A hard X-ray survey of the Crux Galactic spiral arm tangent. A catalog of sources

© 2005 . M.G. Revnivtsev¹,², S.Yu. Sazonov¹,², S.V. Molkov¹, A.A. Lutovinov¹,
E.M. Churazov¹,², R.A. Sunyaev¹,²

¹ Space Research Institute, Moscow, Russia
² Max-Planck-Institut fuer Astrophysik, Garching, Germany

This work is part of a large solid angle hard X-ray survey. We analyzed a number of observations by the IBIS telescope aboard the INTEGRAL observatory covering the Crux Galactic spiral arm tangent. We have detected 46 hard X-ray sources, with 15 of them being new. Among the identified sources there are 12 AGNs, 11 HMXBs, 6 LMXBs and 2 active stars. 13 sources remain unidentifed.

*e-mail: revnivtsev@hea.iki.rssi.ru*
Introduction

The INTEGRAL observatory (Winkler et al. 2003) has devoted a considerable amount of time to observing Galactic hard X-ray sources. The wide field of view (∼15° × 15°) and large effective area (∼2400 cm²) of the main telescope of the observatory IBIS permits to survey large areas of the sky resolving individual point sources. In particular, a record sensitivity was achieved during surveys of the Galactic Center region (Revnivtsev et al. 2004a), the Saggitarius spiral arm tangent region (Molkov et al. 2004), and the Coma cluster region (Krivonos et al. 2005a). A shallower survey of the Galactic plane was presented by Bird et al. (2004).

The high penetrating power of hard X-rays seen by the IBIS telescope permits to study objects previously hardly detectable by telescopes operating in soft or standard X-ray energy bands. Thanks to this, a number of Galactic binary systems with high intrinsic photoabsorption have been discovered (see e.g. Schartel et al. 2003, Revnivtsev 2003, Kuulkers 2005, Lutovinov et al. 2005). The optical companions in such systems are usually quite young and massive and have powerful stellar winds that form an enshrouding cocoon around the X-ray source. The INTEGRAL observations have thus strongly increased the number of known massive binary X-ray systems.

A region of the Galaxy close to the tangent to the Crux spiral arm, relatively poorly covered by previous INTEGRAL observations, was the goal of a deep surveying campaign during INTEGRAL AO-3 cycle (observations 0320102). The large exposure time has allowed us to achieve a sensitivity 0.8–1.0 mCrab in the energy band 17–60 keV. In this paper we present a catalog of detected sources, which can be subsequently used for source identification and study in different energy bands.

Observations

We used all publicly available observations by IBIS/INTEGRAL covering a 50° × 50° region of the sky around the position l = 305°, b = 0.0. The main contributions to the net exposure come from observational set 0320102 (deep survey of the Crux spiral arm tangent) and from scans of the Galactic plane performed during 2003–2004 as part of the Core program of INTEGRAL. At the edges of the region a considerable contribution comes from deep observations of Large Magellanic Cloud and supernova remnant SN1006. The total exposure time used in our analysis is ∼2 million seconds.

The data analysis and detection of sources were performed using methods described in Revnivtsev et al. (2004a) and Molkov et al. (2004). The achieved high quality of sky images allows us to lower the detection limit (the flux at which the probability of a false source detection is of the order or 100%) down to ∼5σ, i.e. virtually to the pure statistical limit taking into account the number of independent pixels on the image. The corresponding sensitivity contours are presented in Fig.1.
Results

In total 46 sources have been detected. Out of them 41 sources show a statistically significant flux on the time averaged map. A number of sources (5 in total) were detected only during particular observations. The list of detected sources is presented in Table 1. The accuracy of source localization worsens with decreasing statistical significance and is $\sim 6'$ (radius of the 90% confidence contour) for the weakest sources.

Search for correlations of detected sources with current X-ray catalogs (e.g. the X-ray binary catalog, Liu et al. 2000, 2001; ROSAT bright source catalog, Voges et al. 1999; RXTE catalog, Revnivtsev et al. 2004b) has allowed us to identify 34 sources. For identification of IGR J12026-5349 observations by the CHANDRA satellite were used (Sazonov et al. 2005, in preparation). The accurate localization of a bright X-ray counterpart found by CHANDRA led to a firm association of the INTEGRAL source with the active nucleus of the galaxy WKK 0560.

In our sample there 12 active galactic nuclei, 11 Galactic high mass X-ray binaries, 6 low mass X-ray binaries, 1 active binary system of RS CVn type, and one source is a likely symbiotic star. 13 sources remain unidentified. 15 new hard X-ray have been discovered.

