On the location of gamma-ray emitting region in blazars

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Poutanen & Stern (2010, ApJ Letters, 717, L118)

Stern & Poutanen (2011, MNRAS Letters, 417, L11)

Stern & Poutanen (2014, ApJ, 794, 8)

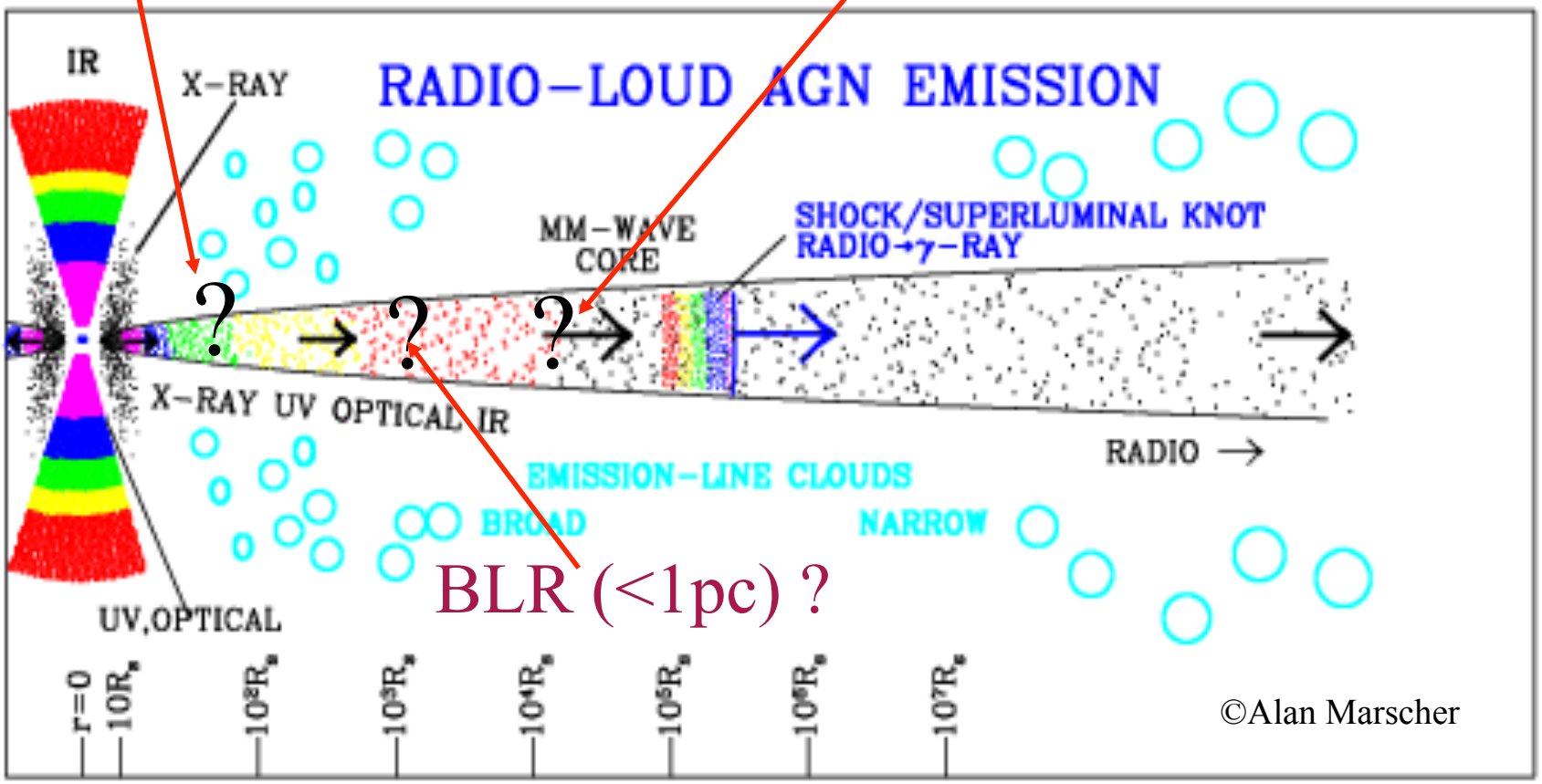
Plan

- Fermi spectra of blazars, early results.
- Physics of broad-line region (BLR). Photon opacity.
- Fermi spectra of individual bright blazars and the stacked redshift-corrected spectra.
- A proof that the gamma-ray emitting region lies within the BLR.

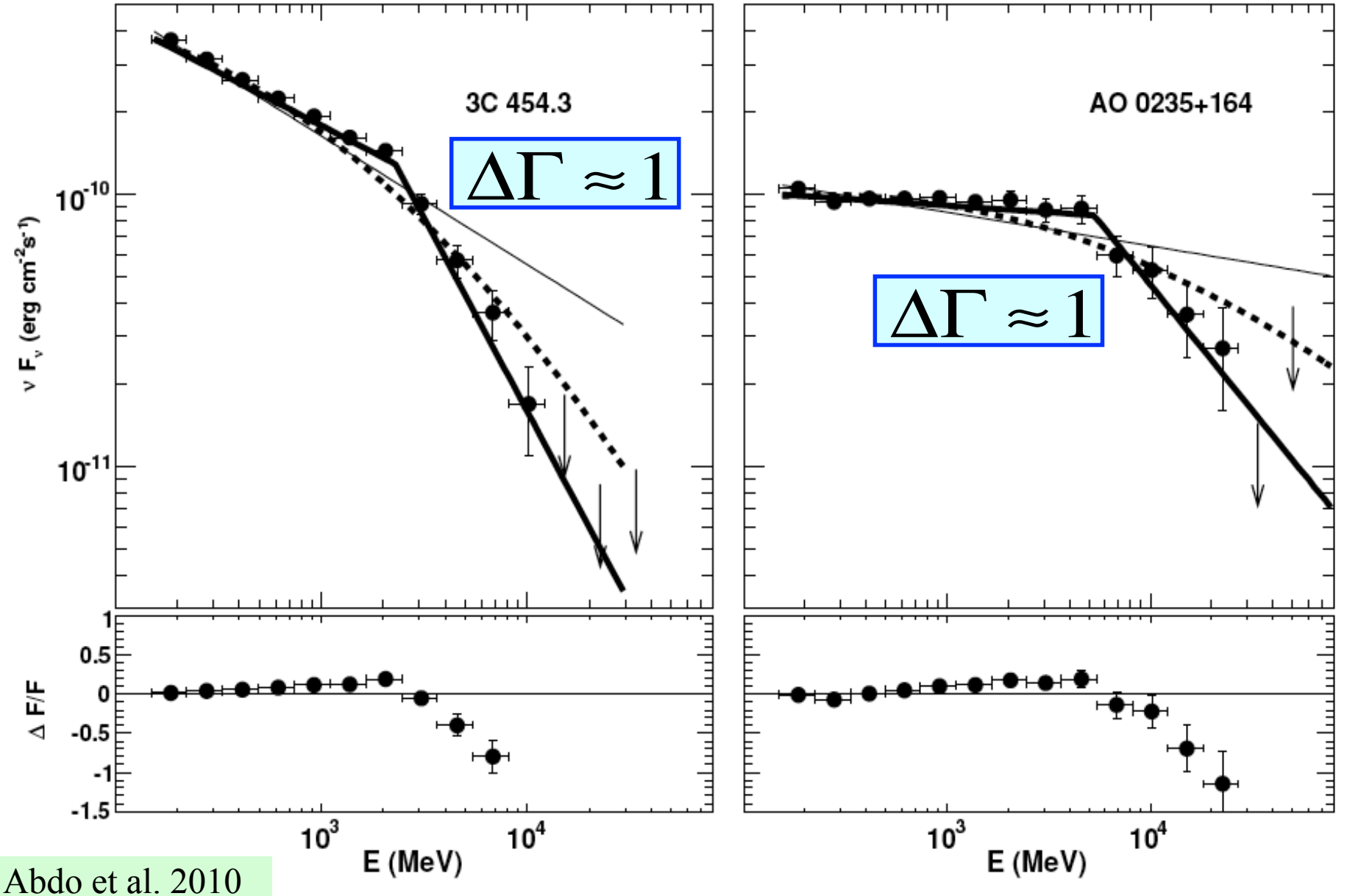
Where the gamma-ray emitting region is located?

