Multiwavelength monitoring of gravitationally lensed blazar QSO B0218+357 between 2016 and 2020

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Abstract:

QSO B0218+357 is currently the only gravitationally lensed source from which both high-energy (HE, >~100 MeV) and very-high-energy (VHE,>~100 GeV) gamma-ray emission has been detected. We report the *Fermi*/LAT and multiwavelength monitoring observations of this source in radio interferometry, optical and X-rays performed between 2016 and 2020. During the monitoring individual flares in optical, X-ray and HE bands have been observed. We analysed the MAGIC telescopes data during the flaring states to search for the associated VHE emission, constraining the VHE gamma-ray duty cycle of the source.

QSO B0218+357:

- The only gravitationally lensed source known in VHE gamma rays
- A time delay of 10-12 days between the two images has been estimated
- Nominally the farthest known VHE gamma-ray source (redshift z = 0.944 ± 0.002, Cohen et al.2003)
- In 2012 underwent an extended high state seen in *Fermi*/LAT (Cheung et al. 2014).
- In 2014 a follow up by the MAGIC telescopes of the flare seen by *Fermi*/LAT (Buson et al 2016) led to the detection of the source as a VHE gamma-ray emitter (Ahnen et al 2016)

Monitoring strategy:

- Broadband monitoring of the source in radio (including interferometry with KaVA), optical and gamma rays, with additional measurements in the UV and X-ray bands performed between 2016 and 2020
- Monitoring slots selected to allow observations after the expected image delay of the source emission

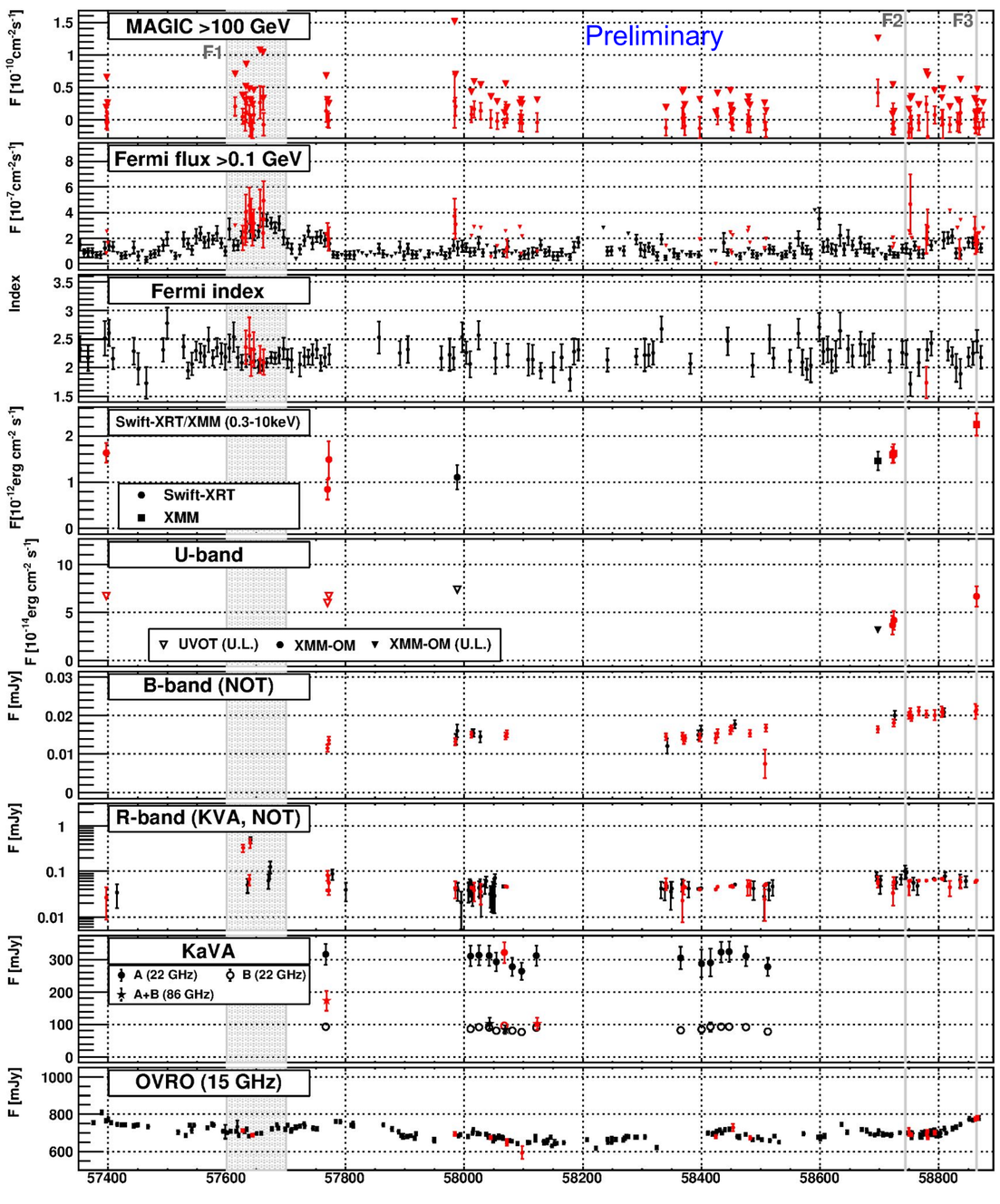
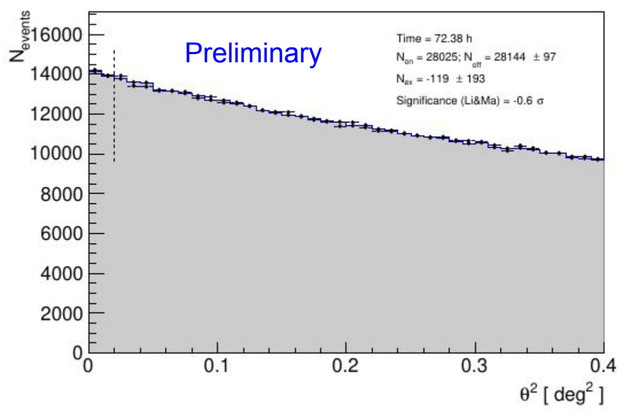


