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FURTHER RADIO OBSERVATIONS OF SCORPIUS X-1

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ABSTRACT

Continuing interferometric observations of Sco X-1 at 2695 and 8085 MHz have provided more complete data on its structure and variability. To date, nearly 300 hours of observation have shown that major flaring activity is in progress about one-sixth of the time. The triple structure of the source is a persistent feature, but the position of one component may have changed somewhat during the past year.

We recently described observations of Sco X-1 at 2695 and 8085 MHz with the NRAO three-element interferometer (Hjellming and Wade 1971, hereinafter called Paper I). The radio source was shown to comprise three major components on an approximately straight line; the central one coincides with the star which has been identified with the X-ray source. The latter component was found to be highly variable on a time scale of hours, with occasional intense flares. No changes were seen in the other two components, $1'.3$ to the northeast and $2'.0$ to the southwest of the X-ray star, during the period covered by the first observations (1970 March–November). The present paper describes further observations through 1971 May.

The procedures of observation and data analysis were essentially the same as those described in Paper I. There were four observing periods: 1970 December 3–5, 1971 February 23–27, 1971 March 22–April 2, and single observations on 1971 May 14 and 20. During the first two periods, simultaneous interferometer baselines of 800, 1900, and 2700 meters were used; during the other two periods, the spacings were 900, 1800, and 2700 meters.

Figure 1 shows the flux density of the central component (the one at the position of the X-ray star) at each observing frequency as a function of time for 20 of the observing days. Each plotted point is the amplitude of the vectorial difference between the observed fringe visibility and the contribution from the two steady components of Sco X-1,[1] averaged over the different simultaneous baselines at the frequency in question. The phases of the vectorial differences show that the varying radiation in Figure 1 comes from within $1''$ of the position of the X-ray star. This is confirmed by aperture synthesis maps formed from data taken on days when major flares occurred (flux density reaching 0.04 f.u.[2] or more at 2695 MHz). The apparent flux densities derived from the maps for each observing day are given in the upper part of each frame of Figure 1. They generally agree well with the average level of the plotted points for the same day.

The data shown in Figure 1 for 1971 February 23 and 24 are unique in that the flux density of the central source remained sensibly constant (at a little less than 0.01 f.u.) during these 2 days. This is markedly at variance with the usual behavior of the source, which is characterized by continual variation.

Including the data given in Paper I, we now have flux density measurements at 2695 MHz for the central source on 37 days in the period from 1970 March 26 to 1971 May 20.

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[1] The contributions of the steady components were found from the observations of 1970 December 5 (for 1970 December 3 to 1971 February 24), 1971 February 23 and 24 (for 1971 February 25, 26, and 27), and 1971 March 23 and 28 (for 1971 March 22 to May 20).

[2] 1 f.u. = 10^{-26} W m^{-2} Hz^{-1}.

