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Black hole X-ray transients: mass accumulation in the disk - constraints for the viscosity

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Abstract. The outburst cycles of black hole X-ray transients are now generally understood as caused by a thermal instability in the accretion disk, the same mechanism as in dwarf novae outbursts. During quiescence the accretion occurs via a cool disk in the outer region but changes to a coronal flow/ADAF in the inner region. The transition to the coronal flow is caused by evaporation of matter from the cool disk. This process is an important feature for the disk evolution. We present a critical discussion of different ways to model X-ray transient outburst cycles and compare with the requirements from observations. When the accretion disk has been significantly depleted during the outbursts as indicated by their long duration the accumulation of mass during quiescence becomes independent of the details of the outburst. We show that then the observations indicate a frictional parameter of the cool disk of order $\alpha_{\rm cold}$ =0.05, similar to that in dwarf nova disks during quiescence, with no need to resort to much lower α values of order 0.005.

Key words: accretion disks – black hole physics – X-rays: stars – stars: individual: A0620-00, Nova Vul 1988, Nova Mus 1991, 4U 1630 -472

1. Introduction

Soft X-ray transients (SXT), also known as X-ray novae, contain a black hole or neutron star primary and a low-mass companion star. We consider here the black hole sources. These systems are characterized by the high luminosity X-ray outburst after a long-lasting quiescence and are usually detected in X-rays. An optical counterpart is known for a number of systems. During quiescence the optical light is dominated by the secondary star allowing detailed photometry and spectroscopy to determine the system parameters of the binary. A0620-00 was the first low-mass X-ray binary proven in this manner to contain a black hole (Mc Clintock & Remillard 1986). For this well observed system at the distance of only about 1kpc two outbursts in optical light were observed, originally interpreted as classical nova outbursts, 1917 (Nova Mon 1917) and 1975. For several systems only one outburst is known, their recurrence time is longer than 30, possibly 50 years. See Tanaka & Shibazaki (1996) and Tanaka (2000) for a comprehensive description of the observations of X-ray transients. Chen et al. (1997) collected and discussed the available data for properties of X-ray and optical light curves. Charles (1998) also reviewed the X-ray, optical, radio and IR observations of black hole X-ray binaries.

SXTs and dwarf novae are similar in the respect that mass is transferred from a Roche lobe-filling low mass secondary star to a compact primary, a neutron star or black hole in SXTs, a white dwarf in the dwarf nova case. Accretion occurs via a disk. The evolution of the accretion disk and the triggering of an outburst therefore were modeled in the same way as for the dwarf nova outbursts. The first investigations were by Huang & Wheeler (1989) and Mineshige & Wheeler (1989). Later detailed investigations (Cannizzo et al. 1995, Cannizzo 1998, review 1999, 2000) focussed on modeling the exponential decline of the outburst lightcurve.

For the evolution of the disk during quiescence one feature is important in SXTs (present also in dwarf nova disks, but there of lesser importance). It is necessary to have a truncated inner disk. Otherwise the disk cannot be cool throughout. Even with a very low mass flow rate the disk would become ionized in the inner region. This hot region and the further outward cool region cannot exist together in a quasi-stationary state. Instead cooling and heating fronts would move inward and outward in the disk and change the disk back and forth between the hot and the cool state (Meyer 1981). This truncation of the geometrically thin cool disk naturally results from evaporation of mass in the inner disk region into a hot corona (Meyer & Meyer-Hofmeister 1994). For the region further in the concept of an advection-dominated accretion flow (ADAF) was developed as a mode of accretion which allows to explain the low luminosity of X-ray transients in quiescence as well as in AGN. The review paper by Narayan et al. (1998) gives a detailed description of the

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physics of ADAFs as well as the investigations of this mode of accretion by several authors. The application to galactic black hole X-ray binaries and galactic nuclei was very successful in modeling the observed spectra. Best studied systems are A0620-00, V404 Cyg (Narayan et al. 1996, 1997), Nova Muscae (Esin et al. 1997) and GRO J1655-40 (Hameury et al. 1997).

