

ARE MAGNETIC FIELDS AND OUTFLOWS ALIGNED IN PROTOSTELLAR CORES?

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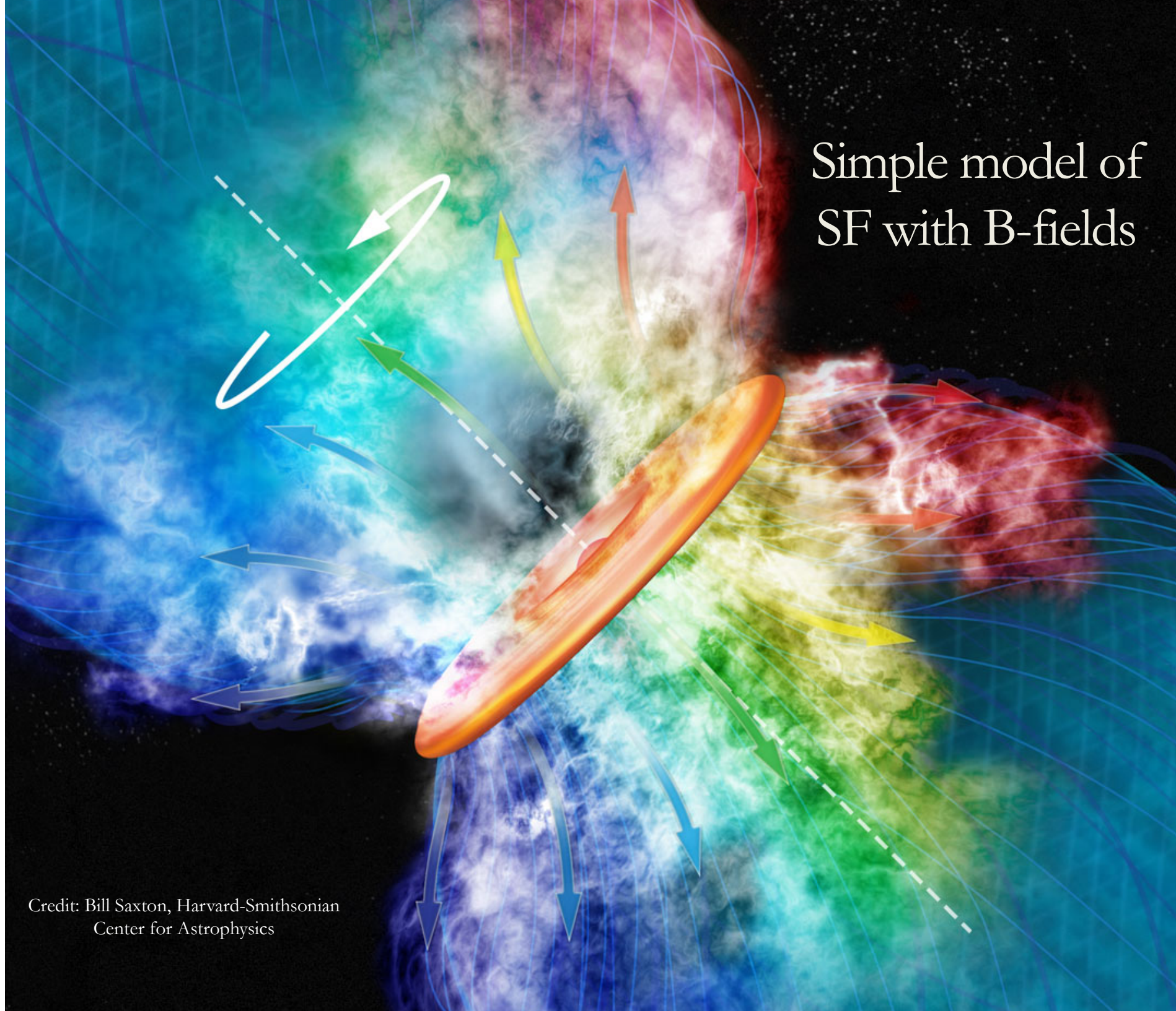
5 February 2013

