An overview on BISTRO and Polarization measurements in Oph-B (I Gen.)

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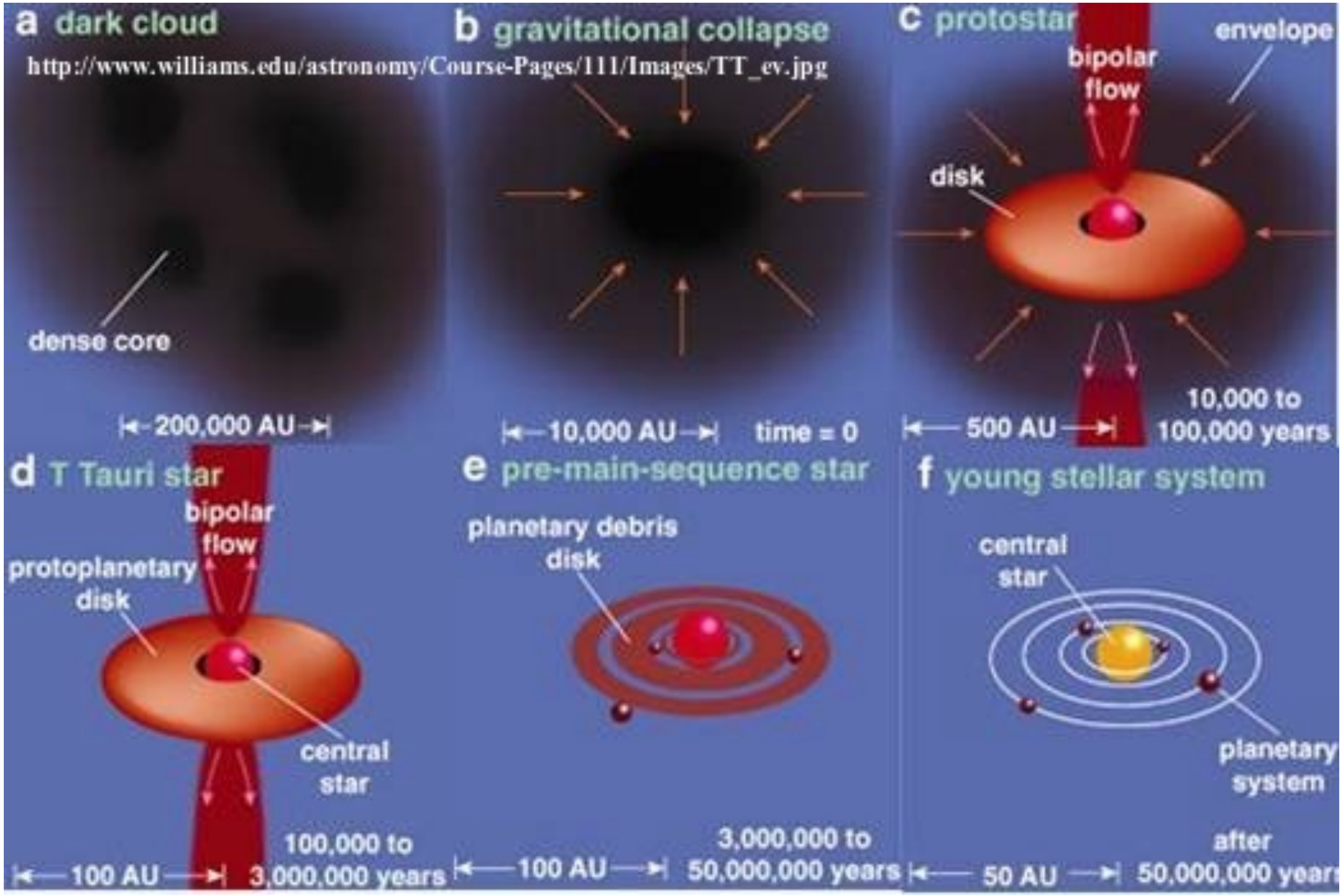
(Virtual)

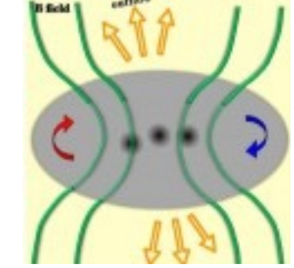
Current scenario of star formation

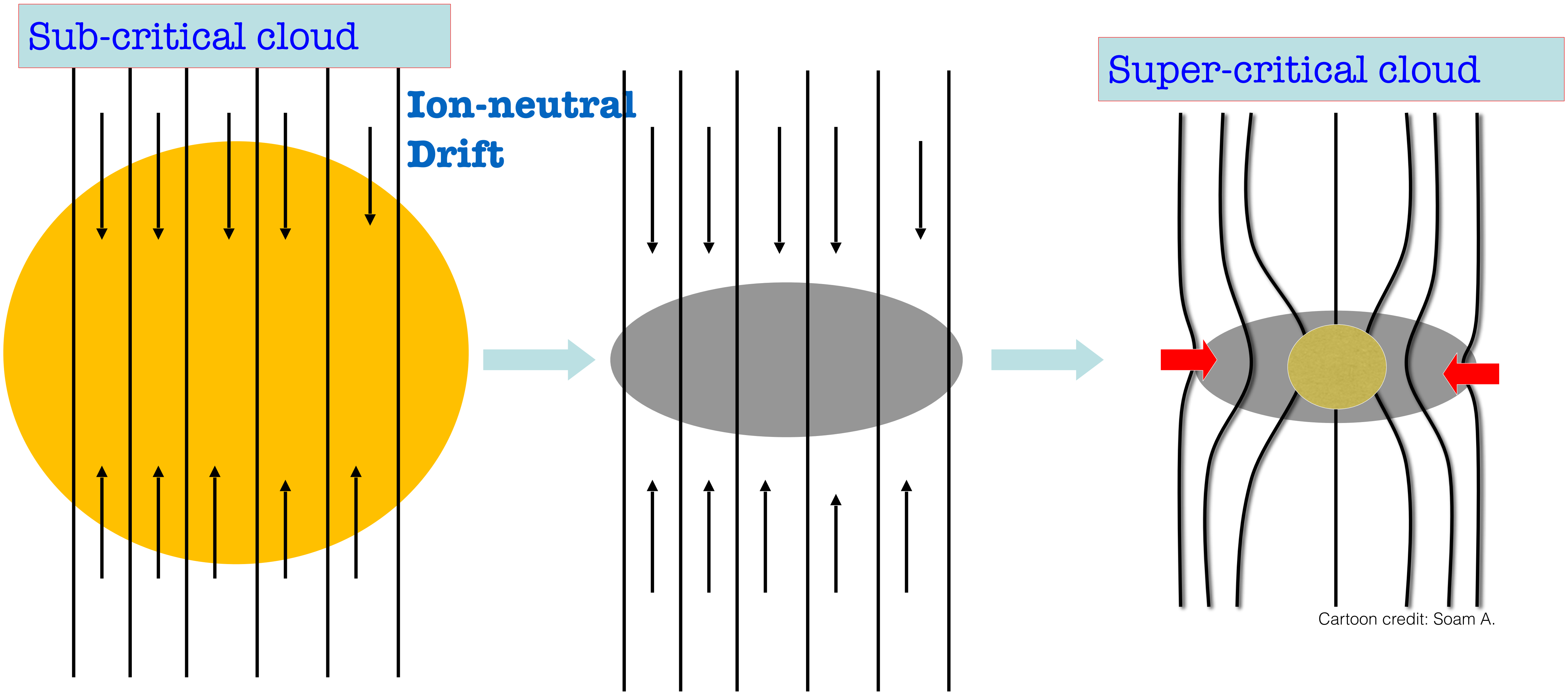


Potential sites

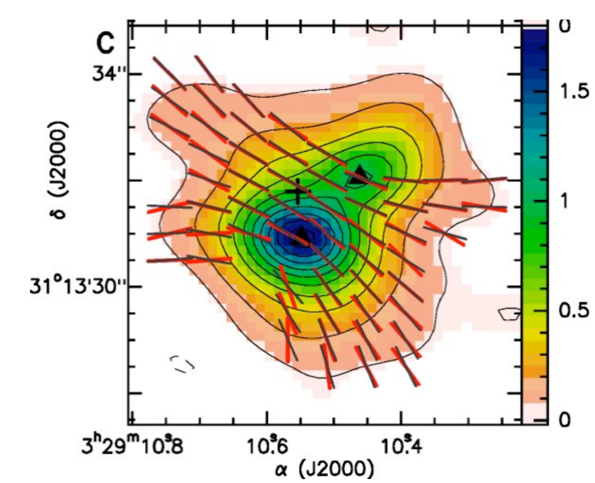
Star-formation is a complicated process of converting almost some vacuum ISM to high density prestellar to protostellar core

Magnetic fields are important





- Magnetic field found parallel to the minor axis of the cloud.
- Magnetic field lines are found pinched and smoothly distributed
- With the advent of ALMA, several observational evidences of pinched morphology are available now

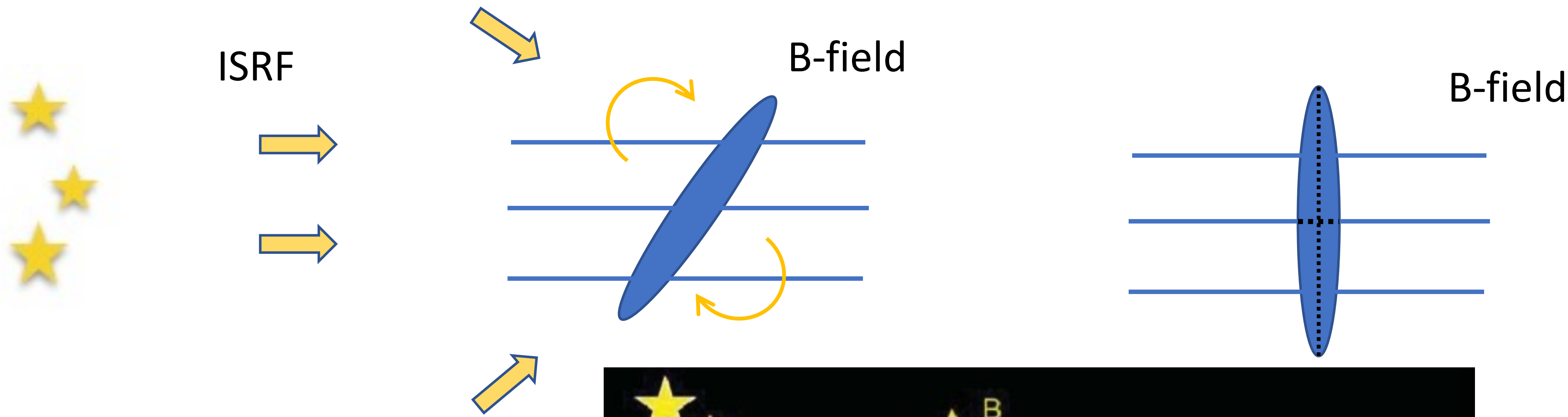


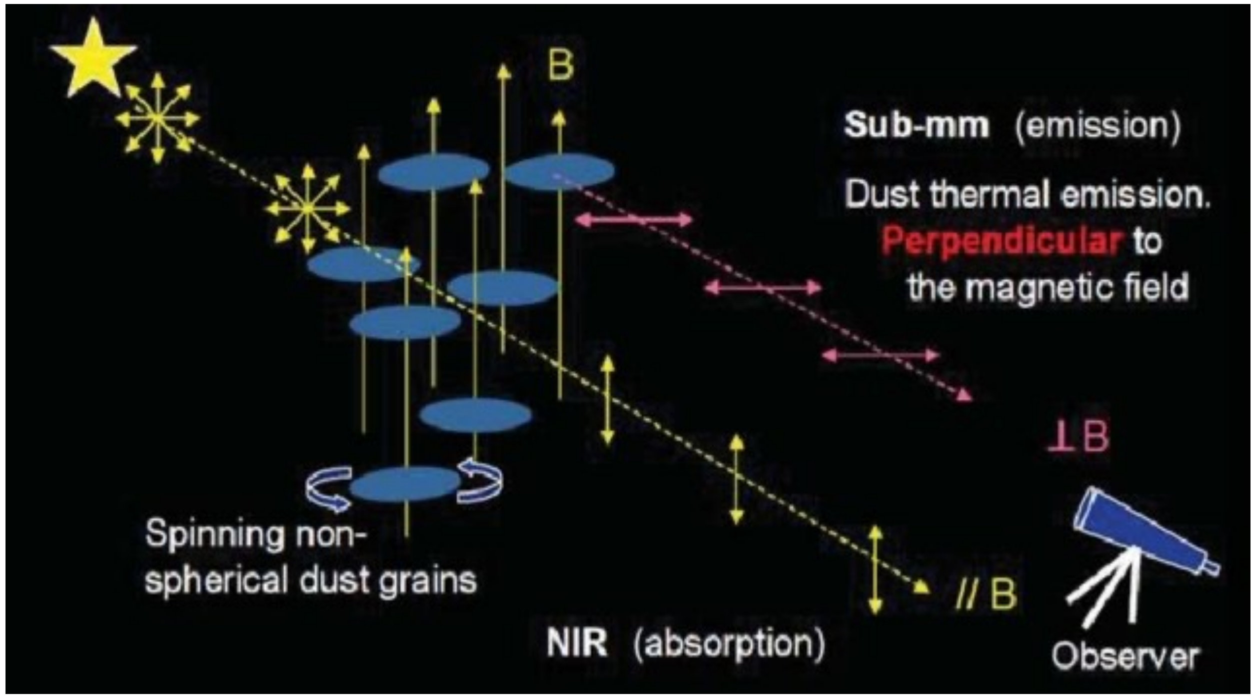
Girart, Josep M., 2006, Sci, 313, 81

Q. How to interpret interstellar magnetic fields?

A. Polarization of starlight

Anisotropic radiation field with $\lambda < 2a$ can help aligning *asymmetric* dust grains via radiative torque alignment (RAT; Dolginov & Mitrofanov in 1976, Draine & Weingartner 1996, Lazarian & Hoang 2007).





