A man who claims all ejection
Is driven below by convection
Gave a rather cold shoulder
To theorists from Boulder
Whose work he felt lacked French connection.

SESSION 2

U.V. SPECTROSCOPY

Chairman: D.G. HUMMER
Introductory Speaker: T.P. SNOW

1. H. LAMERS: Modelling of UV resonance lines.
2. D. MORTON: O VI in stellar winds.
3. S.B. PARSONS, J.D. WRAY, K.G. HENIZE, and G.F. BENEDICT: C IV resonance profiles in O stars.
4. S.R. HEAP: Winds in hot, subluminous stars.
5. A.B. UNDERHILL, L. DIVAN, V. DOAZAN and M.L. PREVOT-BURNICHON: Temperatures and radii of O stars.
6. C. MOROSSI, R. STALIO and L. CRIVELLARI: Analysis of UV spectrophotometric observations for O-type stars.
7. S.R. POTTASCH, P.R. WESSELIUS and R.J. VAN DUINEN (read by A.G. HEARN): Effective temperatures of the O stars.

AN ULTRAVIOLET VIEW OF STELLAR WINDS

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ABSTRACT

Ultraviolet observations of mass-loss effects in O stars have, over the past decade, revealed a broad picture of a phenomenon whose extent was only partially evident from earlier ground-based observations. Ultraviolet resonance lines of a variety of ionization stages of several common elements provide a comprehensive probe of the low-density, extended winds. Three general types of information have been derived from ultraviolet spectroscopy of mass-loss profiles: (1) the nature of the stars which experience mass loss via radiatively-driven winds; (2) the physical conditions in the winds; and (3) variability in the outflow, which in turn may yield clues to the origins of the winds. Observations and results in each of these areas are reviewed, and some new results are included. A good correlation of mass loss rate and luminosity is indicated by the data, in agreement with theoretical predictions. Time variations in the P Cygni profiles may be quite common, with variability on times of hours or longer. Anticipated new observations, which should be possible with existing and planned instrumentation, are described.

I. Introduction

Classical spectroscopy has revealed a great deal of information on mass-loss in hot stars, as Hutchings has shown in his review (1979, this volume). Nevertheless, to obtain a complete picture of stellar winds, it is necessary to observe their low-density outer portions, and this is best done in ultraviolet wavelengths. The numerous strong resonance lines which are accessible in this portion of the spectrum provide information on the velocity, density, and ionization conditions in the outflowing material which, when combined with visible and infrared data, can provide sufficient information to be of use in constraining possible models for the winds. Some important questions remain unanswered, however, and certainly these will be central to the discussions to follow.

P. S. Conti and C. W. H. de Loore (eds.), Mass Loss and Evolution of O-Type Stars, 65–80.

The most striking manifestation of a high-velocity stellar wind is the characteristic P Cygni profile, consisting of an emission component at rest in the stellar frame, and a superposed absorption which is shifted towards shorter wavelengths. The emission results from scattering throughout the volume filled by the expanding atmosphere, while the absorption takes place only in the observer's line of sight, along which material flows outwards from the star. The strength of the emission is controlled by the size of the volume, and in stars with relatively weak winds, is absent. In these cases the presence of the wind may be indicated only by asymmetric absorption lines, with extended short-wavelength wings. In any case, the effects are strongest in resonance lines, which require no excitation, leading to a variety of P Cygni profiles throughout the ultraviolet. The important ions which have been accessible to current and previous UV experiments include He II, C III, C IV, N III, N IV, N V, O IV, O VI, S III, S IV, S VI, Si III, Si IV, and P V. In Figure 1 are shown some example P Cygni profiles of the N V resonance doublet near 1240 A.

The first rocket ultraviolet spectra with sufficient resolution to clearly show mass-loss effects were obtained just over a decade ago by Morton (1967), and were followed shortly by the observations of Carruthers (1968) and Stecher (1968). Since that time, a number of rocket and satellite experiments have provided a large pool of data, and at this moment significant new additions to this pool are being contributed by the International Ultraviolet Explorer (IUE) (see the contribution to this volume by Heap). Copernicus data have provided high quality profiles for a number of OB stars (e.g. Morton 1975; Snow and Morton 1976).

To date, ultraviolet observations of stellar winds from O stars have contributed information bearing primarily on three main questions: (1) the nature of the stars which experience mass loss, and the correlations of wind strength with stellar parameters; (2) the physical conditions in the outflow, particularly the run of velocity, density, and ionization degree with height; and (3) variability with time. This paper will provide a brief survey of results in these three areas, with some new data to be included in the discussion of variability. The concluding section contains a description of further observations which may be useful to carry out with present or planned ultraviolet experiments.

II. Stellar Parameters

Apparently all O stars are losing mass. Relatively low-resolution data such as those from the early rocket experiments and from the objective-prism surveys carried out by Skylab (Henize et al., 1975) or the Orion series (Gurzadyan, 1975) revealed only the fully-developed P Cygni profiles characteristic of the supergiants. Higher-resolution data, especially those supplied by Copernicus, have shown that even in O dwarfs there are at least extended absorption wings symptomatic of mass loss (Snow and Morton, 1976).

