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

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SOUL OF HIGH-MASS STAR FORMATION

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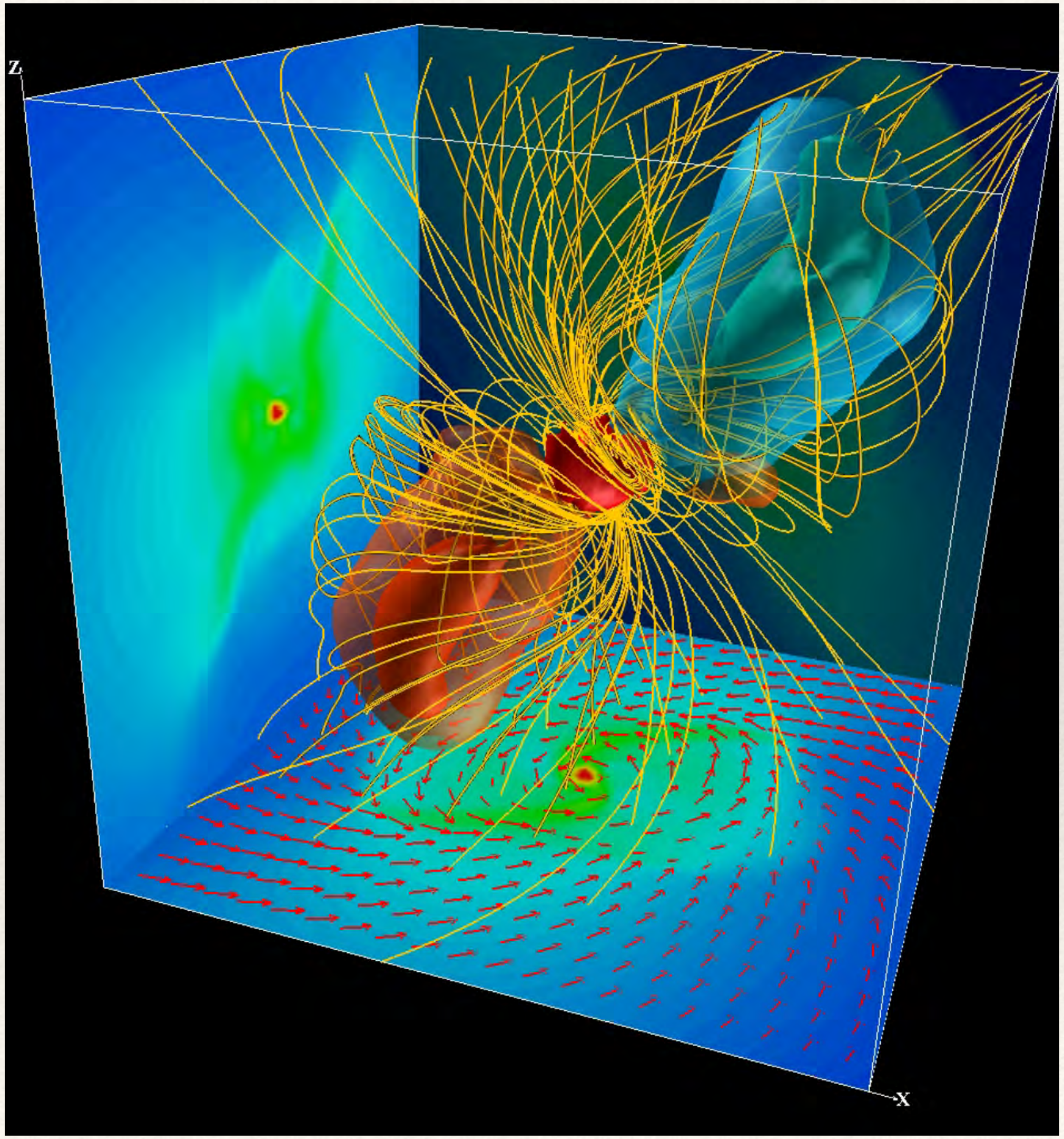
Content

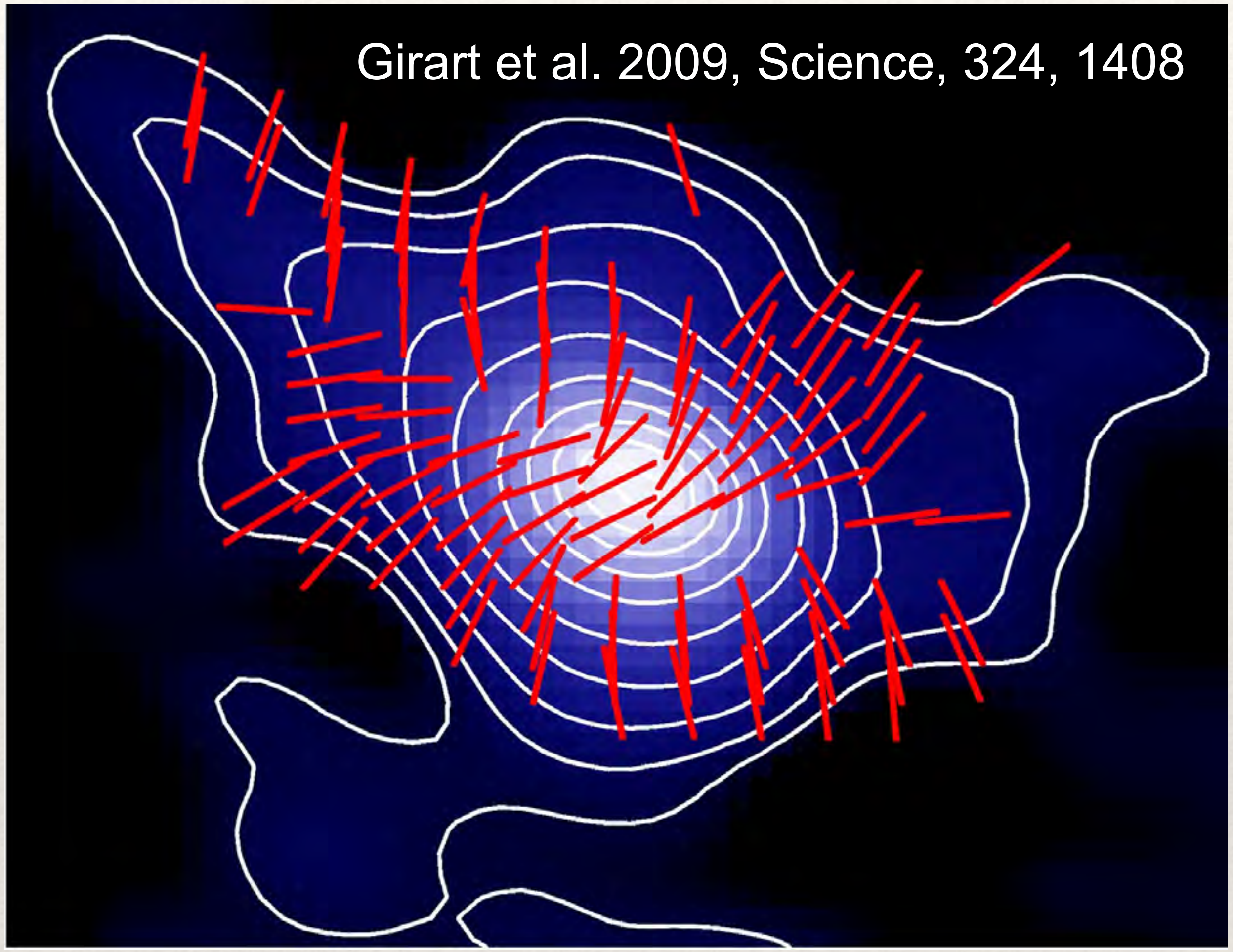
Magnetic fields: why should we care?

- 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 ~10μG in diffuse atomic/molecular gas, ~0.5-10 mG in dense molecular cores, up to ~100 mG at few hundreds AU near low/high mass protostars



Previous observations of magnetic fields at ~0.1 pc scale: G31.41+0.31

- D=7.9kpc; L≈3 10^5 $L_\odot$; M≈500$M_\odot$
- Magnetic field: twisted hourglass
- Supercritical magnetic core (magnetic energy > turbulent energy)
- Inverse P-Cygni profile: infall
- $\dot{M}_{acc}$ =[3×10^{-3}—3×10^{-2}] $M_\odot$ yr^{-1}
- Molecular gas: rotation along major axis
- Evidence of magnetic braking



G31 refs: *Beltran et al. 2004, Osorio et al. 2004; Cesaroni et al. 2011; Mayen-Gijon et al. 2014*