Close to accretion disk?

Dusty torus (10 pc)?

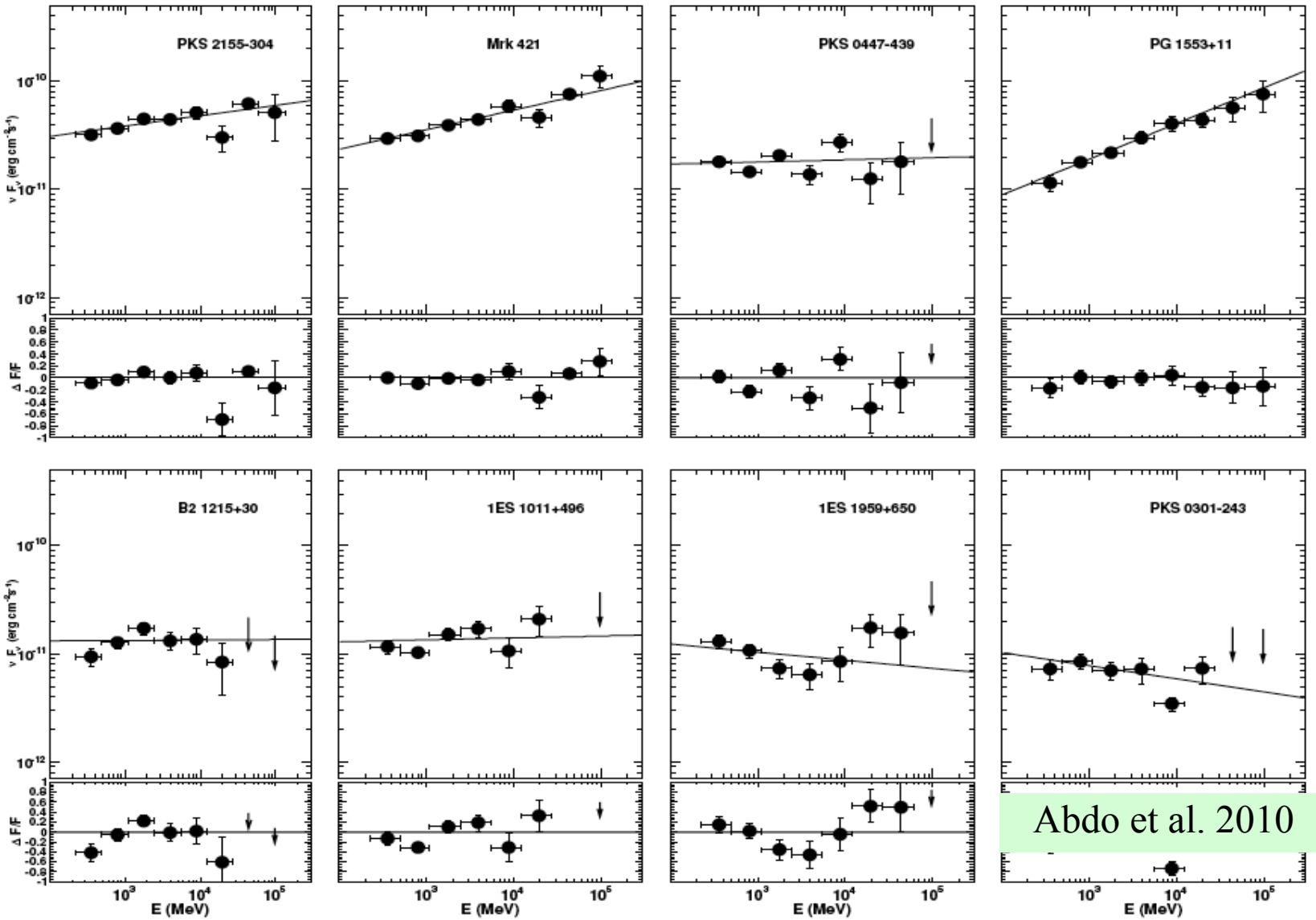


GeV breaks in FSRQ and LSP BL Lacs



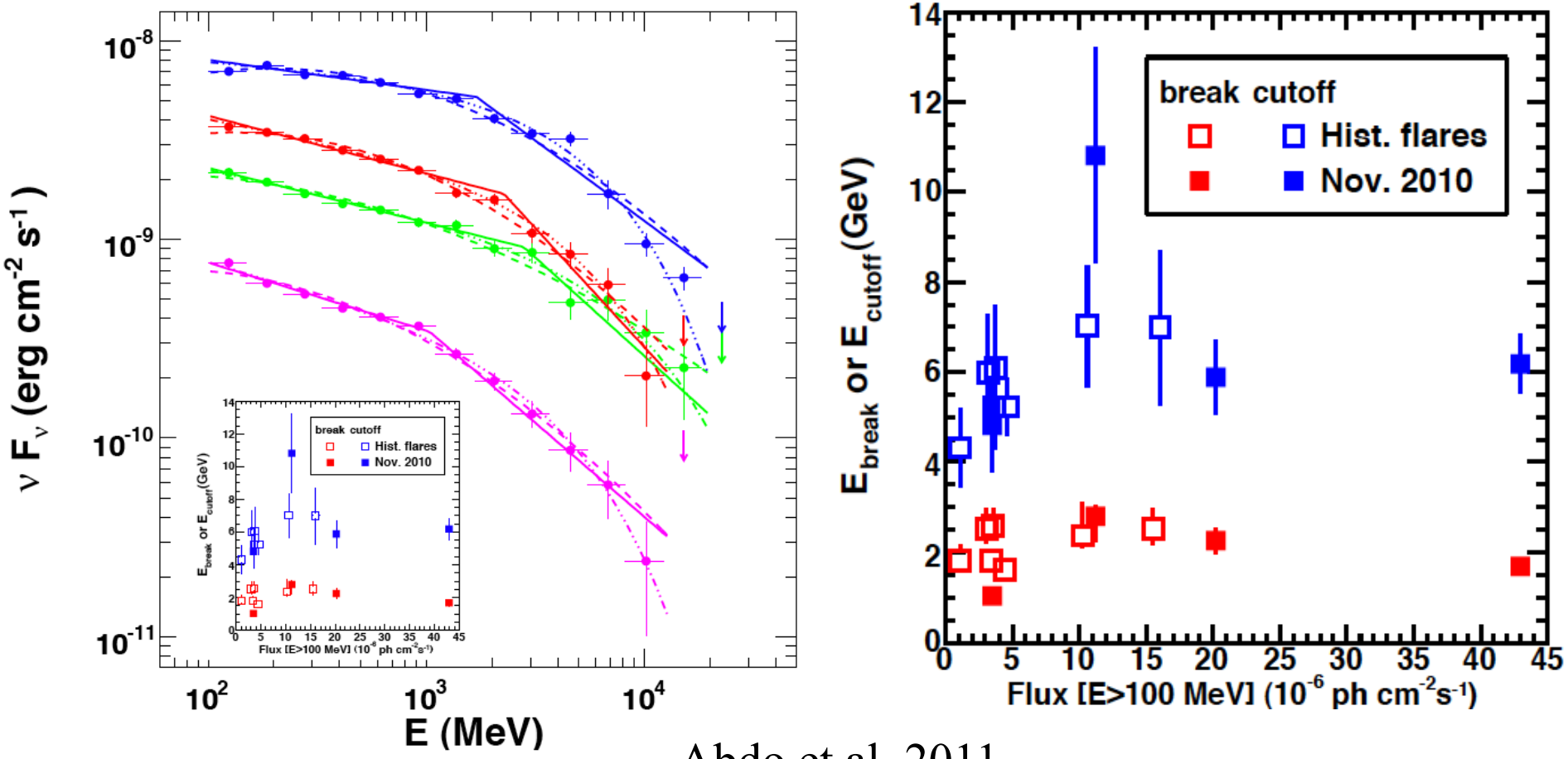
Abdo et al. 2010

Fermi spectra of high spectral-peak (HSP) BL Lacs



Abdo et al. 2010

Stability of breaks during flares

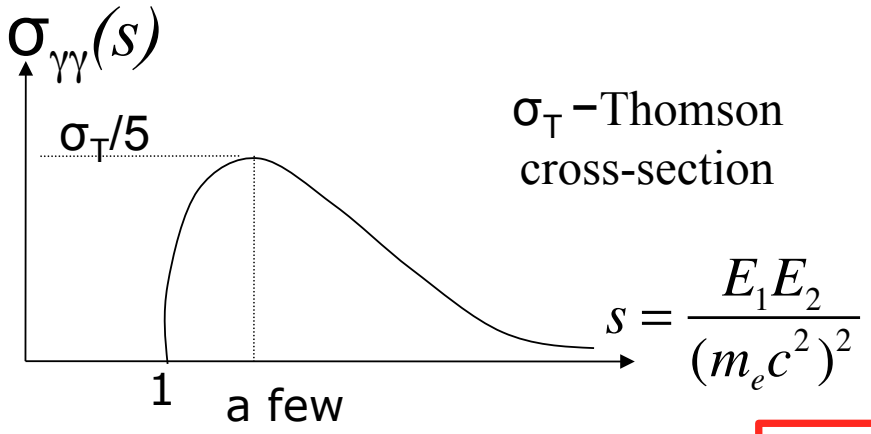


Abdo et al. 2011

Break energy is nearly constant ➔ atomic physics

Gamma-ray absorption by photon-photon pair production

Cross-section for pair production



Threshold at s=1:

