Polarization in the ALMA era


Photo credit: C. Hull

Chat Hull

NAOJ Fellow —

National Astronomical Observatory of Japan
NAOJ Chile Observatory
Joint ALMA Observatory

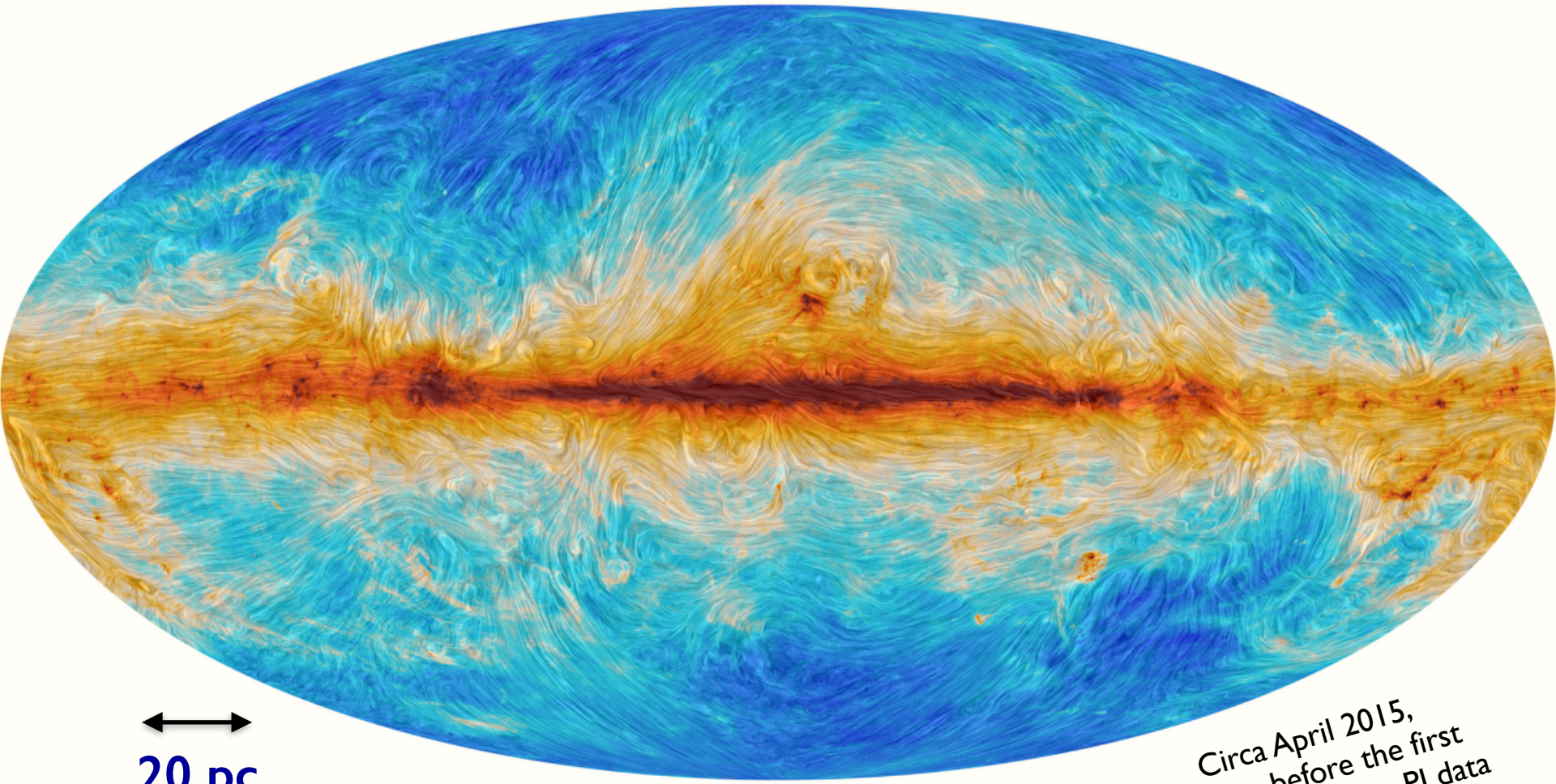
27 March 2018

The ALMA Quest for our Cosmic Origins
Joint ALMA Observatory
Santiago, Chile

Overview

- Introduction: pesky position angles
- What came before…
- The ALMA era
  - Low-mass protostars
  - High-mass star formation
  - Disks
  - Ongoing efforts: spectral-line and circular polarization

We live in a beautiful, magnetized Universe



20 pc

Scaled to nearby SFRs

Planck Collaboration
planckandthemagneticfield.info

Circa April 2015,
<1 year before the first
ALMA polarization PI data
were delivered

NAOJ 国立天文台 ALMA

What is the role of the magnetic field in star formation?

Fundamental?

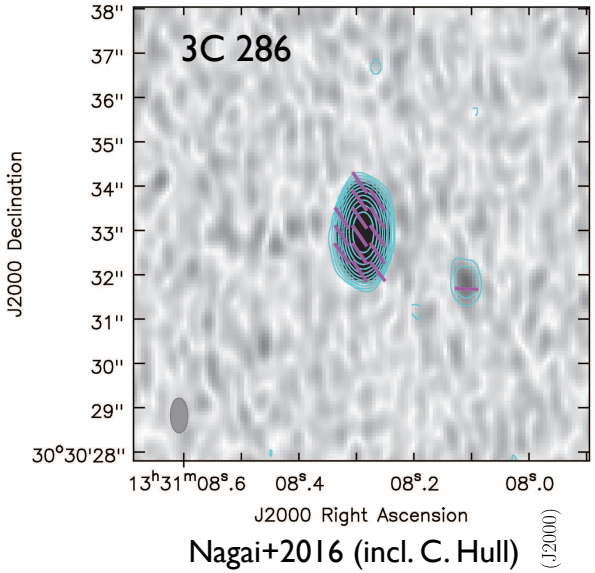
Incidental?

But first…let's talk about everyone's favorite calibrator

It all began with 3C 286

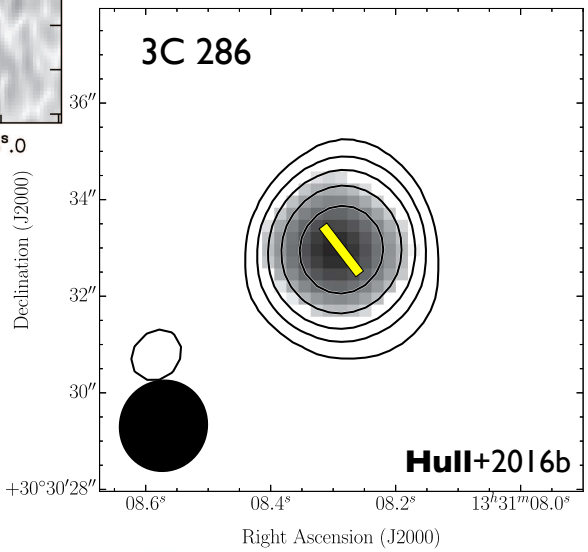
April 2013 (during ALMA Cycle 1, a mere 5 months after Pierre was appointed ALMA Director)
Stuartt: *"Do you have the details and some idea of the error bars from your measurements?"*
Plambeck: *"We tend to find PAs 37 to 41 at 230 GHz."*
Stuartt: *"We got 39....so seems reasonable."* … *"Even George was pretty happy about the calibration accuracy...which is saying a good deal."*

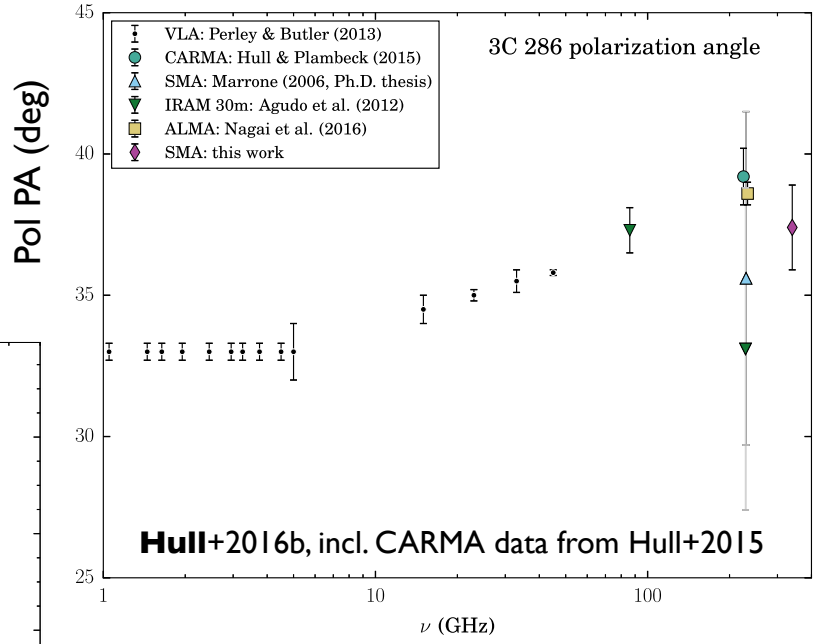
ALMA



Nagai+2016 (incl. C. Hull)

