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An ephemeris for the intermediate polar RE 0751 + 14

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ABSTRACT
RE 0751 + 14 shows an 833-s spin pulsation which is quasi-sinusoidal in the blue, but double-peaked in the red. We present the first ephemeris for this pulsation. A weaker 872-s pulsation is also double-peaked, and is probably caused by reprocessing of the double-peaked X-ray pulse. The optical modulation at the implied orbital period is weaker than in any other intermediate polar, which suggests that RE 0751 + 14 is at a low inclination.

Key words: accretion, accretion discs – binaries: close – stars: individual: RE 0751 + 14 – stars: magnetic fields – novae, cataclysmic variables.

1 INTRODUCTION

As soon as it was identified as an intermediate polar, it was apparent that RE 0751 + 14 was a peculiar member of this class of magnetic cataclysmic variable. The first *K*-band light curve showed a double-peaked 14-min spin pulse, while a follow-up *Ginga* observation showed a similarly double-peaked X-ray pulse (Mason et al. 1992). This contrasts with typical intermediate polar behaviour in which the spin pulses can be roughly described as sinusoidal (see Patterson 1994 for a review of these stars). Soon afterwards, Piirola, Hakala & Coyne (1993) found polarization varying over the spin period in RE 0751 + 14 – the first time that this has been seen in an intermediate polar, although it is ubiquitous amongst the related AM Her stars or 'polars'. It is possible that RE 0751 + 14 has a field strength, 8–18 MG, that is comparable with the lower end of the AM Her field distribution, and so might be the first identified AM Her progenitor.

Such characteristics mean that RE 0751 + 14 deserves intensive study. Further, it will be crucial to determine the relative phasings of the pulsation in the different wavelength bands and types of observation. With this aim we have accumulated 100 h of photometry of RE 0751 + 14 at McDonald Observatory. In this paper we report the optical photometric characteristics, and provide an ephemeris which will serve as a baseline for multiwavelength investigations of this star.

2 OBSERVATIONS

Our photometry of RE 0751 + 14 is summarized in Table 1. The majority of the data were obtained with the McDonald Observatory 0.9-m telescope and the Stiening photometer, a photomultiplier-tube aperture photometer giving data simultaneously in four passbands close to *UBV* and *R* (these are plotted by Robinson et al. 1994). The Stiening photometry was supplemented with *I*-band light curves obtained with

Table 1. Photometry of RE 0751 + 14.

Obs.	Date	Colour	Length (hrs)
SAAO	91 Dec 8-17	Blue	15
McD	92 Nov 29	UBVR	4
McD	93 Jan 20	UBV	7
McD	93 Jan 21	UBV	8
McD	93 Jan 26	UBV	8
McD	93 Feb 26	UBVR	6
McD	93 Mar 12	I	1
McD	93 Mar 14	I	6
McD	93 Mar 15	I	2
McD	93 Nov 6	I	1
McD	93 Nov 7	I	6
McD	93 Nov 8	I	5
McD	93 Nov 9	UBVRI	6
McD	93 Nov 10	UBVRI	6
McD	94 Jan 11	UBVR	8
McD	94 Jan 13	UBVR	7
McD	94 Mar 10	UBVR	4
McD	94 Mar 12	UBVR	5

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the TK2 + WHT CCD camera on the 0.8-m at McDonald. In addition, we observed RE 0751 + 14 with the South African Astronomical Observatory 0.75-m telescope using an unfiltered S11 photomultiplier tube, giving a broad blue response. The time resolution was typically 2 s with the aperture photometers and 40 s with the CCD. Some of these data have been previously reported by Hellier & Ramseyer (1994). In addition, we had access to the photometry published by Mason et al. (1992), Rosen, Mittaz & Hakala (1993) and Hilditch & Bell (1994), kindly supplied by those authors.

