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Turmoil on the accretion disk of GRO J1655−40

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Abstract. During the 1996/1997 outburst of the X-ray transient GRO J1655−40 the *Wide Field Cameras* onboard BeppoSAX observed the system with nearly continuous coverage during some stages of this outburst. On two occasions we find clear evidence for frequent dipping behaviour, characterized by several absorption dips occurring within one binary orbit. However, during preceding and following binary orbits there is no sign of such dips at the same range of orbital phases. We also collected light curves of absorption dips as seen with other X-ray instruments. Although the 65 dips that were collected occur preferably between orbital phases 0.68 and 0.92, there is evidence that the morphology of the material causing the dips is changing over just one binary orbit. The short duration (∼minutes) and phasing of the dips are discussed in the framework of models where the stream from the companion star encounters a hot outer rim on the accretion disk.

Key words: accretion, accretion disks – stars: binaries: close – stars: individual: GRO J1655-40 – X-rays: stars

1. Introduction

The black-hole candidate and soft X-ray transient GRO J1655−40 (X-ray Nova Sco 1994) was discovered on 1994 July 27 by the Burst and Transient Source Experiment (BATSE) onboard the *Compton Gamma Ray Observatory* (Zhang et al. 1994, Harmon et al. 1995). Soon thereafter the optical counterpart was found (Bailyn et al. 1995a). It has since shown irregular outburst activity (e.g. Zhang et al. 1997). After the 1995 July/August hard X-ray outburst the source settled back to quiescence. However, on 1996 April 25 it became active again (Remillard et al. 1996, Levine et al. 1996, Orosz et al. 1997) for a period which lasted ∼16 months (see e.g. Remillard et al. 1999). GRO J1655−40 has an orbital period of 2.62 days, has dynamically been shown to contain a black hole with a mass of $\sim 7\,M_{\odot}$, and is viewed at an inclination of ∼70° (Bailyn et al. 1995b, Orosz & Bailyn 1997, van der Hooft et al. 1998, Shahbaz et al. 1999). The object has become notorious for being one of the systems showing relativistic radio jets, during its first outburst in 1994 (Tingay et al. 1995; Hjellming & Rupen 1995).

Deep short dips in the X-ray light curves of GRO J1655−40 were discovered during its 1996/1997 outburst These dips appeared periodically between orbital phases ∼0.7 and ∼0.85 and were shown to be due to a medium absorbing the radiation coming from the inner parts of the accretion disk (Kuulkers et al. 1998a). Such "orbital" dips are known to occur also in various other low-mass and high-mass X-ray binaries (see Parmar & White 1988; Marshall et al. 1993; Saraswat et al. 1996; and references therein). They probe the interaction between the stream from the companion and the accretion disk, as well as the X-ray emitting region itself (see e.g. Kuulkers et al. 1998a; Tomsick et al. 1998).

We report here on observations made with the *Wide Field Cameras* (WFC) onboard the *Beppo Satellite per Astronomia X* (BeppoSAX) observatory, obtained during various stages of the last outburst in 1996/1997 of GRO J1655−40. Due to the relatively long orbital period of GRO J1655−40, the WFC is ideally suited for monitoring such a system at all orbital phases almost continuously, which is not possible or undertaken with other X-ray instruments carrying out short programs of typically less than a day or with all-sky monitors viewing sources typically up to ten times a day for a short period of order minutes. We summarize all dip events seen during the 1996/1997 outburst with the WFC and other instruments and discuss their origin.

2. Observations and analysis

The Wide Field Camera (WFC) instrument (Jager et al. 1997) consists of two coded aperture cameras that point in opposite directions and perpendicular to the Narrow-Field Instruments on the same BeppoSAX satellite (Boella et al. 1997). The field of view of each camera is 40 by 40 square degrees full-width to zero response with an angular resolution about 5 arcminute in each direction. The detectors are Xenon-filled multi-wire proportional counters with band passes of 2 to 28 keV. The sensitivity in the 2–10 keV band is about 10 mCrab in 10^4 s. The imaging

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Table 1. BeppoSAX WFC observation log of GRO J1655−40

Date	JD−2450000
1996 Aug 20–30	315–325
1996 Sep 2–4; 12–13; 15–18; 22–25	328–330; 338–339; 341–344; 348–351
1996 Oct 5; 10–13	361; 366–369
1997 Mar 7–8; 13–20; 23–25; 29–31	514–515; 520–527; 530–532; 536–538
1997 Apr 1; 7; 11; 13–15	539; 546; 548; 550–553
1997 Aug 12–13	672–673

capability and sensitivity allow an accurate monitoring of complex sky regions, like the Galactic bulge. The WFCs are carrying out a program of monitoring observations of the field around the Galactic Center. The purpose is to detect X-ray transient activity, particularly from low-mass X-ray binaries (LMXBs) whose Galactic population exhibits a strong concentration in this field, and to monitor the behaviour of persistently bright X-ray sources (see e.g. Heise 1998). This program consists of campaigns during the spring and autumn of each year. Each campaign lasts about two months and typically comprises weekly observations. The favorable position of GRO J1655−40 ($l = 344\fdg98$, $b = +2\fdg46$ or $\mathrm{R.A.} = 16^h54^m00^s, \mathrm{Dec.} = -39°50'45''$, J2000.0) within the vicinity of the Galactic Center implies therefore a relatively large coverage of the source during its 1996/1997 outburst.

