Hot exozodiacal dust: Infrared thermal emission spectroscopy in the laboratory

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Abstract

This new project aims to contribute to the identification of the materials that make up **hot exozodiacal dust disks (exozodis)**. A common feature of debris disks, exozodis appear to consist of **submicronic grains** that are **possibly as hot as 2000 K** for those closest to the central star. **The composition and the origin of the grains are currently undetermined.** Given that the presence of hot exozodiacal grains is revealed by their thermal emission at near- and mid-infrared wavelengths, **we intend to obtain the optical constants of relevant materials at high temperatures in the infrared (IR) wavelength range.** These data will allow us to compute thermal emission spectra for different grain geometries and sizes, which we will compare to astronomical observation data in order to identify or constrain the composition of hot exozodis. In order to perform **IR thermal emission measurements**, an objective of the project is to bring the **Fourier-transform IR emission spectroscopy** technique into our laboratory.

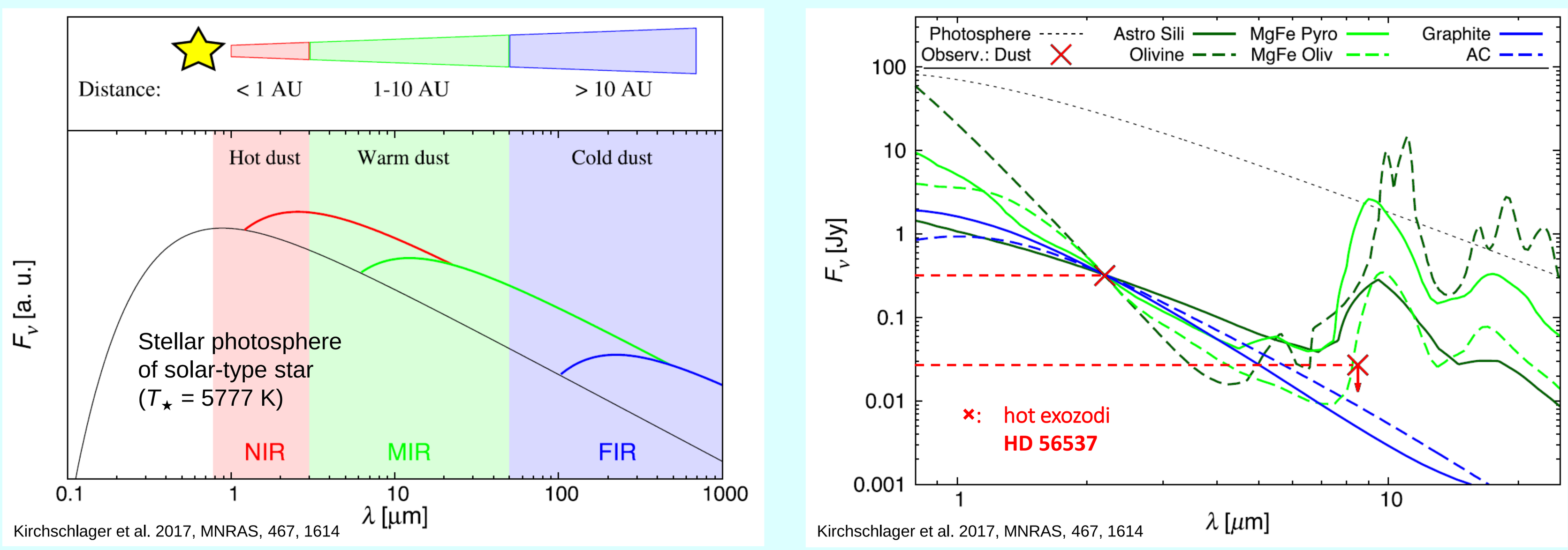
Hot exozodis

Grains composing exozodis may be as hot as 2000 K. Observations of exozodis have reported warm (~300 K) and hot (>300 K) grains with temperatures possibly reaching 2000 K [1] at the closest point from the central star. Accordingly, warm exozodis are seen in the mid-IR wavelength domain at ~10 μm while hot exozodis are detected in both the near- and mid-IR domains from ~1 to ~10 μm [2].

The grains are located from ~0.01 to 1 AU from the central star and they would be between 0.04 and 1 μm in diameter. Their emission spectrum is such that F (2.2 μm) > 10 F (8.5 μm) (see figure below).

The origin of the hot grains is still unknown: they may have migrated from an outer dust belt of the stellar system because of Poynting-Robertson drag; they may be remnants of comets; they may be products of asteroid disruption.

