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DISCOVERY OF ECLIPSES IN THE X-RAY SOURCE HD 155638

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ABSTRACT

Photometry at three different observatories shows that HD 155638, a G8 IV star, undergoes total eclipses every $27^{\mathrm{d}}.55$. The depths are 0.23 mag in V, 0.43 mag in B, and 0.76 mag in U. A time of mid primary eclipse is JD 2,445,214.7. Durations are $D = 0^{\mathrm{P}}.065$ and $d = 0^{\mathrm{P}}.035$. There is also a nearly sinusoidal RS CVn type of light variation outside eclipse, with about the same period and with an amplitude of 0.09 mag in V, B, and U.

Subject headings: Ca II emission — photometry — stars: binaries — stars: eclipsing binaries — stars: variables — X-rays: binaries

We began photoelectric photometry after learning that X-ray and optical observations by Stern *et al.* (1981) had shown this star to have a remarkably active chromosphere and corona. The G8 IV spectral type, the variable and remarkably strong Ca II reversals, and the soft X-ray emission suggested that HD 155638 might be an RS CVn binary, although there was no direct evidence that it is a binary. Most RS CVn binaries are optically variable with amplitudes around 0.1 mag and periods very near their orbital periods (Hall 1981); this is because most RS CVn binaries contain one star which is darkened unevenly by large starspot regions and rotates in approximate synchronism with the orbital motion. Our hope, therefore, was that discovery of optical variability would support the case for duplicity and provide an estimate of the orbital period.

Hanson and Bloomer observed on 35 nights between JD 2,445,129.8 and 2,445,245.6 with the 24 inch (61 cm) reflector at the United States Air Force Academy, obtaining 141 differential magnitudes in V, B, and U. Henry observed on 20 nights between JD 2,445,017.0 and 2,445,227.6 with the 48 inch (1.2 m) reflector at Cloudcroft Observatory, obtaining 54 differential magnitudes in V and 11 in B. Fried observed on five nights between JD 2,445,153.9 and 2,445,169.8 with the 16 inch (41 cm) reflector at Braeside Observatory, obtaining 12 differential magnitudes in V and B. Henry used SAO 46540 as his comparison star, but the others used HD 155541 as the comparison star. The differential magnitudes were corrected for differential atmospheric extinction and transformed differentially to the UBV system. On nights when observations only in V were obtained, a mean color index difference between variable and comparison was used in the reductions. On 22 nights at the Air Force Academy, 41 differential magnitudes in V, B, and U were determined between the comparison star HD 155541 and a check star, SAO 46492; the standard deviation of a single differential measure from the mean was only ± 0.011 mag in V, ± 0.014 mag in B, and ± 0.024 mag in U.

Examination of our photometry showed that HD 155638 was varying in light by two mechanisms. First, there was a nearly sinusoidal variation with an amplitude of about 0.1 mag and a period of about $27^{\mathrm{d}}.5$. Because at least one cycle was covered by observations made on virtually consecutive nights, we could rule out fractional periods. Second, observations on five different nights fell below the sinusoidal light curve and suggested an eclipse with about the same period.

Analysis showed that those five low measures could be arranged most reasonably with an orbital period of $27^{\mathrm{d}}.55 \pm 0^{\mathrm{d}}.05$. With such an arrangement, the overall eclipse duration (first to fourth contact) appears to be about $0^{\mathrm{P}}.065$, and there appears to be a constant phase lasting (second to third contact) about $0^{\mathrm{P}}.035$. A representative time of mid-eclipse would be JD 2,445,214.7.

Then, with the five eclipse points excluded, we used Fourier analysis to fit the rest by least squares. The best

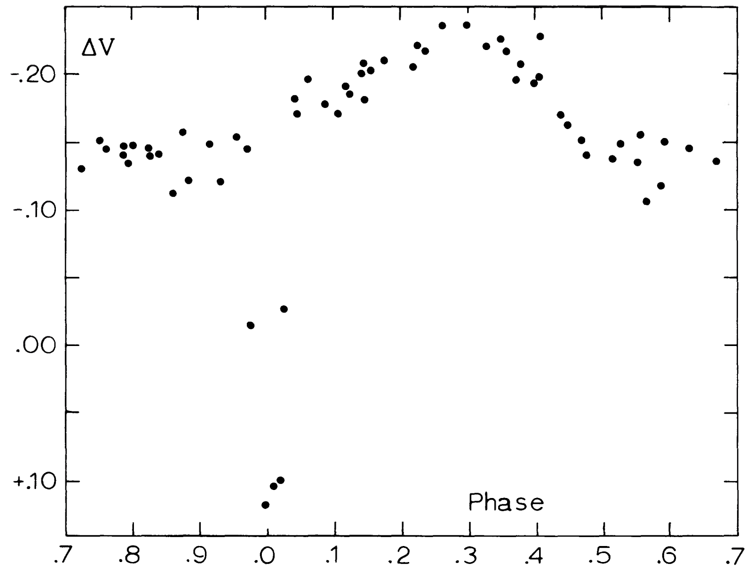

FIG. 1.—The 1982 differential V light curve of the X-ray source HD 155638. Each point is a nightly mean and Δ is in the sense variable minus HD 155541. Phase is computed with the ephemeris in eq. (1), where zero phase is primary eclipse and the orbital period is $27^{\mathrm{d}}.55$. Eclipse depth is 0.23 mag in V, 0.43 mag in B, and 0.76 mag in U; eclipse duration is $1^{\mathrm{d}}.8$, with totality lasting $1^{\mathrm{d}}.0$. The gap around $0^{\mathrm{P}}.5$ may conceal a shallow secondary eclipse. The RS CVn type of variation outside eclipse has an amplitude of 0.09 mag in all three bandpasses.

