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CIRCUMSTELLAR ENVIRONMENT OF T TAURI STARS

Nuria Calvet

Centro de Investigaciones de Astronomía (CIDA)
Mérida, Venezuela

RESUMEN. Se revisan y critican modelos para las atmósferas y envolventes de estrellas T Tauri basados en la analogía solar. Se describe la emisión del disco en términos de modelos de discos activos y pasivos y se discute a la luz de las observaciones. Se revisan los resultados más recientes sobre la temperatura, tasa de pérdida de masa y geometría de la región extendida en expansión.

ABSTRACT. Early models for the atmosphere and envelope of T Tauri stars based on the solar analogy are reviewed and criticized. Disk emission is described in terms of active and passive disk models and discussed at the light of the observations. Recent results on the temperature, mass loss rate, and geometry of the extended expanding region are reviewed.

Key words: **STARS–ATMOSPHERES — STARS–CIRCUMSTELLAR SHELLS — STARS– T TAURI**

I. INTRODUCTION

T Tauri stars (TTS) are young (1×10^6 to 1×10^7 years) visible objects, with mass $\leq 2.5\ M_\odot$, luminosity $\leq 20\ L_\odot$, and effective temperature $\leq$ 5 500 K. They are characterized by peculiar spectral energy distribution with emission lines and continua superimposed on an absorption spectrum with line strength that ranges from normal to almost zero. In addition, these stars present a large degree of variability.

Over the years, different models have been presented to explain the peculiarities of TTS; in recent years, the inclusion of the emission of the disk around the star, which was known to exist for a long time although its effects were not really considered, has brought a new perspective into the field. In this work, I will briefly review the early models that were proposed to explain these objects, and describe the main criticisms to them. Then, I will refer to the newest models to explain the emission; since these ideas are very new, there are still a number of unknowns in the general picture. I will mention some of them in turn.

II. EARLY MODELS

Until the early 1980's, the activity observed in TTS was understood as an "amplification "of the solar type of activity observed in other type of active stars. Atmospheres of TTS were thought to consist of a photosphere, a chromosphere, a corona, and an extended expanding region (Giampapa *et al.* 1981). Several lines of evidence pointed to the inhomogeneous nature of this atmosphere (see references in Calvet 1983). In addition, the lack of correlation between A_V and the infrared excess, together with polarization studies (Bastien and Landstreet 1979; Bastien 1981, 1982), and studies of the continuum of HL Tau reflected by HH30 (Cohen and Schmidt 1981) pointed to dust in a non-spherical distribution as responsible for the infrared excess.

The solar activity analogy implied that magnetic processes were ultimately responsible for the stellar activity. There was evidence in favor of this interpretation. Flare-like activity has been observed in X-rays (Feigelson and DeCampli 1981; Montmerle *et al.* 1983). Stars tend to get fainter when redder, as if spots on the surface were responsible for the variability (Herbst, Holtzmann, and Phelps 1982), although some stars do not follow this behavior (Walker 1987). Periodic photometric variability observed in a number of (weak line) TTS has been interpreted in term of rotational modulation of the flux of a spotted surface (Bouvier, Bertout and Bouchet 1986; Bouvier and Bertout 1989).

On the theoretical side, deep chromosphere models for TTS have temperature profiles similar to those calculated for stellar flares (Cram 1979; Calvet, Basri and Kuhi 1983). These models could reproduce in general terms fluxes in emission lines, except for Hα and Mg II k in the most active stars, as well as blue and ultraviolet continuum and veiling of absorption lines. The chromospheric contribution to the total flux was that of an optically thin gas, superimposed to a late type photosphere. The predicted excess continuum then became more conspicuous in the blue and ultraviolet region, where line blanketing strongly depressed the photospheric flux. Chromospheres that produced emission characteristics similar to those observed had a large Balmer jump in emission.

Deep chromospheres could not account for the flux in Hα. A large geometrical extension of the emitting region in Hα was required to produce enough flux in the line (Calvet, Basri and Kuhi 1983), which agreed with the evidence of the observed P Cygni line profiles. Hartmann, Edwards and Avrett (1982, HEA) proposed that MHD waves originating in the stellar surface could deposit enough energy and momentum in the envelope for the material to accelerate to terminal velocities ≈ 200 km s^{-1} in distances less than 2.5 R_*, with $\dot{M} \approx 1 \times 10^{-9}$ to 1×10^{-8} $M_\odot$ yr^{-1}. A large broadening velocity in the innermost region ($r < 3 R_*$) was a natural consequence of the wave propagation through the envelope. Predicted fluxes and line widths in spherically symmetric models were consistent with observations.

