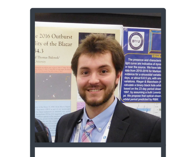
The June 2016 Multi-Frequency Outburst and Optical Micro-Variability of the Blazar 3C454.3

Weaver, Z.R.[1,2], Jorstad, S.G.[1,3], Marscher, A.P.[1], Balonek, T.J.[2], Larionov, V.M.[3,4], & Smith, P.S.[5]

1. Boston University, USA, 2. Colgate University, USA, 3. St. Petersburg State University, Russian Federation, 4. Astronomical Observatory of RAS, Russian Federation 5. Steward Observatory, USA



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Abstract

In June 2016 the quasar 3C454.3 underwent a uniquely-structured multi-frequency outburst. The blazar was observed at gamma-ray frequencies by the *Fermi* Large Area Telescope and in the optical *R* band by several ground-based telescopes. In contrast to previous outbursts, the June 2016 outburst exhibited a precipitous decay at both gamma-ray and optical frequencies, with the source decreasing in flux density by a factor of 6 over a 24-hour period at gamma-ray frequencies. The gamma-ray outburst exhibited a three-flare structure previously observed in other outbursts. A low-amplitude outburst was observed in 2016 March. Analysis of 43 GHz VLBA images indicates that the 2016 March outburst is consistent in time with the forward shock of a knot passing through the radio core of the quasar, while the 2016 June outburst is consistent with a reverse shock from the same knot. Intraday variability during several nights was observed throughout the outburst in *R* band, with flux density changes between 1 and 5 mJy over the course of a night. The precipitous optical decay featured quasi-periodic micro-variability oscillations with an amplitude of ~2-3% about the mean trend and a characteristic period of 36 minutes. If the quasi-periodic micro-variability oscillations are caused by the periodic variations of the Doppler factor of emission from a turbulent vortex, we derive the speed of rotation of the vortices of 0.2c. The multi-wavelength and polarization behavior of 3C454.3 is presented in Fig. 1.

Fig. 1 (right). Flux and polarization vs. time of 3C454.3. From top to bottom: (a) *Fermi*-LAT γ-ray flux with varying time bins. The blue, solid lines divide 24-hr and 6-hr time bins, and the black, dashed lines divide 6-hr and 3-hr time bins; (b) optical light curve in *R* band; (c) degree of optical linear polarization; (d) position angle of optical polarization. The horizontal lines correspond to polarization angles parallel (red dashed) and perpendicular (blue dot-and-dash) to the radio jet (see Jorstad et al. 2017).