Session: Magnetic Fields in the ISM and Star-forming Regions I

Magnetic Fields in the Universe IV

Playa del Carmen, Quintana Roo, México

Simple model of
SF with B-fields



Credit: Bill Saxton, Harvard-Smithsonian
Center for Astrophysics

Misalignment of B-fields and outflows

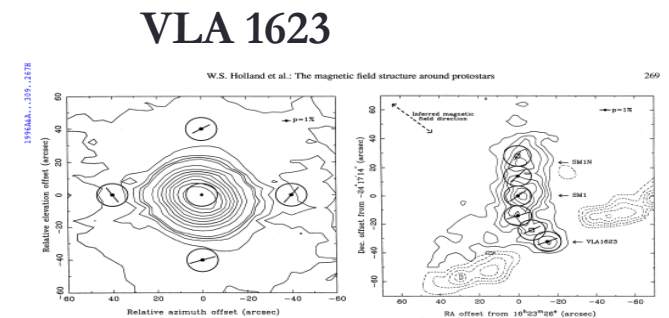
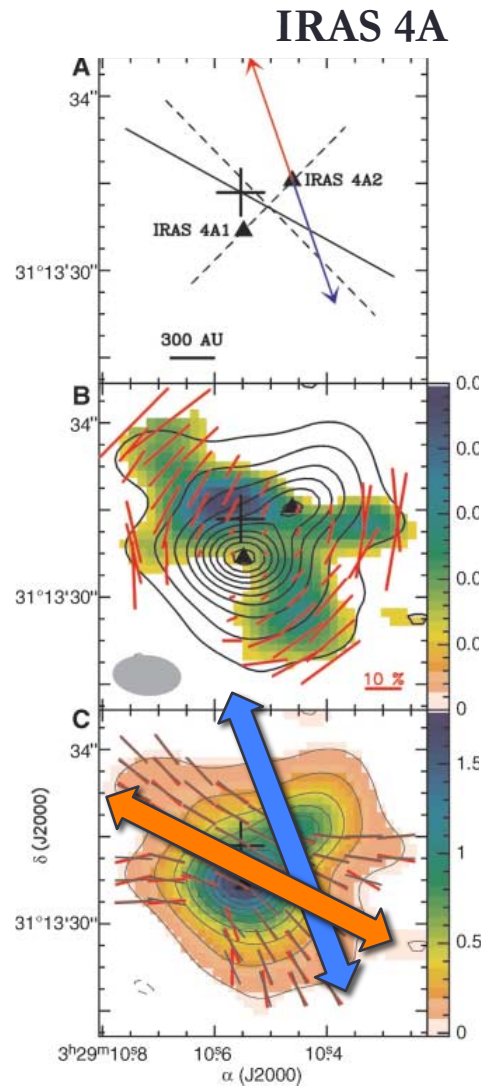
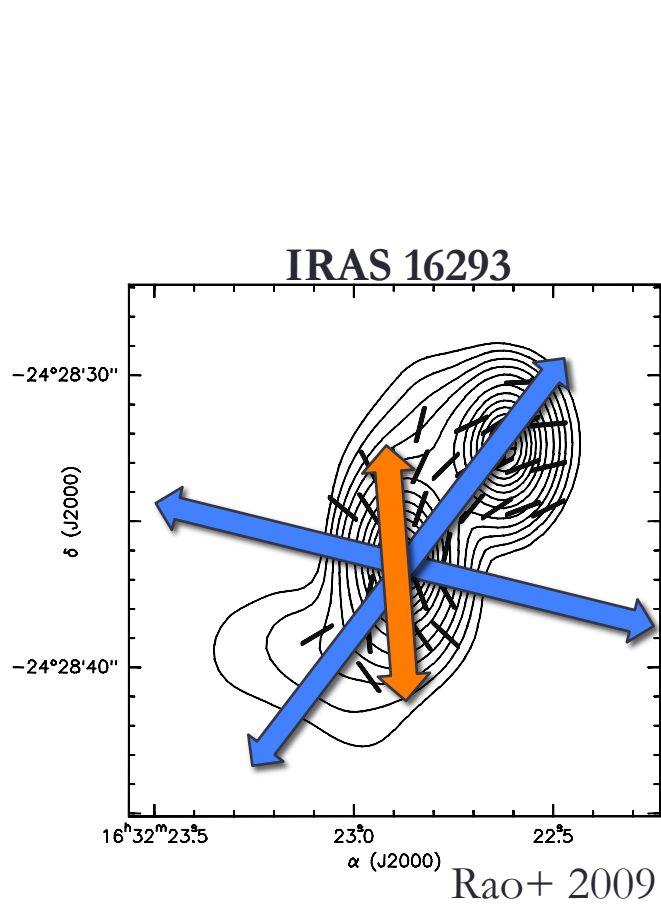


