SECTION OF PHYSICS

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STELLAR CHROMOSPHERES

During a total eclipse of the sun, when the corona is the prime spectacle, a bright narrow pink ring is seen for a few moments in the vicinity of the solar limb. This thin layer ot the solar atmosphere, termes the "Chromosphere" because of its vivid red colour, is the source of numerous strong emission lines that flash into visibility for a few second around second and third contact. Much interest centres on this layer because the properties that we derive from the spectroscopic features cannot be explained by an extension of the classical atmosphere that is in radiative, hydrostatic and local thermodynamic equilibrium. The presence of the neutral and ionized helium lines in the flash spectrum indicates the presence of an increase in temperature beyond the solar limb. A myriad of inhomogeneities characterize the chromosphere that we see on the disc when we resort to monochromatic photography with high spatial resolution. The occurrence of spicules, supergranulation, flares, call for energy sources different from those of a classical atmosphere. The solar chromosphere is a plasma of large scale that is permeated by strong magnetic fields and heated by the dissipation of mechanical and magnetic energy in wave modes.

If the sun, which is a typical average star, has a chromcsphere, we should expect stars of different luminosities and masses that have effective temperatures comparable to the solar value, display spectral features indicative of similar phenomena and perhaps on a more grand scale. The first of the difficulties we encounter when we go over to survey other stars is that we have no more the advantage of the availability of a disc for close scrutiny that the sun represents. The manifestation of a chromosphere and chromospheric activity can be identified only from the the integrated spectrum or from monochromatic light intensity variations, if such exist. The task is a difficult one as one can see from the fact that if we were to locate ourselves on a hypothetical planet of the star nearest to us, we would recognize the presence of a solar chromosphere only by the use of high dispersion spectroscopy; if precision monochromatic measures of intensity in the core of the K-line of calcium were made we may be able to speculate on the presence of active regions on the solar surface. To search for stellar chromospheres and to distinguish their physical characteristics, we must be aware of the different chromospheric indicators and formulate the necessary diagnostic techniques.

We have in the solar case a temperature minimum that is a few hundred kilometres above the visible limb. The spectroscopic features of the layers beyond this minimum show that the temperature increases outward. We believe that such an increase is caused by the dissipation of mechanical energy that originates at photospheric levels and below. A similar process could naturally be the cause of formation of stellar chromospheres. However, it is important to realize that we define a chromosphere as that region which experiences a temperature rise and where mechanical energy dissipation is dominant.

The source function is defined as the ratio at any frequency of the volume emissivity and the absorption coefficient per unit length in the gas. The emergent flux which depends on the temperature structure of the gas is determined in the case of a line by the temperature dependence of the population ratio. This ratio of concentrations of atoms in the two levels of the line is also the ratio of the rate of all transition paths direct and indirect that carry the atom from one level to the other. Both collisional and radiative mechanisms prevail in the formulation. The source function in the line core thus depends on the Planck function at the local kinetic temperature and a parameter that measures the importance of direct collisional excitation relative to radiative de-excitations of the atom in the upper level of the line. The collisions then control the production of new photons at a rate dependent on the kinetic temperature. Hence the temperature distribution in the atmosphere will manifest in the line profile for a collisionally controlled line. Thomas (1957) showed that for stars of spectral type similar to the sun and later, strong resonance lines of non-metals and ionized metals are collisionally controlled. The resonance lines of ionized calcium at 3934°A and 3968°A or similar lines of MgII at 2800°A fall into this category. The resonance lines of neutral metals are controlled less by collisions than by the strength of the continuum radiation field. Hence the source functions for such lines reflect the temperature in the region of continuum emission and not of the region where the lines are formed.

The relative roles of collisional or photoelectric control depend on gas temperature, the local density and the continuum flux. For an atmosphere where the temperature increases to the top, line profiles calculated on this reasoning show profiles that resemble those observed in late type stars in H and K, with the characteristic double-hump self-reversal in the core. The extent of the temperature rise, the optical depth at which it begins and the thermalization depth, control the shape of the line profile. The self-reversal is strong if the optical depth of the beginning of temperature rise is greater than the thermalization depth ; this parameter is the average optical distance of photon travel from its origin following collisional excitation to its destruction by collisional deexcitation. Hence strong emission reversals in H and K signify high densities and deep chromospheres while weak or no emission is seen at low densities and for thin chromospheres. A self reversed emission core in H and K gives direct evidence of an outward temperature rise and a deep chromosphere.

