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A 0″.25 JET IN THE QUASAR 3C 446

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ABSTRACT

We have mapped the quasar 3C 446 with VLBI techniques at 18 cm with a resolution of 10 × 25 milliarcsec (mas). The radio structure of this quasar exhibits a core-jet morphology, with the length of the jet exceeding 0″.25. For the redshift of 3C 446 ($z = 1.4$) this corresponds to a projected length of ~1.5 kpc; simple models of the emission in 3C 446 suggest, however, that the angle of the jet to our line of sight may be less than ~9°, leading to a true jet length of more than 10 kpc. In order to align the jet with the low-frequency, arc-second emission, the dominant position angle of the jetlike structure in 3C 446 may bend through ~130°.

VLBI observations at 2.8 cm reveal that the 1 mas core of 3C 446 has a rising radio spectrum from 18 to 2.8 cm. A simple synchrotron-emission model of the radio emission from 3C 446, taking into account both the observed X-ray flux and the rapid variability of the radio flux density, implies that bulk relativistic motion may be occurring in the core of 3C 446. We suggest that 3C 446 is a likely candidate for apparent superluminal motion, based both on these calculations and on the strong radio, optical, and X-ray activity observed in this quasar.

Subject headings: interferometry — quasars — radiation mechanisms — radio sources: variable

I. INTRODUCTION

The quasar 3C 446 has a combination of properties which makes it unique among bright, compact 3CR quasars. While the meter-wavelength radio spectrum in this object is similar to a number of other 3CR quasars, with a power-law spectrum to ~1 GHz, the higher frequency spectrum reflects the existence of an extremely compact component (Brown *et al.* 1981). The decomposition of the spectrum presented by Brown *et al.* (1981) suggests that, above ~3 GHz, the radio spectrum is dominated by a compact component. It is this small component which is presumably responsible for the more interesting properties in the object: powerful X-ray emission (Zamorani *et al.* 1981), rapid flux variability in both radio and optical wavelengths (Sandage, Westphal, and Strittmatter 1966; Andrew *et al.* 1978; Miller 1981), and high optical polarization (Kinman, Lamla, and Wirtanen 1966; Visvanathan 1973; Stockman and Angel 1978). Of the 226 quasars studied by Ku, Helfand, and Lucy (1980), Zamorani *et al.* (1981), and Tananbaum *et al.* (1983), 3C 446 has the fourth highest X-ray luminosity; it is the most X-ray luminous 3CR quasar.

The current study was motivated by the VLA results of Brown *et al.* (1981), which indicated that 3C 446 had both a dominant compact core and substantial structure on the 0″.1–1″.0 scale and was thus suitable for mapping by VLBI. We undertook VLBI observations at 18 cm, as a reasonable compromise between sensitivity to the larger scale structure and resolution of the compact component, and at 2.8 cm, to study the behavior of the core at a higher frequency. We also present a map made at 2 cm with the VLA, which indicates that the jet in 3C 446 is also present at high radio frequencies.

II. OBSERVATIONS AND RESULTS

a) 18-cm VLBI Observations

VLBI observations were made of 3C 446 (IAU designation 2223−052) on 1981 February 7 with a seven-station interferometer, observing at a center frequency of 1660.9 MHz (see Table 1 for a list of stations involved and their acronyms). The observations were recorded at each telescope on magnetic tape in standard Mark II format (Clark 1973) with an effective recording bandwidth of 1.8 MHz. After the experiment, the tapes were processed in three passes on the five-station California Institute of Technology/Jet Propulsion Laboratory VLBI Correlator in Pasadena. After correlation it was necessary to edit the data, removing spurious and degraded data points from each baseline. Finally, the data were incoherently averaged to 4 minutes and then calibrated using the procedure of Cohen (1973).

The major observing difficulty encountered during these observations was extremely short coherence times on most baselines. This can probably be attributed to interplanetary scintillation, since 3C 446 was only ~10° away from the Sun at the time of the observations. As a result, we were unable to detect fringes on several baselines, effectively reducing the

TABLE 1

INTERFEROMETER ELEMENTS

Station Name	Location	Diameter (m)	System Temperature (K)	Sensitivity (K/Jy)
BONN	Effelsberg, W. Germany	100	80	1.48
HSTK	Haystack, MA	37	260	0.11
NRAO[a]	Green Bank, WV	43	125	0.21
GRAS	Fort Davis, TX	26	66	0.106
VLA[b]	Socorro, NM	125	102	2.5
OVRO	Big Pine, CA	40	140	0.20
HCRK	Hat Creek, CA	26	55	0.1

[a] The feed at NRAO was linearly polarized during these observations.

[b] At the VLA, 25 antennas (each of 25 m diameter) were used in a phased-array mode, yielding a combined collecting area equivalent to a 125 m diameter dish. These were the first VLBI observations to use the VLA in this mode. The sensitivity for the VLA was assumed. The ratio of antenna temperature to system temperature was then used to derive an effective system temperature.

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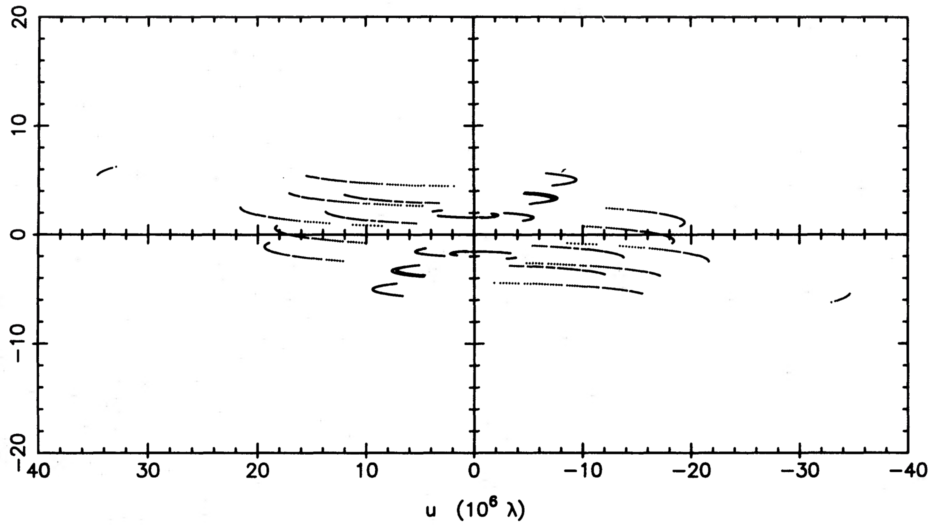

