TOO OBSERVATIONS OF GRO J1655-40 IN OUTBURST WITH INTEGRAL

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ABSTRACT

In this paper we present the results of the analysis of the INTEGRAL data for the black hole transient GRO J1655-40. The observations consist of four ToO (100 ks each) observations's AO-3 spread from February to April of 2005. We present here the preliminary spectral analysis of this source between 5 and 200 keV. Also, some comments of the light curves obtained during this period are shown.

Key words: Gamma rays: observations; Black hole physics; Accretion, accretion disks.

1. INTRODUCTION

The X-ray transient GRO J1655-40 (also called X-ray Nova Scorpii 1994) was discovered with the Burst and Transient Source Experiment (BATSE) on board the Compton Gamma-Ray Observatory (CGRO) on 1994 July 27 [20]. The optical counterpart was discovered soon after by Bailyn et al. [1]. Subsequent optical studies showed that the system is an LMXB composed of a blue subgiant (spectral type F4 IV) as the secondary and a black hole as the primary ($m_{BH} = 7.02{\pm}0.22 M_{\odot}$) [12], located at a distance of 3.2 kpc [17] (see also Foellmi et al. [6]). Bailyn et al. [2] (see also Orosz et al. [13] and van der Hooft et al. [19]) established the orbital inclination of the system to be $\simeq 70^{\circ}$.

Galactic black hole binaries (hereafter BHB) show interesting luminosity/spectral properties which appears to be strongly related with the accretion behaviour onto the black hole (hereafter BH). Matter accretes onto the BH through an accretion disk, which has nearly Keplerian orbits; the last stable orbit is called "Innermost Stable Circular Orbit" (i.e. ISCO) [16] which is located at $R_S = 6R_g$ (for a Schwarzschild BH; where $R_g = GM/c^2$ is the gravitational radius).

There are five states known in BHB: quiescent, low-hard, intermediate, high-soft and very high states in the unification scheme (e.g. Remillard & McClintock [8]). At lower mass accretion rate, corresponding to several percent of the Eddington luminosity, a BHB usually enters the low-hard (LH) state and at very low accretion rates it reaches the quiescent state, which may be just an extreme of the LH state. In both of these states, the spectrum of a BHB is dominated by a hard, nonthermal power-law component (photon index $\sim$1.7); it is most plausibly explained as due to Comptonization of soft photons (from a hot optically thick disk) by a hot optically thin plasma. Narayan [11] postulated that in these states the disk does not extend down to the ISCO, but is truncated at some larger radius and the interior volume is filled by a hot ($T_e \sim 100$ keV), radiative inefficient, advection-dominated accretion flow or ADAF.

The Multicolor Disk Model (MCD) (Mitsuda et al. [10], which is an application of the Shakura & Sunyaev [15] disk) is used to describe the thermal component that is dominant in the Very High (VH) and High-Soft (HS) states. The VH state seems the HS although the flux of the disk component is higher and the photon index of the power law is steeper.

In this paper, we briefly report on observations of the BHB GRO J1655-40 made by INTEGRAL. After describing the observations and our analysis techniques, we present the preliminary results of the spectral fits. We then briefly discuss the results and end with some concluding remarks.

2. OBSERVATIONS

The data were obtained with INTEGRAL and cover the outburst using the instruments SPI, IBIS/ISGRI, JEM-X and OMC. These first part of the observations were made during 4 ToO (of 100 ks each) spread from 27 February to 11 April of 2005. The dithering pattern used during the observations was 5×5. Data analysis (in the case of JEM-X, IBIS/ISGRI and SPI) was performed using the standard OSA 5.1 analysis software package available from the INTEGRAL Science Data Centre (hereafter ISDC). In the case of SPI, because of the lower angular resolution and crowdedness of the Field of View (FOV) in γ-rays at this position of the sky (l,b)=(344.98°,+2.46°), (see Fig-

Table 1. Dates of the INTEGRAL observations (SPI data will be presented in a forthcoming paper).

ToO number	INTEGRAL revolution	Start & End Date	JEM-X [ks]	ISGRI [ks]
1	290	2005/02/27-2005/02/28	44504.83	69212.87
2	295-296	2005/03/16-2005/03/18	43641.93	71827.16
3	299	2005/03/26-2005/03/28	44673.42	69848.25
4	304	2005/04/10-2005/04/11	46037.85	67883.58

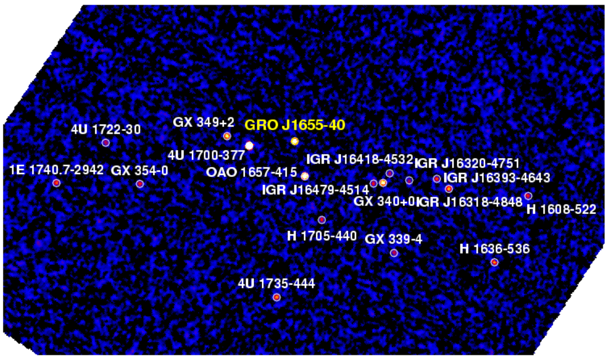

Figure 1. Mosaic image (obtained in revolution 295) of the GRO J1655-40 region as seen by ISGRI in the 20-40 keV energy range. Besides the target source, several other high energy sources are visible.