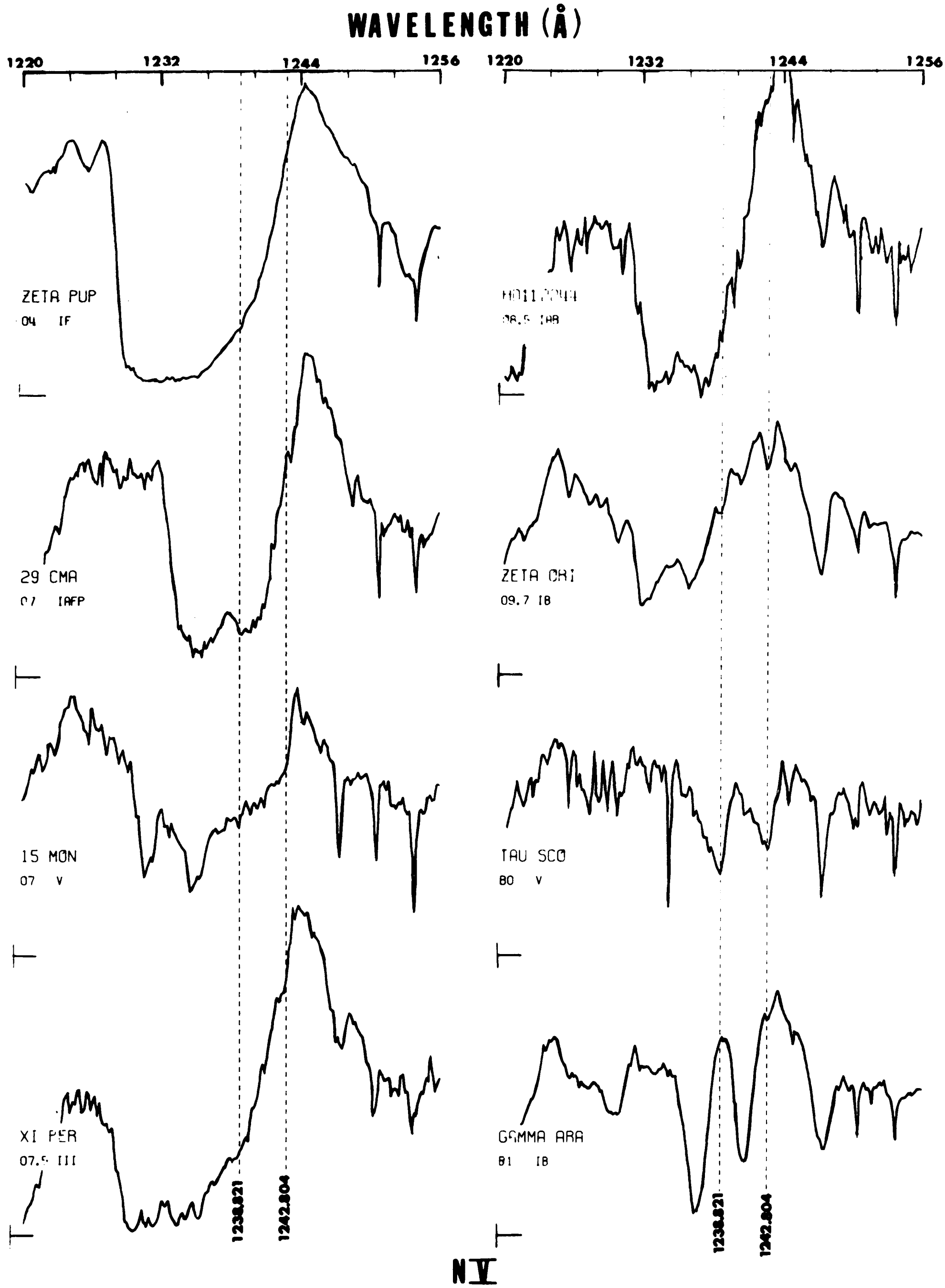

Figure 1. Example of NV P Cygni profiles. The manifestations of mass loss can consist of fully developed profiles with emission and absorption components in the case of a strong wind, or only asymmetric absorption in the case of a weaker wind.

III. Physical Conditions in the Winds

A. Ionization

One of the early discoveries made with Copernicus was the presence of asymmetric O VI absorption in the spectrum of the BO V star τ Sco (Rogerson and Lamers, 1975). This ion is produced thermally at a temperature in excess of 10^5 K, yet it appears in the spectrum of a star with T_{eff} = 32,000 K. Rather than being a peculiarity in a single star, the presence of highly-ionized species is a general feature of the winds in OB stars (Lamers and Snow, 1978). The ion O VI would not be expected to exist in the photospheres of even the O stars, yet it is almost invariably present in the winds. Similarly, N V P Cygni profiles are found in all O stars and a number of early B stars whose photospheres are too cool to produce this ion radiatively. Evidently some form of non-radiative heating is present. Recent soft X-ray upper limits for a number of early-type stars (Cash, private communication) may provide significant constraints on the nature of this heating.

