16th Agile Science Workshop, ASI, Rome, May 2018

Gamma-rays from broad-lined Blazars: *Which origin ?*

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Strong vs Weak Lined Blazars

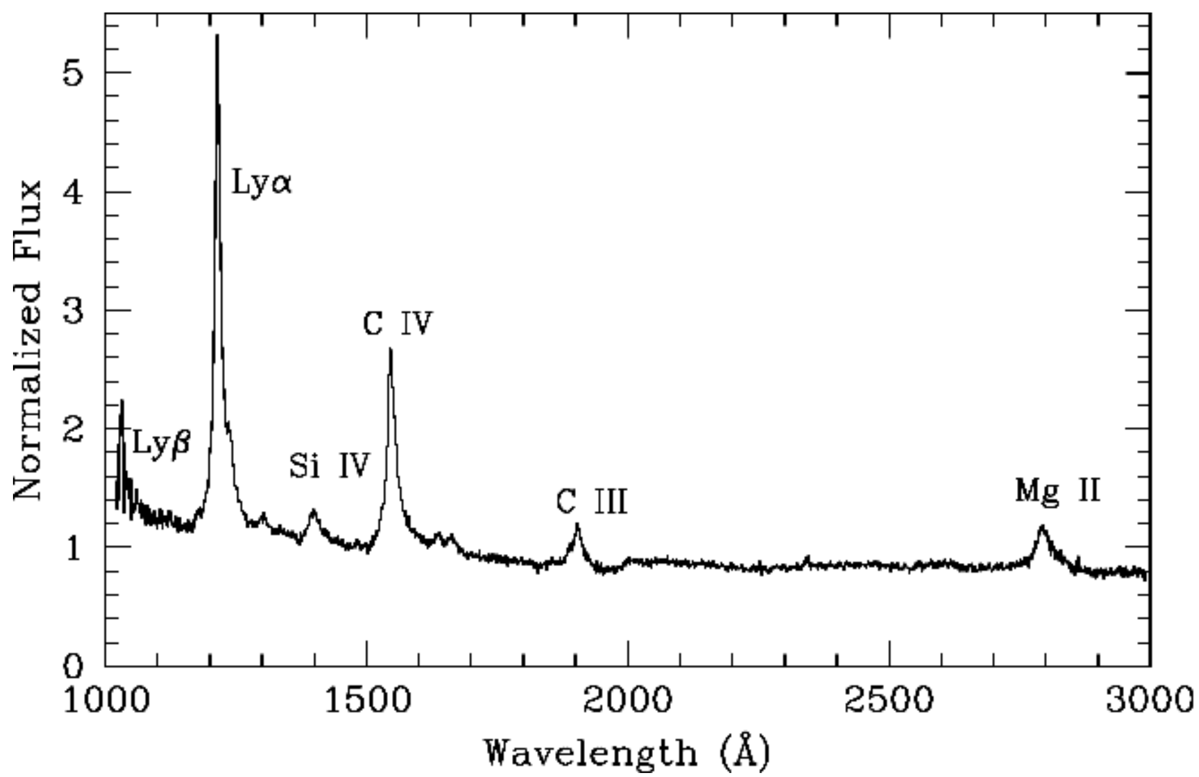
FSRQ (FR II) | **BL Lacs** (FR I)

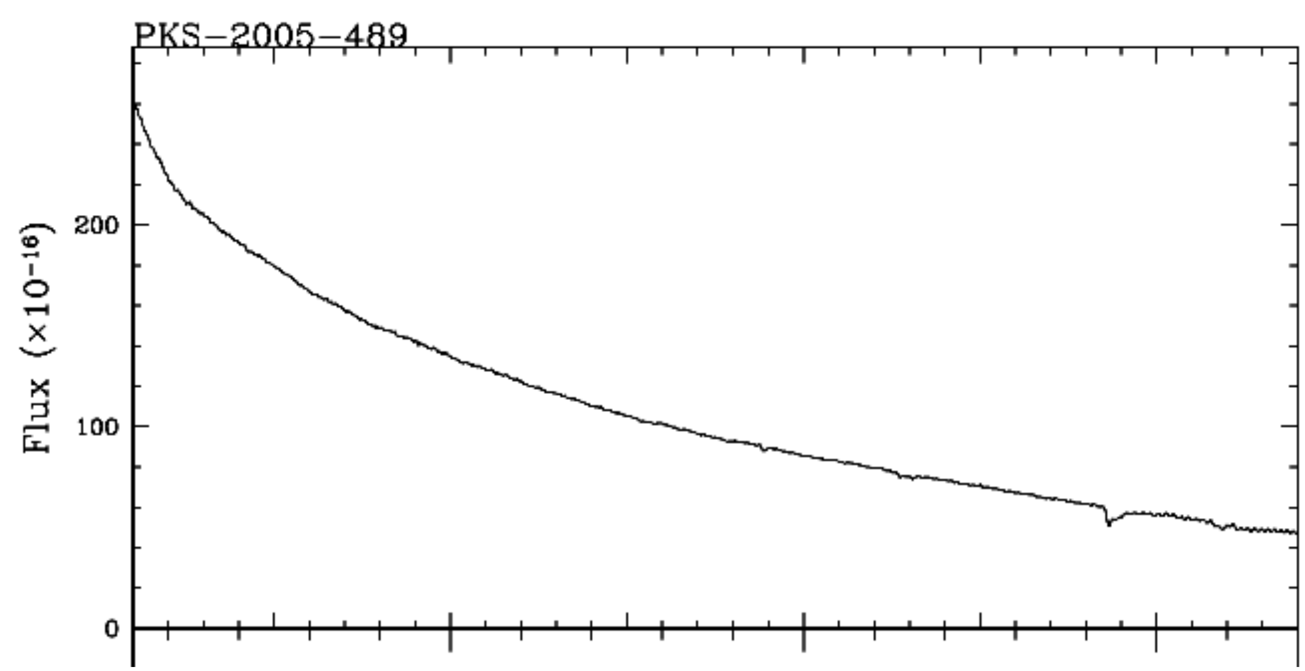
Broad Emission Lines:

EW>5 Å | **EW<5 Å**

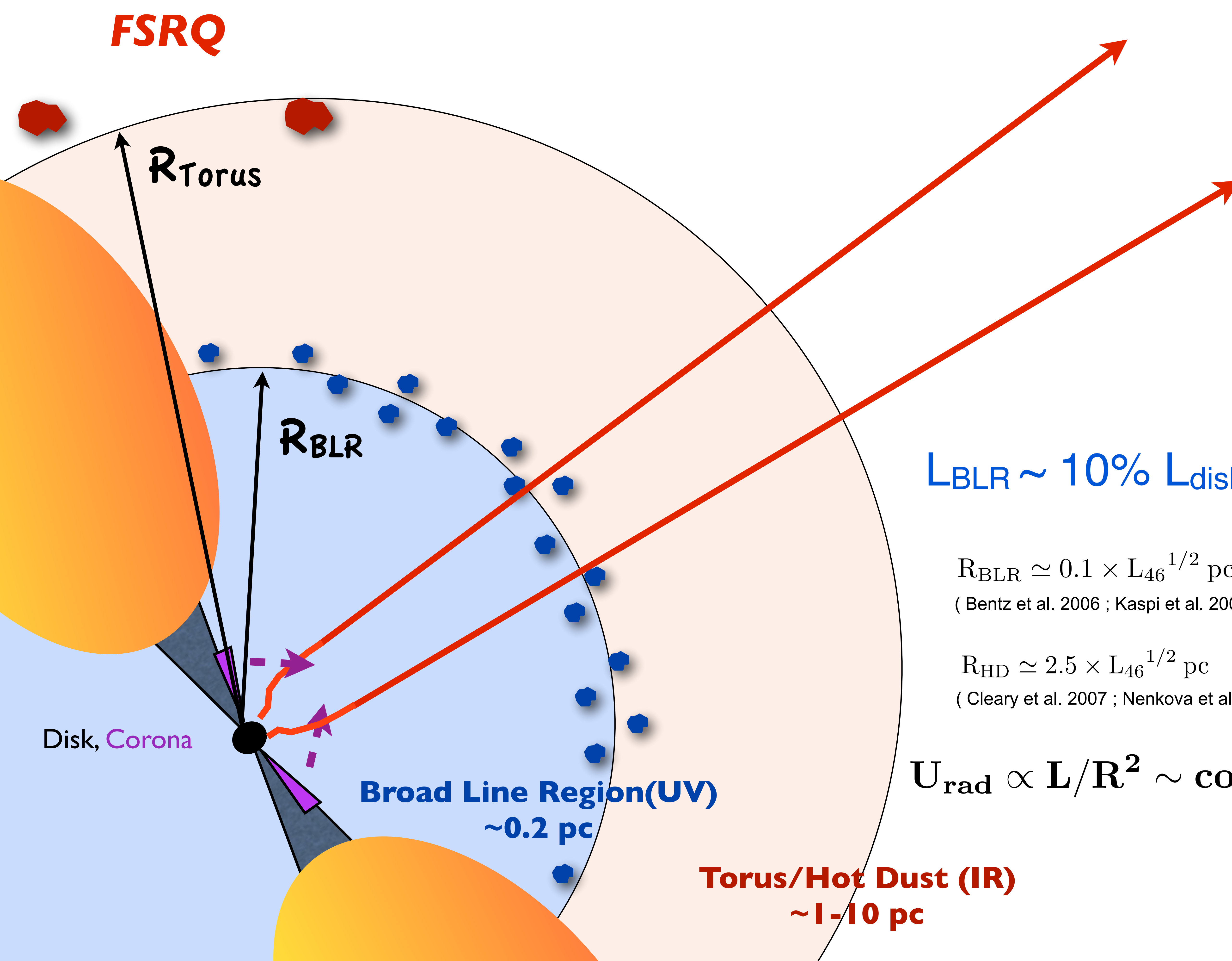
Continuum range of EW and line luminosities:

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





Pian et al. 2005



$L_{BLR} \sim 10\%\ L_{disk}$

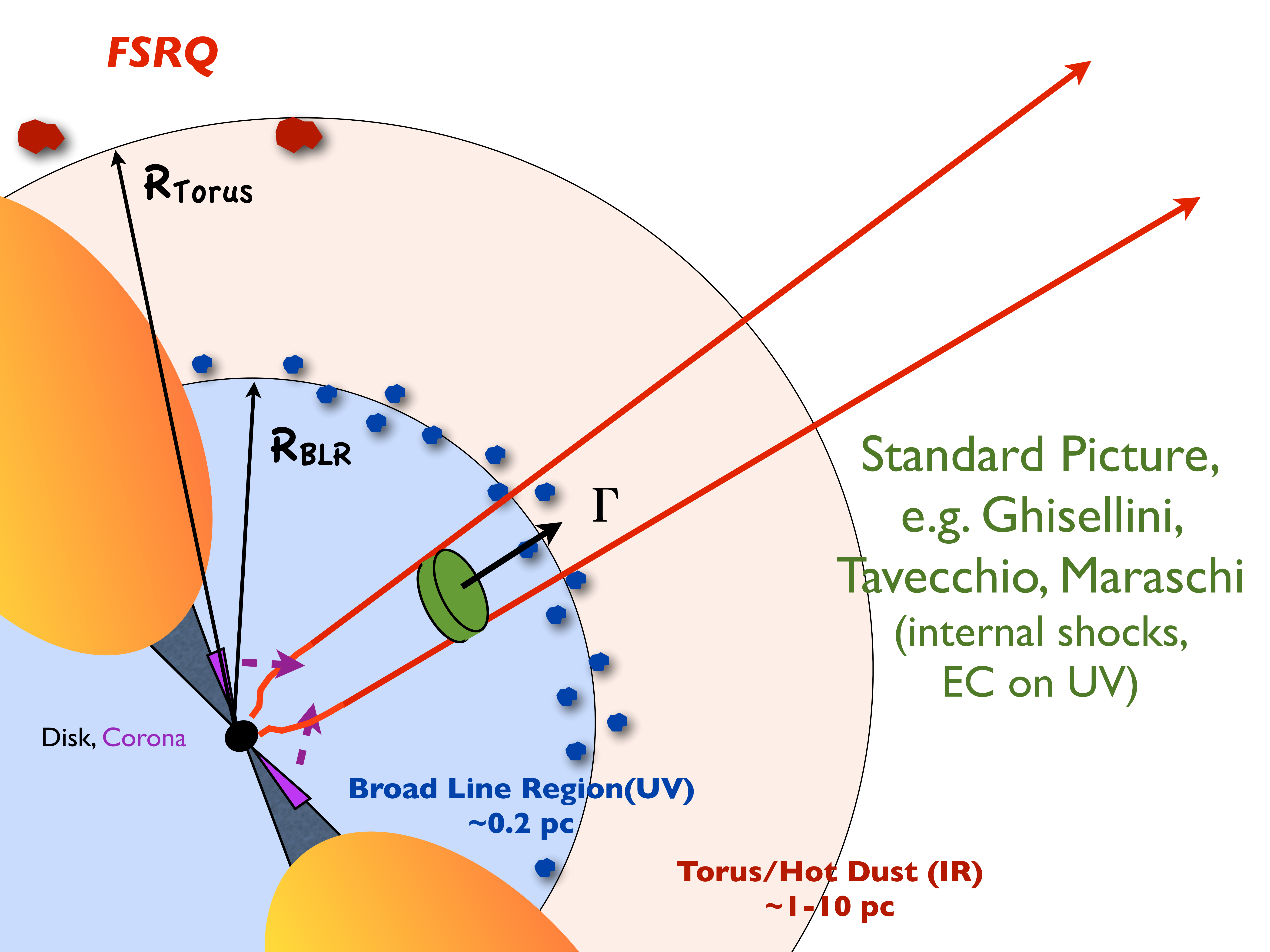
$$R_{BLR} \simeq 0.1 \times {L_{46}}^{1/2}\ \mathrm{pc}$$

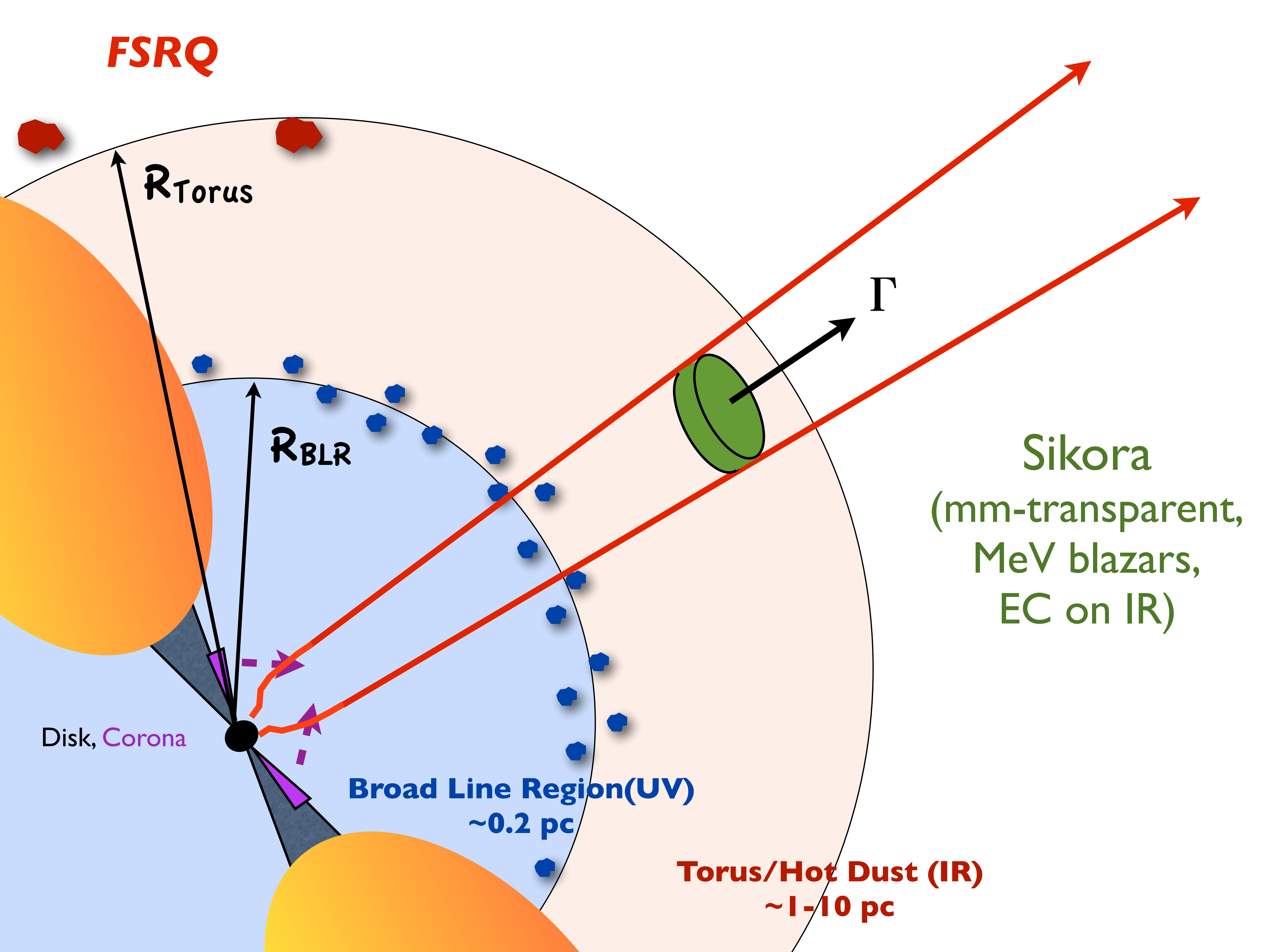
(Bentz et al. 2006 ; Kaspi et al. 2007)

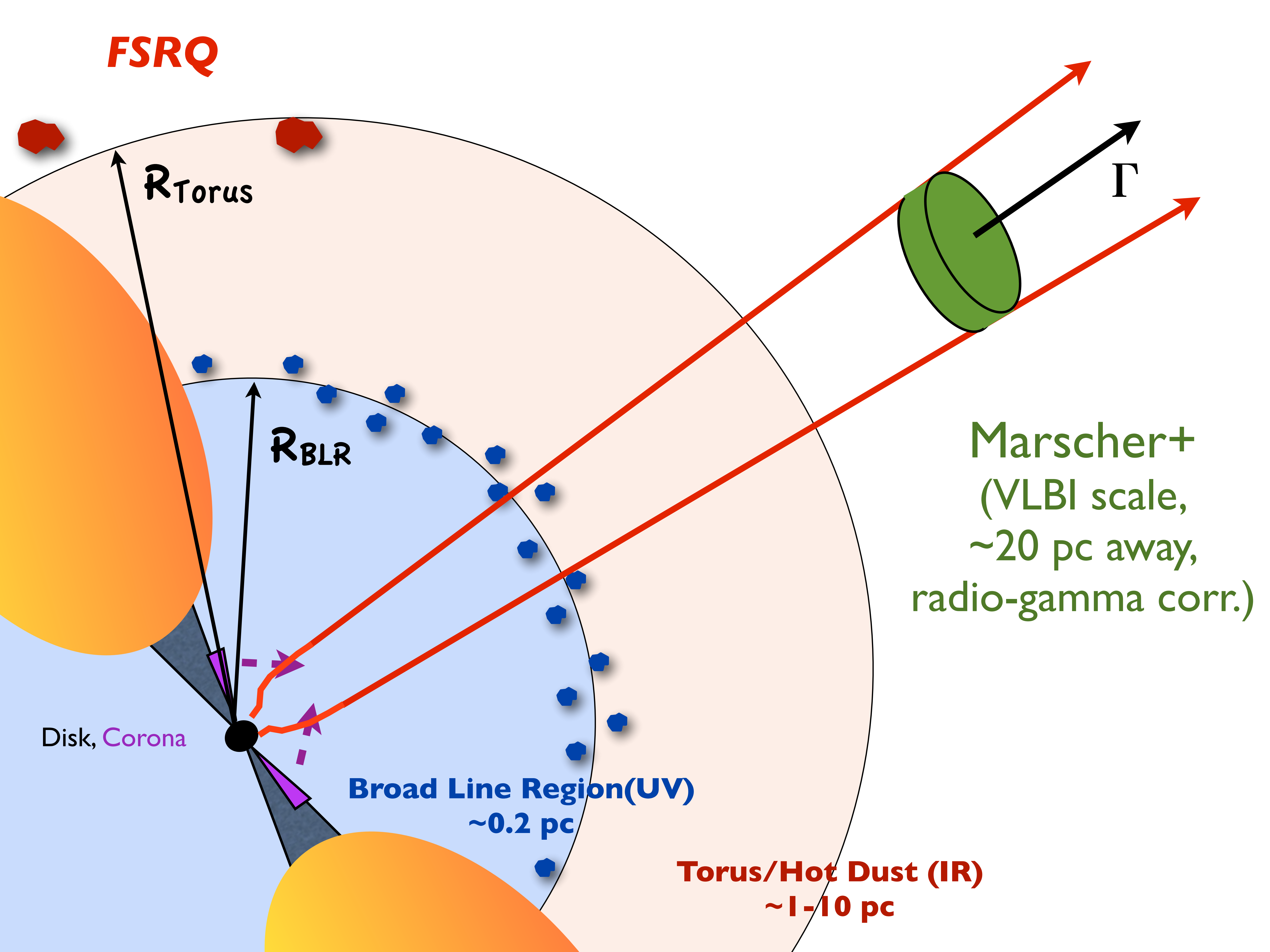
$$R_{HD} \simeq 2.5 \times {L_{46}}^{1/2}\ \mathrm{pc}$$

(Cleary et al. 2007 ; Nenkova et al. 2008)

$$\mathbf{U_{rad} \propto L/R^2 \sim const.}$$

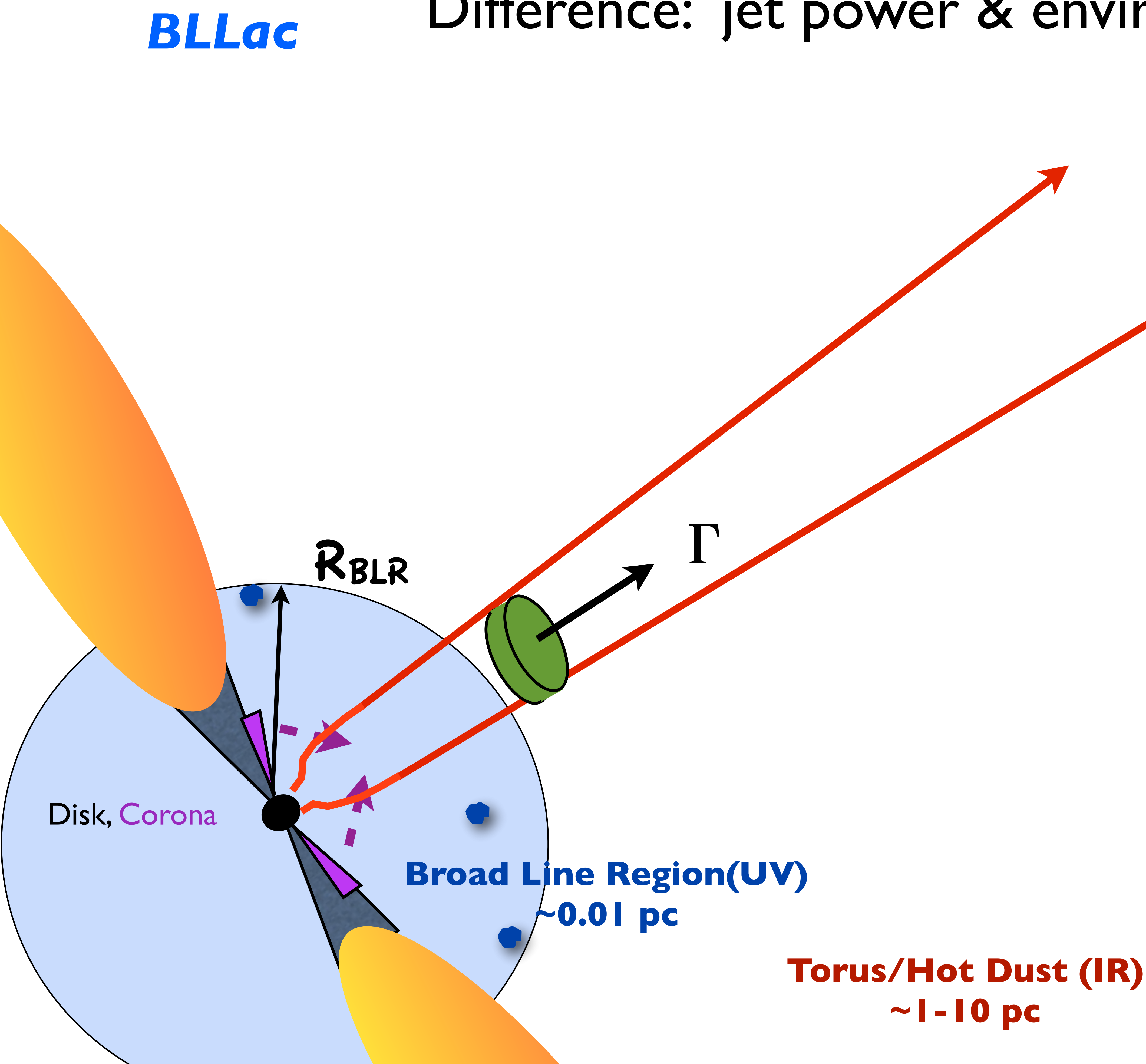

FSRQ
R_{Torus}
R_{BLR}
Γ
Standard Picture,
e.g. Ghisellini,
Tavecchio, Maraschi
(internal shocks,
EC on UV)
Disk, Corona
Broad Line Region(UV)
~0.2 pc
Torus/Hot Dust (IR)
~1-10 pc


FSRQ
R_Torus
R_BLR
Γ
Sikora
(mm-transparent,
MeV blazars,
EC on IR)
Disk, Corona
Broad Line Region(UV)
~0.2 pc
Torus/Hot Dust (IR)
~1-10 pc

