TIMMI2 and VLT-ISAAC Spectroscopy of Circumstellar Dust Disks – A Spatially Resolved 3.3 \( \mu \text{m} \) PAH Feature Around HD 100546

Vincent C. Geers\(^1\), Jean-Charles Augereau\(^1\), Klaus M. Pontoppidan\(^1\), Hans U. Käufl\(^2\), Anne-Marie Lagrange\(^3\), Gaël Chauvin\(^3,4\), and Ewine F. van Dishoeck\(^1\)

\(^1\) Leiden Observatory, P.O. Box 9513, 2300 RA Leiden, The Netherlands
\(^2\) ESO, Garching, Germany
\(^3\) Laboratoire d’Astrophysique de Grenoble, France
\(^4\) ESO, Santiago, Chile

Abstract. We present preliminary results of spectroscopic data obtained with the La Silla 3.6 m TIMMI2 and the VLT-ISAAC instruments. We have obtained 23 TIMMI2 N-band and 18 Q-band spectra for our total sample of 36 stars in March 2003 to investigate the evolution of the grain properties in circumstellar disks. Our sample consists of Herbig stars, T Tauri stars and Vega-like stars, some of which have recently been identified to be members of nearby (<100 pc) stellar associations. Silicate and Polycyclic Aromatic Hydrocarbon (PAH) emission features are detected and the spatial resolution of TIMMI2 allowed to place upper limits on the spatial extent of the emission. We also obtained ISAAC L-band spectra of 4 well-studied disks. For the Herbig Be star HD 100546, we detect spatially extended PAH emission at 3.3 \( \mu \text{m} \) which corresponds to a source with radius 11\( \pm \)3 AU in this line.

1 Introduction

In the last decade, circumstellar disks at different evolutionary stages have been intensively studied from optical to millimeter wavelengths. Low-mass (T Tauri) and intermediate-mass (Herbig Ae/Be) young stars have been shown to have young dusty and gaseous protoplanetary disks for which imaging can provide constraints on the structure \([6,9,17]\). More evolved gas-free dust disks around main-sequence stars, studied at sub-millimeter and near-infrared wavelengths, show a “lumpy” structure with gaps, holes and/or asymmetries in the dust distribution, indicative of gravitational perturbations by stellar companion(s) or unseen planet(s) \([2,3,18]\). Near- and mid-infrared spectroscopy of circumstellar disks around Pre Main Sequence (PMS) stars at different evolutionary stages has shown a wealth of gas and dust features, enabling detailed studies of dust mineralogy and its relation with grain processing and disk evolution \([10]\). The shape of the 10 \( \mu \text{m} \) feature can serve as a tracer of grain growth in disks and the presence of crystalline silicates, not observed in the ISM, is interpreted as evidence that the dust composition evolves as the disk is dissipating and large protoplanetary bodies are forming \([13,15]\).
The Spatially Resolved ISAAC Spectrum of HD 100546

With ISAAC at VLT we obtained in mid-2000 low resolution (R~600) L-band (2.8–4.2 µm) spectra of four old PMS stars using a 0.6′′×120′′ slit with a spatial resolution of 0.146′′/pixel. For HD 100546 the long slit was aligned with the major axis of the disk resolved in scattered light [1,7]. The reduction procedure is described in [12]. It includes the removal of bad pixels and jitter correction before co-adding 2-D spectra, spectrum extraction, wavelength and flux calibration.

The L-band spectrum for HD 100546 is plotted in the top panel of Fig. 1 together with the ISO spectrum. The two spectra agree reasonably well on absolute flux, although the ISAAC continuum flux is ∼20% lower than the ISO flux. This difference cannot be explained by airmass difference between the science and standard target. The spectrum shows several hydrogen emission lines, which are stronger in the smaller aperture ISAAC data. The Pfδ line falls on top of a broad spectral feature at 3.3 µm attributed to PAHs [10]. Tabulated HI recombination line ratios from [8] were used to estimate and subtract the contribution of the HI Pfδ line to the intensity of the PAH feature. The PAH emission feature to continuum ratios are similar for both ISAAC and ISO spectra.

In the bottom panel of Fig. 1, the measured FWHM of the spatial profile, assumed to be Gaussian, as a function of wavelength is plotted for HD 100546 and the standard star BS 4757, which was used for telluric correction and flux calibration. The wavy pattern of the FWHM profiles is currently not understood.
but it is similarly observed for the science and standard stars. Distortion correction of the 2D spectra before FWHM extraction does not improve the results. The spike at $\sim 3.31 \mu m$ is caused by almost complete atmospheric extinction. When rescaling the measured FWHM of BS4757 according to the difference in measured airmass and DIMM seeing and dividing by a factor 1.05, we find that the rescaled FWHM of BS 4757 fits reasonably well with the FWHM of the continuum of HD 100546. Assuming BS 4757 is a point source, we conclude that the continuum of HD 100546 is unresolved. A significant bump is observed at 3.3$\mu m$ with a spatial extent (FWHM) of $0.22'' \pm 0.064'' (3\sigma)$ after correcting for interpolated FWHM of the continuum. Adopting a Hipparcos distance of $103_{-6}^{+7}$ pc [16], this corresponds to a radius of 11$\pm$3 AU, where the uncertainty is largely due to the noise in the extracted FWHM. In conclusion we find a significant bump in the FWHM at the wavelength of 3.3$\mu m$ which indicates that the disk is spatially resolved in this PAH feature. The 3.3$\mu m$ PAH carriers are thus spread over a larger area than the thermalized dust grains responsible for the adjacent continuum or the ionized gas responsible for the H lines.

