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Time-dependent Evolution of Accretion Disk Mass in a Black Hole Microquasar Candidate A0620-00

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블랙홀 마이크로퀘이사 후보 A0620-00의 강착원반 질량의 시간적 진화

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Abstract: The time-dependent evolution of disk mass for outburst limit cycle in a black hole microquasar is calculated based on the non-linear hydrodynamic model of thermally unstable accretion disk. The physical parameters such as black hole mass, disk size and mass transfer rate are adopted to reproduce the historical 1975 outburst observed in a prototype black hole X-ray nova A0620-00. The time-dependent effect of irradiation from the central hot region to the disk is considered in two ways: direct irradiation and indirect irradiation reflected from hot accretion flow above the disk. The accretion disk thermal instability model can account for the bolometric luminosity appropriate to typical characteristics of system luminosity observed in X-ray transients during the whole cycle of the outburst evolution. The maximum mass of the accretion disk, $\sim 4.03\times10^{24}$ g, is achieved at the ignition of an outburst, and the minimum value, $\sim 8.54\times10^{23}$ g, is reached during the cooling decay to quiescence. The disk mass varies ~5 times during outburst limit cycle.

Keywords: accretion disks, black holes, X-ray binaries, viscous instability, radiation hydrodynamics

요 약: 열적으로 불안정한 강착원반의 비선형 유체역학적 모형에 기초하여 블랙홀 마이크로퀘이사의 광폭발 한계 순환 주기에 대한 원반 질량의 시간적 진화 모형을 계산하였다. 블랙홀의 질량, 원반 크기 및 질량 유입률과 같은 물리적인 매개변수들은 블랙홀 X-선 신성의 원형인 A0620-00에서 관측된 역사적인 1975 광폭발을 재현하도록 선택되었다. 중심부에서 원반으로 쪼여지는 조사(照射)의 시간에 따른 효과는 직접 조사와 원반위의 뜨거운 강착 흐름으로부터 굴절되어 원반에 쪼여지는 간접조사의 두 가지 방법이 고려되었다. 우리의 강착원반 열적 불안정성 모형은 광폭발의 순환과정 전반에 걸쳐 X-선 변광체들에서 관측된 광도의 전형적인 복사 광도를 설명할 수 있다. 강착원반의 최대질량 $\sim 4.03\times10^{24}$ g은 광폭발의 점화 때에 얻어지며, 최소질량 $\sim 8.54\times10^{23}$ g은 차가운 쇠퇴기와 정지기(靜止期) 때에 이루어진다. 원반의 질량은 광폭발 한계 순환주기에 걸쳐 약 5배 정도 변한다.

주요어: 강착원반, 블랙홀, X-선 이중성, 점성 불안정성, 복사 유체역학

Introduction

Dozens of black hole binary sources have been discovered with characteristic, cataclysmic phenomena called “outbursts” for last 30 years (Tanaka and Lewin 1995, Lewin and van der Klis 1995, Remillard and McClintock 2006). The prototype of the black hole X-ray transients, A0620-00 (X-ray nova Monocerotis 1975) was discovered in 1975 by X-ray observation of the Ariel 5 satellite (Elvis et al., 1975). It turns out that the nature of the transient is recurrent, as identified with another outburst in 1917 (Eachus et al., 1976). Furthermore, an additional outburst could have occurred in 1940s, possibly during the World War II (Gallo et al., 2006), which suggests that the recurrence time of A0620-00 may not be 60 years but ~30 years.

