



Gamma-ray Flares from the Gravitationally Lens Blazar B0218+357

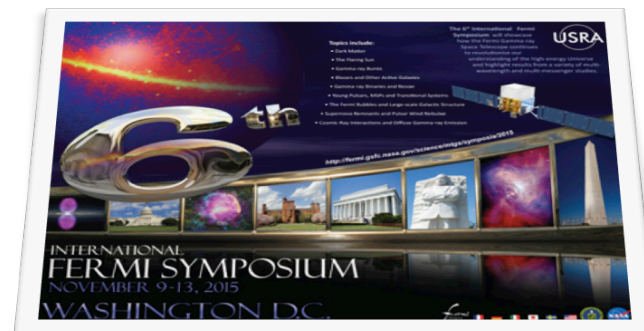
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on behalf of the *Fermi* LAT
collaboration

¹ NASA GSFC/UMBC/CRESST

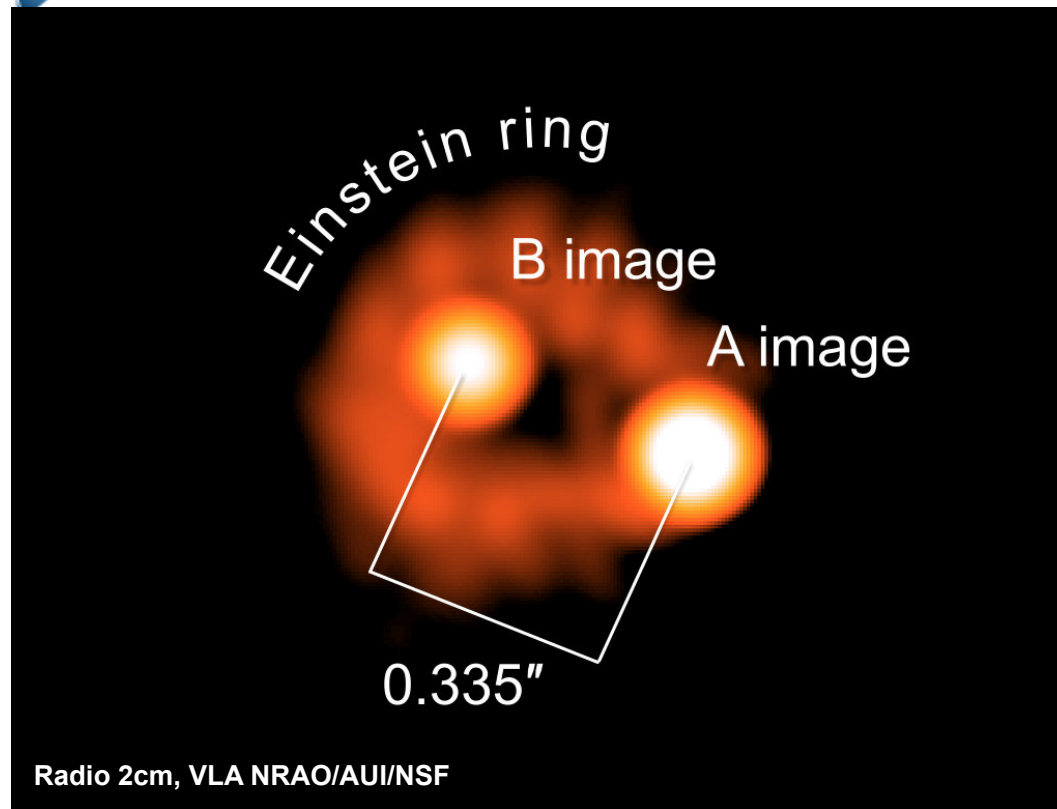
² Naval Research Laboratory

³ Stockholm University

⁴ NASA Ames Research Center



“Golden Lens” B0218+357

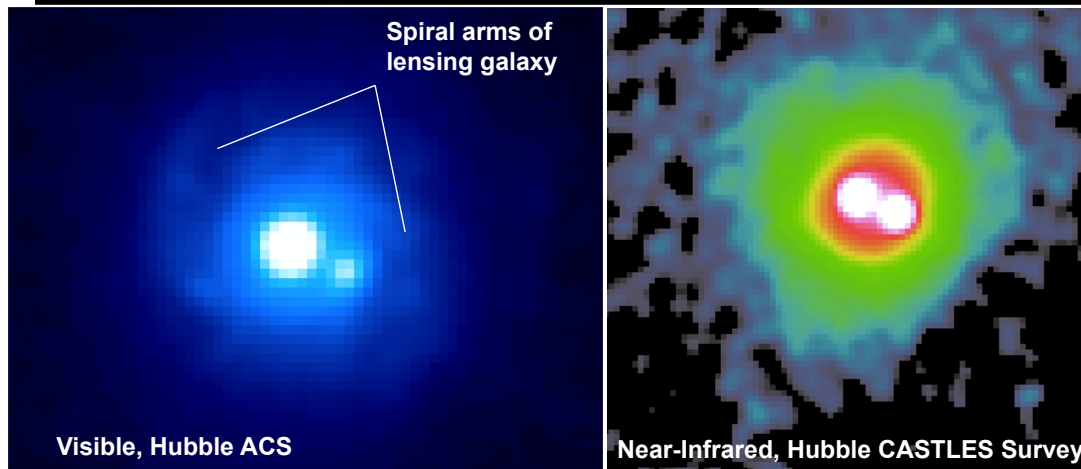


B0218+357 discovered in NRAO S3 strong radio source survey (Pauliny-Toth, Kellermann 1972)

Revealed in 1990s as **smallest-separation gravitational lens known**; $z=0.944$ blazar lensed by $z=0.685$ galaxy

Brighter radio A image ($\sim 4x$ at 15 GHz) leads B image by $\Delta t_r = \mathbf{10.5 \pm 0.2 \text{ days}}$ (Biggs et al. 1999); also Cohen et al. (2000)