3 TIMMI2 N-band Spectra of Circumstellar Disks

With TIMMI2 at the ESO/3.6m telescope we obtained 23 low resolution N-band (7.5–13.9$\mu m$; R$\sim$160; 1.2$''\times$70$''$ slit) and 18 low resolution Q-band (14.5–23.9$\mu m$; R$\sim$130; 3.0$''\times$70$''$ slit) spectra for our sample of 36 Herbig Ae/Be and T Tauri stars with a spatial resolution of 0.45$''$/pixel in N-band and 0.6$''$/pixel in Q-band. Spectra for targets with IRAS 12$\mu m$ fluxes as faint as about 0.5–1 Jy
could be observed in N-band. The reduction procedure is similar to that of the ISAAC observations. Absolute flux calibration is not performed; for comparison of features all the spectra are normalized to their flux at 12 µm, except HD 100546 which is scaled to match the ISO spectrum. Preliminary mid-IR N-band spectra for a selection of our TIMMI2 sample are shown in Fig. 2.

For HD 100546, the shape of our TIMMI2 spectrum agrees reasonably well with the ISO spectrum but we do observe some interesting differences: the sharp feature at 11.0 µm in the ISO spectrum does not show up in our TIMMI2 spectrum while we do see a more pronounced feature at 11.8 µm. The HD 100546 spectrum has a clear feature at 11.2 µm, which can be attributed to blended features from both forsterite and PAH [4]. Using the same approach as for our ISAAC spectrum, we do not find any evidence of an excess spatial extent at the 11.2 µm feature compared to the extent of the continuum in our TIMMI2 data, with an upper limit of a radius of 50±11 AU.

KK Oph, a Herbig Be star, shows a broad emission feature peaking between 9 and 12 µm, which could be attributed to small amorphous silicate grains, plus additional smaller features like e.g. that close to 11.2 µm, possibly due to crystalline silicates. TY CrA is a triple, perhaps quadruple [5], system and shows clear emission features at 8.5 and 11.1 µm of which the latter feature has, based on ISO-SWS data, been attributed to PAHs [14]. HD 34282 is another Herbig star for which a gas disk in Keplerian rotation has recently been resolved at millimeter wavelengths [11]. We detect in its mid-IR spectrum two features at 8.6 (Δλ = 0.28 µm) and 11.2 µm (Δλ = 0.20 µm) again consistent with the presence of PAHs confirming the tentative detection by ISO.

4 Future Work with VLT Facilities

In relation to the work presented here, we plan to use the high spatial and spectral resolution of VISIR to obtain spatially resolved N- and Q-band spectra of young Pre Main Sequence stars with circumstellar disks. This will provide the unique opportunity to simultaneously obtain a clean spectral separation of amorphous and crystalline silicates and distinguish for example the 11.2 µm PAH and 11.3 µm forsterite features as well as constrain their spatial distribution. Compared to TIMMI2 on the La Silla 3.6m telescope, VISIR at the 8.2m VLT will allow us to put much stronger constraints on the spatial extent of the 11.2 µm PAH feature of HD 100546 because of the higher spatial resolution.

Acknowledgements: Astrochemistry in Leiden is supported by a NWO Spinoza grant. J.C. Augereau is supported by a fellowship from the European Research Training Network “The Origin of Planetary Systems” (PLANETS; contract number HPRN-CT-2002-00308) at Leiden Observatory.
References

1. Augereau, J. C., Lagrange, A. M., Mouillet, D., et al. 2001, A&A, 365, 78
2. Augereau, J. C., Nelson, R. P., Lagrange, A. M., et al. 2001, A&A, 370, 447
3. Augereau, J. C. & Papaloizou, J. C. B. 2004, A&A, 414, 1153
4. Bouwman, J., de Koter, A., Dominik, C. et al. 2003, A&A, 401, 577
5. Chauvin, G. et al. 2003, A&A, 406, L51
6. Dartois, E., Dutrey, A., & Guilloteau, S. 2003, A&A, 399, 773
7. Grady, C. A. et al. 2001, AJ, 122, 3396
8. Hummer, D. G. & Storey, P. J. 1987, MNRAS, 224, 801
9. Mannings, V. & Sargent, A. I. 1997, ApJ, 490, 792
10. Meeus, G., Waters, L. B. F. M., Bouwman, J. et al. 2001, A&A, 365, 476
11. Piétu, V., Dutrey, A., & Kahane, C. 2003, A&A, 398, 565
12. Pontoppidan, K. M., Fraser, H. J., Dartois, E. et al. 2003, A&A, 408, 981
13. Przygodda, F., van Boekel, R., Abrahám, P. et al. 2003, A&A, 412, L43
14. Siebenmorgen, R., Prusti, T., Natta, A., et al. 2000, A&A, 361, 258
15. van Boekel, R., Waters, L. B. F. M., Dominik, C. et al. 2003, A&A, 400, L21
16. van den Ancker, M.E., The, P.S., Tjin A Djie, H.R.E. et al. 1997, A&A, 324, L33
17. Wolf, S., Padgett, D. L., & Stapelfeldt, K. R. 2003, ApJ, 588, 373
18. Wyatt, M. C. 2003, ApJ, 598, 1321