

POLARIZATION IN FORMING STARS

Chat Hull

UC Berkeley

Radio Astronomy Laboratory

Collaborators

CARMA 1mm dual-pol commissioning

- Dick Plambeck
- Greg Engargiola
- All the OVRO staff

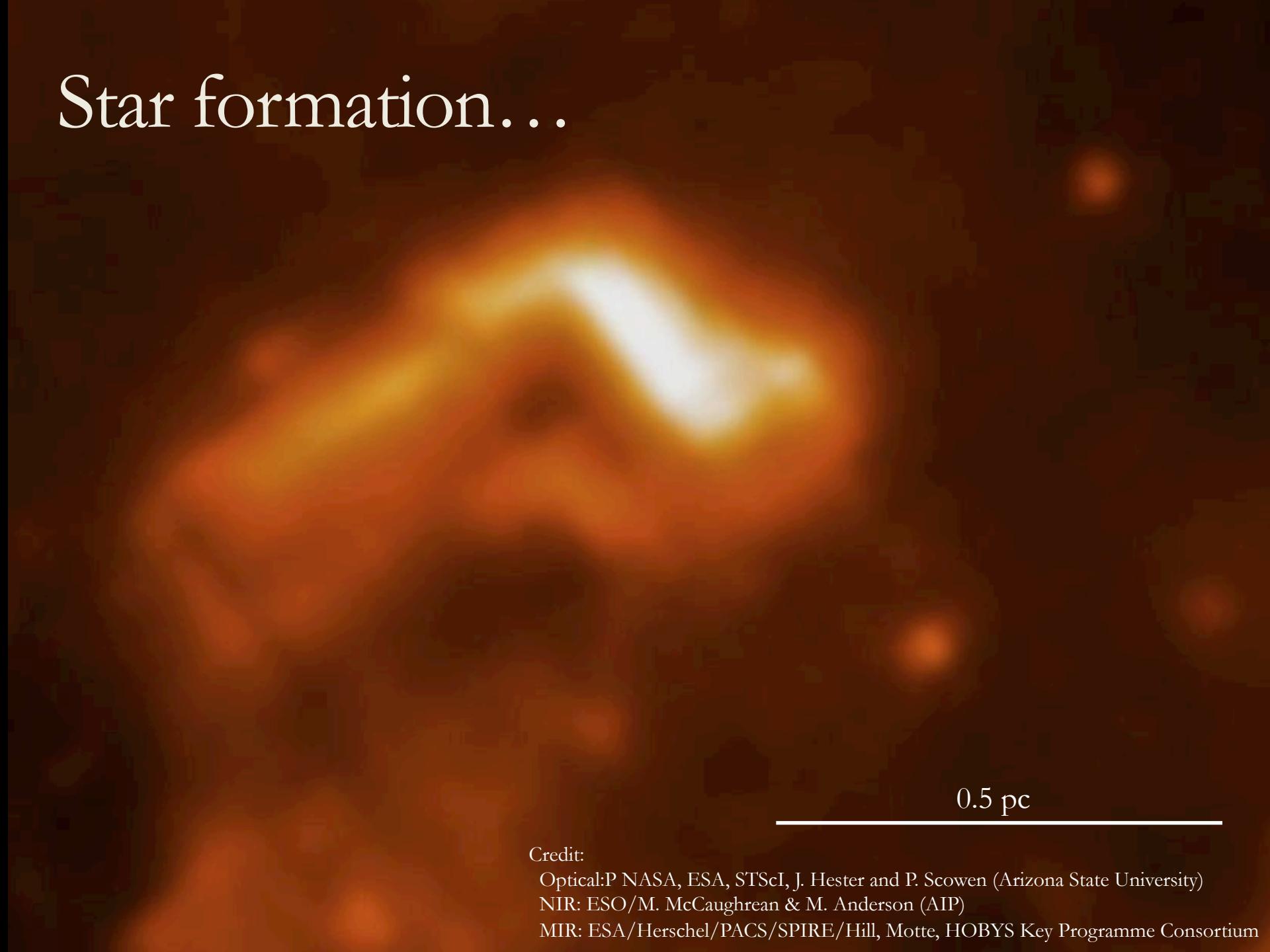
TADPOL project

- **UC Berkeley**
Dick Plambeck, Geoff Bower, Carl Heiles, Meredith Hughes, Mel Wright
- **University of Maryland**
Alberto Bolatto, Katherine Jameson, Lee Mundy, Marc Pound
- **Caltech**
John Carpenter, James Lamb, Thushara Pillai, Nikolaus Volgenau
- **University of Illinois, Urbana-Champagne**
Dick Crutcher, Nick Hakopian, Woojin Kwon, Leslie Looney, Ian Stephens
- **University of Chicago**
Roger Hildebrand
- **Other**
Jason Fiege (Manitoba), Erica Franzmann (Manitoba), Martin Houde (UWO, Caltech), Dan Marrone (Arizona), Brenda Matthews (HIA), John Vaillancourt (USRA-SOFIA)

Outline

- **B-fields in star formation**
 - Motivation & overview
- **B-fields from large to small scales**
 - B-field regulation of SF from large to small scales
 - Alignment of B-field in core, and outflow direction
- **The TADPOL survey**
 - Probing B-fields at core scales

Star formation...



0.5 pc

Credit:

Optical: NASA, ESA, STScI, J. Hester and P. Scowen (Arizona State University)

NIR: ESO/M. McCaughrean & M. Anderson (AIP)

