INTEGRAL/IBIS survey of the Sagittarius Arm Tangent region: A source catalog

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Analysis of 18-120 keV images of the Sagittarius Arm Tangent region (SATR) obtained by IBIS telescope onboard INTEGRAL observatory during the spring of 2003 is performed. In the 18-60 keV energy range, 28 sources have been detected with a flux level above 1.4 mCrab. Of these sources, 16 were identified earlier as galactic X-ray binary systems, 3 as extragalactic objects, 2 as pulsars inside supernova remnants, and 7 has unknown nature. The analysis revealed the presence of three previously unknown sources. Fourteen sources show significant flux in the 60-120 keV energy range.

Introduction

Sagittarius Arm is the next toward the Galactic center spiral arm of the Milky Way, ~ 2 kpc away from the Sun. Sagittarius arm is very rich in young massive stars and remnants of their evolution (high-mass X-ray binaries, microquasars, X-ray pulsars, supernova remnants etc.).

A set of very interesting X-ray sources, including the brightest microquasar GRS1915+105, the peculiar object SS433 and other black hole candidates (X1908+094, X1901+014), soft gamma-ray repeaters, supernova remnants, about dozen of persistent and transient X-ray bursters (e.g. 4U1915-05, Ser X-1, Aql X-1) and X-ray pulsars (1855-026, 1907+097, GS 1843+009, X1901+03) fall within SATR. Some of the sources in this field were discovered by INTEGRAL during the AO-1 observations.

Observations of this field and the Galactic Center regions during the INTEGRAL AO-1 demonstrated excellent capabilites of the INTEGRAL telescopes to construct sensitive maps, to perform good surveys and monitor transient sources in the field of view (Cherepashchuk et al. 2003, Molkov et al. 2003).

This paper is a part of work on hard X-ray cartography of our Galaxy and search for new point-like sources based on the IBIS data of the INTEGRAL observatory. First results on the deep Galactic Center survey are published elsewhere (Revnivtsev et al. 2004).

Observations and data analysis

The international gamma-ray observatory INTEGRAL was launched by the Russian launcher PROTON from the Baikonur cosmodrome in the high-apogee orbit on October 17, 2002 (Eismont et al. 2003). The payload includes four principal instruments which allow simultaneous observations of sources in the X-ray, gamma-ray and optical energy range (Winkler et al. 2003). The cartography and detection of point-like hard X-ray sources can be best performed with the top-layer detector ISGRI of the IBIS telescope (Lebrun et al. 2003). This telescope uses the coded aperture method and allows imaging of a given sky area within a field of view of 29° × 29° (the fully coded area is 9° × 9°) in the 15-200 keV range with an angular resolution of 12′.

The SAT field have regularly been observed by INTEGRAL during the first year of operation in the orbit. In the present work we used data obtained in the TOO observations of the Aql X-1 flare in March-April 2003 (Molkov et al. 2003) and SS433 in May 2003 (Cherepashchuk et al. 2003a). The total exposure in these observations amounts to ~ 830 ks. The dithering mode used during the observations (24 pointings 2 and 4 degrees off the central source) enables recovering the image of a substantial sky area 35° × 40° in this part of the Galaxy.

The data of all observations were processed using methods described in Revnivtsev et al. (2004) paper. Analysis of an extensive set of calibration observations of the Crab nebula with different location of this sources within the IBIS FOV suggests that with the approach and software employed the conservative estimation of uncertainty in measurements of the absolute fluxes from the sources is about 10%. The localization accuracy of bright
Crab-like sources is \( \sim 0.4' \) (1\( \sigma \)) decreases to \( \sim 2-3' \) for weak sources (with the signal-to-noise ratio \( \sim 5 - 6 \), see below).

The presence of a peak above some threshold was considered to be a signature of a point-like source. The statistical threshold was chosen after the entire image had been analyzed. The signal-to-noise ratio \( (S/N) \) that ensures registration of at most one false source in the full studied field was derived.

Fig. 1 shows the signal-to-noise ratio distribution for all sources found in the full image of the region in a logarithmic scale. For an ideal image with negligibly small systematical deviations this distribution in the region without sources should be described by the normal law with zero mathematical expectation and unit variance. In Fig. 1 such a distribution is shown by the solid curve in the logarithmic scale. Fig. 1 clearly indicates that the negative part of the actually obtained \( S/N \) distribution is well fitted by the theoretically expected one down to values of order \( S/N \sim -4 \). Note also that small deviations in the range \(-5 < S/N < -4\) are also seen, with the measured distribution showing a slightly larger number of points than theoretical one. So we can conclude that it would be incorrect to utilize purely theoretically calculated value of the source registration threshold \( \sim 4.2\sigma \). Therefore, the lower threshold of the confident source detection was chosen to be \( (> 5\sigma) \).

