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

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on behalf of the *Fermi* LAT collaboration

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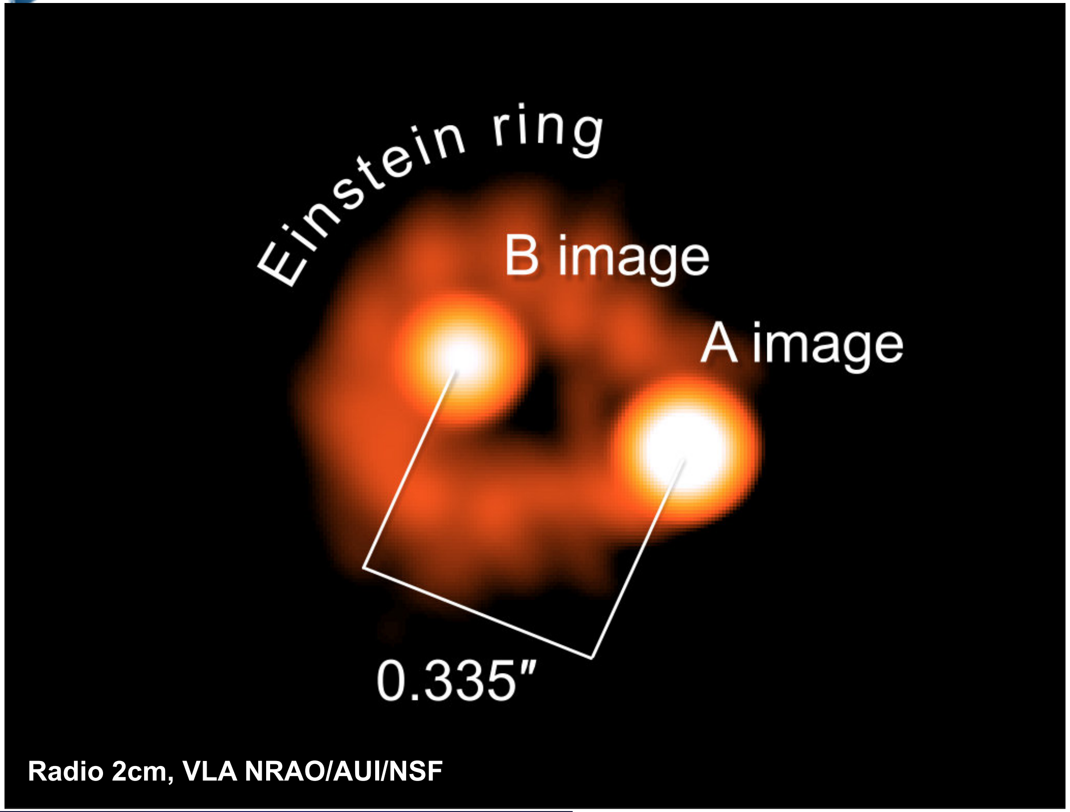
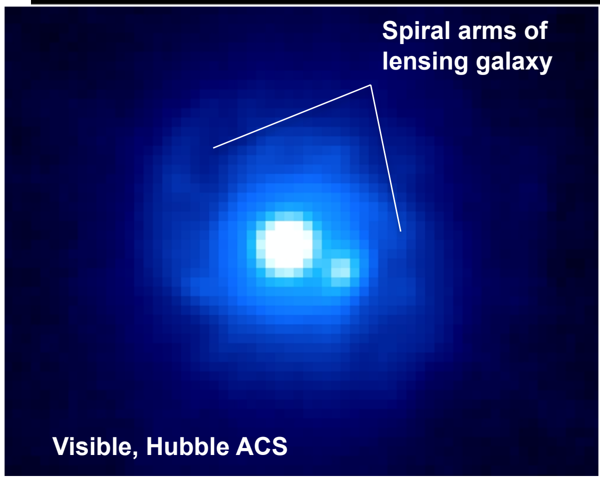
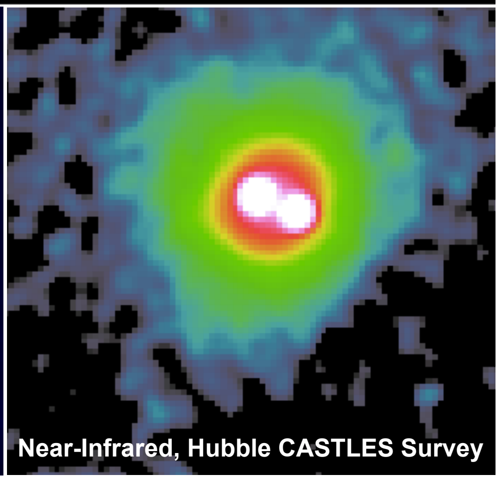
“Golden Lens” B0218+357







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 (~4x at 15 GHz) leads B image by Δt_r = **10.5 ± 0.2 days** (Biggs et al. 1999); also Cohen et al. (2000)

Gamma rays detected by *Fermi* LAT since 2008

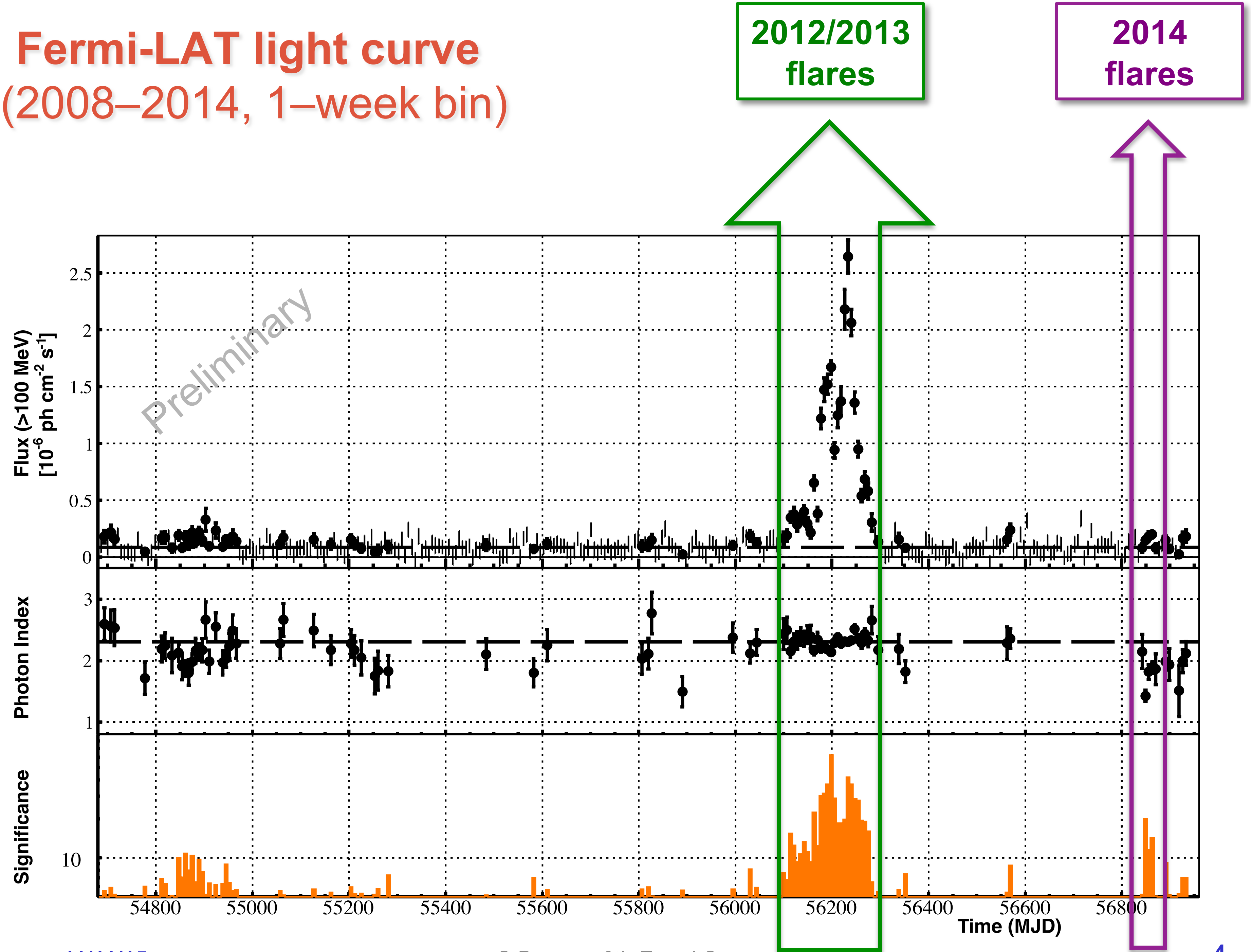
Gravitational Lensing in Gamma Rays

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)