FIG. 1.—The (u, v)-plane sampling for the 1981 February observations of 3C 446 at 18 cm (1.66 GHz) with a seven-station (BONN–HSTK–NRAO–HRAS–VLA–OVRO–HCRK) interferometer. The very short (u, v)-track most distant from the origin is from the baseline BONN–NRAO, the only transatlantic baseline sensitive enough to detect 3C 446.

available (u, v)-plane sampling and the number of closure relations. An additional difficulty in these observations is the low declination of 3C 446, which further limits the (u, v)-plane sampling. The final (u, v)-plane sampling we obtained is presented in Figure 1.

After calibration of the data, we mapped the source using the iterative hybrid-mapping procedure described by Readhead and Wilkinson (1978), but with the phase solutions derived from the computer program AMPHI (S. C. Unwin's implementation of the CORTEL procedure of Cornwell and Wilkinson 1981). After the map had converged to a stable solution, limited changes to the antenna gains were allowed to be applied by AMPHI. Due to the limited (u, v)-sampling in the data set, we were forced to tightly constrain the field of view for the initial iterations of the mapping procedure. The final iteration, however, used a field of view for the image which was considerably larger than the observed source size, indicating that our solution is reasonably stable, and thus correct.

In Figure 2 we present our full-resolution, 18 cm map of 3C 446. The CLEANed components in the map have been convolved with the nominal restoring beam (based on the FWHM of the dirty beam) of 10 × 25 mas. At the resolution of Figure 2, 3C 446 is dominated by a single compact component (the "core"). To the east of that component, along position angle 100°, are two or three more components, each of which is obviously resolved.

In order to show the extent of the low brightness emission better, the CLEANed components were convolved with a circular 0.″025 beam (Fig. 3). This reconvolution increases the sensitivity of the map to low surface brightness emission at the expense of resolution. Figure 3 suggests that the emission is continuous over a roughly 0.″25 length at this resolution, with the components seen in Figure 2 appearing as knots of relatively bright emission. North and south of the core there are some weak features in the map whose reality is questionable because of the poor beam shape of our interferometer in the

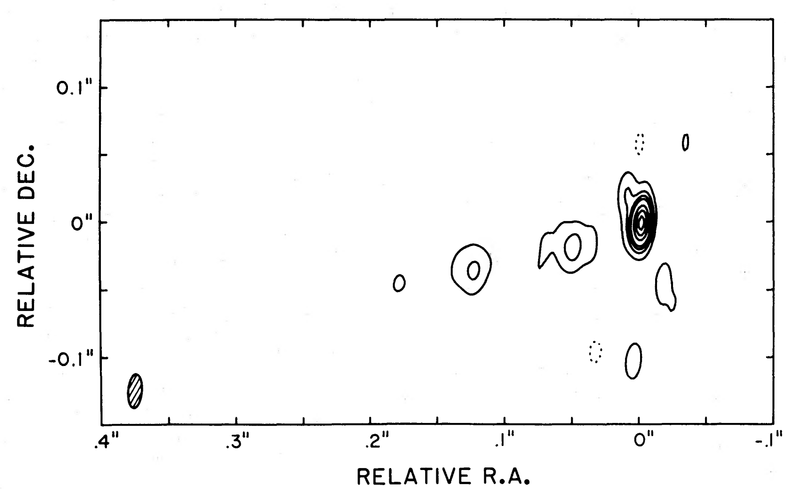

FIG. 2.—CLEANed map of 3C 446 from the 1981 February VLBI observations, convolved with the nominal beam of 0.″10 × 0.″25 in P.A. −5°. Contour levels are −4, 4, 12, 20, 28, 50, 70, and 90% of the peak brightness of 0.94 Jy beam^{-1}. Ticks on the border of the plot are spaced by 0.″050. In this and the following two maps (Figs. 3 and 5), the restoring beam is represented by the hatched ellipse in the lower left corner of the map.

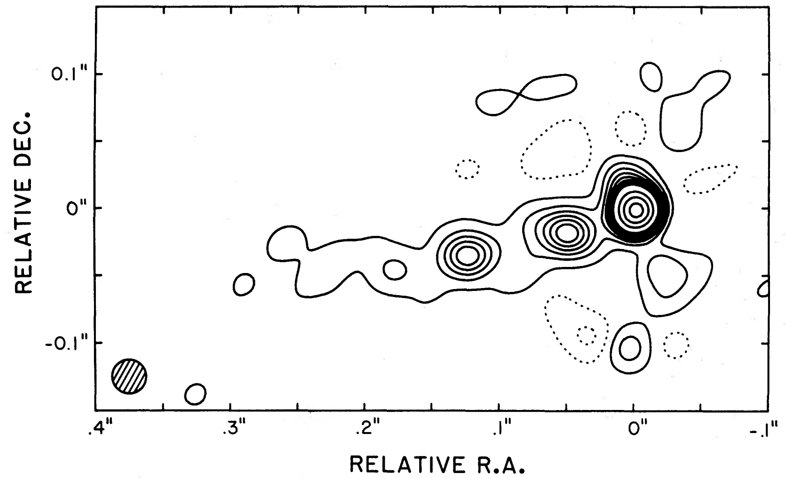

FIG. 3.—CLEANed 18 cm VLBI map of 3C 446 convolved with a 0."025-diameter circular beam to show low-brightness emission. Contour levels are −6, −2, 2, 6, 10, 14, 18, 22, 26, 30, 50, 70, and 90% of the peak brightness of 1.01 Jy beam^{-1}. Scale is the same as for Fig. 2.

north-south direction. The structure is obviously asymmetric and is suggestive of the "core-jet" morphology described by Readhead *et al.* (1978).

