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RADIO EMISSION FROM X-RAY SOURCES

R. M. HJELLMING AND C. M. WADE
National Radio Astronomy Observatory,* Green Bank, West Virginia
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ABSTRACT

Variable radio sources probably associated with the X-ray sources GX 17+2 and Cyg X-1 have been found. Efforts to detect radio emission near the positions of Cyg X-2, GX 5−1, GX 9+1, and GX 3+1 have been unsuccessful.

It is now well established that the radio emission of the X-ray star Sco X-1 is rapidly and erratically variable over a range of two orders of magnitude (Ables 1969; Hjellming and Wade 1971; Lampton *et al.* 1971; Wade and Hjellming 1971). In the hope of finding more objects of this kind, we have periodically, during the last year, observed the fields of six other X-ray sources (Cyg X-1, Cyg X-2, GX 17+2, GX 5−1, GX 9+1, GX 3+1) with the NRAO three-element interferometer. Most of the observations were made at 2695 MHz, by the use of simultaneous interferometer baselines of 900, 1800, and 2700 m.

Variable radio sources were found close to GX 17+2 and Cyg X-1. They are probably associated with these X-ray sources. Radio sources were found several arc minutes from Cyg X-2 and GX5−1, but no variation of strength has been detected, and their positions differ appreciably from those of the corresponding X-ray sources. For these reasons, it is at the present time unlikely that they are related to the X-ray objects. No radio sources as strong as 0.005 flux units (1 f.u. = 10^{-26} W m^{-2} Hz^{-1}), were found within 10 arc minutes of the X-ray positions of GX 9+1 and GX 3+1. The results for the six X-ray sources are summarized in Table 1, and the detected objects are discussed individually below.

GX 17+2.—The field of this X-ray source was observed on 1971 April 2, May 27, and May 30. Aperture-synthesis maps derived from the data for April 2 and May 30 (following procedures described in Hjellming and Wade 1971) show no sources as strong as 0.005 f.u. The map for May 27, however, shows a source with an apparent flux density of 0.013 f.u. close to the known position of the X-ray source (see Table 1). This map is given in Figure 1. The source is unresolved, since the contours closely match the expected response to a point source. The map center, which is marked with a +, is at the X-ray position (weighted mean) measured by the MIT group (Schnopper *et al.* 1970). Two independent positions were determined by the MIT group; the 3 σ error circle associated with the 4′ collimator is represented by segments of a circle in Figure 1. The position measured from preliminary data by the *Uhuru* X-ray satellite (Tananbaum *et al.* 1971*b*) is also shown, with part of the polygon which defines the 90 percent confidence region. The position of the radio source is well within the uncertainty range for the X-ray position. It is clear that this radio source flared to a measurable strength on May 27, and then faded to invisibility within the next 3 days.

The GX 17+2 radio source varied during the observations on May 27. The amplitudes and phases of the fringe visibility functions measured on May 27 and 30 are shown in Figure 2 (for May 27, reduced to an equivalent 900-m baseline). During the observing period on May 27, the amplitude of the signal rose to a maximum of 0.022 f.u., and then

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TABLE 1

SUMMARY OF RESULTS FOR SIX X-RAY SOURCES

	X-RAY POSITION				RADIO POSITION		
OBJECT	α_{1950}	δ_{1950}	Error Limit (arc min)	Ref.	α_{1950}	δ_{1950}	FLUX DENSITY AT 2695 MHz (flux units)
GX 17+2...	$18^h13^m10^s$	$-14°03'.0$	2.6	1	$18^h13^m10^s.82\pm0^s.2$	$-14°03'13\pm3''$	<0.005–0.022
	18 13 06	−14 02 53	~2×1.2	2			
Cyg X-1....	19 56 27.6	+35 04 07	~1	3	19 56 28.65±0.3	+35 03 58±5	<0.005–0.015
	19 56 25	+35 03 25	~2×1	4			
GX 5−1....	17 58 04	−25 04.7	1.2	1	17 58 22.6 ±0.7	−25 07 30±10	0.019±0.003
Cyg X-2....	21 42 33	+38 03 42	~1	5	21 42 36.5 ±0.4	+38 00 25±5	0.008±0.002
GX 9+1....	17 58 35	−20 31.5	1.7	1	...	...	<0.005
GX 3+1....	17 44 49	−26 33.0	1.7	1	...	...	<0.005

REFERENCES:
1. Schnopper *et al.* 1970
2. Tananbaum *et al.* 1971*b*.
3. Rappaport *et al.* 1971.
4. Tananbaum *et al.* 1971*c*.
5. Tananbaum *et al.* 1971*a*.

declined. The phases[1] are well defined, varying with time precisely as expected for a point source offset from the center as shown in Figure 1. The observations of May 30 were made under identical conditions, but the amplitudes for the individual 25-minute integrations fluctuate about the mean Rayleigh noise level of 0.0065 f.u. and the phases scatter randomly.