**Results**

Table 1 shows the list of all registered sources with their coordinates and fluxes in units of mCrab in two energy ranges. A flux of 1 mCrab in the 18-60 keV and 60-120 keV energy ranges from a source with power-law spectrum and photon index \( \Gamma = 2.1 \) corresponds to energy fluxes \( \sim 1.4 \times 10^{-11} \text{ erg/s/cm}^2 \) and \( \sim 7.1 \times 10^{-12} \text{ erg/s/cm}^2 \), respectively. The localization accuracy of the sources is \( \sim 2-3' \) (the 90\% radius of the confidence contour). The sources are listed in the order of decreasing detection confidence, which is dependent upon both their intensity and the effective observation time of each object.

The 18-60 keV image of the Sagittarius Arm Tangent region with a size of \( \sim 35' \times 25' \) is shown in Fig. 2, in galactic coordinates. The analysis performed allowed us to detect 28 sources in the 18-60 keV energy band, part of which (14) persists sufficiently bright to be detected in harder 60-120 keV energy range (Table 1). We repeat that sources are listed in the order of their detection confidence, which is determined not only by the intrinsic source flux level but also by the effective exposure time.

Some of the detected sources (21 of 28) are of the known nature and either belong to high-mass X-ray binaries (HMXB) or low mass X-ray binaries (LMXB). In Table 1, the classification of the registered sources is shown in the last column using the following notations: LMXB – low mass X-ray binaries with the optical companion mass \( \sim 1M_\odot \); HMXB – high mass X-ray binaries with the optical companion mass \( \geq 8M_\odot \); BH – black hole candidates; T – transient sources; P – X-ray pulsars, B – X-ray bursters, Z – Z-sources; G – sources in globular clusters; AXP – anomalous X-ray pulsars, SNR – supernova remnants; AGN – active galactic nuclei.

Four black hole candidates were confidently detected during observations, including the well-known microquasar GRS 1915+105 (Hannikainen et al. 2003), SS433 (Cherepashchuk et al. 2003), XTE J1908+094 and X 1908+075 (Wen et al. 2000).

In addition, a significant X-ray flux was detected from seven X-ray pulsars, including X 1901+03, 4U 1907+097, XTE J1855-026, GS 1843+009, A 1845-024, 1E 1841-045 (anomalous X-ray pulsar) and PSR J1846-0258. The first of them (X 1901+03) has been known earlier only as a transient high mass binary (Forman et al. 1976), which was in inactive state since 1971. In the beginning of 2003, the source became active again and coherent X-ray pulsations were found (Galloway et al. 2003a,b; Molkov et al. 2003).

Of seven detected low mass X-ray binaries with neutron stars six are X-ray bursters, with one of them residing in globular cluster NGC 6712.

During the observations, significant X-ray fluxes were also detected from three supernova remnants and two active galactic nuclei (NGC 6814 and SS 442/1H1934-063). The identification of the last source is ambiguous. The point is that the location of the source as derived from our analysis is different from more accurate location.
SS 442/1H1934-063 taken from catalog by about ∼ 5.6′. However, as the source is only marginally detected (∼ 5σ) and the 90% level of its localization contour is ∼ 3′, there is the ∼10% probability that its location differs from the real one by more 3′. Nonetheless, it can not be excluded that this is the new source IGR J19378-0617.

Two known X-ray sources discovered by RXTE (XTE J1901+014) and ASCA (AX J183800-0655) were reliably registered in our observations. As yet, their nature remains unclear.

Finally, seven new INTEGRAL sources fell within the IBIS telescope FOV. Of these sources, five are confidently detected in our observations: IGR J19140+098 (Hannikainen et al. 2003b), IGR J18483-031 (Chernyakova et al. 2003), IGR J18490-0000, IGR J18406-0539, IGR J18450-0435 (the last three were first discovered in the present work). The remaining two sources IGR J18325-0756 and IGR J18539+0727, discovered earlier by the INTEGRAL observatory (Lutovinov et al. 2003a,b), were not registered in our observations and we provide here only upper limits of their fluxes. Note that the IGR J18539+0727 is apparently a black hole candidate (Lutovinov and Revnivtsev 2003).

To conclude, of 28 sources detected during the INTEGRAL AO-1 Saggitarius Arm Tangent region observations, seven objects are of unknown nature, with five of which are first discovered by the INTEGRAL observatory.

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Table 1. List of sources, detected during observations of Sgr Arm tangent region in March-May 2003

