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HR 6392: a double star with very high luminosities

P. J. Andrews *Royal Greenwich Observatory, Herstmonceux Castle, Hailsham. Sussex BN27 1RP*

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Summary. HR 6392, an overluminous G5 supergiant, is shown to have a companion of type WN6. Photometric and spectroscopic observations indicate that the pair is a physical one. Luminosities are derived for both stars and the evolution of the pair is discussed.

1 Introduction

HR 6392 (HD 155603) is a known multiple system (Innes 1927). The brightest star, classified G5 Ia by Bidelman (1954), has been compared to the extremely bright supergiants HR 4337 (G0 Ia$^+$) and HR 5171 (G8 Ia$^+$) by Humphreys, Strecker & Ney (1971). They concluded that although HR 6392 has strong silicate re-radiation from a surrounding shell it was not quite as luminous as the other two stars. Humphreys *et al.* used the companion to HR 5171, which is of type B0 Ip, to obtain the luminosity of HR 5171. This suggested investigation of the companions to HR 6392.

2 Observations

There are three faint companions within 30 arcsec of HR 6392. Approximate position angles and distances from the bright star, A, were measured at the time of the photometry described below using the graticule normally employed for measured offsets of faint stars. The positions of companions B and C are very similar to those measured by Innes (1927), who did not measure star D, from 1896 to 1920. The measures are given in Table 1. The relative positions of stars A and B are compatible with common proper motion while there is a suggestion that star C does not share this motion.

2.1 PHOTOMETRY

Photoelectric *UBV* observations, using the technique described in Andrews & Thackeray (1973), have been made at the Cassegrain focus of the Radcliffe 1.88-m reflector of the three companions and of the G5 Ia star. Published observations of HR 6392 refer to the combined light of stars A and B. Allowance for the light of star B, assuming it to be of constant brightness, has been made using the mean of the Radcliffe measures to give the values quoted in Table 2, which also gives the Radcliffe measures of all three companions.

Table 1. Measures of the multiple system HR 6392.

	Position angle (degrees)	Distance (arcsec)	Reference
AB	333.7 ± 0.8	14.6 ± 0.3	1
	330 ± 5	14 ± 1	2
AC	209.2 ± 0.8	17.1 ± 0.2	1
	202 ± 5	20 ± 1	2
AD	80 ± 5	22 ± 1	2

References:

1. Means and standard deviations from four measures 1896–1920 (Innes 1927).
2. Measures by the author in 1973 with estimated errors.

Table 2. *UBV* observations of HR 6392 and its companions.

Star	JD 2440000+	*V*	*B–V*	*U–B*	Notes
HD 155603	748	6.56	2.41	2.39	
=HR 6392A	1799	6.49	2.27	2.45	
	1840	6.46	2.27	2.38	
	1922	6.41	2.27	2.40	
		6.59	2.33	2.22	1, 2
		6.52			1, 3
		(6.63)	2.34	2.22:	1, 4
		6.64	2.38		1, 5
HR 6392B	748	10.43	0.55	−0.30	
	1799	10.41	0.49	−0.30	
	1840	10.42	0.52	−0.33	
	1922	10.46	0.51	−0.32	
	Mean	10.43	0.52	−0.31	
HR 6392C	748	11.40	1.58	1.28	
HR 6392D	1922	13.96	0.85	0.34	

Notes:

1. Allowance for the light of B has been made to measures of (A + B).
2. Westerlund (1959).
3. Hogg (1958).
4. Cousins (1964), range 0.15 in *V*.
5. Humphreys *et al.* (1971).

The photometry of the companions indicates that stars C and D are likely to be foreground objects while star B appears to be an early-type star. The measures of the G5 Ia star show that it is variable with a range of at least 0.3 mag in *V*. This is associated with a variation of colour, *B–V*, in the sense that the star is redder when faint. This behaviour is very similar to that of similar stars, for example HD 268757 in the Large Magellanic Cloud (Andrews 1976, in preparation) and the behaviour of HR 5171 during 1970. HR 5171, however, shows peculiar long-term variations (Harvey 1972) which are not shared by the other two stars.

2.2 SPECTRUM

Three spectra of HR 6392B were taken on three different nights with the Image Tube Spectrograph on the Radcliffe reflector using a Carnegie two-stage phosphor image tube at

50 Å/mm with a baked IIaO emulsion. These showed not a 'normal' early-type spectrum but that of a Wolf–Rayet star. Comparison with spectra of other stars gives a best fit at type WN6-B, on the system of Hiltner & Schild (1966). A density tracing of one of the spectra is shown in Fig. 1 with the major contributors to each emission feature identified. No significant differences in radial velocity or in the appearance of the spectrum were apparent in the three spectra.