For details see, Andersson, Lazarian, Vaillancourt, 2015, ARAA

We estimate Stokes parameters Q, and U from observed fluxes and P and theta are estimated from Q and U

$$Q, U = \frac{\frac{I_e(\alpha)}{I_o(\alpha)} - 1}{\frac{I_e(\alpha)}{I_o(\alpha)} + 1} \qquad P = \frac{1}{I}\sqrt{Q^2 + U^2} \quad \theta = \frac{1}{2}\tan^{-1}\left(\frac{U}{Q}\right)$$

BISTRO

B-field In STar-forming Region Observations

"Taking the challenge of understanding magnetic personality of the Universe"

The BISTRO Survey: Overview

- A James Clerk Maxwell Telescope (JCMT) Large Program mapping Galactic star-forming regions in 850μm and 450μm polarized light with the POL-2 polarimeter

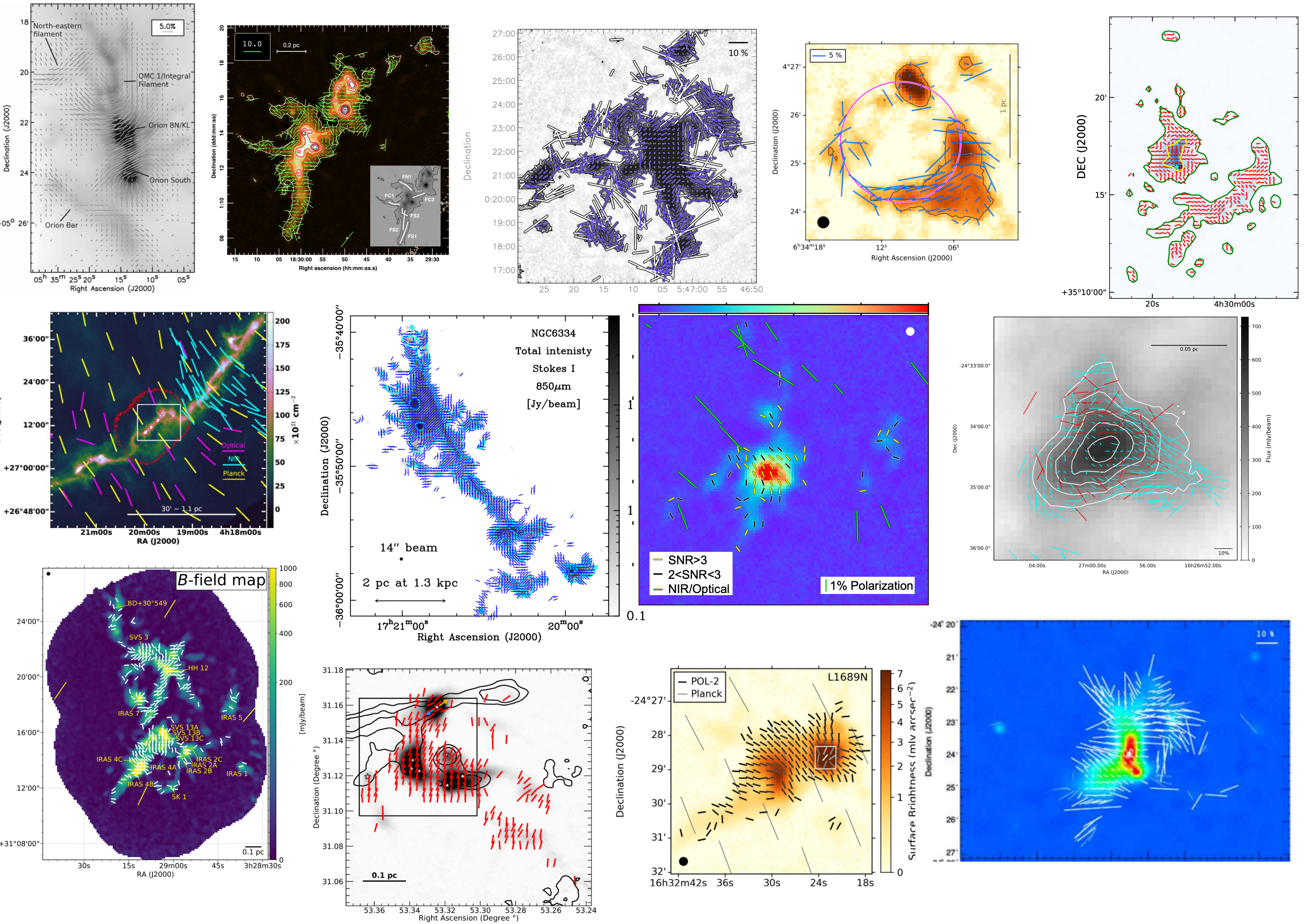
- ~180 survey members across 7 partner regions and the East Asian Observatory

- P.I.s: Derek Ward-Thompson (UK & Ireland), Pierre Bastien (Canada), Keping Qiu (China), Tetsuo Hasegawa (Japan), Woojin Kwon (Korea), Shih-Ping Lai (Taiwan)

- BISTRO-1, -2 and -3 awarded 672 hours of observing time to map:
  - Ophiuchus, Orion A & B, Perseus, Serpens, Taurus L1495/B211, Auriga, IC5146, M16, DR15, DR21, NGC 2264, NGC 6334, Mon R2, Rosette, various IRDCs, nearby prestellar cores and the Galactic Centre

Credit: Kate’s slides

Beauty of BISTRO



BISTRO Survey publications

22 refereed papers published to date...

Survey paper: Ward-Thompson et al. 2017, ApJ 842 66

Orion A: Pattle et al. 2017, ApJ 846 122
M16: Pattle et al. 2018, ApJL 860 L6
Ophiuchus A: J. Kwon et al. 2018, ApJ 859 4

Ophiuchus B: Soam et al. 2018, ApJ 861 65

Ophiuchus C: Liu et al. 2019, ApJ 877 43
IC5146: Wang et al. 2019, ApJ 876 42
Perseus B1: Coudé et al. 2019, ApJ 877 88
Oph polarisation fracs.: Pattle et al. 2019, ApJ 880 27

Perseus NGC 1333: Doi et al. 2020, ApJ 899 28

Outflow/field comparison: Yen et al. 2020, ApJ 907 33

Ophiuchus L1689: Pattle et al. 2021, ApJ 907 88

Auriga: Ngoc et al. 2021, ApJ 908 10

NGC 6334: Arzoumanian et al. 2021, A&A 647 A78

Taurus B213: Eswaraiah et al. 2021, ApJ 912 L27

Rosette: Könyves et al. 2021, ApJ 913 57
More Orion A: Hwang et al. 2021, ApJ 913 85

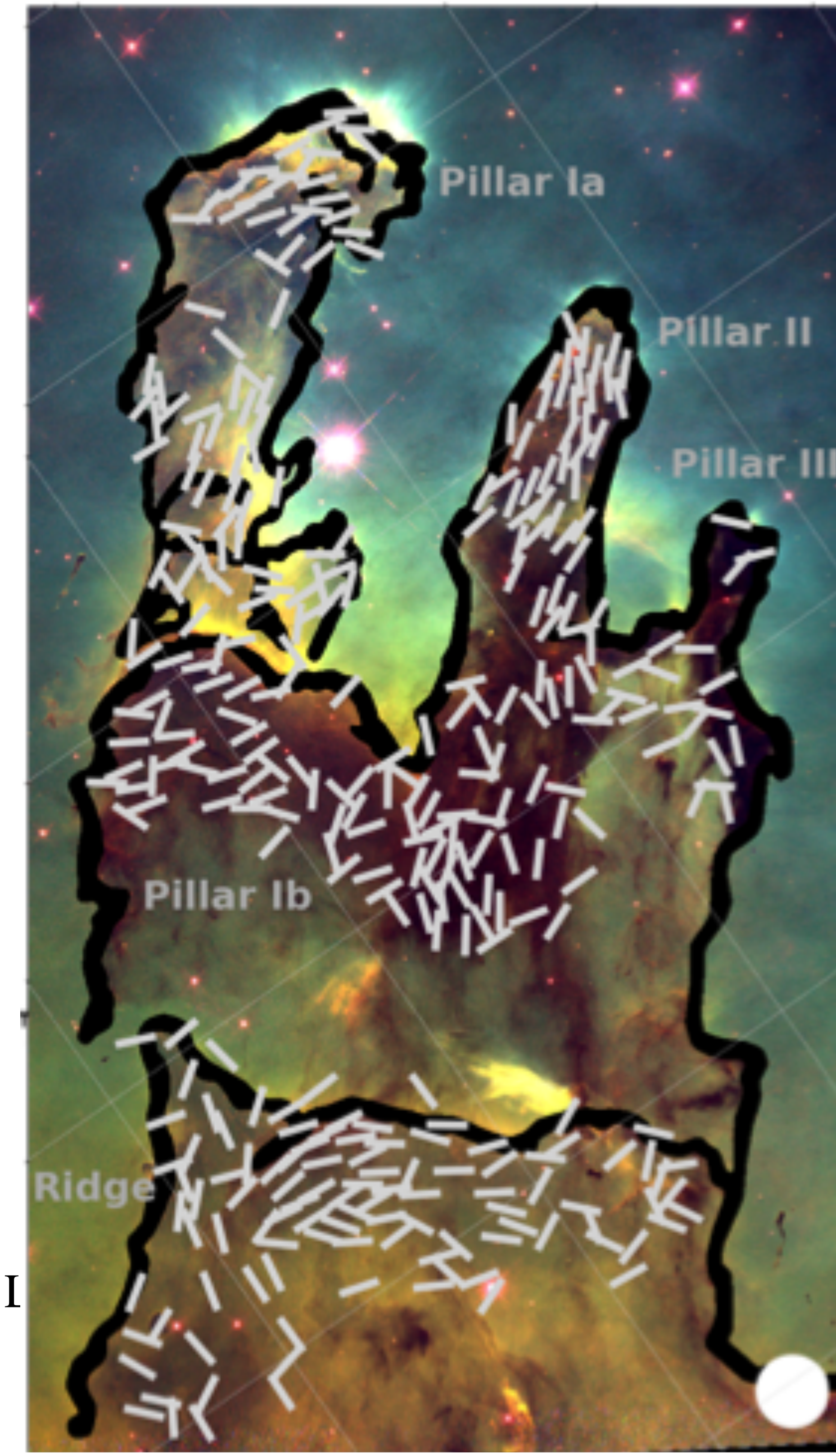
Orion B: Lyo et al. 2021, 918 85

NGC 1333 filament widths: Doi et al. 2021, ApJL 923 I

Serpens Main: W. Kwon et al. 2022, ApJ 926 163

Fanciullo et al. MNRAS in press

... with many more under review and in prep.