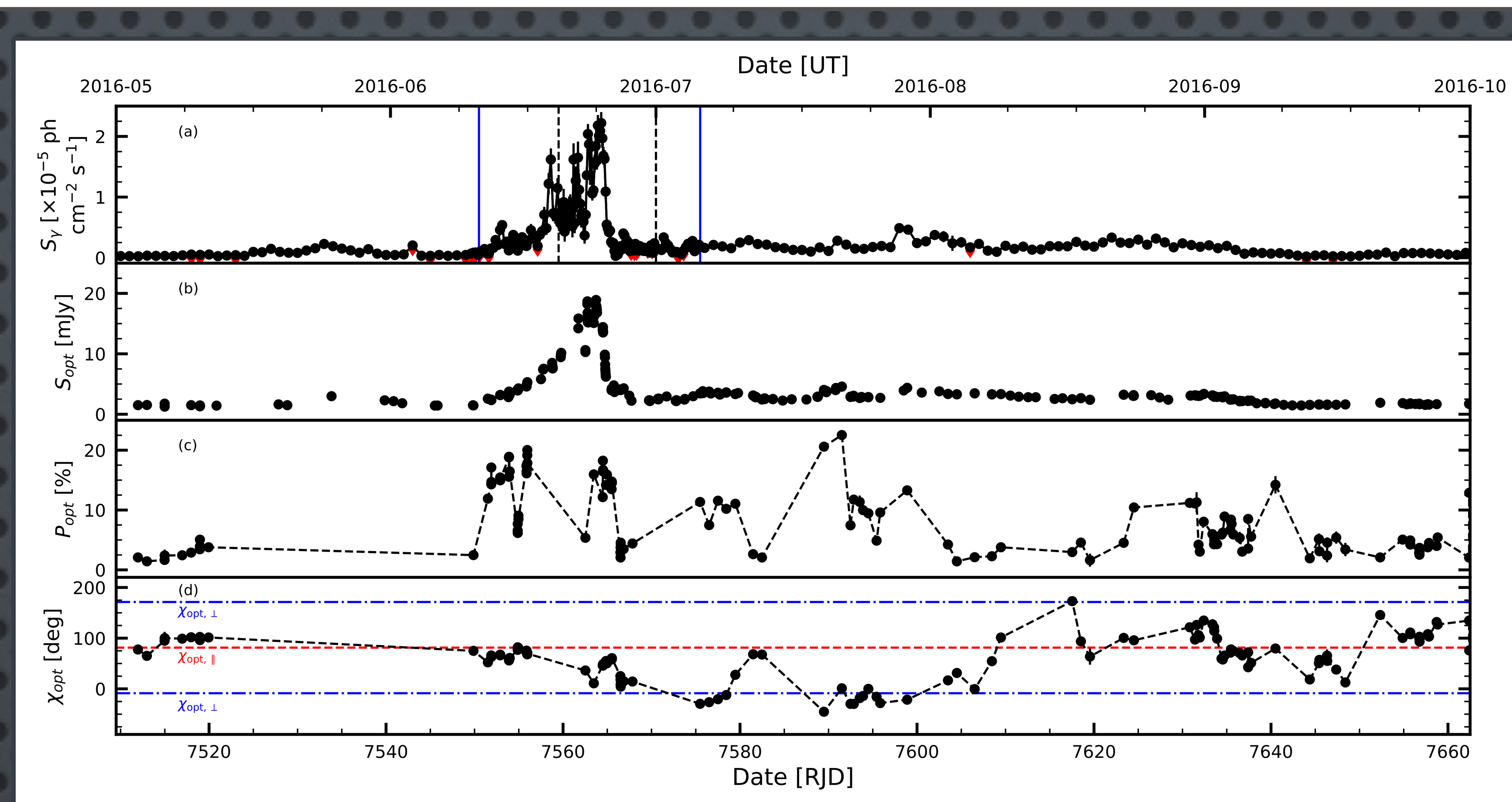


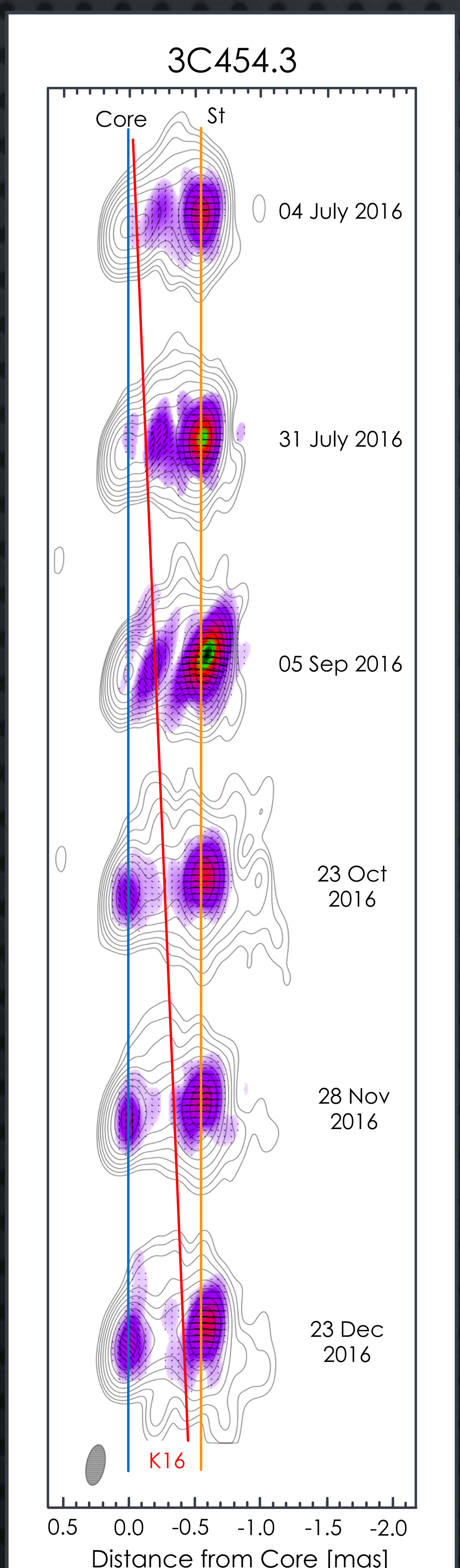
Fig 2 (below). γ-ray light curve of the June 2016 outburst, relative to T_γ^{max} = 7564.3 (June 24) and S_γ^{max} = 22.20 ± 0.18 x 10^{-5} ph cm^{-2} s^{-1}. Upper limits are denoted with red downward arrows. Flares *a*, *b*, and *c*, pre- and post-flare *a* plateaus, and pre- and post-outburst times are marked with dotted lines. The inset shows the shape of flare *a* in more detail in units of the main figure.