Fig. 1. 800 μm contour map of Jupiter (Dec. 1994), showing the on-axis and sidelobe contributions to the IP. Base contour level is 2%, and the interval for the first 5 levels is 2%. Subsequent levels are spaced at 10% intervals. The peak flux is approximately 13000 Jy/beam. The circles represent the 13.5" FWHM beam of the JCMT and the polarization vectors are shown for scaling purposes. An open arrow indicates polarization data which has a polarization signal-to-noise of ≥ 10 shown on the plot are the CCK2-1 outflow data (from SM1, 1990). Both the red-shifted and blue shifted lobes (negative and positive VLA 1623, respectively) have contours starting at 3 K km/s and intervals of 1 K km/s. A dashed line represents the direction of the inferred magnetic field throughout the protostar.

Fig. 2. 800 μm map of ρ Oph A region (from AWB), with a base contour level of 1.75 Jy/beam and equally-spaced intervals of 0.75 Jy/beam. Overlaid on top of the map are circles representing the 13.5" FWHM beam size, within which are the measured 800 μm polarization vectors (the three northern-most points are from GMH). A polarization vector is shown for scaling purposes. An open arrow indicates polarization data which has a polarization signal-to-noise of ≥ 10 shown on the plot are the CCK2-1 outflow data (from SM1, 1990). Both the red-shifted and blue shifted lobes (negative and positive VLA 1623, respectively) have contours starting at 3 K km/s and intervals of 1 K km/s. A dashed line represents the direction of the inferred magnetic field throughout the protostar.

IP effects should therefore be less than our estimated errors in Table 1.

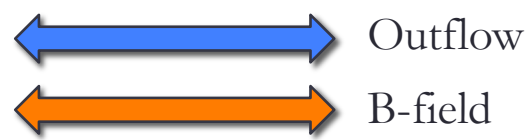
3.2. Source results

3.2.1. The ρ Oph A cloud core and VLA 1623

The ρ Oph A cloud core is a well-studied region of low-mass star formation, which has recently been shown to contain one of the youngest candidate protostars yet discovered, the prototype Class 0 source VLA 1623. The submillimetre observations of AWB have revealed that this YSO, which has a luminosity $L_{\text{bol}} \approx 0.5 - 2.5 L_{\odot}$, is surrounded by a cold ($T \leq 20$ K), compact ($R \approx 1000$ AU) and relatively massive ($M_{\text{c}} \approx 0.6 M_{\odot}$) spherically-symmetric circumstellar structure. VLA 1623 has an extended and extremely highly-collimated bipolar outflow aligned roughly NW-SE (André et al. 1999). MT observations of AWB suggest there is little or no evidence for a circumstellar disk around the source, such as is found, for example, around L1551 - IRS 5 (Keene and Mason 1990). The question therefore arises as to what is collimating the bipolar outflow, and one possible candidate for this mechanism is the large-scale magnetic field of the cloud. In this scenario the bipolar outflow should lie parallel to the observed large-scale field.

The results for the ρ Oph A core are shown in Fig. 2. For completeness, and to assist in the interpretation of the data, we include the measured and published points (the three most northern points, as viewed in Fig. 2) from GMH. Superimposed on the 800 μm contour map (from AWB) is the polarization data (see the caption for the map), and the vector direction indicates the position angle of the magnetic field. During our June 1994 run we also checked the accuracy and reliability of the measurements by repeating the observations at the peak of the SM1 source. The results were found to be consistent, with both the polarization magnitude and position angle agreeing, within the errors, for the two datasets (the original data for SM1 is plotted in Fig. 2). The values of q , u and p , θ (non-weighted averages) from all our measurements on the ρ Oph A region are presented in Table 1. The errors result from the scatter on individual measurements; between 10 and 28 waveplate cycles were made at each sky position.

