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 its physical reason, we analysed multi-epoch VLTI/MIDI interferometric observations. We found that the inner disk ($r<3$ au) exhibits a 10 μm absorption feature related to amorphous silicate grains, while the outer disk shows a variable crystalline feature in emission, similar in shape to the spectrum of comet Hale-Bopp. We propose that the mid-infrared variability is originated in the outer disk, where the mass of the dusty material above the disk plane may change with time, possibly due to turbulence in the disk.

DG Tauri

DG Tau is a low-mass K6V pre-main sequence star in the Taurus star forming region. Its protoplanetary disk has a radius of ~80 au, and a mass of few times 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. The 10 μm silicate emission feature shows dramatic changes on month-to-year timescales, even turning the feature temporarily into absorption. Although different models have been proposed (e.g. Bary et al. 2009), the origin of variability is not yet understood.

Figure 1: The Very Large Telescope Interferometer at ESO's Paranal Observatory (Credit: ESO).

Observations

- dedicated 5-epoch monitoring with VLTI/MIDI in 2011–2014, using UTs.
- spectrally resolved interferometric data in the 7.5–13 μm range.
- baselines between 33 and 89 m (3–1 au resolution at 140 pc).
- all standards of a given night were considered to improve the calibration.
- the typical measurement error is 6% for the correlated spectra, and 10–20% for the total spectra.

Acknowledgements

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Results

In all epochs the correlated spectra, corresponding to the inner disk (r<3 au), exhibited a 10 μm feature in absorption, whose depth remained constant over the observed period. On the contrary, the outer disk exhibited a variable emission feature, whose amplitude changed by more than a factor of two. **The striking difference 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.** Between 2011 and 2014, also the half-light radius of the mid-infrared-emitting region decreased from 1.15 to 0.7 au, suggesting long-term structural changes.

