Spectroscopic study of the dipping behaviour of MXB 1658-298 with *XMM-Newton*

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Abstract

MXB 1658-298 is a transient low mass X-ray binary (LMXB), which has recently undergone a phase of enhanced X-ray emission after a long period of quiescence. It has an orbital period of $\sim$ 7.1 hours, which includes an X-ray eclipse of duration $\sim$ 15 minutes. The source also shows dipping and burst behavior. Study of eclipsing and dipping LMXBs is useful to probe the structures in the accretion disk. The X-ray intensity dips observed in MXB 1658-298 are indicative of obscuration by a thickened accretion disk at the outer regions. We have carried out a detailed study of this dipping source using *XMM-Newton* archival data of the current outbursts during 2015. During the 2001 observation, when the source was relatively brighter, dipping region lied between $\sim$ 0.7–0.96 orbital phase; while for 2015 observation, dipping region is narrower and it lied between $\sim$ 0.7–0.86 orbital phase. It is observed that the dipping during 2015 observation is shallower than 2001 observation. In this work, we will discuss the results of spectral analysis of dipping as well as the persistent phase of the source.

Introduction

MXB 1658-298 is a Low Mass X-ray Binary (LMXB) which was discovered by SAS-3 in 1976 (Lewin et al. 1976). It shows dip, burst and eclipse behaviors. It shows periodic X-ray eclipses in every 7.1 hours, with a duration of $\sim$ 15 mins (Cominsky & Wood 1984,1989). About 2 years after its discovery, the X-ray intensity declined and the source was not detectable for more than 20 years. After being X-ray bright for about 2.5 years since 1999, the source went into quiescence near the beginning of 2001. It was again detected with renewed activity in August 2015 by *MAXI* observatory (Negoro et al. 2015).

The 1-10 keV spectra of most of the dip sources become harder during dipping. However, these changes are inconsistent with a simple increase in photo-electric absorption by cool material. These changes are often modeled by the "progressive covering", or "complex continuum" approach (e.g., Church et al. 1997), in which the X-ray emission is assumed to originate from a point-like blackbody, or disk-blackbody component, together with an extended power-law component. This approach models the spectral changes during dipping intervals by the partial and progressive covering of the power-law emission from an extended source. During the dips, absorption lines are also detected and correspond to electronic transitions from less ionized species than during the persistent intervals. Boirin et al. (2005) demonstrated that an increase in column density and a decrease in the ionization state of a highly-ionized absorber, associated with the increase in column density of a local neutral absorber could model the changes between persistent and dipping intervals both in the X-ray continuum and the narrow absorption features. Above method was successfully applied to MXB 1658-298 with other LMXBs; X 1254-690, X 1624-49, 4U 1746-371 and XB 1916-053 observed with *XMM-Newton* (Díaz Trigo et al. 2006).

Main Objectives

- Spectral study of the archived *XMM-Newton* observation during the recent outburst.
- To investigate any variation in the intrinsic source spectrum and characters of the absorbing medium during dipping.
- Model the spectral change during dipping by partial covering absorption by partially ionized material.

Observations & Analysis

X-ray observations of MXB 1658-298 were carried out using the European Photon Imaging Camera (EPIC) aboard the *XMM-Newton* satellite on September 26, 2015. We have processed *XMM-Newton* observation data files (ODFs) to produce calibrated event lists using the *epproc* task (Science Analysis System, SAS, v.15.0.0) for the EPIC-pn camera. The EPIC-pn was operated in timing mode during 2015 observation. Products were extracted from CCD columns 27-47. The corresponding background products were extracted by using columns 2-6. In order to account for systematic effects a 2% uncertainty was added quadratically to each spectral bin. We used spectral program *XSPEC* version: 12.8.2 for fitting of spectral models.