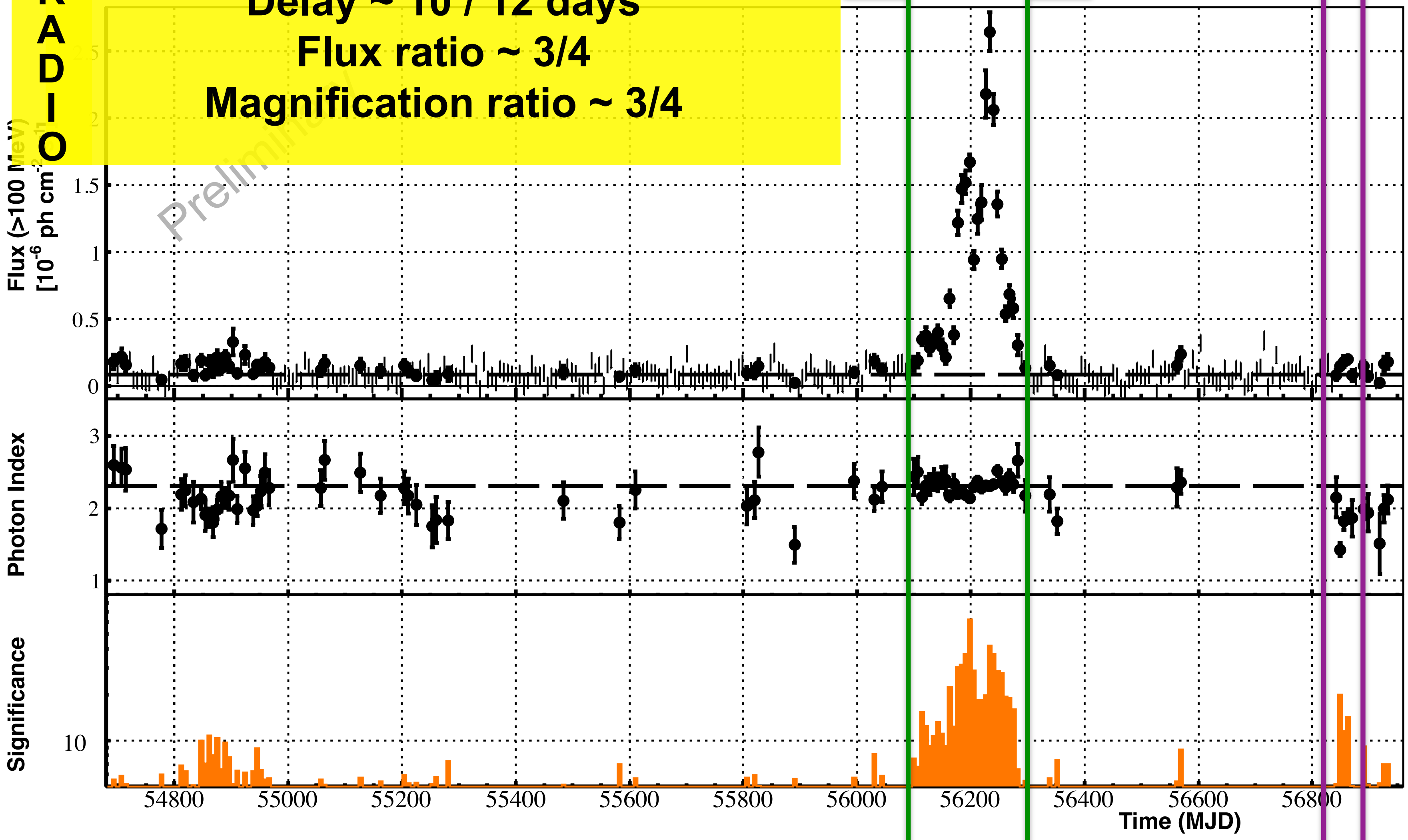
Fermi-LAT light curve
(2008–2014, 1–week bin)

2012/2013 flares

2014 flares

RADIO

Delay ~ 10 / 12 days
Flux ratio ~ 3/4
Magnification ratio ~ 3/4



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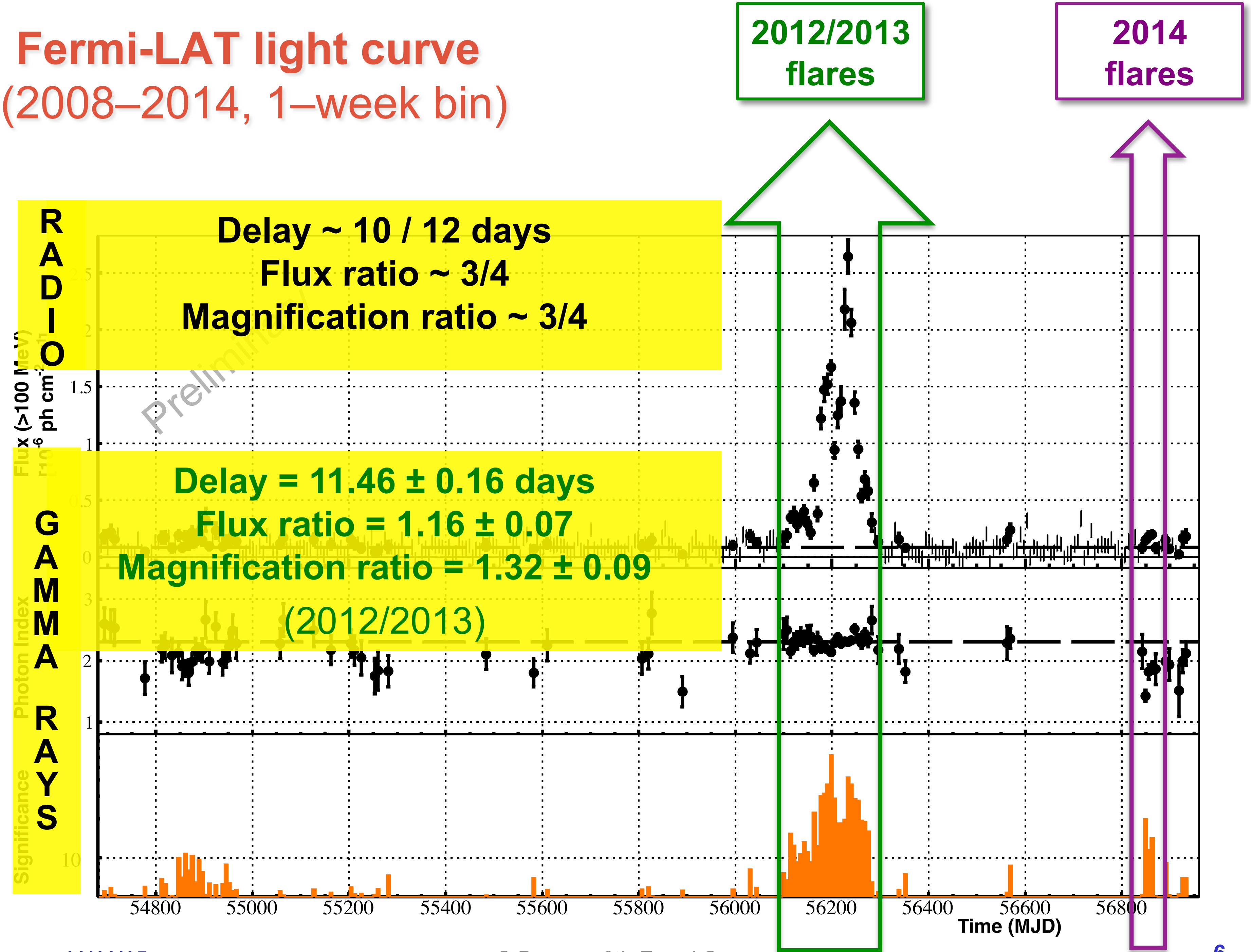

