THE ASTROPHYSICAL JOURNAL, 284:631–636, 1984 September 15


# ON THE NATURE OF THE WOLF-RAYET COMPONENT IN THE CORE OF THE MASSIVE GALACTIC H II REGION NGC 3603

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*Received 1983 February 11; accepted 1984 March 28*

## ABSTRACT

The dense, luminous central core (HD 97950) of the massive star cluster NGC 3603 in the galactic giant H II region G291.6−0.5, exhibits a composite WN6+O5 spectrum. The WN6 emission lines yield a periodic radial velocity variation of 72 km s$^{-1}$ amplitude with $P = 3.7720$ days. This is interpreted in terms of binary motion for one of at least two, and probably three, W-R stars present in the spectroscopically unresolved core. The actual companion is not evident in the absorption spectrum, which does not show intrinsic radial velocity variations and which probably results from the superposition of many unresolved, mostly fainter O stars in the line of sight to the W-R stars in the dense core of NGC 3603.

The orbital motion shows variable amplitude and systemic velocity. Long-term radial velocity variations for the W-R component indicate that a second binary orbit may be present. The relative number of W-R stars to O stars in NGC 3603 is 0.1, which is normal for regions containing young, massive stars.

The alternate explanation for the periodic velocity variations as due to radial oscillations of a very massive star, like that claimed currently for R136 at the core of the giant LMC H II region 30 Dor, appears improbable.

*Subject headings:* nebulae: H II regions — nebulae: individual — stars: binaries — stars: individual — stars: Wolf-Rayet

## I. INTRODUCTION

The nature of the diffuse central objects HD 97950 and HD 38268 = R136 of the massive H II regions NGC 3603 in the Galaxy and 30 Dor in the LMC, respectively, is still ambiguous. On the one hand, Walborn (1973) demonstrated with short exposure photographs in good seeing that HD 97950 contains a Trapezium-like system of OB stars and a W-R component. Exactly which star(s) among the close visual components ABCD has a W-R spectrum, could not be determined. The dominant object, denoted AB, is made up of at least two luminous stars separated by only 0″.6 (van den Bos 1928). When measured through a diaphragm of diameter 7″, HD 38268 appears intrinsically about a magnitude brighter visually than HD 97950; but when measured within a linear diameter of 0.5 pc, corresponding to 2″ in R136, the core of NGC 3603 is actually intrinsically brighter (Moffat and Seggewiss 1983). However, HD 38268 is located about 8 times farther away and its star cluster core nature was presumed by Walborn to be similar to HD 97950. HD 38268 too contains a W-R component with similar WN6 spectral characteristics (cf. Walborn 1973; Moffat 1982*b*), although Ebbets and Conti (1982) assign a somewhat hotter WN type for HD 38268.

On the other hand, Feitzinger *et al.* (1980), Cassinelli, Mathis, and Savage (1981) and Meaburn *et al.* (1982) claim the central, blue component of HD 38268 = R136 to be an unusually supermassive single star of mass 2500 $M_{\odot}$, which produces an immense W-R–type wind. They also note its possible scaled-down resemblance to active galactic nuclei.

One approach to resolving the question whether these central objects contain many massive, but normal, stars or one dominating supermassive star is to monitor the W-R component in the core for periodic radial velocity variations. If found, this could imply the presence of a W-R binary. Analysis of the mass function might then allow one to decide whether this is due to normal stars or not.

W-R stars are frequently found in close binary systems with either OB or, in some cases, low-mass, compact companions. W-R stars occur about 10 times less frequently than OB stars; thus, any binary motion of one OB pair in a dense, unresolved cluster is likely to be masked by the contribution to the total spectrum of the remaining OB stars, while the W-R type emission lines are more likely to arise in fewer stars.

Alternately, periodic radial velocity variations could also be attributed to the pulsation of a supermassive star if of the correct period. For example, Ledoux, Noels, and Boury (1982) predict $P = 3^{\mathrm{d}}.048$ for the (unstable) fundamental mode and $P = 0^{\mathrm{d}}.5076$ for the (stable) first harmonic of R136a. One would also expect photometric variations with the same period.

In this paper we examine a sequence of optical spectra of HD 97950 in an attempt to probe the nature of this object.

