DISCOVERY OF PULSED X-RAYS FROM THE SMC TRANSIENT RX J0052.1−7319

M. H. FINGER
National Space Science and Technology Center, ES 50, 320 Sparkman Drive, Huntsville, AL 35805; mark.finger@msfc.nasa.gov

D. J. MACOMB
Laboratory for High Energy Astrophysics, Code 661, NASA/Goddard Space Flight Center, Greenbelt, MD 20771; macomb@coss.gsfc.nasa.gov

R. C. LAMB AND T. A. PRINCE
Space Radiation Laboratory, California Institute of Technology, Pasadena, CA 91125; lamb@srl.caltech.edu, prince@caltech.edu

AND

M. J. COE AND N. J. HAIGH
Department of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ, England, UK; mjc@astro.soton.ac.uk

Received 2000 April 11; accepted 2001 June 14

ABSTRACT

Coherent 65 mHz pulsations in the X-ray flux of the Small Magellanic Cloud (SMC) transient source RX J0052.1 − 7319 have been detected by us in an analysis of ROSAT data. We report on the pulsations we detected in ROSAT HRI data and simultaneous detection of these pulses in hard X-rays using BATSE data. The BATSE data show an outburst of the source lasting 60 days. We report on optical observations of the candidate companion, and a new source position we determined from the HRI data, which is consistent with the candidate’s location. From the measured fluxes and observed frequency derivatives we exclude the possibility that the pulsar is in the foreground of the SMC and show that an accretion disk is present during the outburst, which peaked near Eddington luminosity.

Subject headings: accretion, accretion disks — binaries: general — pulsars: individual (RX J0052.1−7319) — X-rays: stars

1. INTRODUCTION

RX J0052.1 − 7319 is an X-ray source located in the Small Magellanic Cloud (SMC), first detected with Einstein (1E 0050.3 − 7335, Wang & Wu 1992). It was classified by Kahabka & Pietsch (1996) as a transient X-ray binary candidate based on the ROSAT PSPC data from 1991 October and 1992 April.

As part of a systematic search of the ROSAT data for pulsed sources, we have discovered pulsations from RX J0052.1 − 7319 at a frequency of 65.4 mHz (period = 15.3 s) using ROSAT HRI observations from 1996 November to December. Our search had previously detected another SMC pulsar, J0117.6−7330 (Macomb et al. 1999).

After a preliminary report of our discovery of the pulsar nature of RX J0052.1 − 7319 (Lamb et al. 1999), Kahabka estimated a new source position based on HRI observations of 1995 May (Kahabka 1999a) and confirmed the detection of pulsations using HRI observations from 1996 October (Kahabka 1999b). Israel, Stella, & Mereghetti (1999) identified a Be star as the likely optical counterpart to the source. Udalski (1999) then reported on the long-term optical variability of this candidate, based on Optical Gravitational Lensing Experiment (OGLE) monitoring.

Here we report on the pulsations we detected in the ROSAT HRI data, detection of these pulses in hard X-rays using simultaneous BATSE data, the history of the outburst visible in the BATSE data, and optical observations of the candidate companion and nearby stars.

2. OBSERVATIONS

We initially discovered pulsations from RX J0052.1 − 7319 in observations made with the High Resolution Imager (HRI) detector of the ROSAT (Trümper 1983) in 1996 November and December. The HRI, which consisted of two cascaded microchannel plates (MCPs) with a crossed grid position readout system, was sensitive to X-rays in the ~0.2−2 keV range. Thereafter, we detected the pulsations in observations from the Burst and Transient Source Experiment (BATSE) (Fishman 1989) on the Compton Gamma Ray Observatory (CGRO) using data from the Large Area Detectors (LADs) which are NaI scintillation detectors sensitive to hard X-rays/soft gamma rays in the 20 keV−2 MeV range.

