High Energy Flares of FSRQs

(searching for FSRQs flares dissipating beyond the BLR)

L. Pacciani
IAPS-INAF

Collaborators:
F. Tavecchio, I. Donnarumma, A. Stamerra

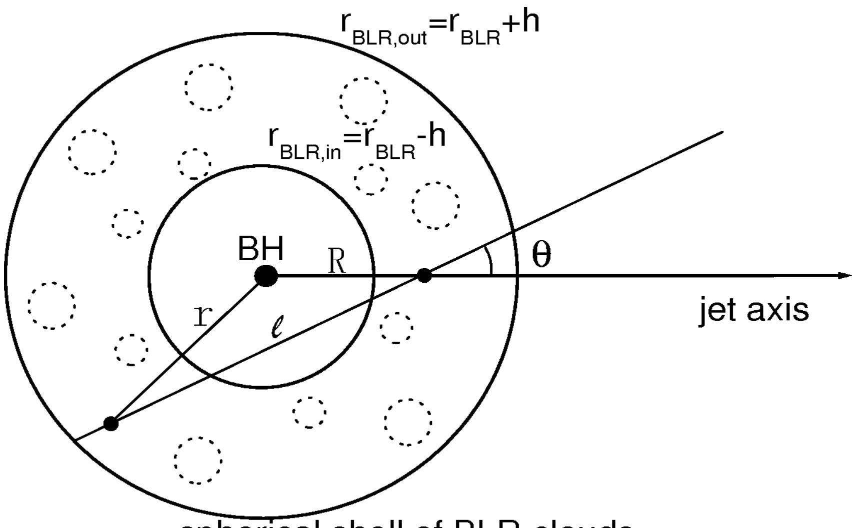
Financial contribution from

PRIN-INAF 2014

$\gamma\gamma$ absorption from BLR

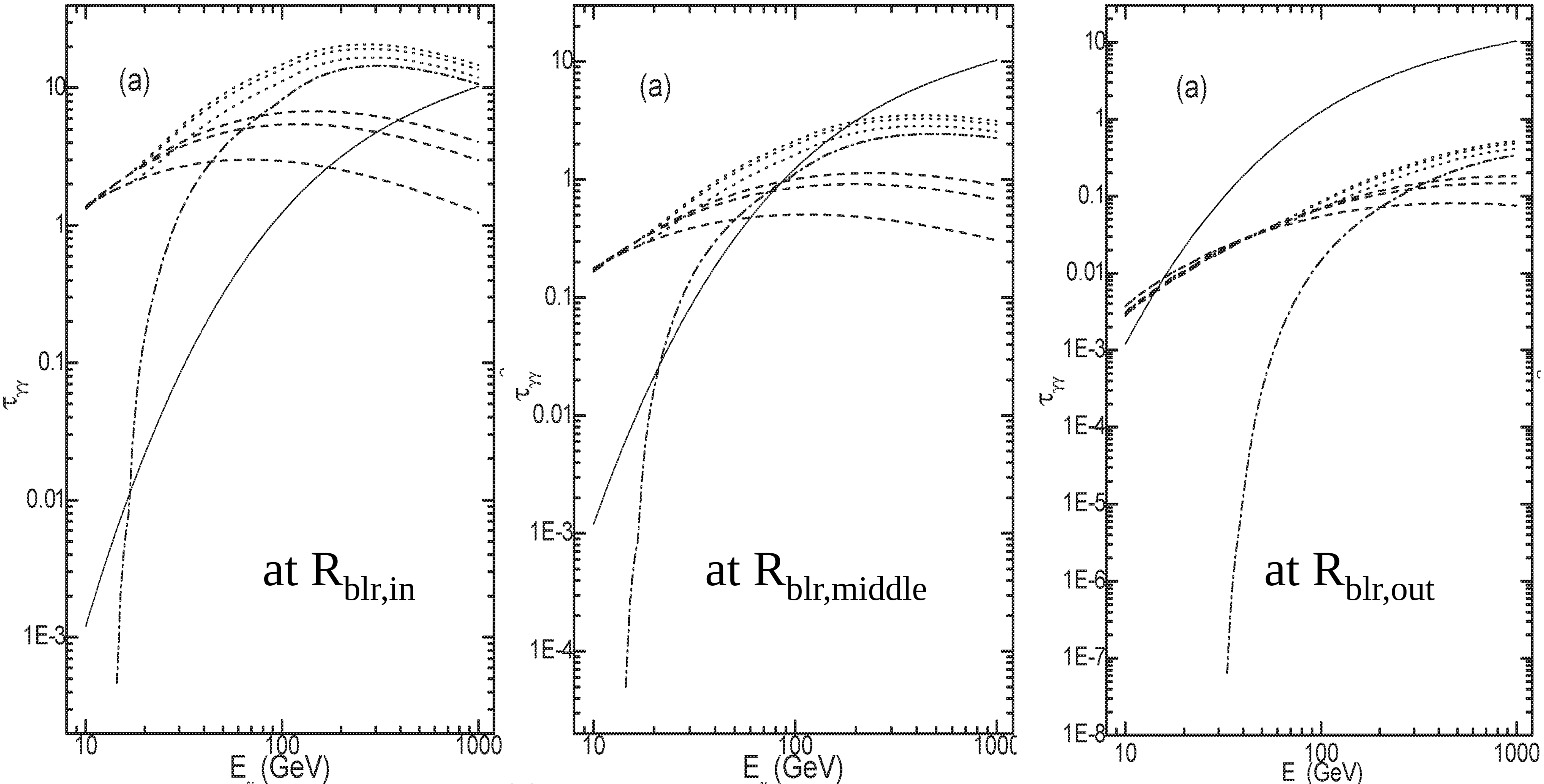
via $\gamma\gamma \rightarrow e^+e^-$ interaction

Liu & Bai 2006
Liu, Bai, Ma 2008



$\gamma\gamma$ absorption from BLR

Liu & Bai 2006; Liu, Bai, Ma 2008

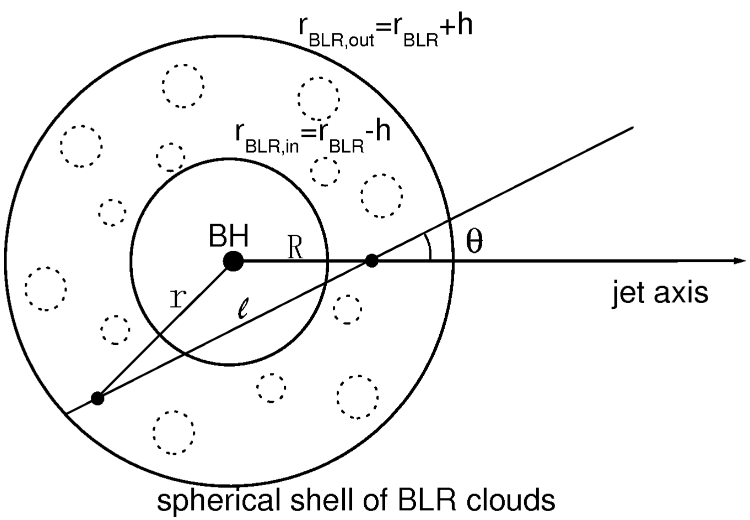


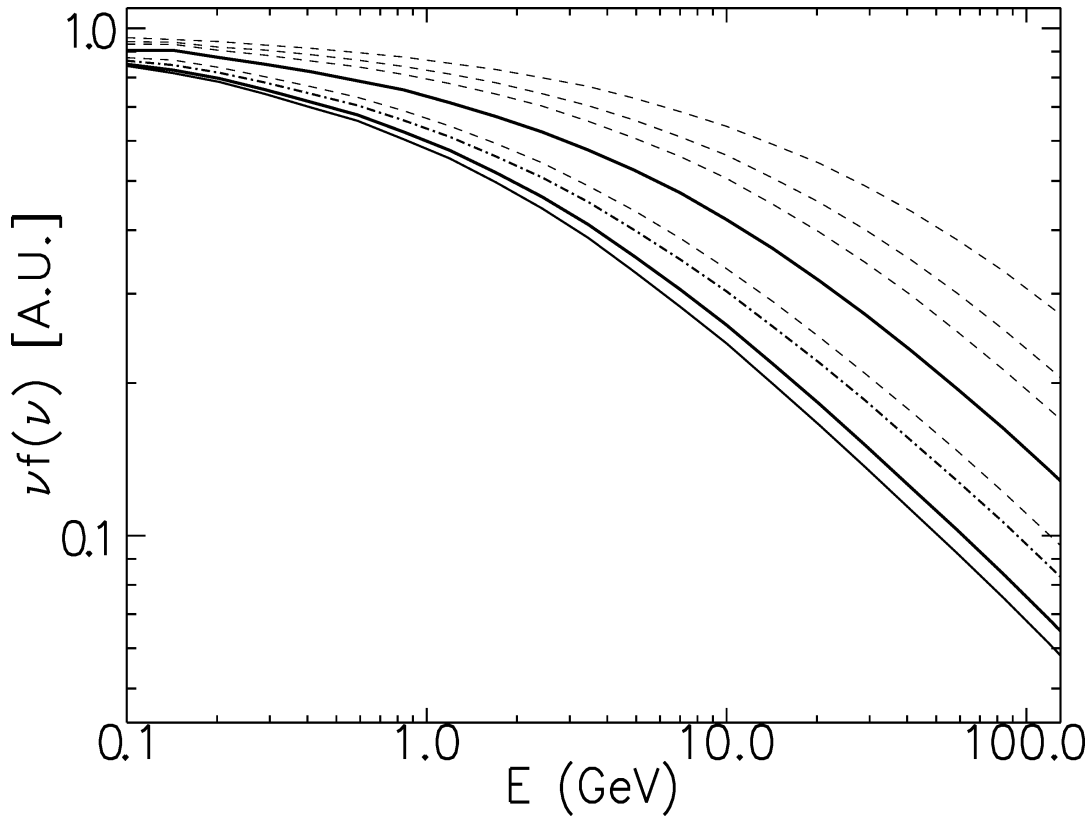
L_{BLR}=2.6x10^{44} erg/s (this is the case of 3C 279,
but for 3C 454.3 the BLR is >10 times more luminous)

$\tau_{\gamma\gamma}$ scales as $L_{BLR}^{1/2}$

KN suppression
(External Compton on BLR photons)

Pacciani, Tavecchio et al, 2014, ApJ 790, 45





Klein-Nishina suppretion for a dissipation region at:

solid curves: 0, R_{in}, R_{out} (from Bottom Up)

solid dashed curve: at the center of the shell

dashed curves: 0.95 R_{out}, 1.25 R_{out}, 1.5 R_{out}, 2 R_{out}

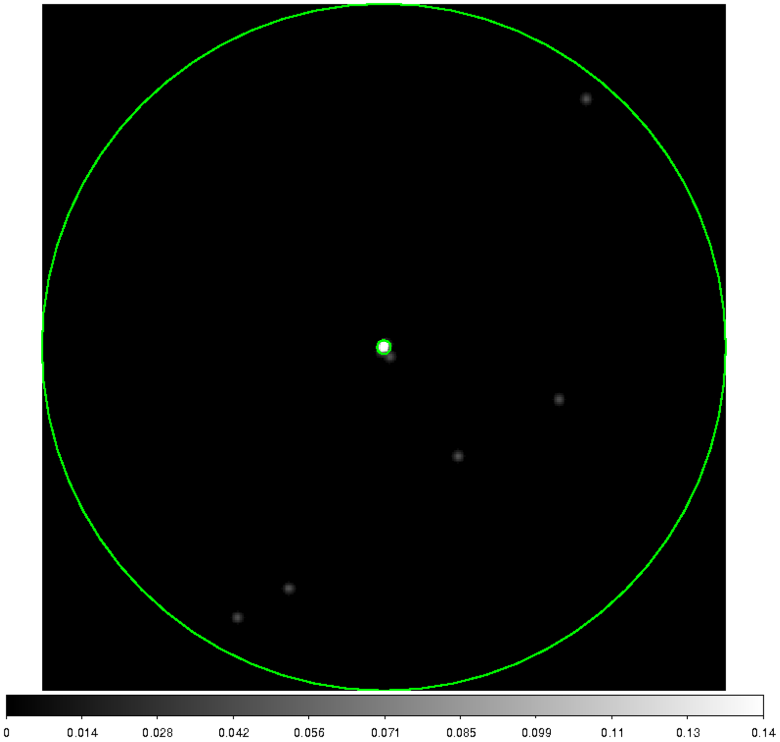
SEARCH within the FERMI-LAT FSRQs sample

SEARCH within the FERMI-LAT FSRQs sample

We started to search for relevant signal at E > 10 GeV in the FERMI-LAT archive from FSRQs and on incoming gamma-ray data (and triggering ToO observations to Swift).

