EMISSION MEASURES AND HEATING MECHANISMS FOR STELLAR TRANSITION REGIONS AND CORONAE

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ABSTRACT. In order to determine the heating mechanisms for stellar transition regions and coronae we try to determine the damping lengths for the mechanical flux(es) responsible for the heating. For the lower part of the transition regions (30,000< T≤100,000 K) the damping lengths are consistent with shockwave damping. This appears to be also true for the upper part of the transition region in Procyon, while for the upper part of the solar transition region the damping length is much larger.

1. THE LOWER TRANSITION LAYER

In the Lower Transition Layer (L Tr) 30,000 K<T<100,000 K we find an equilibrium between the mechanical energy input and the radiative losses Erad, i.e.,

$$(1) \quad -\frac{d\ Fm\ell}{dh} = \frac{Fm\ell}{\lambda_\ell} = E_{rad} = n_e^2 \cdot f(T) = n_e^2 \cdot B \cdot T^\beta \quad \text{where } \beta \sim 2$$

Here $Fm\ell$ is the mechanical energy flux in the L Tr and λ_ℓ its damping length. f(T) is the radiative loss function which in the L Tr increases approximately as T^2. B is a constant. Assuming $\lambda_\ell = \lambda_o T^\alpha$ equation (1) leads to

$$(2) \quad T^{\beta+\alpha-2} = \frac{Fm\ell}{\lambda_o} \cdot \frac{1}{B} \cdot \frac{1}{P_e^2} \quad \text{with } P_e = n_e \cdot T$$

For the emission measures we find

$$(3) \quad Em = 0.35\ P_{eo}^2\ \frac{(\beta+\alpha-2)\cdot R}{\mu\ g_{eff}} \cdot \frac{1}{T} \left(\frac{T_o}{T}\right)^{\beta+\alpha-2} \frac{e^{-\int dh/\lambda_\ell}}{1-H/2\lambda_\ell}$$

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with $H = \frac{RT}{\mu g_{eff}}$ and R=gas constant, g_{eff}=effective gravity
μ=atomic weight,

The observed Em(T) permit the determination of $P_e^2(T)$, which in turn permits the determination of $Fm\ell/\lambda_o$ from equation (2). The observed temperature dependence of the Em determines $\alpha=0.4 \pm 0.5$, in agreement with expectations for shockwave damping.

2. THE UPPER TRANSITION REGION

In the Upper Transition zone (U Tr) with $10^5K<T<10^6K$ the radiative loss function f(T) decreases for increasing T, a stable equilibrium between mechanical energy input and radiative losses is therefore not possible. The temperature stratification is governed by the conductive heat flux Fc(h). The energy equation tells us that the downward flowing conductive flux must equal the upward flowing mechanical flux Fmu(h) reduced by the amount of energy lost above the height h due to radiation and the stellar wind. For the emission measure in this layer we obtain

$$(4) \quad E_m(h)=(P_e^2(h)/F_c(h)\ T^{1.5}\cdot 0.7\ \ e^{-2\Delta h/\overline{H}}$$

For constant $P_e^2(h)/Fc(h)$ the observed increase of Em with $T^{1.5}$ is recovered (see also Jordan 1980). From the observed Em only the conductive flux Fc can be determined which relates to Fmu but not to λ_u.

3. THE CORONAL TEMPERATURES

Integration of the equation for the conductive flux from the base of the U Tr with $h=h_2$ and $T=T_2$ to the height h_c, where the conductive flux becomes zero and $T=T_c$, leads to the equation for the coronal temperature

$$(5) \quad T_c^{7/2}-T_2^{7/2} = -\frac{7}{2}\,\eta\cdot\lambda_u\cdot Fmu(h_2)\cdot[1-e^{-\Delta h_c/\lambda_u}(1+\Delta h_c/\lambda_u)]-E_r$$

where E_r describes the integral over the radiative losses in the U Tr. The coronal temperature T_c increases with increasing λ_u. The observed coronal temperatures thus permit a determination of the λ_u. For Procyon (Jordan et al. 1986) the derived value agrees with expectations for shockwave damping while for the sun the value is at least an order of magnitude too large for this heating mechanism.

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ON THE EXISTENCE OF HOT CORONAE AROUND COOL STARS

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ABSTRACT. A star cannot have a solar-like corona if the available mechanical energy flux in the chromosphere is either too large or decreases outward more rapidly than the pressure. This result might be relevant for hybrid stars and cool giants.

The canonical explanation for the existence of the hot solar corona is based on a discussion of the local energy balance between radiation and heating in the chromosphere. The effectively optically thin emission can be approximated by pressure squared times an emissivity function f(T). Theoretical arguments and empirical models show that the heat input into the solar chromosphere, and thus also the available energy flux F itself, decreases outward less rapidly than linearly with p (case C in Fig. 1). Nevertheless, initially the chromosphere can achieve energy balance by means of a gentle outward temperature rise, since f(T) increases steeply with T for small temperatures.

Finally, however, a critical temperature is reached where the emissivity has a maximum. Beyond this point, which is marked by the asterisk on curve C in Fig. 1, energy balance at cool chromospheric temperatures is no longer possible. Therefore, the transition region to the solar corona, which is governed by a different type of energy balance since thermal conduction is important, must lie at or below this critical position. Its actual location is determined by the intersection of the curve F(p) with another curve that specifies the total coronal energy losses as a function of the coronal base pressure (cf. Hammer et al. 1982). Theoretical models of closed (e.g. Rosner et al. 1978, eq. (4.4)) and open (e.g. Hammer 1982, Fig. 2) coronal regions as well as semi-empirical studies (e.g. Jordan 198o, Fig. 4) show that the coronal energy losses increase with the base pressure to some power that is slightly larger than one.

It is interesting to apply this picture to stars near the dividing "line" that appears to separate the solar-like stars with hot coronae from the cool giants with massive winds and extended chromospheres. When we go from the Sun (case C in Fig. 1) towards these stars, it is well possible that the run of energy flux vs. pressure changes. Recently, Böhm-Vitense (1986) discussed the possibility that in the cool giants

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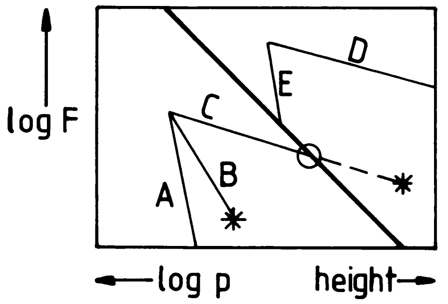

Figure 1. Available energy flux F in a stellar chromosphere as a function of height or pressure (thin curves) and energy requirements of a hot corona (thick curve).

F decreases more rapidly than pressure squared (case A), so that the chromospheric temperature decreases outward, and a corona is not formed. If that is true, however, we should also find stars in which F varies with p to some power between 1 and 2 (case B). In such a star, the chromospheric temperature increases outward, and beyond a certain critical height the heat input can no longer be radiated away at cool temperatures. On the other hand, a solar-like hot corona is also not possible because at any height F is far too small to balance the coronal losses. Such a star would need other means of solving its energy dilemma. Its outer atmosphere could, e.g., oscillate temporally between the cool (overheated) and the hot (underheated) state. Or it could have a warm envelope (with T near the maximum of f(T), beyond which energy is transported outward by means of convection. Such stars, should they exist, might exhibit some characteristics of hybrid stars.