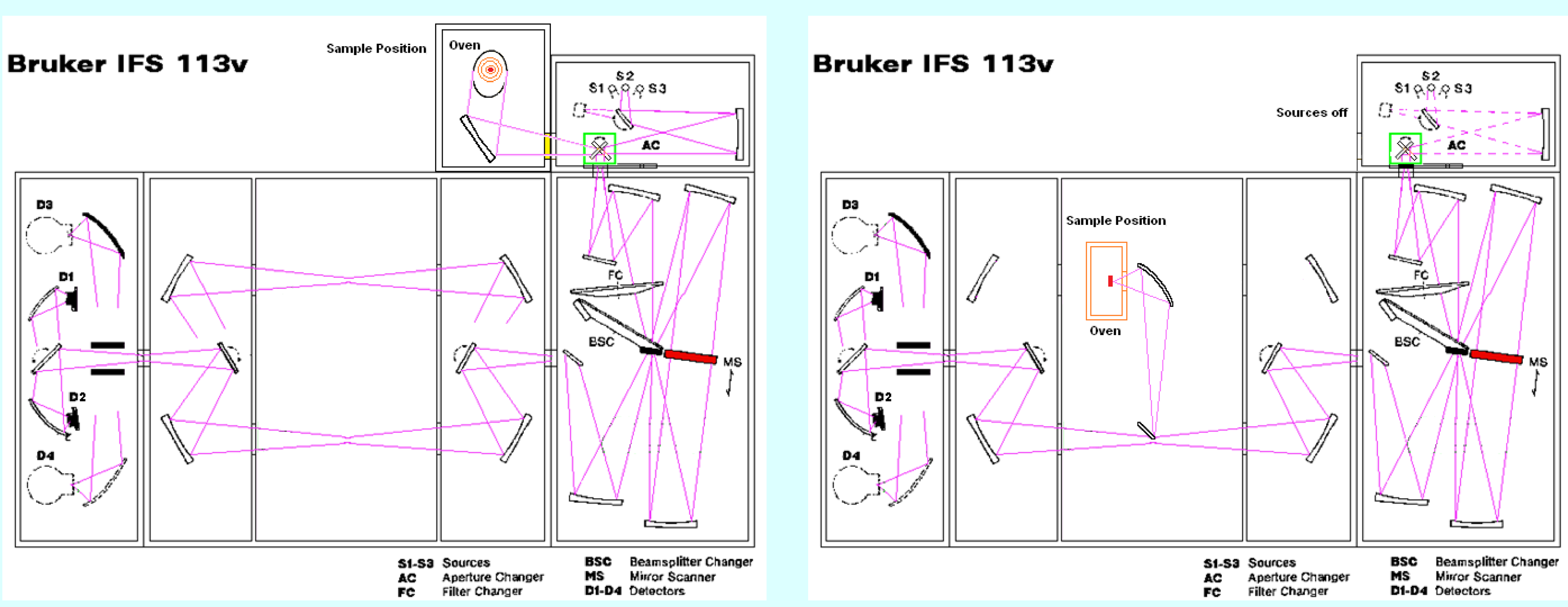
The survival of hot exozodis is also a puzzle: one would expect the grains to sublimate at temperatures lower than 2000 K or blow away.



***Left:** Spectral energy distribution of a dust disk. **Right:** Flux attributed to the hot exozodi of HD 56537 (red crosses) compared to simulated emission spectra (normalized) of dust at 0.4 AU from the star for various grain materials. Astro Sili: astronomical silicate; Pyro: pyroxene; Oliv: olivine; AC: amorphous carbon. The observation at 8.5 μm is an upper limit. Figures adapted from Kirchschlager et al. 2017 [3].*

Thermal infrared emission spectroscopy

Fourier-transform infrared (FTIR) spectroscopy is a well established analytical technique. Using an FTIR absorption spectrometer, the sample heated with an oven takes the place of the IR radiation source.



***Left:** Optical layout for the use of a Bruker IFS 113v FTIR absorption spectrometer for measuring the thermal emission of a heated sample. **Right:** Alternative layout with injection of the thermal photons into the interferometer through its exit port. One observes the thermal emission as it is reflected by the interferometer [4]. Drawback: the attenuation of the signal by a factor of two.*

