Challenges from γ-ray Spectra of Blazars at the Two Ends of the Blazar Sequence

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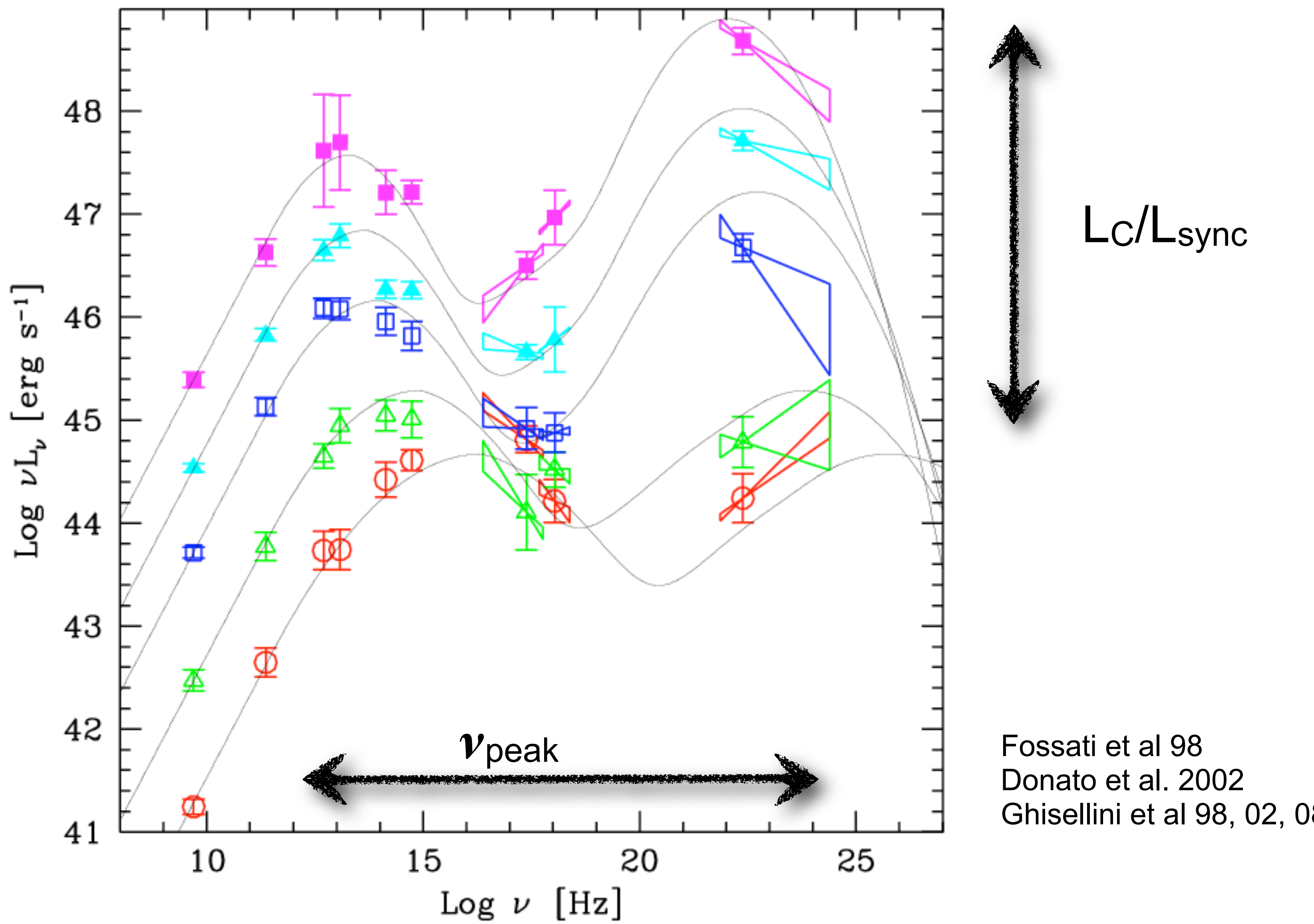
Once upon a time... in Blazarland:

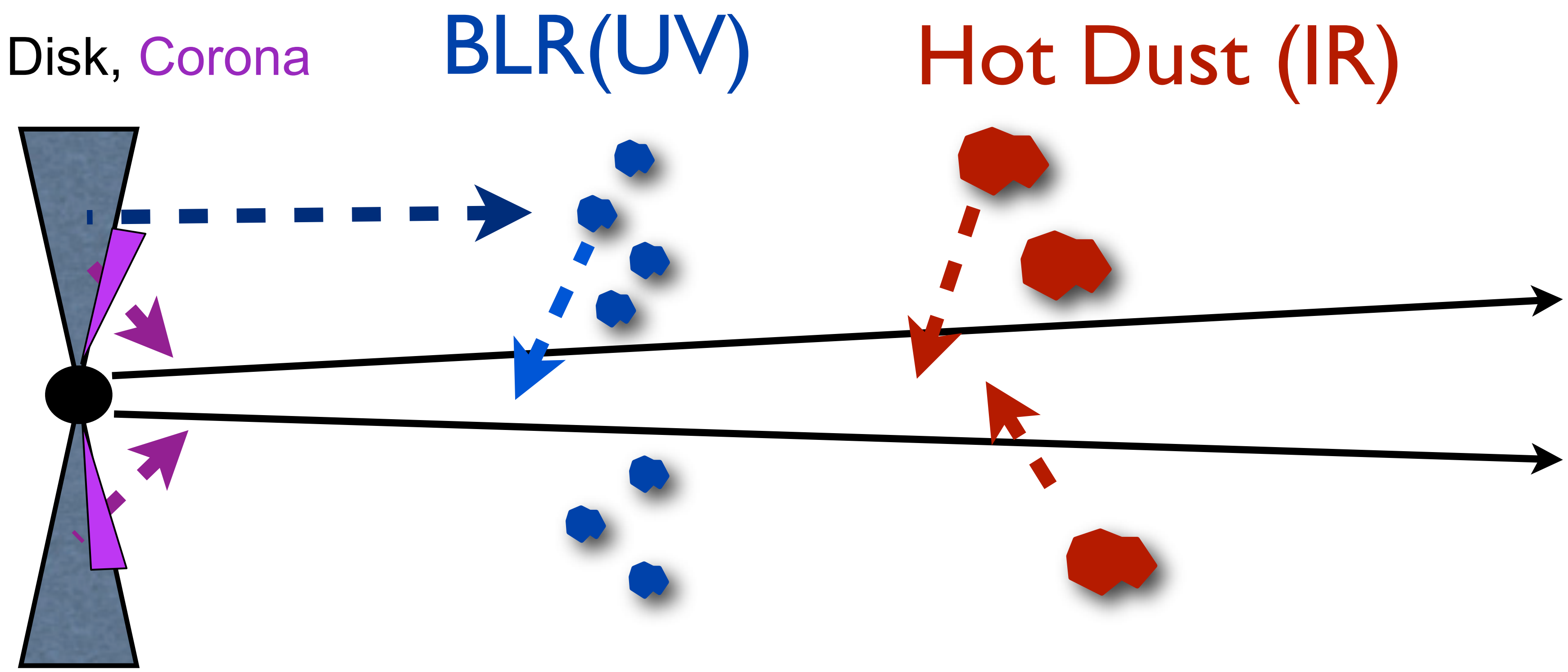


Fossati et al 98
Donato et al. 2002
Ghisellini et al 98, 02, 08

Powerful objects
High accretion rate, high L_{disk}
Radiatively efficient accretion disks
Broad Line Region(BLR), Hot Dust (HD)
High $L_{lines\ BLR}$, ~10^{45-46} erg/s
External Compton (EC)

Low luminosity objects
Low accretion rates, low L_{disk}
Radiatively inefficient disks
Absence BLR, HD
Low $L_{lines\ BLR}$, < 10^{40-41} erg/s
Synchrotron Self Compton (SSC)

Seed photons for Inverse Compton (IC)



$$R_{BLR} \simeq 0.1 \times L_{46}{}^{1/2}\ \mathrm{pc}$$ (Bentz et al. 2006 ; Kaspi et al. 2007)

$$R_{HD} \simeq 2.5 \times L_{46}{}^{1/2}\ \mathrm{pc}$$ (Cleary et al. 2007 ; Nenkova et al. 2008)

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

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

Basic 0th-order assumptions/approximations:

a) R ~ as above

b) isotropic field (shell)

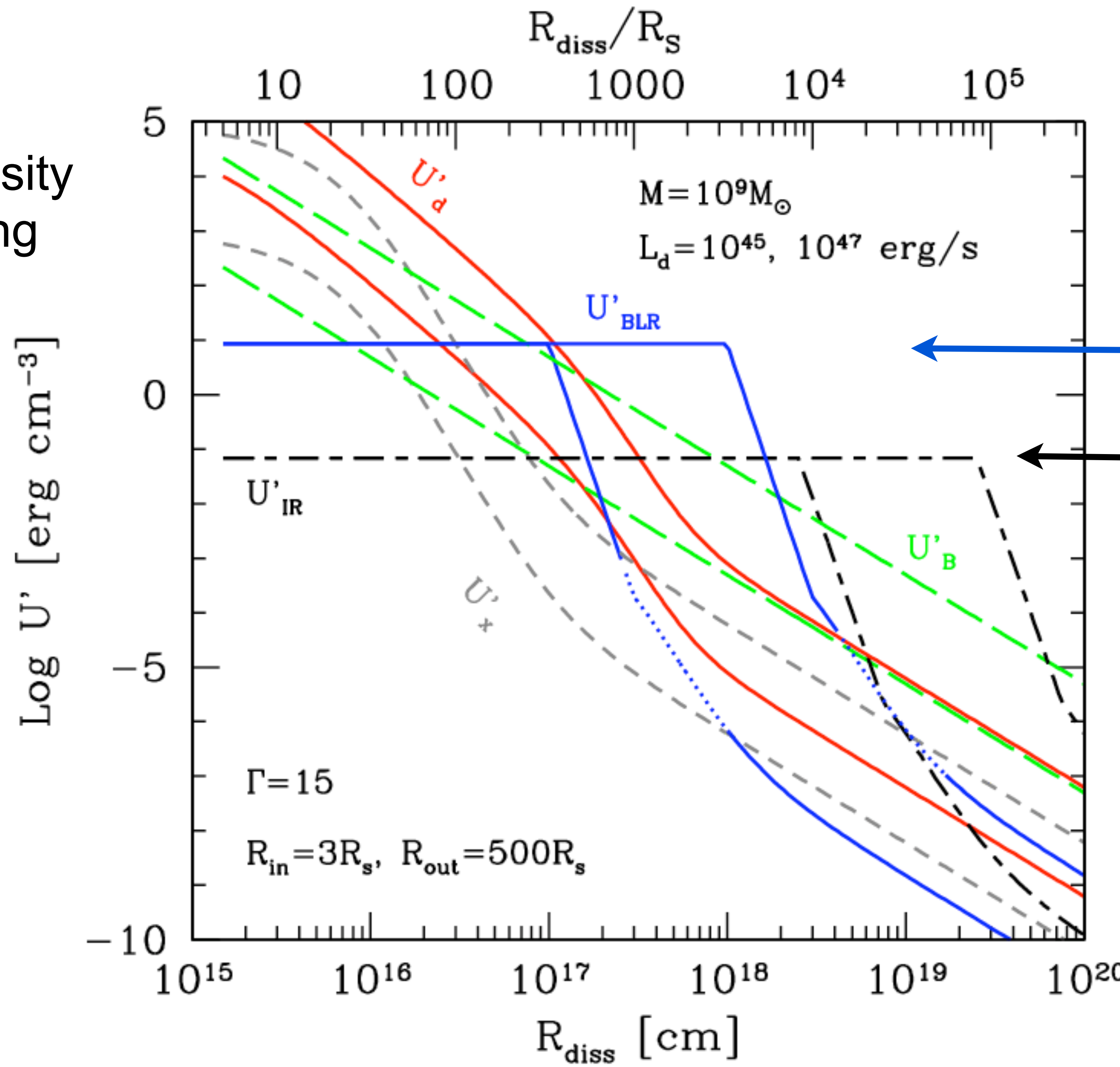
c) BlackBody spectrum @9eV (0.2 eV)

d) reprocessing factor η~ 10% (20-30%)

(e.g. Ghisellini et al. 2009
Sikora et al. 2009)

Seed photons for Inverse Compton (IC)

