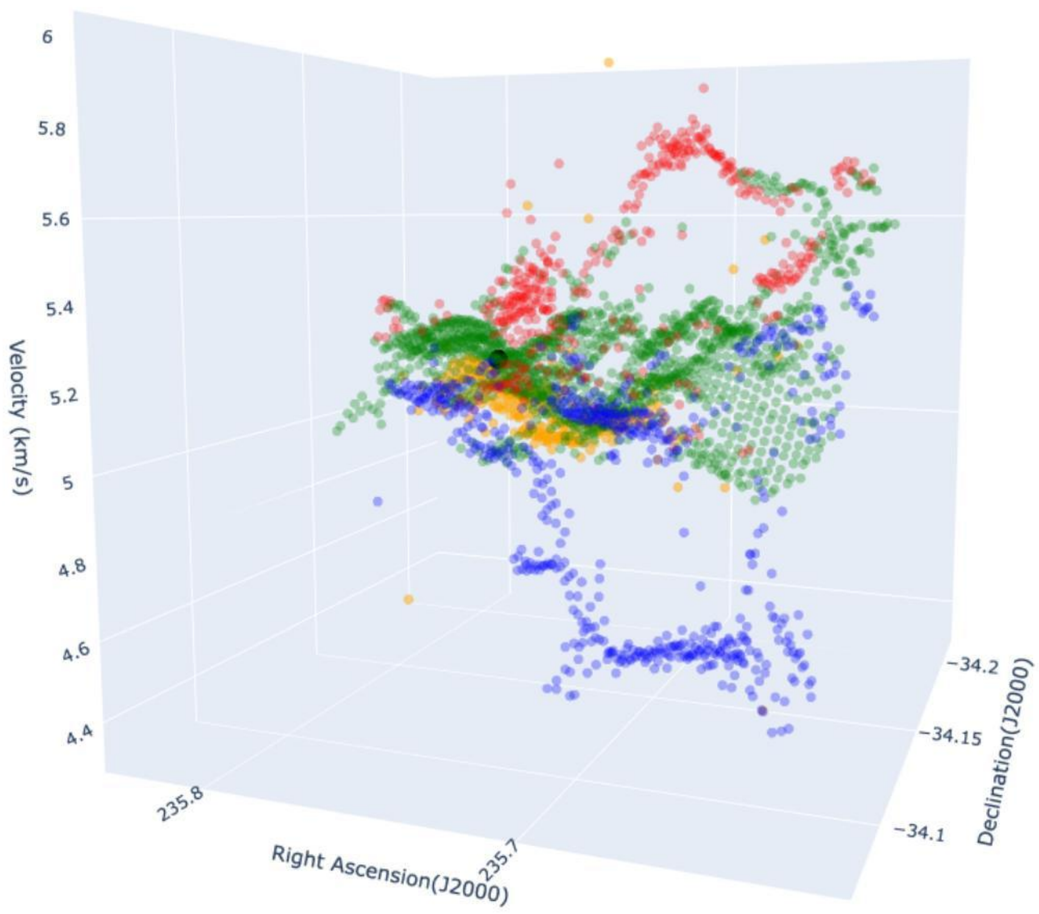

Fig. 7: PPV image of $C^{18}O$ (2-1) and DCO^+ (3-2) gas. Each data point denotes the location and centroid velocity of a Gaussian component and each color refers to a different Gaussian fit. The the centroid velocity is shown for the DCO^+ (3-2) line (in orange), and the green data points represent the brightest component of the $C^{18}O$ (2-1) line. The red and blue data points indicate the two lower intensity velocity components. The black circle represents the position of the protostar.

Figure 7 shows that the main velocity component of the $C^{18}O$ (2-1) data and the DCO^+ (3-2) line present a systematic velocity shift. The $C^{18}O$ (2-1) data always appear at a higher velocity than the DCO^+ (3-2) spectra. In order to investigate this point further, we show in Fig. 8 the velocity difference $V_{lsr}(C^{18}O)$ - $V_{lsr}(DCO^+)$ with the H_2 column density overlaid on top. In addition, we did not find any correlation between the velocity shift and the H_2 column density map. In this figure the shift between $C^{18}O$ (2-1) and DCO^+ (3-2) is clearly visible. We report a mean velocity shift of 0.13 km s^{-1} across the whole source. The largest velocity shift values are found on the west side of the protostellar core, where the infalling material from the envelope reaches the core, under the assumption that the small velocity gradient seen along the filament represents an accretion flow. On the southeast and northwest sides of the core there is a very low-velocity shift, equal to $\sim$ 0.06 km s^{-1} and these values are increasing toward the protostar position up to 0.10 km s^{-1}. To calculate these low-velocity shifts we use the pixels indicated with a black plus sign in Fig. 8.