We note that for this 18 cm map, data from only six of the seven stations could be used. The only baseline to Effelsberg on which fringes were reliably detected (NRAO–BONN) provided too little data ($\sim$1 hr) to include in the final map. The Effelsberg data do provide an estimate for the flux density of the most compact (<5 mas) structure in 3C 446 of 0.55 Jy. In comparison, the US data alone imply that the most compact component (the core) has an integrated flux density of $\sim$1.1 Jy within the inner 10 mas. Thus the core in our map is partially resolved on scales of 6–10 mas.

The map shown in Figure 2 (or Fig. 3) is a reasonable fit to the data on all but the shortest baselines. Figures 4*a*–4*d* show the fit of the CLEANed components of the maps in Figures 2 and 3 to the visibility data. The poorer fit on the shortest baselines (see, e.g., the baseline OVRO–HCRK in Figs. 4*b* and 4*d*), shows that there is missing large-scale structure. This missing structure is probably an extension of the jet. Based on model fitting, this extension probably bends to the north through 90° or more, just beyond the eastern limit of the jet in our map. Such larger scale structure is heavily resolved on all but the shortest baselines in our data.

b) 2.8 Centimeter VLBI Observations

Additional, more limited, VLBI observations were made of 3C 446 on 1980 December 4 at 10.65 GHz. As described above for the 18-cm data, these higher frequency observations were recorded and reduced with the standard Mark II VLBI techniques. Unfortunately, only four stations (BONN, HSTK, NRAO, and OVRO) were able to successfully participate in the 2.8 cm observations, with no mutual visibility between BONN and OVRO. The 2.8 cm data allowed us to estimate the core flux density as 1.5 ± 0.5 Jy (out of a total flux density of 4.3 Jy), contained within a size of ≤ 1 mas. On the two triangles of closure-phase information derivable from the 2.8 cm data, the closure phases were very nearly zero, implying that the compact core of 3C 446 is dominated at high frequency by a single compact component. The only conclusion we can draw about the missing 2.8 Jy at 2.8 cm is that it appears in components which do not produce strong beating (phase changes $\geq 10°$) in the closure phases HSTK−NRAO + OVRO or HSTK − NRAO + BONN. Thus, less than $\sim$0.3 Jy (10%) of the missing flux is in structure with a size of less than 5–10 mas. Our 2.8 cm observations were not sensitive to emission from the larger jet components seen in the 18 cm map.

c) 2 Centimeter VLA Observations

The final observation of 3C 446 we wish to present is in the form of a 2 cm map made with 22 antennas of the partially completed Very Large Array (VLA) in 1980 June. With the array available at that time, the resolution was $\sim$0."17 × 0."31. The existence of the jet at that frequency is clear from the map, as shown in Figure 5. It shows up as a slight extension from the bright, unresolved core at a position angle of $90° \pm 15°$. Due to the steep spectrum of the extended emission, the VLA map (Fig. 5) accounts for most of the flux density from 3C 446 at 2 cm of $\sim$5.9 Jy, but it excludes the $\sim$0.6 Jy from the arc-second component. There is $\sim$5.3 Jy in the sum of the unresolved core and the jet. With the resolution of the VLA map, the core feature includes not only the VLBI core but also an undetermined amount of flux density from the inner part of the jet. Thus, we are able to estimate that the jet flux density is greater than 0.3 Jy at 15 GHz.

d) The Radio Spectrum

The 18 cm and 2 cm results we have presented suggest that the spectrum of 3C 446 can be properly decomposed into contributions from four regions: the compact (≤ 1 mas) core, emission near the core (1–10 mas), the $\sim$0."25 jet, and finally the more extended arc-second emission.

We first consider the spectrum of the extended emission in 3C 446. From the 18 cm VLBI map we can estimate the flux density in the arc-second emission, since that map only accounts for 2.5 Jy of the 6.5 Jy flux density observed in 3C 446 at 18 cm. Presumably the remaining 4 Jy is in the more extended arc-second structure observed by Browne *et al.* (1982); an extrapolation of their spectrum for the extended arc second component gives $\sim$4 Jy and is thus consistent with the flux missing from our map. A least-squares fit of the spectral index ($S_\nu \propto \nu^{-\alpha}$) of the extended emission to the combined data gives $\alpha \approx 0.73$, in agreement with the results of Brown *et al.* (1981).

