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# POSITIONS OF X-RAY SOURCES IN THE SAGITTARIUS REGION*

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ABSTRACT

A rocket experiment yielded data concerning the celestial positions and intensities (1.5–8 keV) of twelve X-ray sources in the region of Sagittarius. Comparison with data from other experiments yields no clear evidence for gross time variations in the intensity of these sources.

The determination of the celestial position of an X-ray source can lead to its identification at optical or radio wavelengths. This, in turn, permits extensive studies of the object from ground observatories. The celestial region near the galactic center contains a large number of X-ray sources (1–10 keV) and has been examined by many groups (Bowyer *et al.* 1965; Clark *et al.* 1965; Fisher, Johnson, Jordan, Meyerott, and Acton 1966; Fisher, Jordan, Meyerott, Acton, and Roethig 1966, 1968; Friedman, Byram, and Chubb 1967; Gursky, Gorenstein, and Giacconi 1967; Bradt *et al.* 1968; Bunner and Palmieri 1969). The present experiment refines the positions reported by Bradt *et al.* (1968), and reduces the uncertainty in position of several other sources south of the galactic center.

The experiment was carried aboard an Aerobee rocket, launched from White Sands Missile Range at $17^h44^m$ sidereal time on 1968 July 26. Two X-ray detection systems viewed the celestial sphere through an opening in the side of the rocket. System ABC consisted of three proportional counters behind a combination collimator (a $1\overset{\circ}{.}2 \times 60^\circ$ FWHM slat collimator and a $3\overset{\prime}{.}1$ modulation collimator). System DEFG consisted of four proportional counters behind a simple slat collimator ($1\overset{\circ}{.}2 \times 60^\circ$ FWHM). Three of the counters (D, F, G) were filled with argon (5.6 mg $cm^{-2}$) and had 7.7-$\mu$ Al windows with an effective area of 30 $cm^2$ each. These counters have been described by Rappaport, Bradt, and Mayer (1969). The fourth counter (E) contained xenon (20 mg $cm^{-2}$) and had a 50-$\mu$ Be window with an area of 110 $cm^2$. The two slat collimators were aligned parallel to each other and were oriented on the rocket such that, for most of the flight (a "roll" at $\sim 15'$ $sec^{-1}$), a source would transit them perpendicular to their long direction. The collimator orientation, the rocket motion, and the characteristics of system ABC are described by Polucci *et al.* (1970).

The aspect of the rocket was determined by means of stellar photography. Consecutive 0.6-sec exposures of the celestial sky were made with two 16-mm cameras, with 50-mm, f/1.4 lenses. The relative alignments of the cameras and the slat collimators were determined by laboratory calibrations before and after the flight with a precision of $\pm 4'$. During the flight, this precision was confirmed by the fact that the position of Sco X-1 derived from this experiment was in error by less than $2\overset{\prime}{.}5$.

The X-ray data obtained during the roll maneuver (132–285 sec after launch) are shown in Figure 1. Only pulses in the 1.5–8-keV range are included to improve the signal-to-noise ratio. A dead-time correction of 2 msec has been applied. The data of

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Figure 1, *a*, were fitted with the minimum possible number of point sources by means of a least $\chi^2$ analysis. Due to apparent fluctuations in the background level, possibly arising from unresolved sources, this best-fit analysis was also used to determine a local background for each source from the adjacent "non-source" regions. The uncertainty in background rate does not significantly affect the best-fit time. We obtained the 90 percent error limits on this time by varying the peak time in the $\chi^2$ analysis and accepting only those times for which the $\chi^2$ probability was greater than 10 percent. The histogram for counters ABC (Fig. 1, *b*) has distorted peak shapes due to the modulation collimator, but it does confirm the existence of the peaks in the DEFG data.

