STUDY OF THE HIGH ENERGY EMISSION OF GX339-4 AND H1743-322 DURING STATE TRANSITIONS WITH *INTEGRAL* AND *RXTE*

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ABSTRACT

GX339-4 and H1743-322 are transient Galactic black holes which demonstrate a complex X and radio activity. H1743-322 exhibited correlated X and γ ray flare events within a timescale of one day after the relativistic ejection that occured around the maximum luminosity. We will compare the spectral evolution of both sources during the state transition occuring during their outbursts of 2002-2004 and 2003 for GX339-4 and H1743-322 respectively using *INTEGRAL* and *RXTE* data.

Key words: GX 339-4, H1743-322 - gamma rays : observations - black hole physics.

1. PRESENTATION OF SOURCES

X-ray transients exhibit dramatic outbursts caused by changes in mass accretion rate. They go through a complex multistate which can be followed by studying their spectral and timing evolution. In the X/γ energy domain, their energy spectra consist of two main components which allow to characterise the state of the sources. In the High Soft (hereafter HS) state, the soft X-ray emission (below 10 keV) dominates the spectrum in the form of a blackbody component. In the Low Hard (hereafter LH) state, the hard X-ray emission (above 10 keV) dominates the spectrum in the form of a powerlaw component with an exponential cutoff around 100 keV.

The main goal of this article is the comparison of the spectral evolution of the outbursting Galactic black holes H1743-322 and GX339-4 during a LH to HS state transition.

1.1. H1743-322

H1743-322 was discovered in August 1977 by *HEAO1* [11]. Early 2003, *INTEGRAL* observations showed a slowly rising hard X-ray flux of IGR J17464-3213 which

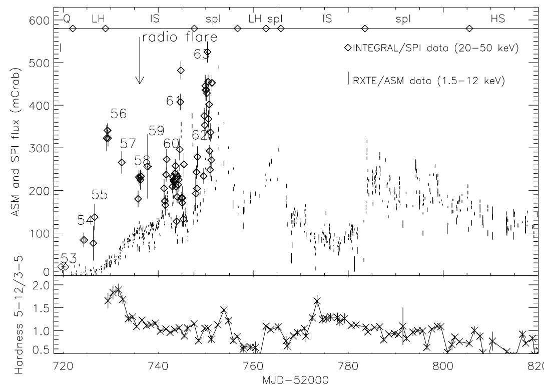

Figure 1. ASM and SPI light curves of H1743-322 during the 2003 outburst. The different states harboured by the source are : Q(=quiescent), LH(=low hard), HS(=high soft), IS(=intermediate) and spl(=very high) states as defined in [18]. We indicate the INTEGRAL revolution numbers.

was detected [22] with the IBIS imager onboard the *INTEGRAL* observatory, and then from *RXTE* observations [16]. It was demonstrated that the position of the source was consistent with the H1743-322 transient from PCA data onboard the *RXTE* observatory [17]. That was the beginning of a long outburst which lasted until the end of November 2003 (see Fig. 1). During this period, the source was monitored by *RXTE* [7] and *Chandra* [20] showing the occurrence of various spectral/timing states. A strong radio flare (and hence a massive plasma ejection) was reported on April 8 [23] and is likely consistent with emission from a jet [19]. The analysis presented here is based on the data recorded from revolution 53 starting 2003 March 21 (MJD 52719) to revolution 63 finishing 2003 April 22 (MJD 52751) from *INTEGRAL* and quasi-simultaneous *RXTE* observations.

1.2. GX339-4

GX339-4 can be classified as a quasi-persistent as well as a recurrent transient source with a recurrence time of about 1 year. In 2002, GX339-4 started a new outburst

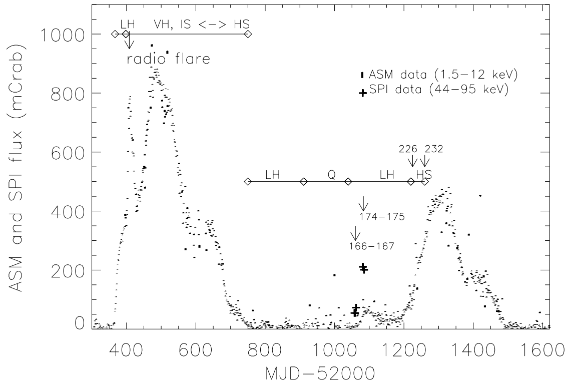

Figure 2. ASM and SPI light curves of GX339-4 during the 2002 and 2004 outbursts. See Fig. 1 for the caption.

