12th AGILE Science Workshop, Rome, May 2014

Re-thinking Blazars

open issues - recent surprises (4)

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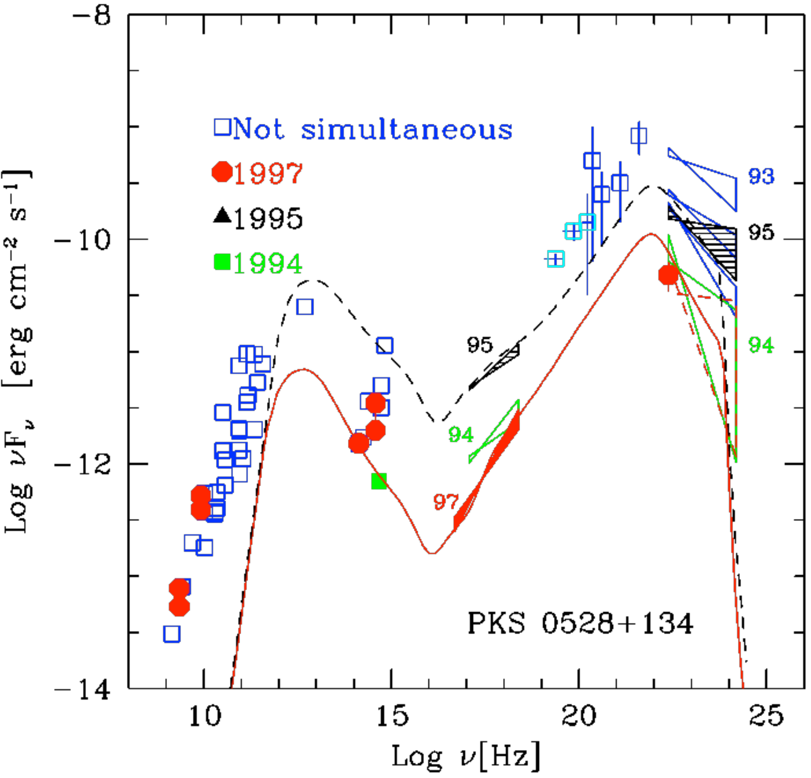
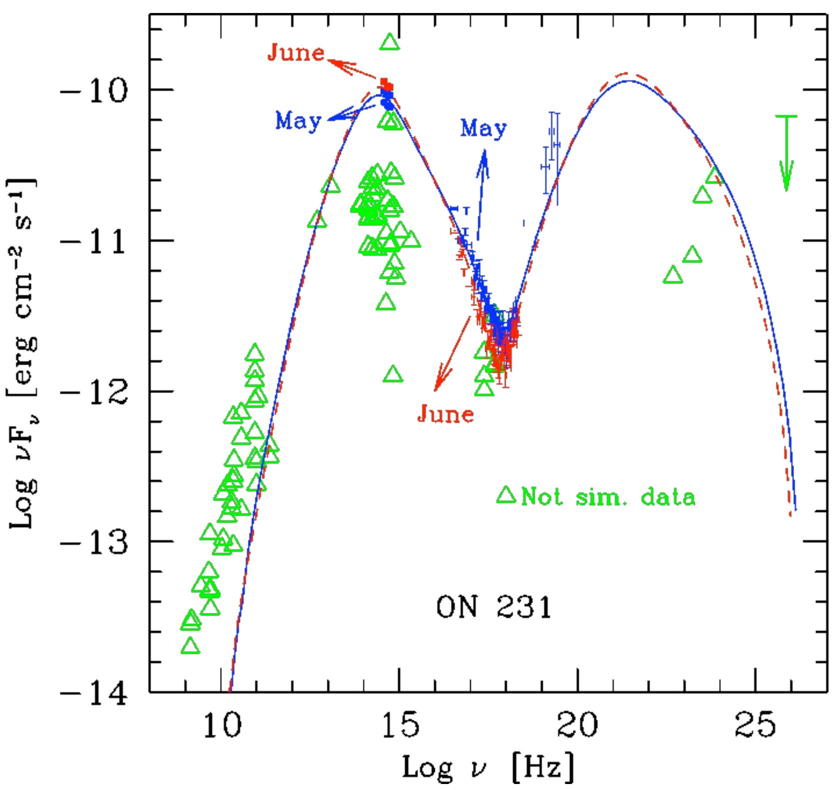
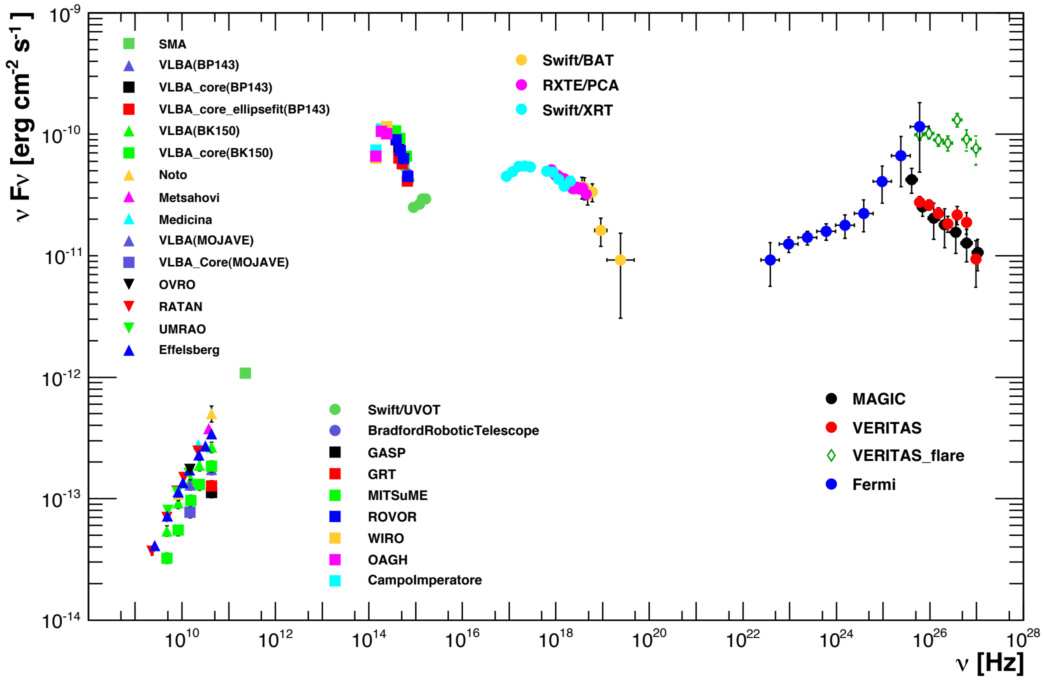
1) Jet SED properties: peak frequencies

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) Thermal Properties

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

Broad Emission Lines:

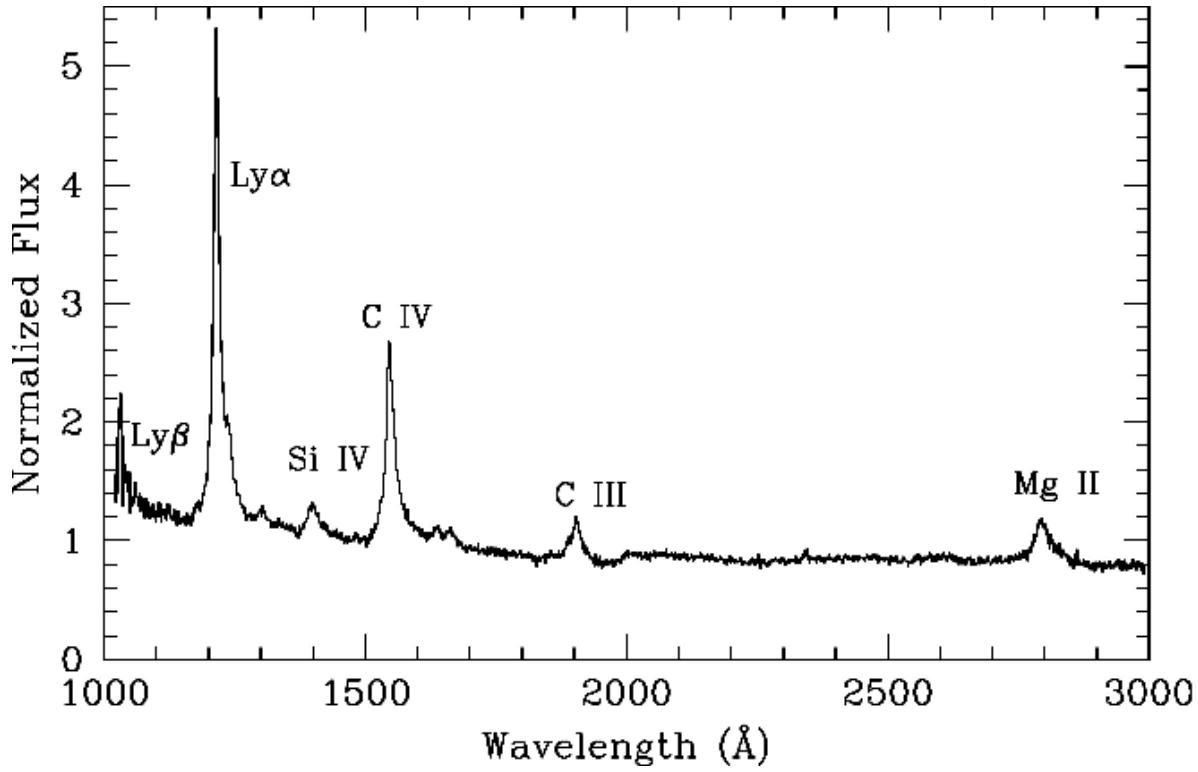
EW>5 Å **EW<5 Å**

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

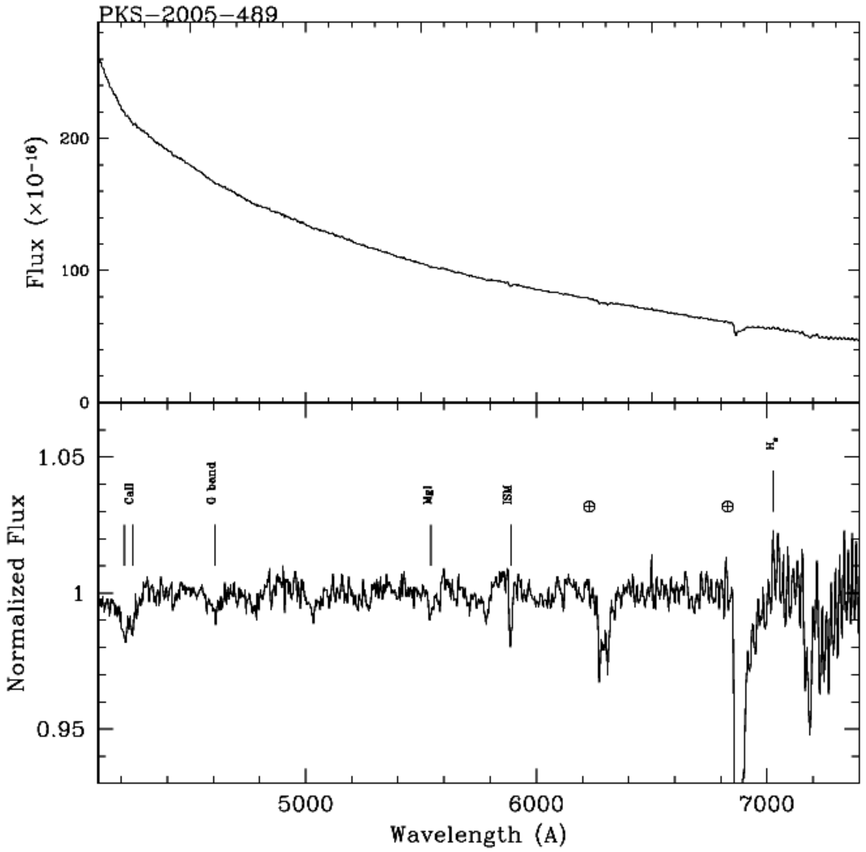
Dusty Torus
=> high U_{rad} (IR)

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

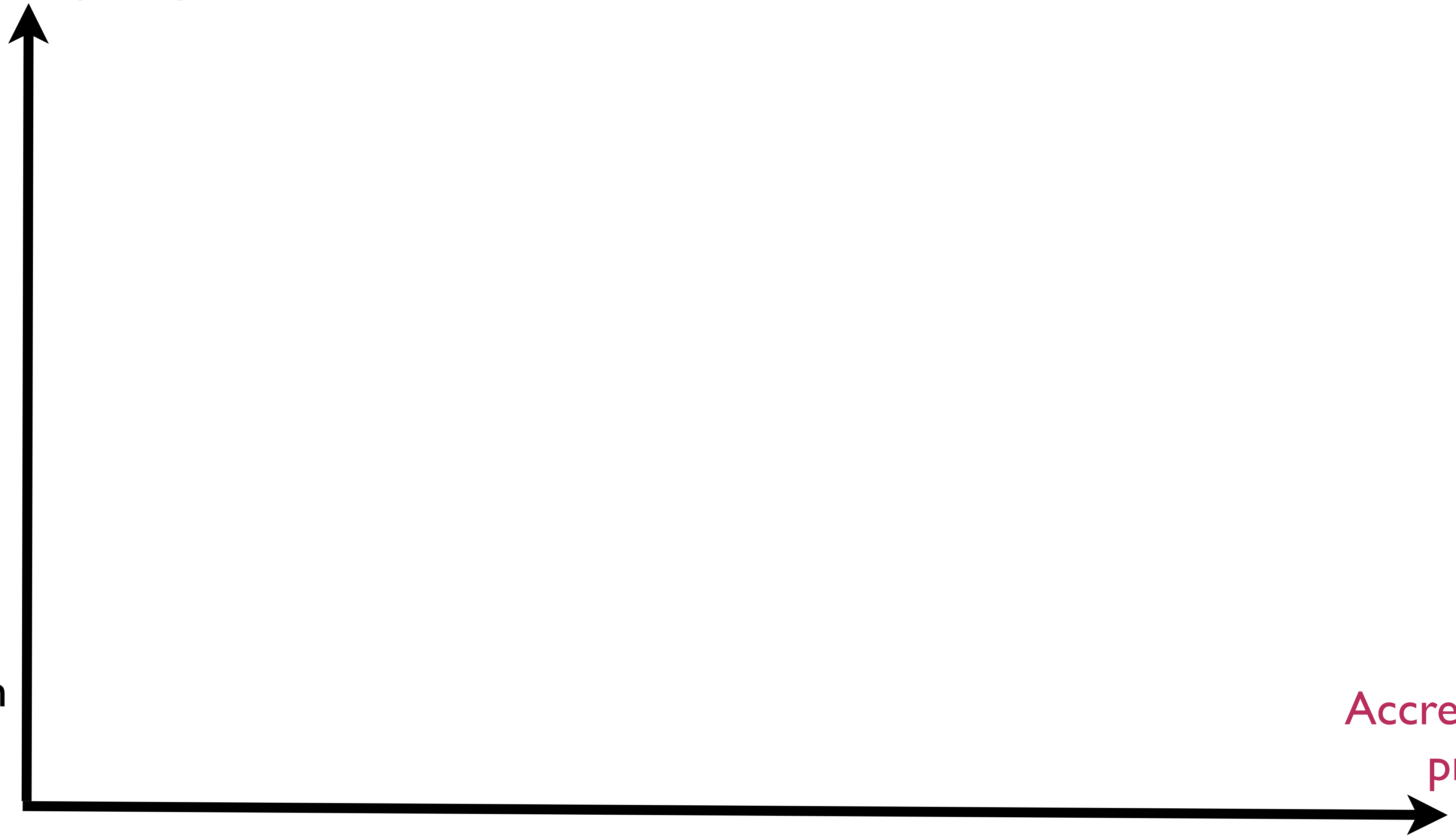
No Dusty Torus ? (FRI)
=> low/weak U_{rad}(IR)



Pian et al. 2005



The Main Plane of Blazars



Jet non-thermal properties
SED peak frequency

High-peaked
Low Compton
dominance

Low-peaked
High Compton
dominance

Accretion/Thermal
properties

Radiatively inefficient disk,
Absent/weak emission lines
Low accretion rate

Radiatively efficient disk,
Strong broad emission lines
Blue bump, high accretion rate

The Main Plane of Blazars

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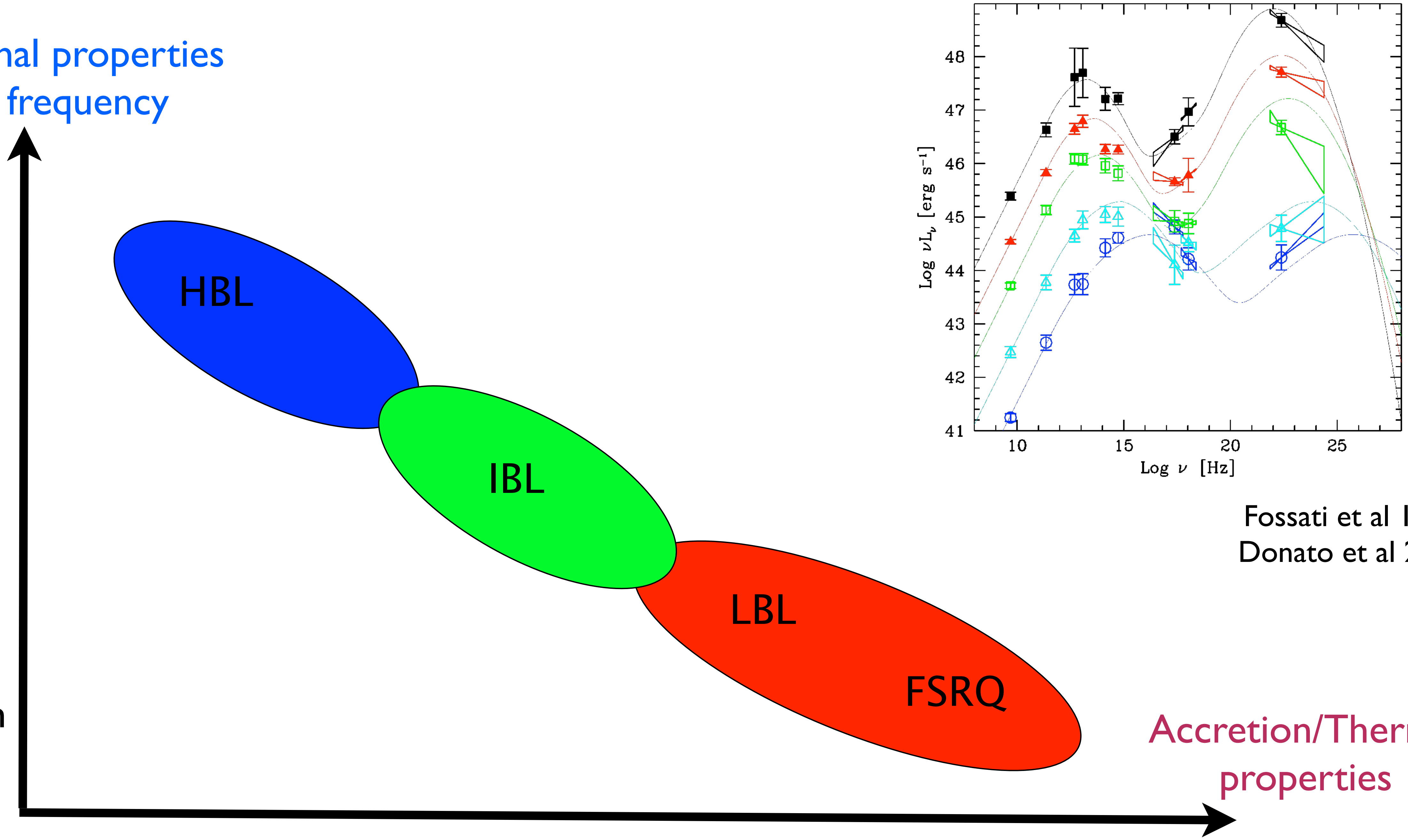


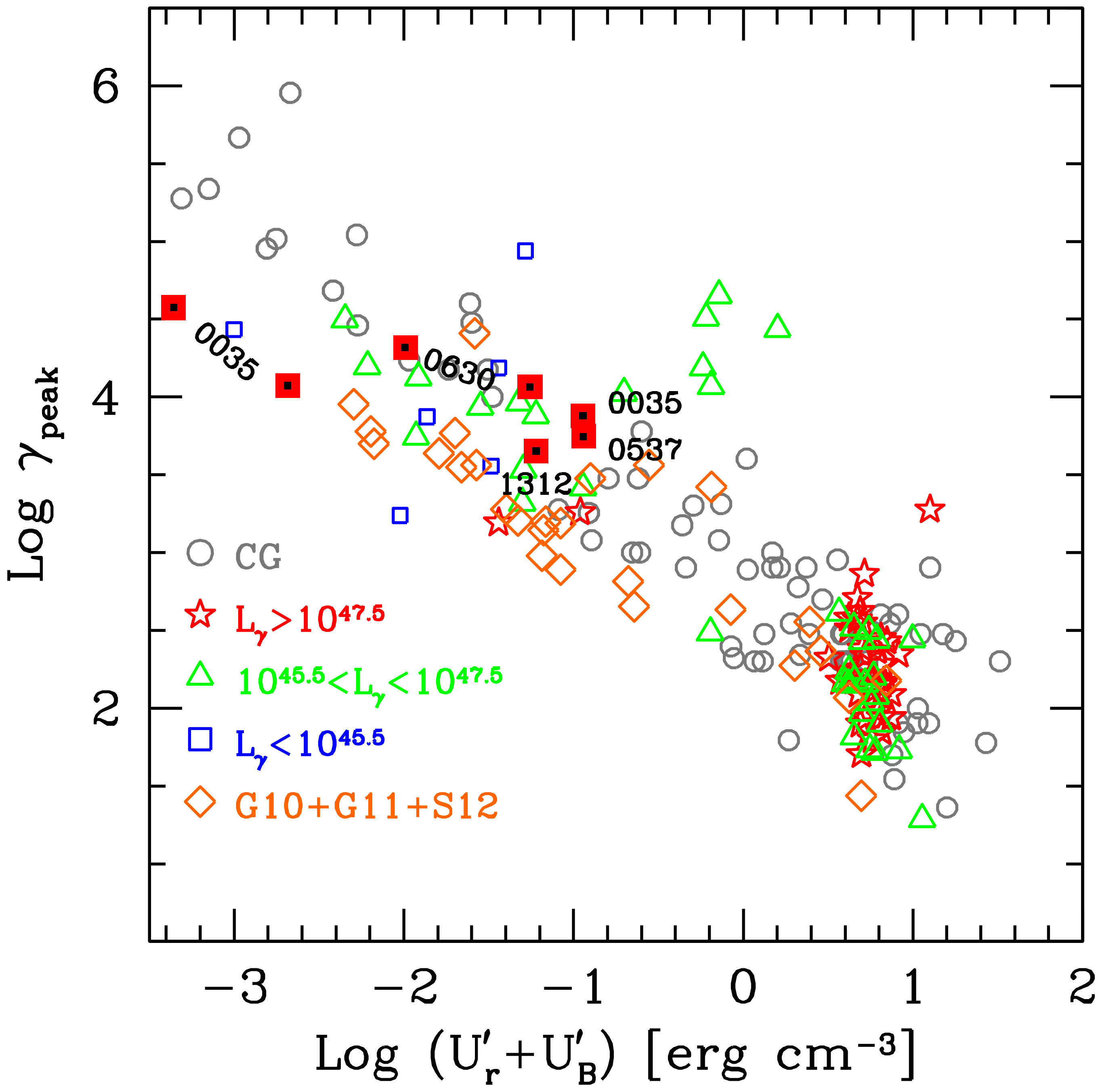
Fossati et al 1998
Donato et al 2002

Accretion/Thermal
properties

Radiatively inefficient disk,
Absent/weak emission lines
Low accretion rate

Radiatively efficient disk,
Strong broad emission lines
Blue bump, high accretion rate

Common dissipation zone, leptonic mechanism: equilibrium between acceleration and cooling



