A Belgian astronomer I kneux
Pointed out what some O stars deux
Their spectral lines flicker
He said with a snicker
Which serves all wind theories to screux.

SESSION 1

OPTICAL SPECTROSCOPY

Chairman: E. VAN DEN HEUVEL
Introductory Speaker: J.B. HUTCHINGS

. J.M. VREUX and Y. ANDRILLAT: H alpha variations in two mass-losing stars.

2. W.G. WELLER and S. JEFFERS: Short term variability of line strengths in some Of and Wolf-Rayet stars.

3. G. HAMMERSCHLAG-HENSBERGE: Mass loss in the spectrum of the O6.5f binary HD 153919.

4. B. WOLF and C. STERKEN: Mass loss of B1 Ia-O supergiants and evolutionary consequences

5. T. NUGIS, I. KOLKA and L. LUUD: On the formation of continuous spectrum and emission line profiles of P Cygni.

6. P. PISMIS: Evidence for non-isotropic mass loss from central stars of some emission nebulae.

7. C.D. ANDRIESSE and R. VIOTTI : Mass loss from Eta Carinae.

8. J. BREYSACHER and M. AZZOPARDI: Wolf-Rayet stars in the Magellanic Clouds.

9. B.T. LYNDS: Stellar outflow: Relative motions of nebulae and Of stars.

THE O STARS: OPTICAL REVIEW*

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1. INTRODUCTION

I would like to start with a quick overview of the O stars - their significance and role in the galaxy and in astrophysics - just to remind ourselves of why we are here and what we hope to talk about. In Table 1 I show a rough outline of the contribution of O stars to what happens in the galaxy as a whole. Because of their extreme luminosity, they contribute a large fraction of the radiation of the galaxy, while forming a very tiny group of objects and mass. Because of their short lifetime they are a population that has gone through 10^4 generations in the life of the galaxy. Their high mass loss rates may account for a large fraction of the new matter injected into the interstellar medium, and they probably power some significant fraction of the hard X-ray sources in the galaxy, by virtue of the fact that a companion can become a neutron star a) without disrupting the binary and b) while the companion is still a mass losing O star.

TABLE 1. O Stars in the Galaxy

	Each	Total	Fraction of galaxy
stellar mass	30 $M_{\odot}$	10^7 $M_{\odot}$	10^{-5}
number	-	$3X10^5$	10^{-6}
luminosity	$\sim 10^{39}$ erg s	10^{44}erg s	10^{-1}
mass loss	3X10 $M_{\odot}$/y	1 $M_{\odot}$/y	0.3?
lifetime	10^6y	-	10^{-4}
hard X-rays	10^{37}erg s	$60X10^{37}$erg s	> 0.1

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P. S. Conti and C. W. H. de Loore (eds.), Mass Loss and Evolution of O-Type Stars, 3–22.

Clearly, O stars are important in the galaxy (or any galaxy) and can be seen a long way off. We know roughly what they are doing, and we need to discuss how they got there, how they are doing it, and where they go to.

II. MASS LOSS SIGNATURES

It is generally accepted that one looks at the UV resonance lines to see if a star is losing mass. There, one looks for recessional velocities in excess of escape, and in most cases there they are. However, it has been known for just as long that there are mass-loss indicators in the visual and it is clearly relevant that we consider them here.

First, it is not necessary for matter to be moving in excess of escape velocity to escape, provided it is being pushed. Further, if we see matter moving away from a star and none returning, we may conclude that it escapes. Finally, the escape velocity falls with distance from the photosphere (as R^{-2}) so that at $1R_*$ it is only of the order of 125 km s^{-1}. These points are elementary but often overlooked.

There are several mass-loss indicators in the visual and blue spectrum which are easily seen, and others which require good high dispersion spectra. They are listed below and are mostly self-evident. In general, the more extreme the phenomena the greater the mass-loss, and by calibration with detailed models, it seems that we can detect stellar winds down to $\sim 10^{-7}$ $M_\odot$/year by a careful study of the ground based spectrum.

1. Hα emission present.
2. Hβ emission present, He I λ 5875 emission present.
3. Balmer velocity progression.
4. Velocity excitation-potential relation present.
5. He I λ 4471, Mg II λ 4481, He I λ 4026, C II λ 4267 velocities separate out.
6. He I λ 3888 separates from H8.
7. Hγ emission, other He I emission, further emission lines.

Some words of caution. A Balmer progression may be caused by P Cygni emission which displaces the absorption minimum. A little care and sense will suffice to check this, but in general I would be suspicious of a Balmer progression which shows only in Hα and Hβ, when there is any sign of emission at Hα. The velocity-excitation relation can be confused by 1) not using the Balmer asymptotic value, but some sort of average which includes the highly shifted Hα, β etc. lines and 2) clear deviations from LTE populations, such as occur in N III, Si IV in extreme mass-loss O stars. In these cases there is obviously a contribution to the visible line spectrum from the regions of high velocity where the UV lines are formed, and we are not measuring the acceleration of the inner parts of the atmosphere.

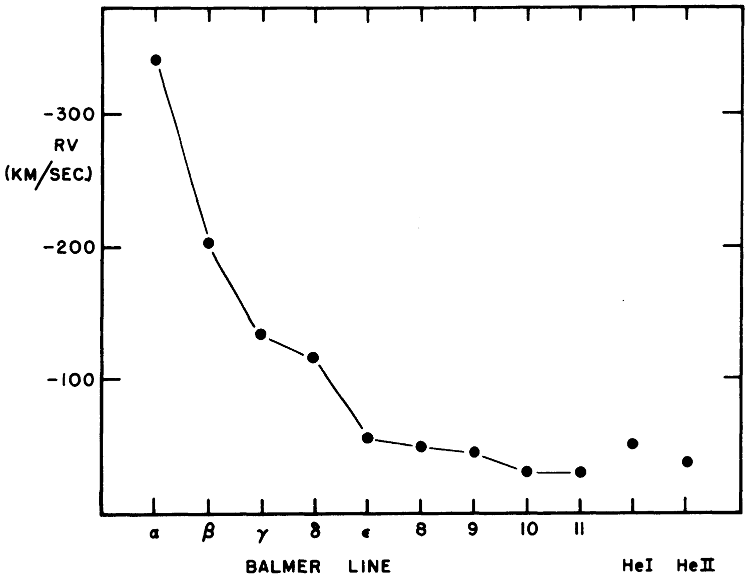

Fig. 1a). Balmer velocity progression in Of star HD 148937, and mean He I, He II velocities.