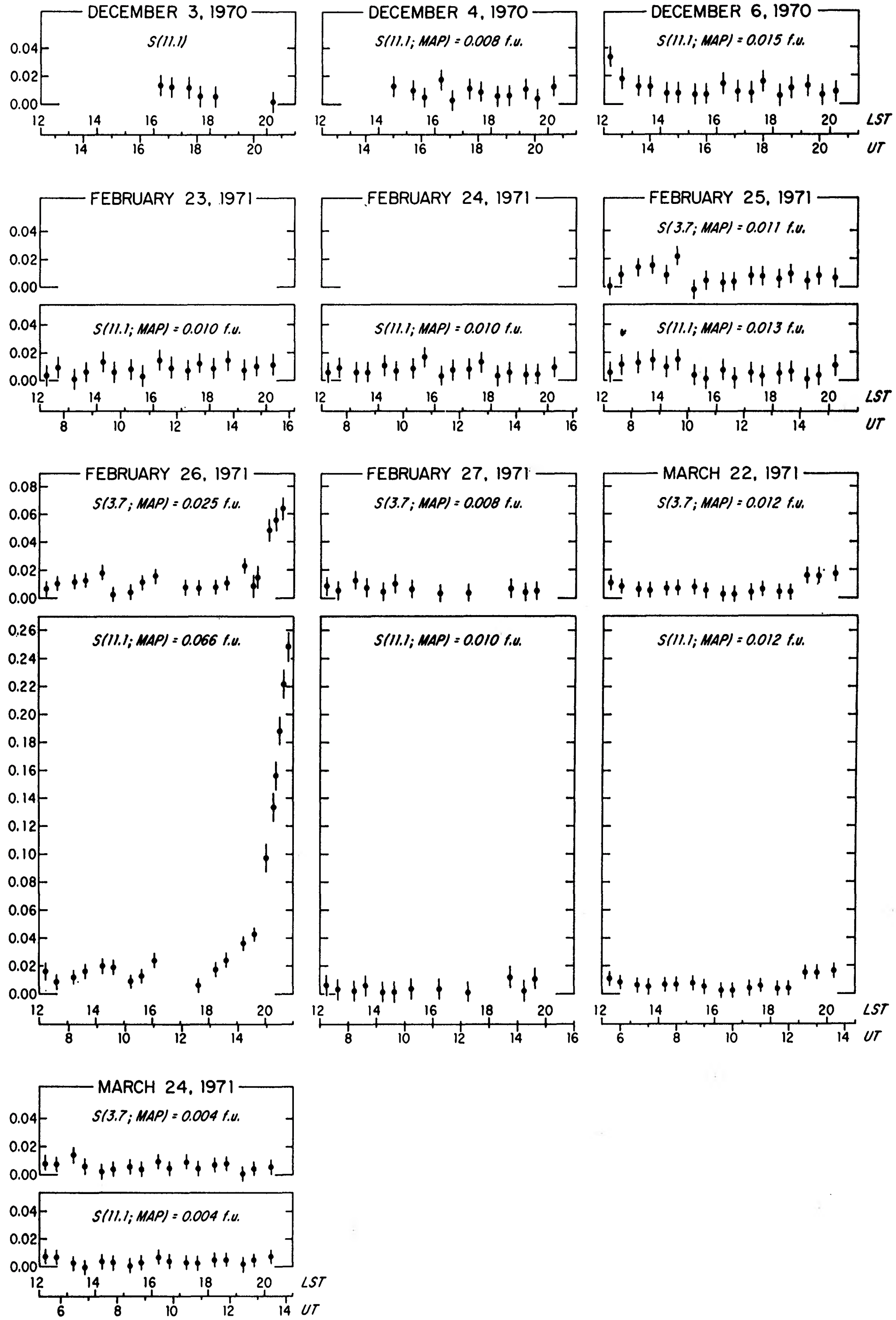

FIG. 1.—Flux density of the central component of Sco X-1 at 2695 MHz (11.1 cm) and 8085 MHz (3.7 cm) as a function of time during 20 days of observation. Abscissa shows universal time and local sidereal time at Green Bank.

