MASS LOSS FROM COOL STARS

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Abstract. Recently obtained spectroscopic observations indicating mass loss in cool stars are reviewed with analogies to the solar atmosphere. Spectral diagnostics of mass loss are discussed with new theoretical calculations of chromospheric line profiles. A general picture of mass loss from cool stars is developed and related to chromospheric and coronal emissions measured by IUE and the HEAO-2 Observatory. These winds range in characteristics from the hot (10^6 K) and fast wind with low mass loss found in the dwarf stars to the warm ($\sim 10^5$ K), moderate speed winds present in hybrid luminous supergiants, and the coolest massive winds emerging from the latest type supergiants exhibiting lowest thermal velocities and circumstellar shells. Evidence for stellar surface inhomogeneity and variability of outflow is briefly discussed.

1. Introduction

Mass loss from the cool stars shows a great variety of behavior. The rate of mass loss ranges over 9 orders of magnitude; stars from which we know mass loss to occur have luminosities that span over 5 orders of magnitude although the effective temperatures may change by only a factor of 10. From recent space observations, we have new evidence concerning the relationships between mass loss, its possible variability, and chromospheres, coronae, and circumstellar material. These results complement the extensive ground-based observations that began with Adams and MacCormack's (1935) detection of blue-shifted absorption cores in neutral and ionized species in the spectra of M giants and supergiants. However it was Deutsch

C. Chiosi and R. Stalio (eds.), Effects of Mass Loss on Stellar Evolution, 87–110.

(1956) in measurements of α Her who discovered circumstellar absorption features from an M supergiant against the continuum provided by a G star companion. The velocity of these circumstellar features is larger than the escape velocity at the companion's distance and confirmed the loss of mass from the system. Since then optical, infrared, and ultraviolet studies have generally confirmed the existence of mass loss in a great variety of cool stars. Figure 1 shows the location of stars of concern to this review. Conti (1981) in this volume has

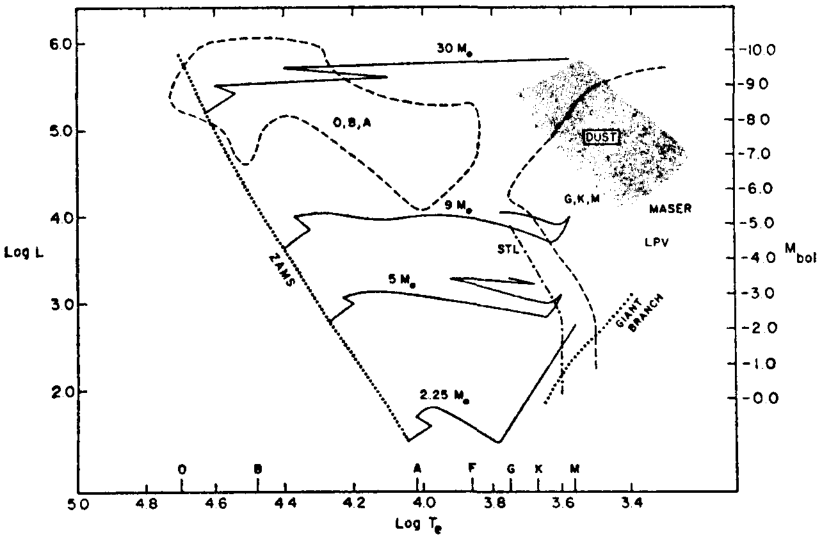

Figure 1: H-R diagram indicating the position of stars with high rates of mass loss. The broken line enclosing an area marked O, B, A marks the domain of the hot stars discussed by Conti (1981); the area to the right of the open broken line shows the zone where cool stars are thought to undergo increased mass loss. Also shown are the Zero Age Main Sequence (ZAMS), evolutionary tracks (solid lines), and the red-giant branch (dotted lines). From Goldberg (1979).

discussed the observational characteristics of mass loss from hot stars; we shall consider principally observational aspects of mass loss in the G, K, and M stars. Several good perceptive reviews have been written recently on these topics by Cassinelli (1978), Goldberg (1979), and Holzer (1980). Optical observations have been carefully summarized lately by Reimers (1981) and Hagen (1980).

Recent results from space experiments now provide an abundance of measurements which, coupled with new quantitative observations made possible by photon-counting ground-based detectors are giving a broad outline of the mechanism of mass loss in cool stars. Such results provide constraints for the theory of stellar winds as well.

In this paper diagnostics of mass flow and loss in a stellar atmosphere are summarized. The Sun is then used as a beginning example. This dwarf star, although losing mass at a spectroscopically inconspicuous rate, serves to illustrate fundamental considerations about the interplay between hot plasma, magnetic fields, and mass loss from a star. Some recent ultraviolet and optical observations of mass loss in the luminous stars are noted in Section 4. Following this is an overview of the relation between the presence of chromospheres and coronae and the character of stellar winds. Such observations define constraints for theories of mass loss discussed in Section 6. Finally we remark on some recent results concerning stellar surface inhomogeneities and possible variability of the mass loss rate.

2. Diagnostics of Mass Outflow

There are several means to infer the presence of mass outflow in a stellar atmosphere. These include:

- circumstellar lines (metals, Ca II, Mg II);
- circumstellar envelopes (IR);
- radio emission (OH masers, Si O);
- asymmetries in chromospheric resonance lines;
- direct Doppler shift measurements.

None of these methods is without an accompanying problem of interpretation either to determine the degree of mass outflow or the eventual mass loss rate in the stellar atmosphere. For instance, as Hagen (1980) has emphasized, the standard determination of a mass loss rate in a star such as α Ori suffers from the uncertainty in stellar radius, r, where the mass loss occurs. Additionally the optical lines used for determination are primarily from neutral species whereas the singly ionized stage is dominant in the atmosphere. Usually the additional losses from molecules and dust grains are not included. Even if ultraviolet lines are measured, there is at present great uncertainty in their interpretation in terms of mass loss rates. In fact, inspecting the literature, Goldberg (1979) found values of the mass loss rate for α Ori to vary by a factor of 200. In the search for a scaling law of mass loss rate with physical parameters such as gravity, temperature, and radius, Goldberg found that no one scaling law provided better agreement with the empirical rates than any other. Reimers (1981) has also recently stressed the inaccuracies of existing mass loss determinations.