Fig 1. MWL light curve of QSO B0218+357 between January 2016 and January 2020. From top to bottom: MAGIC flux >100 GeV, *Fermi*/LAT flux >0.1 GeV, *Fermi*/LAT spectral index, *Swift*/XRT and XMM-Newton X-ray flux in 0.3 – 10 keV range (corrected for Galactic absorption), Swift-UVOT and XMM-OM observations in U-band, NOT observations in B-band, optical observations in R-band with KVA and NOT. OVRO monitoring results at 15 GHz. KaVA VLBI observations at 22 GHz (filled symbols show A image, empty ones B image) and 86 GHz (sum of A and B images shown with stars). Flux upper limits are shown with downward triangles. Optical data are corrected for the host/lens galaxy contribution and Galactic absorption. The points in red are contemporaneous (within 24 hr slot) with MAGIC observations. The gray filled regions mark the enhanced emission periods (F1, F2, F3)

Search for VHE gamma rays:

- No VHE gamma ray emission has been seen in individual nights of monitoring with MAGIC
- *Fermi*/LAT data used to evaluate the GeV state of the source during the monitoring
- Large data sample of 72 hr collected for constraining the low state emission of the source



Enhanced states of the source:

- Three periods of enhanced state of the source were observed during the monitoring
  - F1: a a ~three months long period within a high GeV state during which optical variability by an order of magnitude was observed
  - F2: moderately enhanced optical flux of the source (a factor 2 with respect to low state in optical)
  - F3: X-ray flare with simultaneous marginal UV flux increase (+70 +/- 41)%
- Periods F1 and F3 have simultaneous MAGIC data, however no VHE gamma-ray emission was detected

Tag	MJD	description
F1	57600 – 57700	optical and GeV flare
F2	58744	small optical flare
F3	58863.7	X-ray flare

