Blazars

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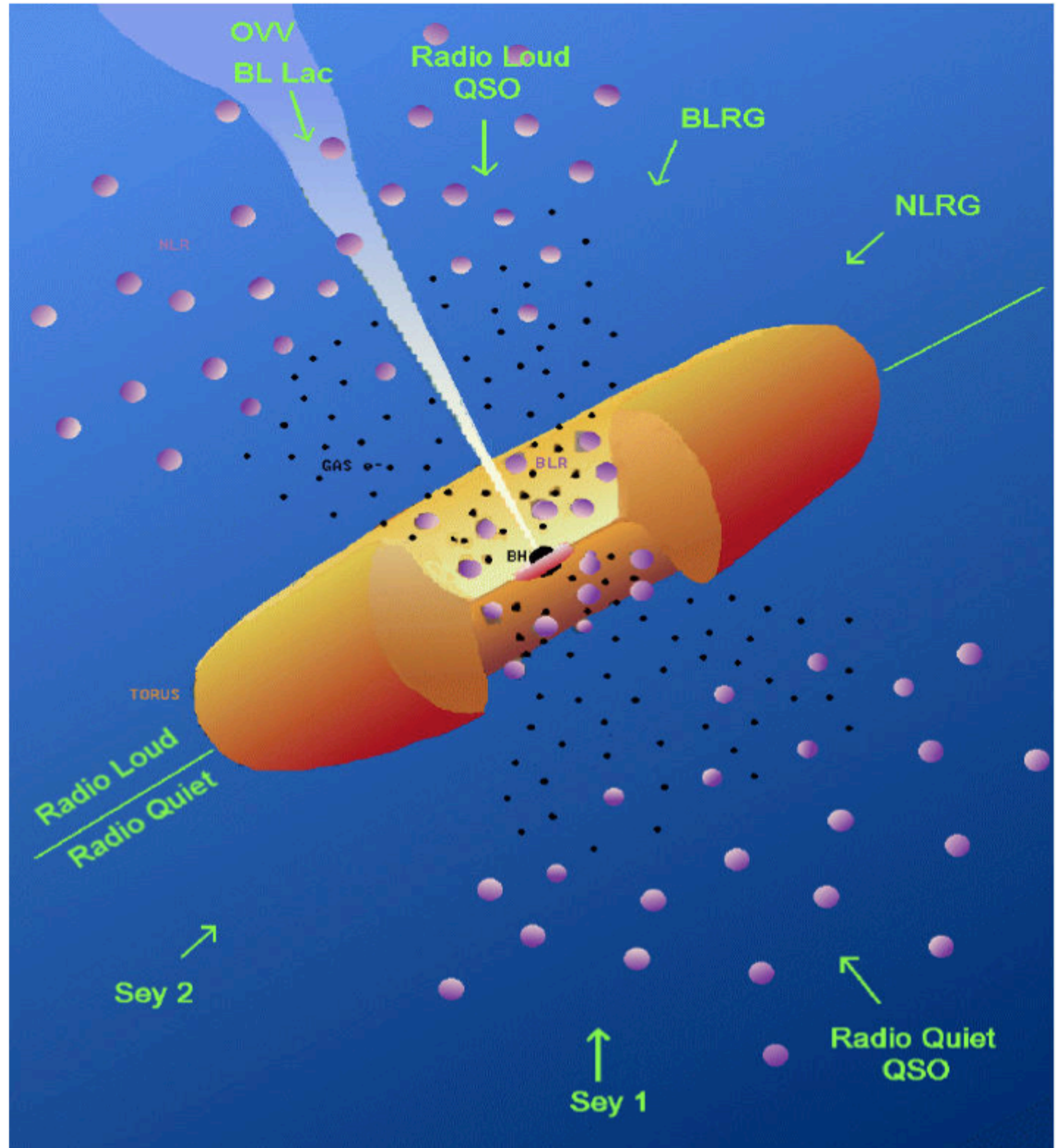
HEPL/KIPAC, Stanford University

The “LEGO” structure of AGN/Blazars

Of all galaxies:

~1% Active Nucleus

~0.1% relativistic jets



“Unification scenario”

Terminology: from zoology to physics

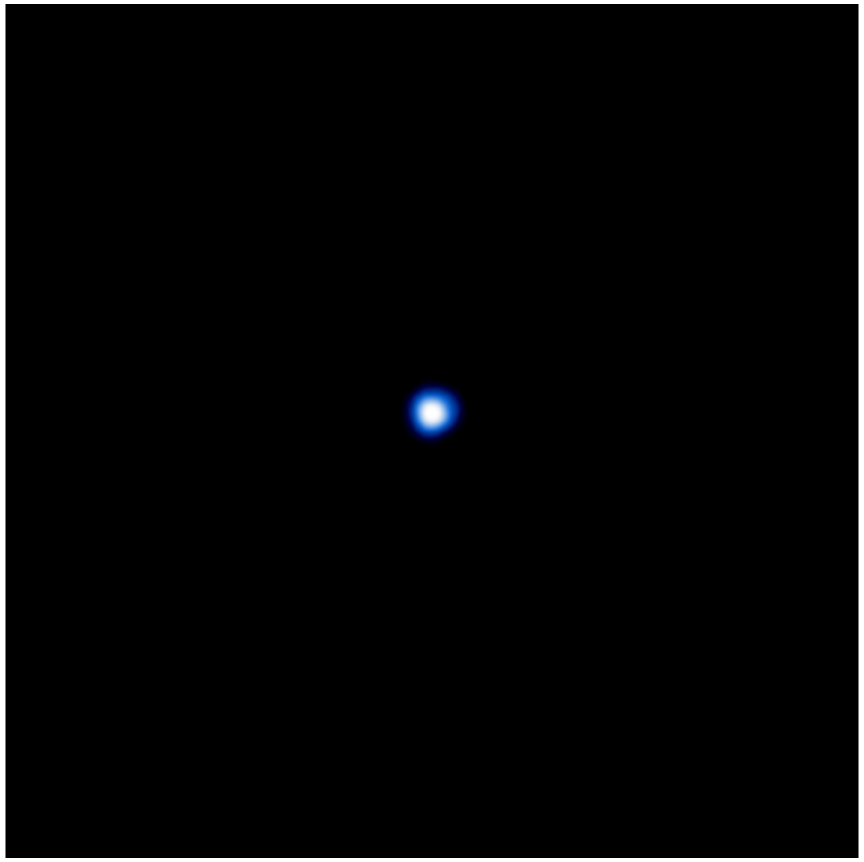
OVV CDQ FSRQ XBL HPQ BLLac RBL SSRQ BLRG NLRG LPQ

BLAZAR (term invented in 1978 by E. Spiegel to denote objects with properties of both BL Lacertae and OVV quasars):

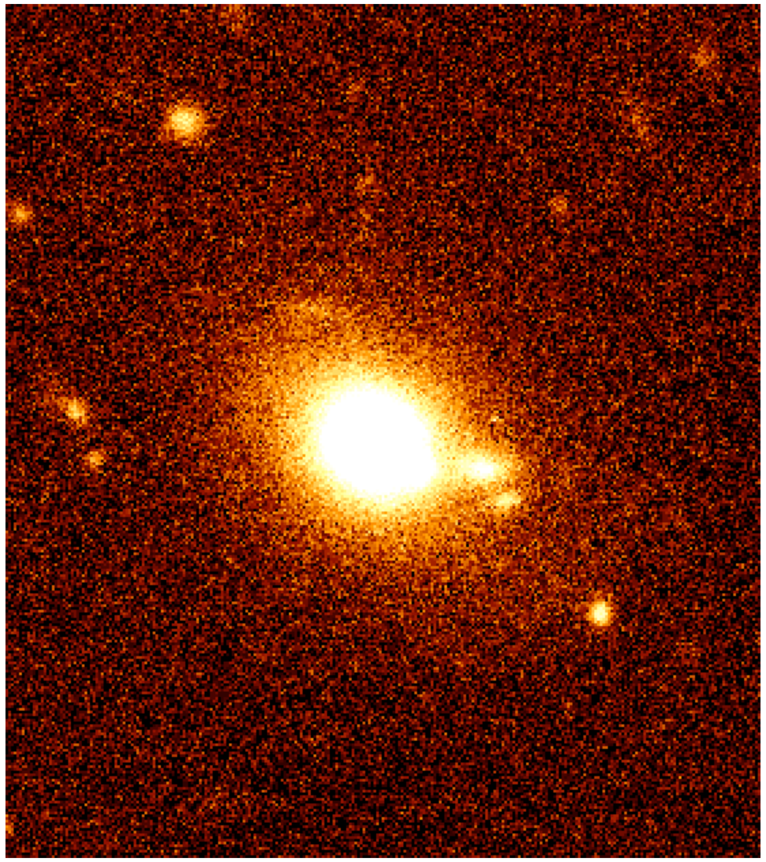
any AGN with a relativistic jet pointing at angles close to the line of sight, and whose emission is dominated by relativistic effects.

No pretty pictures...

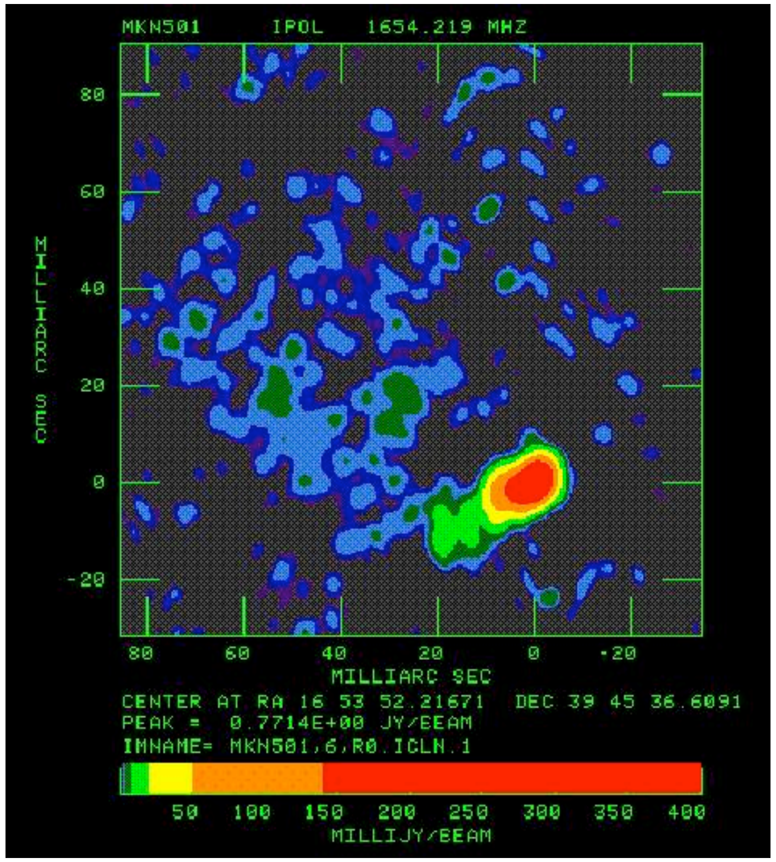
X-ray



Optical



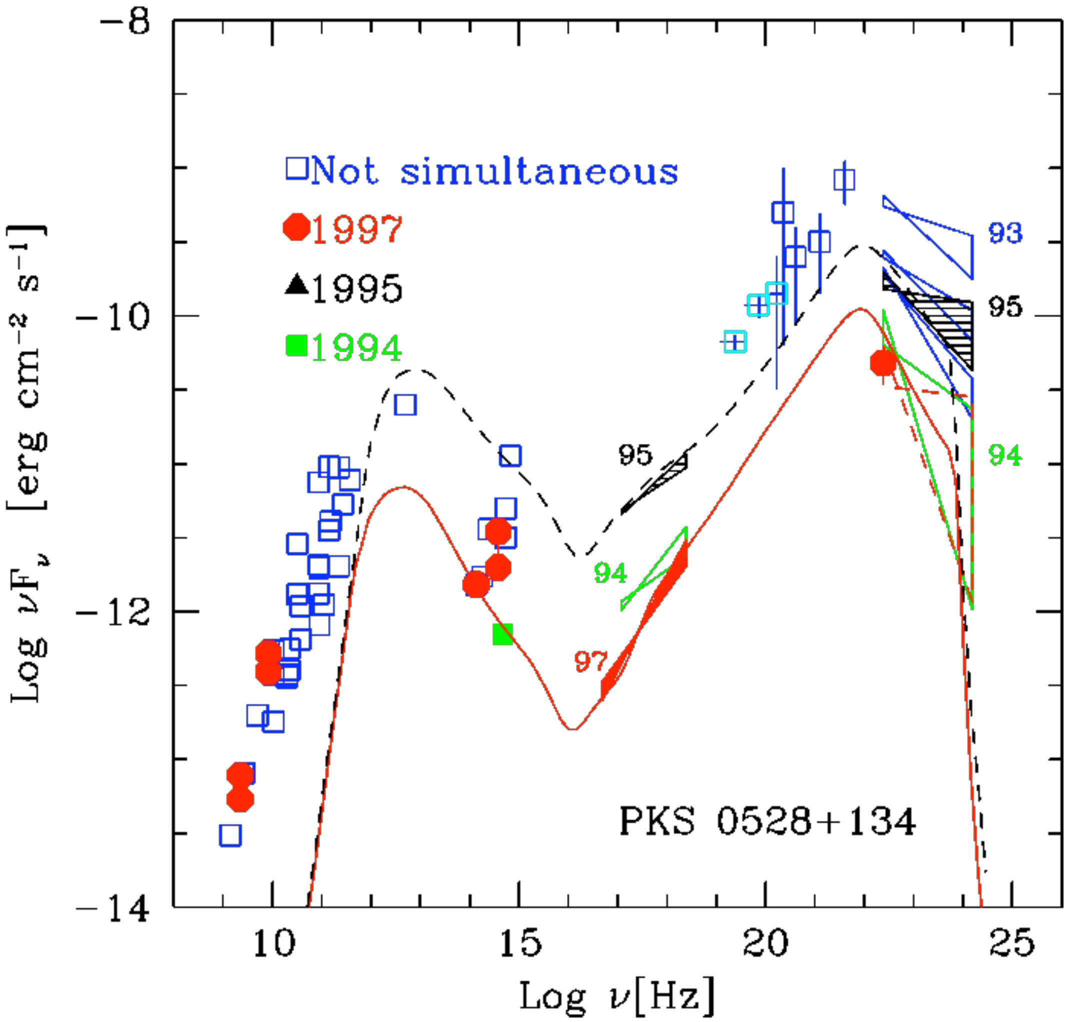
Radio



...but fantastic spectra & lightcurves !

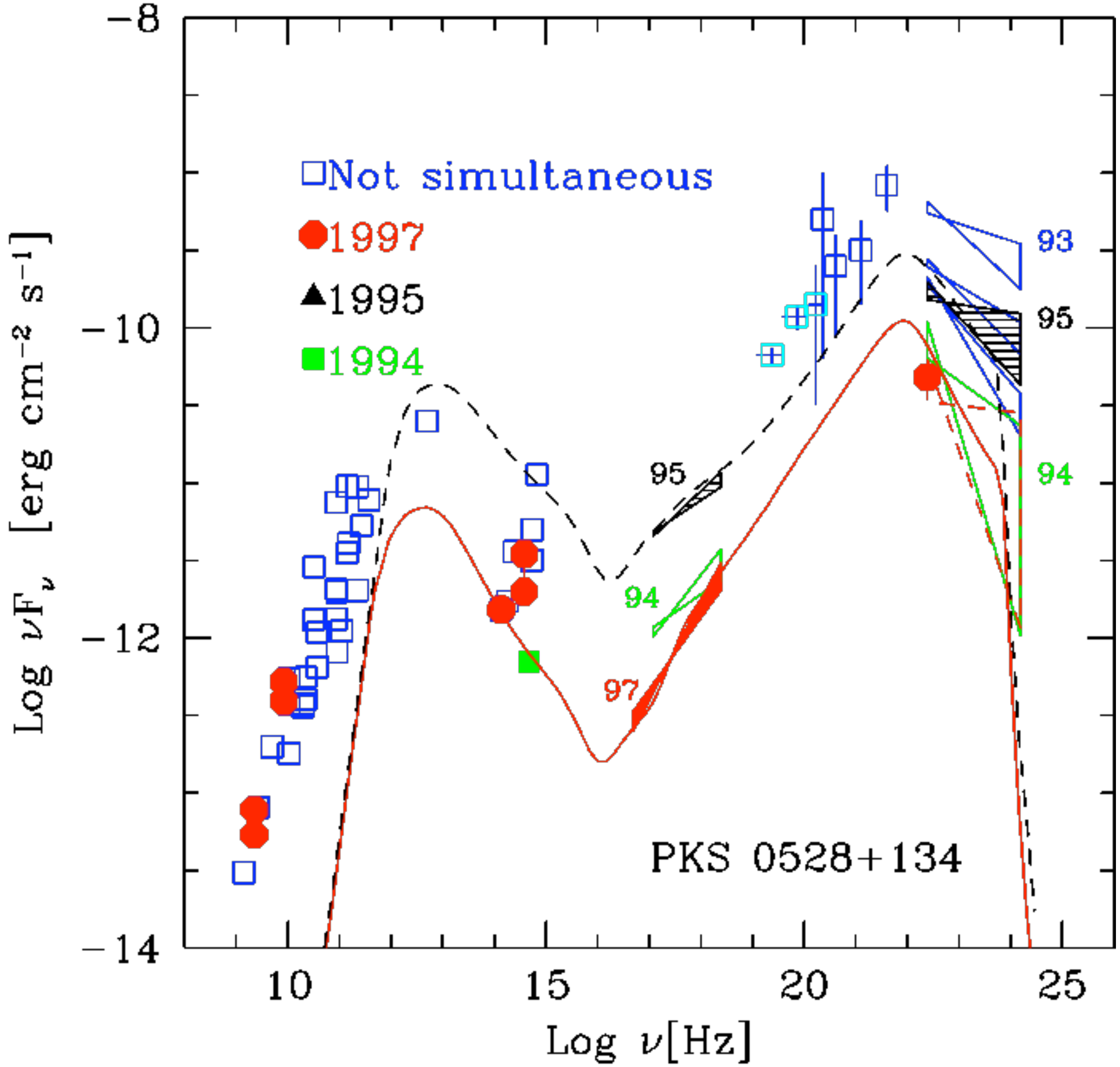
Remember:

Blazer



Blazar

Photo-ID of a Blazar: the Spectral Energy Distribution (SED)



Relativistic Beaming

Usual relativity:
(rulers and clocks)

$$\Delta x = \frac{\Delta x'}{\Gamma} \qquad \Delta t = \Delta t' \, \Gamma \qquad \Gamma = \frac{1}{\sqrt{1-\beta^2}}$$

Not so when information is carried by photons !
(understood 50 years after SR, see Terrel 1959)

Relativistic Beaming

Usual relativity
(rulers and clocks)

$$\Delta x = \frac{\Delta x'}{\Gamma} \qquad \Delta t = \Delta t' \, \Gamma \qquad \Gamma = \frac{1}{\sqrt{1-\beta^2}}$$

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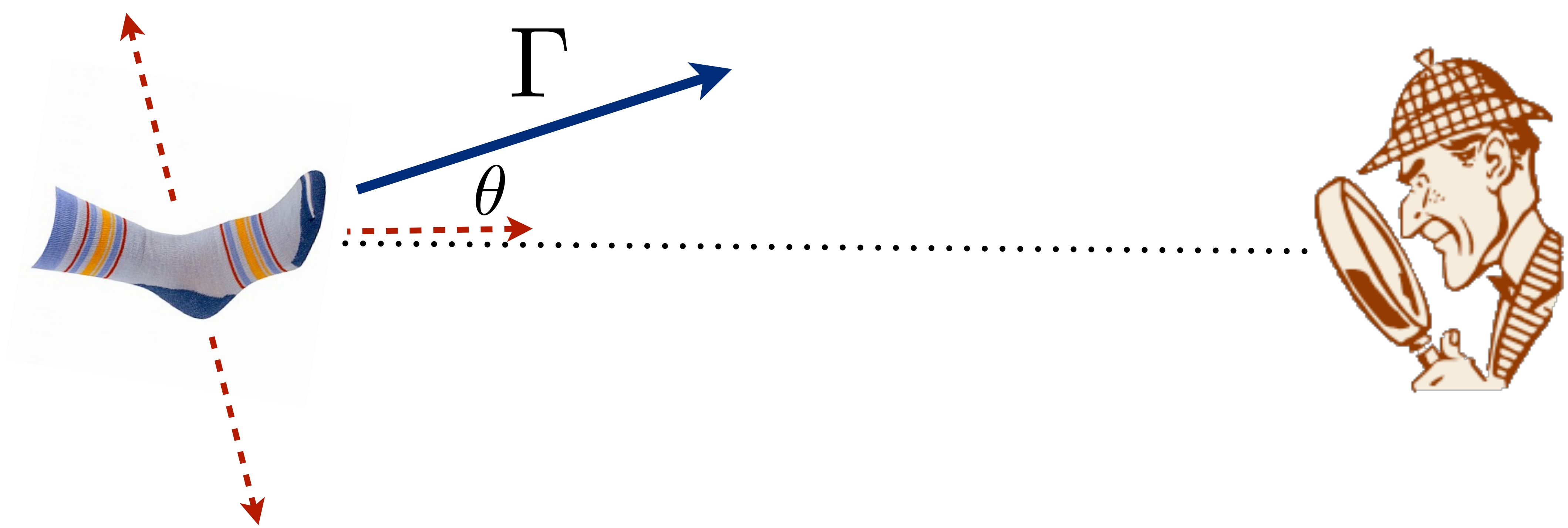
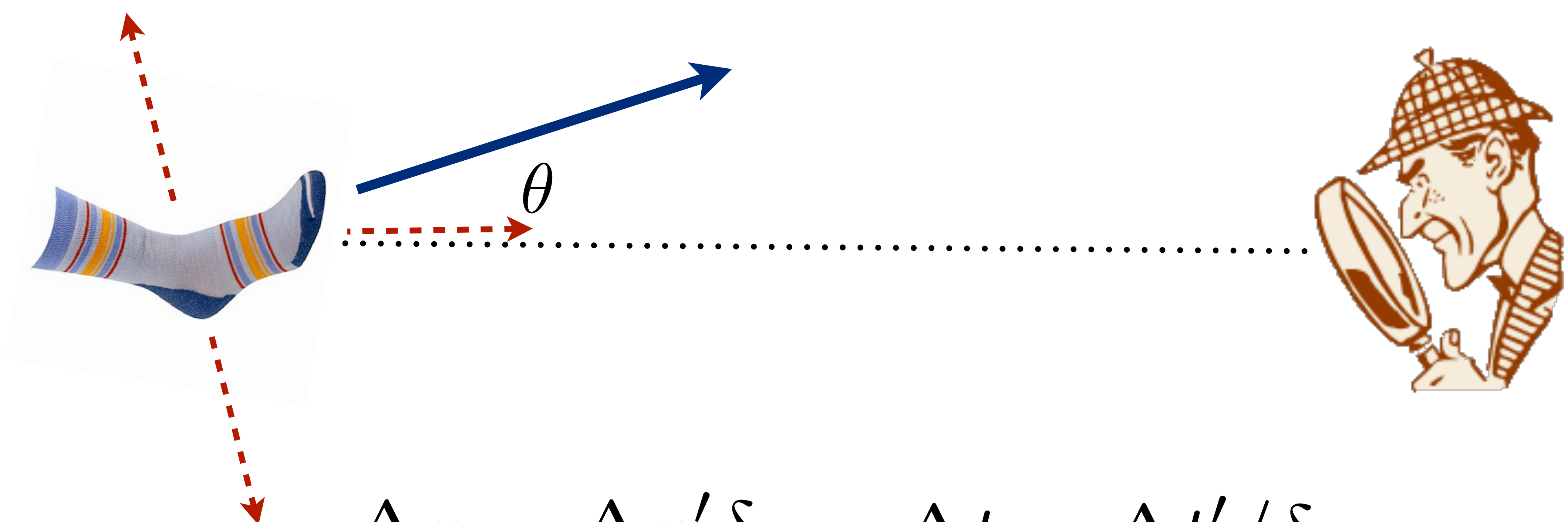


Relativistic sock... (Lemoine's daughter, Dublin 2011)

Relativistic Beaming

Usual relativity
(rulers and clocks)

$$\Delta x = \frac{\Delta x'}{\Gamma} \qquad \Delta t = \Delta t' \, \Gamma \qquad \Gamma = \frac{1}{\sqrt{1-\beta^2}}$$

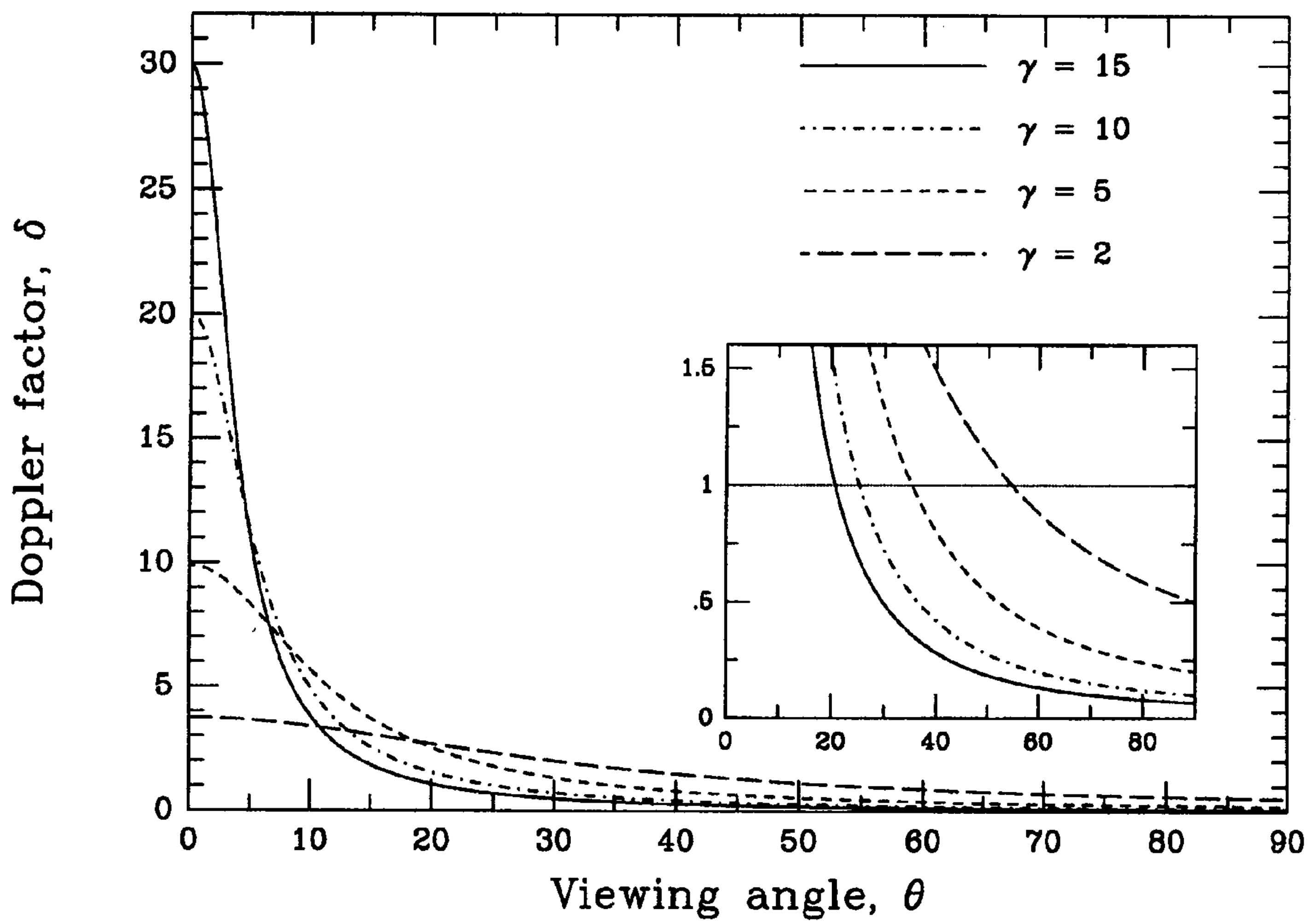


$$\Delta x = \Delta x' \delta \qquad \Delta t = \Delta t' / \delta$$

$$\sin\theta \approx \theta = 1/\Gamma \quad \rightarrow \quad \delta = \Gamma$$

Opposite than
usual Relativity !

Beaming factor δ



$$\delta = \frac{1}{\Gamma(1 - \beta \cos\theta)}$$

Beaming effects:

$$h\nu = h\nu' \, \delta$$

$$d\Omega = d\Omega' / \delta^2$$

$$\Delta t = \Delta t' / \delta$$

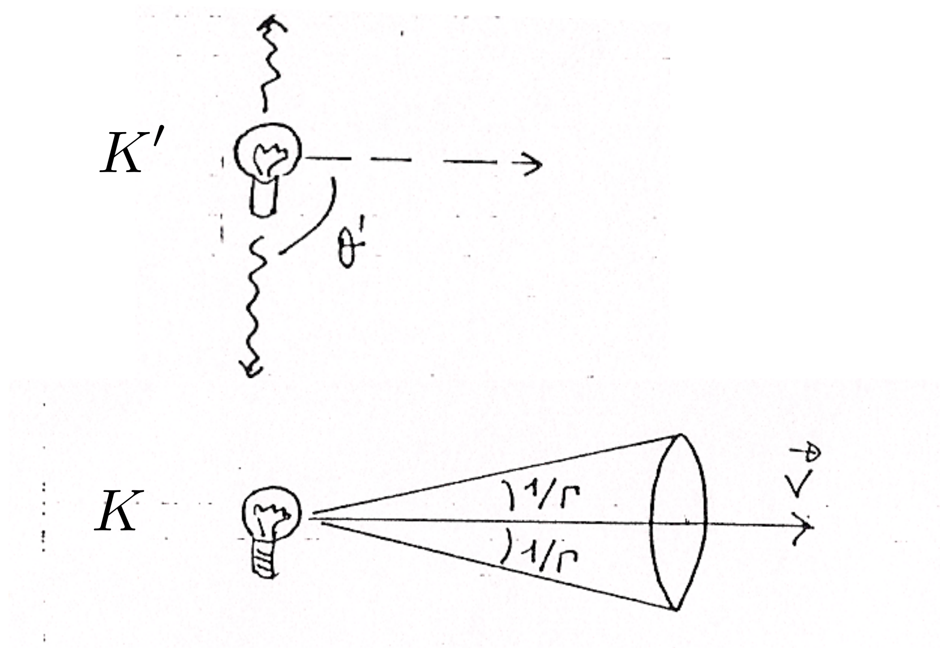
$$V = \delta \, V'$$

$$I(\nu) = \delta^3 \, I'(\nu')$$

$$U'_{rad} \simeq U_{rad} \, \Gamma^2$$

$$F(\nu) = \delta^3 \, F'(\nu')$$ Blob

$$= (\delta^2 / \Gamma) \, F'(\nu')$$ Continuous flow



$$\frac{N(\theta < \theta_0)}{N_{tot}} = \frac{2\pi \int_0^{\theta_0} \sin\theta \, d\theta}{4\pi} = \frac{1}{2\Gamma^2}$$

Superluminal motion:

$$\beta_{app} = \frac{\beta \sin\theta}{1 - \beta\cos\theta}$$

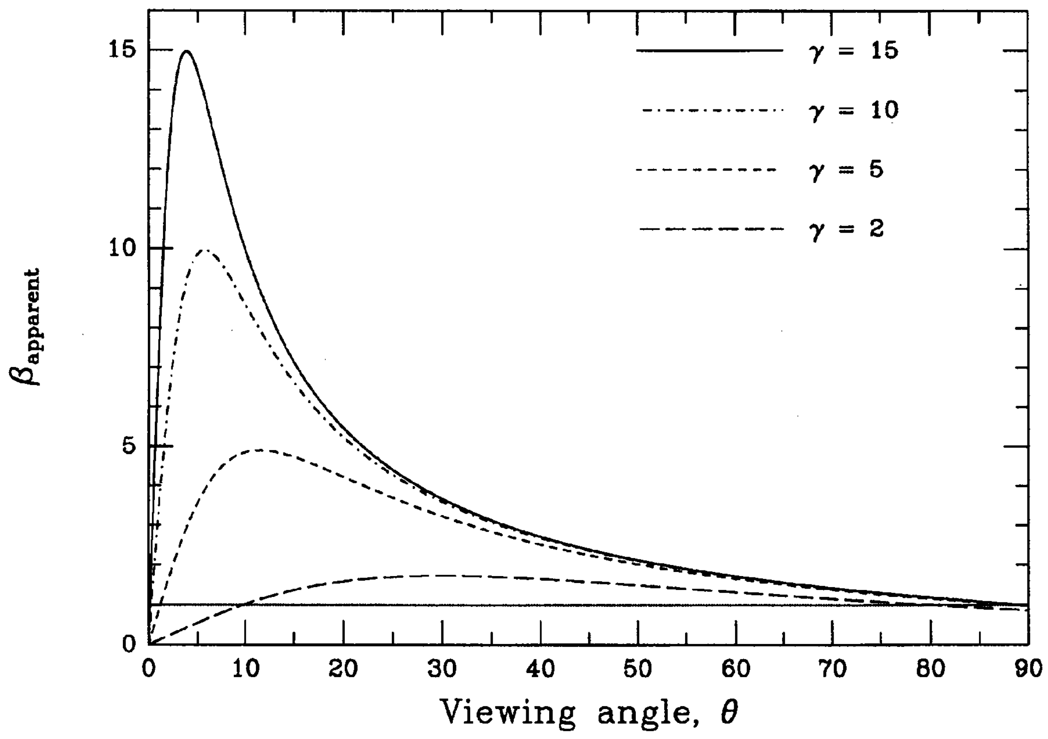


FIG. 21—The apparent velocity relative to the speed of light vs. angle to the line of sight for an emitter approaching at relativistic speed. Different curves correspond to different Lorentz factors: from the top down, γ=15, 10, 5, 2. The dotted line corresponds to $\beta_a = 1$. Note that β_a is essentially independent of γ at large angles.

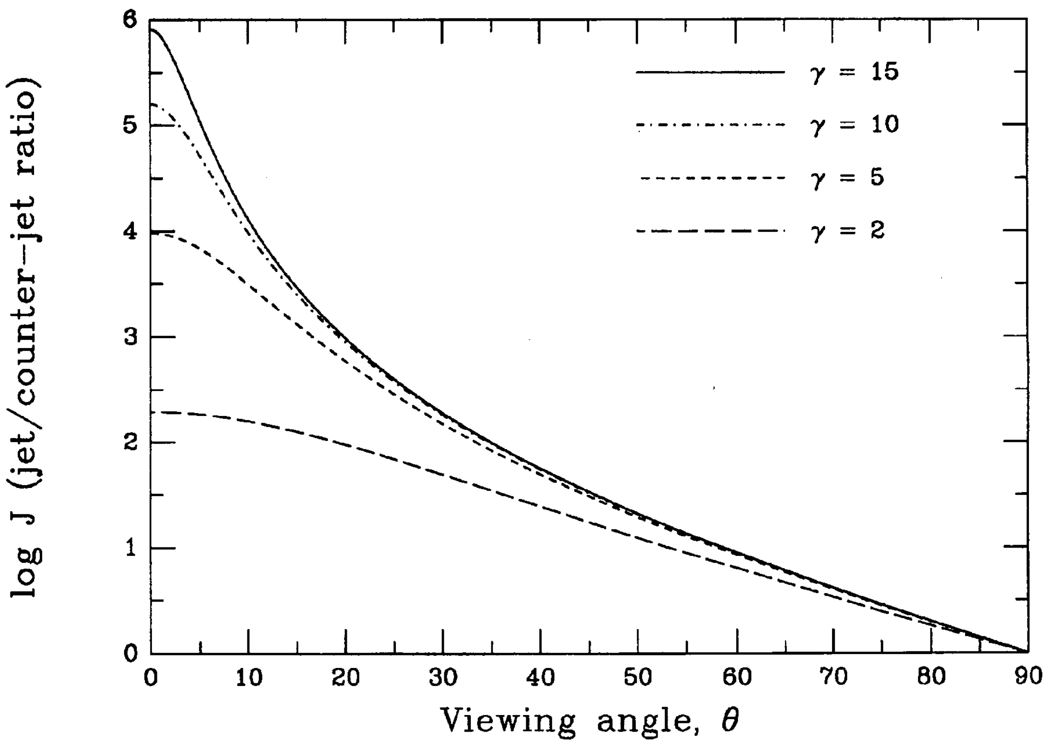
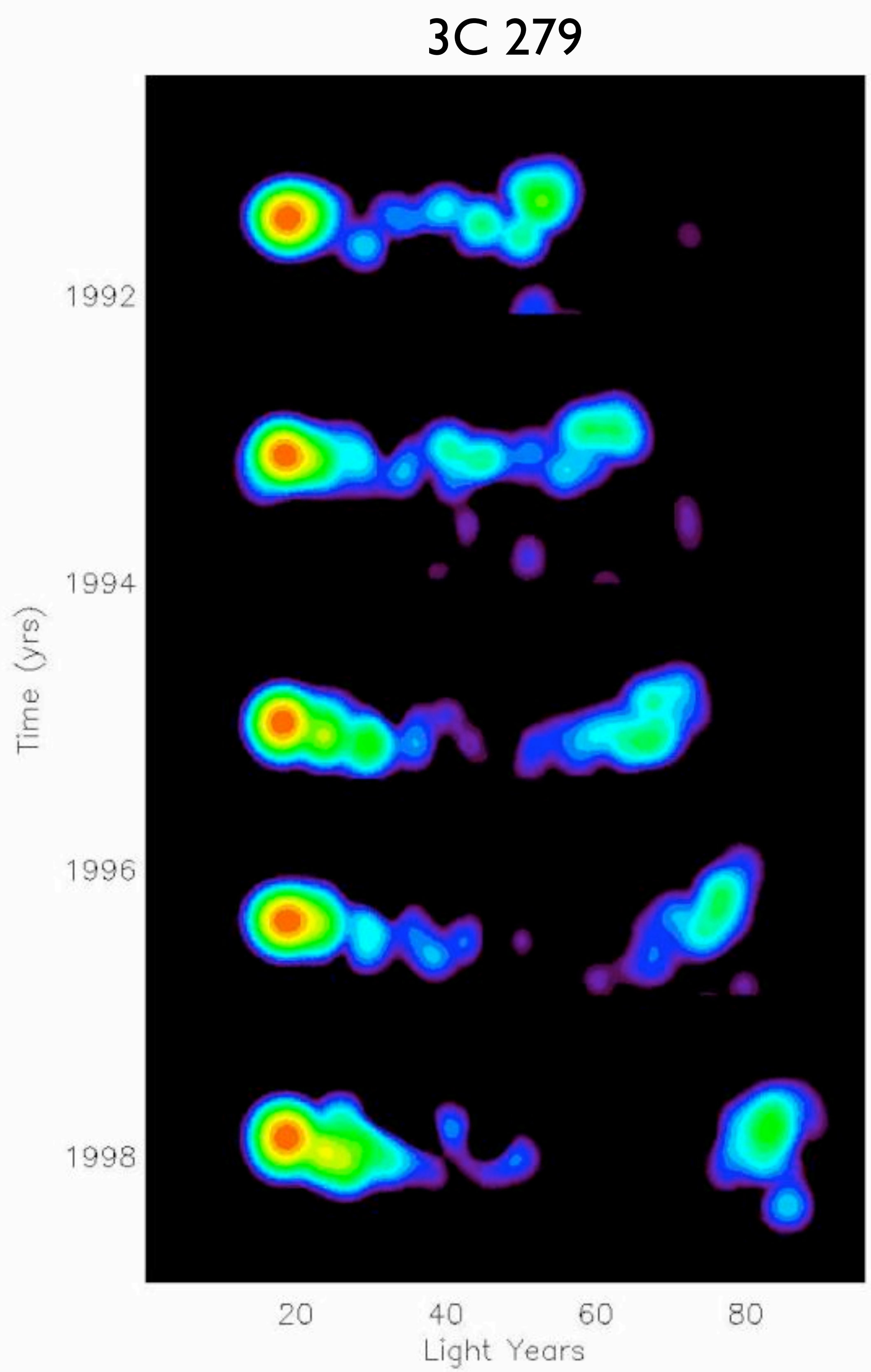
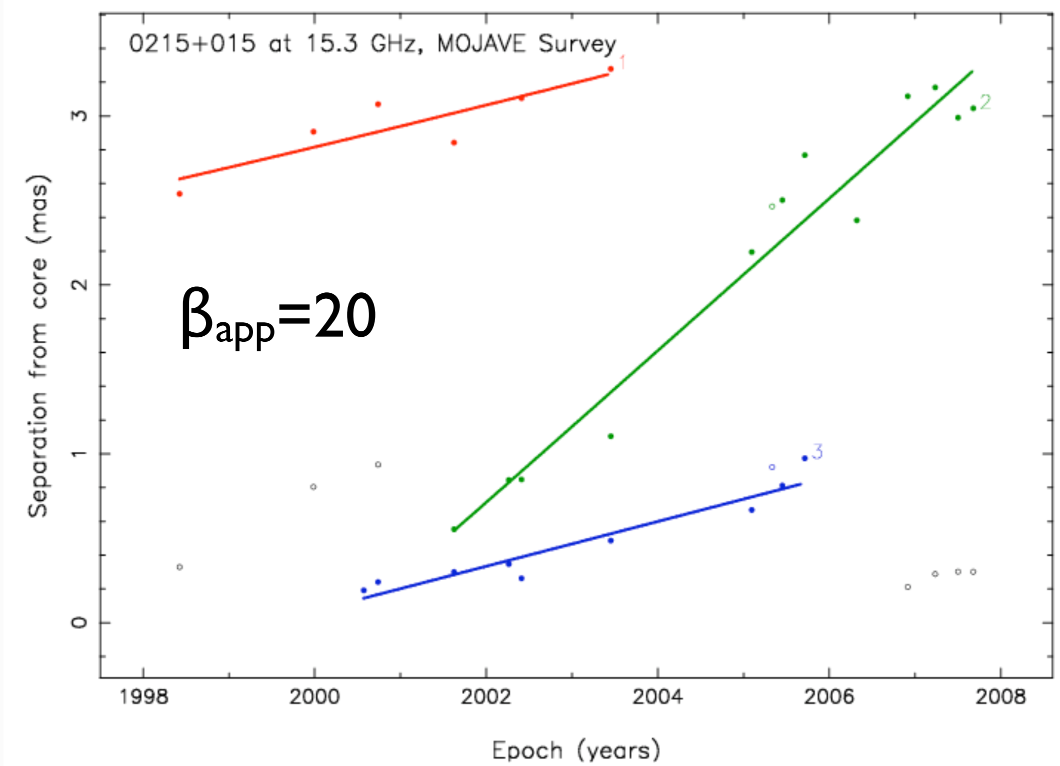


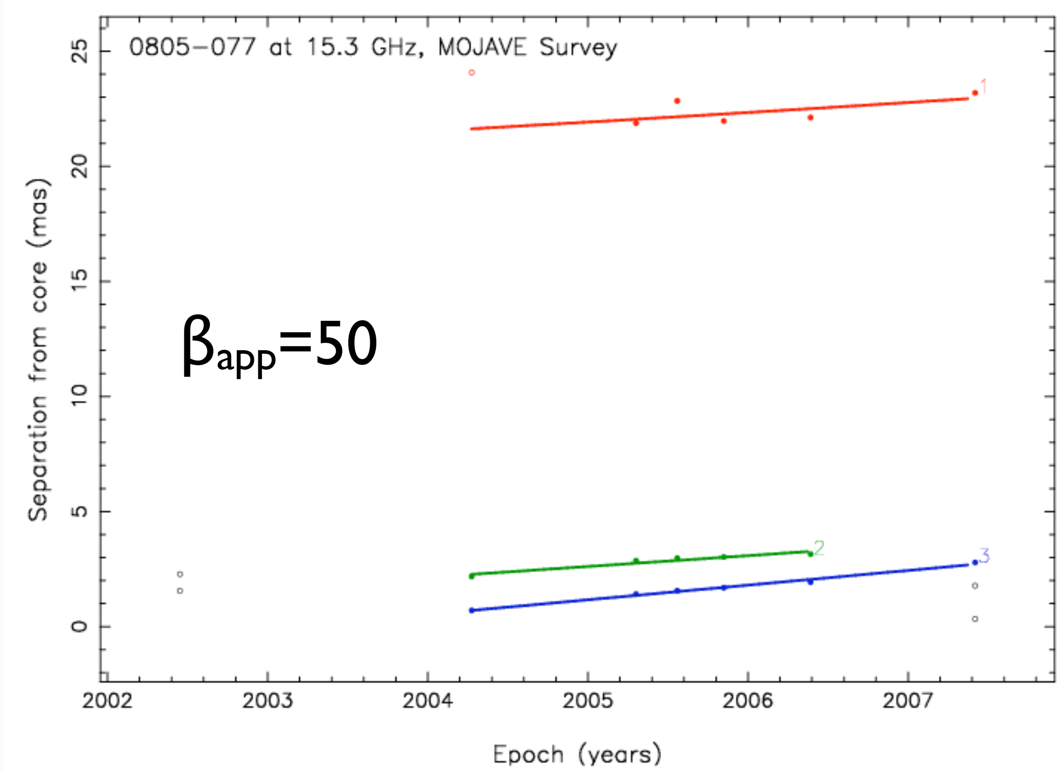
FIG. 22—The jet to counterjet ratio, J, vs. angle to the line of sight for $p = 2$. Different curves correspond to different Lorentz factors: from the top down, γ=15, 10, 5, 2. Note that the ratio is essentially independent of γ at large angles.

Urry & Padovani 1995

Proofs of Beaming: Superluminal Motion







$\Gamma \geq \beta_{app}$ **!!**

Beaming proofs: Gamma-ray transparency

$$x = h\nu / m_e c^2$$

$$\Delta t = \Delta t' / \delta$$

$$R \leq \frac{c t_{var} \delta}{1+z}$$

$$\tau_{\gamma\gamma}(x) = \frac{\sigma_T}{5} R \, \frac{L_x(1/x)}{4\pi R^2 m_e c^3}$$

$$\tau_{\gamma\gamma} \simeq \frac{l(1/x)}{60}$$

Compactness parameter

Without beaming, l~ 5000-50000

$$\delta \geq \left(\frac{\sigma_T \, d_l^2 \, (1+z)^{2\alpha}}{5 \, h \, c^2} \; \frac{F(\nu_0)}{t_{var}} \right)^{\frac{1}{4+2\alpha}}$$

$$\delta \geq 5 - 50 \, !$$

See e.g. Dondi & Ghisellini 1995

1) Thermal Properties

Flat Spectrum Radio Quasars (FR II) **BL Lacs** (FR I)

Broad Emission Lines:

EW>5 Å

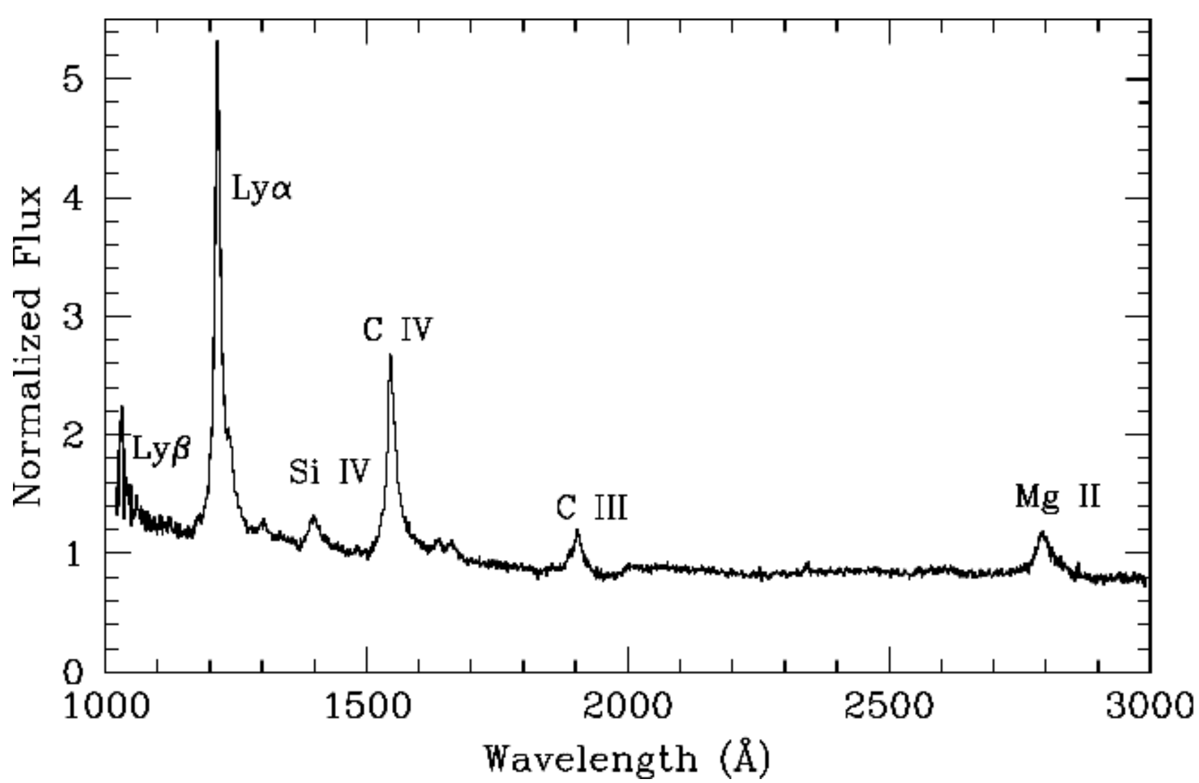
Intense disk & BLR emission
=> high U_{rad} (UV)

Dusty Torus
=> high U_{rad} (IR)

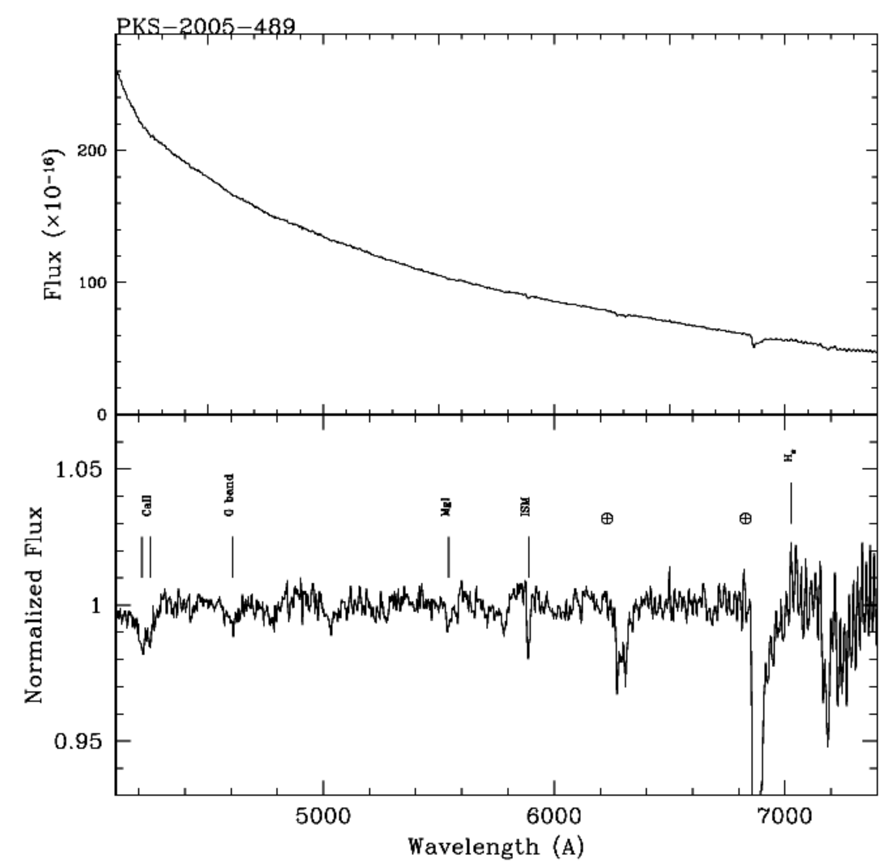
EW<5 Å

Weak disk & BLR emission
=> low/absent U_{rad}(UV)

No Dusty Torus ? (FRI)
=> low/weak U_{rad}(IR)



Pian et al. 2005



1) Thermal Properties

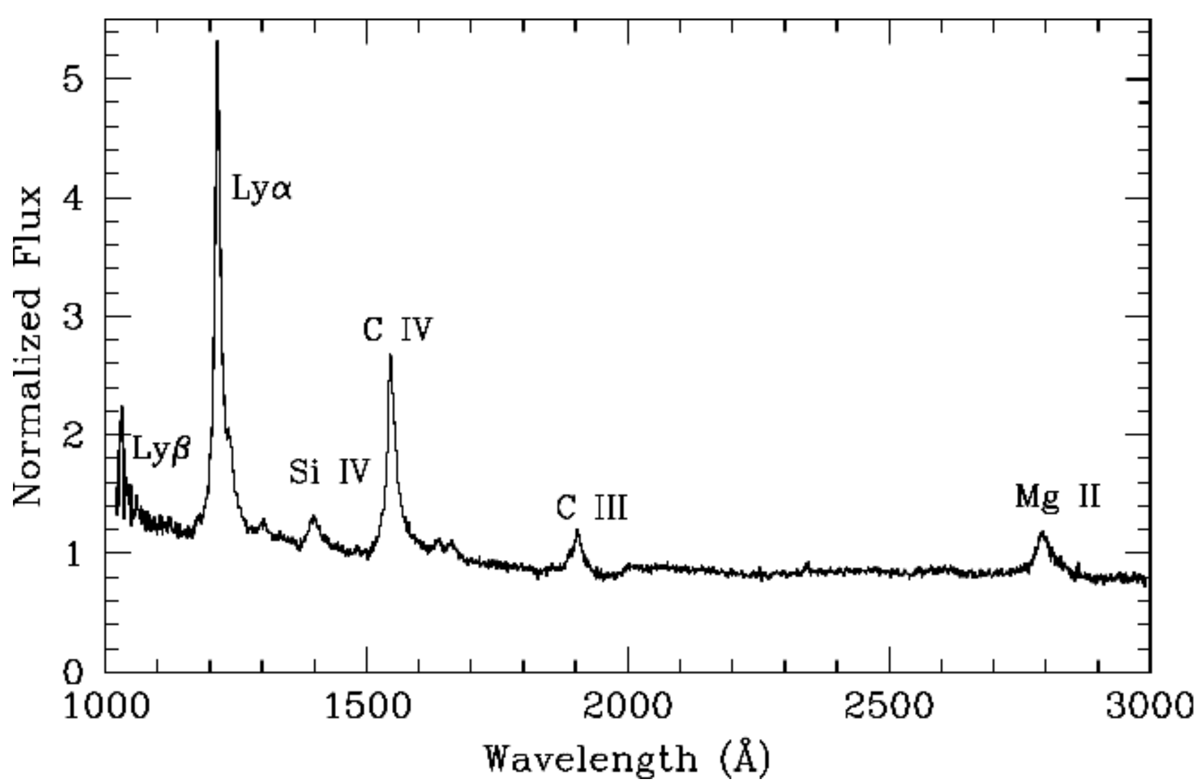
FSRQ (FR II) | **BL Lacs (FR I)**

Broad Emission Lines:

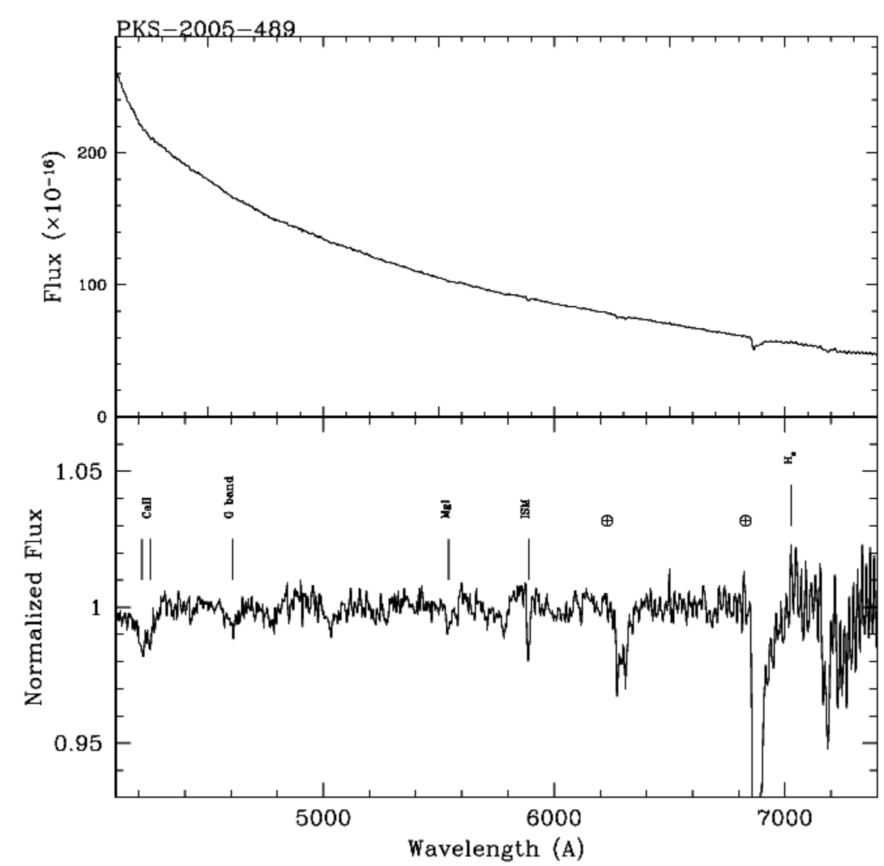
EW>5 Å | **EW<5 Å**

Continuum range of EW and line luminosities:

10^{46} erg/s ---------------------------► $<10^{40}$ erg/s



Pian et al. 2005



I) Thermal Properties

FSRQ (FR II) **BL Lacs** (FR I)

Broad Emission Lines:

EW>5 Å **EW<5 Å**

CAVEAT: EW is a ratio between line luminosity and continuum
U_{rad} is given by absolute line luminosity !

1) FSRQ and BLLacs can have SAME LINE LUMINOSITY ! (e.g. PKS 0208-512, $L_{MgII} \sim 10^{44}$)

2) if the non-thermal continuum has lower and lower luminosity
=> a BLLac/Blazar can be misclassified/not recognized hidden in a normal or RQ galaxy

1996: - BL Lac *was not* a BL Lac...
- 3C279 *was* a BL Lac...