3 THE LIGHT CURVES

Fig. 1 shows the light curves from 1993 November 10, with *UBVRI* data obtained from the McDonald 0.9-m and 0.8-m

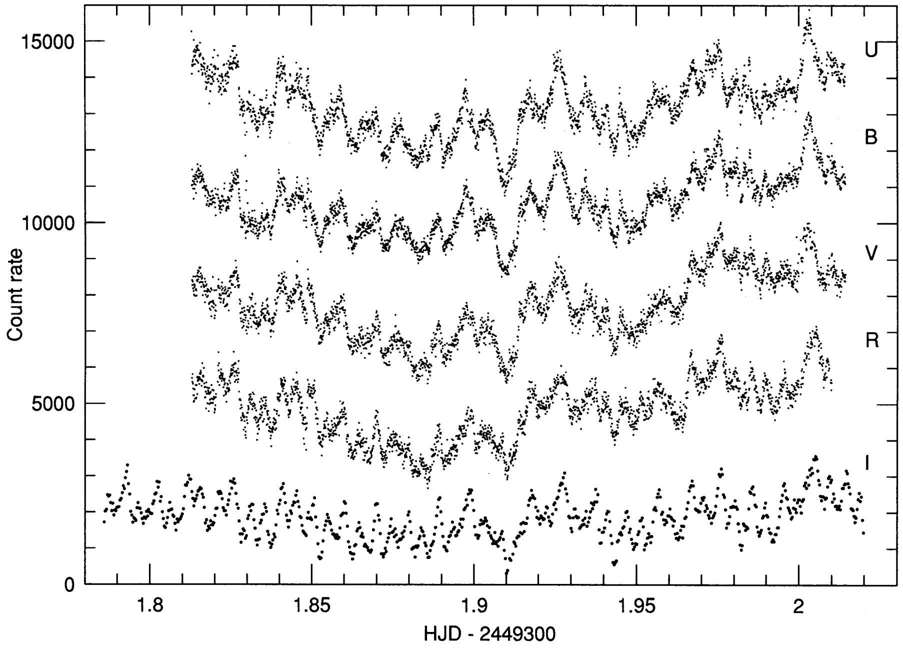

Figure 1. Sample *UBVRI* light curves of RE 0751 + 14. The *y*-axis is correct for the *B*-band data; all other colours are displaced.