The behavior of GX 17+2, as shown by these data, is much like that of Sco X-1 (Hjellming and Wade 1971; Wade and Hjellming 1971). This similarity suggests strongly that GX 17+2 is an X-ray *star*, like Sco X-1; hence the accurate radio position given in Table 1 should permit an optical identification to be made if the obscuration in the field is not too great.

Cygnus X-1.—Interferometric observations of the Cyg X-1 field on 1970 June 14 and 1971 March 21 and 22 showed no radio sources as strong as 0.005 f.u. Observations on 1971 May 13, 14, 20, 21, 26, 27, 28, 29, and June 1, however, show a source at 0.015 f.u., very close to the X-ray position of the object. Both the *Uhuru* X-ray satellite position (Tananbaum *et al.* 1971*c*), with the polygon showing the 2 σ error limits, and the MIT position (Rappaport, Zaumen, and Doxsey 1971), with a 3 σ error ellipse, are superposed on our map of the source in Figure 3. The response to a point source is shown in the upper right-hand corner of the figure; the source in the map is apparently a point source because of its excellent correspondence to a point-source image.

The May observations reveal no short-term variability; rather, it seems that the source brightened significantly between March 22 and May 13 to a stable level which it maintained until the last observation on June 1. This is very different from the behavior of Sco X-1 (and GX 17+2). Nevertheless, the apparent change in radio flux and the excellent positional agreement with the X-ray source makes it probable that the radio source is related to Cyg X-1.

In closing, we must emphasize that repeated failure to detect an X-ray source is not conclusive evidence that it is never a radio source. The three sources detected with the NRAO interferometer, Sco X-1, GX 17+2, and Cyg X-1, all have frequently been too faint to be observable. It is clear that radio emission of X-ray sources of this type is inherently erratic, and continued observations of undetected sources are worthwhile.

[1] Only the phases observed on the 2700- and 1800-m baselines are included, since the phases from the 900-m baseline show evidence of modulation by a fainter source elsewhere in the field (which is resolved out at the longer baselines).

