Polarimetry with the SMA

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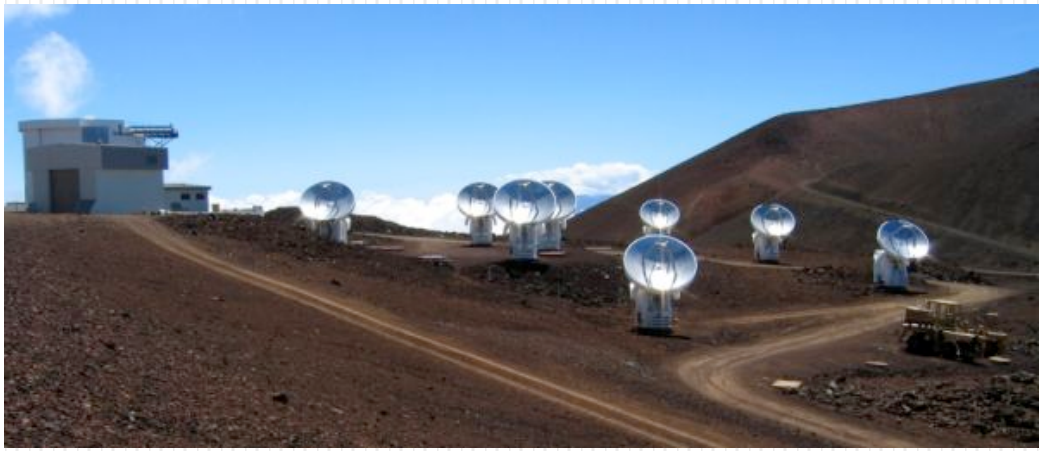


Collaborators: J. M. Girart (IEEC-CSIC), D. P. Marrone (NRAO/U. Chicago), Y. Tang (ASIAA), and a large number of others

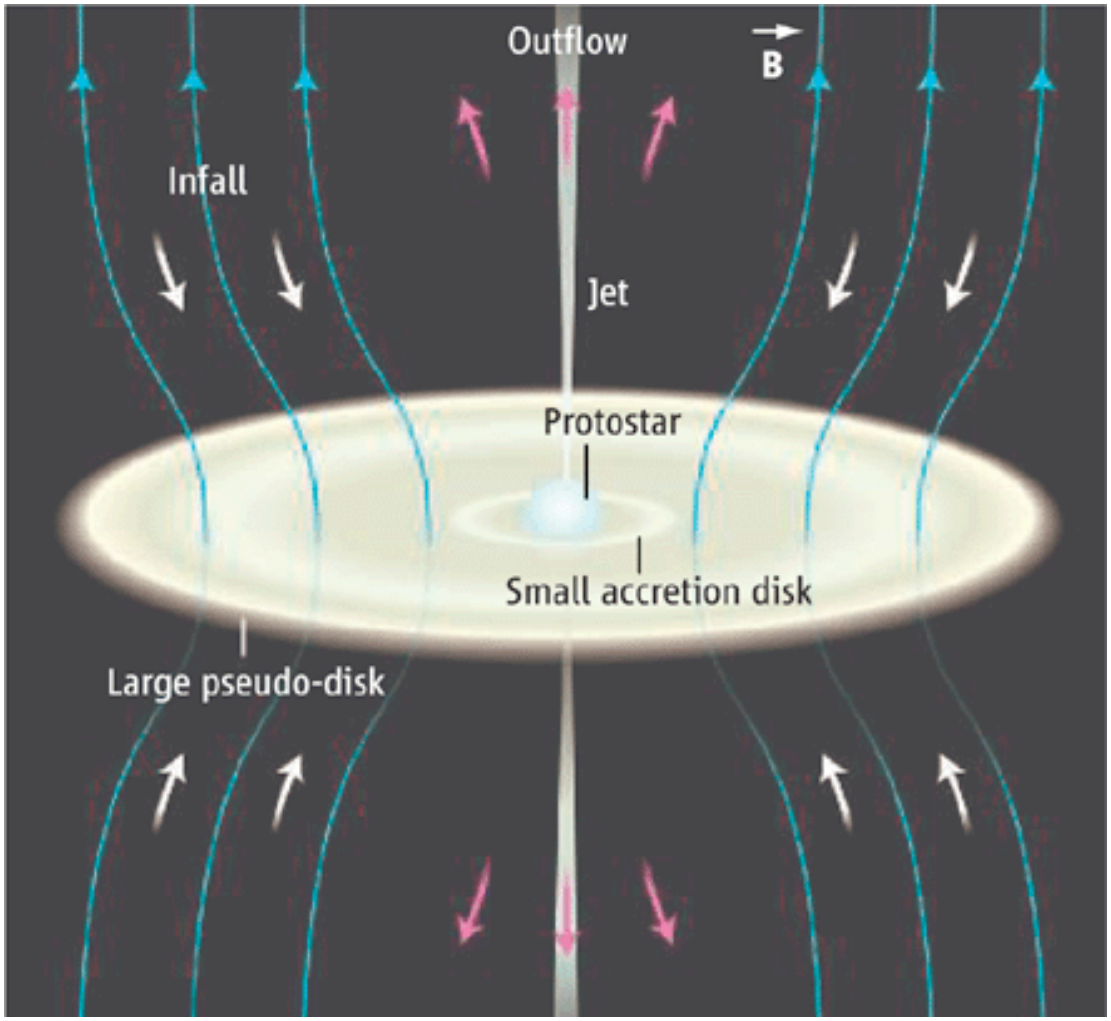
Regulation of Star Formation

- Two possible processes:
  - Magnetic Fields
    - Cloud support
    - Ambipolar diffusion
    - Magnetic braking
  - Turbulence
    - Weak magnetic fields
    - Intersecting supersonic flows create density enhancements leading to core formation
- Can observations distinguish between the two?

Magnetically Regulated Star Formation

B-Field Ambipolar Diffusion
Regulated star formation
Crutcher (2006)