The ADAF in the inner disk region together with the geometrically thin disk further out provides a consistent picture for the accretion in SXTs. From observations for the quiescent state properties of the accretion disk can be derived. The "standard disk instability model" for dwarf nova outbursts allows to understand the triggering of the outbursts in SXTs after the long recurrence time. This has been proven in the application to A0620-00 (Meyer-Hofmeister & Meyer 1999, hereafter MHM99), using the viscosity values typically found for dwarf novae. There it was assumed that the disk is practically empty after the outburst due to the strong irradiation of the disk which prevents the disk from changing back to the cool state and causes the long lasting outburst decline (King & Ritter 1998). If this is the case the accumulation of mass in the disk is independent of the details of the outburst.

Menou et al. (2000) model the full outburst cycle of A620-00 in a way that about 90% of the mass in the disk remain there during the outburst. Evaporation was taken into account in a rough approximation (details will be discussed later). They conclude that the viscosity in quiescence has to be very low ($\alpha_{\rm cold}$=0.005) to reproduce the long recurrence times. In their investigation the effect of disk irradiation during the outburst is not included, also the possibility to model A0620-00 with standard viscosity values as in MHM99 was not noted apparently.

The aim of the present investigation is a critical comparison of the predictions of various theoretical models, including earlier results from Cannizzo (1998), with the available data for black hole transients.

In Sect. 2 we show examples of computed disk evolution for A0620-00. Evaporation in the inner region reduces the accumulation of mass and for low mass transfer rates the instability can only marginally be triggered. The evaporation of mass therefore is the important feature which governs the disk evolution during the long-lasting quiescence and needs to be taken into account for the evolutionary computations in a way, so that the physics is included. We discuss how far the models agree with the requirements from observation. In Sect. 3 we focus on the total amount of mass accumulated when the outburst occurs and compare with collected data for several black hole SXTs. In Sect. 4 we discuss consequences for the viscosity in the case of long recurrence time. Additional computations shed light on the situation in systems with short recurrence time where an essential part of the mass in the disk might be left over after the outburst.

2. Disk evolution during quiescence - models for A0620-00

2.1. Computational method

Diffusion governs the evolution of the mass distribution in the disk. Given a black hole mass and an orbital period the mass transfer rate determines the disk evolution (given an initial mass distribution). For systems with long recurrence time we assume that the disk becomes depleted during the long-lasting outburst, caused by the irradiation which prevents the disk to go back to the cool state (King & Ritter 1998). This has an essential consequence for the conclusions.

Our computer code includes the variation of the outer and inner disk edge during the evolution. The disk size changes as determined by redistribution of matter and angular momentum. The size is limited by the 3:1 resonance radius (Whitehurst 1988, Lubow 1991), which lies inside the tidal truncation radius for systems with a small mass ratio as the SXTs. For the initial size of the disk we assume 90% of the resonance radius. The maximal disk size is related to the orbital period and the secondary star mass. We take the secondary star mass according to the mass of a Roche-lobe filling main-sequence star for the given period. The location of the inner disk edge also varies. It is determined by the evaporation of matter into the corona. The total evaporation efficiency computed in a one-zone model is applied to this interval. For mass flow rates lower than about 0.01 $\dot M_{\rm Edd}$ ($\dot M_{\rm Edd}=40\pi GM/\kappa c$, κ electron scattering opacity) and a coronal α-parameter of 0.3 the evaporation rate (in g/s) can be approximated by the following formula

$$\dot M_{\rm evap}(M,r) \;=\; 10^{14.9}\cdot (M/M_\odot)^{2.3}\cdot (r/10^{9.5})^{-1.2} \qquad (1)$$

with M the mass of the compact star (see Liu et al. 1995, Meyer et al. 2000). Coronal friction like that of a standard disk leads to redistribution of angular momentum and also to a partial outward flow that is taken into account (Liu et al. 1997, application to evaporation around a white dwarf). A detailed description of the computational method is given in MHM99. The black hole mass an important parameter for the disk evolution, unfortunately can be deduced from the observations only within some range of uncertainty. We choose the rate of mass transferred from the secondary star to meet the requirements from observations.

