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The X-Ray Source 1E1615.0+3114 Is an Eclipsing Binary

From an examination of the Einstein Observatory Extended Medium Sensitivity Survey, Fleming et al. (1989) compiled a list of seven stars expected to be W UMa systems. In a continuing investigation of these systems we have observed six of them. We have published results on 1E1654.0+3515 (Robb 1989), 1E1806.1+6944 (Robb and Scarfe 1989), 1E2119.7+1655 (Robb 1990), HD197010 (Robb et al 1990), and reports on others are in preparation. This is a report of our observations of 1E1615.0+3114 another of the stars from the list. In the Guide Star Catalog its identifier is GSC 02580 01971 and its position is Right Ascension +16:16:54 and Declination +31:07:21 (Equinox 2000) (Jenkner et al 1990). Its brightness of 12.6 in the V band and spectral class of G0 were given by Fleming et al. (1989). A finder chart adapted from Papadopoulos et al. (1980) is given for this star in figure 1.

1E1615.0+3114 was observed using the 0.5 meter reflector of the Climenhaga Observatory at the University of Victoria on nineteen nights between 26 June 1990 and 23 September 1990. Computer control of the telescope allows us to point it at each of the stars at the beginning of the night and then leave it to follow a program of observations until the star reaches too large an airmass. Due to the similarity of the variable, comparison and check stars in both position and color, mean extinction and transformation coefficients were used to correct the differential magnitudes to the Johnson V and Cousins R system (Landolt 1983). The observations of the variable star were bracketed by observations of the comparison star SAO 065206, whose constant brightness was monitored with more than one hundred observations of the check star, GSC 02580 02402, an 11th magnitude star at Right Ascension 16:16:34 and Declination 31:10:31 (Equinox 2000). The mean check star minus comparison star magnitude was 3.962 ± 0.023 in V and 4.035 ± 0.032 in R. The errors are standard deviations about the mean, and assure the constancy of the comparison and check stars at this level. Means of each of the fifteen nights of data were calculated and the standard deviation of the nightly means was 0.015 in both bands, assuring the night to night variations are smaller than this amount.

A time of minimum brightness was found using a program based on the method of Kwee and Van Woerden (1956) and checked using the tracing paper method. Observations in each color were treated individually, but since there was no significant difference between the times obtained, they were

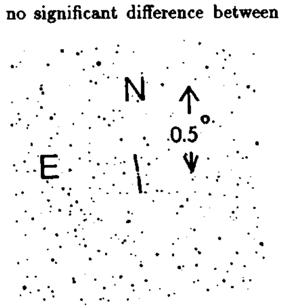
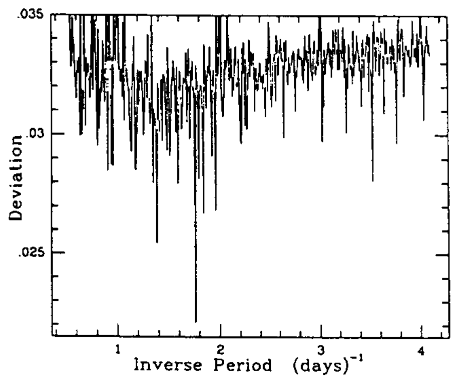


Figure 1. - Finder chart for X-Ray source, 1E1615.0+3114; centered on Right Ascension 16:16:54 and Declination +31:07:21 (2000.0).

Figure 2.



Average standard deviation of forty bins versus inverse period.

combined in a mean, weighted inversely by the error in each color's determination. The heliocentric time of minimum based on all points within 0.05 days of the minimum is 2448117.7698. Branches of eclipses were observed on four nights and times of minima could be estimated approximately. The period found from these times of minimum light was $0^{d}.5679 \pm 0.0001$ with residuals of about eight minutes.

Another estimate of the period was found using a method based on the Phase Dispersion Minimization method of Jurkevich(1971). Plotted in figure 2 is the average standard deviation of forty phase bins as a function of the inverse period. The deep minimum at 1.76 inverse days indicates the orbital period of the system and the shallow minima are fractions and aliases of the true period. The period given below is found from inspection of a similar plot with ninety bins and much smaller inverse period spacing. A precise estimate of the epoch is the minimum of the light curve based on all the data points folded on the period below. The ephemeris best fitting the light curve is found to be:

$$\text{Helio. J. D. of Primary Minimum} = 2448117.7714(4) + 0.56789(5)E.$$

This period is too long to be in agreement with the period-color relation of Eggen (1967) for contact binaries.

The radial velocities reported by Fleming et al (1989) plotted according to this ephemeris do not fit the sine curve expected of a close binary star. The largest and smallest velocities occur at almost the same phase and considering the orbital period imply a system mass of about ten solar masses. If they are ignored, the four remaining velocities can be fitted by a sine curve with an amplitude of 104 ± 34km/sec and a mean velocity of 21 ± 27km/sec. In this case maximum velocity precedes the predicted phase of mid primary eclipse by $0.03 \pm .07$ of the period, which is barely consistent with the hypothesis that it is the star, which produces the observed spectrum, that is eclipsed at primary minimum. The phase of the ignored points would then be that of the secondary minimum, where we would not be surprised to see the effects of rotation or gas streams. The amplitude is consistent with a mass of one solar mass for the observed star for a range of plausible mass ratios. However due to the small number of velocities and the large uncertainties in their determination, we do not feel it prudent to use them to refine our estimate of the orbital period.