The variation of ionization with height can be deduced from ultraviolet observations by comparison of observed profiles with empirical models. Here some contrasts show up from star to star, and it is not yet known whether any systematic trends exist. In the O4If star ζ Pup, it appears that the ionization is nearly constant out to large heights in the wind (Lamers and Morton, 1976), whereas in τ Sco the degree of ionization decreases outwards (Lamers and Rogerson, 1978). Work in progress by Lamers and Snow (1979), in which profile-fitting will be done for a number of OB stars, should show how the ionization gradient varies with stellar parameters.

B. Velocities

Even from low-resolution UV spectra it is apparent that velocities as high as 2-3000 km s^{-1} or greater exist in the outer portions of the winds from hot supergiants (e.g., Morton, 1967). The regions where these extreme velocities occur are transparent to visible-wavelength photons; hence, the magnitude of the wind terminal velocities was unknown before UV observations were possible.

For strongly saturated absorption components, the wind terminal velocity is readily determined from the position of the short-wavelength edge. For the stars with weaker mass loss, however, there is no clear-cut edge, and only a lower limit can be found directly from the profile, by estimating the wavelength at which the extended absorption wing returns to the continuum level. From the UV profiles, terminal velocities ranging from about 300 km s^{-1} to over 3400 km s^{-1} were found in the Copernicus survey of mass loss (Snow and Morton, 1976). Anomalously high velocities were found from the N V profiles in several Orion supergiants; subsequent examination of Copernicus data on early B stars reveals that a blend of photospheric lines near 1234 A may contribute to the absorption in these stars, exaggerating the derived terminal velocity.

Evidently the atmosphere is not sufficiently extended in these lower-luminosity objects to produce strong emission except in the earliest types. From the Copernicus data, it is seen that mass loss generally occurs in all OB stars with $M_{bol} \leq -6$ (Snow and Morton, 1976), and is found in addition in a number of B dwarfs below this luminosity (Snow and Marlborough, 1976; Lamers and Snow, 1978).

Although mass-loss rates are not yet known for a large number of stars, some discussion of the dependence of mass loss on stellar parameters is possible at this point. For example, a crude index of mass loss rate can be formulated directly from the observational data and correlated with stellar parameters such as luminosity or temperature. Since the mass loss rate is roughly given by:

$$\dot{M} \sim 4\pi\rho v r^2 \qquad (1)$$

we can make rough approximations and write:

$$\dot{M} \propto R_* V_\infty W\lambda, \qquad (2)$$

where R_* is the stellar radius, V_∞ is the terminal velocity, and $W\lambda$ is the absorption equivalent width of an ion observed in the wind. The following assumptions are included in this simplification: (1) that all of the material in the wind is at a height of $1R_*$ and has the velocity V_∞; and (2) that the column density $N = \rho/r$ is proportional to $W\lambda$ (i.e., that saturation and photospheric absorption are not important, clearly an oversimplification in many cases). Finally, in order to compare this index from star to star, it is necessary to assume that the ion chosen is dominant throughout the spectral types covered. For this purpose N V was chosen, since it appears to be the dominant form of nitrogen in the winds of all the O stars, because it is not predominant in their photospheres, and because it is well-observed by Copernicus.

Figure 2 shows the correlation of the mass loss index $R_* V_\infty W\lambda$ with absolute bolometric magnitude for several O stars. It is clear that a good correlation exists, confirming that luminosity alone strongly governs the mass-loss rate for these stars. One interesting sidelight is that for these stars at least, other parameters such as rapid rotation (λ Cep) or the presence of a close binary companion (29 CMa) do not appear to strongly affect the mass-loss rate. There is evidence for the stars of marginal luminosity that rotation may play a decisive role in producing mass loss (Snow and Marlborough, 1976; Marlborough and Snow, 1976), but evidently once the luminosity is great enough to produce mass flow unassisted, as it is for all the O stars, other influences are insignificant.

In Figure 3 is shown the plot of $R_* V_\infty W\lambda$ versus temperature, where it is seen that no correlation exists. Similar results were found from correlations with other parameters such as vsini.

