

Comparing properties of the two microquasar GX 339–4 and 1E 1740.7–2942

Melania Del Santo*

INAF/IASF-Roma, Italy

E-mail: melania.delsanto@iasf-roma.inaf.it

Julien Malzac, Elisabeth Jourdain

CNRS/CESR Toulouse, France

Angela Bazzano

INAF/IASF-Roma, Italy

Laurent Bouchet, Jean-Pierre Roques

CNRS/CESR Toulouse, France

Tomaso Belloni

INAF/OAB Merate, Italy

Giovanni De Cesare, Pietro Ubertini, Memmo Federici

INAF/IASF-Roma, Italy

We report on *INTEGRAL* observations of the two microquasars GX 339–4 and 1E 1740.7–2942. Even though both sources are black hole candidates in LMXB systems, GX 339–4 has a transient behaviour, while the prototype of microquasars, 1E 1740.7–2942, is a persistent, even though variable source. We analysed a uniform data-set of GX 339–4 observations collected during the 2004 outburst using all *INTEGRAL* instruments. Observations were long enough to cover transitions between spectral states. Moreover, IBIS and SPI spectra of GX 339–4 showed a high energy excess with respect to pure thermal Comptonisation model, even during the hard/intermediate state. We analysed three years of SPI and IBIS data of 1E 1740.7–2942 during which two main states have been observed: the canonical low/hard state of black-hole candidates and a “dim” state, characterised by a ~ 20 times fainter emission. The low/hard state spectrum up to ~ 600 keV is well represented by a thermal Comptonisation plus an additional component modeling data above 200 keV. finally, we summarise results and make a comparison between the two sources.

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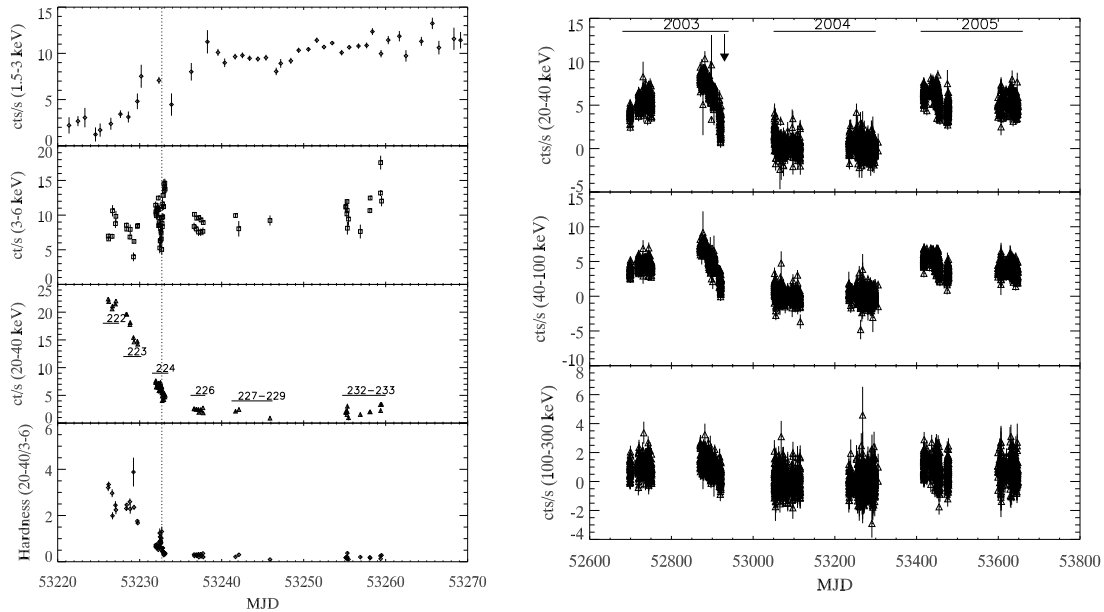


