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The properties of X-ray binaries

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1.1 Introduction

An X-ray binary contains either a neutron star or a black hole accreting material from a companion star. X-ray binaries constitute the brightest class of X-ray sources in the sky, and were the main focus of the first 15 years of X-ray astronomy, until the advent of X-ray imaging instruments in the late 1970s allowed fainter classes to be studied. Sco X-1, the first non-solar X-ray point source discovered (Giacconi *et al.* 1962), was subsequently classified as an X-ray binary (Gursky *et al.* 1966; Sandage *et al.* 1966; Gottlieb *et al.* 1975). Approximately 175 X-ray binaries have now been identified from various X-ray surveys and optical identification programs (see Ch. 14). An optical identification is crucial to establish the nature of the mass-donating companion star, the overall geometry of the accretion flow and the mass of the X-ray source (see Ch. 2 and 3, and references therein).

The primary factors that determine the emission properties of an accreting compact object are (1) whether the central object is a black hole or a neutron star, (2) if it is a neutron star, the strength and geometry of its magnetic field, and (3) the geometry of the accretion flow from the companion (disk vs. spherical accretion). These determine whether the emission region is the small magnetic polar cap of a neutron star, a hot accretion disk surrounding a black hole, a shock heated region in a spherical inflow, or the boundary layer between an accretion disk and a neutron star. Two more factors are the mass of the central object, and the mass accretion rate; these influence the overall luminosity, spectral shape and time variability of the emission.

A neutron star with a strong magnetic field ($\sim 10^{12}$ G) will disrupt the accretion flow at several hundred neutron star radii and funnel material onto the magnetic poles (Pringle and Rees 1972; Davidson and Ostriker 1973; Lamb, Pethick and Pines 1973). If the magnetic and rotation axes are misaligned, X-ray pulsations will be observed if the beamed emission from the magnetic poles rotates through the line of sight (e.g. Mészáros, Nagel and Ventura 1980; Nagel 1981a,b; Wang and Welter 1981). When the magnetic field of the neutron star is relatively weak ($< 10^{10}$ G), the disk may touch or come close to the neutron star surface. The energy released from the inner accretion disk and the boundary layer between the disk and the neutron star will dominate the emission (e.g. Mitsuda *et al.* 1984). If the central object is a black hole, the X-rays come from the inner disk and are the results of viscous heating (Shakura and Sunyaev 1973).

Instabilities in the emission region, or its influence on the nearby accretion flow, can give rise to rapid fluctuations, or quasi-periodic oscillations (see Ch. 6). The material, as it accumulates on the neutron star, may reach a critical mass and undergo a thermonuclear flash, resulting in an X-ray burst (see Ch. 4). Instabilities in the accretion flow can also give rise to X-ray bursts, or flares (Taam and Fryxell 1988).

The spectral type of the companion determines the mode of mass transfer to the compact object and the overall environment in the vicinity of the compact object. In the low-mass X-ray binaries, LMXBs, the companion is later than type A, and can, in some very evolved systems, even be a white dwarf. A late type or degenerate star does not have a natural wind strong enough to power the observed X-ray source. Significant mass transfer will occur only if the companion fills its critical gravitational potential lobe, the Roche lobe. X-ray heating of the accretion disk and the companion star dominates the optical light, and LMXBs appear as faint blue stars (see Bradt and McClintock 1983 and references therein).