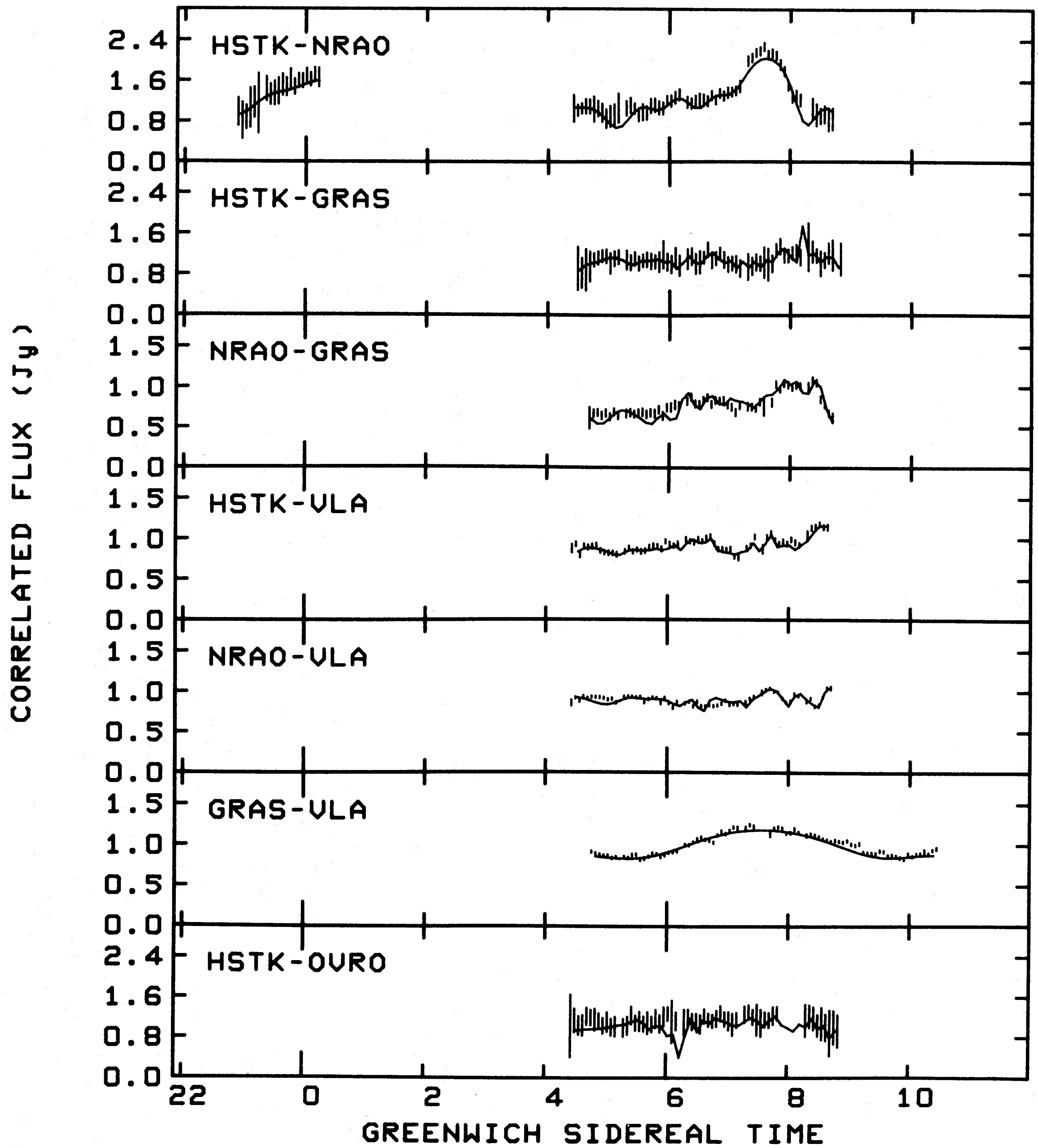

FIG. 4*a*

FIG. 4*a*–4*d*.—Fit of the delta functions which compose the 18 cm map to the 1981 February 7 observations at 1660 MHz. The total flux density was 6.5 Jy. Explanation of abbreviations for station names is given in Table 1. The phase data presented have been corrected for antenna-based phase errors using an implementation of the CORTEL algorithm of Cornwell and Wilkinson (1981).

We next consider the spectrum for the VLBI core and the emission on the inner 6–10 mas scale. In comparing the results from our 2.8 cm and 18 cm data, we see that the 18 cm core does have a significant amount of flux on the 6–10 mas scale while the 2.8 cm core does not. We can draw two conclusions from this: First, the most compact structure (≤ 1 mas) brightens from 18 to 2.8 cm by a factor of ~ 3. This corresponds to a spectral index for this structure of $\alpha \sim -0.6$. Second, the flux density in structure on the 6–10 mas scale fades by at least 30% from 18 to 2.8 cm, implying a spectral index for that structure of $\alpha \geq +0.2$.

It is possible for flux density variations to mimic the effects of a spatially variable spectral index; in the present case, variations with >1 Jy ($\sim 20\%$) amplitude would be required at either 18 cm or 2.8 cm. We can discount this possibility for two reasons: First, the long-term variability of 3C 446 at 2.8 cm displays time scales of ~ 2 yr for 40% of the flux density variations (Andrew *et al.* 1978), much greater than the 65 days between our 2.8 and 18 cm observations. Second, the 15.5 GHz (2 cm) flux density of 3C 446 varied by less than 0.2 Jy, out of a total of 4.7 Jy, between 1980 December and 1981 February (Balonek 1982). These facts suggest that the high-frequency

