Investigating the MIR variability of the protoplanetary disk of DR Tau

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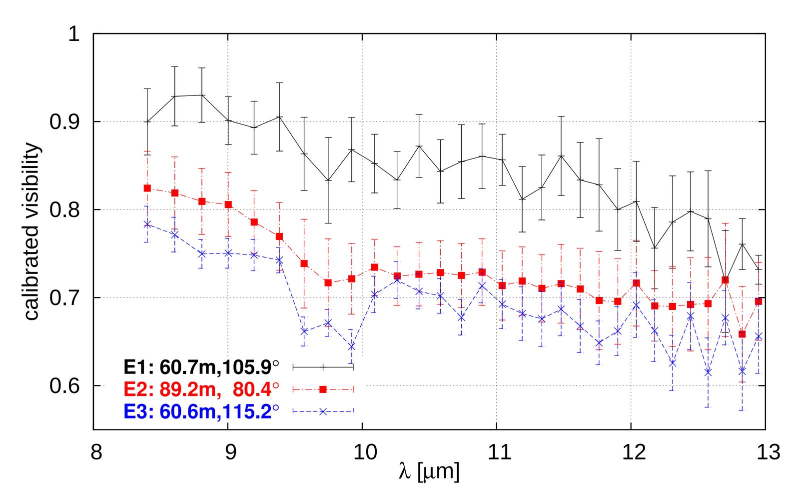
1. Introduction

We investigate the variability of the protoplanetary disk of DR Tau and present self-consistent disk models. These models reproduce highly spatially resolved interferometric data obtained with MIDI at the VLTI at three different epochs as well as photometry data. Young stellar objects such as T Tauri stars show brightness variabilities. These flux variations can be traced from UV up to MIR wavelengths beeing subject of many photometric and spectroscopic studies in the past. Due to its quite strong, long and short term photometric and spectroscopic variability, the obtained parameters of DR Tau and its surrounding disk vary with every new study.

2. MIR observations and data analysis

- Observed with MIDI/VLTI (fed by UT's) at three epochs
- Visibility for E1 is the arithmetic mean of the two calibrated measurements



Epoch	Date of Observation	proj. [m]	Baseline [deg]
E1	01-01-2005	61.0	106.1
	01-01-2005	60.4	105.6
E2	20-10-2013	89.2	80.4
E3	20-12-2013	60.6	115.2

Figure 1: *Left:* Calibrated MIR visibility of DR Tau for the three different epochs January 2005 (E1), October 2013 (E2), and December 2013 (E3). *Right:* Journal of observation.

- Visibilities of E1 differ significantly from those of E3 (9 years apart) although baseline lengths (BL) and orientations are nearly the same
- This indicates changes of brightness distribution and hence the underlying density distribution in the innermost regions of the disk ($\lesssim$4 AU)
  $\Longrightarrow$ Observations E1 and E3 cannot be reproduced by a static disk model!
- Visibility of E2 is higher than visibility of E3, although resolution is higher (much longer BL)
  $\Longrightarrow$ It could be a hint for short term variations or for a non-rotationally symmetric disk!

In summary, our interferometric observations indicate the presence of a non-axisymmetric structure of the disk and/or temporal variations of the disk structure in mid-infrared bright regions of the disk.

3. Disk model and fitting

- Density distribution:

$$\varrho(r,z) \propto r^{-\alpha} \exp\left[-\frac{1}{2}\left(\frac{z}{h(r)}\right)^2\right] \qquad h(r) = h_{100}\left(\frac{r}{100\ \mathrm{AU}}\right)^{\beta}$$

- Due to coupling of temperature and surface density, α and β are not independent.
- Mixture of 62.5% astronomical silicate and 37.5% graphite
- $n(s) \propto s^{-3.5}$, with $s \in [5, 250]$ nm
- Two blackbodies in the center: star ($T_\star = 4050$ K) + accretion heating ($T_{\mathrm{accr}} = 8000$ K)
- Total luminosity fixed to $L_{\mathrm{tot}} = L_\star + L_{\mathrm{acc}} = 1.9\ \mathrm{L}_\odot$

In the standard fitting approach, the photometric and interferometric data were used simultaneously to reduce the SED degeneracies. This approach is not suitable for our observations. The visibilities obtained at the three epochs cannot be reproduced by a disk with only one parameter set. **Thus, we fit all four sets, SED + 3 visibilities, independently.**

4. Results

Best SED+E3 fit

Interestingly, the best SED fit parameters result in MIR visibilities which are in agreement with those obtained in E3, although the visibilities were not considerd during the SED fitting process!