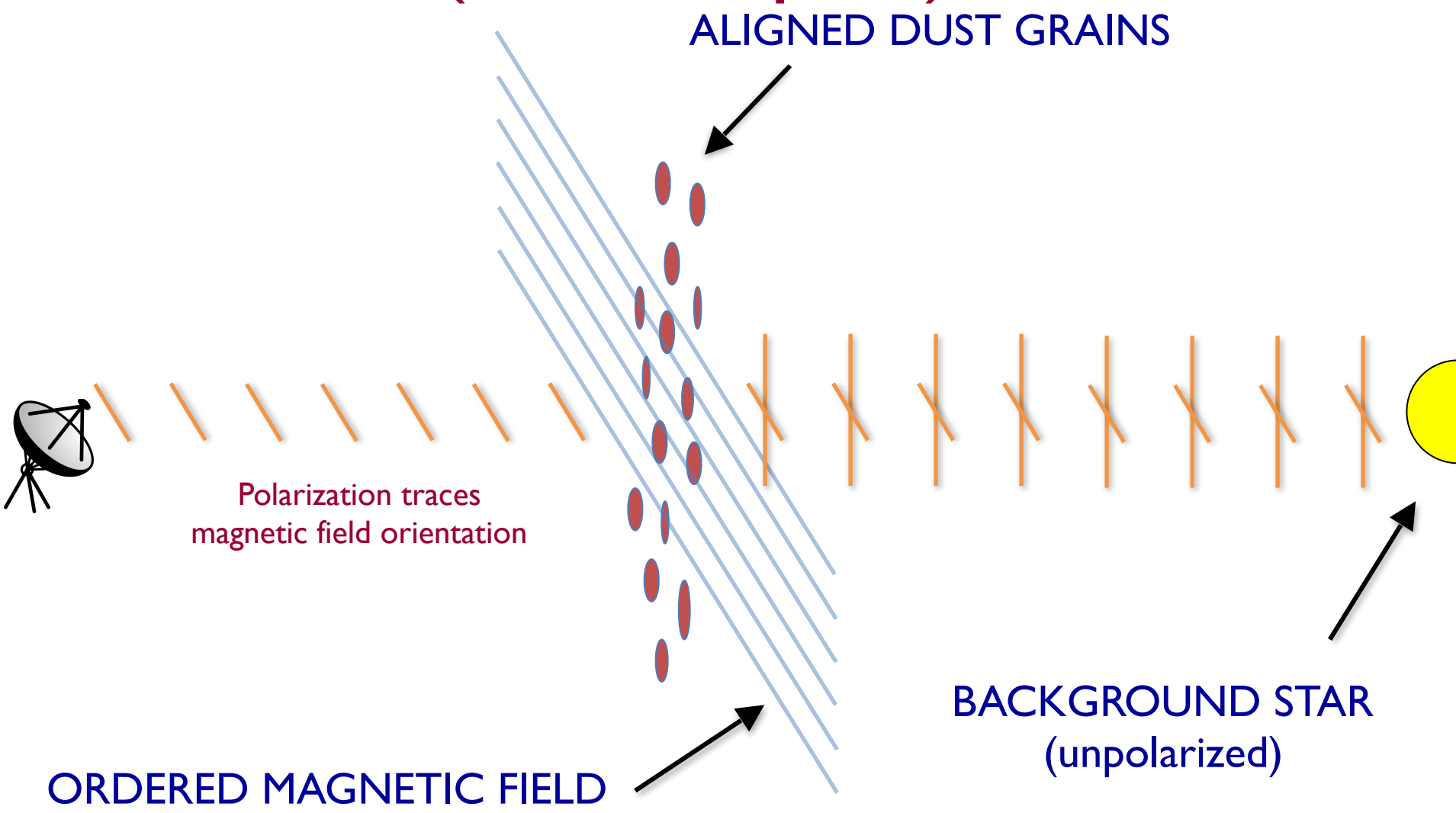
SMA



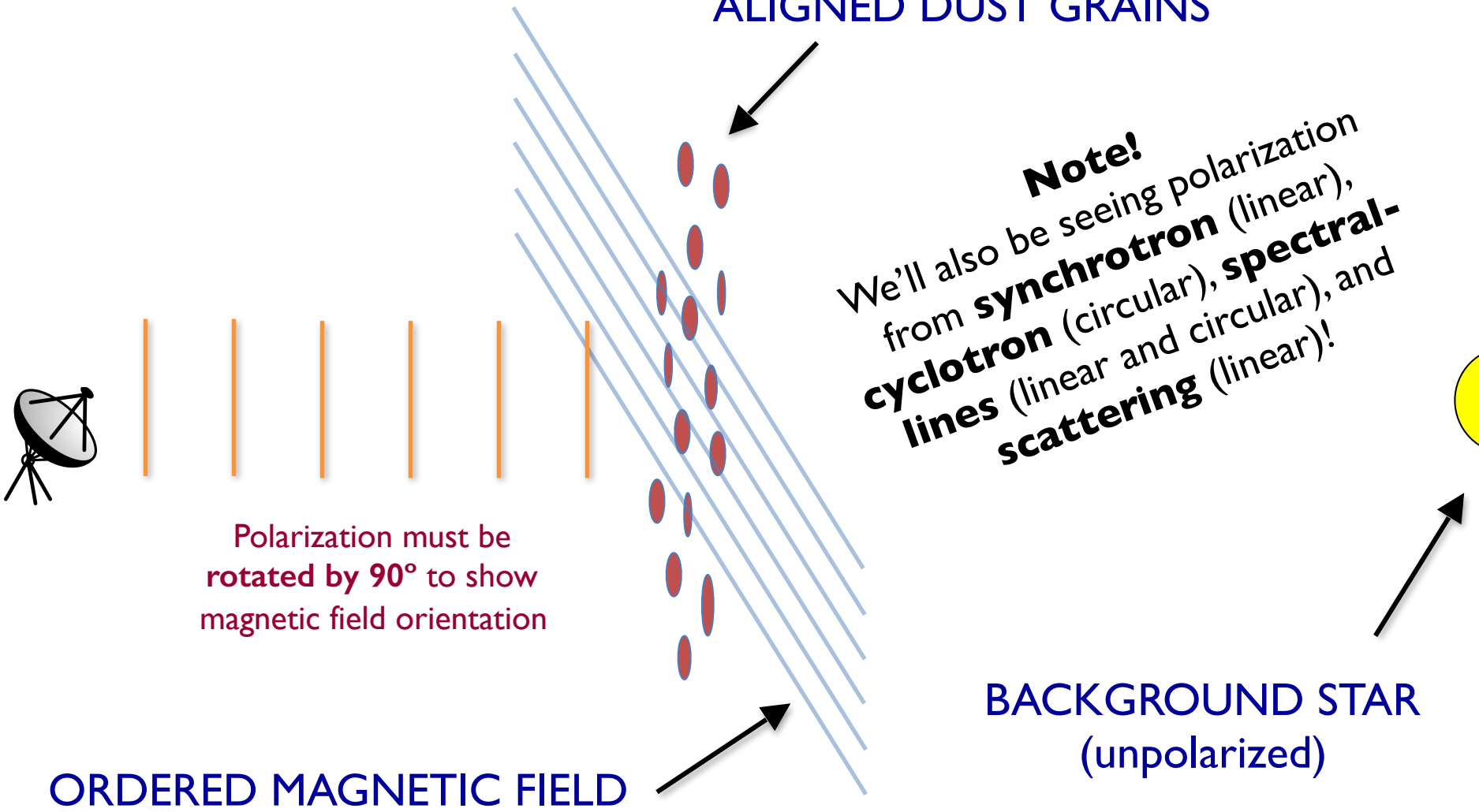


It *actually* all began with BIMA, CARMA and the SMA

Polarization (dust absorption)



Polarization (dust emission)



CARMA

Combined Array for Research in Millimeter-wave Astronomy

Consortium: Berkeley, Caltech, Illinois, Maryland, Chicago

Photo credit: C. Hull

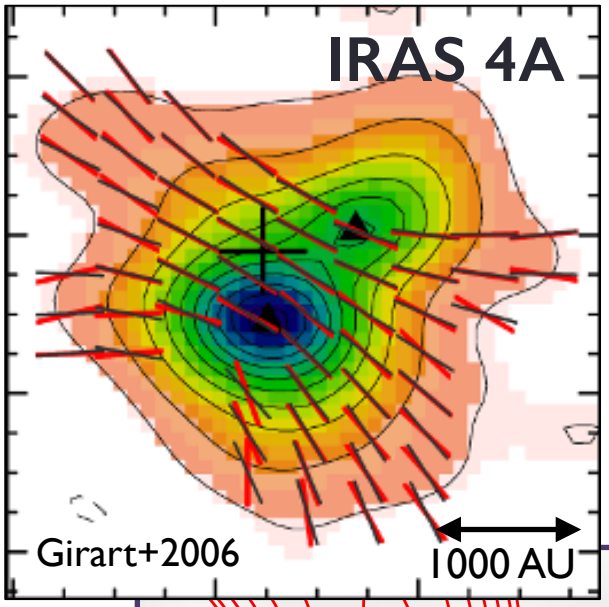
- 6 ×10-m, 9 × 6-m, and 8 × 3.5-m telescopes
- Observations at 1 cm, 3 mm, and **1 mm (polarization!)**
- Was located in Cedar Flat, CA (near Bishop)

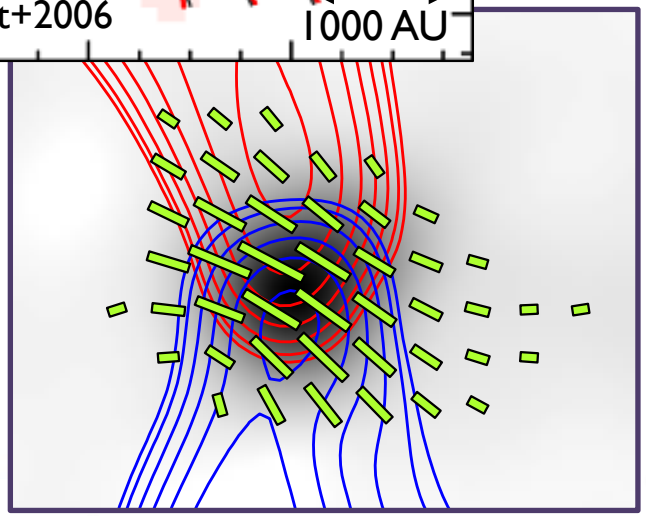
← This is me installing a 1 mm polarization receiver between 2010 and 2012

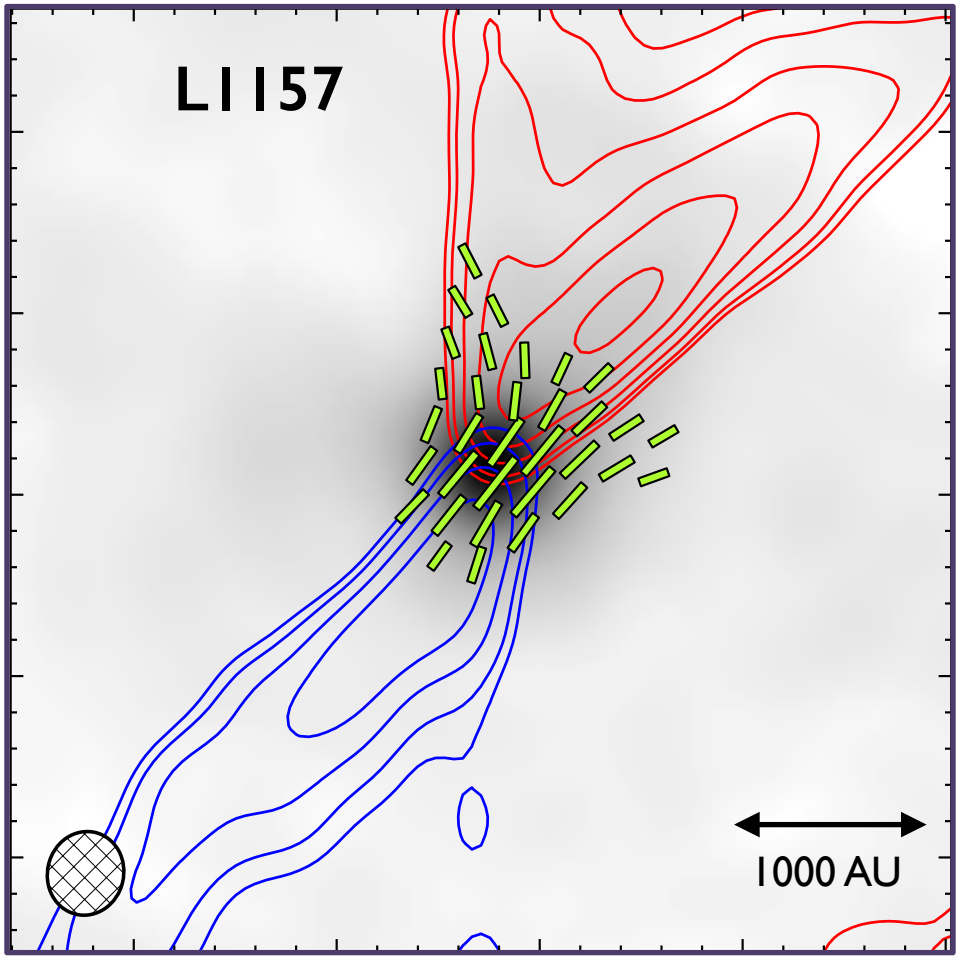
The Submillimeter Array (SMA)

Photo credit: C. Hull

State of affairs before Cycle 2 (low-mass)



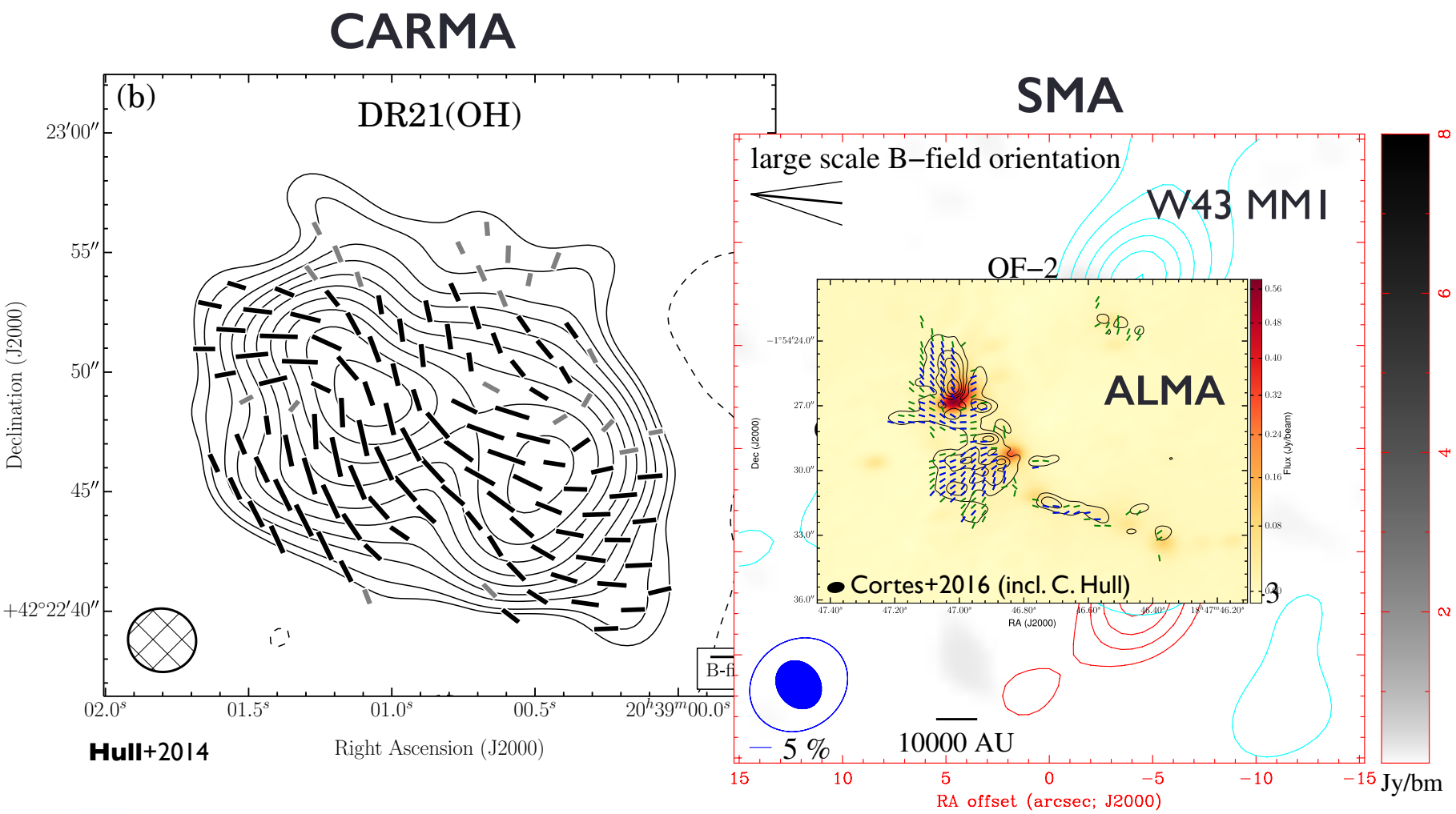




Hull+2014, TADPOL survey

See also Stephens+2013 (incl. C. Hull)

