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Sub-AU study of CI Tau with VLTI/GRAVITY

The key to link stellar activities, disks and planets.

For a few million years after the gravitational collapse that led to their formation, young stellar systems remain surrounded by a circumstellar disk from which planets form. ALMA and VLT/SPHERE have provided spectacular images of the planet-forming disks on a scale of a few 10 au (Garufi et al. 2017) and, even more recently, led to the direct detection of forming planets within the disk (Benisty et al. 2021). In contrast, the exploration of the innermost disk regions (≤1 au) has remained quite challenging so far. Moreover, the Kepler satellite has revealed that the most ubiquitous planetary systems consist of compact strings of super-Earth and mini-Neptunes orbiting close to their host star (P_{orb} ≤ 100 days, e.g., Otegi et al. 2022,). It is, therefore, crucial to investigate the physics of the star-planet-inner disk interaction in young stars, not only for the role it plays in the early evolution of solar-type stars (e.g., accretion/ejection, angular momentum, etc.) but also to determine the environmental conditions that prevail at the time of planetary formation. This is a necessary step towards understanding the formation of the plethora of compact inner low-mass planetary systems observed across the Galaxy. CI Tau is so far the only pre-main sequence star still accreting from its surrounding disk (classical T-Tauri star) claimed to host a hot Jupiter planet. However, the periodic radial velocity variation could result from magnetospheric accretion onto the star rather than from an orbiting body (Donati et al. 2020). The most interesting aspect of CI Tau regards its extreme magnetic field (3.7 kG) that disrupts the inner gaseous disk and generates accretion funnel flows down to the stellar surface. We propose to present our investigation about the inner region of CI Tau, aiming at reconnecting the different spatial scales of the system down to a few stellar radii (≤0.1 AU).

Method: We investigated this puzzling question using the long-baseline interferometry technique, the only way to probe the inner region of the system at sub-AU precision. Thanks to the high spectral resolution of VLTI/GRAVITY (R=4000), we are both sensitive to the emitting dusty part of the inner rim (K-band continuum), and the magnetosphere itself traced by the Brγ emission line.

Results: In the continuum, we characterise the disk's inner rim, which appeared to be disconnected from the outer disk with a large misalignment both in inclination and position angle. We report an internal rim position at 0.17 ± 0.02 AU, remarkably more significant than the theoretical sublimation radius of 0.03-0.06 AU. Such difference could infer the presence of a planet carving the inner part of the disk, as recently supported by hydrodynamical simulation (Muley et al. 2021). The non-zero closure phases measured by GRAVITY suggest an important asymmetry in the disk: the southwest side appears brighter than the northeast. Such difference argues in favour of an inclined disk where the brilliant (and farthest) part is seen from the bottom (distant observer point of view). We confirmed such behaviours using radiative transfer modelling with RADMC3d. In the Brγ line (2.1661 μm), our model suggests a bright but smaller emitting region than the thermal emission with a radius of 0.04 ± 0.01 AU (4 times smaller than the inner rim). Such characteristic is strongly supported by the magnetosphere accreting models developed in our team and will be presented for comparison.

Conclusion: With GRAVITY, we characterise the inner disk of CI Tau with a sub-AU precision, allowing a direct comparison with the standard YSO's characteristic sizes such as sublimation, co-rotation or magnetic truncation radii. The existence of a larger than expected central cavity could be an observational signature of the well known 11.6 Mj planet (CI Tau b). The substantially detected misalignment between inner and outer disks constitutes a challenge for the modelling efforts and should be carefully investigated in the future.