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X-RAY SOURCES NEAR THE GALACTIC CENTER OBSERVED BY *UHURU*

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ABSTRACT

X-rays emitted from the direction of the galactic nucleus have been detected for the first time. The emitting region is of the order of one-tenth as strong as the strongest X-ray emitters in the Sagittarius complex, and is extended by about 2° in galactic longitude. Its spectrum indicates considerable absorption at low energies. A highly variable discrete source close to the galactic center has also been observed; it lies about 2° off the galactic plane.

I. INTRODUCTION

The region near the center of our Galaxy has been known to be the location of several X-ray sources for a few years (see Bowyer *et al.* 1965; Gursky, Gorenstein, and Giacconi 1967; Bradt *et al.* 1968; Mayer, Bradt, and Rappaport 1970). Rocket flights using the modulation-collimator technique by the MIT group (cf. Schnopper *et al.* 1970) in the last two years have resulted in position and spectral data on several of the stronger sources. However, it has been recognized that the region must be more complex than the above experiments have revealed so far. In the present Letter we report new information on the galactic center based on data obtained from the *Uhuru* satellite. We find that there is an extended X-ray emitting region of moderate strength with an unusual spectrum located near the center of our Galaxy close to the radio source Sgr A and the far-infrared source complex report by Hoffmann, Frederick, and Emery (1971). The X-ray source (or complex of sources) is also extended, with a size of about 2°. We have also discovered a highly variable source at $l = 359.^\circ6$, $b = 2.^\circ1$.

II. LOCATIONS

The data presented here were obtained on 1970 December 27, 1971 March 11, 1971 April 12, and 1971 April 27. Details of the *Uhuru* instrumentation were given by Giacconi *et al.* (1971). On December 27, the spin axis of the satellite was pointed at the galactic pole, and on March 11 and April 12 at the antipole. On April 27 the spin axis was 231° from the galactic center at a galactic latitude of −27°. These four scans all showed a source at the galactic center based on analysis of quick-look data.

The counting-rate distributions observed on three days are shown in Figure 1. On December 27 when the detector, whose field of view was $0.^\circ5 \times 5^\circ$ full width at half-maximum, was scanning along the galactic plane with increasing azimuth corresponding to decreasing longitude, we saw an extended source at the galactic center $1.^\circ8$ in size with a strength of 40 counts s^{-1} (2.4–6.9 keV). On March 11, in scanning the plane in the opposite sense, we observed a strong point source of 450 counts s^{-1} intensity superposed on a weaker extended source. On April 12, the scan of the galactic plane in the same direction as March 13 showed a weak extended source, 40 counts s^{-1}. On April 27, the scan at 63° to the plane showed an extended weak source very close to the galactic center. Figure 2 shows a map of the galactic-center region obtained from a partial analysis of these data.

The extended source GCX is located close to the direction of the galactic center, and overlaps the infrared isointensity contours. The highly variable source GX 359+2 shows no evidence of a finite angular extent. Both of these sources can be seen in Figure 1*B*.