Fig. 1 suggests another possibility for a star to have no corona; namely, if at some chromospheric level F is larger than the energy losses of a given type of corona. If now F drops slowly with p (case D), no equilibrium solution exists. And if F drops rapidly (case E), the equilibrium solution can be shown to be thermally unstable (Hammer et al. 1982).

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EVIDENCE FOR EXTENDED CHROMOSPHERES AND TRANSITION ZONES IN THE UV SPECTRA OF FK COMAE STARS

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ABSTRACT. The chromospheres and transition zones of the fast rotating giants of the FK Comae type can be studied by analysing their ultraviolet emission line spectra. From relative line intensities, electron densities of the order of 10^{10} to 10^{11} cm^{-3} are found for the region where the Si IV emission arises. The sizes of the chromospheres and transition regions can be inferred from the emission measure distribution, and a temperature-height relation can be found on the assumption that hydrostatic equilibrium holds. We find the atmospheres of these stars to be clearly more extended than those of normal giant stars, and the flux in the higher excitation chromospheric and transition zone lines (e.g. C II, C IV, Si IV) is significantly stronger than in other stars of similar spectral type. Indeed, the location of these stars in the standard rotation-activity-correlation diagrams places them close to or even above the saturation limit for main sequence stars.

At present there are four stars known which are fast rotating, apparently single late type giants which have been named after the prototype object as FK Comae type stars (Bopp and Stencel 1981). The other members of the group are HD 32918, HD 36705, and HD 199178 (Bopp and Rucinski 1981, Bopp 1982, Collier 1982). Also, UZ Lib is counted as a member of this group (see e.g. Bopp et al. 1984), despite the fact that radial velocity variations have been discovered which reveal the presence of a low mass companion. All five stars show signs of strong chromospheric activity at optical wavelengths (CaII and H-alpha emission) and optical light curves somewhat similar to those of RS CVn stars or other stars with surface spots. At ultraviolet wavelengths they all show strong chromospheric and transition region lines (Bopp and Stencel 1981, Bopp et al. 1984, Bianchi et al. 1984,1985, Grewing et al. 1986), and with the exception of HD 199178 they all have been observed to emit soft x-rays.

Here we shall focus the discussion on the ultraviolet spectra of the three stars FK Comae, HD 32918, and UZ Lib. The observational data,

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which were obtained with the International Ultraviolet Explorer (IUE) satellite, are displayed in Fig.1 and 2., covering the 1200-2000 A and the 2400-3200 A range, respectively.

In Table 1 we have compiled the absolutely calibrated UV line fluxes for the three stars discussed here. These data have been corrected for interstellar extinction when necessary and refer to the emission at the surface of the stars. Also included in the Table are the surface fluxes for β Cet (Engvold et al. 1984), a K 1 III star which shows no sign of rapid rotation.

Table 1

Chromospheric and TZ line fluxes
for three FK Comae stars and β Cet

	FK Comae G2 III	HD 32918 K1 III	UZ Lib K0 III	β Cet K1 III
N V 1240	2.8(30)	2.8(30)	0.2(30)	-
O I 1304	9.2(')	2.7(')	0.8(')	16.1(28)
C II 1335	3.2(')	1.8(')	1.2(')	1.3(')
SiIV 1393	2.5(')	1.6(')	1.1(')	1.1(')
C IV 1548/50	8.1(')	5.6(')	3.0(')	1.0(')
HeII 1640	2.6(')	3.3(')	3.2(')	1.1(')
SiII 1808/17	4.7(')	3.2(')	1.3(')	8.5(')
MgII 2800	125.9(')	69.4(')	44.9(')	-

Note: the fluxes are given in units of ergs/ s.

Table 1 shows that the UV line intensities of the FK Comae stars are similar to each other and differ significantly from those of a normal giant : their absolute intensities are higher by typically a factor of 100, and the transition zone lines are relatively more intense than the chromospheric lines. This clearly demonstrates the fact that their atmospheres are much more active - very likely due to their fast rotation.

The absolute emission line fluxes as given in Table 1 can be used to derive the emission measure distribution by assuming a spherically symmetric atmosphere, an effectively optically thin collisionally excited plasma. Furthermore, by assuming also hydrostatic equilibrium, a temperature-height-relation can be obtained. Results for HD 32918 are given by e.g. Grewing et al. 1986.

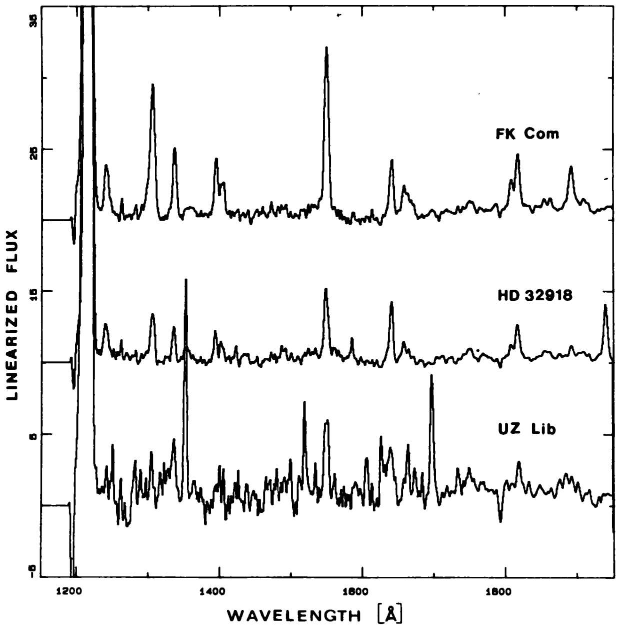

Figure 1:
The short-wavelengths IUE-spectra of three FK Comae stars showing strong chromospheric and transition zone lines.

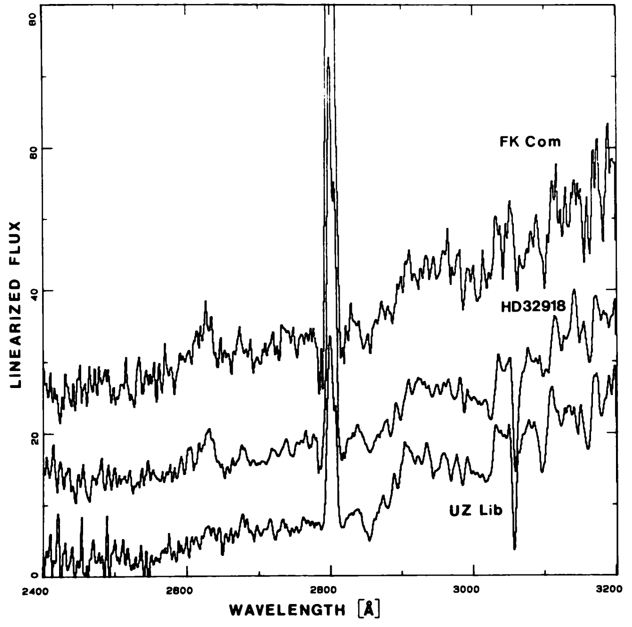

Figure 2:
The long-wavelengths IUE-spectra of the same three FK Comae stars. Note the strong MgII-emission which is found to vary over a timescale of months.