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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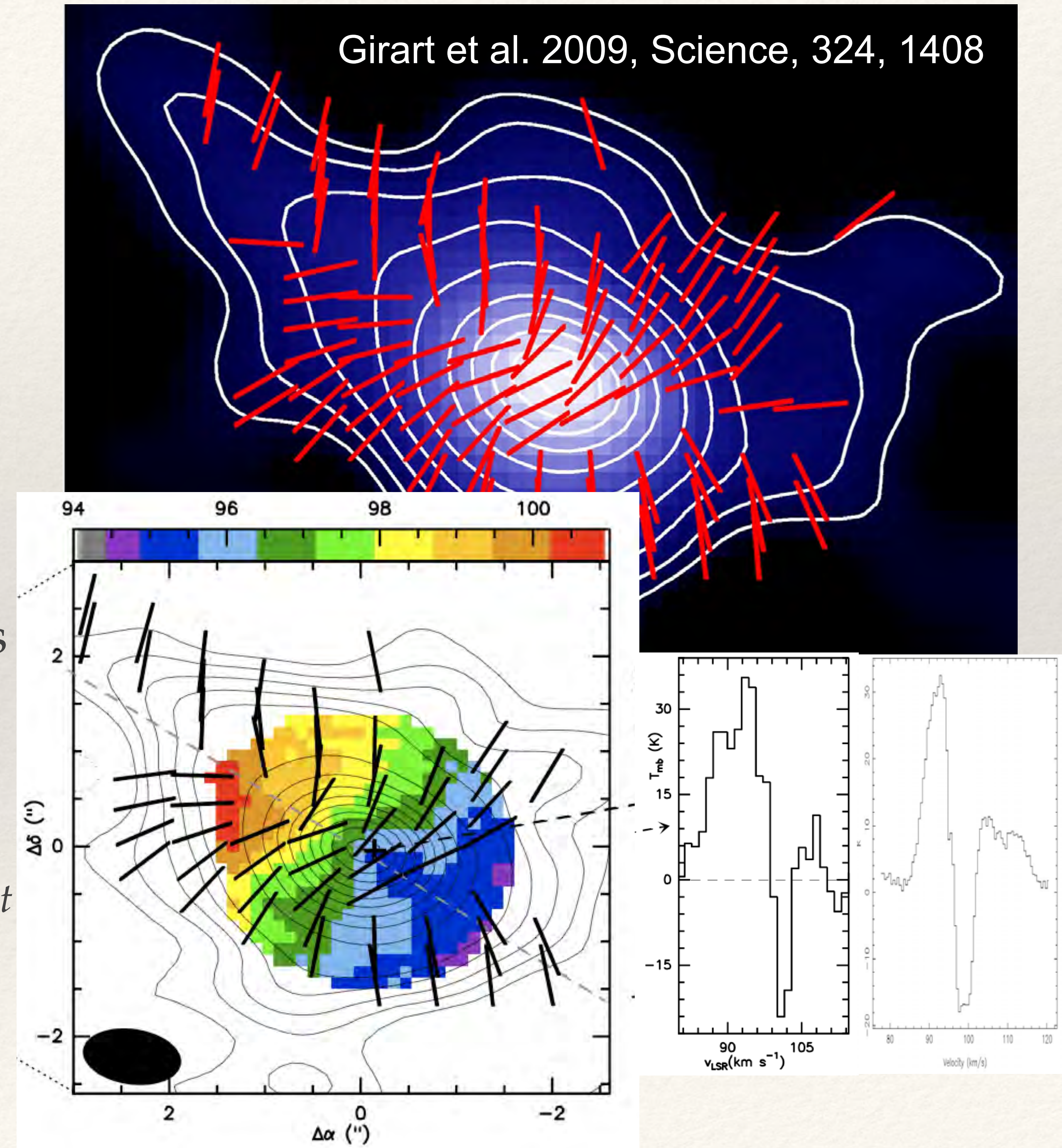
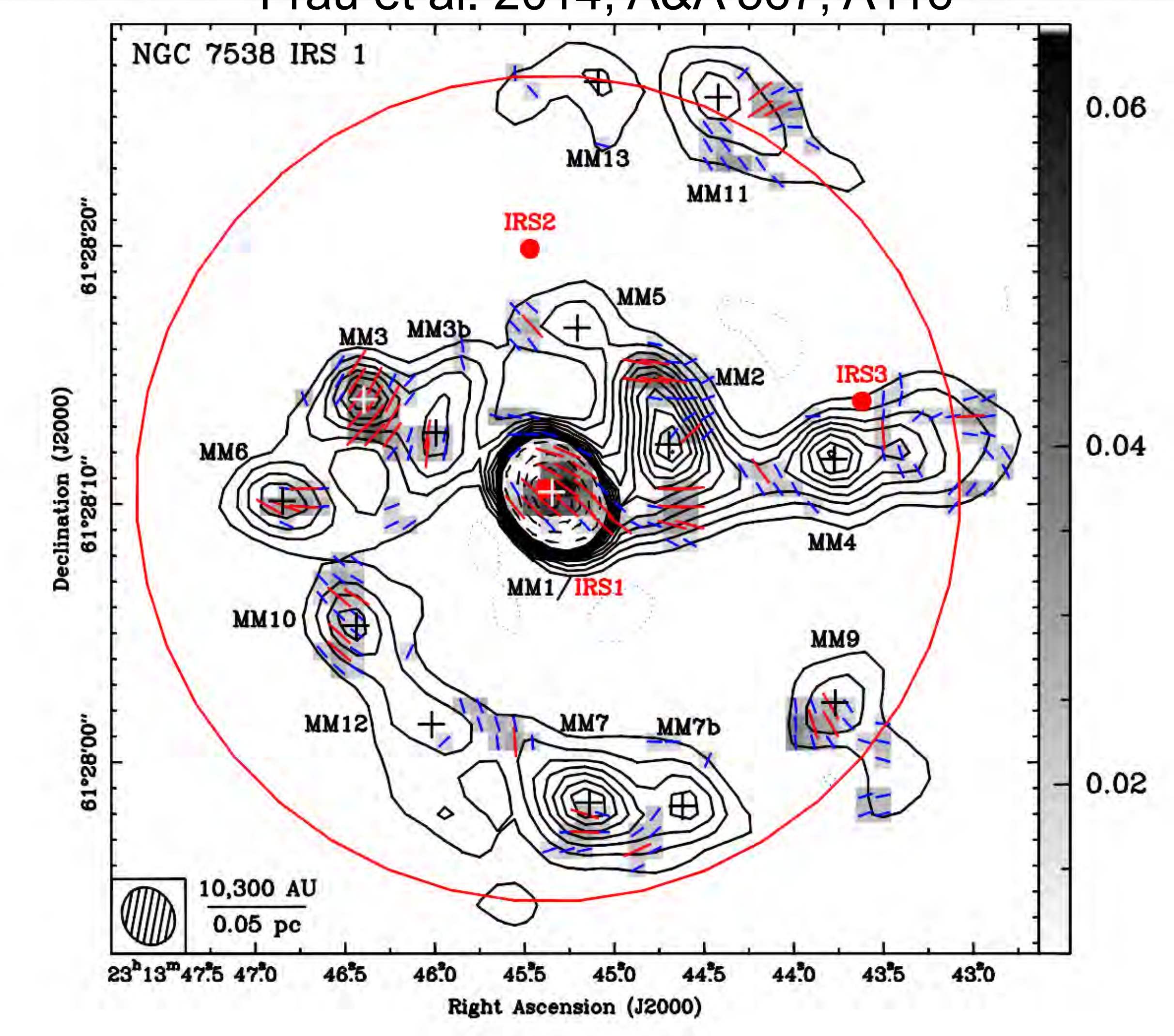


Previous observations of magnetic fields at ~0.1 pc scale: NGC 7538 IRS 1

- D=2.65 kpc; L≈ 10^4 L$_\odot$; M≈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

Frau et al. 2014, A&A 567, A116



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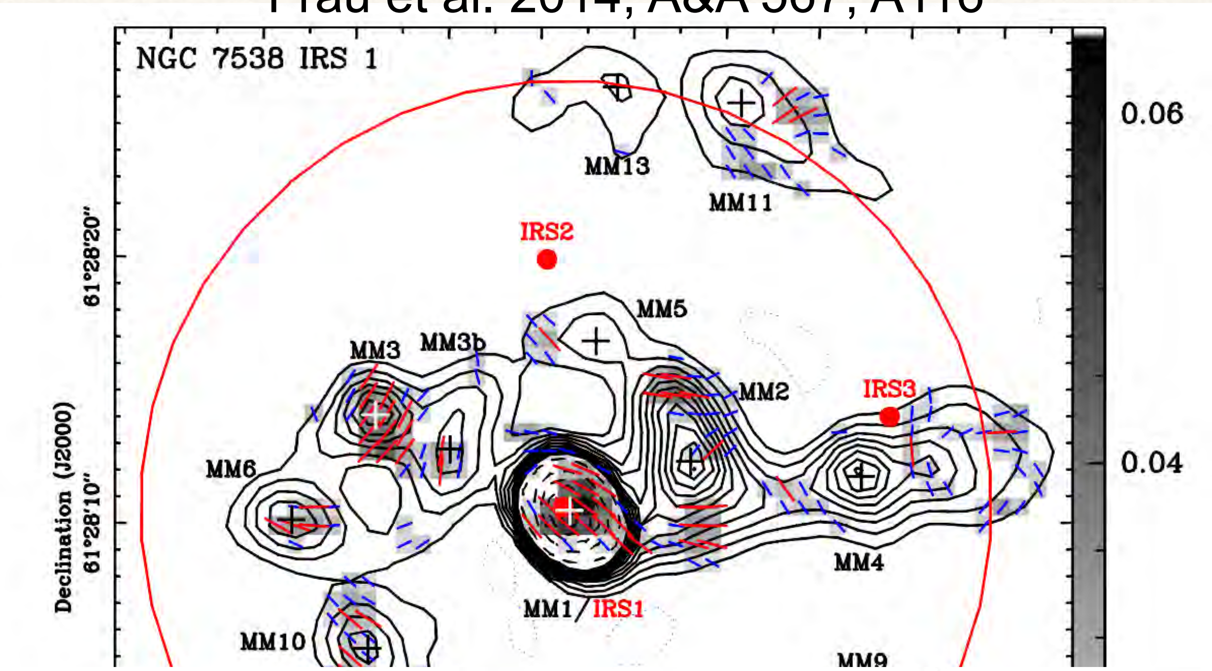
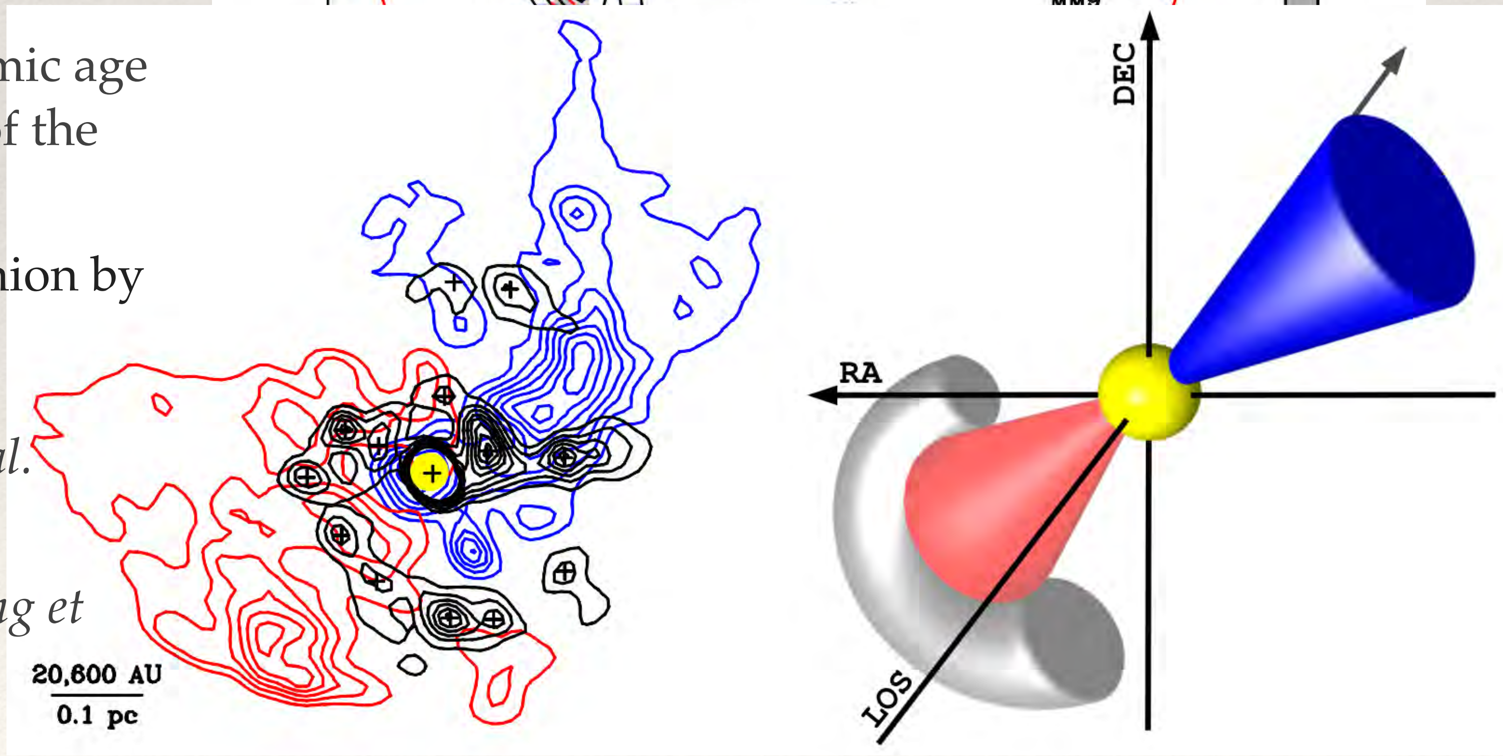