MIR: ESA/Herschel/PACS/SPIRE/Hill, Motte, HOBYS Key Programme Consortium

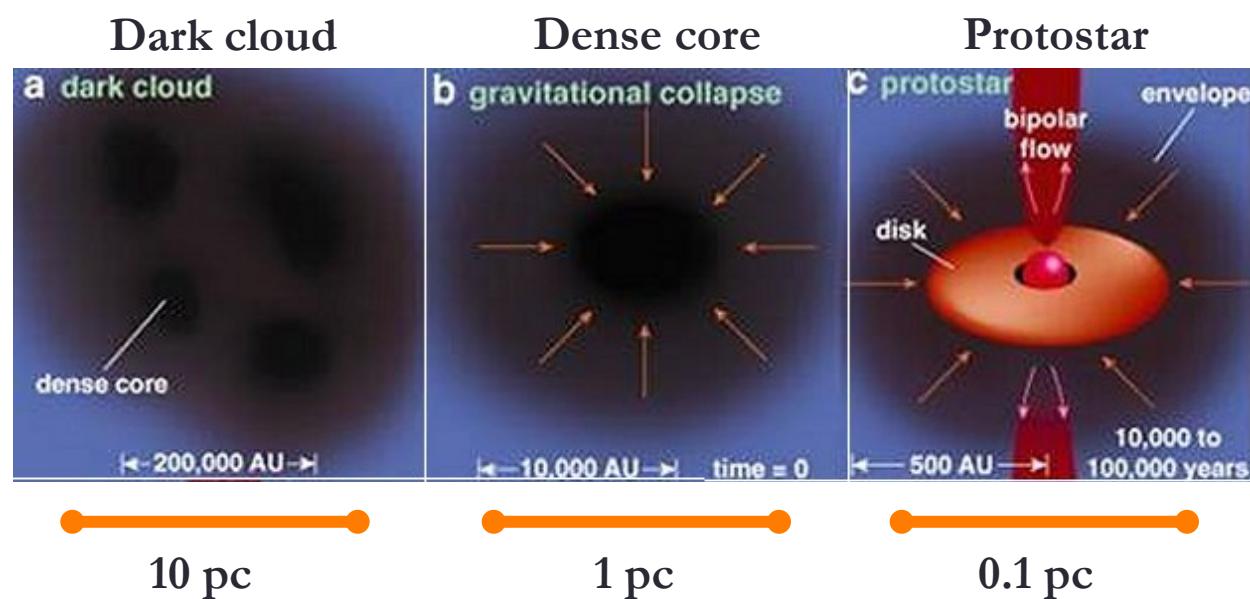
Non-magnetized star formation

- **Pulling in:**

- Gravity

- **Pushing out:**

- Turbulent pressure
- Thermal pressure
- Rotational support



Magnetized star formation

- Pulling in:

- Gravity

- Pushing out:

- Turbulent pressure
 - Thermal pressure
 - Rotational support
 - Magnetic pressure

- Will the cloud collapse?

$$\frac{E_{\text{grav}}}{E_{\text{mag}}} < 1$$

“Subcritical”
(WILL NOT collapse)

$$\frac{E_{\text{grav}}}{E_{\text{mag}}} > 1$$

“Supercritical”
(WILL collapse)

OUR QUESTIONS

How important are B-fields in star formation?

On what scales are B-fields important?

CARMA

Combine Array for Research in Millimeter-wave Astronomy

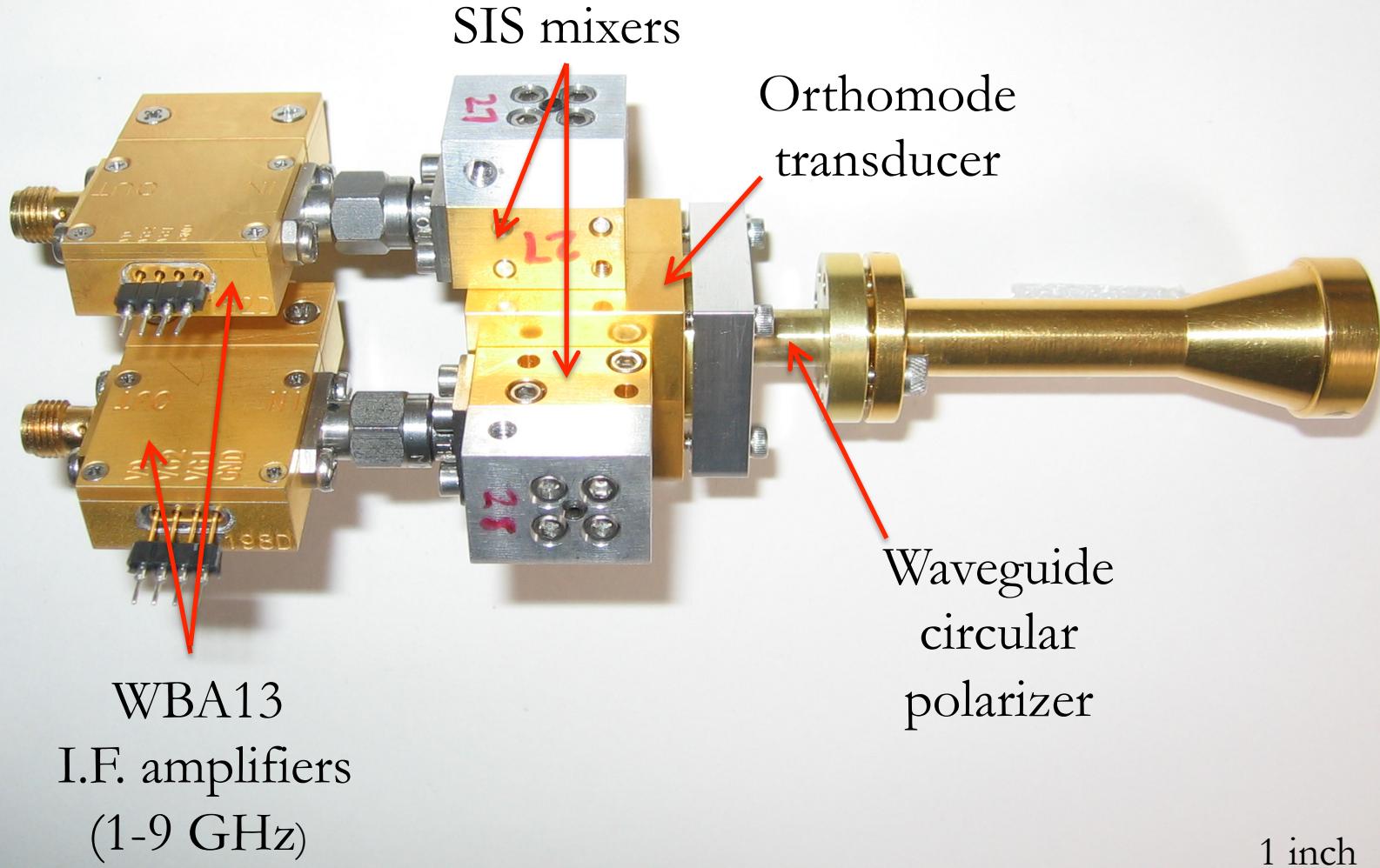


Consortium: Berkeley, Caltech, Illinois, Maryland, Chicago

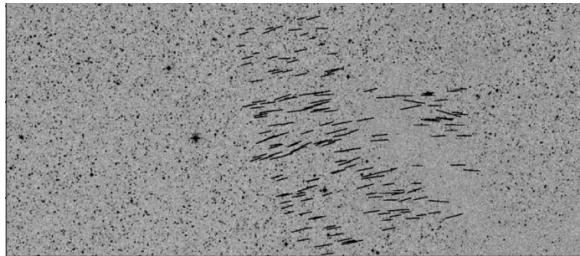
- $6 \times 10\text{-m}$, $9 \times 6\text{-m}$, $8 \times 3.5\text{-m}$ telescopes
- Observations at 1 mm, 3 mm, and 1 cm
- Located in Cedar Flat, CA (near Bishop)



