GeV breaks in blazars as a result of gamma-ray absorption within the broad line region

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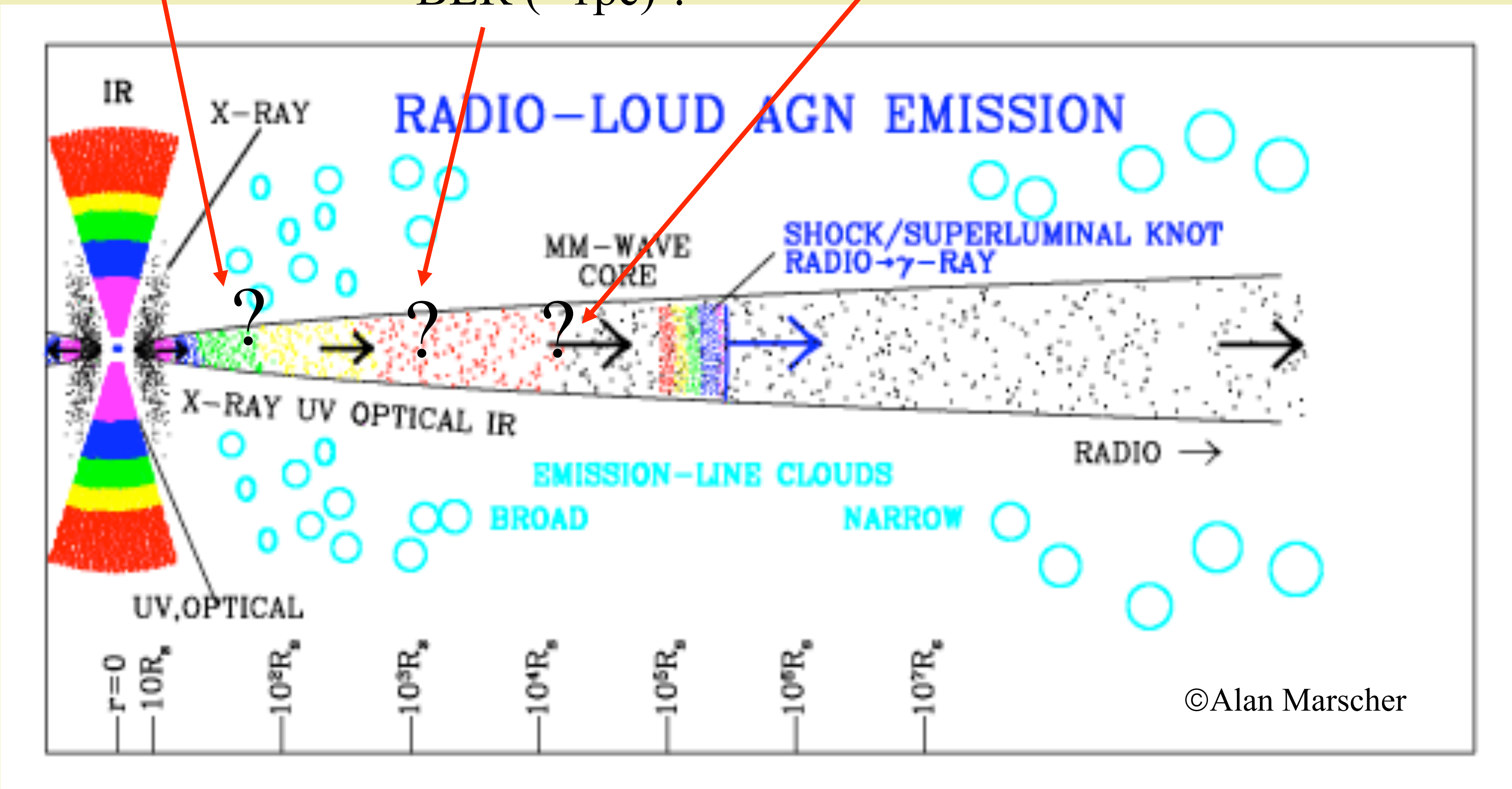
Poutanen, Stern, 2010, ApJ Letters, 717, L118

Where lies the gamma-ray emitting region?

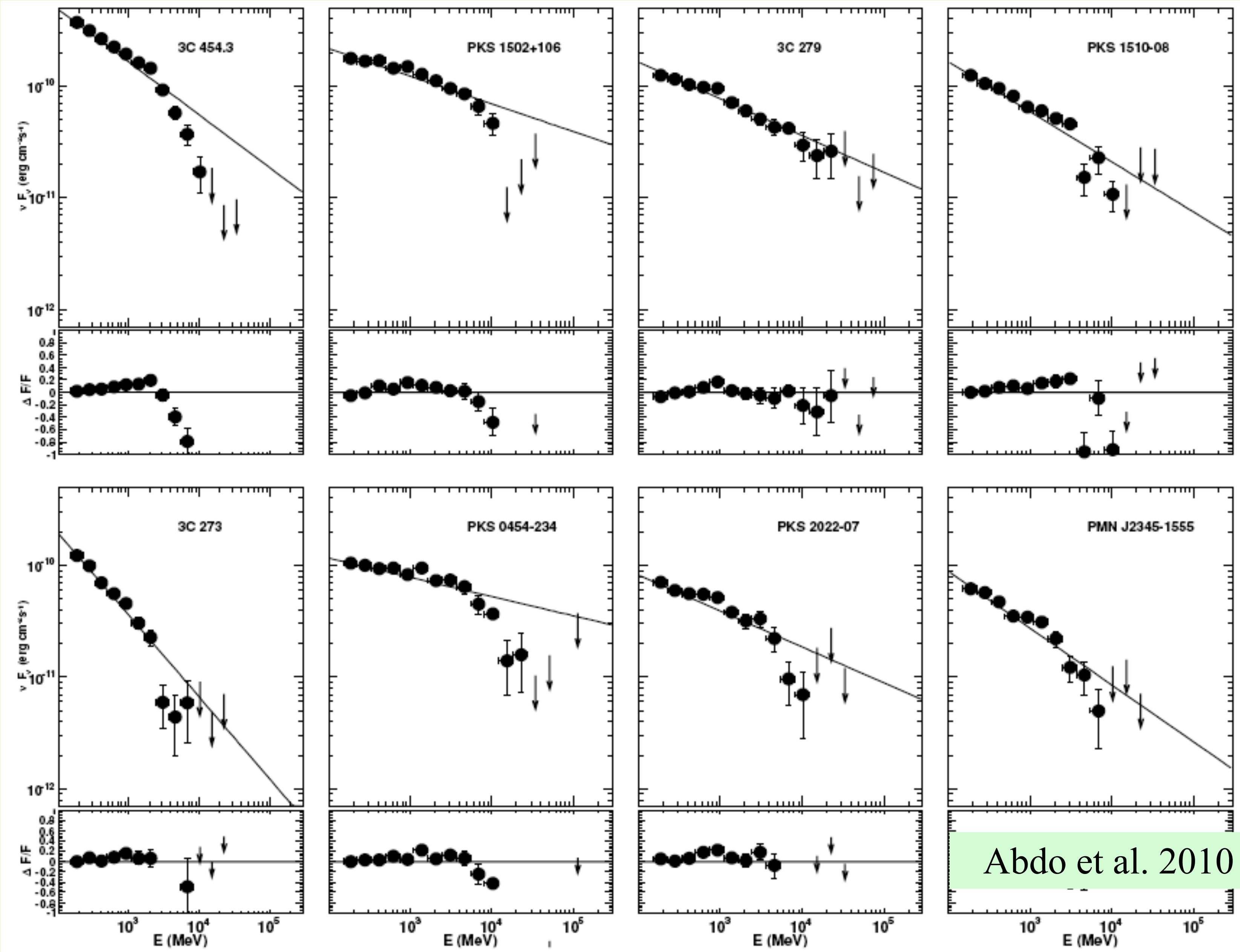
Close to accretion disk?

