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Change in Accretion Torque in the Binary Accreting Pulsar 4U 1626-67

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ABSTRACT

We describe two years of BATSE observations of the 7.66 s accreting pulsar 4U 1626-67. Power spectral analysis and period folding techniques with the 1.024 s resolution DISCLA data from the Large Area Detectors (LADs) have provided nearly continuous monitoring of 4U 1626-67 in the 20-60 keV range. The long term frequency history of the source shows nearly constant spin-down at a rate of $\dot{f} \approx -7.4 \times 10^{-13}\ \mathrm{s}^{-2}$, in contrast to the continuous spin-up (with $\dot{f} \approx 8.5 \times^{-13}\ \mathrm{s}^{-2}$) observed previously. We discuss the implications of these results for accretion torque theories and compare this behavior to that of GX 1+4.

1. INTRODUCTION

The source 4U 1626-67 was first found to be a $P_s = 7.7$ s accreting X-ray pulsar by Rappaport et al. (1977). Although Doppler delays in the X-ray arrival times have yet to be detected, Middleditch et al. (1981) deduced an orbital period from an optical observation of the counterpart, KZ TrA. The current best estimate for the orbital period is $P_{orb} = 2485.8 \pm 2.5\,\mathrm{s}$ (Middleditch et al. 1981; Levine et al. 1988; Middleditch 1992). Levine et al. (1988) have limited the projected semi-major axis, $a_x \sin i$, to less than 13 lt-ms for orbital periods in the range 10 minutes to 10 hours, implying a very light companion ($\sim 0.05 M_\odot$). All observations previous to BATSE showed 4U 1626-67 in a steady spin-up state. Here, we present the first 2 years of BATSE observations, which show that the neutron star is now spinning down at a nearly steady rate.

2. BATSE OBSERVATIONS OF 4U 1626-67

We have continuously observed 4U 1626-67 since the launch of the Compton Gamma Ray Observatory (GRO) in April 1991. The long-term frequency history was obtained using the lowest energy channel (20-60 keV) of the 1.024 second resolution DISCLA data from the LAD's. The low count rate of this source prohibits a time of arrival analysis on timescales < 5 days, so we present results based on daily power spectral analyses. We determine the spin frequency, $f = 1/P_s$, by fitting the peak power of the Fourier power spectrum in the neighborhood of the expected 0.1305

Hz frequency. The long term frequency history in Figure 1 shows BATSE measurements compared with all previous values. Detailed BATSE results are shown in Figure 2, indicating all significant detections (normalized power > 10) between TJD 8370-9150.

Since the source is only detectable in a fraction ($\sim 1/3$) of the data in a single-day power spectrum, we also analyzed groups of 10 days of data and performed a power spectral analysis to find the spin frequency. To show the detailed variations, we plot in Figure 3 the frequency residuals relative to a frequency ephemeris with $\dot{f} = -7.4 \times 10^{-13}$ and $f = 0.130529$ Hz at TJD 8370. These show clear evidence for accretion torque deviations of order 10 %.

3. IMPLICATIONS FOR ACCRETION TORQUES

Early studies of X-ray pulsars accreting from disks found that the observed long term spin-up timescale, $< t_{su} > \equiv P/\dot{P} \lesssim 10^4$ yr was much less than the system evolution time ($t_{evol} \gtrsim 10^6$ yr), implying that the long term spin-up could not be the steady-state behavior of the system. Ginga's discovery of extended spin-down in GX 1+4 (Makishima et al. 1988) showed that this was indeed the case for the source with the shortest spin-up time ($< t_{su} > \approx 40$ yr) (see Chakrabarty et al. 1993 for current information on GX 1+4).

Figures 1 and 2 show that 4U 1626-67 also undergoes torque switching behavior, and with nearly the same torque magnitude in spin-up and spin-down states. Since a disk reversal in this Roche-lobe overflow system is unlikely, we interpret the steady spin-down as a sign that the pulsar is spinning near its equilibrium period, where the magnetospheric radius is just less than the co-rotation radius, R_{co}, the radius where the Keplerian period equals the spin period (see Ghosh & Lamb 1979), requiring a dipole magnetic field strength at the surface of $\sim 3 \times 10^{12}$ G. The theoretical expectation is that the torque smoothly passes through zero before the magnetospheric radius moves outside of the co-rotation radius, in which case there is a wide range of possible torque values. It is thus intriguing to see that the star has nearly the same torque in spin-up as in spin-down.