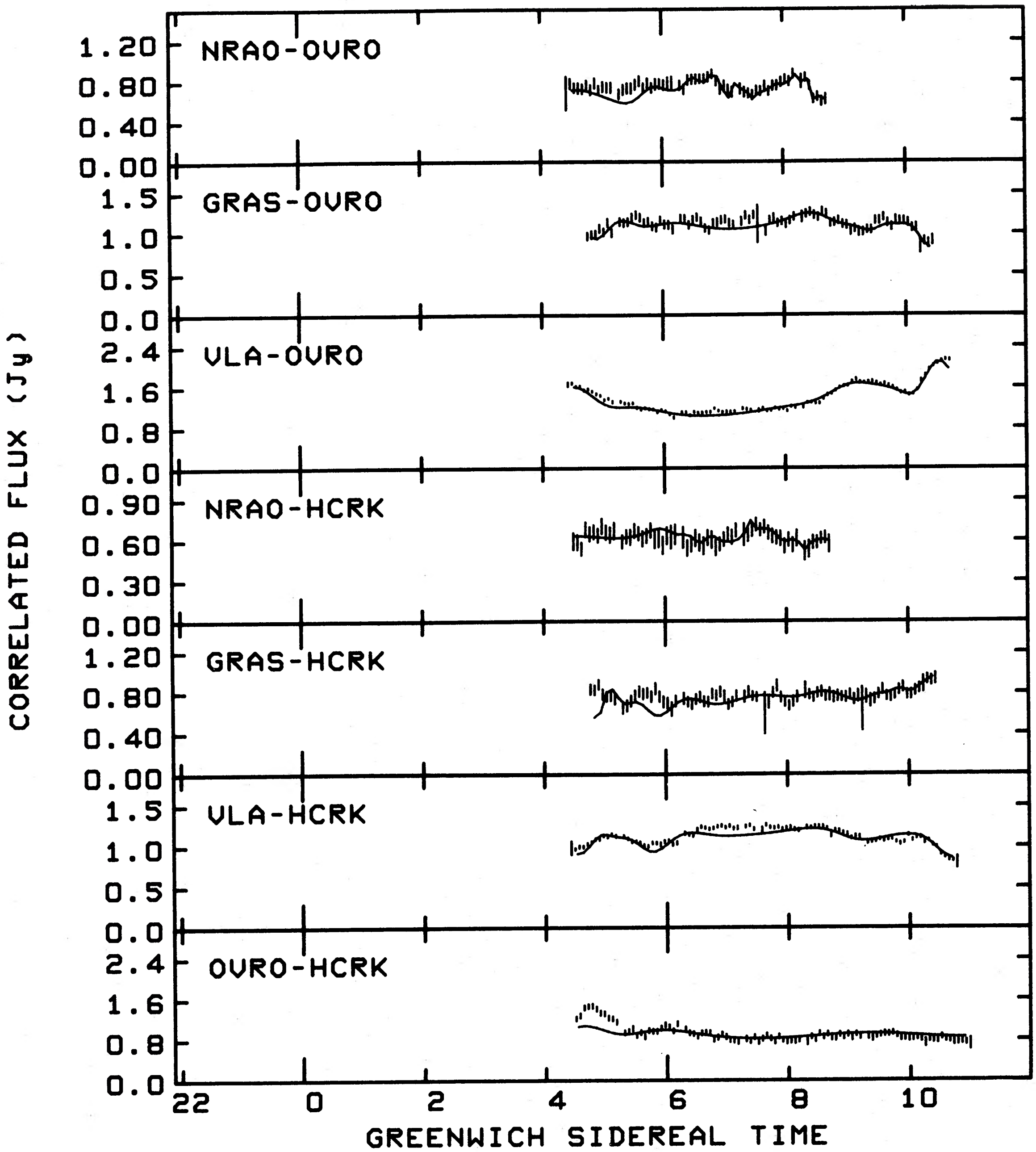

FIG. 4*b*

flux density was stable enough to allow us to determine the spectral indices of components from our observations over that time.

Our results are in disagreement with Brown *et al.* (1981), since the most compact structure in the core has a rising spectrum ($\alpha \sim -0.6$), while the slightly larger (6–10 mas) structure in the core has a flat or slightly positive spectral index ($\alpha \geq 0.2$). We see that the "core" component discussed by Brown *et al.* (1981) is not a single, simple component, and it is not the compact core to which we refer in this paper. The core spectrum cannot be parameterized as Brown *et al.* (1981) suggested. Rather, the compact structure which they observed was a combination of the most compact core structure and the more compact parts (knots) of the jet.

We are unable to deduce a detailed spectrum for the jet in 3C 446 due to the variations in the total flux density of 3C 446, although it is possible to estimate the jet flux density at two frequencies. From our 18 cm map, the jet has a flux density of ~ 1.4 Jy at 18 cm. The 2 cm VLA map implies that the jet has a flux density greater than 0.3 Jy. From the data we have presented, the most we can say is that the jet spectrum peaks below 15 GHz. If the spectral index were approximately constant along the length of the jet, so that the structure in the jet were the same at 2 cm as at 18 cm, the VLA map would imply that the 15 GHz jet flux density is ~ 0.5 Jy, leading to a jet spectral index of $\alpha \sim 0.5$. If the jet spectrum peaks between 1.6 and 15 GHz (which cannot be ruled out from our data alone), $\alpha \approx 0.5$ would be a lower limit to the jet spectral index.

