CIRCUMSTELLAR MATTER IN HERBIG AeBe STARS

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ABSTRACT

The observational evidence for large envelopes and disks in the immediate environment of Herbig AeBe stars are reviewed. In particular, I firstly summarize the results of far infrared observations, then discuss the capability of very small grains (VSG) and policyclic aromatic hydrocarbons (PAHs) to account for the observed mid-infrared fluxes. Finally, I briefly discuss the possibility that the disk properties are deeply affected by the surrounding matter, and suggest that, at least for large number of these stars, accretion may play a less relevant role than previously thought.

1. INTRODUCTION

Herbig Ae/Be stars are early-type emission-line stars associated to optical nebulosities. As first shown by Herbig [1], they are pre-main–sequence stars of intermediate mass and luminosity.

The presence of large amount of circumstellar matter around Herbig Ae/Be stars is shown by a variety of observations. According to the selection criterium first defined by Herbig [1], they are associated to extended optical nebulosities. The average extinction, derived from the reddening of the stellar spectrum, is of the order of 2-3 mag, significantly larger than the values found, for example, in T Tauri stars in Taurus. The spectral energy distributions are characterized by the presence of large infrared excesses. Polarization maps [2][3][4] reveal the existence of extended clouds of dust. Molecular observations show that dense gas is associated to several Herbig Ae/Be stars [5][6][7][8]. On smaller scales, speckle interferometry results indicate that matter exists very near the central stars, with complex geometrical configurations [3][9]. Finally, there is ample spectroscopic evidence of high velocity winds [10], CO outflows [11] and HH objects [12] associated to Herbig Ae/Be stars.

In spite of the large and growing body of observations, up to now most of the information on the circumstellar matter around these stars has been obtained through studies of their spectral energy distributions. Observations in the far infrared [13]and detection of the silicate feature [14]indicate that the infrared excess of Herbig Ae/Be stars is likely due to dust. However, attempts to model it with spherically symmetric dust shells have failed (see, for example, [15][16][17]). Hillenbrand et al.[18] have divided Herbig Ae/Be stars in three groups. Group I includes 29 stars (out of 51) with large infrared excess and spectral energy distribution decreasing with increasing λ in the range 2.2-20 μm. Group II includes 13 objects with flat or raising infrared spectra. Group III is formed by 9 stars with small infrared excess, probably arising from free-free emission. Hillenbrand et al. propose that in Group I stars the infrared excess is due to a geometrically flat, optically thick circumstellar disk, similar to those advocated for T Tauri stars [19][20]. Natta et al.[16][17] have shown that the spectral energy distribution and the far infrared brightness profiles of some Group II objects can be fit by models where the star and its circumstellar disk are embedded in a large envelope of dust of moderate optical depth.

However, the accretion disk interpretation is not entirely satisfactory. The observed near infrared colours, in fact, are compatible with the disk hypothesis only if the disks have inner holes of several stellar radii [17][18][21]; these, in turn, are not consistent with the high accretion rates derived by various authors, as discussed by Hartmann et al.[22].

In this paper, I will present recent results on some aspects of the star+disk+envelope system. I will first summarize the results obtained from 50 and 100 μm brightness profiles, then discuss the possible role of very small grains and polyciclyc aromatic hydrocarbons. Finally, I will show that disk properties can be changed by the presence of surrounding matter, and how this may affect our estimates of the disk properties themselves.

2. THE FAR INFRARED PROPERTIES OF Herbig Ae/Be STARS

Observations at 50 and 100 μm from the Kuiper Airborne Observatory using a multi-channel scanning photometer have been obtained for a total of 14 Herbig Ae/Be stars [16][17][23]. The system compares a stable, well known point-source profile with a scan across the source; in good signal-to-noise observations, it can resolve objects with FWHM sizes of the order of 10 arcsec. Table 1 summarizes the results available so far. It gives in Column 1 the name of the source, in Column 2 the classification according to Hillenbrand et al.[18], in Column 3 the distance, in Column 4 the bolometric luminosity, in Column 5 the position angle of the scan on the plane of the sky, measured counter-clockwise from the declination axis, in Column 6 the

FWHM at 100 μm in pc, S_{100}, computed assuming that both the source and the point source have gaussian profiles. Typical uncertainties on S_{100} are of 10%.