BLR (<1pc) ?

Dusty torus (10 pc)?

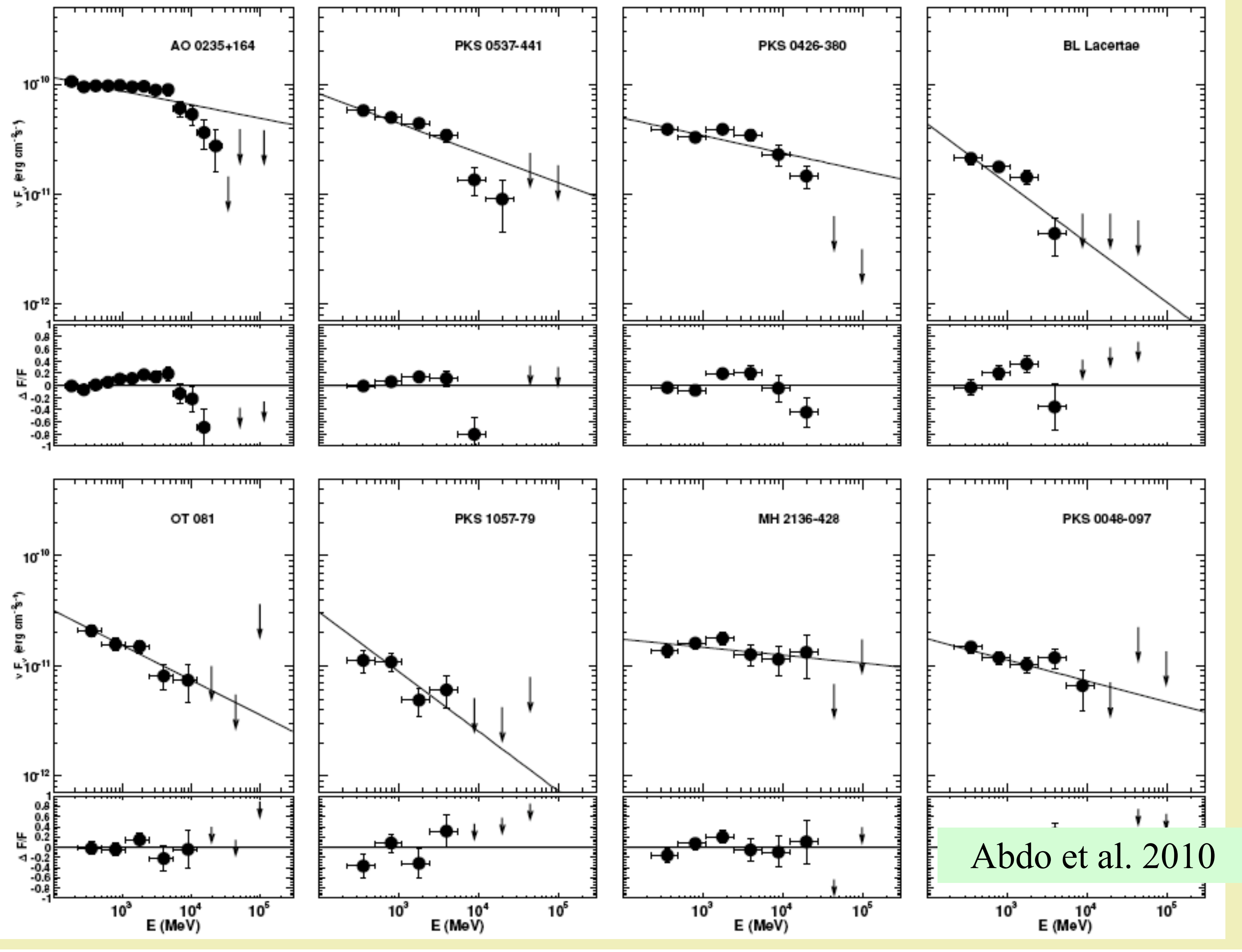


Fermi spectra of FSRQ



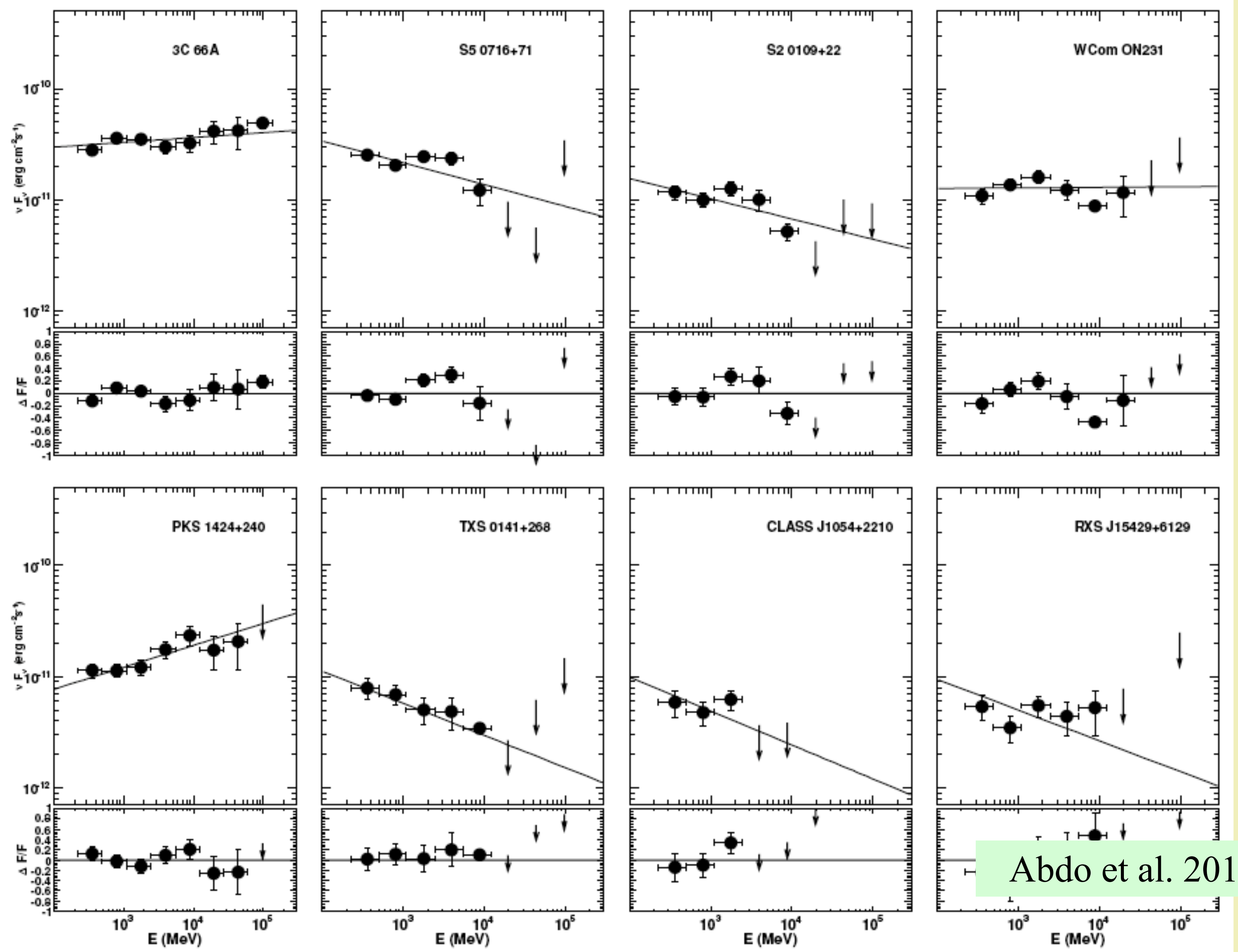
Abdo et al. 2010

Fermi spectra of LSP BL Lacs



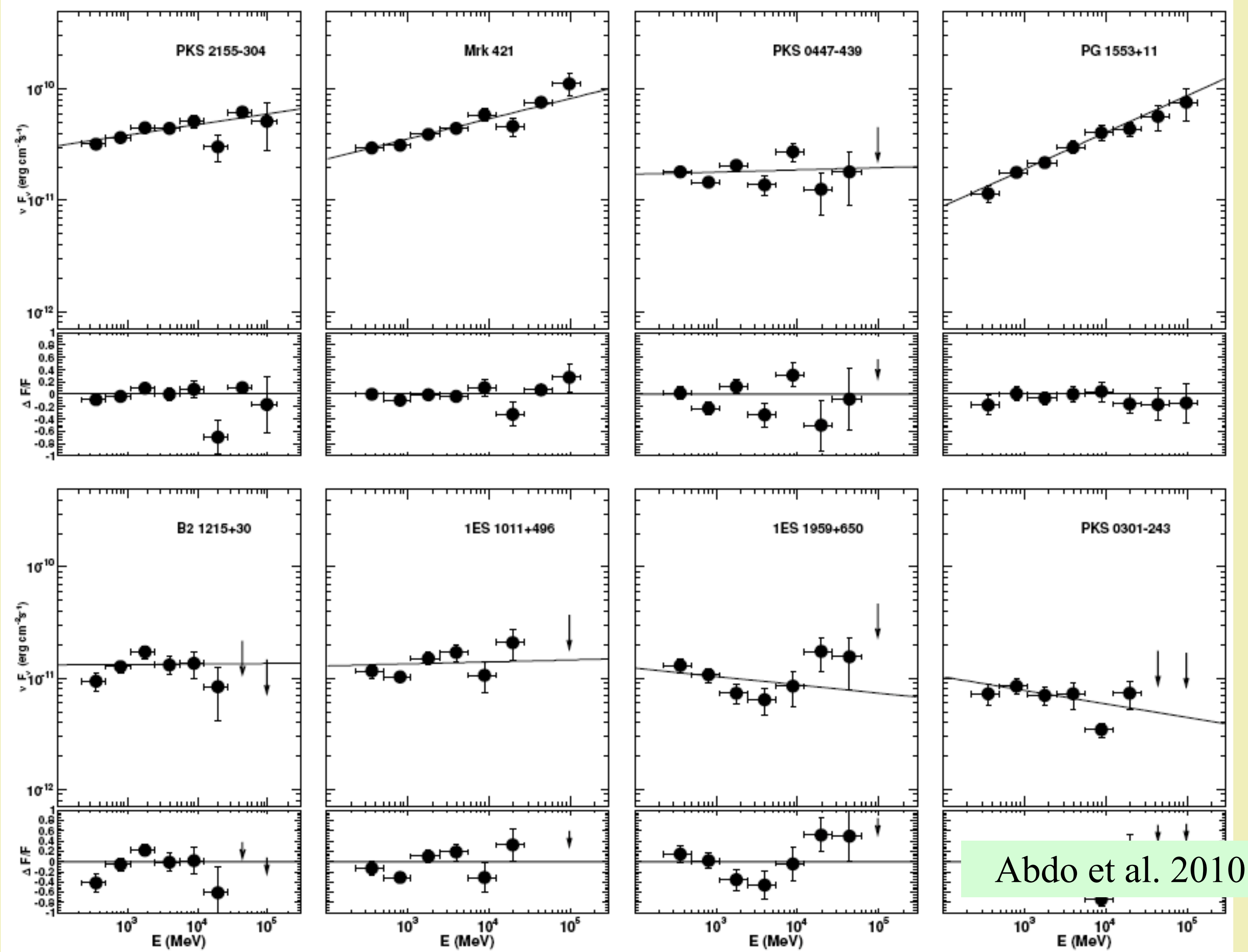
Abdo et al. 2010

Fermi spectra of ISP BL Lacs



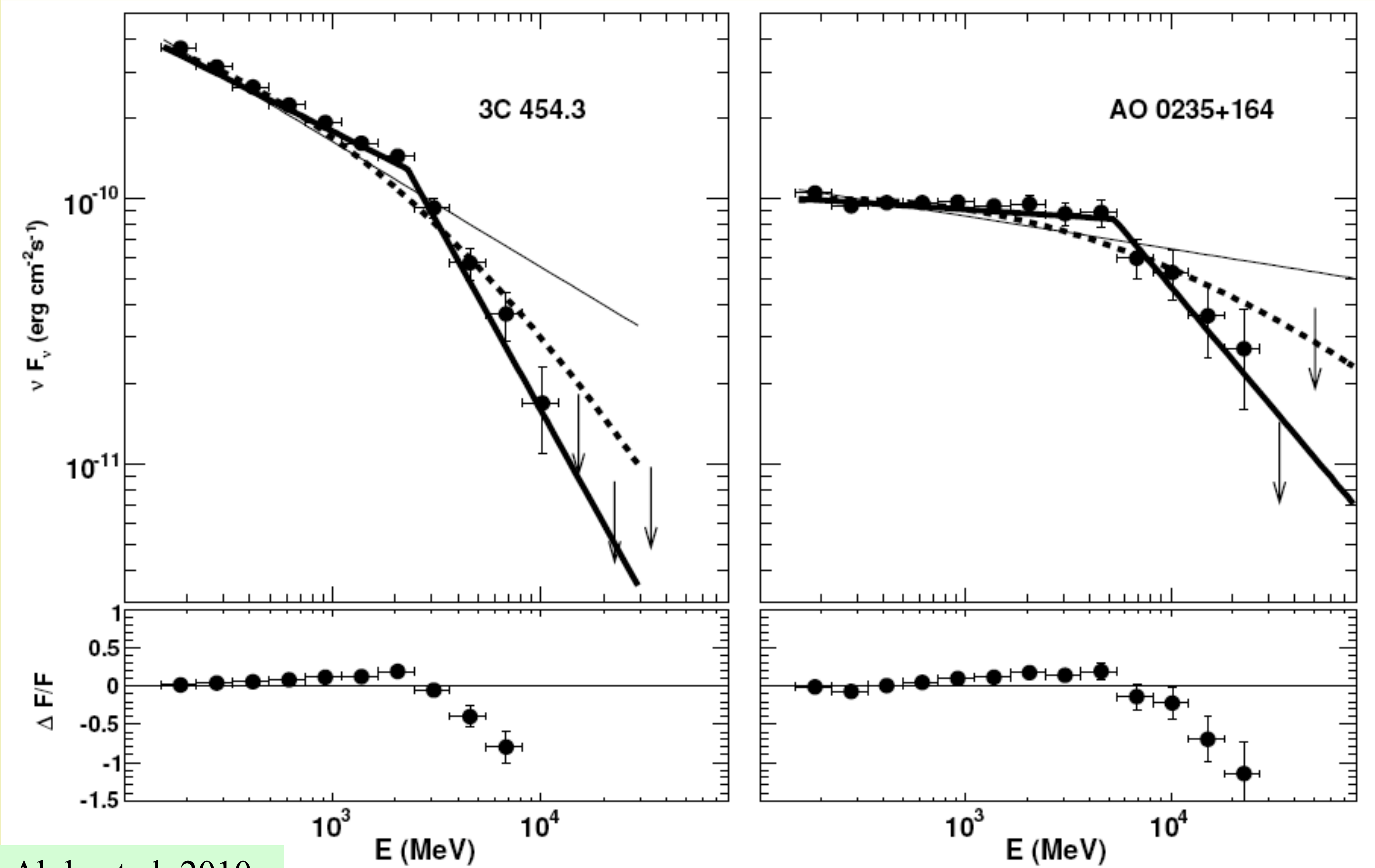
Abdo et al. 2010

Fermi spectra of HSP BL Lacs



