N 69-35466

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†Supported in part by the National Aeronautics and Space Administration under contract NGR 22-009-015, in part by the U.S. Atomic Energy Commission under contract At(30-1)2098, and in part by a grant from the Sloan Fund of M.I.T.

Abstract

The positions and spectra of four high energy x-ray sources near the galactic center ($-30° < \ell^{II} < 20°$) are derived from balloon observations made in October 1967 in the energy range above 20 keV.

We made x-ray observations in an eight-hour balloon flight launched from Mildura, Australia on October 15, 1967 in which we surveyed the x-ray emission above 20 keV from the region of the sky from declinations -70° to -5° and from right ascensions 150° to 280° (angular resolution 13° FWHM). In a previous publication[1] we noted that the data showed several sources in a region near the galactic center. We have now completed a more detailed analysis of the data from this region and find that we can account for the bulk of the hard x-rays we observed in terms of four sources whose positions and spectra we report here.

We adopt as our solution to the problem of deconvolving the source distribution and the detector response function the smallest set of hypothetical discrete sources that account for most of the x-ray counts in excess of the background, and predict the observed data with maximum likelihood.

Tests on simulated data showed that the method recovers the assumed source positions to an accuracy of ≈2° (RMS) and their intensities to an accuracy of ≈20% (RMS) provided no two sources are separated by less than five degrees if their intensities are equal, and by less than eight degrees if their intensities differ by a factor of four. Since rocket surveys have shown the presence of ten or more discrete sources along the galactic equator in the galactic

longitude range $-20° < \ell^{II} < +20°$, it is probable that the positions and intensities of some of the hypothetical sources we find correspond to the mean positions and composite intensities of unresolved sources.

We analyzed the data from our energy channels 1 and 2 (20-30 keV, 30-40 keV) separately with the results summarized in Table I. We observe that the positions for sources M1, M2 and M3 derived separately for the two statistically independent channels agree with one another. However, when a fourth source was added to the analysis of the channel 2 data the solution did not converge satisfactorily so that the analysis of channel 2 data was stopped there.

Figure 1 is a map in galactic coordinates showing the source positions together with the positions we previously reported for Cen XR-2 and a source in Norma[1,2]. Around each of our positions is an error circle with 3 degree radius representing our estimate of the 1σ position uncertainty resulting from a combination of the statistical fluctuations as indicated in the tests on simulated data, and possible systematic errors arising from inaccuracies in calibration and alignment of the apparatus. Also shown are some of the data reported by various groups from rocket surveys using narrow slat collimators[3,4,5].

To find the spectra of the four sources we fixed their locations at the positions derived from the 20-30 keV data, and then found the maximum likelihood values of their intensities.

in each of the energy channels. The results, adjusted for the detector response and corrected to the top of the atmosphere, are shown in Figure 2. The corrections have been made as outlined in detail in an earlier paper[6].

A possible cause of systematic error in the spectra (and the number of pulses unaccounted for) would be a variation in the background rate as the instrument rotates in azimuth. A careful examination of the data shows that this effect, if it exists at all, would not change the values quoted by more than 6% in the case of source M1, and 12% in the cases of sources M2, M3 and M4.

M2 lies close to the strong source designated Ara XR-1 in the low resolution (8° FWHM) NRL 1965 rocket survey[7] and the "hard" source labeled #3 in the higher resolution (~2° FWHM) Lockheed survey[5]. The intensity in the 1-10 keV range[5], and our data at higher energies are fitted by an exponential law of the form exp(-E/kT) with kT=16±4 keV, as shown in Figure 2.