High energy (HE) activity period is defined as the period of time in which the HE photon rate is > 3 x mean HE rate

3C 454.3
Sept. 2013 HE flare



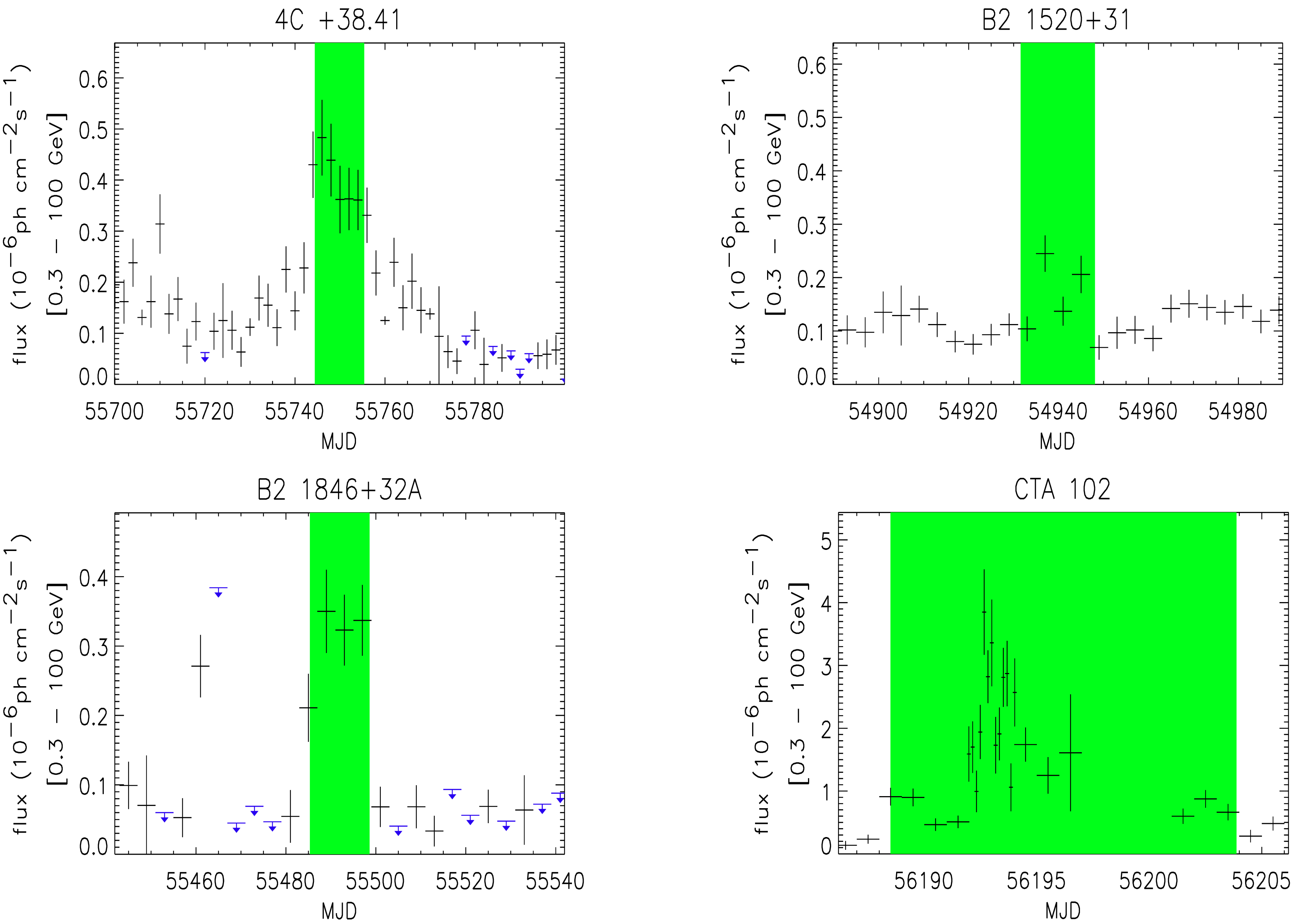
Search within the FERMI-LAT FSRQs sample

We obtained ~40 flares candidates with detections with TS significance
$26 < TS < 136$ ($E_{THR} > 10$ GeV,
but now we have changed the E_{THR} definition)
and
High Energy activity periods
lasting from 1 to 12 days in the host galaxy frame

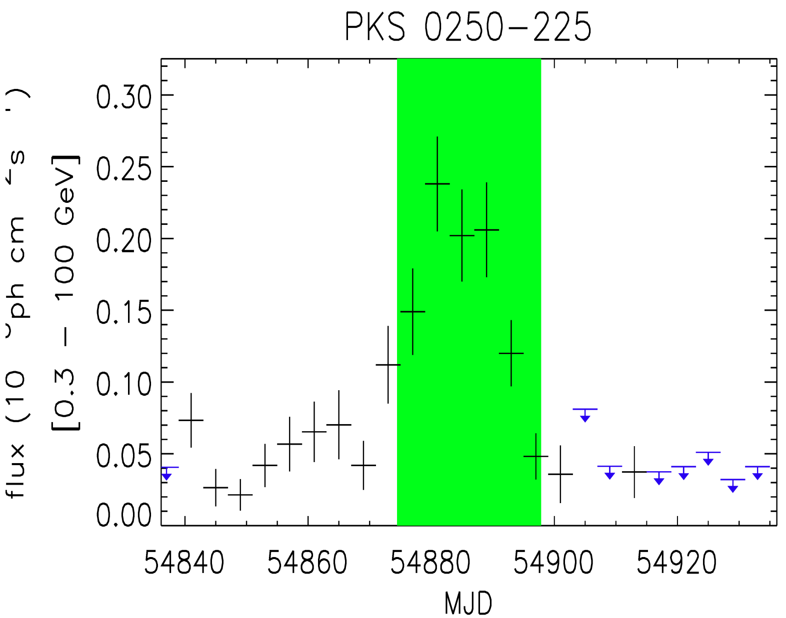
We selected for flares with MWL coverage, for sources with available Broad lines luminosities (to infer the disk luminosity using the mean ratios of Broad Lines luminosities in **Francis 1991** and in Celotti 1997, and assuming **$L_{disk}=1/10\ L_{BLR}$**).

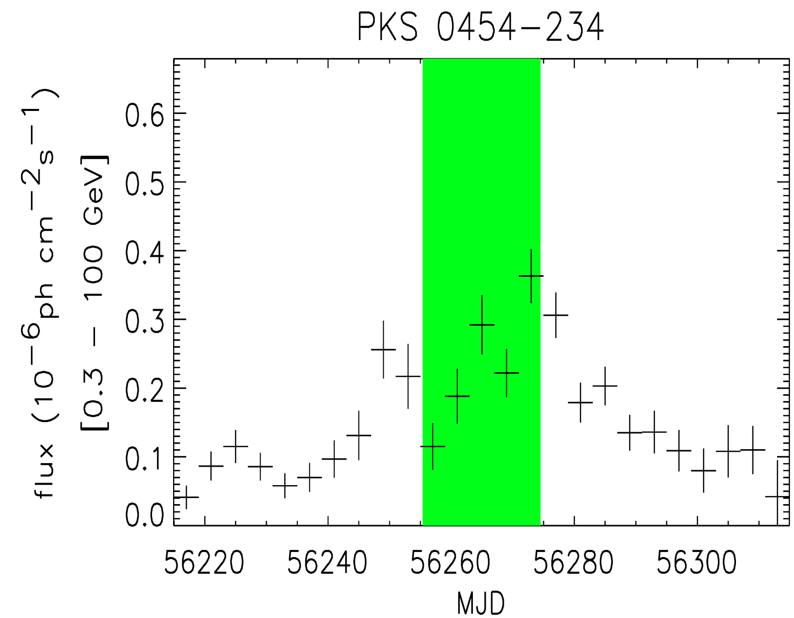
We obtained 10 sources up to Sept. 2013
(3 ToO from HE flares triggered by our program:
PKS 0454-234, PMN J2345-1555, 3C 454.3)
apart GB6 J1239+0443 (Pacciani et al., 2012),
PKS B1424-418 (Tavecchio, Pacciani et al., 2013, **ToO triggered by us**),
3C 279, 4C +21.35, PKS 1510-08
(but we collected other HE flares within the last year)

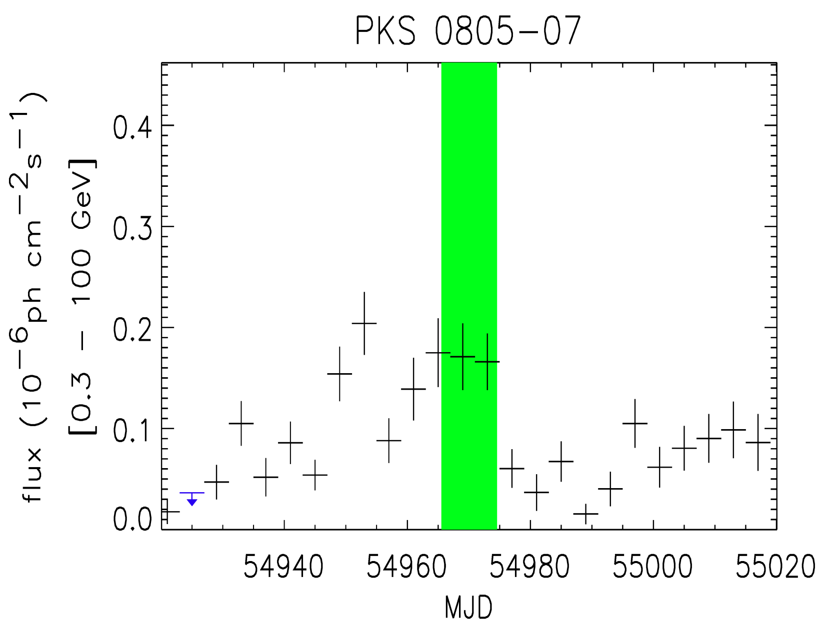
Search within the FERMI-LAT FSRQs sample (I)

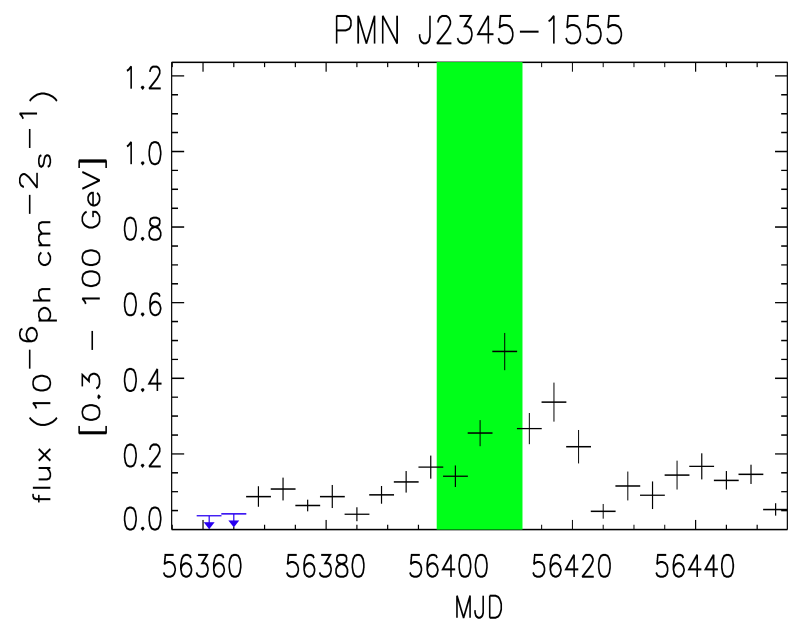


Search within the FERMI-LAT FSRQs sample (II)

