# The massive GMC NGC 6334 from scales of filaments to clusters and cores: gas kinematics derived from submm observations

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## Motivation

The formation of high-mass stars and how they accrete their gas mass is still unclear, although their impact on the interstellar medium is immense. Our goal is to understand the mass flows from the low density gas of molecular clouds to the center of dense hot cores, and to connect the largest with the smallest spatial scales in order to answer: what scales affect star-formation within a galaxy? The galactic star-forming region NGC 6334 (distance = 1.7 kpc) is one of the best targets for studying massive star formation in the Milky Way (*Russeil et al. 2012, A&A 538*). We surveyed this region at different scales from 60 pc down to 0.01 pc, see **Fig. 1, 2**.

## Observations

| Telescope | Spectral Lines | Purpose |
|---|---|---|
| APEX | $^{13}$CO(2-1),C$^{18}$O(2-1), HCN | probe low density gas of the filaments on large scales |
| SMA | HCN(4-3) + isotopologues | trace dense gas of hot cores, study two clusters in detail |
| Herschel | HCN $J_u$=6...13 | use high-J lines from line survey |

## Analysis

We developed a toolkit which connects two 3D radiative transfer codes, RADMC-3D (*C. Dullemond*) for dust temperature calculation and LIME (*Brinch et al. 2010, A&A 523*) for full non-LTE excitation of chemical species. Simulated spectral line cubes and dust continuum images can be compared with observational data after considering the instrumental response function. This way we derive several physical parameters (temperature, density, velocity, chemical abundance) of sources and deal with multiple components and the fragmentation of clumps (**Fig. 3**).

For the analysis of the filaments, we decompose the spectral line profiles by Gaussian fitting to find and distinguish several velocity components. In contrast to previous Herschel continuum observations, the velocity information allows us to characterize the kinematic structure and turbulence in this region.

## Results

**Filaments: Fig. 1**

- Previous HCN/HCO$^+$ observations with APEX revealed a gravitational collapse of the main filament (*Zernickel et al. 2013, A&A 554*). In the vicinity of the clusters, the filament's mass flows are 1600 $M_\odot$/Myr.
- Molecular gas motions are supersonic ($M_s$=3.2) and sub-Alfvénic ($M_A$=0.5) on many scales. The total mass is 2.3x10$^5$ $M_\odot$ and average temperatures are 20 K. Typical velocity gradients are ~1 km/s/pc with a preferential alignment parallel to the magnetic field B.

**Clusters: Fig. 2, 3**

- Several aspects indicate that NGC 6334I(N) is in a younger evolutionary stage than NGC 6334I. The infall velocity in NGC 6334I (with an embedded UCHII region) is reduced in the center.
- Molecular outflows are misaligned with the large scale magnetic field, which runs mainly along the galactic latitude and seems to be important in regulating the geometry and collapse from the large scales.
- The derived mass accretion rates are 1-2 x10$^{-3}$ $M_\odot$/yr for the envelopes of the clusters and 3x10$^{-4}$ $M_\odot$/yr on average for the cores.

## Conclusions & Questions

- Turbulence seems to govern the motions on small scales, whereas on large scales systematic motions are present.
- Deriving mass accretion rates of the deeply embedded cores is complicated by self-absorption of the surrounding gas envelopes.
- What is the role of the magnetic field in the creation and motions of the filaments? How did the large HII regions influence or trigger a potential new star formation cycle?

