Tracing characteristic perturbations resulting from Planet-Disk and Binary-Disk interaction in protoplanetary disks

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Overview, Context and Objective

The perturbation by an additional, gravitating component (planet, binary star) within a protoplanetary disk induces characteristic large-scale structures in the disk density profile. We investigate the observability of these perturbations.
On the basis of a large number of (M)HD and SPH simulations, we calculate synthetic scattered and polarized light images as well as thermal re-emission maps of these models and predict the observational results for different instruments from the optical to the (sub)mm wavelength range with a special focus on ALMA.

In the **first study (A)** (Ruge et al., 2013a,c) we investigate the observability of the planet-disk interaction for different star-disk-planet configurations. We predict that ALMA is able to observe planet-induced gaps around stars of various types and for a large range of disk masses. Besides this, we find that ALMA can trace small, local perturbations indicating zonal flows in the disk. The detectability of gaps in scattered light is limited to a range of total disk masses between $10^{-4}\,\mathrm{M}_\odot$ and $10^{-6}\,\mathrm{M}_\odot$. Gap detections in both wavelength ranges are feasible for $M_{\text{disk}} \approx 10^{-4}\,\mathrm{M}_\odot$.

In our **second study (B)** (Ruge et al., 2013b) we investigate the observability of perturbations in young circumbinary disks for several orbital elements of the binary system. We find that ALMA will allow one to trace characteristic AU-sized spiral arm features in disks in face-on orientation and also to detect binary-induced perturbations in the edge-on brightness profiles. We find that the technique of differential polarimetry offers the potential for significantly clearer detections of these disk structures than imaging in scattered light alone.

A.1 Model Setup for Planet-Disk study

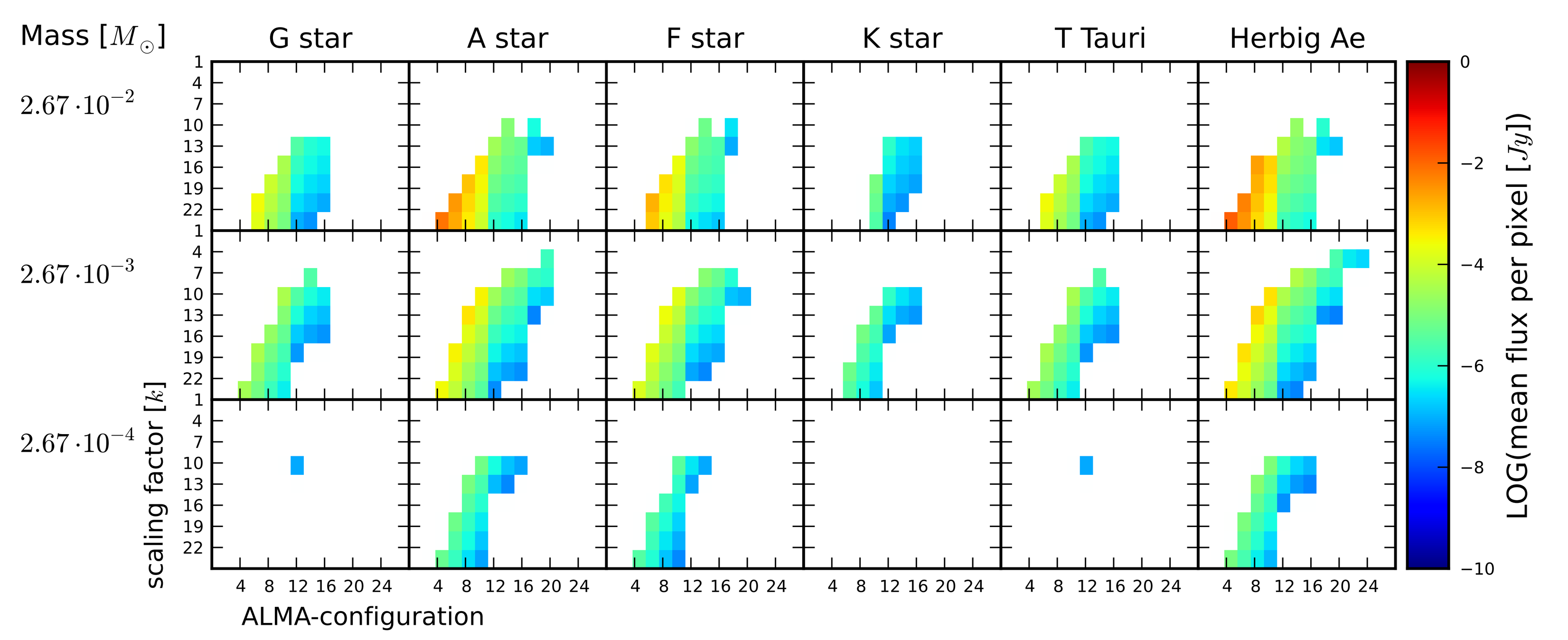
We performed three-dimensional HD and MHD simulations with PLUTO (Mignone et al., 2007) and follow-up radiative transfer simulations with MC3D (Wolf et al., 1999; Wolf, 2003) to produce ideal images of the disk model at ALMA bands. Subsequently, ALMA observations were simulated with the CASA ALMA simulator (Petry et al., 2012). To adapt the size of the disk models we scale their radial extent by the factor k.

