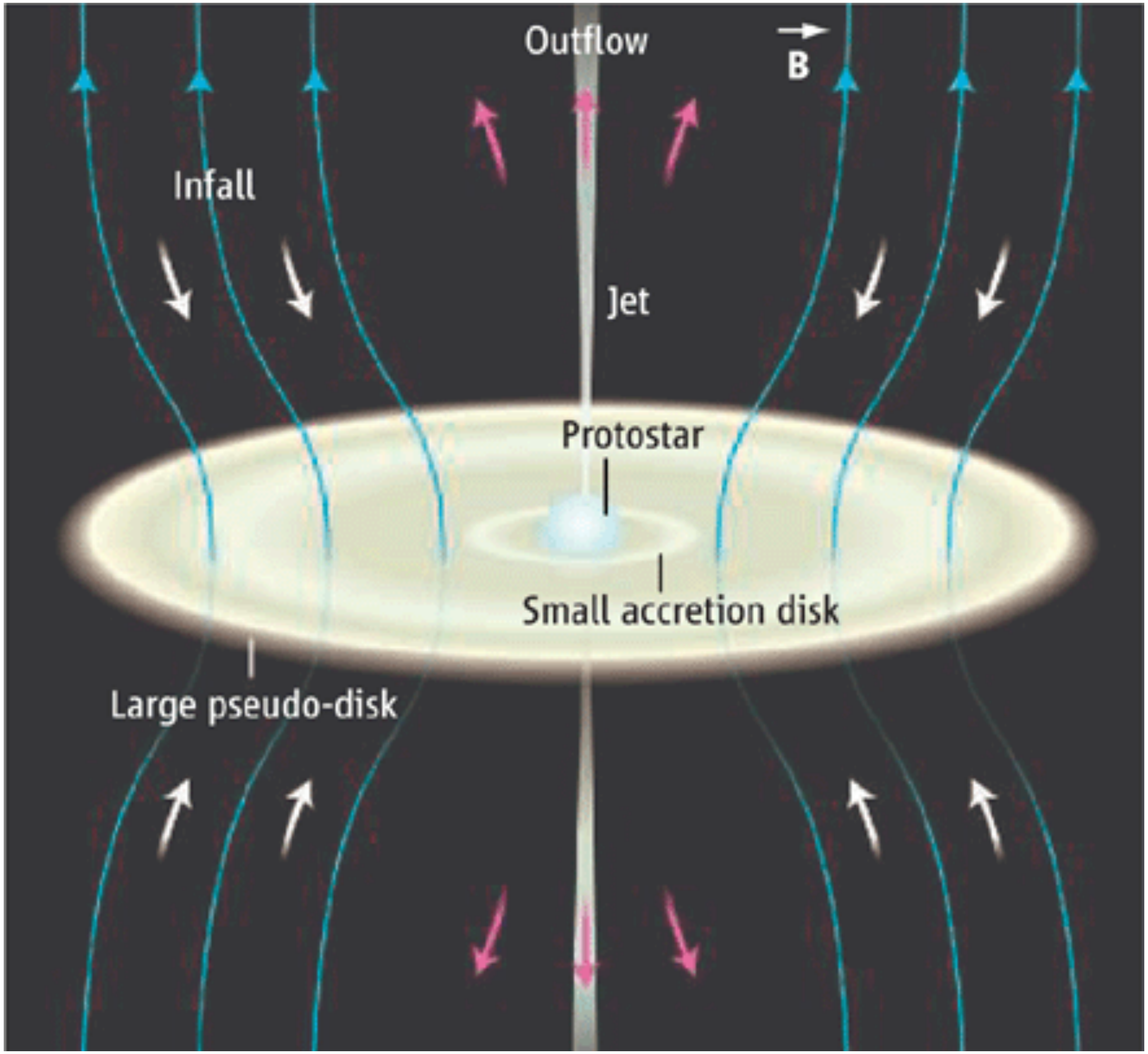
Submillimeter Array Observations of Magnetic Fields in Star Forming Regions

Ramprasad Rao,
ASIAA and the
SMA Polarimetry Team

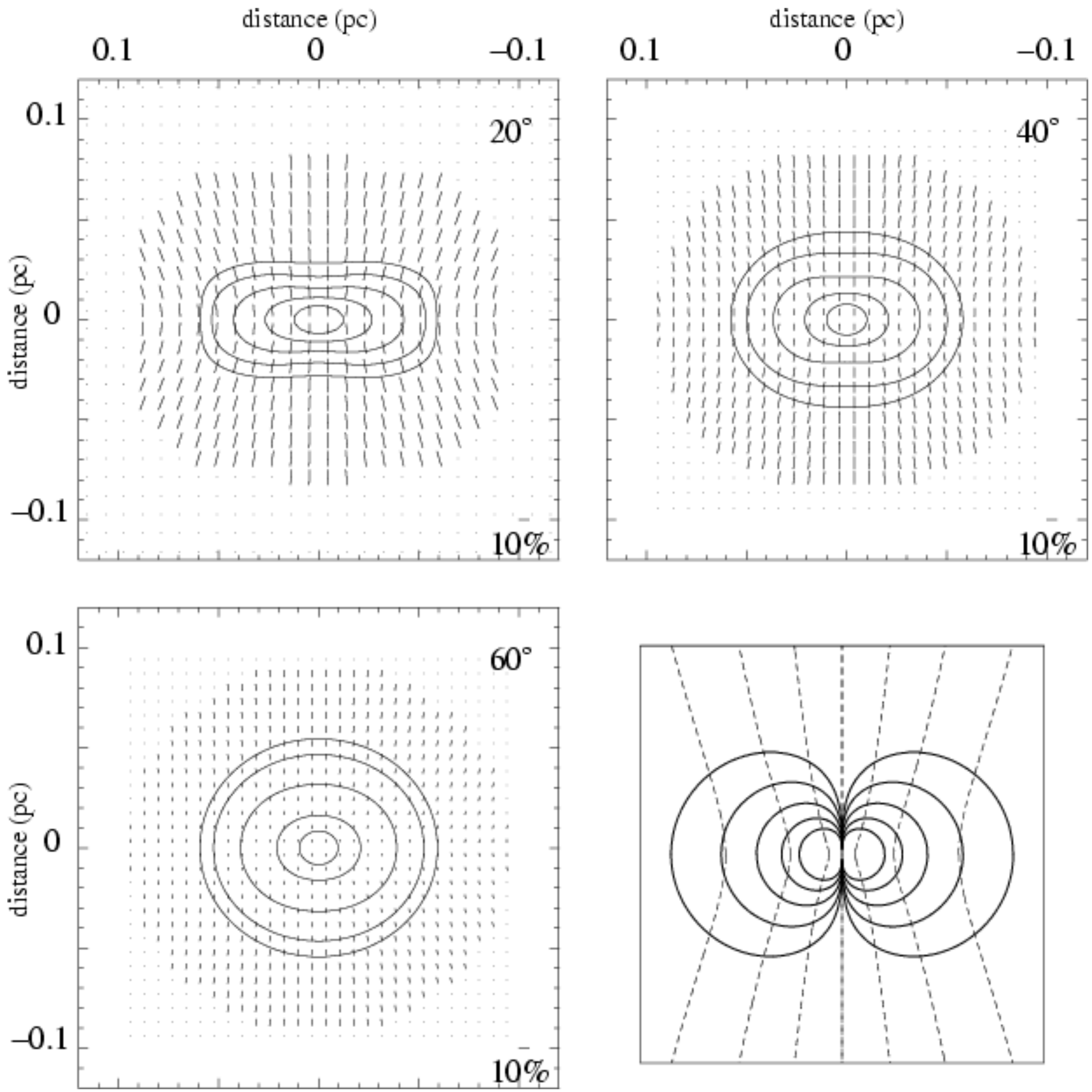
And what these observations tell us about **B**.



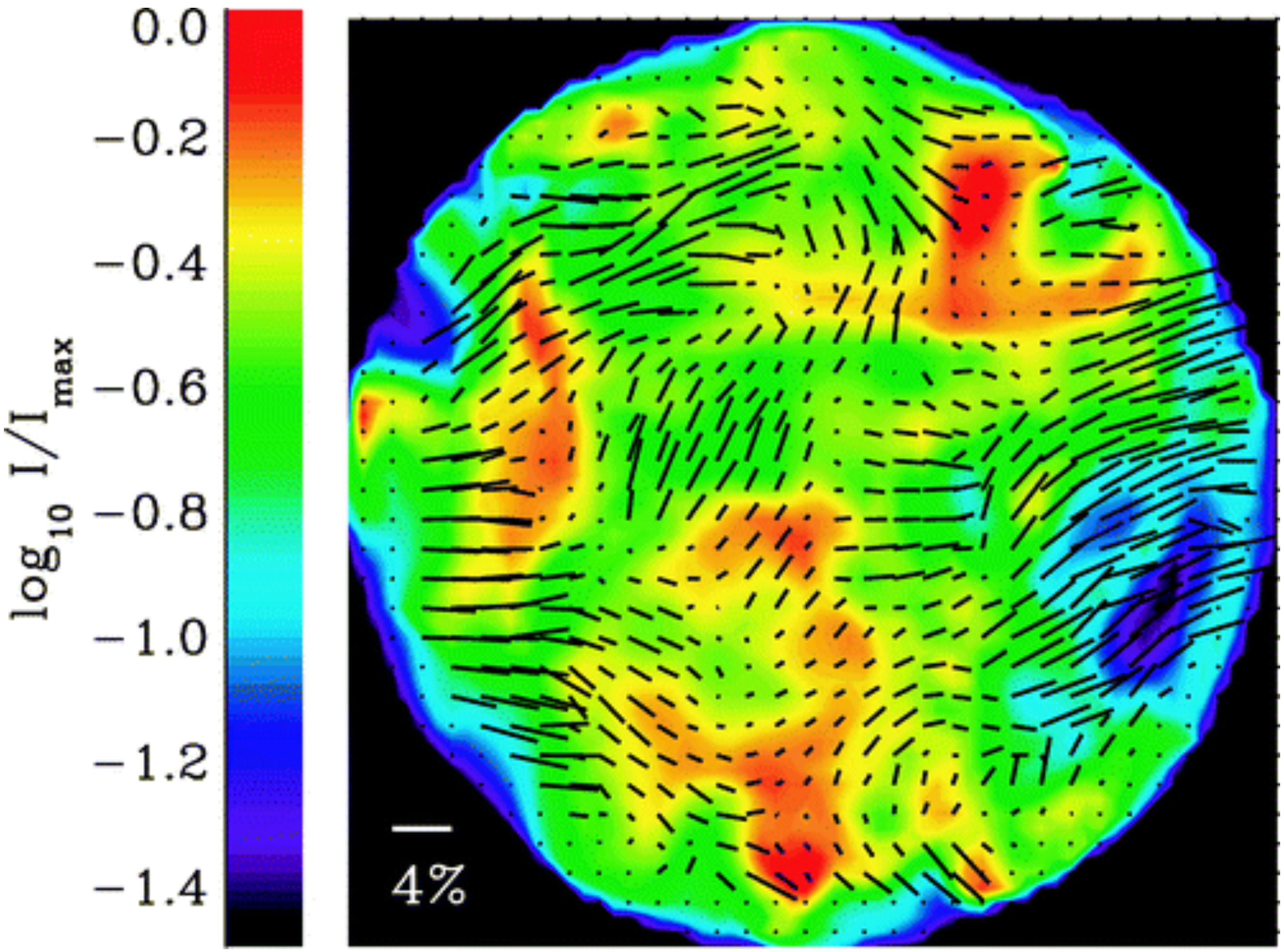
B-Field Ambipolar Diffusion Regulated star formation

