SALT observation of X-ray pulse reprocessing in 4U 1626-67

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ABSTRACT

We investigate optical reprocessing of X-rays in the LMXB pulsar 4U 1626-67 in its current spin-up phase using observations with Southern African Large Telescope (SALT), near-simultaneous observations with Swift-XRT and non-simultaneous RXTE-PCA observations and present the results of timing analysis. Using SALT observations carried out on 2014, March 5 and 6, we detect some interesting reprocessing signatures. We detect a weak optical Quasi Periodic Oscillation (QPO) in the power density spectrum on March 5 at 48 mHz with a fractional rms of 3.3\% in spite of the fact that source shows no corresponding X-ray QPO in the spin-up phase. In the light curve obtained on March 5, we detect a coherent pulsation at the spin period of $\sim$7.677 s. A previously known, slightly down-shifted side-band is also detected at 129.92 mHz. The frequency spacing between main pulse and this side-band is different from earlier observations, though the statistical significance of the difference is limited. The light curve of March 6 displays short time-scale variability in the form of flares on time-scales of a few minutes. Folded pulse profiles resulting from data of this night show an interesting trend of pulse peak drifting. This drift could be due to i) rapid changes in the reprocessing agent, like orbital motion of an accretion disc warp around the neutron star or ii) intrinsic pulse phase changes in X-rays. We also examine some X-ray light curves obtained with RXTE-PCA during 2008-2010 for pulse shape changes in short time-scales during X-ray flares.

Key words: stars: neutron – X-rays: binaries – X-rays: individual: 4U 1626-67 –X-rays: stars

1 INTRODUCTION

Reprocessing of X-rays into the visible and UV bands is a useful diagnostic tool to characterize and map the surrounding medium responsible for reprocessing and also to investigate the physics of reprocessing. In Low Mass X-ray Binaries (LMXBs), the accretion disc dominates the optical emission, whereas in High Mass X-ray Binaries (HMXBs), the massive companion star overwhelms the optical emission. Thus, LMXBs present the right setting to explore the matter distribution in regions around the neutron star. LMXBs show many interesting X-ray timing variabilities. These X-ray variabilities sometimes get reproduced in the Optical/UV band through reprocessing. There are several possible reprocessing sites, namely different parts of the accretion disc, the surface of the companion star facing the neutron star, or sometimes both. The observed reprocessed emission could be modulated at the orbital period while different portions of the X-ray heated region come in and out of view. These optical signatures of emission processes could get delayed, smeared or may also possess a phase shift with respect to the X-ray variability. A number of sources show correlated thermonuclear bursts in X-rays and Optical (EXO 0748-676: Hynes et al. 2002; Paul et al. 2012). Some LMXBs show Quasi Periodic Oscillations (QPOs) in their X-ray Power Density Spectra (PDS) that are also seen in the optical band (4U 1626-67: Chakrabarty 1998; GX 339-4 Motch et al. 1982). Some X-ray pulsar sources show coherent optical pulsations (GX 1+4 Jablonski et al. 1997; 4U 1626-67 Middleditch et al. 1981) indicating that a large fraction of their optical emission is due to reprocessing. Then there are sources that show correlated flaring behavior (4U 1626-67: Joss et al. 1978; McClintock et al. 1980). Extensive study on broad and narrow, fast and slow X-ray and optical flares and their mutual time lags in some black hole sources has been carried out by Gandhi et al. (2010). Co-variability studies between the X-rays and optical are thus crucial in understanding different scenarios of X-ray reprocessing.

4U 1626-67 has a magnetic field strength of about $3\times10^{12}$ Gauss, estimated using the cyclotron resonance scattering feature detected in the X-ray spectrum (Orlandini et al. 1998; Camero-Arranz et al. 2010). The pulsar has a spin period of about 7.7 s with no evidence of pulse arrival time delay due to orbital motion and at the 42 min orbital period measured from an optical sideband by Middleditch et al. (1981), the upper limit of the projected semi-major axis is 10 lt-ms (Rappaport et al. 1977; Levine et al. 1988). Based on these, and faintness of the optical counterpart the neutron star was understood to have an extremely low mass and degenerate companion (Levine et al. 1988; Chakrabarty 1998). It has one of the lowest mass functions...
of $<1.3 \times 10^{-6} \, M_\odot$ (Levine et al. 1988) as measured for any X-ray binary. A very low inclination or a nearly face on geometry ($i<10^\circ$) allows a higher mass companion although the a priori probability of finding such a system is only 0.015. The lower limit for the mass transfer rate has been calculated by Chakrabarty (1998) as $2 \times 10^{-10} \, M_\odot$ per year, using the maximum possible torque that can act on the neutron star during spin-up, which is when the magnetospheric radius comes very close to the co-rotation radius. Chakrabarty (1998) showed that a 0.08 $M_\odot$ hydrogen-depleted companion, with an $i<8^\circ$ (apriori probability of ~ 1%) would satisfy the minimum mass transfer rate criterion and would also be at a reasonable distance of 3 kpc. The system shows no type 1 X-ray thermonuclear bursts, but does show frequent X-ray flares.