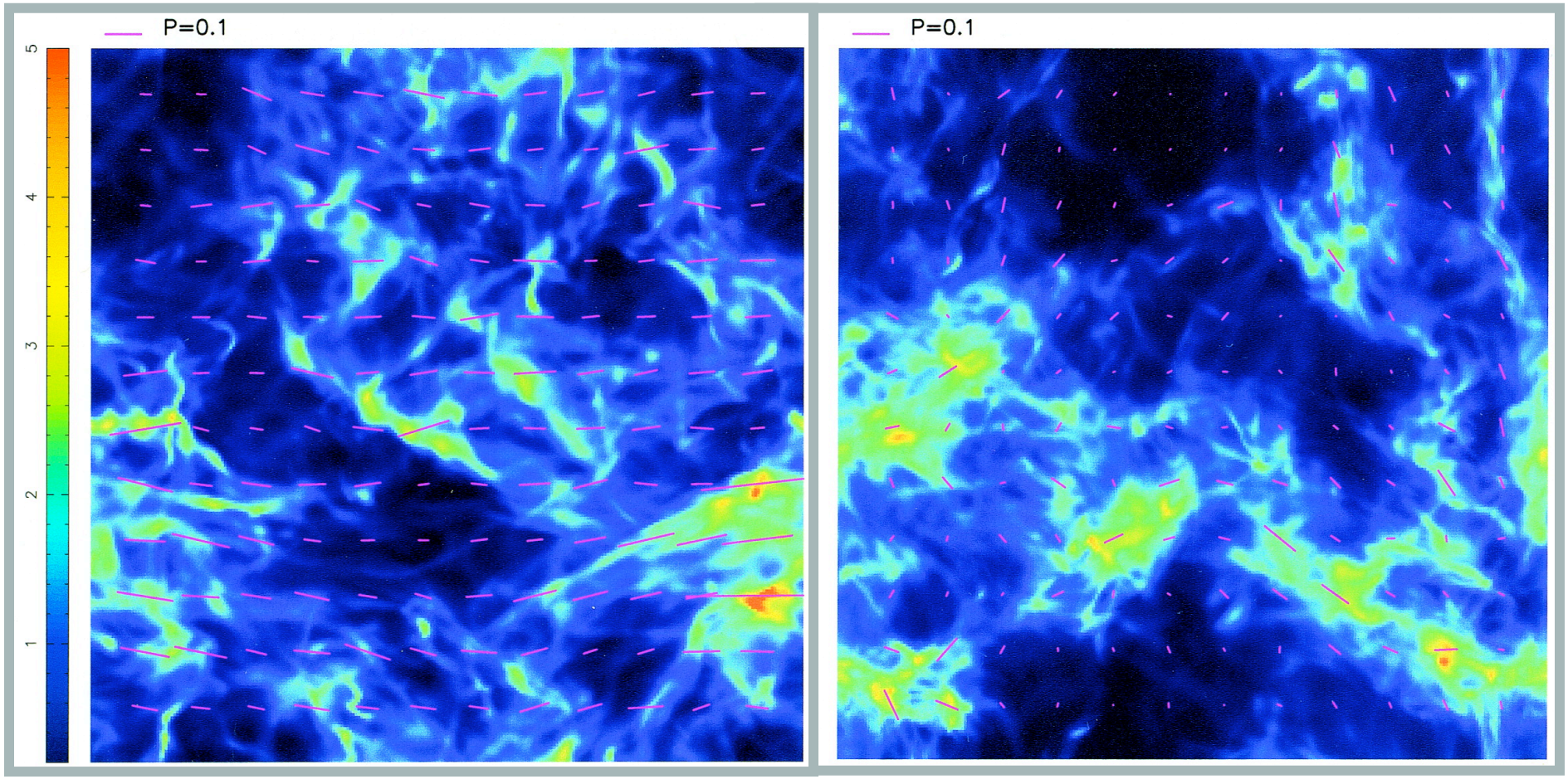
"Hour-glass" Pattern



~ a few 100 AU

Magnetohydrodynamic Models

Synthetic Polarization Maps from Ostriker, Stone & Gammie 2001; see also Heitsch et al. 2001; Padoan et al. 2003



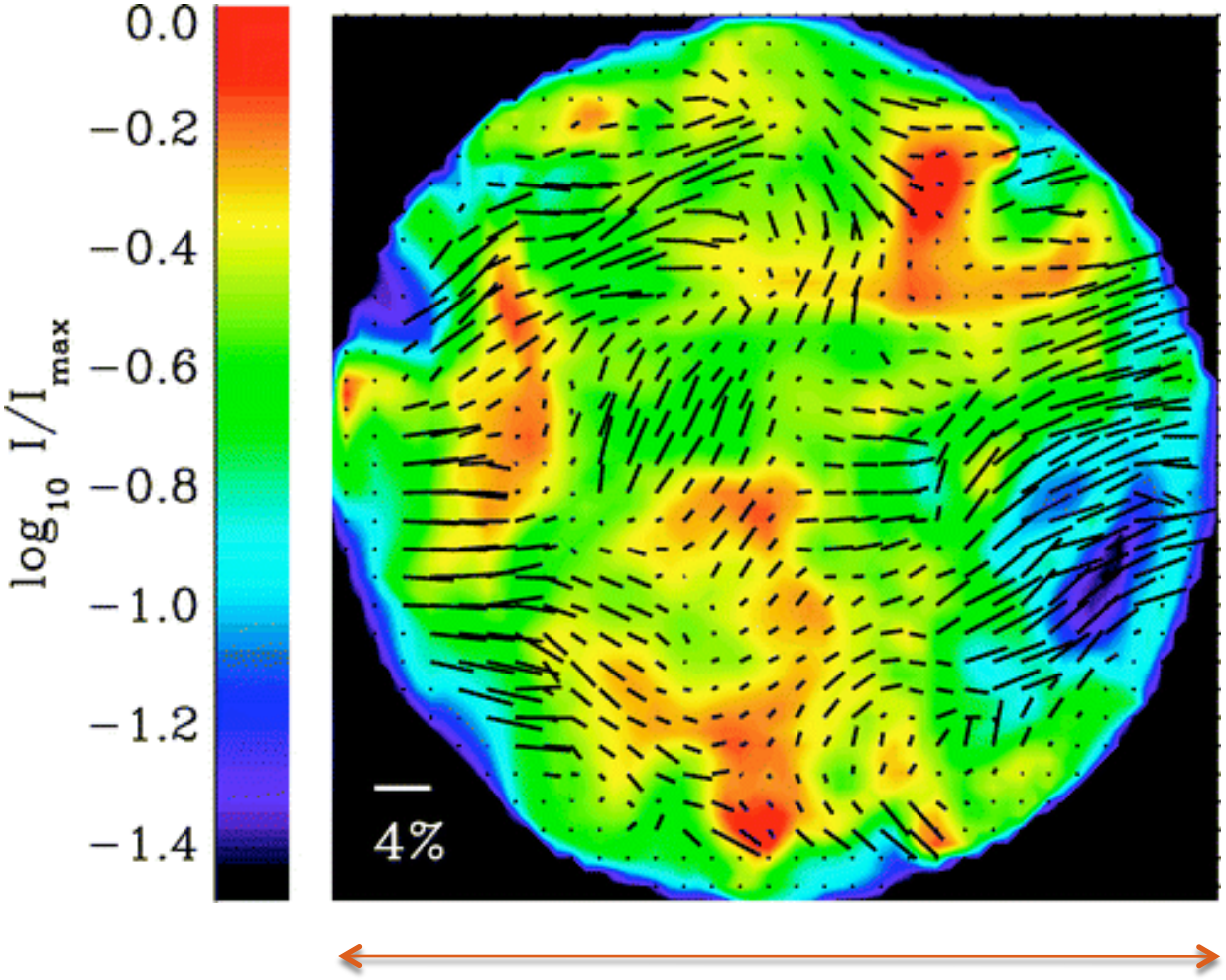
Strong Field

Weak Field

Methods of Detection

- Circular polarization arising from the Zeeman Effect – difficult; provides strength/direction of B_{los}
- Spectral line linear polarization via the Goldreich-Kylafis effect – also difficult to observe and ambiguity of direction of B_{pos}
- **Linear polarization of dust continuum emission – direction of B_{pos}**

Turbulence Dominated Scenario



~ a few 1000 AU

Compressible MHD Turbulence present
Alignment via radiative torques

Bethell et al. 2007

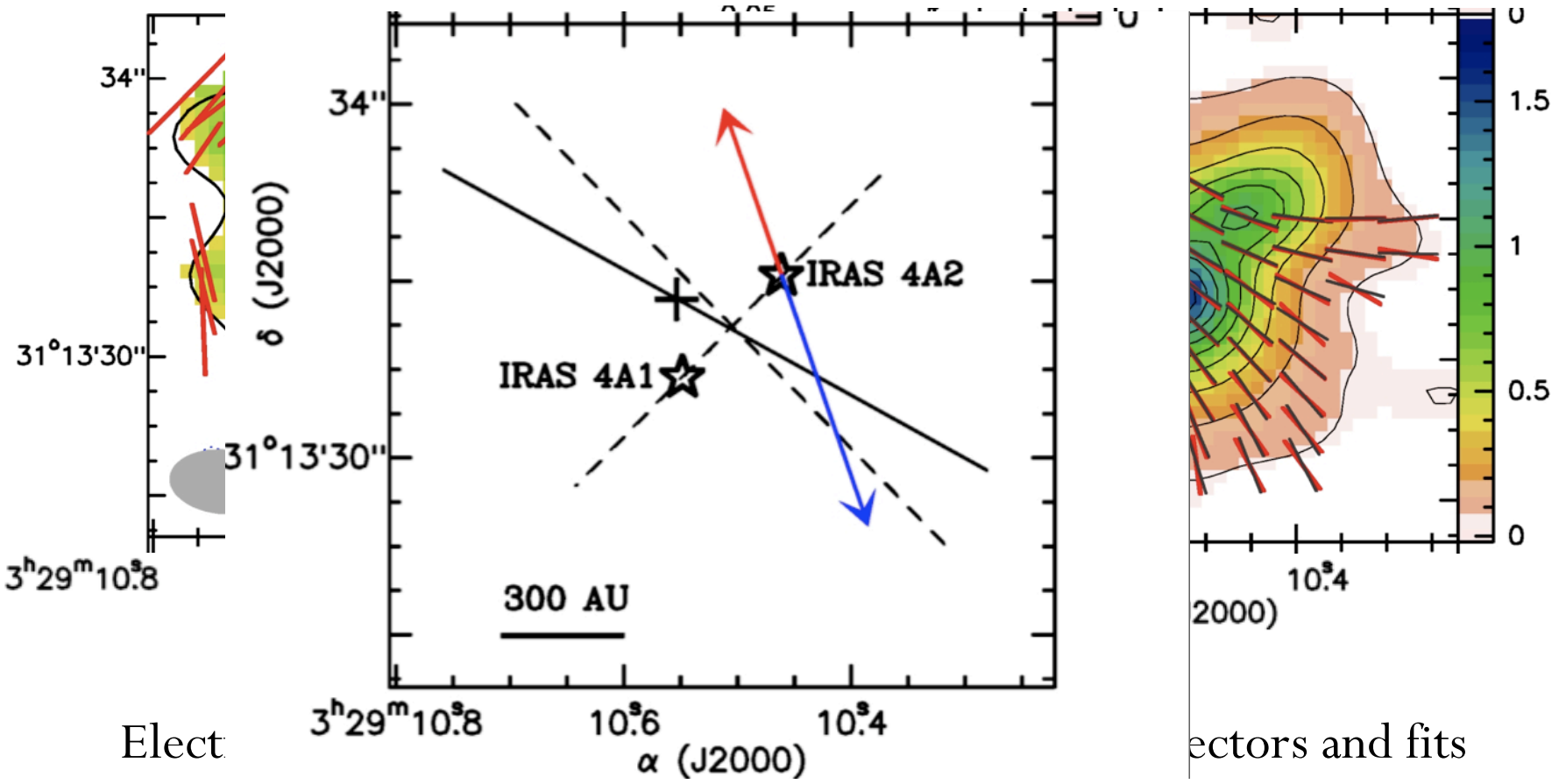
SMA Polarization Hardware

Hardware: First Iteration (2003-2007)