Crutcher 2006

Simulations of polarized dust emission



Goncalves et al. 2005



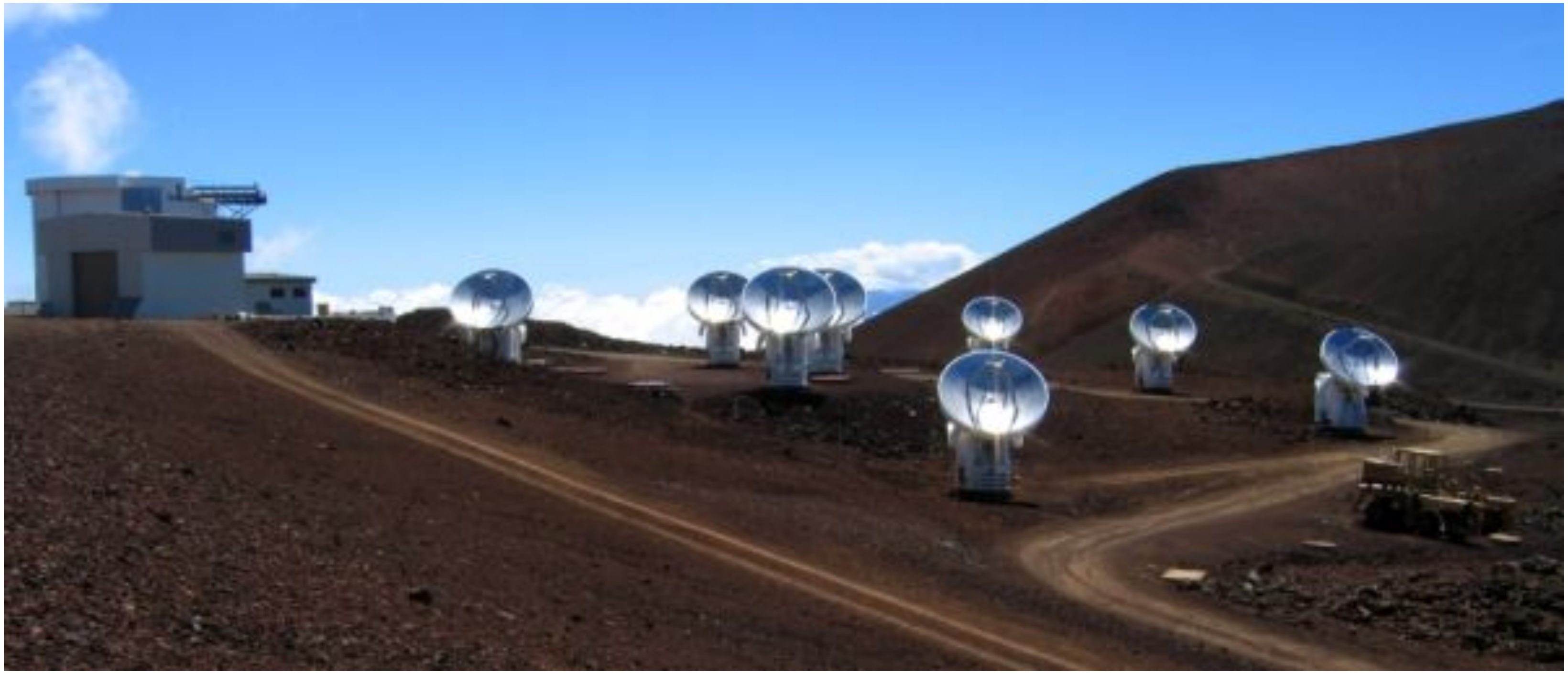
R=0.02 pc ~
4000 AU

Bethell et al. 2007

Tool of Choice: Submm/mm Polarimetry

- Advantages of emission polarimetry
  - emission is optically thin
  - no contamination from scattering, absorption etc.
- Single dish measurements (CSO/Hertz,JCMT/Scuba)
  - good sensitivity to large scale structure
  - Dust emission strong at submm
  - Resolution is low ~10”
- Highly sensitive interferometer array observations are needed. OVRO and BIMA earlier, currently SMA, CARMA and ALMA in the future
- BUT, cannot directly give strength of B

Submillimeter Array



- **SMA is an important instrument - Improves resolution AND sensitivity**
- BUT, cannot directly give strength of B

SMA Polarization Observations

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/OVRO)
- 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

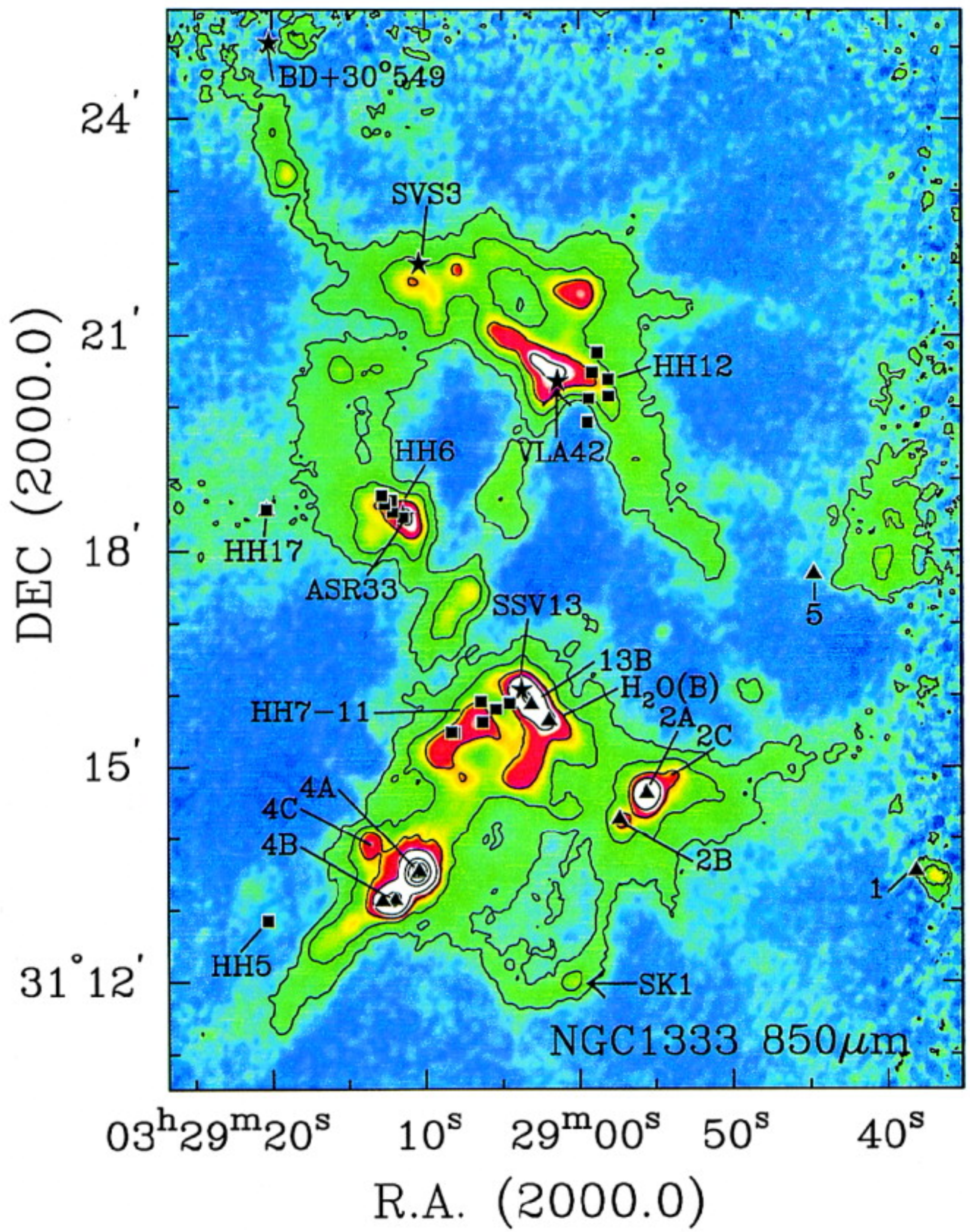
Polarization Targets

- Low Mass: NGC 1333, IRAS 16293 A/B, HL Tau, L1551IRS5, VLA1623, Barnard 1c, Serpens Molecular cloud etc.
- High mass: G5.89, G30.79 FIR10, IRAS20126, G31.41, Orion-KL etc.
- SMA High Mass Legacy project: Zhang Q. PI

NGC 1333 Cloud

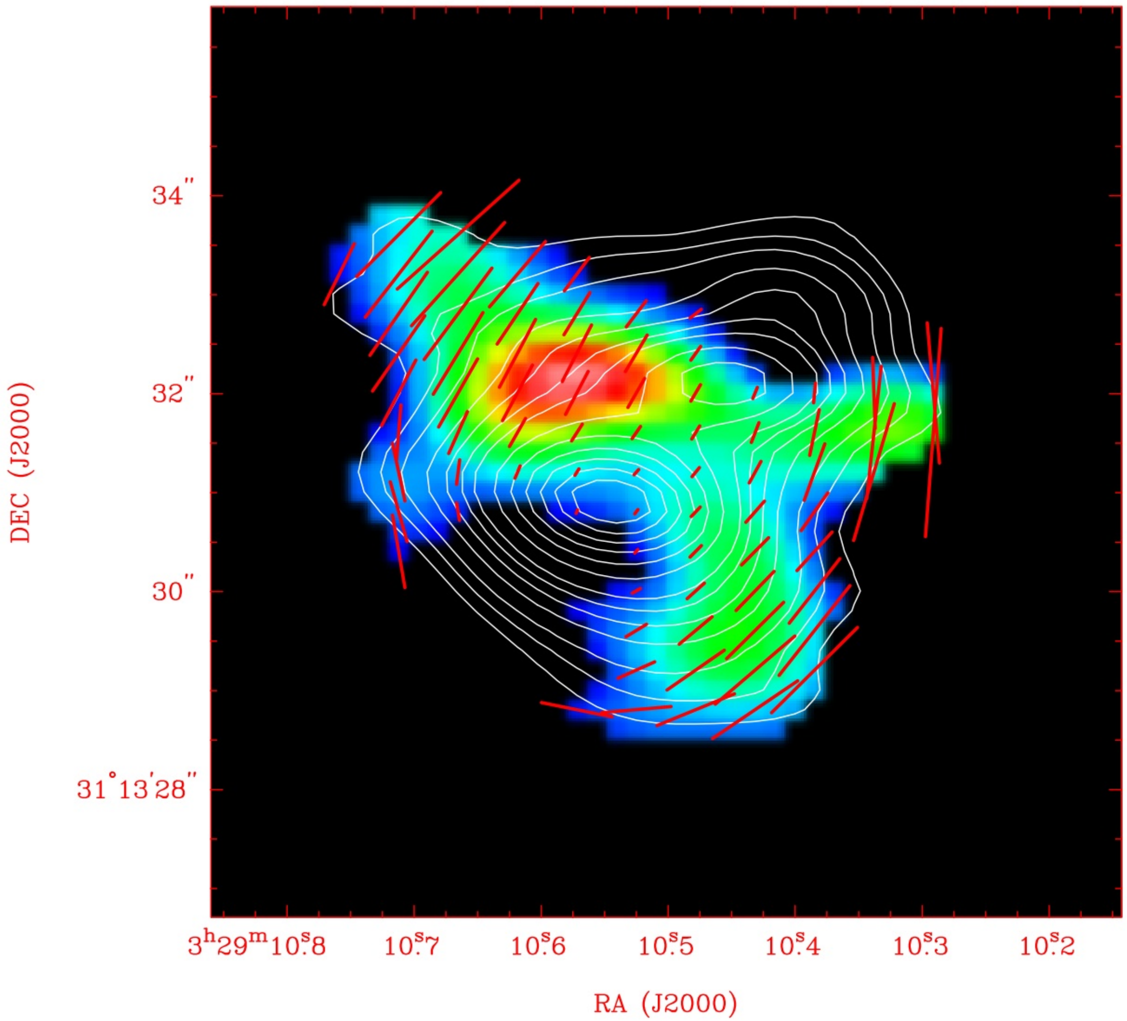
Sandell & Knee 2001

SCUBA 850 μm



NGC 1333 IRAS 4A (SMA)

