High-mass X-ray Binaries: Illuminating the Passage from Massive Binaries to Merging Compact Objects
Proceedings IAU Symposium No. 346, 2019
L. M. Oskinova, E. Bozzo, T. Bulik & D. Gies, eds.

doi:10.1017/S1743921318007925

Orbital resolved spectroscopy of GX 301–2: wind diagnostics

Nazma Islam

Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
email: nazma.syeda@cfa.harvard.edu

Abstract. GX 301–2, a bright high-mass X-ray binary with an orbital period of 41.5 days, exhibits stable periodic orbital intensity modulations with a strong pre-periastron X-ray flare. Several models have been proposed to explain the accretion at different orbital phases. In Islam & Paul (2014), we presented results from an orbital resolved spectroscopic study of GX 301–2 using data from MAXI Gas Slit Camera. We have found a strong orbital dependence of the absorption column density and equivalent width of the iron emission line. A very large equivalent width of the iron line along with a small value of the column density in the orbital phase range 0.1–0.3 after the periastron passage indicates the presence of high density accretion stream. We aim to further investigate the characteristics of the accretion stream with an *AstroSat* observation of the system.

Keywords. stars: individual: GX 301–2, stars: neutron

1. Introduction

GX 301–2 is a bright High Mass X-ray binary pulsar, with an orbital period $\sim$ 41.5 days of the binary system and spin period of the neutron star $\sim$ 685 sec (Koh *et al.* 1997). It exhibits periodically varying intensity modulations: a bright phase during X-ray flare (pre-periastron passage around orbital phase 0.95), dim or low intensity phase (after periastron passage around orbital phase 0.15–0.3) and intermediate intensity phase (during the apastron passage around orbital phase 0.5). A strong X-ray flare occurs before the periastron passage as well as a medium intensity peak is observed at the apastron passage, indicating accretion onto the neutron star due to both spherical stellar wind along with a possible equatorial disk or accretion stream (Pravdo & Ghosh 2001, Leahy & Kostka 2008).

GX 301–2 has a highly absorbed X-ray spectrum with a partial covering high energy cutoff power-law component and several emission lines. It has a very high line of sight photoelectric absorption ($\sim 10^{23}$ cm^{-2}), which is attributed to the dense circumstellar environment in which the neutron star moves. A prominent Fe Kα line is found to exist in almost all orbital phases. This fluorescence line is produced due to reprocessing of X-ray photons from the pulsar by the surrounding circumstellar matter. The equivalent width of the Fe Kα line depends on the distribution (geometry and column density) of the surrounding matter (Kallman *et al.* 2004). Therefore, by comparing the equivalent width of Fe Kα line with N_H, we can study the distribution of circumstellar matter around the neutron star at different orbital phases and can be further used to examine various accretion models.

Monitor of All sky X-ray Image (MAXI) is all sky X-ray monitor, operating on the International Space Station since 2009 (Matsuoka *et al.* 2009). The main instrument on MAXI, Gas Slit Camera, are proportional counters, operating in energy range 2–20 keV (Mihara *et al.* 2011). Its uniform orbital coverage of GX 301-2 for multiple orbital

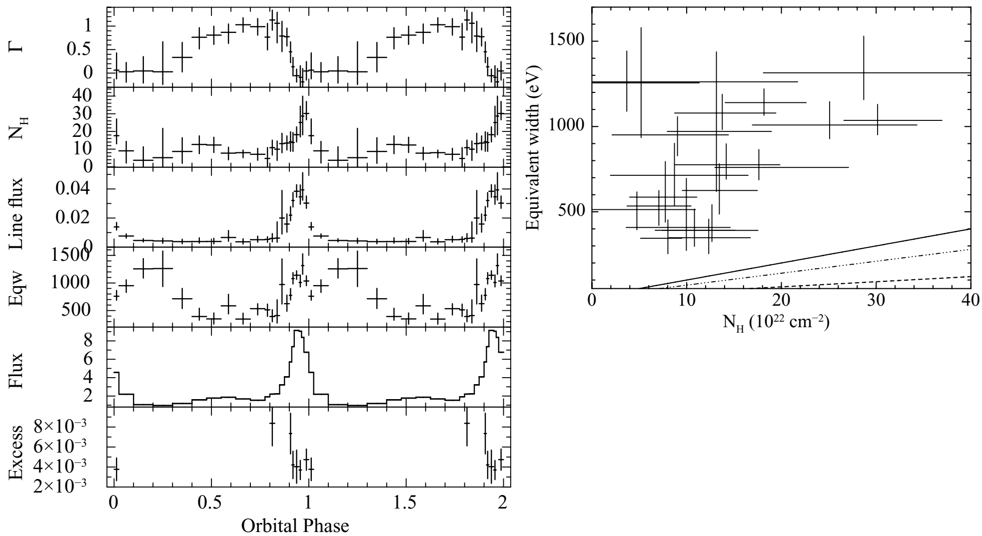

Figure 1. Left panel (a): Orbital variation of Photon index (Γ), column density (N_H in 10^{22} cm^{-2}), Line flux of Fe Kα (photons cm^{-2} s^{-1}), Equivalent width of Fe Kα line (Eqw in eV) and Flux of source (F in 10^{-9} ergs s^{-1} cm^{-2}) for power-law model with high energy cut-off model. Right panel (b): Plot of equivalent width of Fe Kα versus N_H. Solid line and dashed lines represents the relation between equivalent width and column density of absorbing matter for isotropically distributed matter at different Γ (Inoue 1985, Kallman *et al.* 2004).