$$E = 25.6\ \text{GeV}\frac{10.2\ \text{eV}}{E_0}$$

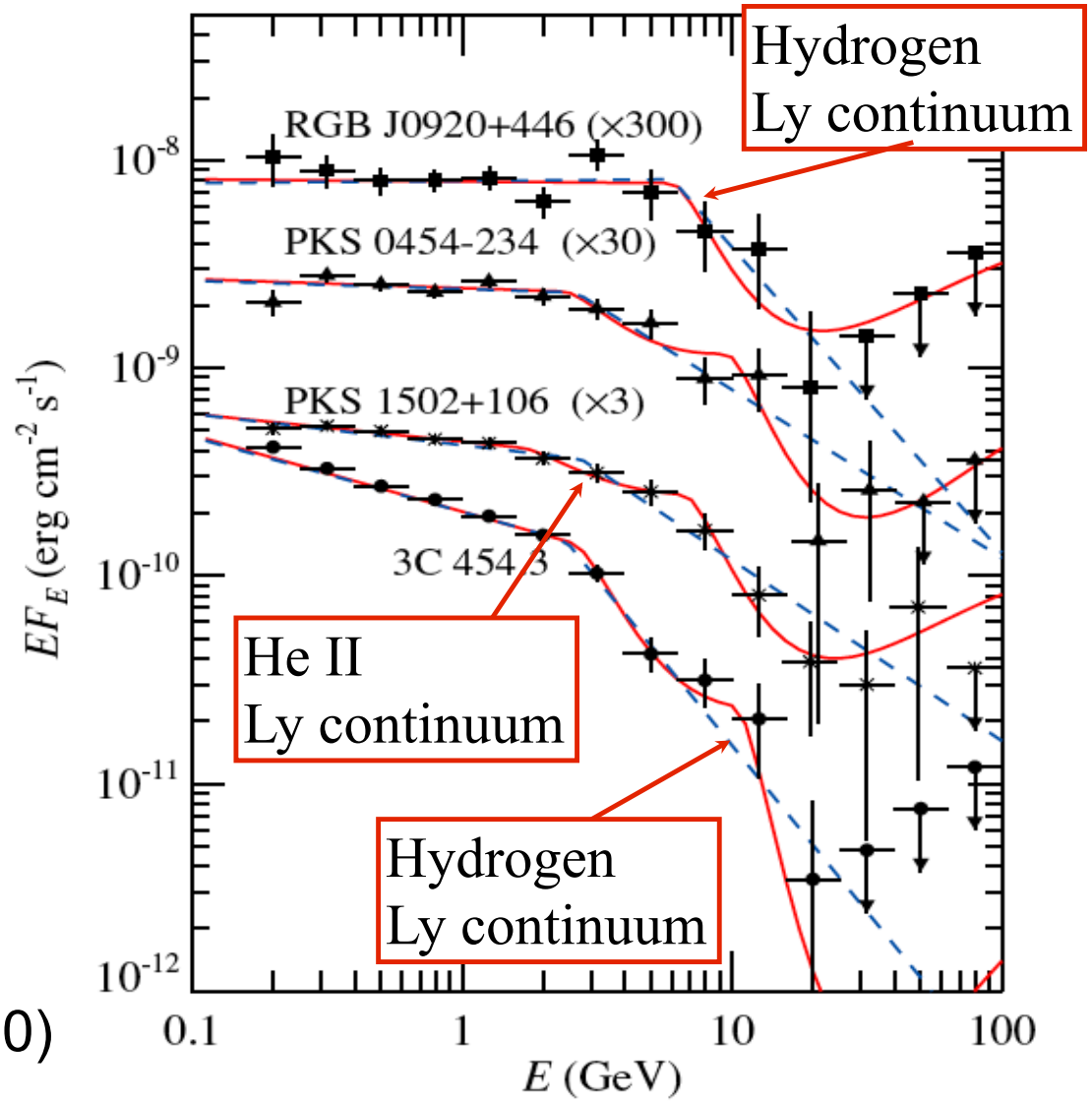
GeV breaks cannot be produced by Ly α photons!

But there are also LyC from H and He.

	"Line" energy	Threshold
H I Ly α	10.2 eV	– 25.6GeV
H I Ly cont.	13.6 eV	– 19.2GeV
He II Ly α	40.8 eV	– 6.4 GeV
He II Ly cont.	54.4 eV	– 4.8 GeV

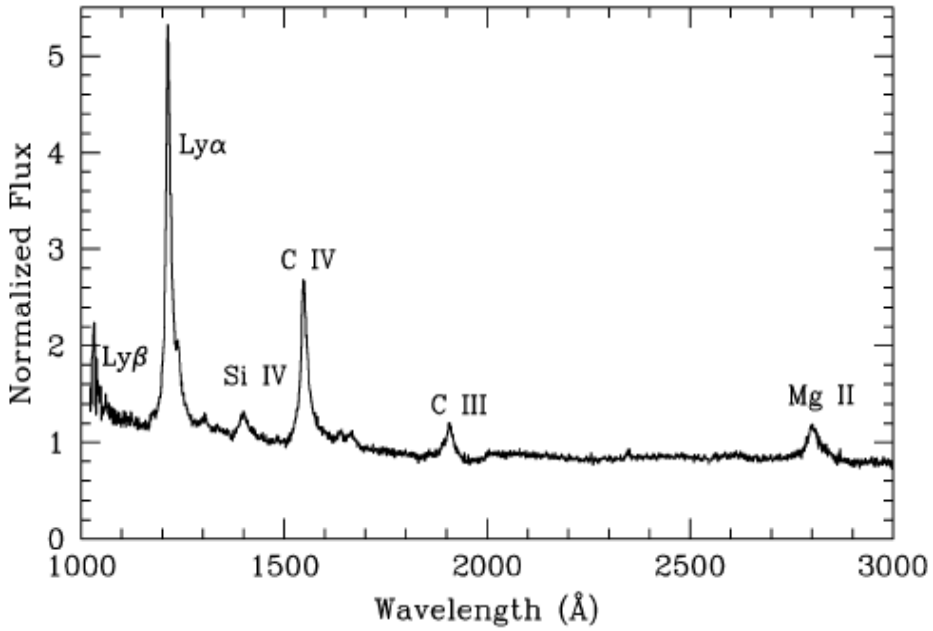
Absorption dips by He II and H I Lyman recombination continuum

Power law +
dual absorber
(produced by H I and He II Lyman recombination continua)

