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# 10 MICRON DETECTION OF THE HARD X-RAY TRANSIENT GRO J0422+32: FREE-FREE EMISSION FROM AN X-RAY–DRIVEN ACCRETION DISK WIND?

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## ABSTRACT

We report the detection of 10 $\mu$m emission from the transient low-mass X-ray binary (LMXB) and optical nova GRO J0422+32 near the maximum of its outburst. We discuss this result in terms of (1) a "standard" model according to which low-energy radiation of LMXB is caused by reprocessing of X-rays in an accretion disk; (2) emission from a cool secondary star; (3) emission from dust grains heated by the transient X-rays, and (4) free-free emission from an X-ray–driven wind from the accretion disk. Only the fourth alternative provides a viable explanation for the observed 10 $\mu$m emission, with a mass-loss rate in the disk wind that may be substantially higher than the rate of accretion onto the compact star. The presence of such a wind may have a profound effect on the evolution of the binary, and contribute to the solution of the "birthrate problem" of millisecond radio pulsars.

*Subject headings:* accretion, accretion disks — binaries: close — stars: individual (GRO J0422+32)

## 1. INTRODUCTION

On 1992 August 9, the bright transient X-ray source GRO J0422+32 was discovered with the Burst and Transient Source Experiment (BATSE) on board the *Compton Gamma Ray Observatory* (Paciesas et al. 1992). In 5 days the (25–300 keV) flux rose to $\sim 4 \times 10^{-8}$ ergs cm$^{-2}$ s$^{-1}$, or $\sim 3$ times that of the Crab Nebula. The flux remained at this level for $\sim 10$ days, and then decreased smoothly, with an *e*-folding decay time of 40 days (Paciesas et al. 1994). About 110 days after the peak of the outburst, the X-ray flux showed a temporary increase by a factor of about 2, after which the X-ray source continued to decrease at approximately the initial decay rate (Paciesas et al. 1994).

GRO J0422+32 has been identified with an optical nova (Castro-Tirado et al. 1992, 1993; Shrader et al. 1993) that reached a peak visual magnitude $V = 13.2$ from a quiescent value $\gtrsim 17$ (Chevalier & Ilovaisky 1993); this indicates that the source is a low-mass X-ray binary (LMXB; for a recent review see van Paradijs & McClintock 1994). The source has also been detected as a radio and ultraviolet transient (Han & Hjellming 1992; Shrader et al. 1993). The optical flux decayed smoothly with an *e*-folding time of $\sim 90$ days (Chevalier & Ilovaisky 1993). During the decay of the outburst, Chevalier & Ilovaisky (1993) found a periodic (5.1 hr) brightness variation. This period (or double its value) is likely to be the orbital period (see also Chevalier & Ilovaisky 1994; cf. Bailyn 1992 and Remillard et al. 1992, on Nova Muscae 1991).

We report here details of observations of 10 $\mu$m emission from GRO J0422+32, the detection of which was announced previously (Telesco et al. 1992). In § 2 we describe the observations. In § 3 we discuss the results of our observations in terms of (1) reprocessing of X-rays in an accretion disk; (2) emission by dust near the X-ray source, and (3) free-free emission from an X-ray driven wind from the disk. In § 4 we summarize our conclusions. To our knowledge this is the first detection of an LMXB at such long infrared wavelengths.

## 2. OBSERVATIONS

GRO J0422+32 was observed at the NASA Infrared Telescope Facility (IRTF) on 1992 UT September 9.52–9.58 (near the peak of the outburst) and on 1993 April 3.21–3.25 (then the source had become undetectable with BATSE, i.e., its flux had decreased by at least a factor of 30 below its peak value). For the 1992 observations we used the Marshall Space Flight Center 20 pixel bolometric array (see, e.g., Telesco, Joy, & Sisk 1990) at 10.8 $\mu$m ($\Delta\lambda = 5.3$ $\mu$m). The FWHM pixel size was $4''.3 \times 4''.3$, and the separation between the source and the sky-reference positions was 15″ in declination. The total integration time was 1.17 hr. The photometric standard for both dates was $\alpha$ Tau, with a 10.8 $\mu$m magnitude of $-3.03$, corresponding to 570 Jy, based on values in the IRTF list of standard stars. We offset to GRO J0422+32 from the *HST* guide star SAO 057182 (1950: $04^{\rm h}17^{\rm m}58^{\rm s}.4$, $+32°42'43''$) using coordinates kindly provided by Dr. C. Shrader of the *GRO* Science Support Center. We determined that the coordinates of the optical counterpart of GRO J0422+32 are (1950) $04^{\rm h}18^{\rm m}29^{\rm s}.67$,

