VLBI OBSERVATIONS OF THE GRAVITATIONAL-LENS IMAGES OF Q0957+561 +

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We have conducted a series of VLBI observations of the gravitational-lens images of the quasar Q0957+561 (Walsh et al., 1979), utilizing the Mark III VLBI data acquisition system (Rogers et al., 1983). The goals of our observations are to (1) map the milliarcsecond structure of the A and B images, (2) detect the predicted third image of the quasar, and (3) determine the time delay between the images. We will use these results to constrain the mass distribution of the lens and, possibly, cosmological constants.

1. THE VLBI STRUCTURE OF THE IMAGES

The quasar, Q0957+561, is a radio source, albeit a weak one (Greenfield, Burke, and Roberts, 1980; Pooley et al., 1979). Our VLBI observations in February 1980 at 13 cm wavelength, with three antennas (Gorenstein et al., 1983a), revealed two images, each with a partially resolved core with a full-width at half-maximum (FWHM) of about 1 milliarcsec (mas), and each elongated toward position angle (p.a.) 20 deg. The flux densities of these cores were 22 ± 2 and 18 ± 2 mJy for the A and B images, respectively.

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More extensive observations in March 1981, again at 13 cm wavelength, but with six antennas, detected in each core a weak "inner" jet whose center was displaced from the core by about 3 mas, also along p.a. about 20 deg. These observations also confirmed the existence in each image of a larger "outer" jet whose center was displaced about 50 mas from the core along p.a. about 15 deg, as first reported by Porcas et al. (1981).

Are these resolved brightness distributions consistent with their being images of a single quasar? Given that the 50 mas extent of each image is very small compared to the size of the "lens", the images must be related by a linear transformation of coordinates. The transformation is specified by four parameters: two linear magnifications (one with negative sign to account for the parity reversal of one of the images with respect to that of the source) and two position angles along which the respective magnifications apply. From the data collected in February 1980, which confirmed this hypothesis quantitatively (Gorenstein et al., 1983a), we determined preliminary values for these magnification parameters. We are now carrying out a similar analyis for the data collected in March 1981.

2. ADDITIONAL IMAGES OF Q0957+561

In general, a transparent, non-singular, bounded lens should produce an odd number of images of a point source (e.g. Burke, 1981). Detailed models of the gravitational lens for Q0957+561 (Young et al., 1981) show that a third image should appear between the B image and the galaxy, G1, primarily responsible for the multiple imaging and located about 1 arcsec north of the B image (Stockton, 1980).

The data collected in March 1981 allowed us to perform a sensitive search for additional compact sources of radiation in a 1 arcsec region that included the B image and the G1 galaxy. We used the bright B image as a phase reference to allow us to coherently add visibilities obtained on the most sensitive baselines. The search revealed a third compact component, designated G', that appears near the center of the G1 galaxy. The component's flux density of 0.6 ± 0.1 mJy, extent of less than 2 mas, and position all seem consistent with it being either radio radiation from the center of the galaxy or the third image of the quasar (Gorenstein et al., 1983b).

In May and June of 1983 we performed a new series of VLBI observations of Q0957+561 at 13, 6, and 3.6 cm wavelengths. The results of these observations will help clarify the nature of G' by allowing us to compare the spectral indices of A, B and G'. Moreover the additional data taken at 13 cm wavelength can be combined coherently with those from March 1981 to increase the detection sensitivity by about 40%.

3. THE TIME DELAY

Fluctuations in the brightness distribution of the quasar must produce corresponding, "time-delayed", fluctuations in the images. But the time delays are different for the different images due to the combination of differences in the geometric paths of the rays for the different images and of differences in the speeds of traversal of the rays along these paths. The detection of correlated, time-delayed, variations between images may provide a useful new means of determining the distance to an object (Refsdal, 1964).

A prime goal of our reobservation of Q0957+561 at 13 cm wavelength in May 1983, was the detection of any superluminal motion of the inner jets away from their respective cores. If we assume that we are observing images of the same jet, and, further, that the jet moves on a simple ballistic trajectory, then the measurement of the core-jet separations at the March 1981 and May 1983 epochs is sufficient in principle to determine the apparent epoch of ejection of the inner jet in each image. The difference in these epochs of ejection is the time delay. This idea was independently suggested by Vanderriest (1982).

In the case of Q0957+561 a single epoch of observation may be sufficient to determine the sign of the time delay. The presence of the outer jet in each image determines the relative one-dimensional magnification along the jet axis. If the ratio of the separations between the cores and the inner jets is not consistent with the ratio of the separations of the cores and the outer jets, than we can reasonably attribute the discrepancy to motion of the inner jet. Preliminary examination of the March 1981 data suggests that the inner jet appeared first in the A image; however, we cannot as yet attach any significance to this result as we have yet to consider the errors in our estimates of the core-jet separations. First-epoch observations at the 6 and 3.6 cm wavelengths, if they yield detections of the inner jet, may provide increased accuracy in determining its position relative to the core.

4. MODELING THE LENS

Young et al. (1981) presented their models of the mass distribution of the lens that accounted for their optical data. Our analysis of one of their detailed models shows that the estimates of some of their parameters are so highly correlated (Falco et al., 1983) that these estimates are not "robust", but are very sensitive to systematic error. We intend to use our VLBI data in conjunction with all of the other available data to constrain more reliably the parameters of simple models of the lens system. For example, a three-parameter quadrupole shear (Falco et al., 1983) seems adequate to describe the contribution of the cluster of galaxies to the lens.

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