Investigating Magnetic Fields in High-Mass Pre-stellar Cores in W43-MM1 using ALMA



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Abstract

High-mass pre-stellar cores are likely to be the precursors to high-mass (>8 M⊙) stars and are predicted to be in substantially different dynamical conditions by different high-mass star formation (HMSF) paradigms. The two primary paradigms for HMSF are (1) the core accretion model and (2) the competitive accretion model. The core accretion scenario forms near-virial cores that are supported by nonthermal mechanisms (i.e., magnetic fields and turbulence), while the competitive accretion scenario produces highly sub-virial cores accreting within fast collapsing clumps. Previous studies have estimated the gravitational and turbulent energies in HMPSC candidates, resulting in strong sub-virial states (virial parameter α <0.3) ignoring the magnetic fields. Thus, the final piece of the energy puzzle lies in estimating the magnetic field strengths in these cores. Although a few HMPSC candidates have been identified in the literature, the role of magnetic fields in their formation is yet to be explored. Our pilot study using Atacama Large Millimeter/submillimeter Array (ALMA) dust polarization at 250 GHz finds relatively strong magnetic fields in five HMPSC candidates located in W43-MM1 region, which were previously discovered in the ALMA-IMF Large Program. We aim to estimate their energy balance, which will help us to understand their dynamical phases in the presence of magnetic fields, i.e., if the HMPSC candidates are in equilibrium (α ~1 and <2) or collapsing rapidly (with α <1). In this workshop, we will present the initial results of these HMPSC candidates.

Motivation

The initial mass function (IMF), implying the number of stars forming with initial masses ranging between 0.01 M⊙ and >100 M⊙, has been considered universal so far in Galactic environments (e.g., Bastian et al. 2010; Kroupa et al. 2013). Since the last few decades, it has been claimed that the mass distribution of the cores, i.e., the core mass function (CMF), is conspicuously similar to the IMF, indicating that the shape of the IMF might have inherited from the CMF (e.g., Motte et al. 1998, 2001; Könyves et al. 2015). Now, in the CMF, the contribution of massive counterparts is extremely significant as they are rare in number but append to the higher mass range. Therefore, the study of the formation of HMPSCs is critically important. In the presence of adequate B-fields, a dense core that would have otherwise fragmented into low-mass parts could instead be supported against gravitational contraction and therefore survived the fragmentation, which led to the formation of an HMPSC and eventually a high-mass star (Hennebelle & Teyssier 2008; Tan et al. 2013). However, the study of B-fields towards the HMPSCs at envelope scale is rare, which is the motivation of this study.

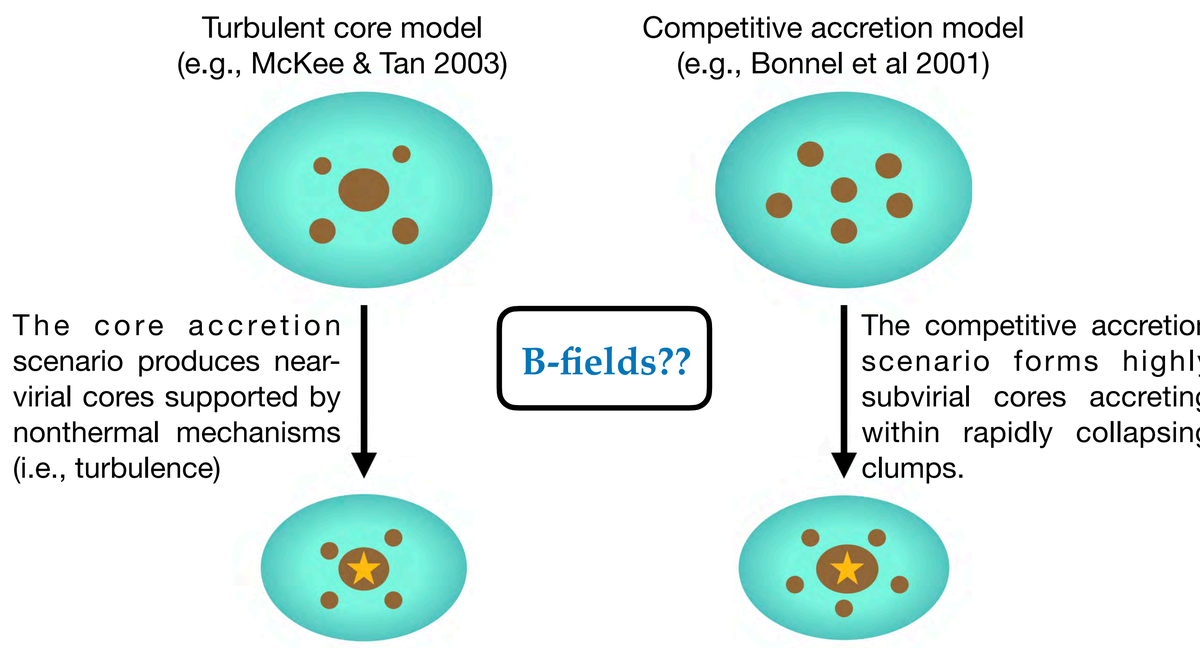


Figure 1: An illustration of two main paradigms of high-mass star formation

Observations & Analysis

- Angular resolution of ~0.3” (a few 1000 au) in Band 6 using ALMA with two pointings.
- Observed frequency for the continuum is 250 GHz (~1.2 mm)
- Molecular lines such as $HN^{13}C$ (3-2), $H^{13}CO^{+}$ (3-2), CS (5-4), $C^{33}S$ (5-4) are also observed.
- The imaging were done in mosaicked mode and with briggs weighting and robust=0.0.

