complex kinematics in a highly filamentary irdc

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What are the initial conditions required to form massive stars?

We study the kinematics of dense molecular gas within a highly filamentary Infrared Dark Cloud (IRDC), G035.39-00.33, using high-angular resolution (4'') PdBI observations of N_2H^+ (1-0).

Case Study: IRDC G035.39-00.33 (distance ~ 2.9 kpc; Simon et al. 2006):

- Mass ~ 10^4 M_{sun} (Kainulainen & Tan 2013; hereafter KT13); density ≥ 10^4 cm^{-3} (Henshaw et al. 2013); temperature < 20 K (Nguyen-Luong et al. 2011)
- Extended quiescent regions; multiple massive cores (> 20 M_{sun}; Nguyen-Luong et al. 2011), without 8/24 μm emission (Carey et al. 2009).
- Widespread SiO emission - remnant of large-scale shock interaction induced by cloud-cloud collisions (Jimenez-Serra et al. 2010)?
- Widespread CO depletion - freeze-out (Hernandez et al. 2011).

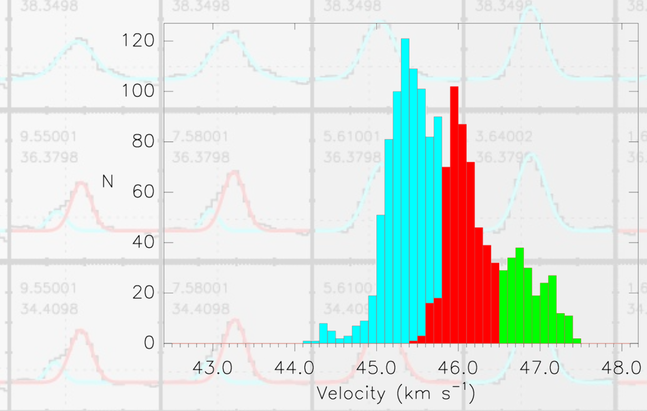

Figure 1: Histogram of the three velocity components across the IRDC, identified through the fitting routine highlighted in the background figure. The identification of the three filaments (F2a: cyan, F2b: red, F3: green) has been made possible due to the high-sensitivity and high-spectral resolution PdBI data.

Background Figure: (Grey) Integrated intensity of high-angular resolution (~4'') N_2H^+ (1-0) PdBI data (isolated comp. only), focusing on massive clump H6. Overlaid on top are the results from our semi-automatic Gaussian fitting routine. Individual velocity components are colour-coded: F2a (cyan), F2b (red), and F3 (green). The vertical dotted line in each spectrum is at 45.5kms^{-1}, for reference.

results:

• multiplicity:

3, non-thermally broadened (FWHM ~ 0.5-1.5 kms^{-1}), velocity components observed in the mapped region (F2a, F2b, and F3, see Gaussian fits in the background figure, and Fig.1).

Velocity components are spatially resolved. In the left panel of Fig. 2 we show coloured lines indicating the intensity-weighted offsets for each of the three velocity components, tracing different "tracks" in mass surface density.

The densest IRDC filament (F2; Henshaw et al. 2013) is spectrally and spatially resolved (Fig. 2 left panel) into two components (F2a & F2b).

The central panel of Fig. 2 is a 3D Position-Position-Velocity (PPV) of G035.39-00.33. F2b and F3 reside to the North of H6 (see vertical dotted line for location), whereas F2a is more dominant to the South of H6. All filaments are evident at H6.

• velocity structure:

Velocity fluctuations are apparent throughout each filament (see Fig. 2, centre).

Core H6 (white diamond, left panel Fig. 2) exists at the location of two converging velocity gradients. Towards H6, F2a displays an increasing South-North velocity gradient, whereas F3 shows the opposite. Opposing velocity gradients have magnitudes ~ (2.5 ± 0.06) km s^{-1} pc^{-1}.

• shear motions:

Right hand panels of Fig. 2 show PV slices perpendicular to the main axis of the cloud.

Multiple peaks are evident, corresponding to the individual velocity components.