In this paper we report on part of the X-ray monitoring program during 1996 August-October and 1997 March-April and August, as well as serendipitous observations close to the Galactic Center (see Table 1), yielding a total of 1.37 Msec of good data. These observations were either performed with WFC unit 1 or 2. For the light curves we used as intensity measure the count rate per cm^2 in the 2–8 keV band. All measurements are corrected for dead time.

The All-Sky Monitor (ASM; Levine et al. 1996) onboard the *Rossi X-ray Timing Explorer* (RXTE) scans the X-ray sky in series of 90 sec dwells in three energy bands between 2 and 12 keV. A given source is observed typically 5 to 10 times a day. For our purpose we used the ASM quick-look results in the 2–12 keV band as provided by the RXTE/ASM team at the Massachusetts Institute of Technology (MIT).

Numerous pointed target-of-opportunity observations were obtained during the 1996/1997 outburst of GRO J1655−40 with the Proportional Counter Array (PCA: 2–60 keV; Bradt et al. 1993) onboard RXTE (Sobczak et al. 1999; Remillard et al. 1999). Dips in the light curves were seen in observations taken on 1996 June 20 (Hynes et al. 2000, in preparation), 1997 January 5 (Remillard et al. 1999) and 1997 February 26 (Kuulkers et al. 1998a,b). We used the data collected with a time resolution of 0.125 sec in the total 2–60 keV energy band from the so-called 'Standard 1' mode.

The High Resolution Imager (HRI: 0.1–2.4 keV; e.g. Zombeck et al. 1995) onboard the *Röntgen Satellite* (ROSAT) observed GRO J1655−40 various times in the periods 1996 August 28 to September 24 and 1997 March 10 to 13. During the second epoch deep short drops in intensity were found on March 12, similar to those seen with the RXTE/PCA. For the light curve we used all counts registered by the HRI; we did not correct for background, vignetting and dead-time, since the source is bright and since we are mainly interested in the dip light curves and times of dip occurrence.

The *Advanced Satellite for Cosmology and Astrophysics* (ASCA) satellite (Tanaka et al. 1994) is equipped with two Solid State Imaging Spectrometers (SIS; 0.4–10 keV) and two Gas Imaging Spectrometers (GIS; 0.7–10 keV). For our purposes we only used the data taken by the GIS instruments since they provide a higher time resolution compared to the SIS instruments. ASCA observed GRO J1655−40 during its 1996/1997 outburst on 1997 February 26–28. The GIS instruments were set to PH mode with timing resolution of 62.5 ms in high bit rate and 0.5 s in medium bit rate. Standard data screening was employed[1]. Data taken at a geomagnetic cut-off rigidity lower than 4 GeV, at an elevation angle less than $5°$ from the Earth limb and during passage through the South Atlantic Anomaly were rejected. After filtering, the total net exposure time of each GIS was 33.7 ks. We extracted the GIS light curves from a circular region of radius $6'$ centered at the position of the source.

3. Results

3.1. The quest for X-ray dips

In the upper panel of Fig. 1 we show the outburst light curve of GRO J1655−40 as obtained with the ASM. The outburst seems to consist of two stages separated by JD 2450450 (1997 January 1). The first stage shows strong flaring behaviour, whereas the second stage shows a smoother light curve. In the lower panel of Fig. 1 we show the observations as obtained with the WFC. Note that the last set of WFC observations were taken just before the source returned to quiescence (see also Sobczak et al. 1999, Remillard et al. 1999). The deep drops clearly seen in the ASM light curve are due to absorption dips, previously identified by Kuulkers et al. (1998a). In the WFC light curve such dipping behaviour is clearly present at the end of the second period of WFC observations.

We constructed WFC light curves with a time resolution of 5 sec, and searched for clear drops in intensity. On several occasions we found clear dipping behaviour in the X-ray light curves; they all appeared between orbital phases 0.68 and 0.89. During the observations on 1996 August 22 and 1997 April 14 various dips appeared; their detailed light curves are given in Figs. 2 (left panel) and 3 (right panel). On other occasions only single dips were found (see Table 2). It is clear that the dips are very deep, i.e. down to ∼1% of the out-of-dip intensity, as was already noticed for other dips from RXTE/PCA and ASM observations discussed by Kuulkers et al. (1998a). Their durations range from ∼15 sec to ∼3.5 min. The profiles of the dips are reminiscent of those of the dips seen previously with

[1] See the *ASCA* Data Reduction Guide, Version 2.0 (http://heasarc.gsfc.nasa.gov/docs/asca/abc/abc.html).