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+32°47′22″.4, with an uncertainty of about ±1″ in each coordinate, which agrees within the uncertainties with those communicated to us by Dr. Shrader (see also McCroskey 1992). Only the pixel centered on the optical counterpart of GRO J0422+32 showed a statistically significant detection, corresponding to a flux density of 51 ± 9 mJy at 10.8 μm; the error does not include the ±7% uncertainty in the absolute calibration. (The system sensitivity was relatively poor but stable on that date, due to significant degradation on the previous night of the hygroscopic pressure window.)

At the time of this observation the $V$ magnitude of GRO J0422+32 was ~13.4 (Chevalier & Ilovaisky 1993); with $E_{B-V} = 0.4$ (Shrader et al. 1993) this corresponds to a reddening-corrected $V$ band flux of 50 mJy.

The observations on 1993 April 3 were made at 10.2 μm ($\Delta\lambda = 5.0$ μm) using the IRTF single-channel bolometer. The total integration time was 0.67 hr. The FWHM size of the circular beam was 4″.7, and the separation between the source and sky-reference positions was 10″ in declination. Again we offset to GRO J0422+32 from the *HST* guide star, but this time the optical counterpart was barely visible using the IRTF optical acquisition camera; we estimate its $V$ magnitude to be 15–16, based on a comparison with offset star B for *IRAS* 10214+4724, which was observed during the same run and is of comparable magnitude (see Telesco 1993). This estimate is in good agreement with the long-term light curve of GRO J0422+32 presented by Chevalier & Ilovaisky (1993). The 10.2 μm flux density of J0422+32 was 19 ± 12 mJy, which corresponds to a 3 σ upper limit of 36 mJy.

## 3. DISCUSSION

During the second observation the 10 μm flux had decreased, but not by a sufficient amount (just over 2 σ) to exclude that the flux had remained constant. We have investigated the possibility that the 10 μm source is not related to the X-ray source, but is rather a chance superposition. Using the *IRAS* point source catalog (12 μm) we have, for a circular field (3° radius) around the X-ray source determined the (cumulative) distribution of sources as a function of their flux, down to 250 mJy (we have ignored the 10% difference in wavelength between the *IRAS* and IRTF passbands). From a conservative (i.e., on the high side) extrapolation we find that there are 30 such sources per square degree with fluxes of at least 50 mJy. The corresponding probability of finding, by chance coincidence, a source in the pixel that contains the X-ray source is $4 \times 10^{-5}$. We conclude that the 10 μm emission we detected is related to the X-ray source.

We have considered three possible explanations for this 10 μm emission from GRO J0422+32. (1) The 10 μm flux is the long-wavelength extension of the optical/UV emission of the LMXB, which originates from reprocessing of X-rays in the accretion disk; we have also investigated the possibility of a contribution from the nonirradiated parts of a cool companion star. (2) The 10 μm emission comes from dust grains near the X-ray source that are heated by X-rays. (3) Free-free emission from an X-ray–driven wind from the accretion disk.

### 3.1. *Thermal Emission from the Accretion Disk*

To estimate the 10 μm (and optical) flux from the disk in GRO J0422+32 we made the following simplifying assumptions. (1) Everywhere in the disk the optical and 10 μm emission is Planckian. For $\lambda > 0.5$ μm, disk spectra for this simple model differ from those calculated for detailed models of X-ray–irradiated disks by an amount that is small enough for our purpose (see, e.g., Vrtilek et al. 1990); (2) For a given X-ray luminosity $L_X$, the temperature $T$ in the disk varies with radial distance $r$ from the X-ray source as $r^{-3/7}$ (Vrtilek et al. 1990); (3) At a given value of $r$, $T$ is proportional to $L_X^{1/4}$. We ignore the possible dependence of the $T-L_X$ relation on the shape of the X-ray spectrum.

A crude measure of the average disk temperature of GRO J0422+32 can be obtained from the relative rates of decay of the X-ray and optical light curves (Endal et al. 1976); it is ~20,000 K.