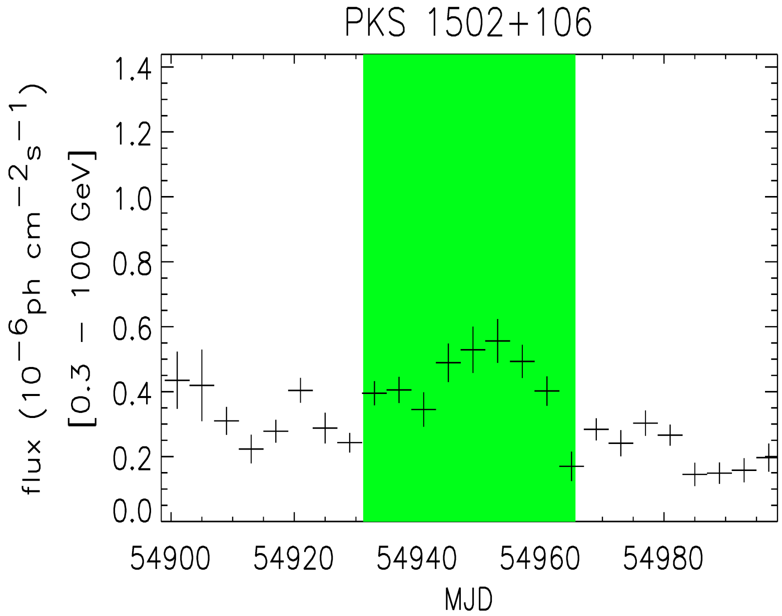




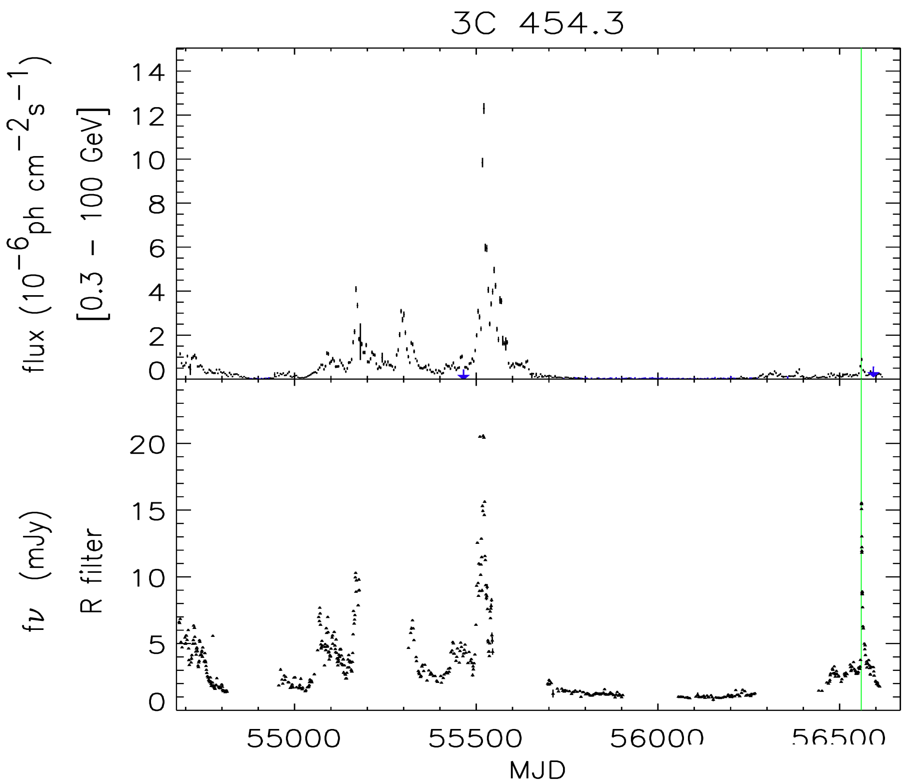


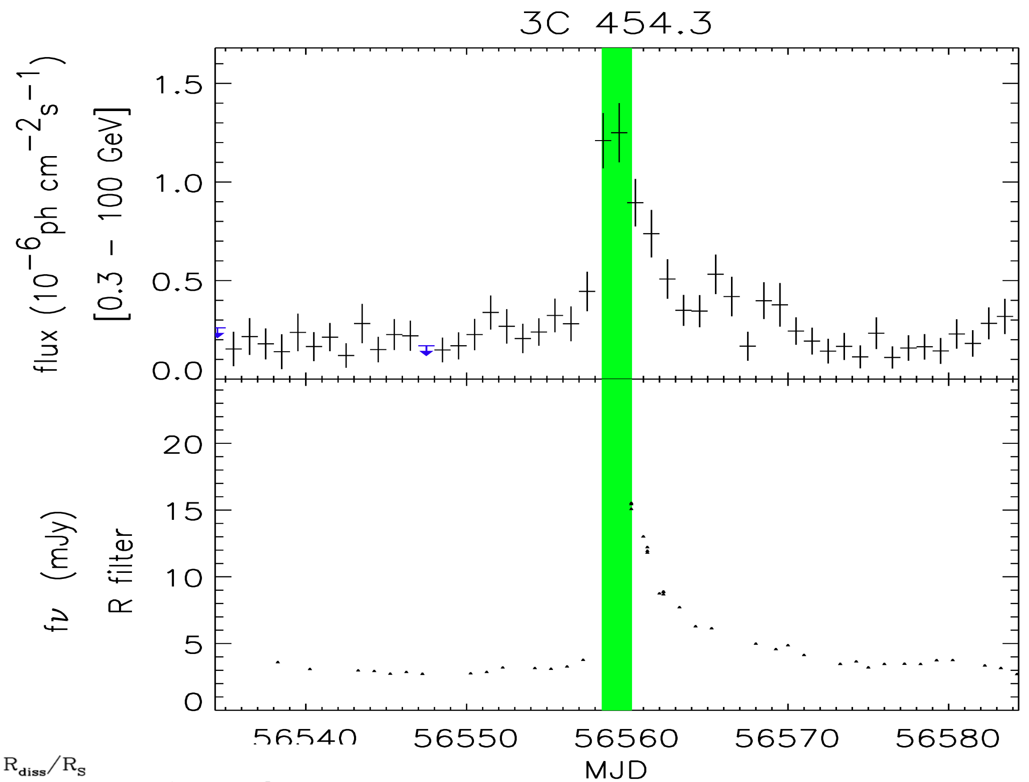


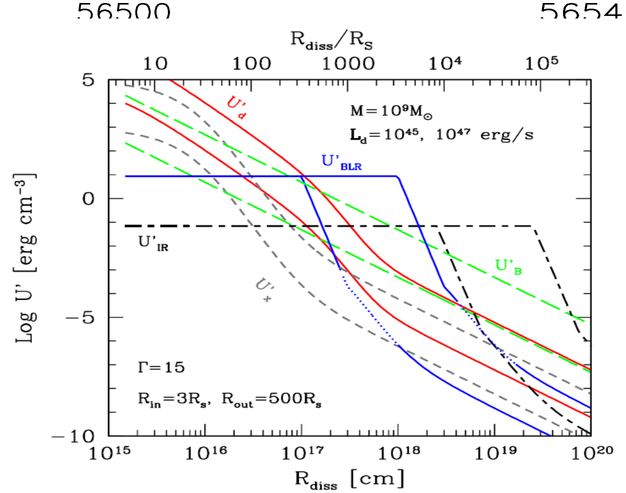
Search within the FERMI-LAT FSRQs sample (III)



Search within the FERMI-LAT FSRQs sample (IV)

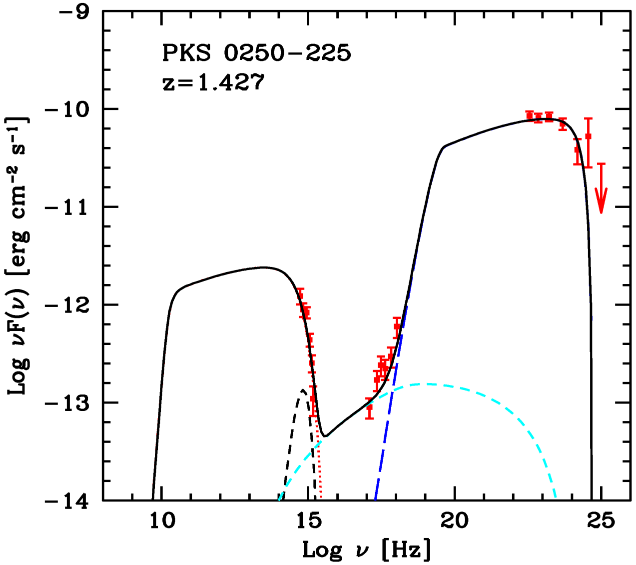




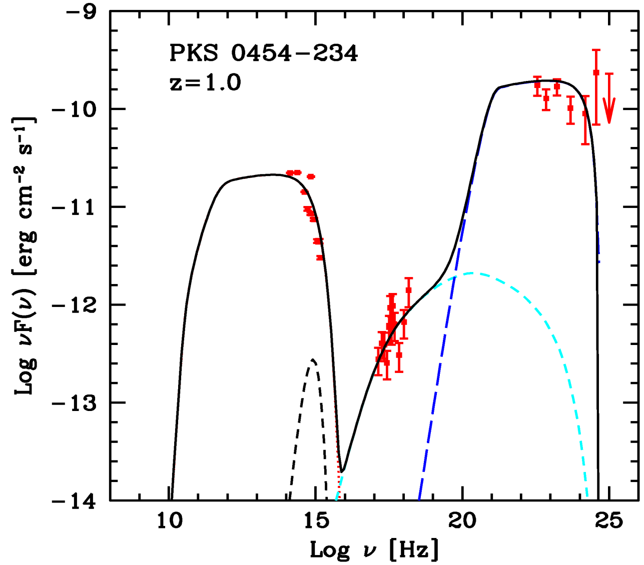


Ghisellini & Tavecchio 2009

SEDs and modeling (i)

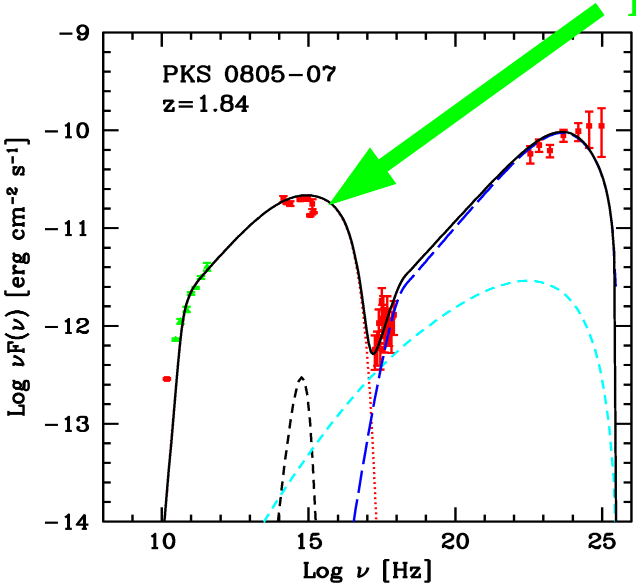


dist=3 pc
B=25 mG
L_{disk}=5.3x10^{45}
erg/s

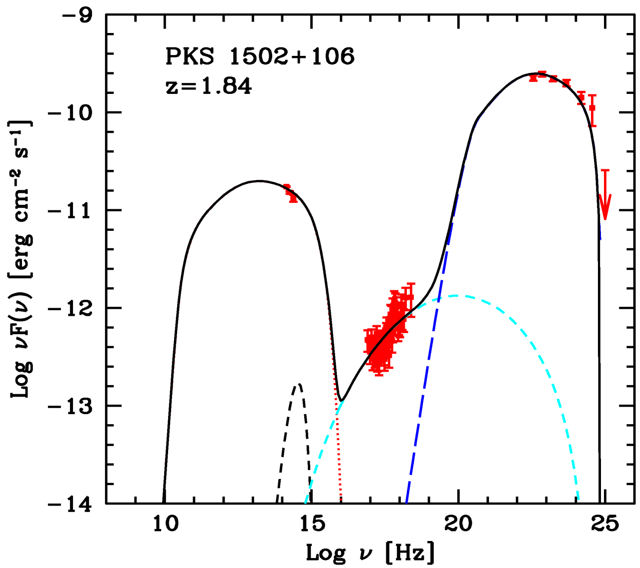


dist=2.5 pc
B=35 mG
L_{disk}=3.7x10^{45}
erg/s

IGM absorption in UV

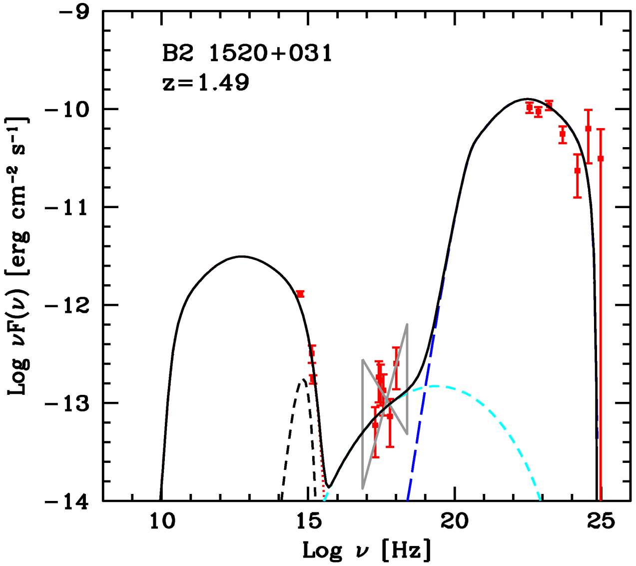


dist=0.8 pc
B=315 mG
L_{disk}=24x10^{45}
erg/s

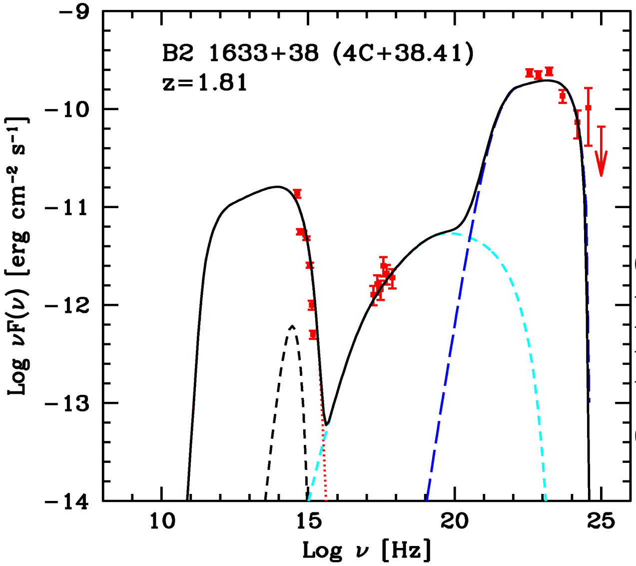


dist=2 pc
B=110 mG
L_{disk}=15x10^{45}
erg/s

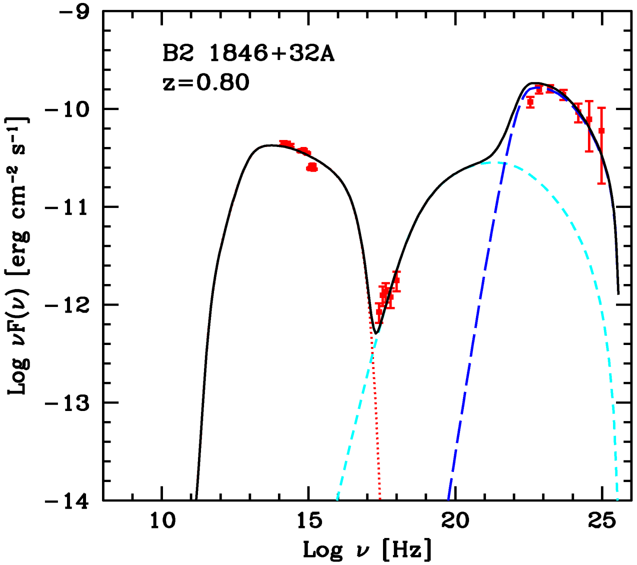
SEDs and modeling (ii)