fit was achieved with a period of $27^{\mathrm{d}}.4 \pm 0^{\mathrm{d}}.2$. Since this period does not differ significantly from the previously derived orbital period, we computed phases with the ephemeris

$$\mathrm{JD} = 2{,}445{,}214.7 + 27^{\mathrm{d}}.55E \qquad (1)$$

and plotted the resulting light curve in Figure 1, where each point is a nightly mean of the ΔV magnitudes. The amplitude (maximum to minimum) of the nearly sinusoidal wave is 0.087 ± 0.006 mag in V, 0.093 ± 0.007 mag in B, and 0.090 ± 0.010 mag in U. The minimum of the wave, when the spotted region faces Earth, falls at $0^{\mathrm{P}}.74 \pm 0^{\mathrm{P}}.01$. The rms deviation from the least squares fit is ± 0.013 mag in V, ± 0.014 mag in B, and ± 0.017 mag in U.

It can be seen in Figure 1 that the depth of the eclipse is 0.23 mag in V. Similar plots (not shown) give depths of 0.43 mag in B and 0.76 mag in U. Because the depth is greater at shorter wavelengths, this must be primary eclipse.

Although a formal solution of this eclipse light curve would be premature at this time, we can say something about the geometry of the system. The eclipse must be total, because an annular eclipse with durations of $D = 0^{\mathrm{P}}.065$ and $d = 0^{\mathrm{P}}.035$ cannot possibly be deeper than about 0.1 mag. In the limiting case of $i = 90°$, these durations would suggest relative radii (i.e., radii relative to the orbital semi-major axis) of $r_h = 0.045$ for the hotter star and $r_c = 0.155$ for the cooler star. An assumed total mass of $4 \pm 1\ M_{\odot}$, typical of other long-period RS CVn binaries, then would lead to $R_h = 2.8 \pm 0.2\ R_{\odot}$ and $R_c = 9.5 \pm 0.8\ R_{\odot}$. The star visible at totality, the cooler of the two, contributes 77% of the light in V, 67% in B, and 50% in U; presumably that is the G8 IV star which is seen in the spectrum.

The photometry outside eclipse cannot itself rule out a period twice $27^{\mathrm{d}}.5$. A period of 55^{d}, however, would imply primary and secondary eclipses of equal depth and hence two stars of equal temperature, which is not permitted by the eclipse depth's wavelength dependence.

The depth of the (annular) secondary eclipse should be about 0.08 mag in V, or less if $i < 90°$. Such an eclipse is not obvious in Figure 1, but we note it may be concealed by the $1^{\mathrm{d}}.0$ gap straddling $0^{\mathrm{P}}.5$.

The magnitudes listed in the SAO catalog ($m_v = 8.5$ mag for HD 155638 and $m_v = 7.9$ mag for HD 155541) need to be improved, since our photometry shows the variable outside eclipse is almost 0.2 mag brighter than the comparison in V, not 0.6 mag fainter. Magnitudes in the SAO catalog often can be in error by a half-magnitude, so this discrepancy, by itself, probably is not reason to suspect long-term variability.

With the discovery of eclipses, it is definite that HD 155638 is a binary. Our rough analysis of the light curve indicates it is a typical long-period RS CVn binary, by the definition of Hall (1976). In fact, it is almost a twin of HR 7275 (Fried *et al.* 1982), as is shown in Table 1. Although not an unusual RS CVn binary as such, HD 155638 should prove valuable since it is the fourth brightest totally eclipsing RS CVn binary, only AR Lac ($V = 6.1$ mag), RZ Eri ($V = 7.7$ mag), and RS CVn ($V = 7.9$ mag) being brighter.

TABLE 1

Two Similar RS CVn Binaries

Name	Spectrum	P(orb.)	P(phtm.)	ΔV
HR 7275	? + K1 IV	$28^{d}.59$	$27^{d}.8 \pm 0^{d}.1$	0.22 mag
HD 155638 ...	? + G8 IV	$27^{d}.55$	$27^{d}.4 \pm 0^{d}.2$	0.09 mag

Additional photometry will be productive. A more precise determination of the orbital period and the period of the light variation outside eclipse will show to what extent the rotation differs from exact synchronism. And complete coverage of the eclipse phases, in both primary and secondary eclipse, should yield a highly determinate solution of the light curve because of the total-annular configuration. Because the inclination is near 90°, radial velocity measures should yield a velocity curve of respectable amplitude. Moreover, because the hotter star probably contributes an appreciable fraction of the total light (about 1/3 in B), the spectrum should be double-lined and should yield accurate masses for both stars.

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