2.3 RADIAL VELOCITY

Wavelengths of the emission features described above were measured on a Hilger long-screw measuring machine relative to the Argon arc comparison spectrum. They are given in Table 3 together with laboratory wavelengths corresponding to the major contributors for each feature. Heliocentric velocities, derived for each feature, are also given together with their mean value. Struve (1944) gives individual velocities for features in HD151932, a WN7 star associated with the open cluster NGC 6231. The difference between the measured velocity of each feature and the mean for all features is given in Table 3 for both stars. The correlation between the velocity differences is good suggesting that the differences between the mean observed and the true radial velocities for the two stars will be very similar. If we assume that the true radial velocity of HD 151932 is the mean velocity of the cluster NGC 6231 we deduce a correction of −52 km/s to the observed mean velocity. Applying this correction to HR 6392B gives a derived radial velocity of −6 km/s. In view of the assumptions made and the size of the correction applied it must be regarded as fortuitous that this is exactly the radial velocity given by Buscombe & Kennedy (1969) for HR 6392A from only one spectrum. The radial velocity of star C of −30 km/s confirms that it is not physically related to stars A and B.

3 Discussion

3.1 REDDENING

From the observed colours of the two stars A and B we may attempt to determine their reddening. Intrinsic colours on the *UBV* system for WN stars have been given by Feinstein (1964) as $(B-V)_0 = -0.29$, $(U-B)_0 = -1.00$, giving $E_{(B-V)} = 0.81$ and $E_{(U-B)} = 0.69$ for

Table 3. Radial velocity measures of HR 6392B.

Feature	Lab	Obs	Heliocentric velocity	Velocity − mean	Velocity − mean 151932
Hβ	4861.33	63.35	+98	52	
He II	4685.74	87.54	+88	42	28
N III	4638.74	37.98	−77	−123	−72
N V	4603.2	06.53	+190	144	159
He II	4541.61	43.34	+87	41	81
N III	4513.06	13.74	+18	−28	0
N III	4379.10	81.18:	+115:	69:	−68
Hγ	4340.47	42.54	+113	67	7
He II	4199.86	01.02	+56	10	4
Hδ	4101.74	01.67	−32	−78	34
N IV	4057.80	56.85	−97	−143	−58
He I	4026.19	26.39	−12	−58	−35
Hε	3970.07	72.09	+126	80	

Mean +46 (4379 excl).

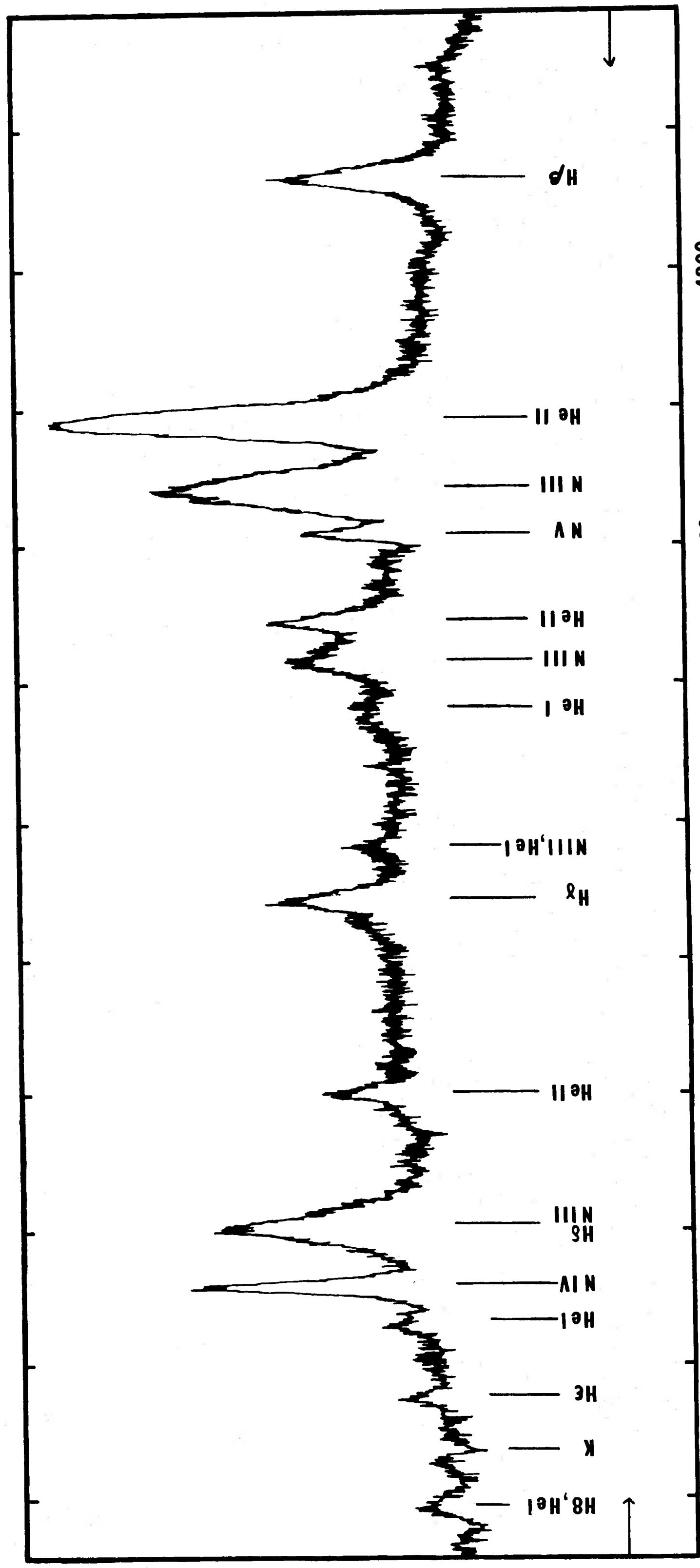

Figure 1. Density tracing of the spectrum of HR 6392B. The clear plate level is indicated by the two arrows. The major contributors to each emission feature are indicated.