2) Jet SED properties: peak frequencies

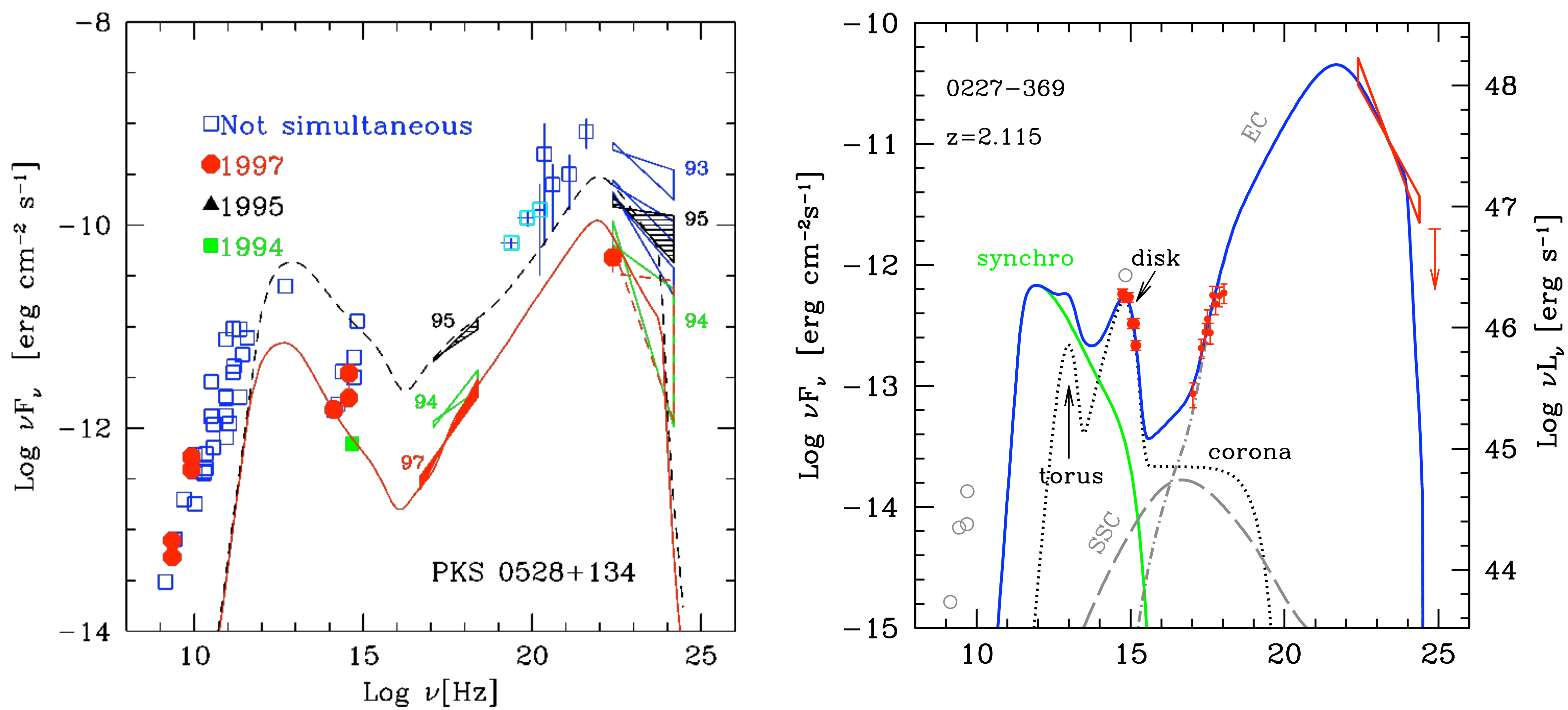
From Low to High-energy peaked Blazars:
FSRQ - LBL - IBL - HBL - Extreme BL

X-ray spectrum defines/proxies the classification

Giommi & Padovani 1994,1995

2) Jet SED properties: peak frequencies

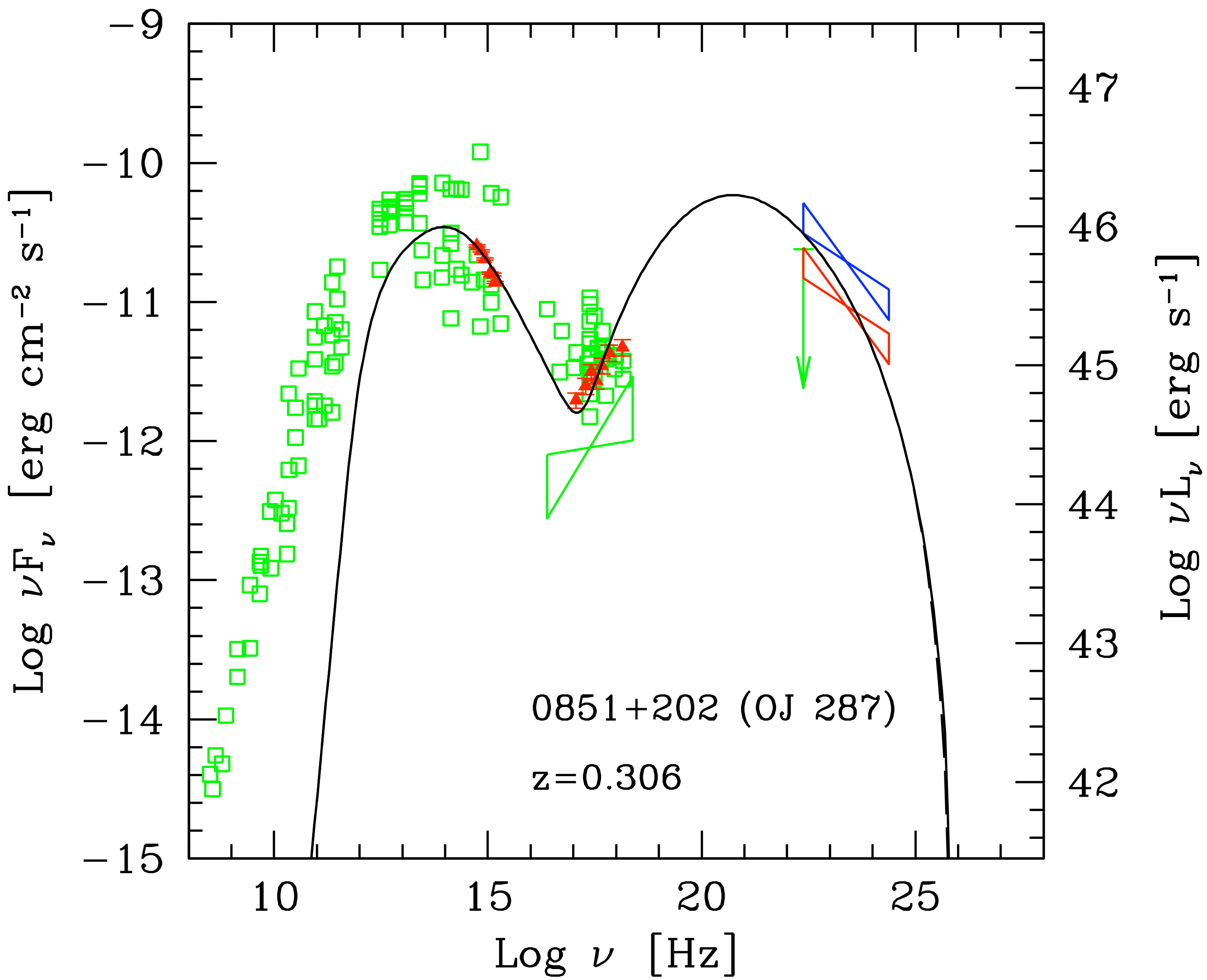
From Low to High-energy peaked Blazars:
FSRQ - LBL - IBL - HBL - Extreme BL



Ghisellini, Costamante et al. 1998

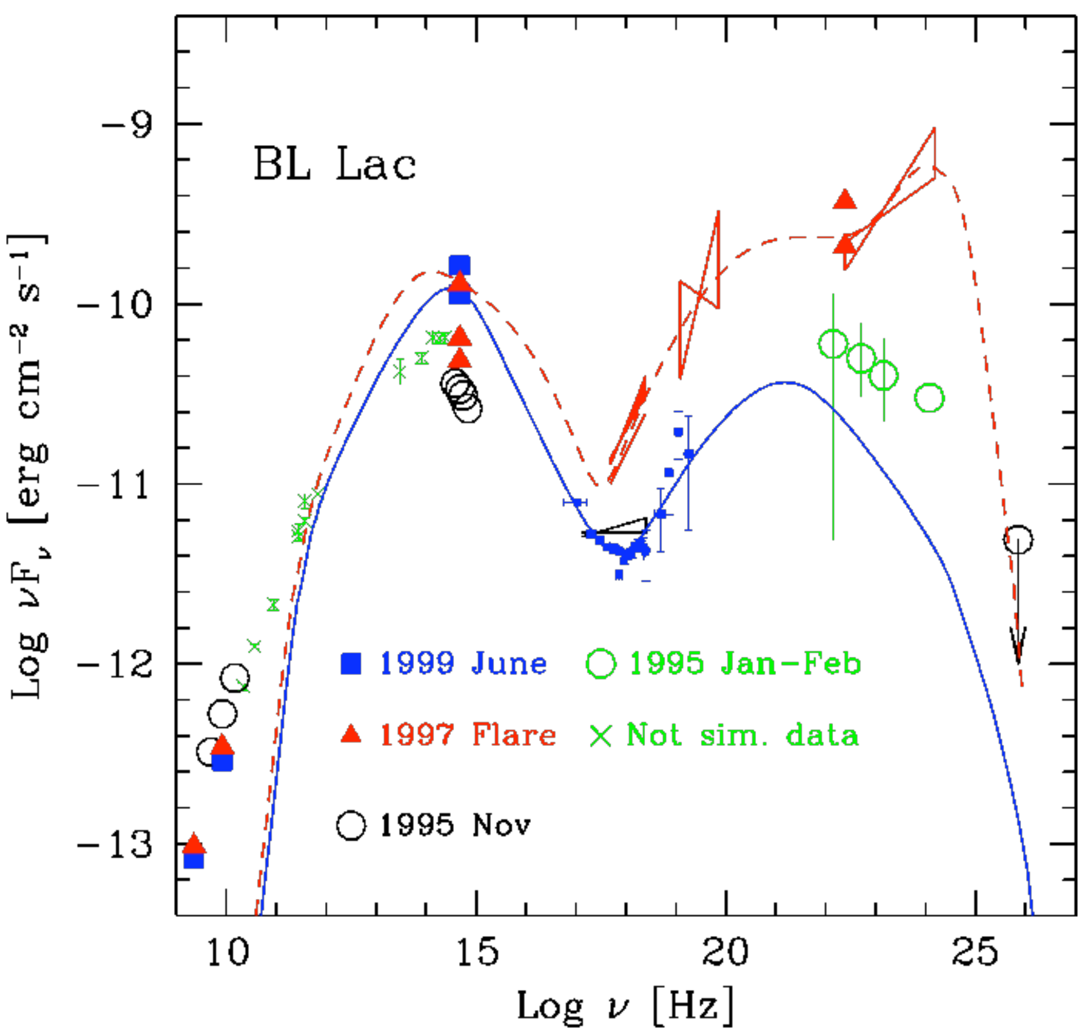
2) Jet SED properties: peak frequencies

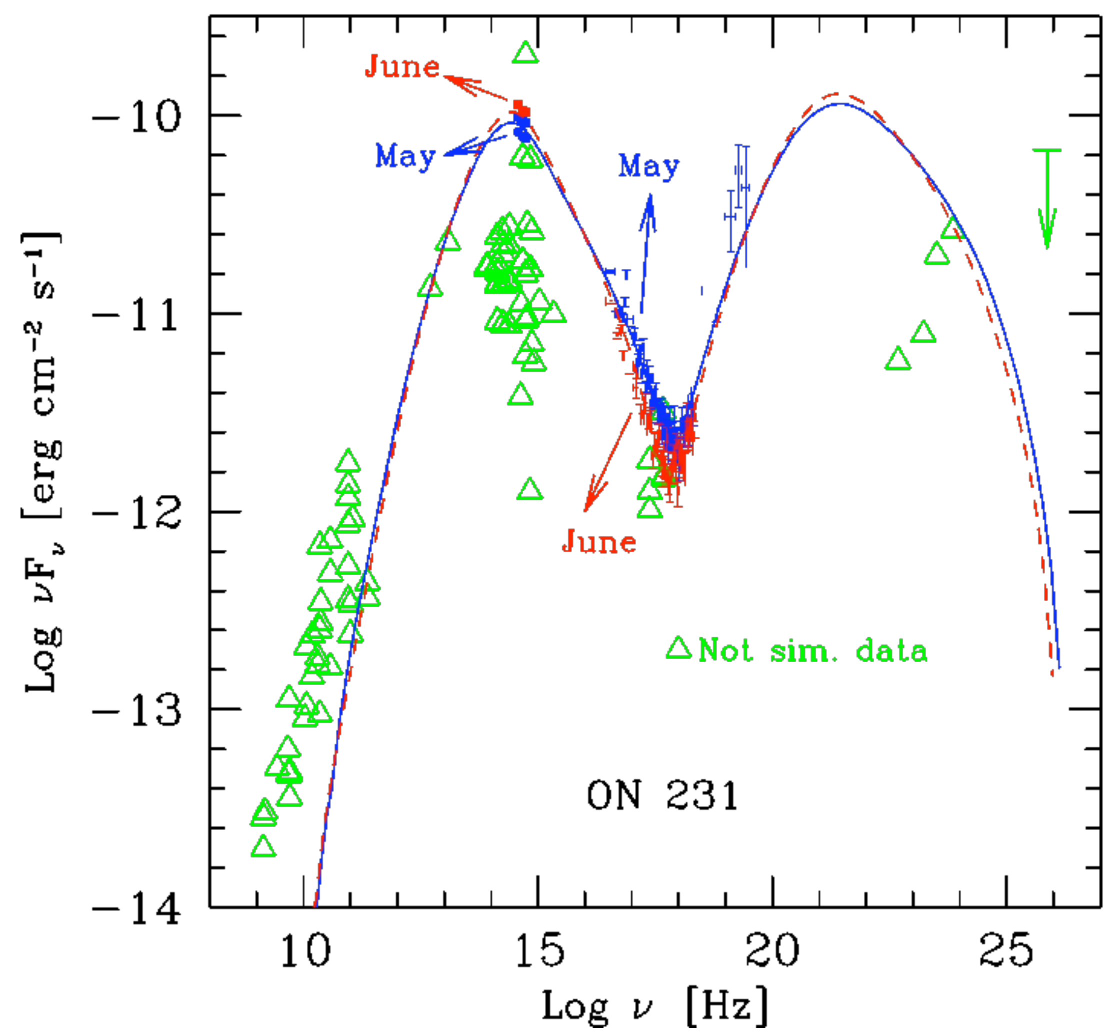
From Low to High-energy peaked Blazars:
FSRQ - **LBL** - IBL - HBL - Extreme BL



2) Jet SED properties: peak frequencies

From Low to High-energy peaked Blazars:
FSRQ - LBL - **IBL** - HBL - Extreme BL





Tagliaferri et al. 2002

2) Jet SED properties: peak frequencies

From Low to High-energy peaked Blazars:

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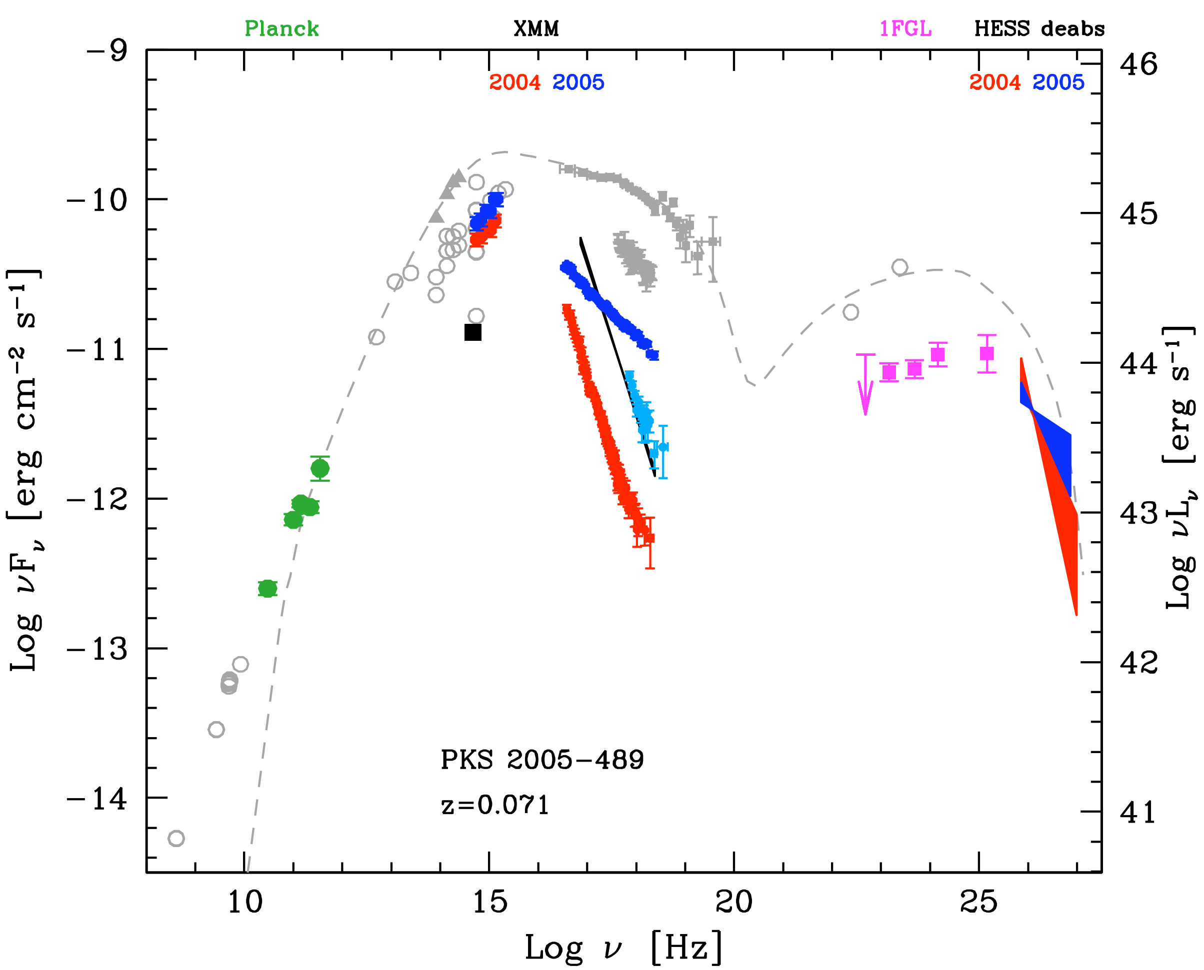
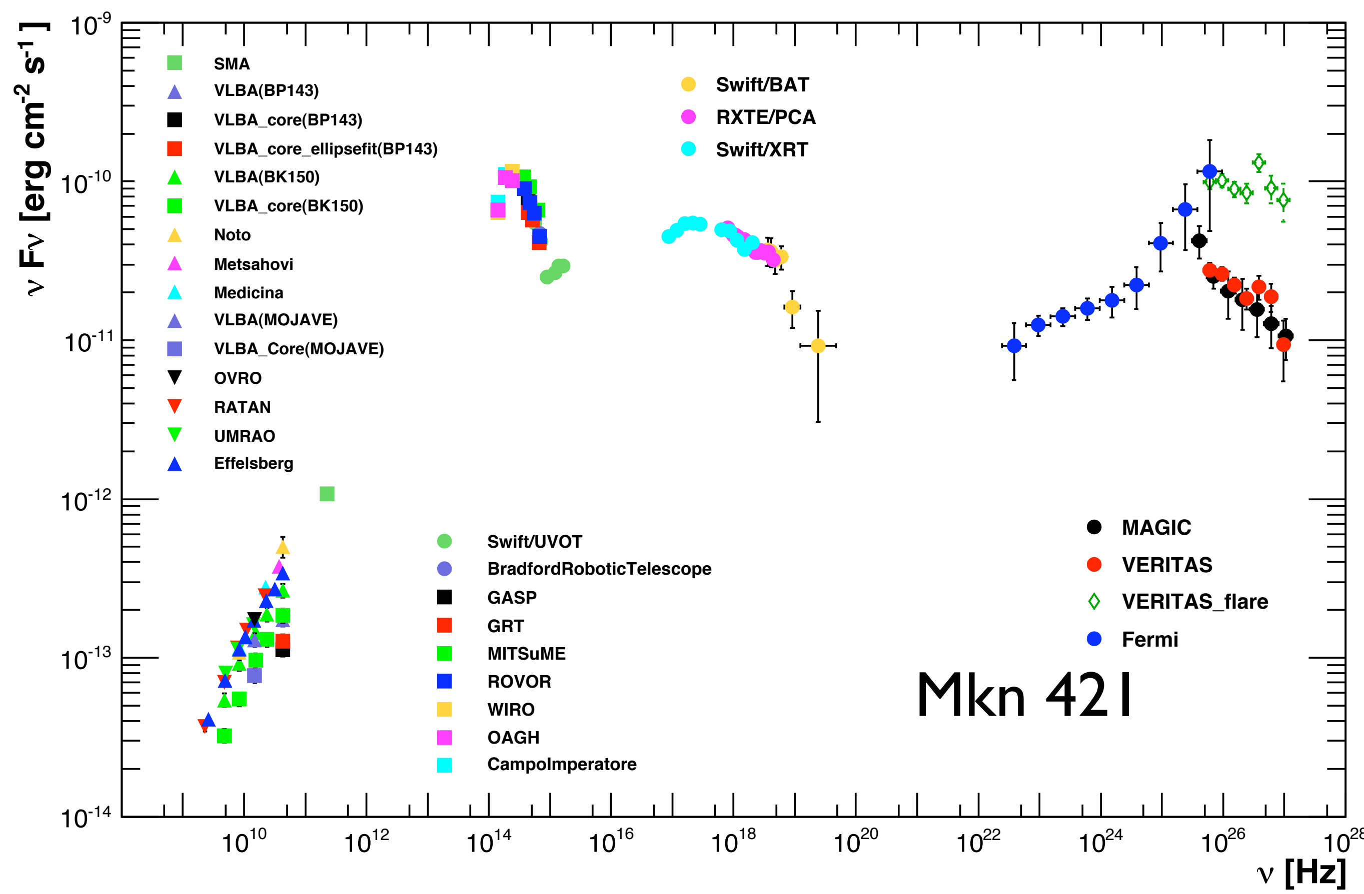


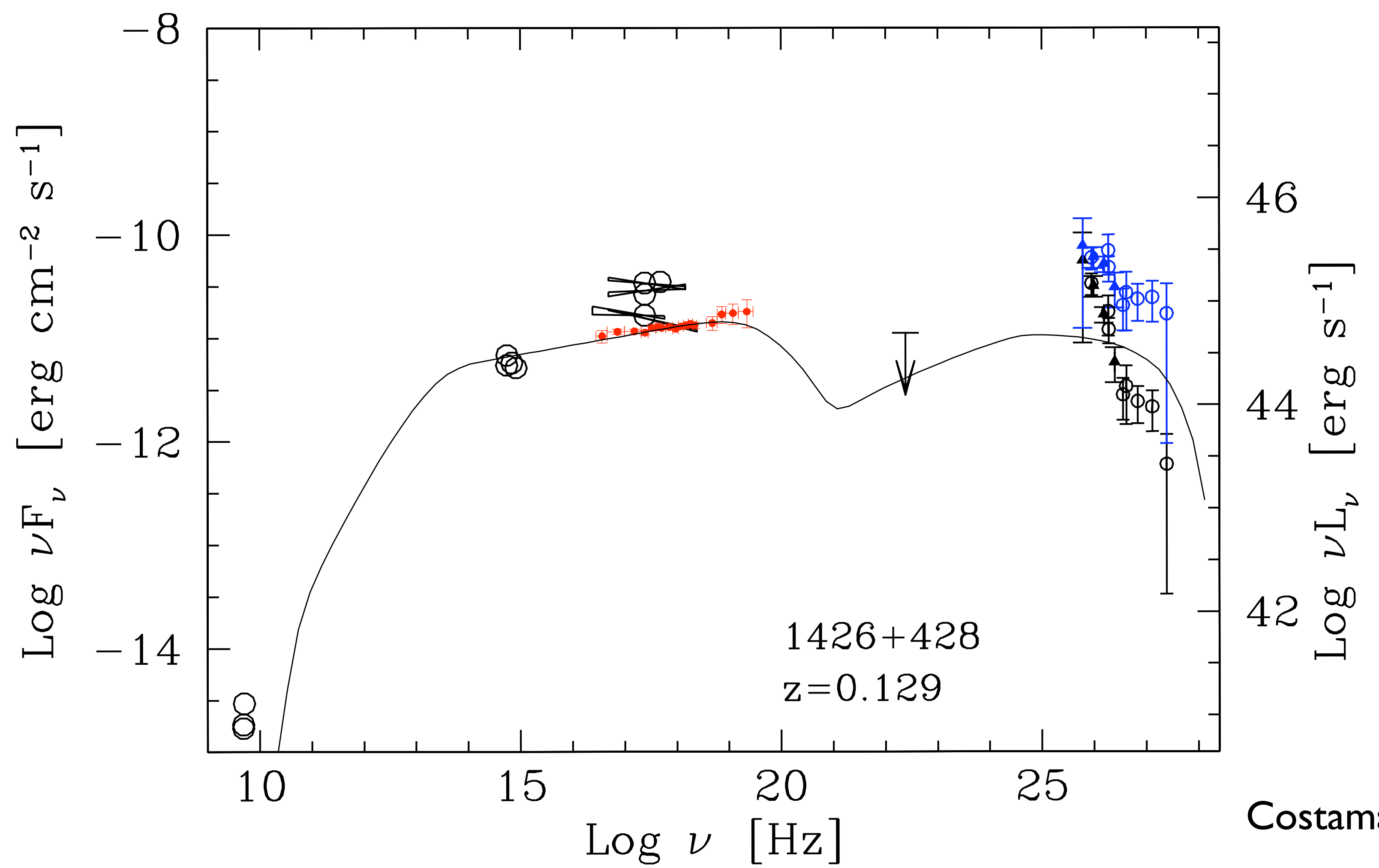
Aharonian et al. 2010



Abdo et al. 2010

2) Jet SED properties: peak frequencies

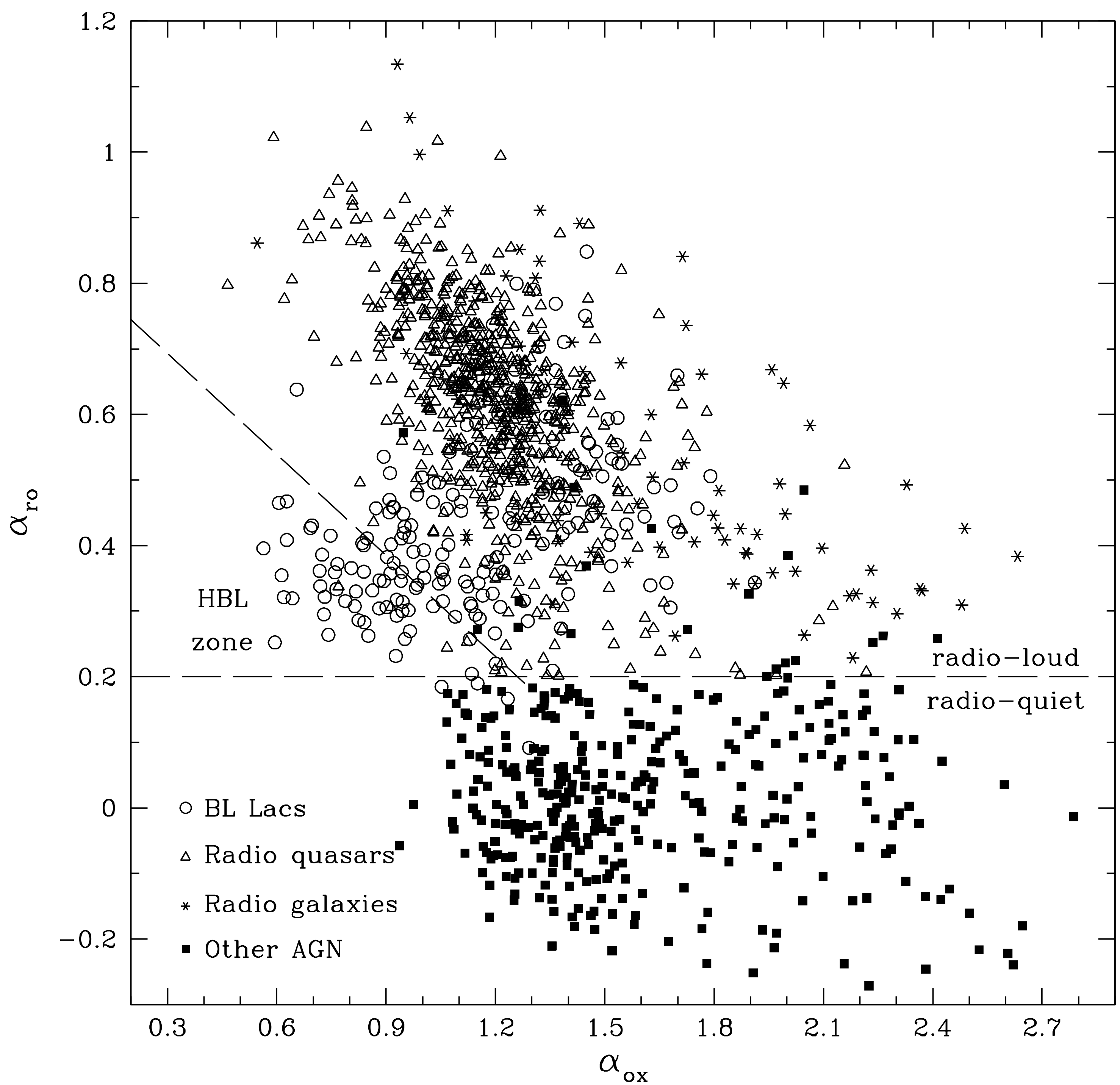
From Low to High-energy peaked Blazars:
FSRQ - LBL - IBL - HBL - **Extreme BL**



Costamante et al. 2001, 2008

Note: blazars are *not* extreme accelerators:
10^{-4} less efficient than Crab !

How to find/classify blazars ?
Radio+X-ray surveys, broad-band indexes



HBL-LBL:
α_{RX}=0.75

Giommi & Padovani 1994

Emission mechanisms:

Hadronic

Leptonic

Hadronic scenarios:

pp : not efficient, $L \sim 10^{45}$ erg/s needs target 10^6 cm^{-3}

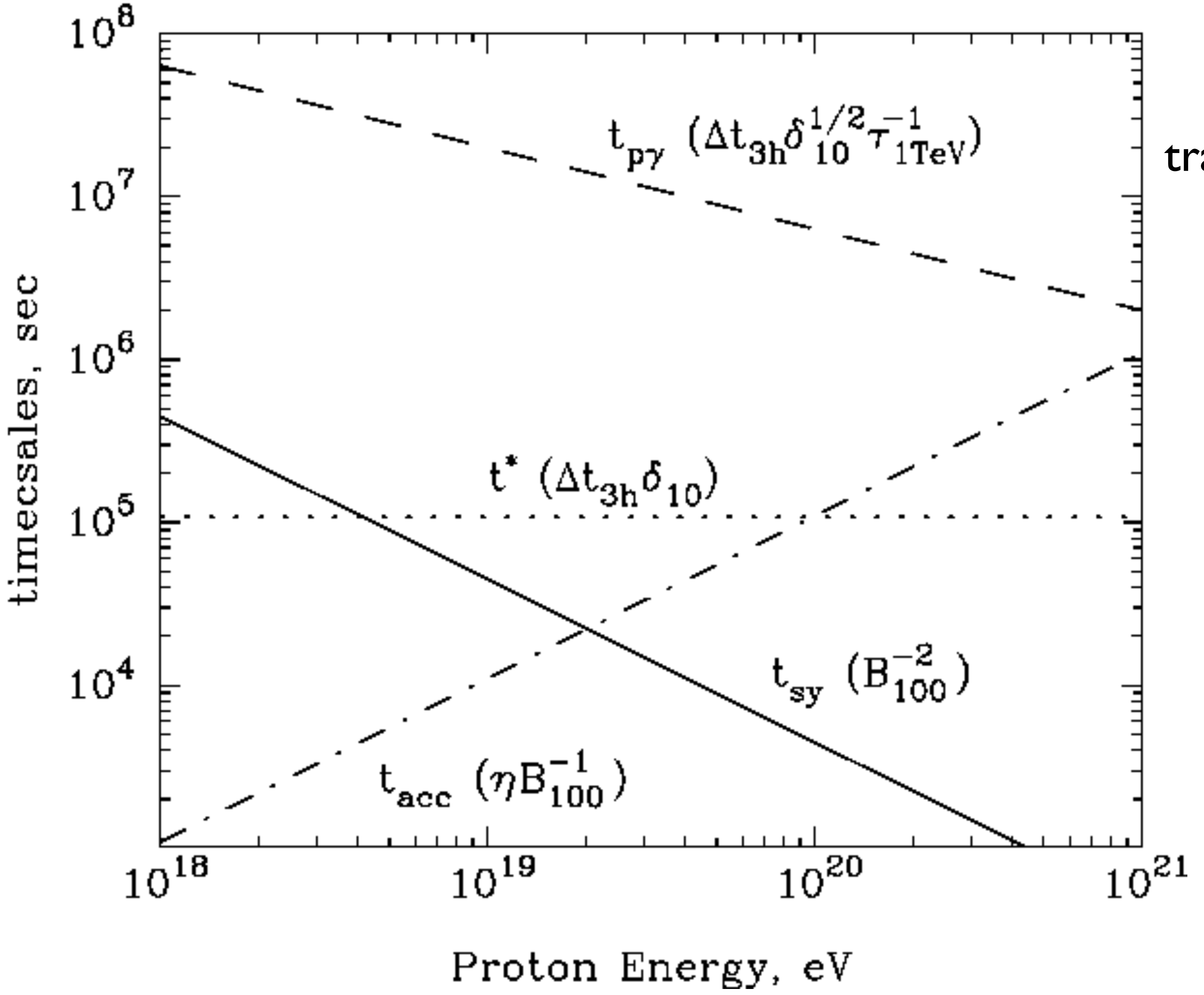
For typical blazar variability (few hrs):

pγ : $E_p > 10^{19}$ eV, needs large densities of target photons

pB : $E_p > 10^{19}$ eV, needs large magnetic fields

See e.g. Muecke & Protheroe 2000, Aharonian 2000

Hadronic scenarios: cooling times

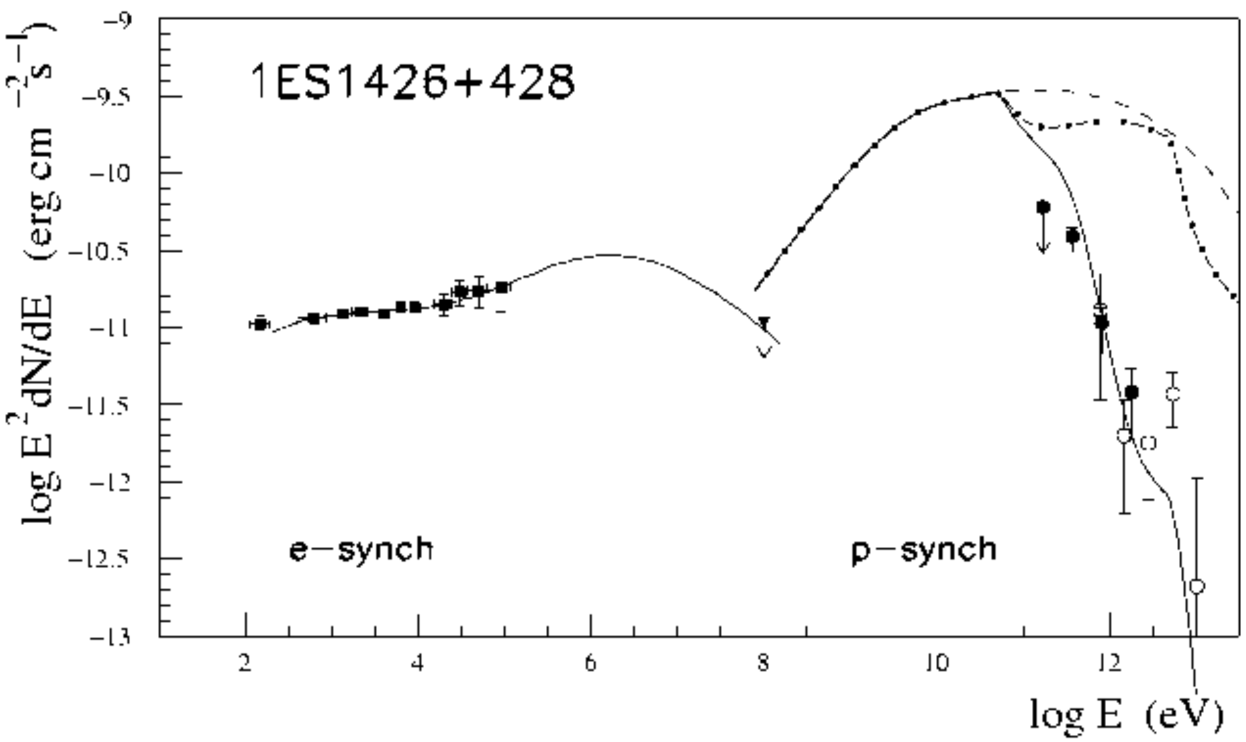


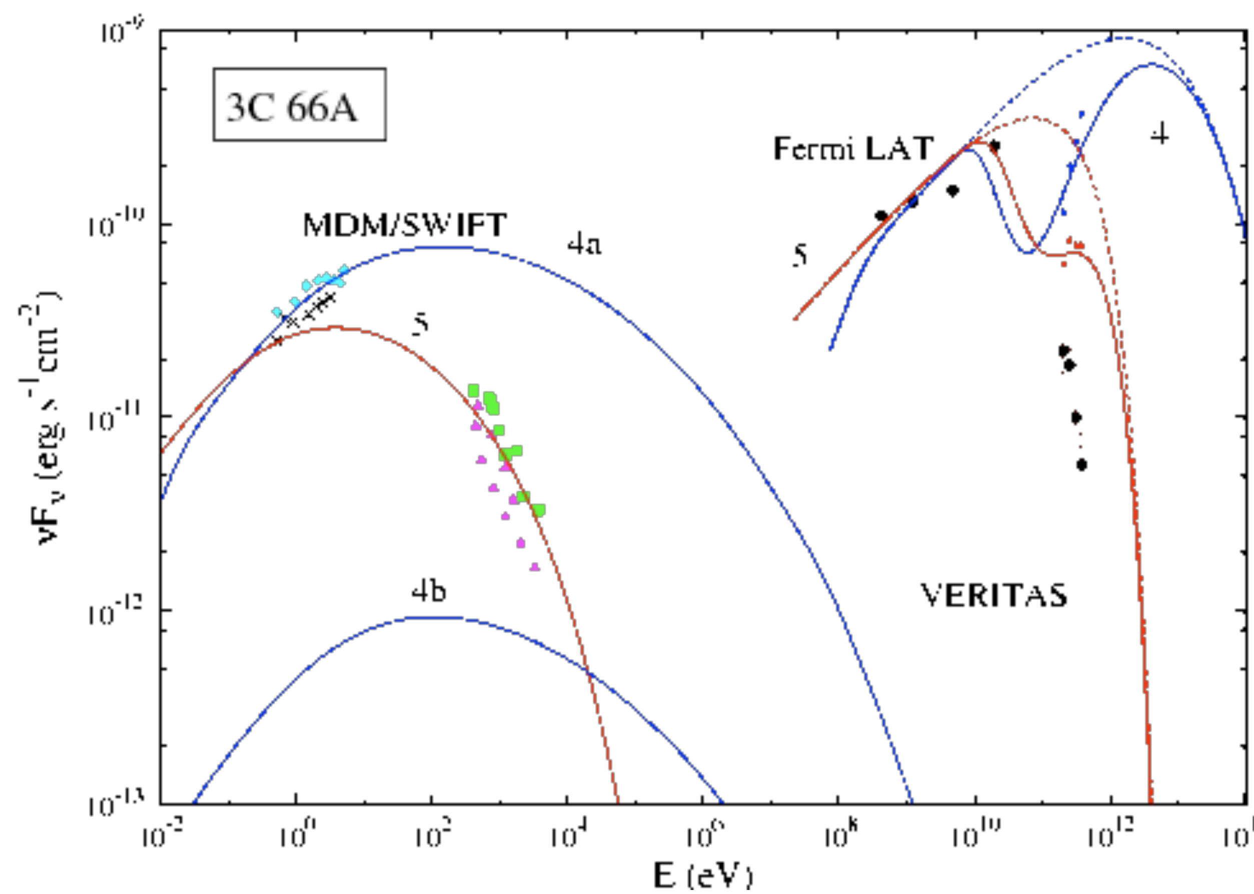
$p\gamma$ with TeV transparency (Mkns)

Aharonian F., 2000

For HBLs, only proton synchrotron (B>100G) works !

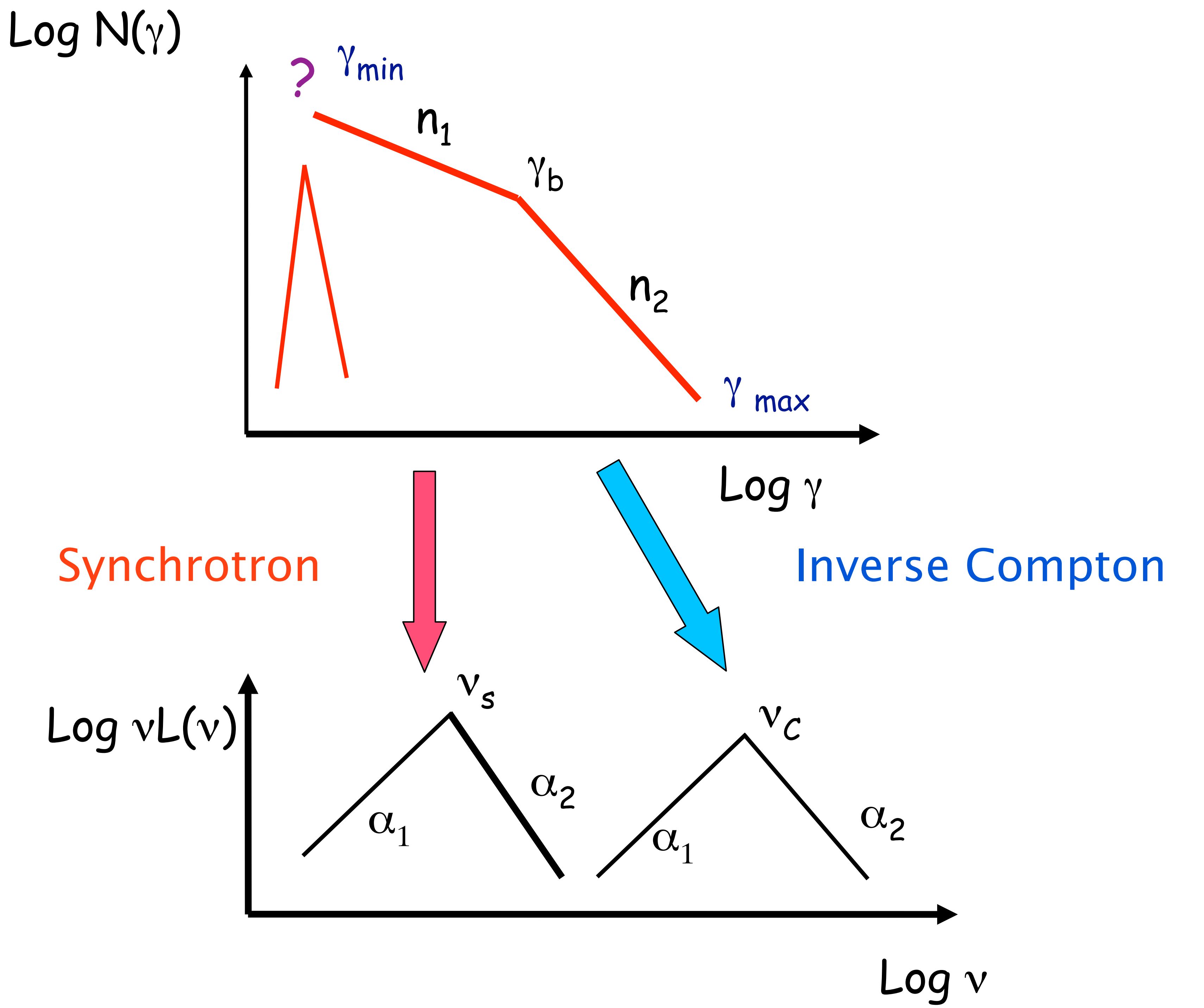
Examples of applications of proton-synchrotron scenario:





Aharonian 2000, Zacharopulou 2011

Leptonic Scenarios: population of relativistic electrons



U'synch (SSC)
U'BLR (EC)
U'disk (UV)
U'dust (IR)

Cooling: who wins ? Highest energy density U' in comoving frame

Leptonic scenarios:

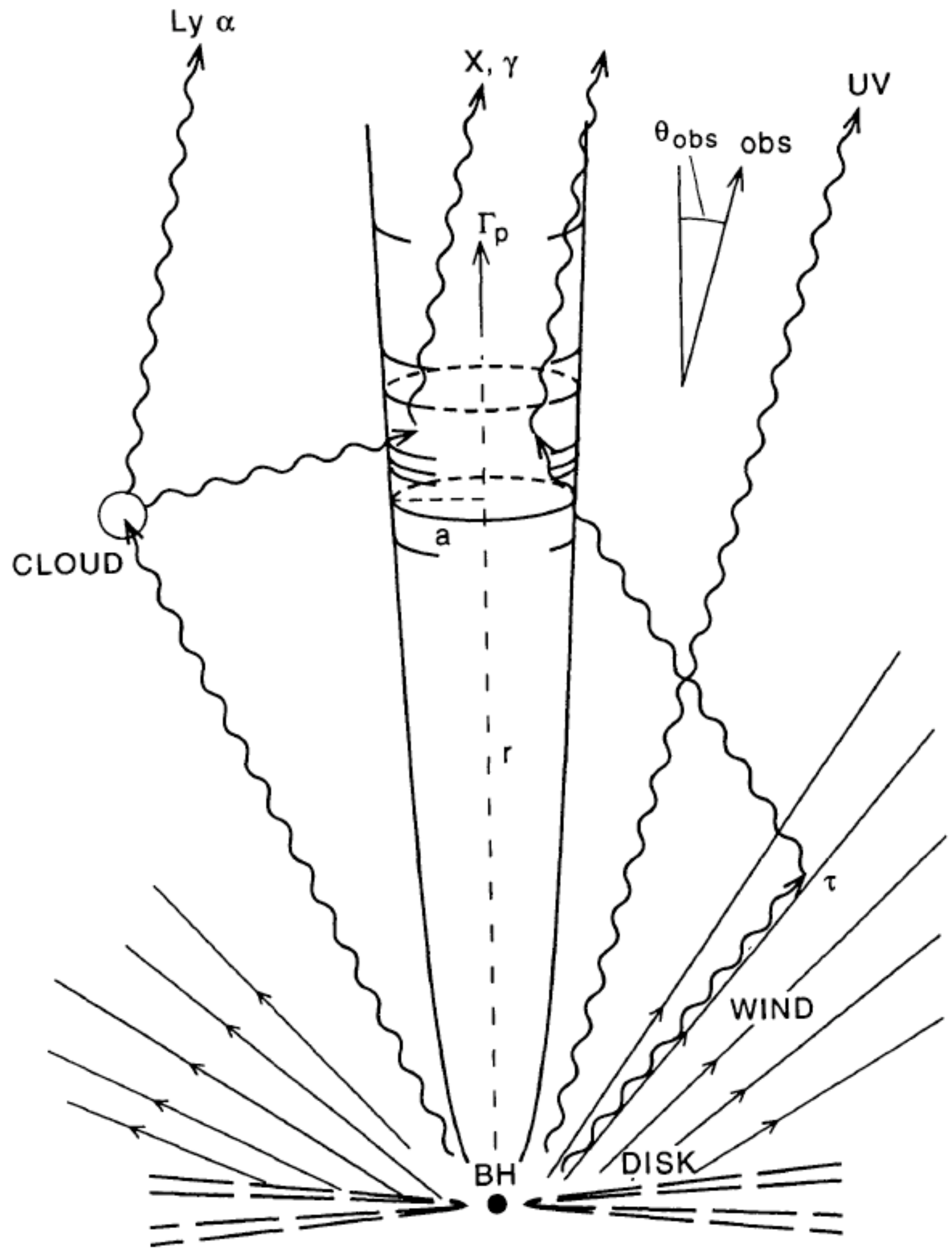


FIG. 2.—Geometry of the source. The radiating region, denoted by short cylinder of dimension *a*, moves along the jet with pattern Lorentz factor Γ_p. Underlying flow moves with Lorentz factor Γ, which may be different.

IR radiation from Hot Dust

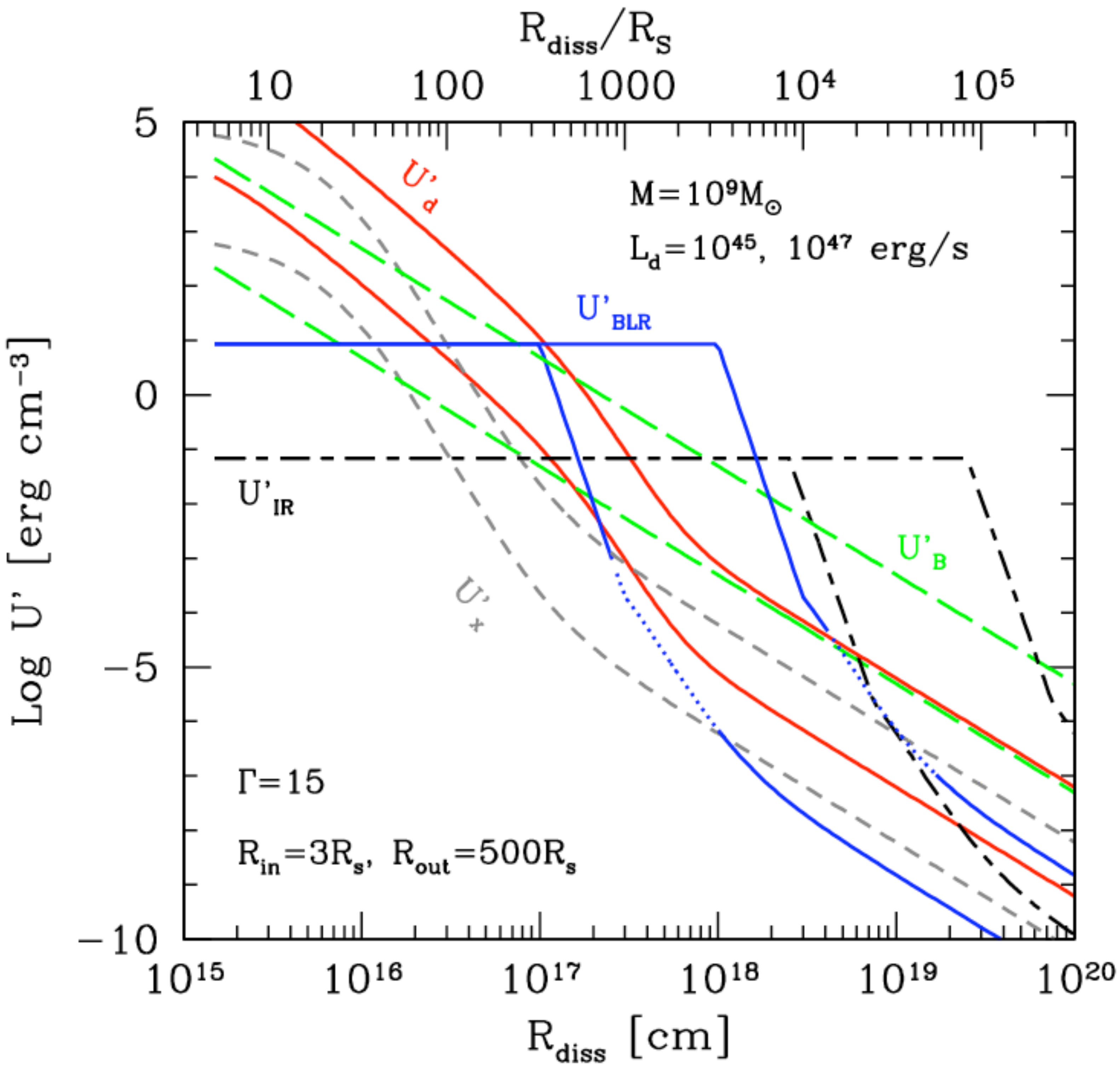
Broad Line Region clouds

$$\mathbf{R \propto L_{disk}^{1/2}}$$ (Bentz et al. 2006 ; Kaspi et al. 2007)

$$\mathbf{U_{rad} \propto L/R^2 \sim const. \sim 10^{-2} erg/cm^3}$$

Sikora et al. 1994

Leptonic scenarios



Ghisellini et al. 2009
Sikora et al. 2009

SED diagnostic

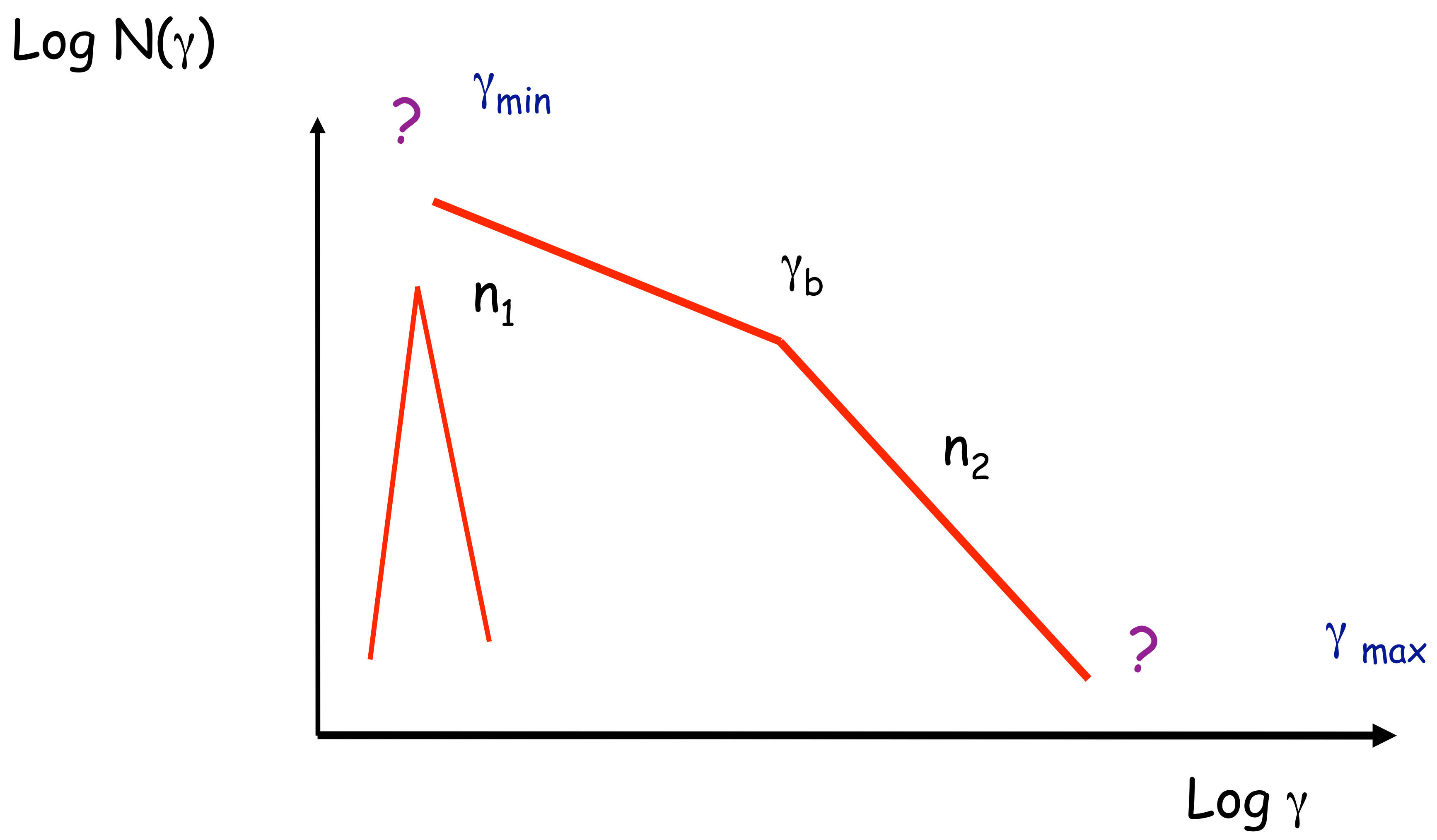
$$\nu_s = \frac{4}{3}\,\gamma_b^2\,\delta\,\nu_L$$

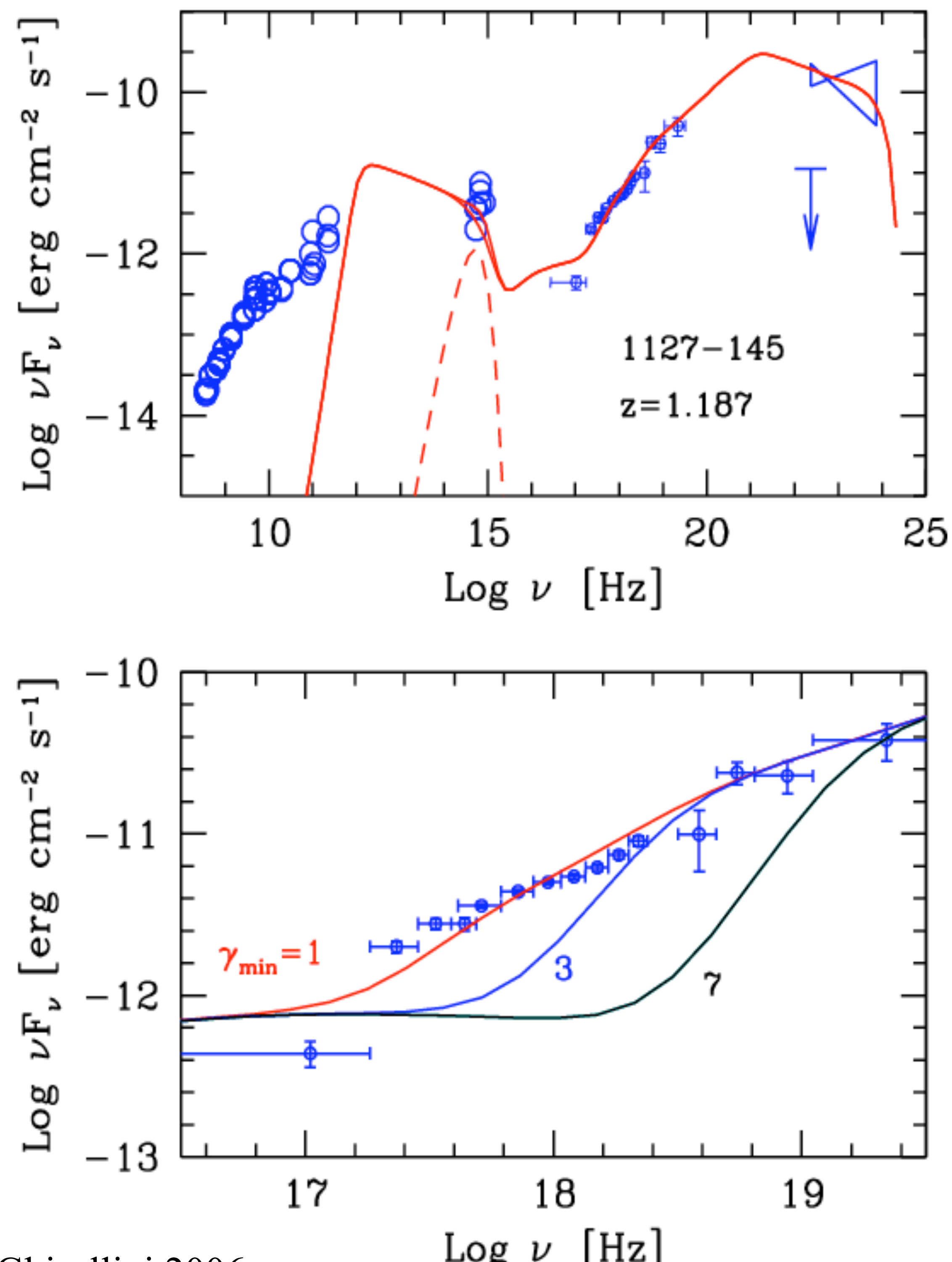
$$\nu_{SSC} = \frac{4}{3}\,\gamma_b^2\,\nu_s$$

$$\nu_{EC} = \frac{4}{3}\,\gamma_b^2\,\Gamma\,\delta\,\nu_{ext}$$

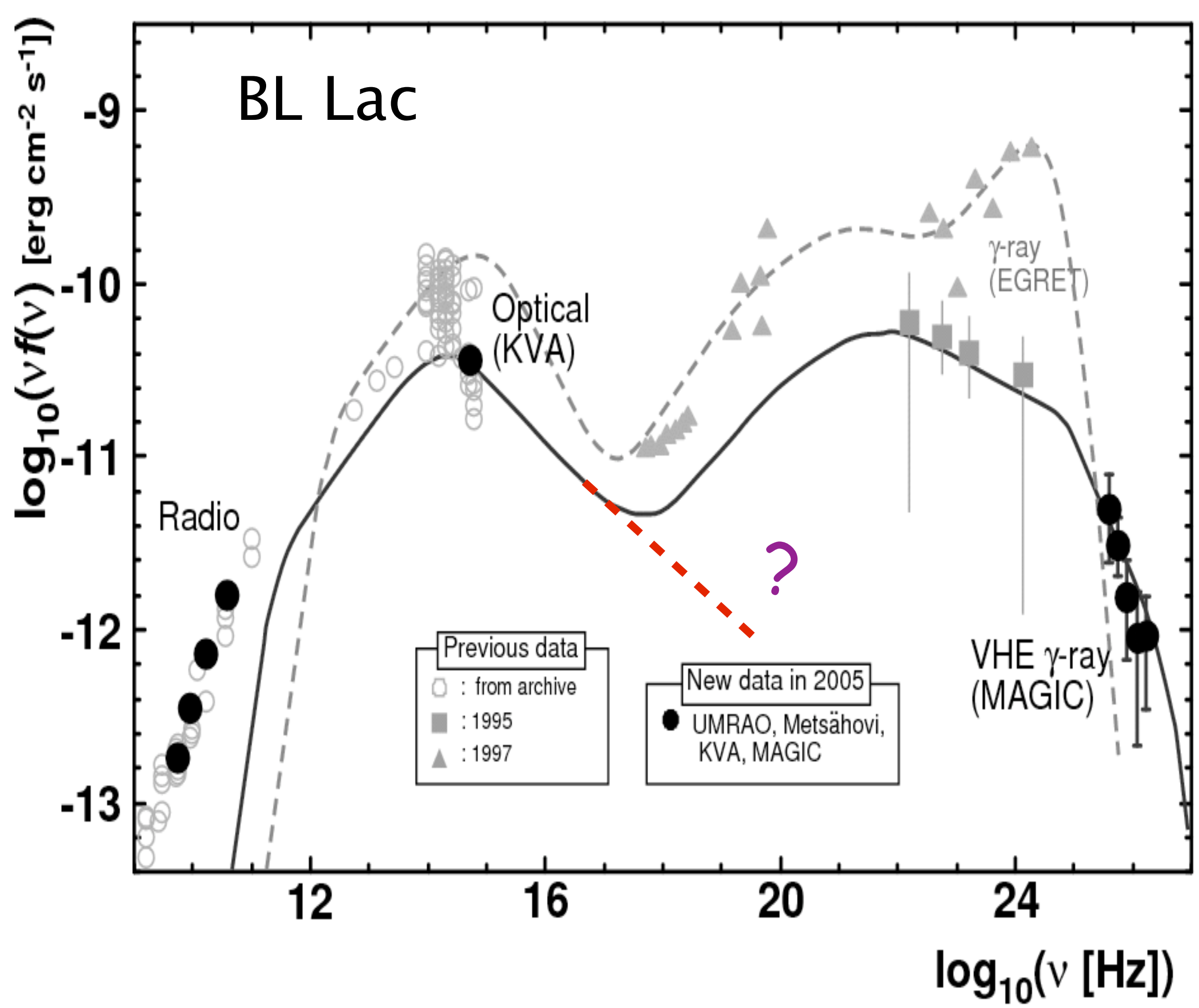
$$\nu_L = eB/m_e c \;\simeq 2.8\;10^6\;B\;(\mathrm{Hz})$$