2.1. ROSAT Observations

Our discovery was made in the ROSAT HRI observations of 1996 November 10.71–December 9.16, as part of a systematic search of the ROSAT data for previously undetected pulsars. These data were among 1365 data sets we selected from the catalog of 59,911 ROSAT/HRI point source observations based on the potential for detection of significant pulsations. Each data set was processed using standard “Ftools,” with barycentered arrival times for the first 200 ks of each observation binned with 5 ms resolution, and Fourier transformed. The power spectra were searched for significant pulsed signals unassociated with the ~5760 s spacecraft orbit or the 402 s period spacecraft orientation wobble. The RX J0052.1−7319 HRI observations were selected for further analysis because of a strong signal near 65 mHz.

These HRI observations, rh00811n00 and rh00812a01, are of two SMC fields which contain RX J0052.1 − 7319. The observations for these two fields are partially contemporaneous. Figure 1 shows the count rates in 1000 s bins for events within 60° of the source in these observations. The roughly 10%−20% difference in counting rates between contemporaneous portions of the two observations may be due principally to differences in source vignetting. For observation rh00812a01, the source is 17° from the center
Mean count rates in 1000 s bins for the 1996 November 11 (MJD 50398)–December 9 ROSAT HRI observations of RX J0052.1–7319 showing the time structure of the observation window and the declining flux of the source. The upper panel is for observation rh600811n00 and the lower for rh600812a01. Between the panels is shown both the time interval for the initial FFT in which the pulsations were discovered and the interval used for the analysis resulting in Figs. 2 and 3.

of the HRI field and vignetting corrections are 10%–20%; for observation rh600811n00 the source is 8/4 from the HRI center and vignetting is substantially less. From observation rh600811n00 it is clear that the source flux is declining.

As can be seen in Figure 1, the initial 200 ks (2.3 days) interval of the observations, which was used for the initial search fast Fourier transform (FFT), contained only a portion of either of the two observations. We chose for further analysis the data of November 11.21–16.83 (all of rh600812a01 and the first portion of rh600811n00).

From initial analyses of this data set we knew pulse frequency was changing significantly and that there was substantial power at higher harmonics of the pulse frequency. To accurately estimate the pulse frequency and frequency derivative, we maximized the statistic (Buccheri et al. 1983), where and the Rayleigh statistic is calculated as

\[ p(f) = \frac{2}{N} \left| \sum_{k=1}^{N} \exp \left( i2\pi f \left( t_k + \frac{1}{2} \alpha(t_k - \tau) \right) \right) \right|^2. \]  

Here \( N \) is the number of photons detected in the interval, \( f \) is the analysis frequency, \( \alpha = \dot{\nu}/\nu \) with \( \nu \) the pulse frequency, \( t_k \) is a barycentric arrival time of photon \( k \), and \( \tau \) is an epoch within the data interval.

For epoch MJD 50401.0 (1996 November 14.0) we obtained \( \nu = 0.06545850(7) \) Hz and \( \dot{\nu} = 5.48(7) \times 10^{-11} \) Hz s\(^{-1}\). The maximum value of \( Z_2^2 \) was 524, which is highly improbable by chance.\(^2\) The Rayleigh statistic for this ratio of \( \dot{\nu}/\nu \) is shown in Figure 2. In addition to the pulse fundamental, four pulse harmonic overtones are clearly detected.

The HRI data from the 1996 November 11.21–16.83 interval epoch-folded with this ephemeris is shown in Figure 3. The pulse profile has a single asymmetric peak, with a narrow valley at minimum. The pulsed fraction \( (\text{mean/minimum})/\text{mean} \) is 35% ± 3%.

For the HRI data from the interval 1996 December 5–9 we obtain a frequency \( \nu = 0.0655330(3) \) Hz at epoch MJD 50401.0.