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DISCOVERY OF FK COMAE AND RS CVn SYSTEMS BY OBSERVATION OF THEIR X-RAY EMISSION

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We are currently working with a statistically complete, unbiased sample of 125 x-ray-bright stars which were serendipitously detected by the Einstein Observatory Medium Sensitivity Survey (MSS). A program of optical spectroscopy and photometry is currently underway to measure radial velocities, distances, and such stellar parameters as rotation, temperature, surface gravity, metallicity, chromospheric activity, and age and to correlate them with absolute x-ray luminosity. So far, the majority of the sample (which was defined at $|b^{II}| > 20^{o}$) appears to be composed of either flare stars (e.g. dMe, dKe) or active binary systems (e.g. cataclysmic variables, RS CVn, W UMa).

We have already identified six new RS CVn candidates. These stars exhibit rapid rotation, strong Ca II H & K emission, and are binaries. We also have two such stars which show no evidence of being binaries. These are possible candidates for the class of FK Comae stars. This class of star is rare because it represents a relatively short phase in the evolution of a star: the moment at which the two cores of a contact binary coalesce to form a single, rapidly rotating star. In this paper, we discuss the x-ray characteristics of RS CVn and FK Comae stars.

In searching for new candidates for the RS CVn and FK Comae classes, the established method is to search objective prism plates for Ca II H & K emission objects. As demonstrated by this sample of stars from the Einstein MSS, one can easily find candidates for these classes of stars by looking at stellar objects with high f_x to f_v ratios. Unfortunately, at the moment it is more economical to take objective prism plates than it is to put x-ray telescopes into orbit.

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RELATIONS BETWEEN CORONAL AND CHROMOSPHERIC ACTIVITY DIAGNOSTICS IN T TAURI STARS

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ABSTRACT. The study of the relationships between various activity diagnostics in T Tauri stars (TTS) suggests that the CaII K, MgII k and H_α lines are formed in a similar region of TTS' atmosphere. For the more active TTS, an extended circumstellar region seems to be the major source of the emission, whereas a solar-type atmosphere alone may be able to account for the emission spectrum of low-activity TTS.

1. INTRODUCTION

The atmosphere of TTS is the seat of a high degree of non-radiative heating which results in a number of emission lines (CaII, MgII, H_α) typical of the spectrum of these low-mass pre-main-sequence stars and in a strong X-ray emission, up to 10^3 times larger than the X-ray flux observed in late-type dwarfs. Two broad classes of models have been proposed to account for TTS' emission line spectrum. The "deep chromosphere" model assumes that TTS possess a solar-like chromosphere beginning however at higher optical depth than in the Sun /1/. The second class of models assigns the origin of the emission line spectrum to an extended circumstellar region of a few stellar radii /2/. It seems now widely accepted that both a chromosphere and an extended envelope are needed to describe the various features of TTS' emission spectrum. However, the detailed structure of the immediate circumstellar environment of TTS remains unclear.

2. ACTIVITY DIAGNOSTICS

Informations about the structure of stellar atmospheres can be gained from the analysis of relationships between activity diagnostics formed at different atmospheric levels. Such relationships are known to exist for late-type dwarfs where the intensities of various chromospheric diagnostics (CaII, MgII, H_α) are linearly correlated /3,4/ whereas coronal X-ray emission varies with the intensity of chromospheric diagnostics following a power-law with a slope of 2.6 /5/. The existence of these

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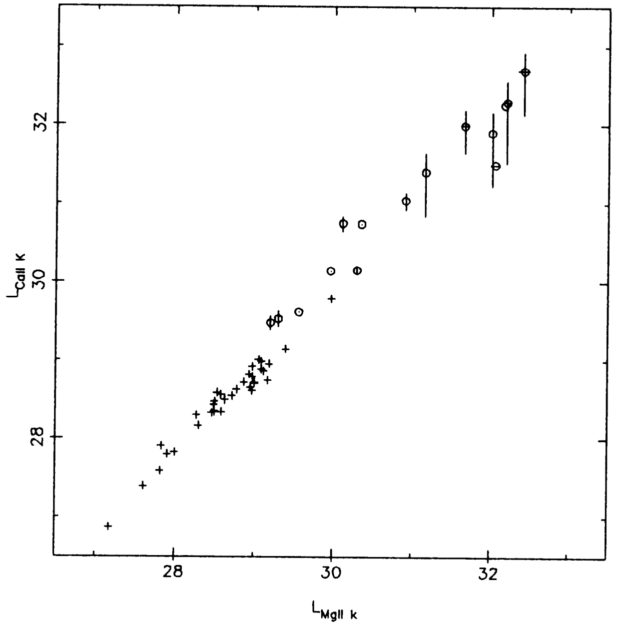

Fig. 1. CaII K-line luminosity versus MgII k-line luminosity for dwarfs(+) and T Tauri stars(o).

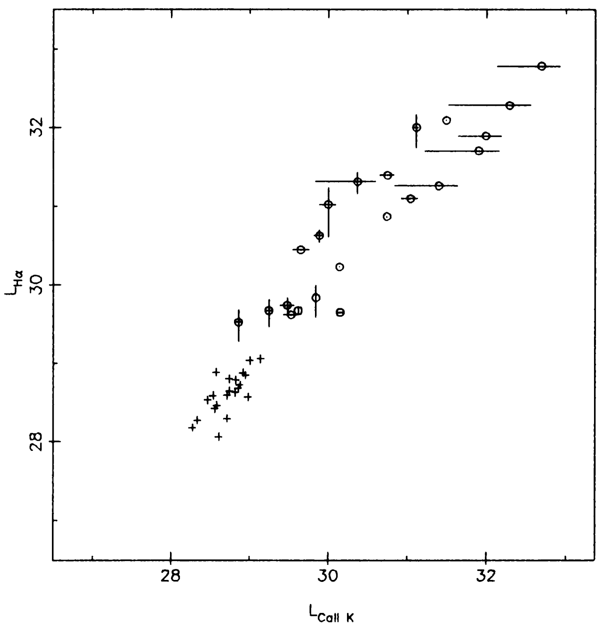

Fig. 2. H_α-line luminosity versus CaII K-line luminosity for dwarfs(+) and T Tauri stars(o).

tight correlations between various activity criteria implies that the different atmospheric layers are physically associated by a unifiing mechanism which, in the case of late-type dwarfs as in the solar case, is believed to be the magnetic field/6/. In Figures 1 to 4 we study the relationships between several activity criteria in TTS and compare them to those found in dwarfs. In each figure, the crosses represent late-type dwarfs and the open circles represent TTS. The bars associated with TTS reflect the range of observed variability between consecutive measurements. The axis are luminosities expressed in erg/s on a logarithmic scale. In figure 1 we have plotted the stellar luminosity observed in the CaII K-line versus that measured in the MgII k-line. The one-to-one correlation appears clealy for dwarfs and seems also to be fulfilled by TTS. Although this result doesn't indicate a similar atmospheric structure between dwarfs and TTS nor does it mean that the heating mechanism is the same in the two stellar groups, it suggests that the CaII K and MgII k lines are formed in the same region of TTS's atmosphere. This conclusion appears to be valid also for the H_α-line, the luminosity of which is plotted versus the CaII K-line luminosity in Figure 2. Although the scatter, both for dwarfs and for TTS is much higher than in Figure 1, these two diagnostics seem to be linearly correlated. The in-