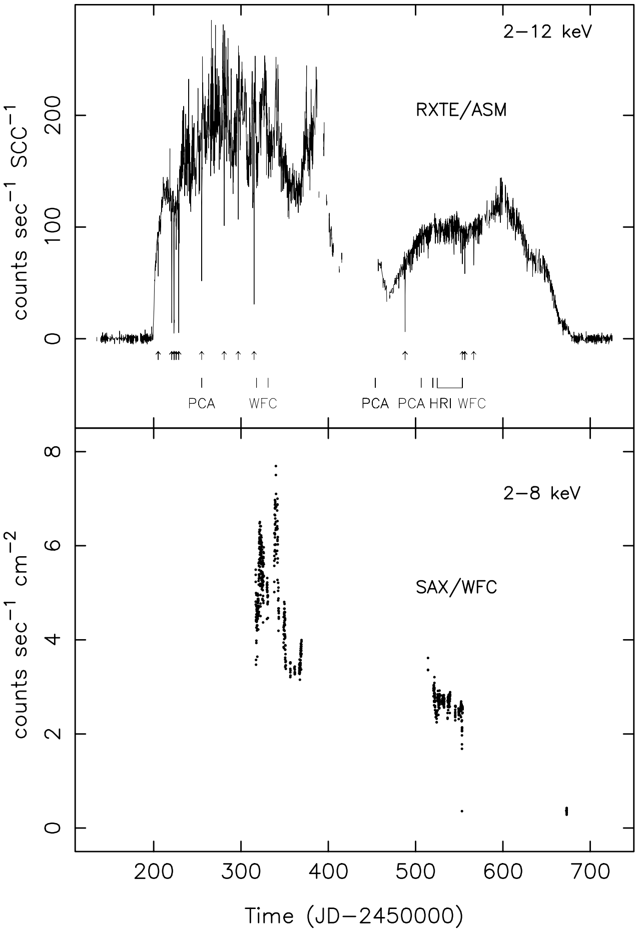

Fig. 1. Upper panel: RXTE/ASM light curve of the 1996/1997 outburst of GRO J1655−40. Shown are the 90-sec measurements; data points lying less than ∼2 d apart are connected by a line to guide the eye. Clearly, deep drops can be seen which are due to the absorption dips; they are indicated by arrows at the lower part of this panel. Also at the lower part of this panel are indicated the times at which absorption dips were seen with other instruments (see Table 2). Lower panel: BeppoSAX/WFC coverage of the 1996/1997 outburst. Shown are averages over one satellite orbit. JD 2450200 corresponds to 1996 April 26, 12:00 (UT).

the RXTE PCA (Kuulkers et al. 1998a). Particularly interesting is the light curve of 1997 April 14 (Fig. 3, right panel), during which continuing dip activity occurred for a total time span of ∼9.2 hr, i.e. between orbital phases 0.68–0.79 of binary cycle[2] 272.

In Fig. 4 we show our collection of X-ray light curves from other instruments (a–e: RXTE/PCA, f: ROSAT/HRI) during which clear dips were seen. Again, the dips are short, i.e. they have durations of up to a minute, and deep. Some of the light curves (e.g. Fig. 4c) show already a slight depression in the intensity just before and after the dips. The main differences in the dip profiles can be discerned by comparing Figs. 4d and e. Apart from a difference in the out-of-dip intensity, the dips on 1996 June 20 (Fig. 4d) are more gradual and somewhat less deep (down to ∼10% of the out-of-dip intensity), than those that occurred on 1997 January 5 (Figs. 4a–c) and February 26 (Fig. 4e).

[2] Binary cycle is defined as the number of binary orbits since JD 2449838.4198 (van der Hooft et al. 1998).

Table 2. GRO J1655−40 dip occurrence times

Time range (JD−2 450 000)	$\phi_{\rm orb}$[a] range	Cycle[b]	Instrument
205.0785–205.0796	0.86	139	RXTE/ASM
220.5827–220.5850	0.77	145	RXTE/ASM
223.1122–223.3692	0.81–0.83	146	RXTE/ASM
225.7172–225.7183	0.73	147	RXTE/ASM
228.6535–228.6546	0.85	148	RXTE/ASM
254.8466–255.0469	0.84–0.92	158	RXTE/ASM, RXTE/PCA
280.7353	0.71	168	RXTE/ASM
296.7989	0.84	174	RXTE/ASM
314.9044	0.75	181	RXTE/ASM
317.6420–317.7279	0.79–0.82	182	BSAX/WFC
330.9884	0.88	187	BSAX/WFC
453.8334–453.9162	0.74–0.77	234	RXTE/PCA
487.9261–487.9909	0.74–0.77	247	RXTE/ASM
506.4138–506.4159	0.80	254	RXTE/PCA
519.6519–519.6574	0.85	259	ROSAT/HRI
524.7309–524.7795	0.78–0.80	261	BSAX/WFC
553.3015–553.5831	0.68–0.79	272	BSAX/WFC, RXTE/ASM
556.2916–556.2927	0.82	273	RXTE/ASM
566.4994	0.71	277	RXTE/ASM

[a] Photometric orbital phase (Orosz & Bailyn 1997, van der Hooft et al. 1998).
[b] Number of binary cycles since JD 2449838.4198 (van der Hooft et al. 1998).