Electrons distribution



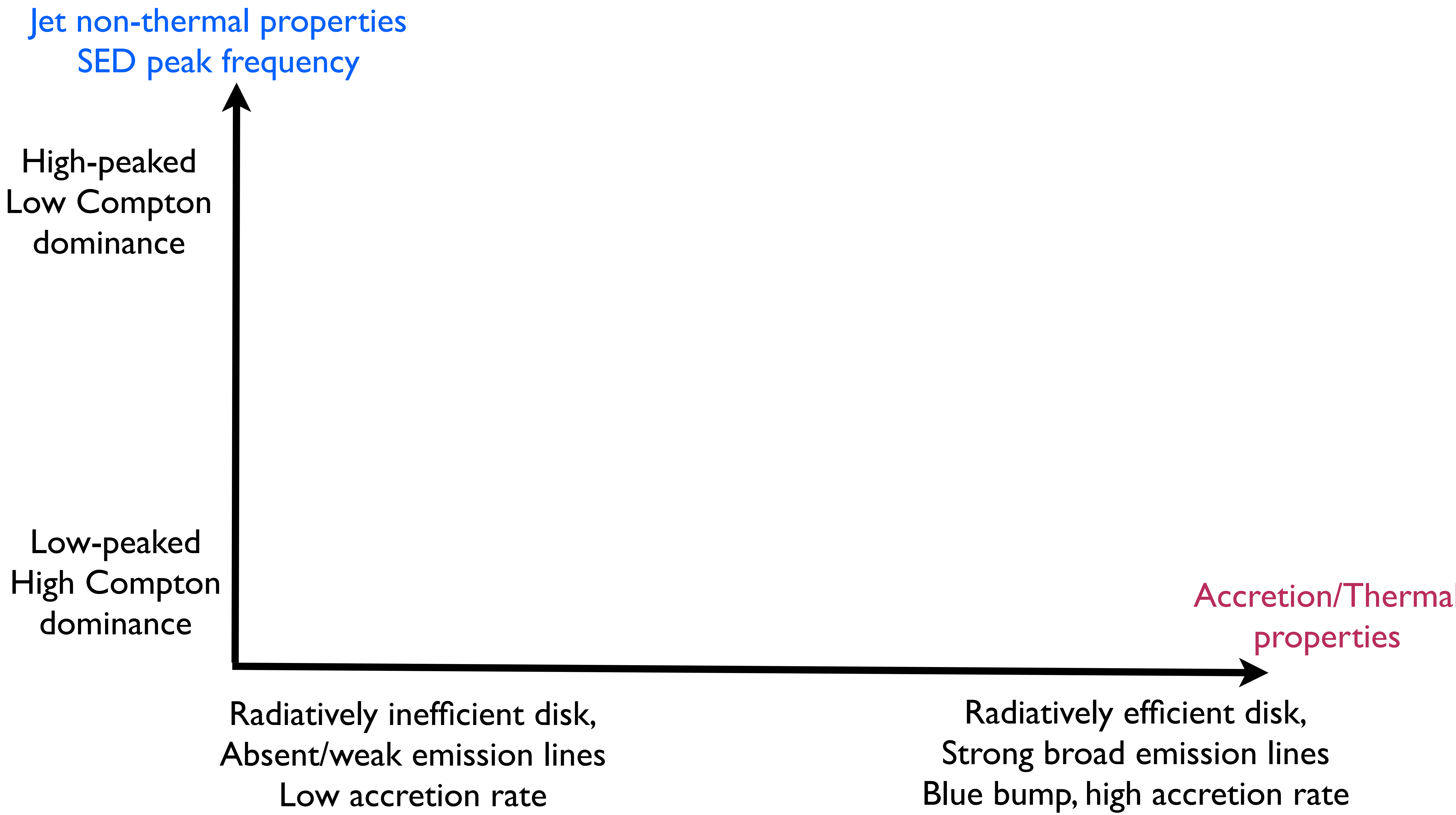


Ghisellini 2006

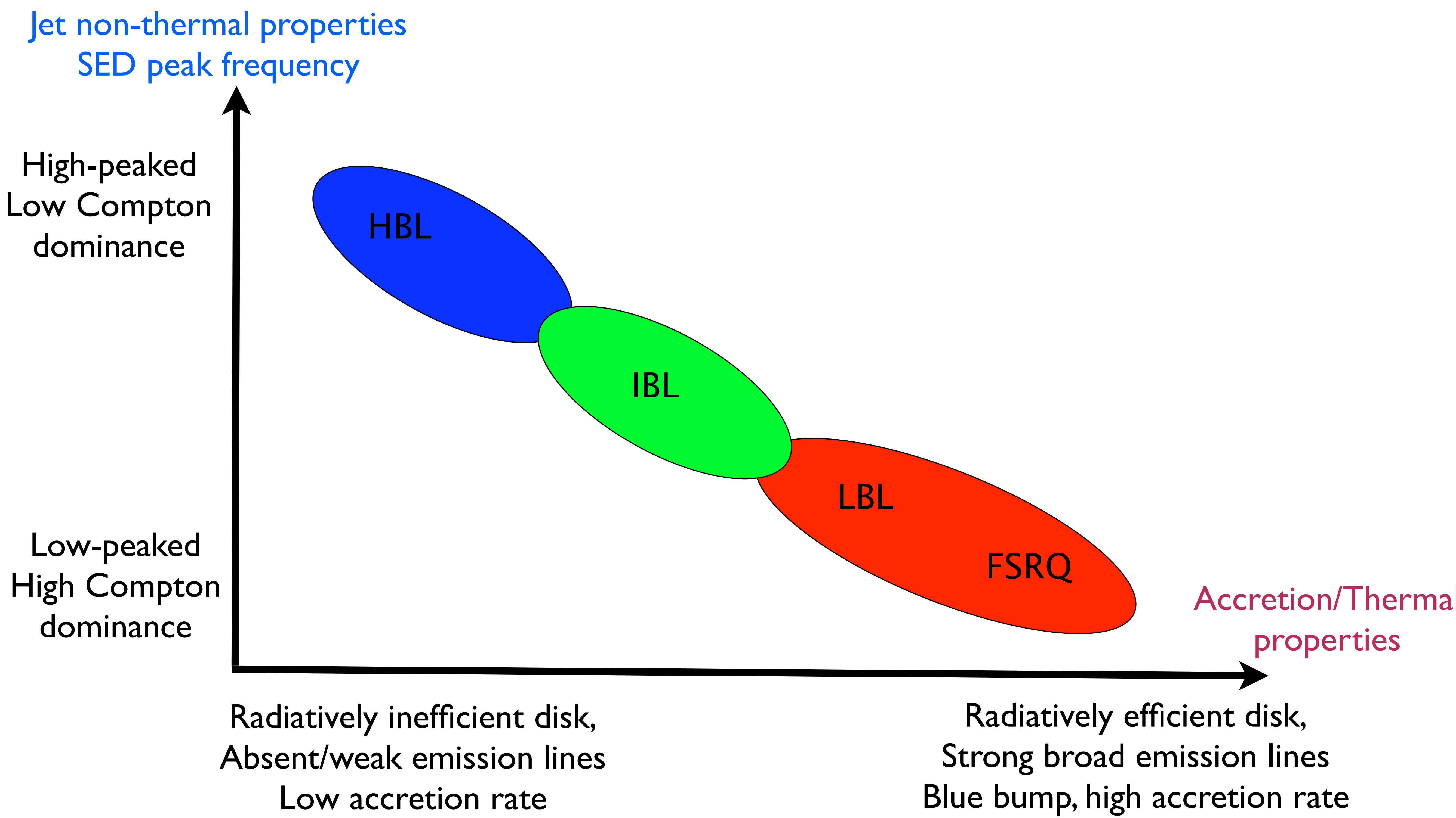


Albert et al.2007

The Main Plane of Blazars

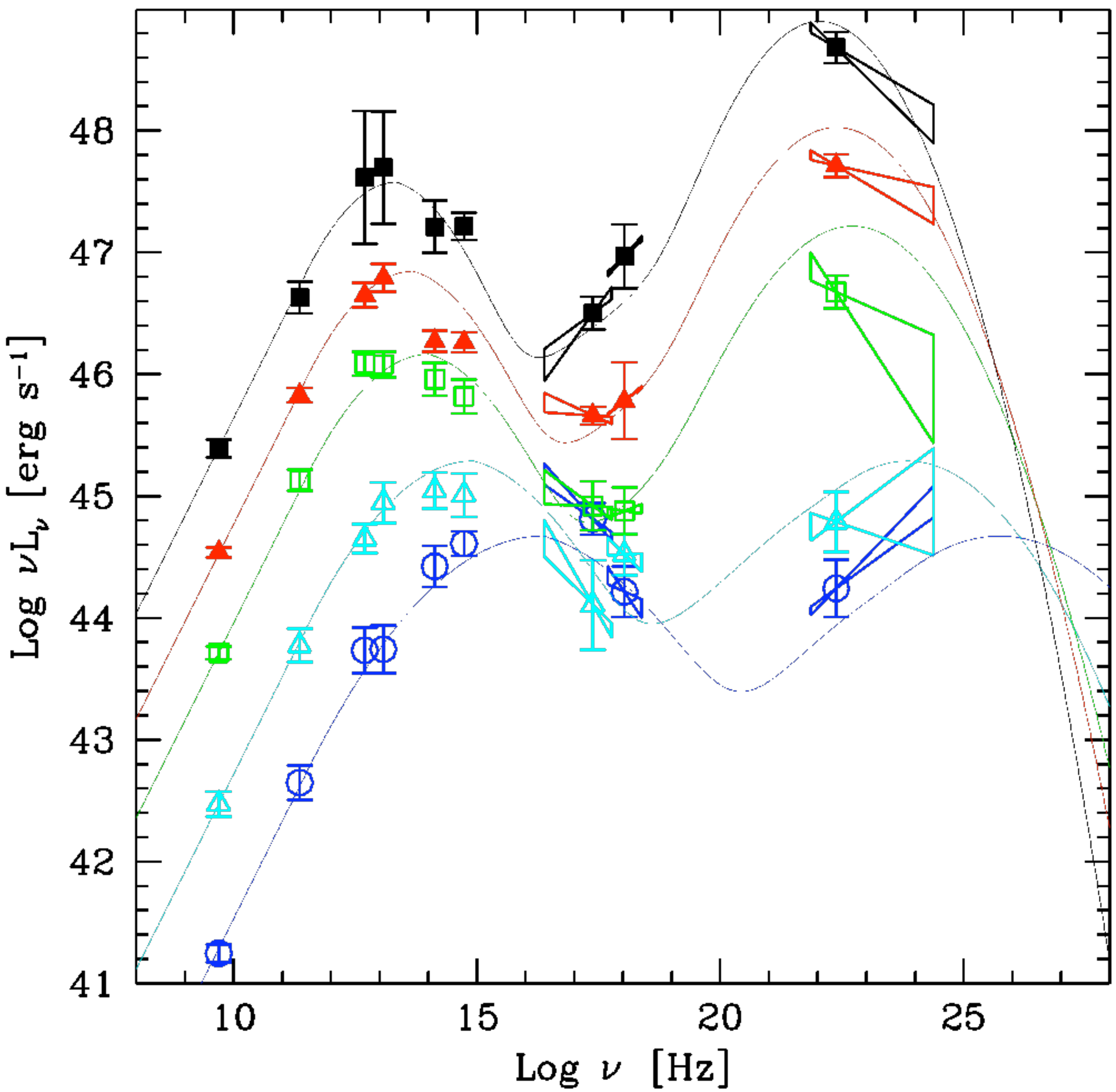


The Main Plane of Blazars



Blazars Sequence(s)

1) sequence of SED peak frequencies (Giommi et al.)
2) peak frequencies vs bolometric luminosities

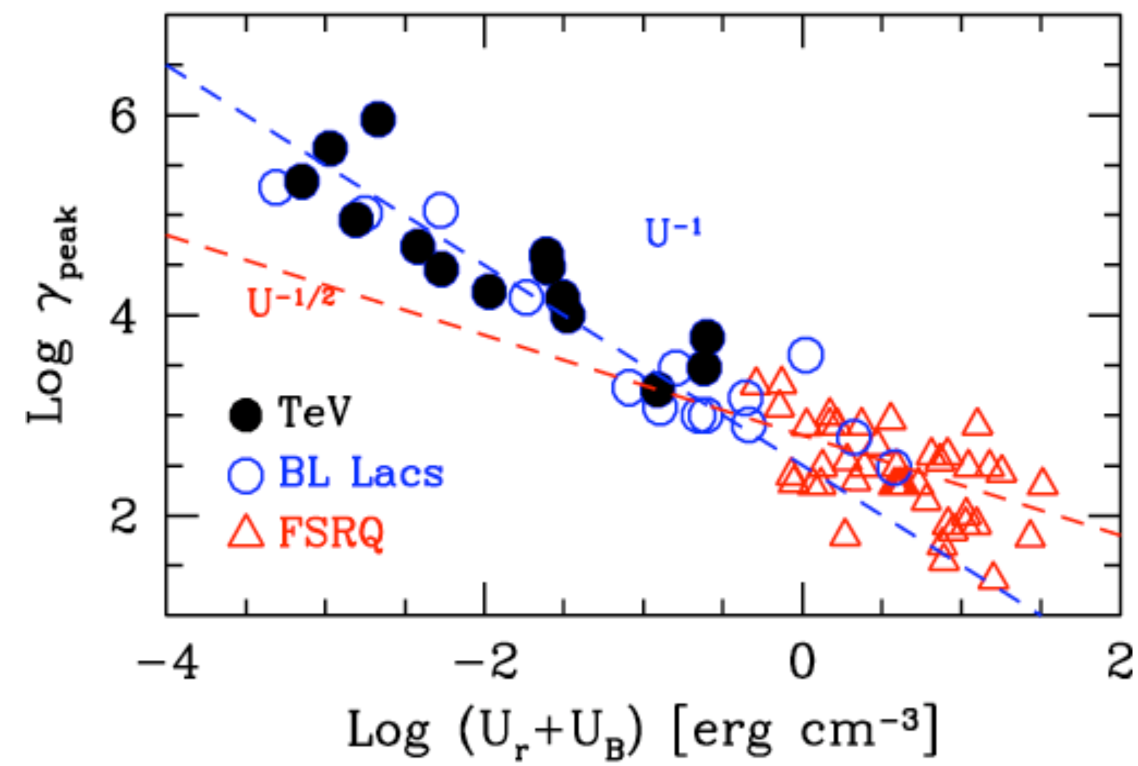


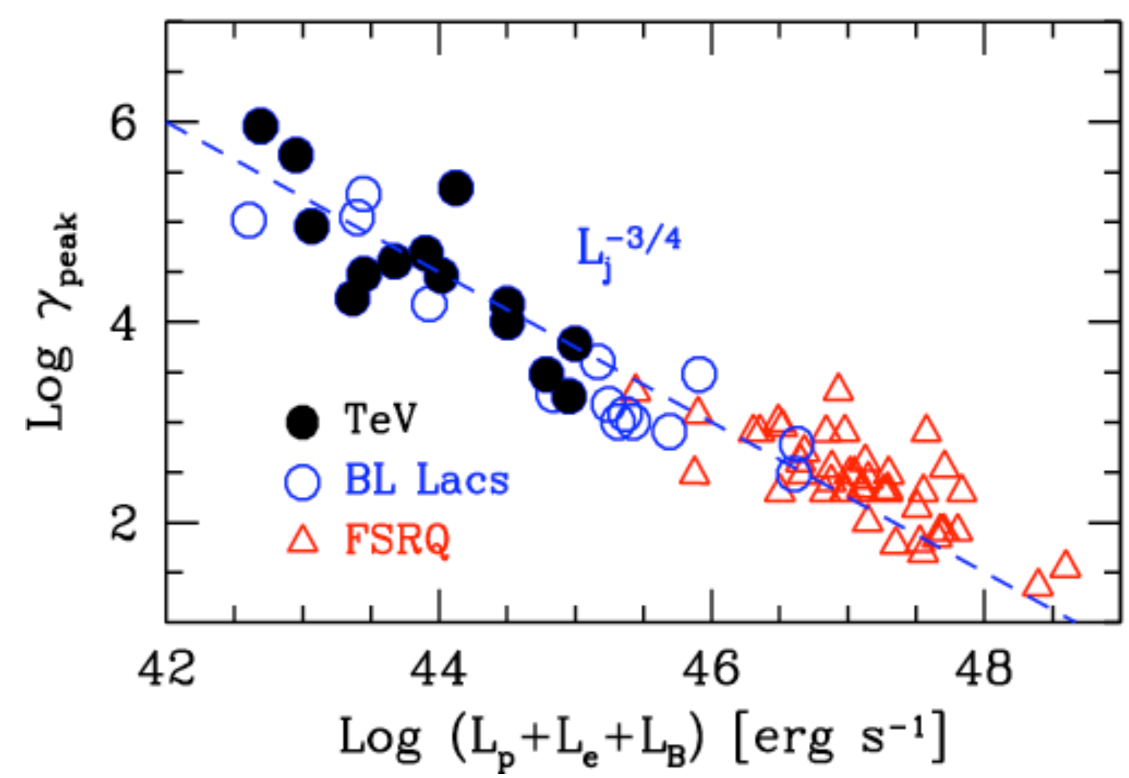
EGRET era,
Fossati et al 1998
Donato et al 2002

3) “Theoretical” Sequence

one-zone SSC+EC modelling:
parameters form a sequence

Caveat: observational biases
(Egret gets mostly high states
and almost no HBL)



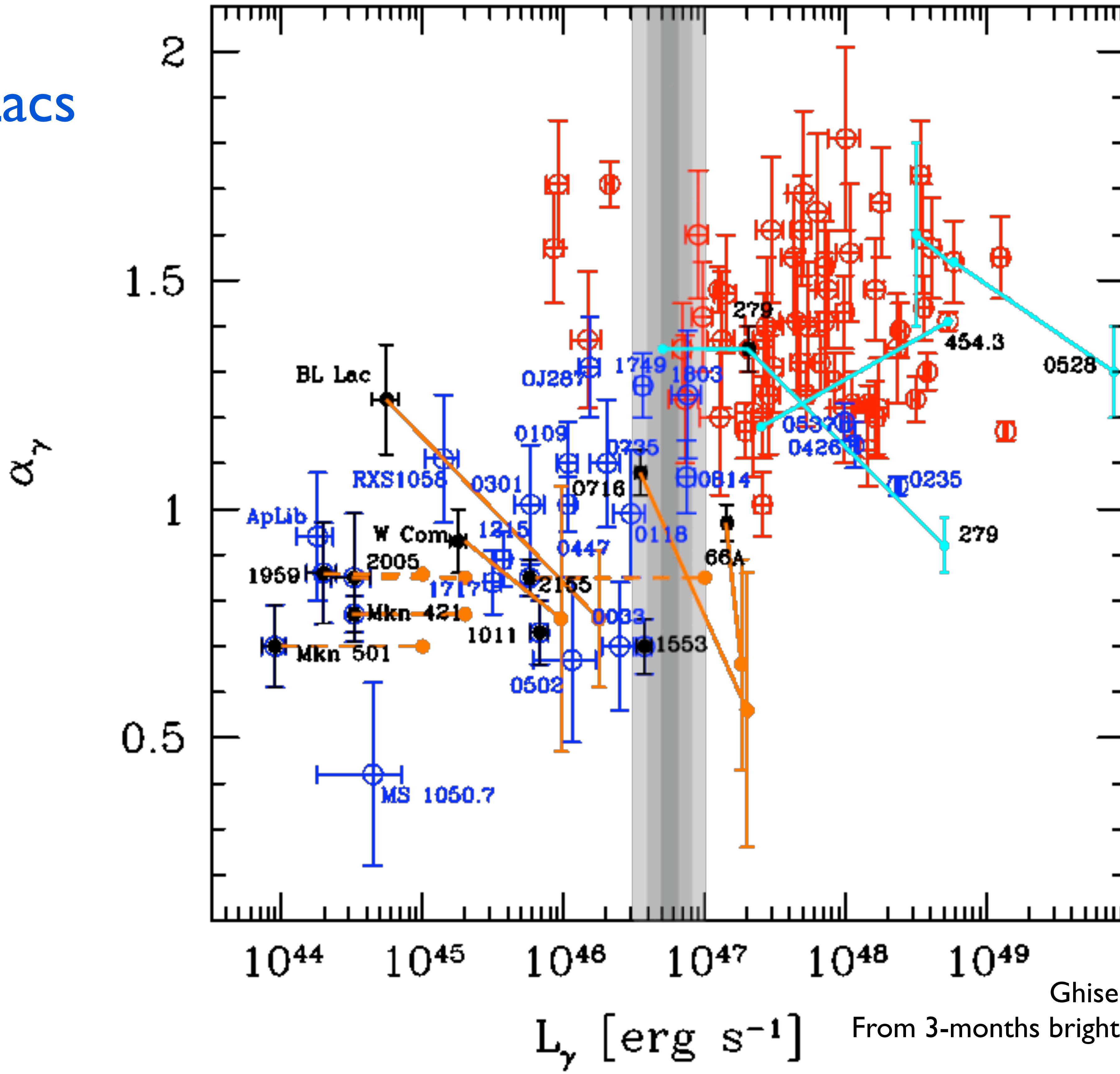


Ghisellini et al. 1998, 2002

The Fermi Blazars' Divide

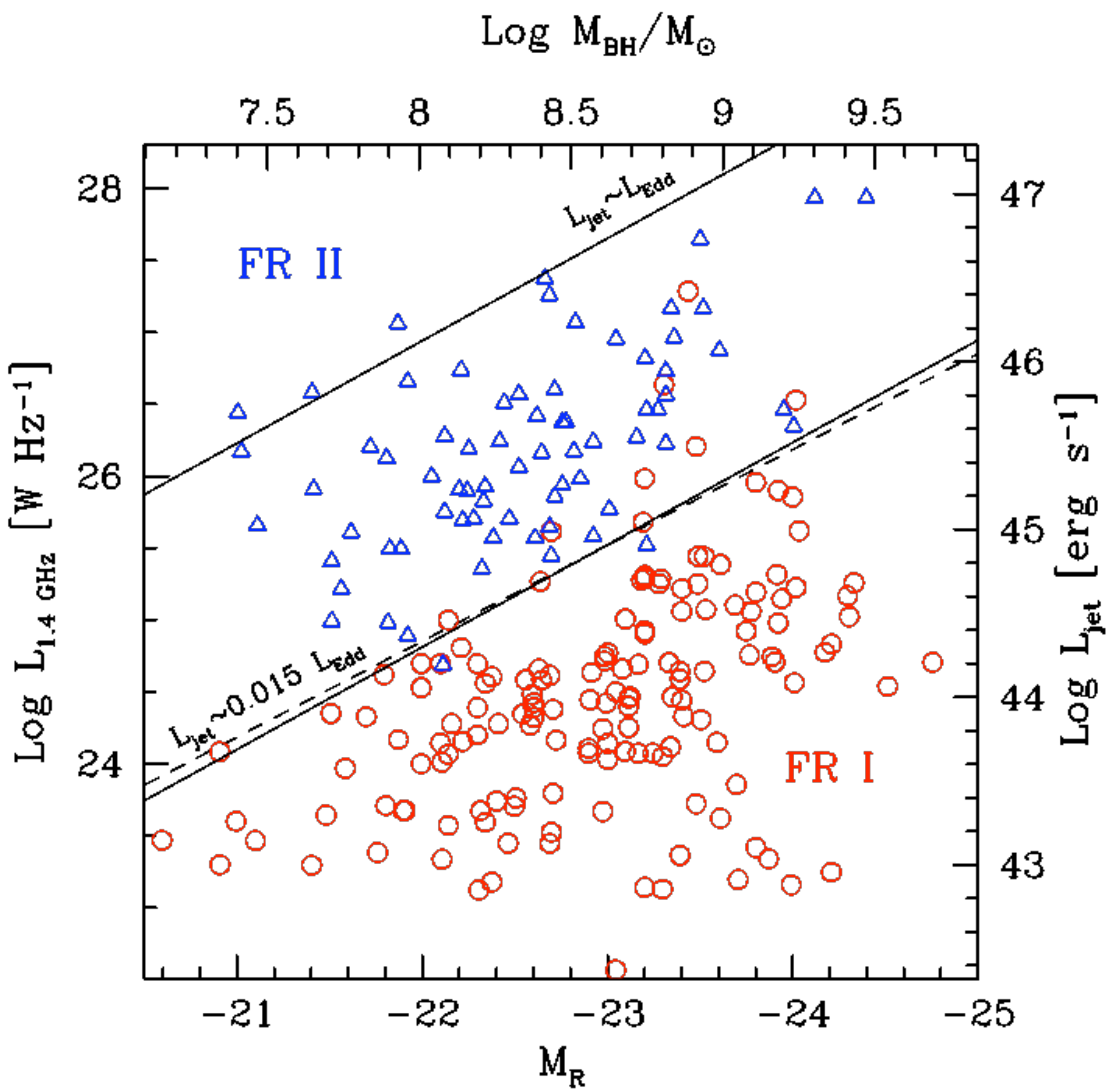
BLLacs

FSRQ



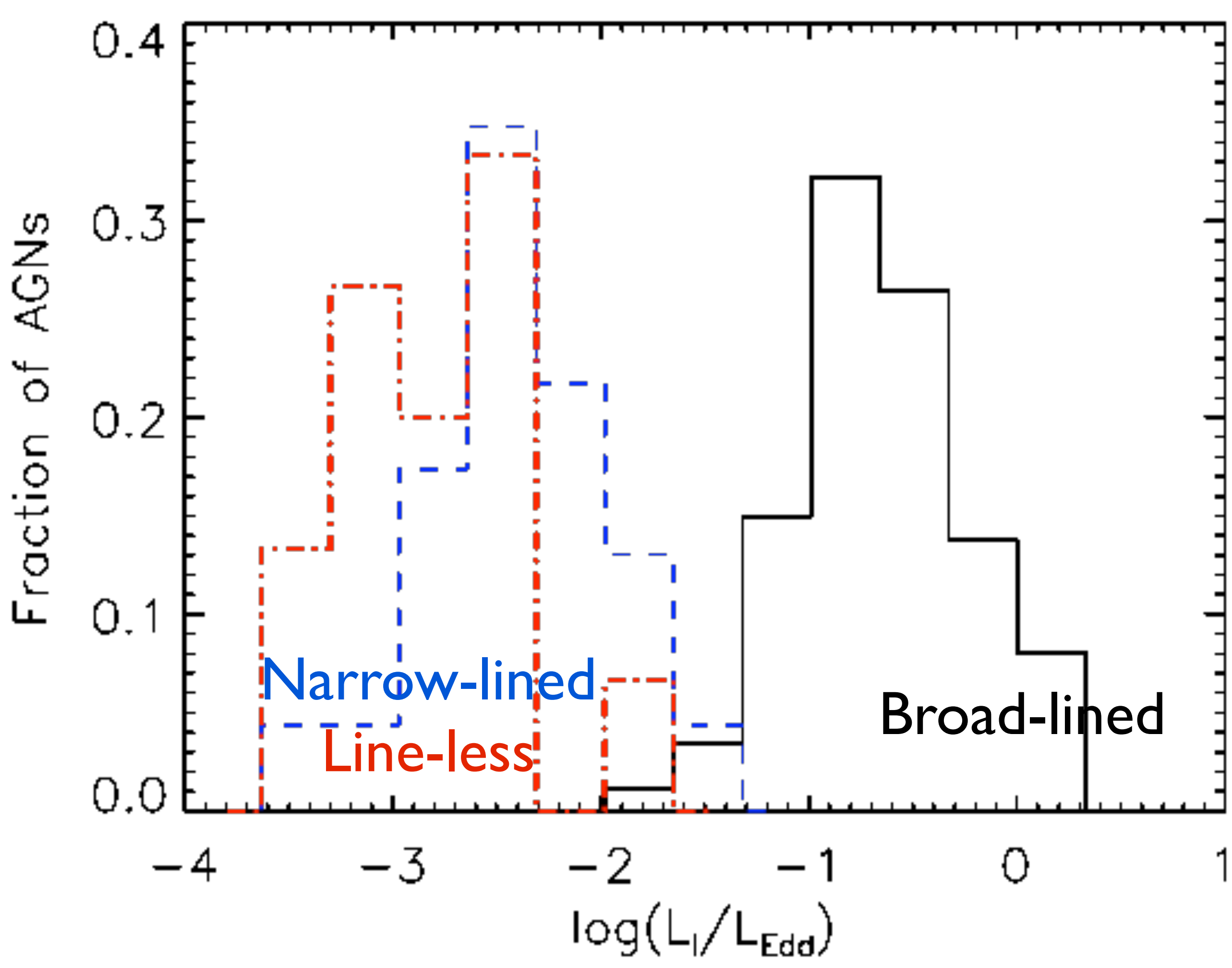
Ghisellini et al. 2009
From 3-months bright AGN catalog, Abdo et al. 2009

Something is happening at L ~0.01 L_{Edd}

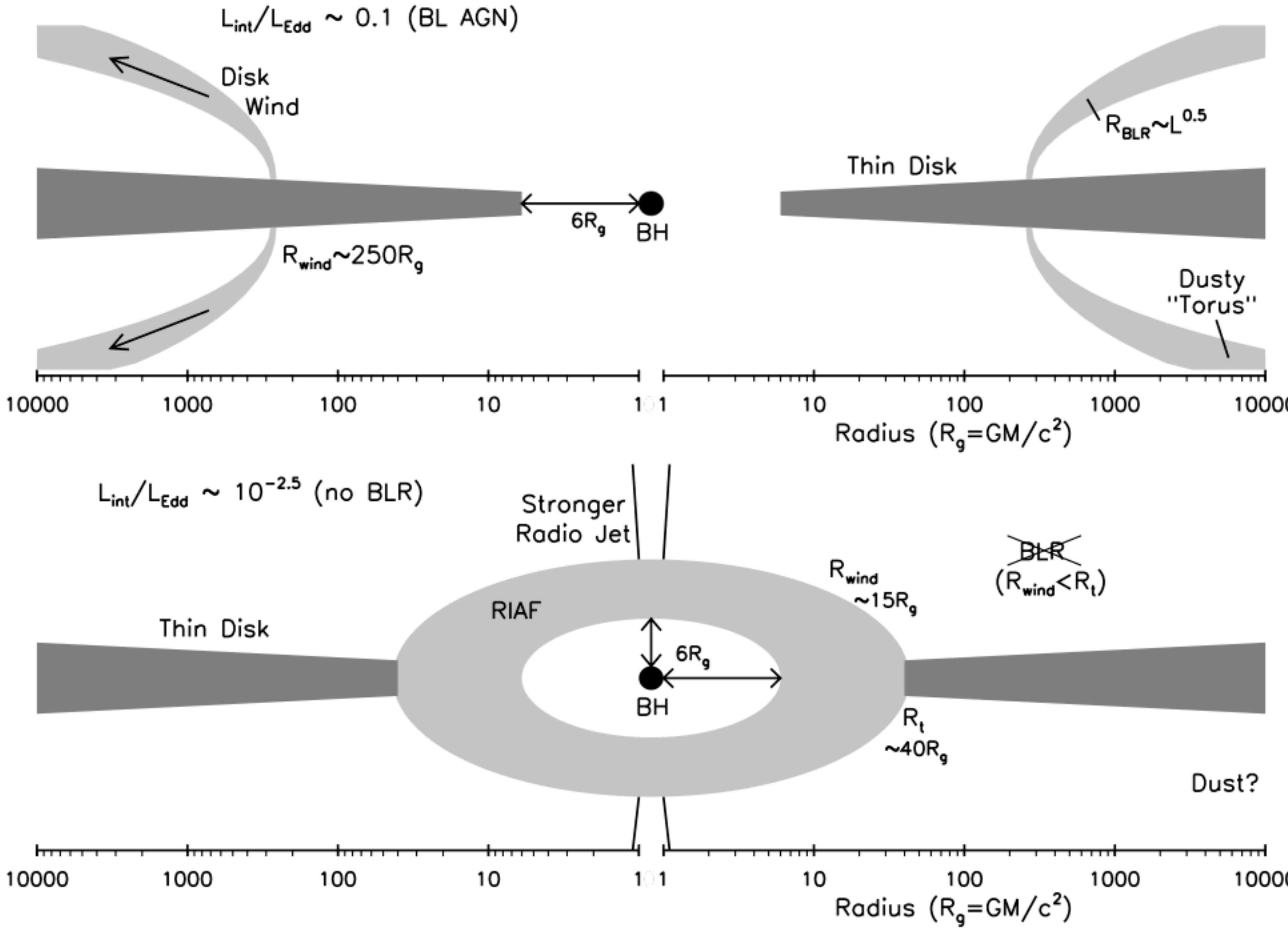


Ledlow & Owen 1996
Ghisellini & Celotti 2002

Sample 82 unobscured AGNs



Trump et al. 2011



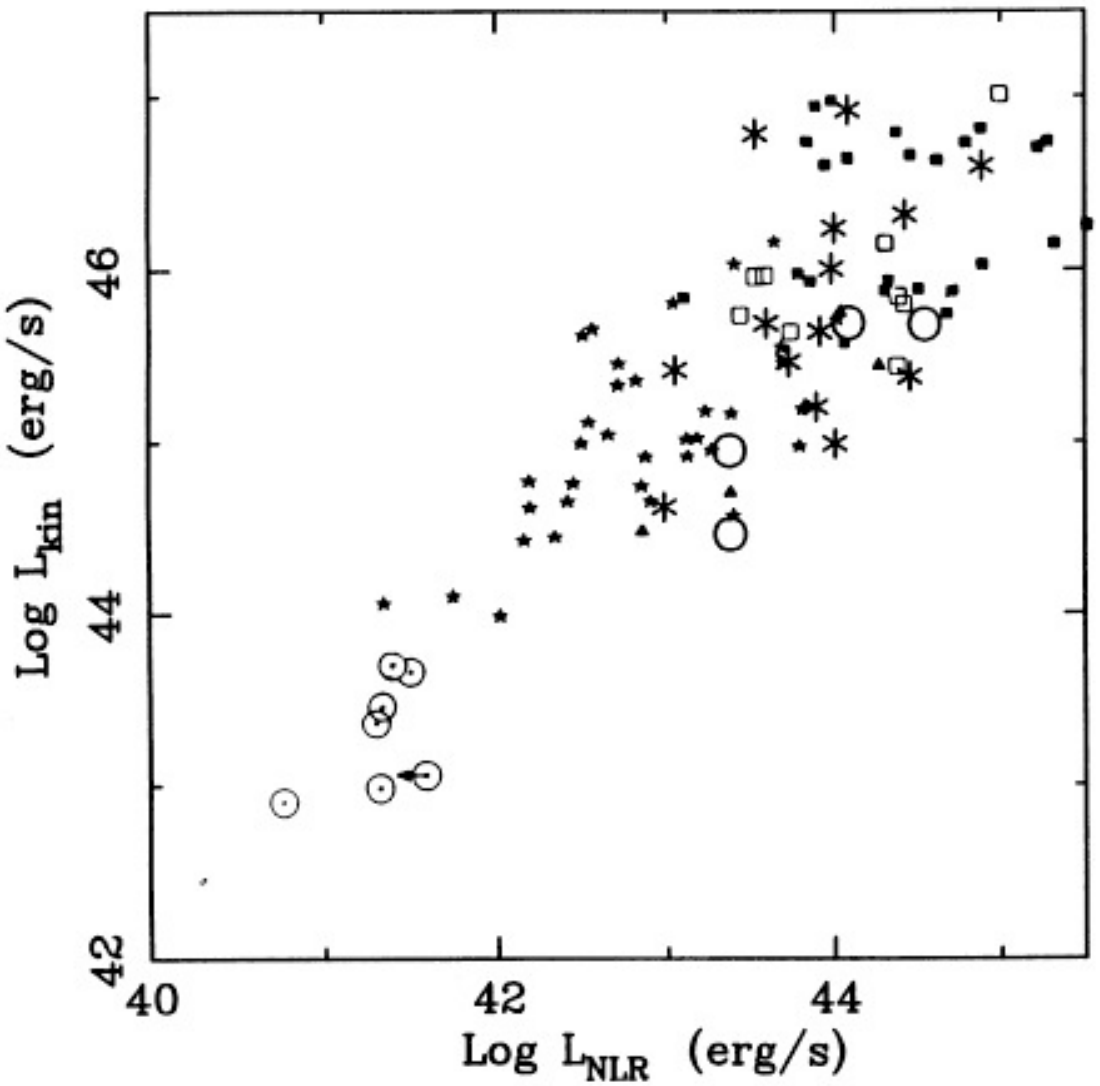
L_{int}/L_{Edd} ~ 0.1 (BL AGN)
Disk
Wind
R_{BLR}~$L^{0.5}$
Thin Disk
6R_g
BH
R_{wind}~250R_g
Dusty
"Torus"
10000
1000
100
10
1
1
10
100
1000
10000
Radius (R_g=GM/c^2)
L_{int}/L_{Edd} ~ $10^{-2.5}$ (no BLR)
Stronger
Radio Jet
R_{wind}
~15R_g
BLR
(R_{wind}<R_t)
RIAF
Thin Disk
6R_g
BH
R_t
~40R_g
Dust?
10000
1000
100
10
1
1
10
100
1000
10000
Radius (R_g=GM/c^2)

Jet Powers (kpc scale):

To power the Lobes:

$$Q = \frac{E}{\eta T} \approx \frac{10^{60-61} erg}{\eta 10^8 \ yrs} \simeq 10^{45-46} erg/s$$

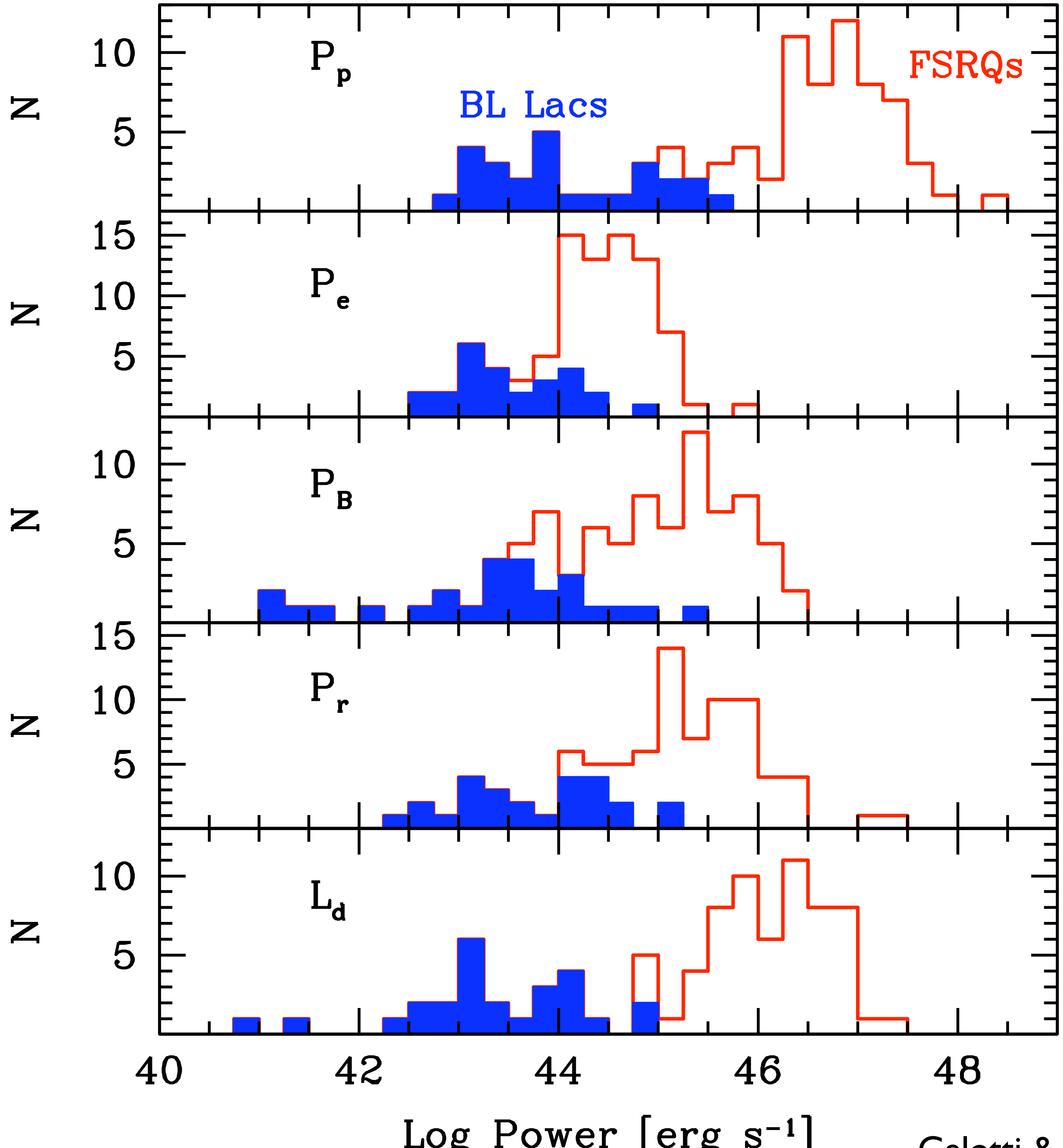
$L_{disk} \sim L_{kin}$:



Rawling & Sanders 1988

Jet Powers (pc-scale):

$$P_{\rm i} = \pi R^2 \Gamma^2 c U'_{\rm i}$$



Cold protons (one per electron)

Cold+Hot electrons

Magnetic field

Radiation produced (SED)

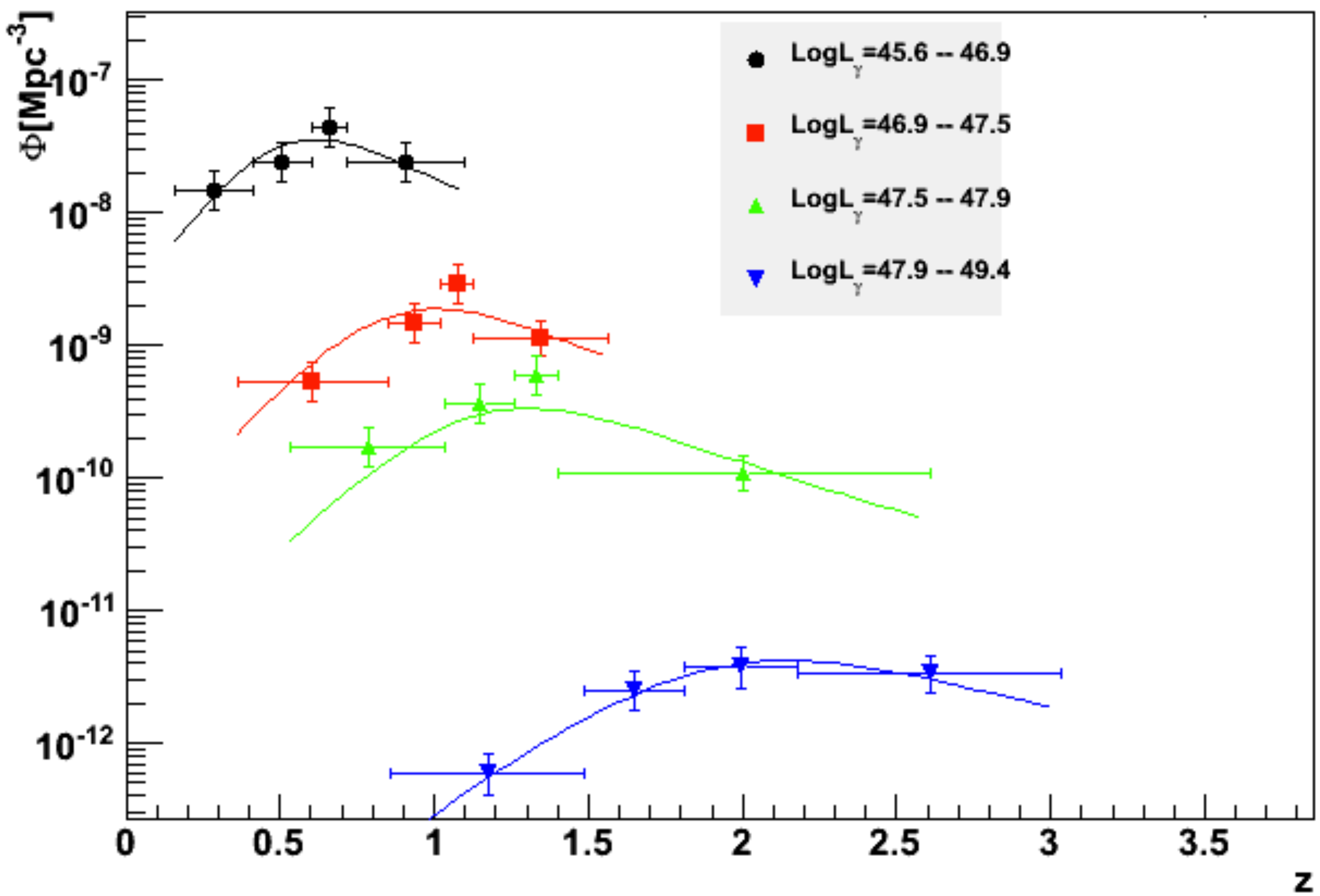
Accretion luminosity

Celotti & Ghisellini 2008, from SED modeling

Cosmic Evolution:

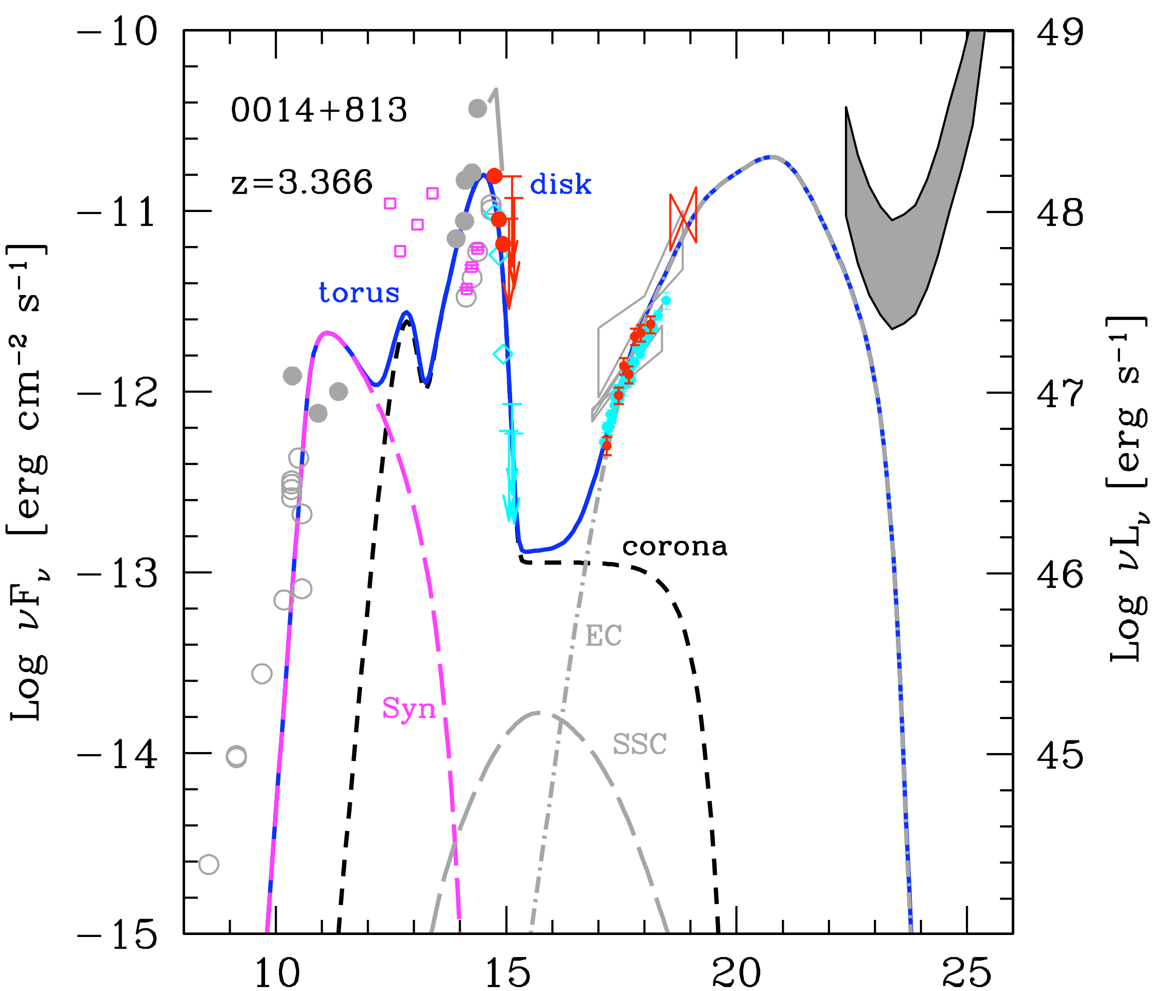
FSRQ evolve positively (V/V_{max} ~0.64-0.76)
BLLacs still unclear: LBL   ~ + or no evolution
HBL ~ negative evolution

A lot is changing now with Fermi

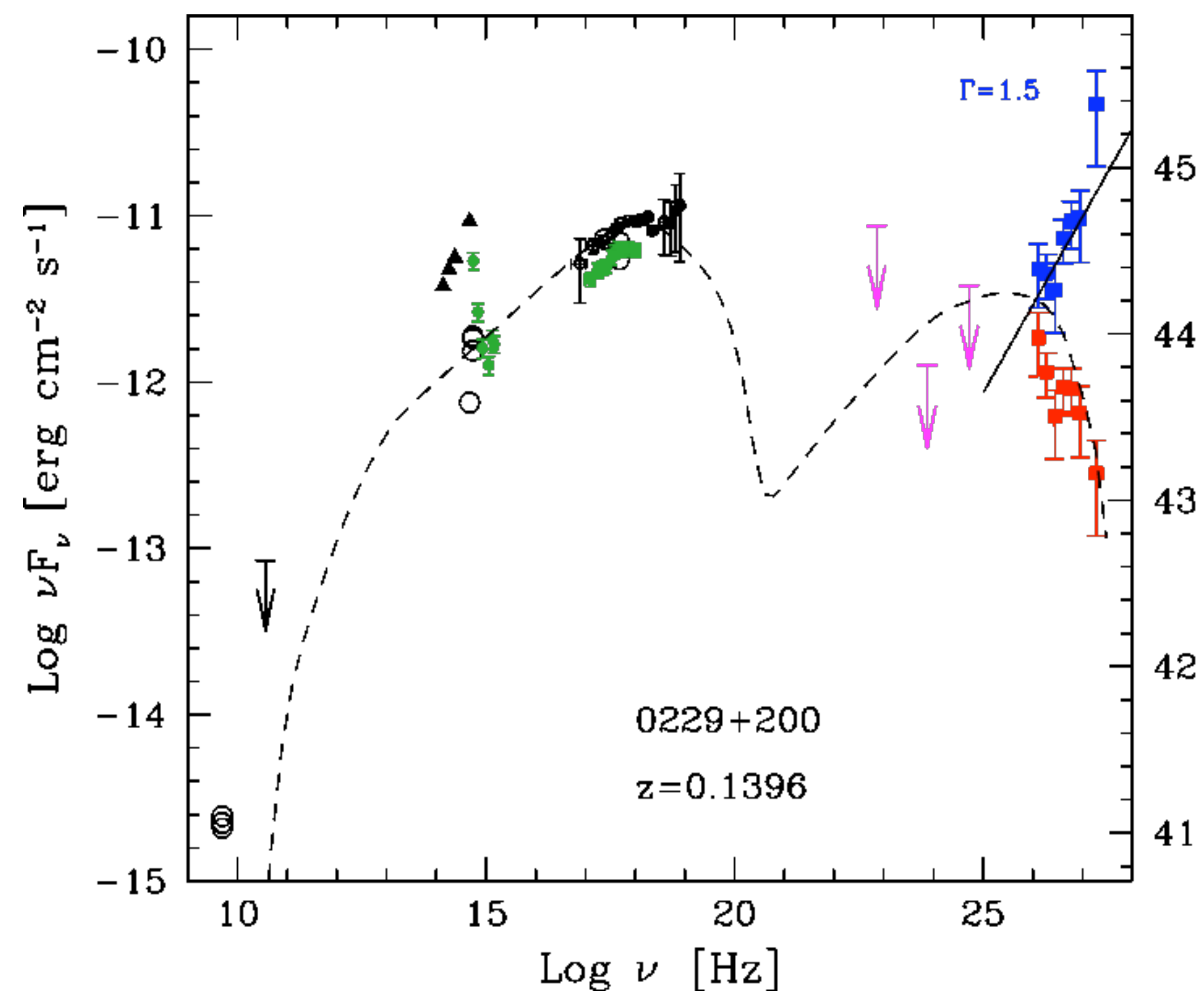


Ajello et al 2011,
Fermi symposium

Fermi does *not* detect all type of blazars: misses at the two ends of SED sequence



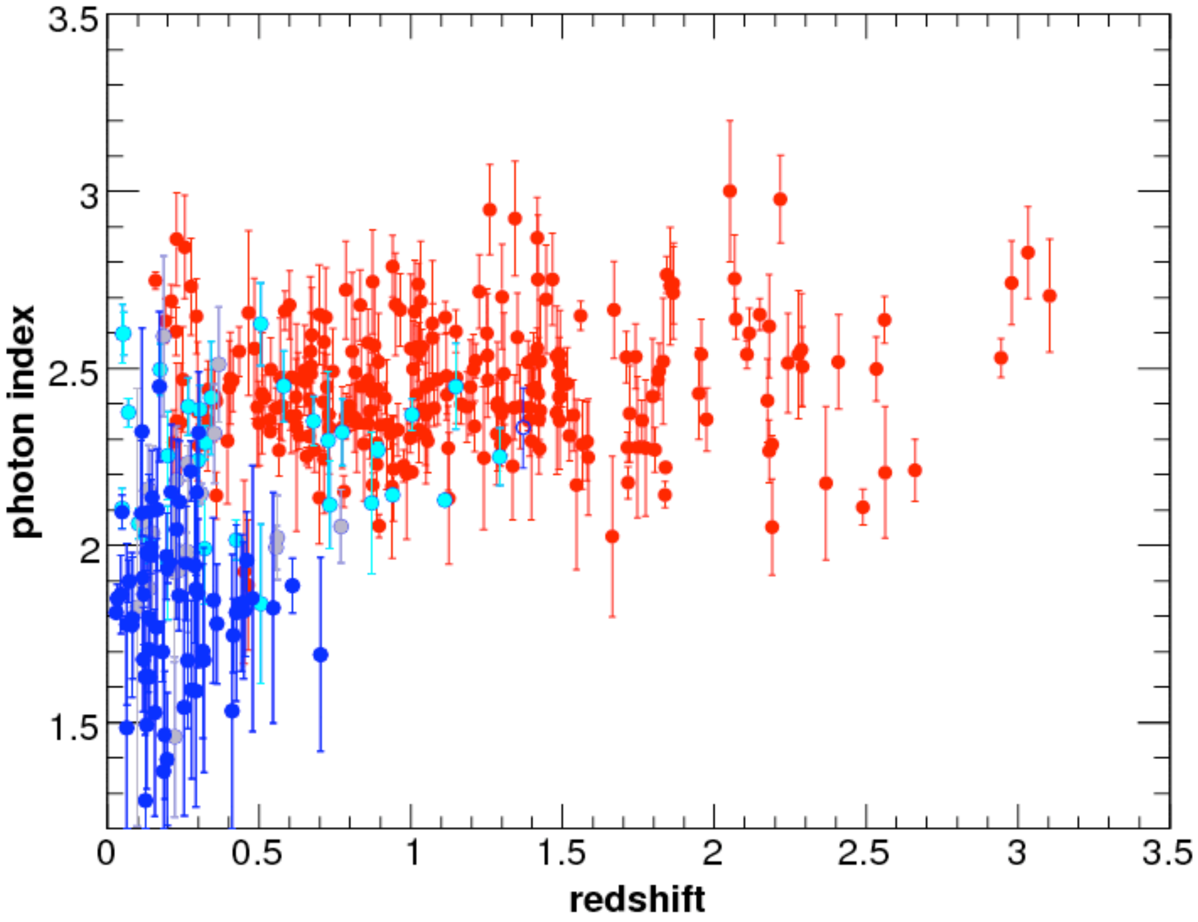
MeV-blazar



Hard TeV BL Lac

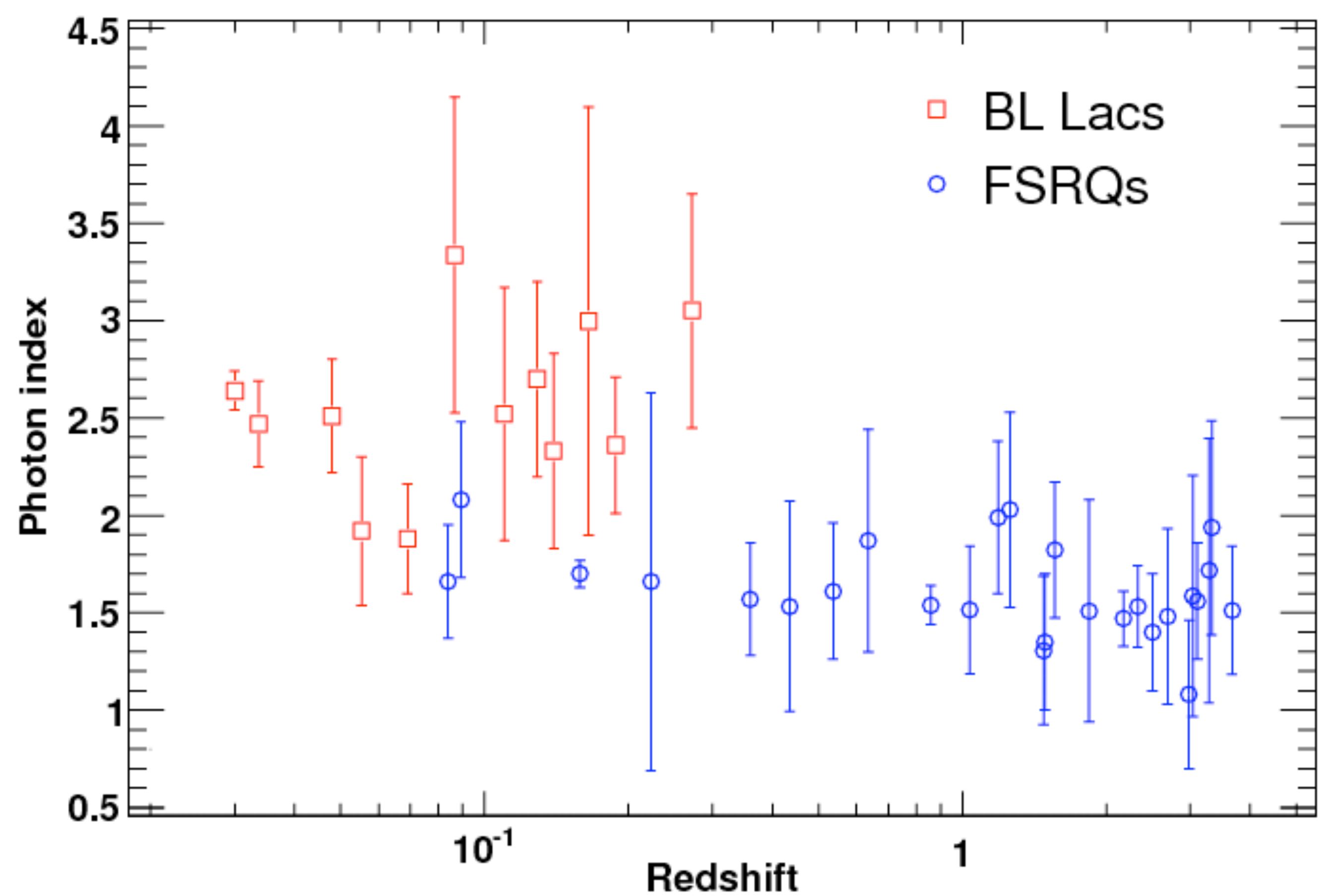
Redshift distribution

Fermi-LAT



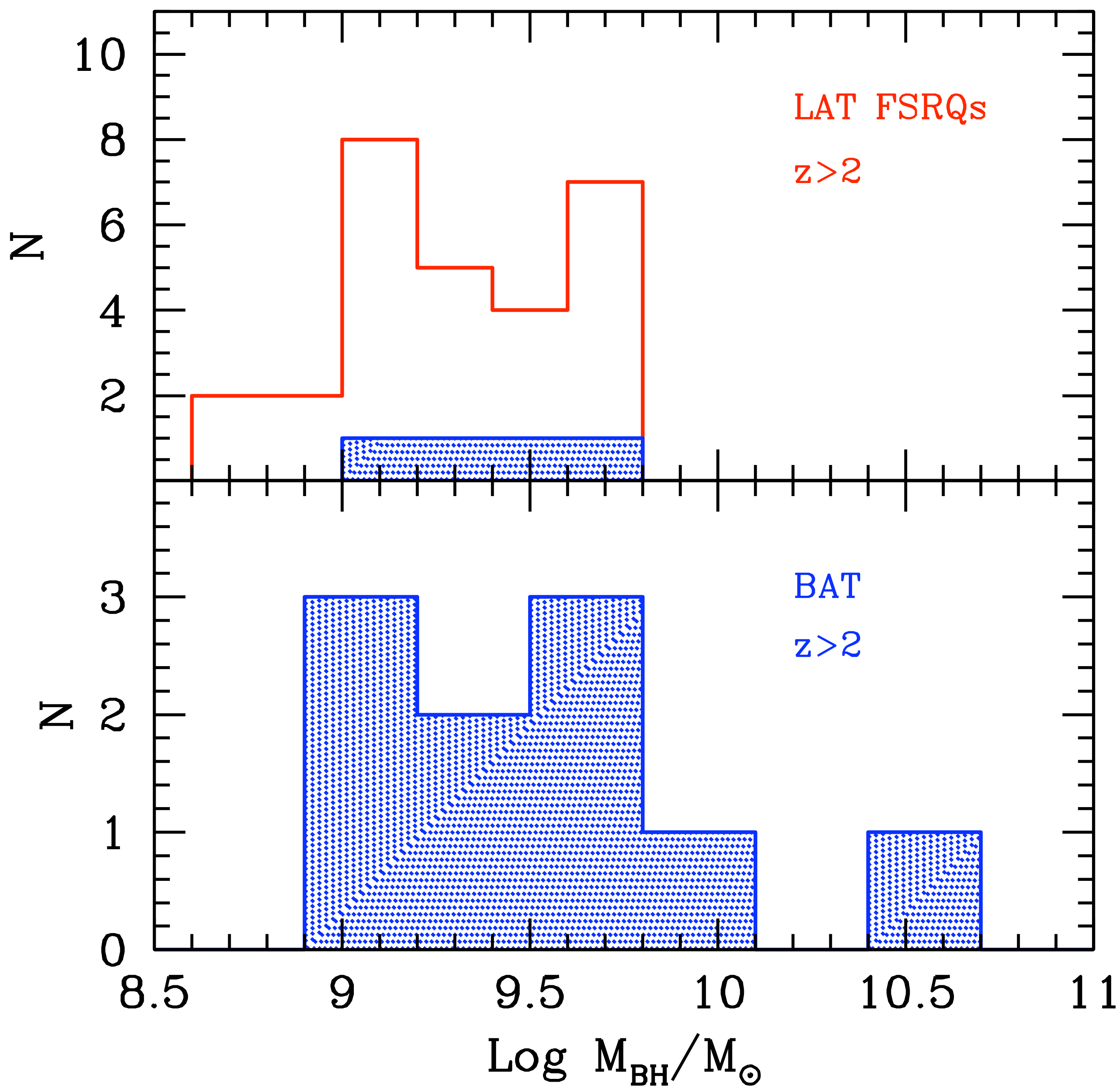
1LAC, Abdo et al. 2010

Swift-BAT



Ajello et al. 2010

Overlap is small (not the same objects)



Ghisellini et al. 2010

Outline Part II

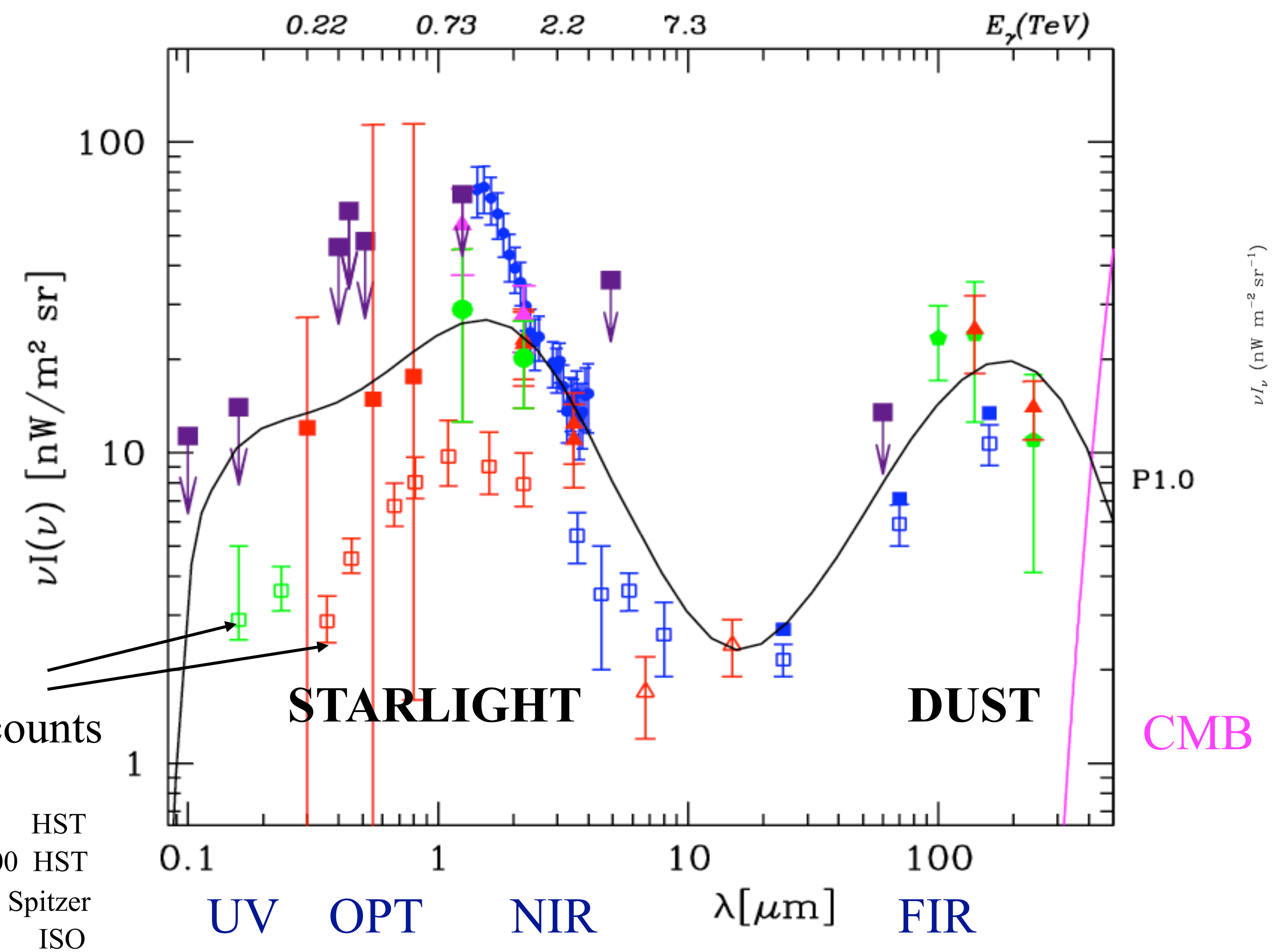
- The problem of EBL-absorption

- Variability

- The X-ray/TeV connection

- Size and location of the gamma-ray emitting region (HBL vs FSRQ ?)