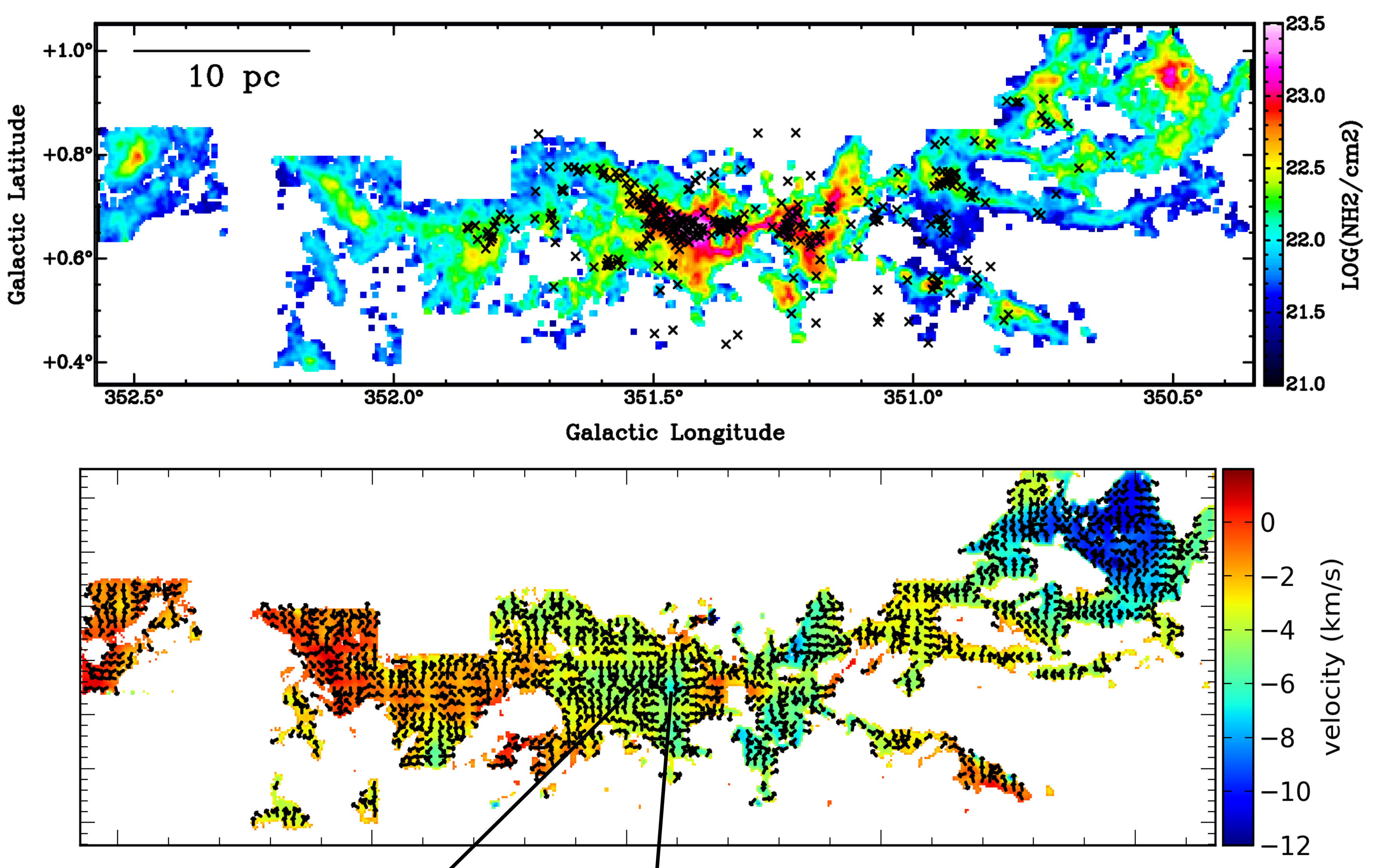


**FIGURE 1.** Top: N($H_2$) column density map of NGC 6334 derived from $^{13}$CO. Crosses mark Class I YSOs (*Willis et al. 2013, ApJ 778*). Bottom: Centroid velocity map of $^{13}$CO. Normalized arrows denote velocity gradients derived from linear fits to this map after the method of *Goodman et al. 1993, ApJ 406*.