2.2. Requirements from observations

Given the orbital period (known from observations) and a black hole mass there are only two free parameters left, the rate of mass transfer from the companion star and the viscosity parameter in the cool disk $\alpha_{\rm cold}$. But several requirements have to be fulfilled connected with quiescence

and outburst (this is the same situation for all X-ray transients). The relevant data with which the results of modeling should agree are:
(1) The accretion rate in quiescence derived from ADAF model based spectral fits (Narayan et al. 1998);
(2) the radius of the transition from the outer geometrically thin disk to the inner ADAF region derived from the Kepler velocity which corresponds to the maximum velocity width of the accretion disk Hα emission line;
(3) the amount of matter accreted during the outburst estimated from the outburst light curve (for an assumed distance);
(4) The outburst recurrence time.

The mass transfer rate affects the outcome for all these requirements. In the accretion disk the transition to an coronal flow occurs where the evaporation rate exceeds the mass flow rate in the disk. The computed evolution then self-consistently determines the location at each time. The transition radius becomes smaller with proceeding mass accumulation and hence increasing mass flow rate in the inner disk (compare Fig. 3, MHM99). The viscosity value affects the amount of mass in the disk, higher for lower viscosity.

2.3. Matter accumulation

For different models, all designed to describe the X-ray nova A0620-00, we show in Fig. 1 how the mass in the disk accumulates with time. The amount is highest in the model of Cannizzo (1998, Fig. 9, model with long recurrence time). The viscosity is chosen as proportional to $(h/r)^{1.5}$, h pressure scale height. Less than 10% of the mass in the disk is accreted during the outburst. This is the scheme used successfully in modeling of dwarf nova outbursts, but probably not adequate if irradiation affects the mass flow during outburst. In recent computations of only the outburst (Cannizzo 2000) irradiation is included and much more mass accretes. In the modeling of Menou et al. (2000) $\alpha_{\rm cold}$=0.005 is taken, irradiation is not included and most of the mass remains in the disk during the outburst. The dashed line gives the total amount of mass transferred (in Cannizzo's model the total amount of mass transferred is practically the same as the amount accumulated). The two lower curves (solid lines) show the mass accumulation in our models for 4 and 6 $M_\odot$ black holes. The higher amount for the disk around the 6 $M_\odot$ black hole results from the then higher evaporation rate (see Eq. 1). This has the consequence that the critical surface density can only be reached at larger distance r and more mass needs to be stored in the disk before an outburst occurs (see Fig. 5, MHM99). The dashed line indicates the total amount of matter transferred for 4 $M_\odot$. During the late quiescence an increasing part of the matter transferred is evaporated and accreted, less and less mass is still accumulating until the critical surface density for triggering the outburst is reached. For comparison we show the disk evolution for a mass transfer rate only 5% lower (dot-dashed line): no outburst occurs, the disk becomes stationary. Such a system resembles a case of faint nontransient X-ray binaries. As discussed in earlier work (Meyer-Hofmeister & Meyer 2000) such an evolution raises the question how many black hole binaries exist in permanent quiescent state (see also Menou et al. 1999).

