PART C

CHROMOSPHERES AND CORONAE OF STARS

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WHAT DO WE KNOW THROUGH SPECTRAL INFORMATION ON STELLAR CHROMOSPHERES AND CORONAS?

by

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ABSTRACT

Four problems in interpreting spectra to infer chromospheres-coronas are summarized. (1) The a priori difficulties in interpreting spectra lie in uncertainty on the range of possible models, coming from uncertainty as to which conservation equations may be applied, and from lack of an exhaustive list of spectral indicators that may be used for uniqueness tests. (2) As spectral indicators we consider: emission lines, self-reversed emission cores, the presence of He I lines in stars not of early type, coronal-type high ionization, excess continuum emission in the rocket UV and the far infrared. (3) To determine what we can infer from observations, we summarize information inferred by comparison of models to data, on velocity fields, and on spectral variability which might suggest chromospheric activity. (4) We summarize the evidence for chromospheres in A stars, as being those where convection-induced acoustic heating is marginal.

Key words: chromosphere, corona, spectral indicators, conservation equations.

In the framework R. N. Thomas proposed at this colloquium* for approaching the problem of extended atmospheres, stellar chromospheres and coronas come both under case 3 and case 4.

Case 3: Spectral features that disagree with

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* See pp. 38-45.

classical atmosphere (CA) predictions appear in stellar spectra. For a few stars, eclipse observations are possible; for many others even non-eclipse observations imply the existence of a chromosphere or corona. At this point, the last sentence says no more than: "CA assumptions are insufficient." However it leads to a first definition of a stellar chromosphere.

Taking account of the very common occurrence of H and K reversals in stars later than F0, one can give a symptomatic definition of one type of stellar chromosphere: an outer layer giving rise to emission in the H and K lines of ionized calcium. This definition applies to otherwise "normal" and rather cool stars even if they are variable in light, and suggests an analogy with the sun. But exceptions to this statement appear immediately. Stars with a majority of emission lines, like Wolf-Rayet stars, or with a certain number of emission lines, recurrent novae, P Cyg or Be, or peculiar systems like β Lyr, are not included in such an empirically based, and necessarily limited, definition. However some of these stars show certain chromospheric or coronal indications like the He I λ 10830 line (β Lyr, P Cyg). On the other hand, the only coronal lines of highly ionized atoms observable in stars appear in repeating novae like T CrB, in variable stars like CI Cyg, AG Peg, RX Pup, or in stars like Z And. Thus, the symptomatic definition, based only on the K line (or on other lines, whatever they are), is not satisfactory.

Case 4 is the logical consequence of case 3; it stresses the search for the physical causes that act to violate the CA assumptions so as to produce peculiar spectral features attributable to an extended atmosphere. A causal definition of a chromosphere or corona is then more satisfying: chromosphere and corona are hot (relative to the photosphere), tenuous extended parts of the atmosphere, transparent in all but a few wavelengths, produced by the dissipation of mechanical energy waves; Cayrel's mechanism (1963) appeals to a purely radiative source, and may be efficient in the lowest chromospheric layers as a subsidiary cause for the increase of electron temperature. One must admit that the heating mechanisms can act even if no striking observational consequences appear at first sight. They produce a rise of the electron temperature T_e, after some minimum obtained in the low photospheric layers. As a result, the excitation and ionization conditions in the chromosphere (or corona) and the spectroscopic state of the gas cannot be described by a simple LTE theory, or even a non-LTE theory that imposes radiative equilibrium.

The plan of this talk will be:

I. Introduction: What are the difficulties in interpreting spectral information about stellar chromospheres and coronas?
II. Spectral indicators of chromospheres and coronas.
III. Interpretation of chromospheric (and coronal) spectral features.
IV. Do the A stars have chromospheres?

Neither the heating mechanisms nor the generation process of a stellar wind will be reviewed, and I will completely exclude the solar case, only referring to it as a powerful guide toward the study of the outer layers of stars.

I. INTRODUCTION

a. Model Problem

The basic problem in interpreting spectral information in chromospheres and coronas is not essentially different from what it is in any atmosphere: one wants to deduce the complete physical state of the gas from the observed distribution of radiation intensity with the frequency ν, and from the shape of spectral lines. That is what Jefferies (1968) calls the analytical problem in interpreting the observations.