In high-mass X-ray binaries, HMXBs, the companion is an O or B star whose optical/UV luminosity may be comparable to, or greater than, that of the X-ray source (Conti 1978; Petterson 1978). X-ray heating is minimal, with the optical properties dominated by the companion star. The OB star companion has a substantial stellar wind, removing between 10^{-6} and 10^{-10} $M_\odot$ yr^{-1} with a terminal velocity up to 2000 km s^{-1}. A neutron star or black hole in a relatively close orbit will capture a significant fraction of the wind, sufficient to power the X-ray source. The X-rays must propagate through the wind to the observer, which causes photoelectric absorption in the X-ray spectrum. Roche lobe overflow can also be a supplement to the mass transfer rate in HMXBs. However, if the mass ratio of the compact object to its companion is greater than unity, then mass transfer via Roche lobe will become unstable $\sim 10^5$ yr after it starts (see Savonije 1983 and references therein). Quasi-Roche lobe overflow may occur as the supergiant approaches its Roche lobe, where the reduced gravity can cause a focusing of the wind towards the compact object (Friend and Castor 1982).

Many X-ray binaries are transient sources that appear on a timescale of a few days, and then decay over many tens or hundreds of days (White, Kaluzienski and Swank 1984; Van Paradijs and Verbunt 1984). These transient sources can, for a few weeks, be amongst the brightest in the sky, before they fade away. They are particularly important in the study of X-ray binaries since they cover an enormous dynamic range in luminosity (typically 10^4–10^5). This allows models for the emission region and the accretion process to be tested over a large range of mass accretion rate. The transient episodes may result from an instability in the accretion disk, or a mass ejection episode from the companion. Many transients are seen to recur on a timescale that ranges from days to tens of years. Some transients recur periodically, others do so randomly.

The flow geometry is determined by the angular momentum per specific mass of the accretion flow (see Ch. 10). If the companion star fills its critical Roche lobe, then a stream of material will be driven through the inner Lagrangian point. This stream will orbit the compact object at a radius determined by its specific angular momentum (Lubow and Shu 1975). Viscous interactions and angular momentum conservation cause the ring to expand into a disk. The disk's outer radius is limited by tidal forces, which will transfer angular momentum back to the binary orbit.

The specific angular momentum captured from a stellar wind is determined by gradients and asymmetries in the wind across the accretion cylinder (e.g. Shapiro and Lightman 1976). The magnitude of the captured specific angular momentum is much less in this case (Davies and Pringle 1980), and any resulting accretion disk may, depending on the circumstances, be very tenuous.

The emission from the vicinity of the compact object propagates to the observer through the surrounding environment, which modifies the spectrum by absorption and scattering. Important environmental zones are the magnetosphere of the neutron star, the accretion disk, the accretion disk corona/wind, the wind and/or atmosphere of the companion star and last, but not least, the interstellar medium. The prime result of this is that the X-ray spectrum undergoes substantial absorption at low energies, caused by the increasing absorption cross-section of the medium-Z elements such as iron, oxygen and carbon (Brown and Gould 1970). This results in K and L absorption edges in the spectra, and emission lines from fluoresence and recombination. The relative edge to line strength can be used to infer the geometry of the surrounding material. The line and edge energies are used to constrain the ionization state of the material, which in turn provides insight into its density and location. Lastly, the intervening interstellar medium causes low-energy absorption and dust scattering halos.

In this review, we describe the properties of X-ray binaries containing neutron stars and how they can be used to classify and understand the nature of the compact object, the companion star and the mass transfer process. We will concentrate on the X-ray properties measured using a number of X-ray astronomy satellites over the past two decades. The review by Tanaka and Lewin (Ch. 3) gives an overview of the X-ray properties of black hole systems. Sect. 1.2–1.4 outline the orbital, pulse and other periods found in X-ray binaries; Sect. 1.5 describes the properties of the underlying emission region; and in Sect. 1.6 the influence of the environment, i.e. the material flowing in and around the compact object, is described.

1.2 Orbital periods

1.2.1 Overview

The orbital periods of X-ray binaries have been determined from the observation of one or more of the following:

- eclipses,
- a smooth periodic modulation,
- periodically recurring X-ray absorption dips,
- periodically recurring transient X-ray outbursts,
- pulsar arrival time variations,
- radial-velocity variations, and/or
- a pulsar-orbital beat period.