The situation around the sources M1, M3 and M4 is evidently more complicated. The position we find for the brightest and hardest of these three sources, namely M1, lies in a region in which no source was apparently detected in the rocket survey by Bradt et al.[4]. Moreover, we are unable to reconcile the position with that of GX3+1 and therefore disagree with the conclusion by Buselli et al.[8] that the dominant contribution to the hard x-ray emission near the galactic center is made by GX3+1. At the same time the galactic

longitude of M1 coincides with that of GX-2.5[3] and with that of source #13 in the survey of Fisher et al.[5]. The latter was characterized as having a "hard" spectrum, and this fact supports its identification with M1. Clearly new measurements are necessary to solve the apparent discrepancies. The shape of the energy spectrum for M1 can be characterized by an exponential law of the form exp(-E/kT) with $kT=19^{+6}_{-3}$ keV, or equally well by a power law of the form $E^{-\alpha}$ with values for the energy spectrum index α of 2±0.5 (see figure 2). The spectral results for M1 with respect to both intensity and shape are in agreement with those reported by Buselli et al.[8] for GX3+1 and by Haymes et al.[10] We therefore believe that the high energy x-rays as detected by them are primarily due to the source that we identify as M1. Values for α reported by them are 1.0±0.2 and 1.2±0.4. The low value of 1.0±0.2 as reported by Buselli et al. was derived from combining their balloon results with earlier rocket results[3,4] on GX3+1. If only the balloon results are taken into account, we derive a value for α from Buselli's data of ~1.5±0.3 which is consistent with our result on M1.

The remaining two hypothetical sources M3 and M4 probably each represent a composite of several weak sources. The spectrum of M3 can be characterized by kT=9±4 keV and that of M4 by kT=12±7 keV. We note that the spectral data and source position for M4 are consistent with those reported by Buselli et al.[8] for the source they identify as GX354-5.

We thank the Australian Ministry of Supply, E. Curwood, D. Scott and the staff of the Balloon Launching Station at Mildura for their assistance in carrying out the flight operation.

Table I: Summary of results from the maximum likelihood analysis of the balloon survey data from 20 to 40 keV. The values listed under α (right ascension), δ (declination), ℓ (galactic longitude), b (galactic latitude), and I (the counting rate per 358 cm^2 corrected to the top of the atmosphere) are the maximum likelihood values for the complete set of hypothetical sources.

Source Designation	Possible Other Designations	α (deg's)	δ (deg's)	ℓ^{II} (deg's)	b^{II} (deg's)	I (cts/sec)	α (deg's)	δ (deg's)	ℓ^{II} (deg's)	b^{II} (deg's)	I (cts/sec/ 358 cm^2)
M1	GX-2.5[3] 13[5]	261.6	-29.3	357.5	+2.5	21.8	261.6	-31.0	356.4	+1.8	9.0
M2	2,3[5] Ara XR-1[7]	251.6	-47.0	338.9	-1.6	17.8	254.4	-45.8	341.1	-2.4	7.0
M3	GX5-1[4] GX9+1[4]	266.2	-21.4	6.5	+3.4	15.5	266.1	-20.8	7.1	+3.7	3.8
M4	GX-5.6[3] GX-10.9[3] 6[5] Sco XR-6[7] Sco XR-2[7] GX354-5[8]	264.2	-38.4	351.3	-4.0	11.5					

Figure Captions

Figure 1. Galactic map of x-ray source locations near the galactic center region. The small open circles are the positions of the sources located by Bradt et al. as the intersections of two sets of position lines derived from a rocket survey in July 1967, and another set of position lines obtained in a survey by Gursky et al. The rectangular boxes indicate the positions of hard x-ray sources observed by Buselli et al. in February 1968. The rectangular error box around GX3+1 is our estimate of their uncertainty, this error is not quoted by them. The field of view of our own observations and that of typical rocket observations are shown in the figure.

Figure 2. Spectra of four sources which account for the hard x-rays observed by us from the galactic center region. Rocket data in the 1-10 keV range are shown for M2 only under the assumption that this source is the same as source #3 observed by Fisher et al. For convenience only we have indicated lines representing energy spectra with values for kT of 16 keV, 19 keV, and $\alpha=2$.