The main difficulty in that problem has often been underlined by Thomas and Jefferies and by others: to solve this analytical problem, one has to go first through a preliminary and unavoidable synthetic approach; namely, the theoretical computation of the radiation emitted by a gas specified by the distribution of density, kinetic temperature, and chemical composition. So one needs a good theory of line and continuum formation.

Moreover, and this distinguishes the chromospheric and coronal situation from the classical photospheric case, the equation of energy conservation includes a mechanical contribution in addition to the radiative one. The energy is transported and dissipated under several qualitatively well-known forms, and eventually the whole heated material of the corona expands hydrodynamically, as first suggested by Parker (1963). Delache has shown (1967) that the equation of momentum conservation must include a wave-radiation pressure term, which at least in the transition region between the solar chromosphere and corona prevents the hydrostatic equation from being a good approximation. Therefore the *a priori* models that are built as a preliminary step to compute, even by a good theory, the emergent spectrum from a chromosphere or corona are not complete.

It makes no sense to infer the physical conditions in the chromospheric or coronal gas from the spectral information unless one checks that the conservation laws are not violated at each height. Omitting this check would imply that the transport and dissipation phenomena are completely known and that one knows where the mechanical energy is generated (Lighthill 1967), which is far from true. Thus the conservation laws can at best be used to put boundary conditions on the run of T_e and N_e.

Finally, the very few models that have been computed in the stellar case are *stationary* and assume that the material is *homogeneous*. The last assumption is known to be far from reality in the solar case.

b. Uniqueness of the Models

Due to these theoretical limitations and to the scarcity of easily accessible spectral features (i.e., in the near UV or visible part of the spectrum) in stars other than the sun, one cannot be sure, at the present time of being able to derive unique interpretations from the chromospheric and coronal observations. Each observed characteristic in the spectrum, especially in the line spectrum, depends on the model via several parameters, which are all depth dependent. As an example, let us quote the systematic study of the H and K lines by Athay and Skumanich (1968b). For stars not too different from the sun, they show the dependence of the intensity I_2 and of the width w_2 of the K_2 emission with (1) the Doppler width and its gradient through the atmosphere, (2) parameters describing the run of $B_\nu(T_e)$, the Planck function, with τ_c, the continuous optical depth, and (3) characteristics of the line such as $\varepsilon = C_{21}/A_{21}$, the optical depth τ_0 at the line center, the damping constant a, each depending on N_e, T_e. We adopt

$$B_\nu(T_e) = 1 + \beta\tau_c + A\,e^{-(C\tau_c)^x} - \alpha\,e^{-(300\,\tau_c)^{1/2}} ,$$

$$D = \frac{\Delta\lambda_D(\tau_c)}{\Delta\lambda_D(\tau_c=1)} = 1 + \zeta\,e^{-(d\tau_c)^z} ,$$

$$r_o = \frac{d\tau_c}{d\tau_o} = r_{o,1}\,\tau_o^{1/3} + 10^{-10}$$

With several restrictions on a, $r_{o,1}$, and C, Athay and Skumanich give the following expressions for I_2 and W_2:

$$I_2 \sim \frac{A\varepsilon}{(r_{o,1}Ca^2)^{1/4}} \cdot \frac{1}{(1+\zeta)^{1/2}} ,$$

$$w_2 \sim \left(\frac{a^2}{r_{o,1}^2 C}\right)^{1/4} (1+\zeta) .$$

Of course, all these parameters cannot be left free *a priori* if one has at one's disposal only the observed profile of the K line, i.e., essentially 3 measurable quantities: I_2, w_2, and their product, which varies like the energy loss in the chromosphere.

Therefore it is urgent both to search for more observable chromospheric and coronal spectral indicators and to improve the model theories.

II. THE KNOWN CHROMOSPHERIC AND CORONAL INDICATORS

Normal stars as well as variable stars show strong observational evidence of the presence of chromospheres and coronas. One often speaks of chromospheric "activity," even for normal stars, because of the variation in the structure of the H and K lines from night to night.