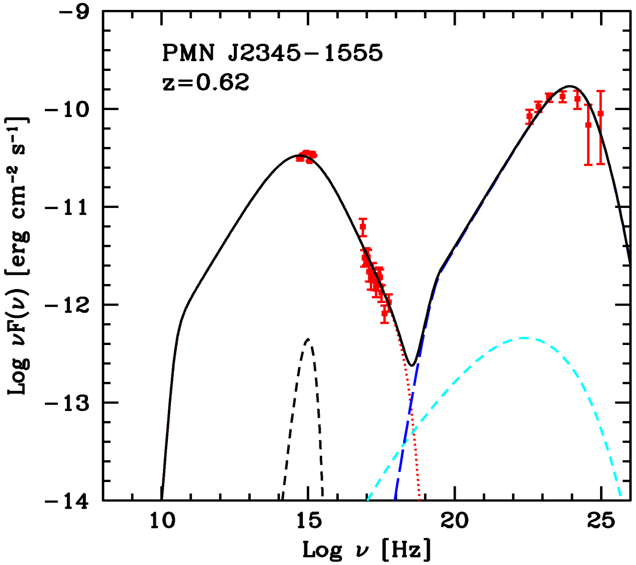
dist=1.3 pc
B=63 mG
$L_{disk}=8x10^{45}$ erg/s



dist=0.5 pc
B=250 mG
$L_{disk}=50x10^{45}$ erg/s

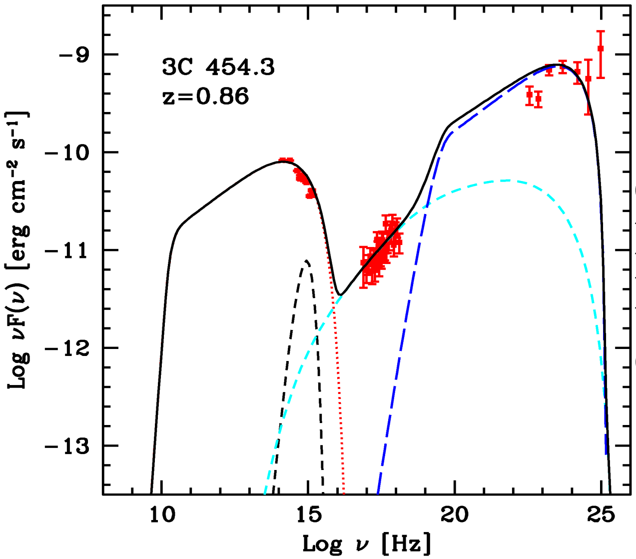


dist=0.2 pc
B=620 mG
$L_{disk}=3.4x10^{45}$ erg/s

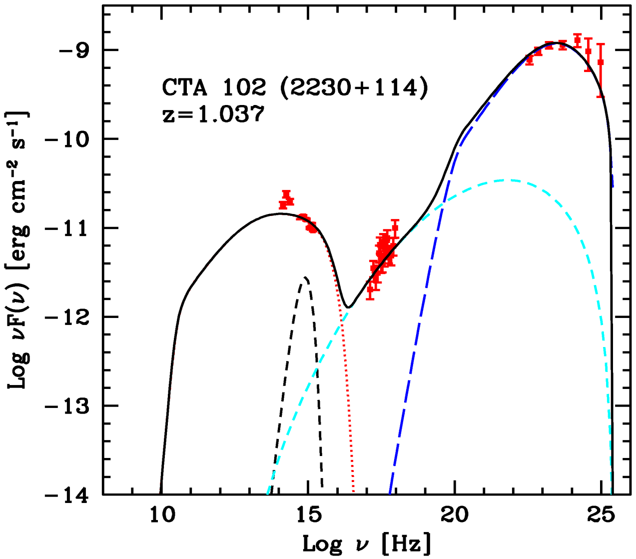


dist=0.7 pc
B=210 mG
$L_{disk}=1.5x10^{45}$ erg/s

SEDs
and modeling (iii)



dist=0.5 pc
B=230 mG
L_{disk}=33x10^{45} erg/s



dist=0.3 pc
B=140 mG
L_{disk}=41x10^{45} erg/s

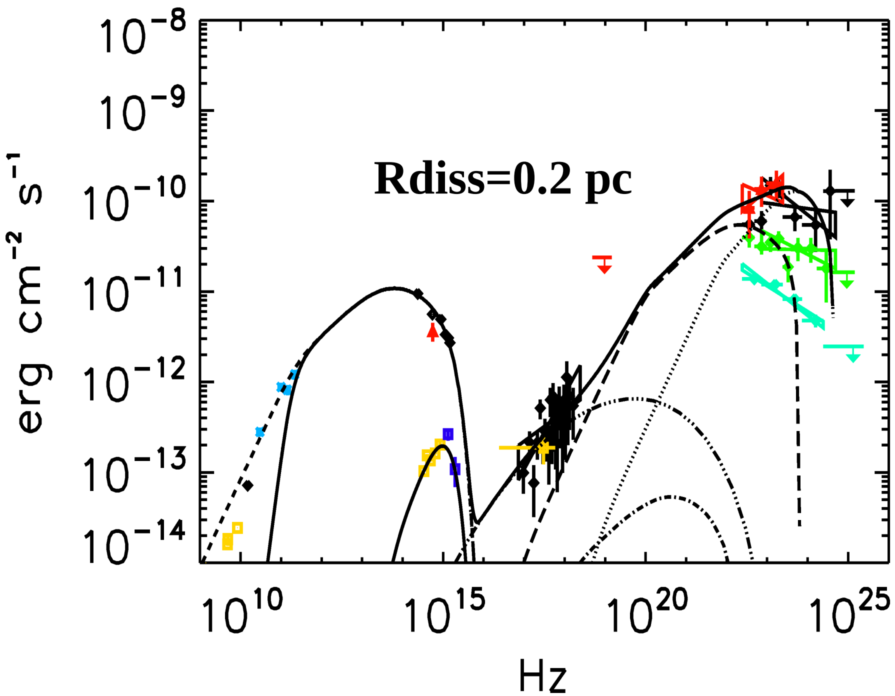
GB6 J1239+0443 (z=1.76) Multiepoch SED (I)

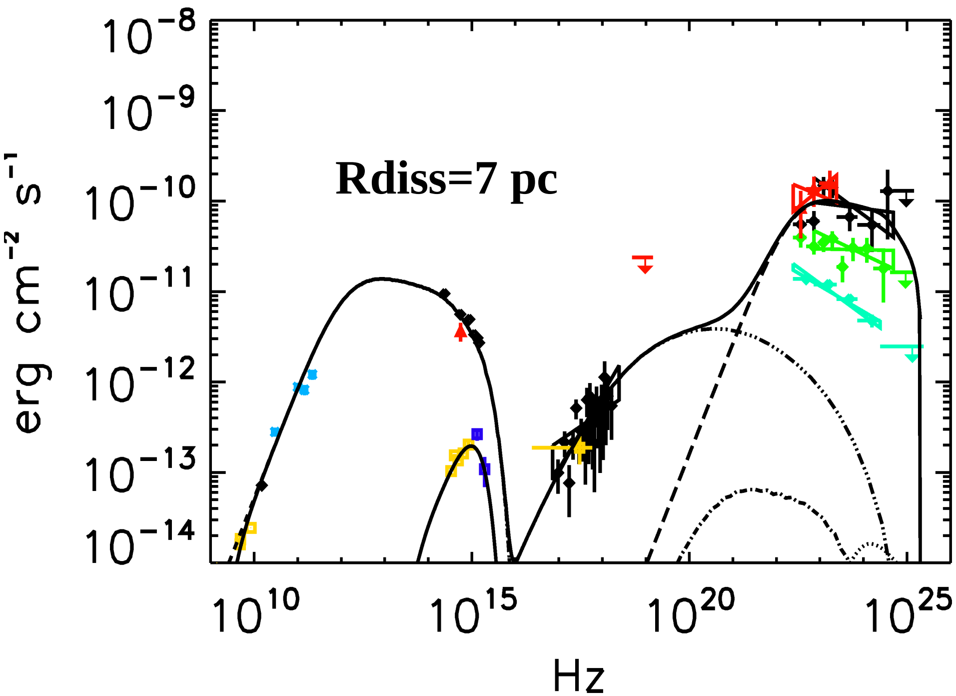
AGILE/GRID and simultaneous data in red

FERMI-LAT data (4-day integration around the flare) and simultanous data in black

Fermi-LAT data in green (30-day integration around the flare)

Fermi-LAT data in cyan (2FGL catalog)





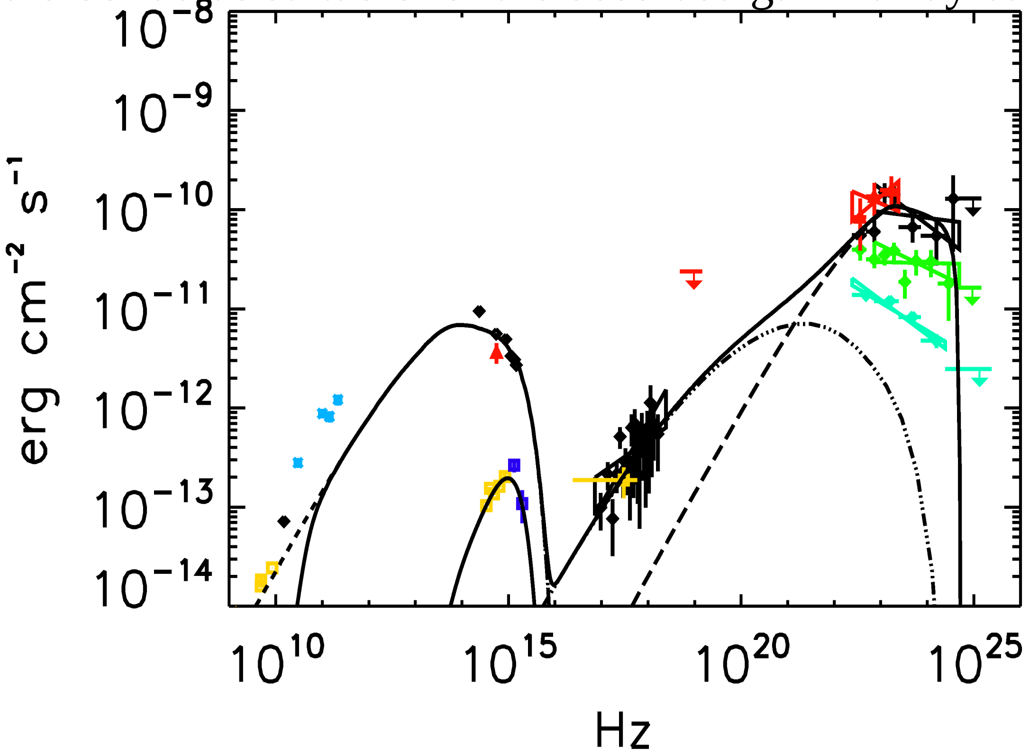
Dissipation region at 0.2 pc from the SMBH
(Just outside the BLR)
Rblob=6.7*10^{16}cm
B=0.6 Gauss

Dissipation region at 7 pc from the SMBH
Rblob=2*10^{18}cm
B=1*10^{-2} Gauss

This model gives a satisfactory gamma-ray spectral shape, but the expected variability is ~10^2 days

GB6 J1239+0443 (z=1.76) Multiepoch SED (II)

Relaxing the relation between blob radius and dissipation region (as in Tavecchio 2011), and using a blob radius suitable for the observed gamma-ray variability



Model is for a dissipation region at 5 pc from the central BH, a blob radius of $1*10^{17}$ cm, B=$7*10^{-2}$ Gauss

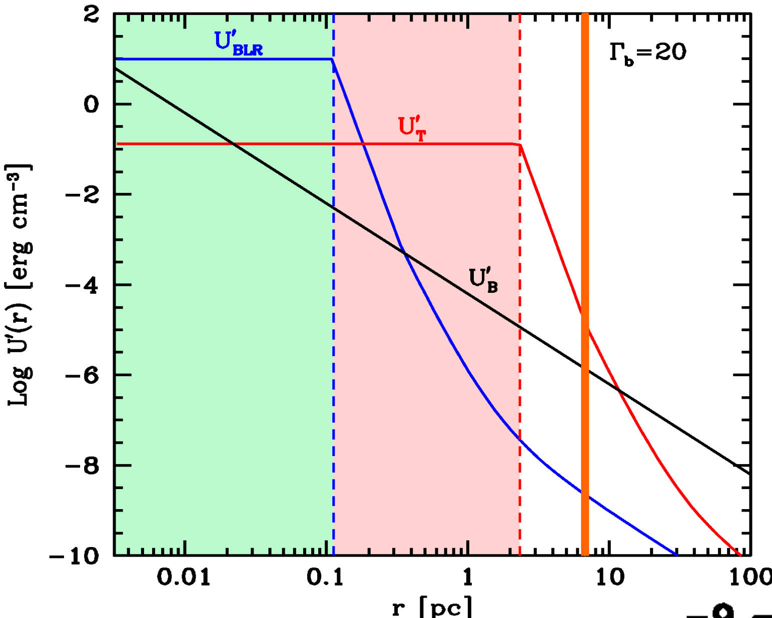
R_{blob}=0.0067*R_{diss} in agreement within a factor 2 with Bromberg and Levinson 2009 ($R_{blob}=10^{-2.5}$ R_{diss})

inverting $R_{diss}=2.5*L_{jet,46}(R_{BLR}/0.1\ pc)^{-1}$ and using R_{diss} =5 pc, we obtain $L_{jet}=3.5*10^{46}$ erg/s.

We need to assume that the p/e number ratio is ~0.1 to accomplish such a luminosity.

