Fermi observations of blazars: implications for gamma-ray production

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

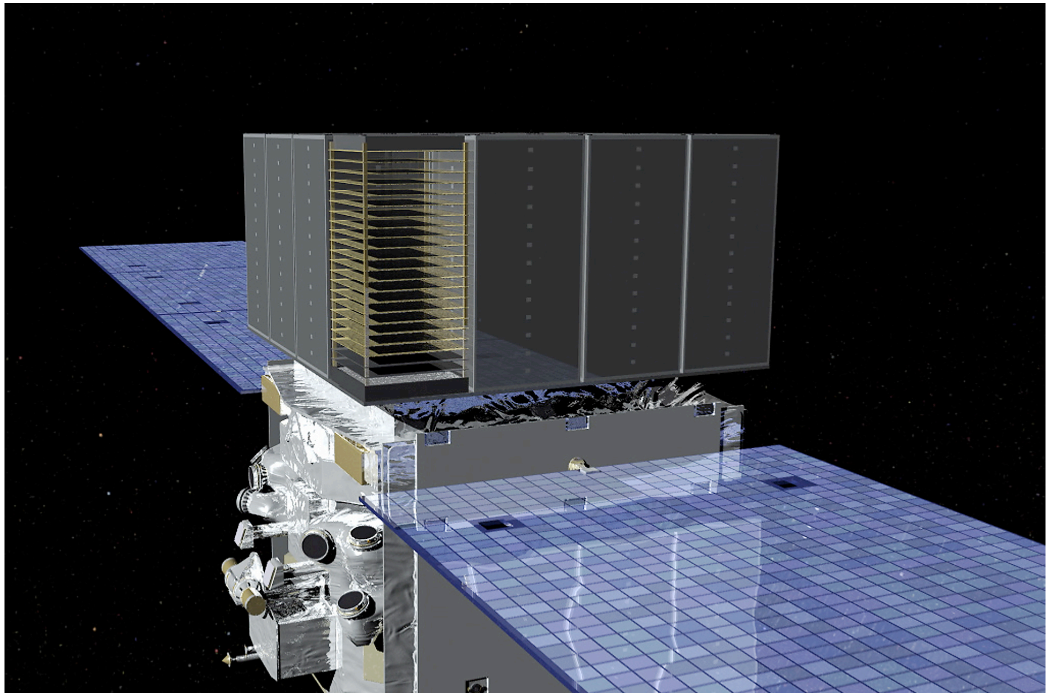
Stern & Poutanen (2011, MNRAS Letters, 417, L11)

Stern & Poutanen (2012, in preparation)

Plan

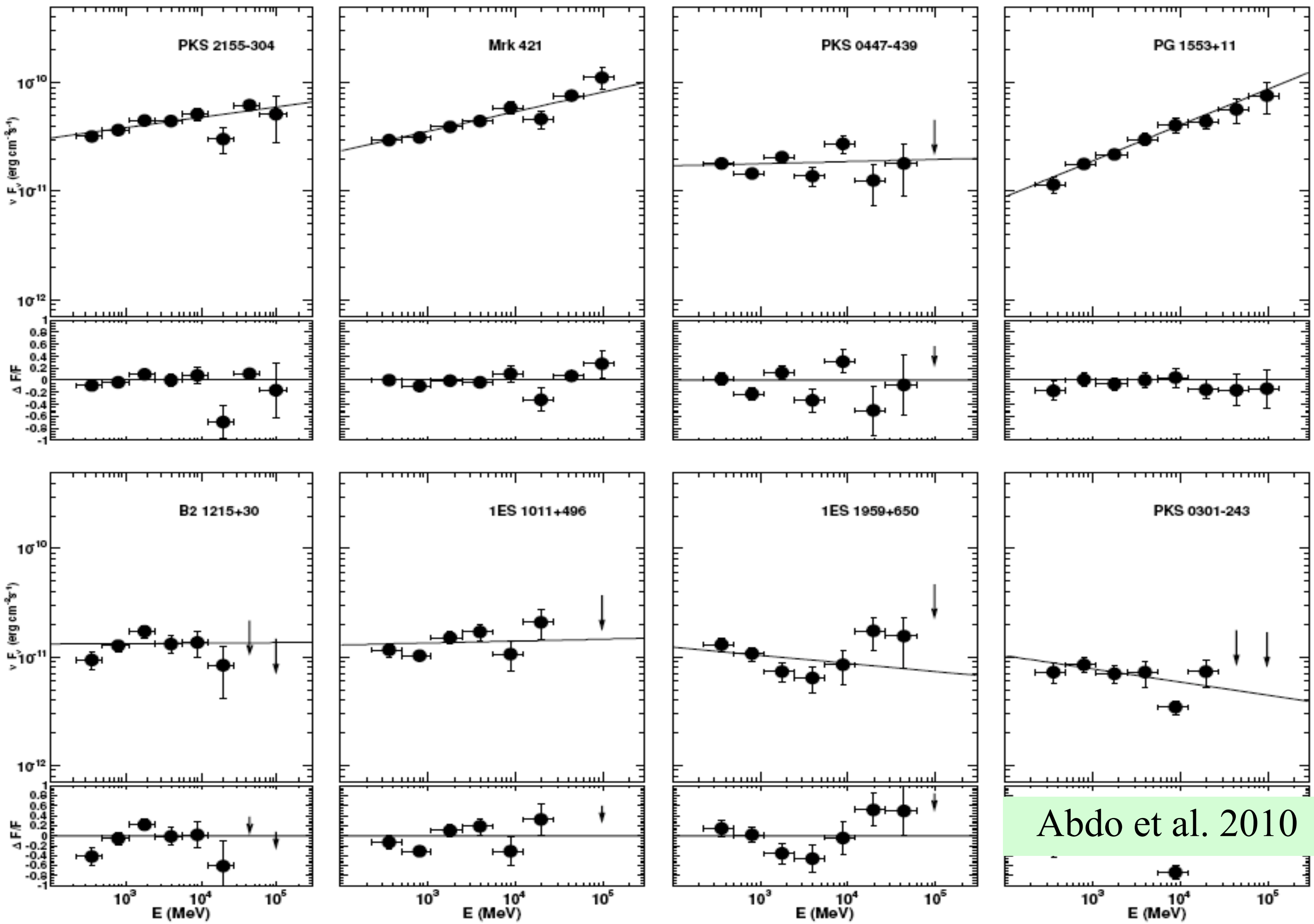
- Fermi LAT observations of blazars.
- GeV breaks produced by photon-photon absorption on BLR photons.
- What is the size of BLR?
- Alternative interpretations from the radio, optical, gamma-ray correlations.