For a $1.4 M_{\odot}$ neutron star with radius $R_x = 10$ km and $I_x \approx 2 M_x R_x^2/5$, the observed $\dot{f}$ implies a torque $N_{obs} = 2\pi I|\dot{f}| \approx 5.2 \times 10^{33}$gr cm^2 s^{-2}. The fiducial torque scale for the near-equilibrium regime is set by the specific angular momentum of matter at the co-rotation radius,

$$N_o \equiv \dot{M}(G M_x R_{co})^{1/2}$$

where $\dot{M}$ is the accretion rate, G is the Gravitational constant, and M_x is the neutron star mass. The best bolometric flux measurement is that of Pravdo et al. (1979), which was made during steady spin-up, $F_x(0.7 - 60 \text{ keV}) \approx 2.4 \times 10^{-9}$ erg cm^{-2} s^{-1}. At what we feel is the maximum distance (larger distances would place the source more than 1 kpc above the galactic plane) of 5 kpc, this flux implies $\dot{M} \approx 4 \times 10^{16}$g s^{-1} and a fiducial torque of $N_o = 1.4 \times 10^{34}$gr cm^2 s^{-2}, thus $N_{obs} \approx 0.4 N_o$. There are no recent measurements of the bolometric luminosity. Our preliminary $17 - -70$ keV pulsed flux measurement from BATSE gives $F_x(17 - -70 \text{ keV}) \approx 2 \times 10^{-10}$ erg cm^{-2} s^{-1}, a factor of ~ 4 lower than the hard flux measured by Pravdo et al. (1979). It would be intriguing if the bolometric luminosity was actually smaller during the spin-down, especially in light of the identical value of the torque. However, other factors may influence the hard-to-soft ratio, such as a reduction in pulse fraction or softening of the spectral shape. ASCA measurements will resolve this ambiguity and may indicate that the flux has decreased.

The simplest working hypotheses that emerge from these data are: (1) since $t_{su} \ll t_{evol}$, accreting pulsars quickly reach the equilibrium period, as determined from the accretion rate and magnetic field strength, (2) once there, the accreting pulsar oscillates about the equilibrium period by having counteracting periods of spin-up and spin-down at near the characteristic torque, N_o. We have yet to determine what sets the few-year timescale for the switching, and further long-term observations will be needed to actually observe a torque transition.

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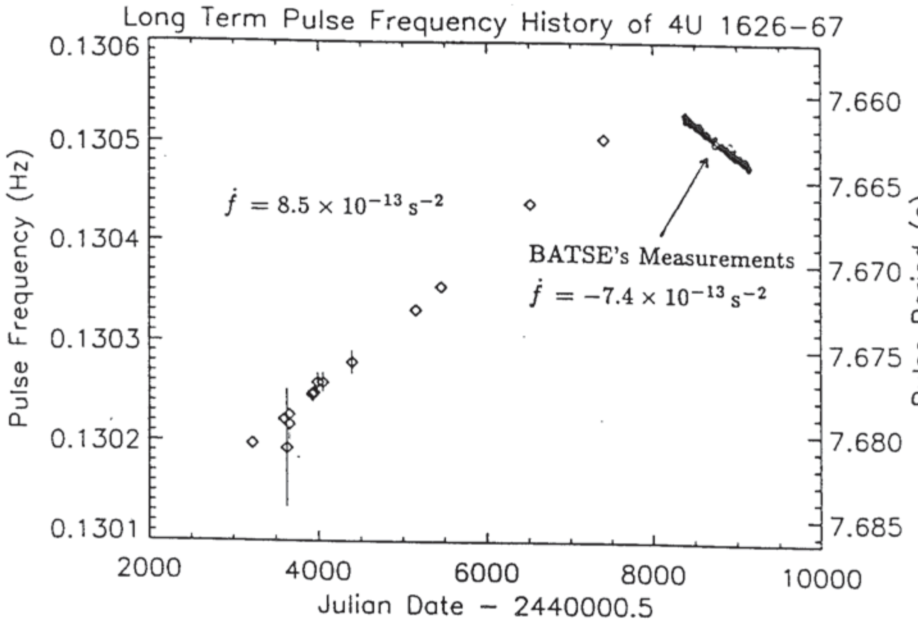

Figure 1: Long term pulse frequency history of 4U 1626-67.

