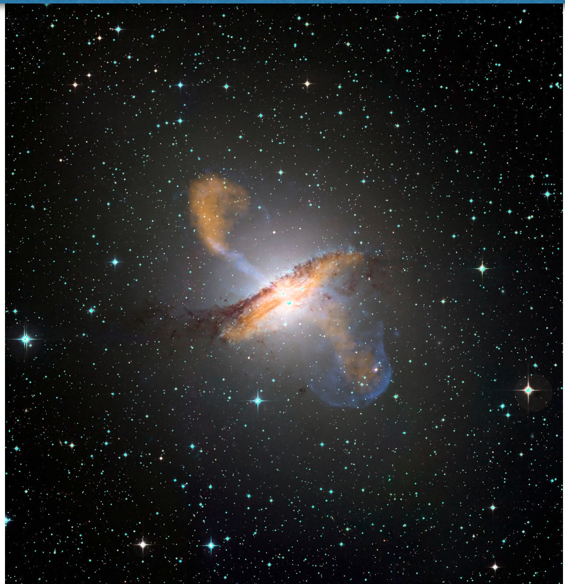
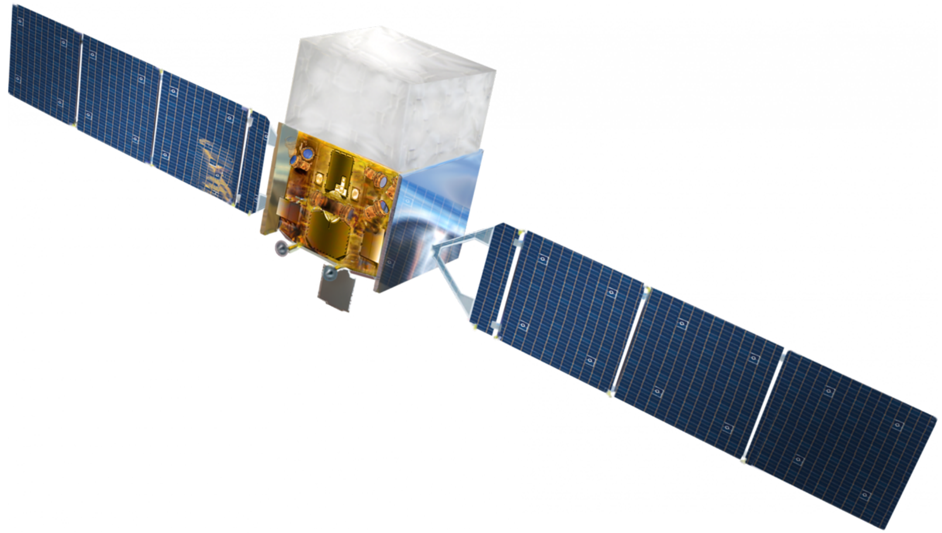
Implications of observed short-timescale gamma-ray variabilities on blazars jets





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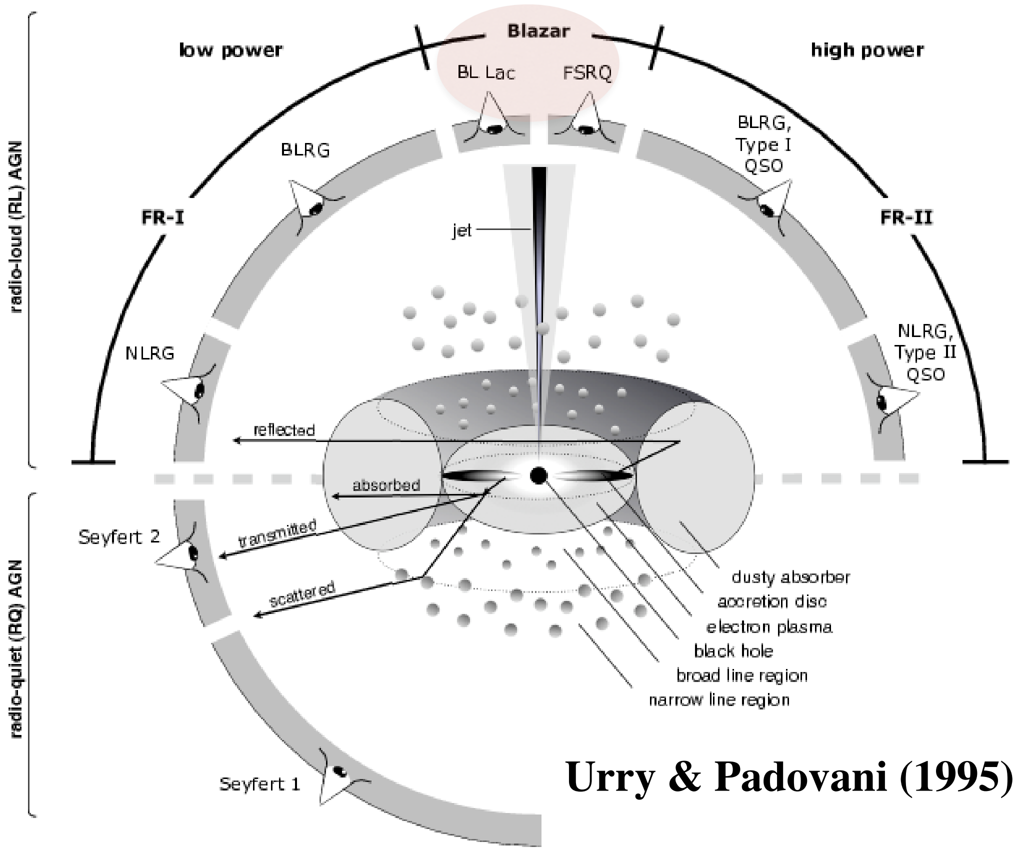
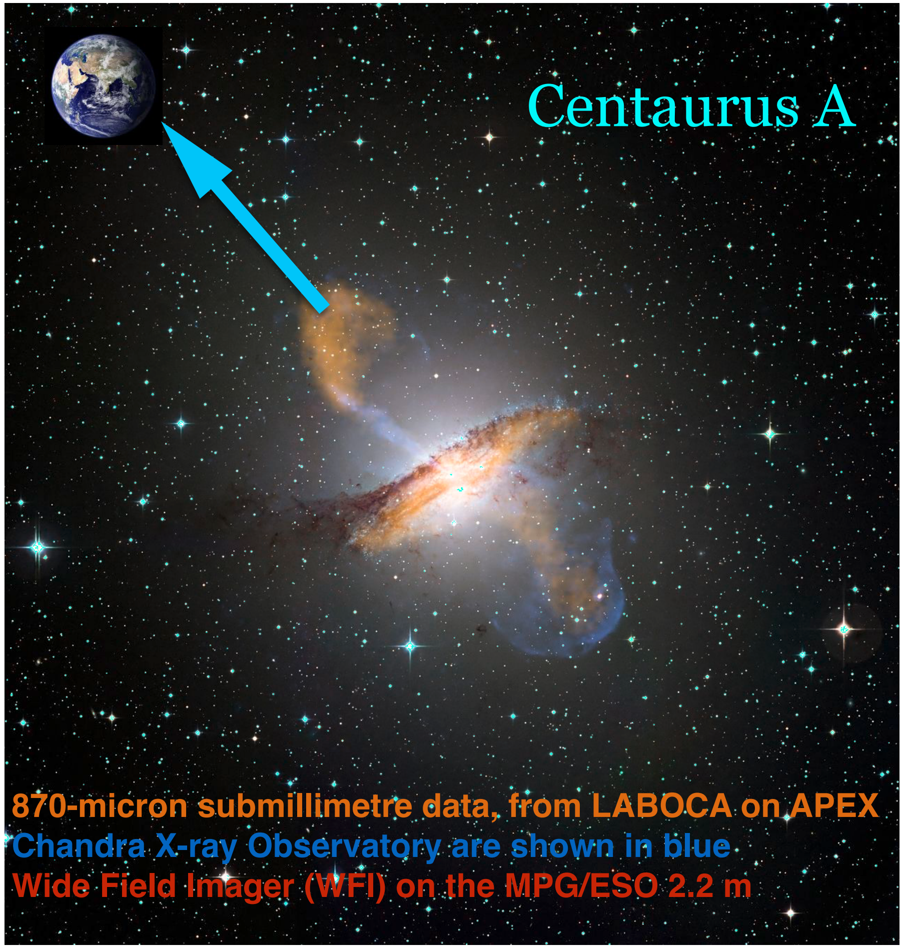
ASTROPHYSIK