U' = energy density in blob co-moving frame

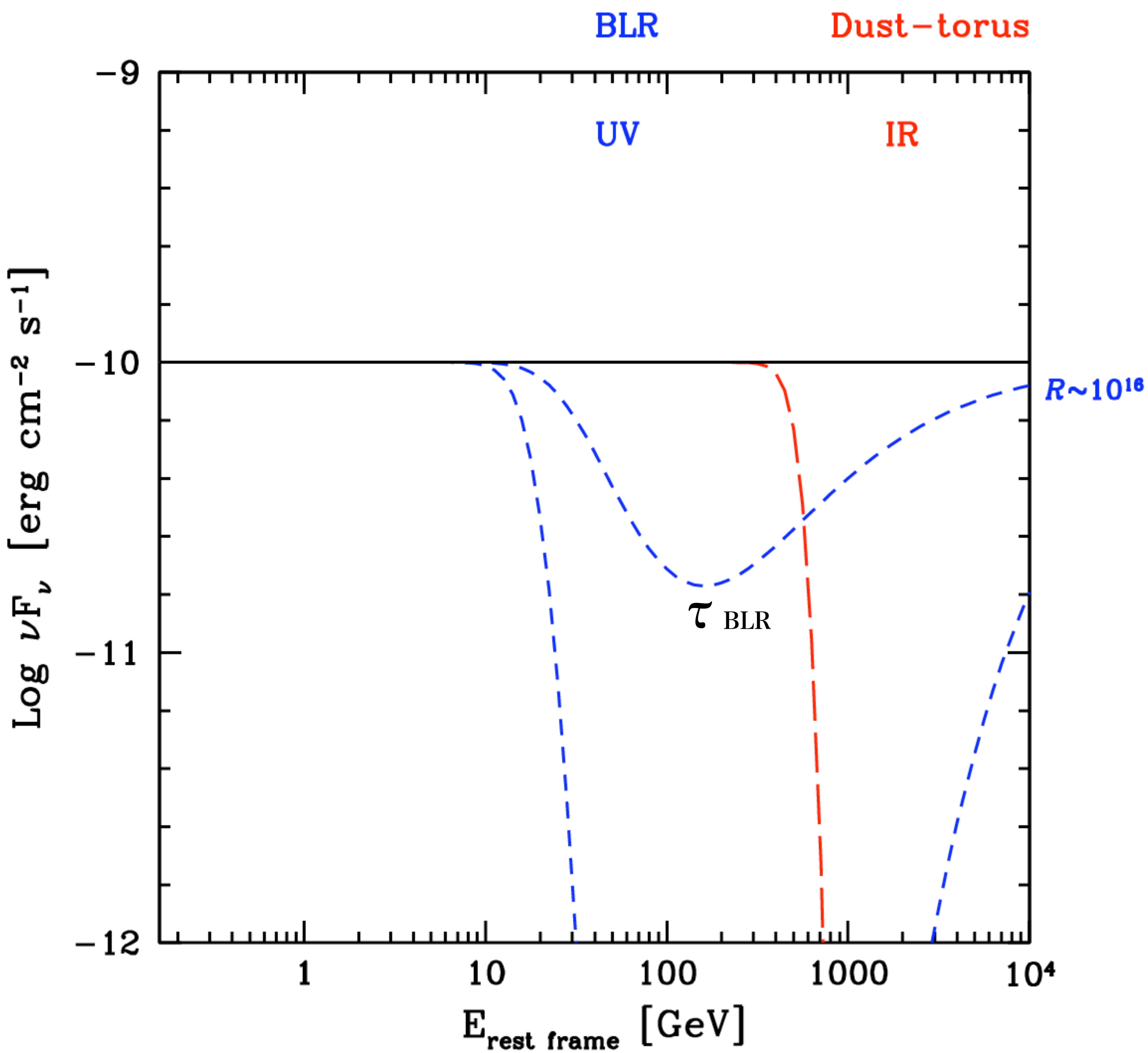


Ghisellini et al. 09
(also in Sikora et at. 09)

SED of FSRQ generally modeled always with External Compton, either on BLR or HD radiation, to explain the typically high Compton Dominance (10-100).

Absorption feature by γ-γ interactions

But: the same seed photons for EC are targets for γ-γ interactions.
"Double wall" of target photons !



Optical depth τ is high !

U_{rad} ~const ⇒ τ depends only on path length inside BLR/HD

Always not negligible (≥1), even in the minimal case: photon path ~ size of emitting region (typically ~10^{16} cm)

Fermi now samples this energy range for the first time (1-100 GeV rest frame)

Look for BLR absorption/cut-off features in Fermi spectra >10 GeV

Target selection:

- FSRQ detected (TS>25) in the Fermi-LAT sky above 10 GeV.

- Data and associations from 18-months internal source list, by the LAT team.

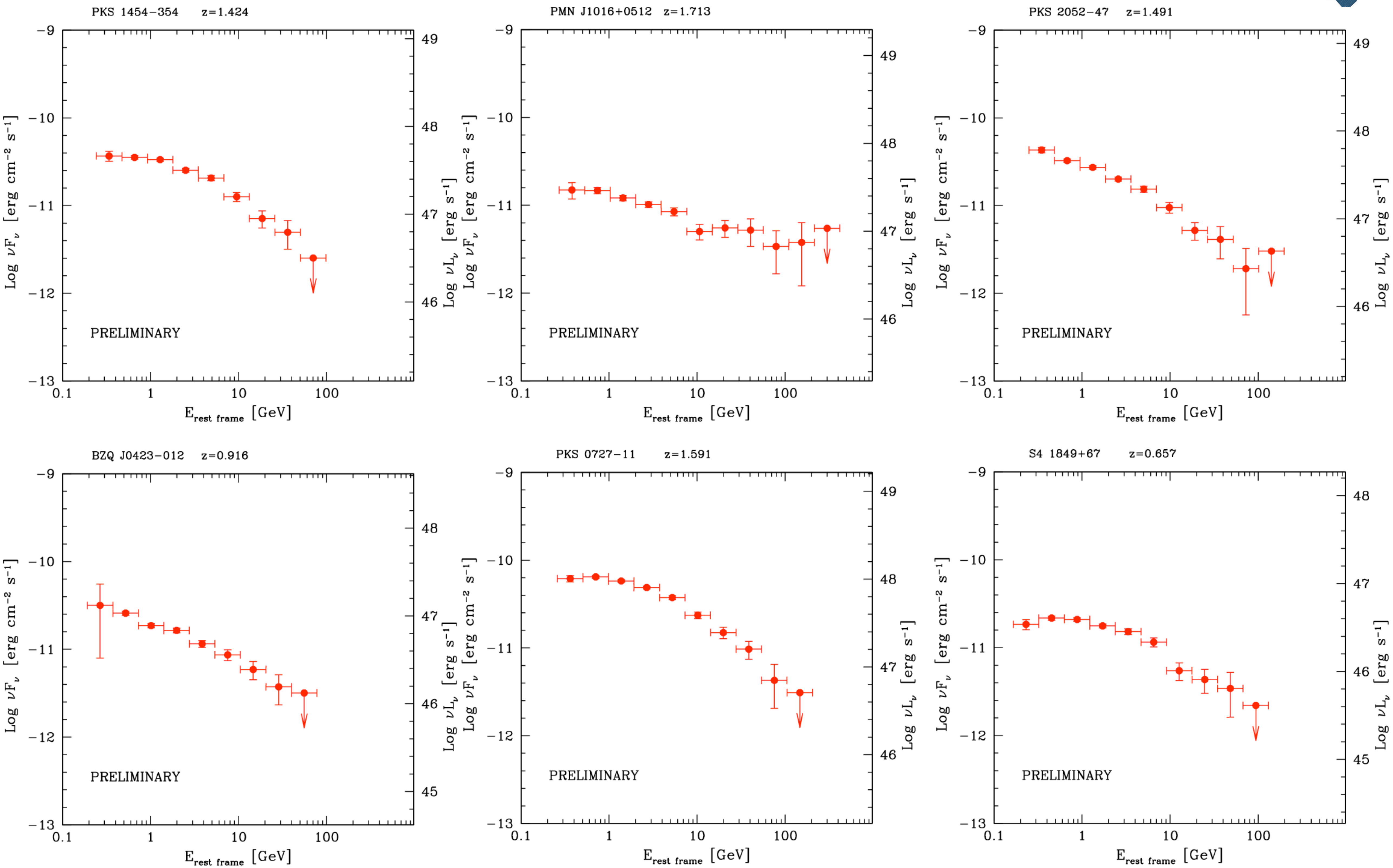
LAT data analysis:

- E >100 MeV, ROI of 7 deg. from region of 12 deg, P6V3 irfs.
- All sources from 1-year catalog inside the 12 deg region included.
- Maximum likelihood fit in each energy bin; Spectra from **24-months** exposure.
- **All analyses still preliminary !!** Statistical errors only.

Notes:

- **All plots have Energy axis in REST FRAME energies**
- **EBL absorption not (yet) relevant at these energies and redshifts**
  (for the most realistic, recent calculations, e.g. Primack et al., Franceschini et al.)

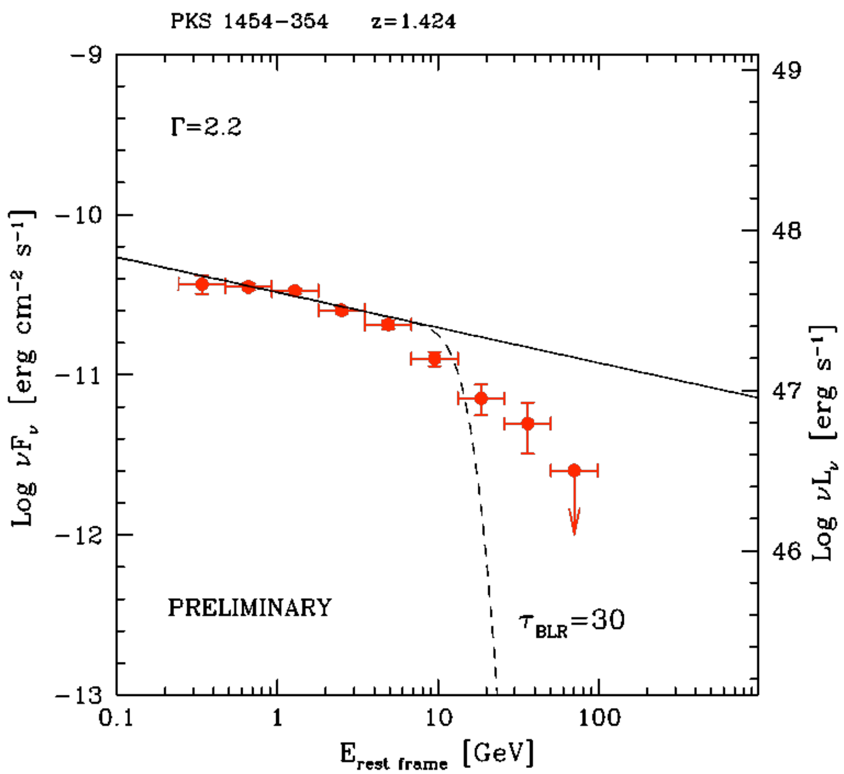
NO evidence of strong BLR cut-offs !

