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THE ENERGY INPUT MECHANISM INTO THE LOWER TRANSITION REGIONS BETWEEN STELLAR CHROMOSPHERES AND CORONAE

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ABSTRACT

The ratio of the emission line fluxes for the C II and C IV lines in the lower transition regions ($3 \times 10^4 < T < 10^5$K) between stellar chromospheres and transition layers depends mainly on the temperature gradient in the line emitting regions which can therefore be determined from this line ratio. The temperature gradient is determined by the equilibrium between energy input and energy loss. From the observed temperature gradient we can therefore determine the temperature dependence of the energy input, which is expected to be different for different energy input mechanisms. We study the flux ratios of the C II to C IV emission line fluxes in order to obtain information about the energy input mechanism.

Key Words: Transition layer, heating, Emission lines, T Tauri stars.

1 THEORETICAL BACKGROUND

We follow the derivations by Böhm-Vitense (Ref. 1). We assume that the energy input E_{in} per cm^3 and sec is due to the damping of some mechanical energy flux F_m. This means

$$E_{in} = -\frac{d\,F_m}{dh} = \frac{F_m}{\lambda}, \tag{1}$$

where λ is the damping length. Using T as the independent variable such that the gas pressure $P_g = P_g(T)$ we can express a possible dependence of the damping length on P_g and T as a dependence on T only. We write

$$\lambda = \lambda_o \cdot T^{\alpha} \tag{2}$$

α is a parameter which can be determined from the emission line fluxes.

The energy input is balanced by radiative energy losses E_{rad} per cm^3 sec^{-1} which can be described by

$$E_{rad} = E_{loss} = n_e^2 \cdot f(T) \tag{3}$$

where f(T) has been calculated by many authors for solar element abundances (see Rosner, Tucker, and Vaiana 1978, (Ref. 2)). It can be approximated by

$$f(T) = B \cdot T^{\beta} \tag{4}$$

where for 30,000 K $< T <$ 1.2 $10^5 K$ the $\beta \sim 1.9 \pm 0.1$ and B is a constant.

The energy equilibrium then requires

$$n_e^2\ f(T) = P_e^2\ B\ T^{\beta-2} = \frac{F_m}{\lambda_o} \cdot T^{-\alpha} \quad \text{or} \tag{5}$$

$$T^{\beta-2+\alpha} = \frac{F_m}{\lambda_o}\frac{k^2}{B}\cdot\frac{1}{P_e^2} \tag{6}$$

The electron pressure P_e is determined by the hydrostatic equilibrium equation which for fully ionized gas means

$$d\ln P_e^2 = -\frac{2}{H}dh \quad \text{with} \quad H = \frac{R_g\ T}{\mu g_{eff}}, \tag{7}$$

where R_g = gas constant, μ = mean atomic weight, g_{eff} = effective gravitational acceleration.

With

$$d\ln F_m = -\frac{1}{\lambda}dh \tag{8}$$

we find for the temperature gradient

$$(\beta - 2 + \alpha)\ \ d\ln T = d\ln F_m - d\ln P_e^2 = (-\frac{1}{\lambda} + \frac{2}{H})dh \tag{9}$$

and

$$\frac{dh}{d\ln T} = (\beta - 2 + \alpha)(\frac{2}{H(T)} - \frac{1}{\lambda(T)})^{-1} \tag{9a}$$

If for a given temperature we can determine $\frac{dh}{d\ln T}$ we can determine α, which describes the temperature dependence of the damping length.

For different heating mechanisms we expect different values of α (Ref. 2). The determination of α for different stars therefore tells us whether different heating mechanisms work for different stars. Finding the same α for all stars means that the same heating mechanism is working for all stars.

2 METHOD OF ANALYSIS

In the following we are considering only layers with 30,000 K $< T <$ 1.2 10^5K, *i.e.*, layers for which equation (3) holds with $\beta \approx 1.9 \pm 0.1$.