Abdo et al. 2010

GeV breaks



Abdo et al. 2010

Stratified broad line region

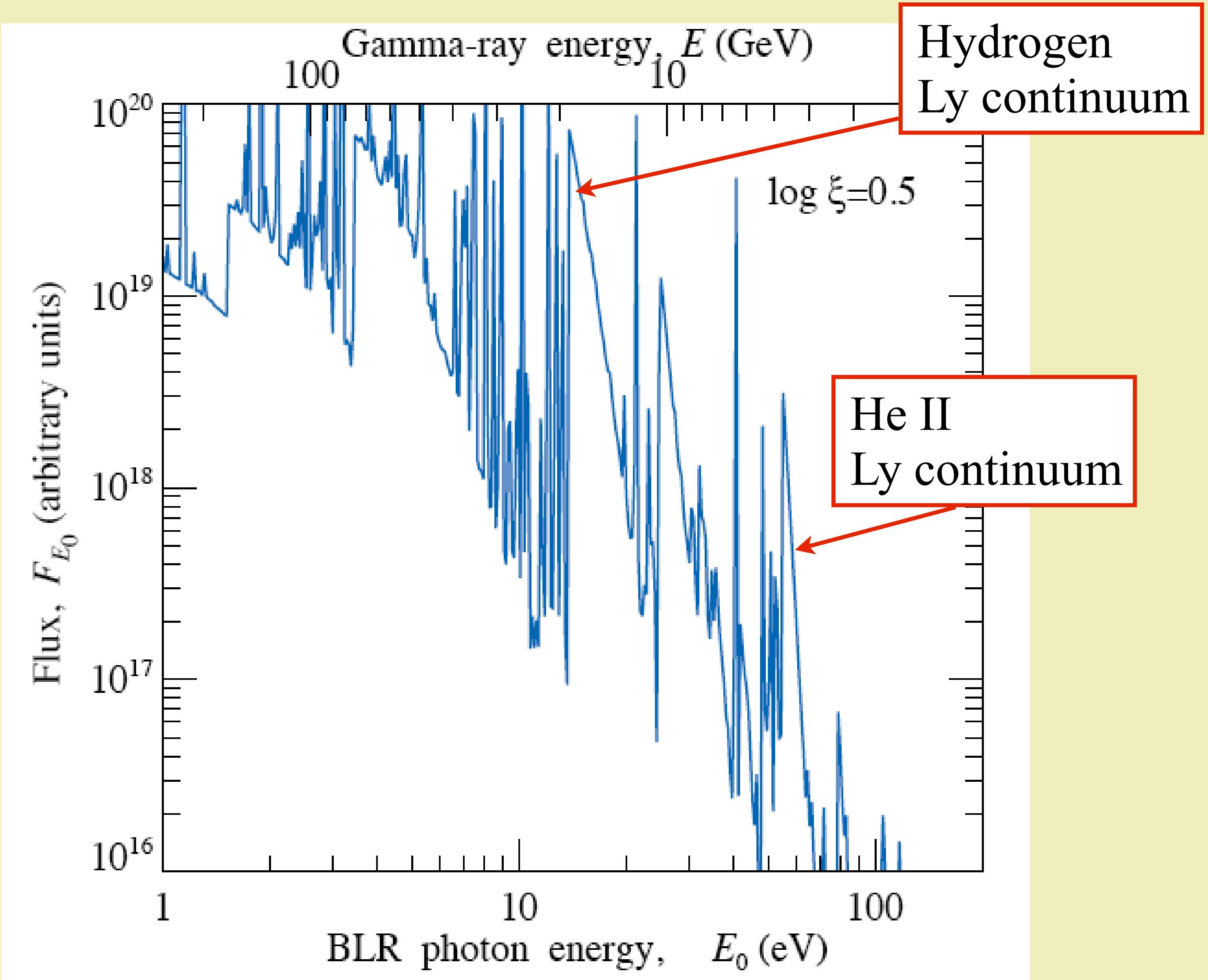
The size of BLR determined from reverberation mapping depends on the line:
The size determined from C IV 1549 (Kaspi et al. 2007)

$$R_{\mathrm{C\,IV},18} \approx 0.4 L_{47}^{1/2}$$

Balmer lines give sizes 2-3 times larger.