Most accretion powered X-ray pulsars show torque reversals in time-scales of weeks to months and years that is often related to the X-ray luminosity (Bildsten et al. 1997). Not only does 4U 1626-67 not show the standard X-ray luminosity- accretion torque relation (Beri et al. 2014), but it has undergone only two such torque reversals in the last 40 years (Chakrabarty et al. 1997; Jain et al. 2009; Camero-Arranz et al. 2010). The source shows different X-ray features during the spin-up and spin-down eras. For example, the X-ray pulse profiles are energy dependent and show a double horned shape during the two spin-up eras, which gets turned into a dip during the spin-down era (Beri et al. 2014). The strong 48 mHz QPO found consistently during the spin-down phase (Kaur et al. 2008), is absent in the power spectrum of the current spin-up phase (Jain et al. 2009), although a weak X-ray QPO was reported by Shinoda et al. (1990) during the first spin-up epoch. The X-ray spectra are similar during the spin-up eras as against the spin-down era (Camero-Arranz et al. 2010). All of these indicate that there are changes in the accretion mode from the inner disc to the neutron star that are associated with the torque reversals (Beri et al. 2014). The very faint blue optical counterpart KZ Ter was discovered by McClintock et al. (1979) and was found to have an UV excess in its spectrum. The magnitudes obtained with the identified source were not consistent with a main sequence or supergiant companion, but were more likely supportive of a system containing a late type dwarf or a degenerate dwarf where most of the optical light came from reprocessed X-ray flux by an accretion disc and/or the inner face of the companion star (Joss et al. 1978). After that, optical pulsations were detected by Hovaisky et al. (1978) at the same X-ray pulse period of 7.67 s with a pulsed amplitude of 4% and pulsed energy fraction of 2% (Crampton & McClure 1979) established that if the system was an ultra compact binary, then the X-ray heating of the companion must be negligible and that the UV excess seen in the source must be associated with an accretion disc (Chester 1978, McClintock et al. 1980) discovered intense correlated X-ray and optical flares and also suggested that a large fraction (>8%) of the pulsed emission is produced within 0.5 lt-s from the Neutron star. This again confirmed the fact that the accretion disc could be the source of the reprocessed optical pulsations. They found a 6.2% pulsed amplitude, and that the optical pulsations were mainly driven by the 1-3 keV soft X-ray pulses.

In the first spin-up era, along with the main pulsation, a sideband of a slightly lower frequency was observed and explained as reprocessed pulsation from the donor's surface (Middleitch et al. 1981) that was beating with the main pulsation at the orbital period. An orbital period of 42 min and a pulsed fraction of 2.4% was obtained. The sideband and orbital period was confirmed by Chakrabarty (1998). The fact that the side band occurred at a lower frequency indicated that the pulsar spin was in the same direction as the orbital motion. After the first torque reversal, in the spin-down era, Chakrabarty (1998) reported a 48 mHz optical QPO with a fractional rms amplitude of 6-8% in the power density spectrum and a pulsed fraction of 6%. Another 1 mHz QPO was detected by Chakrabarty et al. (2001) without a simultaneous X-ray QPO at that frequency. This was associated with a possible warp in the accretion disc.

Detailed observations in the last four decades have indicated change in accretion mode associated with change in accretion torque (Jain et al. 2009; Beri et al. 2014). In this paper we investigate the optical temporal characteristics of 4U 1626-67 after the second torque reversal, when it is in a spin-up phase to re-examine various features like the relative pulse amplitudes in X-rays and optical, the strength of the previously reported orbital sidebands and the pulse profile evolution. New observations were carried out with the Southern African Large Telescope (SALT) telescope, Swift-XRT and we have also done analysis of archival X-ray data to examine the pulse characteristics during X-ray flares.