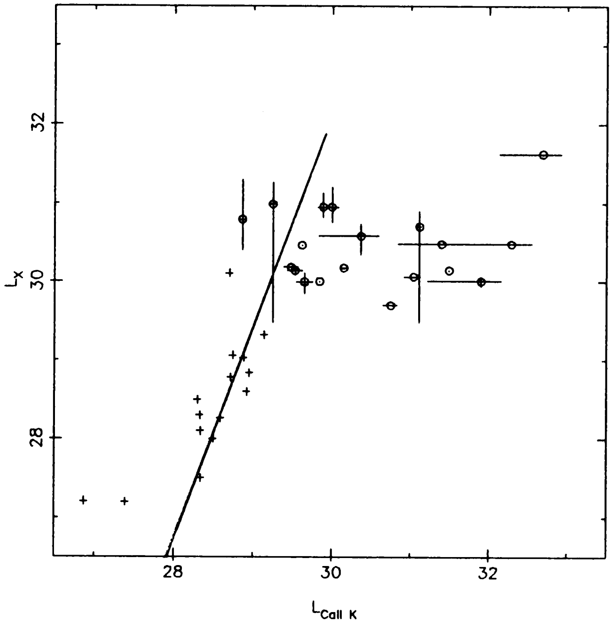

Fig. 3. X-ray luminosity versus CaII K line luminosity for dwarfs(+) and TTS (o). Solid line: $L_X \propto (L_{CaII\ K})^{2.6}$.

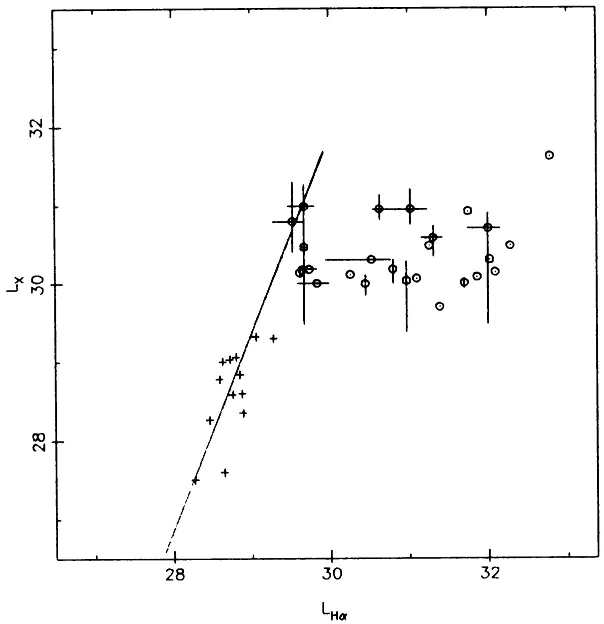

Fig.4. X-ray luminosity versus H_α-line luminosity for dwarfs(+) and TTS(o). Solid line: $L_X \propto (L_{H_\alpha})^{2.6}$.

creased scatter may arise from the fact that, in dwarfs, the H_α-line forms at higher chromospheric level than CaII K-line so that these two lines are more loosely connected than are the CaII K and MgII k lines. Remarkable is that the above relationships are valid over almost five decades and appear to remain the same for low-mass and high-mass TTS.
In Figure 3 and 4 we plotted the stellar luminosity observed in the X-ray range versus the one observed in the CaII K and H_α-line respectively.
In dwarfs the luminosities of these activity diagnostics are related by a power-law with a 2.6-slope which is represented in both figures by a solid line. Obviously this statistical relationship breaks down when dealing with TTS: whereas the intensity measured in the CaII K and H_α lines describes almost four decades, the X-ray luminosity varies only over one decade.

3. DISCUSSION

Clearly, most of the TTS in our sample namely the more active ones, do not appear to fit the solar-like atmosphere assumption. The failure appears in Figure 3 and 4 where the departure of a number of TTS from the correlation found in dwarfs goes in the direction of an excess of emission line intensity relative to X-ray emission. Moreover, emission line intensity and X-ray emission seem to a large extend uncorrelated in TTS contrary to what is expected in the case of a solar-like atmosphere governed by magnetic fields. Thus it appears necessary to call for an extended circumstellar envelope as the main contributor of the emission line intensity observed in the more active stars of our sample. And the conclusions drawn from the one-to-one correlations existing between CaII K, MgII k and H_α-line intensities in TTS seem to indicate that these three activity diagnostics form mainly in the circumstellar envelope. However, few TTS displaying lower emission characteristics lie on the extrapolation of the correlation between coronal and chromospheric diagnostics verified by dwarfs, a result that suggests that these low-active TTS do not possess large circumstellar envelopes and that the emission arises mainly from a solar-like atmosphere.

4. CONCLUSION

The study of various activity diagnostics reinforces the growing evidence that two different circumstellar regions may play a leading role in the emission characteristics of T Tauri stars. For low-active TTS a solar-like atmospheric structure may account for the behaviour of the different activity diagnostics although a larger non-radiative heating input than in the Sun is necessary to reproduce the observed activity level /7/. For more active TTS an hot, extended circumstellar region seems to be the main contributor to the intense emission line spectrum, keeping in mind that the additive contribution of an underlying solar-type atmosphere cannot be dismissed.

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WHAT CAN BE LEARNT FROM FULL DISK X-RAY OBSERVATIONS OF STELLAR FLARES?

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The **Einstein Observatory** demonstrated the existence of hot envelopes, i.e., stellar coronae, around most classes of normal stars (Vaiana et al. 1981). The coronae of late type stars of spectral type F through M are generally thought to be solar-like, i.e., structured and organised by the magnetic field topology and heated by some process(es) involving magnetic energy. Here the property "solar-like" does not refer to the optical appearance of a star, but rather to the role played by magnetic fields in the outer stellar envelope (Linsky 1985). Since it is difficult to measure magnetic fields on other stars directly, a number of indirect indicators is used in order to infer whether a corona should be considered "solar-like" or not.

Stellar flares are thought to be an excellent indicator of the magnetic nature of the underlying corona (Linsky 1985); in addition, the flare X-ray light curve and spectrum allow a determination of physical parameters such as density, temperature and scale size of the flaring plasma. As pointed out by Haisch (1983) most stellar flares observed so far in X-rays (with the possible exception of HD 27130) seem to be similar to solar flare events, except that the derived plasma densities in stellar flares are far higher than those of their solar counterparts.

The analysis procedures used to interpret stellar flares are rather crude, and further, only full disk observations with rather low spectral resolution and low signal to noise ratio (SNR) are available. Solar flares on the other hand are typically observed with rather high spatial, spectral and temporal resolution with good SNR, and we simply do not know what solar flares would look like if observed with the same instrumentation used on other stars.

Using the **Einstein Observatory** Imaging Proportional Counter (IPC) we have studied in detail solar X-ray light scattered in the upper atmosphere, i.e., data taken when the X-ray telescope was pointed at the Sun-lit Earth. By computing the propagation and scattering of solar X-rays in a realistic atmosphere model, we can determine the scattered X-ray flux as a function of viewing geometry and hence flight time; by comparing the expected and observed bright Earth X-ray light curves we can assess whether the incident solar X-ray flux was constant or not. In fig. 1 we show an example of a solar flare observed in scattered X-ray light; the medium panel shows the observed light curve as function of time, the lower one the hardness ratio increase during the flare. In fig. 2 we compare (upper panel) the observed and best fit light curve, and give in the lower panel the flare light curve of a fiducial observer, i.e., an observer in the subsolar point looking downwards.