State of affairs before Cycle 2 (high-mass)

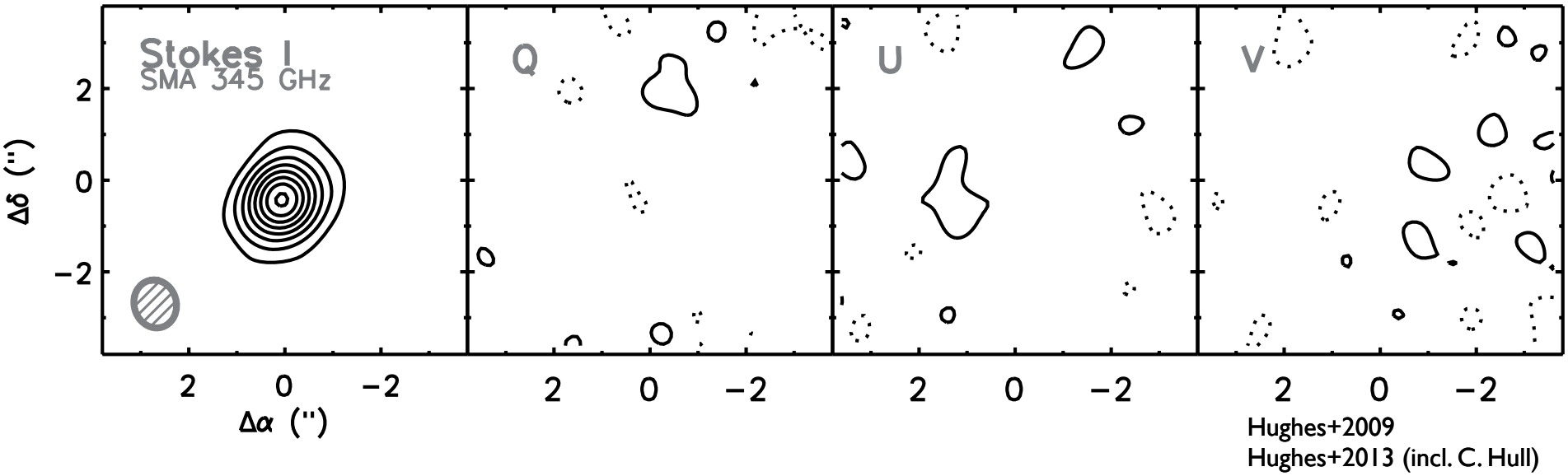


For a review of SMA polarization studies of high-mass tars, see Zhang+2014

State of affairs before Cycle 2 (disks)

No polarization in HD 163296…

…or TW Hya, DG Tau, MWC 480, or GM Aur



Hughes+2009
Hughes+2013 (incl. C. Hull)

Then came ALMA


ALMA
Photo credit: C. Hull

Image credit: Dana Berry, NRAO/AUI/NSF
Press release: public.nrao.edu/news/2017-alma-serp/

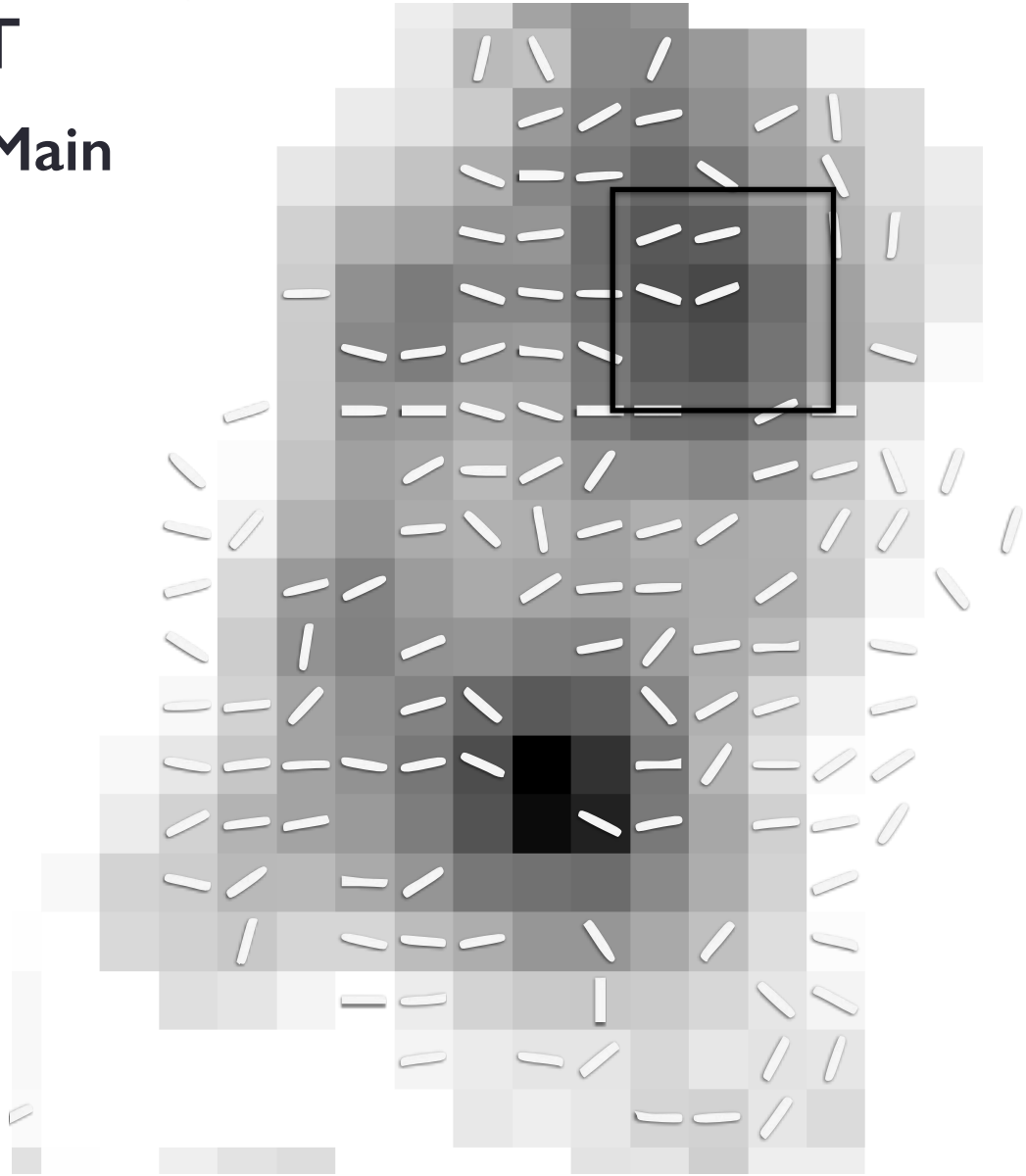
The ALMA era

Low-mass protostars

Ser-emb 8: a source with a chaotic magnetic field

JCMT

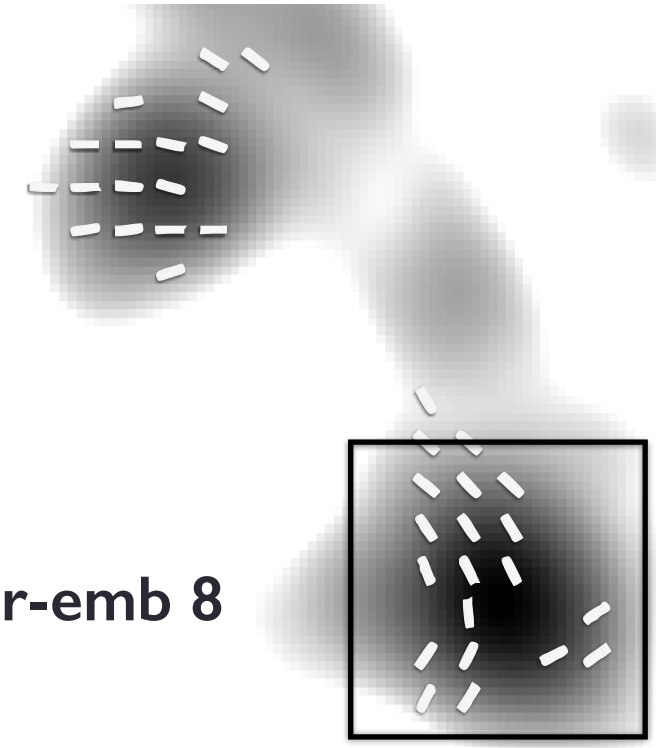
Serpens Main



85,000 AU

Hull, Mocz, Burkhart+2017 (data from Matthews+2009)