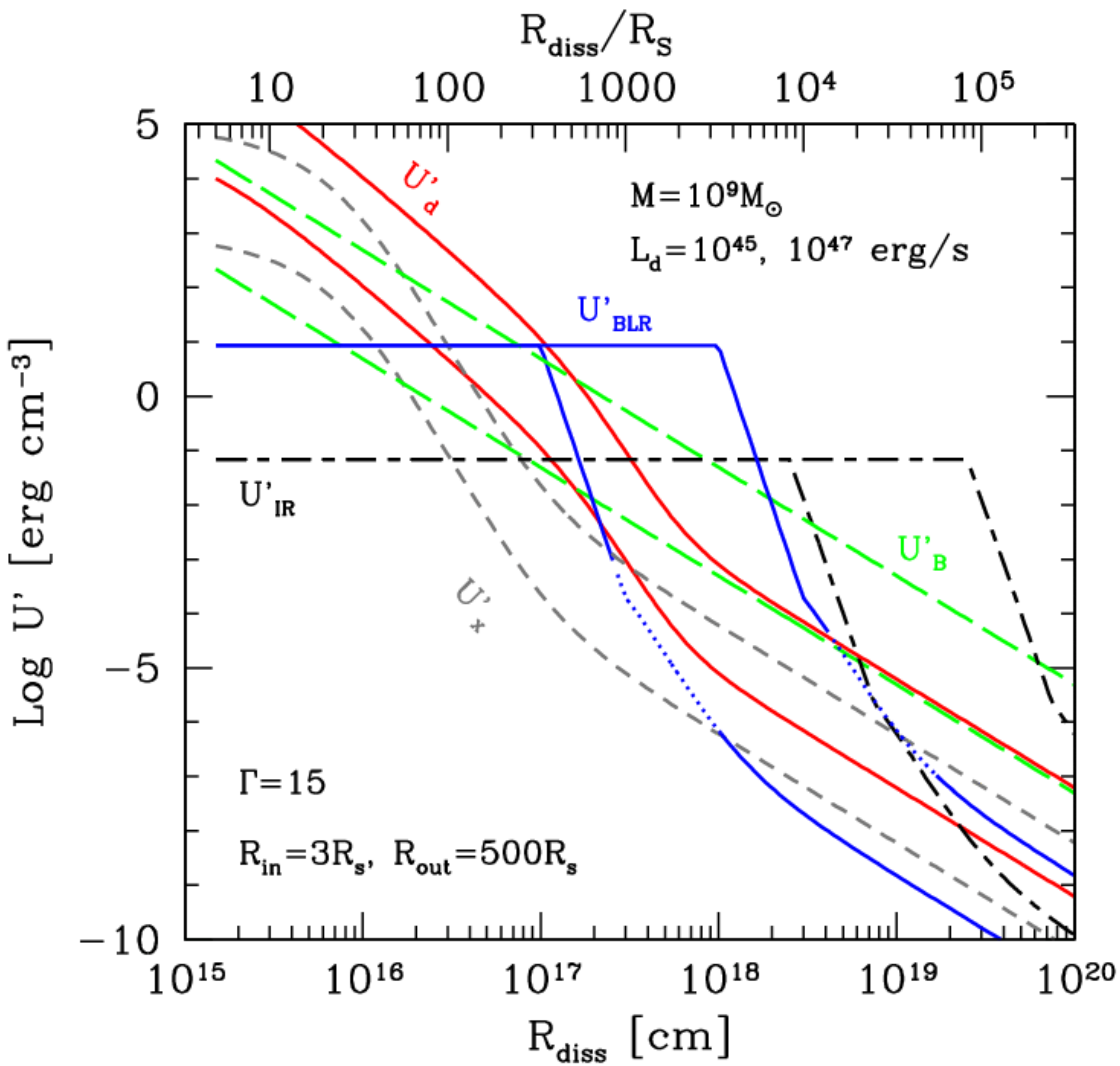


FSRQ
R Torus
R BLR
Γ
Marscher+
(VLBI scale,
~20 pc away,
radio-gamma corr.)
Disk, Corona
Broad Line Region(UV)
~0.2 pc
Torus/Hot Dust (IR)
~1-10 pc

Difference: jet power & environment



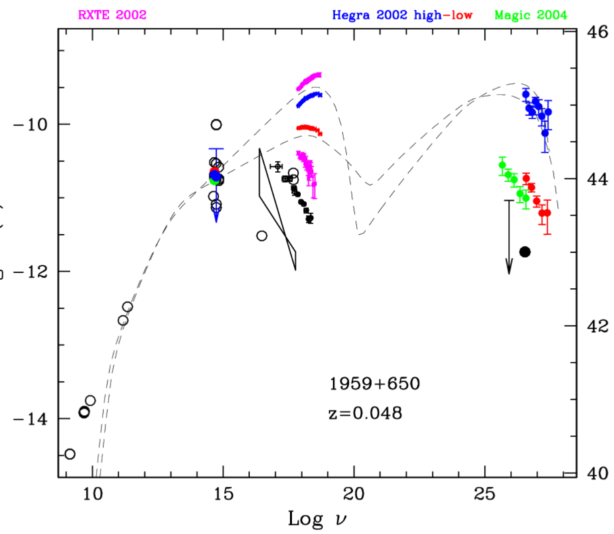
Energy density U along the jet:



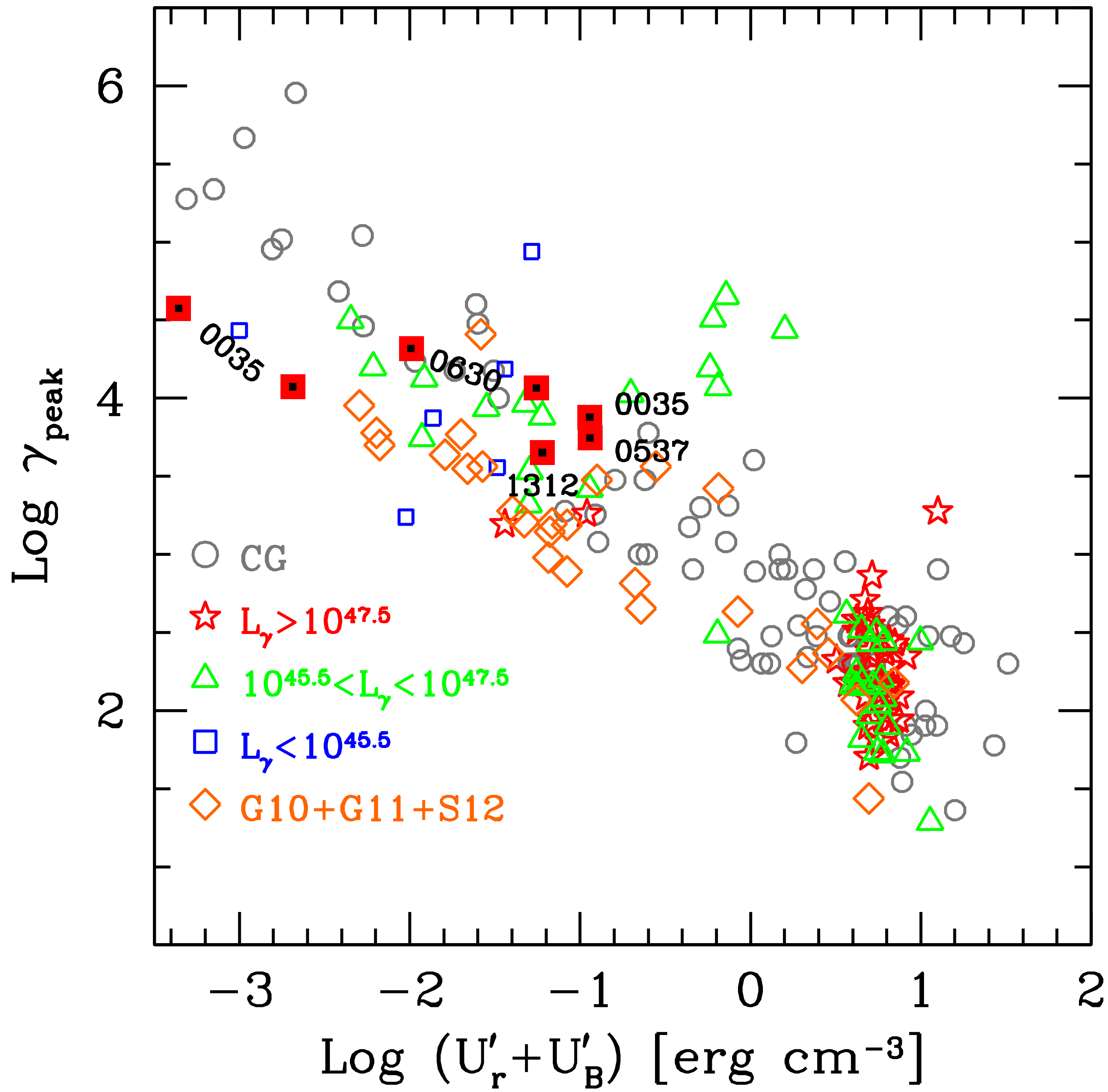
Ghisellini et al. 2009
Sikora et al. 2009

gamma-rays: Inv.Compton on highest-U seed photons

Standard modeling: environment counts

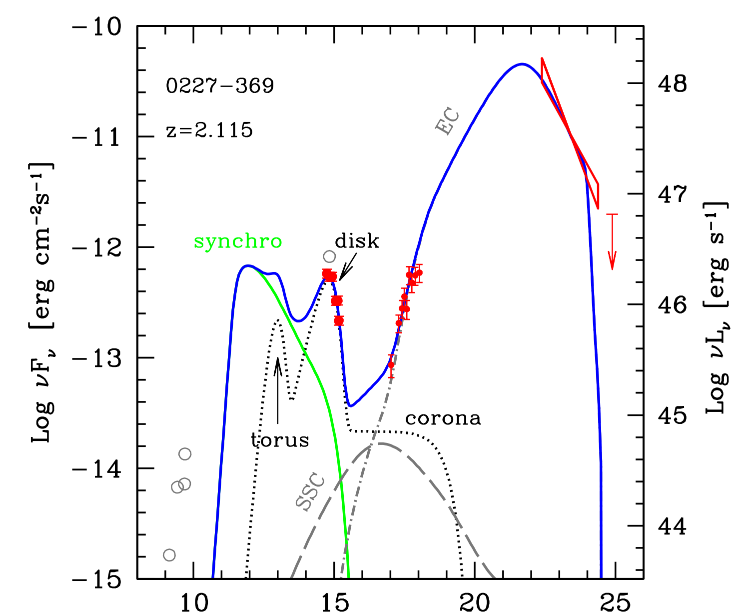


BLLacs: SSC



FSRQ

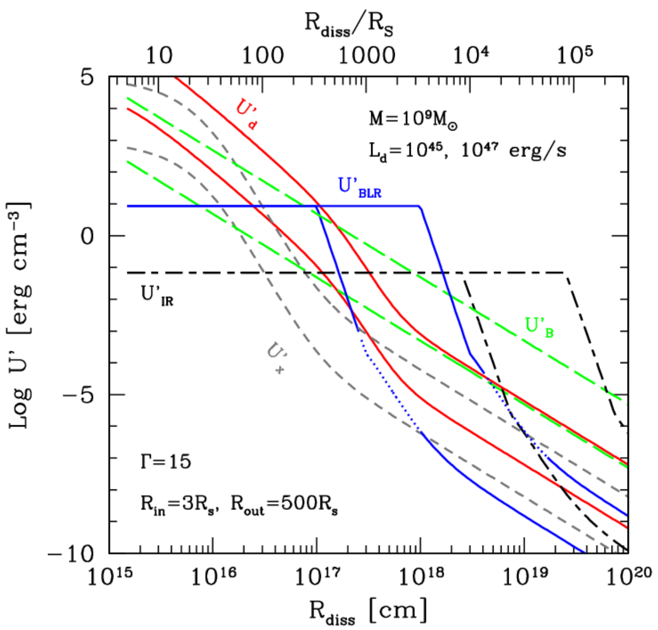
EC(BLR)

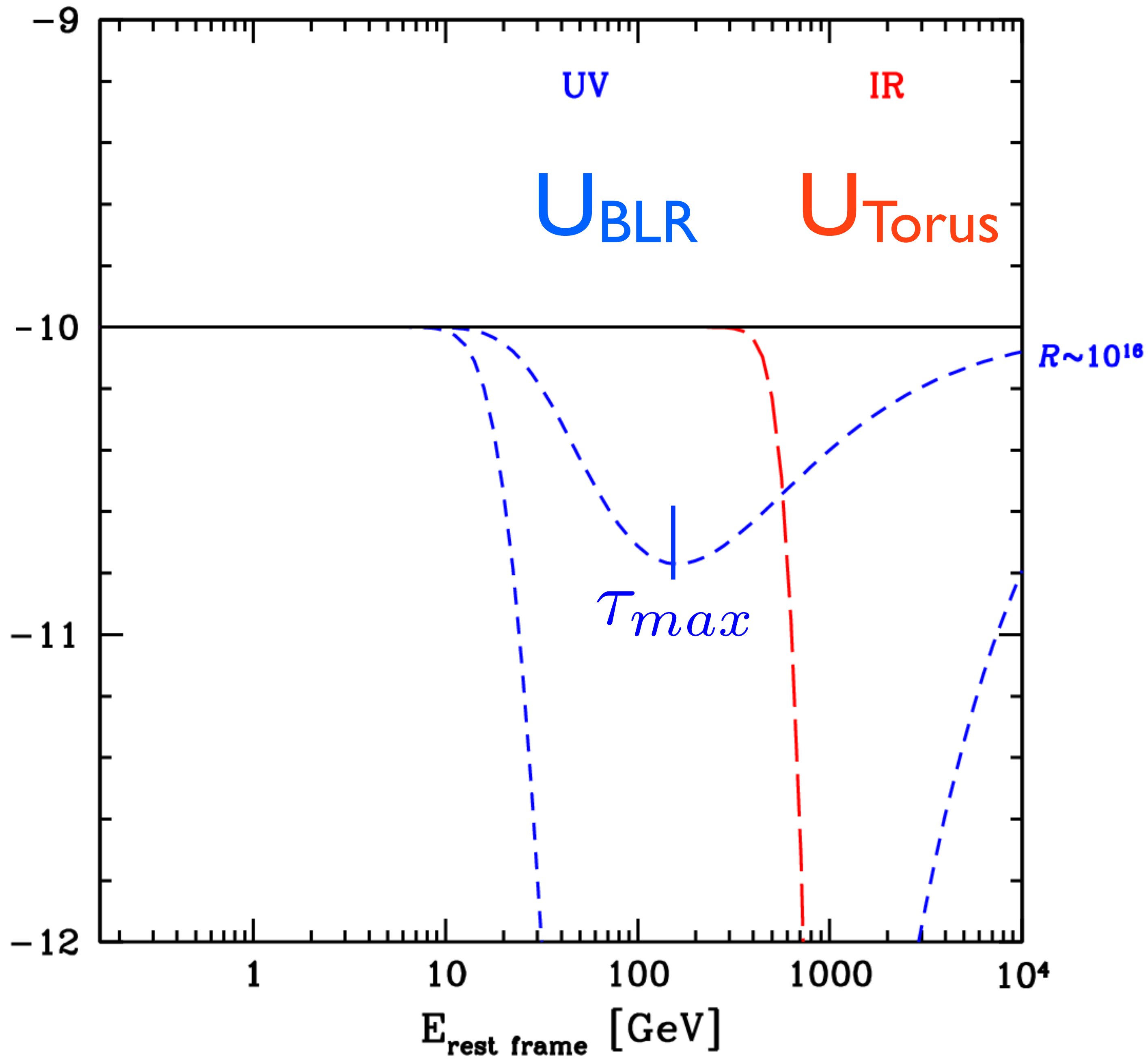


Ghisellini et al 1998-2017,
Sikora et al 1994-2013

BLR opacity: optical depths >>1

$\gamma\gamma \rightarrow e^+ e^-$ $\quad x_1 x_2 \geq \frac{2}{1-\cos\theta}$ $\quad x \equiv h\nu/m_e c^2$





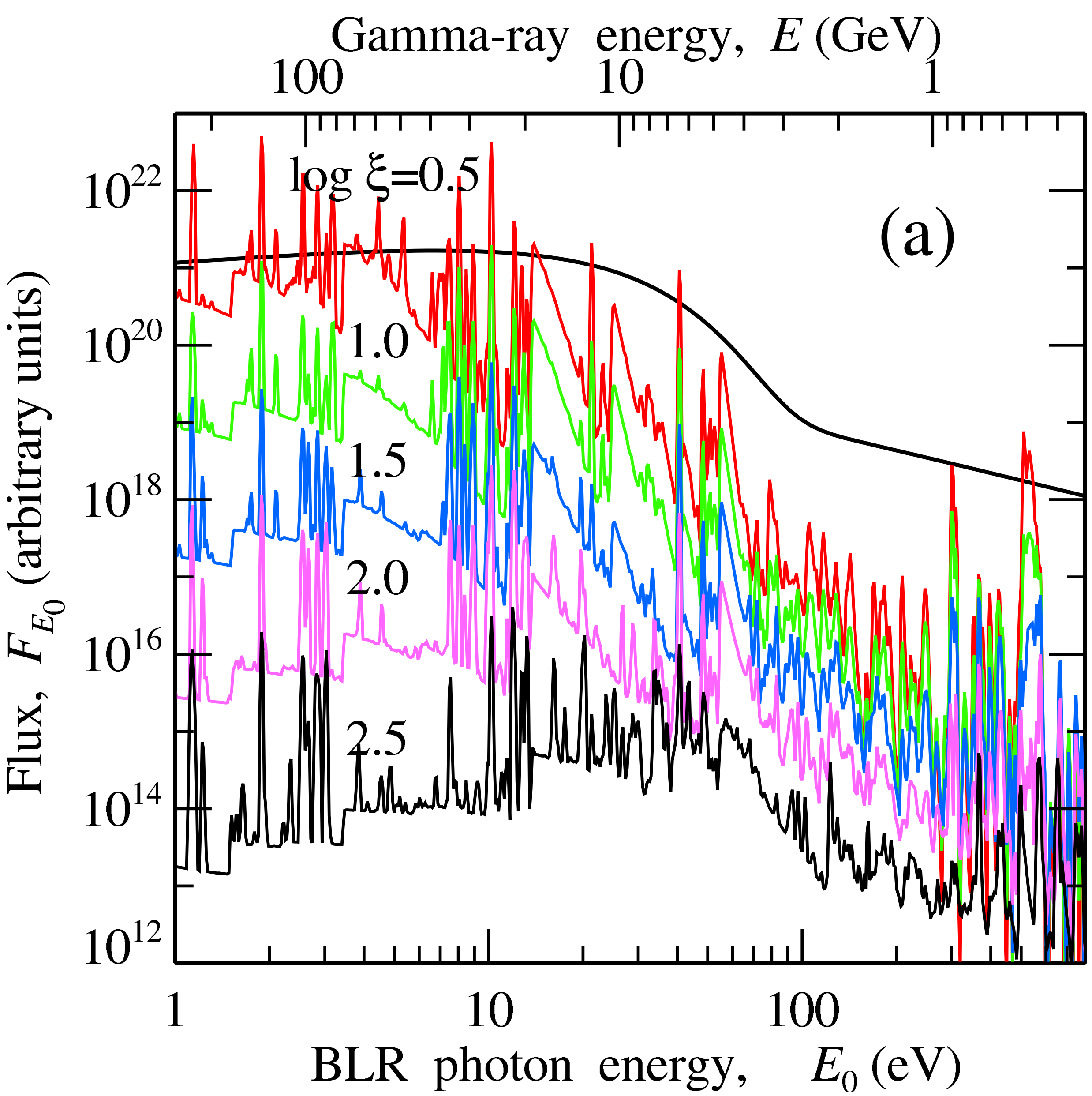
e.g. on BlackBody target field (good approximation to BLR attenuation)