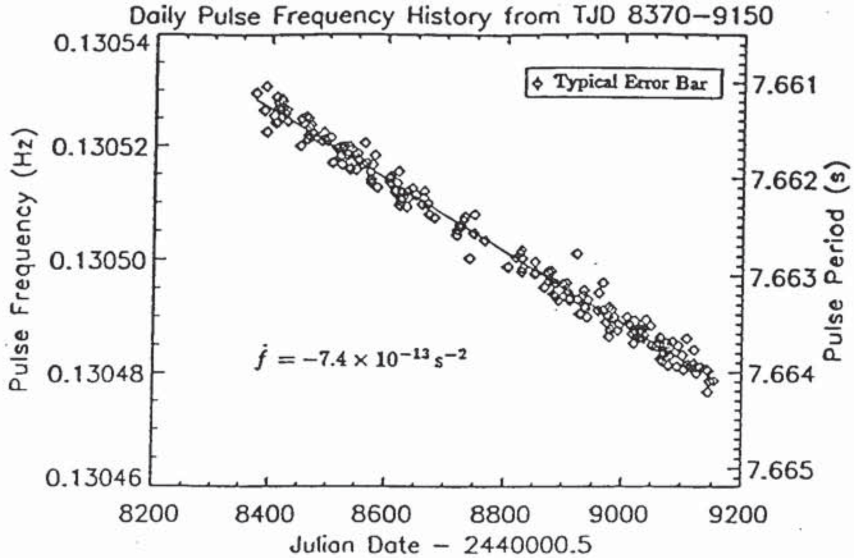

Figure 2: Detailed BATSE frequency measurements. Each measurement is obtained by fitting the power spectrum of the daily FFT of the 20-60 keV DISCLA data.

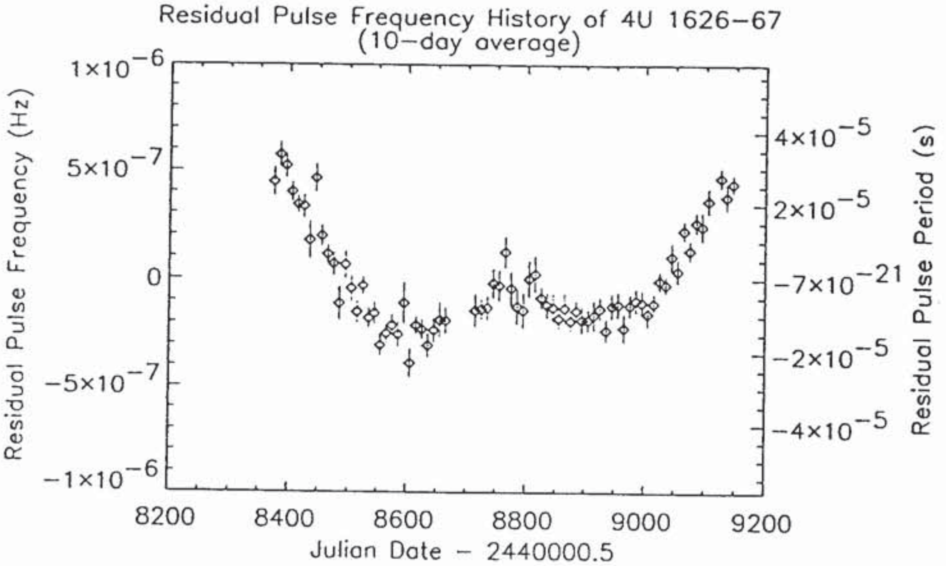

Figure 3: Residual pulse frequency history of 4U 1626-67. Measurements are obtained by fitting the Fourier power spectra of 10-day segments of the 20-60 keV DISCLA data. Displayed are the frequency residuals relative to the best fit frequency ephemeris ($\dot{f} = -7.4 \times 10^{-13}\,\mathrm{s}^{-2}$ and $f_0 = 0.130529\,\mathrm{s}^{-1}$ at TJD = 8370).