The data obtained near the start of the roll maneuver are shown in Figure 2. Peaks S1A and S1B were obtained during a rotation of 48° about the view ("pitch") axis. The widths of these peaks yield the distances of the sources from the view axis under the

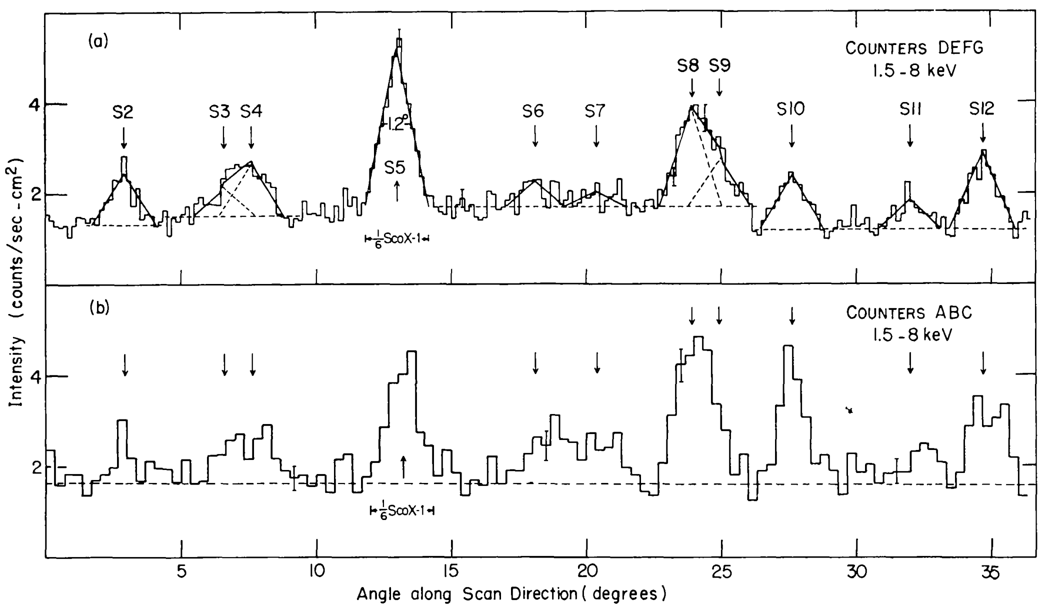


FIG. 1.—(*a*) Observed X-ray intensity in the Sagittarius region as a function of angle along the scan direction. Triangles (1°.2 FWHM) represent the point sources which were fitted to the data. For multiple sources, the solid line is the sum of the two triangles. (*b*) Data obtained from counters ABC. Peaks are not triangular due to distortion caused by the modulation collimator.

assumption that each peak represents a single source. For each source, the relative intensities in counters D, F, and G limit the possible source locations on the line of position defined by the collimator. Counter D cannot detect a source that is more than 25° below (south of) the view axis. Hence, the data of Figure 2, *b*, *c*, *d*, indicate that S1B, S2, and probably S1A are south of the scan track.

Each triangular peak in Figures 1 and 2 corresponds to a celestial line of position for an X-ray source. These lines, for sources observed after the transit of Sco X-1, are presented in Figure 3. The dashed lines are the error limits for the source locations previously reported by Bradt *et al.* (1968). They were derived from the results of the MIT experiment of 1967 July 7 and from the lines of position reported by Gursky *et al.* (1967). The solid circles in Figure 3 are the error circles obtained from a reconsideration of the results of all three experiments. In particular, we determined the 90 percent error limits for the two earlier sets of data and also reanalyzed the earlier MIT data to take into account the presence of two sources in peak A5. The "best-position" circles were then constructed so as to include the region that is within the 90 percent error limits of all three experiments.