We note that ASCA observed GRO J1655−40 from 1997 February 26 00:46:49 to February 28 16:50:49, i.e. around the time of the RXTE/PCA observations on 1997 February 26. However, the X-ray coverage was rather sparse between orbital phases 0.76–0.94, and no X-ray dips could be found at these or other phases.

We determined all times of the dips found in the observations described in this paper; the time and orbital phase ranges of their occurrences are displayed in Table 2 and indicated in the upper panel of Fig. 1. The total orbital phase range between which dips occur is 0.68–0.92. In Fig. 5 we plot the histogram of the orbital phase occurrences of all the dips. The occurrences cluster near $\phi_{\rm orb} \sim 0.8$ and the distribution is consistent with being Gaussian. It may be interesting to note that all dips were only seen during the first halves of the two stages of the outburst, i.e. dips occurred during JD 2450205–331, i.e. 1996 May 1 to August 17, and JD 2450453–567, i.e. 1997 January 4 to April 28 (Table 2, Fig. 1).

3.2. From binary orbit to binary orbit

Due to the long continuous coverage of the WFC it is now possible for the first time to follow the behaviour from binary orbit to

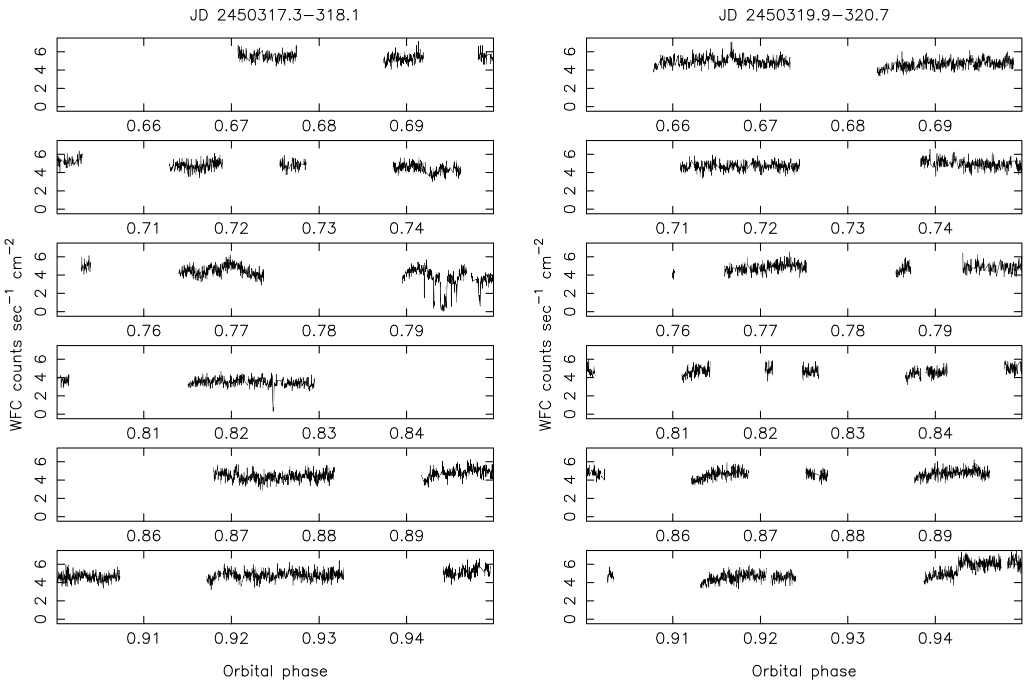

Fig. 2. WFC light curves of GRO J1655−40 from two consecutive binary orbits at $\phi_{\rm orb}$=0.65–0.95 near the start of the WFC observations (JD 2450317 [left] and JD 2450320 [right] correspond to 1996 August 21 and 24, respectively, at 12:00 UT). The time resolution is 5 sec. In the left panel dips can be seen near $\phi_{\rm orb}$=0.79–0.80, whereas one binary orbit later (right panel) they are absent at the same orbital phase range.