The classification as low- or high-mass X-ray binary is based on the spectral type of the companion obtained from an optical identification, and/or on the mass function from X-ray pulse arrival time measurements. If neither is available, a classification may be inferred based on the similarity of the X-ray properties to other identified systems. An unidentified system is classified as an LMXB containing a neutron star if one or more of the following properties are observed:

- type I X-ray bursts (which to date have only been seen from LMXBs),
- the 1–10 keV spectrum is *soft* with a characteristic temperature of 5–10 keV, and/or
- the orbital period is less than about 12 hr.

The last criterion is adopted because a *normal* O or B star will not fit into such a small orbit, although at the extremes of the evolutionary scale this may not always be the case (cf. Van Kerkwijk *et al.* 1992). An unidentified system is classified as an HMXB containing a neutron star if the X-ray source shows one or more of the following features:

- strong flaring and absorption variability on a timescale of minutes,
- transient outbursts,
- pulsations,
- and/or has a hard 1–10 keV spectrum with a power-law energy index of order 0–1.

1.2.2 LMXBs

1.2.2.1 The period distribution

Table 1.1 lists the 32 LMXBs with well established orbital periods. The orbital periods range from 0.19 hr to 398 hr. The table also lists the bands in which the modulation is detected, the band where it was first found and key source properties. Note that about twice as many periods are seen from optical studies than from X-ray studies. This is because an X-ray modulation is only seen when the system is viewed close to the orbital plane, so that eclipses by the companion star and absorption by material in the accretion flow occur. An optical modulation can be caused by much more subtle effects, such as viewing the rotating face of an X-ray heated or tidally distorted companion, and are detectable over a greater range of inclination angle.

Figure 1.1 compares the distributions of the orbital periods of LMXB and cataclysmic variable (CV) systems, where the compact object is a white dwarf (see Ch. 8). There are no X-ray binaries with orbital periods corresponding to the gap in the CV period distribution between 2 and 3 hr. In the case of the LMXBs the period gap may extend down to $\lesssim 1$ hr (White 1985; White and Mason 1985); in the CV systems the 1–2 hr period range is populated by the SU Uma and AM Her type systems. This difference appears to be significant, since there is no selection effect against detecting LMXBs with periods in this range.

The lower X-ray luminosity systems ($\sim 10^{36}$–10^{37} erg s^{-1}), which are predominantly X-ray burst sources, typically have orbital periods of $\lesssim 15$ hr. The orbital period distribution of the high ($\sim 10^{38}$ erg s^{-1}) luminosity systems (many located in the optically obscured galactic bulge region) is still largely unknown, but in two cases (Sco X-1 and Cyg X-2) orbital periods of 19 and 235 hr have been found from optical studies.

Table 1.1. *The orbital periods of LMXBs*

Source	Alternative name	Period (hr)	Modulation		Discovery	Source properties[b]	Reference
			Optical[a]	X-ray[a]			
X1820−303		0.19	-	M	X	B,G,Q	1,2,3
X1627−673		0.70	B	-	O	P,Q?	4
X1916−053		0.83	M	D	X	B	5,6,7
X1323−619		2.93	-	D	X	B	8
X1636−536		3.80	M	-	O	B	9,10
X0748−676		3.82	M,E	D,E	X	B,T	11,12
X1254−690		3.93	M	D	O/X	B	13,14
X1728−169	GX 9+9	4.19	M	M	X	-	15,16
X1755−338		4.46	M	D	X	-	17,18
X1735−444		4.65	M	-	O	B	19
X2129+470		5.2	M,E	M,PE	O	B,T	20,21
X1822−371		5.6	M,E,S	M,PE	O	-	22,23,24
X1746−370		5.7	-	D	X	B,G	25,26
X2023+338	V404 Cyg	5.7/155	M,S	-	O	T,BHC	27, 56
X1658−298		7.1	-	D,E	X	B,T	28
X0620−003	N'Mon 75	7.7	M,S	-	O	T,BHC	29
X2000+251	N'Vul 88	8.3	M	-	O	T,BHC	30,31
X1556−605		9.1	M	-	O	-	32
X1957+115		9.3	M	-	O	-	33
X1124−684	N'Mus 91	10.4	M	-	O	T,BHC,Q	34,35
X0547−711	CAL 87	10.6	M	-	O	SS	36,37
X1659−487	GX 339−4	14.8	M	-	O	T,BHC,Q	38
X1455−314	Cen X−4	15.1	M,S	-	O	B,T	39,40
X2127+119	AC211	17.1	M,S,PE?	-	O	B,G	41
X1617−155	Sco X−1	18.9	M,S	-	O	Q	42,43
X1908+005	Aql X−1	19.0	M	-	-	B,T	44
X1624−490		21.0	-	D	X	B	45
X0543−682	CAL 83	25.0	M	-	O	SS	46
X1656+354	Her X−1	40.8	M,S,E	E	X	P	47,48,49
X0921−630		216	M,S	PE	O	-	50,51,52
X2142+380	Cyg X−2	236	M,S	D	O	B?,Q	53,54
X1516−569	Cir X−1	398	-	O	X	B,Q	55