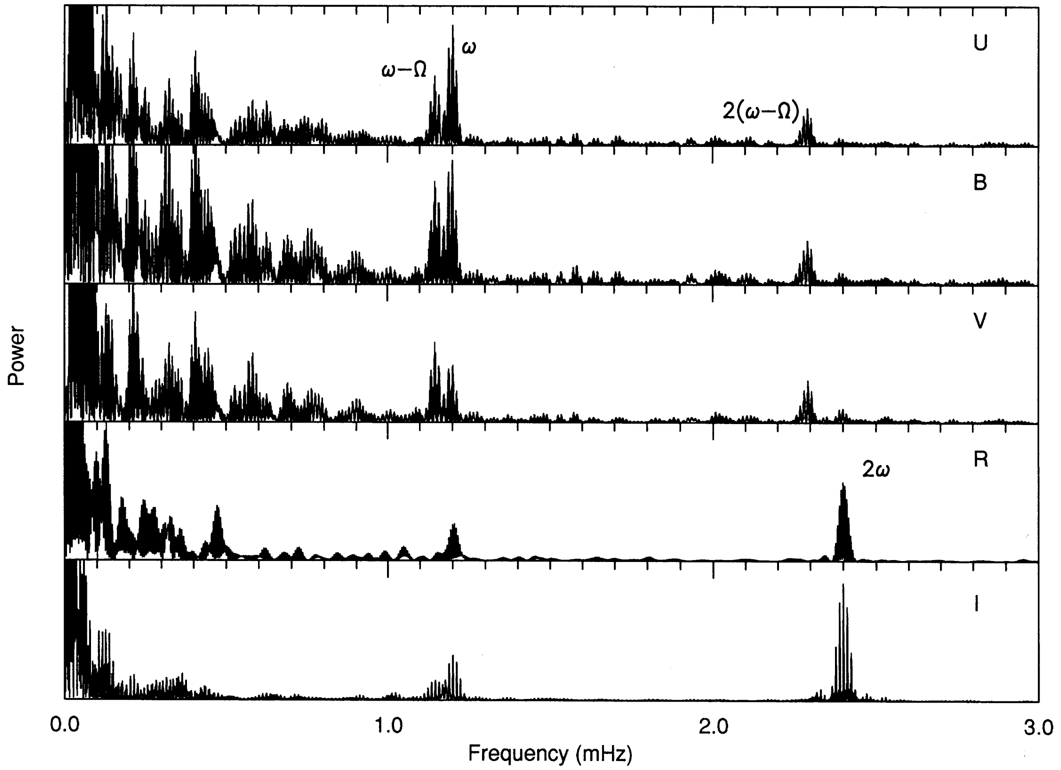

Figure 2. Fourier transforms of subsets of our data. The *UBV* data are from 1993 January, the *R* data from 1994 January and the *I* data from 1993 November. The spin, orbital and beat frequencies are labelled with the usual notation, where ω = spin and Ω = orbit.

simultaneously. As is usual for this star, there are times when a clear spin pulse is seen (e.g. the section from HJD − 244 9300 = 1.85 to 1.90), and times when the light curve is dominated by flickering. It can also be seen that the pulsation is single-peaked in the blue but double-peaked in the red.

In Fig. 2 we show sample Fourier transforms (FTs) from subsets of the data. The different colours are not simultaneous, since we have insufficient simultaneous data. Instead, we chose the transforms to show typical behaviour. The *UBV* FTs are from 1993 January, and show a strong 13.9-min spin pulsation. There is also a pulsation at a longer period of 14.5 min, together with its first harmonic. From comparison with the characteristics of other intermediate polars, this is almost certainly the lower orbital sideband of the spin pulse (the 'beat' period), although we have no proof of this since the orbital period has not yet been reliably determined. The *R* FT is from 1994 January, and shows that at this wavelength much of the power of the spin pulse has shifted to the first harmonic. This is even more marked in the *I*-band FT, which is from 1993 November.

Fig. 3 shows the data folded on the spin period, using the ephemeris presented below. The *UBVR* data are simultaneous from 1994 January; the *I*-band data are from 1993 November. The striking change in pulse profile from blue to red is consistently seen throughout our data set. Further, the pulse profiles (although not the amplitudes) reproduce reliably at different epochs, so we are confident that the colour dependence of the profile is real. This behaviour is unique amongst the known intermediate polars.

The spin-pulse fraction has a long-term average of 4 per cent (peak to trough in the *B* band); it varies, however, on hourly and nightly time-scales from ~8 per cent to absence. The beat pulse has a long-term average of 1.5–2.0 per cent (peak to trough), and similarly varies from night to night.

4 THE EPHEMERIS

To determine accurate periods for RE 0751+14, we calculated the slow Fourier transform of our combined data from 1993 and 1994. Portions of this transform are shown in Fig. 4. From an examination of our data, we found that the most reliable period determinations are made from the spin harmonic in the red, which is least affected by flickering and interference by the sideband. The FT of the combined data gives an unambiguous frequency of 207.3401 ± 0.0003 cycle d^{-1} for the spin harmonic (top two panels of Fig. 4). This value provides a secure cycle count throughout our data. For further information, we have timed the spin pulse from portions of our data. In the blue we fitted a sinusoid after folding the data on the above period, and recorded the time of its maximum. We included only data of sufficient length that distortions by the sideband and flickering are minimal. For the *I*-band data, we measured the arrival time of the higher peak of the pulse. The timings are collected in Table 2. To refine the spin period, we used the timings with the longest baseline in similar data – the span between the 1991 December and 1994 January blue photometry. For a fiducial marker, however, we have chosen the main peak in the *I* band, which seems to be the most reliable and readily observable feature of the light curves. Combination of the two gives the ephemeris:

$$\mathrm{HJD}_{I-\mathrm{peak}} = 244\,9297.9730(3) + 0.009\,645\,966(11)E.$$

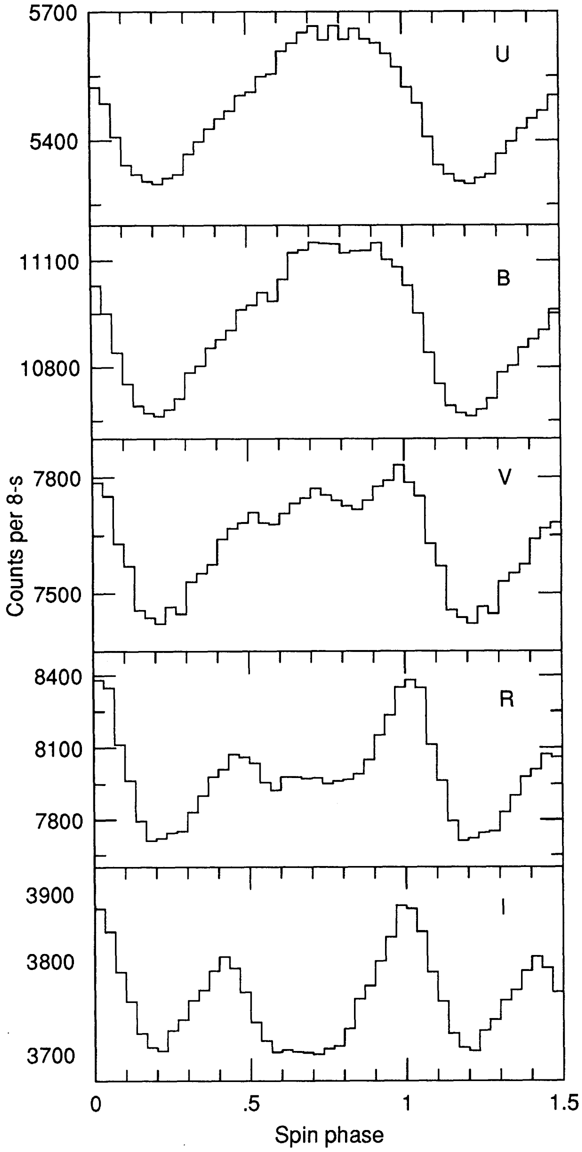

Figure 3. *UBVRI* light curves folded on the spin cycle, showing the colour dependence of the spin pulse profile.

4.1 The orbital and beat periods

Although we are confident of the cycle count of the spin pulse, the beat pulse is weaker and present on fewer nights, and so gives a less secure result. The FTs from Fig. 2 confine the first harmonic of the beat pulse to the frequency range shown in the third panel of Fig. 4 (all peaks seen are aliases; the noise level away from this region is ~200). The highest peak has a frequency of 198.0967(5) d^{-1}. If this is the beat harmonic then, taken with the above ephemeris, it would imply an orbital frequency of 4.6219(5) d^{-1}. The relevant region of the FT is shown in the lowest panel of Fig. 4; there is clearly no peak significantly above the noise, although the second highest peak has a frequency of 4.6213(4) d^{-1}. The chance of one of the ~10 highest peaks in this range overlapping the predicted frequency to this accuracy by chance is only ~1 per cent. Thus we have some confidence that we have correctly identified the beat and orbital cycles, although clearly we cannot claim that they are secure. If so, we have a beat period of 872.301(4) s and an orbital period of