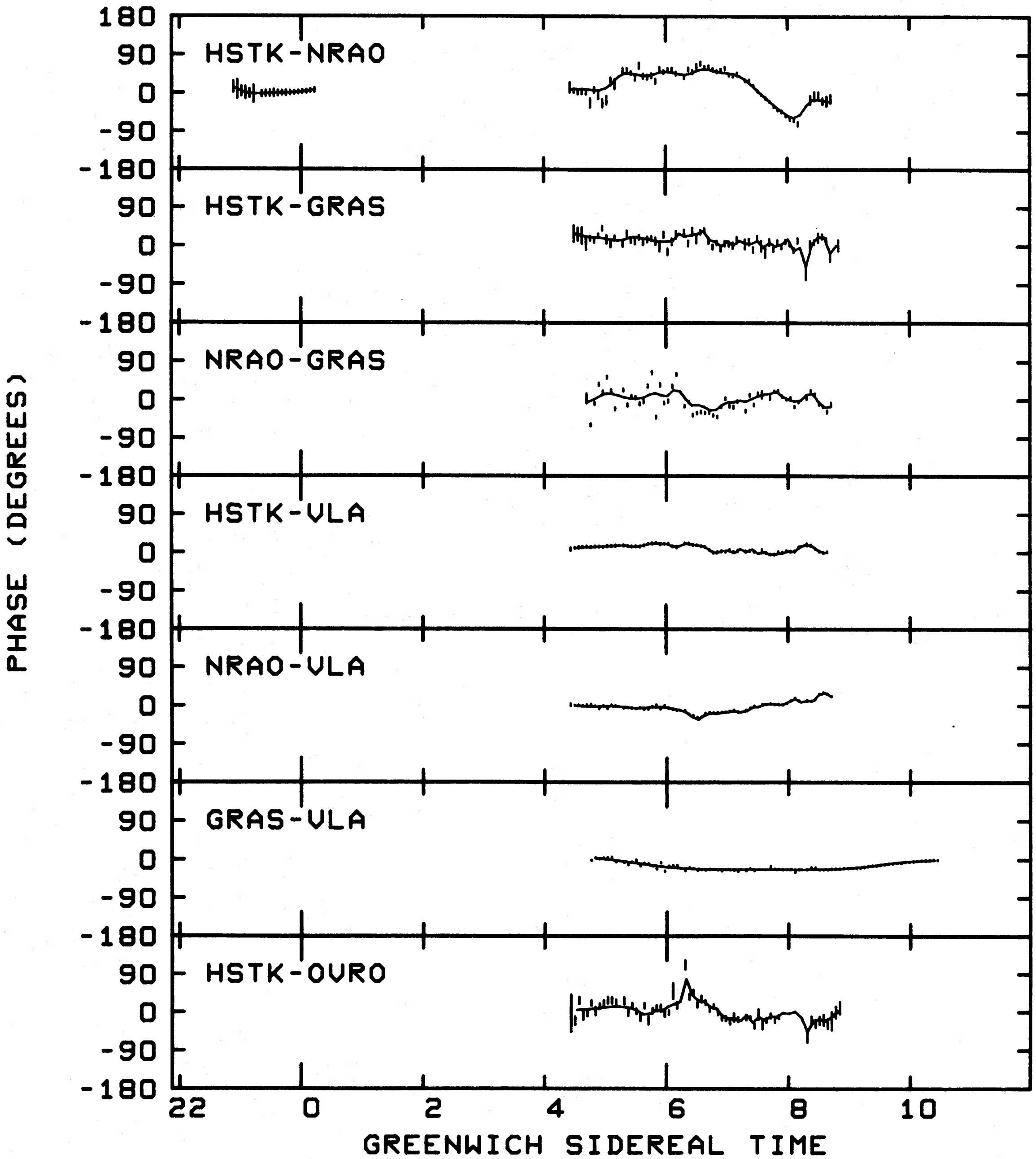

FIG. 4c

In Figure 6 we present an updated spectral decomposition of 3C 446, including the present 18, 2.8, and 2 cm data, as well as the integrated spectrum for 3C 446. Values for the total flux density are taken from Kühr *et al.* (1981, and references therein), Balonek (1982), and Landau *et al.* (1983). Both the Balonek data and the Landau *et al.* data consist of a snapshot of the spectrum as it appeared for a single epoch. Since the scatter in the flux densities measured above a few GHz is due mostly to variability in the total flux density, only total flux densities from the spectral snapshots of Landau *et al.* and Balonek are included above 5 GHz in Figure 6. The Balonek data (epoch 1978.8) run from 1.7 to 86 GHz and has the generally lower flux density of the two snapshots. The Landau *et al.* data (epoch 1981.9) run from 1.4 to 300 GHz.

Figure 6 also shows the best-fit power law to the spectrum of the arc second structure in 3C 446 ($\alpha = 0.73$). The data plotted in Figure 6 and their associated errors are summarized in Table 2 (for the individual-component flux densities) or in the references above (for the integrated spectrum).

III. DISCUSSION

The total angle through which the jet in 3C 446 is bent can be estimated by comparing our observations with the structure seen at lower radio frequencies. Our 18 cm map of 3C 446 suggests that the jet is not linear but is slightly bent over its length by $\sim 10°–15°$ before fading and bending to the north into an approximately north-south component. As mentioned

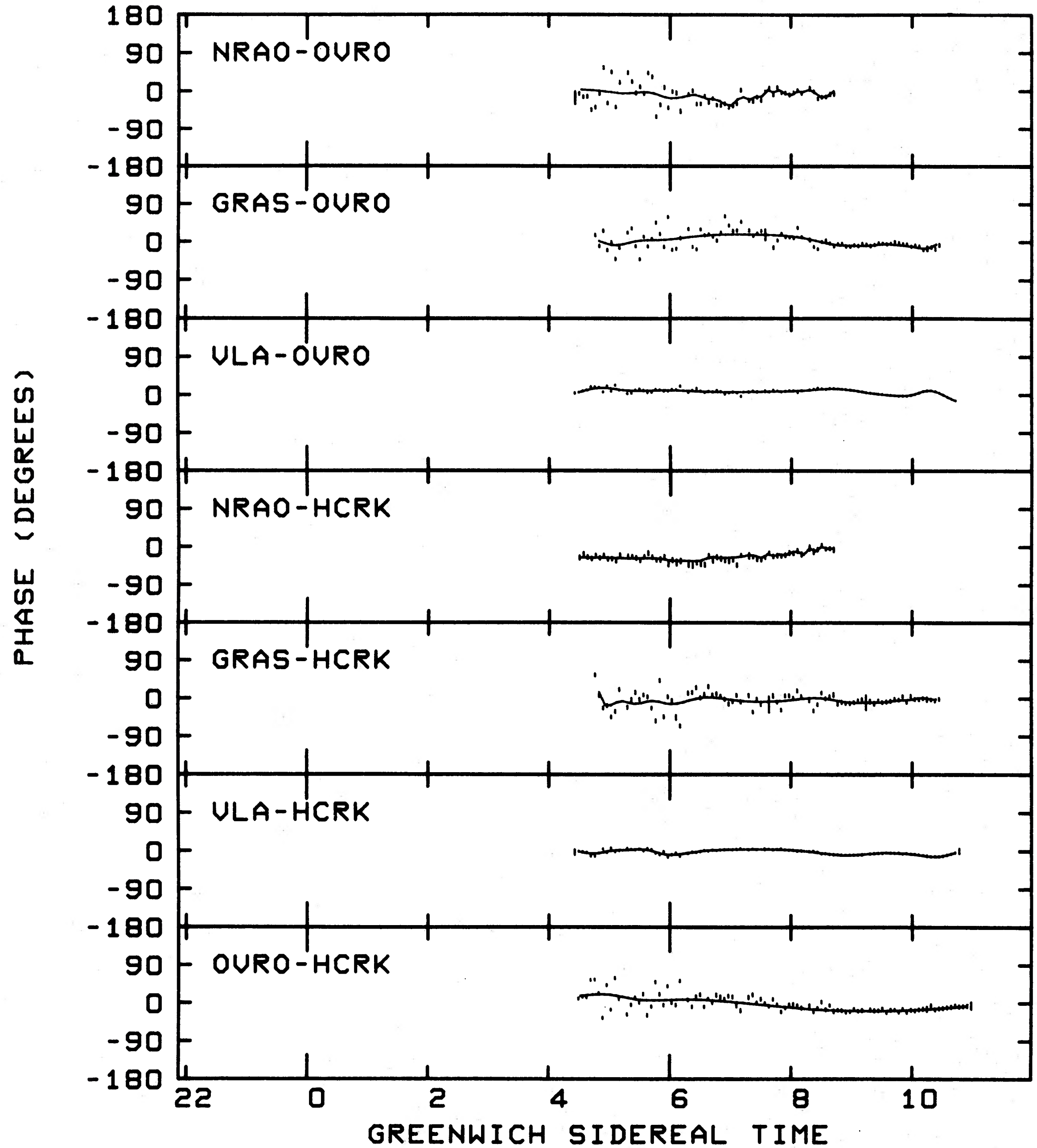

FIG. 4*d*

above, this large component, derived from model fitting to the data, is too heavily resolved to be well constrained by our data.