ure 1), we used a non-standard procedure in the analysis of the data, described in Deluit [4] and Roques & Jourdain [14]. For the same reason, in the case of OMC, we used a non-standard pipeline for extraction of fluxes (A. Domingo , private communication), which will be delivered under OSA 6.0 in the very near future. The data we analized come from the observations with P.I.: Miller. In the case of OMC, all the public data from ISDC were downloaded (this implies only a slight increase of data). In order to avoid large off-axis angles in the case of JEM-X and because of its reduced FOV (5° of diameter), we limited the radius of directions of pointings with respect to the GRO J1655-40 position to be 4° only. In the case of SPI and ISGRI, with large Fully Coded Fields of View (FCFOV) ($16^\circ \times 16^\circ$ for SPI and $9^\circ \times 9^\circ$ for IBIS) this selection of pointings was not applied. Summarizing, 199 individual pointings were used for SPI and IBIS/ISGRI, 96 pointings for JEM-X and 66 pointings for OMC. We ommit the SPI results in the current paper, since the analysis is still in progress and will appear in a forthcoming paper. The dates of the observations are presented in Table 1.

3. LIGHT CURVES

Figure 2 shows the GRO J1655-40 light curves obtained by IBIS/ISGRI (from the INTEGRAL Galactic Bulge Monitoring Program) in two energy bands (60-150 keV and 20-60 keV) together with OMC (optical). The ASM/RXTE (2-10 keV) light curve in the same period of time is shown in the same figure. A progressive delay in the outburst can be seen in the softer energy range with respect to high energies. In the optical the delay is $\sim$10 days as noted for the same period of observations [3]. The horizontal lines indicate the time intervals (one revolution each) over which spectra were obtained. The optical/soft X-rays light curve behaved very differently from that of the hard X-rays; this might suggest that the X-ray light curve is actually a composite of the two known spectral components, one gradually increasing with the optical/soft X-rays emission (accretion disk) and the other following the behaviour of the hard X-rays (jet and/or corona). Brocksopp et al. [3] propose that during this outburst a transition occurs from LH to HS state.

Table 2. Table with some information of interest of this very preliminar spectra fitting (ν means the number of degrees of freedom of the spectral fitting).

Rev.	Model	χ^2/ν	Relevant par.
0290	abs×plw	114/48	$\Gamma = 1.73{\pm}0.02$
0295	abs(bb+cTT)	163/140	$T_{in} = 1.2{\pm}0.8$ keV $T_e = 279{\pm}77$ keV
0296	abs(bb+cTT)	175/126	$T_{in} = 1.3{\pm}0.5$ keV $T_e = 67{\pm}45$ keV
0299	abs(bb+cTT)	584/84	$\Gamma = 2.2{\pm}0.4$
0304	abs(bb+cTT)	609/83	

4. SPECTRAL ANALYSIS

We performed spectral analysis of the JEM-X and IBIS/ISGRI data. For JEM-X and ISGRI, individual spectra were obtained for each ScW. The spectra were then combined to obtain an averaged spectrum per revolution (i.e. INTEGRAL revolution 290, 295, 296, 299 and 304) using the *spe_pick* OSA tool. This was done, since there was not a significant evolution of the spectra during a revolution and it improved the signal to noise. We then performed a simultaneous fit to the JEM-X and IBIS/ISGRI data, for each of the five revolutions using XSPEC v.12.

In Figure 3 we show spectra from revolutions 290, 295 and 299 because these are the most significant to see the evolution of the source during the total period of observations. In Table 2 we summarize some information obtained during these very preliminary fits. We fixed the value of the column density to $N_H{\approx}0.8{\times}10^{22}$ atoms$/cm^2$ as in Brocksopp et al. [3].

From this analysis, we observe a strong evolution of the spectrum from a pure hard power law, in revolution 290, to a model constituted by a photo-absorbed accretion disk bathed in a comptonizing corona (Titarchuk [18]), in revolutions 295 and 296. This is accompanied by a strong increase of the photon index (from $\Gamma{\sim}1.73{\pm}0.02$, in revolution 290, to $\Gamma{\sim}2.2{\pm}0.4$, in revolution 299, the source is almost not detected by ISGRI in revolution 304) together with an increase of the input photon temperature (from $T_{in}{\ll}1$ keV, in revolution 290, to $T_{in} = 1.2{\pm}0.8$ keV, in revolution 295, and $T_{in} = 1.3{\pm}0.5$ keV, in revolution 296). All together would indicate an increasing of the input photon flux coming from the innermost regions of the accretion disk, which are scattered with the electrons present in the hot corona [18]. In revolutions 299 and 304 the photo-absorbed and comptonized disk model is also better than photo-absorbed disk alone, but a more complex spectrum (which requires reflection and likely a weak iron line) appears to be more appropiate.