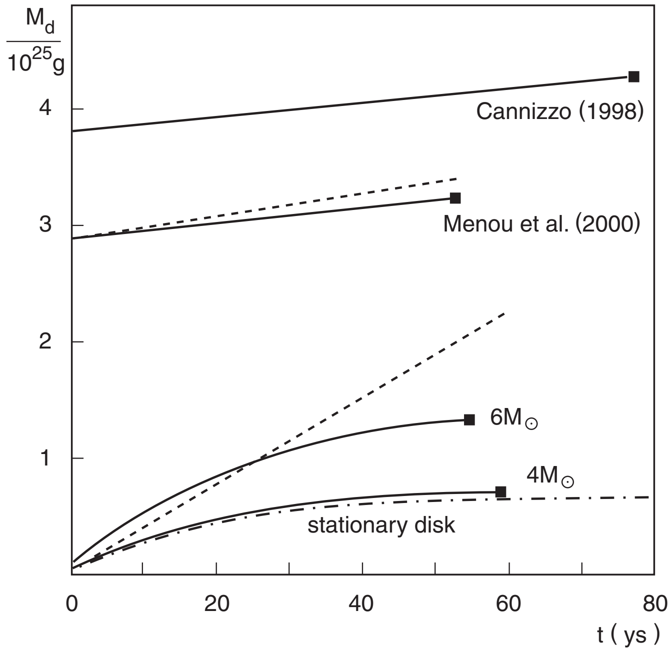

Fig. 1. Accumulation of mass in the disk during quiescence for different models, solid lines: Cannizzo (1998), Menou et al. (2000), Meyer-Hofmeister & Meyer (1999), 4 and 6$M_\odot$, squares mark the onset of the outburst; dashed lines: total amount of mass transferred from the companion star; dashed-dotted line: quasi-stationary disk, see text.

How well do the various models now meet the requirements from observations?

2.4. Observational requirement (1), evaporation rate - mass accretion rate

The accretion rate found from the ADAF model (M=6.1$M_\odot$) fit of the spectrum of A0620-00 is 3-6$\cdot10^{15}$g/s (Narayan et al. 1997, 1998). In Table 1 we summarize the results of the models with respect to the evaporation rate. To compare with the observations we consider the theoretical values for 20 years after the outburst that occurred 1975, reduced by the wind loss ($\approx$ 20%, Meyer et al. 2000). The theoretical evaporation rate should roughly agree with the accretion rate derived from observations. In Cannizzo's model the assumed evaporation gives values as low as 2$\cdot10^{14}$g/s. In the model of Menou et al. (2000) an assumed evaporation rate is taken, designed to be signifcantly smaller than the mass transfer rate. The value after 20 years is 9 10^{14} g/s, less than one third of the value

Table 1. Mass accretion rates for A0620-00

	BH mass ($M_\odot$)	$\alpha_{\rm cold}$	$\dot{M}_{\rm acc}$ (g/s)
observations:			
spectral fit by Narayan et al. (1997, 1998) (data McClintock et al. 1995)	6.1		3-6 10^{15}
models:			
Cannizzo (1998)	10.	$\sim (h/r)^{1.5}$	2. 10^{14}
Menou et al. (2000)	6.	0.005	9. 10^{14}
MHM99	4.	0.05	3.7 10^{15}
MHM99	6.	0.05	5.5 10^{15}
stationary disk (MHM99)	4.	0.05	2.8 10^{15}

Note: Model mass accretion rates taken 20 years into quiescence, which corresponds after the outburst in 1975 to about the year 1995; for the models MHM99 the rates of accretion onto the black hole (evaporation rate minus 20% wind loss) are given.

derived from the observations. In our models the evaporation rate (Eq.1) is not free but determined according to the evaporation theory.

2.5. Observational requirement (2), transition radius

For Cannizzo's model no results are given for the inner truncation of the disk. In the model of Menou et al. the transition radius follows from their choice of an evaporation formula and is about 10^{10}cm 20 years after outburst. In our treatment of evaporation the transition radius depends on the mass flow rate in the disk, the location therefore changes during the evolution. For 20 years after an outburst the radii found from our computations for 4 and 6 $M_\odot$ are close to 10^{10} cm, in good agreement with observations. The inner disk edge derived from the maximum velocity of the Hα emission line, $v_{\rm in}$ = 2100km (Orosz et al. 1994), is located at 1.3 or 1.1$\cdot 10^{10}$cm for a 4.4 or 6.1 $M_\odot$ black hole (Narayan et al. 1996, 1997).

