An Overview of BISTRO and a Look Ahead at BISTRO-3

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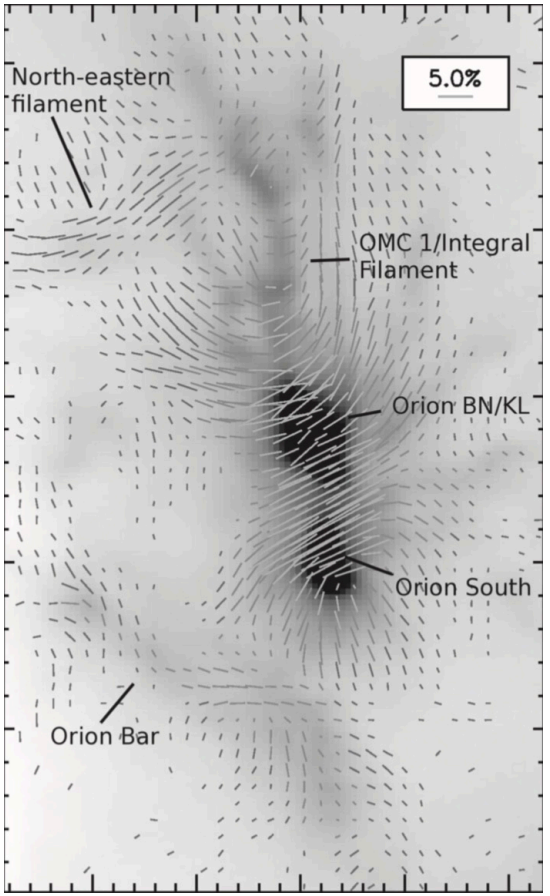
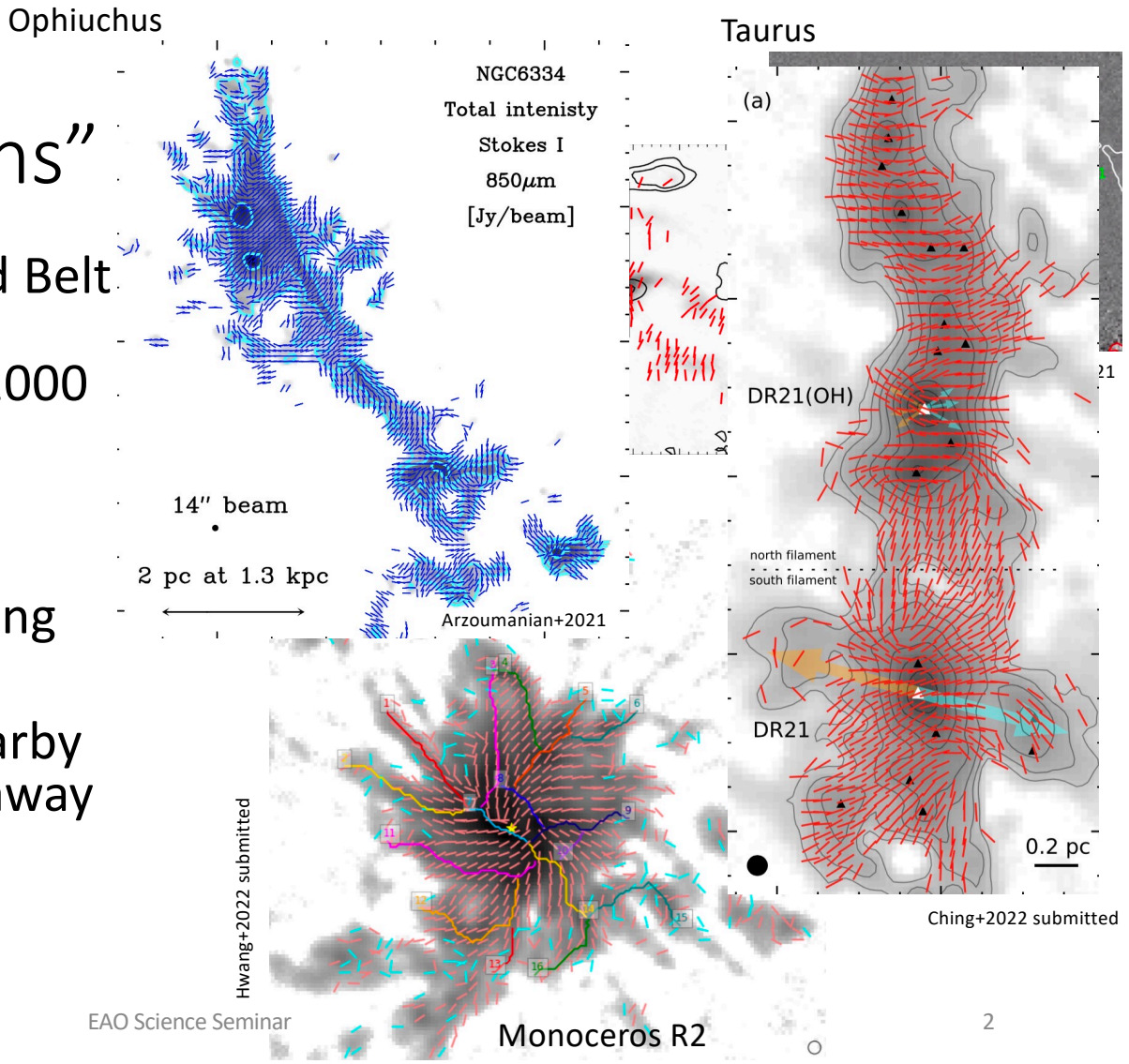
B-fields In STar-forming Regions Observation

- Determine the effect of magnetic fields on forming:
  - Filaments
  - Molecular clouds
  - Cores
  - Stars
- Measure and compare magnetic field strength against:
  - Turbulence
  - Gravity

