THE ASTROPHYSICAL JOURNAL, 360: L11–L13, 1990 September 1

223 GHz VLBI OBSERVATIONS OF 3C 273

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Received 1990 February 19; accepted 1990 June 6

ABSTRACT

In the first $\lambda = 1.4$ mm VLBI test observations, we have detected fringes on the active nucleus of 3C 273 on a baseline from Owens Valley Radio Observatory to Kitt Peak. The observations are consistent with a source whose angular size is smaller than 0.5 mas.

Subject headings: galaxies: individual (3C 273) — interferometry

I. INTRODUCTION

VLBI observations at millimeter wavelengths can probe the broad line emission and jet-forming regions of quasars and the scale of the accretion disk around massive black holes in nearby active galaxies. Millimeter observations can also probe the optically thick synchrotron components seen at centimeter wavelengths.

Eight VLBI experiments have now been conducted at $\lambda = 3$ mm, and these are summarized by Wright *et al.* (1988). Observations at even shorter wavelengths are important because they can probe regions closer to the active nucleus of a quasar. In this *Letter* we report the detection of fringes in the first test observations at $\lambda = 1.4$ mm.

II. OBSERVATIONS

We made observations of 3C 273 and 3C 279 at $\lambda = 1.4$ mm on 1989 March 27, following VLBI observations at $\lambda = 3$ mm. The $\lambda = 1.4$ mm observations used a 10.4 m antenna at the Owens Valley Radio Observatory (OVRO) and the 12 m antenna at Kitt Peak (KTPK). At OVRO we used a double-sideband SIS receiver which was sensitive to a single linear polarization with a horizontal electric field. Signals were recorded on a VLBA terminal. At KTPK we used a double-sideband, dual-channel Schottky receiver configured to accept orthogonal linear polarizations with electric fields at 45° to the horizontal. Both polarizations were recorded on a Mk III terminal (Rogers *et al.* 1983). The recording bandwidth for the experiment was 56 MHz.

Measurements of the quasar flux densities were obtained at KTPK using calibration observations of the planets Jupiter and Saturn. The observations of Saturn, and the quasars were obtained in similar weather conditions with opacities ranging from 0.20 to 0.25.

The signals were correlated at Haystack Observatory, and the results are summarized in Table 1. Since the $\lambda = 1.4$ mm observations were adjacent to a $\lambda = 3$ mm experiment, we were able to use the clock parameters from the $\lambda = 3$ mm experiment to restrict the delay–fringe rate search window for the $\lambda = 1.4$ mm observations. The search window contained ~40,000 cells, and for the 04:00 scan on 3C 273 where the SNR of the initial search was 5.2 the probability of a false detection is ~0.05 (Thompson, Moran, and Swenson 1986). For the 05:00 scan, the SNR of the initial search was 5.5 and the probability of a false detection is ~0.01. The residual rate and delay are the same as for the 04:00 scan (within the resolution), and this greatly increases the significance of the detection. Also, the $\lambda = 1.4$ mm scans have clock delay within 100 ns and rate within 2×10^{-14} of that expected from the adjacent $\lambda = 3$ mm experiment as shown in Table 2. The increase in SNR with reduced coherent integration time (see max SNR in Table 1) is added evidence for detection.

The 04:30 scan on 3C 279 does not reach a significant SNR but may represent a very marginal detection because the residual fringe rate is within the range expected for atmospheric fluctuations. (The peak-to-peak fringe rate scatter on the OVRO-KTPK baseline for the 1989 $\lambda = 3$ mm observations was 2×10^{-12}.)

We detected fringes only for channel 1 of the KTPK receiver. The noise temperature for channel 1 at KTPK was about 10% less than for channel 2. Also, the angle between the electric fields at the two sites was smaller for channel 1, and we expected about a 10% higher fringe amplitude for the interferometer containing the channel 1 receiver. Since our detection is marginal, the greater sensitivity and higher fringe amplitude for the channel 1 interferometer could explain the absence of fringes for channel 2.

The double-sideband noise equivalent flux for KTPK was obtained from measurements of the source flux density, the double-sideband system noise temperature (~700 K), and the antenna temperature due to the source. The double-sideband noise equivalent flux for OVRO was obtained from measurements of the double-sideband system temperature (~2000 K) referred to the top of the atmosphere (Masson *et al.* 1984) and the antenna aperture efficiency (0.34). The single-sideband noise equivalent fluxes which are required for calibration of the fringe amplitudes were calculated from the double sideband results assuming equal responses for the two sidebands. The

TABLE 1

FRINGES DETECTED AT $\lambda = 1.4$ MILLIMETERS

UT	Source	Flux Density (Jy)	Max SNR[a]	Rate[b]	MB Delay[c] (ns)	ρ[d]	S_{KTPK}[e] (Jy)	S_{OVRO}[e] (Jy)	φ[f]	Correlated Flux[g] (Jy)	Projected Baseline (λ)
04:00........	3C 273	15	6.9	5×10^{-15}	27	0.73×10^{-4}	1.2×10^5	2.7×10^5	41°2	35	3.8×10^8
04:30........	3C 279	12	4.2	5×10^{-13}	17	0.54×10^{-4}	2.0×10^5	4.0×10^5	42.5	42	3.1×10^8
05:00........	3C 273	15	5.6	-2×10^{-14}	31	0.69×10^{-4}	2.2×10^5	1.6×10^5	42.3	35	4.2×10^8

a Maximum signal-to-noise ratio, and this occurs for 15 s coherent integration time for the 04:00 scan and 60 s coherent integration time for the other scans.

b Ratio of the residual fringe rate and the observing frequency and is relative to the average for the 1989 March $\lambda = 3$ mm observations.

c Residual multiband delay relative to the $\lambda = 3$ mm observations.

d Correlation coefficient at 10 s coherent integration time.

e Double-sideband noise equivalent flux.

f Angle between the electric fields at OVRO and the KTPK channel 1 receiver.

g Correlated fluxes are for equal responses for the two sidebands in both receivers.