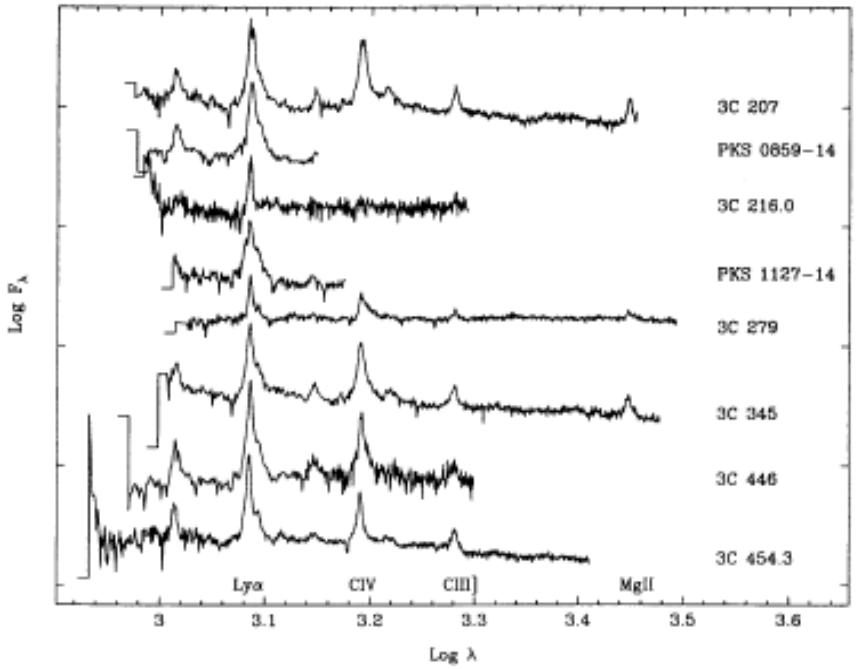


Poutanen & Stern (2010)

UV spectra of FSRQs

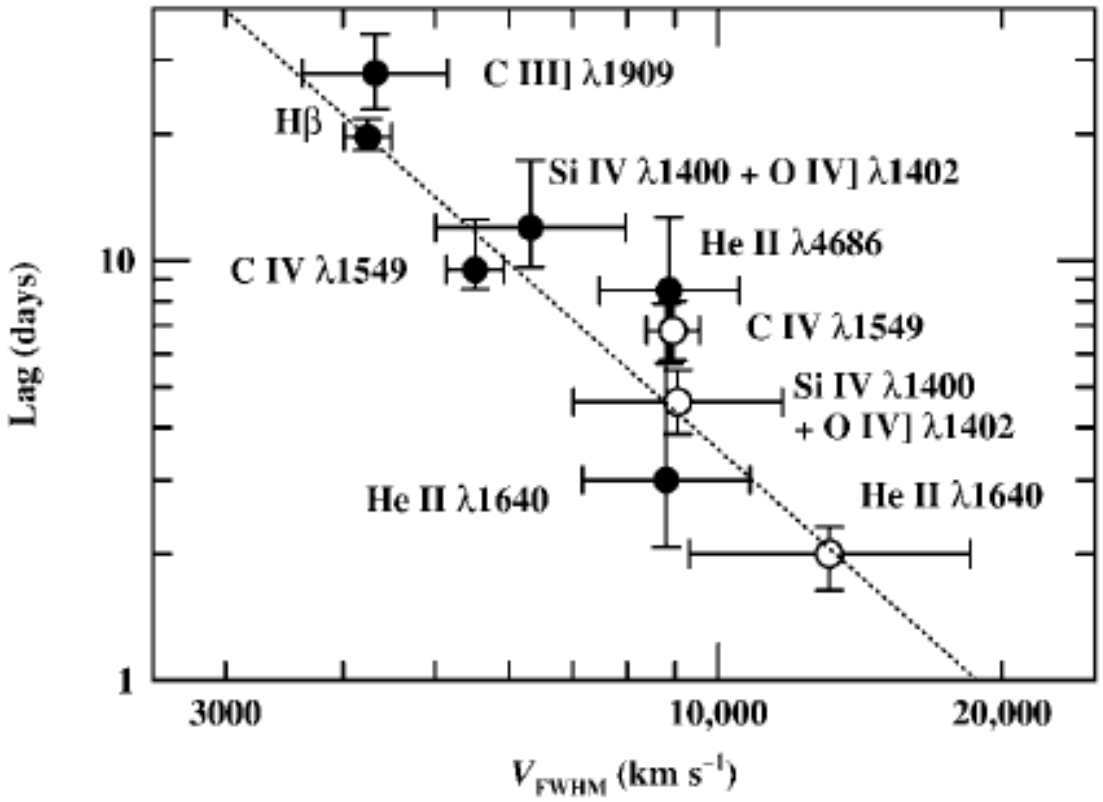


Composite blazar spectrum (Pian et al. 2005).



HST spectra of blazars (Wills et al. 1995).

The “size” of broad-line region

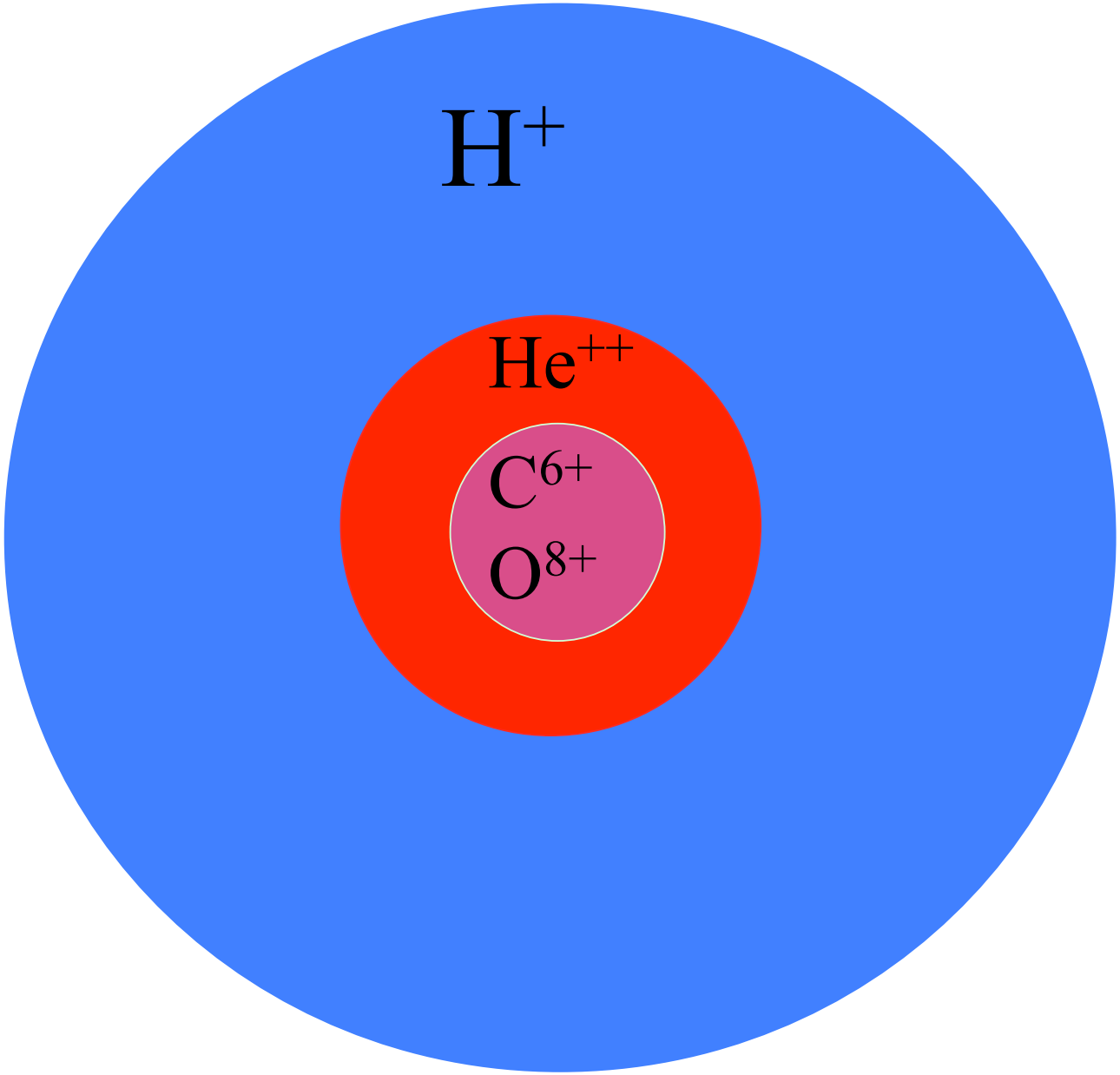


Reverberation in Sy 1 NGC 5548.