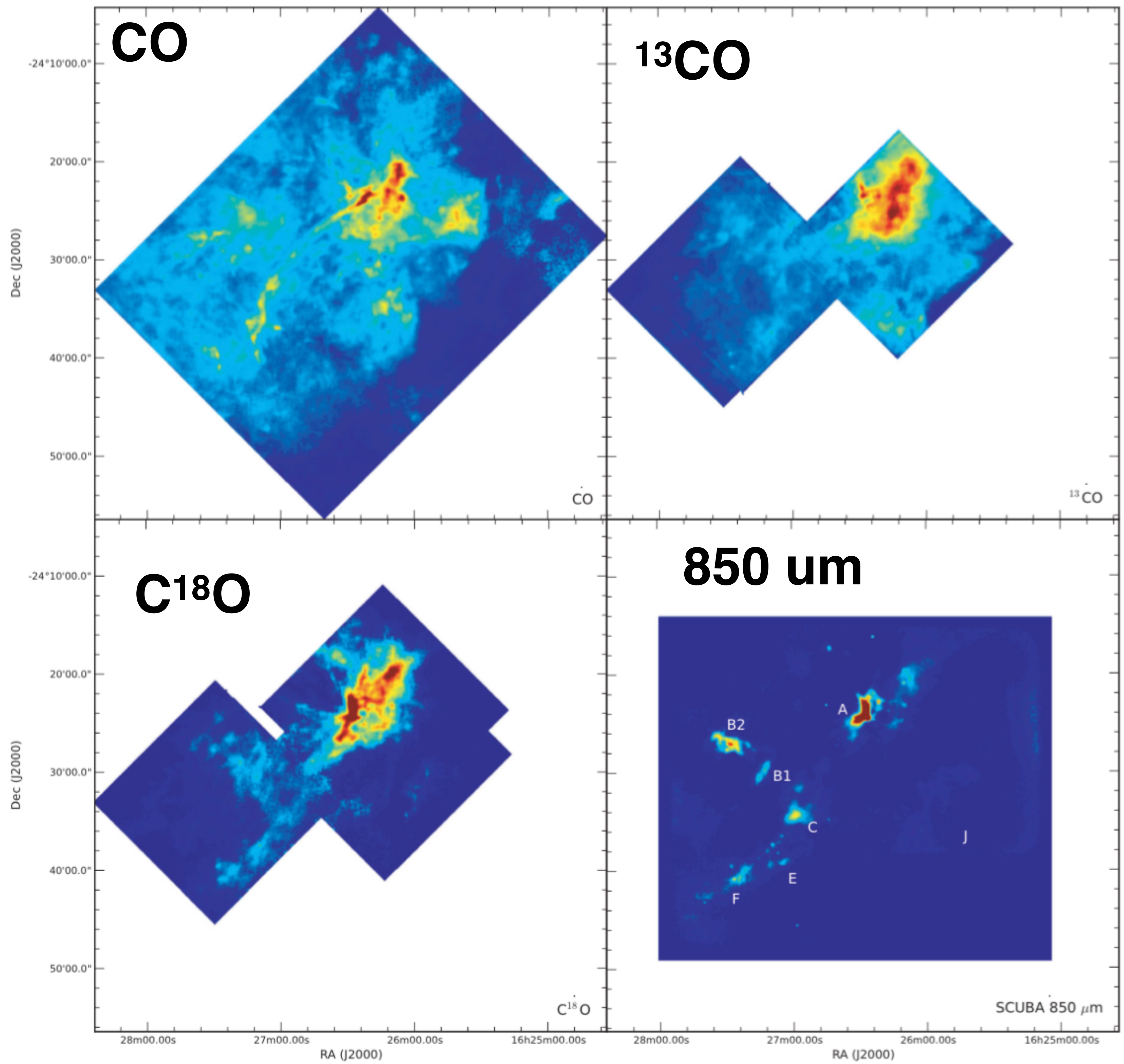


Ophiuchus-B (Oph-B; BISTRO-1 IstG.)

- This is one of the BISTRO regions considered for JCMT/POL-2 observations
- Distance 120 pc (Loinard et al. 2008; Lombardi, Lada & Alves 2008)
- Closest active star forming region
- Harbors numerous kind of YSOs such as class 0,I,II and III
- Consists of various filamentary structures known as streamers

Structure of kinematics of Ophiuchus

- ◉CO, 13CO and C18O are mostly bright in Oph-A region.
- ◉ The CO emission shows some clumps well correlated to 850 um emission map

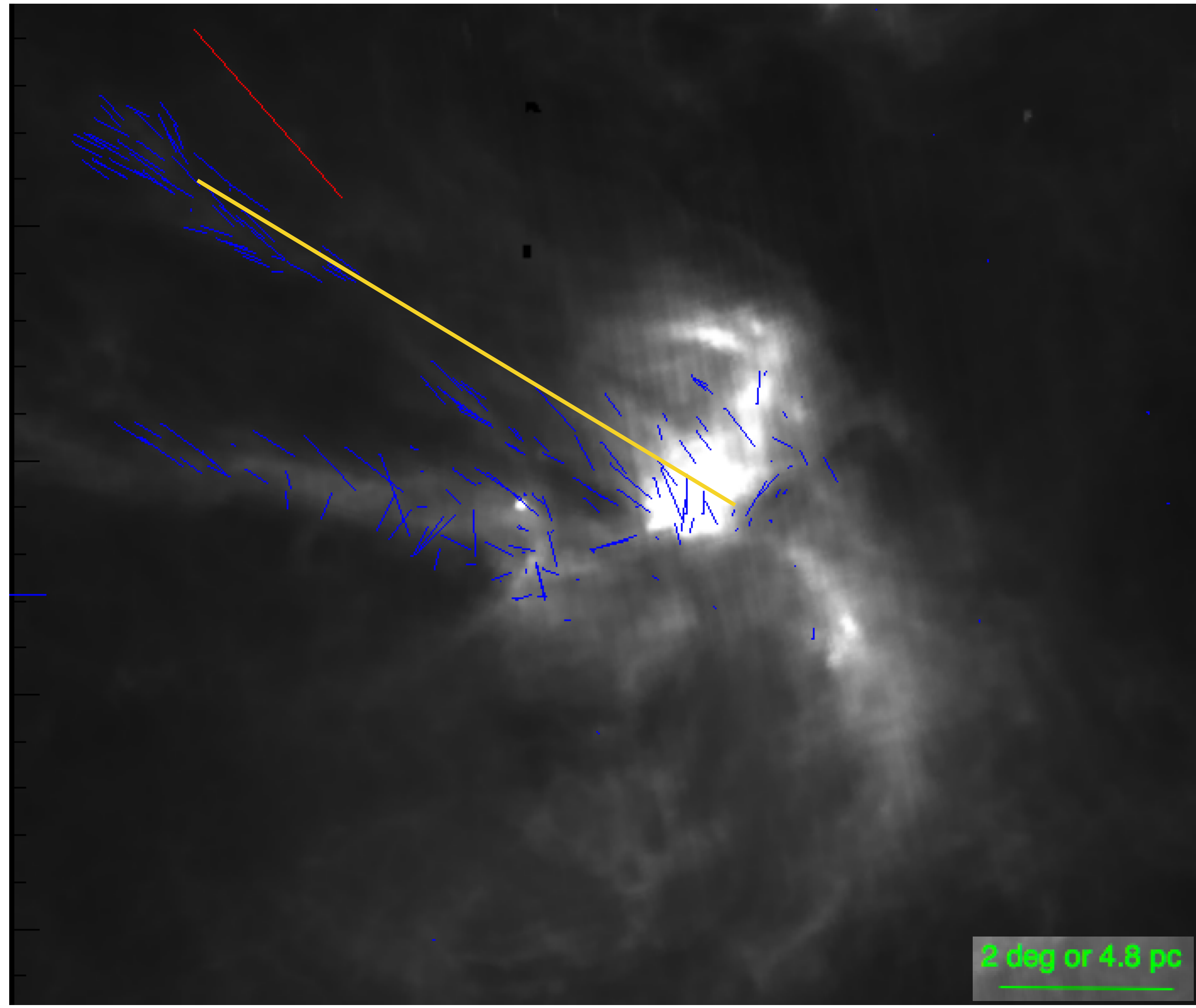


850um map: Johnstone et al. 2010, CO, ^{13}CO & $C^{18}O$ emission; White et al. 2015

B-fields in Ophiuchus

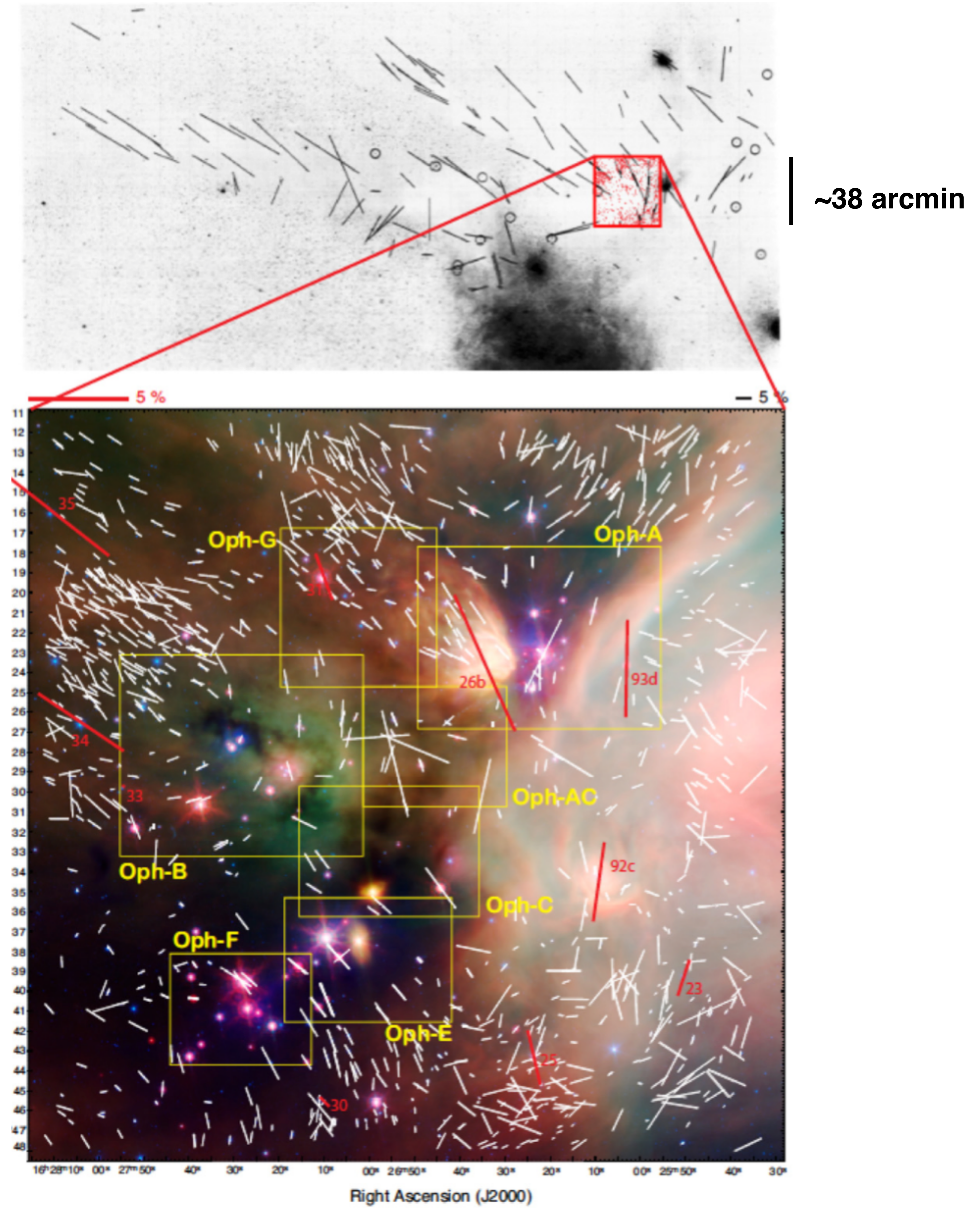
- The B-fields inferred from optical polarization from Heiles+2000 data shows the major component from NE to SW.

