



Universiteit
Leiden
The Netherlands

The distribution of X-ray sources in the Milky Way

Meurs, E.J.A.

Citation

Meurs, E. J. A. (1978). The distribution of X-ray sources in the Milky Way. *Astronomy And Astrophysics*, 62, L5-L8. Retrieved from <https://hdl.handle.net/1887/7383>

Version: Not Applicable (or Unknown)

License: [Leiden University Non-exclusive license](#)

Downloaded from: <https://hdl.handle.net/1887/7383>

Note: To cite this publication please use the final published version (if applicable).

Letter to the Editor

The Distribution of X-ray Sources in the Milky Way

E.J.A. Meurs

Sterrenkundig Instituut, Universiteit van Amsterdam and Sterrewacht, Huygens Laboratorium, Wassenaarseweg 78, NL-2405 Leiden, the Netherlands

Received September 29, 1977

Summary. The fourth Uhuru catalogue is analysed for the spatial and intensity distributions of the galactic X-ray sources. It appears that (1) there is no convincing evidence for an excess of bright sources around the galactic centre, (2) the observations of the weak sources are heavily confused, (3) almost all sources may have a population I origin.

Key words: X-ray sources - Stellar populations

Introduction.

A picture of the sky in galactic coordinates with the observed Uhuru sources (Forman et al., 1977) shows clearly a concentration of the X-ray sources in latitude towards the galactic plane, as well as a less pronounced concentration in longitude towards the galactic centre. The concentration in latitude of (galactic) sources is that obvious because of the location of the sun in the galactic plane.

The distribution of the galactic X-ray sources has been investigated by several authors (Johnson, 1966, 1975; Ryter, 1970; Setti and Woltjer, 1970; Salpeter, 1973; Gursky, 1973; Gursky and Schreier, 1975). Their conclusion was that two kinds of galactic X-ray sources might exist: a small number of bright sources in the central part of the galaxy and a larger number of weaker sources in the outer regions. The existence of apparently brighter sources at longitudes between -30° and $+30^\circ$ led to the supposition of a special class of sources (Johnson, 1966) and also to the suggestion of an intermediate population II origin for them (Salpeter, 1973). Dilworth et al. (1973) used this distinction to construct X-ray luminosity functions for inner and outer parts of the Milky Way.

However, this interpretation of the distribution of the galactic X-ray sources, although rather established by now, is not quite obvious as will be argued in the paragraphs 1 - 4. In particular, the evidence from the concentration in longitude of the sources (used to infer a possible intermediate population II origin for them) is not very strong due to our excentric position in the galaxy, and in paragraph 2 it will be shown that also a population I origin can produce the observed distribution. We will start from three assumptions: (a) the brighter galactic X-ray sources are essentially all known (Setti and

Woltjer, 1970; Ryter, 1970), (b) X-ray sources with $|b| < 20^\circ$ are mainly galactic and sources with $|b| \geq 20^\circ$ mainly extragalactic (Matilsky et al., 1973), (c) to infer populational consequences from the observed distribution of the galactic X-ray sources, the globular clusters and supernova remnants identified with X-ray sources have to be considered as separate classes of objects. We used for this analysis the fourth Uhuru catalogue (Forman et al., 1977).

1. Are the "galactic centre sources" related to globular clusters?

To explain the presence of the bright central sources one might consider globular clusters. The required luminosity for the bright central sources, of the order of 10^{38} erg s⁻¹ (see e.g. Giacconi, 1974), is not met by the observed globular clusters as can be concluded from table 1. This table lists the observed X-ray intensities as given in the 4th Uhuru catalogue (Forman et al., 1977), with maximum intensities for variable sources. Even then, the X-ray luminosities of the brightest clusters NGC 6624 and NGC 6440 are of the order of a few times 10^{37} erg s⁻¹, but are a bursting and a transient source respectively. Thus it seems likely that globular clusters cannot account for the bright central sources.

Table 1. Max. 4U-intensities for globular clusters

NGCnr	4Unr	4U-int ₁ (Uct s ⁻¹)	dist. (kpc)	ref.	X-ray luminosity (erg s ⁻¹)
1851	0513-40	18	9.5	1	3.3×10^{36}
6440	1757-17	150	10:	2,3	3×10^{37}
6441	1746-37	40	9.3	2,4	7.0×10^{36}
6624	1820-30	320	8:	3,5,6	4×10^{37}
6712	1850-08	9	6.8	1	8.5×10^{35}
7078	2129+12	4.5	10.0	1	9.2×10^{35}

References refer to distances; a colon(:) indicates an uncertain distance. Distances have been taken from ref. 1 preferentially; otherwise a mean of more than one ref. is given. Ref.'s code: 1 Peterson and King, 1975; 2 Bahcall and Hausman, 1976; 3 Woltjer, 1975; 4 Illingworth and Illingworth, 1976; 5 Liller, 1976; 6 Liller (1977), comm. by W. Lewin.