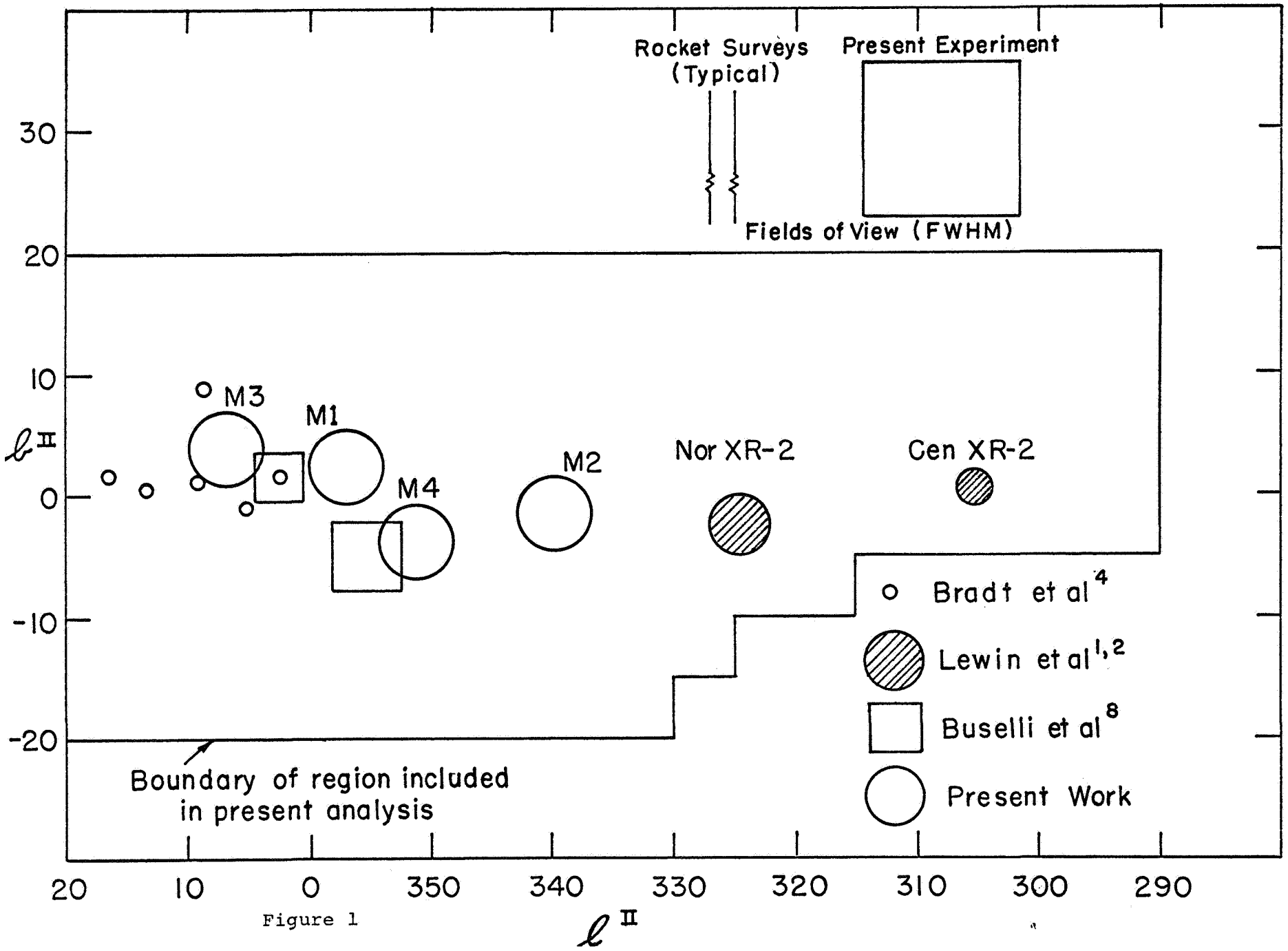
Rocket Surveys
(Typical)
Present Experiment
Fields of View (FWHM)
M3
M1
M4
M2
Nor XR-2
Cen XR-2
Bradt et al 4
Lewin et al 1,2
Buselli et al 8
Present Work
Boundary of region included
in present analysis
30
20
10
0
-10
-20
b^{II}
20
10
0
350
340
330
320
310
300
290
ℓ^{II}