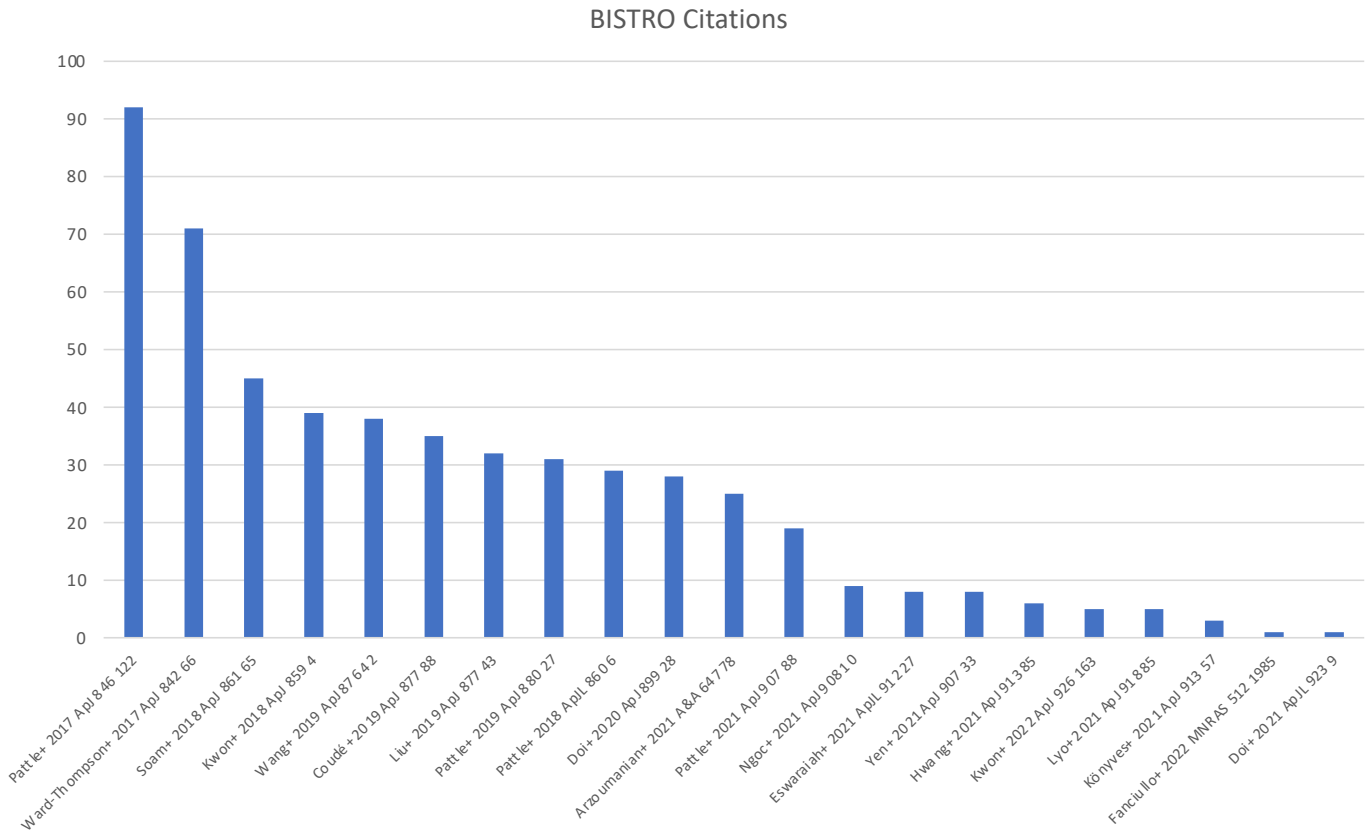


BISTRO “Generations”

- BISTRO-1: Follow up of Gould Belt objects, nearby star-forming regions – high resolution (~ 2000 AU or 0.01pc)
- BISTRO-2: Start to push the envelope, further away and intermediate mass star-forming regions (~0.05-0.1pc)
- BISTRO-3: Two extremes, nearby dim prestellar cores and far away massive star-forming regions (Galactic Centre)



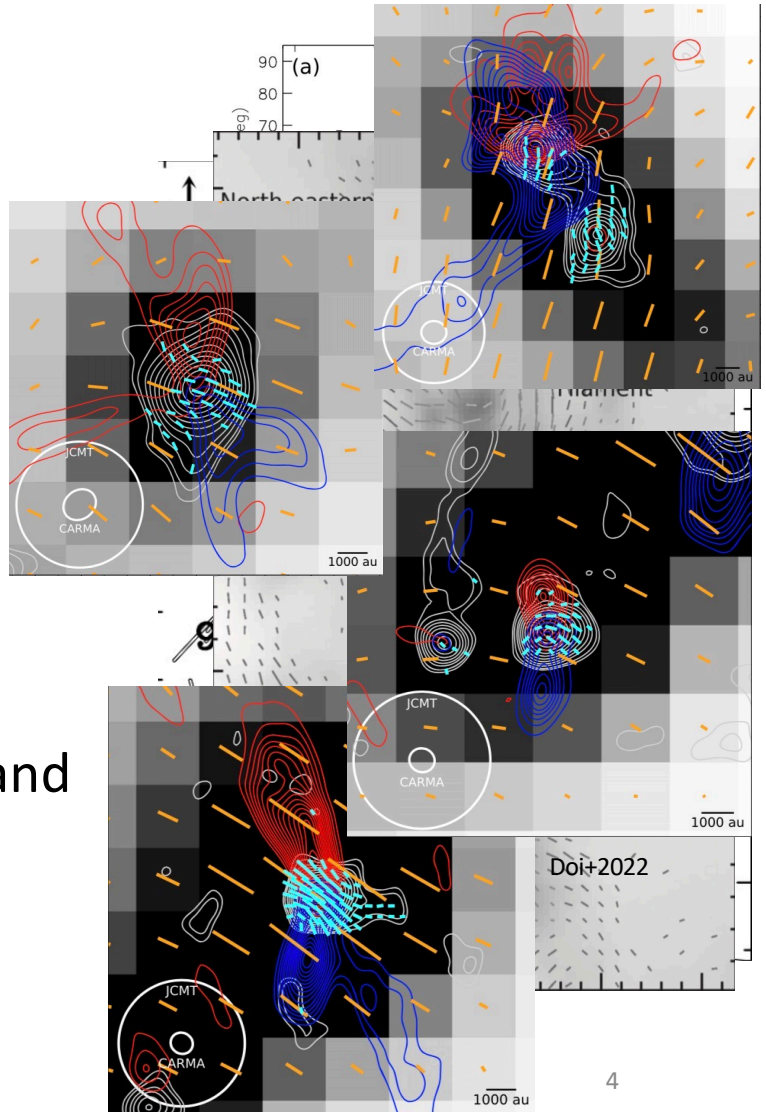
Publications to date



- All BISTRO-1 objects published
- 3 BISTRO-2 papers published, 2 submitted, 5 in prep
- 6 BISTRO “2-G” papers published, 1 submitted, 2 in prep
- 1 BISTRO-1 Summary paper published, 2 in prep