There is evidence for additional bending beyond the $\sim 100°$ we have estimated. 3C 446 has substantial structure on the few arc second scale at low radio frequencies. In the 408 MHz MERLIN map of Browne *et al.* (1982), the large-scale ($\geq 2''$) structure is elongated along position angle $-32°$. That position angle agrees well with occultation observations at 327 MHz from the Ooty radio telescope (Joshi and Gopal-Krishna 1977) which indicate a size of $1''.3 \times 0''.6$ in a position angle of 150° (equivalent to $-30°$). Thus the arc second emission is substantially misaligned from either the small scale $0''.25$ jet or the moderate-scale ($\sim 0''.5$), north-south component suggested by our 18 cm data. This suggests that the jet in 3C 446 is bent through a total angle of $\sim 130°$. Further VLBI observations have been undertaken to confirm the existence of this bending.

It is useful to compare the morphology we observe in 3C 446 to that seen in other compact quasars which have been well studied with VLBI techniques. Assuming the cosmological distance to 3C 446 based on its redshift of $z = 1.404$ (Hewitt and Burbidge 1980), and assuming $H_0 = 95$ km s^{-1} Mpc^{-1}, and $q_0 = 0$, the projected length of the jet is 1.5 kpc. Thus the jet is very similar in overall length to the kpc-sized jets seen in other compact quasars, notably 3C 147 (Wilkinson *et al.* 1977; Readhead and Wilkinson 1980; Simon *et al.* 1983; Simon, Readhead, and Wilkinson 1983), 3C 138 (Geldzahler *et al.* 1984), and 3C 273B (Conway *et al.* 1981). In size or $\sim$1-GHz surface brightness, it is not comparable to the small-scale (10–100 pc)

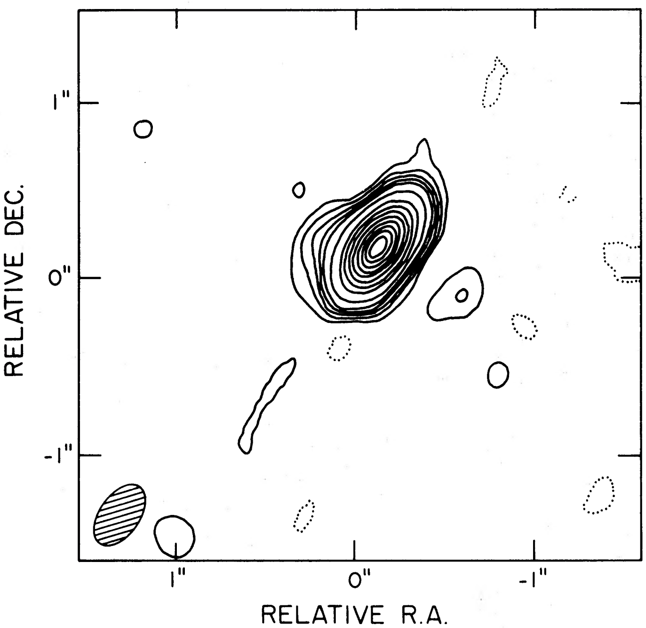

FIG. 5.—3C 446 at 2 cm from VLA observations taken in 1980 June. The map has been convolved with a restoring beam of 0".18 × 0".32 FWHM, P.A. −45°. Contour levels are −1, 1, 2, 3, 4, 5, 10, 20, 30, ..., and 90% of the peak brightness of 4.99 Jy beam^{-1}.

superluminal jets seen in such quasars as 3C 345 (Unwin *et al.* 1983), 3C 273A (Pearson *et al.* 1981), NRAO 140 (Marscher and Broderick 1982), or 3C 279 (Cotton *et al.* 1979). Morphologically, 3C 446 is most similar to either 3C 147 or 3C 138, exhibiting a distorted core-jet morphology (Readhead *et al.* 1978; Readhead 1980; Wilkinson *et al.* 1983).

In many other respects 3C 446 looks just like a superluminal radio source. Its jet is smaller than the ~40 kpc jet seen in 3C 273, but its physical length is comparable to the arc second jets in 3C 345 and 3C 454.3 (Browne *et al.* 1982). The major difference is that 3C 446 has a large fraction (~85%) of its flux density in structure on the 1" to 10 mas scale. It is the high surface brightness of the 1.5 kpc jet which makes 3C 446 stand out from the superluminal quasars. The lack of a low-frequency spectral turnover is a property 3C 446 shares with superluminal quasars like 3C 345 and 3C 273, and is in contrast to quasars like 3C 138 or 3C 147 in which the spectrum peaks in the few hundred MHz range.

The variability of 3C 446 also tends to place it in a class with objects like 3C 273 or 3C 345, but the high brightness of its kpc-scale radio jet, in comparison to the core, would make it stand out. Finally, 3C 446 is one of the most X-ray luminous quasars known (Zamorani *et al.* 1981; Tananbaum *et al.* 1983), making it a notable object however it is classified. 3C 446 clearly shares properties with both steep-spectrum compact sources and flat-spectrum compact sources (e.g., see Orr and Browne 1982); thus it is possibly an intermediate class of quasar in the unified scheme discussed by Orr and Browne (1982).