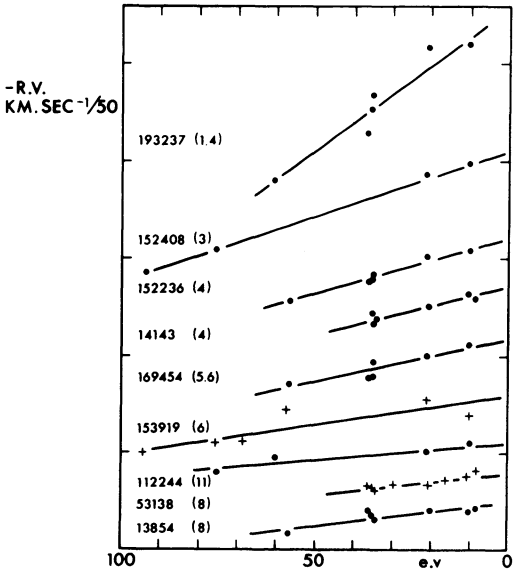

Fig. 1b). Velocity excitation linear slopes for absorption lines in mass-loss stars. HD numbers given and increase slopes of lines in parentheses. Steeper slopes indicate greater mass loss.

Figure 1 shows examples of a Balmer progression and velocity-excitation slopes in mass-loss stars. In the discussions that follow we shall use and refer to these mass-loss criteria as empirical indicators of stellar winds. They should also be of use in a detailed theory of stellar mass-loss, and naturally must complement the UV spectral information. One of the curiosities we must explain is that in the stars with the most obvious visual mass-loss characteristics (e.g. P. Cygni), the UV lines show no P Cyg profiles, and very low velocity shifts.

MASS LOSS RATES

There are two large scale surveys at present - that of Barlow and Cohen (1977) based on I-R data and my own (Hutchings 1976), based on optical spectroscopic data (fig. 2). These deal with 40 and 65 stars respectively of which 23 and 59 respectively are OB stars (i.e. earlier than B5). There are probably systematic errors in each: in the B + C sample, a velocity law derived for P Cyg is applied to all. In view of the unique nature of the P Cyg wind, and new data concerning its distance and mass loss (T.P. Snow; preprint) this is not a good idea. Also, B + C use estimated (i.e. unobserved) values of V for a number of stars, to derive mass loss rates. My own work is a quantitative compilation of mass-loss indications in the spectra, but the mass loss rates are based on a poorly defined grid of a few detailed models. It is clear that this grid needs revision. The result is that I think my rates tend to be high and B + C's tend to be low. The diagram 3 shows the comparison of 18 common stars. The general agreement is encouraging and it is clear at least that we are dealing with rates in the 10^{-5} to 10^{-6} $M_\odot$/year for the luminous OB stars, with the higher rates occurring in the O stars. In the case of ζ Pup there are now several independent estimates of the mass loss rate which agree to within a factor two, at a mean of 5×10^{-6} $M_\odot$/year.

IV. EXTREME OF STARS

There are a few Of stars with very pronounced Of characteristics, P Cygni Balmer profiles and emission in most of the N III lines. They also have broad emission bands underlying the Hδ and λ 4630-4690 region, reminiscent of weak W-R bands. There are five such stars in the galaxy which are well studied (see table 2; Hutchings 1976 and references therein) and close investigation shows them all to have very strong stellar winds. They also appear to have very high luminosity and lie in a very small region of the H-R diagram.

It seems reasonable to suppose that they are stars of initially very high mass (>60 $M_\odot$) which have lost much of their initial mass. The strong N III spectrum could be processed material which has reached the surface (so they are He burning objects?), or a result of peculiar level populations and ionisation in the extreme stellar wind conditions.

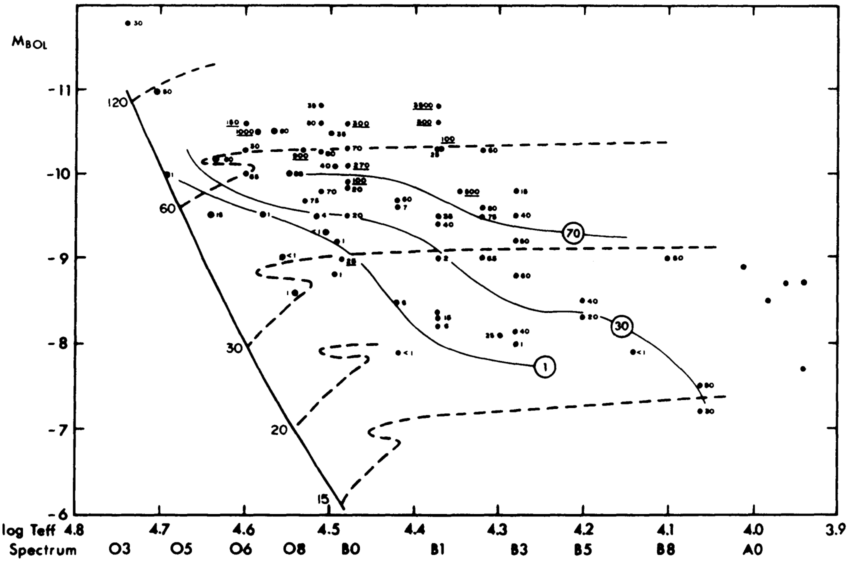

Fig. 2. Theoretical HR diagrams with conservative mass loss evolution tracks. Mass loss rates of Hutchings in 10^{-7} $M_\odot$/yr units and suggested contours in same units.