2.6. Observational requirement (3), total amount of mass in the disk

Fig. 2 shows the amount of mass $M_{\rm d}$ (total amount of mass in the cool disk) from model computations for A0620-00, together with data from observations. The computations for 4$M_\odot$ agree better with the total amount of mass derived from observations. In earlier investigations (Narayan et al. 1996) a value of 4.4$M_\odot$, corresponding to an inclination of 70°, was used to model A0620-00, later Barret et al. (1996) suggested an inclination of 55° which leads to a black hole mass of 6.1 $M_\odot$. The evaporation efficiency still depends on the exact value of the viscosity used for the hot coronal gas. The result might change somewhat if another value would be chosen, further investigations are planned. The results of Cannizzo (1998) and Menou et al. (2000) are based on model computations where during the outburst most of the mass remains in the disk. In Fig. 2 we therefore also give the amount $\Delta M_{\rm d}$ accreted during the outburst. If irradiation during the outburst were not important the value $\Delta M_{\rm d}$ of Menou et al. (2000) would be in agreement with the estimates from observations. The key assumption of an empty disk after the outburst, used in our models, leads to a much lower amount of mass. (In the recent investigation of Cannizzo (2000) irradiation during the outburst is included and more mass than in the foregoing model is accreted; but the disk evolution in quiescence is not computed). In the next section we compare more general results for disks of different size with observations.

2.7. Observational requirement (4), recurrence time

The models of Cannizzo (1998) and Menou et al. (2000) were developed to show that long recurrence times can be achieved. Slight changes in the parameters choosen might reproduce the exact recurrence time, certainly involving also changes in the mass accumulation. Our computations yield the observed recurrence time together with all the other requirements from observations.

3. Comparison of the theoretical results with the data for SXTs established as black hole sources

3.1. SXTs and WZ Sge stars

A similarity of SXTs and WZ Sge stars, a subgroup of dwarf novae, was often pointed out (see e.g. Kuulkers 1999). This similarity concerns the long recurrence times and the long duration of the outbursts, the best example being WZ Sge (Patterson et al. 1981). For a review on the modeling of WZ Sge stars see Osaki (1995). The total amount of mass accreted on to the white dwarf during an outburst (1-2 $\cdot$ 10^{24}g, Smak 1993) is actually of the same order of magnitude as the amount of mass involved in SXT outbursts (Chen et al. 1997).

However the different disk size in these two classes of systems has interesting consequences for the viscosity (in Sect. 4.3 we discuss its possible origin). The size of the disk in WZ Sge (orbital period 81.3 minutes) is only 1.6$\cdot 10^{10}$cm, limited by the 3:1 resonance radius. In A0620-00 the disk is roughly ten times larger. To store the same amount of mass as accumulated in SXT disks in the much smaller disk of WZ Sge requires a lower value of the viscosity parameter α_{cold} in WZ Sge systems (0.001

Table 2. X-ray transients established as black–hole sources

Source name		BH mass ($M_\odot$)	companion star	orbital period (h)	outburst year	rec. time Δt (ys)	distance (kpc)	$\Delta M_{\rm d}$ (10^{24}g)	$M_{\rm h}$ (10^{24}g)
J0422+32	XNova Per	3.57± 0.3	M 2 V	5.1	'92	>30	2.2	0.8	0.8
A0620-00	XNova Mon	4.9-10.	K 4 V	7.8	'17,'75	58	0.87	3.3	2.5
GS2000-25	XNova Vul	8.5± 1.5	K 2 - K7 V	8.3	'88	>30	2	11.7	2.7 *)
GS1124-68	XNova Mus	5.-7.5	K 2 V	10.4	'91	>30	4	10.	8.8
H1705-25	XNova Oph7	4.9± 1.3	K3 V	12.5	'77	>30	4.3	3.3	-
4U1543-47	XN '71,'83,'92	2.7-7.5	A 2 V	27.0	'71,'83,'92	≈ 10	4	8.1	18.3*)
J1655-40	XNova Sco	7.02±0.22	F 3-6 IV	62.7	'94	>30	3.2	0.5	4.2
GS2023-338	XNova Cyg	12.3± 0.3	K 0 IV	155.3	'38,'56,'79,'89	10-20	3.5	58.9	-