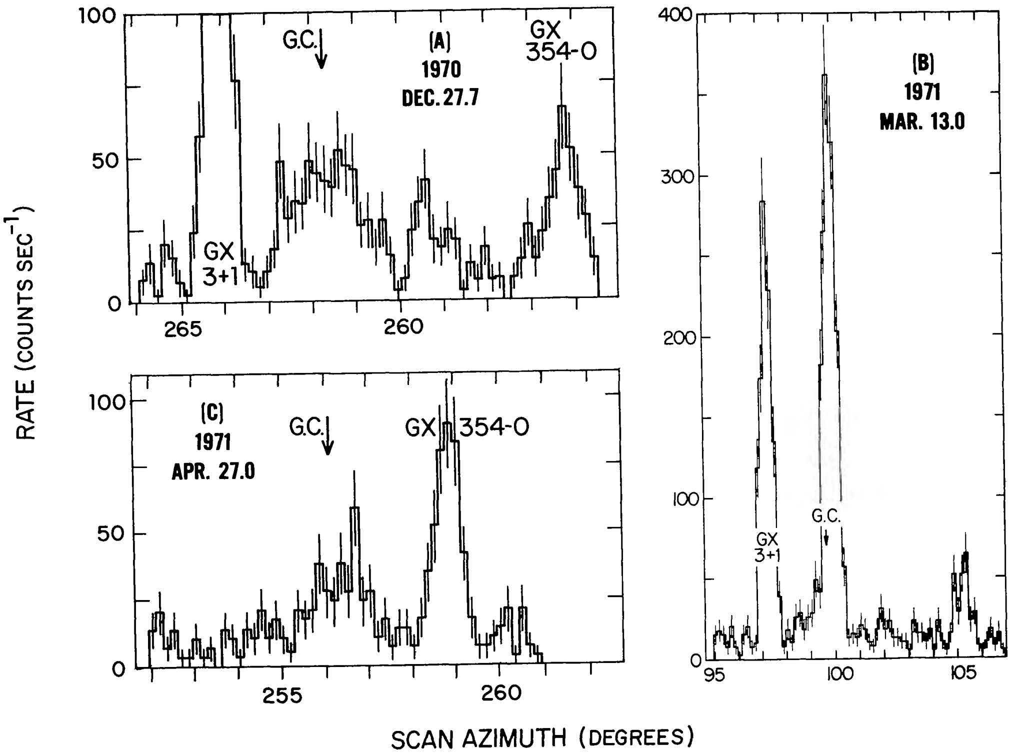

FIG. 1.—Counting rate versus azimuth from the 0°5 collimator (2.4–6.9 keV). (*A*) Scan along the galactic plane. Four sources are seen: GX 3+1; GCX; a new weak source at about 259° azimuth (l = 357°6 ± 0°1); and GX 354−0 (previously known as GX−5.6). (*B*) Scan along the plane done several months later than (*A*). The very strong source GX 359+2 has appeared at an azimuth of ~100°. GCX is still barely visible as an excess in the counting rate to the left of the main peak from GX 359+2. GX 354−0 is seen at an azimuth of ~105°. (*C*) Scan at about 63° to the galactic plane. GCX is still visible as an extended source, but GX 359+2, which should appear at about 256° azimuth, has disappeared.

GCX is visible as a weak shoulder on the left side of the main peak due to GX 359+2. The location of the centroid of GCX is:

$$(1950)\ \text{R.A.} = 17^{\text{h}}43^{\text{m}}.4\,, \quad \text{decl.} = -29^\circ 8'\,; \quad l = 359^\circ.9\,, \quad b = -0^\circ.3\,.$$

The galactic coordinates are from IAU Comm., *33b*, 1959. GX 359+2 is located at $l = 359^\circ.6 \pm 0^\circ.1$, $b = 2^\circ.1 \pm 0^\circ.5$. We also observe a source at $l = 354^\circ.26 \pm 0^\circ.05$, $b = -0^\circ.09 \pm 0^\circ.05$ which we call GX 354−0. This source was previously detected by Gorenstein, Giacconi, and Gursky (1967) and has been known as GX−5.6. There is also a 4 σ peak in the counting-rate data from 1970 December 27 centered at $l = 357^\circ.6 \pm 0^\circ.1$. We expect to obtain a definitive location for this new source when more *Uhuru* data are analyzed.

III. X-RAY SPECTRA

Seven-channel pulse-height spectra were analyzed for GCX and GX 359+2 by means of our usual technique (Gorenstein, Gursky, and Garmire 1968). GCX fits either an exponential, power-law, or blackbody spectrum and shows no significant intensity variation with time. The average spectrum from December 27, February 20, and April 12 (1.8–19.8 keV) is

$$f_\nu = (1.85 \pm 0.05) \times 10^{-10} \exp\{-[(2.8 \pm 0.2)/E]^{8/3}\} E^{(-0.4 \pm 0.1)}\ \text{ergs cm}^{-2}\ \text{s}^{-1}\ \text{keV}^{-1}$$