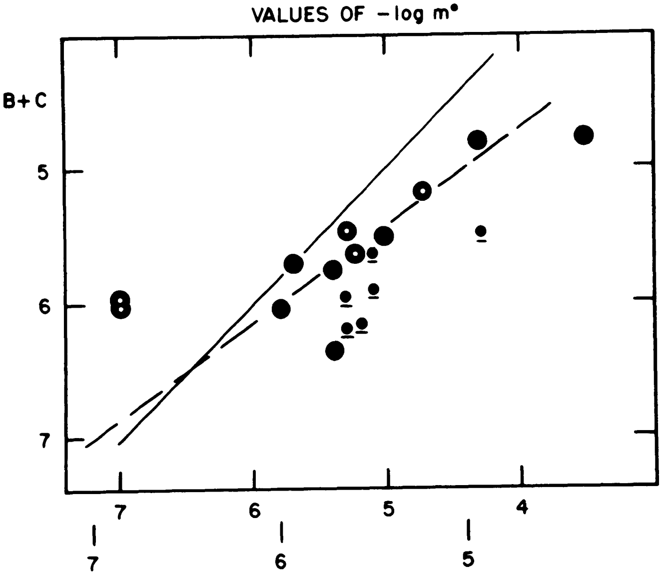

Fig. 3. Comparison of mass loss rates of Hutchings (JBH) and Barlow and Cohen (B+C). Open symbols O stars; closed symbols B stars. Small symbols are stars for which B+C guessed $V_{terminal}$. Lower JBH scale is revised after recalibration of detailed models and rejection of P Cyg.

Table 2. 5 Extreme Of Stars and 2 which are not

HD	Sp	M_V	$-\dot{m}$ $M_\odot/yr$	RV_{phot} km s^{-1}	Hβ km s^{-1}	M_{BOL}	λ 4686 emis. peak
108	07f	-7.0	$2X10^{-5}$	-70	-300	-10.5	30%
148937	07f	-7.2	$7X10^{-6}$	-45	-200	-10.5	15%
151804	09f	-7.2	$6X10^{-6}$	-40	-145	-10.3	10%
152408	08f	-7.1	$4X10^{-5}$	-50	-275	-10.3	80%
153919	06f	-6.9	$7X10^{-6}$	-65	-150	-10.6	40%
66811	04f	-6.4	$5X10^{-6}$	-10	- 40	-10.3	30%
210839	06f	-6.5	$3X10^{-6}$	-70	- 90	-10.2	15%

These stars are of special interest as they show a wealth of detail which we can hope to interpret in the theory of stellar mass loss. The Balmer progressions are very clear (see Fig. 1) and the excitation-velocity relation has a large slope for these stars. Almost every line in the spectrum has a characteristic profile; asymmetry velocity, width and possibly P Cygni emission. I have derived detailed ad-hoc models for the winds of two stars, which, fortuitously or not, indicated high mass loss rates and slow acceleration envelopes, a number of years before they were found reasonable by the real pundits in the field. If for no other purpose than to initiate discussions, I show the main features of these models in Figure 4. They are based

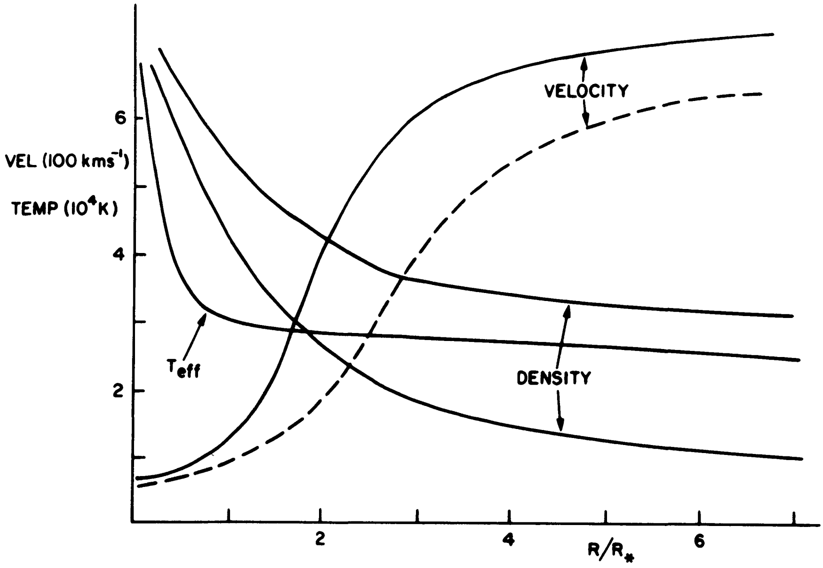

Fig. 4. Velocity temperature and density fields of HD 152408, from Hutchings (1968).

mainly on fitting observed profiles by calculating ones in an accelerating wind using a simple numerical solution of the transfer equation. These models show too that ionisation (and hence temperature?) increase in the envelope, after an initial drop, as also deduced much more recently by Lamers and Snow (1978).

Two of the stars are binaries, with low mass (and hence evolved) companions, so that we can obtain further information on the fundamental parameters of the O stars. The X-ray star system 4U1700-37/HD 153919 is particularly valuable in this regard, since it eclipses, and the optical to X-ray luminosity is high enough (∿5000:1) that there is little alteration of the O star behaviour by the X-radiation. In this system we find the wind stratification indicated by a relation between K and V_0 for different ions (see Table 3). We also see a phase dependent variation in the wind, as aspect and varying tidal distortion in a slightly non-circular orbit vary the surface gravity over the observed disk of the star. We find evidence that the wind is quite sensitive to surface gravity. Similar evidence is found in HD 108, and some less extreme Of stars (e.g. 29 CMa).