2. The distribution in longitude.

To consider the observed longitude distribution, the sources listed in the 4th Uhuru catalogue with $|b| < 20^\circ$ are counted in intervals of 20° in

galactic longitude, excluding the sources identified with SNR's and globular clusters. These counts are presented in figure 1 (upper curve) together with the longitude distribution calculated for a galactic plane uniformly populated with X-ray sources (i.e.: a population I origin). In this figure the ℓ -intervals 0° - 180° and 360° - 180° are superimposed. To compare the observed and calculated distributions properly, one has to add a constant level of extragalactic sources to the calculated distribution. From the number of X-ray sources in the catalogue which have $|b| \geq 20^\circ$ and are not identified with galactic objects one expects about 4 extragalactic sources to be present in each 20° interval in galactic longitude. The calculated distribution applies then to the remaining 103 sources.

From figure 1 it is clear that the observed distribution, allowing for a constant level of extragalactic sources, is even flatter than a population I distribution. If one takes a disc with a central hole of 3 kpc radius, as might be suggested from observations of the neutral hydrogen distribution in galaxies, this will only slightly affect the first point of the calculated distribution. Incomplete scanning of the sky might have a small effect, mainly in the $\ell=20^\circ$ - 40° interval. On the other hand, the regions in the $\ell=60^\circ$ - 80° and $\ell=260^\circ$ - 280° intervals have been more thoroughly scanned, which probably causes the enhancement in fig.1 at these intervals. As will be argued in §3b, the flatness of the observed curve is likely to be due to source confusion: a number of weaker sources is not seen in the central region of the Milky Way where many strong sources are concentrated. For sources with $I > 10 \text{ Uct s}^{-1}$ little confusion is expected, nor problems with extragalactic sources, and it is reasonable to assume these sources to be spread over the whole galactic disc (see §4a below). The comparison between the observed and calculated longitude distribution for these sources is also shown in fig.1 (lower curve), and makes clear that the observed longitude distribution for the brighter galactic X-ray sources is consistent with a population I distribution. Only the third column of the histogram seems to be too low, but this may be due to the fact that the corresponding longitude intervals ($\ell=40^\circ$ - 60° and $\ell=320^\circ$ - 300°) are situated just aside spiral arm regions where a smaller number of sources might be expected. As to the anticentre region ($\ell=100^\circ$ - 260°), one has to take into account that we are dealing with small number statistics, making comparisons difficult. For this region 2.8 sources are expected in total, to be compared with 4 (+2) sources observed. In conclusion, it seems clear that no dramatic excess of bright sources around the galactic centre exists.

3. The distribution in longitude and in intensity

To analyse the global properties of the galactic X-ray sources in further detail, the observed sources are counted in intervals of galactic longitude of 20° as well as in (nearly) logarithmic intervals of intensity: $3 \times 10^{i-1}$ to 10^i Uct s^{-1} and 10^i to $3 \times 10^i \text{ Uct s}^{-1}$ with $i=1$ to 3 (the interval of $1-3 \text{ Uct s}^{-1}$ will be not reliable because of varying depth of sky scanning and the above mentioned source confusion). These counts

are presented in figure 2. In this figure the sources are plotted at their mean 4U intensities, excluding transient sources, and also deleting bursters except in cases that an associated steady source is known (Lewin, 1976).

Also given are computed longitude distributions for each intensity interval. These calculations were done for a galactic disc with a radius of 13 kpc and a distance to the galactic centre of 10 kpc as in §2, using a luminosity function intermediate between the ones derived by Dilworth et al. (1973) for inner and outer regions of the galaxy: $dN/dL \propto L^{-1.2}$ (L is the X-ray luminosity of the sources), with L ranging from 10^{35} to $10^{38} \text{ erg s}^{-1}$.

a) The brighter sources ($I > 10 \text{ Uct s}^{-1}$).

The longitude distribution per intensity interval for these sources is depicted in figure 2^{b-e}. The observed distributions do not differ too much from the computed ones, given the fact that the true luminosity function of the galactic X-ray sources is not known, and taken into account the defect of sources in the third column of the histograms as discussed above. The 300 - 1000 Uct s^{-1} interval is the only one with a rather distinct excess of observed sources. This excess of about 4 sources might indicate a small (intermediate) population II contribution to the most likely overall population I distribution of the sources, rather than a non-population I distribution. But, with the results of §2 in mind, one must also think of possibilities like a population I distribution with two luminosity functions involved.