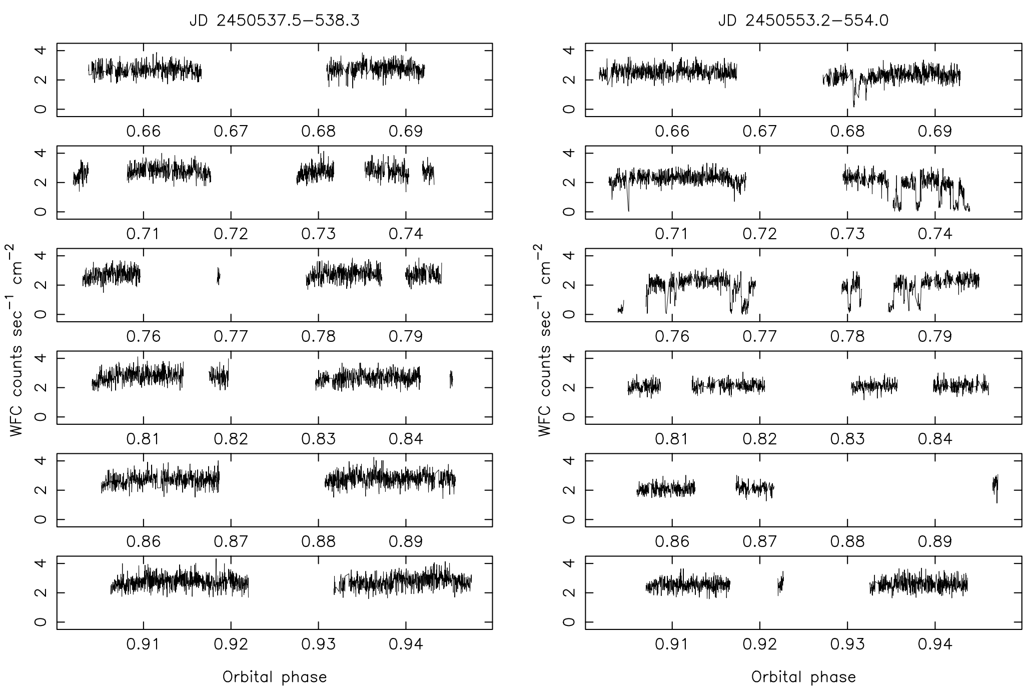

Fig. 3. WFC light curves of GRO J1655−40 from $\phi_{\rm orb}$=0.65–0.95, which are taken 6 binary orbits apart near the end of the second part of WFC observations (JD 2450538 [left] and JD 2450320 [right] correspond to 1997 March 30 and April 14, respectively, at 12:00 UT). The time resolution is 5 sec. Note that the y-axis scale is different from that in Fig. 2. In the right panel dips can be seen from $\phi_{\rm orb}$=0.68–0.79, whereas 6 binary orbits earlier (left panel) they are absent at the same orbital phase range.

the next binary orbit. If one looks at the light curves exactly one or several binary orbit(s) earlier and/or later than the binary orbit which did display dips, no dips are found. This is illustrated in Figs. 2 and 3. In Fig. 2 we show the WFC light curves from orbital phases 0.65–0.95 taken one binary orbit apart. Clearly, the dips observed in binary cycle 182 (left panel) just after orbital phase 0.79 are not there in binary cycle 183 (right panel) at the same orbital phase. In Fig. 3 we show light curves 6 binary orbits apart from each other. The strong dipping behaviour in binary cycle 272 (right panel) is clearly not repeated at exactly the same phases in binary cycle 266 (left panel).

The dipping behaviour seen in cycle 272 is stronger, i.e. much more dips occur, than in cycle 182, as well as compared to other binary orbits covered by the WFC. We attribute this to the transient nature of the dips, since we do not think that most or all of the dips are missed by earth occultations or SAA passages.

To illustrate the changes per binary orbit further we constructed a light curve in the 2–20 keV band (Fig. 6, upper panel) and hardness curve given by the ratio of 5–20 keV and 2–5 keV (Fig. 6, lower panel) of the first nine consecutive days of observations in 1996. This is a unique data set from a continuous

