SECTION I

CHAIRMAN: M.K.V.BAPPU

THE WOLF-RAYET STARS – THE GENERAL PROBLEMS OF EXTENDED ATMOSPHERES AND NON-CLASSICAL ATMOSPHERIC MODELS

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1. Introduction

The Organizers of this Symposium asked that I make some introductory remarks on the general problems of extended atmospheres, the degree of common behaviour among stars having such a feature, and how the Wolf-Rayet stars may contribute to the progress of our inference in this area. In a Symposium entitled *Wolf-Rayet and High Temperature Stars*, not 'Stars With Extended Atmospheres', the implication of your charge to me is clear. You are implicitly assuming that the Wolf-Rayet phenomenon is primarily one of extended atmospheres. I can indeed give you a succinct summary of my outlook on these three points under such an implicit assumption, elaborating in more detail only to the extent as is necessary in order to be specific. And, as I am sure you had planned, because my outlook is considerably contrary to this implicit assumption, at least my remarks will spark controversy from the outset of this Symposium. I would like to emphasize that it is the summary of outlook to which I attach most weight and which I think is correct. The more specific details may change as we develop the mosaic of the summary, which has two main points. First, when you ask the physical picture of the general structure of a stellar atmosphere, you will eventually reach the conclusion that part of this general structure is an extended atmosphere for *all* stars. A focus upon some class, or classes, of them as exhibiting 'extended atmospheres' simply reflects the degree to which particular observations focus upon a particular part of the atmosphere as a function of the particular characteristics of the considered star. Second, in this context, I think that the implication that the Wolf-Rayet phenomenon is primarily one of extended atmospheres is incorrect. You are confusing a single system with a more deep-seated disease. My emphasis will lie on the disease as a whole, and the Wolf-Rayet stars as a guide to its diagnostics. I want to emphasize that this outlook on the general model of an atmosphere has developed jointly with K. B. Gebbie, J-C. Pecker, and F. Praderie; so most of what I say simply reflects this joint work.

First, I think it clear that the primary problem of extended atmospheres lies in the definition and understanding of what one means by an extended atmosphere, and how one interprets the observations which one thinks imply its existence. 'Extended' means relative to something, and of course that something is the classical model of a stellar atmosphere. When one interprets the observations, one again does so relative to the predictions of the classical model, to decide that it is an anomalous geometrical

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extent rather than an anomalous something else, which one needs to understand these observations. Now, the essential physical characteristic of the classical model lies in its representation of the atmosphere simply as the outer layer of the internal structure of the star. It is described by the same parameters as is the interior, and these parameters satisfy the same interrelations as in the interior. The earliest representation of the classical atmospheric model was that of a thin surface layer, homogeneous in the boundary values of these parameters. Later models permitted gradients in them, but the notion of a thin, surface layer, whose chief function is to give boundary values for the parameters describing the interior, persisted. An 'extended' atmosphere simply meant that observed atmospheric phenomena could not be represented by such a thin surface layer. At least, they could not be so represented if one retained the description of the atmosphere by the parameters, and inter relations among them, of the interior. Now, my own outlook rests on a preference for simply speaking of non-classical atmospheric models, dropping completely the notion of the atmosphere as a surface layer that is necessarily described by the parameters and interrelations of the interior. Rather, I suggest that we should view the atmosphere as a transition region, or a boundary region rather than layer, between the stellar interior and the rest of the Universe or, in practice, the interstellar medium. The parameters, and relations between them, required to describe such a transition or boundary region can differ very considerably from those characterizing either the interior of the star or the regions completely exterior to it. Different kinds of observations of a star may relate to quite different parts – or possibly different aspects of a given part – of this transition layer. For a particular star, the relation between type of observations and part of atmosphere mav depend upon gross properties of the star – mass and chemical composition – and upon transfer characteristics of mass, momentum, and energy in this boundary-transition region, and upon the way in which these are described. In this sense, we would regard stars with unusual properties attributed to extended atmospheres simply as stars whose particular properties focused the observations on regions considerably removed from the thin, deepest-observed, layer usually discussed. But we must also be very careful that such unusual observational properties can indeed be uniquely attributed to atmospheric extent.