Note: Data for black hole mass, spectral type of companion star, orbital period, outburst year, distance and mass accreted during outburst $\Delta M_{\rm d}$ from Chen et al. (1997, see references therein); distance for GS 1124-68 as used by Shabaz et al. (1998), $\Delta M_{\rm d}$ according to this value; heated mass at the start of the outburst $M_{\rm h}$ from Shabaz et al. (1998); companion star spectral type for 4U 1543-47 from Tanaka (2000). *) the difference between $\Delta M_{\rm d}$ and $M_{\rm h}$ arises from a discrepancy in the value $\Delta M_{\rm d}$ for GS 2000+25, and from the larger distance, 8 kpc, for 4U1543-47 (Shabaz et al. 1998) respectively.

Meyer-Hofmeister et al. 1998). In the larger SXT disks, on the other hand, the similar amount of accumulated mass points to a standard value of a few times 0.01.

3.2. Data from observations of SXTs

In Table 2 we give data for systems established as black hole transient sources. Knowledge of the distance of the sources is important for the estimate of the luminosity and therefore also the outburst energy and amount of accreted mass. Unfortunately for some systems, e.g. GS 1124-68, the values are very uncertain. For J0422+32 recently the distance 1.39 kpc was derived (Webb et al. 2000). The properties of black hole transients compiled in the reviews of Tanaka and Shabazaki (1996), Chen et al. (1997), Charles (1998) and Tanaka (2000) mainly differ with respect to the black hole mass estimates.

For our modeling the black hole masses are important, since the evaporation efficiency depends on it. Chen et al. (1997) derived estimates for the amount of mass accreted during the outburst from the outburst light curves of the systems. In the analysis of Shabaz et al. (1998) the exponential/linear decays of the light curves were studied and estimates for the amount of mass heated during the outburst were derived.

3.3. Comparison with observations for SXTs

In Fig. 2 we show more general results for mass accumulation in disks around 4 and $6M_\odot$ black holes. The disk size depends on the orbital period. We computed the disk evolution for periods from 4 to 12 hours and different mass transfer rates. We started with little mass at the beginning of the quiescence and followed the evolution until the critical surface density was reached in the disk and the outburst was triggered. The higher the rate is the earlier the next outburst occurs. The total amount of mass accumulated depends on the transfer rate. We limit our study to cases with outburst recurrence times ten years or longer. The shaded areas in Fig. 2 describe the corresponding range of values of total mass accumulated. Our two models for A0620-00 lie in these ranges. Later in this paper we compare with data for a number of SXTs observations.

In a very detailed investigation of outburst light curves of SXTs Chen et al.(1997) derived estimates for the amount of mass accreted. We show these values in Fig. 2 (for GS 1124-68 we have taken the smaller distance 4 kpc as used in Shabaz et al. 1998). These values are uncertain if the distance is not well known. In their investigation of the effect of irradiation of the accretion disk during the outburst Shabaz et al. (1998) give estimates for the mass in the disk heated in the outburst. These latter estimates are particularly valuable since they limit the total mass in the disk in the outburst not just the part accreted and thus exclude models which accrete only a small fraction of the mass of the disk. We give these values also in Fig. 2. All estimates for the amount of mass accreted in the outburst or heated are in the range 10^{24} to $1.2{\cdot}10^{25}$g.