Marrone 2006 Ph.D. Thesis

- Interferometric observations require cross-correlation of orthogonal circular (L,R)
- SMA receivers are currently single linear polarization X,Y (similar to BIMA and CARMA)
- Quarter wave plate converts linear to circular pol. X,Y => L,R
- Time multiplex using Walsh switching
- Average to get quasi-simultaneous dual-pol
- Future dual pol receiver conversion is in progress

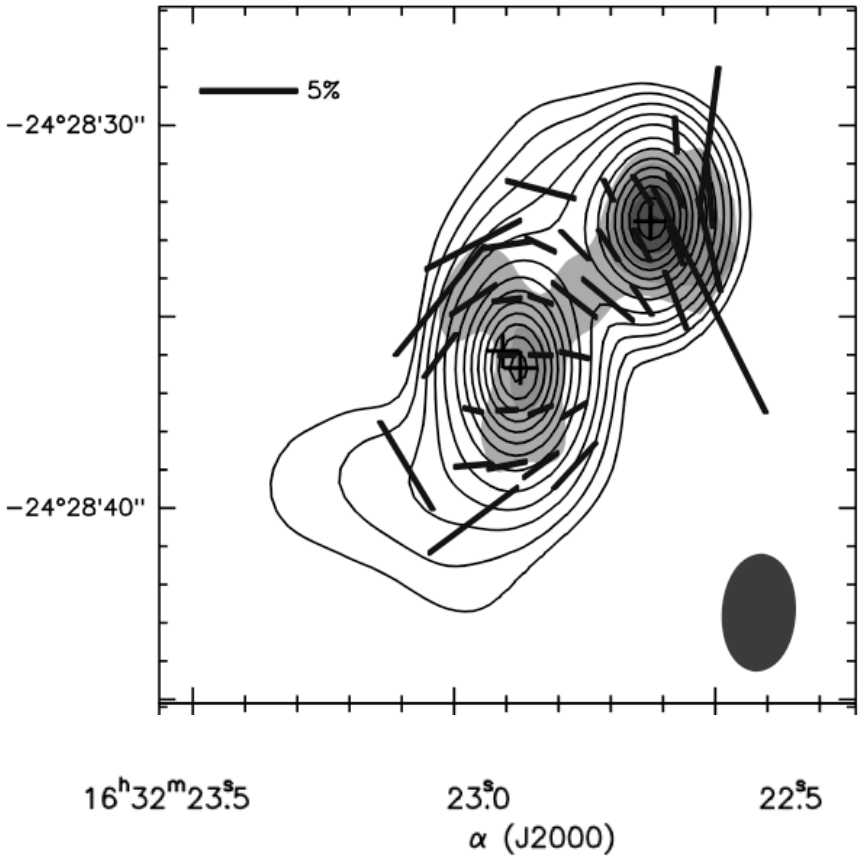
NGC 1333 IRAS 4A



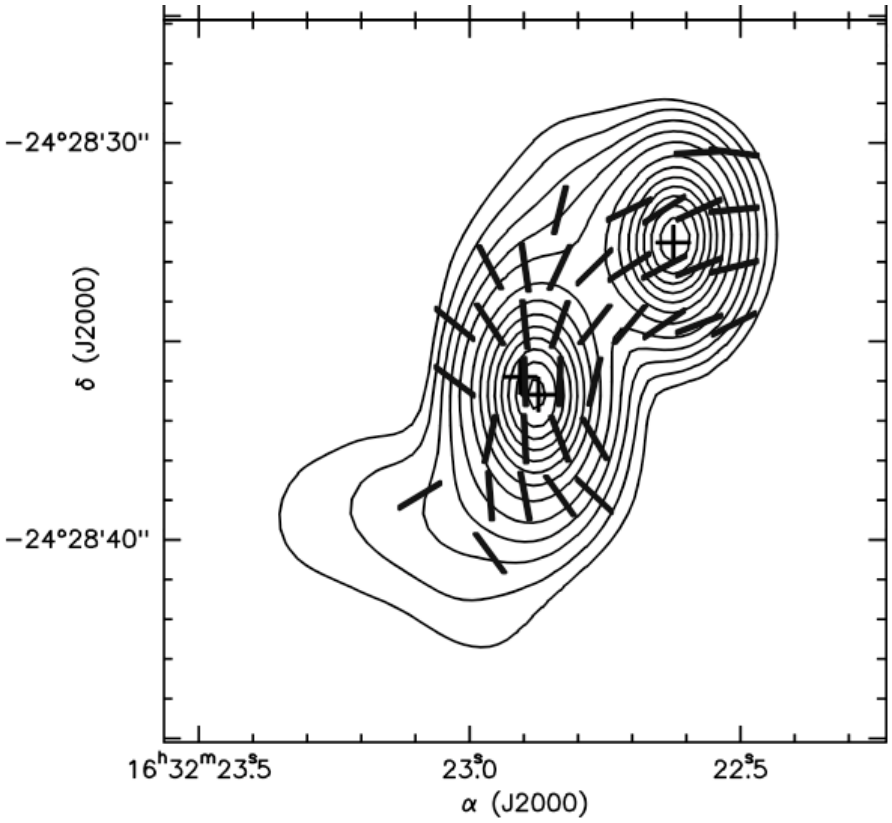
Elect ectors and fits

Girart, Rao, & Marrone (2006)

