Magnetic fields in the formation of massive stars: The SMA view

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1. Introduction.
2. Previous SMA results
3. SMA Legacy Survey. The sample and Individual targets
4. SMA Legacy Survey. Statistical results
5. SMA and CSO Statistics
6. Conclusions
Magnetic fields: why should we care?

- Magnetic braking: angular momentum removal,
- Control accretion disk formation and evolution, launch of bipolar outflow
- Slow and regulate collapse of the dense molecular cores
- Observations show magnetic fields have strength from $\sim 10\mu G$ in diffuse atomic/molecular gas, $\sim 0.5-10$ mG in dense molecular cores, up to $\sim 100$ mG at few hundreds AU near low/high mass protostars
Previous observations of magnetic fields at ~0.1 pc scale:

\[ \text{G31.41+0.31} \]

- \( \text{D=7.9kpc; L\approx3 \times 10^5 \, L_\odot; M\approx500M_\odot} \)
- Magnetic field: twisted hourglass
- Supercritical magnetic core (magnetic energy > turbulent energy)
- Inverse P-Cygni profile: infall
- \( \dot{M}_\text{acc} = [3\times10^{-3} - 3\times10^{-2}] \, M_\odot \, \text{yr}^{-1} \)
- Molecular gas: rotation along major axis
- Evidence of magnetic braking


Other examples of well organized B: W51e2/e8 (Lai et al. 2001; Tang et al. 2009); G35.2-0.74 N (Qiu et al. 2013)
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Previous observations of magnetic fields at ~0.1 pc scale: **NGC 7538 IRS 1**

- D=2.65 kpc; L\(\approx\) 10\(^4\) L\(_\odot\); M\(\approx\)200M\(_\odot\)
- IRS1, UC HII region of 500 AU
- Filamentary structure: central bar formed with gravitationally bound cores (15 –37 M\(_\odot\)) and a “spiral arm” formed gravitationally unbound cores (3 – 12 M\(_\odot\))
- **Central bar** is forming massive stars
- **Spiral arm** is expanding
- Magnetic field: twisted following spiral arm
- The kinetic energy, linear momentum, and dynamic age of the spiral arm are compatible with the values of the bipolar CO outflow
- **Spiral arm** formed/enhanced in a snowplow fashion by the outflow

NGC7538IRS1 refs: Kawabe et al. 1992, Klaassen et al. 2009; Wright et al. 2014; Goddi et al. 2015

Other examples “disorganized” B: G5.89-0.39 (Tang et al. 2009)
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SMA Polarization Legacy project: Observing magnetic fields in a sample of massive star forming regions

**Method:**
- Image polarization at 880 μm with the SMA in
  - Beam of ≈1″ (subcompact, compact and extended configurations)
  - 1σ rms noise of 2 mJy beam⁻¹.
- Frequency tuning to observe molecular tracers of
  - the core’s kinematics (H¹³CO⁺ 4-3, SO lines),
  - hot core lines (CH₃OCH₃, CH₃CH₂CN)
  - outflow activity (CO 3-2, SiO 8-7)

**Sample:**
- 21 massive star forming regions from mm surveys and polarization with SCUBA
- Continuum flux limit of 0.5 Jy/beam (interfero.)
- Most of sources in a relatively nearby distances (<2 kpc)
- Earliest stages of star formation: avoid HII regions
SMA pol survey in massive cores: G240.31+0.07


D=5.3 kpc; $L \approx 3 \times 10^4 L_\odot$; $M \approx 125 M_\odot$

A well aligned case: bipolar outflow, magnetic field and rotation axes
Evidence of magnetic braking

G240.31+0.07 refs: Chen et al. 2007; Trinidad 2011,
SMA pol survey in massive cores: G240.31+0.07


D=5.3 kpc; L ≈ 3 × 10^4 L ☉; M ≈ 125 M ☉

A well aligned case: bipolar outflow, magnetic field and rotation axes
Evidence of magnetic braking

v_{LSR} (km/s)
SMA pol survey in massive cores: DR21(OH)


D=1.6 kpc; L ≈ 2 \times 10^4 \, L_\odot; M \approx 300 \, M_\odot. High level of fragmentation

No apparent aligned between bipolar outflow, magnetic field and rotation axes

Angular momentum dominates over magnetic field, causing a complex toroidal B morphology

DR21(OH) refs: Crutcher 1999; Lai et al. 2003; Hennemann et al. 2012,
SMA pol survey in massive cores: Images

SMA pol survey in massive cores: Statistical results: $B_{\text{core}} \ versus \ B_{\text{clump}}$


Bimodal distribution
- 60% SMA pol $\Delta \theta < 40^\circ$
- Smaller group of pol $\Delta \theta \sim 80-90^\circ$
- Analysis suggests a $||$ to $\perp$ ratio of 5:3
SMA pol survey in massive cores: Statistical results: $B_{\text{core}}$ vs $\text{Major Axis}_{\text{core}}$


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SMA pol survey in massive cores:
Statistical results: $B_{\text{core}} \ vs \ \text{Outflow direction}$

No apparent correlation

Similar result found for low-mass star forming cores: Hull et al. 2013
Statistical results from pol SMA + CSO obs


Analysis of the magnetic field direction and the dust emission gradient shows that:

- Cores with magnetic fields along the minor axis of the cores, appear to have slowed collapse
- Other cores (B field along major axis, other configuration) should show a faster collapse (close to free-fall collapse)
Conclusions

❖ In general magnetic fields appear to show a uniform pattern at core scale
❖ Magnetic fields at core scale show a bimodal distribution \textit{wrt} to the larger scale direction and \textit{wrt} to the core’s major axis
❖ \textbf{Bimodal distribution: why? Can simulations reproduce qualitatively the results from the SMA survey?}
❖ Outflow direction is not correlated with core’s magnetic field
❖ Evolved regions (i.e., with UC HII regions) show a more chaotic B field distribution: energetically it is overwhelmed by stellar feedback

Thanks for your attention!