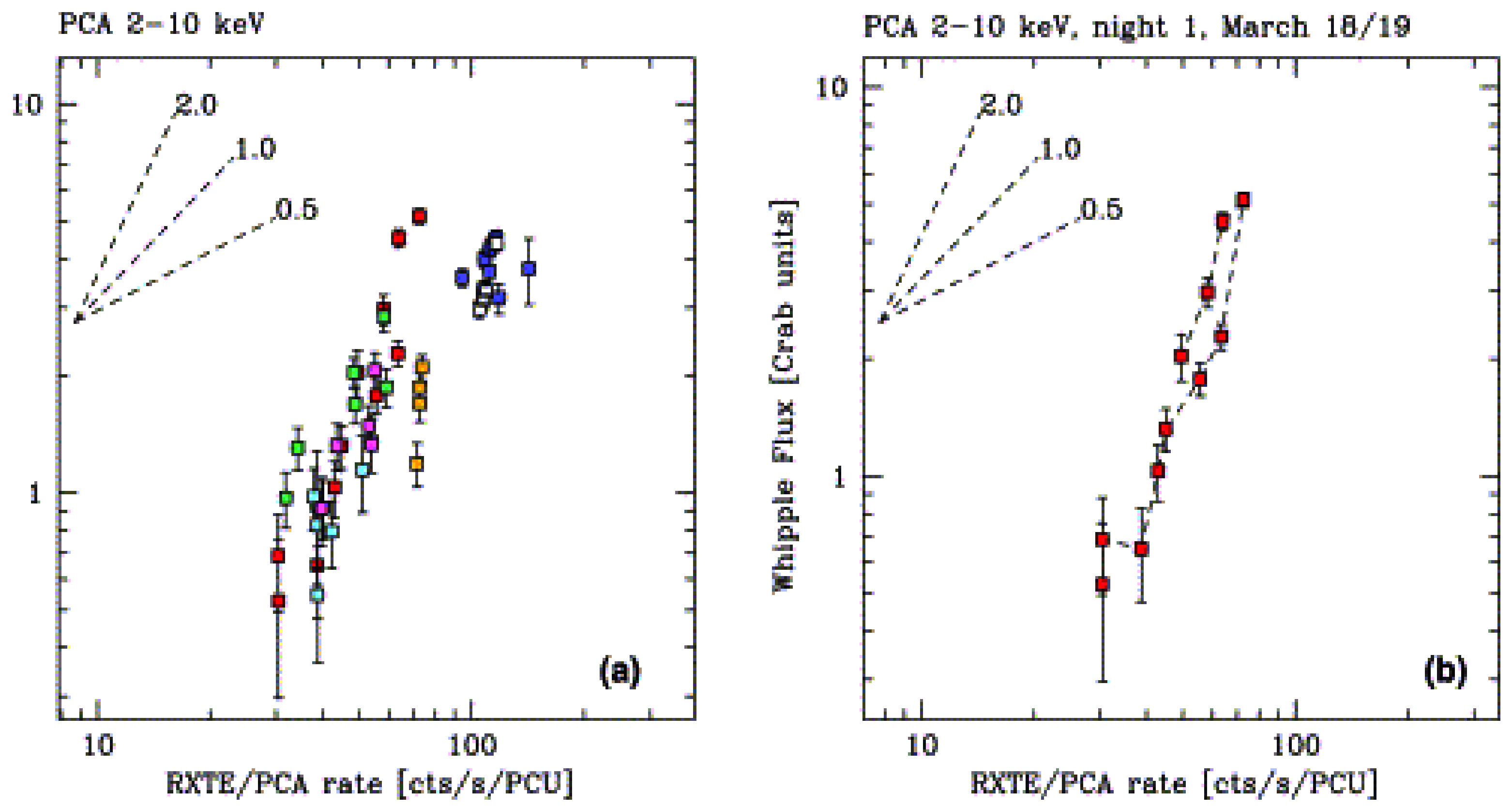
Around 1 TeV.. $\gamma \geq 2 \times 10^6 / \delta$ $E_{sync} \geq 20 B / \delta \, keV$