III. CRITICISMS TO THE SOLAR-TYPE MODELS

Several criticisms have appeared over the years to the solar-type models:

1) In other type of late-type active stars, a correlation is found between the degree of activity, as measured by the flux of various emission lines and continua, and the rotational velocity (Pallavicini *et al.* 1981; Marilli and Catalano 1984; Hartmann *et al.* 1984; Noyes *et al.* 1984; Simon, Herbig and Boesgaard 1985; Basri, Laurent and Walter 1985; Basri 1986). This correlation is interpreted as indicative of the action of the dynamo process in amplifying and regenerating seed magnetic fields at the expense of convection and differential rotational velocity (Parker 1970). Only lately, by the acquisition of rotational velocities of a large number of TTS by various groups (Vogel and Kuhi 1981; Bouvier *et al.* 1986; Hartmann *et al.* 1986), it has become possible to check if this correlation holds for TTS. Bouvier (1986) finds that only for the X-ray flux a correlation with rotational velocity exists. Fluxes in emission lines, which correlate among themselves, do not vary as expected from a model in which the excess flux is due to an increased dynamo action.

2) From the chromospheric model interpretation, the largest veiling of the absorption lines would be accompanied by the largest Balmer jump in emission, both arising from emission from an optically thin gas. However, the tendency in the high resolution spectra for classical TTS shown in Basri and Bertout (1989) goes in the opposite sense. Stars with the largest degree of veiling, as RW Aur and DR Tau, show a Balmer jump smaller than that in stars where the photosphere is conspicuous, as DE Tau.

3) In some cases, the energy loss from the atmospheres is higher than 10% of the radiative luminosity σT_{eff}^4. An estimate of the flux in MHD waves produced in the convection zone of the stars, reveals that generally this flux is less than the energy lost by the star (Calvet and Albarrán 1984). Thus, the energy requirements on the star to support the degree of emission observed, at least in the extreme TTS, seem to be excessive.

4) Blueshifted line profiles of forbidden lines cannot be reproduced by spherically symmetric winds (Jankovics, Appenzeller and Krautter 1983; Appenzeller, Jankovics and Ostreicher 1984; Edwards *et al.* 1987).

IV. DISKS AROUND T TAURI STARS

Disk-like configurations had been claimed over the years as responsible of the infrared excess in TTS. Lynden-Bell and Pringle (1974) had suggested that accretion disks around TTS could be responsible for the infrared excess and the associated boundary layer for the ultraviolet excess, an idea expressed again by Bertout (1987). Rucinsky (1986), analyzing data from IRAS, found that the slope of the flux for TTS in the infrared was close to that expected from accretion disks.

Disks around TTS are expected as a result of the collapse of a slowly rotating cloud (Terebey, Shu and Cassen 1984; Shu, Adams and Lizano 1987). Predicted radii for the disk, assumed to correspond to the centrifugal radius, are of the order of 50 AU. Most of the mass of the configuration in this case resides in the central object. Direct observation of disks exists from the infrared imaging of HL Tau (Grasdalen *et al.* 1984; Beckwith *et al.* 1984, 1986; Sargent and Beckwith 1987). In this case, the estimated mass of the disk is of 0.01 to 0.1 $M_\odot$ and the estimated radius of 100 AU.

Disks can explain the observed profiles of forbidden lines. If they are optically thick, then the receding part of the outflow would be obscured, and the resultant line profile would be blue-shifted (Jankovics, Appenzeller and

Krautter 1983; Appenzeller, Jankovics and Ostreicher 1984; Edwards *et al.* 1987). From the size of the emitting region, Edwards *et al.* (1987) estimate a radius for the optically thick disk of 50 to 200 AU.