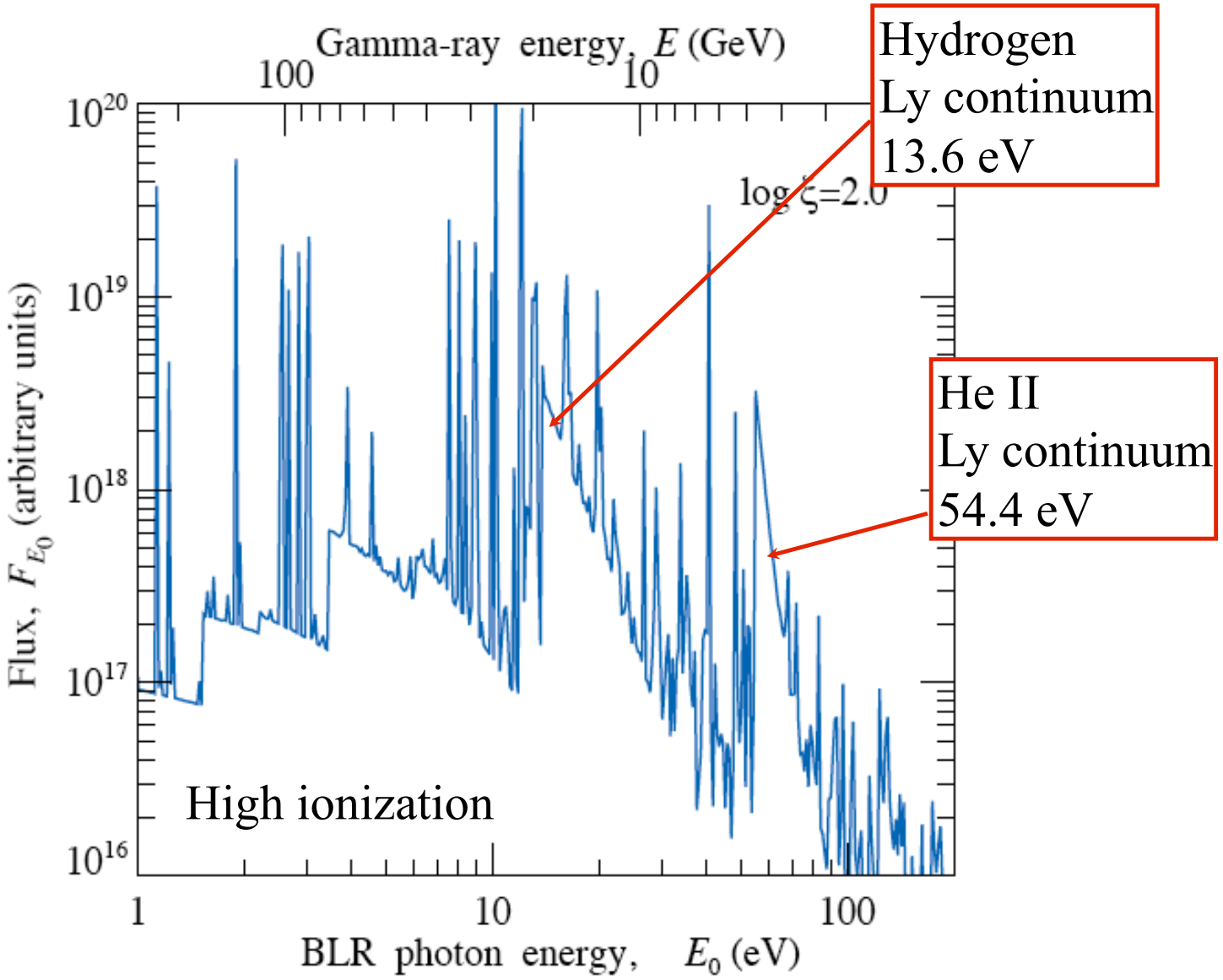
Peterson & Wandel (1999)

High-ionization lines (e.g. He II 1640) are produced 10 times closer than the Balmer lines and 5 times closer than C IV 1549.

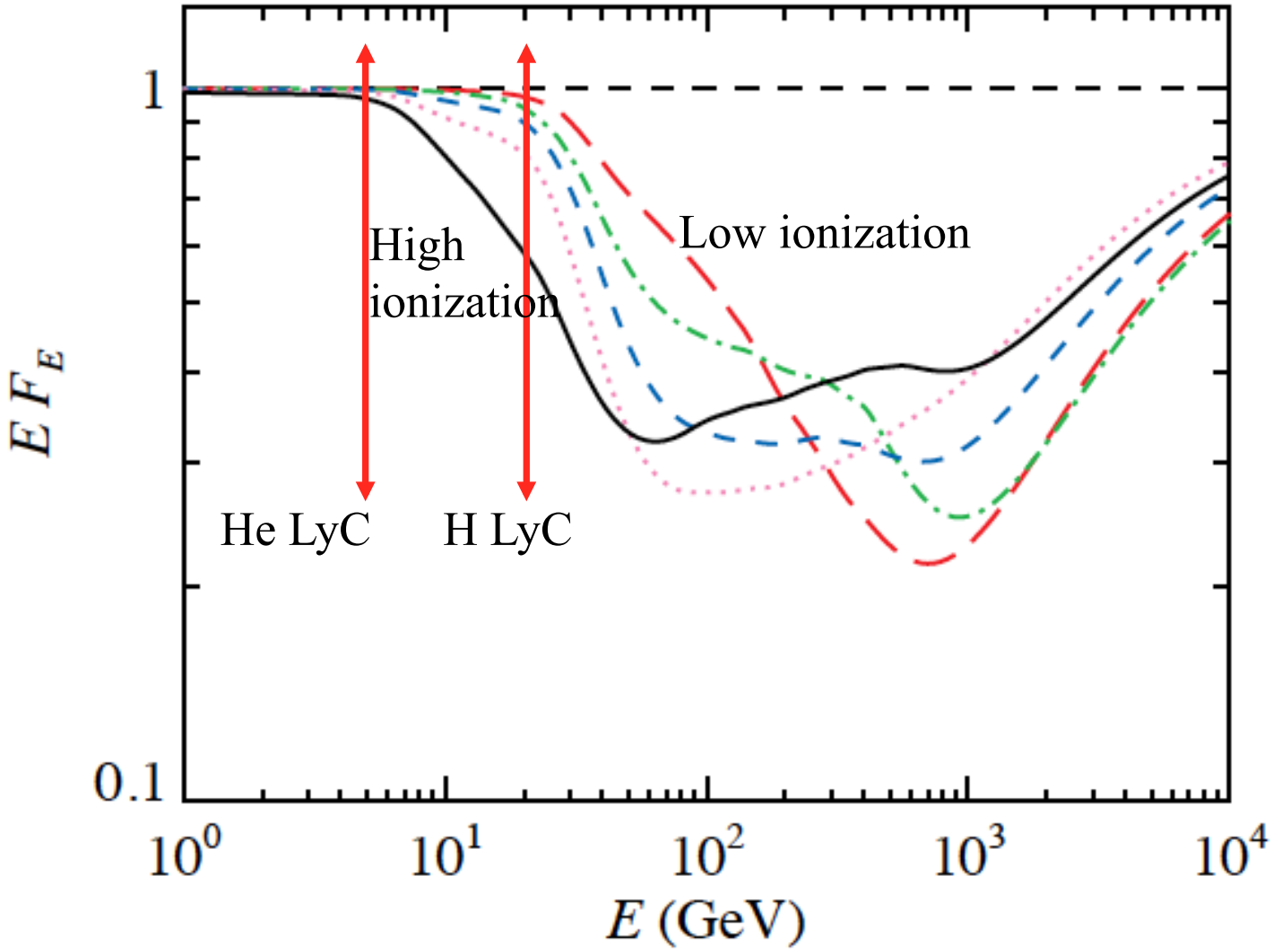
BLR structure



BLR spectra


Gamma-ray energy, E (GeV)
100
10
log ξ=2.0
Hydrogen
Ly continuum
13.6 eV
He II
Ly continuum
54.4 eV
High ionization
Flux, F_{E_0} (arbitrary units)
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
1
10
100
BLR photon energy, E_0 (eV)