Expected in FSRQ: no VHE detections, cutoff ~10-20 GeV

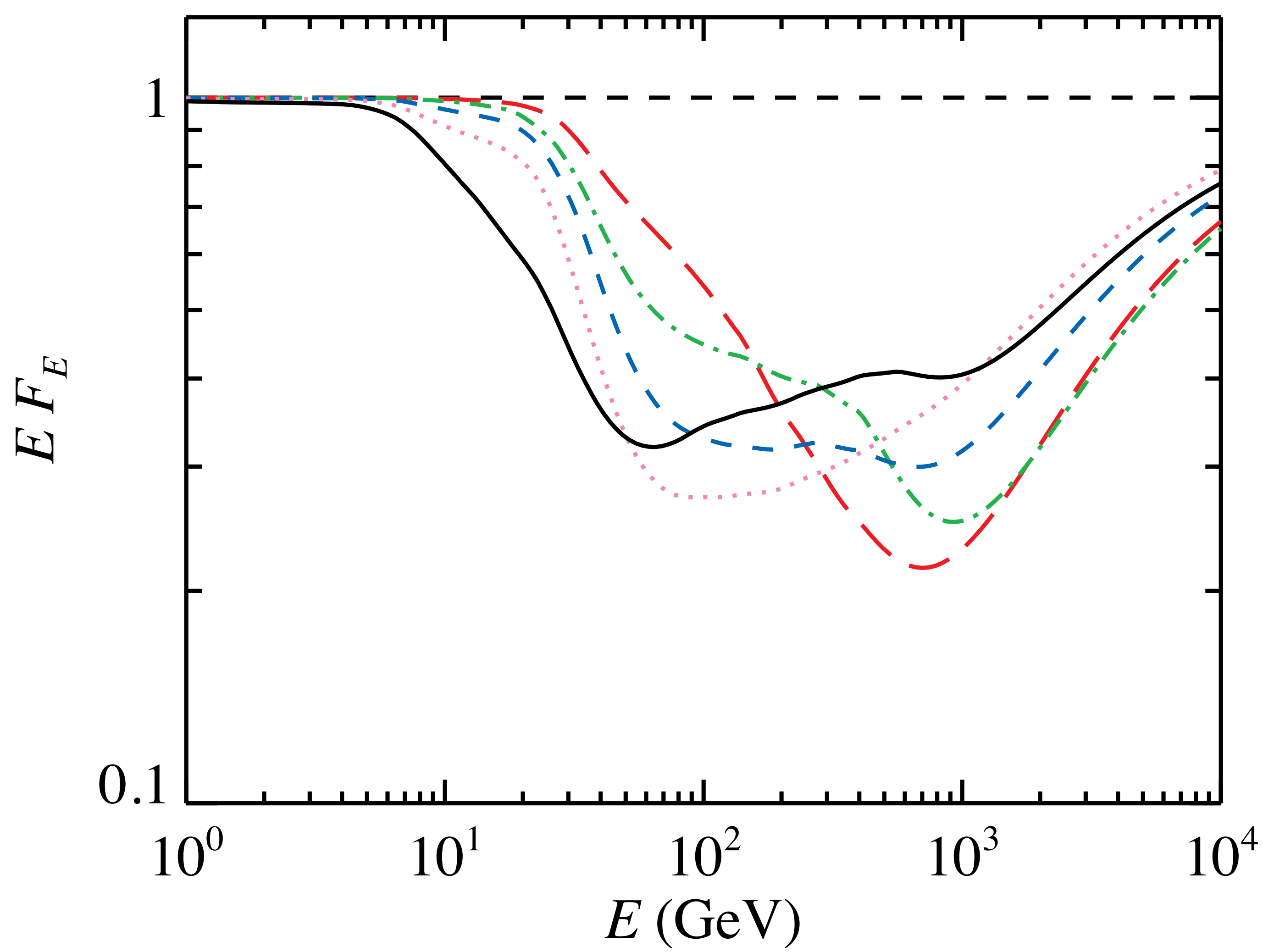
BLR spectra

BBody is a good approximation for attenuation curves

BLR at different ionization parameter



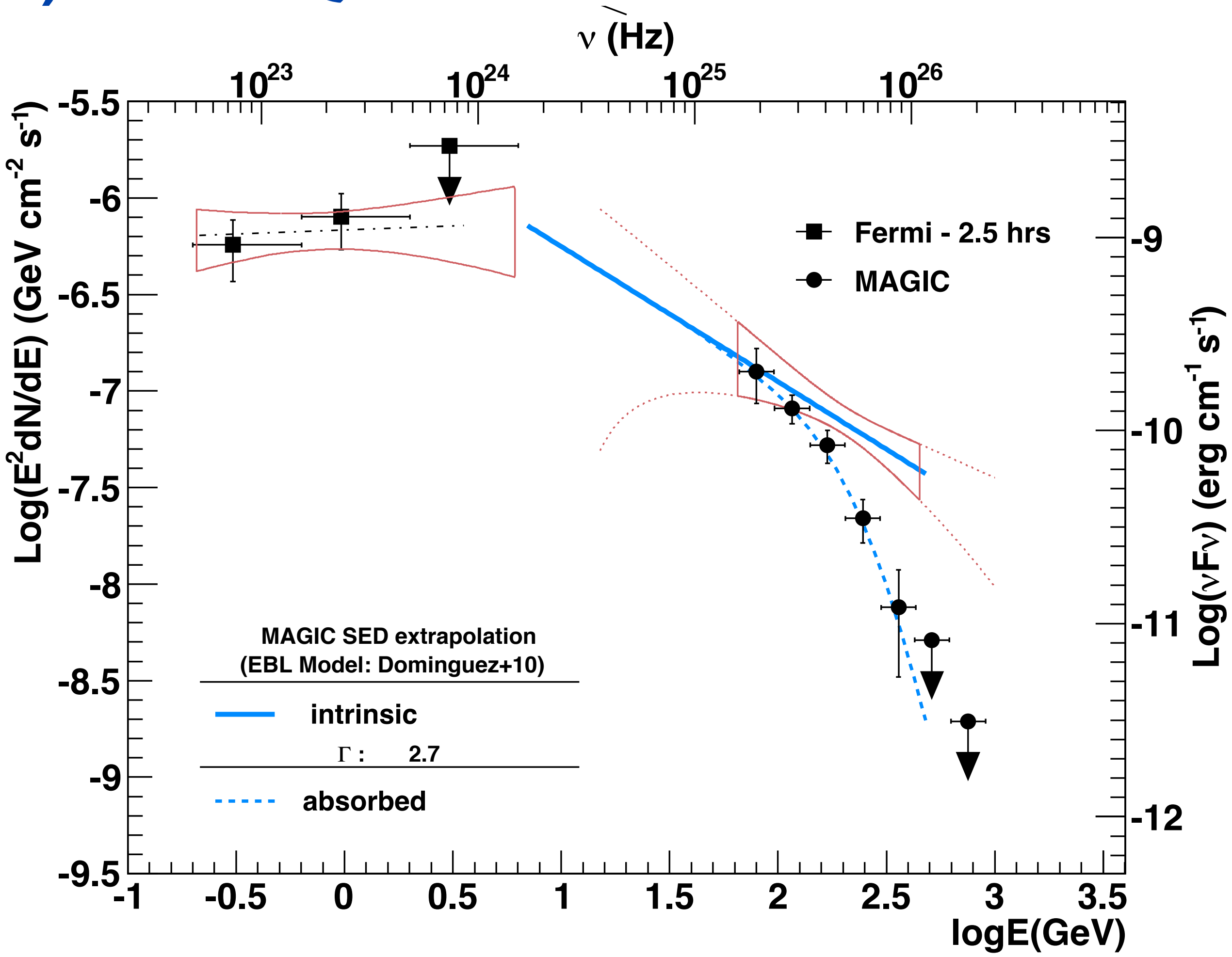
BLR absorption feature



Stern & Poutanen 2014

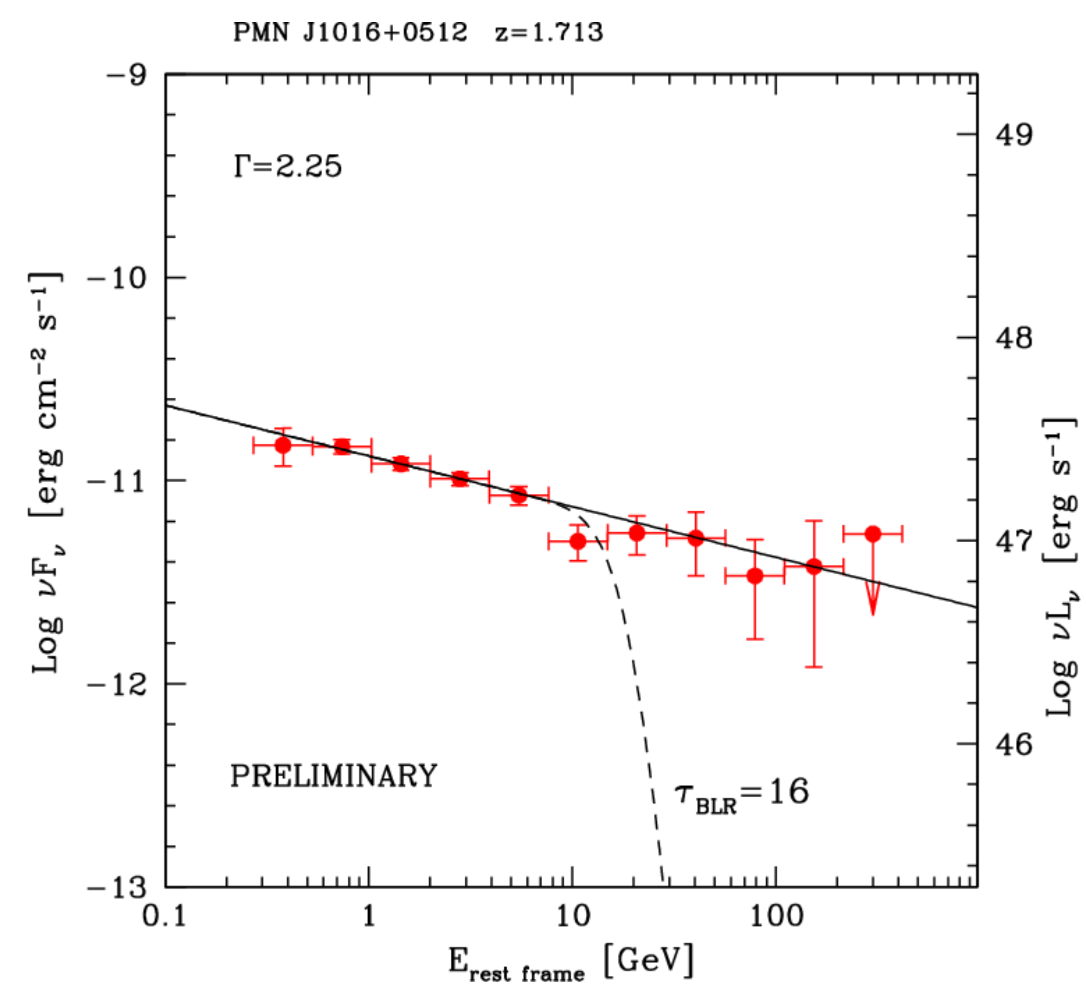
Gamma-rays beyond the BLR:

a) FSRQ detected at VHE



Aleksic et al. (MAGIC Coll) 2011

b) >10 GeV in LAT



Detections 4C 21.35 (Magic)
PKS 1510-089 (HESS, Magic)

PMN J1016+0512:

$L_{disk} \sim 9\times10^{45}$ erg/s , $R_{blr} \sim 3\times10^{17}$ cm

if $R_{diss} \sim 2.5\times10^{17} \Rightarrow \tau_{BLR} > 16$!

Costamante et al. 2009, 2010

What is the typical origin of gamma-rays in FSRQs ?

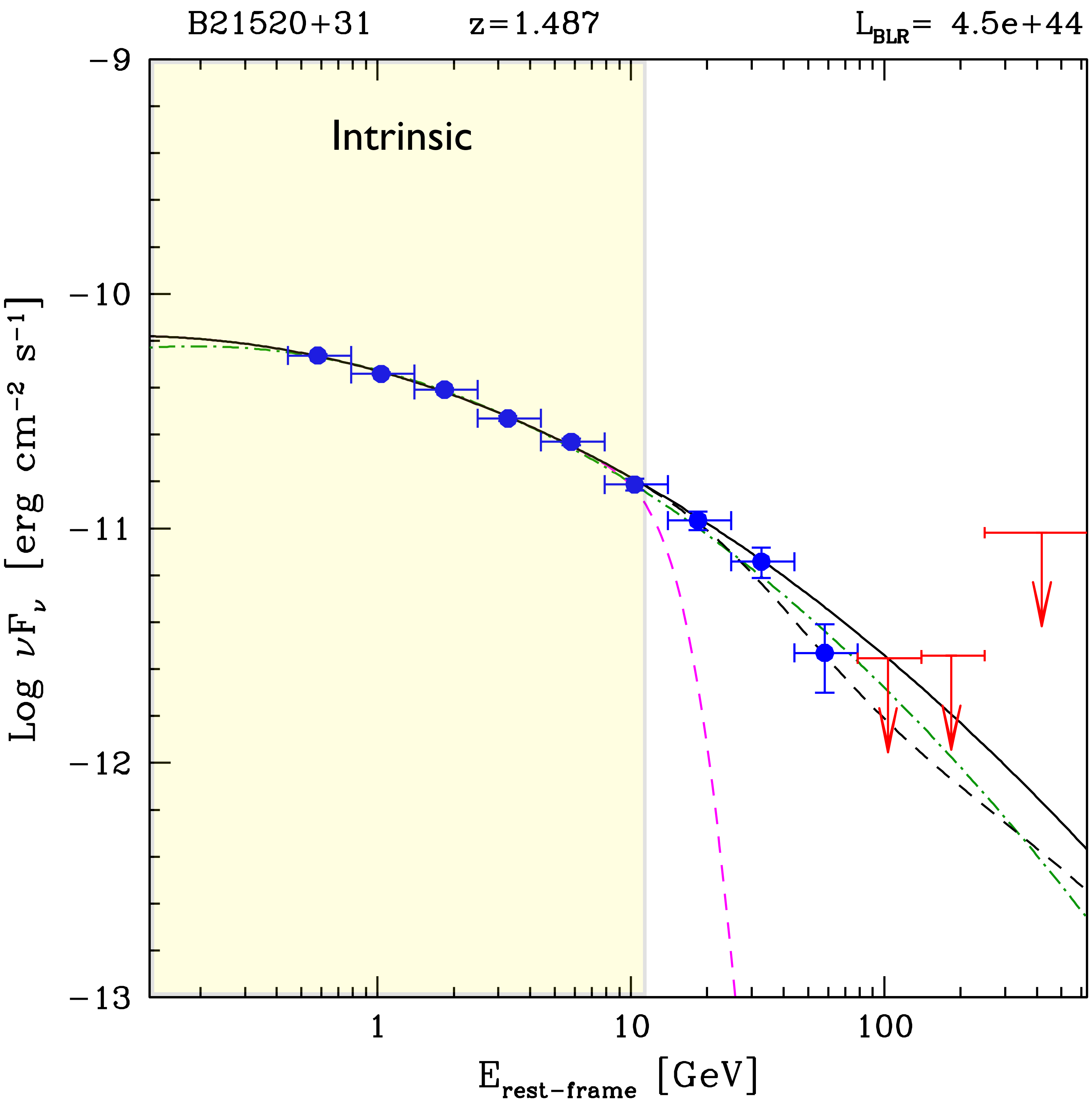
1) is BLR absorption a common phenomenon ?
2) is it consistent with EC modeling ?
3) different location in high-flaring vs steady state ?

100 highest-significance Gamma-ray Blazars in the 3LAC
+ 6 large-BLR cases

Fermi-LAT Data, PASS8, 7.3-years exposure

106 in total, 83 with L_{BLR} estimates

Costamante, Cutini, Tosti, Antolini, Tramacere 2018, MNRAS, in press (arXiv 1804.06282)



Power-law or
Log-parabolic model

— Intrinsic extrapolated

--- Fitted tau_BLR

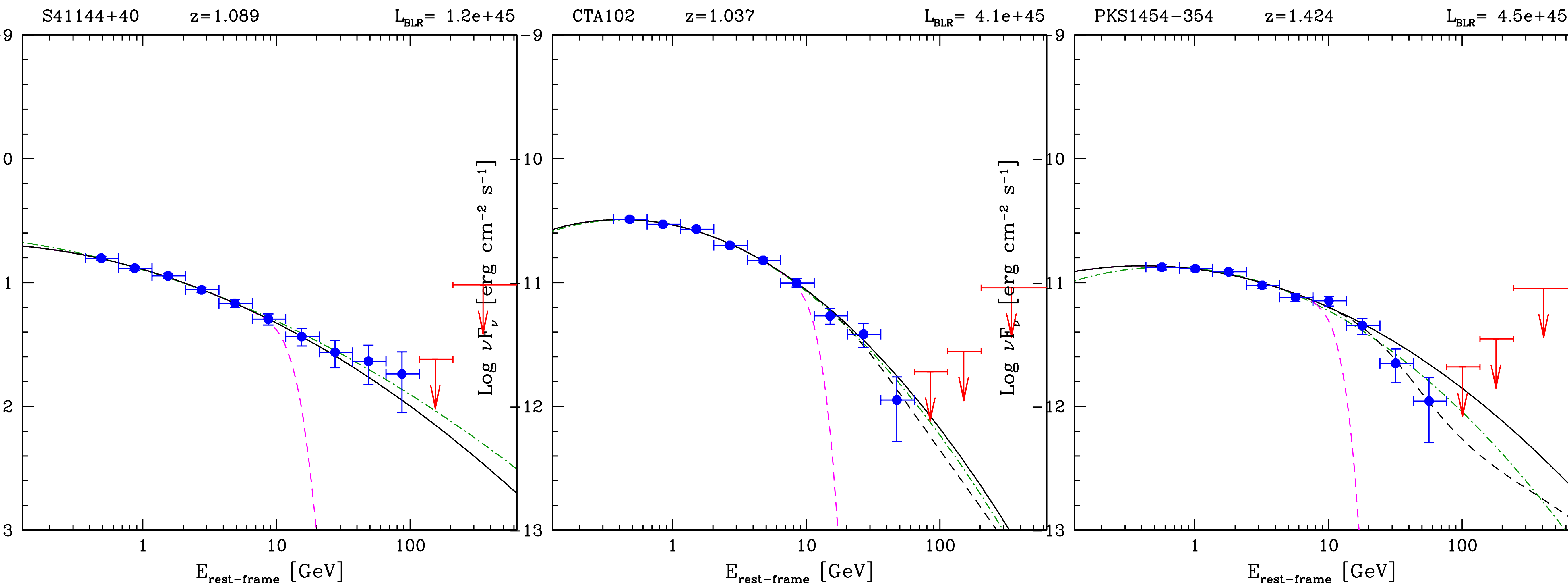
--- Expected tau_BLR (deep in BLR, ~R_{BLR}/2)

-.- Full band (no BLR)

Upper limit if:
TS <4 or Npred <3 or Err>50%

NB: Rest-Frame Energies ! E*(1+z)

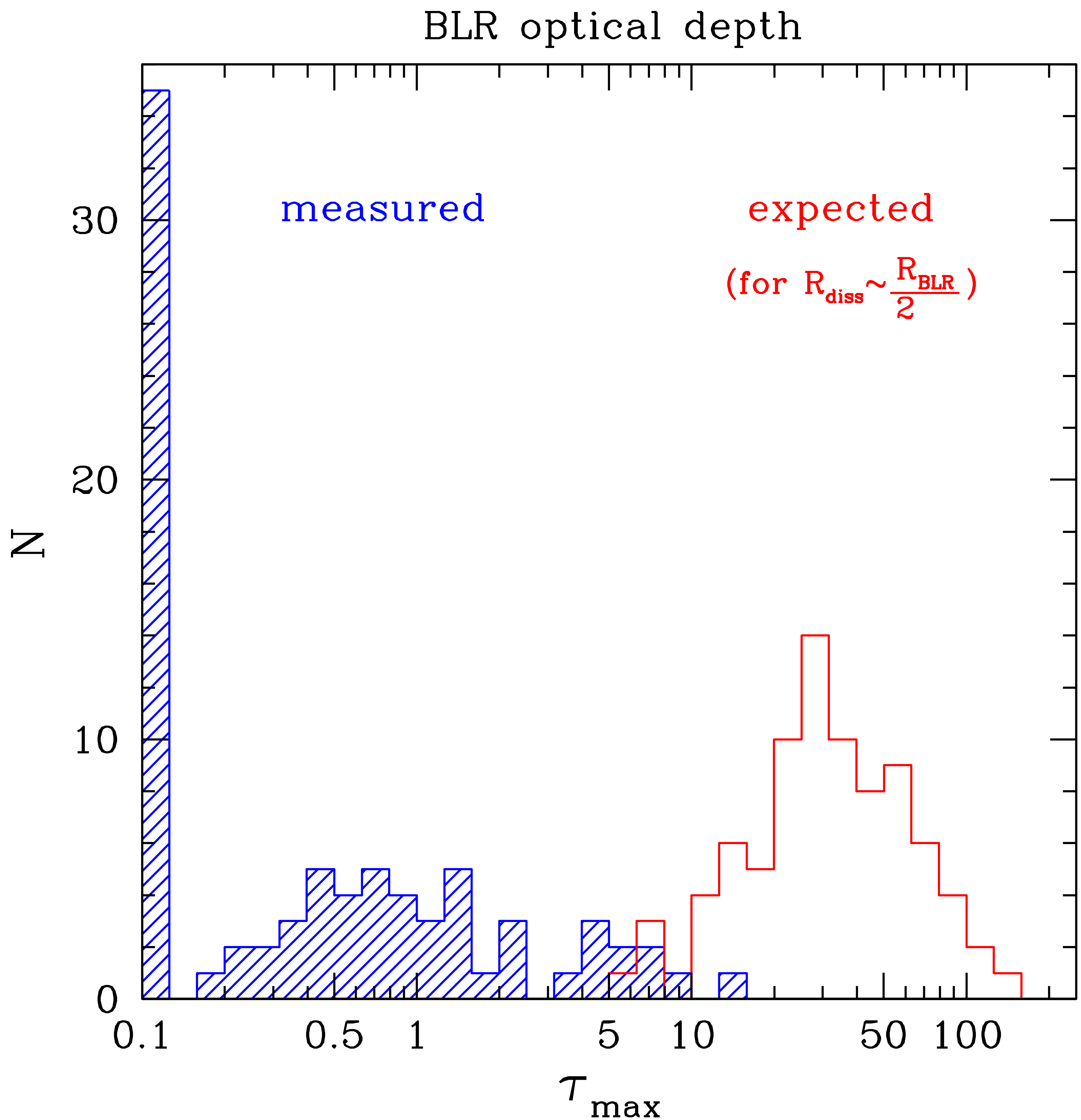
NO evidence of BLR cut-offs !



2/3 of the sample: $\tau_{max} < 1$

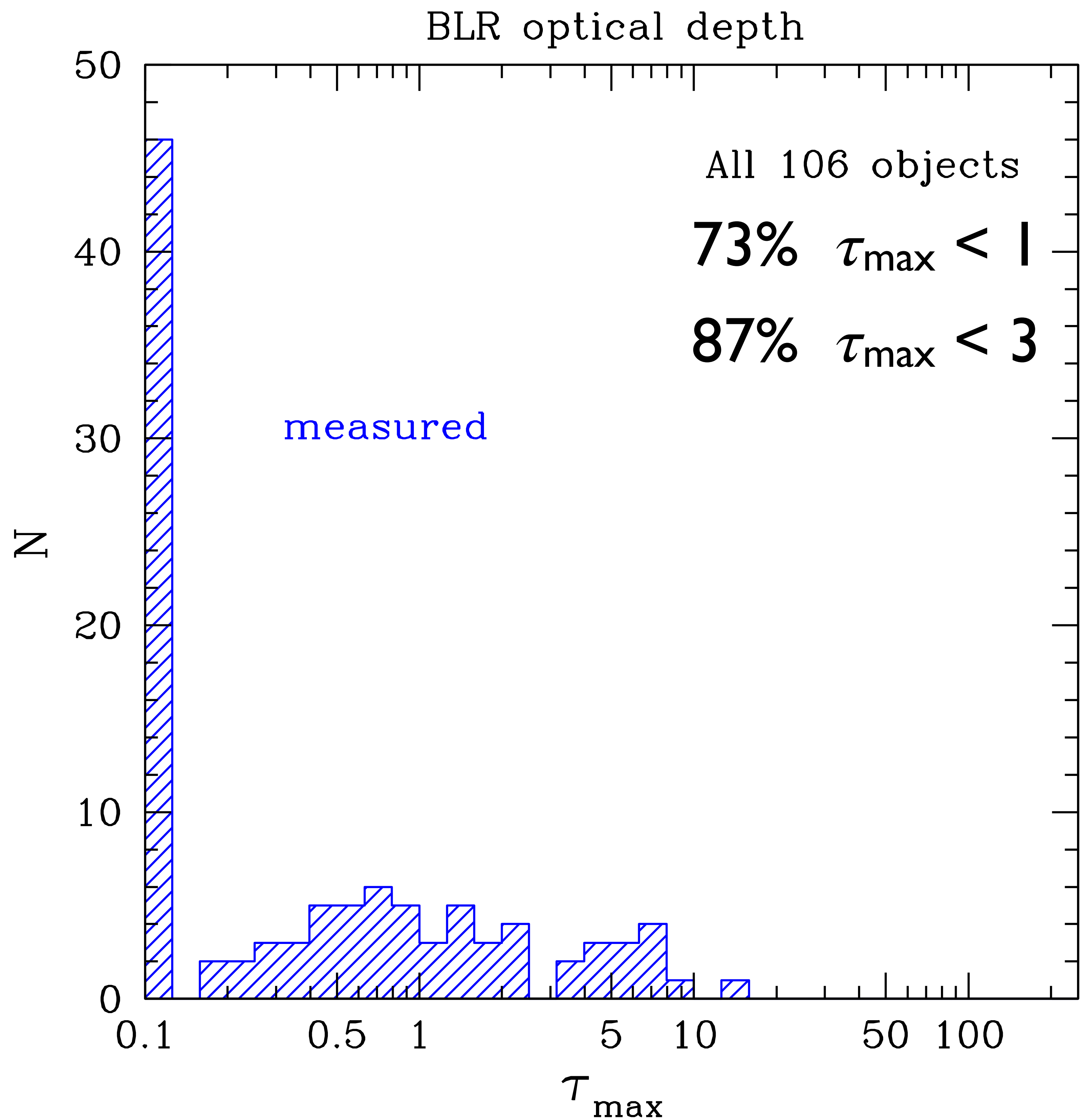
9/10 objects: $\tau_{max} < 3$

Only 1 out of 10 FSRQ compatible with significant BLR absorption

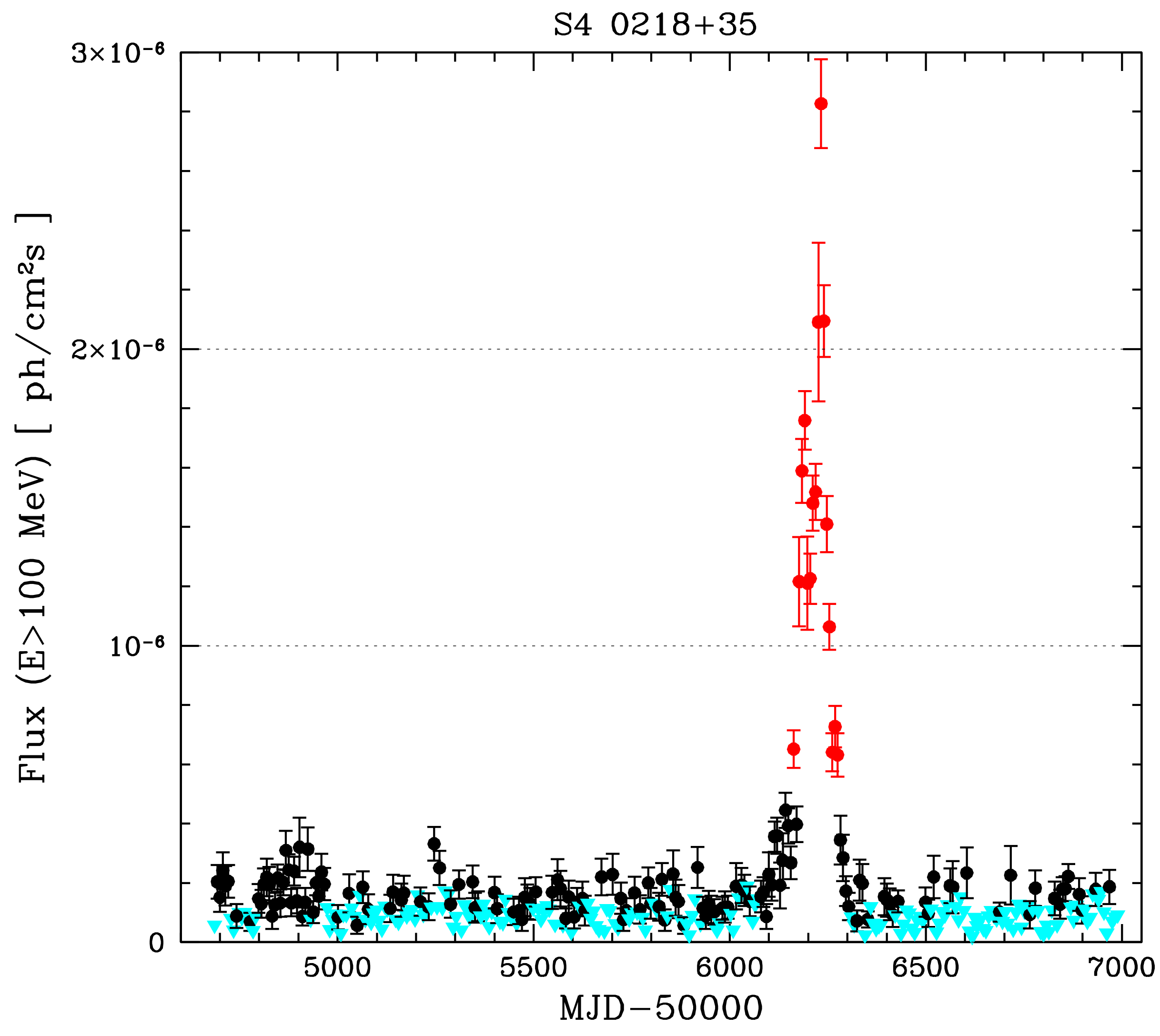


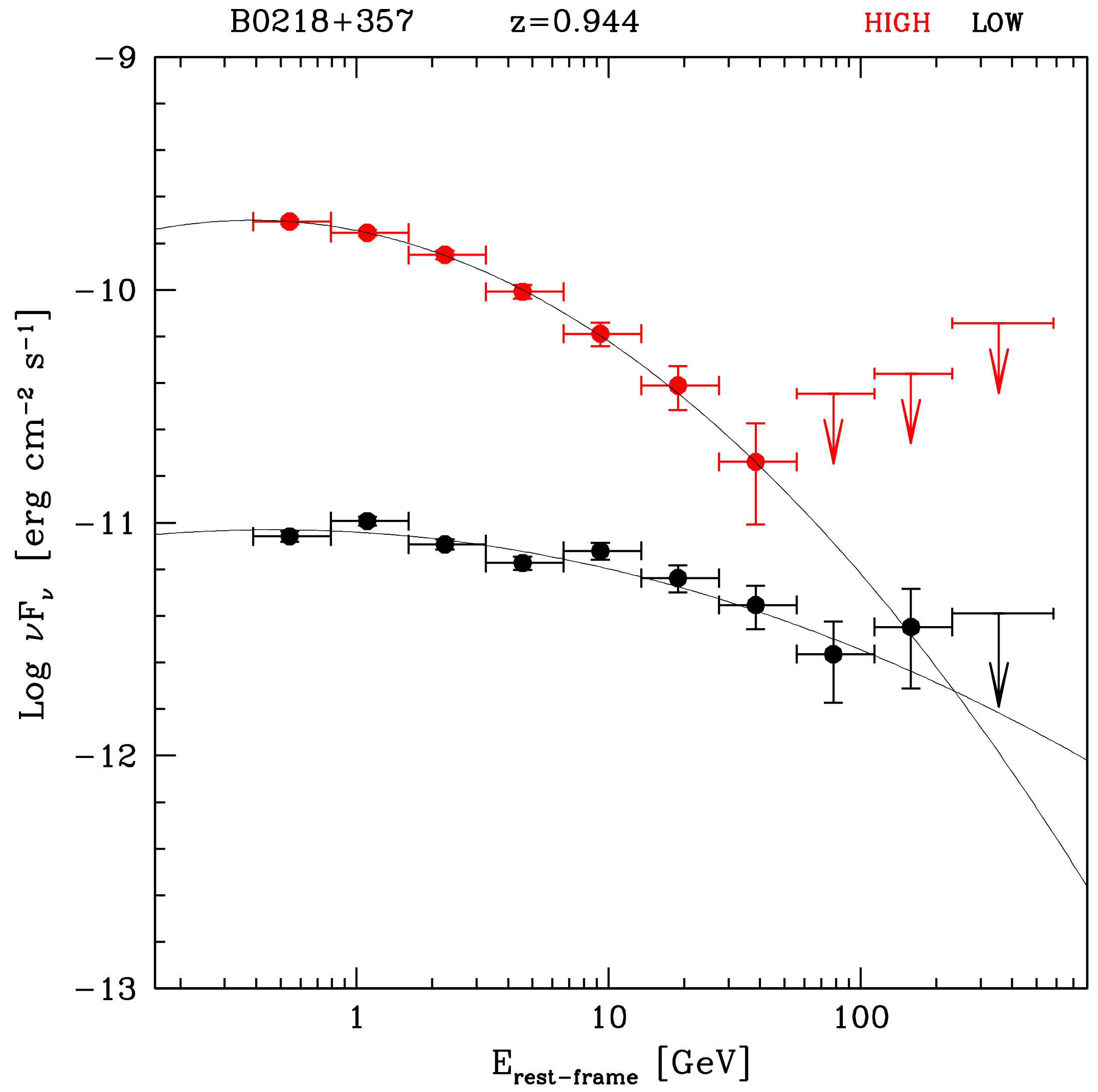
for EC(BLR)