Fermi Gamma-ray Space Telescope: a revolution



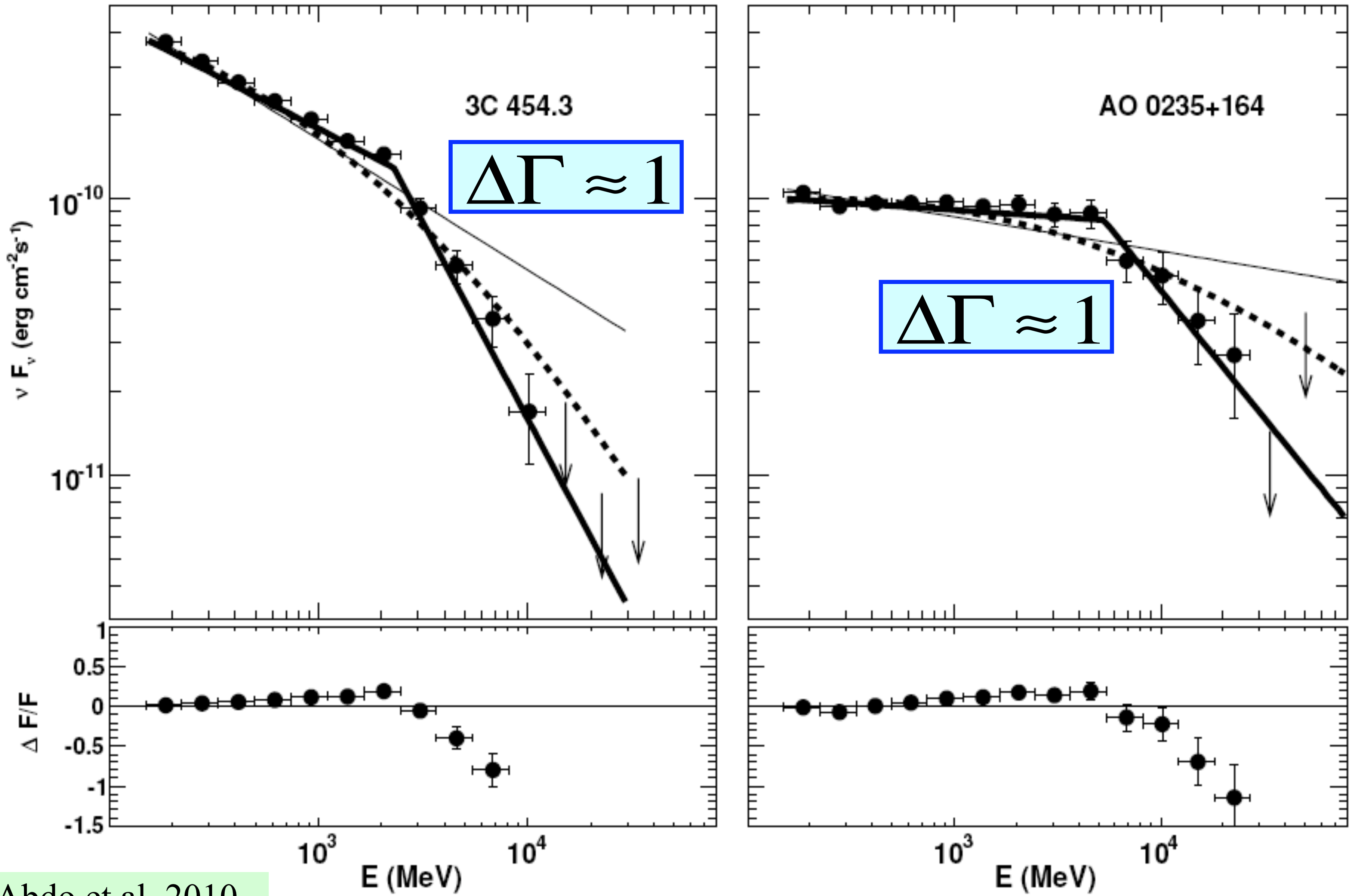
- Launched in June 2008
- Sensitive in 8 keV - 30 MeV (GBM) and
  100 MeV - 300 GeV (LAT)
- All sky survey in 3 hours