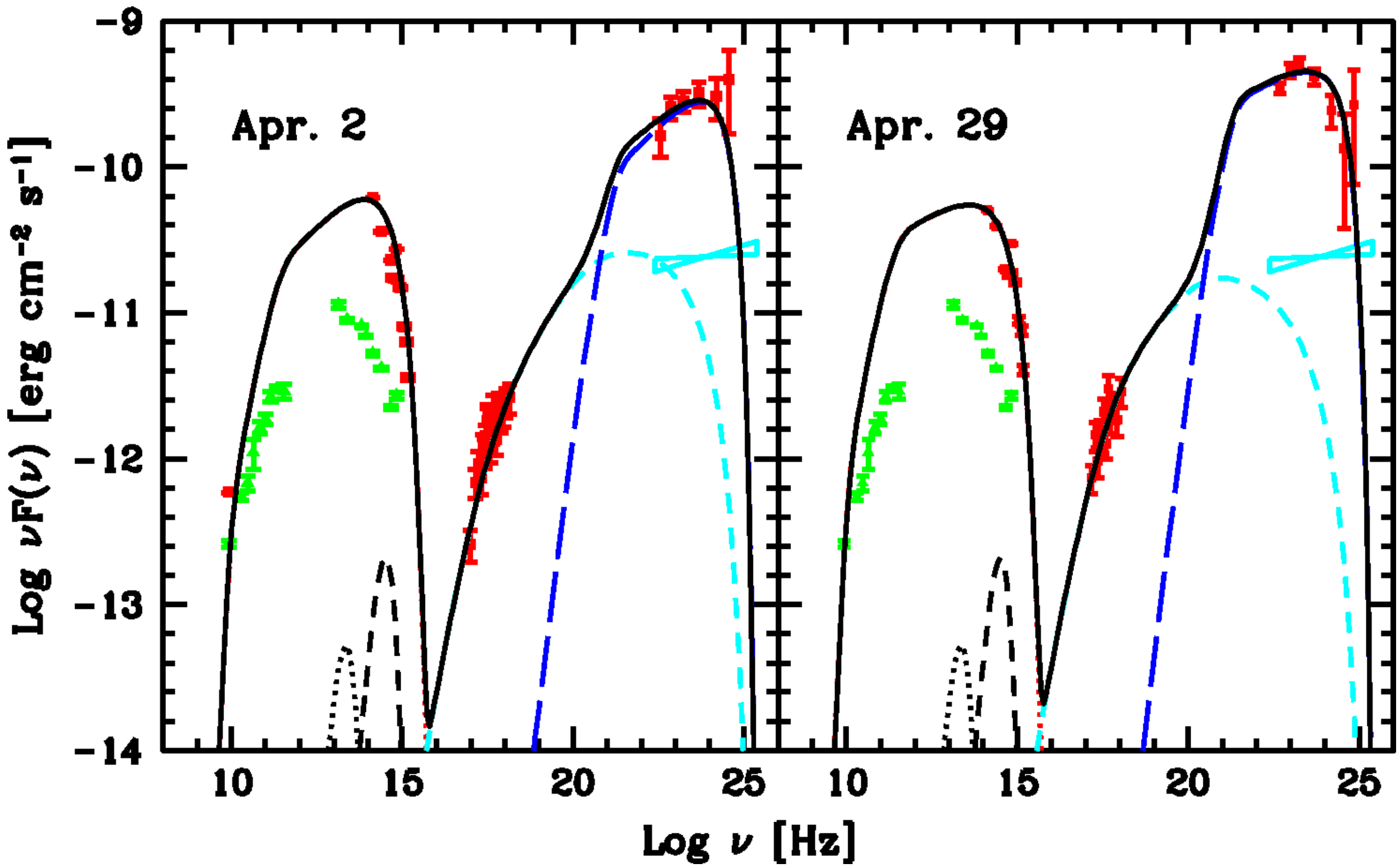
PKS 1424-41

z=1.52

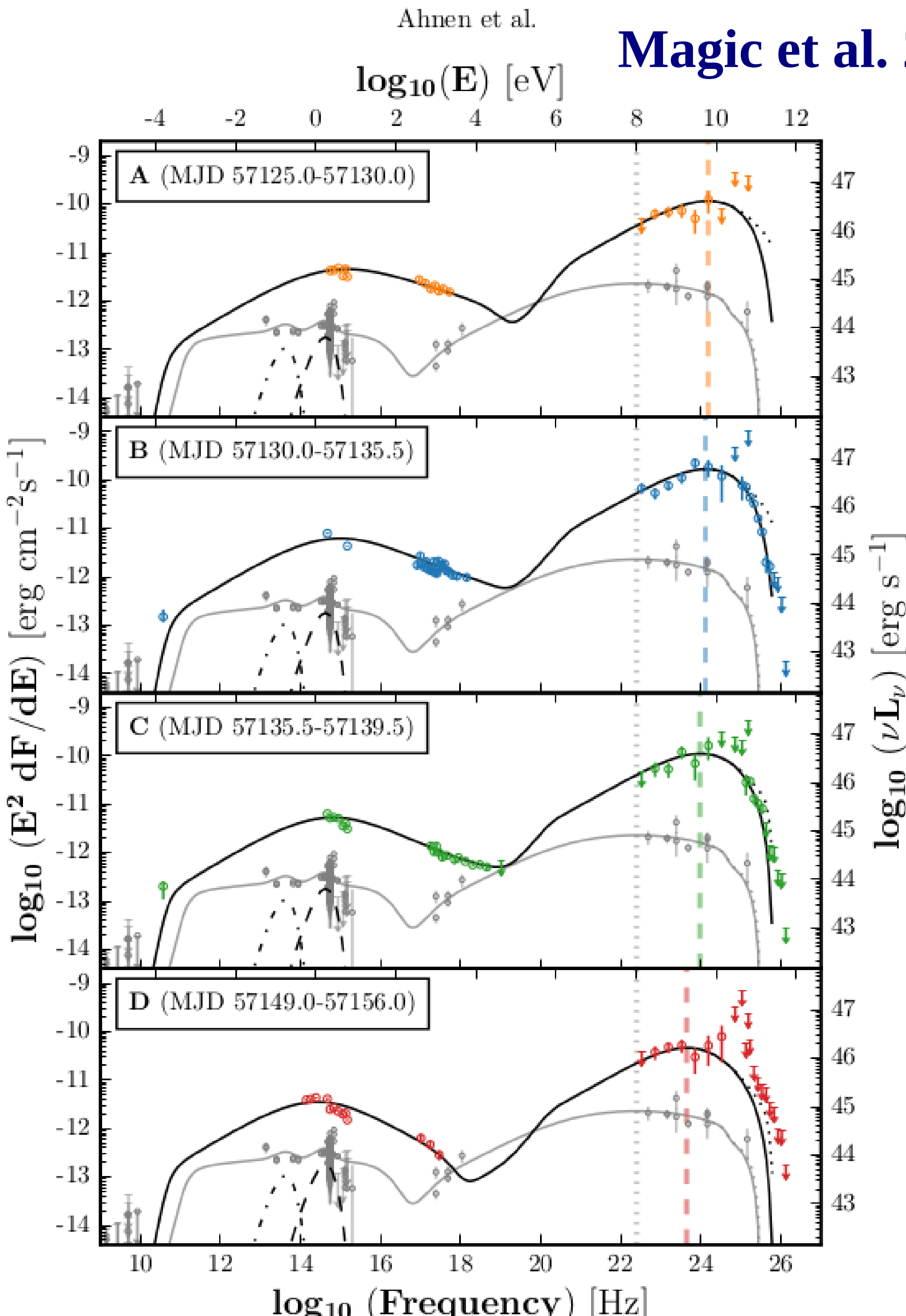


From the broad Mg II line:
$L_{Mg\ II}$=5.4*10^{43} erg/s (Stickel 89)
we derived the BLR luminosity (Celotti 1997)
and in turn the disk luminosity
(we assumed a BLR/disk luminosity ratio 0.1)
L_{disk}=1*10^{46} erg/s

B =6*10^{-3} G
Γ=20
Dist = 7 pc
R=1-1.2 pc
Variability time Scale 30 d, comparable with long term modulation of the light curve, but not with the daily variability.



Magic et al. 2015



PKS 1441+25

z=0.94

L_{disk}~2*10^{45} erg/s

R_{in}^{BLR}~0.05 pc

dist~0.1 pc

A pessimistic evaluation of attenuation (γγ abs + KN) at 100 GeV (sat frame) is < 3

So the emission region must be at the edge or outside the BLR.

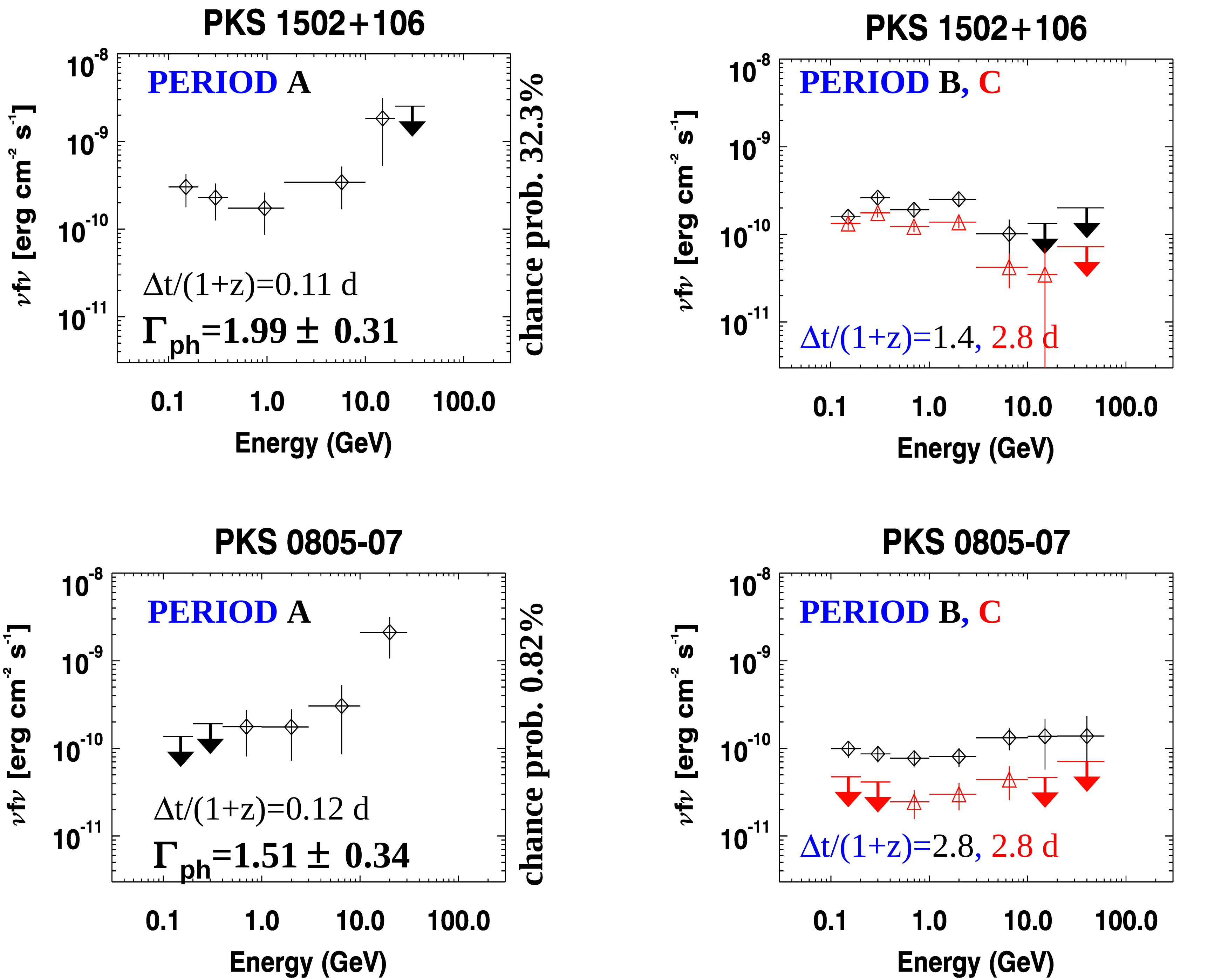
Fast HE flares

From the 4 brightest HE flares we searched for fast variability at HE (E> 10 GeV).

For all these 4 sources we found **short periods (period A)** lasting from **1.5 hours** to less than **6 hours of very bright HE emission and hard spectra.**

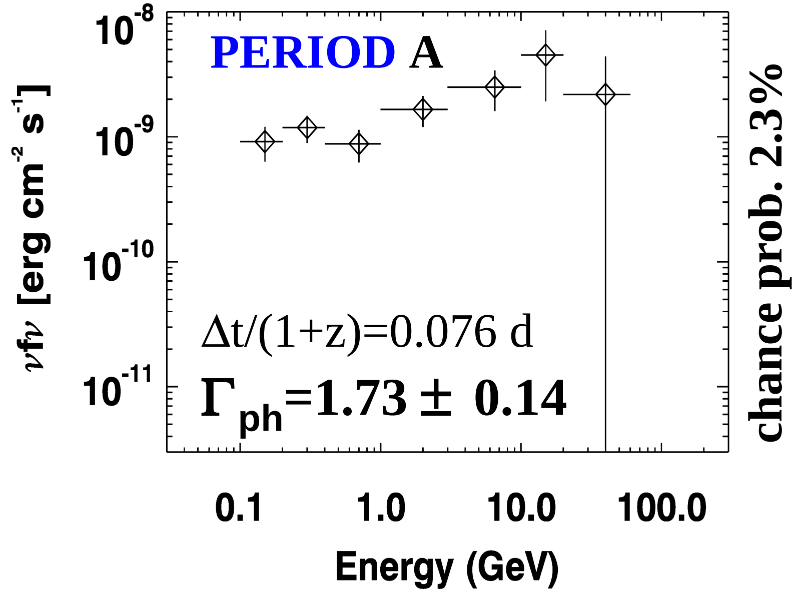
NB: in the following, the gamma-ray photon index of periods A (Γ_{ph}) are **evaluated in** the energy range **0.2-10 GeV** (they are **not biased by the selection criteria**, i.e. the search for bright emission at HE, E>10 GeV)

Fast HE flares and spectral evolution (i)

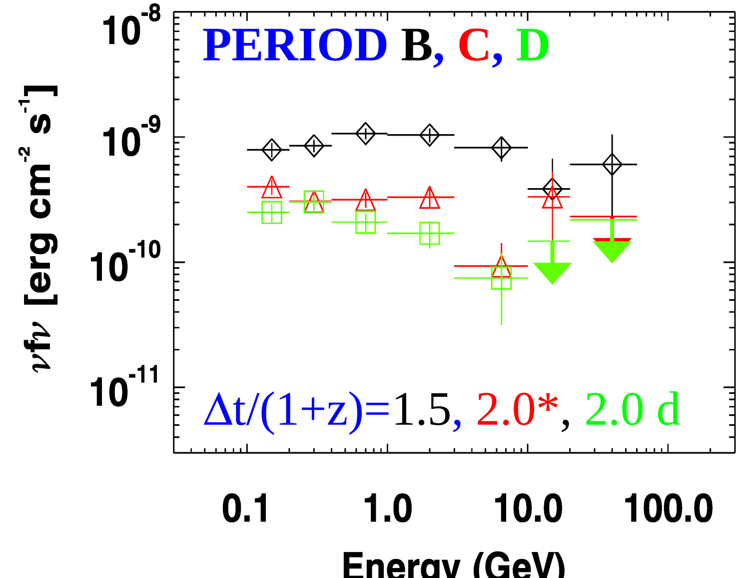


Fast HE flares and spectral evolution (ii)

