ISO-SWS OBSERVATIONS ON PROTO-PLANETARY SYSTEM CANDIDATES

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ABSTRACT

We present a preliminary analysis of ISO-SWS spectra of a sample of Vega-type and pre-main sequence stars, which were observed from the ground in a project devoted to the study of formation and evolution of planetary systems, carried out during the 1998 International Time of the Canary Islands Observatories.Most of the Vega-type stars shows photospheric spectral energy distributions up to $\approx 10\mu m$, while an IR excess is normally observed at wavelengths larger than $\approx 20\mu m$. Pre-main sequence (PMS) stars usually shows IR excesses along the whole SWS spectral range. The $10\mu m$ silicate feature is observed in emission towards most of the PMS stars, while it is observed in only one Vega-type star in our sample, 51 Oph. The comparison of the silicate features observed towards the protoplanetary systems with the silicate band profiles of the Trapezium and comet Kohoutek suggests a better agreement with the solar system cometary silicates.

Key words: Vega-type stars, Pre-main sequence stars, ISO-SWS, silicate features

1. INTRODUCTION

The detection with IRAS of a far-IR excess around Vega (Aumann et al. 1984) and many other normal stars stated the existence of residual dust around main sequence (MS) stars. The discovery of a gas disk around β Pic (Smith and Terrile 1984), the most prominent member of the Vega-type stellar objects, was a proof for the disk-like distribution of this residual material, at least in some of these stars. Thus, Vega-type stars possibly are systems in which ongoing formation of planetary systems similar to the solar system is taking place.

As part of a larger project, the EXPORT (EXo-Planetary Observational Research Team) collaboration carried out during 1998 extensive ground-based observations of a large sample of Vega-type and pre-main sequence stars (Eiroa et al. 2000). One of the objectives was to study the characteristics of protoplanetary disks around these kinds of objects. The observations included high and intermediate resolution optical spectroscopy, optical photopolarimetry and near-IR photometry.

Dust particles are a major constituent of protoplanetary disks. This implies that the chemical and physical characterization of the circumstellar environment are revealed by means of solid state spectral features. Due to the very broad profile and accessibility from ground, the 10 μm silicate emission band is the better studied one. Moreover, the presence of silicate emission in solar system comets, supposed to be chemical samples from the proto-planetary solar nebula, turns silicate mineralogy into an important tool for the study of the formation and evolution of planetary systems. This point is stressed by the discovery of silicate emission in close agreement with cometary features around β Pic (Telesco and Knacke 1991) and other MS and PMS stars (Sitko et al. 1999). Thus, to complement the EXPORT observations we have analyzed the ISO-SWS[1] data of EXPORT targets since they contain relevant information concerning the spec-

[1] Based on observations with ISO, an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with the participation of ISAS and NASA.

Table 1. EXPORT target stars with SWS01 observations from ISO.

Object		**Type**	**TDT**
HR 10		Vega	37802001
BD+31 643		Vega	65201414
HD 53179	Z CMa	HAeBe	72201607
HD 31293	AB Aur	HAeBe/	68001206
MWC 480	HD 31648	HAeBe/	83501201
HD 34282		HAeBe/	83301240
HD 34700		Vega	66302638
HD 109085	GL 9411	Vega	24002304
λ Boo	HD 125162	Vega?	35101303
HD 141569		HAeBe/	62802937
HD 142666		HAeBe/	10402952
			44901283
HD 144432		HAeBe/	45000284
HD 150193	MWC 863	HAeBe	8200444
51 Oph	HR 6519	Vega	10703103
HD 163296		HAeBe/	32901191
MWC 297		HAeBe/	70800234
HD 179218		HAeBe/	32301321
WW Vul		HAeBe	17600305
V 1686 Cyg	LkH$_\alpha$ 224	T Tauri	85800502
SV Cep		HAeBe	28800703
HR 9043		Vega	40400904

tral energy distribution and dust properties of the disks around those stars.

2. DATA AND REDUCTION

The ISO post mission archive was surveyed for observations of the EXPORT targets. Only SWS01 observations (2.4-45μm; R$\approx$1000) have been considered. Table 1 lists the objects and the corresponding SWS01 observations.