He II 1640, N V 1240 give size 2-3 times smaller.

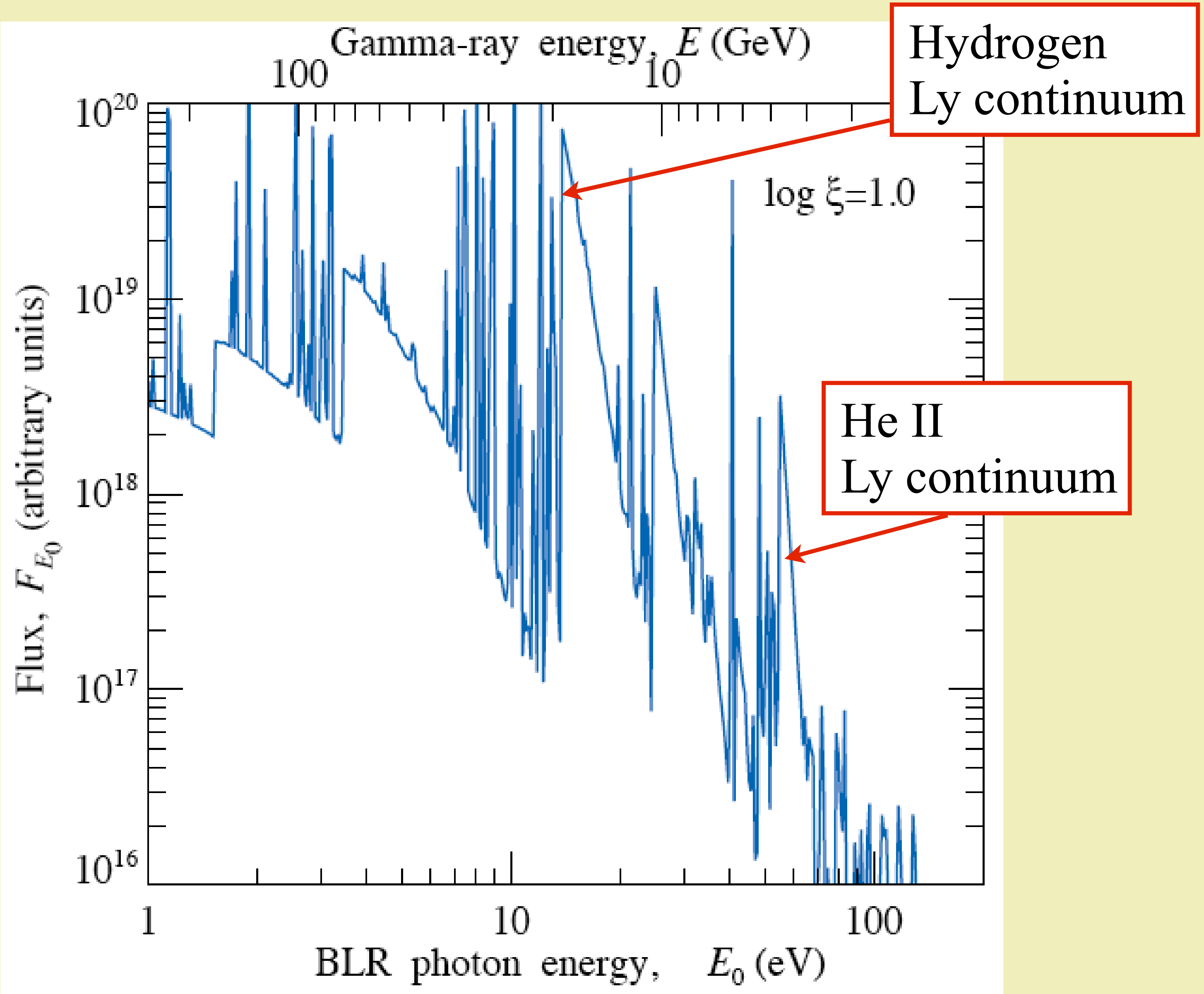
Assume density profile $n(r) \propto 1/r$
Ionization parameter is then $\xi = L/(r^2 n) \propto r^{-1}$
This is broadly consistent with constraints on BLR structure from reverberation (Kaspi & Netzer 1999).
Photo-ionization is computed by xstar 2.2 (Kallman & Bautista 2001).