Active Galactic Nuclei & Blazars

- AGN are the sub-class of galaxies which emit extremely luminous emission from the nuclear regions of the galaxy.
- They are powered by accretion of matter onto super massive black-hole.
- They are classified by their pointing directions in unified model of AGN.

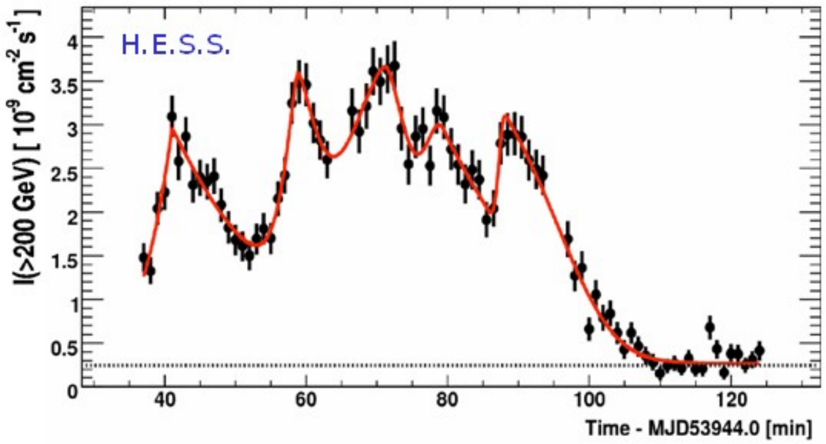


Urry & Padovani (1995)



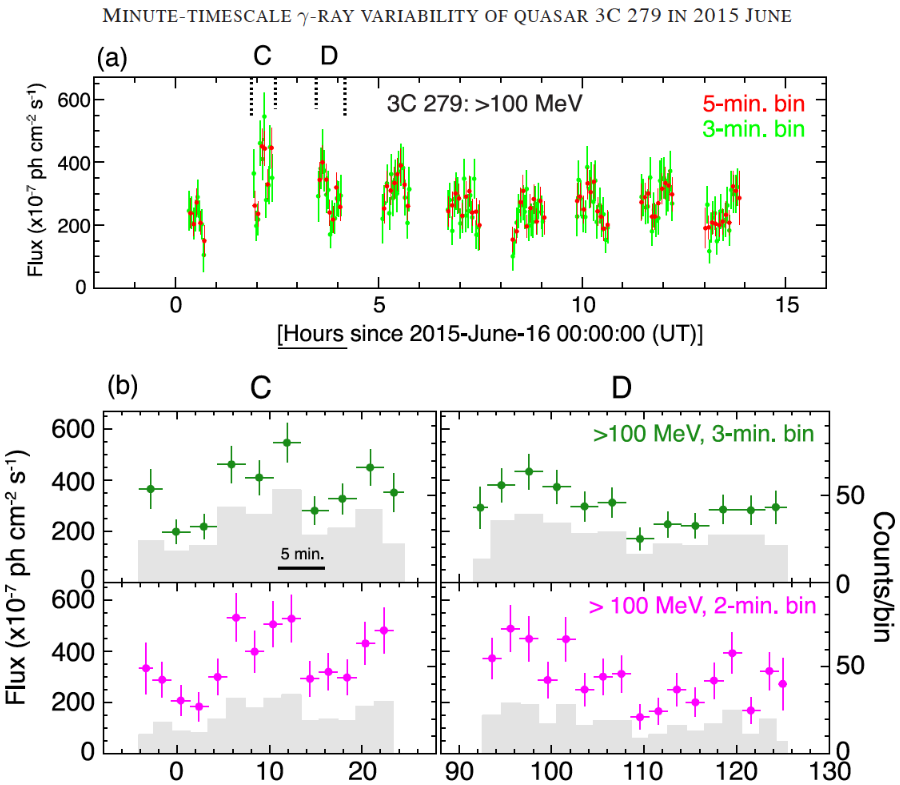
Rapid variability in Blazars

PKS 2155-304 (BL Lac)



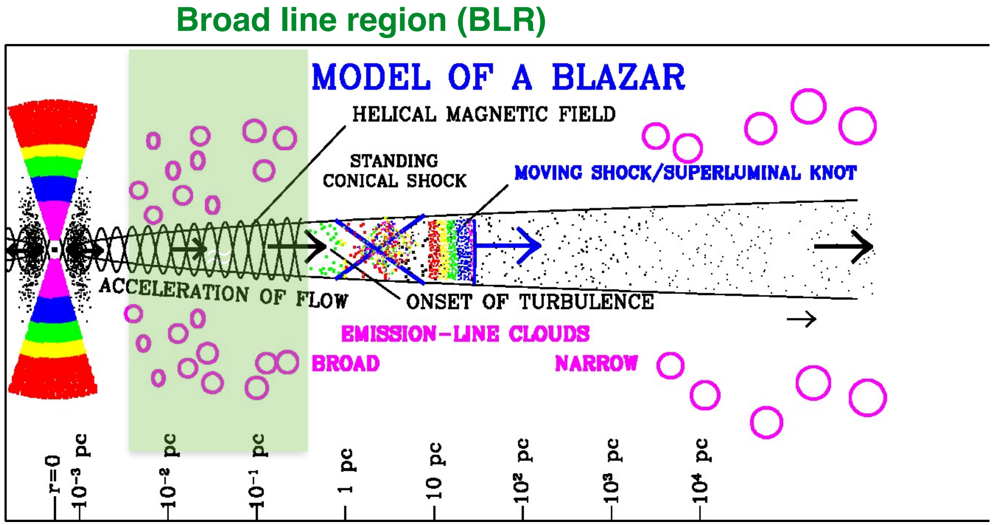
Aharonian, F. et al 2007 , ApJL

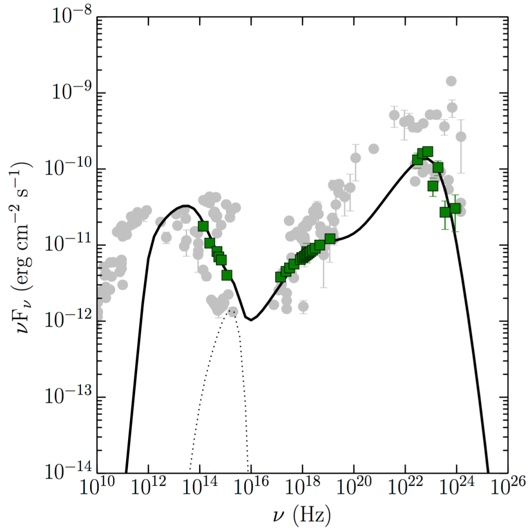
3C 279 (FSRQ)



Ackermann, et al 2016, ApJL

The location of gamma-ray emission in FSRQ ?