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The outburst of A0620-00 in 1975 is very complicated, and numerous models have been explored to account for its rise, maximum, reflare, decay and secondary, mini-outbursts (see Remillard and McClintock, and references therein). These features turned out to be common in black hole binaries as confirmed with observations in other black hole transients such as GS 2000+25 and GS/GRS 1124-683 (Tanaka and Lewin 1995). In the radio, multiple jet ejections during outburst in A0620-00 were proposed with the reanalysis of 1975 radio outburst data (Kuulkers et al., 1999). This means that, like a few known relativistic jet-ejecting black hole transients and persistent sources, A0620-00 could be a member of microquasars. There have been growing belief that all black hole binaries could be microquasars (Fender 2006). Recent observations with radio interferometry have suggested radio-emitting outflows in the quiescent states of A0620-00 and GS 2023+338 (Kuulkers et al., 1999, Miller-Jones et al., 2008). Since microquasars are regarded as miniatures of quasars, the study of microquasars would play an important role for exploring the jet-emitting mechanism in quasars (Hyung et al., 2006).

The outburst phenomena can be explained by the so-called accretion disk thermal instability, or shortly, disk instability model (for reviews, see Kato et al., 1998). The disk instability model was originally proposed to explain dwarf nova phenomena (Osaki 1974), and has been successfully account for basic features in outbursts (e.g., Kim 2002, Kim et al., 1992, Yi et al., 1992). The model has been also developed to reproduce dwarf nova-like outbursts in black hole X-ray transients (e.g., Kato et al., 1998; also see Kim and Mineshige 2001, Kim et al., 1999, Mineshige and Wheeler 1989, Mineshige et al., 1990). The essence of the disk instability model is that, in quiescence, the accreted materials from a companion star is piled up mostly in the outer portion of the disk, and the heating fronts propagate inward when the disk density and temperature rise up over the critical limit for ionization. This results in black body radiation from the disk, observed as an optical outburst. Although the basic properties of observed outburst phenomena have been qualitatively explained with the disk instability model, there are numerous unsolved issues to account for observations both in dwarf novae and X-ray binaries (e.g., Lewin and van der Klis 2007, Remillard and McClintock 1995, Kato et al., 1998, Kim 2006).

One of such problems is the time-dependent behavior of disk mass (e.g., Dubus et al., 2001). The mass accumulated inside a disk must be time-dependent and radially variable quantity in particular in transients. The disk luminosity also varies as a function of disk mass. However, the disk mass and disk surface density cannot be directly measured, although the quantities are critically important to trigger outburst phenomena. In this paper, we investigate the time-evolution of mass accumulated in the accretion disk of black hole transients, which has not been quantitatively investigated in detail. In §2 and §3, model description and numerical results are presented, respectively. In §4, we discuss the implication of the model in the theoretical and observational aspects.

Procedure

Based on the time-dependent disk instability model, we showed that the disk in A0620-00 is thermally unstable; hence ionization instability associated with hydrogen and helium causes outbursts observed (Mineshige et al., 1990, Kim et al., 1999, Kim 2004, Kim 2006). As soon as the instability is triggered, heating waves in the outer disk propagate inward, which is observed as the primary maximum (Kim 2004). In these models, the time-dependent irradiation from a central hot region (e.g., accretion disk corona) to the disk is adopted based on the disk instability model. These models can account for the basic feature of 1975 outburst in A0620-00 (Mineshige et al., 1990, Kim et al., 1999, Kim 2004, Kim 2006). Other models based on the disk instability also have reproduced similar properties of outbursts in black hole transients such as light curves, profiles of disk temperature and surface density (see Kim 2006 and references therein). However, a fully time-dependent, self-consistent evolution of accretion disk mass through out the outburst limit cycle have been rarely discussed. In this section, we describe our model for the time-dependent evolution of the black hole disk mass.

We adopted the basic prescription of hydrodynamics for differentially rotating, viscous accretion disk presented in Kim (2006; also see Kim et al., 1999), based on the standard gas disk model (Shakura and Sunyaev 1972). We here state a few key points of the model, necessary to emphasize in this paper. Our disk model calculation is time-dependent to reproduce the disk evolution from quiescence to outburst. The model is also implicit in which the radially-dependent basic equations of mass conservation, angular momentum conservation and energy equation are solved with the equations obtained by integration of the vertical structure of the disk. The implicit functional dependence for a function f can be expressed as, for example,