Gamma rays detected by *Fermi* LAT since 2008



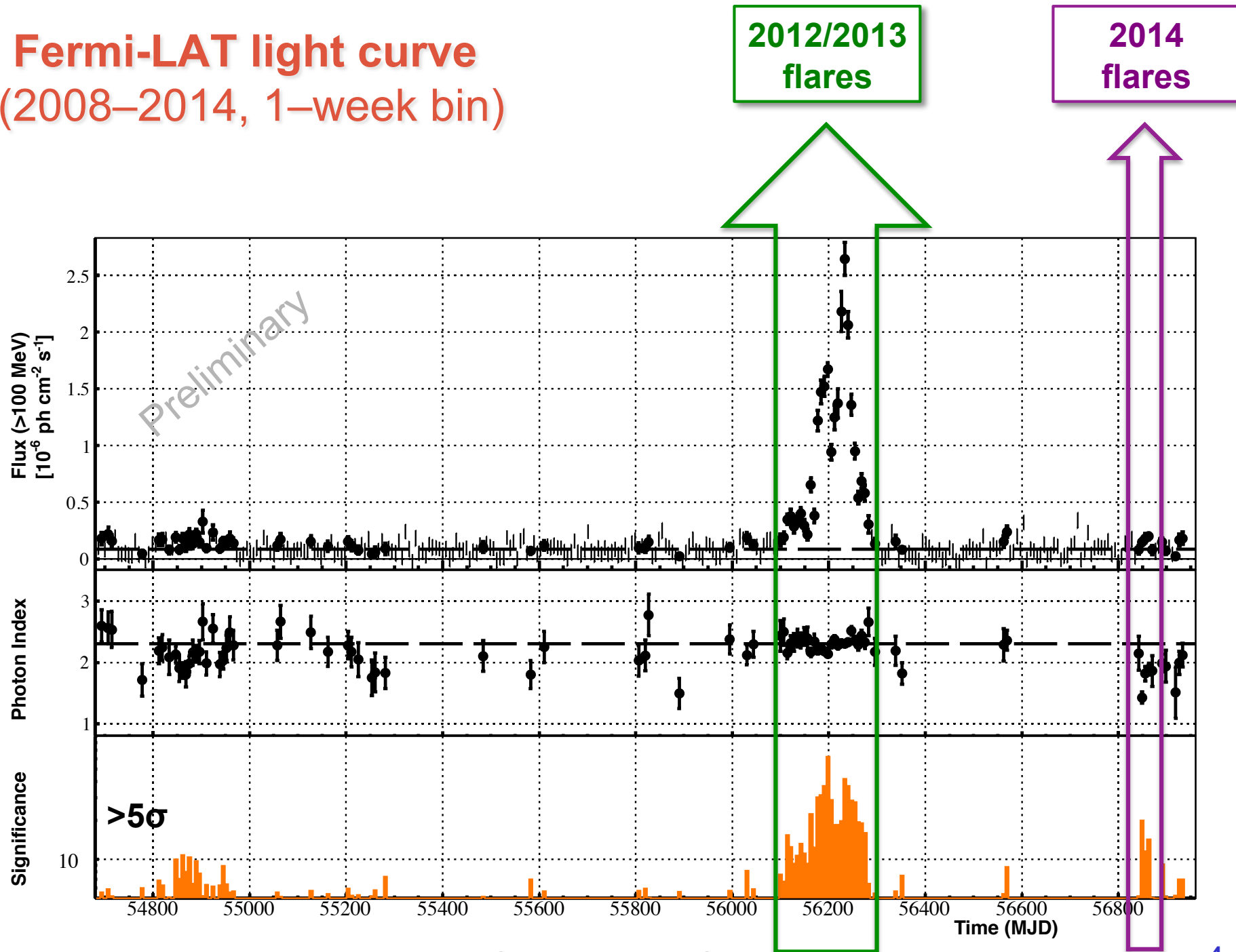


With gamma rays (Fermi-LAT) we can not spatially separate the two images but can

measure the time delay

between components of a lensed variable source

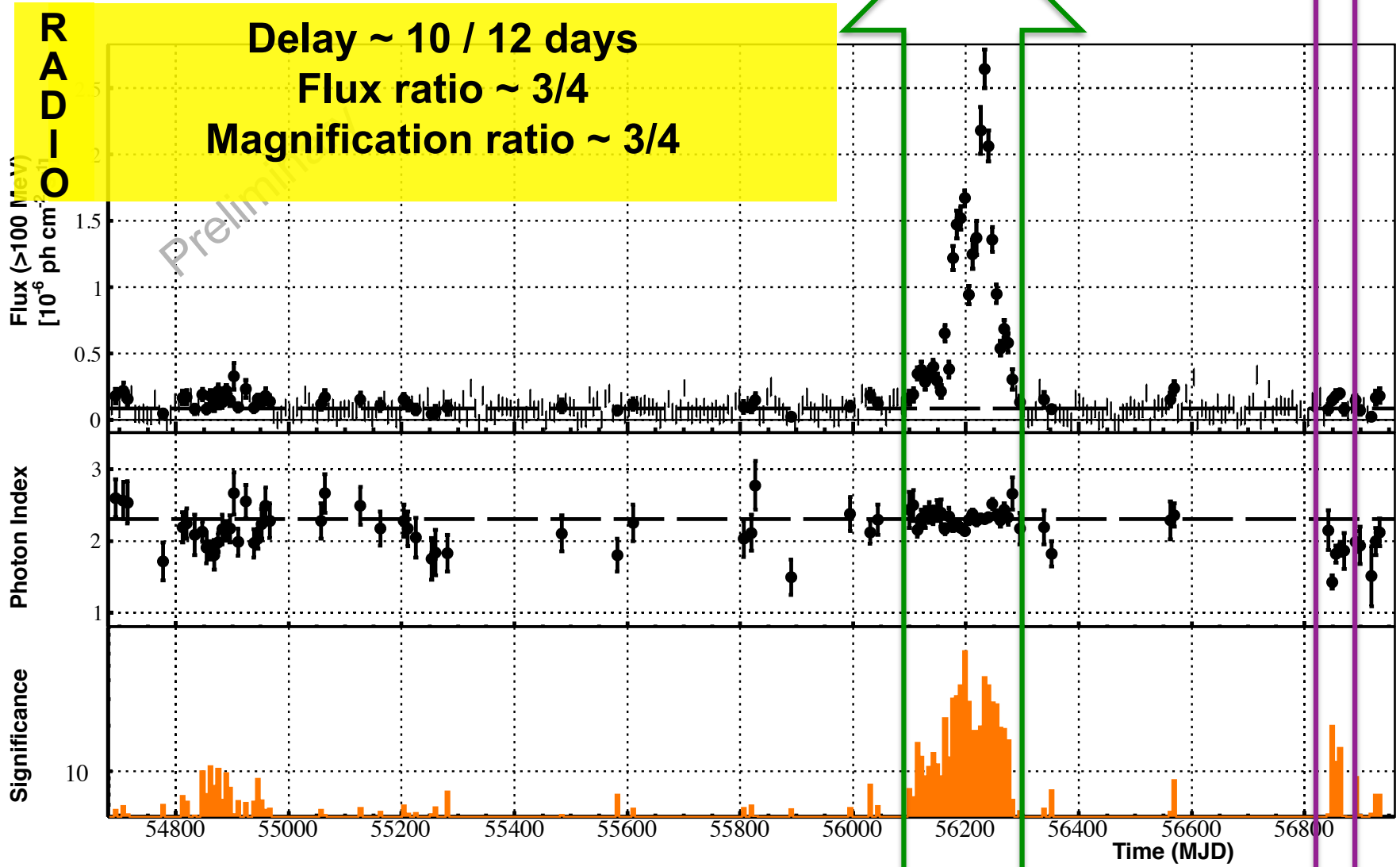
Fermi-LAT light curve (2008–2014, 1-week bin)



