STELLAR VARIABILITY AND INDIVIDUALITY: OBSERVATIONS AND IMPLICATIONS

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ABSTRACT

Customarily, one assumes that the internal structure of the star is not changed by a mass-flux from the atmosphere; thus one changes evolutionary calculations with mass-loss from those without it only by homologously decreasing the mass at each static evolutionary step. Furthermore, it is customary to assume that the mass-flux can be expressed in terms of only the thermal parameters (luminosity, T_{eff}) or (g, T_{eff}). Sometimes rotation is introduced, but only as a modification of equatorial gravity, not of internal nonthermal structure. The phenomena of large-amplitude variability in times short compared with evolutionary ones, and of individuality (two stars of the same taxonomic class having different atmospheric distributions of T_e and density) invalidate such static evolutionary calculations. We summarize the evidence for such large-amplitude variability in Be and Ia supergiant B stars. We also summarize the evidence for individuality as exhibited by observations: of OVI in OB stars; of x-ray luminosity across the HR diagram; of far-UV spectra of O stars; and of visual and far-UV spectra of Be stars. These observational results require nonthermal fluxes of mass and nonradiative energy to be imposed from below by the subatmosphere; which implies a nonthermal structure of subatmosphere and at least some part of the interior. Such nonthermal structure must then be included in evolutionary calculations. Thus current observations of nonthermal mass-flux from essentially all stars require including a nonthermal internal structure, not simply a mass-loss, in evolutionary calculations.

I. INTRODUCTION

C. Chiosi and R. Stalio (eds.), Effects of Mass Loss on Stellar Evolution, 131–153.

The title of this Colloquium has been made too vague by the great increase in high-quality observational material over the last few years. A better description of what should be the focus of the Colloquium might be something like: "Implications of the Observed NonThermal Mass-Fluxes on Modeling of Stellar Structure and Evolution".

The fault of the original title is that it implies we know the change in stellar structure at a given epoch, when we observe a nonthermal mass-flux of some size at that epoch, relative to the wholly-thermal structure we customarily compute. If the mass-flux were simply by thermal-evaporation from the outermost atmospheric layers, or by any other mechanism whose presence introduces no significant change in modeling of subatmospheric regions, then one could proceed as the title implies, and as do the thermal models in sections V-VII, to adopt present static structural models, and introduce mass-loss as a simple homologous decrease of mass between steps in the sequence of evolutionary phases computed according to conventional thermal structure in which mass-loss is ignored. One could try to represent mass-loss as a function of only (mass, luminosity, radius, composition) or any equivalent set of static-modeling parameters. Under such circumstances, all stars having the same values of these thermal parameters should show the same mass-loss, and the same outer-atmospheric structure compatible with such mass-loss. Furthermore, since we do not discuss internal models of cepheids, etc here, the "statically -modeled" stars should show no variability in such atmospheric structure (or mass-loss) in times short compared with evolutionary.

In the same way, those astronomers focused on observing and modeling stellar atmospheres could try to proceed as many have in sections I-IV, trying to represent wind-data in terms of a dependence on only the thermal parameters of two-dimensional classical taxonomy and modeling: luminosity, spectrum, or gravity, effective-temperature; possibly, the third parameter of composition might be added. They can debate wether luminosity, gravity alone suffice to represent mass-loss size, as in the radiative-acceleration theories; or whether some coronal-heating mechanism is necessary to fix mass-loss size, with "terminal" velocity fixed otherwise, as in radiative acceleration for the hot stars, and something else for the cool stars. But each of these representations/ theories assumes, a priori, that all stars within some given taxonomic class --- which is defined by the classical thermal parameters --- should have the same time-independent characteristics of that part of the atmosphere lying above the photosphere, including the mass-flux or wind atmospheric expansion, atmospheric heating as reflected in the chromosphere-corona, and interaction with the environmental ISM.Then any variability of a given star, or differences between stars in a given taxonomic class, should only represent classical thermal type fluctuations, be expressible in terms of fluctuations in such thermal parameters, and be small, with negligible effect on subatmospheric structure.

Elsewhere (1980a) and possibly here (1980b), Lamers has tried to present the best case for this "small departure about the classical model", drawing his data from the hot stars, mainly the O supergiants. He has tried to express, statistically, mass-loss in terms of an algebraic dependence upon only, L, T_{eff}, and g. The group around Castor (1980) have produced a similar such expression. The scatter-diagram presented by Conti and Garmany (1980) when mass-loss is plotted vs luminosity, is reduced to a systematic trend, by Lamers and by Conti (1980), by interpreting different regions of the graph as representing different evolutionary phases of the O, Of, and WR stars, each phase having a differing mass-loss. These authors attribute variability, which they find small in the O supergiants, again to fluctuations.

Andriesse (1981) has introduced a fluctuation theory of mass-loss, extending all across the HR diagram rather than just to some hot stars as above. He derives explicit algebraic expressions for mass-loss in terms of powers of luminosity and (R/M), multiplied by a factor depending upon the internal structure of the star, but the same for all stars of a given taxonomic class. Its value ranges over about a factor 50, but is computable, a priori, from internal, static, thermal models.

From the above, it is clear that most current efforts of determining, and using, mass-loss are directed toward the above assumption of homogeneity of such mass-loss within given taxonomic classes. There appear gross trends across the HR plane in such mass-loss. In the same way, there appear to be gross trends in the level of x-ray emission (Vaiana et al., 1980), which presumably measures some aspect of nonradiative atmospheric heating, which is ultimately responsible for chromospheres-coronas. However, the range in such x-ray emission is large, powers of ten, within a given taxonomic class, and there is some evidence for variability. In the same way, from a study of a number of OB stars --- both main-sequence and supergiants --- there is strong evidence for variability and "individuality" among stars of the same taxonomic type, superimposed on the above "trends". We summarize some aspects of those observations; and conclude that such data link mass-loss to a non-negligible change in subatmospheric structure from that computed for strictly thermal models; and that such subatmospheric structure is not necessarily the same for all stars of a given classical taxonomic type nor for a given star over all periods short compared with evolutionary.

II. VARIABILITY

From modern observations, an increasingly-large number of stars show some degree of variability in spectrum and luminosity. This is even more striking in the far-UV than in the visual spectral regions. The current question among astronomers is whether such variability is sufficiently-large to require fundamental change in modeling stellar atmospheres over the classical models, which depend only on T_{eff} and g; or whether only small perturbations are required, whose sizes can be predicted from knowledge of T_{eff} and g alone. Such fundamental change is required if we can show that values of nonradiative energy and mass fluxes are independent parameters; not predictable from only T_{eff} and g; but require a knowledge of a subatmospheric nonthermal structure. The presence of large-amplitude variability would support such a situation. In the last few years, concurrent visual, far-UV, and x-ray observations have put into strong focus the essential characteristics of many examples of such variability. Probably because of the long history of visual observations of bright B stars, such evidence is particularly striking for them. We summarize it.