Sample 83 objects with L_{BLR} estimate

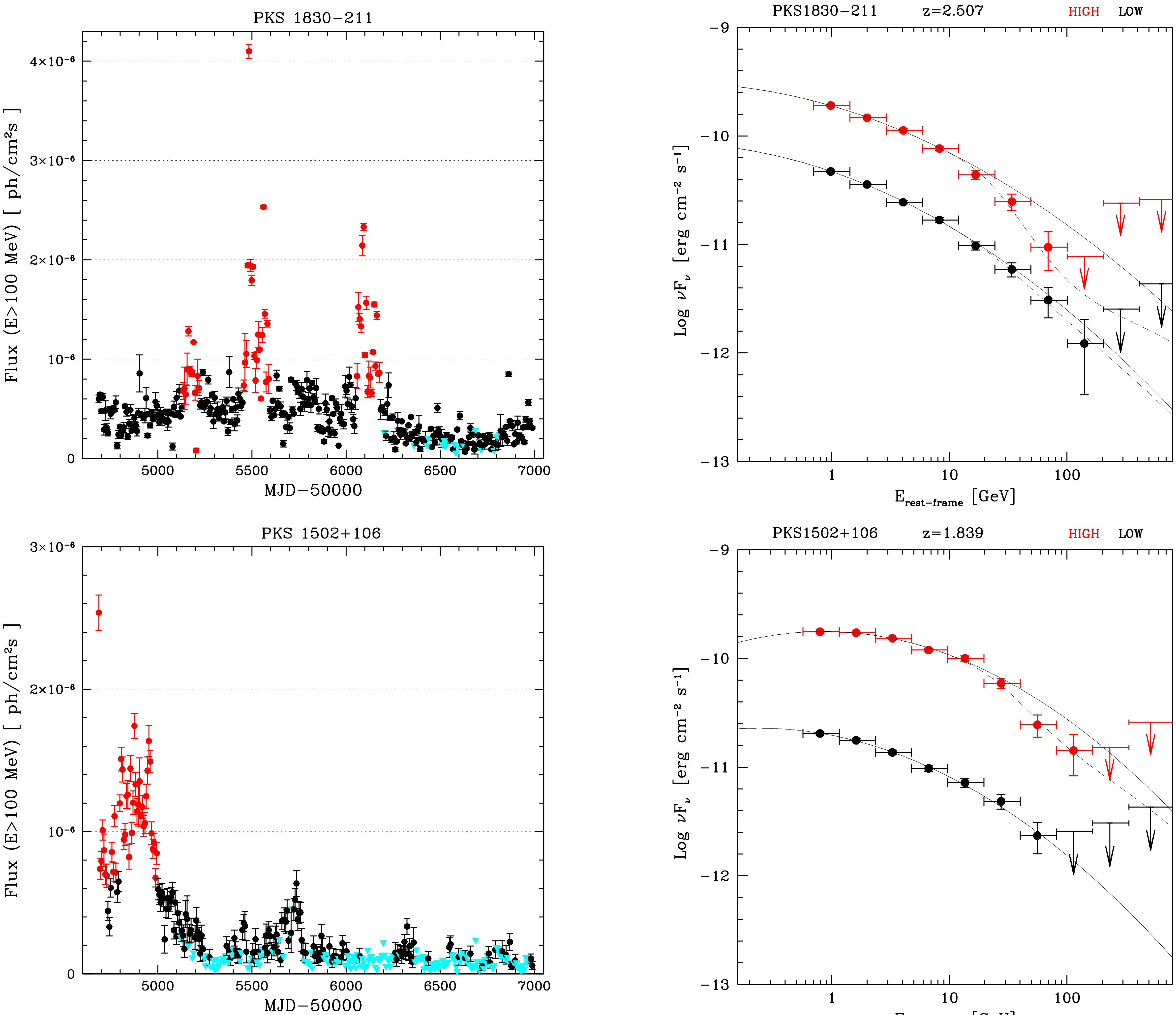

BLR optical depth
All 106 objects
73% τ_{max} < 1
87% τ_{max} < 3
measured
N
τ_{max}
0
10
20
30
40
50
0.1
0.5
1
5
10
50
100

High/Low state ?

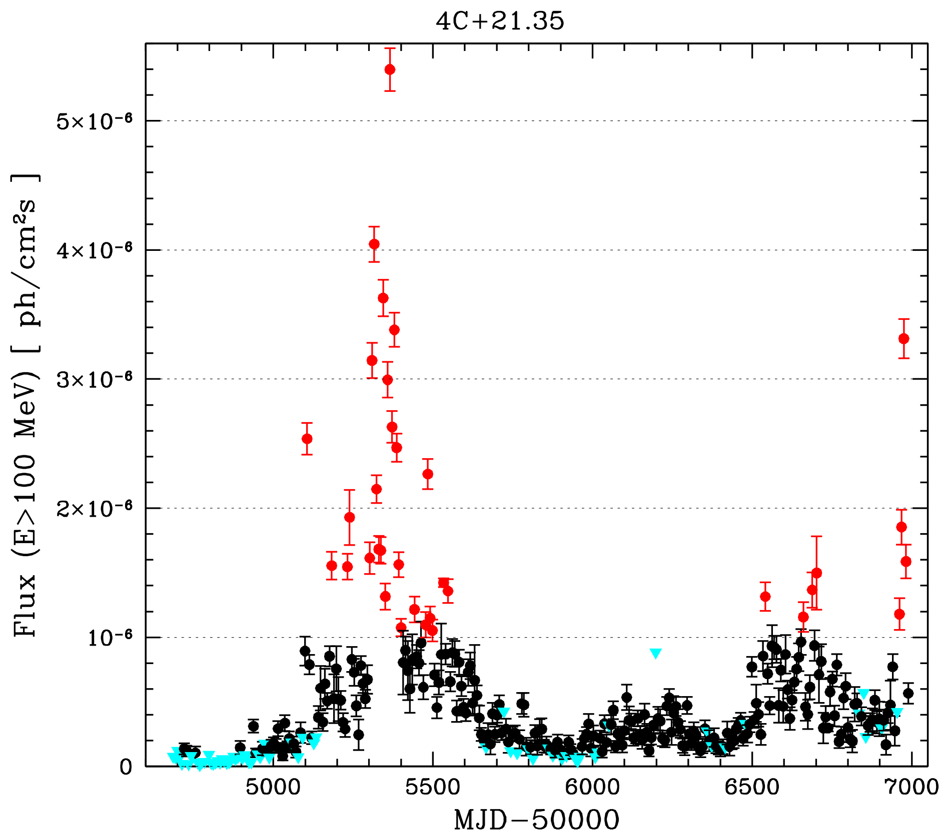


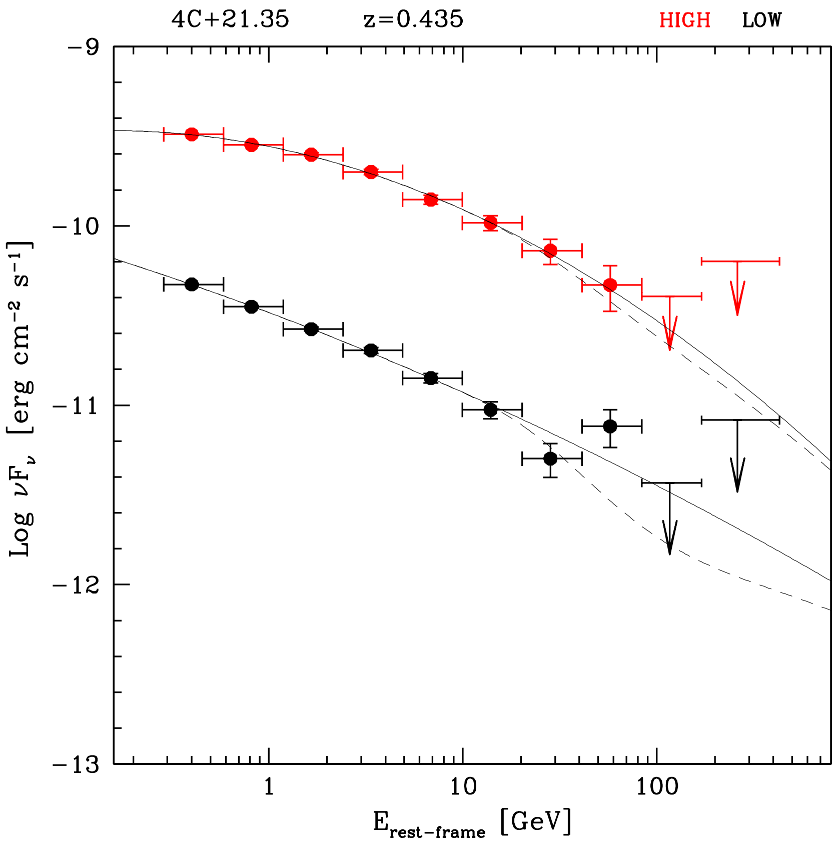


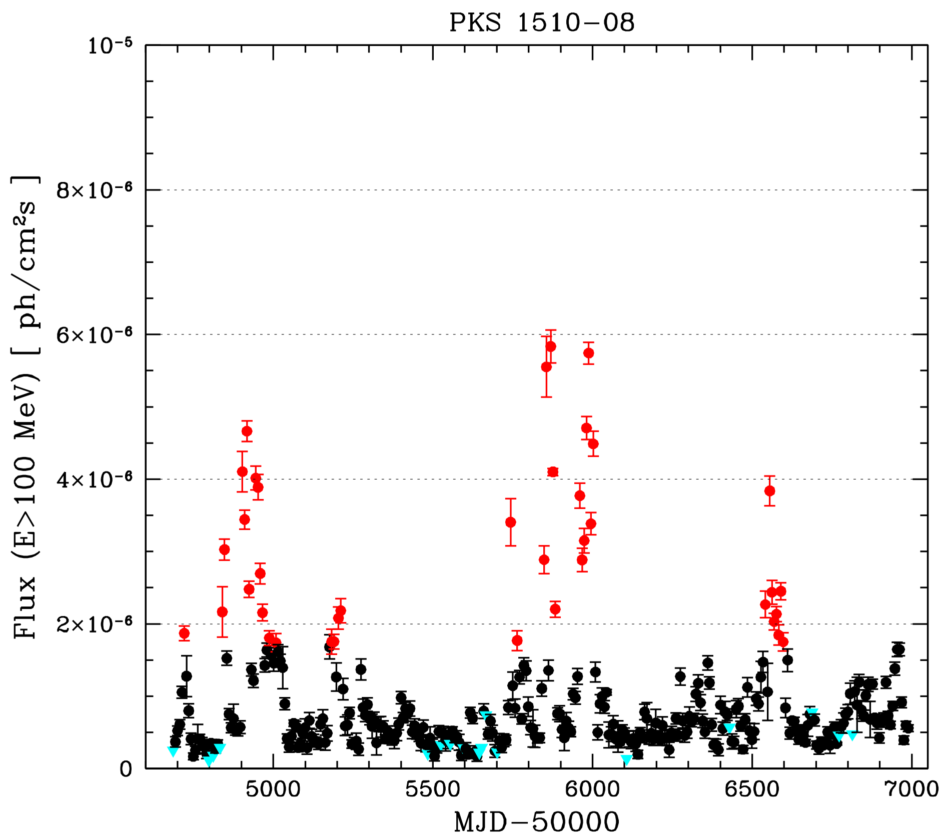
No evidence of strong interaction with BLR photons

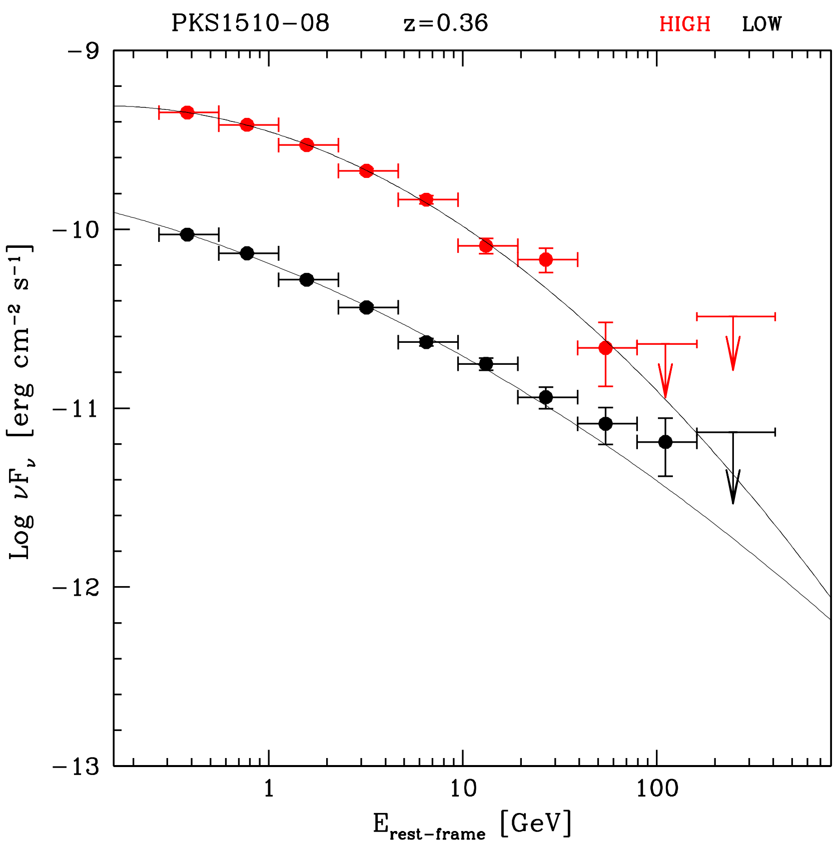

PKS 1830−211
Flux (E>100 MeV) [ph/cm²s]
4×10⁻⁶
3×10⁻⁶
2×10⁻⁶
10⁻⁶
0
5000
5500
6000
6500
7000
MJD−50000
PKS1830−211
z=2.507
HIGH
LOW
Log νFν [erg cm⁻² s⁻¹]
−9
−10
−11
−12
−13
1
10
100
E_rest−frame [GeV]
PKS 1502+106
Flux (E>100 MeV) [ph/cm²s]
3×10⁻⁶
2×10⁻⁶
10⁻⁶
0
5000
5500
6000
6500
7000
MJD−50000
PKS1502+106
z=1.839
HIGH
LOW
Log νFν [erg cm⁻² s⁻¹]
−9
−10
−11
−12
−13
1
10
100

VHE-detected FSRQs

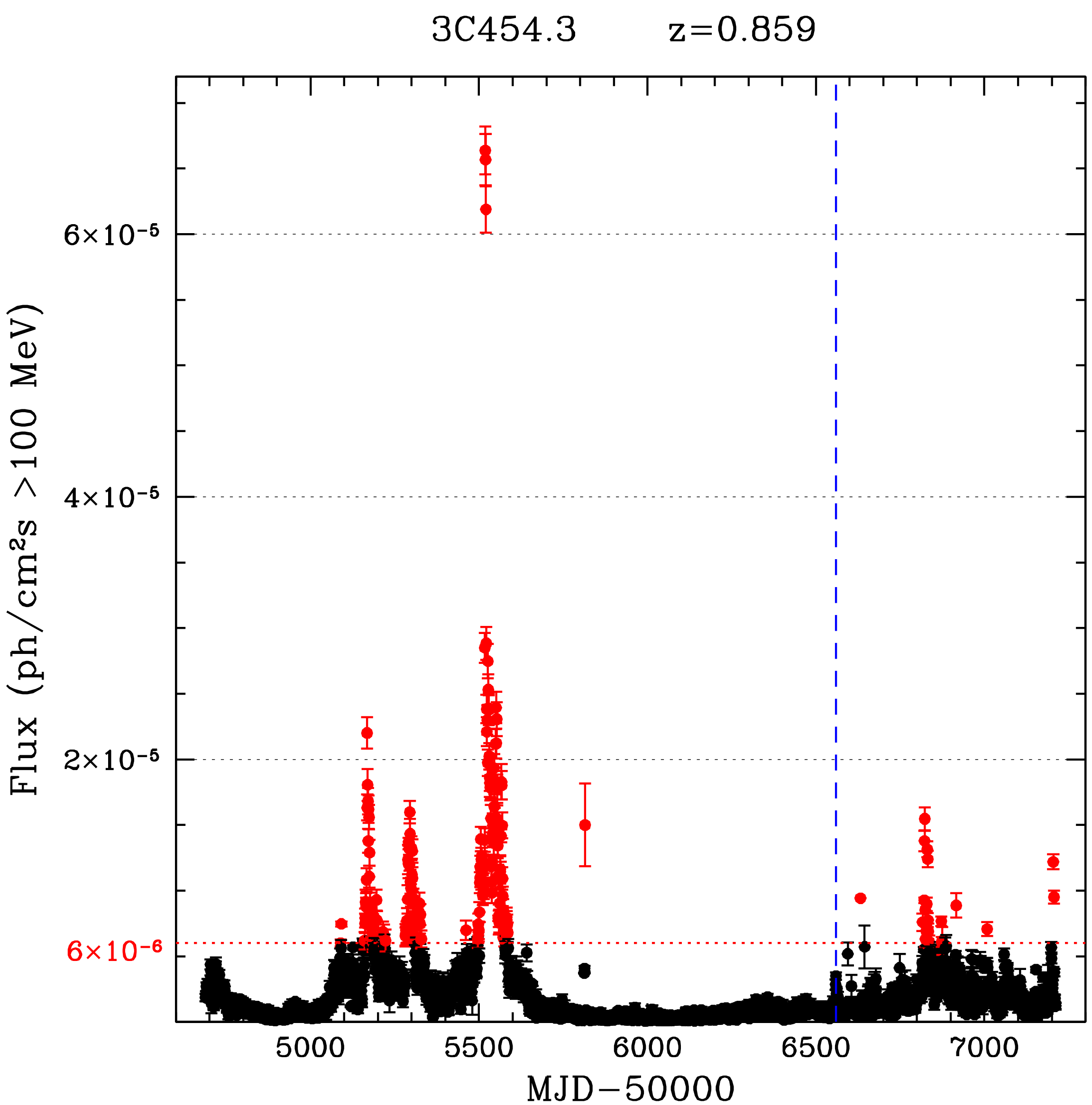


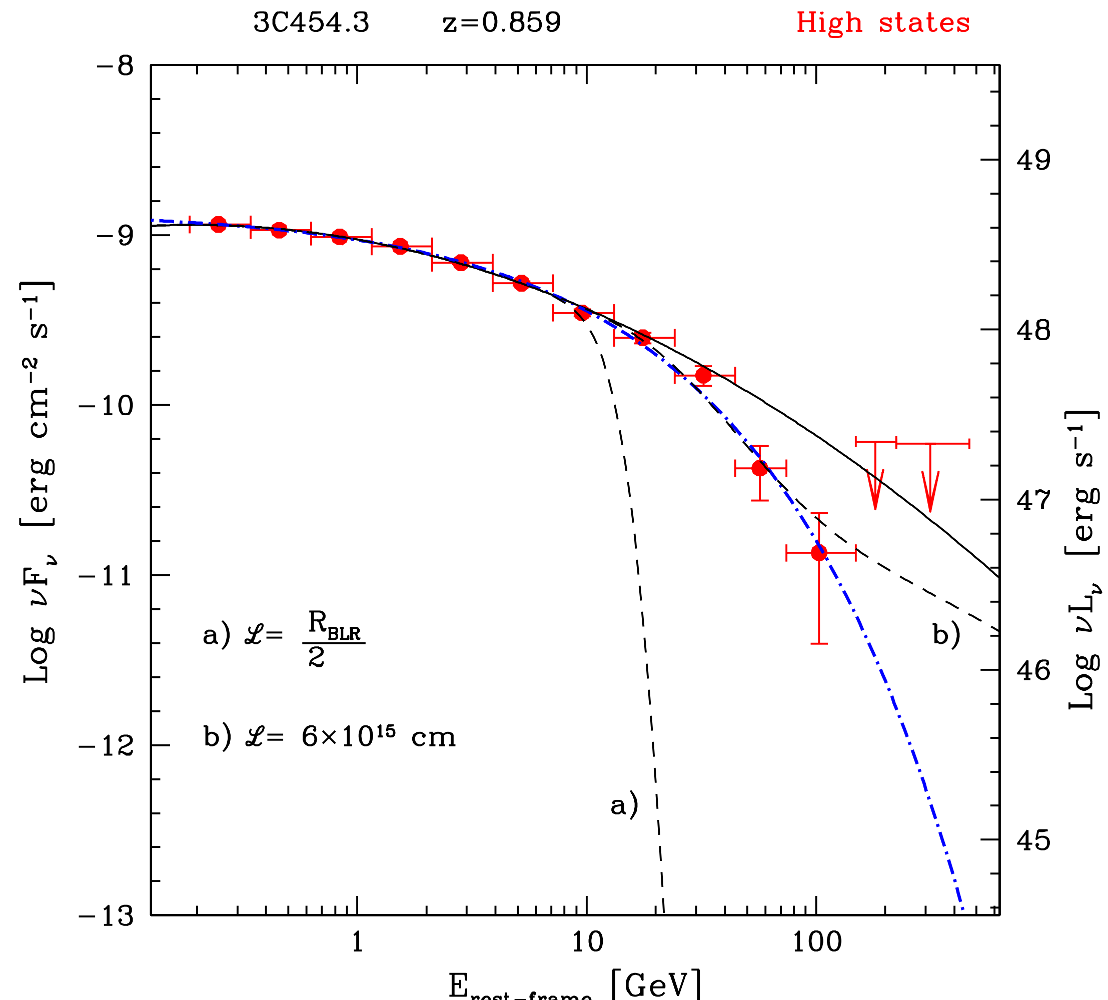


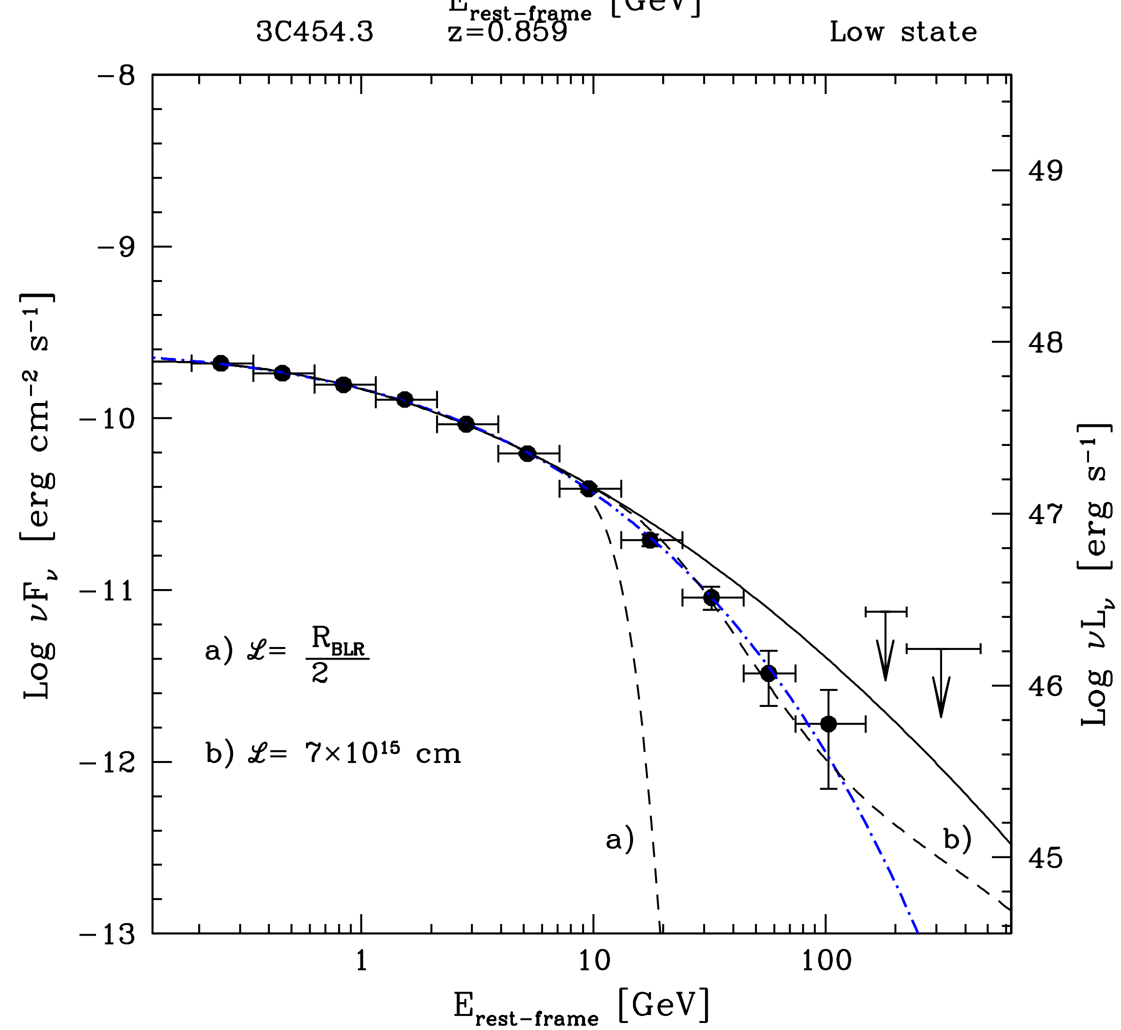




Even 3C 454.3 !