At this point it is more profitable to concentrate not on the rates of mass loss for different cool stars but on the characteristics of the mass loss, new results, and the development of constraints for stellar wind theory.

3. The Solar Example

The Sun, a G2 V star, provides a unique and useful example of the relationship between winds, mass loss, and surface activity which we believe to exist on other stars to a greater or lesser degree. The soft X-ray photograph of the solar corona in Figure 2 displays typical characteristics of a stellar atmosphere with highest contrast. The surface inhomogeneity is immediately apparent - the bright areas (active regions) dominated by the looping structures indicative of closed magnetic field lines - and the extended "dark" areas. These areas where X-ray (and ultraviolet) emissions decrease were recognized as regions of lower density and temperature where the magnetic field lines are not closed but open, material escapes easily, and forms the source of the high speed streams in the solar wind (see discussion in Bohlin, 1977 and Zirker 1977). At solar activity minimum it is believed that a high proportion, if not all, of the solar mass loss occurs through such coronal holes. For our later analogies to the stellar cases of mass loss there are three important facts apparent from such an image:

- the dominance of the magnetic field in structuring the atmosphere and the mass loss;
- the inhomogeneity of the stellar surface emissions;
- the presumed long term variability of the proportion of open and closed magnetic regions with solar activity.

Examination of the solar example is also useful for we believe we understand the structure of the atmosphere and its components more accurately than that of other stars. In particular, to anticipate the later parts of this review, the

Figure 2: A soft X-ray photograph of the Sun with a large extended coronal hole (the large dark area) crossing the center of the disk. Courtesy of HCO/AS&E.

spectroscopic consequences of a mass outflow can be evaluated in detail for chromospheric lines. Using the non-LTE approach of the PANDORA code including effects of partial frequency redistribution, we can calculate the Mg II profile, for instance, based on the average quiet solar chromosphere model derived by Vernazza, Avrett, and Loeser (1981). In Figure 3 we see that the asymmetry of the Mg II lines occurs for a mass-conserving flow. This asymmetry results from the increased atmospheric opacity towards the shorter wavelengths in a differentially expanding atmosphere and has as a consequence that the short wavelength (blue) side of the profile is weakened relative to the long

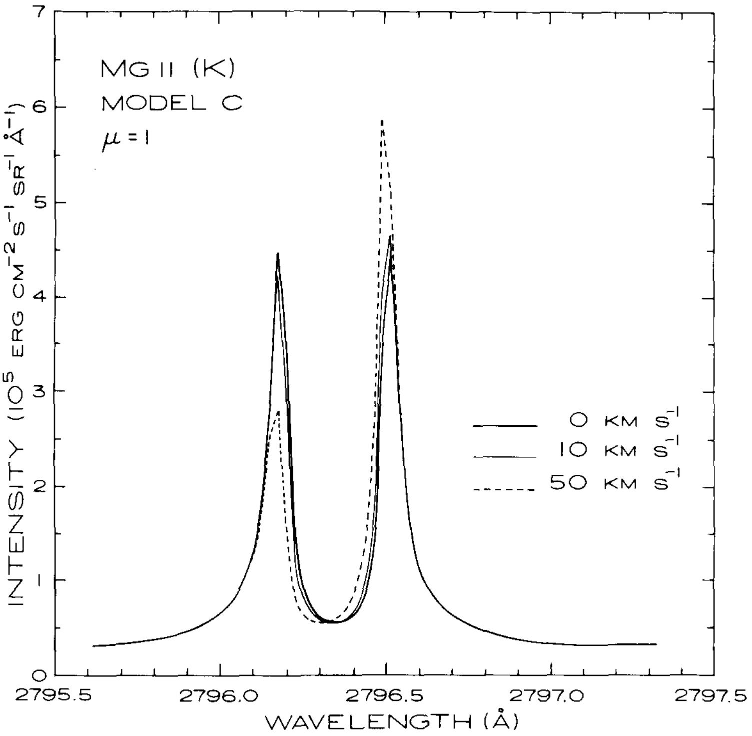

Figure 3: The calculated Mg II (λ2800) profile for a model of the quiet Sun assuming a mass conserving outflow normalized at 10^5 K to 3 values: 0, 10, and 50 km s^{-1}. The wavelength scale is centered on the vacuum wavelength λ2796.3 for the transition which in air is λ2795.523.

wavelength side. Our calculations show that the Ca II K line exhibits less asymmetry as one expects the flow velocities to be generally smaller at lower levels of the atmosphere.

Such asymmetries have in fact been observed by Brueckner *et al.* (1977) at different points on the Sun. They simultaneously measured the Ly-α profile and the Doppler shift of the C IV (λ1550) transition which is formed at a higher level of the atmosphere (see Figure 4). There is a great deal of scatter, however the general trend is clear - outflow at higher levels occurs in conjunction with a red > blue line asymmetry and *vice versa*. Such observations and theoretical models give support to the interpretation of stellar observations.