| J2000 α (°) | δ (°) | Mean flux, mCrab \(^{a}\) | Identification | Class |
|-------------|-------|-----------------|----------------|-------|
|             |       | 18-60 keV       | 60-120 keV     |       |
| 1           | 288.80 | 10.95           | 252.6 ± 0.2    | 80.0 ± 0.7 | GRS 1915+105, LMXB, BH |
| 2           | 285.91 | 3.21            | 77.4 ± 0.2     | 3.2 ± 0.6 | X 1901+03 \(^{b}\), HMXB, TP |
| 3           | 287.96 | 4.99            | 14.0 ± 0.2     | 6.2 ± 0.6 | SS 433 \(^{c}\), HMXB, BH |
| 4           | 287.71 | 7.60            | 10.9 ± 0.2     | 6.8 ± 0.6 | X 1908+075, HMXB, BH? |
| 5           | 287.42 | 9.83            | 10.9 ± 0.2     | 0.8 ± 0.7 \(^{h}\) | 4U 1907+097, HMXB, TP |
| 6           | 283.87 | -2.60           | 8.8 ± 0.2      | 4.4 ± 0.7 | XTE J1855-026, HMXB, P |
| 7           | 279.99 | 5.03            | 7.5 ± 0.2      | 0.6 ± 0.7 \(^{h}\) | Ser X-1, LMXB, B |
| 8           | 288.53 | 9.87            | 6.5 ± 0.2      | 2.8 ± 0.7 | IGR J19140+098 \(^{?}\) |
| 9           | 281.40 | 0.86            | 6.3 ± 0.2      | 3.6 ± 0.7 | GS 1843+009 \(^{b}\), HMXB, TP |
| 10          | 287.79 | 0.56            | 4.1 ± 0.2      | 1.3 ± 0.6 \(^{h}\) | Aql X-1 \(^{b}\), LMXB, TBA |
| 11          | 289.69 | -5.24           | 5.2 ± 0.2      | 1.4 ± 0.8 \(^{h}\) | 4U 1916-053, LMXB, BD |
| 12          | 285.41 | 1.45            | 3.6 ± 0.2      | 3.9 ± 0.6 | XTE J1901+014 \(^{?}\) |
| 13          | 282.10 | -3.16           | 4.3 ± 0.2      | 3.2 ± 8.1 \(^{h}\) | GX 17+2, LMXB, ZB |
| 14          | 274.03 | -14.02          | 2.9 ± 2.4      | 4.4 ± 0.6 | XTE J1908+094, HMXB, BH |
| 15          | 287.22 | 9.35            | 20.6 ± 1.7     | 24.0 ± 5.8 | M 1812-12, LMXB, B |
| 16          | 273.77 | -12.12          | 2.7 ± 0.2      | 1.7 ± 0.9 \(^{h}\) | A 1845-024, HMXB, TP |
| 17          | 282.08 | -2.48           | 2.6 ± 0.3      | 3.7 ± 1.1 | 4U 1850-087, LMXB, GB |
| 18          | 283.25 | -6.70           | 2.7 ± 0.4      | 1.8 ± 1.1 \(^{h}\) | AX J183800-0655 \(^{?}\) |
| 19          | 279.50 | -6.91           | 2.1 ± 0.3      | 6.8 ± 0.9 | 1E 1841-045, AXP, SNR |
| 20          | 280.37 | -4.94           | 1.6 ± 0.2      | 3.4 ± 0.8 | PSR J1846-0258, P, SNR |
| 21          | 281.61 | -2.97           | 4.1 ± 0.6      | 4.6 ± 2.1 \(^{h}\) | NGC 6814, AGN |
| 22          | 295.60 | -10.36          | 1.4 ± 0.2      | 0.6 ± 0.7 \(^{h}\) | IGR J18490-0000 \(^{c}\) |
| 23          | 282.25 | -0.00           | 2.2 ± 0.3      | 0.5 ± 1.1 \(^{h}\) | 4U 1822-000, LMXB |
| 24          | 276.32 | -0.03           | 2.0 ± 0.3      | 1.7 ± 1.0 \(^{h}\) | IGR J18406-0539 \(^{c}\) |
| 25          | 280.23 | -5.65           | 1.5 ± 0.3      | 1.7 ± 0.9 \(^{h}\) | IGR J18450-0435 \(^{c}\) |
| 26          | 281.25 | -4.58           | 1.7 ± 0.3      | 1.1 ± 1.1 \(^{h}\) | SS 442/1H1934-063 \(^{d}\), AGN |
| 27          | 294.46 | -6.28           | 3.1 ± 0.6      | 4.6 ± 2.1 \(^{h}\) | SNR 21.5-0.9, SNR |
| 28          | 278.40 | -10.58          | 1.6 ± 0.5      | 1.1 ± 1.5 \(^{h}\) | IGR J18325-0756 \(^{?}\) |
| 29          | 278.12 | -7.93           | 0.6 ± 0.2      | 0.5 ± 0.7 \(^{h}\) | IGR J18539+0727 \(^{e}\), BH? |

\(^{a}\) — only statistical errors are given (systematical error is \(\sim 10\%\));

\(^{b}\) — sources observed during flares (Molkov et al 2003; Cherepashchuk et al. 2003 a,b));

\(^{c}\) — sources discovered in the present observations;

\(^{d}\) — the observed location of this source differs from more accurate localization of SS 442 by \(\sim 5.6^\circ\); possibly this is a new object IGR J19378-0617 (see the text);

\(^{e}\) — sources discovered by the IBIS telescope in other INTEGRAL observations;

\(^{h}\) — upper limits for fluxes of these sources.
Fig. 2. The mosaic image of the Sagittarius Arm Tangent region obtained by the INTEGRAL IBIS telescope in the energy range 18-60 keV. The total exposure time is \(\sim 800\) ks.