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2012/2013 flares

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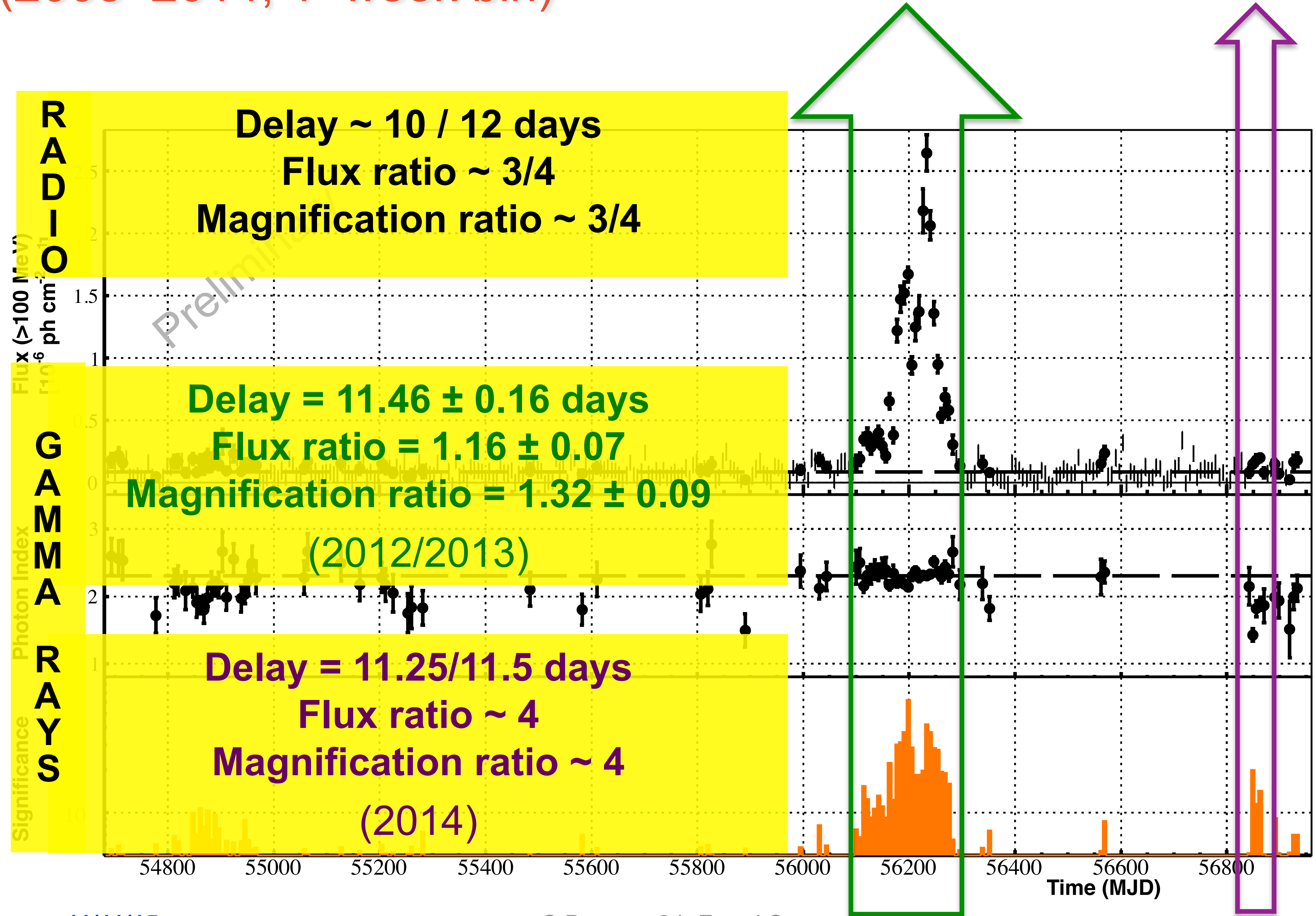
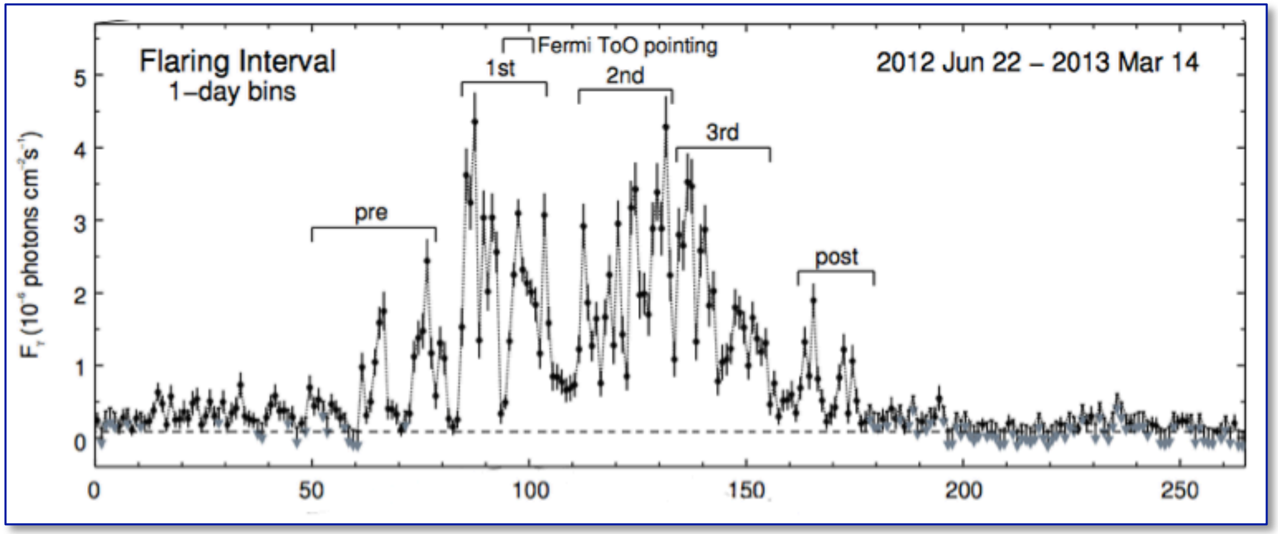
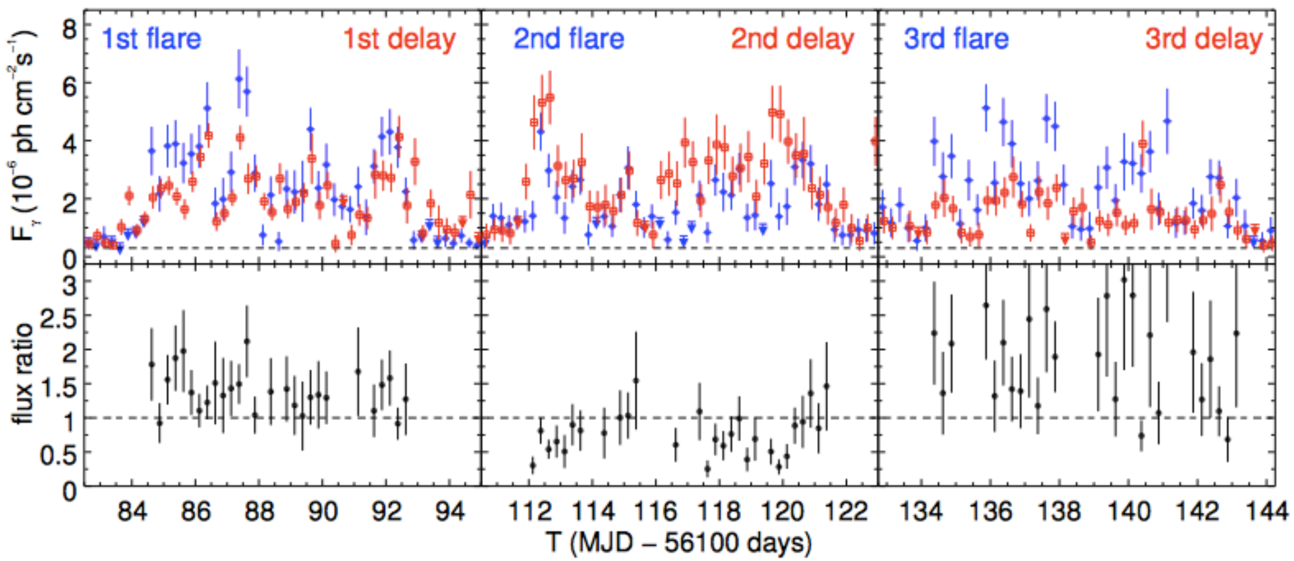


