Stellar Chromospheres

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One of the earliest discoveries in observational astrophysics has been the flash spectrum during the few moments immediately preceding and following the totality phase of a solar eclipse. The study of the nature of the solar chromosphere that gives rise to the flash has been one of the principal goals of solar physicists during the years since the discovery of the flash spectrum one hundred years ago. Progress in this field has been slow principally due to the fact that eclipses were a principal source of much needed observational information. The last of adequate physical theory to elucidate the intricacies of excitation of the radiating atoms and ions has been another factor. Even to-day, we have much to observe and interpret of features and phenomena that occur in the relatively thin layer of the solar atmosphere which we consider the chromosphere.

The situation is very much a picture of ignorance when we consider the chromospheres of stars other than the sun. One of the principal features of the solar chromosphere is the bright emission in the H and K lines of ionized calcium over most of its surface and the enhanced radiation in the flocculi associated with active regions. In the visible spectrum the Ca^+ resonance lines afford the best means of detection of stellar chromospheres. There are several stars known, particularly among the late spectral classes, that show bright emission within the cores of the strong H and K lines. It is obvious that these emission features result from the chromospheric features of the star. Viewed in this context these stars have chromospheres more intense in the light of ionized calcium than the sun, since we can barely detect the solar chromosphere in integrated light and the low dispersions that have normally been employed to detect the stellar chromospheric contributor. The chromospheric emission in K can be detected only on integrated spectra of dispersion 5Å /mm or higher.

A study of the chromospheres of stars other than the sun is, therefore, capable of throwing much light on the phenomena prevalent in these atmospheres that produce these characteristics. There is also much that we can learn of stellar chromospheres in general when we view the sun as a typical star and use detailed studies of the solar chromosphere to interpret the characteristics we see in the stellar case.

We knew little of stellar chromospheres and of their potentialities in the general astrophysical interpretation of stellar evolution until it was shown that the widths of the emission components had a remarkable relationship with the star's luminosity over a range of absolute magnitude of nearly fifteen magnitudes (Wilsion and Bappu 1957). Close on the heels of this discovery came the finding that the intensity of the emission was greater for a younger star than an older one of the same spectral class (Wilsion 1963). Double stars and galactic clusters that typify a genetically related group demonstrate this age dependence well. The chromospheric display as an active indicator of the stage of evolution is a feature that we can effectively utilize in our efforts to follow the 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 44Å/mm (Dyck and Jennings 1969) 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 pickout faint members of the Pleiades with dispersions as low as 200Å/mm. Such a technique has a tremendous potential.

The solar situation has taught us that the presence of the chromosphere and corona calls for the need of a source of mechanical energy to produce not only the temporary dynamical features like the spicules but also the distension of the atmosphere we call the chromosphere and corona. The hydrogen convection zone is the source of such a maintenance. Hence, we associate chromospheres with stars that we know possess hydrogen convection zones. Wilson (1966 a) has demonstrated quite effectively how the chromospheric technique can be utilized for yet another astrophysical interpretation. It is well known that the rotational velocities of stars decrease as one proceeds along the main sequence. Wilson has chosen several stars of different rotational velocities and colours and measured for these K line intensities. He finds that rotation sets in quite abruptly at about spectral type F4, while chromospheres are evident for most of the later type stars commencing from spectral class F5. The deduction is that chromospheres are not detectable amongst the stars that have any appreciable rotational velocity greater than, say, a v.sini of 10 Km/sec. Hence, the presence of a strong hydrogen convection zone, necessary for the chromospheric emission, becomes responsible in some unknown way for breaking a rotating star and removing its angular momentum.

In making postulates on the origin and nature of the source of such chromospheric emission over the 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 our scrutiny. Calcium emission on the solar surface originates principally in active regions from the well known calcium flocculi. In the quiet regions of the solar atmosphere, Ca^+ spectroheliograms show such emission to be confined to bright fine mottles, aggregates of fine mottles that form the coarse mottles (de Jager 1959) and the supergranular network. Magnetic fields are known to be associated with the calcium flocculi and Leighton has shown a similar association with weak magnetic fields and the supergranular network. These characteristic features imply that the prevalent surface magnetic fields are in some way responsible for the calcium emission. If so the diverse properties demonstrated by the K line widths and intensity of correlation with absolute magnitude, age and stellar rotation would necessarily find a most critical dependence on the prevalence or otherwise of surface magnetic fields and their strengths.