The presence of disks around TTS is well accepted in all these grounds. However, the exact nature of these disks and the relationship to other components of the T Tauri system is not well determined yet. Disks must be responsible for infrared excesses characterized by $\lambda F_\lambda \propto \lambda^{-z}$, where z goes from 4/3 to 0, and $\langle z \rangle \approx 0.7$ (Rucinsky 1985; Rydgren *et al.* 1984; Rydgren and Zak 1987). It can be shown that for a collection of black body radiators and a power law $T \propto r^{-q}$, then $\lambda F_\lambda \propto \lambda^{(4-2/q)}$. The spectral energy distribution of the disk emission is then intimately related to its temperature profile. Conditions that determine the temperature profile in the disk include:

1) Internal turbulent viscosity, which in turn depends on characteristics as the onset of convection. Viscosity also determines the rate of accretion of matter.

2) Irradiation from the central object (and boundary layer).

3) Rate of accretion of infalling matter on the disk.

4) Growth and propagation of instabilities within the disk.

In the studies that pertain to TTS, condition (3) has been ignored, probably under the assumption that the low angular momemtum material has already fallen when the star becomes visible, and accretion, if any, is taking place in the outermost regions of the disk. Predominance of either one of the effects (1) or (2) has lead to the division between *active* and *passive* disks. In passive disks, reprocessing of the stellar radiation by the disk is the most important effect in determining conditions within it. In the optically thick case, $T(r) \approx (F_{rep}(r)/\sigma)^{1/4}$, where F_{rep} is the stellar flux intercepted by the disk. Flat thin disks are expected to have temperature profiles similar to the $r^{-3/4}$ law found in accretion disks (Adams and Shu 1986; Adams, Lada and Shu 1987), so in this case $\lambda F_\lambda \propto \lambda^{-4/3}$. Since the actual height of the disk must be a factor of the scale height, which in turn is given by

$$h(r) = \left[\frac{kT}{\mu m_h G M_*} \right]^{1/2} r^{3/2} \quad ,$$

the disk thickness is expected to increase with r. Here, symbols have their usual meaning. That is, if $T \propto r^{-q}$, then $h(r) \propto r^{(3-q)/2}$. Kenyon and Hartmann (1987) take this "flaring "of the disk into account and find that the increased amount of stellar radiation intercepted results in a temperature profile that falls less steeply with r than in the case of the flat disk. For the case of an M0 star, they calculate the resultant disk temperature, assuming that the disk is optically thick and isothermal in the vertical direction, with a height equal to 3 scale heights. They find that for $r \leq 10\ R_*$, $T \propto r^{-4/3}$, but for $30 < r/R_*$, $T \propto r^{-1/2}$. The disk spectral energy distribution is then higher than that expected for a flat disk, closer to the mean value $q \approx -0.7$. If stars have passive disks, then their estimated position in the HR diagram is appropriate.

In active disks, mass accretion is the most important factor determining the temperature distribution. In this case, the star has available an additional energy source drawn from the interstellar medium.

The active disk hypothesis has its best application in the case of the FU Ori stars, in which disks instabilities are supposed to have increased the mass accretion rate to $\approx 1 \times 10^{-4}\ M_\odot\ yr^{-1}$ (Hartmann and Kenyon 1985, 1987; Kenyon, Hartmann and Hewett 1988). In this case, the flux from the FU Ori "star ", would actually be from the accretion disk. The hypothesis is supported by the fact that the rotational velocity decreases as the wavelength of the feature from which it is determined increases. Since in the disk model the redder the feature, the outer and cooler the annulus in the disk where the feature is formed, the difference in rotational velocity would be indicative of the Keplerian velocity field of the disk. Still, the absence of boundary layer emission remains to be a puzzle (Kenyon, Hartmann, Imhoff, and Cassettella 1989).