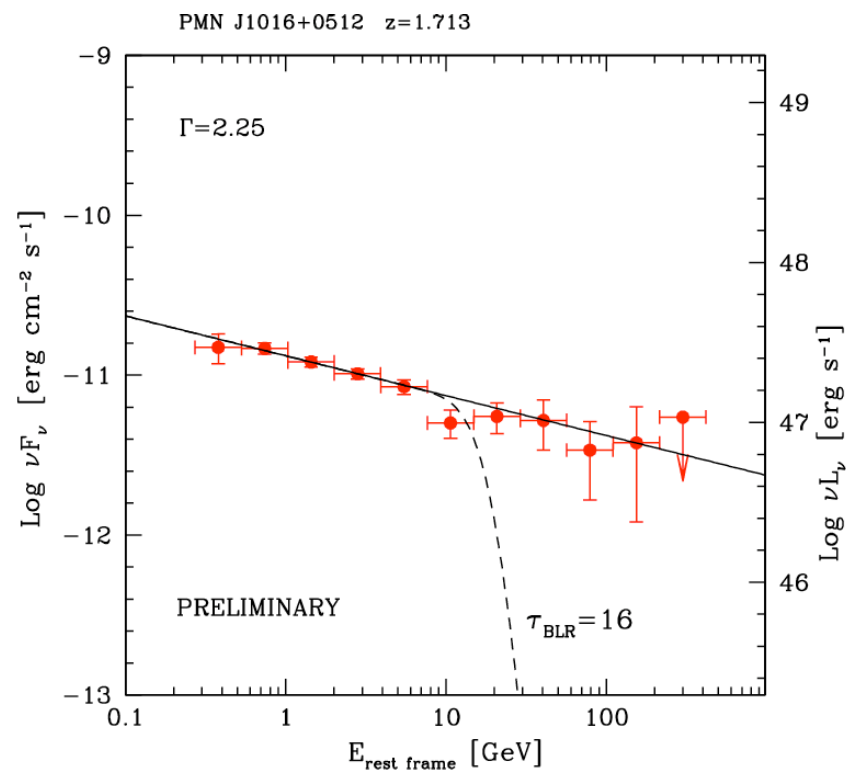


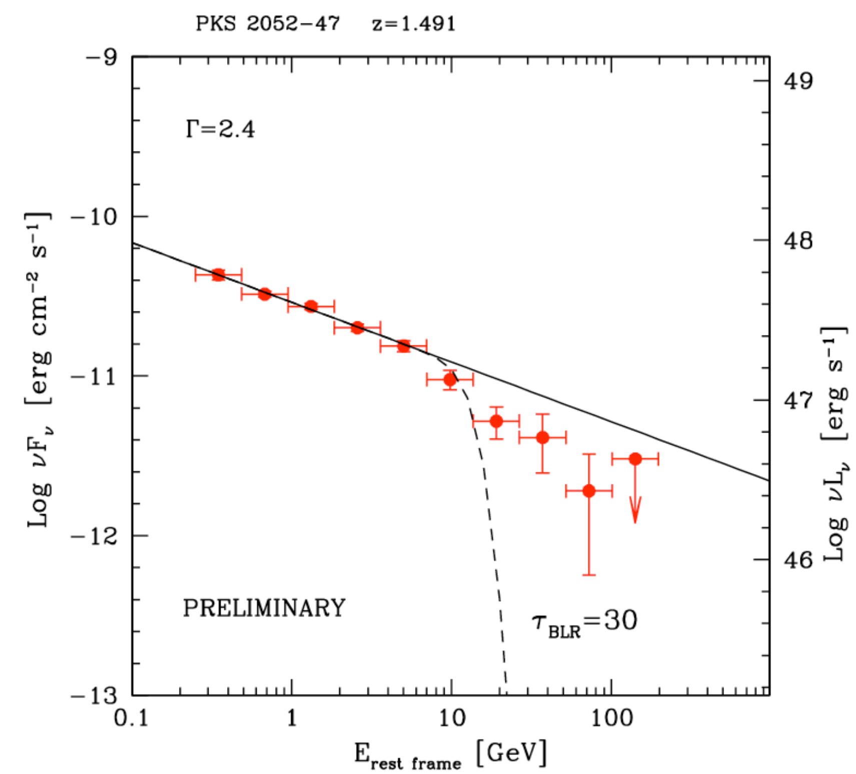
Also among the most powerful objects !

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} $\Rightarrow$ **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} $\Rightarrow$ **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} $\Rightarrow$ **τ_{BLR} > 30** !

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

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

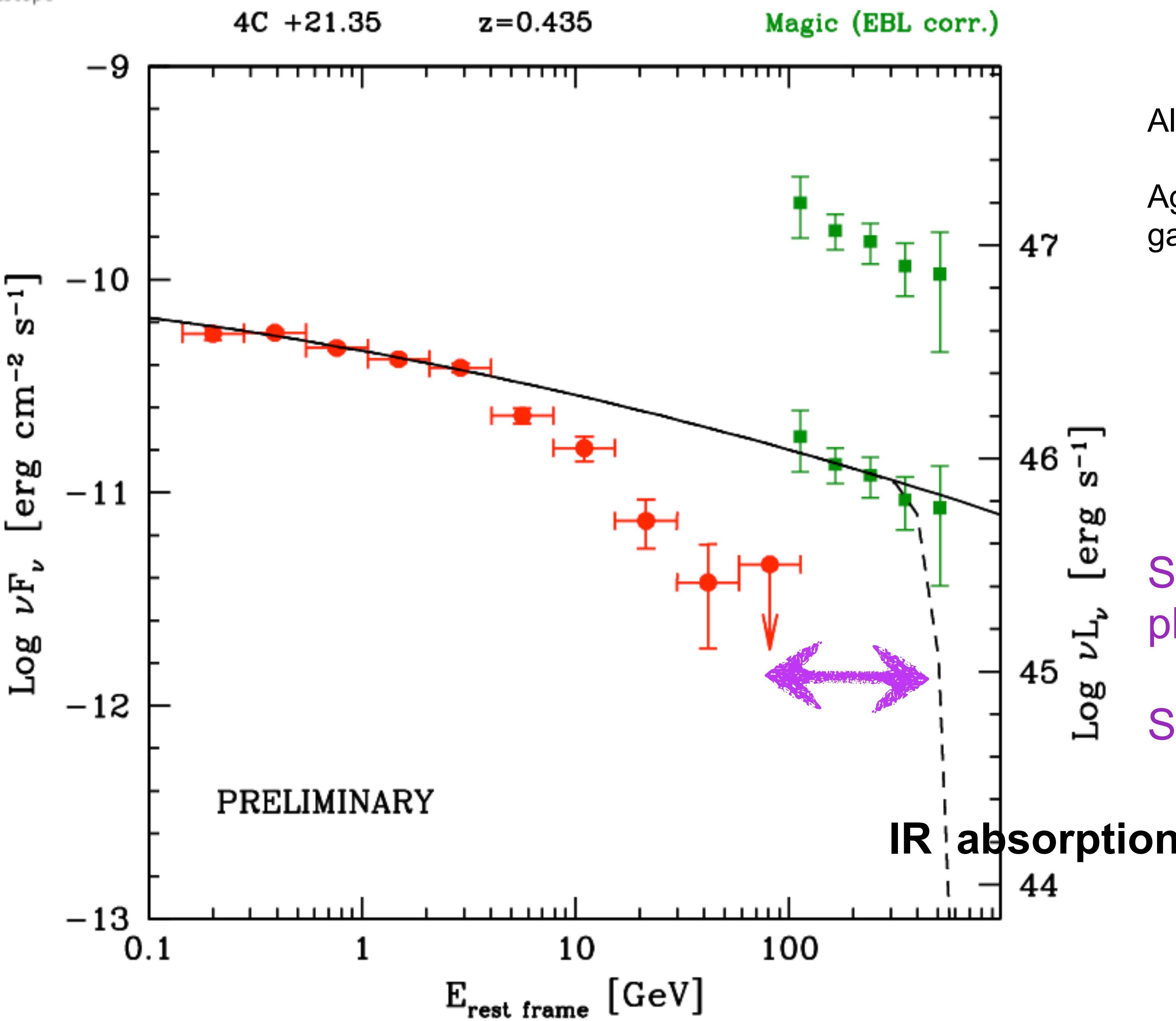
Confirmed by detection of FSRQ at VHE

Recently, some close-by FSRQ have been detected at VHE (80-300 GeV) :   4C 21.35 (MAGIC)   and PKS 1510-08 (HESS).

VHE detections would be impossible if emission comes from within the BLR (huge absorption, right at energies where tau is maximum)

So,   is EC on IR radiation from Hot Dust the solution ?

$R_{diss} > R_{BLR}$, so EC (HD) is ok ? Not really !



Aleksic et al. 2011 (MAGIC coll)

Again IR photons absorb VHE gamma-rays !

Survival zone for VHE photons is narrow !

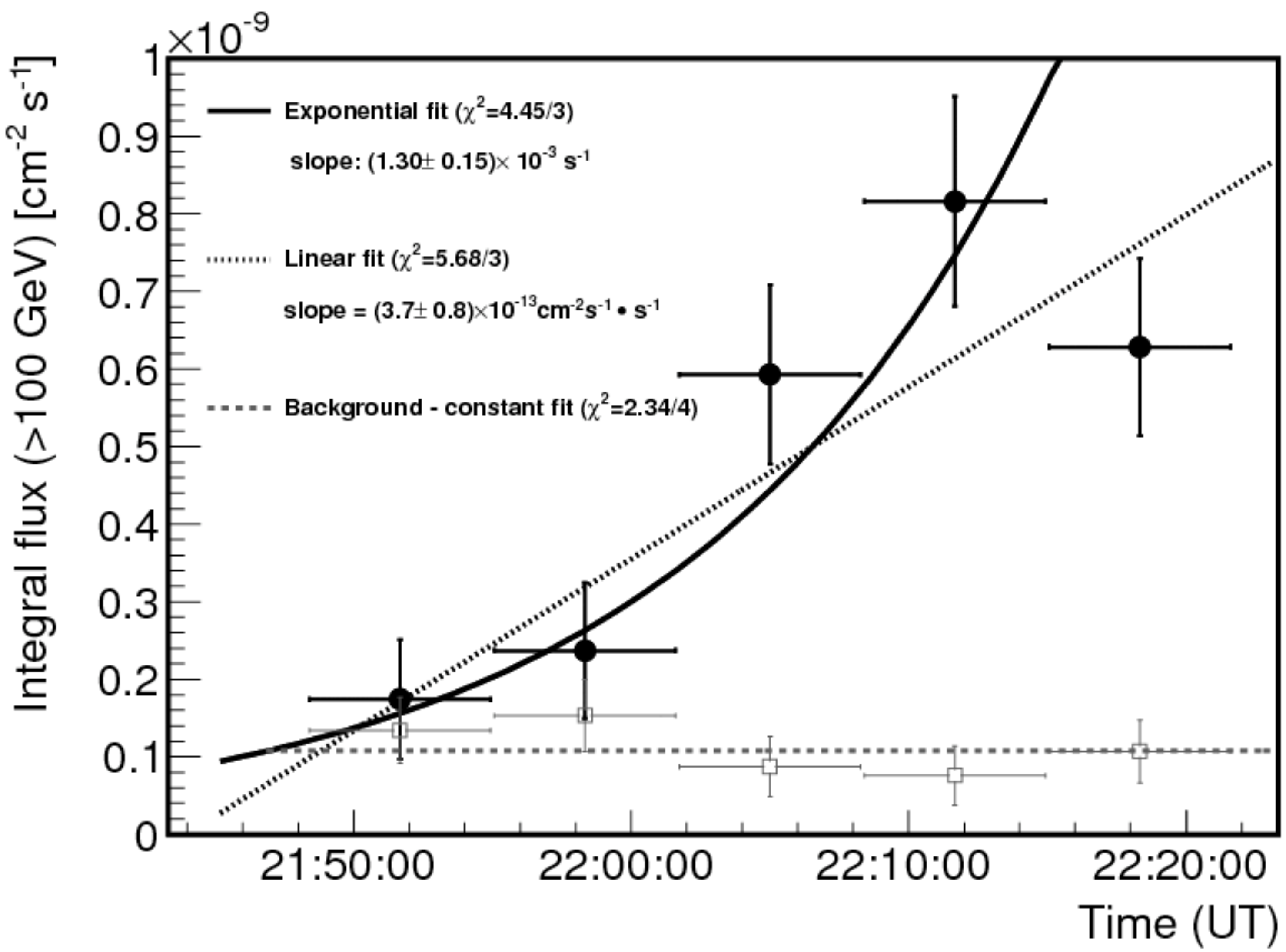
Same problem for 1510-08

4C 21.35 has strong IR emission from HD, T~1200K, $L_{IR} \sim 8\times10^{45}$ erg/s (Malmrose et al. 2011)

$R_{diss} > R_{BLR}$, so EC (HD) is ok ? Not really !

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

b) variability ~days-week



Aleksic et al. 2011 (MAGIC coll)

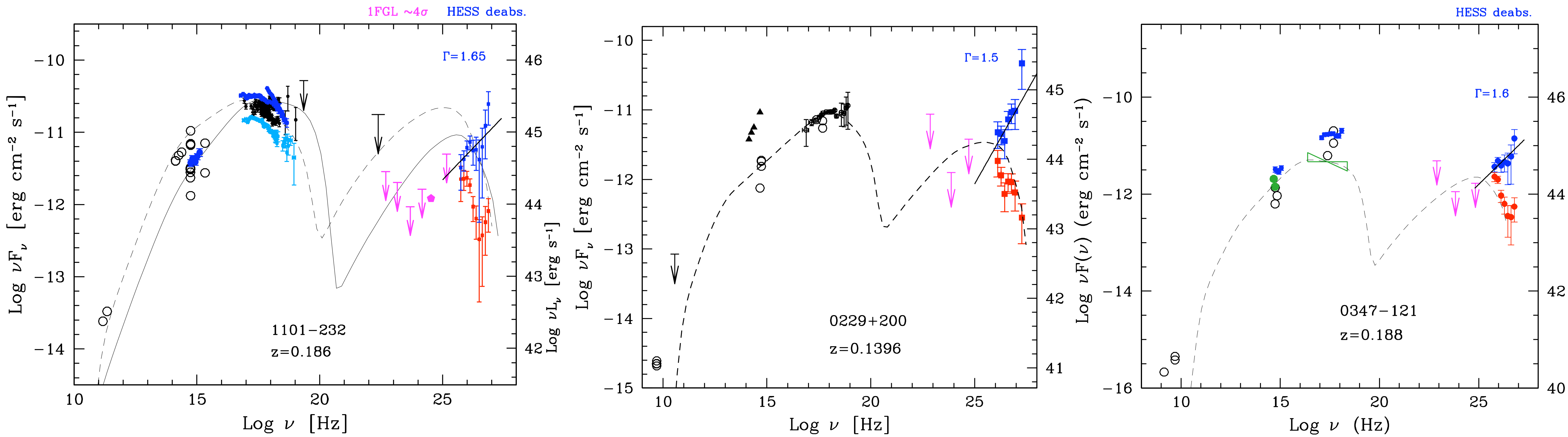
Instead, 10-min variability !