From Fig. 2 it is evident that the polarization angles are roughly constant throughout the cloud (although from SM1 N to VLA 1623 there is a weak tendency for the angles to swing from



CARMA

Combined Array for Research in Millimeter-wave Astronomy

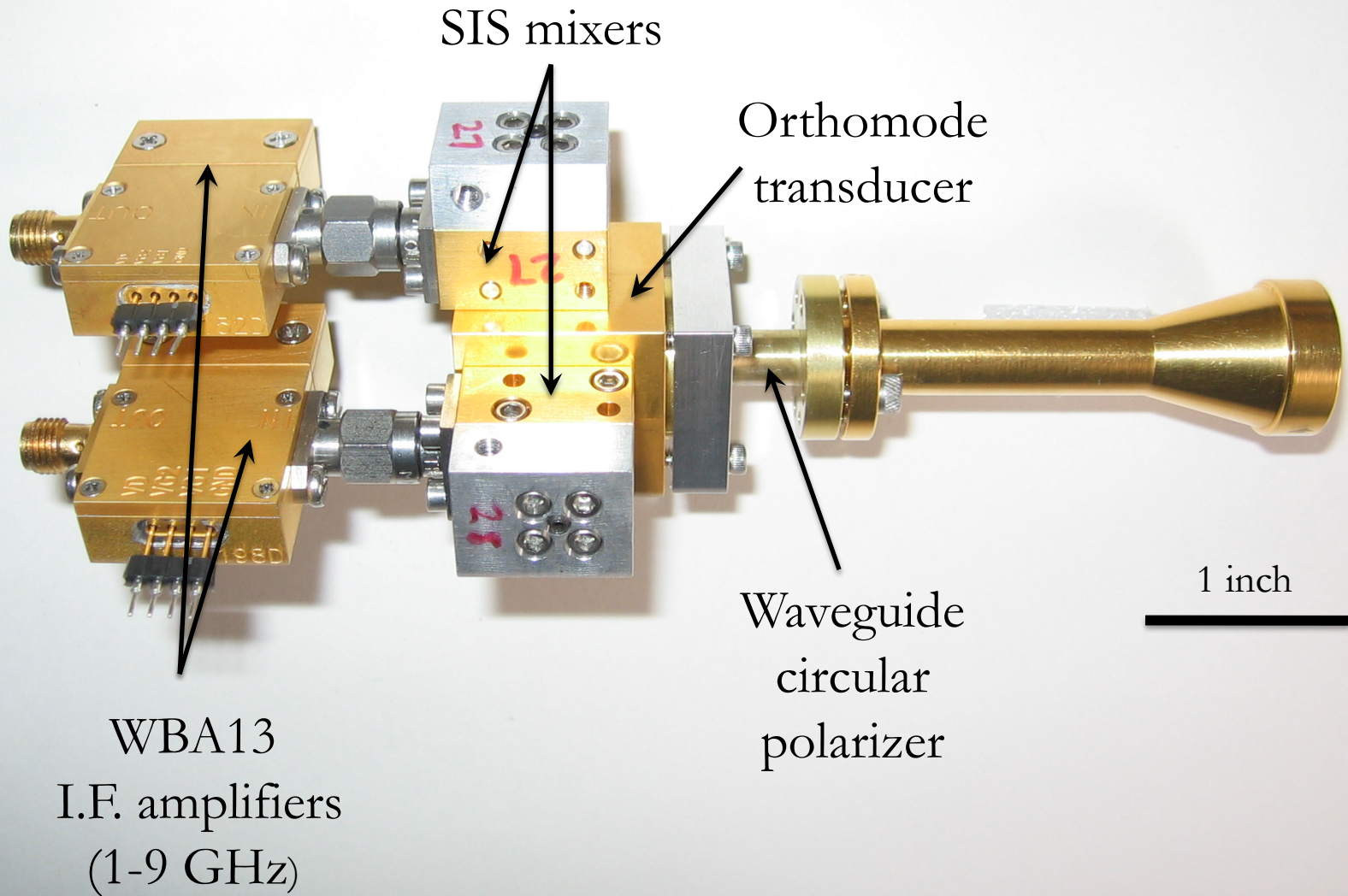


Consortium: Berkeley, Caltech, Illinois, Maryland, Chicago



- 6 × 10-m, 9 × 6-m, 8 × 3.5-m telescopes
- Observations at 1 cm, 3 mm, and 1 mm (**polarization!**)
- Located in Cedar Flat, CA (near Bishop)

1 mm dual-polarization receivers



TADPOL survey

35 sources

Triples number of interferometric polarization maps

~300 observing hours \neq 75 seconds

CARMA C, D, & E arrays

1 – 4" resolution

10× higher resolution than CSO & JCMT

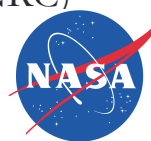
Probes intermediate region between ~ 0.1 pc (single-dish) and ~ 100 AU (ALMA)

