

Polarization Monitoring as a Probe of Blazar Jets on the Finest Scales

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Abstract. Polarization variability combined with imaging in total and polarized intensity and multiwaveband flux monitoring can identify which regions in the jets of blazars produce the optical to γ -ray emission. Here we present evidence that the fluctuating high frequency components are co-spatial with the millimeter-wave jet as seen on VLBI images on scales less than 1 milliarcsecond. Using currently available and future instruments, we plan to use polarization to explore the link between high and low frequency emission processes in blazars.

1. Introduction

Relativistic jets are now recognized as direct consequences of accretion onto black holes. One of the main goals of studying jets is to understand the physical processes that convert infall near the equator of the accretion disk into extremely high-speed, energetic outflow along the poles. These processes, however, occur on size scales less than a parsec, corresponding to angular scales measured in microarcseconds. Astronomers possess two main weapons in their battle against the limitations of angular resolution of telescopes: very long baseline interferometry (VLBI) and variability of flux and polarization across the electromagnetic spectrum. The former produces detailed images with resolutions ~ 0.1 milliarcseconds (mas) at millimeter wavelengths. Based on timescales of variability as short as hours or even minutes, we know that variability probes structures even smaller than this, although the exact conversion of timescales to sizes depends on the magnitude of the Doppler time contraction (blueshift) of emission in jets shooting almost right at us. (Note that size and distance from the central engine do not necessarily correspond: a condensed clump of emitting plasma one light day across could be parsecs from the black hole.)

The most powerful probe would be a marriage between three techniques: (1) monitoring of polarization variability at radio, submm, near-IR, and optical wavelengths, (2) total-flux light curves across the electromagnetic spectrum, and (3) direct total and polarized intensity imaging of the sections of the jet that produce the variable high-frequency emission. We intend to exploit the current opportunity to carry out such a program, which will allow us to explore the compact jets of blazars much more extensively than has been possible to date.

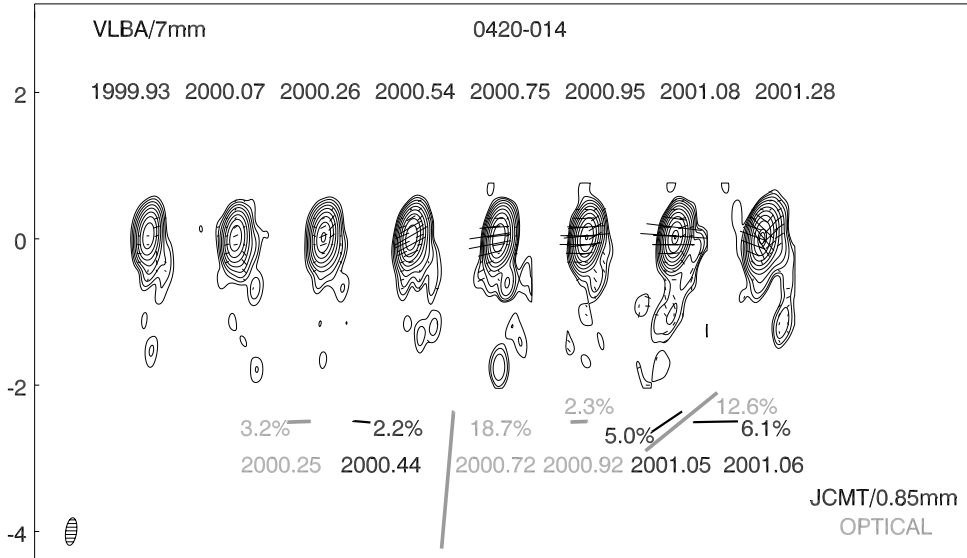


Figure 1. Total intensity VLBA images, with polarization data, of quasar 0420–014. Contours: factors of 2 up to 64%, plus 90% of the maximum cross-epochs brightness. Lines on the images are polarization E-vectors; lines along the bottom represent the E-vectors integrated over the entire source at 230 or 350 GHz (dark, measured with the JCMT) or optical (gray, from Steward Obs.), with the dates and percent polarization also given. Note the strong time variability of the polarization and the frequent similarity in polarization at 43 GHz, 230/350 GHz, and optical. Angular scale is in milliarcseconds. From Jorstad et al. (2005).