- B-fields are following the cloud structure



Pol data from Heiles 2000 Av 1~2 mag

B-fields in further smaller scales mapped in NIR from SIRPOL

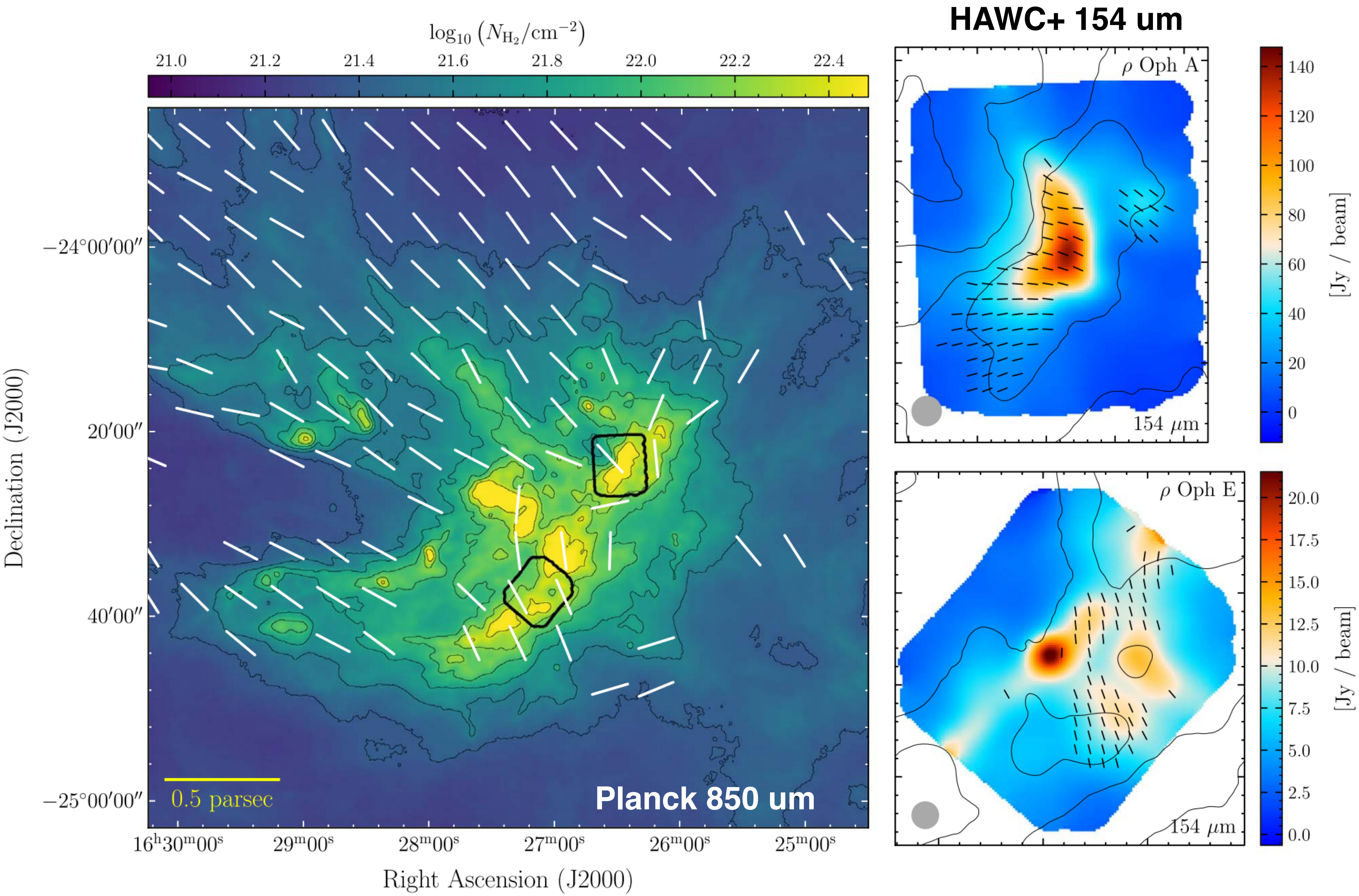


- The large scale B-fields are nicely connected to the smaller scale fields structure obtained from NIR polarization observations.

- This suggest the inherent ambient field orientation is largely from NE to SW

J. Kwon + 2015 Av 10~50 mag

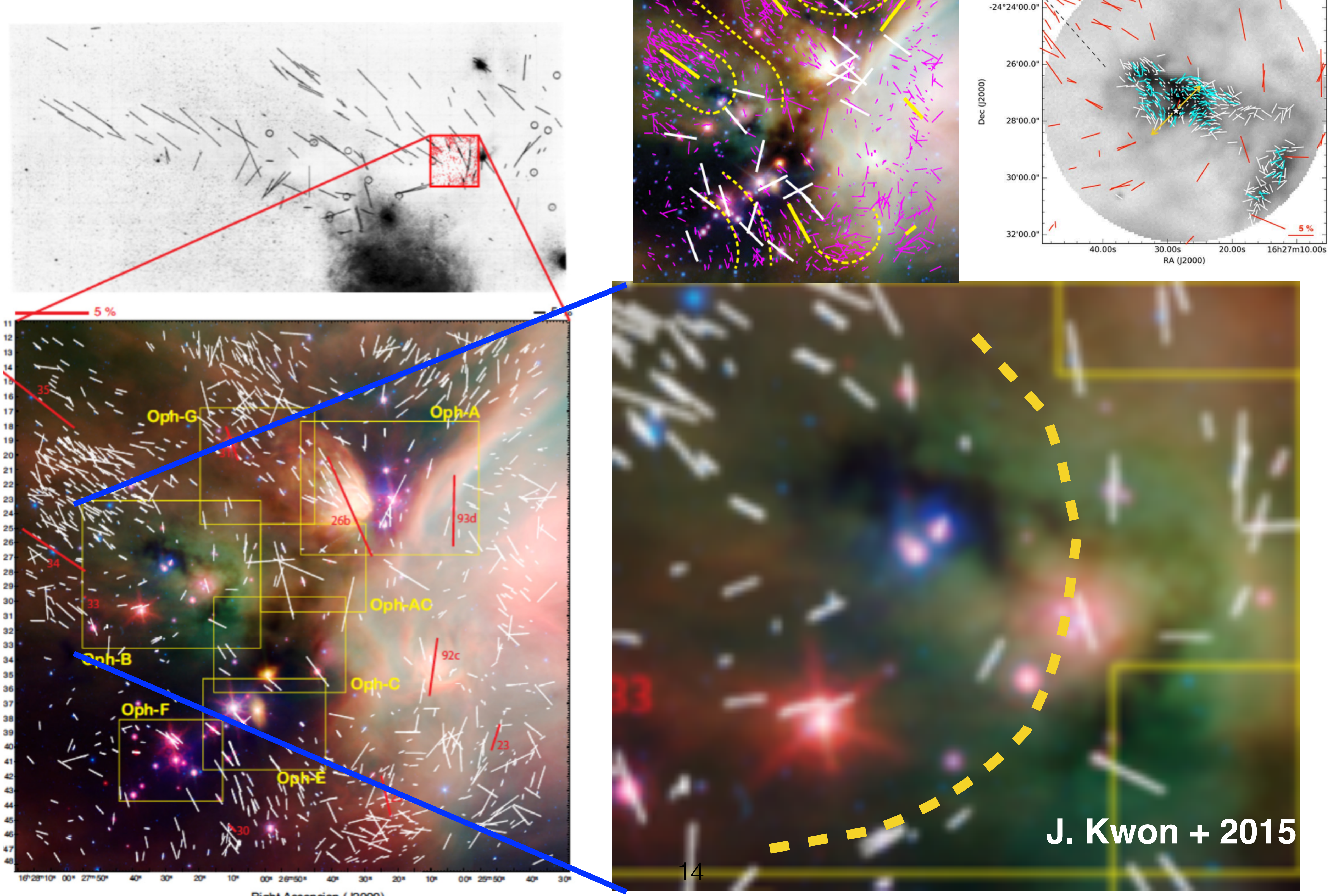
What do Planck and SOFIA see in Ophiuchus?



Lee et al. 2021

B-fields from NIR and submm observation
Seems to be connected and large scale B-fields appear to be curved

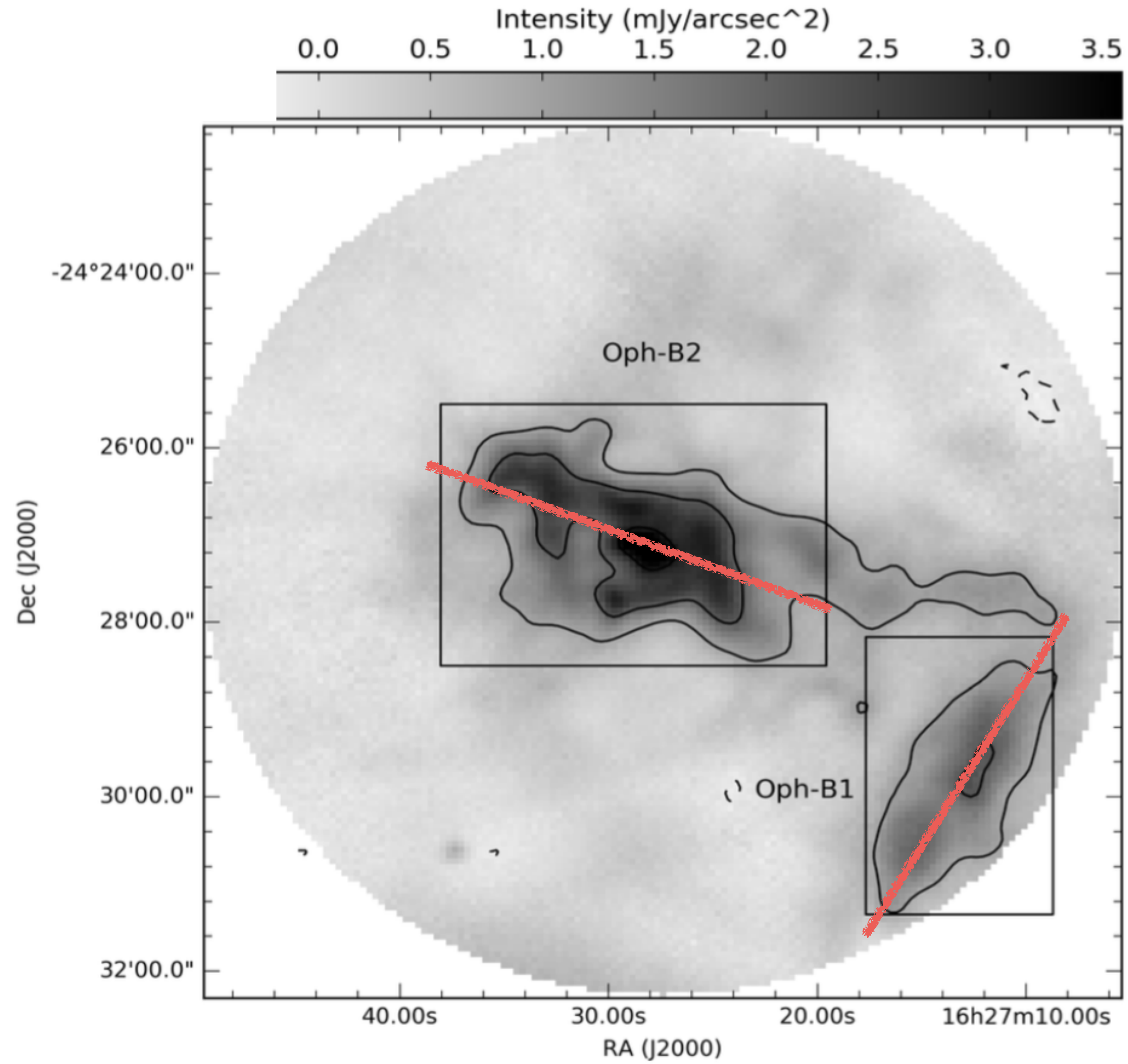
J. Kwon + 2015



BISTRO-1 region: Oph-B
(Cloud structure in SCUBA-2 850 um emission)

◉Oph-B1 (south) and Oph-B2 (north) can be identified.

◉Two sub-clumps are oriented with major axes orthogonal to each other.