To relate $T(r)$ and $L_X$ we use the properties of the Z-type (Hasinger & van der Klis 1989) LMXB Sco X-1, for which $V = 12.2$ at the transition from the normal to the flaring branch (Augusteijn et al. 1992). At this transition, $L_X$ is close to the Eddington limit $L_{\rm Edd}$ (van der Klis & Lamb 1994), which equals $\sim 2 \times 10^{38}$ ergs s$^{-1}$ for matter of cosmic abundances accreting onto a neutron star (1.4 $M_\odot$). The average X-ray flux of Sco X-1 (Warwick et al. 1981) then corresponds to a distance $d$ to Sco X-1 of 2.3 kpc. For an assumed outer disk radius in Sco X-1 ($R_{\rm Sco\,X-1}$) of 85% of the average radius of the Roche lobe of the X-ray source, the system parameters as given by Crampton et al. (1976) imply $R_{\rm Sco\,X-1} \sim 1.2 \times 10^{11}$ cm. From a numerical integration [$F_V \sim (2\pi \cos i/d^2)\Sigma_i B_V(r_i) r_i \Delta r_i$, where $B_V(r_i)$ is the Planck function at radius $r_i$] we then find that, for $L_X = 2 \times 10^{38}$ ergs s$^{-1}$ the temperature $T_0$ at the outer edge of the disk of Sco X-1 equals 22,500 K. (In the following, we will indicate with $T_0$ the disk temperature in any disk, at $r = R_{\rm Sco\,X-1}$).

We calculated, for a range in disk sizes, the ratio of the $V$ band and 10 μm fluxes by numerical integration of the disk brightness (as above) in the two passbands from the center to the outer disk radius. For the 10.2 hr orbital period of GRO J0422+32 the disk radius $R_{\rm disk}$ (in units of $R_{\rm Sco\,X-1}$) is between 0.6 (if the X-ray source is a neutron star) and 1.6 (if it is a 10 $M_\odot$ black hole). We used values of $T_0$ between 10,000 K and 30,000 K (corresponding to $L_X$ between $8 \times 10^{36}$ and $6 \times 10^{38}$ ergs s$^{-1}$). In all cases the expected 10 μm flux is less than 1% of the $V$-band flux. This result strongly disagrees with their observed approximate equality.

The basic reason why the observed 10 μm flux is not reproduced by the standard accretion disk reprocessing model is that the disk is much too small to contain the large cool outer regions required for efficient IR emission. We have estimated the disk size that, for a given value of $T_0$, would reproduce the observed ratio $F_{10\mu}/F_V$ by continuing the numerical integration of the disk brightness following the $r^{-3/7}$ temperature dependence. We find that for $T_0$ between 10,000 K and 30,000 K the disk radius is between ~70 and ~$10^3$ times that of Sco X-1. The corresponding range in orbital period is 1.3 to 55 yr for a neutron star. For a 10 $M_\odot$ black hole, these boundaries are about a factor of 3 lower. It should be noted that the outer disk regions may become optically thin for very large disk radii, which would make the required disk radii (and orbital periods) even larger.

We conclude that the standard accretion disk reprocessing does not explain the observed 10 μm flux of GRO J0422+32, unless its orbital period is very long.

### 3.2. *Contribution from the Companion Star*

Can the 10 μm flux come from the cool, nonirradiated parts of the companion star? Since the heated part of the companion is generally much less bright than the disk (van Paradijs &

McClintock 1994), we have approximated the observed emission as the sum of the disk emission (see § 3.1) and a blackbody with trial temperatures in the range 2000–4000 K.

For specific values of $T_0$ and $R_{disk}$, the radius $R_{bb}$ of the blackbody emitter is given by $\Delta F_{10.8\mu} = \pi R_{bb}^2 d^{-2} B_{10.8\mu}(T_{bb})$, where $\Delta F_{10.8\mu}$ is the amount of 10.8 $\mu$m flux not accounted for by the disk (we know the value of this amount quantity because the observed ratio $F_{10.8\mu}/F_V$ has to be reproduced). As $R_{disk}$ increases, $\Delta F_{10.8\mu}$ and $R_{bb}$ decrease. We have taken as acceptable solutions those for which the ratio $R_{bb}/R_{disk}$ is below a value dictated by the fact that GRO J0422+32 is an LMXB (for a companion mass of 0.5 $M_\odot$ and a 1.4 $M_\odot$ neutron star this value is $\sim$0.7; with a 10 $M_\odot$ black hole it is $\sim$0.3). Conversely, this requirement leads to solutions which, for chosen values of $T_0$ and $T_{bb}$, provide a lower limit to $R_{disk}$.