TABLE 3. 153919 Line Velocities in km s^{-1}

Absorption	V_0	K	exc*	Emission	V_0	K	I.P.
N IV	- 60	25:	94	He II 4686	18	13	54
He II	- 64	19	76	Si IV 4116	-40	18:	45
O III	- 65	22:	68	C III 5696	-74	16	48
Si IV	- 83	--	57	N III 4640	-77:	15	47
He I	- 87	12	21				
Balmer	- 79	16	10				
H	-110	12:	10				
C IV	-117	22	85				
Mg II	-136	--	16				
Hβ	-150	<10	10				

*I.P. of lower ions + e.p. of line lower level.

V. PHOTOMETRY AND POLARIMETRY

Since this aspect has not been specifically included in the program I will spend a few moments on it here. Firstly, we know little about the stability of single O stars, beyond a few scattered observations indicating variability at the $0^{m}.1$ level over periods from weeks to years. We also know little about the polarisation produced by extended moving envelopes. Considering what has been learned about Be star envelopes in this way, I think this would be a valuable observational program.

Turning to binaries, we find that there are 6 eclipsing systems in the graded catalogue of Koch et al (1973), of 200 entries. In addition there are several X-ray binaries with good photometry, and a couple of ellipsoidal systems. Now that good light curve synthesis programs are available, photometry of interacting binaries can yield important fundamental data on the stars: temperatures radii, mass-ratios, limb and gravity darkening, and inclinations and masses for the systems. These analyses have been particularly fruitful in the X-ray systems (see Figure 5). This type of analysis has also been pursued by Leumg and Wilson whose models indicate several contact O star systems. I find this somewhat worrying, as there are discrepancies with spectroscopic and other photometric analyses, and this is a point we may do well to discuss here. If they did exist, what would contact O stars become?

On the polarisation, it is encouraging that two groups (Koch et al. and Kemp et al.) are doing observations which, combined with a simple model, yield information on circumstellar envelopes in O star

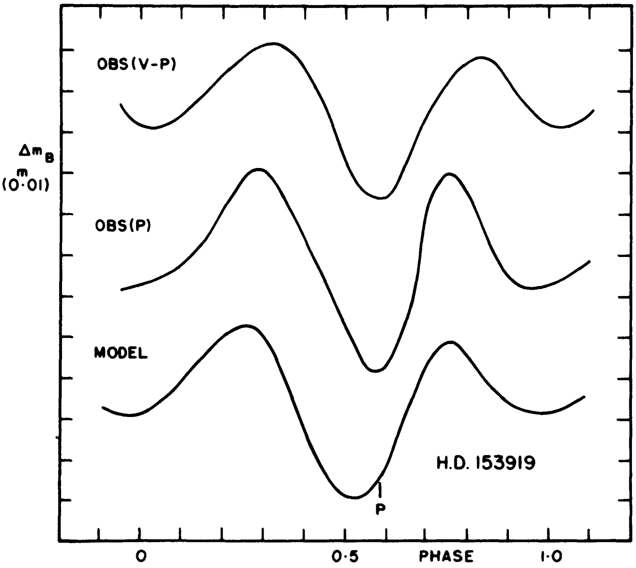

Fig. 5. Light curves of X-ray binary HD 153919. Upper: Van Paradijs et al. observations. Centre: Petro observations. Lower: model with e∿0.05. P marks periastron passage.

binaries, and inclinations for the systems. Clearly, such work is a valuable complement to spectroscopy and should be pursued on as many binaries as possible. Again, a word of caution: the analysis applied to Cyg X-1 yields a value of $\underline{i}$ (76°) inconsistent with the non-existence of eclipses. A closer look at the situation shows that a more complex model is called for which allows lower values of $\underline{i}$. It is clear that we must all beware of the crank-the-handle approach even to very standard looking problems.

A final word about photometry is to emphasise the value of a wide wavelength base. We have the capability of observing from 1000A to several microns, and in the O stars, UV data are particularly sensitive to temperature, reddening, limb darkening and line blanketing. They are well worth getting for the extra information they may yield on these points, and because light curve analysis is much more powerful over a long λ base.

VI. BINARIES AND MASS-LOSS

An important question is that of the effect of a companion on the mass-loss and the disentangling of the Roche lobe overflow versus stellar wind dichotomy, especially in the X-ray systems, where the accretion rate of a neutron star depends on the flow velocity.

The observational picture is as follows. A binary companion does not have a detectable effect on mass loss unless the tidal interaction brings the star close to its critical surface (say within $\sim$10%). I say this on the basis of ground-based data. It may be that UV data from IUE will show effects not detectable in the visible. If we look at the X-ray binaries which have circular orbits (SMC X-1, 1538-52, Cen X-3 - the latter not set studied in sufficient detail) we see no evidence for increased flow towards the companion (see e.g. Hutchings et al. 1977). In fact, we find no clear evidence for a wind > 10^{-7} $M_{\odot}$/year at any phase. Yet the X-ray luminosity is evidence that mass flow exists. However, it is significant that all OB star X-ray binary orbits show e=0 and $\omega \simeq 0$ (Table 4), and this is qualitatively the effect of increased outflow (by only 3-5 km s^{-1}) along the line of centres (i.e. where g_{eff} is reduced). If this is the explanation we note also that this effect apparently dominates over gravity darkening and T_{eff} variation effects, which should yield spurious ω values of 90° or 270°.