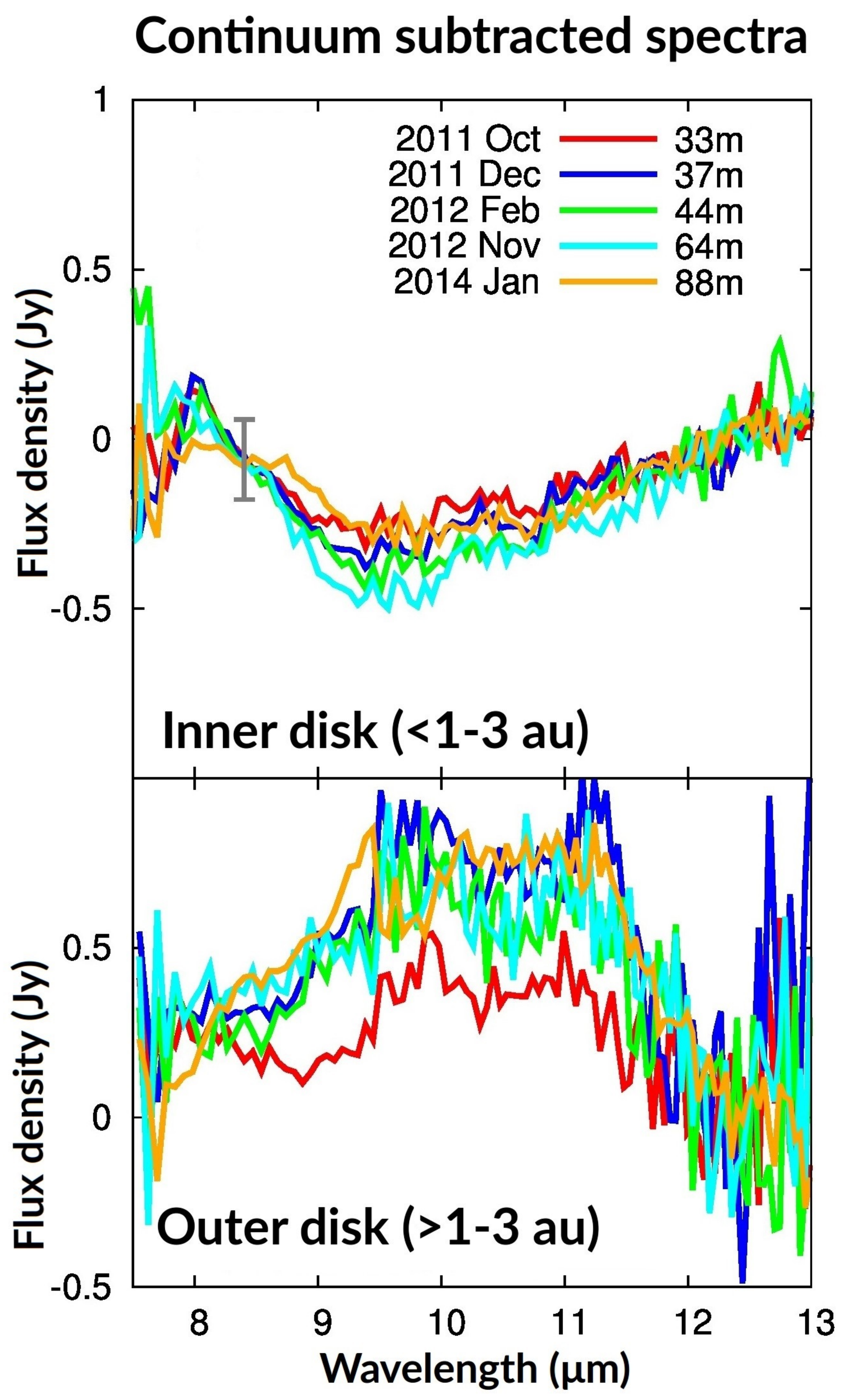

Figure 2: Inner and outer disk spectra for selected baseline configurations. The plots demonstrate the relative constancy of the inner absorption feature and the highly time variable nature of the outer emission.

Spectral fitting

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).

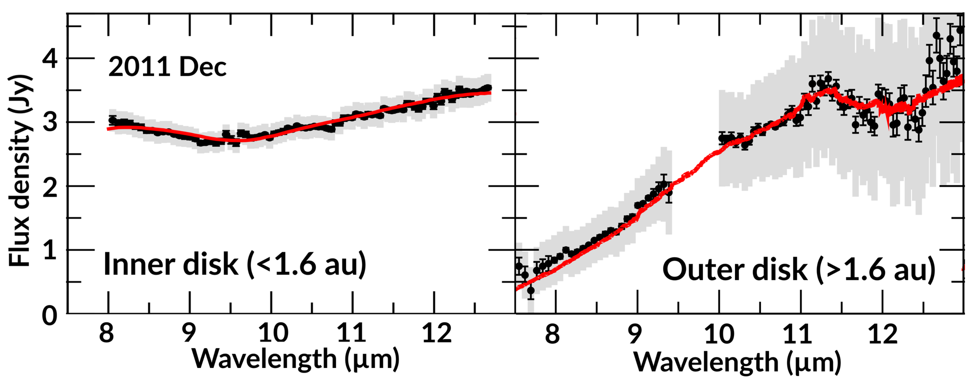

Figure 3: Inner and outer disk spectra of DG Tau at a selected epoch. Amorphous dust (left) and crystalline Hale-Bopp (right) spectra, fitted to the DG Tau data, are overplotted in red.

Discussion

Inner disk. Possible scenarios for the origin of the absorption include: (1) cold obscuring envelope, (2) 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 an alternative, which needs special geometry.

Outer disk. We performed a radiative transfer modeling of the disk, including an extra cloud above the disk plane at ~5 au from the star. Changing the mass of this cloud could account for the observed variability of the emission feature. However, we cannot explain the shortest observed timescales of weeks-to-months.