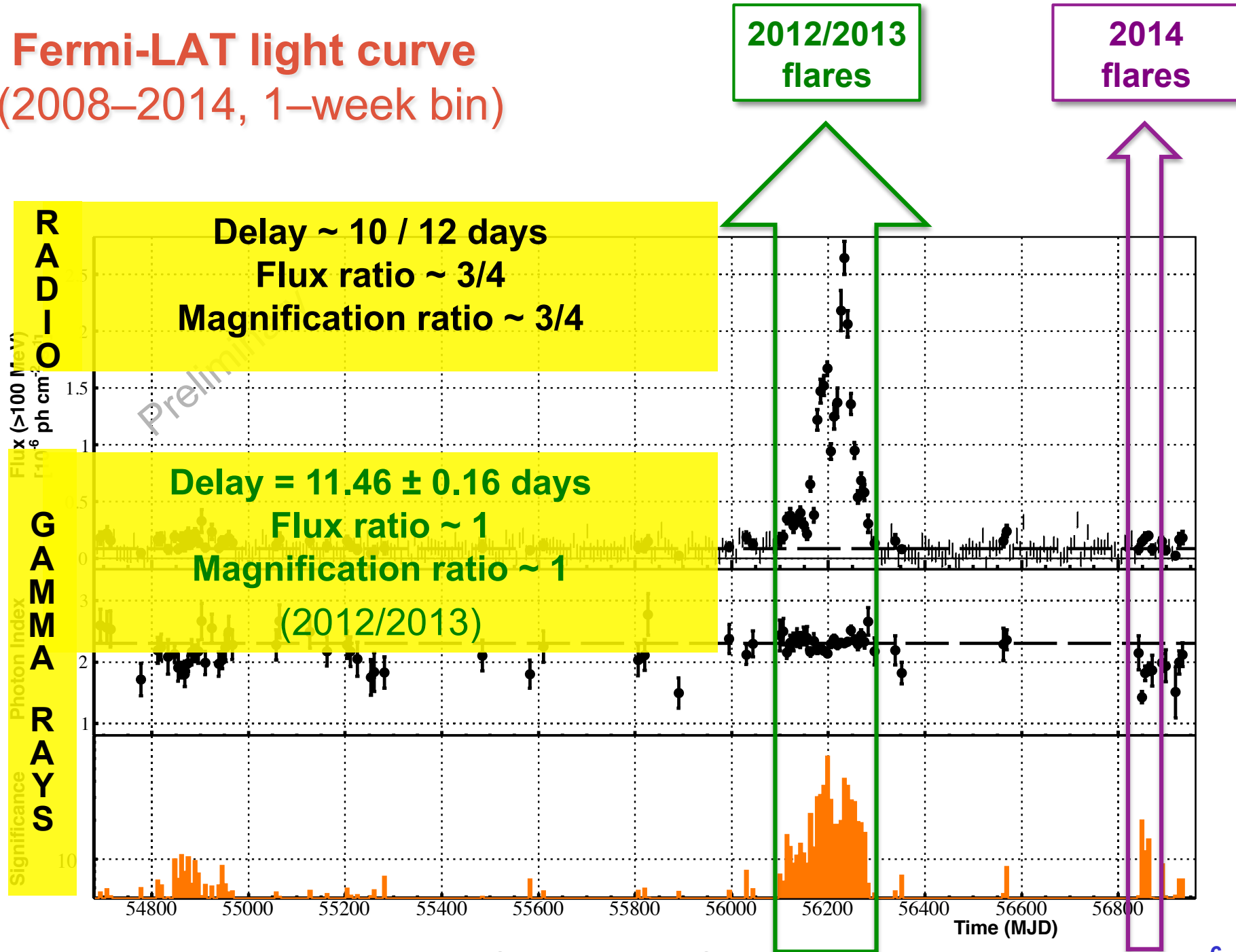
Fermi-LAT light curve (2008–2014, 1-week bin)

2012/2013
flares

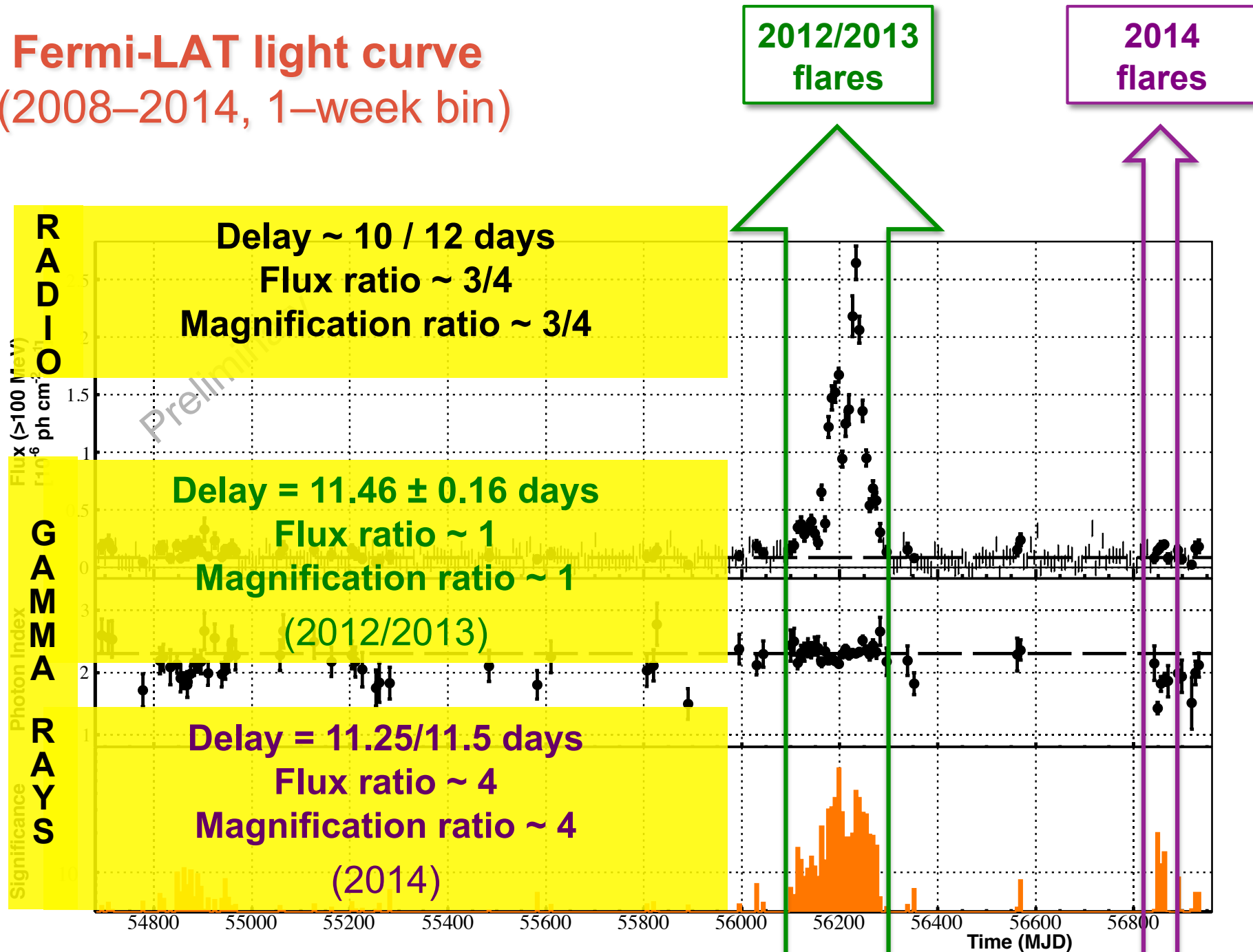
2014
flares



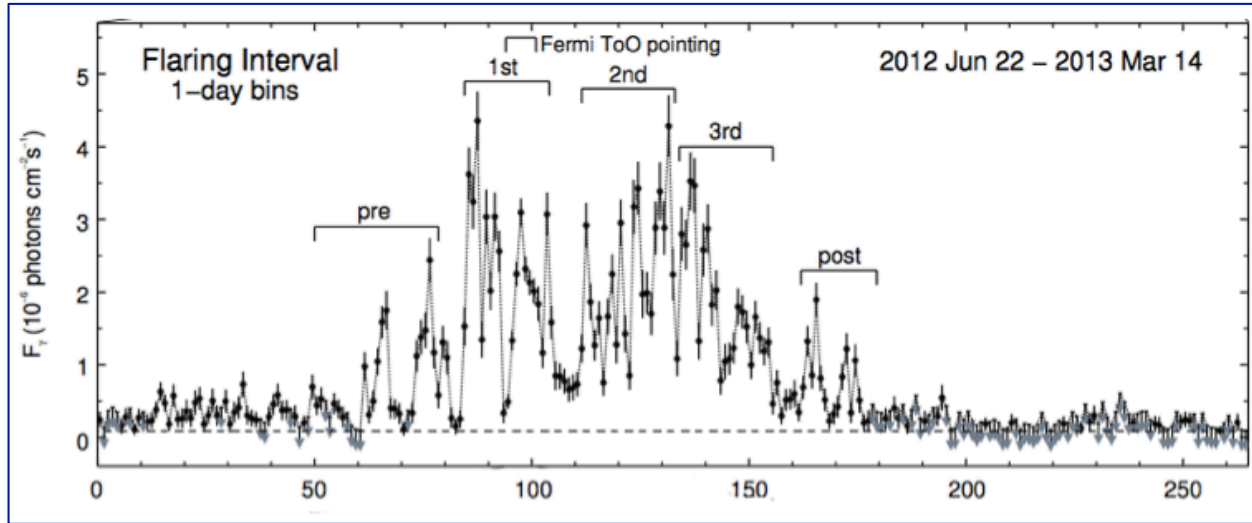
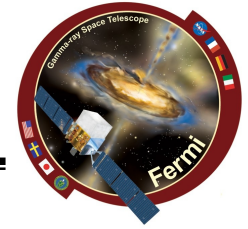
Fermi-LAT light curve (2008–2014, 1-week bin)



