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11. THE SPECTRUM OF GAMMA VELORUM

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Abstract

From a measurement of the equivalent width of $H\gamma$ in the star γ_1 Velorum, it is found that M_v (γ_1 Vel) $= -3.1$. Assuming γ_1 and γ_2 Velorum are at the same distance, a distance modulus of 7.4 magnitudes for γ_2 Velorum is obtained. From a study of the absorption lines of the O9I component and the emission lines in the infra-red of the WC8 component the difference in magnitude between the two components is found to be about one magnitude. The O component is brighter and the derived magnitudes are M_v (WC8+O9I) $= -5.6$, M_v (O9I) $= -5.2$ and M_v (WC8) $= -4.2$.

1. Introduction

Spectrographic Observations of γ_2 Velorum during the years 1968-1972 have revealed that the sharp violet displaced HeI 3888Å line always occurs at selected phases near zero or 16 days. At phase 17 to 19 days, this line sometimes remarkably splits into two components. Combining all published data about this feature, a correction to the period of this binary and the rate of change of period has been estimated. The period is decreasing and corresponds to a mass loss of $1.3 \times 10^{-4} m_{SUN}$ per year.

A systematic work on the absolute magnitudes of Wolf-Rayet stars is due to Smith (1968). Her results are based on the observations of these stars found in the L.M.C. However, WC6 to WC9 stars were not found in the L.M.C. and their absolute magnitudes had to be based on studies of these stars found in our galaxy. Especially for the WC8 and WC9, the absolute magnitude derived is entirely based on the WC8 star γ_2 Velorum. Since WC9 is spectroscopically similar to WC8, the absolute magnitude for both these sub-classes are assumed to be the same. γ_2 Velorum is a Wolf-Rayet binary of class WC8+O9I, while γ_1, Velorum is its optical double assumed to be at the same distance since they share a common proper motion. In Section 2 we discuss the determination of the absolute magnitude of these two objects. The relative luminosities of the two components of γ_2 Velorum is discussed in Section 3. The interesting behaviour of the sharp violet displaced HeI 3888 is discussed in Section 4.

2. Distance Modulus

The distance modules of Gamma Velorum is a subject of controversy. Different investigators find that either it is 7.5 or 8.3 magnitudes. Baschek (1970) derived from a spectroscopic comparison of γ_1 Velorum with other B stars that M_v (γ_1 Vel)$=-3.2$ leading to a distance modulus of 7.5 magnitudes. Hanbury Brown et al (1970) combining their interferometric measures with the orbital elements of γ_2 Velorum published by Ganesh and Bappu (1967), derive the distance modulus as 7.7 magnitudes. Graham (1965) from Hβ and UBV photometry determined M_v (γ_1 Vel)$=-4.0$ and, therefore, a distance modulus of 8.3 magnitudes. Brandt et al (1971), assuming that γ_2 Veolrum is a member of a group of 9 B stars surrounding it, determined the distance modulus as 8.3 magnintudes. All other quoted values depend on assigning a spectral luminosity class for γ_1 Velorum. It is classified as B1IV by Hilther et al (1969) and by Baschek (1970) while Smith (1955) classified it as B2 IV.

We have obtained spectra of γ_1 Velorum and a number of standard stars at a dispersion of 45Å/mm with the 51cm reflector at Kodaikanal. All spectra were taken with IIa-0 plates and the projected slit width at the focal plane of the camera was 20μ. Microphotometer tracings at a magnification of 80 have been utilised for the determination of the equivalent width of the Hγ and from these absolute magnitudes were derived using Petrie's (1963) revised calibration curve. The results are summarised in Table 1. Columns 1, 2, 3 and 4 are self-explanatory. Columns 5 and 6 give the values of WHα measured at Kodaikanal and at Victoria. The Victoria values are taken from Petrie and Maunsell (1950), Petrie (1953) and Petrie and Moyls (1956). Sixteen of the stars in Table 1 have equivalent width measures in common. They are plotted in Figure 1. A least square fit for the relationship between the measures at the two observatories is given by:-

$$WH\gamma\ (\text{Kodaikanal}) = 0.9789\ WH\gamma\ (\text{Victoria}) - 0.0169$$

On an average, the equivalent width measured at Kodaikanal are smaller by about 0.10Å introducing an error of 0.1 magnitudes in the measured absolute magnitudes. The error being negligible, no corrections were made in our measured values to derive the absolute magnitude on the Victoria system.