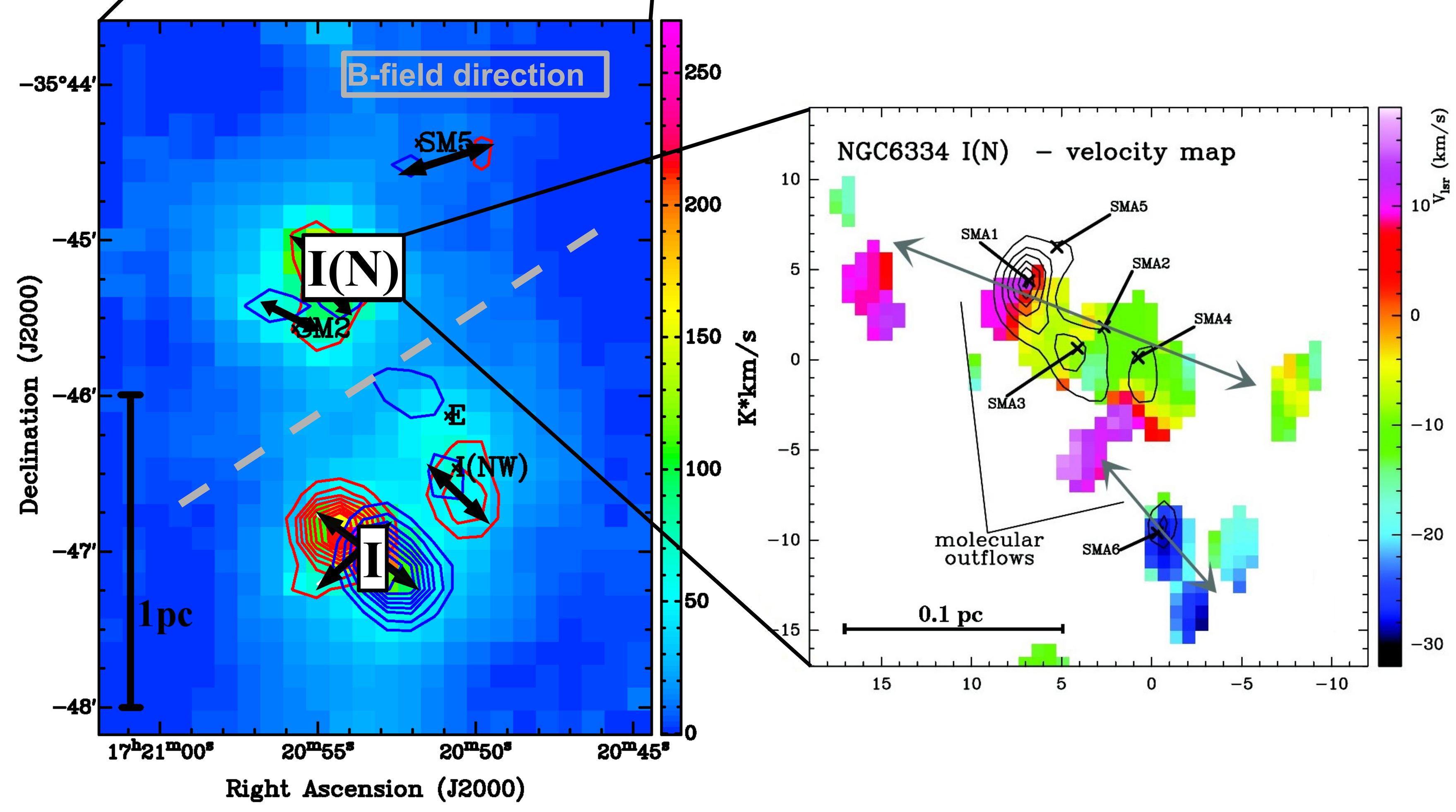


**FIGURE 2.** Left: Integrated HCN and $^{12}$CO (in contours) map with APEX of the two central protostellar clusters NGC 6334I & I(N). Outflows are marked by black arrows, the direction of the magnetic field is shown as gray dashed line. Right: Velocity map in HCN of NGC 6334I(N) with SMA at arcsec scales, demonstrating the fragmentation and dynamics. Black contours denote the dust continuum emission.