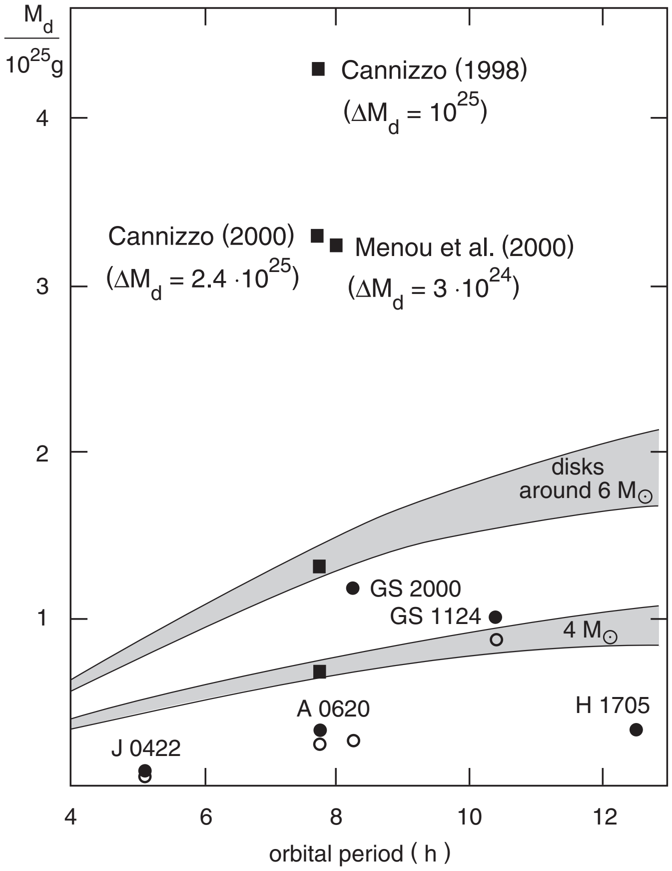

Fig. 2. Total amount of mass in the disk accumulated for the outburst. Models: (a) results for the evolution of A0620-00 (squares), (b) results for disks of different size, amount of mass accumulated during the evolution for different mass transfer rates, recurrence times $\geq$ 10 years (shaded areas). Observations: (a) values from observed outburst lightcurves (from Chen et al. 1997) (filled circles), (b) estimates for the amount of heated mass in the disk (from Shabaz et al. 1998) (open circles); compare Table 2
.

4. Viscosity in the cold disk

4.1. Systems with long recurrence time

We first discuss the situation in systems with long recurrence time and long-lasting outbursts. If in these systems the irradiation causes the long-lasting decay (King & Ritter 1998) the disk is depleted. The triggering of the outbursts after decades can well be modelled with a standard value around 0.05 as usual for dwarf nova outburst computations (all the observational requirements are fulfilled, see Sect. 3 and earlier work (MHM99)). Inspite of this result Menou et al. (2000) claimed that the viscosity would have to be low ($\approx$ 0.005) to model the SXT outbursts. Disk structure calculations show that the surface density and therefore the mass in the disk scales with $\alpha^{-0.8}$ approximately. For a viscosity ten times lower the amount of mass accumulated and the outburst energy would be roughly ten times higher. In the modeling with low viscosity the way out always is that only a small part of the total mass accretes. This is in conflict with the effect of irradiation and in general disagrees with the above mentioned amounts of mass heated up in the disk.

4.2. Systems with short recurrence time

There are a few systems with more frequent outbursts. 4U 1630-472 e.g. has outbursts about every two years. Their duration differs, also the observed luminosity which reaches values around $4{\cdot}10^{38}$ erg/s. The amount of mass accumulated in the disk is derived as several 10^{25}g, based on the uncertain distance of 10 kpc (values from Chen et al. 1997). It is unclear whether the disk is empty after the outburst.