Stars:	MS: K, G, F, A & PMS: T Tauri, Herbig Ae
Grain size distribution:	$a \in [0.005\,\mu\text{m}, 0.25\,\mu\text{m}]$ (*small dust grains*)
$\mathrm{d}n(a)/\mathrm{d}a \propto a^{-3.5}$	$a \in [0.005\,\mu\text{m}, 100\,\mu\text{m}]$ (*large dust grains*)
Planet-to-star mass ratio:	10^{-3} ($\sim$ *Jupiter*), 10^{-4} ($\sim$ *Neptun*)
Scaling factor:	$k \in \{1, 4, 7, 10, 13, 16, 19, 22, 25\}$
Disk size (unscaled $\hat{=}$ $k = 1$):	$R_{\text{in}} = 2\,\text{AU}$, $R_{\text{planet}} = 5\,\text{AU}$, $R_{\text{out}} = 9\,\text{AU}$
Total disk mass:	$M = 2.67 \times 10^{-7\cdots-2}\,\mathrm{M}_\odot$

A.2 Detecting Planet-induced Gaps

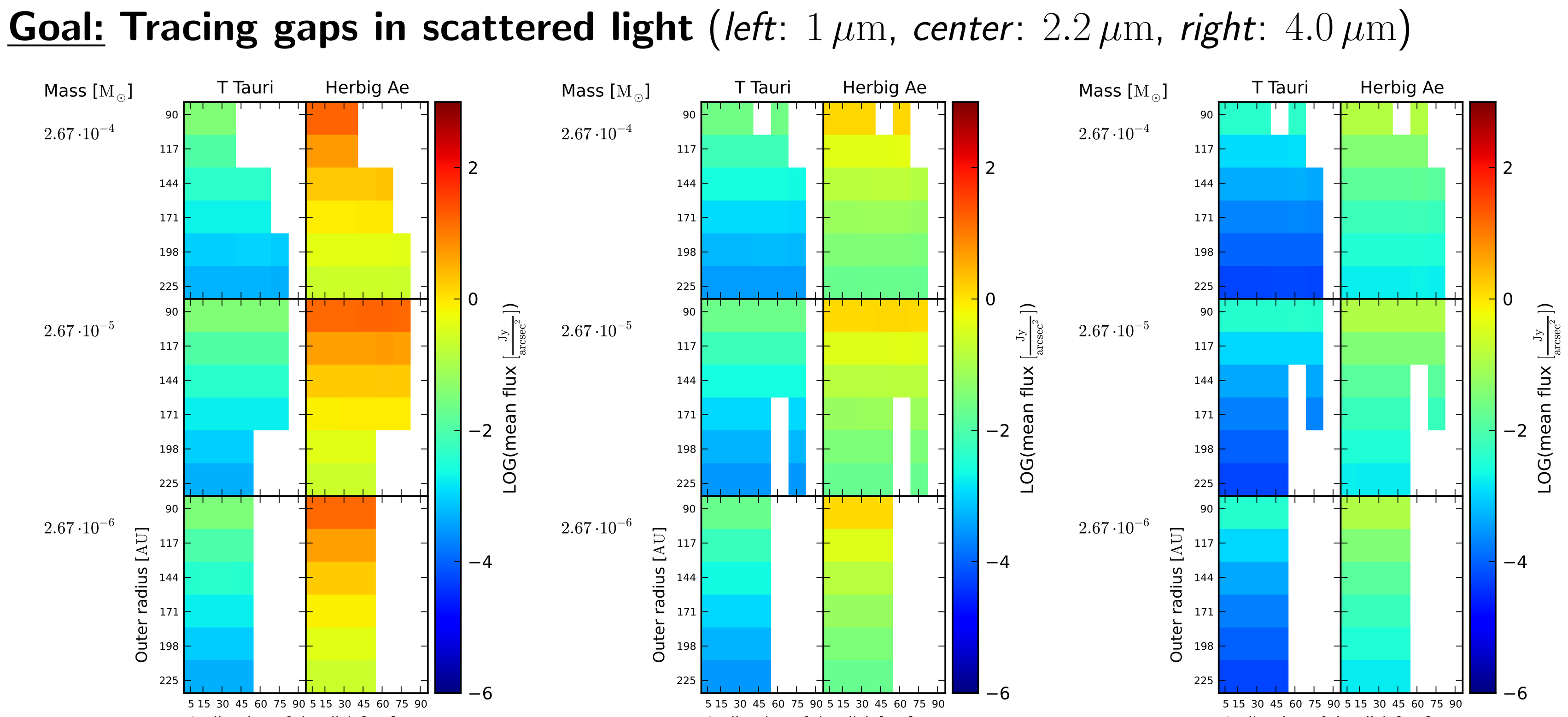
All combinations of the properties of the central star, disk mass and size, and ALMA configuration (for the scattered light: inclination instead of ALMA configuration), which allow one to trace a planet-induced gap are printed color-coded in the overview chart below. Exposure time: $2\,\text{h}$, Dust: large grains.

Goal: **Trace gaps induced by a Jupiter-mass planet ($R_{\text{planet}} = k \times 5\,\text{AU}$) at $430\mu\text{m}$**



In scattered light the gap is detectable if the $\tau_\lambda = 1$-surface of the disk is located within a region of the density distribution where the gap is already prominent.

Goal: **Tracing gaps in scattered light** (*left*: $1\,\mu\text{m}$, *center*: $2.2\,\mu\text{m}$, *right*: $4.0\,\mu\text{m}$)



Publication and Online Material

For a detailed preparation and proper analysis of observations and surveys see:

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All simulation results are available online at:

http://www1.astrophysik.uni-kiel.de/~placid/

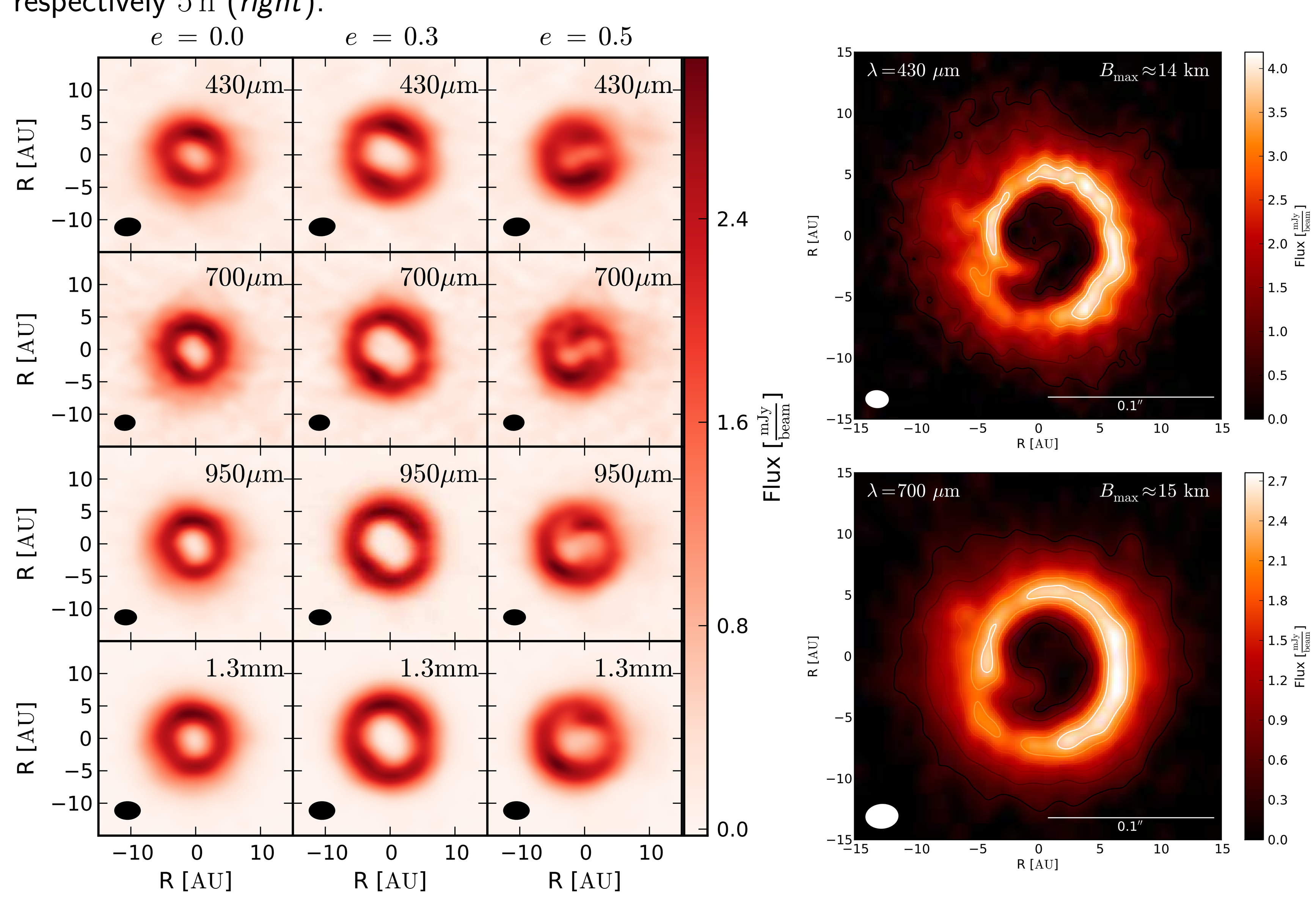
B.1 Model Setup for Circumbinary-Disk study

The procedure is similar to those mentioned in **A.1** with the exception that the disk structure is simulated with the SPH method (see Demidova et al., 2010a, 2013).