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

at several pc from Black Hole

At opposite end of blazar sequence:

New class of HBL is emerging: **HARD TEV BL LACS** or TeV-peaked HBL

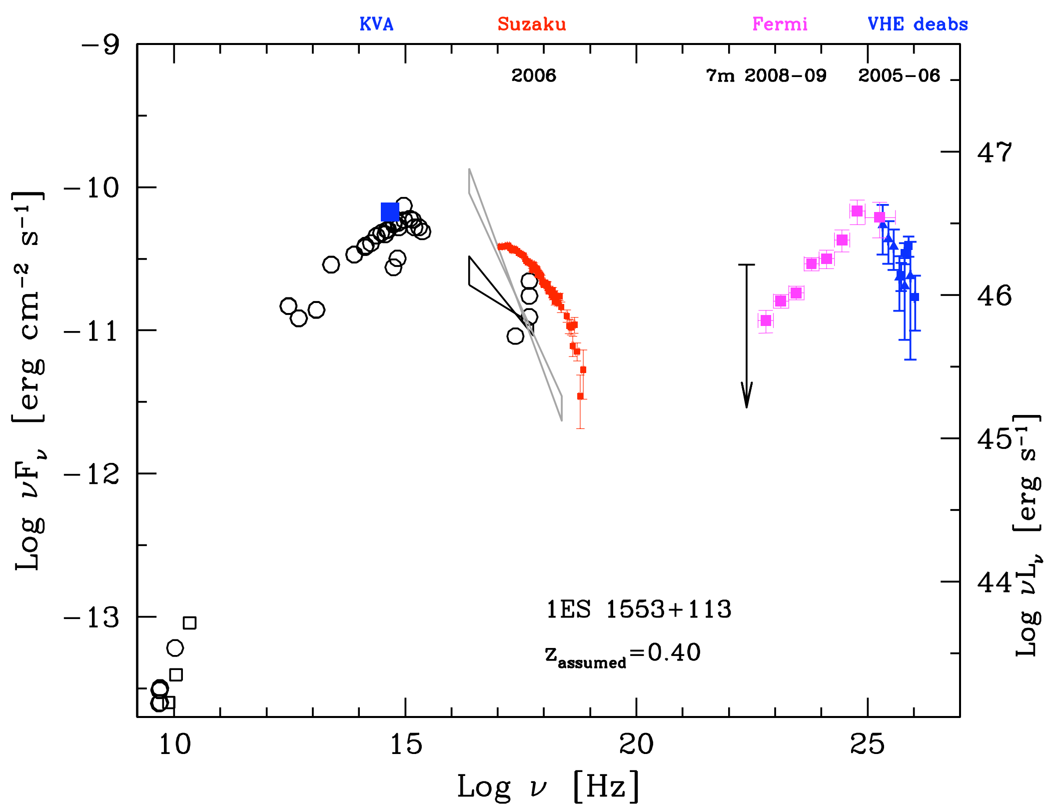


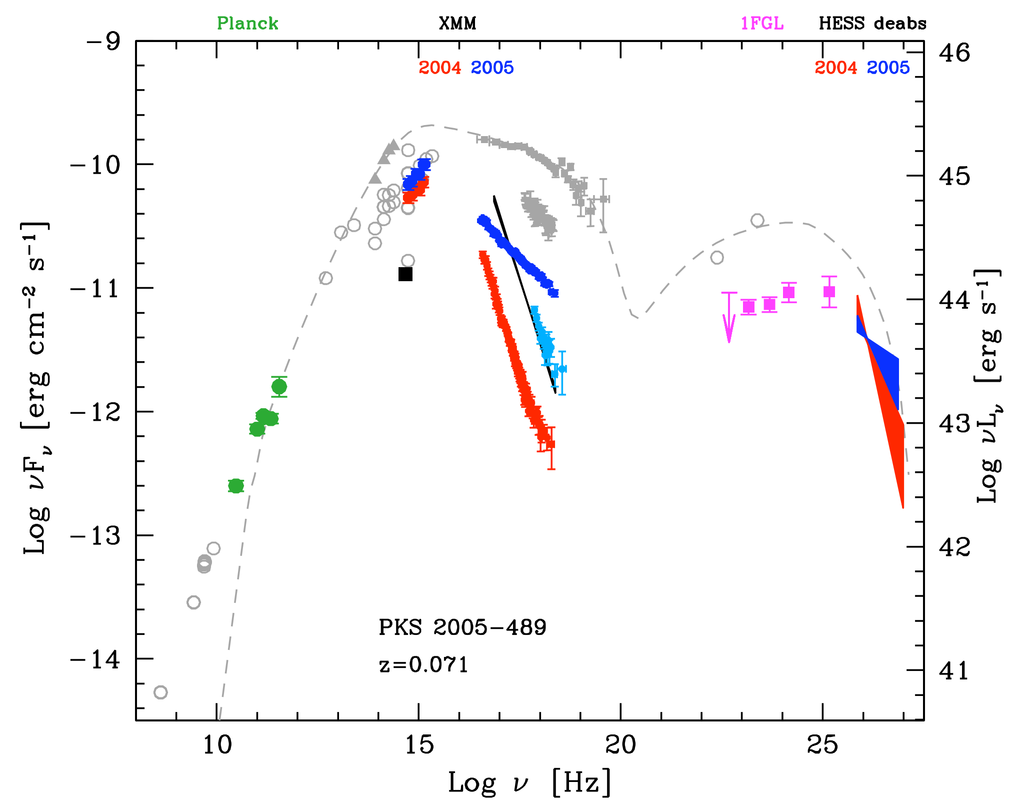
characterized by $\Gamma_{VHE} < 2$ (typically 1.5-1.7) with any EBL intensity (even lowest one).
⇒ IC peak ≥ 3-20 TeV

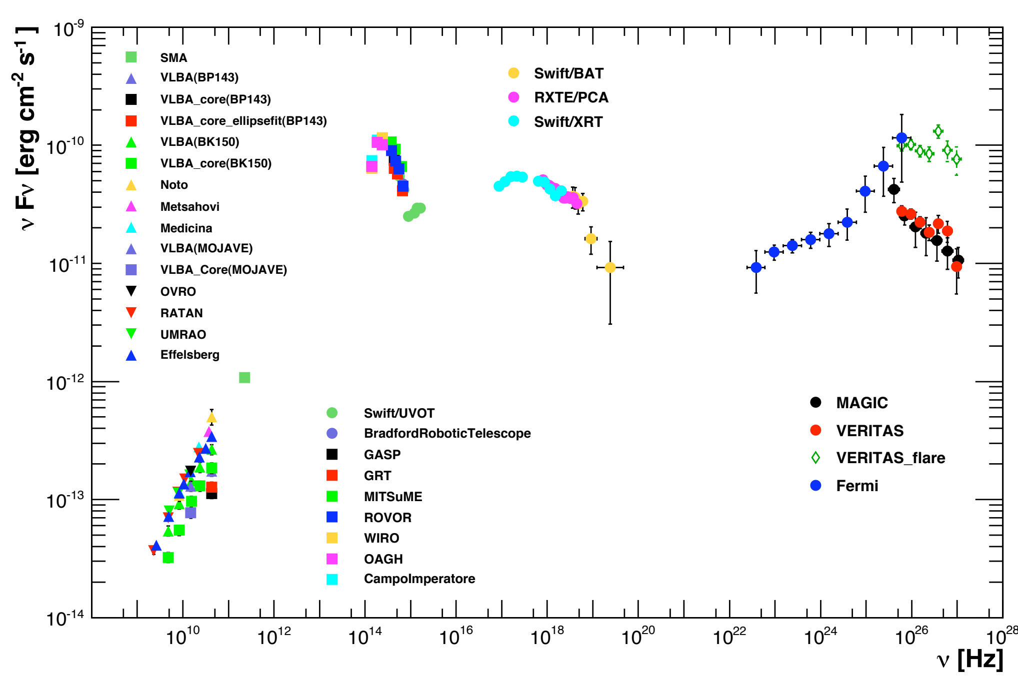
Extremely difficult to model witn one-zone SSC, due to Klein-Nishina effects at high energies. Many scenarios proposed (low-energy cutoff at very high energies, internal absorption, extended emission) but none satisfactory (need extreme parameters, B<mG, low radiative efficiency <<1%, additional ad hoc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

Different from the typical Fermi-bright HBL

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



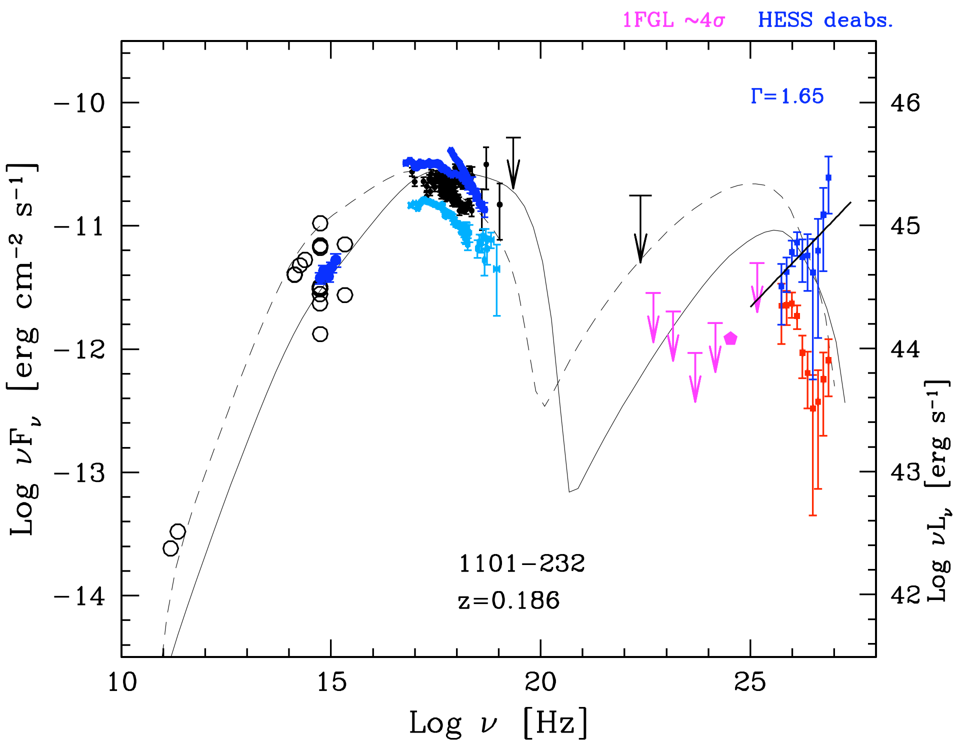


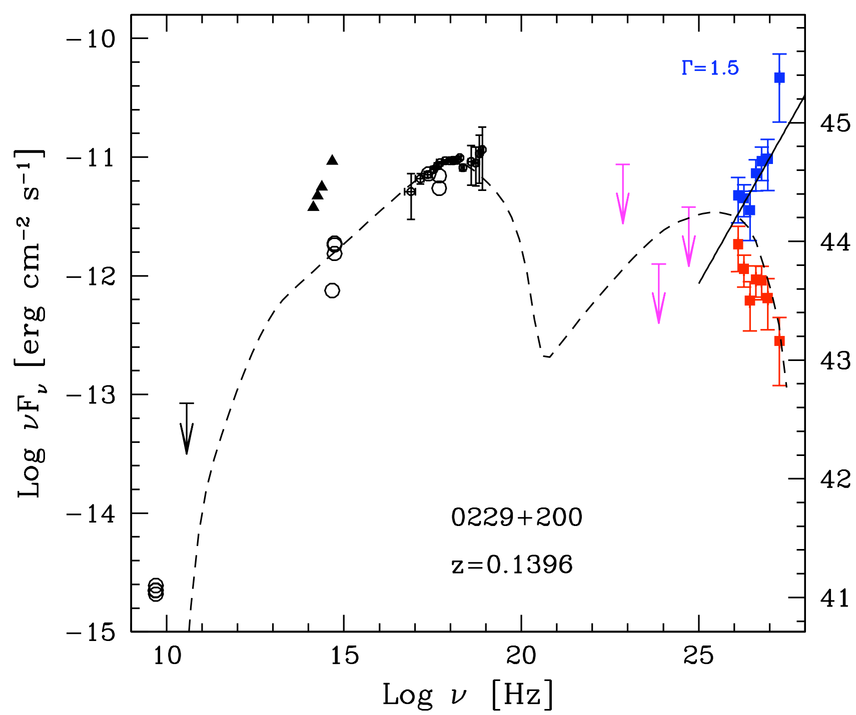


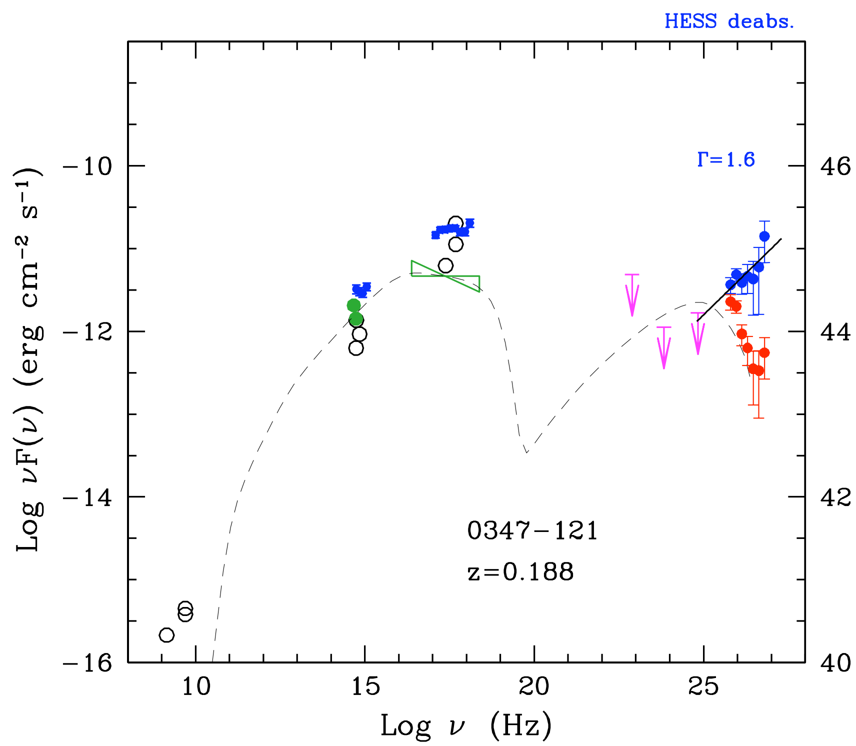
Abdo et al. (LAT coll) 2010a, 2010b, 2011