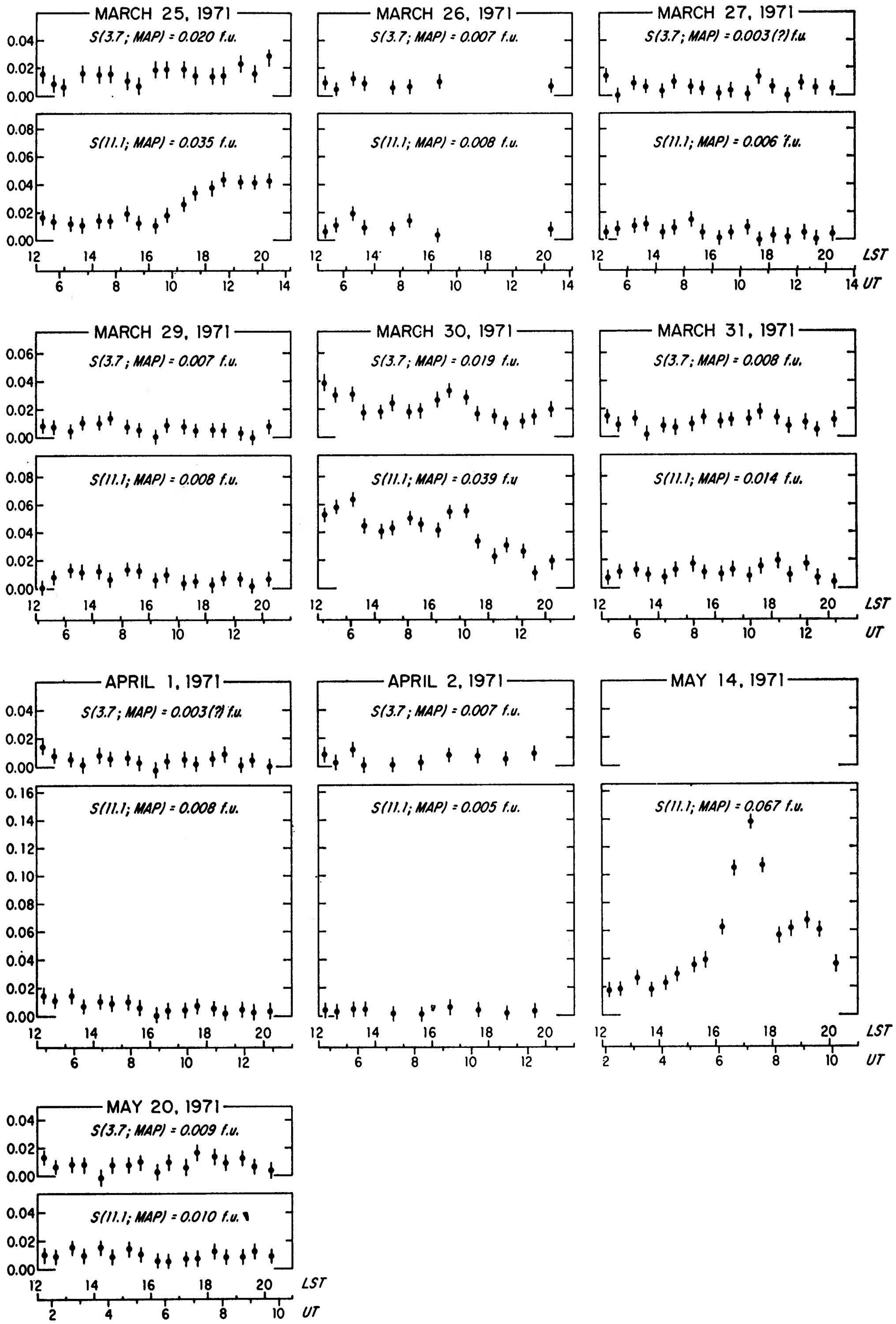

FIG. 1.—*Continued*

On most of these days, the observation was continuous for 8.5 hours, with 10 min of each hour devoted to calibration. The total material covers 293 hours, enough to justify a preliminary estimate of the relative times during which the central source is at different levels of intensity. Significant flares were seen on 6 days; these are listed in Table 1 with their peak flux densities at 2695 MHz and the lower limits to their durations (in no case have we seen the complete course of a flare from base level to base level). The strongest flare yet seen, on 1971 February 26, began about 2 hours before Sco X-1 set; by the time it set, *the flux density had reached 0.26 f.u. and was still increasing rapidly*. In marked contrast to the days when major flares were seen, there were 7 days when the central source was "dormant," with the flux density remaining below the lowest measurable level (about 0.003 f.u.) throughout the 8.5-hour observing period. On the remaining 24 days (except for 1971 February 23 and 24, noted above), the central source varied erratically at a low level, usually between 0.01 and 0.03 f.u. The typical behavior seen on these days is a variation by about a factor of 2 on a time scale of a few hours.

The pattern seen during the 5-day period 1971 February 23–27 is particularly interesting. As noted earlier, the strength of the central source remained practically constant on February 23 and 24. Weak flaring was seen on the twenty-fifth, followed on the twenty-sixth by the strongest flare yet observed. On the twenty-seventh, the central source had returned to "normal," with an intensity some 30 percent lower than on the twenty-third and twenty-fourth. The dominant physical processes operating during the steady and the variable phases are probably quite different, and their close association during the February observing period suggests that the combinations of phenomena which can take place in the central source must be complex and varied.

In summary, it appears that the central source (*a*) has a major flare in progress about 15 percent of the time; (*b*) is "dormant" about 20 percent of the time; (*c*) is in a rare "steady" state perhaps 5 percent of the time; and (*d*) is relatively weak, but erratically and continually variable, during the remaining 60 percent of the time.

There is a fairly persistent peculiarity in the minor flares seen on 1970 March 26, June 3, June 20, 1971 February 26 (before the major flare), and possibly on 1971 May 14. These small flares have a "sawtooth" shape—the flux density increases slowly for 2 or 3 hours and then it drops abruptly. This is followed at once by another gradual rise. The cycle was repeated at least 3 times during the hours preceding the great flare on 1971 February 26. The variation is usually similar and simultaneous at both observing frequencies. It may be significant that the intensities and time scales of the "sawtooth" flares seem to be much the same every time they occur. This contrasts strongly with the major flares, which have little resemblance to one another.

In Paper I, the two companion sources flanking the central source were discussed briefly. The declinations quoted for these objects were slightly in error; the correct

TABLE 1

MAJOR FLARES OF SCO X-1

Date	Peak Flux Density at 2695 MHz (f.u.)	Duration (hours)
1970 September 29.......	0.13	>6
1970 November 6.........	0.06	>8
1971 February 26.........	>0.26	>2
1971 March 25...........	0.04	>4
1971 March 30...........	0.06	>7
1971 May 14.............	0.14	>8

positions are given in Table 2. They agree well with the positions found by Braes and Miley (1971) with the Westerbork array at 21.2-cm wavelength.