Spectra transmitted through BLR



Pass 7 Fermi blazar spectra

The Brightest GeV Blazars

Object	Group[a]	Redshift
3C 454.3		0.859
4C +55.17	1, 2	0.896
PKS 0537−441	1, 2	0.892
PKS 2326−502	1	0.518
4C +21.35 (PKS 1222+21)	1, 2	0.433
PKS B1424−418	1, 2	1.522
PKS 0426−380	1, 2	1.111
PKS 0454−234	1, 2	1.003
PKS 0727−11	1	1.591
PKS 1510−08	1, 2	0.360
3C 279	1	0.536
PKS 1502+106	1, 2	1.893
B2 1520+31	1	1.484
PKS 0235+164	1	0.940
4C +38.41	1	1.813
BL Lacs		
Mrk 421	3	0.030
3C 66A	3	0.444
S5 0716+714	3	0.310
PKS 2155−304	3	0.117

Group 1: brightest above 1 GeV

Group 2: brightest above 5 GeV

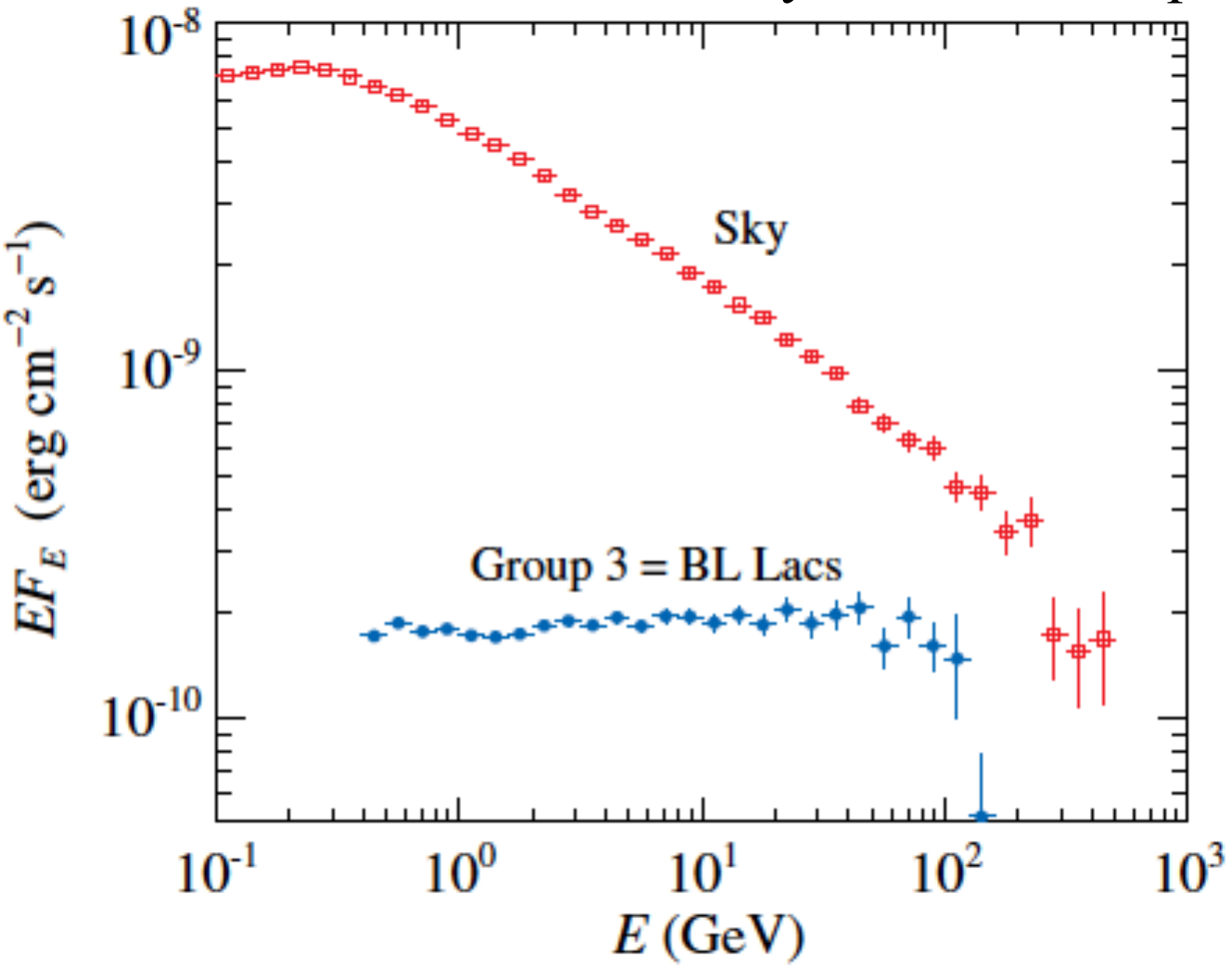
No source confusion.

Known redshift.

Stern & JP (2014)

Tests

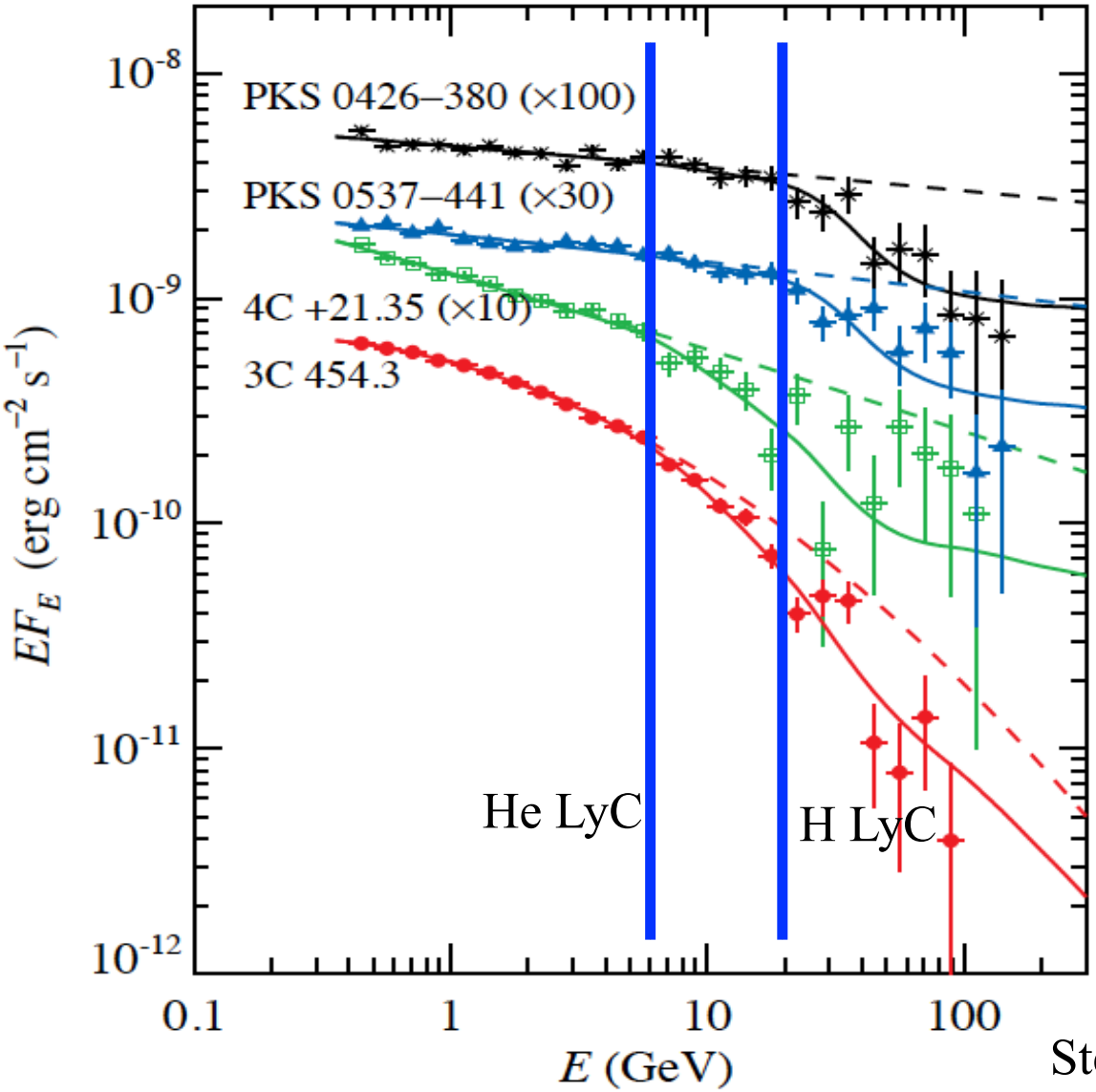
No breaks in the sky or BL Lacs' spectra