A. Be stars:

We have a century of visual observations of these stars, which constitute 25% of the population of B stars--so are hardly negligible. Be stars are well-known to show many aspects of variability; but during the last few years, from combined visual and far-UV observations, many characteristics of the most pronounced and largest amplitude aspect, that of the three phases of Be stars, have emerged; so we place the greatest emphasis on it.

1. 3-Phase aspect of Variability: Once thought to represent 3 different kinds of objects, the three distinct types of spectra --- Be, B-shell, B-normal --- have been repeatedly observed to be shown by the same star at different epochs, separated by times enormously shorter than evolutionary. So, we recognize these as simply different phases of variability, which a given star can traverse many times during nonevolutionary times. Figure 1 gives typical $H\alpha$ profiles for these phases: the Be phase is interpreted, roughly, as one of an extended atmosphere, 5-20 photospheric radii in extent; the B-shell phase can be the same, but surmounted by a cooler region, marked by the presence of FeII; the B-normal phase simply has an atmosphere not sufficiently extended to produce $H\alpha$ emission. Clearly such extended atmospheres link to a mass-flux. What size mass-flux is to be associated with a given atmospheric extent is presently open to question, as well as is the question whether an interaction with the ISM is necessary to produce such an

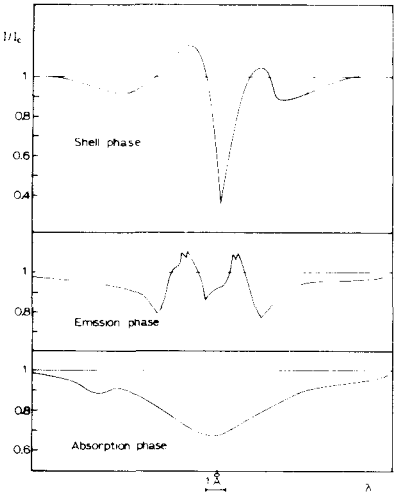


Figure 1: Typical H_α profiles for B-shell, Be and B-normal phases.

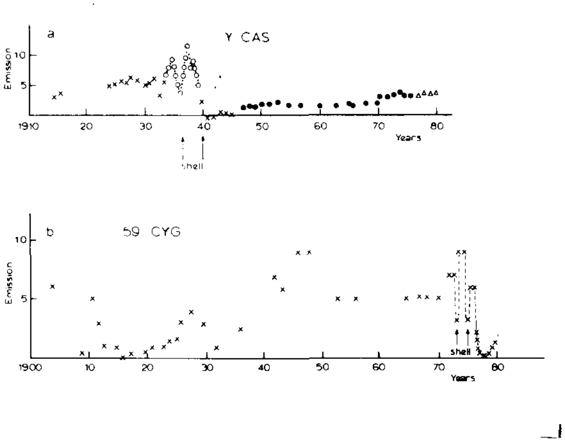
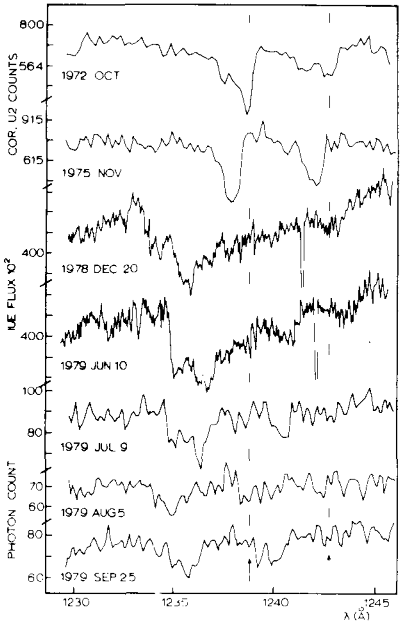


Figure 2: Long term variation of γ Cas and 59 Cyg in the visual.



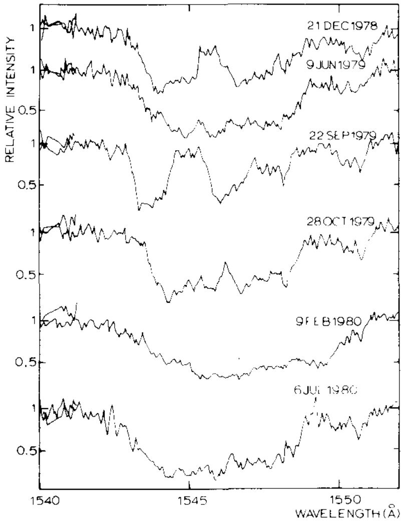


Figure 4: CIV resonance lines in 59 Cyg.

Figure 3: NV profiles in 59 Cyg. 1972 and 1975, Copernicus; December 1978 and June 1979, IUE; July-September 1979, Copernicus.

atmospheric configuration with or without the "FeII shell". This last is, apparently, characterized by expansion velocities of less than some 100 Km/s in the region of the FeII formation, and certainly a $T_e < T_{eff}$ for at least the earlier Be stars.

Figure 2 is an 80-year summary of two stars exhibiting such a 3-phase variability: γ Cas (B0.51Ve) and 59 Cyg (B1.5Ve). There is a similarity in pattern of behavior, but not in amplitude, time-scale, or epoch. We were fortunate to "catch" 59 Cyg in a combined sequence of visual and far-UV observations during the last phase-sequence shown in Figure 2. (Doazan et al. 1980a, 1980b). The behavior of the NV resonance lines between 1972 and 1980 are shown in Figure 3. The wind-velocities change systematically from -100 Km/s to -1000 Km/s as the star passes from the Be, through the B-normal, and approaches Be again; superposed on this is an apparently-erratic fluctuation of some 500 Km/s during the increasing-Be phase. We have not such a long coverage of CIV lines, as shown in Figure 4; but the behavior is similar. To derive a mass-flux requires an atmospheric model, which does not exist. If one simply follows many current approaches and multiplies an equivalent width by a velocity, the mass-fluxes show a variation following that of the velocities cited. Note that on this basis, the largest mass-flux would come at the smallest H_α emission; and the largest rate-of-change in mass-flux, during change from one phase to another.