# Spectra of sources for low EBL:



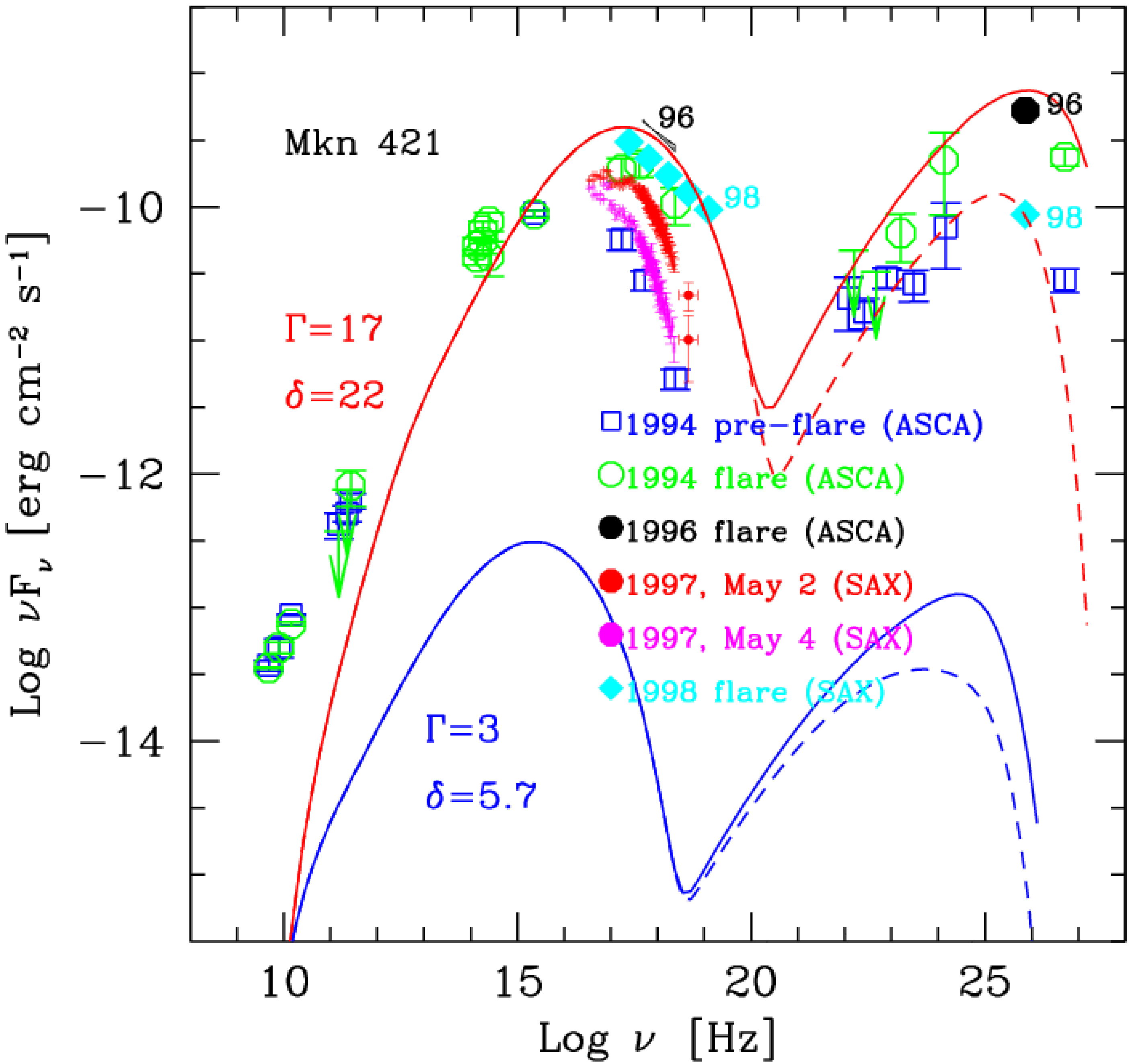



# Another problem possibly solved by very high Lorenty factors



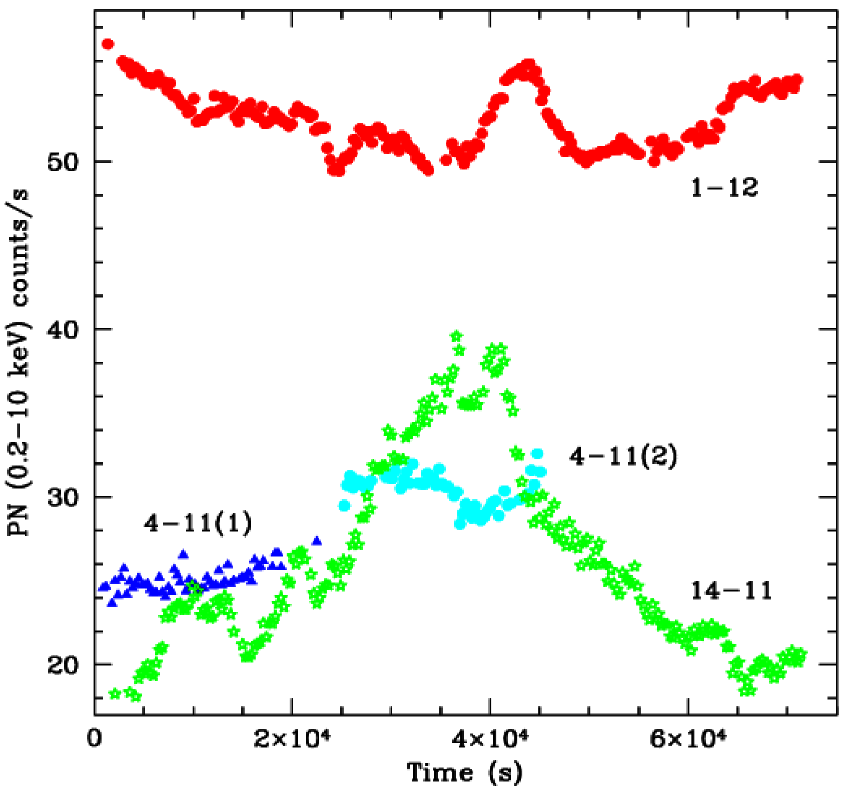