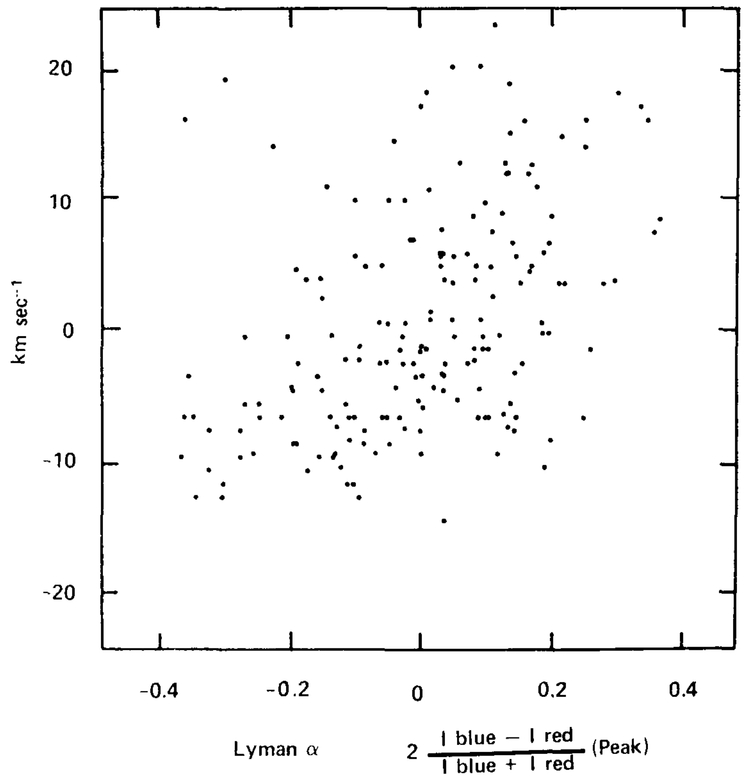

Figure 4: The velocity of the C IV line (λ1550) as a function of the asymmetry in the Ly-α transition for various points on the solar surface. A negative value on the abscissa corresponds to a weakened blue emission relative to the red peak. Such behavior tends to correlate with outward motion at a higher level in the atmosphere. From Brueckner, Bartoe, and Van Hoosier (1977).

Now these asymmetries have been observed on restricted solar regions. The mass loss rate for the Sun is small - about 10^{-14} $M_{\odot}$ yr^{-1}. If the Sun were observed with no spatial resolution, apparently a large region of outflowing material would be necessary to measure an asymmetry in integrated sunlight. Moreover, active regions would contribute enhanced (symmetric) emission to the composite profile. This is apparently true for other dwarf stars as the spectra in Figure 5 show.

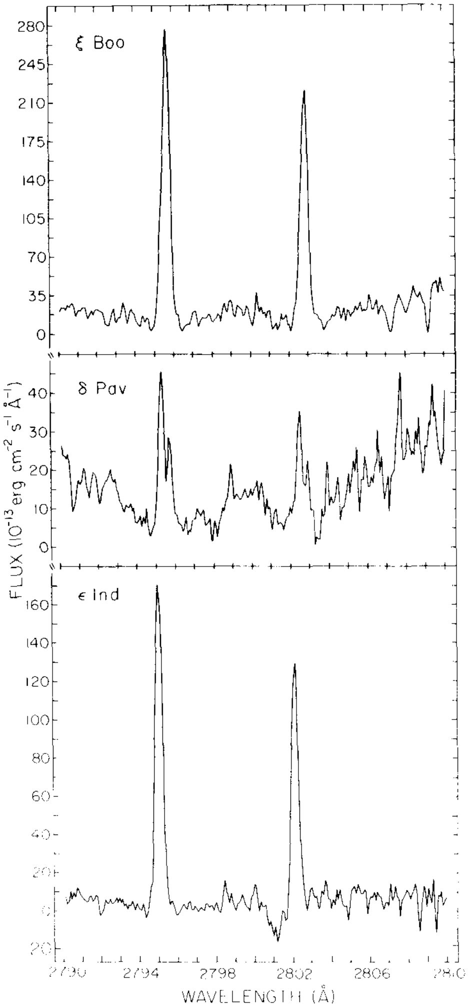

Figure 5: The Mg II resonance line as measured with IUE in three cool dwarf stars. The lines are narrow and asymmetries are not observable. From Hartmann, Dupree, and Raymond (1981b).

Two active dwarfs Xi Boo and Epsilon Ind show strong and structured emission profiles similar to those found in solar active regions; the dwarf star Delta Pav shows a reversal typical of the quiet Sun at Sun center (Kohl and Parkinson 1976). IUE has a spectral resolution of 25 km s^{-1} whereas the solar Mg II emission peaks in various disk positions are separated by 30-40 km s^{-1} (Kohl and Parkinson 1976) making a measurement of the stellar profile difficult. To date the presence of mass flow has not been detected or inferred spectroscopically in any cool single main sequence star other than the Sun.

4. Mass Loss in Giant and Supergiant Stars

Optical observations such as the surveys by Reimers (1977a,b) defined the luminous stars where circumstellar absorption lines were present. The early ultraviolet observations (Dupree 1976) merely hinted at the onset and existence of flows in the low chromospheric regions of stars. The Mg II resonance lines are now easily accessible in a wide variety of cool stars through the International Ultraviolet Explorer satellite and many giants and supergiants show substantial asymmetries such as those found in Beta Aqr (Figure 6). Here the velocity correspondence between the Ca II and Mg II absorption is apparent. The Mg II line displays an asymmetry; the Ca II lines do not. Theoretical calculations of solar line profiles suggest that the asymmetry is greater in Mg II than Ca II for a mass-conserving flow. Modeling of the atmosphere is necessary to determine absolute velocities.

Generally the asymmetric profiles are found in the most luminous cool supergiant stars and the coolest giant stars. Surveys (Stencel 1980) of the Mg II profiles show they mimic the regions in the H-R diagram where circumstellar optical lines are found although at slightly hotter effective temperatures for a given luminosity.

The supergiant stars offer an interesting sequence to illustrate the relationship between hot atmospheres and winds. The three supergiants whose spectra are shown in Figure 7, α Aqr (G2Ib), λ Vel (K5Ib) and α Ori (M1-M2 Ia-Ib) show asymmetric Mg II profiles and circumstellar absorption. However the coolest of these supergiants Lambda Vel and Alpha Ori show only low temperature ionic species in their spectrum (O I, C I, Fe II *etc.*) whereas Alpha Aqr - a supergiant with a massive wind - exhibits not only these species but high temperature ions as well (N V, C IV, Si IV). Such stars have been termed hybrid stars by Hartmann, Dupree, and Raymond (1980) for they support a substantial (10^{-8} M_0 yr^{-1}) wind in the presence of a warm (at least 2 x 10^5 K) corona. Five stars now appear to have this hybrid characteristic - Alpha Aqr (G2Ib), Beta Aqr (G0Ib), Alpha TrA (K4II), Iota Aur (K3II), and Theta Her (K3II) (Hartmann *et al*. 1980, 1981a; Reimers 1981).