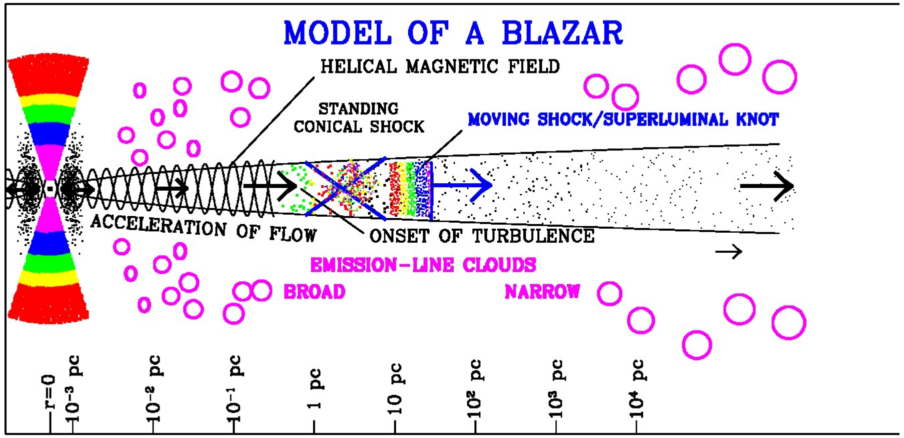


- The recent observations of a few FSRQs (PKS 1222+216, 3C 279, PMN J2345-1555, PKS 1510-089) (Aleksi´c et al. 2011 ; Abdo et al. 2010 ; Hayashida et al. 2012 ; Ghisellini et al. 2013 ; Nalewajko et al. 2012, Lindforset al. 2005) show that gamma-ray emission can occur much farther down in the jet, up to few pc from the central super massive black hole (SMBH).

- "Origin of gamma rays in Fermi blazars: beyond the broad line region (106 blazars)", Costamante et al 2018

- Detection of fast variability in FSRQs such as 3C 279 (Ackermann et al. 2016) and PKS 1222+216 (Aleksi´c et al. 2011) poses additional constraints.
    - Inside BLR : gamma ray absorption
    - Outside BLR: Lack of seed photons for IC scattering to produce a strong Compton hump

Plausible explanations of minute scale variability



- **Main issue with detection of rapid variability**
  - **Internal VHE gamma-ray absorption by the co-produced synchrotron radiation.**

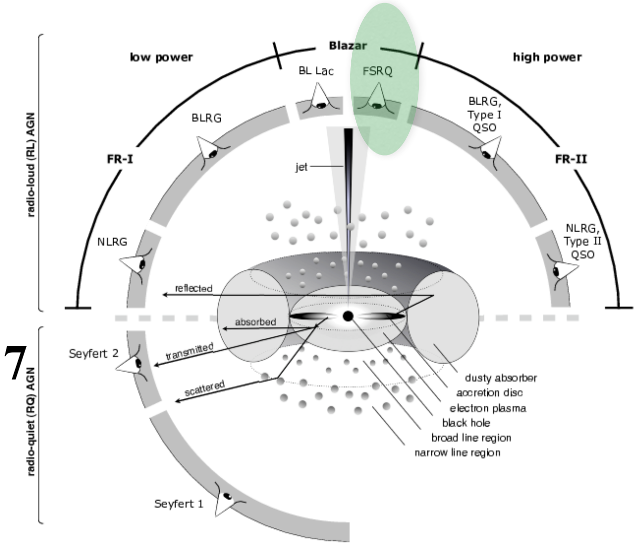
Solution: Proposed jet models to explain rapid variability in blazers

- **A very large Doppler factor for (Mrk 501 & PKS 2155-304)**
  - **$\Gamma \geq 50$ (Not yet observed)**
- **Plasma instabilities (Mrk501 & PKS 2155-304)**
  - **Problem with total jet power and only explains decay part of the flare**
- **Star or Cloud interaction (Mrk501 & PKS 2155-304)**
  - **P-P or P-Gamma interaction (Problem with Proton cooling time scales)**
- **Magnetospheric gap model (IC 310)**
  - **Pulsar-like particle acceleration by the electric field across a magnetospheric gap (Problems with total power (energy budget of the jet))**

In case of FSRQs : Additional photon fields such as BLR, disk or torus are present

No fast variability is expected from FSRQs with high energy photons (>10 GeV)