F_tev vs F_x: quadratic correlation also decaying phase

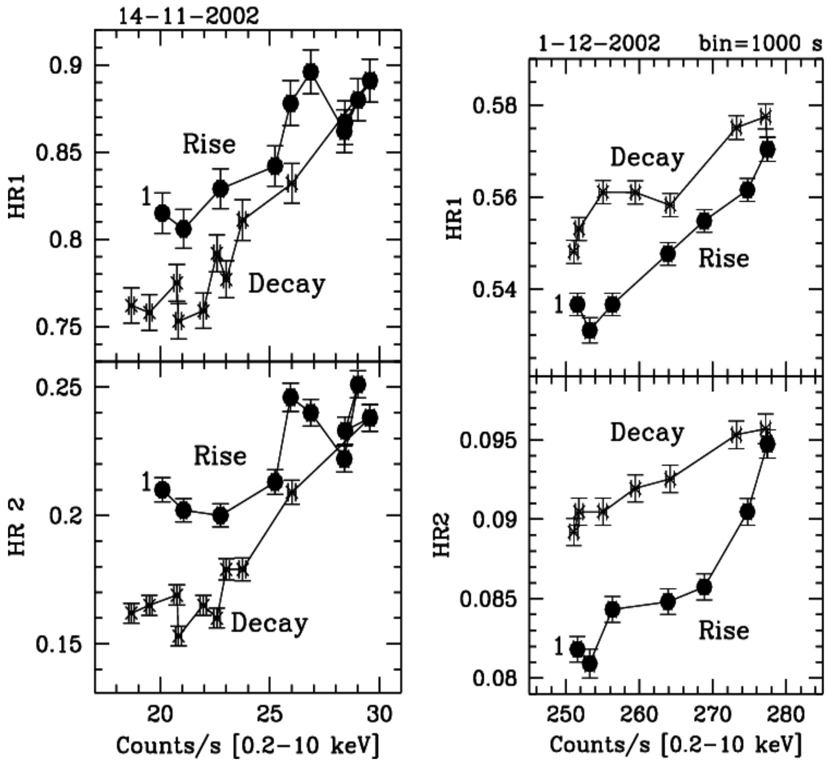
Number of sources solved by the spine-layer scenario



