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Protoplanetary disks around Herbig Ae/Be stars: Indications from ISO spectroscopy

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Abstract. An analysis of solid-state features in infrared spectra of 46 Herbig Ae/Be stars is presented. The presence of solid-state emission bands is compared to other indicators of circumstellar material, such as Hα emission, optical variability and sub-mm continuum fluxes. The correlation between these different indicators is weak, if present at all, in our sample. However, a strong dependence on spectral type of the central star seems to be present: stars with spectral type earlier than B9 show either amorphous silicate in absorption or infrared spectra dominated by PAH emission, whereas more than 70% of the stars of later spectral type show silicate emission. We conclude that the infrared spectrum of Herbig Be stars is in general dominated by emission from the circumstellar envelope, whereas the lower-mass Herbig Ae stars show a spectrum that is dominated by a disk that is passively heated by the central star.

1. Introduction

Herbig Ae/Be stars are young intermediate-mass (2–10 $M_\odot$) stars which are still surrounded by gas and dust from their natal cloud. Many possess circumstellar disks which are believed to be the site of on-going planet formation. The dust in these circumstellar disks, heated by the central star and possibly by viscous heating of material that is being accreted, shows up as excess emission above photospheric levels at infrared to sub-mm wavelengths. The circumstellar gas can be traced in spectral lines, of which Hα is most prominent. Large-amplitude ($> 1^{\rm m}$) variations in optical brightness are seen in some Herbig Ae stars, and are commonly ascribed to circumstellar dust clouds moving in and out of our line of sight towards the central star. Although the optical to sub-mm energy distribution of Herbig Ae/Be stars has been well explored by previous authors (e.g. Hillenbrand et al. 1992), the chemical and mineralogical composition of the dust remained poorly studied until the 1995 launch of the *Infrared Space Observatory* (ISO; Kessler et al. 1996). This first possibility to study the complete infrared spectrum of these objects in detail revealed a large variety in dust properties, from small aromatic hydrocarbons to silicate dust. Moreover, some sources were shown to contain partially crystalline dust grains, similar to those found in comets in our own solar system (Malfait et al. 1998, 1999; van den Ancker et al. 1999; Meeus et al., these proceedings). Here, the first inventory of solid-state features in all Herbig stars observed by the *Infrared Space Obser-*