CTA 102

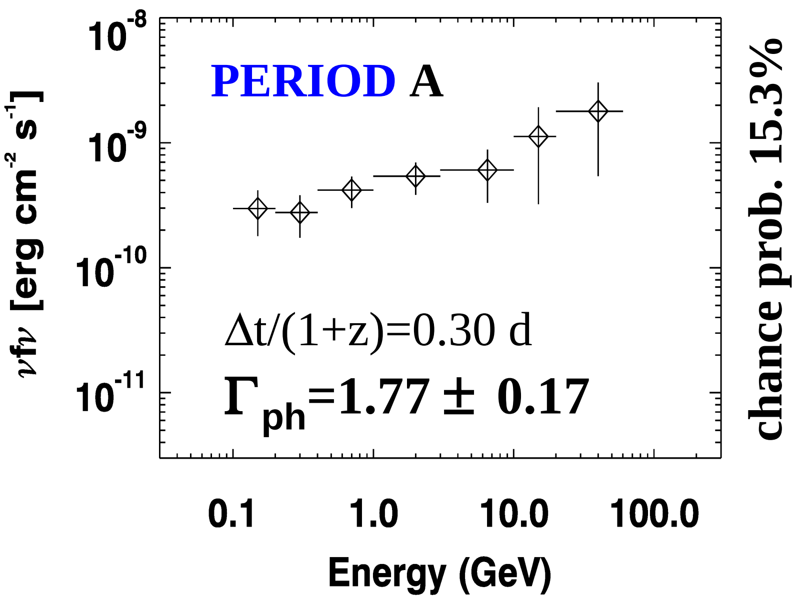


CTA 102

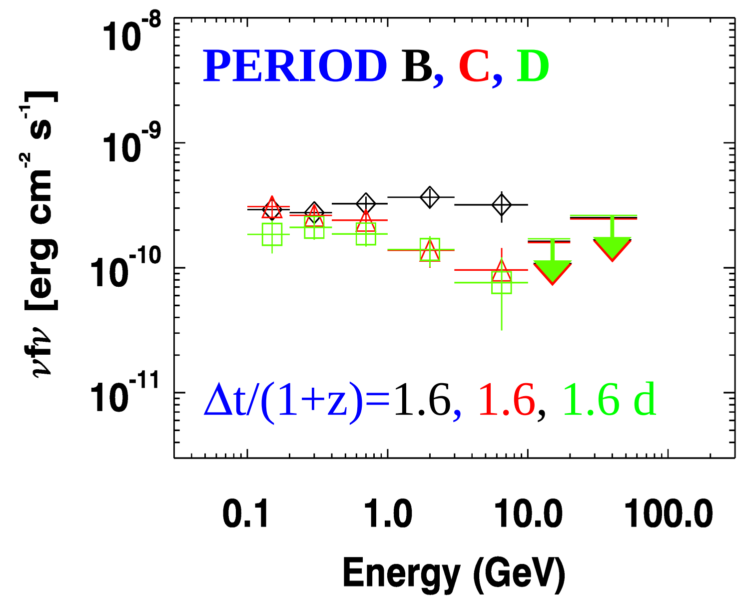


*period C starts 5 d after period B due to a gap in the telemetry

3C 454.3



3C 454.3



Fast HE flares and spectral evolution (ii.j)

CTA 102 and 3C 454.3 gamma-ray spectra of period B are consistent with the slow cooling scenario, with:

low energy Γ_{ph} consistent with Γ_{ph} of period A,

and

$\Delta\Gamma_{ph}$=0.75 ± 0.32 (3C 454.3)

$\Delta\Gamma_{ph}$=0.72 ± 0.35 (CTA 102)

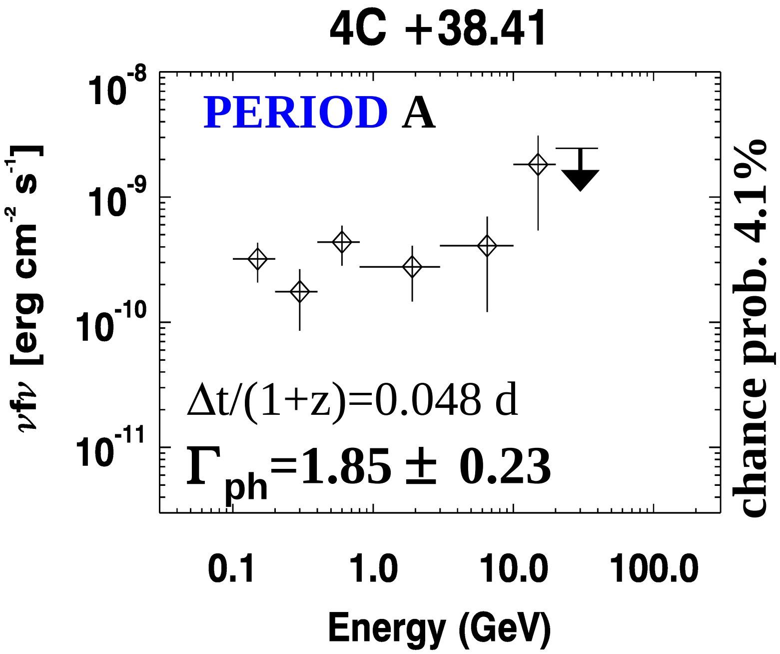
In the dusty torus photon field, the expected cooling time is ~ 1 hour for electrons with γ=30000 (~ 30 GeV EC photons)

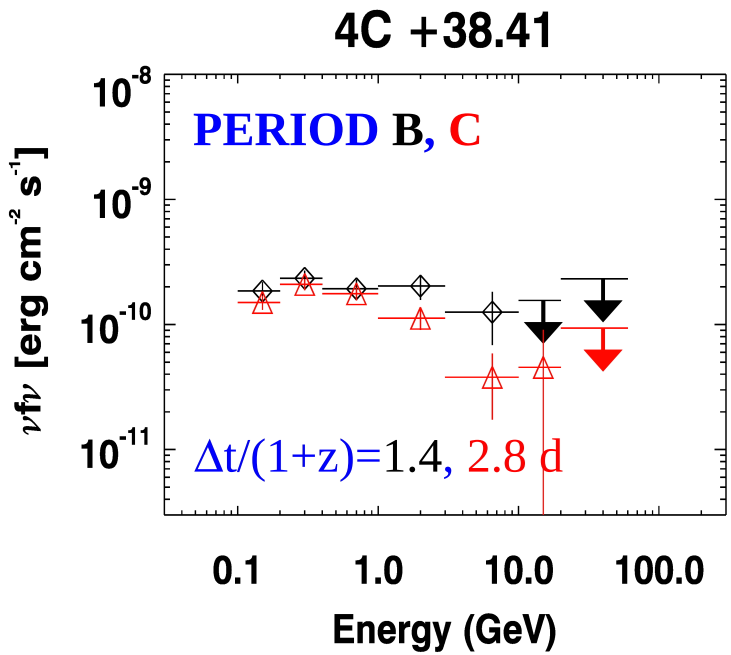
Fast HE flares and spectral evolution (iii)

We have **some** source (B2 1520+031, 4C 38.41, PKS 0250-225) with a **gamma-ray spectrum that mimics the BLR absorption features** proposed in Poutanen & Stern 2010.

We performed the time-resolved spectral analysis for the brightest of these sources: **4C 38.41, revealing a pattern similar to the 4 sources above.**

The absorption like feature of the gamma-ray spectrum integrated on long periods is produced by integrating together the two periods: the hard flare (period A) and its spectral evolution(period B).





The distant scenario

- The bright HE emission witnesses against BLR absorption and Klein-Nishina suppression (for EC on BLR photons)
- The leptonic SED modeling is only consistent with a dissipation region at parsec scale
- The spectral evolution from an hard spectrum is consistent with the slow cooling scenario (chromatic cooling) on Torus seed photons (while the cooling on BLR photons is in Klein-Nishina regime and it is expected to be achromatic).
- **But the CTA 102 light curve** shows a variability pattern which is **inconsistent with slow cooling** (what is the lower activity period in between two higher activity periods, with a duration of 0.5 days?).

what is the engine?

Reasonable engines acting at large distance from the SMBH are:

- Magnetic reconnection (Giannios 2013)
- Turbulence in the jet (Narayan & Piran 2012, Marscher 2014)

Magnetic reconnection scenario

at ~1 TeV:

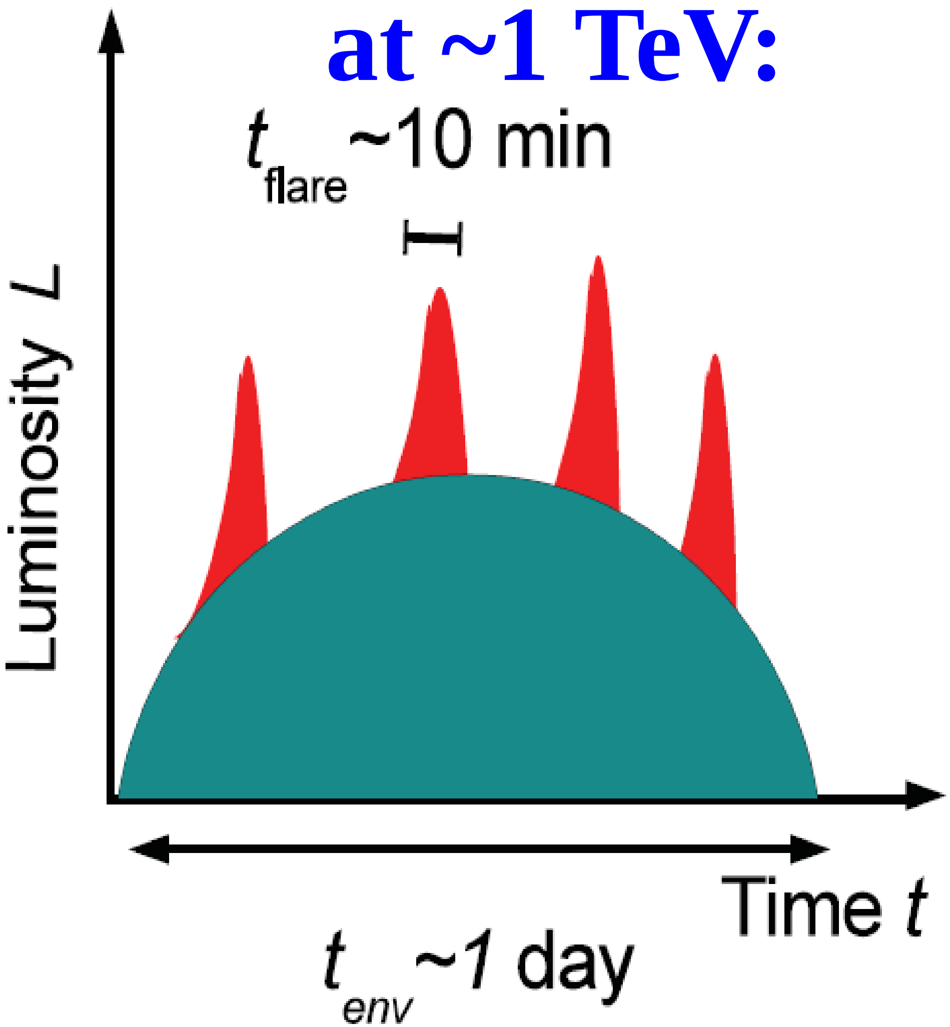


Figure 2. A sketch of the envelope-flare structure of the emission from a reconnection layer. The envelope duration corresponds to that of the reconnection event: $t_{\rm env} = l'/\Gamma_{\rm j}\epsilon c$. Monster plasmoids power fast flares which show exponential rise and last for $t_{\rm flare} = 0.1 l'/\delta_{\rm p} c$. For an envelope of ~1 d blazar flaring, the model predicts that monster plasmoids result in ~10-min flares.

Giannios 2013

Variability time scale from the SED modeling is ~30 d, comparable with long term modulation of the light curve, but we observe also sub-daily variability.

Recent scenario for magnetic reconnections proposed for strongly magnetized jets (Giannios 2013) includes an envelope emission (lasting ~1 day) powered by plasmoids, together with fast flares (lasting ~10 min) generated by grown “monster plasmoids”.

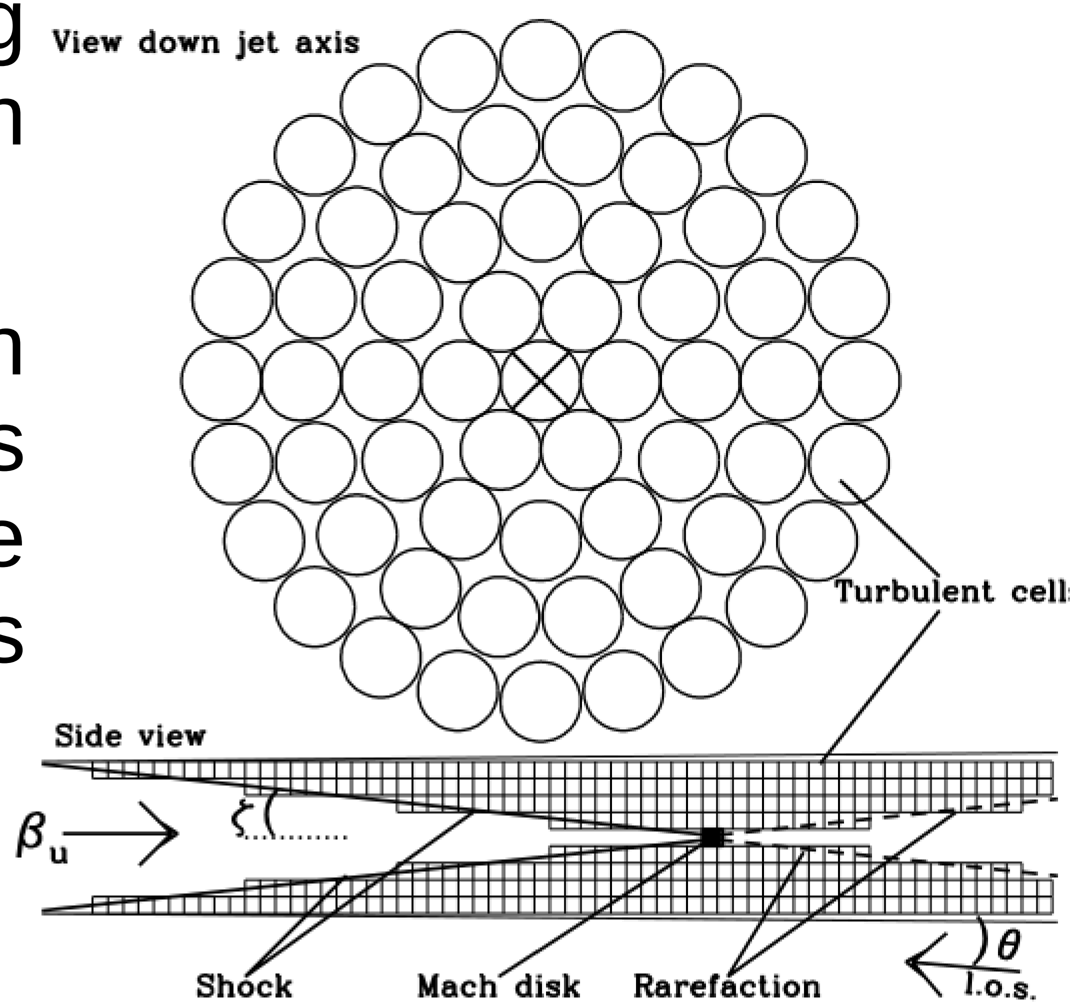
In low magnetized plasma (such as at several parsec), reconnection time scales are longer and longer flares (days to weeks) could arise (Giannios 2013).