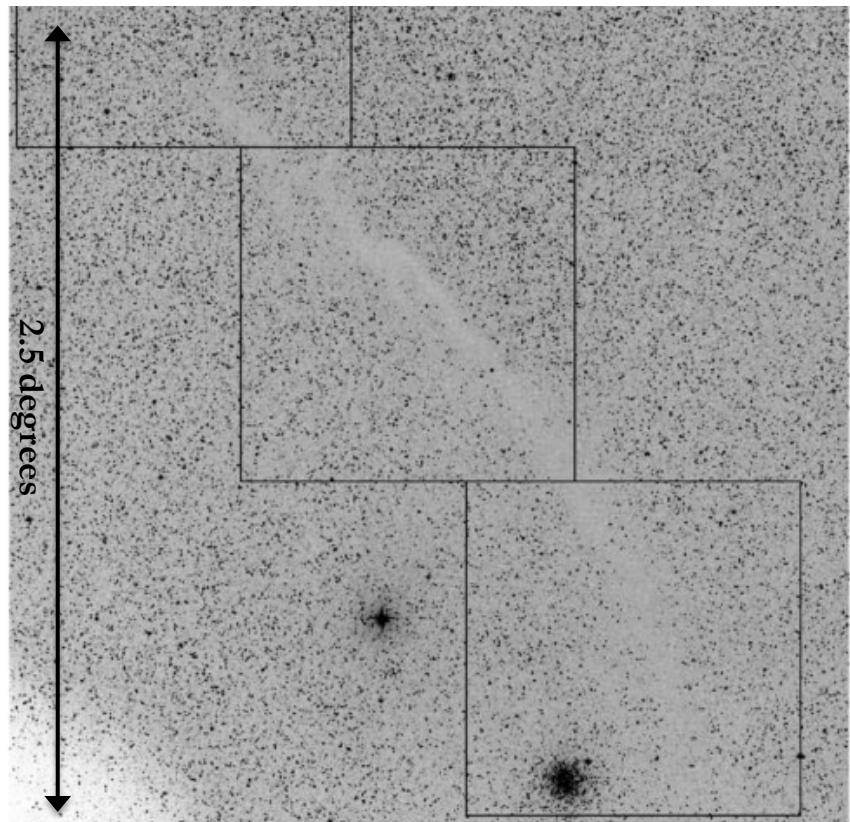
1 mm dual-polarization receivers



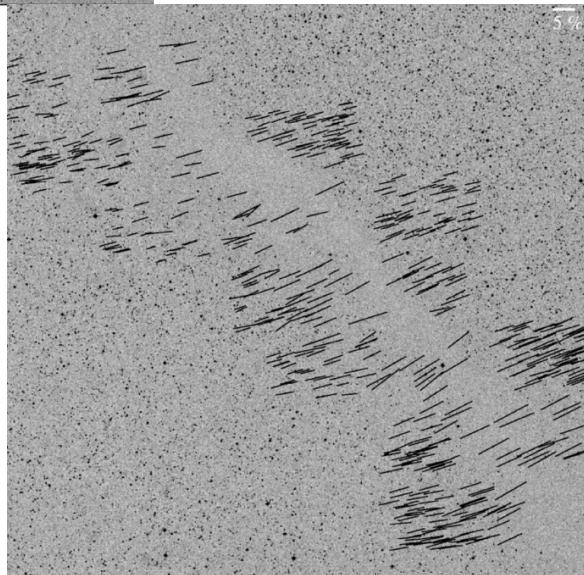
Large-scale:
ordered fields



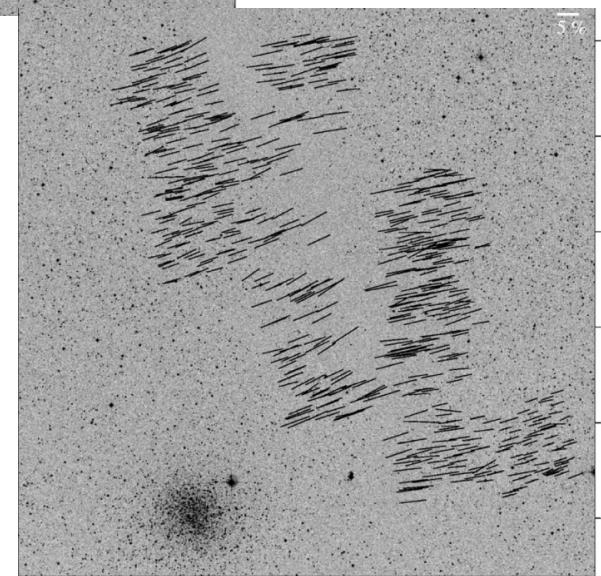
Musca dark cloud



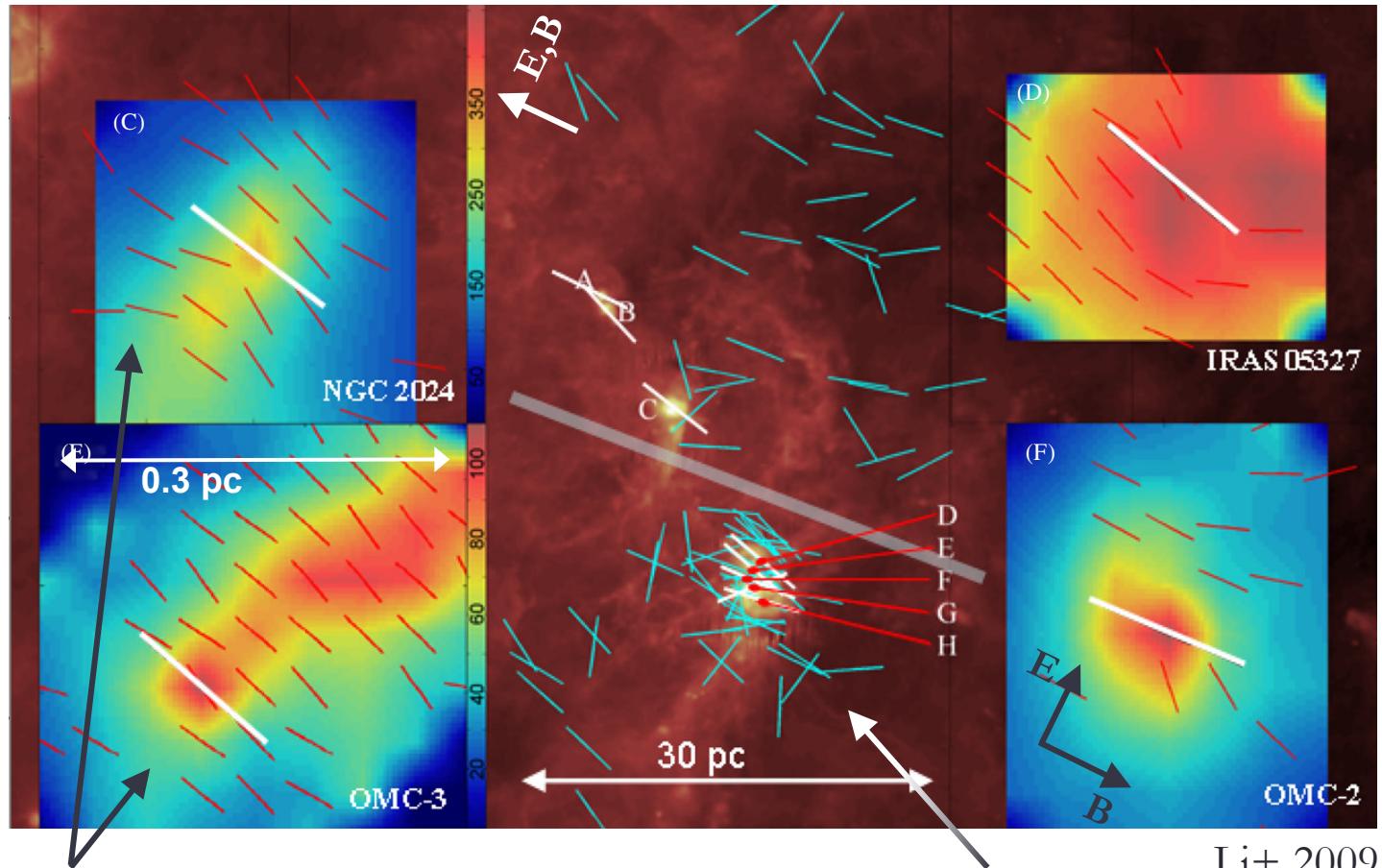
Images: Pereyra & Magalhães 2004



↑
E,B



Large-scale: consistent B-field in clouds & cores



Smaller-scale: still important?

- Fields clearly are important between the ~ 100 pc and ~ 1 pc scales
- Are fields dynamically important once you get below the ~ 1 pc core scale?
- If so, B-fields should be:
 - **Well ordered**
 - **Aligned with outflows**, to allow for angular momentum transport (if past simulations are correct)

