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OPTICAL PULSATIONS FROM 4U 0900−40: DO THEY EXIST?

Jerry Nelson,*† France Córdova,‡ and John Middleditch*
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ABSTRACT

A search for optical pulsations from 4U 0900−40 (HD 77581) was made in 1977–1978 using Hβ interference filters. No pulsations were detected above 10^{-3} of the observed flux. This contrasts with Steiner's detection of pulsations at the 2% level. *Ariel 5* data covering both our observations and Steiner's show that X-ray variability does not support this discrepancy.

Subject headings: pulsars — stars: binaries — stars: individual — X-rays: binaries

I. INTRODUCTION

The discovery of X-ray pulsations from 4U 0900−40 by McClintock *et al.* (1976) has produced increased interest in the search for optical pulsations from the visual counterpart, the 6.88 mag B0 supergiant HD 77581. The parameters of the binary system have been refined by Ögelman *et al.* (1977), who found an orbital period of 8.9643 days and an eclipse duration of 1.90(6) days. A shorter eclipse duration of 1.69(6) days has been reported by Watson and Griffiths (1977). The pulse period of 282.9 s appears to both speed up and slow down, but according to Becker *et al.* (1978), the X-ray pulsar has a long-term spin up with $\dot{P} = -1.0 \times 10^{-9}$. From the observed Doppler shift of these pulsations, the length of the semimajor axis was determined to be $a \sin i = 113(4)$ lt-sec (Ögelman *et al.* 1977).

In 1976 a search for broad-band optical pulsations was made by Nelson *et al.* (1979), who reported pulsed fraction upper limits as low as 2×10^{-4}. Charles *et al.* (1978) have also reported broad-band upper limits of $\sim 8 \times 10^{-3}$. More recently, a positive detection of optical pulsations using Hβ interference filters was reported by Steiner (1977). These pulsations were claimed to be present at all observed binary phases, including the X-ray eclipse, with a fractional modulation of up to 2%.

If this result is confirmed, a study of the optical pulsation period as a function of time may reveal details of neutron-star structure (Lamb, Pines, and Shaham 1978) as well as improved physical parameters for the binary-system components (Middleditch and Nelson 1976). A study of the spectrum of the optical pulsations along with the spectrum of the X-ray pulsations could provide insight into the physical processes which produce this modulation.

In an effort to confirm the results of Steiner (1977), a search for optical pulsations from 4U 0900−40 using Hβ interference filters was undertaken by the authors. Steiner's results were not confirmed. On five nights of observations no pulsations were seen; the pulsed fraction upper limits were $\sim 10^{-3}$, a factor of 20 lower than the value reported by Steiner.

The X-ray satellite *Ariel 5* has been continuously monitoring 4U 0900−40 since 1974. Results of this survey (Holt *et al.* 1978; Holt 1978) suggest that intrinsic X-ray variability is not the source of the discrepancy between our measurements and Steiner's; the average X-ray intensity during Steiner's observations is the same as the average X-ray intensity during our observations.

The details of our observations are discussed in this paper.

II. OBSERVATIONS

Observations of 4U 0900−40 using the CTIO 90 cm telescope were made by one of us (F. C.) on 1977 November 9 and 10. By use of a dichroic filter, the light beam was split so that simultaneous measurements through a narrow (25 Å) and a wide (175 Å) Hβ filter were made. The counts were recorded in 0.5 s intervals for subsequent analysis.

On 1978 February 2, 3, and 4, observations of this source were obtained (by J. N.) using the KPNO 90 cm telescope. These data were obtained using either a narrow (30 Å) or a wide (170 Å) Hβ filter, and were recorded in 0.1 s intervals for analysis. A summary of the observations is given in Table 1.