2 OBSERVATIONS AND DATA ANALYSIS

2.1 SALT

2.1.1 Observations

4U 1626-67 was observed using the SALT for two consecutive nights on 2014 March 5 and 6. The SALT telescope is the largest ground-based optical telescope operating in the Southern hemisphere with a 11 m spherical primary. It is fixed at a constant elevation angle at 37$^\circ$ from the vertical (Buckley et al. 2006, O’Donoghue et al. 2004). So it can observe only a given annulus of the sky. This gives an observing time of nearly 2 hours twice as the source drifts through the annulus (Günthel 2010). The observations were made using the SALTICAM instrument. Details of the observations are given in Table 1. The SALTICAM was operated using the V band filter (central wavelength 550 nm). The slot mode gives a fast readout time with practically no dead time, and so, with a 3x3 pixel binning, a sampling time of nearly 0.2 s was achieved. The clocks used for time sampling produced a binning of 0.203 or 0.204 s. For a very small fraction of the observation, the binning is uneven, separated by 0.1 or 0.6 s. We note here that the instrument configuration was identical on the two nights and therefore the difference between the results obtained on the two nights of observation are not due to any instrumental artefact. The photons are collected by two CCDs separated by 1.5 mm, each with two readout amplifiers. The readout noise is less than 3 electrons pixel$^{-1}$. The gain specified was 2.6 electron per ADU.

2.1.2 Data reduction

The bias subtracted SALT data were first extracted using the package IRAF. The target star and two other comparison stars were chosen from a single amplifier. The image frames that contained these stars were then further reduced. The overscan regions in the raw images were trimmed. An aperture photometry was then carried out on these images using the Sextractor software. The magnitude and fluxes of the target star and comparison stars were extracted using an aperture with inner and outer radii as 16 and 25 pixels, respectively. The point spread function had a full width at half-maximum of 3 arcsec. These images were then used to remove all the identified stars and create a flat image. Around 50 flat images were averaged to produce a master flat, which was then used for flat fielding the images. The flat fielded, bias subtracted images were
then used for determining the magnitudes and the fluxes of the target and comparison stars. In some of the exposures, the algorithm could not identify the star and hence the light curve had certain individual bins that had very low counts. All such bins (<2% of the total bins) were manually removed.

### 2.1.3 Timing analysis

Figure 1 shows the light curves for both the nights with a bin size of 7 s. The March 5 light curve shows slow variations around an average rate. The optical intensity varies by about a factor of 2 on the first night and by a factor of 3 on the second night. The March 6 light curve shows many flares of duration between 3 and 15 minutes recurring at shorter time-scales during some parts of the light curve. The flaring amplitude is about 1.5 to 2 times above the quiescent levels. These flares are of shorter duration with shorter recurrence time-scales as compared to earlier reports (Joss et al. 1978), which had 500 s co-incident X-ray and optical flares, recurring every 1000 s. In the spin-down phase of 4U 1626-67, it is known to show no X-ray flares (Chakrabarty et al. 1998). The amplitude of the side-band relative to the main pulsation is \( \sim 0.395 \) mHz (Chakrabarty 1998). The amplitude of the side-band measured by Chakrabarty (1998).

The PDS generated from the two nights are shown in Figure 2. The PDS was normalized such that its integral gives the squared rms fractional variability and it was also white noise subtracted. The PDS was fit with a Lorentzian centred around the known X-ray pulse period of 7.6736 s obtained from Swift-Burst Monitor (GBM) shows a period change of the order of a few micro-seconds per day in the current spin-up phase, which is much smaller than the period measurement error from the first night's

Table 1. Log of all optical and X-ray observations of 4U 1626-67 used for this work.

| Observation            | Date            | Exposure time (ks) | Observation length (ks) |
|------------------------|-----------------|-------------------|-------------------------|
| SALT night 1           | 2014 March 5    | 4.8               | 4.8                     |
| SALT night 2           | 2014 March 6    | 6.6               | 6.6                     |
| Swift-XRT (00031156002) | 2014 March 5    | 4.6               | 4.6                     |
| RXTE-PCA (95313-01-01-08) | 2010 December 9 | 18.2             | 20.3                    |
| RXTE-PCA (95338-05-01-00) | 2010 January 14 | 10.9             | 17.1                    |
| RXTE-PCA (95338-05-02-00) | 2010 January 15 | 7.3               | 9.6                     |

from the SALT light curve is 129.921 mHz giving a frequency down-shift of 0.338 mHz and the corresponding beat period of \( \sim 49.3 \) min as compared to the earlier measured value of 42.2 min or a difference of 0.395 mHz (Chakrabarty 1998). The amplitude of the side-band relative to the main pulsation is \( \sim 30\% \), compared to 20\% measured by Middleditch et al. (1983) and 25\% measured by Chakrabarty (1998).