γ Cas, in Figure 2, has been observed only in the same quasi-steady Be phase, within which visual changes occur only in the relative intensity of the H_α emission peaks. Figure 5 shows NV, and Figure 6 shows SiIV, at the stated epochs. Note two differences with 59 Cyg, at its observed epochs. First, γ Cas shows two sets of lines: one near -100 Km/s which is always present; one near -1400 Km/s which comes and goes, but always at essentially the same velocity. We interpret these as pre- and post-coronal velocities. Second, 59 Cyg appears to have shown the same velocity configuration just before it left the Be phase in 1972.

Finally, relative to internal structure calculations, note that statistically Be stars are 1 magnitude brighter in the visual than B-stars; and such difference can persist over decades. We are currently trying to assemble far-UV data to make precise any luminosity differences in this spectral region. Note also that the very small amount of existing IR data on Be stars suggests atmospheres extending out to some 100 photospheric radii. Tomorrow, Zorec, from our group, will present some very preliminary ideas on interaction of these Be-winds, at different phases, with the ISM.

2. Be-variability within phases: Such variability comes in a variety of time-intervals and amplitudes. Very roughly, the greater the

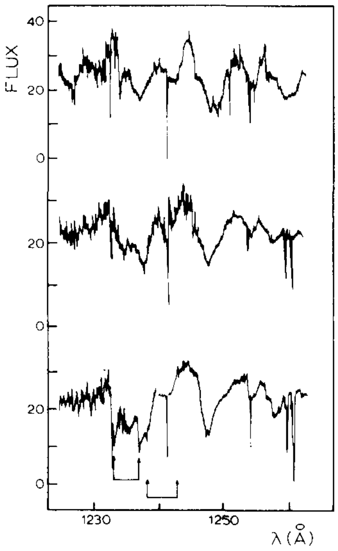


Figure 5: NV resonance lines in γ Cas; periods of observation are the same as for the next figure.

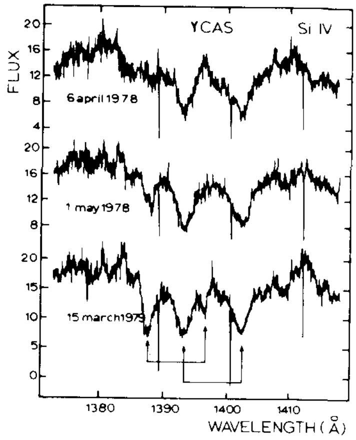


Figure 6: SiIV resonance lines in γ Cas.

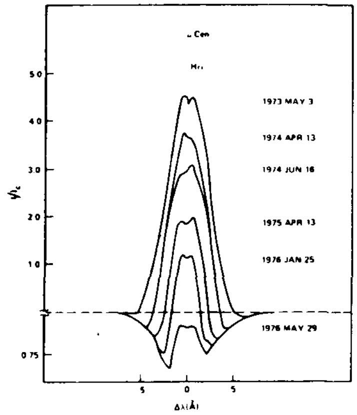
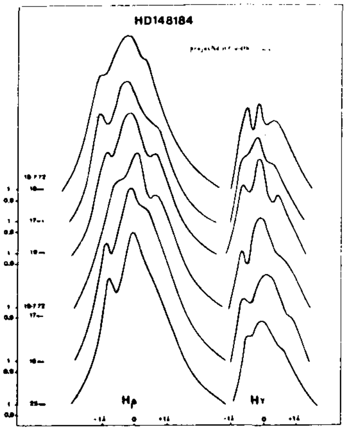


Figure 7: H_α profiles of μ Cen.



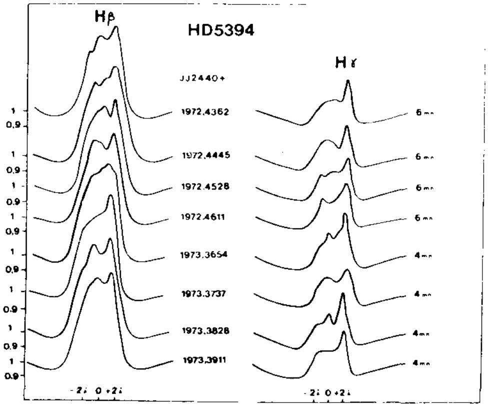


Figure 8: H_β and H_γ profile variations over time intervals of days in χ Oph.

Figure 9: H_β and H_γ profile variations over time intervals of hours in γ Cas.

time-scale of variability, the greater the amplitude. Figure 7 (Peters, 1979) shows H_α variation within a Be phase over some 3 years. Figures 8 and 9 (Doazan, 1976) shows H_β and H_γ variation over time-intervals of days and hours.

B. B Supergiants:

Just as the Be stars show the greatest amplitudes of variability among the main-sequence hot stars, so the B supergiants show the greatest amplitude of variability among the hot supergiants. Also, we stressed that when one divides main-sequence B stars according to the presence or absence of emission lines, one finds the emission line stars to both show the greatest amplitude variability, and to be associated with a greater visual luminosity in those phases where they shows emission lines. In a similar way, one finds two types of B supergiants: classified Ia and Ib. Type Ia shows greater variability than Ib; has, statistically, about 1 magnitude greater luminosity in the visual; and while Ia usually shows some kind of emission in H_α , Ib rarely shows this. Note that these characteristics are trends, not invariant properties as required by strictly-thermal models; we return to this in section III. We summarize the variability characteristics.

1. Profile changes in 2-3 year time-scales: Figure 10 shows the MgII resonance lines in β Ori(B8Ia) between 1975 and 1978. The profiles consist of an unchanging component at zero velocity displacement, which is strong and symmetric with a line-width of about 140 Km/s; and of absorption components which are variable and shifted by up to -200 Km/s. They were absent in Boksenberg's (1975) data; weak in Selvelli et al. (1977) data; and strong in the Lamers et al. data of 1978.

2. Profile changes in months and days: Figures 11 and 12 show, respectively, H_α and NV profiles in $\varkappa$ Ori(B0.5Ia). The striking feature of the H_α behavior is the oscillatory nature of the line-center; however, the associated changes in the line-wings are hardly minor. The intervals between A, B, C are months; between A1 and A2, and B1-B2-B3 the time interval is days. Thus we see that there can be as large-amplitude changes in days as in months. Clearly, a physical picture is completely lacking. Note also that the line widths, (expressed in terms of velocities but with no implication on explanation in such terms) change from 1000 Km/s to 500Km/s in the same few days. The NV data was, unfortunately, not taken at the same epoch. However, the profile-changes, while not as spectacular, show indeed significant changes in terms of any modeling.

