Infer exoplanets within or outside a planetesimal belt with debris disk observations

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Introduction

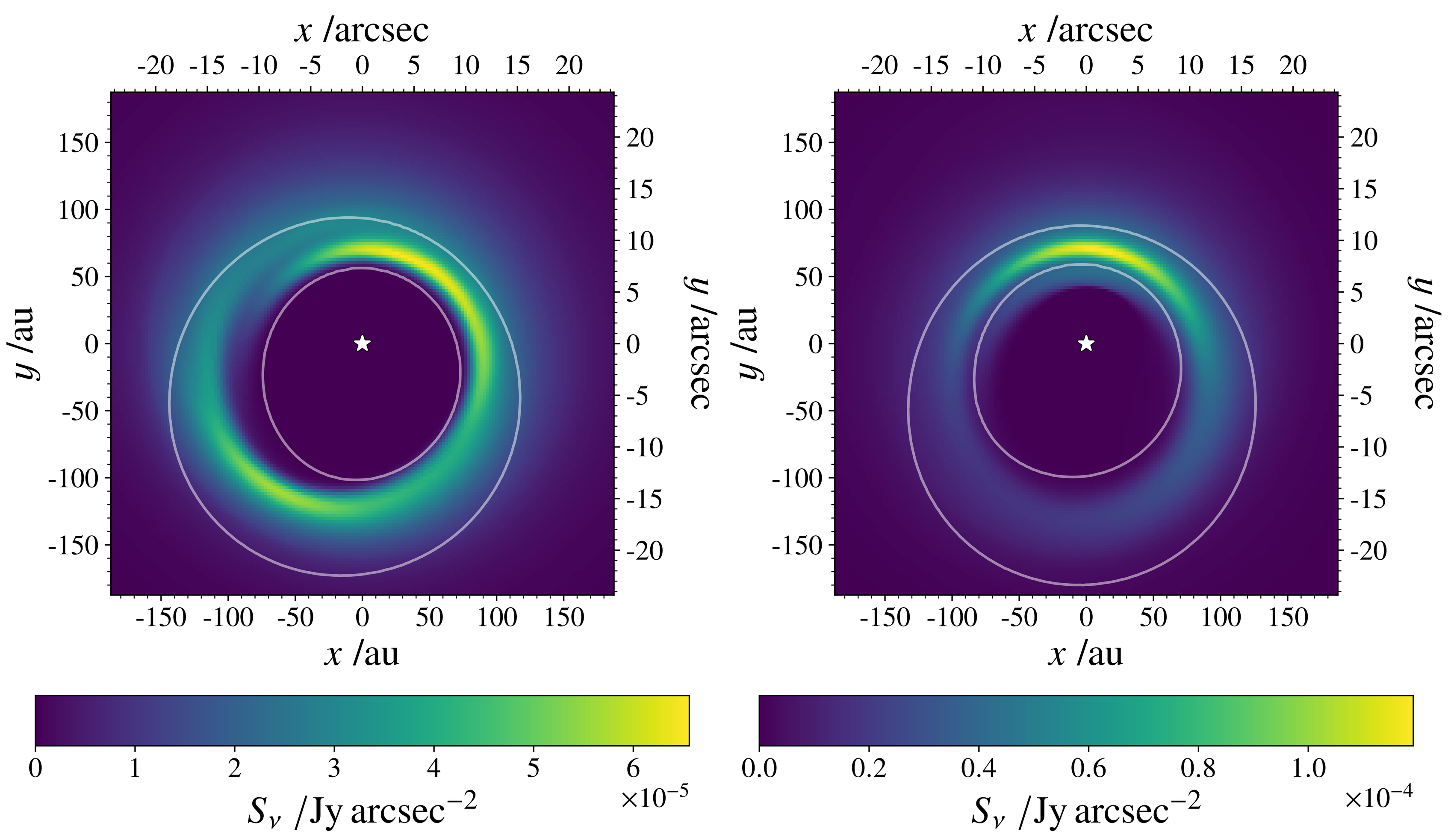
Debris disks and exoplanets often exist in the same system. The possibly unseen exoplanets influence the dust dynamics via their own gravitational potential. Thus, from spatially resolved observations of dust conclusions regarding the co-orbiting planets can be drawn.
We simulated the collisional evolution of narrow and eccentric cold planetesimal belts (e.g., Fomalhaut) that are secularly perturbed by an exoplanet. Using the results we performed observational simulations.
In maps of surface brightness we identified several features suitable for distinguishing between systems with an exoplanet orbiting within or outside the parent planetesimal belt, especially by using combined observations with JWST/MIRI in the Q band tracing small grain emission and ALMA tracing large grain emission (Stuber et al. 2023).

Simulation parameters

Central star	$T_{\rm eff} = 8600\,$K,	$M_\star = 1.92\,M_\odot$,	$L_\star = 16.6\,L_\odot$,	$d = 7.7\,$pc
Planetesimal belt	$M_{\rm b} = 0.09\,M_\oplus$,	$a_{\rm b} = 100\,$au,	$\Delta a_{\rm b} = 10\,$au	
Inner Planet	$a_{\rm p} = 20\,$au,	$e = 0.6\,$au,	$M_{\rm p} \in \{0.5, 2.5, 12.5, 62.5\}\,M_{\rm J}$	
Outer Planet	$a_{\rm p} = 500\,$au,	$e = 0.6\,$au,	$M_{\rm p} \in \{2.5, 12.5, 62.5\}\,M_{\rm J}$	

Here $M_{\rm b}$ is the total belt mass in objects with radii $s < 500\,$m and $\Delta a_{\rm b}$ the spread in orbital semi-major axes of the belt.