TADPOL survey: overview

30 objects

Triples number of low-mass, forming stars observed to date

280 observing hours

CARMA C, D, & E arrays

1 – 4'' resolution

10× higher resolution than CSO & JCMT

Probes intermediate region between ~1 pc (single-dish) and ~100 AU (ALMA)

1 mm wavelength

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

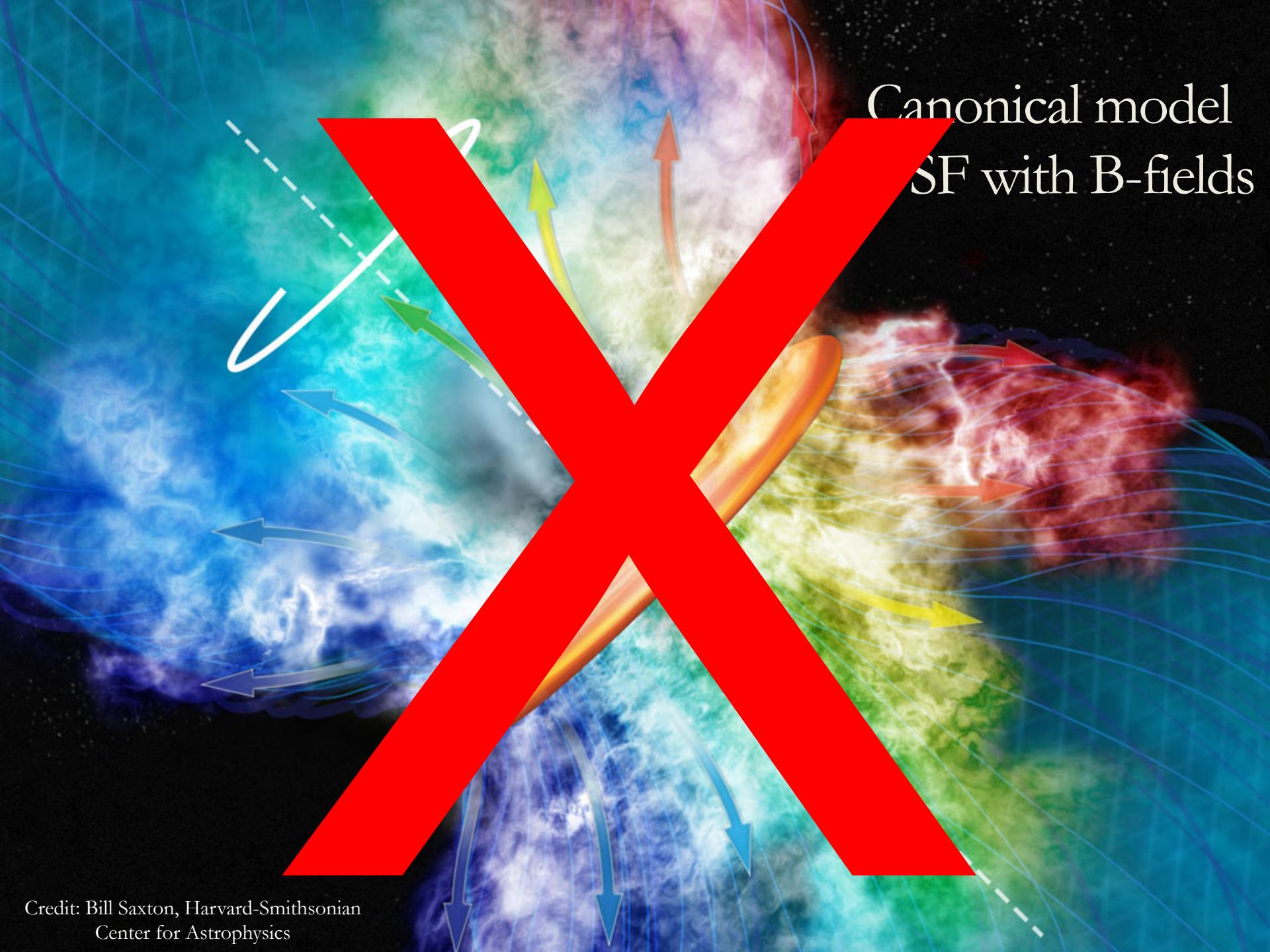
TADPOL survey: goals

- **Isolated, star-forming cores**
 - Measure projected field vs. outflow directions
 - Model intrinsic field morphology
- **Extended regions**
 - Look for orderliness in B-fields on ~ 0.01 pc scales
 - Compare with larger-scale polarization in cloud envelopes

Smaller-scale: still important?