CARMA

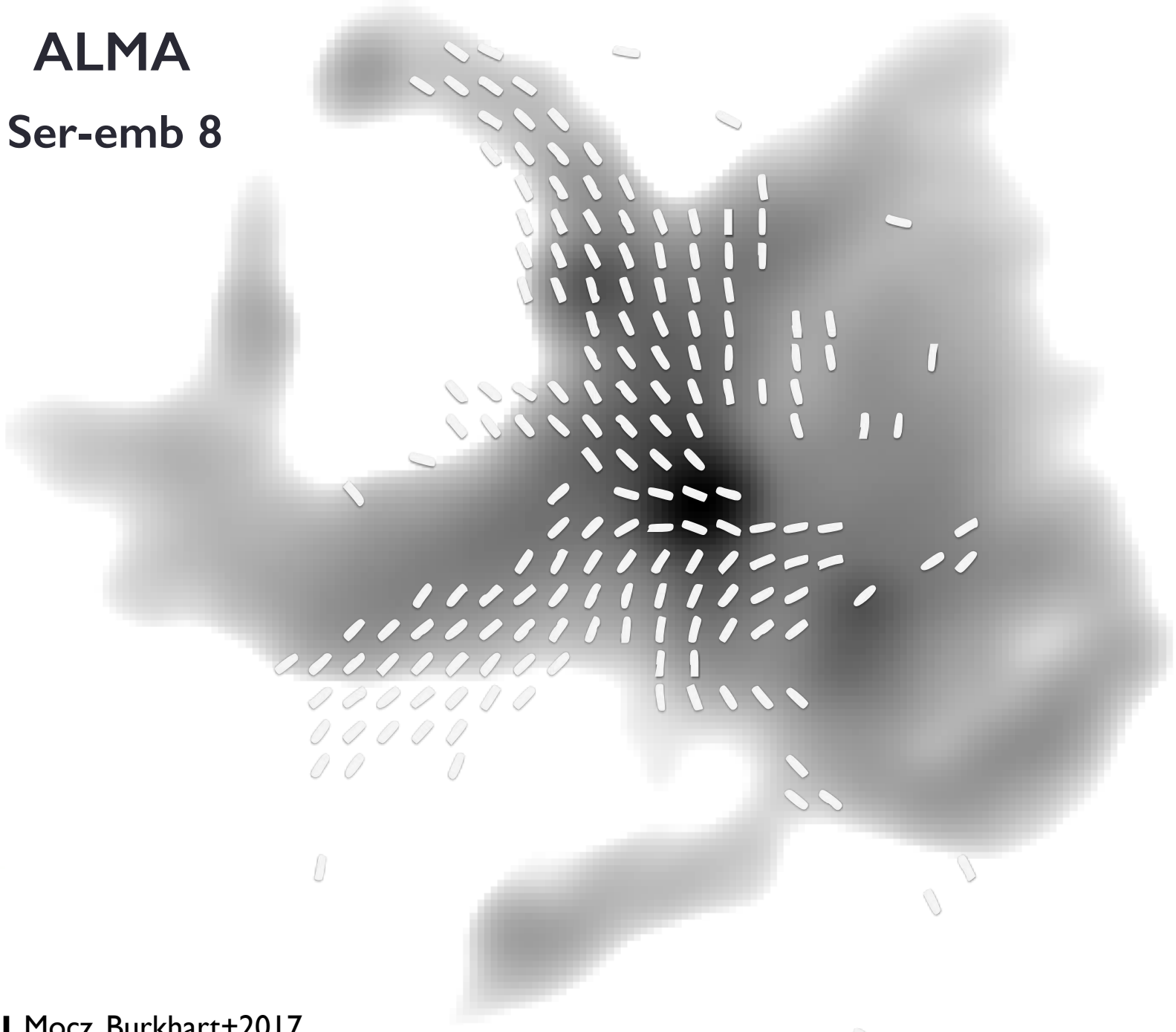


15,000 AU

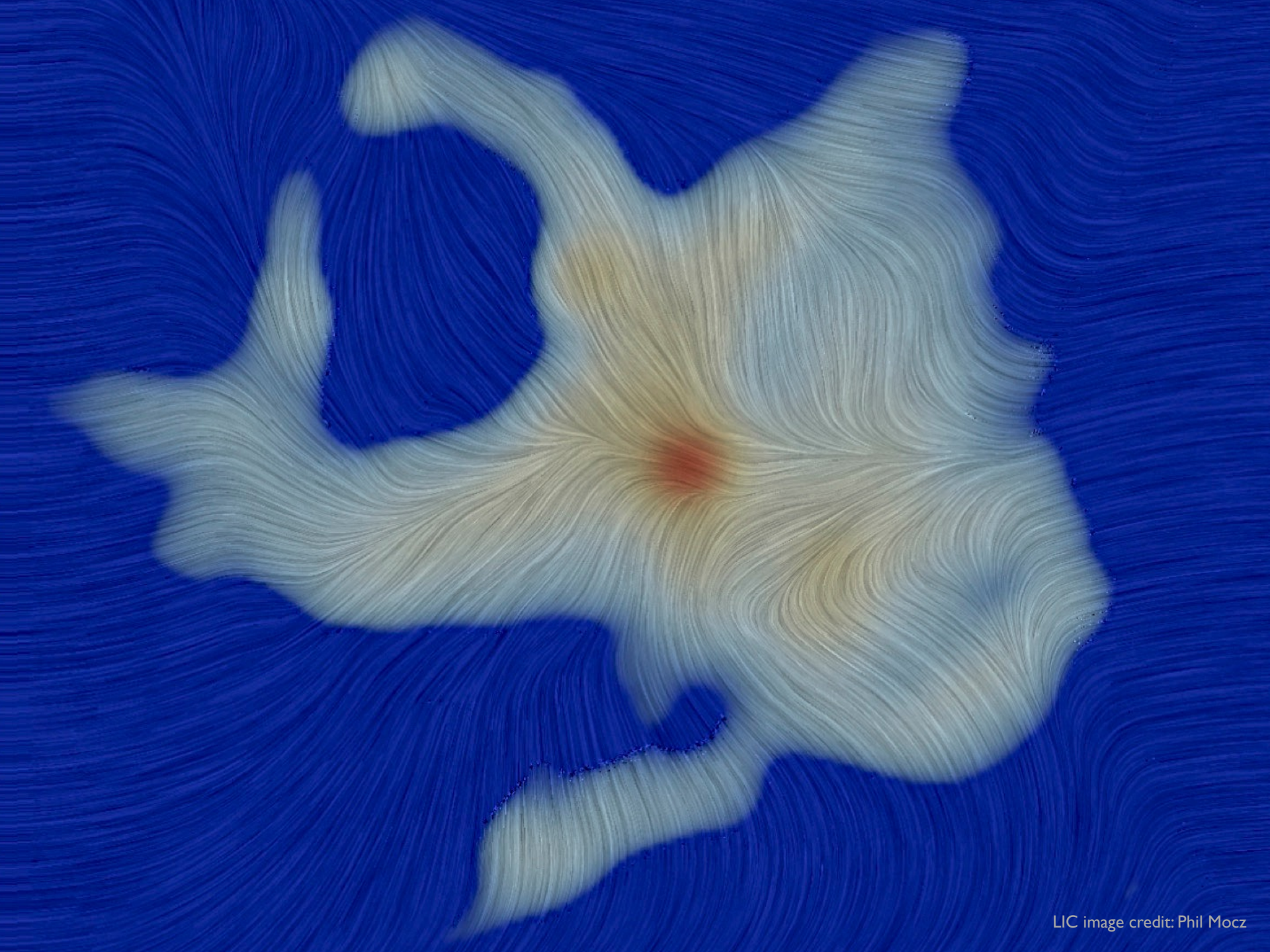
Hull, Mocz, Burkhart+2017 (data from Hull+2014)