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



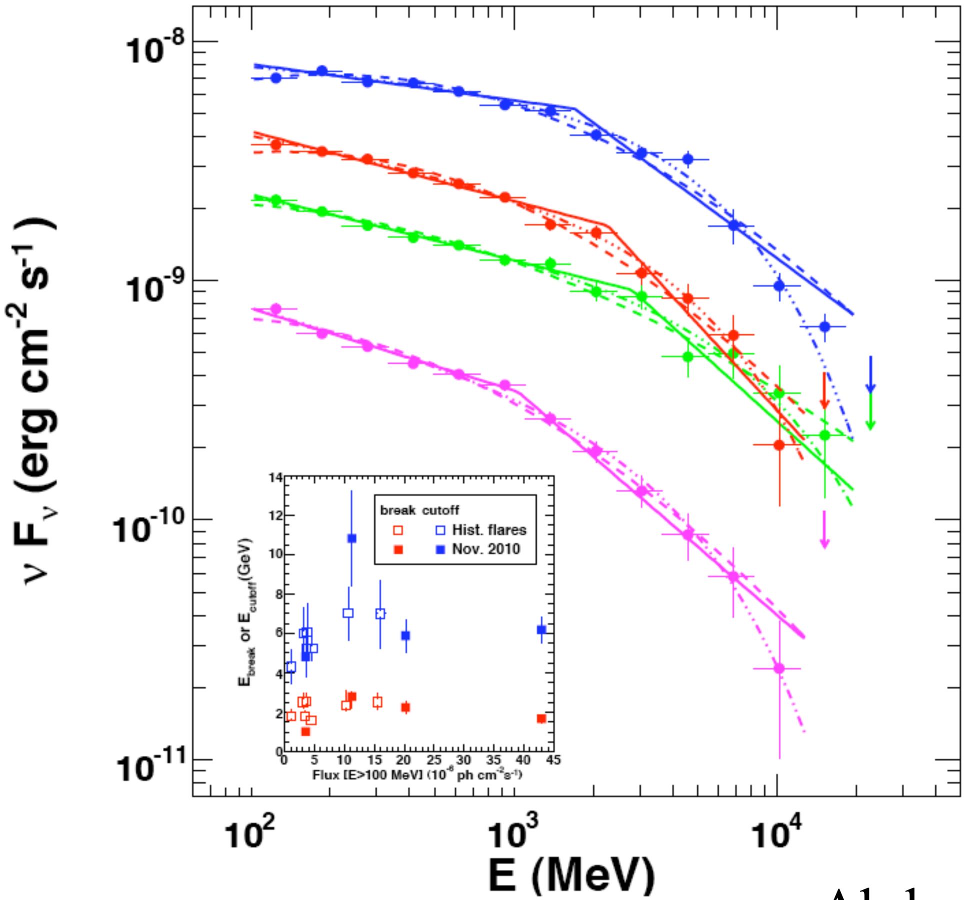
Abdo et al. 2010

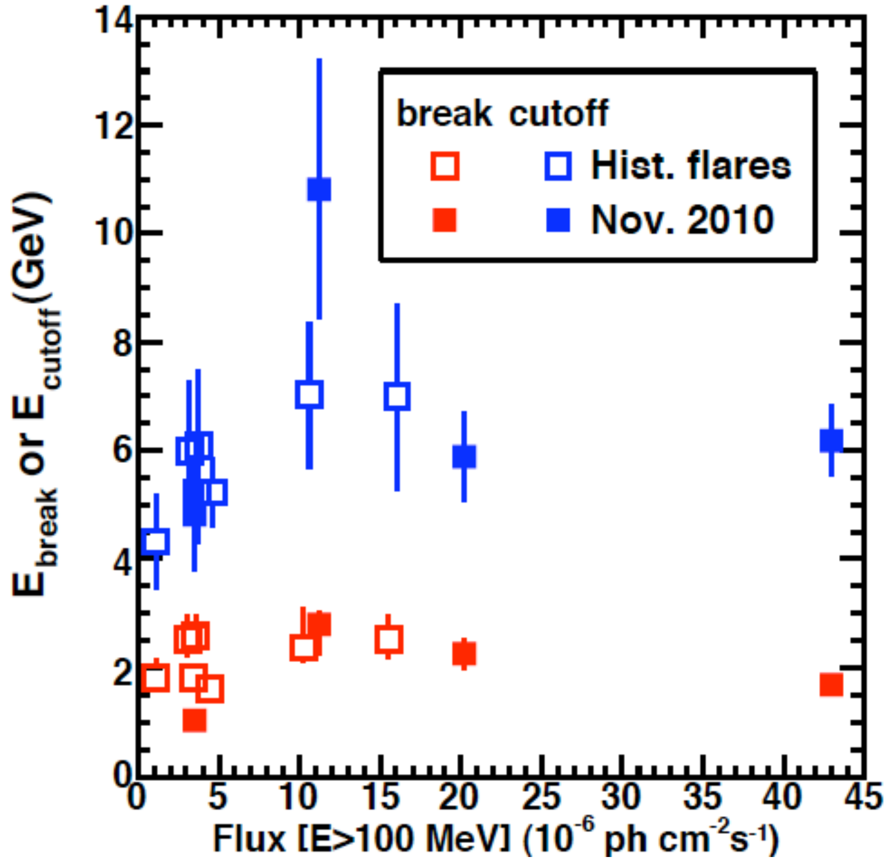
GeV breaks in FSRQ and LSP BL Lacs



Abdo et al. 2010

Stability of breaks during flares



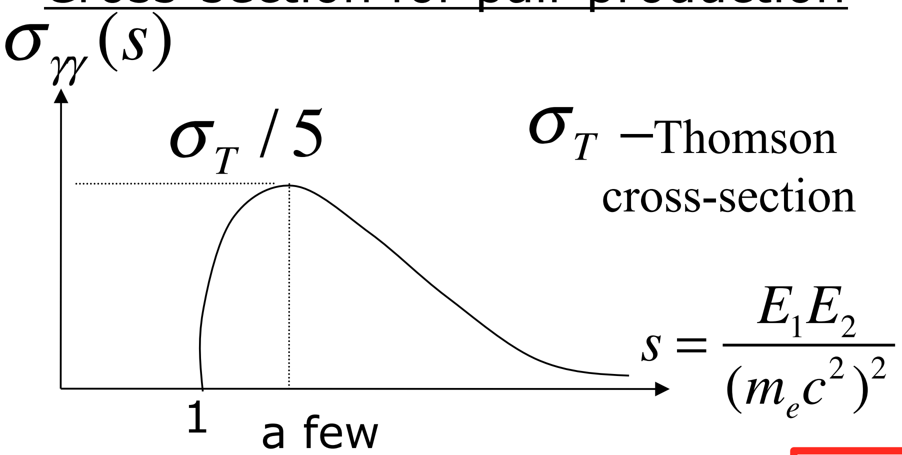


Abdo et al. 2011

Break energy is nearly constant ➔ atomic physics

Gamma-ray absorption by photon-photon pair production

Cross-section for pair production



σ_T –Thomson cross-section

Threshold at s=1:

