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Mid-infrared interferometric variability of DG Tau: implications for the inner-disk structure

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Abstract. DG Tau is a low-mass young star whose strongly accreting disk shows a variable 10 μm silicate feature, that may even turn temporarily from emission to absorption. Aiming to find the physical reason of this variability, we analysed multiepoch VLTI/MIDI interferometric observations. We found that the inner disk within 3 au radius exhibits a 10 μm absorption feature related to amorphous silicate grains, while the outer disk displays a variable crystalline feature in emission, similar in shape to the spectrum of comet Hale-Bopp. The variability may be related to a fluctuating amount of dusty material above the disk surface, possibly due to turbulence.

1. Introduction

DG Tau is a low-mass K6V-type pre-main sequence star in the Taurus star forming region. Its protoplanetary disk has a radius of ~80 au, and a mass of ~0.01 $M_\odot$ (Isella et al. 2010). The accretion rate onto the star ($\dot{M}$=4.6×10^{-8}–7.4×10^{-7} $M_\odot yr^{-1}$) is relatively high and variable (Agra-Amboage et al. 2011).

The 10 μm silicate feature exhibits dramatic changes on month-to-year timescales, even turning temporarily from emission to absorption.

Although different models have been proposed (e.g. Bary et al. 2009), the origin of variability is not yet understood. Our aim is to resolve the inner disk and identify its variable component with the help of interferometry.

2. Observations

We monitored DG Tau with the MID-infrared Interferometric instrument (MIDI) on ESO's Very Large Telescope Interferometer at 5 epochs between 2011 and 2014.

By combining the signal of two 8.2 m telescopes, we obtained spectrally resolved ($\lambda/\Delta\lambda\approx30$) interferometric data in the 7.5–13 μm range. The baselines were between 33 and 89 m, corresponding to 3–1 au resolution at 140 pc, the distance of the Taurus region. The position angles fell between 30° and 45° or around 80°. We utilized all standard star observations of a given night to improve the calibration. The typical measurement error was 6% for the correlated spectra, and 10–20% for the total spectra.

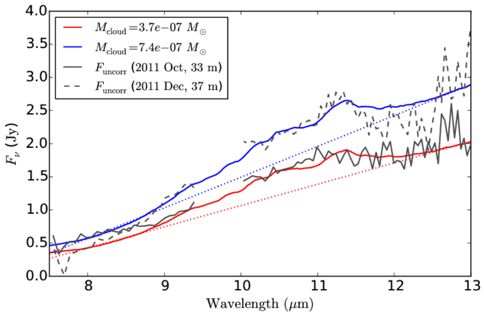

Fig. 1. Mid-infrared uncorrelated (outer disk, r> 3 au) spectra obtained with VLTI/MIDI at two epochs with similar baseline configurations (dashed and solid gray curves). Overplotted are the results of our radiative transfer modeling assuming different cloud masses (blue and red curves). The corresponding dotted lines show the continuum of the radiative transfer model.

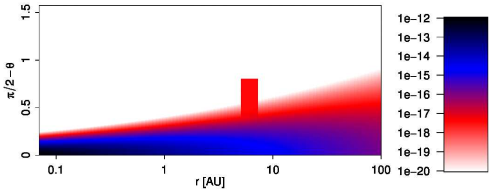

Fig. 2. Dust density distribution in spherical coordinates of our radiative transfer model including a cloud component between 5 au and 7.5 au. The density scale is in g cm^{-3}.

3. Results

In all epochs the correlated spectra, corresponding to the inner <3 au, exhibited a 10 μm feature in absorption, whose depth remained constant over the observing period. On the contrary, the outer disk showed a variable emission feature, whose amplitude changed by more than a factor of two (Fig. 1). The remarkable differences between the inner and outer disk spectral properties, revealed for the first time by our high resolution interferometric measurements, is unusual among T Tauri stars. The half-light radius of the mid-infrared-emitting region also changed between 2011 and 2014, decreasing from 1.15 to 0.7 au, suggesting long-term structural changes.

We performed spectral fitting to the spectral profiles at each epoch. The shape of the inner absorption feature could be fitted by an amorphous silicate grain template (Kemper et al. 2004). The emission profile corresponds to that of crystalline silicate grains, and could be successfully fitted by a scaled spectrum of comet Hale-Bopp (Crovisier et al. 1997).

4. Discussion

In the inner disk possible scenarios for the origin of the absorption include: (1) a cold obscuring envelope, (2) an accretion-heated inner disk, (3) temperature inversion on the disk surface, and (4) misaligned inner geometry. We suggest a combined effect of the first three processes, and consider the last one as a less likely alternative, which needs special geometry.

In the outer disk we performed a radiative transfer modeling, including an extra cloud above the disk plane at ~5 au from the star (Fig. 2). By changing the mass of this cloud we could account for the observed variability of the emission feature (Fig. 1, blue and green curves). We cannot explain the shortest observed variability timescales of weeks-to-months.

5. Summary

In DG Tau we found a striking difference between the inner and outer disk spectral features (absorption vs. emission; amorphous vs. crystalline; constant vs. variable) which is a highly unusual behavior among T Tauri stars, and points to a radially changing inner disk structure/dynamics. For more details, see Varga et al. (2017).

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