A very strong line in the solar spectrum is that of H-alpha which seldom shows an emission reversal. Lines of this kind, as the Balmer series, are examples of excitation by indirect transitions wherein atoms are transferred from the lower to the upper state via an intermediate state, which most often is the continuum. The background radiation lower down in the atmosphere governs such processes and hence, the local temperature of the chromosphere where the line is formed, plays little role in determining the emergent line profile. Photoelectrically controlled lines are therefore independent of the kinetic temperature structure of the chromosphere. H-alpha is, therefore, most often in absorption, when the H and K lines have strong emission in the core. Exceptions to such a situation will be at high densities, as in solar flares, when collisions become more important than indirect photoelectric processes.

Spectral features that indicate a temperature rise, besides the ionized calcium resonance lines, have to be chosen with care and an understanding of the physical processes involved. Such symbiotic aspects yield temperature or abundance values that disagree with similar values derived from other spectral features of the same star. In some M-giants the Balmer lines are much too strong for the effective temperature of the star derived by other means ; this indicates over population of the second level. Since the lines have a large excitation potential, it can only be a layer more hot than the photosphere, that can give the observed intensity. Neutral helium is a fine example where 10830°A is seen in many cool stars and 5876°A seen in a smaller number. Calculations of the population of the lower level of 10830°A indicate that it is negligible for temperatures less than 20000°. Hence this line is a good indicator of a high temperature rise in the outer atmosphere of a star that has a much lower effective temperature.

The continuum in some cases can also be used as an indicator of the positive temperature gradient. In a case where the brightness temperature of the radiation increases as the opacity increases, the inference will be that there is an outward rise in temperature.

In summary, for ground based observation the resonance lines of ionized calcium, when seen in emission in the integrated spectrum of a star, seem to be efficient indicators of stellar chromospheres in the spectral range F5 to M. For stars that have very hot chromospheres the neutral helium lines at 10830°A and 5876°A are good means of identification ; the D3 line is specially so for stars of spectral type earlier than spectral class Go.

Emission components in the cores of the H and K lines of CaII were first discovered by Schwarzschild and Eberhard in 1913. As a *byproduct of other spectroscopic programmes, notably those of measurement* of radial velocity, several lists of stars became available in the decades that followed, which displayed the H and K lines in emission. Until the early fifties, little was known from systematic study of such emission in stellar spectra. Primarily to search for possible solar cycle equivalent effects in other stars, Wilson and I commenced at the time, a programme to search for intensity fluctuations or changes in violet-red intensity ratios of the emission components, in a search for some clue that would show up secular changes in the emission. We observed these stars at a dispersion of 10A/mm with the 100-inch telescope on Mount Wilson and this instrumental combination gave us spectra well exposed for the bottom of the K absorption line, in reasonable exposure times, for the bright stars of naked eye visibility. Our initial working list covered a range of spectral type and especially luminosity. First results from microphotometer tracings and micrometer measures of emission width showed that the widths of the *absorption core in the self reversed emission and of the emission* itself had a dependence on luminosity (Bappu 1954, Wilson 1954). An immediate extension of the observations to a large number of stars showed, that when the emission line widths, corrected for instrumental width, are plotted against the absolute magnitudes, the points define a straight line, which in astronomical parlance extends ever a 15 magnitude range in Mv, or a range of 10^6 in absolute brightness

(Wilson and Bappu 1957). The line widths vary as the one-sixth power of the luminosity, and are independent of line intensity or star surface temperature. The sun conforms to this relation and so do four giant stars that are members of the Hyades cluster with a well established distance. The establishment of such a relationship provided two reasonable conclusions. Firstly, the relation could be used effectively for luminosity determinations of late type stars which have the K line in emission. The second is of greater importance astrophysically ; it shows up the presence of an uniquely fundamental mechanism which prevails in all chromospheres and which, in magnitude, depends on the stellar output of energy.