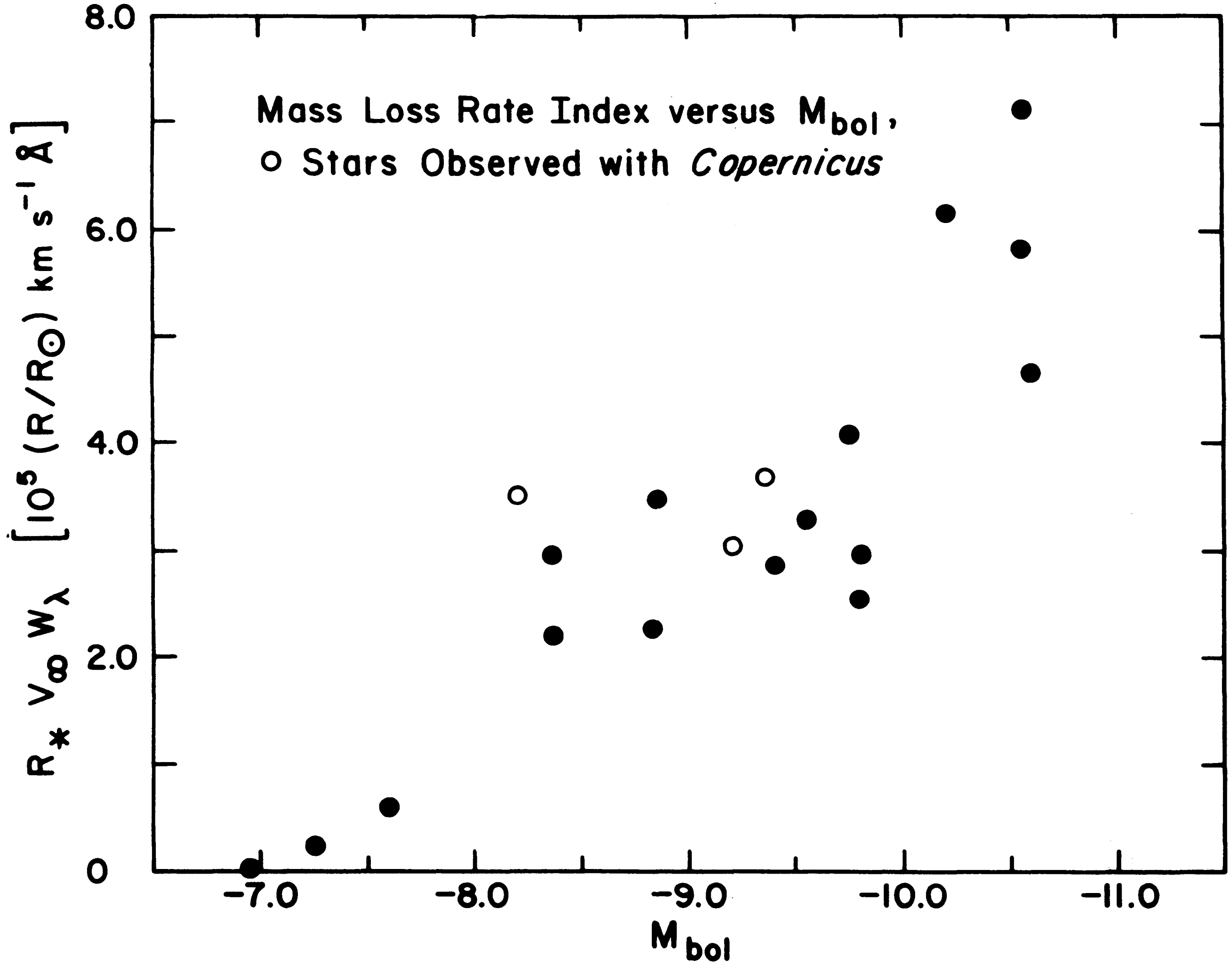

Figure 2. Correlation of the mass-loss rate parameter $R_* V_\infty W_\lambda$ with bolometric absolute magnitude. For the O stars, there appears to be a good correlation, confirming theoretical expectations that the mass-loss rate should be strongly dependent upon luminosity.