## II. OBSERVATIONS

A total of 70 photographic Carnegie image tube spectrograms were obtained during the interval 1979 February to 1982 June with the 1 m Tale telescope at CTIO. The spectra cover the range 3700–4900 Å with inverse dispersion 45 Å mm$^{-1}$.

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With the plate rocker and sky suppressor, the spectra refer to a rectangle of the sky, centered on HD 97950, with angular dimensions 6″–9″ in $\alpha$ and 2″.5 in $\delta$. The spectra will therefore be dominated by the central pair (or more likely group) of bright stars AB with some contribution from the fainter objects C and D (cf. Walborn 1973).

Figure 1 illustrates the spectrum of HD 97950 based on the mean of the four plates E4971–4985. The emission component contains lines of H I and the ions He II, N III, N IV, and N V, whose strength ratios suggest a subclass of WN6 based on the classification system of Smith (1968), slightly revised by van der Hucht *et al.* (1981). Although the N IV/N III ratio leans toward WN7, the absence of He I P Cygni components suggests that WN6 is more appropriate. Judging from the strongly alternating Pickering series emission line decrement, it is clear that the W-R wind contains a significant amount of hydrogen. The Balmer and Pickering lines appear somewhat wider than average, reaching a total width of about 4800 km s$^{-1}$ at the line base.

The absorption component shows signs of a very early spectrum, about O5. This is based on the line ratio He I $\lambda$4471/He II $\lambda$4542 not only in Figure 1 but also on all our spectra in general. This agrees with the spectral classes among the hottest resolved stars surrounding HD 97950 which are of type O4–5 (Walborn 1982; Moffat 1983). Also, the interstellar component, especially H and K of Ca II and the diffuse feature at 4430 Å, is strong, in accordance with the object's high reddening based on photometry of individual stars around the core: $E(B-V) = 1.4$ after Sher (1965), Moffat (1974), van den Bergh (1978), and Melnick and Grosbøl (1982). A recent discussion of the interstellar spectrum of HD 97950 is given by Somerville and Blades (1980). In summary, our spectral classification for HD 97950, WN6 + O5, agrees with that of Walborn (1977) who gives O5–6(n) + WN6-A(B). Conti, Leep, and Perry (1983) give WN7 + absorption.

Radial velocities were obtained for the best lines; they are listed in Table 1. The IIa-O plates were measured using the PDS at the David Dunlap Observatory, while the others were measured using a Grant machine at V.S.N.'s home institute. Both sets of plates give concordant results on the average, despite differences in emulsion, comparison spectrum and measuring technique. The high degree of stability of the spectrograph has been well established (cf. Augensen 1979; Mendez and Niemela 1981).

## III. PERIODICITY AND CAUSES

A search for periodicity among the radial velocities of the emission component of HD 97950 was made using the narrowest, strongest, and least blended emission lines: He II $\lambda$4686 and N IV $\lambda$4058. For each of these lines and each of the nine groups of data in Table 1, periods were scanned from 0.4 to 50 days with increment $\Delta P(\mathrm{d}) = 0.0025P(\mathrm{d})^2$. A simple sine fit was