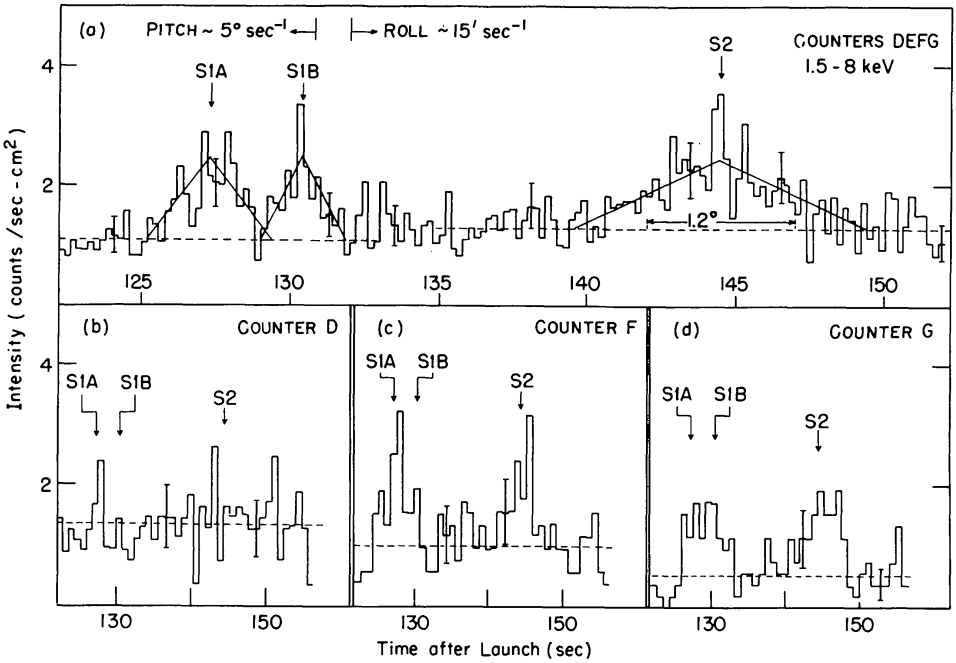


FIG. 2.—(*a*) Intensity versus time for sources observed during the pitch-roll sequence. Widths of peaks S1A and S1B depend on the distances of the sources from the center of rotation, whereas S2 is fitted to a triangle of width 1°.2 (FWHM), as required for a point source observed during the roll maneuver. (*b*), (*c*), (*d*) Data obtained in the individual counters D, F, and G. Peaks S2, S1B, and, to some extent, S1A are not observed in counter D. This indicates these sources are south of the view axis.

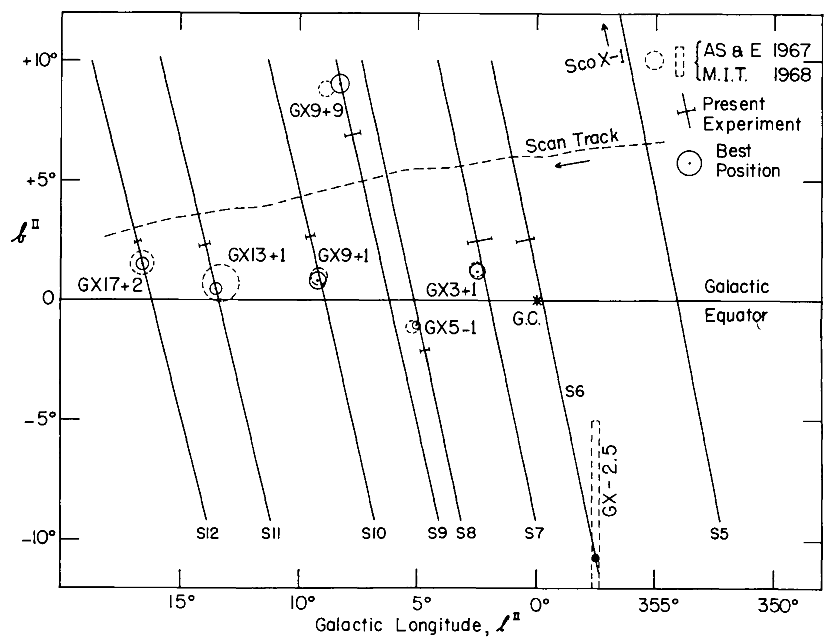


FIG. 3.—Celestial lines of position derived from the times of peaks S5–S12 and from the collimator aspect determined by means of star photography. Dashed circles and rectangle were taken from Bradt *et al.* (1968). They were derived from an MIT experiment and from the lines of position published earlier by AS&E (Gursky *et al.* 1967). The "best-position" circles were constructed from the results of all three experiments. Large dot on the line of position for S6 is our estimate of the most probable source location.