And better fitted with intrinsic cutoff:

Conclusion:

NO evidence of jet interaction with BLR photons !

EC(BLR) seems the exception, not the normality,
of the gamma-ray emission in Fermi Blazars

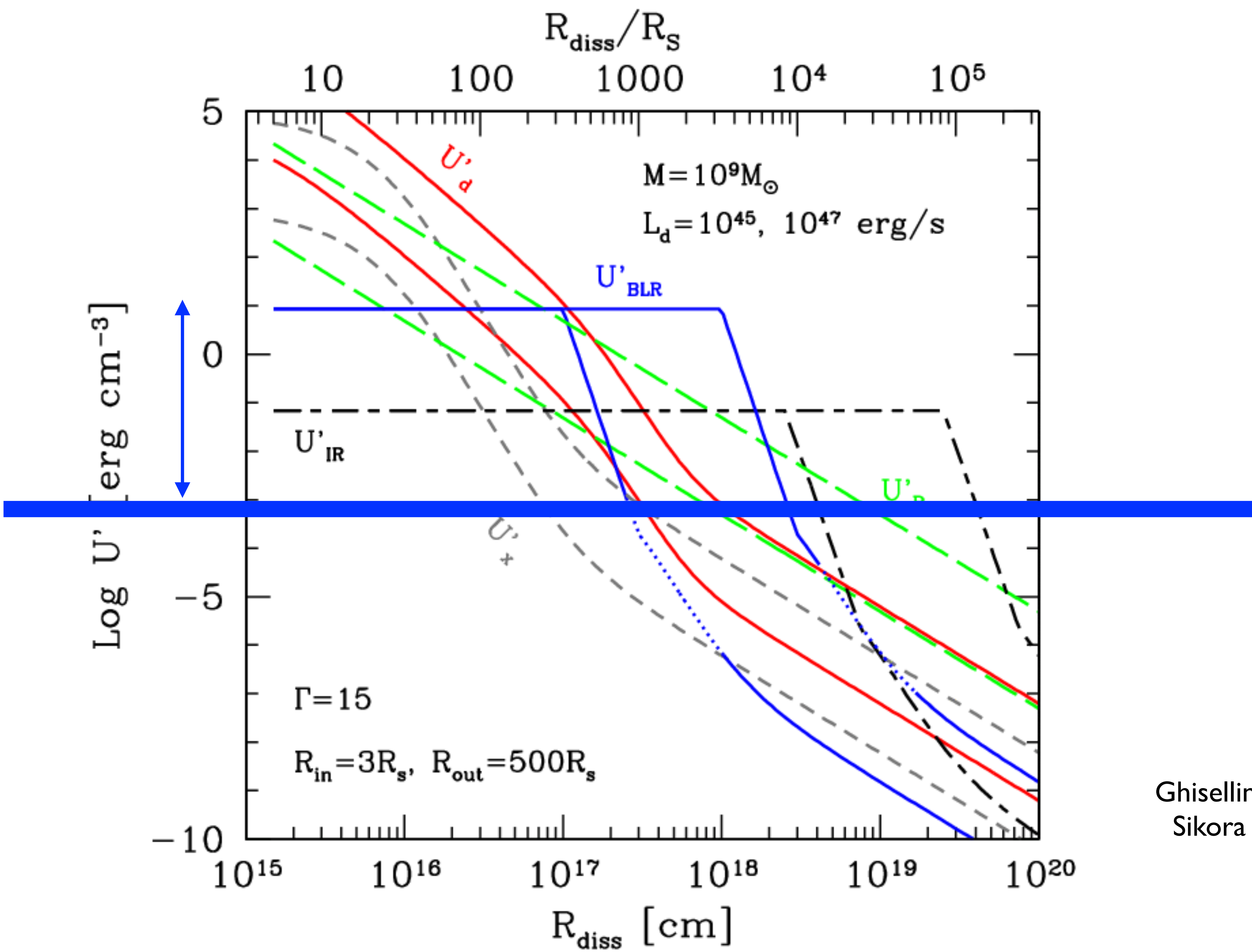
Alternatives?

how to reduce absorption but stay within the BLR ?

- *Much larger BLR (~100x)* $\tau \propto 1/R_{\rm BLR}$

- *Shift* $\gamma\gamma$ *threshold by selecting angles (Flattened BLR)*

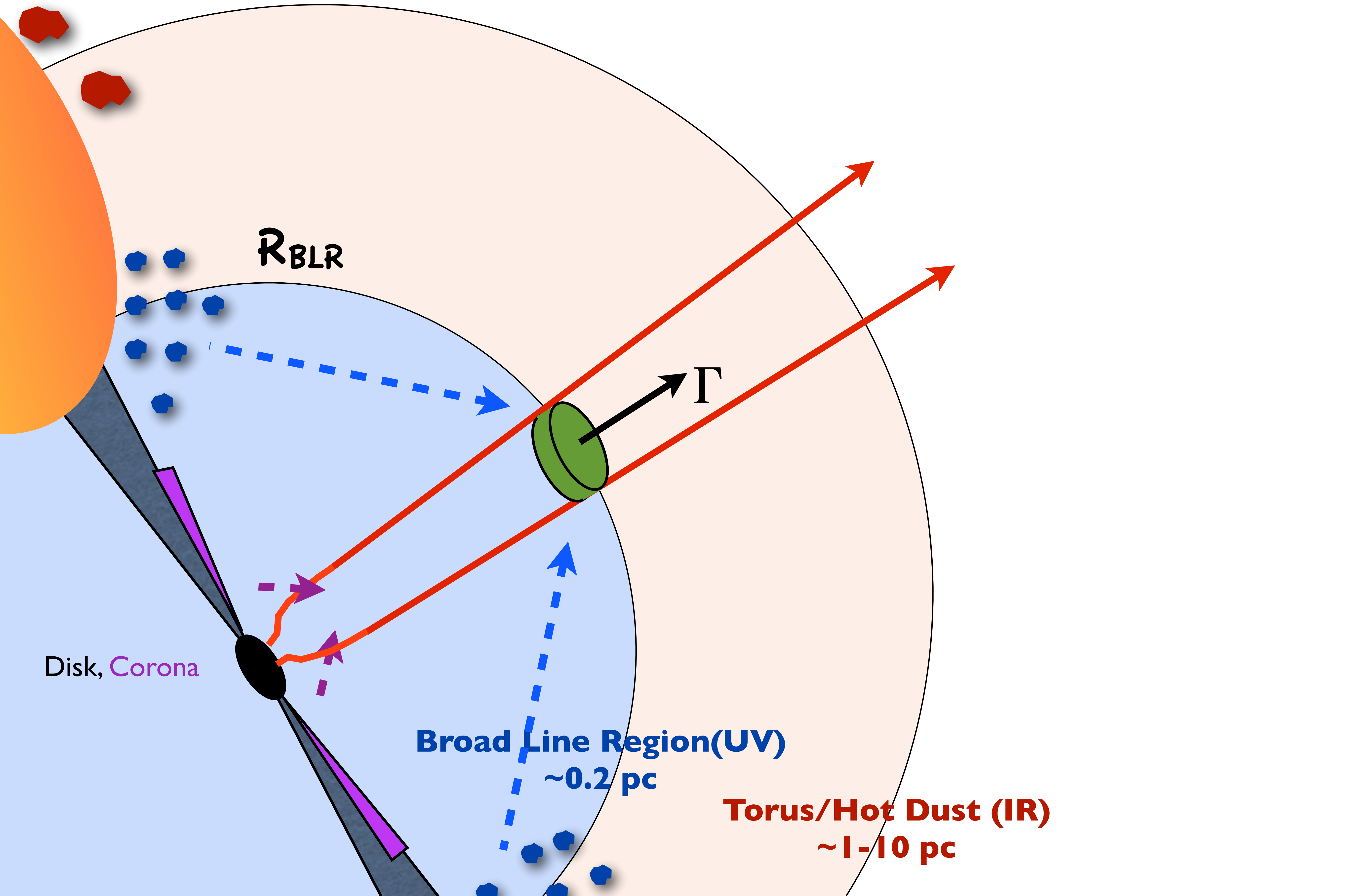
Energy density U along the jet:



Ghisellini et al. 2009
Sikora et al. 2009

U_{BLR} becomes lower than any other radiation field —> EC(BLR) disfavoured

Shift threshold 5x (to ~100 GeV) —> $\vartheta \leq$ 30 deg



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Both do NOT keep EC(BLR) viable

Caveats:

1) Long integration time (years)

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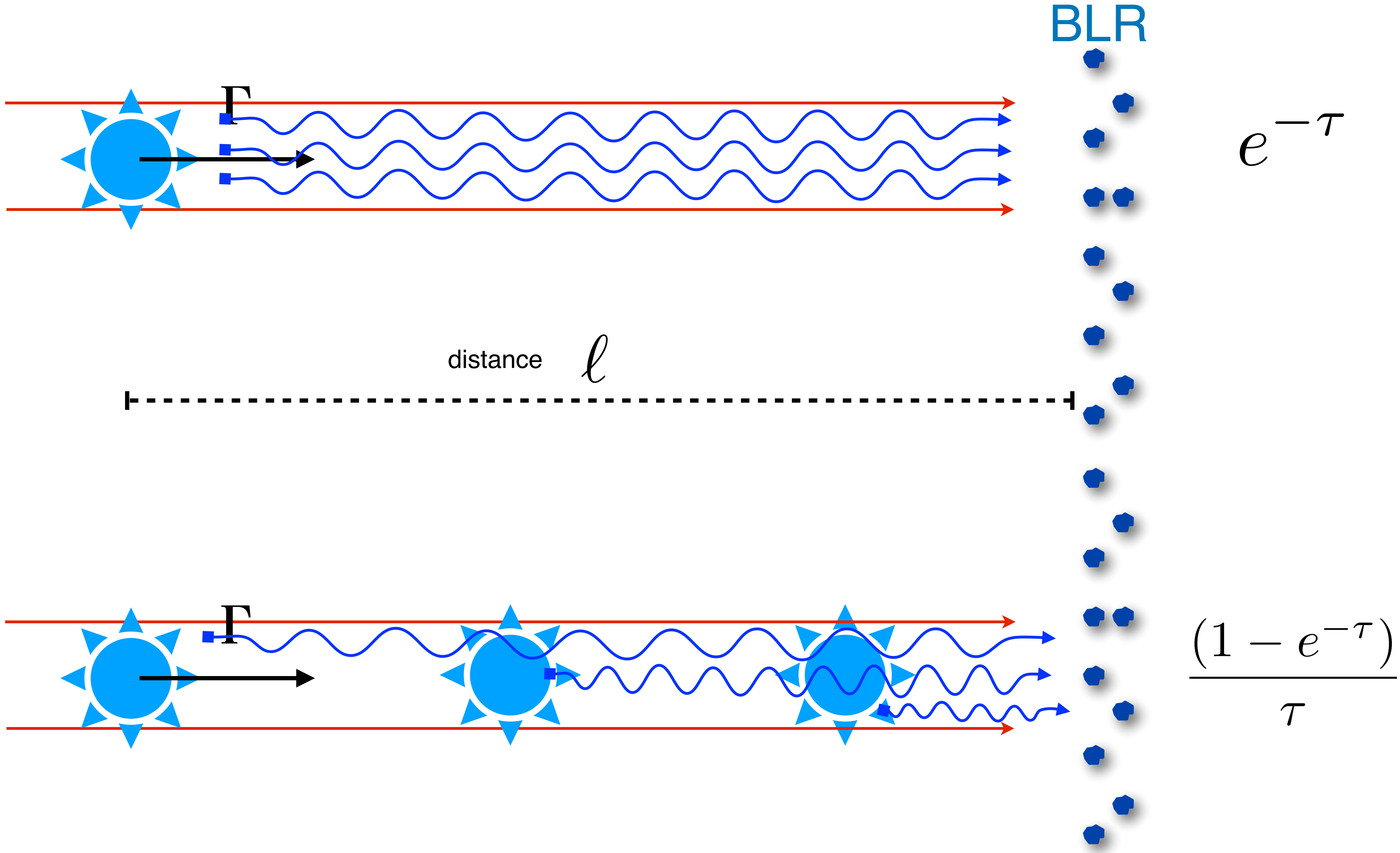
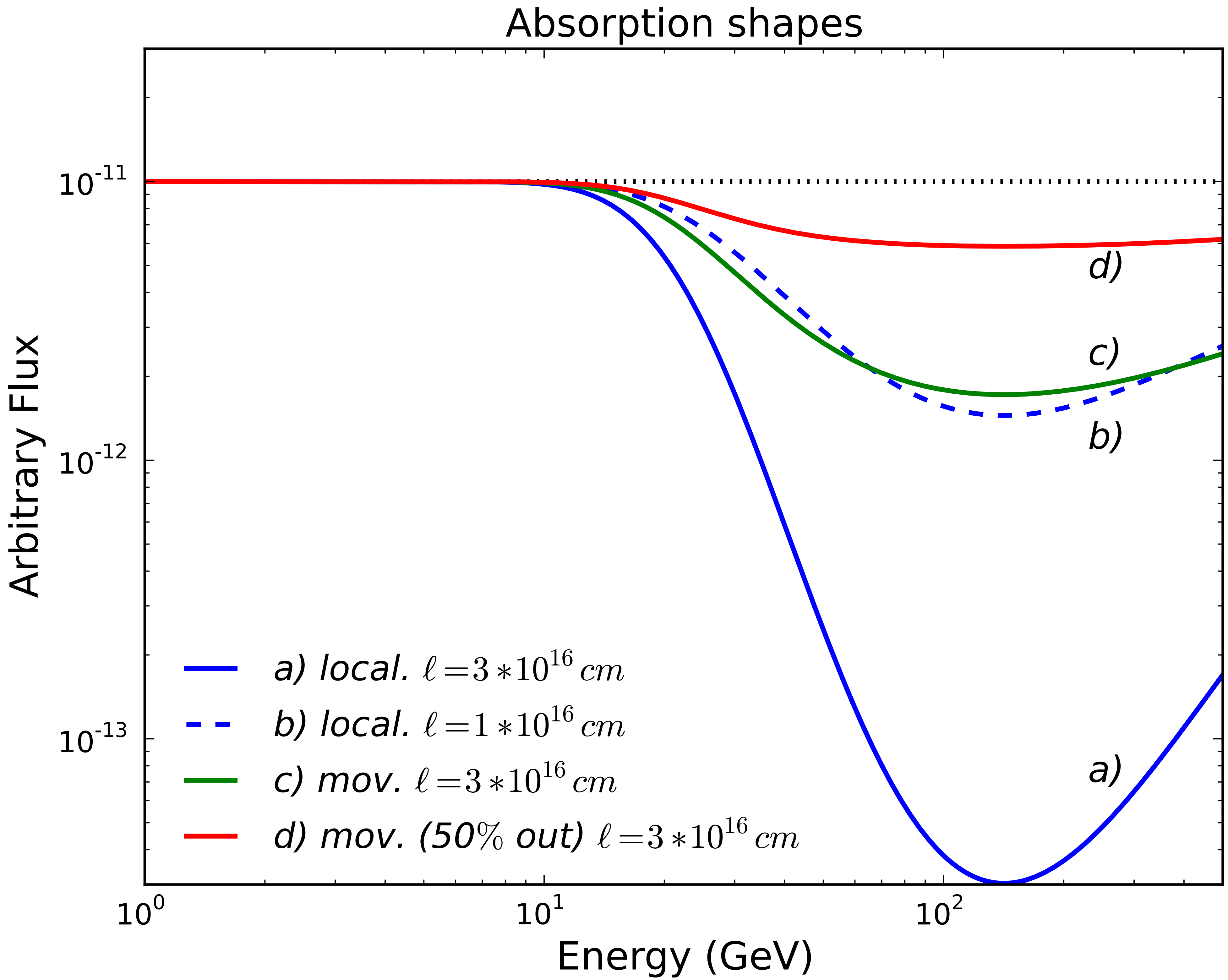
2) Kinematics of the emission
(localized dissipation vs moving blob)

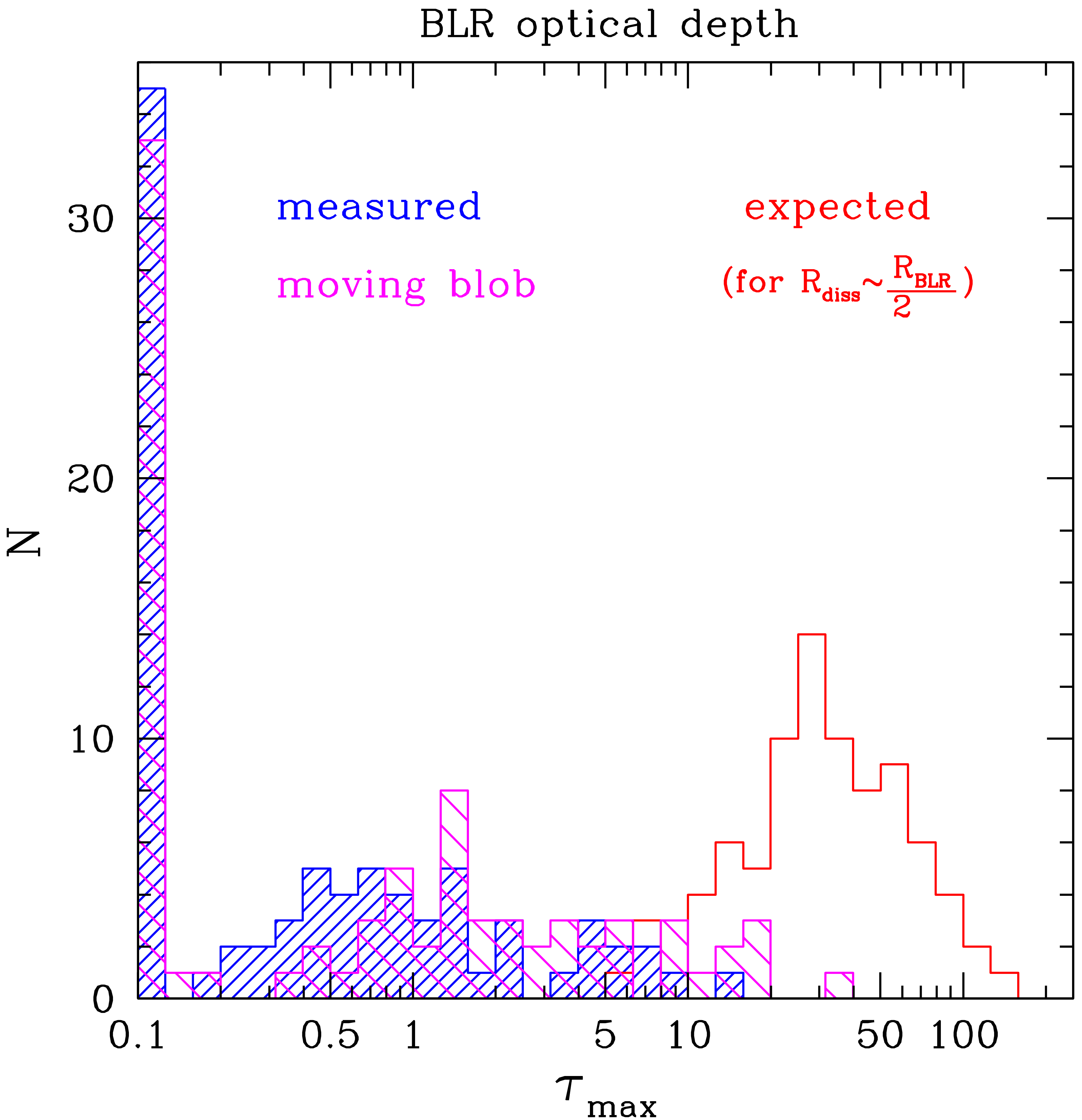
Doppler effect: $\Delta R \simeq \Delta t_{obs} * \beta * \Gamma^2$

$$\begin{matrix} \Gamma = 10 \\ \Delta t_{obs} \geq 10^5 s \end{matrix} \implies \Delta R \geq 10^{17} cm$$


BLR
Γ
$e^{-\tau}$
distance ℓ
Γ
$\frac{(1-e^{-\tau})}{\tau}$



Absorption shapes
Arbitrary Flux
Energy (GeV)
10^{-11}
10^{-12}
10^{-13}
10^{0}
10^{1}
10^{2}
d)
c)
b)
a)
a) local. $\ell = 3 * 10^{16}\, cm$
b) local. $\ell = 1 * 10^{16}\, cm$
c) mov. $\ell = 3 * 10^{16}\, cm$
d) mov. (50% out) $\ell = 3 * 10^{16}\, cm$



It does <u>not</u> change the main result

Conclusion & Consequences

1) EC(BLR) is disfavoured as gamma-ray emission mechanism in Broad-line Blazars *(EC-IR or SSC or EC-ambient)*

   ⇒ *re-model SED for jet parameters*

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2) Gamma-ray spectrum is mostly intrinsic (particle distribution)

   ⇒ *new diagnostic possibilities*

The Astrophysical Journal, 753:176 (14pp), 2012 July 10 doi:10.1088/0004-637X/753/2/176

ON THE SPECTRAL SHAPE OF RADIATION DUE TO INVERSE COMPTON SCATTERING CLOSE TO THE MAXIMUM CUTOFF

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Received 2012 March 10; accepted 2012 May 11; published 2012 June 26

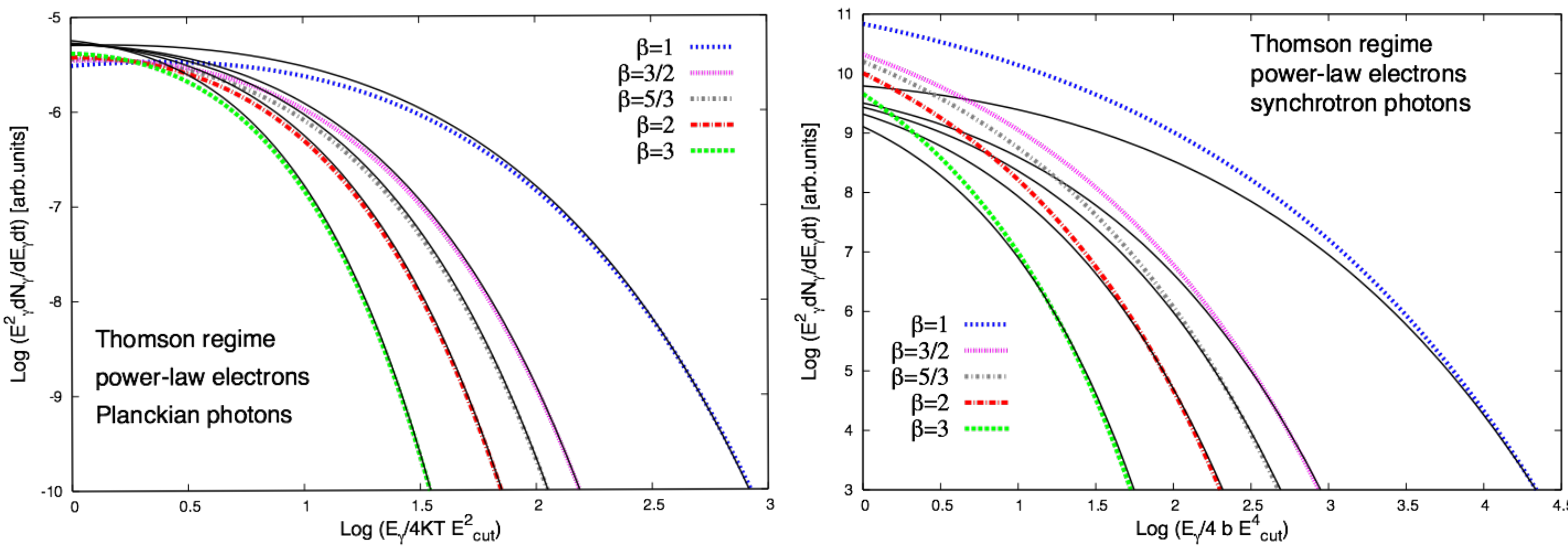


Table 1
The Index of the Exponential Cutoff in the Energy Spectrum of IC Radiation β_C Calculated for Three Different Target Photon Fields, in the Thomson and Klein-Nishina Regimes

Scattering regime	Thomson	Klein-Nishina	Thomson	Klein-Nishina
Radiation field electrons	β	β	abrupt cutoff	abrupt cutoff
Monochromatic photons	$\beta/2$	β	∞	∞
Planckian photons	$\beta/(\beta+2)$	β	1	∞
Synchrotron photons	$\beta/(\beta+4)$	β	1	∞

Note. The index β characterizes the exponential cutoff in the electron energy distribution given by Equation 1.

