THE CIRCUMSTELLAR STRUCTURE OF WEAK- AND POST-T TAURI STARS.

J. Gregorio-Hetem, G. Rojas, *Universidade de São Paulo, IAG/USP*, A. Hetem Jr., *Fundação Santo André, FAFIL, SP, Brasil (jane@astro.iag.usp.br).*

A flared disk model has been adopted to reproduce the observed spectral energy distribution (SED) of young stars detected in the Pico dos Dias Survey. We studied a sample of 43 stars previously identified as weak-T Tauri stars in order to estimate the circumstellar contribution to the total emitted energy. The circumstellar characteristics, related to the physical conditions of the disk, are discussed in terms of the evolutionary classification of the sample, which contains 44% of weak-T Tauri stars, 23% of classical T Tauri, 5% of post-T Tauri, and 28% of young main sequence Fe/Ge type stars. In the present work 15 of these objects have been studied. The disk structure was evaluated by adopting the models suggested by Chiang and Goldreich (1997) and Dullemond et al. (2001) and using the genetic algorithm method for the optimisation of parameters estimation.

Introduction

We have conducted a detailed analysis of different categories of low-mass objects in the pre-main sequence. Abundances and metallicity have been determined by synthetic spectra, aiming to compare the stellar characteristics with the circumstellar structure evolution. The presence of post-T Tauri and young main sequence stars has been verified among the objects of our sample, previously classified as weak-T Tauri stars (WTTs). The distances derived from Hipparcos parallaxes allowed us to estimate stellar ages by comparison with evolutionary tracks in the HR diagram. The classification is also discussed on basis of lithium abundance, spectral type and infrared excess, following Gregorio-Hetem and Hetem (2002).

The contribution of the circumstellar dust to the emitted radiation of young stellar systems is mainly evaluated as a function of the infrared excess observed in these objects. In a previous study of WTTs, Gregorio-Hetem & Hetem (2002) adopted the simplest scenario assuming a flat, passive disk that re-radiates the energy absorbed from the central star. A tenuous dust envelope, surrounding the star and the disk, was included in the calculations aiming to reproduce the flattened spectral energy distribution (SED) exhibited by most of the studied TTs. In the present work we use a disk model that has been improved to better be applied to objects having different disk geometries.

Following Chiang & Goldreich (1997) and Dullemond el al. (2001), we use the hydrostatic, radiative equilibrium model for passive, reprocessing flared disk. Three disk components are considered: the inner rim, the shadowed region and the flared region (this has two layers: an illuminated hot-layer and an inner cold-layer). The grains in the surface of the disk are directly exposed to the radiation from the star and the interior of the disk is heated by diffusion from the surface. Recently, Hetem & Gregorio-Hetem (2007) improved the calculation method in order to optimise the parameters estimation by using the technique based on genetic algorithms (Bentley & Corne 2002).

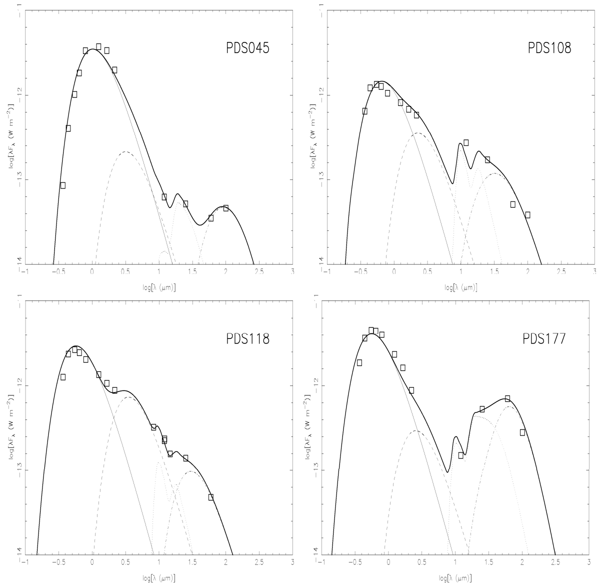

Figure 1: Synthetic SED (thick continuous line) obtained for some stars of the sample. A continuous thin line is used to represent the stellar emission; dashed line represents the rim emission. The contributions from the disk cold-layer (dot-dashed line) and hot-layer (dotted-line) are also shown. The photometric data are indicated by open squares.

Circumstellar Structure

The optical photometry was obtained from the *PDS*, near-infrared data are from *2MASS*, and far-infrared from *IRAS* Point Source Catalogue. The optical and near-infrared data were corrected for interstellar extinction by using the normal relation (Savage & Mathis 1979) $A_V = 3.1E(B-V)$ and extinction law A_λ/A_V from Cardelli et al. (1989). Considering the UV excess presented by T Tauri stars, the (*B*-*V*) excess was estimated by adopting $E(B-V) = E(V-R)/0.78$ (Schultz & Wiemer 1975). The intrinsic colours and bolometric corrections from Bessell et al. (1998) were adopted in the estimation of A_V, absolute bolometric magnitude and luminosity.

Stellar temperatures were obtained by using the Spectral Type-T_{eff} relations given by de Jager & Nieuwenhuijzen (1987). Distances are derived from the Hipparcos parallaxes, when available, or adopting the distance of the associated star forming region. These stellar proprieties were considered as fixed input parameters of the model, by adopting small error-bars that are used to constraint the parameters range required in the genetic algorithm (GA) method. The free parameters are: stellar mass; radius, mass and inner temperature of the disk; and inclination angle.

Table 1: List of PDS stars studied in the present work showing some of the adopted parameters. The stars are classified as weak-TT, classical-TT, post-TT or young object of the main sequence (YMS). Last column indicates the amount of circumstellar emission.