Result & Discussion

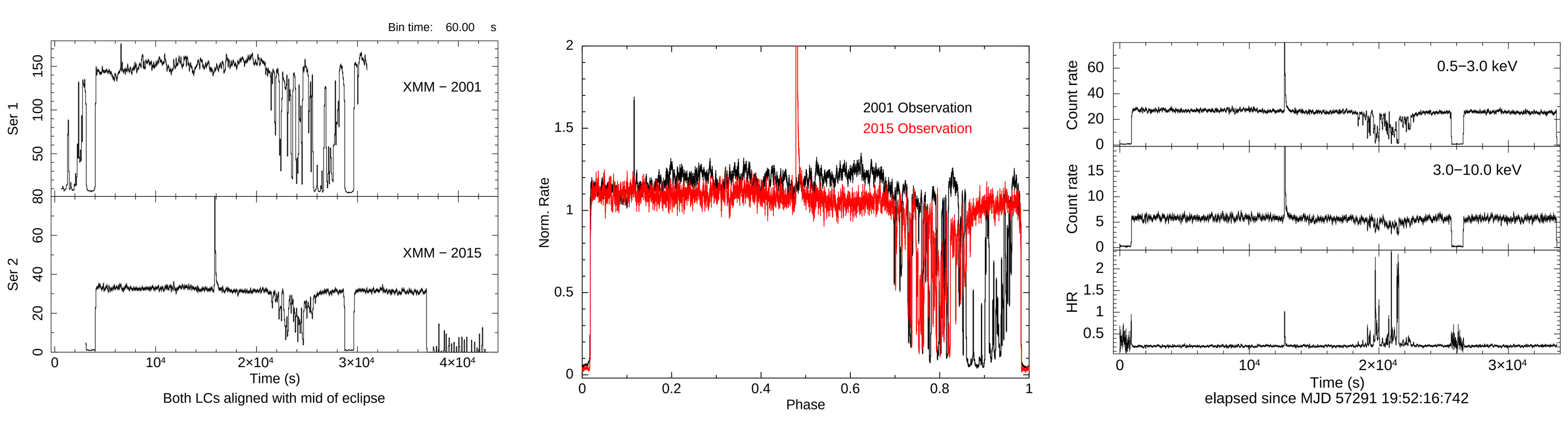

Figure 1: *Left panel*: Full Lightcurves of MXB 1658-298 extracted from 2001 and 2015 *XMM-Newton* observation in 0.5-10.0 keV energy band. During 2015 observation, source is fainter. *Middle panel*: Normalised lightcurve from both observation. Clearly showing different dipping region in both observations. For 2001 observation, dipping region lie between $\sim 0.7-0.96$ phase while for 2015 observation, dipping region lie between $\sim 0.7-0.86$ phase. Dips are shallower for 2015 observation. *Right panel*: Lightcurve extracted from 2015 *XMM-Newton* observation in 0.5-3 keV and 3.0-10.0 keV energy bands with their hardness ratio (Hard/soft) in bottom.

The persistent emission spectrum of MXB 1658-298 can be modeled by the absorbed disk blackbody (kT$_{in}$=0.197 keV) with radius $R_{in}/cos\theta = 63^{+47}_{-37}$ km, blackbody (kT=0.45 keV) with radius 4^{+4}_{-3} km for distance of 15 kpc (Sidoli et al. 2001), powerlaw ($\Gamma = 1.75$) and Gaussian lines at 2.23 keV for Au calibration edge ($\chi^2_{red} = 1.02$ for $163\ dof$) (left panel of Fig. 2). To check for consistency of spectral model, we also tried to fit two persistent spectra (taken from two parts of persistent emission) simultaneously with above model by varying all parameters. The parameters of fit from two spectra are consistent with each other and giving the $\chi^2_{red} = 0.92$ for $343\ dof$. We do not detect absorption lines due to highly ionized elements (Fe XXV or Fe XXVI near 7 keV) in the persistent emission spectrum as earlier reported from 2001 *XMM-Newton* observation by Sidoli et al. (2001).

The spectral change during dips of 2001 *XMM-Newton* observation has been modeled with complex continuum approach (Sidoli et al. 2001) and ionized absorber approach (Díaz Trigo et al. 2006). We have modeled the spectral change during dipping for 2015 observation by partial covering absorption by partially ionized material (*zxipcf* in XSPEC). The dipping region is divided into shallow dip and deep dip. The shape and normalizations of all continuum components were held fixed at their persistent emission values and only partial absorption by partially ionized absorber with covering fraction are allowed to vary. Gaussian line at 2.23 keV of fixed width 0.01 keV is also added for Au edge with variable normalization (middle panel of Fig. 2). During dipping, an absorption feature is added at 6.64(8) keV using Gaussian absorption line (*gabs* in XSPEC) ($\Delta\chi^2 = 26$ with 4 dof) (see right panel of Fig. 2). N_H^{zxipcf} reduces by small value and covering fraction increases to 53% from 37%, where the ionization parameter (ξ) is nearly constant (see Table 1). This is in contrast with previous results where continuum are seen to undergo strong absorption during deep dips. The increase in covering fraction would indicate that the emission region is angularly more extended than the absorbing region and that a larger fraction of it is covered during deep dipping. However decrease in absorber column density means that the absorbing layer is thinner during deep dipping (Younes et al. 2009).