# Origin and dynamics of flares: still need of MWL opt-X-TeV campaigns

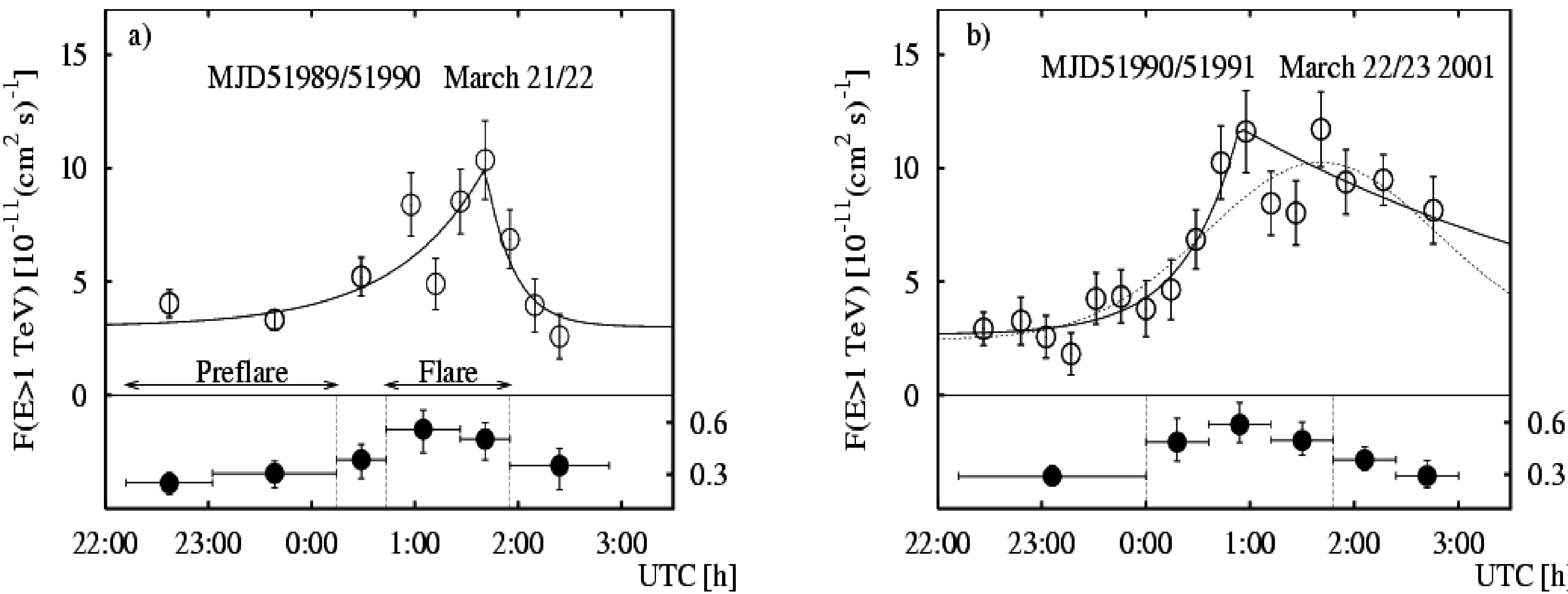
Different epochs/flares of the same source --> different behaviours