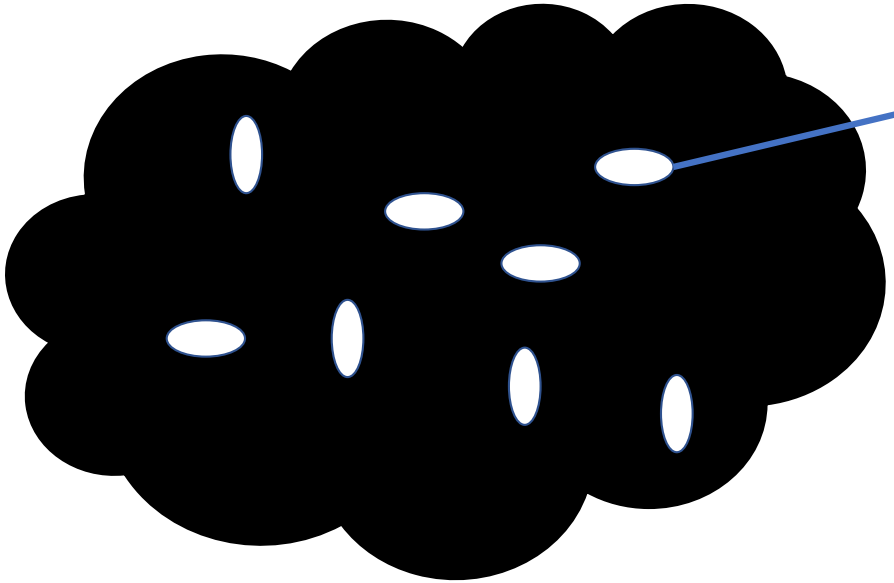
Science from BISTRO

- Found a general misalignment with outflows and field around 15º-35º
  - Misalignment not the mechanism to reduce magnetic braking
  - Smaller misalignment -> equal energy of B-field and kinematics
- Variation of alignment between sub-filament directions and magnetic fields from diffuse into dense
- Agreement with Planck results of magnetic field and filament orientation
- Determining how magnetic field structures vary along spatial scales

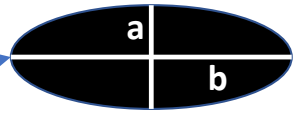


Observations of Magnetic Fields

Molecular Cloud (gas and dust)