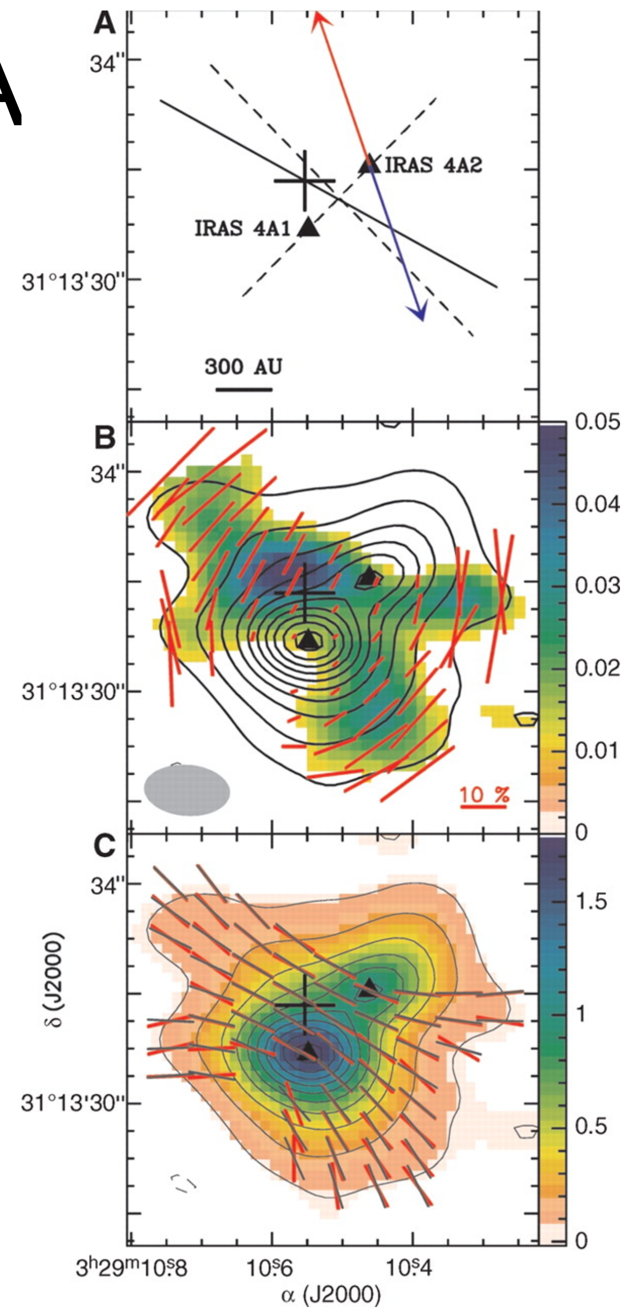
E Field



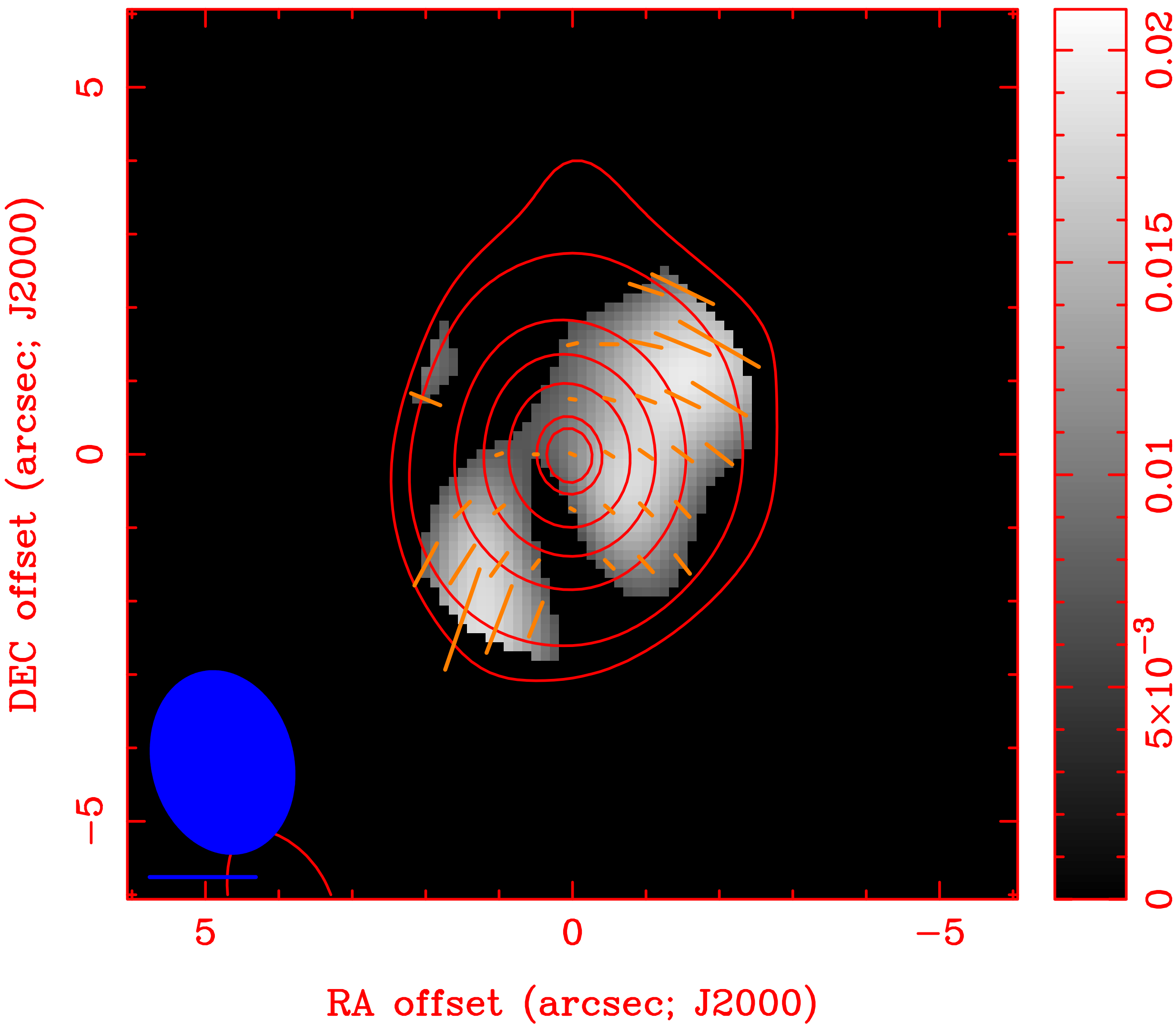
Girart et al. 2006

B-Fields in IRAS4A

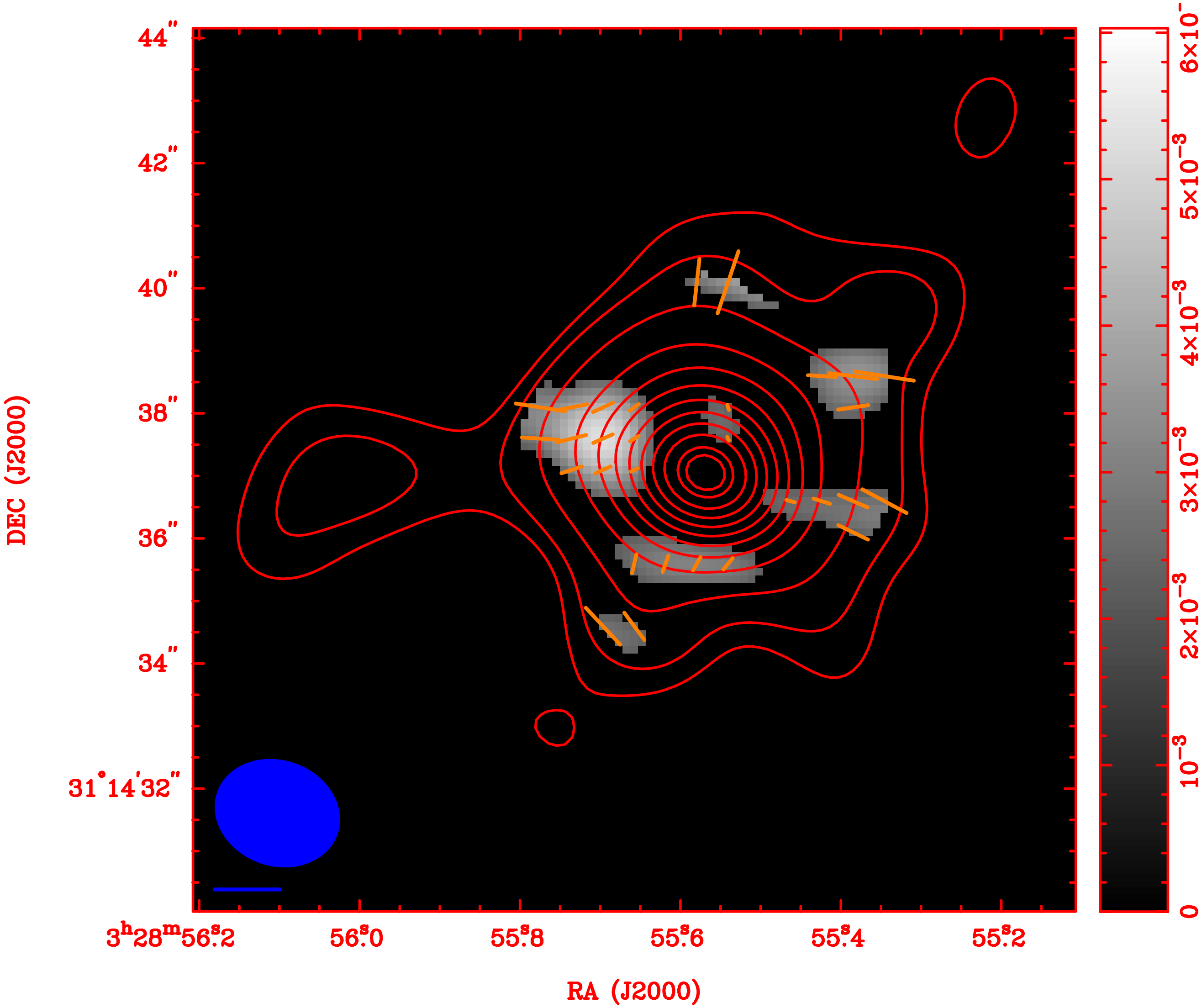
- Estimate strength of B-field from PA residuals and velocity dispersion (Chandrasekhar-Fermi method)
- B ~ 5mG
- Cloud is marginally supercritical λ~1.7
- Turbulence is small - especially on these scales
- Axes misalignment between cloud/B-field/outflow
- Fragmentation?