TABLE 2

CLOCK DELAY AND RATES FOR THE $\lambda = 3$ AND $\lambda = 1.4$ MILLIMETER OBSERVATIONS

Date	UT	Source	Delay (μs)	Rate
$\lambda = 3$ Millimeter Scan				
1989 Mar 25........	05:30	OJ 287	6.4	4×10^{-12}
$\lambda = 1.4$ Millimeter Scan				
1989 Mar 27........	04:00	3C 273	7.2	4×10^{-12}
Expected Delay and Rate for $\lambda = 1.4$ Millimeter Scan Extrapolated from $\lambda = 3$ Millimeter Scan				
1989 Mar 27........	04:00	...	7.1	4×10^{-12}

TABLE 3

CORRELATED FLUXES (Jy) FOR 3C 273 AND 3C 279

SOURCE	$\lambda = 3$ mm 3C 273	$\lambda = 3$ mm 3C 279	$\lambda = 1.4$ mm 3C 273	$\lambda = 1.4$ mm 3C 279
1987 March				
Flux density (Jy)	20	10	...	...
OVRO-HCRO	10	5	...	...
OVRO-KTPK	7	4	...	...
KTPK-HCRO	5	4	...	...
QBBN-KTPK	2	2	...	...
QBBN-OVRO	2	2	...	...
1988 March				
Flux density (Jy)	28	15	32 ± 6	...
OVRO-HCRO	17	7	...	...
OVRO-KTPK	15	...	...	...
KTPK-HCRO	13	...	...	...
1989 March				
Flux density (Jy)	16	12	15	12
OVRO-HCRO	11	9	...	...
OVRO-KTPK	11	...	~15	~12
KTPK-HCRO	...	8	...	...

NOTES.—Errors are typically $\pm 10\%$ except for the $\lambda = 1.4$ mm data which are discussed in the text. Source flux density errors are typically $\pm 5\%$. The station nomenclature is OVRO, Owens Valley Radio Observatory; KTPK, National Radio Astronomy Observatory 12 m telescope; HCRO, Hat Creek Radio Observatory; QBBN, Five College Radio Observatory.

ratio of the upper to lower sideband responses for the receivers used at OVRO is typically unity (Sutton 1983), but the uncertainty may be as much as a factor of 2. The sideband ratio for the KTPK receiver is also typically in the range 0.5–2. The uncertainties in the receiver sideband ratios translate to a correlated flux scale factor in the range 0.75–1.50. However, even with the smallest scale factor the correlated flux in Table 1 always exceeds the source flux density. This implies an additional calibration error which we believe is due to poor weather at OVRO causing rapid variations in the system temperature. The OVRO system temperature during a VLBI scan could differ from that measured just before the scan by as much as a factor of 2. If the OVRO system noise has been overestimated by a factor of 2, the correlated flux for 3C 273 would be equal to the total flux. Since larger errors in the system noise measurement are unlikely, our fringes are consistent with all the flux being unresolved.

III. DISCUSSION

The projected baseline for our 3C 273 observations is 4×10^8 wavelengths at $\lambda = 1.4$ mm and an emitting region which is unresolved on this baseline is smaller than 0.5 mas. The brightness temperature of a 15 Jy source of this size is 2×10^9 K. While our $\lambda = 1.4$ mm fringes are consistent with unresolved emission, in the adjacent $\lambda = 3$ mm experiment 3C 273 was substantially resolved even on baselines shorter than OVRO-KTPK. This could be due to continuing injection of electrons radiating at $\lambda = 3$ mm or an increase in the magnetic field (and hence a shorter synchrotron lifetime) closer to the core.

Correlated fluxes for 3C 273 and 3C 279 for the period 1987 March to 1989 March are summarized in Table 3. The $\lambda = 3$ mm data show the evolution of a flare in 3C 273 which probably occurred within about 1 month of our 1988 experiment. The visibility increase in 3C 273 is consistent with the new emission being unresolved on the HCRO-OVRO-KTPK triangle, and this implies an emission region smaller than 0.8 mas. If the decay at $\lambda = 3$ mm during the period 1988 March to 1989 March were due to the synchrotron lifetimes of the electrons, then a field $\sim$0.2 G is implied. Electrons radiating at 223 GHz in this field have lifetimes of only $\sim$0.7 yr. The short lifetime implies compact emission, and if this is typical, other active nuclei should also exhibit high fringe visibilities at $\lambda \sim 1$ mm.

IV. CONCLUSIONS

We have detected fringes at $\lambda = 1.4$ mm on 3C 273 with a probability of false detection better than 0.01. The calibration of our results is poor because of unknown receiver sideband ratios and extremely bad weather at OVRO, but the data are consistent with all the flux arising in a region smaller than 0.5 mas.

Astronomical VLBI at Owens Valley Radio Observatory is supported by the NSF. NRAO is operated by Associated Universities Inc. under contract to the NSF.

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