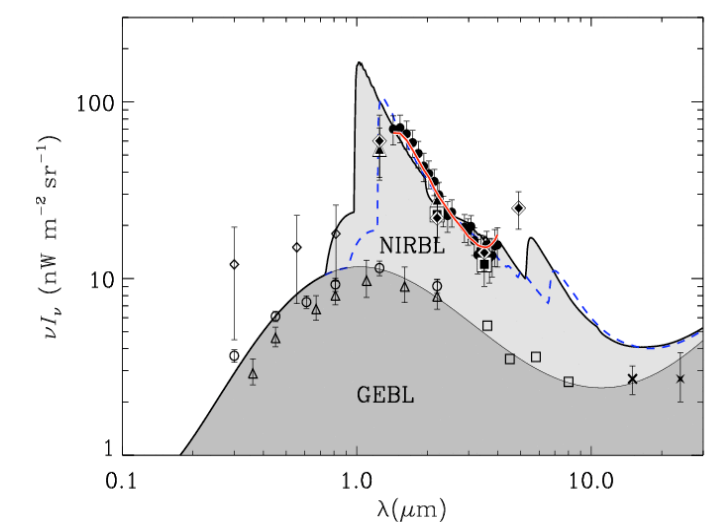
The diffuse Extragalactic Background Light (EBL): Spectral Energy Distribution



Lower limits
from source counts

Gardner et al. 2001 HST
Madau & Pozzetti 2000 HST
Fazio et al. 2004 Spitzer
Elbaz et al. 2002 ISO
Dole et al. 2006 Spitzer

Pop III stars ?

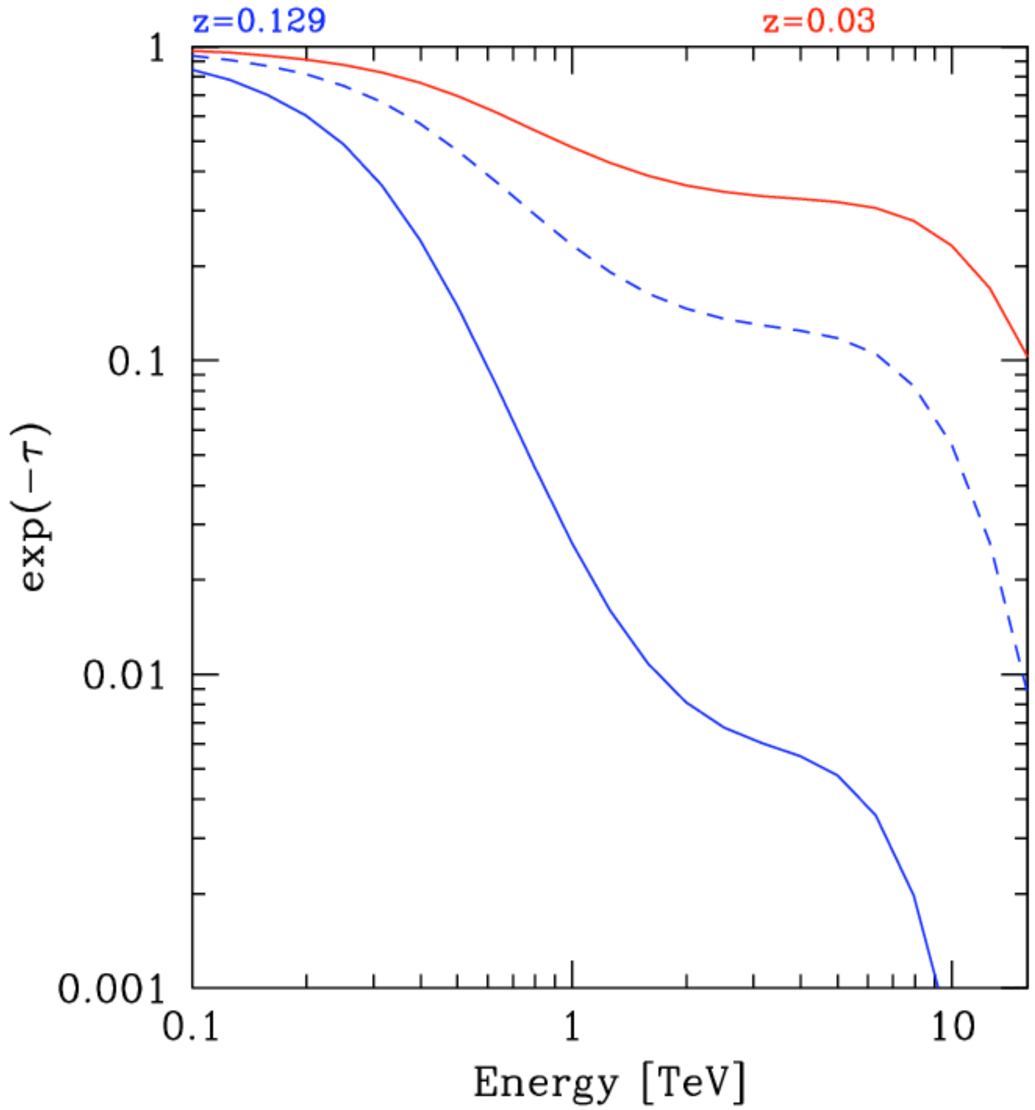


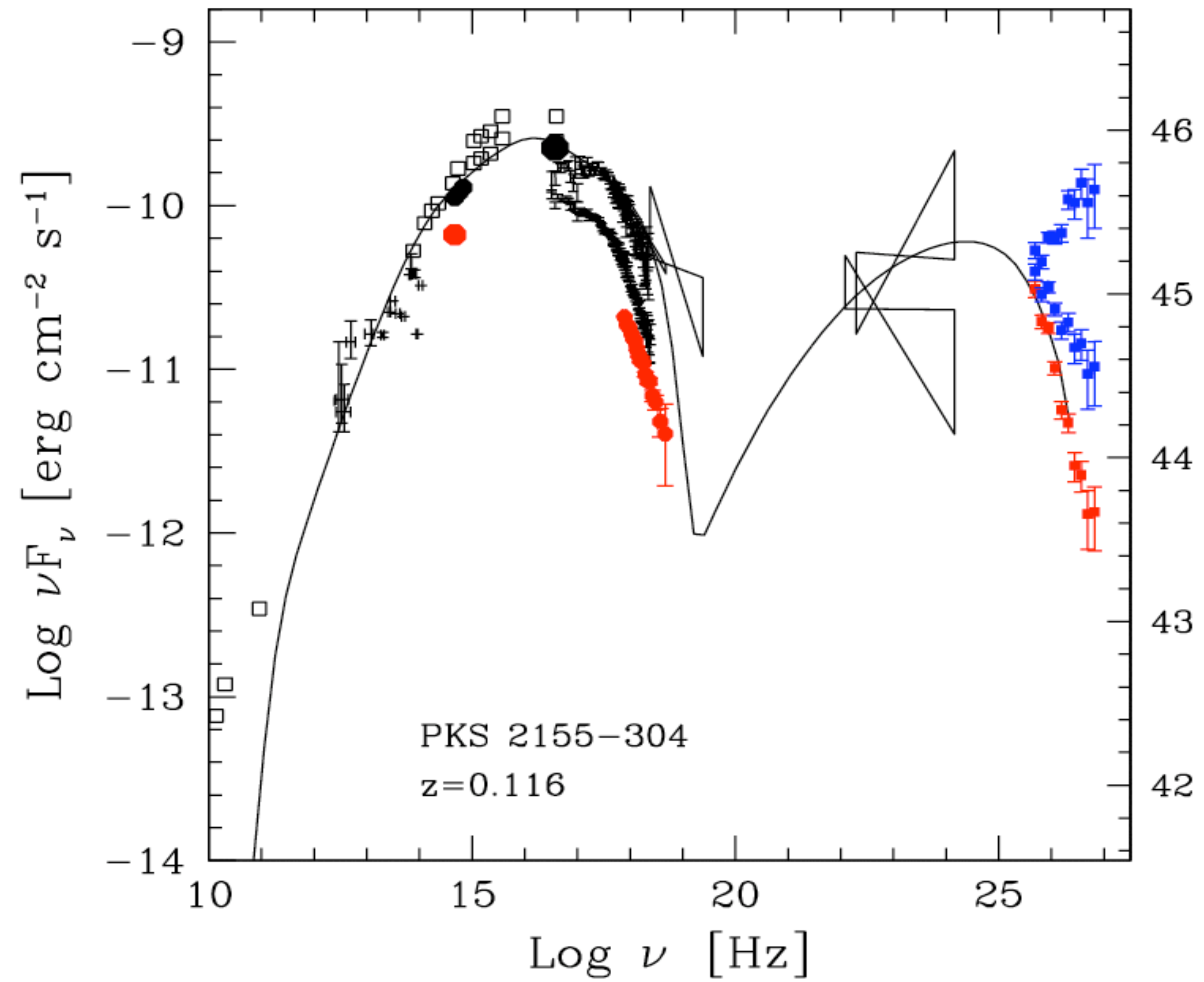
Santos et al. 02
Salvaterra & Ferrara 03,
Kashlinsky et al. 03-05

zodiacal light
Dwek et al. 2006

Problem: γ-γ interaction with EBL photons

The large uncertainty on the EBL caused a fundamental ambiguity in the interpretation of gamma-ray spectra



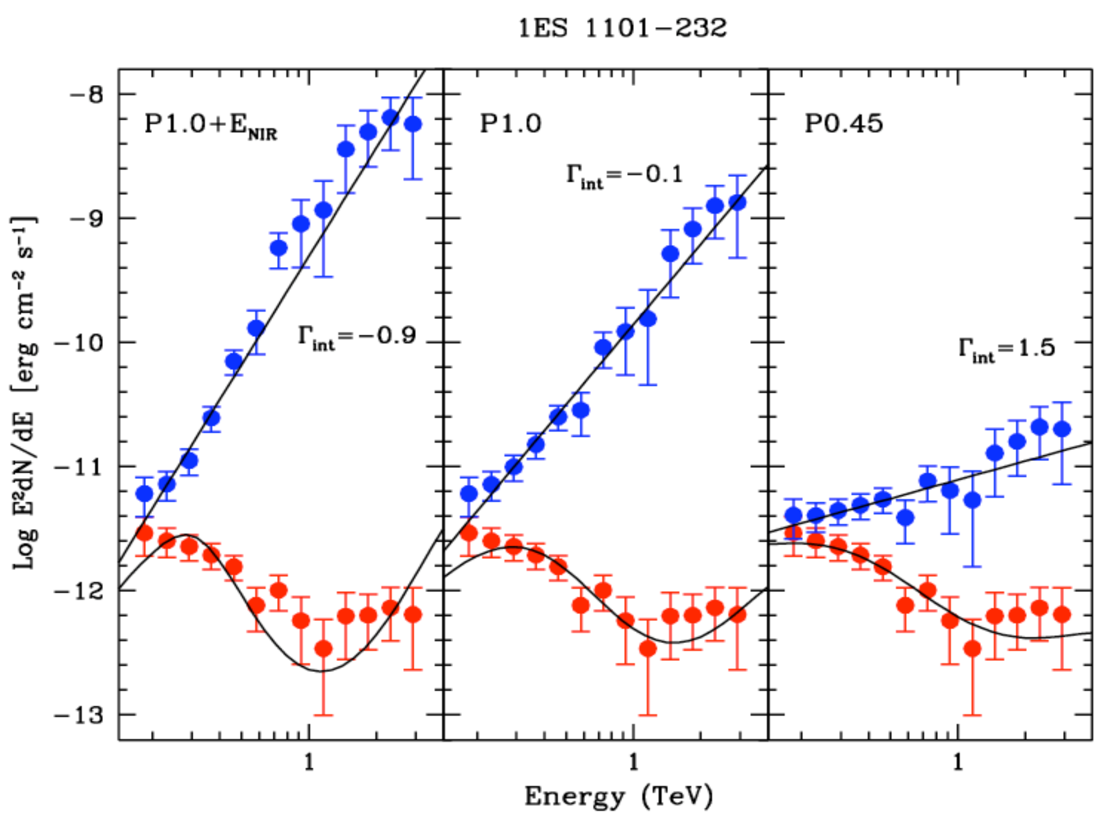


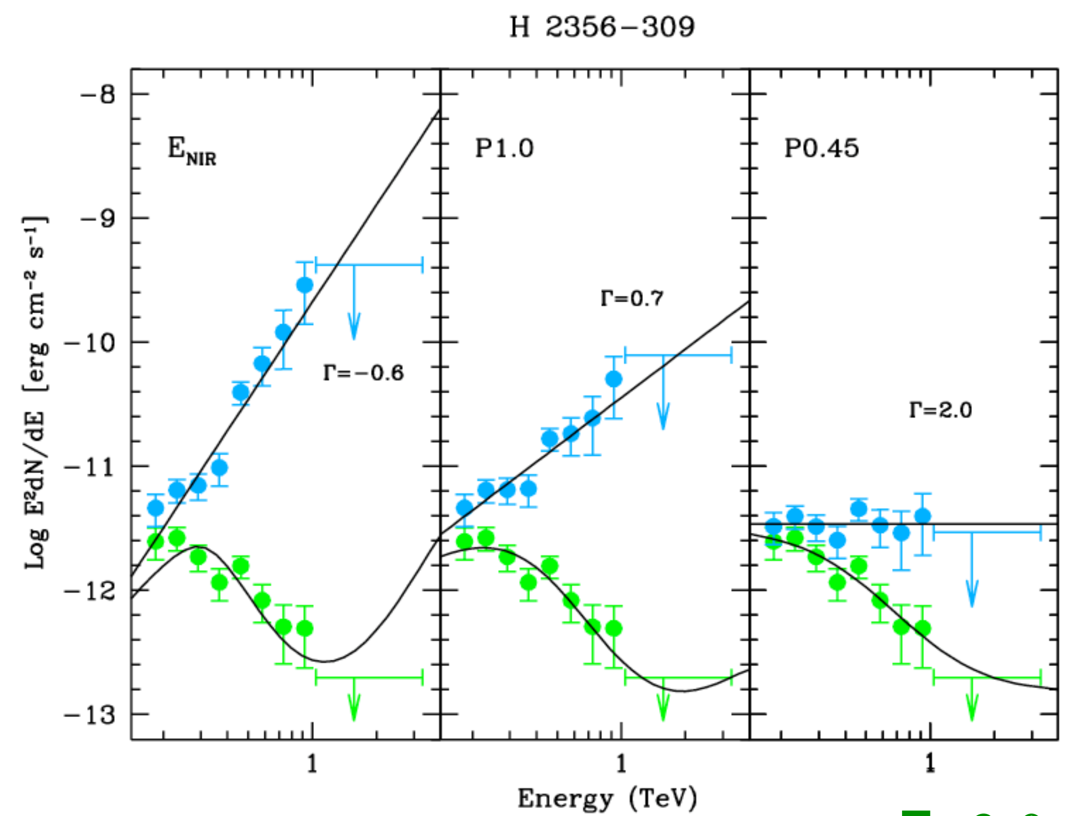
Opportunity: at the same time, blazars (as TeV beamers) can provide independent constraints on the EBL

Jelley 1966; Gould & Schreder 1967; Aharonian 2001 (ICRC review and refs therein); Aharonian et al. 2005 (HESS Coll); Costamante et al. 2004, 2005, 2006

Breakthrough in 2005 :

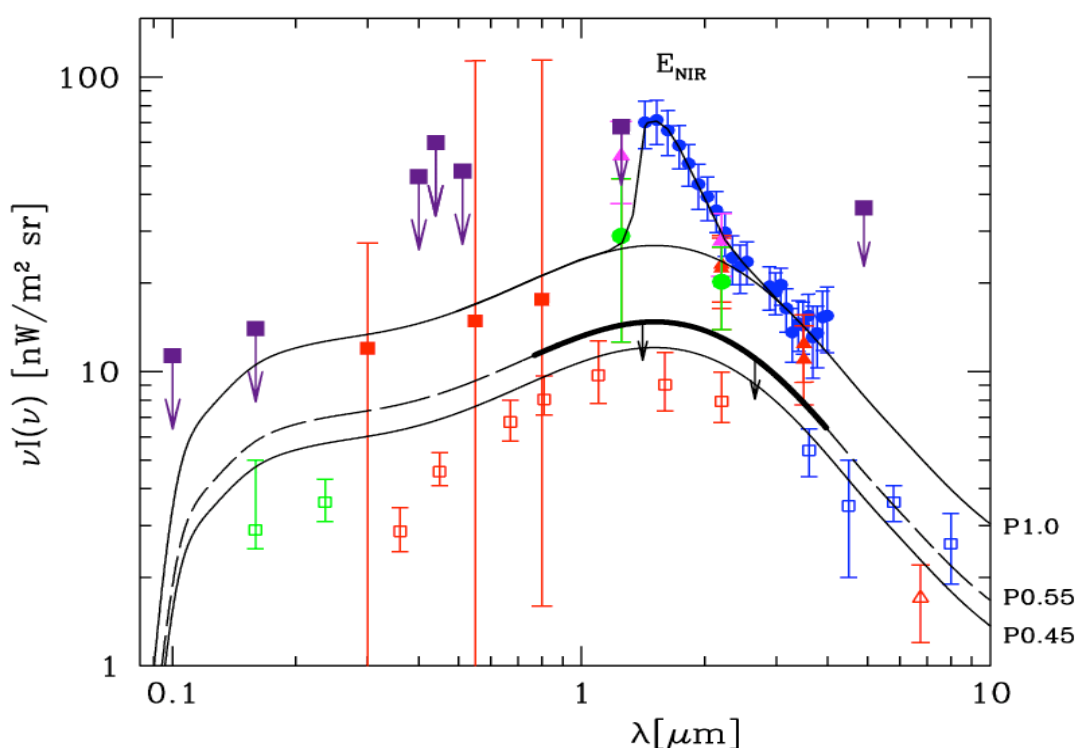
H.E.S.S. spectra of 1ES 1101-232 & H 2356-309





Γ=2.88 ±0.17
z = 0.186

Γ=3.06 ±0.21
z = 0.165



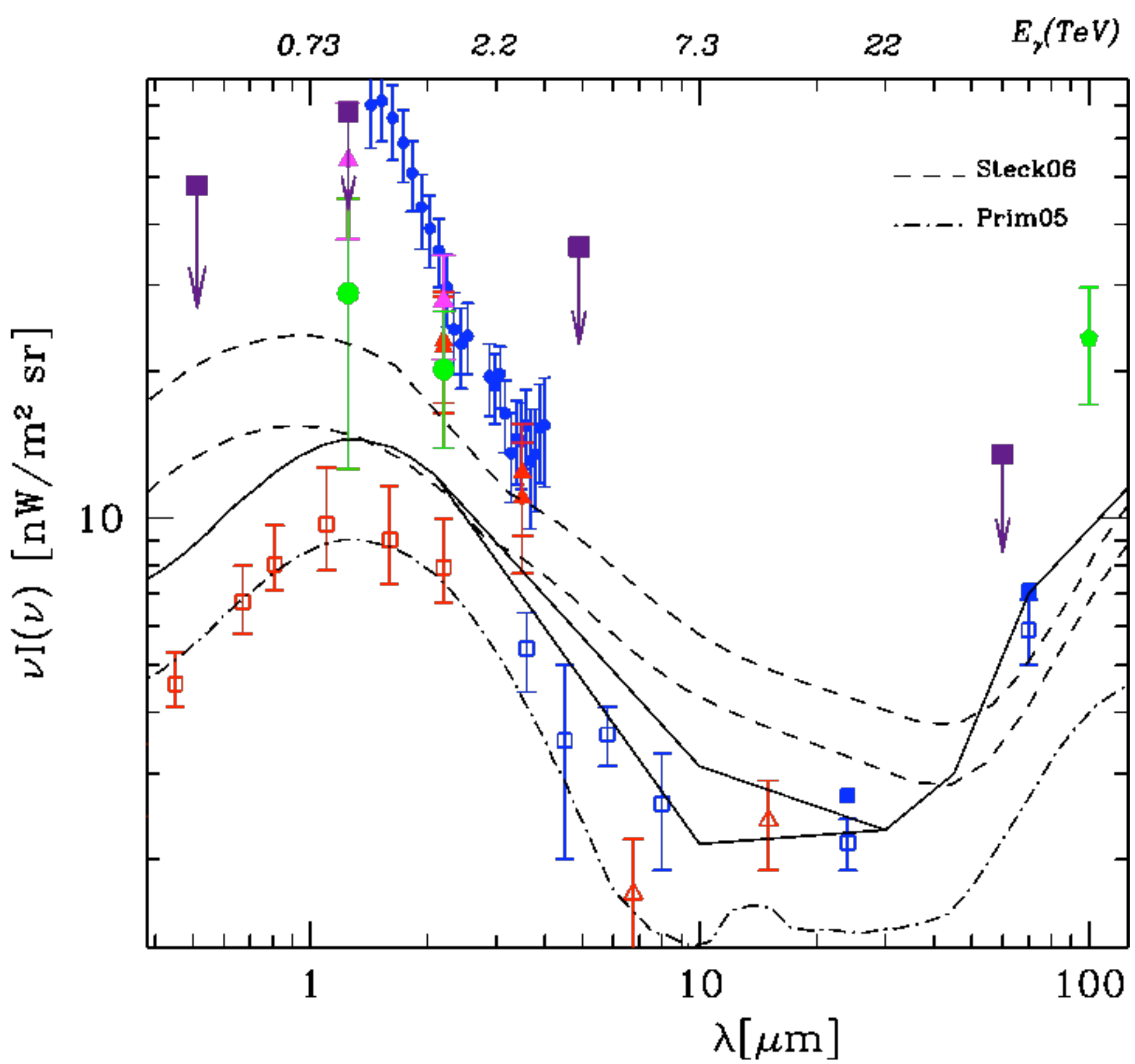
- EBL mainly done by normal galaxies
- Larger gamma-ray horizon
- Much less uncertainty on blazar spectra

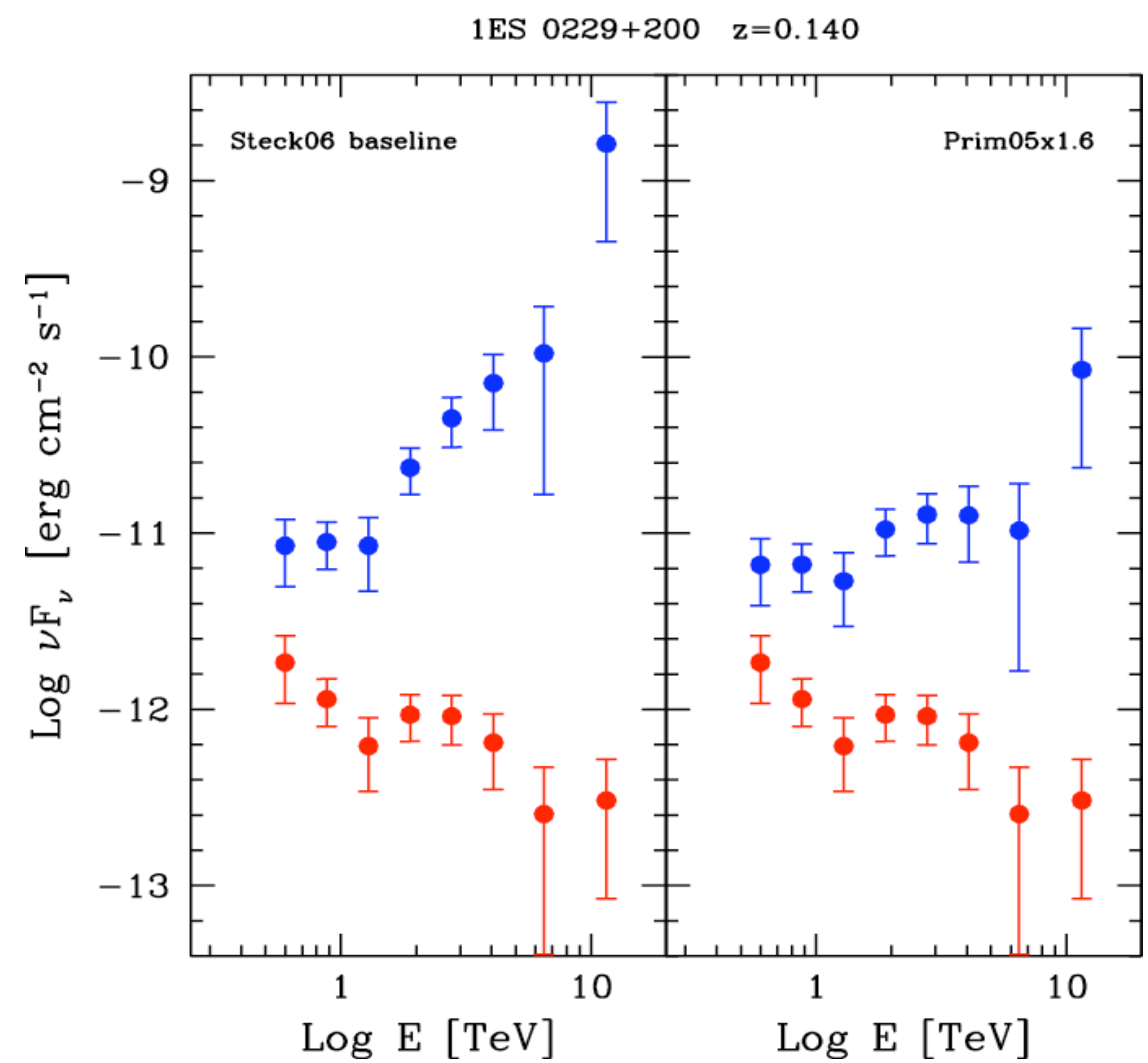
Aharonian et al. 2006 (HESS Coll), Nature

New constraints also in the NIR band:

H.E.S.S. spectrum of 1ES 0229+200 constrains EBL to slope λ^{-1}

(confirming HEGRA indications on 1ES 1426+428)



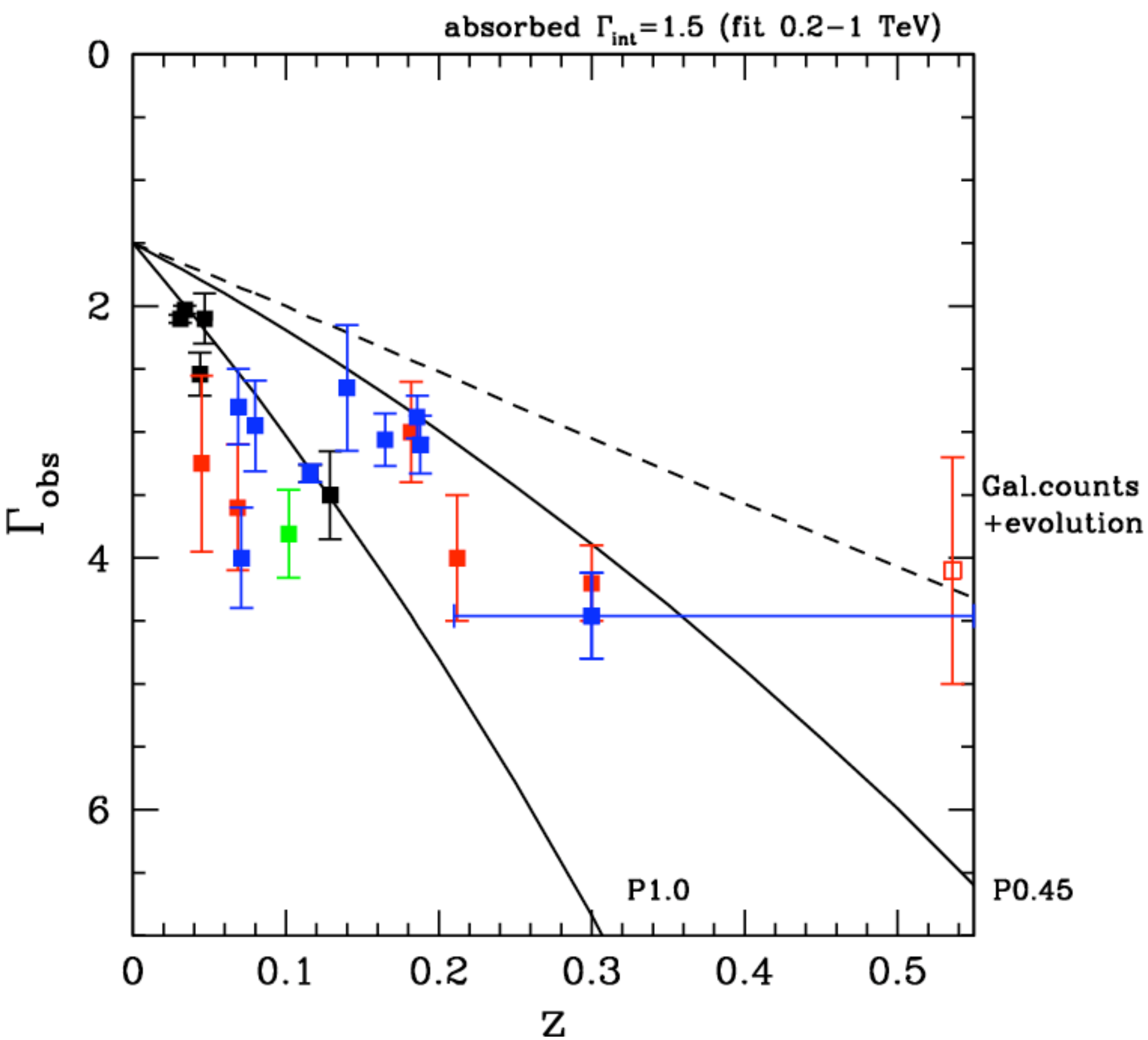


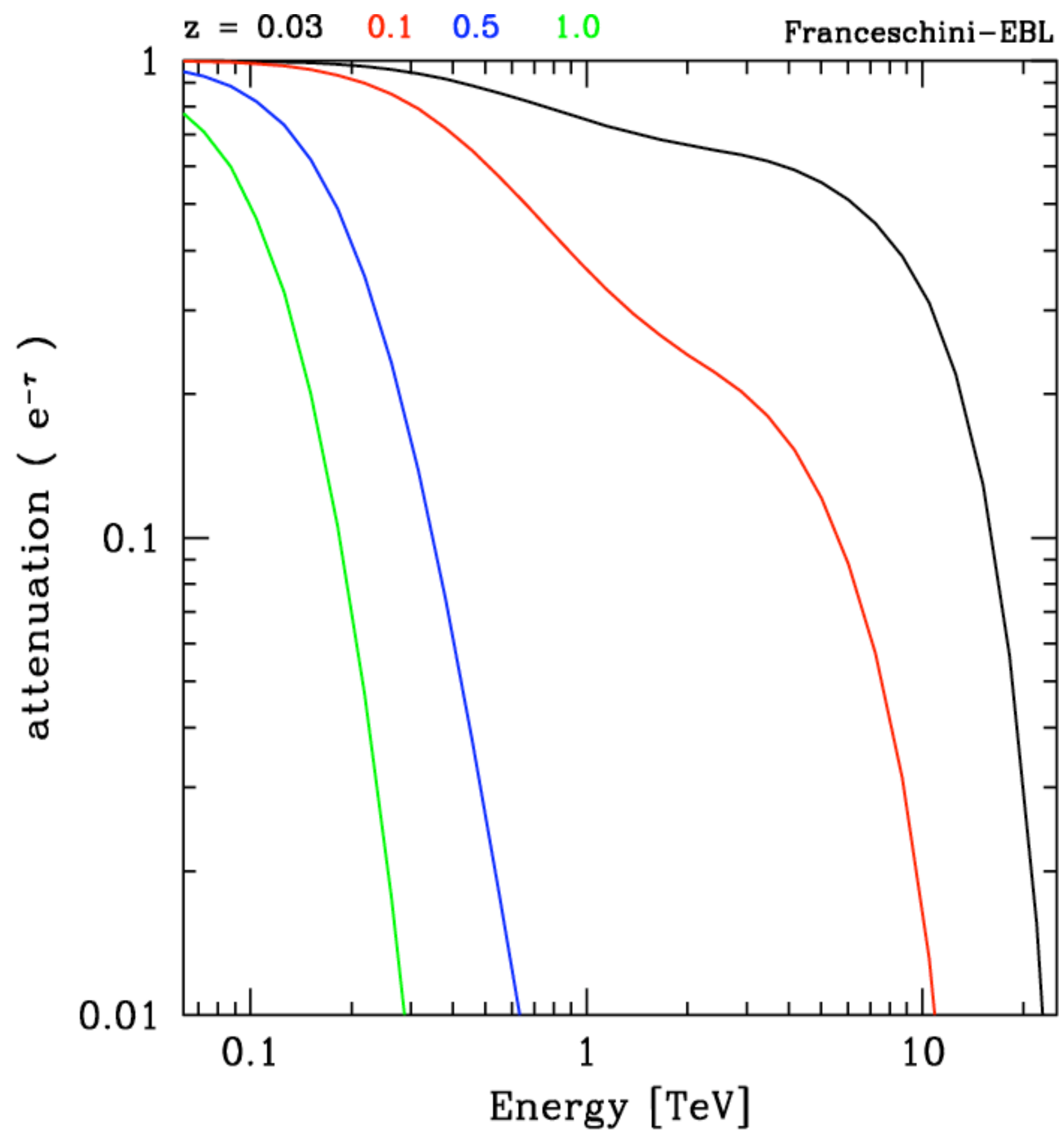
1ES 0229+200 (z=0.140)

H.E.S.S. (Aharonian et al 2007)

Photon-wise, NO need (yet) of new physics

At present, VHE detections and spectra are ALL consistent/explainable with a low EBL level and standard blazar physics. Not even for objects at z=1

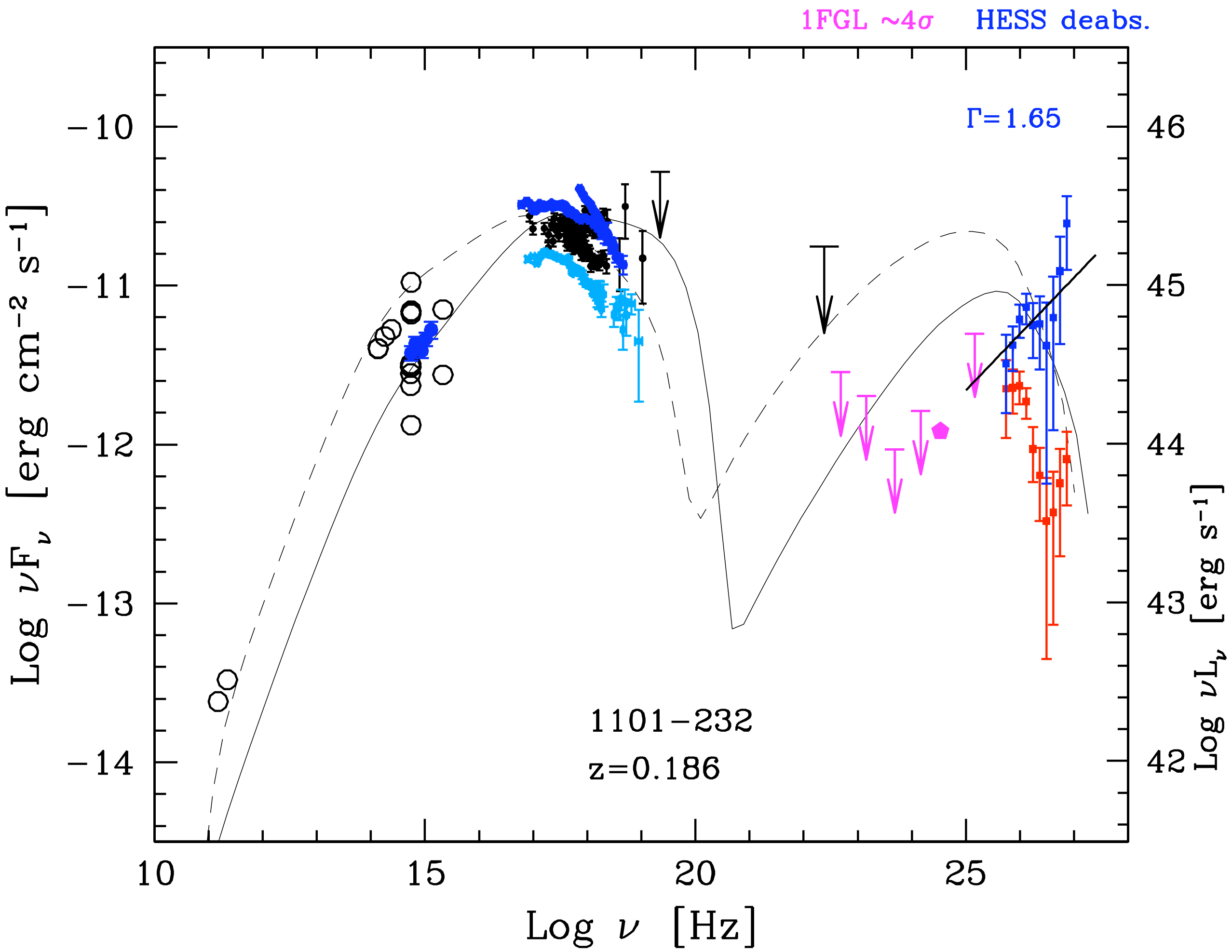


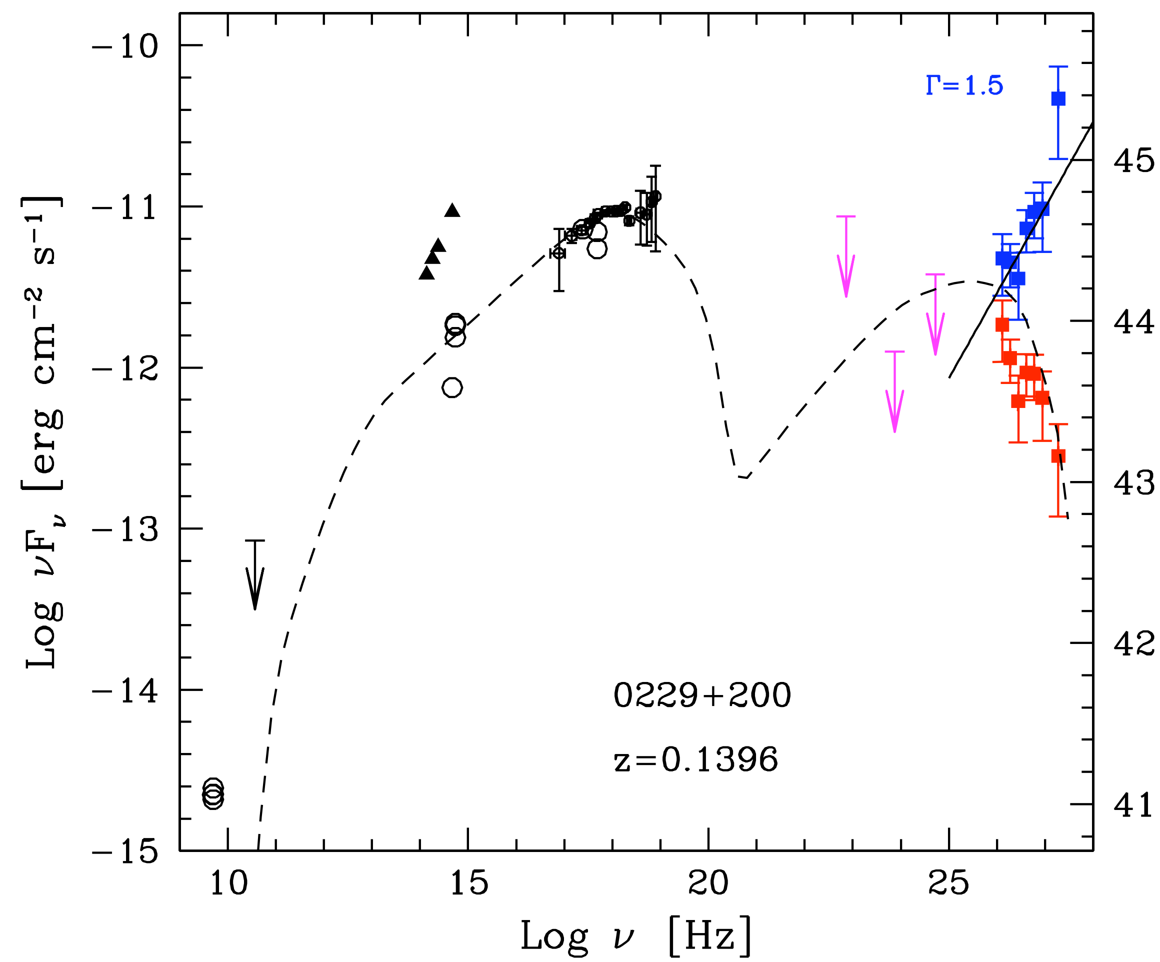


Costamante et al. 2006

Even with low EBL, some VHE spectra remain hard !

New class of HBL is emerging: **TeV-peaked BL Lacs**





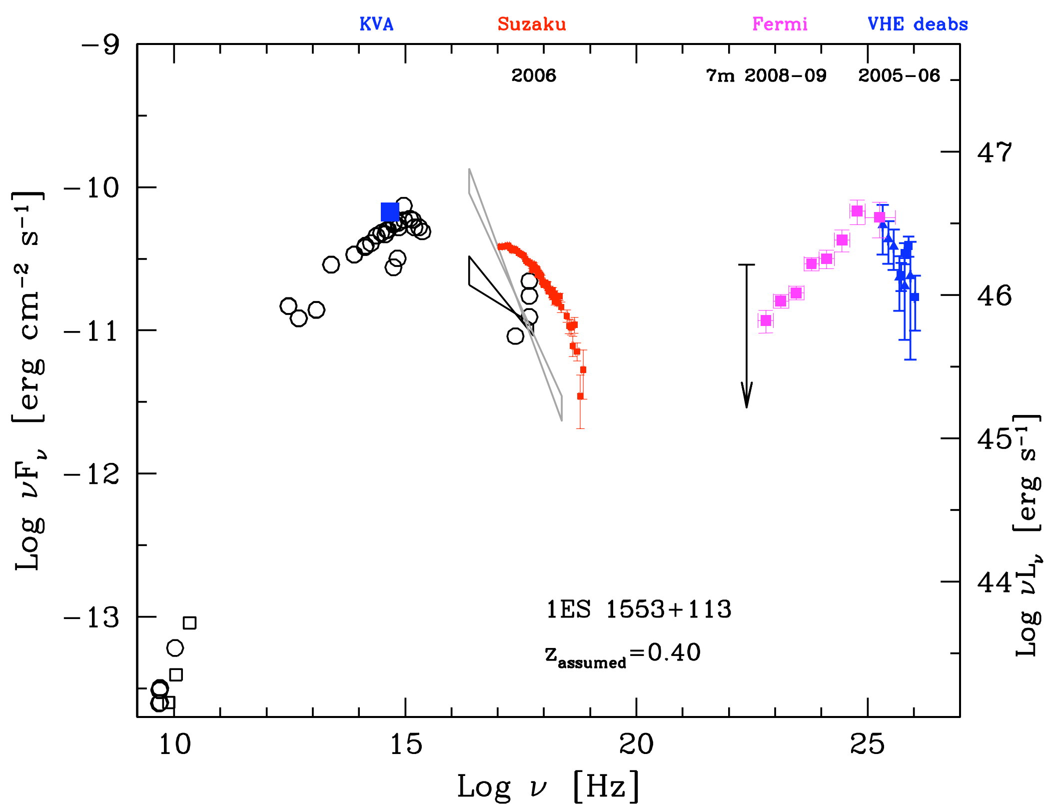
Characterized by $\Gamma_{VHE} < 2$ (typically 1.5-1.7) with any EBL intensity (even lowest one).

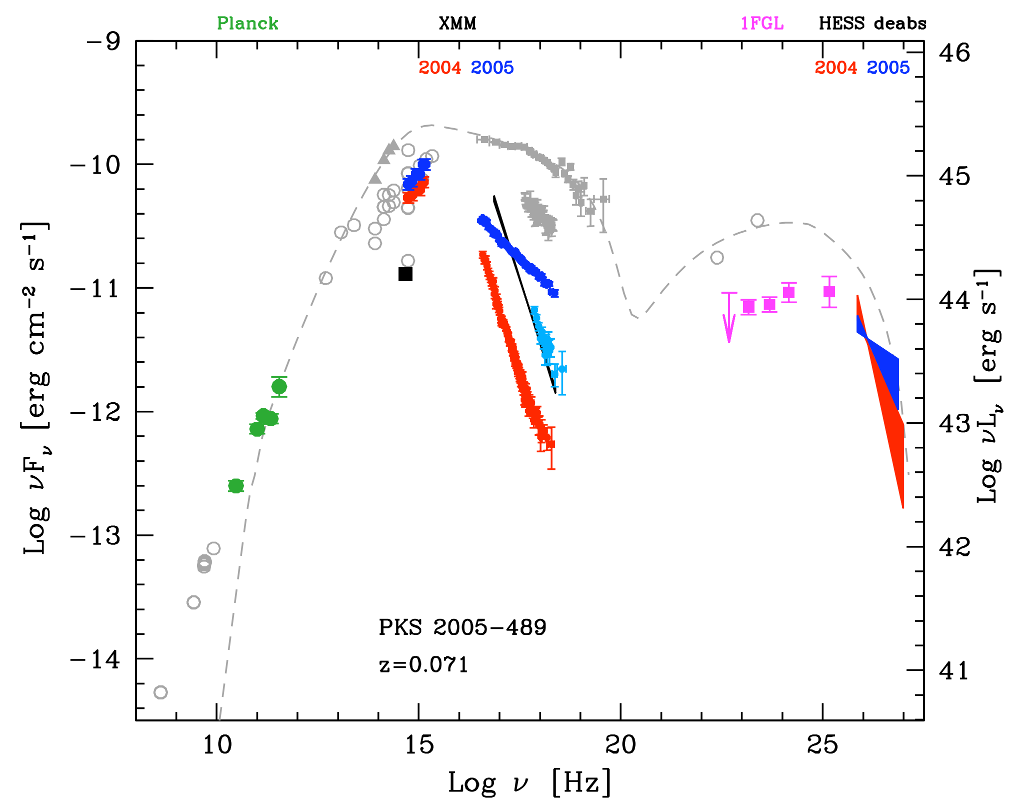
⇒ **Compton peak ≥ 3-20 TeV**

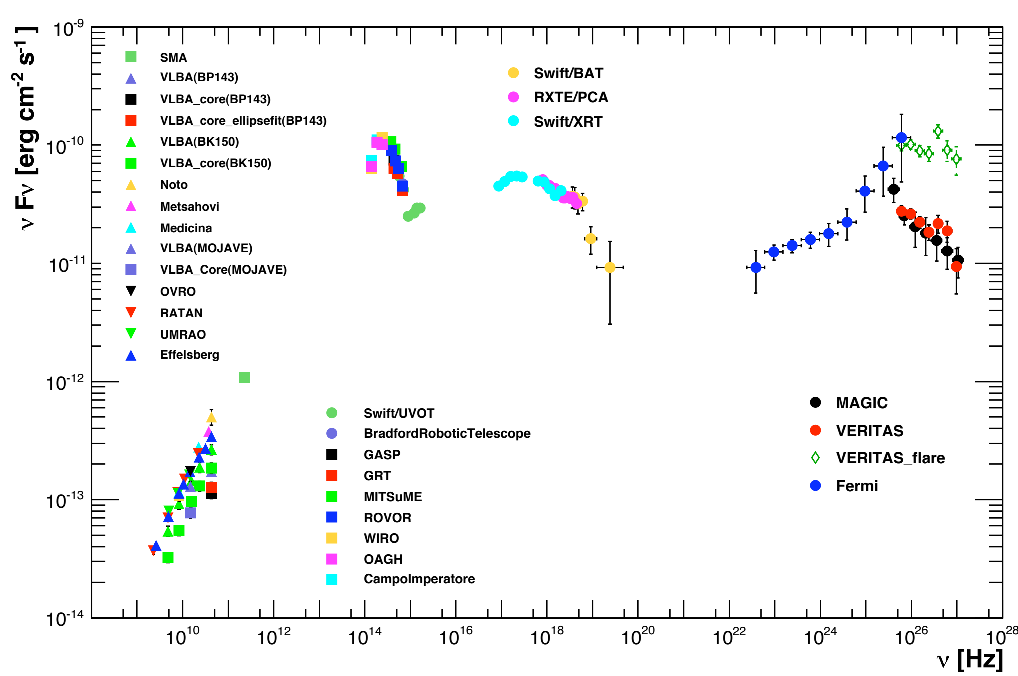
Extremely difficult to model with one-zone SSC models, due to Klein-Nishina effects at high energies. Many scenarios proposed (low-energy cutoff at very high energies, internal absorption, extended emission) but none seems satisfactory (need extreme parameters, B <mG, low radiative efficiency <<1%, additional ad hoc conditions etc...).

Different from the typical HBL detected by Fermi !

“100 GeV”-peaked HBL objects (bright and easily detected in Fermi-LAT)







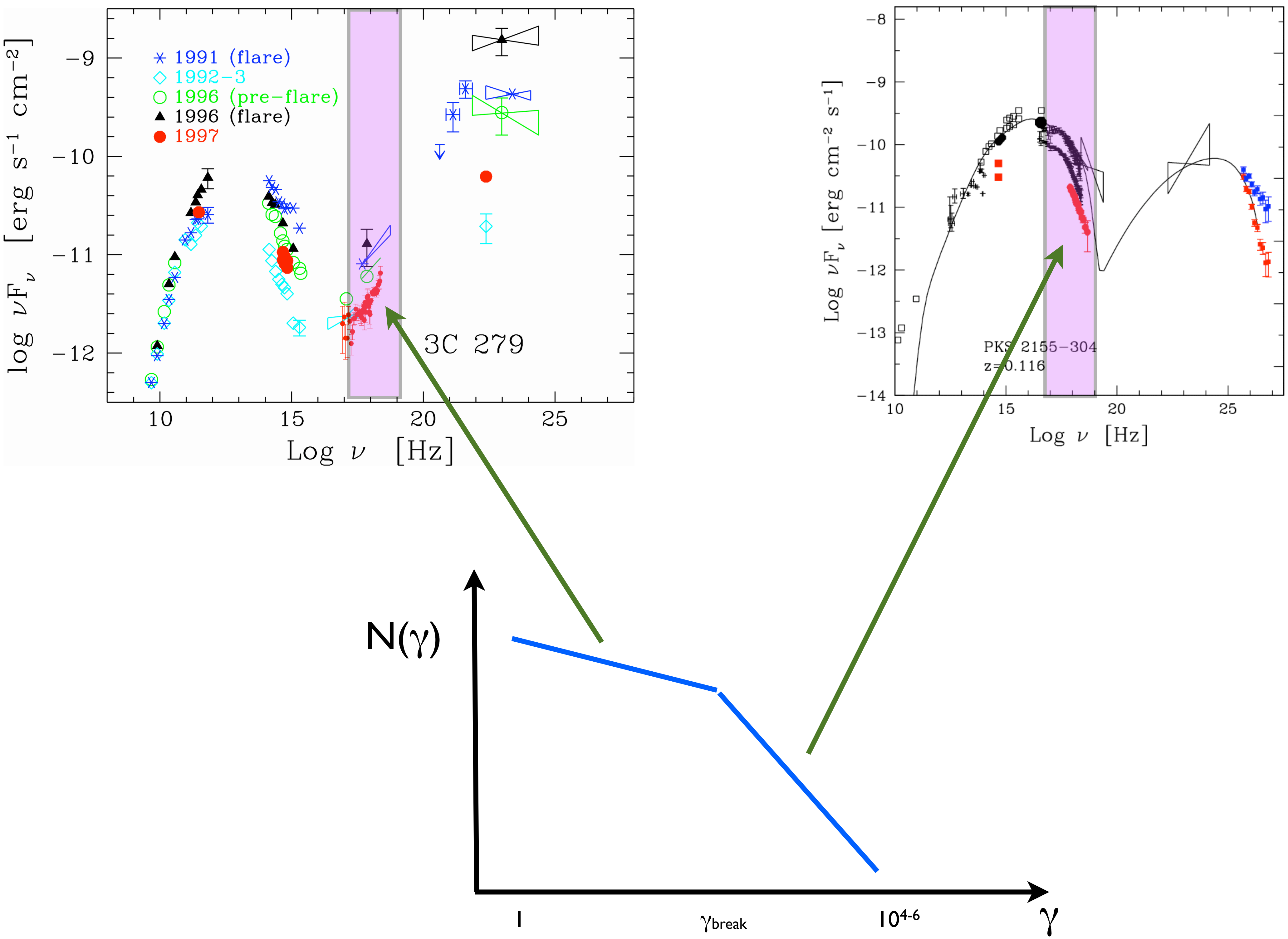
Abdo et al. (LAT coll)
2010a, 2010b, 2011

Variability

Variability depends on the position of the observed band relative to the SED peaks

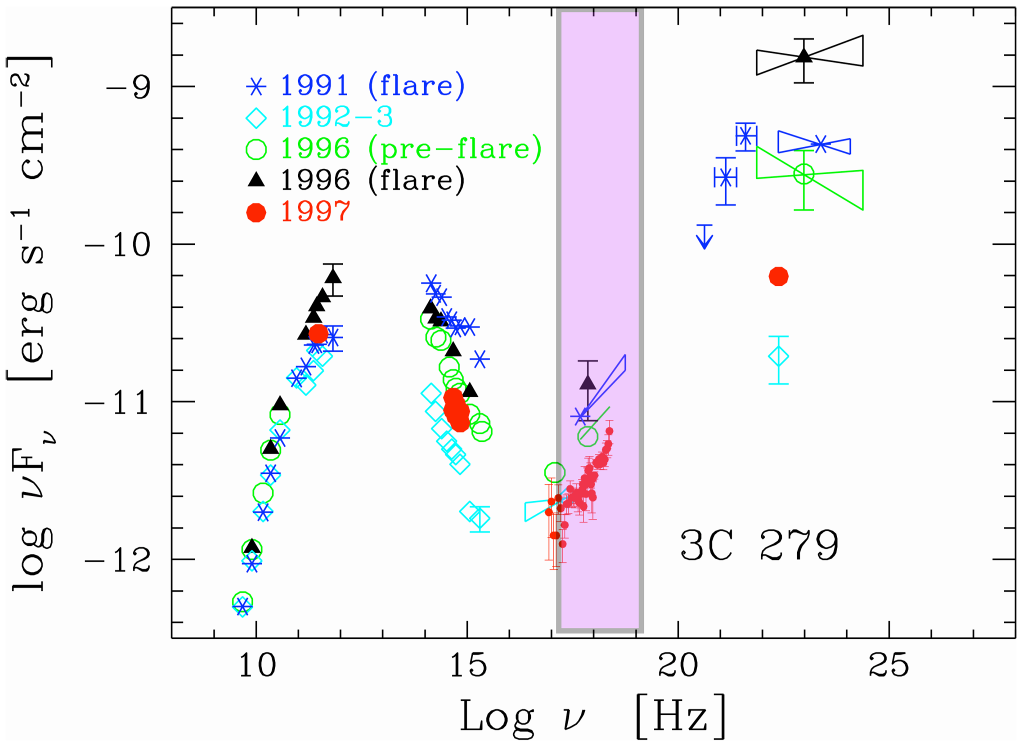
LBL/FSRQ

HBL

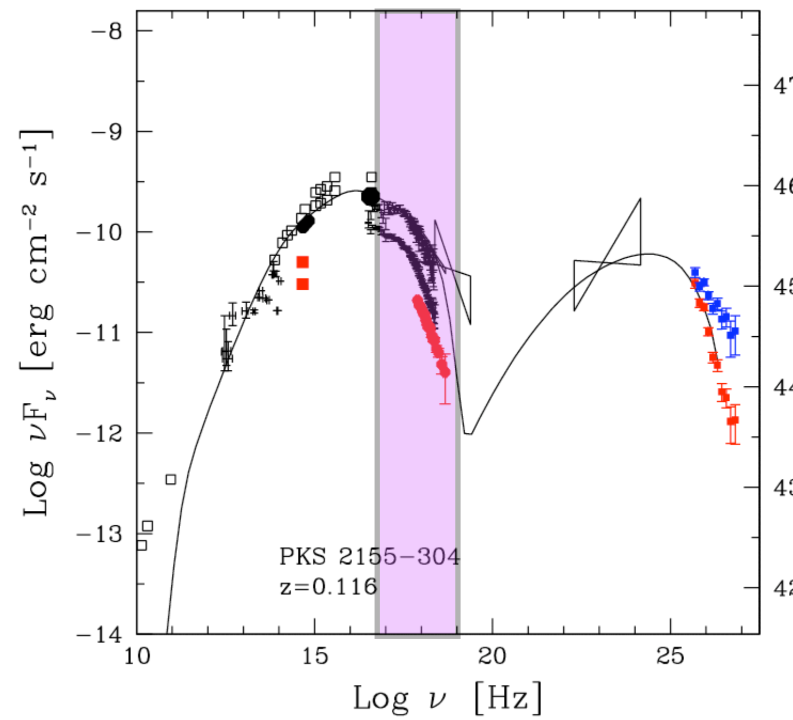


Variability depends on the position of the observed band relative to the SED peaks

LBL/FSRQ



HBL

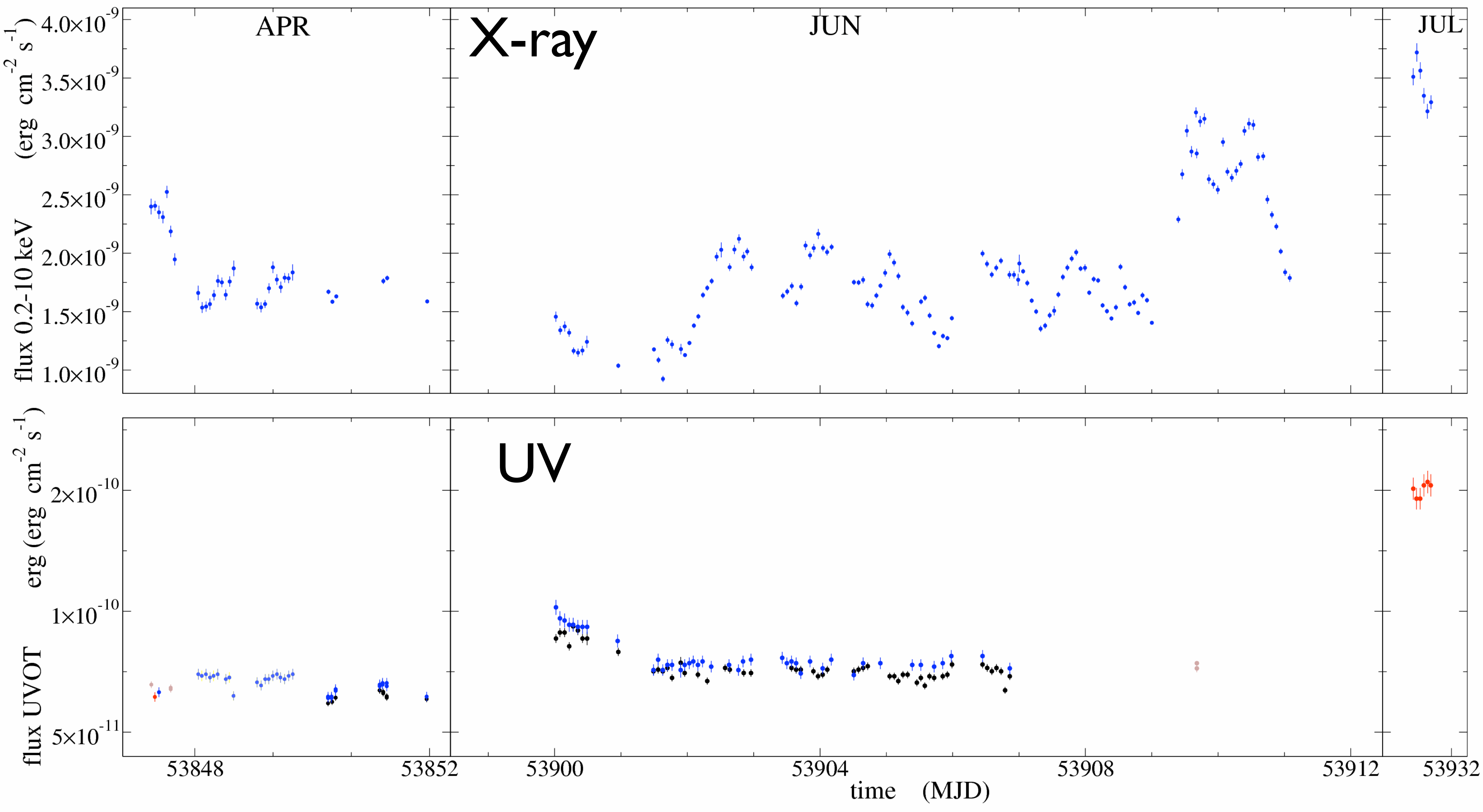


Do not compare apples with oranges...