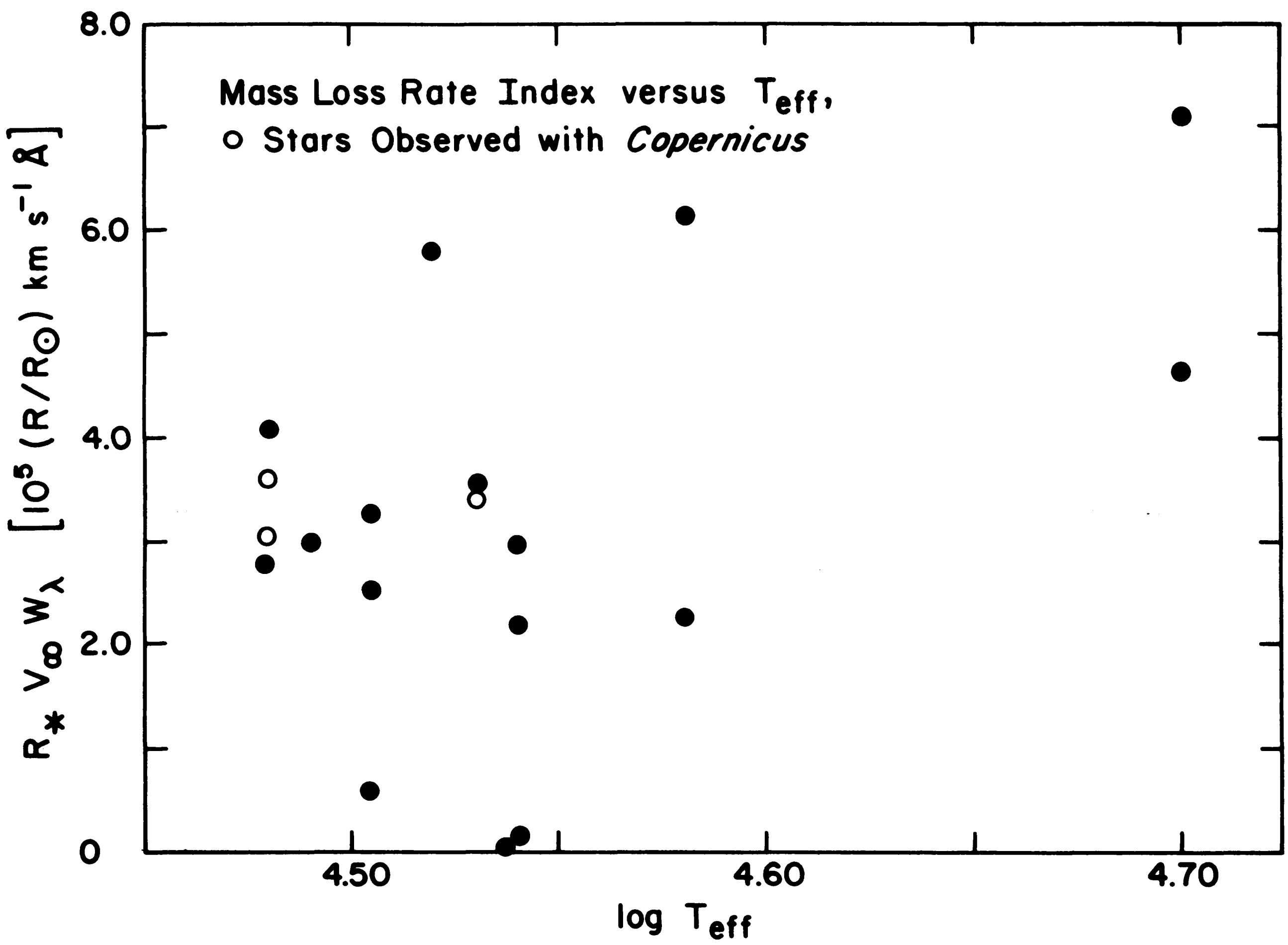

Figure 3. Correlation of the mass-loss parameter with effective temperature. No strong correlation is seen, indicating that stellar luminosity is a more important influence than temperature in governing the mass-loss rate.

While there was a general tendency for the hottest stars to have the greatest velocities, there was no strong correlation of terminal velocity with either stellar effective temperature or luminosity. Abbott (1978) has shown, however, that the terminal velocity does vary in a uniform way with the stellar escape velocity, as expected from the theory of radiatively-driven winds. In order to estimate the escape velocities, it was necessary to estimate the stellar masses from evolutionary calculations which take mass loss into account, and the gravitational binding force was modified to allow for radiative pressure. Abbott found that the terminal velocity correlates with the escape velocity according to:

$$V_\infty = (535 + 2.64\ V_{escape})\ \mathrm{km\ s^{-1}}. \qquad (3)$$

This is consistent with the theoretical expectation that:

$$V(r) \propto V_{escape}\ (1-R_\star/r)^{\frac{1}{2}} \qquad (4)$$

or

$$V_\infty \propto \mathrm{Vescape}. \qquad (5)$$

The slope of the observed correlation allows an empirical evaluation of the net acceleration created by the radiation pressure.

From empirical profile-fitting techniques (e.g., Lamers and Morton, 1976; Lamers and Rogerson, 1978), it is possible to derive the form of the velocity law for the winds. This has been done only for two stars so far (Lamers and Morton, 1976; Lamers and Rogerson, 1978), but it is expected that similar analyses of additional stars will soon be completed. In general, smooth laws similar to equation (3) above produce adequate fits to the overall profiles, neglecting detailed structure.

The presence of relatively narrow (PWHM ∿100 km s^{-1}) absorption components superposed on the broad P Cygni profiles in some stars may indicate the presence of structure in the velocity law, however. Such components are quite common, and could form as a result of plateaus in the height dependence of the velocity, so that enhanced column densities occur at specific velocities. If this interpretation is correct, then the data imply the existence of several plateaus at different velocities in some stars, since the velocities of these components are seen to vary from ion to ion. This further implies that each plateau has a different characteristic temperature. Perhaps the plateaus could result from changing ionization conditions with height, since the radiative acceleration at each height depends on the abundances of the ions which absorb most strongly.

On the other hand, the narrow absorption components could simply reflect steep gradients of the ionization equilibrium in a wind with a smooth velocity law, so that within a narrow velocity range, the observed ionization stage is dominant, producing enhanced absorption at that velocity.

In either case, the apparent permanence of these components in times of years (Snow, 1977) implies that the velocity law structure or ionization gradients which cause them are stable. The optical depth of a particular absorption component may vary with time (see discussion below), but the velocities are quite invariant.

IV. Time Variations in the Winds

Since it appears likely that some form of mechanical heating is present in the outer layers of early-type stars with mass loss, it is important to gather data on the nature of this heating. If the situation is analogous to the solar chromosphere and corona, it might be expected that mass motions occur near the surface, which could result in turbulence or other forms of random or non-random variations in the material in the wind. To observe such variations would provide valuable information on the nature and stability of the lower regions of the winds, and could help answer fundamental questions about the entire phenomenon of mass loss.

