Signatures of dynamical collapse during High-Mass Star Formation

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Abstract

Observations of atomic or molecular lines can provide important information about the physical state of star forming regions. In order to investigate the line profiles arising from dynamical collapse in massive star forming regions (MSFRs), we model the emission from hydrodynamic simulations of a collapsing cloud in the absence of outflows. By performing radiative transfer calculations, we compute the optically thick HCO^+ and optically thin N_2H^+ line profiles from two collapsing regions at different epochs. Due to large-scale collapse, the MSFRs have large velocity gradients, reaching up to 20 $kms^{-1}pc^{-1}$ across the central core. The optically thin lines typically contain multiple velocity components resulting from the superposition of numerous density peaks along the line-of- sight. The optically thick lines are only marginally shifted to the blue side of the optically thin line profiles, and frequently do not have a central depression in their profiles due to self-absorption. As the regions evolve the lines become brighter and the optically thick lines become broader. The lower order HCO+ (1-0) transitions are better indicators of collapse than the higher order (4-3) transitions. When sightlines pass through filaments or the central protostar of MSFRs optically thick line profiles generally portray the blue asymmetry associated with the large scale collapse motions. Low mass star forming regions do not always show a blue asymmetry, as the surrounding medium may or may not be collapsing. We also investigate how the beam sizes affect profile shapes. Smaller beams lead to brighter and narrower lines. The blue asymmetry becomes more pronounced with decreasing beam size, suggesting that high resolution observations (e.g. with ALMA) can provide insight into the nature of MSFRs

1. The Simulations

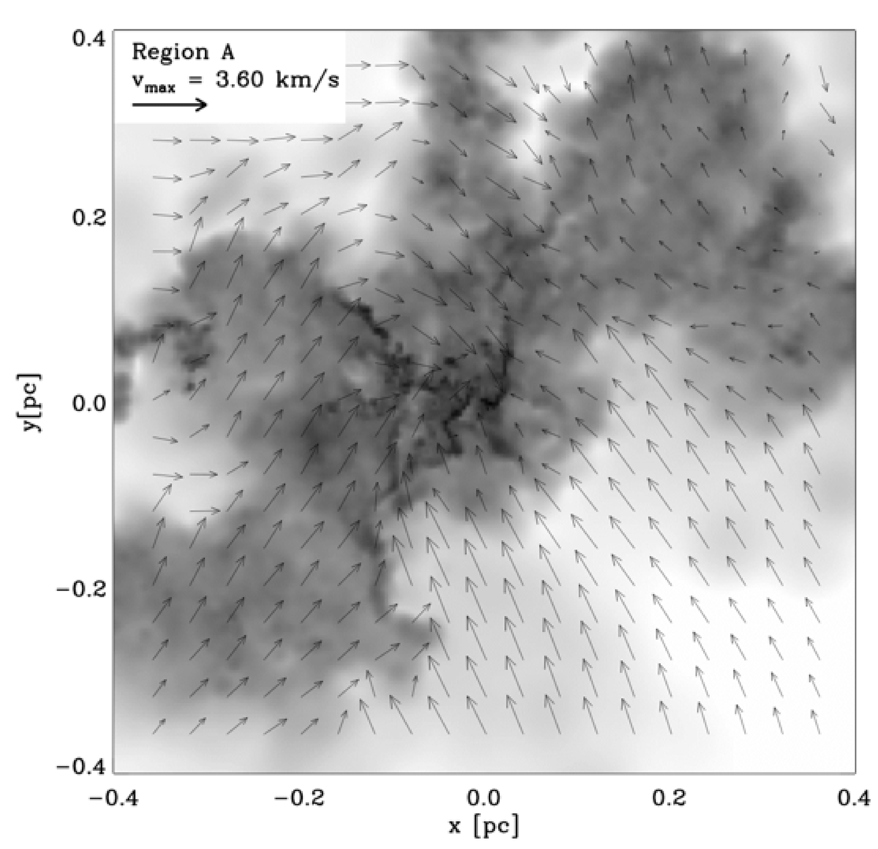

Fig1. A slice through the centre of a massive star forming region centred on the protostar that forms the most massive star. The grayscale shows the density field and the vectors the velocity field.