IRAS 16293 A and B



Electric Field vectors

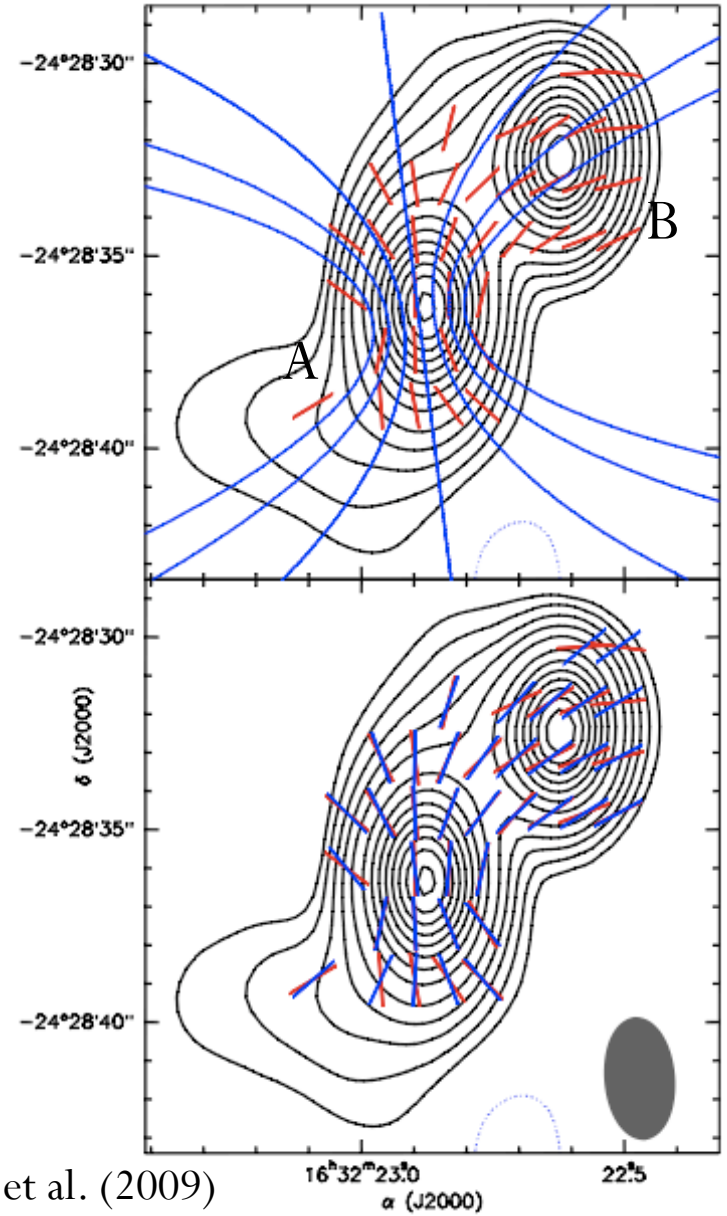


Magnetic Field vectors

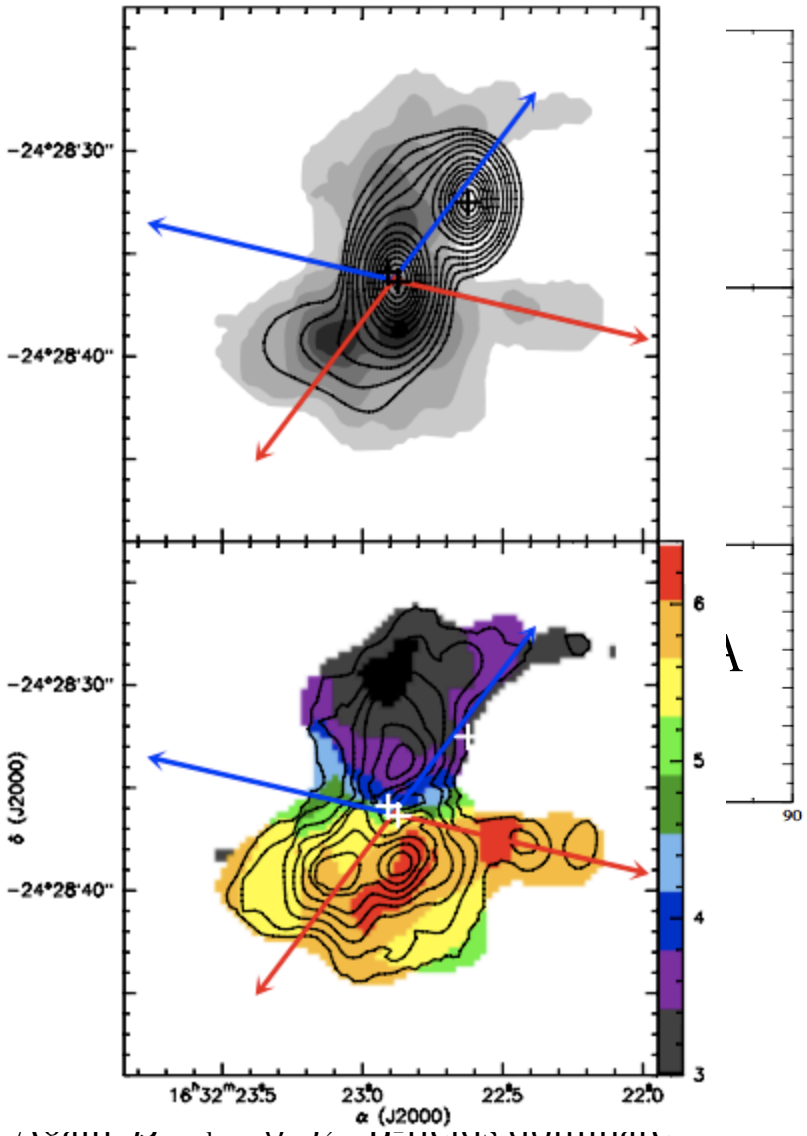
Low mass stars in Ophiuchus at a distance of 160 pc

Rao et al. (2009)

Fits to the Magnetic Field



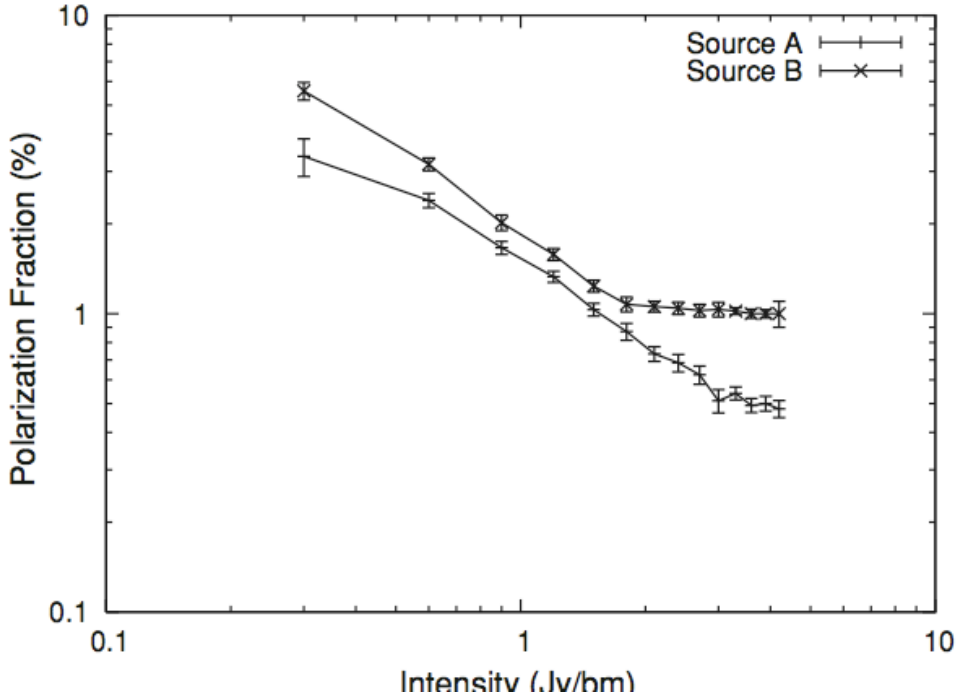
Rao et al. (2009)



Again β_{turb} 0.92; B-fields dominate turbulence

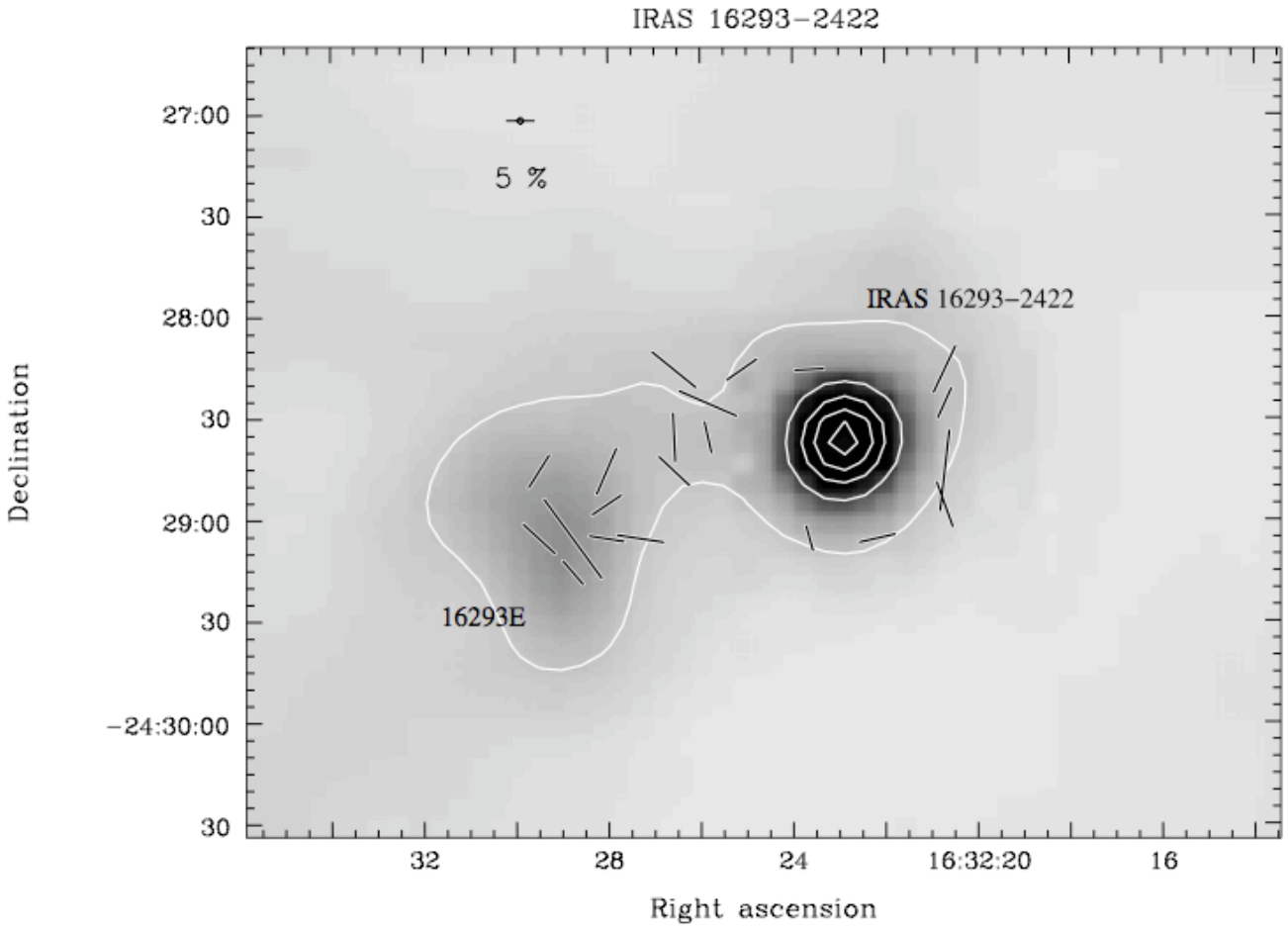
Polarization Hole

- Decrease in polarization towards the center
- Could be due to either
  - Unresolved structure
  - Alignment inefficiency
  - Grain properties
- This effect is seen in other regions such as NGC1333IRAS4A, Orion, etc.



