Recent Trends in the Study of Compact Objects: Theory and Observation
ASI Conference Series, 2013, Vol. 8, pp 79–83
Edited by Santabrata Das, Anuj Nandi and Indranil Chattopadhyay

Spectro-temporal evolution during the onset-phase of the 2011 outburst of IGR J17091-3624 – Implications on accretion disk dynamics

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Abstract. We re-analysed the archival data of RXTE / INTEGRAL / Swift satellites at the onset phase of the 2011 outburst of the X-ray source IGR J17091-3624. The evolution of the spectral and temporal properties of the source in this phase clearly exhibits state transition as Hard (HS) → Hard-Intermediate (HIMS) → Soft-Intermediate (SIMS) → Soft (SS) state, before entering the variability phase (VP). We attempt to understand the evolution of X-ray features and the state transitions based on two different types of accreting material (i.e., the Keplerian and sub-Keplerian flow).

Keywords : stars: individual: IGR J17091-3624 – methods: data analysis – black hole physics – radiation mechanisms: general

1. Introduction

The X-ray source IGR J17091-3624 was first observed in 2003 by IBIS on board the INTEGRAL satellite (Kuulkers et al. 2003). In early 2011, the source brightened again (Krimm et al. 2011). The subsequent observations (in 2011) have led to the discovery of similar intensity-time variations (i.e. the variability phase) in this source as shown by GRS 1915+105. We make an attempt to re-look at the initial few days ($\sim$ 40 days) of the outburst in 2011. We believe that the onset phase of the outburst though looked at by others (Pahari, Yadav & Bhattacharyya (2011) and Capitanio et al. (2012)), can be looked at in greater detail to understand the disk dynamics. In the following sections, we outline the observations and analysis techniques and draw inferences from the results based on our analysis.

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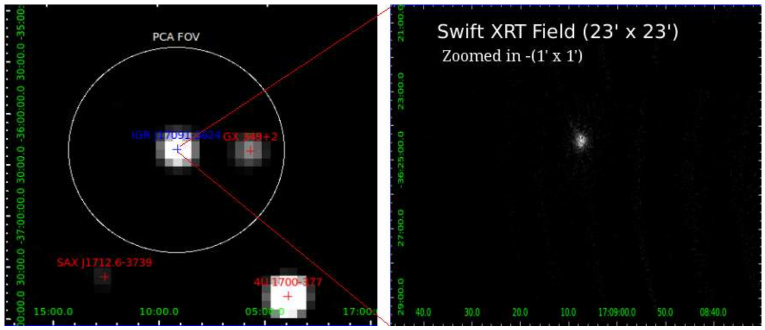

Figure 1. IGR J17091-3624 and surrounding field (left panel INTEGRAL IBIS, right panel Swift XRT). As seen, the PCA FOV has two sources leading to source confusion.

2. Observation and analysis

The observations we used in the rising phase of the outburst were from the dates `2011 Feb 03` to `Mar 14` (~ 40 days). In this duration, we used the archival data from Swift, INTEGRAL and RXTE satellites. The source field being rather crowded (Fig. 1; see also Pahari et al. (2011)), the RXTE PCU observations were contaminated until `Feb 23` by the nearby bright X-ray LMXB source GX 349+2. Hence only the central frequency of the QPO was extracted from the contaminated RXTE data. The QPO feature of the PDS was confirmed to be from the IGR J17091 source by looking at the absence of such a feature from simultaneous observation of the nearby source (GX 349+2) using INTEGRAL JEM-X for the same energy band.

Temporal analysis was done using Swift XRT (0.5 – 10 keV) and RXTE data sets with the above mentioned constraints. For analysing the data, GHATS v1.1 [1], a customised IDL based timing package was used. The Swift XRT data extraction was done using HEASOFT 6.12 and the ftools package `xrtpipeline`. The INTEGRAL data reduction was done using the OSA 10.0 software. We used XSPEC v12.7.1 for spectral fitting. For 0.5 – 10 keV Swift XRT data, we used `diskbb` and `powerlaw` modified by an absorption column (`phabs`). For simultaneous Swift and INTEGRAL data (0.5 – 150 keV), the `powerlaw` model was replaced by the `cutoffpl` model, which enabled us to study the cutoff/fold energy evolution with time. The data in the rising phase (until the observation of `Feb 22`) did not require additional `diskbb` component, and fit well with a `powerlaw` (or `cutoffpl`) and a `phabs` model. For modelling the power spectra as well as the QPO frequencies, a combination of the `lorentz` models were used.