The lines of position for the sources observed prior to the transit of Sco X-1 are presented in Figure 4. Previous results of source positions and intensities in this region are also shown. The 90 percent limits of the possible source locations along a given line of position (*hatched area*) are determined wholly or in part by (1) the width of the peak (S1A and S1B), (2) the relative intensity of the peaks in counters D and G (S1B and S2), and (3) the clear, unambiguous correlation with a previously reported intense source (S4, which we designate GX 349+2). During the pitch maneuver, the width of a peak determines two possible locations equally distant from the center of rotation. This ambiguity is removed for S1B by the additional information that it lies south of the

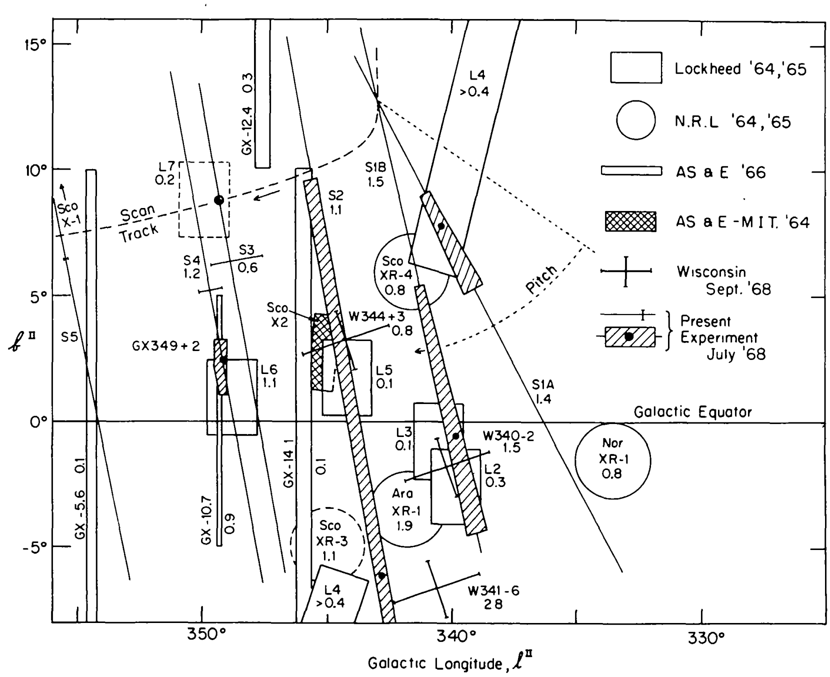


FIG. 4.—Lines of position for data peaks S1A–S5 and a summary of the results of other groups. Source designations and reported intensities (counts $cm^{-2}$ $sec^{-1}$) are shown. Due to different counter efficiencies, intensities should be compared only if they were reported by the same group. Each hatched area represents the 90% error limits obtained from this experiment and, in the case of S4, other published results. Each large dot indicates our estimate of the most probable source position as deduced from all the data shown in this figure. Data of other groups are taken from: Lockheed (Fisher *et al.* 1968); NRL (Friedman *et al.* 1967); AS&E (Gursky *et al.* 1967); AS&E-MIT (Clark *et al.* 1965); and Wisconsin (Bunner *et al.* 1969). The dates listed in the key refer to the time the experiment was performed. We have not included NRL sources which have error limits $\geq 2°$.

scan track. For S1A, the fact that it was not observed a second time during the pitch-roll sequence indicates that it does not lie north of the scan track.

The position of the large dot on each line of position (Fig. 4) represents our estimate of the most probable source location and is based on all available published data. In particular, for the position of S2, we considered the following facts: (1) our data (Fig. 2, *b*, *c*, *d*) indicate a most probable position for this source at $b^{II} \simeq -10°$, (2) source W341−6 is quite intense, (3) the sources L5 and W344+3 have relatively low intensities, and (4) the data for Sco X-2 were obtained from a spinning rocket in 1964 and could suffer from time variations and possibly from a systematic error in position (compare the positions of Sgr X-1 and GX 5−1 in Fig. 6 of Bradt *et al.* 1968). During the pitch maneuver prior to the transit of S1A, no sources were observed above a level of 2 standard deviations (0.45 counts $sec^{-1}$ $cm^{-2}$ at the reported positions of Nor XR-1). However, if Nor XR-1