Stern & JP (2014)

Spectra of individual blazars

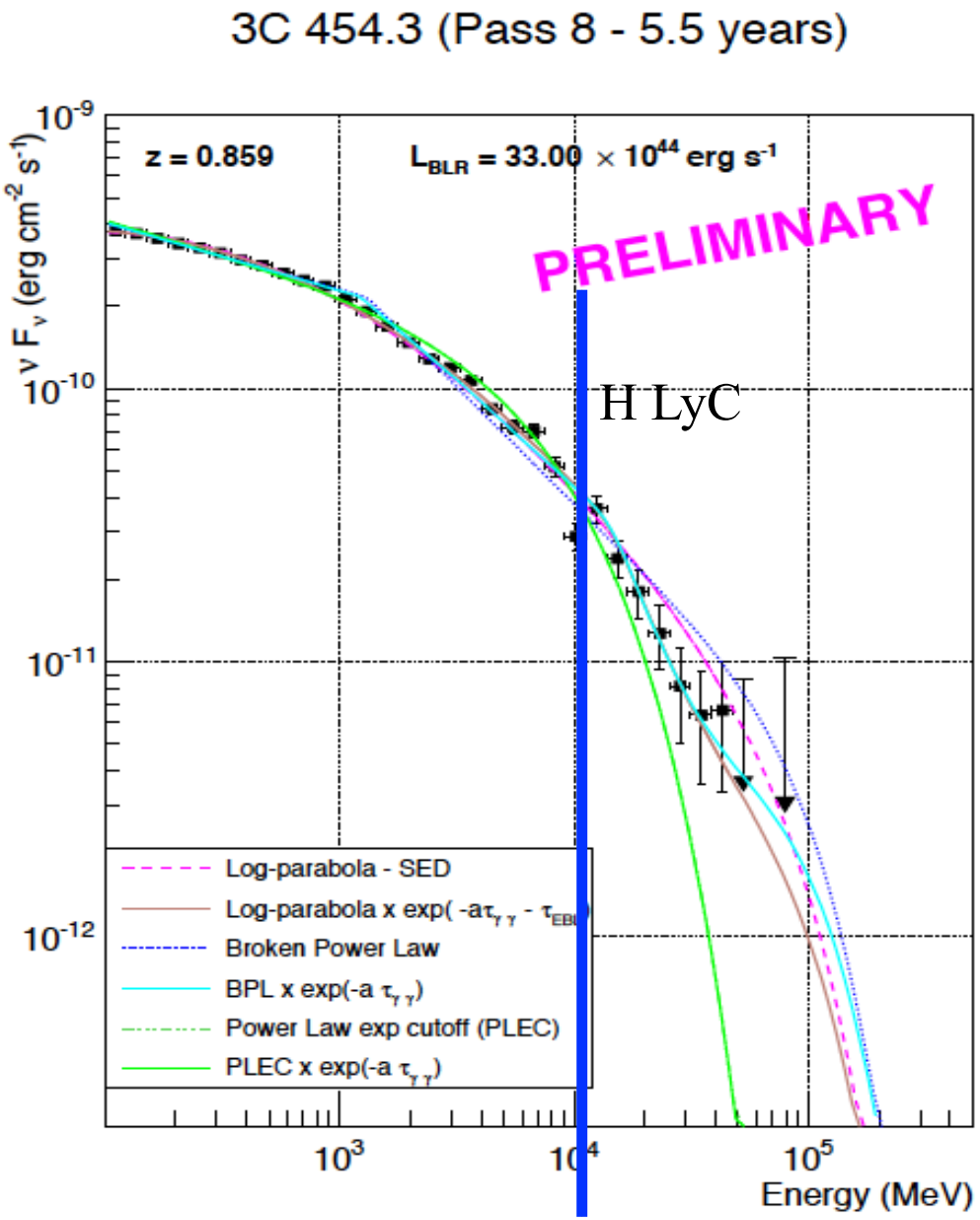
H LyC breaks are ubiquitous;
He II LyC breaks are visible in a couple of sources.



Pass7 spectra

Stern & JP (2014)

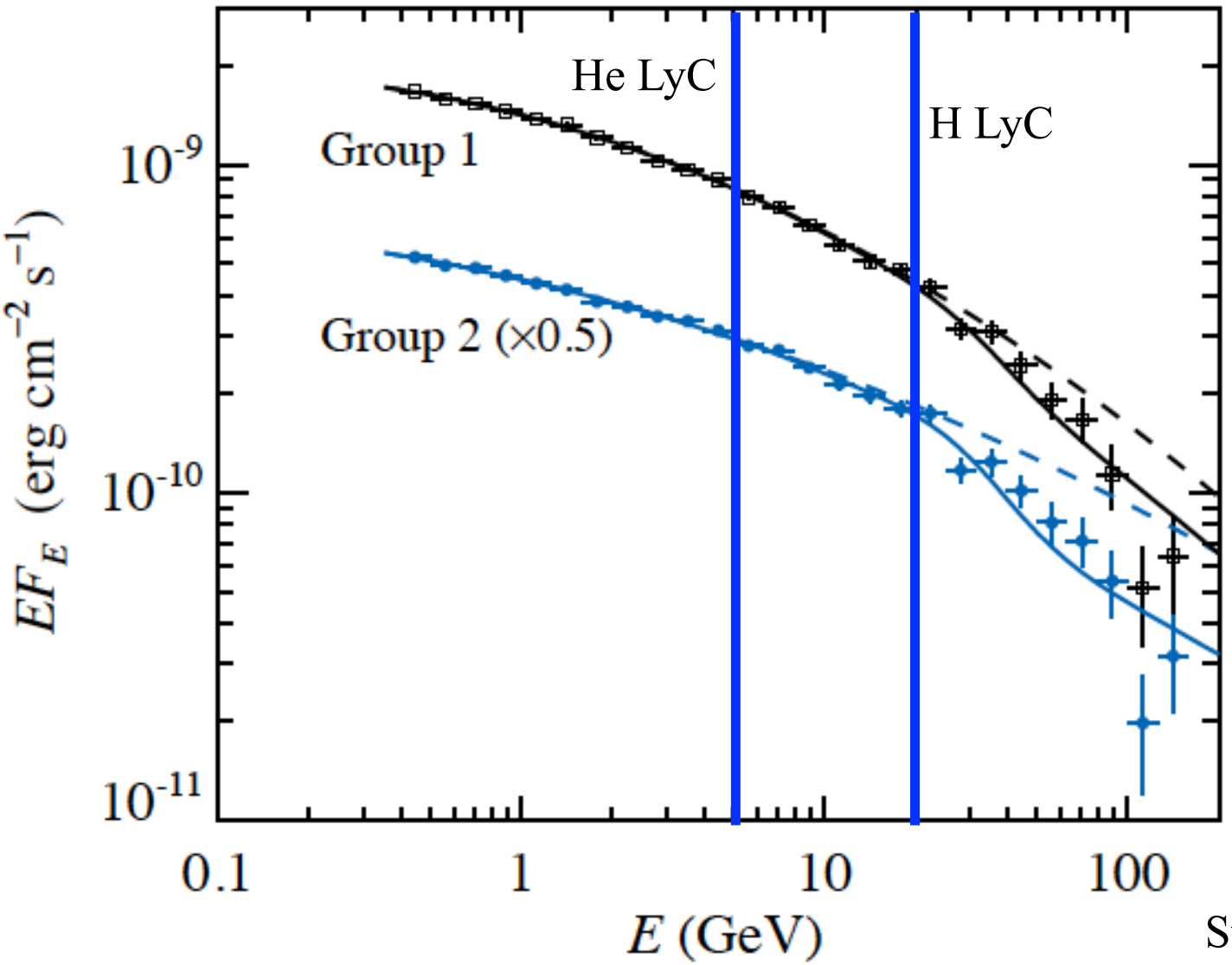
Spectra of individual blazars



Consistent with the results of the Fermi team (Britto, Razzaque, Lott 2014) with pass 8.