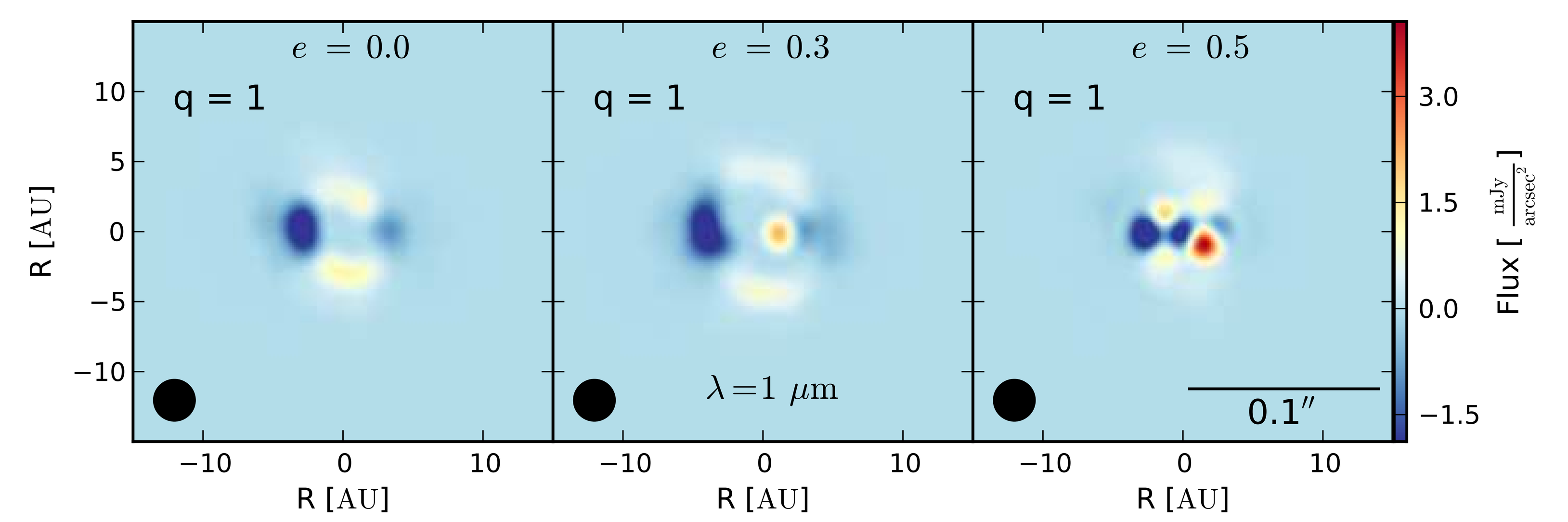
Primary component:	$M = 2.5\,\mathrm{M}_\odot$, $L = 43\,\mathrm{L}_\odot$, $T = 9500\,\mathrm{K}$
Secondary components:	$q = 1.0$: $L = 43\,\mathrm{L}_\odot$, $T = 9500\,\mathrm{K}$
(q : binary-mass ratio)	$q = 0.1$: $L = 0.7\,\mathrm{L}_\odot$, $T = 4000\,\mathrm{K}$
	$q = 0.01$: $L = 0.003\,\mathrm{L}_\odot$, $T = 2700\,\mathrm{K}$
Disk size:	$R_{\text{out}} = 15\,\text{AU}$, $a_{\text{bin}} = 2\,\text{AU}$
Grain size distribution:	$\mathrm{d}n(a)/\mathrm{d}a \propto a^{-3.5}$, where $a \in [0.005\,\mu\text{m}, 100\,\mu\text{m}]$
Eccentricities & Inclinations:	$e \in \{0.0, 0.3, 0.5\}$ & $i \in \{0°, 5°, 10°, 20°, 30°\}$
Total disk mass:	$M = 4.4 \times 10^{-3}\,\mathrm{M}_\odot$

B.2 Observing Binary-induced Structures

The figures show simulated ALMA observation that allow one a detection of the inner cavity (*left*) and the spiral arms (*right*) resulting from the binary-disk interaction. Exposure time $2\,\text{h}$ (*left*), respectively $5\,\text{h}$ (*right*).



In polarized light ($\lambda = 1\,\mu\text{m}$) observations with an ideal $8\,\text{m}$-class telescope would allow one to trace a nearly circular ring in the disk, complementary to potential ALMA observations.



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