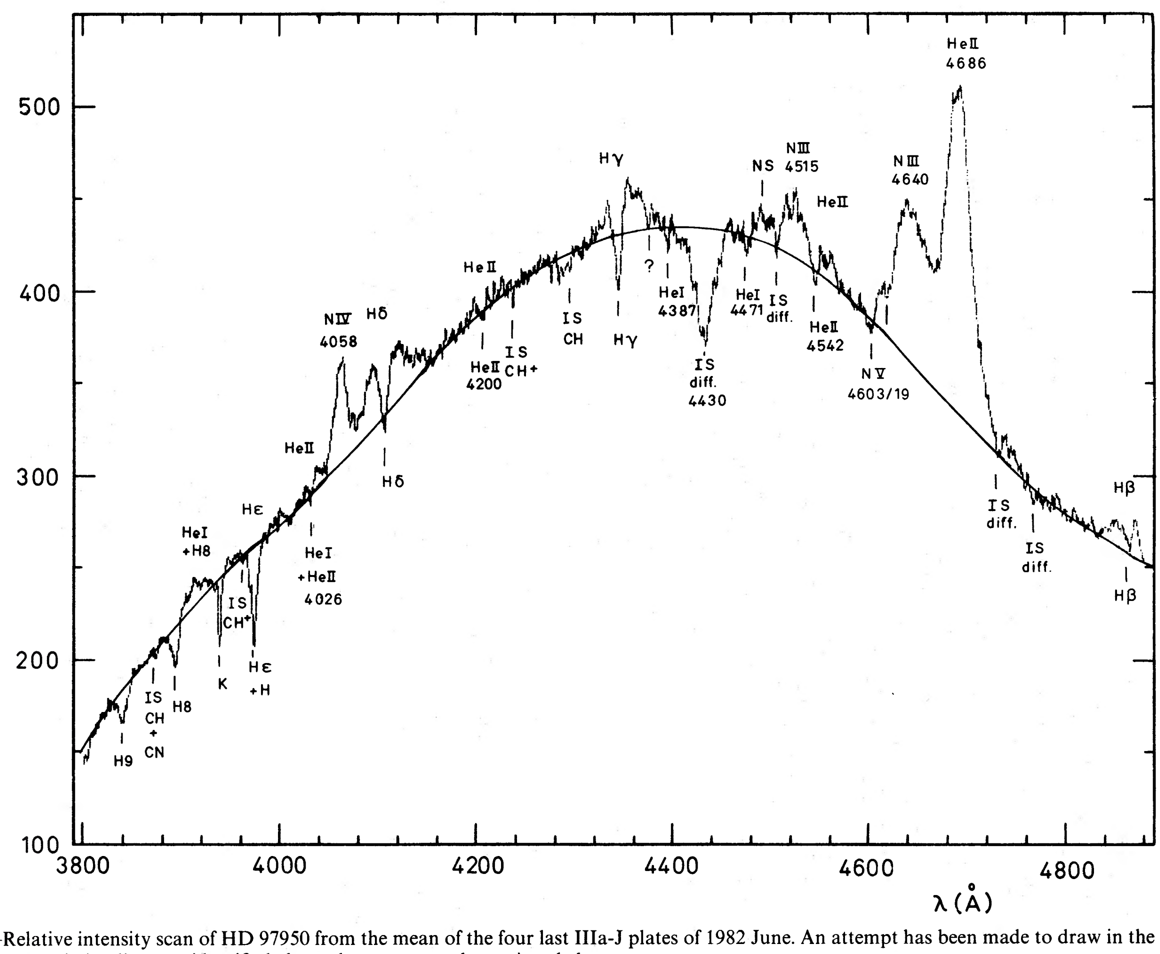


FIG. 1.—Relative intensity scan of HD 97950 from the mean of the four last IIIa-J plates of 1982 June. An attempt has been made to draw in the continuum. The most prominent emission lines are identified above the spectrum, absorptions below.