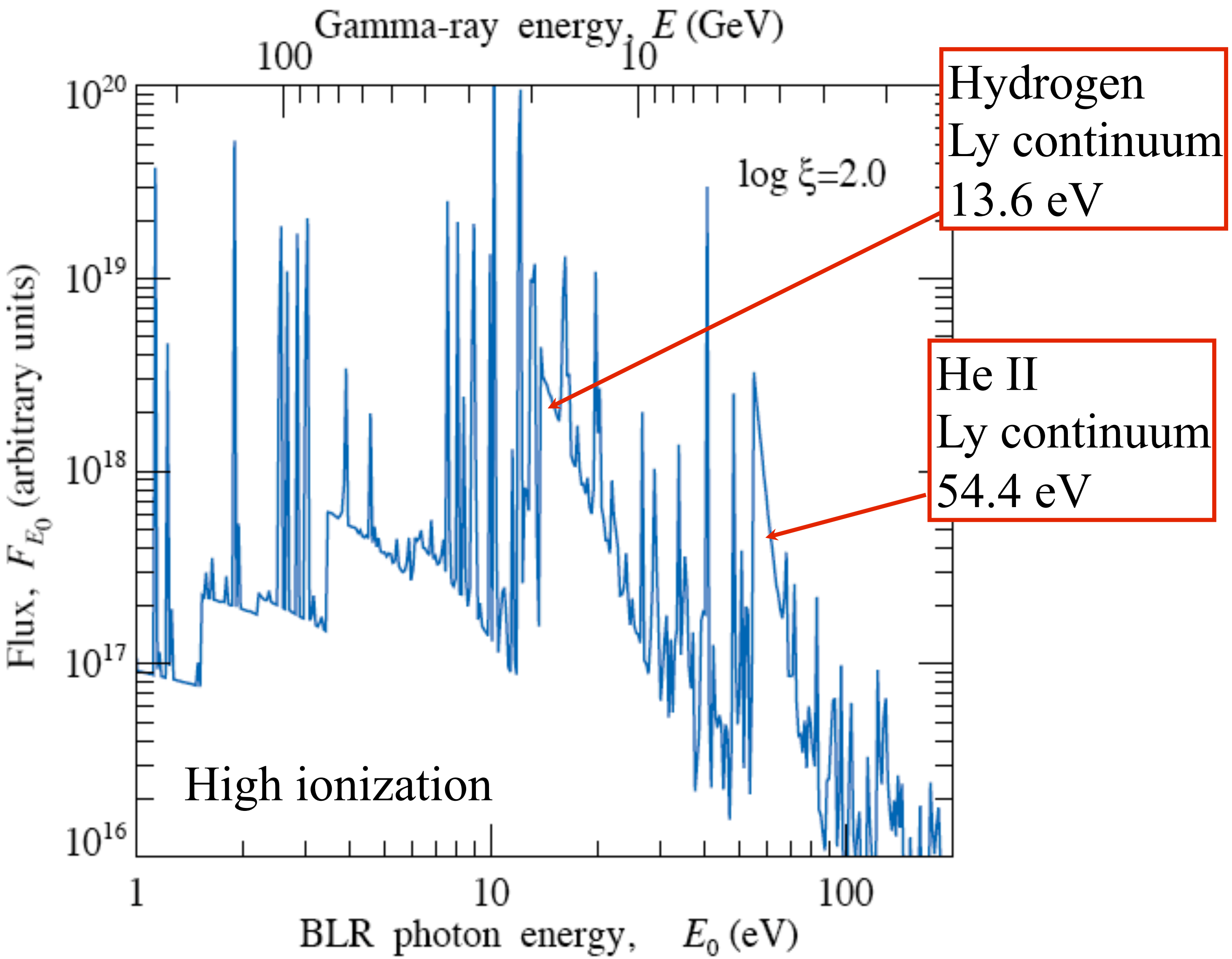
$$E = 25.6 \text{ GeV} \frac{10.2 \text{ eV}}{E_0}$$

	"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

Most GeV breaks cannot be produced by Ly α photons!

But can be produced by Lyman continuum of ionized helium.

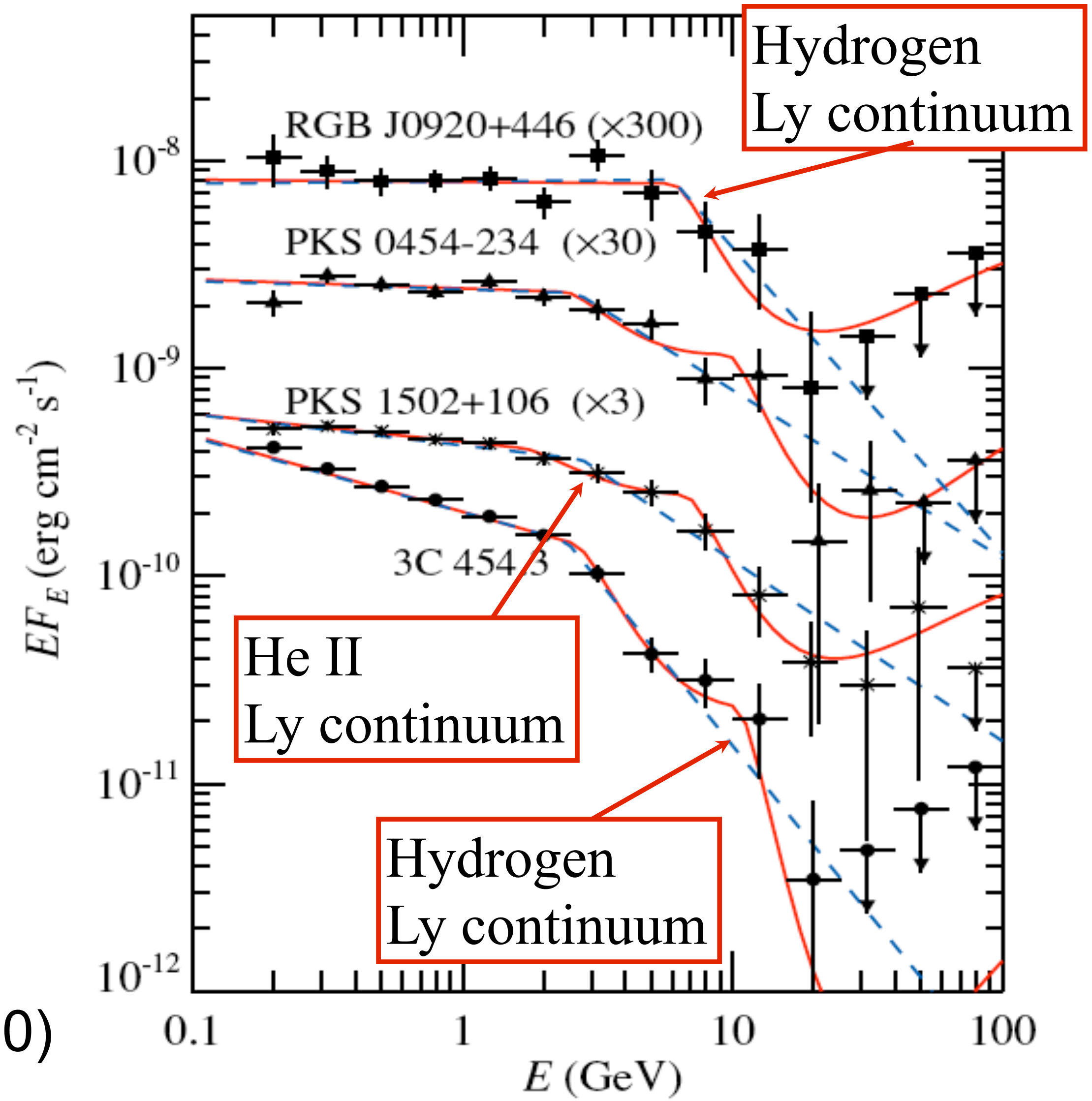
BLR spectra



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)