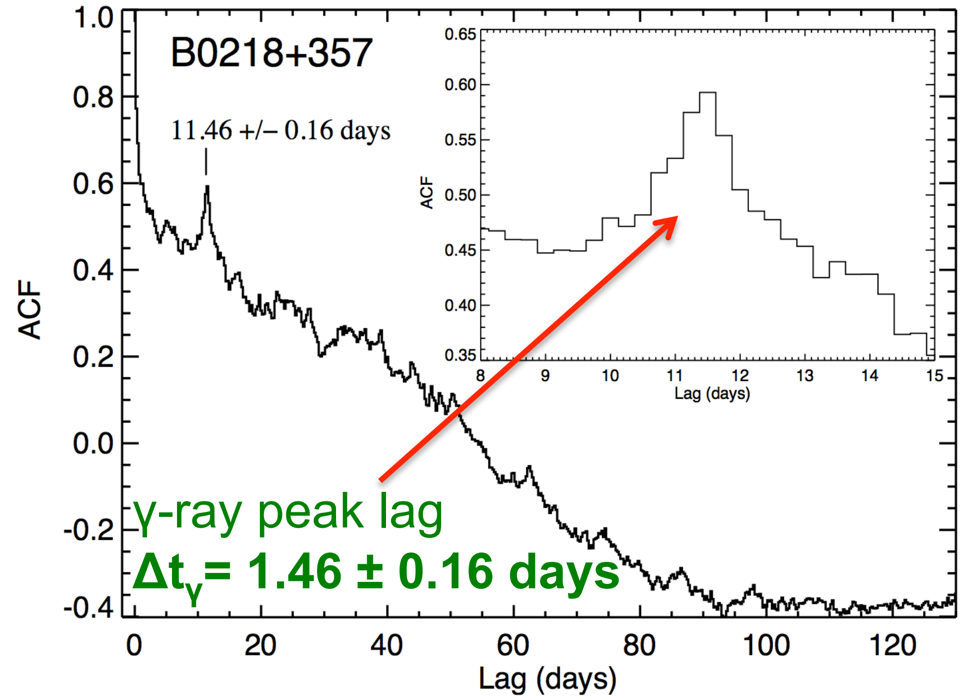
2012/2013 Gamma-ray Flares





Cheung et al.
2014 ApJ 782, L14

Gravitational Lens Delay in 2012/2013 γ-ray Data



Cheung et al. 2014 ApJ 782, L14

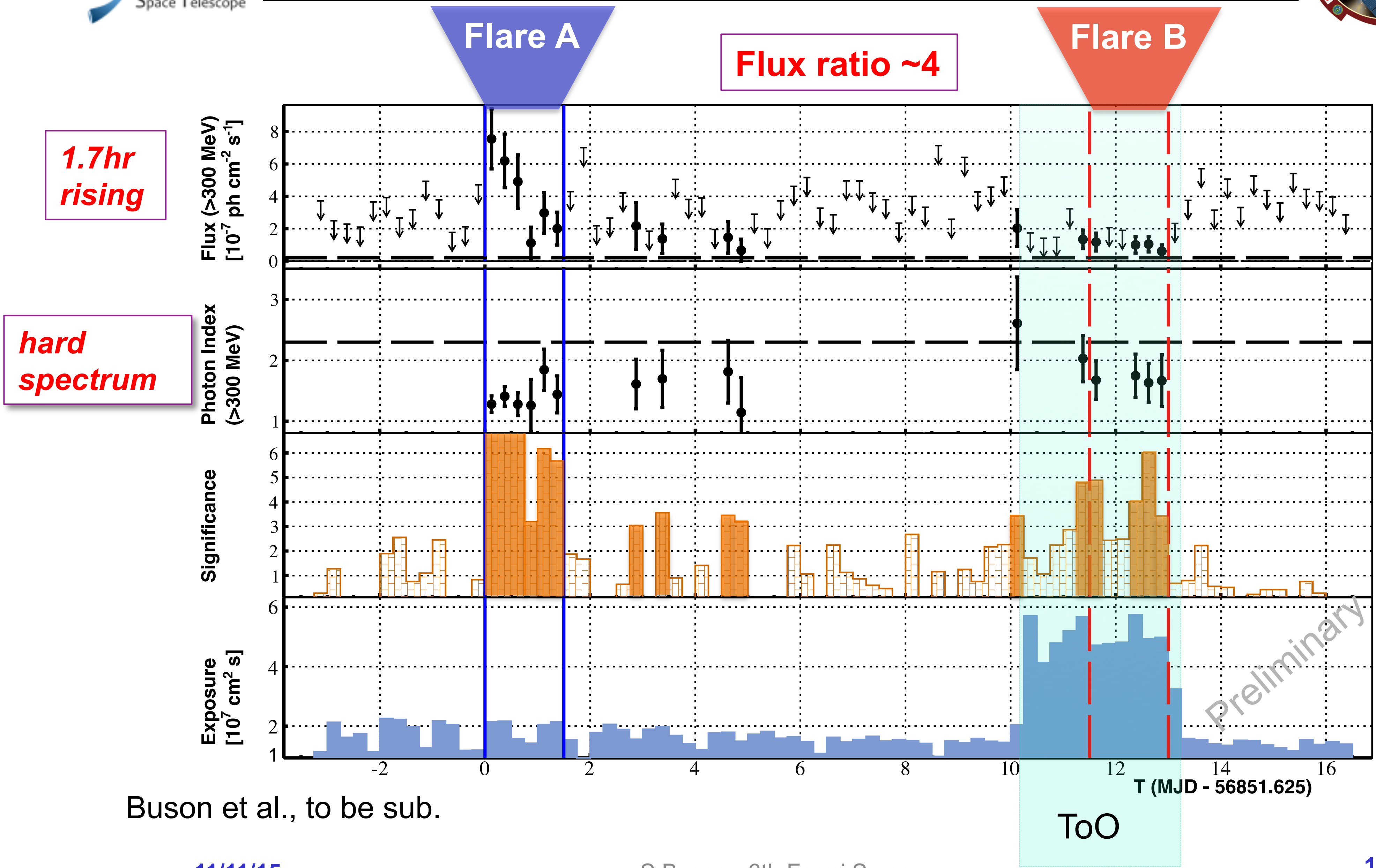
Difference between γ-ray and radio delays:

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

- **1.0 +/- 0.3 days (Biggs et al. 1999)**
- **1.4 +/- 0.8 days (Cohen et al. 2000)**

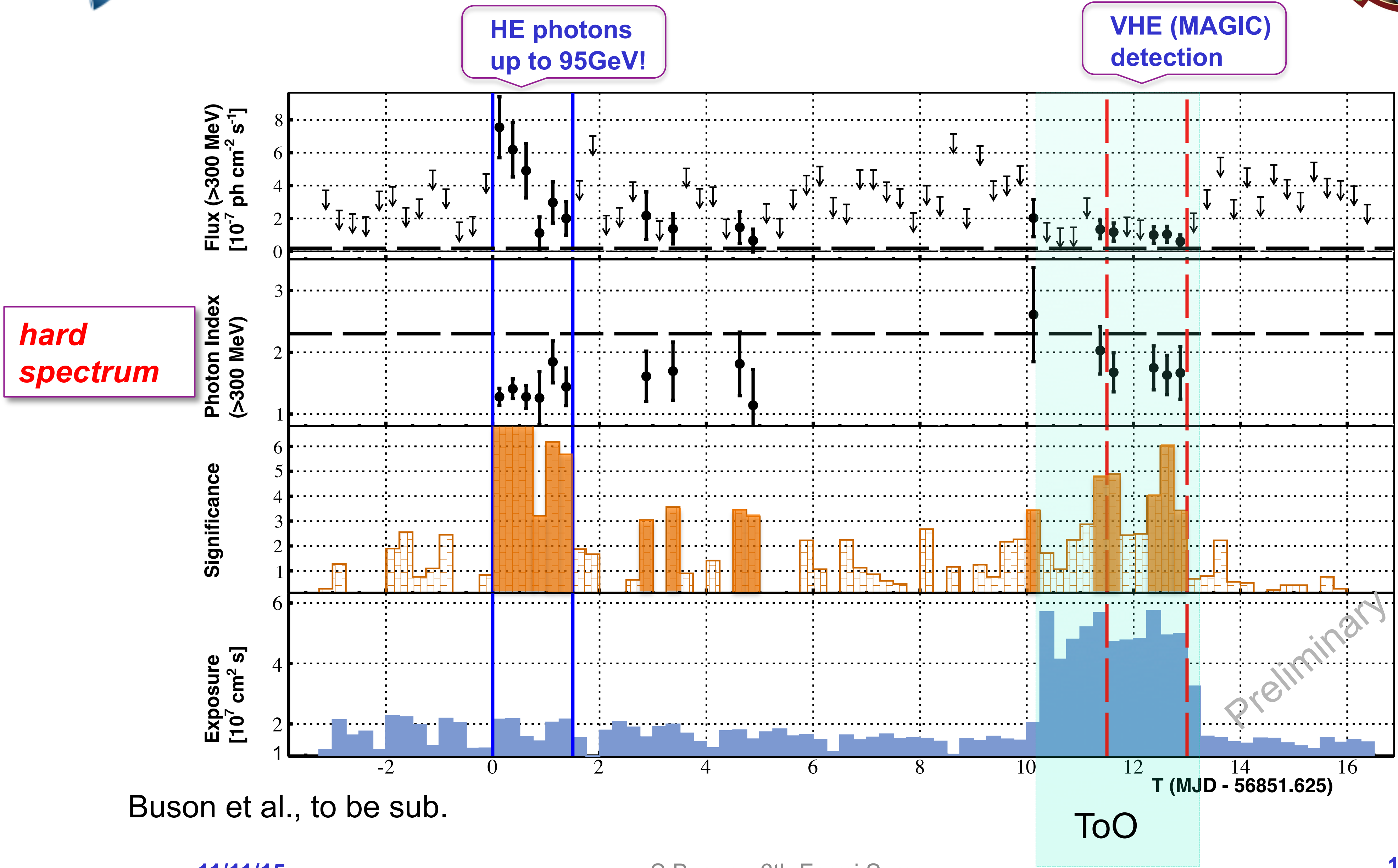
Displacement between the radio / gamma-ray region ~ 80 pc (projected)

2014 Light Curve (6-hr bin)



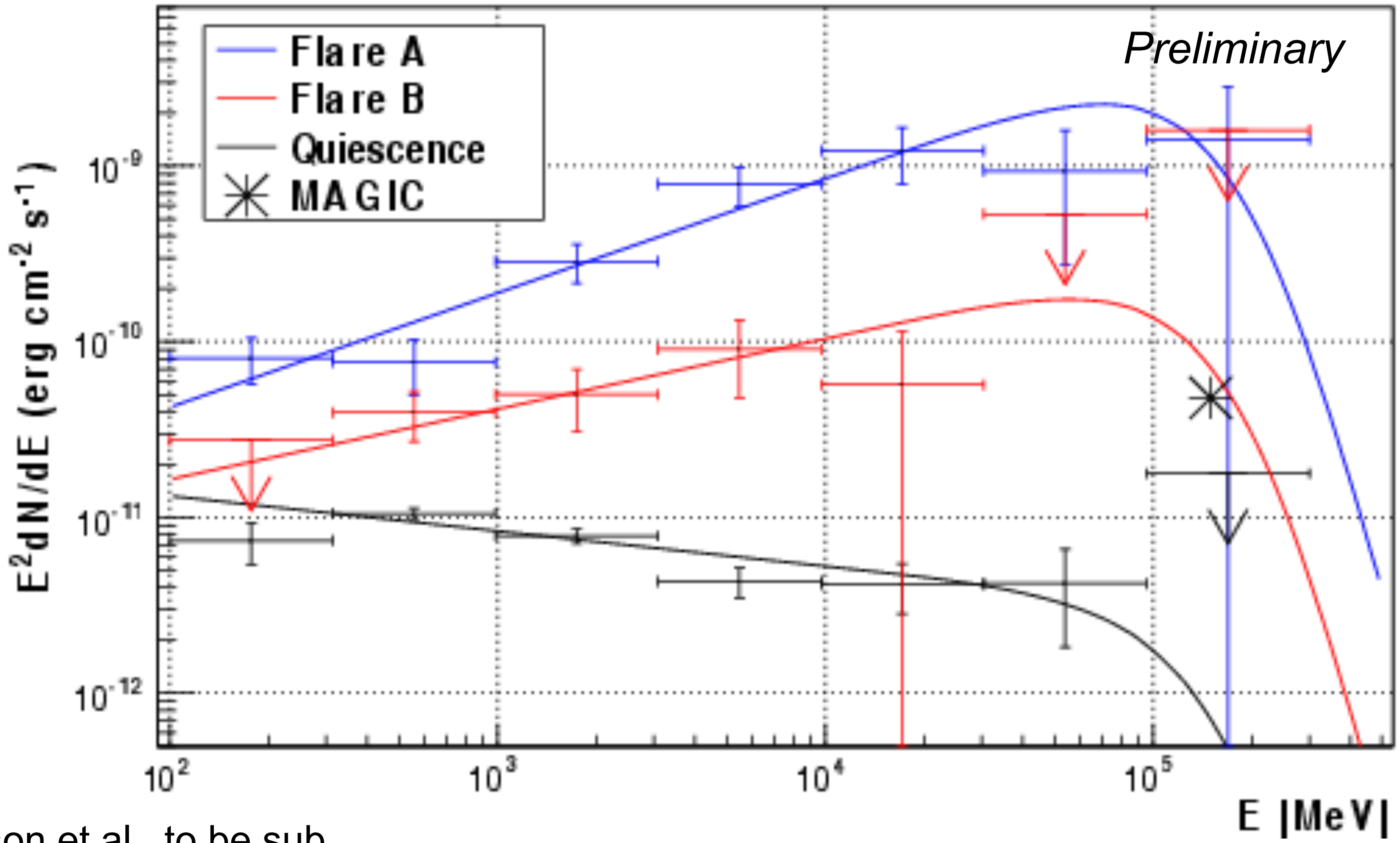
Buson et al., to be sub.