ALMA

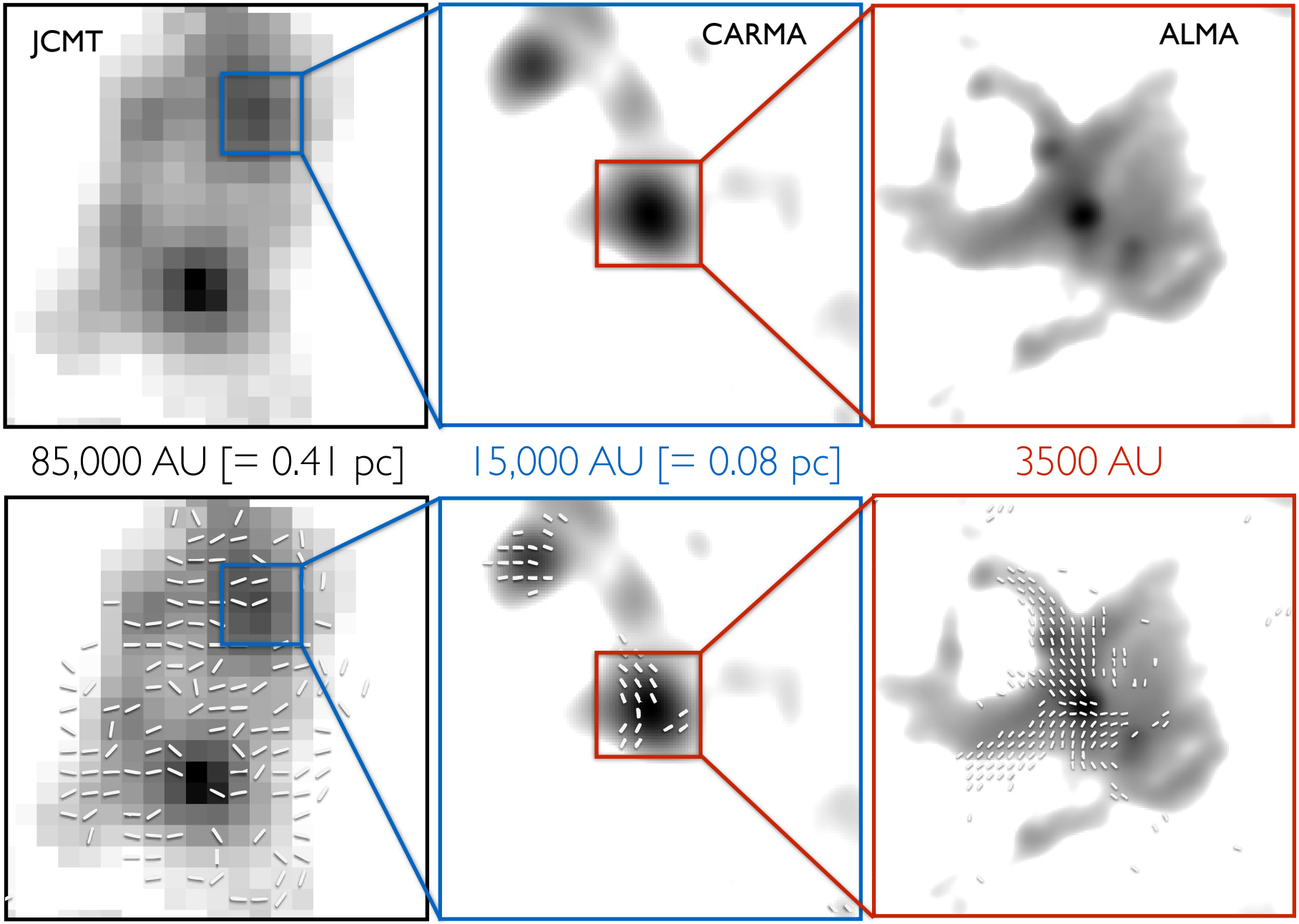
Ser-emb 8



Hull, Mocz, Burkhart+2017



LIC image credit: Phil Mocz

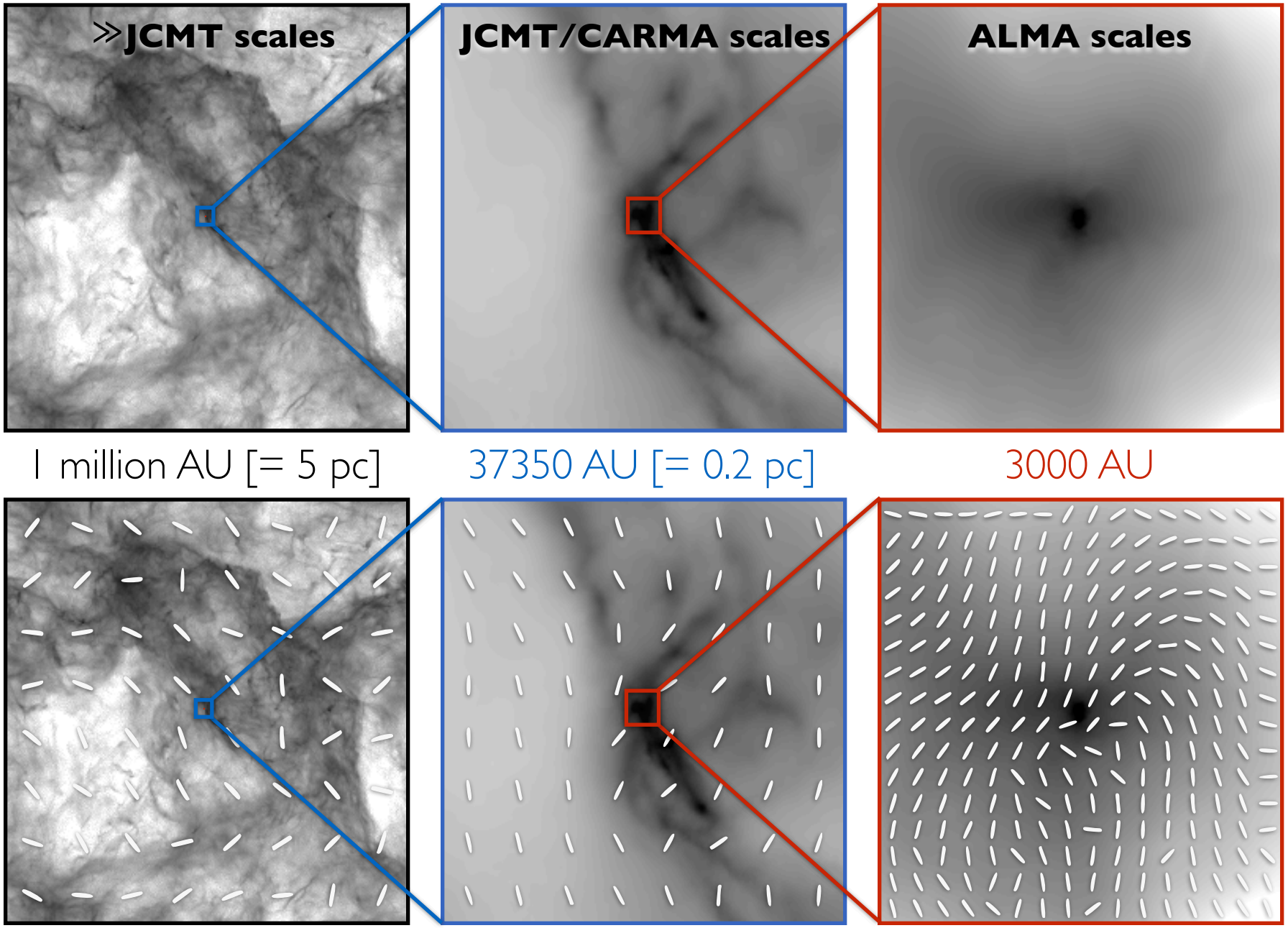


Hull, Mocz, Burkhart+2017

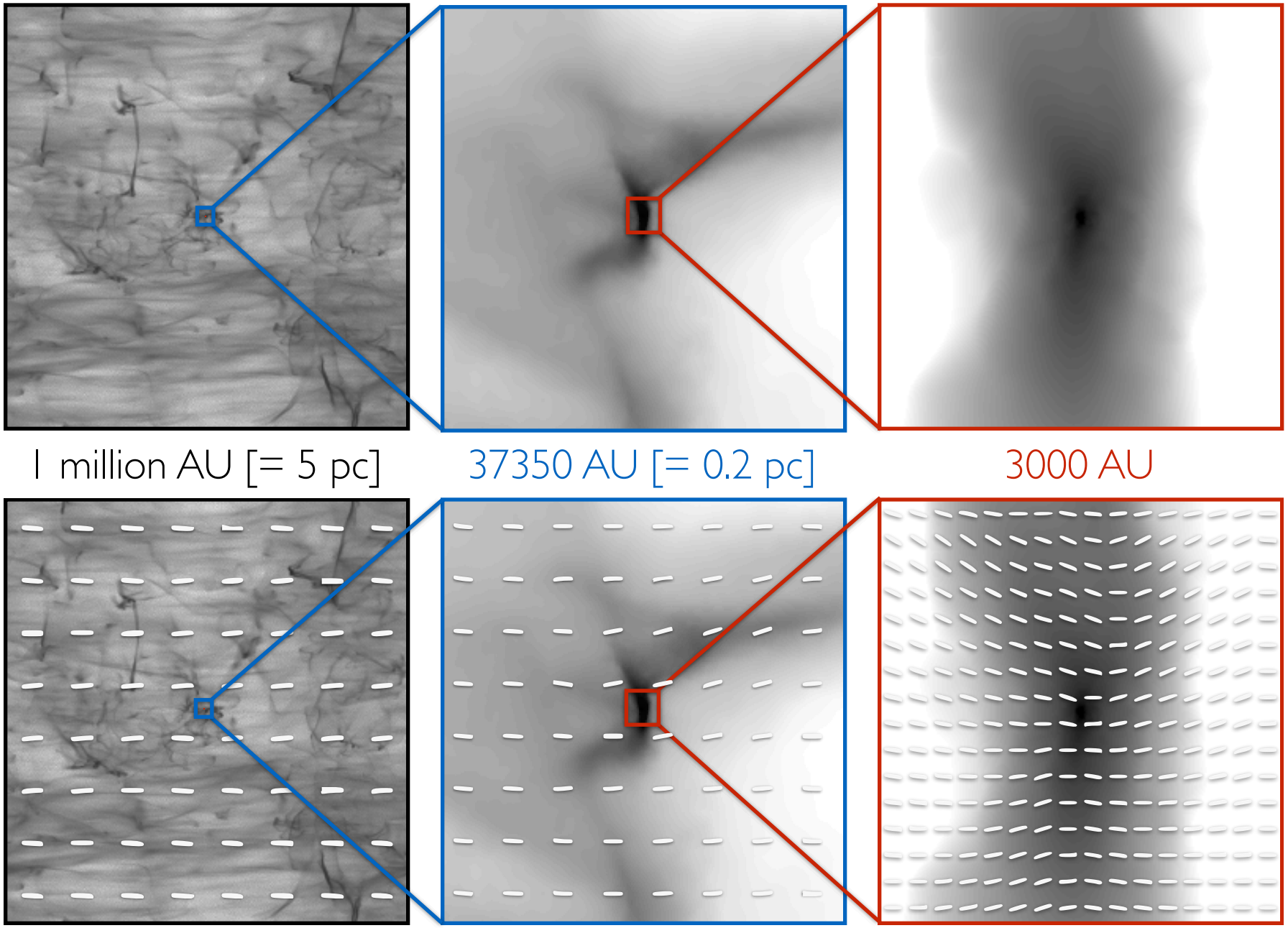
Keep an eye on the magnetic field strength here (in microgauss)

AREPO simulations

B=1



Hull, Mocz, Burkhart+2017



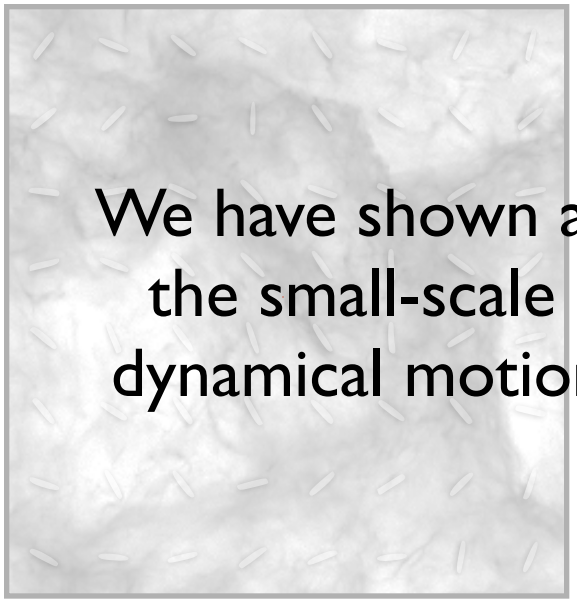
Hull, Mocz, Burkhart+2017

A statistical comparison shows that the ALMA observations best match the *weakly* magnetized simulations

1 million AU [= 5 pc]

37350 AU [= 0.2 pc]

3000 AU



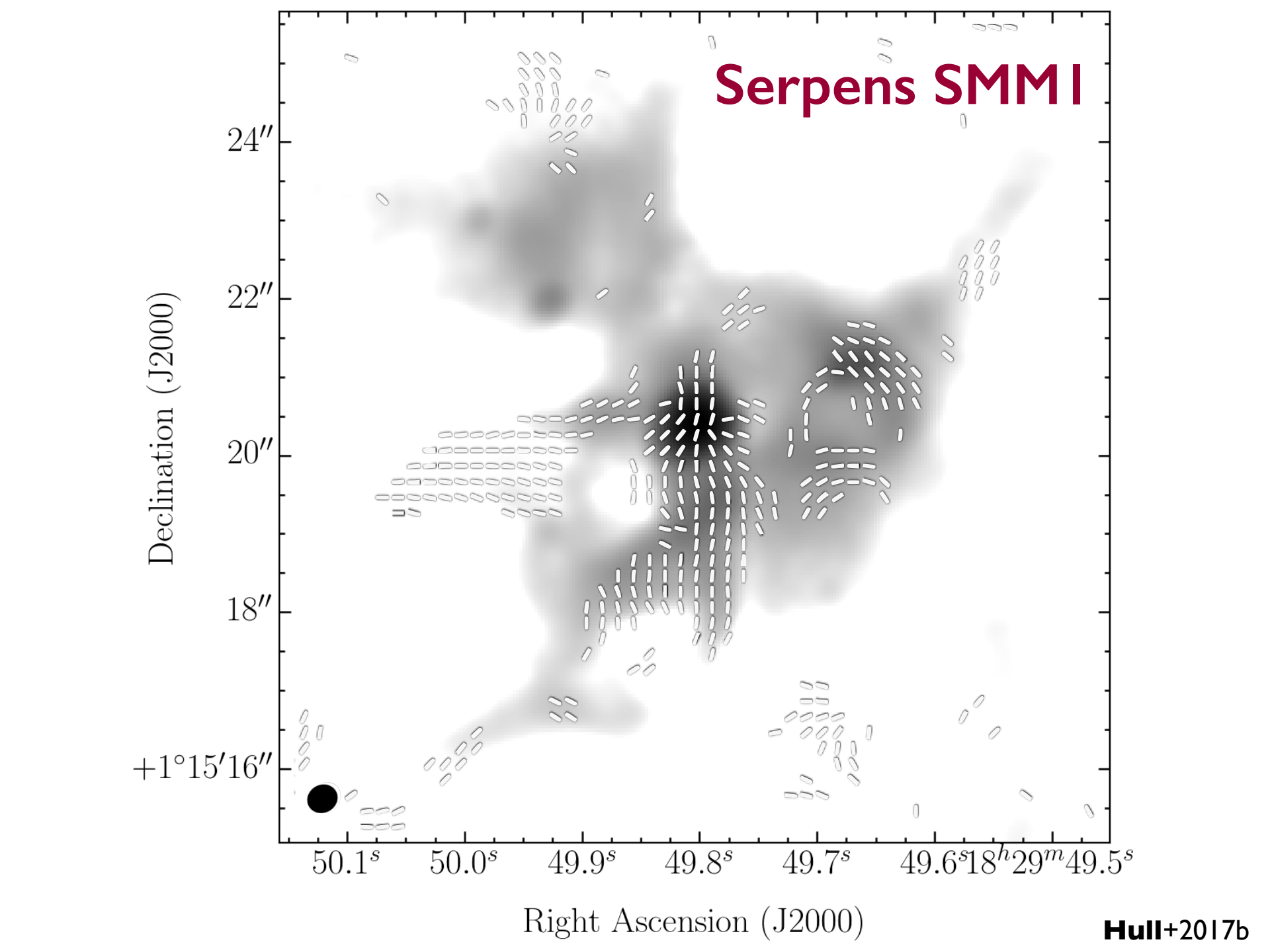
We have shown an alternate mode of star formation where the small-scale magnetic field morphology is dictated by dynamical motions (e.g., turbulence) and **not** by the large-scale magnetic field

Hull, Mocz, Burkhart+2017

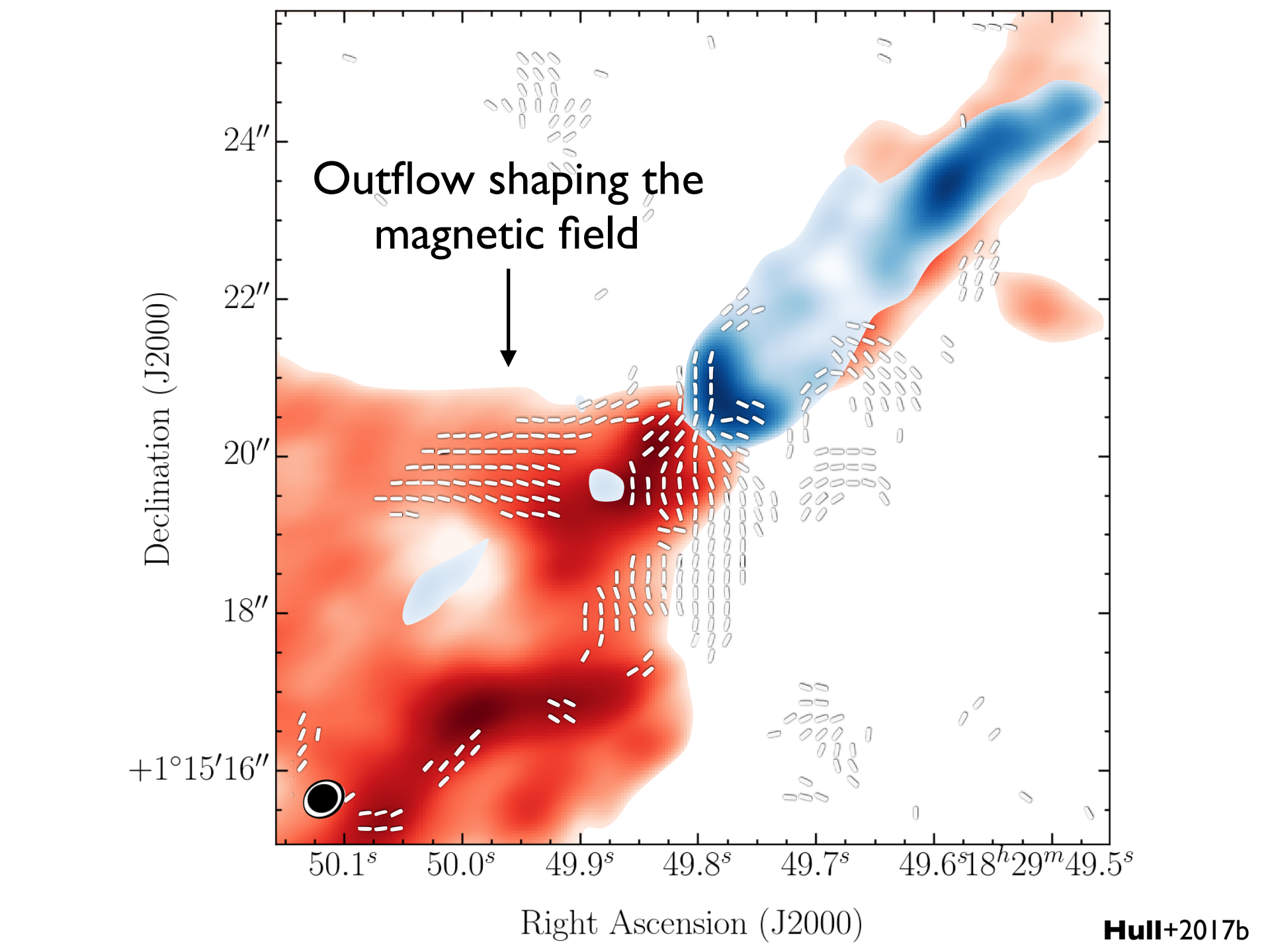
The ALMA era

Low-mass protostars

Serpens SMM1: a source whose outflow shapes the magnetic field


Serpens SMM1
24″
22″
20″
18″
+1°15′16″
Declination (J2000)
50.1s
50.0s
49.9s
49.8s
49.7s
49.6s
18h29m49.5s
Right Ascension (J2000)