References

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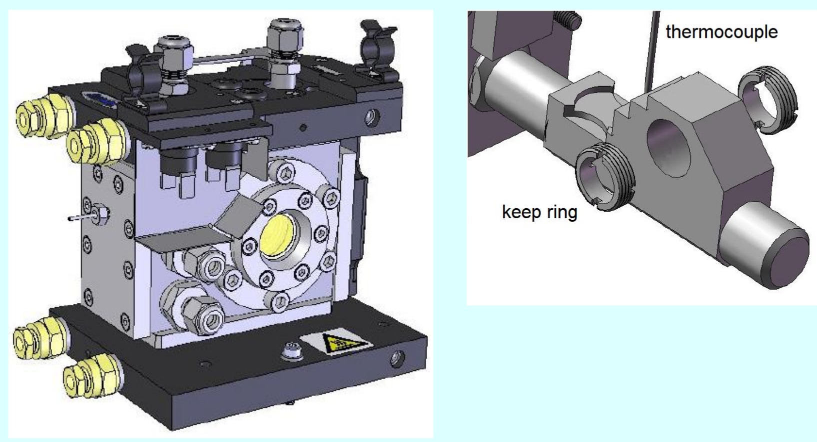
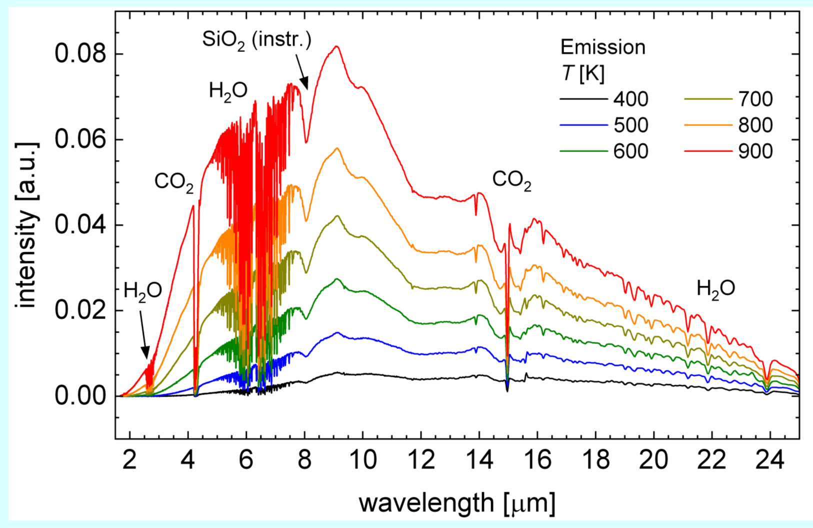
First measurements

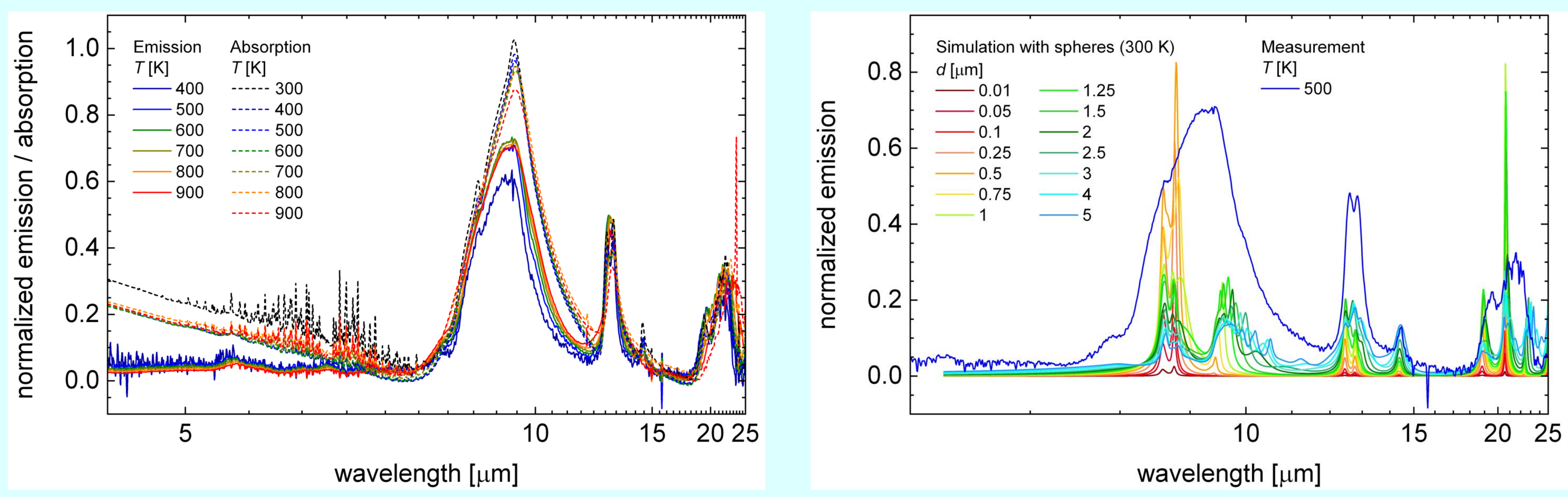


Sample heating device. A commercial high-temperature cell [5] capable of heating samples up to 800 °C under vacuum is used for testing the feasibility of thermal IR emission spectroscopy. The cell can be set up for reflection measurements to obtain absorption spectra. All measurements presented here were carried out without window on the cell.