CTA 102 and 3C 279



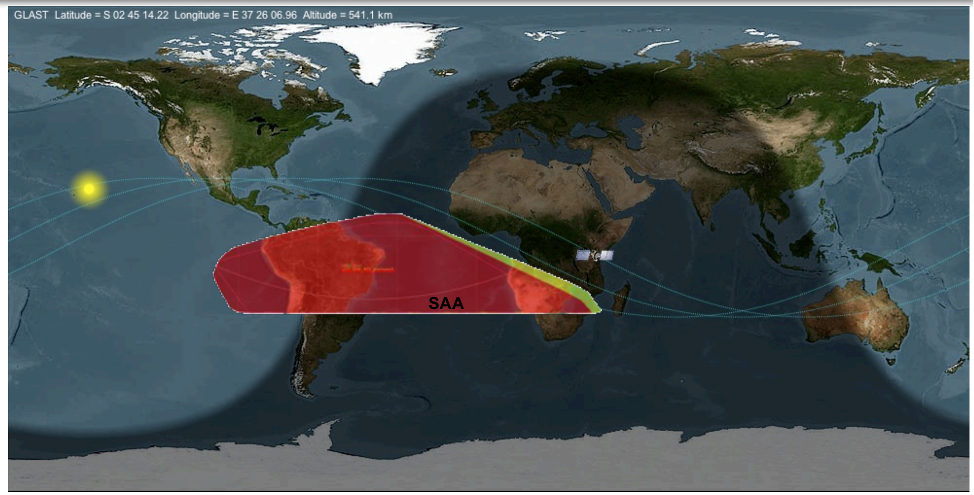
- **CTA 102 and 3C 279 —> FSRQ**

- **CTA 102 showed few bright gamma-ray flares during 2016-17**

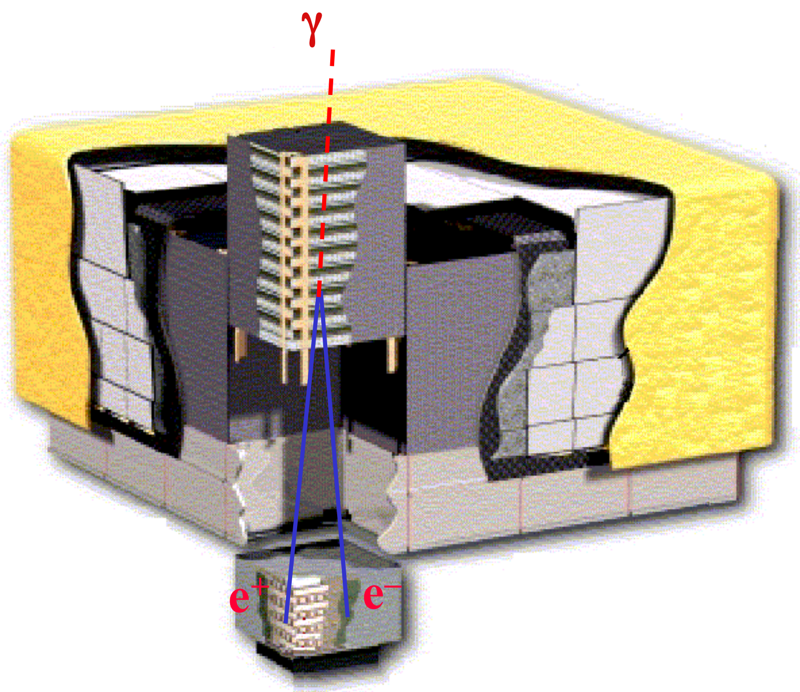
- **Both are high redshift sources**
  - **CTA 102 : z=1.037**
  - **3C 279 : z=0.536**
- **Black hole mass**
  - **CTA 102 : 8.3** $\times 10^8 M_\odot$

  - **3C 279 : 3-5** $\times 10^8 M_\odot$

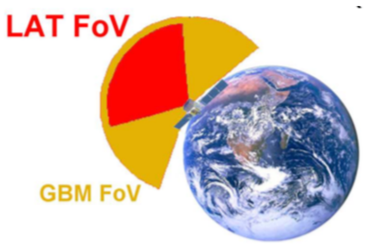
Fermi-Large Area Space Telescope (LAT)



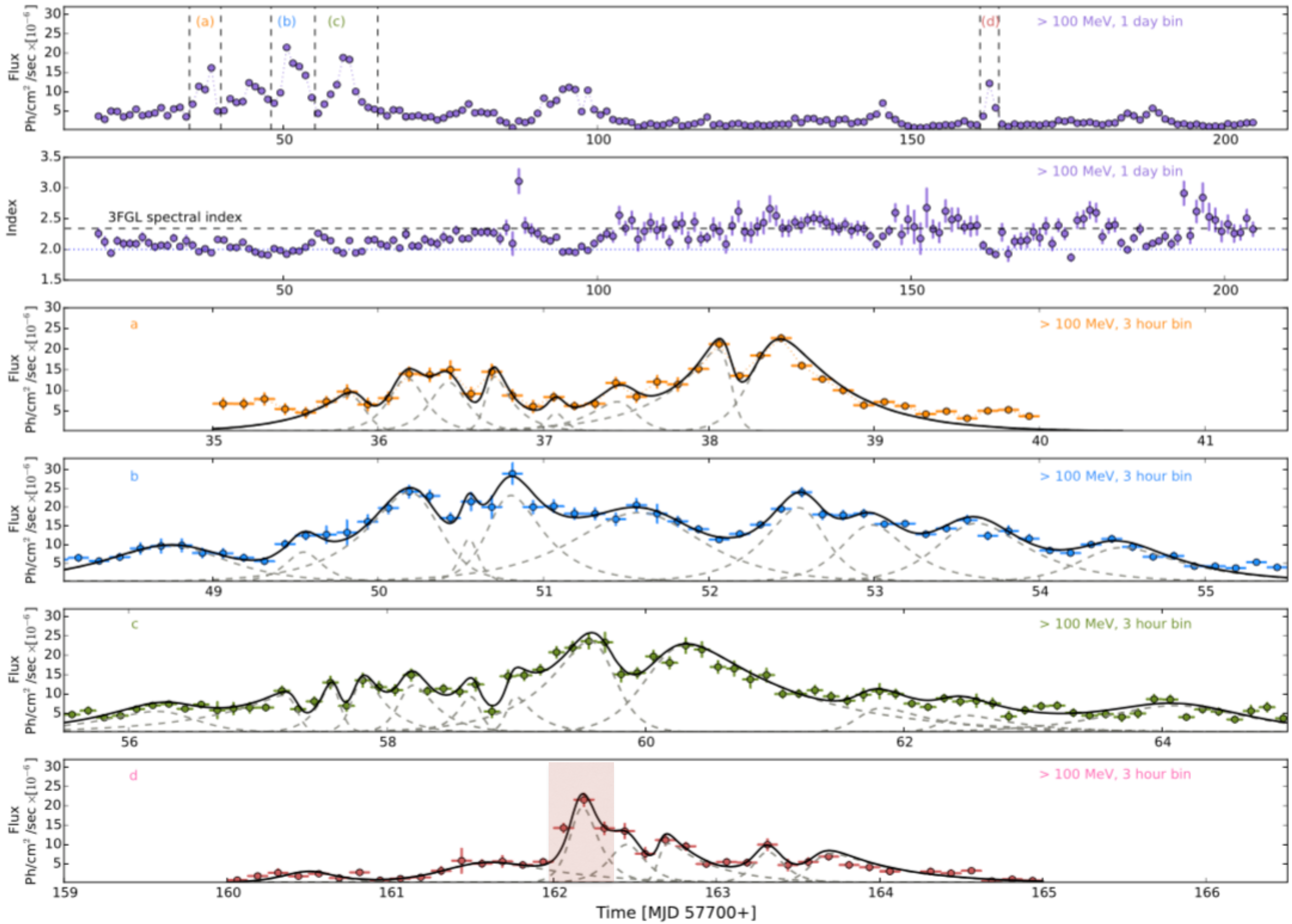
- **Energy range ~ (20 MeV – 300 GeV)**
  - Circular orbit, 565 km altitude (96 min period), 25.6 degrees inclination
  - LAT is a pair production telescope
    - •High-resolution converter trackers (silicon-strip tracking detectors)
    - •CsI(Tl) crystal calorimeter



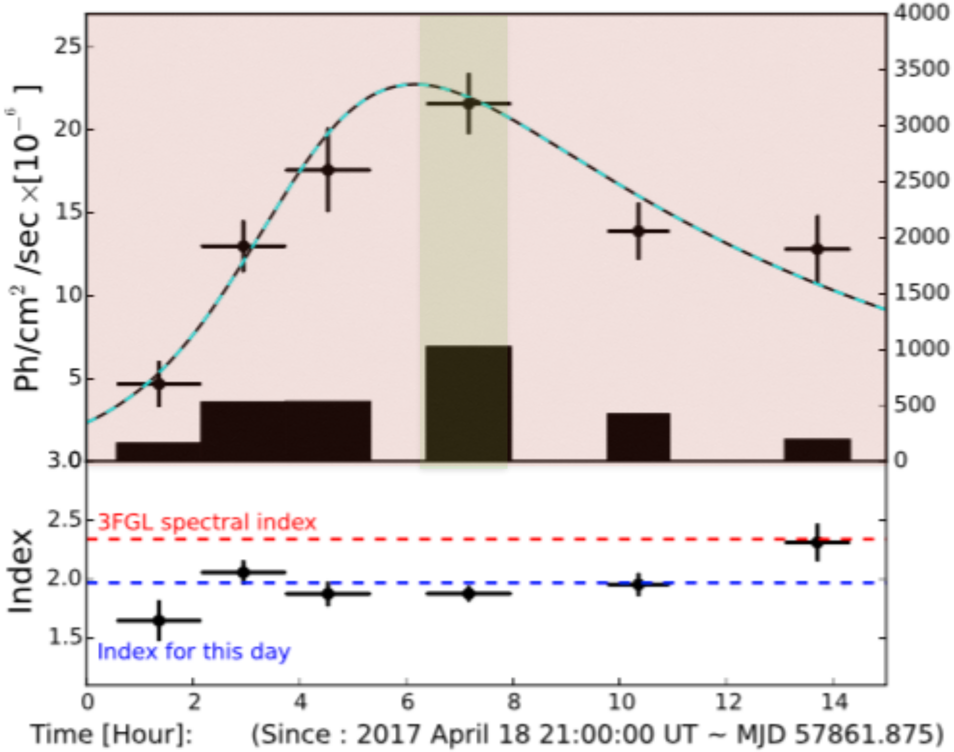
- **Feld of view ~2.5 sr**
  - Effective area is about 7000 cm^2 at 1 GeV
  - PSF : 68% containment radius of 3 degree at 100 MeV and 0.04 degree at 100 GeV