Secondly, I think we should rephrase the question asking degree of common behaviour of stars having extended atmospheres, if we adopt this view of the atmosphere as a transition region. Placing a star in the category of having an extended atmosphere corresponds to recognizing that the star has certain properties – either intrinsic or because of favourable geometric location – that permit us to observe parts of the general atmospheric structure that are generally not observed. But while such parts may be 'extended' relative to 'normally' observed regions, they may not be the same parts, for all stars. Nor may the reason why they are observed always be the same. Consequently, this question of possible common behavior embodies several questions. First, we ask what is an operationally-useful set of subdivisions of the atmosphere, viewed as a transition region. Second, we ask what is the variation in observing conditions, observational techniques, or peculiarities of the star that provide information on particular subdivisions. In particular, under what conditions will we observe 'extended' regions. Thirdly, we ask whether we can establish general categories of stars according to the relative importance of particular atmospheric subregions in interpreting their spectra. To answer these questions, we require specific details of the general atmospheric model, and an understanding of what physical and observational effects correspond to these atmospheric subdivisions. We proceed to consider these specific points in Section 2.

Thirdly, when we ask how the Wolf-Rayet stars may contribute to the progress of our inferences in this area, I interpret area to mean 'non-classical atmospheric models' rather than 'extended atmospheres'. To explain my assertion that the Wolf-Rayet phenomenon is not primarily one of extended atmospheres, and to suggest how study of Wolf-Rayet stars may extend our understanding, I return to a suggestion I made some years ago. One should use observations of the Sun and of Wolf-Rayet stars as a guide to developing general models of stellar atmospheres, because they represent extreme examples in the then-vague beginnings of attempts to develop non-classical atmospheric models. At that time, the idea of a non-classical model was intuitively associated with the idea of a mechanical energy flux producing a stellar chromosphere. The Sun represented an object with a chromosphere so small in its 'obvious' effect on the spectrum that it might be undetectable were the Sun not so close to us that the wealth of different kinds of observations permitted us to develop an understanding of just what observations were chromospheric indicators. We were able to distinguish between physical anomaly and observational uncertainty by requiring consistency between a large number and a large variety of observations. The Wolf-Rayet stars represented objects in which the chromospheric phenomenon was so well-developed that even at their large distances and with rudimentary theory the effects could not be confused. Or, so I claimed at that time. My suggestion then was that the solar atmosphere reflected almost wholly only the energy dissipation from a set of aerodynamic motions, while the Wolf-Rayet star reflected both energy dissipation *and* a strong momentum supply from such aerodynamic motions. Consequently, one should carefully study the similarities and differences in these two kinds of stars, as a guide to the general kinds of effects to be associated with such aerodynamic motions in stellar atmospheres. I particularly stress this suggestion here, in the light of the implicit charge that the Wolf-Rayet phenomenon be viewed as primarily one of extended atmospheres. For I remind you that the solar chromosphere phenomenon was long regarded as primarily one of an extended atmosphere, induced by a system of 'turbulence', whose only effect was to distend the atmosphere in the same way as would an enhanced thermal velocity, but which was not allowed to change either kinetic temperature or internal excitation state of the atoms. And this suggestion of mine rested on the then-current evolution in our thinking on the solar chromosphere *away* from regarding it as primarily reflecting an extended atmosphere. The chromosphere phenomenon was being re-interpreted as primarily reflecting a mechanical energy flux, which did indeed distend the atmosphere but also changed the excitation very considerably. Thus many of the observational anomalies were reconciled in terms of those excitation effects accompanying a mechanical energy dissipation. In the years since, our understanding of the solar chromosphere phenomenon has further evolved, so that we now understand it as the consortium of a number of effects. These are best described as those effects associated with the atmosphere viewed as a boundary-transition layer. So, in Section 2, I summarize this outlook and this model. Here, I would only again emphasize my belief in the utility of the Wolf-Rayet studies as a probe of the utility and sufficiency of this kind of nonclassical model, especially as a cooperative probe blended with solar studies, and with intermediate classes of stars once we identify them.