Is the observed X-ray flux from 3C 446 consistent with the inverse-Compton X-ray emission predicted for a simple model? Due to the large uncertainty in the angular size of the most compact component, we shall use the approach of Simon

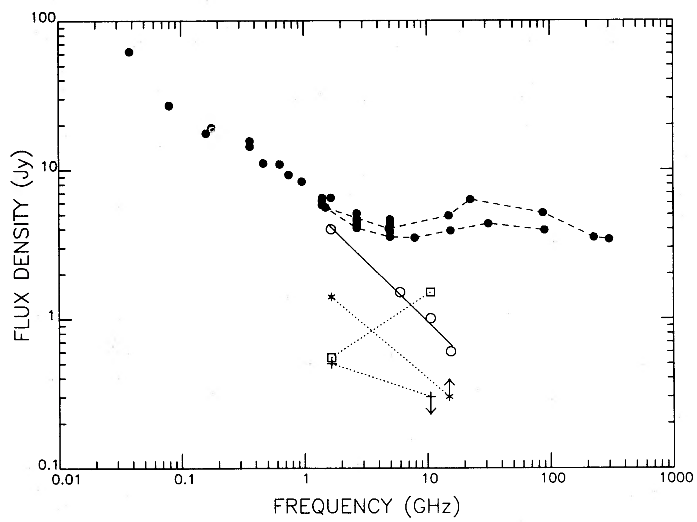

FIG. 6.—Radio spectrum of 3C 446. Values for the total flux density are plotted as *filled circles*, with measurements from each spectral snapshot being connected with a *dashed line*. Points in the component spectra are plotted as *open circles* (the arc second structure), as *open squares* (the ≤1 mas core component), as *crosses* (the 6–10 mas structure), or as *stars* (the 250 mas jet). The *solid line* is the best fit straight line to the spectrum of the arc second structure. Each of the estimates of the VLBI component fluxes has been connected with a *dotted line* for clarity. See text for explanation.

TABLE 2

INDIVIDUAL-COMPONENT FLUX DENSITIES

Component	Frequency (GHz)	Flux Density (Jy)	Reference
< 5 mas core	1.66	0.55 ± 0.1	this work (18 cm VLBI)
	10.65	1.5 ± 0.5	this work (2.8 cm VLBI)
6–10 mas outer core	1.66	0.5 ± 0.1	this work (18 cm VLBI)
	10.65	< 0.3	this work (2.8 cm VLBI)
250 mas jet	1.66	1.4 ± 0.2	this work (18 cm VLBI)
	15.05	< 0.3	this work (2 cm VLA)
Arc second halo	1.66	4.0 ± 0.4	this work (18 cm VLBI)
	4.90	1.5 ± 0.2	Brown *et al.* 1981
	10.65	1.0 ± 0.2	Brown *et al.* 1981
	15.05	0.6 ± 0.2	Brown *et al.* 1981

NOTE: mas = milli-arcsec.

et al. (1983) to find limits on the relationship between the angular size of the source θ and the equivalent Doppler factor δ (Simon *et al.* 1983; Marscher 1983; Burbidge, Jones, and O'Dell 1974). We assume that the core of 3C 446 is a uniform sphere radiating via incoherent electron synchrotron radiation at radio wavelengths. The limit to the inverse-Compton X-ray flux density is set by the X-ray flux of 9.8×10^{-7} Jy at an X-ray energy of 0.83 keV (Zamorani *et al.* 1981). This X-ray flux is derived from their calculated value of the rest-frame X-ray luminosity at 2 keV.

Assuming the decomposition of the radio spectrum discussed above, and taking into account the high-frequency observations of Balonek (1982), the core radio spectrum may be parameterized by $S_m \approx 4$ Jy, $\nu_m \geq 50$ GHz, and $\alpha \approx 0.25$ (assumed). These parameters are also roughly consistent with those obtained by Balonek (1982). The variability time scale, given by $\tau \equiv |d \ln S/dt|^{-1}$ (Burbidge, Jones, and O'Dell 1974), is in the range of 6 months to 2 yr for outbursts in 3C 446 at 90 GHz (Balonek 1982; Barvainis and Predmore 1984), with even more rapid variability at optical wavelengths (Pollack *et al.* 1979). In our calculations of the limits on the Doppler factor, we have used 6 months for the variability time scale. We find that the following two rough limits are available for 3C 446:

$$\delta \geq 0.23\theta^{-1.56} \tag{1}$$

(from the observational limit to the inverse-Compton X-ray flux) and

$$\delta \geq 48\theta \tag{2}$$

(from causality considerations, based on the variability time scale). These two limits on δ and θ are independent, and together they can be used to constrain the behavior of the core. Further discussion on the derivation of these relationships can be found in Simon (1983) and Marscher (1983).

Together, the above relationships imply that $\delta \geq 6$. Thus, bulk relativistic motion is a distinct possibility in 3C 446. This in turn implies that 3C 446 is a likely candidate for superluminal motion. Finally, given the lower limit to the Doppler factor, an upper limit to the inclination of the jet to the line of sight is derivable from the relations defining the Doppler factor (see, e.g., Unwin *et al.* 1983). In the case of 3C 446, this limit is $\phi \leq 9°$; the actual length of the jet would then be greater than 10 kpc.

These conclusions are valid only if the simple model which we have assumed is applicable to the core of 3C 446. In general, a more complicated structure in the core than that which we have assumed will raise this lower limit on δ, since more complicated structure only tends to lower the effective angular diameter of the core. To lower the required value of the Doppler factor, the assumptions we have made regarding the homogeneity or incoherence of the emission mechanism would have to be violated. Further VLBI observations of this quasar, at a variety of frequencies, would be useful to learn more about the linear extent of the jet, its morphology, and its relationship to the arc second emission, as well as to probe the core and its relationship to the jet. 3C 446 seems to exhibit a number of properties that suggest it may be an intermediate-type quasar between the most active, superluminal quasars and the less-variable, core-dominated quasars. The combination of luminous radio jet, extreme core variability (both radio and optical), and enormous X-ray luminosity seen in 3C 446 makes it an important quasar for further study.

We wish to thank the US and European VLBI networks and the staffs of the various observatories for their contributions to these observations. In particular, we wish to thank B. G. Clark for his efforts at the VLA, where the technique of using the VLA as a phased array for VLBI was new and untested at the time of our 18 cm observations. VLBI at the George R. Agassiz Station in Fort Davis, Texas, is supported by the National Science Foundation. The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation. Radio astronomy at the Haystack Observatory of the Northeast Radio Observatory Corporation (NEROC) is supported by a grant from the National Science Foundation.

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