I will list the spectral features that indicate the presence of a chromosphere or a corona and in which stars they appear; I will omit the peculiar case of eclipsing systems, which are reviewed in Groth's paper.

a. Line Spectrum

Prominent chromospheric stellar lines lie in the visible, ultraviolet, and near infrared spectral regions. A self-reversed emission core in a strong resonance line is often a signature of a chromosphere because it reflects a map of the source function with depth, showing a maximum for small values of τ_{5000}*. But the cores of all strong lines are formed in the low part of the chromosphere and even in absorption they give insight to the properties of the corresponding layers.

(1) H and K reversals are observed in numerous G, K, M giants and supergiants and in many main-sequence stars (Wilson and Bappu 1957). The K_2 intensity, I_2, takes very different values for stars of the same luminosity and spectral type. For main-sequence stars, the brighter the emission, the closer the position of the star to the lower boundary of the zero-age main sequence (Wilson and Skumanich 1964). The width of the emission, w, is correlated with the visual luminosity (Wilson-Bappu effect, $w \sim L_V^{1/6}$) independently of I_2 and of the spectral type. This relation does not apply to cepheids (Kraft 1957) nor to T Tauri stars (Kuhi 1965).

For stars of earlier spectral type than the sun, the spectral type in which the H-K emission ceases seems to be a matter of dispersion of the spectrograms, as long as the photospheric brightness is not too high. With a dispersion of 10 Å/mm, no emission is found for $b-y < 0.30$ (type F5), but weak emission appears on high dispersion spectra of α CMi, F5 IV (Kraft and Edmonds 1959, 3.2 and 4.8 Å/mm) α Car F0 Ib (Warner 1966, 6.8 Å/mm and γ Vir B, F0 V (Warner 1968, 4.7 Å/mm).

(2) Traces of variable chromospheric activity have been searched for in 139 stars by Wilson (1968), who observed the flux at the center of the H and K lines with a two-channel photometer over one year. The results are not clearly in favour of a variability. Deutsch (1967) found large changes of K_2

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* See R. N. Thomas, pp. 38-45.

emission in two K giants: α Tau (K5 III) and γ Aql (K3 II).

H-K emission is the only chromospheric emission feature observable in the visible spectrum of a great majority of the stars studied by Wilson. In T Tauri stars, however, the near infrared triplet of Ca II seems to be characteristic (Herbig, quoted by McConnell, 1967). Due to the presence of many other emission lines in the spectrum of T Tauri stars, to their irregular variability, and to the peculiarities of their UV spectrum, one cannot safely compare their chromospheric problem to that of normal stars, even if one can be sure that there is one.

Hα is often observed in absorption in stars with H and K reversals. Suspecting that its central part is formed in the same region as the K_2 emission, Kraft, Preston, and Wolff (1964) tried to correlate the width of the core with the luminosity of stars. The relation between this width and the absolute ultraviolet magnitude is not as good as the relation discovered by Wilson and Bappu.

He I λ 10830 was first observed in emission in P Cyg and in carbon Wolf-Rayet stars (Miller 1954), with IZ emulsion and a very low dispersion (1300 Å/mm at 1μ); then Kuhi (1966) made photoelectric scans around the helium line in Wolf-Rayet stars, and observed it in emission in all Wolf-Rayet stars. The development of image tubes and the Lallemand camera now allows one to observe the helium line in absorption and in late type stars. Vaughan and Zirin (196 (1968) looked for this line at 8.4 Å/mm in 86 stars, the majority being of G and K type. About 30 of them show the He line in absorption; in 5 others the line appears in emission. Among the 12 B, A, and F stars of the sample, only β Ori (B8 Ia) and α CMi (F5 IV) show the line, in absorption. For 2 stars an activity is detected by variations of the helium line with time. In several cases, the line shows a structure.

Although it does not constitute a simple case of a star with a chromosphere, β Lyr presents a broad emission feature at λ 10830 (observation by Knappenberger and Fredrick, 1968, with a mica window image tube, 58 Å/mm.

In the ultraviolet spectrum of stars, the resonance doublet of Mg II at 2800 Å has been reported (Heinze et al. 1967) in absorption in the spectrum of αCMa. One would think it would be observed, with an emission, in all stars where H and K emission exists, since in the sun the emission in Mg II is stronger than that in Ca II (Dumont 1967, Kandel 1967, Athay and Skumanich 1968a).