We use simulations of clustered massive star formation from Smith et. al. 2009b without kinetic feedback to investigate the signatures of dynamic collapse during the early evolution of Massive Star Forming Regions (MSFRs) . We use the radiative transfer code RADMC-3D to post-process areas of massive star formation and study the resulting line-profiles. We focus on the profiles of optically thick HCO^+ and optically thin N_2H^+. In the cluster simulation the massive star forming regions contain filaments and are undergoing large scale collapse.

3. Higher Order Transitions

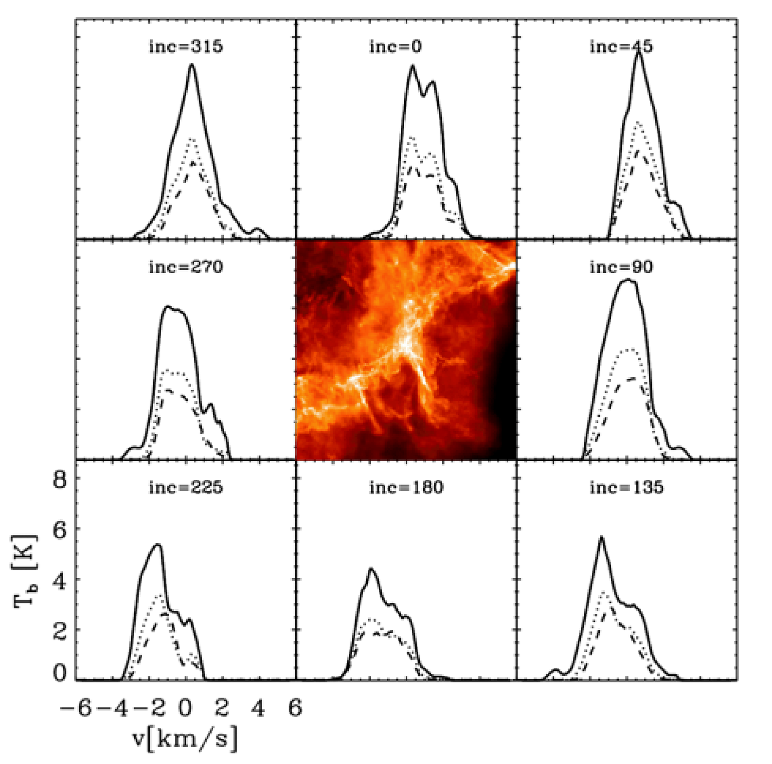

Fig 3. The line profiles of the higher order transitions of HCO^+. The solid line shows (1-0), the dotted (3-2) and the dashed (4-3).

A predicted observable of a collapsing core is a double peaked line with a blue asymmetry (Zhou 1992, Myers et. al. 1996). In our MSFRs the higher order transitions of HCO^+ are less blue skewed than the lower order transitions. We find that this is because the MSFRs in our simulations lack a surrounding static envelope and so there is little self-absorption in the dense centre of the core where the velocities are small relative to the protostar. Since the higher transitions preferentially trace high densities they are poorer indicators of the large scale collapse of the region.

Region	Transition	Critical Density [cm^{-3}]	χ^2	Blue	I_p [K]	$v_{95\%}$ [km/s]
A	1-0	1.85×10^5	1.55×10^{-1}	8	6.27	3.95
A	2-1	1.10×10^6	4.11×10^{-1}	8	4.79	3.79
A	3-2	3.51×10^6	1.31×10^{-2}	6	3.83	3.61
A	4-3	9.07×10^6	4.84×10^{-3}	3	2.94	3.55
B	1-0	1.85×10^5	1.48×10^{-1}	3	4.63	4.39
B	2-1	1.10×10^6	2.83×10^{-2}	4	3.25	3.90
B	3-2	3.51×10^6	7.62×10^{-3}	2	2.61	3.31
B	4-3	9.07×10^6	2.03×10^{-3}	2	1.92	3.20

Table 2. The mean χ^2 goodness of fit to a Gaussian profile for various transitions of the HCO^+ line. Also shown are the number of blue profiles in each case with a blue excess of over 0.5 kms^{-1}.