$$f = f[T_c(r), \Sigma(r), r], \tag{1}$$

where T_c and Σ are central, or mid-plane, temperature and surface density at a given disk radius r. The prescription for the direct irradiation can be analytically derived from the assumption of hydrostatic equilibrium and concave-type standard disk model (e.g., Kim et al., 1999). The intensity of direct irradiation is proportional to $(h/r)^N$, where h is the disk scale height and $N \geq 0$. On the contrary, the indirectly irradiated flux, F_i can be only parameterized, for example, as

$$F_i(r,t) = C_X \frac{L_X(t)}{4\pi r^2}, \tag{2}$$

where C_X is a positive constant which can only be determined by the comparison with the observational data because it cannot be directly derived from models. We take $C_X = 1.21 \times 10^{-3}$. The X-ray luminosity L_X is given by

$$L_X(t) = \varepsilon \left(\frac{dM}{dt} \right)_{in} c^2, \tag{3}$$

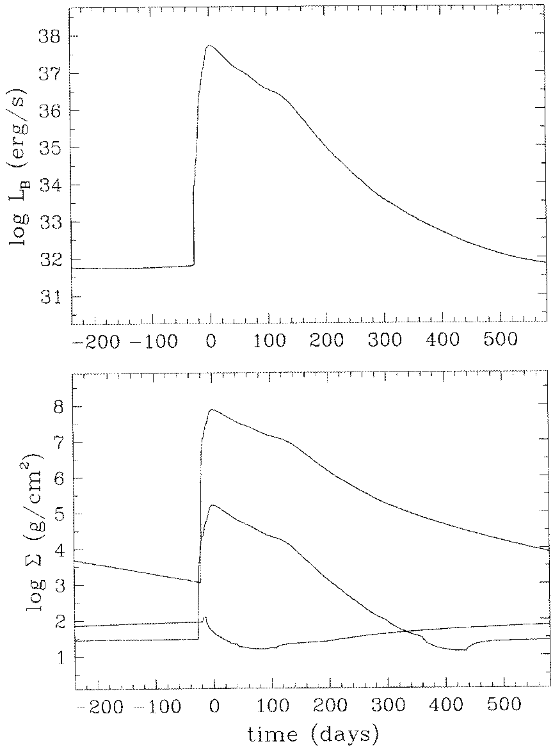

Fig. 1. The model light curve (upper panel) and corresponding evolution of surface density for the outer, middle and inner portions of disk (lower panel). The light curve is described in terms of the bolometric luminosity. The time zero is set by the time of maximum bolometric luminosity. At time zero, the surface density is the highest (~8 g/cm^2) at the outer disk and the lowest (~2 g/cm^2) at the inner region of the disk. The surface density is ~5.2 g/cm^2 in the middle of the disk at time zero.

where we adopt the typical value of the efficiency $\varepsilon = 0.057$ for the non-rotating black hole, and $(dM/dt)_{in}$ is the mass accretion rate at the inner edge of the disk with the disk mass as a function of disk radius and time, $M=M$ (r,t), and c is the speed of light.

We adopt the black hole mass, $M_{BH} = 3.2\ M_\odot$, where $M_\odot$ is the solar mass, derived from the optical and infrared observations of A0620-00, which corresponds to the minimum allowed mass for stellar black hole (see Tanaka and Kewin 1995, Lewin and van der Klis 2006, and references therein). The inner edge of the disk, $R_{in} = 2.8 \times 10^6$ cm, is an innermost stable circular orbit for the non-rotating Schwarzschild black hole. The outer edge of the disk, R_{out}, is set by 9.6×10^{10}

cm, based on the consideration of Roche geometry (Lubow and Shu 1975, Shu and Lubow 1981), which is consistent with quiescence observations of A0620-00 (Tanaka and Kewin 1995). The mass transfer rate from the red companion, $(dM/dt)_T$, is assumed to be 5×10^{16} g/s (see discussion in Kim et al., 1999).