The conditions in the wind of such stars are particularly interesting. High dispersion ultraviolet spectra of Alpha TrA from IUE (Hartmann, Dupree, and Raymond 1981a) show that profiles of species of low ionization are narrow as compared to broad

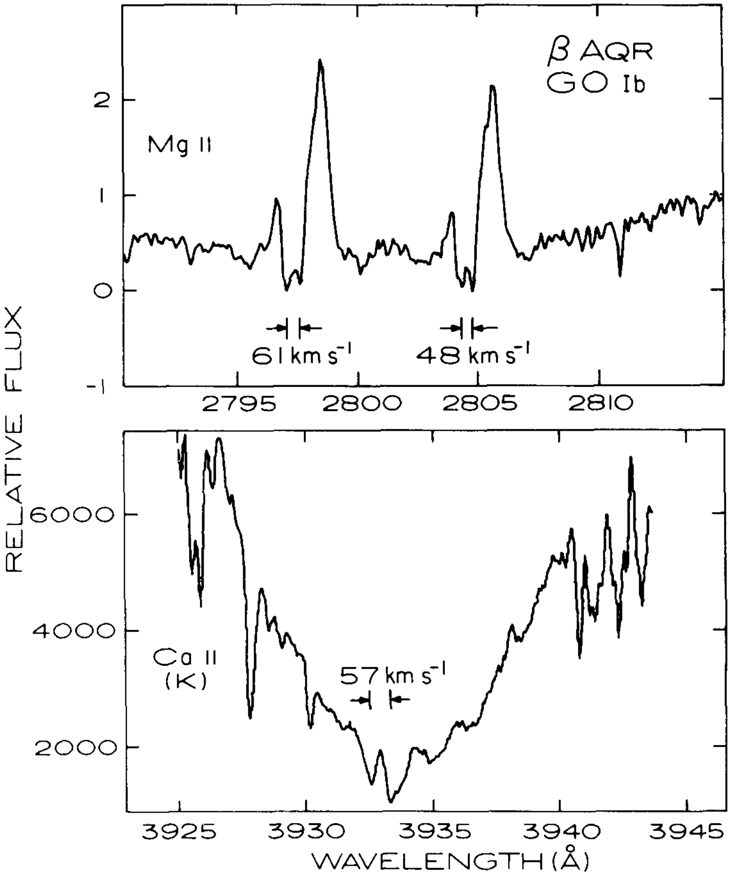

Figure 6: The Mg II and Ca II lines in the hybrid supergiant star Beta Aqr. Note the correspondence of circumstellar absorption features in both profiles. From Dupree (1980).

profiles of higher excitation species, for instance, C III and C IV (see Figure 8). The broad profiles correspond to a width similar to the velocity indicated by the circumstellar absorption lines. The most straightforward explanation of such observations is the existence of a warm (T ~ 2 x 10^5 K) wind - a corona through which the high temperature species are formed (Hartmann et al. 1981a). Recombination occurs as the wind cools, forming species such as Mg II that give rise to the circumstellar absorption features near the terminal velocity.

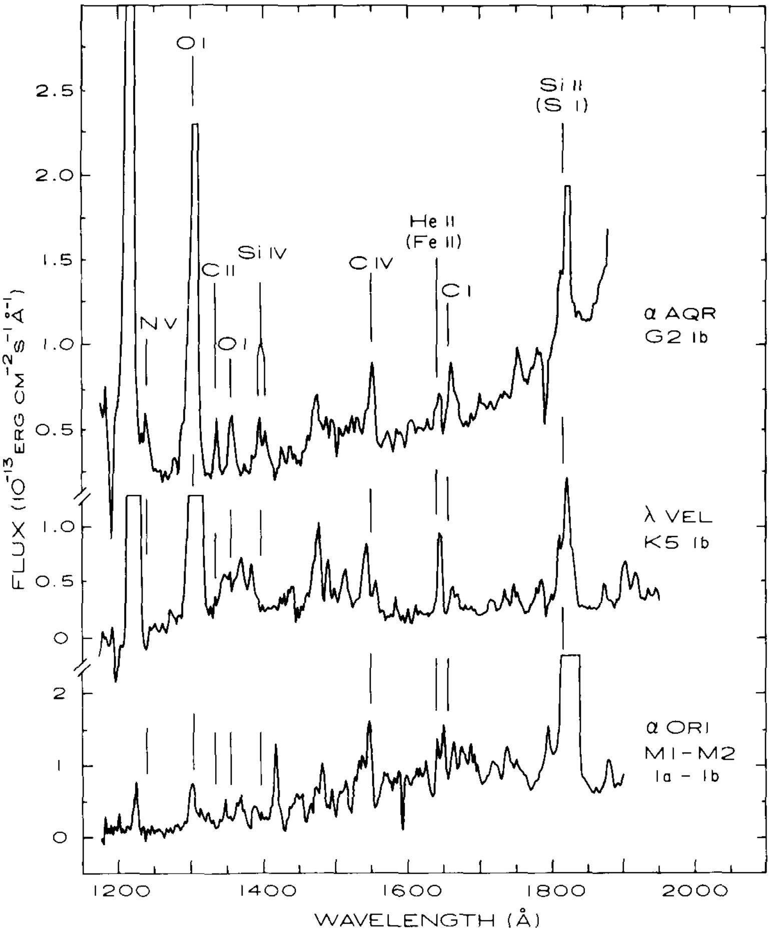

Figure 7: Short wavelength IUE spectra of three cool supergiant stars showing the lack of high temperature species in Lambda Vel and Alpha Ori and their presence in Alpha Aqr - the latter a hybrid supergiant.

