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# Spatially Resolving the Innermost Regions of the Accretion Discs of Young, Low-Mass Stars with GRAVITY

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**Low-mass, young stars — the T Tauri stars — make up the majority of young stellar objects. They have been relatively unexplored with optical long baseline interferometry owing to the cooler temperatures of their stellar photospheres which makes them fainter and more compact than the more frequently studied intermediate mass, young stars — the Herbig Ae/Be stars. With its greater flux sensitivity, GRAVITY has allowed us to explore T Tauri stars at high angular resolution in unprecedented detail. Here we present highlights from two such studies.**

GRAVITY is enabling substantial progress in high-angular-resolution studies of star formation. Its spectrograph's greatly improved *K*-band flux sensitivity compared to the first-generation VLTI instrument Astronomical Multi-BEam combineR (AMBER), for example, has unlocked the previously poorly studied sample space occupied by the low-mass (T Tauri) stars — which comprise the majority of young stellar objects. The flux sensitivity is further increased by GRAVITY's unique dual-field mode which allows for longer integration observations with the spectrograph if a sufficiently bright, neighbouring star exists within a few arcseconds. GRAVITY's ability to observe with high angular and high spectral resolution across the *K*-band allows us to study the dynamic inner regions of protoplanetary discs and to directly measure the processes by which mass is accreted onto stars and launched into outflows.

## Discs identified around the low-brightness stars in the binary CO Ori

Wide-separation young stellar binary systems often feature circumprimary and circumsecondary discs. During GRAVITY science verification, we used the VLTI's Auxiliary Telescopes (ATs) to observe the individual components of the CO Ori young stellar binary (Programme ID 60.A-9159; PI Davies). While the primary component (CO Ori A) was sufficiently bright ($K$ = 6.0 magnitudes) for standard single field mode observations, the secondary (CO Ori B: $K$ = 9.0 magnitudes) required GRAVITY's unique dual-field mode. Our observations confirmed the existence of individual circumstellar discs around both components and spatially resolved them for the first time.

CO Ori B displayed Brγ emission in its spectrum, which is typically associated with accretion and related outflow processes in young stars. This provided further evidence for the existence of a circumsecondary accretion disc. Meanwhile, the absence of Brγ emission in the spectrum of CO Ori A may indicate that accretion onto the primary star is weaker or otherwise inhibited. We investigated whether the characteristic size of the near-infrared emission is consistent with the location of the dust sublimation rim, as has been seen to be the case for discs around more massive young stars (for example, Lazareff et al., 2017). We compared the continuum visibilities to geometric models incorporating a central point source and a Gaussian component, finding a characteristic radius of 2.31 ± 0.04 milliarcseconds. At first glance, this appears large compared with the expected location of the dust sublimation rim and observations with GRAVITY on longer baselines are required to confirm this result.

CO Ori A also exhibits a 12.4-year periodicity in its optical photometry (Rostopchina et al., 2007), potentially indicating the presence of an additional, as yet undetected, companion. Using our best-fit geometric modelling result and the fringe tracker visibilities and closure phases obtained for CO Ori A, we searched for evidence of off-centre brightness contributions which may indicate the presence of such a companion. Within the field of view probed by our short baseline observations, we found no evidence for an additional companion to CO Ori A. Furthermore, we were able to rule out the presence of companions providing as much as 3.6 per cent of the total $K$-band flux within 7.3 to 20 milliarcseconds (Figure 1). These results are presented in greater detail in Davies et al. (2018).

## Magnetospherically truncated discs

In 2018, we used GRAVITY's high spectral dispersion ($R$ = 4000) mode to observe the low-mass, young star CW Tau (Programme ID 102.C-0755; PI Hone) in single-field mode. We fit the fringe tracker visibilities with a two-dimensional geometric model comprising a central point source (simulating the star), a ring (simulating

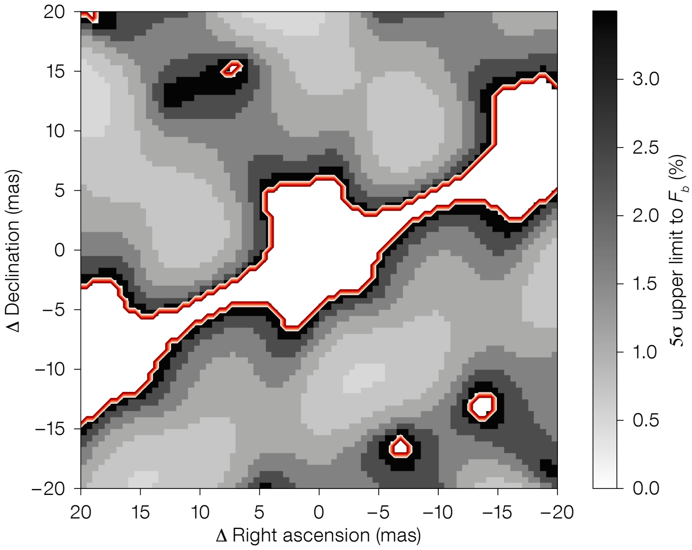


Figure 1. CO Ori A sensitivity map produced using the best-fit model from our modelling of the continuum visibilities. Each pixel in the map is coloured to reflect the maximum possible flux contribution that a companion could have at that position and remain undetected. As our observations do not sample the entire uv plane, we are not sensitive to companions in regions outlined in red.