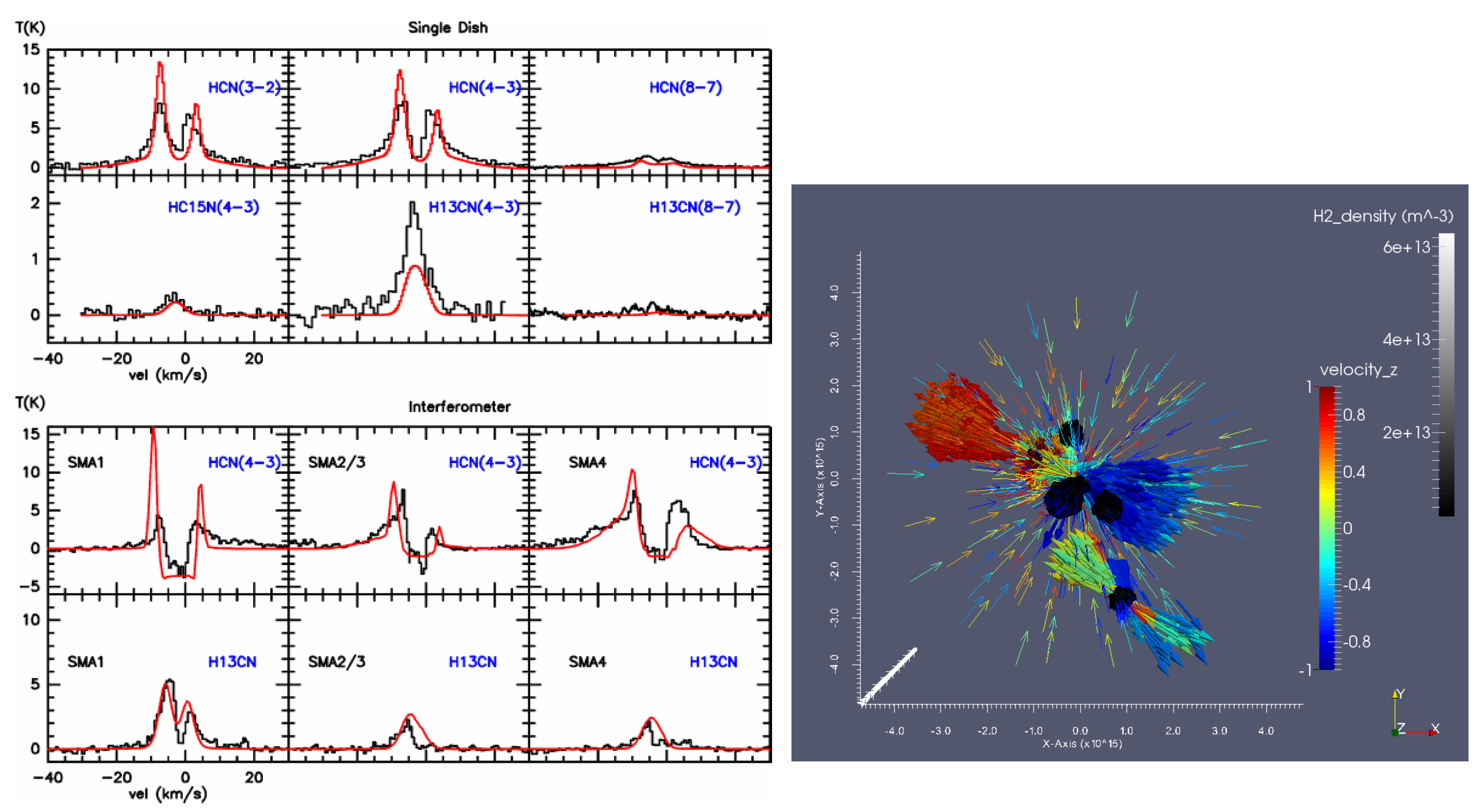


**FIGURE 3.** Left: Observed HCN spectra (black) overlaid with the simulated spectra (red) from the model. Right: 3D representation of the model of NGC 6334I(N), showing the velocity field (normalized in z-direction) and the density distribution of the cores.