If we look at systems with non-circular orbits, which cause tidal interactions at periastron, we see very clear effects. In HD 187399 and AZ Cas (both B stars), e $\sim$ 0.4, and mass-loss is spectacular at periastron. In the low e>0 stars (Hutchings 1978b) shown in Table 5 we see a continuous variation in the wind, with maximum at periastron. HD 163181 (B0 Ia + 0) is another example, and we also note that a periodic wind modulation is seen in HD 153919 by Hammerschlag-Hensberge (1978). In this connection it is significant that my light curve analysis shows that e>0 and that this effect once again is maximum at

TABLE 4. X-ray System Parameters
Summary of approximate values

System	X-ray		Spectroscopy		q	light curve		i	$\frac{L_{opt}}{L_x}$
	e	eclipse	e	ω		e			
4U1700-37	-	±46°	0.2	330°	∼20	0.05	300°	87°	5000
4U0900-40	0.12	±35°	0.2	10°	13	0	0	73°	1300
Cyg X-1	-	-	0.06	330°	∼ 2	0.04	330°	30°-60°	100
Cen X-3	0.0008	±40°	-	-	∼15	(0	0)	∼ 90°	100
4U1223-62	-	-	-	-	-	< .05	(90)	< 60°	100
LMC X-4*	-	±32°	(0.2	50)	9	-	-	72°	3
SMC X-1*	<0.0007	±26°	(0.3	0)	16	(0	0)	64°	4
4U1538-52	-	±28°	0.2	350°	10	-	-	70°	500

* e = 0 orbits adopted

TABLE 5. Stellar Winds in Noncircular Binary Orbits

System	$-\dot{m}$ ($M_\odot$ year^{-1})			e
	max	min	max/min	
29 CMa	$1.5\text{x}10^{-5}$	10^{-7}	150	0.09
163181	$1.5\text{x}10^{-5}$	10^{-6}	15	0.08
47129	$1.5\text{x}10^{-5}$	$2\text{x}10^{-6}$	7	0.04
108	$4\text{x}10^{-5}$	10^{-5}	4	?

the phase of periastron. (Note that the spectroscopic e, ω values are once again spurious, and attributable to the permanent tidal deformation of the primary, as mentioned above.)

There is a further indication. In my mass-loss survey, the known binary stars have twice the mean mass loss rate of the average for all objects. This is not highly significant in a small sample, but supports the general picture above. We need more detailed studies of close binaries to clarify the whole position, and quite possibly the UV will provide more clear cut answers.

There is every indication that many O stars are in close binary systems. Thus, in determining their fundamental parameters we must beware of distortions to the velocity curves. Alternatively, we may regard high quality spectra of close binaries as containing information on the structure of the stellar winds.

It is of interest to look at the statistics of O star binaries. Since new binaries are being found and studied all the time I may have missed a few and my numbers will certainly be out of date soon. At present the rough picture is as follows. There are 11 eclipsing systems known, of which two have O star companions, 5 B stars, 1 W-R star, and 3 neutron stars. There are 45 spectroscopic binaries, of which 16 have O star companions, 17 are single-lined, 8 have W-R companions and 4 have neutron stars (or Black holes). This bears out the ideas that massive stars spend very little time between being OB stars and neutron stars, and that the W-R stage is a shortlived but significant part of the evolutionary scheme. Note that the VV Cep systems include stars very close to being O stars and should be studied in the evolutionary scenario. They are probably over-represented because their spectroscopic peculiarities makes them easy to discover.

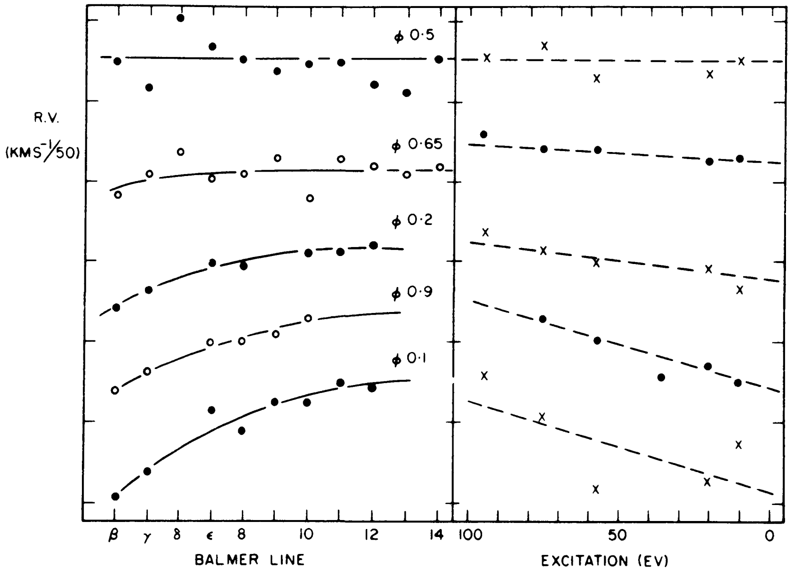

Fig. 6. Systematic variation of Balmer progression and velocity-excitation slope with phase, in e>0 binary 29 CMa.

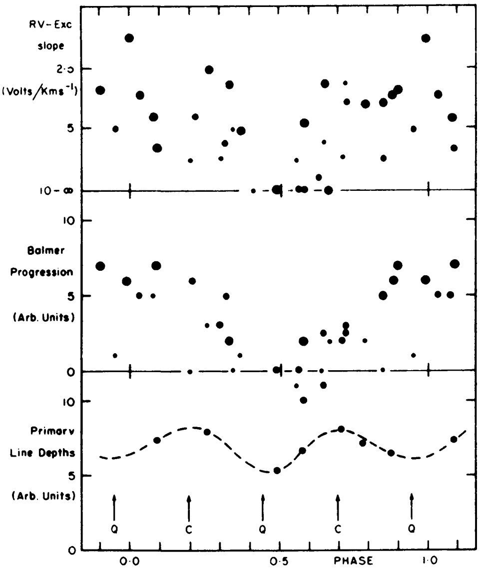

Fig. 7. Variation of mass-loss rate of primary in e>0 orbit of HD 47129.