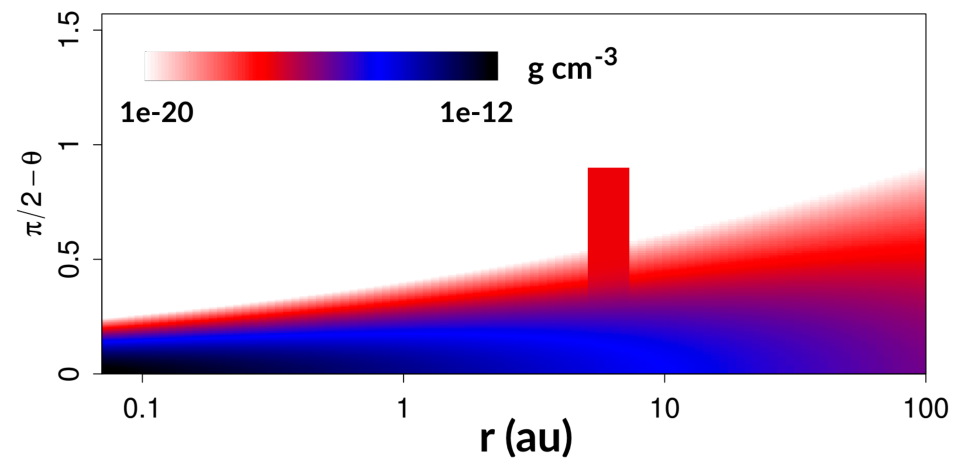

Figure 4: Density distribution of our radiative transfer disk modeling, including a vertical cloud at 5 au, consisting of crystalline dust.

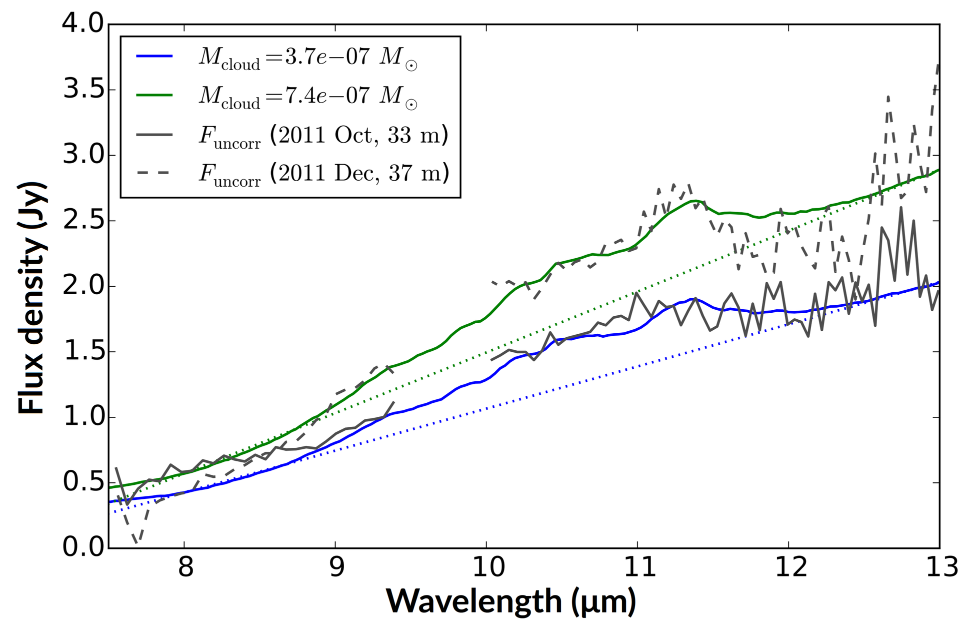

Figure 5: Model spectra (color lines) at two epochs, by varying the cloud mass by a factor of 2. Grey lines depict the observations.

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 radially changing inner disk structure/dynamics. For details, see **Varga et al. A&A, in press, astro-ph: 1704.05675.**

References

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