5. Relationship Between Stellar Winds and Hot Plasma

From the many ultraviolet and X-ray observations available, we can develop an understanding of the presence and characteristics of extended stellar atmospheres and winds in cool stars. Figure 9 contains a summary from available ultraviolet observations of the presence of specific line emission in cool stars (from Dupree 1980). Results from various authors have been summarized, namely Baliunas, Hartmann, and Dupree (1980); Bohm-

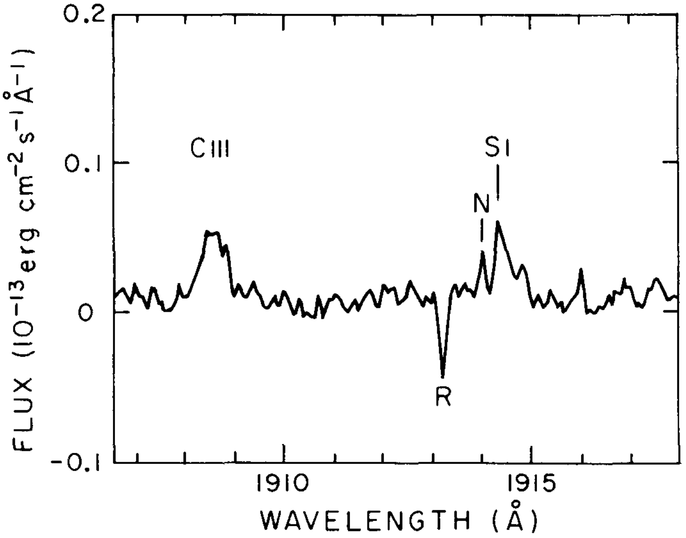

Figure 8: A portion of a high dispersion spectrum of Alpha TrA (K4II) showing the broad - perhaps flat - topped profile of C III and the relatively narrow S I line. R denotes Reseau - a fiducial mark. N marks a noise spike on the image. From Hartmann et al. (1981a).

Vitense and Dettmann (1979); Brown, Jordan, and Wilson (1979); Dupree et al. (1979); Hartmann, Dupree and Raymond (1980); Linsky and Haisch (1979); Linsky et al. (1978); Carpenter and Wing (1979); Reimers (1981). The dwarf stars generally show C IV indicative of temperatures on the order of 2 x 10^5 K. Their ultraviolet spectra are similar to that found in the Sun although the value of the surface fluxes of ultraviolet species can be substantially higher than the solar values. The stars of luminosity class III show more diverse characteristics; some have an atmosphere with high temperature species similar to a dwarf star, others contain only the signatures of cool species. As one proceeds to cooler stars along the giant branch, it is obvious that temperature and luminosity do not uniquely control the surface flux in the ultraviolet emission features. Neither does membership in a close binary system confer a specific surface flux. The coolest giants however uniformly lack high temperature species. There is no indication of a "sharp division" as

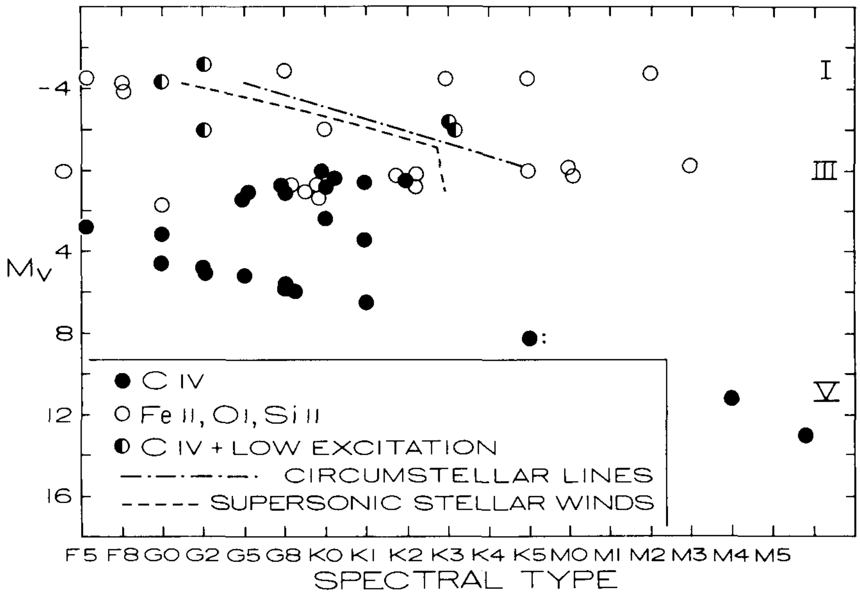

Figure 9: The presence of various spectral features in stars of different spectral types and luminosities. The broken line indicates the locus proposed by Mullan (1978) for the onset of strong stellar winds; the dot-dash line denotes the high temperature boundary of the appearance of circumstellar lines in optical spectra (Reimers 1977a).

suggested by Linsky and Haisch (1979) based on early observations of a few stars.

The behavior of stars at spectral type K 0 III is most dramatically illustrated by the four giant stars in the Hyades: 77 Tau, γ Tau, δ Tau, and ϵ Tau. Two of the systems 77 Tau and δ Tau are known to be widely separated binaries. These four stars are extremely similar K 0 giants as judged by all studies to date. Cluster membership indicates that their ages, chemical compositions, and evolutionary history are all alike. Their photospheric similarity is borne out by detailed analyses of spectroscopic and photometric observations (Chaffee, Carbon, and Strom 1971; Lambert, Dominy, and Sivertsen 1980). Baliunas, Hartmann, and Dupree (1980) have measured both the optical Ca K and ultraviolet emissions from these stars. The Ca K lines show a range of a factor of two in the emission cores, similar also to the Mg II (k) line fluxes. However in two of the stars, 77 Tau and γ Tau, emission from C IV and N V is found; the other two stars δ and ϵ Tau do not show these high temperature species. Lower limits for the ratio of detected to undetected flux are on the order of 6. The X-ray fluxes measured for 3 of the 4 giants (Stern et al. 1980) show a similar variation; the ratio of soft X-ray luminosity of 77 Tau to δ Tau is 10. We cannot resolve this discrepancy by the presence of a wind in the stellar atmosphere. Only 77 Tau and γ Tau show Mg II profiles indicative of mass outflow; and 77 Tau is a bright chromosphere-corona star. Two of the four giants (77 Tau and δ Tau) are known to be in long period binary systems; assignment of the ultraviolet and X-ray flux to an unseen companion appears difficult because the widths of the Ca and Mg lines are consistent with a luminous giant which is the primary star.

Thus we are left with the fact that giant stars with very similar physical properties show diverse chromospheric and coronal emissions, indicating a different atmospheric structure. The heating mechanism may also reflect the same range of variation.