“Monster plasmoids” contain energetic particles freshly injected by the reconnection event (Uzdensky et al. 2010)

Turbulence in the jet

electron acceleration is caused by standing conical recollimation shocks.

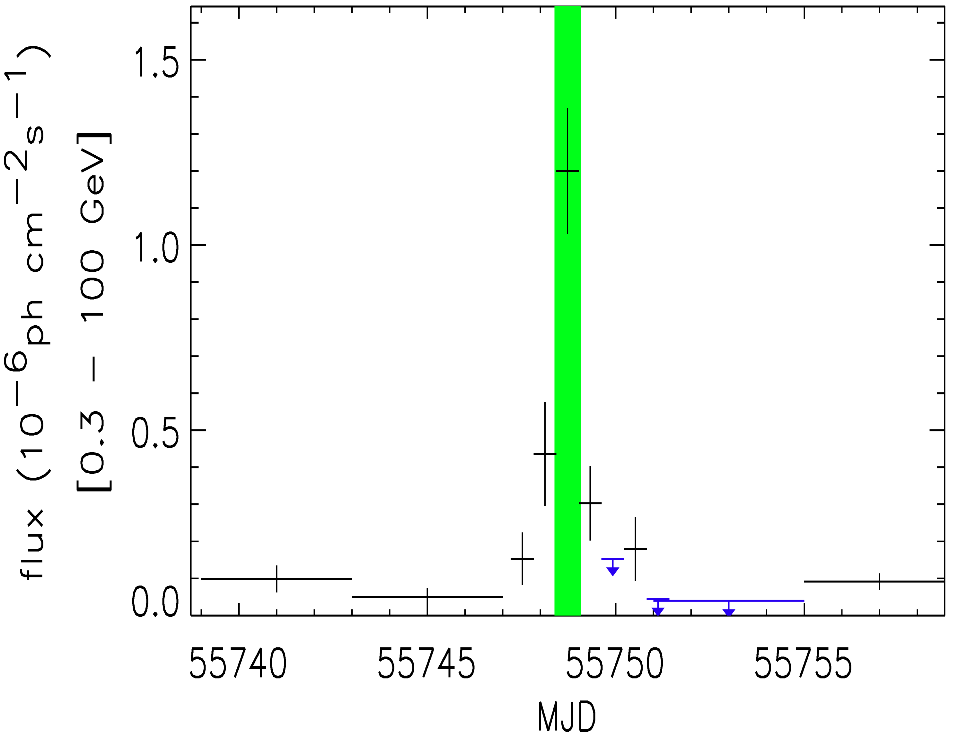
Flux and polarization variability originates from turbulence in the flow, approximated as cilindrical cells

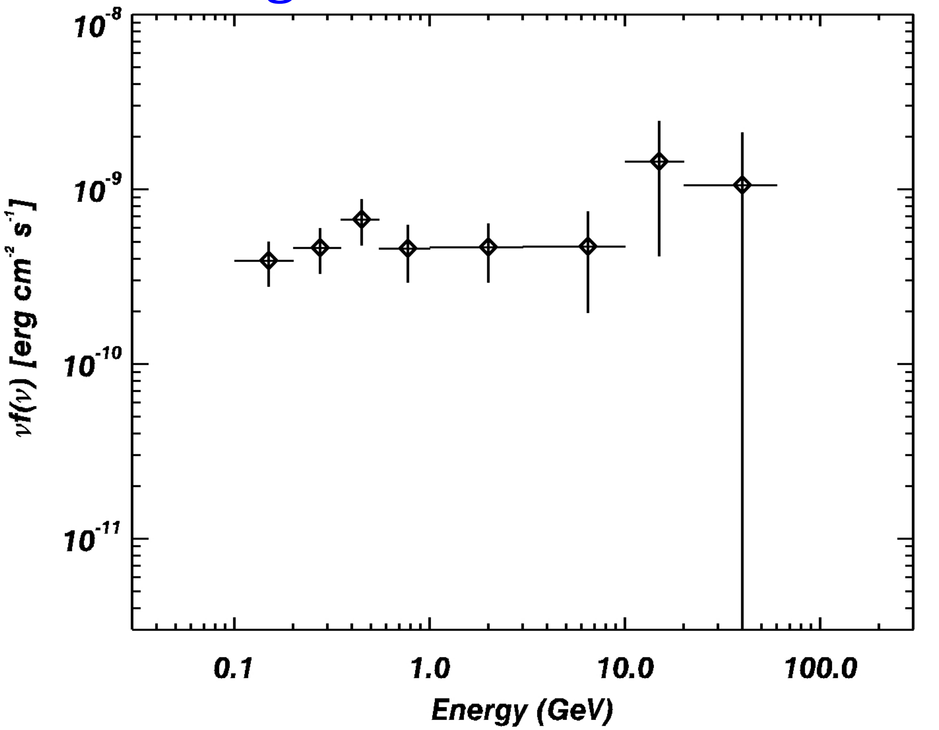


But there are also short HE flares for which the slow-cooling scenario does not work

(we did not had it in the 12 source sample because of the request of simultaneous Swift data)

Z=0.7 , L_{disk}~$1.5x10^{45}$ erg/s





But see also Britto 2015 (3C 454.3 may-July 2015 flares), Hayashida 2015 (3C 279, December 2013 – April 2014).

HOW MANY SOURCES?
HOW MANY FLARES?

Work in progress

HOW MANY SOURCES?
HOW MANY FLARES?

Work in progress

- We slightly changed the search criteria, we scan the FERMI-LAT data sample searching for HE emission from FSRQs (with almost the same method shown before:
  - We defined HE gamma-ray with a threshold
    E_{THR} > min (10 GeV, 20 GeV /(1+z))
  - Selecting periods with HE gamma-ray **counting rate grater than 3 times the average** counting rate
  - **at least 3 HE gamma-rays** (E> E_{THR}) within the period
  - TS > 25 (S/NR > 5) for E > E_{THR}

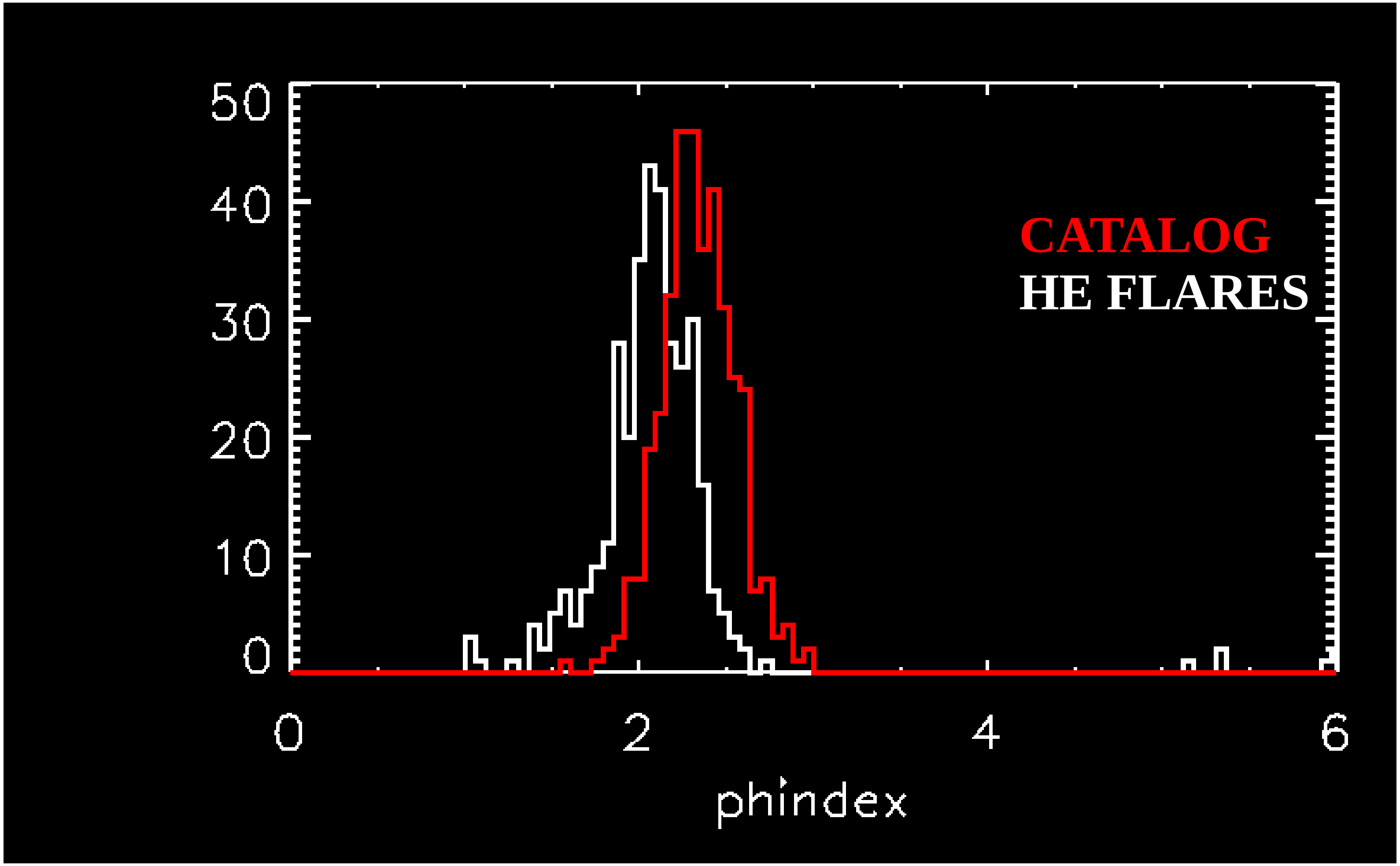
HOW many sources?
HOW many FLARES?

(work in progress)

- We are **investigating** **85 sources**
  - **40 FSRQs with PowerLaw spectrum** from the 2nd FERMI-LAT CATALOG
  - **45 FSRQs with LogParabolic spectrum** from the 2nd FERMI-LAT CATALOG
- for a **total of 275 flares**

PowerLaw photon-index distribution for HE flares (I)

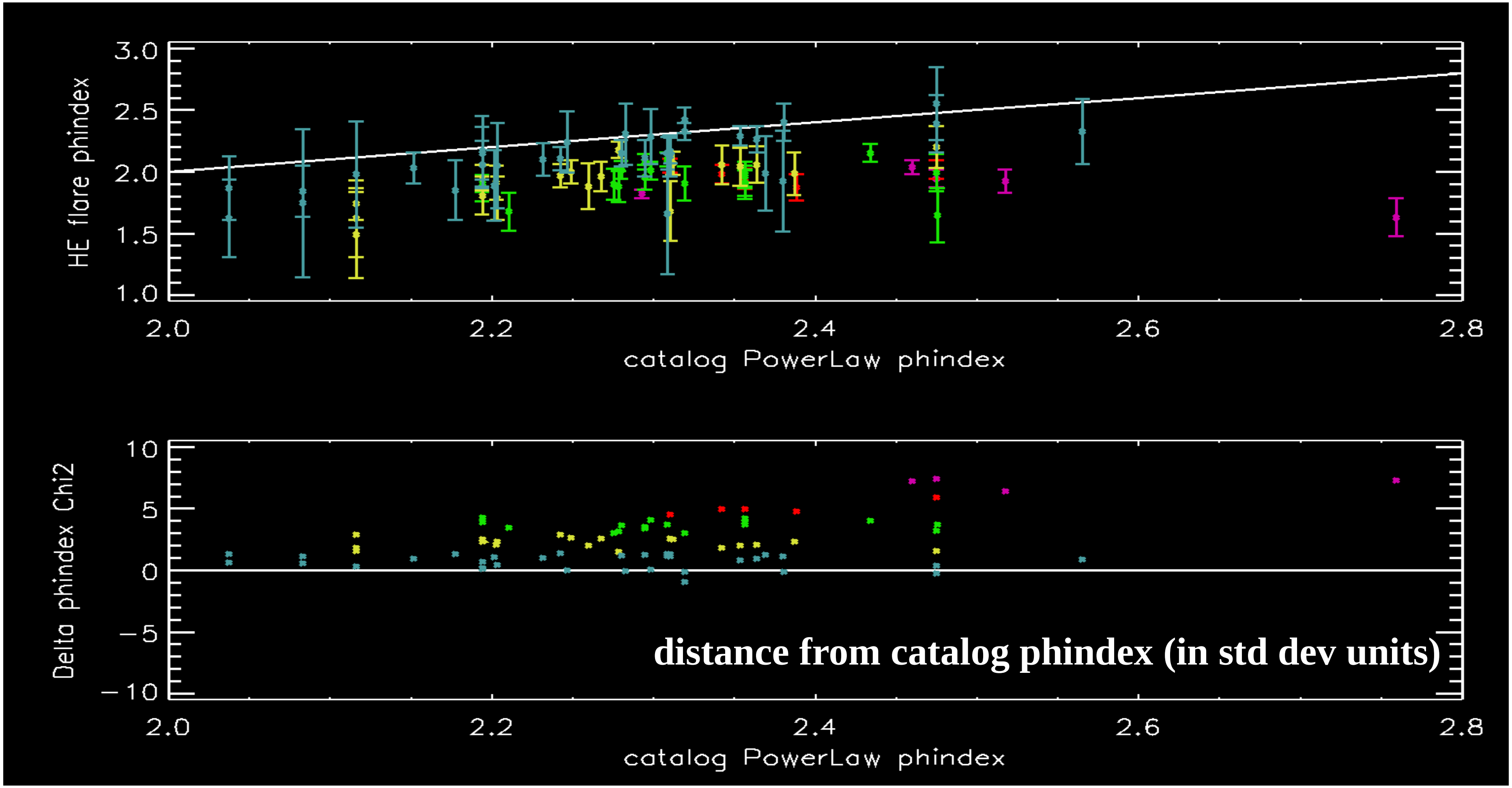
(fitting below E_{THR}: **200 MeV - E_{THR}**)