Evidence of variability in mass loss from hot stars has been accumulating at a rapid pace. Visible-wavelength indications have been reported previously by several authors (e.g., Rosendhal and Wegner, 1970; Rosendhal, 1973a,b; Brucato, 1971; Conti and Frost, 1974) showing that variations on timescales as short as days occur commonly for B supergiants and the Oe star λ Cep. More recently, Conti and Niemalä (1976) found variations in the Hα profile of the Of star ζ Pup over a time of three years. Other results on variability in O star Hα profiles are being reported in this volume (Vreux and Andrillat).

In the ultraviolet, recent data obtained with Copernicus have revealed significant variability in the UV P Cygni profiles for many O stars. York et al. (1977) found O VI profile variations in three stars (ι Ori, δ Ori A, and ζ Pup) which occurred in times of hours, and Snow (1977) found upon re-observing some 15 O stars that most had undergone significant alterations in their profiles over 3-4 years. Lamers, Stalio, and Kondo (1978) found similar results for the MgII lines in B supergiants, using BUSS data. To date, no UV experiments have allowed searches for variability on timescales shorter than about one hour, and the new IUE satellite will not offer much improvement in this regard. Figure 4 shows an example of long-term variability found by Snow (1977).

While the true timescales for variability are not yet known, some remarks can be made, based on very recent results. Copernicus data have been used to study variations in several ions in the stars δ Ori A (O9.5II; studied by Snow and Hayes, 1978) and ζ Pup (O4If; analyzed by Wegner and Snow, 1978). Neither study showed changes as large in magnitude as those reported by York et al. (1977) for the same stars, but both did reveal significant fluctuations in the UV P Cygni profiles. In both cases it appeared that the variations can be characterized as sporadic events which disturb the otherwise quiescent profile. Such events apparently

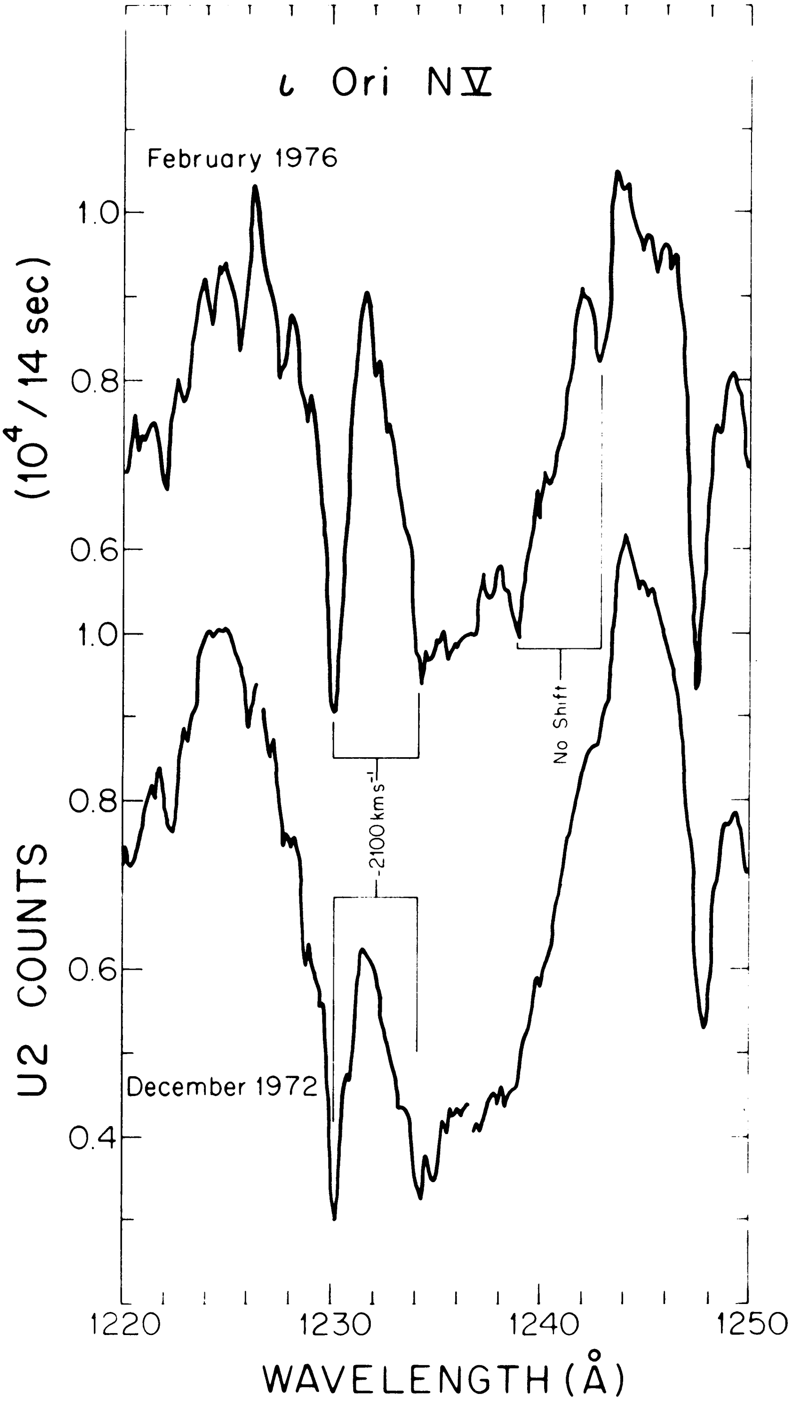

Figure 4. Example of time variations in an ultraviolet P Cygni profile.

can occur and diminish, at least in the portion of the wind where the UV profiles form, in times of hours. This is suggestive of perturbations which flow outward at the wind velocity, since the transit time for a fluid element through variable portions of the profile at the large observed velocities is typically of order 2-3 hours.