The surface flux F_L of optically thin emission lines is given by

$$F_L = C(L,T)A(el)\int_{h_1}^{h_2} n_e^2 dh \tag{10}$$

$$= C(L,T)A(el)\cdot\int_{T_1}^{T_2} n_e^2\frac{dh}{d\ln T}d\ln T = C(L,T)\cdot A(el)\cdot E_m(T)\,.$$

where the integral has to be extended over the line emitting region, which corresponds to a height difference over which the temperature changes by approximately a factor of 2 or $\Delta\ln T \approx 0.7$ The integral is called the emission measure $E_m(T)$ and depends on the temperature $T(h)$. The $C(L,T)$ are determined by the collisional excitation rates for each line. $A(el)$ is the abundance of the line emitting element. Using average values for the integrand and using equation (9a) we find

$$E_m(T) = \frac{P_{eo}^2}{k^2}\cdot\frac{(\beta+\alpha-2)}{2}\cdot\frac{0.7}{T}\cdot\frac{R_g}{\mu g_{eff}}\left(\frac{T_o}{T}\right)^{\beta+\alpha-2}\varphi(T) \tag{11}$$

where

$$\varphi(T) = \frac{e^{-\int_0^h \frac{1}{\lambda}dh}}{(1-\frac{H}{2\lambda})} \tag{12}$$

depends on the ratio of $\frac{H}{\lambda}$ but varyies only slowly with T.

For the C II (1335 Å) lines originating at $T_1 \sim 35{,}000$ K and the C IV (1550 Å) lines originating at $T_2 \sim 10^5$ K the ratio of the emission measures becomes

$$\frac{E_m(T_1)}{E_m(T_2)} = \left(\frac{T_2}{T_1}\right)^{\beta+\alpha-1}\cdot\frac{\varphi(T_1)}{\varphi(T_2)} \tag{13}$$

The ratios of the observed emission line fluxes f_L equal the ratios of the surface fluxes F_L and are for the C II and C IV lines

$$RC = \frac{f_L(C\,II)}{f_L(C\,IV)} = \frac{C(1335Å,T_1)}{C(1550Å,T_2)}\cdot\frac{E_m(C\,II)}{E_m(C\,IV)}\cdot\frac{\varphi(T_1)}{\varphi(T_2)}$$

or

$$\ln\frac{f_L(C\,II)}{f_L(C\,IV)} = \text{const} + \ln\frac{E_m(T_1)}{E_m(T_2)} + \ln\frac{\varphi(T_1)}{\varphi(T_2)}$$

where the second term on the right hand side is given by equation (13) and depends on α

The value of α can then be determined from the ratio of the observed line fluxes

3. RESULTS

In figures 1-3 we show the observed flux ratios RC for different groups of stars The observational error for the flux ratio is expected to be at least 50% (25% for each line), or $\Delta\log RC \approx \pm0.2$ and more for weak lines.

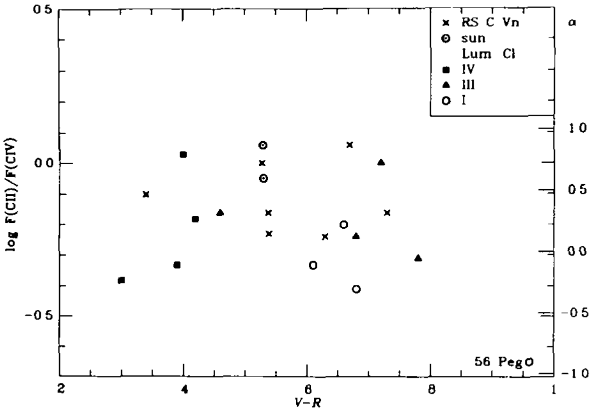

Figure 1 The line flux ratio of the carbon lines is shown as a function of the V-R colors for the stars studied by Ayres *et al.* The different symbols indicate different types of stars as explained in the figure. The RS CVn stars and the normal stars occur in the same region of the diagram For 56 Peg at the UV emission lines originate mainly in a hot disk

In figure 1 we have plotted the observed flux ratios as a function of the V-R colors for stars observed by Ayres *et al* 1982 (Ref. 3). We see that there is no dependence of this flux ratio on T_{eff} nor on luminosity class nor on activity level The RS CVn stars fall into the same general region as the other stars. α therefore seems to be independent of all these parameters There may be a hint that some supergiants and some luminosity class IV stars may have excess C IV emission 56 Peg clearly shows a lower RC For this star we know that the emission comes from a disk around a white dwarf companion (Dominy and Lambert 1983, Ref 4) and not from the chromosphere of the red supergiant