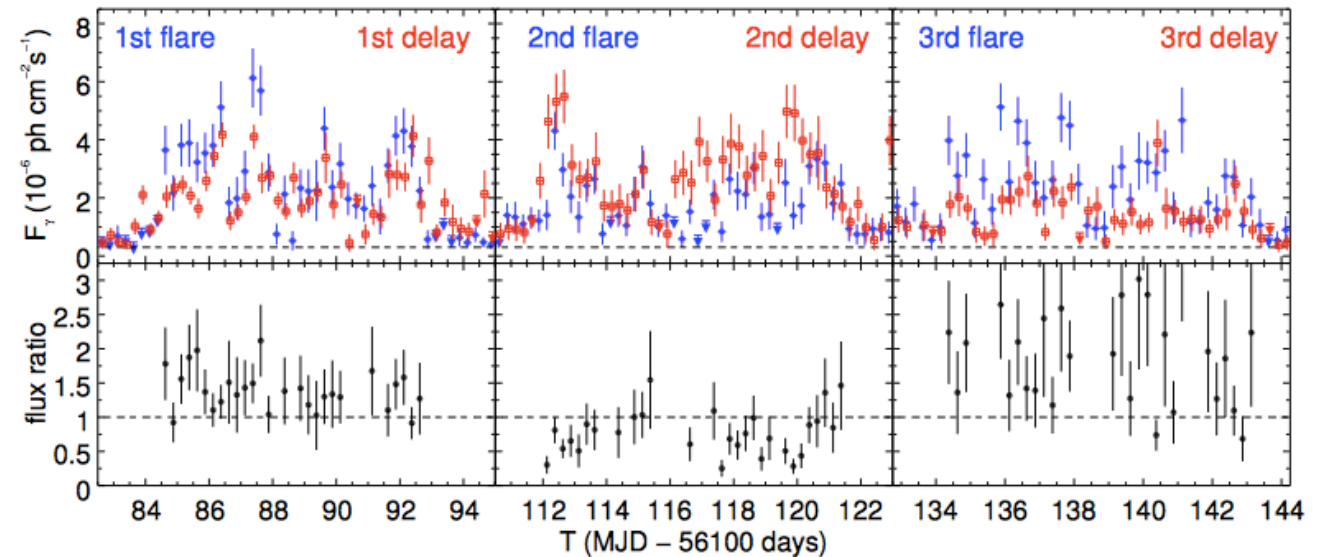
Fermi-LAT light curve (2008–2014, 1-week bin)

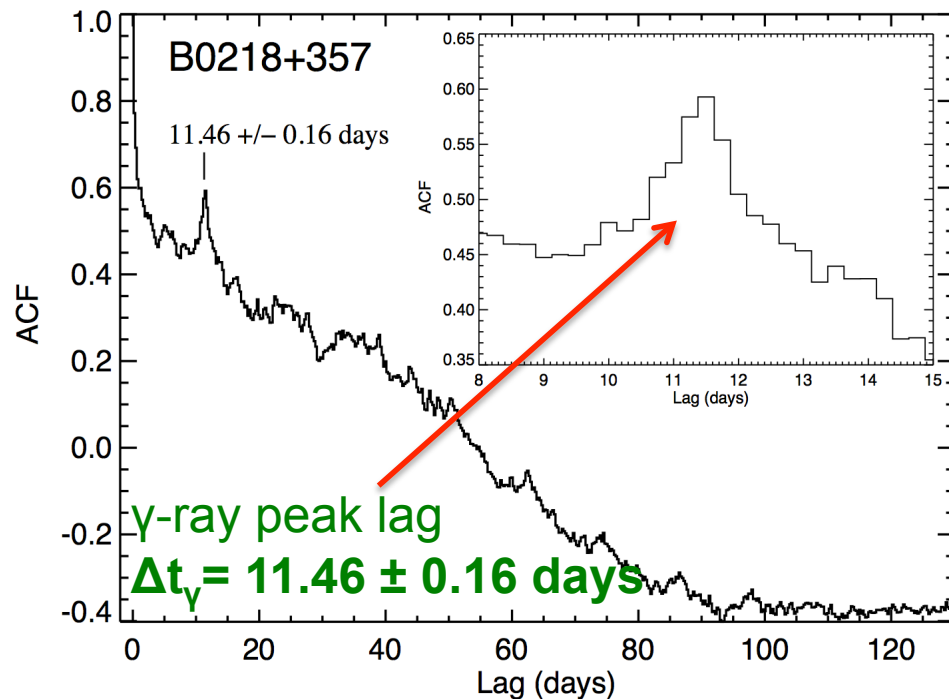
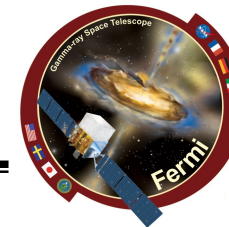


2012/2013 Gamma-ray Flares



Cheung et al.
2014 ApJ 782, L14





Difference between γ -ray and radio delays:

$$\Delta t_\gamma - \Delta t_r =$$

- 1.0 \pm 0.3 days (Biggs et al. 1999)
- 1.4 \pm 0.8 days (Cohen et al. 2000)

Cheung et al. 2014 ApJ 782, L14

Inferred displacement between the radio / gamma-ray region \sim 80 pc (projected)