The work of Wegner and Snow (1978) on ζ Pup included simultaneous UV and visible-wavelength spectroscopy, with the Hα and He II λ4686 profiles being sampled at a rate of roughly one observation every 10 minutes through several nights. The ground-based data showed strong variations in both the Hα and λ4686 profiles, consisting of the appearance of a secondary blue-shifted emission peak over a time of roughly one day, with the feature persisting for at least one day thereafter. From the good time coverage during the nights the star was observed, it appears that this feature developed gradually over the one-day timescale. Unfortunately, the feature did not diminish before the observing run was interrupted, so it is impossible to determine how rapidly it died out. In any case, it had disappeared some 27 days later, but then began to re-appear again within two days.

If these variations are all caused by outbursts at the surface which result in perturbations which flow out through the wind, then it is quite reasonable to expect that longer timescales would be found for the visible-wavelength profile variations than for the UV, because the Hα and λ4686 lines are formed at low levels in the wind, where the flow velocity is still quite low, of order 10^2 km s^{-1}.

In the case of ζ Pup, as well as in a recent study of the variable Oe star λ Cep (Leep and Conti, 1978), the magnitude of the variations seen in the visible lines is greater than that found in the UV. This implies that the disturbances which cause the fluctuations must diminish in strength as they flow outward; or that they are so localized that they can flow out of our line of sight by the time they reach high levels in the wind if they don't happen to be ejected directly towards us (yet are so intense that they can cause significant effects in the integrated profile when they are at low levels in the wind). The latter possibility may be ruled out, however, since even strong disturbances which did not flow outward exactly along our line of sight should noticeably affect the UV emission components, and strong variations in these emission lines have not been seen. Hence, it may be concluded that, at least in the two cases where simultaneous UV and visible-wavelength spectroscopy have been carried out, the events which disturb the profiles diminish in strength by the time they reach high levels in the wind.

In the cases of both δ Ori A (Snow and Hayes, 1978) and ζ Pup (Wegner and Snow, 1978), the strength and frequency of variations found in the UV P Cygni profiles seem to change with time. Both of these stars were evidently very active when observed by York et al. (1977), but not so active when observed two years later in the studies cited here. Perhaps the variability in O-star winds is itself a variable phenomenon, analogous to the solar activity cycle.

One of the most intriguing and potentially useful aspects of the variability observed is the fact that the narrow velocity components which are often seen within the broad P Cygni profiles do not change in velocity, even though their strength may vary drastically. This seems to be telling us that, even though ephemeral density enhancements can occur, there is an underlying structure to the winds which is constant.

V. Future Observations

New instrumentation, some of it still in the planning stage, should allow continued advances in our empirical knowledge of stellar winds. The IUE satellite is now in successful operation, with an echelle spectrograph capable of 0.1 A resolution throughout the region from 1200 A to 3400 A, covering several important ions. The Space Telescope will, in a few years, provide greater sensitivity and resolution over the same spectral region.

The first goal of these instruments with regard to mass loss will be to determine better the limits of the region in the HR diagram where the phenomenon occurs. Already IUE has observed subluminous hot objects such as central stars of planetary nebulae (Heap, this volume) and early-type stars in the Magellanic clouds (Conti, private communication). In the future we may expect a greater variety of objects to be sampled, including stars in a number of nearby galaxies, where it will be interesting to see the effects of abundance variations and to test our ideas of the relationship of mass loss and stellar evolution.

Another obvious area of improvement will occur in our understanding of time variability and hence of stability, structure, and energy deposition in the winds. A cooperative effort is planned for late 1978 using IUE from both sides of the Atlantic to get full 24-hour coverage of a single O supergiant (α Cam) for a few days. This project, which will be coordinated with ground-based spectroscopists, will allow simultaneous sampling of a range of ions, including N V, C IV, Si IV, H I, and He II, on a timescale of some 30-40 minutes.

Other experiments, perhaps on space shuttle payloads, should provide coverage of shorter timescales in the UV to complement data already being obtained from the ground. While most of the current evidence for the O stars seems to indicate that UV variability occurs on times of one hour or more, there have been hints of more rapid variability in the visible-wavelength lines (e.g., Brucato, 1971 Vreux and Andrillat, this volume).

While the past decade of research in space astronomy has revealed the broad outlines and general nature of the phenomenon of mass loss from hot stars, the next decade should begin to fill in the details and provide answers to many of the questions raised during this symposium. We can look forward not only to this, but also to the challenges of new questions which will arise.