X-ray (or Gamma-ray) variability means very different electron energies for different SED types

Blazars typically vary much more above each 'peak'

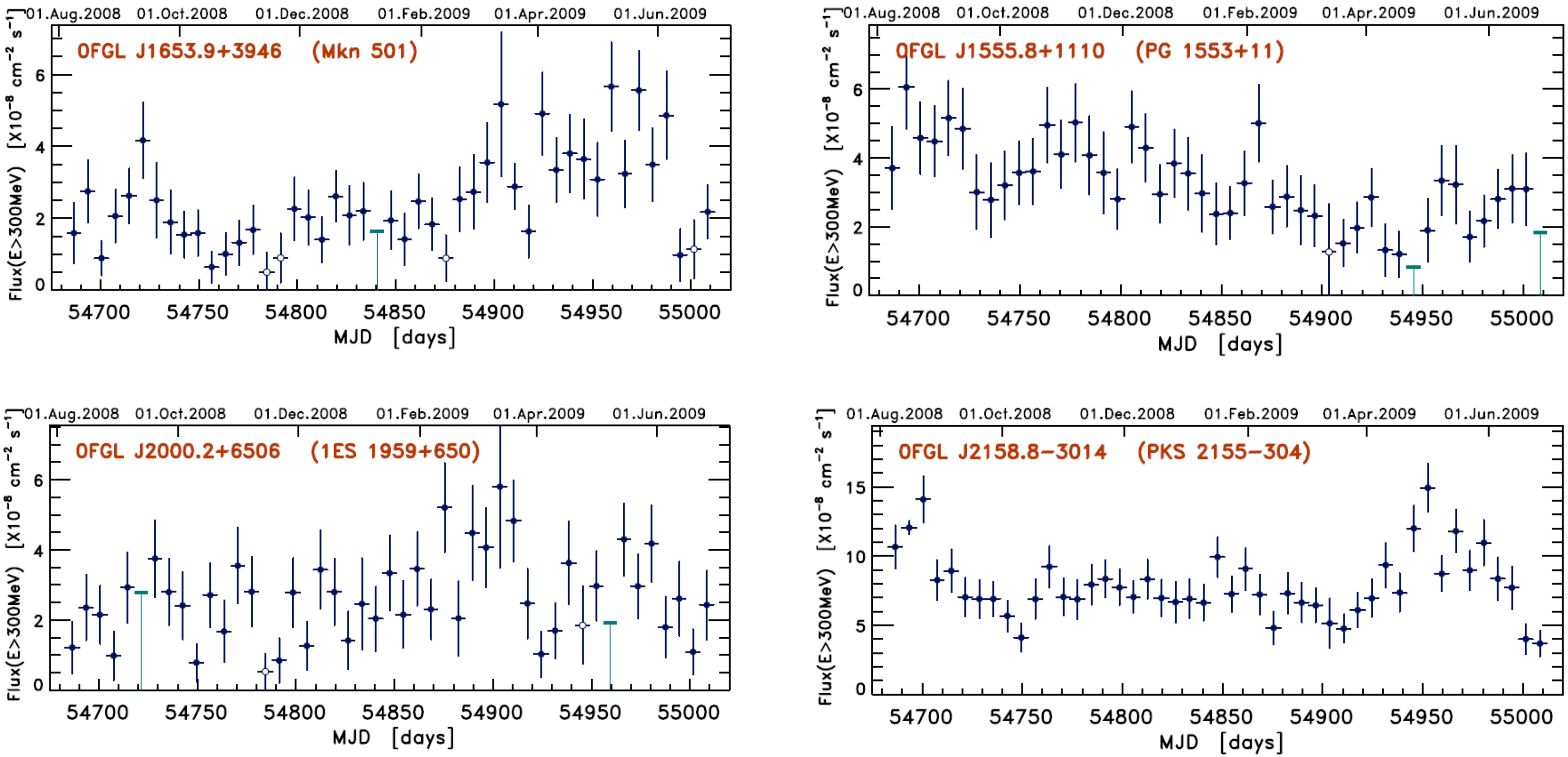
e.g. Mkn 421 in 2006



Tramacere et al 2009

Fermi band: little/no variability

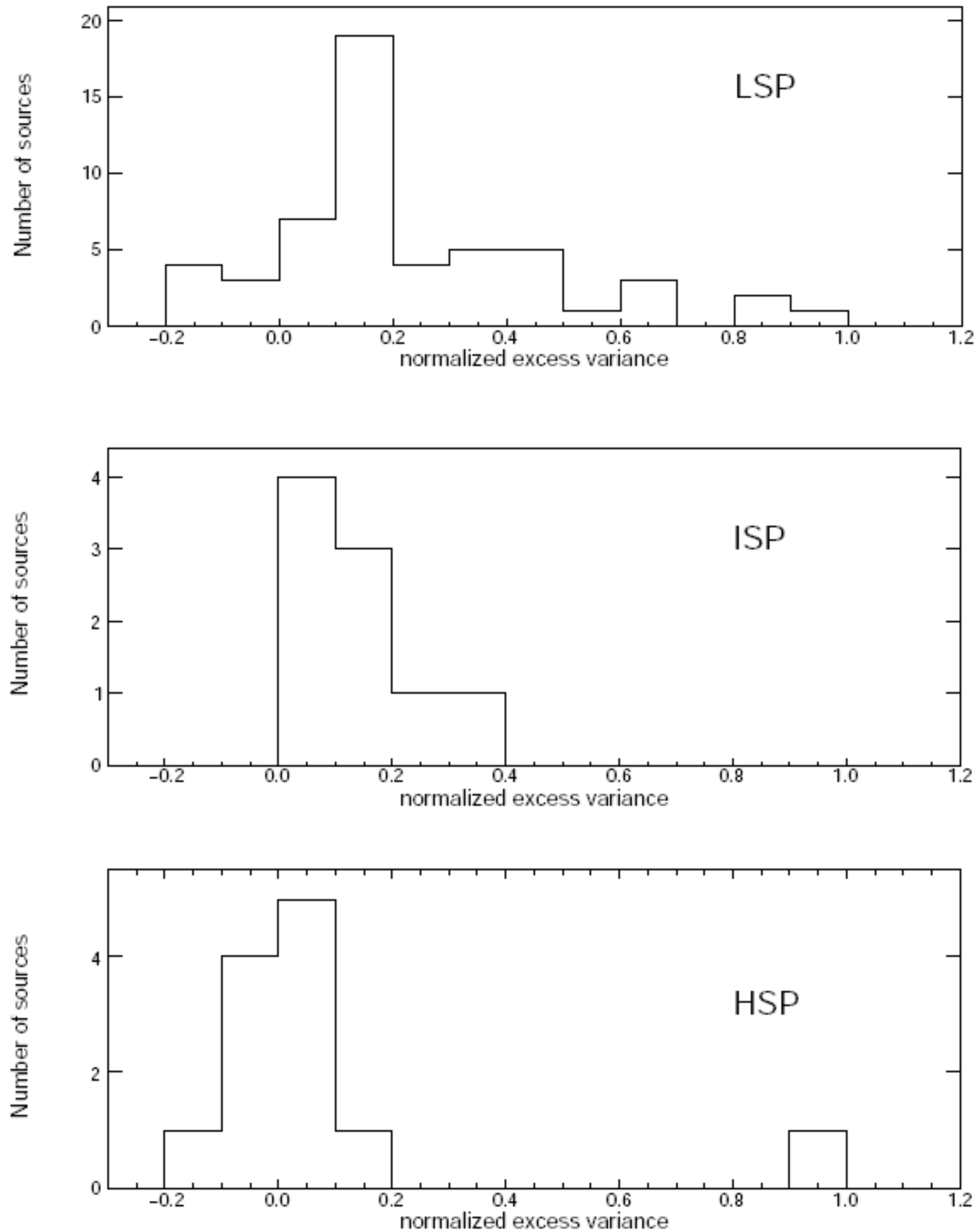
(as in the optical...)



Abdo et al. 2010

see talk by S. Ciprini, G. Tosti

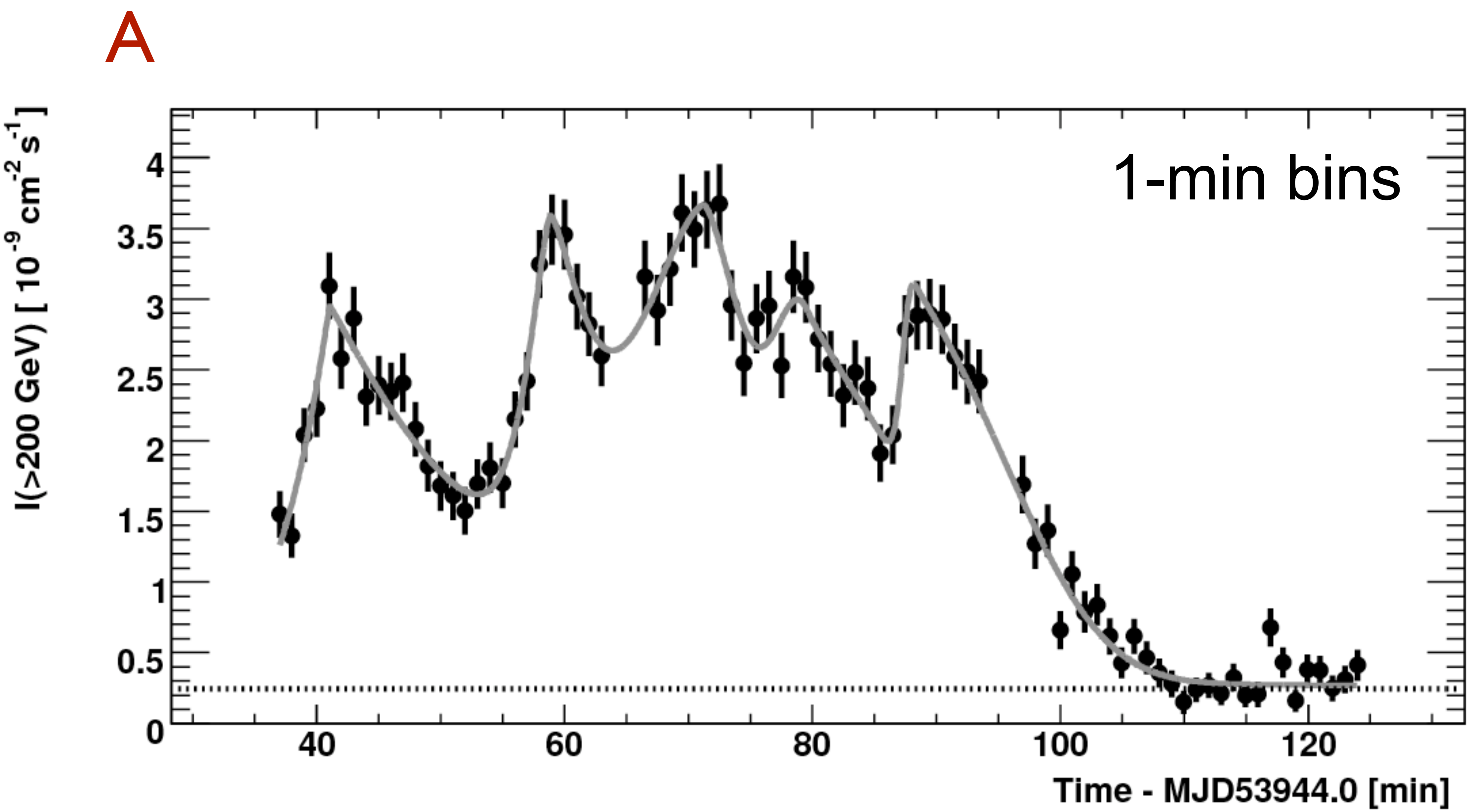
Fermi band: excess variance



LBL/FSRQ

HBL

Ultra-fast variability !   2x flux in ~2-3 min.
10x in less than 1 hr



R ~5×10^{12} δ cm ≈ 0.01 δ R_S

Aharonian et al. (HESS coll) 2007

$\Gamma \geq$50-100   Needle in jet ?   Jets in a jet ?   magneto-centrifugal acceleration ? ...

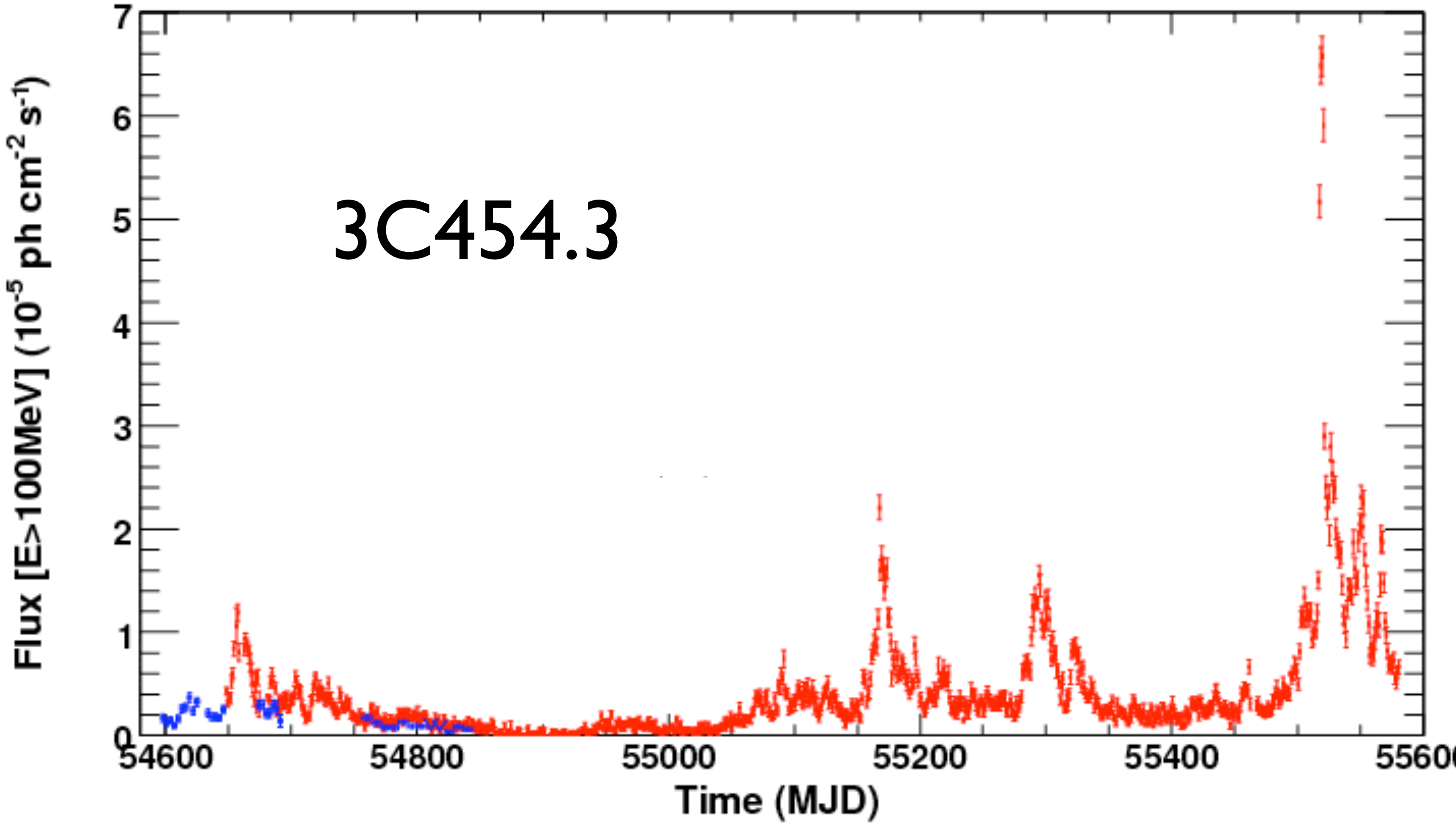
(Ghisellini & Tavecchio 2008)   (Giannios et al 2009)   (Ghisellini et al 2008)

Rapid variability seems ubiquitous !

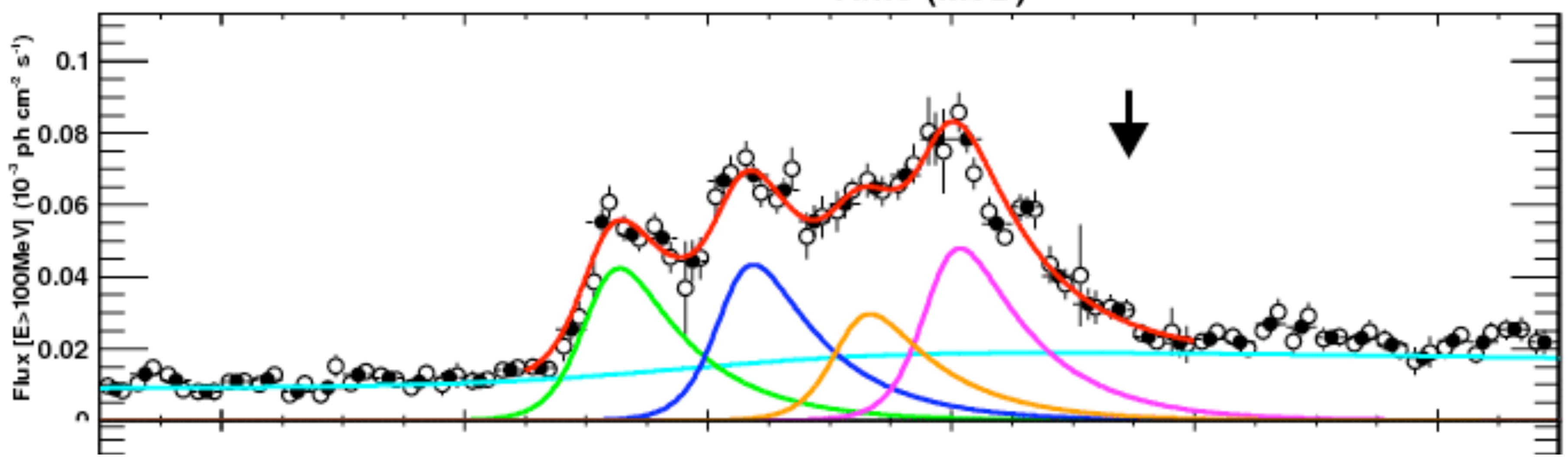
(detected down to shortest timescales allowed by statistics)

M87 (F. Rieger),

3C454.3



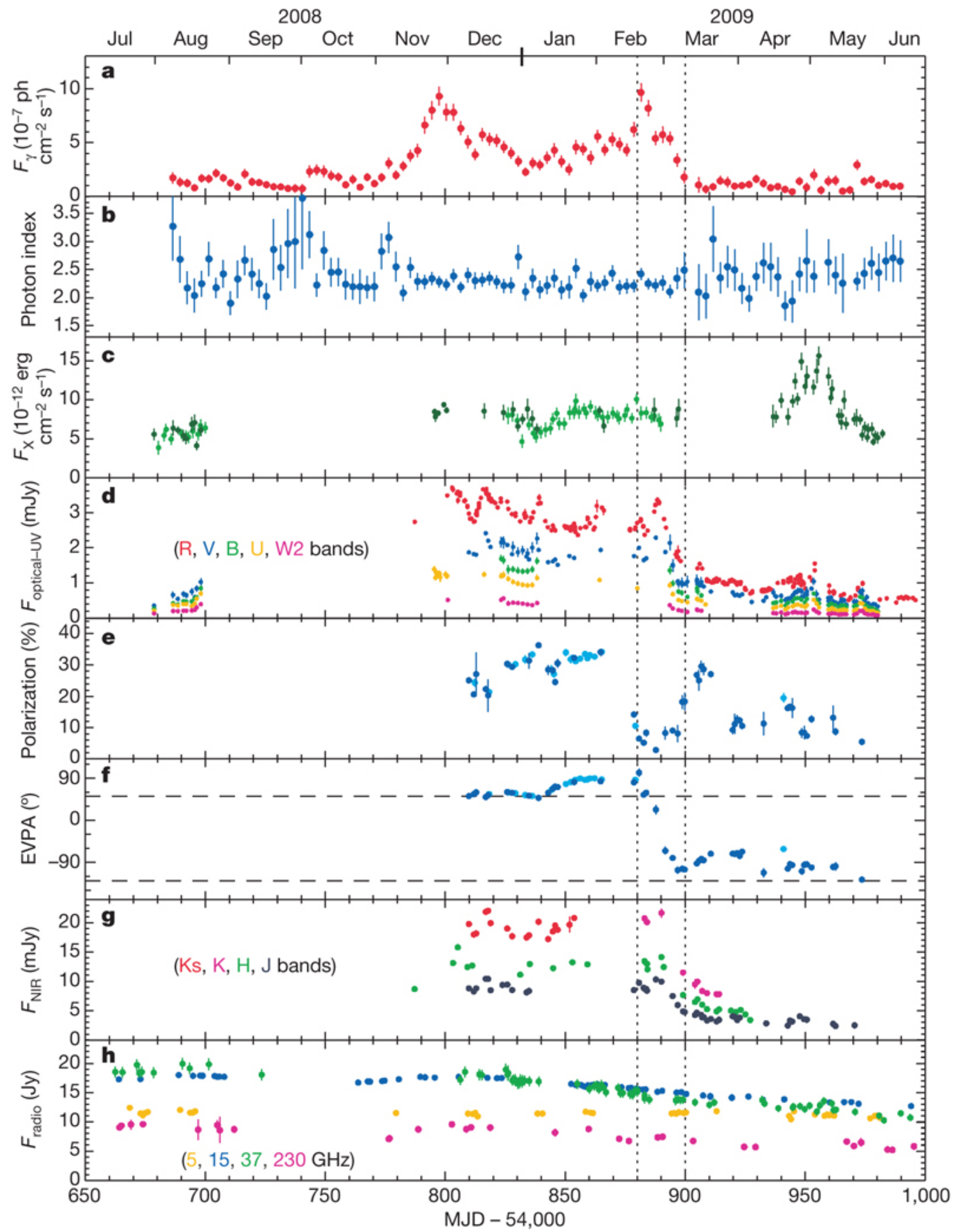
L~10^{50}

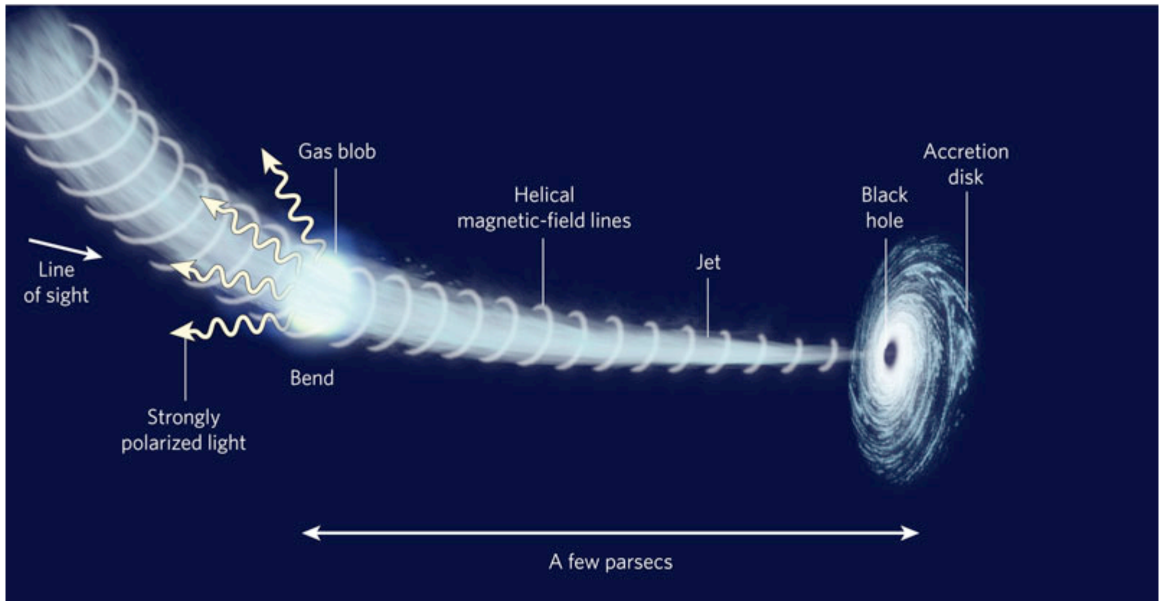


o = 3-hrs bin

Abdo et al. 2011

3C 279: variability gamma + optical polarization





Abdo et al. 2010, Nature

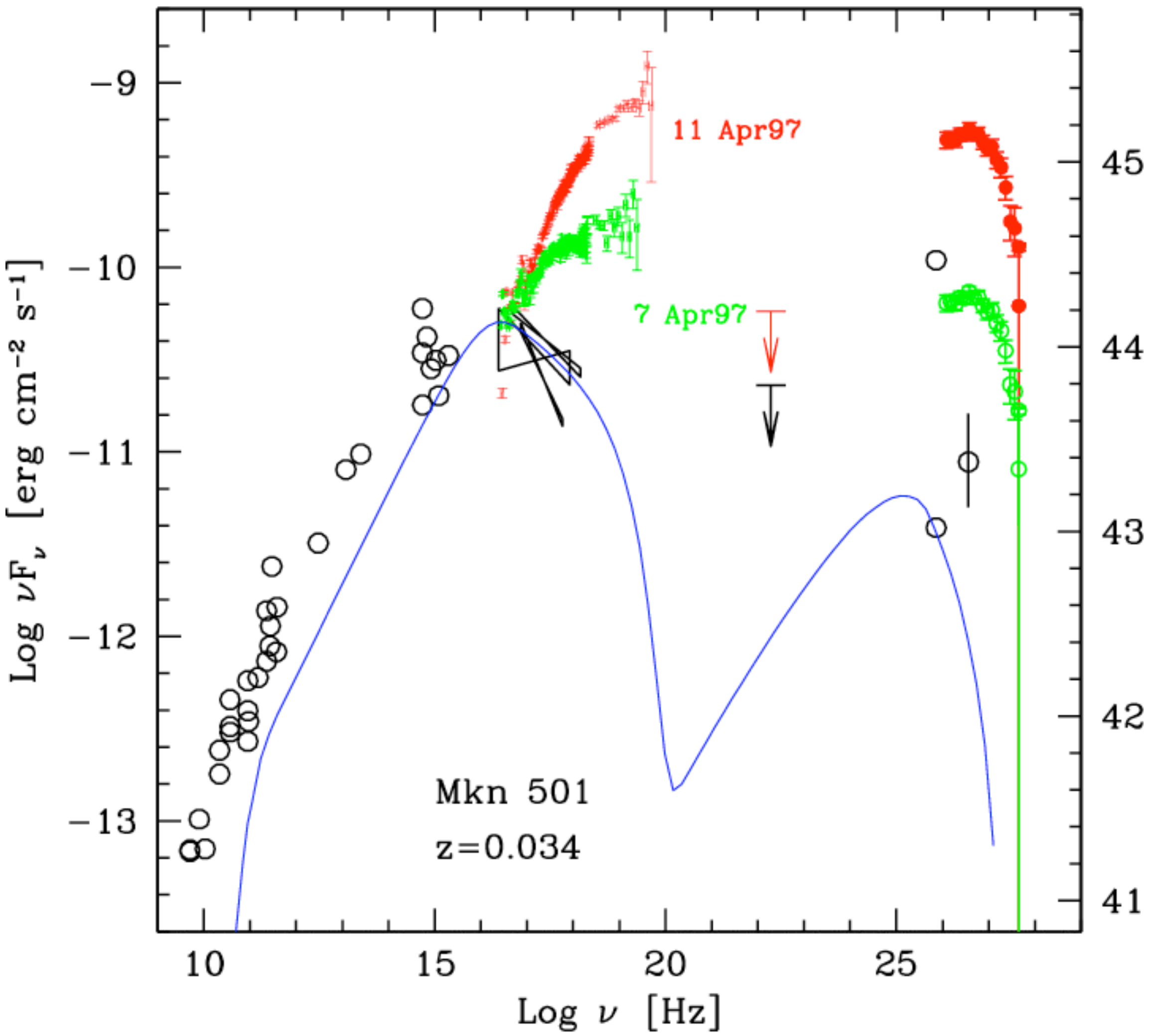
We focus now on HBLs, and the
high-energy branch of the electron distribution

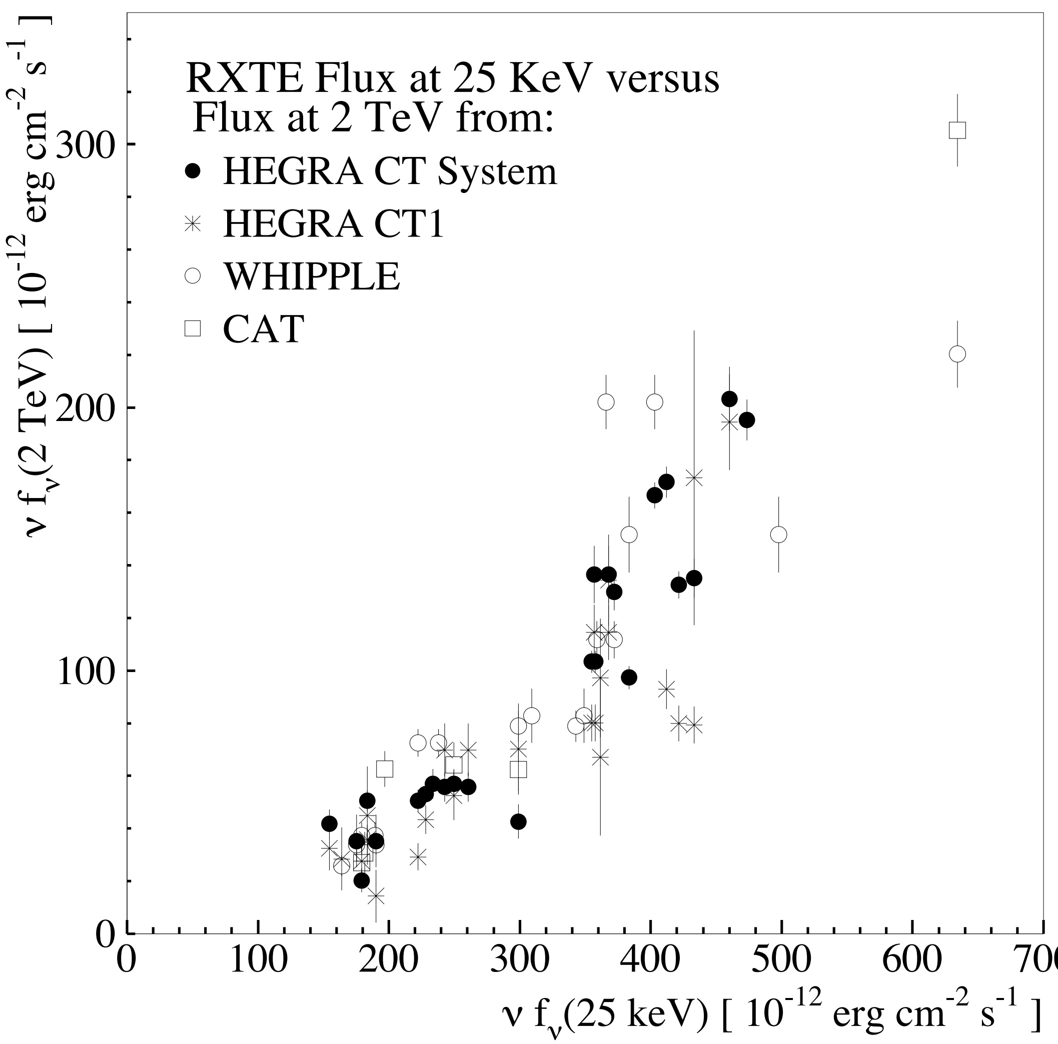
X-ray — TeV connection:
same-energy electrons emitting by Sync & IC

What have we learned so far? and recently ?

X-ray & TeV are typically highly correlated during flares

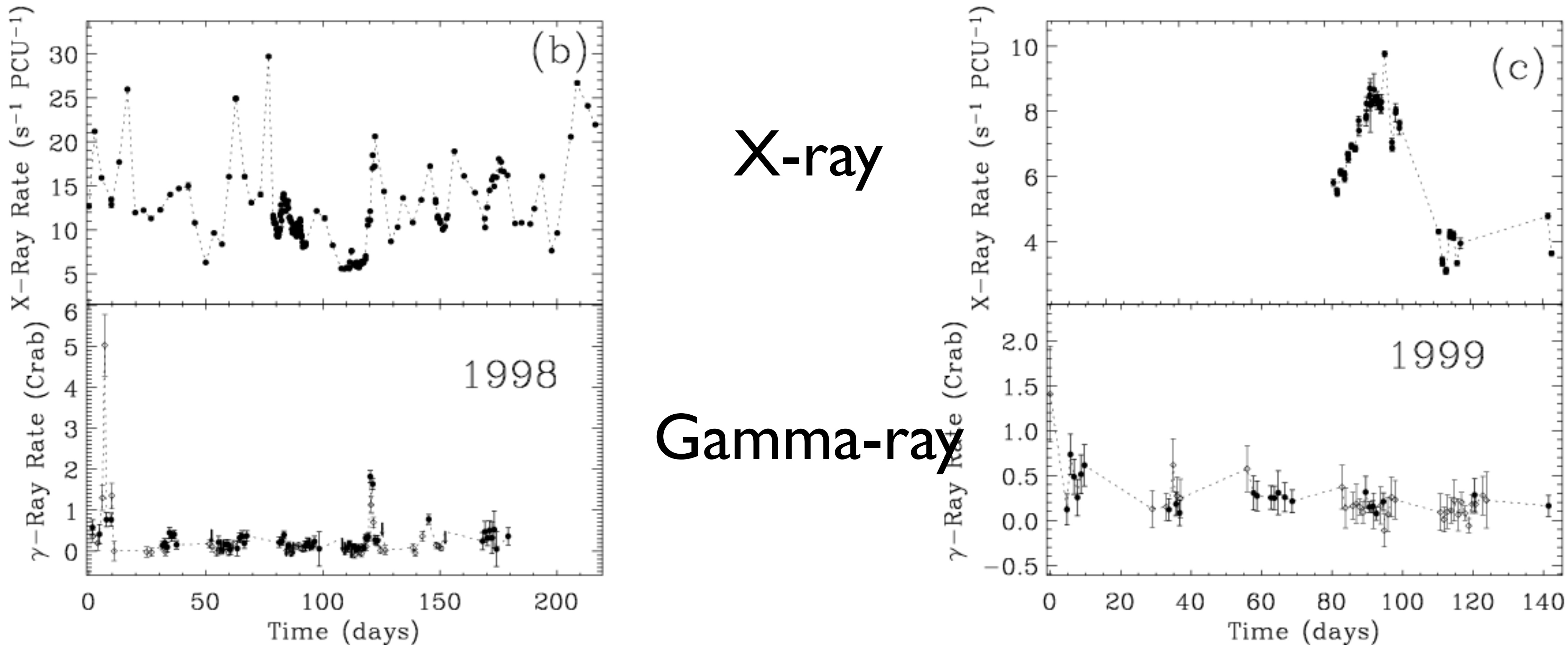
Classic case: Mkn 501 in 1997



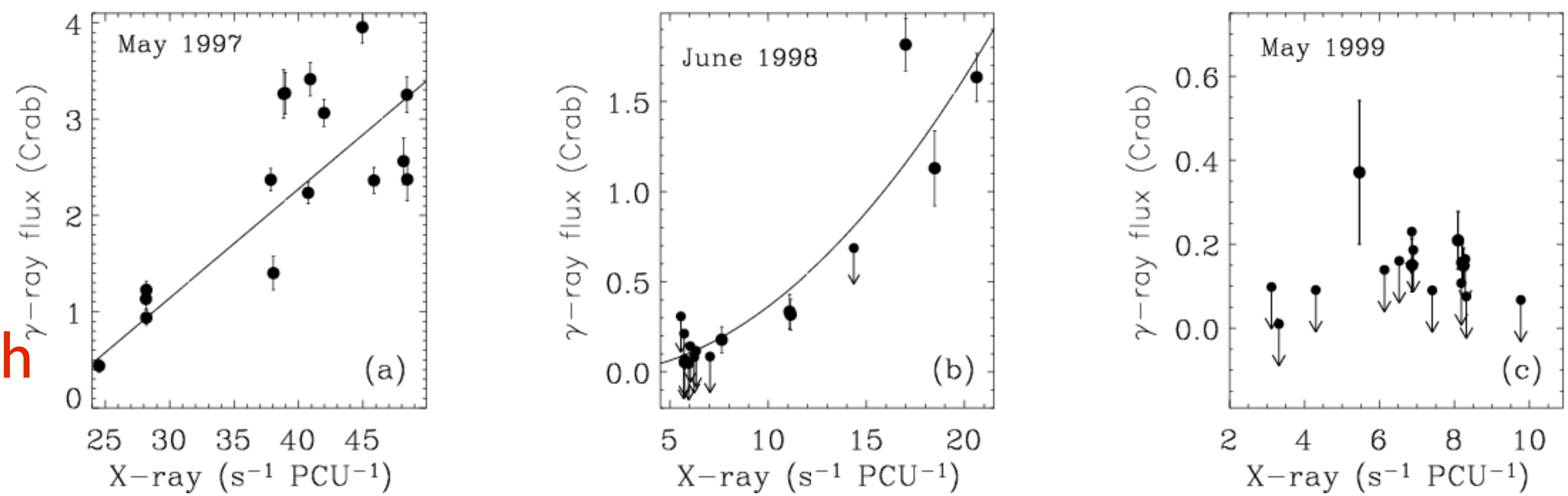


Pian et al 1998, Krawczynski et al 2002

However, during the two following years...



High

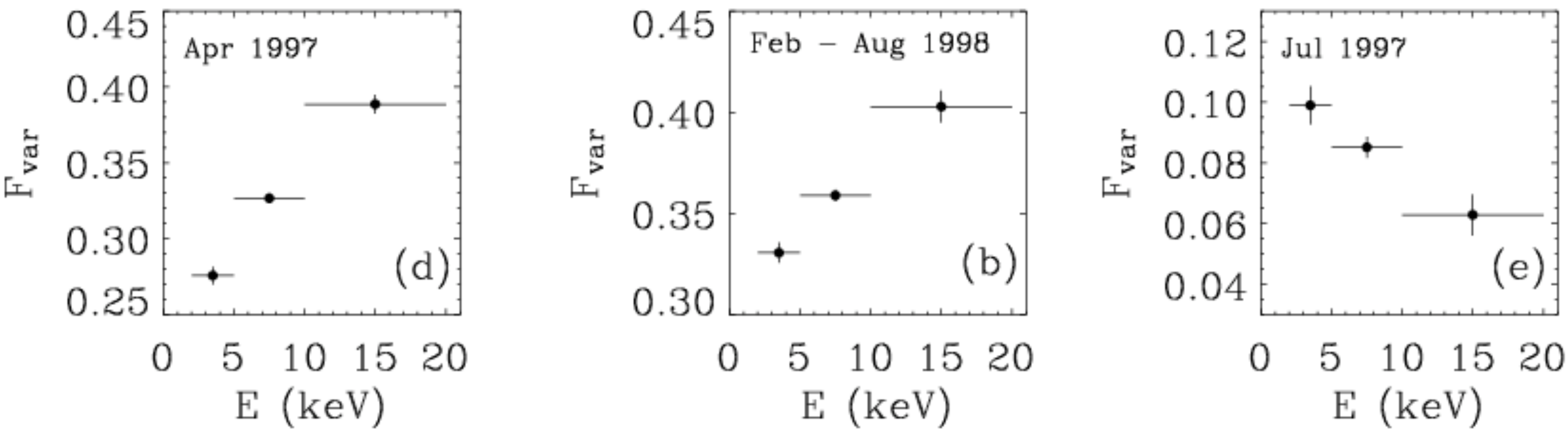


Low

Note the flux-scales on the axes !

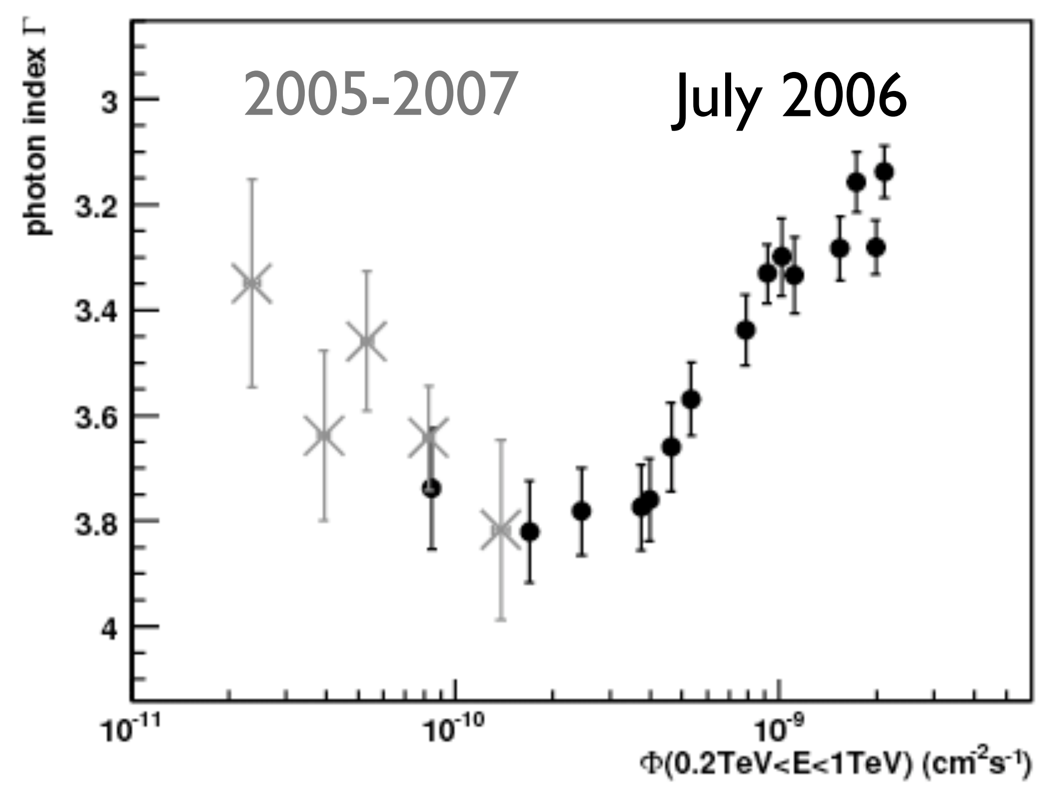
Gliozzi et al. 2006

Fractional variability in X-ray:



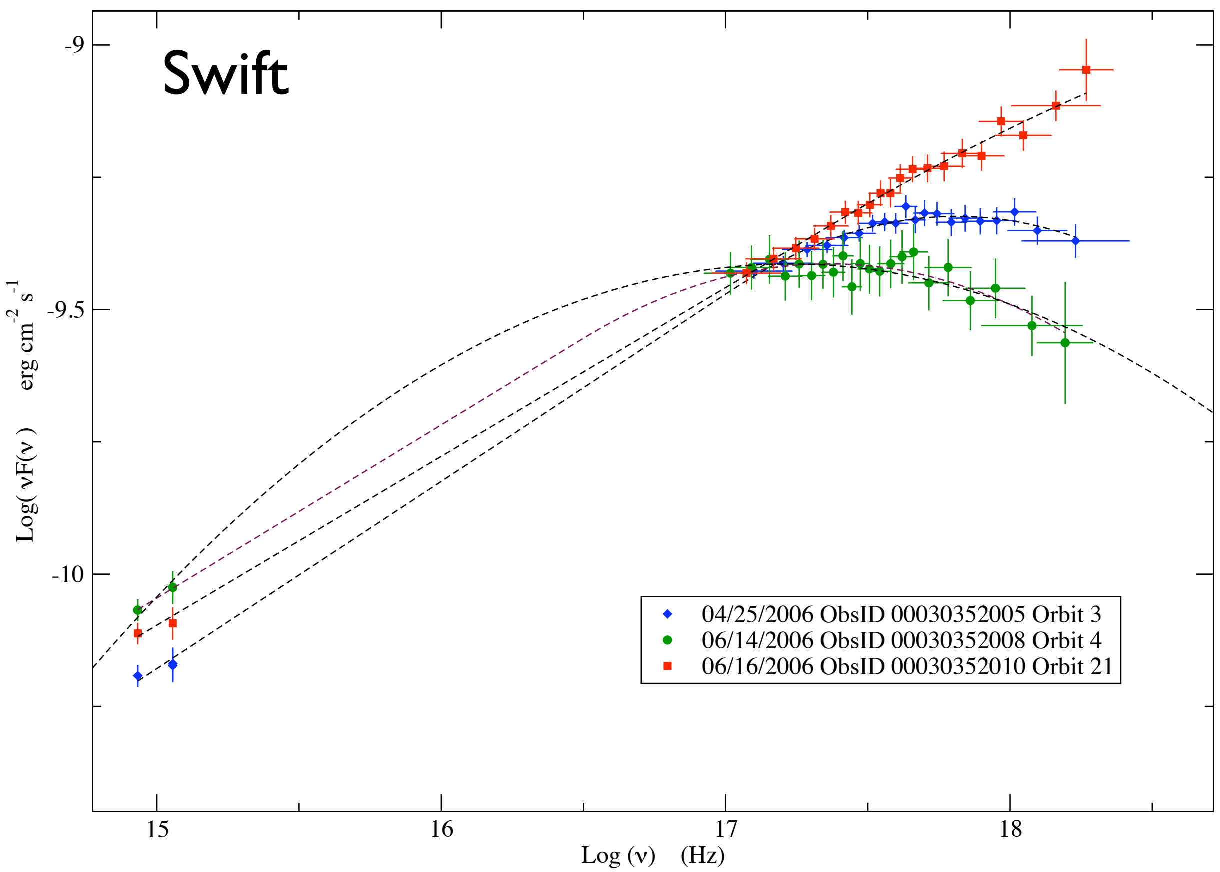
Also PKS 2155-304 at VHE shows different behaviors

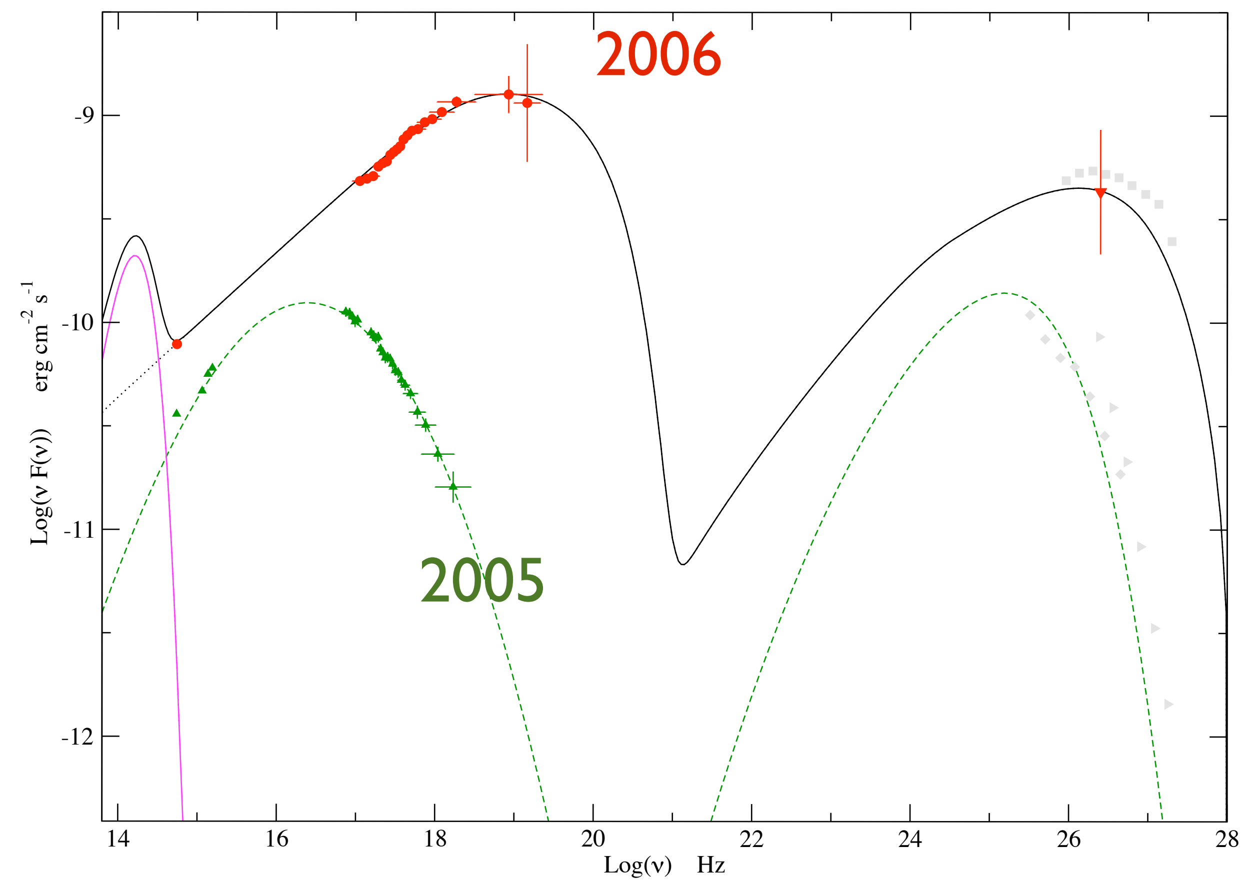
Aharonian et al. (HESS coll) 2010



Mkn 421 in 2006

Changes from log-parabola to pure power-law spectra
over 4 decades in energy

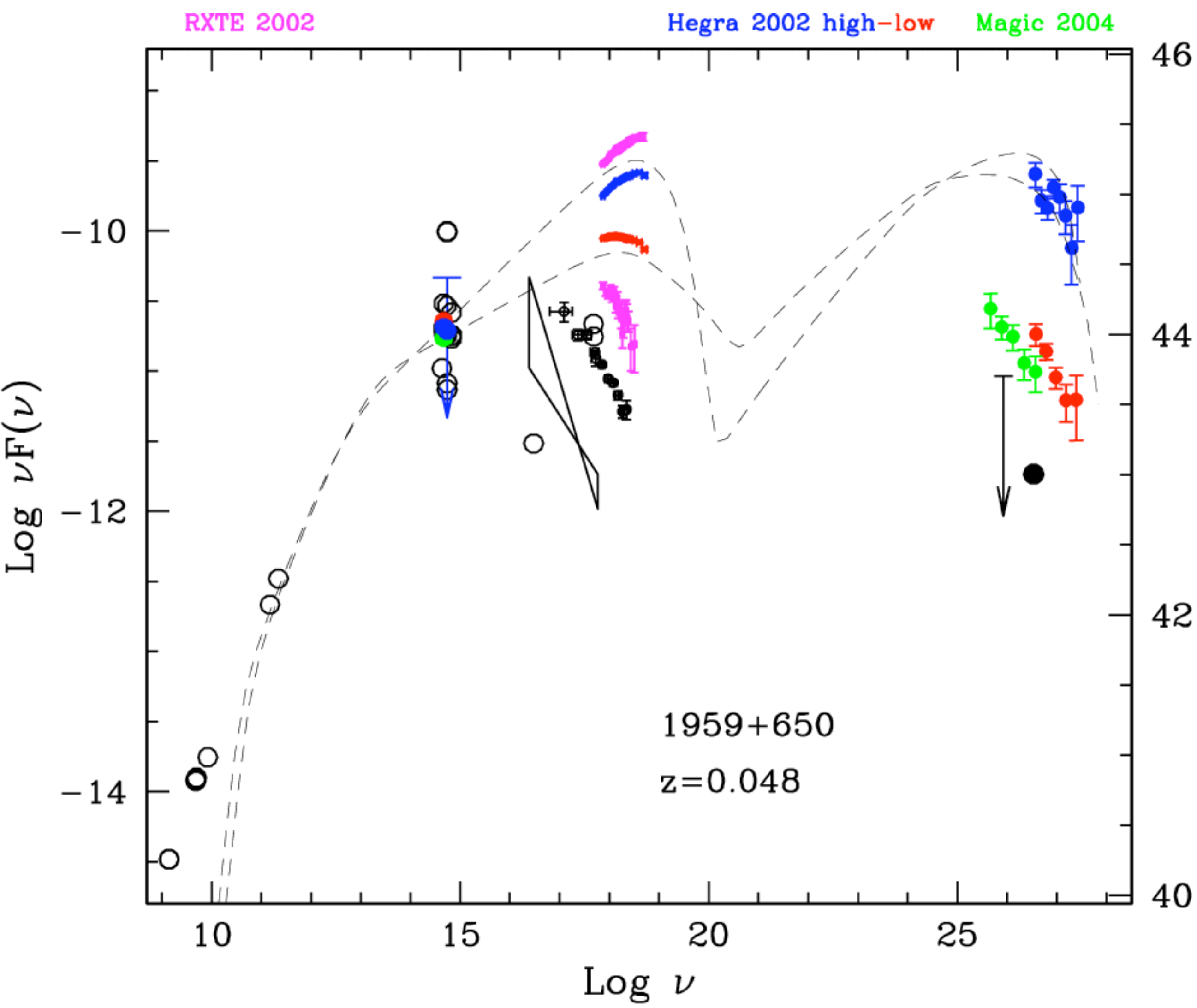


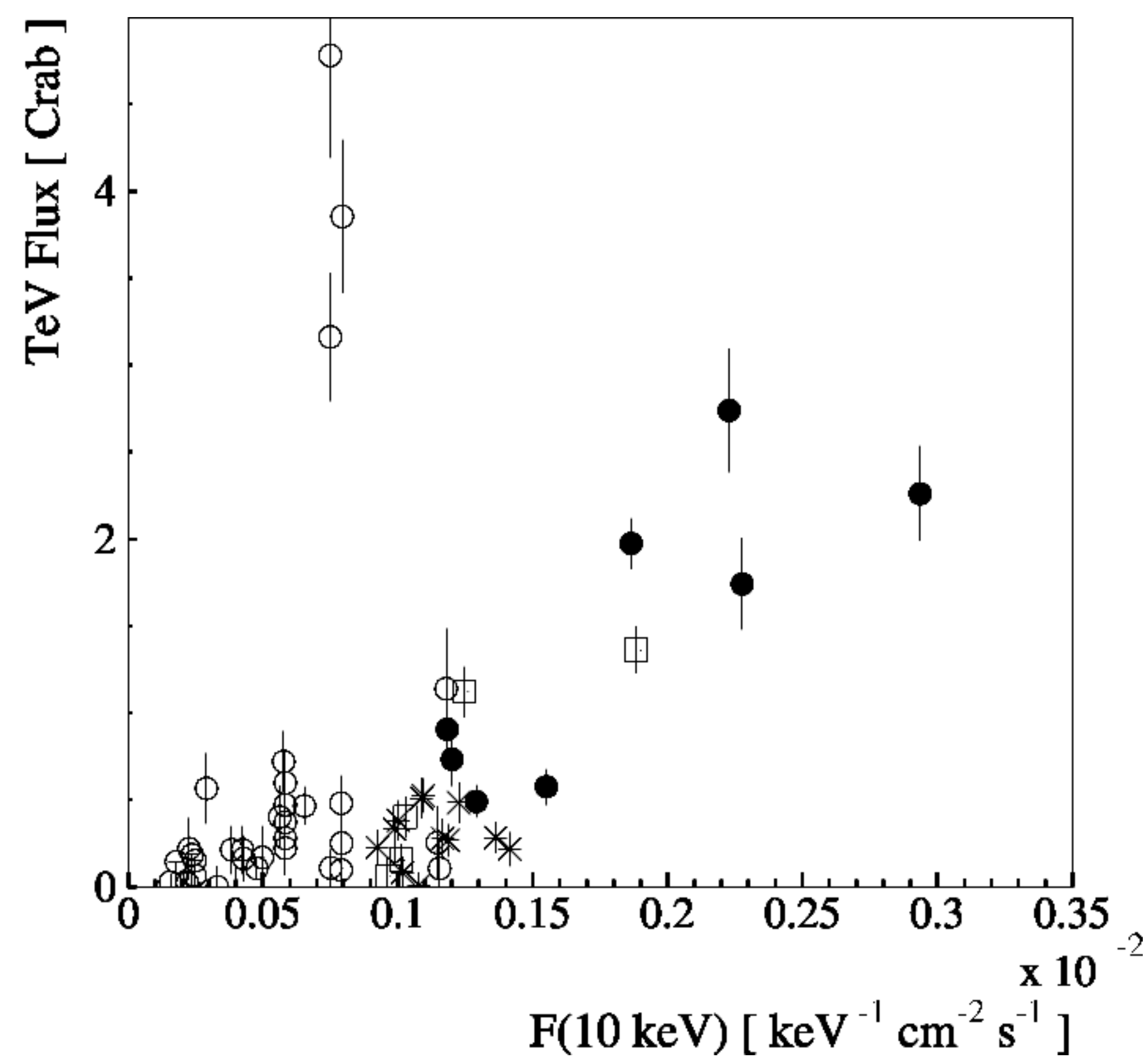


Tramacere et al. 2009

Hint of different acceleration processes at work, in low/high state

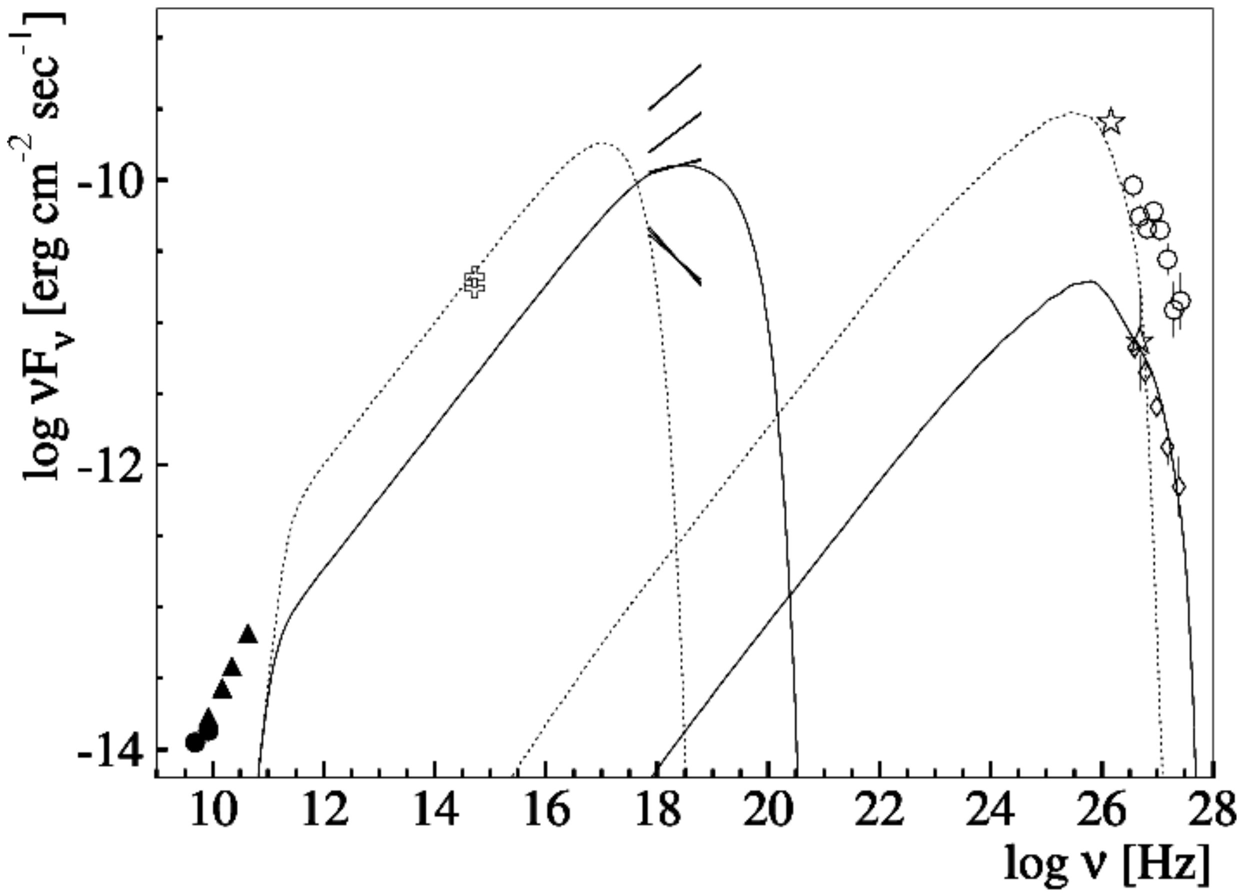
Other classic case: 1ES 1959+650 flaring in 2002