An overall picture of the relationship between X-ray emission and chromospheric and coronal plasma is given in Figure 10. Here we show the stars detected (Vaiana et al. 1980) in various survey and pointed observations in the Center for Astrophysics program on HEAO-2 ("Einstein"). It is important to remember that a detection limit is the product of the source strength and integration time. Thus many of the regions in the H-R diagram in which X-ray sources have not been detected may well turn out to contain weak sources; the upper limits for detection are high. It is apparent that cool stars away from the main sequence are not abundantly represented as X-ray sources. In particular there is an anticorrelation between the appearance of strong circumstellar Ca II lines and the detection of C IV emission and X-rays. Perhaps the X-rays exist and are absorbed in the wind (Hartmann, Dupree, and Raymond 1980) or the atmosphere may not reach sufficiently high temperatures to produce X-ray emission (Hartmann, Dupree, and Raymond, 1981a). The shaded region of the hybrid stars and diverse C IV characteristics is not heavily populated with X-ray sources. In the case of the hybrid supergiants α and β Aqr, C IV is present (Hartmann et al. 1980) but these stars appear devoid of X-ray emission (Linsky 1980) consistent with the presence of a warm corona and wind suggested by Hartmann, Dupree, and Raymond (1981a) in α TrA. Cool dwarf stars generally exhibit ultraviolet signatures of hot material as well as X-ray emission.

Thus the presence of a strong wind appears to diminish the

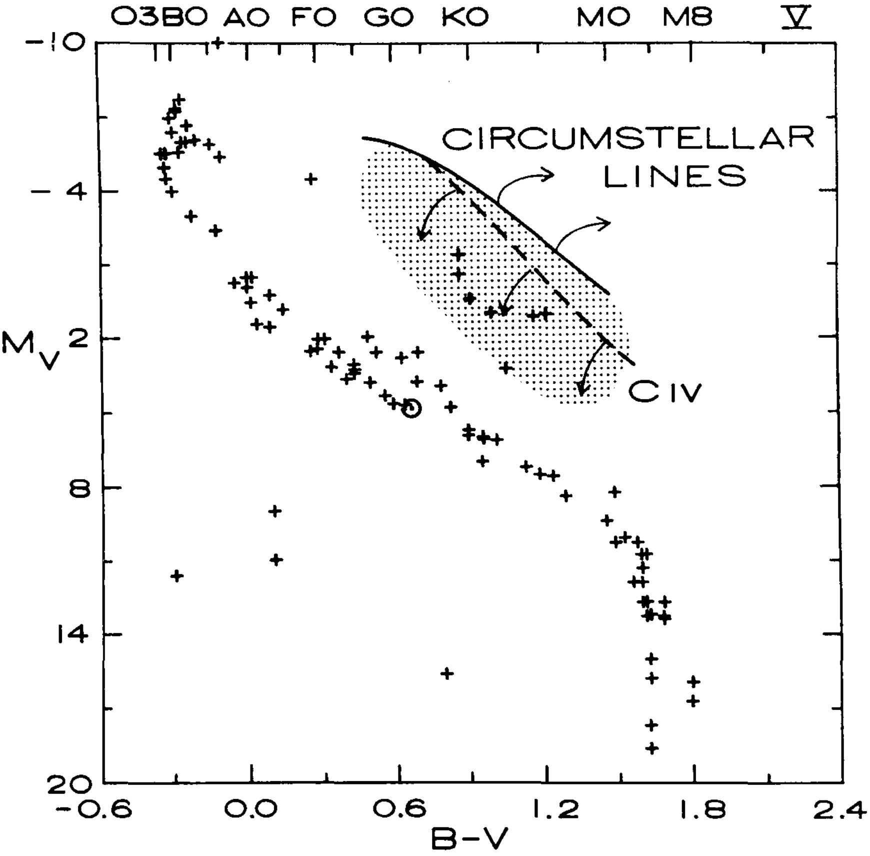

Figure 10: Stars of various absolute magnitudes and colors that have been detected by the CfA stellar survey on HEAO-2 ("Einstein") as described by Vaiana *et al*. (1980). The position of the Sun is indicated by an open circle. The hatched region indicates the locus of hybrid stars, and also where stars may possess a hot or cool outer atmosphere. The C IV boundary drawn from Figure 9 is indicated by a broken line. The position of stars with constant circumstellar features is indicated by the solid line. The relation between soft X-ray emission and optical and ultraviolet spectral features.

degree of ultraviolet and X-ray emission. It is interesting to recall from Figure 2 that this is precisely the behavior that is found on the solar surface between the regions of activity where closed loop structures dominate and the open field regions which tend to be devoid of X-ray emission. The presence of warm plasma (indicated by the C IV lines) does not appear to be a unique predictor of the degree of mass loss nor of the presence of high temperature emission. However, when more observations are available, it may be possible to specify such a relation.

6. Constraints on a Theory of Mass Loss

The observational results discussed earlier suggest the following picture of the characteristics of the winds and mass loss in cool stars (Figure 11). Using principally the solar example, we conclude that dwarf stars possess hot (10^6 K) winds, with fast (~ 500 km s^{-1}) terminal velocities and a low mass loss rate $\sim 10^{-14}$ $M_\odot$ yr^{-1}. The more luminous stars - exemplified by the hybrid atmospheres - possess a warm wind with moderate terminal velocities and an enhanced mass rate: 10^{-8} $M_\odot$ yr^{-1}. Such terminal velocities are apparent not only from the

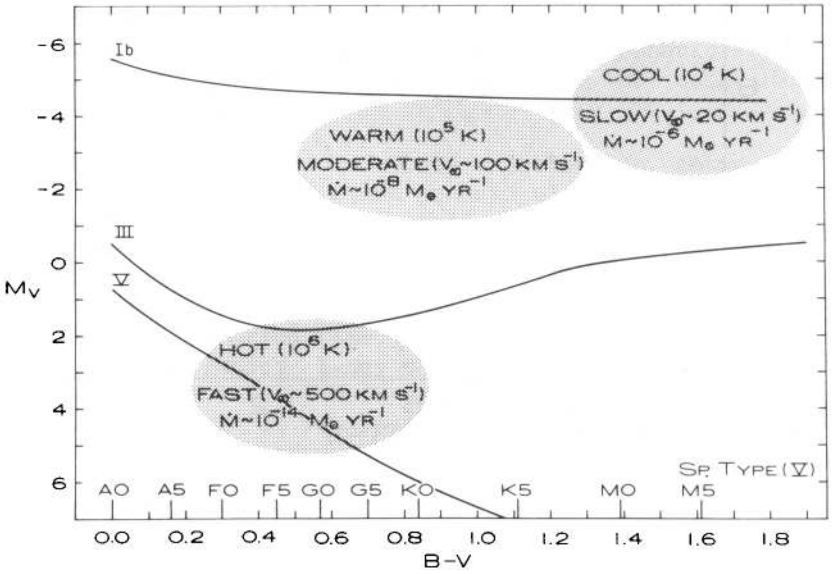

Figure 11: Characteristics of mass loss rates and winds in stars of various luminosities.