Absorption dips by He II and H I Lyman recombination continuum

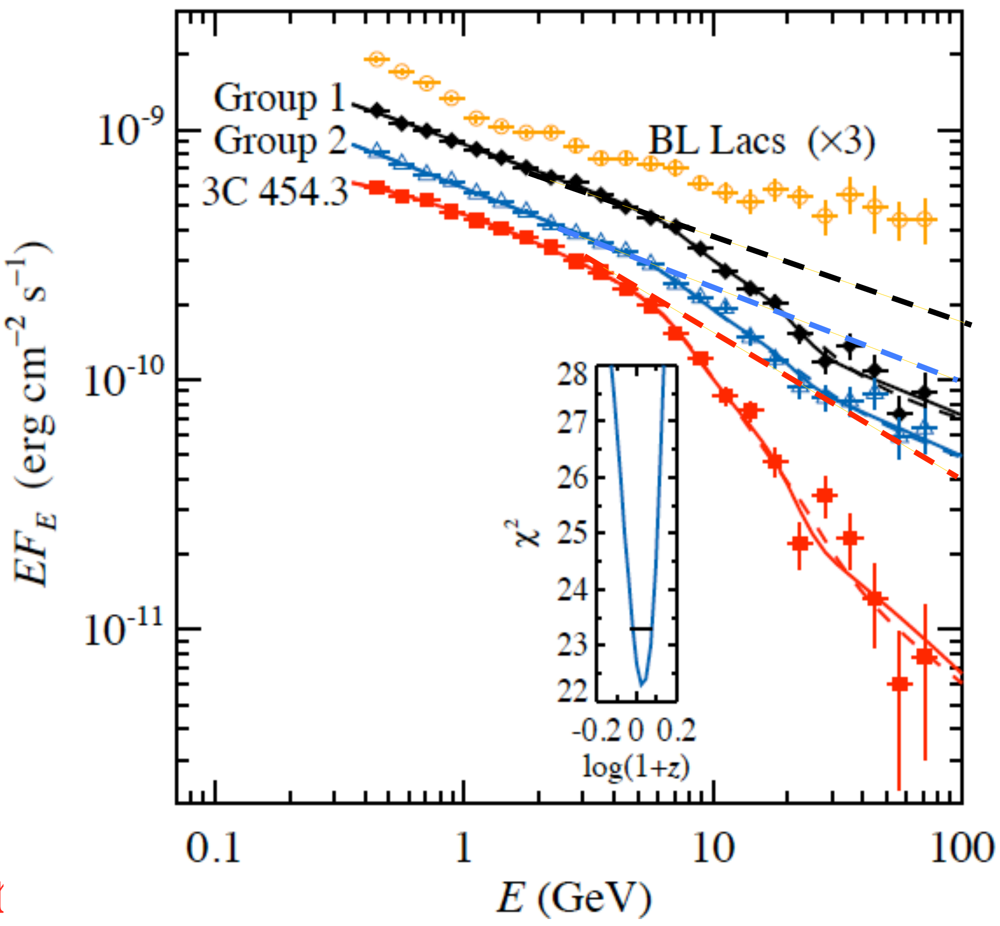
Power law +
dual absorber
(produced by H I and He II Lyman recombination continua)



Poutanen & Stern (2010)

Stacked (redshift corrected) blazar spectra

	Group 1	Group 2	3C454.3
N	12	27	
Counts >1GeV	>1400	600-1400	
χ^2/dof Log normal	88/20	29/20	112/20
χ^2/dof Log normal +abs Logξ=2.5	21/18	17/18	25/18



Stern & Poutanen (2012)

Extremely significant 5 GeV br

Absorption by He II Ly C is ubiquitous.

The best-fit requires 50% partial covering.

A puzzle: BLR size

The optical depth for pair production on line photons:

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

$$\left.\begin{array}{l} \tau_{\rm H} \approx 5 \quad \text{in 3C 454.3} \\ L_{Ly\alpha,45} = 1 \Rightarrow L_{\rm Ly\ cont,45} \approx 1 \end{array}\right\} \Rightarrow R \approx \text{a few pc}$$

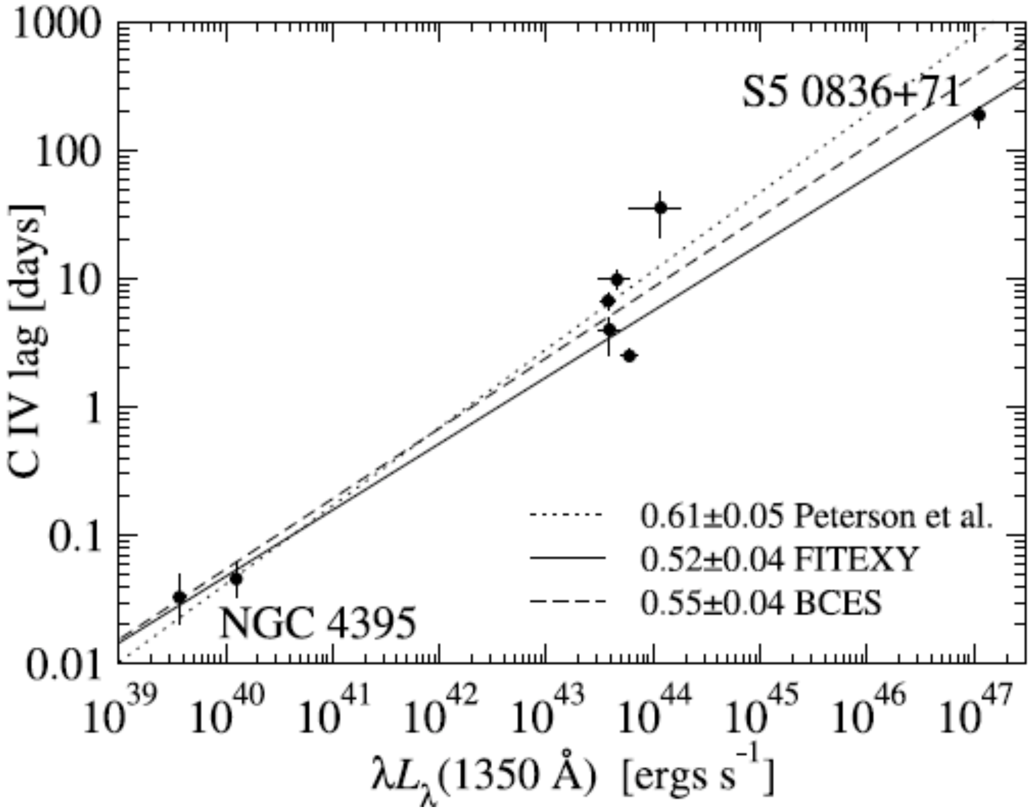
Contradiction with the reverberation results:

$$R_{\rm CIV\ 1549Å} \approx 0.2{\rm pc}\ \ L^{1/2}_{\rm disk,47}$$ Kaspi et al. 2007

Solutions?

1. The BLR size is underestimated. Reverberation gives the size of the variable component.
2. Gamma-ray are also produced outside of BLR.