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Ly α observed in six Orion hot stars by Morton et al. (1968) is probably of interstellar origin only. The same difficulty in separating the stellar Lyman lines from the interstellar ones is quoted by Smith (1969) in a paper on rocket observations of α Vir B1 V).

Anway, it seems preferable to search for Ly α in late type stars, where the maximum of the photospheric flux is very far from the spectral range of the Lyman lines and where ultraviolet emission, if it exists at all, can only be of chromospheric origin. Predictions have been made by Oster and Patterson (1968), who conclude that chromospheric Ly α could be detectable with a 10 cm reflector for very near cold stars (distance less than 3 parsec).

Coronal line observations in stellar spectra are rare. Coronal lines were discovered by Adams and Joy (1933) in RS Oph, a repeating nova, but were not identified until 1945. Other repeating novae show lines of highly ionized atoms: T Pyx, T CrB. For this last star, Bachonko and Malville (1968) measured the equivalent widths of the following lines: λ 5303 [Fe XIV]; λ 6374 [Fe X]; λ 5536 [A X], on spectra obtained during the 1946 outburst of the star, and analyzed the green coronal line, from which they deduced a relation between the radius of the corona and the density necessary to produce the observable green line: $N_e = 3\text{-}5 \cdot 10^7 \text{cm}^{-3}$, T_e is assumed to be 10^6 °K.

Other coronal lines have been observed in CI Cyg and AG Peg (lines of [Fe X]), in RX Pup (lines of [Ca VII]), in Z And (lines of [Fe VII]). Sahade (1960) has discussed these peculiar emission-line stars, and further work is due, among others, to Bloch (1964), Boyarchuk (1966), and Boyarchuk et al. (1964, 1967).

Coronal ions could be observed in ultraviolet spectra, but severe limitations exist. (1) Below 912 Å, all stellar flux is absorbed by interstellar hydrogen even for the nearest stars. (2) The total light flux emitted by the solar corona is several powers of ten lower than the visible flux. A stellar corona would have to be much more powerful than the solar one to be detected with the available space equipment, except for very hot stars.

b. *Continuous Spectrum*

For the same reason as in the sun, it is possible to see the low chromospheric layers of a star by observation of the continuous spectrum in the ultraviolet and infrared regions, where $\tau_\lambda = 1$ corresponds to very small values of τ_{5000} (Noyes et al. 1966). But the lack of angular resolution in the observations is a very strong limitation, and the derivation of semi-empirical models by inversion of limb-darkening curves is excluded thus far.

Nevertheless, absolute intensities in the ultraviolet spectrum below 2000 Å, especially in A and F stars where the opacity due to metals (Mg, Si, Al) and to carbon dominates that of hydrogen (H I and H^-) and is very strong, will help to check the validity of theoretical model atmospheres in the very superficial layers. But it seems impossible to expect that these observations will be of as much help in determining stellar chromospheric models as those coming from the study of the cores of strong lines.

Towards the longer wavelengths, observation of an intense infrared emission near 10μ has been reported first in 1965 for 3 late-type stars: α Ori, α Tau, and μ Cep (Low 1965). Gillett et al. (1968) have confirmed this feature for 4 cool stars (α Ori, μ Cep, o Cet, χ Cyg), but nothing appears for a hot star like α CMa; they suggest two interpretations, one implying a chromospheric temperature, the other an emission by circumstellar matter around the star. Other authors now favour the last item, on the basis of the general appearance of such circumstellar envelopes around several types of cool stars (Stein et al. 1969), and of the resemblance of the emission to that of solid particles (see Wolf and Ney, 1969).

The evidence of a stellar wind in α Ori (Deutsch 1959, Weymann 1962) led Weymann and Chapman (1965) to compute the theoretically predicted free-free emission of a hydrodynamic hot flow emitted by α Ori. They concluded that between 1 mm and 3 cm the absolute flux is just at the limit of detectability for radio astronomers. Kellermann and Pauliny-Toth (1966) searched for that emission at λ = 1.9 cm, but could not detect it.