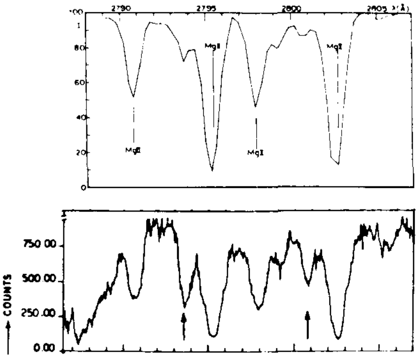


Figure 10: Selvelli et al.(1977) and Lamers et al. (1978) MgII resonance profiles in β Ori.

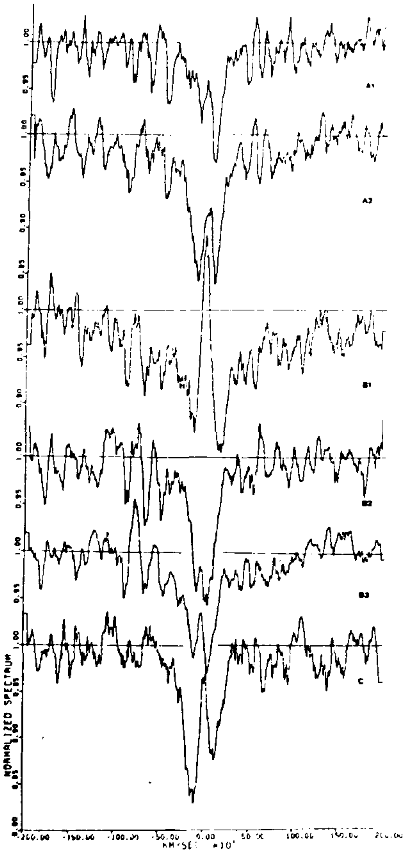


Figure 11: H_α profile in $\varkappa$ Ori Stalio et al. (1979).

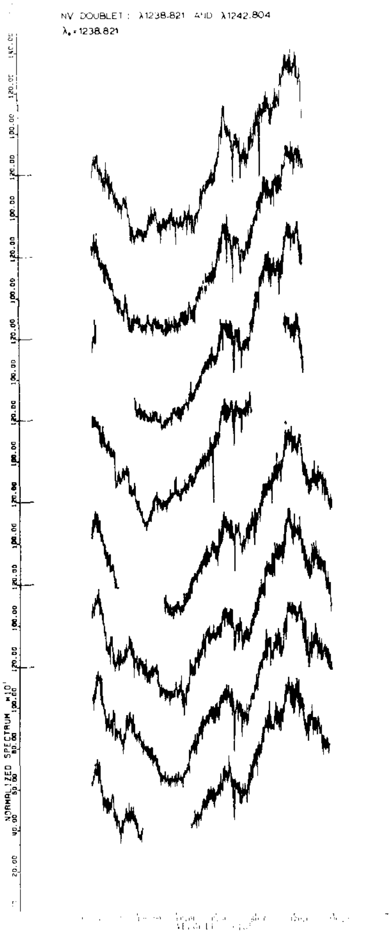


Figure 12: NV profile in $\varkappa$ Ori Stalio et al. (1980)

III. INDIVIDUALITY

Once one admits that there is a large-amplitude variability in atmospheric structure, then one must be prepared --- in any survey of stars taken at one given epoch --- for an apparent "individuality" in appearance among stars of the same taxonomic class. Figure 2, comparing the phase-change behavior of γ Cas and 59 Cyg, shows well this point. However, there are stars which, during the whole time-range during which they have been observed, consistently differ from other stars of the same taxonomic class, over their time-range of observation. So, one interprets these differences between these stars as "individuality"; at least over time-scales shorter than the maximum time-range of observation. This "individuality" is important, for anyone using data from these stars, as a basis for mass-loss evolutionary calculations.

With the above qualification, it is then well-known that Be and supergiant B stars show strong characteristics of individuality. One can find two Be or B-sg stars showing some similar features; but one can hardly find two of these stars showing identical spectra and patterns of variability. In the same way, among "normal" main-sequence stars, all observers know that increasing resolution leads to the conclusion that two stars in the same taxonomic box are hardly identical. While, for "normal" stars, these differences in the visual spectral region are reasonably small, the situation in the far-UV is quite different. We summarize some aspects of it.

A. OVI Behavior:

From Copernicus high-resolution data, Morton (1979) found strongly individualistic characteristics in normal stars, the variety of their spectra not being correlated with spectral type. Figure 13 shows the OVI profiles in τ Sco and ν Ori: both are BOV, and have Vsini = 25 Km/s Note the emission in ν Ori and not in τ Sco; and the strong differences in line shapes and widths.

B. O8III:

Our IUE observations of λ Ori and HD 175754, of the same spectral type--Figure 14 ---show quite similar profiles and displacements for CIV and NV; but for SiIV, there are striking differences in strength, displacement, and asymmetry. Clearly the velocity varies through the atmosphere, but differently for the two star: Carrasco, Costero, and Stalio (1981) have just obtained an observation of HD 175754 at another epoch, which shows a 300 km/s change in position of the blue edge of CIV; no change in SiIV; and changes in the NV profile.

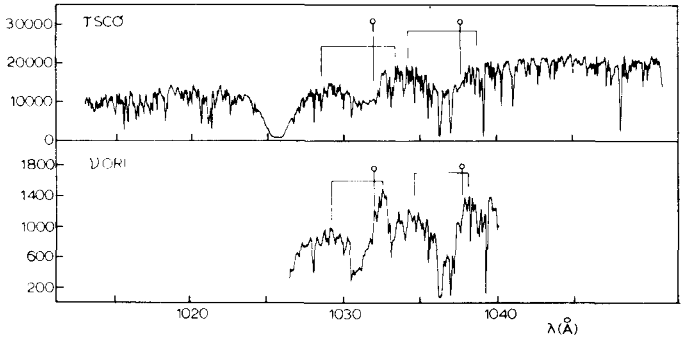


Figure 13: OVI profile in τ Sco and ν Ori.

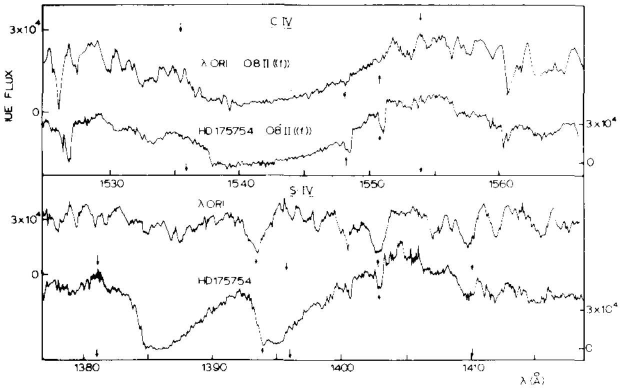


Figure 14: CIV and SiIV profiles in λ Ori and HD 175754.