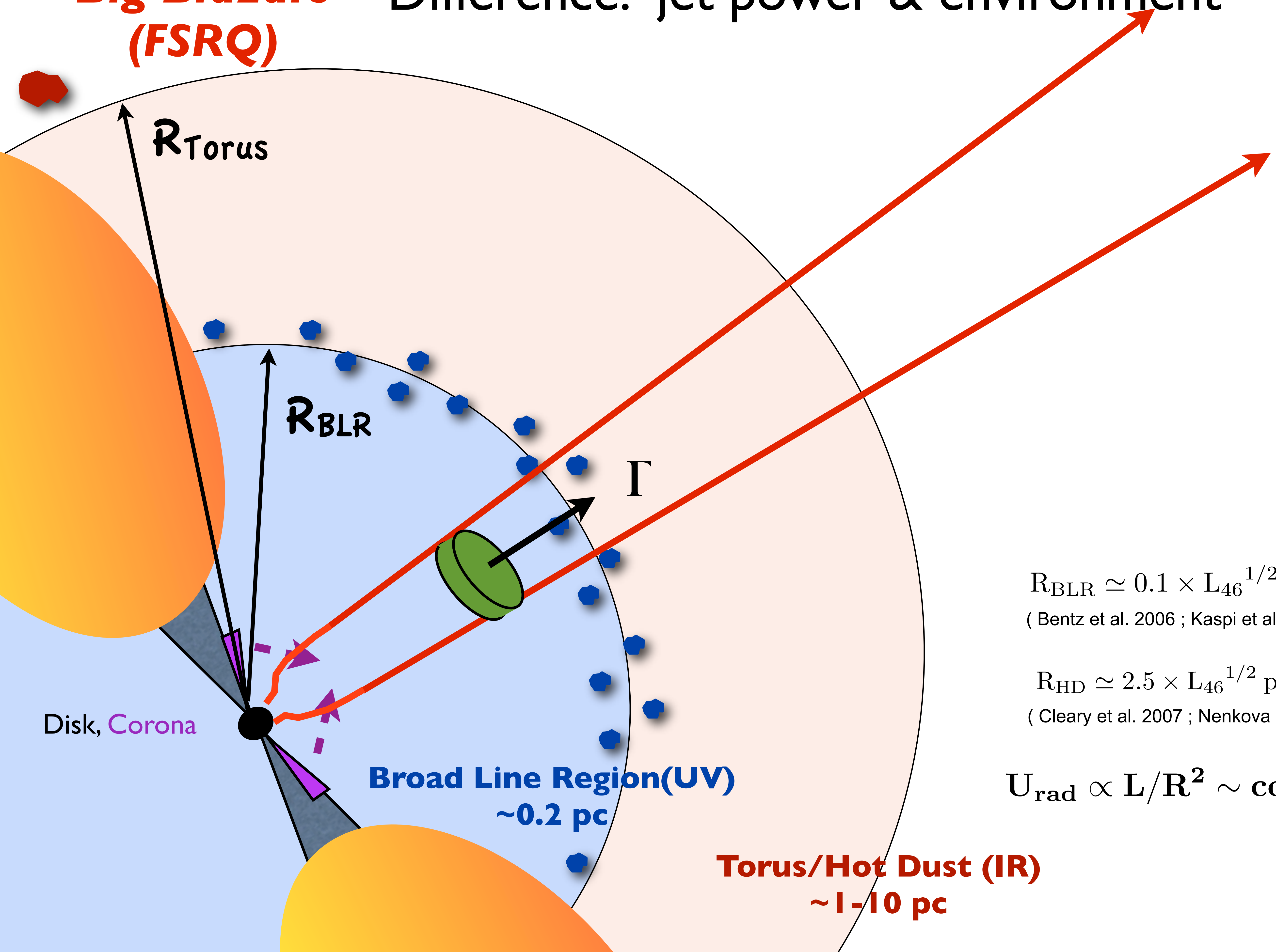
Ghisellini et al. 98-12

Powerful,
strong disk/BLR/Torus → EC-dominated
strong cooling → Red SED
High Compton dominance

Low-power jet,
weak/no disk/BLR/Torus → Sy/SSC-dominated
less cooling → Blue SED
Low Compton dominance

Big Blazars (FSRQ)

Difference: jet power & environment



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

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

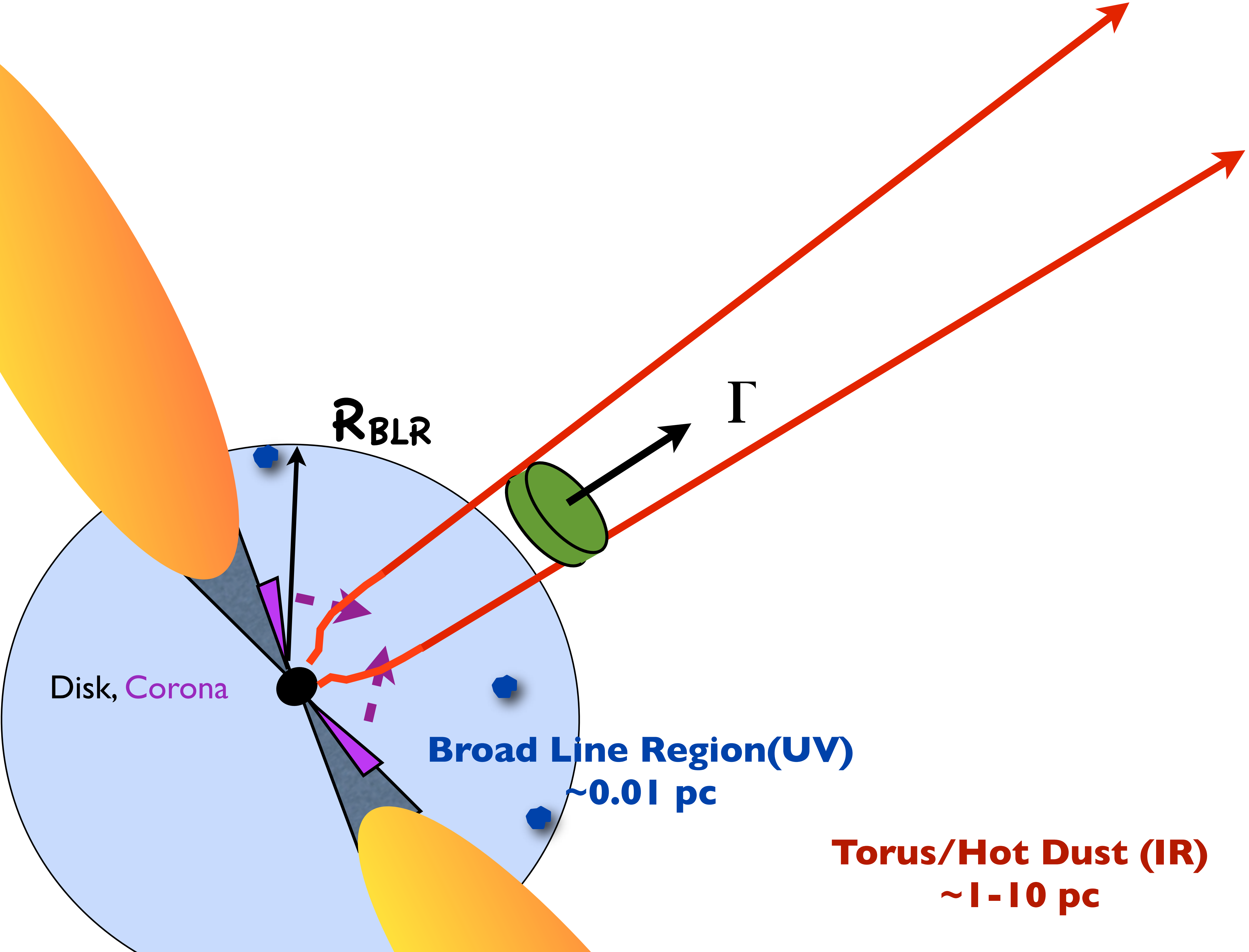
$$R_{HD} \simeq 2.5 \times {L_{46}}^{1/2}\ \mathrm{pc}$$

(Cleary et al. 2007 ; Nenkova et al. 20

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

Difference: jet power & environment

BLLac
(e.g. HBL)



Broad Line Region(UV)
~0.01 pc

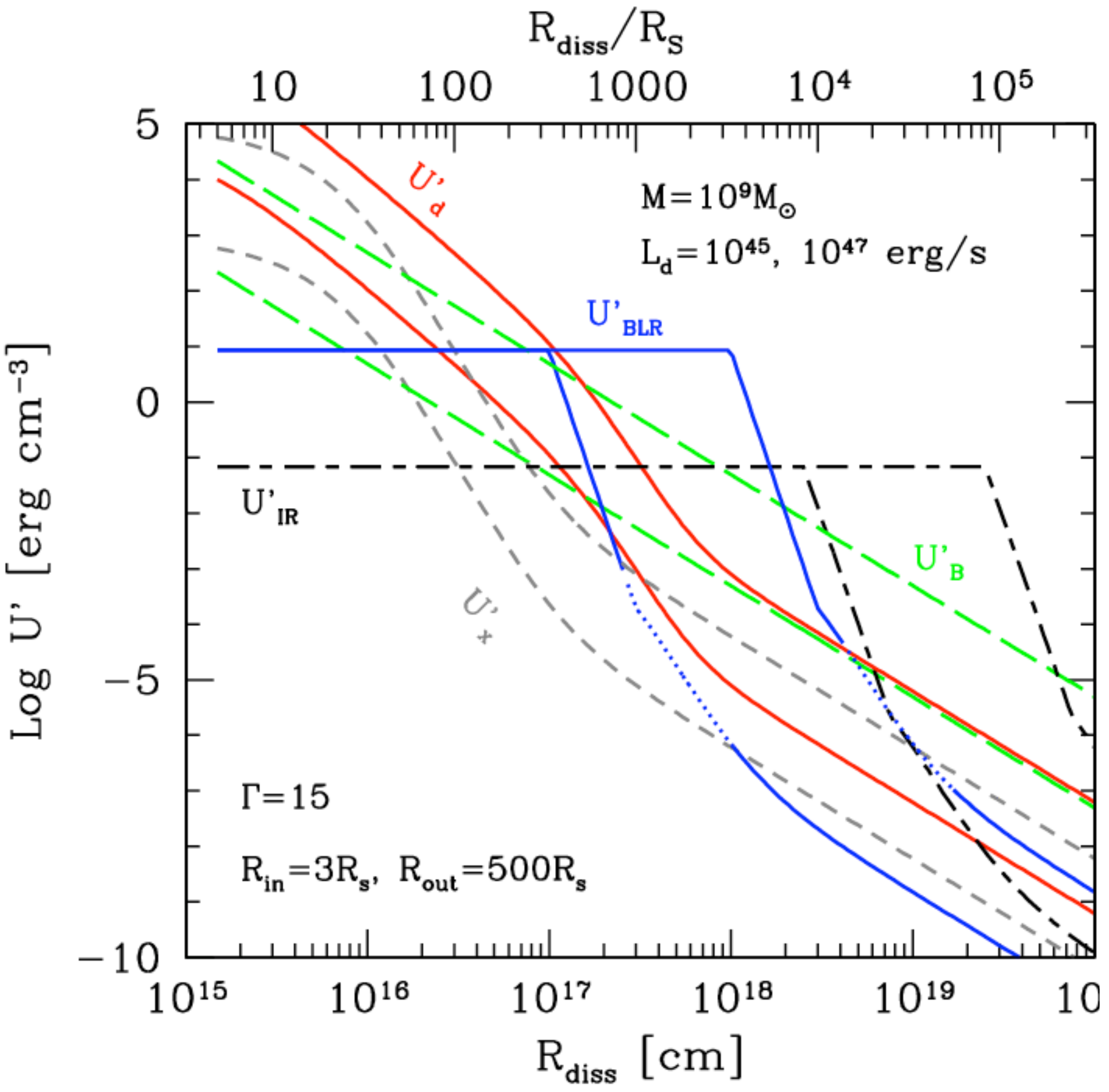
Torus/Hot Dust (IR)
~1-10 pc

Recent Surprises / Problems

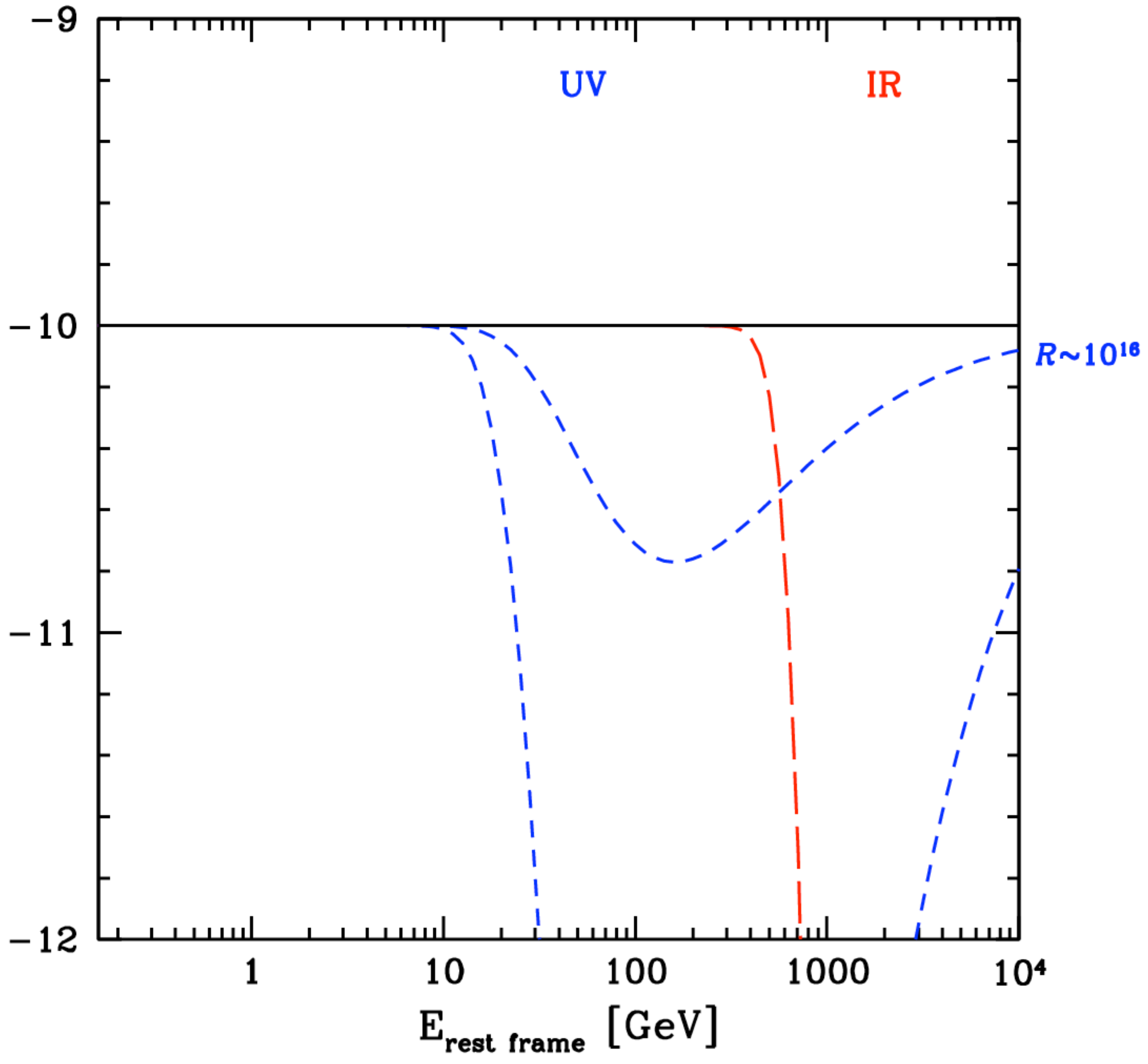
#1

GeV-TeV photons interact with UV-to-IR photons (easy to get optical depths >>1)

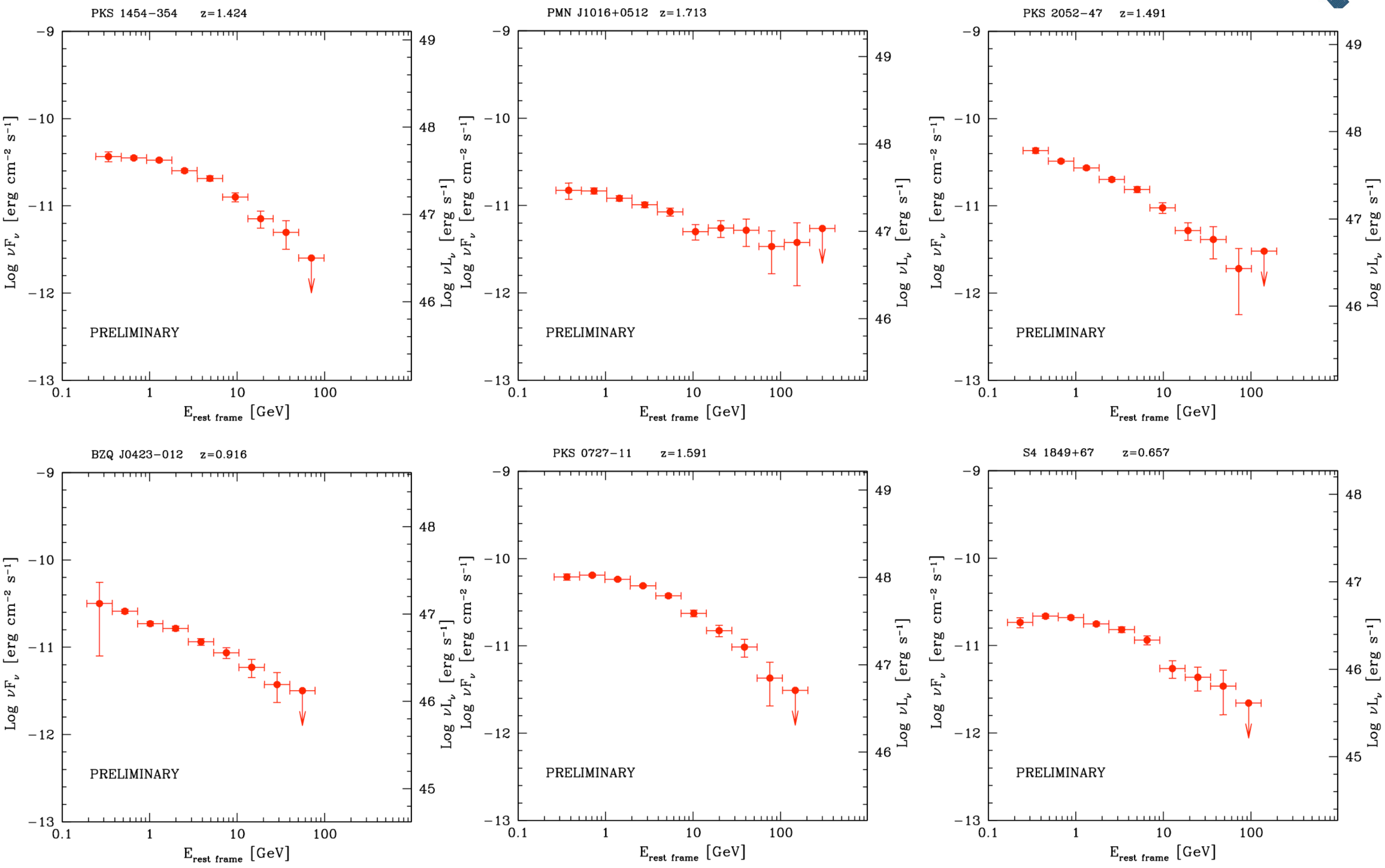
$\gamma\gamma \rightarrow e^+e^-$ $\qquad$ $x_1 x_2 \geq \frac{2}{1-\cos\theta}$ $\qquad$ $x \equiv h\nu/m_e c^2$



e.g. on BlackBody target field:



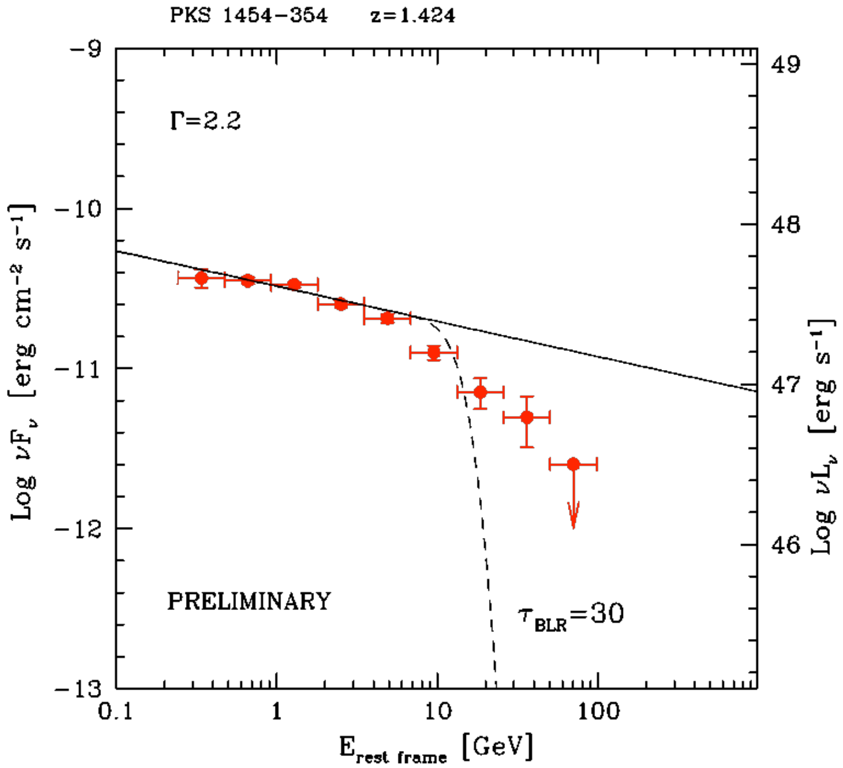
Fermi-LAT results on several FSRQ: NO evidence of strong BLR cut-offs !

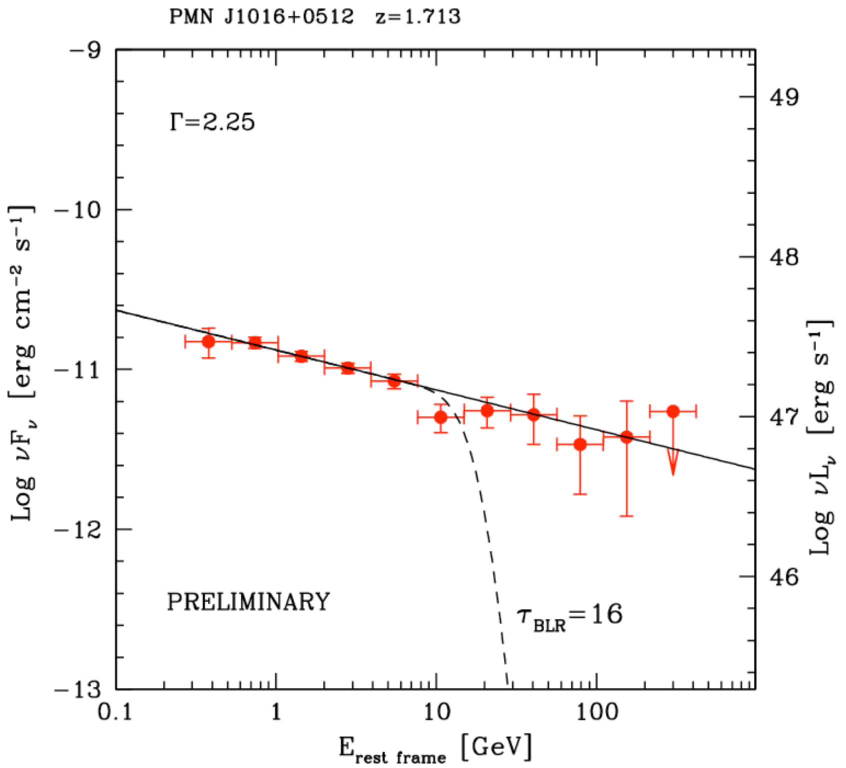


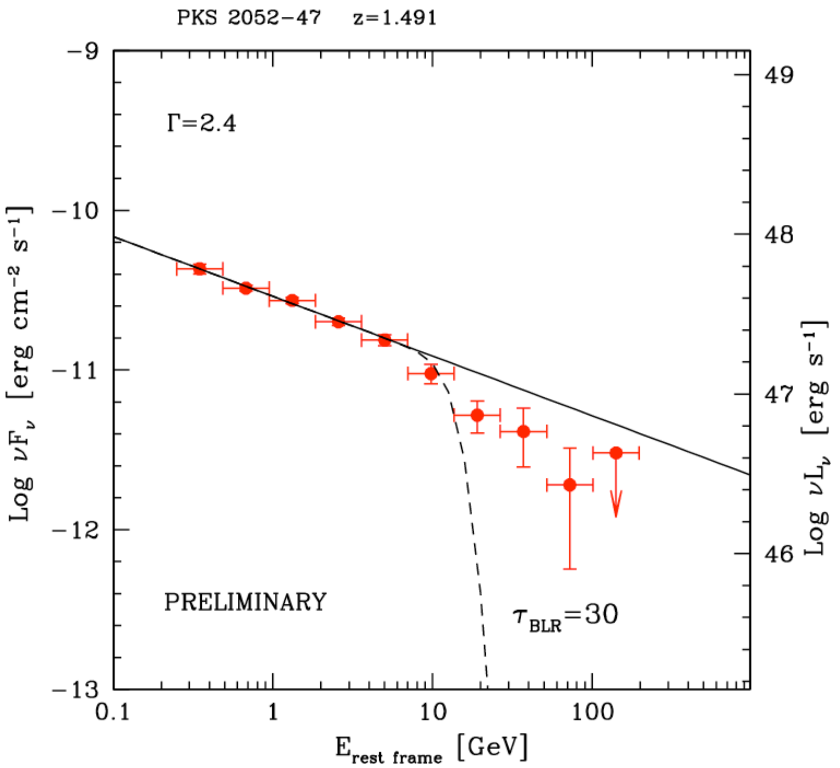
Even among the most powerful objects !