ultraviolet measurements (Hartmann, Dupree, and Raymond 1980) but also from the surveys of Ca II circumstellar features by Reimers (1977a,b). The mass loss rates are obtained by modeling the wind structure considering momentum and energy deposition by Alfven waves (Hartmann and MacGregor 1980; Hartmann et al. 1981a). The coolest luminous stars have massive, low temperature (10^4 K) winds, slow terminal velocities, and a mass loss rate on the order of 10^{-6} $M_\odot$ yr^{-1}.

Such a picture and the previous observations define the overall criteria that a theory of mass loss must satisfy. Namely:

- the mass loss process must result from a similar and continuous mechanism;
- the acceleration begins in the chromosphere;
- the terminal velocity of a wind decreases as the effective temperature and gravity of a star decrease;
- the electron temperature in the wind decreases as the effective temperature of the star and/or the gravity decrease;
- the range of radiative losses at a given effective temperature and gravity can be an order of magnitude or more;
- other factors such as rotation, magnetic field, and age can significantly affect the atmospheric structure.

Hartmann and MacGregor (1980) have had success in reproducing these general characteristics using Alfven waves known to exist in the solar wind. Damped Alfven waves give good agreement in reproducing the behavior of wind temperature and terminal velocity as a function of stellar effective temperature and gravity.

7. Special Considerations - Variability

Much of our understanding of stellar mass loss has been based on few observations or on those without necessary quantitative measurements. As a first approximation, it was natural to think of a star with a homogeneous surface structure and a smooth continuously flowing stellar wind. We know from the solar example that this is not the case, and recently it has been possible to direct more effort into the detection of inhomogeneous structures in the atmospheres of cool stars.

Circumstellar features in the hybrid stars, in particular α Aqr (G2 Ib) have been found to vary (Reimers 1977a); moreover the opacity increased as measured in the Mg II line over a period of months (Dupree and Baliunas 1979). Concurrently with this the chromospheric emissions increased as if the intrinsic level of activity in the atmosphere increased. It is of interest also that the chromospheric emission profiles of Ca K varied on a time scale unrelated to the Mg II emissions, suggesting a much different atmospheric structure in this atmosphere than in a dwarf star like the Sun where the emissions are closely coupled.

The RS CVn-type binaries are also of particular interest since they are believed to possess solar-type activity on a much larger scale. In particular many systems show an optical light modulation thought to arise from "spots" like sunspots on the stellar surface. Such an analogy is suggested not only by the color variation of the systems (Eaton and Hall 1979) but also by spectroscopic evidence (Ramsey and Nations 1980) of TiO bands which vary in strength in agreement with the photometric light waves. At light wave minimum, when spots are present, the TiO bands - a temperature-sensitive diagnostic - are strong and *vice versa*. Such behavior underscores the surface inhomogeneity. In another such system, λ And, there is a suggestion that such behavior may be related to the mass loss as well (Baliunas and Dupree 1980). As Figure 12 shows, the Mg II profile, an indicator of mass loss, changes asymmetry at different phases. At light minimum (spot area maximum) the symmetrical profiles are similar to those found in a solar active region. A semi-empirical model of the atmosphere (Baliunas *et al*. 1979), based on chromospheric line profiles confirms that the pressure in the low chromosphere is comparable to that found in solar active regions. At light maximum (spot area miniminum) the typical asymmetric profile indicative of mass outflow is present. High velocity expansion components in Mg II have also been noted (Weiler *et al*. 1978) in HR1099 - another short period RS CVn system - although this may be associated with a transient radio event. Clearly as observations are accumulated we will be able to define more precisely the degree of stellar surface activity and its connection with stellar mass loss.

This work has been supported in part by NASA Grants Nos. NAG 5-87, NAG 5-5 and NSG 5370 to the Smithsonian Astrophysical Observatory and the Harvard College Observatory. I am also indebted to the N.R.C. of Italy (Astronomy Division) for financial assistance.

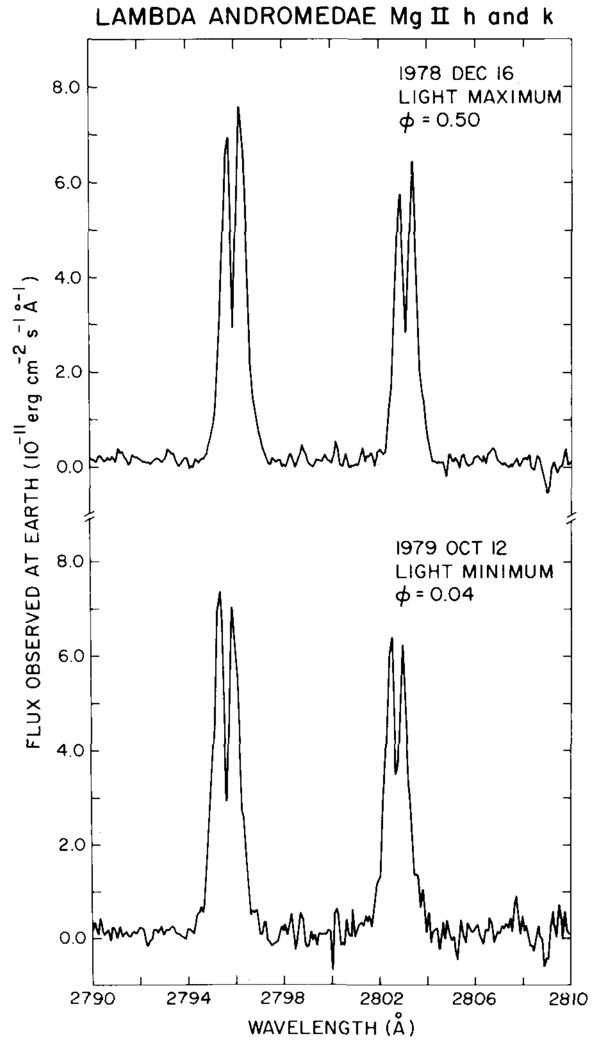

Figure 12: Profiles of the Mg II lines in the RS CVn type binary Lambda And at various phases (ϕ) in the optical light period. Light maximum corresponds to spot minimum and vice versa. (From Baliunas and Dupree 1981.)