The available spectra were recovered from the archive and an interactive reduction[2] began at SPD level, using the SWS Interactive Analysis[3] package (IA3) in a way very close to the standard interactive procedure. Each dark scan was visually inspected to reject notorious bad points, and to check the presence of bimodal or highly spreaded dark distributions. Once this step was completed, the standard interactive dark subtraction tool (`dark_inter`) was used to estimate dark levels using sigma-clipping algorithms. When dark points were available in both sides of the scan a linear interpolation was subtracted. The resulting scans were compared for consistency among detectors, inspected to detect up-down effects and corrected with the standard `updown1_inter` tool when present. In those cases with signal jumps, the affected points were deleted. Finally, the spectra were response and flux calibrated and a radial velocity correction was applied before the transformation into the AAR level.

The SWS band 4 data (29-45μm; Ge:Be detectors) from 51 Oph have no valid dark points, and the spectra was scaled to match the band 3E (27.5-29μm) flux level after response and flux calibration. In those stars only partially affected by this effect, the bad detectors were offsetted to match the valid ones. The two spectra available for HD 142666 were averaged up to 18μm. Beyond this wavelength, one dataset was rejected due to a notorious bad behaviour in bands 3D to 4.

3. RESULTS

The SWS spectral energy distributions of the stars reveal differences between the Vega-type and HAeBe stars. The different behaviour is evident when the observed SWS fluxes are compared with extrapolated photospheric fluxes, assuming a blackbody with the effective temperature of the star normalized to the observed flux in the 2.5-3.5μm interval (Fig. 1). Thus, we assume that the observed 2.5-3.5μm flux is photospheric, though we are aware that near-IR excesses are present in HAeBe stars. However, this fact does not affect qualitatively our general conclusions. All Vega-type stars (except 51 Oph and HD 34700) show a featureless continuum that agrees well with the extrapolated fluxes up to approximately 10 μm, where most of these stars become too faint and the observed fluxes are unreliable (Fig. 1). Several of these are again detectable at wavelengths longer than $\approx$ 20 μm, in agreement with their

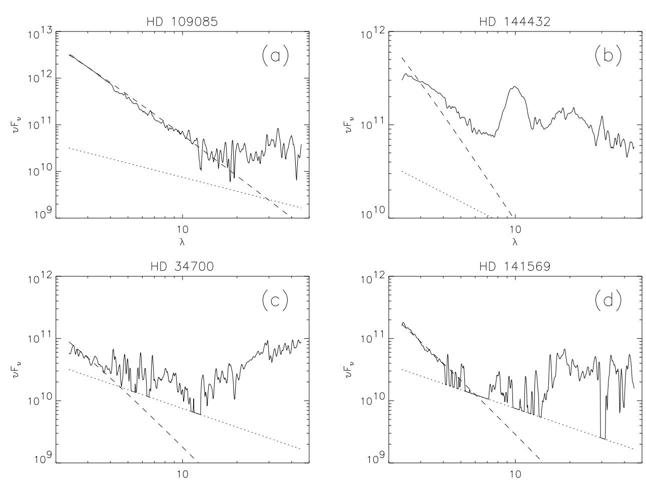

Figure 1. Some examples of the SWS spectral energy distributions of stars in our sample (see text). (a) 'typical' Vega-type star, (b) 'typical' HAeBe star young Vega, (c) HD 34700: a likely PMS star previously classified as Vega-type (d) HD 141569: a HAeBE/ZAMS star similar to Vega-type stars. The dashed line is the extrapolated photospheric blackbody as described in the text. The dotted line is an arbitrary 0.25 Jy level, chosen to avoid the noise associated with very low flux signals.

[2] Still ongoing for some objects.

[3] IA3 is a joint development of the SWS consortium. Contributing institutes are SRON, MPE, KUL and the ESA Astrophysics Division.

classification as Vega-type stars. With respect to 51 Oph and HD 34700, both objects are the only Vega stars in the EXPORT sample with a small near-IR excess, which is consistent with the SWS results. In fact, HD 34700 is most likely a pre-main sequence star as indicated by the LiI 6707 Å absorption line detected in the EXPORT spectra; in addition, it has the strongest IR excess, raising well before 10 μm (Fig. 1). On the other hand, most of the HAeBe stars show very strong infrared excesses at wavelengths shorter than 10 μm with approximately flat SWS01 SEDs (Fig. 1), as expected from a dusty disk-like envelope with a temperature distribution. HD 141569 is the only star in this group which is not clearly detected at 10 μm in the SWS spectra, though it has measurable fluxes at longer wavelengths; this star also shows a photospheric spectra in the shorter wavelength range (Fig. 1). HD 141569 shares many of the observed properties with the Vega-type objects and in fact it is among the oldest HAeBe stars (van den Ancker et al. 1998).

