Exoplanets: Detection, Formation and Dynamics
Proceedings IAU Symposium No. 249, 2007
Y.-S. Sun, S. Ferraz-Mello and J.-L. Zhou, eds.

doi:10.1017/S1743921308016839

Astromineralogy of protoplanetary disks

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Abstract. We review mid-infrared N-band spectra (8–13 μm) for a sample of 28 targets, obtained with the TIMMI2 camera at La Silla Observatory. The sample contains 5 FU Orionis stars, 6 Herbig Ae/Be objects, 7 T Tauri stars and 10 Vega-type main sequence objects. All targets show infrared excess, but for several the proof of circumstellar matter was lacking up to our observations. We model the N-band emission features with a mixture of silicates consisting of different grain sizes and composition, and determine the status of dust processing in these disks. While for some targets the emission spectrum resembles those of known pre-main sequence stars of evolved dust, other objects show strong isolated PAH bands but no silicate emission. For the first time we find evidence of PAH processing occurring in a T Tauri star. The Vega-type object HD 113766 exhibits highly-processed secondary generation dust, likely released by the collision of planetesimal-sized bodies. The findings of our dust analysis are set in context to previous dust studies of young stellar objects.

Keywords. Circumstellar matter, Planetary systems: protoplanetary disks, Stars: pre-main sequence, Infrared: stars

1. Introduction

Up to now a full understanding of dust evolution and grain growth in protoplanetary disks is missing. There is no global correlation of dust properties with age, not even when considering stellar spectral types (e.g. Schegerer *et al.* 2006). Therefore, the observed grain sizes in pre-main sequence disks must also depend on other factors like, e.g., turbulence and the gas content in the disk (Kessler-Silacci *et al.* 2006), while the exact dependencies thereof remain to be characterised.

This work describes mid-infrared (MIR) spectra of circumstellar disks. We selected targets with infrared excess that have not yet been discussed conclusively in the literature, i.e. objects which were suspected disk candidates, but for which no MIR spectroscopy had been obtained yet. In Schütz *et al.* (2005a), hereafter Paper I, we analysed silicate processing in a sample of pre-main sequence stars, while Schütz *et al.* (2005b), hereafter Paper II, focuses on debris disks and their collisional dust. A mixed target sample is discussed in Schütz *et al.* (2008), hereafter Paper III.

In this contribution we review our previous target samples, summarised in Table 1, and describe observed trends in the dust properties for the pre-main sequence objects. For details on all sources, as well as for a description of the observations and data reduction, we refer to Paper I–III.

2. Data analysis

The data were obtained in the years 2002–2006 with the ESO mid-infrared camera TIMMI2 at La Silla Observatory. One object, HD 34700, is also observed with the IRS on board the Spitzer Space Telescope.

Table 1. Our target sample. Spectral types are obtained from SIMBAD, or the literature if a revised classification exists. V-band magnitudes and IRAS 12 μm fluxes are from SIMBAD. Some targets are multiple systems or variable. Stellar ages and distances are from the literature.