All in all, there is very little indirect evidence for chromospheres and coronas in the stellar case. The only exception consists of the K-line emission, which has been detected for more than a hundred stars.

III. WHAT IS INFERRED FROM THE OBSERVATIONS?

The observed quantities are essentially (1) relative continuous intensities, and (2) line parameters: central intensity I_0, emission width, half-width $\Delta\lambda_{1/2}$, equivalent width W, and in rare cases, structure of the whole profile.

Due to the significant results obtained in recent years on the solution of the transfer problem (Cuny, Dumont) which allow one to consider the "synthetic problem" in line formation to be fairly well solved, I will focus my attention on three main fields where physical information has been gained from stellar chromospheric observations.

a. Construction of Models
(i.e. Jefferies' "analytical problem")

Given my restricted definition of stellar chromospheres, I will review only the work done by Kandel on late-type emission dwarfs. Groth will report on chromospheres in K giants belonging to eclipsing binaries. In the first case, deduction of the model from the observations is mainly based on the Ca II K line. Other chromospheric indicators have not yet been intensively used for the purpose of models; we will consider them later.

(1) Kandel (1967) constructed chromospheric models to interpret the strong K line emission observed in K and M dwarfs that showed no Hα emission. He specifies the chromosphere by a temperature profile $T_e(N)$, electron temperature versus the number of hydrogen nuclei, N, in a column of 1 cm^2 above a reference level corresponding to the surface of a photospheric model; the parameters are the temperature T_C and the mass N_C of a large plateau, and the gradient $C = -d\ (\log T_C)/d\ (\log N)$ of the temperature law just under the plateau. Other basic assumptions in Kandel's computation are hydrostatic equilibrium and LTE ionization balance. They are questionable, but are adopted for simplicity.

A series of such a priori chromospheric models was put at the top of convenient photospheric models that were built to reproduce the visible absorption spectrum. Kandel computed the Ca II emission equivalent width, E_K, by using the non-LTE theory of Dumont (1967) and traced iso-E curves in a (N_C, T_C) diagram. Computing then the radiative energy loss by these theoretical chromospheres, Kandel eliminated those models that are thermally unstable and those that should produce emission in Hα. A very limited region remains acceptable, with $T_C < 10{,}000$°K.

Despite its evident limitations, Kandel's approach is a physically well-grounded one. One can suspect his photospheric models, as he does himself, because of the importance of convection; the mechanical flux he pumps in the convection zone to heat the chromosphere is as uncertain as the application of Lighthill's theory to stars. But, given the present set of developed theories, he tries to derive the most complete model. If one remains unsatisfied by all the approximations involved in such an exercise, one must return to the problem of improving the energy generation and transport theories.

(2) Rough indications about chromospheric conditions have been derived from other lines. The He I λ 10830 line has been shown by Athay (1963) to be very sensitive to the temperature between 10^4 and $2 \cdot 10^4$ °K. When it is observed, the He I absorption line indicates a hot chromosphere or more explicitly, a chromosphere hotter than that of stars with only K reversal ($T > 20,000$°K). Let us recall that λ 10830 appears in emission in three supergiants, including ε Ori (BO Ia) (Vaughan and Zirin 1968); its presence in absorption in β Ori might be used as a test of Underhill's hypothesis on helium overabundance in B supergiants if the non-LTE problem is solved uniquely.

The Hα core has been suggested by Cuny (1968) to be a test for low chromospheric solar models. She computed the non-LTE Hα profile with two solar models, HA01 and the interspicular model of Athay and Thomas. With the latter the residual intensity is larger than observed; with the former, smaller. Collisions have a greater contribution to the source function in the interspicular model, which is denser, so she proposed that the central part of the Hα line could be used, by comparison with observations at high spectral resolution, at least to check plausible chromospheric models, if not to establish them.

In a rather similar way, Kandel has used the absence of Hα emission in 61 Cyg B to limit the possible range of his chromospheric parameters for that star.

The Ly α and Ly β lines, if they can be ever observed in cool stars, will be an excellent tool for studying stellar chromospheres.

