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Statistics of low and high galactic latitude ROSAT sources based on archival photographic plates

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1. Introduction

We present preliminary results on classification, total numbers, and population characteristics of selected ROSAT X-ray point sources and their optical counterparts based on hundreds of archival plates of a low- (γ Sge, $bII = -5°$, in the following abbreviated "Sge") and a high- (26 Com, $bII = +83°$, in the following abbreviated "Com") galactic latitude field, respectively. Each field encompasses 10° by 10°, and the plates reach a magnitude limit of $B \approx 18^{m}$.

During the ROSAT all-sky-survey in 1990 with the PSPC, sensitive in the energy range 0.1–2.4 keV (Trümper 1983) these sky fields were scanned. By means of a maximum likelihood detection algorithm based on standard EXSAS programmes (Zimmermann et al. 1994), 238 (Com) and 132 (Sge) X-ray point sources were detected within the above fields with a likelihood of existence larger than 10. The ROSAT source positions are accurate to typically less than $30''$.

2. Optical identifications of the ROSAT sources

For optical identifications we used two entirely different methods: (i) Statistical test, and (ii) Variability tests and spectroscopic observations of individual objects.

2.1 Search for optical counterparts with a purely statistical method

This method is applicable only to special groups of objects. For individual objects one can estimate only the reliability of an identification.

The method is practically the same as given by Richter (1975): Objects of similar properties (e.g., of a certain brightness interval), in first approximation assumed to be randomly distributed, will in reality show a surplus within the error boxes of X-ray sources if there are any real optical identifications. We proceed as follows: We draw concentric circles around each X-ray position, with radii $r_1, r_2, ...r_n$ such that the area of each resulting ring is equal to the area of the inner circle. Suitably, r_1 should be of the order of the rms error (about $30''$) of the ROSAT positions. In our case we have (arbitrarily) chosen $r_1 = 22\farcs4$.

If there are no optical counterparts at all, the area density of the objects in such a group is $D = \frac{n_i}{N_R \pi {r_1}^2}$ where N_R is the number of ROSAT sources and n_i the number of all objects in the rings with index i.

If there are real optical counterparts, they will accumulate in the annuli with small indices i, and their number can easily be read off, as can be seen in Fig. 1a+b. Of course, this is true only statistically, and about the individual identifications only reliabilities can be estimated (Richter 1975), which will soon be published in A&A.

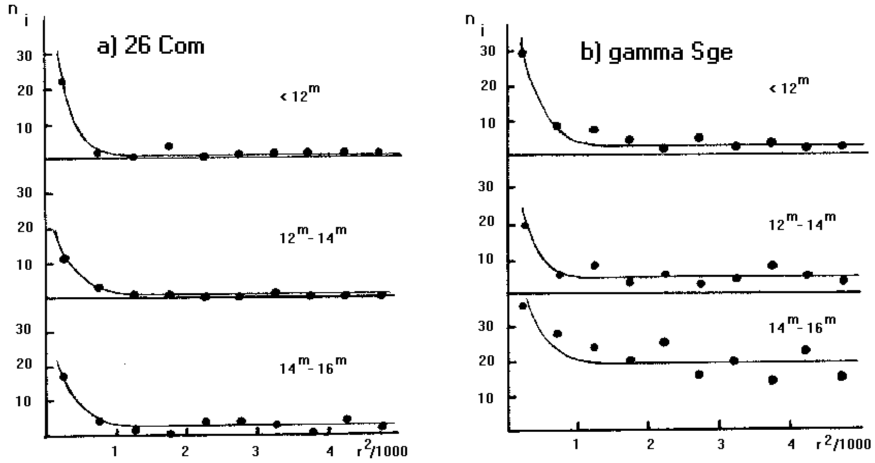

Fig. 1 Total numbers of optical objects of different magnitude intervals in rings of equal area densities around ROSAT sources for the Com (left) and Sge (right) fields.

We divided our sample of objects into 4 groups according to apparent magnitude: brighter than $12^{\rm m}, 12^{\rm m} - 14^{\rm m}, 14^{\rm m} - 16^{\rm m}$, and $16^{\rm m} - 18^{\rm m}$. Fig. 1a shows the total numbers n_i of objects in the rings with the indices i in Com (Abscissa: Square of the outer radii of the annuli;

Ordinate: n_i). The concentration of objects towards small radii r_i is obvious. It reflects the existence of real optical identifications. The expected number N_R of real identifications can easily be estimated: It is the number of surplus objects exceeding the noise level K. But there will of course be some misidentifications. The higher the noise level, the larger the number of misidentifications and the lower the reliability of each identification (see Fig. 1a for the increase in background noise with fainter magnitude).

Things are more difficult in the low-latitude field Sge (Fig. 1b), where the stellar area density is generally larger by a factor of about 20. Especially in the brightness group $16^{\mathrm{m}}-18^{\mathrm{m}}$ an estimate of the number of real counterparts is hardly possible and the reliability approaches zero.

The bright ($\leq 12^{\mathrm{m}}$) probable counterparts in Com and Sge are mainly HD stars with late F, G or K type spectra, and the fainter ones ($12^{\mathrm{m}} - 14^{\mathrm{m}}$) may be of similar type because they are of the same colour. Surely most of them (probably $> 90\%$) are chromospherically active stars. It is known that only a few of them have photographically traceable light changes (too small amplitude).