2014 Light Curve (6-hr bin)



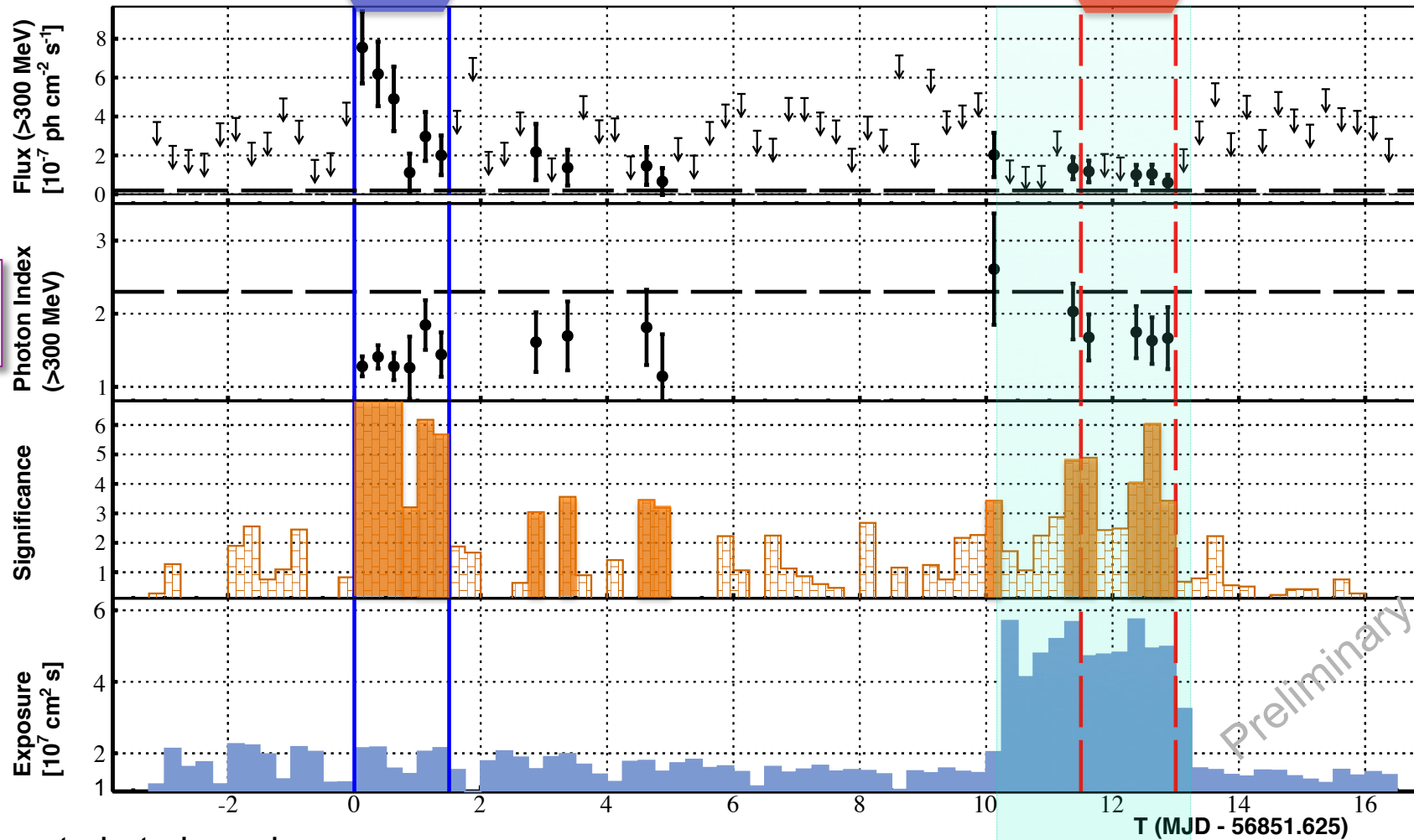
Flare A

Flux ratio ~4

Flare B

1.7hr
rising

hard
spectrum



Buson et al., to be sub.

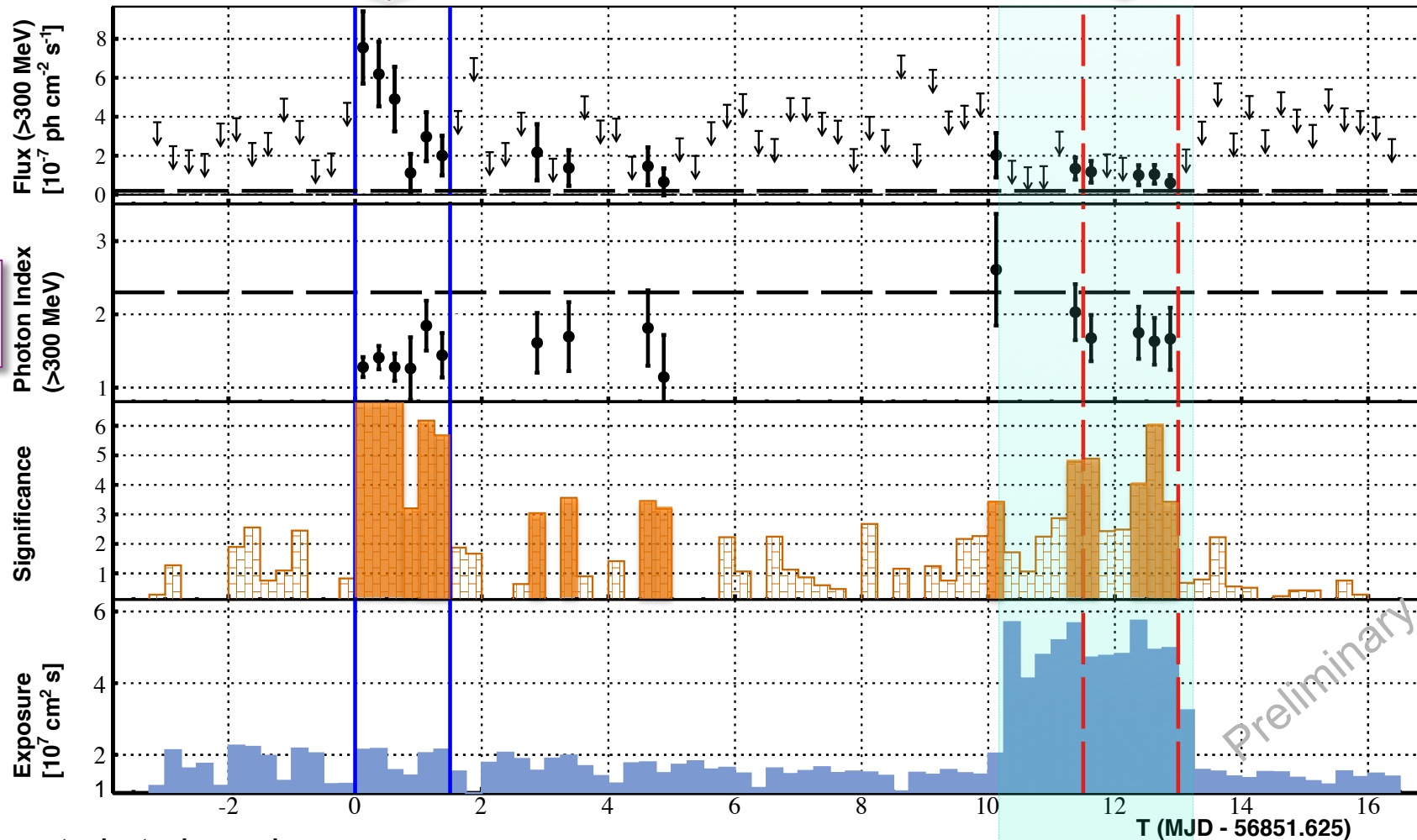
2014 Light Curve (6-hr bin)



LAT photons
up to 95GeV!