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:

$L_{disk} \sim 5\times10^{46}$ erg/s , $R_{blr} \sim 7\times10^{17}$ cm

if $R_{diss} \sim 2\times10^{17}$ $\Rightarrow$ **$\tau_{BLR} > 30$!**

PMN J1016+0512:

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

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

BZQ J2056-471:

$L_{disk} \sim 4\times10^{46}$ erg/s , $R_{blr} \sim 6\times10^{17}$ cm

if $R_{diss} \sim 2\times10^{17}$ $\Rightarrow$ **$\tau_{BLR} > 30$!**

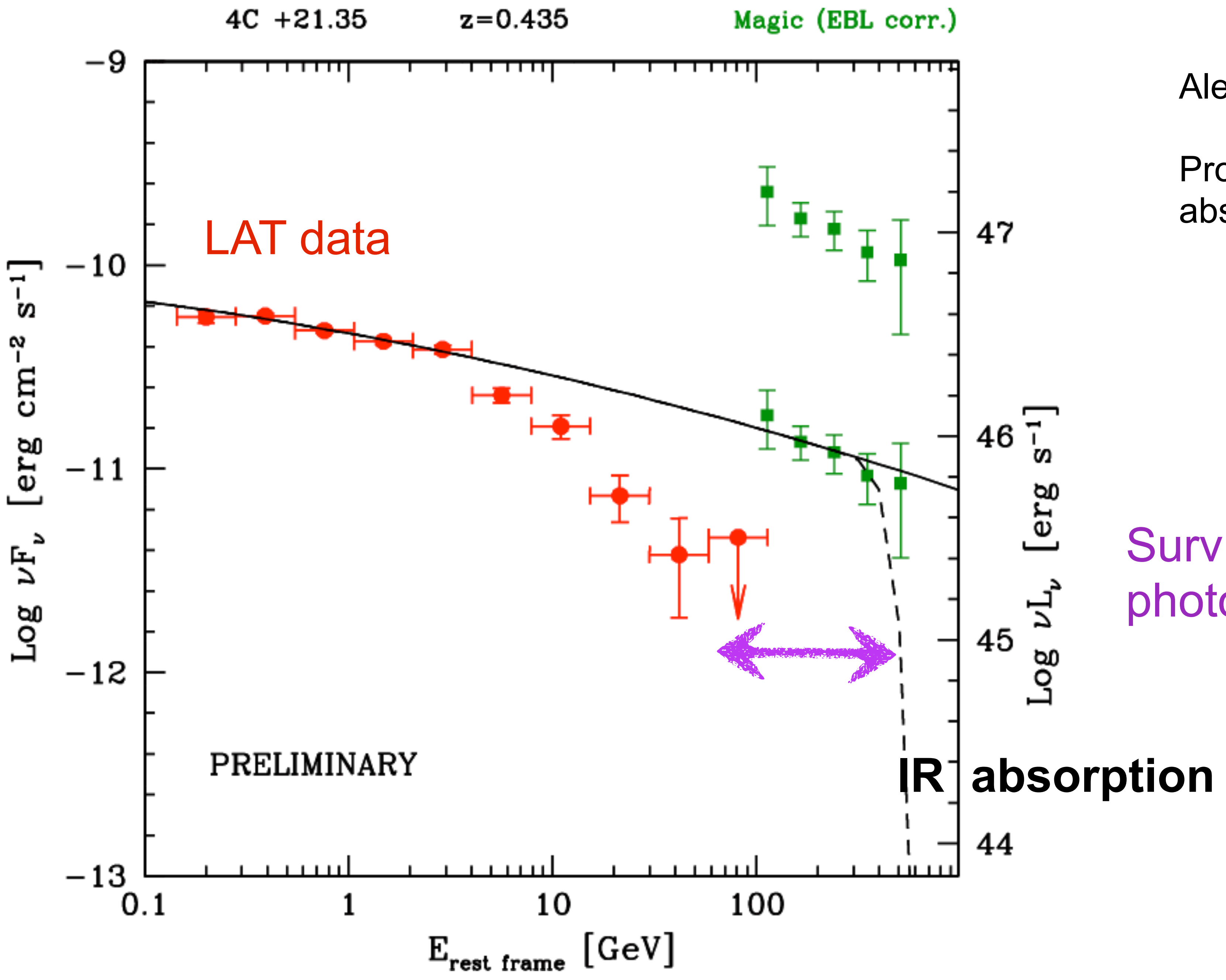
Values of R_{diss} L_{disk} R_{blr} used in
Ghisellini et al 2009

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

Costamante et al. 2009, 2010
Abdo et al. 2014 (in prep.)
Pacciani et al 2014 (flares)

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)

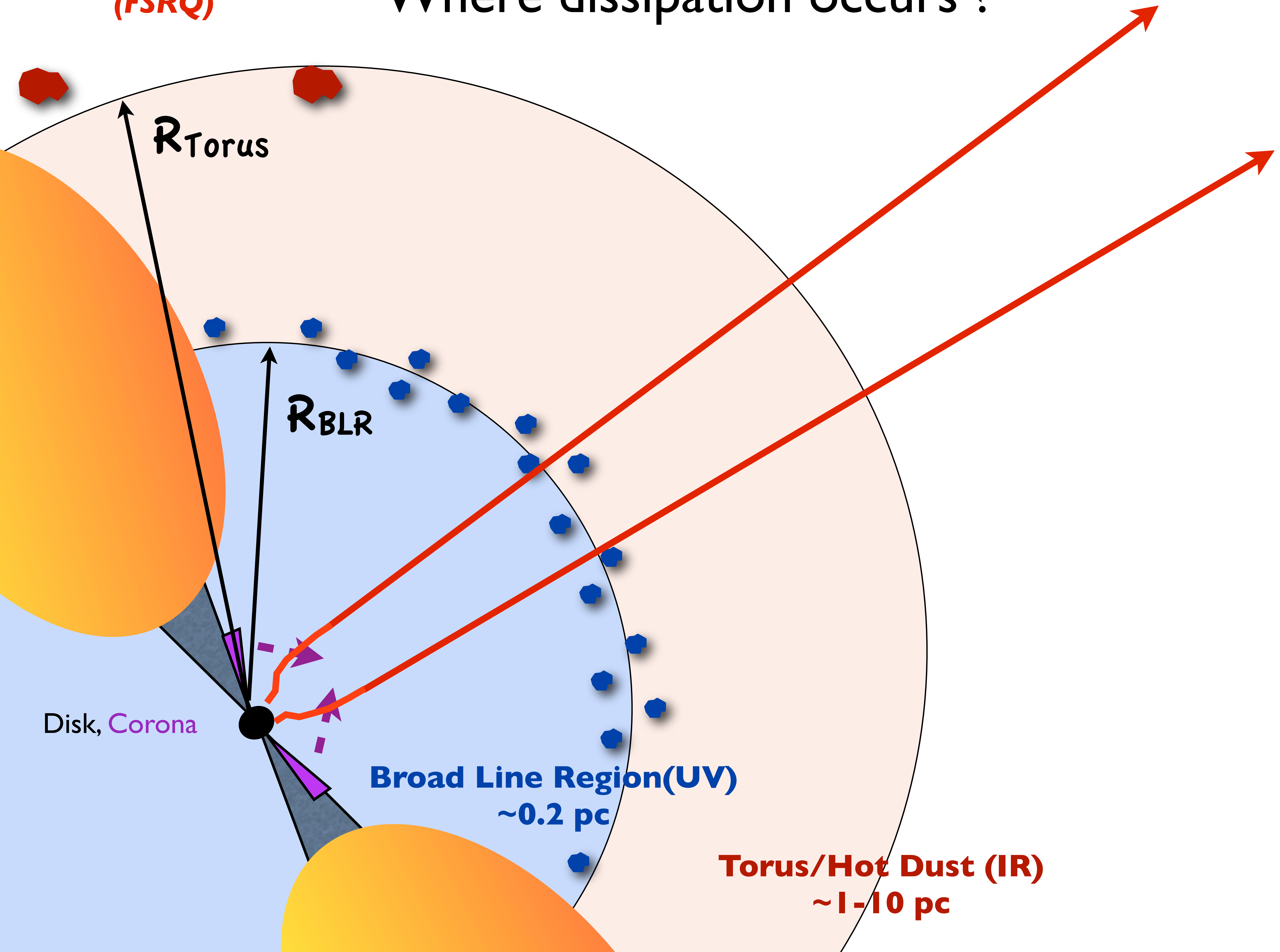
Problem: again IR photons absorb VHE gamma-rays !

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)

Where dissipation occurs ?

Big Blazars
(FSRQ)



R_{Torus}

R_{BLR}

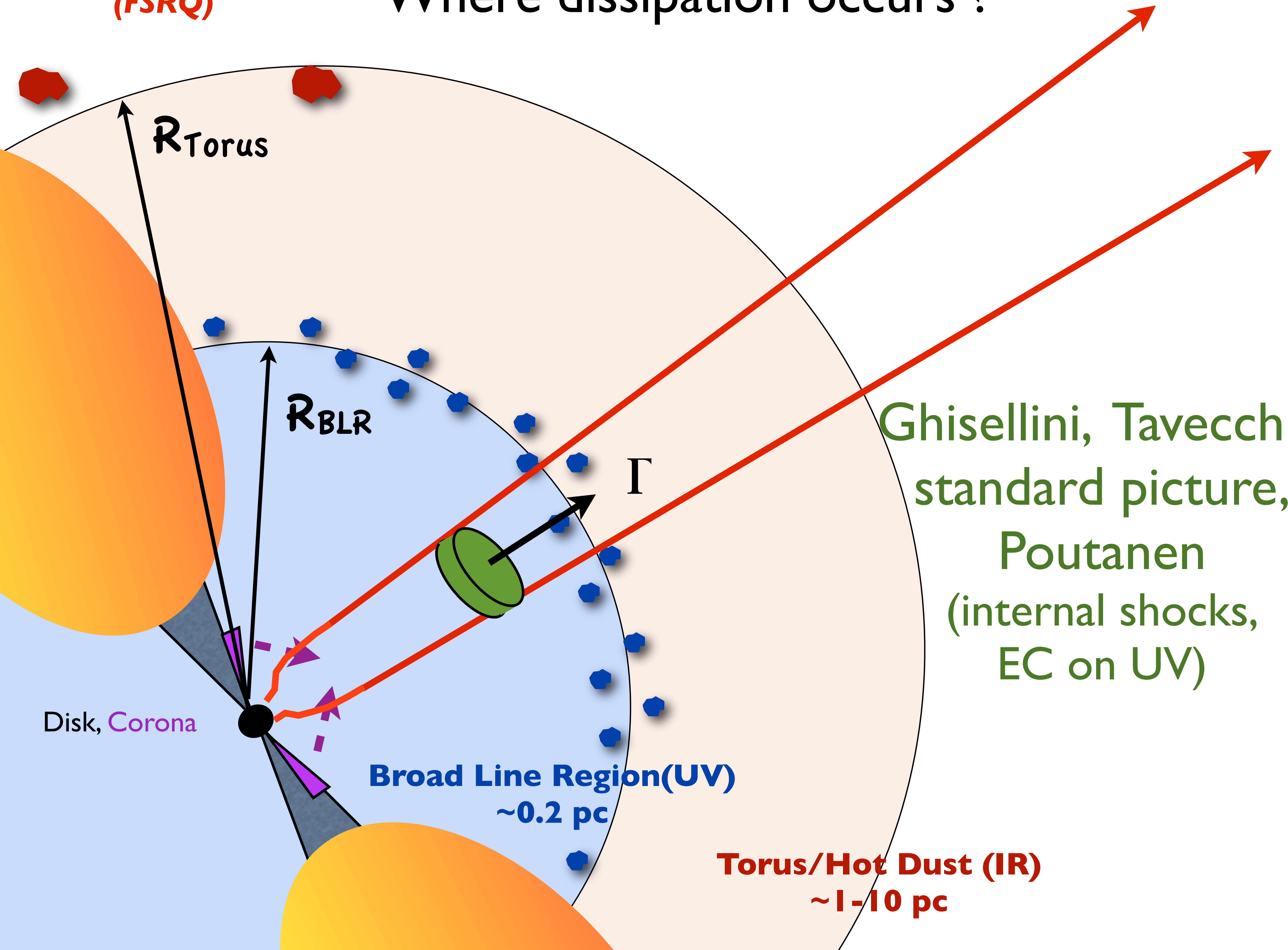
Disk, Corona

Broad Line Region(UV)
~0.2 pc

Torus/Hot Dust (IR)
~1-10 pc

Big Blazars (FSRQ)

Where dissipation occurs ?



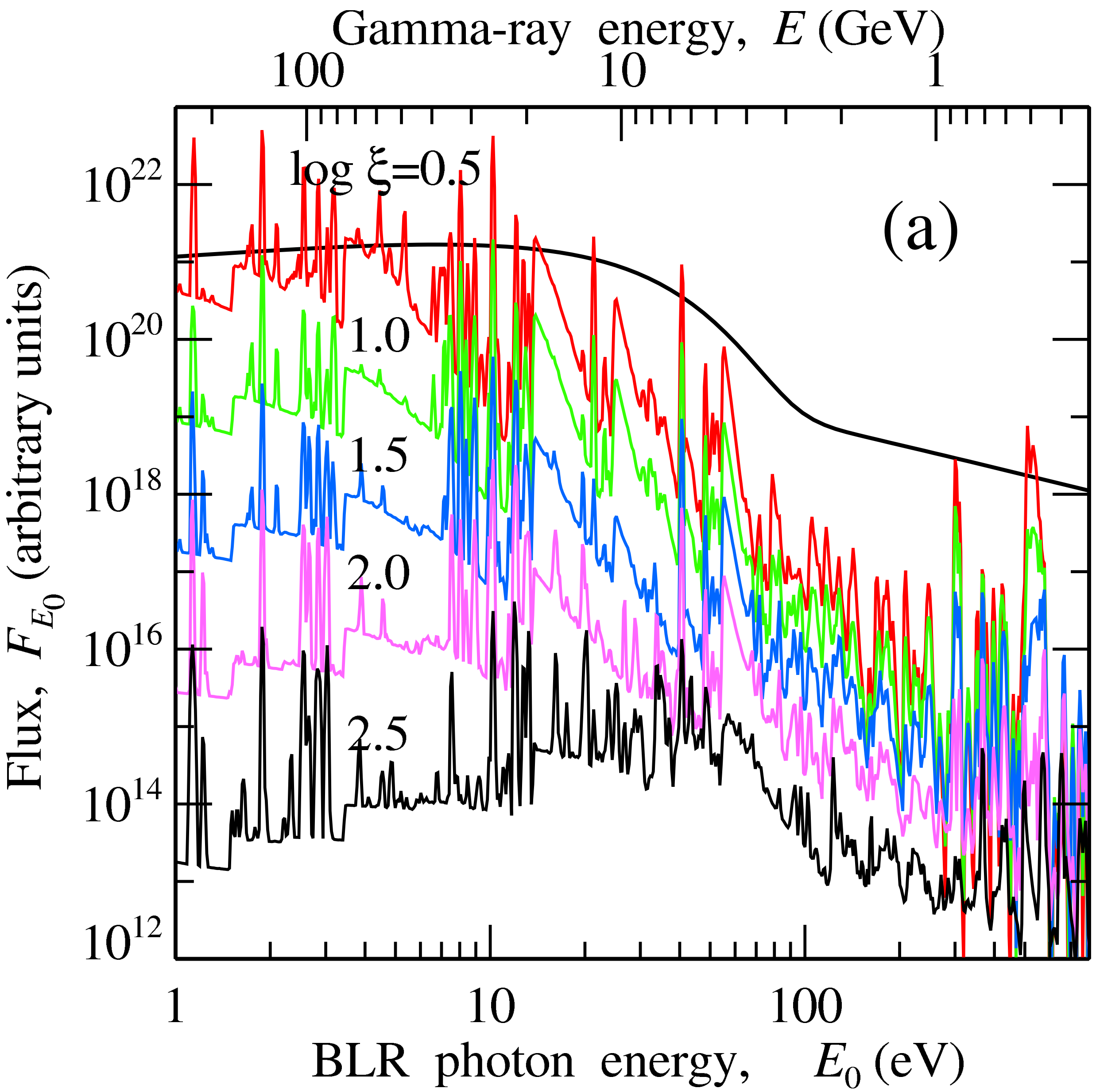
Ghisellini, Tavecchio standard picture, Poutanen

(internal shocks, EC on UV)

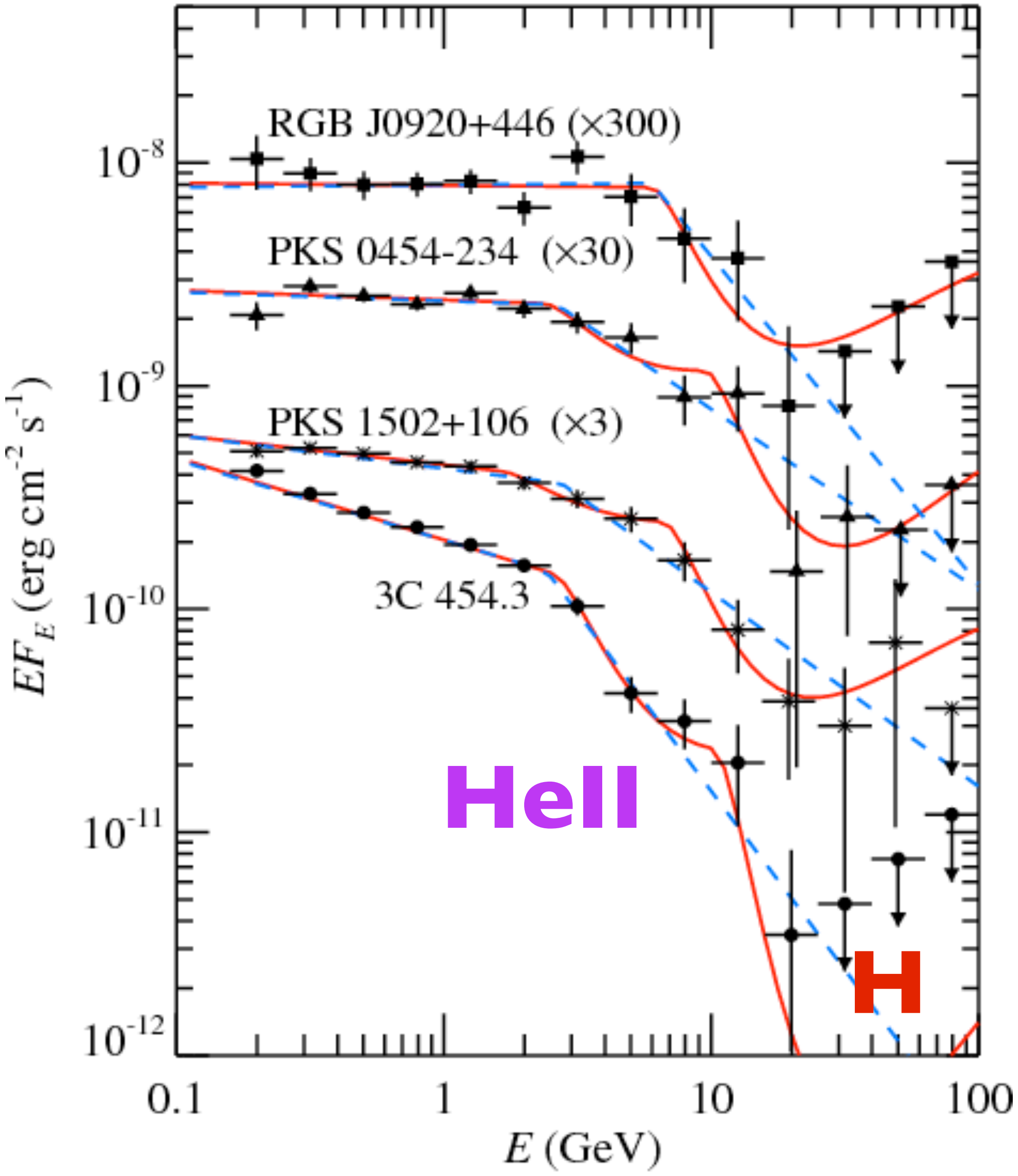
Stratified BLR: High and Low excitation lines

R_H~0.2-0.3 R_0 R_L~3-5 R_0

BLR at different ionization parameter



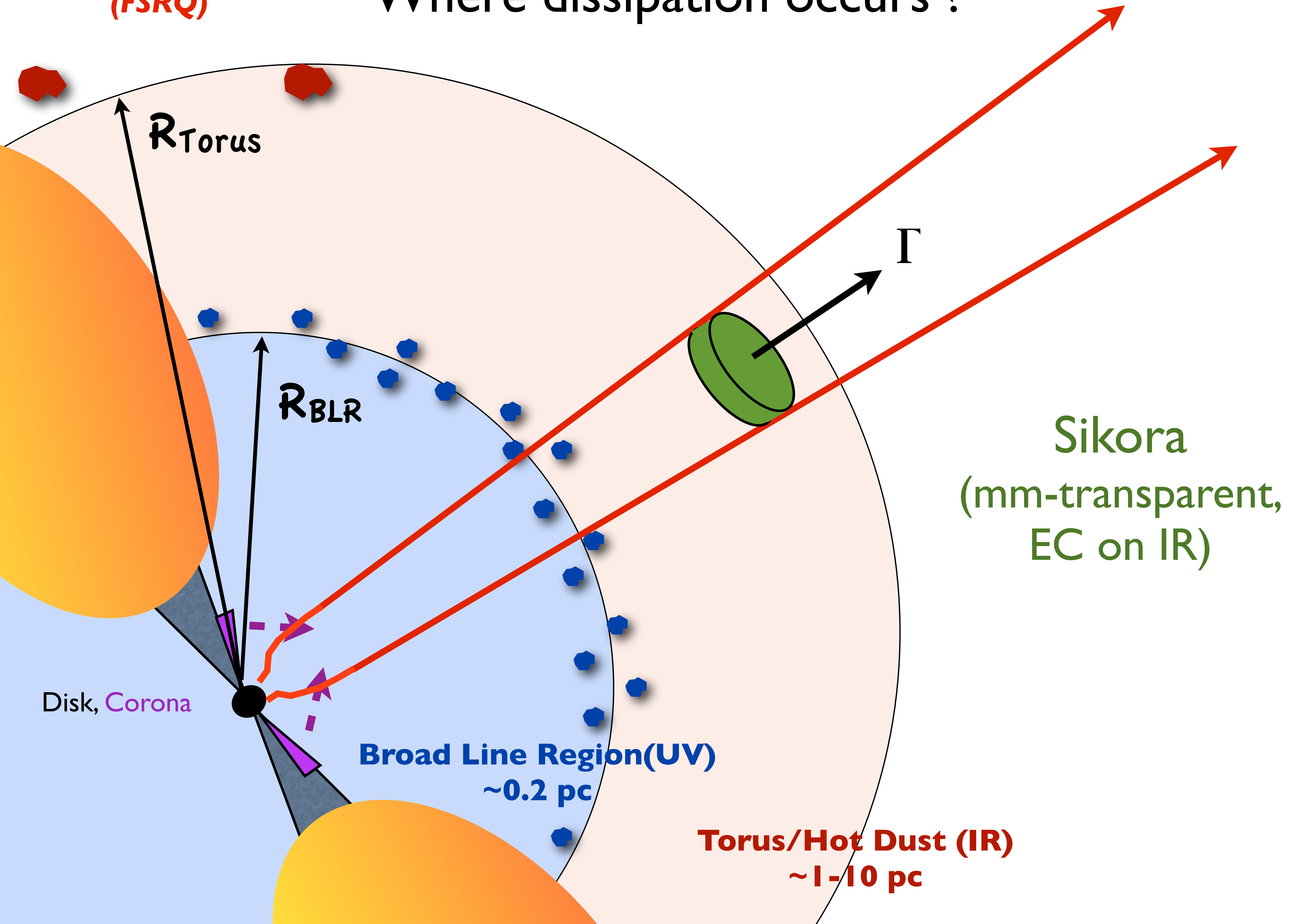
Double absorption:



Poutanen and Stern 2010-2012

Big Blazars
(FSRQ)

Where dissipation occurs ?