TABLE 1

JOURNAL OF OBSERVATIONS AND RADIAL VELOCITIES (km $s^{-1}$) FOR HD 97950

| E Plate | JD 2,440,000+ | He II e 4685.682 | N IV e 4057.759 | Mean abs. H8, $\delta$, $\gamma$ |
|---|---|---|---|---|
| | (1979 Feb) | | | |
| 2594......... | 3920.69 | −21 | −71 | −38 |
| | a (1980 Jan) | | | |
| 3298......... | 4256.87 | +14 | −66 | −88 |
| 3302......... | 57.86 | −150 | −26 | −59 |
| 3307......... | 58.88 | +74 | +55 | +40 |
| 3313......... | 59.88 | +83 | +30 | −19 |
| 3320......... | 60.87 | +14 | −93 | +28 |
| 3327......... | 61.88 | +51 | −80 | −42 |
| 3332......... | 62.89 | +101 | +115 | −10 |
| | b (1980 Jan–Feb) | | | |
| 3343......... | 4265.83 | +89 | −14 | −44 |
| 3346......... | 66.81 | +110 | +73 | +7 |
| 3351......... | 69.81 | +103 | +18 | −10 |
| 3355......... | 70.85 | +164 | +28 | −66 |
| 3359......... | 71.88 | +49 | −91 | −38 |
| 3362......... | 72.76 | +15 | −57 | −43 |
| 3366......... | 73.85 | +37 | −18 | −11 |
| 3369......... | 74.82 | +55 | −12 | −49 |
| 3372......... | 75.84 | −3 | −54 | −29 |
| 3376......... | 76.79 | −50 | −59 | −23 |
| 3382......... | 77.82 | +32 | +96 | −27 |
| | (1980 May) | | | |
| 3529......... | 4386.56 | +80 | −43 | −21 |
| | c (1980 Dec) | | | |
| 3784......... | 4584.86 | −48 | −19 | +40 |
| 3788......... | 85.86 | −59 | −43 | −20 |
| 3800......... | 87.87 | +3 | −77 | −41 |
| 3804......... | 88.87 | +22 | −146: | −17 |
| 3809......... | 89.87 | +25 | −115 | +15 |
| 3819......... | 95.87 | −1 | +34 | −36 |
| 3825......... | 96.86 | −19 | −21 | −25 |
| 3830......... | 97.86 | +72 | +35 | −95 |
| 3835......... | 98.86 | +7 | +62 | −82 |
| 3840......... | 99.86 | −20 | −40 | −40 |
| | d (1981 Feb) | | | |
| 3869......... | 4653.78 | −37 | −34 | +6 |
| 3873......... | 54.75 | +98 | −5 | +11 |
| 3878......... | 55.75 | +10 | −31 | −41 |
| 3882......... | 56.70 | +15 | −87 | +7 |
| 3886......... | 57.70 | −33 | −58 | −37 |
| 3891......... | 58.76 | +31 | −84 | −38 |
| 3895......... | 59.74 | +70: | −128 | −32 |
| 3899......... | 60.72 | −9 | −104 | −33 |
| 3903......... | 61.76 | −74 | +12 | −53 |
| 3906......... | 62.83 | +8 | −58 | −10 |
| | e (1981 May) | | | |
| 4023......... | 4739.62 | −52 | −77 | −35 |
| 4029......... | 40.63 | −151 | −167 | −32 |
| 4034......... | 41.62 | −6 | +79 | −74 |
| 4047......... | 44.57 | −93 | −78 | −19 |
| 4053......... | 45.61 | −7 | +31 | −9 |
| | f (1982 Jan) | | | |
| 4724......... | 4974.87 | +20 | −8 | −87 |
| 4729......... | 75.88 | +41 | −14 | −47 |
| 4734......... | 76.87 | +78 | −3 | −13 |
| 4739......... | 77.87 | −95 | −195 | −42 |
| 4745......... | 78.87 | +61 | +17 | −113 |
| 4751......... | 79.88 | +53 | +89 | −167 |
| 4757......... | 80.88 | +66 | +19 | −72 |
| 4762......... | 81.88 | −17 | −38 | −15 |
| 4768......... | 82.88 | +133 | +65 | −131 |
| | g (1982 Feb) | | | |
| 4807......... | 5012.80 | +61 | +12 | −28 |
| 4812......... | 13.75 | +56 | −36 | −36 |
| 4819......... | 14.83 | −51 | −26 | −58 |
| 4824......... | 15.80 | −51 | −140 | −4 |
| 4829......... | 16.81 | +49 | −50 | −44 |
| 4834......... | 17.78 | +61 | +117 | −84 |
| | h (1982 Apr) | | | |
| 4838......... | 5067.63 | −27 | −38 | −54 |
| 4845......... | 68.68 | −71 | −77 | −13 |
| 4850......... | 69.65 | +96 | −68 | −34 |
| 4857......... | 70.72 | +74 | +62 | −39 |
| 4862......... | 71.65 | +103 | +46 | −3 |
| | i (1982 Jun) | | | |
| 4869......... | 5121.57 | −14 | −145 | −32 |
| 4971......... | 23.54 | +88 | +16 | −45 |
| 4976......... | 24.56 | +6 | −4 | −6 |
| 4980......... | 25.53 | +4 | −61 | −61 |
| 4985......... | 26.54 | +140 | +92 | −37 |

NOTES.—a–i refer to group numbers; a, c, f are 0.7 mm wide spectra on IIa-O plates, the rest 1.0 mm on IIIa-J. Fe-Ar hollow-cathode comparison was used for a and c; He-Ar for the rest.

applied, which clearly and unambiguously led to the best period lying in the range $3^{d}_{.}3$–$4^{d}_{.}4$. This occurred consistently for each emission line in each independent data set except "c" (cf. Table 1 and Fig. 2*b*), where the 3–4 day period showed up but at a reduced level of significance. Combining all the observations, allowing for possible radial velocity (RV) zero-point differences among the nine groups, and with a correspondingly smaller period search increment, led to a refinement of the period to $P = 3^{d}_{.}7720$. However, due to windows in the whole data sample, it is not possible to eliminate entirely other inferior periods near to, but in discrete intervals on either side of, the $3^{d}_{.}7720$ period.