2. Connections between Low and High Frequency Emission

Figure 1 displays an example of the similarities we (Jorstad et al. 2004, 2005) have found in the polarization electric-vector position angles (EVPAs) at 7 mm, 1.3/0.85 mm, and optical wavelengths. See the Jorstad et al. paper in these proceedings for more examples. This was from a roughly bi-monthly monitoring program, with some high-frequency data lost owing to bad weather and equipment failures. Nevertheless, the ~ 1 mm and optical EVPAs often line up with those of features seen in the VLBA images in a number of the blazars that we monitored. Similar longer wavelength VLBI and optical polarization were noted previously by Gabuzda & Sitko (1994) and Gabuzda, Sitko, & Smith (1994).

We often see changes in the high-frequency EVPA such that it lines up with an emerging superluminal knot seen at 7 mm. More frequent multifrequency monitoring can establish such connections (or lack thereof) more clearly as well as search for time lags that would indicate the dependence of location on the frequency of emission.

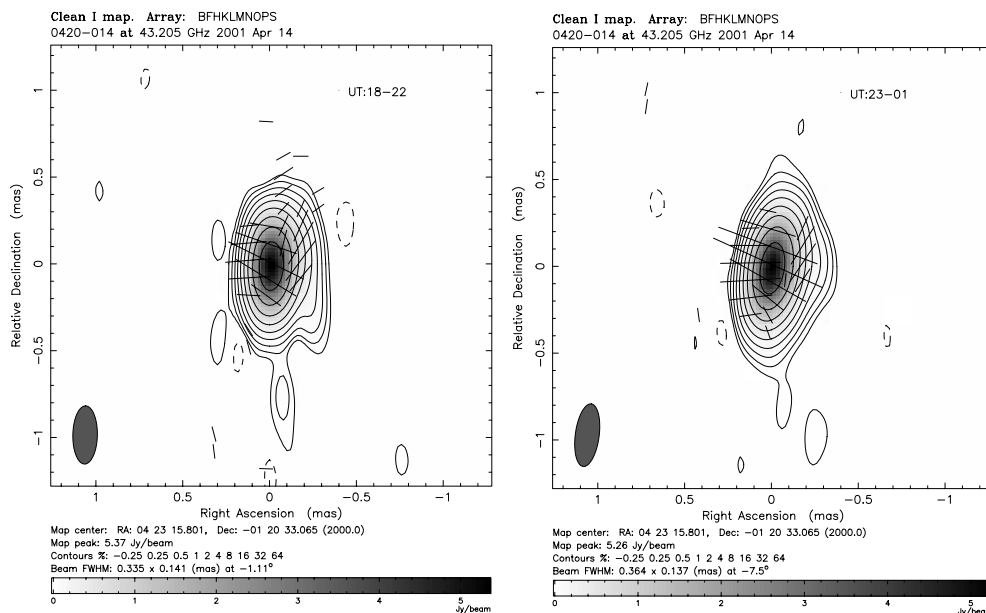


Figure 2. Total intensity 43 GHz VLBA images, with polarization vectors, of 0420-014, from the same day in April 2001: *left*—first half of observation; *right*—second half.