(3) Purely theoretical non-grey, radiative-equilibrium atmosphere-models were computed by Feautrier (1968). Taking account of H^- departures from LTE, Feautrier's models present a rise of temperature above the purely photospheric layers; these models constitute a good set of a priori models to be used in studying chromospheric conditions from spectral features in stars hotter than the sun.

b. Velocity Fields

Although this subject is not completely separate from the model problem, because of coupling between dynamical phenomena, transfer, and physical structure of the atmosphere, one can only be very short and restrict one's attention to qualitative or first approximation theory results. The whole theoretical problem lies indeed in a premature state. Velocity fields are however deduced from two types of observations.

(1) Line displacements. Stellar chromospheric lines often show an absorption component displaced towards the violet, the emission component being shifted longward. The case of the K line in cepheids is typical, but the phenomenon is more general. For instance, He I λ10830 in the most luminous stars observed by Vaughan and Zirin presents the same feature. P Cygni type profiles are observed also in extended atmospheres which may not be chromospheres in the restricted sense given above. In the expanding envelopes discovered by Morton (1967) for 3 supergiants, the absorption components of the strong resonance lines of Si IV, C IV, N V, and Si III indicate velocities in excess of the estimated escape velocity. A P Cygni profile is characteristic of the He I λ10830 line in β Lyr (Knappenberger and Fredrick 1968).

(2) Line asymmetries. As in the sun, where both the Ca II and Mg II resonance lines show asymmetry in the reversed part of the core, large asymmetries are observed in stellar K_2 components (Wilson and Bappu 1957, Deutsch 1969), which vary with time, so that it seems difficult to think of any interpretation of the K-line profile that would ignore motions and inhomogeneities in the atmosphere of those stars.* The most prominent feature of chromospheric line profiles is broadness, so that their halfwidth cannot be interpreted as being due to a purely thermal Doppler effect. Large turbulent motions are present in chromospheric layers. Several authors have argued that these motions are macroturbulent ones, arising from large mass motions. Moreover, there seems to be a correlation between K-line emission and photospheric turbulence: (1) In cepheids, Kraft (1967) reported that the turbulence increases after minimum light, at the same time as the K emis-

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*I am indebted to Dr. A. J. Deutsch for having stressed this point to me.

sion appears. (2) Bonsack and Culver (1965), on the other hand, have produced evidence that the K-line emission width w is correlated with the halfwidth $\Delta\lambda_{1/2}$ of photospheric V I lines in a sample of G, K, and M stars. The correlation being less clear between w and the curve-of-growth velocity, they concluded that macroturbulent motions exist in the photosphere of the stars studied, and stressed a possible common origin of the K reversal width and broadening of photospheric lines.

c. Activity

One gets a very qualitative insight to chromospheric activity from the following facts:

(1) Emission in the K line has been found to be variable in cool giants, first by Griffin (1963) and later by Deutsch (1967) and Liller (1968).

(2) The K-line reversal seems to be associated with magnetic field in the hottest star in which it has been found (Warner 1968).

(3) The λ10830 He I line shows intensity variations which recall the increase of intensity of that line in solar plages and prominences.

Wilson (1963) suggested that the existence of a chromosphere and the strength of the K-line emission are correlated with the presence of magnetic activity and that they decline with time as do the magnetic fields.

A very special case is that of the transitory character of the K-line emission in cepheid atmospheres; the appearance and disappearance of the emission is connected with the phase of the pulsation, and may be interpreted by periodic modifications of the excitation in the atmosphere, which are probably not of the same nature as those which appear, periodically or not, in the above quoted examples. Indeed, the change in excitation is generally associated with the passage of a shock wave through the atmosphere.

To end this paragraph, I would only mention the problem of correlation of chromospheric properties with general properties of the stars. The fundamental explanation of the Wilson-Bappu effect seems to be still unknown; on the other hand, stars like the cepheids or T Tauri stars do not obey the Wilson-Bappu relation, supporting the idea that the K emission may have a different origin in stars where the chromosphere is heated by different mechanisms. If one tentatively accepts the idea that the type of variability that gives rise to light variation in cepheids or in T Tauri stars, and that probably differs between both types of stars, generates mechanical energy in the outer layers of these stars, one is prepared to admit that the Wilson-Bappu effect is relevant only to stars in a certain stage of their evolution, which stage is characterized by a certain kind of heating. As pointed out by Athay and Skumanich (1968), "W_2 reflects on the nature of the energy conversion mechanism." Of course the interpretation of chromospheric observations in stars can be considered as being directed towards discovering the mechanical energies at work in a star.