The analytic treatment of viscosity remains unsolved, and the parameterization is a typical way to handle it. The kinematic viscosity parameter, α, can be written in the form of power law:

$$\alpha = \alpha_0\left[\frac{h(r,t)}{r}\right]^N, \qquad (4)$$

where the constant α_0=4.3 and N=2.0. The detailed discussion of the so-called α-prescription can be found in Kim (2006) and (Kim et al., (1999). In the next section, we present the numerical results based on the model we described in this section.

Result and Discussion

The light curve of the bolometric luminosity computed based on the time-dependent disk instability model, described in the previous section, is presented in the upper panel of Fig. 1. The model light curve is similar to the previous models (see Kim et al., 1999, Kim 2004, Kim 2006), but is different from previous models in its reproducibility. In previous models, outbursts reproduced by a model were repeated with slightly different patterns due to numerical instability. In the model we present here, the repeated, same patterns of outbursts (i.e., "limit cycle") are reproduced by improving implicit descriptions for iteration for opacity and viscosity values. More detailed description for these improvement with parameter study will be published elsewhere (Kim 2009, in preparation). The maximum bolometric luminosity, L_B, of 5.26×10^{37} erg/s is achieved at the model peak, and, during quiescence, the model displays minimum value of $\geq5.42\times10^{31}$ erg/s. In the rise, the disk luminosity first rapidly changes from $\leq10^{32}$ erg/s to $\sim10^{34}$ erg/s for 12.5 hours, while it takes about 30 days to the maximum luminosity.

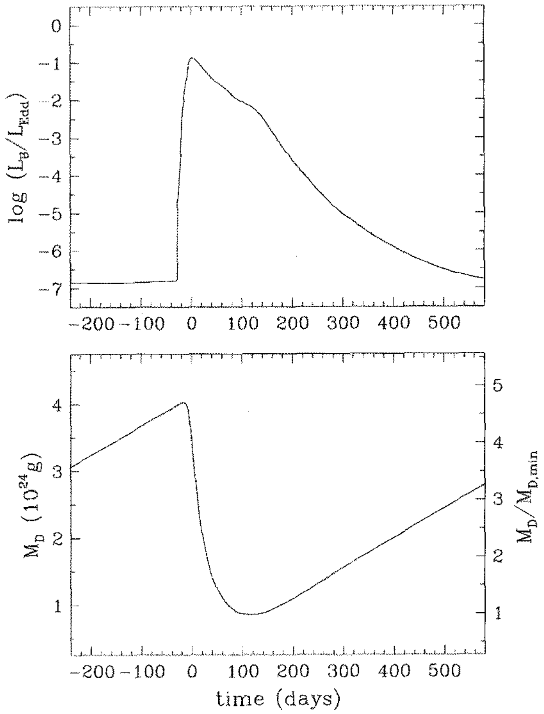

Fig. 2. The model light curve (upper panel) and evolution of disk mass (lower panel). The light curve is displayed with the ratio of bolometric to Eddington luminosity. The zero day is set to the maximum bolometric luminosity, same as in Fig. 1. The maximum value of the bolometric luminosity, $\sim5.26\times10^{37}$ erg/s, or ~0.13 L_{Edd}, is achieved at the day zero. The maximum disk mass, $\sim4.03\times10^{24}$ g is achieved with the bolometric luminosity of $\sim1.04\times10^{-3}$ L_{Edd} at ~16.41 days prior to the maximum luminosity. The minimum disk mass is $\sim8.54\times10^{23}$ g at ~119 days after the peak luminosity.