BLR spectra



Gamma-ray energy, E (GeV)
100
10
log ξ=0.5
Hydrogen Ly continuum
He II Ly continuum
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)

BLR spectra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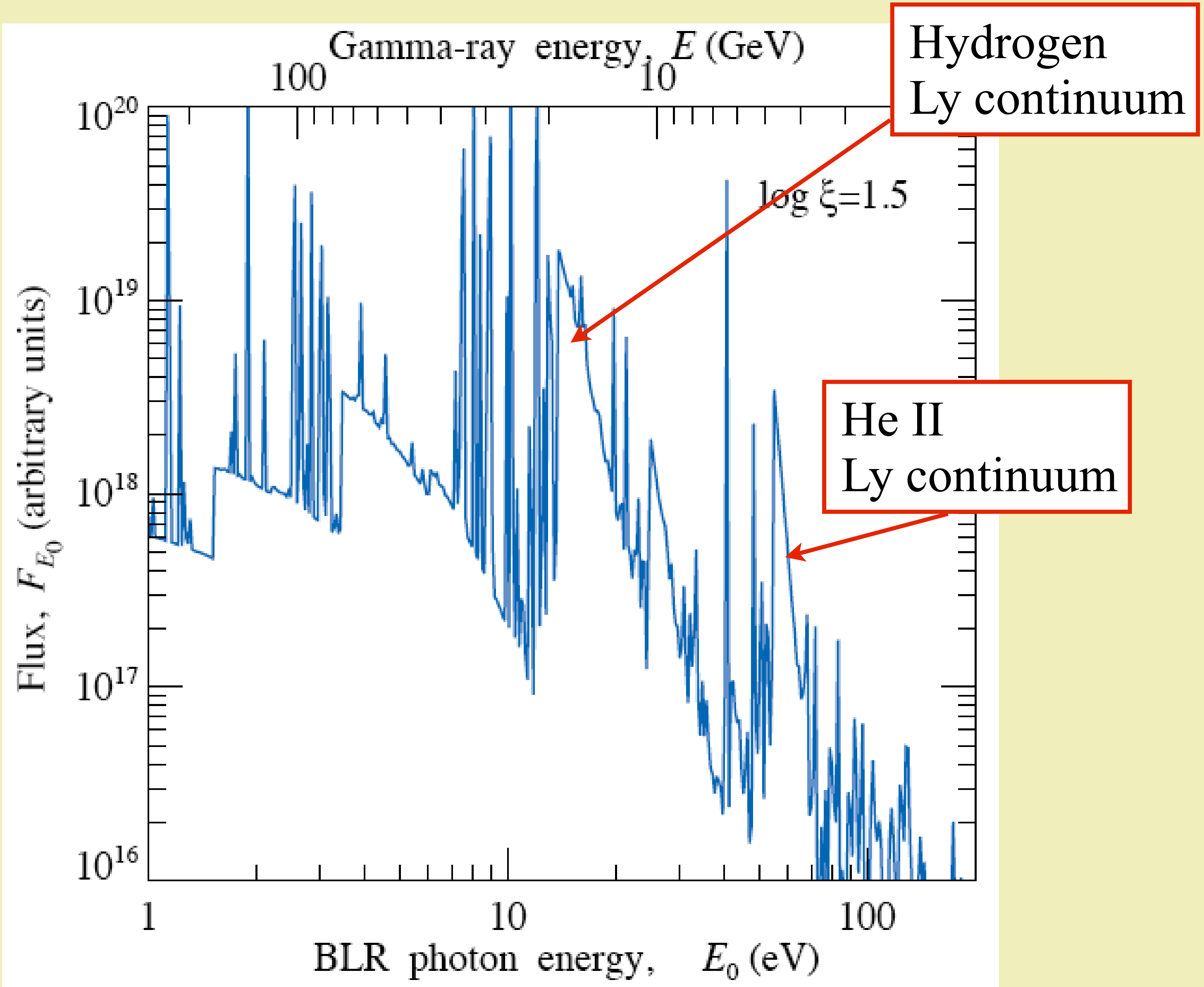
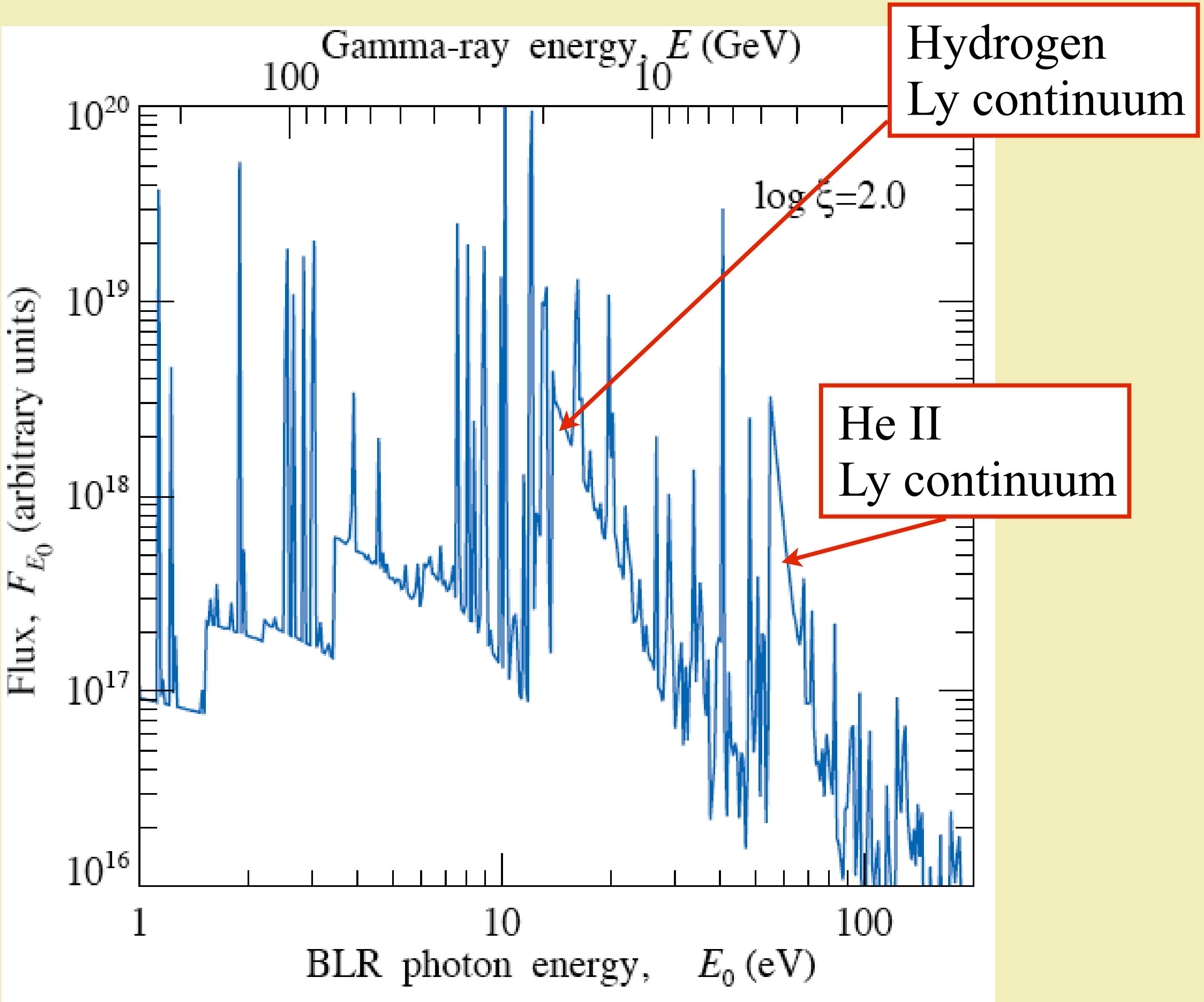
BLR spectra