A population I origin for these sources is also indicated by their total number. For $I > 10 \text{ Uct s}^{-1}$ mainly the intrinsically bright sources are seen, because the effective area in the galaxy from which low luminosity sources can contribute to these intensities has become very small. Of course there are exceptions, like X Per with $L = 4 \times 10^{33} \text{ erg s}^{-1}$ and indicated by an X in fig.2^b. The intrinsically bright sources then, correspond in general to massive X-ray binaries of which 3 are seen within 3 kpc from the sun, and thus about 56 are expected in the galaxy (cf. Van den Heuvel, 1973, 1974, 1976), to be compared with 61 sources brighter than 10 Uct s^{-1} . Also, from the theory of close binary systems numbers of this order of magnitude are predicted (Van den Heuvel, 1976; Meurs et al., 1978).

b) The weaker sources ($3 < I < 10 \text{ Uct s}^{-1}$).

The longitude distribution for this intensity interval is given in figure 2^a. In each longitude interval, 4 sources were added to the theoretically predicted numbers in each column of the histogram, as can be inferred from the intensity distribution of non-galactic sources with $|b| \geq 20^\circ$ which have with a few exceptions intensities in the $1-3$ or $3-10 \text{ Uct s}^{-1}$ intervals. With possible source confusion in the central parts of the Milky Way taken into consideration, there seems to be an excess of these weaker sources in the outer parts of the galaxy. It can be argued, however, that for example uncertainties in the luminosity function have their effects especially in the lower intensity intervals: the precise dependence of dN/dL on L is not known, and dN/dL was used with a lower limit of $10^{35} \text{ erg s}^{-1}$ whilst

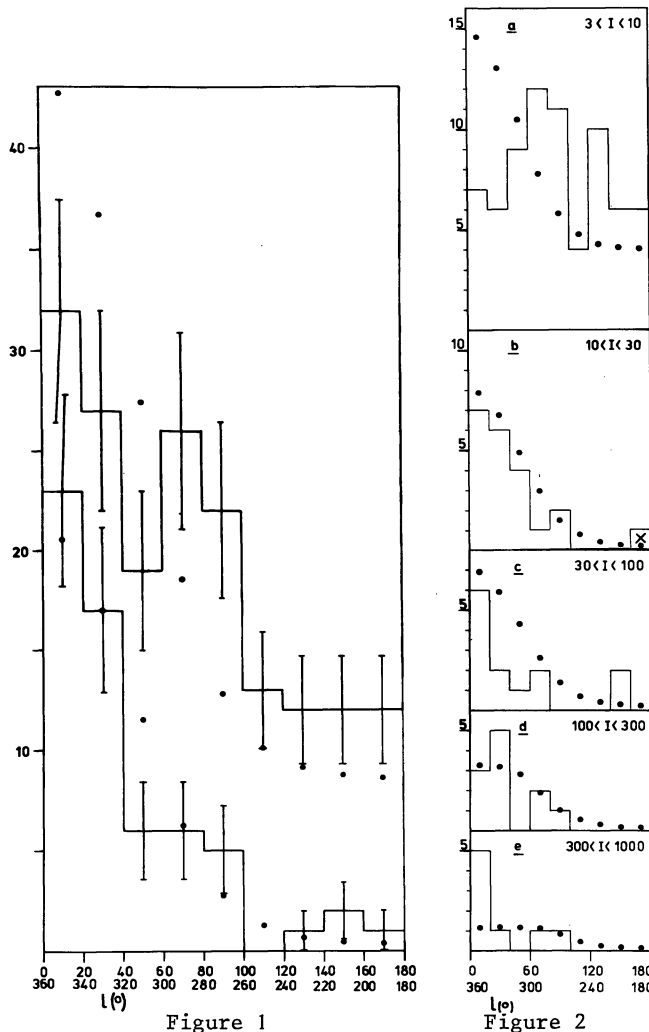


Figure 1

Figure 2

Figure 1. Counts of 4U sources with $|b| < 20^\circ$ in intervals of 20° in galactic longitude (solid line) compared with a calculated distribution expected for a population I distribution of sources (dots). Statistical errors in the counts are given with errorbars. Sources identified with SNR's and globular clusters have been deleted. Upper curve: all sources; a constant level of 4 extragalactic sources per 20° interval in l has been assumed. Lower curve: sources with $I > 10$ Uct s^{-1} . The calculated distributions apply to resp. 103 and 61 sources. The galaxy was assumed to have a radius of 13 kpc and the distance from the sun to the galactic centre was taken as 10 kpc.