Accretion disks are connected to the star through the boundary layer, a region of small size in which matter is decelerated from roughly the Keplerian velocity at the stellar radius to the rotational velocity of the star. Since rotational velocities of TTS are less than 25 km s^{-1} (Bouvier *et al.* 1986; Hartmann *et al.* 1986) an energy approximately equal to half of the accretion energy $GM\dot{M}/R_*$ must be dissipated in the boundary layer. If the boundary layer is assumed to be optically thick, its temperature can be estimated by equating $4\pi R_*^2 \delta \sigma T_{bl}^4$, where δ is the assumed thickness of the layer, to 1/2 of the dissipated energy. If the boundary layer is thin, then a temperature can be estimated by fitting the flux of an optically thin, isothermal layer of gas, $B_\nu(T)(1-e^{-\tau_\nu})$, to the spectral energy distribution attributed to the boundary layer. In either case, for thickness of the order of 0.01 to 0.001 R_*, $T_{bl} \approx 7000 - 10\,000$ K, for conditions appropriate to TTS. The emission from the boundary layer is then expected to be present in the ultraviolet and blue region of the spectrum. Kenyon and Hartmann (1987), Bertout, Basri and Bouvier (1987, BBB) and Basri and Bertout (1989, BB) propose that the blue and ultraviolet excess continuum flux is due to emission from the boundary layer. From fitting excess, BBB and BB infer mass accretion rates of the order of 1×10^{-8} to $1 \times 10^{-7}\ M_\odot\ yr^{-1}$. In their treatment, they include reprocessing but in a similar manner as Adams and Shu (1986), that is, assuming that the disk is flat. The slope of the infrared in their case is –4/3, which does not agree with the slope of the fluxes for most of the stars for which the fitting is done. Including the effect of flaring of the disk would decrease the slope, but, as Kenyon and Hartmann (1987) show, the mass accretion rates $\dot{M} \geq 1 \times 10^{-7}$ $M_\odot$ yr^{-1}, the effects of reprocessing are washed out by accretion, and the slope in the infrared would be similar to that of an accretion disk.

In any event, emission from the boundary layer can explain observations of the blue and ultraviolet excess. In particular, emission from a boundary layer with moderate optical depth can explain the observations of stars with large veiling and comparatively small Balmer jump shown in Basri and Bertout (1989), which the chromospheric model cannot. In the case of the boundary layer, the largest the optical depth, the largest its flux and the resultant veiling of the absorption lines, but the smaller the Balmer jump.

BB propose that since the Balmer lines show no occultation effect as do the forbidden lines, then they do not originate in the expanding envelope, but in the boundary layer. However, in a model for the wind as that presented by HEA and Hartmann *et al.* (1989), the bulk of the Balmer lines form in the innermost regions of the envelope ($r < 3$ R_*) where turbulent velocities are high. Particularly, the wings of the lines are formed in a region where turbulent, isotropic velocities are more important than the expansion velocity. Little effect on the line profile is then expected from the presence of the disk (Calvet and Hartmann 1989). Also, although an optically thin hot emitting region as the boundary layer would indeed contribute to the flux in the Balmer lines, the same argument about Hα that applied for the chromosphere would be valid here. Hα requires of a region of large geometrical extent to have fluxes similar to observations. This region would also contribute to the flux in other lines. Therefore, the boundary layer cannot be the only contributor to the flux in the Balmer lines. On the other hand, the Ca II resonance lines in the spherically symmetric models of Hartmann *et al.* (1989) are formed in the densest part of the envelope, the chromosphere, at $r < 1.1$ R_*, because CA II is ionized in most of the envelope and $\tau \approx 1$ is reached only in the chromosphere; this result is in agreement with the large degree of variability found for this line (Calvet *et al.* 1985). The flux in this line could have a large contribution from an optically thin boundary layer, as profiles showing two components seem to imply (Basri 1987).

However, it is not clear that all the ultraviolet flux would come from the boundary layer. BBB propose that the underlying star is similar to a weak-line TTS, since all weak-line TTS seem to have similar strengths of emission lines and *UV* excess. This argument could be criticized in that since weak-line TTS are not expected to have disks around them, any effect of accreting matter arriving on the photosphere would not be present. The photospheres and chromospheres of stars accreting matter could and probably should be perturbed relative to an isolated case. In this respect, the lack of emission from highly ionized metals in stars with the highest degree of emission (Imhoff and Giampapa 1982; Brown and Jordan 1982), that is, in stars for which accretion is expected to be active on energetic grounds, may be pointing out to a different atmospheric structure in these stars.

In addition, if there is an extended region producing Hα, then the optically thin gas that forms it will also produce produce a Balmer jump in emission (Hartmann *et al.* 1989). Therefore, if the emission in the *UV* is taken as coming solely from the boundary layer, then mass accretion rates may be overestimated.