\(^2\) We estimate that the probability of obtaining a \( Z_2^2 \) of 524 or more due to Poisson noise is less than \( 10^{-40} \), including the number of trials introduced by searching in frequency and frequency derivative. This calculation, however, neglects systematic signatures in the data, which would likely play a dominate role in any false detection with a \( Z_2^2 \) this large.
50524.0 and $v = 2.3(2) \times 10^{-11}$ Hz s$^{-1}$. Thus, the decrease in counting rate noted above was accompanied by a decrease in spin-up rate, as would be expected from the intrinsic correlation between mass accretion rate and angular momentum accretion rate in a disk fed accreting pulsar.

For the 1996 November 11–16 and December 5–9 intervals, we find source count rates of 0.92 and 0.46 counts s$^{-1}$, respectively. These rates are corrected for vignetting (David et al. 1999$^3$) and the 15$''$ radius circle used to select the data, using the HRI off-axis encircled energy profile (Boese 2000). To estimate fluxes from these count rates we have used the spectrum estimated for the source by Kahabka & Prietsch (1996) based on a fit of ROSAT PSPC data. This consists of a thermal bremsstrahlung model with $kT = 17$ keV, a galactic absorption column of $3 \times 10^{20}$ cm$^{-2}$, an absorption column within the SMC with density of $N_H = 7.0 \pm 4.0 \times 10^{21}$ cm$^{-2}$ (95% confidence errors), and with metallicities reduced by a factor of 7 from solar system abundances. This model results in 0.1–2.0 keV unabsorbed flux estimates of $5.9 \pm 1.0 \times 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$ and of $3.0 \pm 0.5 \times 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$ for the 1996 November 11–16 and December 5–9 intervals, respectively.

Using the 1996 November data of observation rh600811n00, we have determined the position of the source to be R.A. = 0$^\circ$52$^\prime$13$''$.65, Decl. = $-73^\circ$19$'$19.5, with a statistical uncertainty (1$\sigma$) which is negligible in comparison to systematic position errors, which result in a 68% confidence error circle of radius 7$''$ (ROSAT Users Handbook$^4$). These systematic errors are due to uncertainty in the aspect of ROSAT. We note that this position differs by nearly 10$''$ from the position quoted by Kahabka (1999b; 2000). However, since these latter determinations used either very low rate data ($\leq$0.01 counts s$^{-1}$) or data in which the source was at the edge of the HRI field of view, we believe that the position given above may be the more accurate.

2.2. BATSE Observations

The Burst and Transient Source Experiment was an all-sky monitor which flew on board the CGRO. The data used in the analysis presented here were from the Large Area Detectors, which were NaI(Tl) scintillation counters 1.27 cm thick, with a 2025 cm$^2$ area, that were located at the eight corners of the CGRO spacecraft. Count rate data from the LADs were continuously available from 1991 April to 2000 May, except during South Atlantic Anomaly (SAA) passages and occasional telemetry outages.

The 20–50 keV channel of the BATSE LAD discriminator rates (DISCLA channel 1) was analyzed for pulsations from RX J0052.1 – 7319 using techniques discussed in Finger et al. (1999). Rates were combined from different detectors with coefficients optimal for a source with a spectrum of the form $dN/dE = A \times \exp(-E/kT)/E$ with $kT = 20$ keV. A large number of pulse profiles are obtained by fitting short segments of these combined rates with a model consisting of a quadratic spline background, plus a low-order Fourier expansion pulse profile model. These profiles are then combined over multiple day intervals using trial frequencies and frequency rates. The resulting combined profiles are evaluated with the $Y_n$ statistic (Finger et al. 1999), which is similar to the $Z_n$ statistic, but accounts for possible non-Poisson noise.

Using data from the interval 1996 November 11.0–17.0, $Y_3$ was searched over a frequency range of width $10^{-7}$ Hz centered on the ROSAT measurement and a frequency rate range of $10^{-11}$ to $10^{-10}$ Hz s$^{-1}$, resulting in maximum value of $Y_3 = 57.0$, which we estimate$^5$ has a probability of being exceeded by chance of less than $2 \times 10^{-7}$. The resulting frequency and frequency rate estimates were $\nu = 0.06545830(10)$ Hz at epoch MJD 50401.0, and $\nu = 5.62(12) \times 10^{-11}$ Hz s$^{-1}$, in good agreement with the ROSAT results.