There is also the possibility of a cyclic pattern in the existence of these magnetic fields similar to the sunspot cycle. These are vital problems, and for guidance in improved speculation we must necessarily resort to a closer scrutiny of the solar chromosphere.

One can assume that the large intensities of the K emission line in many stellar chromospheres originate from the active region emission of Ca^+. Wilson, (1966 b) appears to come to such a conclusion and Unsold (1969) appears to definitely conclude that they represent the integrated contribution of the calcium plages. To do so would be to ascribe that the property of the K line width-absolute magnitude relation in particular depends entirely on the line widths characteristics in plages. If star cycles exist, and it would be normal to assume so, the intensities would vary over the cycle duration. A similar line of reasoning has stimulated Liller (1968) and Wilson (1968) to search for variations in the K emission line intensity with time.

The occurrence of calcium flocculi and their areas over the sun's visible hemisphere are well chronicled (Kurien 1967). Sivaraman and I at Kodaikanal have examined plots for each year of the total areas of calcium flocculi. We assume with Dodson and Hedeman that the mean intensity in the flocculus is of the order of 3 in terms of the surrounding neigbhourhood and that a mean value of around 2.2 or 2.3 would be representative of the plage as a whole. The variation of total area and consequently total intensity is quite striking.

Near maximum when Ca^+ flocculi are numerous, the variations of area and intensity are quite irregular. There is of course the fact that in the bottom of the K line the sun would look more intense at maximum than at minimum. It would vary by 0.6 magnitude in K-emission and appear as a light variable with a 11 year period. This is much less than Sheeley's value of 40 per cent, which we consider as optimistic (Sheeley, 1967). Superposed on these are short term fluctuations caused by solar rotation. Away from solar maximum, when there may be only one large flocculus on the solar surface, the change in intensity is simple and periodic that provides a good value of a rotation period. It is not often that one can find such cases but specially in the 3 or 4 years around solar minimum such effects are easily noticed. Hence, we conclude that variations of K-emission intensity that Liller and Wilson can pick up, are manifestations of plage activity on the star's surface and in the course of time should yield information on the nature of star cycles.

The interpretation of the K line widths - absolute magnitude relation as caused by plages similar to those seen on the solar surface is very much less definitive. The investigations of Smith (1960)show the diverse widths that one obtains over a plage, To depend on the sum totalof these to provide a unique relationship that holds over a millionfold in intrinsic luminosity would seem to be too remote a possibility.

Sivaraman and I have, therefore, examined the line widths provided by the bright points that appear in abundance over the solar disc. We have on several good quality spectrograms taken with the Kodaikanal solar spectrograph at a dispersion of 9mm/Å made successive microphotometer scans along the dispersion at close spaced intervals on the solar surface. We have also obtained at the same dispersion integrated solar spectra by photographing the spectrum of sunlight diffused and brought to a focus by the same optics used earlier. Our conclusions are that while we can detect Ca^+ emission almost all over the sun, the bright fine mottles are the principal contributors to the emission in the quiet areas of the solar disk. Measures of the K line widths of several of these features show that the values cluster around a value of 25.5 Km/sec. for a specified definition of the line width. The line width as measured in the integrated spectrum is very slightly larger; this increased width is to be expected by virtue of the doppler displacements associated with the bright fine mottles. The fine mottled structure and the photospheric granulation can be inferred to be visible manifestations of the hydrogen convection zone. We believe, therefore, that the principal contribution to the K line width-absolute magnitude relation comes from the fine mottling in the stellar chromosphere. The contribution of the plages to these values is additional, and will change the integrated value very little. In the solar case the integrated spectrum is the sum of two components; the fine mottling and supergranules both of whom have nearly identical widths form one component and the plages with different widths constitute the other. While the plages vary in area and total intensity, the quiet background comprising the mottles and the supergranules have more or less permanent integrated characteristics. It is the latter which contributes primarily to the line width-absolute magnitude relationship while the former's share is confined principally to the intensity variation. Viewed in this fashion one might speculate on the possibility that the best candidates for detection of star cycles may not be those that follow rigorously the K line width-absolute magnitude relation.

The future has much to offer in this area of interesting observation and deduction. With the availability of the additional facility of observations from outside the earth's atmosphere, we are really poised on the threshold of a vista of much discovery of the intricacies of stellar chromospheres.

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