Fermi-LAT Light curve during Dec.16 -May 17 Intra-day variability CTA 102



Sub-horizon scale variability in flare "C"



$$\tau_d = \Delta t \times ln2/ln(F_1/F_2),$$

Flux doubling time scale ~ 30 min in source frame

Size of event horizon for CTA 102 for maximally rotating BH ~ 70 min
spin zero BH ~ 140 min

A strong hint of rapid variability is observed

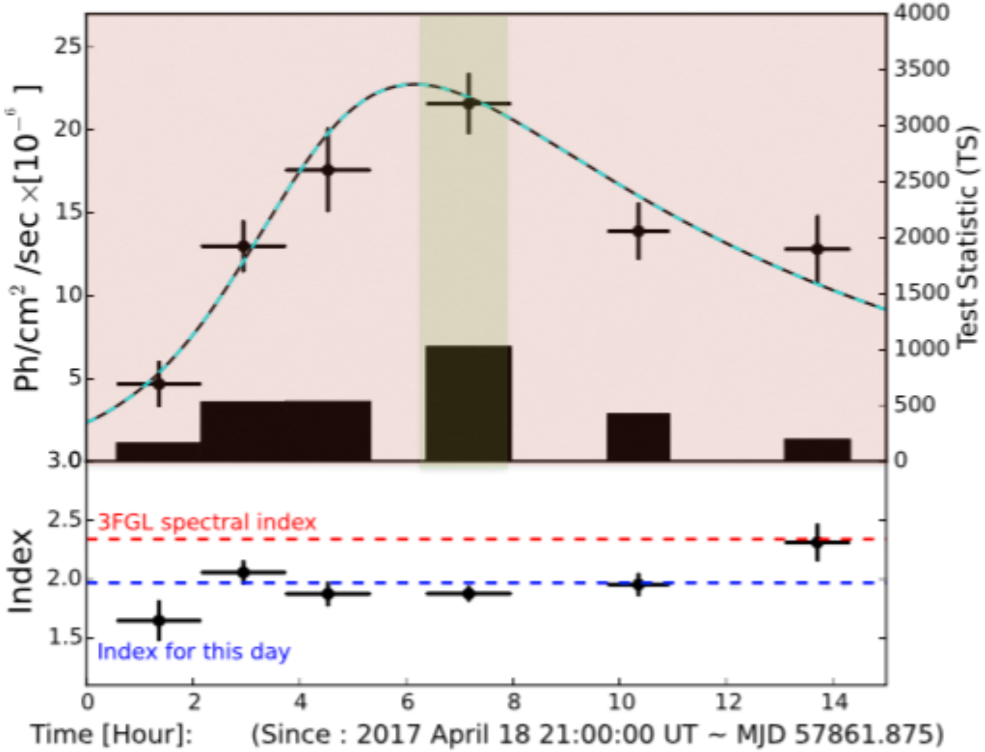
Flux halving time scale ~ 3 min with 4.7 sigma in source frame

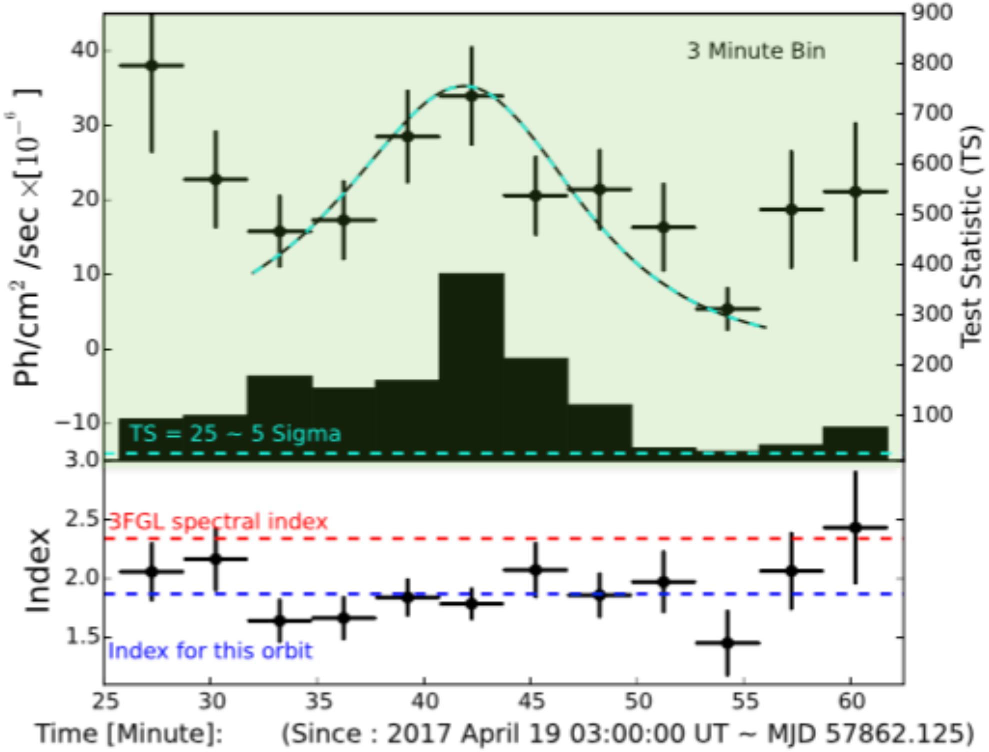
p=0.0011 value for a constant flux

Shukla et al 2018, ApJL, 854:L26

- **Several photons above 10 GeV including two ~ 25 GeV photons were observed**

Sub-horizon scale variability in flare "C"