5. Discussion

Star-forming regions can be more completely understood by analyzing the distribution of different molecular species in the velocity. We compare the velocity shift between these two tracers in the cloud. The velocity shift between a neutral and an ionized species was observed in the past. For instance, Henshaw et al. (2013) studied the large-scale velocity field throughout the cloud in G035.39-00.33, and found a velocity shift between the two tracers of N_2H^+(1-0) and $C^{18}O$ (1-0), in agreement with a model of collision between filaments that is still ongoing. It follows that the velocity structure of the core does not have intrinsic properties but is a product of large-scale motions on filamentary

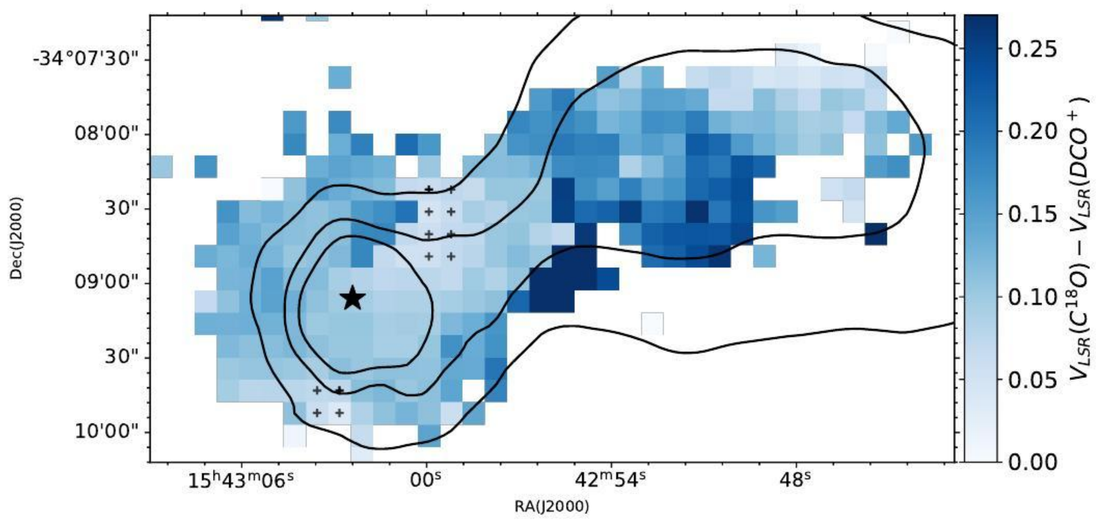

Fig. 8: Map of velocity shift between $C^{18}O$ (2-1) and DCO^+ (3-2). Overlaid in black contours is the H_2 column density (levels:[1.0,1.5,2.0] 10^{22} cm^{-2}). The black star represents the position of the protostar and the black plus signs are positions of the lowest velocity shifts, which are used for the mean value.

scales. They proposed that the velocity difference in the cloud occurs because of filament merging, implying that higher velocity filaments are interacting with a lower velocity, less massive filament, increasing the density of an intermediate velocity filament (Barnes et al. 2018).

Another scenario is that the velocity shift between the $C^{18}O$ (2-1) and DCO^+ (3-2) reveals relative motions between the dense gas, traced by DCO^+ (3-2), and the surrounding less dense envelope, traced by $C^{18}O$ (2-1). DCO^+ (3-2) is simply tracing higher densities, which may not necessarily have the same velocities as the gas traced by $C^{18}O$ (2-1), especially because the $C^{18}O$ (2-1) emission is much more extended, so the kinematics derived from the line profile is affected by lower density material not seen in DCO^+ (3-2). According to Zhang et al. 2017, velocity shifts between high-density and low-density tracers within a cloud are indicative of gas expanding and contracting. It is based on the assumption that the higher critical density molecules trace the dense gas closer to the inner of a core, while lower critical density molecules trace the more extended gas in the outer envelope.

Magnetic braking might have had a great impact in this cloud. We determined that the rotation axis of the core and magnetic field lines are almost aligned. According to the magnetohydrodynamic (MHD) collapse models, magnetic braking should be effective in this cloud, which is in agreement with the absence of a resolved Keplerian disk. Magnetic braking is an effective way to remove angular momentum from infalling and rotating material, suppressing envelope fragmentation and the formation of large disks.

6. Conclusions

We studied the region around the young low-mass Class 0 source IRAS15398 using APEX. The kinematic analysis performed with the $C^{18}O$ (2-1) emission line as a low-density material tracer (extended gas) and with the DCO^+ (3-2) line as a tracer of dense gas closer to the protostar. The measured kinematics parameters revealed several properties by performing Gaussian fitting, using the PYSPECKIT package. Our main conclusions can be summarized as follows:

- From the spectral line profiles we conclude that the two velocity components of $C^{18}O$ (2-1) in the west side of the region have merged together toward the position of the protostar. $C^{18}O$ (2-1) is a lower-density tracer than DCO^+ (3-2); the fainter velocity component seen only in the former tracer