Many partial explanations of the K line width-absolute magnitude relationship have appeared in the literature in the two decades since it has been established. The width is ascribed mostly to turbulent motions. Athay and Skumanich (1968) have studied the formation of the self-reversals in the H and K lines for optically thick chromospheres with a temperature increasing outwardand find the line width sensitive to chromospheric opacity, the damping parameter and the chromospheric Doppler width. The K line width-absolute magnitude relation according to them arises principally from changes in the Doppler width.

Close on the heels of the discovery of the dependence of widths on the luminosity, came the finding that the emission intensities were age dependent with the younger main sequence stars having higher values than an older star of the same spectral class (Wilson 1968). Double stars and galactic clusters that are typical of a genetically related group demonstrate well, this age dependence. The chromospheric display, as an active indicator of the stage of main sequence evolution, is a feature that can effectively be utilized in any effort directed towards the study of evolutionary trends displayed by an ensemble of stars.

These findings have been applied to the study of galactic structure quicker than we have found an interpretation for the astrophysical behaviour. The K line width-absolute magnitude relation is an extremely dependable absolute magnitude criterion in cases where such measures can be made. Its principal handicap is the need of dispersions that restrict the freedom of sampling. However, dispersions as low as 40A/mm have been usefully utilized for determining absolute magnitudes of stars brighter than $M_v = 1.0$. The age dependence of the intensity has been used convincingly by Greenstein and Kraft to pick out faint members of the Pleiades, with dispersions even as low as 200A/mm. Such a technique has immense potential.

The calcium emission on the main sequence commences rather abruptly at spectral type F5 as one goes to lower temperatures. This point on the main sequence coincides, with great precision, with the point where large rotational velocities, which are a characteristic of the early spectral types, cease. Theoretical studies indicate that this is the domain on the H-R diagram wherein deep hydrogen convection may set in. The presence of a hydrogen convection zone seems responsible for the onset of chromospheric activity and the transition from large to small rotational velocities. Schatzman's mechanism of braking the rotation, effectively explains the relationship with a chromosphere.

In making postulates on the origin and nature of the source of such chromospheric emission over a stellar surface, we obviously depend heavily on our familiarity with a similar pattern of behaviour on the surface of the only star whose disc is amenable to close scrutiny. The sun fits well the K line width absolute magnitude relationship and this assures us that the emission cores we see in other stars are of chromospheric origin. Hence much interest centres on an identification on the solar surface of the feature that gives rise to the width-luminosity relation.

A calcium spectroheliogram of the solar disc shows primarily three principal characteristics. If we have a centre of activity on the visible portion at the time, it will manifest itself with enhanced calcium emission over a sizeable region and this we term a calcium plage. Then, there is the network of calcium emisson which has been shown by Leighton to coincide with the boundaries of the supergranulation. And within the configuration of a network cell, we come across localized bright points of emission which we recognize as bright fine mottles. The boundary of the supergranule has enhanced emission with a twofold contribution. The fine mottles are there too and some of them clump together to form a coarse mottle of roughly 7000 km diameter. There is also enhanced emission at the boundary by magneto hydrodynamic heating accentuated by the piling up of the magnetic field swept up by the horizontal flow within the domain of the supergranule. The three principal sources of calcium emission are thus the plage, the network boundaries and the fine mottle.