PDS	T_{eff}	d	A_V	$logL$	Class	L_c
	K	pc	mag	$L_\odot$		%
008	5230	133	1.2	0.7	YMS	28
13	5472	308	0.5	1.2	YMS	44
14	6531	450	0.3	1.0	YMS	29
40	3837	140	0.2	-0.7	WTT	27
46	5943	21	1.7	-1.0	YMS	26
054^a	4450	47	0.2	-0.1	PTT	18
60	5152	60	1.6	-0.6	WTT	31
073^a	4838	160	1.1	0.7	WTT	26
75	4405	160	0.6	-0.2	WTT	24
90	4539	150	2.3	0	WTT	30
093^a	6653	145	0	0.7	YMS	24
108	5943	500	0	1.0	YMS	29
117	6531	100^b	0	-0,5	YMS	27
118^a	6531	100^b	0.4	0.1	CTT	22
171	5152	150	2.7	0.4	WTT	30
177	5998	1160	0.4	2.5	YMS	20
181	4656	460	4.0	1.3	WTT	36
330	4989	150	1.4	0.2	WTT	18
390S	6531	100^b	0.3	0.6	YMS	23
401	6368	198	0.8	1.5	WTT	29

Notes: (a) Four PDS stars studied by Gregorio-Hetem & Hetem (2000) have been included in the sample aiming to compare the previous results with those ones obtained in the present work; (b) A distance of 100 pc is assumed when this parameter is unknown.

Results and Discussion

The best fitting of the SED is obtained based on maximum likelihood statistics and χ^2 tests for the *goodness-of-fit*. The calculation of the synthetic SED for each component of the adopted model gives us an estimation of the circumstellar contribution as compared with the total emission, indicated by $L_c = (L_T - L_{star})/L_T$. Figure 1 shows examples of the obtained SED fittings and Table 1 gives some of the stellar parameters and the fraction of the circumstellar emission. Most of the objects of our sample do not present significant dust contribution in the total luminosity of the system, showing $L_c \sim 0.3 L_T$.

The whole sample of PDS stars previously identified as WTTs contains 43 objects. Gregorio-Hetem & Hetem (2002) studied 27 of them by adopting a flat disk model. The stellar characteristics, as temperature and lithium abundances, were compared with the circumstellar emission in order to re-classify some of the objects in other categories as classical T Tauri (CTT); post-T Tauri (PTT) or young main sequence stars (YMS). Recently we adopted the GA method to improve the disk parameters calculation. A flared disk model, based on Chiang & Goldreich (1997) and Dullemon et al. (2000) suggestions, was assumed in order to consider other circumstellar structure than the flat geometry surrounded by a spherical envelope (Hetem & Gregorio-Hetem 2007). The calculation method was applied for the remaining 16 PDS objects previously considered WTTs. Partial results are indicated in the last columns of Table 1, showing that only 50% of the objects can actually be considered WTTs. Four stars: PDS054, PDS073, PDS093, and PDS118, representing respectively the categories of PTT, WTT, YMS, and CTT, were included in the present study in order to compare the results obtained with different calculation methods. As expected, the circumstellar contribution to the total emission does not change from one method to the other, but an improvement of the *goodness-of-fit* was verified in the present work.

The next steps of this ongoing research is to compare the disk mass and radius with stellar mass and age, aiming to study the disk evolution, as can be indicated by the disk geometry and grains distribution. As suggested by Hernández et al. (2007) grain growth and/or settling, and transitions objects, which are stars with inner gaps in their disks (Scilia-Aguilar et al. 2006), are a possible combination to explain evolved disks. One example is the Herbig Ae star HD141569 (PDS398) showing an evolved disk, which was analysed with our GA method. The correlation between the mid-infrared and the sub millimetre slope, found by Acke (2004) for this star, indicates that as the grains grow the disk evolves from flared to geometrically flat structure (Dullemond 2002).

References

Acke B., van den Ancker M. E., Dullemond C. P., van Boekel R., Waters L. B. F. M., 2004, A&A, 422, 621

Bentley P. J., & Corne D. W., 2002, Creative Evolutionary Systems. Morgan-Kaufmann, San Francisco

Bessel M. S., Castelli F., Plez B., 1998, A&A, 333, 231

Cardelli J. A., Cleyton G. C., Mathis J. S., 1989, ApJ, 345, 245

Chiang E. I.; Goldreich, P., 1997, ApJ 490, 368

Dullemond C.P., Dominik, C., Natta, A. 2001, ApJ 560, 957

Dullemond C. P., 2002, A&A, 395, 853

Gregorio-Hetem J., Lépine, J., Quast, G., Torres, C.A., de la Reza, R. 1992, AJ 103, 549

Gregorio-Hetem J., Hetem Jr., A. 2002, MNRAS 336, 197

Hernández J., Hartmann L. W., Megeath T., Gutermuth R., et al., 2007, preprint (astro-ph/0701476v1)

de Jager C., Nieuwenhuijzen H., 1987, A&A, 177, 217

Savage B. D., Mathis J. S., 1979, ARA&A, 17, 73

Schultz G. V., Wiemer W., 1975 A&A, 43, 133

Sicilia-Aguilar A., Hartmann L. W., Fürész G., Henning T., Dullemond C., Brandner W., 2006, AJ, 132, 2135

Torres C.A., Quast, G., de la Reza, R., Lépine, J., Gregorio-Hetem, J. 1995, AJ 109, 2146

Torres C. A. O. 1998 PhD. Thesis, CNPq/Observatório Nacional, Brasil