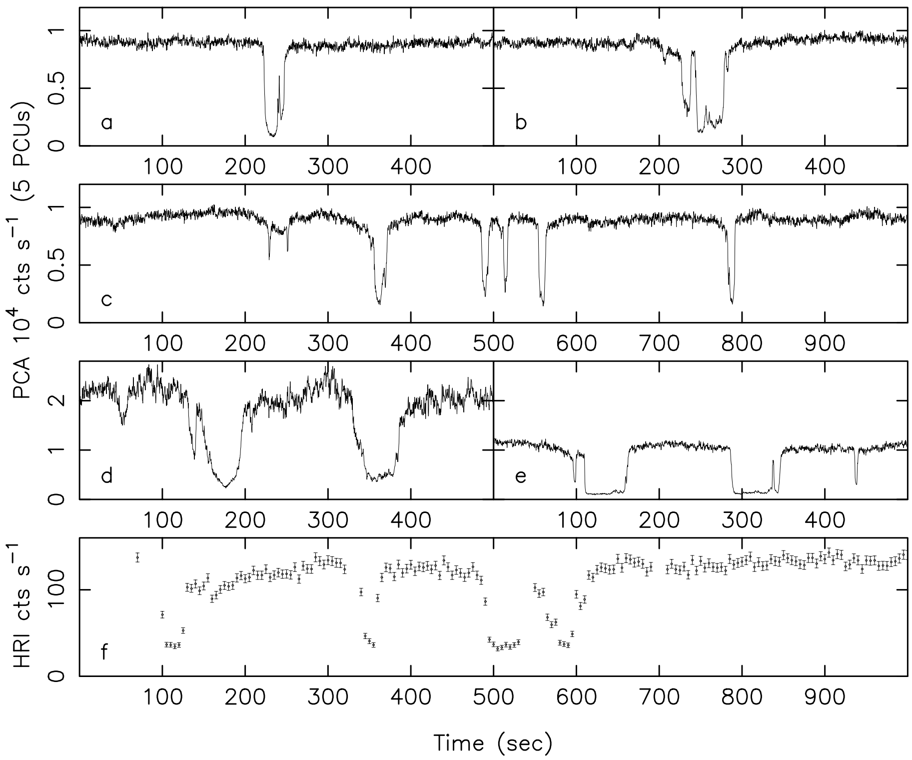

Fig. 4a–f. Collection of light curves from other instruments in which dips have been seen. **a**–**e** RXTE/PCA; **f** ROSAT/HRI. T=0 sec corresponds to UTC 1997 January 5 07:56:19, 08:23:49, 09:46:19, 1996 June 20 13:01:35, 1997 February 26 21:53:35, and 1997 March 12 03:38:01, for the light curves in **a**–**f**, respectively. The RXTE/PCA (2–60 keV) light curves have a time resolution of 0.25 sec, while the ROSAT/HRI (0.1–2.4 keV) light curve has a time resolution of 5 sec. Note that the y-axis in **d** and **e** differs from **a**–**c**

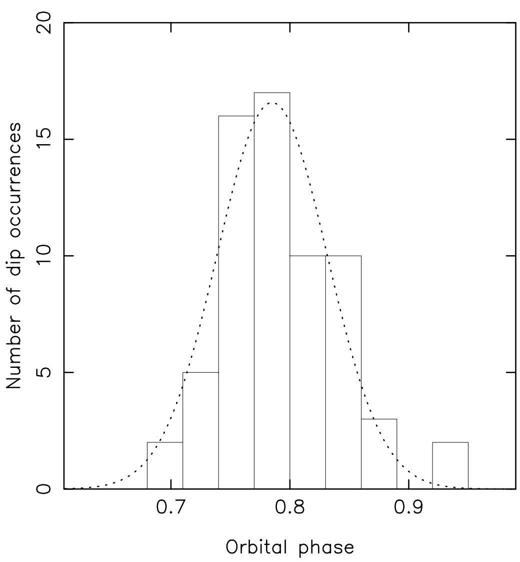

Fig. 5. Histogram of the orbital phases at which the 65 dips we collected occur (see text). Drawn also with a dotted line is a Gaussian with a mean of $\mu = 0.785$ and standard deviation of σ=0.046.

monitoring campaign of the Galactic Center (Cornelisse et al. 2000, in preparation). For clarity we have indicated the phase intervals of observed dipping behaviour (dashed lines) and the time when the companion star is closest to us, i.e. phase zero (dotted lines). Overall, both the intensity and hardness increased during the nine-day period. No clear repeatable features per orbit are seen, apart from a depression in the intensity near orbital phases 0.6–0.9 and 2.6–2.9. Moreover, the dip features which occur in the beginning of the observation (see also Fig. 2), are not repeated in subsequent orbits, although some might have been missed due to earth occultations or SAA passages (see also above). Note that the depressions in the light curves near orbital phases 0.6–0.9 and 2.6–2.9 are accompanied by a softening in the hardness values. On the other hand, no clear hardness changes are discerned during the depressions in the light curves near orbital phases 3.3–3.4 and 3.9–4.0.

4. Discussion

4.1. Orbital phase dependence

Combining all times of X-ray dip occurrences during the 1996/1997 outburst of GRO J1655−40 we find that the dips occur between orbital phases 0.68 and 0.92, i.e. extending the dip range with respect to that quoted by Kuulkers et al. (1998a). The occurrence of the observed dips concentrate near orbital phases 0.75–0.80. Similar deep short dips have now been seen in other X-ray transient systems: 4U 1630−47 (Tomsick et al. 1998; Kuulkers et al. 1998a) and Cir X-1 (Shirey et al. 1999). As noted by Kuulkers et al. (1998a) the duration of the dips is also of the same order as those seen in Cyg X-1 and Her X-1 (e.g., Kitamoto et al. 1984, Leahy 1997), but is shorter than those typically seen in LMXB dip sources (see e.g. Parmar & White 1988).

For the first time, we were able to obtain a nearly-continuous view of the system for several binary orbits during different parts of the outburst. On one occasion we found long irregular dipping behaviour for a period of ∼9.2 hr, which spans about ∼0.15 in orbital phase. This duty cycle is much larger than quoted