Sikora
(mm-transparent,
EC on IR)

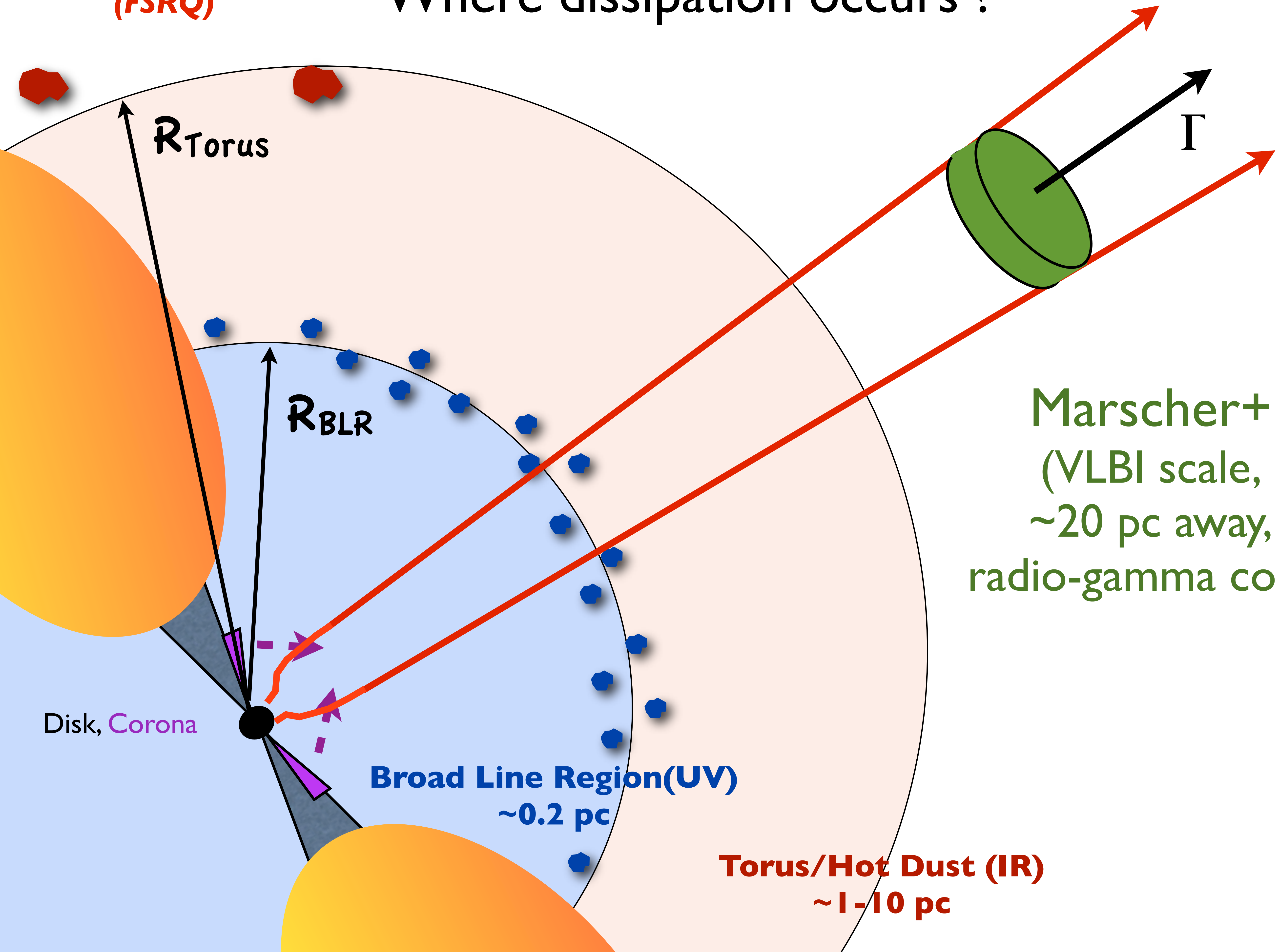
Disk, Corona

Broad Line Region(UV)
~0.2 pc

Torus/Hot Dust (IR)
~1-10 pc

Big Blazars (FSRQ)

Where dissipation occurs ?



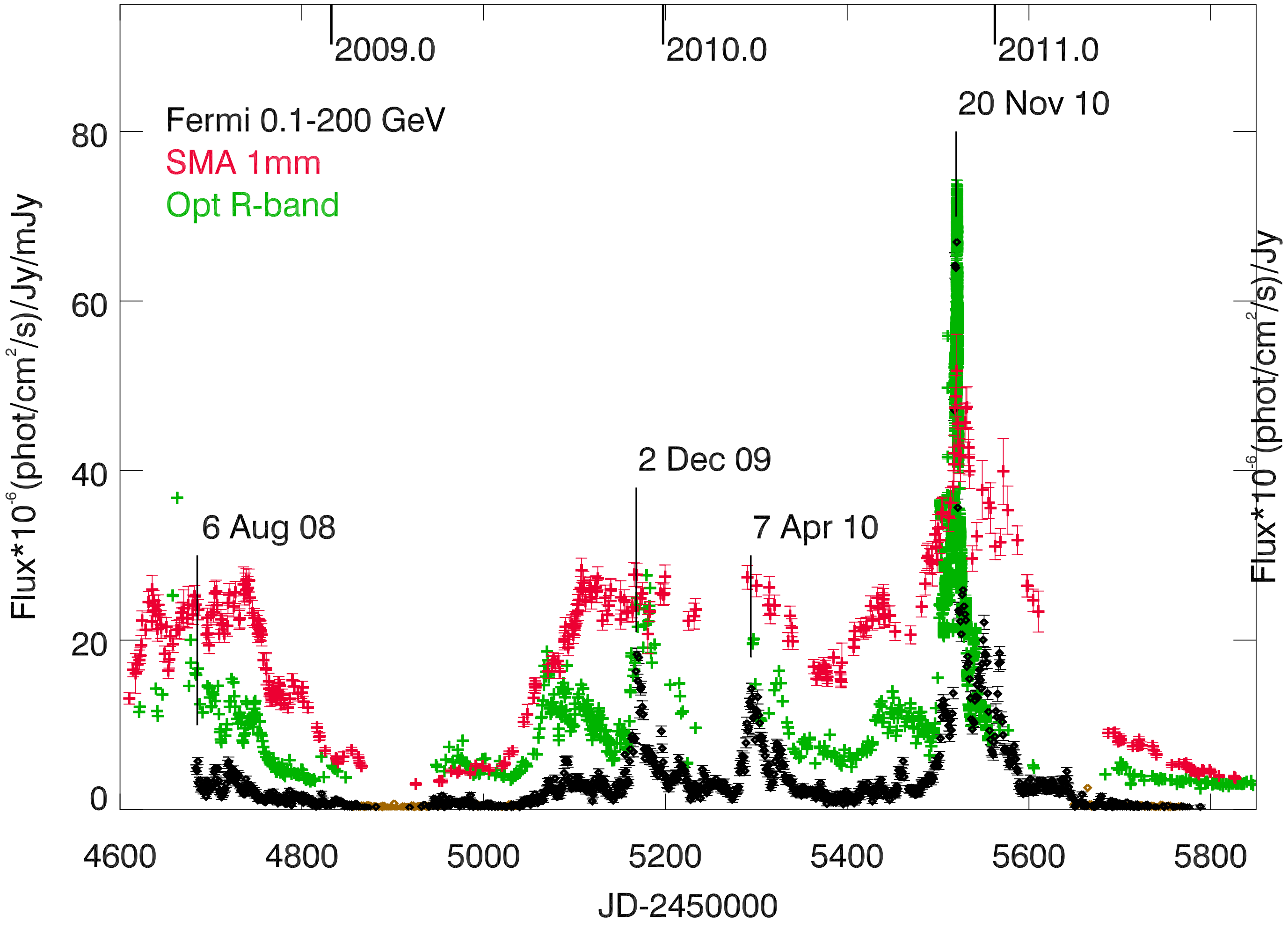
Marscher+
(VLBI scale,
~20 pc away,
radio-gamma corr.)

Broad Line Region(UV)
~0.2 pc

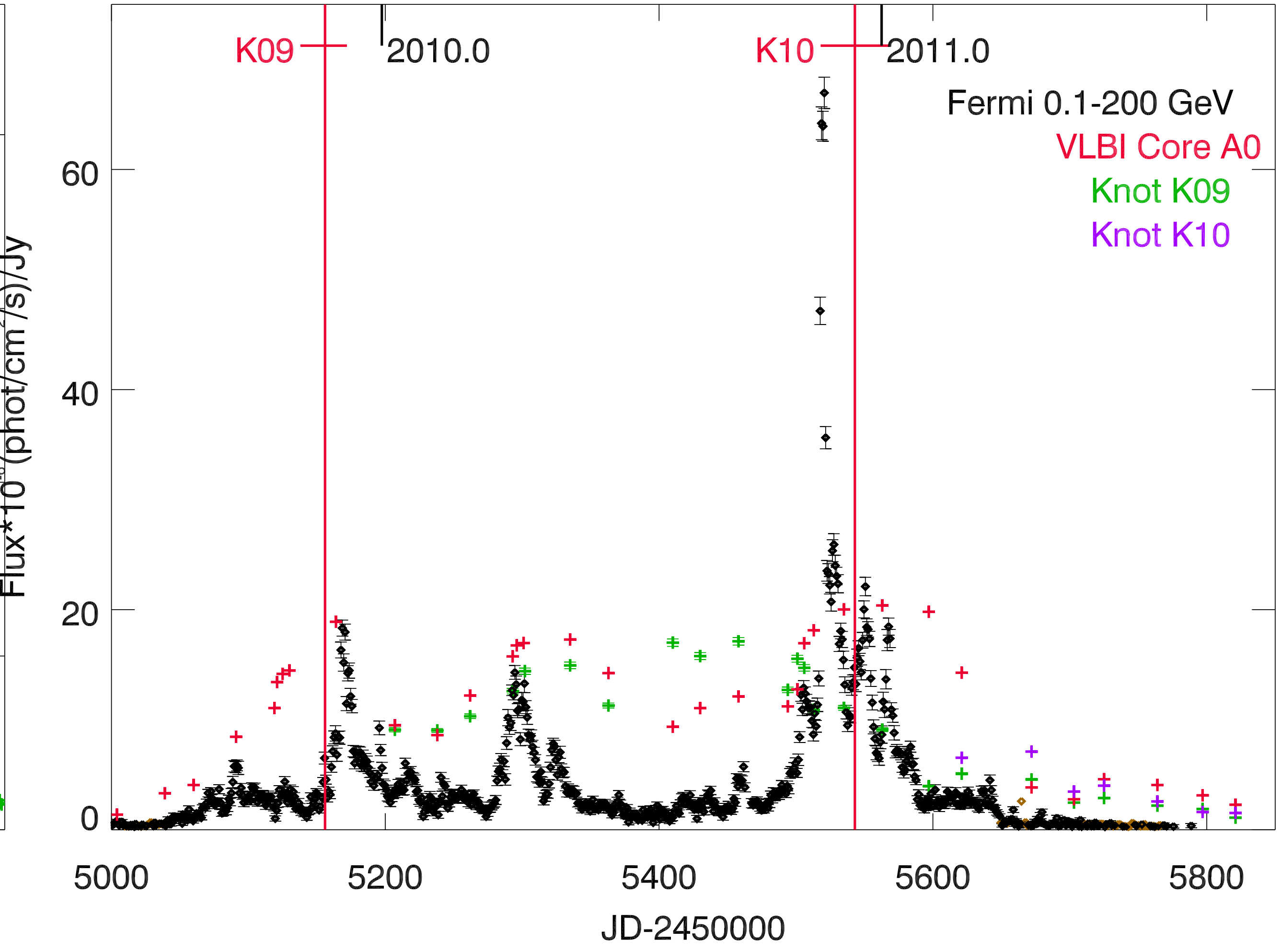
Torus/Hot Dust (IR)
~1-10 pc

Radio-Gamma Correlation:

Simultaneous flares



Knots passage through core



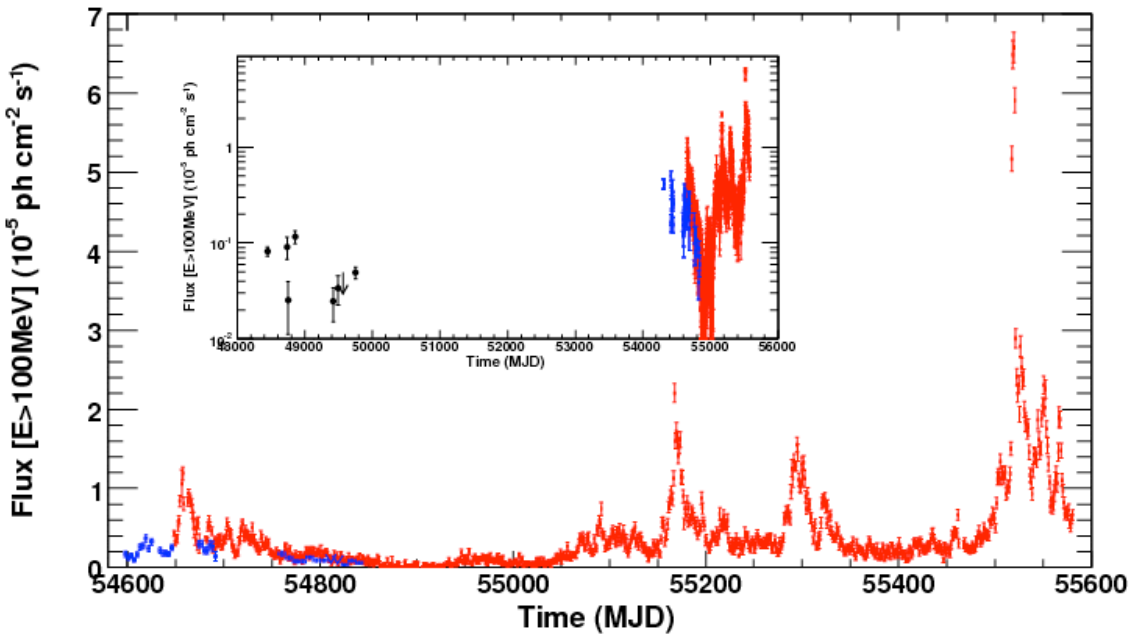
Jorstad 2011, Marscher et al 2011-2012

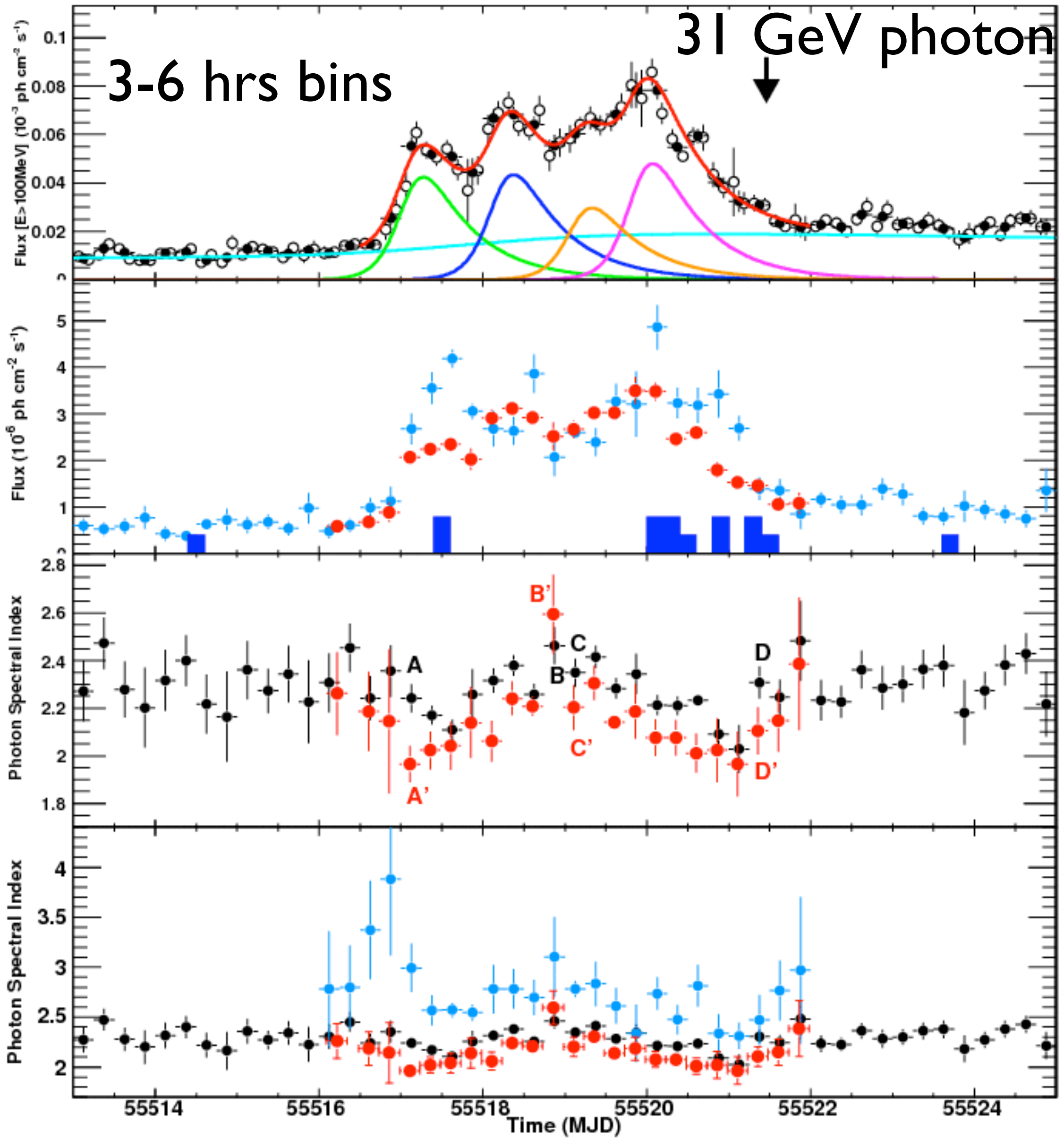
Radio/Gamma Co-spatial, transparent to radio

Flares: 43 positives, 13 negatives (34 Fermi blazars)

But Gamma region compact !

varability seen down to the shortest timescales allowed by statistics (0.1-1 GeV)




3-6 hrs bins

31 GeV photon

$r_{diss} \approx$ few 10^{15} $(\delta/10)$ cm

Not transparent to radio

Abdo et al (LAT coll) 2010, 2011

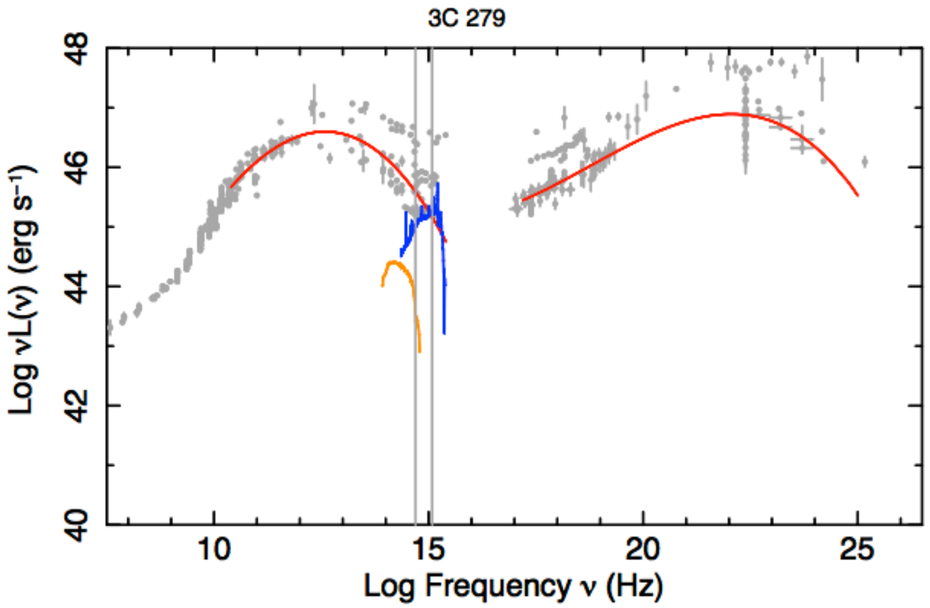
If dissipation occurs beyond BLR...

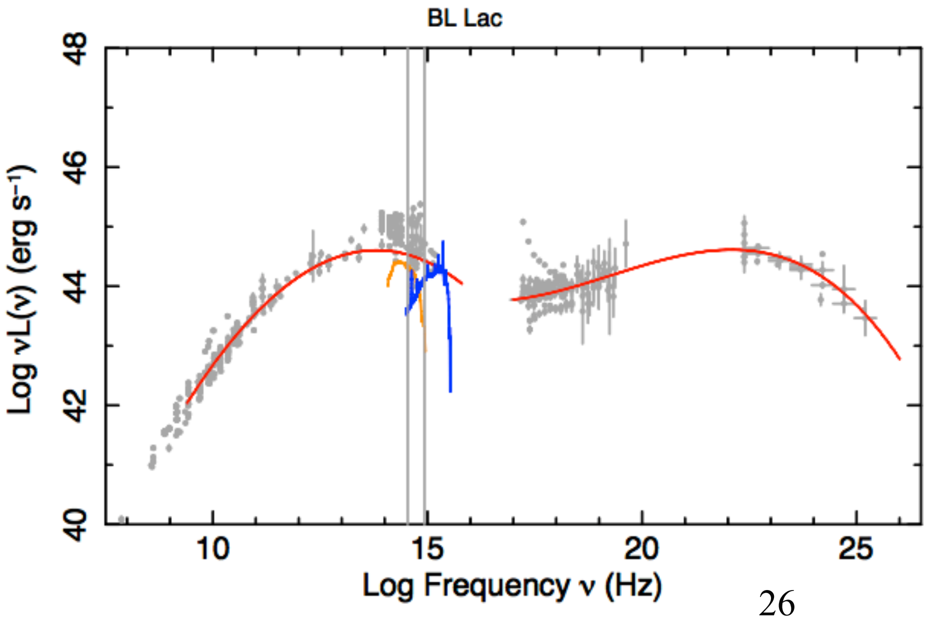
what's the difference between FSRQ and BL Lacs ?

If dissipation occurs beyond BLR...

what's the difference between FSRQ and BL Lacs ?

