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Disk properties in high-mass star formation

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Abstract. We present a case-study for one of the sources in the CORE survey, W3(H_2O). We resolve two fragments at ~700 AU resolution with velocity gradients of ~5 km s^{-1} whose rotational axes are consistent with the observed directions of two molecular outflows. Assuming the structures to be in differential Keplerian-like rotation around ~10 $M_\odot$ (proto)stars, a stability analysis of the fragments shows small Toomre Q values in the outskirts of the rotating structure, hinting at the possibility for further fragmentation of this core via disk fragmentation.

1. Introduction

Among the unanswered questions in the field of high-mass star formation are those related to the existence of inner accretion disks and their characteristics. Recent theoretical models have shown that high-mass stars can be formed through disk accretion (e.g., Krumholz et al. 2009; Kuiper et al. 2011). Observationally, only a few disks have been found around the most massive, O-type stars (e.g., Johnston et al. 2015; Ilee et al. 2016; Cesaroni et al. 2017). Our IRAM NOEMA large program, CORE, aims to study a sample of 20 highly luminous clumps/cores to study fragmentation and disk formation in the early phase of high-mass star formation through continuum and line observations at 1.36 mm. An overview of the survey is presented separately in this volume (Beuther et al.) as well as a case study focusing on larger-scale effects (Mottram et al.). In the following, we showcase our results for one of the most chemically rich sources in our sample, W3(H_2O).

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2. W3(H_2O)

At the source distance of 2 kpc (Hachisuka et al. 2006), we resolve two cores separated by ~2000 AU in our 1.36 mm dust continuum observations of W3(H_2O) at ~700 AU scales. The top panel in Figure 1 shows the intensity-weighted peak velocity (moment 1) map of CH_3CN (12−11) $K = 3$ in colour with 1.36 mm dust continuum contours. While the full entity shows an overall velocity gradient in the E-W direction, there exist gradients of ~5 km s^{-1} in velocity across each of the cores. Two collimated bipolar molecular outflows are detected with one emanating from each of the cores perpendicular to the observed velocity gradients. Further analysis of the position-velocity diagrams of each of the cores excludes the possibility of the rotating motion being due to infall motions and the core to the west shows signatures of differential rotation with higher velocity gas closer to the center. The core to the east does not, and therefore could either be a circumstellar disk-like object, or be harbouring multiple sources in circumbinary rotation and unresolved by our observations.

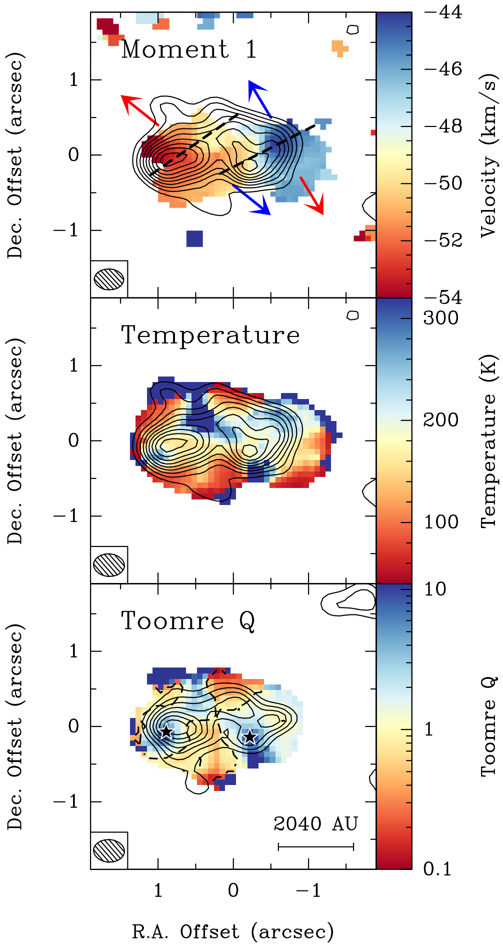

Fig. 1. *Top:* Moment 1 map of CH_3CN (12−11) $K = 3$ in colour with 1.36 mm continuum contours, starting at 6σ and increasing in steps of 3σ. The dashed lines present the directions of rotation. The blue and red arrows show the positions and directions of the two bipolar molecular outflows emanating from each source as extracted from our ^{13}CO spectra and according to Zapata et al. (2011). *Middle:* Rotational temperature map obtained by fitting CH_3CN (12−11) $K = 4-6$ lines with XCLASS. *Bottom:* Toomre Q map obtained by assuming two disks in Keplerian rotation about the positions of peak continuum emission as depicted by stars. The solid contours correspond to our continuum data in the most extended configuration, starting at 6σ and increasing in steps of 3σ. The dashed line corresponds to $Q = 1$.

Using the XCLASS software (Möller et al. 2017), we fit the CH_3CN (12 − 11) $K = 4 - 6$ lines under LTE assumptions valid for such high-density environments. We obtain a rotational temperature map for the object as presented in the middle panel of Fig. 1 with average temperatures of ∼180 K. To understand the stability of these rotating structures against axisymmetric gravitational collapse as quantified by Toomre (1964), we use our temperature map to create a Toomre Q map presented in the bottom panel of Fig. 1. We have assumed the existence of disks in Keplerian rotation about two 10 $M_\odot$ (proto)stars at the positions of the continuum peaks as depicted by the stars in the figure.

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