The “size” of broad-line region



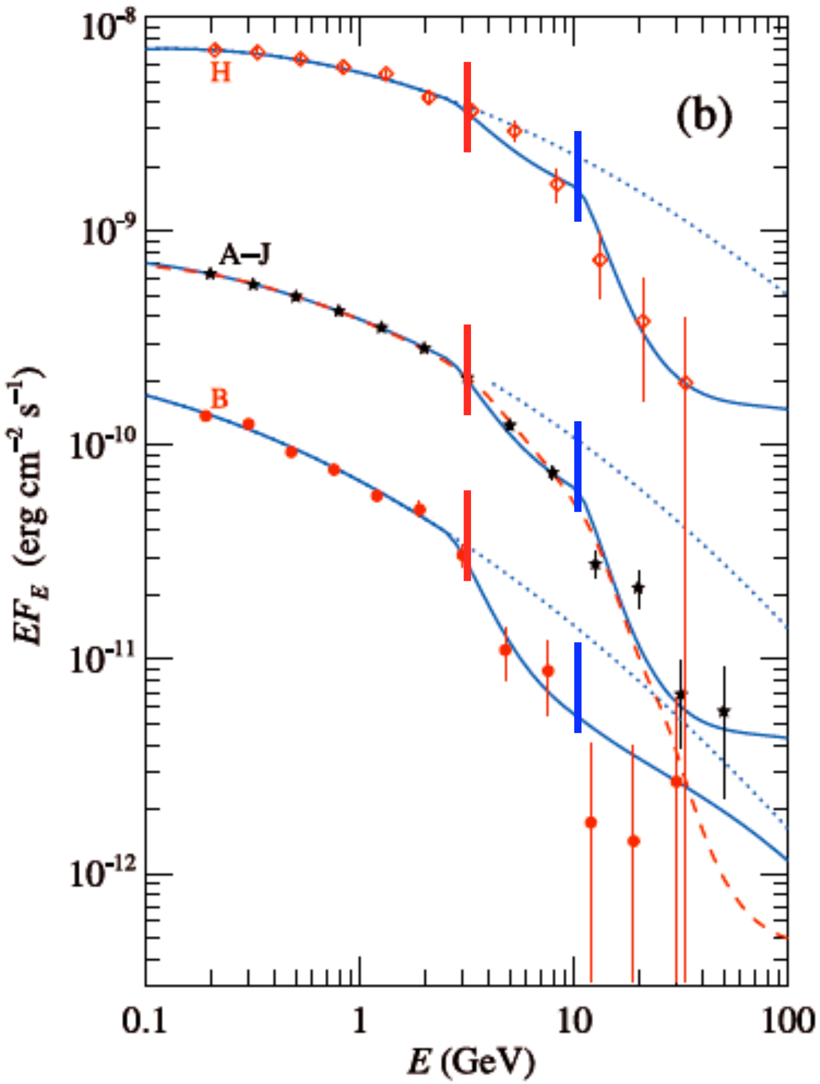
Scaling of BLR size (Kaspi et al. 2007)

$$R_{\mathrm{CIV}\,1549} \approx 0.02(\lambda L_{\lambda,1350\,\text{Å}})^{1/2}_{45}\,\mathrm{pc}$$

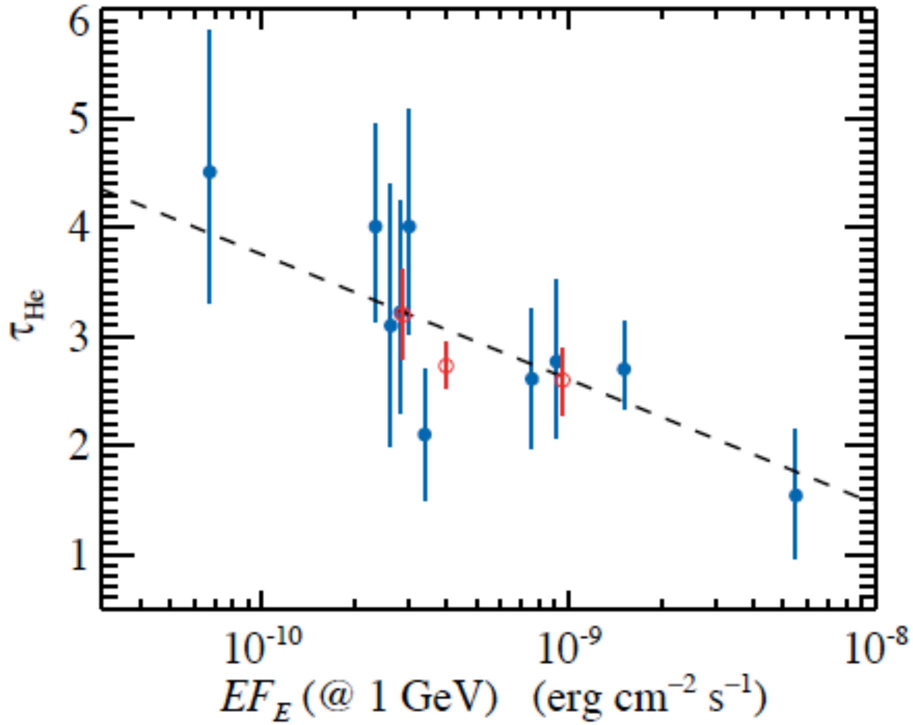
is based on one object and one line!
Size might be in error by a factor of 10 !

Kaspi et al. (2007) write:
“no Lyα variability is detected…”.
Lyα has to be produced further away than CIV.

Are all gamma-rays produced with BLR?