Hull+2017b


Outflow shaping the magnetic field
24″
22″
20″
18″
+1°15′16″
Declination (J2000)
50.1s
50.0s
49.9s
49.8s
49.7s
49.6s
18h29m49.5s
Right Ascension (J2000)

Hull+2017b

The ALMA era

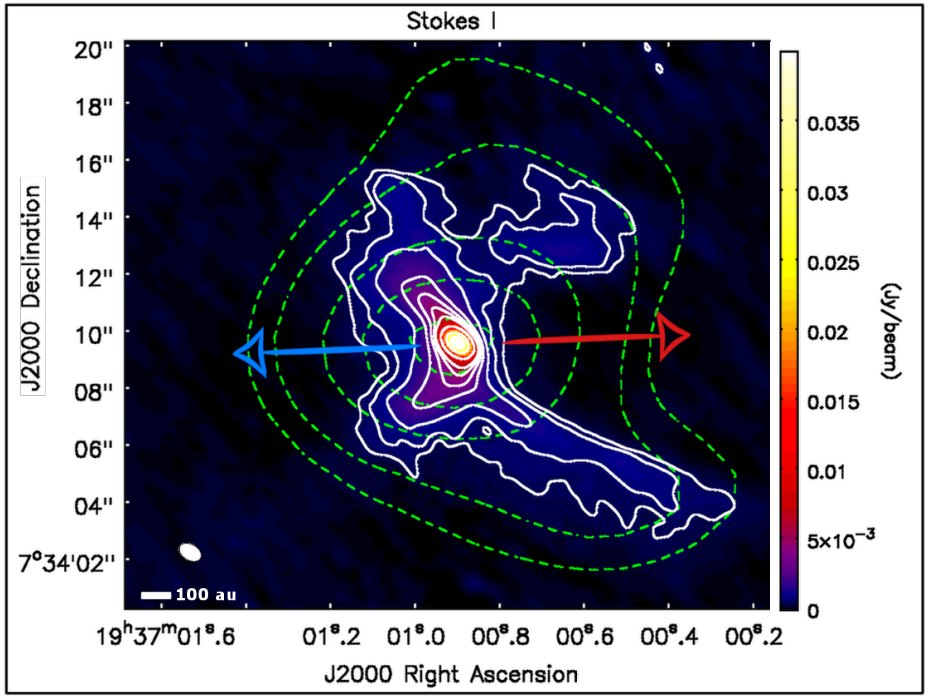
Low-mass protostars

B335: magnetic field shaped by outflow and possible infall

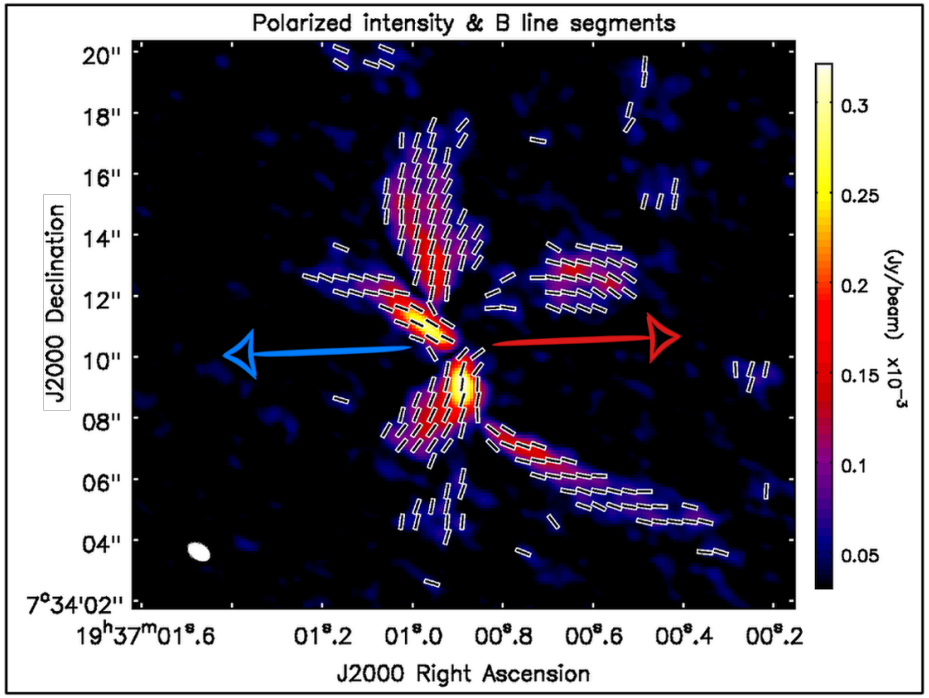
B335: magnetic field shaped by infall & outflow

New ALMA observations of B335, an embedded, low-mass, Class 0 protostar with a magnetic field that lies along both the *outflow cavity* as well as the *dense equatorial plane*

Total intensity



Magnetic field



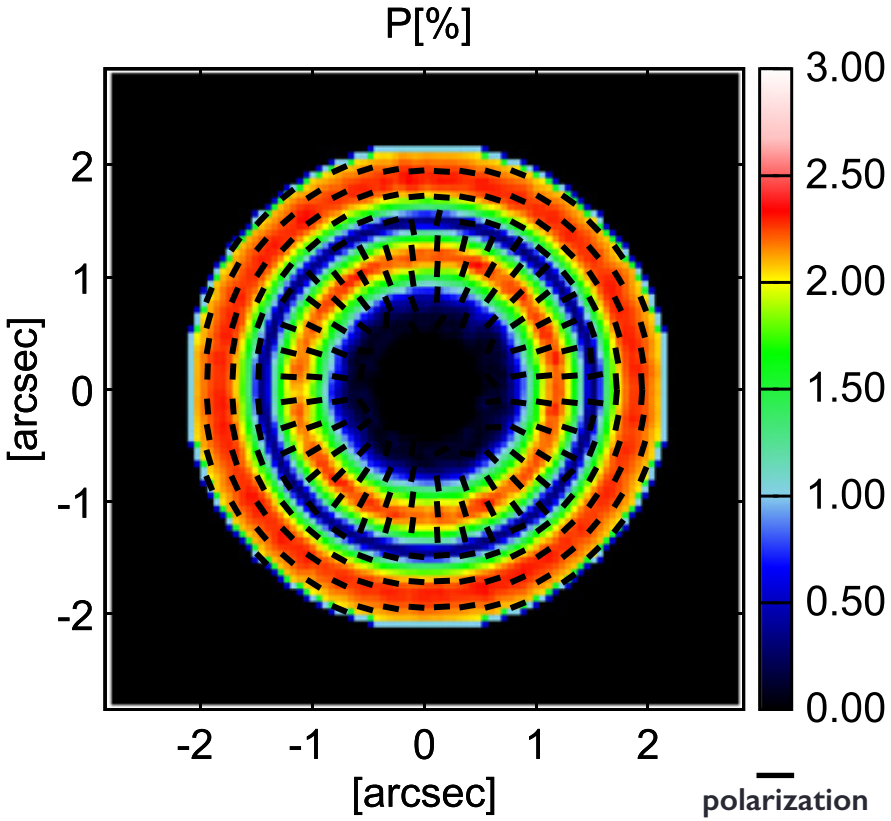
Maury+2018

The ALMA era

Disk polarization

Polarization from mm-wave scattering

High optical depth at high resolution could lead to polarization from self-scattering by large dust grains