In an earlier investigation such short cycles were already computed assuming a depleted disk and $\alpha_{\rm cold}$=0.05 (Meyer-Hofmeister & Meyer 2000). Now we performed test computations to clarify whether, in principle, these short outburst cycles can also be modeled with a not depleted disk and the standard viscosity value $\alpha_{\rm cold}$=0.05. The black hole mass and the orbital period of 4U 1630-472 are not known. We performed test calculations for $6M_\odot$ and 7.75 hours (period as A0620-00). For the initial mass distribution we assume a surface density distribution as adequate from dwarf nova outburst modeling experience ($\log\Sigma_{\rm initial}(r)= 0.5(\log\Sigma_{\rm A}(r)+\log\Sigma_{\rm B}(r))$, $\Sigma_{\rm A}$ and $\Sigma_{\rm B}$ critical surface density values), viscosity in the hot state 0.3). The mass transfer rate $2\,10^{-9}M_\odot$/y is high enough to produce the outburst after two years. The accumulated amount of mass in the disk is $1.1{\cdot}10^{25}$g, in rough agreement with the observations. We conclude that values of order 0.05 are also suitable to describe the short outbursts in cases where the disks are not depleted.

4.3. The general picture of the origin of the viscosity in cold SXT disks during quiescence

The values, $\alpha_{\rm cold}\approx$0.05, in quiescent X-ray transients appear to support a general picture of magnetic friction in disks in SXTs and dwarf novae. In outburst the magnetic field caused viscosity (Balbus & Hawley 1991, 1992) is high sustained by dynamo action in the accretion disk (for recent numerical simulations see Hawley et al. 1995, Brandenburg et al. 1995, Armitage 1998, Hawley 2000). As the disk returns to the quiescent state and becomes cool the electrical conductivity drops and the dynamo can no longer operate (Gammie & Menou 1998), the high outburst viscosity vanishes. However a magnetosphere of the secondary star in which the accretion disk is embedded can still provide magnetic flux through the disk on which the Balbus-Hawley mechanism can work and supply a smaller magnetic friction in quiescence than that in outburst. WZ Sagittae systems have probably lost this source of magnetic flux since their secondaries have become cool degenerate brown dwarfs which can not sustain dynamo action or keep fossil fields in their interior. This could explain why their remaining viscosity is so much smaller than that of all other systems in quiescence though they have similar viscosity in outburst (Meyer & Meyer-Hofmeister 1999). Then the derived α-values for SXTs in quiescence would indicate that their secondaries have magnetospheres. In this respect we also note that these stars appear to be evolved (King et al. 1996) and tend to have outer convective zones, an ingredient for solar type dynamos.

5. Conclusions

King & Ritter (1998) argued that strong irradiation during the long-lasting outbursts of SXTs keeps the disk hot, and almost all mass in the disk flows towards the black hole. We make the key assumption that in black hole transients with long recurrence time the disk is depleted after the outburst. The estimates for the amount of mass in the disk heated during the outburst (Shabaz et al. 1998) confirm this picture. When one follows the disk evolution and mass accumulation one finds that the long recurrence times can well be modelled with a "standard" viscosity value $\alpha_{\rm cold}$=0.05. Evaporation of the inner disk region is an important feature in such disk evolution. The requirements from observation are fulfilled.

The models of Cannizzo (1998, α proportional to $(h/r)^{1.5}$, h pressure scaleheight) and Menou et al. (2000, $\alpha_{\rm cold}$=0.005), suggest that only a small part of the total mass in the disk is accreted during an outburst. But, even if the disk in A0620-00 would not be depleted the models only agree marginally with the other requirements from observations.

We further find that SXTs with a recurrence time as short as two years can also be modeled with $\alpha_{\rm cold}$=0.05, assuming a depleted or a not depleted disk.

We thus conclude that the accretion disk in SXTs in quiescence display rather standard cold disk friction common to SXTs and dwarf novae and do not need nor indicate very low α-values of order 0.005.

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