The equivalent width of Hγ of γ_1 Velorum from two plates is 4.7Å. This leads to Mv (γ_1 Vel.)$=3.1$. Photometry of γ_1 and γ_2 Velorum by Johnson et al (1966) show that γ_2 Velorum is 2.44 magnitudes brighter than γ_1 Velorum and hence the absolute magnitude of γ_2 Velorum, Mv (WC8+O9I) $=-5.6$ and the distance modulus (V_o-M)$=7.4$ magnitudes. There is very little absorption in this direction. The intensity of CaII K-line in γ_2 Velorum is 31mÅ and that in ζ Puppis is 351mÅ. These values were derived from high dispersion plates of the two stars.

3. Relative Brightness of the Two Components

Until recently it was always assumed that the Wolf-Rayet component is brighter than its O companion. But we now know that the light of the O star dominates the spectrum of γ_2 Velorum. This has been determined by comparing the intensities of the absorption lines of the O component

TABLE 1

S. No.	Name	HD	Spectral type	WH (Å) Kodaikanal	WH (Å) Victoria	Mv Kodaikanal	Mv Victoria
1	η Tau	23630	B7 III	5.4	5.5	−2.6	−2.1
2	ζ Per	24398	B1 Ib	2.2	2.4	−5.7	−4.8
3	ϵ Per	24760	BO V	3.1	3.5	−4.4	−3.3
4	β Tau	35497	B7 III	7.3	7.4	−1.3	−1.5
5	δ Ori	36486	O9.5 II	4.7	5.3	−5.6	−5.2
						−4.7	−3.4
1	VV:Ori	36695	B1 V	5.0	4.8	−2.9	−2.6
7	ϵ Ori	37128	B0 Ia	1.5	1.4	−6.6	−6.2
8	β CMi	58715	B7 V	8.9	9.2	−0.5	−0.5
9	γ_1 Vel	68243	B2 IV	4.7	..	−3.1	..
10	α Leo	87901	B7 V	8.6	8.5	−0.7	−0.0
11	ν Gem	120307	B2 IV	6.0	..	−2.0	−2.9
12	κ Ven	132200	B2 V	4.8	..	−3.0	−3.7
13	δ Lup	136298	B2 IV	3.9	..	−3.8	−3.4
14	τ Lib	138485	B2 V	5.5	5.9	−2.3	−1.0
15	γ Lup	138690	B2 V	3.7	..	−4.1	−3.9
16	..	138764	B7 IV	7.8	8.8	−0.9	−0.9
17	ρ Sco	142669	B2 V	5.8	..	−2.1	−2.3
18	48 Lib	142983	B Pe	4.3	4.7	−3.4	−1.4
19	η Lup	143118	B2 V	4.7	..	−3.1	−2.8
20	δ Sco	143275	B0 V	3.1	..	−4.3	−4.4
21	β_1 Sco	144217	B0.5V	7.7	7.9	−4.3	−4.3
						−3.2	
22	β_2 Sco	144218	B2 V	6.8	5.6	−1.4	−1.9
23	ω^1 Sco	144470	B1 V	4.7	4.4	−3.0	−2.9
24	τ Sco	149438	B0 V	3.5	3.3	−4.0	−3.5