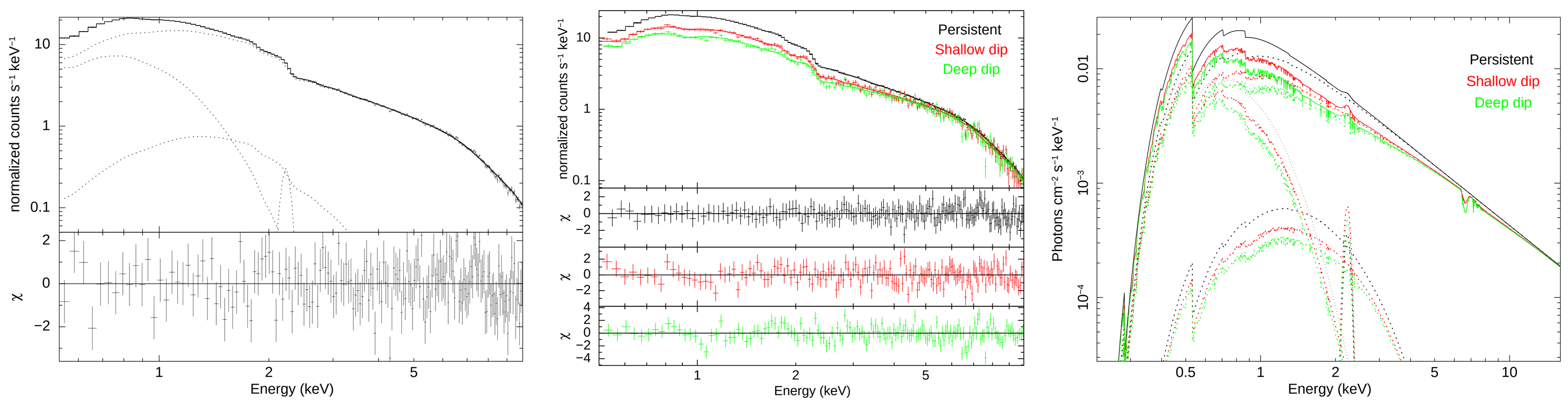

Figure 2: *Left panel* : Spectrum of persistent region modeled with *wabs*(diskbb+bbodyrad+powerlaw)+gaussian*, *Middle panel* : Spectra of persistent and dipping regions fitted simultaneously with *wabs*zxipcf*(diskbb+bbodyrad+powerlaw)+gaussian*, *Right panel* : Unfolded spectra with all component of spectrum. A Gaussian absorption line (*gabs*) is added at 6.64 keV in shallow and deep dip spectra.

Table 1: Spectral parameters of MXB 1658-298 during outburst of 2015

Model	Parameters	Persistent	Shallow dip	Deep dip
wabs	$N_H(10^{22}$ cm$^{-2})$	0.259 ± 0.012		
diskbb	kT_{in} (keV)	0.197 ± 0.012		
	$Norm_{disk}$	1780^{+994}_{-610}		
bbodyrad	kT_{bb} (keV)	$0.45^{+0.09}_{-0.07}$		
	$Norm_{bb}$	7^{+8}_{-4}		
powerlaw	Γ	1.75 ± 0.03		
	$Norm_{pow}$	0.024 ± 0.001		
	χ^2_{red}/dof	1.02/163		
zxipcf	N_H^{zxipcf}	-	$13.6^{+1.8}_{-1.6}$	$11.4^{+0.9}_{-1.0}$
	$log(\xi)$	-	$2.08^{+0.09}_{-0.05}$	2.07 ± 0.07
	CvrFract	-	0.371 ± 0.026	0.53 ± 0.03
gabs	E (keV)		6.64 ± 0.08	
	width (keV)		0.1 (fixed)	
	Strength	-	0.057 ± 0.038	0.10 ± 0.05
	χ^2_{red}/dof		0.90/468	

Note : ξ is the ionization parameter in units of erg s^{-1}cm. N_H^{zxipcf} is the absorber hydrogen column density in units of 10^{22} cm^{-2}. f is the covering fraction. Gaussian absorption line (gabs) energy and width are kept fixed for shallow and deep dips. These parameters are allowed to vary to explain the spectral changes from persistent to deep dipping. The strength of gabs is also allowed to vary between shallow and deep dipping. Uncertainties are given at a 90% confidence level.

Conclusions

- Dipping region, during 2015 observation is narrower and shallower than 2001 observation (left and middle panel of Fig. 1).
- Spectral hardening during dipping (right panel of Fig. 1).
- The persistent emission spectrum can be modeled with the absorbed disk blackbody, blackbody and power-law (Table 1).
- No absorption lines are detected due to highly ionized elements (Fe XXV or Fe XXVI near 7 keV) in the persistent emission spectrum of 2015 observation while absorption line at 6.64 and 6.90 keV is observed in 2001 observation (Sidoli et al. 2001).
- During dips, an absorption feature of Fe is detected at 6.64(8) keV.
- Modeling of dipping spectra with partial covering absorption by partially ionized material.
- There is small decrease in N_H^{zxipcf} from shallow to deep dips.
- ξ is constant and covering fraction is increasing from shallow to deep dips.

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