2. General Structure of a Stellar Atmosphere

I stress that this general model reflects the viewpoint that a stellar atmosphere is the transition region between the stellar interior and the interstellar medium. Therefore, it must be described in terms of those concepts, parameters, and relations we would apply to the free-boundary regions of a quasi-isolated gaseous ensemble, not to interior regions. Mainly, the difference lies in the quasi-homogenous conditions of the interior as opposed to the anisotropic, inhomogeneous situation characterizing a boundary-transition region. As a particularly-fitting example, recall the evolution of the boundary layer as developed in fluid mechanics, whose introduction changed enormously the understanding of the interaction between fluid flows and the solid boundaries containing the flow. The change was significant when one considered only the momentum interchange associated with drag problems. It became very much more so when one considered the energy and mass interchange associated with heating and ablation problems. Similarly, the simple radiative transfer problems in stellar atmospheres require careful examination in the boundary-transition regions as collisional control of source-functions gives way to radiative, because of the fall in particle concentration. But the mass, momentum, and energy transfer associated with various kinds of atmospheric instabilities in the transition regions assume even more importance in these transition regions, and their effect on the interpretation of observations.

I have stressed the example of the solar chromosphere phenomenon as illustrating an evolution from a focus on it as a wholly extended atmosphere effect to a more general one. A more contemporary description of the anomaly would focus on the symbiosis exhibited by the chromosphere – the simultaneous presence of effects which, under the classical atmospheric model, would signal the presence of several different kinds of atmospheres. The most timely example at the present Symposium would be Mrs. Gaposchkin's remark that the solar rocket spectrum would be classified WC6, lacking any other information. So we have the symbiosis of a G0 and WC6 star. The presence of the He lines, especially in the eclipse spectrum, suggest another stellar class. And the self-reversed Ca II and Mg II lines, together with the residual intensities of the Balmer lines, all suggest, on the classical model, a puzzling super-position of several atmospheres, ranging from 'cold' to 'hot' stars. So I suggest the primary starting point in analysing peculiar stellar spectra of the type we are here concerned with is the star as 'symbiotic' rather than as 'extended atmosphere'. Now, Katharine Gebbie and I have recently presented (1971a) an extensive description of the evolution of the solar chromosphere anomaly, blending it with ideas on symbiotic stars, to reach the suggested general atmospheric structure. Pecker and I are trying to resolve some of the problems of infrared excesses in terms of choices of the source of the required additional energy; interior or contraction. And Françoise Praderie and I have been trying to develop a simple approach to obtaining the main features of the electron-temperature behaviour in such an atmosphere as a function of differing opacity sources. And we are all trying to put all this together into a more coherent specific picture. So there is no point to duplicating in detail here what you will see elsewhere. But it is useful to summarize two things: the physical basis of the general model in terms of atmospheric subdivisions, and the pattern of these subdivisions.

2.1. PHYSICAL BASIS FOR SYSTEM OF ATMOSPHERIC SUBDIVISION

So long as all microscopic processes fixing populations of energy levels are either dominated by collisions, or dominated by radiative processes in detailed balance, and only radiative transport processes exist, the description by the classical atmosphere model suffices. So a deviation from that description begins either when unbalanced radiative processes become competitive with collisions, or when non-radiative transfer processes become important, or both. The former can occur independently of the existence of the latter, but not conversely; so it is convenient to consider the sequence of events as one moves outward in an atmosphere as though the *population* effects begin before *transfer* effects, although, they may in fact begin simultaneously.

By *population* effects, we mean a change in microscopic distribution functions accompanying a change in domination of distribution function from one microscopic process to another unaccompanied by any change in energy supply. Such occurs, for example, when radiative processes become comparable to collisional because of a decrease in particle concentration. It may also occur when one radiative process becomes relatively more important because it departs from the condition of detailed balance associated with greater optical depth. In terms of the continuous spectrum, such population effects underlie the change from control of electron temperature by total energy density of radiation to control by its spectral distribution. It may further be affected by a change in the relative influence of different continua on this mean photoionization energy, induced because an increased unbalance in radiation processes in either continua or lines changes the populations of the absorbing levels of these continua. All these effects can produce an outward rise in T_e that is not caused by a change in radiation field or an addition of a mechanical energy supply. Thus the symbiotic effect of an outward increase in excitation level, for properly sensitive lines, may occur. Independently, this population effect can also produce the symbiotic appearance of high and low-excitation spectra in the same atmospheric region if, for example, the source-function for one line remains collision-controlled while that for another becomes photo-ionization-controlled. Clearly, what we call symbiotic affects can also, erroneously, be interpreted as 'extended atmosphere' effects if we infer the existence of these from abnormally-low rates of outward decrease in excitation. This was a false path in early solar studies.