Assuming this periodicity to be a consequence of Keplerian motion, circular orbits were fitted through all the N IV and the He II emission line data separately using $P = 3^{d}_{.}7720$. This reduces the scatter $(O-C)$ in the velocities to values of $\sigma \sim 45$–$50$ km $s^{-1}$ for each line, somewhat larger than for lines like these in other WN6+OB binaries (Massey 1981; Niemela, Conti, and Massey 1980) but significantly smaller than that obtained from a straight average of the corresponding velocities. The data do not warrant a search for nonzero eccentricity in the orbit.

These two emission lines vary essentially in phase. Their semiamplitudes differ only at the 0.9 $\sigma$ level, in the sense that the 4686 amplitude is smaller. The overall mean velocity difference RV (He II 4686) minus RV (N IV 4058) from Table 1 is

$+46 \pm 8$ km s$^{-1}$. This is typical for WN6–7 stars (Moffat and Seggewiss 1979; Lamontagne *et al.* 1982). The corresponding dispersion of this RV difference is $\sigma = 65$ km s$^{-1}$; divided by $2^{1/2}$, this yields 46 km s$^{-1}$ like the $O-C$ scatter above for each line. We therefore consider that these two lines show essentially equivalent radial velocity variations. In Figures 2*a*, *b*, and *c* the velocity curves for different epochs are displayed. These Figures clearly show that the best orbit is determined from the three weeks of consecutive observations obtained during 1980 January–February (Fig. 2*a*).

The F-test probability that these variations are random in origin is $<0.1\%$. Table 2 lists the corresponding orbital elements from the 1980 January–February data, assuming that there is only one W-R component. The mass function which emerges is at least an order of magnitude smaller than that typically seen for W-R components in isolated binaries involving WN6 or WN7 stars with observed or suspected O-type companions (cf. Niemela 1983). These range from about $f(m) = 2\ M_\odot$ for HD 92740 (WN7+O) to 12 $M_\odot$ for HDE 311884 (WN6+O5V), with a mean of 6 $M_\odot$ for six systems. We conjecture that the low mass function for HD 97950 can be explained by dilution effects due to the presence of more than one W-R star with similar emission lines in the spectrograph slit. This is borne out by recent observations (Moffat, Seggewiss, and Shara 1984) of (*a*) CCD image structure in net 4686 emission at FWHM = 1″ seeing, and (*b*) IDS spectroscopy across HD 97950 with a resolution of 2″. These show that possibly both A and B each contain a W-R component, as well as component C. Component D is clearly non–W-R (cf. Moffat 1983). Thus, we are probably seeing at least two and more likely three W-R stars within the spectrograph slit. Taking three stars of similar line strength and shape, as suggested by the above mentioned IDS data, and supported by the similarity of the N IV and He II orbits, yields a corrected RV amplitude for the binary component $K' \sim 3K = 216 \pm 15$ km s$^{-1}$. This gives $f(m) = 4\ M_\odot$ which is close to the mean expected (see above). Since the binary frequency for W-R stars, as for most other stars, is of the order of 50%, it is quite likely to find only one W-R binary in a group of three such stars.

TABLE 2

CIRCULAR ORBIT SOLUTION FOR HD 97950 FROM THE MEAN EMISSION (He II and N IV) OF THE 1980 JANUARY–FEBRUARY DATA ONLY (cf. Fig. 2*a*)

| Parameter | Value |
|---|---|
| Period (adopted) .... | 3.7720 days |
| $\gamma$ .................... | $+12 \pm 4$ km s$^{-1}$ |
| $K$ .................... | $72 \pm 5$ km s$^{-1}$ |
| $E_0$ .................... | JD 2,444,258.39 $\pm$ 0.1 |
| $\sigma\,(O-C)$ ........... | 25 km s$^{-1}$ |
| $\sigma$ (const. RV) ....... | 57 km s$^{-1}$ |
| $f(m)$ ................ | $0.15 \pm 0.03\ M_\odot$ |

NOTE.—This assumes that only one W-R component is observed.