Figure 1

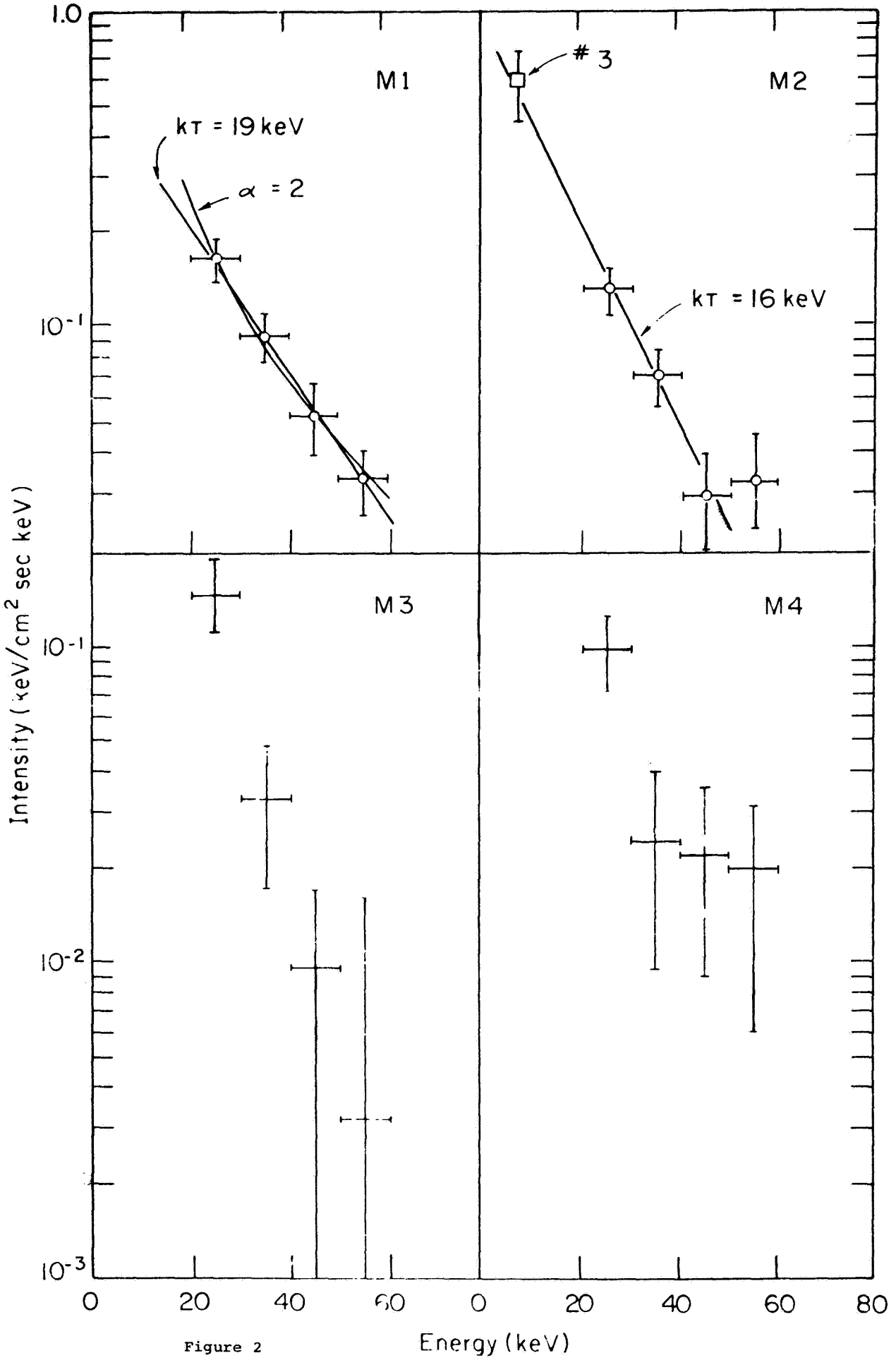
M1
M2
M3
M4
kT = 19 keV
α = 2
# 3
kT = 16 keV
1.0
10⁻¹
10⁻²
10⁻³
Intensity (keV/cm² sec keV)
0
20
40
60
80
Energy (keV)

Figure 2

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