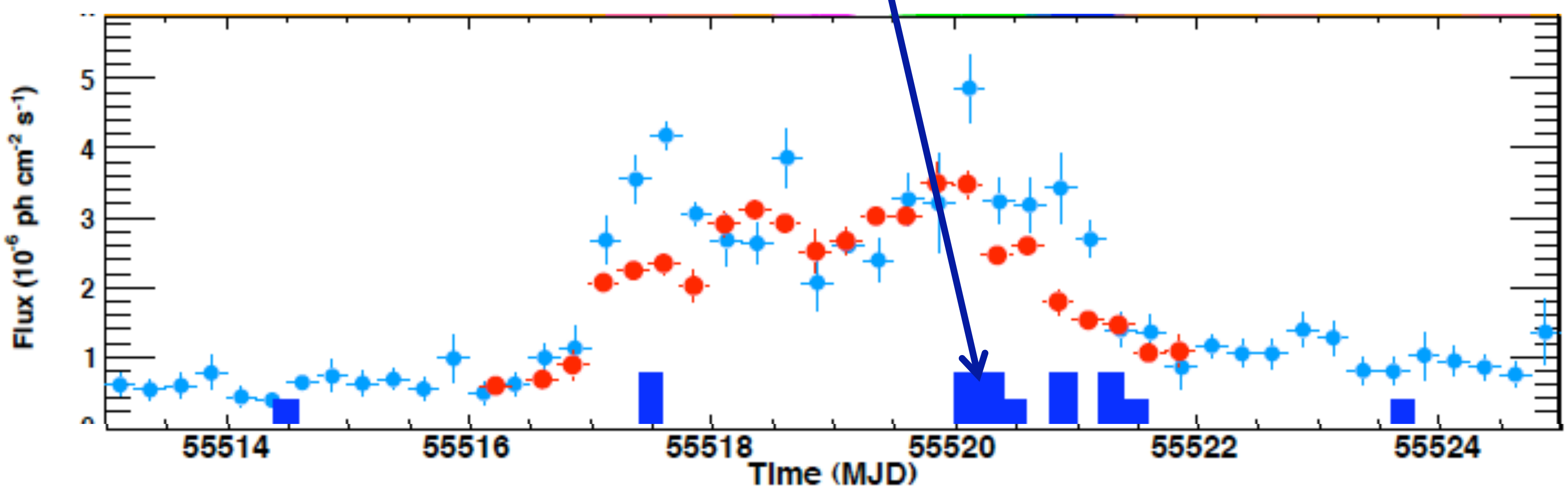
Stern & Poutanen (2011)



Opacity in He II drops with flux ➔ the gamma-ray emission region is located at the boundary of He^{++} zone and moves away from the BLR high-ionization zone at high fluxes.

Moving gamma-ray region

Moving source model is consistent with the arrival of >10 GeV photons in the end of the flare (Abdo et al. 2011).



Alternative interpretation

Gamma-ray are produced at 10 pc, because gamma-ray flare appears at a rising phase of the radio flare, i.e. after its start (Valtaoja).

Objections:

1. One cannot “fit” flares, because variability is red noise.
2. If not 1, then one should at least compare peaks of the flares. When has the gamma-ray flare started?
3. What cross-correlation function shows?

Large radio delays!

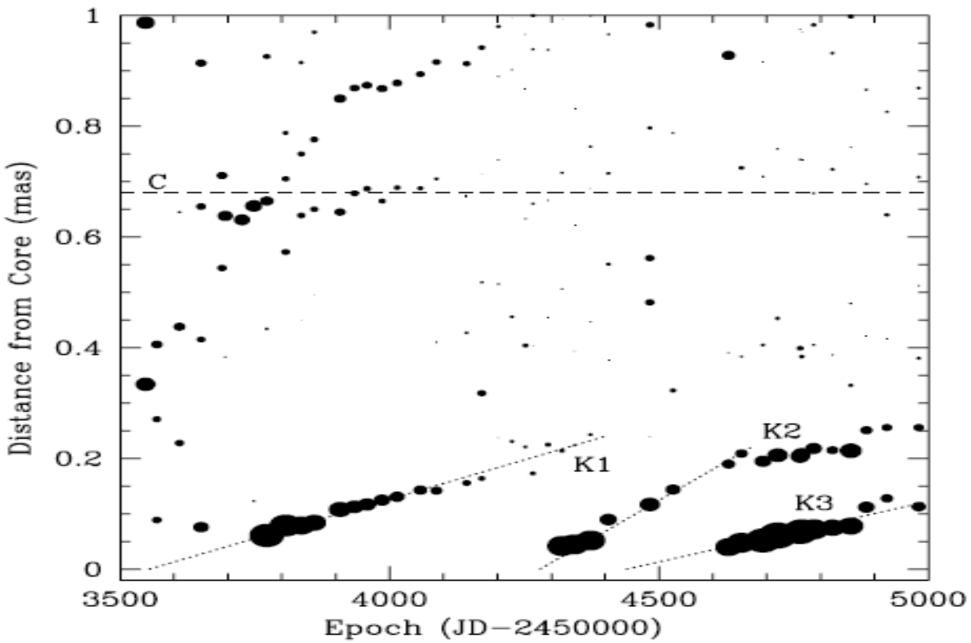
Alternative interpretation

Optical/gamma-ray flares in 3C 454.3 are produced within 20 days from the moments of "passage through" the radio core which is *18 pc from the source* (Jostad++2010).

Objections:

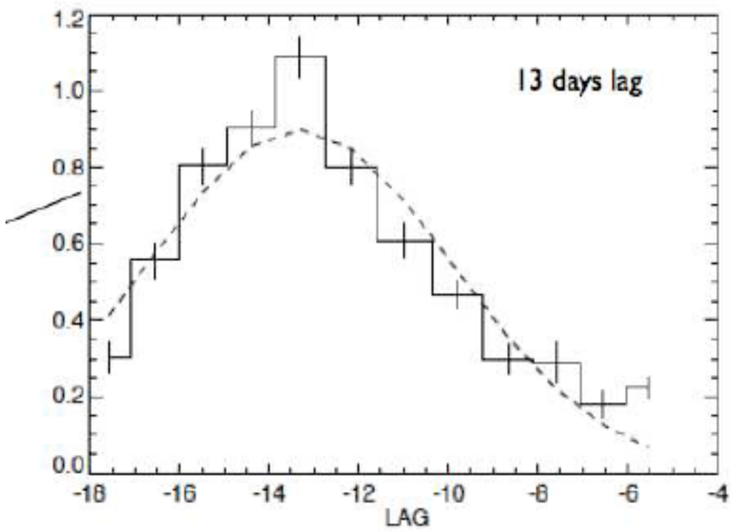
1. In reality there is only an *upper limit* on the radio core size of R<18+-3 pc.
2. The error in the time of ejection of radio components is 20-30 days!

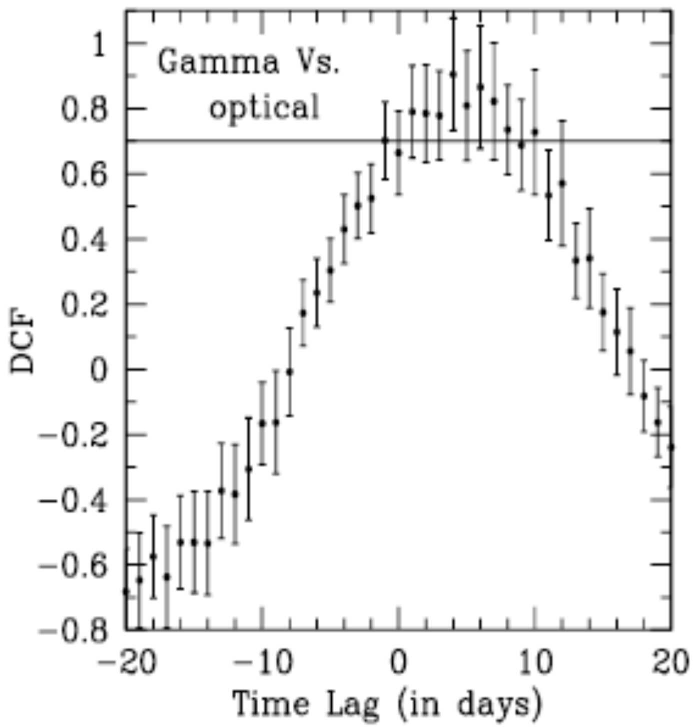
3. Gamma-ray and optical can be produced during the "passage", i.e. blob ejection from the source at distance R=0 pc!