Table 1 gives the calculated number N_R of optical counterparts of the ROSAT sources in comparison with the total number N_t of all objects of our magnitude groups (Com left, Sge right).

mag	$<12^{\mathrm{m}}$	12^{m}–14^{m}	14^{m}–16^{m}	16^{m}–18^{m}
	26 Comae			
N_t	2437	2437	9050	23300
N_R	21	12	16	46
	γ Sagittae			
N_t	18500	29500	126000	1090000
N_R	31	16	26	(22 ?)

Tab. 1 Total numbers N_t and numbers N_R of optically identified ROSAT sources for the high (left) and low (right) galactic latitude fields

Table 2 shows the magnitude domain in the first line; the concentration towards the low latitude field for all stars, in the second; and the concentration of the supposed counterparts towards low latitude, in the third. The low concentration of the counterparts towards Sge is remarkable, and will be discussed at the end of section 3.

mag	12^m	$12^{\rm m}-14^{\rm m}$	$14^{\rm m}-16^{\rm m}$	$16^{\rm m}-18^{\rm m}$
$\frac{N_{t,\rm Sge}}{N_{t,\rm Com}}$	7.59	12.11	13.92	(46.7)
$\frac{N_{R,\rm Sge}}{N_{R,\rm Com}}$	1.48	1.33	1.62	(0.48)

Tab. 2 Ratio of area densities in the two fields, for all N_t objects and for the optical counterparts N_R of ROSAT sources (calculated from Table 1)

2.2 Search for optical variability

We know from experience that most of the X-ray sources have optically variable counterparts. Therefore, if there is a variable object in the error circle of a ROSAT source, we may conclude that we are, with high probability, dealing with a real optical identification. From our search we have excluded (1) bright objects which are, as we have seen in section 3, mostly chromospherically active stars with small amplitudes, and (2) optically empty error boxes. Altogether, we checked about 180 objects, each on several hundred plates, for variability. The results are given in Tab. 3.

3. Discussion

From Tab. 3 we can deduce the following:

- In Com, the number of identified AGN decreases beyond $18^{\rm m}$. Probably, the majority of real counterparts in the "empty" fields as well as some of the faint galaxies are still undiscovered AGN, which will fill the gap. Therefore, more than half of all ROSAT sources in Com may be of extragalactic origin.
- Many of the optically tested AGN proved to be variable.
- 6 of the 51 AGN were found to have steep soft X-ray spectra. All of them are optically variable (Greiner et al. 1996).
- Because of the large area density of faint extragalactic objects in Com the reliability of such an object to be a counterpart of an X-ray source is rather small.
- Sge is free of AGN and other galaxies ≡ zone of avoidance.

		26 Com	γ Sge
AGN	$< 16^{\mathrm{m}}$	5	0
	$16^{\mathrm{m}} - 17^{\mathrm{m}}$	6	0
	$17^{\mathrm{m}} - 18^{\mathrm{m}}$	22	0
	$18^{\mathrm{m}} - 19^{\mathrm{m}}$	11	0
	$> 19^{\mathrm{m}}$	7	0
	sum	48	0
empty fields ($< 17^{\mathrm{m}}$)		51	0
constant		13	33
bright stars, not tested for variability		31	33
probable chromosph. active stars		16	18
UV and UV?		5	2
CV and CV? (including exnovae)		6	13
LB and SRB		0	2
not classified		6	5
variable?		11	18
planetary nebula		0	1
SN remnant		0	1^*

Tab. 3 Number of probable counterparts of ROSAT sources (* 8 sources closely together).

- Objects classified "constant" are either spurious counterparts, or their light amplitudes are too small to be detected photographically, or they are real counterparts without brightness changes (e.g., hot white dwarfs, brown dwarfs; see Neuhäuser and Comeron 1998).
- "variable?" means that because of small amplitude, faintness or blend, the variability is not quite sure.
- In several cases the exact classification of a variable object is uncertain because photoelectric or spectroscopic measurements are still needed.
- Red semiregular and irregular variables are usually not X-ray sources. On the other hand, two such objects in Sge (HH Sge and δ Sge) have a very small distance to the ROSAT position. Possibly, they are members of X-ray radiating symbiotic binaries. This is still to be checked spectroscopically.
- CV: In spite of their low luminosity (at minimum; M = +5 ... +12 mag), their high concentration towards low galactic latitude

is obvious, indicating a young (disk) stellar population. This corresponds to the results of Richter (1968) who derived a density gradient perpendicular to the galactic plane as large as 3.9.

- Chromospherically active stars and UV Cet stars (= flare stars) are known to exist not only isolated, but also in T associations and star clusters, representing a very young stellar population. According to Gershberg and Shakhovskaya (1974) and Rodono (1980), flare stars and chromospherically active stars are related and both should therefore be young. Thus, the large number of these objects in this Coma field is not a feature of stellar population, but it reflects the fact that a large area of Com field is covered by the extended, young open cluster Mel 111. Based on a literature comparison (Randich et al. 1996, Odenkirchen et al. 1998, Abad et al. 1999), we found that many of our objects are indeed cluster members. (A more detailed analysis of individual objects will be given elsewhere.)

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