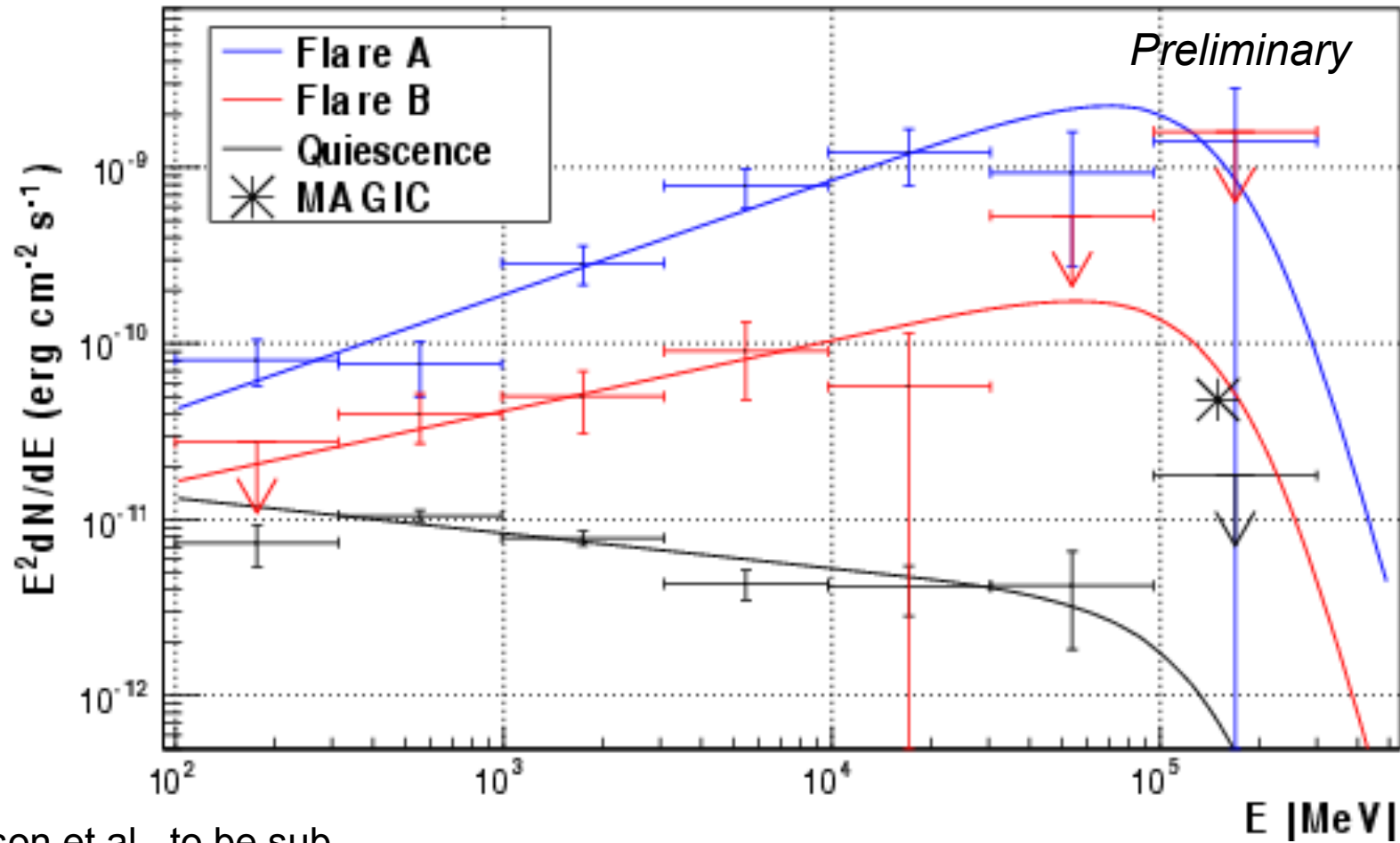
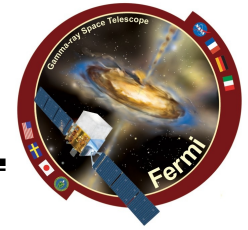
VHE (MAGIC)
detection

*hard
spectrum*



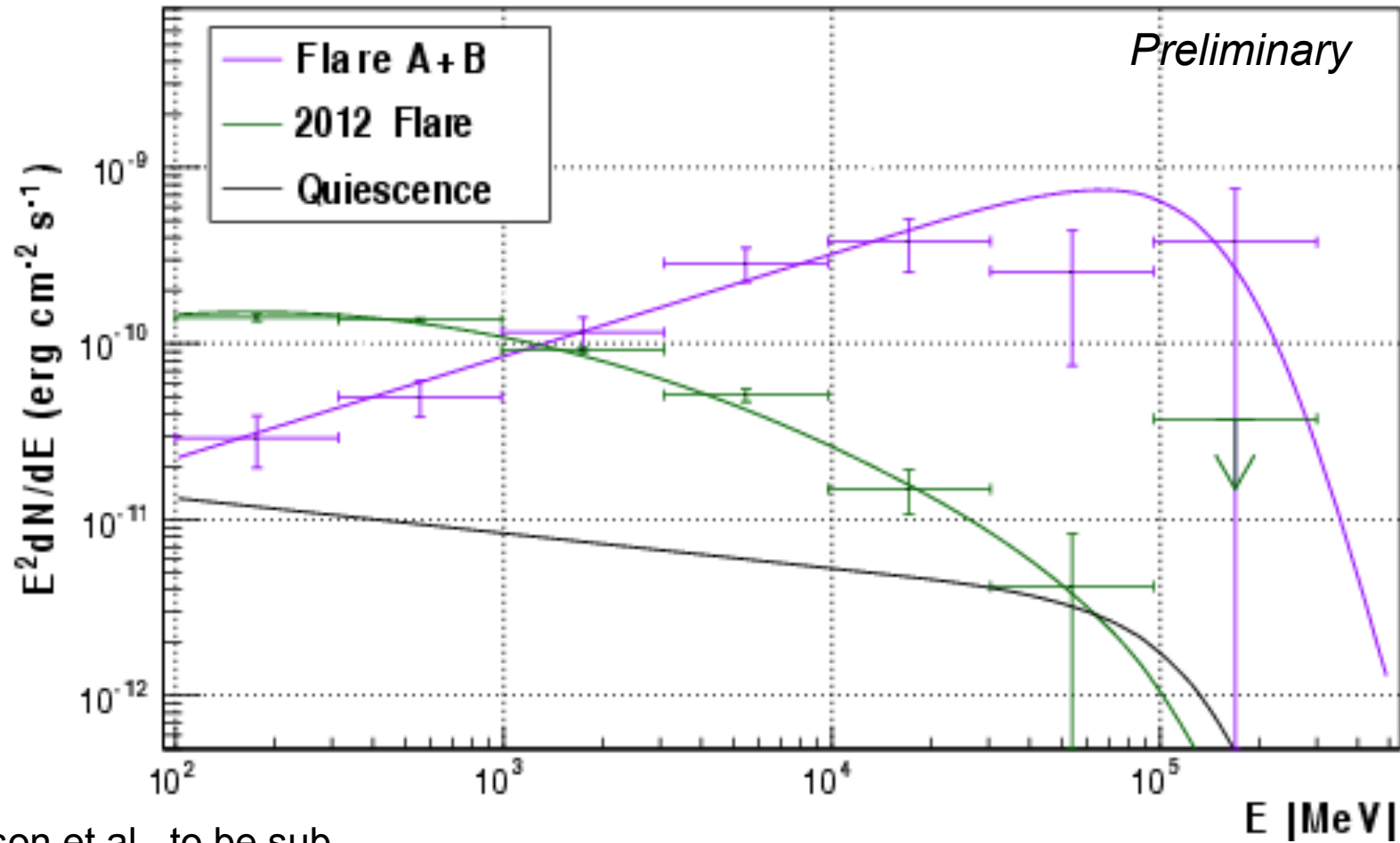
Buson et al., to be sub.

2014 Flare SED



Buson et al., to be sub.