To calculate the disk mass, we first need to estimate the surface density, Σ. The implicit, time-dependent profile of the disk surface density as a function of radius is presented in the lower panel of Fig. 1. To avoid ambiguity, we only present the selected portions of inner, outer and middle of the disk. The surface density profile is widely distributed from ~10 in the inner disk to $\sim10^6$ g/cm^2 in the outer disk. In the outer region of the disk, as the critical temperature of $\geq10^4$ K is reached, the avalanche of ionization occurs, which results in the rapid increase of the opacity and, in turn, disk surface density. Since the heating wave of the outburst rapidly propagates inward from the outer disk within a day, the surface density of the middle portions in the disk can also rapidly increase, as displayed for the middle of the disk at ~5×10^{8} cm. On the contrary, in the inner region, the increment of surface density is much smaller because the inner portion of the disk ($\leq 2\times10^{8}$ cm) is always in its permanently thermally stable state of $>10^{4}$ K; hence, the opacity change is much smaller than the colder, outer region. A full description of the implicit, time-dependent behavior of the disk surface density as functions of time and radius will be presented elsewhere (Kim 2009, in preparation).

The total mass of accretion disk, M_d, is defined as

$$M_d(r,t) = 2\pi \int_{R_{in}}^{R_{out}} r\Sigma(r,t)dr\,. \tag{5}$$

The implicitly computed disk mass as a function of time, based on the time-dependent profile of the disk surface density (Fig. 1) is displayed in Fig. 2, together with the bolometric luminosity estimated in terms of the Eddington luminosity (e.g., see Chapter 2 in Kato et al., 1998). The maximum disk mass, 4×10^{24} g, is achieved about 16.4 days before the maximum luminosity. About 119 days after the outburst peak luminosity, the model disk reaches its minimum disk mass of 8.54×10^{23} g; hence, the disk mass varies about 4.7 times during the outburst limit cycle. Further theoretical and observational considerations are necessary to explore the detailed physical meaning of time-evolution of disk mass.

The time-evolution of the disk mass with irradiation effect was previously studied only by Dubus et al., (2001). They calculated time-dependent models for 7 $M_\odot$ black hole model with $R_{in}=10^{9}$ cm, $R_{out}=10^{11}$ cm and $(dM/dt)_T=10^{16}$ g/s. Note that they adopted truncated inner edge of the disk. They computed three different models with (1) irradiation effect only, (2) irradiation and evaporation, and (3) variable $(dM/dt)_T$ of 0.5, 5 and 50×10^{16} g/s and $R_{out}=2.5\times10^{11}$ cm. They employed $C_X=5\times10^{-3}$ (see Eq. (2)), more than 4 times bigger than our value. Unlike the standard, power-law type viscosity prescription we adopted, Eq. (4), they adopted the so-called "double-valued α-prescription", where the minimum, α_C, and maximum, α_H, value of viscosity parameters are employed with arbitrary functional dependency on the disk temperature. They adopted

$$\log\,\alpha(t)=\log\,\alpha_C+\xi(r,t)^{-1}[\log\,\alpha_H-\log\,\alpha_C], \tag{6}$$

and

$$\xi = 1+\left[\frac{T_{crit}(r,t)}{T_c(r,t)}\right]^{8}, \tag{7}$$

where $T_{crit}=0.5T_c[Tc(\Sigma_{max})+Tc(\Sigma_{min})$. They adopted $\alpha_H=0.2$ and $\alpha_C=0.02$.

In the irradiation-only model they calculated, the computed values of disk mass are $3.5\text{-}7\times10^{24}$ and $3.5\text{-}10\times10^{24}$ g from minimum to maximum, respectively. The addition of evaporation results in more massive disk because of longer time scale of quiescence with more depletion (also see Kim et al., 1999). In the model (3) with different values of $(dM/dt)_T$, the larger disk size results in more massive disk. In addition, the larger, truncated inner edge of the thermally unstable disk also causes longer time scale of quiescence (also see Kim et al., 1992). The coupled effect, therefore, results in more massive disk mass in the model (3): $3\text{-}4\times10^{25}$, $4\text{-}9\times10^{25}$ and $4\text{-}20\times10^{25}$ g for $(dM/dt)_T=0.5$, 5 and 50×10^{16} g/s, respectively.