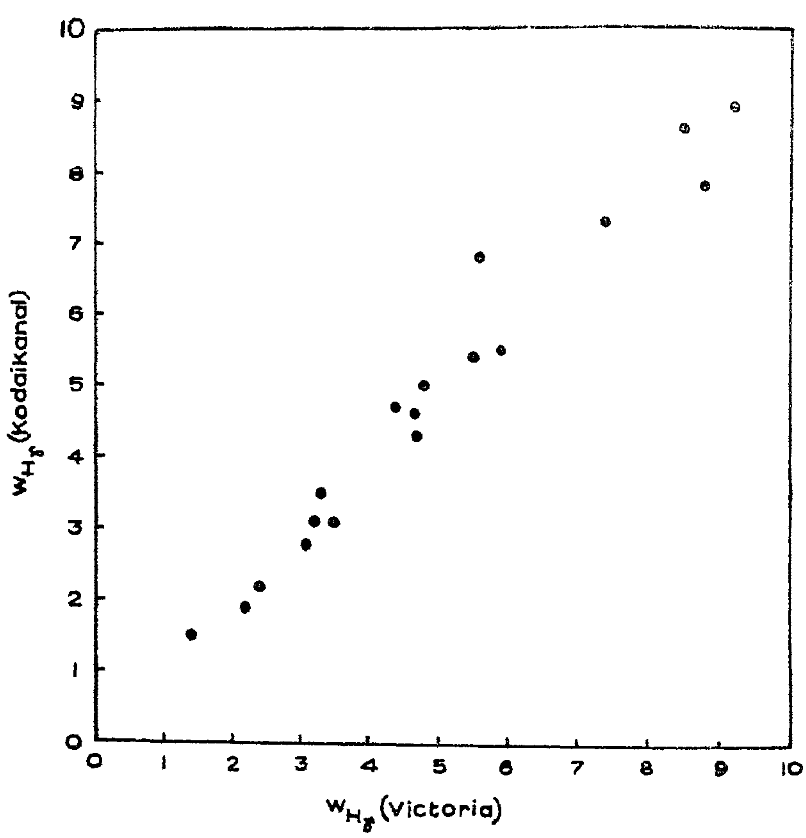

10
9
8
7
6
5
4
3
2
1
0
W_{H_γ} (Kodaikanal)
0
1
2
3
4
5
6
7
8
9
10
W_{H_γ} (Victoria)

FIGURE 1

with other single stars of similar spectral types. (Baschek and Scholz, 1971, Rajamohan 1972) and the emission lines of γ_2 Velorum with the WC8 star HD 192103 (Conti and Smith 1972), (Rajamohan 1972).

TABLE 2

Absorption Line (Å)	O9I	Standard	Apparent: 'q'	Correction factor	Weight:	Corrected 'q'
4101	0.95Å	1.31Å	0.38	2.20	½	0.17
3970	0.65Å	1.33Å	1.05	1.42	1	0.74
3835	0.73Å	1.34Å	1.05	1.35	1	0.78
3797	0.99Å	1.33Å	0.34	1.20	1	0.28

Weighted mean value of 'q' $=0.54$

Its reciprocal $=1.85$

M_v (WC8) $-$ M_v (O9I) $=0.70$ magnitudes.

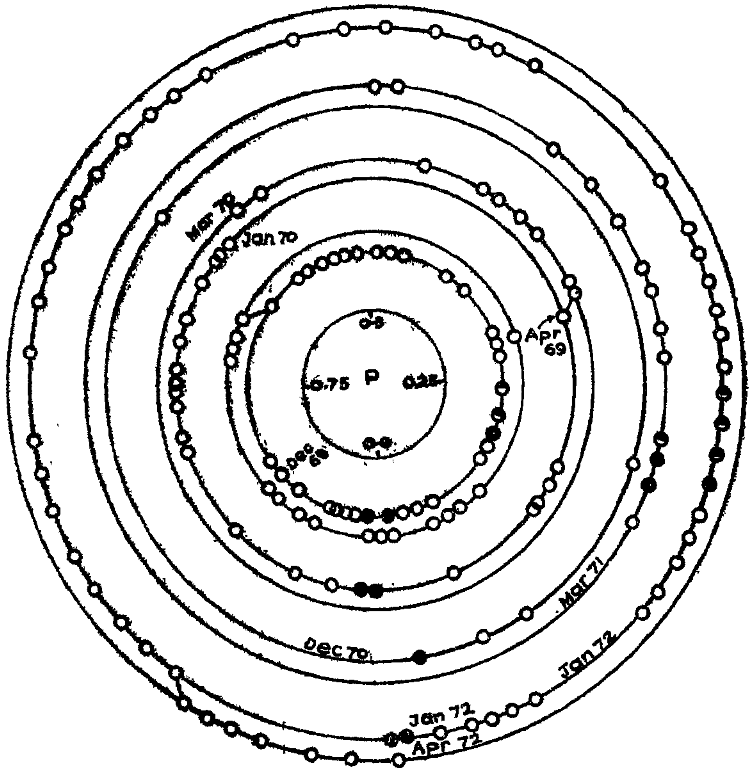
One high dispersion plate at 6Å/mm of γ_2 Velorum obtained by Dr. Bappu at Mount Stromlo was used to derive the absorption line intensities of the O9I companion. These are listed in column 2 of Table 2. Column 3 lists the avergae intensities of HD 36486 and HD 57061 used as standards. These values were taken from the high dispersion work of Buscombe (1969). Column 4 gives the derived apparent value of $q = Eo/E - 1$ where Eo is the intensity of the absorption line in the undistorted spectrum(Column 3) and E is the intensity of the combined spectrum (Column 2). Column 6 gives the weights assigned empirically. A correction factor due to the contribution of emission of the WC8 component at these wavelengths must be applied before evaluating the relative brightnees of the two components. These factors were determined from a high dipsersion intensity tracing of the WC8 star HD 192103. These factors are listed in Column 5. The corrected value of q is listed in Column 7. The weighted mean value of $q = 0.54$ and its reciprocal $=1.85$. Therefore, the O star is brighter than the WC8 component by 0.7 magnitude.