2. Line Profiles

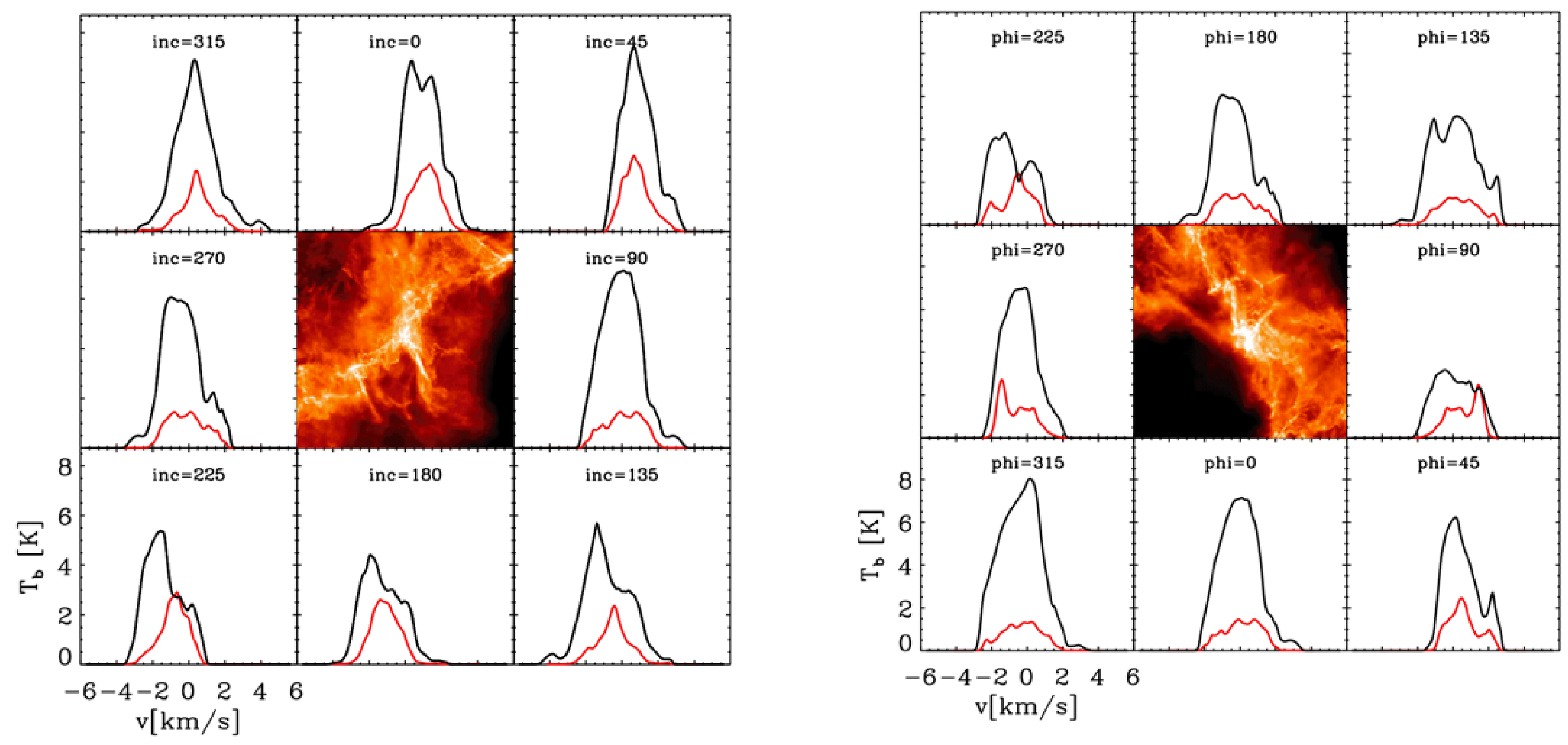

Fig 2. The HCO^+ (black) and N_2H^+ line profiles from a region of massive star formation. The N_2H^+ line profile is multiplied by a factor of 4 to be visible. The central box has a physical size of 0.8pc and shows the intrinsic column density in each plane. The line profiles are calculated for a 0.06pc beam centred on the embedded core.