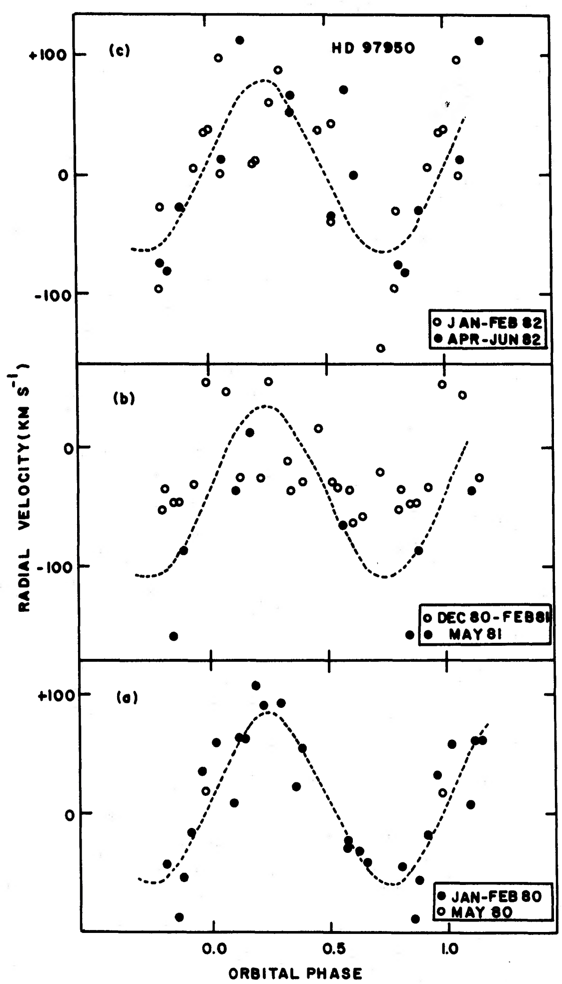


FIG. 2.—Radial velocity variations of the mean of N IV 4058 and He II 4686 for distinct epochs. The curve represents the orbit as defined in Table 2.

We further suspect that the binary component is contained in component A, whose brightness exceeds that of components B and C by about 1 mag (Jeffers and van den Bos 1963). The absolute magnitude of HD 97950 in a diaphragm of diameter $\varnothing = 5''$ is $M_v = -8.6$ (Moffat and Seggewiss 1983). If there are four stars of equal brightness (two in A, one in each of B and C) within this area, each would have $M_v = -7.1$ which is bright but not outside the range for normal WN6–7 stars. This type of star within the 30 Dor complex is even brighter (e.g., Conti, Leep, and Perry 1983). Since there may be many more unresolved fainter stars in this area, the actual brightness may be well below $M_v = -7$ (cf. Moffat 1983).

A test of our working hypothesis that there are two or more W-R stars, one of which is a binary, could be made by checking for periodic variations in the width of the emission lines. With the present data, the noise level prevents our doing this.

The multiple star hypothesis appears to us to be the most natural explanation for the behavior of HD 97950. Other possibilities, such as (*a*) an ordinary-mass O star orbiting a supermassive star with W-R–like emission, (*b*) a lower-mass B-type or compact companion (necessarily a black hole) to a normal WN6 star, or (*c*) an extremely low orbital inclination, are probably contrived.

The radial velocity curves of the mean emission in the spectrum of HD 97950 exhibit variations in shape and velocity zero-point from one epoch to another, as can be seen from Figures 2*b* and 2*c*, where the observations corresponding to 1981 (including 1980 December) and 1982 are depicted. Since the individual groups of observations were always obtained during less than 10 consecutive nights, we have superposed the better determined velocity curve from the 1980 data in Figures 2*b* and 2*c*, allowing for a shift in zero-velocity.

The radial velocities of 1980 December and 1981 February deviate from the velocity curve of Figure 2*a* both in shape and zero-point, while the observations from 1981 May seem to fit well the orbit of Figure 2*a*, but with more negative systemic velocity. The observations of 1982 January–February and April–June again agree well with the orbit from the 1980 data.

