Investigating the "hourglass" magnetic field in G333.46-0.16 using ALMA

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Abstract: High-mass stars play a significant role in the physical and chemical evolution of their immediate vicinities, by their powerful stellar wind, ultraviolet emission, and supernova explosion. Although a notable progress has been achieved in understanding the formation of low-mass stars, the physical mechanisms behind the formation of high-mass stars is still not well understood. As the molecular clouds consist of partially ionized gas and dust, the magnetic field has been found to be omnipresent in the interstellar medium, and therefore, expected to affect the formation of low-mass as well as high-mass stars. However, the contribution of magnetic fields in the formation of high-mass stars is not entirely clear. Recently, because of its very high angular resolution, ALMA has opened an opportunity to study the magnetic field in the molecular clouds with minute details. We report the magnetic field geometry towards the high-mass star-forming region G333.46-0.16, which is obtained by ALMA at high-angular-resolution (~0.3") 1.2 millimeter observations. This is one of the targets observed in the survey of **Magnetic fields in Massive star-forming Regions (MagMaR)**, that contains 30 targets in total. This region likely shows the formation of a binary system separated by ~1740 AU. The magnetic field lines threading this area are found to be deformed, resembling an "hourglass" morphology in northeast-southwest orientation on the plane-of-sky. Our aim is to investigate the interplay among turbulence, gravity, and magnetic field in the formation of stars at the core scale, and to find out the dominant agent between them. Based on the Davis-Chandrasekhar-Fermi method, we estimate the magnetic field strength in the plane-of-sky. We also estimate the mass-to-flux ratio, the turbulent to magnetic energy ratio and other physical parameters to understand the current star formation scenario in this region. We present here the preliminary results obtained from our study.

Introduction:

As a dense cloud gradually collapses perpendicular to the field because of neutrals being driven towards the core by gravity, they will drag along the ions and the magnetic field. This will result in an hourglass shape of the magnetic field in a dense core (see Figure 1). At the same time, the bent magnetic field lines resists gravity, slowing down the collapse from the much faster free-fall rate.

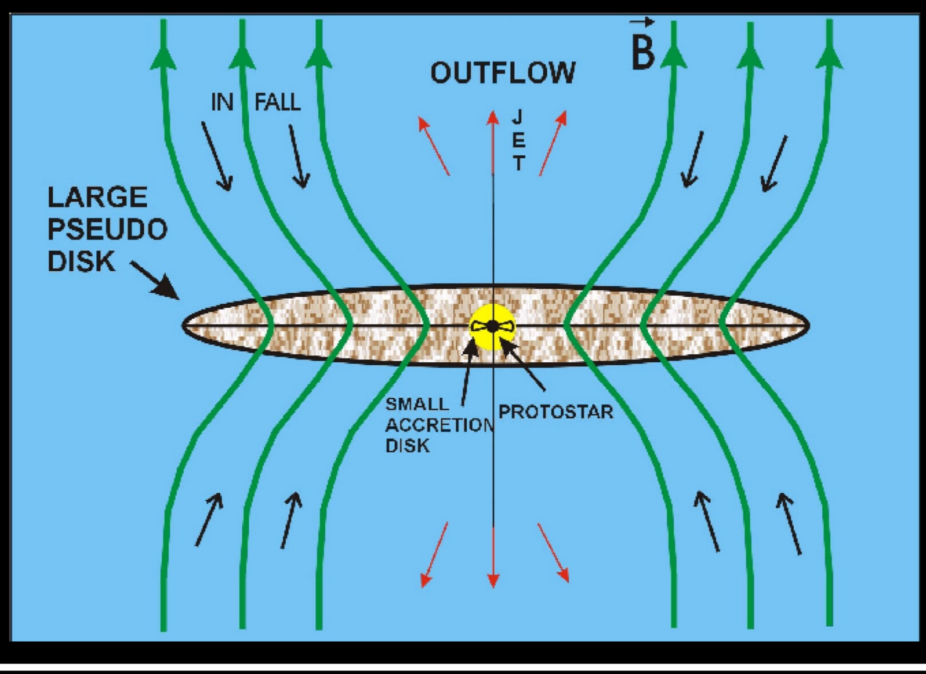

Figure 1: An illustration of an hourglass shaped magnetic field. Credit: J. P. Vallee, Astron. J.123, 382 (2002)

Target studied:

The MagMaR project contains 30 targets with more than 60 cores in dust polarization and line emission at 250 GHz with ~0.3" resolution. Out of 30 targets, G333.46-0.16 (selected from Csengeri et al. 2017) shows a very distinct hourglass morphology of the projected magnetic field (B_{POS}), as presented in Figure 2. The central region of the target shows the formation of a binary system with a separation of ~1740 AU. The distance to G333.46-0.16 is 2.9 kpc (Urquhart et al. 2018). The V_{LSR} is considered as -42.5 kms^{-1} (Csengeri et al. 2017).