The first model with irradiation in Dubus et al., (2001) is appropriate for us to compare with our model presented here. Although the parameters adopted are different, their first model (1) and our model are consistent with each other. This is because, for example, the ratio of the inner disk area smaller than 10^{9} cm to the total disk area is negligible since $(10^{11}\text{-}10^{9})^{2}/(9.6\times10^{10}/2.8\times10^{6})^{2}$ ~1.06. The black hole mass they adopted is 7 $M_\odot$ ~2.2 times bigger than 3.2 $M_\odot$ in this work, while, in the standard steady state disk model, $\Sigma\propto M_{BH}^{1/4}$; hence there is only a factor of ~1.2 difference in Σ.

In Dubus et al., (2001), the maximum and minimum values of α_H and α_C are constant. This means that, in spite of the big difference of surface density from the inner to outer disk radii, the viscosity is enforced to be independent of radii. On the contrary, in the standard power-law prescription for viscosity we adopted, because the disk height $h=C_s/\Omega_K$, where C_s

is the sound speed, and the Keplerian angular velocity, Ω_K is defined by

$$\Omega_K(r) = \left[\frac{GM_{BH}}{r^3}\right]^{1/2}, \tag{8}$$

where G is the gravitational constant, we know that $C_s(r,\ t) \propto T_c(r,\ t)^{1/2}$ (e. g., Frank et al., 2002) and

$$\alpha(r,t) \propto T_c(r,t)^{N/2} \tag{9}$$

Since we adopted $N=2$, the viscosity parameter is linearly proportional to the disk temperature (see Kim et al., 1998, Kim 2004, Kim 2006 for detailed discussion). Therefore, the viscosity is not only time-dependent, but also radial-dependent, consistent with a large deviation of surface density and disk temperature in different disk radii. Further parameter study is necessary to investigate the distribution of the viscosity as a function of disk radius during an outburst limit cycle.

Summary and Conclusion

In this paper we present the time-dependent model of the accretion disk mass for a transient black hole binary A0620-00, based on the disk instability model. The results are summarized as follows:

1. The model bolometric luminosity varies $\leq 10^6$ times, with L_B/L_{Edd} of 0.13 and 1.36×10^{-7} at the maximum and minimum, respectively.
2. The surface density varies more than 1,000 times in the thermally unstable disk portions larger than $\geq 2\times10^8$ cm, while, in the inner hot disk, it varies within a factor of ≤ 10 from quiescence to outburst.
3. As soon as the critical surface density above which the disk is thermally unstable is achieved in the outer disk, the maximum value of the disk mass is also achieved due to the ionization instability.
4. The disk mass varies ~5 times from quiescence to outburst.
5. The disk mass calculated in this paper is consistent with previous calculations.

The time-dependent evolution of disk mass in microquasars has been poorly studied; hence, further fully consistent, time-dependent study is necessary to investigate the correlation of the disk mass to other observable physical parameters in the disk.

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References

Dubus, G., Hameury, J.-H., and Lasota, J.-P., 2001, The disc instability model for X-ray transients: Evidence for truncation and Irradiation. Astronomy and Astrophysics, 373, 251-271.

Eachus, L.J., Wright, E.L., and Liller, W., 1976, Optical observations of the recurrent nova associated with A0620-00-1917-1975. Astrophyscal Journal, 203, L17-L19.

Elvis, M., Page, C.G., Pounds, K.A., Ricketts, M.J., and Turner, M.J.L., 1975, Discovery of powerful transient X-ray source A0620-00 with Ariel V Sky Survey Experiment. Nature, 257, 656-657.

Fender, R.P., 2006, Jets from X-ray Binaries. Compact Stellar X-Ray Sources, Cambridge University Press, Cambridge, 381-419.

Frank, J., King, A., and Raine, D., 2002, Accretion Power in Astrophysics, Cambridge University Press, Cambridge, Chapters 2, 8-22 and Chapter 4, 48-79.

Gallo, E., Fender, R.P., Miller-Jones, J.C.A., Merloni, A. Jonker, P.G., Heinz, S., Maccarone, T.J., and van der Kils, M., 2006, A radio-emitting outflow in the quiescent state of A0620-00: Implications for modelling low-luminosity black hole binaries. Monthly Notices of the Royal Astronomical Society, 370, 1351-1360.

