

DISCOVERY OF OPTICAL VARIABILITY IN THE HARD X-RAY SOURCE HD 8357

DOUGLAS S. HALL¹ AND GREGORY W. HENRY¹

Dyer Observatory, Vanderbilt University

AND

HOWARD LOUTH

Sedro Woolley, Washington

Received 1982 January 14; accepted 1982 February 25

ABSTRACT

Photometry obtained at three different observatories on 27 different nights in the 1980–1981 season shows this RS CVn binary to be variable. The light curve is sinusoidal in shape, the total range in V is 0.08 mag, the photometric period is $12^d.3 \pm 0^d.1$, and an epoch of minimum light is JD $2,444,504.5 \pm 0^d.1$.

Subject headings: stars: binaries — stars: variables

I. INTRODUCTION

After learning that the hard X-ray source H0123+075 had been identified with the optical counterpart HD 8357 = SAO 109841 and shown to be a probable RS CVn binary (Garcia *et al.* 1980), we began observing this star photometrically to detect the optical variability which is characteristic of virtually all RS CVn binaries (Hall 1981).

The spectral type is G5 according to the Henry Draper catalog. The spectroscopic observations of Garcia *et al.* showed remarkably strong Ca II K emission, extending well above the continuum. Cross-correlation analysis of their spectra showed them that HD 8357 was binary, with two late-type stellar components, and that the bright chromospheric emission was dominated by the component which showed stronger photospheric absorption lines. That same analysis indicated an orbital period of something less than 1 month.

It is generally accepted now that the photometric variability in RS CVn binaries is produced by an area of low surface brightness (a spot or group of spots cooler than the surrounding photosphere) predominantly on one hemisphere of one star which rotates very nearly synchronously with the orbital motion. For this reason we hoped to discover optical variability, determine its period, and (because of the presumed synchronism) provide an estimate of the orbital period.

II. PHOTOMETRY

We observed HD 8357 at three different observatories on 27 different nights between JD 2,444,262.5 and

2,444,641.6. Observations were made differentially with respect to the comparison star 88 Psc, with the variable bracketed by the comparison star three times each night. Most of the observations were made with one filter, chosen to match V of the UBV system, although a few were made also with a filter chosen to match B . G. W. H. observed with the 24 inch (61 cm) Seyfert reflector at Dyer Observatory and with the no. 4 16 inch (41 cm) reflector at Kitt Peak National Observatory; H. L. observed with the 10 inch (25 cm) reflector located in Sedro Wooley, Washington.

The individual differential magnitudes, corrected for differential atmospheric extinction and transformed differentially to V and B of the UBV system, have been deposited in the IAU Commission 27 archive for unpublished observations of variable stars (Breger 1979), where they are available as file no. 93. The standard deviation of the three individual differential magnitudes from each nightly mean indicates that the nightly means should be uncertain by about ± 0.002 mag at Kitt Peak and about ± 0.003 mag at the other two observatories. Systematic errors related to the transformation should increase these uncertainties to about ± 0.003 mag and ± 0.004 mag, respectively.

III. PERIOD DETERMINATION

It was evident from our data that HD 8357 was variable, having a roughly sinusoidal light curve with a range of almost 0.1 mag in V and a period of around 12 days. The Kitt Peak run covered one cycle completely with no significant gaps, thereby ruling out values of the period smaller by multiples of small integers. The true period could be longer by multiples of 2 or 3 but that would imply a double or triple sinusoid, which is unlikely.

¹Visiting Astronomer, Kitt Peak National Observatory, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

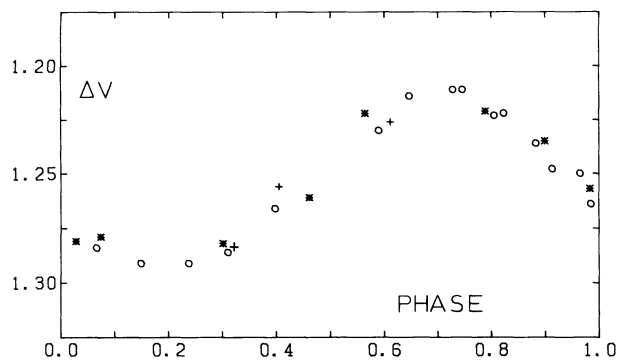


FIG. 1.—The light curve of HD 8357. The differential magnitude is ΔV in the sense HD 8357 minus 88 Psc. Phase is computed with the photometric period of $12^d.245$. Each symbol is a nightly mean determined by G. W. H. at Dyer (*asterisk*), by G. W. H. at Kitt Peak (*open circle*), or by H. L. (*plus*).