The average pulse profiles folded at the pulse period and sideband period are shown in Figure 4. The profile shows a single broad peaked feature. The pulse fraction obtained from the average pulse profile on March 5 night was 5\%. An orbital phase resolved analysis was carried out using the March 5 light curve. The light curve was divided into four orbital phases corresponding to the beat period obtained on night 1 (0.338 mHz or 49.3 min), and separate pulse profiles were created from each segment by folding with the same pulse period. The four resultant profiles are shown in Figure 5. The pulse profile shape clearly varies as a function of orbital phase.

The **EFSEARCH** test carried out on the light curve of the second night produced several peaks, no single one stands out like that from the data of March 5. We have then searched for coherent pulsations in small segments of the light curve in a wider trial period range and the result is shown in Figure 3 (right-hand panel). Clear pulsations are detected in at least five segments, but with a pulse period which differ by as much as 0.1 s. The pulse period monitoring of 4U 1626-67 with the Fermi Gamma-Ray Burst Monitor (GBM) shows a period change of the order of a few micro-seconds per day in the current spin-up phase, which is much smaller than the period measurement error from the first night’s
light curve. The true spin period of the neutron star on the two nights must be quite similar and we have therefore created pulse profiles from the March 6 light curve with the same period.

To study the pulse shape variation as a function of time, the V-band light curves of March 5 and 6 each were folded on 7.677 s pulse period. A total of 20 and 27 pulse profiles were created for the two nights respectively which are shown in Figure 6. Each pulse profile, corresponding to a time segment of $\sim 244$ s, was given count rate offset and plotted below the previous profile. The segment-wise pulse profiles of March 5 shows no significant drift. However, the March 6 data show a phase shift in the pulse profile.

Figure 3. Period search results for March 5 (left) and 6 (right) light curves. A clear side-band peak is seen on March 5 data at 7.697 s. The earlier reported side-band is shown by the dashed line. The March 6 light curve has been divided into smaller segments and epoch folding period searches yield variable pulse periods along the course of the observation.

Figure 2. White noise subtracted PDS of March 5 (top) and 6 (bottom) night data normalized relative to the mean source power. The broad 48 mHz optical QPO detected in the March 5 SALT PDS is fit with a power law and a Lorentzian and shows a fractional rms amplitude of 3.3%.

Figure 4. Average pulse profiles for March 5 night folded on the main pulse period 7.677 s (top) and sideband period 7.697 s (bottom).
peak as we go along the light curve segments at the rate of 3 pulses per 0.02 days, corresponding to a pulse period difference of about 0.1 s as is also seen in pulse period of the second night (Figure 3, right-hand panel). We have also examined if the phase drift seen on March 6 night was due to the overall intensity variation in this light curve. The analysis was repeated after de-trending the light curve with a fourth-order polynomial. The pulse peak drifting effects were found to be same in the de-trended light curve.

To further probe this drift in the pulse period, we created dynamic power spectrum for segments of 1000 s of both the light curves with a moving window of 20 s. The dynamic power spectra are shown in Figure 7 in two frequency ranges around the fundamental and first harmonic of the pulse frequency. PDS of the 5 night shows persistent features at the fundamental and the harmonic with lower power at around 2/3rd of the observation. This is consistent with a smaller pulse fraction in the pulse profiles at that time. The dynamic power spectrum of March 6 shows many interesting patterns of decreasing pulse frequency with lower power in the last 20% of the observation and at around 1/5th of the observation. It also shows an upward turn in the frequency near the discontinuity. Two frequencies are present simultaneously at about 1/4 th and 3/4 th of the observation.

2.2 Simulation of the orbital sideband

The peak of the side-band feature seen from the observation on the night of March 5 has an offset of 0.338 mHz which is different from values of the same measured earlier (Middleditch et al. 1981; Chakrabarty 1998). We carried out a simulation to find the significance of this difference. Gaussian randomized lightcurves were simulated at the same time bins as the observed data using the main band and side-band pulse profiles as shown in Figure 4 (left and right-hand panels) with random phase offset. Period searches were carried out on 10000 simulated light curves and we found that the short duration of the observation, covering only about two orbital cycles, is insufficient to constrain the separation between the two components with simulations.

