Evidence for Shocks as the Origin of Gamma-Ray Flares in Blazars

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ABSTRACT

We present cm-band total flux density and linear polarization light curves illustrating the signature of shocks during outbursts temporally associated with γ-ray flares detected by Fermi. The spectral evolution in these events is well-explained by new radiative transfer simulations incorporating oblique shocks. This finding supports the idea that in at least some events shocks in the jet are responsible for activity from the radio to the γ-ray bands.

Overview

Since the mid 1980s, the leading paradigm for the production of AGN flares in the radio-to-optical bands has been shocks (Hughes, Aller, & Aller 1985; Marscher & Gear 1985); such structures develop naturally within the relativistic jets of these objects. To test whether shocks also play a role in the production of γ-ray flares, and to identify conditions in the radio jet during γ-ray flaring, we are monitoring the total flux density and linear polarization at 14.5, 8.0, and 4.8 GHz in a sample of 24 blazars with the University of Michigan 26-m paraboloid (UMRAO). Our sources are bright and variable in the GeV γ-ray band and historically have exhibited well-resolved flares at centimeter band. Specific goals are: 1) to identify during γ-ray flaring the generic shock signature in the radio band data -- a swing in the electric vector position angle (EVPA) and flaring in total flux density and linear polarization; 2) to quantitatively test whether or not the observed spectral evolution in total flux density, polarized flux, and EVPA during individual events matches the predictions of new radiative transfer simulations which allow for shocks which propagate at an arbitrary orientation relative to the flow direction.

The Observations

Program blazars are: 3C 66A, 0235+164, 0420-014, 0454-234, 0528+134, 0716+714, 0727-115, 0805-077, OJ 287, 0906+015, 1156+295, 1222+216, 3C273, 3C279, 1329-049, 1502+106, 1510-089, 1633+382, 3C345, NRAO 530, OT 081, BL Lac, CTA 102, and 3C454.3. Observations are typically obtained twice per week at 14.5 GHz and once per week at 8.0 and 4.8 GHz; the cadence is increased, if needed, to follow the variations in individual flares. An `observation' consists of a series of on-off measurements over 25-45 minutes. Calibrators are observed every 1-2 hours to determine the antenna gain and pointing, and to verify the instrumental polarization. Figures 1-3 show examples of the shock signature in the radio data at or near times at which large flares were detected in the γ-ray band by the Fermi LAT.

Examples of Shock Signatures During Gamma-Ray Flaring

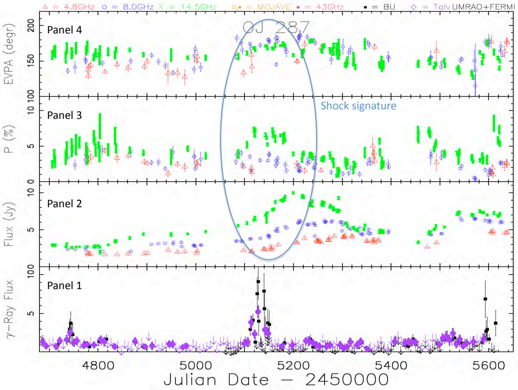

Figure 1. Daily averages of the radio band total flux density (panel 2) and linear polarization (panels 3 & 4) in OJ 287. The blue oval marks a shock signature. The bottom panel shows the γ-ray light curve. Black squares denote reductions with a bin size adjusted to the variability state (1 and 5 day binning during flare and non flare phases respectively). Purple denotes constant 7 day binning. Units are photons/s/cm^2 X 10^{-7}.

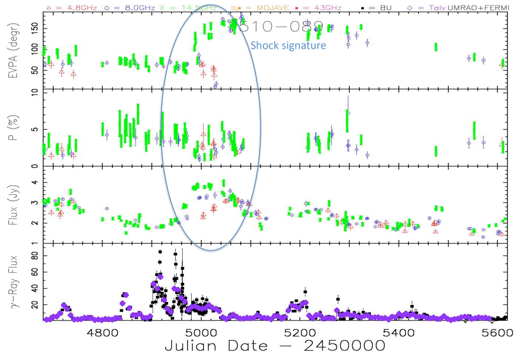

Figure 2 Daily averages of the radio band total flux density and linear polarization in PKS 1510-089 in the same format as in Figure 1 (panels 2-4). Panel 1 (bottom) shows the γ-ray light curve (units as in Figure 1). Black squares denote a variable bin size of 3d, 1d, and intraday (binning adjusted to the variability state); purple denotes constant 7 day binning.

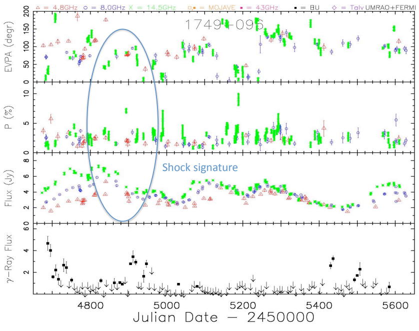

Figure 3. Daily averages of the total flux density and linear polarization in 1749+096 at 14.5, 8.0, & 4.8 GHz. Several increases in P% and ordered swings in EVPA can be seen, indicating rapid and complex radio band behavior. Events in the 1980s were fit assuming a transverse shock (Hughes, Aller, & Aller 1991). Fermi light curve: 7 day binning and units as above.

The Radiative Transfer Modeling

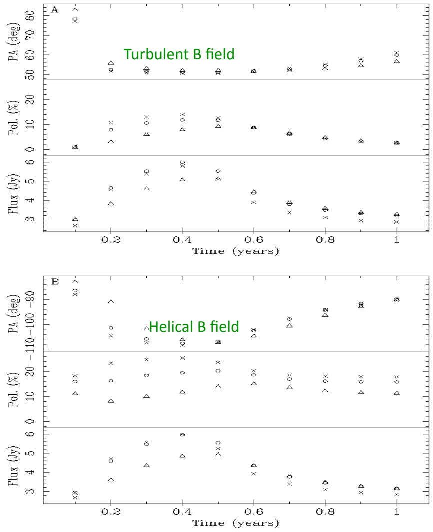

Figure 4. Oblique shock models. Simulated light curves assuming a compression of 0.7, a forward moving shock, a shock obliquity of 45°, and a viewing angle of 10°. A (top): a random magnetic field dominates. B: a helical magnetic field dominates. Symbols correspond to UMRAO frequencies as shown in Figures 1-3. The helical case does not match the observed maximum % polarization or the spectral evolution in EVPA.

To test the shock scenario, we have developed models incorporating shocks propagating at an arbitrary angle to the flow direction (Hughes, Aller, & Aller 2011). Representative results are shown in Figure 4. The swing in EVPA in the oblique shock case is typically through tens of degrees, as observed, rather than thru 90° (transverse shock).

Summary of Results

The monitoring data identify the expected shock signature during several Fermi events supporting a shock-in-jet origin. EVPA swings typically occur on a timescale of weeks-to-months over tens of degrees.

Simulations incorporating a propagating oblique shock reproduce the observed spectral behavior.

A comparison of the UMRAO data with simulations incorporating a purely ordered magnetic field (helical), a random field, or a mix of the two, shows that they are best explained if the magnetic field within the density enhancement is predominantly random before it passes through the shock.

REFERENCES:

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