As mentioned before, standard passive or active disks cannot reproduce fluxes for the flat sources. Adams and Shu (1986) and Adams, Lada and Shu (1987) consider reprocessing from the distribution of dust outside the centrifugal radius and can reproduce fluxes for the flat sources with varying parameters, in some cases, for this external distribution. Adams, Shu and Lada (1988) assume a temperature law in the disk that goes as $r^{-1/2}$, which can reproduce the flux for the flat sources. For viscous transport of angular momentum, $\Omega \propto r^{-3/2}$ implies $T \propto r^{-3/4}$, and $\Omega \propto r^{-1}$ implies $T \propto r^{-1/2}$. The original suggestion (Adams, Lada and Shu 1987) was that a self-gravitating disk with $\Omega \propto r^{-1}$, could be responsible for the required T law. However, Adams, Lada and Shu (1988) find that the maximum mass for a stable disk is comparable to the mass of the star, so a particle in the disk moves in a nearly central potential and the rotational velocity is nearly Keplerian, if the disk is stable. So, they propose that non-viscous processes are in action, such as instabilities in the disk.

Strom *et al.* (1989) find that for 80–90% of the young stellar low mass objects in their sample, the excess luminosity of the system above that due to the star alone is less than $\approx$ 0.5 - 0.8, which is the amount expected from reprocessing of stellar light by the disk (Adams, Lada and Shu 1987; Hartmann and Kenyon 1987). For the rest of the stars, the excess luminosity cannot be due to reprocessing, so that accretion energy would be the natural alternative energy source. Roughly, 50% of the stars with excess energy are "continuum "stars.

Nonetheless, Strom *et al.* (1989) find that in only 45% of the stars with large excess luminosity there is an ultraviolet excess comparable or greater than the infrared excess. Figure 1 shows a histogram for the stars with $\Delta L > 0$ in the Strom *et al.* sample showing the distribution of the excess luminosity stars according to the slope in the infrared, as measured by the index $\log(f_{25}/f_{12})$. The dashed stars are those for which $L_{UV}/L_{IR} \geq 1$, where L_{UV} is the *excess* luminosity at optical and ultraviolet wavelengths. If accretion was active, then one would expect that a boundary layer were emitting in the ultraviolet, with a luminosity of the same order as the disk. But this does not seem to be the case for roughly half of the excess energy stars. Is this indicating that boundary layers are not a necessary signature of accretion disks, as the case of the FU Ori objects seem to indicate, or rather that, there is an alternative energy source to accretion for heating the disk, as instabilities, present in roughly 50% of the cases?

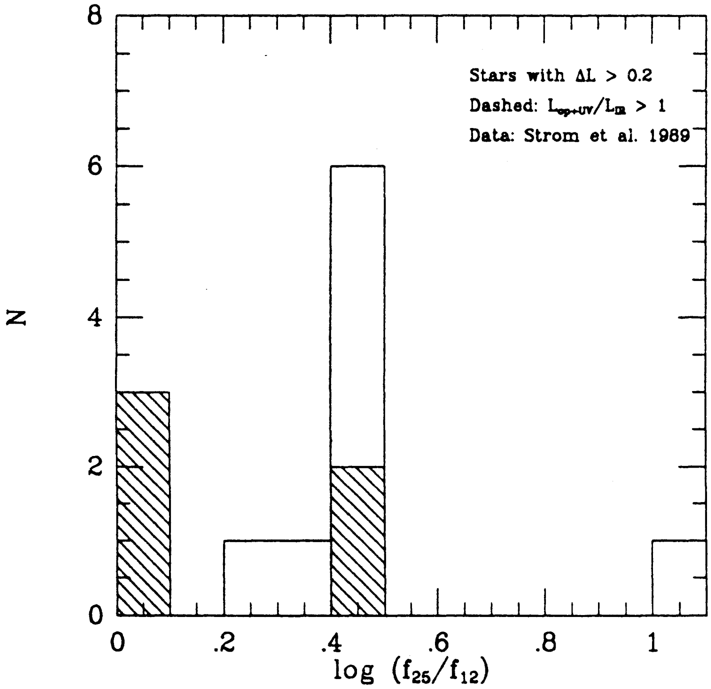

Fig. 1. Distribution of excess stars according to infrared slope in the Strom *et al.* (1989) sample. See text for details.