3. Results

In Fig. 2, we have plotted the Hardness Intensity Diagram (HID) that was obtained by plotting the XRT count rate (0.5 – 10 keV) against the ratio of counts in the 4 – 10

[1] http://www.brera.inaf.it/utenti/belloni/GHATS_Package/Home.html

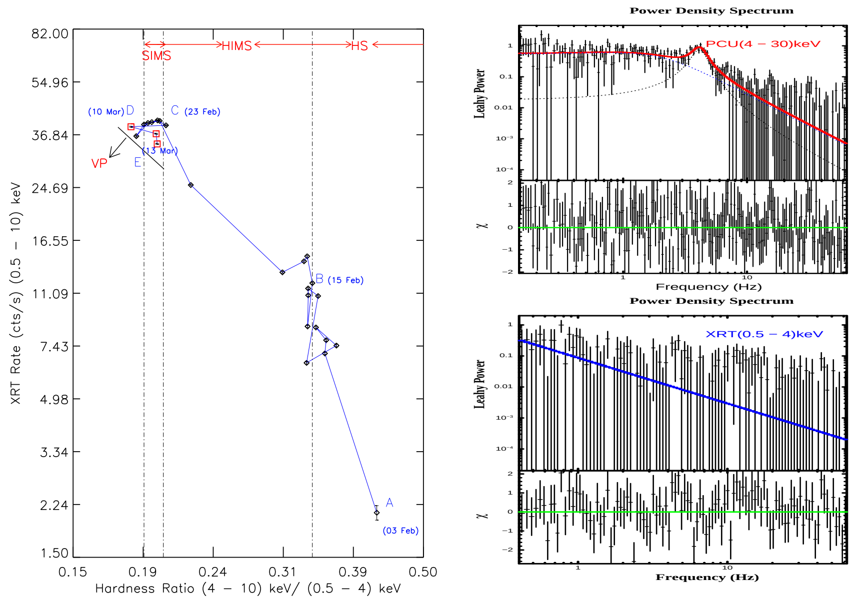

Figure 2. In Hardness Intensity Diagram (left), the states are demarcated by the vertical lines, except the Soft state (marked by red boxes) and the VP. Energy dependence of QPO (right) – the QPO is visible in the (4 – 30) keV range and is not seen in the soft photons (0.5 – 4) keV, which mostly arise from the Keplerian accretion disk. Power spectra are from 23 Feb (PCU) and 24 Feb (XRT) observations.

keV band to that in the 0.5 – 4 keV band. The evolution of HID is clearly seen to vary with distinct transition between states. The transitions are also seen in the variations of hardness, QPO frequency, soft flux, photon index (Γ) and overall RMS as shown in Fig. 3. Hence, we propose that the evolution is along the lines as seen in other black hole binaries, as outlined –

`(a) Hard state` (from `03 Feb - MJD 55595.90`) – marked by mostly constant low frequency QPO ($\sim$ 0.1Hz) and Γ ($\sim$ 1.6) with high values of HR ($\sim$ 0.35).

`(b) Hard Intermediate state` (from `15 Feb - MJD 55607.25`) – marked by decrease from the peak value in the BAT counts, gradual increase in the QPO frequency, Γ and a significant drop in the HR value indicative of a state transition.

`(c) Soft Intermediate state` (from `23 Feb - MJD 55614.21`) – marked by higher and very slowly increasing values of (Γ) and QPO frequency as compared to the previous states and the appearance of a disk component, as shown in Fig. 4 .

`(d) Soft State` (`10 Mar to 13 Mar`) – marked by absence of QPO (0.5 – 30 keV) and soft spectra with higher Γ and disk temperature, as shown in Fig. 3

It is also observed that the QPO is not seen in the soft photons (0.5 - 4 keV), once the disk is observed in the spectrum (right panel of Fig. 2). All these variations (temporal as well as spectral) can be interpreted in terms of the Two Component Advective Flow (TCAF) model proposed by Chakrabarti & Titarchuk (1995). The right-most state in the HID corresponding to the HS is mostly dominated by the Sub-Keplerian flow with hot electron plasma causing the hard emission. The central states in the HID