Scattered solar X-ray light provides us with full disk low spectral resolu-

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tion observations obtained with the same instrumentation used for stellar flare observations. Employing the same data analysis and data interpretation techniques, we find extremely good agreement between physical flare parameters derived from our IPC observations and "known" properties of compact solar loop flares, and hence full disk low resolution IPC observations can accurately reveal temperature and density of solar flare plasma. Thus we are confident that the interpretation of stellar X-ray flare observations is on a physically sound basis, and therefore stellar X-ray flares constitute an important diagnostic tool for the determination of physical conditions in stellar coronae. A detailed account of this work will be published elsewhere.

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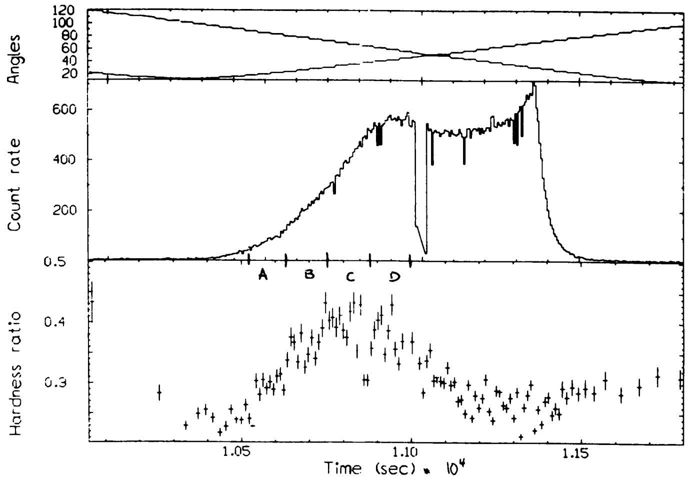

Fig. 1: X-ray light curve of bright Earth data segment on July 21, 1980 (medium panel) and hardness ratio (lower panel).

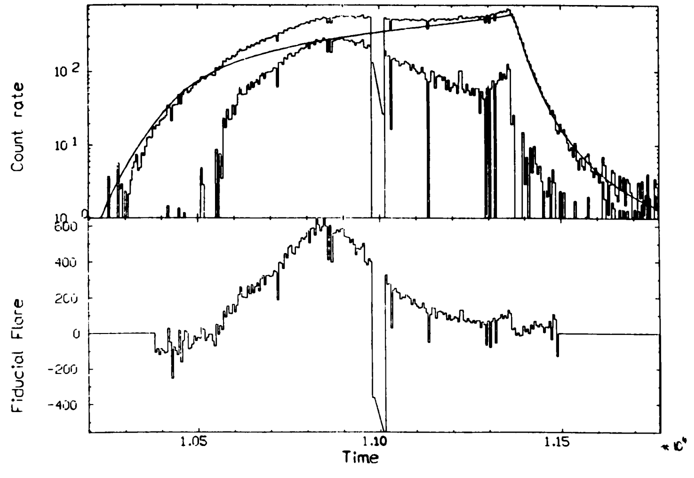

Fig. 2: X-ray light curve, best model fit and residual for the same data segment as in Fig. 1 (upper panel) and fiducial observer flare light curve (lower panel).

CIRCUMSTELLAR CaII LINES IN R Leo

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ABSTRACT. Qualitative results on the H and K CaII lines in R Leo are presented from spectra throughout all the cycle of this mira star. A scenario of explaining the observations by an outward shockwave is proposed.

The figure shows tracings of the region of H and K CaII lines in spectra of the mira star R Leo that were taken at Haute Provence Observatory with a dispersion of 20 Å mm^{-1}. These spectra correspond to different phases of the light curve of R Leo.

A quantitative detailed study of these spectra is in progress, only qualitative results are presented here :
- Our observations confirm that an emitting hot region surmounted by an absorbing colder slab exists during the pre-minimun phases (Merrill, 1952 and Kraft, 1957).
- During the pre-maximum phases, largely blueshifted emission features seem to appear. They could be due to the front of a shockwave in the lowest region of the Ca circumstellar envelope.
- At the phase 0.48, the H and K CaII central features appear in emission.

So we propose the following scenario : the emission is due to an outward shockwave which reaches the Ca envelope during the premaximum phases. The emission lines are self-absorbed by the overlying cool ions. With increasing phase, the heated layer is higher and higher within the atmosphere and the absorbing slab diminishes, the apparent blueshift of the emission features decreases and tends to correspond to the velocity of the other emission lines due to the shock. Near the minimum, the hot layer is high in the atmosphere, so the absorbing slab disappears.

This agrees with the study of the infrared CaII triplet (Contadakis and Solf, 1981), the observations of H_α lines (Gillet et al., 1983) and the deduced model of shockwave (Gillet et al., 1985).

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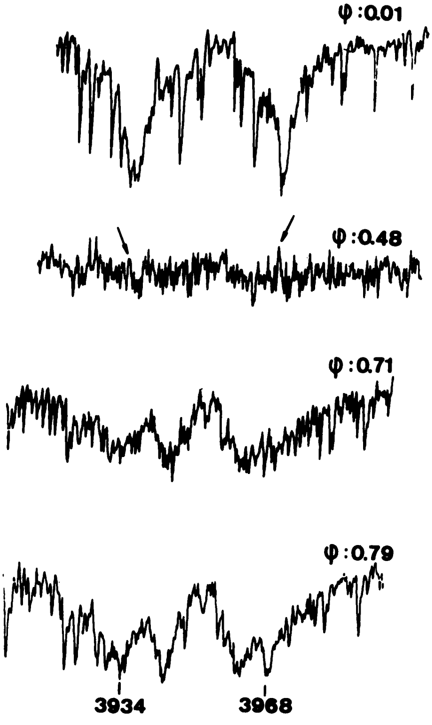

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CO MOLECULE IN TRANSITION REGION BETWEEN CHROMOSPHERE AND COOL STELLAR WIND: A NEW PROBE ON THE OUTER ATMOSPHERES OF COOL LUMINOUS STARS

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ABSTRACT. Presence of CO layer well separated from photosphere is confirmed and this revealed a presence of quasi-static turbulent transition layer in normal red (super)giant stars. This layer may be related to an outer part of the extended chromosphere and/or a cool part of the chromospheric inhomogeneity, and will play major role in stellar mass-loss.

As is well known, the circumstellar matter in outer envelope of cool luminous stars is being lost from the stellar system(Deutsch,1956), but it is not clear where the mass-flow starts. There is a suggestion that the mass-loss already starts in chromosphere(Goldberg,1979), but the observed flow velocities are smaller than the local escape velocity in chromosphere and it is not clear if the chromospheric expansion could be a direct origin of stellar mass-loss. Furthermore, presence of a static layer, possibly situated above the chromosphere, is suggested not only in Mira variable stars(Hinkle et al.,1982) but also in non-Mira stars(Hall,1980). While little attention has been given to such a static layer in recent theories of stellar mass-loss, we have found some convincing evidences on the presence of such a static layer in normal red giant and supergiant stars during our analysis of high resolution infrared spectra of CO first overtone bands(Tsuji,1986a; to be referred to as Paper I).