Preliminary results

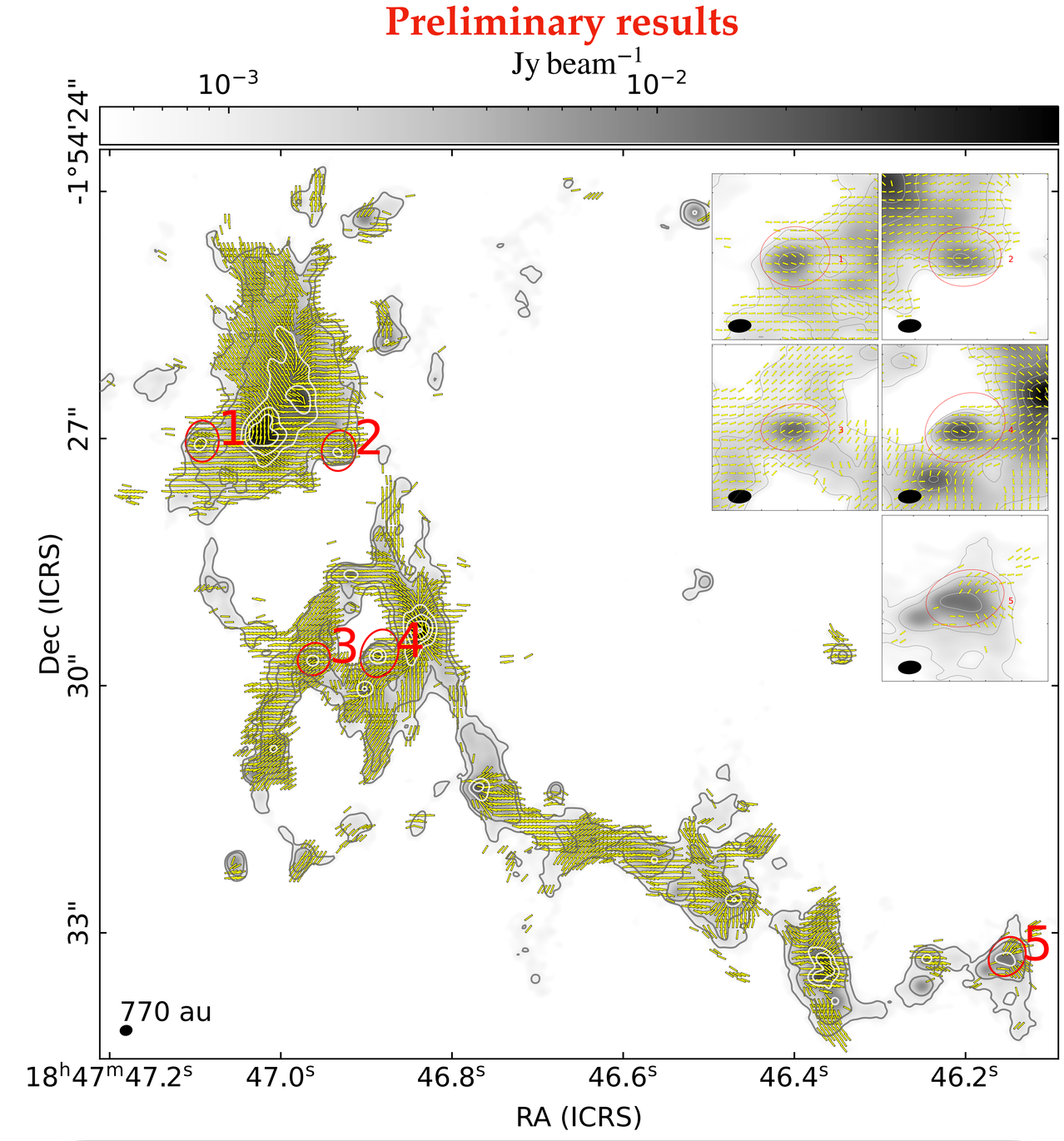


Figure 2: ALMA 1.2 mm dust continuum emission (color scale and contours) towards W43-MM1 with overlaid magnetic field vectors (yellow line segments) plotted above the 3σ level, with σ = 27 μJy beam^{-1}. Contours correspond to the dust continuum emission in steps of 5, 10, 50, 100, 200, 500, 1000, and 3000 times the σ (rms) value of 0.2 mJy beam^{-1}. The HMPSCs are marked using ellipses in red, which are obtained from Nony et al. 2023. The enlarged views toward the five HMPSCs are shown in the left side.