cycles smears out of short time scale variations and long-term accretion characteristics are brought forth. In Islam, & Paul (2014), we carried out orbital phase resolved spectroscopic study of GX 301–2 using long term data from MAXI–Gas Slit Camera. We studied the orbital phase dependence of the column density and the line equivalent width, which are then used to examine the various models about the distribution of circumstellar matter and the mode of accretion in GX 301–2.

2. Data and analysis

Using MAXI on demand data† we extracted orbital resolved spectra in 21 independent orbital bins. These orbital resolved spectra are fitted with two models: an absorbed power-law continuum, with and without a high energy cut-off. A Fe fluorescence line was found in all the orbital phases, which was modelled by a single Gaussian line. For some orbital phases near the X-ray peak, a low energy excess is found to be present in the spectra. To only estimate the flux in the soft excess, we have modelled the low energy excess with an unabsorbed blackbody component.

3. Discussions and conclusions

Figure 1(a) shows the orbital variation of Γ, N_H, flux and equivalent width of Fe fluoresence line, total flux of the system and ratio of flux included in the low excess to the total flux, for the absorbed power-law with a high energy cutoff model. The column density and flux of the Fe fluorescence line has a large value around the pre-periastron passage, suggesting the possible origin of X-ray flare due to enhanced mass accretion. The column density N_H is found to vary with a pattern similar to the flux of the system, indicating a possible origin of flare due to increased mass accretion. The orbital variation of equivalent width of Fe Kα line shows a different trend as compared

† http://maxi.riken.jp/mxondem/

https://doi.org/10.1017/S1743921318007925 Published online by Cambridge University Press

to the orbital variation of column density. The highest equivalent width occurs at the dim phase of 0.1–0.3 which also has lowest N_H along the line of sight. Figure 1(b) is the plot of equivalent width of the iron line and the absorbing column density N_H in different orbital bins. These observations highly deviate from the relation expected for an isotropically distributed gas (Inoue 1985, Kallman *et al.* 2004). Instead, there seems to exist high anisotropicity in the distribution of circumstellar matter around the X-ray pulsar, especially in some orbital phases. The optical studies of GX 301–2 done by Kaper *et al.* (2006) confirms the presence of gas stream trailing the X-ray pulsar around the orbital phases 0.18–0.34. These results strongly favour a high density gas stream plus a stellar wind model for mode of accretion on to the neutron star in GX 301–2 and provide stronger constraints to the model (Leahy & Kostka 2008).

4. *AstroSat* observations

Due to limited statistics with MAXI/GSC, we cannot further investigate the characteristics of the inferred high density accretion stream. *AstroSat* is an Indian astronomical observatory (Agrawal 2006, Singh *et al.* 2014), with five payloads to carry out simultaneous multi-wavelength observations. With the objective to further investigate the accretion stream characteristics, we carried out a 40 kilosec observation of GX 301–2 with Soft X-ray Telescope (SXT) and Large Area Xenon Proportional Counters (LAXPC) of *AstroSat*. This observation was carried out at the dim phase (orbital phase 0.1–0.3) where maximum anisotropicity in the distribution of the circumstellar matter is found. Further work in analysing these observations and interpreting the results are in progress.

References

Agrawal, P. C. 2006, *Advances in Space Research*, 38, 2989
Inoue, H. 1985, *SSRv*, 40, 317
Islam, N., & Paul, B. 2014, *MNRAS*, 441, 2539
Kallman, T. R., Palmeri, P., Bautista, M. A., Mendoza, C., & Krolik, J. H. 2004, *ApJS*, 155, 675
Kaper, L., van der Meer, A., & Najarro, F. 2006, *A&A*, 457, 595
Koh, D. T., Bildsten, L., Chakrabarty, D., *et al.* 1997, *ApJ*, 479, 933
Leahy, D. A., & Kostka, M. 2008, *MNRAS*, 384, 747
Matsuoka, M., Kawasaki, K., Ueno, S., *et al.* 2009, *PASJ*, 61, 999
Mihara, T., Nakajima, M., Sugizaki, M., *et al.* 2011, *PASJ*, 63, S623
Pravdo, S. H., & Ghosh, P. 2001, *ApJ*, 554, 383
Singh, K. P., Tandon, S. N., Agrawal, P. C., *et al.* 2014, *Space Telescopes and Instrumentation 2014: Ultraviolet to Gamma Ray*, 91441S