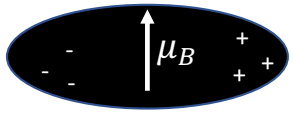


Dust grains

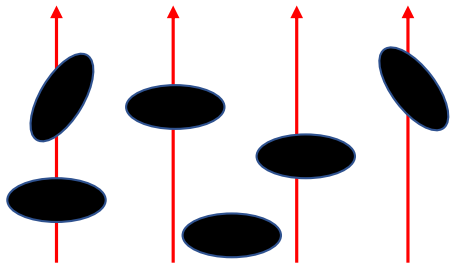


- Paramagnetic
- Irregular

External radiation pressure



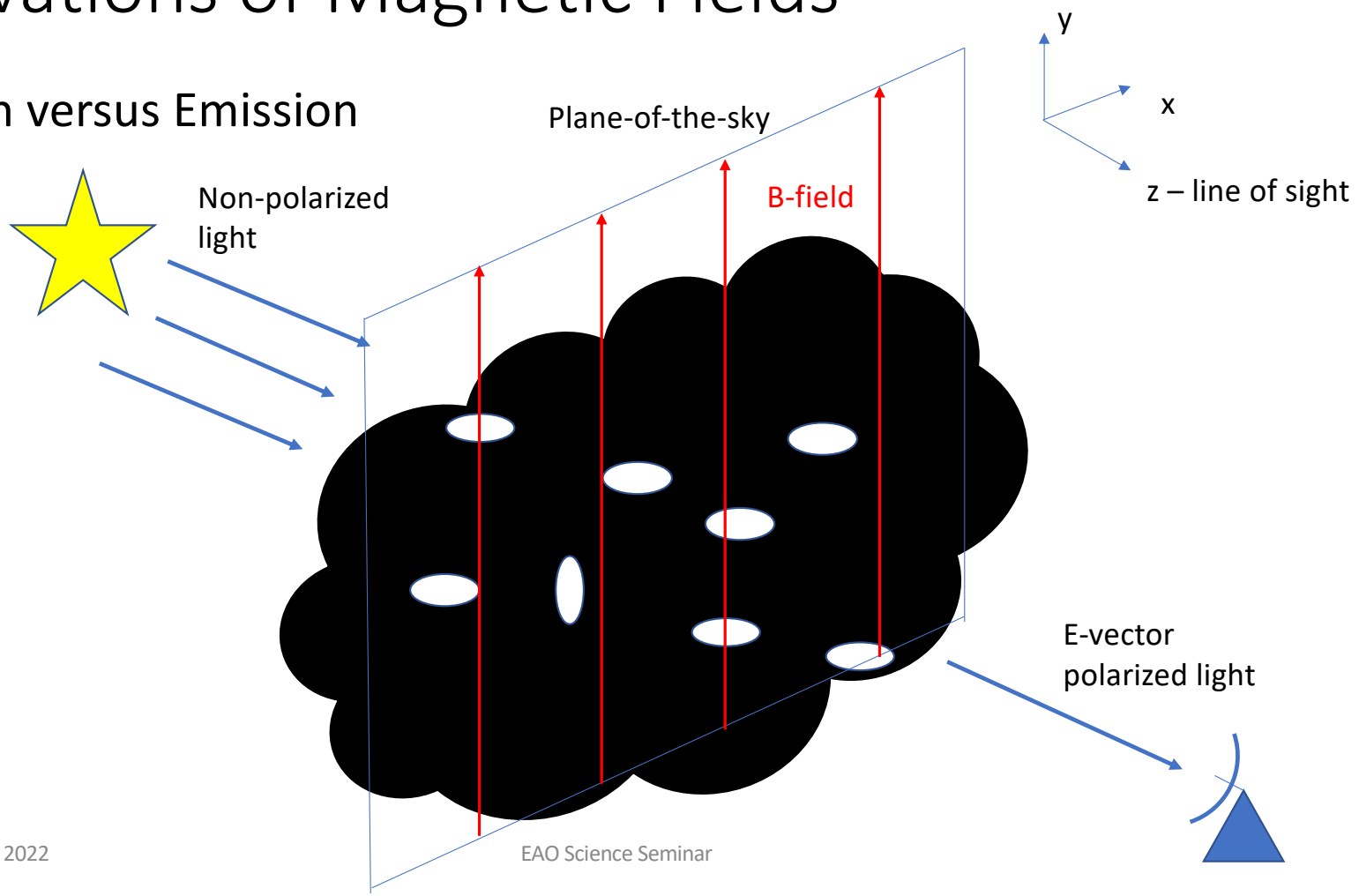
Radiative Alignment Torque (RAT) Theory



B-field

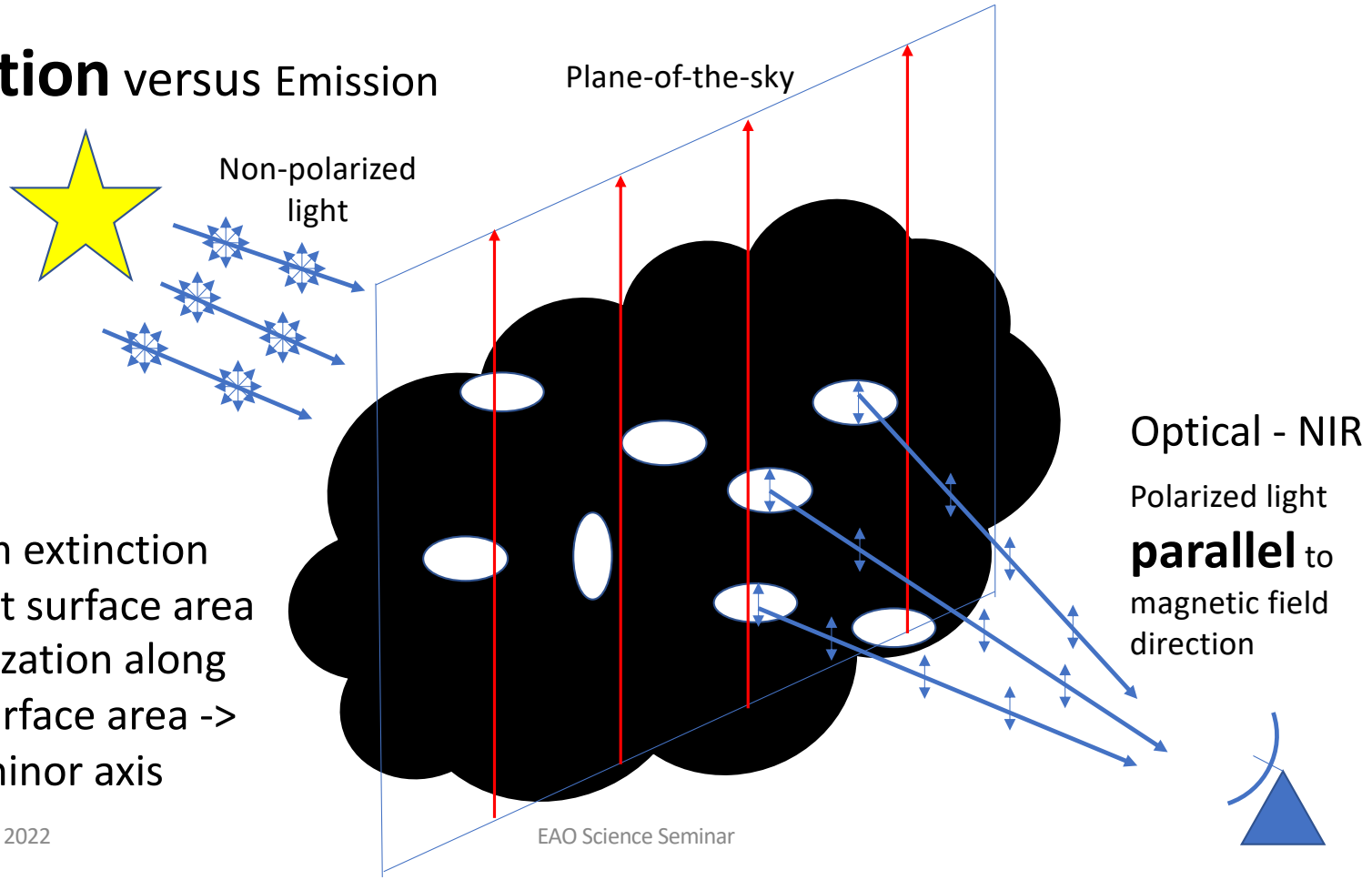
Observations of Magnetic Fields

Absorption versus Emission



Observations of Magnetic Fields

Absorption versus Emission



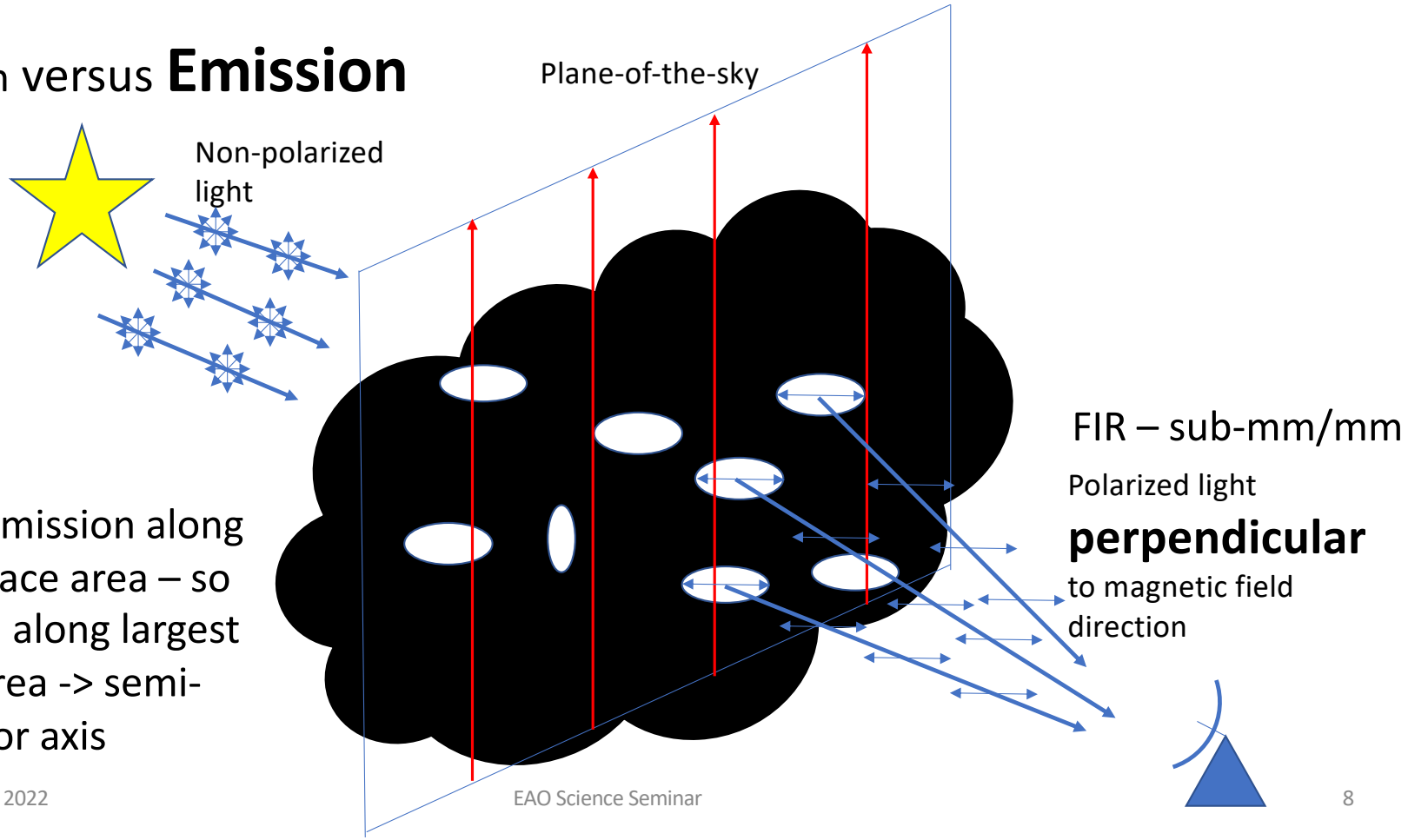
Maximum extinction along largest surface area – so polarization along smallest surface area -> semi-minor axis