Bappu and Sivaraman, (1971) have carried through a study that shows which of these three features is responsible for the K line width-absolute magnitude relation found by Wilson and Bappu (1957). This study was from a single frame of excellent quality which we had obtained in a K line time sequence of a specific region at the centre of the disc. A spectroheliogram taken soon after this exposure showed us the location of the slit in terms of the K_{232} network and other features seen in the light of ionized calcium. The dispersion of the spectrogram was 9.4mm A^{-1}, almost a hundredfold larger than what Wilson and I had used earlier in the stellar case. It is well to realize however, that the K emission feature in the case of the Sun is seldom seen at dispersions lower than about 4A mm^{-1}. At the large values of dispersion employed currently for the study of solar inhomogeneities, one sees a large amount of details, pecially when the spectrogram is obtained during the moments of good seeing. One sees numerous emission streaks of sizes in the range 1—2", mostly with emission greater in the violet portion of K_2 than in the red or $I_{k1v} > I_{k2R}$. About one in twenty have the two portions equal and it is very seldom indeed that both K_{2V} and K_{2R} are absent simultaneously. Our study shows a typical characteristic of K_2 emission from a quiet region of the Sun to be the case $I_{k2V} > I_{k2R}$. We interpret the changes from this normal aspect as due to the action of two types of absorbing components that are present on the same scale of inhomogeneity in sizes as the bright features. One component with minor Doppler displacements acting on the normal K_{232} profile produces the changes observed between I_{k2v} and I_{k2R}, relatively enhancing one at the expense of the other. The other component arises from what we call 'dark condensations' with down flowing velocities of 5—8 kms^{-1} and sizes of about 5000 km. These dark condensations can be seen easily on any good K_3 spectroheliogram and in our opinion give rise to the situation $K_{2R} = 0$.

These details of intensity fluctuations are of interest to the stellar case where we necessarily measure the integrated characteristics of K_2 emission and all those features that upset the intensity ratio between I_{k2v} and I_{K2R}. In cases like α Bootis it is well to remember this aspect as one possibility that we could utilize to explain changes in the relative intensities of the K_2 emission components.

Sivaraman and I have also measured the widths along the dispersion of all the double peaked emission features that we have on this particular frame. We measured the separations of the emission peaks as well as the separation of the minima between the emission feature and the regular K absorption feature. We call the former a K_2 width and the latter a K_1 width. When we plot a histogram of the frequency of the K_2 widths we find a remarkable uniqueness of the value of the K_2 width about a particular value of 26 km s^{-1}. The K_1 widths do not show such a sharp clustering about a single value ; however, they also have a mean characteristic spacing giving rise to a K_1 width of 41 km s^{-1}. Since the intensities in the solar case of I_{k2v}' I_{k2R}'; are close to I_{k1v} and I_{k1R} we get a width at half intensity of 33.5 km s^{-1}, by taking a straight mean of the values given above. Compare this with the value of Wilson and Bappu (1957) obtained from an 'averaged' disc spectrogram of 34 km s^{-1} and by a micrometer setting on the emission feature. Since the sun fits well on the K line width-absolute magnitude relation with a measured width of 34 km s^{-1} it is clear that bright points of K_2 emission are the principal contributors to the line width-absolute magnitude relation. The intensity scans perpendicular to the dispersion show that they have typical sizes of the order of 1—2". Hence, we conclude that these bright points that enable the sun to follow the line width-absolute magnitude relation are the fine mottles seen on a good quality spectrogram. We stabilize this identification from a comparative study of the auto correlation function obtained from intensity scans perpendicular to the dispersion as well as that obtained on a two dimension scale from a high quality K_{232} spectroheliogram. Both these give full widths at half maximum of 7000 km. We conclude that the average spacing between the bright streaks on the spectrogram are the same as that of the fine mottles on the two dimension spectroheliogram. The argument thus secures our identification.

The value of 7000 km is the spacing between the brightest features within the supergranular network and also that between the bright streaks on the spectrogram. The spacing between these streaks also shows the emission peaks but of lower intensity. We may ascribe these to an unrseolved background of fine mottles that awaits detection with the improved resolution techniques of the future.

The life times of the emission streaks on the spectrogram and of the fine mottles on spectroheliograms provide an additional confirmation of identity. Both have values around 200 s and hence both are identical.

The behaviour of emission peak separations on plage regions have been known for a very long time. From the stand point of our terminology the K_2 widths decrease with enhanced plage intensity and proximity to the seat of the centre of activity. Elske Smith (1960) has expressed this quantitatively. She also finds a minor change in the widths of the emission feature as one goes to plages with enhanced magnetic fields. In terms of the discussion above, it is seen that the plage regions offer little hope of being the source of a unique value for the K_2 separations similar to the case of the fine mottles.