SMA Polarization Legacy project: Observing magnetic fields in a sample of massive star forming regions

Method:

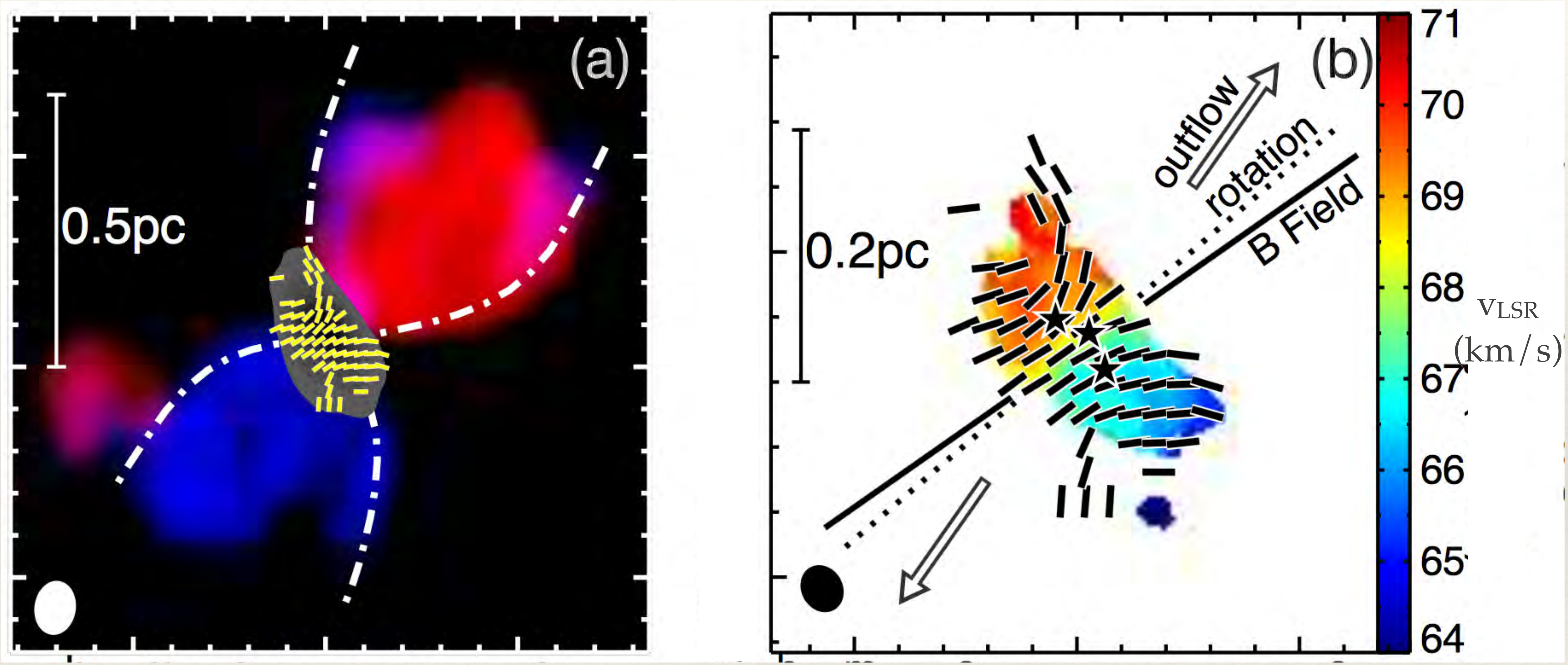
- Image polarization at 880 μm with the SMA in
  A. Beam of ≈1″ (subcompact, compact and extended configurations)
  B. 1σ rms noise of 2 mJy beam^{-1}.
- Frequency tuning to observe molecular tracers of
  C. the core's kinematics ($H^{13}CO^+$ 4-3, SO lines),
  D. hot core lines (CH_3OCH_3, CH_3CH_2CN)
  E. 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

Qiu et al. 2009, ApJ, 696, 66 and 2014, ApJ, 794, L18



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

G240.31+0.07 refs: *Chen et al. 2007; Trinidad 2011,*

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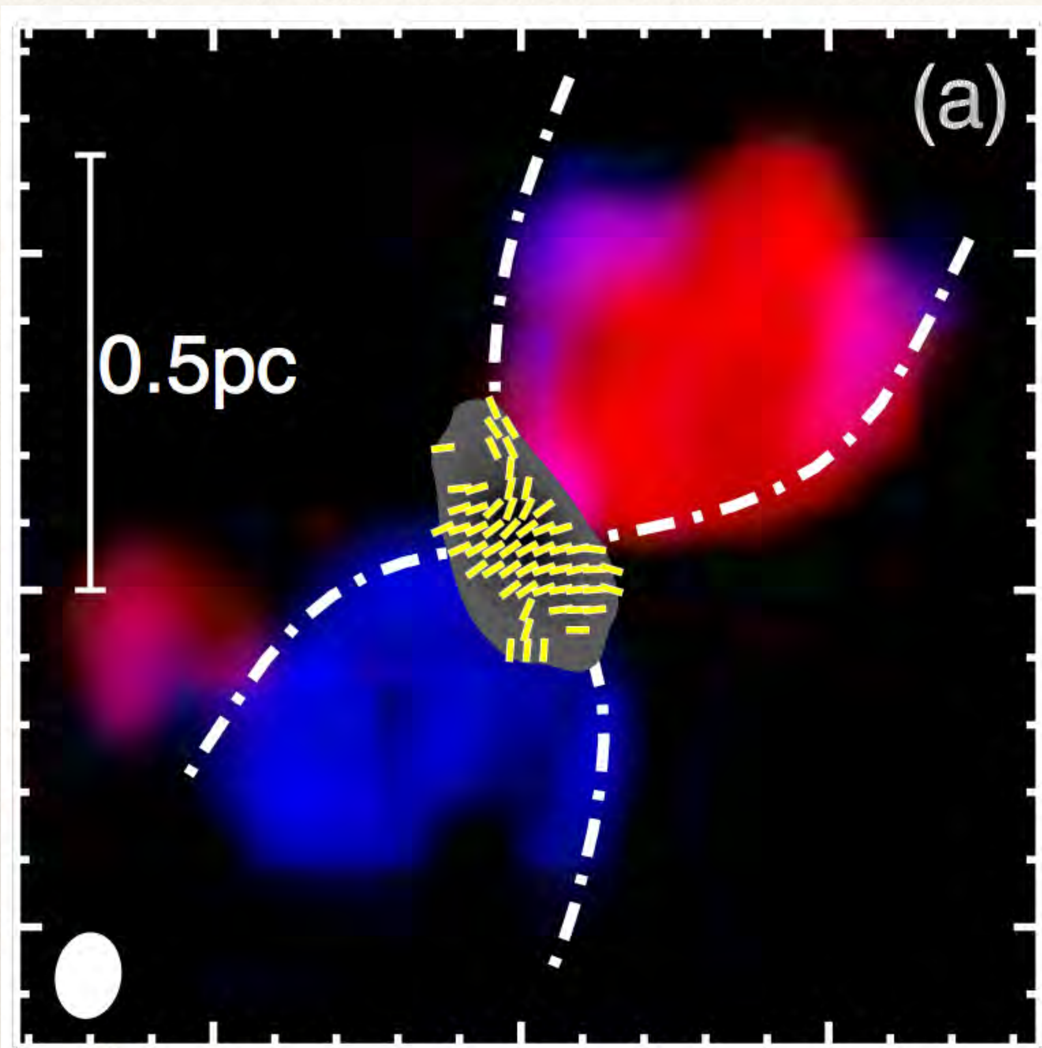