[24] after almost three years in quiescence [12]. Fig. 2 shows the ASM light curve of the source in the 1.5-12 keV energy range. There is a first rising phase during which the source reaches a maximum flux of $\simeq$ 0.8 Crab (2-12 keV) on 2002 May 15 (MJD 52410). It was associated with the brightest radio flare [28] ever observed from this source. It lasted for a few hours and was observed 1-2 days before the transition to the very high state [4]. After a slow decay phase and few months in quiescence, the source was reactivated entering into the LH state. The analysis presented here is based on the data recorded from 2004 February 4 (MJD 53039) corresponding to the beginning of the outburst [13] up to 2004 August 19 from *INTEGRAL* (SPI and IBIS) and completed by *RXTE* (PCA and HEXTE) observations.

2. THE SPECTRAL EVOLUTION DURING THE STATE TRANSITION

One of the main interest in studying the spectral evolution of a source during a state transition is **the study of the structure of the accretion flow**. It allows to follow the evolution of the soft X-ray emission of the accretion disc (during the HS state) to the appearance of a hard X-ray component (during the LH state). Does this component relate to the coronal or to the jet emission ? Which physical process initiates the state transition ? We attempt to solve these questions by performing the spectral analysis of these sources along their transition state. The discussion of this article is based on the detailed studies of both sources presented in [9] and [1] for H1743-322 and in [10] for GX339-4.

The different states summarized on the light curves of H1743-322 (Fig. 1) and GX339-4 (Fig. 2) fulfill the criteria of the spectral classification of [18]. Both sources present some similarities during the rise phase of their outbursts. First, there is a decrease of the hardness in the 3-12 keV energy range. Second, they both present a relativistic event ejection during the LH to the HS state transition. From several studies (i.e. [3]), it was shown that the jets and the X-ray states are closely related. For H1743-322, the radio flare event marks the beginning of the intermediate state which is caracterized by the presence of correlated X and γ-ray flare events within a timescale of about one day.

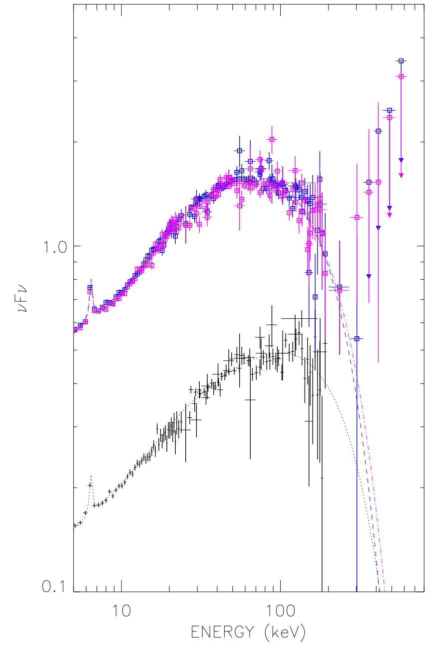

Figure 3. Spectra from simultaneous PCA, HEXTE, IBIS and SPI observations of GX339-4. They correspond to INTEGRAL revolutions 166+167 (black plus signs), 174 (dark squares), 175 (light gray squares). Data was fitted using the Comptonization model described in text (see section 3.2).