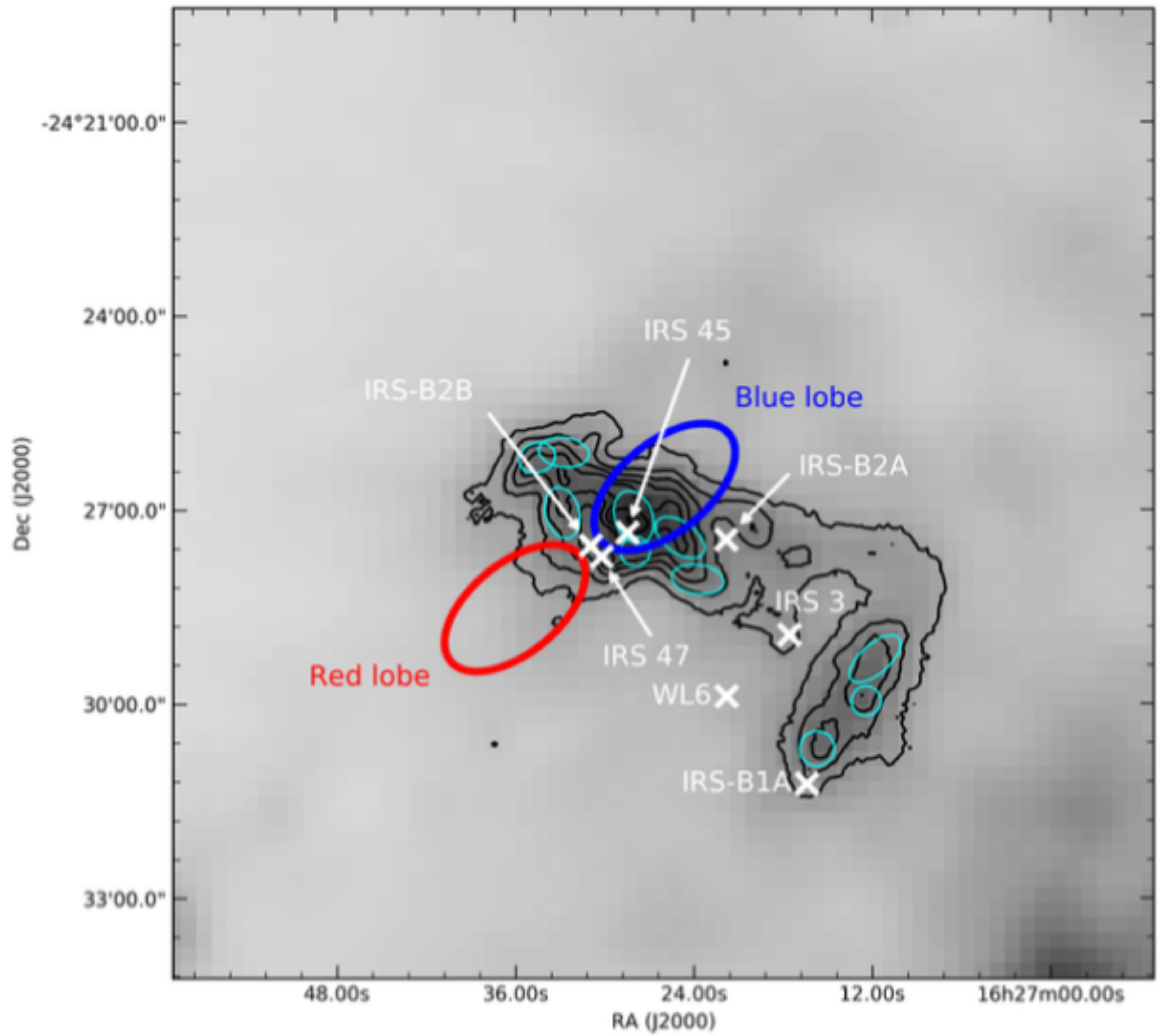
Soam A. +BISTRO 2018, ApJ, 861,65

Star-formation activity in Oph-B

- Distribution of YSOs in Oph-B is shown as crosses in the figure.

- IRS 47 is identified with prominent outflows shown in blue and red lobes

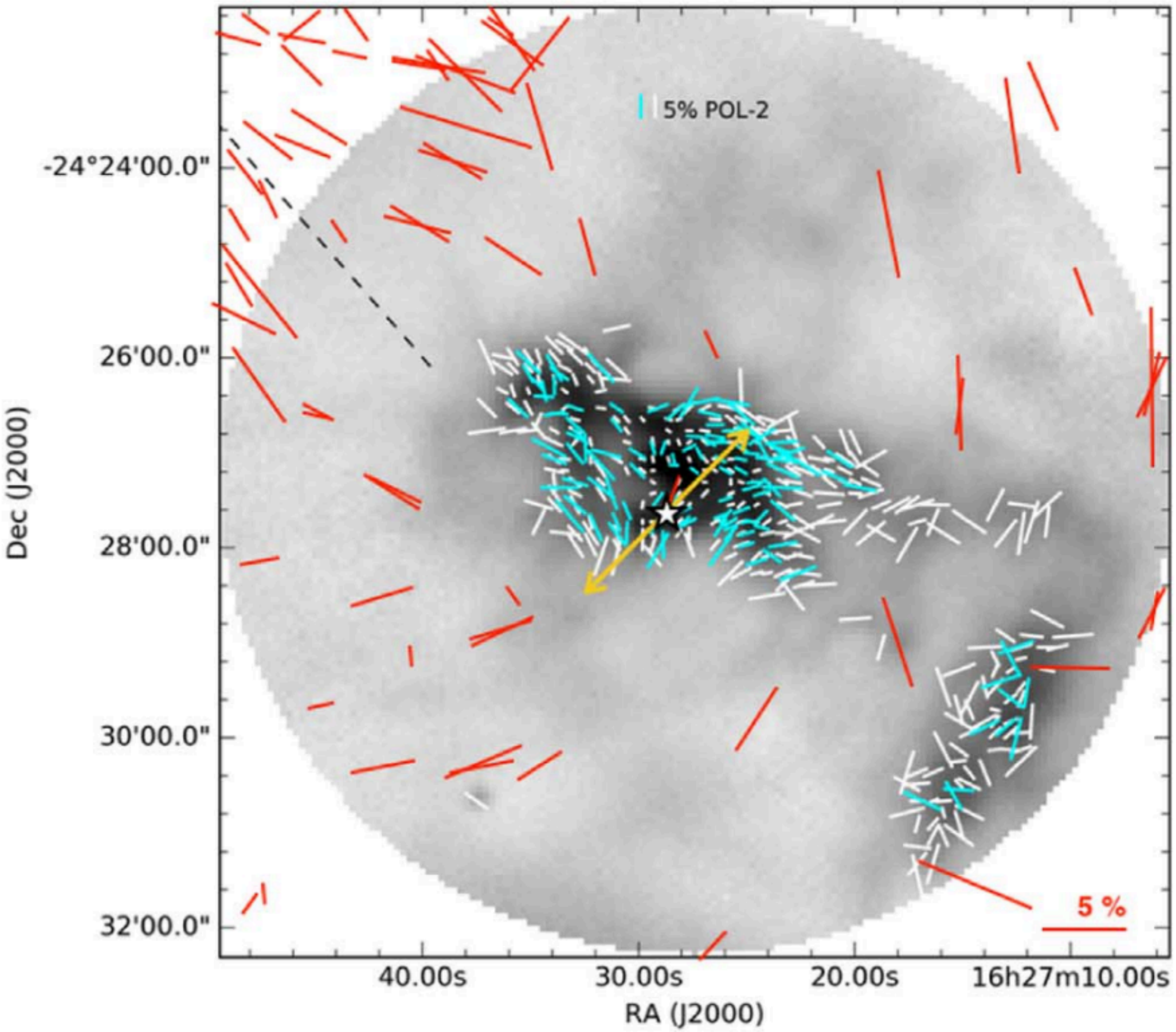
- Ellipses are dense condensations identified by Gaussclump using $N_2H^+(1\text{-}0)$ data from Andre et al. 2007.



YSOs information from White et al. 2015

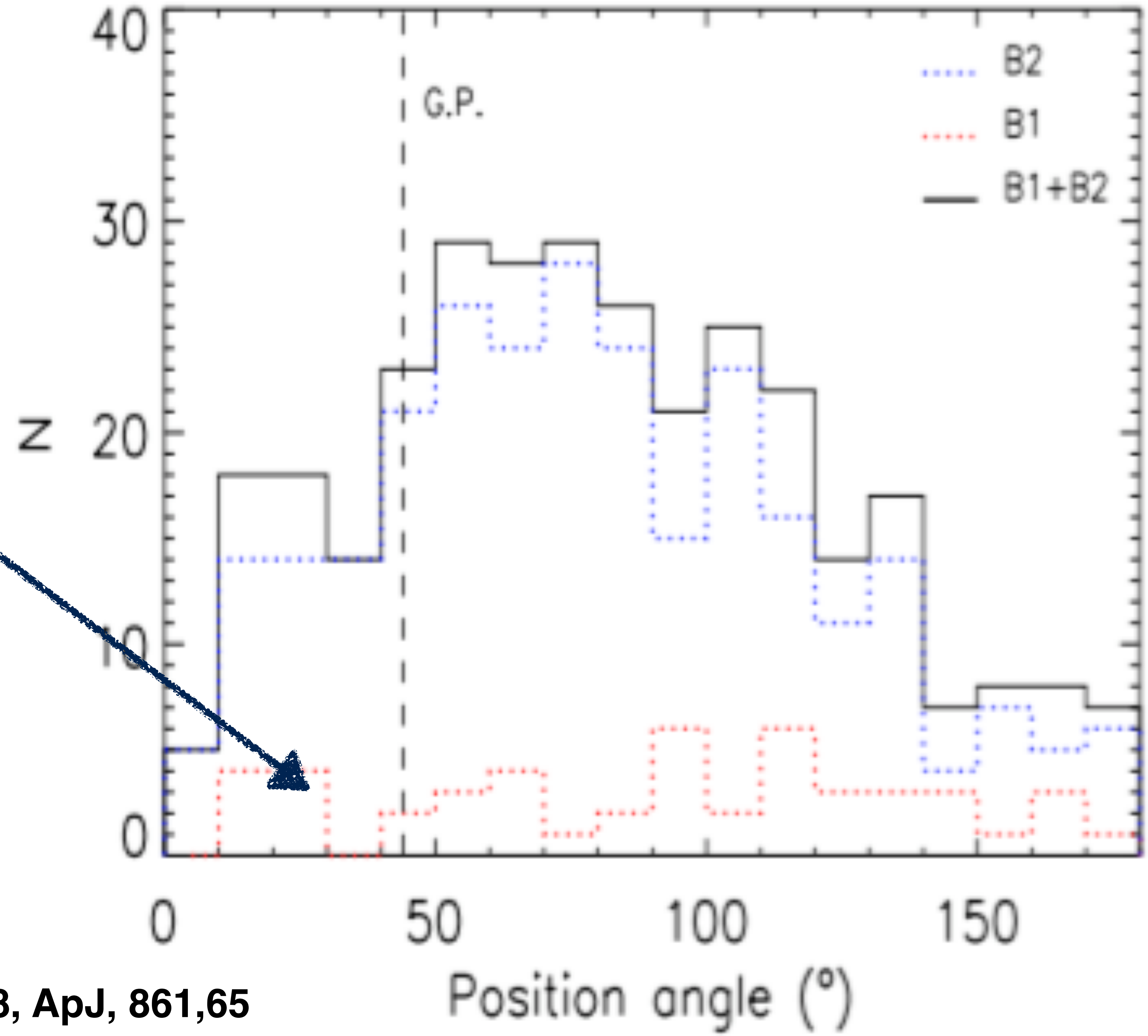
B-field geometry in Oph-B
(White:POL-2, red: NIR)

Cyan: SNR=3
White: SNR=2



Distribution of B-field position angles

•B-fields in Oph-B1 are mostly disordered (see large dispersion in the distributions of position angles)