Preliminary results:

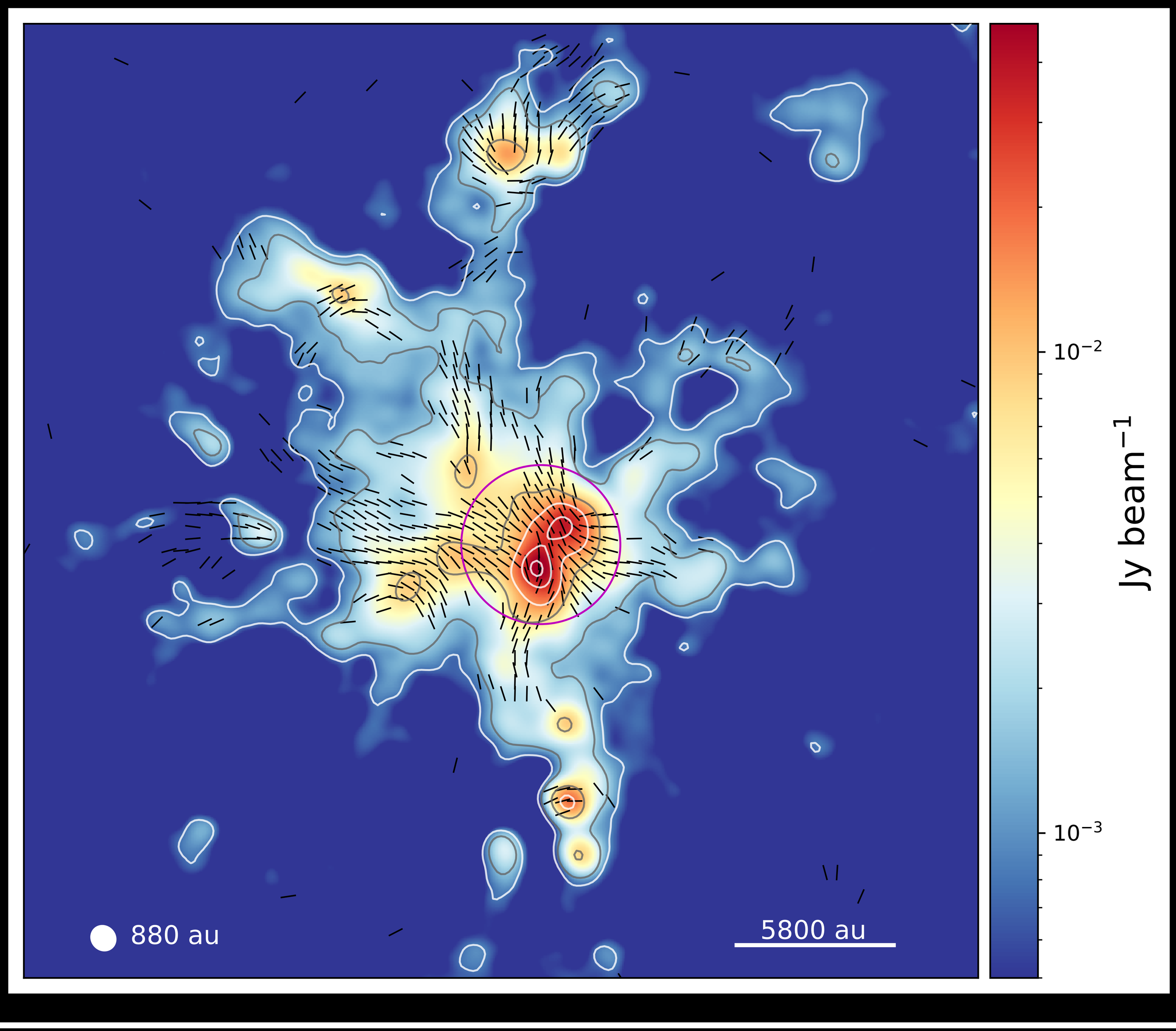

Figure 2: ALMA 1.2 mm dust continuum emission (color scale and contours) towards G333.46-0.16 with overlaid magnetic field vectors (black line segments) plotted above the 3σ level, with σ = 29 μJy beam^{-1}. Contours correspond to the dust continuum emission in steps of 5, 10, 50, 100, 200, and 300 times the σ (rms) value of 161 μJy beam^{-1}. The circle represents the area of our analysis to estimate the Bpos.