Concerning the silicate feature, only 51 Oph among the Vega-type stars presents the 10 μm feature in emission. On the other hand, 9 HAeBe stars show the 10 μm feature in emission, 2 (Z CMa and MWC 297) in absorption, and 1 (V 1686 Cyg) shows no silicate feature in the SWS01 observations. 2 stars, HD 141569 and HD 34282, are too faint to establish any conclusion.

Finally, we would like to point out that PAH emission features are observed in the spectra of two stars in Table 1: AB Aur, where the PAHs are of moderate strength, and HD 179218, where the PAH features are very strong.

4. The 10 μm SILICATE EMISSION FEATURE

As stated above, the 10 μm silicate emission feature is seen in 10 stars of our sample, including 51 Oph. In order to study the emission feature we have removed the underlying dust thermal emission assuming a single blackbody temperature along the feature spectral range. The underlying blackbody temperature has been estimated by selecting two spectral windows at both sides of the feature, chosen to match approximately narrow filter passbands used in ground-based studies. The selected central wavelengths and widths are λ_c=7.5 μm ($\Delta\lambda$=0.7) and λ_c=13.5 μm ($\Delta\lambda$= 1.0). The selected ranges were modified in the cases of 51 Oph, to avoid what seems a strong band red wing, and SV Cep, due to bad signal behaviour in the red window. In addition, the SWS spectra were rebinned to a resolution of 50 before subtracting the estimated blackbody thermal emission. The procedure has allowed us to estimate the emission feature profile of each object, the wavelength where the emission reaches the maximum (λ_{max}), the FWHM of the band and also the strength of the feature, defined as the quotient between the band emission flux and the underlying dust blackbody, both measured at λ_{max}. The equivalent width of the band has also been measured. There is a good correlation of this parameter with the silicate strength which suggest a similar emissivity of the silicate population in our objects. Table 2 provides the values of these parameters together with the estimated temperature of the underlying thermal emission, T_d.

Table 2. Parameters of the silicate emission feature.

Object	T_d	λ_{max}	Strength	FWHM
AB Aur	427	10.0	1.3	2.4
MWC 480	504	10.2	1.1	2.9
HD 142666	341	10.2	0.5	1.8
HD 144432	333	9.9	1.4	2.4
HD 150193	358	9.5	1.6	2.8
51 Oph	480	10.5	0.4	2.8
HD 163296	407	9.9	1.1	2.6
WW Vul	247	9.8	1.8	1.6
SV Cep	318	9.9	2.3	2.2

There is a change of λ_{max} among the different objects. The features peaking at the longer wavelengths could be related to the presence of crystalline silicates. Crystalline silicates are expected to show narrower bands than amorphous ones. Thus, we would expect to see a trend among the width of the feature and the wavelength of the maximum emission. Such a trend is not evident in our data, although a definitive conclusion cannot be achieved at present, considering the status of our analysis. In addition, the absence of reliable age estimates for most of the stars in our sample prevents us from any evolution analysis concerning the type of silicates, though objects with the stronger IR excesses tend to present larger silicate strengths.

In order to make a first statement on the nature of the observed silicates we can compare the observed profiles with other well known astronomical silicates, as those observed in the interstellar medium, the Trapezium emission or the solar system comet silicates. Figure 2 shows the observed silicate emission towards nine sources of our sample together with the comet Kohoutek emission silicate (Merrill 1974) and that observed towards θ^1 Ori D (Hanner et al. 1995). All the emission profiles have been normalized to have an equal 9.7μm flux. None of our objects shows a silicate feature profile similar to that observed in the Trapezium. Although some objects show profiles partially comparable, a strong mismatch is found at the longer wavelengths, where the silicate emissivity from the Trapezium decays more slowly than in the case of our stars.

Silicate emission observed in solar system comets spans a wide range of characteristics (see Crovisier, this volume), yet they share a certain degree of crystallinity, and emission profiles are easily distinguishable from common astronomical silicates. The comparison with the comet Kohoutek silicate profile shown in Figure 2 gives a good agreement in many cases, thus suggesting a similar composition and pointing to the presence of a crystalline com-