VII. MASSES AND DIMENSIONS

The masses of the O stars are not well known. Conti and Burnichon (1975) derived M_V and temperatures for a sample of stars of uniform classification and well established distances. Applying bolometric corrections, they showed that they lie on the H-R diagram occupied by evolutionary tracks for stars of mass 20 to 120 $M_\odot$. Masses from spectroscopic binaries are few in number and are generally at the low end of this range. However, they are generally consistent with the picture. Nevertheless, these cases are rare and one can point to uncertainties in every one. Probably the best determined masses are those of the X-ray binaries, but, as pointed out earlier, they are all low for their luminosity, if we believe the above picture. We can brush this off as being the result of extensive mass-loss or exposure to a supernova explosion but we should perhaps still worry a little about this anomaly and the comparison between observational and theoretical H-R diagrams (i.e. do we really know T_{eff}'s and the B.C.'s?).

The X-ray systems provide us with radii and in general the luminosity derived from these, the accepted T_{eff} values and B.C.'s agree well with those derived from distance and reddening determinations (i.e. to within $0^m\!.1$ in most cases). The few eclipsing normal systems yield numbers consistent with these too. Thus, the main sequence radii run from $\sim$ 8$R_\odot$ at B0 to 25$R_\odot$ at O5, and supergiants in the 15-30 $R_\odot$ range. Figure 8 shows Conti and Burnichon's stars on the H-R diagram, and binary stars whose masses are known.

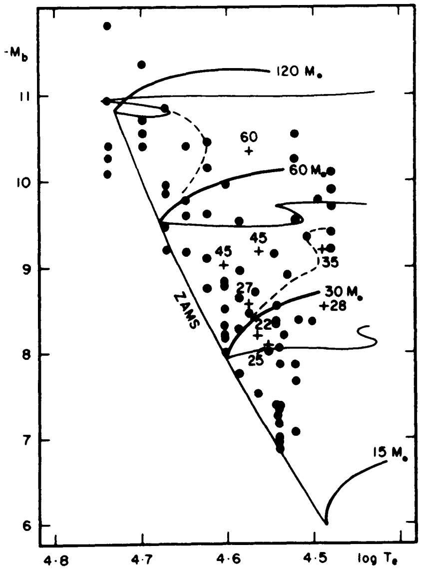

Fig. 8. HR diagram for O stars showing apparent agreement of observed and calculated positions. Crosses are binaries for which masses (as marked, in $M_\odot$) are known.

VII. SOME SPECTROSCOPIC MYSTERIES

The optical spectra of O stars contain a few features which are still unidentified - a rare phenomenon in modern astrophysics. The most famous are the emission features at λλ 4485, 4503. These lines are almost always 3-4 A wide and have intensities from 3-10% above the continuum. They have been associated with C III λ 5696 emission but the unidentified lines seem to occur more frequently. It is of interest that these lines have been seen in LMC X-4, where abundances may be different from the galaxy.

A less well known line is an absorption at λ 4726, which has been seen in X Per, HD 47129, HDE 245770, Cen X-3, and the optical primary of 4U1538-52. Three of these are X-ray source companions and all are O8-O9.5 stars. The line is similar in profile and strength to He I λ 4713. It is listed by Herbig as an interstellar feature, and its strength correlates with reddening in the above stars.

Next I would point out the broad emission bands seen around Hδ and the λ 4650 region in extreme Of stars like HD 152408, 153919. They are up to 5% in intensity and ∿50 A wide. I guess they originate in the outer parts of the wind, are connected with W-R bands, and arise in the strong Si IV, N III and He II transitions in these regions of the spectrum. Figure 9 shows the bands in the extreme Of stars.

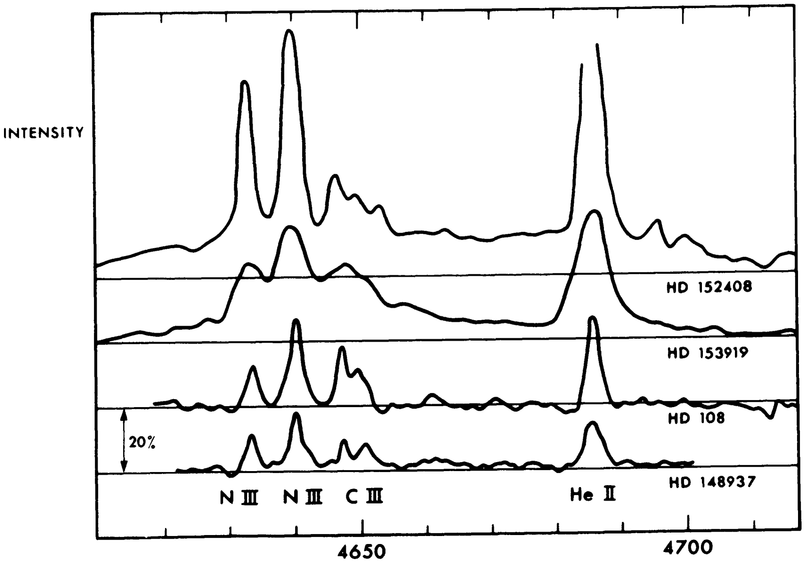

Fig. 9. Tracings of spectra of extreme Of stars, showing broad emission features in HD 152408, 153919.

I want next to mention He I λ 5875. This line shows a high velocity *extra* component, at times. It is seen e.g. in HD 152408 at $\sim$ -800 km s^{-1}, and in HD 153919 at about this velocity at $\phi = 0.7$ (X-ray). The latter case is often associated vaguely with a "wake" trailing the X-ray emitter, which is immersed in the stellar wind (< 1 $R_\star$ away). The only similar spectral feature is He I λ 3888 in HD 152408, in which the line is formed through a large depth, accumulating enough absorption near the terminal velocity, to give a second dip. It is not known why this process should occur in λ 5875.