Figure 1: *Left:* GX 339–4 count rate in the energy ranges 1.5–3 keV, 3–6 keV, 20–40 keV with ASM, JEM-X and IBIS/ISGRI, respectively. The related *INTEGRAL* orbits are also marked on the IBIS light curve. IBIS/ISGRI to JEM-X hardness ratio is shown in the bottom panel. *Right:* 1E 1740.7–2942 temporal behaviour observed with IBIS/ISGRI in 2003, 2004, 2005. In 2004 the source was very weak, both in hard X-rays (2.6 mCrab in 20–40 keV) and in X-rays. In 2003 and 2005 it was most of the time in LHS, except in fall 2003, when it showed a soft/intermediate state before it quenched (arrow).

1. Introduction

Black hole candidates (BHCs) are known to show different spectral states in the X and γ -ray domain. The two main spectral states are the Low/Hard State (LHS), with a dominant Comptonised spectrum empirically described by a cut-off power-law (typically $\Gamma \sim 1.5$ and $E_{cut} \sim 100$ keV), and the High Soft State (HSS) with a spectrum described by a thermal component peaking at few keV and a high energy power-law much softer ($\Gamma > 2.2$) [19]. Intermediate spectral states with different contributions from the two components are also observed [20].

2. *INTEGRAL* observations of the two microquasar

2.1 GX 339–4

Before the launch of *RXTE*, the transient black-hole candidate (BHC) GX 339–4 was observed being very bright mostly in LHS for long time, until 1999 when it went into quiescence. Thereafter new outbursts occurred in 2002/2003 [17], in 2004 after one year in quiescence [5] and end 2006 [12]. The Hardness Intensity Diagrams (HID) of the three outbursts showed a similar pattern (i. e., the q -track of Homan & Belloni 2005); a number of spectral states with different spectral and timing characteristics were observed in each a single outburst [2, 21, 3, 8, 9].

The 2004 outburst was observed two times by the *INTEGRAL* satellite: during the first part of the hard X-ray activity (19 February–20 March) and during the decay of the hard X-ray flux, i. e. 9