Optical - NIR

Polarized light **parallel** to magnetic field direction

Observations of Magnetic Fields

Absorption versus **Emission**



Maximum emission along largest surface area – so polarization along largest surface area -> semi-major axis

FIR – sub-mm/mm

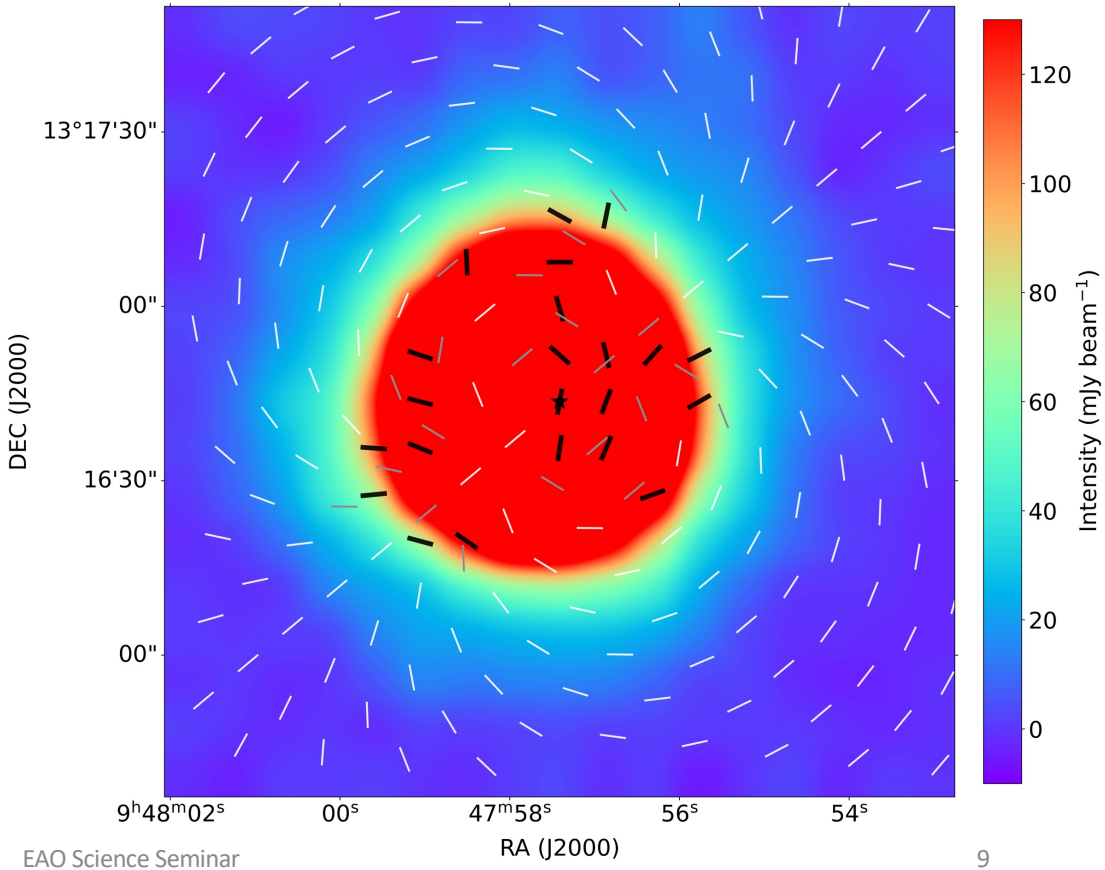
Polarized light

perpendicular

to magnetic field direction

Testing Grain Alignment with IRC+10216

- How are grains aligned in IRC+10216?
- Carbon-rich CSE
- Radial k-rat alignment from HAWC+
- What does POL-2 see?