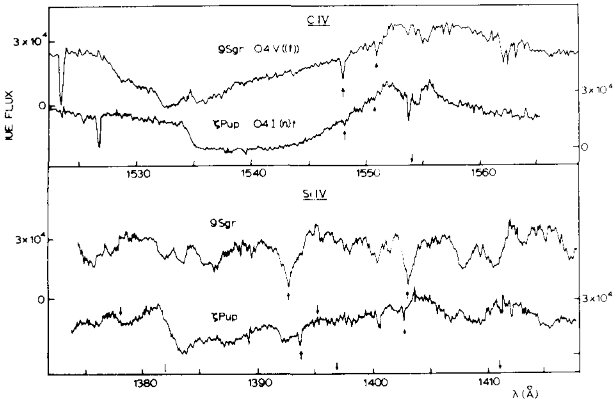


Figure 15: CIV and SiIV profiles in 9 Sgr and ζ Pup.

C. Comparison of an O-sg and O-ms of same spectral type:

A comparison of 9 Sgr (O4Vf) and ζ Pup (O4Iaf), Figure 15, shows that the so-called terminal velocity, from NV the CIV resonance lines, is larger in the ms star than the sg by about 1000km/s. The SiIV lines are undisplaced in the ms, but displaced in the sg. Further, the total absorption is greater for the ms star. Thus, for this example, the mass-flux from the ms star is much larger than that for the sg, contrary to the usualbelief.

D. The Be Stars:

The wide variety of line-profiles in the visual, the great diversity in amplitude, time-scale, and pattern of variability in the visual, and now, the great variety of profiles, line-displacements, etc shown in the far-UV are well-established observational facts. Although no theory of the Be phenomenon --- either atmospheric or subatmospheric--represents even a small fraction of these facts, all the ad hoc models proposed for them rest essentially on only geometrical considerations: the inclination of their rotational axis to the line-of-sight. The interpretation of their statistically larger values of Vsini in terms of rotational velocity has led to the ideas of rotationally-forced ejection; so that mass-loss effects are presumed greater at the equator.

Very recent IUE observations by Peters (1980) contredict,fundamentally, this picture.We had observed for 59 Cyg,having Vsini=320 km/s, the largest line-displacements ever found, to that epoch: in NV and CIV, not in SiIV. To these data Peters has now added two more stars: of the same spectral type: B2V. ω Ori, a pole-on star with Vsini = 130 km/s; and 66 Oph, with Vsini = 260 km/s. Each of these stars shows -800 km/s line-displacements in the CIV lines. Above, we have already noted such velocities in 59 Cyg are highly variable; we await further observations to see what happens for these other stars. But clearly, "rotational instability" can hardly be called the sole underlying explanation of Be phenomena. And it is very hard to see how to interpret the three-phase Be star behavior of Figure 2 in such terms.

E. X-ray Observations:

Vaiana et al. have in press their data on X-ray observations of some 140 stars, covering all luminosity and spectral classes. Their conclusion is that some stars in each spectral class show coronal-level soft X-ray emission. By itself, this is significant; but equally significant is the fact that their data show a range of such X-ray luminosity of nearly 2 dex for each spectral class. Whether this reflects a range in the coronal intrinsic emission, or a range in the absorption by the overlying, postcoronal part of the atmosphere, is not the critical point here. Whichever is the cause, these results reflect an individuality in X-ray flux from "similar" stars; thus, in whatever way, a range in atmospheric structure --- hence in mass-flux and nonradiative energy flux. Vaiana et al. main results one presented in Figure 16.

IV. CONCLUSION:

With this weighty evidence for large-amplitude ---ie nonthermal and nonlinear ---variability, and stellar individuality, for a wide variety of hot stars --- peculiar and normal, ms, g, and sg --- we fail to see how anyone can take seriously models and computations for mass-loss and its evolutionary effects, which are expressed wholly in terms of thermal parameters. Such computations are exercises in mathematics, not in physics or astrophysics.

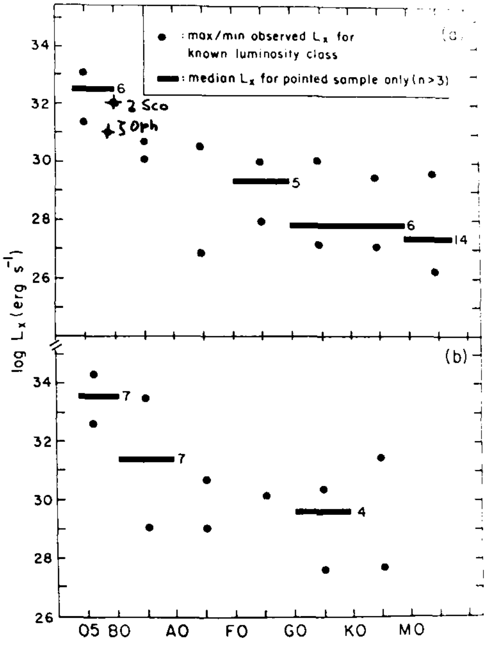


Figure 16: Einstein X-ray fluxes for different spectral types.

REFERENCES

Andriesse, C.D.: 1981, this conference.

Boksenberg, A., Kirkham, B., Towlson, W.A. Venis, T.E., Bates, B., Carson, P.P.D., Courts, G.R.: 1975, Space Res. 14, 533.

Carrasco, L., Costero, R., Stalio, R.: 1980 submitted to Astron. Astrophys.

Castor, J.I.: 1980, Workshop on Mass Loss from Early-type Stars, Boulder.

Conti, P.S.: 1980, Workshop on Mass Loss from Early-type Stars, Boulder.

Conti, P.S., Garmany, C.D.: 1980, Astrophys. J. 238, 190.

Doazan, V.: 1976, in "Be and Shell Stars", IAU Symposium No. 70, D. Reidel Publ. Co, p. 37.

Doazan, V., Kuhi, L.V., Marlbourough, J.M.,Snow, T.P., Thomas, R.N.: 1980a in "Proceedings of the Second European IUE Conference" ESA-SP-157, p. 151.

Doazan, V., Stalio, R., Thomas, R.N.: 1980b in "The Universe at Ultraviolet Wavelengths: the First Two Years of IUE" Washington, Goddard SFC, in press.

Lamers, H.J.G.L.M., Stalio, R., Kondo, Y.: 1978, Astrophys. J. 223, 207.

Lamers, H.J.G.L.M.: 1980a, Workshop on Mass Loss from Early-type Stars, Boulder.