At opposite end of blazar sequence:

HARD TEV BL LACS: most challenging objects for particle acceleration and BLLacs emission models







Abdo et al. (LAT coll) 2010, Tavecchio et al 2010, Costamante et al. 2002, Aharonian et al (HESS coll) 2006-08.

How to find them ?
a) high X-ray flux + low-weak GeV flux
b) high X-ray/UV flux ratios: SWIFT campaign on-going

By end of the year, several new candidates for CT observations

Conclusions

- Fermi is providing indications that the Blazar-zone in some, even powerful FSRQ, must lie on average beyond the BLR ! ($\sim 10^{18}$ cm)
  ⇒ but EC on Hot Dust (IR) might not be the solution; variability problem !

- Growing number of HBL with the IC peak in the multi-TeV range ! Very problematic for one-zone SSC models, stretched parameters

- At both ends of the blazar sequence, we are missing some fundamental aspects of the physics and/or structure of these objects.

Back-up slides

CAVEATS !

- **Variability**
  - different zones in time, inside or outside BLR
  - absorption features can come and go (should be present during fast flares, ≲1-2 days; if compact means closer to BH)
  - answers from temporal clustering of high energy photons
    NB: expected anti-correlation F>10 GeV vs F<10GeV !!

- **Geometry of BLR region**
  - if flattened onto accretion disk (e.g. Gaskell 2009) ⇒ anisotropic angle
  - $E_{threshold}$ of γ-γ can be shifted at higher energies
  - This affects EC mechanism as well (lower energy density, redshifted ν_{ext}). EC(UV) might not be so efficient (though it is a way to avoid KN effects)

- **Statistics**
  - still very few photons at highest energies (typically 3-10)

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).

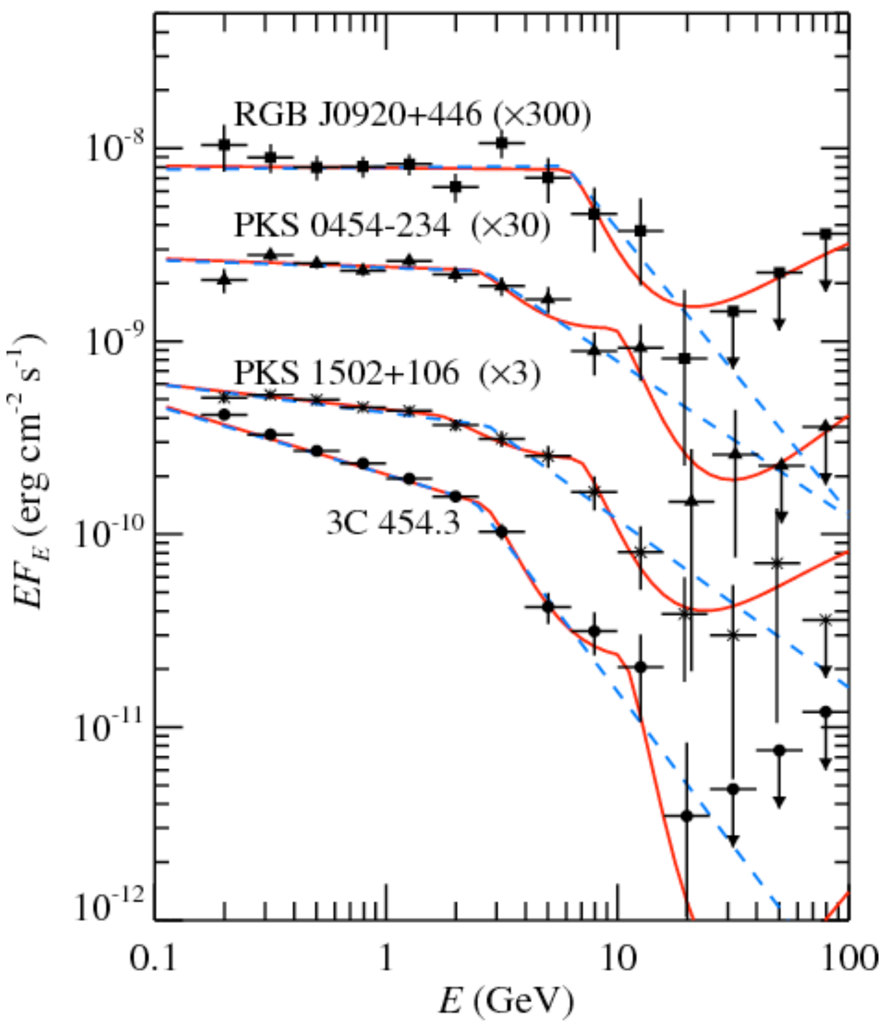


Table 2
Spectral Properties of Blazars

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

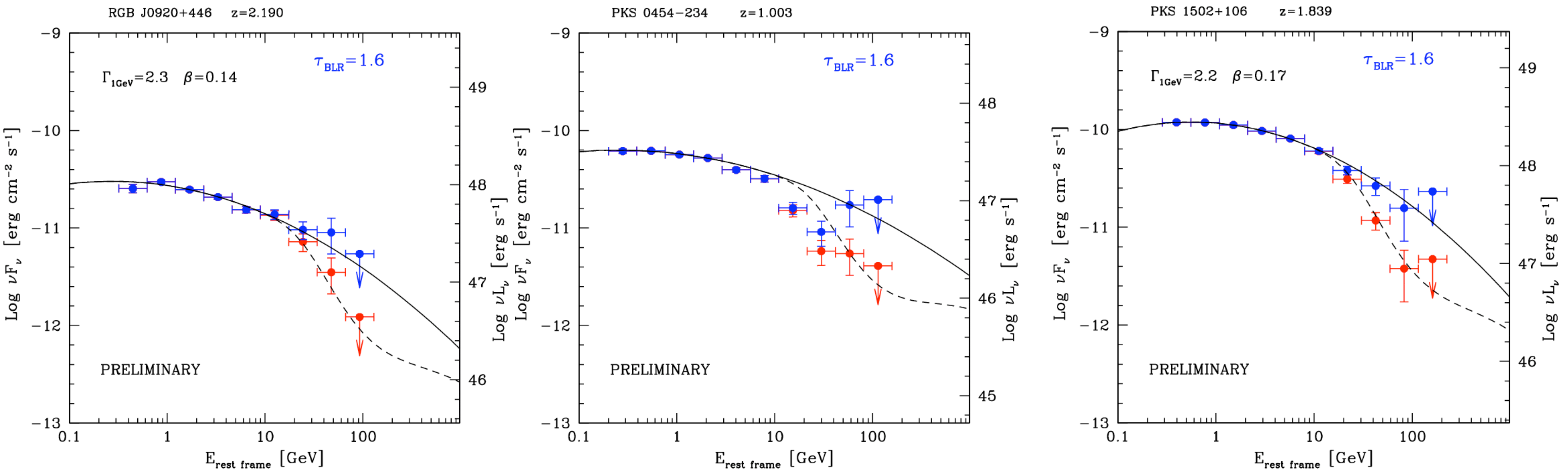
Note. The number of degrees of freedom is 12 for the power-law model and 10 for other models.

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.

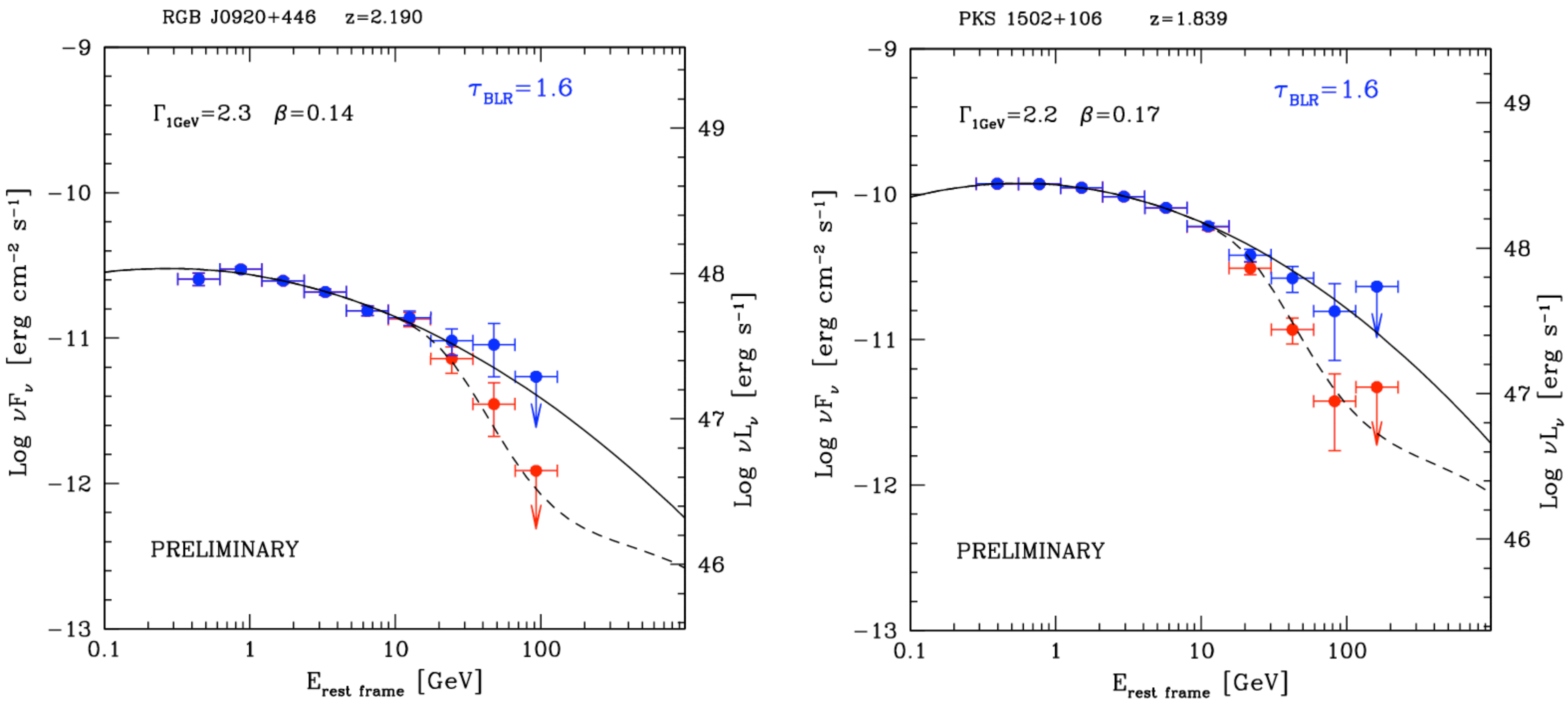
Where Poutanen & Stern 2010 does not work