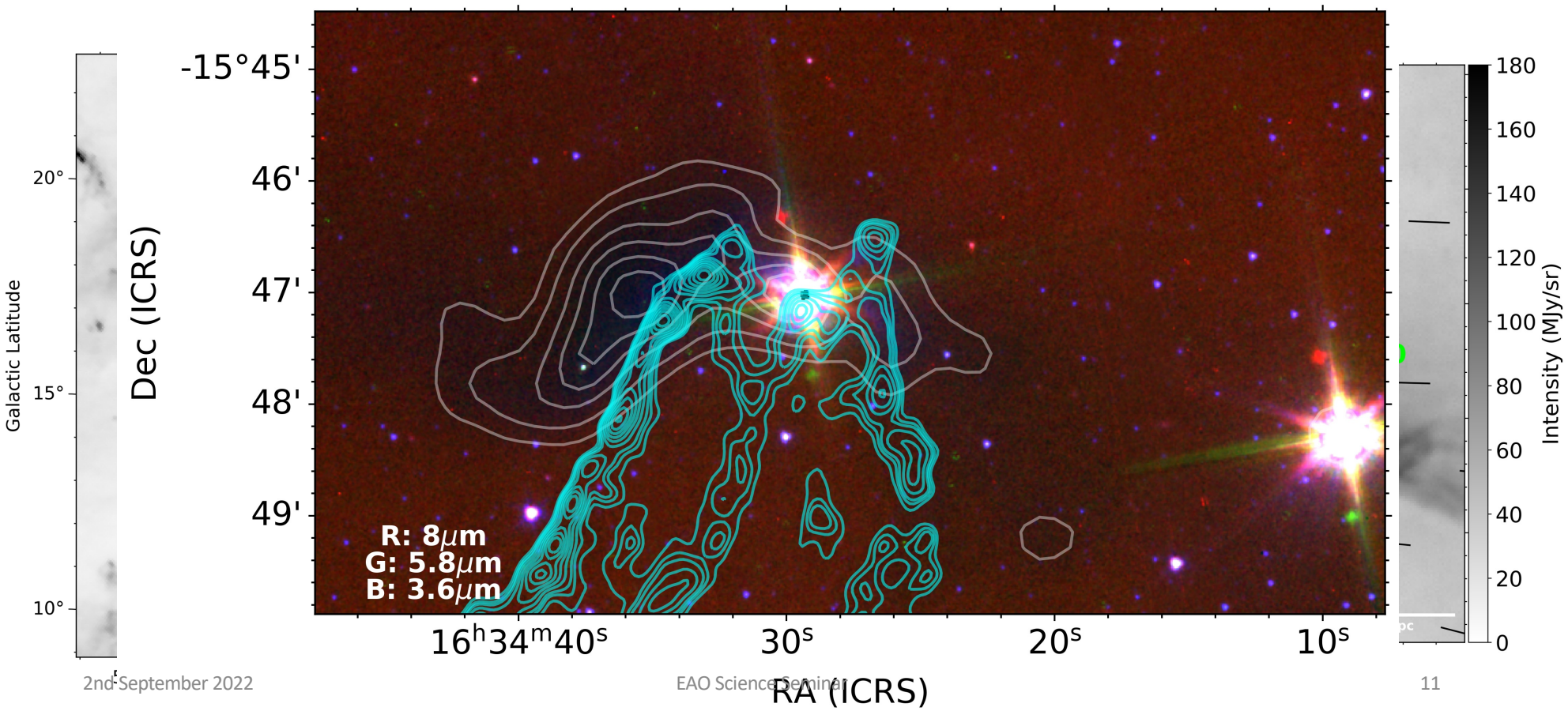


BISTRO-3

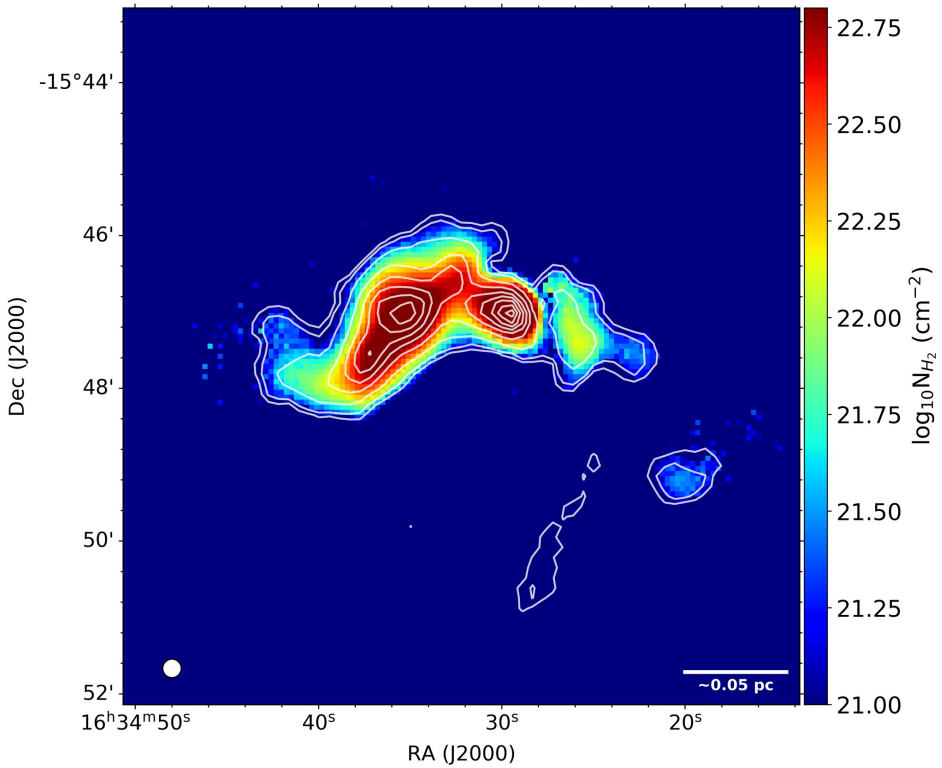
Source	R.A. (J2000)	Dec. (J2000)	Dist. (kpc)	Lin. Res. (pc)	Peak FD (mJy/beam)
Prestellar Cores					
L1544	05:04:16.6	+25:10:48	0.135	0.009	314
L1498	04:11:00.0	+24:58:00	0.140	0.010	∼140
L43	16:34:29.3	−15:47:11	(Oph)		369
L1517B	04:55:18.8	+30:38:04	(Tau)		136
B68 (L57)	17:22:38.2	−23:49:34			58
FeSt 1-457	17:35:45.0	−25:33:12	(Pipe)		∼180
Zhang+14 Sources					
G192.16	05:58:13.6	+16:31:58	1.9	0.130	1993
G35.2N	18:58:13.0	+01:40:37	2.2	0.150	8588
G240.31	07:44:52.0	−24:07:43	4.7	0.321	2157
I18360	18:38:40.7	−05:35:04	4.8	0.328	5854
W51 e2/e8	19:23:43.9	+14:30:35	6.3	0.431	61740
Other massive filaments					
G28.34+0.06 (Dragon)	18:42:50	−04:03:30.3	4.8	0.328	4934
Galactic Centre					
Sgr B2	17:47:20.4	−28:23:07	8	0.547	131737
G0.253+0.016 (Brick)	17:46:09.7	−28:43:31	8	0.547	4225
Clouds e/f	17:46:48.0	−28:32:00	8	0.547	5115
20 km/s cloud	17:45:38.0	−29:05:34	8	0.547	6066

- Dim, small and nearby
- Various stages of evolution
- Far away but massive and bright