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TABLE 1

POSITIONS AND INTENSITIES OF OBSERVED X-RAY SOURCES

| Source | Data Peak | Coordinates* (1950) α | δ | $l^{II}$ | $b^{II}$ | Error Limits† | Observed Intensity‡ | Pole of Collimator $l^{II}$ | $b^{II}$ | Other Designations§ |
|---|---|---|---|---|---|---|---|---|---|---|
| ... | S1A | $16^h14^m.0$ | −39°31′ | 340°.40 | + 7°.80 | 20′× 2°.2 | 1.4 | 66°.31 | −27°.53 | L4; Sco XR-4 |
| ... | S1B | 16 45.2 | −45 42 | 339.80 | − 0.60 | 20′× 5°.0 | 1.5 | 70.06 | −12.78 | L2–L3; W340−2; Ara XR-1? |
| ... | S2 | 17 21.0 | −46 39 | 342.80 | − 6.10 | 17′×16°.0 | 1.1 | 73.90 | − 9.87 | W341−6; Sco XR-3?; Ara XR-1? |
| ... | S3 | 16 40.2 | −32 25 | 349.30 | + 8.80 | 66′×30°.0 | 0.6 | 77.68 | −10.17 | L7 |
| GX 349+2 | S4 | 17 04.0 | −36 29 | 349.20 | + 2.40 | 15′× 1°.1 | 1.2 | 78.67 | −10.32 | GX−10.7; L6; Sco XR-2 |
| Sco X-1 | S5 | 16 17.1 | −15 31 | 359.10 | +23.78 | ... | 29.0 | 84.07 | −11.13 | |
| ... | S6 | 18 21.1 | −36 18 | 357.50 | −10.70 | 24′×30°.0 | 0.6 | 89.78 | −11.87 | GX−2.5; Sco XR-6 |
| GX 3+1 | S7 | 17 43.6 | −26 11 | 2.46 | + 1.22 | 20′ | 0.4 | 92.01 | −11.96 | See Table 1 of Bradt *et al.* (1968) |
| GX 5−1 | S8 | 17 58.1 | −25 07 | 5.04 | − 1.05 | 10′ | 2.2 | 95.15 | −12.28 | |
| GX 9+9 | S9 | 17 28.4 | −17 07 | 8.29 | + 9.02 | 22′ | 1.1 | 96.19 | −12.78 | |
| GX 9+1 | S10 | 18 00.0 | −20 35 | 9.20 | + 0.82 | 20′ | 1.2 | 98.93 | −13.01 | |
| GX 13+1 | S11 | 18 10.3 | −17 00 | 13.52 | + 0.47 | 15′ | 0.7 | 103.42 | −13.26 | |
| GX 17+2 | S12 | 18 12.7 | −13 48 | 16.60 | + 1.50 | 15′ | 1.8 | 106.20 | −13.79 | |

* Obtained from the consideration of all available data (see text).

† Half-width of error limits (e.g., radius of error circle). See Figs. 3 and 4 for orientation and position of error limits. The probability that a source lies within the limits is ~90 percent.

‡ Counts $cm^{-2}$ $sec^{-1}$ in the energy interval 1.5–8 keV. The error in intensity is $\sim\pm0.3$ due to the uncertainty in the background level. An intensity of 1 count $cm^{-2}$ $sec^{-1}$ corresponds to an energy flux of $7\times10^{-9}$ erg $cm^{-2}$ $sec^{-1}$.

§ Source notation is: L, Fisher *et al.* (1968); XR, Friedman, Byram, and Chubb (1967); GX $l^{II}$, Gursky, Gorenstein, and Giacconi (1967); *W* $l^{II}b^{II}$ (published as GX $l^{II}b^{II}$), Bunner and Palmieri (1969).

were to lie on the line of position for S1A, it would be obscured by the strong source at $l^{II} \simeq 340°$, $b^{II} \simeq +8°$. Finally, we note that a high-energy (>20 keV) X-ray source reported by Lewin *et al.* (1969) lies at the position chosen for S1B but has 90 percent error limits of $\sim \pm 5°$.

The source information presented in Figures 3 and 4 is also listed in Table 1. The coordinates of the X-ray sources were derived from both the present experiment and other published results as previously indicated. We have given GX $l^{II}b^{II}$ designations only to those sources which have an uncertainty in position less than about 1°. We also give the galactic coordinates of the poles of the great circles which constitute the lines of position obtained from this experiment.

The X-ray data presented in Figures 3 and 4 indicate that the locations of sources from $l^{II} \simeq 348°$ to $l^{II} \simeq 18°$ are well known, whereas the situation for $l^{II} \leq 348°$ is relatively confused. In either region, it is our view that the data of the various experiments do not compel one to invoke gross time variations in intensity. In fact, the data appear to be consistent with sources which have been stable, within a factor of 2, for a period of several years.

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