[a] 'E' - total eclipse, 'PE' - partial eclipse, 'D'- periodic dips, 'M' - other modulation, 'B' - beat period, 'O' - periodic outbursts.

[b] The source properties are indicated by 'B' - burster, 'G' - globular cluster, 'P' - pulsar, 'T' - transient, 'SS' - super-soft, 'BHC' - black-hole candidate, 'Q' - QPO.

References: [1]Stella *et al.* 1987; [2]Sansom *et al.* 1989; [3]Tan *et al.* 1991; [4]Middleditch *et al.* 1981; [5]Walter *et al.* 1982; [6]Grindlay *et al.* 1988; [7]White & Swank 1982; [8]Parmar *et al.* 1989a; [9]Pedersen *et al.* 1981; [10]Smale & Mukai 1988; [11]Parmar *et al.* 1986; [12]Parmar *et al.* 1991; [13]Courvoisier *et al.* 1986; [14]Motch *et al.* 1987; [15]Hertz & Wood 1988; [16]Schaefer 1987; [17]White *et al.* 1984; [18]Mason *et al.* 1985; [19]Corbet *et al.* 1986; [20]Thorstensen *et al.* 1979; [21]Ulmer *et al.* 1980; [22]White *et al.* 1981; [23]Mason *et al.* 1980; [24]Hellier *et al.* 1990; [25]Parmar *et al.* 1989b; [26]Sansom *et al.* 1993; [27]Casares & Charles 1992; [28]Cominsky & Wood 1984; [29]McClintock & Remillard 1986; [30]Chevalier & Ilovaisky 1990; [31]Charles *et al.* 1991; [32]Smale 1991; [33]Ilovaisky *et al.* 1987; [34]Bailyn 1991; [35]McClintock *et al.* 1992; [36]Callanan *et al.* 1989; [37]Cowley *et al.* 1990; [38]Callanan *et al.* 1992; [39]Chevalier *et al.* 1989b; [40]Cowley *et al.* 1988; [41]Ilovaisky *et al.* 1993; [42]Gottlieb *et al.* 1975; [43]Cowley & Crampton 1975; [44]Chevalier & Ilovaisky 1991; [45]Jones & Watson 1989; [46]Smale *et al.* 1988a; [47]Tananbaum *et al.* 1972; [48]Bahcall *et al.* 1974; [49]Voges *et al.* 1985; [50]Mason *et al.* 1987; [51]Branduardi-Raymont *et al.* 1983; [52]Chevalier & Ilovaisky 1982; [53]Cowley *et al.* 1979; [54]Vrtilek *et al.* 1986b; [55]Kaluzienski *et al.* 1976; [56]Casares *et al.* 1992.