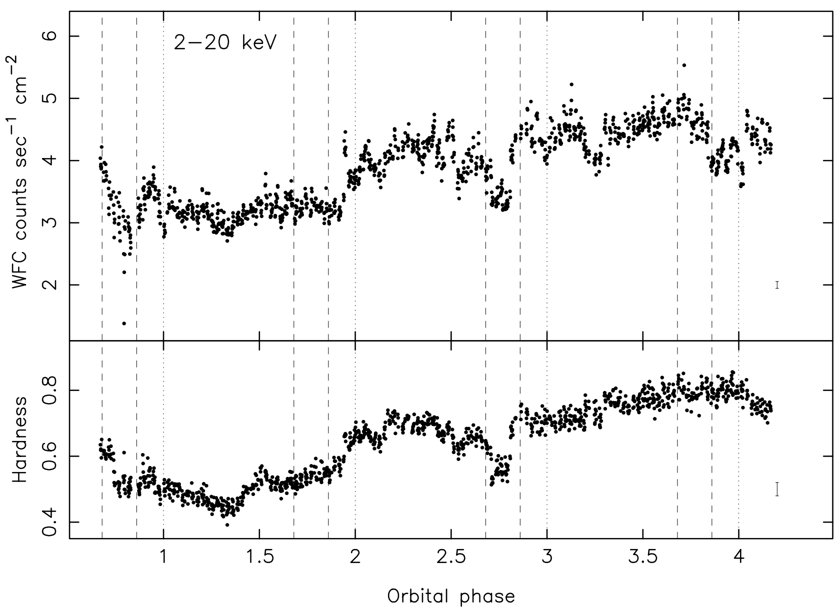

Fig. 6. WFC light curve (upper panel; 2–20 keV) and hardness curve (lower panel; hardness is the ratio of the count rates in the 5–20 keV and 2–5 keV bands) of GRO J1655−40 during the uninterrupted (except for earth occultations or South-Atlantic anomoly pasages) nine-day Galactic Center campaign in 1996 as a function of orbital phase. The time resolution in both panels is 5 min. The start of the observations corresponds to 1996 Aug 21, 19:46:01. Two consecutive dashed lines denote the phase ranges between which dipping behaviour has been observed. The dotted lines denote zero orbital phase, i.e. when the secondary star is closest to us, in front of the accretion disk and compact object. Typical uncertainties are indicated in the lower right corners of the panels.

by Tomsick et al. (1998) for GRO J1655−40; it is similar to that seen in low-mass X-ray binary dip sources ('dippers'; e.g. Parmar & White 1988; White et al. 1995).

Do the dips recur every binary orbit? At certain times they do, as was shown by Kuulkers et al. (1998b) to be the case during the early part of the 1996/1997 outburst using the RXTE/ASM light curves. Our collection of dip times suggests the same during other parts of the outburst (see Table 2). If one compares in detail the light curves from binary orbit to binary orbit, it is clear that the dips do not persist at exactly the same phase. Moreover, if the strong dipping behaviour seen in binary cycle 272 were present every orbit, we would certainly have seen this in the WFC light curves. In contrast most of the WFC light curves do not show evidence for any strong dipping behaviour. Such a transient nature of the dip activity has been noted before as well in the other LMXB dip sources, see e.g. Parmar et al. (1986) for the case of EXO 0748−676. We note that it looks as if dipping only occurred during the first halves of the two stages of the outburst, i.e. they appear during the rise and plateau phases of the outburst.

4.2. Stream-disk interaction

The orbital phase dependence of the dip occurrences suggests the dip mechanism to be fixed in the binary orbit. For illustrative purposes (Fig. 7) we show views of the system at the extremes of the dip phase range. The most straightforward site is the interaction region between the mass transfer stream from the companion star and the accretion disk (e.g. Frank et al. 1987). However, it is not the bulge on the accretion disk itself which obscures the X-ray emitting region. This would result in a rather long X-ray dip as seen in e.g. accretion disk corona sources (see e.g. White et al. 1995); moreover, the inclination at which we view GRO J1655−40 is too low for such an effect to be seen (see Frank et al. 1987). Rather the short duration of the dips

$\phi = 0.68$

$\phi = 0.92$

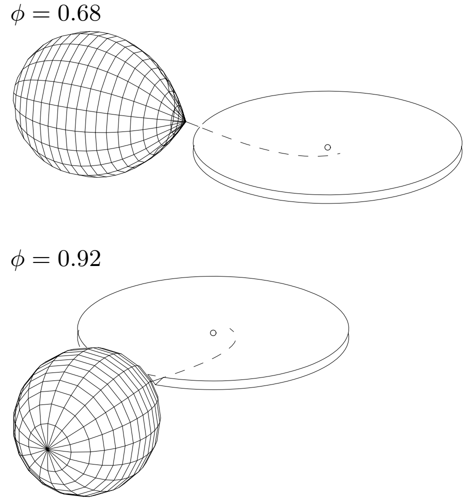

Fig. 7. View of GRO J1655−40 at the extreme ends of the dip phase range, i.e. $\phi_{\rm orb} \sim 0.68$ (upper panel) and $\phi_{\rm orb} \sim 0.92$ (top panel). We set the following binary parameters: q=0.354 (Shahbaz et al. 1999) and i=67.2° (van der Hooft et al. 1998). We arbitrarily choose a disk opening angle of 2° (see Phillips et al. 1999) and a disk radius of 0.85 $R_{\rm L1}$ (see Orosz & Bailyn 1997). The dashed line shows the ballistic path of a stream from the secondary to the compact object in the absence of an accretion disk.

points to an absorbing medium which is filamentary in nature and probably situated above and/or below the impact region (Kuulkers et al. 1998b). A similar filamentary nature has been proposed for the medium in Cyg X-1 that causes the second peak in the distribution of (short) dips with orbital phase at $\phi_{\rm orb}\sim$0.6 (where phase zero corresponds to superior conjunction of the black hole). This peak has been attributed also to a mass transfer stream from the O-supergiant interacting with the accretion disk (Bałucińska-Church et al. 2000). Note that the main peak occurs at $\phi_{\rm orb}$~0.95, which is due to absorption in the wind of the supergiant.