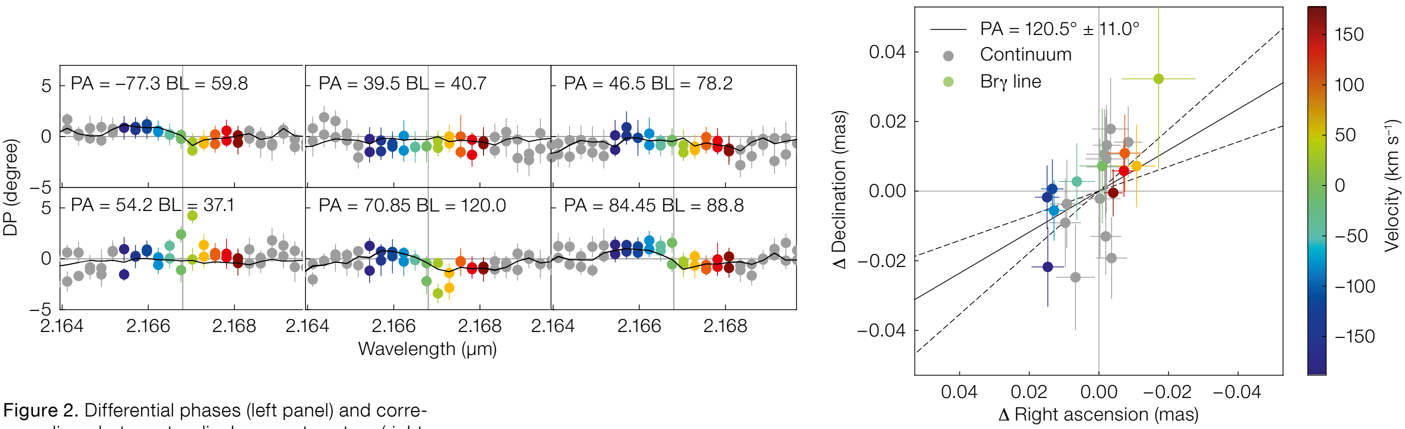


Figure 2. Differential phases (left panel) and corresponding photocentre displacement vectors (right panel) across the Brγ line for CW Tau. The black lines in the left panel indicate how well the photocentre shifts match the differential phases. The solid black lines in the right panel show the best-fit position angle of the motion between redshifted and blueshifted vectors, with the dashed line indicating the uncertainty.

disc emission on milliarcsecond scales) and an extended Gaussian component (simulating over-resolved larger-scale disc emission). The best-fit ring radius from our model (0.56 ± 0.2 milliarcseconds) corresponds to a physical distance of 0.074 ± 0.03 astronomical units. We find this distance to be consistent with the magnetospheric truncation radius and, from this, estimate a dipolar magnetic field component strength of ~ 2 kG for CW Tau. This value is consistent with those previously found for low-mass young stars via spectropolarimetric techniques (for example, Donati et al., 2010; Hill et al., 2019).

We also used our differential phases to calculate model-independent photocentre shifts across the Brγ emission line, tracing the small-scale displacement of the centroid as a function of wavelength. The photocentre displacement vectors reveal a clear displacement between redshifted and blueshifted material along a position angle of 120.5 ± 11.0 degrees, (Figure 2). The position angle of the motion traced by the photocentre shifts is closer to the minor axis of the disc of CW Tau as seen by ALMA (150.7 degrees; Bacciotti et al. 2018), suggesting that the Brγ emission predominantly traces motion out of the disc plane. This indicates the existence of a complex velocity field traced by the Brγ emitting gas, such as the launching of a jet or the motion of material being carried along magnetospheric accretion funnels. Indeed, the presence of a jet emerging away from the star-disc system, towards the south-east, along a position angle of ~ 150 degrees has been observed previously by, for example, Gomez de Castro (1993) and McGroarty, Ray & Froebrich (2007). These results form part of the PhD thesis of Edward Hone and will be presented in more detail in Hone et al. (in preparation).

## GRAVITY's impact and outlook for the future

GRAVITY has extended high-resolution studies of star formation to the low-mass T Tauri stars. The availability of four-telescope beam combination has also enabled more efficient uv-plane sampling. The arrival of NAOMI, the adaptive optics system for the ATs, during the summer of 2019 has further improved the flux sensitivity and we look forward to further probing how well our understanding of star formation, garnered from the study of intermediate-mass young stars, is transferable to the low-mass T Tauri stars.

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The landscape of the Chajnantor Plateau on which the antennas of the Atacama Large Millimeter/submillimeter Array (ALMA) are located.