2.3 Swift-XRT data

A Target of Opportunity X-ray near-simultaneous observation was carried out on 2014 March 5 (Table 1) using Swift-XRT. The XRT aboard the Swift satellite was operated in the Window Timing mode and given an exposure of 4594 s with a time resolution of 0.1 s. The raw data were processed using XRTPIPELINE task and using standard screening criteria. The source image and light curve were extracted using XSELECT in the energy band 0.3 to 10 keV from a circular region centred on the source co-ordinates. The background subtracted Swift light curve with a bin size of 10 s is shown in Figure 8 (top left panel). The EFSEARCH task was used to determine the pulse period and a sharp peak was obtained at 7.6736 s (Figure 8 top right panel). The light curve was folded using this pulse period. The characteristic double-horned profile is discernible (Figure 8 bottom panel). The Swift observation was carried out to know if the properties of the X-ray source (pulse profile, power density spectrum) were the same as the other X-ray observations in the spin-up phase.

2.4 RXTE observation of pulse profiles in flaring state

The near simultaneous Swift-XRT observation which was carried out on March 5 showed no flares and has limited statistics. So we could not separately investigate intrinsic variations in the X-ray pulse profile using the Swift-XRT light curve. We analysed archival data of the Proportional Counter Array (PCA) on board RXTE. The standard 1 light curve in the 2-60 keV band was extracted for all the observations after the second torque reversal in 2008. The PCA light curve with a bin size of 7 s for one such Obs-Id 95313-01-01-08 (Table 1) is shown in Figure 9. The light curve shows intermittent flares. However, in contrast with the March 6 optical data, period search on the X-ray light curve gives a single sharp peak at the pulse period of 7.67 s. The light curve from small segments was folded at this pulse period and plotted above one another by giving them a finite offset (Figure 10). The X-ray profile is dominated by dips, which are locked in phase. They are probably produced by
absorption in the accretion stream/column. Flaring portions of the X-ray light curve seem to change the amplitude of the peaks in the X-ray pulse profiles to some extent, but no phase shift is seen in the X-ray pulse profile. We also analysed the PDS from two of the data sets from the post second torque-reversal era that had large exposure times and did not have flares in them (Obs Id 95338-05-01-00 and 95338-05-02-00). The power spectra were fit between the frequency range 2 to 200 mHz with a power law continuum and a Lorentzian at the same QPO frequency as obtained from the current SALT dataset. We obtain an upper limit to the rms power of the X-ray QPO of 0.9%.

3 DISCUSSION

4U 1626-67 is an X-ray pulsar that has been found to consistently display timing signatures in the optical that mirror the X-rays timing features due to reprocessing phenomenon. Our current results indicate many reprocessed X-ray signatures like optical pulsations at the spin frequency of the neutron star, the orbital side band due to reprocessing of the X-ray pulse from the surface of the companion star, optical flares of a few hundred seconds time-scales, optical QPOs at 48 mHz and drift in the phase of the reprocessed optical pulses in data from one night. The accretion
disc contributes to most of the reprocessing that is observed, with the companion star surface also partly being responsible for reprocessing the main X-ray pulsation. The optical emission from the disc arises from a combination of viscous dissipation and X-ray heating (Chakrabarty et al. 2001).

A 48 mHz QPO was detected simultaneously in the X-ray and optical bands in the spin-down phase right after the first torque reversal (Chakrabarty 1998). Although the first spin-up phase showed a weak QPO at \(\sim 40\) mHz in X-rays (Shinoda et al. 1990), it is absent in the X-ray light curves of the current spin-up phase (Beri et al. 2014). Interestingly, current SALT results point towards the presence of the same 48 mHz QPO in the optical.

The presence of the optical 48 mHz QPO at the same X-ray QPO frequency indicates that the X-ray signal is being reprocessed. However, detection of the QPO feature in the optical light curve with an rms of 3\%, while the non-simultaneous X-ray light curves with the RXTE-PCA in the current spin-up phase having an upper limit of 1\% in the QPO rms at that frequency indicates various possibilities. There could be an underlying X-ray QPO which is anisotropic and the optical QPO is produced in a reprocessing region which has different visibility of the X-ray QPOs than the observer. Or, there is a second possibility that there is an X-ray QPO in the spin-up phase, but it has variable rms and during the observation on March 5, the X-ray QPO rms was higher than usual. A third scenario could be that the QPO generation mechanism in the spin-down phase produces a larger rms in the optical band.