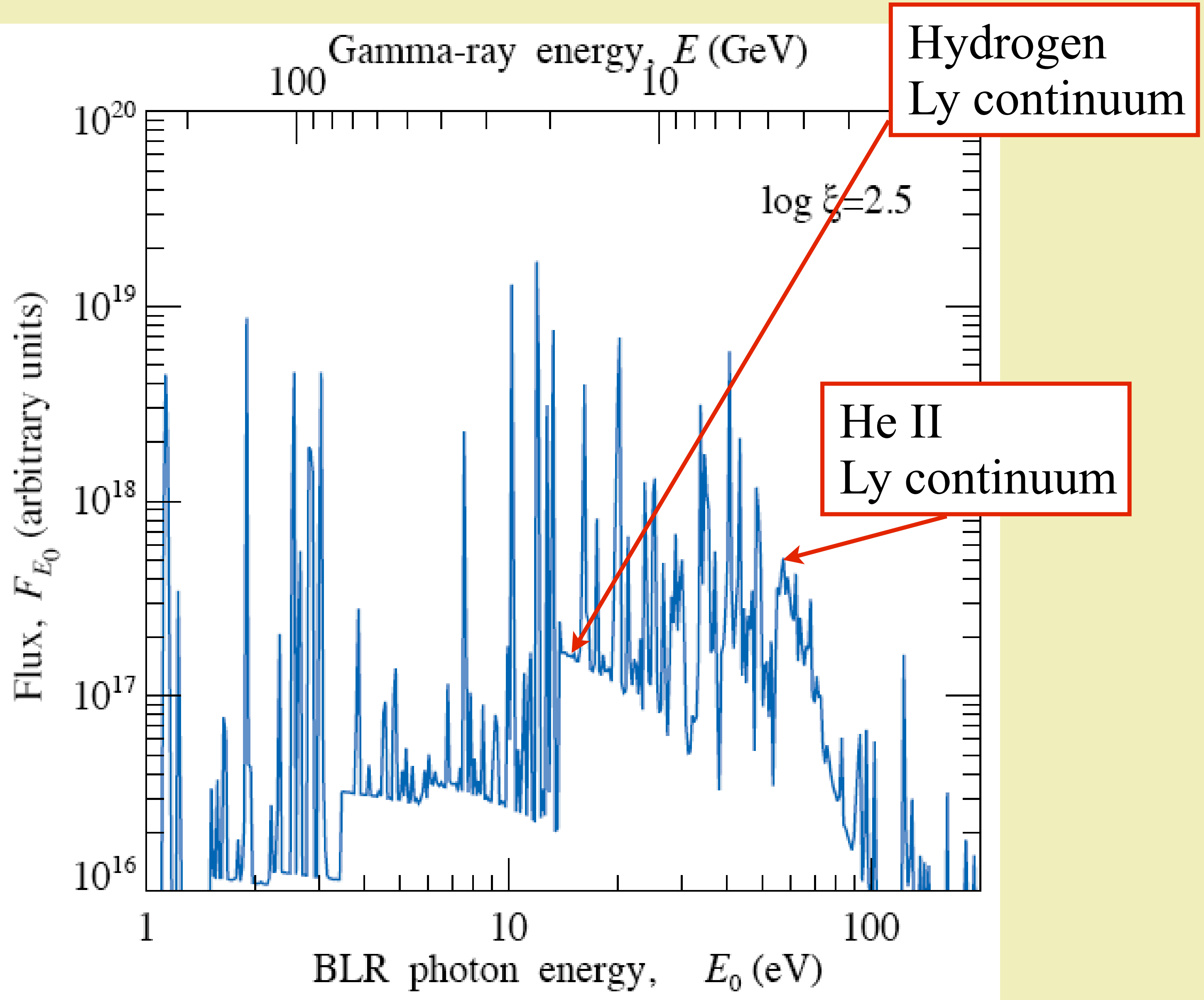
Gamma-ray energy, E (GeV)
100
10
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
Flux, F_{E_0} (arbitrary units)
log ξ=1.5
1
10
100
BLR photon energy, E_0 (eV)
Hydrogen
Ly continuum
He II
Ly continuum