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REFERENCES

A. Bird, E. Barlow, L. Bassani et al., Astroph. J., 607, 33L (2004)

M. Chernyakova, T.J.-L. Courvoisier, J. Rodriguez, A. Lutovinov, Astronomer’s Telegram 519 (2005)

S. Grebenev, P. Ubertini, J. Chenevez et al., Astronomer’s Telegramm 350 (2004)

R. Krivonos, A. Vikhlinin, E. Churazov, A. Lutovinov, S. Molkov, R. Sunyaev, Astroph. J. 625, 89 (2005)

E. Kuulkers, in Proc. of the Interacting Binaries Meeting of Cefalu, Italy, July 2004 (astro-ph/0504625)

Q.Z. Liu, J. van Paradijs, E.P.J. van den Heuvel, Astr. Astroph. Suppl., 147, 25 (2000)

Q.Z. Liu, J. van Paradijs, E.P.J. van den Heuvel, Astr. Astroph., 368, 1021 (2001)

A. Lutovinov, M. Revnivtsev, M. Gilfanov, P. Shtykovskiy, S. Molkov, R. Sunyaev, Astron. Astroph, in press (2005), astro-ph/0411550

P. Lubinski, M. Gadolle Bel, A. von Kienlin et al., Astronomer’s Telegram 469 (2005)

N. Masetti, L. Bassani, A.J. Bird, A. Bazzano, Astronomer’s Telegram 528 (2005)

S.V. Molkov, A.M. Cherepashchuk, A.A. Lutovinov, M.G. Revnivtsev, K.A. Postnov, R.A. Sunyaev, Astron. Lett, 30, 534 (2004)

I. Negueruela, D.M. Smith, S. Chaty, Astronomer’s Telegram 470 (2005)

N. Produit, J. Ballet, N. Mowlavi, Astronomer’s Telegram 278 (2005)

M.G. Revnivtsev, Astron. Lett. 29, 644 (2003)

M.G. Revnivtsev, R.A. Sunyaev, D.A. Varshalovich et al., Astron. Lett.,30, 382 (2004a)

M.G. Revnivtsev, S. Sazonov, K. Jahoda, M. Gilfanov, Astron. Astroph., 418, 927 (2004b)