The next question then is, do these solutions satisfy the constraint that in quiescence the $V$ magnitude can be as high as 19 (Zhao et al. 1994)? This puts a strong constraint on $T_{bb}$, since the quiescent flux (i.e., no contribution from the disk) should be at most 0.6% of that of the disk (this corresponds to the difference between the observed $V$ magnitudes, 13.4 and >19, respectively). It turns out that, virtually independent of the assumed value of $T_0$, this requirement implies very low values of $T_{bb}$: below 2000 K if the compact star is a neutron star, and below 2200 K if it is a 10 $M_\odot$ black hole.

Once $T_0$ has been selected the size is determined for systems that obey these constraints. For $T_0$ = 10,000–30,000 K, the corresponding orbital periods (with neutron star accretors) are between 0.9 and 40 yr, i.e., $\sim$75% of the periods for the corresponding disk-only models in the previous section. For 10 $M_\odot$ black holes the periods are a factor $\sim$3 shorter.

Therefore, the conclusion reached in § 3.1 remains unaffected, even if we include a possible contribution from a cool companion star.

### 3.3. *10 Micron Emission from X-Ray-Heated Dust Grains*

We assume that X-ray heating of dust grains takes place inside a "heating sphere" whose radius $R_h$ equals the distance traveled by X-rays in the time interval since the start of the outburst till our first 10 $\mu$m observation ($R_h \sim 9 \times 10^{16}$ cm). We used the theoretical IR spectral energy distributions emitted by an X-ray–irradiated "average dust grain surface" (Voit 1991), for incident X-ray fluxes $f_X$ between $10^2$ and $10^8$ ergs cm$^{-2}$ s$^{-1}$. This dust grain surface is an average over a distribution of grain sizes $a$ given by the power law $f(a)da \propto a^{-3.5}\,da$ proposed by Mathis, Rumpl, & Nordsieck (1977). Voit presents his results in terms of $\nu f_\nu$, where $f_\nu$ is the total flux density leaving the "average" dust grain per unit area; the specific intensity $I_\nu = f_\nu/\pi$.

For a given $L_X$ (the source distance $d$ is fixed by the observed X-ray flux $F_X$), we have taken $f_X = L_X/(4\pi R_h^2)$ and used the results of Voit (his Figs. 13, 15, and 16) to interpolate to the corresponding value of $f_\nu$ at 10 $\mu$m.

The BATSE X-ray flux refers to the 20–300 keV range. To estimate the total X-ray flux $F_X$ we extrapolated the X-ray spectrum near the time of our first observation to lower energies using the best-fit exponential spectrum ($kT \sim 115$ keV; Paciesas et al. 1994). We find $F_X = 2.4 \times 10^{-8}$ ergs cm$^{-2}$ s$^{-1}$. Since GRO J0422+32 may harbor a black hole (Paciesas et al. 1994), this estimate may be too low because it does not include a possible ultrasoft spectral component, as is often seen in the spectra of accreting black holes (Tanaka & Lewin 1994). However, *Granat* observations in 1992 September show no evidence for such a component (Sunyaev et al. 1993).

We can estimate an upper limit to the expected 10 $\mu$m flux according to $F_{10\,\mu m} = I_{10\,\mu m}\Omega$, where $\Omega = \pi R_h^2/d^2$ is the solid angle of the X-ray–heated dust sphere. In making this estimate we assume that dust grains fill the whole solid angle $\Omega$. We find that for assumed values $L_X = 10^{37}$, $10^{38}$, and $10^{39}$ ergs s$^{-1}$, the expected 10 $\mu$m fluxes are 110, 230, and 420 $\mu$Jy, respectively, i.e., about two orders of magnitude below the observed value.

Dust grains are also heated by UV photons produced by reprocessing of X-rays in the accretion disk. UV photons are much more effective (by up to a factor 30; see Voit 1991) than X-rays in heating dust particles. However, since the luminosity of this reprocessed emission is at most a few percent of the X-ray luminosity (van Paradijs & McClintock 1994; Vrtilek et al. 1991) this contribution cannot alleviate the large discrepancy noted above.