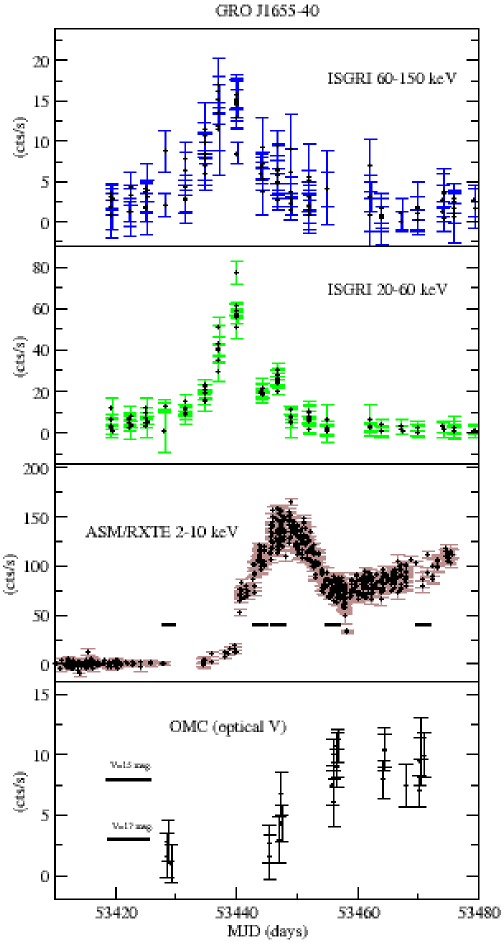

Figure 2. Light curves obtained with IBIS/ISGRI from the INTEGRAL Galactic Monitoring Program in two energy bands (60-150 keV and 20-60 keV), together with OMC (optical). The horizontal lines in the OMC panel show the equivalence in magnitudes of the fluxes. In the third panel, ASM/RXTE (2-10 keV) light curve is shown in the same period of time. The horizontal lines indicate the time intervals (one revolution each) over which INTEGRAL spectra were obtained.

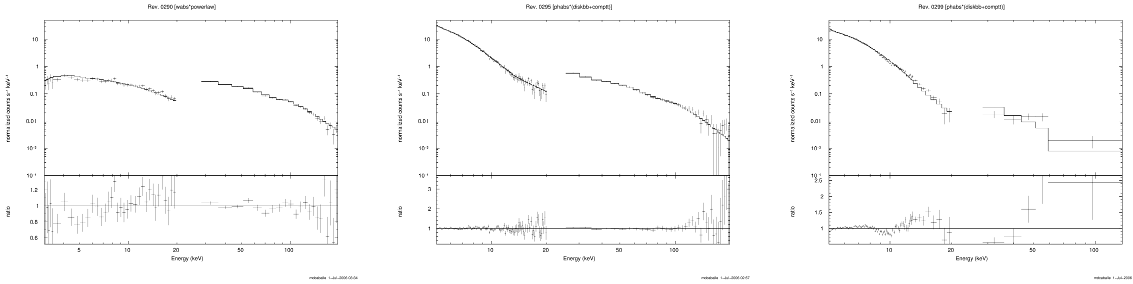

Figure 3. Spectra obtained by JEM-X and IBIS/ISGRI on board INTEGRAL for revolutions 290, 295 and 299 (left to right panel).

5. DISCUSSION

As we noted above, there was a transition from an LH state to an HS state [3]. This can be explained in the common accepted view of black hole X-ray transients, in which the low-mass companion star undergoes Roche-lobe overflow, but at a sufficiently low rate that the gas is accumulated in the (cool) disk until a critical level is reached, at which point the outburst occurs (Lasota [7]; Meyer-Hofmeister [9]). In between outbursts, the accretion rate is low and is conjectured that an ADAF model region fills the inner accretion disk. With this scenario, in the quiescent and low states the accretion is low and the spectrum is hard as is shown in our spectrum from revolution 290. During the outburst, the spectrum changes to a $\sim$1keV thermal spectrum, often interpreted as the radiation from a geometrically thin, optically thick accretion disk, superposed on a softer power law (photon indices $\Gamma \sim 2 - 3$) extending to $\sim$200 keV, as shown in our spectra from revolutions 295 and 296. When the accretion disk becomes thick and very hot, then the reflection features are manifested in the shape of the spectra (see Done & Nayakshin [5] and references therein), as can be seen in our spectra from revolutions 299 and 304. It is worth noticing that another plausible mechanism alternative to the Comptonizing medium in order to explain the energy emission at energies $\geq$20keV is the jet production.

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