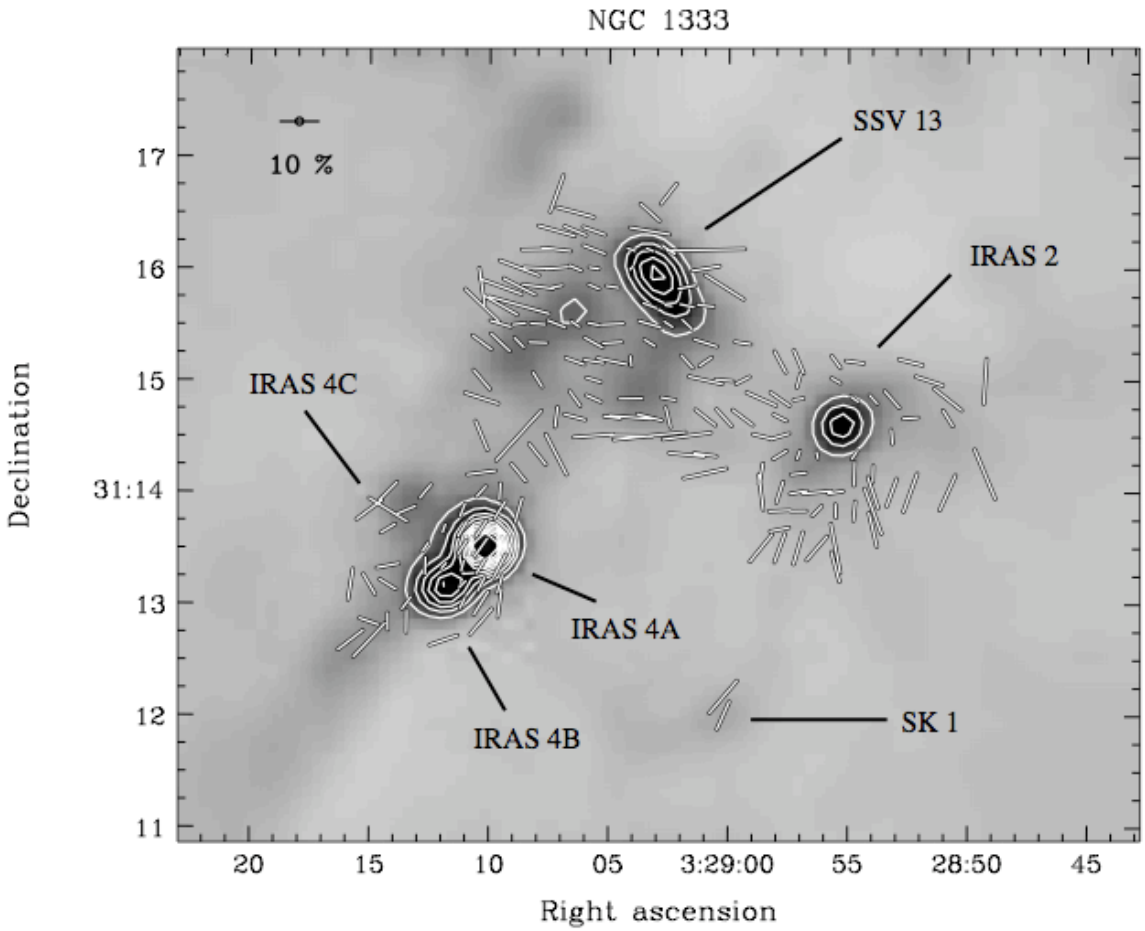
Rao et al. (2009)

Larger Scale Polarization Structures: SCUBA IRAS 16293



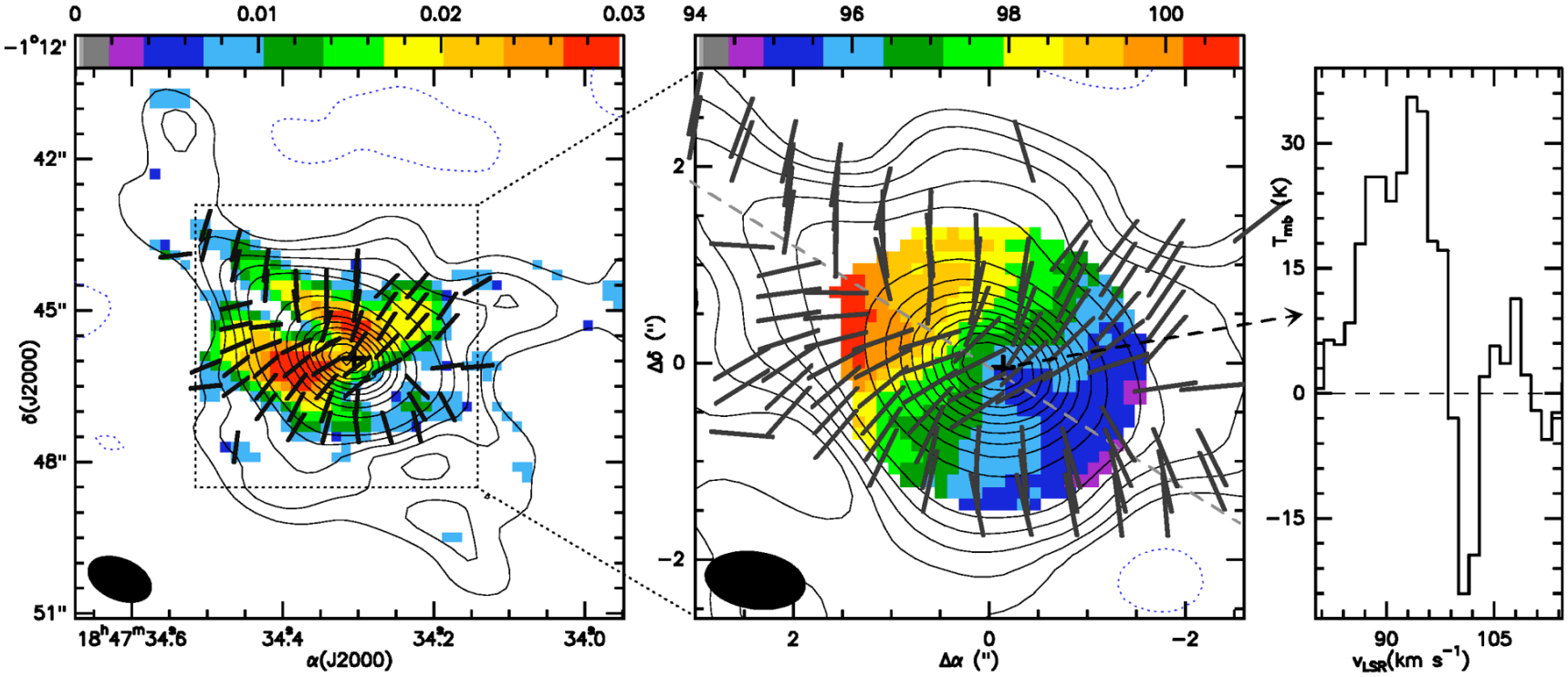
Matthews et al. 2009

NGC 1333 SCUBA



Matthews et al. 2009

G31.41 High mass star forming region (D ~ 8 kpc)