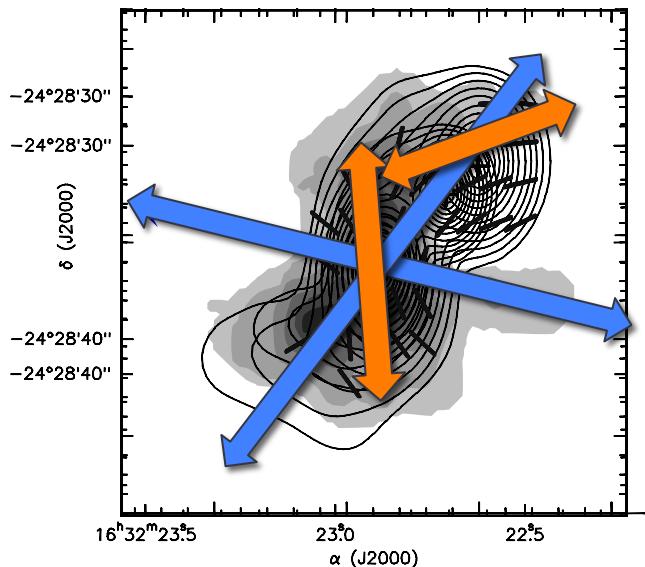
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Canonical model
SF with B-fields

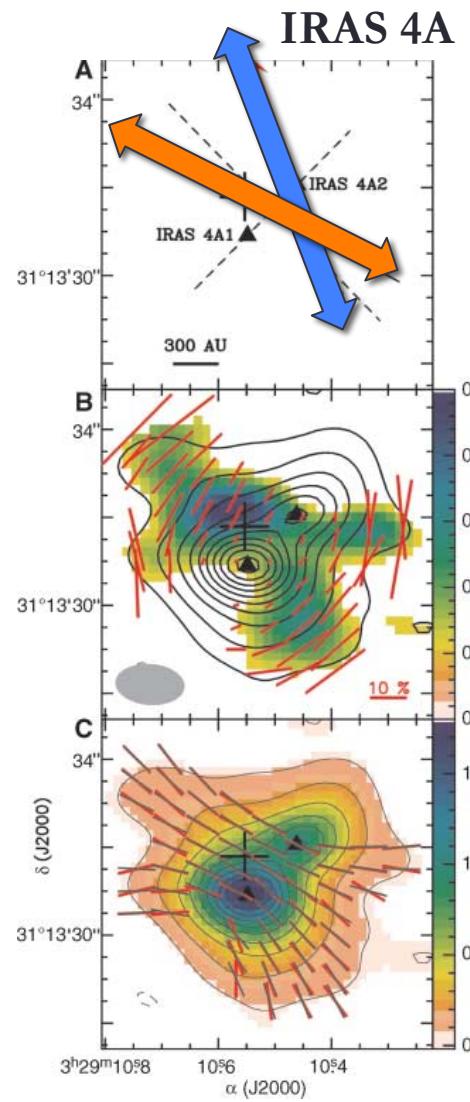
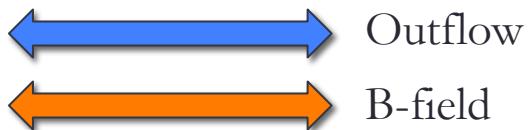