The dynamics of mass transfer streams from the companion up to the place of impact onto the accretion disk was first investigated by Lubow & Shu (1975, 1976). More recently it has become possible to study in more detail the impact region itself and what happens with the matter after it reaches this region (e.g. Armitage & Livio 1998, and references therein). The hydrodynamic simulations by Armitage & Livio (1998) show that the fate of the stream after it impacts the disk depends on the efficiency of cooling in the shock-heated gas created by the impact. If the cooling is efficient, the upper and/or lower parts of the stream are able to freely overflow the disk, unless the disk rim is too thick. This ballistic stream will reimpact the disk near to its closest approach to the compact object (see also Frank et al. 1987, Lubow 1989). Observationally this may lead to rather broad dips occurring near orbital phase 0.6 (Lubow 1989, see also Armitage & Livio 1996). If cooling is inefficient than the stream 'splashes' onto the disk rim, i.e. the material overflowing the disk is not in a coherent stream but rather erratic. Moreover, more material is able to reach greater heights from the disk, which leads to substantially higher absorption columns with respect to the former case, for lines-of-sight well away from the disk plane. At such lines-of-sight one expects a plethora of dips to be observed from orbital phases ~0.7–1.0, with a peak near orbital phase 0.8 (Armitage & Livio 1996, see also Frank et al. 1987). In the latter case one expects a bulge extending along the disk rim as well (Armitage & Livio 1998).

The dips observed during the 1996/1997 outburst of GRO J1655−40 all share the characteristics of the case of non-efficient cooling: they are short, show absorption columns up to $\sim 10^{24}$ atoms $\rm cm^{-2}$ (Kuulkers et al. 1998a) and the distribution of dip occurrence times extends from binary orbital phases ~0.7–0.9, with a peak near binary orbital phase 0.8.

Apart from the 'splashing' material causing the deep short dips, the presence of an extended bulge along the disk rim is supported by the observed decrease in optical polarisation near orbital phase ~0.7–0.8 (Gliozzi et al. 1998). The observations were obtained just after the peak of the second part of the outburst during 1997 July 2–9. The polarisation region must be rather extended and is located primarily around the inner disk regions. A thickening of the disk rim or the remnant stream passing under and over the disk then obscures smoothly this polarisation region (Gliozzi et al. 1998).

ASCA observed a ~4 hr drop in intensity by ~75% in the light curve of GRO J1655−40 on 1994 August 23 (Ueda et al. 1998). These observations were obtained just after the peak of the first hard X-ray and radio outburst (Harmon et al. 1995; Tavani et al. 1996). Using the ephemeris by van der Hooft et al. (1998), the ASCA dip occurred between orbital phases ~0.53–0.61, i.e. outside the phase range we see for the short and deep dips during the 1996/1997 outburst[3]. No deep short dips have been reported for the outbursts which occurred in 1994/1995, however, the soft X-ray (<10 keV) coverage during these outbursts was very sparse. The long ASCA dip is in agreement with what is expected when the stream encounters a cold accretion disk rim, so that part of the stream can continue to flow above and under the accretion disk (see above). According to Ueda et al. (1998), the material causing the dip by absorption must consist of slightly ionized (warm) and non-ionized (cold) material, which is also in line with the fact that the stream will re-impact the disk sufficiently close to the region where ionisation becomes important (Frank et al. 1987).

We suggest that the difference between the observed X-ray dips during the 1994 and 1996/1997 outbursts may be due to the efficiency in irradiating the outer disk regions. In 1994 the disk rim may have had a shape such that it does not see the X-ray emitting regions (i.e. self-screening by the disc of its outer regions; see Dubus et al. 1999), possibly due to a large enhancement of mass transfer from the secondary, and the gas at the stream impact region could cool efficiently. During the 1996/1997 outburst the outer disk regions were less affected by the mass transfer stream from the secondary, which were therefore more easily prone to X-ray irradiation by the X-ray emitting region, keeping the outer disk hot.

[3] We note that an eclipse-like feature in the optical light curves was found on 1994, August 17 by Bailyn et al. (1995a), i.e. close in time to the ASCA dip; a possibly similar optical feature occurred one binary orbit earlier (Bianchini et al. 1997). The eclipse-like light curve of Bailyn et al. (1995a) lasted from orbital phase ~0.0–0.1. Bianchini et al. (1997) suggested this to be due to a bright spot region, or an extended optically thick disk rim shielding part of the disk.

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