Both sets of data were analyzed in a similar fashion. Each observation was fitted with a low-order polynomial, and the occasional points which deviated widely from this fit (caused by guiding errors) were replaced by their respective polynomial values. The polynomials were then subtracted from the data streams. The resulting smoothed data streams were Fourier transformed, and their power spectra were examined for signals at the expected pulsation frequency and its low harmonics. No obvious signals

* Lawrence Berkeley Laboratory, University of California, Berkeley.

† Visiting Astronomer, Kitt Peak National Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

‡ California Institute of Technology. Also, Visiting Astronomer, Cerro Tololo Inter-American Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE 1

SUMMARY OF OBSERVATIONS

Time of Observation JD 2,443,450+*	Duration of Run (s)	Binary Phase	Hβ Filter	Counts s^{-1} from Star	Pulsed Fraction Upper Limit 90% Confidence Level
6.875	1160	94°–95°	N	4850	2.9×10^{-3}
			W	14500	2.9×10^{-3}
7.792	6000	131°–133°	N	4500	0.8×10^{-3}
			W	13500	0.6×10^{-3}
91.789	7000	264°–267°	N	10000	1.2×10^{-3}
92.775	8627	304°–308°	W	90000	1.3×10^{-3}
93.750	10945	343°–348°	N	10000	1.0×10^{-3}

* 1977 November 3.

were seen. As a result of the detrending process, the power spectra were flat, even for the low frequencies of interest, so reliable estimates of the statistical uncertainties were obtained. The upper limits derived from the observations (90% confidence level) are typically ~0.1% pulsed fraction and are given in Table 1.

III. INTERPRETATION

Our results are in clear disagreement with those of Steiner (1977). Since Steiner saw pulsations at all observed phases and our observations cover a range of binary phases, it is unlikely that a model invoking a pulsed intensity which varies with binary phase can explain the discrepancy.

Since the X-ray flux from the source is variable, another possible explanation is that when Steiner's observations were made, the X-ray flux was much greater than during our observations. Data from the *Ariel 5* X-ray satellite spanning 1974–1978 (Holt *et al.* 1978; Holt 1978) were examined in order to check this possibility. Using intensities averaged over one binary cycle, no systematic difference is seen. The averaged intensity covering Steiner's observations can be no more than 50% higher than the averaged X-ray intensity covering our observations; thus long-time-scale X-ray variability cannot be the source of the discrepancy. 4U 0900−40 is also known to exhibit short-time-scale variability. Watson and Griffiths (1977) describe the variability of this source on a short time scale (~2 hour resolution) covering 19 binary cycles. Their most extreme flare is 10 times the average X-ray intensity. Thus, even if all of Steiner's observations were made during intense X-ray flares and all of our observations were made during periods of average X-ray intensity, a factor of 2 discrepancy remains.

Theoretical models producing continuum optical pulsations by reprocessing the X-ray flux in the atmosphere of the companion star (Chester 1978) predict pulsation amplitudes less than ~0.2% for this object. If the pulsations are actually in lines, as is implied by Steiner's results, and not in the continuum, then a different pulsation mechanism is needed. Until a detailed pulsation model exists, no certain relation between X-ray pulsed intensity and optical pulsed intensity can be made.

An additional possibility for explaining the discrepancy exists. The relatively well studied optical pulsations in HZ Her–Her X-1 (Middleditch and Nelson 1976) reveal that the optical pulsation strength varies over the 35 day cycle, but for the most part in a quite different fashion than the observed hard X-ray strength. It is thought that shadows cast by the accretion disk in the direction of the nondegenerate companion produce this apparent noncorrelation between the pulsed optical and X-ray fluxes. If one could invoke a similar mechanism in 4U 0900−40, then perhaps one could explain the wide range of optical pulsation strengths reported as against the relative constancy of the X-ray flux detected at the Earth.

The resolution of this perplexing issue clearly requires additional optical observations.

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FRANCE CÓRDOVA: California Institute of Technology, Pasadena, CA 91125

JOHN MIDDLEDITCH and JERRY NELSON: Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720