Finally, there is the mysterious emission line at λ 5300 seen in HD 153919 by Dupree and tentatively identified as Fe XIV. She claims to have confirmed the observation in this and other O stars. If it is real (and perhaps it needs further demonstration) its identification may indicate the existence of a hot corona, and/or special line passes.

IX. ROTATION

The study of rotation in O stars by Conti and Ebbets (1977) showed that the situation is much as might be expected, and similar to the B stars. There is probably some macroturbulence which adds 30-90 km s^{-1} to V sin *i* going from O9 to O3. The main sequence stars show higher velocities, corresponding to the rapid rotating Be class. It is interesting to note that the rapid rotators also have high $\dot{m}$ (10^{-5} $M_\odot$/year). This would imply that rotation enhances a stellar wind by lowering surface gravity. More work along these lines needs to be done on the Oe stars. Unfortunately, the high rotation leads to weak lines and difficulties in measuring velocities, so that high quality data would be required.

I would like to emphasise a pet point here. In the extreme cases a stratified expanding envelope will underestimate V sin *i* measured from absorption lines. This leads directly to a controversy over HD 153919 whose absorption line V sin *i* is much slower than synchronous. My recent light curve analysis (Hutchings 1978) suggests that rotation must be synchronous (as do circularisation arguments, and V sin *i* estimates from emission lines).

X. RAPID VARIATIONS

There has been a great deal written about rapid spectrum variations in OB stars (see Lacy 1977 for critical comment and references). Claims have been made for changes within a star or from night to night, based on narrow band photometry, photographic spectroscopy, line scanners, and electronic detectors of various types. In nearly every case there is a possibility that the effect is instrumental, or measuring errors, and the experimenters have not made sufficient control observations. On the other hand, *some* good experiments *have* been done and in some cases, very similar results have been obtained by very different techniques. Later in this volume some very spectacular changes in the B supergiant HD 190603 are reported.

Figure 10 shows changes in the Of emission lines in λ Cep (Hutchings and Walker 1977), on a moderate time scale.

It is known that over periods of years or months spectral changes do occur in O and particularly Of stars, and so do changes of order $0^{m}1$ in brightness. A star with a typical stellar wind will replace its entire line forming envelope in about a day, a time shorter than the average rotation period. Thus, inhomogeneities in the flow or modulations in the wind could show up as rapid variations, and indeed seem very probable to me. It is more questionable what we will learn from them, especially as a proper observational job calls for large expenditure of telescope time. Irregular looks at stars and occasional cries of "oh look it's changed" are not getting us very far. We should look at these changes photometrically and spectrophotometrically over a wide range of λ's and spectral lines. This may show us whether brightness or temperature changes occur, and show whether we can follow disturbances propagating outwards in the wind, or stellar rotation, etc.

XI. RUNAWAY STARS

Blaauw (1960) estimated that some 20% of O stars are runaways, based on radial velocity data. Stone (1978) comes to a similar conclusion, estimating their space velocities. Conti _et al._ (1977a) give 8% on a larger sample and paying more attention to the confusing effects of stellar winds and binary membership. It is clear (Conti _et al._ 1977b) that in extreme cases, photospheric velocities up to 65

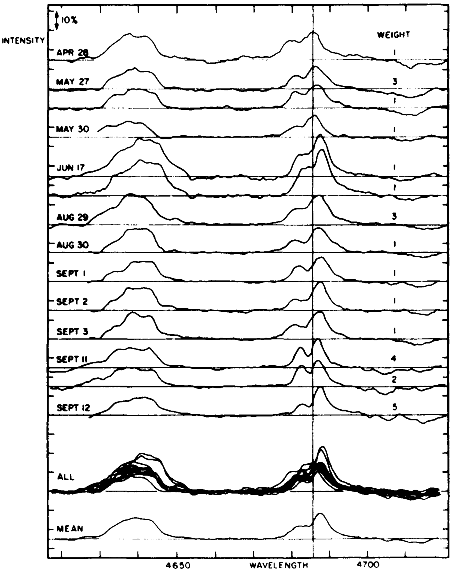

Fig. 10. Image Isocon scans of Of emission lines in λ Cep, showing short term profile changes in 1976.

km s^{-1} can arise from mass flow. We should also expect in general that stars from a finite area of the galactic plane that are runaway stars with high velocity will show more with positive than negative velocities. It seems to me that there are probably 10% of O stars that are runaways (i.e. receding by > 40 km s^{-1}), and this is probably a direct result of supernova explosions. In this connection it is worth noting the high (-110 km s^{-1} wrt local standard of rest) radial velocity of the O8 primary of the X-ray pulsing source 4U1538-52. Evidently the system can achieve high velocity and remain bound. Note the discussion in this volume on runaway stars.

Perhaps it is worth searching for supernova remnants near to O stars which may have (had) an evolved companion. O stars generally outlive SNR's by 1-2 orders of magnitude, but the chance seems to me not negligible. There is intriguing nebulosity associated with HD 148937, γ Cas, and R148, a candidate star for LMC X-1.

XII. ABUNDANCES

A question which aries in connection with extensive mass-loss is whether the surface abundances are altered by exposing evolved material. This may well occur if 30-50% of the outer layers are removed. Abundance determination however, is complicated by the extreme non-LTE conditons in the envelopes of the stars: particularly the apparent existence of a hot corona-like outer layer in which the high ionised UV resonance lines are generated.