Although CO lines originating from such a static layer show little Doppler shift against photospheric lines, they could be recognized by the following facts: 1) Equivalent widths of low excitation lines show systematic excess as compared with expected ones based on model atmosphere(Fig.3 of Paper I), while higher excitation lines can quantitatively be well understood by the same model(Tsuji,1986b). 2) The low excitation lines show shifts and asymmetries that indicate excess absorption in blue wing in some stars and in red wing in other stars(Figs.4 & 5 in Paper I). 3) Radial velocities show differential variations between low excitation lines(remain almost stationary in the case of α Her shown in Fig.1) and high excitation lines(change is larger, possibly due to small amplitude pulsation of the photosphere). These observations suggest that at least a part of low excitation lines should be originating in a layer well separated from the photosphere. Further, comparison of the observed spectrum with predicted photospheric spectrum revealed residual absorption for low excitation lines while there appeared no residual for

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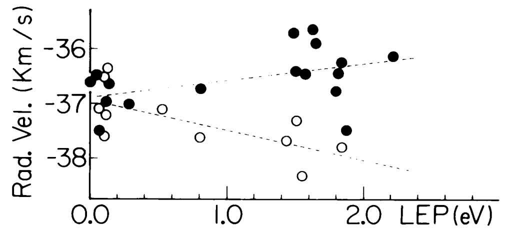

Fig.1 CO radial velocities in α Her plotted against lower excitation potential: Feb.19,1977(open circle) and June 24, 1977(filled circle).

TABLE 1 Physical properties of the quasi-static CO absorption layer

Star	Sp.Type	T_{ex}	v_{tur}	log N_{CO}
α Ori	M2I$_{ab}$	1450K	>9Km/s	20.1
μ Cep	M2I$_{a}$	1100	>9	19.8
ρ Per	M4II	1940	>5	19.8
α Her	M5II	1670	>5	20.0
SW Vir	M7III	2160	>5	19.9

high excitation lines. In low excitation lines, the contribution by the CO layer has been separated by subtracting the photospheric contribution from the observed profile. A curve-of-growth analysis on equivalent widths of the separated CO profiles gave the results summarized in TABLE 1: note that the excitation temperature is surprisingly high(this is based on more consistent analysis than in Paper I that gave lower temperature) and the turbulent velocity is rather large. Estimated total mass of the CO layer based on the deduced column density is as high as $10^{-4} M_{\odot}$.

As the excitation temperature is pretty high while the CO layer should be well separated from the photosphere as noted before, the CO layer may be an outer part of the extended chromosphere(which has been recognized only recently; see e.g., Linsky,1987) and/or a cool component of the chromospheric inhomogeneity. Anyhow, the CO absorption layer should represent a transition region between the chromosphere and the cool wind in luminous stars of non-coronal type. Probably, deposition of mass, momentum, and energy to the outer atmosphere from the photosphere may be sufficient to form the turbulent transition layer together with the extended chromosphere, but it may be not sufficient to be the direct driving force of stellar mass-loss. However, once the transition layer is formed, it provides an ideal environment for dust formation and radiation pressure on dust could drive mass-outflow. Such a hybrid model of mass-loss is well consistent with the known observations on the outer atmosphere of α Ori,for example. Also, even if dust could not be formed, the Maxwellian tail of the turbulent motion could lead to mass-loss, since the local escape velocity in the transition layer may be already small enough to be comparable with the observed flow velocities.

I am indebted to Drs.S.T.Ridgway and K.H.Hinkle for kind help in an observation at KPNO FTS, for archival data, and for useful discussions.

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INFRARED AND RADIO EXCESSES OF LATE-TYPE STARS

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The IRAS catalogues have been searched for cool (G,K,M) giant and supergiant stars to investigate the occurrence of circumstellar (C/S) silicate dust, revealed by its emission features at 9.7 and 18μm. Low Resolution Spectrograph (LRS) spectra covering the 7-23μm range were used, plus the 60 and 100μm photometric points. M Supergiants were found in White & Wing (1978), other stars by correlating the Bright Star Catalogue with the LRS catalogue: this discriminated against very cool stars reddened by dust; however it can be seen in Table I that there is a clear trend for cooler and more luminous stars to have a dust shell. M Supergiants almost all have dust shells, whilst only the cooler M bright-giants and giants do. Of the G and K stars, only a very few of the Supergiants have dust shells. The silicate features fell into two categories:
(1) narrow, sharply peaked 9.7 and 18μm features, typified by μ Cephei, observed in C/S shells of solitary cool giants/supergiants;
(2) much broader 9.7 and 18μm features (e.g. VX Sgr), reminiscent of the features seen in the Trapezium region, often seen in binary systems where the companion is a hot star. Few radio observations have been made of the continua of late-type stars; only the closest and brightest stars are above current observing thresholds. These observations are summarised in Drake & Linsky (1986), and it is apparent that the stars they observed have excesses at cm-wavelengths attributable to free-free emission from extended chromospheres. It is concluded that most stars in the present survey have radio excesses, while only the cooler and more luminous have infrared excesses (C/S dust shells).
An attempt has been made to model the prototype M-Supergiant α Ori (Skinner & Whitmore). Of the optical data available for amorphous silicate dust, that of Kratschmer & Huffman (1978) was found to give the best fit. With an optically thin C/S shell, and a photosphere approximated by a blackbody of 3600K appropriate to an M2Iab star, the observed spectrum cannot be satisfactorily reproduced. It was found necessary to change the spectral index of the IR continuum by invoking free-free emission from the extended chromosphere in order to fit the spectrum. The electron -density and -temperature distributions used were in keeping with those derived from chromospheric line-profile

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Table I

Stars with/without silicate dust shells.

	I	II	III
M	74/74	2/15	13/206
K	1/6	0/25	0/125
G	1/10	0/3	0/23

Figure 1

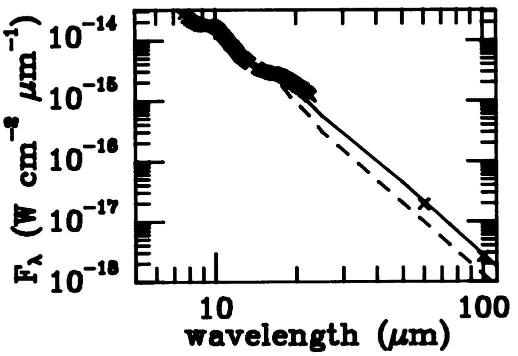
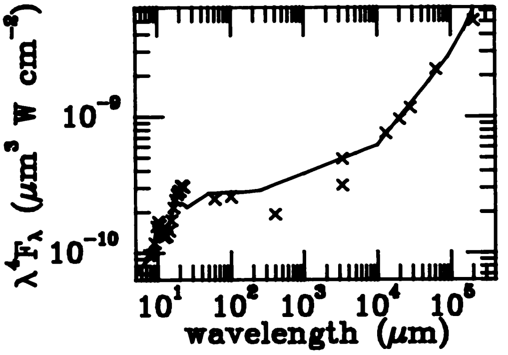


Figure 2



x observations - - - dust-only model -----dust+chromosphere model
Figure 2 : a black-body would be represented by a horizontal line

fitting, and the resulting spectrum fitted the IRAS observations and all available radio observations. It appears that other M-Supergiants can be fitted in the same way, the chromospheric contribution to the continuum varying from star to star.
Free-free emission seems more important in M-Supergiants than other cool, luminous stars, and mass loss is also more pronounced. Schwarzschild (1975) suggested convective hot spots caused the irregular variability of these stars, and speckle observations indicate that mass is lost episodically in blobs, rather than continuously. Mullan (1981) suggested that closed flux loops would be unstable above the photosphere of cool giant/supergiants, and this author suggests that convective cells may draw out bubbles of magnetic flux, which are driven away from the star carrying plasma with them. In the hotter stars, convection is less important and the magnetic field is more stable.
This work was carried out whilst in receipt of an SERC studentship which I gratefully acknowledge.

