CONFIRMATION OF THE 62 DAY X-RAY PERIODICITY FROM M82

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ABSTRACT

Using 400 days of new X-ray monitoring of M82, we confirm the 62 day periodicity previously reported. In the full data set spanning 1124 days, we find a period of 62.0 ± 0.3 days and a coherence, Q = 22.3, that is consistent with a strictly periodic signal. We estimate that the probability of chance occurrence of our observed signal is 6 × 10⁻⁷. The light curve folded at this period is roughly sinusoidal and has a peak-to-peak amplitude of (0.99 ± 0.10) × 10⁻¹¹ erg cm⁻² s⁻¹. Confirmation of the periodicity strengthens our previous suggestion that the 62 day modulation is due to orbital motion within an X-ray binary.

Subject headings: black hole physics — galaxies: individual (M82) — galaxies: stellar content — X-rays: binaries — X-rays: galaxies

1. INTRODUCTION

Bright, non-nuclear X-ray sources in external galaxies, the so-called ultraluminous X-ray sources (ULXs), represent either intermediate-mass black holes (Colbert & Mushotzky 1999; Makishima et al. 2000; Kaaret et al. 2001) or super-Eddington accretion onto stellar-mass black holes. The brightest X-ray source in the nearby starburst galaxy M82, CXOU J095550.2+694047 = X41.4+60 (Kaaret et al. 2001), is one of the most extreme ULXs. Assuming isotropic radiation, a black hole mass of at least 500 Mₜ⊙ is required to avoid violating the Eddington limit. The source also shows quasi-periodic oscillations (QPOs) at relatively low frequencies, 50–190 mHz, suggesting a relatively high compact object mass (Strohmayer & Mushotzky 2003; Dewangan et al. 2006; Mucciarelli et al. 2006; Kaaret et al. 2006b). The relative proximity and brightness of the source enables studies that are not feasible for other ULXs.

We monitored the X-ray emission from M82 for 240 days in 2004/2005 and detected a period of 62 days (Kaaret et al. 2006a). We interpreted the 62 day period as the orbital period of the companion star represents a significant advance in our knowledge of ULXs. In order to test this interpretation of the phase of the companion star within M82, thus, some part of the fluctuation represents sources other than X41.4+60. There is an X-ray flare around MJD 53,400, which was discussed in Kaaret et al. (2006b). Points with fluxes above 4 × 10⁻¹¹ erg cm⁻² s⁻¹ were removed in the subsequent analysis. The photon index is generally between 2.0 and 2.7, with an average value of 2.4. The distribution of the measured photon indexes are consistent, within the uncertainties, with a constant value of 2.4.

The light curve shows an apparent modulation with a period near 60 days. Figure 2 shows a periodogram with the power normalized by the total variance of the data (Horne & Baliunas 1986). There is a peak at a period of 62.0 days with a power of 77.9. We estimate the 90% confidence error on the period to be 0.3 days. There are two secondary peaks near the main peak, which are aliases due to the gap in the monitoring. Retaining the X-ray flare near MJD 53,400 does not shift the peak, but decreases the power (because of the normalization to the total variance of the data) to 70.5. Using fluxes calculated from spectral fits with the photon index fixed to 2.4 does not significantly change the period or the power of the peak.

We tested the significance of the observed signal using a red noise background, as is appropriate for an accreting X-ray source (Israel & Stella 1996; Vaughan 2005). We fitted the power versus frequency relation for periods in the range 6–280 days to a power-law form and found a spectral index of −1.04 ± 0.06. We generated red noise with a spectral index of −1.10 and with mean and variance equal to those of the data using the randpwrlc routine of the a t t l b IDL subroutine library provided by the Institut für Astronomie und Astrophysik of the Universität Tübingen (Timmer & König 1995). The duration of each generated light
curve is longer than the actual data, in order to minimize the effects of red noise leakage. Each light curve contains 8192 data points with uniform spacing of 0.66 days, and a subset of 330 points from the middle of this set with relative times matching the actual observations are extracted for analysis. These 330 simulated fluxes were processed with the same procedures used to analyze the real data. We generated $2 \times 10^6$ trial light curves and searched for cases where the power at periods of $10^{11} - 150$ days was greater than or equal to the observed value of 77.9. We found one such case, and estimate the probability of chance occurrence of our observed signal to be $5 \times 10^{-7}$. Fitting the distribution of maximum observed powers, we estimate that the probability of chance occurrence of our observed signal is $6 \times 10^{-7}$, indicating good agreement. This procedure is conservative because it includes the signal in the calculation of the power-law slope and the variance, and because the period search range, $10^{11} - 150$ days, extends to significantly lower frequencies than the observed period where the red noise produces high-amplitude fluctuations. If we restrict the search range to periods of 62 days or less, then a fit to the distribution of the maximum observed powers indicates that the probability of chance occurrence of our observed signal is $3 \times 10^{-13}$.