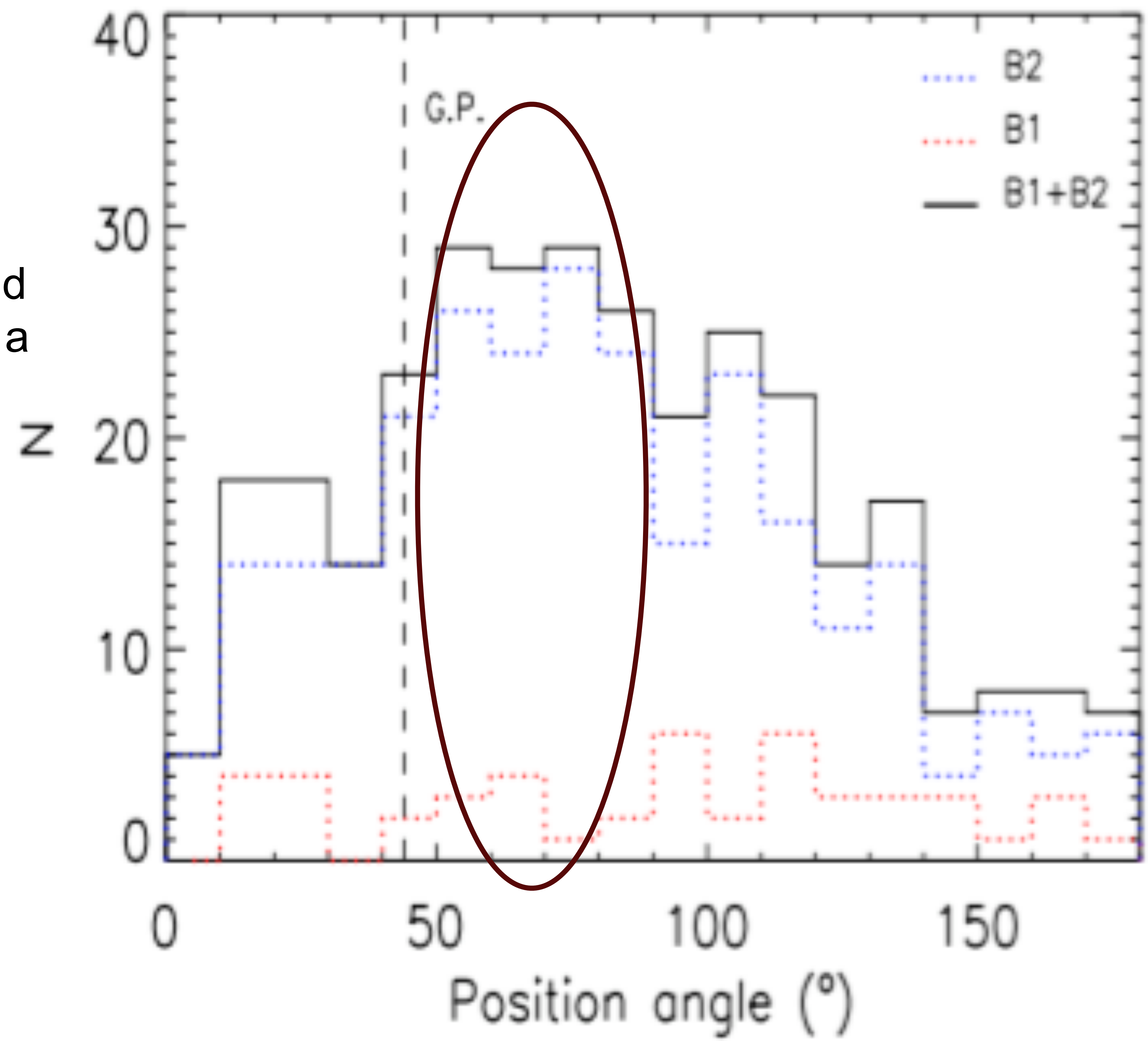


Soam A. +BISTRO team, 2018, ApJ, 861,65

Distribution of B-field position angles

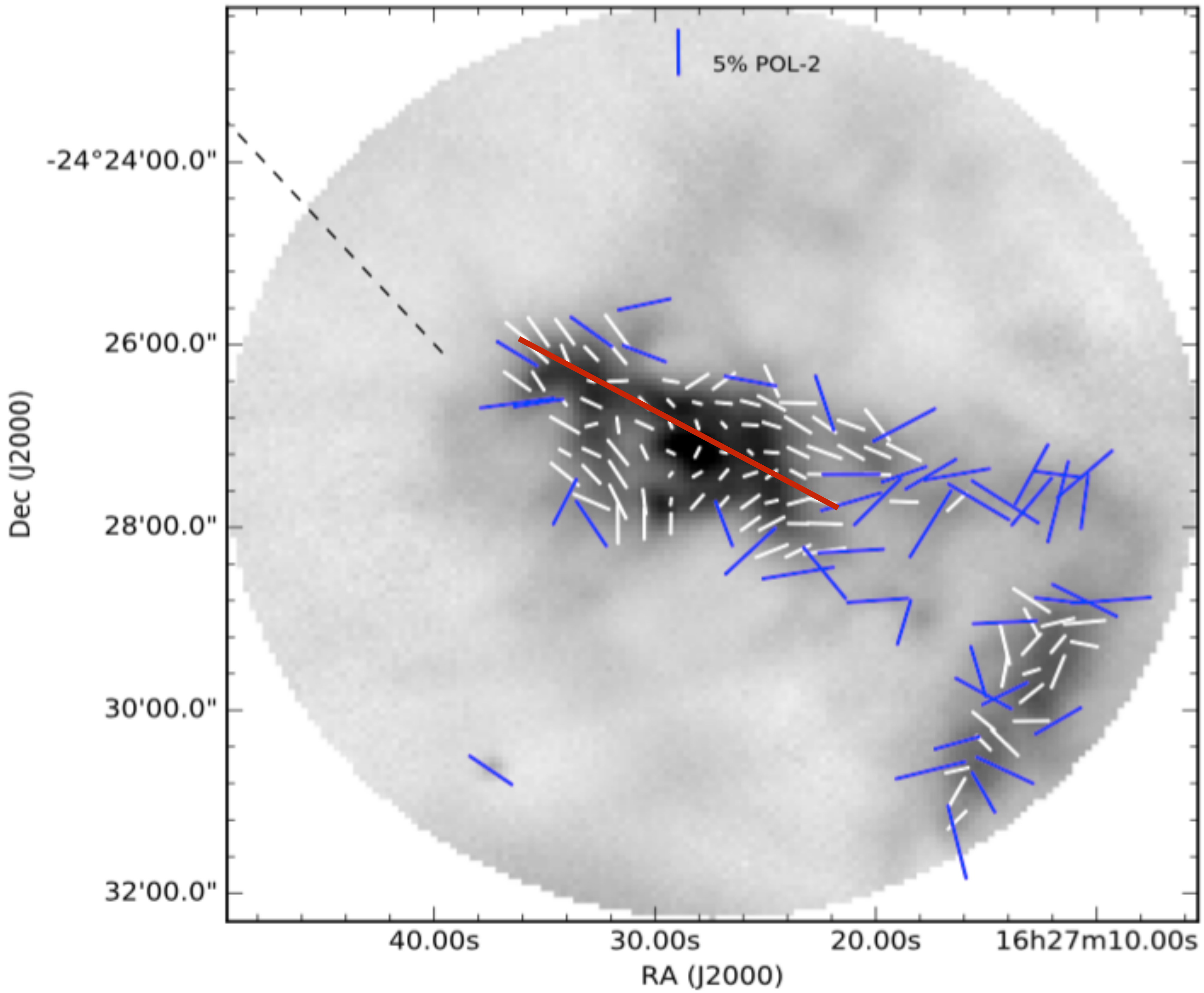
• The B-fields in Oph-2 and overall geometry suggest a 60-80 deg component dominating.

• This component is also seen towards Oph-A (J. Kwon et al. 2018) and Oph-C (Liu et al. 2019)



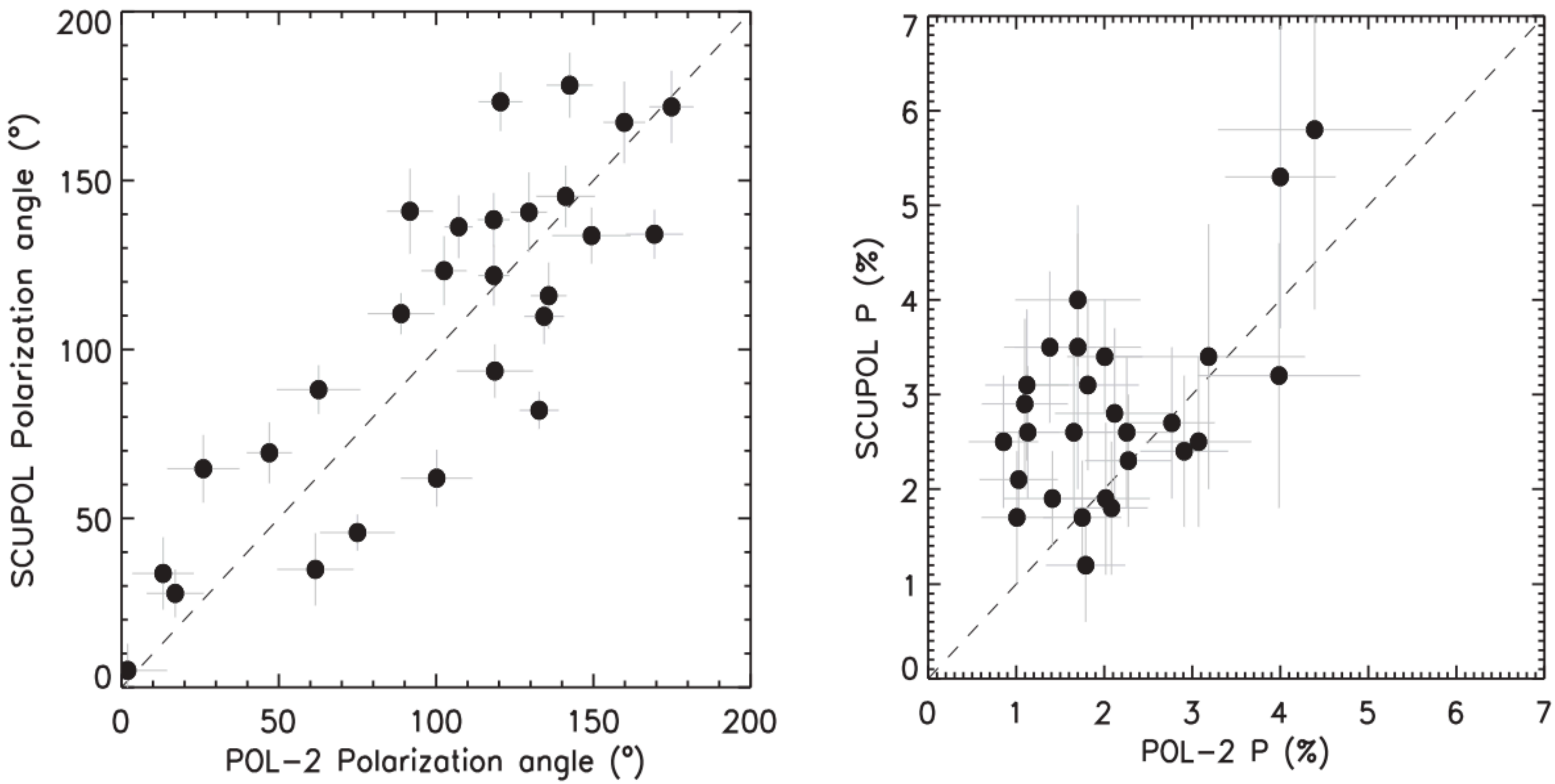
Smoothed B-fields in Oph-B

- POL-2 data smoothed by using 2X2 binning
- Polarization fraction is higher on edges as seen by blue segments with P>5% and lower in high density part as seen by white vectors with P<5%.
- B-fields in Oph-B2 is relatively ordered and roughly parallel to the clump major axis.