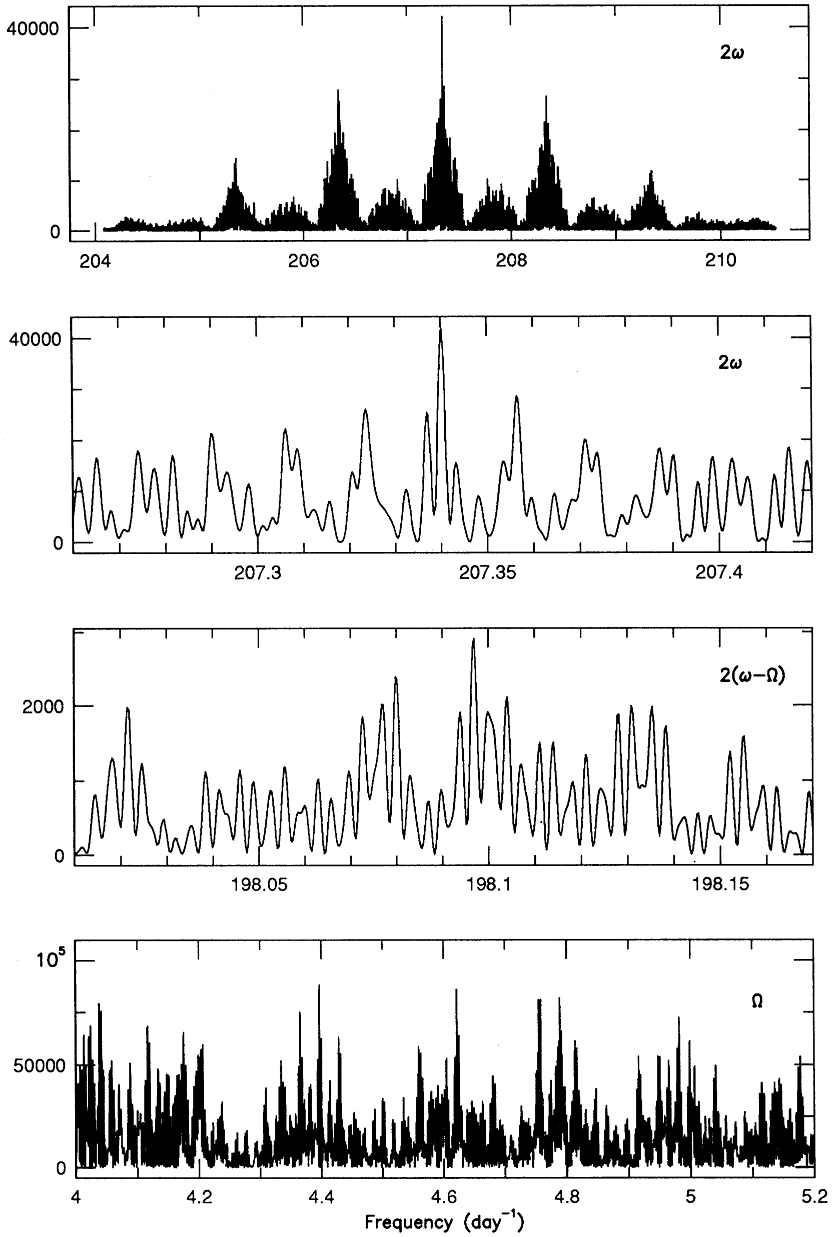

Figure 4. Portions of the Fourier transform of the entire data set from 1993 and 1994. The top panel shows the region around the first harmonic of the spin pulse, while the second panel shows the section near the highest peak greatly expanded. The third panel gives a similarly expanded view of the peak of the first harmonic of the beat frequency. The bottom panel shows the section surrounding the probable orbital frequency.

5.1927(5) h [if not, we fall back on less accurate values of 872.5(3) s and 5.17(4) h].

The FT peak at the orbital frequency (which is either a detection or an upper limit) corresponds to a peak-to-trough amplitude of 5 per cent. The 1993 January data (which show the strongest beat pulse) are shown folded on the beat period in Fig. 5; the time of the main dip is given in Table 2.

5 DISCUSSION

The dominant pulsation in the optical is at the 833-s X-ray period found by Mason et al. (1992). There is a lower amplitude pulsation at 872 s, almost certainly the orbital sideband of the spin pulse, which implies an orbital period of 5.2 h. In this regard, RE 0751 + 14 shows typical intermediate polar behaviour, similar to that of FO Aqr or BG CMi. The double-peaked spin pulse seen in the red and the X-ray band, though, is atypical. In the 'accretion curtain' model, the primary effect producing the X-ray spin modulation is photoelectric absorption in the curtains of material above the magnetic poles (Rosen, Mason & Cordova 1988). If part or all of the upper pole-cap disappears over the white dwarf limb, this would produce a modulation in antiphase with the absorption effects (e.g. Hellier, Cropper & Mason 1991). Mason et al. (1992) suggested that this causes the double-peaked X-ray pulse in RE 0751 + 14.