Figure 2. Counts of 4U sources with $|b| < 20^\circ$ in intervals of 20° in galactic longitude and in (nearly) logarithmic intensity intervals (solid lines), compared with theoretically expected distributions (dots). The latter curves have been calculated for sources with a population I distribution and with a luminosity function $dN/dL \propto L^{-1.2}$.

certainly sources with lower luminosities do exist, like X Per mentioned above, and their numbers and densities are not known at all.

As to the plausibility of source confusion in the central region of the Milky Way, discussions of this phenomenon indicate that one has to observe

one source in a large number of beamwidths to be free of source confusion (Von Hoerner, 1961; see also De Jong, 1976). In the region $-60^\circ < l < +60^\circ$ one can estimate this ratio for the weak sources in a rather conservative way: in this region of about 2400 square degrees are about 30 beams (taking the 5° FWHM Uhuru collimator because confusion for weak sources is considered) for 62 sources with $I > 3$ Uct s^{-1} , thus only about half a beam is available for each source which means source confusion is very important. The 23 sources with $I > 30$ Uct s^{-1} can be considered as free from confusion: ca. 3000 beams (using the $\frac{1}{2}$ FWHM collimator for these bright sources) for 23 sources result in about one source in 130 beams. Assuming these bright sources to be mainly responsible for the confusion of the $3-10$ Uct s^{-1} sources, one is now able to make a rough estimate of the number of weak sources missed with the formula $N = C \cdot A \cdot B$ (analogous to Bahcall, 1973), where N is the number of sources missed, C the number of bright confusing sources, A the area effectively blocked by a bright source and B the number of weak sources per unit area. The computations in figure 2^a indicate a total of about 38 sources if no confusion were present, thus $B \approx 1/60$ per square degree; there are $C = 23$ bright sources; for weak sources to be missed $A = \pi \cdot 2.5$ square degrees; so N is about 30. This is to be compared with the difference of at least (because of the uncertainties involved with sources of very low luminosity) 16 sources between the calculated and observed distributions in figure 2^a. Hence, the expected and observed differences agree rather well with one another.

To have a check on this, one can have a look at the 4U sources that were found after the 3U catalogue was compiled. From the above argued importance of source confusion, one expects the newly found sources around the galactic centre to have a higher mean intensity than the other sources along the Milky Way, because source confusion is still present in the new catalogue. These mean intensities in the $3-10$ Uct s^{-1} interval are given in table 2, with the number of sources at issue in parentheses; the difference between galactic and extragalactic sources is not relevant to this point. Inspection of table 2 shows that indeed the sources found in the galactic centre region have a higher average intensity.

Finally, it should be noted that the source confusion is not contradictory to the absence of a strong galactic ridge (Setti and Woltjer, 1970; Ryter, 1970; see also Giacconi, 1974). The source confusion is mainly important in the central region of the Milky Way where due to the same confusion probably a weak ridge cannot be observed properly, and we are dealing with a small number of weak sources.

Table 2. Mean intensities of newly found 4U sources in the $3-10$ Uct s^{-1} interval

b	l	central region	outer regions
		$300^\circ < l < 60^\circ$	$60^\circ < l < 300^\circ$
$5^\circ < b < 20^\circ$	$ b < 5^\circ$	3.50 (7)	3.69 (14)
	$ b < 5^\circ$	5.88 (11)	3.87 (18)
total $ b < 20^\circ$		4.95 (18)	3.79 (32)

4. Further population I arguments.

A few more arguments that indicate a probable population I origin for the galactic X-ray sources are mentioned briefly:

- (i) some sources (like Her X-1 and Sco X-1) have a rather high galactic latitude, but even these systems seem to have a population I origin and their heights above the galactic plane are explained by runaway velocities received at the explosion as a supernova of the now compact companion (Sutantyo, 1975; Van den Heuvel, 1976);
- (ii) a comparison between moderately strong and very strong variable sources (that is, 85% of the sources brighter than 10 Uct s^{-1} and all the sources brighter than 100 Uct s^{-1}) shows that the very strong sources, sometimes considered as a special population of X-ray sources, have the same fraction of sources with observed periodicities as have the less strong ones, see table 3 (the figures in parentheses give the number of identified sources, all are identified with stars);
- (iii) the observational data are consistent with all X-ray sources being in binary systems like the eclipsing sources, i.e. the usual model for the population I X-ray sources (Gursky and Schreier, 1975).