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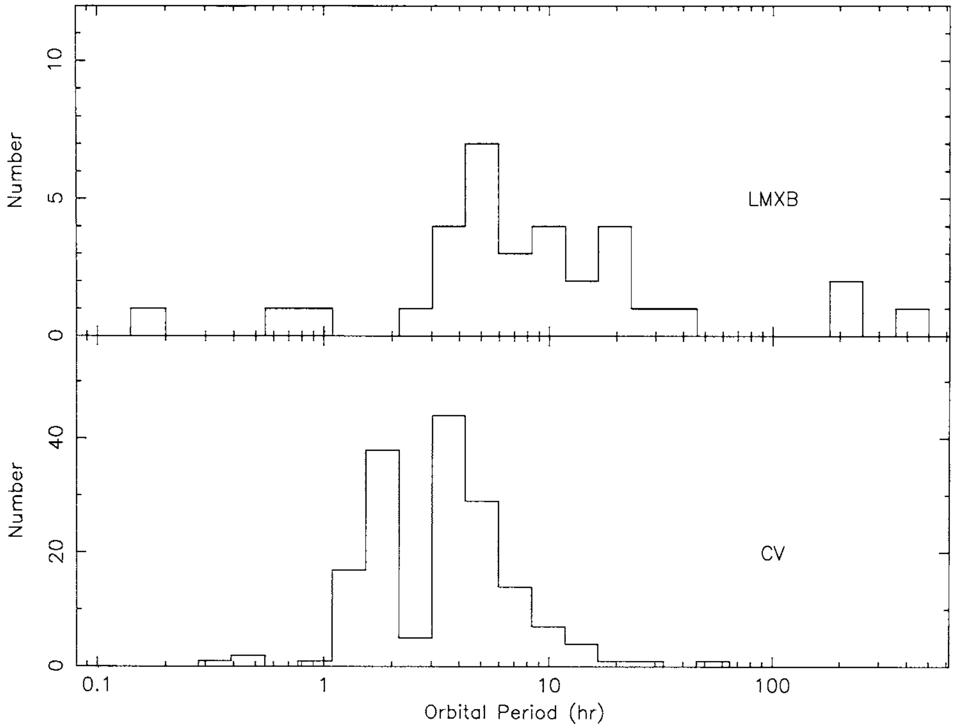

Fig. 1.1. The orbital-period distributions of LMXB and cataclysmic variable (CV) systems. The CV periods are taken from Ritter (1990).

1.2.2.2 Globular cluster systems

There are 12 luminous ($> 10^{35}$ erg s^{-1}) X-ray sources located in globular clusters, which is two orders of magnitude more than expected from the total mass in globular clusters relative to that in the Galaxy (Katz 1975). The tidal capture of neutron stars in close encounters with main-sequence or giant stars in the cluster core may favor the production of X-ray binaries (Fabian, Pringle and Rees 1975). Three orbital periods are known for X-ray sources in globular clusters: an 11 min X-ray modulation from X1820–303 (located in NGC 6624; Stella, Priedhorsky and White 1987); a 5.7 hr X-ray modulation from X1747–371 (in NGC 6441; Parmar, Stella and Giommi 1989b; Sansom *et al.* 1993); and 17.1 hr from the optical modulation of X2127+119 (located in M15; Ilovaisky *et al.* 1987; Naylor *et al.* 1988, Ilovaisky *et al.* 1993).