Hyung, S., Sohn, D.H., Ferruit, P., and Lee, W.B., 2006, OASIS Spectral Images of the Seyfert galaxy NGC 5728. Jounral of the Korean Earth Science Society, 27, 569-578.

Kato, S., Fukue, J., and Mineshige, S., 1998, Black-Hole Accretion Disks. Kyoto University Press, Kyoto, 1-594.

Kim, S.-W., 2002, UV Spectrum at 1981 Outburst Maximum in Disk-Fed Magnetic White Dwarf Binary, GK Persei. Joutnal of the Korean Physical Society, 40, L203-L208.

Kim, S.-W., 2004, Cooling Wave Propagation and Radiation Hydrodynamics in Black Hole X-ray Nova Monocerotis 1975. Journal of the Korean Physical Society, 44, 1000-1006.

Kim, S.-W., 2006, Microquasars: Time-Varying Flares and Time-Dependent Irradiated Disk Models. Journal of the Korean Physical Society, 49, 1805-1811.

Kim, S.-W. and Mineshige, S., 2001, Outer Cool disk in the Quiescent X-ray Nova A0620-00. Journal of the Korean Physical Society, 39, L949-L951.

Kim, S.-W., Wheeler, J.C., and Mineshige, S., 1989, Disk instability and outburst properties of the intermediate polar GK Persei. Astrophysical Journal, 384, 269-283 and 399, 330 (erratum).

Kim, S.-W., Wheeler, J.C., and Mineshige, S., 1999, Black-Hole X-Ray Transients: The Effect of Irradiation on Time-Dependent Accretion Disk Structure. Publications of Astronomical Society of Japan, 51, 393-404.

Kuulkers, E., Fender, R.P., Spencer, R.E., Davis, R.J., and Morison, I., 1999, Multiple ejections during the 1975 outburst of A0620-00. Monthly Notices of the Royal Astronomical Society, 306, 919-925.

Lewin, W.H.G. and van der Klis, M., 2006, Compact Stellar X-ray Sources. Cambridge University Press, Cambridge.

Miller-Jones, J.C.A., Gallo, E., Rupen, M.P., Miduszewski, A.J., Brisken, W., Fender, R.P., Jonker, P.G., and Maccarone, T.J., 2008, Monthly Notices of the Royal Astronomical Society, in press (astroph/0805.4603v1).

Mineshige, S., Kim, S.-W., and Wheeler, J.C., 1990, Time-dependent X-ray Emission from Unstable Accretion Disks. Astrophysical Journal, 358, L5-L8.

Mineshige, S. and Wheeler, J.C., 1989, Disk-instability model for soft-X-ray transients containing black holes. Astrophysical Journal, 343, 241-253.

Osaki, Y., 1974, An accretion model for the outbursts of U Geminorum stars. Publications of Astronomical Society of Japan, 26, 429-436.

Remillard, R.A. and McClintock, J.E., 2006, X-Ray Properties of Black-Hole Binaries. Annual Reviews of Astronomy and Astrophysics, 44, 49-92.

Shakura, N.I. and Sunyaev, R.A., 1973, Black holes in binary systems. Observational appearance. Astronomy and Astrophysics, 24, 337-355.

Lubow, S.H. and Shu, F.H., 1975, Gas dynamics of semidetached binaries. Astrophysical Journal, 198, 383-405.

Shu, F.H. and Lubow, S.H., 1981, Mass, angular momentum, and energy transfer in close binary stars. Annual Reviews of Astronomy and Astrophysics, 19, 277-293.

Tanaka, Y. and Lewin, W.H.G., 1995, X-ray Binaries. Cambridge University Press, Cambridge.

Yi, I., Kim, S.-W., Vishniac, E.T., and Wheeler, J.C., 1992, Disk instability and the time-dependent X-ray emission from the intermediate polar GK Persei. Astrophysical Journal, 391, L25-L28.

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