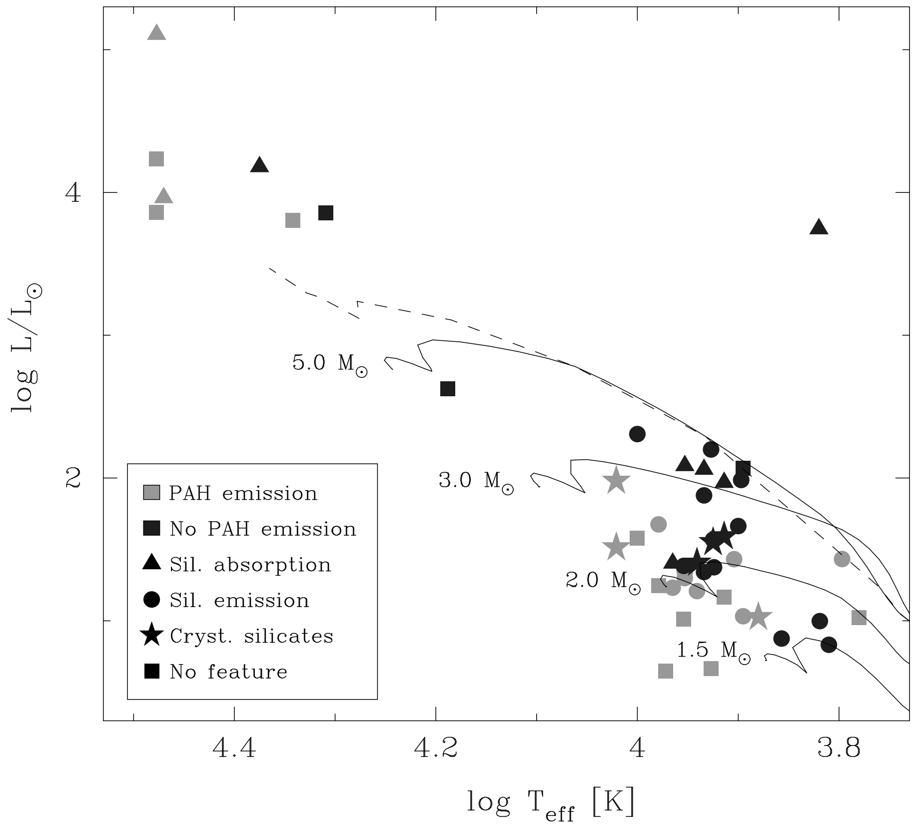

Figure 1. HRD of the stars in our sample. Plot symbols indicate the solid state components present in the ISO spectra (see caption). Also shown in the figure are the pre-main sequence evolutionary tracks (solid lines) and the birthline (dashed line) by Bernasconi (1996).

vatory is presented and we investigate their correlation with more traditional tracers of circumstellar material.

2. Data Analysis

An inspection of the ISO data archive revealed the presence of spectroscopic data on 46 Herbig Ae/Be stars, obtained with the short-wavelength spectrometer (SWS) and the spectroscopic mode of the photometer (ISOPHOT). Spectra were retrieved and reduced, after which they were inspected for the following features: (a) the emission bands at 3.3, 3.4, 6.2, 7.6, 7.8, 8.6, 11.3 and 12.7 μm, often attributed to polycyclic aromatic hydrocarbons (PAHs), (b) the broad band around 10 μm due to amorphous silicates, and (c) sharper emission bands at 10.2, 11.4, 16.5, 19.8, 23.8, 27.9 and 33.7 μm due to crystalline silicates. Using these data, we investigated the correlation of infrared spectral features with parameters of the systems from literature ($T_\star$, $L_\star$, level of optical variability, Hα profile, and dust masses as traced by sub-mm fluxes).

3. Discussion and conclusions

The strongest correlation found is between spectral type of the central star and silicate emission: Herbig stars of spectral type earlier than B9 show silicate absorption, whereas a large majority ($\approx$70%) of the Herbig Ae stars of later type show silicate emission. Since strong optical variability due to variable circumstellar extinction is also only found in Herbig stars with spectral type of B9 or later (van den Ancker et al. 1998), both phenomena may be related. However, no correlation between the level of optical variability and silicate emission could be found, perhaps due to our limited sample size.

In most sources with absorption due to amorphous silicates, we also observe the absorption bands due to H_2O and CO_2 ice, with a relative strength comparable to that in the interstellar medium. However, two sources (Z CMa and V645 Cyg) show strong silicate absorption, but no evidence for water or CO_2 ice bands, demonstrating the chemical evolution that has taken place in the circumstellar environment of these objects.

No strong correlation between spectral type and PAH emission could be found. This is surprising, since the excitation of PAH molecules is thought to require intense ultraviolet radiation fields. This means that on average the particles responsible for the PAH emission must be closer to the central star, and hence suffer less geometric dilution of the stellar radiation field, in Herbig Ae stars than in Herbig Be stars.

Both the differences in silicate and in PAH behaviour can be explained by assuming that the infrared spectrum of Herbig Be stars is in general dominated by their circumstellar envelope rather than a disk. In contrast, the more slowly evolving Herbig Ae stars have time to disrupt their envelope and their spectrum may be dominated by thermal emission from the protoplanetary disk.

Crystalline silicates, as are also found in comets in our own solar system, are visible in 15% of the late-type Herbig stars, all of systems that are relatively isolated and appear to be relatively old (a few million years). Therefore also in young stars longevity appears to be a prerequisite for the annealing process. These systems form a close analog to the young solar system and may provide the strongest clue to date that the same processes that have led to rocky planets in our own solar system are also taking place around other stars.

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