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

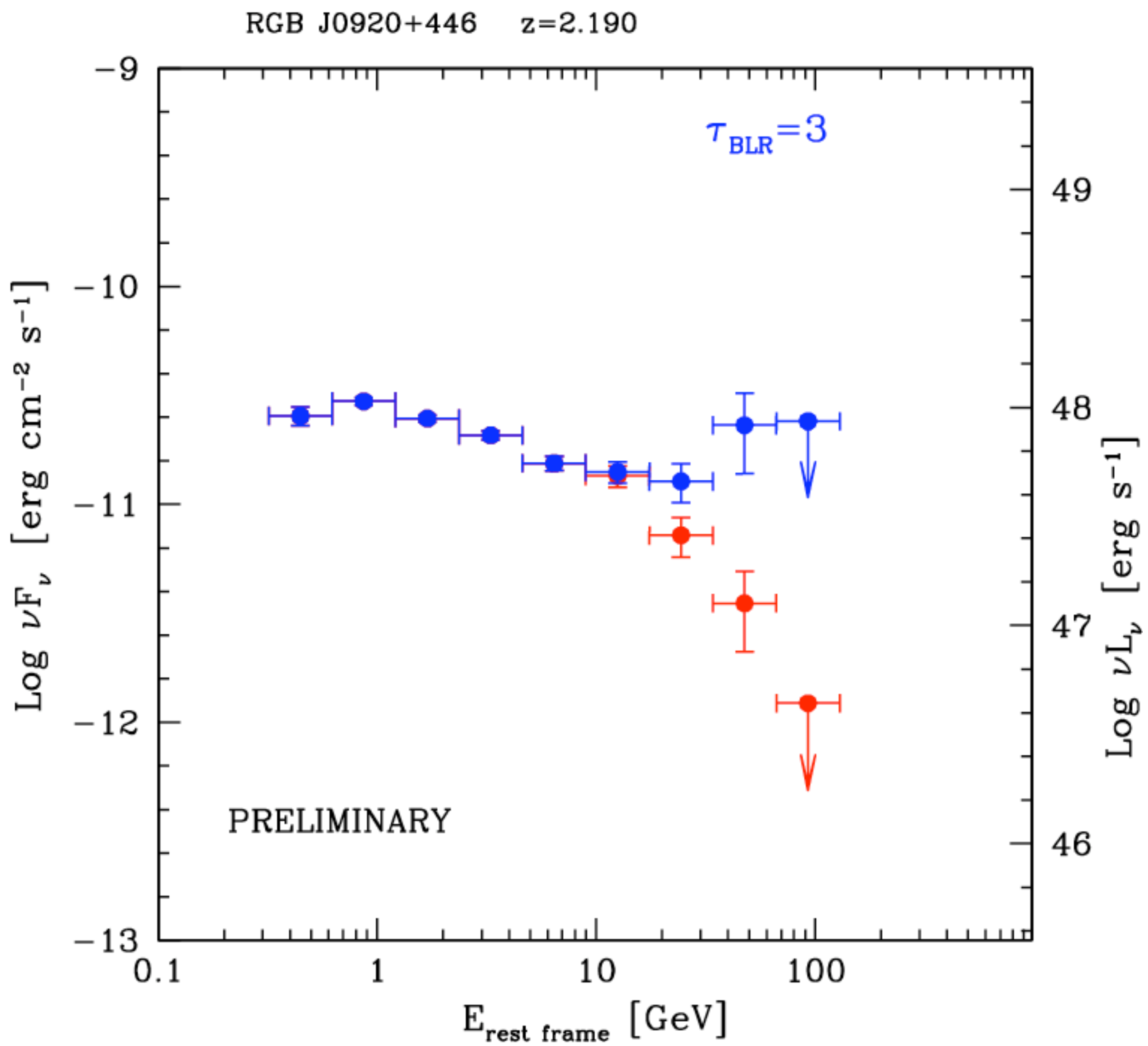


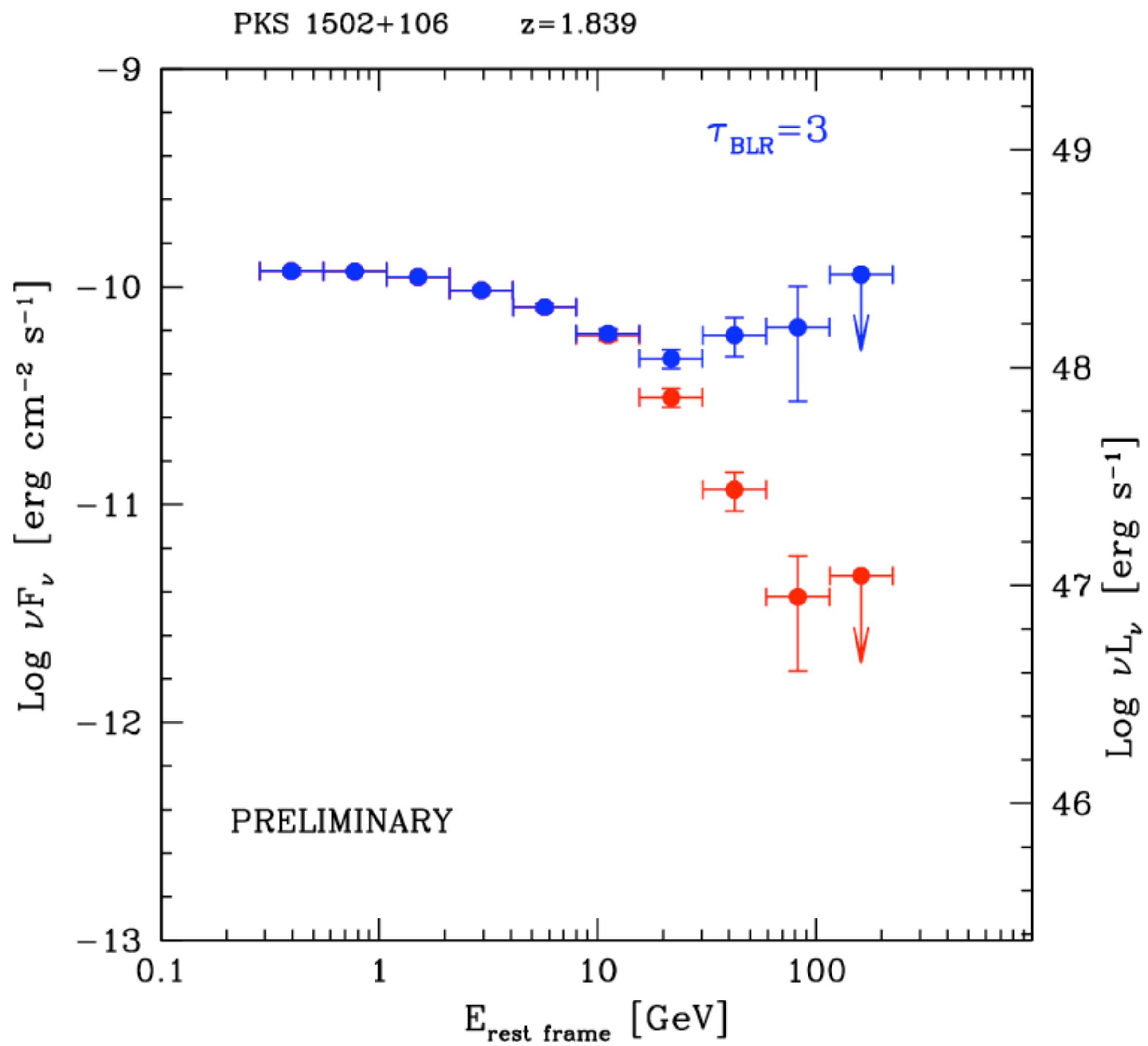
Only moderate (τ ~1-2), corresponding to $R_{diss} \cong R_{BLR}$

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

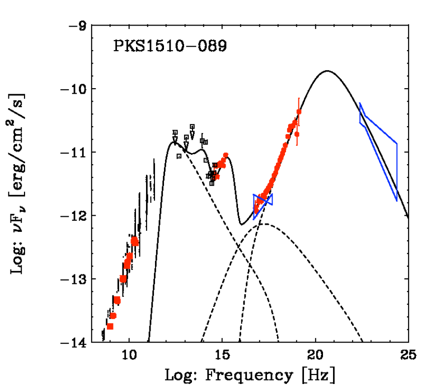
Some objects compatible with mild BLR absorption

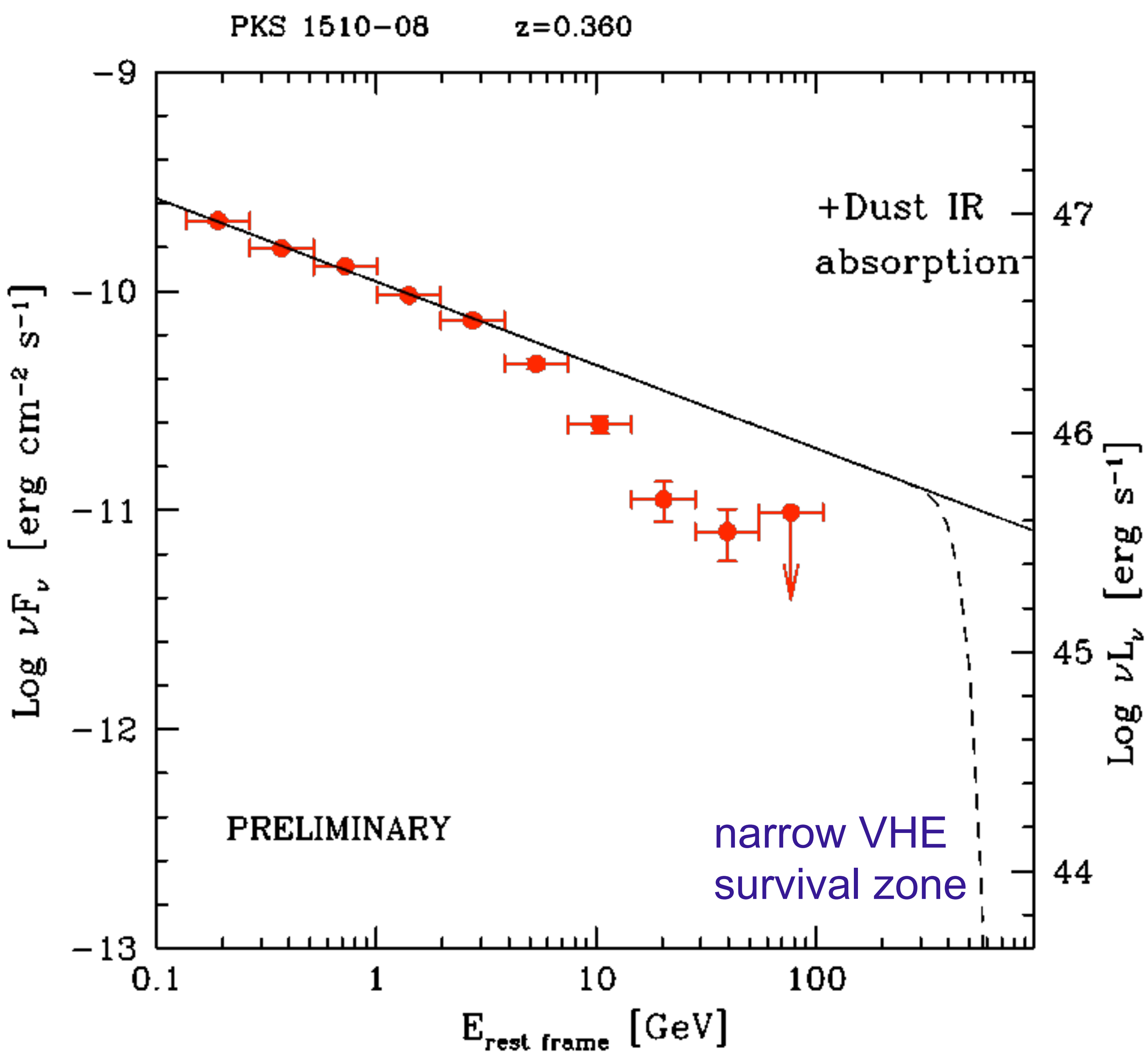
Already with $\tau \geq 3$ (path just a few 10^{16} cm), absorption would become too strong, requiring a second gamma-ray component in the SED