SED: 2014 vs 2012/2013 Flares

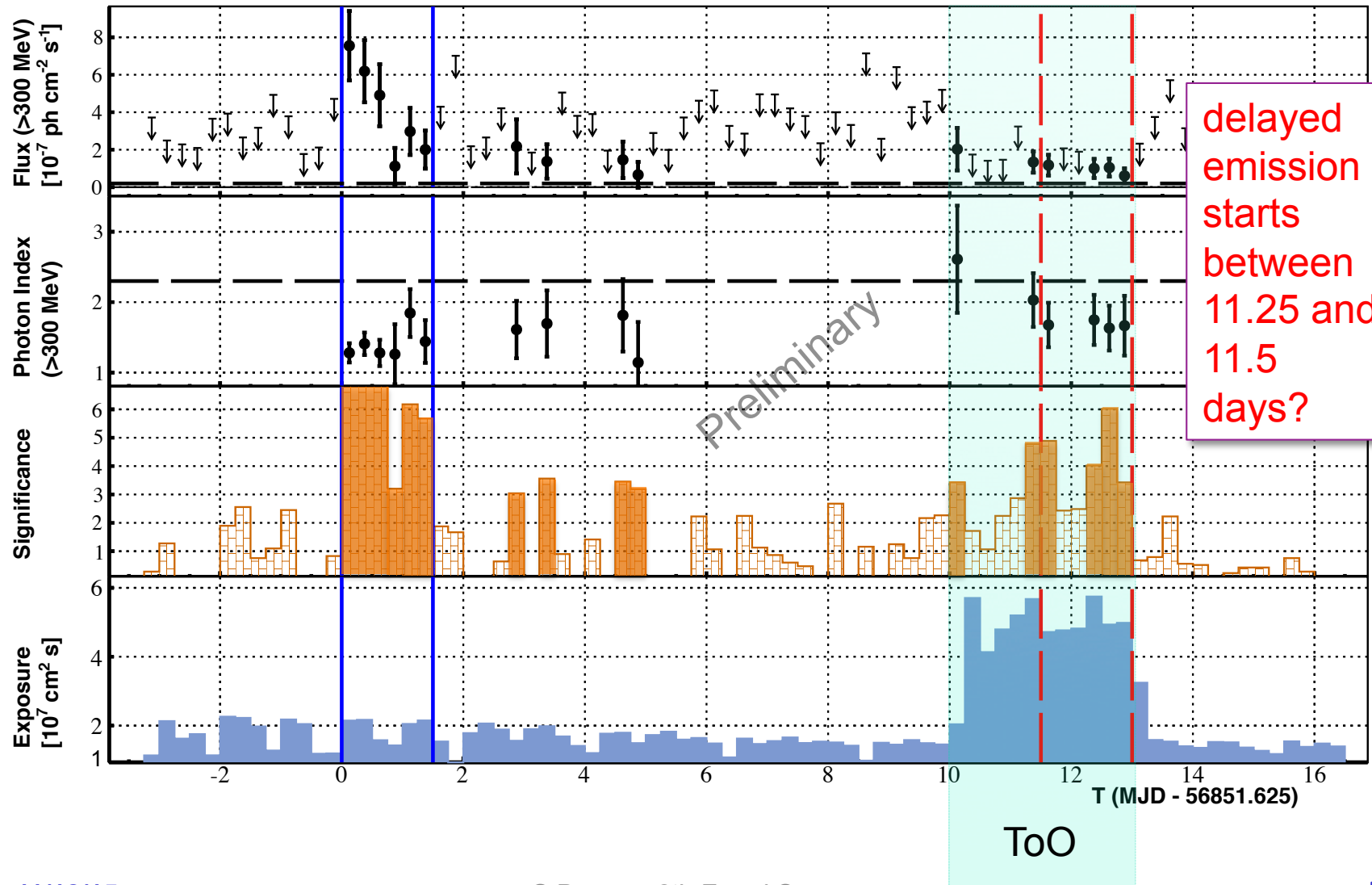


Buson et al., to be sub.

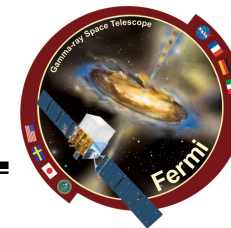


- The spectrum changed during the 6 years of observations
 - Hard-spectrum (power-law) flares observed in 2014
 - Soft-spectrum (log-parabola) characterizes the 2012 activity
- If we envisage that the **soft-spectrum and hard-spectrum emission come from different emission sites**, we can estimate the **offset** between the putative **different offset locations** using (constraint on) the **difference in the measured time delays**
- For the expected delay interval, the span of the highest significance bins look to be 11.25 days offset from the flare
 - ACF not effective (low statistics in 2014)
 - “by eye” estimate: look to light curve with finer binning

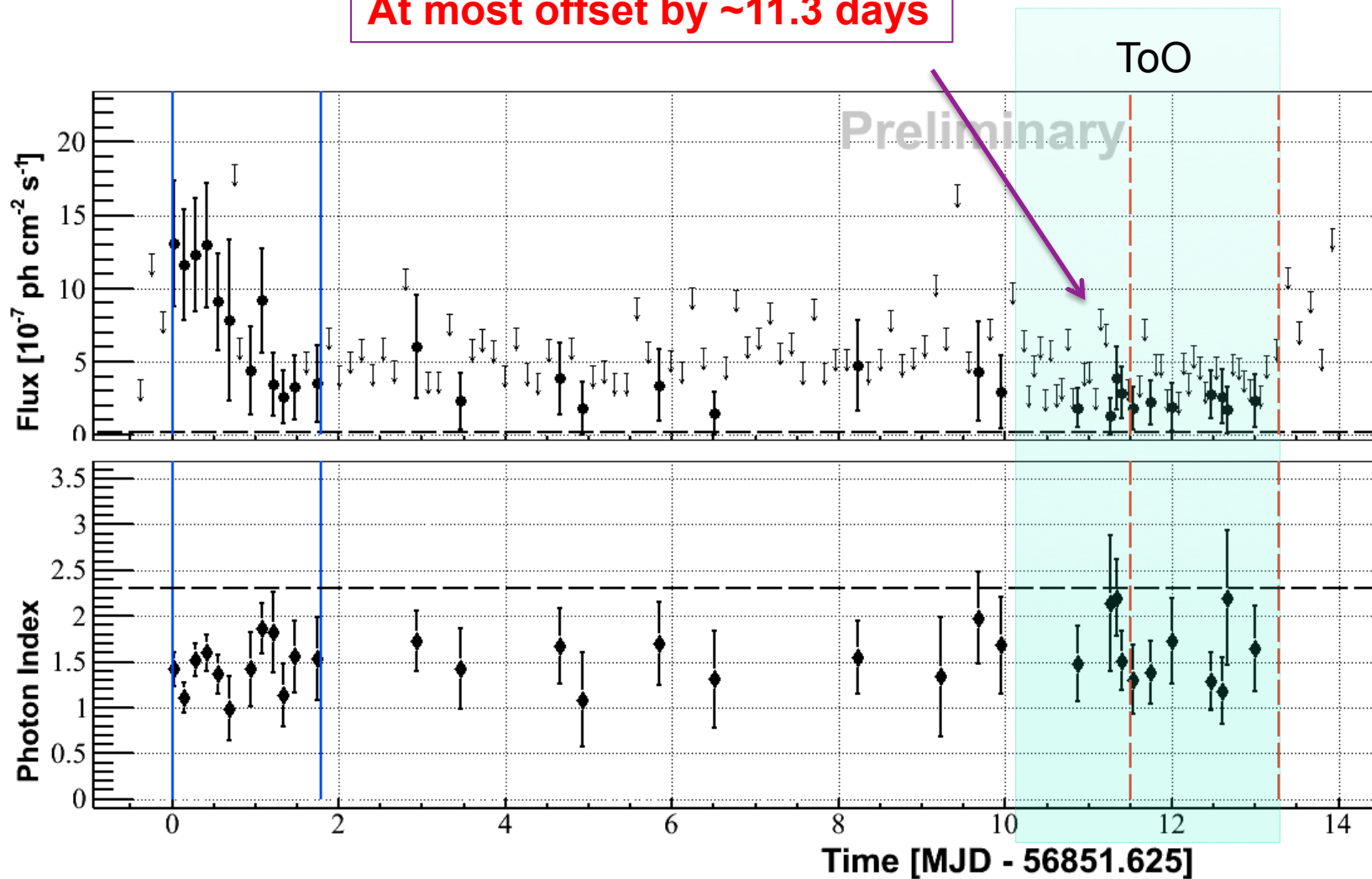
2014 Light Curve (6-hr bin)

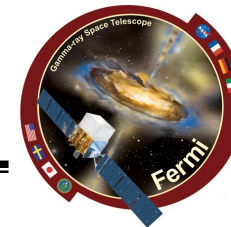


Orbit-by-orbit Light Curve



At most offset by ~11.3 days





- For the first flare constrained to be isolated to ~ 2 days
- The series of bins in the B image with the highest significance are offset by ~ 11.3 days
- Let's assume the error on this measurement is one orbit
 - **formal upper limit would be < 0.4 days,
which would be < 25 pc, projected**