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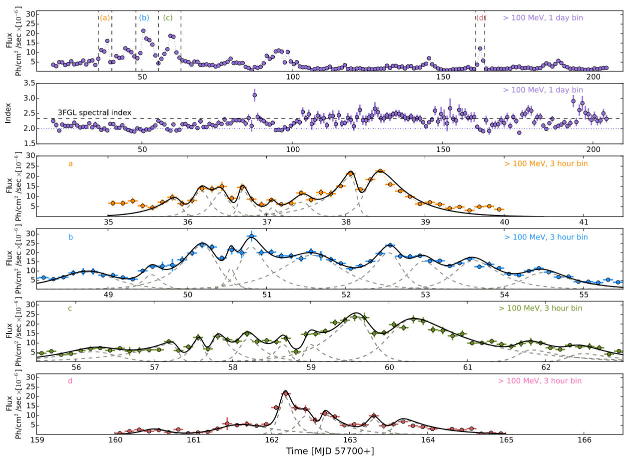
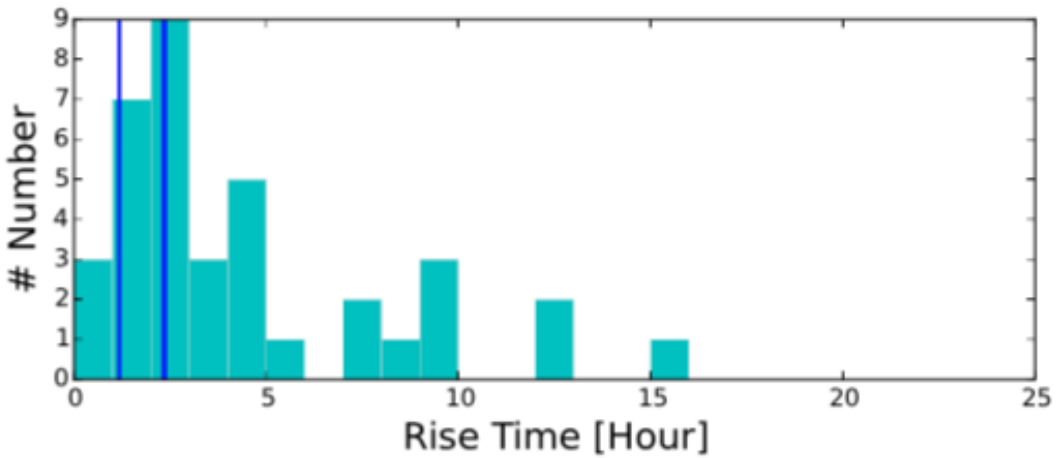
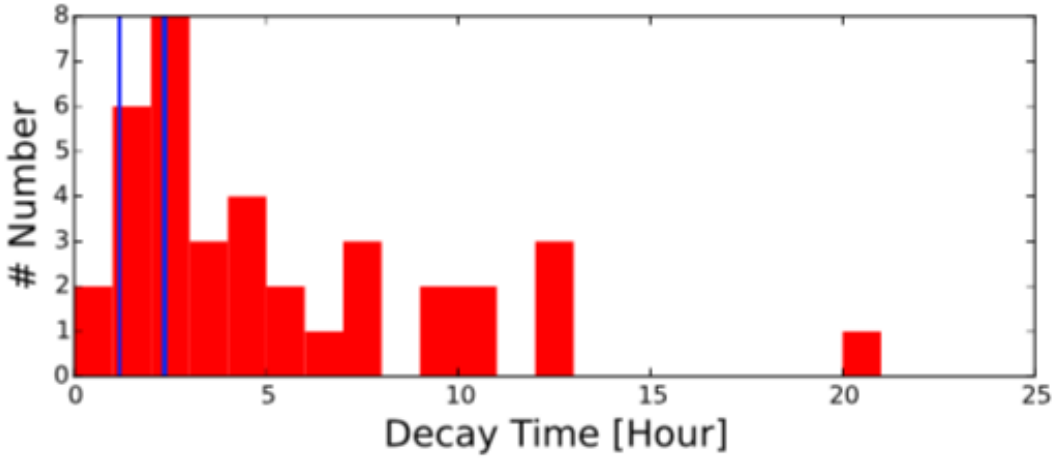
Rise and decay time distribution

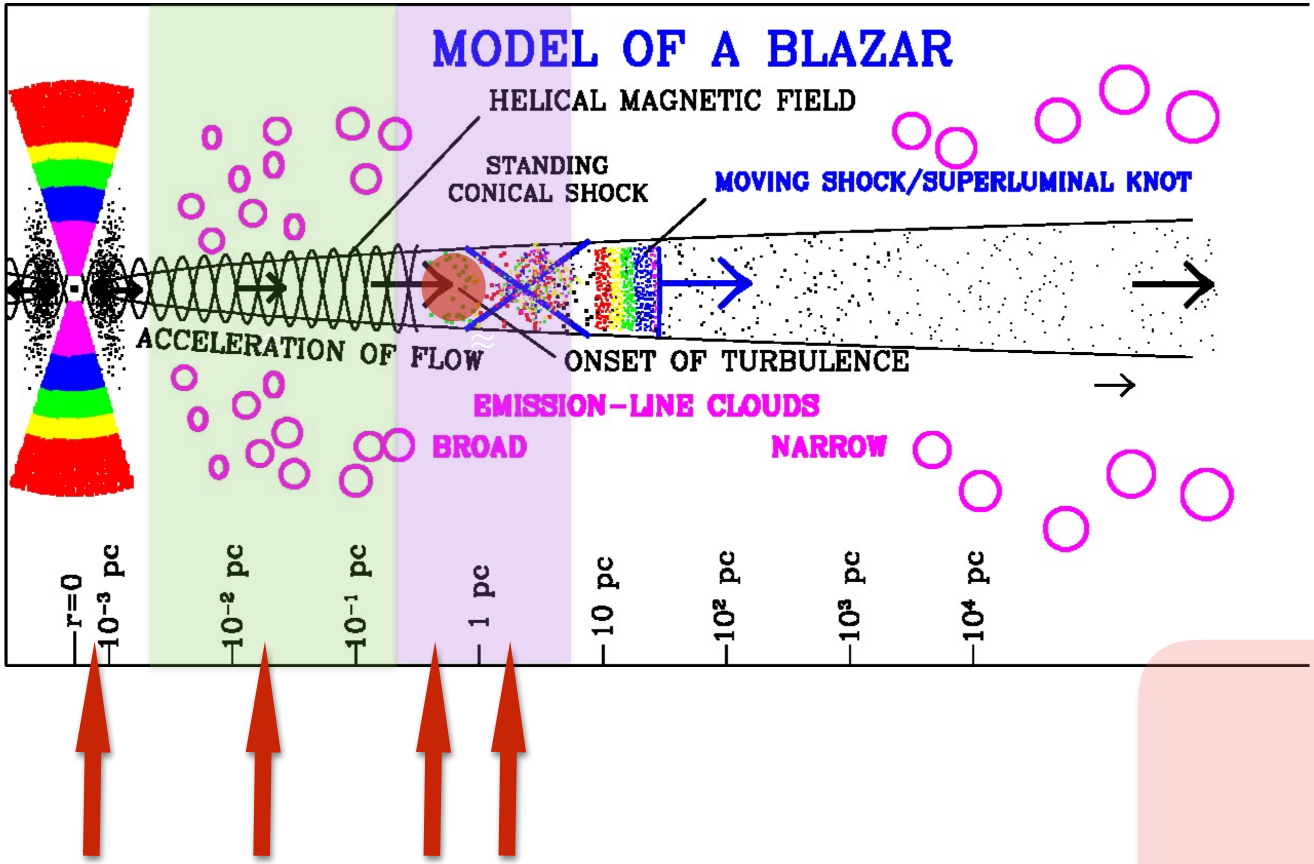
$$F(t) = 2F_0[exp(\frac{t_0 - t}{T_r}) + exp(\frac{t - t_0}{T_d})]^{-1}$$