N. Schartel, M. Ehle, M. Breitfellner et al., IAU Circ. 8072 (2003).

W. Voges, B. Aschenbach, Th. Boller et al., Astron. Astroph., 349, 389 (1999)

C. Winkler, T.J.-L. Courvoisier, G. Di Cocco et al. Astron. Astroph. 411, L1 (2003)
Table 1. List of sources detected in the deep survey of the Galactic plane region near the Crux spiral arm tangent. Sources are ordered according to the statistical significance of their detection. References: (1) – Chernyakova et al. 2005, (2) – Masetti et al. 2005, (3) – Grebenev et al. 2004, (4) – Produit et al. 2004, (5) – Chernyakova et al. 2005, in press; (6) – Krivonos et al. 2005b, (7) – Lubinski et al. 2005, (8) – Negueruela et al. 2005. 1 mCrab corresponds to an energy flux of $1.4 \times 10^{11}$ erg/s/cm$^2$ for a power law spectrum with a photon index $\Gamma = 2.1$. 
|   | Source             | R.A. | Dec.  | σ     | Flux (17–60 keV), mCrab | Comments (Refs) |
|---|--------------------|------|-------|-------|------------------------|-----------------|
| 1 | GX 301-2           | 186.65 | -62.77 | 690.48 | 96.9 ± 0.2 | HMXB,P |
| 2 | XTE J1550-564      | 237.75 | -56.45 | 405.01 | 73.1 ± 0.2 | LMXB,BH |
| 3 | Cen A              | 201.36 | -43.01 | 189.12 | 37.6 ± 0.2 | AGN |
| 4 | Cen X-3            | 170.30 | -60.62 | 172.20 | 26.4 ± 0.2 | HMXB,P |
| 5 | A1145.1-6141       | 176.87 | -61.95 | 131.99 | 19.1 ± 0.2 | HMXB,P |
| 6 | 4U 1538-522        | 235.58 | -52.37 | 111.37 | 18.3 ± 0.2 | HMXB,P |
| 7 | Circinus galaxy    | 213.28 | -65.34 | 70.14  | 11.9 ± 0.2 | AGN |
| 8 | NGC 4945           | 196.37 | -49.46 | 61.79  | 12.2 ± 0.2 | AGN |
| 9 | 4U 1516-569        | 230.17 | -57.17 | 61.02  | 11.4 ± 0.2 | LMXB,B |
| 10| PSR 1509-58        | 228.47 | -59.14 | 43.67  | 8.6 ± 0.2 | PSR |
| 11| 4U 1323-619        | 201.64 | -62.13 | 37.93  | 5.4 ± 0.2 | LMXB |
| 12| 4U 1626-67         | 248.06 | -67.47 | 27.07  | 12.5 ± 0.5 | LMXB,P |
| 13| NGC 4507           | 188.90 | -39.91 | 25.45  | 8.3 ± 0.4 | AGN |
| 14| 4U 1344-60         | 206.89 | -60.61 | 23.50  | 3.6 ± 0.2 | AGN |
| 15| IGR J12346-6434    | 188.71 | -64.56 | 22.34  | 3.2 ± 0.2 | Symb.st.(1,2) |
| 16| 4U 1246-588        | 192.39 | -59.08 | 22.35  | 3.2 ± 0.2 | XB |
| 17| X1145-619          | 176.99 | -62.20 | 20.82  | 3.1 ± 0.2 | HMXB,P |
| 18| IGR J11435-6109    | 175.99 | -61.12 | 18.68  | 2.7 ± 0.2 | HMXB,P (3) |
| 19| IGR J11305-6256    | 172.77 | -62.94 | 16.26  | 2.5 ± 0.2 | - (4) |
| 20| 2S 1254-690        | 194.41 | -69.29 | 12.18  | 2.3 ± 0.2 | LMXB |
| 21| 1RXJ J30159.6-635806 | 195.50 | -63.96 | 11.74  | 1.7 ± 0.2 | HMXB,P (5) |
| 22| IGR J12026-5349    | 180.67 | -53.83 | 11.72  | 2.1 ± 0.2 | AGN,WKK 0560 |
| 23| 4U 1543-624        | 236.94 | -62.55 | 11.59  | 2.7 ± 0.3 | LMXB,NS |
| 24| IGR J14579-4308    | 224.44 | -43.14 | 11.11  | 1.8 ± 0.2 | AGN:IC 4518 |
| 25| XTE J1543-568      | 236.01 | -56.75 | 9.97   | 1.8 ± 0.2 | HMXB,P |
| 26| NGC 6300           | 259.20 | -62.79 | 9.61   | 3.1 ± 0.4 | AGN |
| 27| ESO 323-G077       | 196.60 | -40.42 | 7.58   | 1.7 ± 0.2 | AGN |
| 28| XSS J12270-4859    | 186.99 | -48.90 | 7.60   | 1.8 ± 0.3 | - |
| 29| IGR J13109-5552    | 197.69 | -55.86 | 7.14   | 1.1 ± 0.2 | - |
| 30| IGR J15360-5750    | 234.00 | -57.84 | 6.33   | 1.2 ± 0.2 | - |
| 31| IGR J14175-4641    | 214.30 | -46.68 | 6.11   | 1.2 ± 0.2 | - |
| 32| IGR J16185-5928    | 244.63 | -59.47 | 5.70   | 1.2 ± 0.2 | AGN:WKK 6471 |
| 33| IGR J10109-5746    | 152.71 | -57.78 | 5.57   | 1.3 ± 0.3 | - |
| 34| IGR J14493-5534    | 222.29 | -55.60 | 5.56   | 1.0 ± 0.2 | - |
| 35| IGR J10252-6829    | 156.30 | -68.46 | 5.42   | 1.6 ± 0.3 | - |
| 36| IGR J14552-5133    | 223.81 | -51.55 | 5.37   | 1.0 ± 0.2 | AGN:WKK 4438 |
| 37| 1ES 1210-646       | 183.24 | -64.84 | 5.15   | 0.8 ± 0.2 | - |
| 38| IGR J08023-6954    | 120.57 | -69.91 | 5.14   | 1.7 ± 0.4 | - |
| 39| IGR J14471-6319    | 221.78 | -63.33 | 5.09   | 0.9 ± 0.2 | - |
| 40| IGR J15094-6649    | 227.32 | -66.85 | 5.02   | 1.1 ± 0.2 | - |
| 41| IGR J1321-5311     | 173.03 | -53.18 | 10.5   | 27 ± 2.6 | - (6) |
| 42| IGR J1215-5952     | 170.42 | -59.90 | 8.42   | 1.8 ± 0.2 | HMXB (7,8) |
| 43| HD 101379          | 174.88 | -65.33 | 7.07   | 1.6 ± 0.2 | RS CVn |
| 44| PSR B1259-63       | 195.70 | -63.83 | 6.36   | 0.9 ± 0.2 | HMXB,P |
| 45| IGR J11085-5100    | 167.14 | -51.01 | 5.64   | 1.9 ± 0.4 | - |
| 46| 4U 1022-55         | 159.45 | -56.74 | 5.54   | 1.3 ± 0.3 | HMXB |
| 47| IGR J12415-5750    | 190.35 | -57.84 | 5.00   | 1.0 ± 0.2 | AGN:WKK 1263 |

* – these sources are not statistically significantly detected on the time averaged map, but are detected in subsets of observations. In column 5 the maximum detection significance is quoted.
Fig. 1: Statistical uncertainty in flux measurement over the sky region covered by the survey. Contours show regions where 1σ statistical error is 0.16, 0.22, 0.3, etc. mCrab
Fig. 2: Map of the galactic plane near the tangent to the Crux spiral arm in the energy band 17–60 keV. Only brightest sources are marked