INTEGRAL/IBIS OBSERVATIONS OF PERSISTENT BLACK HOLE SPECTRAL STATES DURING THE CORE PROGRAM

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ABSTRACT

The Imager on Board the Integral Satellite (IBIS) is one of the two main telescopes of Integral, the ESA soft $\gamma$-ray mission to be launched in 2002. The Integral Core Program will be divided into two main parts, the Galactic Centre Deep Exposure program and the Galactic Plane Scan for a total amount of around 6.610\textsuperscript{6} seconds each year. In this paper, we will study the visibility of persistent galactic black holes as observed by IBIS during these two phases of the Core Program. We will also present what information may be derived from the IBIS observations of spectral/temporal properties (variation of the spectral index, presence/absence of a spectral break, ...) of these binary systems in different spectral states, in particular in the framework of the bulk motion Comptonization model.

Key words: Black hole candidates; Core Program; Integral/IBIS.

1. THE INTEGRAL SATELLITE AND ITS INSTRUMENTS

Integral is a 15 keV-10 MeV $\gamma$-ray mission with concurrent source monitoring at X-rays (3-35 keV) and in the optical range (V, 500-600 nm). All instruments are coaligned and have a large FOV, covering simultaneously a very broad range of sources. The Integral payload consists of two main $\gamma$-ray instruments, the spectrometer SPI and the imager IBIS, and of two monitor instruments, the X-ray monitor JEM-X and the Optical Monitoring Camera OMC.

The Imager on Board Integral Satellite (IBIS) provides diagnostic capabilities of fine imaging (12' FWHM), source identification and spectral sensitivity to both continuum and broad lines over a broad (15 keV-10 MeV) energy range. It has a continuum sensitivity of $2 \times 10^{-7}$ ph cm\textsuperscript{-2} s\textsuperscript{-1} at 1 MeV for a 10\textsuperscript{6} seconds observation and a spectral resolution better than 7 % @ 100 keV and of 6 % @ 1 MeV. The imaging capabilities of IBIS are characterized by the coupling of its source discrimination capability (angular resolution 12' FWHM) with a field of view (FOV) of 9° x 9° fully coded and 29° x 29° partially coded.

The IBIS detection system is composed of two planes, an upper layer made of 16384 squared CdTe pixels (ISGRI) with higher efficiency below about 200 keV and a lower layer made of 4096 CsI scintillation bars (PICsIT) more efficient above 200 keV. A photon may interact with only one of the two layers giving rise to an ISGRI or a PICsIT event (the PICsIT event can be single or multiple). If it interacts with both, undergoing a Compton scattering, its energy and arrival direction can be reconstructed leading to the definition of a third type of event, the Compton one which again can be single or multiple depending on interaction in PICsIT.

The spectrometer SPI will perform spectral analysis of $\gamma$ ray point sources and extended regions with an unprecedented energy resolution of $\sim$ 2 keV (FWHM) at 1.3 MeV. Its large field of view (16° circular) and limited angular resolution (2° FWHM) are best suited for diffuse sources imaging but it retains nonetheless the capability of imaging point sources. It has a continuum sensitivity of $7 \times 10^{-8}$ ph cm\textsuperscript{-2} s\textsuperscript{-1} at 1 MeV and a line sensitivity of $5 \times 10^{-8}$ ph cm\textsuperscript{-2} s\textsuperscript{-1} at 1 MeV, both 3$\sigma$ for a 10\textsuperscript{6} seconds observation.

The Joint European Monitor JEM-X supplements the main Integral instruments and provides images with 3' angular resolution in a 4.8° fully coded FOV in the 3-35 keV energy band. The Optical Monitoring Camera (OMC) will observe the prime targets of Integral main $\gamma$ ray instruments. Its limiting magnitude is $M_V \sim 19.7$ (3$\sigma$, 10\textsuperscript{3} s). The wide band observing opportunity offered by Integral provides for the first time the possibility of simultaneous observations over 7 orders of magnitude in energy.

2. THE INTEGRAL CORE PROGRAM

The Integral observing time will be divided into two main parts, the Open Time devoted to Guest
Table 1. Available observing time in the different parts of the Core Program in $10^6$ seconds unit.

| Year | Total | GPS | GCDE | P.O. |
|------|-------|-----|------|------|
| 1    | 9.32  | 4.30| 2.30 | 2.72 |
| 2    | 7.98  | 4.30| 2.30 | 1.38 |
| 3+   | 6.64  | 4.30| 1.47 | 0.87 |

Table 2. List of the selected Target of Opportunity for the Core Program, with the Flux limit at the given Energy above which a TOO is declared.

| Name            | Limit Flux | Energy (keV) |
|-----------------|------------|--------------|
| GRS 1915+105    | 300 mCrab  | 30           |
| GROJ 1655-40    | 300 mCrab  | 100          |
| 1E 1740.7-2942  | 200 mCrab  | 100          |
| Cyg X-1         | 400 mCrab  | 30           |
| Cyg X-3         | 400 mCrab  | 30           |
| GX 339-4        | 400 mCrab  | 30           |

Observers selected by the Integral Time Allocation Committee, and the Guaranteed Time given to the member of the Integral Science Working Team, representing mostly laboratories which have worked on the Integral program.