The BATSE pulse profile for this interval using the ROSAT HR1 ephemeris is shown in Figure 4. The profile is shown relative to the mean flux level, which cannot be determined from the data, due to the weakness of the source and the high background level. The solid curve is the profile corresponding to six Fourier coefficients which have been estimated with the same fitting technique used with the frequency search. Error bars for the value of the curve at 13 approximately independent points are shown. Six harmonics were chosen because this approximately matches the 1.024 s resolution of the data.

Pulsations were then detected in nine additional 6 day intervals, extending the total period the source was detected with BATSE to 60 days between 1996 September 18 and November 17. Beginning with the November 11–17 interval, the total period of detection was progressively extended

$^3$ http://hea-www.harvard.edu/rosat/rsdc_www/HRI_CAL_REPORT/ hri.html.

$^4$ http://heasarc.gsfc.nasa.gov/docs/rosat/rhu/handbook/node34.html. See also ROSAT Status Report 67 by M. Kürster (1993), http://hea-www.harvard.edu/rosat/status/status.html.

$^5$ This estimate approximates the distribution of $Y_3$ with the chi-squared distribution with 6 degrees of freedom, which is valid in this case because of the large number of profiles being combined, and accounts for 1100 independent trials.
outward by frequency and frequency rate searches in the adjacent 6 day intervals, using $5 \times 10^{-3}$ Hz frequency ranges centered on the extrapolation from the neighboring frequency and frequency rate estimate, and the frequency rate range given above. Searching in this manner at the boundaries of the known frequency history reduces the required frequency search range, providing the best sensitivity. Figure 5 shows the resulting measurements of frequency, frequency rate, and rms pulsed flux in the 20–50 keV energy band. The figure also shows for comparison the frequency and frequency rate measurements from the ROSAT HRI data.

Efforts were made to detect the source from 1996 August 1 to September 18 and from 1996 November 17 to 1997 January 8, but these failed. These attempts used searches with a frequency range of $3 \times 10^{-4}$ Hz centered on the nearest detection and a frequency rate range of $-10^{-11}$ to $10^{-10}$ Hz s$^{-1}$. Prior to 1996 September 18, pulsations from the 130.4 mHz pulsar 4U 1626–67 interfered with the first harmonic (i.e., $2 \times f$) contribution to $Y_1$ in a narrow frequency band near 65.2 mHz. For this narrow band, this harmonic was left out of the search. We conclude that in these intervals, prior to and following our 1996 September 18 to November 17 detections, the source had pulsed flux below our sensitivity level. We estimate an upper limit of 8 mCrab for the 20–50 keV rms pulsed flux for these intervals.

2.3. Optical Observations

In Figure 6 we show a $V$-band image taken from the South African Astronomical Observatory (SAAO) 1.0 m telescope on 1999 January 20. Marked on the figure is the X-ray error circle of Kahabka (2000), which has a 6” radius, and the error circle from this work, with a 7” radius. The object marked “A” is the source identified as the counterpart by Israel et al. (1999), based upon a red spectrum. The objects labeled “A,” “B,” “C,” and “D” are also identified in Figure 7.

If the optical counterpart of RX J0052.1–7319 is a Be star, then it should show excess H$\alpha$ emission. In Figure 7 we show H$\alpha$ versus $R$-band counts for 25 stars in the vicinity of Kahabka’s X-ray error circle. The line is a linear best fit
through all the data points shown. Stars that lie above the line are ones that show an Hz excess—i.e., objects A, B, and C as identified on Figure 6. Object D, the one inside the Kahabka (2000) error circle, shows no excess. Objects B and C, though exhibiting an Hz excess, are too far away from the X-ray position to be the counterpart. If, as we might expect, the optical companion is a Be star, the only reasonable counterpart is object A, the star identified by Israel et al. (1999). Object A is well contained with the error circle for RX J0052.1—7319 presented here, and thus the identification of the X-ray source as a member of a Be system seems reasonable.