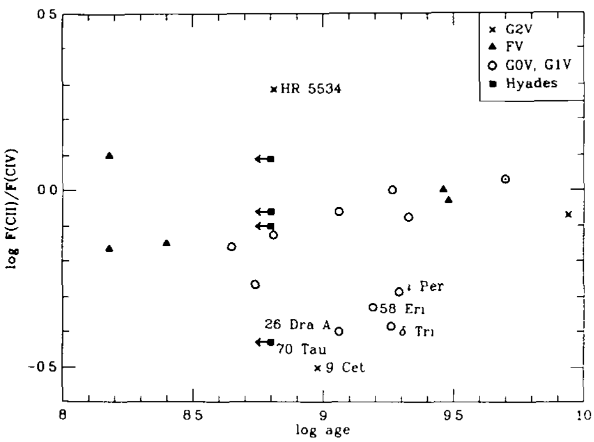

Figure 2 For the stars studied by Simon *et al* the line flux ratio of the carbon lines is shown as a function of age of the stars The age of the Hyades stars is probably smaller than used here, as indicated by the arrows The different symbols refer to different types of stars as explained in the figure. Peculiar stars with abnormally low or high flux ratios are given by name.

In figure 2 we show the results for main sequence G stars with different ages studied by Simon, Herbig and Boesgard (1985, Ref 5) There is no obvious dependence of RC on age either, except for the somewhat smaller RC for a group of stars with ages around 10^9 years which again seem to show excess C IV emission We suspect that circumstellar emission enhances the C IV line flux, though for these stars we cannot exclude that a different heating mechanism may contribute to the heating of the lower transition region For all the other stars with logRC = -0.1 ± 0.2 a value of $\beta + \alpha - 1 = 1.3 \pm 0.3$ is found, which means $\alpha \approx 0.4 \pm 0.3$ if $\beta = 1.9$

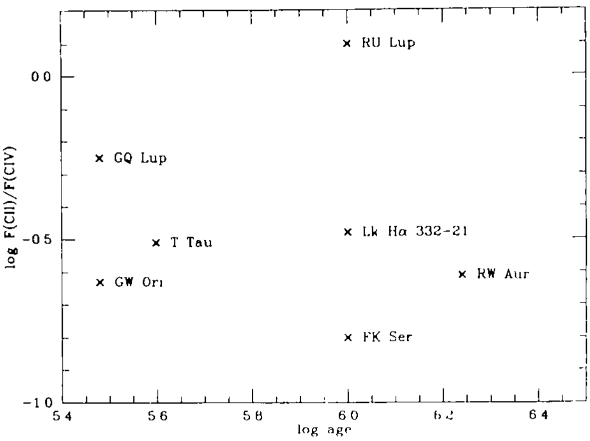

Figure 3 The carbon line flux ratios are shown as a function of age for the T Tauri stars studied by Simon *et al* The line flux ratio is generally lower for the T Tauri stars than for the normal giants and main sequence stars They show a large scatter

In figure 3 we show the RC values for T Tauri stars according to Simon, Herbig and Boesgard (Ref 5) The points scatter all over the diagram The C II and C IV emission lines are not due mainly to a transition region formed by the same heating mechanism as for nearly all other stars This conclusion is in agreement with the one found by Simon, Herbig and Boesgard but derived from very different arguments We suspect that circumstellar emission possibly due to shocks, gives a major contribution to the emission line fluxes for the T Tauri stars

4 SUMMARY

From the observed constant (within the limits of observational error) ratio of the emission line fluxes of the C II (1335 Å) and C IV (1550 Å) lines we conclude that the temperature gradients in the lower transition layers are similar for the large majority of stars independently of T_{eff} L and degree of activity This means that the temperature dependence of the damping length for the mechanical flux must be the same for all these stars Since for different kinds of mechanical fluxes the dependence of the damping length on gas pressure and temperature is quite different (Ref 2) we conclude that the same heating mechanism must be responsible for the heating of all the lower transition layers of these stars, regardless of their chromospheric activity Only the amount of mechanical flux changes

The T Tauri stars are exceptions For these stars the emission lines are probably mainly due to circumstellar material

5 REFERENCES

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