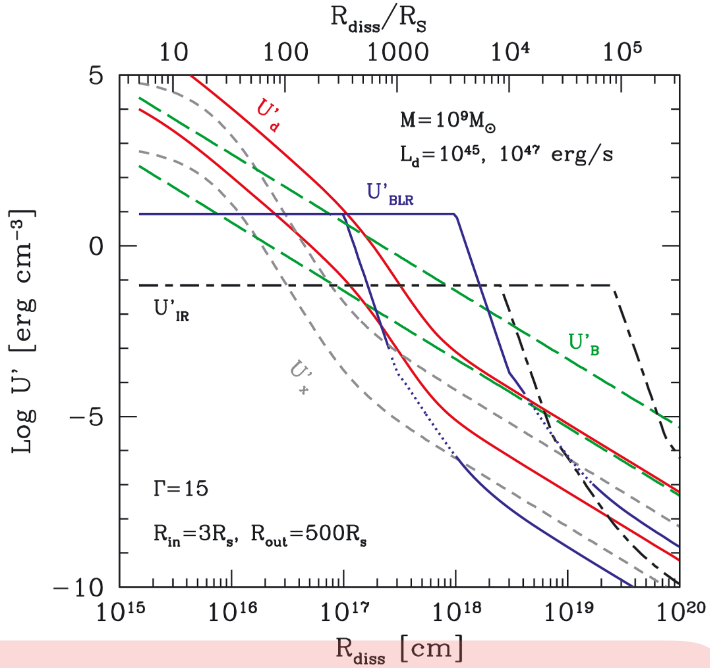






Possible locations of gamma-ray emission





G. Ghisellini and F. Tavecchio, 2009

$R_{\rm BLR} = 10^{17}\, L_{\rm d,45}^{1/2}$ cm. ~ 0.2 pc

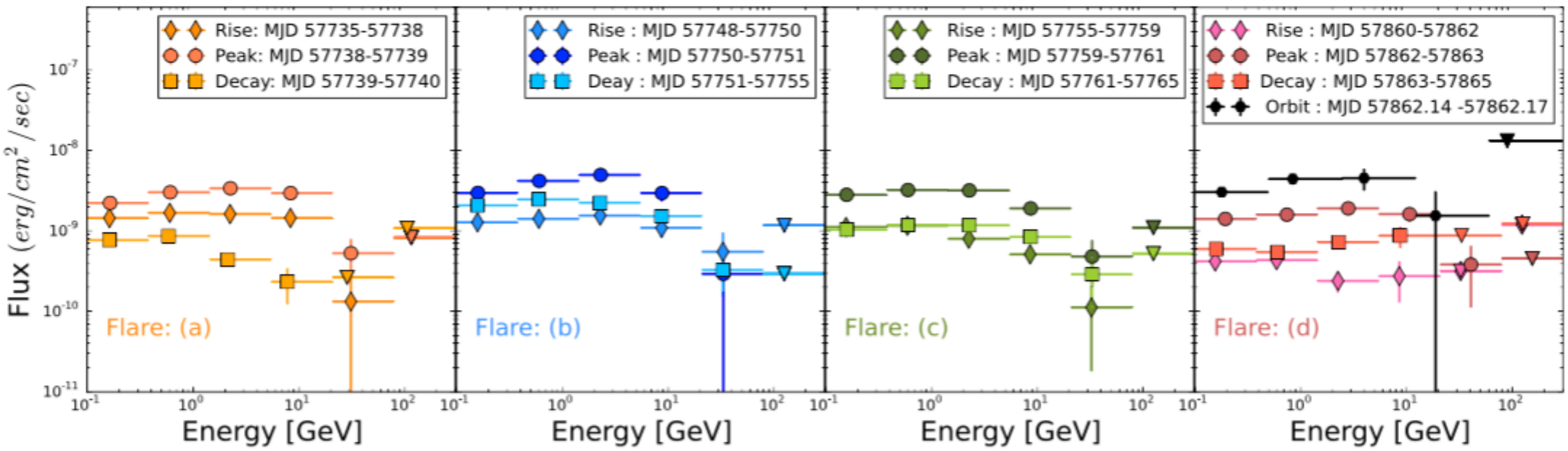
$R_{\rm IR} = 2.5 \times 10^{18}\, L_{\rm d,45}^{1/2}$ cm, ~ 5 pc