The absolute V magnitude of object A may be determined from the value quoted by Udalski (1999) of $m_v = 14.67$. The distance modulus to the SMC determined by Westerlund (1997) is $(m - M)_0 = 18.9$. In addition, the average extinction is $E(B-V) = 0.07-0.09$ (Schwering & Israel 1991), though there are regions in the SMC where it can rise as high as 0.25. Combining these parameters leads to an estimate of $M_V = -4.47 \pm 0.02$. This magnitude corresponds to a star in the range $B1$–$B0 \, V$, very similar to the value obtained for Be/X-ray binary counterparts (e.g., that of RX J0117.6—7330 quoted in Coe et al. 1998).

3. DISCUSSION

The ROSAT HRI observations we have presented show that RX J0052.1—7319 is a pulsar with a 65 mHz rotation frequency. Variations in the flux by more than 2 orders of magnitude between $0.1$ Hz ergs s$^{-1}$, and for peak frequency rate observed we have $L > 2.0 \times 10^{38}$ ergs s$^{-1}$. Using the $0.1$–20 keV flux $F = 5.9 \times 10^{31}$ ergs cm$^{-2}$ s$^{-1}$ observed in the 1996 November 11–17 HRI observation, we find the lower limit on the source distance of

$$d > 46 \left(\frac{\epsilon}{0.1}\right)^{1/2} \text{ kpc},$$

where $\epsilon$ is the fraction of the luminosity in the $0.1$–20 keV energy band. This eliminates the possibility that the RX J0052.1—7319 is in the foreground of the SMC.

The limit in equation (2) is reached only with disk accretion. Using the measured frequency rate, fluxes, and the distance of 60 kpc to the SMC, we find a ratio of $\dot{v}/L$ comparable to this limit, suggesting that an accretion disk is present during the outburst.

The pulse periods of Be binary pulsars range from 69 ms to 1400 s, with determined orbital periods ranging from 17 to 250 days. Corbet (1986) showed that the orbital period is correlated with the pulse period. From the observed distribution of spin and orbital periods, we would expect an orbital period in the range of 25–100 days. In giant outbursts of Be/X-ray pulsars we expect a strong correlation of flux and frequency rate (see, e.g., Finger et al. 1996). We note, however, that the history of the frequency rate in Figure 5 is dissimilar in profile to that of the pulsed flux. This could be due to the Doppler signature of a binary orbit. An alternate explanation would be changes in the spectra or pulse fraction. However, giant outbursts typically have simple flux and intrinsic spin-up rate profiles, with a steady rise to peak and a somewhat slower fall (see, e.g., Parmar et al. 1989; Whitlock 1989; Finger et al. 1996; but also, Negueruela et al. 1997).

The plausible identification of RX J0052.1—7310 as a Be binary system in the SMC accentuates further the rather dramatic difference between the SMC and our Galaxy with regard to the population of high-mass X-ray binaries. This fact has already been noted by several authors (Schmidtke et al. 1999; Yokogawa et al. 2000). A recent compilation of the known X-ray pulsars gives within the SMC one supergiant system, three known Be systems, and 11 transients with uncertain companion class (likely to be Be systems), making 15 high-mass X-ray pulsar binaries. For the Galaxy the corresponding number is 40. Therefore, using a mass ratio of the SMC to the Galaxy of 1/100, this suggests that

\[ r_s = \left(\frac{GM}{c^2}\right)^{1/2} = 1.0 \times 10^8 \text{ cm}, \]

\[ \text{where we have used } M = 1.4 \ M_\odot. \]

