Linear Polarization as a Probe of Gamma Ray Flaring Blazar Jets

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We describe and present initial results from a Fermi cycle 2 program designed to monitor the behavior of the centimeter-band linear polarization and total flux density emitted by gamma-ray-bright blazars during flaring. The goal of the program is to identify changes in the magnetic field structure in the radio jet associated with gamma-ray flaring and ultimately to test whether gamma-ray flaring is associated with the onset of shocks in the radio jet. Light curves illustrating radio band variability patterns are shown for sample program sources.

1. Overview of Project

As part of a Fermi cycle 2 program, we are obtaining monitoring observations at three centimeter band frequencies (14.5, 8.0 and 4.8 GHz) with the University of Michigan 26-m radio telescope (UMRAO) of the source-integrated total flux density and linear polarization of approximately 30 radio- and γ-ray-bright sources currently or expected to be in γ-ray-flare phase. The goal of our work is to identify jet conditions responsible for the generation of the γ-ray emission and to test the hypothesis that shocks play a role in the production of this emission as suggested by earlier work [1]. A causal connection between activity in the radio jet and γ-ray flaring first proposed based on EGRET data [2, 3, 4] is supported by early Fermi results. For example, statistical studies of the sources in the 15 GHz MOJA VE VLBA sample [5] have found that the members detected during the first three months of Fermi operation [6] are more core-dominated, have higher brightness temperatures and Doppler factors, and are in a more active radio state than non-detected MOJAVE sources [7, 8].

While there has been increasing evidence suggesting that the γ-ray emission arises near the radio core [2], a region believed to correspond to either the τ=1 surface or to a standing shock [9] and not at a site near to the black hole/accretion disk, a number of important questions remain. These include the trigger for the emission of γ-rays, the position of the emission site (upstream or downstream of the radio core) and the nature of the emitting region itself (standing shock, propagating shock, or ‘blob’ with a chaotic magnetic field where turbulence produces the very high energy electrons). A plausible scenario for the broadband features seen as outbursts or flares is that instabilities develop naturally within the collimated relativistic jet outflows giving rise to shocks [10]. With the passage of a shock, there is a compression of the magnetic field within the emitting region and an increase in the degree of order of the magnetic field. The observational signature of such an event is a swing in the electric vector position angle (hereafter EVPA; an orientation orthogonal to the magnetic field direction in a transparent source) and an increase in the fractional linear polarization.

2. The Source Sample

Our program sources are listed in Table 1. In addition to blazars, our source sample includes the radio galaxy 3C 84 (NGC 1275); γ-ray emission has been detected in this source which appears to be associated with compact regions within the radio jet [11]. Selection was based on the following criteria: 1) inclusion in the high confidence list in the LAT catalogue based on the first three months of Fermi’s operation; 2) 15 GHz total flux density of at least 1 Jy in early 2009; and 3) membership in the MOJAVE 15 GHz survey [5]. While AGN light curves regularly show peaks and troughs that can last for months or longer, we expect these objects to be highly likely to exhibit bright flaring states during cycle 2. A minimum radio band total flux density of 1 Jy was chosen to ensure good signal-to-noise in the multifrequency polarimetry data. Typical fractional linear polarizations in blazars are of order a few percent, and the radio band spectra of our targets are characteristically flat or inverted (14.5 GHz total flux density > 4.8 GHz total flux density). The MOJAVE 15 GHz imaging data, typically obtained every few months or longer, will complement our single dish measurements which are more frequent but which integrate over the entire source area. About half of our sources are in the Boston University 43 GHz VLBA program, providing information on morphology and structural changes in
2. As new $\gamma$-ray-flaring radio-bright AGN are identified, they are added to the UMRAO program if they meet our criteria for inclusion in the monitoring program; examples of newly added sources are NRAO 190, a bright EGRET source [12] in which recent Fermi-detected flaring was reported [13], and 3C 345 a well-known bright blazar surprisingly not detected by EGRET. Additionally, we are observing on a time-available basis a few sources which were exceptionally bright during the EGRET era but which are currently relatively quiescent in both the radio and $\gamma$-ray bands. Included in this group is NRAO 530 [14]. Several of the sources listed in Table 1 are new to our core program; others have been observed by UMRAO for many years.