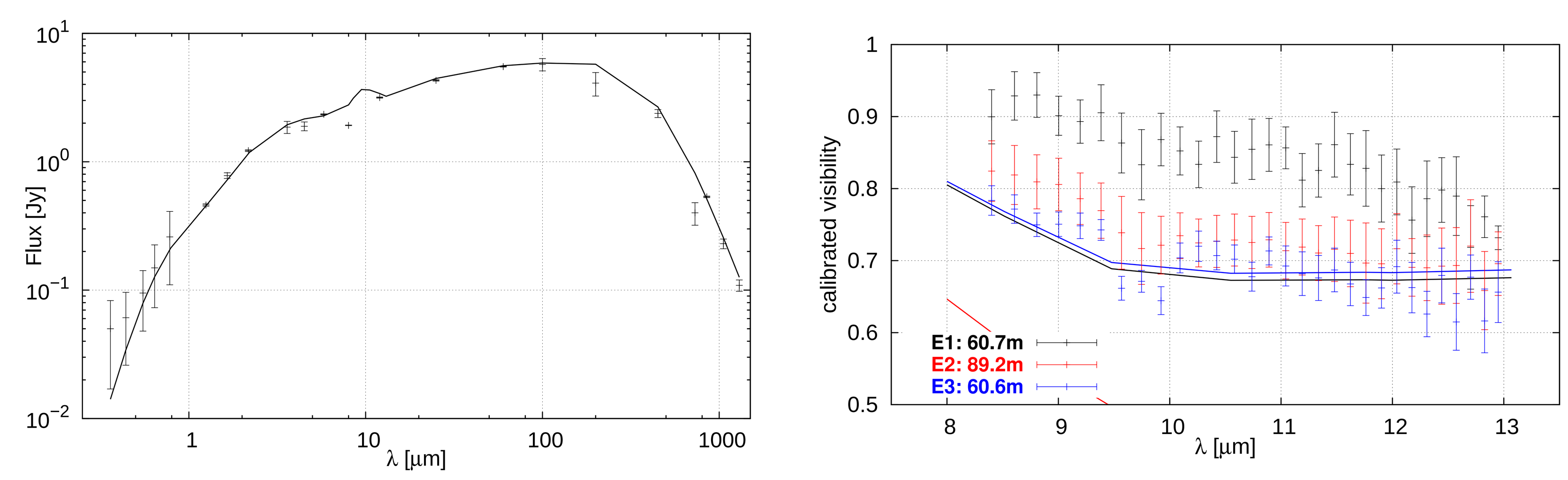


Figure 2: Best SED fit with corresponding MIR visibilities. The three visibility epochs are shown in different colors (black: first, red: second, blue: third). Observations: with uncertainties, Model: solid lines.

Best E1+E2 fit

Our second parameter set reproduces the observations of E1 and E2 simultaneously, although they are almost nine years apart.