Table 3. Variable 4U sources with periodicities

	intensity (in Uct s^{-1})	
	$10 < I < 100$	$100 < I$
without periodicities	21 (1)	20 (2)
with periodicities	6 (3)	6 (4)

Conclusions.

From the lines of evidence given above it seems very likely that practically all sources may have a population I origin. This does not mean however, that the construction of a luminosity function for the galactic X-ray sources has become much easier. One must properly deal with, for example: the source confusion for the weaker sources, the contribution of extragalactic sources (probably decreasing towards the galactic centre in the 4U catalogue), the intrinsically very weak sources like X Per, the runaway systems, and the position in this picture of transient and bursting sources, and of variable sources in general. Also, the correctness of the extension of the above used luminosity function beyond $10^{36} \text{ erg s}^{-1}$ to $10^{35} \text{ erg s}^{-1}$ is not evident. It is possible that there are two luminosity functions, producing intrinsically bright and weak sources, but this has been advocated so far with unconvincing arguments. And of course, a small population II contribution cannot be ruled out. It is expected that the HEAO-A observations will clarify the present situation considerably.

Acknowledgements.

The author is indebted to Professor E.P.J. van den Heuvel for suggesting this investigation and for discussions and critical reading of the manuscript. Thanks are due to Mr H.R. de Ruiter for a clarifying discussion, to Dr J. van Paradijs for discussions at an early stage of this work and to Professor H. van der Laan for his encouragement to finish it. Financial support from the Dutch Organization for the Advancement of Pure Research (ZWO) was received during the later part of the work.

References.

- Bahcall, J.N., 1973, in: The redshift controversy, eds G.B. Field, H. Arp, J.N. Bahcall (W.A. Benjamin, Reading Mass.), p. 89
- Bahcall, N.A., Hausman, M.A., 1976, Ap. J. (Letters) 207, L181
- Dilworth, C., Maraschi, L., Reina, C., 1973, Astr. Ap. 28, 71
- Forman, W., Jones, C., Cominsky, L., Julien, P., Murray, S., Peters, G., Tananbaum, H., Giacconi, R., 1977, submitted to Ap. J. Suppl. Series
- Giacconi, R., 1974, in: X-ray astronomy, eds R. Giacconi and H. Gursky (Reidel, Dordrecht), Ch. 4
- Gursky, H., 1973, in: Black holes, eds C. DeWitt and B.S. DeWitt (Gordon and Breach, New York), p. 291
- Gursky, H., Schreier, E., 1975, in: Neutron stars, black holes and binary X-ray sources, eds H. Gursky and R. Ruffini (Reidel, Dordrecht), p. 175
- Heuvel, E.P.J. van den, 1973, Lecture notes Cambridge summerschool on Physics and astrophysics of compact stars, Ch. III
- Heuvel, E.P.J. van den, 1974, in: Astrophysics and gravitation, Proc. 16th Solvay Conf. (Univ. of Brussels Press), p. 119
- Heuvel, E.P.J. van den, 1976, in: IAU-Symp. no. 73, eds P. Eggleton, S. Mitton, J. Whelan (Reidel, Dordrecht), p. 35
- Hoerner, S. von, 1961, Publ. NRAO 1, 19
- Illingworth, G., Illingworth, W., 1976, Ap. J. Suppl. 30, 227
- Johnson, H.M., 1966, Ap. J. 143, 261
- Johnson, H.M., 1975, Ap. J. 202, 490
- Jong, T. de, 1976, technical note IRAS, Amsterdam
- Lewin, W.H.G., 1976, 8th Texas Symp. (Boston Mass.)
- Liller, W., 1976, Ap. J. (Letters) 207, L109
- Matilsky, T., Gursky, H., Kellogg, E., Tananbaum, H., Murray, S., Giacconi, R., 1973, Ap. J. 181, 753
- Meurs, E.J.A., Heuvel, E.P.J. van den, Reusens, R., 1978, in preparation
- Peterson, C.J., King, I.R., 1975, A. J. 80, 427
- Ryter, C., 1970, Astr. Ap. 9, 228
- Salpeter, E.E., 1973, in: IAU-Symp. no. 55, eds H. Brandt and R. Giacconi (Reidel, Dordrecht), p. 135
- Setti, G., Woltjer, L., 1970, Astr. Space Sci. 9, 185
- Sutantyo, W., 1975, Astr. Ap. 41, 47
- Woltjer, L., 1975, Astr. Ap. 42, 109