1971ApJ...168L..21H

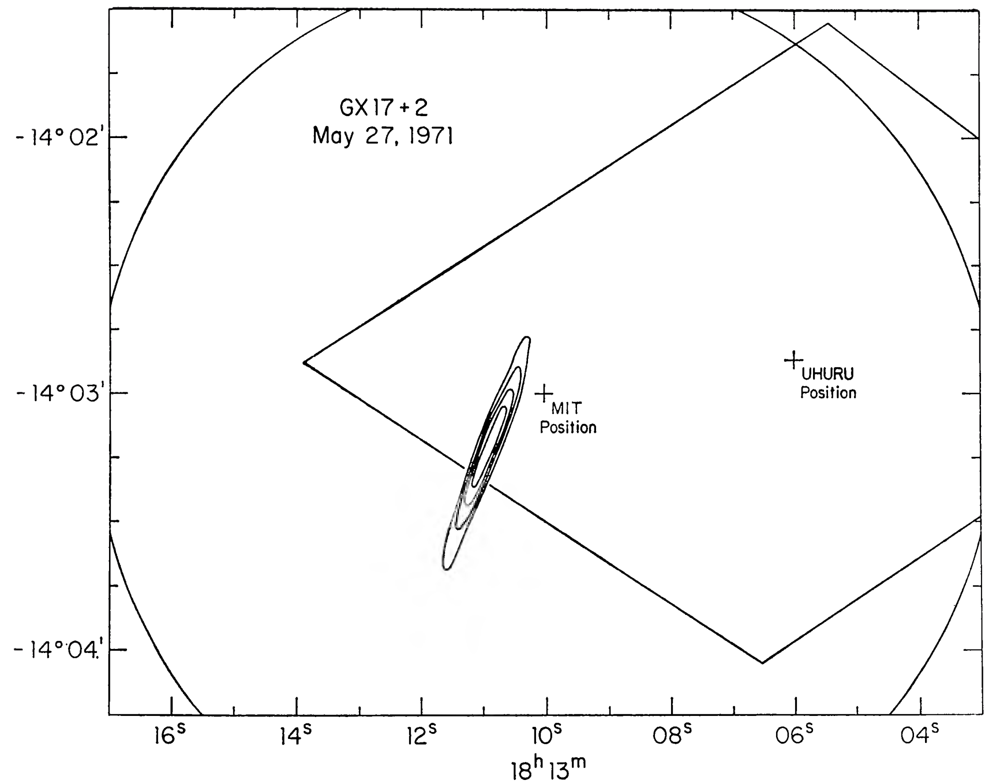

FIG. 1.—Map of the radio source appearing in the GX 17+2 field on 1971 May 27. The circle represents the error limit of the MIT X-ray position (with the 4′ collimator); the polygon represents the error limit of the *Uhuru* X-ray position.

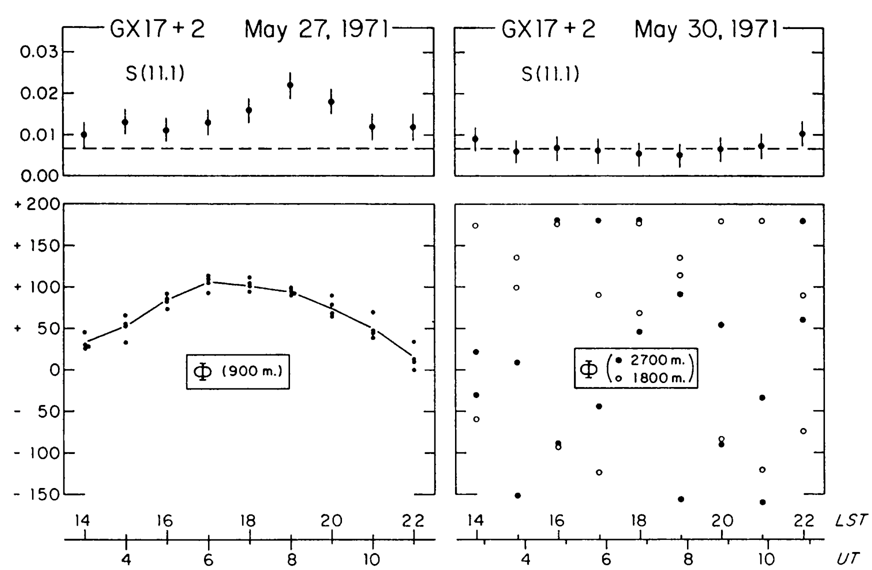

FIG. 2.—The amplitudes, $S(11.1)$, in flux units and the phases, Φ, in degrees for the GX 17+2 visibility function measured on 1971 May 27 and 30.

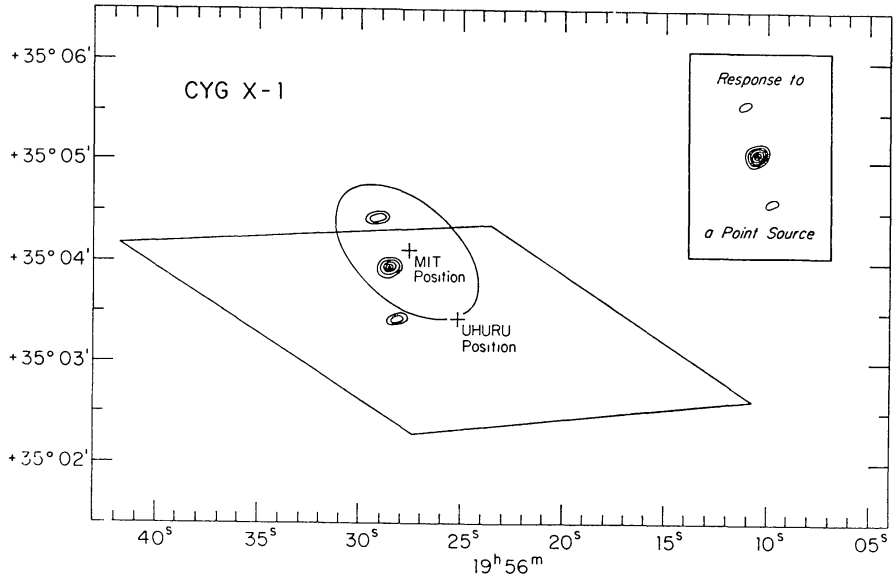

FIG. 3.—Map of the radio source (with the response to a point source in the upper right corner) in the Cyg X-1 field, 1971 May 13–June 1. Ellipse shows the error limits for the MIT position; the polygon, the error limits for the *Uhuru* position.

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