The Gamma-Ray Outburst

The γ-ray light curve of the June 2016 outburst is shown in Fig. 2. A main flare, *a*, and two smaller flares, *b* and *c*, are identified in the outburst. Flare *a* has an asymmetric shape, with the peak occurring late in the flare and a precipitous decay on 2016 June 25, and is similar in shape to the optical outburst (see Fig. 1). The decay lasted over a 24-hr period, dropping from ~2.0×10^{-5} to ~2.0×10^{-6} ph cm^{-2} s^{-1}. Over 40% of this decay occurred over a 6-hr time period. Pre- and post-flare "plateaus" of enhanced γ-ray emission (first discussed by Abdo et al. 2011) were identified. The triple-flare structure of the 2016 outburst is similar to three previous outbursts of 3C454.3 (see Jorstad et al. 2013). The extremely short decay of flare *a* of the 2016 outburst suggests a faster disturbance (in our frame) or a smaller, more violently variable emission region as compared to the previous outbursts. Despite the minor differences in shape and timescale, the similarity in structure of the outbursts argues in favor of a similar mechanism(s) and location of γ-ray production in the June 2016 outburst and the three previous events.

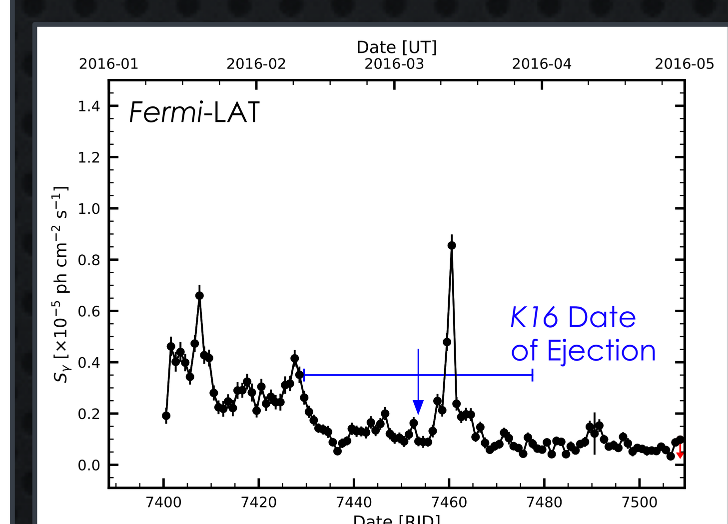
Optical Microvariability

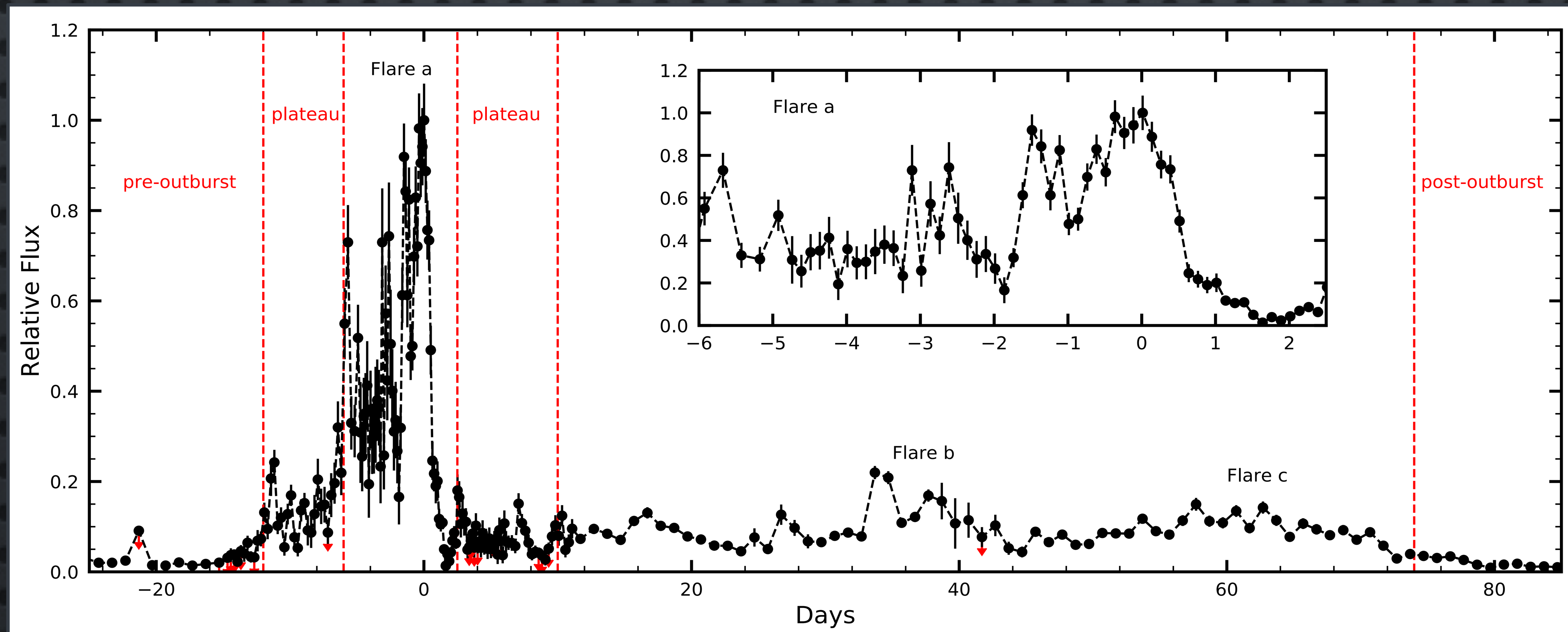
Inspection of the optical *R* band light curve during the June 2016 outburst reveals several periods of intense variability over the course of a single night. A one-way analysis of variance (ANOVA; see de Diego 2014) test was performed on nightly light curves obtained from the Colgate University Foggy Bottom Observatory. Eight nights of intraday variability were identified at the 0.1% (> 3σ) confidence level. The light curve on June 25 (above) exhibits significant intraday variability. We fit an exponential curve to the data and find significant structure in the residual light curve that can be improved with the addition of a decaying sinusoid. The amplitude of the sinusoid is 0.17 mJy and the period is 36 minutes. A changing period may better fit the data, but there are not enough cycles to warrant such a complication. This rapid micro-variability severely constrains the size of the emission region for the outburst.