1.2.2.3 X-ray orbital light curves

LMXBs exhibit fewer X-ray eclipses than might be expected if the systems simply consist of a dwarf companion overflowing its Roche lobe and transferring material to a compact object via a *thin* accretion disk (Joss and Rappaport 1979). Milgrom (1978) suggested that this discrepancy could be resolved if LMXBs contain *thick* accretion disks which block the X-ray source in systems that are viewed close to the orbital plane. The discovery of a partial eclipse with *HEAO 1* from the LMXB

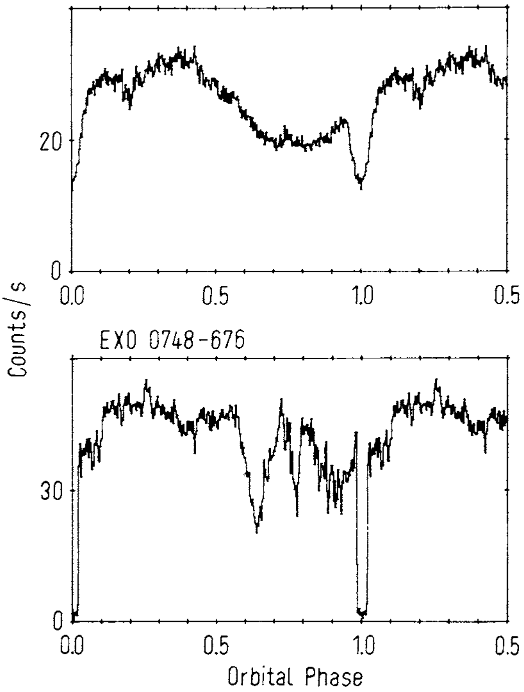

Fig. 1.2. The folded 1–10 keV light curves of X1822–371 (top) and X0748–676 (taken from Parmar *et al.* 1986). One and a half orbital cycles are shown.

X1822–371, proved Milgrom's thick-disk model to be essentially correct (White *et al.* 1981). In X1822–371, the system is viewed almost edge on, and the compact X-ray source is hidden by the disk. X-rays are still seen because they are scattered in a photo-ionized corona above the disk. This makes the source appear extended, and results in the eclipse being partial (Figure 1.2). The orbital light curve also shows a sinusoidal modulation, with a minimum preceding the partial eclipse. This can be ascribed to the partial occultation of the accretion disk corona (ADC), by a bulge at the rim of the disk caused by its interaction with the incoming gas stream (White and Holt 1982).

The LMXB X1916–053 was discovered with the *Einstein* Observatory to show irregular dips that recur periodically every 50 min (Walter *et al.* 1982; White and Swank 1982). These dips are ascribed to material which is projected up above the disk plane by a splash point, where the gas stream from the companion hits the accretion disk. A total of ten dipping sources are now known, most of them having been discovered with *EXOSAT* (Table 1.1). The long, 90 hr, orbital period of the *EXOSAT* satellite (compared with 100 min for most other X-ray observatories) allowed unprecedented continuous coverage, which was ideal for discovering the irregular, but periodic, dipping behavior. The X-ray light curves of three of these *dippers* are shown in Figure 1.3.

The strongest confirmation of the thick accretion disk model was the discovery of

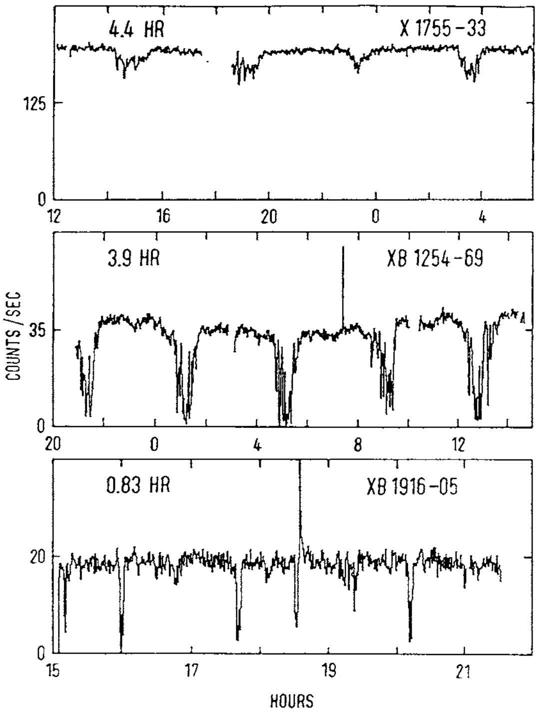

Fig. 1.3. The 1–10 keV light curves of X1755–338, XB 1254–690 and XB 1916–053 recorded by the *EXOSAT* observatory.