A similar situation prevails at the boundary of the supergranular network. Calcium emission here is greatly enhanced and has a noticeable contribution from the magnetic fields accumulated by virtue of the supergranular flow. The K_2 width here is in the neighbourhood of 20 km s^{-1} instead of a value of 26 km s^{-1} for the fine mottles. It is clear that supergranular boundaries do not have any appreciable contribution to the unique value of the solar case.

We are thus left with the bright fine mottle as the principal contributor to the K—line width-absolute magnitude relation. The fine mottle is not known to display any appreciable longitudinal field greater than the limit of photographic detectability. The bright mottle is thus, by some cause as yet unknown, a manifestation in the chromosphere of the mechanical energy dissipation from the convective layers below. It has characteristics prescribed by a combination of the fundamental parameters of the star.

In comparing the values of K line width between the sun and the stars, the solar value must be from a spectrum that averages the myriad of details normally seen on a calcium spectroheliogram. The value wc had used earlier (Wilson and Bappu, 1957) was derived from a high dispersion spectrogram obtained by moving the solar image across the slit. Subsequently Wilson (1959), for a solar value for his sun-Hyades calibration of the K line width-luminosity relationship, had used a value of 33.3km/sec, obtained as a mean of two different procedures; one averaged across the solar disk, avoiding the regions of plage activity and the other taken in the sky off the solar image, but still adjacent to it.

The K emission in the integrated spectrum is visible only when one employs dispersions of the order of 5A/mm or higher. The intensity of K is so weak that one needs a much higher dispersion to be able to make a measurement of the line width with any accuracy. Very recently (Bappu and Sivaraman 1976) two different methdso have been employed for obtaining a truly integrated spectrum and the mean value of several measures is 38-0 km/sec. A difference of 4 km/sec is obtained from the values used earlier. This is easily explained by noting that the 1957 and 1959 measures did not pertain to integration of the K-emission over the entire visible disc. The K-line profile widens as one goes from centre of the solar disc towards the limb. While this characteristic contibutes a share to the line widths, the principal contributor will be that of rotation, since the regions farther away from the centre will contribute more to the integrated behaviour than the centre itself. It is essential, therefore, to employ the integrated spectrum for any comparison of solar behaviour, with that seen elsewhere in the stars. A comparison of the K_{232} profile in the integrated spectrum of the sun with similar profiles of the bright mottles, shows at a glance that the integrated case is an envelope that is a summation of performance of individual bright mottle profiles along with their Doppler displacements and the contribution of the dark condensations. Since the envelope is a weighted mean, the integrated K profile evaluated in terms of red and violet components are closely similar to that of the typical bright mottle.

The physical parameters controlling the excitation of the bright mottle are those of temperature, density and the velocity effects originating from the convection zone, that together with the magnetic fields pervading the medium, characterize the typical mottle. By treating the red and violet components separately by the methods introduced by Jefferies, Thomas, Athay, Skumanich and Linsky, a set of parameters defining the chromosphere characteristic are easily derivable.

It is well to realize that another common aspect on the solar surface, the calcium plage, can compete with the bright mottle for dominance in contribution to the integrated K emission. In the case of the sun, by virtue of intensity and area, the role of the plage is a minor one. Two aspects enable us to identify the plage contribution. If stellar plages are also the result of active regions on the surface, then changes in the areal extent would cause intensity changes in the integrated spectrum. Also, the K line widths would be dependent on the magnetic field values and would show up as deviations from the width-luminosity relationships. Monochromatic light curves of variation of the K emission characteristic show that such changes in intensity are small and that a majority of the stars do not exhibit them. Our information in this regard is, however, very scanty. But all factors point out that the bright mottle or its stellar equivalent is the principal contributor to integrated K emission. Since there is little difference between the emission line profile in the mottle and that in the integrated spectrum, we are in the stellar case, especially where plage activity is ruled out, witnessing the performance of the mottle.

The width of the core of the absorption H-alpha line in late-type star spectra has also a dependence on luminosity (Kraft, Preston and Wolff 1964). The correlation with an ultra-violet absolute magnitude among G and K stars is independent of spectral types. The core of H-alpha has a Doppler origin and arises from the chromosphere. The correlation is seen to be an H-alpha analogue of the K line-width absolute magnitude relationship but of lower sensitivity, and hence accuracy. Its principal advantage over the K line method is in being able to reach faint red stars needed in any galactic structure survey.