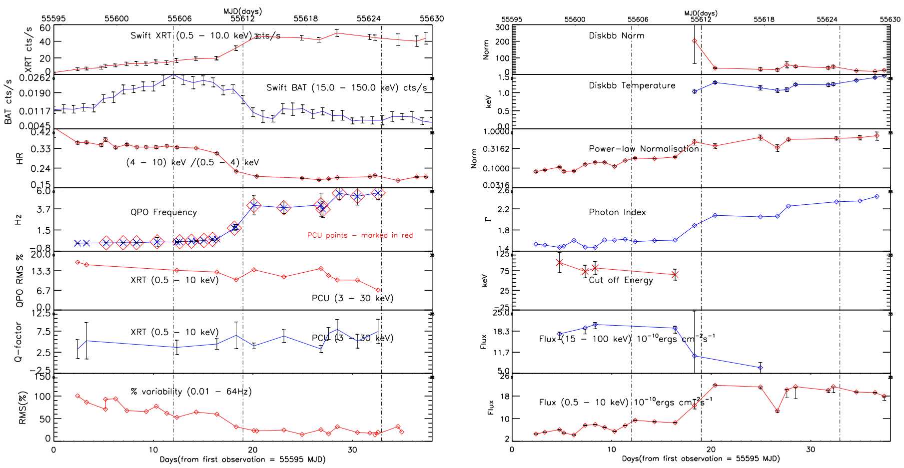

Figure 3. Evolution of temporal (left) and spectral (right) features of the 2011 outburst of IGR J17091-3624 (except the variability phase). The vertical lines indicate the state transitions observed during the outburst (See Fig. 2 and text for details).

– the HIMS (with increasing Keplerian component in the flow) and the SIMS (with comparable Keplerian and Sub-Keplerian inflow matter) states have softer emission with higher fluxes, and are followed by a disk dominated Soft state. After `13 Mar`, the system exhibits a variety of X-ray oscillatory features (ρ, α, ν, μ and other such classes; see also Altamirano et al. (2011)) like GRS 1915+105 but seems to be confined (as indicated by the arrow; see also Capitanio et al. (2012)) in the Soft Intermediate state of the declining phase of the outburst (marked as VP in HID).

The spectrum of the source, as obtained by simultaneously fitting of INTEGRAL and Swift spectra is shown in Fig. 4. We have attempted to fit the broad-band (0.5 – 100 keV) spectrum using a phenomenological model consisting of a multi-color

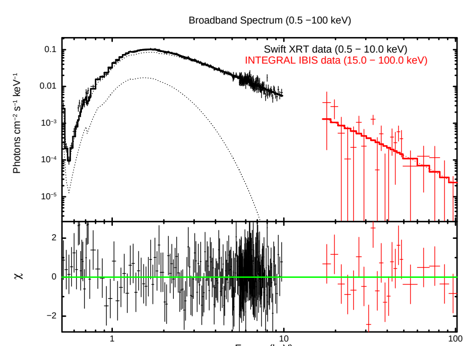

Figure 4. Broadband Spectrum of `2011 Feb 22` observation fitted with `phabs*(diskbb + cutoffpl)` model.

disk and power-law with an exponential roll-off (or cutoffpl) modified by columnar absorption. Similar kind of fitting of the spectrum using the TCAF model and its implications on the disk dynamics and system parameters are investigated further in Iyer et al. 2013 (in prep.).

4. Conclusions

The movement of the system through the HID in distinct states can be interpreted in terms of a sub-Keplerian hot flow responsible for the hard power-law component of the spectrum, and a Keplerian flow giving the soft photons as per the classical multi-color disk model. The QPO variations can be modelled using the movement of an oscillatory shock front in the TCAF model (see Iyer et al. 2013). The continuous inward drift of this shock front causes the QPO frequency to vary as seen in Fig. 3, till the system transits to the SIMS. Here, the QPO frequency initially stabilises indicating that the shock front does not move in further, and then dies out, indicating a Keplerian disk dominated Soft state. The variations in the spectral features can also be explained under the TCAF paradigm as already attempted for the case of GX 339-4 (Nandi et al. 2012). The soft photons from the disk, are not seen in either the HS or the HIMS indicating negligible inflow from the Keplerian component in these states. The modelling of the spectro-temporal correlations (the QPO evolution and Γ-QPO relation) and the broad-band spectrum gives preliminary indication that the source is a massive ($> 10M_{\odot}$) black hole (Iyer et al. 2013), like the galactic black hole source GRS 1915+105. Based on this similarity in mass and temporal variations, we propose that the source GRS 1915+105 could also be currently locked in the variability phase (VP) of its evolution, and that some time in the past had undergone evolution from the Hard to the Intermediate to the present state (i.e., variability phase).

Acknowledgments

The authors would like to thank Dr. S. Seetha (Space Science Office, ISRO HQ) and Dr. P. Sreekumar (Space Astronomy Group, ISAC) for helping them make use of the facilities at ISAC to do this research and to be able to attend the conference.

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