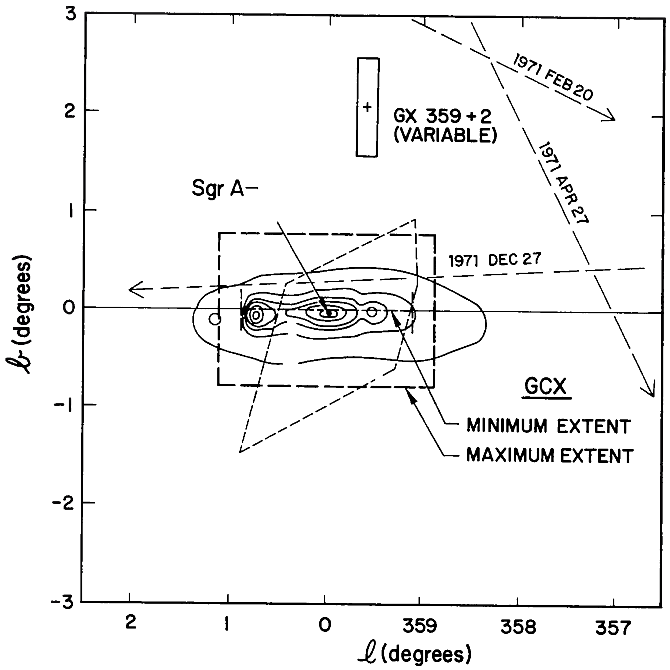

FIG. 2.—Map of the galactic center in galactic coordinates. The polygon in short dashed lines indicates the maximum extent of GCX. The source could cover a smaller range of galactic latitudes; a scan exactly perpendicular to the plane with our slit field of view would be required. The rectangle in heavy dashed lines indicates the maximum extent of GCX based on a model of uniform emission from an extended region with boundaries of constant latitude and longitude, centered at $l = 0°$, $b = 0°$. The minimum extent of GCX for the same model is consistent with a line source indicated by the heavy dashed line along $b = 0°$. We have added the 100-μ brightness contours of Hoffmann *et al.* (1971) for comparison. We also show the error box ($\pm 1\ \sigma$) on the centroid location for GX 359+2. *Long dashed lines*, detector scan tracks for the three days' data used to measure the size and location of GCX.

for a power law, with $\chi^2 = 19$ for 5 degrees of freedom;

$$f_\nu = (1.33 \pm 0.04) \times 10^{-10} \exp \{-[(2.7 \pm 0.2)/E]^{8/3}\}$$
$$\times \exp [-E/(16.3 \pm 2.8)] \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}$$

for thermal bremsstrahlung with $\chi^2 = 17$ for 5 degrees of freedom;

$$f_\nu = (3.0 \pm 0.2) \times 10^{-13} \frac{E^3}{\{\exp [E/(2.3 \pm 0.1)] - 1\}} \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}$$

for a blackbody, with $\chi^2 = 13$, for 6 degrees of freedom.

In each case, the fits were not good. Of course, the possibility cannot be excluded that the source is composed of a number of unresolved discrete sources with different spectra, or that the process giving rise to the emission results in a spectral type different from those we have tried. The X-ray flux (1.8–16 keV) from GCX, if a power-law spectrum index of -0.4 is assumed, is 1.2×10^{-9} ergs cm^{-2} s^{-1}. At 10 kpc, this corresponds to a total luminosity of 1.4×10^{37} ergs s^{-1}.

The spectrum of GX 359+2 is best fitted with a thermal-bremsstrahlung spectrum of the form

$$f_\nu = (2.2 \pm 0.1) \times 10^{-9} \exp \{-[(2.2 \pm 0.3)/E]^{8/3}\}$$
$$\times \exp [-E/(4.8 \pm 0.9)] \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}$$

with $\chi^2 = 8$ for 6 degrees of freedom. This source was present at about the same strength ± 20 percent on March 19, six days after it was first observed on 1971 March 13. We have examined data from March 3, March 8, April 9–12; on these days it was at least a factor of 10 weaker.