TABLE 3

Emission line (Å)	γ_2 Vel.	HD 192103	Weight	'q'
7065	7.87	64.15	½	7.15
7233	9.07	35.27	1	2.89
7726	11.73	39.52	1	2.37

Weighted mean value of 'q' $=3.53$

$\Delta m = M_v$ (WC8) $=$ M_v (O9I) $=1.37$ magnitudes



γ_2 Velorum 3889 absorption

FIGURE 2

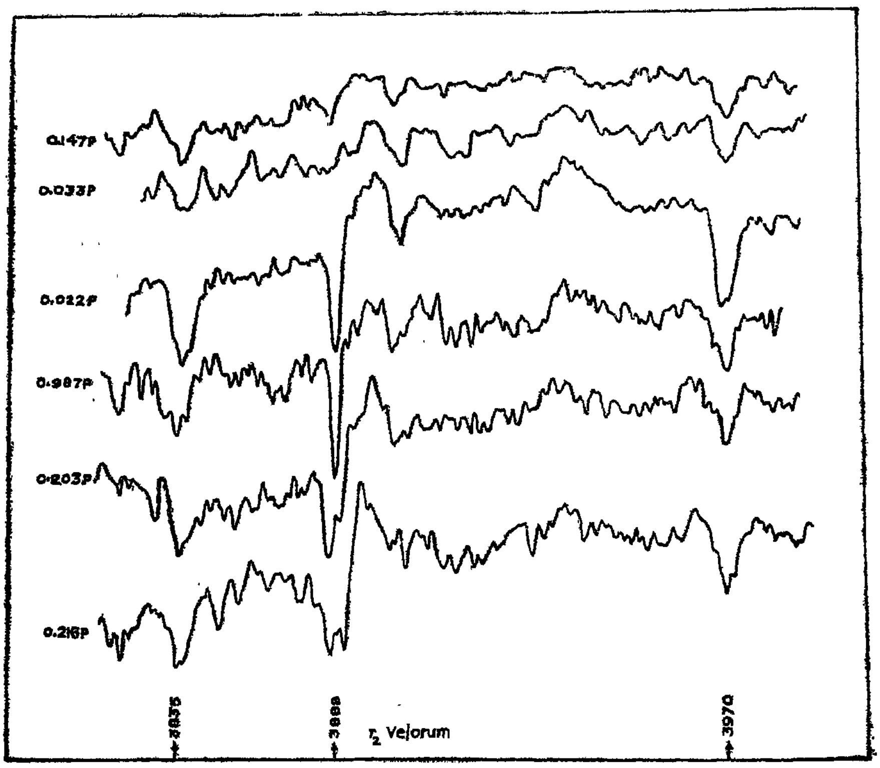


FIGURE 3

Low dispersion infrared spectra (Bappu, Ganesh and Scaria 1972) were used to derive the emission line intensities of λλ 7065, 7233 and 7726. These are are listed in Column 2 of Table 3. Column 3 lists the measured intensities of the same lines in the WC8 star HD 192103 used as comparison. Column 4 lists the weights and Column 5 the derived values of q. The weighted mean value of 'q' is 3.53 and, therefore, $m = M_v$ (WC8) $- M_v$ (O9I) $= 1.37$. Conti and Smith (1972) from similar methods find $\Delta m = 0.6$ and 1.4 magnitudes from absorption and emission lines respectively in the visual region of the spectrum. Baschek and Scholz (1971) find $\Delta m = 1.5$ from absorption lines alone. Thus we find that the O star dominates the spectrum of γ_2 Velorum and assuming it is brighter than the WC8 component by 1.0 magnitudes, we find:

(i) If $(V_o - M) = 8.3$ M_v (WC8) $= -5.0$ M_v (O9I) $= -6.0$

(ii) If $(V_o - M) = 7.5$ M_v (WC8) $= -4.2$ M_v (O9I) $= -5.2$

4. Behaviour of HeI 3888 and Mass Loss

Ganesh and Bappu (1967) determined the period of γ_2 Velorum as 78.5 days. In this paper they also concluded that the sharp violet displaced HeI 3888 is sporadic in nature and is observed chiefly between phases 2 days and 35 days. Montegeudo and Sahade (1970) find this feature to be variable in intensity and related to the phase of orbital motion. Our observations of this object cover a period of 4 years from 1968-1972. The spectrograms were obtained at a dispersion of 45Å/mm with the 51cm reflector at Kodaikanal on IIa-O plates. The radial velocity measurements are in progress and the revised orbital elements will be published shortly. Figure 2 shows the entire coverage of this object at Kodaikanal. Filled circles show whenever the violet displaced HeI 3888 was extremely sharp. Half filled circles are days on which this line was found remarkably split into two components. Microphotometer tracings of this sharp and double feature are shown in Figure 3.

An inspection of the spectrograms (and Figure 2) reveal the following interesting features:

(i) *The Sharp Feature*—is normally found within ± 1 day of zero phase. Whenever there was a good coverage of this star, this line was always found to be sharp near zero phase.

(ii) The splitting which occurs only during certain cycles is found always between 17 to 19 days phase, each time this is preceded by the line being sharp.

In Table 4 we list all dates on which this line was found to be sharp, single or split. An inspection of the table shows that we are justified in assuming the following:

(i) The sharp line appears at zero phase ± 2 days.
(ii) When it is precedes splitting, its phase is 16 ± 1 day.
(iii) When found split, the phase is 18 ± 1 day.

From the observed data we calculate the correction for phase on the above assumptions. This correction is plotted against cycle count in Figure 4. The figure indicates that the period is in error and there is a