1 mm wavelength

Ideal for dust polarization, as well as CO(2-1) for outflow mapping

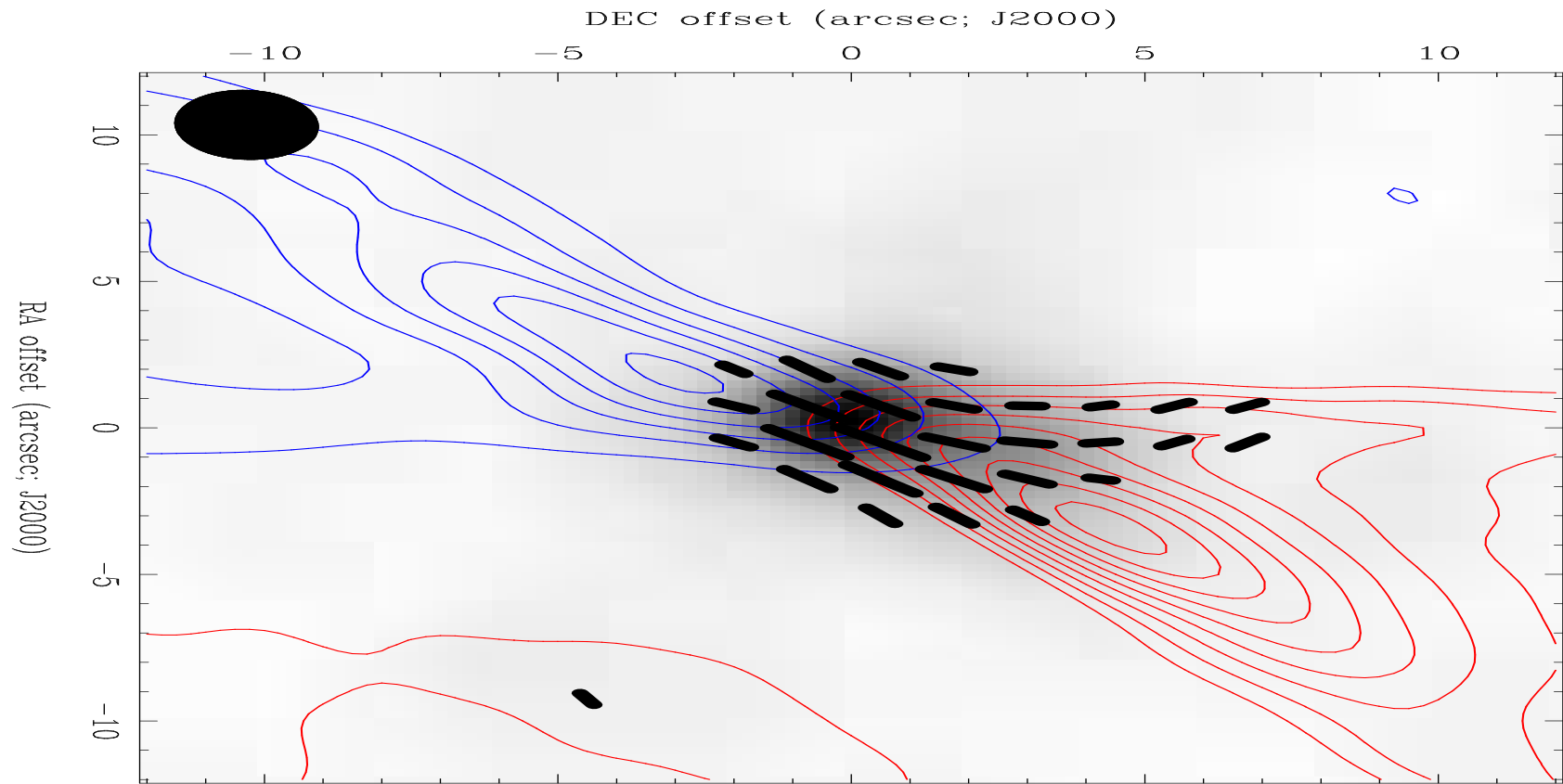
TADPOL collaboration

- **UC Berkeley**
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Geoff Bower
- **University of Maryland**