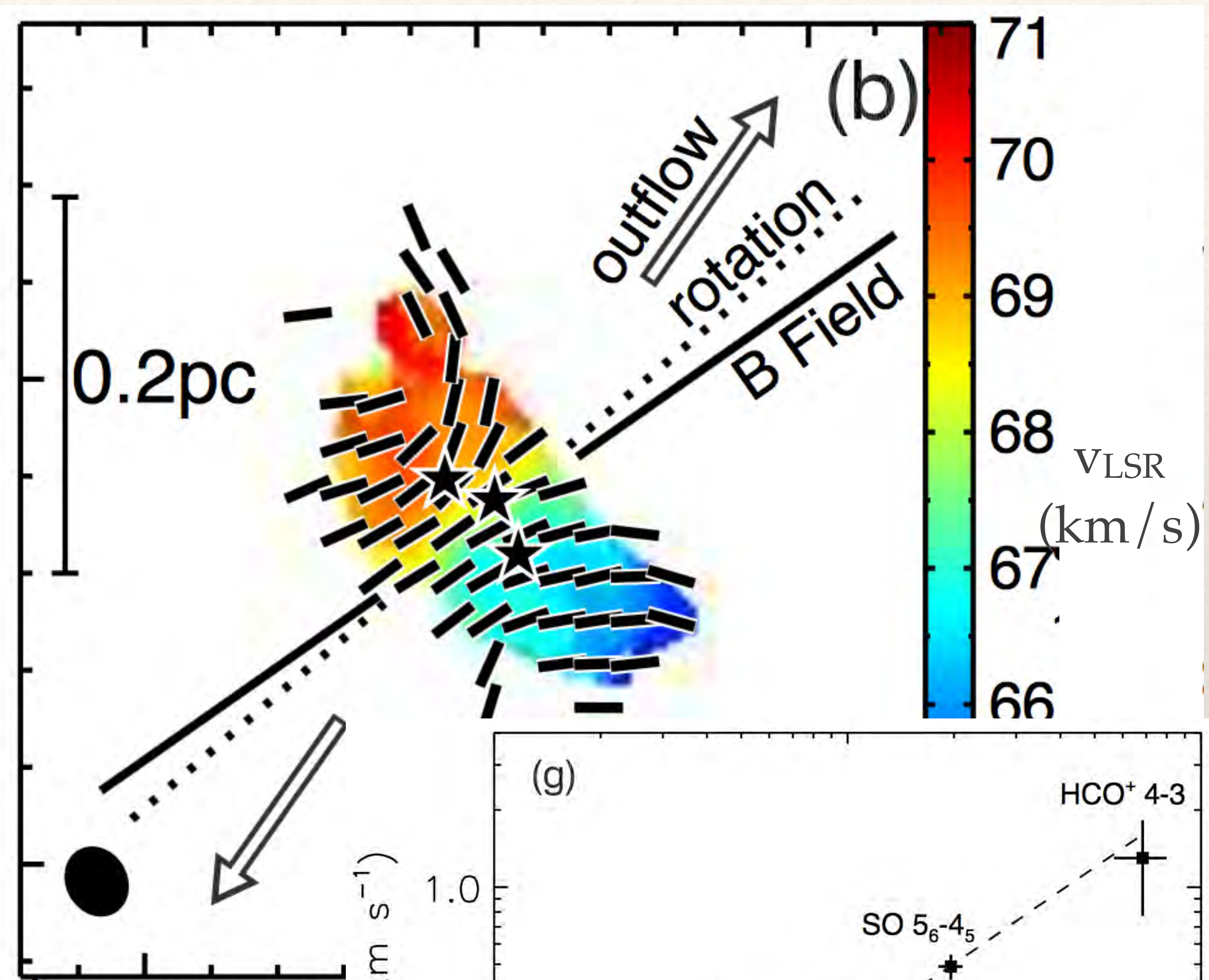

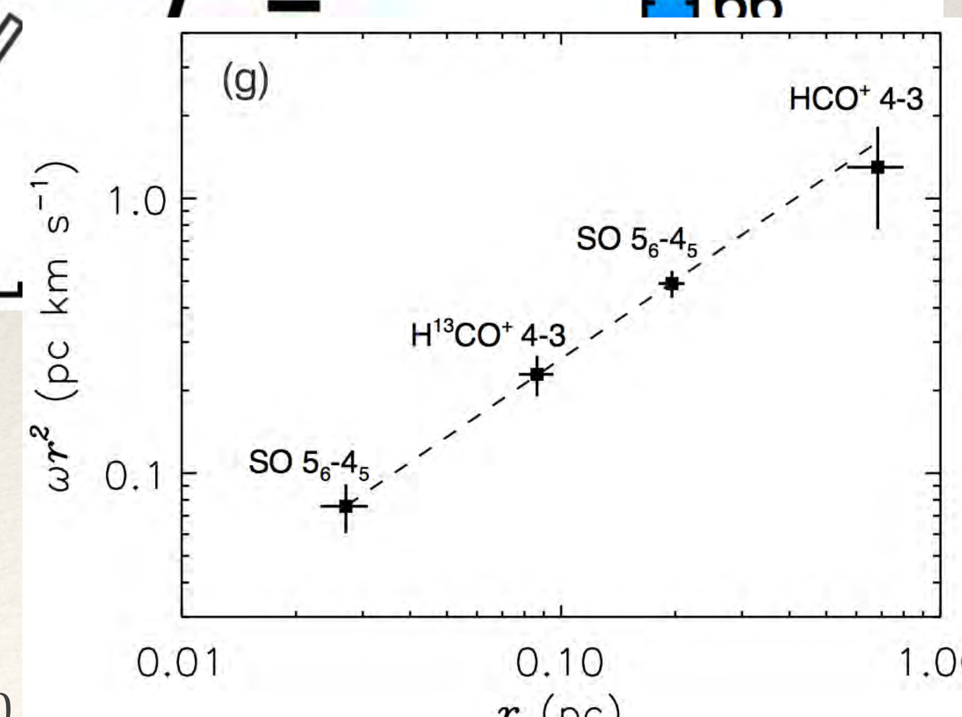

G240.31+0.

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

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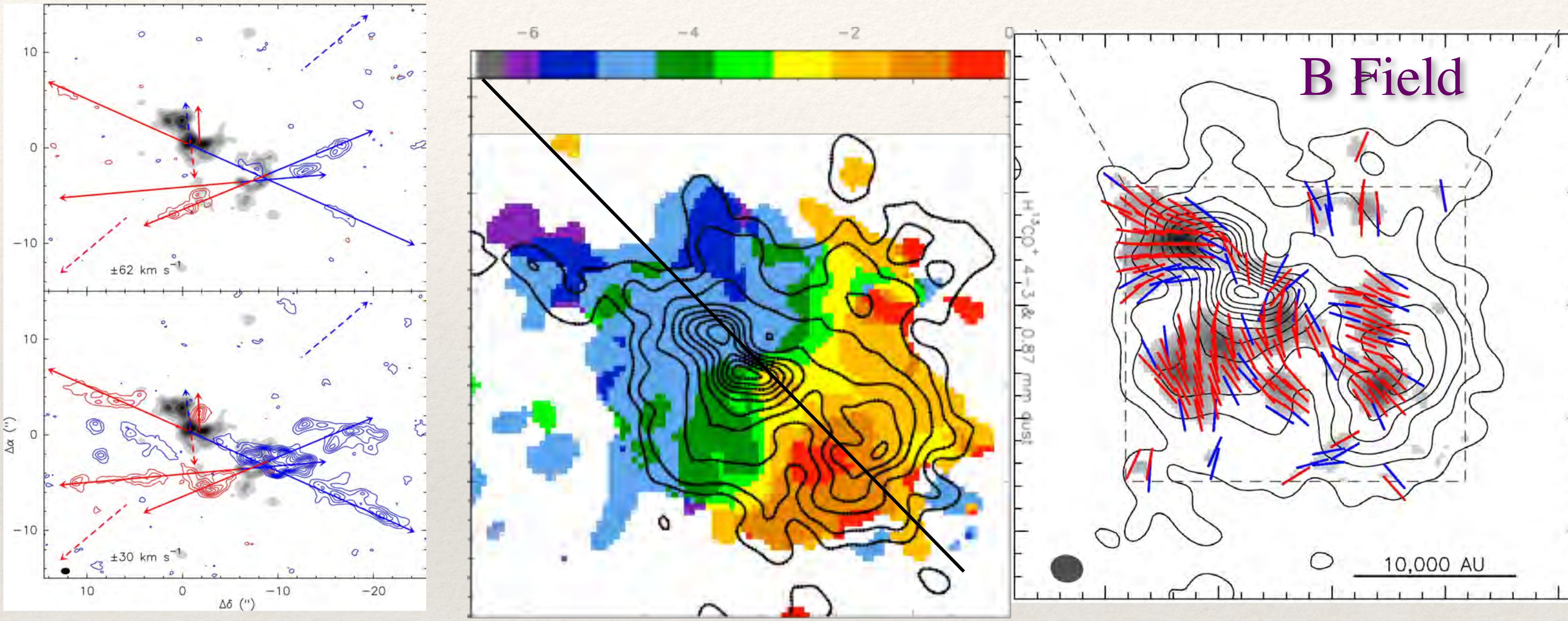
SMA pol survey in massive cores: DR21(OH)