Unless the density of dust around the X-ray source is extremely high, this inability of X-ray–heated dust grains to account for the observed 10 $\mu$m flux of GRO J0422+32 is exacerbated by the fact that, the filling factor of dust inside the solid angle $\Omega$ is much smaller than unity. For the above dust grain size distribution (with minimum and maximum grain sizes of 0.0005 and 0.25 $\mu$m) we find that the surface area ($A$) to volume ($V$) ratio of the dust grains equals $A/V = 2 \times 10^5$ cm$^{-1}$. For a typical interstellar gas density of 1 atom cm$^{-3}$, a dust to gas mass ratio of 0.012, and a dust specific density of 3 g cm$^{-3}$, we find that the filling factor is $\sim 10^{-4}$. Thus, for a normal interstellar medium around GRO J0422+32 the gap between the predicted and observed 10 $\mu$m fluxes is six orders of magnitude.

We conclude that X-ray heating of dust cannot explain the observed 10 $\mu$m emission of GRO J0422+32 unless it is surrounded by a highly nonstandard interstellar medium.

### 3.4. *Free-Free Emission from an X-Ray–driven Disk Wind*

We have considered the possibility that the 10 $\mu$m emission originates from (optically thin) free-free emission in a wind flowing out of the disk (see, e.g., Wagner et al. 1991). Such a wind may be formed by X-ray heating of the disk for X-ray luminosities in excess of a few percent of the Eddington limit (Begelman, McKee, & Shields 1983). This possibility is suggested by the relative ease with which Oke & Greenstein (1977) were able to explain the near-IR (<3 $\mu$m) excess they observed from the black-hole transient A0620−00 by optically thin thermal bremsstrahlung (OTTB) from a hot ($\sim 10^6$ K) plasma.

In the case of GRO J0422+32 such a high-temperature OTTB interpretation faces the problem that the expected low-frequency spectrum is flat. That is, if the 10.8 $\mu$m flux ($\sim$50 mJy) is bremsstrahlung, one expects a flux density of 50 mJy in the $V$ band as well, which leaves little room for reprocessing of X-rays into optical emission in the (optically thick) accretion disk. This would contradict a large body of observational evidence that the optical emission of LMXB is dominated by such reprocessing (see van Paradijs & McClintock 1994). This problem does not arise if the temperature of the plasma is sufficiently low that the OTTB dominates at 10.8 $\mu$m but not in the $V$ band; this "solution" requires that the temperature be less than $\sim$30,000 K.

To test roughly the viability of this model, we have estimated the expected free-free emission from a constant-velocity wind composed of ionized hydrogen at a temperature of 20,000 K. The electron density in this wind is given by

$$n_e = \dot{M}_w/4\pi v_w r^2 m_p\,,$$

where $\dot{M}_w$ is the mass-loss rate in the wind, $v_w$ its outflow velocity, and $m_p$ the proton mass. For the emissivity in this wind we use the expression (Rybicki & Lightman 1979, eq. [6.14b]; we have set the Gaunt factor equal to unity)

$$j_\nu = 6.8 \times 10^{-38} T^{-1/2} \exp(-h\nu/kT)\, n_e^2 \text{ ergs cm}^{-2}\text{ s}^{-1} .$$

The expected 10.8 μm luminosity in the wind is then given by

$$L_{10.8\,\mu\text{m}} = 4\pi \int_{R_0}^{\infty} j_{10.8\,\mu\text{m}}(r)\, r^2\, dr = 1.5 \times 10^7 \dot{M}_w^2/(v_w^2 R_0) .$$

The observed luminosity equals $6 \times 10^{19} d_{\text{kpc}}^2$. From this we infer $\dot{M}_w^2/(v_w^2 R_0) = 4 \times 10^{12} d_{\text{kpc}}^2$; this result is not sensitive to the assumed temperature of the free-free emitting wind.

Following Begelman et al. (1983) we have taken for $R_0$ the radial distance at which the radiation temperature $T_{\text{rad}}$ corresponds to the escape velocity. This escape velocity is not expected to be very different from the wind velocity $v_w$, so that $v_w^2 R_0 \sim 2GM_X$. Therefore, we infer $\dot{M}_w^2 \sim 8 \times 10^{12} GM_X d_{\text{kpc}}^2$, which leads to a mass-loss rate in the wind of $\sim 3 \times 10^{19} (M_X/M_\odot)^{1/2} d_{\text{kpc}}$ g s$^{-1}$. This mass-loss rate is very high, but not so high that this model for the 10.8 μm emission is ruled out: according to the calculations by Begelman et al. (1983) the mass-loss rate in the disk wind may substantially exceed the rate of inflow of matter that eventually makes it to the compact star.