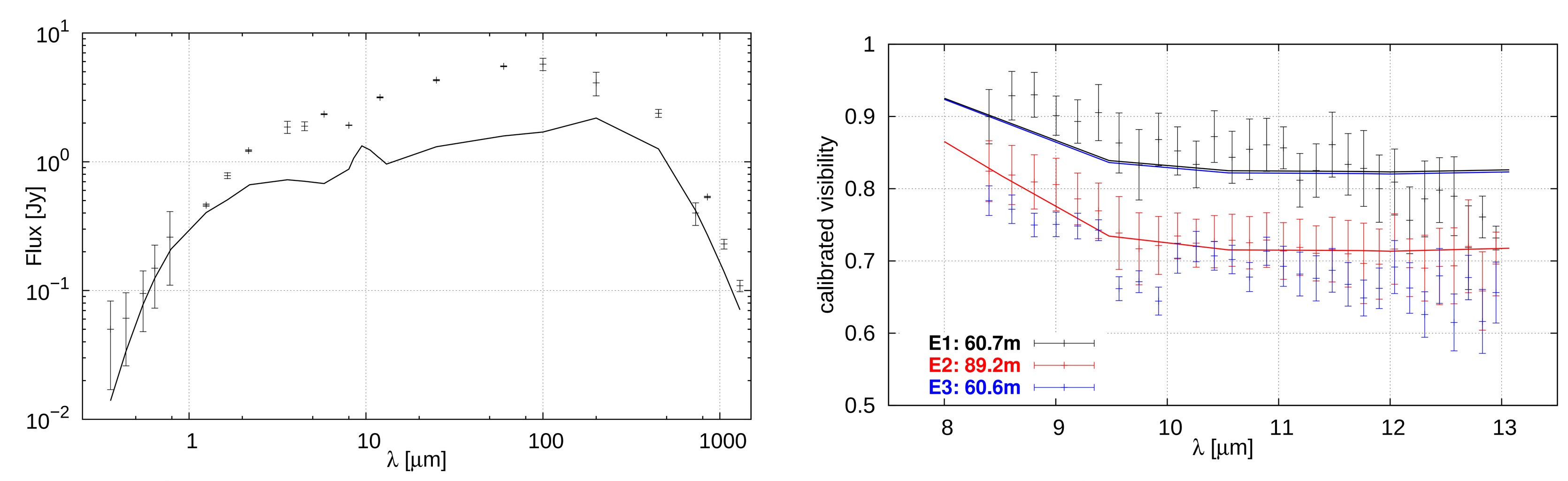


Figure 3: Best fit for first and second epoch visibility with corresponding SED. The three visibility epochs are shown in different colors (black: first, red: second, blue: third). Observations: with uncertainties, Model: solid lines.

Disk parameter	Best fit value	
	SED + E3	E1 + E2
$L_\star$ [L$_\odot$]	0.9	0.9
L_{accr} [L$_\odot$]	1.0	1.0
$T_\star$ [K]$^{\mathrm{fixed}}$	4050	4050
T_{accr} [K]$^{\mathrm{fixed}}$	8000	8000
M_{dust} [M$_\odot$]	3×10^{-3}	3×10^{-3}
R_{in} [AU]	0.111	$0.065^{\mathrm{l.\ bound.}}$
R_{out} [AU]	200	$350^{\mathrm{u.\ bound.}}$
β	1.025	1.025
h_{100} [AU]	18	$10^{\mathrm{l.\ bound.}}$
Inclination i [°]	44	44

- The scale height of model 2 is decreased by nearly 50%
  $\Longrightarrow$ Significantly increases the density in the midplane of the disk
  $\Longrightarrow$ Higher optical depth and hence a more compact emission

Please note, that we fit this model to highly spatially resolved data, and that **only the density of the inner region must have changed from E1/E2 to E3.** For this reason, the SED in Fig. 3 does not match the photometry, for it is a global quantity, not taken into account during this part of the fitting.

5. Conclusion

- Simulations suggest that **hot, inner region of the disk was more compact in January 2005 (E1) and October 2013 (E2) than it was in December 2013 (E3)**
- It is possible that the structural difference is due to a local density variation, such as a density clump
- Orbit of this hypothetical clump is then between 2 and 5 AU, which is the resolution of MIDI at this distance!
- The photometric data set is based on observations made at different epochs, i.e., at different stages of temporal evolution of the disk
  $\Longrightarrow$ Detailed studies over different timescales are necessary to achieve a better understanding of the temporal variations of protoplanetary disks and thus the underlying disk physics.

With the second generation instrument MATISSE, a much better uv-coverage will be possible than with MIDI. MATISSE will measure with four baselines up to six visibilities at once, which is crucial, for a consistent view on the disk at one certain point in time. With existing MIDI data, new observations will enable us to trace disk evolution on timescales of more then 15 years.