BLR spectra



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

BLR spectra



Gamma-ray energy, E (GeV)
100
10
10^20
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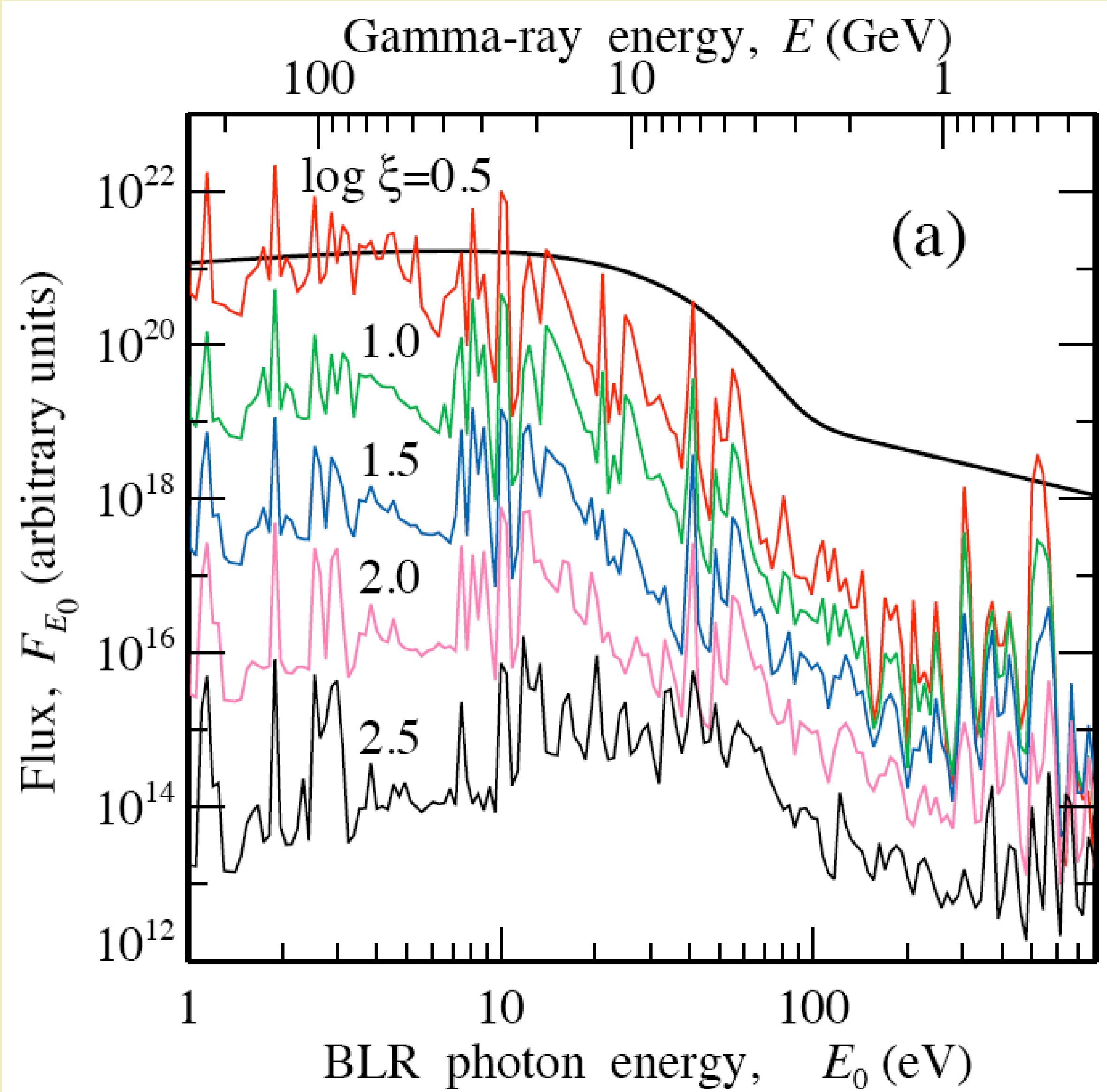
Flux, F_E0 (arbitrary units)
BLR photon energy, E0 (eV)
Hydrogen
Ly continuum
He II
Ly continuum

BLR spectra



BLR spectra for different ionization at 5% resolution to show strong features.

Estimates of opacities

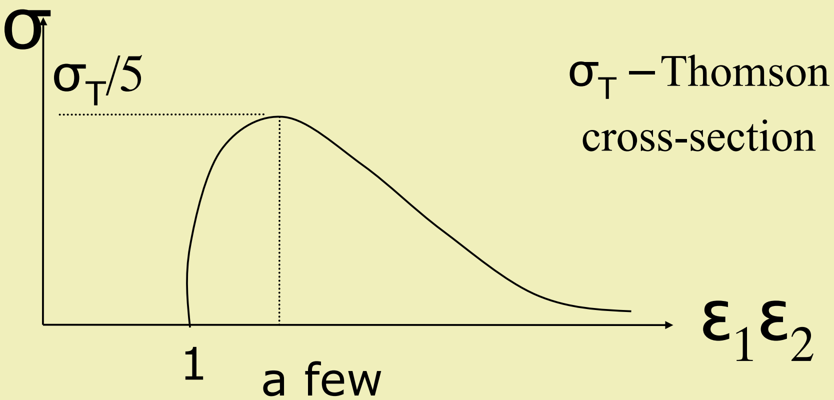
The optical depth for pair production on BLR photons is large in quasars.
For line photons:

$$\tau_T = N_{ph}\sigma_T = \frac{L\sigma_T}{4\pi R c E_0} = 110\frac{L_{45}}{R_{18}}\frac{10\ \mathrm{eV}}{E_0}$$

→ $\tau_T \propto L^{1/2}$

This suggests that absorption is large in FSRQ and weak in BL Lacs.