- **Vovk & Neronov (2015) suggest microlensing effects come into play**
- **Consistent with findings by Barnaka et al. 2015**

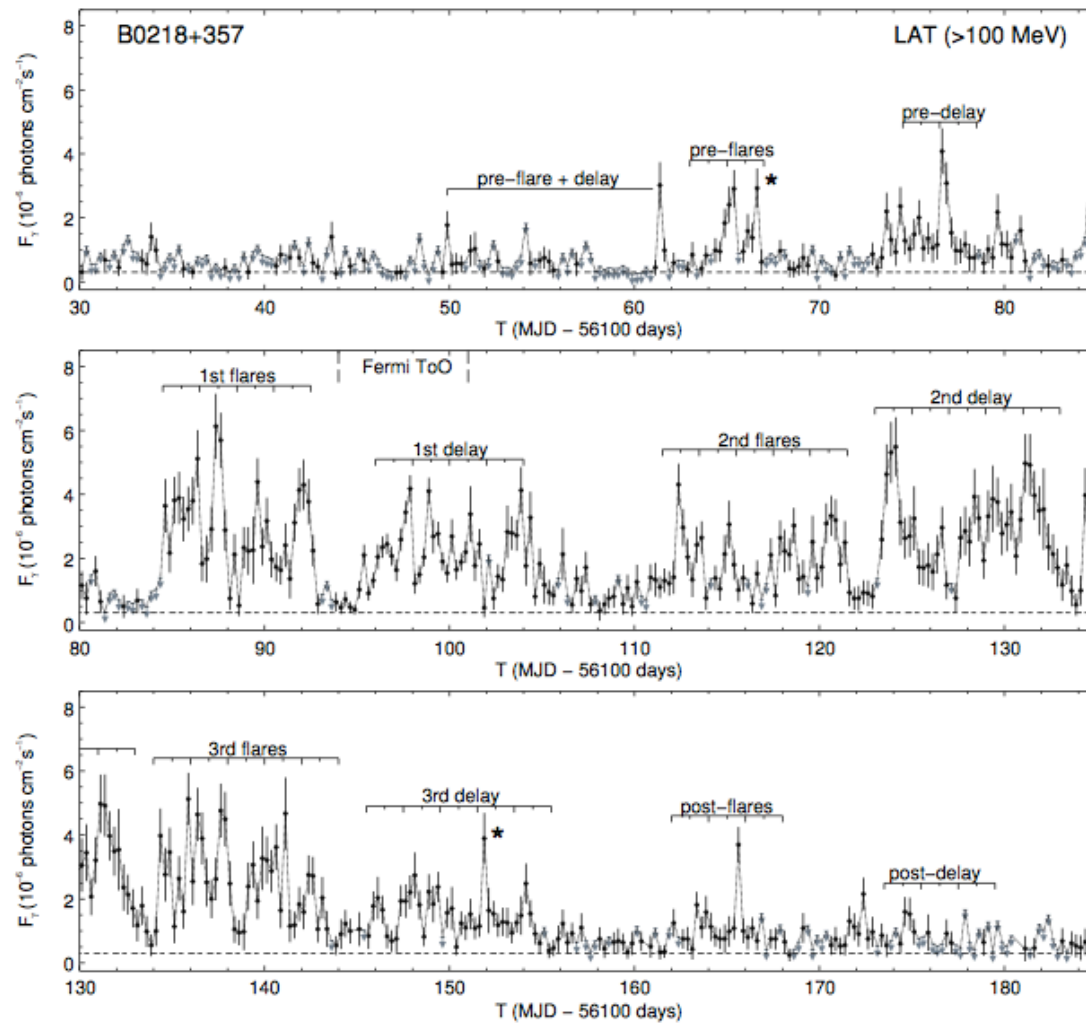
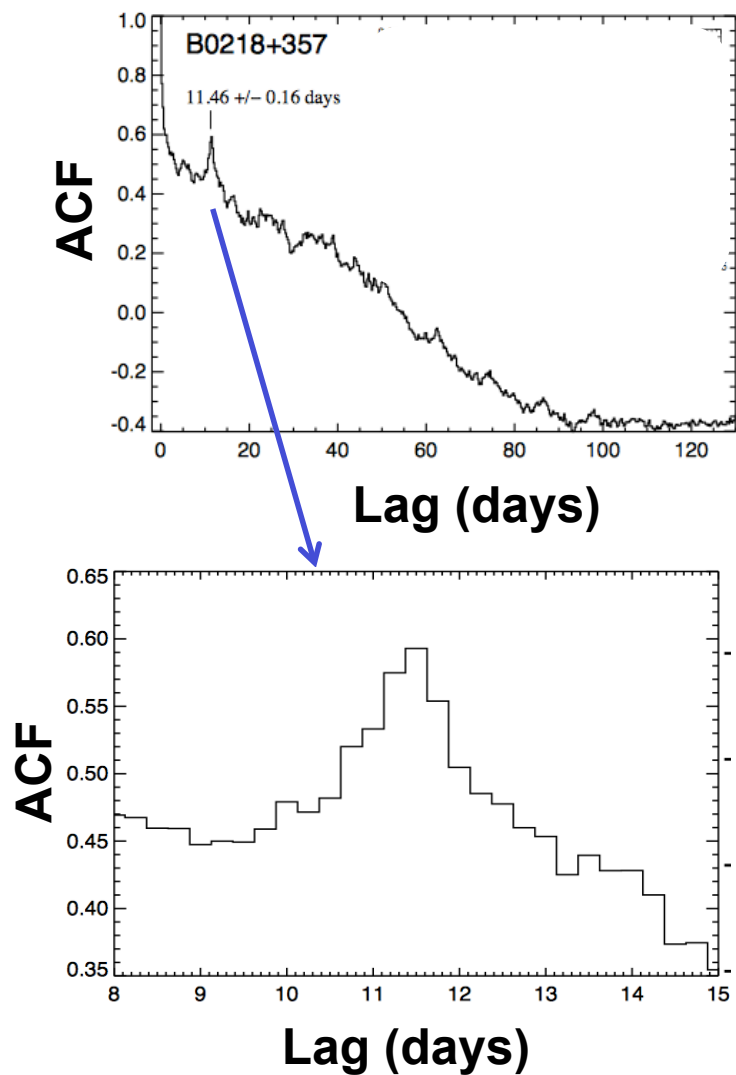
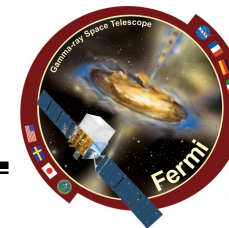


The 2014 gamma-ray **hard-spectrum fast-rise singular event** offers the unique opportunity to isolate the two emission images:

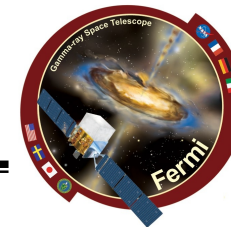
- **LAT flux ratio A/B ~4, close to radio values**
- **Possibly microlensing comes into play**
- **Different dissipation regions suggested by spectral changes**
- **Gamma-ray delay estimate consistent for the flaring episodes, UL to the emitting region offset of <25pc, projected**
- **95 GeV photon detected by the LAT during A-image flare**
- **VHE detection reported 11.5 days after by MAGIC**
- **Fermi-MAGIC detection of B0218+357 allows to test EBL models at $z \sim 1$ (MAGIC coll., in prep.)**



Back up



First Gamma-ray Delay Measurement



Delay estimated = 11.46 +/- 0.16 days

Flux ratio = 1.16 +/- 0.07

Magnification ratio = 1.32 +/- 0.09

Cheung+ 2014,
ApJL, 782, L14

Flare emission divided by the observed flux ratio of 1.16 and shifted by +11.46 days to match the delayed emission