To search for rapid variability, we extracted event files with high time-resolution data for the 187 observations. Events in the 2.4–11.9 keV energy band were selected in the good time intervals defined above and split into segments of 256 s. A fast Fourier transform (FFT) with a time resolution of 1 s was calculated for each segment. The FFTs within each observation were added non-coherently. The resulting total power spectrum was logarithmically rebinned with a bin width of 16%, equal to the widths of the QPOs previously detected from M82. We searched for individual bins with high powers and calculated the significance, taking into account the number of bins in each power spectrum. The highest power was recorded on MJD 54,155.148 in a single 256 s interval of data at a frequency of $20 \times 10^{-5}$ Hz, with a Leahy power of 19.7, corresponding to a chance probability of occurrence of $5.4 \times 10^{-7}$ (4.0 $\sigma$) single trial and 0.0012 taking into account the trials for that single observation. Taking into account all observations in program 92098, the chance probability of occurrence is 0.23, indicating that the QPO detection is not significant. The observations in the new RXTE program are too short to provide good sensitivity for QPO detection.

3. DISCUSSION

Using 400 days of new X-ray monitoring of M82, we confirm the 62 day previously reported (Kaaret et al. 2006a). The coherence of the signal, $Q = 22.3$, is consistent with a strictly periodic signal. The light curve folded at this period is roughly sinusoidal and has a peak-to-peak amplitude of $1.0 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$.
The new observations rule out the possibility that the signal could be red-noise fluctuation. The remaining possible interpretations of the signals are that it represents either the orbital period of the binary system or a superorbital modulation.

Superorbital modulations are most often interpreted as being due to accretion disk precession (Wijers & Pringle 1999; Ogilvie & Dubus 2001); in this case, it would represent variations in our viewing angle of the disk. Indeed, in the one source where both a precessing relativistic jet (thought to be launched perpendicular to the disk) and a superorbital modulation are detected, SS 433, the periods of jet precession and superorbital modulation are the same (Margon & Anderson 1989). If ULXs are beamed sources, then the beaming cone would most naturally be perpendicular to the disk axis. Thus, accretion disk precession would naturally produce modulation of the beam at the superorbital period.

The distribution of superorbital periods of neutron star and black hole candidate X-ray binaries are plotted in Figure 4 (Wijers & Pringle 1999; Smith et al. 2002; Corbet 2003; Rau et al. 2003). We include only black hole candidates as defined by Remillard & McClintock (2006). It is apparent from the figure that there are no black hole binaries with superorbital periods near 62 days. The shortest superorbital period from a dynamically confirmed black hole candidate is the 198 day period of LMC X-3, which is longer by more than a factor of 3. Thus, if the 62 day period from M82 is interpreted as a superorbital period, this would suggest that it arises from a neutron star system. The measured flux modulation implies a luminosity (assuming isotropic emission) of \(1.6 \times 10^{40} \text{erg s}^{-1}\) for a source in M82 at a distance of 3.63 Mpc. This would exceed the Eddington limit for a 1.4 \(M_{\odot}\) neutron star by at least a factor of 86. The brightest known neutron star transient is A0538-66, which reached a peak luminosity of \(8 \times 10^{38} \text{erg s}^{-1}\) (White & Carpenter 1978), a factor of 20 lower than X41.4+60. Compared instead to the peak luminosity of flares from X41.4+60, the peak luminosity of A0538-66 is a factor of 95 lower. Thus, a neutron star interpretation for X41.4+60, as would be expected if the 62 day period is a superorbital modulation, is untenable.

When monitored over many periods, superorbital modulations show reduced coherence in the form of period or phase shifts. The high coherence measured for the M82 periodicity is inconsistent with all but the most stable of the superorbital modulations, specifically that of Her X-1.

Several X-ray binaries produce X-rays modulated at the orbital period, including Cygnus X-3 (Elsner et al. 1980), LMC X-3 (Boyd et al. 2001), 1E 1740.7–2942 and GRS 1758–258 (Smith et al. 2002), and GX 13+1 (Corbet 2003). Thus, the periodicity from M82 may be interpreted as being due to orbital modulation. The coherence of the signal we observe from M82 is consistent with that expected for a strictly periodic signal, given the observational coverage. This is consistent with interpretation as an orbital modulation. We conclude that the 62 day periodicity most likely indicates the orbital period of an X-ray binary. If the companion fills its Roche lobe, as expected in a system with a mass accretion rate high enough to produce the observed X-ray flux even with moderate beaming, then the long period indicates that the companion star has a low average density, \(5 \times 10^{-5} \text{g cm}^{-3}\), and is therefore a giant or supergiant.

P. K. and H. F. acknowledge partial support from NASA grant NNX06AG77G. P. K. acknowledges support from a University of Iowa Faculty Scholar Award.

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Fig. 4.—Distribution of superorbital periods of neutron star binaries (diagonal hatching) and black hole candidate binaries (horizontal hatching). The vertical dashed line shows the period measured from M82; it falls in the neutron star binary range.