Optical, radio vs gamma

- Gamma-rays come earlier: 13 day optical delay in PKS1510-089 (Larsson + Fermi team 2012)
- Optical 4.5 day delay in 3C 454.3 (Gaur ++2011)
- Radio is delayed by a month in 3C 454.3 (Jostad++2011) and 50 days in BL Lac (Marscher++2010)





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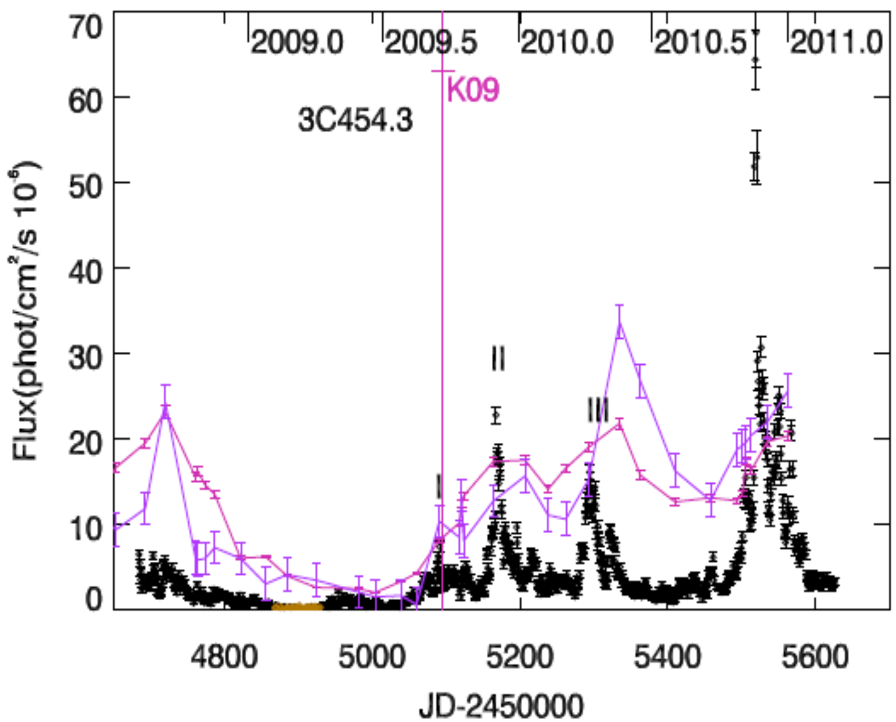

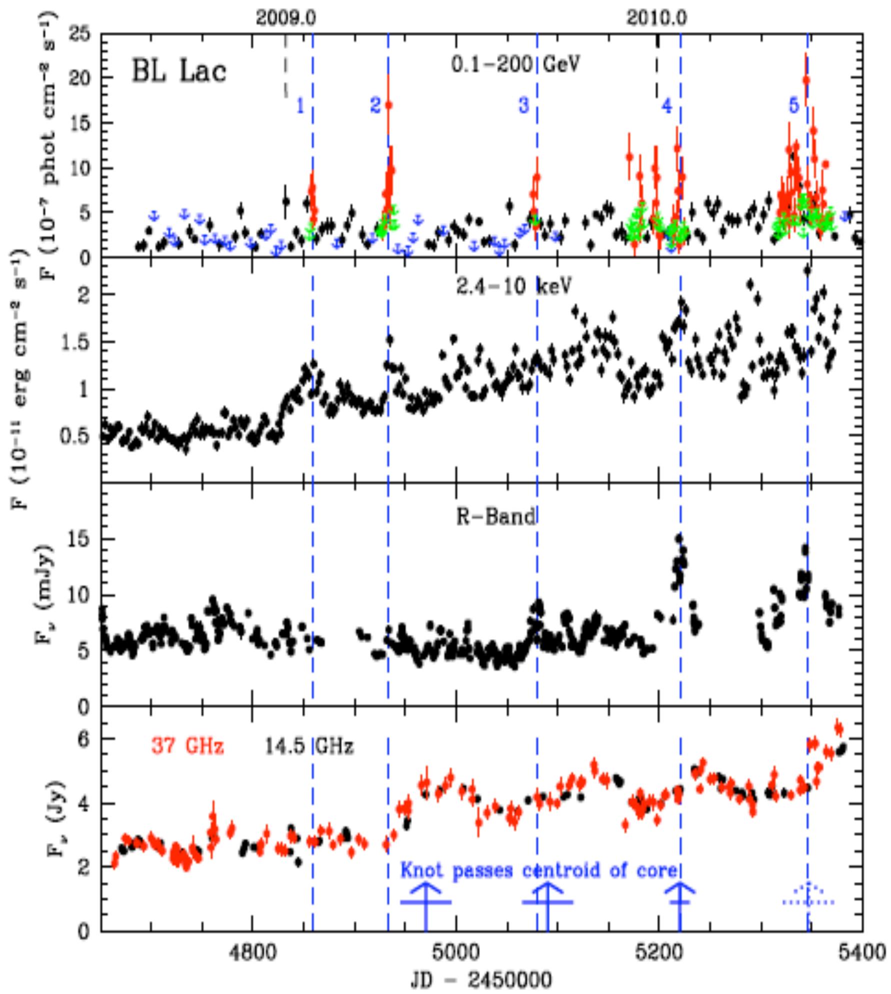

Conclusions

- GeV breaks produced by BLR photons constrain the location of the gamma-ray emitting region within the BLR.
- GeV spectra are potentially powerful diagnostics of the BLR physics.
- The BLR "size" seems to be underestimated in powerful quasars and the sub-TeV opacity is strongly overestimated.
- Gamma-ray emitting region seems to be moving and extended.
- Alternative interpretations that gamma-rays are produced together or even before radio "flares" are ambiguous. These observations can easily be reconciled with the location of the gamma-ray emitting region within or near the BLR.