The specific angular momentum $I$ is proportional to the ratio $\dot{v}/L$, where $L$ is the pulsar’s luminosity. Since the rate at which angular momentum is accreted is $\dot{m} = 2\pi \dot{v}$, where $I$ is neutron star moment of inertia, and $L = GMm/R$, where $R$ is the neutron star radius, we have the upper limit

\[ \dot{v}/L < \left(\frac{2\pi}{45}\right) \left(\frac{GM}{m}\right)^{1/3} I^{-1/3} R^{-v/3} = 3.8 \times 10^{-49} \text{ Hz erg}^{-1}, \]

where we have used a moment of inertia $I = 10^{44}$ g cm$^2$, and a radius $R = 10^6$ cm. For the November 11–17 observation, for which $\dot{v} = 5.6 \times 10^{-11}$ Hz s$^{-1}$, this implies $L > 1.5 \times 10^{38}$ ergs s$^{-1}$, and for peak frequency rate observed we have $L > 2.0 \times 10^{38}$ ergs s$^{-1}$. Using the $0.1$–20 keV flux $F = 5.9 \times 10^{31}$ ergs cm$^{-2}$ s$^{-1}$ observed in the 1996 November 11–17 HRI observation, we find the lower limit on the source distance of

\[ d > 46 \left(\frac{\epsilon}{0.1}\right)^{1/2} \text{ kpc}, \]

where $\epsilon$ is the fraction of the luminosity in the $0.1$–20 keV energy band. This eliminates the possibility that the RX J0052.1—7319 is in the foreground of the SMC.

The limit in equation (2) is reached only with disk accretion. Using the measured frequency rate, fluxes, and the distance of 60 kpc to the SMC, we find a ratio of $\dot{v}/L$ comparable to this limit, suggesting that an accretion disk is present during the outburst.

The pulse periods of Be binary pulsars range from 69 ms to 1400 s, with determined orbital periods ranging from 17 to 250 days. Corbet (1986) showed that the orbital period is correlated with the pulse period. From the observed distribution of spin and orbital periods, we would expect an orbital period in the range of 25–100 days. In giant outbursts of Be/X-ray pulsars we expect a strong correlation of flux and frequency rate (see, e.g., Finger et al. 1996). We note, however, that the history of the frequency rate in Figure 5 is dissimilar in profile to that of the pulsed flux. This could be due to the Doppler signature of a binary orbit. An alternate explanation would be changes in the spectra or pulse fraction. However, giant outbursts typically have simple flux and intrinsic spin-up rate profiles, with a steady rise to peak and a somewhat slower fall (see, e.g., Parmar et al. 1989; Whitlock 1989; Finger et al. 1996; but also, Negueruela et al. 1997).

The plausible identification of RX J0052.1—7310 as a Be binary system in the SMC accentuates further the rather dramatic difference between the SMC and our Galaxy with regard to the population of high-mass X-ray binaries. This fact has already been noted by several authors (Schmidtke et al. 1999; Yokogawa et al. 2000). A recent compilation of the known X-ray pulsars gives within the SMC one supergiant system, three known Be systems, and 11 transients with uncertain companion class (likely to be Be systems), making 15 high-mass X-ray pulsar binaries. For the Galaxy the corresponding number is 40. Therefore, using a mass ratio of the SMC to the Galaxy of 1/100, this suggests that

\[ 6 \text{ http://gammaray.msfc.nasa.gov/batse/pulsar/asm_pulsars.html.} \]
high-mass X-ray pulsar systems in the SMC are over-abundant by roughly a factor of 30 relative to the Galaxy. This analysis ignores the important effects of obscuration within the Galaxy, the relative frequency of observations, and the low-luminosity sensitivities obtained for the Magellanic clouds; nevertheless, the apparent disparity is remarkable.