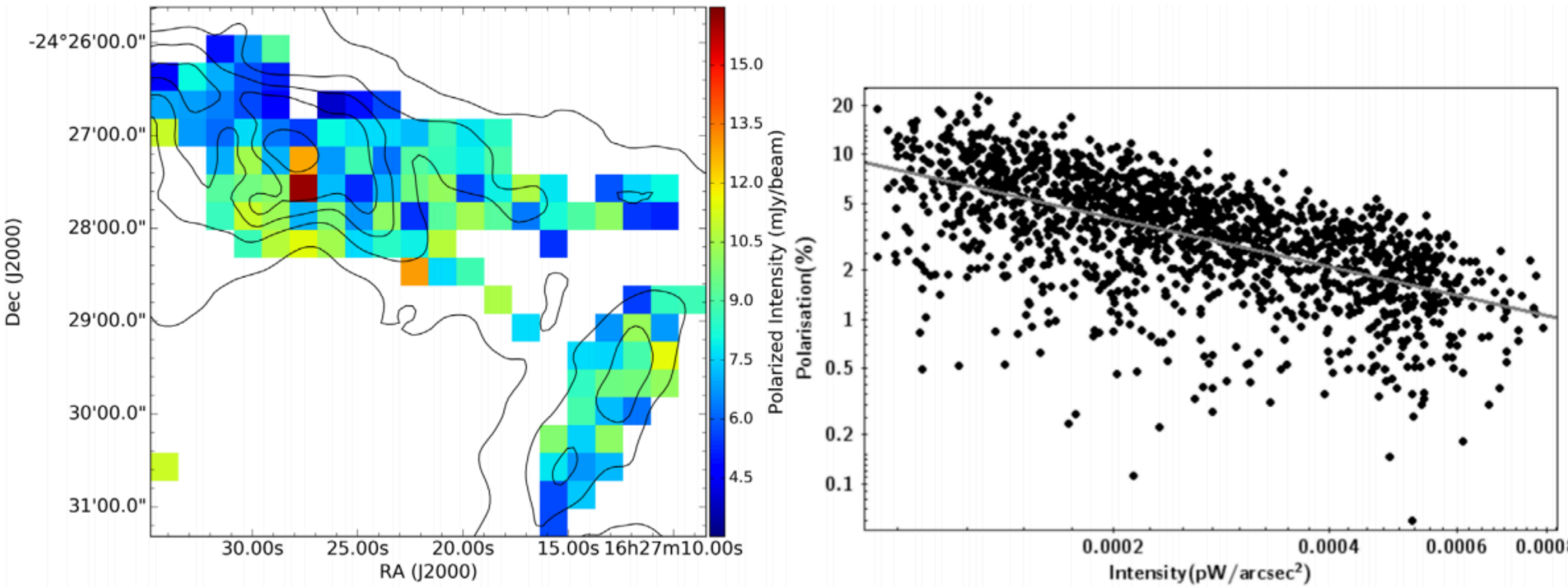
 Soam A. +BISTRO team, 2018, ApJ, 861,65

Position angle and polarization fraction distribution from SCUPOL and POL-2 data



- 1. Position angles are almost linearly correlated (left panel)
- 2. Lower SNR of SCUPOL detections may possibly be causing higher polarization fraction (right panel)

Polarization and intensity



- **1. Pol. fraction decreases towards denser core regions (left panel)**
- **Power-law slope measured using a least square fit is ~ -0.9 (right panel)**

Soam A. +BISTRO 2018, ApJ, 861,65

B-field strength and core stability calculation

Using Chandrasekhar Fermi relation

Davis 1951; Chandrasekhar & Fermi 1953

$$B_{\rm pos} = 9.3\sqrt{nH_2}\frac{\Delta V}{\delta\theta} \quad \mu G$$

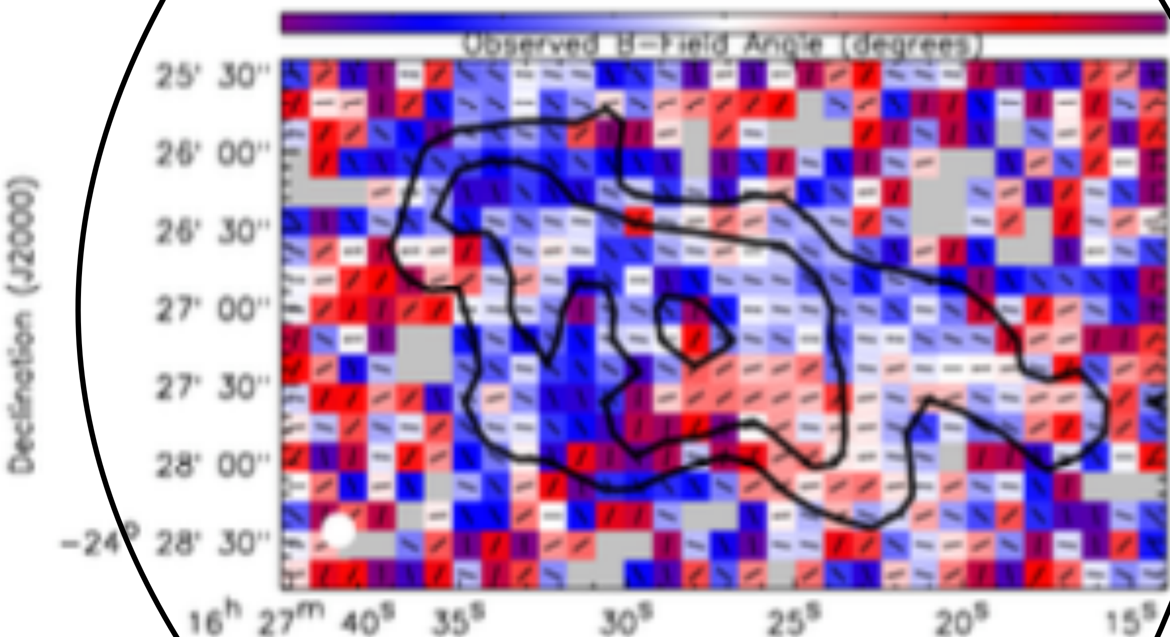
nH_2 :Volume density

ΔV :los velocity dispersion

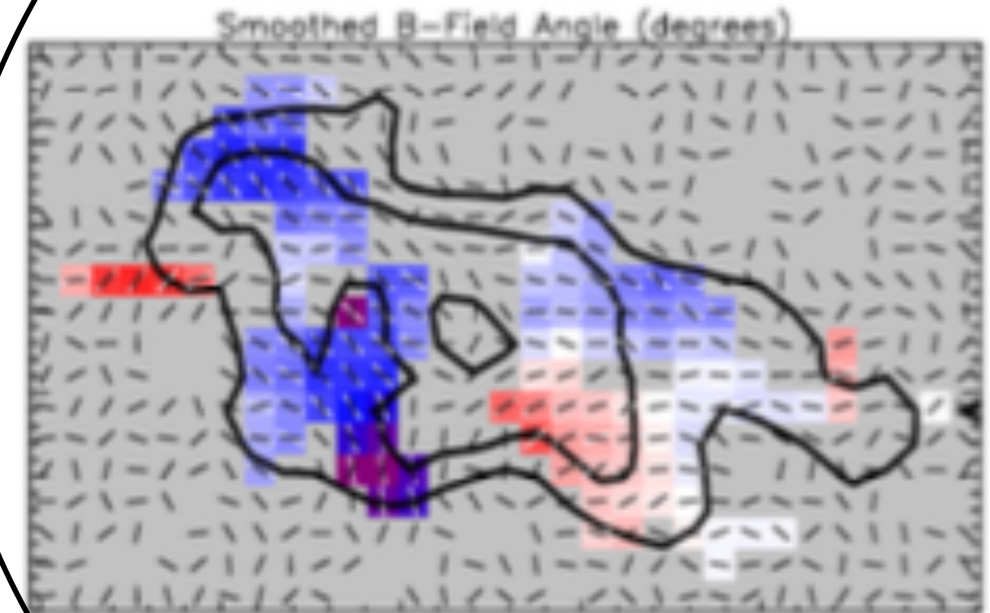
$\delta\theta$:Angular dispersion

$$\lambda = 7.6 \times 10^{-21}\frac{N(\mathrm{H_2})}{B_{\rm pos}},$$

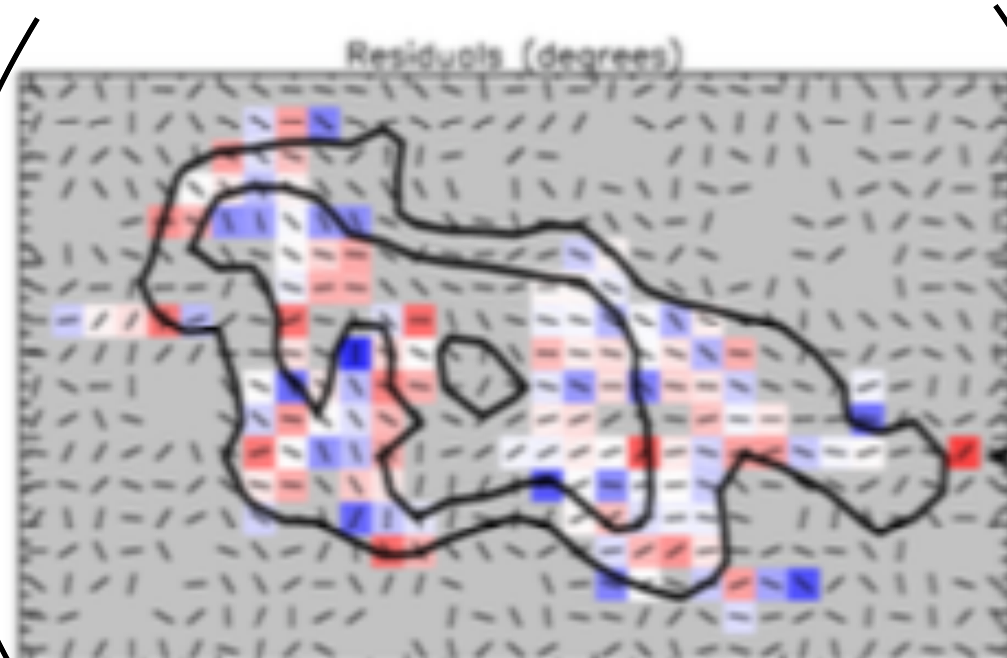
Angular dispersion estimation using unsharp masking
(Detailed method introduced by Pattle et al. 2017)