- A quadratic fit to the observed position angles (ψ_{obs}) was made to obtain the polarization angle residuals (Δψ, see Figure 3 LHS). The intrinsic angle dispersion is estimated as 13.2°.
- The dispersion in the velocity has been estimated as 1.3 kms^{-1} from the available $H^{13}CO^+$ (J=3 —>2) line.
- The mass and the number density in the area of analysis are found to be 32M_{sun} and 4.1X10^7 cm^{-3}, respectively.
- Based on the Davis-Chandrasekhar-Fermi method, the B_{POS} is estimated as 14 mG.

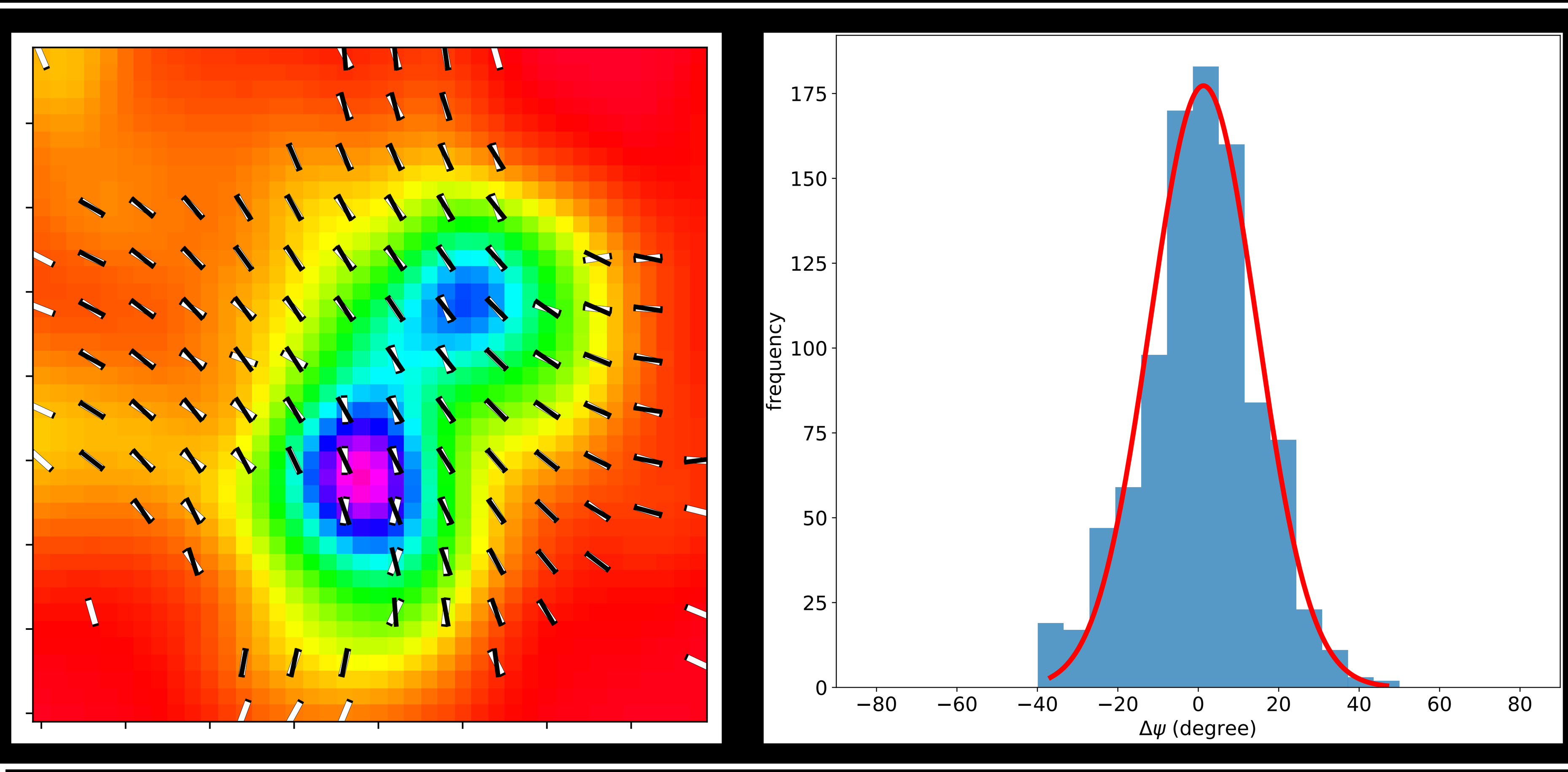

Figure 3: (LHS) Enlarged view of the circular area of Figure 1. The observed polarization angles showing the magnetic field orientation (ψ_{obs}, white segments) on top of which are superposed those obtained from the fitting (ψ_{fit}, black segments). (RHS) The histogram of the polarization angle residuals $\Delta\psi = \psi_{obs} - \psi_{fit}$ with its Gaussian fit (red line). The mean of Δψ is 0.5° with a standard deviation (σ_ψ) of 14.5°. The intrinsic angle dispersion is estimated as 13.2° after correcting σ_ψ with the mean angle uncertainty in the polarization angle image (6°).

- The mass-to-flux ratio normalized to the critical value λ = 1.2.
- The Alfven speed is estimated as 3.0 kms^{-1}.
- The ratio of the turbulent to magnetic energy, β_t, is estimated as 0.5.