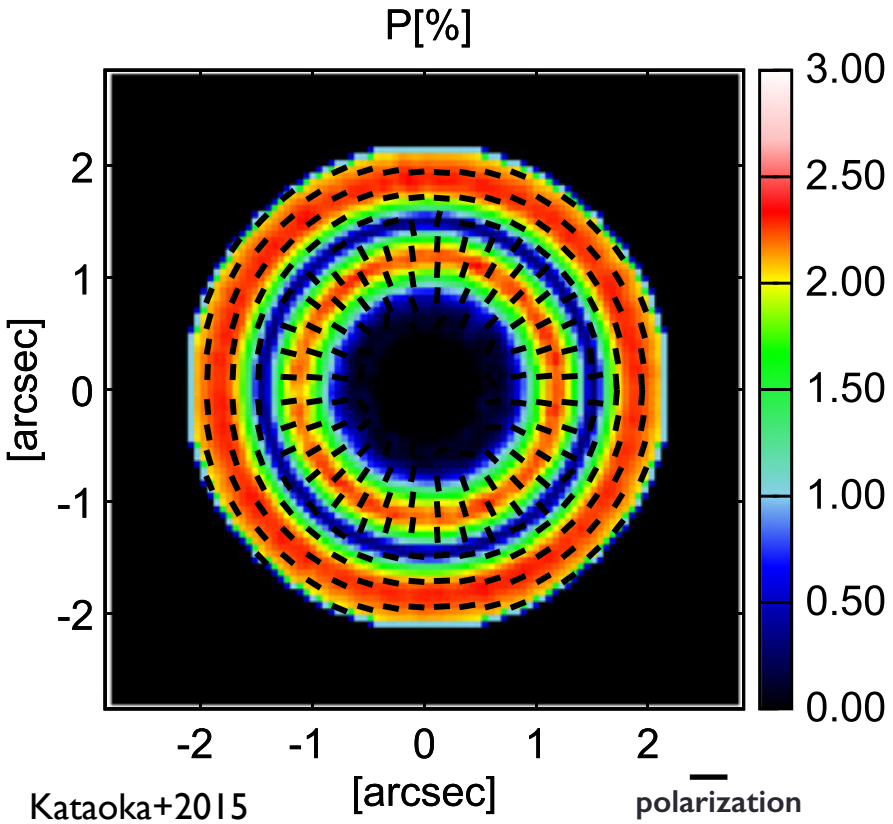


Kataoka 2015
See also Kataoka 2016a, 2016b

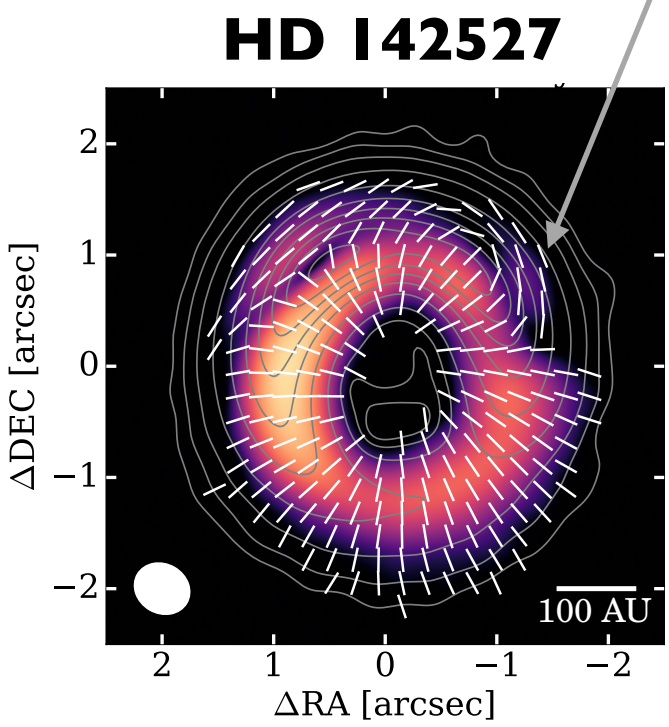
Polarization from mm-wave scattering

Comparison of model & data

E-field polarization,
not inferred magnetic fields

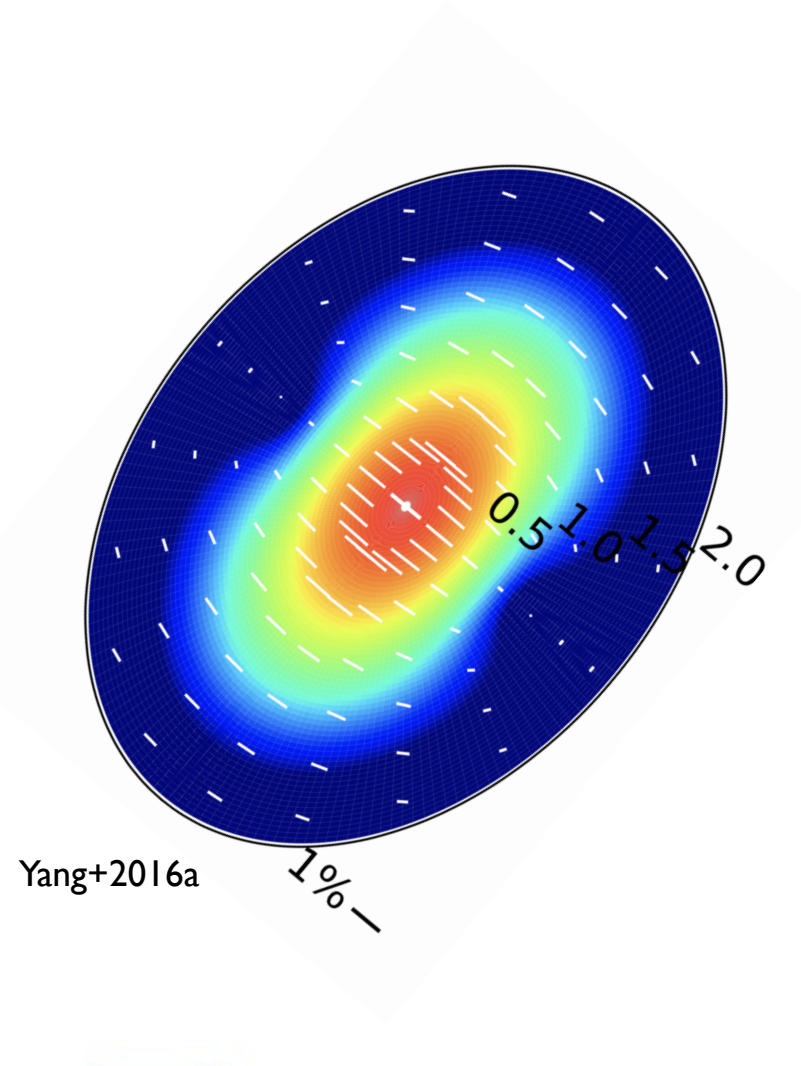


Kataoka+2015

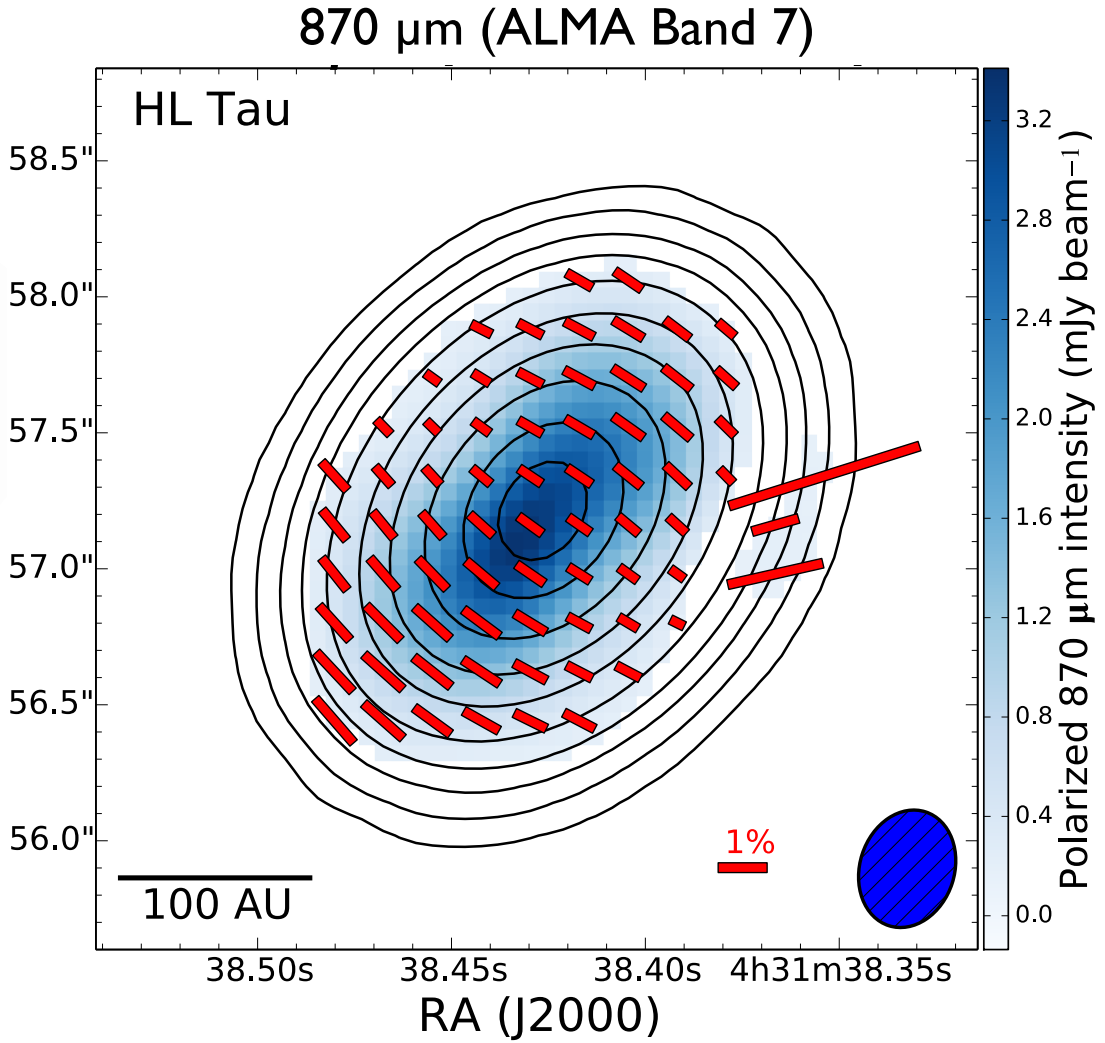


Kataoka+2016b

ALMA 870 μm HL Tau polarization

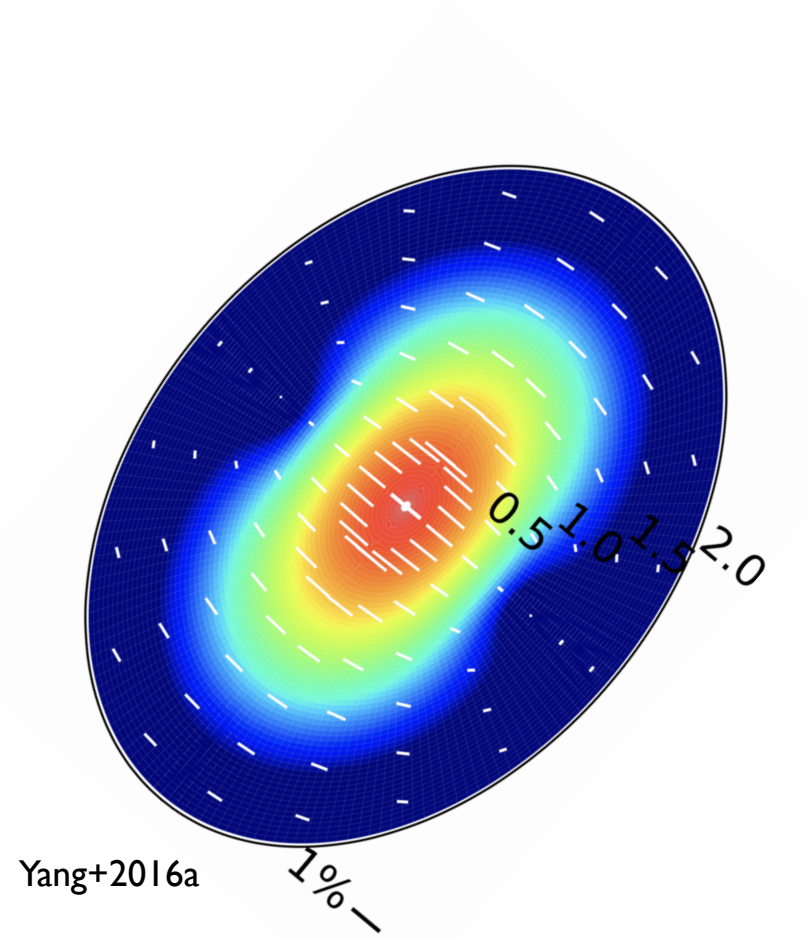


Yang+2016a



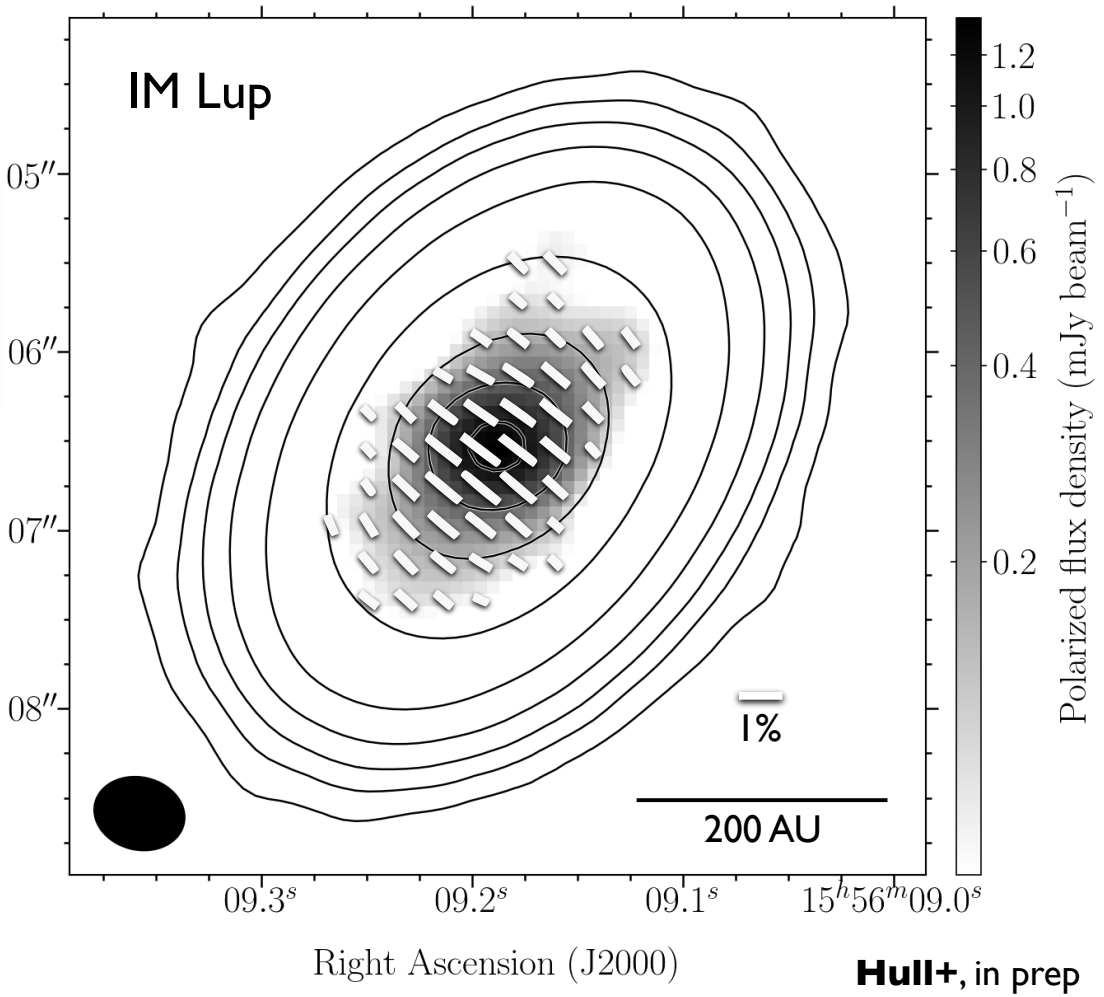
Stephens+2017b (incl. **C. Hull**)