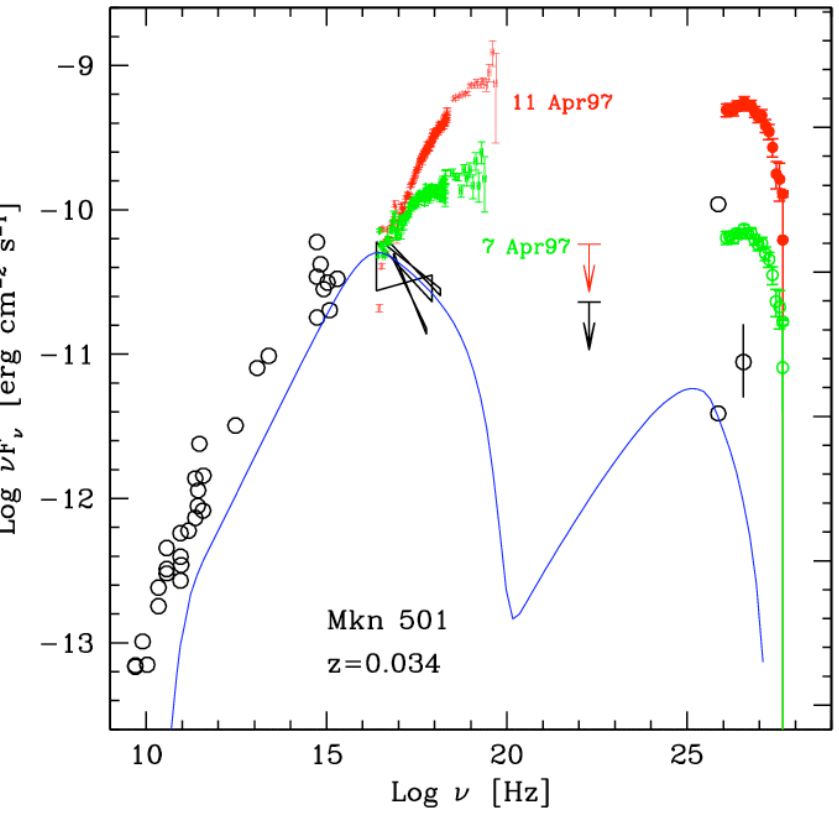
P. Giommi argument



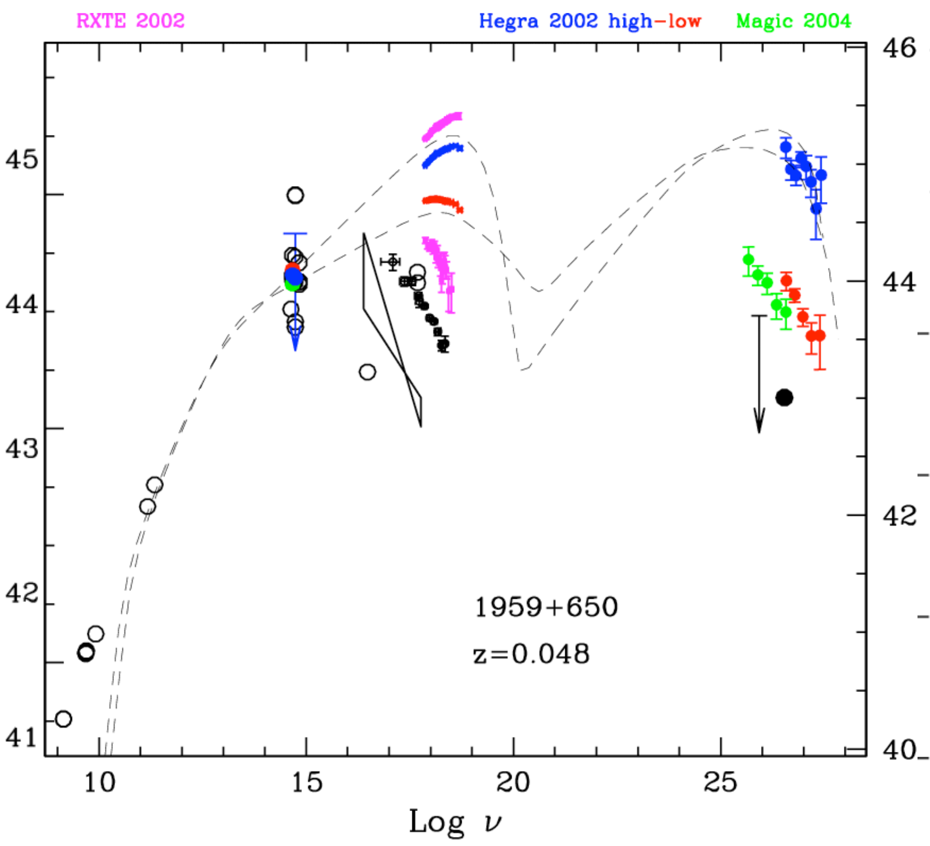


A new mode of flaring in HBL : FSRQ-like

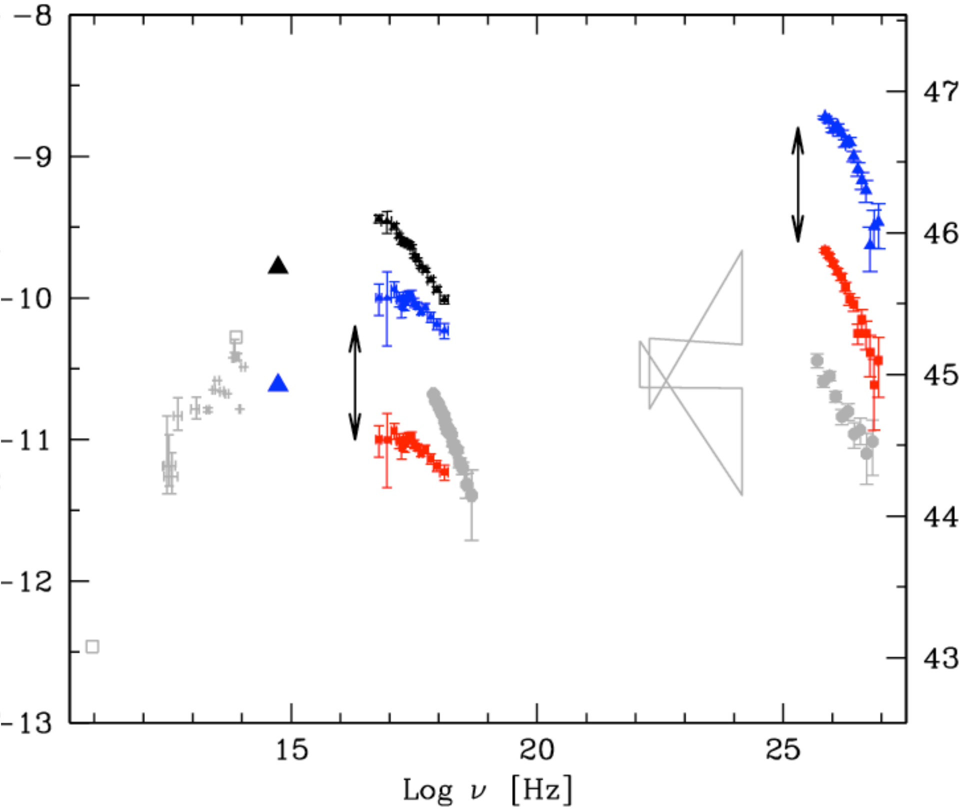
Mkn 501



1ES 1959+650



PKS 2155-304

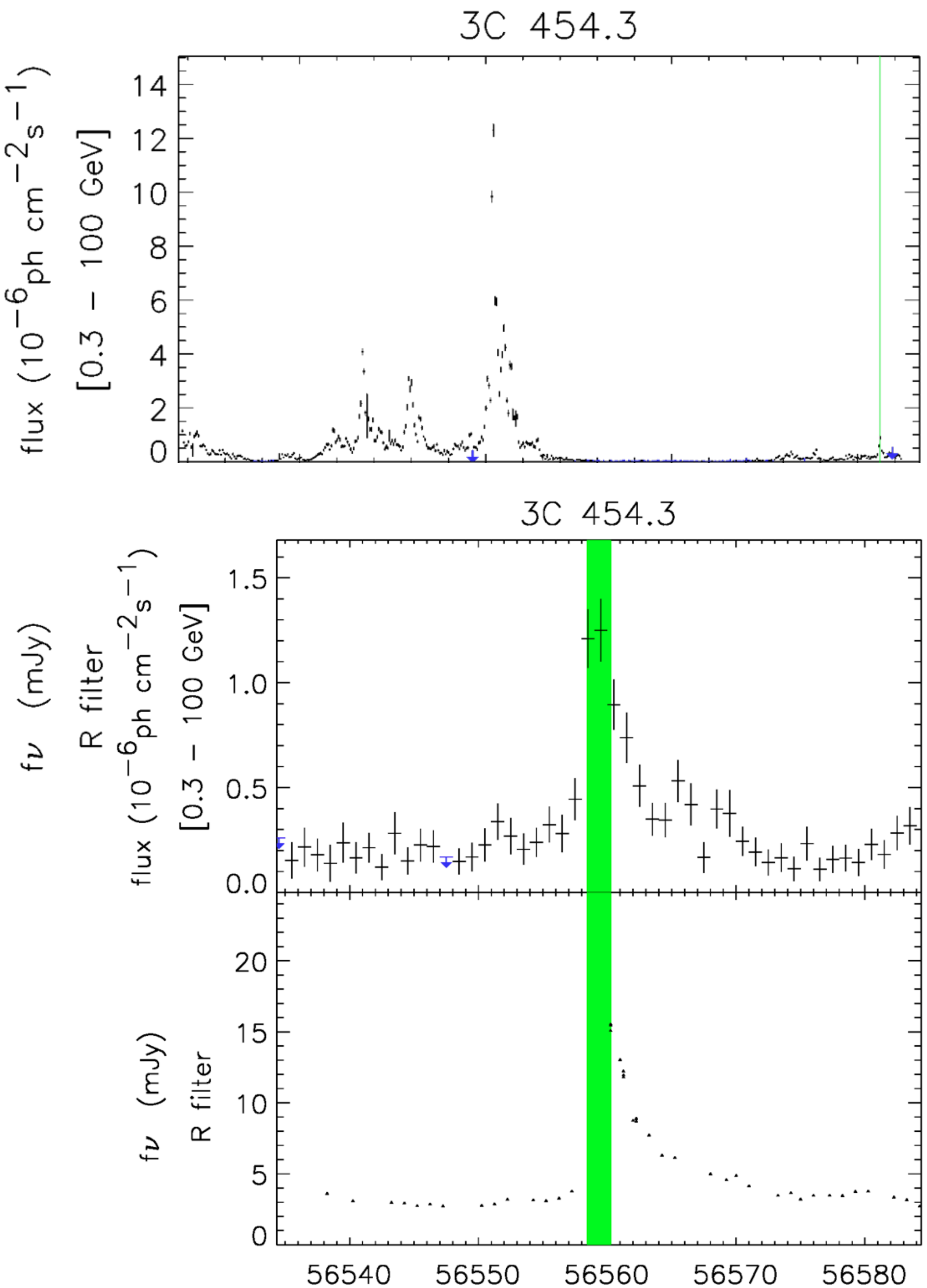


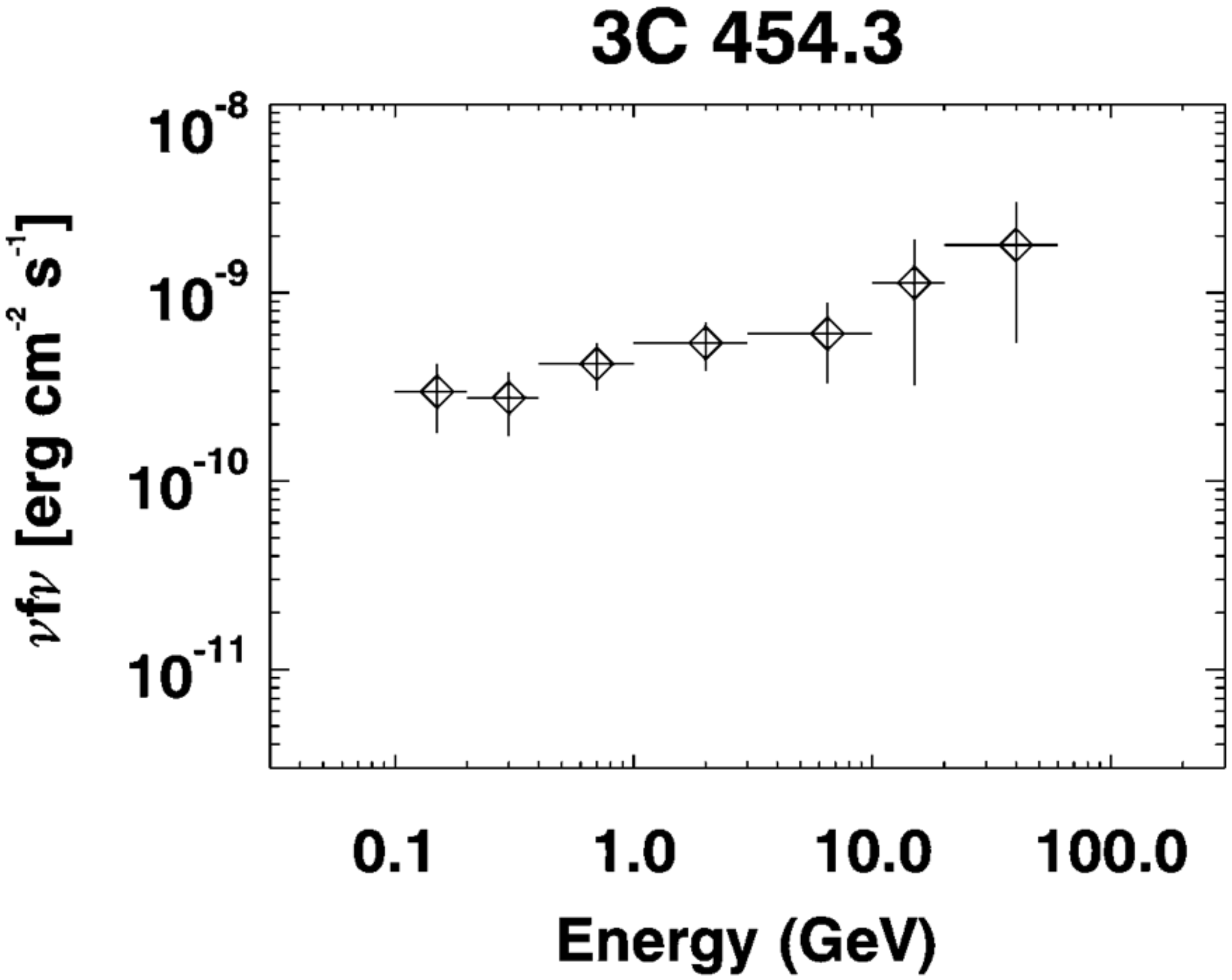
Synchrotron-dominated flares

Compton-dominated

Aharonian et al 2009

HBL-like flares in FSRQ !





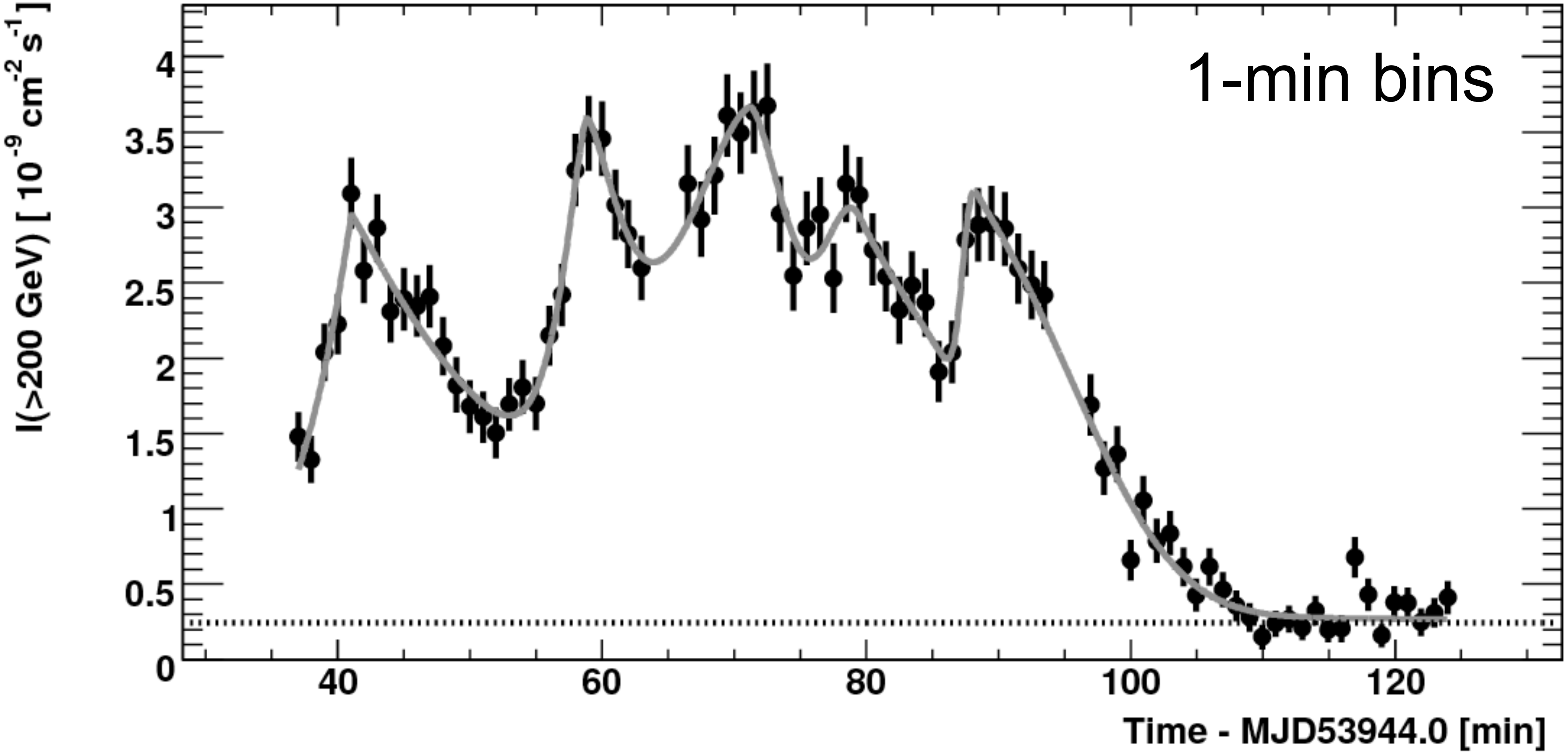
Pacciani et al 2013

#2 surprise: Ultra-fast variability !

2x flux in ~2-3 min.

10x in less than 1 hr

A



$L \sim 10^{47}$

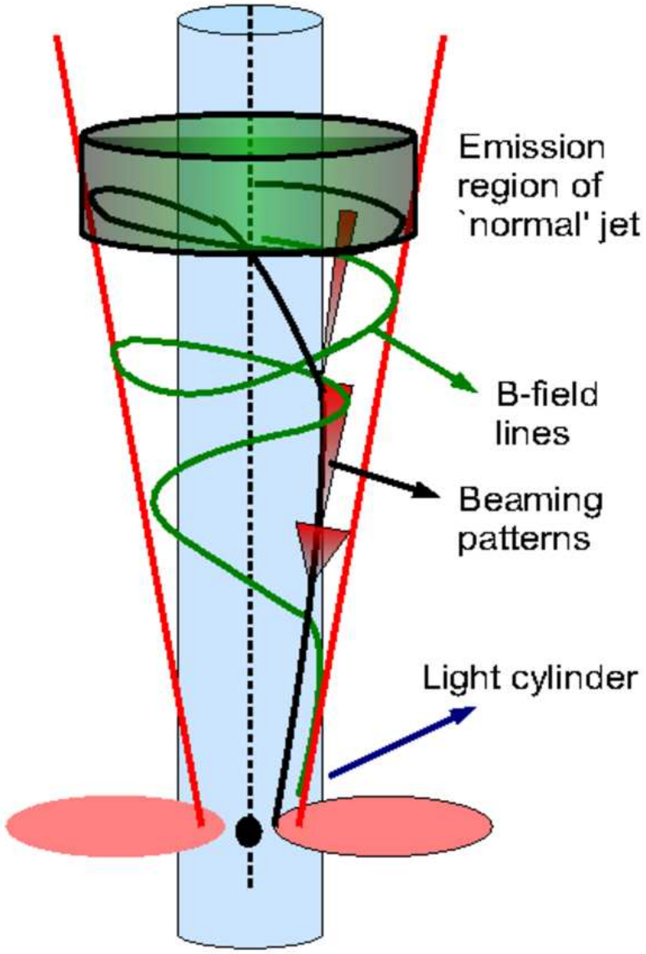
$R \sim 5\times10^{12}\,\delta$ cm $\approx 0.01\,\delta\,R_S$

Aharonian et al. (HESS coll) 2007

$\Gamma \geq 50$-100 for $R \sim R_S$

Possible explanations...

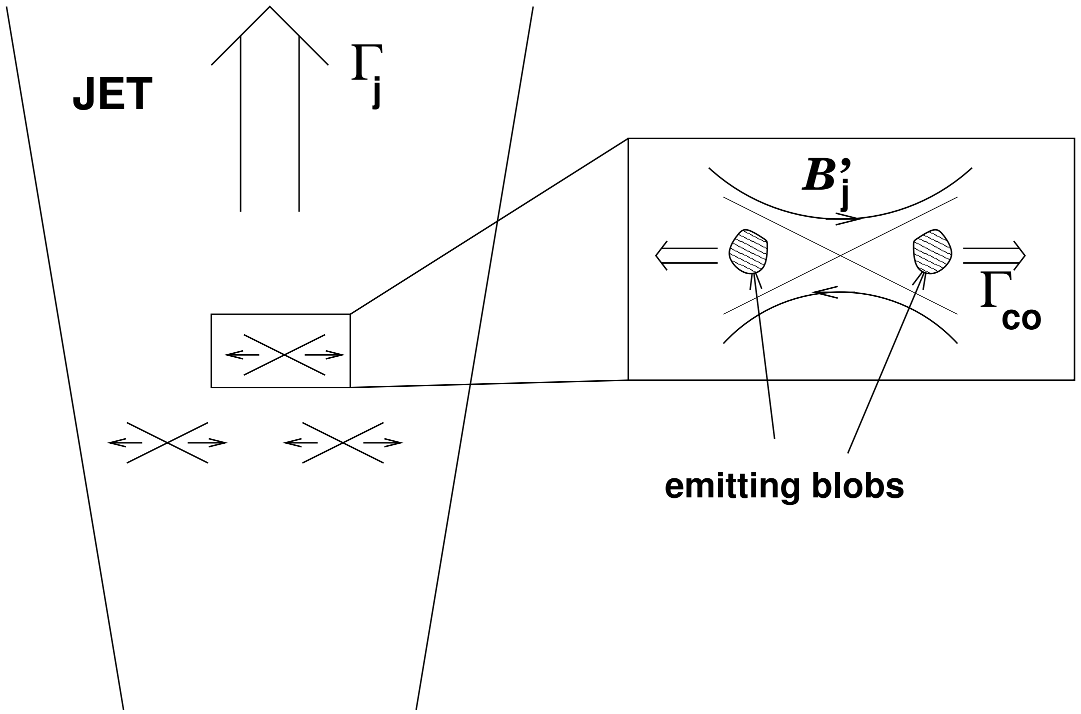
EC



Magneto-centrifugal accel ?

(Ghisellini & Tavecchio 2008; Ghisellini 2009)

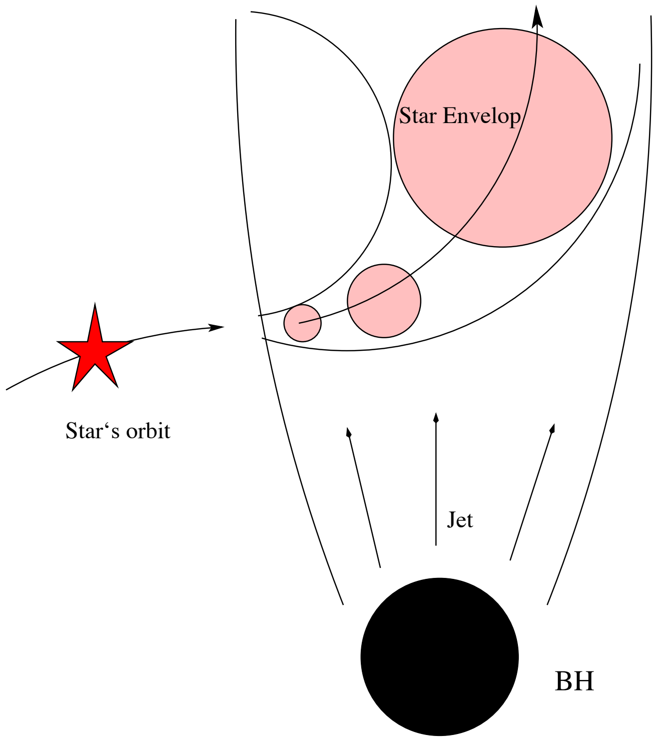
SSC



Jets-in-Jet ?