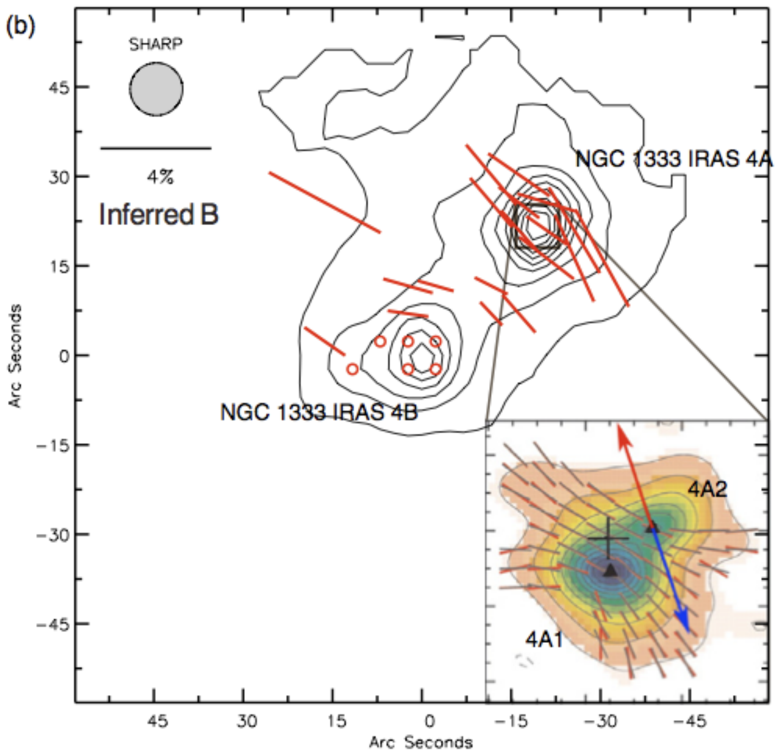
NGC 1333 IRAS 4B

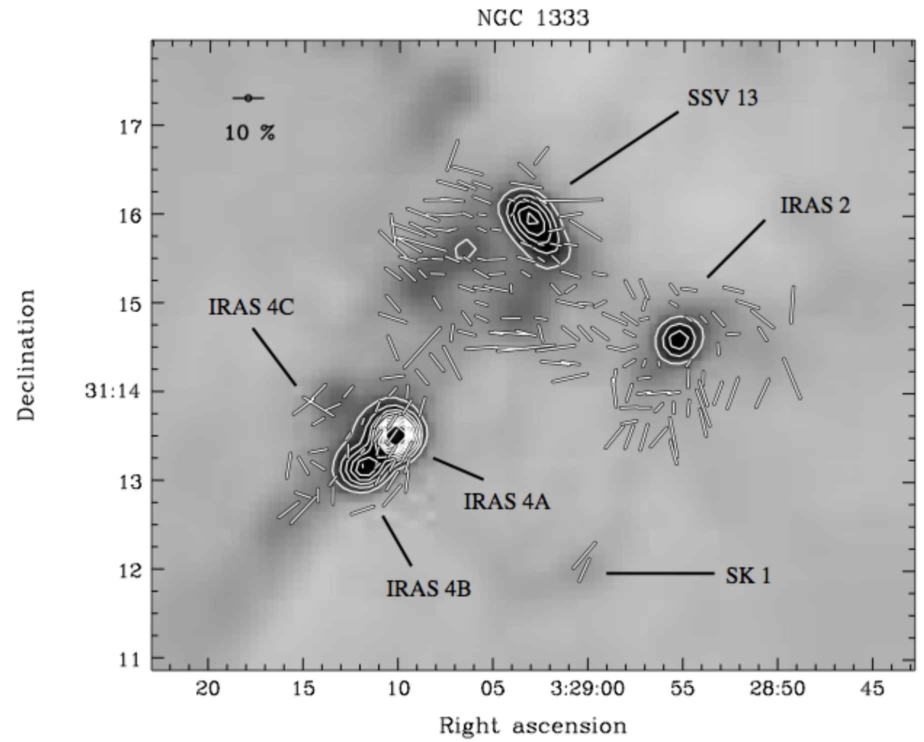


NGC 1333 IRAS 2A



Larger scale fields in NGC1333





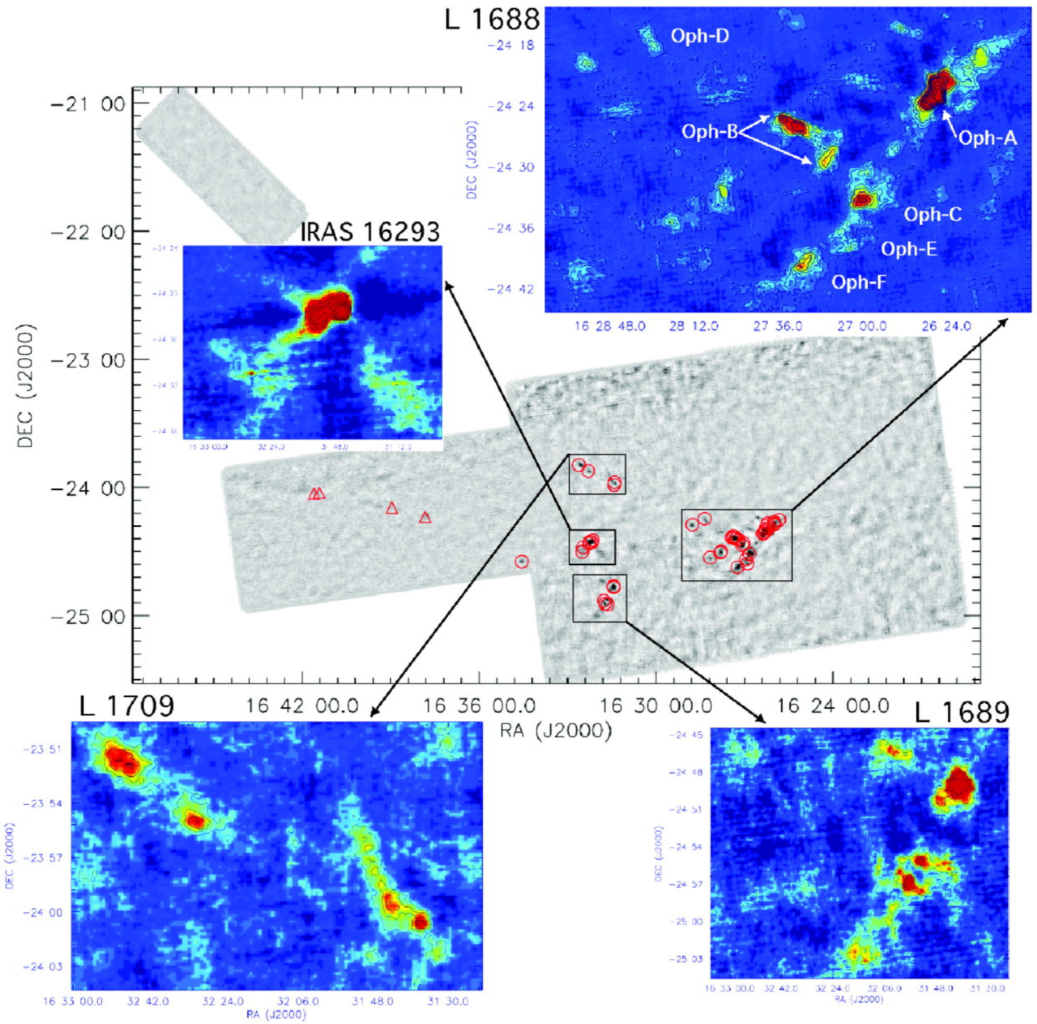
Matthews et al 2009 SCUBA

Attard et al. (2009) CSO SHARP Polarimeter

Ophiuchus

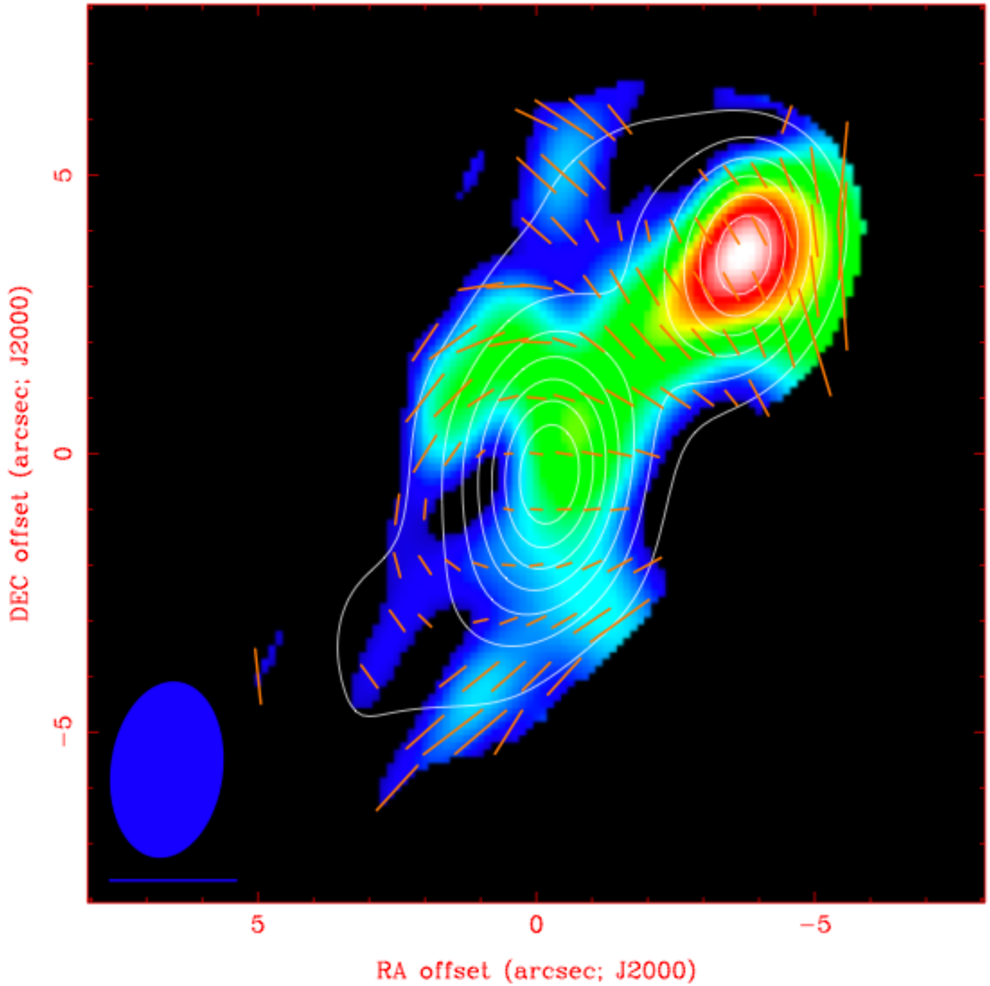
Bolocam 1.1mm
31" resolution