IV. DO A STARS HAVE A CHROMOSPHERE?

In A stars, no chromosphere has been identified with confidence; on theoretical grounds, it is usually thought that since ionization convection zones become thin for stars hotter than spectral F_0- F_5, no strong acoustic energy may be generated. Thus the conditions for a strong chromosphere are not present. But Wilson (1966) has claimed that he sees no good reason why chromospheres should cease towards the uper edge of main-sequence stars. Leaving for the moment the question of B stars, and by close continuity with the observations already available, I will give some arguments in favour of chromospheres in A stars.

(1) There are favorable observational indices for chromospheres in these stars, although at this time they do not constitute indicators:

(a) K reversal in γ Vir B (F0 V), which is a magnetic star. Many A stars are magnetic stars.

(b) Variability in the K line. Henry (1967) observed 4 Ap stars already known to be variable in the K line, confirmed their variability, and discovered 4 others. Baglin et al. (1968) discovered a large variation of that type in γ Boo (A7 III), which is a δ Scuti variable. The variation seems to have nothing to do with the light curve period. This is under further study.

(c) The A stars show a large microturbulent parameter (6.9 km/s) and this feature is not limited to Am stars, as was established by Baschek and Reimers (1969).

(2) What else should one look at to detect chromospheres in A stars?

(a) The core of the K and of the Hα line. If the K line, collision dominated, presents even a small reversal, this will imply a chromospheric temperature gradient. The Lallemand camera is the best detector to use for such a study of the cores of very strong lines because of its lack of threshold at low fluxes and the linearity of its response.

(b) O I, C I, Si II, Al II, Mg II resonance lines in the ultraviolet spectrum.

(c) There is almost no chance of detecting Ly α, even if its emission in an A star would be the same fraction as in the sun of the acoustic flux heating the chromosphere.

An estimate made for a typical A star with $T_{eff} = 8000°$, log g = 3.9 indicates a flux at the ground of 5.10^{-4} photons $cm^{-2}s^{-1}$, to compare with the value of 6 for the sun.

(3) How could one heat a chromosphere in A type stars?

A model study of an Am star (Praderie 1967) shows that if the observed microturbulent parameter ξ_t is not due to other physical effects (such as NLTE effects of the source function for lines on the plateau of the curve of growth), the atmosphere must be very convective to produce the value of ξ_t derived from the curve of growth. But an adequate convective model fails to reproduce the wings of strong lines, which, for A stars, are formed in the convectively unstable layers of the photosphere.

With the help of Lighthill's theory of generation of acoustic noise from convective turbulence, and a convection efficiency compatible with line-wing observations, the acoustic flux produced in the convection zone may be estimated. For a star of $T_{eff} =$ 8000°K, log g = 3.9, it turns out to be one-tenth of the solar value (assumed to be 10^8 ergs $cm^{-2}s^{-1}$). Thus it seems doubtful that one could heat, in that star, a chromosphere as hot as the solar chromosphere.

But the problem of the high ξ_t parameter remains. The acoustic flux produced in the convection can be increased by enhancing the helium abundance and then the depth of the He I and He II parts of the ionization convection zone (Mariai 1969). However, in Am stars, no He I line is observable. In some silicon Ap stars, work by Searle and Sargent (1964) and by Hyland (1967) gave observational evidence for helium depletion in the atmosphere. So no conclusions can be drawn about helium abundance; but significant progress will arise from the search for He I λ10830 in Ap stars with strong magnetic fields, both to decide if a temperature of 20,000°K can be obtained in a possible chromosphere for these stars and to see if the helium abundance distribution in these stars is uniform with depth. In some of those stars, Zirin (1968) has already found evidence of the presence of He^3.

To conclude, I stress that several factors that might have a strong relation to the presence of chromospheres in stars have not been reviewed here. The role of a companion in enhancing the chromospheric spectral features has often been mentioned. The problem of generation of stellar winds was out of the scope of the colloquium, but its importance should not be minimized.

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