Object	Class	Spectral Type	V [mag]	$F_{12\,\mu m}$ [Jy]	Age [Myr]	d [pc]
HD 3003	Vega	A0V	5.07	0.48	50	47
HD 10647	Vega	F8V	5.52	0.82	300 – 3500	17.4
HD 34282	HAeBe	A0e	9.85	0.70	5 – 10	400
HD 34700	TTS	G0IVe	9.15	0.60	–	–
HD 38678	Vega	A2Vann	3.55	2.18	230	21.5
HD 72106	HAeBe	A0IV	8.50	2.22	10	290
HD 80951	Vega	A1V	5.29	0.44	–	220
HD 98800	TTS	K5 / K7 / M1 V	9.11	1.98	8.5	47.6
HD 109085	Vega	F2V	4.31	2.18	~1000	18
HD 113766	Vega	F3 / F5 V	7.56	1.59	16	130
HD 123356	Vega	G1V	10.0 / 12.2	1.36	–	–
HD 143006	TTS	G5Ve	10.21	0.86	5	82
HD 155555	TTS	G5IV / K0IV-V	6.88	0.69	–	32
HD 172555	Vega	A5IV-V	4.78	1.47	12	29.2
HD 181296	Vega	A0Vn	5.03	0.54	12	48
HD 190073	HAeBe	A2IIIpe	7.82	7.16	1.2	> 290
HD 207129	Vega	G0V	5.58	0.81	6000	15.6
HD 319139	TTS	K5Ve / K7Ve	10.44	0.45	5.5	83
BBW 76	FUOR	G0 – G2 I	~ 12	1.02	–	1800
CD-43 344	TTS (?)	M2	9.42	3.73	–	–
FU Ori	FUOR	G0II	8.94	5.95	0.3	450
KK Oph	HAeBe	A6Ve / G6Ve	9.4 – 12.9	9.87	7	160
MP Mus	TTS	K1IV	10.32	0.88	8	86
PDS 144 N	HAeBe	A2IV	14.2	–	–	~1000
PDS 144 S	HAeBe	A5V	13.1	–	–	~1000
V 346 Nor	FUOR	–	16.3	7.50	–	700
V 883 Ori	FUOR	–	~ 15	52.5	–	460
Z CMa	FUOR	–	9 – 11	126.6	0.3	930

2.1. *Silicates*

To derive the composition of the circumstellar dust, we first determine a local continuum to our TIMMI2 spectra, by fitting a blackbody to the 8–13 μm region. Subsequently, we model the spectra with a linear combination of emission features from the following dust species which are commonly found in disks of pre-main sequence stars:

- Amorphous olivine ($[Mg,Fe]_2SiO_4$)
- Amorphous pyroxene ($[Mg,Fe]SiO_3$)
- Crystalline silicates: magnesium forsterite (Mg_2SiO_4) and enstatite ($MgSiO_3$)
- Silica (SiO_2).

Van Boekel *et al.* (2005) showed that the size distribution of grains radiating in the 10 μm region can be represented by two grain sizes: "small" ($r_V = 0.1$ μm) and "large" ($r_V = 2.0$ μm in our model), with the given volume-equivalent radii r_V. We used absorption coefficients of van Boekel *et al.* (2005) and Bouwman (private communication). For

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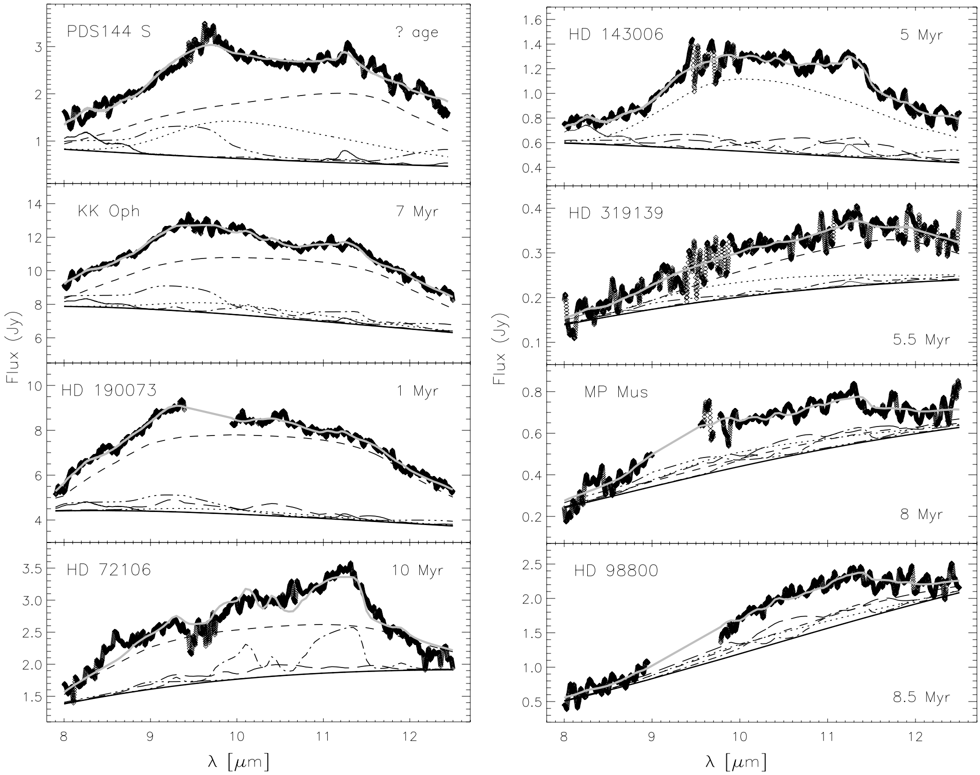