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CHEMICAL COMPOSITION AND CIRCUMSTELLAR SHELLS OF CARBON STARS - ANY OBVIOUS RELATIONS ?

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Evidence for circumstellar absorption around the warm N-type carbon star TX Piscium was found in a high-resolution IUE spectrum by Eriksson et al. (1986). This investigation also included the search, with a positive result, for CO J=1-0 emission from the circumstellar shell. From the Mn I absorption and CO emission a column density of about 10^{20} - 10^{22} H atoms per cm^2 was estimated, as well as a mass loss rate around 10^{-7} - 10^{-6} $M_\odot$ per year.

Lambert et al. (1986) have recently determined CNO abundances and $^{12}C/^{13}C$ ratios for 30 bright, galactic N-type stars. From this sample we have selected twelve stars with different chemical profiles to survey

TABLE I Stellar parameters from Lambert et al. (1986) / Results from CO J=1-0 observations at Onsala Space Observatory

Star	T_{eff} (K)	$^{12}C/^{13}C$	lg $\frac{C-O}{O}$	[N/H]	[O/H]	T_{mb} (K)	v_{LSR} (km/s)	v_{exp} (km/s)	Notes
Z Psc	2870	55	-1.85	-.39	-.23	0.20	12.8	4.2	
U Cam	2530	97	- .52	-.42	-.42	∿0.2	∿10	∿18	1,2
Y Tau	2600	58	-1.40	-.17	-.19	∿0.25	∿15	∿13	1,3
BL Ori	2960	57	-1.41	+.05	-.29	?			1
UU Aur	2825	52	-1.20	+.15	-.18	0.46	6.7	12.4	4
VY UMa	2855	44	-1.22	-.31	-.29	≦0.2			
Y CVn	2730	3.5	-1.06	-.12	-.40	0.36	19.7	9.1	5
RY Dra	2500	3.6	- .74	-.05	-.38	0.15	- 4.9	10.9	
T Lyr	2380	3.2	- .54	-.83	-.50	≦0.08			
UX Dra	2900	32	-1.34	-.12	-.21	0.19	13.7	7.1	
V460 Cyg	2845	61	-1.21	-.06	-.32	0.27	26.3	13.1	
TX Psc	3030	43	-1.57	-.27	-.10	0.25	13.1	12.5	
WZ Cas	2850	4.5	-2.00	+.01	+.07	≦0.08			

Notes:

1. Interstellar lines
2. Previously detected:
   ZDC: 0.16 / 8.5 / 22.0 J=1-0
3. Previously detected:
   ZDC: 0.17 / 15.9 / 10.1 J=1-0
4. Previously detected:
   ZD: 0.66 / 3.6 / 11.5 J=2-1
   ZDC: 0.26 / 7.6 / 12.4 J=2-1
   K: 0.06 / 7.0 / 13.4 J=1-0
5. Previously detected:
   ZD: 0.37 / 23.7 / 6.3 J=2-1
   KM: (0.06 / 21.7 / 7.9) J=1-0
   WS: 0.35 / 21.1 / 7.3 J=2-1

In 2-5 the numbers given are T_{mb} / v_{LSR} / v_{exp}

K Knapp(1986): Princeton Obs. preprint 167
KM Knapp & Morris(1985): Ap.J. 292, 640
WS Wannier & Sahai(1985): JPL preprint 106
ZD Zuckerman & Dyck(1986):Ap.J. 304, 394
ZDC Zuckerman,Dyck & Claussen(1986):ApJ 304,401

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their possible CO emission in the J=1-0 transition with the Onsala 20 m telescope. The observations were performed in December 1985 and April 1986. We detected CO emission from eight of the stars; the results are presented in Table I and two examples are displayed in Figure 1. The main beam brightness temperature, T_{mb}, is the antenna temperature divided by the main beam efficiency (≈ 0.3), and antenna and radome transmission factors. Four of the stars have been detected in CO by other groups independently.

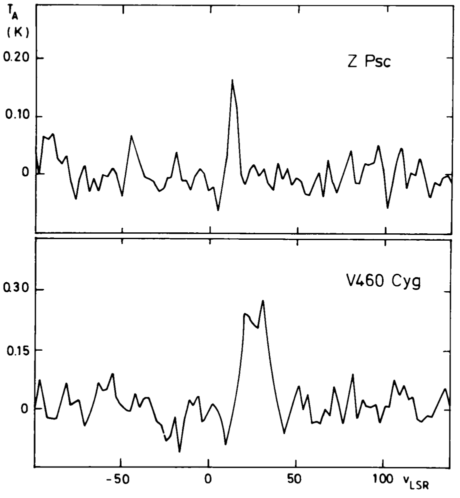

Figure 1: CO J=1-0 emission profiles for two N-type stars in our sample.

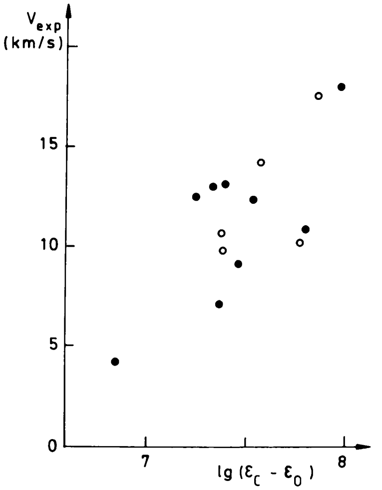

Figure 2: CO expansion velocity vs. carbon excess. Abscissa normalized such that lg ε_H=12. Open symbols are from other investigations.

We have investigated whether the shell emission and expansion velocities correlate with the chemical parameters, the effective temperatures or the flux excess at 11 μm as measured on IRAS low resolution spectra. No significant correlations were found. However, there may be a tentative correlation between the expansion velocity and the carbon excess (relative to oxygen), Figure 2. This correlation, which has the right direction if radiation forces on dust grains is an important mass loss mechanism, is worth further study.

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IMAGES OF THE ENVELOPE OF ALPHA ORIONIS

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ABSTRACT. Two images have been obtained, from observations made almost two years apart, of the H-alpha chromospheric envelope of Alpha Orionis at the diffraction limited resolution of the co-phased Multiple Mirror Telescope. Significant emission out to a distance of several stellar radii above the photosphere is observed.

1. INTRODUCTION

Several recent attempts have been made to design theoretical models for the extended atmosphere of the M type supergiant Alpha Orionis. However, the heights and thicknesses of the chromosphere within a few stellar radii of the star, in the region where the outward flow of matter is accelerated, has been relatively unknown. The H-alpha absorption line provides a valuable diagnostic since it is expected to be formed in this region. Using a narrow (1.2Å) H-alpha filter, and the fully-phased six-mirror Multiple Mirror Telescope (MMT)[1], images were obtained of the H-alpha chromosphere of Alpha Orionis at the greatest resolution available for imaging at optical wavelengths.

2. OBSERVATIONS AND DATA REDUCTION

Differential Speckle Interferometry (DSI) observations were made using the fully-phased MMT (Hege et al. 1985) on 1983 December 16/17, and again on 1985 November 2/4. The observational and data reduction procedures are discussed in detail by Hebden et al. (1986) and Hebden, Hege, and Beckers (1986). In order to extract images of the supergiant in the H-alpha line, the DSI imaging technique requires a reconstruction of the star's image in an adjacent continuum bandpass. A well defined photospheric radius, $R_{\star}$, was found of 17 milli-arcseconds (mas) to 23 mas, dependent on the limb-darkening assumed.