TABLE 1

FAR–IR SIZES

Source	Group	D (pc)	L ($L_\odot$)	θ (deg)	S_{100} (pc)	Ref.
LkHα 198	II	600	250	60	0.1	17
				165	0.1	17
				258	0.1	17
AB Aur	I	160	80	130	<0.010	23
				220	<0.013	23
MWC 137	I	1300	750	170	0.36	23
				255	0.34	23
LkHα215	I	800	700	173	0 20	23
				262	0.37	23
R Mon	II	800	700	266	0.05	17
				176	<0.06	17
Z CMa	II	1150	8000	320	<0.07	17
CD -42° 11721	II	2000	28000	87	0.40	17
				177	0 30	17
MWC 297	I	450	2000	35	0.12	23
				115	0.15	23
R CrA	II	126	90	70	0.027	17
				160	0.026	17
V1686 Cyg	I	1000	1800	340	0.15	23
PV Cep	II	500	100	115	<0.04	17
				255	<0.05	17
V645 Cyg	II	3500	40000	350	0.37	17
LkHα234	I	1000	550	262	0.10	23
				348	0.18	23
MWC 1080	I	2500	30000	280	0.34	23
				15	0.16	23

Of the objects listed in Table 1, only three (AB Aur, Z CMa and PV Cep) are not resolved at 100 μm, and many are also resolved at 50 μm. S_{100} varies between 0.03 and 0.4 pc, and it is independent of the classification as Group I or Group II sources.

The width of the 100 μm brightness distribution can only be accounted for by a large dusty envelope heated by a central source of radiation. The five Group II resolved sources have been studied in detail by Natta et al.[16)17)], who compared the 50 and 100 μm sizes and fluxes to the predictions of radiation transfer models. The results indicate that the envelopes have moderate optical depth (about 5-10 mag in the visual), large inner holes (in the range 0.01 to 0.1 pc), and density profiles which vary from flat ($n \propto r^{-0.5}$) to steep ($n \propto r^{-2}$).

The scan results rule out the possibility that most of the 100 μm flux is emitted by a circumstellar disk. In this case, and regardless of the physical size of the disk, the 100 μm size would be very small (typically, less than 2 arcsec), and would appear unresolved with the KAO resolution. Note, however, that the data do not rule out the existence of disks, in addition to the envelopes, as long as the disk emission does not dominate over the envelope in the far infrared. Group I objects have been interpreted by Hillenbrand et al.[18)] as pure star+disk systems. However, all the Group I stars listed in Table 1 show a far infrared excess, with respect to the disk predictions, which can naturally be accounted for by the emission of dust in an envelope, more optically thin than those found in Group II objects, but otherwise similar.

Notably, the scan data also rule out the possibility that the fir flux is dominated by the emission of a very cold companion.

Model calculations show that star+envelope models account well for the far infrared, submillimetric and millimetric observations, but they fail to explain the large values of the near and mid-infrared fluxes observed in Herbig Ae/Be stars.

3. THE ROLE OF VSG AND PAH

Envelope models discussed so far include only large grains, such as in the ISM, which are in thermal equilibrium with the radiation field. The possibility that the near and mid-infrared missing flux is emitted by very small grains (VSGs) and polyciclic aromatic hydrocarbon particles (PAHs), mixed to larger grains in the envelope, has been mentioned by Natta et al.[16)17)] and Hartmann et al.[22)]. VSGs and PAHs do not achieve thermal equilibrium with the local radiation field, but are transiently heated by ultraviolet photons, so that they attain temperatures much higher than the larger grains in thermal equilibrium. In fact, they emit most of the absorbed radiation at near and mid-infrared wavelengths. VSGs and PAHs account for the extended near infrared emission in various reflection nebulae [24)]. Their presence in the environment of Herbig Ae/Be stars is suggested by the discrepancy of the 10 μm fluxes between large beam IRAS and small beam ground based observations in several young stars [25)26)], and by the detection of PAH features in some Herbig Ae/Be stars [27)].