Girart et al. 2013, ApJ, 792, 116

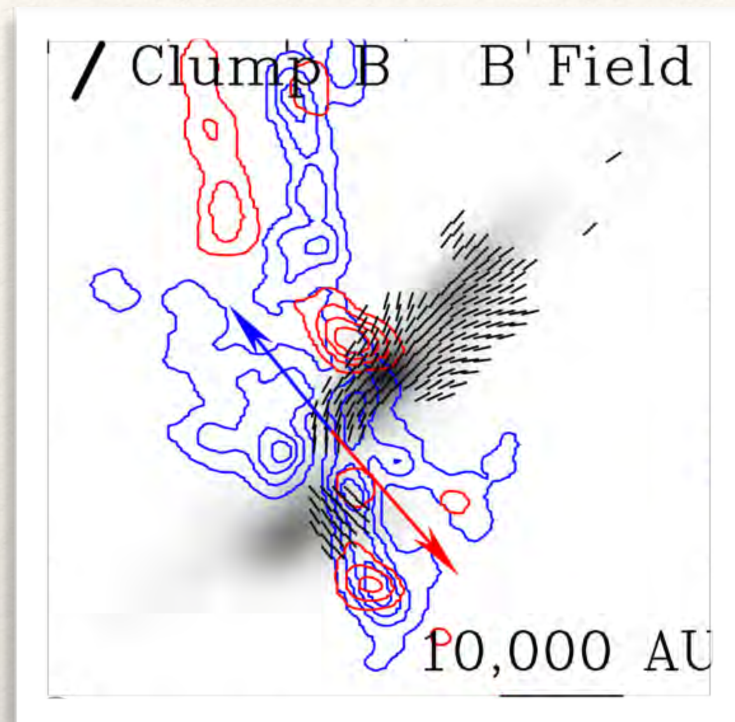


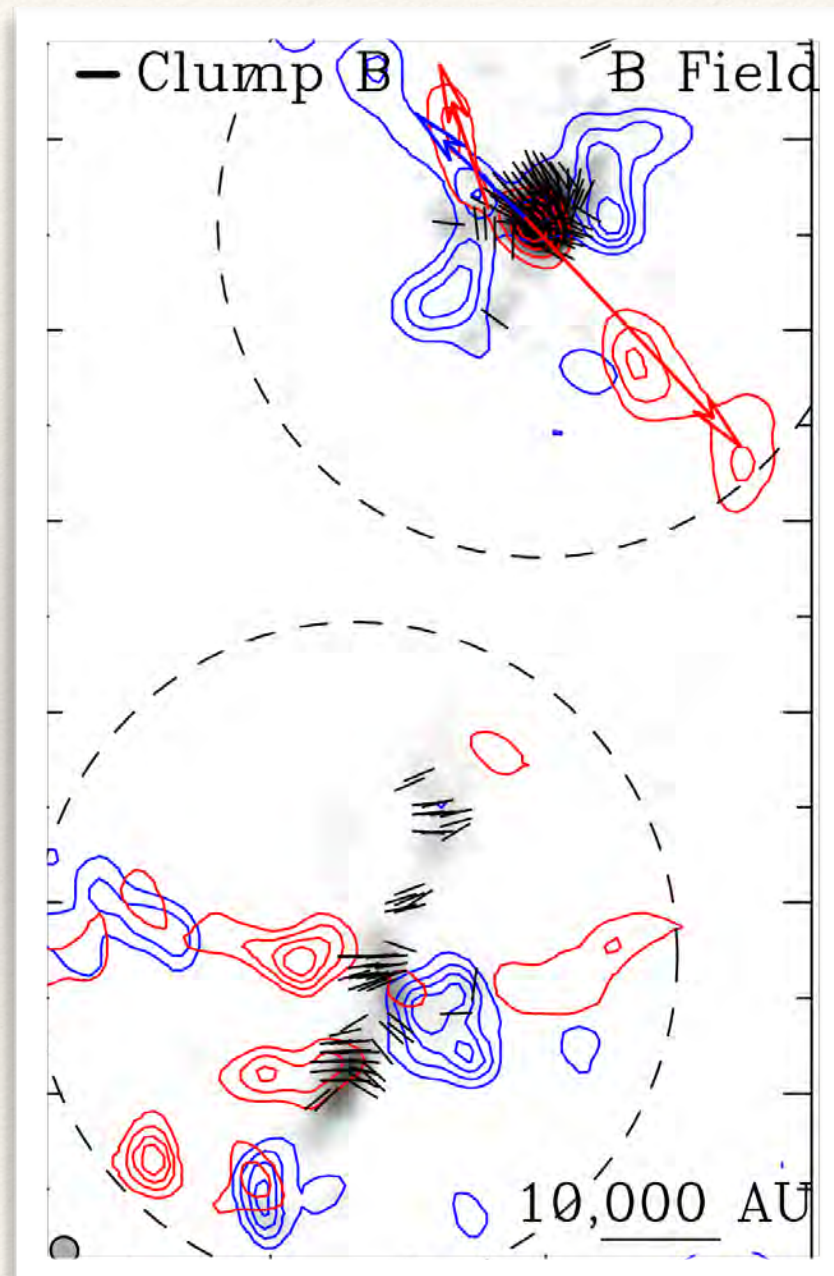
D=1.6 kpc; $L \approx 2\ 10^4\ L_\odot$; $M \approx 300\ M_\odot$. High level of fragmentation
No apparent aligned between bipolar outflow, magnetic field and rotation axes
Angular momentum dominates over magnetic field, causing a complex toroidal B morphology

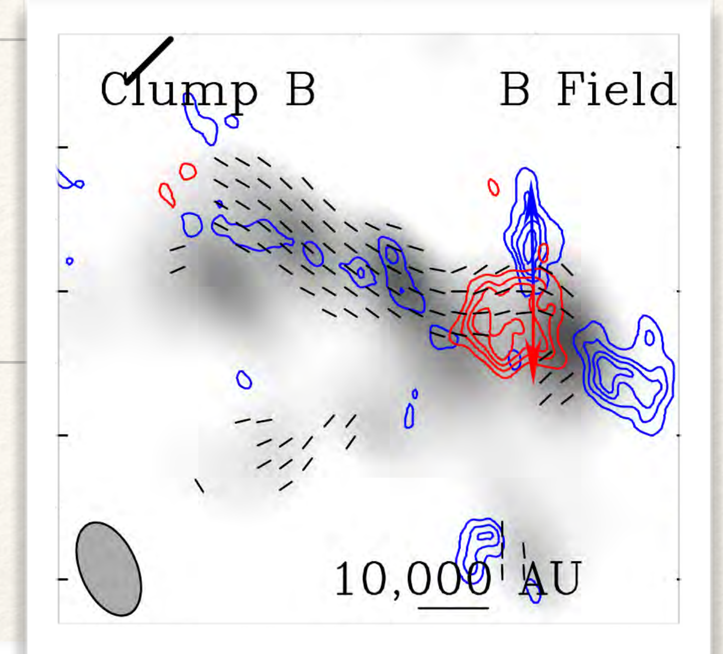
DR21(OH) refs: *Crutcher 1999; Lai et al. 2003; Hennemann et al. 2012,*