Lamers, H.J.G.L.M.: 1981, this conference.

Morton, D.C.: 1979, Mon. Not. R. Astron. Soc. 189, 57.

Peters, G.J.: 1979, Astrophys. J. Suppl. Ser. 39, 175.

Peters, G.J.: 1980, private communication.

Selvelli, P.L., Crivellari, L., Stalio, R.: 1977, Astron. Astrophys. Suppl. 27, 1.

Stalio, R., Rusconi, L., Sedmak, G., Arpigny, C., Georgelin, Y., Rocca, B.: 1979, Astron. Astrophys. 77, L10.

Stalio, R., Sedmak, G., Rusconi, L.: 1981 submitted to Astron. Astrophys.

Vaiana, G.S., Cassinelli, J.P., Fabbiano, G., Giacconi, R., Golub, L., Gorenstein, P., Haisch, B.M., Harnden, F.R.Jr., Johnson, H.M., Linsky, J.L., Maxson, C.W., Mewe, R., Rosner, R., Seward, F., Topka, K., Zwaan, C.: 1980, Center for Astrophysics, preprint.

DISCUSSION FOLLOWING HEARN AND THOMAS

COSTERO: The variation on the CIV resonant lines of HD 175754, just mentioned by Dr. Thomas, was found a few days ago by Carrasco, Stalio and myself, while looking a three spectra of this O8 II ((f)) star. The spectra were obtained with the IUE (high resolution camera) on September 1978, August 1979 and June 1980. The two latter show no appreciable differences between each other. In the doublet CIV wavelenght region, the slope of the shortward wing has changed and the value of V increased by about 300 km s^{-1} in less than a year. We know of no variations of this kind being noted before in early-type stars such as HD 175754, and believe that some attention should be directed towards the possible long-term (and, may be, short-term) changes in the terminal velocity of the stellar wind in OB stars. The other resonant lines from highly ionized ions show no appreciable change of the V value, although some variation of the emission P Cyg components may be real. It is specially worth mentioning the large variation of what could be identified as the CIIIλ1247 line in the emission wing of NVλ1242.In order to conclude that the latter changes are real or not, we must first look very carefully at the raw data and check on possible reduction errors.

CONTI: I would like reiterate a point I made yesterday: lets not lose sight of the forest for the trees of individual stars. There is a general trend of increasing mass loss rate with luminosity and there is less scatter in the $\dot{M}$ - M_{bol} diagram when the effective gravity is considered, as Lamers showed. This suggest to me that no other physical parameters are necessary but clearly others may be involved. These include rotation in which the Oe,Be stars are extreme manifestations. I believe its probably differential rotational energy in put into the stellar wind that modifies its structure. Of magnetic fields we have no direct evidence, but its likely presence in stars may well play a role. My own personal preference is that composition, different from solar, plays an important role in the spectral appearance of WR stars. Their winds are probably different in C/N and/or H/He composition from otherwise normal stars. Let's keep in mind that the stellar wind parameters are p(r), v(r), and I(r) which may not be coupled.

LAMERS: Dick has shown a beautiful list of examples of variations in line profiles and differences in profiles between very similar stars. This demonstrates clearly that there are changes and differences in the structure of the atmospheres between different stars. But the question is: do differences and changes in line profiles also imply large differences in mass loss rates (as Dick assumes)? Our own analysis suggests that stars which have different profiles may still have similar mass loss rates. How do you know that changes in profiles are due to changes in the mass loss rates and not due to changes in the structure (ionization, temperature, velocity, etc)?

THOMAS: Let me paraphrase Lamers, to put his remark into focus:"you, Thomas et al. have shown beautiful examples of line-profile, and line-displacement, variations which show that there are changes and differences in atmospheric structure, between stars, and within a given star. But what makes you sure that such changes imply changes in mass loss? On the contrary, I, Lamers, by assuming: (1) the same unchanging V(r) for all stars; and (2) normalizing everything to same radio spectrum (ie asymptotic density distribution) have reduced the factor-100 scatter in mass-loss rate shown by Conti's data to a factor-2 scatter. So, I conclude that stars with widely different profiles can have the same mass-loss rates; so how do you know profile-change is not simply (V, ionization, temperature, etc) change?" Then let me respond that I do not understand how Lamers can both agree that our data require changes and differences in atmospheric structure, within one star and between different stars, and expect us to believe any conclusions based on his assumption that the V(r) and asymtotic density distribution are constant within one star, and unchanging from star to star. Our data, and his assumptions, are absolutely opposed. Moreover, even his JILA-colleagues (van Bloerkom, Kunacz, for example) have showed V(r) to differ among stars, and to differ from the radiative-acceleration formulae Lamers uses. One must realize that to first approximation, V(r) fixes atmospheric density structure, and mechanical heating fixes T_e-distribution; of course there is a coupling, which gives second approximation . But ignoring these thermodynamic (nonthermal, non-linear) requirements, to speculate models, then use them to force data into the assumed pattern---- I prefer the direct observational results, not these "mistranslated" ones. History, especially speculative-mathematical aerodynamic history, is full of erroneous conclusions resulting from such misdiagnostics of data. I repeat: to assume, a priori, that τ Sco--- a normal B star--- and 59 Cyg, γ Cas, ϑ Oph--- all "emission-line" stars, have the same velocity distribution, is unwise, because we have enough data to check this, and find it invalid. If you want to apply such assumptions to stars for which you have insufficient data to check them---caution. Look at the evolution of Conti's thinking on individuality and variability, as his data have so greatly increased these last two years, since Vancouver. You had better join his conclusions on "scatter" of data between stars, rather than try to explain them away, using bad physics.

DE LOORE: I have objections against the examples Dick Thomas is using. γCas is indeed a far evolved star, an X-ray binary with a neutron companion. It is not exact to use this as an example. Other X-ray binaries with Be-companions show all very strong variations in their spectral lines: varying H_α , filling in of the emission by absorption, changing H_α emission, etc. If we want to say something about the evolutionary states of these stars we have to do computations and therefore we have to include mass losses, with mass loss rates to be defined in a simple not too bad way. Say $\dot{M} \sim L$, or by including some more parameters. So I would join the remark of Icko Iben: either we do nothing concerning evolution and we wait some ten or twenty years, or we try to use the material we have. Hence we try to include into our computations mass losses and we need some equation, in agreement with the bulk of the observations. A single main sequence star is not the same as a "mainsequence component" in a binary system. The first one starts his life, the latter has accreted matter from its companion, and the matter of the interior has been already processed by nuclear reactions. Binaries moreover are not the same thing as single stars!