- The virial parameter $\alpha_{vir} = M_{vir}/M$ = 1.6 and 0.98, for a uniform and centrally peaked density profile, respectively.

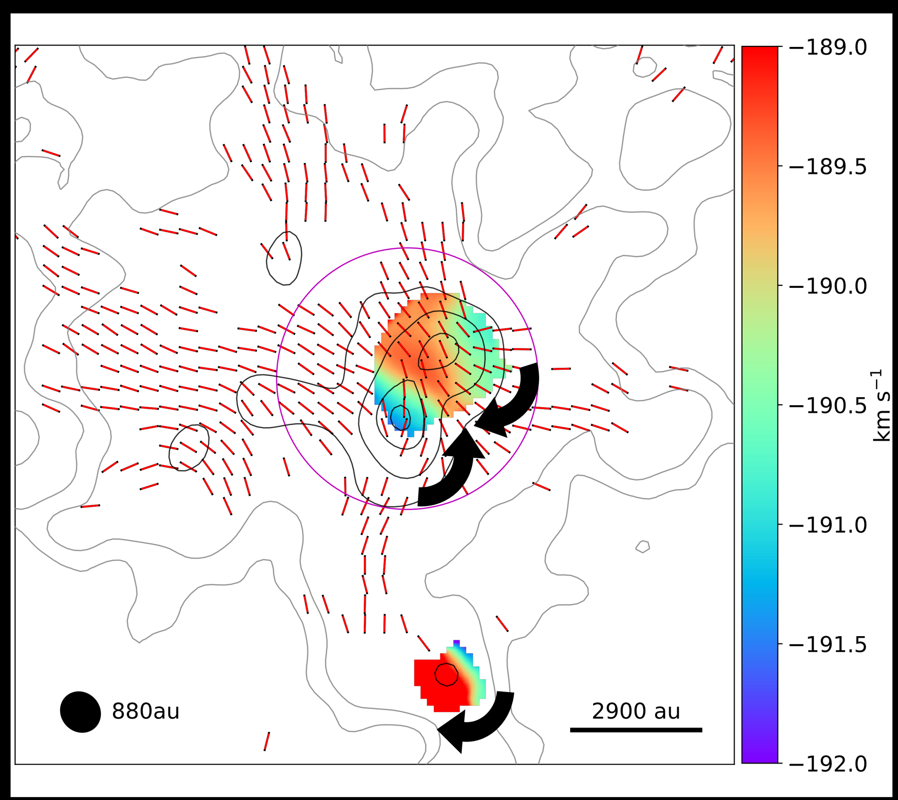

Figure 4: Velocity gradient as obtained from the moment 1 map of CH_3OH line ($J_{Ka,Kc}=20_{3,18}$—>$20_{2,19}$), on top of which are superposed the magnetic field vectors (magenta segments). Contours correspond to the dust continuum emission in steps of 5, 10, 50, 100, 200, and 300 times the σ (rms) value of 161 μJy beam^{-1}. The circle represents the area of our analysis to estimate the Bpos.

Summary and Future Work:

- The region shows an ongoing magnetically regulated star formation scenario with a signature of "hourglass morphology" of the B_{POS}.
- Based on the mass-to-flux ratio the magnetic field and gravity are almost comparable (marginally supercritical), indicating presence of the magnetic support against collapse.
- Also, the magnetic energy seems to dominate the turbulent energy.
- We will investigate the different transition lines in more detail to understand the ongoing stage of star formation in this region.
- The moment 1 map of CH_3OH line towards the central region indicates that the two binaries are having circumstellar material rotating in the opposite direction, this area will be studied thoroughly with high resolution (0.06") ALMA molecular line data.

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