$R_{rcf} \sim 10^{-2.5}\, d_{rcf} \sim \delta c \Delta T/(1+z)$

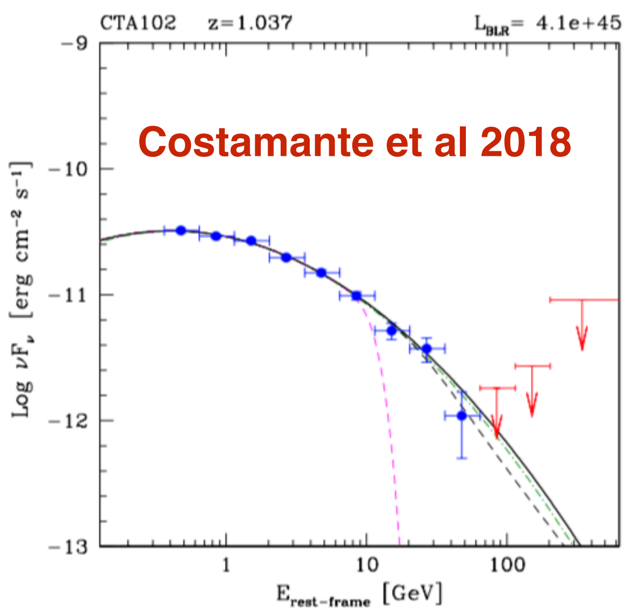
BROMBERG & LEVINSON, 2009

$\delta > 100$

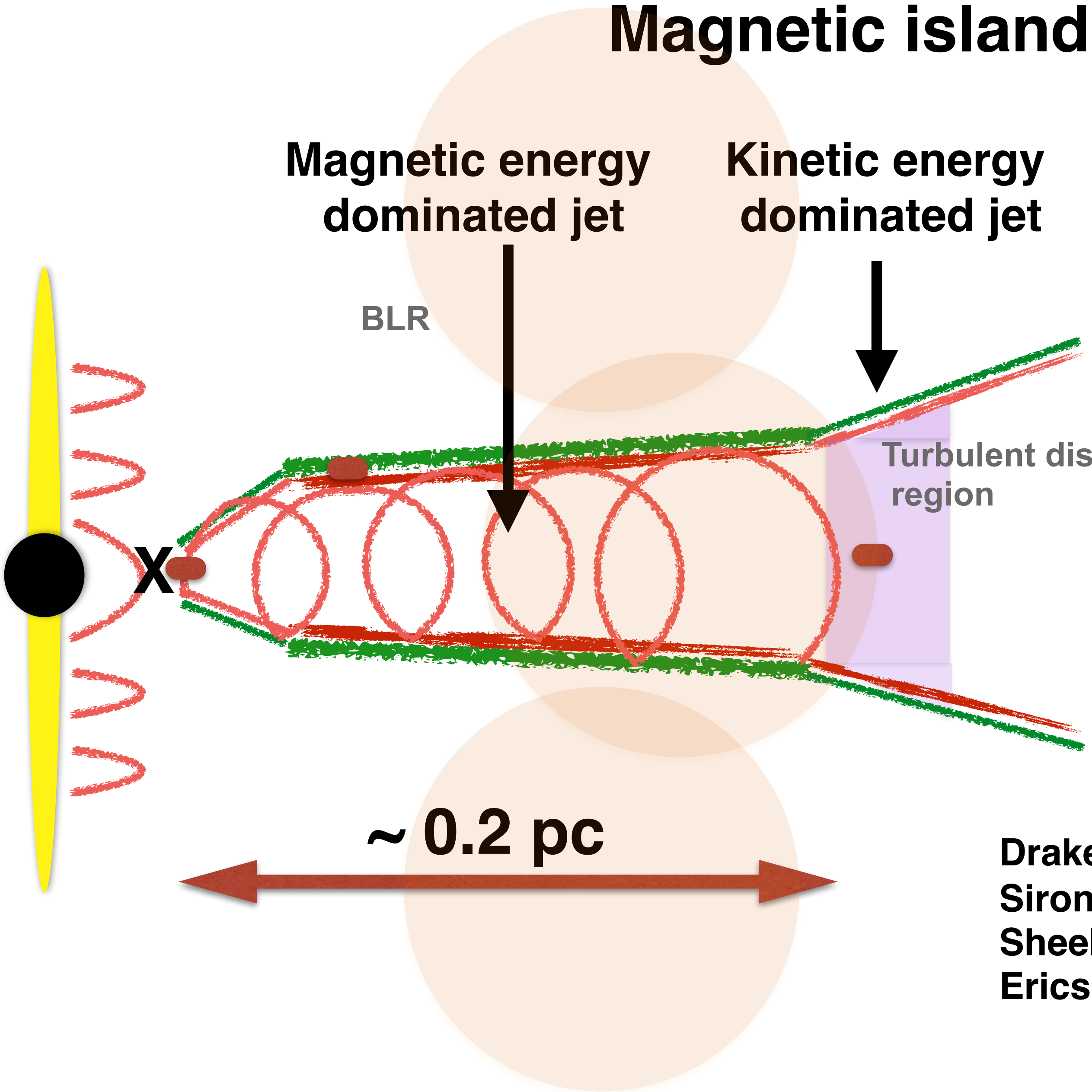
Gamma-ray SED during flares

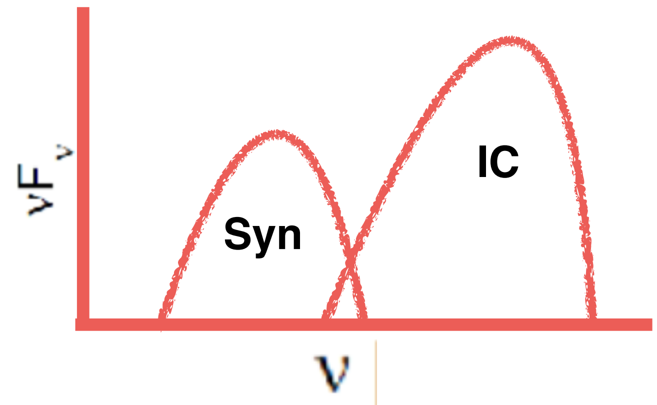


Shukla et al 2018, ApJL, 854:L26



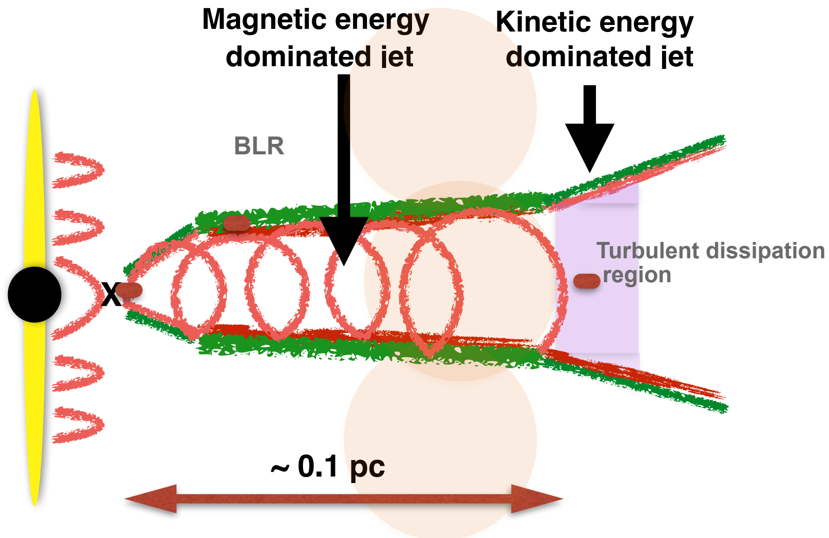
Plausible model to explain intra-day variability

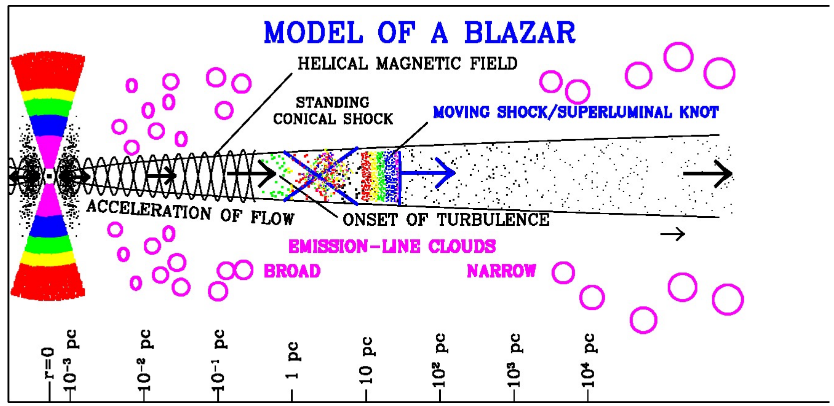




Drake, J.F. et al. Nature 2006, 443, 553–55
Sironi, L. et al. ApJ 2014, 783, L21
Sheeley et al 1997, Apj
Ericsson et al 2014, P P & C F

Energy budget





The total magnetic luminosity dissipated by magnetic island can be defined as

$$0.1\text{–}300\,\mathrm{GeV} \sim 2.3 \times 10^{49}\ \mathrm{erg\ s^{-1}}$$

$L_{Edd} \sim L_B$

for $M_{BH}=8.5\times10^8 M_\odot$

$B{\sim}10^4$ G

$$L_{\rm ph} = \eta\left(\frac{B'^2}{8\pi}\right)\cdot \pi r'^2 c\zeta\, \delta^4\ \mathrm{erg\ s^{-1}}$$
$$\sim 1.5 \times 10^{49}\ \mathrm{erg\ s^{-1}},$$

for $\delta \sim 25; \eta \sim 0.1$ and $\zeta \sim 0.1$ observed luminosity

Results

- Observed photon energies: several photons above 10 GeV including two ~ 25 GeV photons (a few > 60 GeV)
- Variability time scale of the order of few minutes is observed
- Hard spectra are observed during flaring activities
- No evidence of gamma-ray absorption in BLR (no break observed in gamma-ray spectra)
- Observed luminosity (0.1-300 GeV) ~ 10^49 erg/sec
- The dissipation of magnetic islands from the base of the jet encountering the turbulent plasma at the end of the magnetic nozzle.

Shukla et al 2018, ApJL, 854:L26