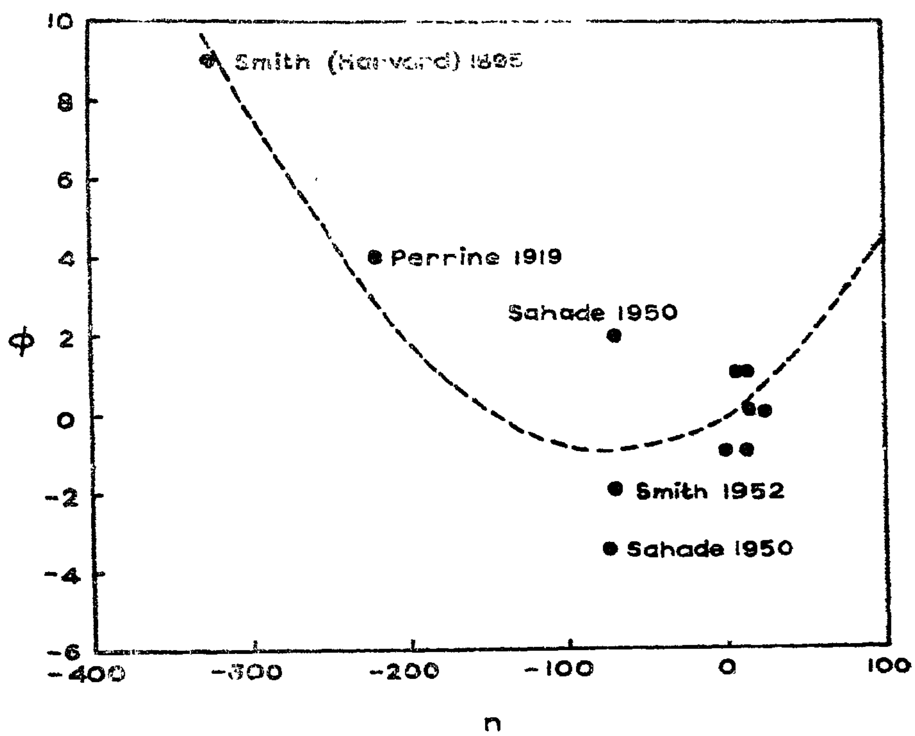

Smith (Harvard) 1895
Perrine 1919
Sahade 1950
Smith 1952
Sahade 1950
Φ
10
8
6
4
2
0
-2
-4
-6
-400
-300
-200
-100
0
100
n

FIGURE 4

TABLE 4

HeI 3888

Sharp and Single				Sharp but Split			
Year	Julian day	Phase	Correction to phase	Year	Julian day	Phase	Correction to phase
	2400000+				2400000+		
1896**	13685	69	+9	§1919	220219	14	+4
1950*	33317	76	+2	1968	40244	17	+1
1950*	33631	76	+2	..	..	..	..
1950*	33637	4	−4	1971	41029	17	+1
1952**	34436	18	−2	1972	41344	18	0
1965	39208	1	−1	..	..	..	..
1968	40227	0	0	..	..	..	..
1968	40242	15	+1	..	..	..	..
1970	40619	77	+1	..	..	..	..
1970	40935	1	−1	..	..	..	..
1971	41028	16	+0	..	..	..	..
1972	41326	0	0	..	..	..	..

*Sahade (Private Communication).

**Smith—Ph.D. Thesis—Harvard University.

§From an illustration of Perrine's plates given by Virpi to Dr. Bappu. The phase and year are known—JD is assumed.

small quadratic term involved. The broken line represents the least square fit for the curve of the form,

$$\phi = n\,\delta p + (n^2/2)\,\Delta p-$$

where ϕ =phase in days, δp= correction to the assumed period at the origin p_o, Δp=rate of change of period per cycle, n=number of cycles elapsed since the origin at p_o=2349128.25+78.5 days.

The solution gives $p = -0.026$ days
$p = -3.4 \times 10^{-4}$ days per cycle.

From equation 170 of Kruszewski (1966) we find that this corresponds to a mass loss of 1.3×10^{-4} m_{SUN} per year. Underhill (1969) from the expansion velocities involved determined the mass loss to be of the order 3×10^{-5} m_{SUN}/year. Our figure is high but not in contradiction to the evolution of such massive widely separated binaries proposed by Barbaro et al (1969).

5. Conclusions

We have determined the absolute magnitude and the magnitude difference between the two components of γ_2 Velorum. Our value of the distance modulus agrees with that of Baschek's value but is in disagreement with those of Brandt et al who use Hβ photoelectric methods to determine the absolute magnitude of γ_2 Velorum. This discrepancy can be caused by emission in the core of Hβ of the stars used in Hβ photoelectric photometry. Our work also confirms that it is the O star which dominates the spectrum of γ_2 Velorum, and is brighter than the WC8 component by one magnitude.

We have used the sharp observed feature of HeI 3888 to determine the rate of change of period and calculate that the mass loss is of the order of 1×10^{-4} m_{SUN}/year. This is in agreement with the proposed models of these objects.

I wish to express my indebtedness to Dr. Bappu for his valuable suggestions and guidance throughout the course of this work.

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Discussion

K. D. Abhyankar:

Do you have any explanation whatsoever about the sharpening of the line?

R. Rajamohan:

Any mass flow through the outer Lagrangian point can account for the sharpening around zero phase.

M. S. Vardya:

I find it very difficult to believe high value of mass loss. Even the value of $10^{-5} m_{SUN}$ year that Underhill has found is on the high side. One should first try to understand fully the various spectroscopic features before one can put faith in mass loss value of the order of $10^{-4} m_{SUN}$ year.