Marc Pound, Alberto Bolatto, Katherine Jameson,
Lee Mundy
- **Caltech**
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- **Other**
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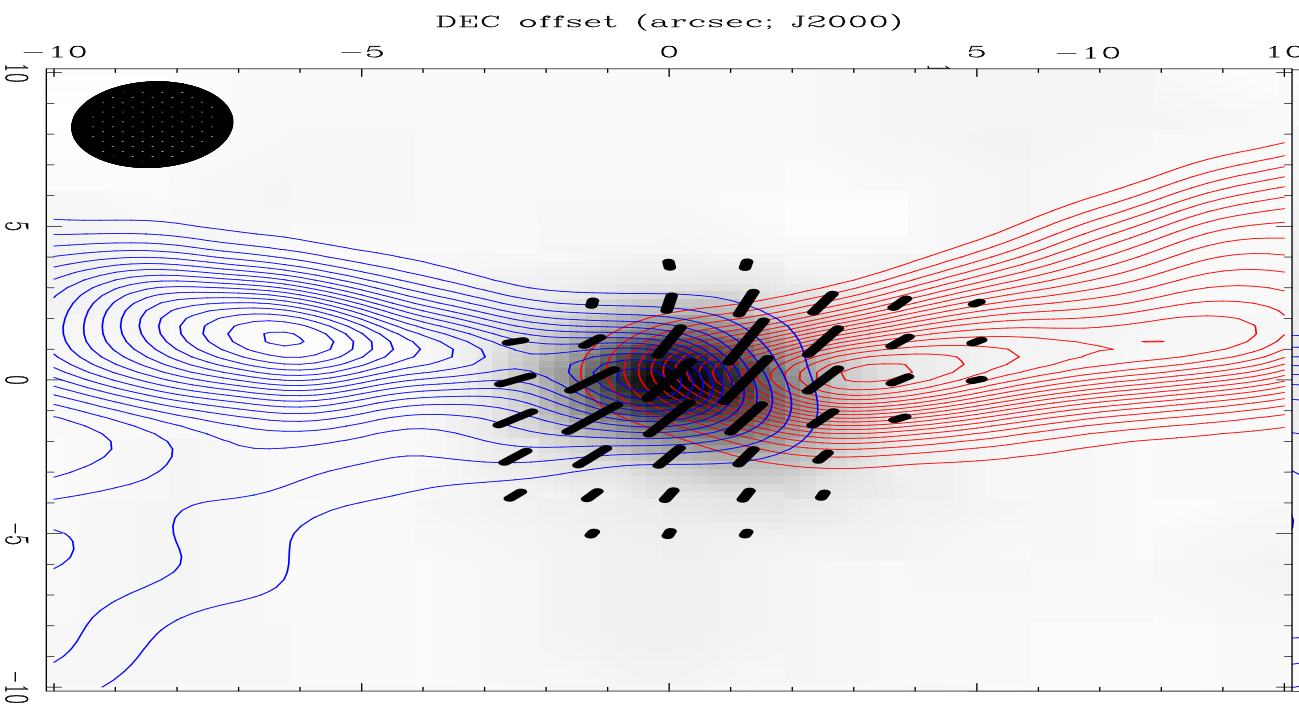
TADPOL results