At the time of our first observation the (5 GHz) radio flux was ~5 mJy, and this flux was nonthermal (Shrader et al. 1993; Hjellming 1994). This nondetection of the expected free-free radio emission can be understood as an optical-depth effect (i.e., the luminosity of a uniform source with optical depth $\tau \gg 1$ is smaller than that calculated on the assumption that it is optically thin by roughly a factor $\tau$). The optical depth $\tau_\nu$ (ff) in the wind above described is given by

$$\tau_\nu(\text{ff}) = \int_{R_0}^{\infty} \kappa_\nu(\text{ff}) dr$$
$$= 3.7 \times 10^8 \nu^{-3} T^{-1/2} (1 - e^{-h\nu/kT}) \int_{R_0}^{\infty} n_e^2\, dr .$$

Using the above expressions for $\dot{M}_w$ and $v_w$ we find

$$\tau_\nu(\text{ff}) = 4.9 \times 10^{20} \nu^{-3} T^{-1/2} (1 - e^{-h\nu/kT}) (4\pi m_p)^{-2} R_0^{-2} d_{\text{kpc}}^2 ,$$

which for the 10 μm and radio (5 GHz) bands gives: $\tau_{10\,\mu\text{m}}(\text{ff}) \sim 25 (R_0/3 \times 10^{10}\text{ cm})^{-2} d_{\text{kpc}}^2$, and $\tau_{5\,\text{GHz}}(\text{ff}) \sim 10^9 (R_0/3 \times 10^{10}\text{ cm})^{-2} d_{\text{kpc}}^2$. In view of the uncertainties in the system parameters and the crudeness of our wind model these results serve to show that at 10 μm the optical depth of the disk wind can be small, while in the radio it is very large. The implied turnover of the IR spectrum is a specific prediction of the free-free model, which can be tested by more detailed observations of the IR spectral energy distribution of LMXB (see, e.g., Wynn-Williams & Becklin 1979).

A similar argument shows that the observed rather small equivalent width (~5 Å) of the Hα line (Shrader et al. 1993) may be reconciled with the large value expected for an optically thin emitter (~400 Å using the emissivity coefficients given by Osterbrock 1974). In the center of the Hα line the optical depth is given by

$$\tau_\alpha = \sigma_\alpha N_2 = \sigma_\alpha \int_{R_0}^{\infty} n_2(r) dr .$$

Here $n_2(r)$ indicates the number density of hydrogen atoms in the lower level of the Hα transition. Using Saha's equation (which confirms that hydrogen is almost fully ionized), and assuming that in the line center thermal broadening dominates, we find for our assumed wind parameters $\tau_\alpha \sim 4 \times 10^3 (R_0/3 \times 10^{10}\text{ cm})^{-2}$, which shows that optical depth effects may play a major role.

## 4. CONCLUSIONS

We have detected 10 μm emission from the X-ray transient GRO J0422+32. We have considered several models to explain this emission: reprocessing of X-rays in an accretion disk, X-ray heating of nearby interstellar dust grains, and free-free emission from an X-ray induced wind from the accretion disk. The first model requires that the orbital period of GRO J0422+32 be very long, which seems inconsistent with the currently available data. The second model requires highly nonstandard interstellar-medium properties. Only the last model appears to account reasonably for the observed 10.8 μm emission.

Through its effect on the angular-momentum balance a high mass-loss rate in the form of a disk wind can have a major influence on the evolution of the system. Also, the usual estimates of the lifetimes of LMXB (roughly the ratio of the mass stored in the secondary envelope to the mass accretion rate) may be substantial overestimates. The presence of a strong disk wind may therefore contribute to the solution of the "birthrate problem" of millisecond radio pulsars (see Lorimer 1994 for a recent assessment of this problem). Infrared observations may be an effective way of studying accretion disk winds in LMXB, as is the case, e.g., for stellar winds of Be stars (see, e.g., Waters & Marlborough 1994).

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