Young et al. 2006



IRAS16293: Polarization

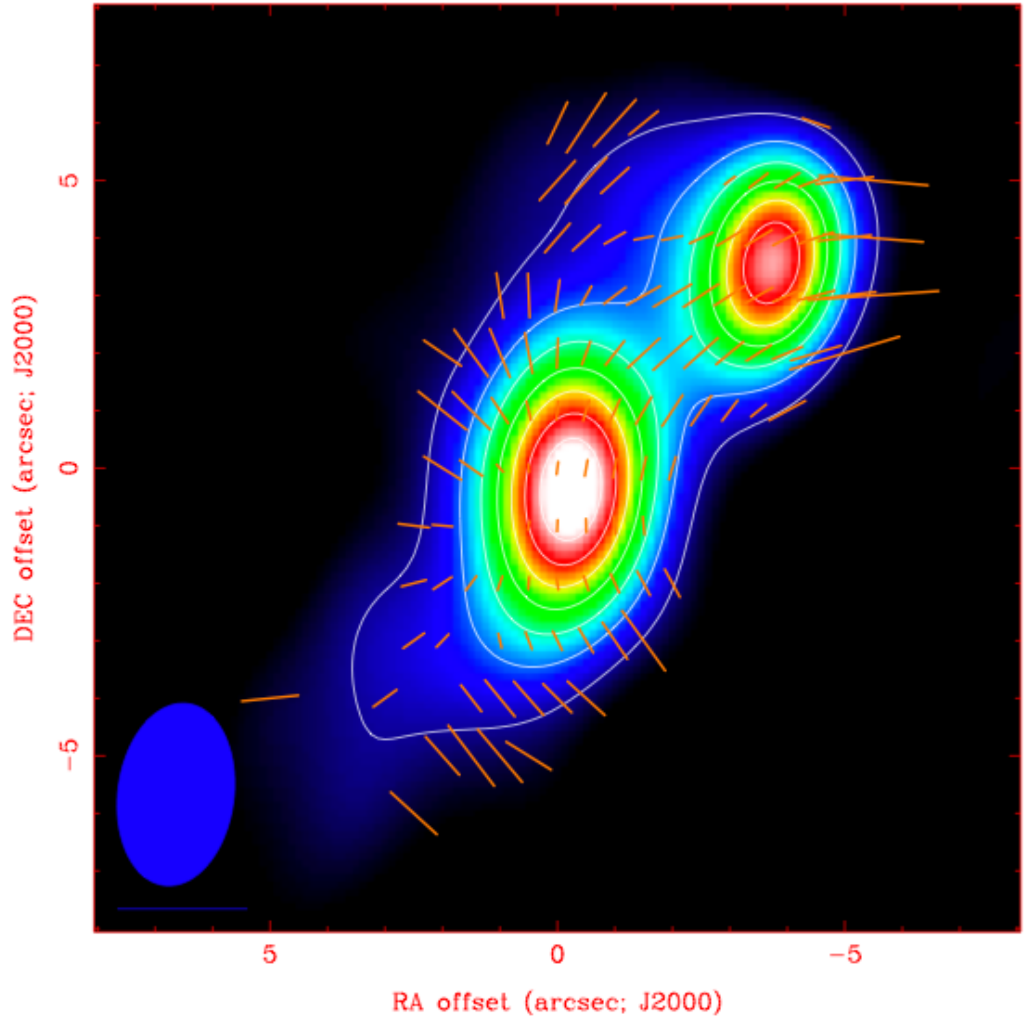
Pmax~5%



Rao et al. 2009

IRAS16293: Magnetic Field

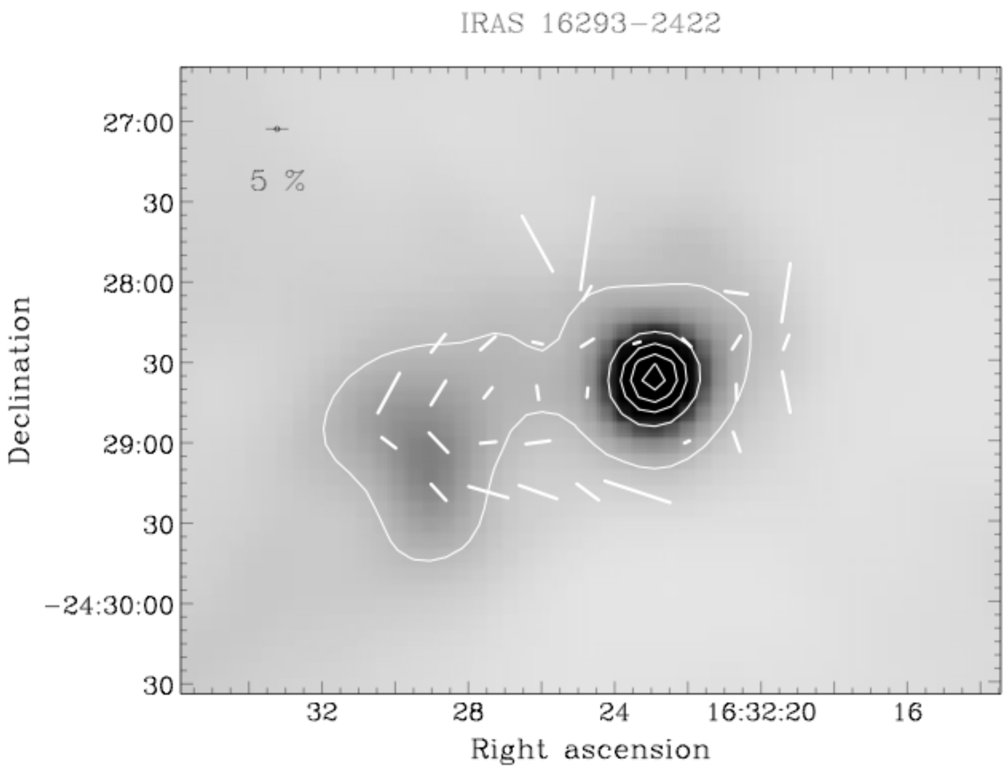
Pmax~5%



Rao et al.

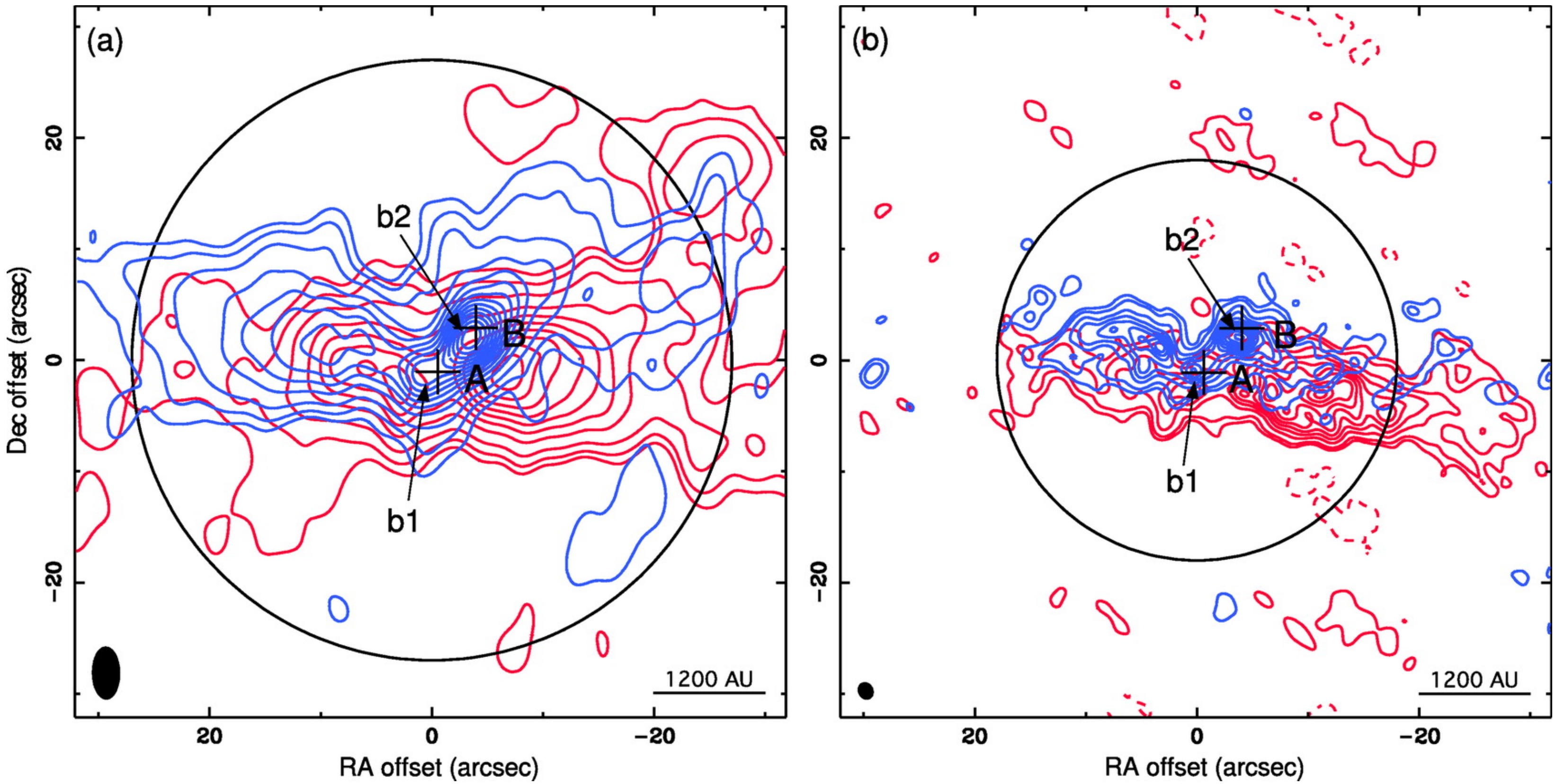
IRAS16293: SCUBA

E Field



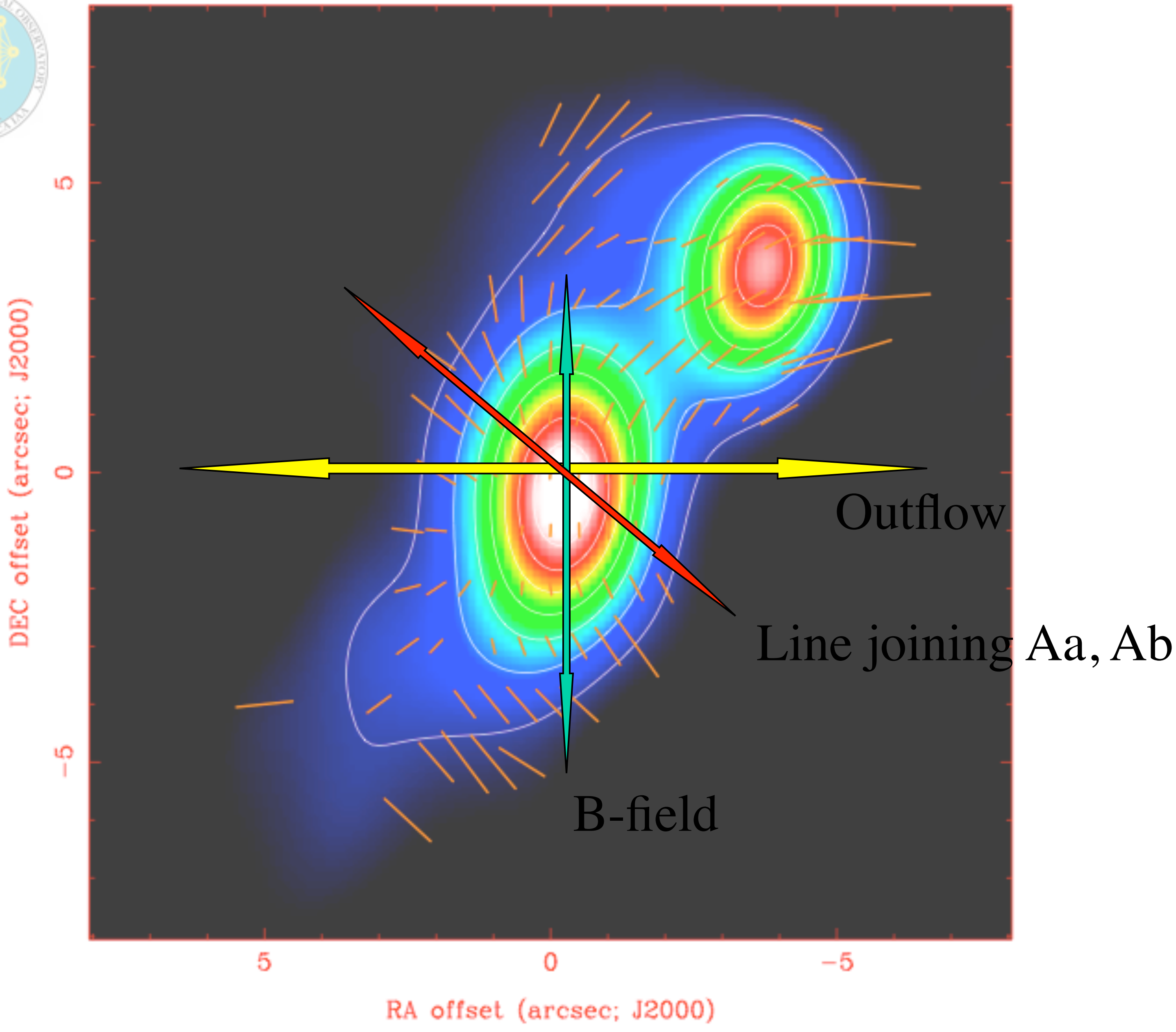
Matthews et al. (2009)