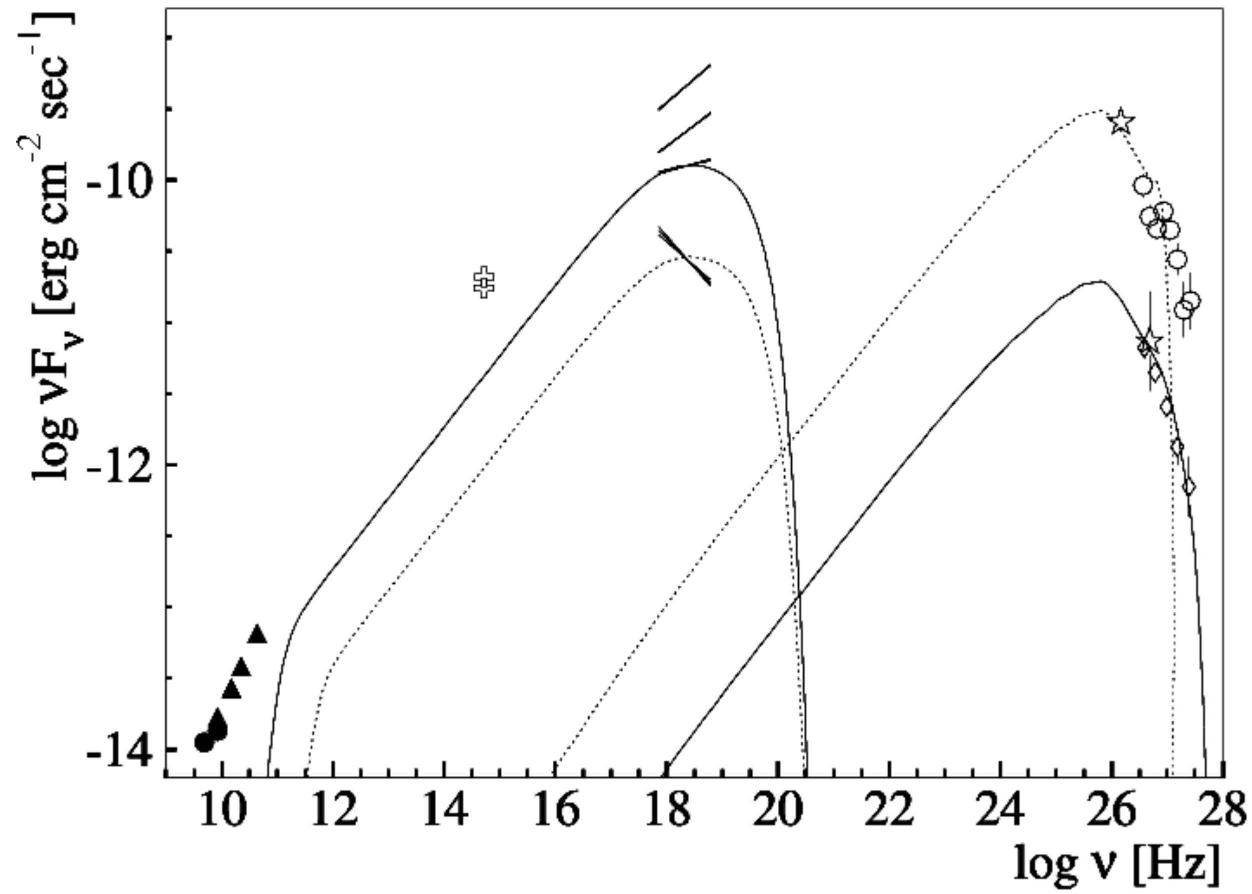




Krawczynski et al. 2004

Possible ways to obtain orphan flare:



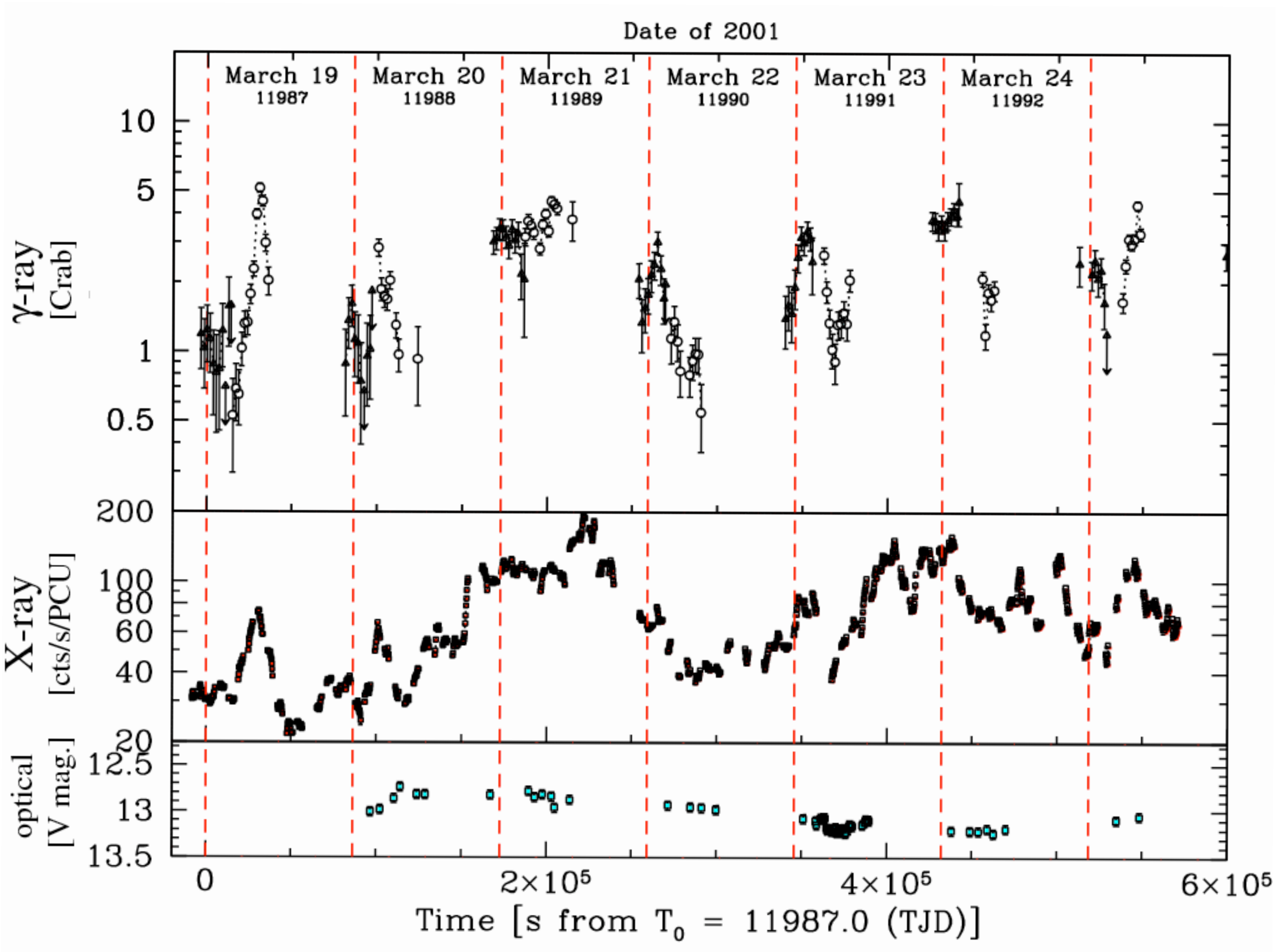


Krawczynski et al. 2004

Two most significant events/campaigns:

- Mkn 421 in March 2001 (Fossati et al 2008; past generation CT)
- PKS 2155-304 in July 2006 (Aharonian et al 2009, 2010)

Mkn 421 campaign in 2001

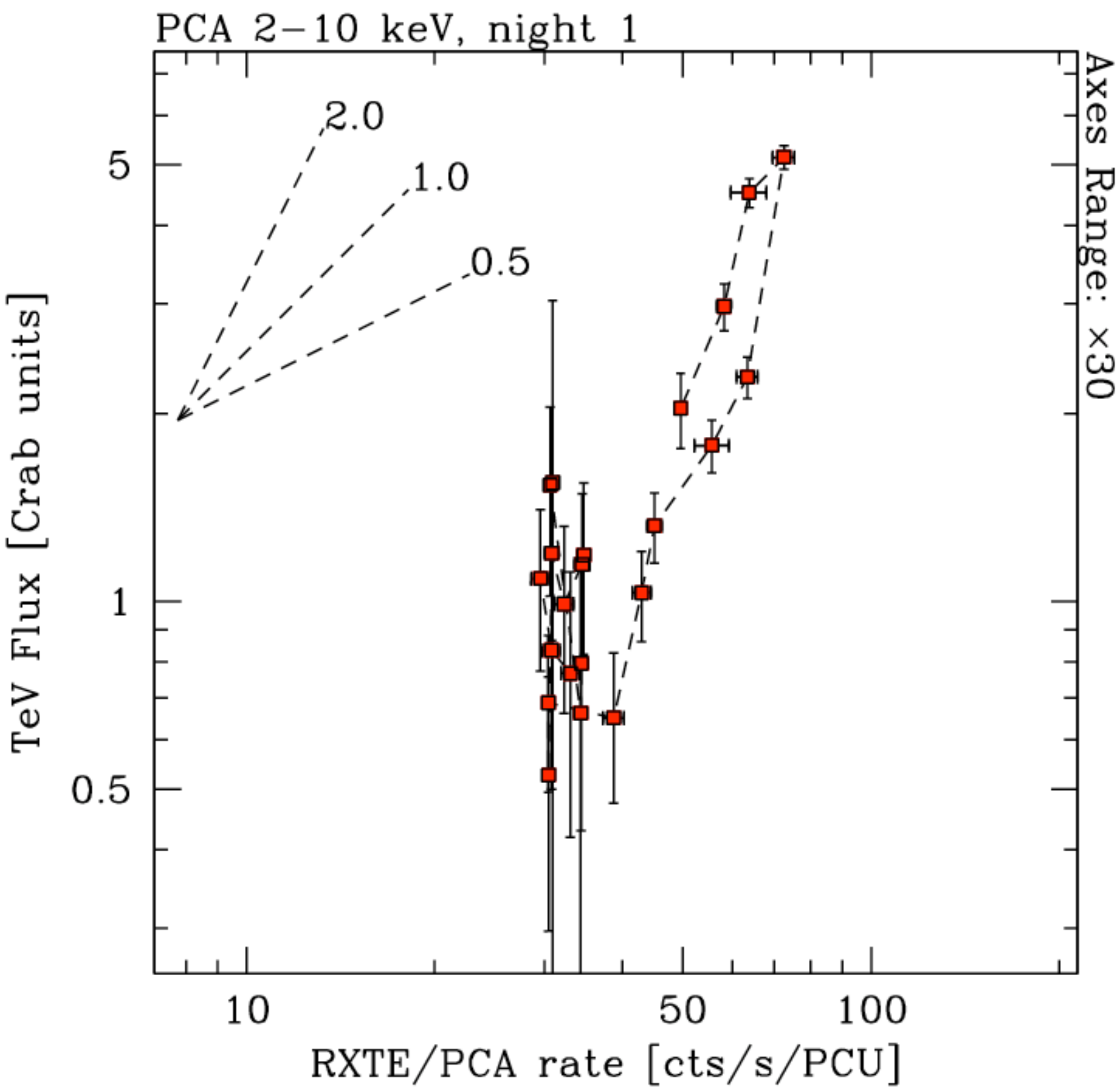


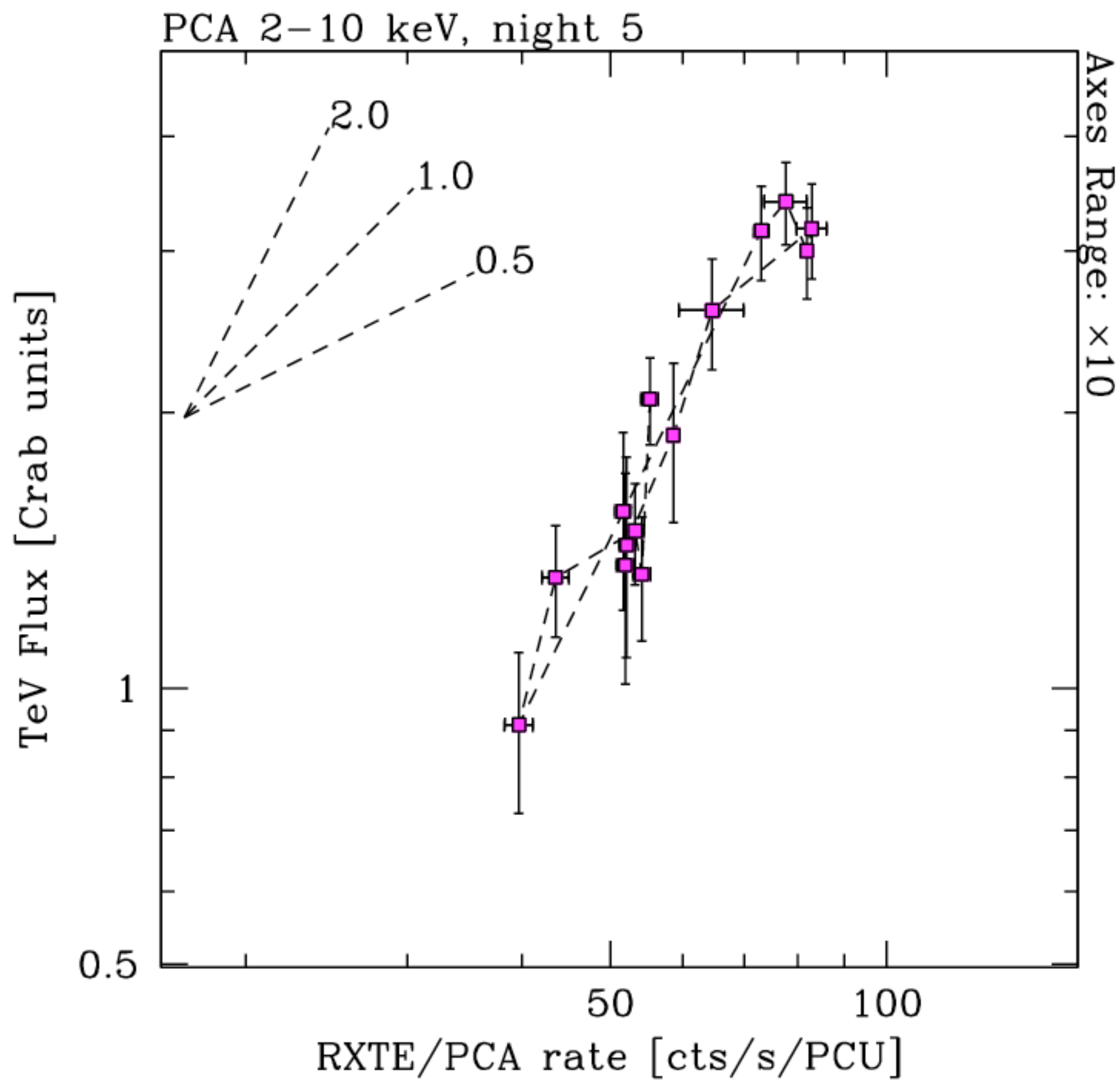
HEGRA
WHIPPLE

RXTE

Fossati et al 2008

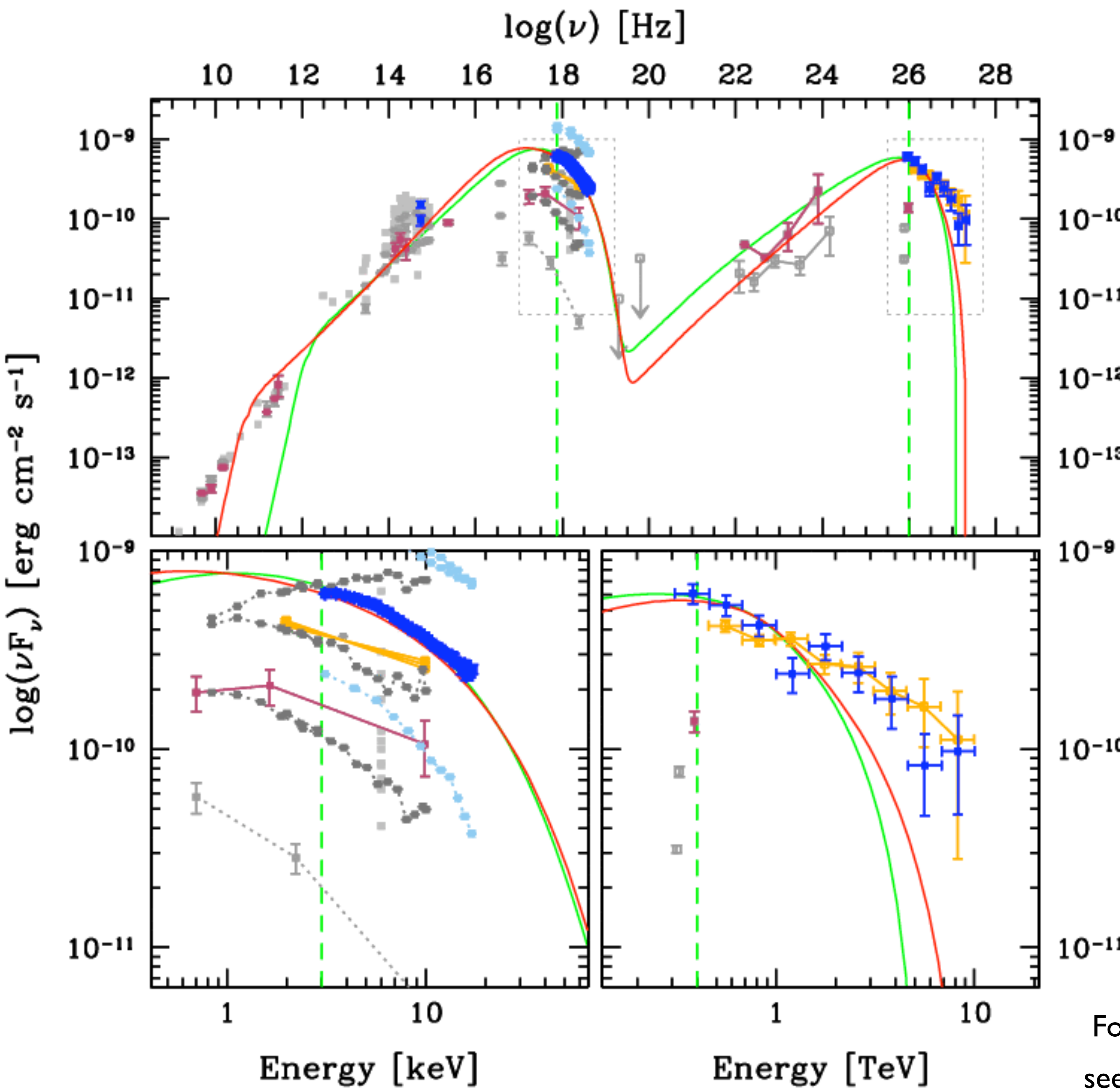
Quadratic relation also in decaying phase !





Fossati et al. 2008

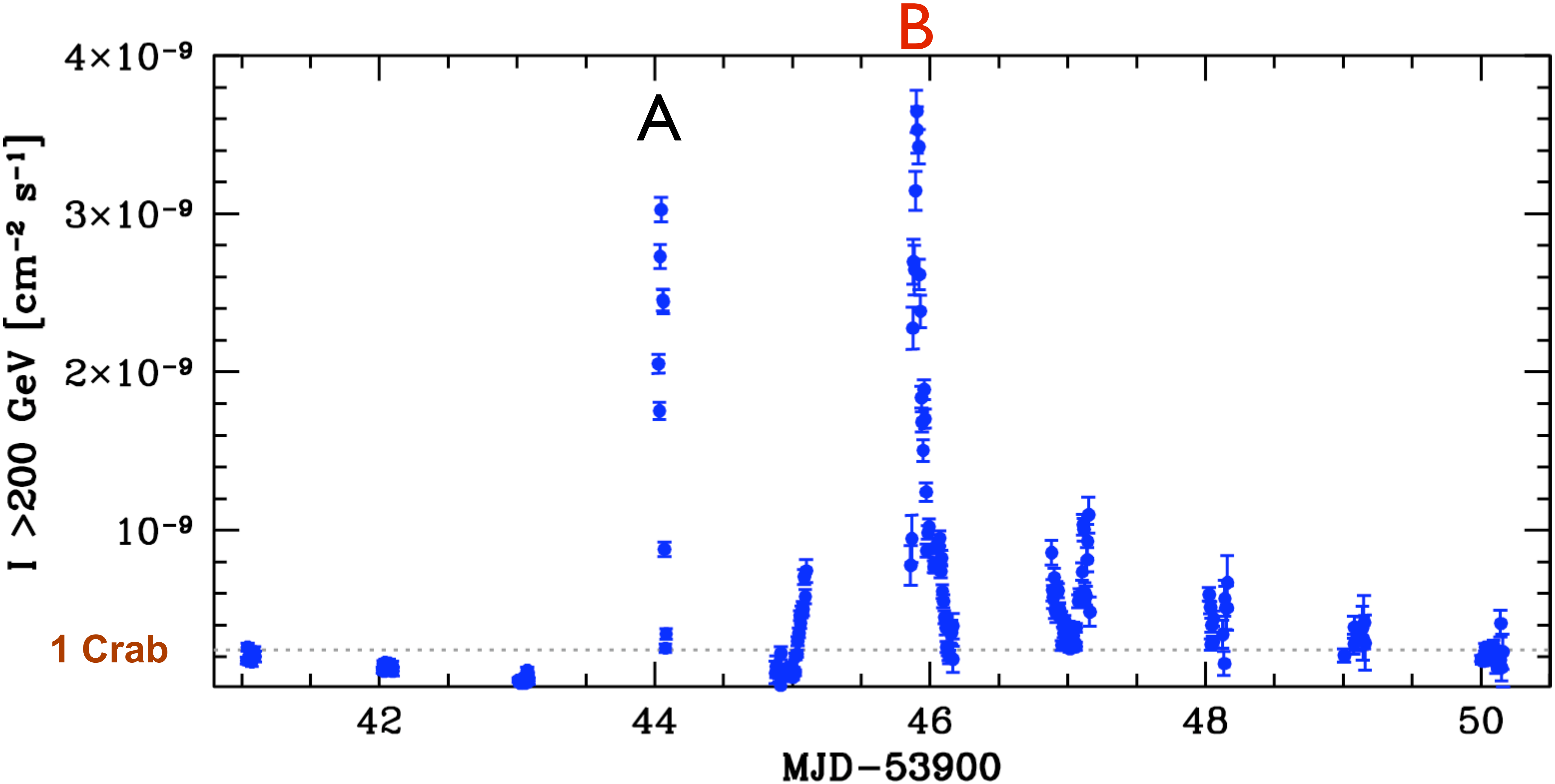
Difficult to obtain even in Thomson condition, because $d\gamma/dt \propto \gamma^2$



Fossati et al. 2008

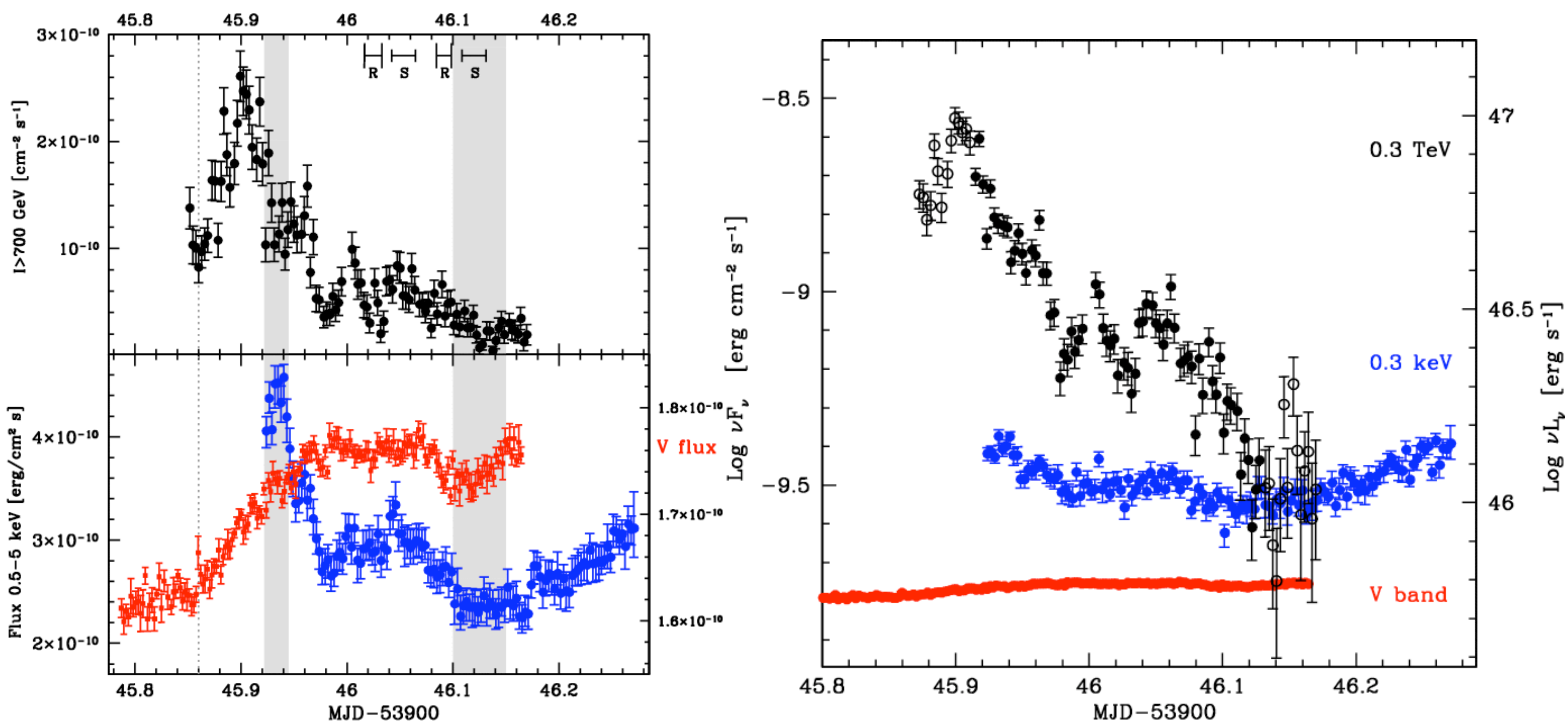
see also Katarzynski et al. 2008

Most surprising case:
PKS 2155-304 in summer 2006



MWL campaign unveiled 3 important properties :

1) First time in HBL: high Compton Dominance !

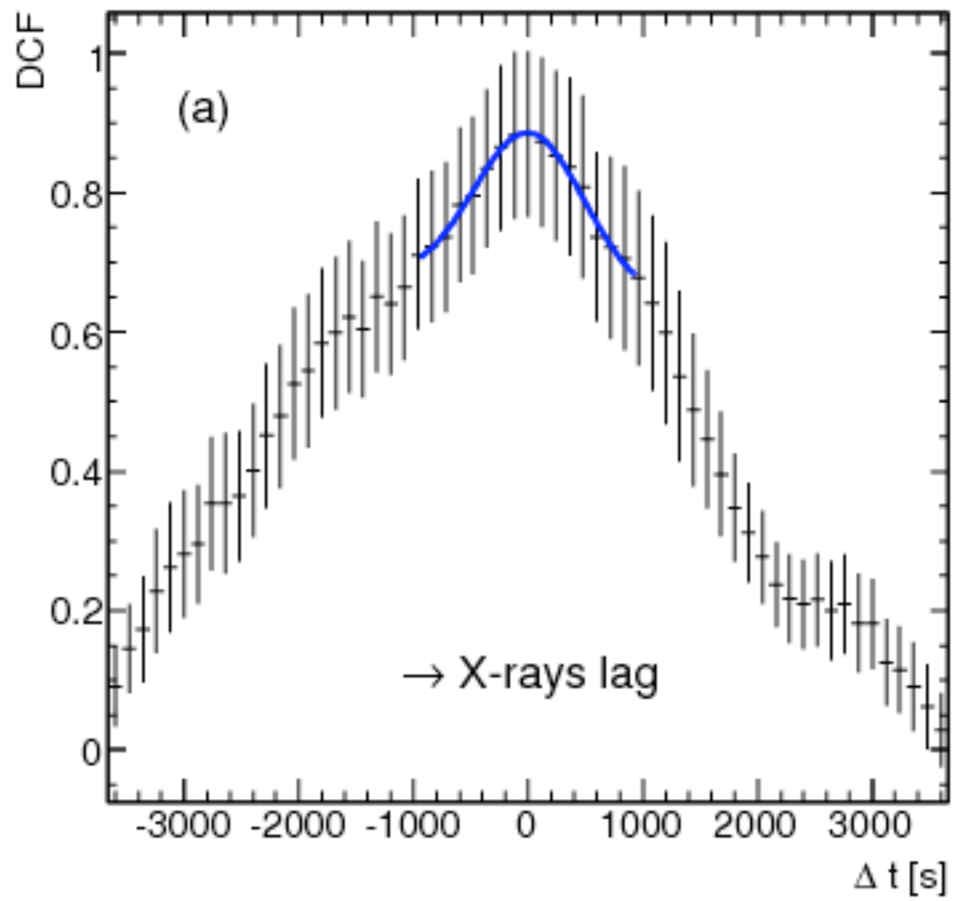


HESS-Chandra-Optical

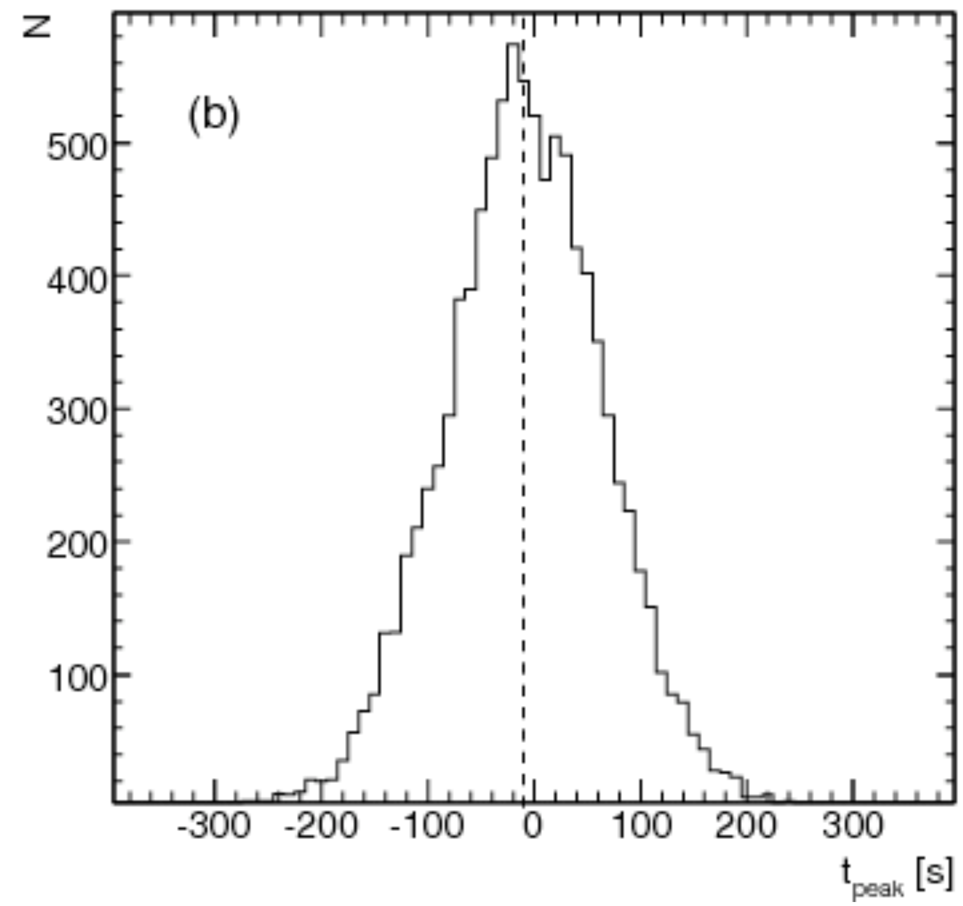
Costamante et al. 2007, 2008
Aharonian et al. (HESS coll.) 2009

2) Strong and strict correlation: X-ray and TeV emissions respond to the same flaring event

DCF X-TeV



Cross-correlation peak distribution of 10000 simulated lightcurves



95% upper limit on lags: ~ 200s

RMS = 76 s

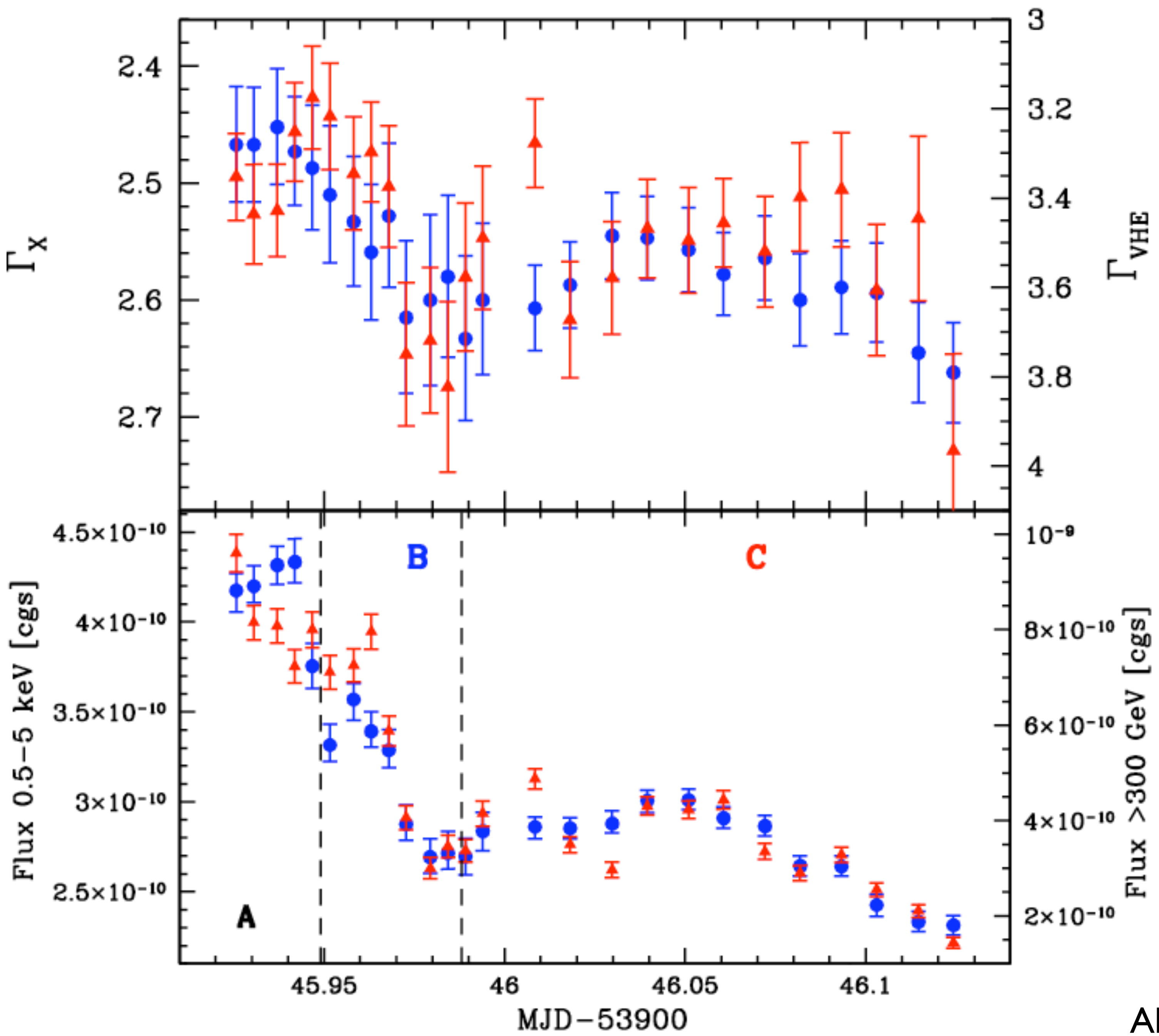
Buehler et al. 2007, 2008
Costamante et al. 2007,2008
Aharonian et al. (HESS coll.) 2009

2) Strict correlation also spectrally !

Time-resolved spectroscopy in both bands, 7-14 min bins

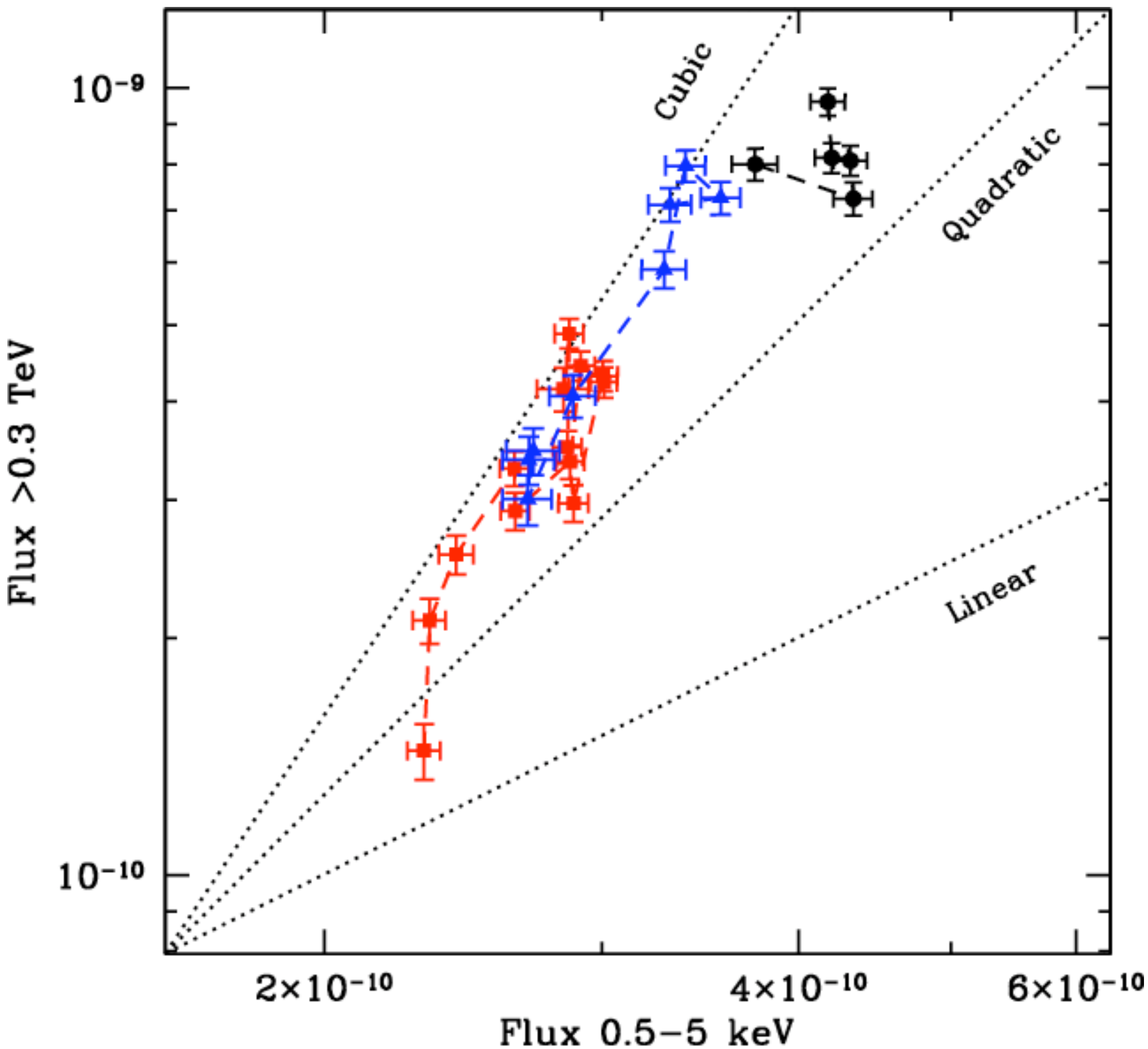
X-ray

VHE



Costamante et al. 2007,2008
Aharonian et al. (HESS coll.) 2009

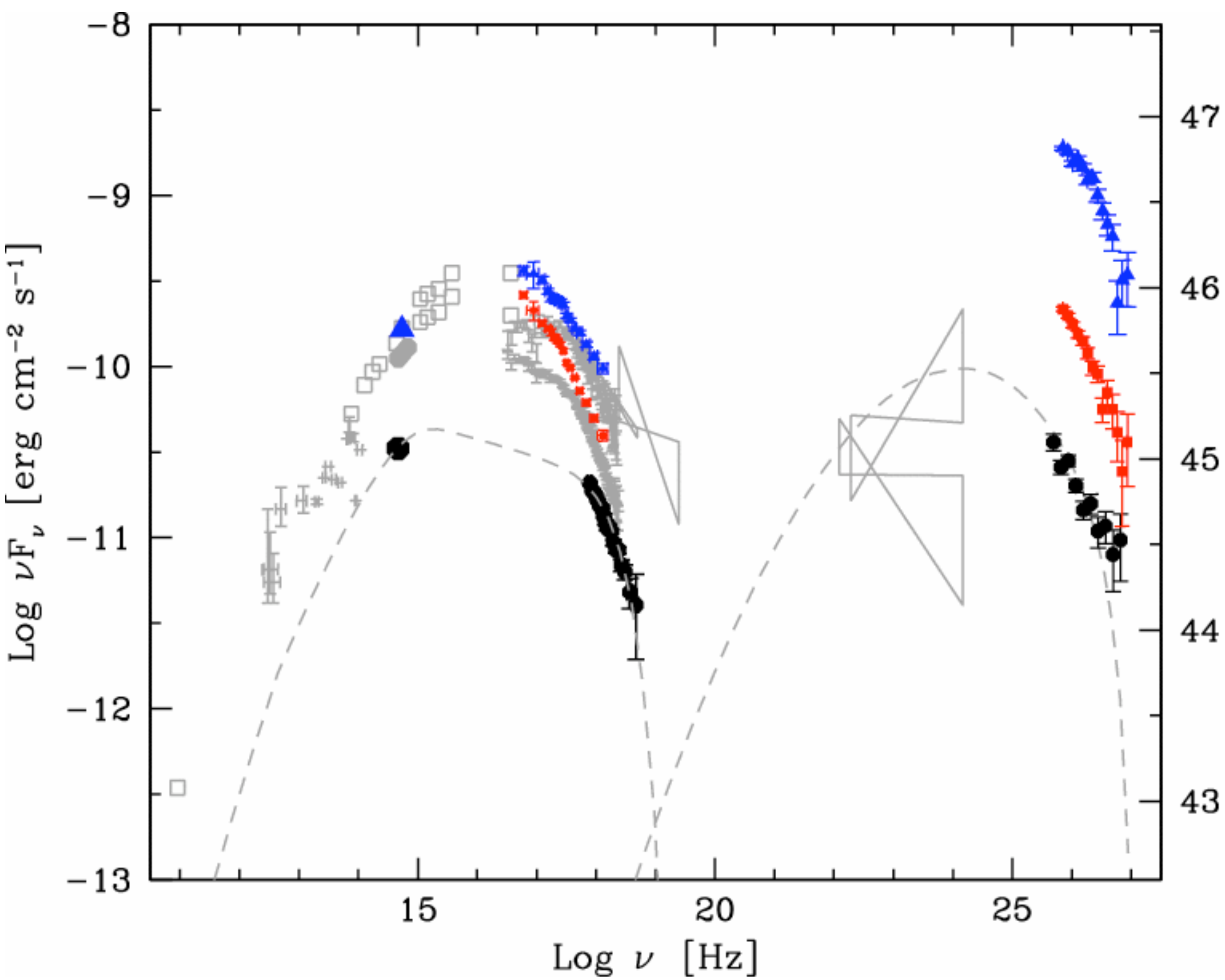
3) Cubic relation X-ray / TeV flux !



Costamante, Buehler et al. 2007, 2008
Aharonian et al. (HESS coll.) 2009

Difficult to explain with one-zone model.

Thomson alone is not enough to explain cubic decay



Aharonian et al. (HESS coll.) 2009

Thomson condition requires:

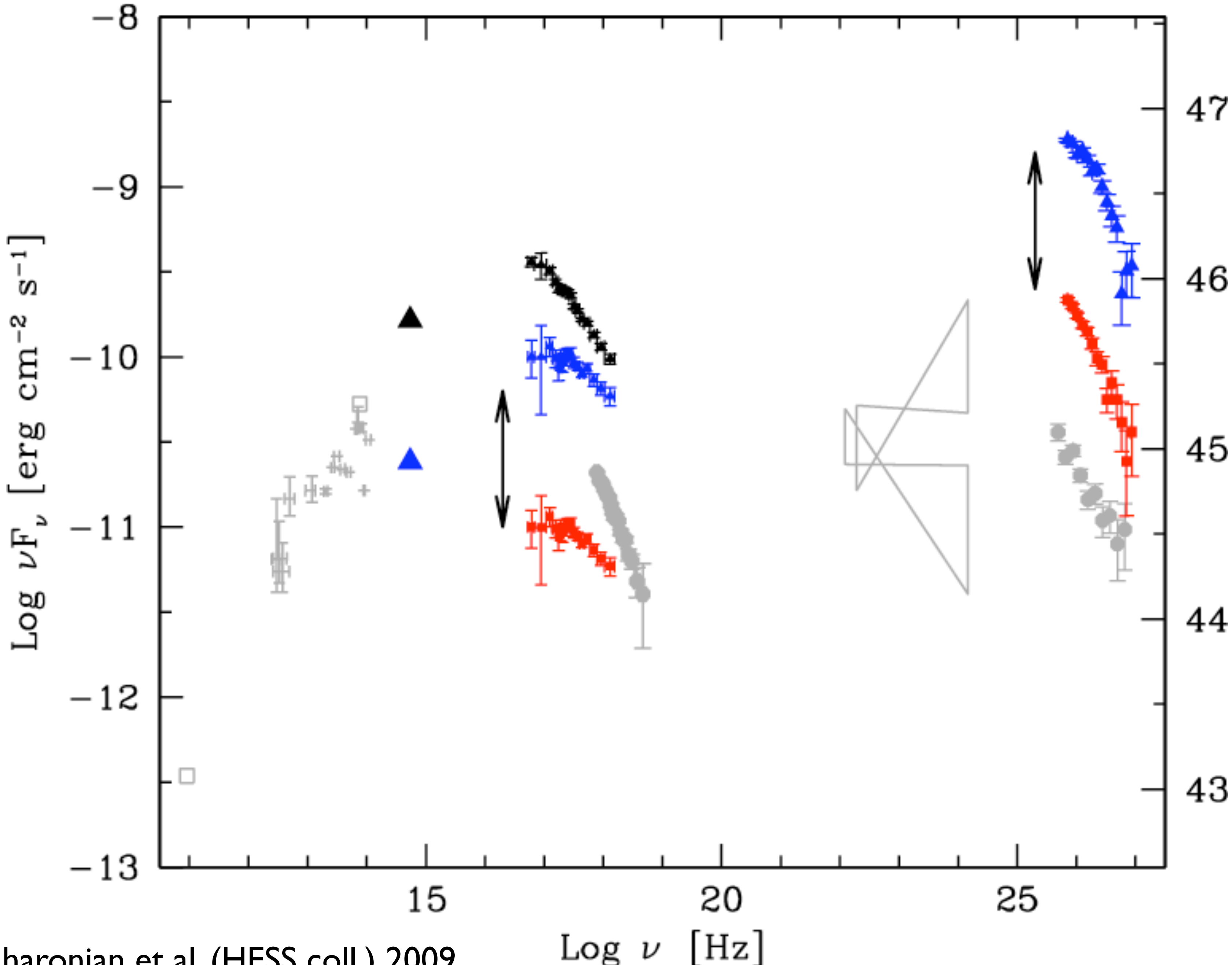
$\delta>100$ & B <5mG

⇒ high energy electrons have not cooled

Decay as adiabatic cooling ? could work, but cubic decay requires B to increase as $B \propto R^{+0.4}$ (i.e. energy density $W_B \sim R^{3.8}$): on same timescales of X-ray/TeV variations and causing as 15% decrease in optical synchrotron emission.

Not observed !

Superposition of 2 SEDs:
2 different components/zones, 1 persistent + 1 flaring



Aharonian et al. (HESS coll.) 2009

a) If $F_\gamma \propto F_x^2$

SSC ok with B ~1G

R ~3-5 x10^{14} cm

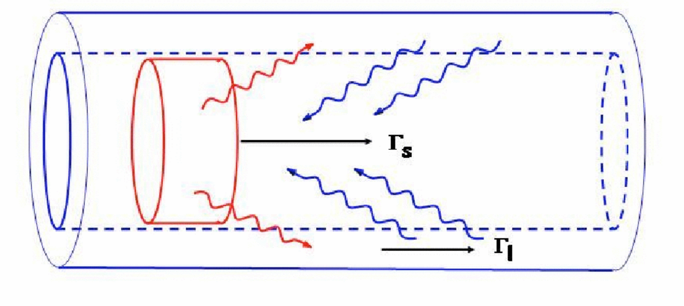
b) If $F_\gamma \propto F_x$

Constantly high

Compton Dominance !

External Compton

on structured jet ?

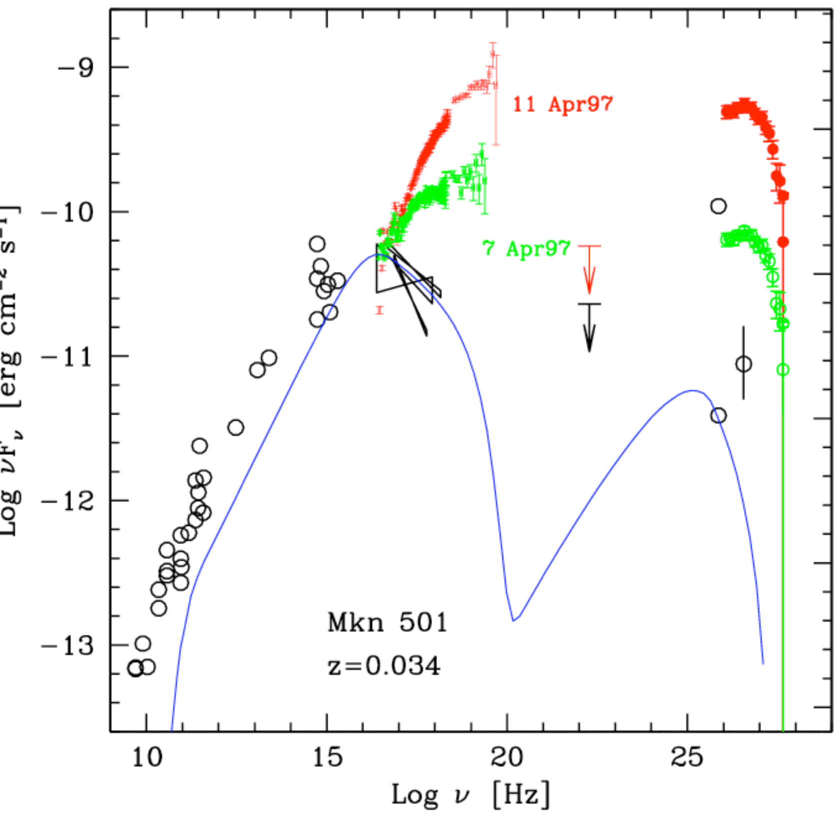


Ghisellini & Tavecchio 2008

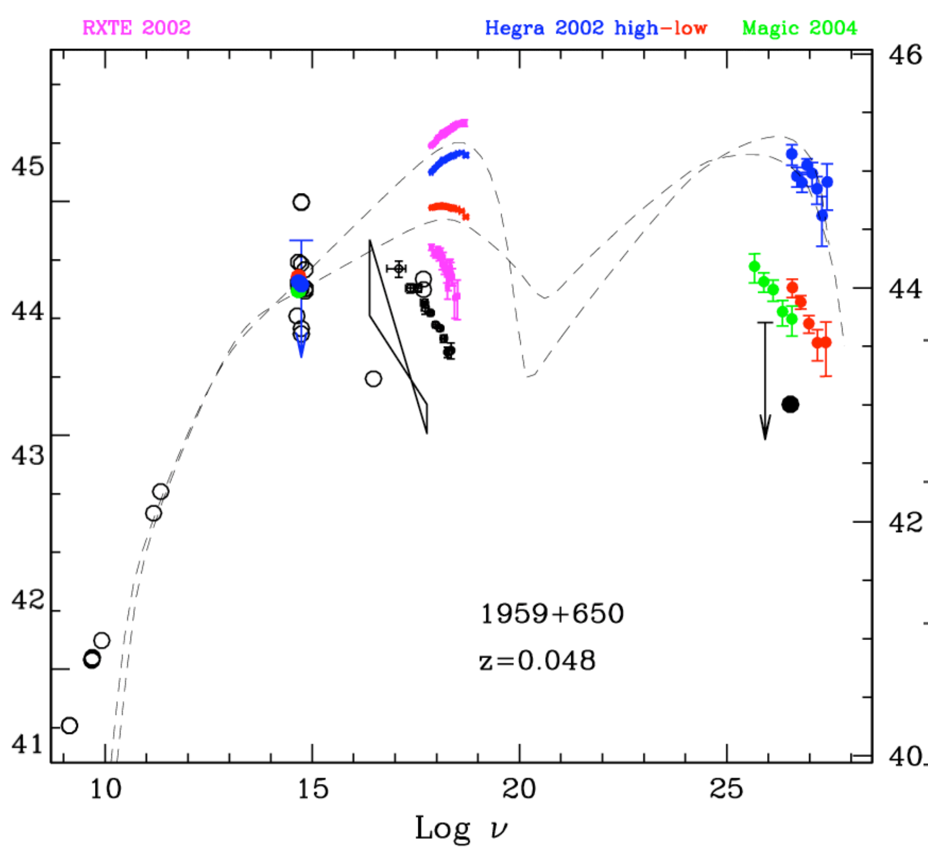
Georganopulous & Kazanas 2004

Unveiled a new mode of flaring in HBL:

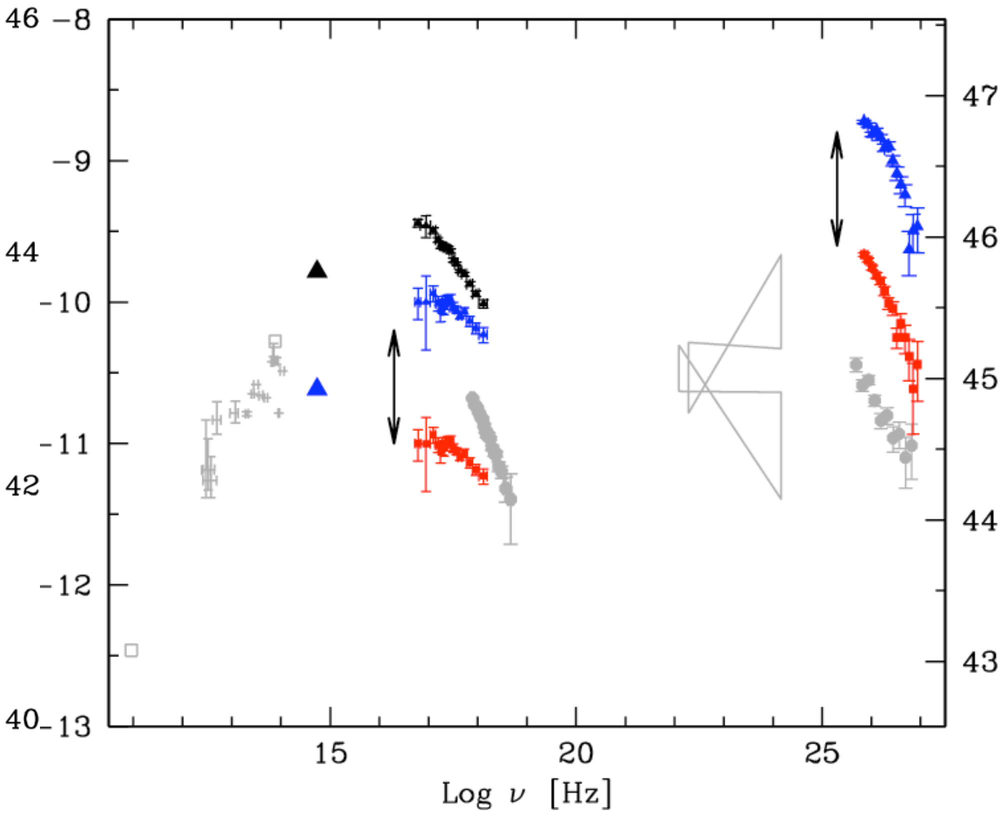
Mkn 501



1ES 1959+650



PKS 2155-304



Synchrotron-dominated flares

Compton-dominated

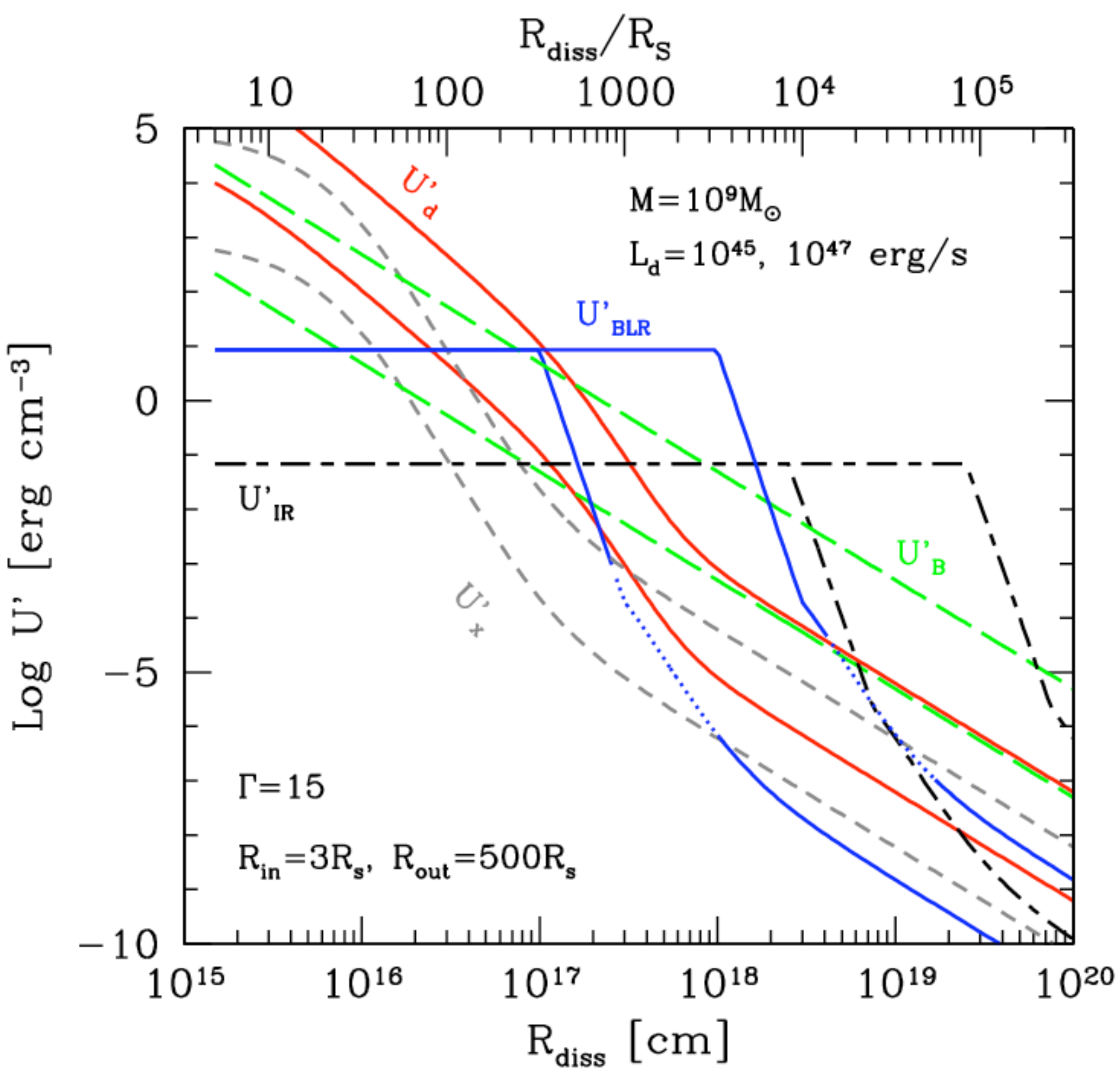
Location and size of the gamma-ray emitting region(s)

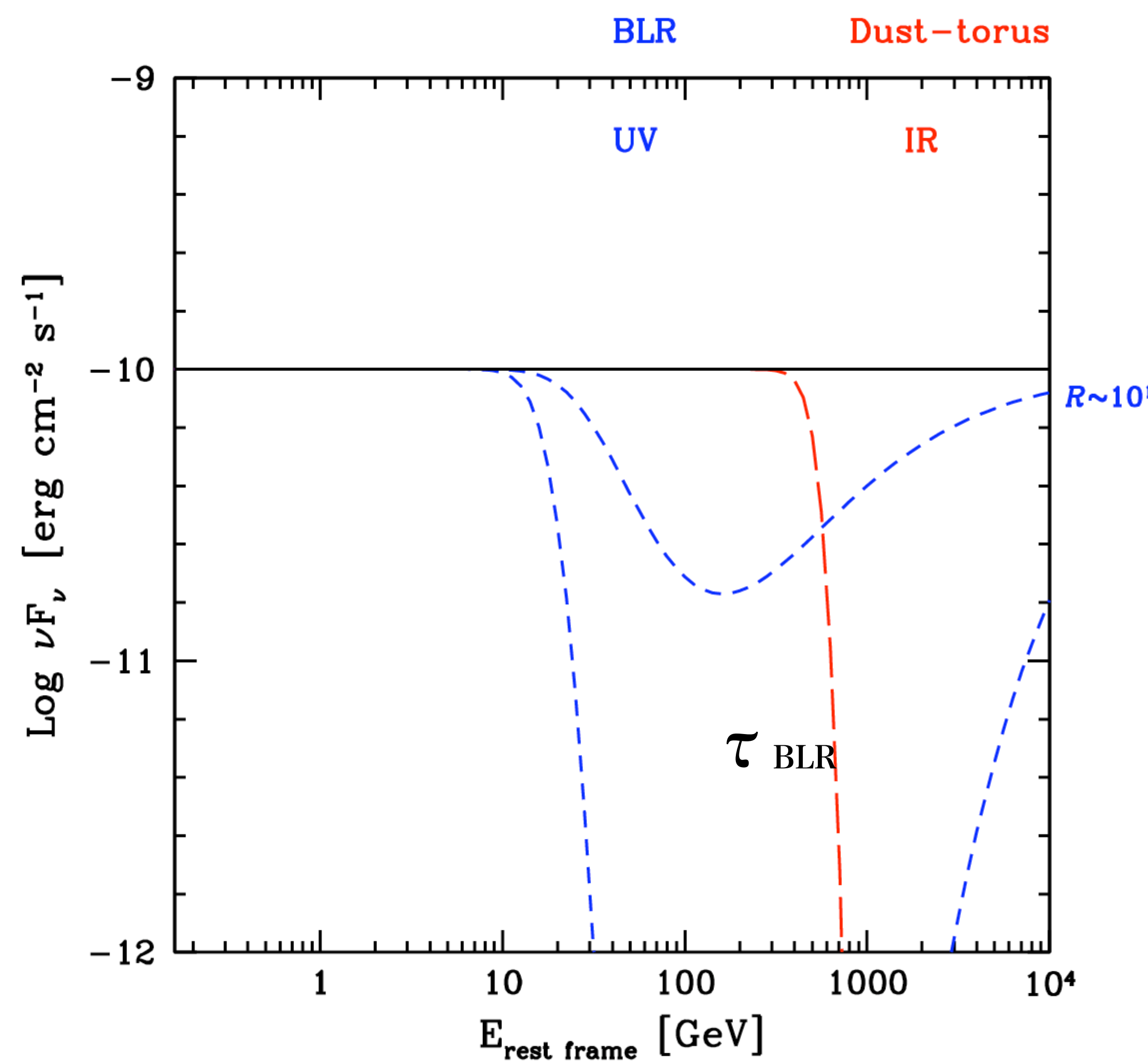
In HBL/FRI, data suggest location is very close to BH

Indication from the FSRQ data is OF OPPOSITE SIGN

In FSRQ, gamma-ray emission seem to come from *far away* from the Black Hole.