By *transfer* effects, we mean changes in microscopic distribution functions, both from their LTE form *and* from their classical outward direction of decrease, associated with the onset of non-radiative energy, momentum, and mass transfer. With these effects are associated all the usual questions of mechanical heating, an aerodynamical momentum supply, mass ejection, etc. Because the *absorption* of radiation, not the *supply* of radiation, *decreases* outward with decreasing particle concentration, while mechanical effects arising from any kind of perturbation *increase* outward in amplitude, the likelihood is great that somewhere in this transition region representation of the atmosphere, transfer effects set in. Once initiated, they introduce an importance to upper atmospheric layers which the classical model did not permit. They can enhance the symbiotic effects associated with population effects above the level permitted by the radiation field alone. They increase the range of possible kinds of observations, thus of the regions of this transition layer atmosphere that can be studied. In this sense, they increase the probability that all stars can be regarded as having extended atmospheres, by increasing the range of atmospheric region that can be studied. But it is not a priori clear that all the associated phenomena are best interpreted as primarily 'extended atmospheric' effects. Such, for example, might be the temptation if one ignored excitation effects and attributed emission lines always to the volumetric effects of a greater emitting disk in the lines than in the continuum. He might infer an erroneous mechanism of line formation, and an erroneous location and extent of the region of origin of such lines.

Finally, I would stress that the increased importance of such mechanical effects, and the consequent increased discrepancy between radiative and mechanical excitation sources, increases the possibility of atmospheric instabilities. In turn, these instabilities induce the onset of the horizontal inhomogeneous structure which becomes of increasing concern with the increased resolution of our observations.

Thus, we have population effects, transfer effects, and instabilities associated with the presence of transfer effects as a guide to setting up atmospheric subdivisions within this general picture of the atmosphere as a transition region.

2.2. PATTERN OF THE SYSTEM OF ATMOSPHERIC SUBDIVISIONS

We define the bottom of the atmosphere as the deepest layer from which we receive direct radiation in the most transparent part of the spectrum. Then, we ask whether, at this bottom level, collisions dominate all distribution functions, and there is only radiative energy transfer. Or, possibly this last is supplemented by a quasi-static convection. If so, we model this deepest atmospheric layer by the classical atmosphere, and call the layer 'the classical photosphere'. Whether this condition holds cannot be decided *a priori*, but only by computation of microscopic rate processes, using the *actual* kinetic temperature and particle concentrations at this level, and by comparing the empirical T_e – distribution with the theoretical. Explicit criteria can be established for the existence of such a classical layer; in essence the region is restricted to densities (gravities) exceeding a certain value, and T_e lying below a certain value. Gebbie and Thomas (1971b) give illustrative formulae for the case of hydrogen opacity.

Once we pass from such a classical photospheric region, we enter one where population effects must be considered: deepest in the atmosphere, in the continuum; higher in both lines and continuum. If *only* population effects occur, we call this the nonclassical photospheric region. The most notable observational effect should be on the T_e value which, apart from line-blanketing effects, should differ in gradient from the classical one. Initially, it may show a steeper decrease; eventually, a slower, than the classical one (again, cf. Gebbie and Thomas (1971a), for illustration). The interplay between line and continuum effects, as a function of kind of line and continuum and their coupling when line and continuous opacity arise from the same ion, is yet in the development stage of understanding. If this region persists sufficiently high in the atmosphere that it encompasses the region of formation of some strong lines, the symbiotic effect reflecting the presence of lines of differing classes of source-functions may occur, and provide a very valuable diagnostic tool. (For an exposition of this diagnostics, under the term 'New Spectroscopy', cf. Thomas, 1965.)

When transfer effects occur, we enter what we call the 'outer atmosphere'. It is not necessarily an extended atmosphere in the conventional sense. When only energy transfer effects occur, we call the region a 'chromosphere'. The solar chromosphere is the prototype stellar chromosphere. If we note that according to the most recent thinking the chromosphere-corona transition occurs only some 1500 km above the level τ_5 (tangential) $= 1$, which itself is only some 500 km above the level τ_5 (radial) $= 1$, with a solar radius of 700000 km, we recognize that the solar chromosphere is hardly an 'extended atmosphere' in the usual sense. Diagnostic approaches stress the rise in excitation above that permitted by population effects alone.