Natta, Prusti and Krügel [28)] have examined the role of the VSGs and PAHs in the circumstellar environment of Herbig Ae/Be stars, by computing the spectral energy distribution and the brightness distribution of models where VSGs and PAHs are added to large grains. The envelopes have either A_V=5 mag, as appropriate to Group II stars, or A_V=0.1, appropriate to Group I stars. In all cases, an envelope inner radius of 0.01 pc has been adopted, so that the large grains contribution in the near and the mid-infrared is negligible. Some examples of the spectral energy distributions are shown in Fig.1. The spectra are all quite flat in the range 2-20 μm; the exact shape of the spectrum depends mostly on the amount and size of the VSGs and only little on the envelope parameters.

Two observational tests have been discussed by Natta et al.[28)]. First of all, they compute the ratio $L_{\rm mir}/L_{\rm bol}$, where $L_{\rm mir}$ is defined between 1.25 and 20 μm, as a function of the various model parameters, and compare it to the average observed values. They find that VSGs and

PAHs can provide a significant fraction of the observed luminosity in this range, but not all, unless there is an extremely large amount of very small VSGs. Secondly, they compute the near-infrared colours indexes J-H and H-K and show that the model predicted colours do not fit the observations significantly better than those of models where only large grains, in equilibrium with the local radiation field, are considered.

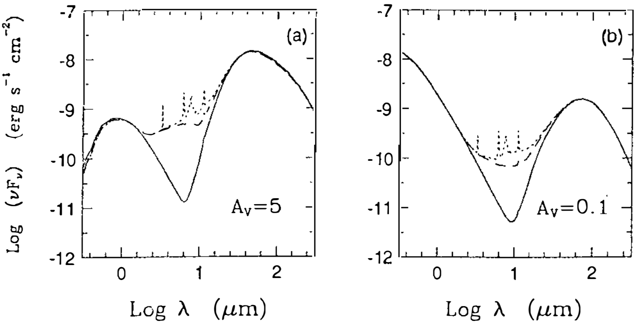

Fig. 1.— Spectral energy distribution for models where VSGs and PAHs are added to large grains. parameters are varied. Panel a: Models with A_V=5 mag. The solid curve is a model with only large grains, the dotted curve one where VSGs are included (relative abundance with respect to the large grains of 10%, minimum and maximum size of VSGs of 5 and 20 Å, respectively. The dotted curve is a model where also PAHs are added. The values of the other parameters are: R_i=0.01 pc, R_{out}=0.5 pc, $n \propto r^{-0.5}$, T_{rad}=15000 K and luminosity of 250 $L_\odot$. Panel b: same for A_V=0.1 mag.

A crucial test of the significance of VSGs and PASHs in the Herbig Ae/Be stars environment may come from studies of the spatial extent of the emission in the range 3 to 10 μm.

4. THE EFFECTS OF THE SURROUNDING MATTER ON DISKS

Good fits to the observed spectral energy distributions of both Group I [18] and Group II objects [16][17] are easily obtained when the emission of the circumstellar disk is taken into account [17].