Flat Spectrum Radio Quasars are characterized by intense circumnuclear thermal fields, as reprocessing of the disk ionizing radiation: by the **Broad Line Region (UV**, Lyα, CIV, Mg II) or by **Hot Dust (IR)**. These target photons are used for External Compton emission mechanism. These same photons cause huge internal γ - γ absorption !





(Ghisellini et al 2009, Sikora et al 2009)

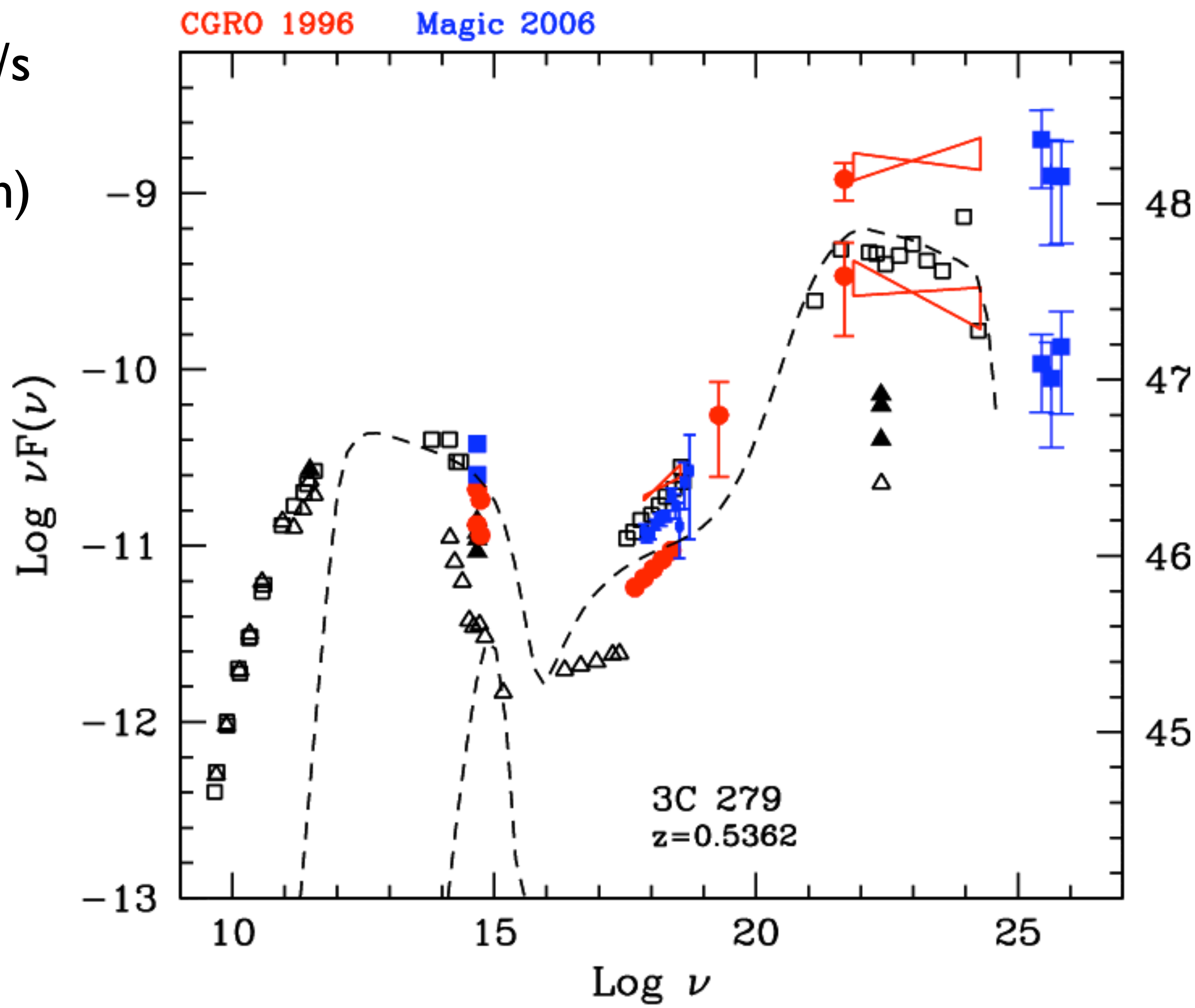
$$\mathbf{R \propto L_{disk}^{1/2}}$$

(Bentz et al. 2006 ; Kaspi et al. 2007)

$$\mathbf{U_{rad} \propto L/R^2 \sim const. \sim 10^{-2} erg/cm^3}$$

First indication of gamma-ray emission likely *beyond* the BLR: 3C 279 detection at VHE

L_{BLR} ~2-3 x10^{44} erg/s
R_{BLR} ~0.1 pc
τ ~9 (path/10^{17} cm)



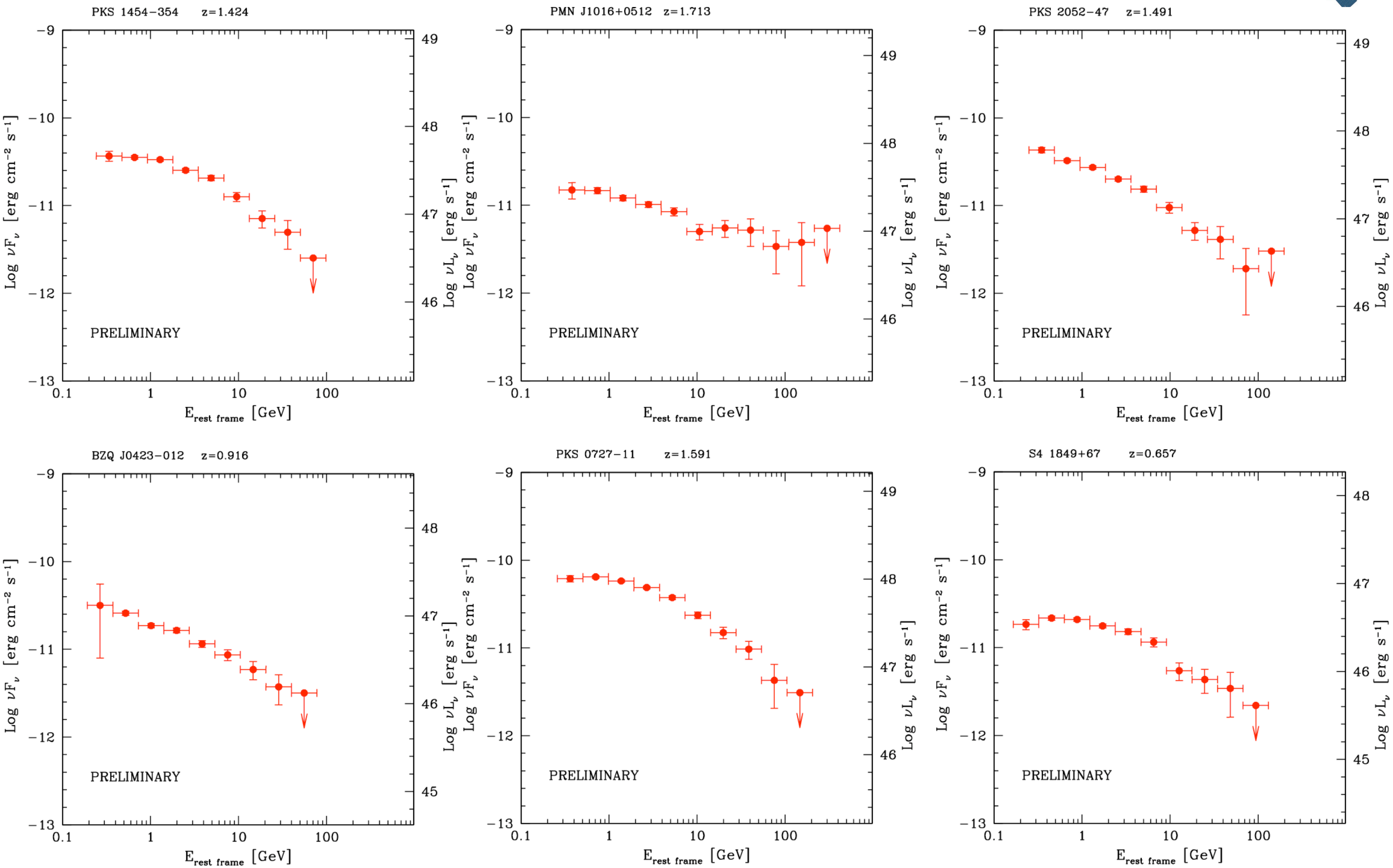
Inside/at BLR: assumed τ =3

Outside BLR

Albert et al. (MAGIC coll) 2008
Costamante et al. 2008

MAGIC detection implies huge fluxes if gamma-ray zone is deep inside the BLR, barely acceptable if close to BLR size (~0.1 pc)

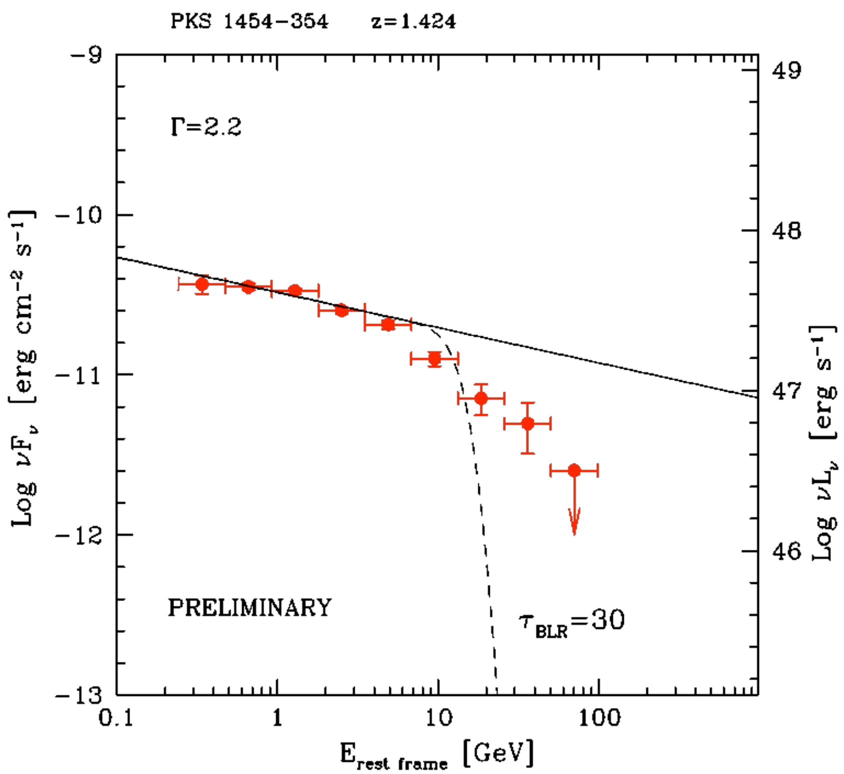
Fermi-LAT results on several FSRQ: NO evidence of strong BLR cut-offs !

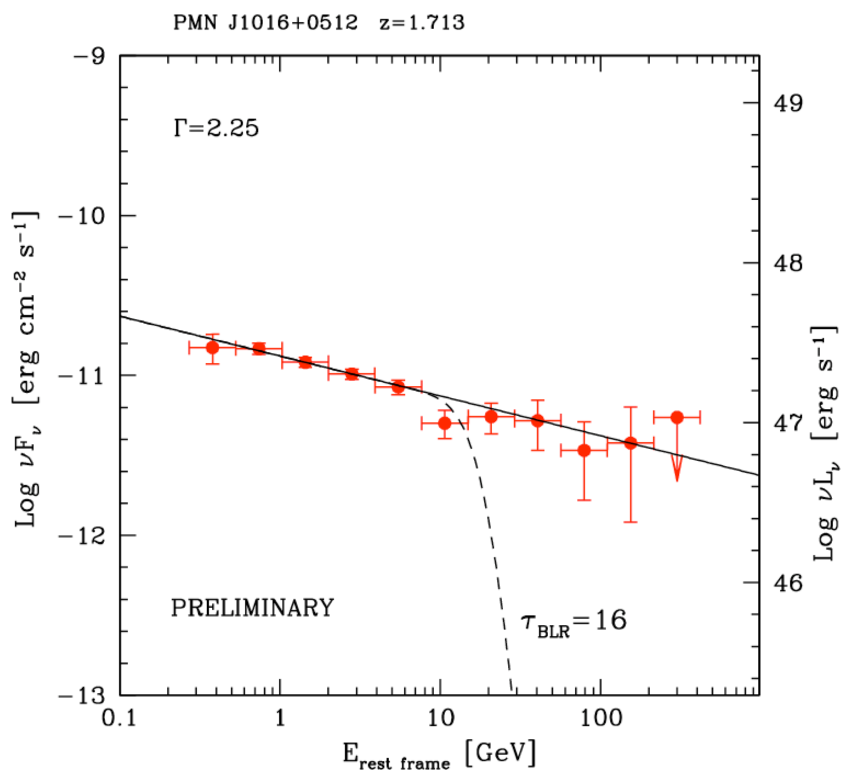


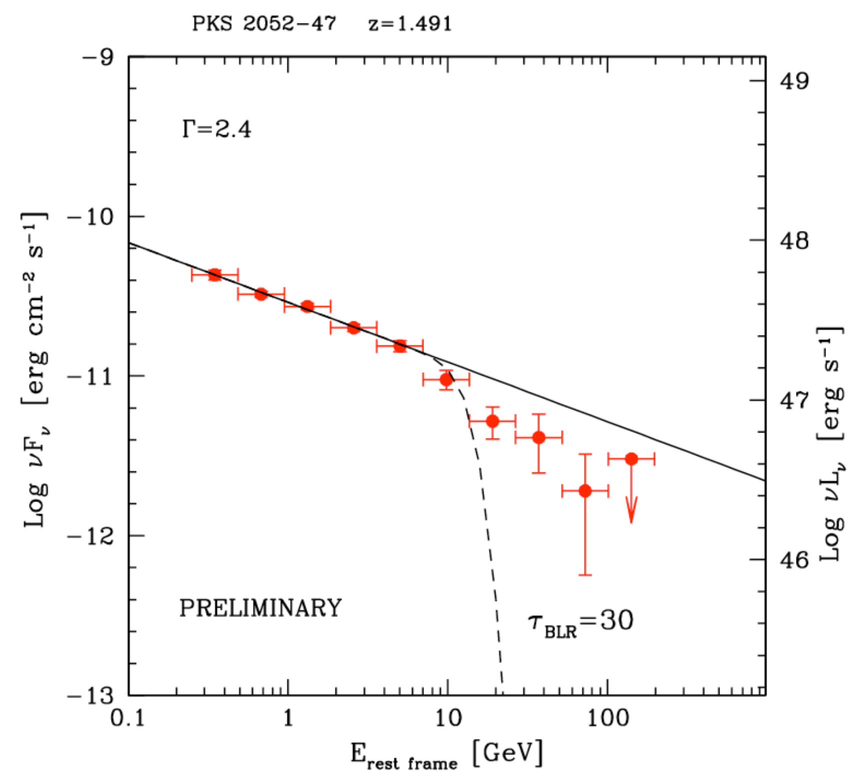
Even among the most powerful objects !

Characterized by strong Disk emission and large BLRs

Examples assuming no intrinsic steepening (case most favorable to absorption):
power-law fits up to ~4 GeV extrapolated at higher energies, with (dashed lines) or without BLR absorption.







PKS 1454-354:

L_{disk} ~ 5×10^{46} erg/s , R_{blr} ~7×10^{17} cm

if R_{diss} ~2×10^{17} ⇒ **τ_{BLR} > 30 !**

PMN J1016+0512:

L_{disk} ~ 9×10^{45} erg/s , R_{blr} ~3×10^{17} cm

if R_{diss} ~2.5×10^{17} ⇒ **τ_{BLR} > 16 !**

BZQ J2056-471:

L_{disk} ~ 4×10^{46} erg/s , R_{blr} ~6×10^{17} cm

if R_{diss} ~2×10^{17} ⇒ **τ_{BLR} > 30 !**

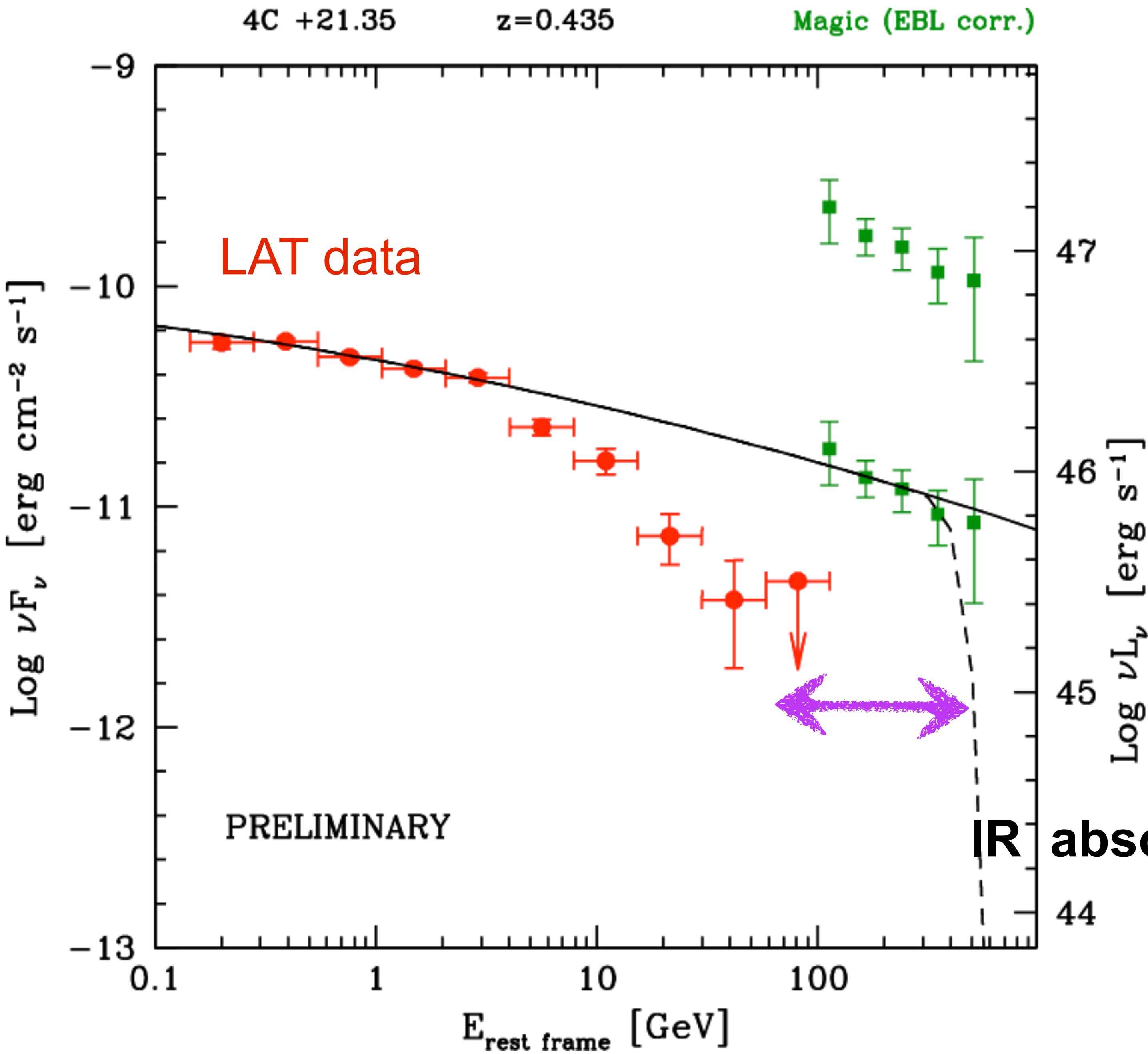
Values of R_{diss} L_{disk} R_{blr} used in Ghisellini et al 2009

$R_{diss} \geq R_{BLR}$

Costamante et al. 2009, 2010,
Abdo et al. 2011 (in prep.)

Further evidence:
VHE detections of 4C 21.35 and PKS 1510-08

If $R_{diss} > R_{BLR}$, does External Compton on IR work ?



Aleksic et al. 2011 (MAGIC coll)

Problem: again IR photons absorb VHE gamma-rays !

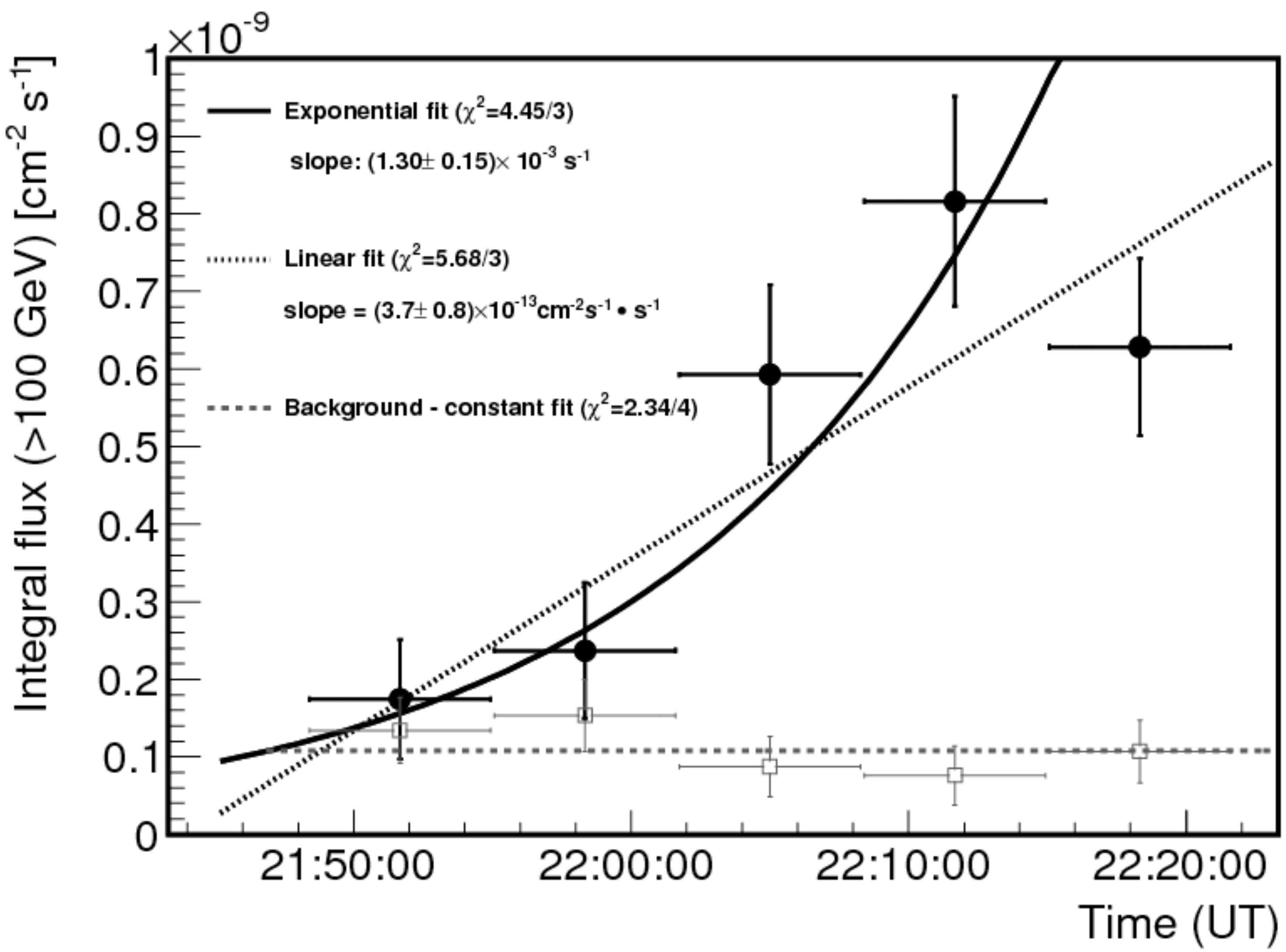
Survival zone for VHE photons is narrow !

4C 21.35 has strong IR emission from Hot Dust, T~1200K:
$L_{IR} \sim 8 \times 10^{45}$ erg/s , R ~2-4 pc (Malmrose et al. 2011)

MAGIC fundamental discovery on 4C 21.35: fast variability !

2) If EC (IR) ok, R_{diss} > 1-10 pc ⇒ a) larger region, mm-transparent

b) variability ~days-week



Aleksic et al. 2011 (MAGIC coll)

Instead, 10-min variability !

$$R \sim 2.5 \times 10^{14}\ \delta_{10}\ t_{\rm var,10min}\ {\rm cm}$$

at several pc from Black Hole

Conclusions

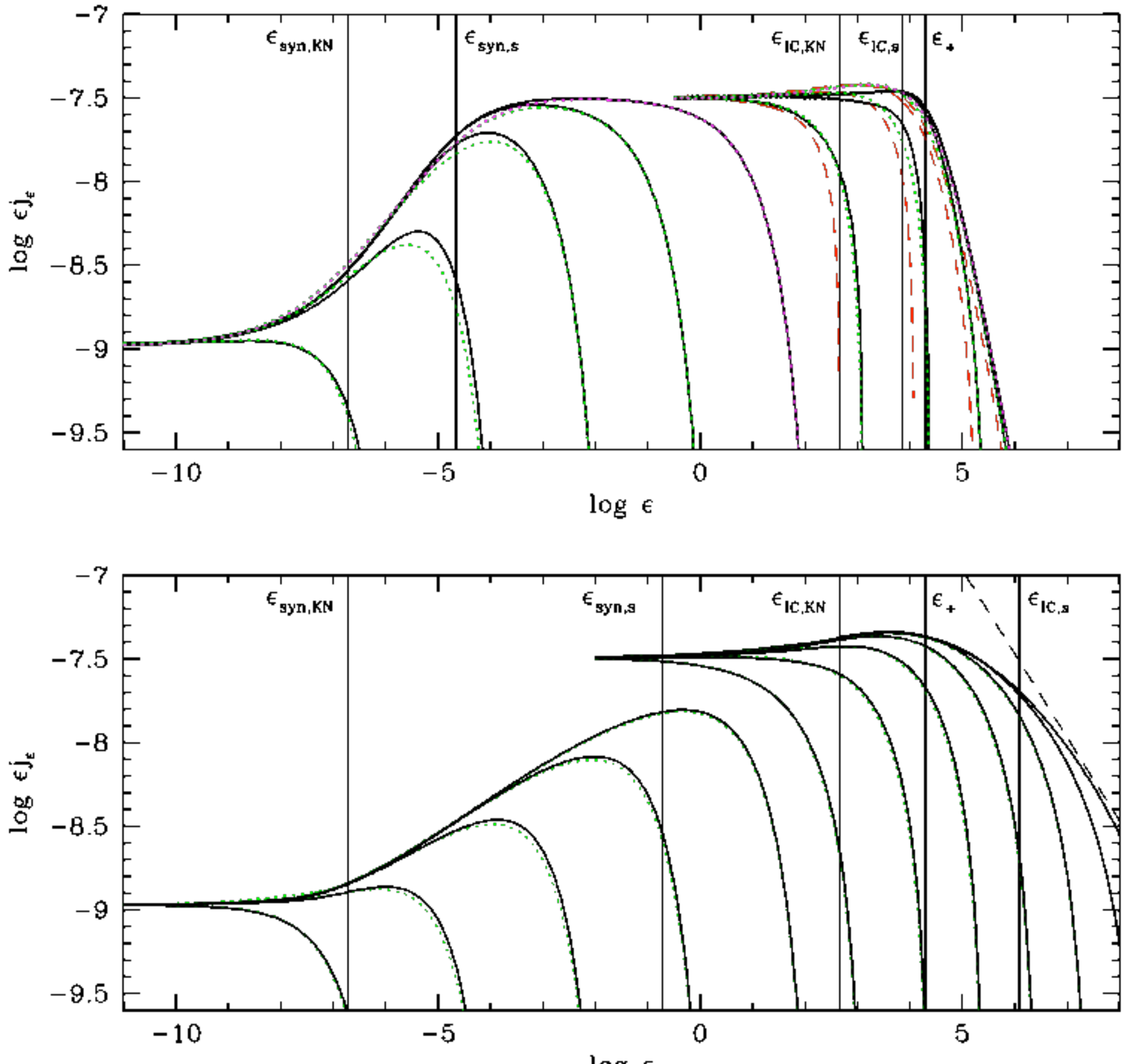
- Last decade we learned a lot, especially at VHE/HE.
- Pinning down the EBL has finally allowed the study and understanding of the real Blazar properties at VHE.
- We start to understand better connection between accretion, jet power and SED properties.
- MWL is providing diagnostic of jet structure & particle evolution

We still don't understand basic aspects !

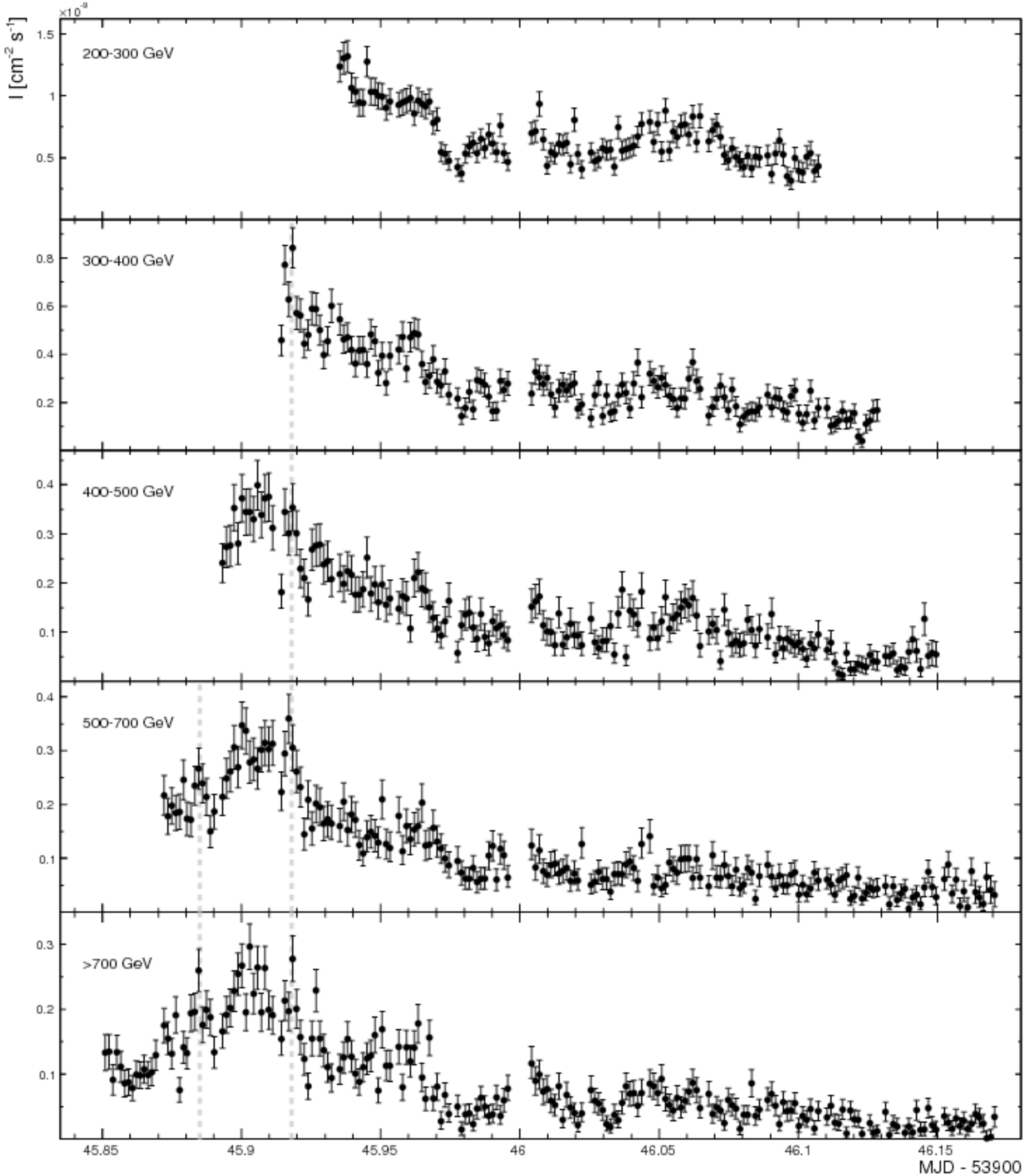
- particle acceleration / emission mechanisms
- location and size of "gamma-ray zone"

Bring fresh air and intellectual power !

back up slides



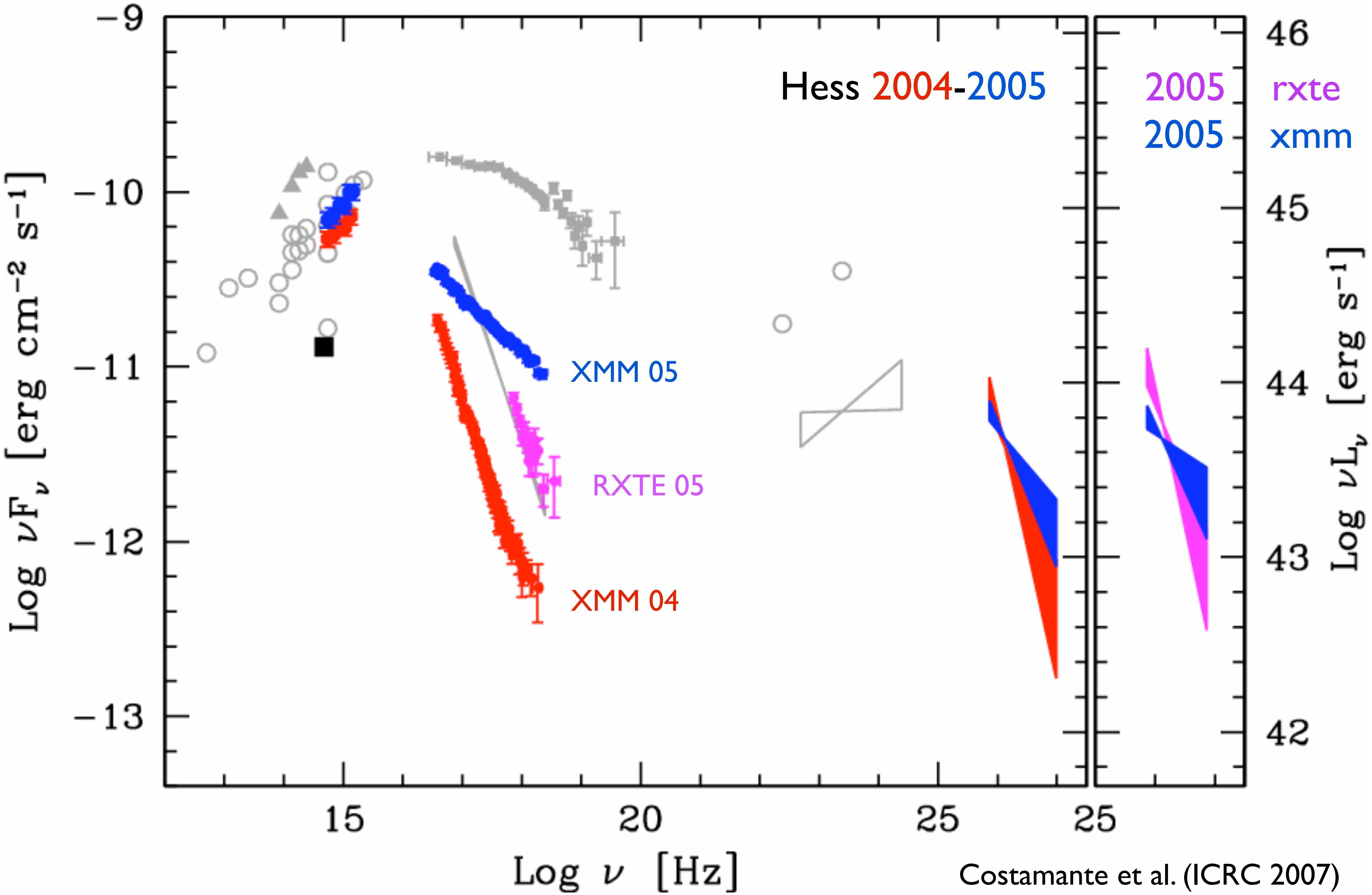
-7
-7.5
-8
-8.5
-9
-9.5
-10
-5
0
5
log ϵ
log ϵj_ϵ
ϵ_syn,KN
ϵ_syn,s
ϵ_IC,KN
ϵ_IC,s
ϵ_+



×10⁻⁹
I [cm⁻² s⁻¹]
200-300 GeV
300-400 GeV
400-500 GeV
500-700 GeV
>700 GeV
45.85
45.9
45.95
46
46.05
46.1
46.15
MJD - 53900

Emerging of new components, also on long timescales: evidence in PKS 2005-489

Mwl campaigns XMM-RXTE-HESS in 2004-2005



Costamante et al. (ICRC 2007)
Aharonian et al. (HESS coll) 2009

$\Gamma = 1.5$

What is NOT: - it's not the hardest possible theoretical spectrum

- it's not the hardest imaginable spectrum in blazars
- it's not a sharp, “hard limit”

Examples: *- bulk motion Comptonization* *(Aharonian et al 2001, 2006)*

- high-energy “low-energy cutoff” in particle spectrum *(Katarzynski et al 2007)*

- internal absorption on narrow-banded target field *(Aharonian et al 2008)*

- uncooled particle acceleration spectrum $\Rightarrow \Gamma \sim 1.2$ *(Aharonian et al 2006)*

- pile-up particle distributions or fine tuned shock-acceleration conditions

(e.g. Stecker et al 2007, but dibated, anyway with $\Gamma > 1.2$*)*

$\Gamma = 1.5$

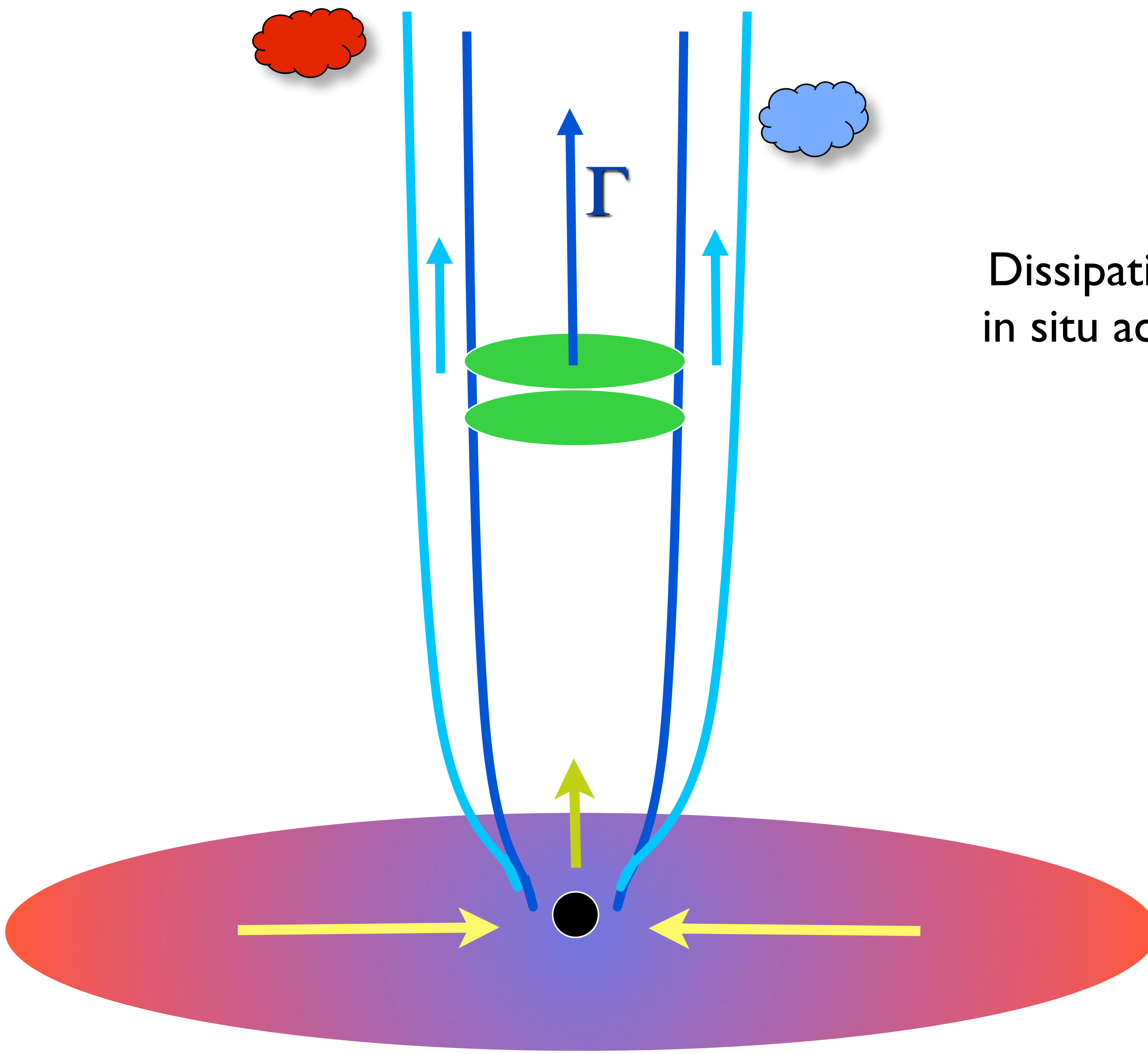
What it is: **It is the borderline between reality and speculation.**

- $\Gamma \geq 1.5$ is observationally confirmed and can be obtained theoretically in many circumstances (no special tuning);
- $\Gamma < 1.5$ is *progressively* more unlikely: it requires either parameters pushed to the limits, or ad-hoc scenarios not supported by data.

- Synchrotron emission traces directly the particle spectrum: so far in blazars never observed spectra from high energy particles ($\gamma > 10^3$) with $\Gamma < 1.5 \pm 0.2$ (~1.2-1 seen but as low-energy cutoff in X-rays, at low electron energies).

- Never observed a "naked" hard source: hard TeV features always seen in connection with EBL effects ("cosmic conspiracy"). It would require a dranatic evolution of blazar properties with z (0.0-0.3).

Blazars have always a combination of at least 2 types/engines of variability:

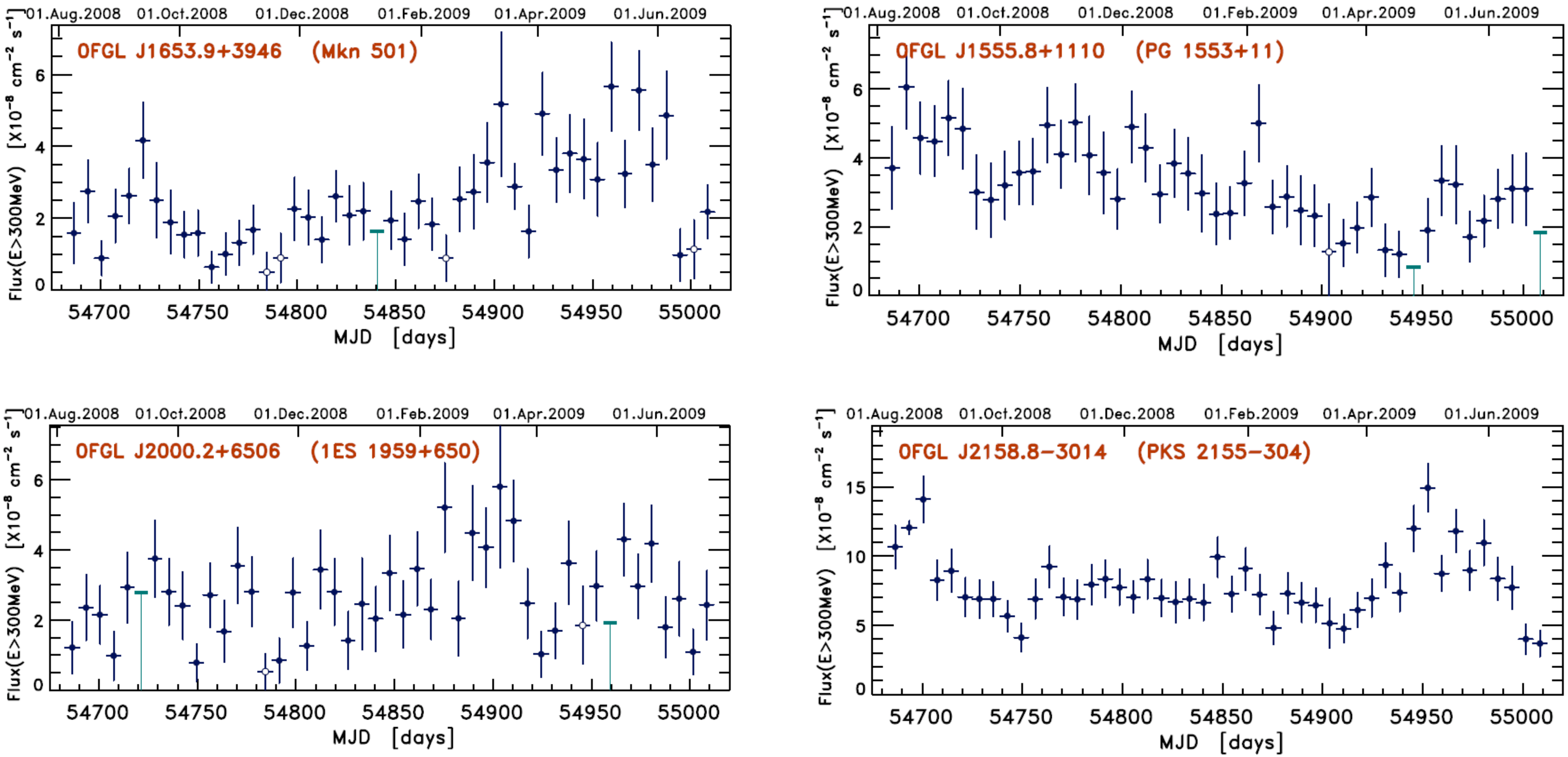


Dissipation events in the Jet:
in situ acceleration & cooling

Accretion & ejection:
modulated by Disk-BH
connection

Fermi band: little/no variability

(as in the optical...)



Abdo et al. 2010

see talk by S. Ciprini, G. Tosti

Poutanen & Stern 2010

GeV Breaks caused by absorption on HeII and HI lines (tau determined from free fits), from high-ionization part of the BLR (close to BH).

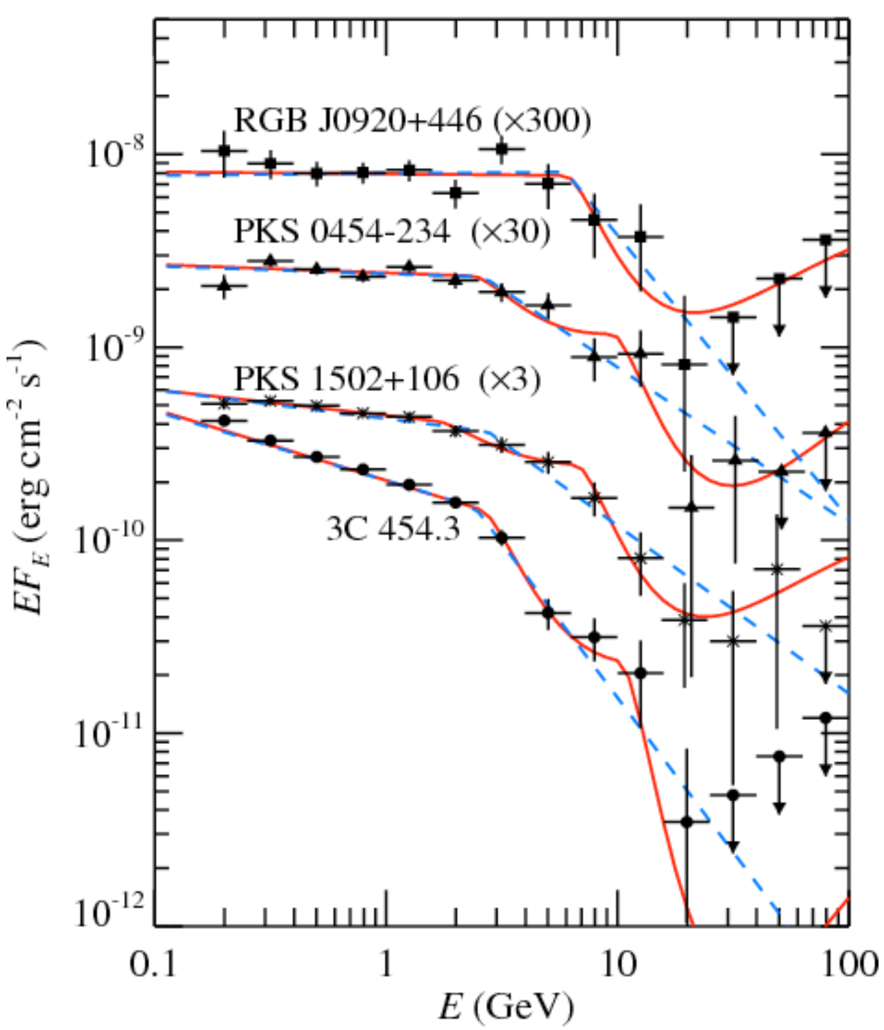


Table 2
Spectral Properties of Blazars

Object	z	Power Law	Broken Power Law				Power Law + Double Absorber			
		χ^2	Γ_1	Γ_2	$E_{\rm break}(1+z)$(GeV)	χ^2	Γ	$\tau_{\rm He}$	$\tau_{\rm H}$	χ^2
3C 454.3	0.859	117	2.36 ± 0.02	3.60 ± 0.22	4.5 ± 0.5	6.5	2.37 ± 0.02	6.1 ± 0.9	18.5^{+19}_{-7}	4.1
PKS 1502+106	1.839	55	2.15 ± 0.03	2.87 ± 0.16	7.8 ± 1.5	7.8	2.13 ± 0.03	1.6 ± 0.6	8.4 ± 1.6	6.3
3C 279	0.536	18	2.17 ± 0.07	2.56 ± 0.09	1.8 ± 0.6	4.6	2.28 ± 0.04	2.0 ± 1.1	4.5 ± 3.1	10.1
PKS 1510–08	0.36	13	2.43 ± 0.05	2.84 ± 0.27	3.1 ± 1.8	6.6	2.45 ± 0.04	2.7 ± 1.5	$2.7^{+8}_{-2.7}$	8.1
3C 273	0.158	10	2.82 ± 0.06	3.40 ± 0.42	$1.9^{+1.0}_{-1.9}$	6.1	2.87 ± 0.05	$3.6^{+6}_{-3.6}$	$0^{+\infty}_{-0}$	7.8
PKS 0454–234	1.003	50	2.04 ± 0.05	2.81 ± 0.17	5.3 ± 1.0	12.3	2.04 ± 0.04	3.0 ± 0.8	9.5 ± 2.7	13.7
PKS 2022–07	1.388	15	2.45 ± 0.05	3.02 ± 0.17	9.6 ± 4.3	11.6	2.48 ± 0.06	$0.8^{+0.9}_{-0.8}$	$2.9^{+4.3}_{-1.8}$	12.9
TXS 1520+319	1.487	11	2.49 ± 0.07	2.89 ± 0.24	4.7 ± 0.5	7.9	2.48 ± 0.74	1.7 ± 1.6	6.5^{+9}_{-5}	7.2
RGB J0920+446	2.19	21	1.99 ± 0.08	3.47 ± 0.4	19 ± 5	7.8	2.01 ± 0.07	$0^{+0.5}_{-0}$	7.6 ± 2.9	11.9

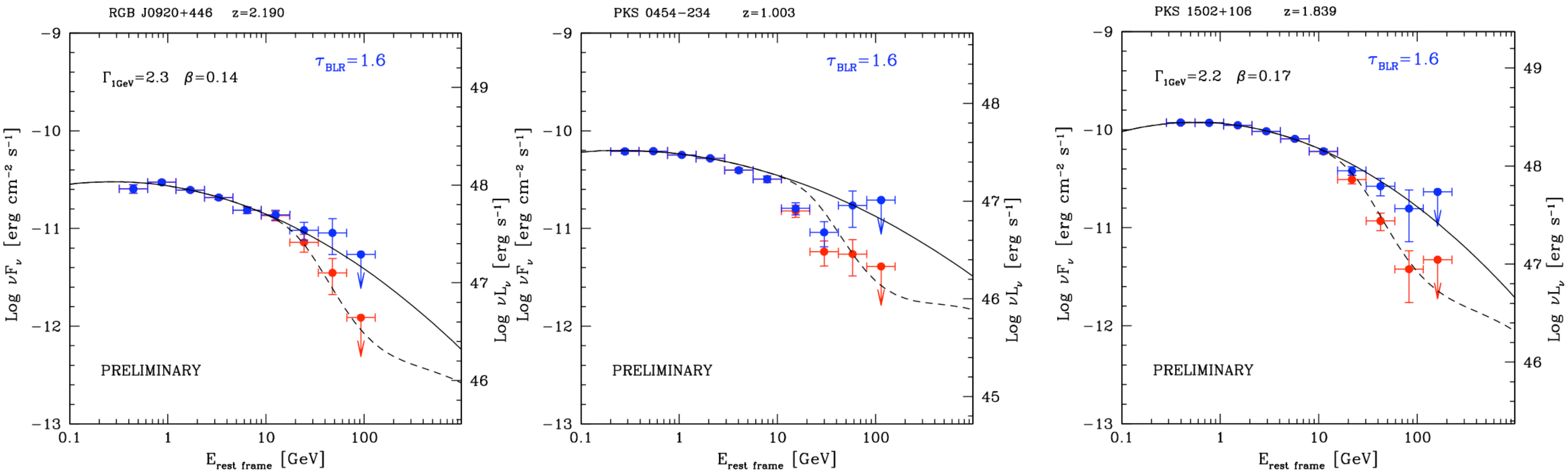
Note. The number of degrees of freedom is 12 for the power-law model and 10 for other models.

Problem: τ_{10eV} ~ 1 - 4× τ_{50eV} !

If gamma-ray zone is deep inside the BLR (highest-ionization region), how can gamma-rays avoid absorption on the main BLR opacity @10eV ?
(much higher photon density, directly seen/derived from UV-opt line luminosities, longer paths inside BLR).

<u>Mechanism does NOT work in general</u>, viable only when LAT spectra show NO photons above ~10-20 GeV (rest frame) => very strong cutoffs. Scenario OK for 3C454.3, does not work in 0920, 0454, 1502.