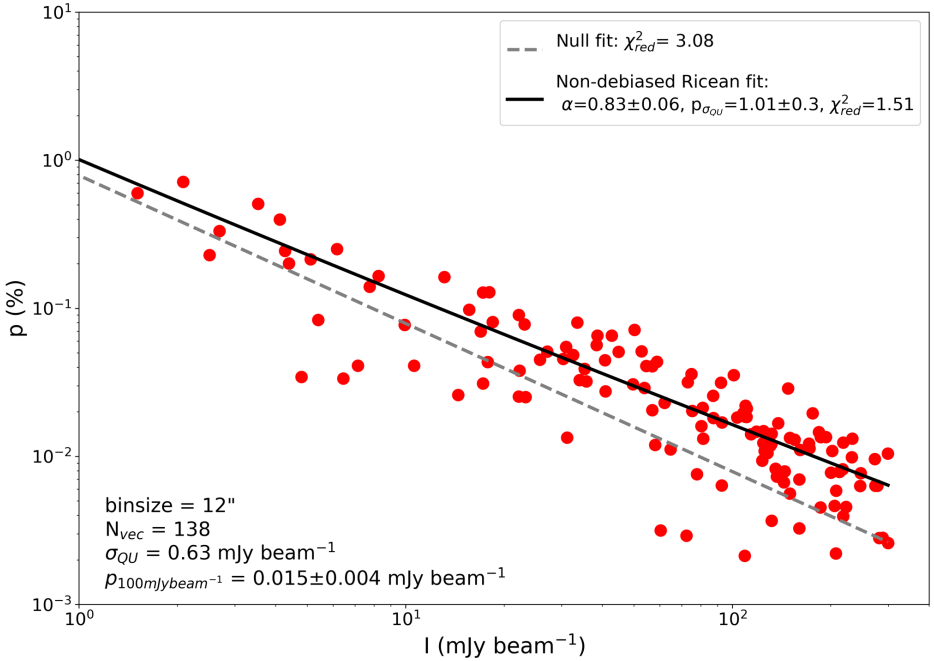
First BISTRO-3 Source: L43



L43 – A dense molecular cloud

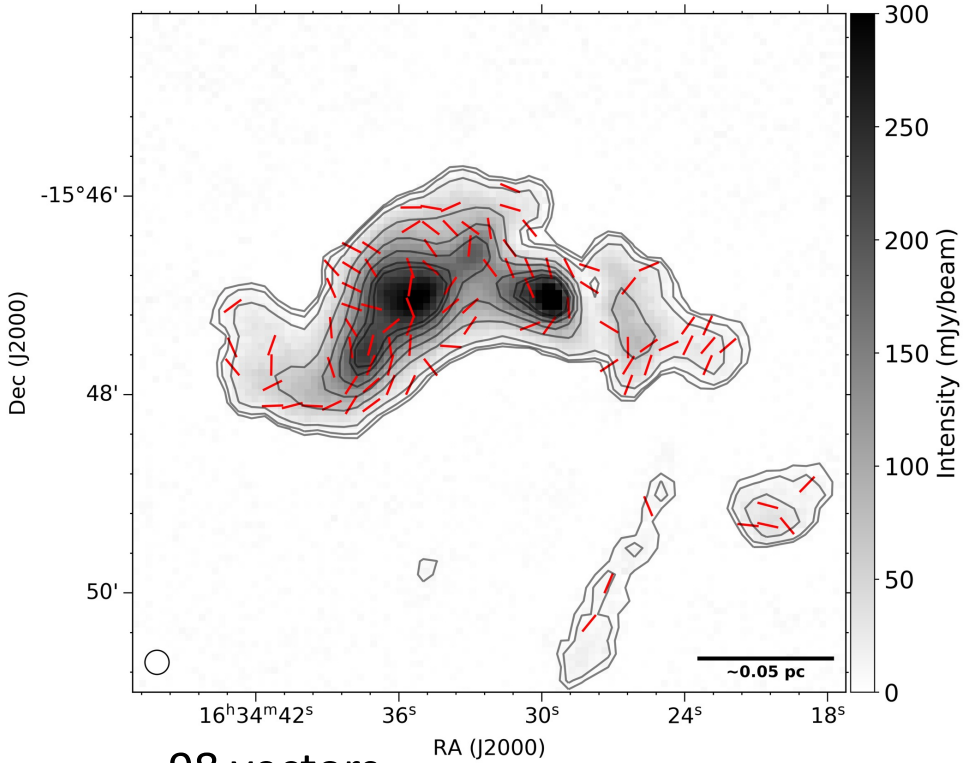


Grain alignment problem?



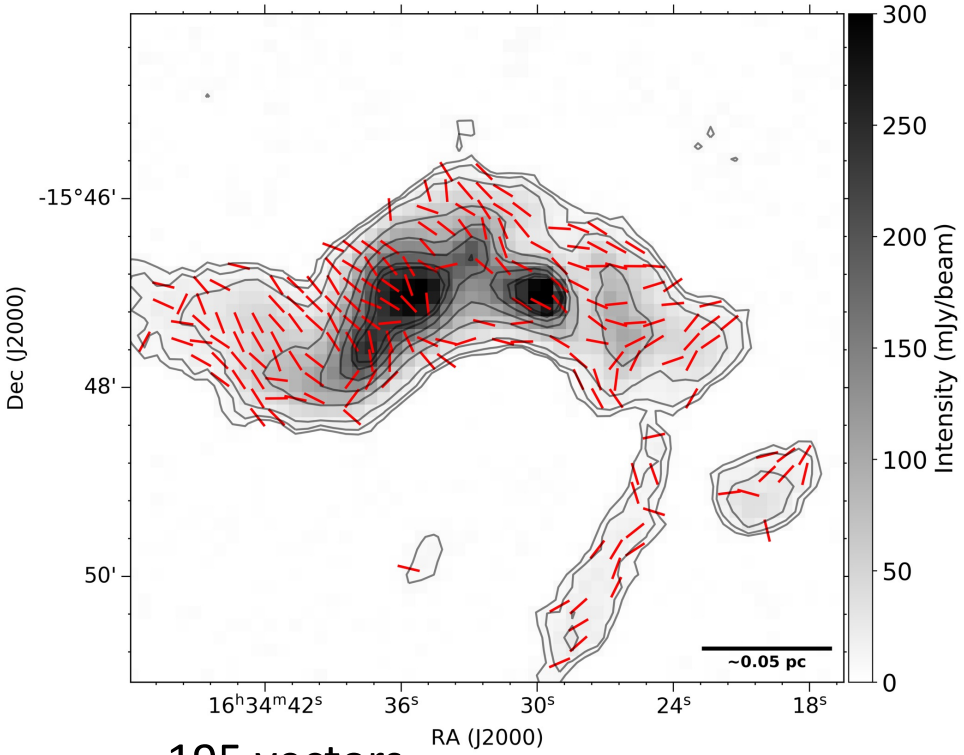
L43 – Data Reduction

4” pixels (pixsize=4)



98 vectors

8” pixels (pixsize=8, 8” auto masks)