THOMAS: Combined response of Doazan and Thomas.
1) the examples of 59 Cyg and γ Cas were selected because the pattern of their long term variations in the visual over a century show striking similarities. Their spectral types, determined with great acracy by L. Divan, are B 1.5 Ve and B0 IVe respectively. 59 Cyg is not known to be a binary and it is an unevolved star. That γ Cas is a far evolved star, an X-ray binary with a neutron companion, is wholly a conjecture by persons who can find no other way to interpret its X-ray flux. By contrast, over a century of observations, one has found no evidence for binarity in all other kinds of data. De Loore stated he has many references showing its binarity. We challenge him to produce just one, which is not just conjectural and not just based on X-ray data. If he wants to interpret γ Cas in terms of a highly evolved interacting binary with a neutron star companion, then he should explain why 59 Cyg, which is a single unevolved star, shows such a similar pattern of variability. 2) Further, in his haste to exclude data on variability, in order to justify simple computing formulae, De Loore apparently did not listen to the main thrust of our paper. This was that many Be stars show, successively Be, B-normal, B-snell phases, passing back and forth between these phases in times very short compared to evolutionary times, but often long compared with those envelope-storage times associated with cepheids. And, mass-loss apparently differs strongly between and within these phases. In spite of the highly individualistic behavior of most

Be stars in this respect, and no established periodicity in such phase-changes, we did succeed in identifying those two Be stars--- γ Cas and 59 Cyg --- which show similarity in such pattern, at least in the last century. We were lucky to catch 59 Cyg just at a phase where it shows rapid and very large changes in velocity --- and, we interpret, in mass-loss, since equivalent widths of the lines at different epochs are roughly similar. We watch with interest to see if it returns to a similarity with γ Cas's, and its own, at earlier epochs, velocity pattern. To ignore all this, in your glib, speculative dismissal of such stars as "evolved", binary, ect, without observational evidence for such, seems to us to set aside important empirical clues, not just to mass-loss, but to the causes of mass-loss, in terms of stellar structure as it is, not as you speculate it to be. 3) If De Loore, Iben, etc justify their use of simple formulae, which do not agree with observations, simply because "we cannot sit still, doing nothing, for 10-25 years", can we simply comment that this has been the perpetual response from the speculative, machine-controlled, model builders against every change in the physics of atmospheric modeling that has been forced by observations: for example, the need for nonLTE diagnostics and structure, the prevalence of chromospheres-coronas which are not necessarily linked to convective-driven acoustic flux, a mass-loss not originated by radiation pressure or a corona. It is always easier to program a simple formula, than to try to understand the basic physics by analysing, coherently with the basic physics, new observational material. It is just 8 years since the Goddard symposium, where the "speculative-theoreticians" insisted we could not use the WR stars as observational examples of early-type stars with chromospheres, coronas, and hot-wind mass-loss, because these WR stars were "exceptional". Eight years, during which the literature was filled with computations and "theory" based on cold-winds, radiative origin, ect; so much so, that people came to believe such "speculations"; and even today, you retain them in your simple formulae for size of mass-loss, not just radiative acceleration. If you believe such erroneous calculations, rather than trying to observe in astronomy, or experiment in aerodynamics, to find valid physics --- ok: amuse yourself. But today, you also enthusiastically embrace the WR stars as "the most normal" of all stars; because, apparently they accord the best with your "evolutionary tracks" for the hot star evolution. But, you want to discard data on the Be stars, because they are "peculiar" in having variable mass-loss, which doesnt accord with you "simple" formulae. Do you really espect us to take seriously this kind of numerology? Better, you should be trying to make non-thermal, dynamical models of stellar structure, before you talk about evolution of structure. And, you might profit by asking how to reconcile the presence of "peculiar" stars with the evolutionary tracks of "normal" stars.

RENZINI: Earlier in this discussion Peter Conti tried to give names to "stellar individuality" and I think that everybody would agree that rotation/magnetic fields/surface composition are good candidates. Does Thomas have additional suggestions?

THOMAS: You confuse observations of stellar individuality with possible causes for such. Observations, by Conti, by ourselves, by others refer to stars of the same classical spectral class (ie same luminosity, same strenghts of certain absorption lines used in classification) showing other spectral features that are widely different. Eg, one star with absorption H_{α} , another with emission: one star with NV line displaced 100 Km/s, another with it displaced 1000 Km/s; same, re line profiles; same, re maximum degree of ionization shown. According to classical atmospheric structure, and classical structural evolutionary calculations, such "characteristics of individuality" should not exist. Eg, according to "radiative-origin" theories of mass-loss, which you adopt for hot stars with your "simple" computing formulae, all stars of same class should show same mass-loss: contrary to observations; and furthermore, these stars should not be variable. Why such individuality? I think it is because your structural-evolutionary theories are static. Hence, all nonstatic (nonthermal) modes are candidates for such "explanation": rotation, convection, pulsation, magnetic fields etc. But not just as eg a rotation that diminishes gravity; but as rotation etc that make a dynamic interior state, whose amplitude may of course vary considerably over the star: but which produces, from below, the non-radiative energy and mass-fluxes, whose effect is to produce the above observational characteristics of individuality.

MAEDER: Variability has been invoked by both preceding speakers as an important mechanism for mass loss. Several features of the instabilities of O, B supergiants are known, which show that these instabilities are very different from those of Be stars referred to by Dr. Thomas: 1) Increase of the amplitudes with luminosity. 2) Existence of cyclic variations with characteristic times from 5 d. (B3 Ia) to more than 100 d. (types later than G). - 3) Period-Luminosity - Color relation parallel to the Cepheid one. Moreover from a study of 22 stars, we see that there exists a relation between the amplitude of the variations and the rate of mass loss, in the sense that the rate of mass loss appears to grow exponentially with the amplitudes of the variations over the range considered.

VAUCLAIR: I didn't hear anything about the polarisation in Be star spectra. I thought that from the polarization of the continuum one could infer that the mass loss is not spherical but rather equatorial. This would give observational evidence that Be stars are different from other stars which loose mass spherically, and that it is linked to rotation effects.

DOAZAN: The polarization in Be stars indicates that their atmospheres are not spherically symmetric. If one assumes that all Be stars are rapid rotators, then one concludes that the atmospheres of all Be stars are flattened at the equator and that mass loss occurs only in the equatorial regions. This simplified picture is contradicted by the recent UV observations made by Peters (1980 Worshop on Mass Loss of Early-type Stars, Boulder) which show line displacement of ~ 800 Km/s in a pole-on star. This is the same size as that observed in Be stars of large v sini. These observations show that mass loss in Be stars occurs in polar regions as well as in equatorial regions; and that the simplest interpretation of a Be star being similar to a normal B star, but differing only by the reduced g_{eff} due to rapid rotation, disagrees with observations. Clearly differential rotation and other nonthermal effects should be taken into account to produce a mass-flux and so to interpret both UV and visual observations, but not simply in terms of reduced g_{eff}.