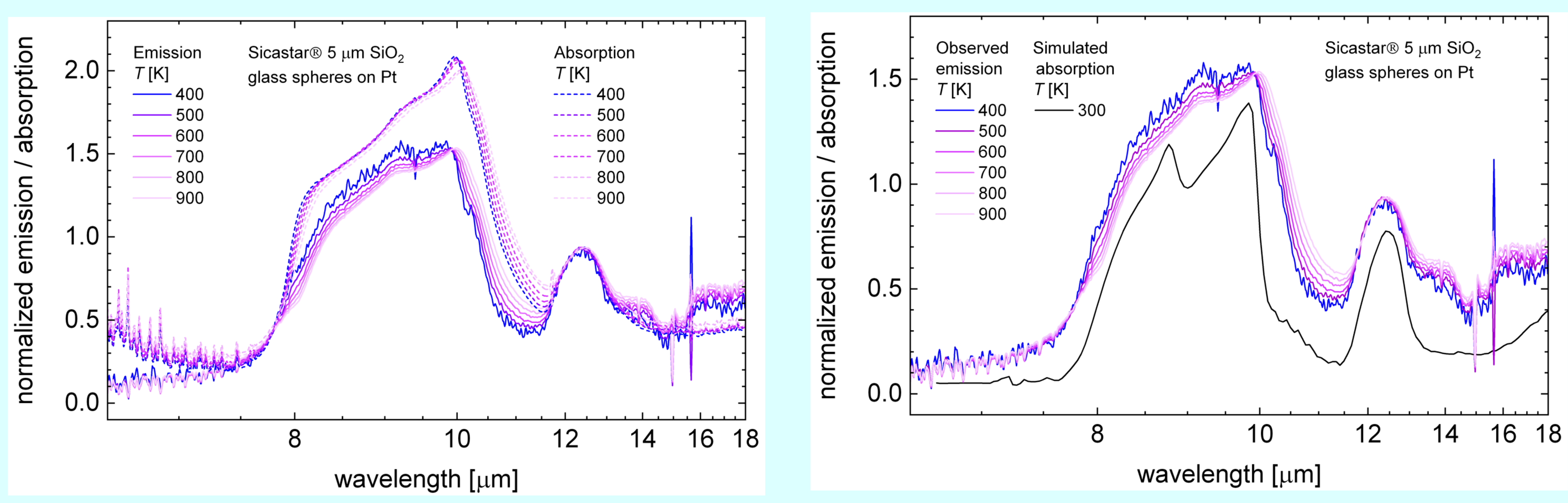


Thermal emission of platinum. The high melting point (2041.4 K or 1768.3 °C) of platinum, its resistance to corrosion and its general chemical inertness make this metal the choice material as substrate for dust samples to be studied at temperatures up to the targeted value of 1800 K. The figure shows emission spectra of a 1 mm thick Pt disk. Emission measurements on samples must be corrected for the instrument and substrate contributions.

Thermal emission of quartz grains. A sample of quartz grains with sizes over 0.5–10 μm is the first material studied. The measurement at 500 K is compared with simulated spectra of spherical grains at room temperature computed using Mie theory with optical constants from Zeidler et al. [6].



Thermal emission of monodispersed spheres. Measurements on sicastar® quartz-glass spherical particles with a diameter of 5 μm are compared with simulated spectra of spherical grains computed using Mie theory with optical constants from Henning & Mutschke [7].



Planned steps

Custom high-temperature cell. The main goal of the project is to characterize grains at temperatures up to 1800 K. Because the maximum working temperature of the commercial cell is 800 °C, a custom cell will be developed.

Samples relevant to exozodis. Silicates and closely related materials have been long thought to be components of zodiacal dust. These materials would emit strongly at 8.5 μm at high temperature and their sublimation would prevent their survival beyond three days at 1400 K. Thus, silicates may not be components of hot exozodis. The project will take refractory materials with low emission at 8.5 μm at high temperature: graphite, diamond, Fe, Fe_2O_3, Fe_3O_4, SiC, MgO, etc. The list is open.

Testing models. Measurements on calibrated spherical grains (e.g., silica nanospheres) are already being compared with spectra predicted with Mie theory (see figures above), which is exact for this grain shape. Expected agglomeration-induced deviations will be examined [8]. For irregular grain shapes, the DFF (Distribution of Form Factors, for small grain sizes [9]) and DHS (Distribution of Hollow Spheres [10]) models will be tested.

Optical constants and database. The laboratory emission spectra obtained for the various targeted materials will be included in a publicly accessible database (e.g., Solid Spectroscopy Hosting Architecture of Databases and Expertise [11]) with the optical constants they yielded.

Analysis of observations. Our laboratory data will be used to analyze observations carried out with the Multi-AperTure mid-Infrared SpectroScopic Experiment (MATISSE) at the Very Large Telescope Interferometer (VLTI) and with the James Webb Space Telescope (JWST).

Acknowledgments

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