2014 Light Curve (6-hr bin)



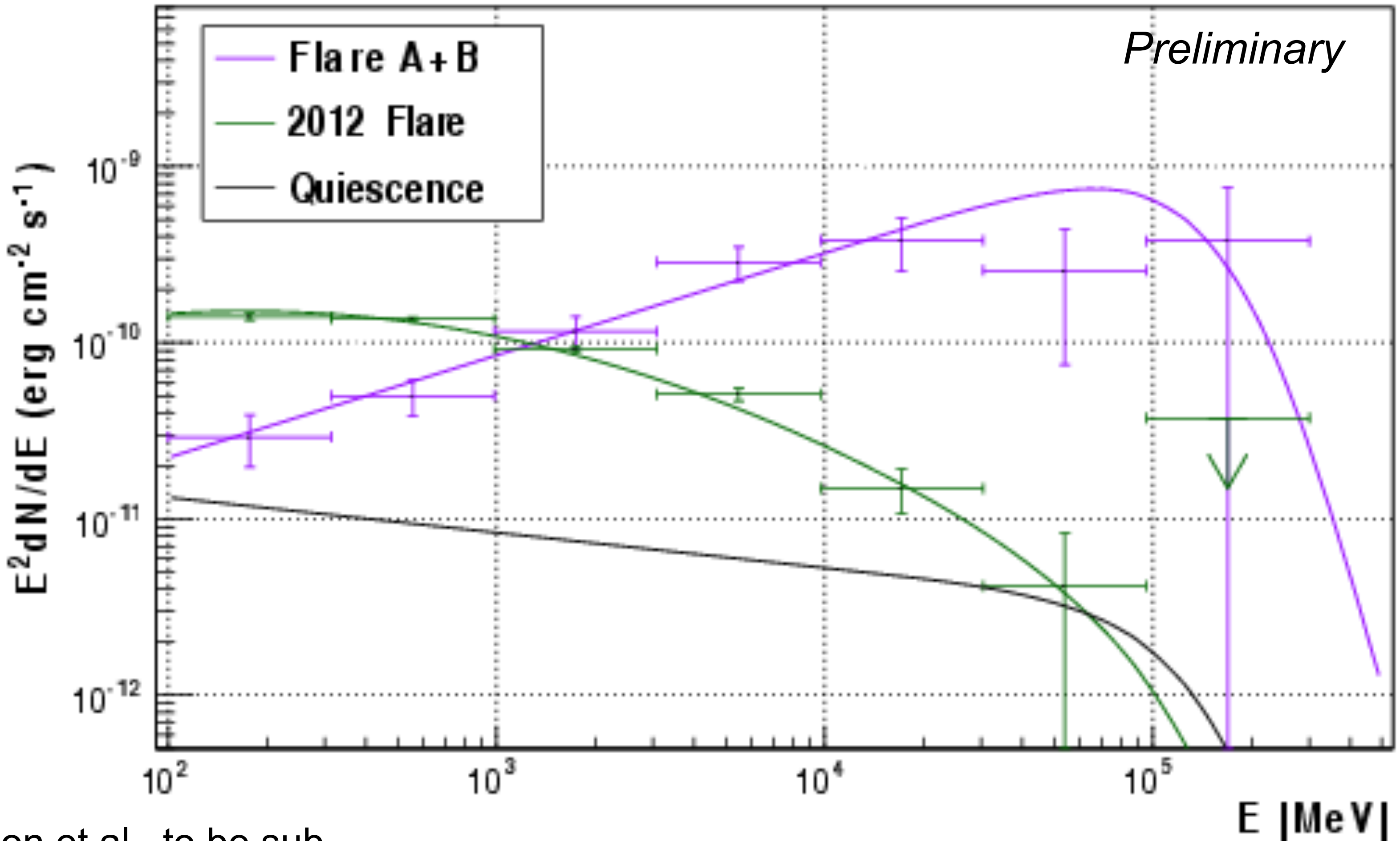
Buson et al., to be sub.

2014 Flare SED



Buson et al., to be sub.

SED: 2014 vs 2012/2013 Flares



Buson et al., to be sub.