PISMIS: Today we have good evidence that profiles of spectral line vary in hot and Be stars, information that was not available at the time of the Vancouver Symposium. But the important thing is not only that profiles vary at all, but also to obtain information on some sort of characteristic period for the variations. I admit that observations are not ample enough to ascertain this; but still I like to know what is the shortest period of variation observed so far. To pursue systematically the variations of profiles of some stars at least and determine a characteristic period will be highly recommendable, as it may offer the possibility to distinguish between the different mechanisms involved in the stellar wind problem: rotation, pulsation or what.

DOAZAN: We knew log before the Vancouver symposium that in the visual, Be stars exhibit strong variations in line-profiles; while in sg, variability is equally present but of smaller amplitude. By far, the greatest amount of data, over the longest time base, almost a century, exists for the Be stars. Such variability shows a variety of time-scales: minutes, hours, days at small amplitude; years and decades at larger amplitude. For some Be stars, emission lines of strenght many times the continuum change to almost-normal absorption lines. As a general rule, such variations are not periodic, although there is evidence, for some stars, of similarity and repetition of pattern of variability. So, answering your question, what "characteristic periods" should we study, to distinguish between rotation; pulsation, etc? In our example of 59 Cyg and γ Cas, should we study the time-interval between two shell phases, two emission phases, two quasi-normal B phases? There is no evidence linking any of these phases to either rotation, pulsation, or binarity. Since the advent of spatial observations, the important addition to our knowledge is observations of strong variability in displacement of super-ionized lines, reaching 10^2 -10^3 Km/s, as well as in the profiles. So, to us, the main problem is to find the links between X-ray, farUV, visual, IR and radio variability, if any exist. The one thing that is presently clear, is that all patterns thus far established are far too short to be linked to change in evolutionary states.

LEROY: I would like to make a comment to what Dr. Hearn said about the Castor, Abbot and Klein model. In fact in my sense the boundary conditions are not treated correctly in this model and the models derived from it. I shall say something about the inner boundary (photosphere) conditions in my communication a little later. However, it appears that also in the outer regions, Castor, Abbott and Klein use a boundary condition that is unlikely, namely they assume a given range of variations of temperatures at distances far from the core of the star, of the order of 10^3 - 10^4 stellar radii, which is in my sense not correct because it is quite too far to give a satisfactory diagnostic of what happens for temperature. In fact the only natural boundary condition for the outwards part of the wind is that the thermal pressure must go to zero.

HACK: Comment to the question of Dr. Pismis on time scale of Be variability. I wish to remind two cases of long time scale variability. Tauri is a binary, $P = 130$d, which shows RV variations of the shell lines with $P \simeq 7$y. If we go back to 1920 this 7y period is no more present. Analogous case is that of 48 Librae, which was believed to be a spectroscopic binary with period ≃ 12y. However, this period is varying, increasing to 13 or 14y. In addition emission line variability in time scales of few days are observed in ζ Tauri, in several other Be and shell stars.

PRADERIE: What is the minimum number of parameters characterising the coronal models presented, which are presumably homogeneous and spherically symmetric? From a published paper by Mangeney and Souffrin (1980), there is a necessary relation between F_m (mechanical flux), T_o (typical coronal temperature) and P_o (typical density), therefore two parameters remain. How do you see the status of this question?

HEARN: The coronal models are specified by the mass and radius of the star, and the flux and period of the saw-tooth waves used for heating the corona. These calculations show that the arguments of Mangeney and Souffrin are incorrect. This is discussed in a paper by Vardavas and Hearn which has been submitted for publication in Astronomy and Astrophysics.

SAHADE: My comment is for the sake of the record. Margherita, in answering Dr. Paris Pismis' question about the time scale of variability in Be stars, mentioned the V/R variables and specifically to 48 Librae that in her view is not a binary as it was claimed. I would like to point out that the possible binary character of the V/R variables has not been disproven so far and is derived from the measurement of the broad photosphere features and not from the behavior of the emission lines.

LAFON: 1) You said that you stated the problem in terms of "two point boundary values problem"instead of" initial value problem". However, your basic parameters are the stellar mass, the stellar radius, the input of mechanical energy, i.e. parameters relevant to the inner part of the atmosphere. Thus, my question is: which kind of boundary condition do you assume as satisfied at the outer boundary of your corona? 2) Since there is the extended atmosphere, much thicker than the corona, between the photosphere and the interstellar medium where pressure tends to zero, should not you formalize the problem as any eigenvalue problem for a boundary layer and match your solution with some description of the outer part of the extended atmosphere?

HEARN: 1) The boundary condition at infinity is the T is zero, and the pressure is zero. 2) The method is a purely numerical solution of the equations of motion, continuity and energy. The last grid point is usually at 400 stellar radii and then an extrapolation procedure is used to extend the solution to infinity.

LINSKY: I would like to urge that people investigate in detail the role that magnetic fields might play in heating coronae and accelerating winds on O stars. Magnetic field can exist in O stars either as (1) remnant fields from the prestellar nebula (the O stars are presumably young enough) or (2) dynamo-generated field produced when the premain sequence star was in a Hayashi convective phase. There is considerable evidence that the atmospheres of these stars are highly turbulent. Magnetic fields in turbulent media can produce heat by many possible mechanism. The Einstein observations show two components in the X-ray emission from O star. The soft component is probably formed in the wind, but the cutoff hard component ($T = 10^7$ K) is probably formed in a corona at the base of the wind. People tell me that the hard component is highly variable. I would like to suggest that the hot corona at the base of the flow is (1) heated by dissipation of magnetic fields in a turbulent medium, (2) is responsible for the initial acceleration of the wind, and (3) is responsible for much of the observed spectroscopic variability since magnetic fields are typically stochastic and highly variable especially if they are rising into the observable atmosphere from below.

STALIO: I want to make a comment on your statement that I have switched from the "small corone + radiative cool wind" model to other ideas. I think that it is just evolution. I still agree that hot regions are common characteristics of all stars. X-rays and superionization give clear evidence for it. I am not sure anymore on their dimension and on the validity of radiation driven forces for the failures of :1) X-rays; 2) the scattered $\dot{M}$ us M_{bol} diagram; 3) the empirical data for V; 4) variability; 5) individuality. So I am looking to alternatives to explain the observations and I think that Thomas and Costero illustrated quite well today what is my feeling.