Same problem with PKS 1510-08





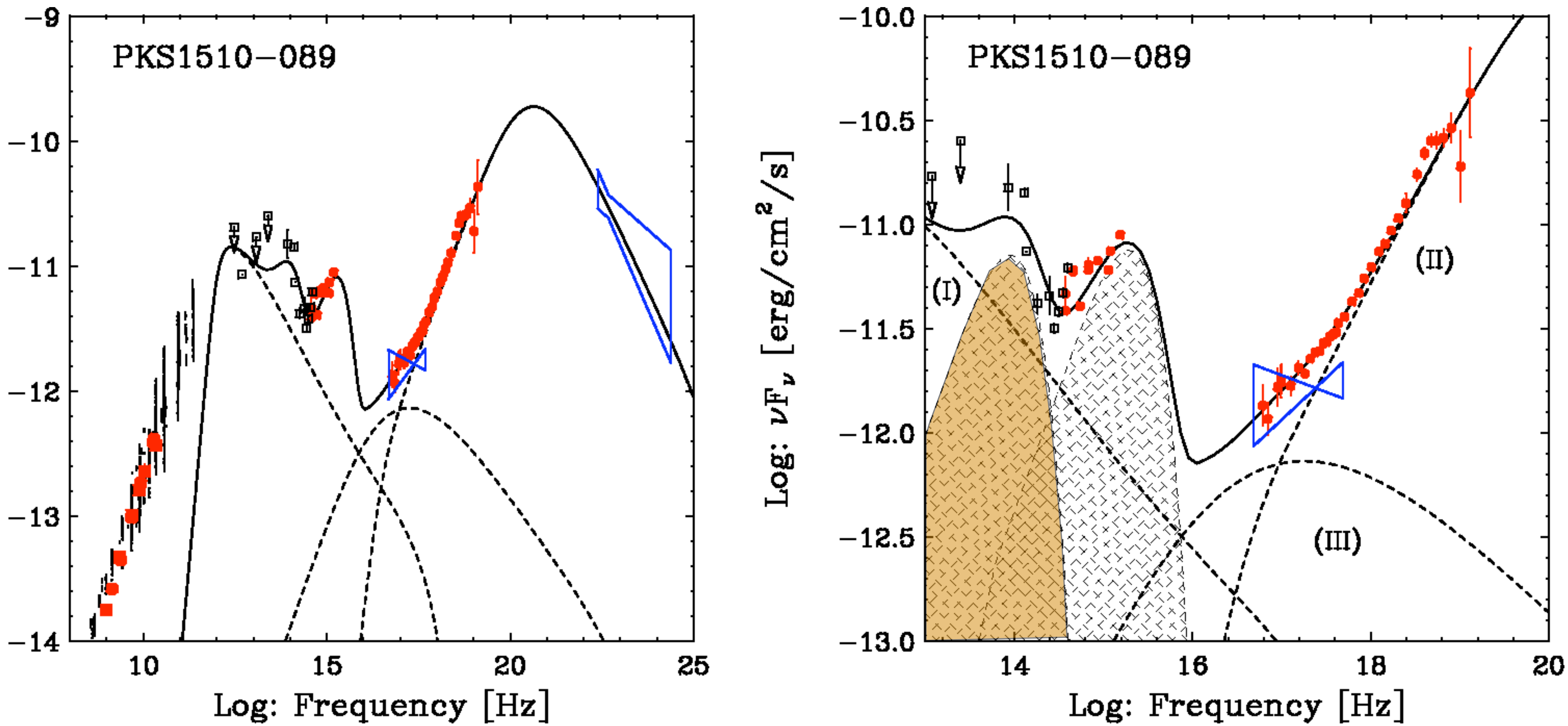
Dust IR parameters from Kataoka et al. 2008

If $R_{diss} < R_{dust}$, IR intensity needed to model the SED with a high Compton Dominance via EC (e.g. Kataoka et al. 2008) implies huge TeV absorption !

If the HESS observed spectrum extends well above ~300 GeV, **BIG PROBLEM !**

PKS 1510-08: Kataoka et al. 2008

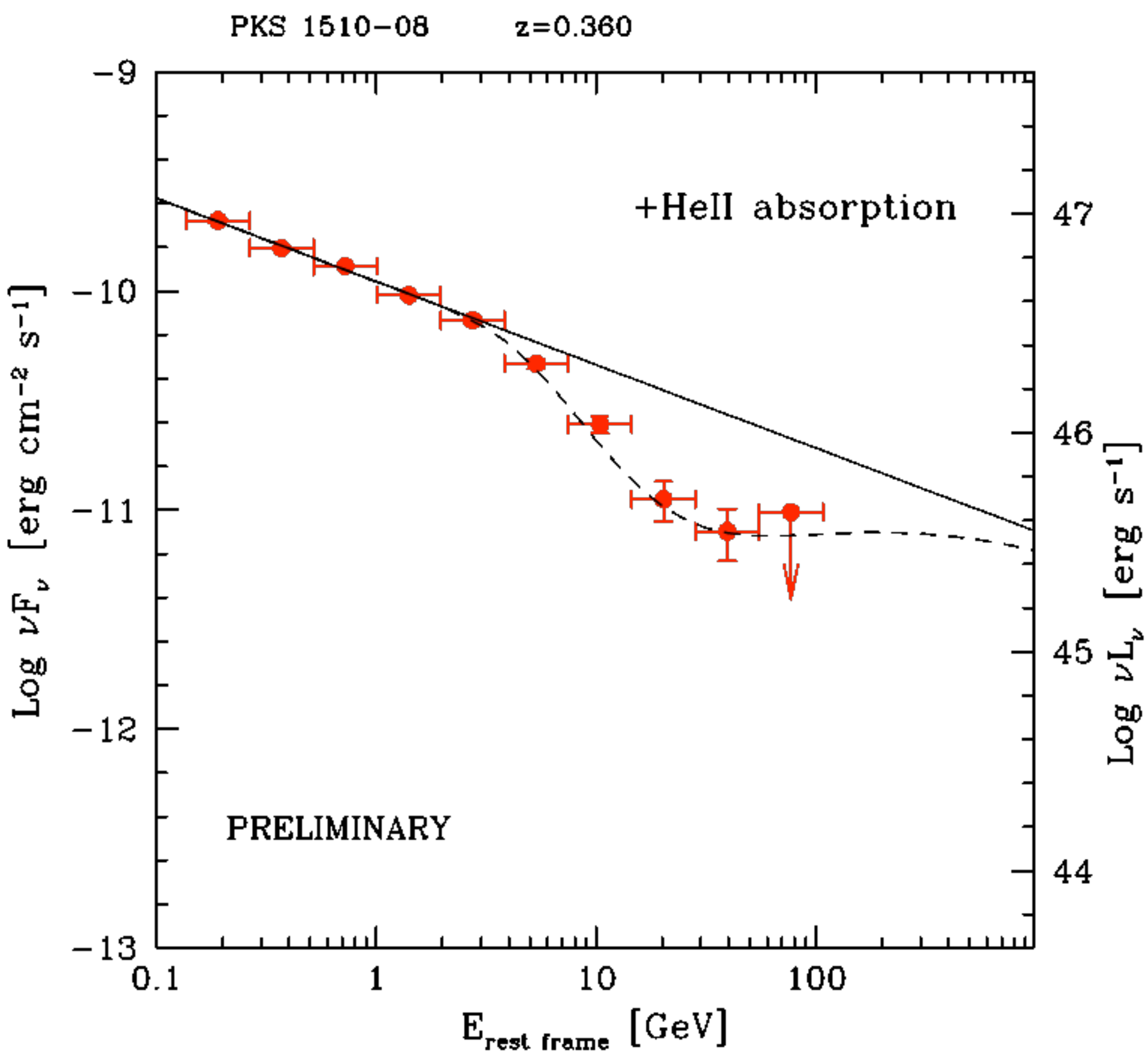
EC over **Hot Dust Radiation** (Sikora et al), as BlackBody @ 0.2 eV



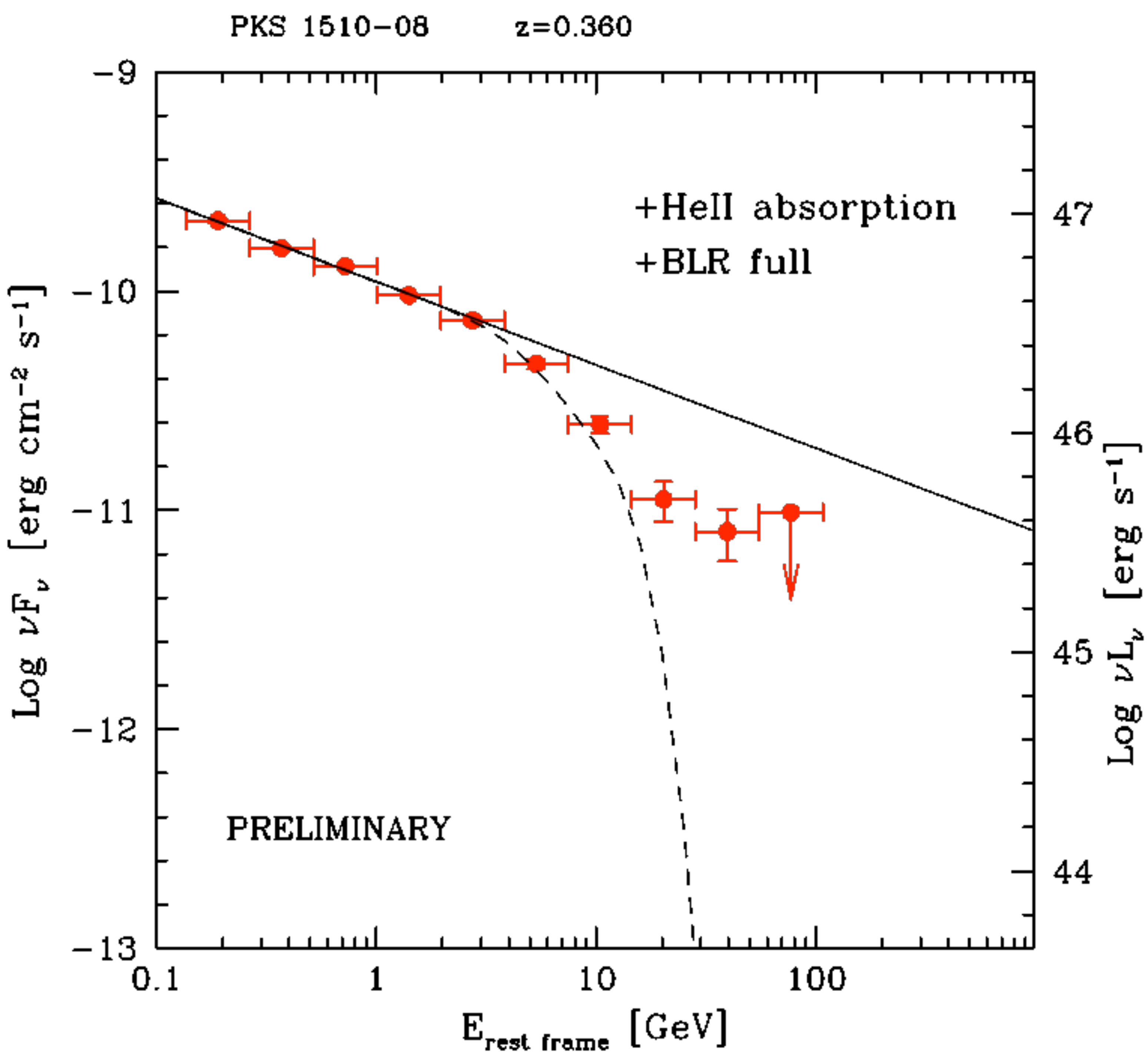
e.g. with $L_{HDR} \sim 1\times10^{45}$ erg/s $R_{HDR} \sim 3\times10^{18}$ cm

