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Exploring the signatures of planet formation with multi-wavelength interferometry

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Abstract

Pre-transitional disks are protoplanetary disks with a gapped disk structure, potentially indicating the presence of young planets in these systems. In this contribution, we present VLTI and Keck near- and mid-infrared interferometric observations that allow us to explore the structure of these objects and their gap-opening mechanism. For instance, our observations on V1247 Orionis revealed a narrow, optically-thick inner-disk component (located at 0.2 AU from the star) that is separated from the optically thick outer disk (radii > 46 AU), providing unambiguous evidence for the existence of a gap in this pre-transitional disk. Surprisingly, we find that the gap region is filled with significant amounts of optically thin material with a carbon-dominated dust mineralogy. The presence of this optically thin gap material cannot be deduce solely from the spectral energy distribution, yet it is the dominant contributor at mid-infrared wavelengths. Furthermore, using Keck/NIRC2 aperture masking observations we detect asymmetries in the brightness distribution within the gap region, indicating an inhomogeneous distribution of the gap material. We interpret this as strong evidence for the presence of complex density structures, possibly reflecting the dynamical interaction of the disk material with the sub-stellar mass bodies that are responsible for the gap clearing.

1. Introduction

Planets are believed to form in the circumstellar disks around young stars, either through a process of core accretion [10] or gravitational instabilities in the more extended disk regions [2]. A particularly interesting phase in this process starts when the newly-formed planetary bodies have gained sufficient mass to interact with the ambient disk material and affect the disk structure significantly [9]. Potential candidates for disks that might have been dynamically affected by planetary bodies are the *transitional disks* [12] and *pre-transitional disks* [5], These objects exhibit a strong far-infrared ($> 20\,\mu$m) excess, but have a significantly reduced near-infrared (NIR) to mid-infrared (MIR) excess compared to classical T Tauri disks. This reduced excess emission indicates that the innermost disk regions contain only optically thin gas and dust or exhibit an extended gap, which separates the optically thick inner disk from the outer disk. The inner “holes” and gaps observed in transitional/pre-transitional disks could be caused by disk-planet interaction [11, 7], but several alternative disk clearing scenarios have been proposed, incl. grain growth [4], magnetorotational instabilities [3], photoevaporation [1], and truncation by close-in stellar companions [6].

2. Spatially resolved constraints on the gap geometry

Most of the aforementioned processes take place in the inner few astronomical units (AU) around the central star, corresponding to angular scales $\rho < 0.01$”, even for the nearest young stars. Given that these scales are not accessible with conventional imaging techniques, earlier studies relied mostly on the modelling of spatially unresolved constraints, in particular the spectral energy distribution (SED). However, these modelling techniques suffer from well-known degeneracies – grain temperature, for instance, is sensitive to both its distance from the illuminating star, the particle size, and the dust composition [13]. Therefore, we initiated a large-scale campaign to study these objects using a multi-wavelength interferometry approach. The data set includes interferometric data from the Keck Interferometer and Very Large Telescope Interferometer (VLTI), single-dish interferometric data from Keck & Gemini South, sub-millimeter interferometry from SMA, and spectroscopic data from IRTF. Given the wide wavelength coverage, our interferometric observations probe a wide range of dust temperatures and material located over a wide range of stellocentric radii, from sub-AU to tens of AU.

For instance, our VLT+Keck interferometric observations on the pre-transitional disk of V1247 Orionis [8] revealed a narrow, optically-thick inner-disk component (located at 0.2 AU from the star), which is separated from the optically thick outer disk (radii > 46 AU). Surprisingly, we find that the gap region is filled with significant amounts of optically thin material with a carbon-dominated dust mineralogy (Fig. 1). The presence of this optically thin gap material cannot be deduced solely from the spectral energy distribution, but might be indicative of a particularly early stage of disk clearing.

Using Keck/NIRC2 H-, K'-, and L-band aperture masking observations, we also detected highly significant asymmetries on spatial scales of tens of AUs. The direction and amplitude of the asymmetries changes with wavelength, which leads us to reject a companion origin and to conclude that the asymmetries are related to strong density inhomogenities in the gap region, possibly caused by the dynamical interaction of the gap material with the gap-opening body/bodies.

3. Conclusions

Multi-wavelength interferometric observations on transitional and pre-transitional disks now provide the exciting opportunity to explore the early phases of planet formation and to study the dynamical impact of the planets on the disk environment directly. Such observational evidence is essential to test planet formation theories and to link our knowledge of planet formation and disk evolution to the planetary system demographics observed in main-sequence systems. In this contribution, we will discuss the objectives of our ongoing observing campaign and present first results.

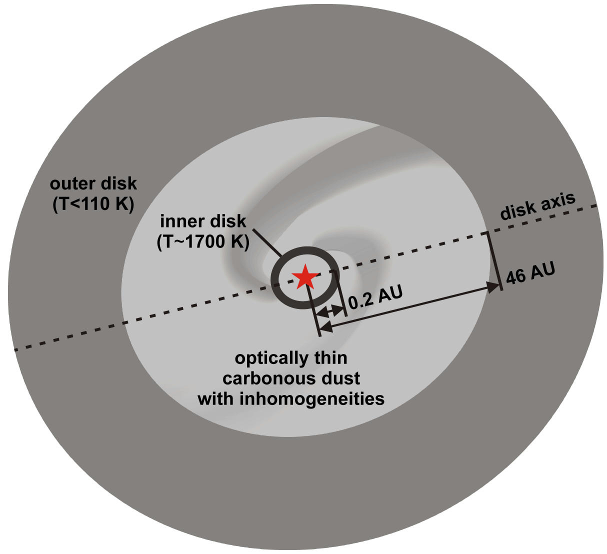

Figure 1: Illustration of the V1247 Orionis system, as constrained by our spectro-interferometric observations [8], featuring a narrow, ring-like inner disk at the dust sublimation radius (0.2 AU), an extended disk gap, and an optically thick outer disk (at radii > 46 AU).

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