3. STUDY OF THE GEOMETRY EVOLUTION DURING THE STATE TRANSITION

3.1. Requirement of a high energy cut-off combined with a reflection component

The spectral evolutions of GX339-4 and H1743-322 are shown in Fig. 3 and 4 respectively and are characteristic of a state transition with the increase of the soft X-ray part (the 3-25 keV energy range) of the spectrum. This last one has been constrained by data from PCA detector onboard the *RXTE* observatory. and modelled by a cold accretion disc described by a blackbody emission (DISKBB in XSPEC) with a temperature kept free for H1743-322 and frozen to 390 eV for GX339-4. The standard accretion disc models [25] cannot produce hard X-ray emission. This latter is generally interpretated as due to thermal Comptonization processes in a hot phase (or corona). The geometry of this hot phase is proposed either as the hot inner part of the disc [26] or as small active

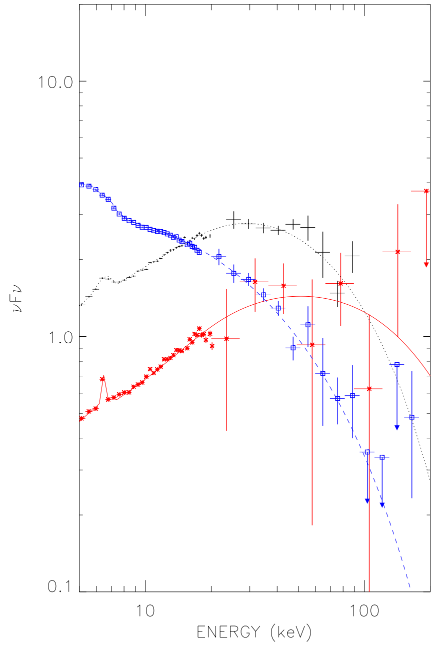

Figure 4. Spectra from simultaneous PCA and SPI observations of H1743-322. They correspond to INTEGRAL revolutions 55 (asterisks), 56 (black points) and 58 (squares). Data was fitted using the model described in Table 1.

regions located above the accretion disc [6]. The hard X-ray spectrum also exhibits reflection features interpreted as reflection of the Comptonized emission on relatively cold matter (disc).

The hard X-ray part of the spectra (above 20 keV) which dominates during the LH state was constrained by SPI data as well as IBIS & HEXTE data for GX339-4. It was described with the PEXRAV model [15] consisting of a power-law with a high energy cut-off combined with the reflection from neutral medium. $\Omega/2\pi$ represents the fraction of the hard X-ray spectra emitted toward the disc where it is reflected. Table 1 and 2 summarized the fit parameters obtained for H1743-322 and GX339-4 respectively. For H1743-322, as the hard X-ray spectrum softens (Γ increases from 1.07 up to 2.6), both the inner disc temperature and the flux grow progressively, as expected when the accretion disc surface increases. The reflection fraction $\Omega/2\pi$ remains around 0.5. For GX339-4, the reflection fraction increases from 0.2 up to 0.5 with the photon index of the power-law and flux. [29] have interpreted the Ω-Γ correlation as being due to feedback in an inner hot (thermal) accretion flow surrounded by an overlapping cold disc.

3.2. Spectral modelling with Comptonization model

The spectra of GX339-4 presented in Fig. 3 has been modelled with COMPPS model [21] in XSPEC. A black-body seed photons with a temperature of 390 eV are injected into a spherical corona of uniform optical depth τ and temperature kT where they are Comptonized. A fraction Ω is scattered back into the disc where it is reflected. During the LH state (revolutions 166 (MJD 53057), 167 (MJD 53062), 174 (MJD 53081) and 175 (MJD 53085)), we notice a decrease of the plasma temperature kT (from 72 keV down to 60 keV) as the spectra becomes softer (the powerlaw slope Γ fitted by PEXRAV model increases as seen from Table 2). There is a cooling of the hot plasma by the blackbody photons emitted by the cold disc which extends closer to the central black hole. As the source evolves toward the HS state (revolution 226, MJD 53437), there is an increase of the plasma temperature (kT $\simeq$ 108 keV) and a decrease of the optical depth ($\tau \simeq 0.08$).

We used the Comptonization model COMPTT [27] to describe the spectral shape of H1743-322 (see Table 5 of [9] for the description of the different fit parameters). We found that the soft photon flux emitted by the accretion disc increases (from the LH to the intermediate state) whereas the optical depth of the corona decreases (from 3.13 down to 0.26). A possible interpretation could be that the inner radius of the optically thick accretion disc moved inward while coronal mater was ejected or collapsed in the accretion disc. The decrease of the coronal optical depth as the source evolves toward the HS state could be related to the disappearance of the compact jet.