KaVA radio interferometry view of QSO B0218+357

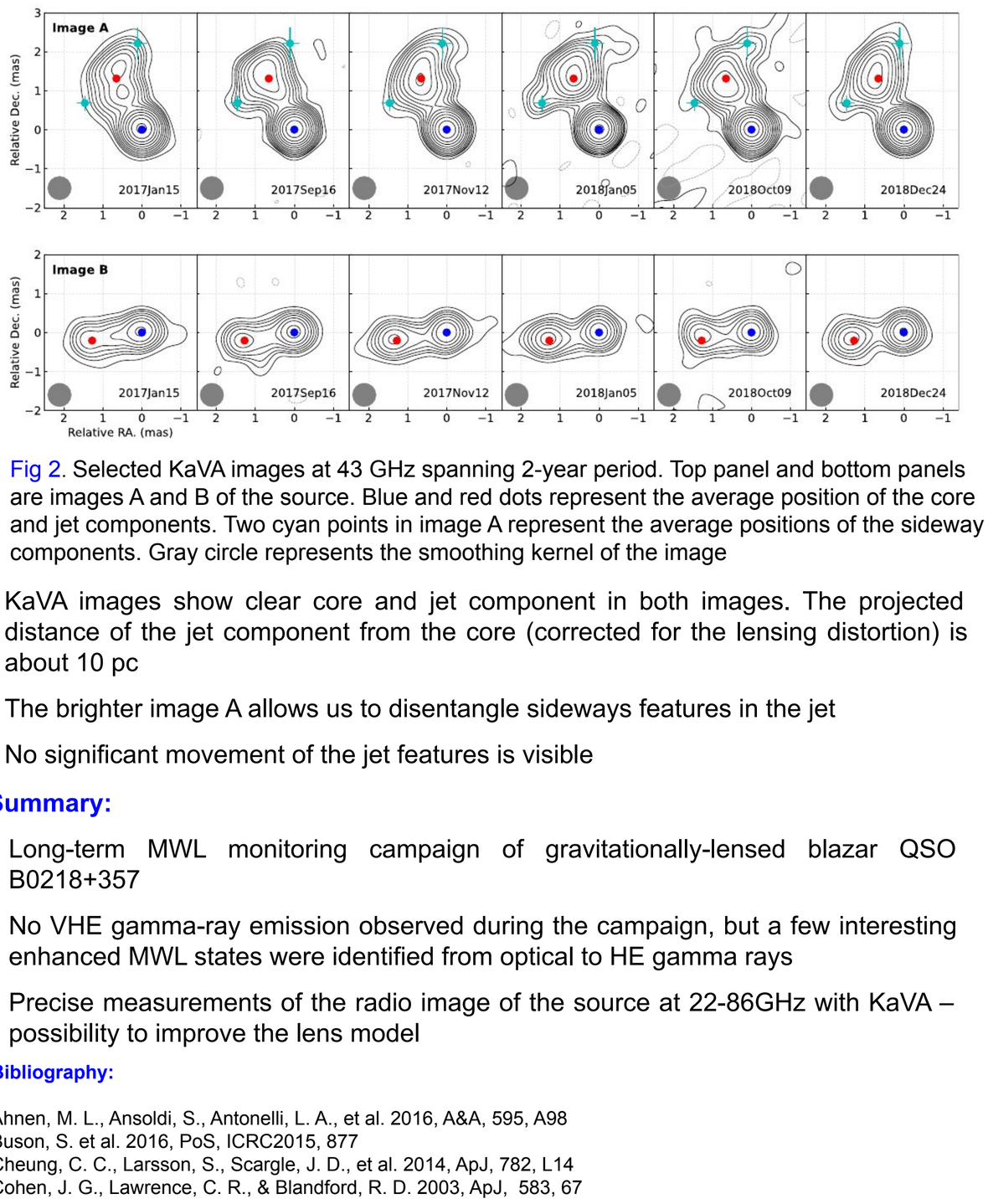


Fig 2. Selected KaVA images at 43 GHz spanning 2-year period. Top panel and bottom panels are images A and B of the source. Blue and red dots represent the average position of the core and jet components. Two cyan points in image A represent the average positions of the sideway components. Gray circle represents the smoothing kernel of the image

- KaVA images show clear core and jet component in both images. The projected distance of the jet component from the core (corrected for the lensing distortion) is about 10 pc
- The brighter image A allows us to disentangle sideways features in the jet
- No significant movement of the jet features is visible

Summary:

- Long-term MWL monitoring campaign of gravitationally-lensed blazar QSO B0218+357
- No VHE gamma-ray emission observed during the campaign, but a few interesting enhanced MWL states were identified from optical to HE gamma rays
- Precise measurements of the radio image of the source at 22-86GHz with KaVA – possibility to improve the lens model

Bibliography:

Ahnen, M. L., Ansoldi, S., Antonelli, L. A., et al. 2016, A&A, 595, A98
Buson, S. et al. 2016, PoS, ICRC2015, 877
Cheung, C. C., Larsson, S., Scargle, J. D., et al. 2014, ApJ, 782, L14
Cohen, J. G., Lawrence, C. R., & Blandford, R. D. 2003, ApJ, 583, 67