The resulting line profiles show three key features

1. The optically thick line most frequently peaks to the blue side of the optically thin peak, in agreement with predictions for a collapsing core (e.g. Zhou 1992).

2. The magnitude of the offset between the optically thin and thick peaks is small relative to the width of the profiles despite the regions collapsing at speeds of order 1 kms^{-1}.

3. The optically thin emission lines often exhibit multiple components due to other dense cores along the line of sight.

Offset	< -1.0	< -0.5	< 0.0	> 0.0	> 0.5	> 1.0
All	3	11	19	9	1	1
Single	1	6	15	3	1	1

NOTE. — Our sample contains 28 lines in total.

Table 1. The number of cases where the offset in kms^{-1} between the optically thick and thin (1-0) peak emission is of a given magnitude. We distinguish between the full dataset (All) and those cases where the N_2H^+ has only a single peak (Single).

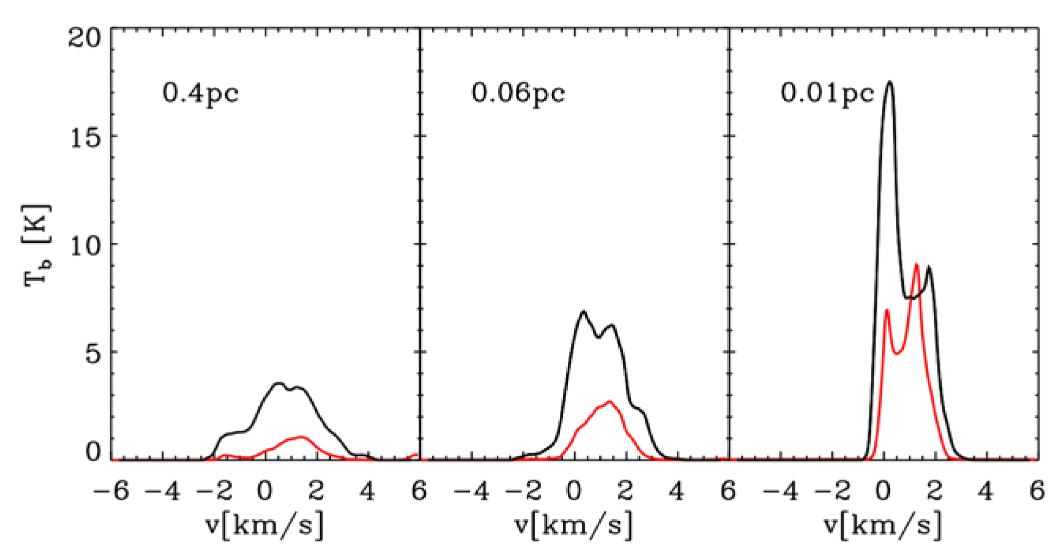

Fig 4. The 1-0 transition of an example sightline observed with a beam fwhm of 0.4, 0.06 and 0.01pc respectively.

Offset	Beam	< -1.0	< -0.5	< 0.0	> 0.0	> 0.5	> 1.0
All	0.01	6	13	23	5	2	1
All	0.06	3	11	19	9	1	1
All	0.40	3	10	22	6	4	1
Single	0.06	1	6	15	3	1	1
Single	0.40	1	7	14	4	1	1

NOTE. — There is no entry for the 0.01pc beam in the single component sample, as only four sightlines fulfilled this criteria.

Table 3. As in Table 1 but for three different beam sizes.

4. The Effect of Beam Size

It is also possible to predict how our results might change with a smaller beam size such as that possible with ALMA. As the beam size decreases the blue peak of the optically thick tracer becomes more apparent. However, the optically thin component also splits into multiple components making it harder to find the rest velocity of the core to define a blue asymmetry from.

The increasing frequency of multiple components in N_2H^+ as the beam size decreases is due to the high degree of fragmentation in the vicinity of the massive core in our model of massive star formation. **This prediction can be directly tested with ALMA.**

For full results and a detailed comparison to observations see the published paper:

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