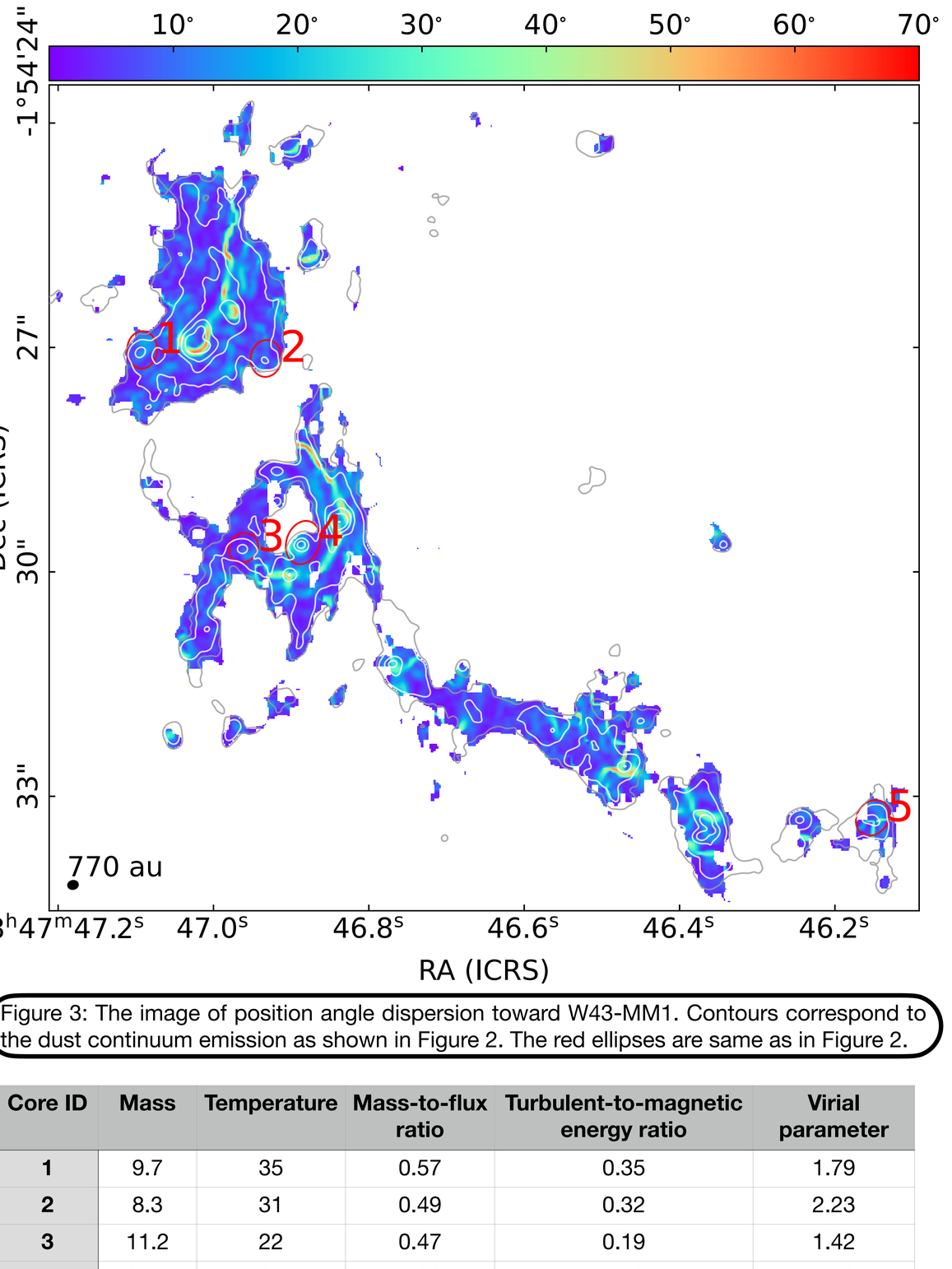


Figure 3: The image of position angle dispersion toward W43-MM1. Contours correspond to the dust continuum emission as shown in Figure 2. The red ellipses are same as in Figure 2.

Core ID	Mass	Temperature	Mass-to-flux ratio	Turbulent-to-magnetic energy ratio	Virial parameter
1	9.7	35	0.57	0.35	1.79
2	8.3	31	0.49	0.32	2.23
3	11.2	22	0.47	0.19	1.42
4	21.4	23	1.96	1.59	0.69
5	36.7	22	2.92	1.38	0.27

Table 1: Physical properties of the HMPSCs. Cols 1 & 2: obtained from Nony et al. 2023; Cols 3, 4 & 5: obtained from this preliminary study.

Future Work

- A detailed study of magnetic fields toward the HMPSCs and overall W43-MM1 will be made to understand the contribution of magnetic fields in their formation.
- Using the available spectral lines ($HN^{13}C$, $H^{13}CO^{+}$, CS, $C^{33}S$ and other lines available in ALMA IMF) we will study the kinematic properties of the HMPSCs and investigate the link between the magnetic fields and the gas kinematics in this region.
- We will refine the virial parameter of the HMPSCs to understand the current dynamical condition in them and the possible formation mechanism of these HMPSCs.

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