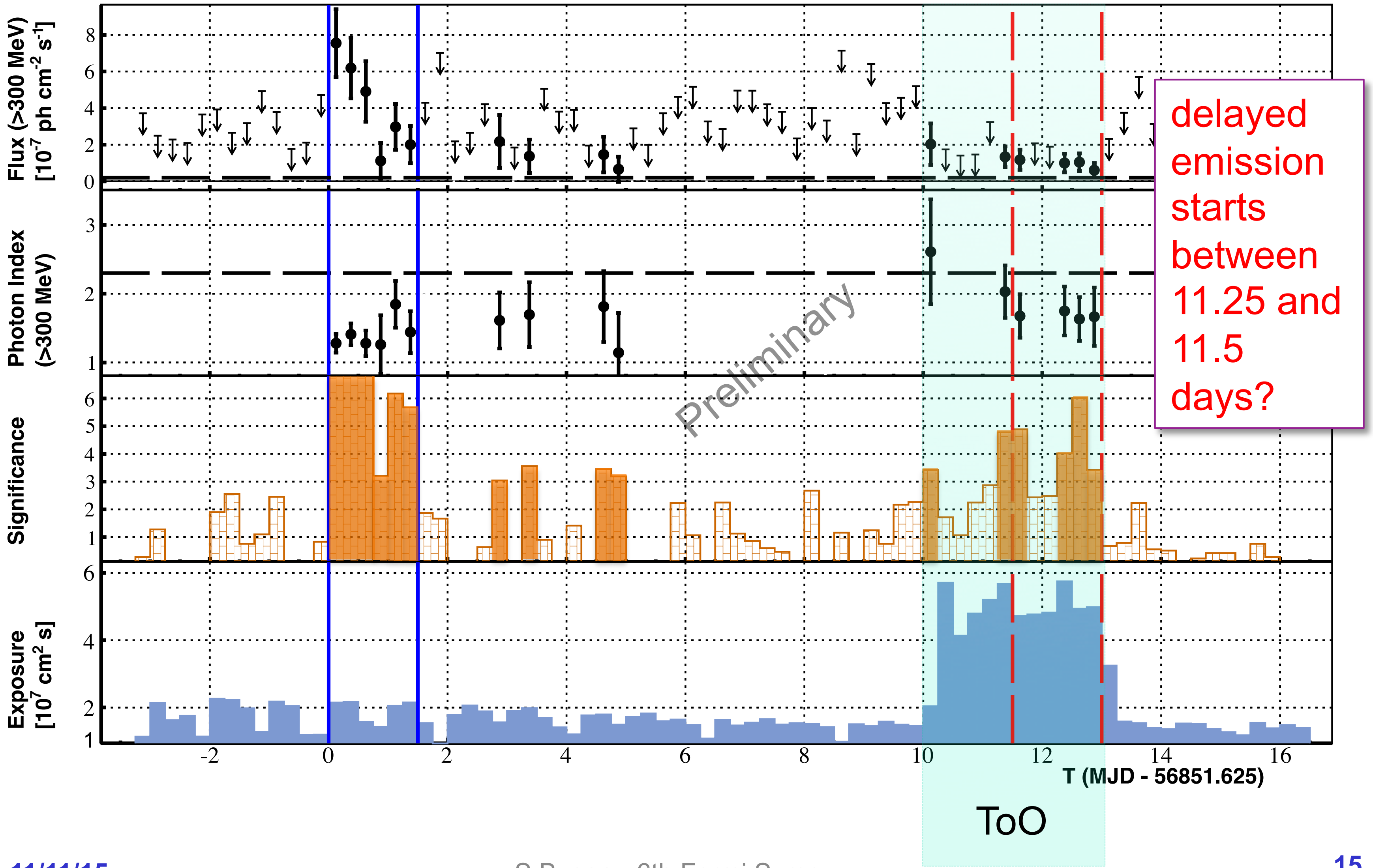
B0218+357 Characteristics

- **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**

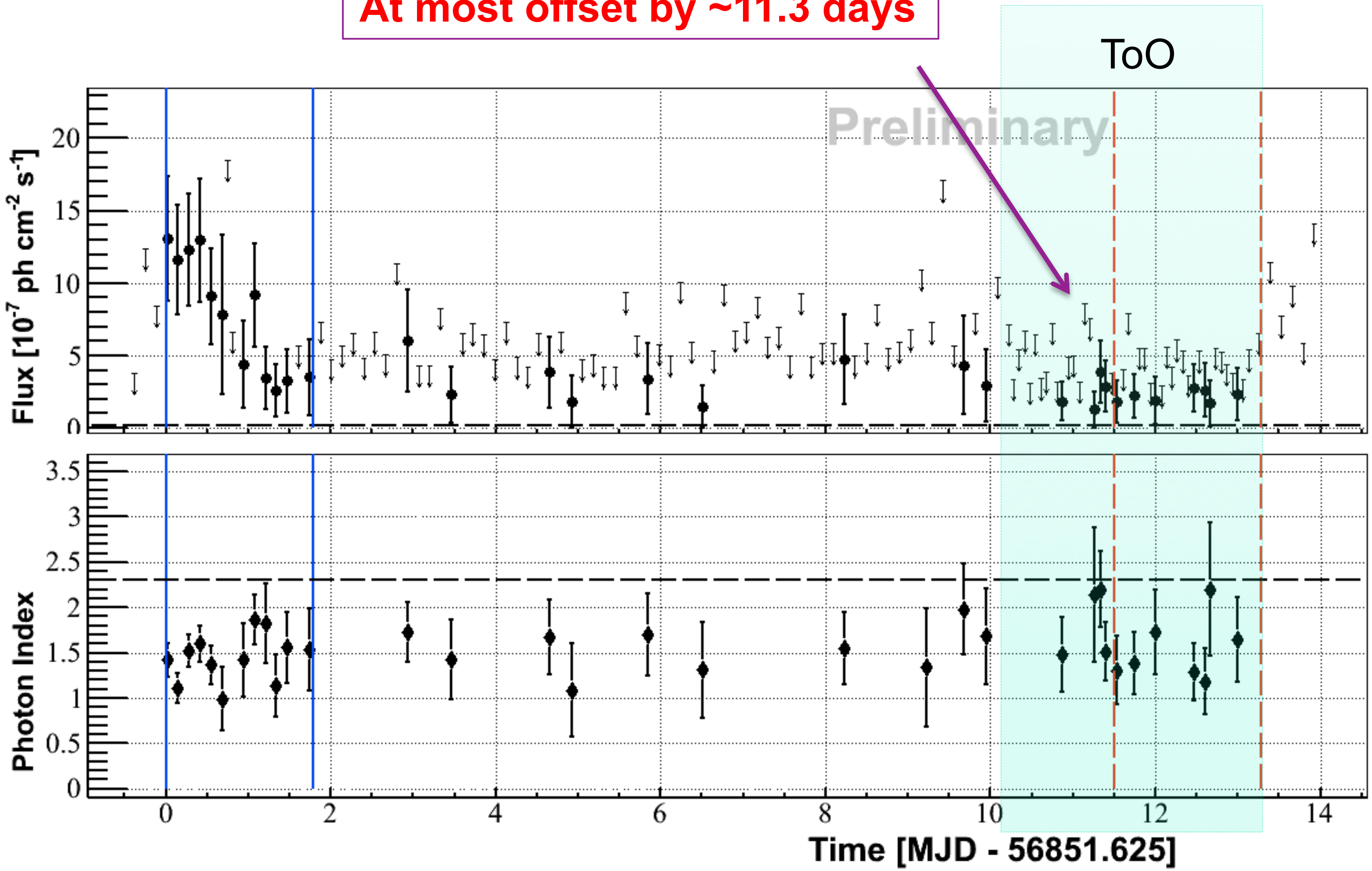
- **For the expected delay interval, the span of the highest significance bins look to be 11.25 days offset from the flare**
  - **ACF not effective (low statistics in 2014)**
  - **“by eye” estimate: look to light curve with finer binning**

2014 Light Curve (6-hr bin)



Orbit-by-orbit Light Curve

At most offset by ~11.3 days



Gamma-ray Emission Region Offset Limit

- 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

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

Summary

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

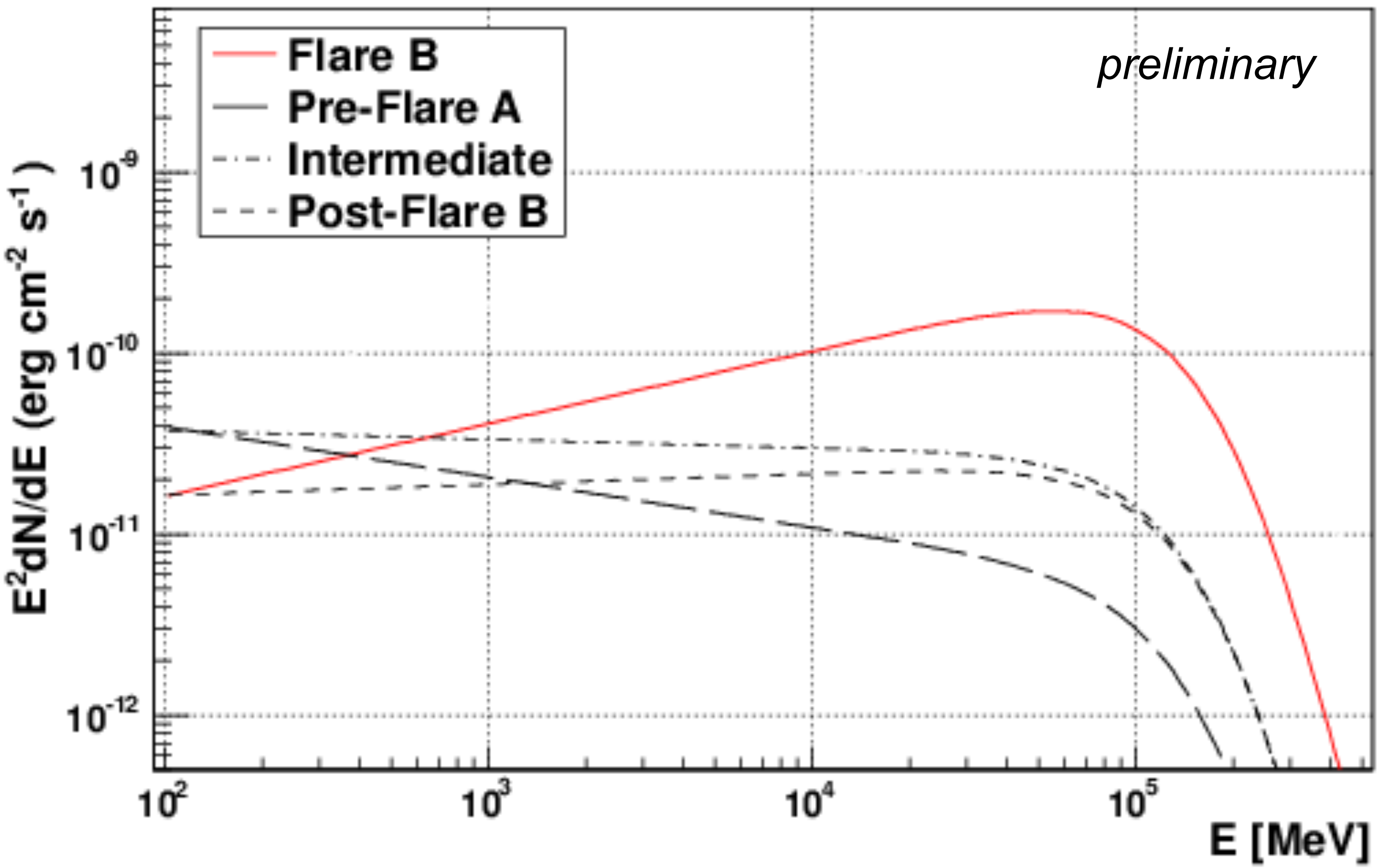
- **Flux ratio A/B ~4, close to radio values**
- **Possibly microlensing comes into play**