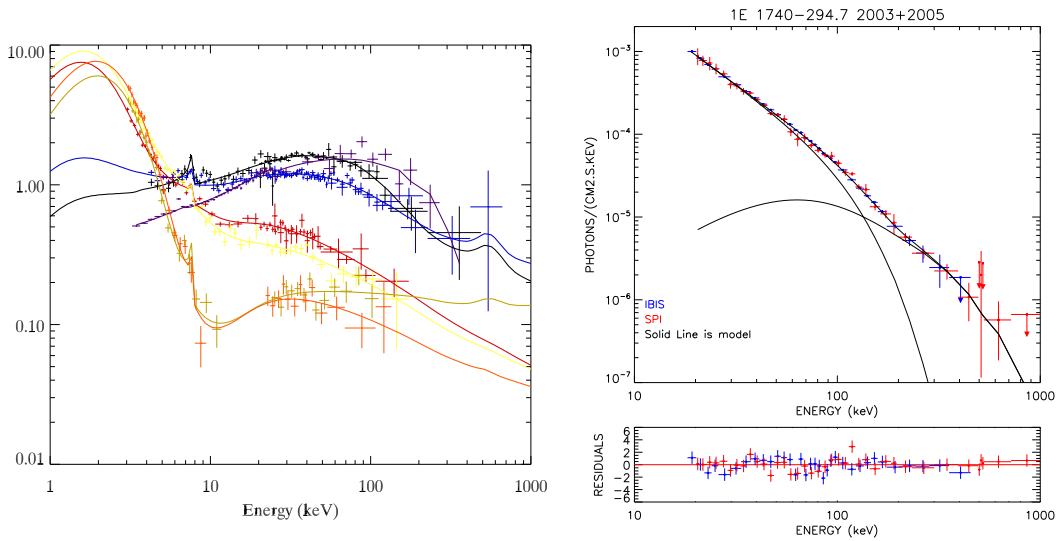


Figure 2: *Left:* Joint JEM-X, IBIS and SPI unfolded energy spectra (Model: EQPAIR) of GX 339–4 averaged during different spectral states in 2004: HIMS for spectra 1 (black), 2 (blue), 3 (red); SIMS for 4 (yellow); HSS for spectra 5 (green) and 7 (orange). In order to give a comparison with a pure Low/Hard state spectrum, we show a spectrum (violet) reported in Joinet et al. (2007). *Right:* 1E 1740.7–2942 spectrum observed by IBIS and SPI for 2003 + 2005 observations. Solid line is a two comptonisation model (2* compt), with hotter temperature fixed to 100 keV. The other parameters are described in the text.

August–11 September. We used *INTEGRAL* data collected during the latter observations (see Fig. 1, *left*) in order to study the broad-band spectral evolution of GX 339–4 during a hard-to-soft state transition [8].

2.2 1E 1740.7–2942

1E 1740.7–2942 spends most of the time in the canonical LH state of BHCs. In a few occasions soft spectral states have been observed [17] and in particular, in 2003 (see Fig. 1) *INTEGRAL* and *RXTE* observed an Intermediate/Soft spectral state occurred just before the source quenching [7].

Since its launch on October 17th 2002 *INTEGRAL* has been observing the Galactic Centre region, including the BHC 1E 1740.7–2942, two times per year, in the Spring and Fall visibility windows. We have analysed all public data collected between Spring 2003 and Fall 2005 by the spectrometer SPI and the imager IBIS. The useful data set consists in about 3500 exposures for a total useful time of 8 Ms along 6 periods (Spring and Fall, 2003, 2004 and 2005; see Fig.1, *right*).

Two main states have been observed: a canonical LHS at a flux level of ~ 50 mCrab and 60 mCrab in the 20–40 keV and 40–100 keV bands, respectively (Fig. 1, *right*), and a very-faint state (as in 2004) when the source was well below the ISGRI detection limit on the revolution time scale (~ 200 ks) and detected at a level of 2.6–2.7 mCrab (14σ over ~ 3 months integration time).

3. Spectral analysis results

3.1 GX 339–4

In the period 2004 August 9th–September 11th we observed GX 339–4 showing different spectral states, namely hard/intermediate (HIMS), soft/intermediate (SIMS), and HSS. According with the spectral analysis and timing, we divided data in seven groups obtaining seven averaged spectra. We refer to [8] for the scientific spectral parameters obtained by fitting joint JEM-X, IBIS and SPI spectra with EQPAIR [6] (Fig. 2, *left*). In the EQPAIR model, emission of the disc/corona system is modeled by a spherical hot plasma cloud with continuous acceleration of electrons illuminated by soft photons emitted by the accretion disc. At high energies the distribution of electrons is non-thermal, while at low energies a Maxwellian distribution with temperature kT_e is established. Our detailed spectral analysis of time averaged spectra at different stages of the transition confirms that the spectral transition is driven by changes in the soft cooling photon flux in the corona associated with an increase of disc temperatures (leading to dramatic increase of disc luminosity). The measured disc temperature versus luminosity relation suggests that the internal disc radius decreases. In contrasts, the heating rate of the electrons in the corona appears to remain nearly constant [8].

Here we outline that fitting spectra of the HIMS, non-negligible values of $I_{\text{nth}}/I_{\text{h}}$ (compactness ratio between the electron acceleration and total power supplied to the plasma) resulted, indicating a non-thermal emission being requested by the data.

Using a simple thermal Comptonisation model, some residuals are present at high energy (Fig. 3), especially in the spectrum collected during the revolution 223 (blue spectrum in Fig. 2, *left*). In order to model the presence of a non-thermal component, we added a power-law with $\Gamma \sim 2$ to the pure thermal Comptonisation model (Fig. 4). This led to an improvement of the χ^2 that is highly significant with the F-test probability as $p_{\text{compps}} = 6.6 \times 10^{-2}$ (see Del Santo et al. 2008 for a complete discussion).