The 10830°A line of neutral helium is the only line in the Fraunhofer spectrum as seen from a ground based observatory, that originates exclusively from the chromosphere. In quiet regions of the sun, its absorption is less than one percent, a value that increases twenty-fold in the plages. Only in greater solar flares does it appear in emission. Theory predicts little excitation of this line at temperatures below 20000°K. Its presence is therefore indicative of a hot chromosphere.

The only detailed study of this line in late type stars is by Vaughan and Zirin (1968) who used an image converter at the coude spectrograph of the 200-inch telescope. The survey covered the spectral domain F0 to M5, and most stars chosen were ones known to have chromospheres from K line measures. The line has commonlye quivalent widths in the range below 200 m°A. It is seen easily in G and K stars with maximum intensities between G2 and K1. There is no close correlation between 10830°A behaviour and K line intensity. While maximum 10830°A intensities are seen in stars that have strong K emission, there is much scatter in a plot of the two line intensities. The helium line widths also have no dependence on luminosity as in the case of ionized calcium. The absorbing or emitting material in 10830°A seems to be distributed heterogeneously in the form of clouds of different dimensions distributed over the surface. In the sun, plages which show up the line in absorption are localized to active regions which have a patchy distribution. A similar situation seems to prevail in the case of the stars. A basic clue to this reasoning comes from the line widths, which if interpreted as due to thermal Doppler broadening would need temperatures of $10^{5°}$ K ; hence the broadening must be due to macroscopic motions. In the sun, moving jets of matter (spicules) produce the line.

The ratio of optical depths between 10830°A and 5876°A is about 10 or greater for G or K stars. Hence hot chromospheric domains are best revealed in these stars by 10830°A. As we go to earlier spectral types this ratio becomes much less. The D_3 line is then a better indicator for detection.

With observations from space becoming increasingly available, the resonance lines of Mg II in many stars can be studied for intensity and profile data. The self reversal in the MgII lines are very much greater than in the case of ionized calcium and as expected the line widths are closely correlated with luminosity. Much will come from studies of this line, as techniques improve, to enable fainter stars come within our range of study. Other approaches to the chromospheric problem in stars are the study of eclipsing binaries like Zeta Aurigae, and emission lines of FeII in the near ultraviolet. The former provides a direct means of obtaining information on the height variation of temperature in the atmosphere of the cool supergiant component; the observations are best intepreted in terms of small scale density condensations in the extended atmosphere. As regards the FeII lines, little is known of the origin of the emission and of the central absorption reversal. The fact that these are seen only in the very cool stars makes observations tedious, because so little continuum radiation is received from these stars in the ultraviolet.

The future has much to offer in this fascinating field. There is enough material now available (Wilson 1976) that provides us with a gross picture of K-line intensities and line widths in a large number of stars. Further progress, in my view, will ensue from detailed studies at dispersions higher than have been employed so far, quantitative values by photoelectric methods of V/R ratios of K_2 emission and extension of such techniques to selected objects with specific questions in mind.

It is clear that we have established the roles of both the "quiet" and the "active" components to the K emission, on lines that prevail *in the case of the sun. These two aspects, may in certain* cases operate together and it would be of considerable interest to evaluate the individual contribution of each. There are also cases of chromospheric K emission in certain stars like the cepheids, the T Tauri stars and few others that violate the line width-absolute magnitude relation and other norms of chromospheric behaviour mostly followed by the majority of stars.

Let us take the cepheids to begin with. K emission in the spectra of these objects has been seen in the phase interval from minimum to maximum and is clearly triggered by the onset of the wave of pulsation in each cycle. The emission vanishes soon after the maximum and is not detected until the commencement of the next cycle of energy dissipation. The width of the K emission is far greater than the width needed for the cepheid to fit the line width-absolute magnitude relation, corresponding to its luminosity.