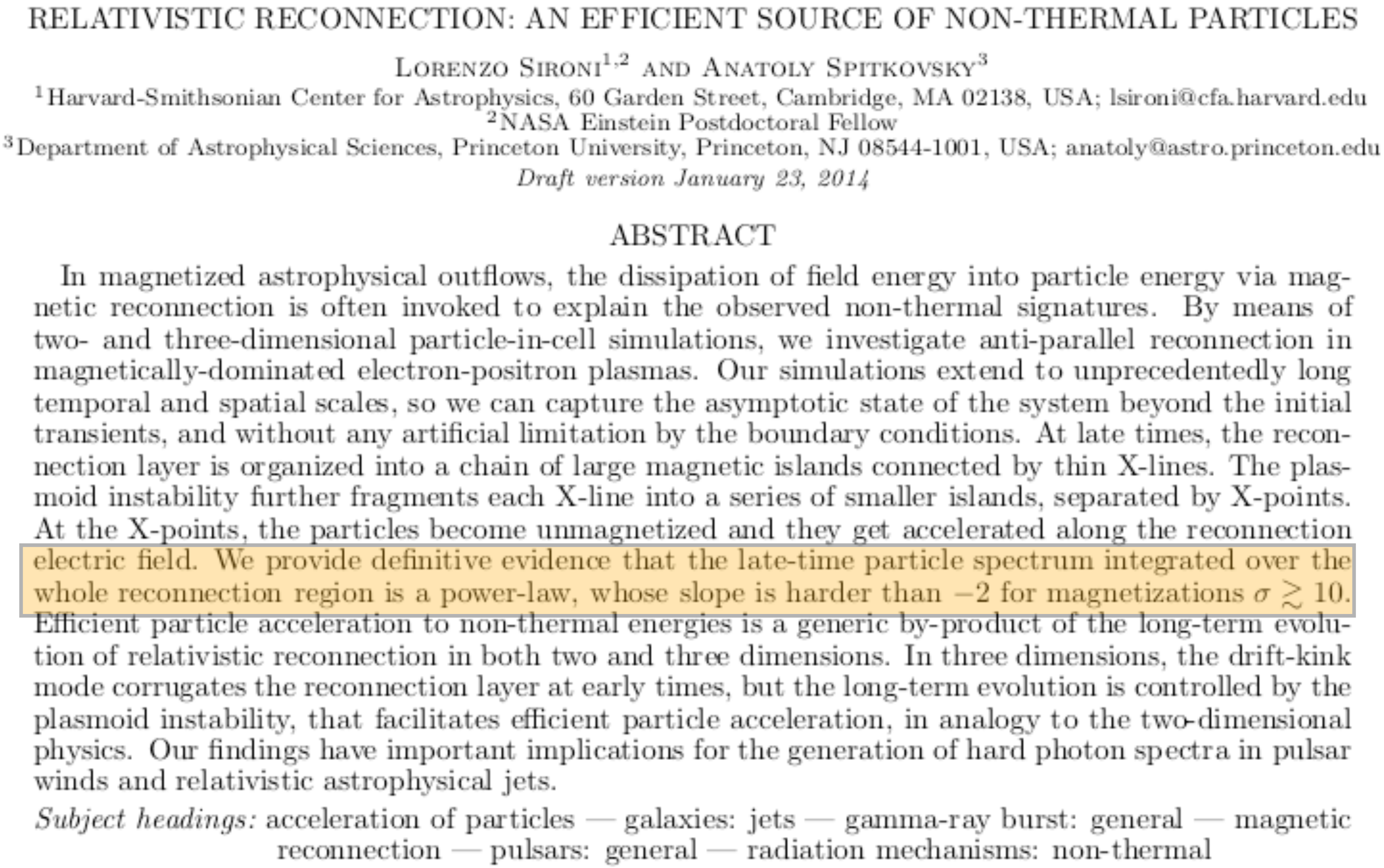
(Giannios et al 2009)

p-γ
EC



Jet-Star interaction ?

(Barkov et al. 2010, 2011)



RELATIVISTIC RECONNECTION: AN EFFICIENT SOURCE OF NON-THERMAL PARTICLES

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Draft version January 23, 2014

ABSTRACT

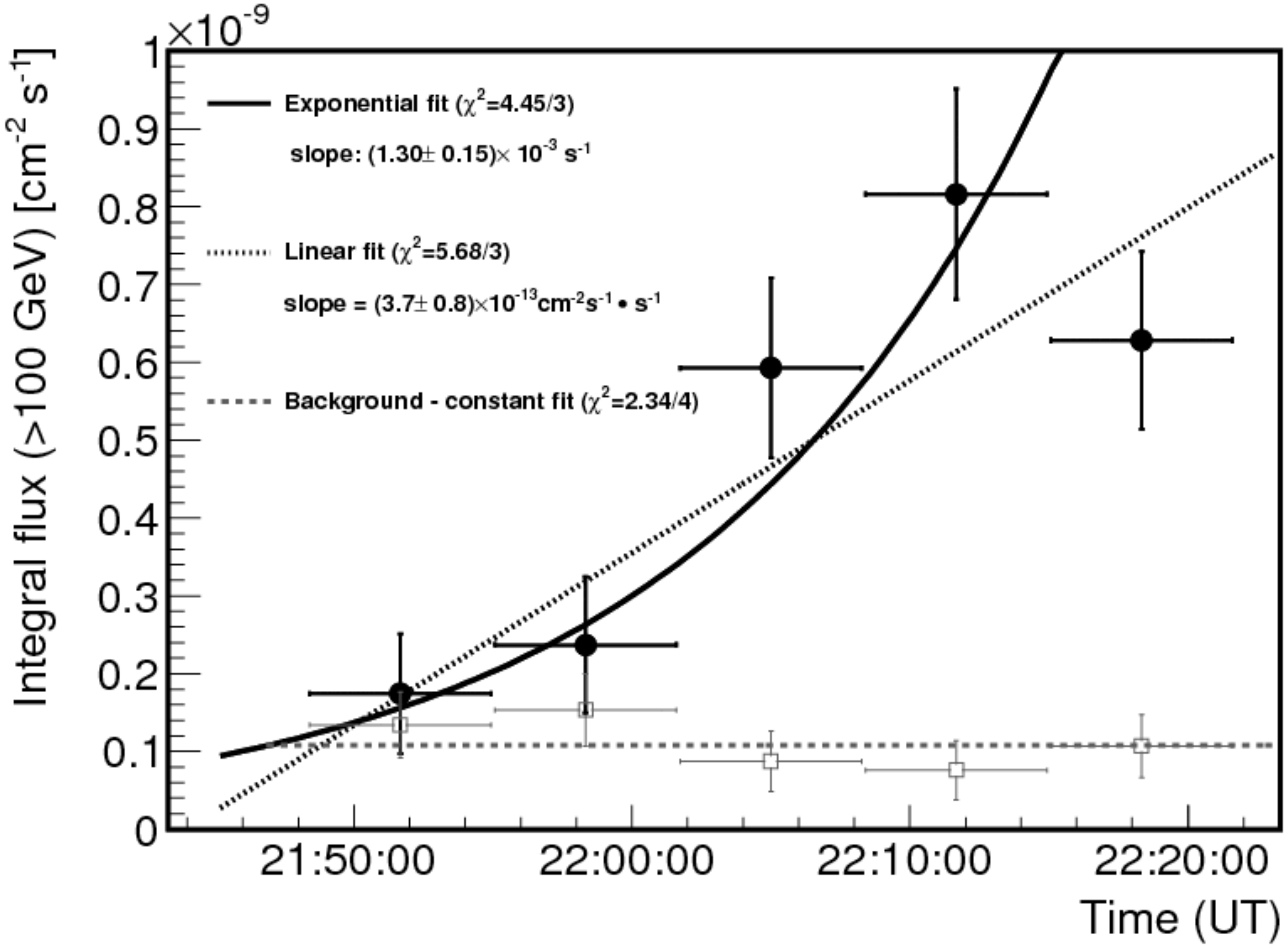
In magnetized astrophysical outflows, the dissipation of field energy into particle energy via magnetic reconnection is often invoked to explain the observed non-thermal signatures. By means of two- and three-dimensional particle-in-cell simulations, we investigate anti-parallel reconnection in magnetically-dominated electron-positron plasmas. Our simulations extend to unprecedentedly long temporal and spatial scales, so we can capture the asymptotic state of the system beyond the initial transients, and without any artificial limitation by the boundary conditions. At late times, the reconnection layer is organized into a chain of large magnetic islands connected by thin X-lines. The plasmoid instability further fragments each X-line into a series of smaller islands, separated by X-points. At the X-points, the particles become unmagnetized and they get accelerated along the reconnection electric field. We provide definitive evidence that the late-time particle spectrum integrated over the whole reconnection region is a power-law, whose slope is harder than -2 for magnetizations $\sigma \gtrsim 10$. Efficient particle acceleration to non-thermal energies is a generic by-product of the long-term evolution of relativistic reconnection in both two and three dimensions. In three dimensions, the drift-kink mode corrugates the reconnection layer at early times, but the long-term evolution is controlled by the plasmoid instability, that facilitates efficient particle acceleration, in analogy to the two-dimensional physics. Our findings have important implications for the generation of hard photon spectra in pulsar winds and relativistic astrophysical jets.

Subject headings: acceleration of particles — galaxies: jets — gamma-ray burst: general — magnetic reconnection — pulsars: general — radiation mechanisms: non-thermal

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

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

b) variability ~days-week



Aleksic et al. 2011 (MAGIC coll)

10-min variability !

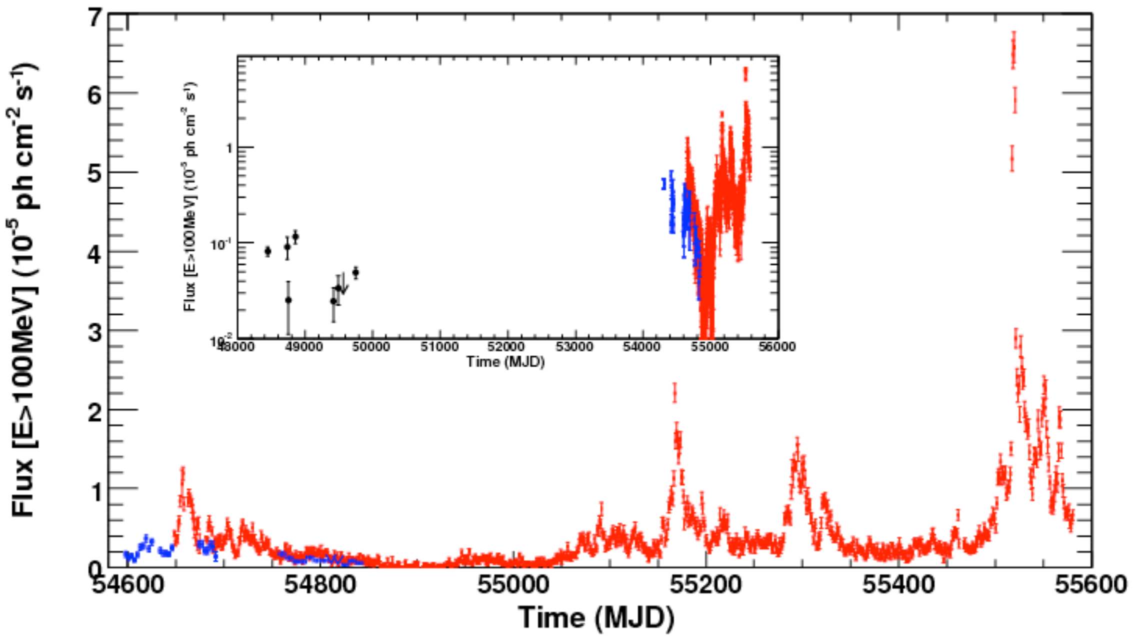
$$R \sim 2.5 \times 10^{14}\, \delta_{10}\, t_{\mathrm{var,10min}}\ \mathrm{cm}$$

at several pc from Black Hole

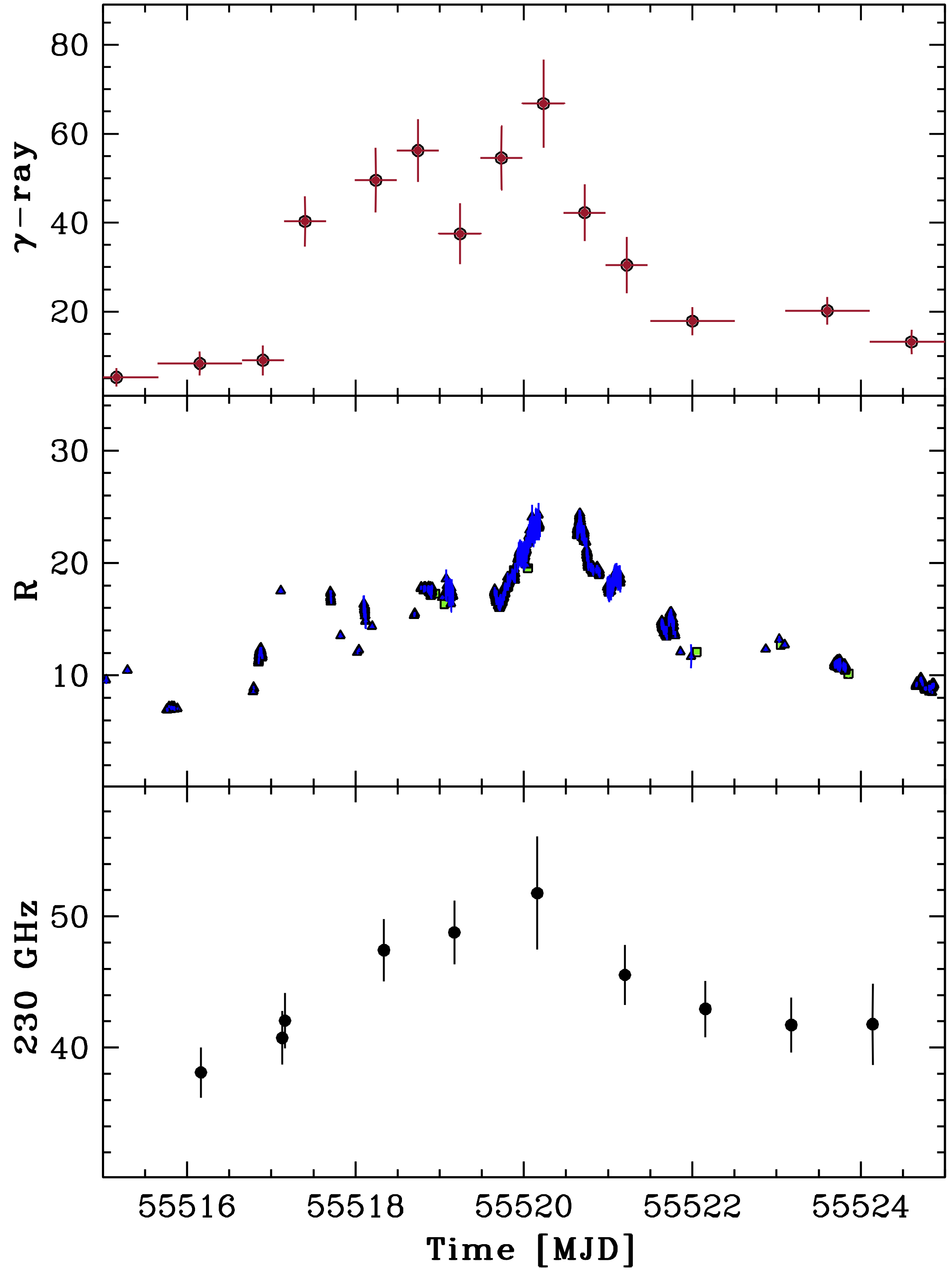
Problem for all models !

3C 454.3 with AGILE & FERMI:

varability seen down to the shortest timescales allowed by statistics (0.1-1 GeV)

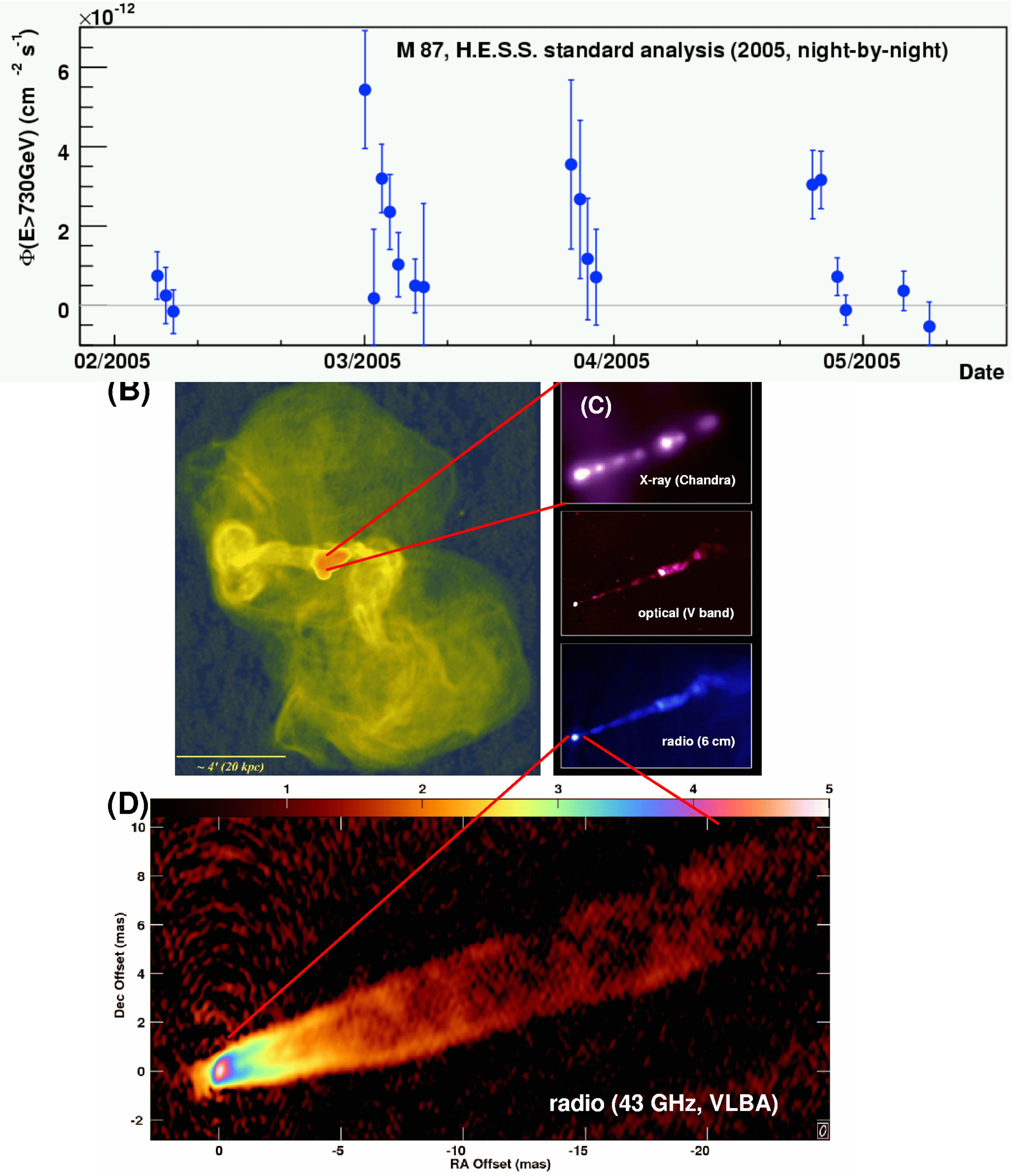


Abdo et al (LAT coll) 2010, 2011
Vercellone et al. 2010-2011



Hope with 10-GeV IACT:
sub-minute sampling

Similarly fast variability in radiogalaxies: M87 !

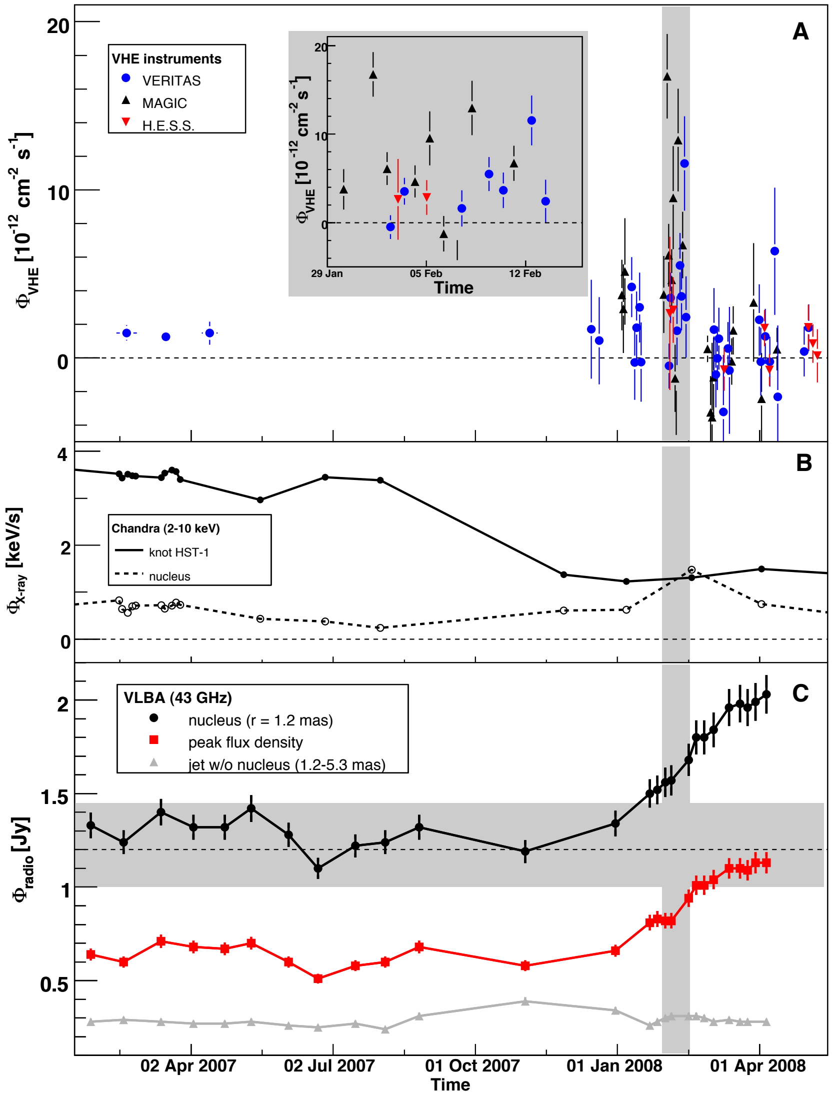


Aharonian et al. (Hess coll) 2006, Nature

Jet viewing angle $\theta \sim 18\text{-}30^\circ \Rightarrow \delta \sim <1$ to a few

$R \sim 5\times10^{15}\,\delta$ cm $\approx 5\,\delta\,R_S$

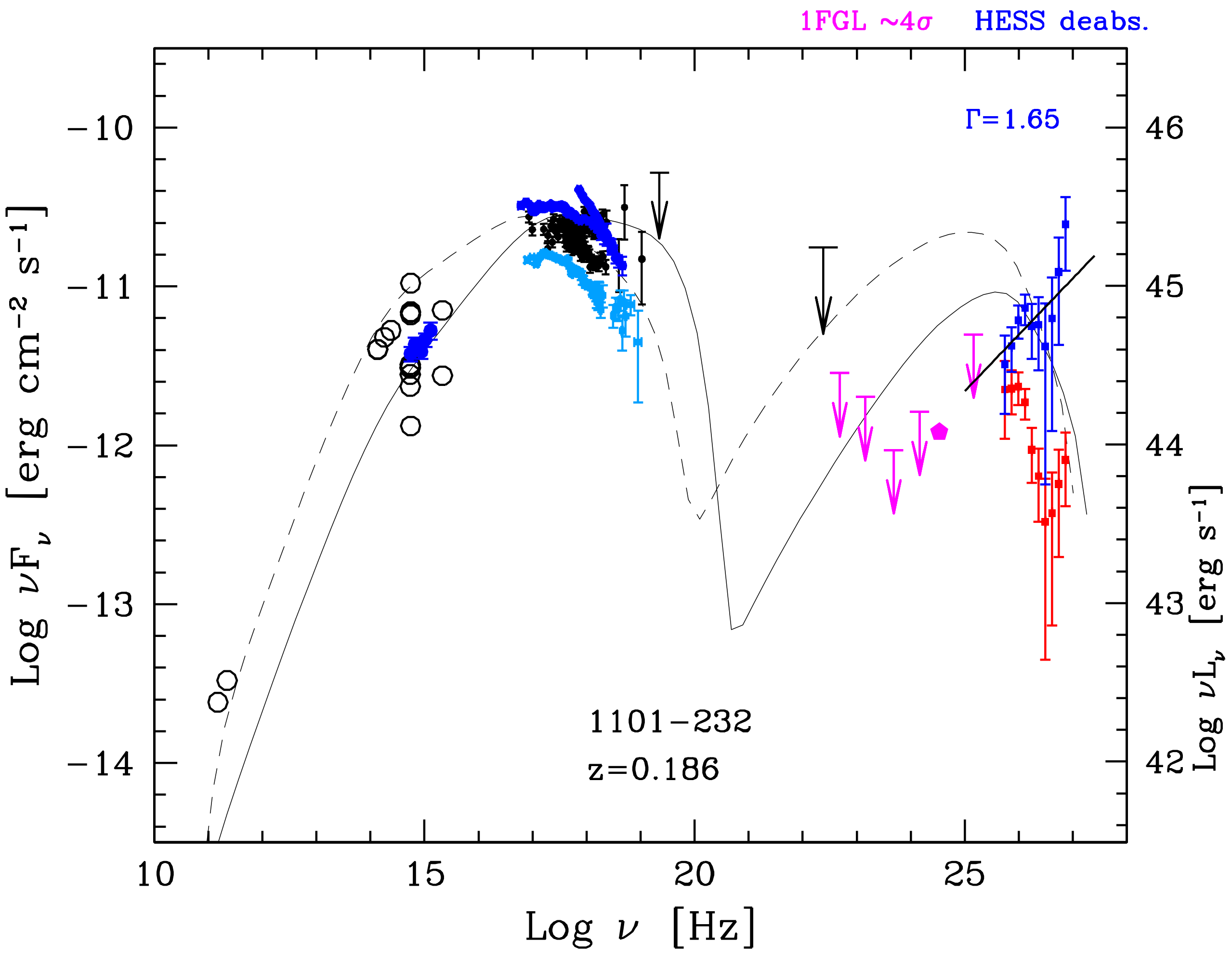
Origin: nucleus ?