V. EXTENDED REGION

Recent studies of the extended expanding region around T Tauri stars have aimed to the determination of the range of physical parameters that better describe this region. In regard to the temperature profile of the region, Hartmann *et al.* (1989) find that, the temperature in the innermost region of the envelope ($r < 3\ R_*$), must get to values of the order or higher than 8 000 K in order to produce fluxes in Hα consistent with observations. A temperature lower than this limit would produce Hα in "absorption". The indicators typically used in studies of the physical properties of the wind are formed in the inner regions ($r \leq 10\ R_*$), including the P Cygni absorption component. Thus, they give little indication of the characteristics of the outer envelope. The only indicator of the wind outermost regions seem to be the forbidden lines. If indeed they are formed in the wind, then D'Alessio *et al.* (1989) find that the temperature of the envelope must be above 5 000 K at least to 20 000 R_* for those stars which show measurable flux in [O I] 6 300.

Mass-loss rates less than $1 \times 10^{-8}\ M_\odot\ yr^{-1}$ better describe observations of most TTS (Natta *et al.* 1988; Hartmann *et al.* 1989). However, stars that show Na I D blueshifted absorption or broad emission must have mass loss rates of the order of $1 \times 10^{-7}\ M_\odot\ yr^{-1}$ (Hartmann *et al.* 1989; Natta *et al.* 1989). On the other hand, stars that show a large Balmer decrement or stars for which only Hα is in emission, must have $M \leq 3 \times 10^{-9}\ M_\odot\ yr^{-1}$. The majority of (weak) TTS falls into this last category.

An additional point that has been addressed in recent studies is that of the geometry of the extended region. From the presence of [O I] emission centered at $\Delta\lambda = 0$, Edwards *et al.* (1987) infer that the velocity law is latitude dependent, with lower velocities away from the disk symmetry axis. If $\dot{M}$ is constant, then the substantial amount of material at very small velocities would be responsible for the emission at zero displacement. However, D'Alessio *et al.* (1989) find that even in the case of a spherically symmetric wind, there is emission at zero displacement, arising from the innermost, turbulent, dense layers of the envelope. The central [O I] emission is basically chromospheric emission, while the wind may be approximately spherically symmetric at large distances from the star.

On the other hand, near the star, there are indications that the situation may be different. Spherically symmetric winds produce profiles for Hα which are not similar to the P Cygni Type III profile observed in many TTS (Hartmann *et al.* 1989). Preliminary calculations assuming a cone-like geometry for the wind with the tip of the cone at the equator of the star, and a temperature, density, and expansion and turbulent velocity field as in the MHD models of HEA and Hartmann *et al.* (1989), seem to indicate that Type III profiles can be obtained in this case (Calvet and Hartmann 1989). The reason for this is basically that, without the obscuring matter in top of them in the case of a cone, inner, brighter regions, emitting at blue wavelengths are exposed, which results in the blue emission peak characteristic of a P Cygni Type III profile. The picture that appears then is that the densest portion of the wind is confined to a small region which then opens up as the distance from the star increases.

REFERENCES

Appenzeller, I., Jankovics, I., and Ostreicher, R. 1984, *Astr. and Ap.*, **141**, 108.

Adams, F. and Shu, F. H. 1986, *Ap. J.*, **308**, 836.

Adams, F., Lada, C. J., and Shu, F. H. 1987, *Ap. J.*, **312**, 788.

Adams, F., Shu, F. H., and Lada, C. J. 1988, *Ap. J.*, **326**, 865.

Bastien, P. 1981, *Astr. and Ap. Suppl.*, **48**, 159.

Bastien, P. and Landstreet, J. D. 1979, *Ap. J. (Letters)*, **229**, L137.

Basri, G. 1987, in *Proc. Fifth Cambridge Workshop on Cool Stars*, eds. J. Linsky and R. Stencel (New York: Springer-Verlag).

Basri, G. and Bertout, C. 1989, *Ap. J.*, in press.

Beckwith, S., Zuckerman, B., Skrutskie, M. F., and Dyck, H. M. 1984, *Ap. J.*, **287**, 793.

Beckwith, S., Sargent, A. I., Scoville, N. Z., Mason, C. R., Zuckerman, B., and Phillip, T. G. 1986, *Ap. J.*, **309**, 755.

Bertout, C. 1987, in *IAU Symposium No. 122*, (Dordrecht: D. Reidel), in press.

Bertout, C., Basri, G., and Bouvier, J. 1987, *Ap. J.*, **330**, 350.

Bouvier, J. 1986, in *Protostars and Molecular Clouds*, eds. T. Montmerle and C. Bertout, Doc. CEN Saclay Y87-257.