This departure is easily explained when we are aware that time-dependent gross phenomena exist in the cepheid atmosphere different from the other stars. A matter of prime interest is the reverse viz. the nondetectability of K-line emission in the cepheid, at the relatively quiescent phases of its pulsation cycle, which would conform with the line width-luminosity relation. The cepheid spectrum can be matched at any phase with a corresponding spectrum of non-variable giant or supergiant star. The experienced spectral classifier sees no striking differences between the two spectra. How is it then, that at these phases, the normal chromospheric. characteristics, seen with ease in the comparsion star, are absent in the cepheid ? Are we, in the case of the cepheid, to find that the hydrogen convection zone is much less virulent than in the normal giant ? These are answers that future observation and cepheid theory can provide.

What of the role of magnetic fields in contributing to K emission ? We have reason to believe that such a situation adds to the normal emission caused by the convection zone and the individual velocity elements that take the from of the mottle. Only by the study of deviations from the line width-luminosity relation and secular changes of such emission can we observe the prevalence of large scale active regions on the star disc. The case of Canopus perhaps demonstrates this argument well. A spectrum taken by Warner (1966) with a dispersion of 6. 8°A/mm showed K emission which had a much narrower width than the value predicted by the line width-luminosity relation. At this relatively low dispersion, emission in the sun would not have been seen. Hence the Canopus emission must have been of some intensity. The narrowness of the emission line is also typical of K emission from a plage on the solar surface. In 1975 and 1976, spectra taken at Kavalur at 4°A/mm and 2.8°A/mm respectively show little trace of K emission. Clearly we are witnessing the change with time, perhaps in some cyclic way, of large areas of magnetic activity on the surface of Canopus. Confirmation of this reasoning comes also from the measures by Wood of an integrated magnetic field of the order of a 100 gauss in the star. The north component of the binary system gamma Virginis is another similar case where both components have similar spectral types and probably were formed together, but only the northern star has K-emission and a measured integrated magnetic field. This star, however, falls within the scatter of the line width-luminosity relatation, but one should not stress this aspect much, since main sequence stars in general have narrow emission lines and these are only measured with accuracies that are not comparable to what we can achieve in the case of the giants and supergiants.

The two instances of Canopus and gamma Virginis show the presence of K-emission because of magnetic fields. We should treat these cases as demonstrative of how emission by magnetic regions can cause deviations in a normal pattern followed by most stars, rather than employ the argument that here we have evidence of a magnetic origin of all K emission seen in the stars.

However, one should not be misled into believing that the magnetic fields do not play a role in the normal formation of the mottle, as we see on the solar surface. As I have indicated earlier, the total intensity of K emission, for main sequence stars like the sun, decreases with age. Now, it is difficult to ascribe this to a decay of the strength of the convection zone. Rather, it seems that the fields prevalent in the chromosphere in the from of localized flux tubes are the heating agencies that cause the K-emission, but with Doppler characteristics that reflect the convection zone kinematic capability. It is this latter factor that governs the width-luminosity relation. The age dependence of emission is presumably related to a general decay of the field in the outer layers.

As a star evolves from the main sequence into the red giant stage, there is a resurgence of chromospheric activity, with intensities increasing as the star gets farther away from the sequence. The evolving star continues to fit the width-luminosity relation. One can only infer that the magnetic fields permeating the chromosphere are slowly augmented with time, presumably by a process that is reactivated as the star structure is readjusted during its evolution to the red giant stage. With increase in ambient field strength the emission from the mottle is more intense, while at the same time the Doppler features show up the characteristics of the hydrogen convection zone. Only further studies, both observational and theoretical can eleborate this conjecture.

And finally, we have seen how even the small values of solar rotation can contribute to the width of the K emission. Seldom have we measured directly in integrated spectra rotational velocities of stars of values even comparable to the solar case. This domain is difficult experimentally, but new procedures of analysis, developed recently, together with line profiles of high accuracy, will in the future, give us a picture of their present day angular momentum characteristics. The chromospheric line will aid in object selection by virtue of deviations from an accurately evaluated line width-luminosity relation. Perhaps, we will then be making very heavy demands on the accuracy of observations and of the models we compare them with, and face the danger of over-interpretation. But it seems our best available procedure of evaluating angular momentum trends in solar type stars and speculating on the likely presence of planetary systems similar to our own.

The effort seems very worthwhile.

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