Misalignment of B-fields and outflows

IRAS 16293

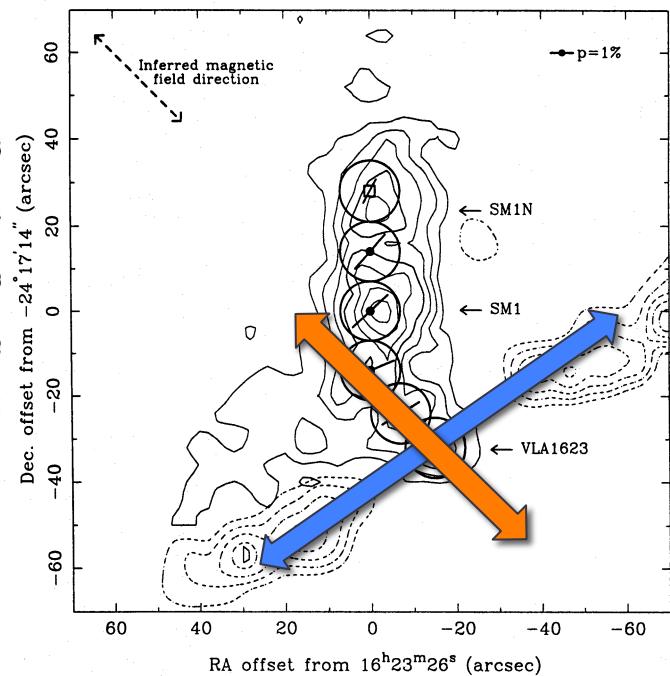


Rao+ 2009



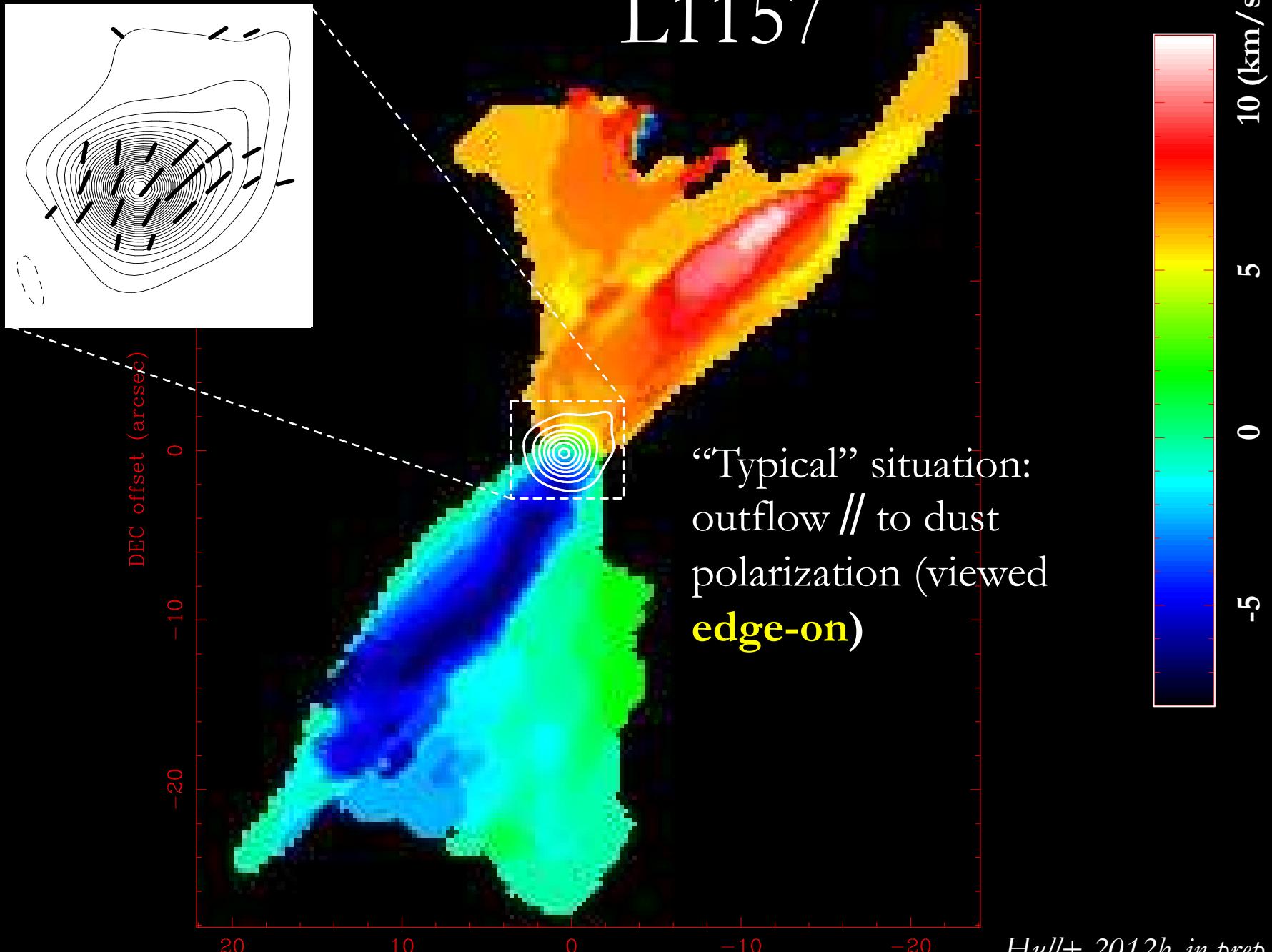
Girart+ 2006

VLA 1623

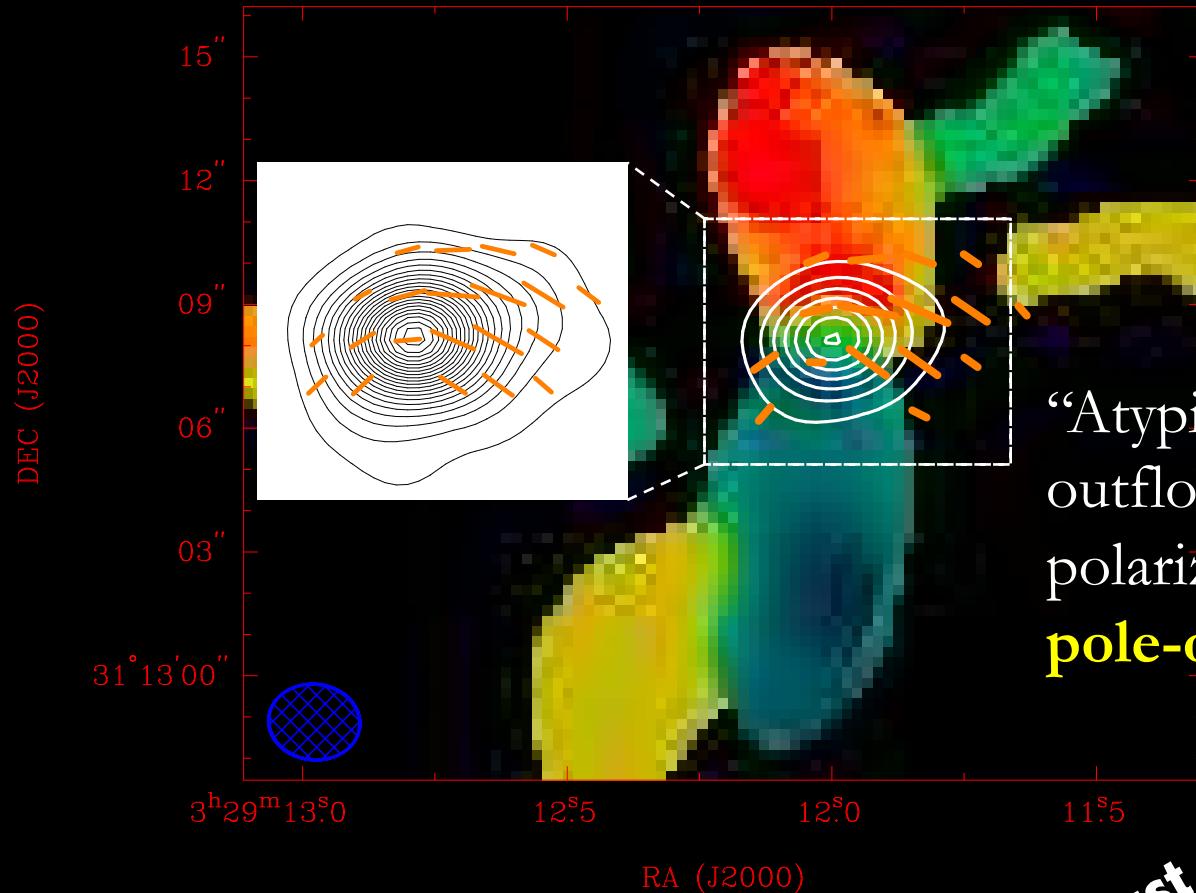


Holland+ 1996

L1157



NGC 1333-IRAS 4B



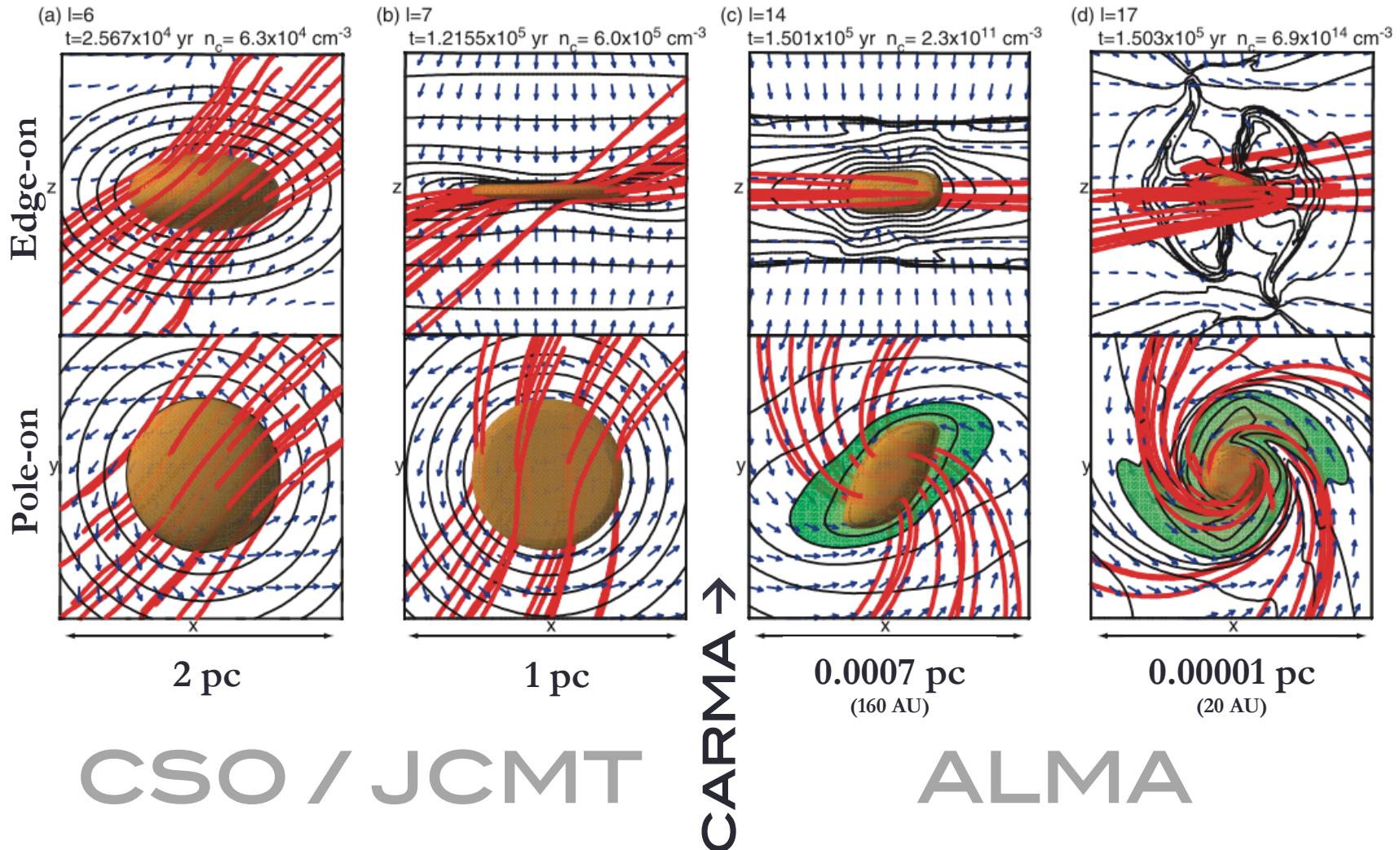
“Atypical” situation:
outflow \perp to dust