Hour glass morphology

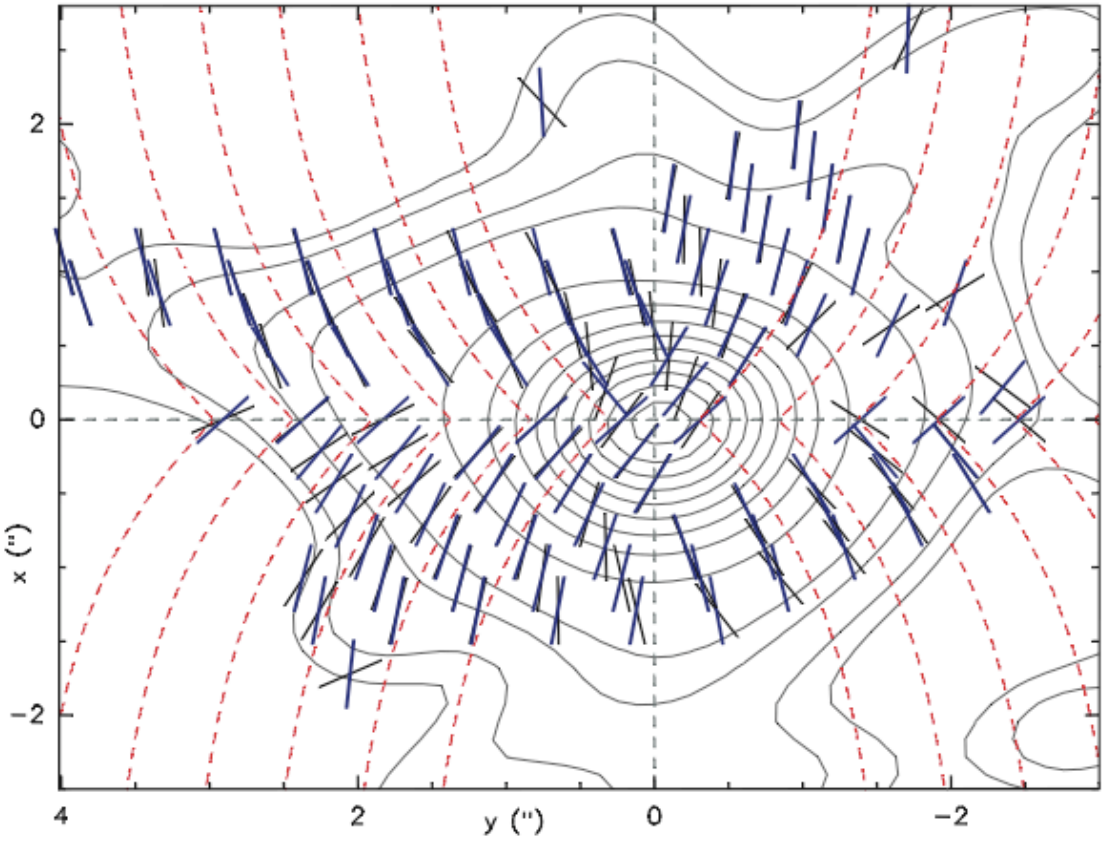
CH_3OH 14_7-15_6 A
Velocity gradient

Inverse P Cygni
Profile $C^{34}S$ with
v_{inf} ~ 3 km/s

Girart et al. (2009)

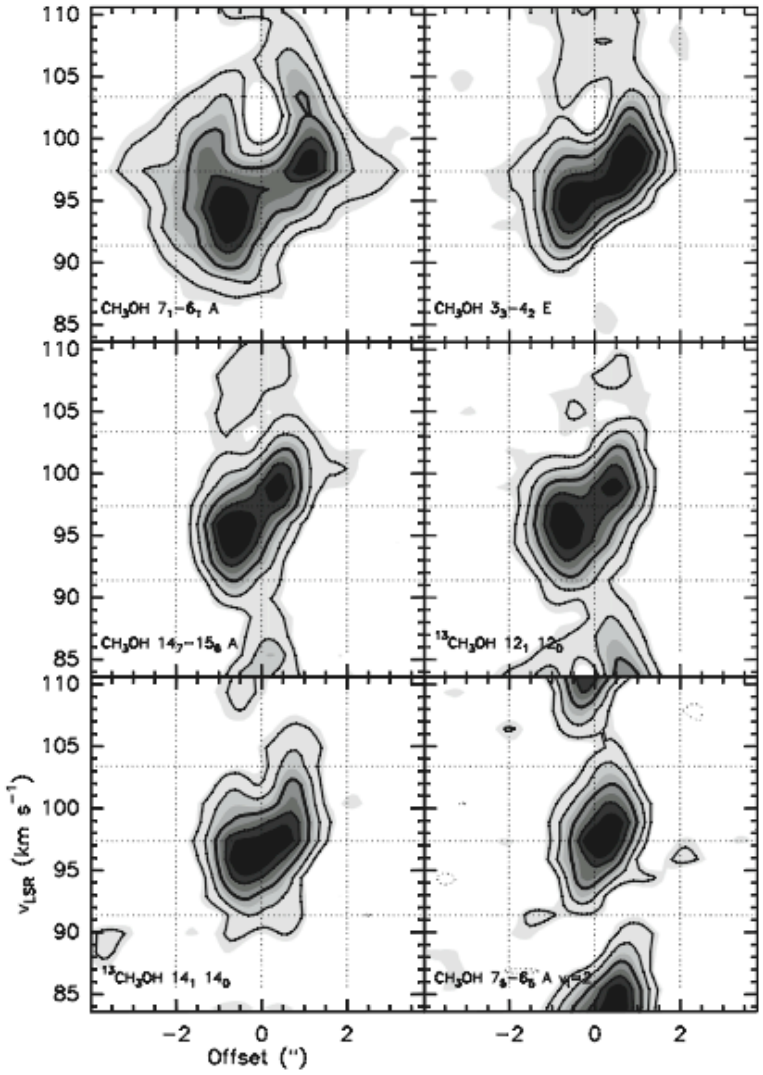
Magnetic Field Properties

- Mass estimated from dust emission ~ 577 $M_\odot$
- Fitted with exponentials e^{-x}
- Get B ~ 9.7 mG
- $M/\Phi \sim 2.7$
- $\beta_{turb} \sim 0.35^{+0.29}_{-0.2}$
- Magnetic energy dominates over turbulence

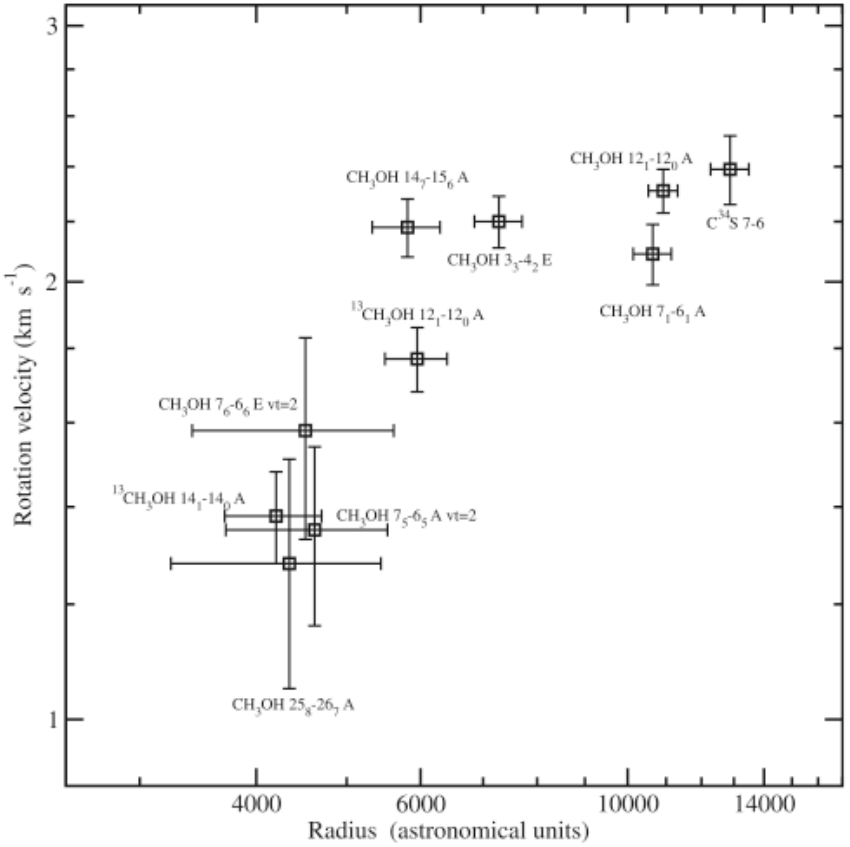


Girart et al. (2009)