The optical counterpart of the accretion curtain model (Hellier et al. 1987, 1991) locates the optical spin-pulsed

Table 2. Pulse timings of RE 0751 + 14.

	Dataset	HJD−2440000
Spin: B band		
(max of sinusoid fit)	Dec 91	8598.40669
	Jan 93	9007.60696
	Jan 94	9363.61152
	Mar 94	9421.58381
Spin: I band		
(max of higher peak)	Nov 93	9297.97299
	Mar 93	9058.77206
	Rosen et al.	8619.53419
	Piirola et al.	8921.64479
Beat: B band		
(bottom of main dip)	Jan 93	9007.60303

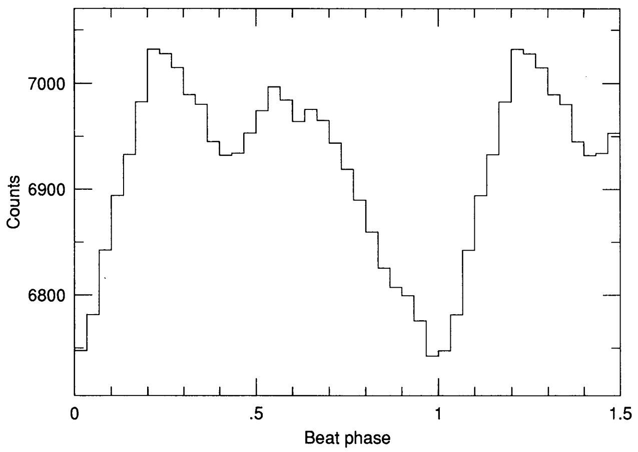

Figure 5. The *B*-band data from 1993 January folded on the beat period using the epoch quoted in Table 2.

emission in the opaque curtains extending to several white dwarf radii. Occultation by the white dwarf would thus be less significant, owing to its small size. Further, a two-pole model is hard to sustain, since in the accretion curtain model the two poles act in phase. Since RE 0751 + 14 is the only system to show the double-peaked pulse-profile, it is likely to be related to the high magnetic field strength in RE 0751 + 14 (Piirola et al. 1993). This could produce a more confined accretion pattern, and might produce beamed cyclotron emission, as is commonly seen in AM Her stars. Since this will be more significant in the red, it could explain the colour behaviour of the spin pulse. This cyclotron emission would originate much closer to the white dwarf than would the accretion curtain emission proposed for other intermediate polars, and thus occultation effects, which dominate the optical light curves of AM Her stars, might be important in this star.

Rosen et al. (1993) also saw the double-peaked red spin pulse, and suggested a cyclotron origin. In addition, though, they judged that the spin pulse disappears in the blue, rather than becoming single-peaked. From our much larger data set of simultaneous multicolour photometry, we conclude that this resulted from observing a pulsation of varying amplitude in different colours at different times.

The beat pulse in RE 0751 + 14 is also double-peaked, another feature peculiar to RE 0751 + 14. If it arises in the usual way, by reprocessing of X-ray irradiation by the hotspot/secondary star, its profile might simply reflect the initially double-peaked X-ray pulse. This could be tested by measuring the relative phasings of the spin, beat and orbital modulations, provided that the phasing of the secondary star could be deduced. The optical orbital modulation ($\lesssim 5$ per cent) is the lowest yet found amongst the intermediate polars. This suggests a low system inclination for RE 0751 + 14. Many of the other intermediate polars show X-ray dips, caused by material in the disc or stream blocking the line of sight to the white dwarf (Hellier, Garlick & Mason 1993). If RE 0751 + 14 were at a lower inclination, such effects should be weaker or absent.

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