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The kinematics of the magnetized protostellar core IRAS15398-3359

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ABSTRACT

Context. Observations of protostellar envelopes are essential in order to understand better the process of gravitational collapse toward star and planet formation. From a theoretical perspective, magnetic fields are considered an important factor during the early stages of star formation, especially during the main accretion phase.

Aims. Our aim is to study the relation between kinematics and magnetic fields at a very early stage of the star formation process by using data from the Atacama Pathfinder EXperiment (APEX) single-dish antenna with an angular resolution of 28".

Methods. We observed the two molecular lines $C^{18}O$ (2-1) and DCO^+ (3-2) toward the Class 0 young stellar object IRAS15398-3359. We implemented a multi-component Gaussian fitting on the molecular data to study the kinematics. In addition, we used previous polarization observations on this source to predict the influence of the magnetic field on the core.

Results. The velocity gradient along the central object can be explained as an ongoing outflow motion. We report the flowing of material from the filament toward the central object, and the merging of two velocity components in the $C^{18}O$ (2-1) emission around the protostar position, probably due to the merging of filamentary clouds. Our analysis shows that the large-scale magnetic field line observed previously is preferentially aligned to the rotation axis of the core.

Key words. Stars: formation – Stars: protostars – Magnetic fields – Astrochemistry – ISM: kinematics and dynamics

1. Introduction

Observing protostellar envelopes around very young protostars is fundamental to gaining a better understanding of the progression of the collapse of protostellar cores toward planetary systems. Class 0 objects are known to represent the youngest stage of protostellar evolution (André et al. 1993; André et al. 2000). Most of their mass is contained in a dense envelope that accretes to the central protostar during the main accretion phase (Maury et al. 2011; Evans et al. 2009). Protostars are deeply embedded in their parent cores, which may cause interactions between protostellar outflows and surrounding gas leading to complex morphologies. Detailing these structures will allow us to learn about the dynamics of protostellar evolution at an early stage. In light of these circumstances, it becomes essential to investigate in detail the earliest stages of star formation for specific sources.

The study of the extent and contribution of magnetic fields in star formation and the competition between magnetic and turbulent forces is still a highly debated topic in modern astronomy (e.g., Mac Low & Klessen 2004; McKee & Ostriker 2007; Crutcher 2012). However, in the star formation process, especially during the early stages, magnetic fields (B) are expected to play a crucial role, providing a source of non-thermal pressure against the gravitational pull (McKee & Ostriker 2007). In light of the fact that interstellar gases are often mildly ionized (Caselli et al. 1998), the matter is likely to be coupled with the magnetic field lines at envelope scales. Due to gravity, magnetic lines bend inward, thus producing an hourglass shape, and in low-mass star-forming regions this effect is not detected frequently (detected in 30 percent of young stellar objects in polarization; Hull & Zhang 2019; Pattle et al. 2022).

IRAS15398-3359 (hereafter IRAS15398) is a low-mass Class 0 protostar at a distance of 156 pc (Dzib et al. 2018), embedded in the Lupus I molecular cloud, $\alpha_{2000} = 15^h43^m02^s.2$, $\delta_{2000} = -34°09'07.7''$. It has a bolometric temperature of 44 K (Jørgensen et al. 2013). The protostellar mass is $0.007^{+0.004}_{-0.003} M_\odot$ (Okoda et al. 2018). Lupus I is the least evolved component of the Lupus complex (Rygl et al. 2013), and optical polarization studies have demonstrated that Lupus I is threaded by a very ordered magnetic field that is perpendicular to its filamentary extension (Franco & Alves 2015). Therefore, it is an ideal place to study the kinematics of the early stages of low-mass star formation and the connection between the source kinematics and the strong large-scale magnetic field. By observing its CO emission line with the single-dish and interferometric observation, a molecular outflow was detected from this source (Tachihara et al. 1996; Bjerkeli et al. 2016; van Kempen et al. 2009). The core is embedded in a less dense ($N(H_2) \sim 10^{22}$ cm^{-2}) filamentary structure, which extends toward the northwest.

Based on magnetic field studies in protostellar core simulation analysis, more magnetized cores show strong alignments of the outflow axis with the magnetic field orientation, whereas less magnetized cores display more random alignment (Lee et al. 2017). Observational results present a mixture of cases. Galametz et al. (2018) used a sample of 12 low-mass Class 0 protostars to investigate the submillimeter polarized emission at scales of ~ 600 - 5000 au, and demonstrated a relation between the field morphology, the core rotational energy, and the multiplicity of the protostellar system. According to that paper's analysis, the envelope scale magnetic field tends to be either aligned or perpendicular to the outflow direction, but for single sources