In Figure 3 we summarize the long-term RV variation of emission and absorption lines in HD 97950. While the Ca II K-line remains constant as expected if interstellar in origin, and the stellar absorption is probably constant also, our data point to a possibility that the emission-line RV is variable over an interval of about 3 years. This may mean that we are seeing yet another binary orbit involving one of the W-R stars, with long period and low amplitude. It is difficult to imagine this long-term variation being caused by problems with centering the nonsymmetric image of HD 97950 on the slit, since such potential problems should not be epoch-dependent. The instrumental stability is confirmed by the constancy of the interstellar Ca II K-line velocities.

While this second potential orbit could explain the change in zero points in Figure 2, it does not account for the change in shape of the velocity curves in this figure, especially during 1980 December–1981 February. Further observations are needed to trace the origin of this.

The mean velocity of the interstellar Ca II K-line is $-12 \pm 3$ km s$^{-1}$, and the mean stellar absorption line velocity in the spectrum of HD 97950 is $-36 \pm 4$ km s$^{-1}$ ($\sigma = 36$ km s$^{-1}$). These velocities are more negative than the heliocentric velocities measured for the nebula surrounding NGC 3603: $+20$ km s$^{-1}$ for H126$\alpha$ (McGee and Gardner 1968) and H109$\alpha$ (Wilson *et al.* 1970), $+22$ km s$^{-1}$ for OH absorption (Manchester, Robinson, and Goss 1970), and $+16$ km s$^{-1}$ for nebular H$\alpha$ (Feast 1970). The difference is unlikely to be due to instrumental effects (cf. Moffat 1982*a*).

The expected heliocentric RV due to galactic rotation is $+9$ km s$^{-1}$, assuming a distance of 7 kpc (Moffat 1983), $R_0 = 8.5$ kpc, and a flat rotation curve with $V_0 = 220$ km s$^{-1}$. Possibly we are seeing the expansion motion associated with the fast winds of the most luminous stars whose light dominates the spectrum. However, the Ca II K-line velocity is similar to the velocity of the strongest absorption component seen in H I along the line of sight (Goss *et al.* 1972).

While the short-term variations in the emission-line velocities in HD 97950 can be interpreted as being due to a close orbit, the absorption lines when plotted versus the $3^{d}.7720$ emission-line phase cannot. The absorption line RVs also do not yield a period of their own. Even if the companion of the orbiting W-R star were an O star with RV amplitude of the same order as the W-R component, like the WN6+O5 binary HDE 311884 (Niemela, Conti, and Massey 1980), it would probably be drowned out by unresolved, independent O stars falling in the slit of the spectrograph. Indeed, the rms scatter about the mean for the absorption lines in Table 1 is $\sigma = 36$ km s$^{-1}$, which is similar to the rms standard error of the mean of the three lines on each plate (32 km s$^{-1}$), i.e., there is no real variation. Note that the mean for one absorption line on one plate is $36(3)^{1/2} = 62$ km s$^{-1}$, which is significantly larger than the mean for either emission line measured, for which $\sigma = 46$ km s$^{-1}$ (see above). This is due to the increased noise level for the weaker absorption lines.

