The INTEGRAL Galactic Bulge monitoring program


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Abstract. The Galactic Bulge region is a rich host of variable high-energy point sources. These sources include bright and relatively faint X-ray transients, X-ray bursters, persistent neutron star and black-hole candidate binaries, X-ray pulsars, etc.. We have a program to monitor the Galactic Bulge region regularly and frequently with the γ-ray observatory INTEGRAL. As a service to the scientific community the high-energy light curves of all the active sources as well as images of the region are made available through the WWW. We show the first results of this exciting new program.

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INTRODUCTION

The bulge of our Galaxy hosts a variety of X-ray and γ-ray point sources (e.g., Knight et al. 1985, Skinner et al. 1987, Churazov et al. 1994; see, e.g., Bird et al. 2006, Bélanger et al. 2006, Revnivtsev et al. 2004, for INTEGRAL observations). These include persistent and transient neutron star and black-hole candidate binaries, X-ray pulsars, X-ray bursters, etc.. Because of the variability these sources possess on time scales of msec to days (quasi-periodic oscillations, pulsations, [absorption] dips, eclipses, type I and type II X-ray bursts, orbital variations, flares) and weeks to years (orbital variations, outburst cycles, on/off states), the region never looks exactly the same.

From 17 February 2005 onwards INTEGRAL has been monitoring this region approximately every 3 days, as part of our approved AO-3 program, whenever the region is visible by INTEGRAL. In this paper we describe this program in more detail and show the first results of the first two periods of monitoring performed between February and October 2005.
INTEGRAL AND DATA ANALYSIS

**INTEGRAL** (The **International Gamma-Ray Astrophysics Laboratory**; Winkler et al. 2003) is an ESA scientific mission dedicated to fine spectroscopy \( (E/\Delta E \sim 500; \text{SPI}) \) and fine imaging (angular resolution: 12 arcmin FWHM; IBIS) of celestial \( \gamma \)-ray sources in the energy range 15 keV to 10 MeV with simultaneous monitoring in the X-ray (3–35 keV; JEM-X) and optical (V-band, 550 nm; OMC) energy ranges.

Our program is to observe the region frequently and regularly, with the aim to investigate the source variability and transient activity on time scales of days to weeks to months at relatively soft (\( \lesssim 10 \) keV) and hard (\( \gtrsim 10 \) keV) energies. One complete hexagonal dither pattern (7 pointings of 1800 sec each, i.e., 1 on-axis pointing, 6 off-source pointings in a hexagonal pattern around the nominal target location, each 2° apart) is performed during each **INTEGRAL** revolution, or orbit around the earth (i.e., roughly every 3 days). This is done whenever the region is visible by **INTEGRAL** (about two times per year for a total period of about 4 months). As a service to the scientific community, the JEM-X light curves (3–10 keV and 10–25 keV) and the IBIS/ISGRI light curves (20–60 keV and 60–150 keV) are made publicly available as soon as possible after the observations are performed. In addition, IBIS/ISGRI and JEM-X mosaic images of each hexagonal observation are provided, with information on the detected sources. Last, but not least, all IBIS/ISGRI 20–60 keV mosaic images per revolution are stacked into a movie, showing the ever-changing gamma-ray sky. All the instruments onboard **INTEGRAL**, except the OMC, have coded masks. With the fully and partially coded field of views (FOVs) we cover about half of the low-mass X-ray binary (LMXB) and high mass X-ray binary (HMXB) Galactic Bulge population (see also, e.g., in ’t Zand 2001). Similar Galactic Bulge monitoring programs have been performed (see, e.g., in ’t Zand 2001) and are currently ongoing (e.g., **RXTE** Galactic Bulge Scans, Swank & Markwardt 2001). However, the **RXTE**/PCA and HEXTE do only have a 2° collimator, so only a small field of view with no imaging resolution, and therefore only provide information on a given source for a short time when the instrument scans over it; moreover, in the Galactic Center region itself there is some source confusion. There are currently other instruments in operation at similar energy ranges (e.g., **Swift**/BAT: 15–150 keV with a FOV of 2 steradians; Barthelmy 2000), but they do not provide frequent and regular monitoring of the Galactic Bulge region, as well as having a worse imaging capability, again leading to some source confusion in the Galactic Center region (**Swift**/BAT PSF angular resolution is 22’ compared to the IBIS/ISGRI angular resolution of 12’ [FWHM]).

For our program at the moment we only consider data from IBIS/ISGRI (Ubertini et al. 2003, Lebrun et al. 2003) and JEM-X (Lund et al. 2003). We do not consider the data from the IBIS/PICsIT, SPI, or OMC instruments. Either the angular resolution is high (SPI: 2.5°) and therefore the various sources in the Galactic Bulge region close to each other complicate the analysis, or the sources are too weak to be detected (IBIS/PICsIT). For the OMC, however, we are currently evaluating the scientific output.