IV. DISCUSSION

a) *GX 359+2*

This source is variable by more than a factor of 10, in the energy range from 2.4 to 6.9 keV, on a time scale of five days or less. We do not yet know whether it varies on a time scale as short as one day or shorter. Within the two days it was observed to be strong, GX 359+2 showed no large changes in intensity (≥ 20 percent). It appears from our sample of observations that the source is weak most of the time, since we saw it on only two days out of eight days of observations spread over more than a month. A high-energy variable source, GX 1+4, has been reported by Lewin, Ricker, and McClintock (1971). However, this is probably not the same source as GX 359+2. The $\pm 1\ \sigma$ positions of these sources do not overlap, and the spectrum reported by Lewin *et al.* is a thermal-bremsstrahlung spectrum with $kT = 28$ keV as compared with 4.8 keV for GX 359+2. Clearly, further observations of this source are necessary.

b) *GCX*

It appears from our data that GCX has a location and size about the same as the extended complex of infrared and radio sources at the galactic center. In fact, an X-ray brightness distribution identical with that in the infrared (shown in Fig. 2) is consistent with our data. However, a complex of X-ray sources consisting of at least three discrete sources located about 1° apart near the two infrared peaks at $l = 359.^{\circ}5$ and $l = 0.^{\circ}5$ cannot yet be ruled out.

The low-energy cutoff of 2.7–2.8 keV observed for this source indicates considerably more absorption than for a typical source near the galactic center. The sources within 15° of $l = 0°$ reported by Gorenstein *et al.* (1967) have cutoff energies within about ± 10 percent of 2.2 keV. Also, GX 359+2, discussed in this paper, has a cutoff of 2.2 ± 0.1 keV. The 2.2-keV cutoffs observed for sources in the general direction of the galactic center imply a column density of 4.2×10^{22} H atoms cm^{-2} (Brown and Gould 1970), whereas a 2.75-keV cutoff for GCX corresponds to 6.3×10^{22} H atoms cm^{-2}, an increase of 50 percent in the amount of absorbing matter between us and the source GCX, compared with the sources clustering within a few degrees of the galactic center. The additional absorption observed for GCX could be due to additional interstellar matter near the nucleus of our Galaxy, or it could be due to absorption in the source.

Although a blackbody fit to the GCX spectrum gave the lowest χ^2, it is not to be accepted as the most likely source spectrum, if the source is located 10 kpc from us at the nucleus of our Galaxy, since much of the low-energy turnover in the pulse-height spectrum observed for GCX is due to interstellar absorption. In fact, the entire spectrum of GCX is rather unusual: The use of a simple blackbody fit is not appropriate for the reason cited above; the (power-law plus absorption) fit gives a very flat spectral index of -0.4; the (exponential plus absorption) fit gives $T = 190 \times 10^6$ ° K, a rather high temperature. The very poor fit to the data given by each of the three spectral shapes cannot be accounted for on the basis of statistics. Possibly the true emission is of a different spectral form altogether.

It is difficult to see how a truly diffuse X-ray source at the galactic center, which would have a size of about 300 pc, could be produced. One might expect that the X-ray distribution would follow the distribution of matter, which is expected to be much more compact than the size of the X-ray source, based upon our knowledge of the structure of galactic nuclei derived from studies of differential rotation. The fact that it is extended may indicate that several centers of activity have been ejected a few hundred parsecs from the galactic nucleus and are the sources of the X-ray emission.

On the basis of the present data, we cannot distinguish between the possibility that GCX is a collection of at least three discrete sources and the possibility that it is an extended region of X-ray emission, perhaps very similar to the infrared and radio regions. Studies with higher angular resolution are necessary to resolve this question.

We wish to thank Miss Christine A. Jones of Radcliffe College for some early work on the GCX source, which was very stimulating to us and which is reported in her thesis (Jones 1971). We would also like to thank Dr. C. Leong and Dr. J. Bishop of AS&E for assistance in the data analysis.

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