Observed



Smoothed with 3x3 pixel boxcar filter



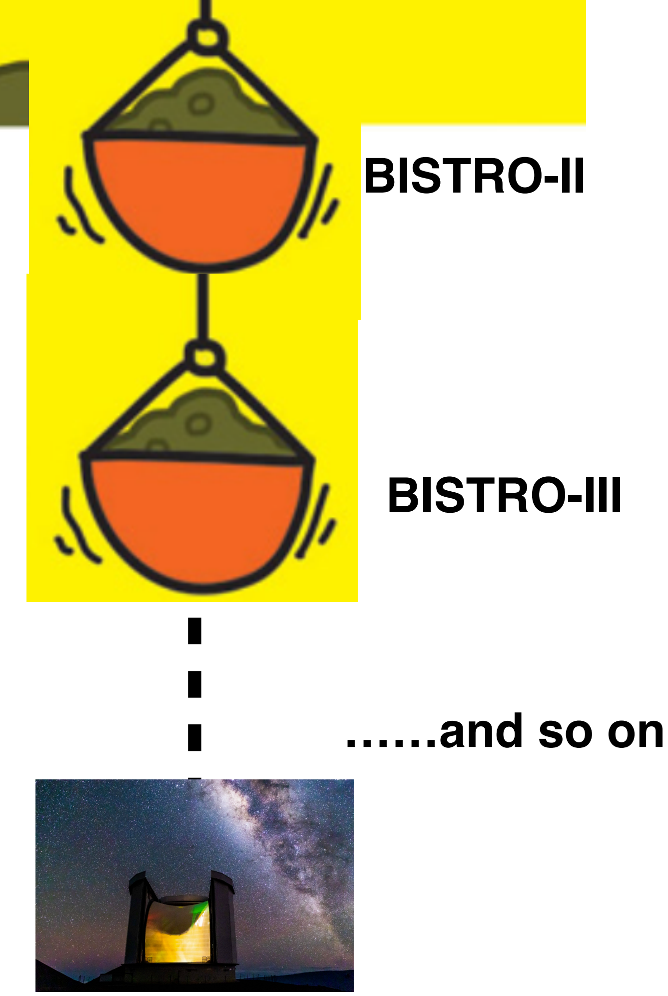
Residual: used to estimate dispersion

Estimated
Bpos= 630+/-410 uG

Summary

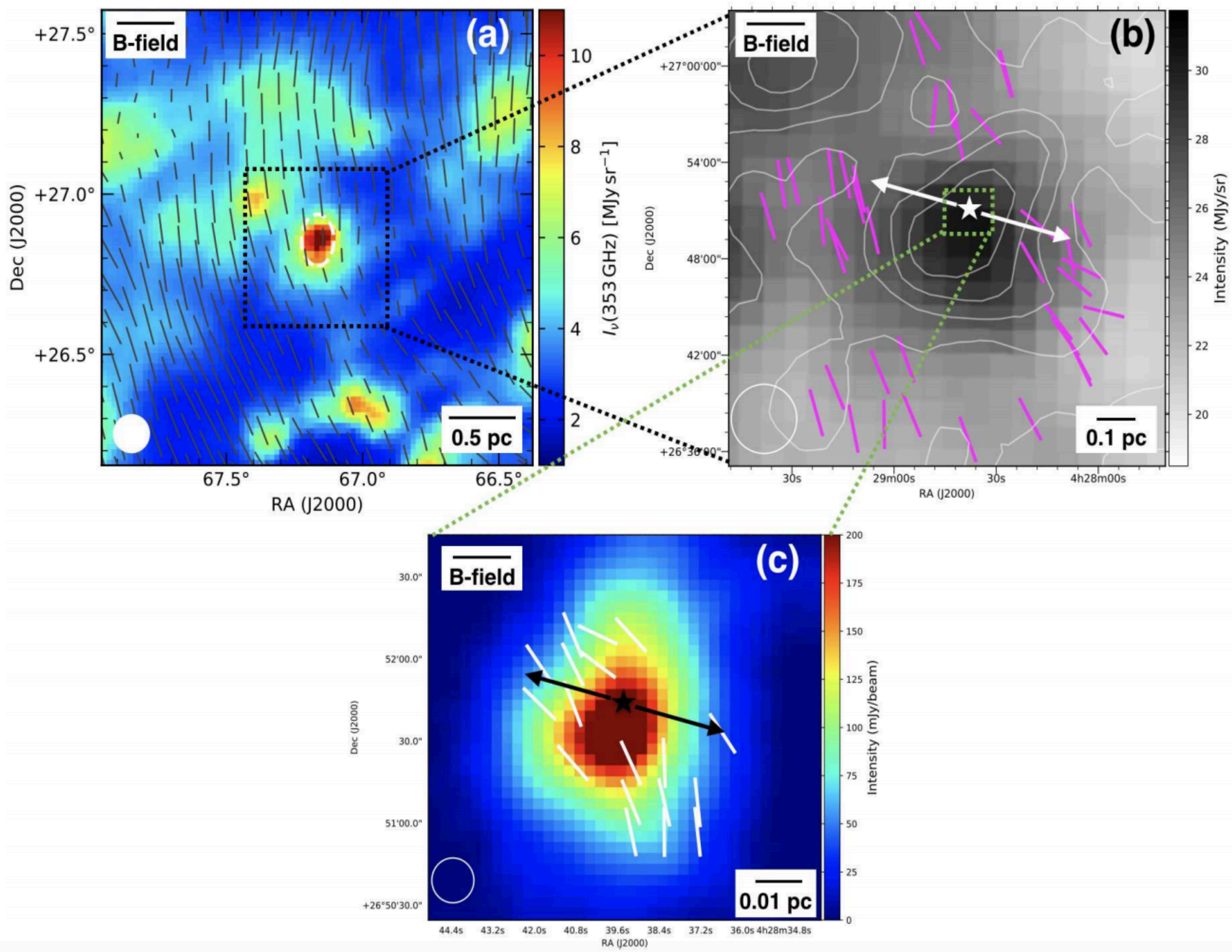
1. Polarization fractions and angles of SCUPOL and POL-2 are found to be consistent but POL-2 map is more sensitive and covers a larger area of the Oph-B.
2. Distance field morphologies are found in two clumps with B1 bearing more random component whereas B2 shows underlying ordered magnetic fields with roughly parallel (~18°) to the long axis of the clump.
3. The Oph-B2 fields on low density peripheries are well connected to the large scale structure identified in NIR observations.
4. The decrease in the polarization fraction is observed in the densest regions of both Oph-B1 and B2.
5. The field strength is measured in Oph-B2 with DCF method and found to be 630 ± 410 μG with a mass-to-flux ratio of 1.6 ± 1.1 suggesting it to be slightly magnetically supercritical.
6. The angular offset between the large-scale magnetic field in Oph-B2 and the IRS47 outflow orientation is ~60°, suggesting consistency with models which predict a misalignment between B-fields and outflows.

Soam A. +BISTRO team, 2018, ApJ, 861,65



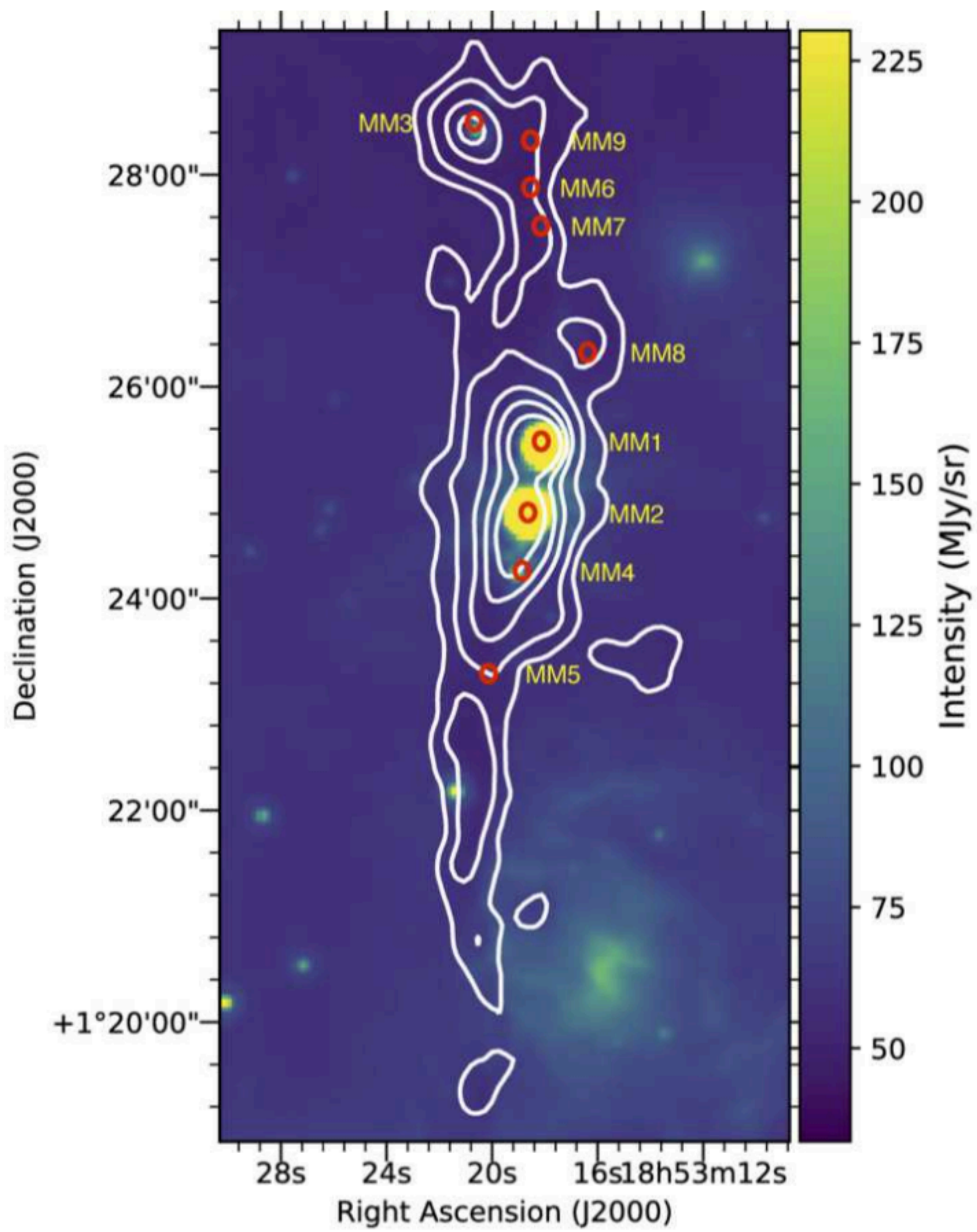
Thank you and keep digging!!

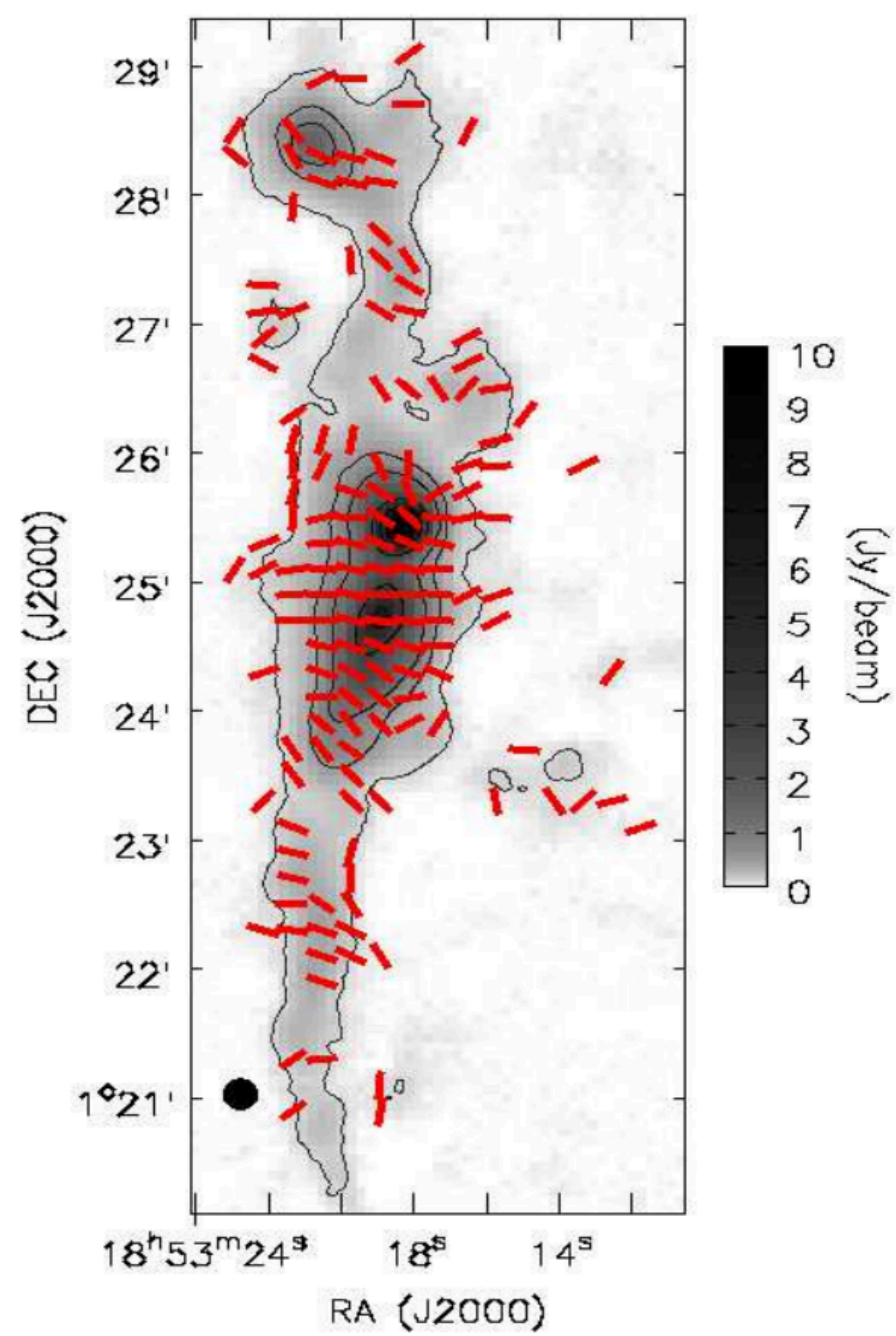
First Sub-pc Sale Mapping of Magnetic Fields in the Vicinity of a Very Low Luminosity Object, L1521F-IRS



Soam A. et al. 2019a, ApJ, 883,9S

Magnetic fields in the infrared dark cloud G34.43+0.24





Soam A. et al. 2019b, ApJ, 883,95S