QPOs in high magnetic field pulsars are believed to be produced as a result of inhomogeneity at the magnetosphere-inner disc connection. There are several models that explain the QPOs observed in accretion powered X-ray pulsars. In the Keplerian frequency model (van der Klis et al. 1987), the QPO frequency corresponds to the Keplerian frequency at the Alfvén radius of the magnetosphere and QPO frequency is larger than spin frequency of the neutron star which is not the present case. The beat frequency model (Alpar & Shaham 1985) suggests that QPO is at the beat frequency between the Keplerian frequency at the Alfvén radius of the disc-magnetosphere and the neutron star spin frequency. This would predict the Keplerian frequency to be, \(\nu_k = \nu_{\text{spin}} + \nu_{QPO} \sim 0.17\) mHz. As shown in Shinoda et al. (1990), this leads to a consistent measure of the magnetic dipole moment. This model however, fails to explain the asymmetric side-band amplitudes.

The inner disc hypothesis of QPOs (Keplerian frequency model or beat frequency model) can be tested in pulsars that show both the cyclotron absorption line and QPO (James 2013). However, in two of the persistent pulsars with known cyclotron line energy in which the QPOs have been detected over a range of X-ray luminosity, the QPO frequency is found to have little luminosity dependence contrary to what would be expected if they had an inner disc origin (4U 1626-67: Kaur et al. 2008; Cen X-3: Raichur and Paul 2008). A number of other X-ray pulsars have shown flares at intervals comparable to those in the optical light curve of the second night which produce mHz QPO features in the PDS: Her X-1 (Boroson et al. 2001), LMC X-4 (Moon and Eikenberry 2001) and 4U 0115+63 (Soong and Swank 1989). A magnetically driven warping/precessing model was used to explain mHz variability in the X-rays and UV/optical for these sources (Shirakawa and Lai 2002). A 1 mHz optical QPO, without a counterpart X-ray QPO at that frequency, was discovered in 2001 (Chakrabarty et al. 2001) for 4U 1626-67. Since during spin-down the source did not show 1000 s flares in X-rays, the optical features were attributed to a possible warp in the system. This current data set, in the spin-up phase does show flares and we see significant power at a 3.32 mHz in the PDS of the March 6 night data. Optical flares which are reprocessed X-ray flares might be responsible for
such a feature. We have no way of confirming this since we do not have simultaneous X-ray data for the second night of SALT observation. But another possible scenario could be that the 3.32 mHz frequency, like an earlier reported 1 mHz signal, might be a geometric modulation effect.

A tantalizing suggestion in our data is of the difference, by about 0.06 mHz, in the sideband frequency from what was observed earlier [Middleditch et al. 1981; Chakrabarty 1998]. If interpreted as a beat between the spin and the orbital frequency, a change of this magnitude is not expected over such a short time-scale. Our result would need a longer stretch of timing data to confirm, but here we speculate on possible reasons that could contribute to such a change. Optical reprocessing by a structure in the outer accretion disc, e.g. a short-lived warp orbiting with a period of 2958 s, could give rise to the observed sideband, and small changes in the warped structure can then lead to frequency drift of this feature. Warps in the accretion discs of LMXBs may be driven by instabilities discussed by Pringle (1996). While the conditions for excitation are met in limited circumstances (Ogilvie and Dubus 2001), strong irradiation of the disc in the present system may help drive such behavior.

The March 6th light curve showed a definite drift of the phase of the optical pulse with time. The reprocessed optical main pulsation could show such a pulse phase shift if the original X-ray pulse suffered a similar phase shift in the first place. From analysis of many RXTE observations in the current spin-up phase, we have detected significant changes in the X-ray pulse profile at short time-scales in terms of changes in the relative intensities of the two peaks. However, the X-ray pulse profiles obtained with the RXTE-PCA light curves including flares do not show pulse phase drift as is seen in the optical light curve of the second night. The SALT observations therefore do not suggest changes in the rotation period of the neutron star or the pulse period of the X-ray emission. The light curve folded with the period of the neutron star pulse period shows the reprocessed optical emission to be shifting in phase, indicating a changing location of the reprocessing region. However, the time-scale for this change is smaller, about 600 seconds, compared to the sideband observed in the first night which is at a five times longer timescale. The SALT observations therefore probably show warps at different radii in the accretion disc for two consecutive nights.

Longer, and simultaneous X-ray and UV/optical timing study would yield a more comprehensive understanding of the size, extent and location of the reprocessing sites within the binary and give more insight into the effects of torque reversal on the inner disc-magnetosphere geometry.

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