ALMA 870 μm IM Lup polarization



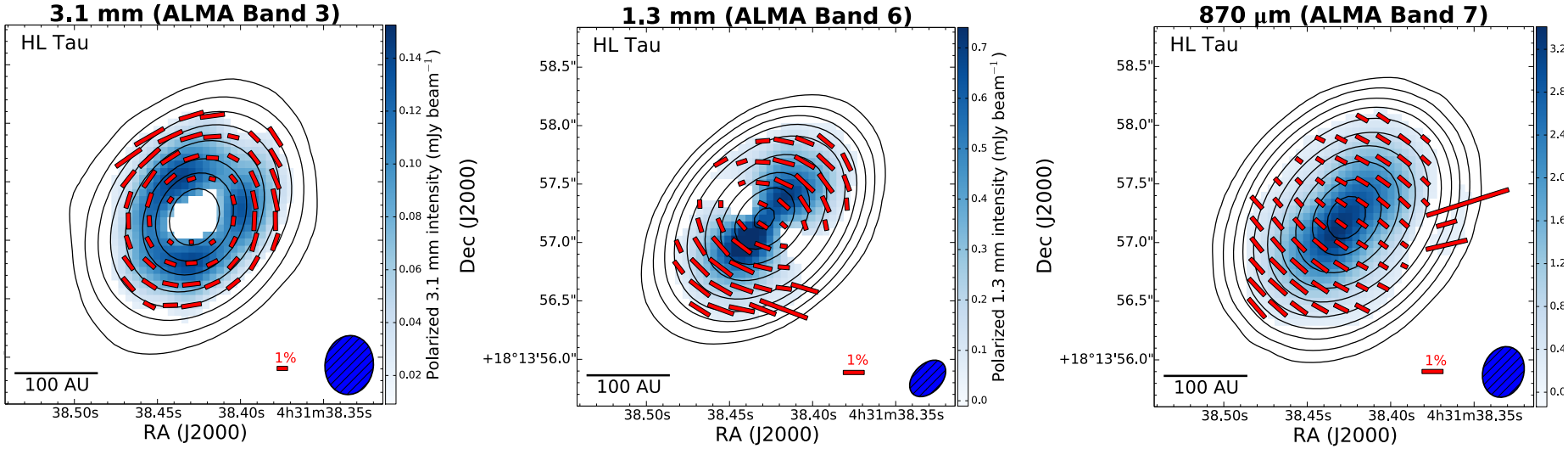
Yang+2016a

870 μm (ALMA Band 7)



Hull+, in prep

ALMA multi-wavelength HL Tau polarization



Stephens+2017b (incl. **C. Hull**)

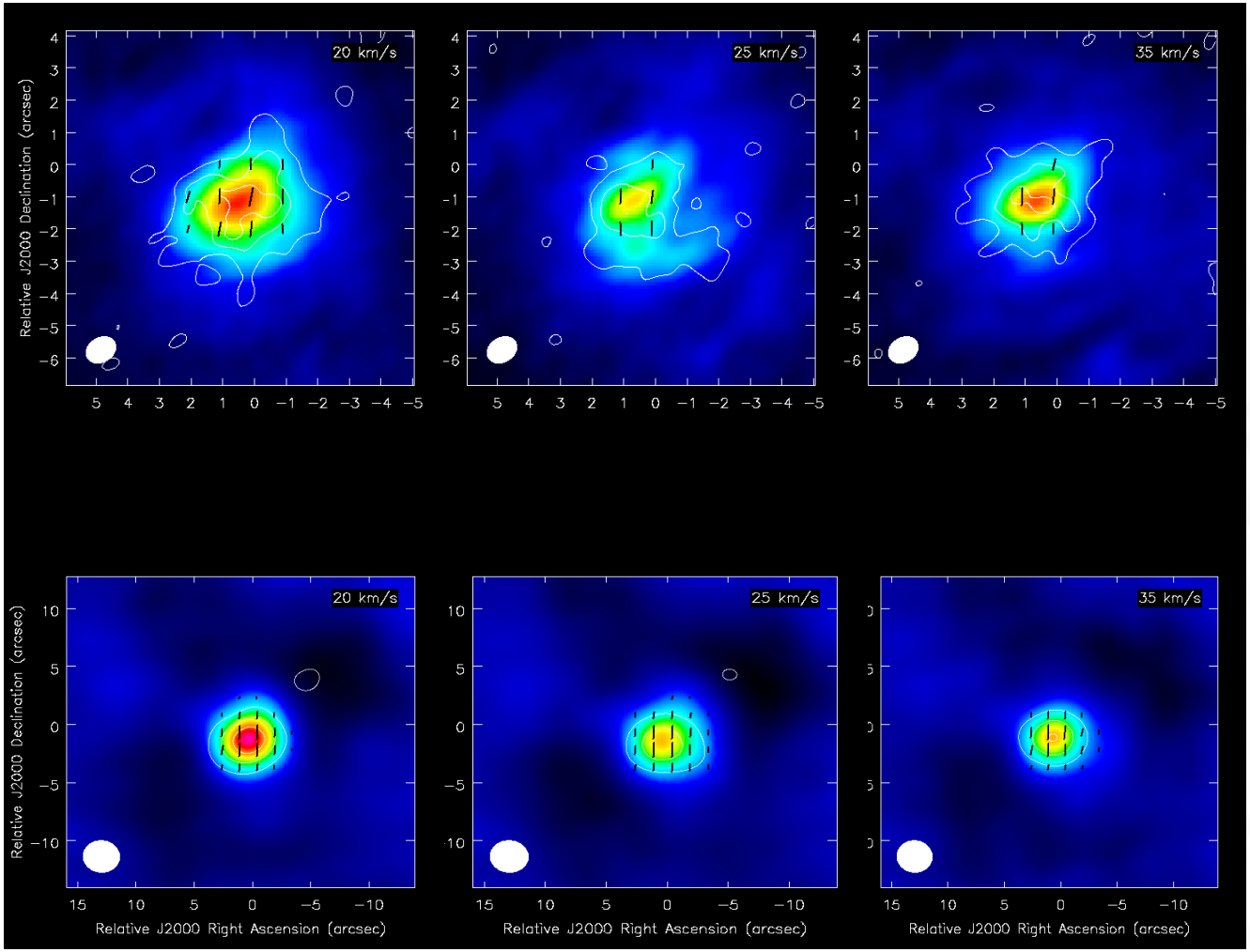
The ALMA era

Spectral-line & circular polarization

Spectral-line polarization: IK Tau

SMA

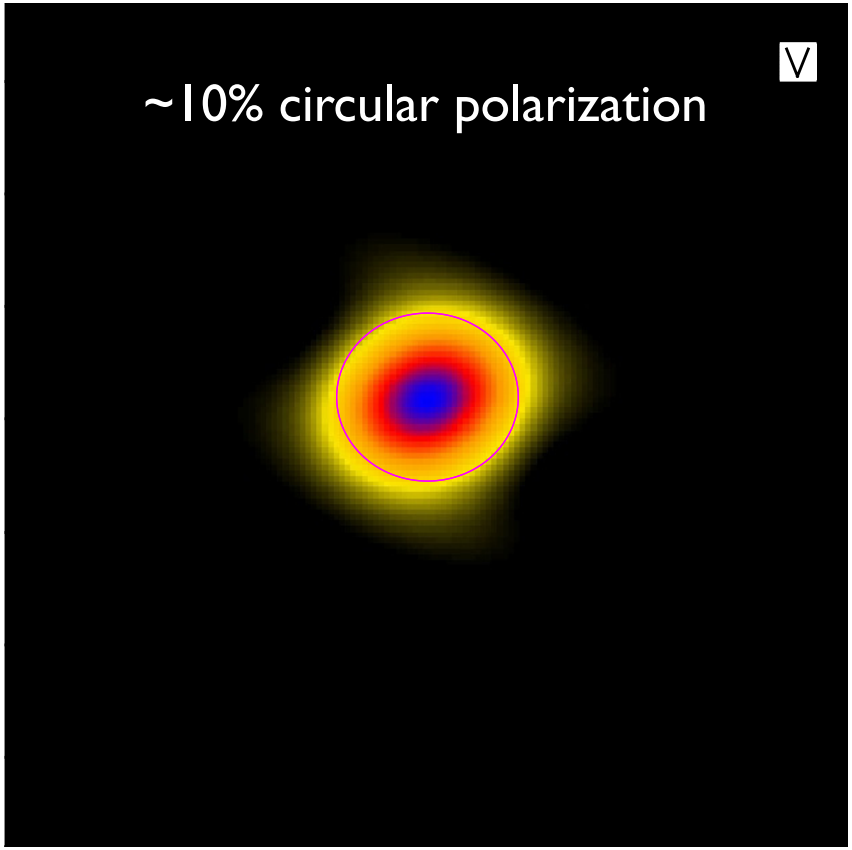
ALMA

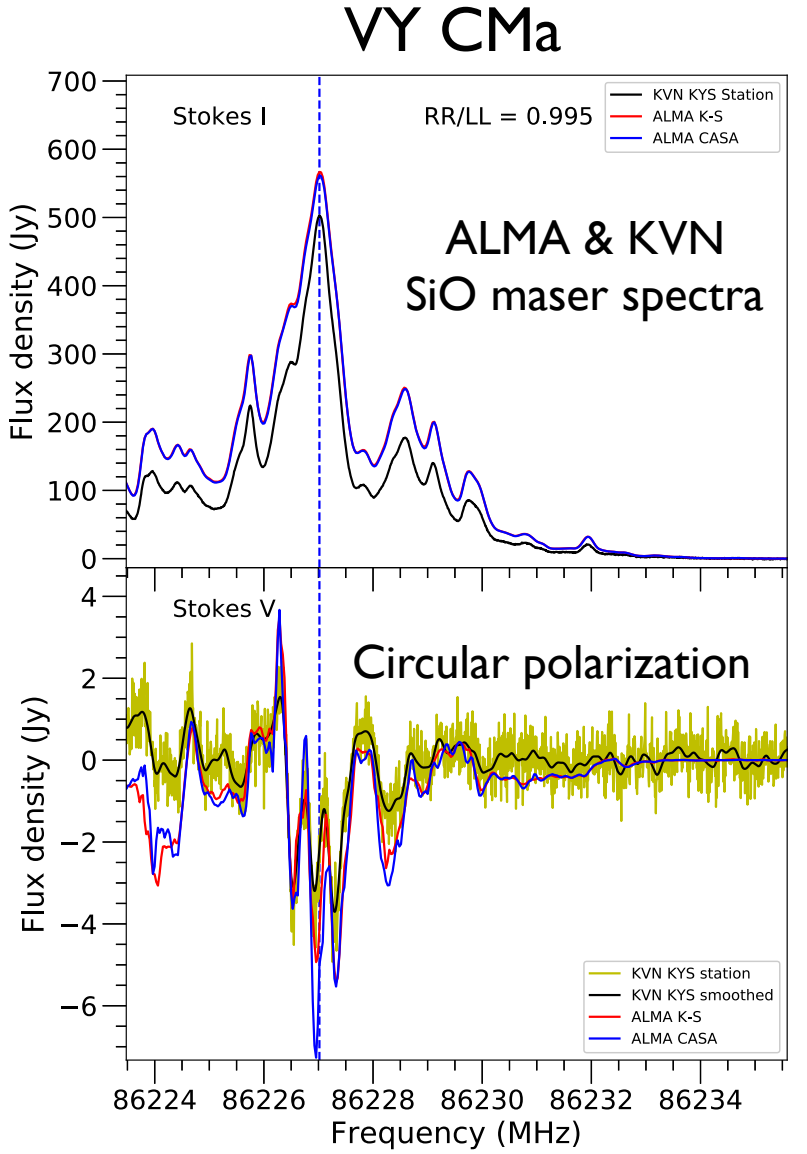


Cortés+2015, ALMA EOC memo

Circular polarization

Circularly polarized star





See also Vlemmings+2018

Cortés+2017 (incl. C. Hull), ALMA EOC memo

Summary

- ALMA is confirming previous observations, and taking it to the next level with dramatic increases in sensitivity and resolution
- Progress in all areas of polarimetry: continuum & spectral-line; circular & linear; thermal & non-thermal; and beyond
- Opening new windows into our understanding not only of magnetic fields, but of dust scattering and other types of grain alignment
- The polarized universe is bright!

Fin