The Integral guaranteed time (also called the Integral Core Program) will be in turn divided into three parts, the Galactic Plane Survey, the Galactic Central Radian Deep Exposure program and some Target of Opportunity (TOO) sources (see Winkler et al., this conference, for more details). Table 1 gives the observing time available for these different parts of the Core Program during the whole mission.

The Galactic Plane Survey will consist on a scanning of the galactic plane once a week. The pointing will follow a saw-tooth pattern, with an observing time on each point of 1050 s. As a given source will be detected in the large field of view of the major Integral instrument during three successive pointing, the total exposure for a given source is around 3000 seconds each week.

The Galactic Central Radian Deep Exposure will be a deep survey of the central Galactic radian. The total observing time for one year will be 2.310$^6$ seconds. Lastly, some TOO sources, given in Table 2, will be followed up, if their flux at a given energy rise above a certain threshold, and if there is time remaining in the Core Program to allocate these observations.

Table 3 gives the significance of detection of the main persistent Black Hole Systems during one GPS scan. It could be seen clearly on this Table that due the high level of detection we will get, the spectral state of these sources will be clearly determined. This is furthermore confirmed by the simulations we made of one GPS scan with the IBIS Mass Model (see Laurent et al., this conference, for a description).

Indeed, we have modelled first the observation of a 300 mCrab Black Hole System in the soft state, by law extending to several hundred of keV (hereafter called the “soft state” see Figure 1), and the other at high luminosity in high energies ($>10$ keV) showing a typical thermal Comptonization component (called the “hard state” in this paper, see Figure 2). The origin of the powerlaw in the soft state is still under debates, but it could result from the Comptonization of soft X-ray photons from the accretion disk, by the free-falling electrons onto the black hole (Laurent & Titarchuk 1999, hereafter LT99). In that optics, the state transition, soft to hard, will be caused only by an increase in the Comptonizing plasma temperature. Indeed, the electrons thermal motion would be dominated in the soft state by the free-falling motion. Conversely, the reverse situation would occur in the hard state. We will now see what information we can get from these systems during the GPS and the GCDE.

4. OBSERVATIONS OF PERSISTENT BLACK HOLES DURING THE GALACTIC PLANE SURVEY

The Black Hole Systems (BHS) are generally observed in two spectral states: one with a high luminosity soft thermal bump and a low luminosity power

Figure 1. Plot of different Black Hole Systems (GRO J1655-40, GRS 1915+105, GRS 1739-278, 4U 1630-47 XTE J1755-32, and EXO 1846-031) in the low state, as observed by RXTE and EXOSAT (Borozdin et al. 1999)
5. OBSERVATIONS OF PERSISTENT BLACK HOLES DURING THE GALACTIC CENTRAL RADIAN DEEP EXPOSURE

During one year of GCDE, we will get with IBIS a sensitivity of the order of the ones given by Figure 5. We can clearly see there that the spectral continuum of a Black Hole System in the central radian will be clearly determined up to a few hundredth...
of keV. Also, we can obtain the same kind of sensitivity for GPS sources, if we sum their observations during the whole Integral mission. To do this, we shall expect however that the source spectrum do not changed much during the mission, which seems not very plausible.

Knowing this sensitivity, we can try to use the IBIS high energy data in order to determine if there is a spectral break in Black Hole System spectra around 400 keV, as it is foreseen in the Bulk Motion Comptonization model. To test this, we have made a simulation of a 400 mCrab system in the soft state (powerlaw of photon index -2.9), and we show in Figure 6 the simulated count PiCsIT (single + multiple events) spectrum, taking into account a predicted background of 5000 cts/s. The observing time simulated was $2.3 \times 10^6$ seconds, that is one year of GCDE.

As it could be seen in Figure 6, the statistics in that case is clearly not enough to analyse a possible break around 400-500 keV. This feature may be detected in fact only if we consider a stronger source (around one Crab), and if we consider also that we can increase our sensitivity by using the SPI data. Such a strong source has however never been observed in the central radian, so the only study of that kind we can foresee for the moment, using the Core Program data, is the study of Cygnus X-1 using the GPS data acquired during the whole mission. So, in our opinion, the study of the > 400 keV part of the spectrum of hundredth of mCrab sources in the soft state should be made during the Open Time.

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