Radio Knot

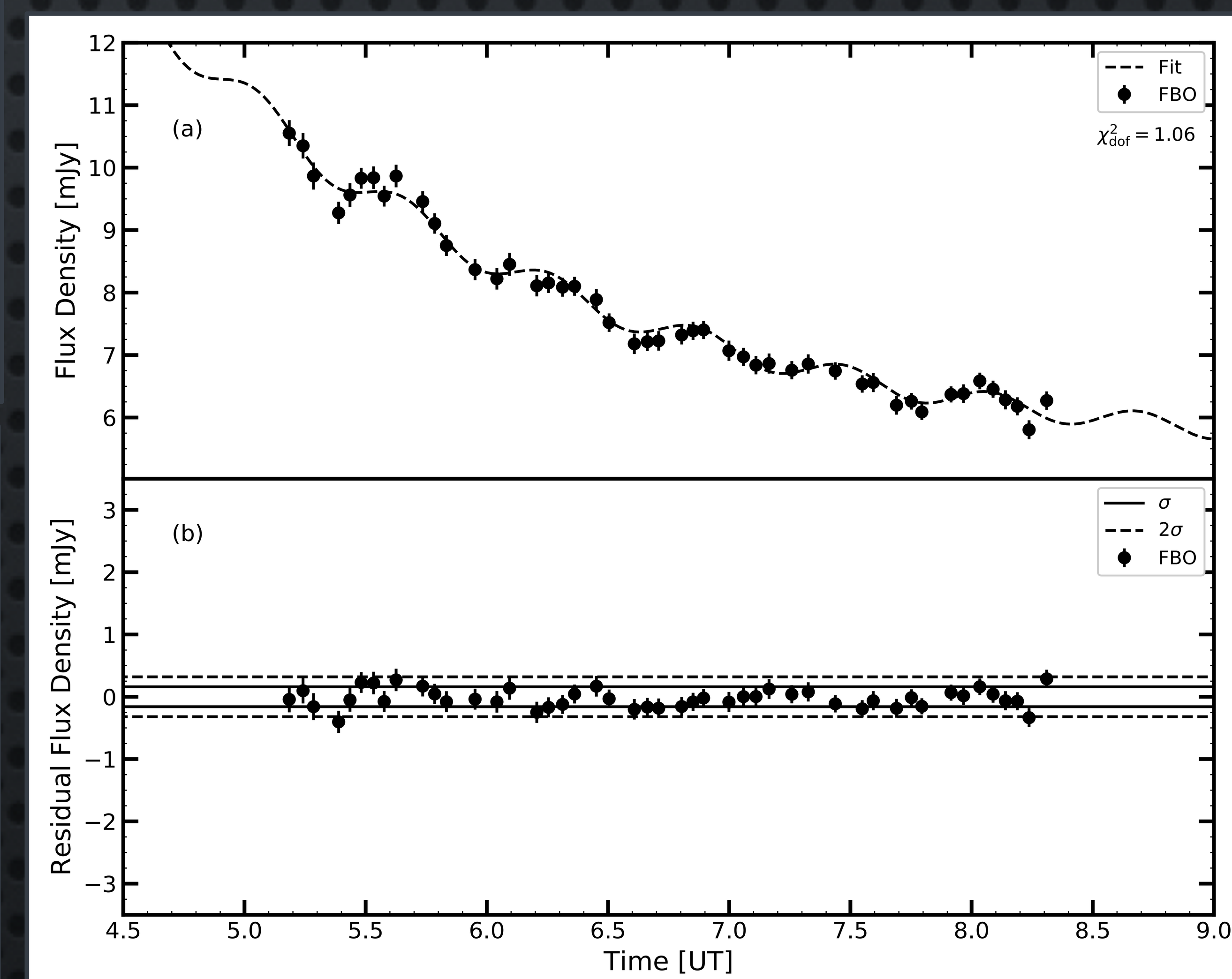
A preliminary analysis of publicly available VLBA data (from the VLBA-BU-BLAZAR program) reveals two knots ejected from the 43 GHz core of 3C454.3 near in time to the 2016 outburst. *K16*, pictured left, was first distinguishable from the 43 GHz core in June 2016. The knot had an apparent speed of 20c ± 4c. A backward extrapolation of the motion under the assumption of constant speed yields a date of 2016 Mar. 6 (± 48 days) when the brightness centroid of the knot crossed that of the core. Analysis of γ-ray data collected with the *Fermi* LAT in the months prior to the June 2016 outburst (pictured below) reveals a small amplitude flare with $S_\gamma^{max} = 8.55 \pm 0.42\times10^{-6}$ ph cm^{-2} s^{-1} on 2016 March 13. The timing of this small flare in March is consistent with a forward shock in *K16*, and the main June 2016 outburst is consistent with a reverse shock in *K16*. A second knot, *K17*, was first visible in March 2017, moved at a speed of 10c ± 4c, and crossed the core near 2016 Dec. 10 (± 226 days). It may also be associated with the June 2016 outburst.