Due to the relative faintness of the star, modest size of our telescope, and small integration times, the individual observations have rather large uncertainties. They have therefore been combined into the twenty-eight V and R band normal points plotted in figures 3 and 4. The error bars represent one standard deviation of the mean. This curve clearly shows the variation expected for an eclipsing

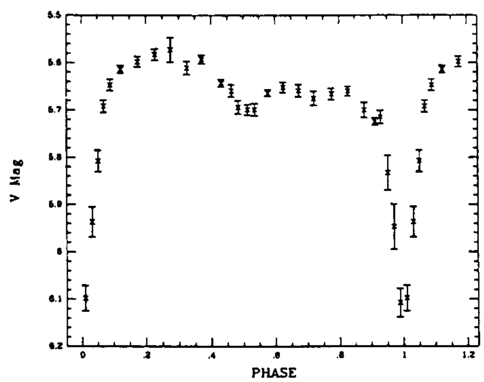


Figure 3. - V filter light curve normal points plotted with PHASE = (JULIAN DATE - 2448117.7714) / 0.56789.

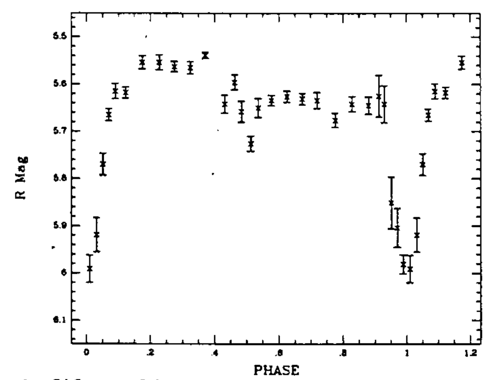


Figure 4. - R filter light curve normal points plotted with PHASE = (JULIAN DATE - 2448117.7714) / 0.56789.

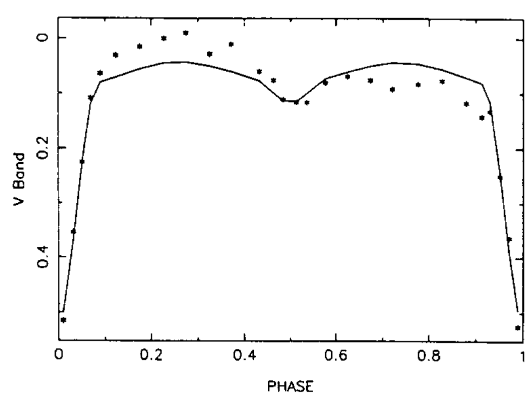


Figure 5. - V band normal points plotted with a model light curve assuming the stars temperatures are 6030 and 3900 degrees and the hot star's fractional radius is 0.25, and that of the cool star's is 0.32. Orbital parameters assumed are a mass ratio of 0.7 and an inclination of 70 degrees.

binary system. The difference in depth of the minima show that the two stars are of very different temperature and thus not in good thermal contact. The (V-R) color curve is 0.1 magnitudes redder at the primary minimum, consistent with the secondary of the system contributing little light at these wavelengths. The unusual curvature in the first maxima relative to the flatness of the second maximum was observed on a number of nights and may be a permanent feature of the light curve.

A computer modelling program written by G. Hill (1979) was used to find approximate elements of the system. From the spectral classification of G0 (Fleming et al. 1989), we assumed a temperature of 6030 degrees and convective envelope with full limb darkening. The atmospheres were assumed to be black bodies. Since we have no information as to the mass ratio of the system we have assumed a mass ratio of 0.7. As shown in figure 5 the best match was found for fractional radii of 0.25 for the hot star and 0.32 for the cool star, a temperature of the cool star of 3900 degrees and an inclination of 70 degrees. These numbers must be regarded as very preliminary values, since the the observed light curve is not of very high precision, the mass ratio is unknown and there is some asymmetry in the brightness of the maxima. However we can see that for a mass ratio less than about 0.7 the secondary star fills its Roche lobe. If the amplitude of the radial velocity curve of the primary star is assumed to be 122km/sec, consistent with the observed velocities, then the primary star has a mass, radius and luminosity consistent with its spectral classification. The secondary star would be very large and cool, but with roughly the bolometric luminosity for its mass.

The X-ray source 1E1615.0+3114 is an eclipsing binary system with a period of 0.568 days and an amplitude of 0.4 magnitudes. Spectroscopic observations of this system will be important to find accurate component masses and the mass ratio. Further photometric observations will be important to refine the orbital period, and to look for changes in the asymmetry of the maxima and to permit a more detailed solution than has been attempted here.

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