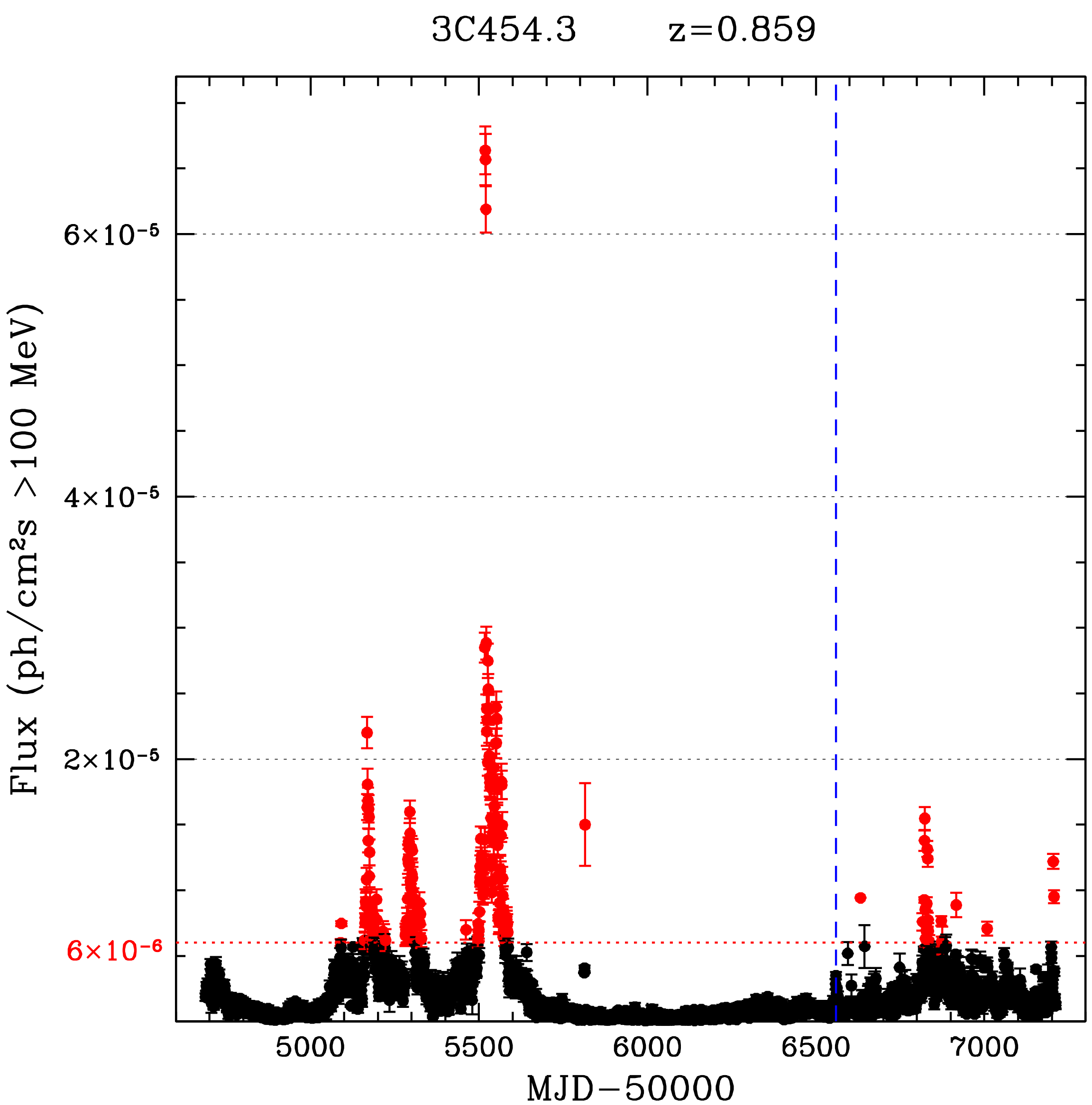
Conclusion & Consequences

1) EC(BLR) is disfavoured as gamma-ray emission mechanism in Broad-line Blazars *(EC-IR or SSC or EC-ambient)*
   ⇒ *re-model SED for jet parameters*

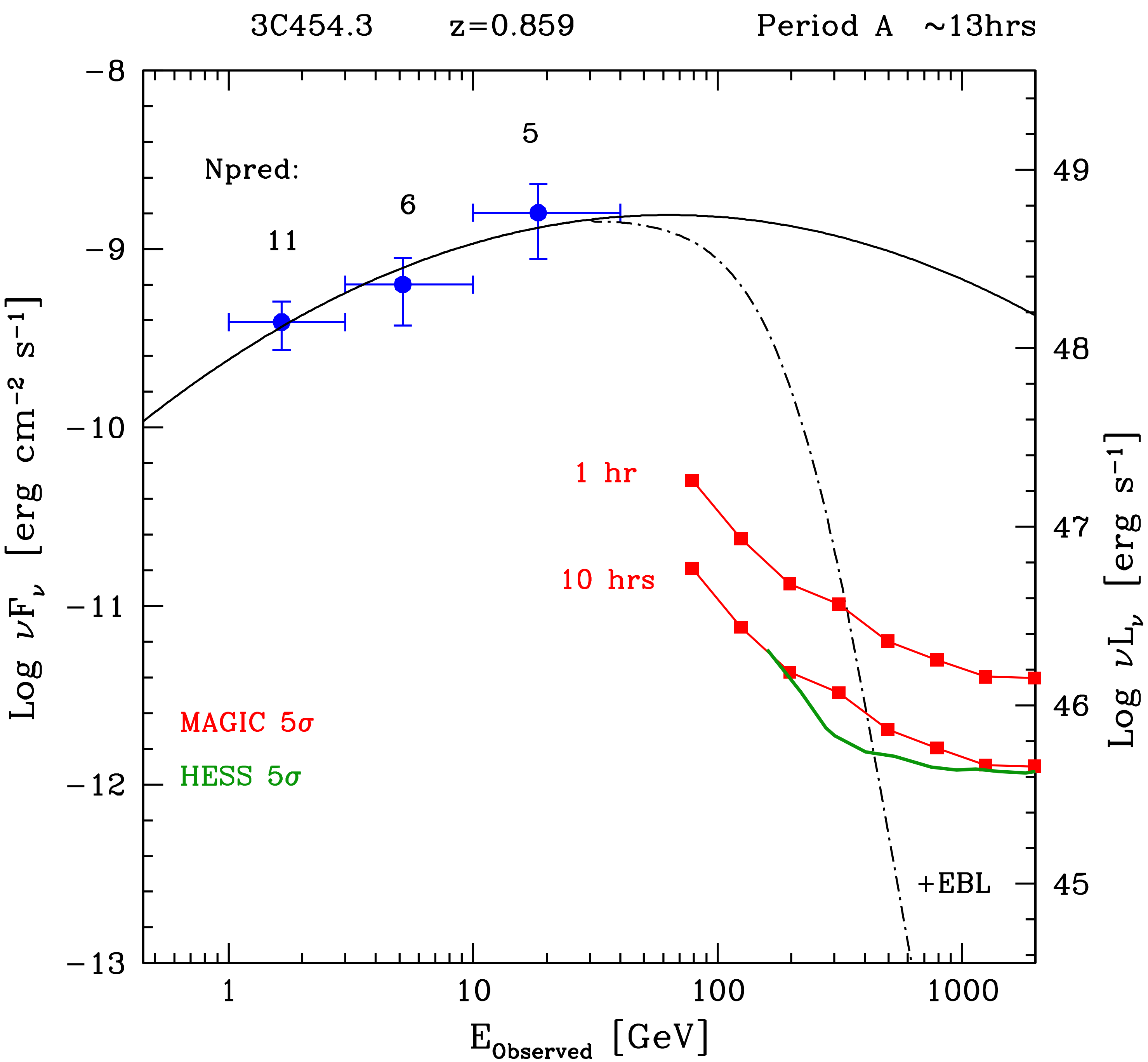
2) Gamma-ray spectrum is mostly intrinsic (particle distribution)
   ⇒ *new diagnostic possibilities (e.g. Lefa et al 2014)*

3) Without BLR suppression, FSRQs luminous at VHE
   ⇒ *CTA sky much richer of FSRQs*

3C 454.3 can be easily detectable at VHE !



Pacciani et al. 2014 - flare



HBL-like flare !

Conclusion & Consequences

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   ⇒ *re-model SED for jet parameters*

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3) Without BLR suppression, FSRQs luminous at VHE
   ⇒ *CTA sky much richer of FSRQs*

4) Differences FSRQ/BLLac are intrinsic to the jet: accretion and jet power

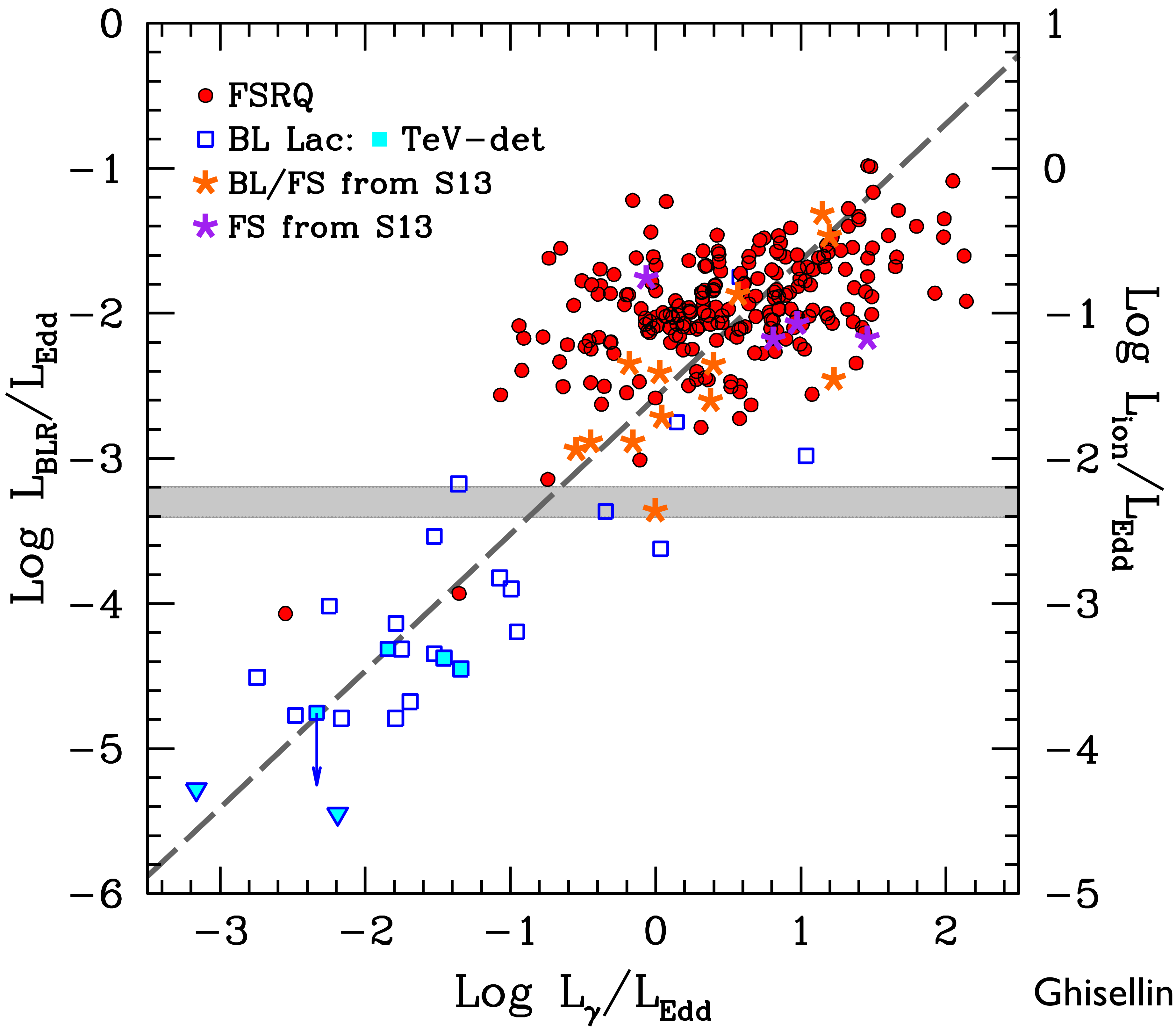
Costamante, Cutini, Tosti, Antolini, Tramacere 2018, MNRAS, in press (arXiv 1804.06282)

back-up slides

Strong vs Weak Lined Blazars

real FSRQ

real BLLacs

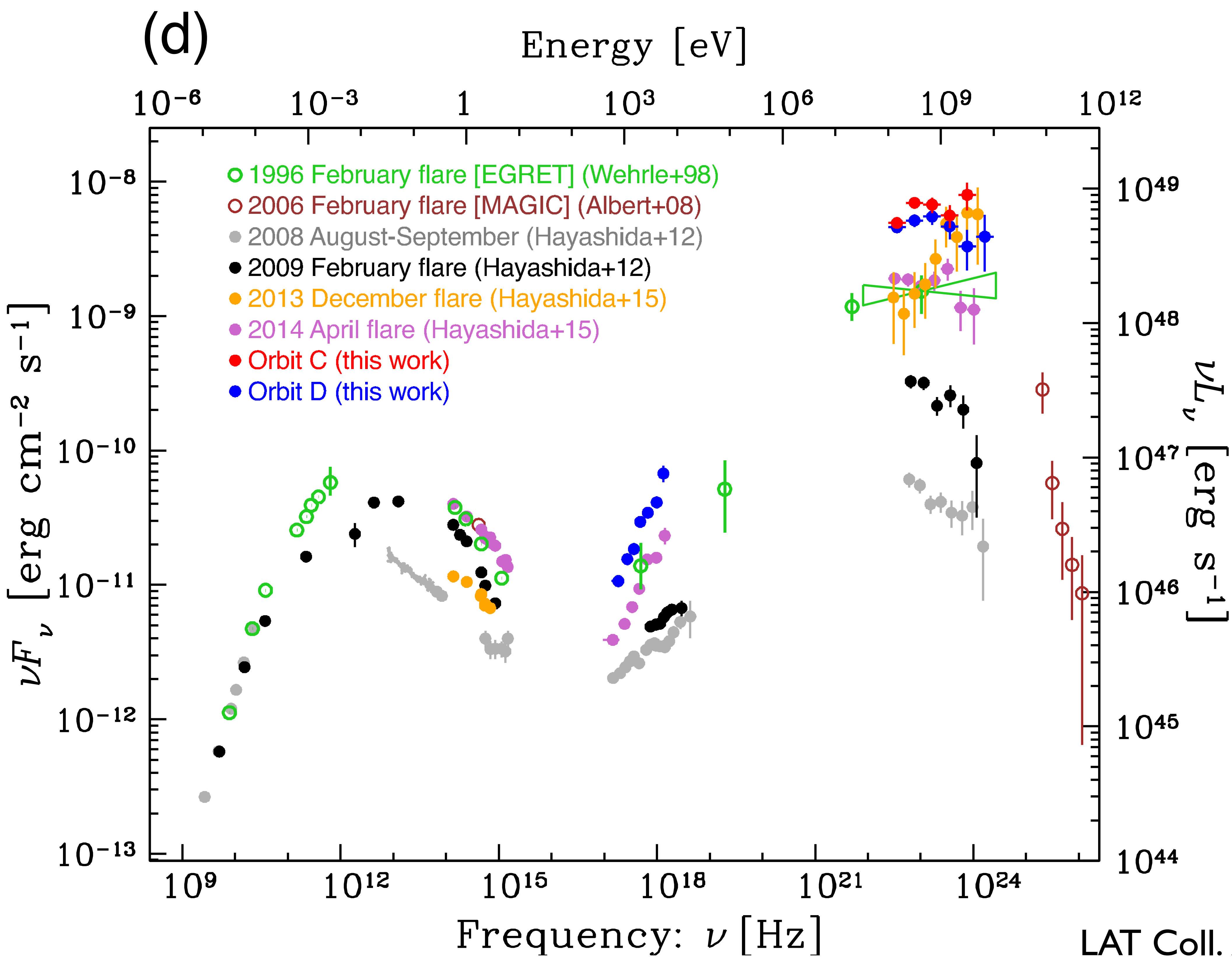


radiatively efficient

radiatively inefficient

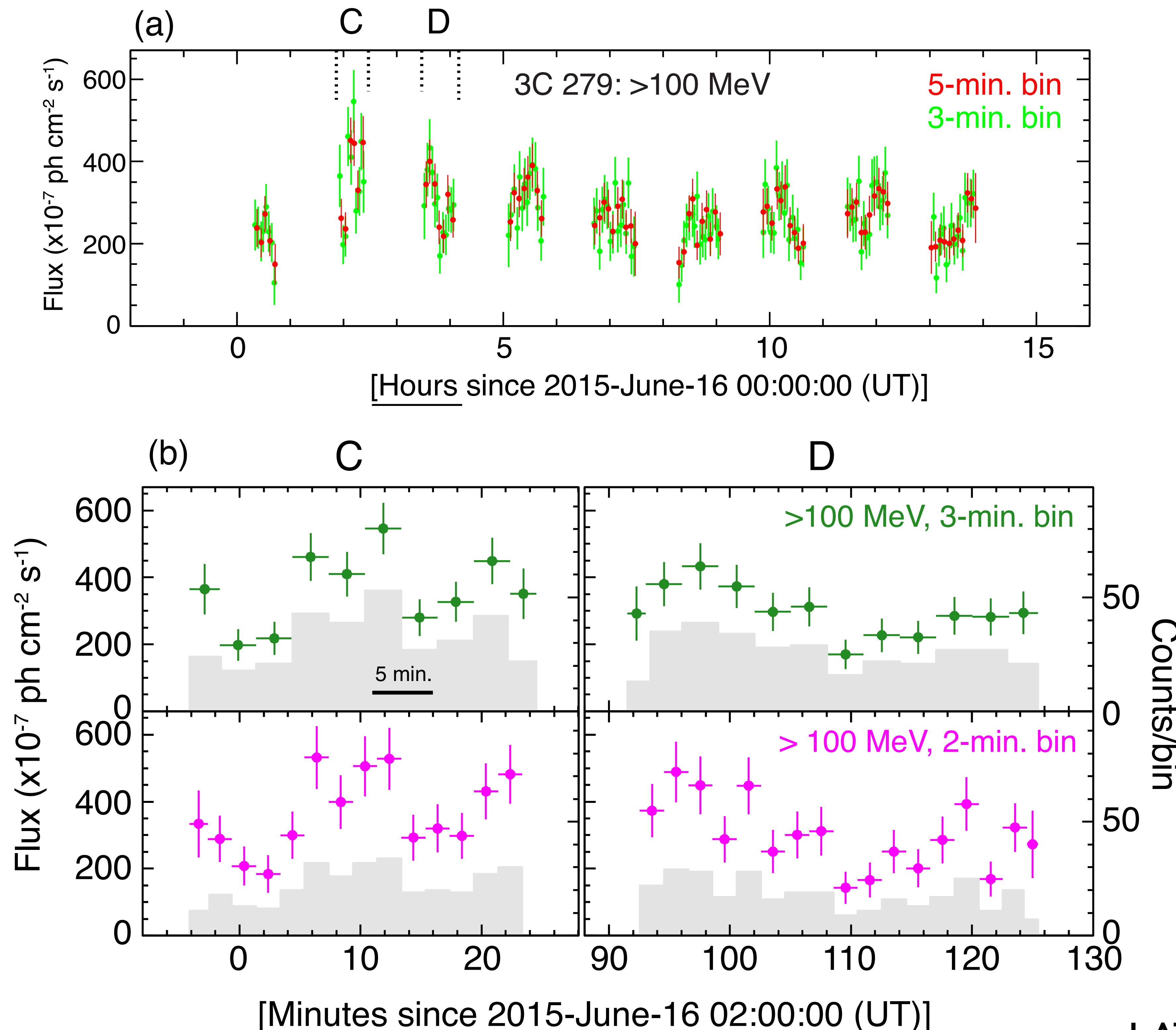
Ghisellini et al 2013

3C 279



LAT Coll. 2016

Also in Fermi: 3C 279 huge flare in 2015

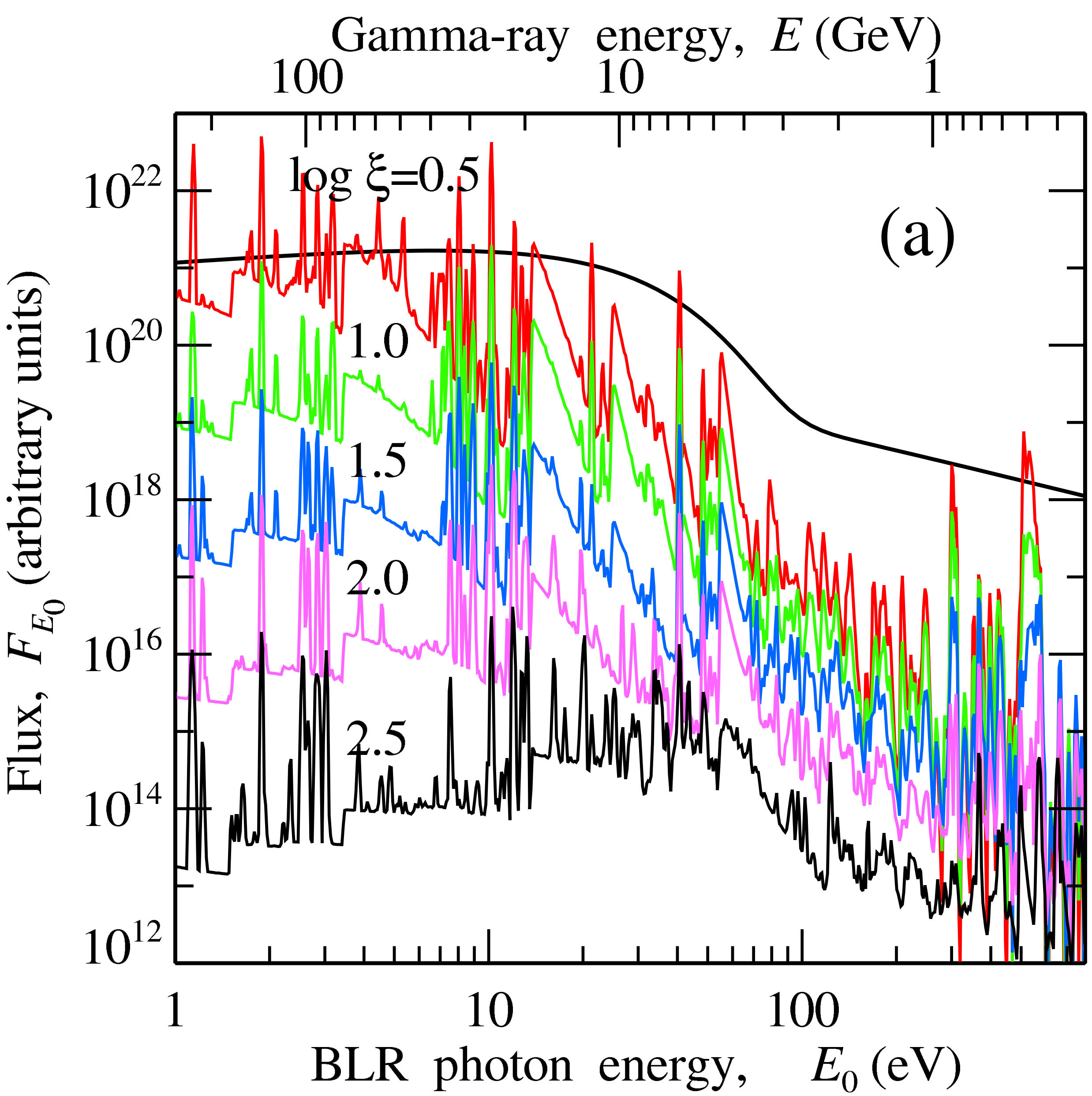


LAT Coll. 2016

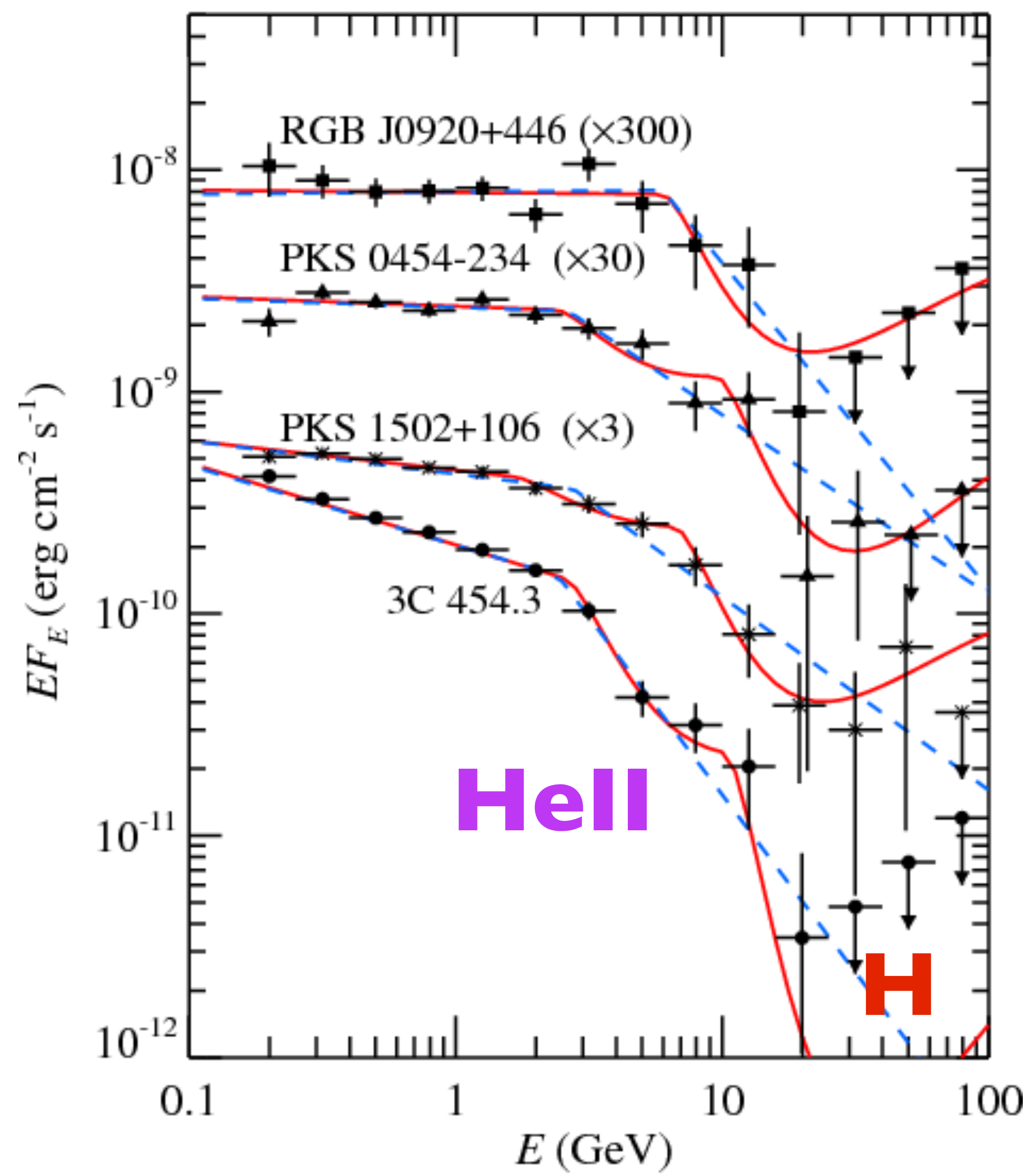
Stratified BLR:
High and Low excitation lines