A map of the Sco X-1 field, derived from the most recent data, is given in Figure 2. The point-source response of the synthesized radiation pattern is shown in the upper right-hand corner. The map represents data taken on 14 days during 1971 February, March, and April; the 3 days with major flares were excluded. Since two different instrumental configurations were used and a large amount of data was obtained in a relatively short time, this map is of a better quality than any we have previously made for this

TABLE 2

POSITIONS AND FLUX DENSITIES OF THE COMPANION SOURCES

	1970 March–November		1971 February–April		
Source	α_{1950}	δ_{1950}	α_{1950}	δ_{1950}	S_{2695}
Northeast. .	$16^h17^m06\overset{s}{.}8 \pm 0\overset{s}{.}4$	$-15°30'18'' \pm\ 5''$	$16^h17^m06\overset{s}{.}8 \pm 0\overset{s}{.}4$	$-15°30'14'' \pm 5''$	0.012 ± 0.002
Southwest. .	$16^h17^m02\overset{s}{.}4 \pm 0\overset{s}{.}8$	$-15°32'54'' \pm 10''$	$16^h17^m01\overset{s}{.}7 \pm 0\overset{s}{.}6$	$-15°32'17'' \pm 8''$	0.007 ± 0.002

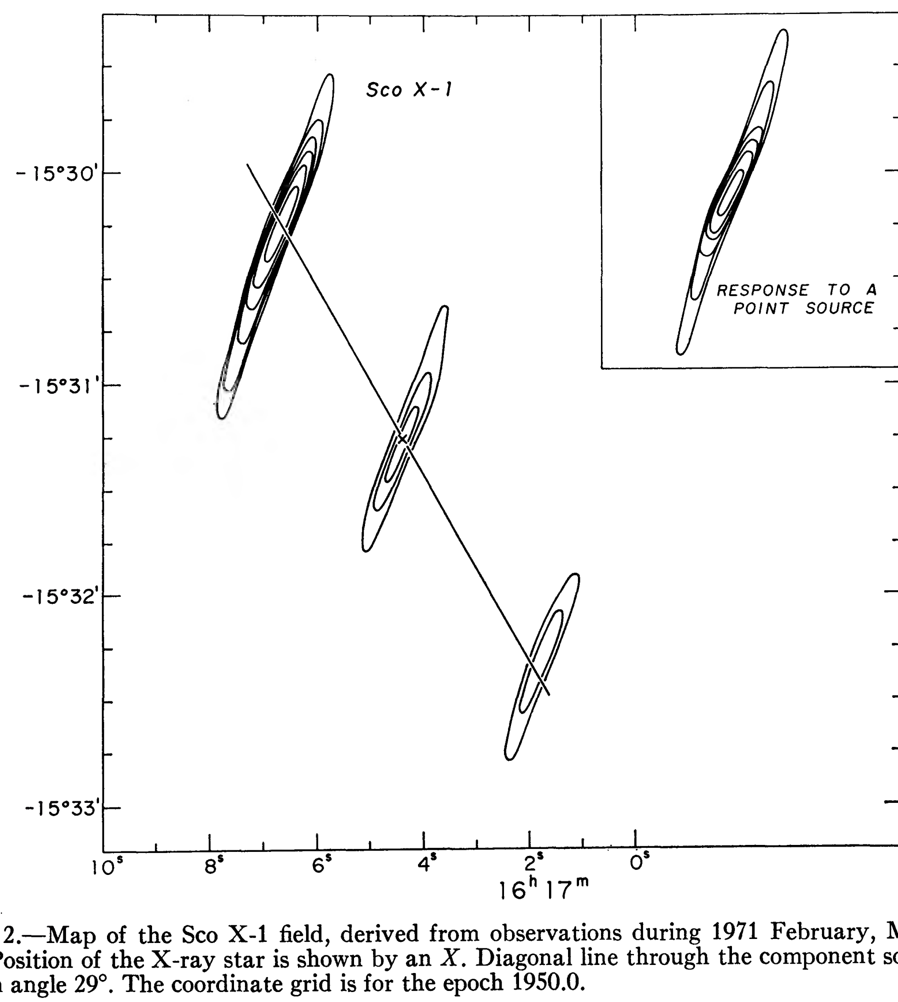

FIG. 2.—Map of the Sco X-1 field, derived from observations during 1971 February, March, and April. Position of the X-ray star is shown by an X. Diagonal line through the component sources is at position angle 29°. The coordinate grid is for the epoch 1950.0.

field. The three sources are almost perfectly aligned on position angle 29°. The positions and flux densities of the outer sources, as given by this map, are listed in Table 2. The northeast and southwest components are, respectively, $1\rlap{.}'18$ and $1\rlap{.}'24$ from the central source. The position of the northeast component agrees well with our earlier measurement and with the position given by Braes and Miley (1971). On the other hand, the position of the southwest component apparently has shifted by 39″. We cannot yet be certain, however, that a real change has taken place because: (1) the two measurements are based on sampling of somewhat different spatial frequencies; (2) an apparent shift mainly in the direction of the beam elongation must be viewed with caution; and (3) the southwest component is the faintest of the three and hence is the one most subject to distortion by sidelobes and noise. Still, it seems entirely possible that there has been a real change in the position. If further study should show this to be the case, there could be little doubt that the three components comprise a single physical system.

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