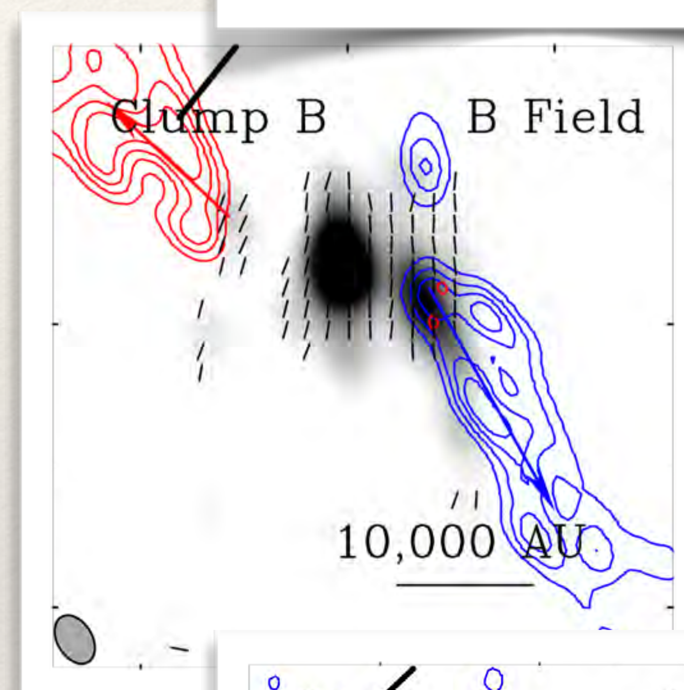
SMA pol survey in massive cores: Images

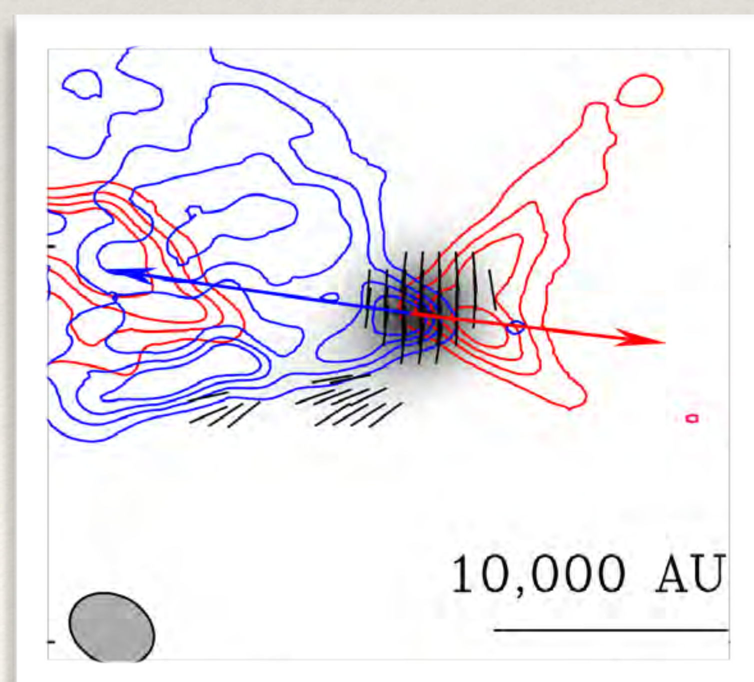
Zhang et al. 2014, ApJ, 792, 116

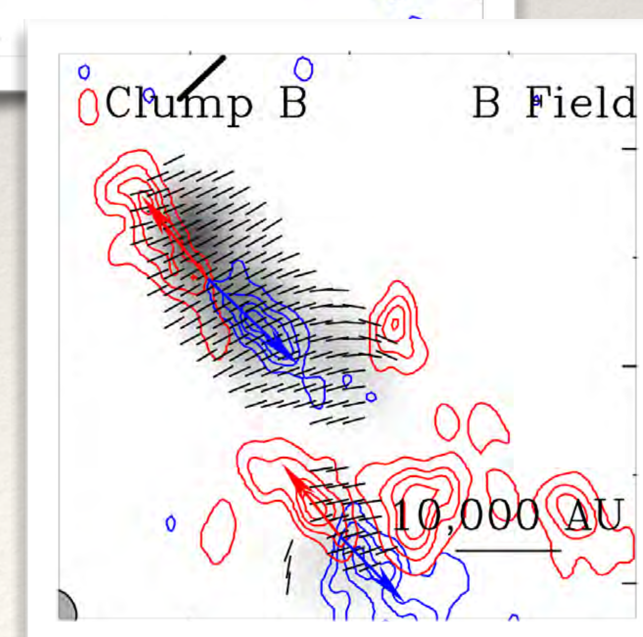






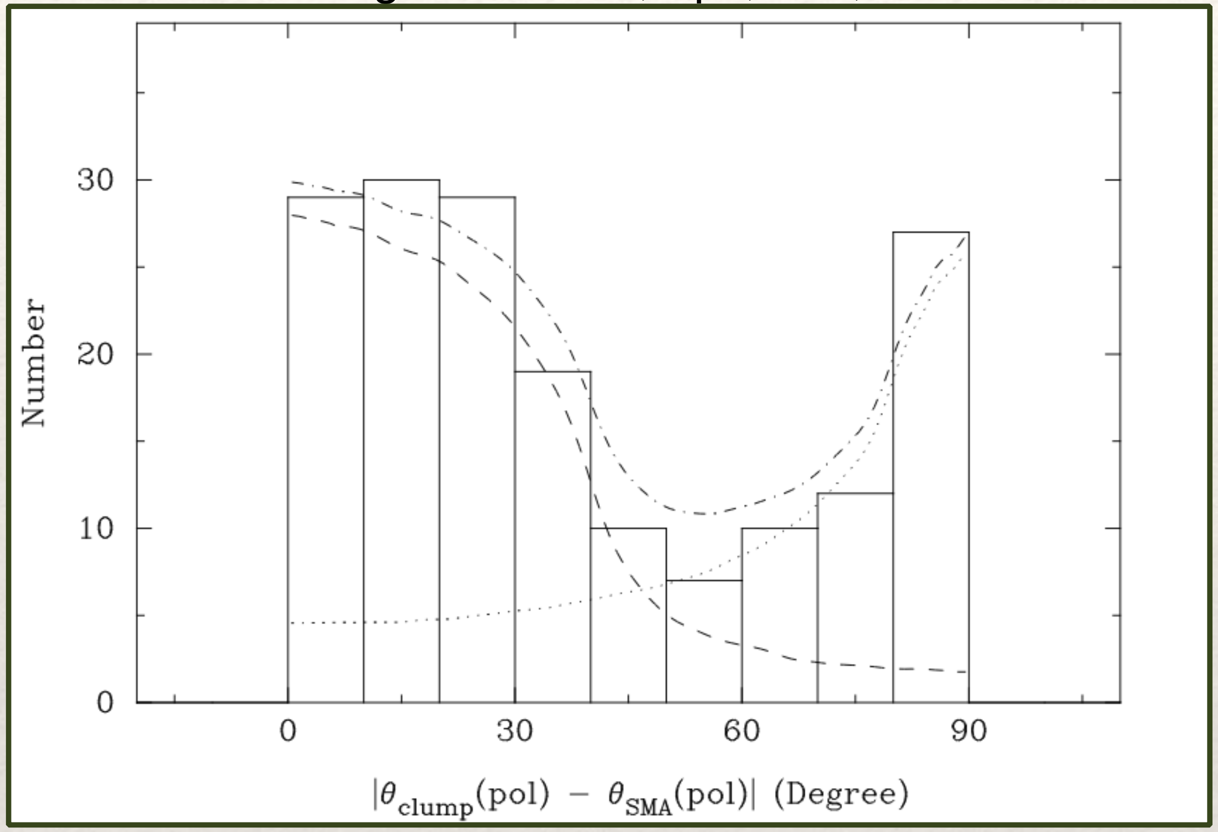


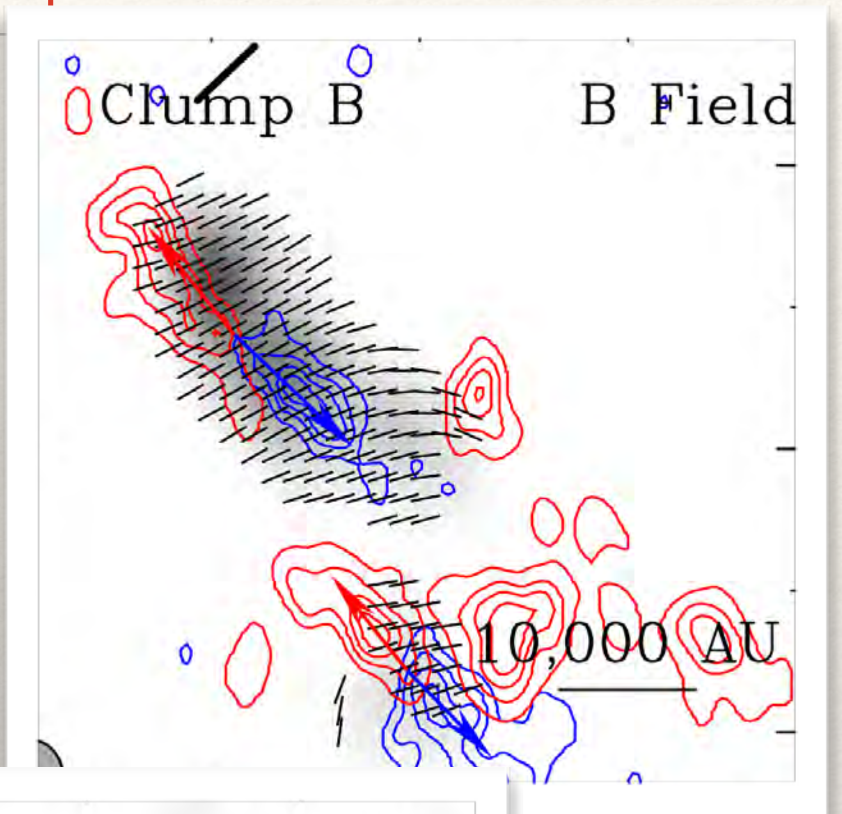


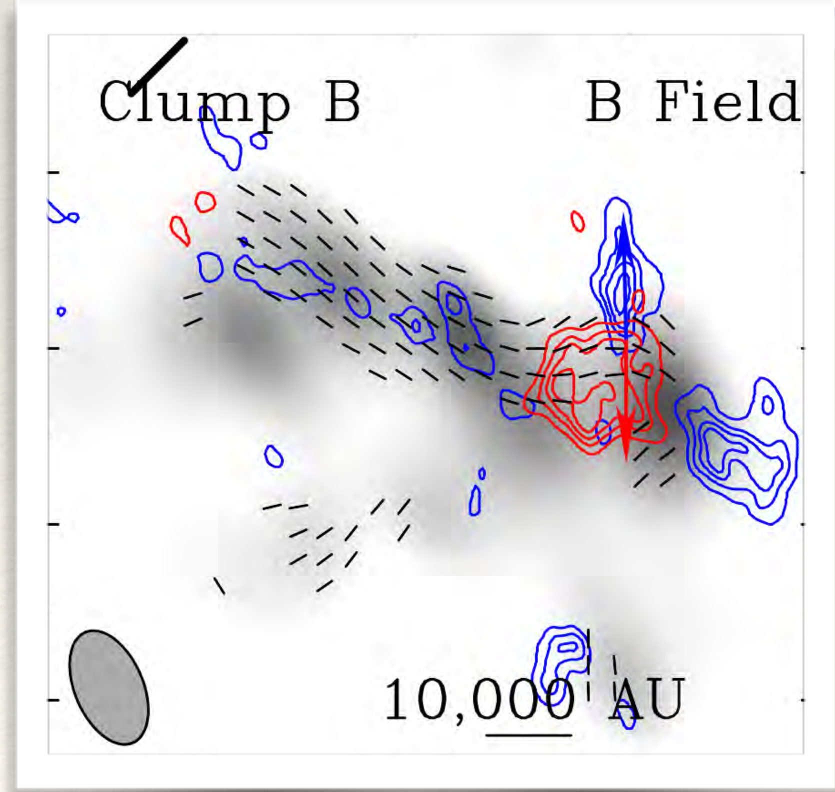


SMA pol survey in massive cores:
Statistical results: B_{core} *vs* B_{clump}