$R_H \sim 0.2\text{-}0.3\ R_0 \quad R_L \sim 3\text{-}5\ R_0$

BLR at different ionization parameter

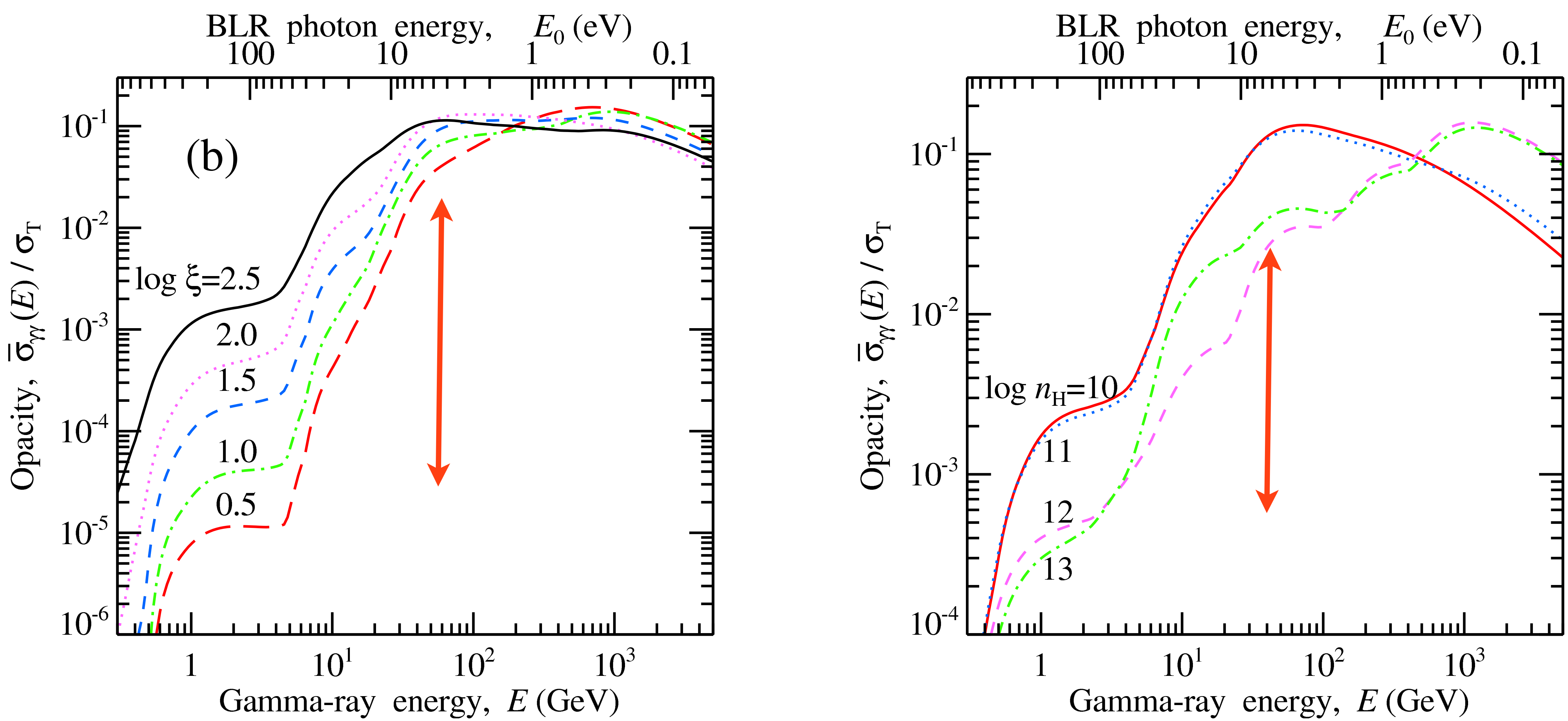


Double absorption:



Poutanen and Stern 2010-2012

Problem with BLR-absorption interpretation:



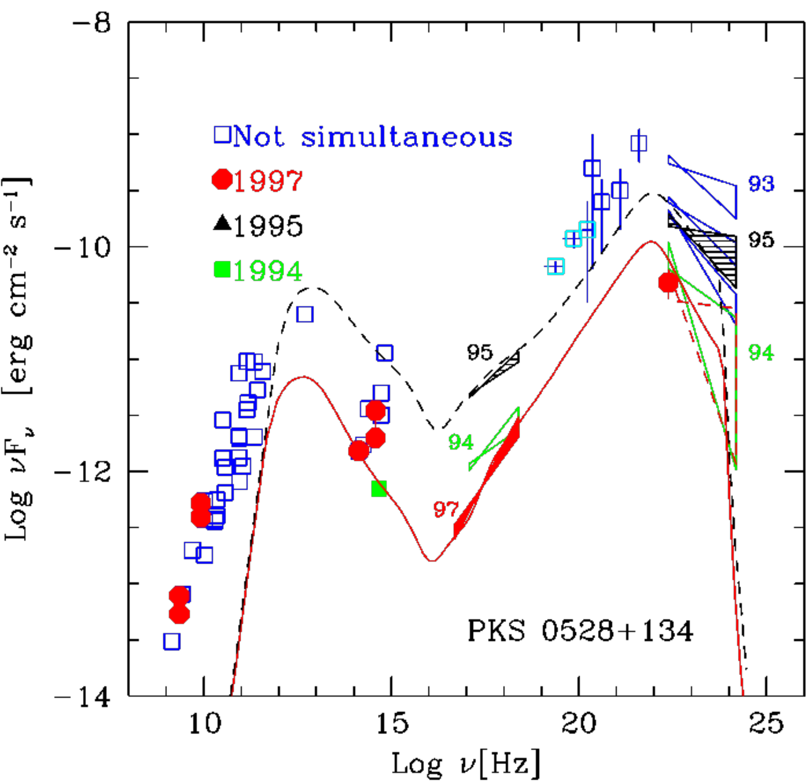
Data from Poutanen 2011

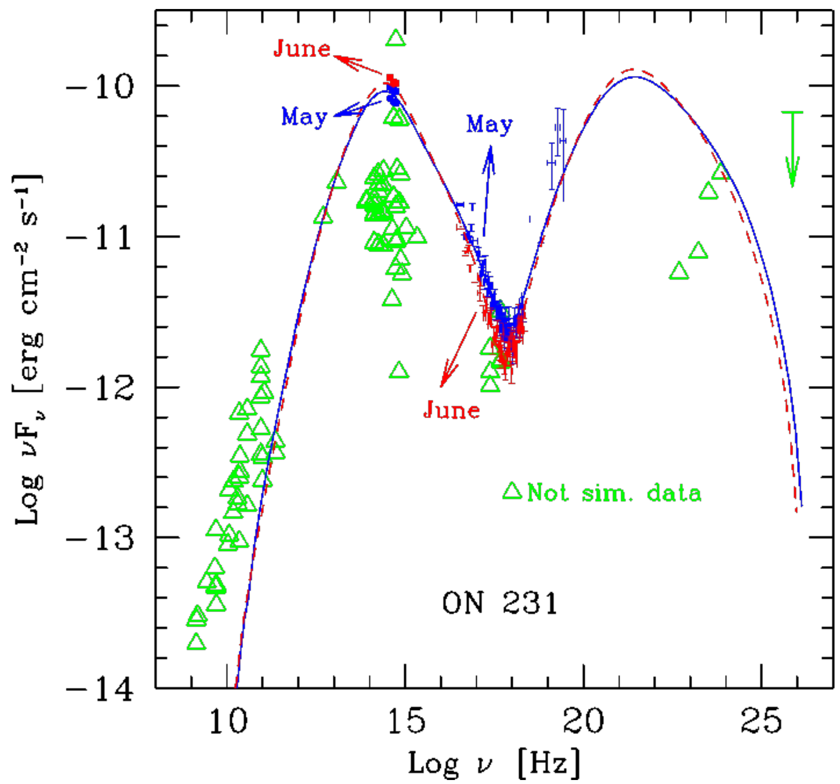
If $\tau_{He} > 1 \quad \Rightarrow \quad \tau_H > 100 \times \tau_{He}$

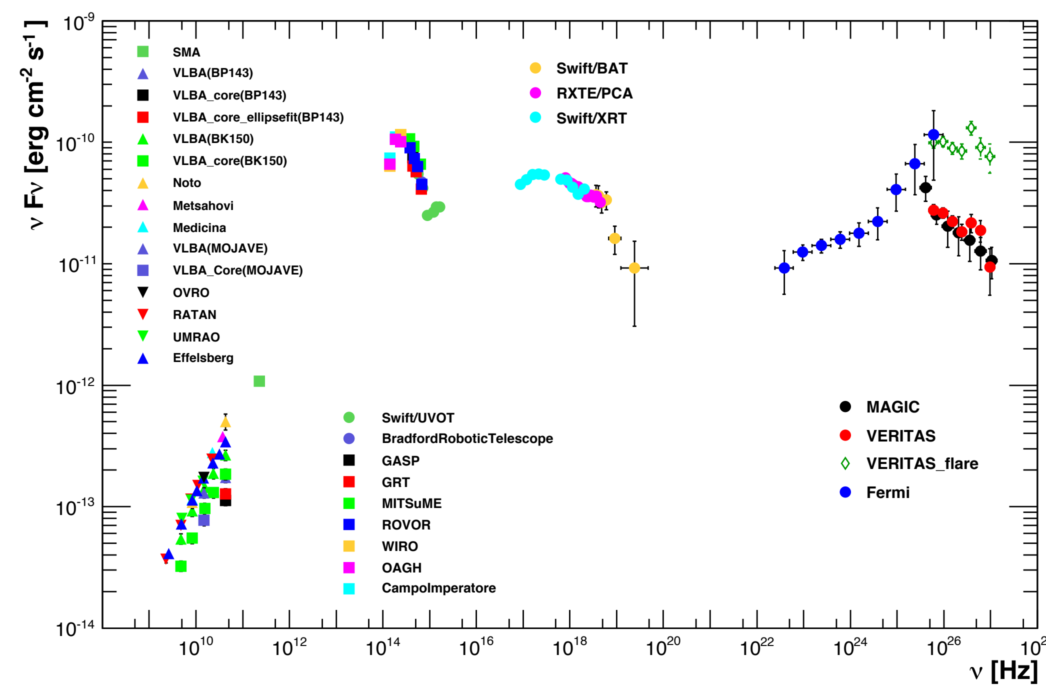
Cannot explain 3GeV break without 10 GeV cutoff

Blazar Zone:

where the emission responsible for the bulk of the SED comes from.



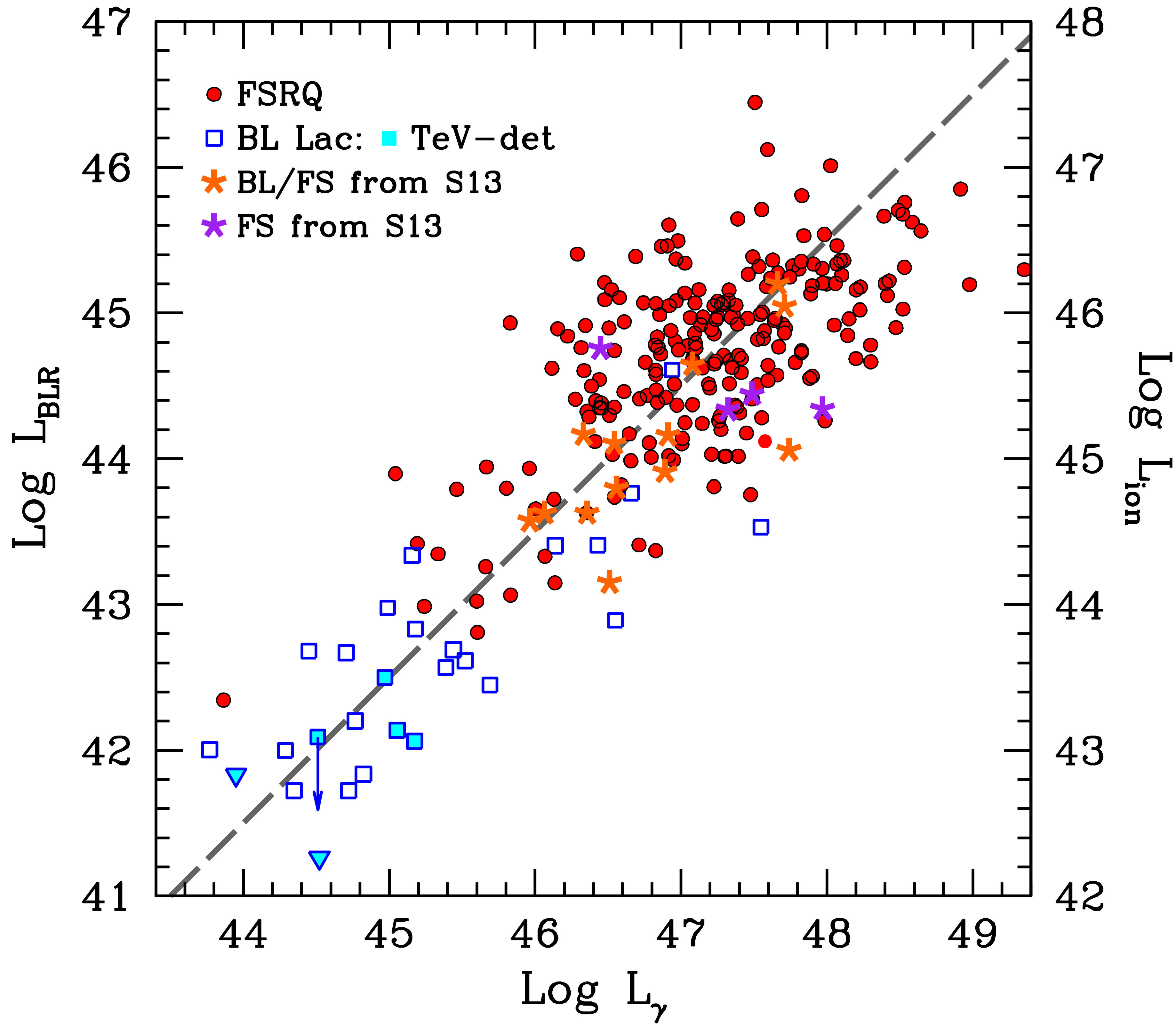




From Low to High-energy peaked Blazars:

FSRQ - LBL - IBL - HBL - Extreme BL

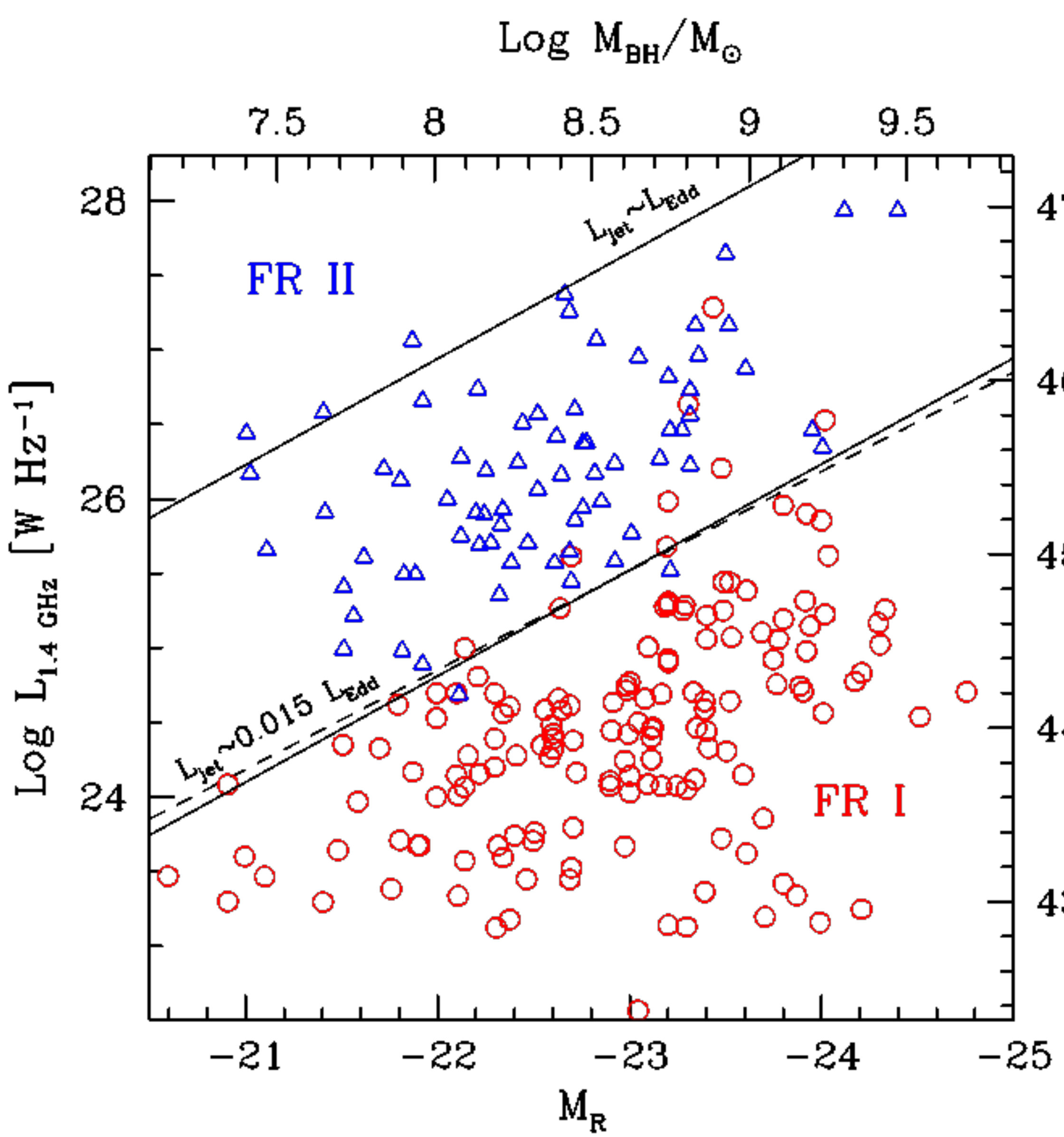
Giommi & Padovani 1994,1995



FSRQ
BL Lac:
TeV-det
BL/FS from S13
FS from S13
Log L_{BLR}
Log L_{ion}
Log L_{γ}
47
46
45
44
43
42
41
48
47
46
45
44
43
42
44
45
46
47
48
49

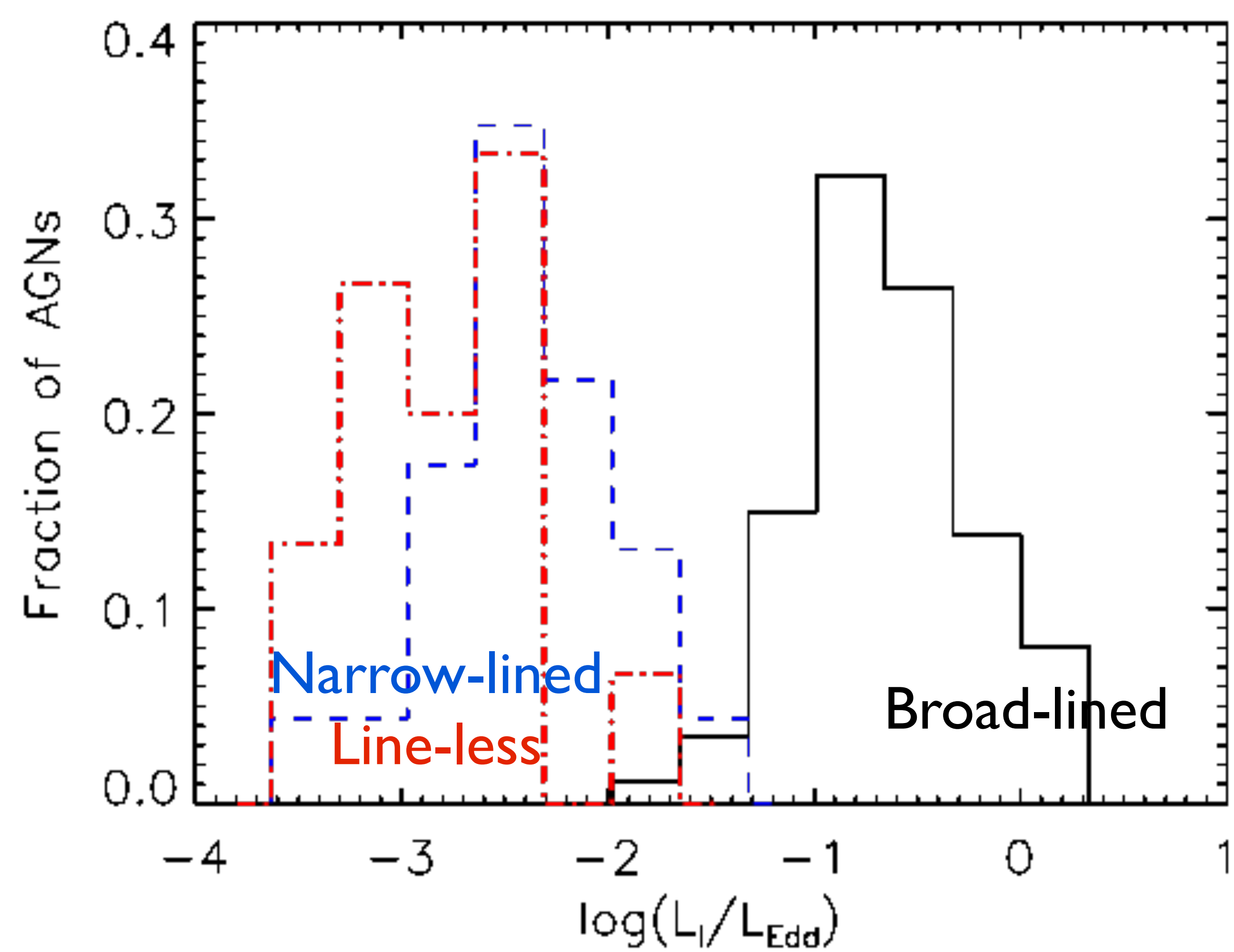
Something is happening at L ~0.01 L_{Edd}

ADAF - Shakura/Sunyaev ?



Ledlow & Owen 1996
Ghisellini & Celotti 2002

Sample 82 unobscured AGNs

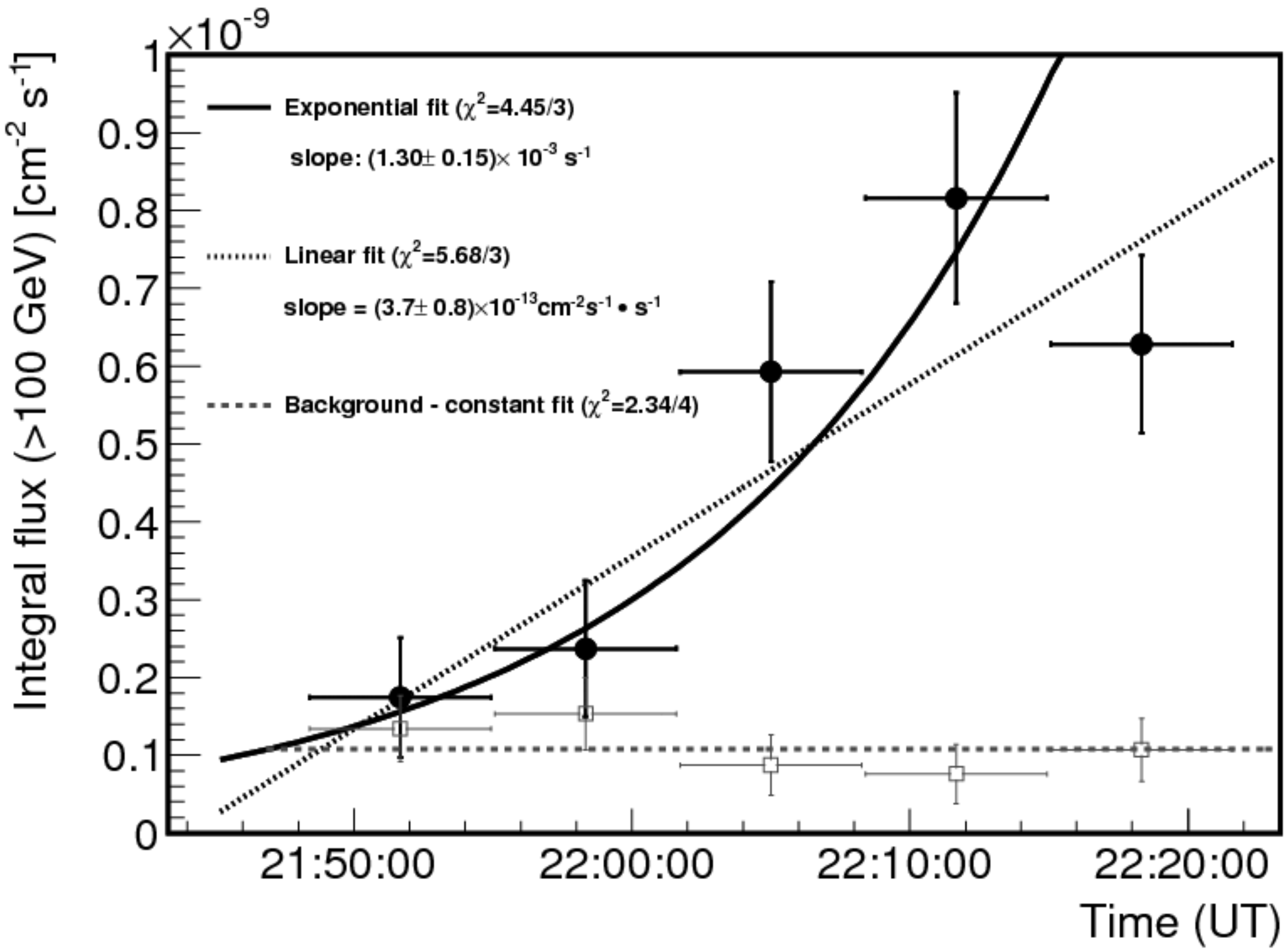


Trump et al. 2011

MAGIC fundamental discovery on 4C 21.35: ultrafast variability also in FSRQ !

2) FSRQ, R_{diss} > 1-10 pc ⇒ a) larger region, mm-transparent

b) variability ~days-week



10-min variability !