star B. The ratio $E_{(U-B)}/E_{(B-V)} = 0.85$ is well within the range observed by Feinstein which he attributed to a range in the $(U-B)_0$ colours. We will adopt $E_{(B-V)} = 0.81$ for star B.

Intrinsic colours of a G5 supergiant given by Johnson (1966) together with Humphreys *et al.* photometry gives a mean value for the total visual absorption of 3.40 mag corresponding to a value $E_{(B-V)} = 1.13$. The difference in reddening for the two stars is large but in view of the large silicate emission from a shell around the G5 Ia star (Humphreys *et al.* 1971) we would expect some circumstellar reddening. If we accept that all of the difference in reddening between the two stars is due to this shell we find that the ratio of reddening to silicate emission is far higher for HR 6392A than for HR 5171A. Humphreys *et al.*, however, remark that the shell around HR 5171A is remarkably efficient at reradiating so much of the star's total emission while producing so little reddening.

3.2 LUMINOSITY AND DISTANCE

Humphreys *et al.* deduce from a comparison of their spectra that HR 6392A, although very luminous, is less so than HR 5171A. They derive a luminosity for HR 5171A assuming its B supergiant companion to have a luminosity $M_v = -5.8$, while noting that the lines in its spectrum are not as sharp as those in normal B-type supergiants. The value $M_v = -8.9$, which they quote for HR 5171A corresponds to the observed magnitude corrected for the interstellar component of the star's reddening but not for the circumstellar component. Allen (1976) has shown that the ratio of total to selective absorption is probably the same for circumstellar as it is for interstellar dust. Assuming this to be so for a thin silicate shell, we may derive the absolute magnitude of HR 5171A corrected for the total reddening to be $M_v = -9.4$. The luminosity of HR 6392A should be less than this.

The absolute magnitudes of Wolf–Rayet stars in the Galaxy and in the Large Magellanic Cloud (LMC) have been discussed by Rublev (1975). He gives, for WN6 stars, a luminosity $M_v = -5.2 \pm 0.7$ from Galactic stars. Although there are no known WN6 stars in the LMC a similar value is obtained from interpolation between values for the WN stars. There is an indication in the LMC that the WN stars in the field have lower luminosity than those in B associations. The spread in visual luminosity at type WN5 is estimated as ± 1.4 mag. The luminosity of HR 6392B may thus be estimated to be $M_v = -5.2 \pm 1.4$.

The evidence from the lack of relative motion, agreement of the radial velocities and the fact that they are two very unusual stars separated by only 14 arcsec indicates that the two stars are extremely unlikely to be a purely optical pair.

The galactic coordinates of HR 6392 ($l = 347°$, $b = 0°$) and radial velocity of -6 km/s preclude any meaningful estimate of distance from galactic rotation. The upper limit to the luminosity of HR 6392A of -9.4 mag gives an upper limit to the distance modulus of the pair of $(m-M)_0 < 12.5$. From the range of luminosity of the WN6 star we obtain $11.8 < (m-M)_0 < 14.6$. Combining these we obtain a distance modulus of 12.1 ± 0.3 mag, corresponding to luminosities for the two components of $M_v(\mathrm{G5}) = -9.0$, $M_v(\mathrm{WN}) = -4.1$. These mean that the G5 supergiant is almost as luminous as HR 5171 whereas the WN6 star is of low visual luminosity for its spectral type. The bolometric corrections for Wolf–Rayet stars are very large; a value of 5.7 is indicated by Rublev (1975) and when this is applied it is seen that the Wolf–Rayet star with $M_{bol} = -9.8$ is brighter than the G5 supergiant with $M_{bol} = -9.25$. The distance of HR 6392 corresponds to that of the Scutum–Norma arm (Thackeray 1956) and the projected separation of the pair is 0.2 pc.

3.3 EVOLUTIONARY STATE

Bisnovatyi-Kogan & Nadyozhin (1972) have computed evolutionary tracks for stars with masses of $30 M_\odot$ which show that after the transition to the red supergiant region an inverse density gradient arises. This results in a rapid out-flow of material which only diminishes when levels close to the hydrogen burning shell are reached. A very hot remnant, similar to a Wolf–Rayet star, is left.

HR 6392 may be explained if it is assumed that it was originally two stars of mass slightly larger than $30 M_{\odot}$. The less massive star, now the G5 supergiant, has evolved to the point where it is starting to lose mass, seen as the shell, whereas the more massive star has almost passed through the mass loss stage and is now the Wolf–Rayet remnant.

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