IRAS16293 Outflows



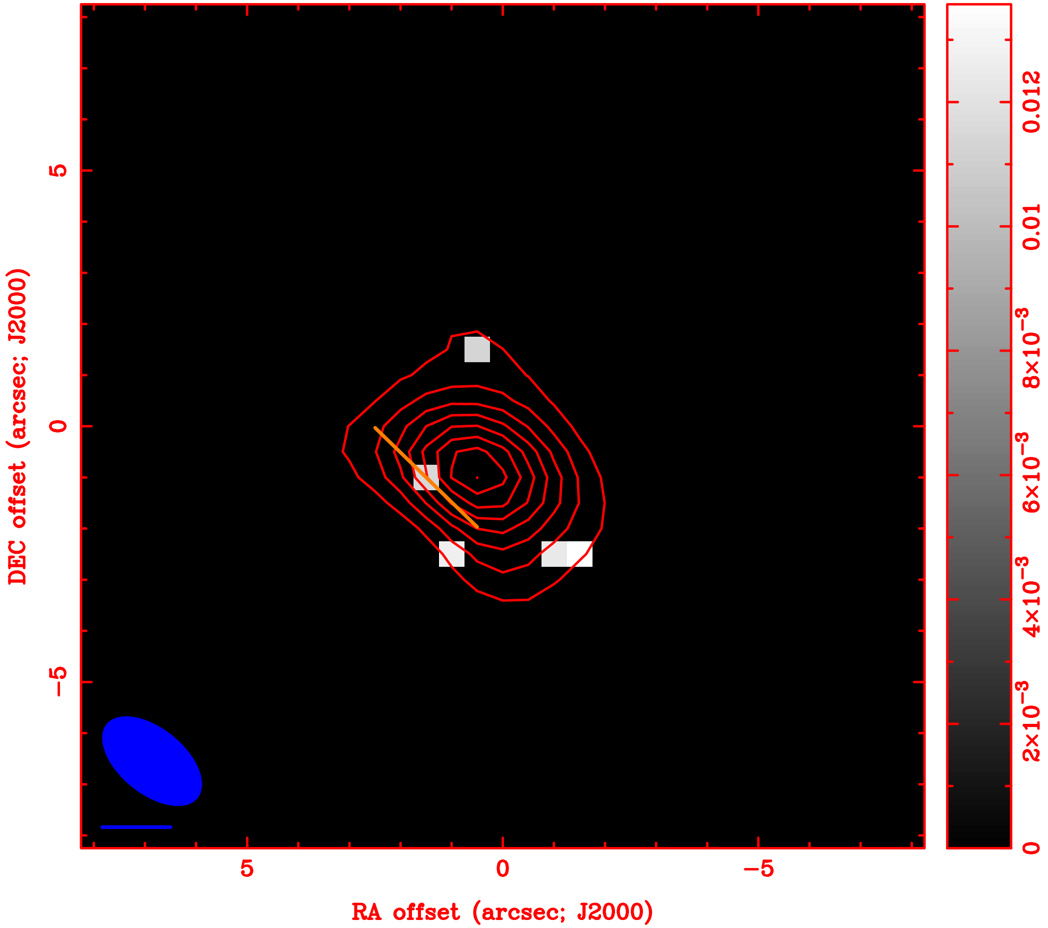
Yeh et al. 2008

SMA CO2-1, CO3-2



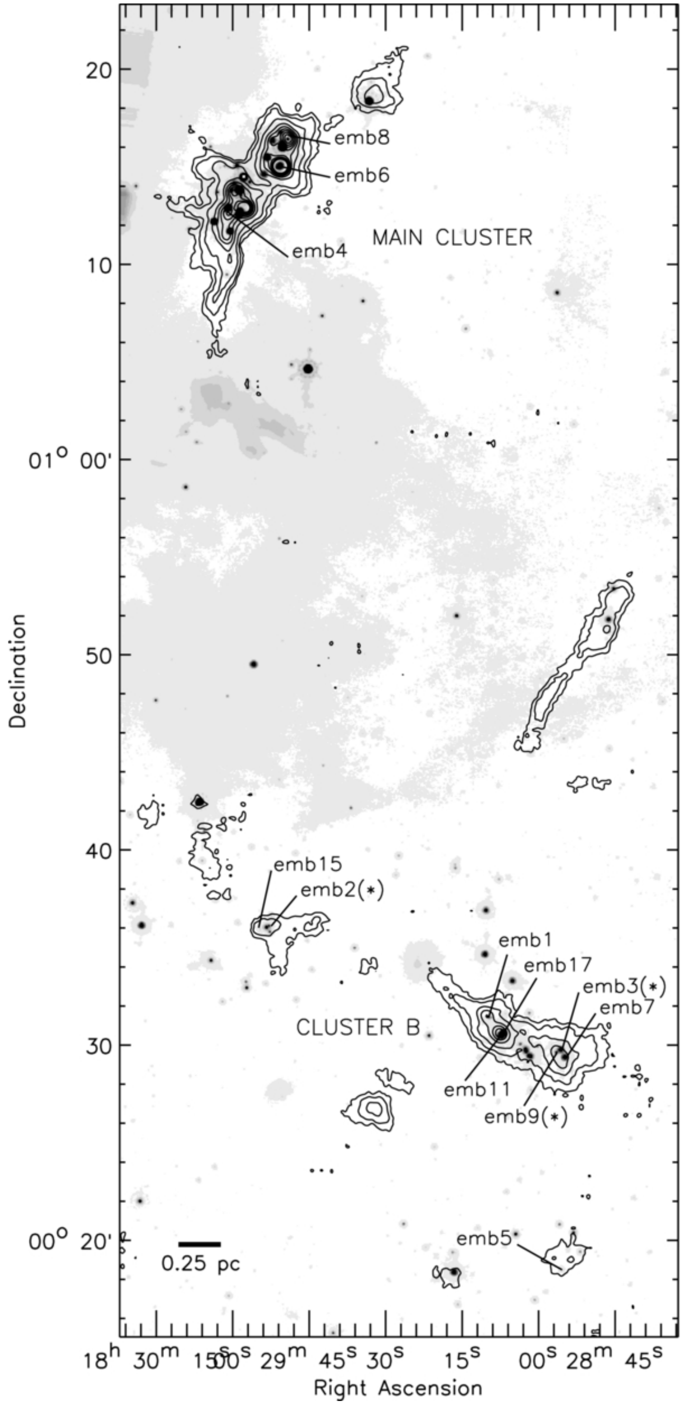
DEC offset (arcsec; J2000)
RA offset (arcsec; J2000)
5
0
−5
Outflow
Line joining Aa, Ab
B-field

VLA1623



DEC offset (arcsec; J2000)
RA offset (arcsec; J2000)
5
0
−5
5
0
−5
0.012
0.01
8×10⁻³
6×10⁻³
4×10⁻³
2×10⁻³
0

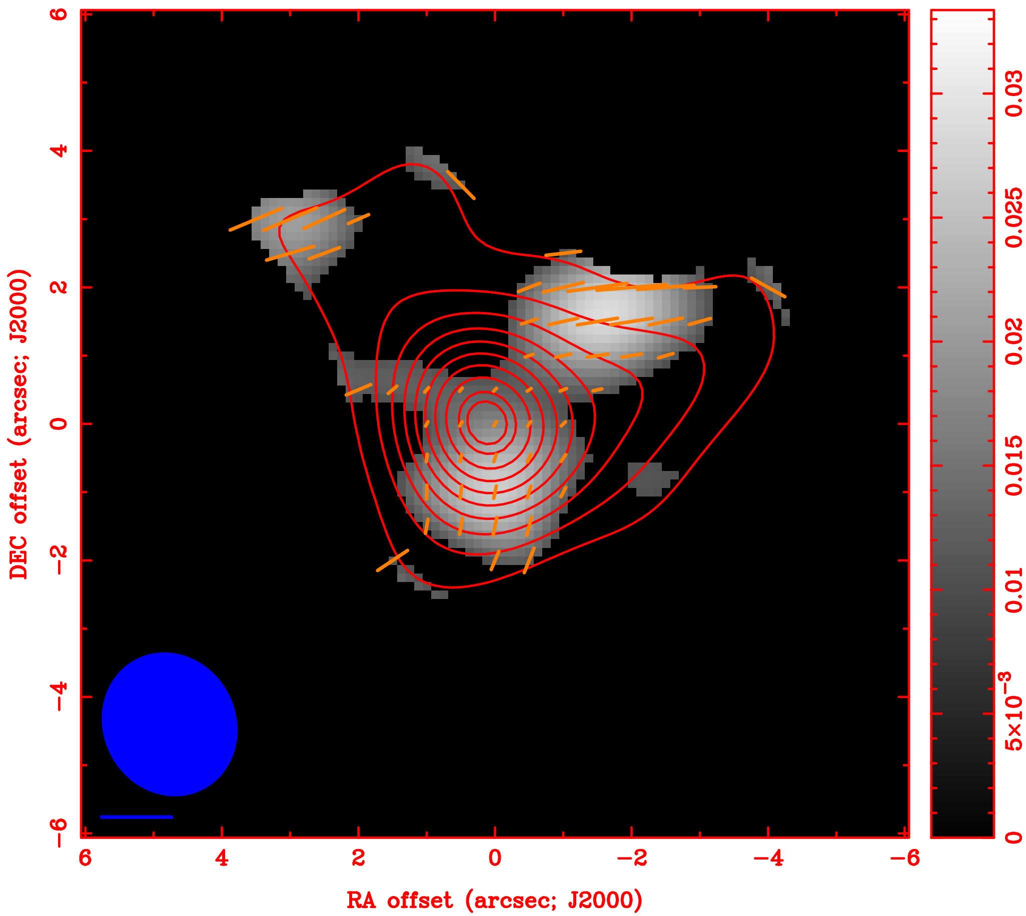
Serpens Molecular Cloud



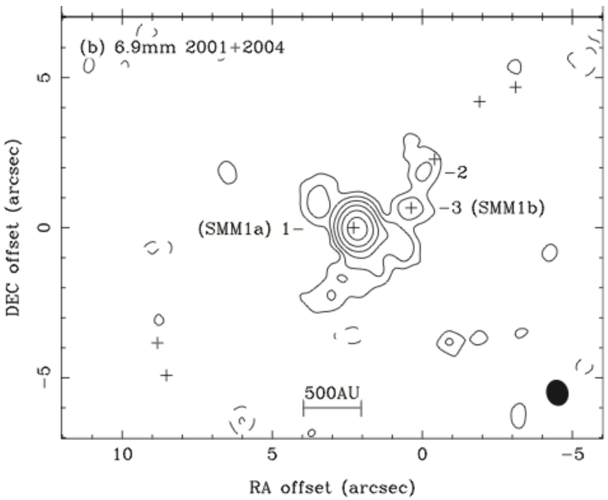
Enoch et al. (2011)
Bolocam 1.1mm
Spitzer 24 micron

Distance ~ 415 pc

Serpens FIR S1

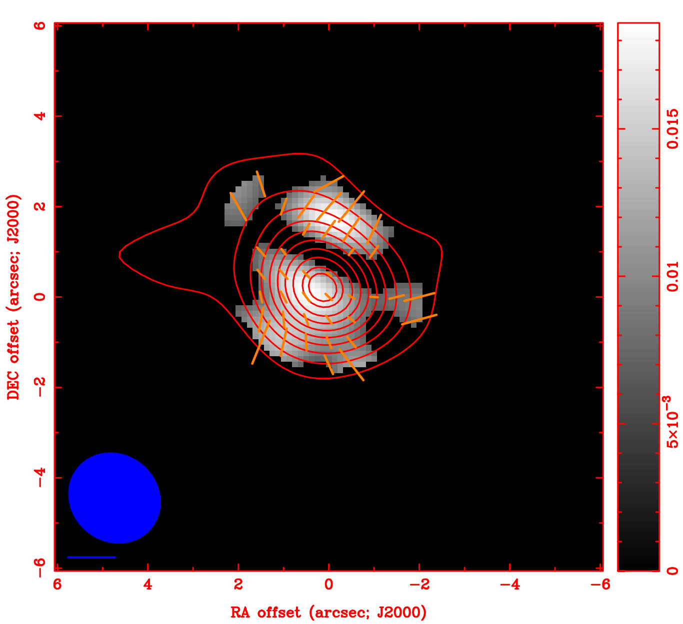


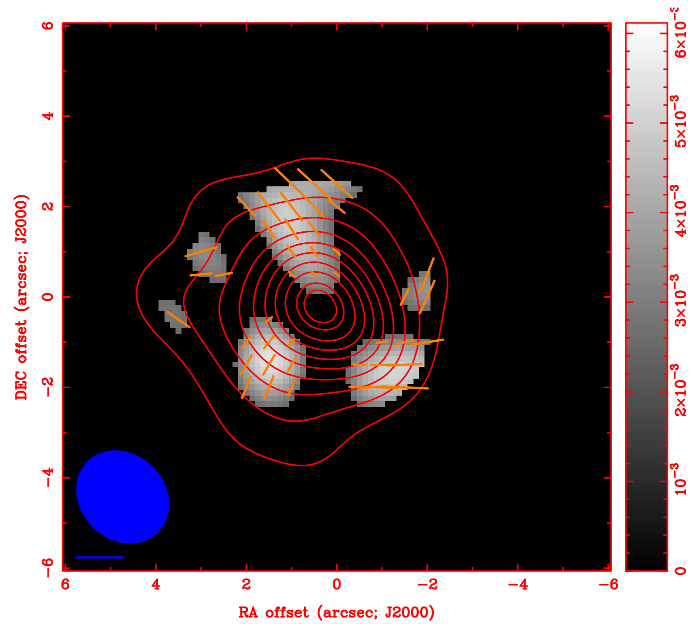
Rao et al. (in prep)