polarization (seen
pole-on)

Is this all just projection effects?!

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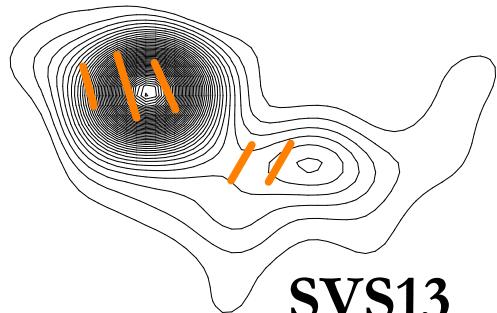
It's all about resolution...



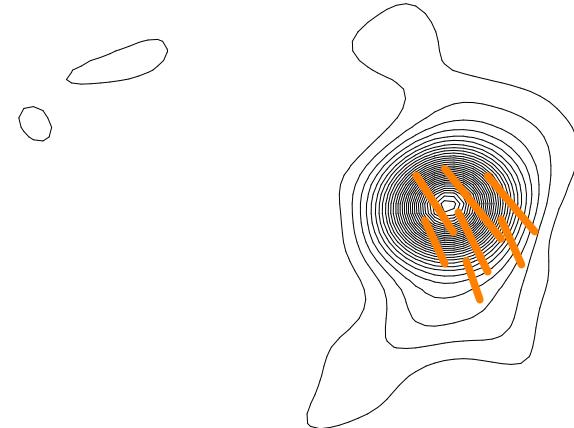
At $d = 500$ pc, the D-array synthesized beam (at 1 mm) spans $2''$, or **0.005 pc** (1000 AU)