Kinematic signatures with radius



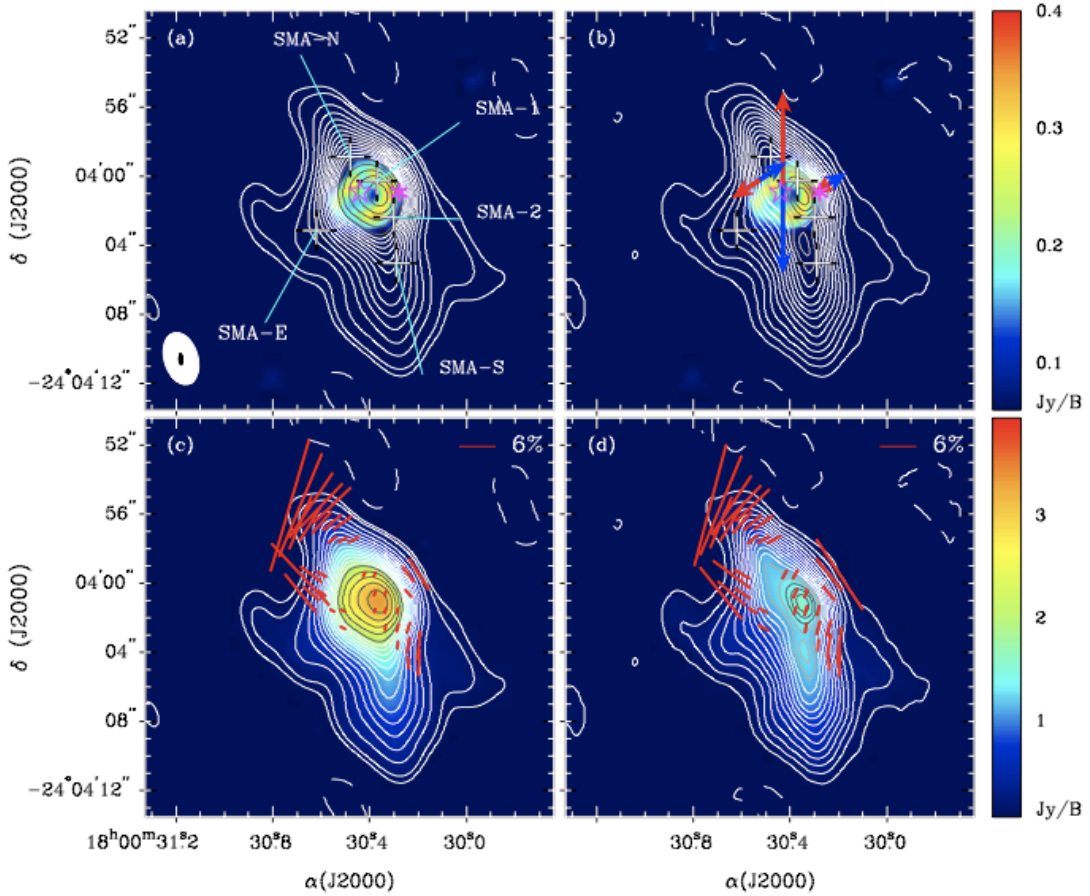
Girart et al. (2009)



- Higher excitation molecules trace close to center
- Conservation of angular momentum requires $\omega \sim 1/R$
- Observations show ω decreases with radius
- **Thus magnetic braking must be occurring**

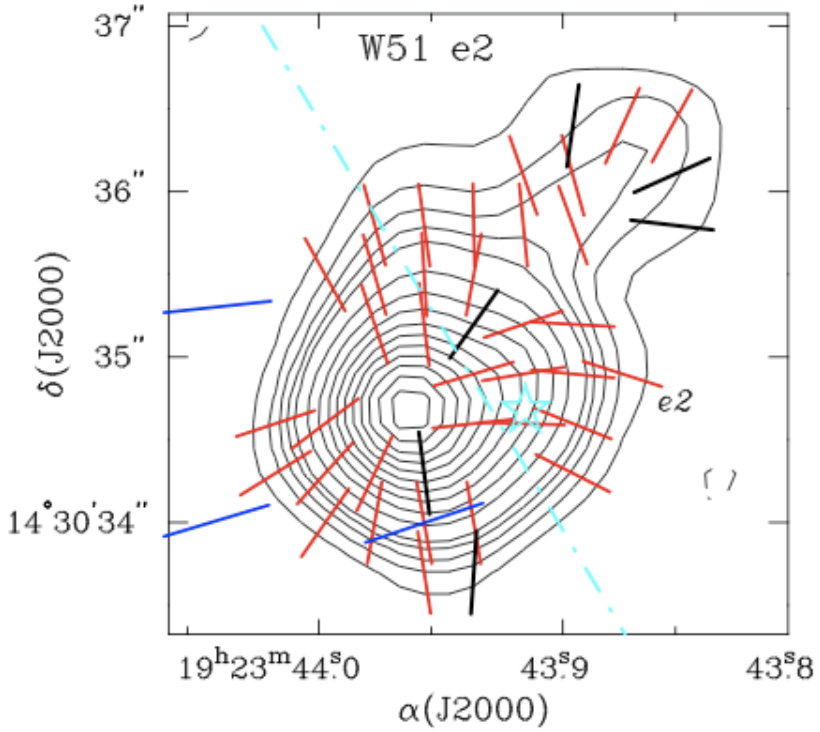
Are hour glasses common?

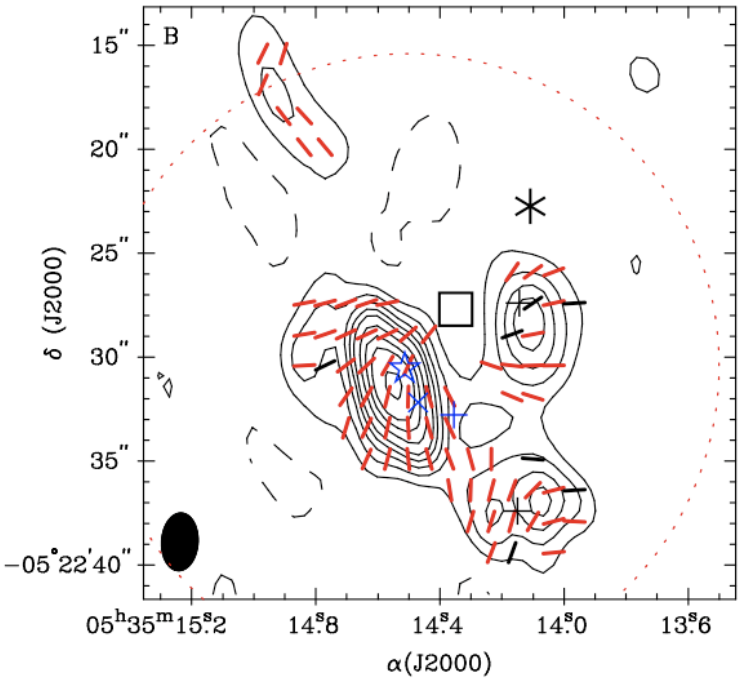
- 3/3 so far
- G5.89 is a high mass region and shows more complicated structure
- Active star formation with jets, outflows, and shocks can significantly affect and distort the observed polarization away from the putative hourglass
- In comparison, G31.41 is relatively ordered



Tang et al. (2009)

W51 e2 and Orion





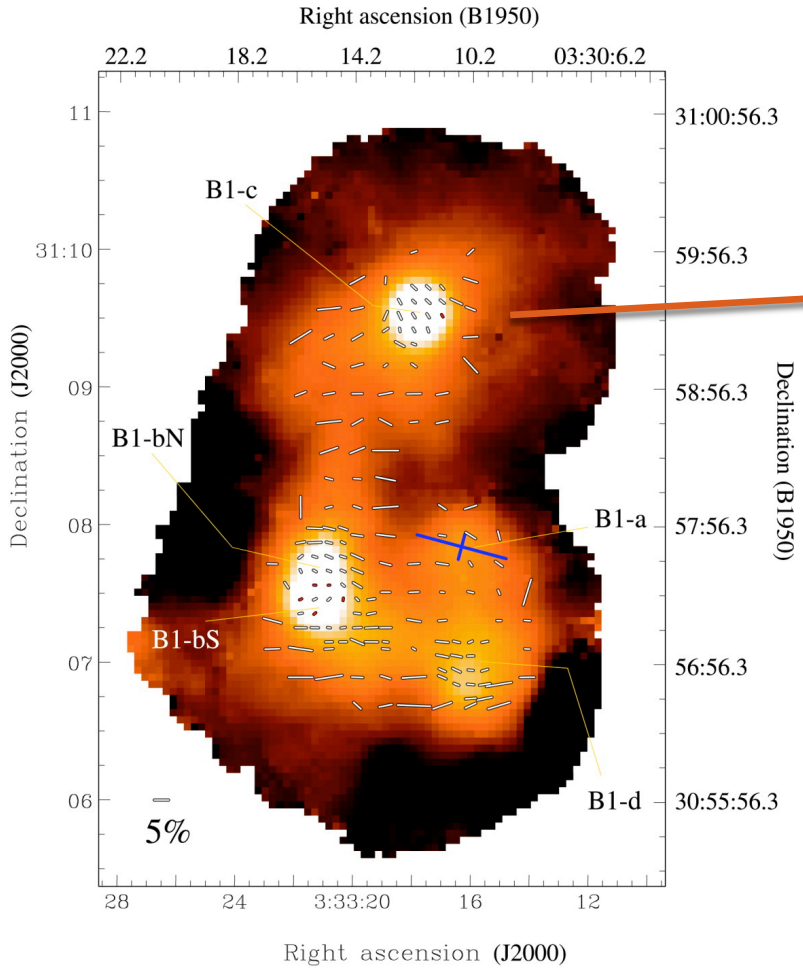
- Another high mass region that shows the hour glass morphology