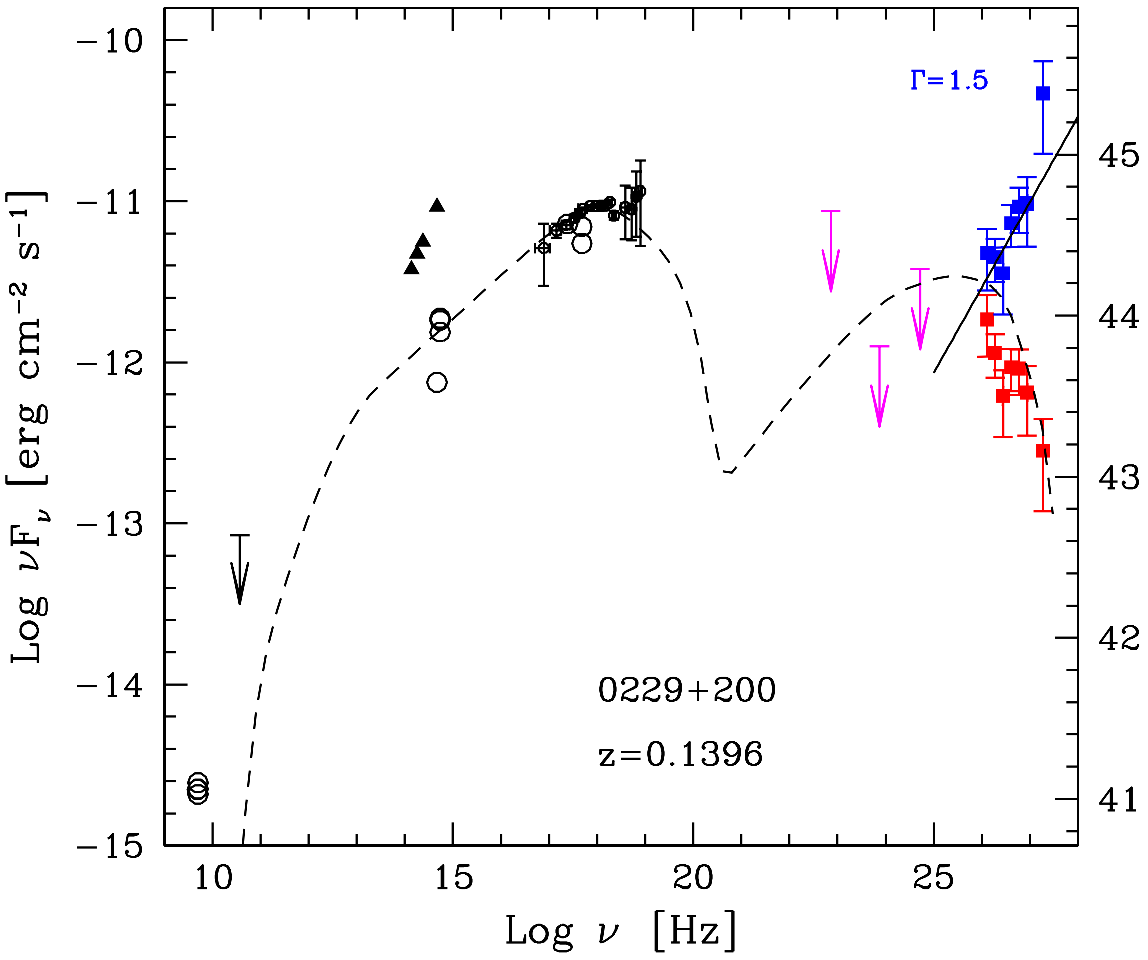


Acciari et al. (Veritas, VLBA, Hess, Magic coll) 2009, Science

#3 surprise: Hard TeV BL Lacs !

Even with lowest EBL, VHE spectra remain hard





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

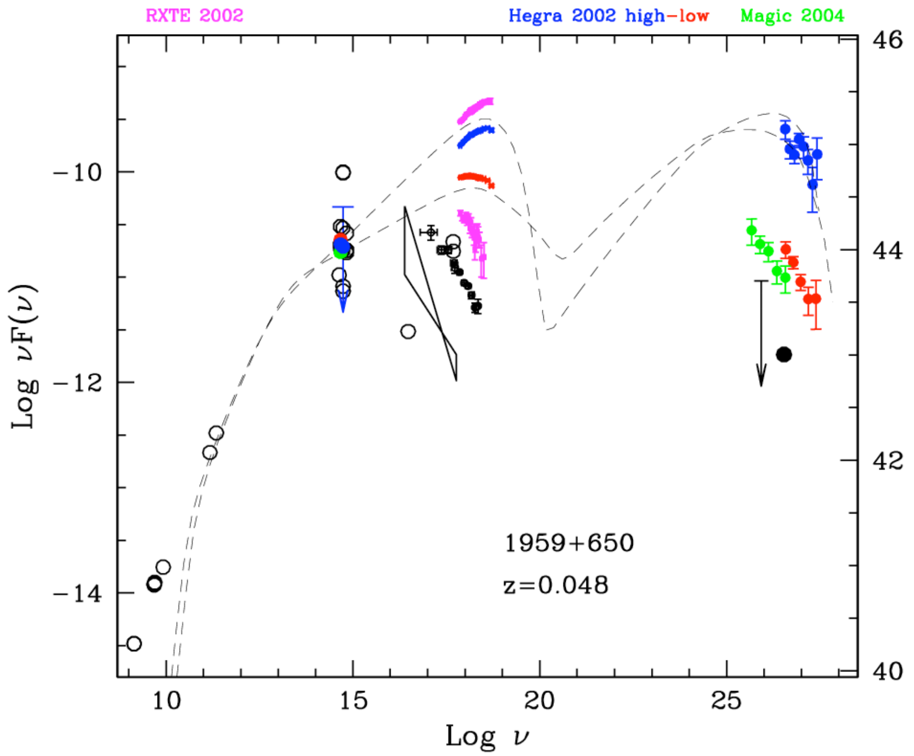
⇒ Compton peak ≥ 3-20 TeV

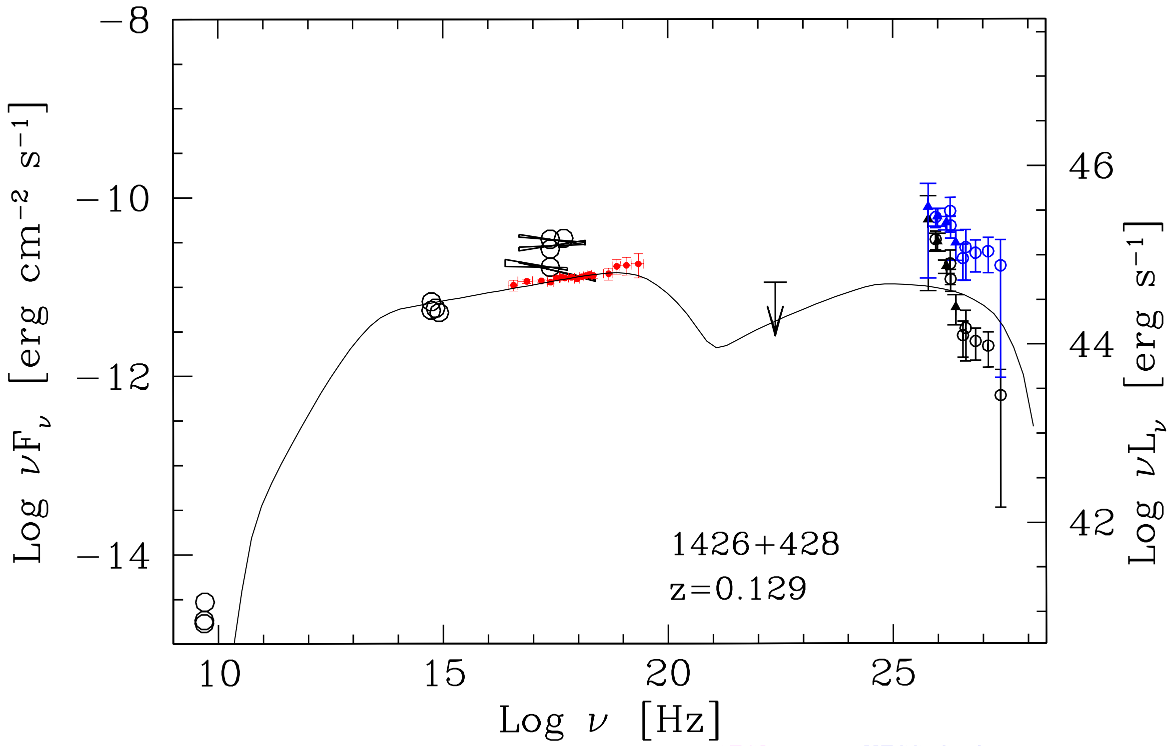
TeV-peaked BL Lac objects

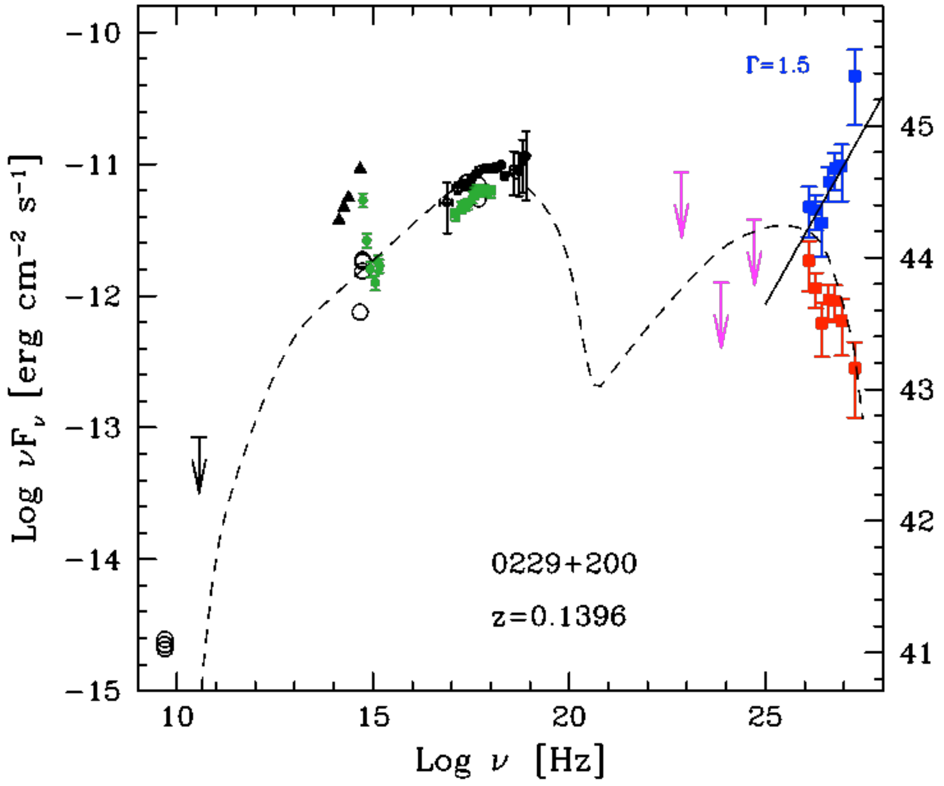
How many ? 9/29: ~1/3 HBL

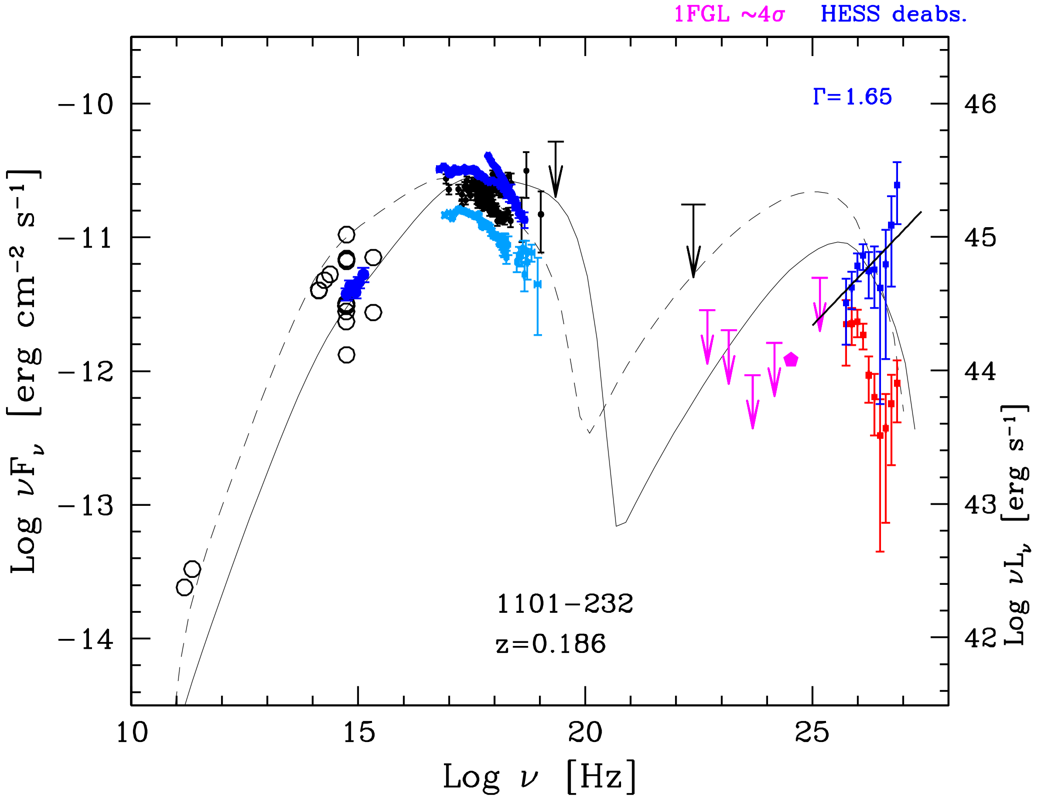
Relation Extreme-X — Extreme-TeV ? No...

Relation Extreme X - Extreme TeV ? Not very clear:





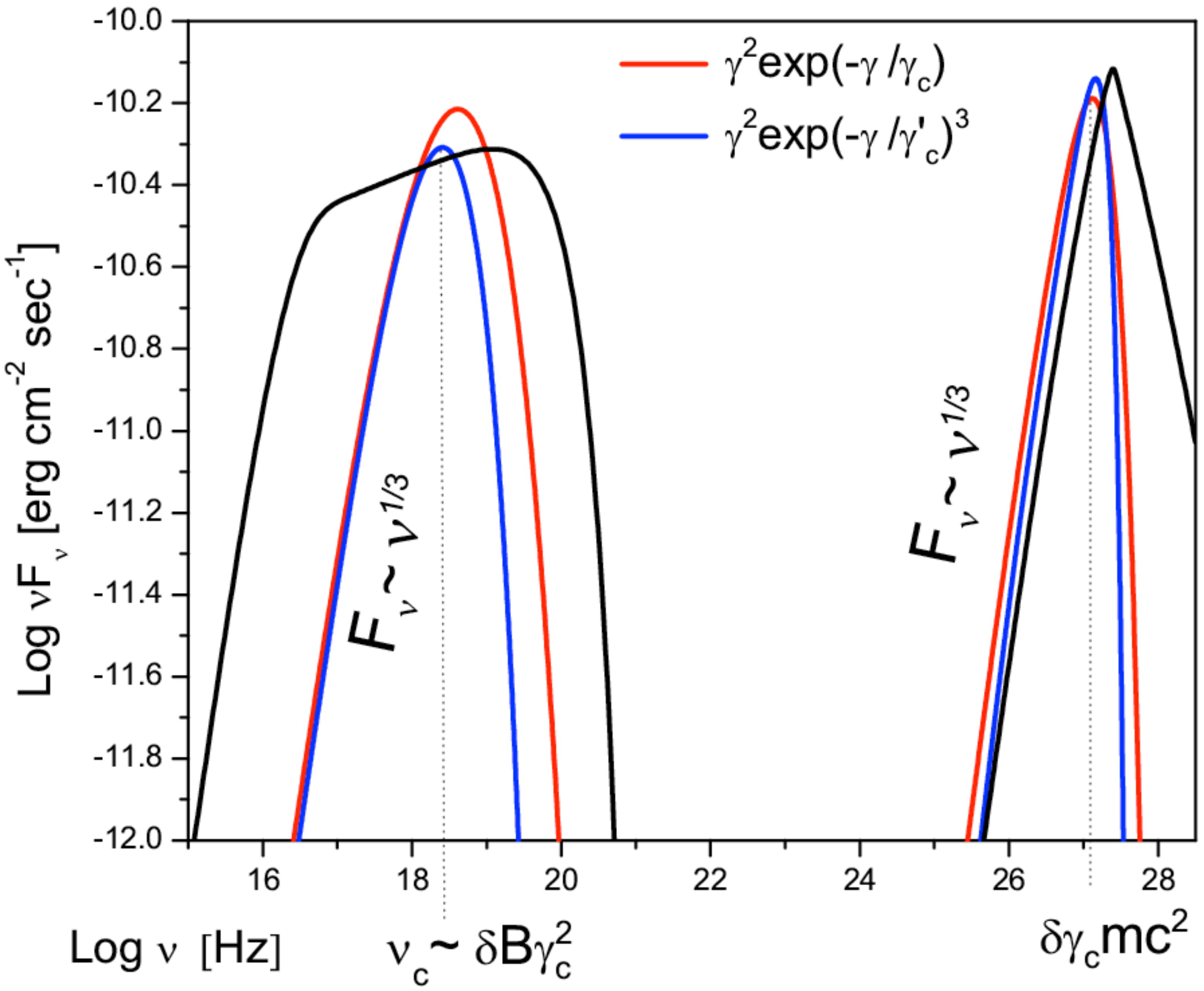




We cannot predict GBL/TBL from SED or Fermi spectrum!

How to make very hard spectra (even <1.5) with one-zone SSC ?