The observational evidence is not compelling either way. However, in some extreme cases, like HD 152408, the N III spectrum is complete, and in emission. This phenomenon is also seen (less markedly) in the X-ray primary of 4U1538-52, which does not show evidence for a strong wind, but which is undermassive by ∿40%. On the other hand, we don't see it in LMC X-4, SMC X-1 or Cyg X-1, which are apparently similar objects. The mass exchange binary HD 163181 has a BO primary which is undermassive by ∿70% and shows strong CNO lines. Its (O type) companion is hard to see but has normal mass. This is the strongest correlation I know of mass-loss and abundance. I don't know of any cases of strong He, except for β Lyr, which is not an O star. It would be worthwhile trying to derive abundances for O and Of stars.

If we consider WN and WC stars to be showing strong abundance anomalies by mass loss, we may expect effects of that magnitude to appear when some 80% or more of the original mass is lost.

XII. THE MAGELLANIC CLOUDS

I have spectra of a number of OB stars in the clouds of which two (Of) are in the SMC and another 4 in the LMC. The brightest of these are M_V -7 and thus compare with high mass loss objects in the galaxy. There are not extreme stellar wind indications in these, though the most likely object has Hβ P Cyg profiles. One star is an Oe star.

The most obvious stellar winds in the clouds are seen in some B supergiants. This is very preliminary and more careful work needs to be done before concluding anything about the cloud stars. It appears that the distribution on the HR diagram of MC and galactic supergiants is similar.

CONCLUSION

This is not the place for summarising. I hope my remarks have opened topics for discussion and brought relevant data forward to be included in the many issues we have to look at in the next few days.

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DISCUSSION FOLLOWING HUTCHINGS

Snow: For OB supergiants which show photometric variations which are non-periodic, what are the typical timescales at these variations?

Hutchings: These timescales are not well known; to date little systematic observational work has been done.

Underhill: The small extra reddening found by Isserstad for the most luminous O stars in some clusters relative to O stars of the same subtype but low luminosity and interpreted as circumstellar reddening may be a result of the fact, see paper by me, Divan, Doazan and Prevot-Burnichon, that the effective temperatures of luminous OB stars are significantly lower than those of main-sequence OB stars of the same subtype. I have considerable doubt that true circumstellar reddening exists at a measurable level and can be determined by the method used by Isserstad.

Hutchings: I too suspect some intrinsic reason of this nature. Still the effect needs to be explained one way or the other.

Lamers: You find your lines of equal mass loss rates in the HR-diagram to decrease towards the A-supergiants; whereas Barlow and Cohen's data suggest that the rates are dependent on luminosity only, so these lines should be horizontal. A possible explanation for this discrepancy might be found in the fact that the stars which you use for calibrating your mass loss indicators are all of spectral type around 09 to B1. If you consider the fact that in late-B or A stars the hydrogen lines are formed at lower density than in the B0 stars, you can get the same Balmer-progression in a late-B supergiant with a smaller mass loss rate than in an early-B supergiant. Consequently, your mass loss rates for late-B and A-type supergiants may be overestimated.

R. E. Wilson: What is it about the spectroscopy of the contact or near contact systems which indicates that they may not be in contact?

Hutchings: The sort of information is indication of eccentric orbits with consistent indication of enhanced mass flow at periastron for quite a random distribution of ω values.

R. E. Wilson: Normally spectroscopy doesn't give this kind of information accurately enough.

Hutchings: I worry about photometric solutions for systems where Roche geometry is imposed, $e = 0$ orbits only are considered, and where we may have photospheric mass flow at tens of km/sec and luminosities near to the Eddington limit (e.g., AO Cas, 29 CMa).

Leung: The spectroscopic eccentricity is not real. The asymmetry in the radial velocity curve is not due to an eccentricity in the orbit but is caused mainly by the effect arising from the tidal distortions of the components [e.g., UW CMa, Leung and Schneider, Ap. J. 222, 924 (1978)].

The luminosity ratio derived from strengths of the spectral line ratio is not dependable, since the mass accreting component most likely has a peculiar atmosphere -- very low density rarified atmosphere.

Hutchings: The effects you mention are calculable and imply $\omega \sim 270°$ or $90°$. In practice ω is well distributed and derived from the primary spectrum. Luminosity ratios may be suspect. I note that your photometric solutions do not consider $e = 0$ so I don't see how you know e is not real.

Seggewiss: You showed several diagrams in which the velocity of the expanding envelope is plotted against "excitation." If one looks through the literature we can find different values used for "excitation." L. F. Smith & L. H. Aller [Ap. J. 164, 275 (1971)] and A. F. J. Moffat & W. Seggewiss (this Symposium) use the maximum of the lower excitation potential (EP) of the line and the ionization potential (IP) of the preceding ion. You used in 1976 (Ap. J. 203, 438) the sum of the line EP and the IP of the preceding ion, and in 1978 (P.A.S.P. 90, 179; also M. de Groot, B.A.N. 20, 225) the sum of the EP of the line plus the sum of the IPs of all preceding ions. I feel that we should come to an agreement about what should be plotted as "excitation" in the future.

Hutchings: I agree with you, although the qualitative sense of what we are showing is not affected. You do not quote me correctly on the 1976 reference: In that and all subsequent references I have summed the IP of all preceding ions. This is supposed to measure the temperature (monotonically falling) to the work done in arriving at the lower level of a given absorption line.

Morton: What are your present calibration stars for mass loss rate?

Hutchings: The stars are the same as I used before, but I think P Cyg is not typical or trustworthy any more (Snow et al. 1978). Also I use ζ Pup and revised numbers for the other stars, taking into account the work of Barlow & Cohen, Conti, etc.

Morton: Are the broad emission lines similar to the features Bob Wilson reported 20 years ago?

Hutchings: Probably.

Morton: Do they have the same velocity width as would be expected by the terminal velocity in the wind.

Hutchings: No. They are larger by 2 to 3 times the UV line values.

Underhill: The lines in the visible and UV are probably coming from different optical depths and so may well indicate different outflow velocities.