2.1. Observing Strategy

Before selecting our sources, we carried out exploratory radio band measurements of a larger group in 2009 March to evaluate the current radio band variability state and to measure the flux levels for all potential program sources. Monitoring of our sample commenced in 2009 August. Throughout cycle 2 we expect to obtain two observations weekly at 14.5 GHz (the frequency at which the variability amplitude is highest in AGN), and one observation weekly at each of 8.0 and 4.8 GHz for flaring sources. This sampling rate is matched to the expected variability timescale and duty cycle in the radio band based on historical measurements obtained over decades by UMRAO [15]. However, the sampling rate will be increased if warranted, e.g. during some phases in the BL Lac object 0716+714 which has historically exhibited large amplitude, very rapid radio band variations. Each daily measurement consists of a series of on-off measurements over a 30-40 minute time span; these measurements are interleaved with observations of a calibrator every 1-2 hours to monitor the antenna gain and pointing, and to verify the instrumental polarization. As a result of these requirements, only 20-25 program sources can be observed in each 24 hour run, and the most active will be selected from the sample.

3. Early Program Results

The first stage of our program, to obtain data exhibiting resolved linear polarization variability temporally associated with time periods of $\gamma$-ray flaring, is in progress. During the first two months of the program we have detected several polarization events, and we are in the process of examining these and our subsequent data to identify characteristic patterns in the light curves. Resolved flares potentially suitable
Figure 2: From bottom to top, daily averages of total flux density, fractional linear polarization, and electric vector position angle at three frequencies illustrating the recent variability at radio band in 3C 279. Note the changes in polarization in 2009 April-May which are resolved in these single dish observations. The variations in this source during the mid 1980s were successfully modeled with a transverse shock [17].

for detailed modeling have been identified in 0727-115, 0805-077, 3C 279, 1502+106, and 1510-089.

We are finding that the timescales of the outbursts in polarized flux and periods of ordered temporal changes in EVPA are relatively short, typically several weeks to a few months in duration. As an example, we show in Figure 1 the light curves for 1502+106 (OR 103), a relatively new addition to our core program, which is highly active at γ-ray band. The MOJAVE 15 GHz source structure in this source is relatively simple, and much of the polarized emission is associated with a single source region. A study of γ-ray flaring in August 2008 used two MOJAVE images separated by several months to identify a change in magnetic field orientation [16], but the sampling of the imaging data did not permit tracing the change in structure. During the subsequent period covered by our monitoring data, there is a resolved outburst in polarized flux (middle panel) and a systematic swing in EVPA (top panel) which commenced in 2009 February. These variations track at 14.5 and 8.0 GHz; but the data follow a different path at 4.8 GHz. The multi-frequency total flux density data (bottom panel) show a spectrum characteristic of a self-absorbed source; thus the emission at 4.8 GHz most likely arises in a somewhat different physical region of the source, further out from the inner region probed by the higher frequencies. In this flare the position angle swing and the development of the linearly polarized outburst are characteristic of a shock event.

Figure 2 shows results for a structurally complex QSO, 3C 279, where the contributions from individual core and jet components are blended in the total flux density light curve. During a series of events in the mid-1980s the variations apparent in the UMRAO data for this source were successfully modeled assuming a transverse shock [17]; and the jet parameters derived in that work will be used as a starting point in the new analysis.

Some sources exhibiting γ-ray flaring have not shown large amplitude changes in either total flux density or in polarized flux in our observing band (e.g. NRAO 190). We do not know yet whether this is due to frequency-dependent time delays across bands, the masking of variability in the UMRAO source-integrated measurements due to competing, independently evolving source components, or whether more than one scenario is required to explain the origin of the high energy emission.

Two very bright EGRET sources on the Fermi LAT list, 0528+134 and NRAO 530, have not exhibited high-amplitude flaring in either the γ-ray or in the radio band since the launch of Fermi. We show the long term light curves for NRAO 530 in Figure 3 which il-
illustrates the relatively low flux level in the radio band since the launch of Fermi. The presence of low fluxes in both bands is consistent with the expected behavior assuming that the activity is broad band and that the same particles are responsible for the high and the low energy emission.

In the next phase of our work, we will carry out shock modeling of resolved radio band events exhibiting the shock signature. This will allow us to set limits on the physical conditions in the radio jet during γ-ray flaring. A set of resolved radio band flares will be selected for detailed shock-in-jet modeling following the procedures in our previous analyses [10, 17] which use multifrequency linear polarization and total flux density observations as constraints. While our earlier work assumed a specific shock geometry (transverse shocks), the new models will employ a transfer code that admits arbitrary shock orientation, resulting in extra degrees of freedom which must be constrained. The complementary VLBA imaging data from the MOJAVE and BU programs will be used to limit the allowable range of orientations. The modeling is expected to yield information on shock strength, the character of the jet flow, and the low energy cutoff in the spectrum of the radiating particles, all of which are key input parameters in jet emission models designed to explain the origin of the γ-ray emission [18].

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