When momentum transfer effects, in addition to energy transfer effects, occur, we call the region a 'corona'. In this sense, it is not clear that the solar corona satisfies everywhere this definition. Also in this coronal region, the likelihood is strong that instability associated with increased ratio of mechanical to radiative effects will occur, and, consequently, an inhomogeneous horizontal structure of the atmosphere. Diagnostic approaches to the region stress the difference in density gradient from that permitted by energy transfer alone. The horizontal inhomogeneities are also of importance, but these are only strongly favoured, not unique, to corona over chromosphere (and even photosphere, classical or non-classical).

When mass transfer effects, as well as momentum and energy, occur, we call the region an 'exosphere'. This term was originally introduced to describe the very outer region of the terrestrial atmosphere where mass exhaustion, under free-particle orbits, occurs. It seems a good term to borrow, pending a better suggestion. I would expect the outermost parts of the exosphere to become confused with the interstellar medium, even in the absence of expanding shells like the H II regions. In their presence, the confusion would become more so. And clearly, such confusion is desirable, in terms of our regarding the atmosphere as the transition region to the interstellar medium; and the similar confusion at the base of the atmosphere, where the classical photosphere represents indeed the transition region from the interior and becomes confused with it.

3. Empirical Investigations Under the Suggested General Model for Atmospheric Structure

Note that the general model suggested in Section 2 is not obviously *a priori* required for all stellar atmospheres, in all its sub-divisions. The necessity for a non-classical as well as classical photosphere does seem to have been established by the analyses of the last 20 years, both from the standpoint of theoretical consistency and empirical investigations. Indeed, Mihalas (1970) refers to the new classical atmosphere; viz., the old one without the LTE assumption. The existence of chromospheres in many stars seems also well-established observationally. For any stellar types where some kind of aerodynamical instability seems required, the occurrence of a chromospheric region would also seem required theoretically. Examples are stars having hydrogen convection zones, rotating stars, pulsating stars, late-type stars where the interior convective zone extends into the atmosphere. In my own opinion, we will ultimately discover causes of mechanical instability in all stellar atmospheres, which is the reason I assert the universality of the chromosphere region. The question of whether coronas are universal is a more uncertain one; for momentum transport varies as v^2 while energy transport varies as v^3, making the former harder than the latter. I consider this problem open for investigation. Finally, the exosphere universality likewise remains open for investigation. The basic reason underlying Parker's suggestion of the stellar wind – boundary conditions a long distance from the star – would seem to suggest its universality. Whether its generation can be satisfied by a chromosphere, without corona, also remains open for question.

On this basis, I would suggest the following scheme of empirical investigations to map out the properties of stellar atmospheres. First, we should delineate those regions of the HR diagram where classical photospheres can exist. We have a guide from the considerations already suggested; minimal gravities and maximum T_e. Mapping classical versus nonclassical photospheres is essentially a problem of T_e-distributions compared with LTE predictions, plus those symbiotic effects associated with population effects only. But the delineation of the atmospheric regions successfully described by the non-classical photosphere represents the second goal. The third one lies in the mapping of stellar chromospheres. There is to be a Symposium, sponsored by IAU Commission 36 and hosted jointly by NASA Goddard and the Smithsonian Astrophysical Observatory, on this subject next February; so there is little point trying to anticipate its considerations here, except as they deal specifically with Wolf-Rayet and high temperature stars. But here, it seems to me that our largest problem lies in the next subdivision of the atmosphere, separating chromospheric, coronal, and exospheric effects.

I would suggest that the focal point of considerations on Wolf-Rayet and hot stars lies there; viz., in casting light on the question of when momentum and mass transfer effects become observationally significant. And here, I would agree to some extent with the direction of prejudice reflected in the emphasis on extended atmospheres in considering Wolf-Rayet and high temperature stars. A primary consideration in making even classical models of such stars lies in the question of the stability of atmospheric structure when the high temperature forces a consideration of radiation pressure, and so a considerable reduction in the effective gravity from the dynamical one. Not only do we have a greatly increased scale-height, on a dogmatic hydrostatic equilibrium approach; but we have the strong possibility of the initiation of instabilities, on a more general aerodynamic approach. I would only insist that one be very careful to take into account chromospheric effects in the analysis of observations, before restricting attention to coronal and exospheric ones.