Since high-mass X-ray binaries have lifetimes which are a very small fraction ($\sim 10^{-3}$) of the age of the Galaxy, the dramatic difference between the SMC and the Galaxy points to a rather recent outburst of star-formation in the SMC within the last $\sim 10^7$ years. Further support of such an epoch of star formation comes from the radio observations of H I by Stavely-Smith et al. (1997) and Putman et al. (1998), which show a strong bridge of material between the Magellanic Clouds, and between them and our own galaxy. Furthermore, Stavely-Smith et al. (1997) have demonstrated the existence of a large number of supershells (created by multiple supernovae) of a similar age ($\sim 5$ Myr), strongly suggesting enhanced starbirth has taken place as a result of tidal interactions between these component systems. Consequently, it seems very likely that the previous closest approach of the SMC to the LMC $\sim 10^8$ years ago may have triggered the birth of many new massive stars which have given rise to the current population of HMXBs. In fact, other authors (e.g., Popov et al. 1998) claim that the presence of large numbers of HMXBs may be the best indication of starburst activity in a system.

M. H. F. acknowledges support through NASA grant NAG5-4238.

REFERENCES

Bildsten, L., et al. 1997, ApJS, 113, 367
Boese, F. G. 2000, A&AS, 141, 507
Buccheri, R., et al. 1983, A&A, 128, 245
Coe, M., et al. 1998, MNRAS, 293, 43
Corbet, R. H. D. 1986, MNRAS, 225, 381
David, L. P., et al. 1999, The ROSAT High Resolution Imager (HRI) Calibration Report, rev. 1999 October 5 (Cambridge: SAO)
Finger, M. H., Bildsten, L., Chakrabarty, D., Prince, T. A., Scott, D. M., Wilson, C. A., Wilson, R. B., & Zhang, S. N. 1999, ApJ, 517, 449
Finger, M. H., Wilson, R. B., & Harmon, B. A. 1996, ApJ, 459, 288
Fishman, G. J., et al. 1989, in Proc. GRO Science Workshop, ed. W. N. Johnson (Greenbelt: NASA/GSFC), 2-39
Israel, G. L., Stella, L., & Mereghetti, S. 1999, IAU Circ. 7101
Israel, G. L., Stella, L., Angelini, L., White, N. E., Kallman, T. R., Giommi, P., & Treves, A. 1997, ApJ, 474, L53
Kahabka, P. 1999a, IAU Circ. 7082
———. 1999b, IAU Circ. 7087
———. 2000, A&A, 354, 999
Kahabka, P., & Pietsch, W. 1996, A&A, 312, 919
Lamb, R. C., Prince, T. A., Macomb, D. J., & Finger, M. H. 1999, IAU Circ. 7081
Macomb, D. J., Finger, M. H., Harmon, B. A., Lamb, R. C., & Prince, T. A. 1999, ApJ, 518, L90
Negueruela, I., et al. 1997, MNRAS, 284, 859
Parmar, A. N., White, N. E., Stella, L., Izzo, C., & Ferri, P. 1989, ApJ, 338, 359
Popov, S. B., Lipunov, V. M., Prokhorov, M. E., & Postnov, K. A. 1998, Astron. Rep., 42, 29
Putman, M. E., et al. 1998, Nature, 394, 752
Schmidtke, P. C., et al. 1999, AJ, 117, 927
Schwering, P. B. W., & Israel, F. P. 1991, A&A, 246, 231
Stavely-Smith, L., Sault, R. J., Hatzidimitriou, D., Kesteven, M. J., & McConnell, D. 1997, MNRAS, 289, 225
Stella, L., White, N. E., & Rosner, R. 1986, ApJ, 308, 669
Trümper, J. 1983, Adv. Space Res., 2(4), 241
Udalski, A. 1999, IAU Circ. 7105
Wang, Q., & Wu, X. 1992, ApJ, 78, 391
Westerdal, B. E. 1997, The Magellanic Clouds (Cambridge: Cambridge Univ. Press)
Whitlock, L. 1989, ApJ, 344, 371
Yokogawa, J. et al. 2000, ApJ, 128, 491