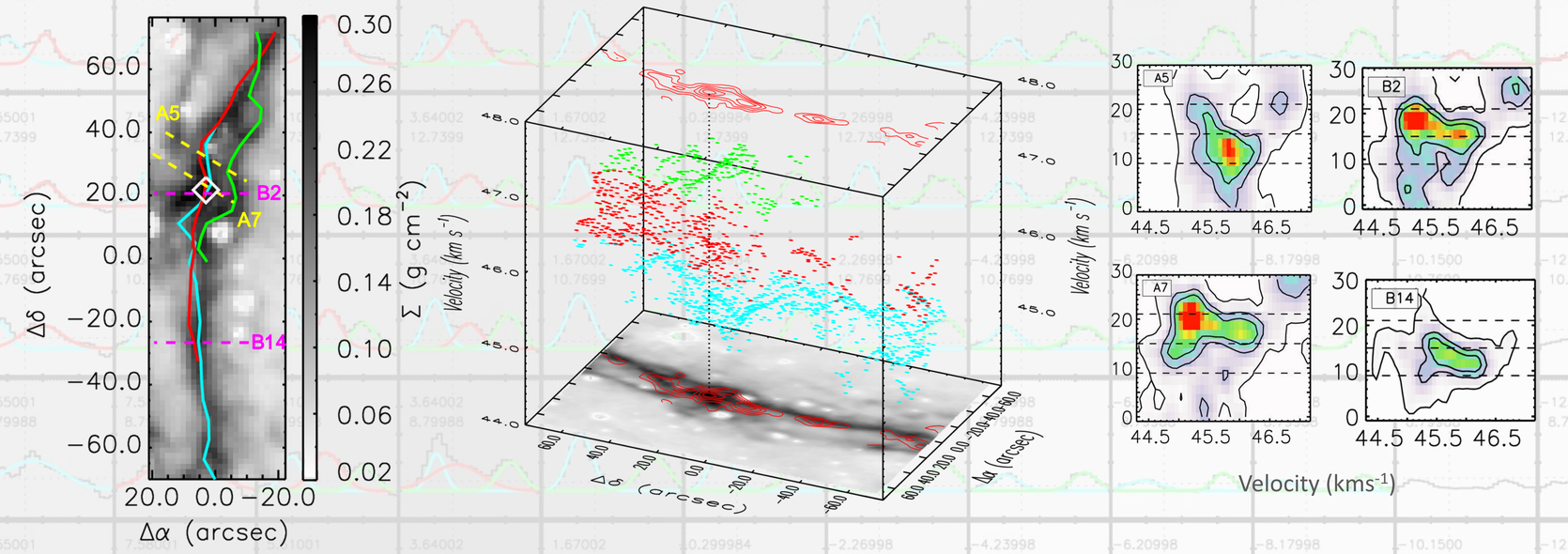

Figure 2: (Left) Mass surface density map from KT13. Coloured lines indicate the "spine" of integrated intensity emission for filaments F2a, F2b, and F3 (cyan, red, and green, respectively). Yellow and Magenta dashed lines refer to the Position-Velocity slices in the far-right panel. The white diamond refers to the position of core H6 from Butler & Tan (2012) **(Centre)** 3D Position-Position-Velocity plot. Grey scale on base – mass surface density from KT13. Red contours – Integrated intensity of N_2H^+ (1-0) PdBI data (isolated comp. only), plotted from 15σ in steps of 5σ (σ ~ 0.1 K kms^{-1}). Coloured points indicate velocity values with respect to position for F2a, F2b, and F3. The vertical dotted line indicates the position of core H6. **(Right)** Position-Velocity plots for the respective slices seen in the far-left panel. Contours show the 3σ, 10σ, and 15σ levels (σ ~ 0.1K). Horizontal dashed lines indicate the central position of the PV slice, and the approximate width of the filament (50% peak mass surface density ~ 0.1-0.2pc).

PV analysis indicates relative shear motions exist between F2a and F2b. The relative motion between these two bodies of gas has a magnitude ~ 13 km s^{-1} pc^{-1}.

conclusions:

- Three distinguishable (both spatially and spectrally) interlocking filaments are observed.
- Filaments display converging velocity flows at the position of H6 (M_{acc} ~ 5.4 x 10^{-5} M_{sun} yr^{-1}).
- Filaments are separated in Velocity by 1-1.5 km s^{-1}, and the individual components have FWHM ~ 0.5-1.5 kms^{-1}.
- Common shear motions exist between F2a and F2b perpendicular to the major axis of the main structure.
- These complex kinematics may be the direct result of a cloud-cloud collision.

references:

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