In establishing the existence of coronas and exospheres, we are basically concerned with an empirical density distribution compared with a hydrostatic one under the T_e consistent with chromospheric effects. Therefore, the first step in the diagnostic approach is to establish the magnitude of chromospheric effects, and the resulting thermal structure. We essentially accomplish this by comparing the excitation level of the spectrum relative to that inferred from the continuous spectrum associated with the deepest observable layers. One approach is simply to compare line and continuous spectra. Another is to compare continuous emission at wavelengths corresponding to differing opacities. Clearly, interferometric studies of the type being performed by Hanbury Brown (1968, 1970) are a most valuable approach to this problem. Another approach is to mimic that found so valuable in solar studies: eclipse observations. If it is possible to establish gradients in excitation as a function of atmospheric height, we can duplicate the solar studies. Some indications exist that this might be possible in extended cool systems like 31 Cyg and ζ Aur. Kuhi's work on WR binaries is thus far inconclusive, or negative, in this respect.

Given some knowledge of chromospheric effects, the next step is to establish a measure of atmospheric density gradient. Again, eclipse studies are a direct approach. The proto-measures of Mrs Shapley and Kopal (1946) remain unique in this approach. The indications from them were of a distinctly coronal, or exospheric, component of the atmosphere, unless you will accept a kinetic temperature of some 10^7 K. But it is unsatisfactory to base much on one set of observations. Another approach would be a study of the spectrum for distinctly 'extended atmosphere' effects on the spectrum. The varieties of 'dilution' effects are examples. Others might be identified. Hopefully, this Symposium will produce suggestions along these lines. So, let us proceed to them.

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DISCUSSION

Underhill: I would like to make just one comment. I go along pretty well with the final division that Dr Thomas has got to. This is indeed what we have to sort out. However, I think he is a little bit harsh on all the observing astronomers who have attempted to lay the ground-work for the study of Wolf-Rayet stars. He has renamed things and somewhat scathingly indicated that the word extended atmospheres was really a misnomer and he has called these atmospheres non-classical. I think that this just indicates that Thomas is a theoretician and the rest of us are observers and the history of astronomy, if you try to deduce it from the papers in the literature, is a study in misunderstandings between the theoreticians and the observers. The theoreticians start by being very simple minded and they necessarily remain simple minded because they cannot put mathematics and all the needed things into what the observers want. It is too complicated. The observers are generally very greatly impressed by the complexity of details they observe. They are usually rather inarticulate and they try to simplify these things a little bit for the benefit of their brothers doing theory and they describe it by talking about extended atmospheres. But all the time they know that things are not simple.

Van Blerkom: Are you suggesting that every one of those regions you have described is present to some extent in a Wolf-Rayet star?

Thomas: I want to be very specific in answering to Anne Underhill's question about each of the effects that we must introduce over the non-classical model and each of the atmospheric subdivisions to which they lead. It seems to me possible that in all stars you have to introduce each one of these effects. First, the population effects. Then, the three types of transfer effects. And those three types of transfer effects also give the possibility of an inhomogeneous structure of the outer part of the star. The chance that all stars show these, seems very high, but I agree this is simply prejudice; what I can actually prove is something else. Now of all the stars that we see, the Wolf-Rayet stars seem to me the most extreme and so the chance that they exhibit all of these effects seems to me almost inescapable. Whether all stars show all features remains to be seen. I hope that a focal point of the Symposium will be whether the WR stars can be shown to exhibit all these effects and all these atmospheric subdivisions. In answer to Anne Underhill, I would say that the structure is a logical and explicit one. If it is what you have always meant by 'extended atmosphere' but never bothered to spell out for some reason, I am delighted to cheerfully admit I am only an explicit recorder of your implicit thoughts.

Bappu: Would you also accept the inhomogeneity of distribution over the surface?

Thomas: Very much so. A lack of explicit emphasis on inhomogeneity of distribution and variability in time is something that Françoise Praderie criticized very heavily when I was discussing this with her before I came here. Also, I should have made a stronger point than I did for Anne Underhill's symposium on stellar chromospheres to be held next February in Goddard at which some of these points will be discussed. But on the inhomogeneities, you are absolutely right, Bappu. I have been very slow to get on the band wagon while other people have been emphasizing these. The only thing is, I think, we somehow have to ask how do they come about. It seems to me that the chief argument is, and again I would like to see it discussed here, that as I go out in the atmosphere, the radiation field present does not change but the amount of it absorbed does decrease. Whereas if you start with any kind of a mechanical disturbance in the outer atmosphere it will amplify as the density decreases rather than decrease. So that I have on the one hand the radiative effect decreasing and on the other hand the mechanical effects increasing, just the conditions necessary for introducing instabilities and inhomogeneities.