Choi et al. 2009

Other Serpens Targets

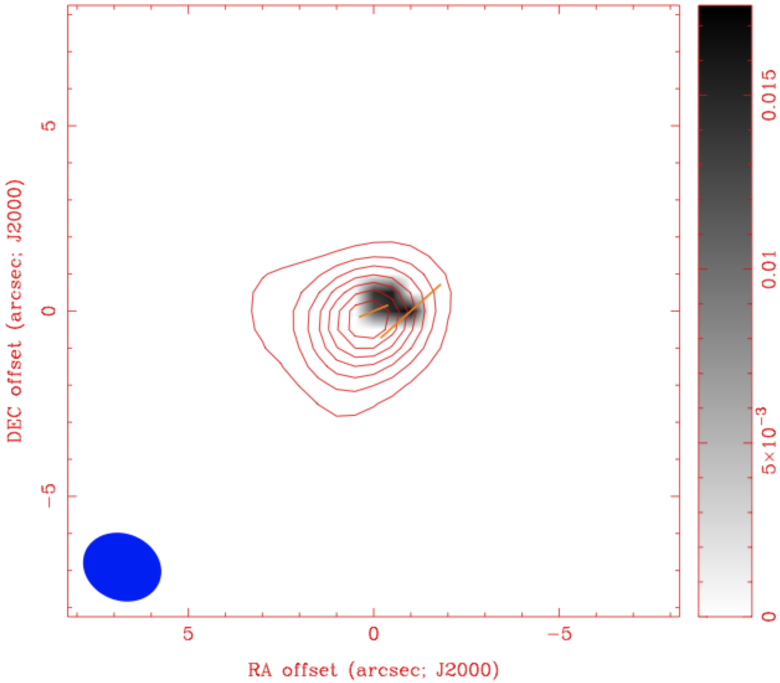




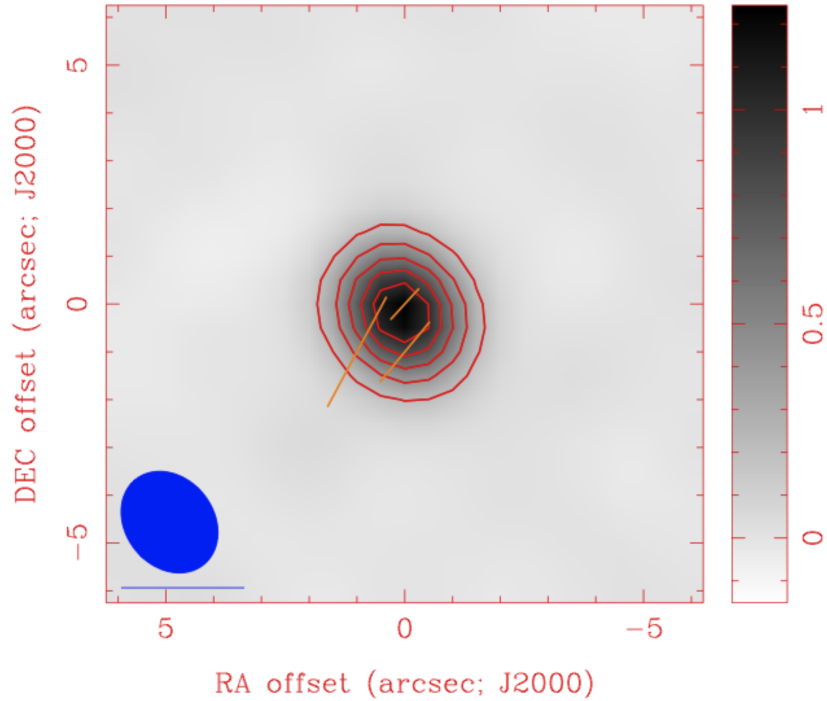
EMB 6

S68N

Taurus: Class I sources



L1551 IRS 5



HL Tau

Pmax~less than 1+/-0.5% at the center

Low Mass Stars: Summary

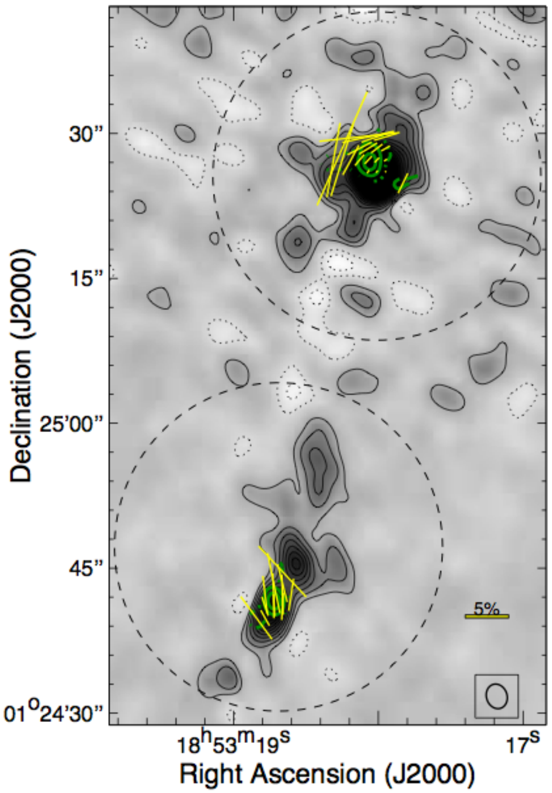
- Some Class 0 sources show resolved and ordered magnetic fields e.g. NGC 1333 IRAS 4A
- Other Class 0 sources show none or disordered e.g. VLA 1623
- Class I sources show weak or undetected polarization

SMA Legacy Project

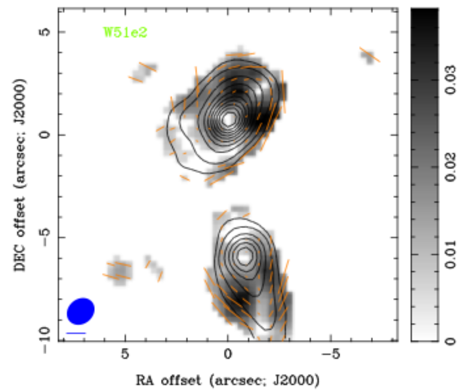
Led by Q. Zhang

- Improve SMA Polarization system to launch more ambitious project
- Sample of dense filaments forming massive stars to study role of magnetic fields in filament and star formation.
- Two step process:
  - conduct a shallow survey to find strong polarized sources (using more compact configurations)
  - second to follow them up in deeper, multi configuration observations

