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DEPENDENCE OF THE CONTINUUM ENERGY DISTRIBUTION OF T TAURI STARS ON THE LOCATION OF THE TEMPERATURE MINIMUM

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RESUMEN

Investigamos en este trabajo la influencia de la posición del mínimo de temperatura sobre el flujo continuo producido por modelos teóricos que consisten de una fotosfera normal y una subida de temperatura correspondiente a una cromosfera, similares a aquellos presentados por Calvet (1981). Se encuentra que, aun con un mínimo de temperatura más profundo que el usado previamente, la discrepancia entre flujos teóricos y observaciones encontrada en dicho trabajo todavía existe. Encontramos, además, un límite superior a la posición del mínimo de temperatura en este tipo de modelos, correspondiente a m $\sim$ 2 g cm^{-2}.

ABSTRACT

We investigate the influence of the position of the temperature minimum on the continuum flux produced by theoretical models. The models consist of a normal photosphere and a chromospheric temperature rise and are similar to those of Calvet (1981). We find that a deeper temperature rise than previously assumed cannot eliminate the discrepancy between theoretical fluxes and observations found in that work. We also find an upper limit to the location of the temperature minimum for the type of models considered here of m $\sim$ 2 g cm^{-2}.

Key words: STARS – PRE-MAIN SEQUENCE – STARS-CHROMOSPHERES

I. INTRODUCTION

T Tauri stars are known to possess a peculiar pectrum (Herbig 1962), and in particular their con- inuum fluxes show a range of excesses relative to those luxes corresponding to their spectral type in the ltraviolet, blue, and infrared part of the spectrum. We ave recently presented model atmospheres for T Tauri tars which produce absolute continuum fluxes of the ıme order of magnitude as those observed (Calvet 981). However, the calculated flux at wavelengths ɔnger than the Balmer Discontinuity (BD) was lower han observed, and it was too high at wavelengths horter than the BD. Several reasons may be given for hese failures: *a)* the assumed location of the tempera- ure minimum may not be correct; *b)* the hypothesis of omogeneity may be completely inappropriate; *c)* the ings of the high members of the Balmer series may roduce an excess over the continuum flux, which has ıot yet been taken into account.

In this paper we investigate the first of these ossibilities. In particular, we calculate continuum fluxes or models with similar temperature profiles, differing in he position of the temperature minimun. The tempera- ure structure in the middle chromosphere is similar to hat of the models which produced the best agreement ith observations in Calvet (1981).

II. METHOD

We assume temperature profiles as shown in Figure 1. Model 1 here is similar to Model 9 of Calvet (1981). These profiles are characterized as follows. The photosphere has $T_{eff} = 4000$ °K and log g = 3.5, taken from Carbon and Gingerich (1969). The temperature minima are located at m = 1, 2 and 5 g cm^{-2} for Models 1, 2 and 3, respectively, where m is the mass column density.

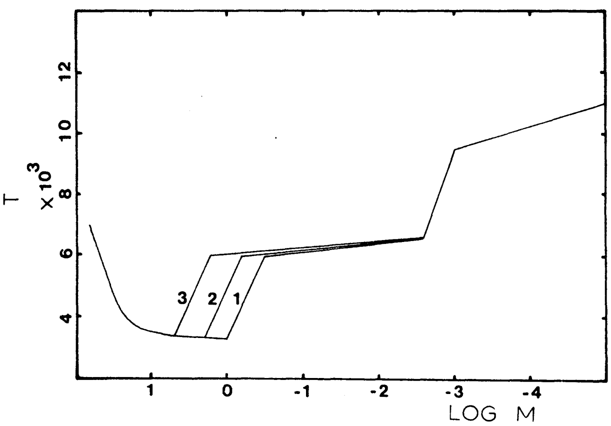

Fig. 1. Temperature structures for Models 1, 2 and 3. The photospheric parameters are $T_{eff} = 4000$ °K and log g = 3.5. Models 1, 2 and 3 have temperature minimum at m = 1, 2 and 5 g cm^{-2}, respectively.

Given the temperature structure, we solve the transfer and equilibrium equations for a 5-level, plus continuum, representation for the hydrogen atom using the complete linearization scheme of Auer and Mihalas (1969). The transfer equations for Hα and the Lyman and Balmer continua are solved explicitly. Lα and Lβ are assumed to be in detailed balance. The remaining transitions are treated with fixed rates, estimated using Basri's (1979) procedure. This calculation gives the electron density and departure coefficients for the first five levels of the hydrogen atom, which are then used to calculate non-LTE source functions for the continuum produced by these levels. Other source functions are assumed in LTE. The continuum calculation includes contributions from H, H^-, He^-, H_2^+, Si, Mg and C, and electron and Rayleigh scattering. The effect of line blanketing has been included as in Calvet (1981). The Eddington approximation is used. The atmosphere is assumed homogeneous and in hydrostatic equilibrium.