Inner vs. outer perturber at 21 µm (Q band)



Surface brightness distribution for a system with an inner planet (*left*) and an outer planet (*right*). The white contour lines enclose the emission of the corresponding 1300 µm map of the same system and hence enclose the position of the parent planetesimal belt.
Note for the *left* system with the inner planet the spiral structure, two bright azimuthal arcs, and an emission free inner region and note for the *right* system with the outer planet the single bright arc and the emission from the inner disk region.

Observations are feasible

- Use JWST/MIRI in Q band to trace small grains with sizes near the blow out limit.
- Use ALMA to trace large grains located close to the planetesimal belt.
- Generally, the best choice of wavelength depends on:
  - The blow out grain size and hence
  - the characteristics of the central star as well as
  - the semi-major axis of the planetesimal belt.

References

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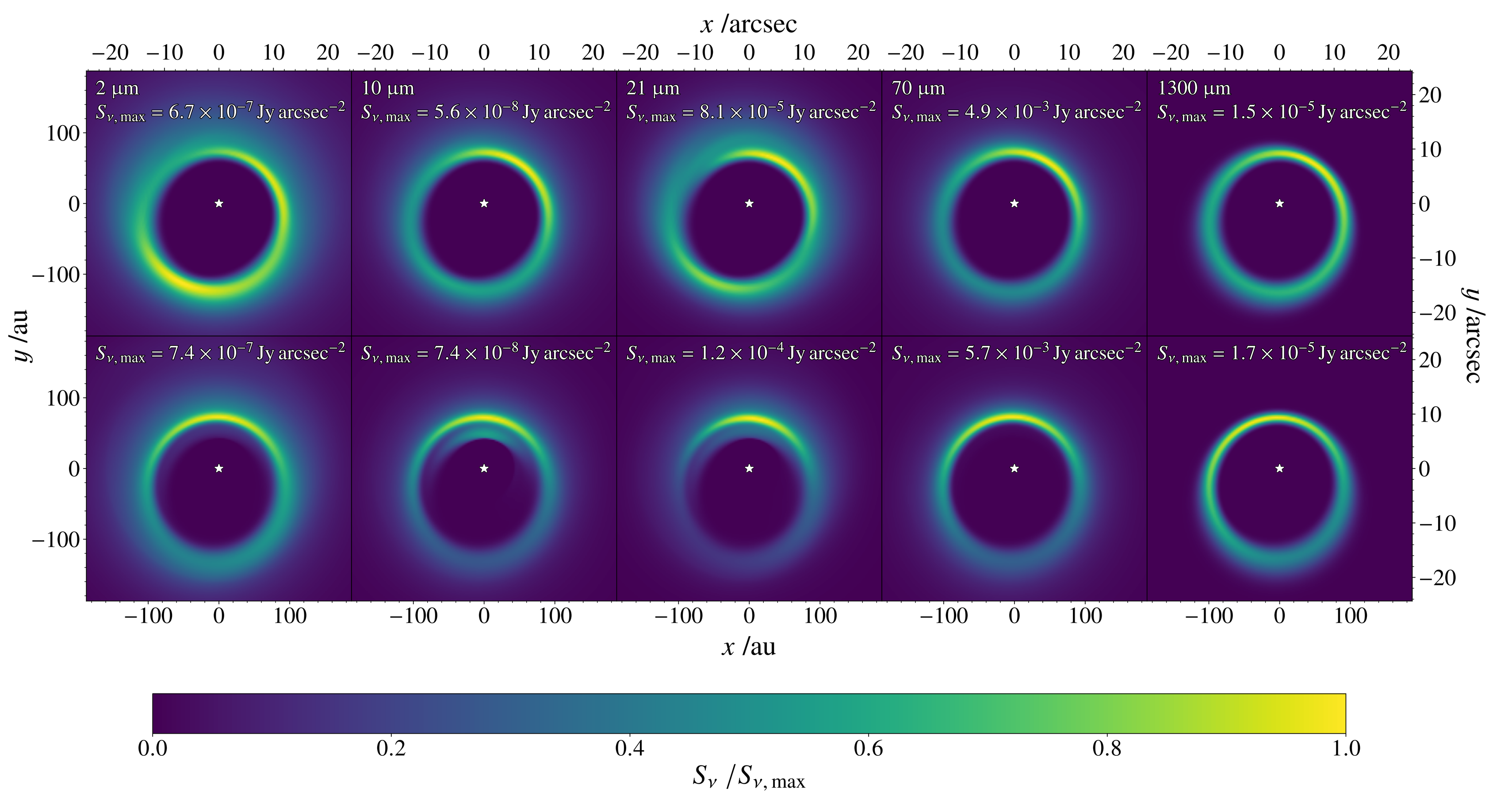
Method

1) Simulate collisional evolution using the N-body code `ACE` (e.g., Krivov et al. 2005; Löhne et al. 2017; Sende & Löhne 2019) considering:
   - Collisional cascade,
   - Pressure by stellar radiation and stellar wind,
   - Poynting-Robertson drag,
   - Secular gravitational perturbation by a planet.
2) Simulate surface brightness distributions using the code DMS (Kim et al. 2018) at the observing wavelengths:
   - 2 µm (scattered stellar light),
   - 10 µm (scattered stellar light),
   - 21 µm (thermal emission of smallest grains with sizes near the blow out limit),
   - 70 µm (thermal emission of small grains),
   - 1300 µm (thermal emission of large grains).

Top: inner planet system
Bottom: outer planet system



Maps of surface brightness for a system with an inner planet (*top*) and an outer planet (*bottom*) at wavelengths ranging from 2 µm to 1300 µm. The assumed distance to the stellar system is 7.7 pc (e.g., Fomalhaut).

Decision tree: inner or outer planet?