Spectra of individual sources are too noisy. We need to combine the spectra from many sources.

Stacked, redshift-corrected blazar spectra



$\tau_{\gamma\gamma} \approx 1$

Stern & JP (2014)

Significance of GeV breaks

Object	lognorm	lognorm+log $\xi = 2.5$[d]		lognorm+log $\xi = 1.5$[c]		Significance[h]
	χ^2/dof[e]	χ^2/dof[e]	τ_T	χ^2/dof[e]	τ_T	
3C 454.3	55.0/21	25.8/19	8.8 ± 1.7	29.6/20	14.0 ± 4.2	5.5σ
PKS B1424−418	23.0/23	23.8/20	<4.2	18.0/20	6.1 ± 2.9	...
PKS 0426−380	42.3/23	36.4/22	6.3 ± 2.6	22.9/22	9.6 ± 1.7	4.5σ
PKS 1502+106	30.5/21	30.2/20	1.5 ± 1.3	21.1/20	9.0 ± 3.3	3σ
PKS 0537−441	46.0/23	40.6/22	5.5 ± 2.6	29.3/22	9.1 ± 1.5	4σ
PKS 0454−234	35.7/23	34.1/22	4.2 ± 3.4	28.2/22	10.6 ± 4.5	2.5σ
4C +21.35	35.7/22	23.8/21	11.2 ± 2.5	33.4/21	25^{+14}_{-21}	3.5σ
PKS 1510−08	20.0/21	20.0/20	<0.9	20.0/20	<1.4	...
4C +55.17	66.0/21	58.0/20	5.6 ± 1.2	57.0/20	7.9 ± 2.7	...
Group 1	44.0/23	44.0/22	<1.2	30.2/22	3.4 ± 1.0	3.5σ
Group 2	65.6/23	52.9/22	2.9 ± 1.2	31.6/22	6.2 ± 1.1	6σ
Group 3 (BL Lacs)	35.4/22	...	...	...	...	...

Location within the BLR

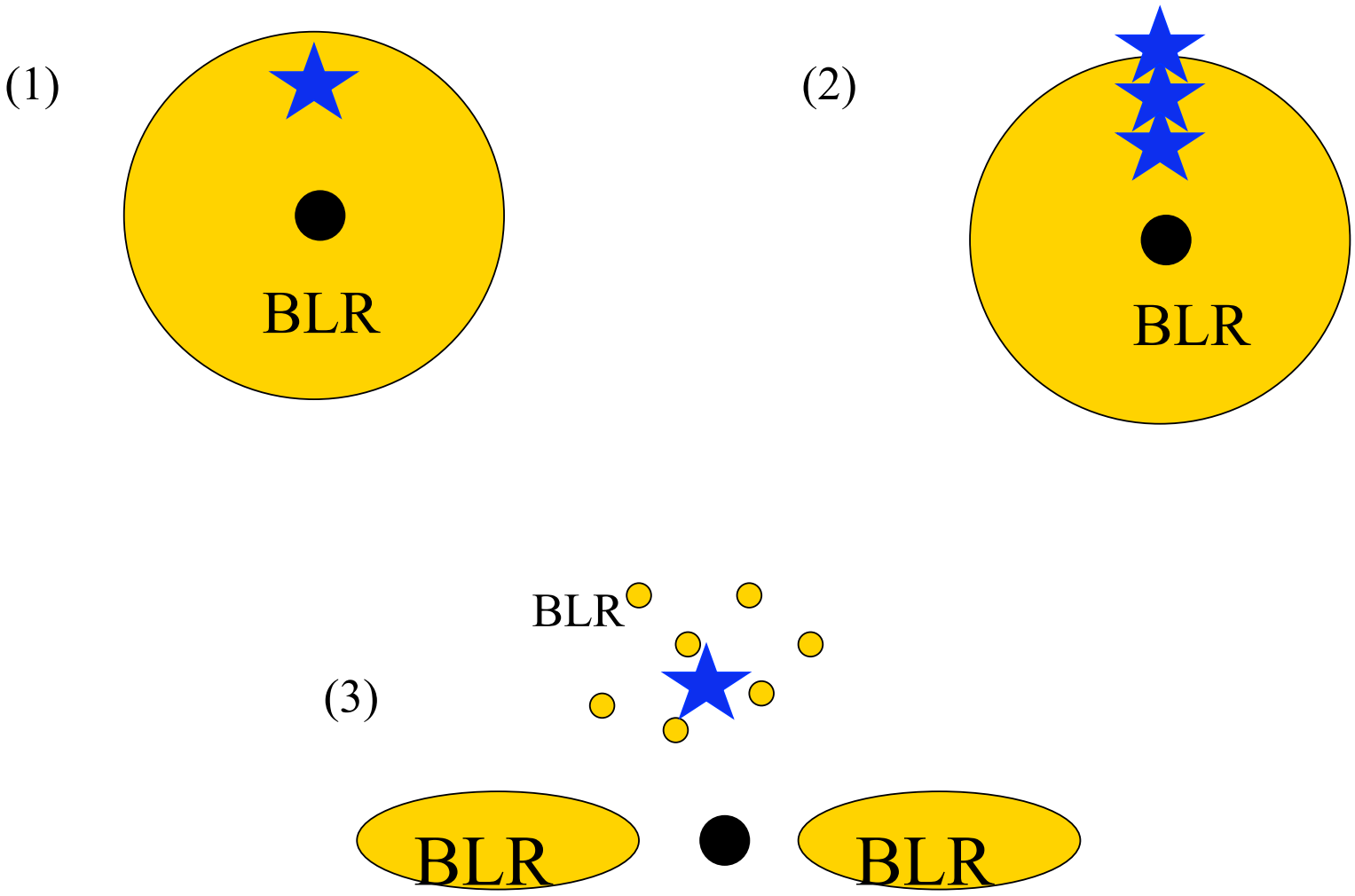
The optical depth for pair production on line photons:

$$\tau_T = N_{ph}\sigma_T = \frac{L}{4\pi R^2 c}\frac{1}{E_{\rm line}}\Delta R\sigma_T = 35\frac{L_{45}}{R_{pc}}\frac{10{\rm eV}}{E_{\rm line}}\frac{\Delta R}{R}$$

$$\left.\begin{array}{l}\tau_{\gamma\gamma}\approx 1 \Rightarrow \tau_T = \tau_{\gamma\gamma}\dfrac{\sigma_T}{\sigma_{\gamma\gamma}}\approx 5 \\ L_{Ly\alpha,45}=1 \Rightarrow L_{\rm Ly\ cont,45}\approx 1\end{array}\right\} \Rightarrow \frac{\Delta R}{R} = \frac{\tau_T}{35}\frac{R_{pc}}{L_{45}}\frac{E_{\rm line}}{10{\rm eV}} < \frac{1}{7}$$

1. Gamma-rays are produced on the outskirts of BLR, or
2. The gamma-ray emitting region is extended, with some multi-GeV photons produced outside BLR, or
3. The BLR is flat and the photon density along the jet is much smaller.

Possible geometries



Conclusions

- GeV breaks observed in FSRQs are very stable and are situated at the same energy in all sources.

- Only two sources show HeII LyC breaks, but most of bright blazars show breaks associated with absorption by H I LyC (as seen in the stacked spectra).

- Gamma-ray emitting region is probably extended, but some gamma-rays are produced within the BLR. The BLR might be flattened.