Zhang et al. 2014, ApJ, 792, 116





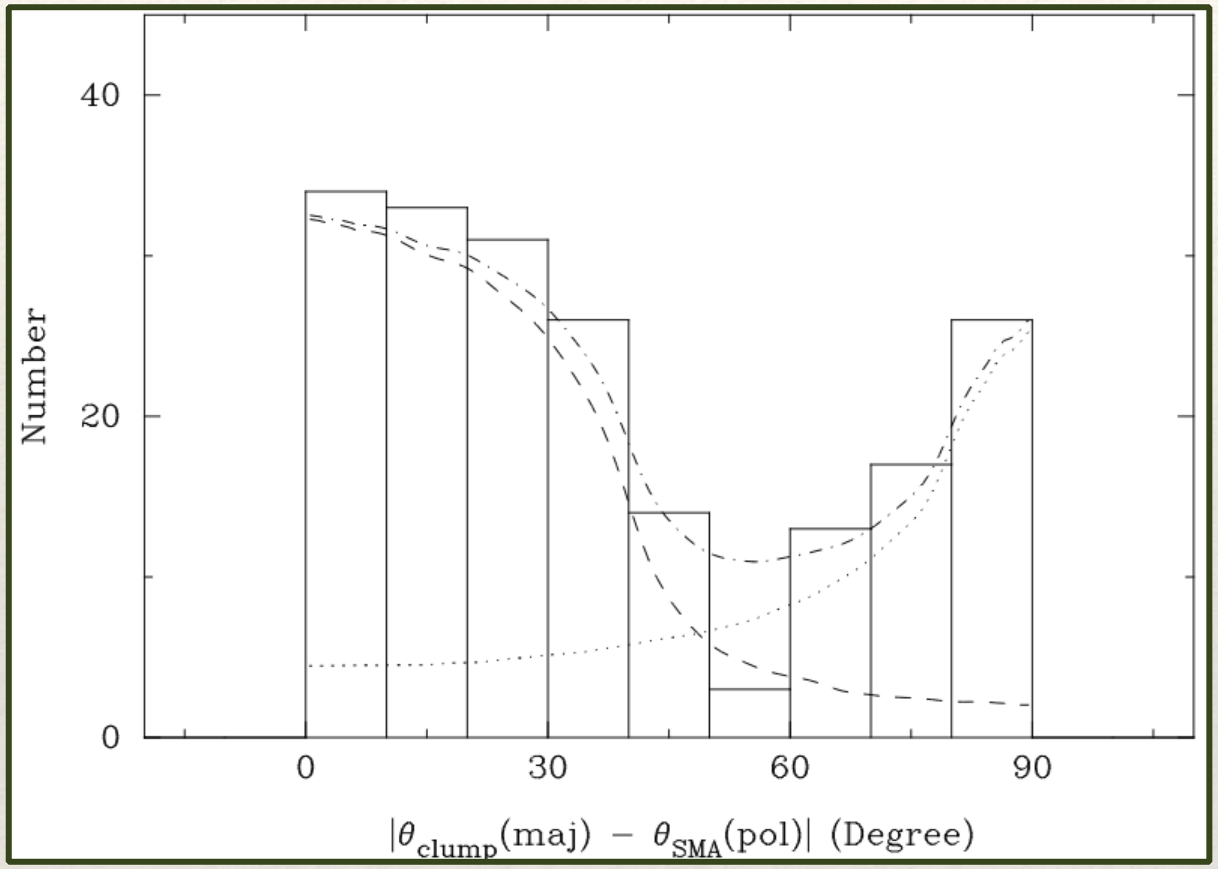


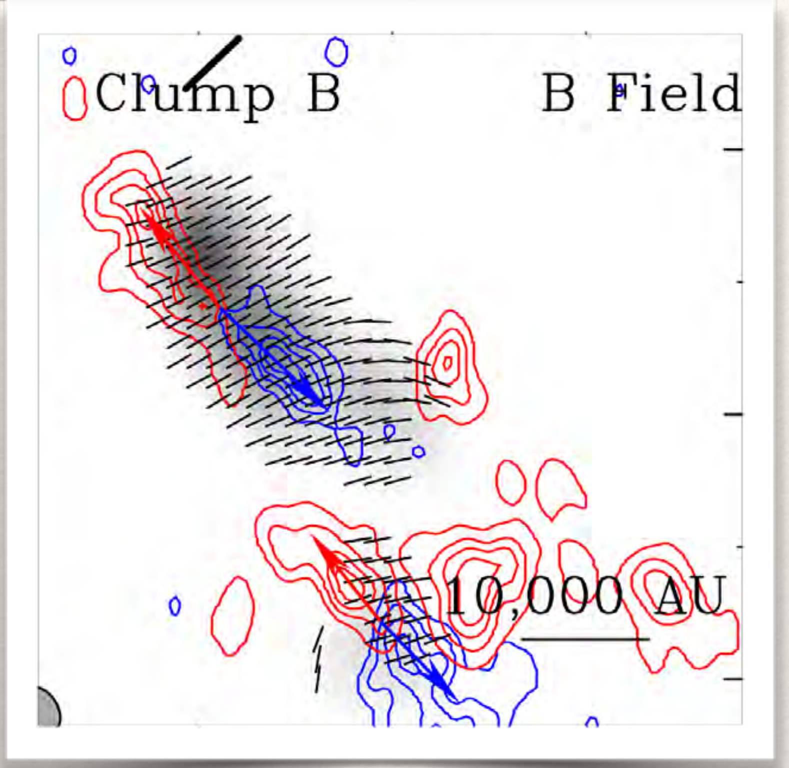
Bimodal distribution

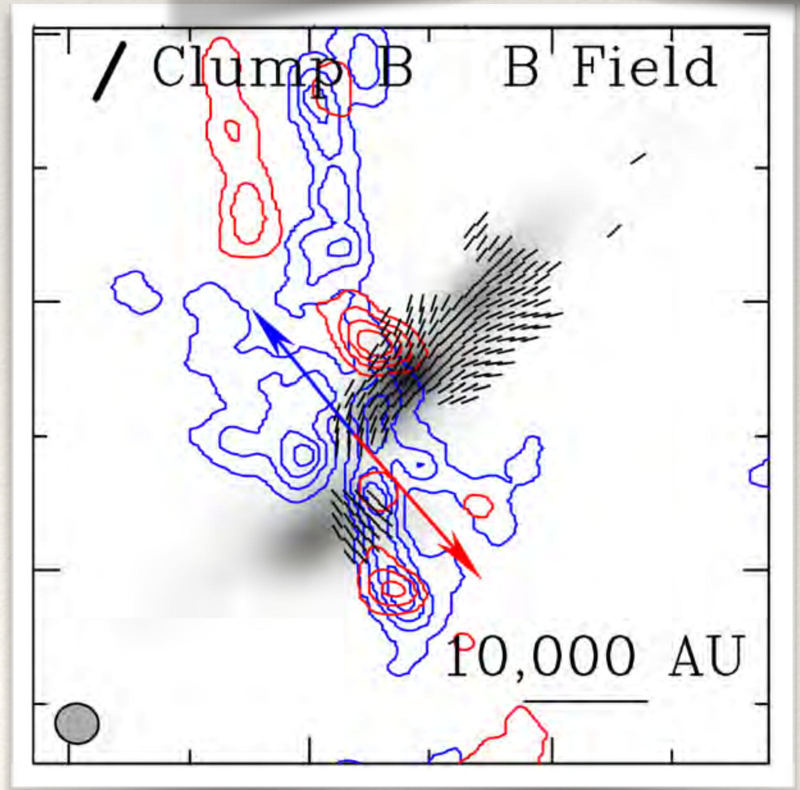
- 60% SMA pol $\Delta\theta<40^o$
- Smaller group of pol $\Delta\theta$~80-90^o
- Analysis suggests a || to ⊥ ratio of 5:3

SMA pol survey in massive cores: Statistical results: B_{core} *vs* Major $Axis_{core}$