$\tau_{HDR} >> 100$

An interesting case: PKS 1510-08



An interesting case: PKS 1510-08



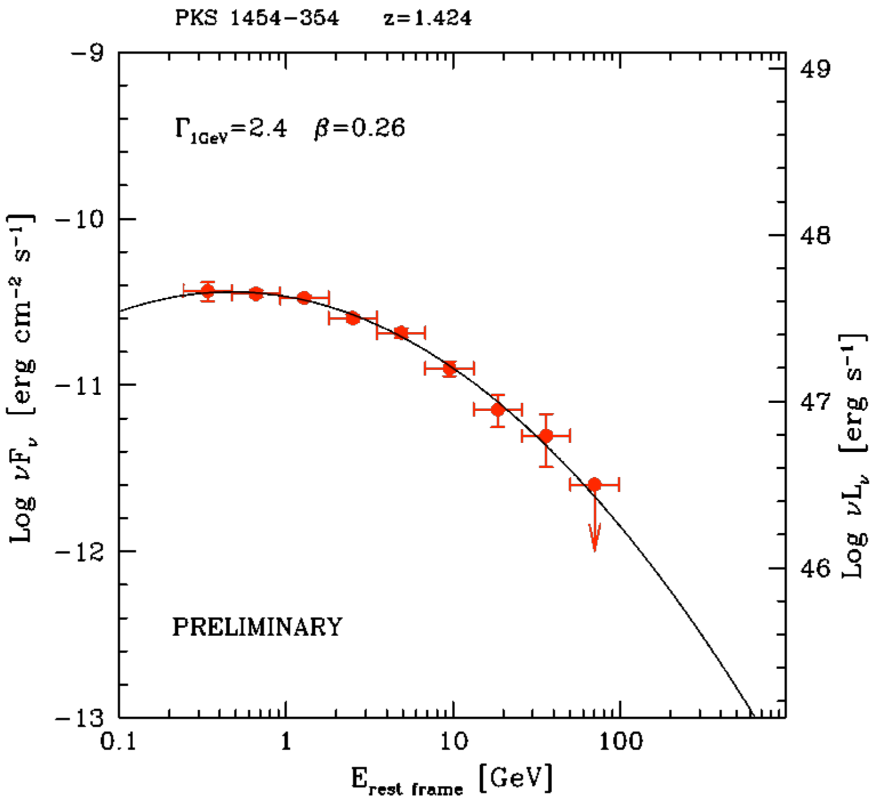
$\tau_{BLR} > 6\ \ell_{17}$

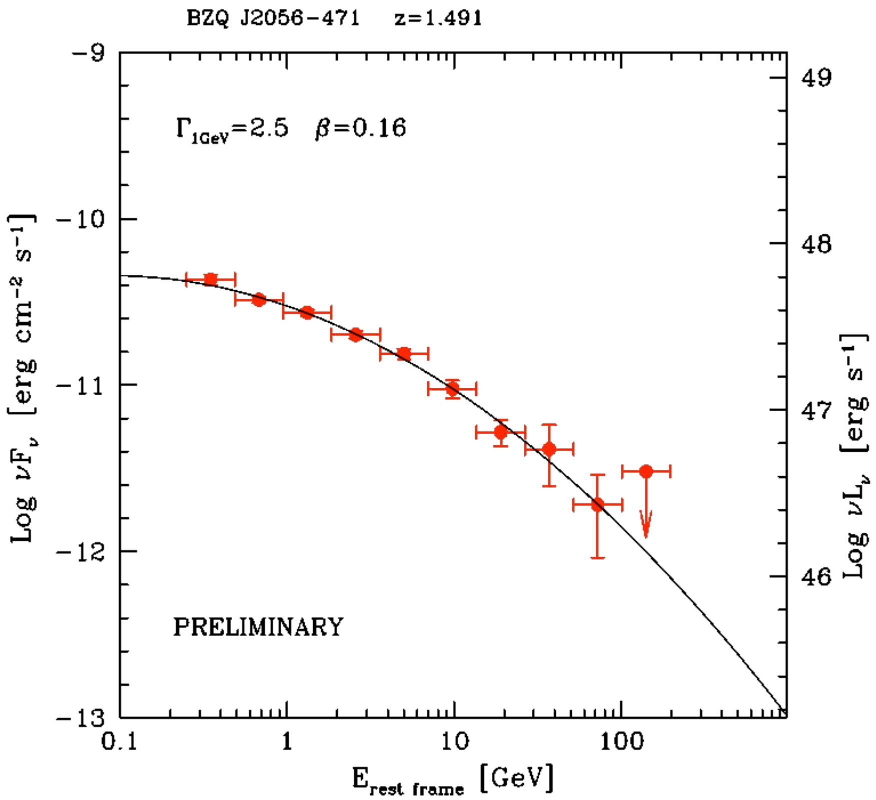
e.g. with
$L_{disk} \sim 9\times10^{45}$ erg/s
$R_{blr} \sim 3\times10^{17}$ cm

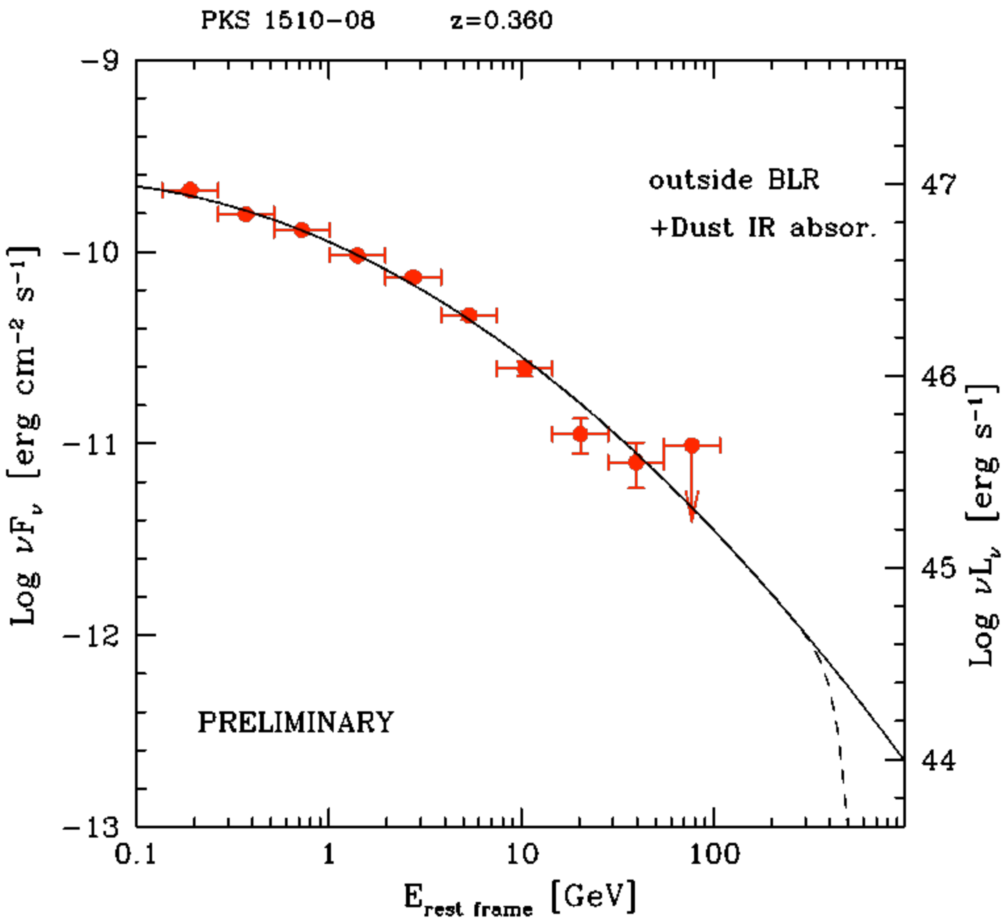
(Maraschi & Tavecchio 2003, Abdo et al. 2010)

Also possible the superposition of multi components:
high flux/flares = inside BLR + low, steadier flux = outside BLR

back-up slides







Band >10 GeV: lots of diagnostics !

If EC is the main γ-ray emission mechanism: @ ~2-10 GeV (restframe), additional possible steepening due to Klein-Nishina effects !

☛ if Lc/Ls~1 **or** Lc/Ls >>1 & BLR spectrum is broad banded
⇒ cooling of e^{+-} in Thomson ⇒ steepening

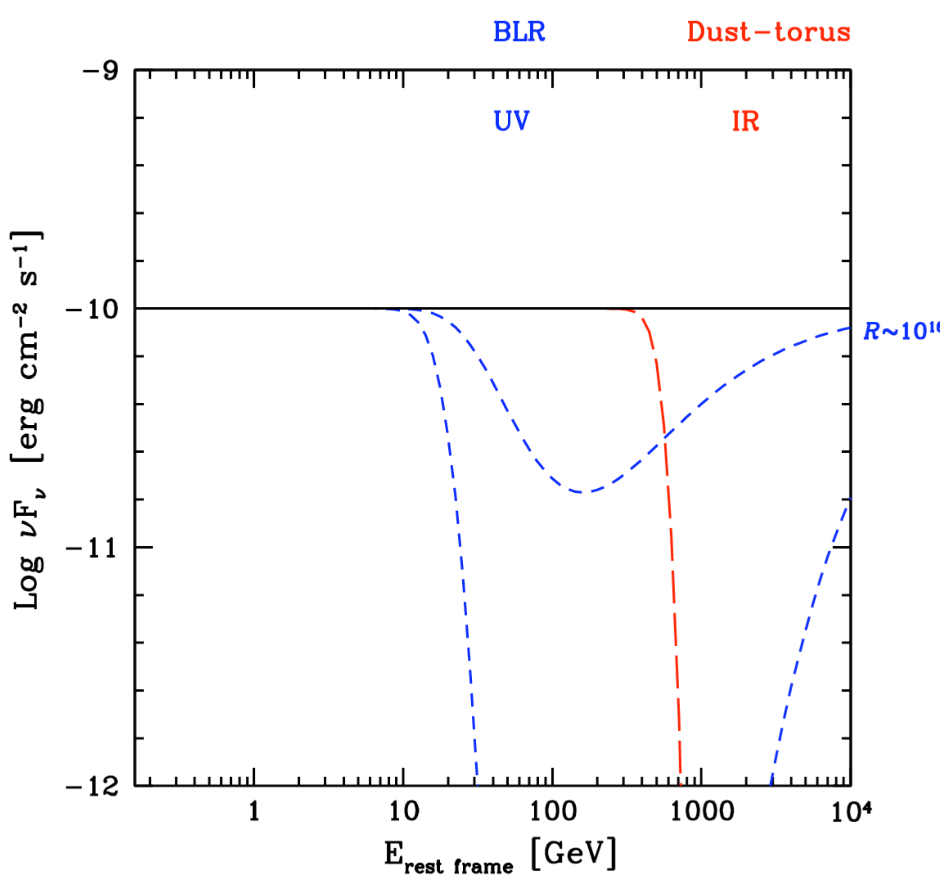
☛ if Lc/Ls >>1 & BLR is narrow banded ⇒ no steepening !
compensated by hardening of the particle distribution when cooling is in KN regime
(e.g. Zidjarski 1989, Dermer et al. 2003, Moderski et al. 2005, Ghisellini et al. 2009)

Presence or absence of cut-offs, tells:

⇒ R_{diss} < or > R_{BLR}

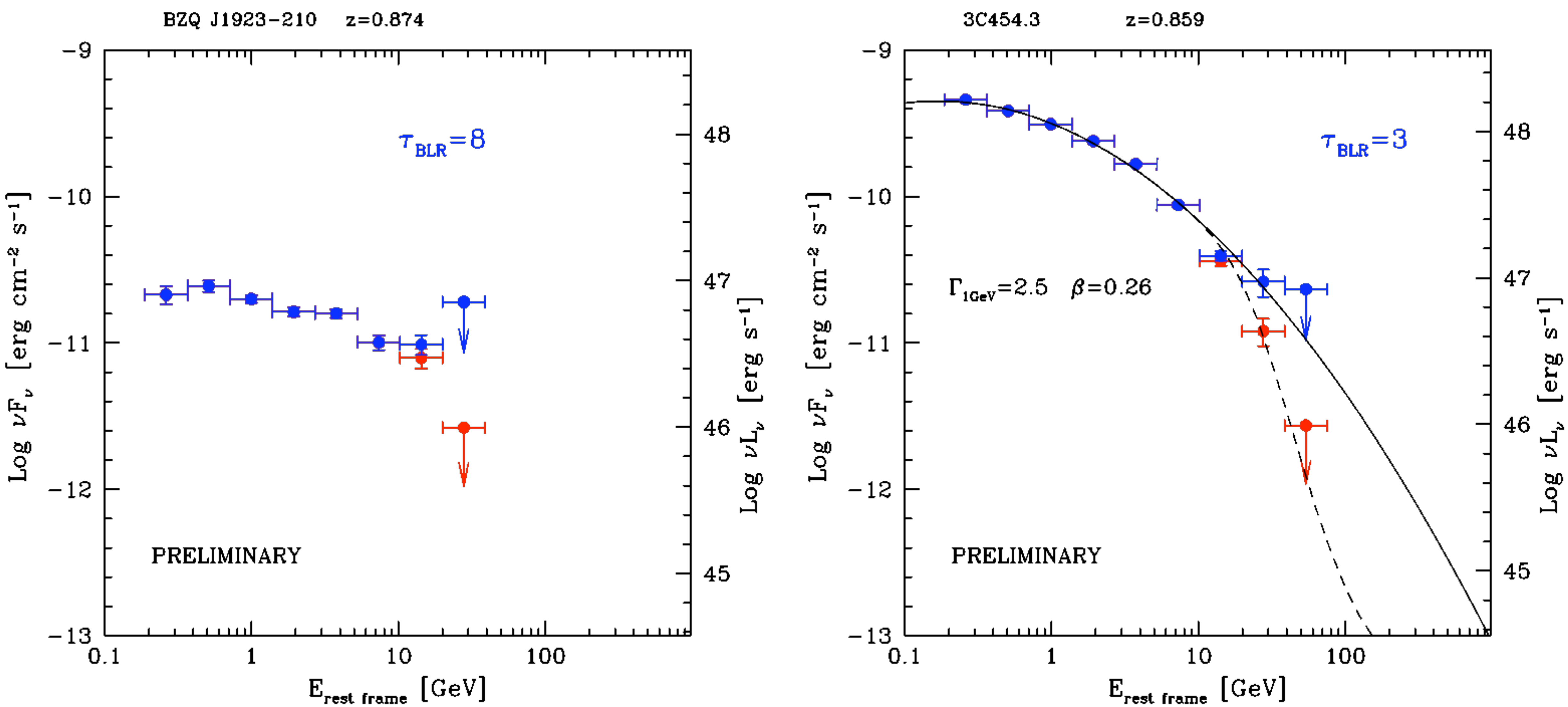
⇒ intensity of cutoff gives an estimate of the photon path inside the BLR

⇒ which EC is viable: UV or IR photons



Some objects are compatible with stronger BLR absorption

In such cases the gamma-ray emitting zone could be inside the BLR



$R_{diss} < R_{blr}$