3.2 1E 1740.7–2942

In spite of the flux variability, in 2003 and 2005 1E 1740.7–2942 was mostly in Low/Hard state with the same spectral parameters [7, 4].

Due to the modest SPI angular resolution ($\sim 2.6^\circ$), the spectrum directly extracted at 1E 1740.7–2942 position may contain contributions from other weak/close/“not detected” sources. Nevertheless, it is possible to obtain the emission spectrum of 1E 1740.7–2942 from SPI data with the information provided by IBIS/ISGRI (angular resolution $\sim 12'$). After the SPI data correction by removing emission of the nearby sources (see [4] for a complete data analysis description), we have built averaged spectra for 2003 and 2005, separately.

In a second step, we averaged a LHS spectrum collected during the whole analysed period. It allowed us to achieve a better statistics at high-energy and eventually give better constraints to the spectral parameters. Spectral fitting was performed with a thermal Comptonisation model (COMPTT, Titarchuk 1994), being the mechanism expected to play the major role in our energy domain (Tab. 1). We obtain electron temperatures of 50 keV with optical depths close to 1 that are quite canonical values for this class of objects. However, the total (2003+2005) averaged spectrum

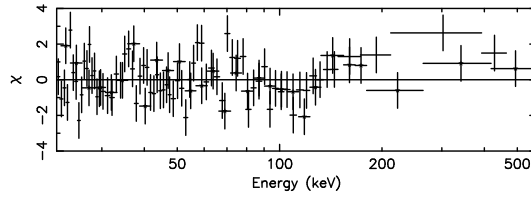


Figure 3: Residuals obtained with a simple thermal Comptonisation model (COMPPS) by fitting IBIS and SPI spectra of GX 339–4 during orbit 223.

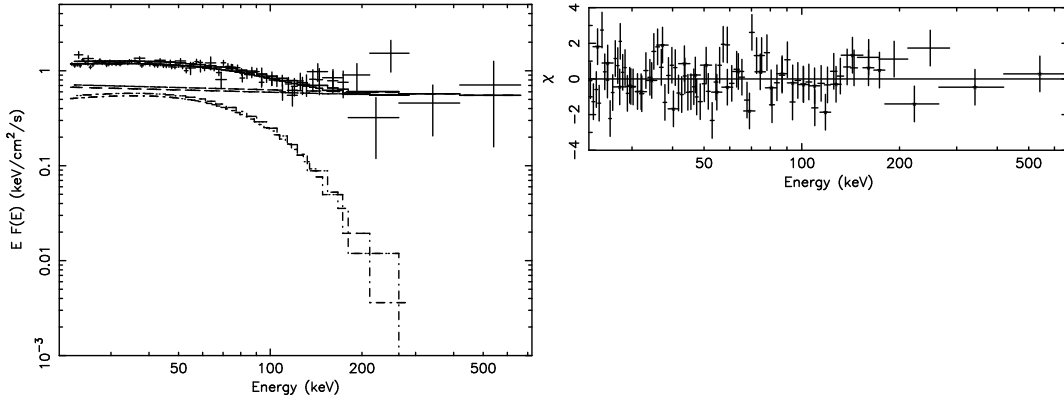


Figure 4: GX 339–4 energy spectrum and residuals of rev 223 fitted with a Comptonisation model (COMPPS) plus power-law.

gives high χ^2_{ν} value (1.8 for 69 dof), which, together with an excess of emission relatively to the proposed model, suggests the presence of a supplementary component to explain data points above 200 keV.