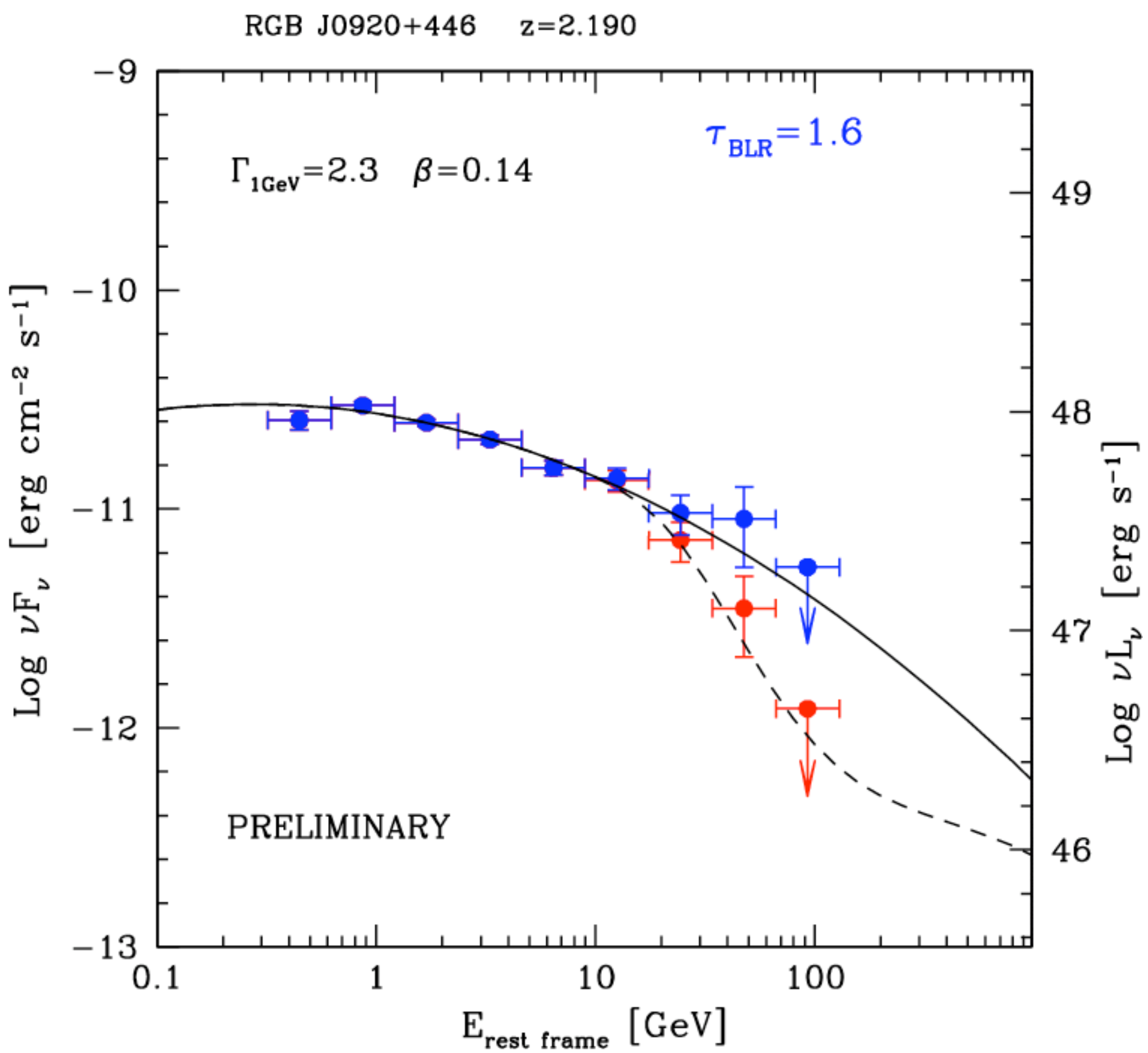
Where Poutanen & Stern 2010 does not work

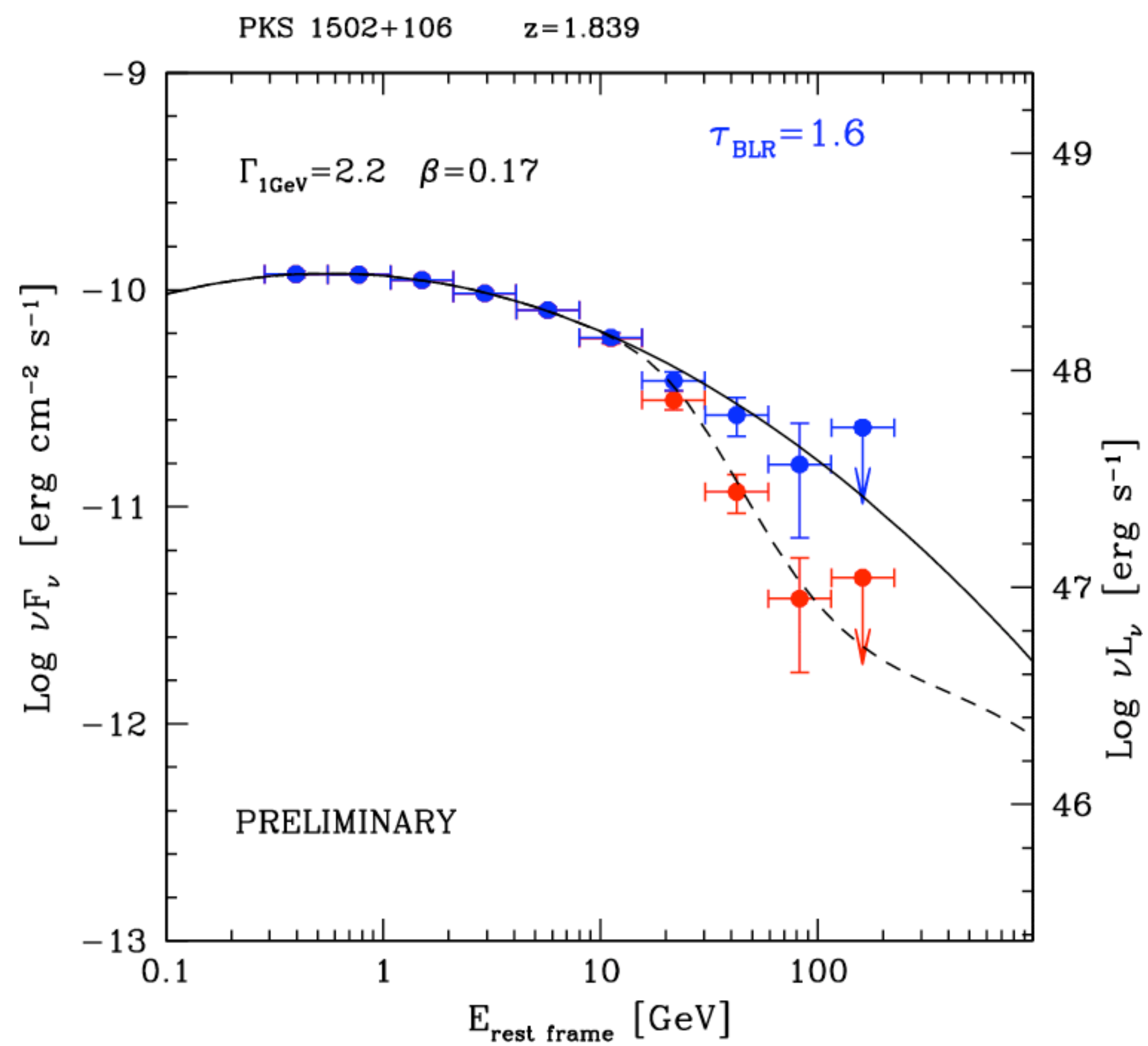


Some objects compatible with mild BLR absorption

Log-parabolic fits to the data only up to ~3-4 GeV, and extrapolated at higher energies

LAT spectra: original, observed ; BLR de-absorbed



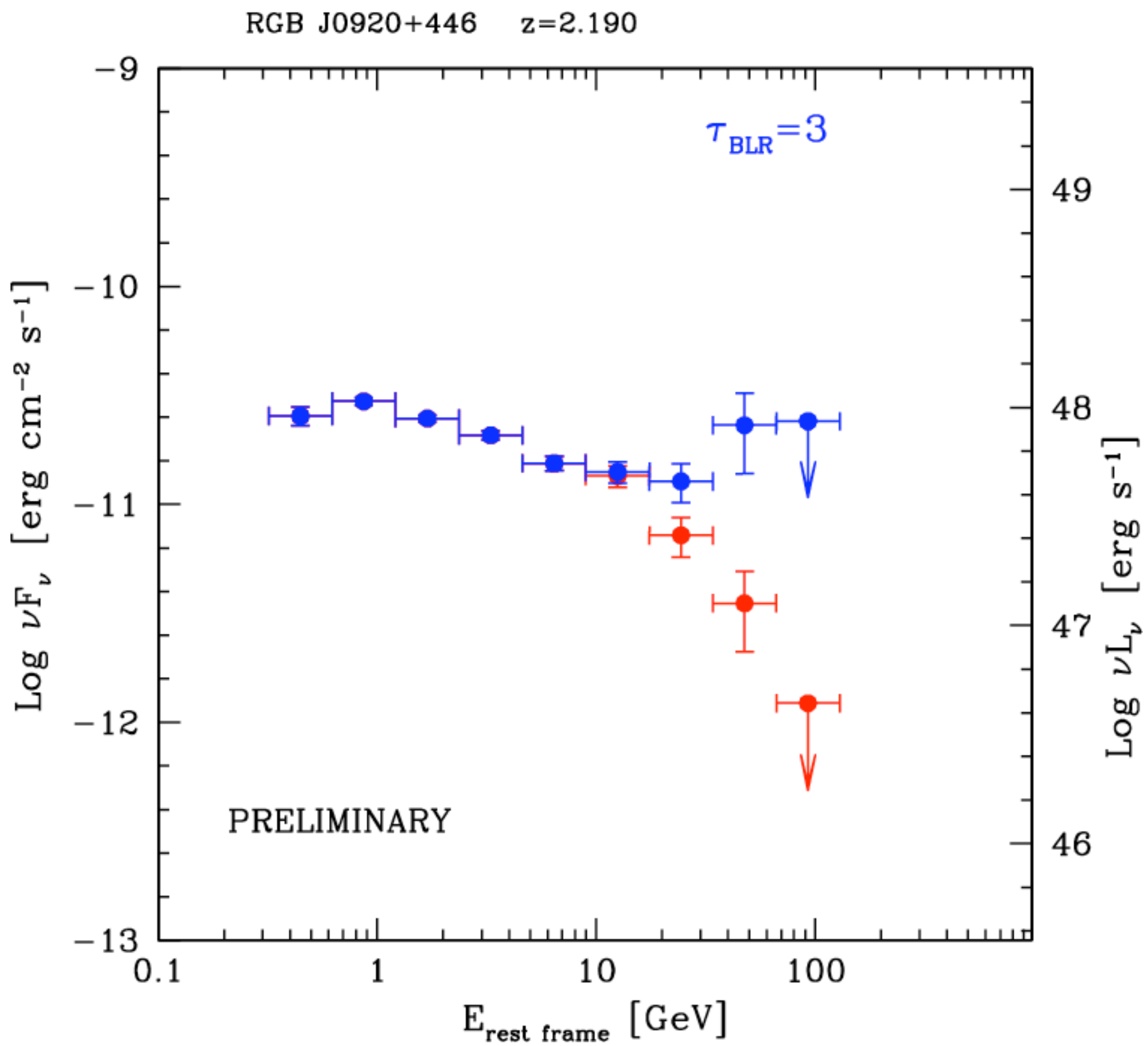


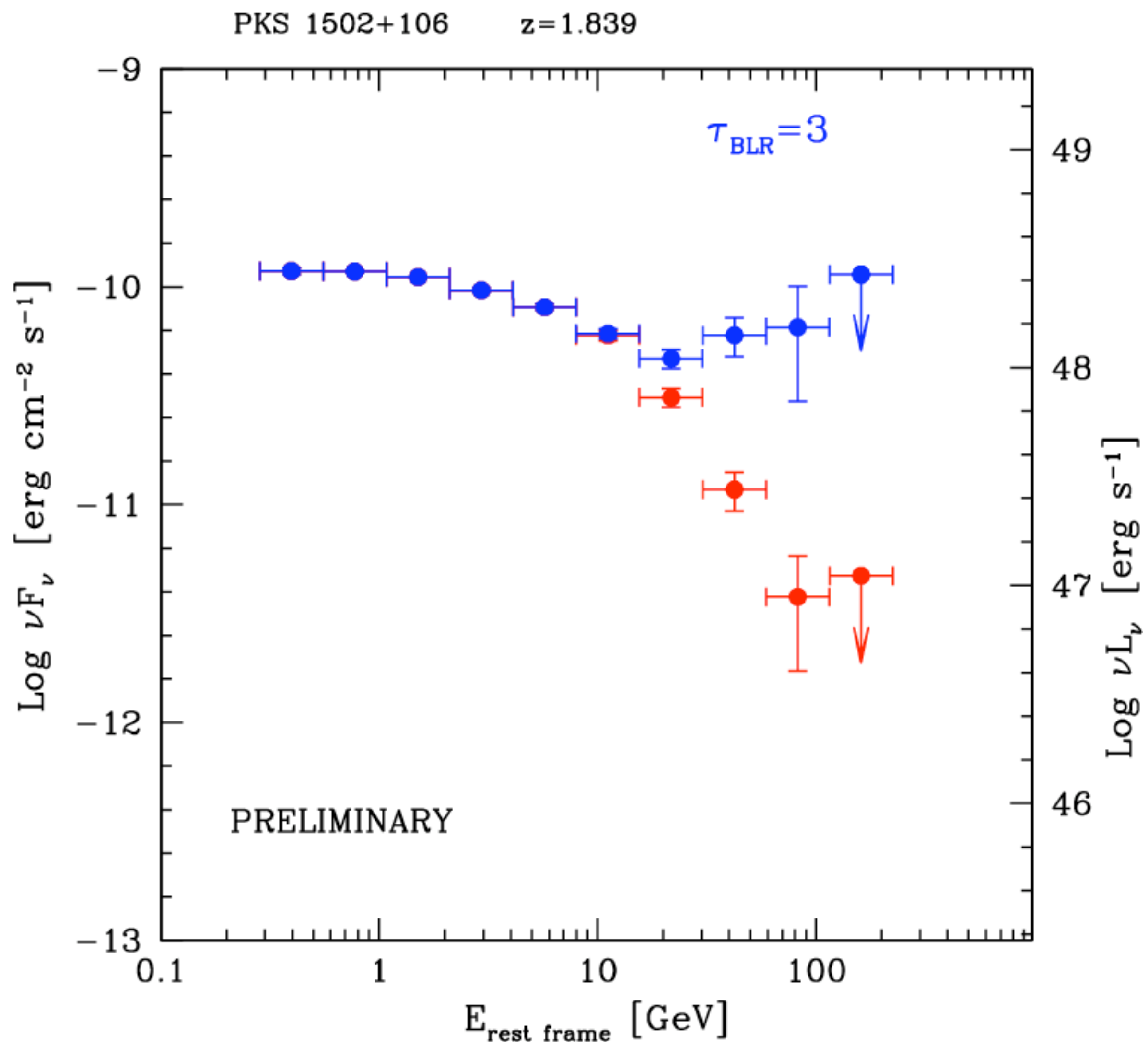
Only moderate (τ~1-2), corresponding to $R_{diss} \cong R_{BLR}$

...But could be also intrinsic cut-offs (end of particle distribution).

Some objects compatible with mild BLR absorption

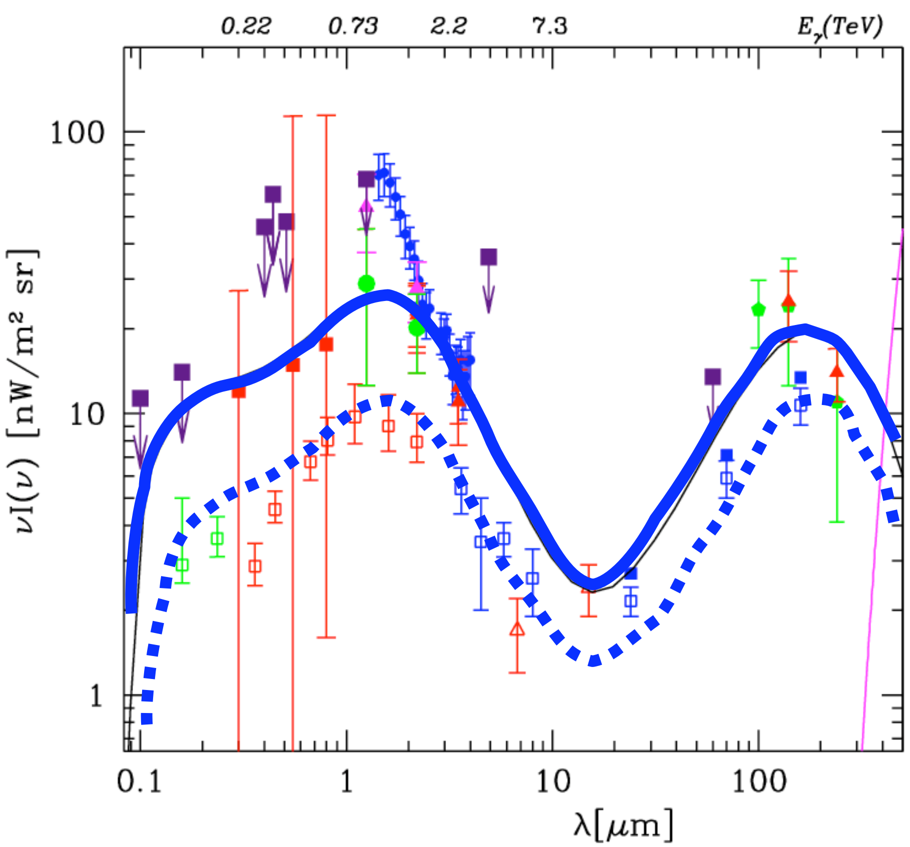
Already with $\tau \geq 3$ (path just a few 10^{16} cm), absorption would become too strong, requiring a second gamma-ray component in the SED

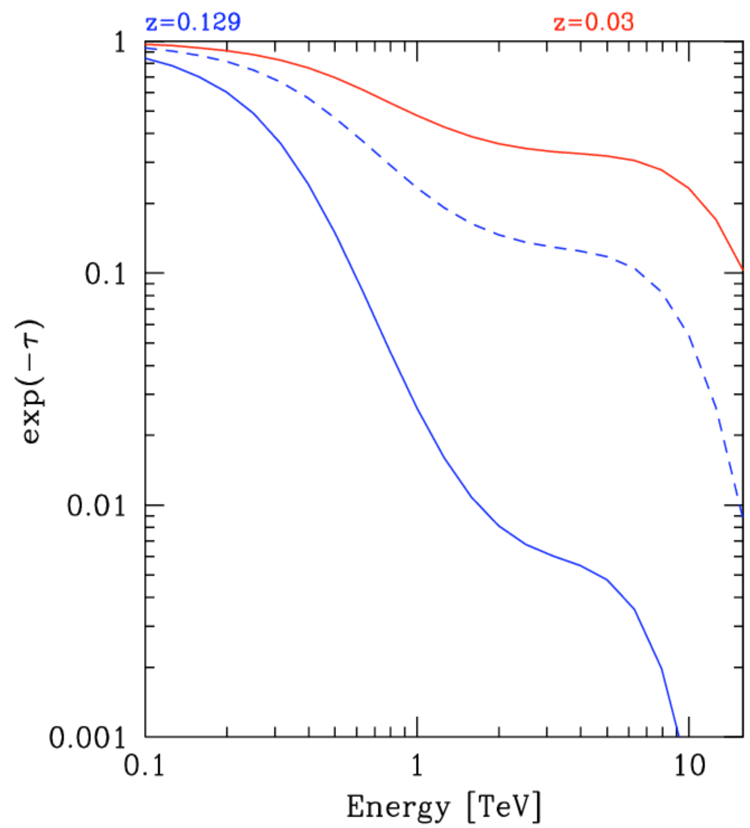


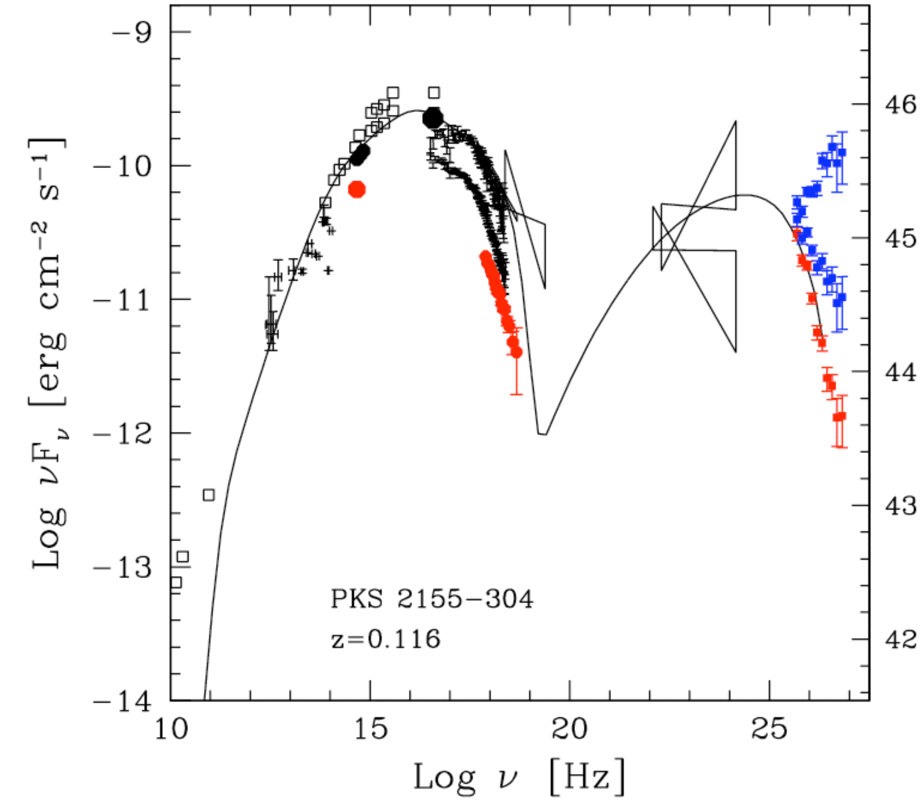


Problem: γ-γ interaction with photons of the Extragalactic Background Light

Uncertainty on EBL caused a fundamental ambiguity in the interpretation of gamma-ray spectra

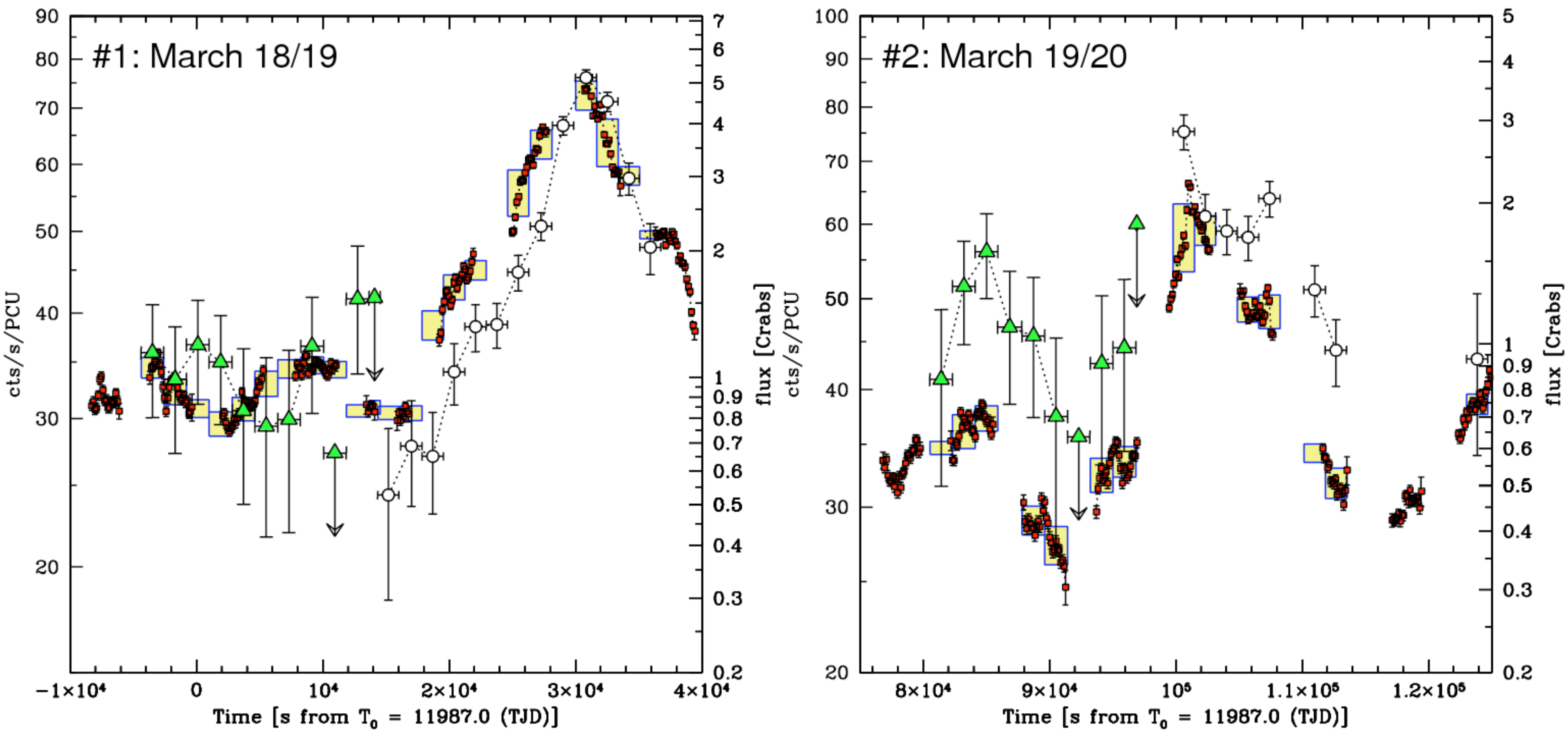




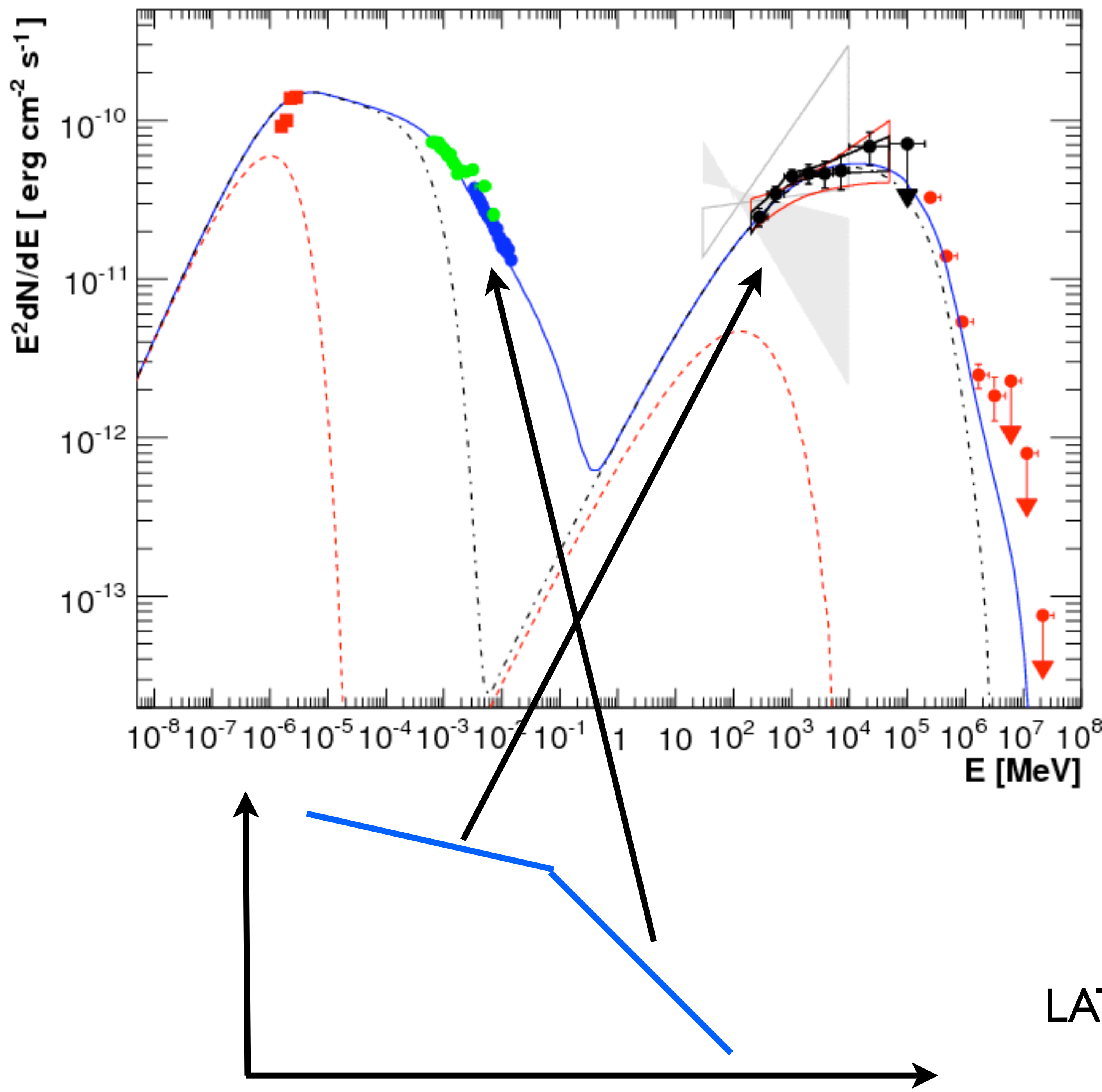


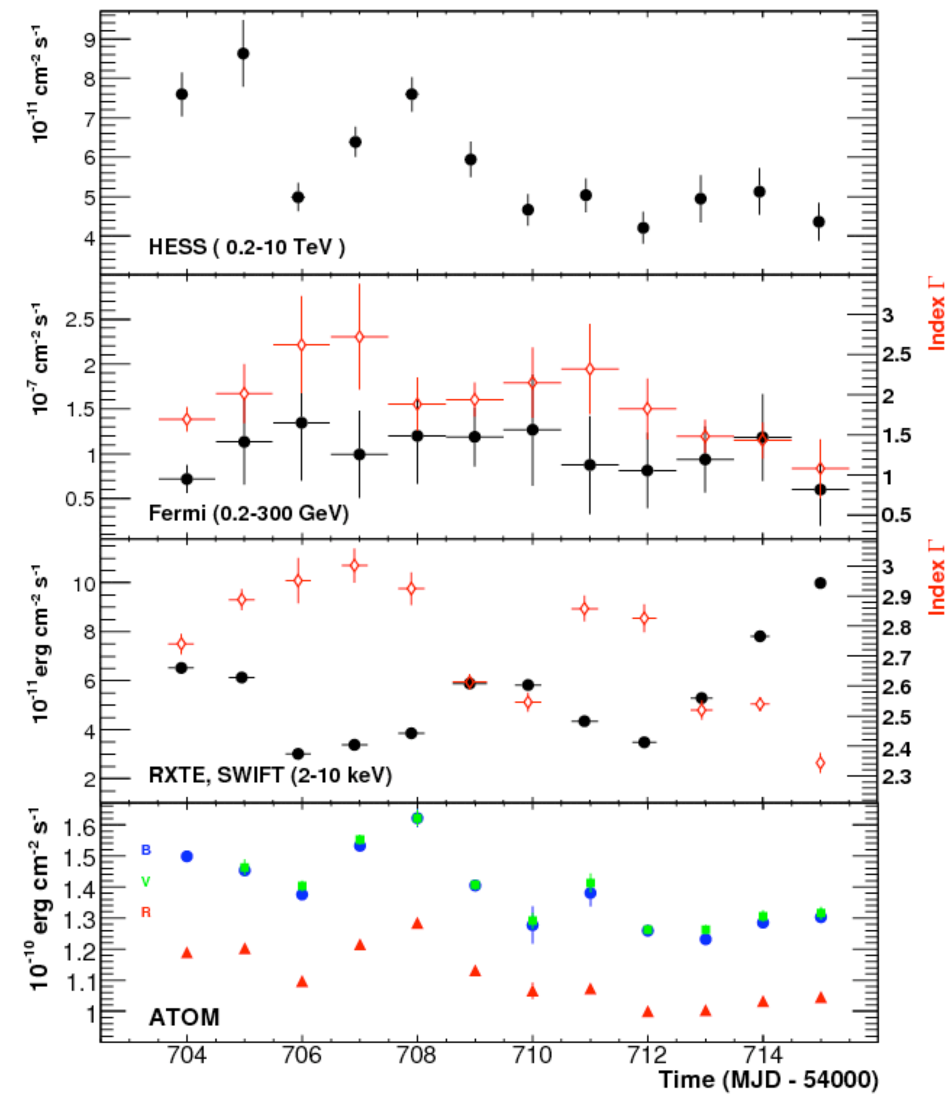
Aharonian 2001 (ICRC review and refs therein)
Aharonian et al. 2005 (HESS Coll)
Costamante et al. 2004, 2005, 2006

Opportunity: at the same time, blazars (as TeV beamers) can provide independent constraints on the EBL


#1: March 18/19
cts/s/PCU
flux [Crabs]
Time [s from T0 = 11987.0 (TJD)]
#2: March 19/20
cts/s/PCU
flux [Crabs]
Time [s from T0 = 11987.0 (TJD)]

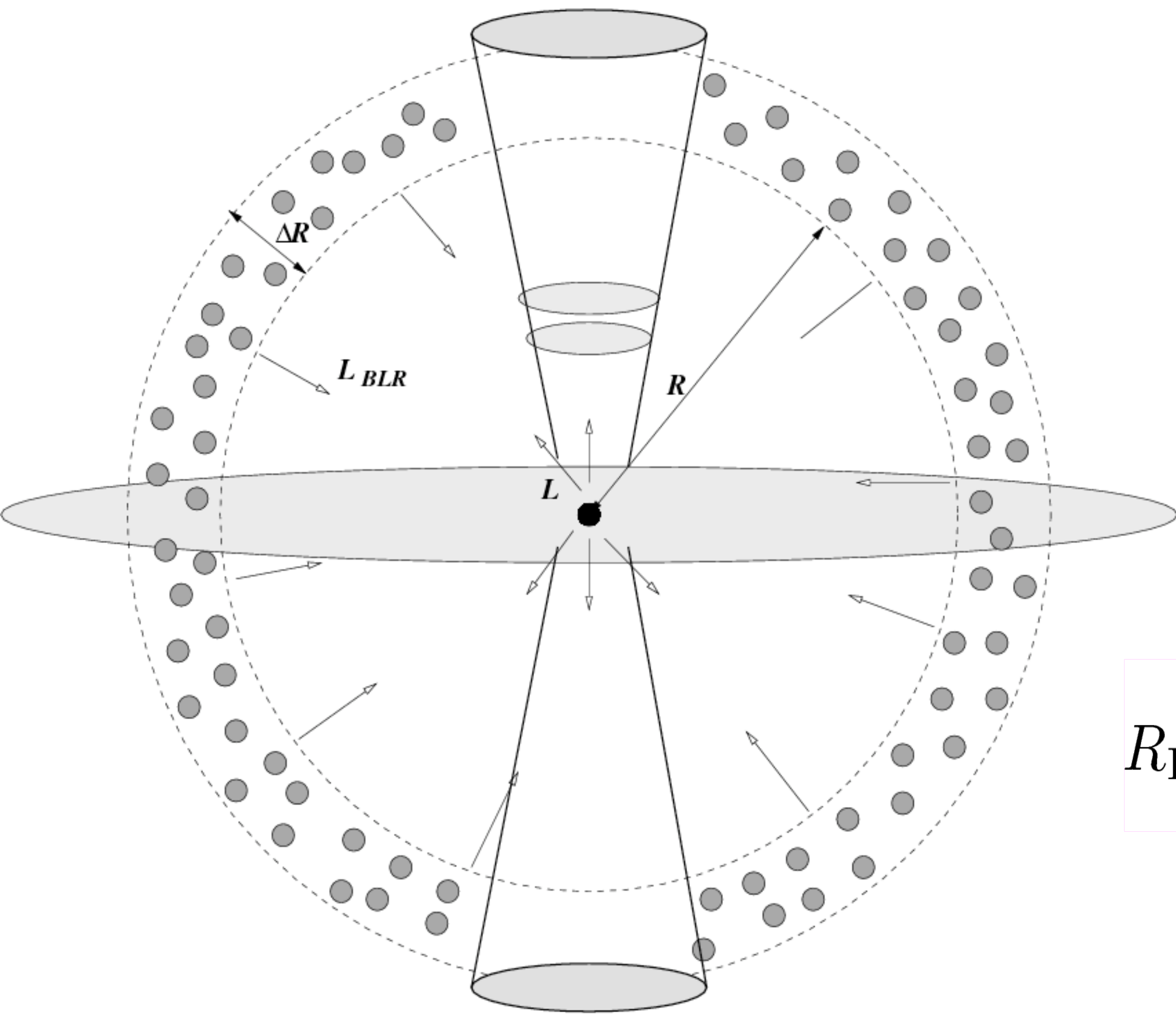
Xray-TeV emission might also correspond to different branches of single electron population





LAT+ HESS collab. (Aharonian et al 2009)

From reverberation mapping technique on AGNs over wide range of luminosity: Relation $R \propto L_{disk}^{1/2}$

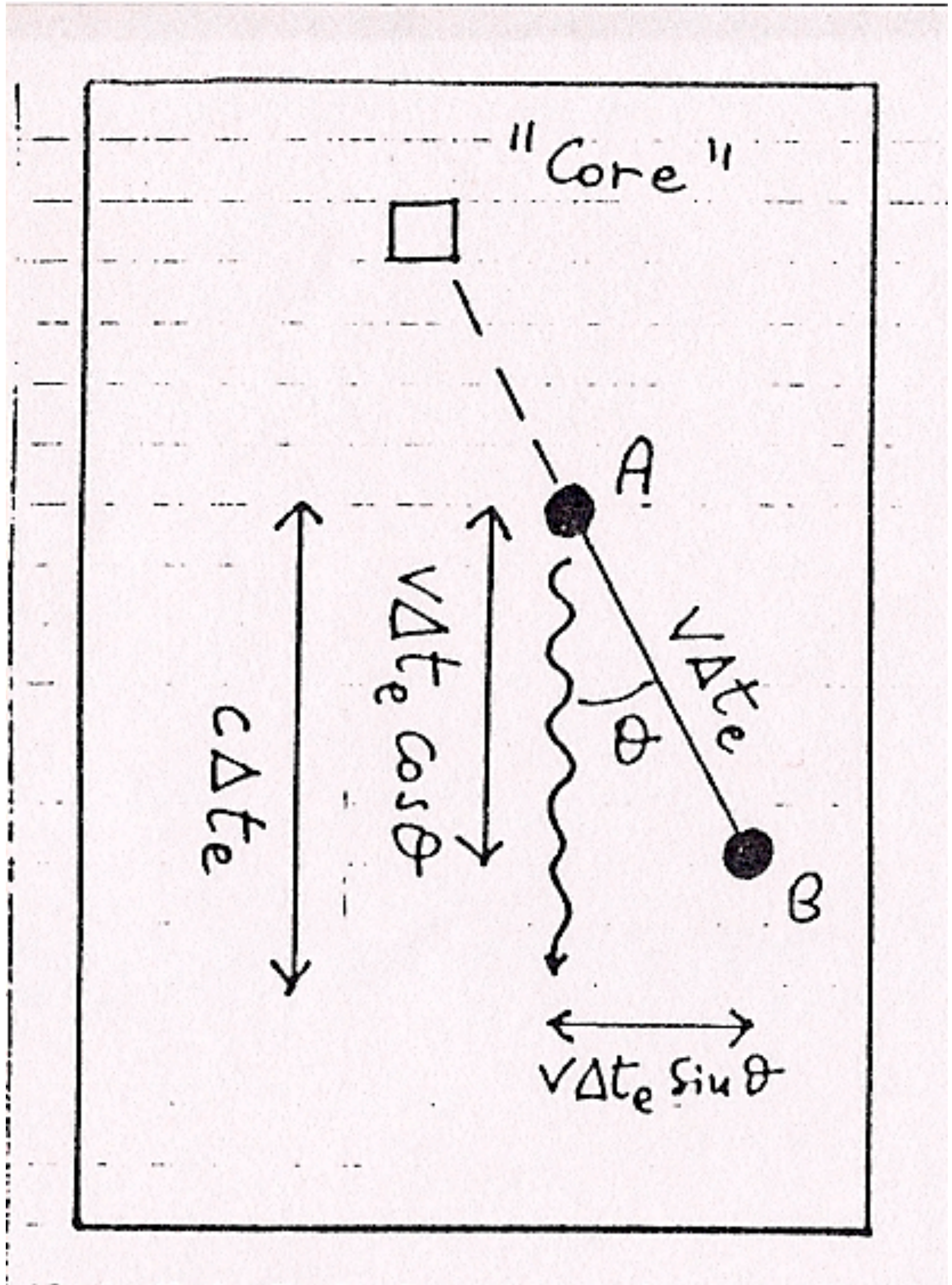


$$R_{\rm BLR} \simeq 2 \left[\frac{\lambda L_\lambda(1350\mathring{A})}{10^{43}\ \rm erg\ s^{-1}} \right]^{0.52\pm0.04} \ \text{lt days} \quad \text{(Kaspi 2006)}$$

$$R_{\rm BLR} \simeq 11 \left[\frac{\lambda L_\lambda(5100\mathring{A})}{10^{43}\ \rm erg\ s^{-1}} \right]^{0.52\pm0.04} \ \text{lt days} \quad \text{(Bentz 2006)}$$

Energy density

$$U_{\rm BLR} = \eta \frac{L_{\rm disk}}{4\pi R_{\rm BLR}^2 c} \simeq 10^{-2}\ {\rm erg\,cm^{-3}}$$



Ghisellini lessons, 1995-98

$$h\nu = \delta\, h\nu'$$

$$\frac{N(\theta < \theta_0)}{N_{tot}} = \frac{2\pi \int_0^{\theta_0} \sin\theta\, d\theta}{4\pi} = \frac{1}{2\Gamma^2}$$

$$d\Omega = d\Omega'/\delta^2$$

$$\Delta t = \Delta t'/\delta$$

$$V = \delta\, V'$$

$$P_{\rm i} \;=\; \pi R^2 \Gamma^2 c U_{\rm i}'$$

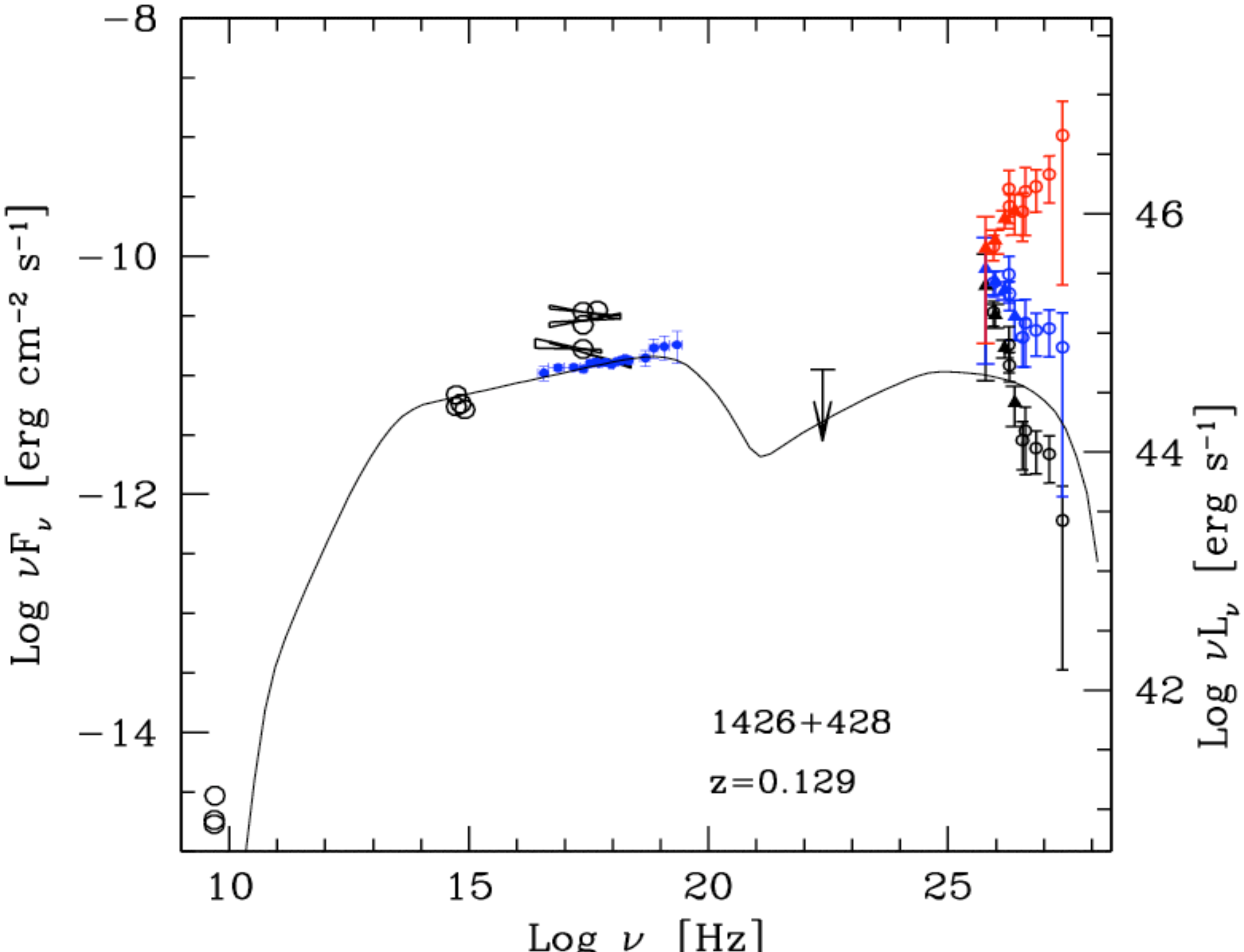
$$I(\nu) = \delta^3\, I'(\nu')$$

$$\Gamma(1 - \beta\cos\theta)$$

$$F(\nu) = \delta^3\, F'(\nu') = (\delta^2/\Gamma)\, F'(\nu')$$

$$Q = \frac{E}{\eta T} \approx \frac{10^{60-61} erg}{\eta 10^8\ yrs} \simeq 10^{45-46} erg/s$$

Problem: interpretation of TeV blazars spectra



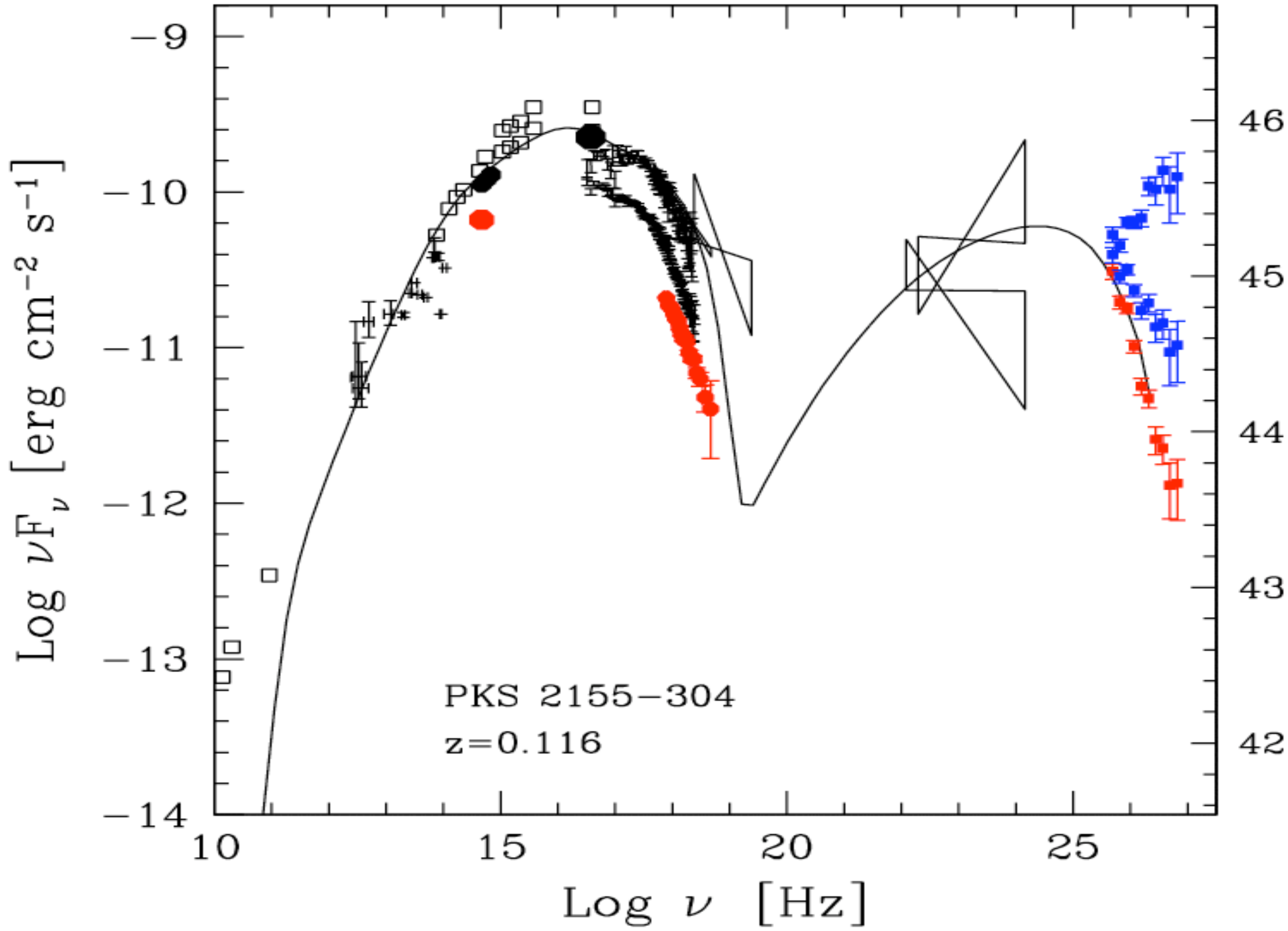
With a high EBL:

- IC peak > 10 TeV
  Lc >> Ls

- Bolometric luminosity is strongly under-estimated

- 1ES 1426+428 one of the most problematic

$\Gamma_{obs} = 3.5 \pm 0.3$



$\Gamma_{int} \simeq 1.5$

$\Gamma_{int} \simeq 2.5$

Aharonian et al. 2005

$\Gamma_{obs} = 3.37 \pm 0.07$

Compton Dominance

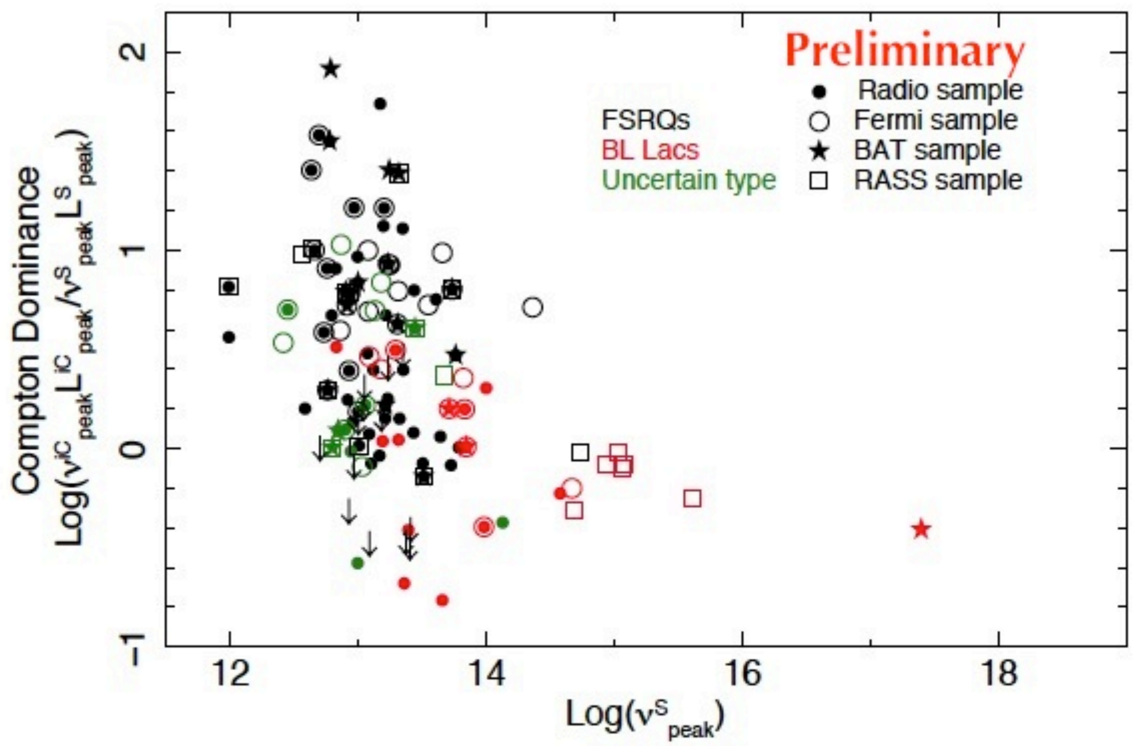
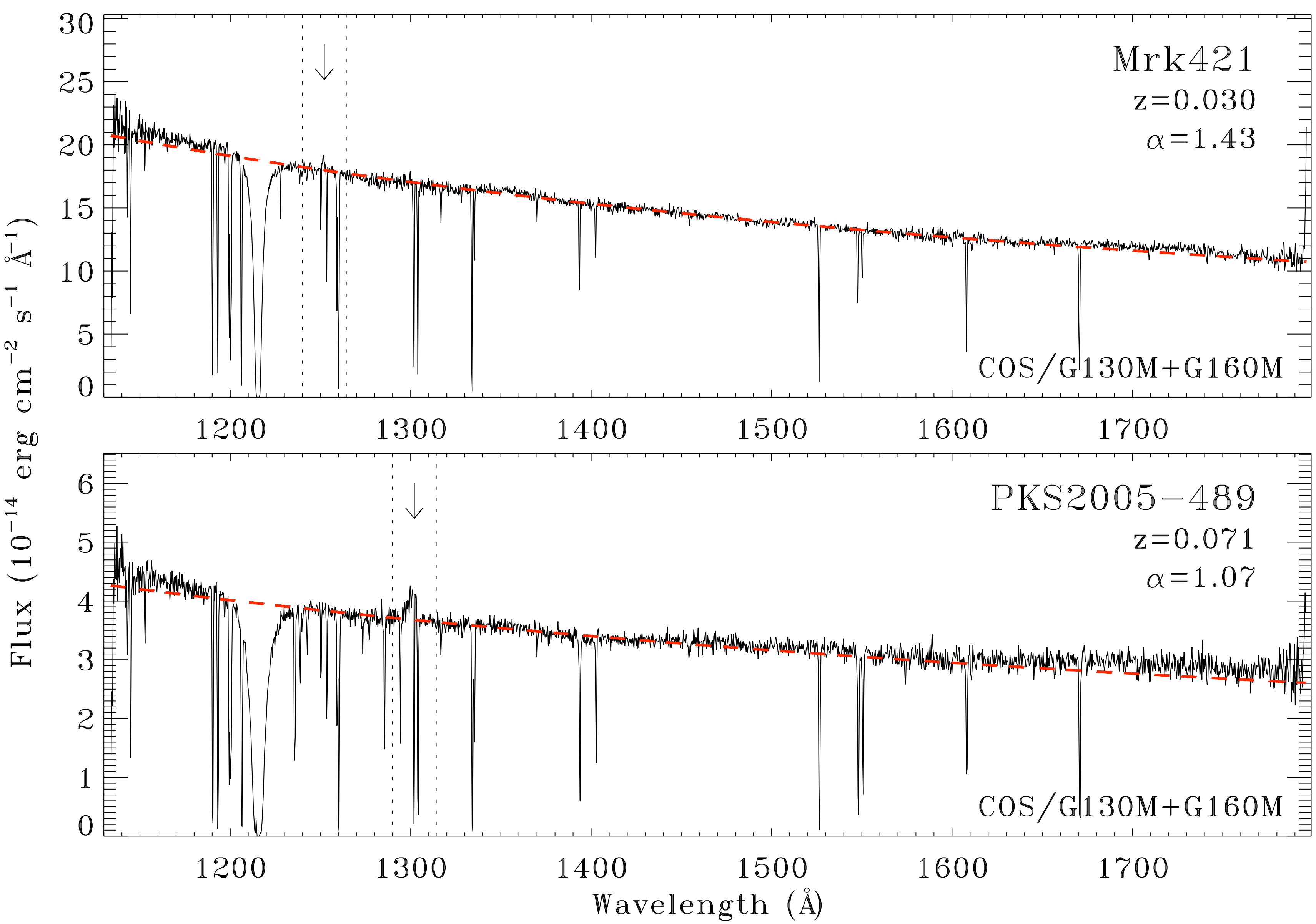


Fig. 17. The logarithm of the Compton dominance is plotted as a function of $\log(\nu^{S}_{peak})$ for all sources detected and for which ν^{S}_{peak} and ν^{IC}_{peak} could be reliably determined.

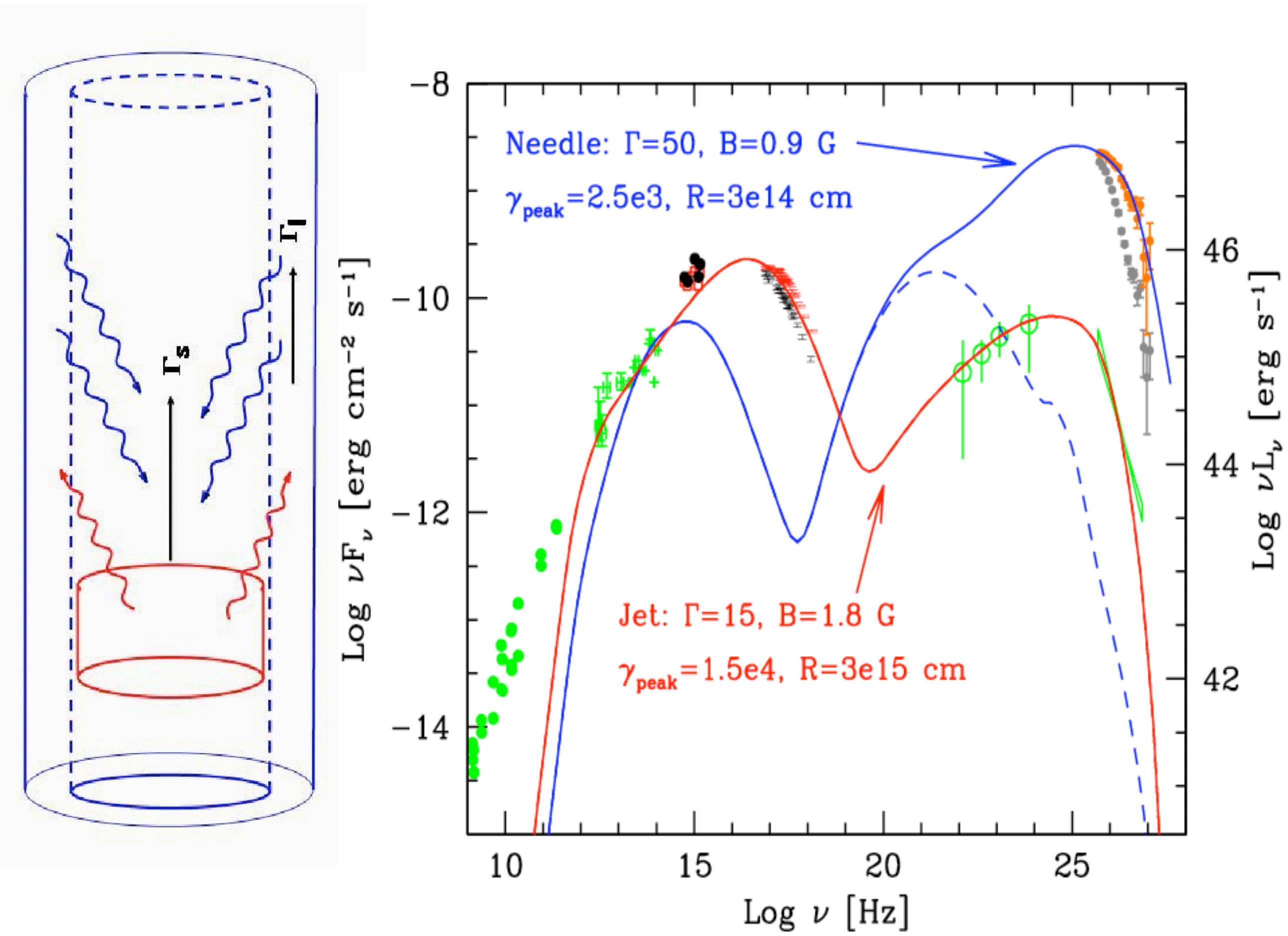


Mrk421
z=0.030
α=1.43
COS/G130M+G160M
PKS2005−489
z=0.071
α=1.07
COS/G130M+G160M
Flux (10^-14 erg cm^-2 s^-1 Å^-1)
Wavelength (Å)

Structured Jets:

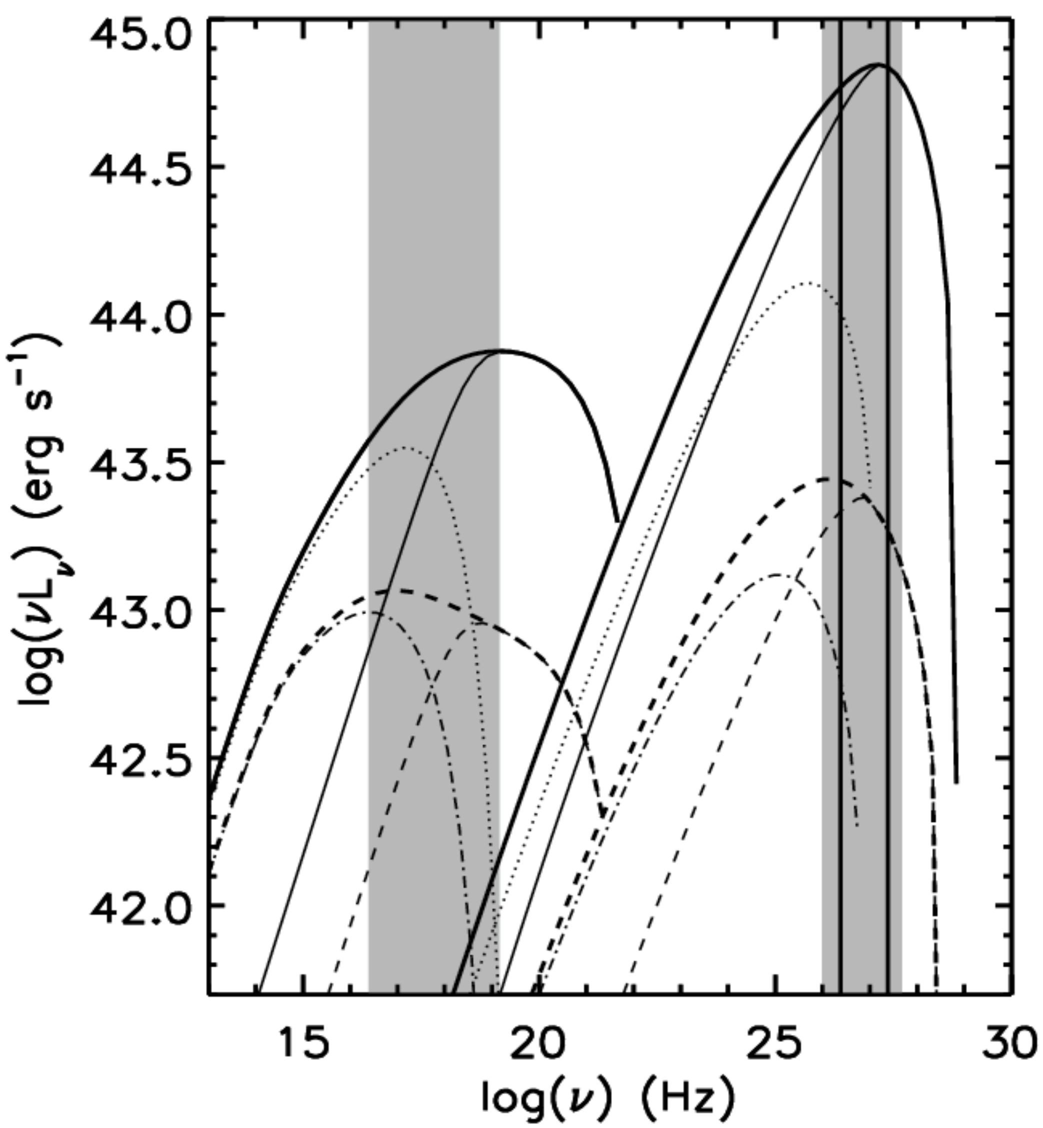
Possible radiative interplay between different jet parts:

Spine-layer



Ghisellini & Tavecchio
2008

Decelerated jet



Georganopulous & Kazanas
2003

Jet structure/composition