Conclusions

The peaks of the γ-ray and optical light curves are coincident to within the time sampling of the γ-ray light curve. The high time-resolution light curve on 2016 June 25 reveals micro-variability in the form of quasi-periodic oscillations with an amplitude of 2-3% around the mean trend and a period of 36 minutes. The average Doppler factor of the observed 43 GHz radio knots *K16* and *K17* is δ = 25, similar to that seen in Jorstad et al. (2017). The observed timescale of variability in the *R* band is 2 hours, indicating an intrinsic timescale of variability of 27 hours and an emission region size $r \lesssim 10^{15}$ cm (due to relativistic causality). The magnetic field strength necessary for such a timescale of variability is $B \approx 1$ Gauss. For the observed micro-variability period of 36 minutes, the intrinsic timescale of variability is ≈ 8 hours, and a smaller region is required; $r \lesssim 9.0\times10^{14}$ cm. In a turbulent scenario, the jet is made of 35 turbulent cells. If the micro-variability is related to this turbulence, and the turbulence includes rotation of vortices, then the vortex dominating the quasi-periodic oscillation rotates at ~0.2c. This is in good agreement with the numerical simulations by Calafut and Wiita (2015). The work presented in this poster is from Weaver et al (submitted).



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Acknowledgements

This project was supported by Colgate University's Justice and Jayne Schlichting Student Research and the Division of Natural Sciences and Mathematics funds. The research at Boston University was supported in part by NASA Fermi GI grant 80NSSC17K0649 and National Science Foundation grant AST-1615796. Data from the Steward Observatory spectropolarimetric monitoring program were used. This program is supported by Fermi GI grant NXX15AU81G. The St. Petersburg University team acknowledges support from Russian Science Foundation grant 17-12-01029.

Fig. 3 (above). (a) The behavior of the blazar 3C454.3 in *R* band on 2016 June 25, with an exponential decay and decaying sinusoid fit to the data. The sinusoid has an average amplitude of 0.17 mJy and a period of 36 minutes. (b) The residual flux from the fit, on the same scale as the light curve. The solid black and dashed black lines represent the 1σ and 2σ error bars, respectively. A χ^2 test for goodness of fit yields $\chi^2_{dof} = 1.06$.