Bouvier, J. and Bertout, C. 1989, *Astr. and Ap.*, submitted.

Bouvier, J., Bertout, C., and Bouchet, P. 1986, *Astr. and Ap.*, **158**, 149.

Brown, A. and Jordan, C. 1982, in *IAU Colloquium No. 71*, p. 75.

Calvet, N. 1983, *Rev. Mexicana Astron. Astrof.*, **7**, 169.

Calvet, N. and Albarrán, J. 1984, *Rev. Mexicana Astron. Astrof.*, **9**, 35.

Calvet, N., Basri, G., and Kuhi, L. V. 1983, *Ap. J.*, **277**, 725.

Calvet, N. and Hartmann, L. 1989, in preparation.

Calvet, N., Basri, G., Imhoff, C. L., and Giampapa, M. S. 1985, *Ap. J.*, **293**, 575.

Cram, L. E. 1979, *Ap. J.*, **234**, 949.

Cohen, M. and Schmidt, G. D. 1981, *A. J.*, **86**, 1228.

D'Alessio, P., Calvet, N., and Cantó, J. 1989, in preparation.

Edwards, S. Cabrit, S., Strom, S. E., Heyer, I., Strom, K. M., and Anderson, E. 1987, *Ap. J.*, **321**, 473.

Feigelson, E. D. and DeCampli, W. M. 1981, *Ap. J. (Letters)*, **243**, L89.

Grasdalen, G. L., Strom, S. E., Strom, K. M., Capps, R. W., Thompson, D., and Castelaz, M. 1984, *Ap. J. (Letters)*, **283**, L57.

Giampapa, M. S., Calvet, N., Imhoff, C. L., and Kuhi, L. V. 1981, *Ap. J.*, **251**, 113.

Hartmann, L., Edwards, S., and Avrett, E. H. 1982, *Ap. J.*, **261**, 279.

Hartmann, L. and Kenyon, S. J. 1985, *Ap. J.*, **299**, 462.

Hartmann, L. 1987, *Ap. J.*, **312**, 243.

Hartmann, L., Calvet, N., Avrett, E. H., and Loeser, T. 1989, *Ap. J.*, submitted.

Hartmann, L., Hewett, R., Stahler, S., and Mathiew, R. 1986, *Ap. J.*, **309**, 275.

Herbst, W., Holtzmann, J. A., and Phelps, B. E. 1982, *A. J.*, **87**, 1710.

Imhoff, C. L. and Giampapa, M. S. 1982, in *Smithsonian Astrophysical Observatory, Special Report No. 392*, p. 175.

Jankovics, I., Appenzeller, I., and Krautter, J. 1983, *Pub. A. S. P.*, **95**, 883.

Kenyon, S. J. and Hartmann, L. 1987, *Ap. J.*, **323**, 714.

Kenyon, S. J., Hartmann, L., Imhoff, C. L., and Cassatella, A. 1989, *Ap. J.*, submitted.

Kenyon, S. J., Hartmann, L., and Hewett, R. 1988, *Ap. J.*, **325**, 231.

Montmerle, T., Koch-Miramond, L., Falgarone, E., and Grindlay, J. 1983, *Ap. J.*, **269**, 182.

Natta, A., Giovanardi, C., and Palla, F. 1988, *Ap. J.*, **332**, 921.

Natta, A. and Giovanardi, C. 1989, in preparation.

Parker, E. N. 1970, *Ap. J.*, **160**, 383.

Rucinsky, S. M. 1986, *A. J.*, **90**, 2321.

Rydgren, A. E., Schmelz, J. T., Zak, D. S., and Vrba, F. J. 1984, *Pub. US Naval Obs.*, **25**, PI.

Shu, F. H., Adams, F. C., and Lizano, S. 1987, *Ann. Rev. Astr. Ap.*, **25**, 23.

Strom, K. M., Strom, S. E., Kenyon, S. J., and Hartmann, L. 1988, preprint.

Terebey, S., Shu, F. H., and Cassen, P. 1984, *Ap. J.*, **286**, 529.

Walker, M. F. 1987, *Pub. A. S. P.*, **99**, 392.

Vogel, S. N. and Kuhi, L. V. 1981, *Ap. J.*, **245**, 960.

Nuria Calvet: Centro de Investigación de Astronomía (CIDA), Apartado 264, Mérida 6101-A, Venezuela.