Since the most compact sections of blazar jets are opaque in the radio, we need to observe at higher frequencies if we want to probe the physics of jet launching and collimation. But it is only in the radio that we can obtain direct images with ultra-fine resolution. In order to make progress, we need to determine whether there is any connection between the mm-wave VLBA images and IR, optical, X-ray, and γ -ray flux variability. Marscher et al. (2004) demonstrate that there is a correspondence between high-frequency radio and X-ray variability in the quasar PKS 1510-089. The radio leads the X-ray variations by up to 20 days except during 2000-01 when the radio showed signs of increased optical depth. The same authors find an extremely good correlation between the optical and X-ray emission in 3C 279, with the optical usually leading. The “reverse” cross-frequency time lags demonstrate that the X-rays are produced at or beyond the sites of the variable lower-frequency synchrotron radiation (see Marscher et al. 2004). Jorstad et al. (2001) have used Very Long Baseline Array (VLBA) monitoring of about 60% of the blazars detected at γ -ray energies with EGRET to show that the γ -ray emission is generally co-spatial with the high-frequency radio core and emerging superluminal knots.

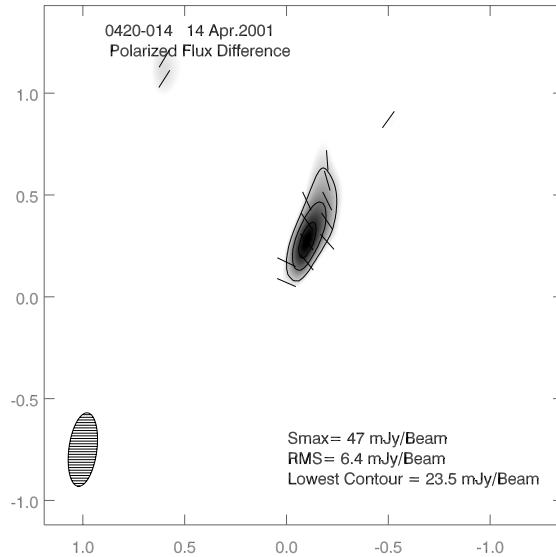


Figure 3. Difference image of 0420–014 made by subtracting the two images in Figure 2 after convolving each with the same restoring beam. The change in polarization structure is highly significant.

3. Rapid Variability of Polarization at 7 mm

Figure 2 illustrates that we can use the VLBA to measure changes in polarization on mm-wave images on time scales of order 0.25 days. There are a sufficient number of antennas (10) that total and polarized intensity images of reasonable quality can be made from each half of a given observation. The difference image shown in Figure 3 demonstrates that intraday polarization variability occurs at a wavelength of 7 mm. We are currently analyzing many of the images from our 1998-2001 VLBA monitoring program in a similar fashion to determine how common such intraday polarization variability is in 0420–014 and other blazars.

4. Future Plans

Given the highly suggestive results of these previous observations, we are planning to start a project in 2005 that will apply the technique to about 25 flat-spectrum extragalactic radio sources, most of which are blazars. The project will make use of new near-IR and optical cameras with polarimetric capability on the 1.8-meter Perkins Telescope at Lowell Observatory. We plan to monitor the sample monthly with the VLBA and 1-2 times per month in the near-IR and optical at Lowell Observatory. We are monitoring five of the sources in the medium-energy X-ray band with RXTE. Twice per year we will look for rapid variability by observing for ten straight nights at Lowell Observatory and 2-3 times with the VLBA and JCMT.

We plan to form collaborations with other optical polarimetrists around the world in an effort to improve our time and frequency coverage. Volunteers are solicited!

5. Conclusion

Multifrequency monitoring of blazars has produced the surprising result that the optical to γ -ray emission appears to be roughly cospatial with the features seen on mm-wave VLBI images. This means that the combination of variability studies with time sequences of the images have the potential to sort out where the emission fluctuations are occurring and how the high-energy photons relate to those at lower frequencies. We plan to use polarization variability as the primary signature that can cross-identify sites of emission at near-IR/optical and millimeter wavelengths. We can then use cross-frequency correlations of multiwaveband total flux light curves to specify where in the jet the X-rays and γ -rays are being produced as a function of time. This is already possible for X-rays observed with RXTE, and GLAST promises to do the same in rays γ -rays. Multiwavelength analysis of blazars is entering a golden age!

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