Figure 1. Decomposition of the silicate emission for the Herbig (left) and T Tauri stars (right) in our sample. The different linestyles represent small amorphous silicates (*dotted*), large amorphous silicates (*dashed*), silica (SiO_2, *dash-three-dots*), crystalline forsterite (*dash dot*) and crystalline enstatite (*long dashes*). The very thick black curve corresponds to the observed spectrum, including – for some targets – noise features. A summary of all silicate components is given by the grey curve. The targets are sorted according to the apparent degree of dust processing.

the dust decomposition we perform a χ^2-fit with 10 free parameters (the mass fractions of above 5 silicate types, with 2 grain sizes each). Resulting model spectra, together with the contribution of each dust type, are shown in Figs. 1–2. While we model the spectra with 10 (grain and size) dust types, we only plot six components for a better visibility. In particular, we added amorphous olivine and pyroxene of 0.1 μm and plot them as "small amorphous silicates". Similarly, "large amorphous silicates" contain the 2.0 μm pyroxene and 2.0 μm olivine grains. For silica, forsterite and enstatite, we each plot the sum of the 0.1 and 2.0 μm grains.

For a discussion of the FU Orionis targets (FUORs) we refer to Paper I and III. These sources show the silicate feature either in emission or absorption. Given the large number of FUORs with silicate absorption features, which cannot be explained only by geometry effects (pole-on vs. edge-on view to the disk), Quanz *et al.* (2007) defined two categories of FUORs: objects with the silicate feature in absorption are likely still embedded in a circumstellar envelope, while the silicate band in emission is thought to originate from the surface layer of their accretion disks, similar as for the Herbig and T Tauri stars.

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2.2. *PAHs*

A key result in observational studies of PAH bands is that their profiles show clear variations in terms of peak positions, profile shape and relative intensities (Peeters *et al.* 2004, and references therein). Based upon their profile, PAHs have therefore been classified into categories A, B and C. These classes also depend on the object type and evolutionary status.

We find PAH bands towards the Herbig stars HD 34282, PDS 144 N and the T Tauri HD 34700 (see Fig. 3). Their appearance is rather expected for Herbig objects and commonly explained with the excitation of PAH molecules by UV photons. However, Li & Draine (2002) and Mattioda *et al.* (2005) have shown that PAH molecules around cool stars can also be excited.

The PAH band profiles of the T Tauri star HD 34700 are clearly unique and show that PAH processing and/or formation has occurred in this source. This is similar to PAH observations towards isolated Herbig stars and suggests that similar PAH processing occurs in protoplanetary disks around low-mass and intermediate-mass stars.

3. Trends observed with stellar, disk and silicate properties

We analyse trends in the dust properties for the pre-main sequence targets, as the dust in Vega-type objects is of collisional nature and would not correlate with the dust properties of the younger stars. The silicate mass fractions of each dust component show no clear relation with stellar parameters. Instead we use the silicate shape, i.e. the ratio of the fluxes at 11.3 and 9.8 μm in the continuum normalised spectra. The silicate shape

