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

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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 $\Delta t_r = 10.5 \pm 0.2$ 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)

Time (MJD)

Flux (>100 MeV) \([10^{-6} \text{ ph cm}^{-2} \text{s}^{-1}]\)

Photon Index

Significance

2012/2013 flares

2014 flares


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

2012/2013 flares

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

Delay = 11.46 ± 0.16 days
Flux ratio = 1.16 ± 0.07
Magnification ratio = 1.32 ± 0.09
(2012/2013)
Fermi-LAT light curve
(2008–2014, 1-week bin)

Delay = 11.46 ± 0.16 days
Flux ratio = 1.16 ± 0.07
Magnification ratio = 1.32 ± 0.09
(2012/2013)

Delay = 11.25/11.5 days
Flux ratio ~ 4
Magnification ratio ~ 4
(2014)

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

2012/2013 flares
2014 flares
2012/2013 Gamma-ray Flares

Cheung et al.
\[ \Delta t_{\gamma} - \Delta t_r = \]

- 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)

Flux ratio ~4

Flare A

Flare B

1.7hr rising

hard spectrum

Buson et al., to be sub.

ToO

11/11/15
2014 Light Curve (6-hr bin)

HE photons up to 95GeV!

VHE (MAGIC) detection

Buson et al., to be sub.

11/11/15

S.Buson - 6th Fermi Symp.
2014 Flare SED

Preliminary

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)

delayed emission starts between 11.25 and 11.5 days?
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

- Consistent with findings by Barnaka et al. 2015
- Vovk & Neronov (2015) suggest microlensing effects come into play
The 2014 **hard-spectrum fast-rise singular event** offers the unique opportunity to isolate the two emission images:

- Flux ratio $A/B \sim 4$, 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 $<25\text{pc}$, 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.)
SED - 2014 intervals

preliminary
2012/2013, Structured Gamma-ray Light curve

B0218+357

11.46 +/- 0.16 days

Lag (days)

ACF

LAT (>100 MeV)

F_\gamma (10^{37} \text{ photons cm}^{-2} \text{ s}^{-1})

T (MJD - 56100 days)

1st flares

1st delay

2nd flares

2nd delay

3rd flares

3rd delay

post-flares

post-delay
Delay estimated = 11.46 +/- 0.16 days
Flux ratio = 1.16 +/- 0.07
Magnification ratio = 1.32 +/- 0.09

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