PowerLaw photon-index distribution for HE flares (II)

(fitting below E_{THR}: **200 MeV – E_{THR}**)

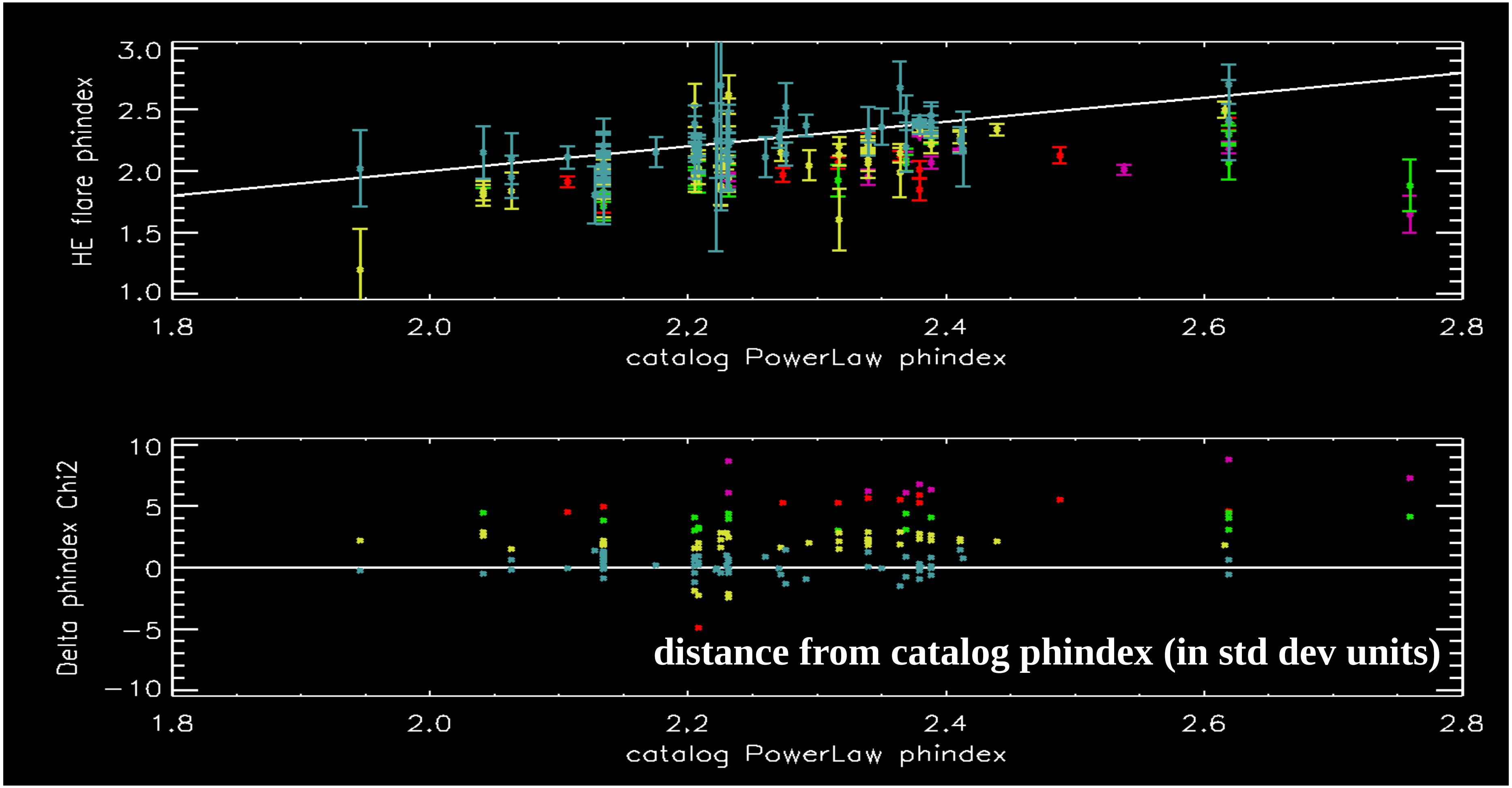
sources with PowerLaw spectrum in the 2nd FERMI-LAT catalog:



PowerLaw photon-index distribution for HE flares (III)

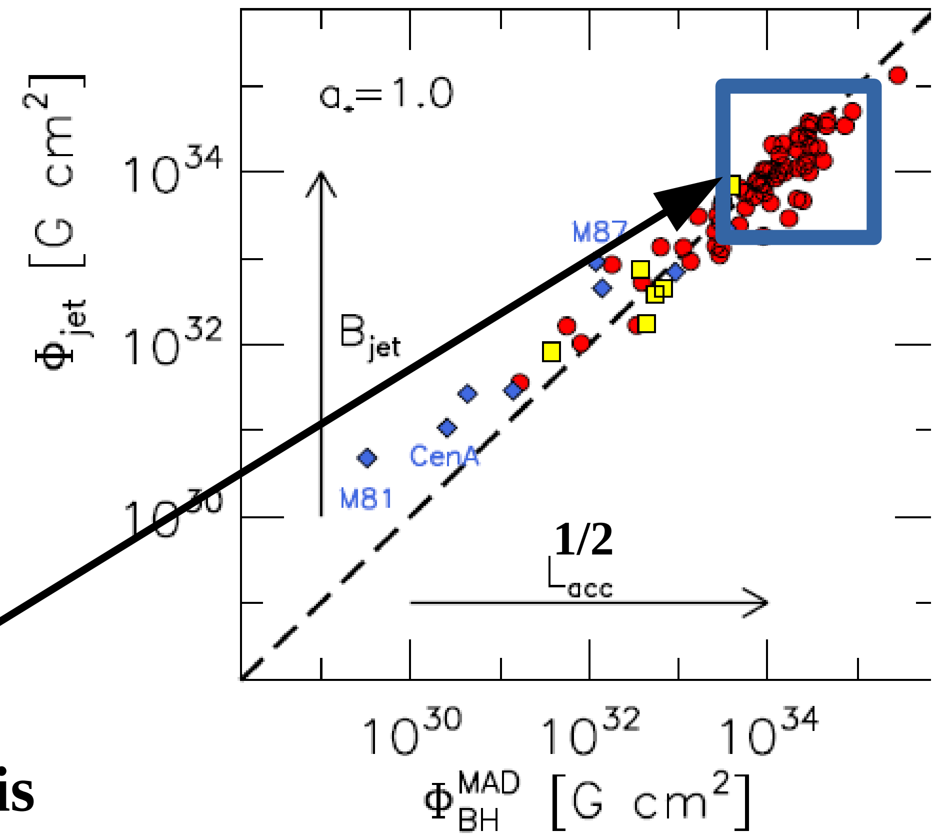
(fitting below E_{THR}: **200 MeV – E_{THR}**)

sources with LogParabolic spectrum in the 2[nd] FERMI-LAT catalog:



Jet B – Accretion connection

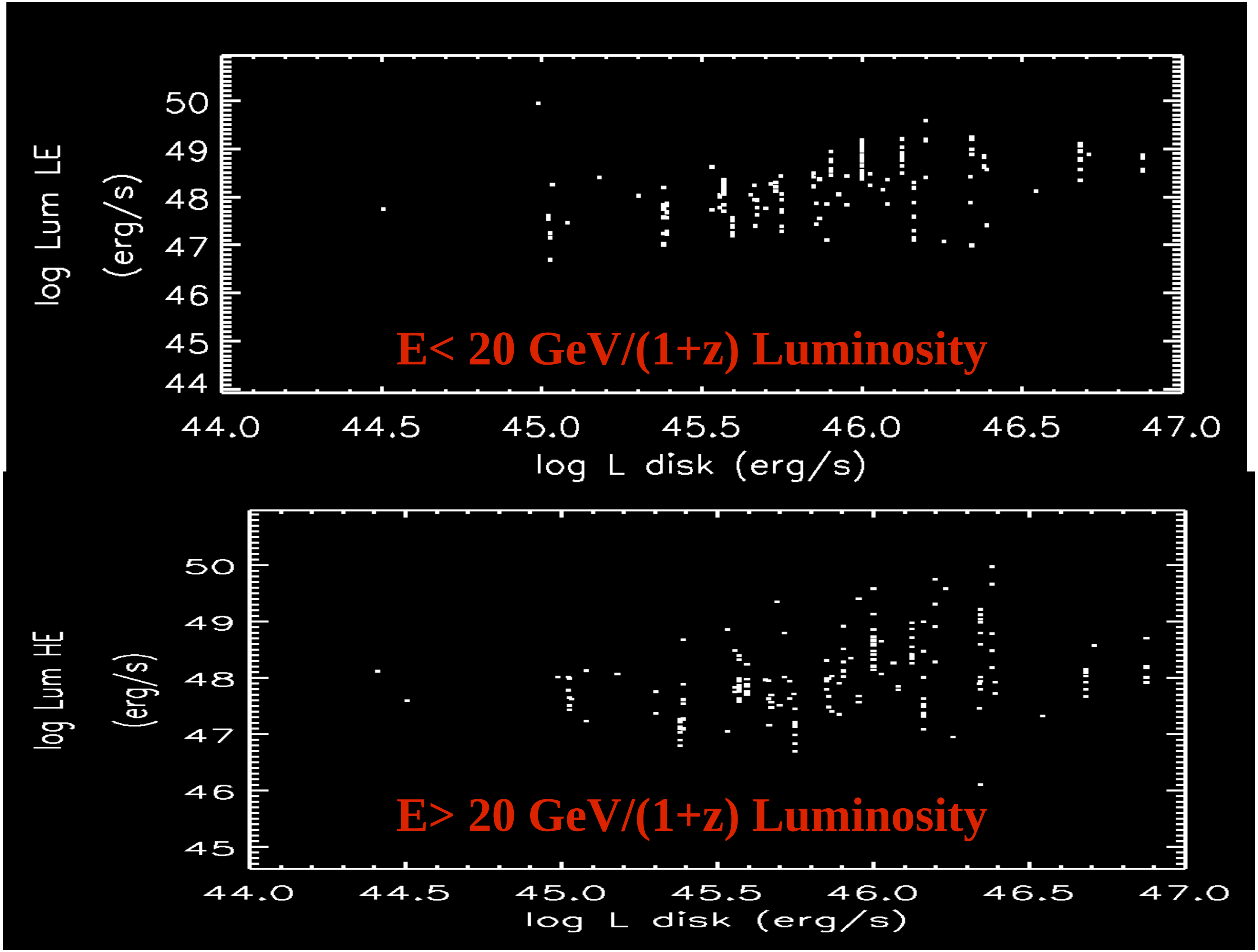
From a sample of
76 Radio Loud AGN
Zamaninasab 2014
evaluated the jet magnetic
field from self absorption
consideration at different
radio wavelength.
Typical distances from SMBH
are of the order of 10^4 r_s.



(Zamaninasab, Clausen-Brown, Savolainen, Tchekhovskoy, 2014, Nature)

We are studying a region like this

HE flares and disk Connection (II)



(See Sbarrato 2014 for the 2 years averaged 0.1-500 GeV gamma-ray Vs Disk luminosity correlation)

HE flares and disk Connection (III)

The prominent HE gamma-ray emission in HE flares suggests their dissipating region is placed toward the edges, or outside the Broad Line Region to avoid gamma-gamma absorption (mainly for bright disks ~10^{46} erg/s)

The Correlations with disk emission requires that the bulk of the HE flares sample is powered or "catalysed" by accretion (by B?) (Narayan 2003, Tcheckhovskoy 2011, Ghisellini 2014)
Does this fact rules out reconnection and turbulences?

Resonably, Zamaninasab 2014, showed that for a sample of 76 Radio Loud AGN the B^2 field at 10^4 r_s correlates with L_{disk}.

Trigger to VHE Cherenkov Telescopes (Mother of ToO proposal to MAGIC Telescope)

- **S3 0218+35 FSRQ? at z=0.944 (Raised both our trigger and FERMI-LAT monitoring**
- **S4 0954+65 BL Lac z=0.368 (Raised both FERMI-LAT monitoring and our trigger Atel #7080, MAGIC triggered first in Optical)**
- **PKS 1441+25 FSRQ at z=0.939 (Raised our trigger, Atel #7416)**
- **S2 0109+22 BL Lac z=0.265 (Raised our trigger, Atel #7844)**
- **We succesfully triggered 2 FSRQs (of a total of 5 FSRQs detected at VHE)**

Some other Trigger had no VHE follow-up due to bad weather conditions or visibility.

Papers and Atels

- L. Pacciani, F. Tavecchio, I. Donnarumma, A. Stamerra et al., 2014, ApJ, 790, 45 (**10 FSRQs**)
- F. Tavecchio, L. Pacciani, I. Donnarumma, A. Stamerra et al., 2013, MNRAS, 435L, 24 (**1 FSRQ)**
- L. Pacciani, I. Donnarumma, K. D. Denney, et al., 2012, MNRAS, 425, 2015 (**1 FSRQ**)
- ATEL 6086, 6165, 7267, 7402, 7526, 7588, 7783, 7844, 8323

Due to the large amount of usefull triggers to High Energy AstroPhysics community, we are going to share new incoming triggers on a webpage without restrictions

Conclusions

- We discussed **12 flare candidates with MWL data (but we triggered ~47 HE flares ToO within the last 2.5 years)**
- Gamma-ray spectra, MWL SED modeling, and spectral evolution are consistent with a **dissipation region at parsec scale**
- we identified **short periods** lasting 1,5-6 hours characterized by **hard gamma-ray spectra**.
- for those 12 FSRQs the following period corresponds to a **cooling phase?**
- Anyway we identified **other HE flares characterized by a faster Light Curve development** in the whole FERMI-LAT band (within less than a day).

  But see also Britto 2015 (3C 454.3), Hayashida 2015 (3C 279).
- recollimation and turbulence models could account for the acceleration at pc scale
- The HE trigger method allowed for the **discovery of VHE emitting FSRQs** up to redshift 0.94.

- There are a huge number of gamma-ray FSRQs (**85 sources**), showing HE flares (**275 HE flares**).
- Their **HE flaring luminosity correlates with disk luminosity.** **Does it rules out the reconnection scenario?**
- Does the **shortest HE flares** confirms the previous picture, being the intermediate cases of **flares dissipating within the BLR shell, near the outer edge**?