III. RESULTS AND DISCUSSION

Figure 2 shows continuum fluxes for Models 1, 2 and 3. Increasing the depth of the temperature minimun has several effects. *a)* The flux increases at all wavelengths. *b)* The increase at wavelengths longer than the BD is larger than it is at shorter wavelengths. The reason for these effects is that as the density of the region just above the temperature minimum increases, its contribution to the total flux also increases, since there is a larger number of emitters. In addition, the main contributor to the opacity in this region is H^- (Calvet 1981), whose emissivity is continuous through the BD. Higher up in the chromosphere the main contributor to the opacity is H^-, and it is in these zones where the discontinuity is formed. As the contribution from the temperature minimun region becomes more important, the flux contrast at both sides of the BD becomes less apparent, due to the increasing influences of the H^- opacity.

Figure 2 also shows observations of BP Tau from Kuhi's (1974) narrow-band photometry. Two sets of observational points are shown, in which the star exhibits different degrees of emission. We have chosen this particular star for comparison with the current theoretical models because other spectral features of BP Tau are known to be well reproduced by the general characteristics of the models. A slight increase in depth of the temperature minimum produces an increase in the continuum flux consistent with the observations. However, the flux at wavelengths longer than the BD does not increase in the proportion required to reproduce the observations. The required depth of the temperature minimum is such that the flux at wavelengths shorter than the BD, and in the visual region is too large.

Moreover, a small change in depth of the temperature minimum (like from Model 2 to Model 3) produces an excessive change in flux, as compared to the observations. This fact sets a strong upper limit to the depth o the temperature minimum in this type of models. I fact, the temperature minimum cannot be located a depths greater than $m \sim 2$ g cm^{-2} because too muc flux would be produced otherwise. The optical depth a 3640 A at $m \sim 2$ g cm^{-2} is smaller by at least a factor o two than the optical depth estimated by Dumont *et a* (1973). However, the uncertainties associated with th latter work are large, and not too much weight should b given to this discrepancy.

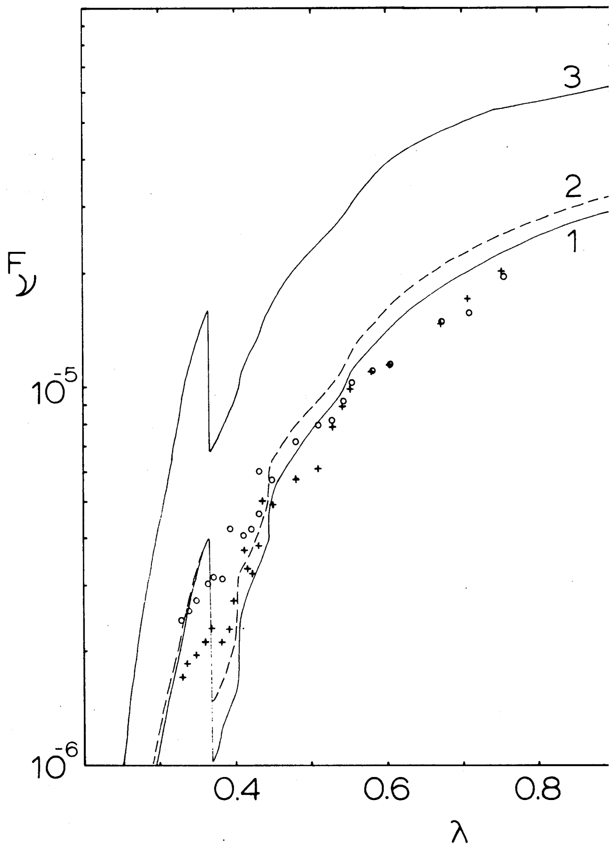

Fig. 2. Continuum energy distribution for Models 1, 2 and 3 and observed fluxes for BP Tau from Kuhi (1974). Filled circle correspond to observations obtained in JD 2439879.4; crosses t JD 2439153.67.

IV. CONCLUSIONS

Two main conclusions arise from this investigation

(1) The discrepancy between theoretical models an observations in the blue and ultraviolet regions of th spectrum found in Calvet (1981) cannot be diminishe by changing the location of the temperature minimum Other factors must be taken into account to improve th agreement.

(2) There is an upper limit to the depth of th temperature minimum in the type of models considere here. This limit is $m \sim 2$ g cm^{-2}, which corresponds t $\tau_5 \sim 2 \times 10^{-2}$.

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DISCUSSION

Campusano: ¿Se incluyeron cálculos de perfiles de algunas líneas?
Calvet: En los cálculos del espectro se incluyeron las siguientes líneas: Hα, Ca II K y Mg II k. Estos perfiles de líneas junto con el flujo del espectro continuo, se usan como diagnósticos espectrales de los gradientes de temperatura en las zonas donde se producen estas líneas. Sin embargo, se usó en este trabajo el flujo total en estas líneas, y no el perfil para comparar con las observaciones por dos razones: *1)* porque no se incluyeron campos de velocidad, que influyen directamente en los perfiles, y *2)* porque para las estrellas a las que estos modelos se refieren se han publicado muy pocos perfiles con la resolución apropiada.
Serrano: ¿Cómo pueden estos modelos reproducir la variabilidad observada?
Calvet: En el trabajo mencionado anteriormente (Calvet 1981) se determinó que variaciones en la localización de la meseta de temperatura que ocurre a 10 000° k determinan variaciones en el flujo continuo, en el flujo de las líneas, y en el espectro de absorción comparables en orden de magnitud a los cambios observados en el espectro de estrellas T Tauri individuales.

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