two dipping sources which also show an eclipse by the companion star: X0748–676 (Parmar *et al.* 1986) and X1658–298 (Cominsky and Wood 1984). In both, the eclipse follows an interval of dipping activity, consistent with the dips being due to the splash from the accretion stream passing through the line of sight. These observations show that the most likely reason that the accretion disk is *thick* is that the incoming gas stream creates turbulence at the outer edge of the disk.

Figure 1.2 compares the folded light curves of the ADC source X1822–371 and those of the dip source X0748–676. The eclipse from X0748–676 has a sharp ingress and egress (with a transition time of 6 s). The dips cause highly irregular structure prior to the eclipse. In contrast, the X1822–371 eclipse has a gradual ingress and egress, and is partial. A smooth modulation occurs over approximately the same range of orbital phase as the dips seen from X0748–676. These differences are consistent with the view that the observed X-ray source is point-like in the case of X0748–676 and extended in the case of X1822–371. The typical L_x/L_{opt} ratio of an LMXB is typically 100–1000, except for the ADC sources, which have L_x/L_{opt} ratios of ~ 20. This lower ratio in the ADC sources results from the fact that the overall X-ray luminosity is reduced because the central X-ray source is hidden.

To summarize, the observed properties of an LMXB depend on the viewing angle. At a low inclination ($< 70°$), no X-ray dips or eclipses are seen, but an optical modulation from the X-ray heated companion may still betray the orbital period.

At an intermediate inclination, periodic dipping behavior is seen which is caused by structure at the edge of the accretion disk; in a few cases, a very brief eclipse by the companion may be seen. In high inclination systems (> 80°), the central X-ray source is hidden behind the disk rim, but X-rays scattered via an ADC are still seen giving rise to a partial eclipse.

1.2.2.4 Individual cases

The orbital modulation of each LMXB has its own peculiarities, and in this section we discuss some of the typical and exceptional examples. We will not discuss the black-hole candidates, X2023+338, X0620−003, X2000+251, X1124−684 and GX339−4, which are described in Ch. 3.

X1820−303, P_o=0.19 hr. The 11 min orbital period of the X-ray burst source X1820−303, located in the globular cluster NGC 6624, is the shortest known of any binary system. The orbital period is detected from a low amplitude (3% peak-to-peak) energy independent modulation of the X-ray flux (Stella, Priedhorsky and White 1987). The modulation may be caused by obscuration of the central neutron star by material in the disk, in a similar way to the irregular X-ray dips seen from other LMXBs, or from the obscuration of the outer regions of an ADC that scatters a small fraction of the observed X-ray luminosity. The extremely short, 11 min, orbital period suggests that the companion star is a degenerate dwarf. A discussion of the likely formation mechanisms of such a system by Verbunt (1987) (see also Bailyn and Grindlay 1987 and Rappaport *et al.* 1987) supports the globular cluster tidal-capture model. This system may be the result of the subsequent spiral-in of the neutron star in the atmosphere of a red-giant companion.

X1626−673, P_o=0.70 hr. The orbital period of this 7.7 s X-ray pulsar was determined from photometric observations of the optical counterpart by Middleditch *et al.* (1981). These revealed not only the 7.7 s X-ray period, but also a low-level sideband period. This sideband can be explained as the beat between the orbital period and the pulse period. The optical sideband pulsation is probably the result of reprocessing of the X-ray pulse on a bulge in the accretion disk and/or on the face of the companion star (see Sect. 2.3.5.2).