Tang et al. (2009)

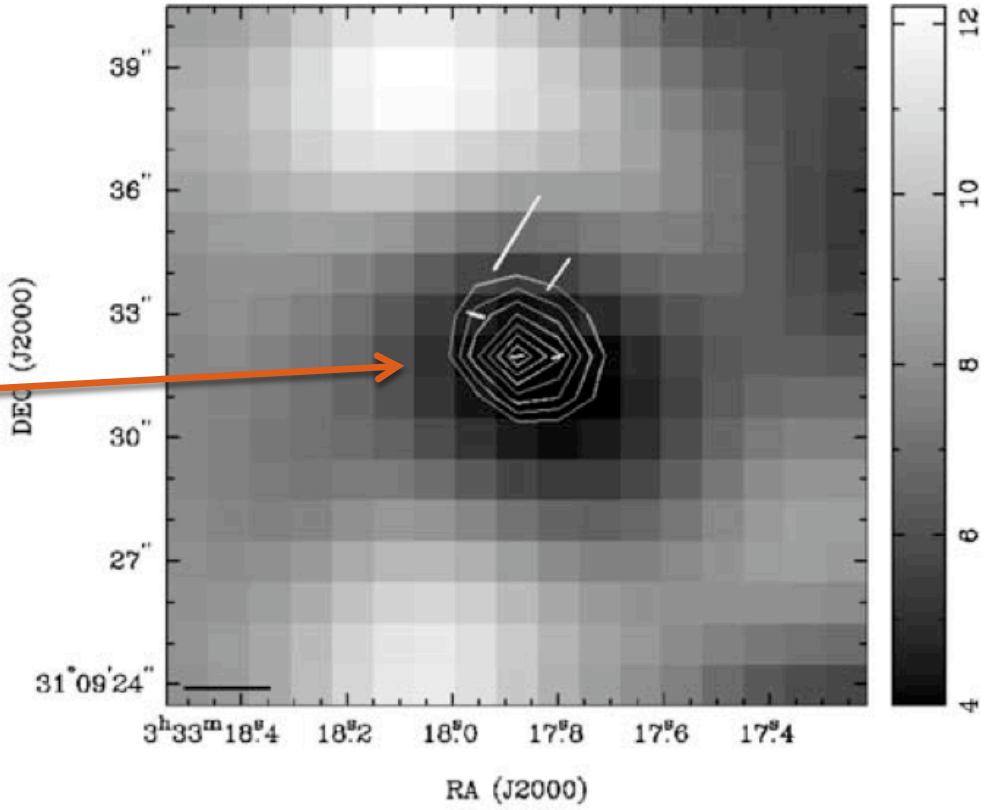
- No small scale hour glass structures in Orion

Tang et al. (2010)

Barnard 1c



SCUBA

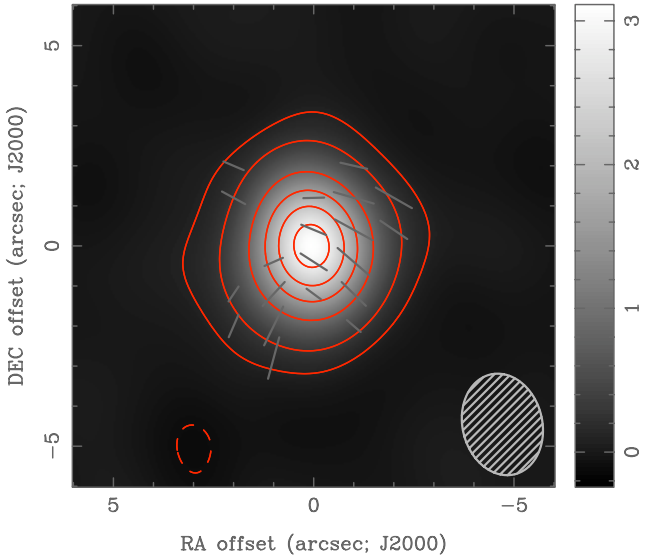


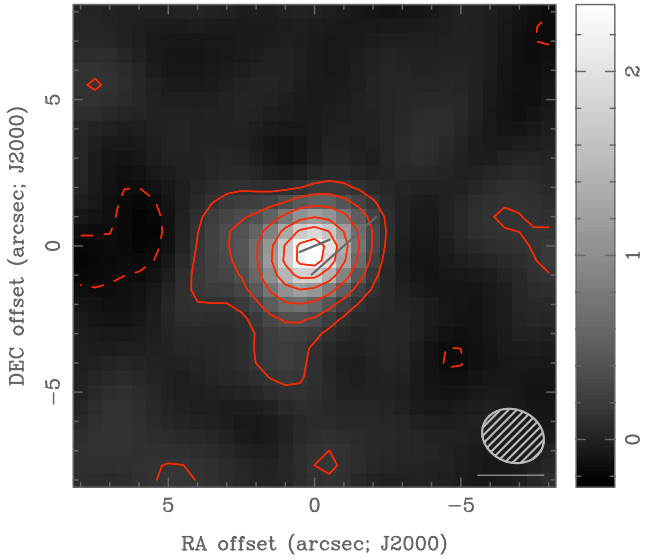
SMA

Matthews et al. 2008

Matthews & Wilson 2002

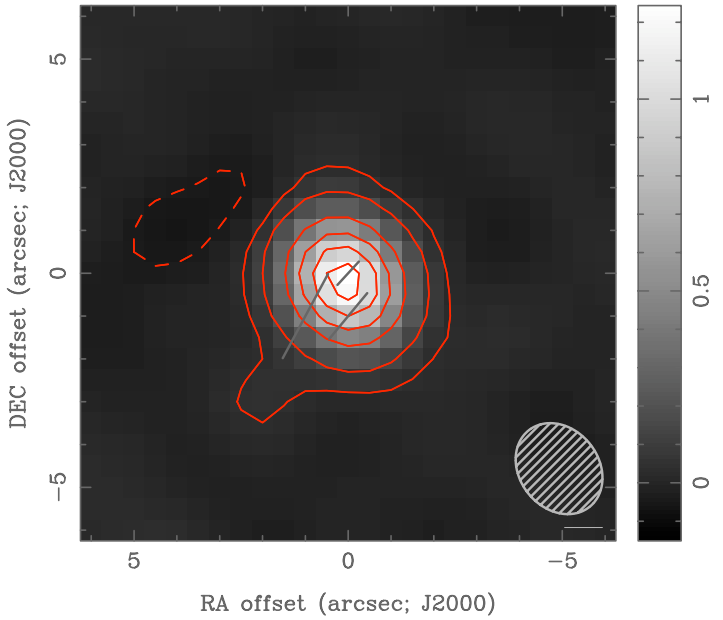
Some other low mass SF regions





- NGC 1333 IRAS 4B => Class 0
- L1551IRS 5 => Class I
- HLTau => Class I/II

Weak or non detections



Lai et al. (in prep.); and Rao et al. (in prep.)

Polarimetry Upgrades

- Dual polarization system using overlap between the existing 345 GHz receivers and the upgraded 400 GHz receivers (see Edward Tong's presentation)
- Improvement in sensitivity by a factor of $\sqrt{5}$
- Tuning setup of CO 3-2 in lower sideband provides optimum performance
- Detection of continuum level at 0.3-0.5 Jy
- Issues –
  - Receiver optimization
  - Software – online and data reduction
  - Antenna pointing and alignment

Summary

- Some objects show "hour-glass" patterns consistent with models where magnetic fields are dominant
- Others show more disturbed and disorganized structures
- While in some others we do not detect any significant polarizations – implying no ordered fields
- We are starting to accumulate reasonable number of objects in order to construct a good statistical sample
- Near Future: SMA upgrades to polarimetry sensitivity