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DISCUSSION FOLLOWING SNOW

Pismis: You emphasized the good correlation between the strength of the stellar wind and the absolute magnitude of O stars. Now the mass-luminosity law is expected to hold for O stars: Therefore a correlation between the wind strength and the absolute magnitude would imply a good correlation between wind and mass of the stars. Physically the mass is a more fundamental property of a star. I understand that the reason why the absolute magnitude was discussed in these correlations is due to the fact that the absolute magnitude is obtained more directly from observation than the mass.

Snow: Not only is luminosity more easily determined, but it is also the parameter which, according to the theory of radiatively-driven winds, directly affects the mass loss rate. Hence, in this context the luminosity can be considered the more fundamental quantity. Furthermore, for the O stars with high mass loss rates, the masses are changing significantly with time while the luminosities no longer follow the usual mass-luminosity relation.

Carrasco: The correlation between mass loss rates and luminosities for the O-type stars shown may be subject to calibration problems. Among the stars used are several runaway stars and these might be underluminous by a factor of 10.

Snow: We took our luminosities from data in the literature, and certainly it is possible that errors exist in the values of M_{bol} we adopted.

Underhill: Some central stars of planetary nebulae have sufficiently strong winds that these winds are seen by means of the visible spectrum. These stars have masses near 1 solar mass. What does this observation mean in terms of your proposed significant correlation between luminosity and mass and rate of mass loss?

Snow: Other parameters such as surface gravity must play a role which doesn't show up very clearly in this small sample. Dr. Heap is going to discuss some recent IUE data later in this session which show strong ultraviolet P Cygni profiles in low-luminosity, hot stars.

Castor: Bowyer's X-ray upper limits are already very interesting. For ζ Puppis the limit on an optically thin corona is a volume emission measure $\int n_e^2\, dV < 10^{55.6}$ if $T_c = 10^6$K, or $<10^{55.5}$ if $T_c = 5 \times 10^6$K. These limits are 10 times less than that required in Joe Cassinelli's optically thin coronal model (3×10^{56} for the observed O VI in ζ Pup). The coronal model might be adjusted to come under the limit, but clearly these limits are already useful.

[Comment added after the session: The HEAO-1 upper limits quoted here are for soft (E < 1 keV) X-rays, and Cassinelli's and Olson's optically thin model produces none of these.]

Sreenivasan: What is the uncertainty in the observationally estimated mass loss rates?

Snow: Substantial, even in the cases where detailed profile-fitting procedures as described by Lamers in this Symposium have been used. The formal uncertainties are about ±50%, I think.

Sreenivasan: Effects of rotation (V sin i) or differential rotation (V sin i and macroturbulence) amount to an increase of ~20% or 30% with inclusion of centrifugal force and to about a factor 2 or 3 for centrifugal force + turbulent pressure due to differential rotation over mass loss rates for non-rotating models. So this may not show up in a correlation analysis, if the observational uncertainty is comparable or greater. Bodenheimer [Ap. J. (1971)] showed that the luminosity of a star in rapid (differential) rotation is much less than that of a non-rotating star, e.g., a 60 $M_\odot$ star in strong differential rotation could have the luminosity of a 30 $M_\odot$ non-rotating star! So, this could also be responsible for the absence of correlation with rotation, etc.

Hutchings: Since you show that $\dot{m}$ is correlated with L, you should normalize to a given L value before looking for $\dot{m}$ as a function of T_{eff}.

Snow: I agree, but I'm not certain this is worth trying on the basis of this crude mass loss rate parameter; it would be preferable, of course, to have better-determined mass loss rates for any discussion of correlations such as this. Ongoing work by Lamers and myself should produce a uniform set of mass loss rates within a few months for most of the stars in the Snow and Morton survey.

Dearborn: Is the lack of correlation shown by you between mass loss rate and T_{eff} possibly due to the fact that you consider only O stars? Would it not be more obvious if you considered later type stars?

Snow: Certainly this is possible, and furthermore, M_{bol} and T_{eff} are not entirely independent, so as Hutchings just pointed out, the luminosity must be normalized before one looks at temperature effects. In any case I would hesitate to extend this to B stars now, because the assumption that N V dominates would certainly not hold so this mass loss rate parameter based on N V absorption would no longer be expected to correlate with the true mass loss rate. Again, my inclination is to wait until we have actual mass loss rates for more stars.

Heap: What is the highest terminal velocity observed in young O stars?

Snow: 3400 km/s seen in 9 Sgr.

Bidelman: The high-latitude B1 supergiant Rho Leonis appears to show, from Copernicus data, substantially higher mass loss than would be expected from its spectral type and luminosity. Perhaps this is an indication of low mass or some other stellar peculiarity.

Morton: The *Copernicus* UV scans show many examples of stars with similar visual spectral types but widely different P Cygni profiles. Since the P Cygni profiles originate in a region where small changes in conditions can have large effects I would believe the visual spectral type.

Conti: The night-to-night optical variability in λ4886 and Hα observed in ζ Pup are reminiscent of similar behavior in λ Cep, another relatively rapidly rotating Of star. I would like to stress that this variability is not a common phenomenon.

Snow: Yes, in fact for both of these stars, which as far as I know are the only ones for which simultaneous UV and visible-wavelength observations of variability have yet been made, the fluctuations seen in the UV are weaker than those in the visible, as though the disturbances dissipate as they flow outwards.