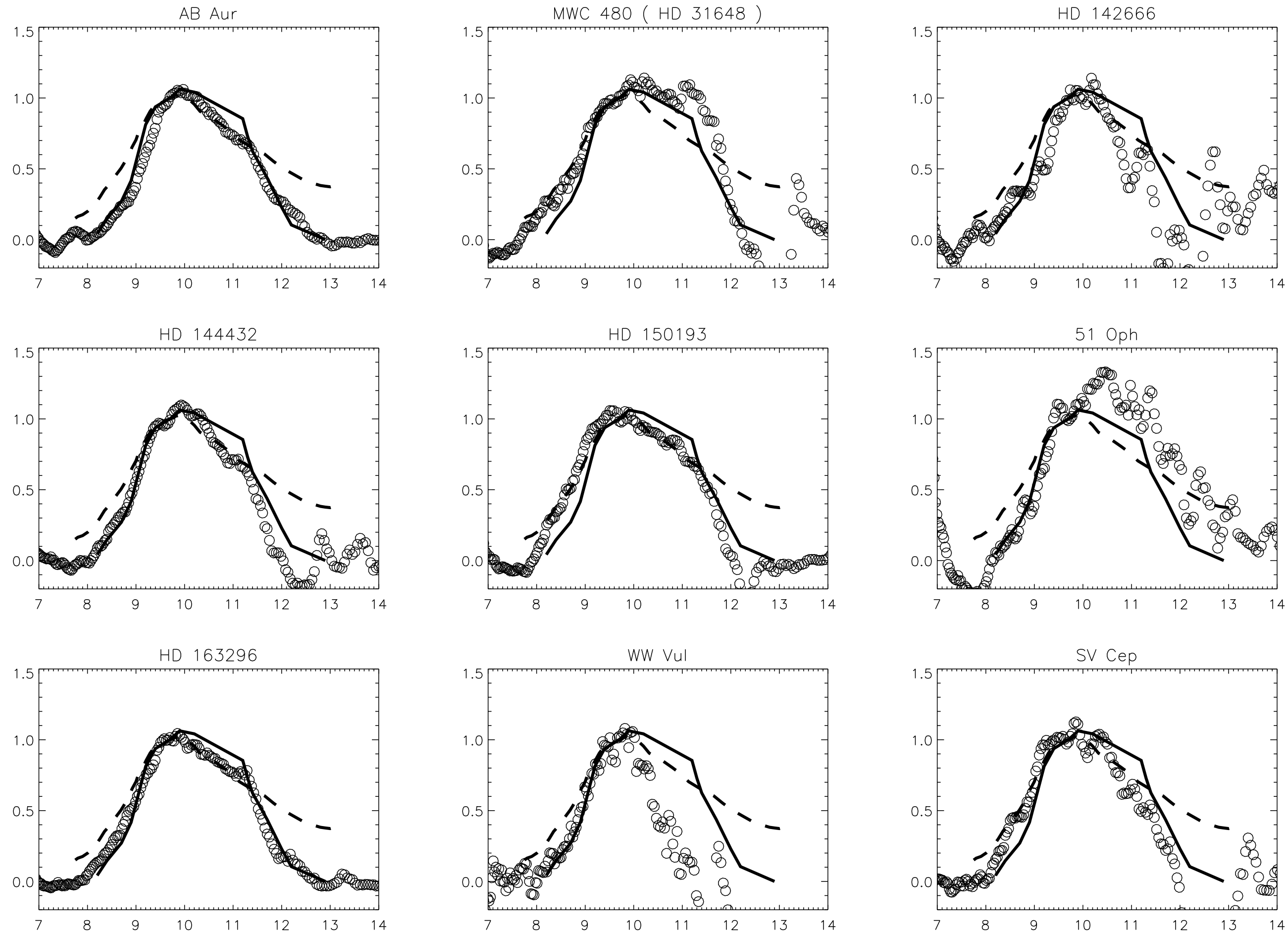

Figure 2. Normalized silicate emission profiles for stars in our sample. The continuous line corresponds to the comet Kohoutek silicate emission, while the dashed line corresponds to the the Trapezium emission.

ponent in the silicates located in the circumstellar disks around the observed stars. WW Vul and HD 142666 represent two extreme cases with silicate features significantly narrower than the Kohoutek one, although we have to point out that the the WW Vul flux signal is very low and the profile in Figure 2 is to be taken cautiously.

5. CONCLUSIONS

A preliminary analysis of ISO-SWS data concerning the SED and the silicate emission of a sample of stars with protoplanetary disks indicates significant differences with the evolutionary age of the stars. Vega-type stars usually have photospheric SEDs, at least up to $\approx 10\ \mu m$, and show no silicate features in their spectra. Pre-main sequence objects usually exhibit large SWS IR excess and have silicate bands in emission. The emission profiles tend to be more similar to those of the solar-system comet silicates than to those observed in the dense interstellar medium (Trapezium silicates).

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