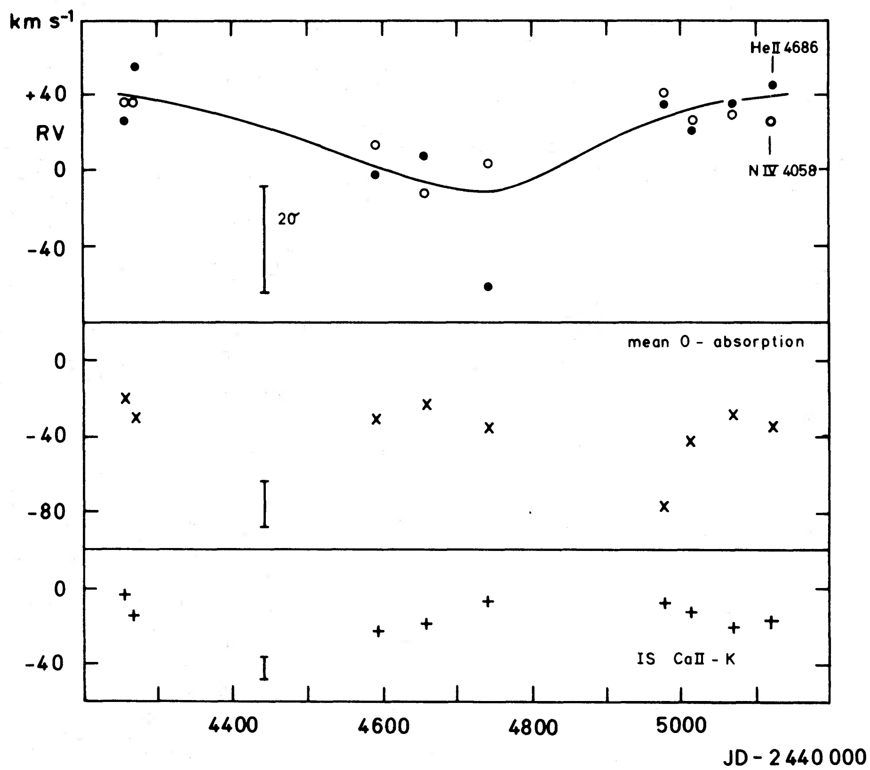


FIG. 3.—Long-term radial velocity variations for the emission and absorption components of HD 97950 based on group means from Table 1. A difference of $+46$ km s$^{-1}$ was added to the N IV 4058 radial velocities in order to reduce them to the same zero-point as He II $\lambda$4686. The line shows a possible trend for the stellar emission variations.

## IV. DISCUSSION AND CONCLUSIONS

Although the spectrum of HD 97950 is composite, WN6+O5, only the W-R emission yields detectable periodic RV variations. The absorption-line spectrum is therefore probably due mainly to a combination of one or more O stars quite distinct from the W-R system, that happen to be located in the spectrograph slit. Other bright resolved stars in NGC 3603 are mostly in the range O4–5 (Walborn 1982; Moffat 1983). The binary nature of at least one of the W-R components and the constant RV of the absorption component support Walborn's (1973) contention that the central core of NGC 3603 is dominated by the light from normal stars of high mass.

The fact that NGC 3603 contains about three luminous W-R stars (Moffat, Seggewiss, and Shara 1984) is not surprising. The total number of hot O stars necessary to explain the radio emission of the H II region and the total stellar light in NGC 3603 is about 20 (Moffat 1983). With a normal IMF this leads to a total of about 30 O stars of all spectral types. Thus, the W-R/O number ratio is 1/10, quite comparable with other regions of our Galaxy and even 30 Dor (Melnick 1983).

That these three W-R stars are all of similar subclass WN6–7 is also like the situation in other H II regions such as the $\eta$ Car Nebula (three WN7 stars) and 30 Dor (about 15 W-R stars, most of which are WN6–7 stars).

Could the $3^d.7720$ periodic RV variation be accounted for by radial pulsation of an unstable supermassive star? For this to be the case, one would expect a period of about $0^d.5$ in the stable mode of the first harmonic (Ledoux, Noels, and Boury 1982). Such a period does not seem to occur in our data, although some aliases of 3.7720 near this value cannot be entirely excluded. In any case, more restrictive arguments against such a star have already been noted; namely, (*a*) that the structure and the spectrum of the core of NGC 3603 can be accounted for by stars of normal luminosity and therefore also normal mass ($< 100\ M_\odot$), and (*b*) that HD 97950 clearly does not consist of just one star.

Another possibility to explain the RV variations might be related to atmospheric instabilities analogous to those seen in hot supergiants (cf. Burki, Maeder, and Rufener 1978). However, such variations are usually not strictly periodic as appears to be the case here. Additional monitoring of the emission lines in HD 97950 would be desirable to check this on a longer time scale. Indeed, recent IDS spectrophotometry with a $2'' \times 2''$ slit in 1982 December confirms the in-phase RV variation of the He II $\lambda$4686 and the N IV $\lambda$4058 emissions (Moffat, Seggewiss, and Shara 1984).

We are grateful to the staff of CTIO for their kind assistance and generous allottment of observing time, without which it would have been impossible to carry out long-term studies like the present one. A. F. J. M. acknowledges financial assistance from the National Research Council of Canada.

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