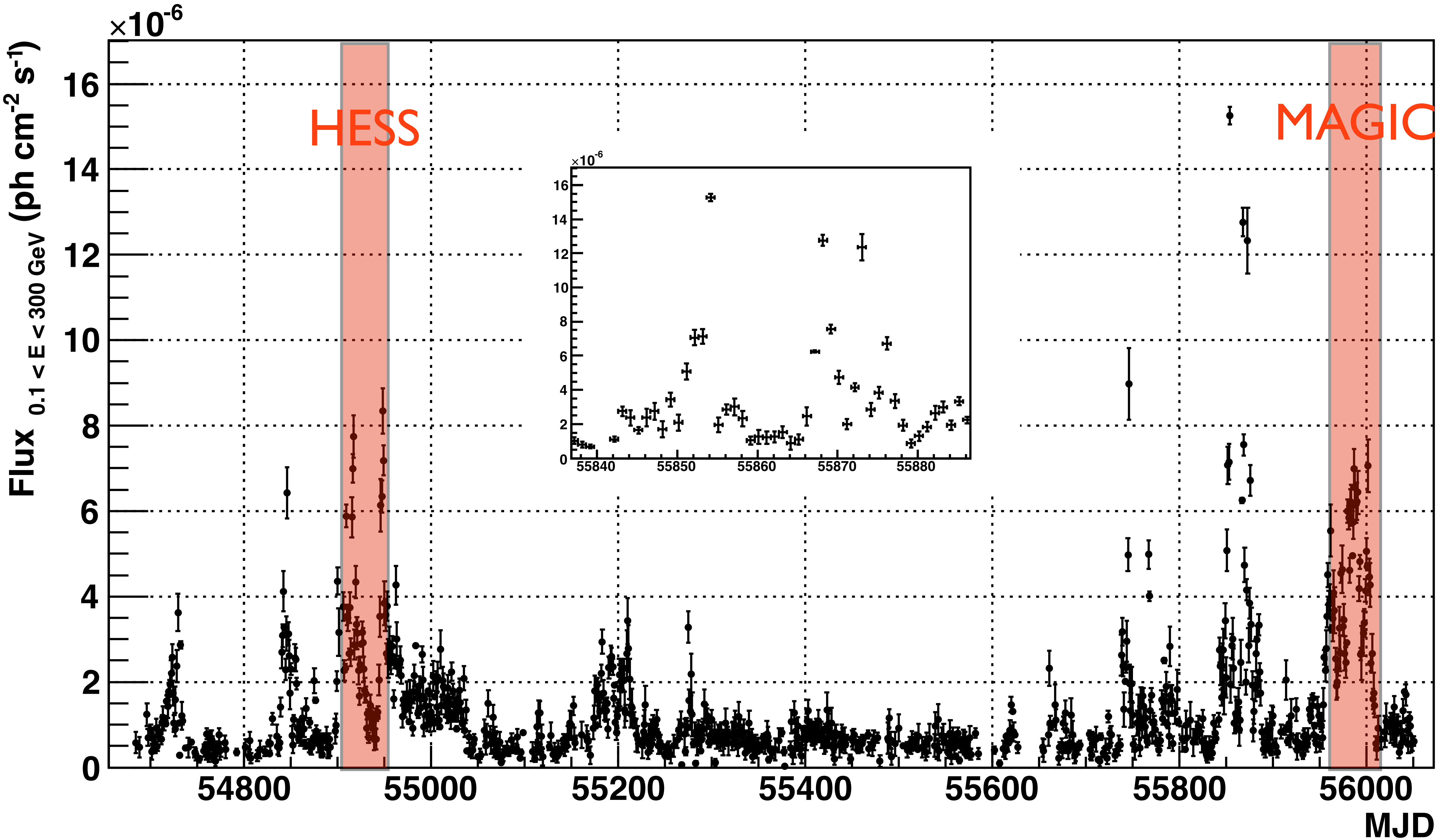
$$R \sim 2.5 \times 10^{14}\ \delta_{10}\ t_{\rm var,10min}\ {\rm cm}$$

at several pc from Black Hole

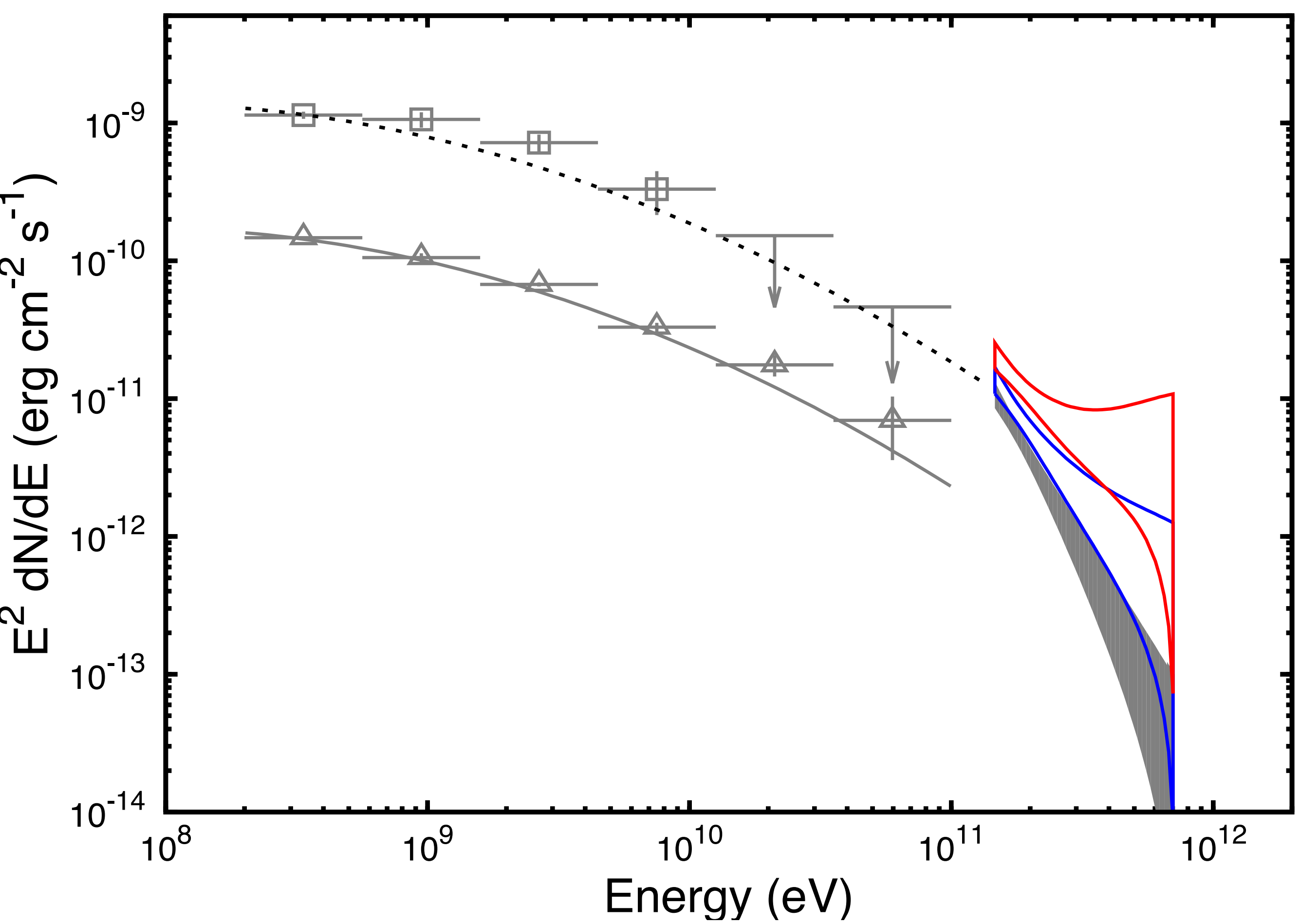
Problem for all models !

Aleksic et al. 2011 (MAGIC coll)

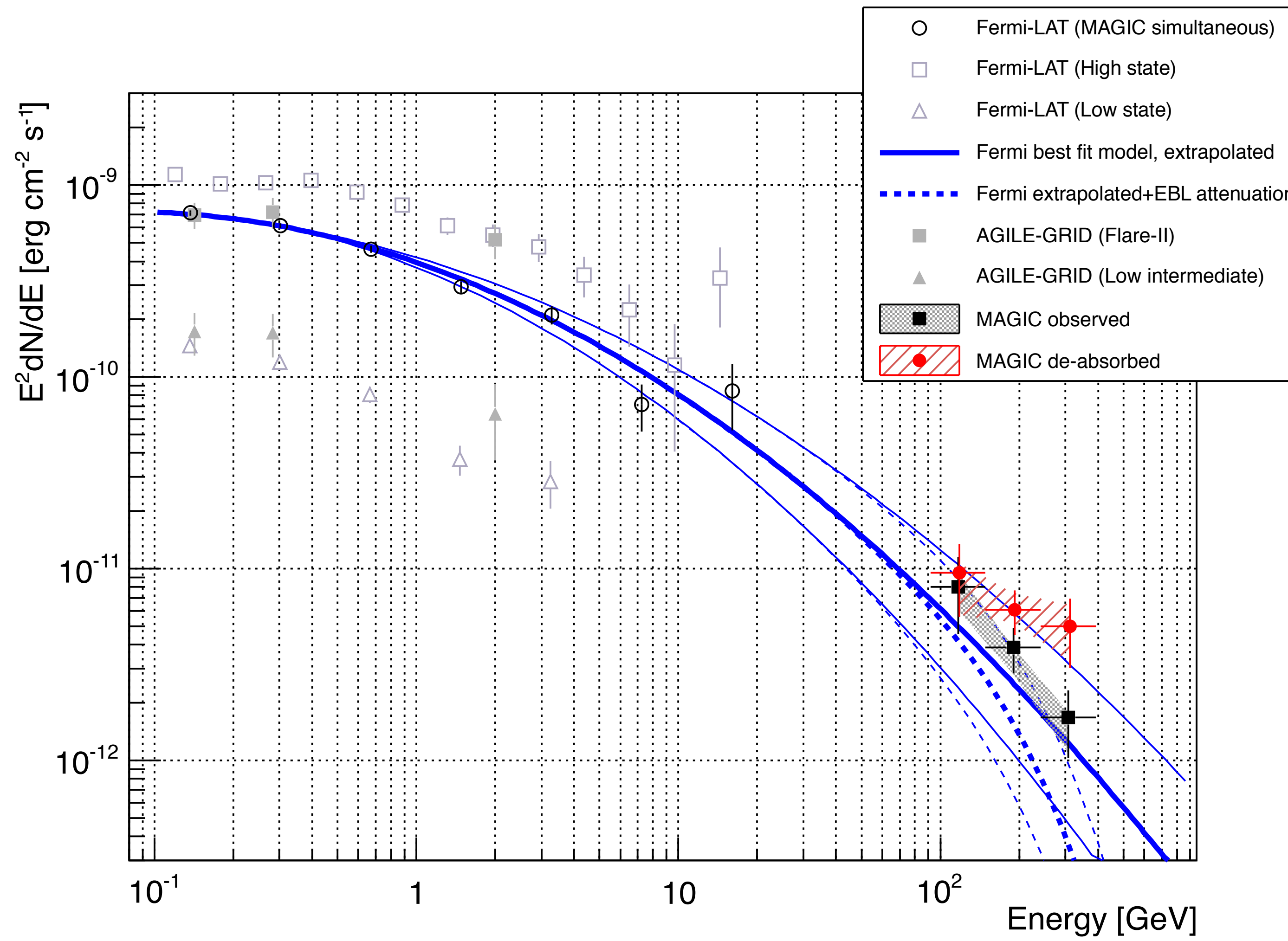
PKS 1510-089



PKS 1510-089: GeV-TeV Spectra



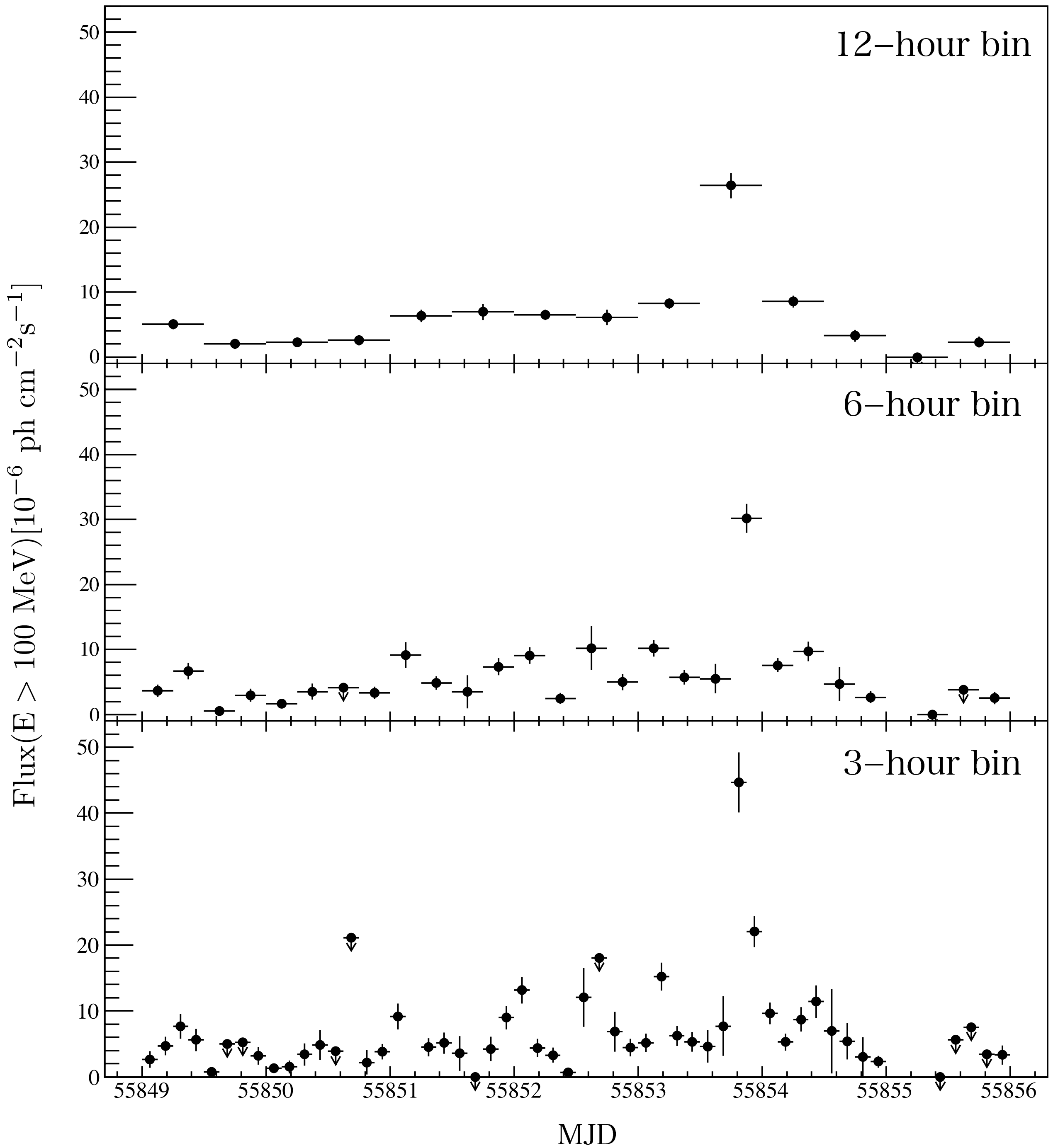
Abramowski et al. (Hess Coll) 2013

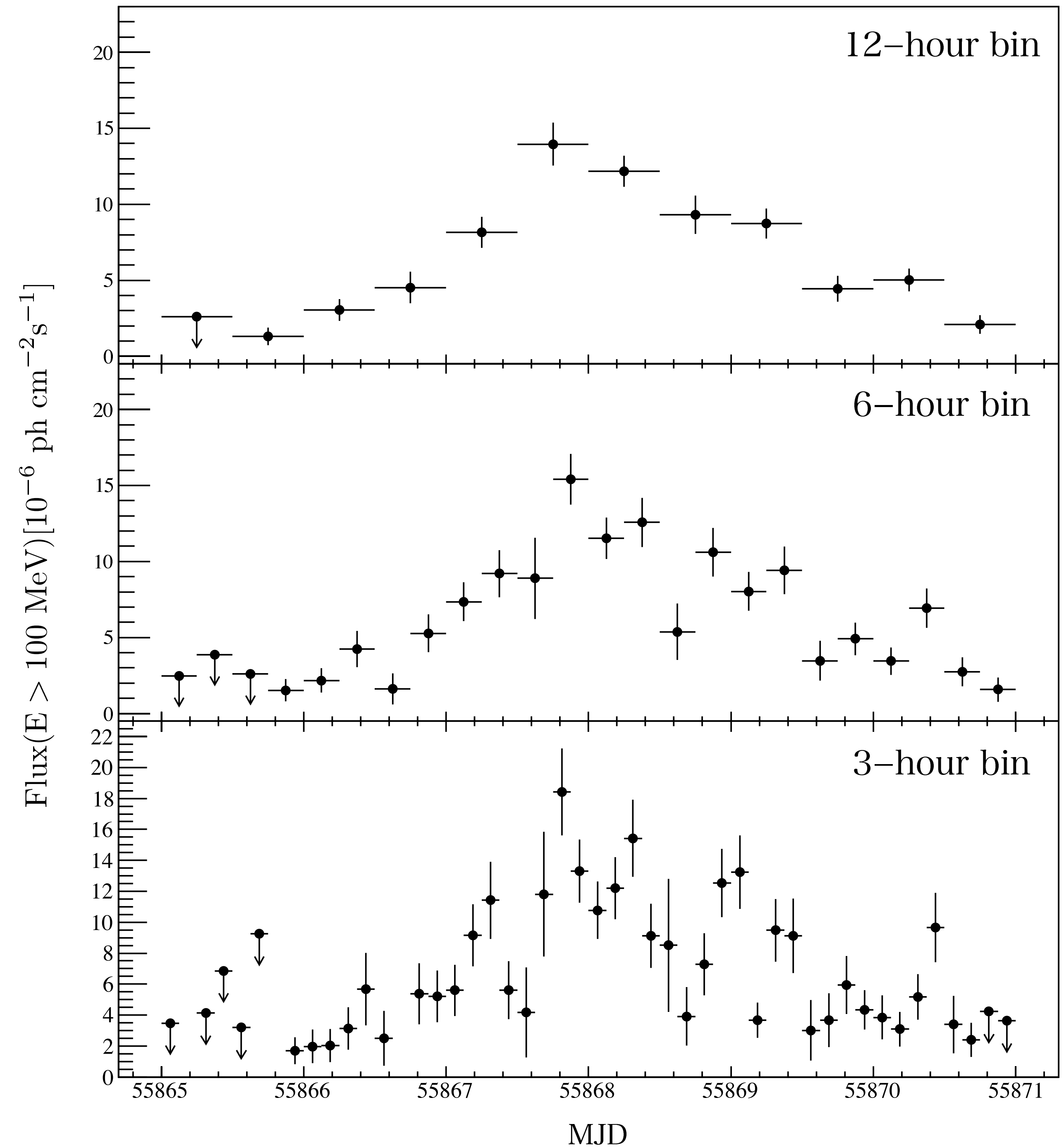


Aleksic et al. (Magic Coll) 2014

NO Jet-BLR interaction

Ultra-fast variability ? (<3hrs)

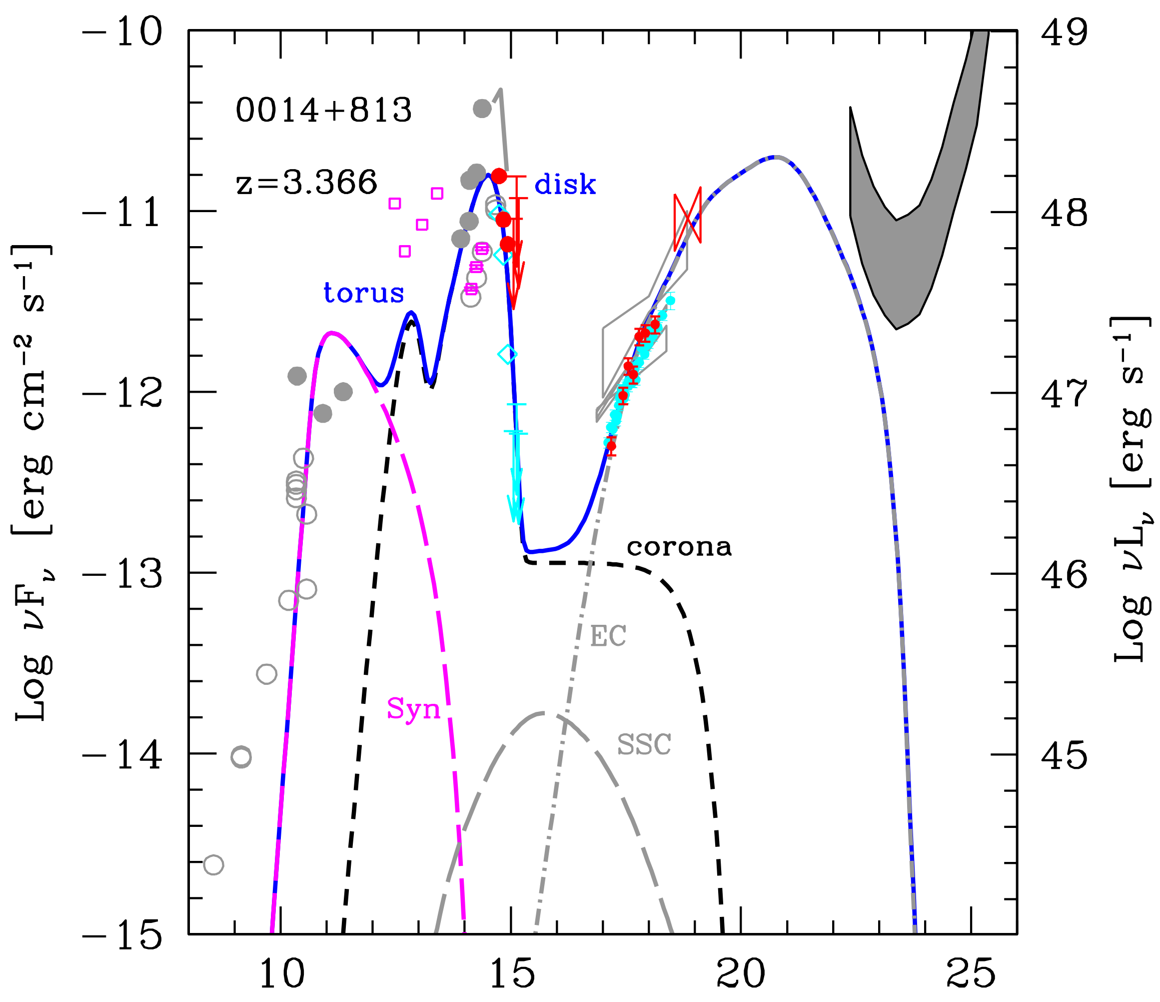




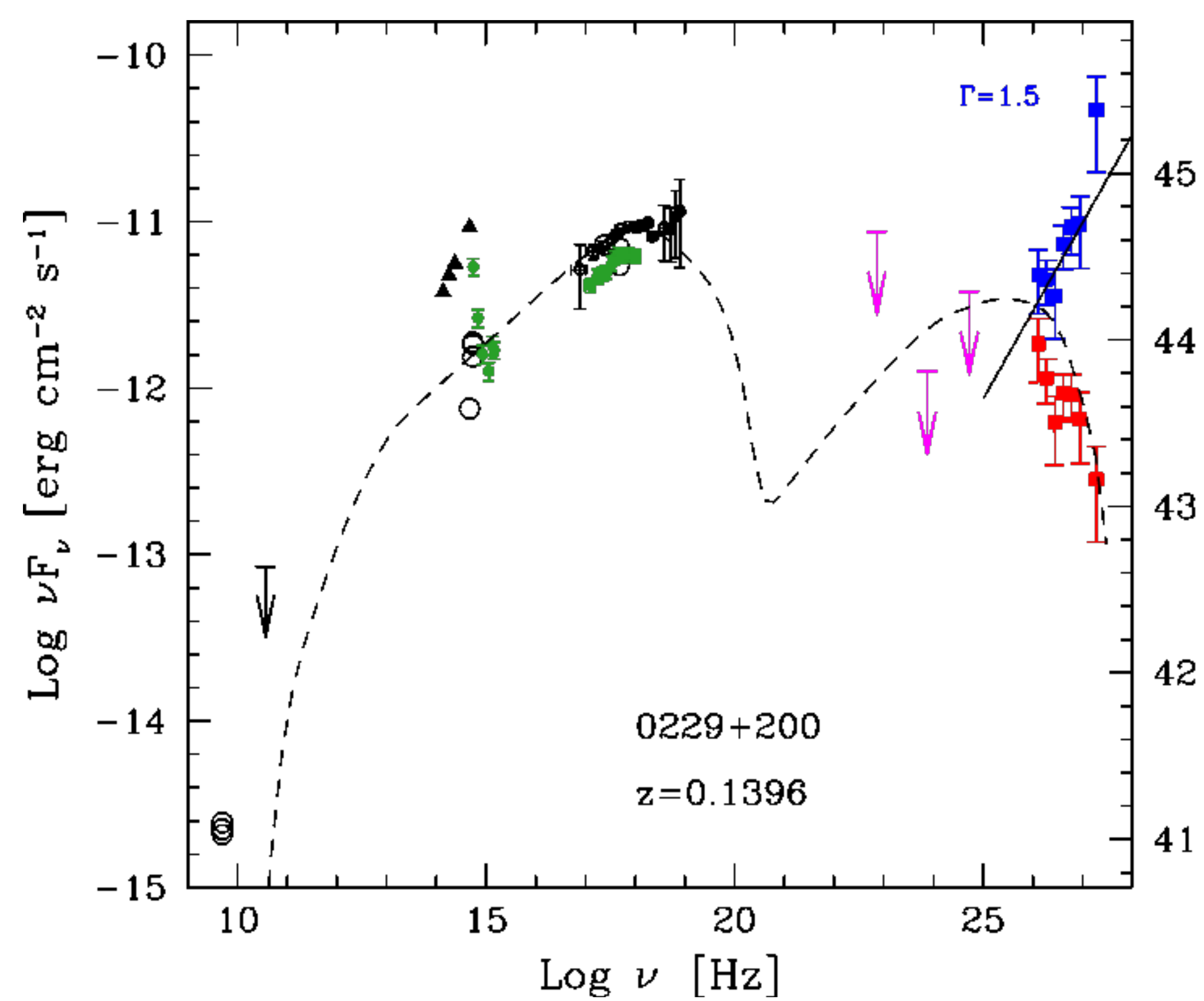
Formally, doubling timescale ~1hr

Saito et al. 2013

Fermi/Agile do ***NOT*** see all type of blazars: misses at the two ends of SED sequence



High-z blazars



Hard TeV BL Lac