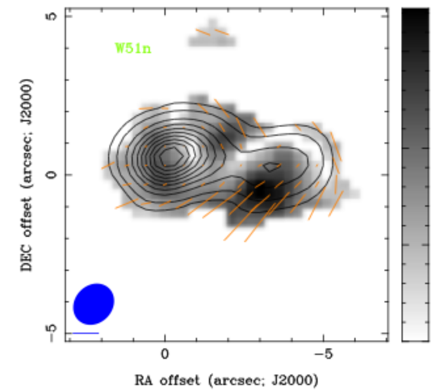
Sample from Legacy Project



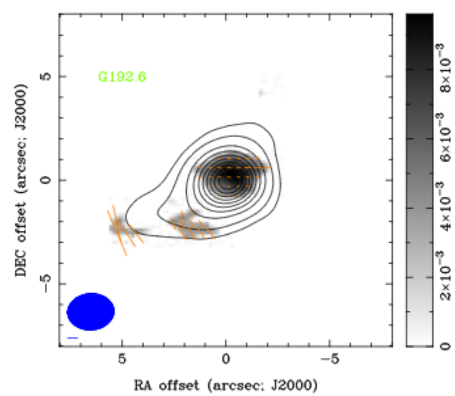
G34.4



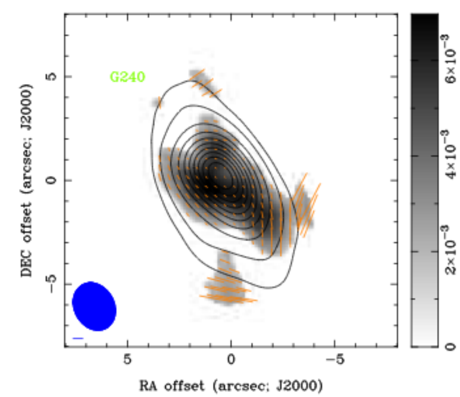
W51e2



W51n



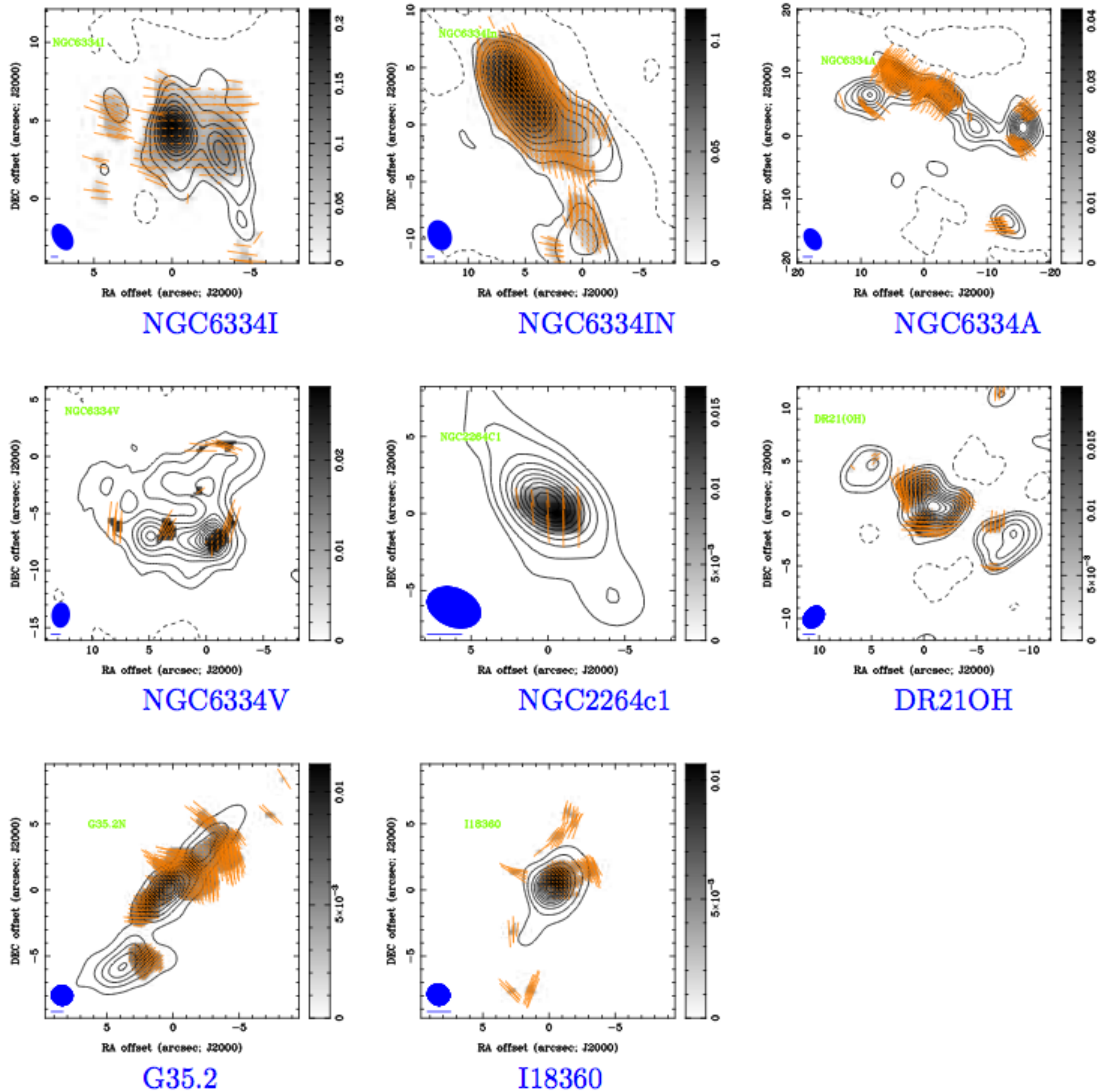
G192



G240

Talk by Y. Tang

Sample contd…



Talk by H. Li

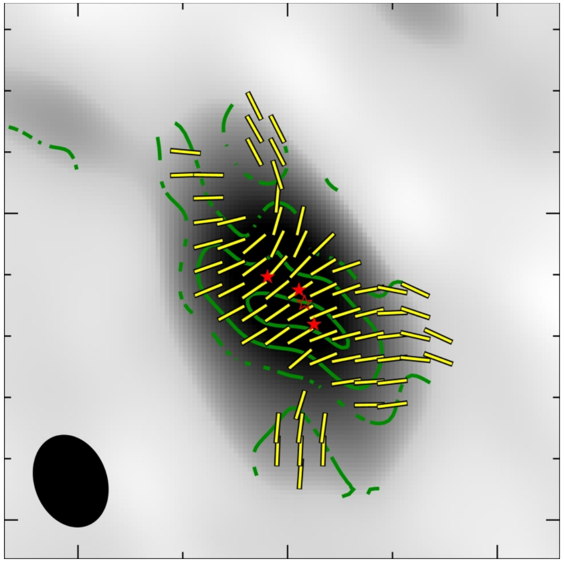
Analysis Tools

- Statistical Tool to Determine Relative Importance between Magnetic Fields and Turbulence (Houde et al. 2009 etc.)
- Phenomenological Method for Magnetic Field Strength (C-F method drawbacks; also see Koch et al. 2011;2012)
- Simulations: along with Zhi-Yun Li; also ARTIST Project (Girart)

SMA Legacy Project: Filaments, Star Formation & Magnetic Fields

Q. Zhang (CfA), J.M. Girart (ICE, IEEC-CSIC), K. Qiu (MPIfR), P. Koch, Y.-W. Tang, R. Rao (ASIAA), S.P. Lai (NHTU), P. Frau (OAN, CAB-CSIC), H. Li (MPIA)
& H.-Y. Liu, H.-H. Chen,, P. Ho, H.-R. Chen, E. Keto, Z.-Yun Li, S. Bontemps, T. Csengeri, M. Padovani

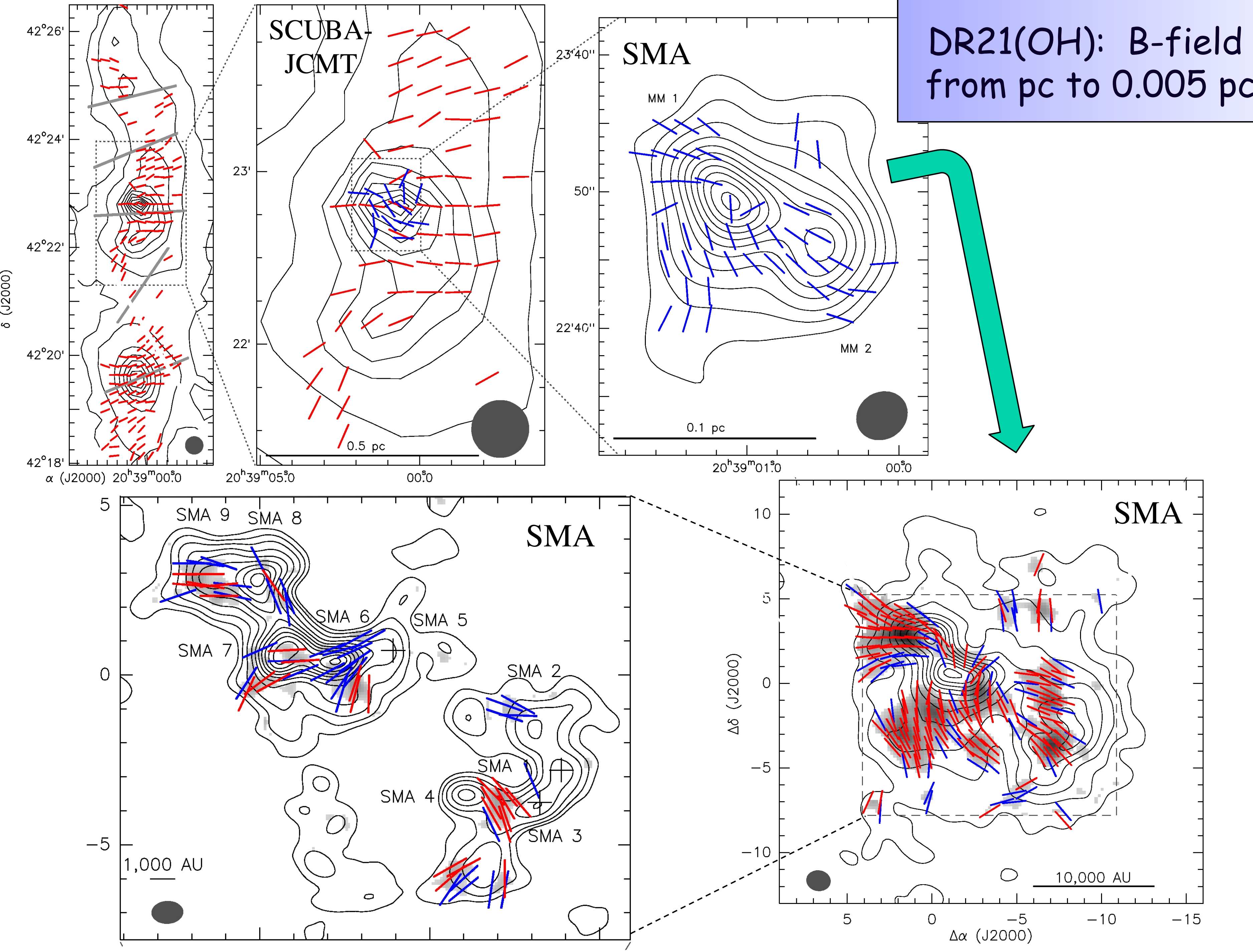
Goal: Get a large sample of massive molecular clumps to investigate the role of magnetic fields in formation and fragmentation of massive filaments. Compare observations with radiative transfer modeling and simulations



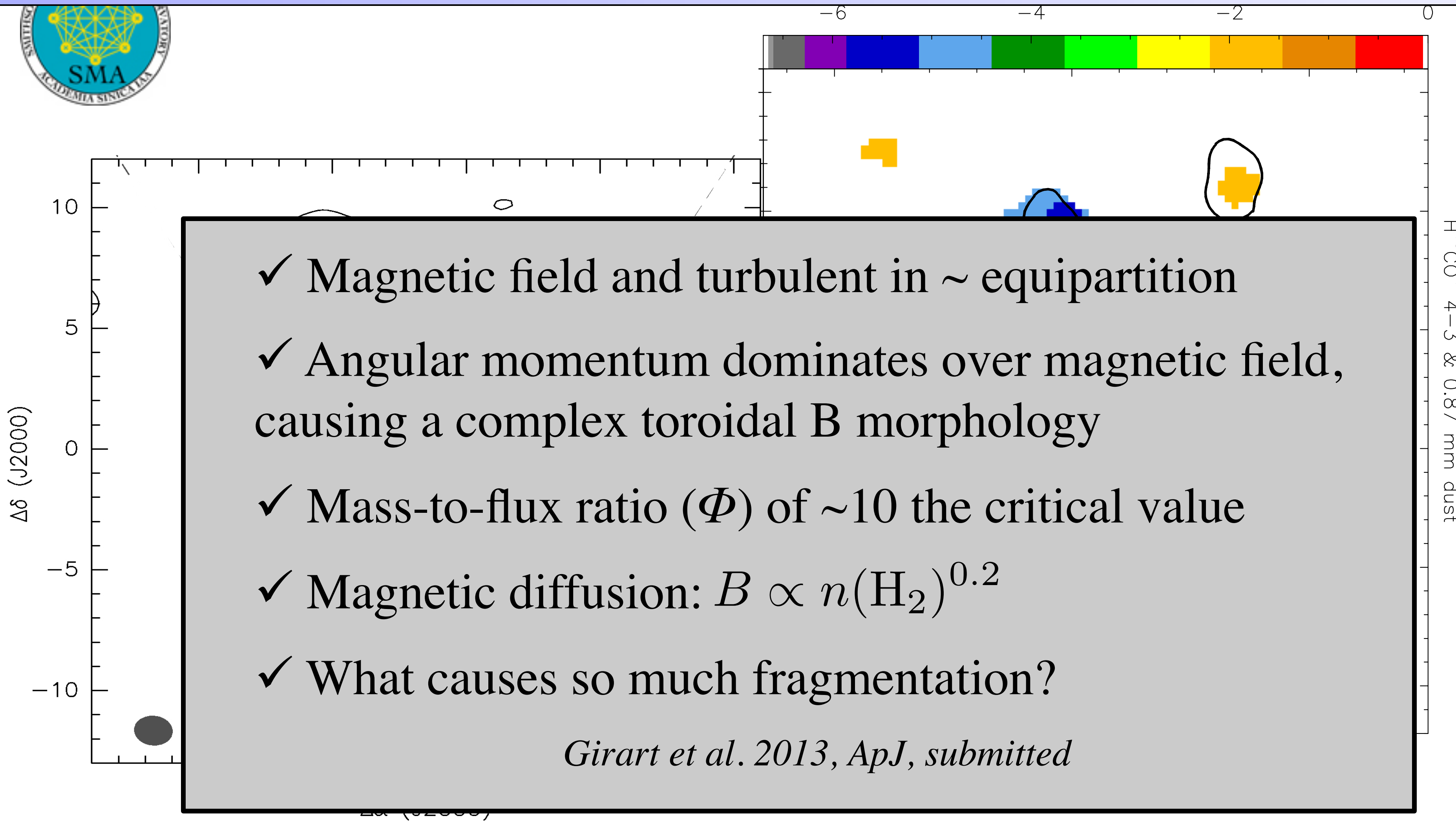
So far:

- ✓ More than 30 tracks (beam ~ 1arcsec)
- ✓ High fraction of dust polarization detections
- ✓ Some sources show a complex B configuration BUT …
- ✓ Some show hour-glass morphology with the B direction almost parallel to the outflow
- ✓ Some sources maintain the main direction observed at larger scales

DR21(OH): B-field from pc to 0.005 pc



DR21(OH): a case with a complex B field morphology



- ✓ Magnetic field and turbulent in ~ equipartition
- ✓ Angular momentum dominates over magnetic field, causing a complex toroidal B morphology
- ✓ Mass-to-flux ratio (*Φ*) of ~10 the critical value
- ✓ Magnetic diffusion: $B \propto n(\mathrm{H_2})^{0.2}$
- ✓ What causes so much fragmentation?

Girart et al. 2013, ApJ, submitted

DR21(OH) ~face-on: are we seeing a toroidal field?

B_{pos}=1.6mG & B_{los}=-0.4mG => i=14^{o} …. wrapped by the core's rotation

Legacy project contd..

- We expect that the outcome of this project will add significantly to that legacy before ALMA fully develops its polarization capability.
- The study will also pave the way for future investigations with ALMA for fainter filaments revealed in the infrared dark clouds.

Conclusions

Magnetic fields appear to be dominant in quite a few of the objects

Sensitivity is still an issue - improvements made at the SMA

ALMA will be great when it comes online for polarization observations - but need short spacings

Thank You !!