Probing magnetic fields in forming stars with ALMA observations and next-generation AREPO simulations

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Intro:
Magnetic fields, forming stars, and the fabled “hourglass”
The “strong-field” scenario

The large-scale magnetic field in the ISM (~100 pc) seems to be preserved…

…in the small-scale cores (0.1 pc)

Figure 1. Magnetic fields in the Orion molecular cloud region. The background image shows the IRAS (Neugebauer et al. 1984) 100 µm logarithmic scale. We superpose on this map the magnetic field directions inferred from optical data (blue vectors), and the mean of all the optical data is shown as the thick gray vector. The Hertz polarimeter (Dotson et al. 2009) at the Caltech Submillimeter Observatory mapped eight clouds (see labels A through H on the IRAS map) in this region at 350 µm with 20′′ resolution, and these CSO results are shown as insets, using red vectors on individual false-color intensity maps. The mean direction of all the 350 µm polarization detections from a given core is shown as a white vector superposed on each core’s map, and these white vectors are also plotted on the IRAS 100 µm map.

All the false-color Hertz intensity maps are plotted to the same scale: 140 arcseconds across (approximately 0.3 pc). Note that the spatial scales and mass densities are very different between the regions probed by the two wavelengths, but the field orientations are very similar.

Hua-bai Li+2009
The canonical picture: hourglass fields

The typical initial condition for the magnetic field in models of star-forming cores is an hourglass with its symmetry axis aligned with the core’s rotation axis (see also Fiedler & Mouschovias 1993)

Allen, Li, & Shu
2003
The canonical picture
Hourglasses in forming stars

See also Stephens+2013, incl. CLHH
Cycle 2, 3, & 4 ALMA obs.

**Class 0**

**CORE POLARIZATION**
(PI: Hull)

0.36″ dust pol @ 850 um

0.36″ and 1″ lines & continuum @ 1 mm

Cycles 3 & 4: 0.06″ dust pol @ 850 um

Probing ~1000 → 25 AU disk scales

Hull+2014, TADPOL survey
Hull, Mocz, Burkhart+2016, submitted (data from Matthews+2009)

Serpens Main

JCMT

AU
44.000

Right Ascension (J2000)
Declination (J2000)

AU
72.000
CARMA

Ser-emb 8(N)

Ser-emb 8

Hull, Mocz, Burkhart+2016, submitted (data from Hull+2014)
ALMA
Ser-emb 8

Hull, Mocz, Burkhart+2016, submitted
CARMA ALMA JCMT

44,000 AU [= 0.21 pc]  15,000 AU [= 0.08 pc]  3500 AU

Hull, Mocz, Burkhart+2016, submitted
The ALMA-scale magnetic field, which is “attached” to the forming stellar system, is not reminiscent of the large-scale field.

This is in contrast to 50 years of theory, and to recent papers such as Li+2009, who suggested that the large-scale mean field direction could be preserved all the way down to the scale of forming stars.

Hull, Mocz, Burkhart+2016, submitted
Keep an eye on the magnetic field strength here

AREPO simulations
$B=1$

- JCMT scales
- JCMT/CARMA scales
- ALMA scales

1 million AU [= 5 pc]
37350 AU [= 0.2 pc]
3000 AU

Hull, Mocz, Burkhart+2016, submitted
B = 10

1 million AU [= 5 pc]  37350 AU [= 0.2 pc]  3000 AU

Hull, Mocz, Burkhart+2016, submitted
B = 30

1 million AU [= 5 pc]  37350 AU [= 0.2 pc]  3000 AU

Hull, Mocz, Burkhart+2016, submitted
B = 100 AU

1 million AU [= 5 pc]

37350 AU [= 0.2 pc]

3000 AU

Hull, Mocz, Burkhart+2016, submitted
HRO analysis

The HRO characterizes the relationship between magnetic fields and filamentary structures in the dust and gas.

HRO = “Histogram of Relative Orientation” (see Soler+2013)

Planck XXXV (Soler+2015)
HRO analysis

A random HRO indicates that the magnetic field is not dictating the morphology of the star-forming material.
HRO analysis: ALMA & AREPO

The ALMA data exhibit a random HRO. The strongly magnetized simulation, has a dynamically important magnetic field, but is inconsistent with our ALMA data.
Summary

- High-DR, ALMA-resolution AREPO simulations
- Initial conditions of the cloud dictate what we see at small scales
- We see an alternate mode of star formation where the field morphology is dictated by turbulence and not by a strong B-field
- ~100 AU resolution ALMA observations of magnetic fields in Ser-emb 8
- Field orientation not preserved from large scales
- No hourglass!