[1] The Multiple Mirror Telescope Observatory is a joint facility of the Smithsonian Institution and the University of Arizona.

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3. IMAGES OF THE H-ALPHA ENVELOPE

The images of the H-alpha envelope of Alpha Orionis for the 1983 December and 1985 November observations are shown in figure 1. The contours are plotted at intervals of approximately five percent.

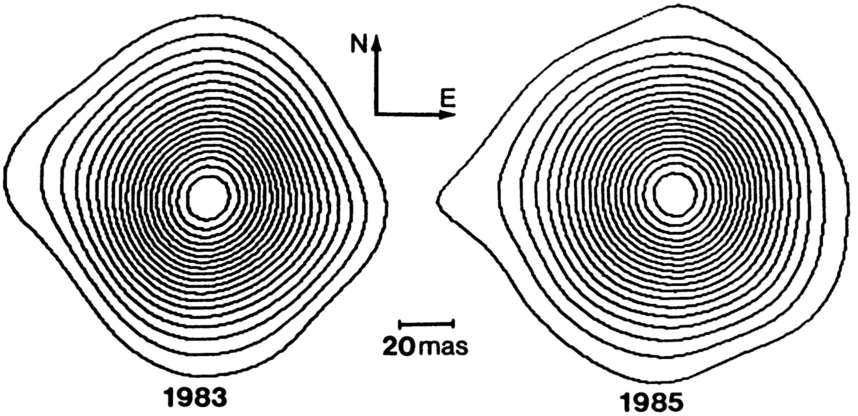

Figure 1. Images of the H-alpha envelope of Alpha Orionis

An intensity greater than one percent of maximum is detectable out to a radius of about 95 mas, or 4.5 stellar radii. Both images exhibit a small degree of asymmetry, corresponding to a position angle of about 280^{o}. The absence of a distinct photospheric limb suggests that the optical depth in H-alpha is probably very large. The radial profiles of the images exhibit a remarkable agreement with a Gaussian-like distribution, with intensity falling to I_o/e at $2R_\star$ and $I_o/10$ at $3R_\star$. The size of the observed H-alpha envelope of Alpha Orionis appears to conform to estimates of the chromospheric radius obtained from radio observations (Altenhoff, Oster, and Wendker 1979; Newell and Hjellming 1982), and to the theoretical model of Hartmann and Avrett (1984). A quantitative comparison of our results and this theoretical model is described by Hebden, Eckart, and Hege (1987).

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MIRA MODEL PHOTOSPHERES

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ABSTRACT. The temperature stratifications and the emitted fluxes of Mira model photospheres based upon the extended density distribution of a pulsation model differ substantially from those of conventional model photospheres based upon a hydrostatic density distribution. Hence, the interpretation of Mira spectra by means of hydrostatic models is inadequate, and the spectral characteristics of Miras may deviate significantly from those of non-Miras.

M type Mira model photospheres have been constructed in essentially the same way as the static models of Scholz (1985) with the technique of Schmid-Burgk (cf. Schmid-Burgk and Scholz 1984) for solving the spherical radiation transport and energy equations, and with opacities calculated from an improved version of Tsuji's (1978) program. The density distributions follow the isothermal limit of Wood's (1979) first overtone pulsation model, modified in order to account for recent spectroscopic results.

Fig. 1 shows the temperature and density stratifications in the model photosphere of a typical Mira at two different phases. The conventional definitions of a stellar radius, R = r ($\bar{\tau}_{Ros}$=1), and of an effective temperature, $Teff^4 \propto L\cdot R^{-2}$, are adopted (r = distance from the stars's center; $\bar{\tau}_{Ros}$= radial Rosseland optical depth) which, however, must here be considered with caution. Note the increase of R from maximum to minimum phase, leading to a lower effective temperature and to a general cooling of the photosphere near minimum even though the luminosity is kept constant in this exploratory computation.

First comparisons with observations show good agreement with the wavelength dependence of the radius of o Cet measured by Labeyrie et al. (1977) and Bonneau et al. (1982) and with typical differences between the spectra of Mira and non-Mira stars.

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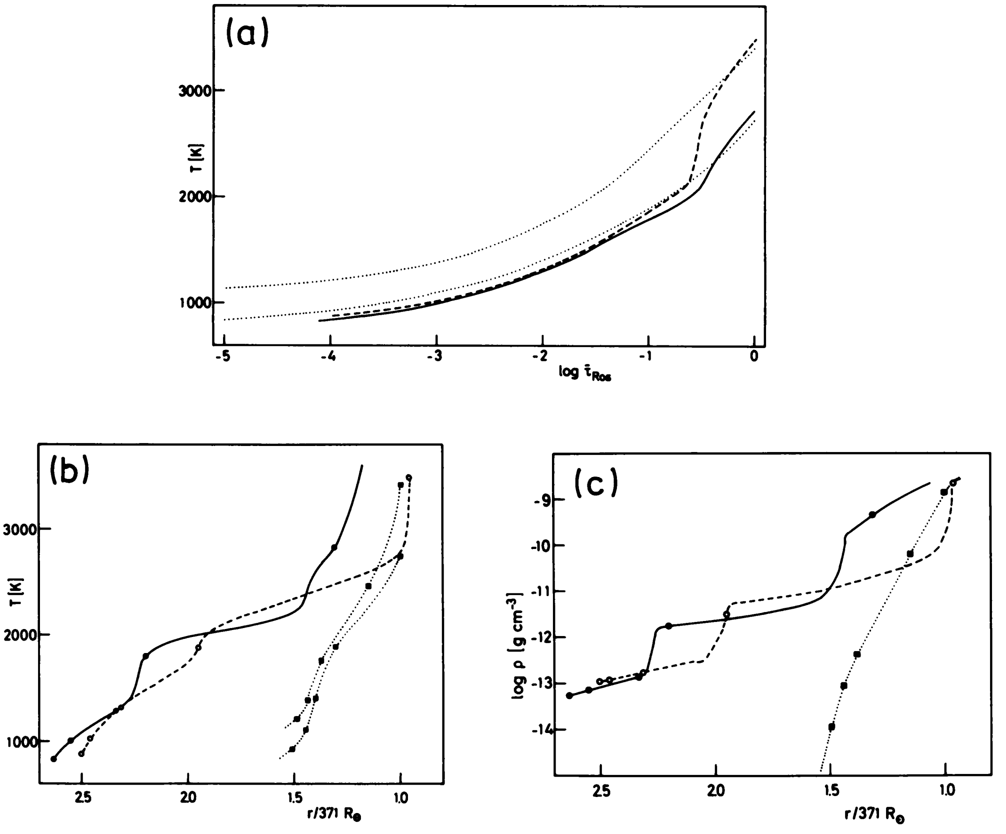

Fig. 1. Temperature and density stratifications in the model photosphere of a Mira variable of 1 M⊙ and 10000 L⊙ near maximum (Teff = 3060 K, dashed line) and near minimum (Teff = 2620 K, full) and in static model photospheres of the same mass and luminosity (Teff = 3000 K {a,b,c} and 2500 K {a,b}, dotted). The squares, circles and dots in {b,c} mark the positions of log $\bar{\tau}_{Ros}$ = -4, -3, -2, -1 and 0.

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