When the disk parameters are constrained to fit the observations, it is found that the disks must dissipate accretion energy, not just reprocess stellar light [17][18]. This result relies on two different kinds of evidence. Hillenbrand et al.[18] compare the bolometric luminosity of the source, to the stellar luminosity. This last is, in turn, obtained from the observed spectral type and visual magnitude of the star, corrected for extinction, and suffers from severe uncertainties [28]. Natta et al.[17] derive the disk luminosity L_D from the observed value of L_{mir}, and estimate the accretion luminosity as $L_{ac} \sim (4 x L_D - L_{bol})/3$. This procedure, which makes use of more reliable data, neglects the effects of the surrounding matter on the disk emission itself. In fact, a small amount of dust around the disk may contribute significantly to the heating of the outer parts of the disk, by scattering and re-emitting back onto the disk part of the stellar radiation [29]. The result is that the disk spectrum is significantly flatter than the $\nu F_\nu \propto \lambda^{-4/3}$, typical of both accretion and reprocessing disks, and that the disk luminosity may exceed significantly the value $1/4 L_{bol}$ assumed in the derivation of L_{ac}. Fig. 2 shows the spectral energy distribution of a typical Herbig Ae/Be disk, embedded in a thin envelope of dust. The L_{mir}/L_{bol} of such a model is 0.38. When we consider that VSG and PAH can easily absorb and reradiate in the mid-infrared about 20% of the stellar luminosity, the predicted values of L_{mir}/L_{bol} come close to the observed average for Group II objects ($\sim$ 0.6).

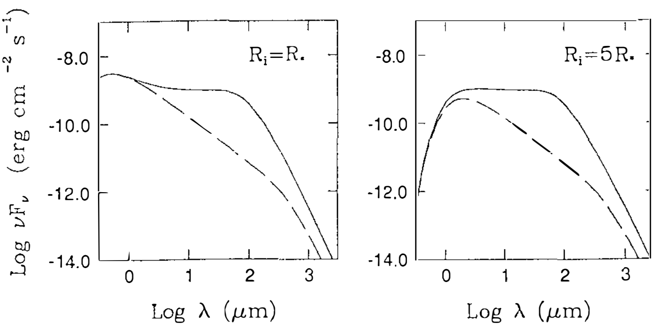

Fig. 2.— Spectral energy distribution for disk models. The dashed curve shows the spectral energy distribution of a disk heated only by direct stellar radiation, the solid curve that of a disk, with the same parameters, which is heated, in addition, by radiation scattered by the surrounding cloud of dust. The dusty envelope has optical depth τ=0.4, a density profile $n \propto r^{-1}$, inner radius of 8 $R_\star$, outer radius of 300 AU. The central star has luminosity $L_\star$=250 $L_\odot$, effective temperature of 15000 K. In Panel a the disk extends to the stellar surface, while in Panel b it has an inner hole of 5 $R_\star$.

Purely reprocessing disks, such as those just described, are not inconsistent with the presence of inner holes, as required to fit the observed near infrared colours. Table 2 compares the properties of two disk models, embedded in an envelope of optical depth 0.4, to those of "naked" disks with the same parameters. In one case the disks extend down to the stellar surface ($R_i=R_\star$), in the other $R_i=5R_\star$. As expected, the near infrared colours of the latter are much closer to the observed values than those of the former. More important, the disk luminosity, when the surrounding matter is taken into account, is much larger than that of "naked" disks, and is still as large as 18% of the stellar luminosity in models with $R_i=5\ R_\star$.

TABLE 2

DISK MODELS

$R_i/R_\star$	τ_{sc}	$L_D/L_\star$	J-H	H-K	K-L
1	0.0	0.25	0.57	0.51	0.73
5	0.0	0.04	1.10	0.90	1.08
1	0.4	0.39	0.68	0.68	1.01
5	0.4	0.18	1.21	1.03	1.39

5. CONCLUSIONS

The results summarized in the previous sections provide further evidence of the fact that there is a large amount of circumstellar matter surrounding Herbig Ae/Be stars, and that its geometrical configuration is quite complex.

We suggest that at least three components must be present, the central star, a circumstellar disk and an extended dusty envelope. Although the 50 and 100 μm scans indicate the existence of an inner cavity, where the dust optical depth is very small, some dust must exist inside this cavity, in the vicinity of the disk.

The resulting spectral energy distribution is deeply affected by the interaction between these various components. Detailed models of star+disk+envelope (including the effect of scattered and re-emitted radiation on the disk heating are taken into account and the emission of VSGs and PAHs in the envelope) need to be computed before conclusions, in particular on the frequency and rate of accretion in Herbig Ae/Be stars, can be reached.

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