More commissioning data

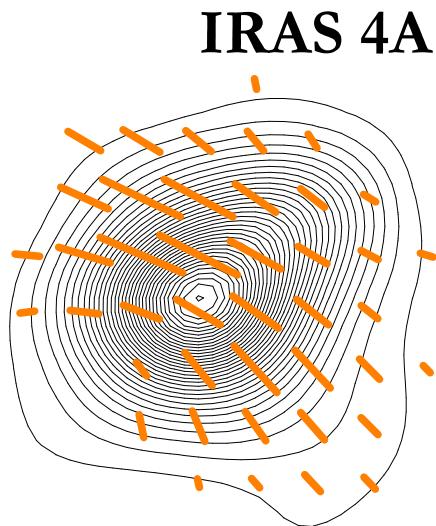
Isolated cores



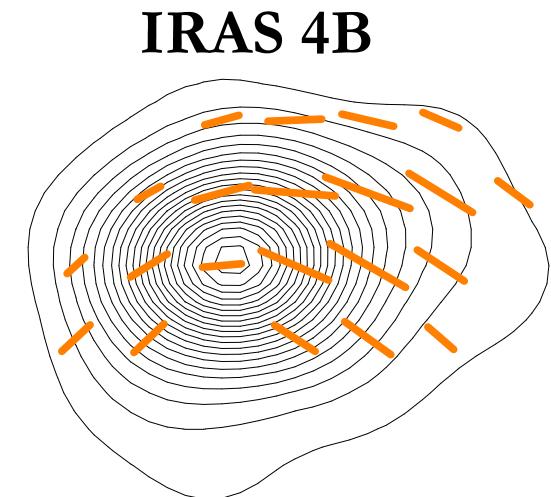
SVS13



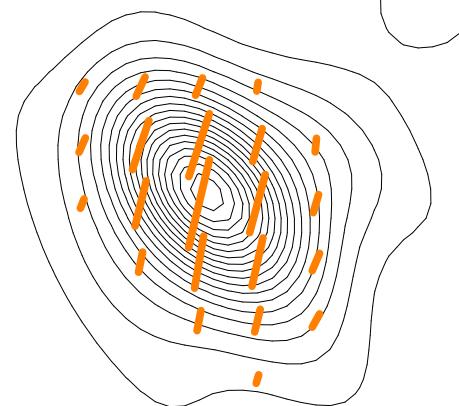
Ser FIR1



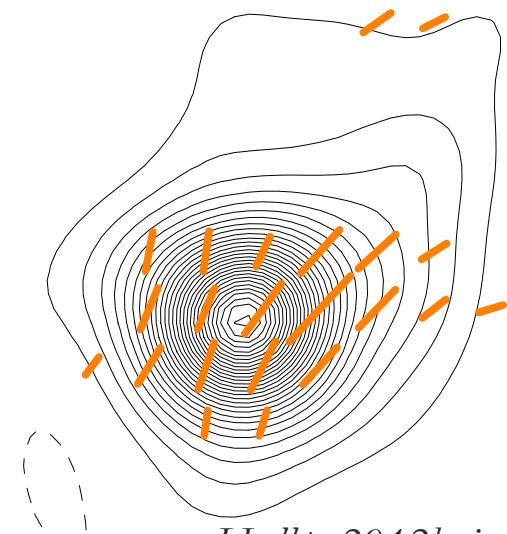
IRAS 4A



IRAS 4B



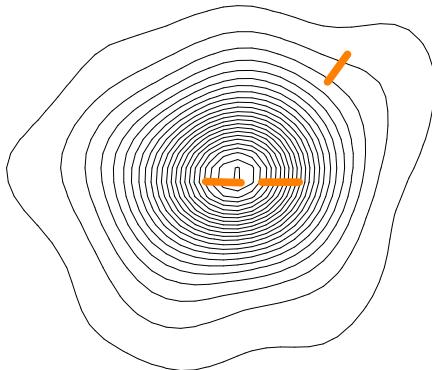
L1157



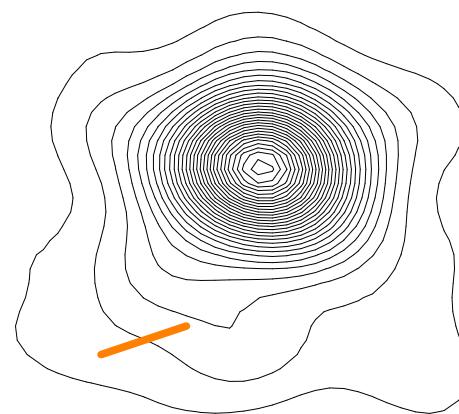
Hull+ 2012b, in prep.

Isolated cores

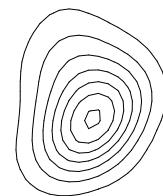
IRAS 2A



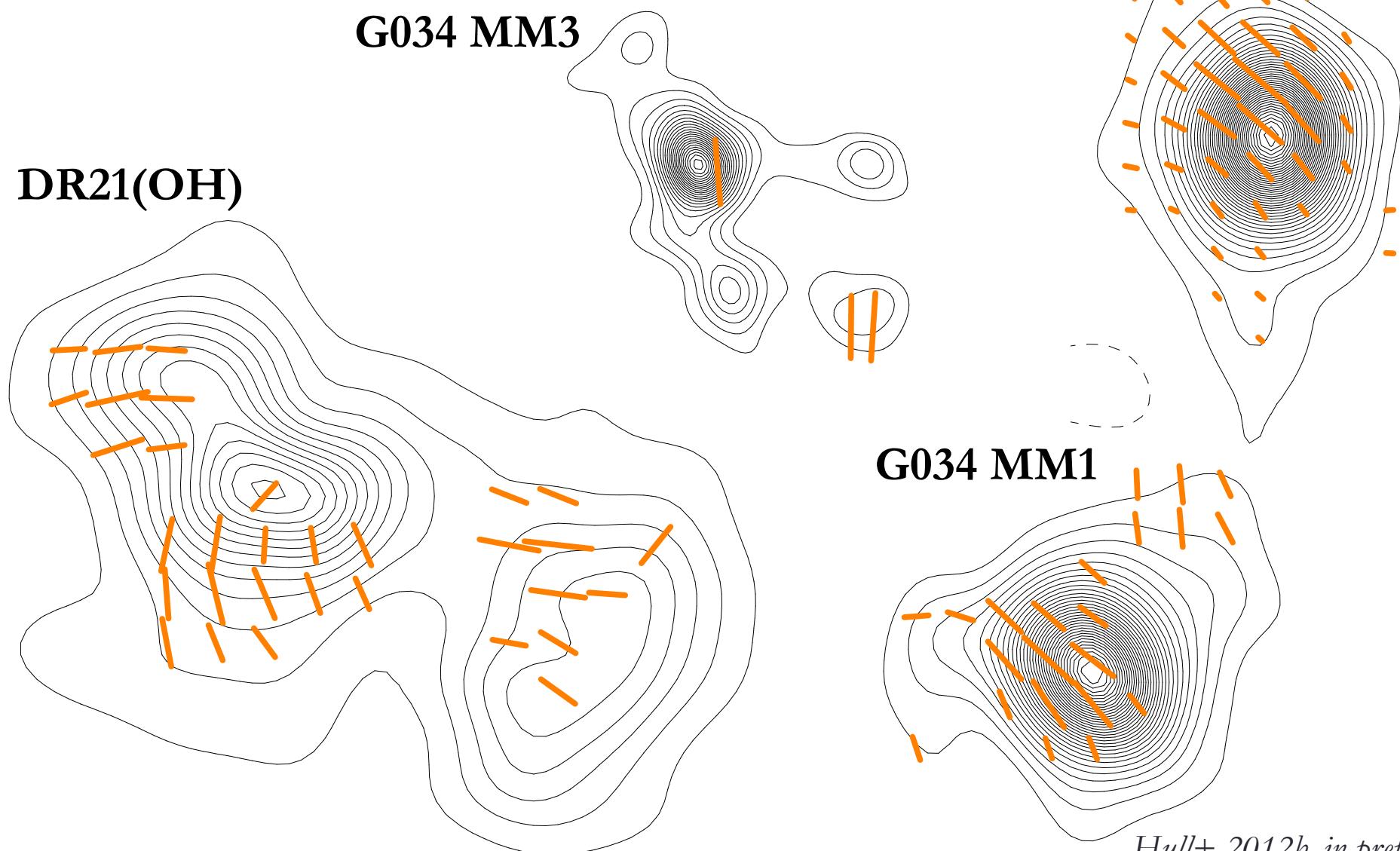
L1448C



B335



Extended SF regions



Fin