X1916−053, P_o=0.83 hr. The orbital period was discovered from the periodic dipping behavior, which shows great variation from cycle to cycle (Figure 1.3). Typically, the dips are narrow (with a duration of < 10 min) and recur every 55 min, but occasionally anomalous/secondary dips are seen 180° out of phase with the main dip interval (Walter *et al.* 1982; White and Swank 1982). The depth and duty cycle of the dips can change dramatically from cycle to cycle and observation to observation (see, *e.g.*, Smale *et al.* 1988b, 1992).

The optical counterpart to X1916−053 is an m_v=21 blue object (Grindlay *et al.* 1988), which exhibits a photometric period that is 1% longer than the X-ray period. Grindlay *et al.* (1988), suggest that the system is part of a hierarchical triple and that the third body modulates the mass transfer (see Sect. 2.6.3). This could cause the X-ray dips to have a slightly shorter period. White (1989) and Smale *et al.* (1992)

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discuss alternative models based on similar double periodicities separated by a small percentage found in SU UMa dwarf novae. Numerical simulations by Whitehurst (1988) suggest that precession of an elliptical accretion disk may be responsible for the brightness maxima or 'superhumps' seen in CVs with orbital periods below the period gap. This precession only occurs when the mass ratio of the companion to the compact object is < 0.15. If this condition is satisfied, the disk becomes tidally unstable, causing it to become asymmetrical in shape, with the axis of the asymmetry rotating slightly faster than the orbital period.

X0748–676, P_o=3.82 hr. This transient X-ray burst source, discovered serendipitously with *EXOSAT* in 1985, exhibits both dips and eclipses (Parmar *et al.* 1986). The center of the dipping activity precedes the eclipses by the companion, confirming that the dips arise from the impact of the gas stream with the disk. Depending on the assumptions made about the mass–radius relation of the companion star, the eclipse duration implies an orbital inclination of 73–83°. Thus, the thickened region responsible for the dips must subtend an angle of at least 7° above the plane of the orbit in order to obscure our line of sight. Since dips are sometimes seen for about half the orbital cycle, this region must also extend halfway around the disk at times. During eclipse, 4% of the flux remains which can be attributed to residual emission scattered by an optically thin ADC (Parmar *et al.* 1986).

This source was not seen before 1985, but has been active since then at about the same level, being detected with *Ginga* and, most recently, with *ASCA* in March 1993. This is typical of this class of LMXBs where the source appears for a number of years and then turns off for a similar number of years. During the X-ray outburst, the optical counterpart is a blue m_v=17 object (Pedersen and Mayer 1985), which is modulated at the orbital period with an optical minimum centered on the time of X-ray eclipse (Pedersen *et al.* 1985; Crampton *et al.* 1986; Schmidtke and Cowley 1987). When the X-ray source is quiescent, the optical counterpart is fainter than m_v=23 (Wade *et al.* 1985). This indicates that the X-ray outburst is caused by an accretion episode, as opposed to a thickening of the disk causing the central X-ray source to be occulted.

X1254–690, P_o=3.88 hr. Courvoisier *et al.* (1986) discovered that the X-ray light curve of X1254–690 shows irregular dips that repeat with a period of 3.88 hr (Figure 1.3). This recurrence interval is consistent with the optical period of this system independently discovered by Motch *et al.* (1987). A 0.4 magnitude quasi-sinusoidal modulation of the m_v=19.1 counterpart is observed, with the minimum occurring 0.15 cycles after the X-ray dips. This phase difference is expected if the material responsible for the dips is located close to where the gas stream from the companion impacts the accretion disk. The depth and duration of the dips show great variety, typical of this class of X-ray source (Courvoisier *et al.* 1986).

X1755–338, P_o=4.4 hr. X1755–338 is a very unusual X-ray dip source. *EXOSAT* observations (see Figure 1.3) revealed shallow energy independent dips in X-ray intensity every 4.4 hr (White *et al.* 1984; Mason, Parmar and White 1985). The duration and irregular variability of the X1755–338 dips are similar to those seen