<u>Cross-section for pair production</u>

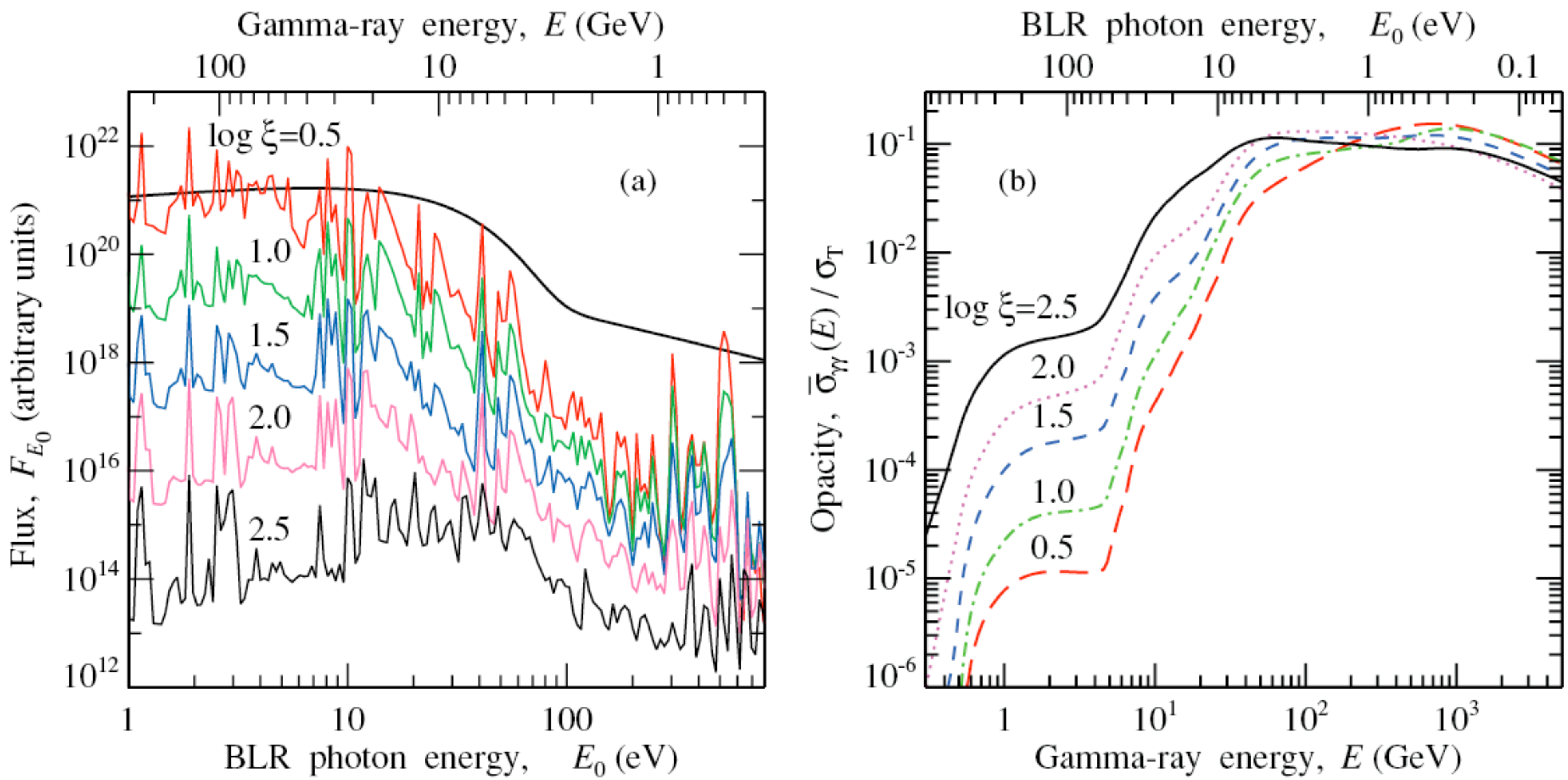


σ_T – Thomson cross-section

Photons at ε_1 start interacting with target photons just above threshold at $\varepsilon_2 = 1/\varepsilon_1$

Example:
H I Ly cont. 13.6 eV - 19.2 GeV
He II Ly cont. 54.4 eV - 4.8 GeV

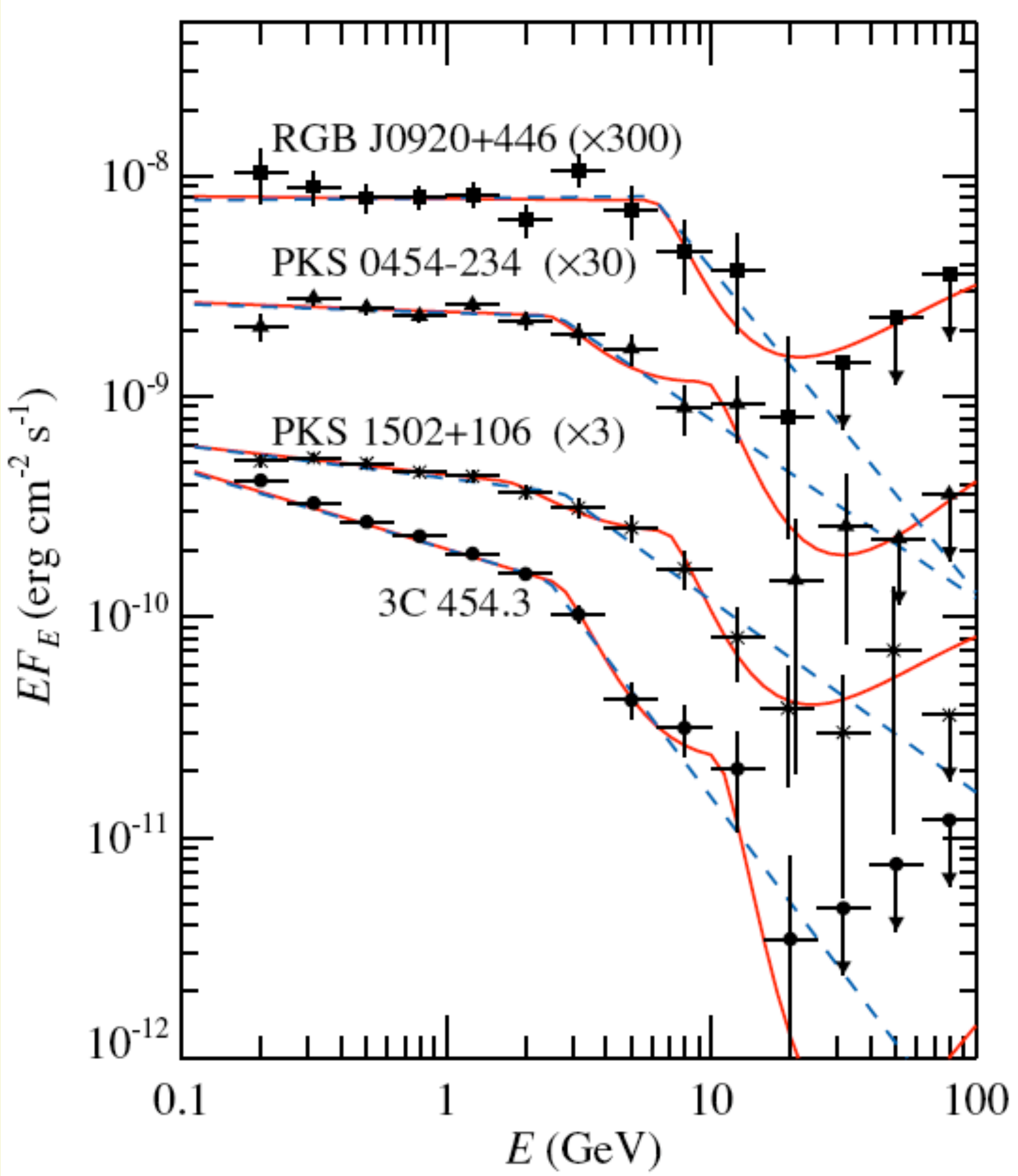
BLR and photon-photon pair production opacity



Photon-photon opacity through the BLR. It can be approximated by absorption on two "lines" of hydrogen and He II Ly continua at 13.6 and 54.4 eV.

GeV breaks in blazars

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



GeV breaks in blazars

Object	z	Power Law	Power Law + Double Absorber			
		χ^2	Γ	τ_{He}	τ_H	χ^2
3C 454.3	0.859	117	2.37 ± 0.02	6.1 ± 0.9	18.5^{+19}_{-7}	4.1
PKS 1502+106	1.839	55	2.13 ± 0.03	1.6 ± 0.6	8.4 ± 1.6	6.3
3C 279	0.536	18	2.28 ± 0.04	2.0 ± 1.1	4.5 ± 3.1	10.1
PKS 1510–08	0.36	13	2.45 ± 0.04	2.7 ± 1.5	$2.7^{+8}_{-2.7}$	8.1
3C 273	0.158	10	2.87 ± 0.05	$3.6^{+6}_{-3.6}$	$0^{+\infty}_{-0}$	7.8
PKS 0454–234	1.003	50	2.04 ± 0.04	3.0 ± 0.8	9.5 ± 2.7	13.7
PKS 2022–07	1.388	15	2.48 ± 0.06	$0.8^{+0.9}_{-0.8}$	$2.9^{+4.3}_{-1.8}$	12.9
TXS 1520+319	1.487	11	2.48 ± 0.74	1.7 ± 1.6	6.5^{+9}_{-5}	7.2
RGB J0920+446	2.19	21	2.01 ± 0.07	$0^{+0.5}_{-0}$	7.6 ± 2.9	11.9

The fits with powerlaw+double-absorber model are as good as with the broken powerlaw model (but more physical).

$$\tau_{He}/\tau_H \sim 1/4 \longrightarrow \log \xi > 2$$

For 3C 454.3, $L_d \approx 10^{47}$ erg/s, $R < 0.1$ pc

Conclusions

- GeV breaks are consistent with being produced by absorption on He II and H I recombination continua.
- The underlying continuum does not need to have a cutoff in the GeV range.
- The gamma-ray emitting region has to lie within the highest ionization zone of BLR at a distance <0.1 pc from the central black hole.
- Additional features in a sub-GeV range are expected due to soft X-ray lines of BLR.