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DISCUSSION

NESCI: You showed that in a light-cycle of λ And the magnesium lines reverse in intensity (the blue one becomes brighter than the red one and viceversa) and you link this fact to star spots. May star spots be responsible for the similar MgII lines behaviour when you pass from main sequence stars to giants and supergiants stars?

DUPREE: I am reticent to make that generalization. It is likely that surface inhomogeneities occur in all cool stars, and even in supergiants as the direct measurements of α Ori and the recent variability of α Aqr suggest. The MgII asymmetry is so prominent in supergiants because of absorption in a massive wind.

HEARN: How hot must a corona round a late type giant be in order to be observed by Einstein.

DUPREE: The Imaging Proportional Counter (IPC) on Einstein covers the energy range 0.2-4.0 keV: the High Resolution Imager (HRI) measures 0.3-3.5 keV fluxes. The minimum detectable temperature is 10^6K. Analysis of spectra from the Solid State Spectrometer (SSS) fields temperature up to 10^8K. Of course, a star must have sufficient material at these temperatures to be detectable. Upper limits from the Einstein Stellar Survey (Vaiana et al., 1980) for many stars now generally range from log L_X (erg s^{-1}) = 27 to 30 for 0.2 - 4.0 keV.

KWOK: Although it is true that UV and optical methods give very poor estimate of the mass loss rate (with errors exceeding two orders of magnitude) because of model dependency, this in not true for radio molecular line observations. For example, both the saturated ^{12}CO and unsaturated ^{13}CO lines have been observed in very late-type supergiants. ^{12}CO gives the kinetic temperature and ^{13}CO gives an independent estimate of the column density.

DUPREE: Molecular line observations certainly can give an estimate of the mass loss rate. However, the abundance of the molecular species must be known as well as the radial distance where the emission occurs. Values must also be increased for the mass loss carried by the dust and gas.

KWOK: The most uncertain parameter is the CO/H ratio. It is true that this ratio only gives a lower limit to the mass loss rate. However, the observed rates are already very high ($> 10^{-5}$ $M_\odot yr^{-1}$) and such estimates cannot be too wrong because a star simply cannot be losing mass at 10^{-2} $M_\odot yr^{-1}$.

FRIEDJUNG: Symbiotic star spectra are similar to some spectra you have described. In a joint study by a number of us, we gave a model for Z Andromedae with a hot layer around a cool star. This may be similar to the binaries you described; the activity around the cool star of a binary may be enhanced with temperatures of at least $2x10^5$ K being produced. You can have cooler coronae; you do not need 10^6.

DUPREE: Observation of emission from binary systems containing cool stars generally show strong enhancements in the optical CaII transition, in the ultraviolet line spectrum and in the X-ray emission as compared to single stars. This increased emission can be related to the stellar rotation rate or angular velocity. Suggesting an enhanced dynamo mechanism with associated radiative losses.

GOLDBERG: You have said that the asymmetries in the MgII and CaII lines (and H_α as well) imply that the mass flow begins to accelerate close in to the star. How close would that be, say, as compared with τ(5000 A) = 1?

DUPREE: Our calculations of line profiles for the Sun and active star models indicate that a (mass-conserving) flow becomes substantial (a few km s^{-1}) in the low chromosphere ($T_e \sim 10^4$ K); velocity profiles assuming Alvén wave - driven winds (Harmann and McGregor, 1980) lead to velocities of 10 km s^{-1} within $R \lesssim 2R_*$.

REIMERS: I have found two further stars with hybrid atmospheres. These are ϑ Her (K 3 II, M_V = -2.5) and ι Aur (K 3 II, M_V = -1.5). ϑ Her shows simultaneously CIV and CS line in MgII ($v \approx -40$ km/s). In 1976, the wind velocity found in CaII K was -69 km/s. ι Aur shows NV, CIV and HeII-λ1640 and also has a variable CS CaII K line. In both cases, the high ionization lines are very weak.

LINSKY: 1) How was the mass loss of 10^{-8} solar masses/yr derived for α TrA? - 2) The CIV line in α TrA is very broad, and you infer the presence of a large wind in the 10^5 K material from the large width. Do you see a Doppler shift in the line indicative of a wind? How do you infer that the width is due to a wind as opposed to large velocity turbulence? I ask the latter question because our IUE, high dispersion spectra of α Can A (G2 V), Capella (mainly the F9 III secondary), and β Dra (G2 II) show a large increase in CIV width with luminosity, but none of these stars show any obvious evidence of a wind.

DUPREE: 1) The mass loss for α TrA was obtained by modeling of the stellar wind. The maximum temperature and terminal velocity were fixed to correspond to the UV observations and Alvén wave damping was assumed. - 2) None of the emission lines in α TrA show Doppler shift motions larger than $\sim |15|$ km s^{-1}. If the broad ($\sim$ 100 km s^{-1}) line widths observed in SiIII, CIII and CIV are attributed to turbulence, then it must be supersonic which is of some concern, and requires large mass motions over a substantial fraction of the surface. However, the broad width of the lines corresponds to the (apparently) terminal velocity observed in the MgII line profile. Moreover, the CIII (λ1909) transition, which is expected to be optically thin, shows a broad square-topped profile consistent with formation throughout an expanding atmosphere. The simplest explanation is that these broad lines are indeed formed over a large region of the stellar atmosphere.