- **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**

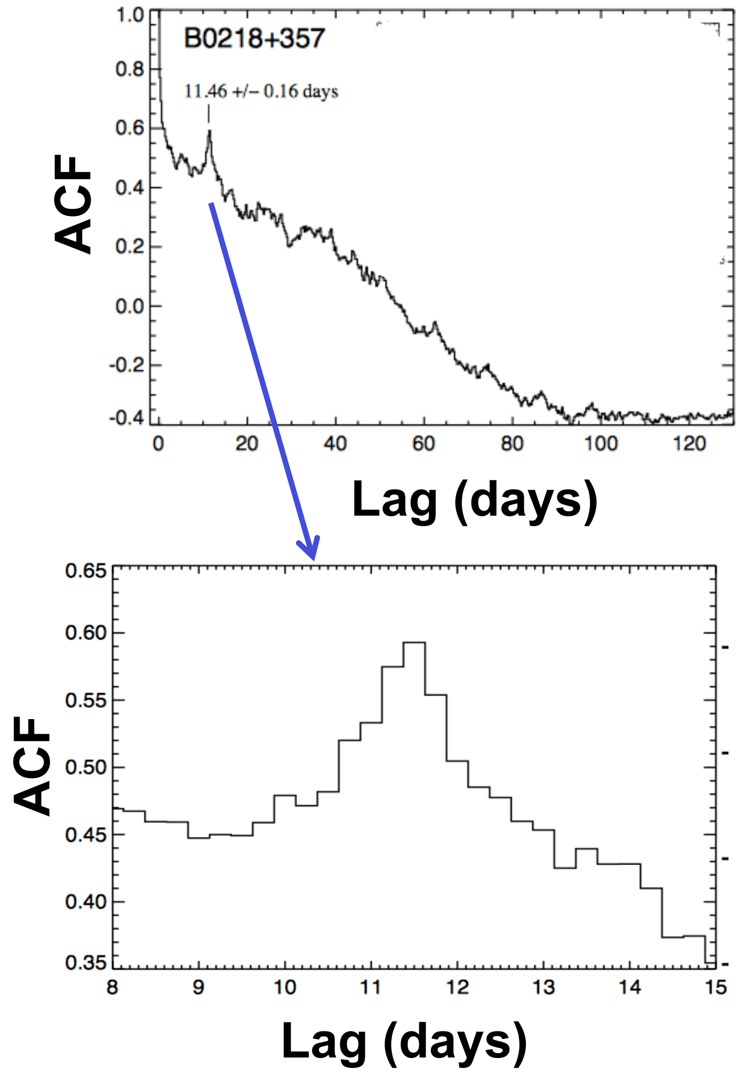
- **95 GeV photon detected by the LAT during A-image flare**
- **VHE detection reported 11.5 days after by MAGIC**
- ***Fermi*-MAGIC detection of B0218+357 allows to test EBL models at z ~1 (MAGIC coll., in prep.)**

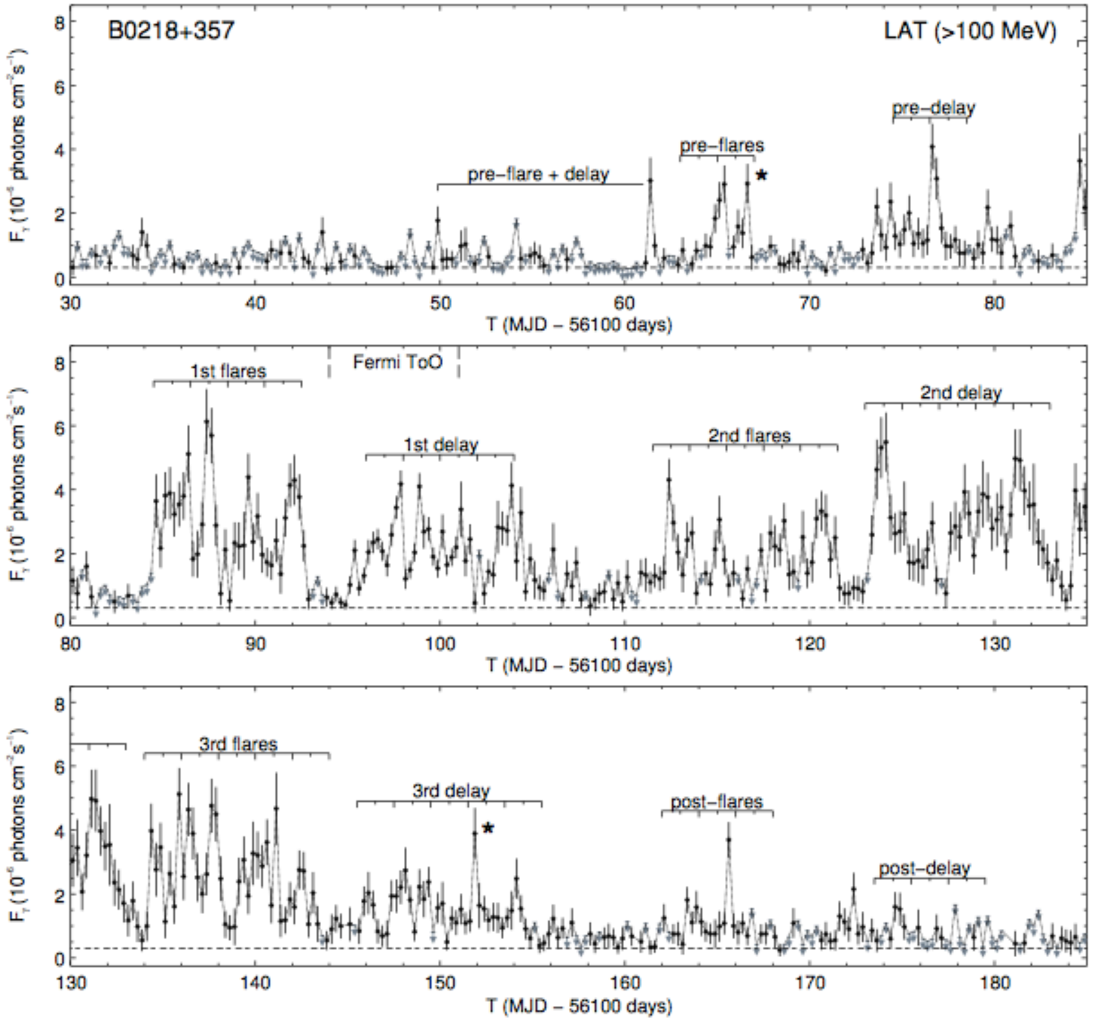
Back up

SED - 2014 intervals



2012/2013, Structured Gamma-ray Light curve





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