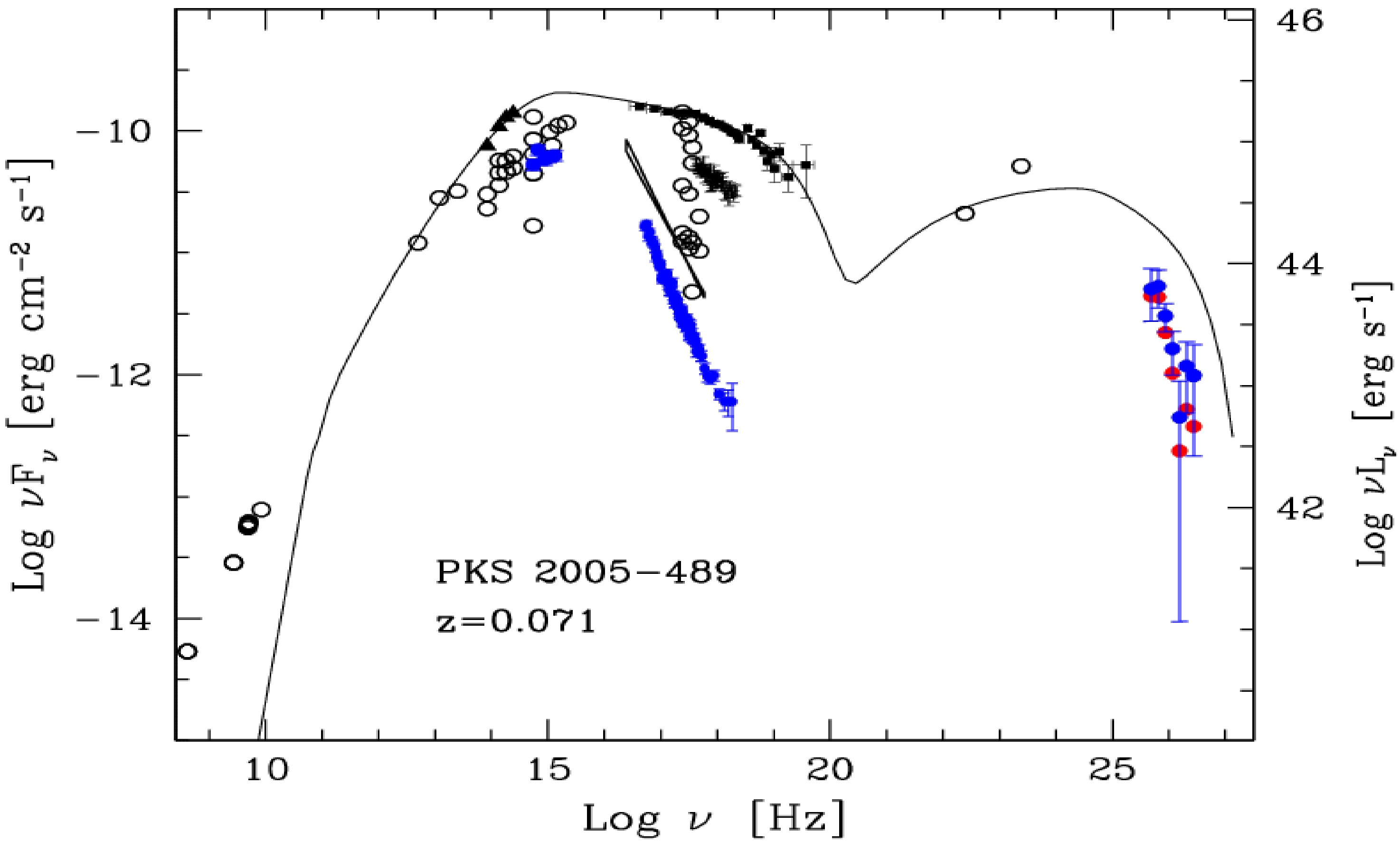

Ravasio et al. 2005

# HEGRA  Mkn 421




Entire zoo of different flares, with different (opposite !) rise and decay timescales.  (Aharonian et al. 2002)

Example: PKS 2005-489    (source with possible multi-crab tev fluxes)




X-TeV  flux and spectral relations  allows lots of diagnostic possibilities: Thomson-KN regime  (100-300 GeV in Thomson, 1 TeV in KN) , emitting regions  location/feedback

# Conclusions:

- FSRQ high delta (VLBI) ; HBLs high delta (many reasons) ---> why not Gamma=100 ? And for both classes ?
- HBL emission might originate much closer to BH/accr. Disk than we thought
- TeV emission in nearby blazars can probe location and ambient fields near Black hole.
- Statistics is needed (for TeV-X correlation etc), but unfortunately no Mkn 421 in southern emisphere...
- Mkn 421, Mkn 501 still best and unique laboratories (nearby (less EBL abs) , highly variable, spectral time sampling down to few minutes with new gen. Cherenkov Telescopes, (VERITAS, MAGIC, HESS >1-2 TeV)