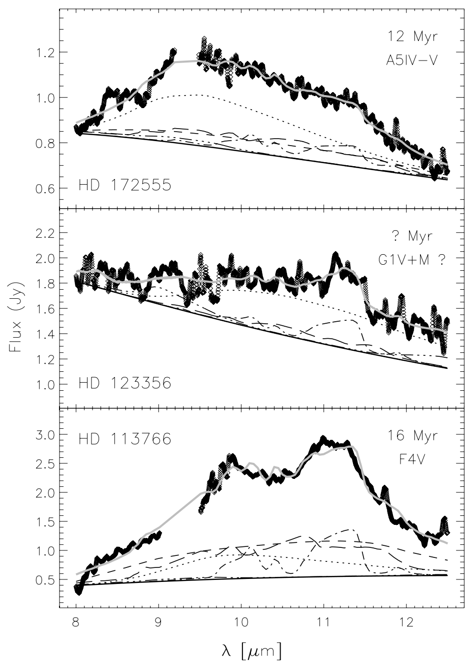

Figure 2. Decomposition of the silicate emission for the Vega-type sources, sorted according to the apparent degree of dust processing. Note the strength in the dust emission of HD 113766 and the diversity between this source and HD 172555, despite the similar age.

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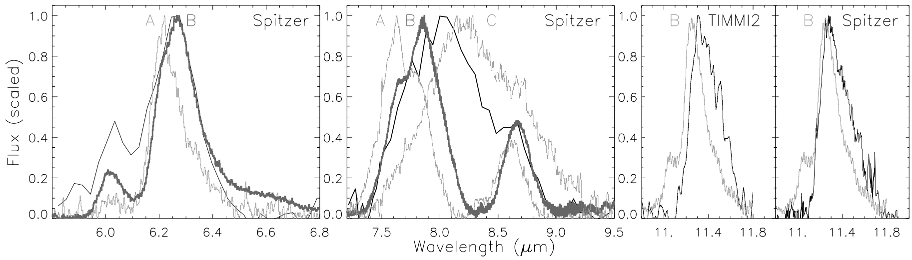

Figure 3. Comparison of the PAH profiles towards HD 34700 with the PAH classes A–C. Observations of HD 34700 are shown in thin black, and the PAH classes in grey shades. The PAH bands of this T Tauri star are clearly unique and point to ongoing PAH processing.

can be seen as an indicator for the grain size composition and the evolutionary dust status (Bouwman *et al.* 2001).

• Silicate shape vs. peak strength: Our sample is lacking sources of very pristine dust, but nevertheless shows the same trend as found in previous works (van Boekel *et al.* 2005, Kessler-Silacci *et al.* 2007): a decrease of the silicate peak strength is observed with higher dust processing status (i.e. with a larger 11.3/9.8 ratio).

• Kessler-Silacci *et al.* (2007) have shown a correlation of the silicate shape with stellar luminosity, in form of an apparent *higher* dust evolution with lower luminosity. This trend can be understood when considering that the 10 μm silicate emission region lies further inward for stars with lower luminosity, while resolved observations (e.g. van Boekel *et al.* 2004) have shown that the degree of dust processing increases towards the star. Our sample is much smaller, but suggests a similar trend with luminosity.

• We see no correlation of the dust and disk evolution with stellar binarity in our sample, i.e. whether the time spans of dust processing and disk lifetime in binary systems would differ from those of isolated stars with the same age. This non-correlation is also affected by a rather imprecise age determination for some targets.

• With the evolution of protoplanetary into debris disks, the IR emission from the inner disk decreases. This results in a falling 2–25 μm slope with progressing disk evolution. An eventual dependence of silicate emission with inner disk evolution should be recognisable as a correlation between silicate strength and SED slope. Sicilia-Aguilar *et al.* (2007) noticed a very weak to absent correlation, to which our data agree.

We refer to Paper III for more details about these trends and correlations.

4. Conclusion

By mid-infrared spectroscopy and modelling of the 10 μm emission feature we characterised circumstellar disks, detected new ones and found the first T Tauri star which shows processing of PAH – HD 34700. For our pre-main sequence targets we confirm a correlation of the spectral silicate shape with decreasing silicate peak strength and with decreasing stellar luminosity, but we find no clear dependence of dust processing with age.

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