To determine the photometric period we used a period-finding program to analyze our photometry in V between JD 2,444,453.9 and 2,444,641.6 (excluding the observations on two early nights which were isolated from the others). This program assumes a value of $P(\text{phtm.})$, uses that value to plot ΔV versus phase, connects the points with straight line segments, and computes the total length L of all the line segments. The value of $P(\text{phtm.})$ which produces the smallest value of L is taken to be the best. The result, scanning between 10 and 14 days with a step size of $0^d.005$, was $P(\text{phtm.}) = 12^d.245$, estimated to be uncertain by $\pm 0^d.1$ because of the uneven spacing of the data.

We can estimate the period another way, which takes advantage of the long baseline in time between the two early nights (not used in the period finding program) and the others. If we assume the light curve does not change appreciably in tens of cycles, then the observation at JD 2,444,263.58 appears to be at maximum light. It and the times of two other well-defined maxima, JD 2,444,498.86 and 2,444,510.89, are fit best with a period of $P(\text{phtm.}) = 12^d.37$.

IV. THE LIGHT CURVE

Nightly means of all the ΔV -magnitudes (except the two early ones) are plotted in Figure 1 versus phase computed with the ephemeris

$$\text{JD (hel.)} = 2444453.0 + 12^d.245 n, \quad (1)$$

where the initial epoch is arbitrary.

Because the light curve is so nearly sinusoidal, we fit the means with a sine curve by least squares. The resulting fit indicates light minimum at phase 0.205 ± 0.006 (which corresponds to an epoch of JD 2,444,504.5 $\pm 0^d.1$), a total light variation of $\Delta V = 0.080 \pm 0.003$ mag, and a mean light level of $\Delta V = 1.253 \pm 0.001$ mag. Given two estimates of the period, $12^d.245$ and $12^d.37$, we conclude the true value is around $P(\text{phtm.}) = 12^d.3$ with an uncertainty around $\pm 0^d.1$. Additional photometry in subsequent observing seasons should yield a more precise determination.

The average residual of the nightly means from the sinusoidal curve is ± 0.0035 mag, no larger than the observational uncertainty expected for each. Thus, we see no optical variability (apart from the smooth sinusoidal variation) which might be correlated with the flarelike variability seen in the hard X-ray.

For our comparison star 88 Psc, Nicolet (1978) gives $V = 6.03$ mag and $B - V = +1.08$ mag. Therefore, we see that HD 8357 has a mean brightness of $V = 7.28$ mag and, because our few differential measures in B indicate $\Delta(B - V) = -0.21$ mag, has a mean color of $B - V = +0.87$ mag.

Douglas S. Hall is happy to acknowledge support from NASA grant NSG 7543, and we all are very grateful to Dr. Sallie L. Baliunas for her suggestion that we observe HD 8357.

REFERENCES

- Breger, M. 1979, *Inf. Bull. Var. Stars*, No. 1659.
 Garcia, M., Baliunas, S. L., Conroy, M., Johnston, M. D., Ralph, E., Roberts, W., Schwartz, D. A., and Tonry, J. 1980, *Ap. J. (Letters)*, **240**, L107.
 Hall, D. S. 1981, in *Solar Phenomena in Stars and Stellar Systems*, ed. R. M. Bonnet and A. K. Dupree (Dordrecht: Reidel), p. 431.
 Nicolet, B. 1978, *Astr. Ap. Suppl.*, **34**, 1.

DOUGLAS S. HALL: Dyer Observatory, Vanderbilt University, Nashville, TN 37235

GREGORY W. HENRY: Cloudcroft Observatory, Box 225, Cloudcroft, NM 88317

HOWARD LOUTH: 2199 Hathaway Road, Sedro Woolley, WA 98248