Table 1. Approximation of PCA and SPI data from observations of H1743-322 with the XSPEC multicomponent model $PHABS \times (DISKBB + PEXRAV + GAUSSIAN)$. T_{in} is the inner disc temperature, Γ the powerlaw photon index and E_c the energy cutoff. The reflection fraction $\Omega/2\pi$ remains around 0.5.

Rev.	T_{in} keV	Γ	E_c keV	χ^2(dof)
55	$0.29^{+0.36}_{-0.29}$	$1.07^{+0.15}_{-0.19}$	80^{+145}_{-37}	1.47(40)
56	$0.34^{+0.46}_{-0.08}$	$1.45^{+0.12}_{-0.18}$	62^{+13}_{-21}	1.30(46)
58	$0.37^{+0.31}_{-0.06}$	$2.37^{+0.06}_{-0.05}$	71^{+26}_{-17}	0.80(45)
60-63 (nf)	$1.33^{+0.03}_{-0.03}$	$2.58^{+0.10}_{-0.15}$	88^{+85}_{-37}	1.70(42)
61,63 (f)	$1.57^{+0.01}_{-0.01}$	$2.58^{+0.03}_{-0.03}$	99^{+28}_{-19}	2.39(39)

(nf) refers to no flare events
(f) to flare events (flux in the 20-50 keV $\geq$ 300 mCrab)

Table 2. Approximation of PCA, HEXTE, SPI and ISGRI data from observations of GX339-4 with the XSPEC multicomponent model PHABS(PEXRAV+GAUSSIAN). Γ is the photon index and E_c the energy cut-off. $\Omega/2\pi$ is the reflection fraction.*

rev	Γ	E_c keV	$\Omega/2\pi$	χ^2(dof)
166+167	$1.58^{+0.02}_{-0.02}$	365^{+100}_{-67}	$0.22^{+0.06}_{-0.06}$	0.82(172)
174	$1.64^{+0.02}_{-0.02}$	293^{+60}_{-41}	$0.43^{+0.08}_{-0.07}$	0.91(114)
175	$1.69^{+0.02}_{-0.02}$	402^{+103}_{-71}	$0.52^{+0.08}_{-0.08}$	1.60(114)

4. PHYSICAL INTERPRETATION OF THE HIGH ENERGY EXCESS OBSERVED FOR GX339-4

During the observation period of the revolution 175, GX339-4 has been detected by SPI with a significant flux of 7.2×10^{36} erg s^{-1} in the 200-437 keV energy range (see Fig. 3 in [10]). The corresponding flux is not highly significant with only 4.6 σ, but can be compared to feature reported by the CGRO detector onboard the *CGRO* observatory with a flux above 200 keV of 11.3×10^{36} erg s^{-1}. The spectrum of GX339-4 during this dataset and from SPI observations only has been modelled by the Comptonization model COMPPS using an electron temperature kT=44 keV and an optical depth τ=4.44 with a reduced χ^2 of 1.35. The addition of a power-law improve the fit at the 90% level according to an F-test with a photon index power-law Γ of 1.07 which supports the presence of an excess above the Comptonization model. Such an extension detected in the LH state has already been observed in the HS state of Cygnus X-1 (see [5] and [14]) and is interpreted by a non-thermal origin due to Comptonization of soft photons by accelerated electrons. Homan et al. [8] suggest a non-thermal jet origin for the optical/near infrared emission in the LH state of GX339-4 during its 2002 outburst. In order to investigate a physical interpretation of this excess, we used the hybrid thermal/non-thermal Comptonization model EQPAIR [2]. We conclude that an electron population with a non-thermal fraction of $\simeq$ 0.28 would describe the high energy part of the spectra. This suggest to investigate the possible contribution from the jet in producing hard X-ray emission. As a non thermal emission is known to be often associated with the HS state of Cyg X-1, a question to be solved is : does the powerlaw extension above a Comptonization component along the different states of a source have always the same origin ?

5. CONCLUSION

The goal of such a comparive study is the elaboration of a scheme to explain the link of the X/γ emission and radio ejection. We know that it could give some clues on the geometry evolution of X-ray transients during a state transition. We have studied the variability of the high energy part (above 20 keV) of the spectra on the timescale of a day. Such a comparative study should be extend to other sources emitting jet.

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