Zhang et al. 2014, ApJ, 792, 116







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- 60% SMA pol Δθ<40°
- Smaller group of pol Δθ~90°
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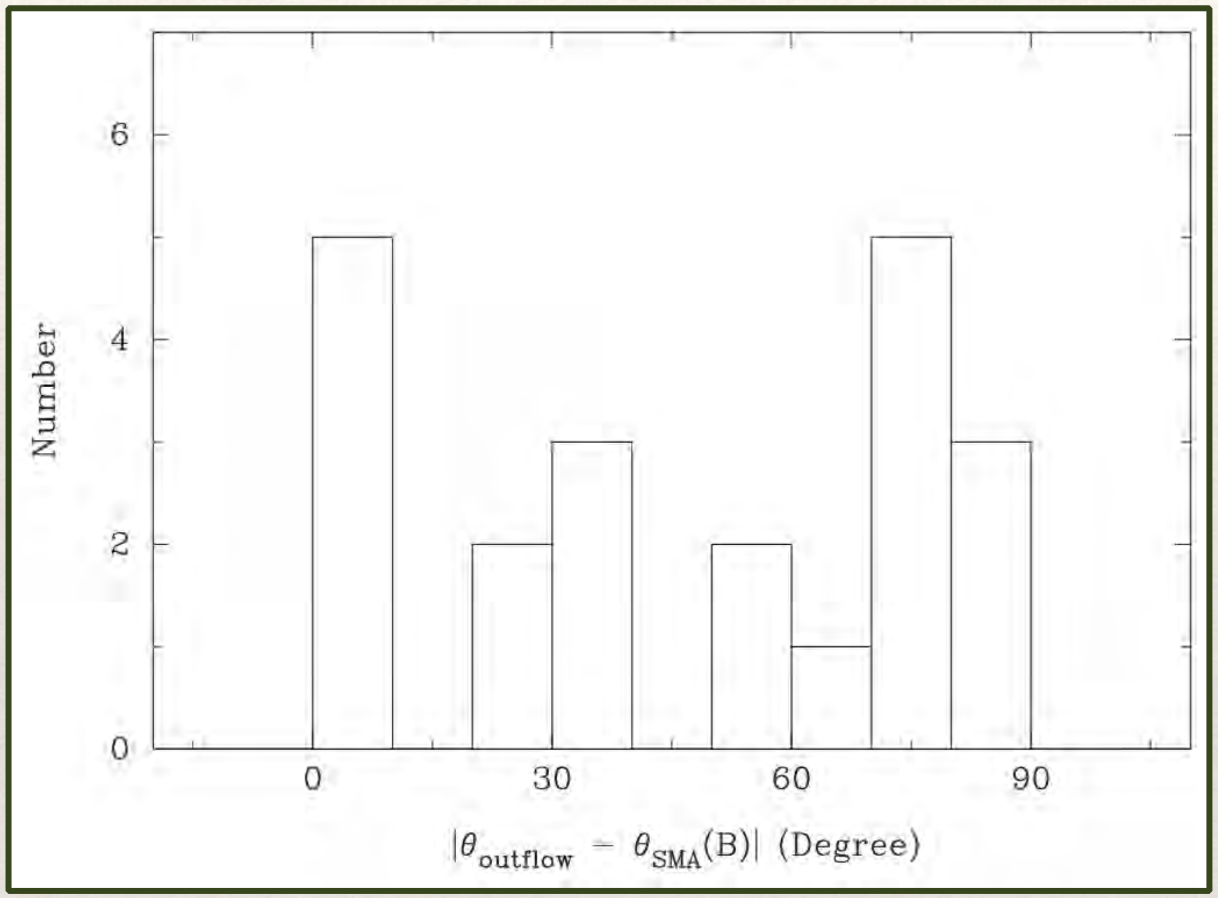
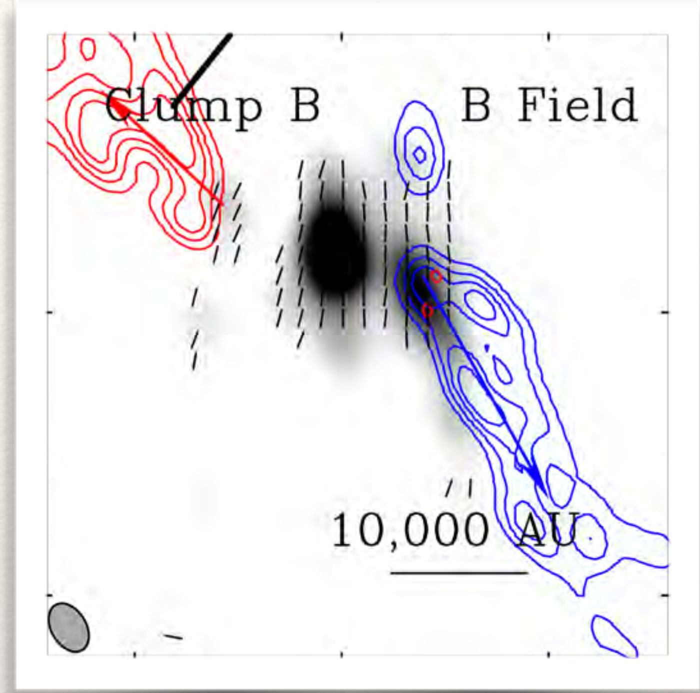
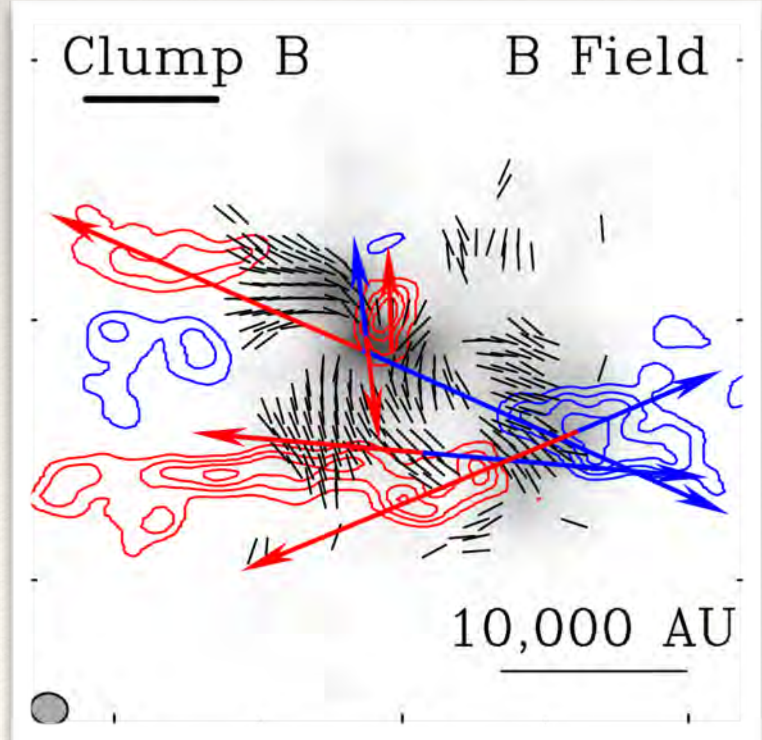
SMA pol survey in massive cores: Statistical results: B_{core} *vs* Outflow direction

Zhang et al. 2014, ApJ, 792, 116







No apparent correlation

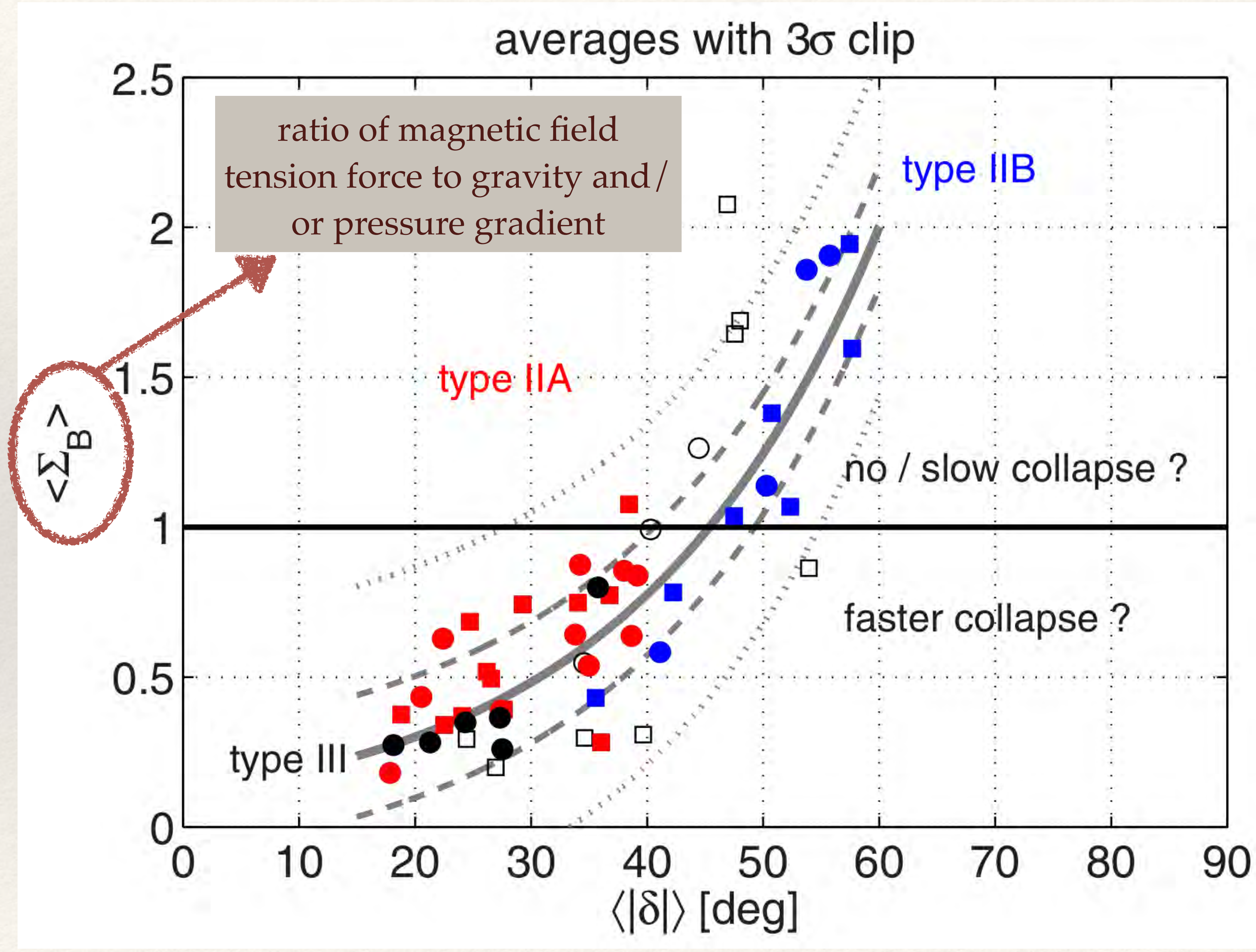
Similar result found for low-mass star forming cores: Hull et al. 2013

Statistical results from pol SMA + CSO obs

Koch et al. 2014, ApJ, 797, 99

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)



Conclussions

- In general magnetic fields appear to show a uniform pattern at core scale
- Magnetic fields at core scale show a bimodal distribution *wrt* to the larger scale direction and *wrt* to the core's major axis
- **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!