Adding a power-law component ($\Gamma = 1.9 \pm 0.1$) when fitting the high energy data, it resulted a χ^2_{ν} close to 1. The plasma temperature is thus decreased as 27 ± 2.2 keV with a value of τ of 1.9 ± 0.25 . Even though this two components model is quite reasonable, with a classical explanation of a non-thermal process responsible of the power-law emission, we tested an alternative scenario with only thermal mechanisms involved (Tab. 1). Indeed, a two (thermal) Comptonisation model gives a similarly acceptable (in term of χ^2) description of the spectrum. However parameters are very poorly constrain, so that we had to freeze temperature of the second electrons population at 100 keV. Moreover, we consider that this population comptonises photons coming from the first Comptonising region, i. e. $(kT_{seed})_2 = (kT_e)_1 \sim 30$ keV. The optical depths of both regions are compatible (Tab. 1) while the $\chi^2_{\nu} = 1.07$ (67 dof) leads to an F-test probability of $\sim 10^{-8}$ for the existence of such a second component. Results corresponding to this scenario are displayed in Fig. 2 (Right).

4. Discussion

GX 339–4: we observed spectral transitions as driven by changes in the soft cooling photon flux in the corona associated with an increase of disc temperatures. This gives rise to a dramatic increase of the disc luminosity. The measured disc temperature versus luminosity relation suggests

Table 1: The best fit parameters for the combined ISGRI and SPI 1E 1740.7–2942 spectra with Comptonisation model (COMPTT, Titarchuk 1994). T0 is fixed to 0.3 keV. For the 2003+2005 spectrum, the second line corresponds to a 2 Comptonisation model ($(kT_e)_1$, τ_1 , $(kT_e)_2$, τ_2) with the 2nd seed photon temperature fixed to $(kT_e)_1$ and $(kT_e)_2$ fixed to 100 keV.

period	$(kT_e)_1$ keV	τ_1	$(kT_e)_2$ keV	τ_2	χ^2_ν (dof)	F-test ⁽¹⁾
2003	50.1 ± 2.6	1.00 ± 0.06			1.1 (69)	
2005	45.4 ± 2.7	1.10 ± 0.08			1.35 (69)	
2003+2005	48.1 ± 2.0	1.06 ± 0.05			1.8 (69)	
2003+2005	29.4 ± 3.1	1.6 ± 0.1	100	2.2 ± 0.8	1.07 (67)	10^{-8}

⁽¹⁾for the presence of a second Comptonisation component.

that the internal disc radius decreases. In contrasts, the heating rate of the electrons in the corona appears to remain nearly constant.

Although other models such as dynamic accretion disc corona model cannot be ruled out, our results are consistent with the so-called truncated disc model [10]. Moreover, in all GX 339–4 spectra, including those in (HIMS), we found a significant contribution from a non-thermal component. This component appears as a high energy excess above the pure thermal Comptonisation spectrum. We associated this component with the presence of a non-thermal tail in the distribution of the Comptonising electron.

1E 1740.7–2942: we have observed two main states, namely the canonical low/hard state of black-hole candidates and a “dim” state, characterised by a ~ 20 times fainter emission, detected only below 50 keV and only when adding more than 1 Ms of data. For the first time the continuum of the low/hard state has been measured up to ~ 600 keV with a spectrum that is well represented by a thermal Comptonisation plus an additional component necessary to fit the data above 200 keV [4]. This high energy component could be related to non-thermal processes, even though this interpretation is more consistent with intermediate and/or soft states [21]. Alternatively, we show that a model composed by two thermal Comptonisations provides an equally representative description of the data: the temperature of the first population of electrons results as ~ 30 keV while the second, kT_2 is fixed at 100 keV. This scenario could be the result of spatial/temporal variations in plasma parameters [14].

Comparison:

- GX 339–4 is a transient BHC which shows frequent outbursts at different peak luminosity levels [3, 8, 9], while 1E 1740.7–2942 is a persistent source which periodically undergoes a dim state.
- GX 339–4 shows a complete set of spectral states, as well as fast state transitions (LHS-HIMS-SIMS-HSS) at different flux levels, while 1E 1740.7–2942 is observed to be most of the time in the canonical LHS at different luminosities and only before the quenching it shows a temporary intermediate/soft state [7, 17];
- we have observed high energy tails in both sources that may be interpreted as non-thermal

components; alternatively, a model with two thermal Comptonisation components can be invoked for the Low/Hard state of 1E 1740.7–2942.

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