The **INTEGRAL** data reduction is performed using the Off-line Scientific Analysis (OSA; Courvoisier et al. 2003), v5.1. We use a source catalog, currently containing 79 sources which have been detected by IBIS/ISGRI up to now in the field we are interested in (but see next Section).
The data from IBIS/ISGRI are processed until the production of images in the 20–60 and 60–150 keV energy ranges per single exposure. We force the flux extraction of each of the catalogue sources, regardless of the detection significance of the source. This method is essential in order to clean the images from the ghosts of all the active sources in the field, but does not make any threshold selection and all the positive fluxes are recorded. In order to detect fainter sources, we then mosaic the images from the single exposures and search for all catalog sources, as well as possible new ones. For JEM-X the analysis is run through the imaging step to the light-curve step in OSA for a single bin of the same length as the exposure window. Light curves are produced for all catalog sources up to 5° off from the center of the FOV. Again, the images from the single exposures are mosaiced in order to create the final image (but no further source detection was done).

Per hexagonal dither (i.e., 7 exposures combined) we are sensitive down to typically between 5 and 15 mCrab (6σ) for both JEM-X and IBIS/ISGRI. The actual sensitivity depends on factors such as source position (fully or partially coded FOV), background (instrument systematics, solar activity), number of exposures (some are lost) and energy (instrument response).

The results, as well as more information about the program, can be retrieved from the INTEGRAL Galactic Bulge Monitoring WWW page hosted at the ISDC in Switzerland: [http://isdc.unige.ch/Science/BULGE/](http://isdc.unige.ch/Science/BULGE/)

**GALACTIC BULGE MONITORING: FIRST RESULTS**

By now we have had two full seasons of monitoring, i.e., from revolutions 287–307 (2005 February - April) and 347–370 (2005 August - October), respectively. The third season started in revolution 406 (February 2006). In Figure 1 we show examples of results from the first two seasons for various types of sources. At the left we show the light curves of (temporary) bright (i.e., easily detected in one exposure) sources. At the right we show the light curves of weaker (persistent or transient) or slowly varying sources, averaged per revolution.

Whereas, for example, GX 3+1 (neutron star LMXB) does not vary much, sources like GX 1+4 (symbiotic binary containing a neutron star) and 1A 1742–294 (neutron star LMXB) vary on monthly times scales, while 1E 1740.7–2942 (LMXB) varies smoothly on even longer time scales. Some sources clearly show transient behaviour, i.e., they show outbursts with durations exceeding months (e.g., H1743–322, a black-hole candidate LMXB; see also below) or flaring on timescales of hours to days (e.g., IGR J17252–3616, an X-ray pulsar HMXB). Some sources vary on all timescales accessible through our program, as displayed by the HMXB 4U 1700–377.

Similarly, sources like 1A 1742–289 and 1E 1742.2–2857 (both unidentified X-ray sources) show low-level activity on various timescales.¹ Sources like the neutron

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¹ These sources are not included in our source catalog, but the light curves displayed here are the result when the ISDC Reference catalog is used as input. Note that these sources were not reported by Bélanger et al. 2006 and Bird et al. 2006, based on long exposure times. Further investigation is in process.
star LMXB transients SAX J1747.0−2853 and XTE J1739−285 showed renewed outburst activity, during the second season (see also below). The neutron star LMXBs 4U 1724−30 (in the globular cluster Terzan 2) and 4U 1820−303 have been persistently on through the seasons, displaying occasionally drops or flares, respectively, in intensity for about a month. The neutron star LMXB GS 1826−24 slowly varied through our observing periods.

So far quick-look results during the two seasons have been reported in 10 ATEL’s. Here we describe some of the highlights. Precisely at the start of the program the black-hole X-ray transient GRO J1655−40 was reported to become active (Markwardt & Swank 2005). The INTEGRAL GRO J1655−40 light curves (see Kuulkers et al. 2005a) nicely complement observations at soft X-ray (RXTE; see Homan 2005) and radio (VLA; see Rupen et al. 2005) wavelengths. Various other transient sources popped up and faded away, such as The Rapid Burster, H1743−322 (both Kretschmar et al. 2005; for H1743−322 see Figure 1, left), IGR J17098−3628 (Mowlavi et al. 2005), SAX J1747.0−2853 (Kuulkers et al. 2005b; see Figure 1, right) and XTE J1818−245 (Shaw et al. 2005a). In 2005 August, the X-ray transient XTE J1739−285 was found by INTEGRAL to be bright at soft and not detected at hard X-ray energies (Bodghee et al. 2005). About a month later the situation had reversed; it was bright at hard and weak at soft X-ray energies (Shaw et al. 2005b; see Figure 1, right). Although at first we attributed the state change to the compact object being a black hole, we proved it to be a neutron star based on the occurrence of type I X-ray bursts detected with JEM-X (Brandt et al. 2005).
CONCLUSIONS

We have shown that most of the sources in the program in the field of view of the INTEGRAL instruments clearly vary on timescales of a few hours to days to months; it is therefore of no surprise that the Galactic Bulge is a region to stay tuned on. MIRAX with its wide-field instruments covering a similar energy range (Braga et al. 2004; see also these Proceedings) will go a step further, i.e., it will continuously monitor the Galactic Bulge region for about 9 months per year down to a sensitivity level of $\simeq 5$ mCrab per day. Our monitoring program is, therefore, also an ideal ‘training session’ for what to expect with MIRAX.

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