L1157

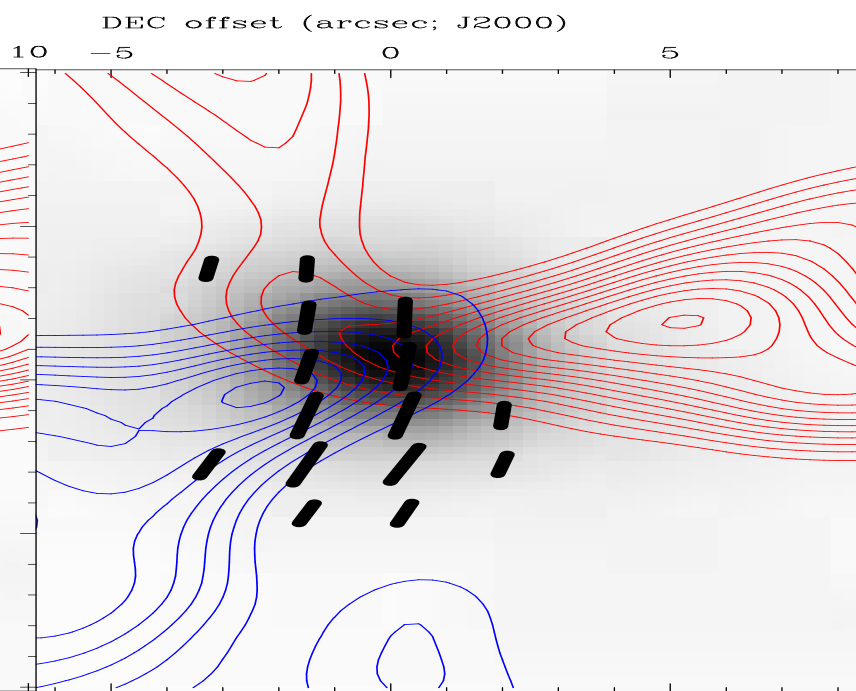


TADPOL results

NGC 1333-IRAS 4A



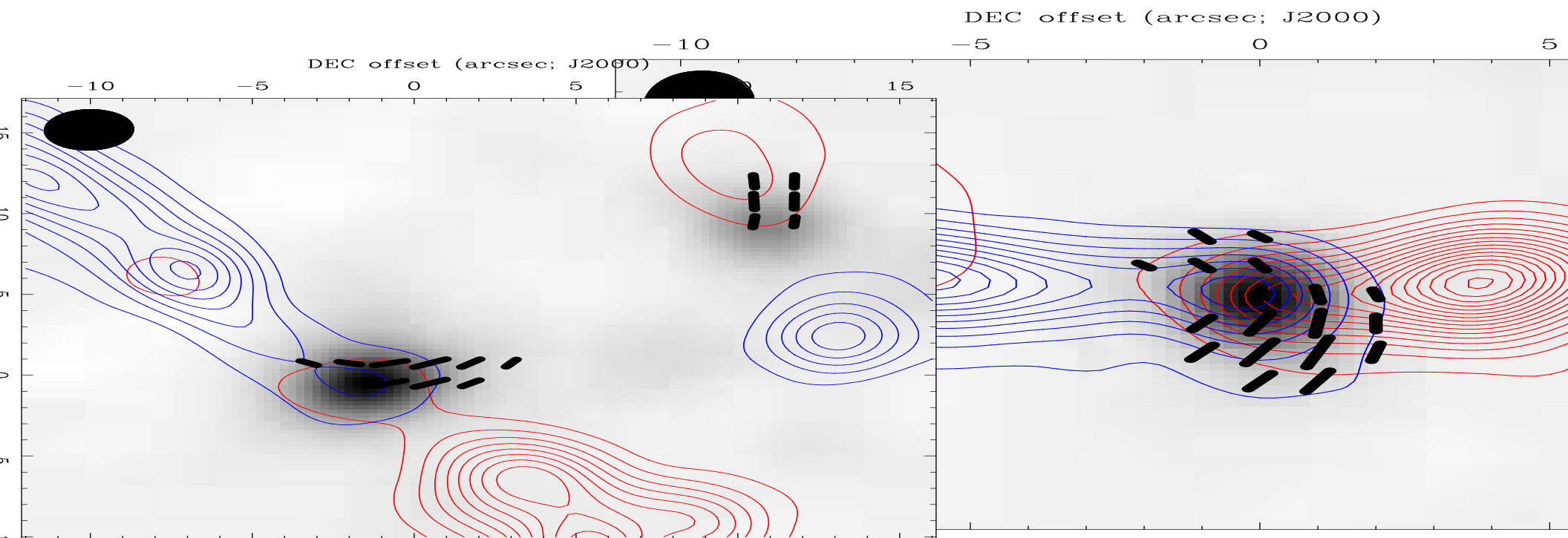
NGC 1333-IRAS 2A



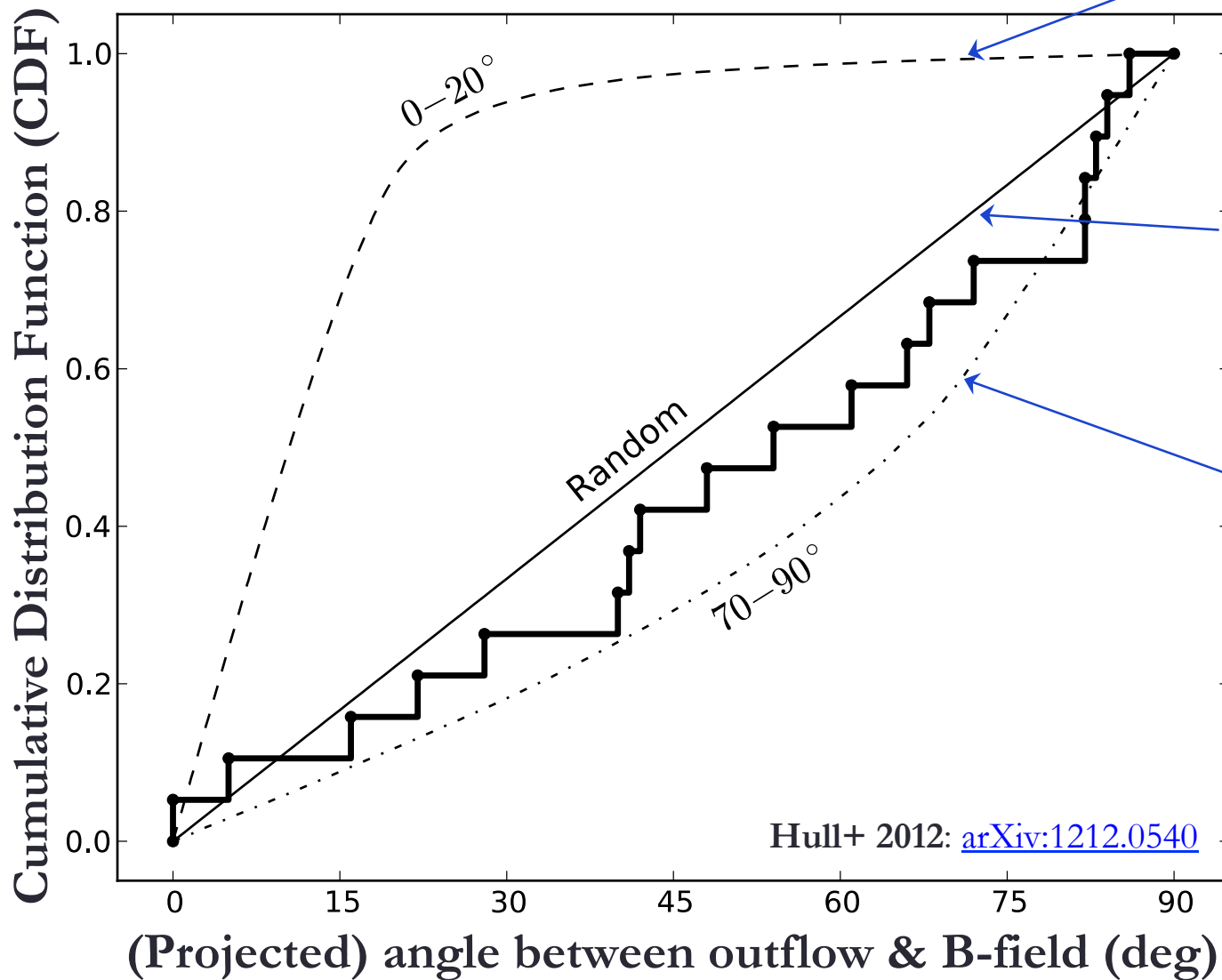
TADPOL results

Ser-emb 8

NGC 1333-IRAS 4B



Outflow vs. B-field: distribution



Simulation: outflows & B-fields aligned within a 20° cone (tightly aligned)

Simulation: outflows & B-fields are randomly oriented

Simulation: outflows & B-fields aligned between 70–90° (preferentially misaligned)

KS-test results:

- 20° cone ruled out (p-value $\sim 10^{-9}$)
- Misaligned (0.79) and random (0.64) cannot be ruled out

Conclusions

- B-fields are either **preferentially misaligned** (perp.) or **randomly aligned** with respect to outflows at the ~ 1000 AU scale
 - Thus, circumstellar disks are misaligned with fields in the cores from which they formed
- Future work:
 - Compare polarization in filaments with ALMA data
 - Compare B-fields in SCUBA (~ 0.1 pc) and CARMA (~ 1000 AU, or ~ 0.05 pc) data
- TADPOL results: [arXiv:1212.0540](https://arxiv.org/abs/1212.0540)
- TADPOL survey (CARMA key project): tadpol.astro.illinois.edu
- Questions? Contact Chat Hull: chat@astro.berkeley.edu



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