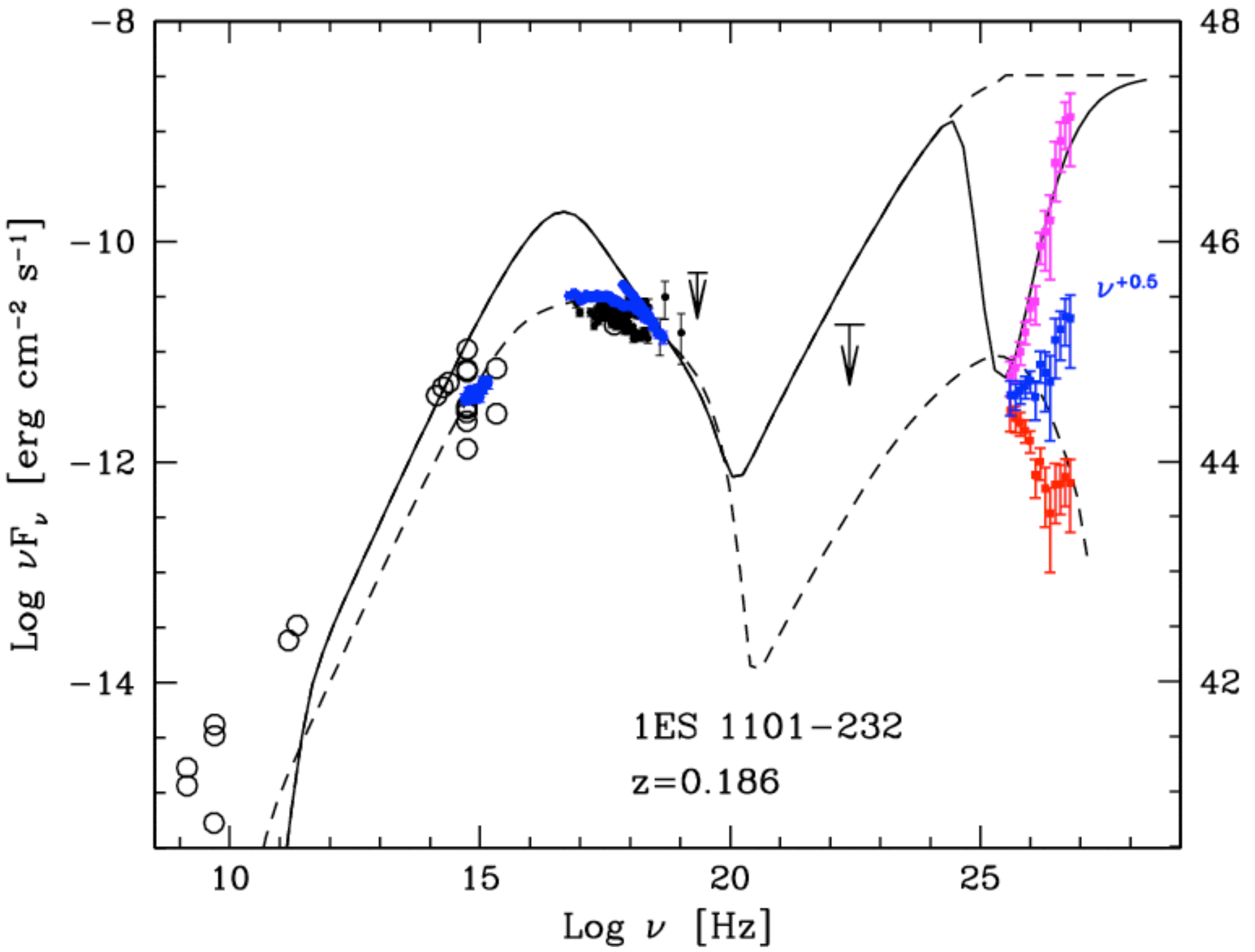
comprehensive discussion in recent paper: Lefa et al 2011



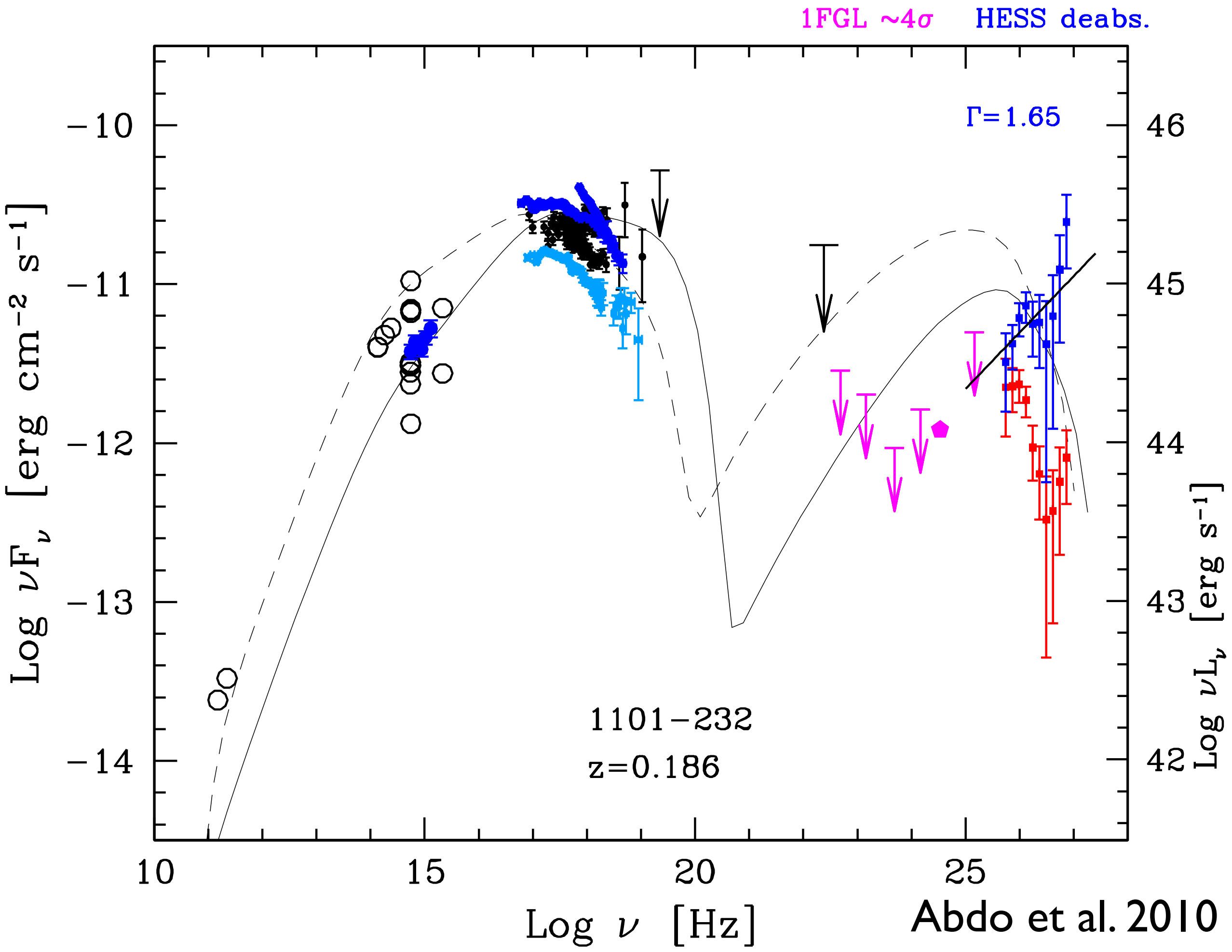
- Low-energy cutoff at high energies (Katarzynski 2007)

- Maxwellian distribution (Henri et al 2002)

Hard spectra without invoking hard particle distributions: internal absorption on Planckian spectrum



see e.g. Aharonian, Khangulyan, LC 2008



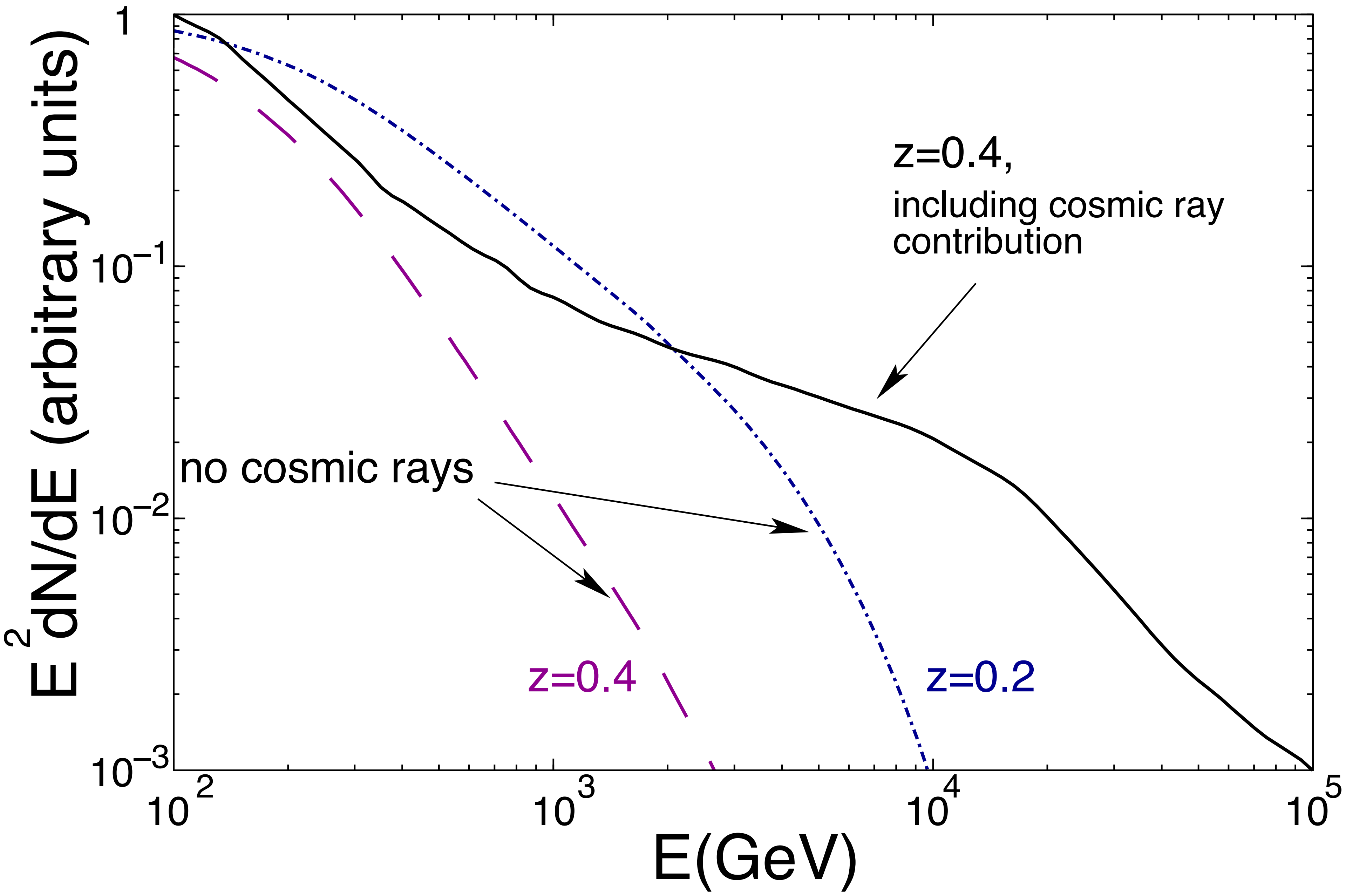
Abdo et al. 2010

But Fermi data seem now to exclude this...

But, if UHE-proton sources...

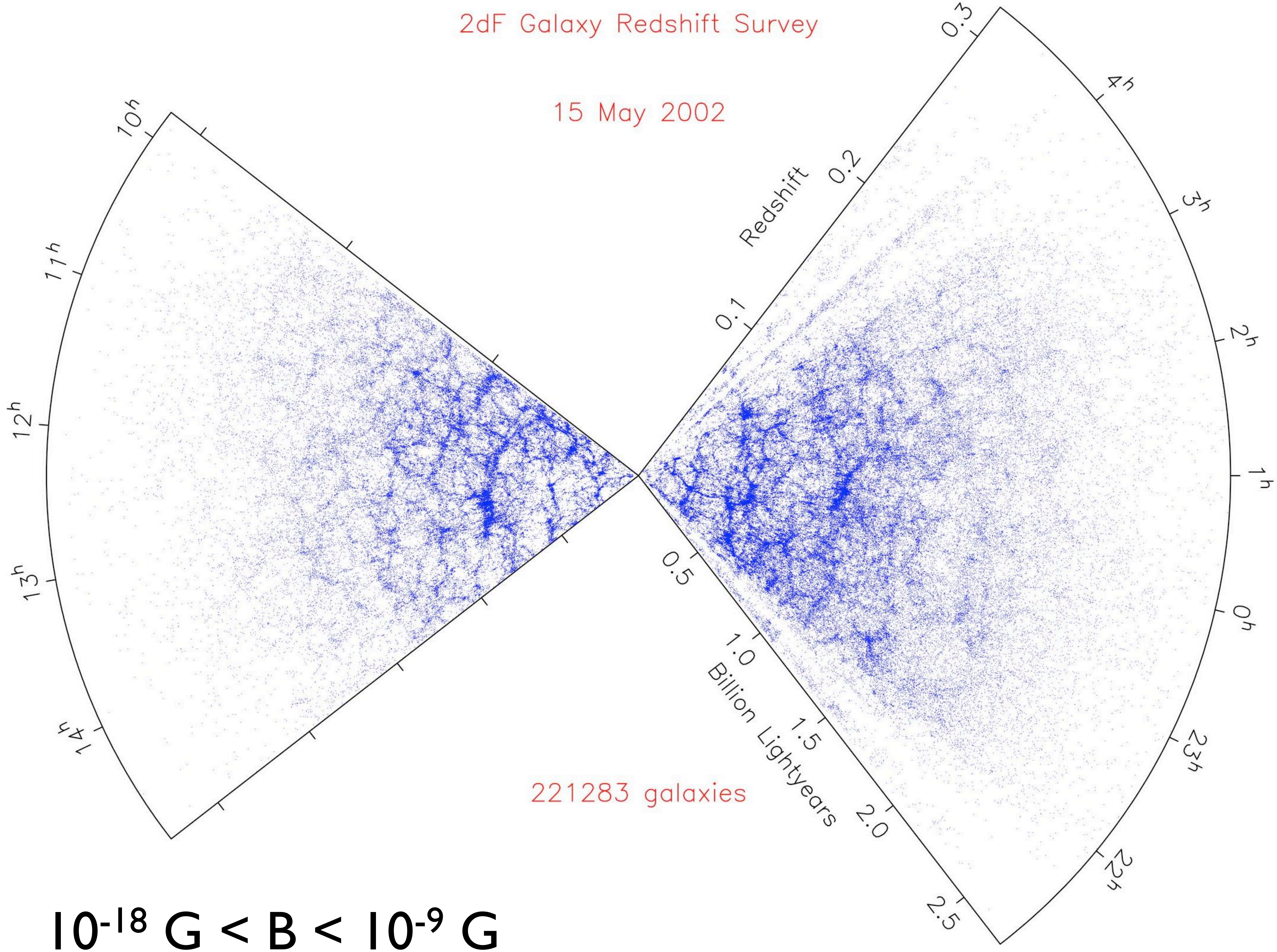
$p + \gamma_{\rm CMB} \to p + e^+ + e^-$ → **cascade**

→ **deposition of gamma-rays closer to us**



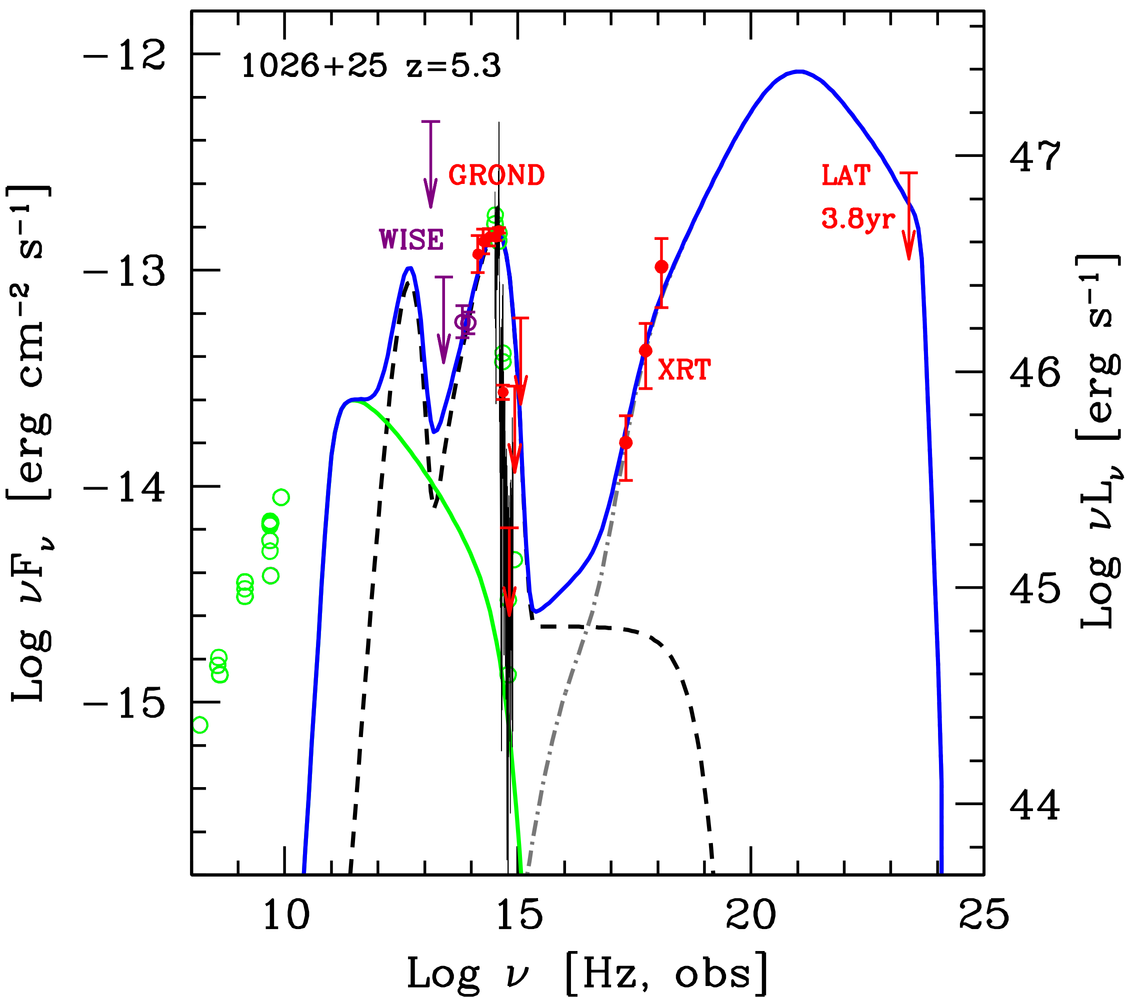
Prosekin, Kusenko, Aharonian, etc

Main problem: Large Scale Structure IGMF

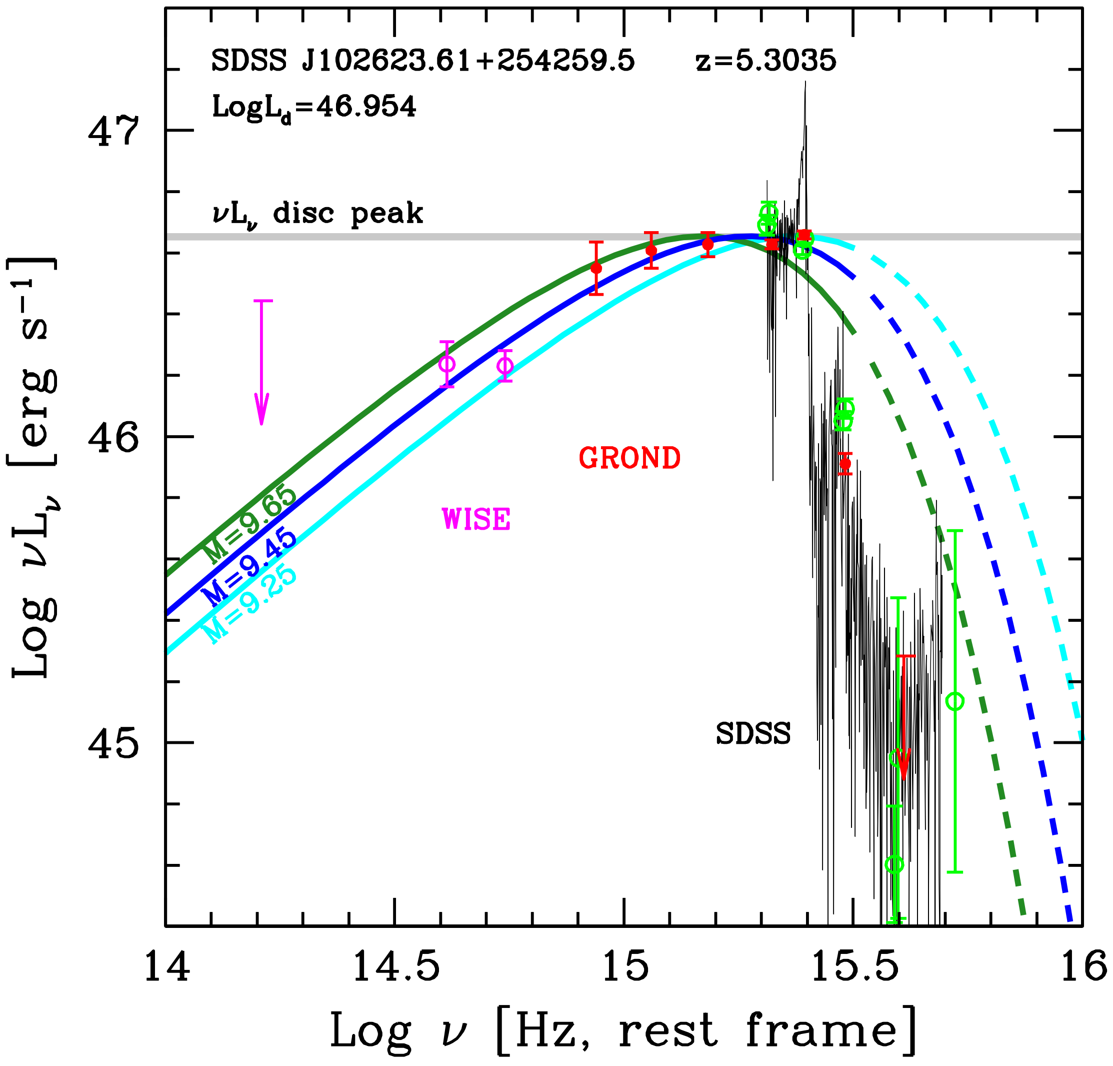


10^{-18} G < B < 10^{-9} G

4 surprise: High-z SMBH blazars



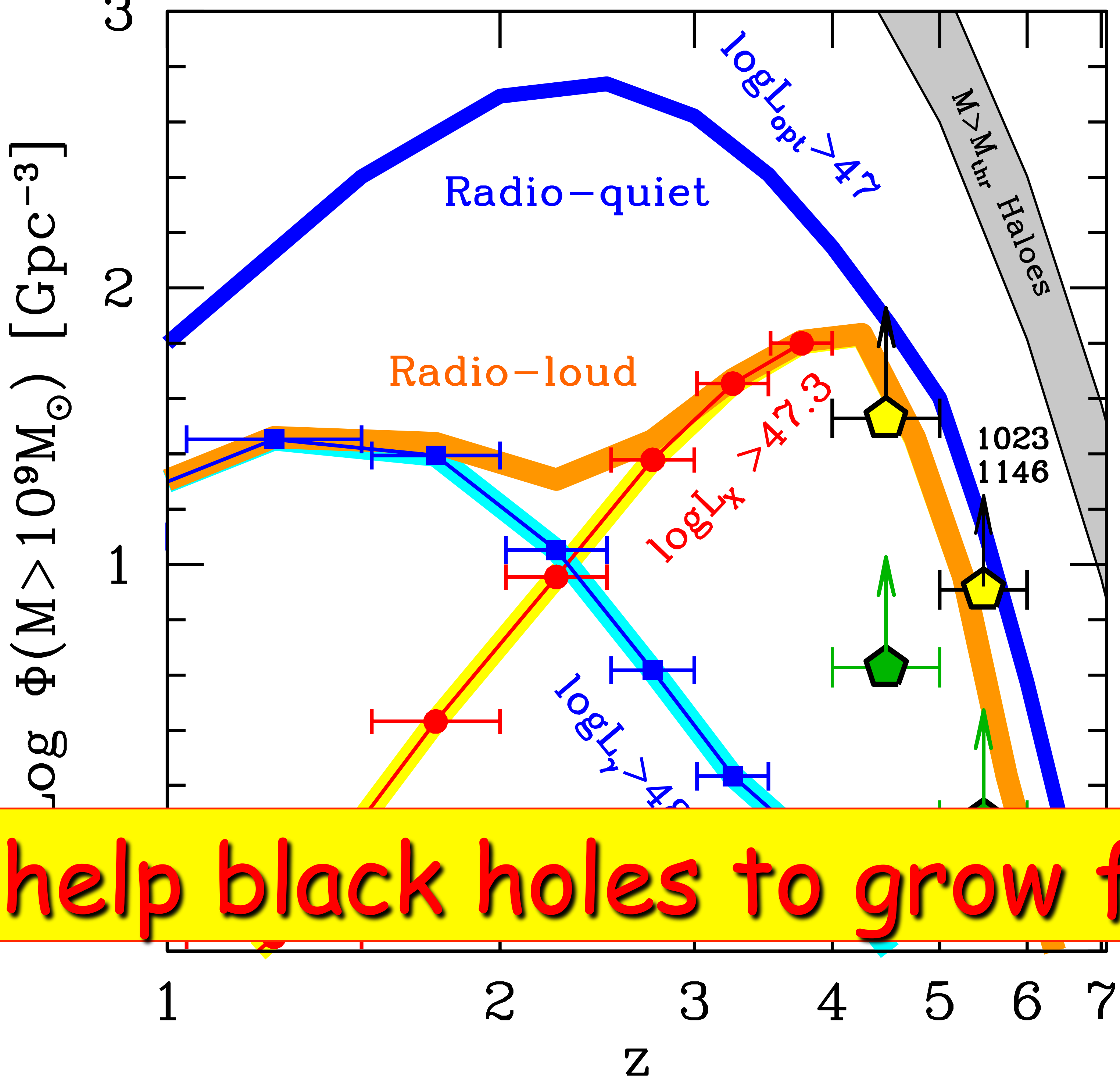
MeV-blazars



Sbarrato et al 2012-14
Ghisellini et al 2012-14

Black hole mass density evolution

Sbarrato Ghisellini (Boheme 2014)



Jets help black holes to grow faster

Summary

- Where blazars dissipate ?
(*are FSRQ and BLLacs really different ? maybe thermal is misleading*)

- How they dissipate ? (*shocks, turbulence, B-reconn. ?*)

- Always the same mechanisms ?

Variable - Persistent ?
Fast - Slow ?
Hard(TeV) - Soft ?

- Role of jets in BH accretion (*SMBH in early universe*)

Data is plenty:

we need to look with different eyes