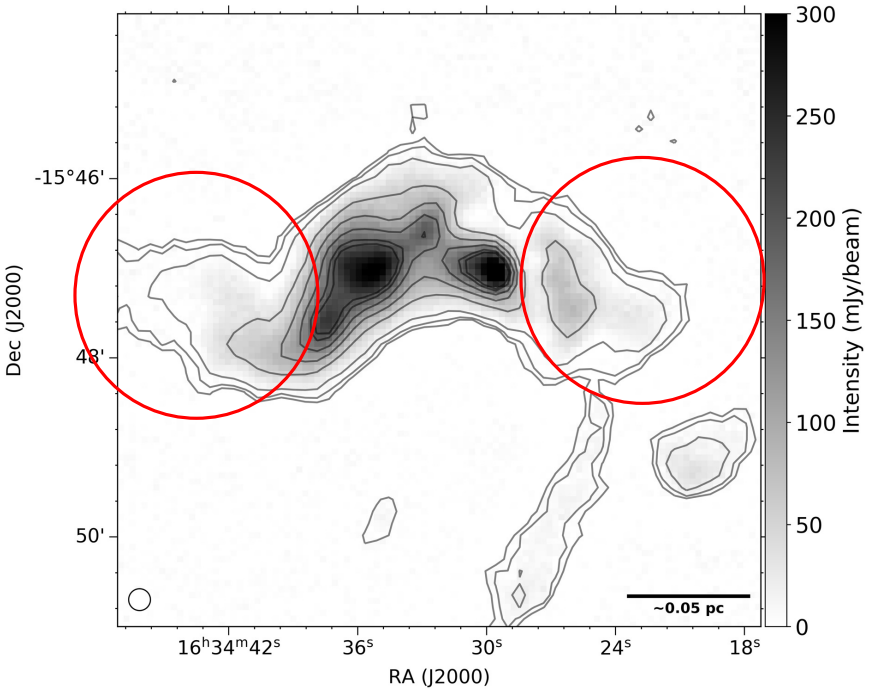


195 vectors

All vectors: 12” binned, p/dp > 2, I/dI > 10

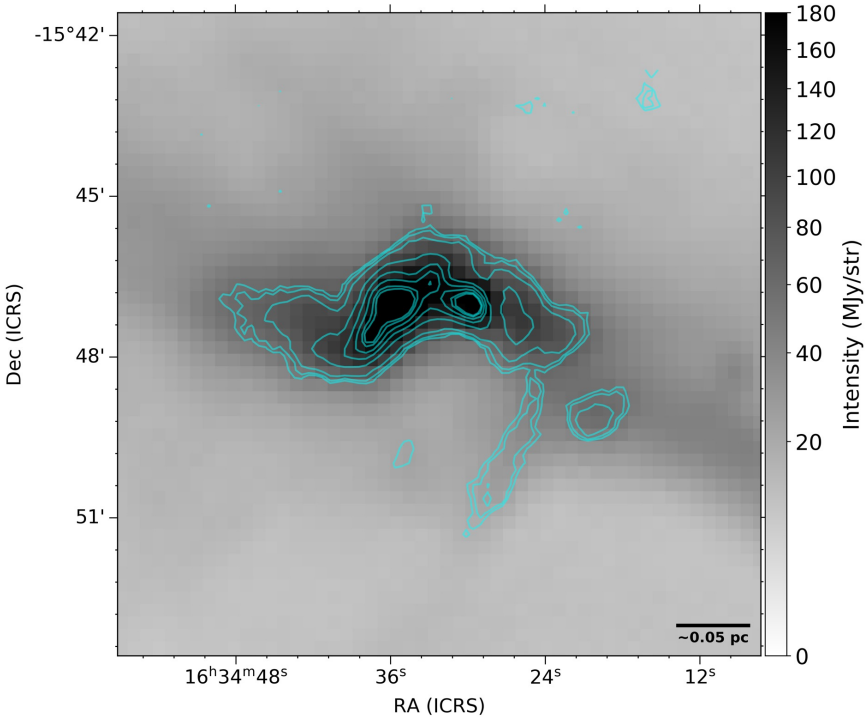
L43 – Data Reduction

Potential Problem – Extra extended emission (artificial or real?)



Background: Stokes I 4” pixel reduction

Contours: 8” pixel reduction (with 8” auto masks)

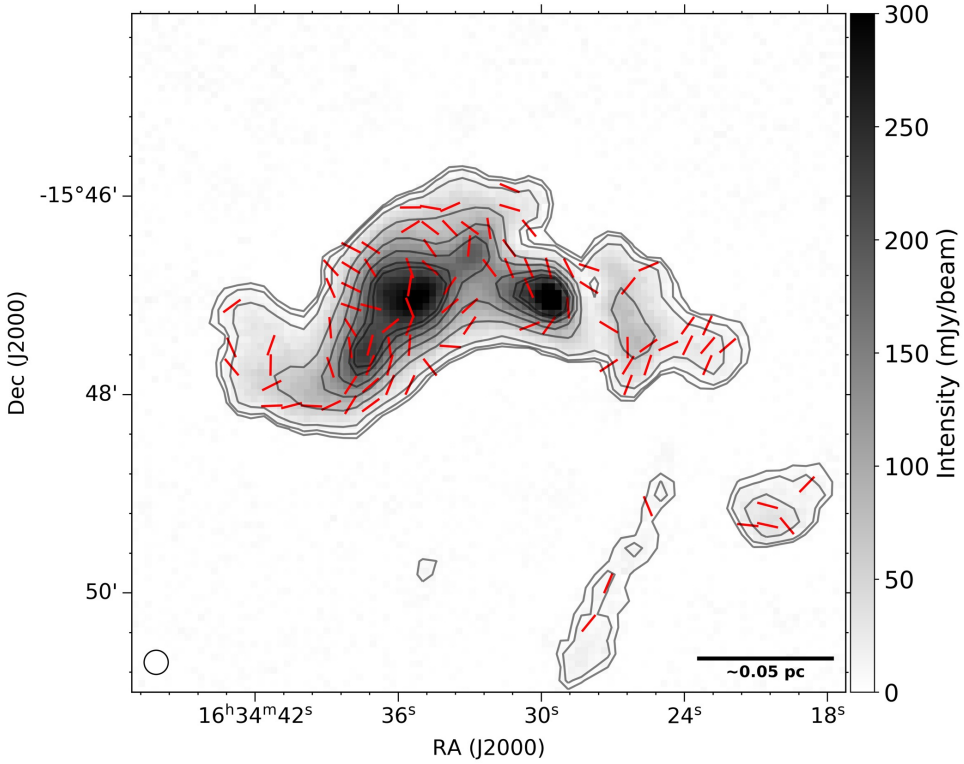


Herschel 500um – do see the extended emission

Contours: same as left

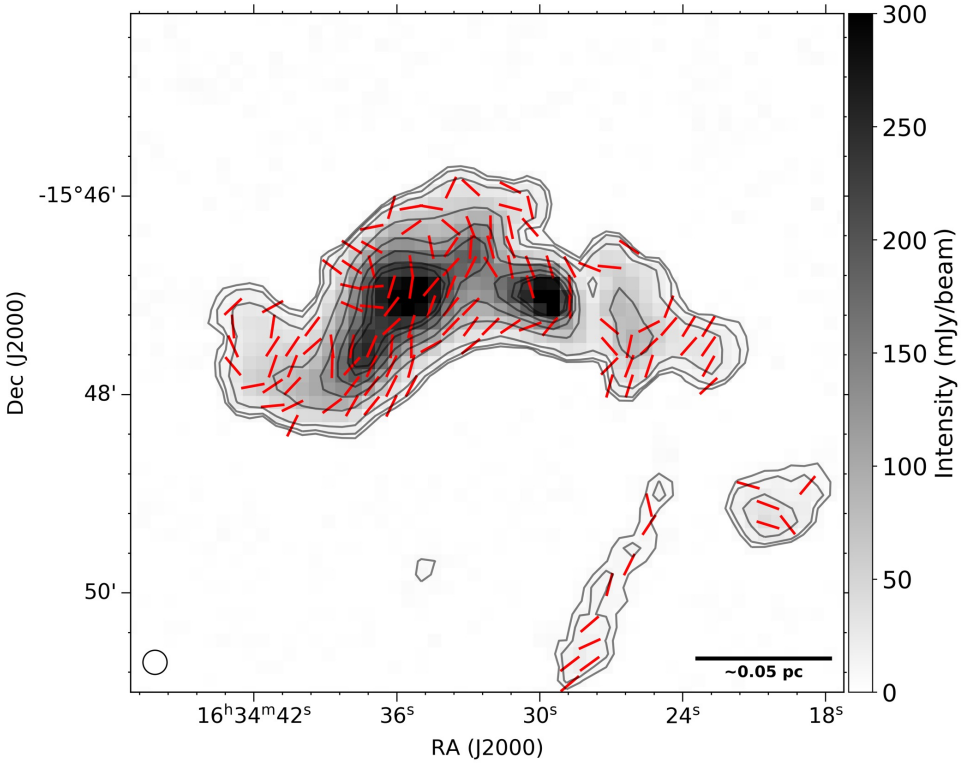
L43 – Data Reduction

pixsize=4”



98 vectors

pixsize=8” (with 4” regridded masks)



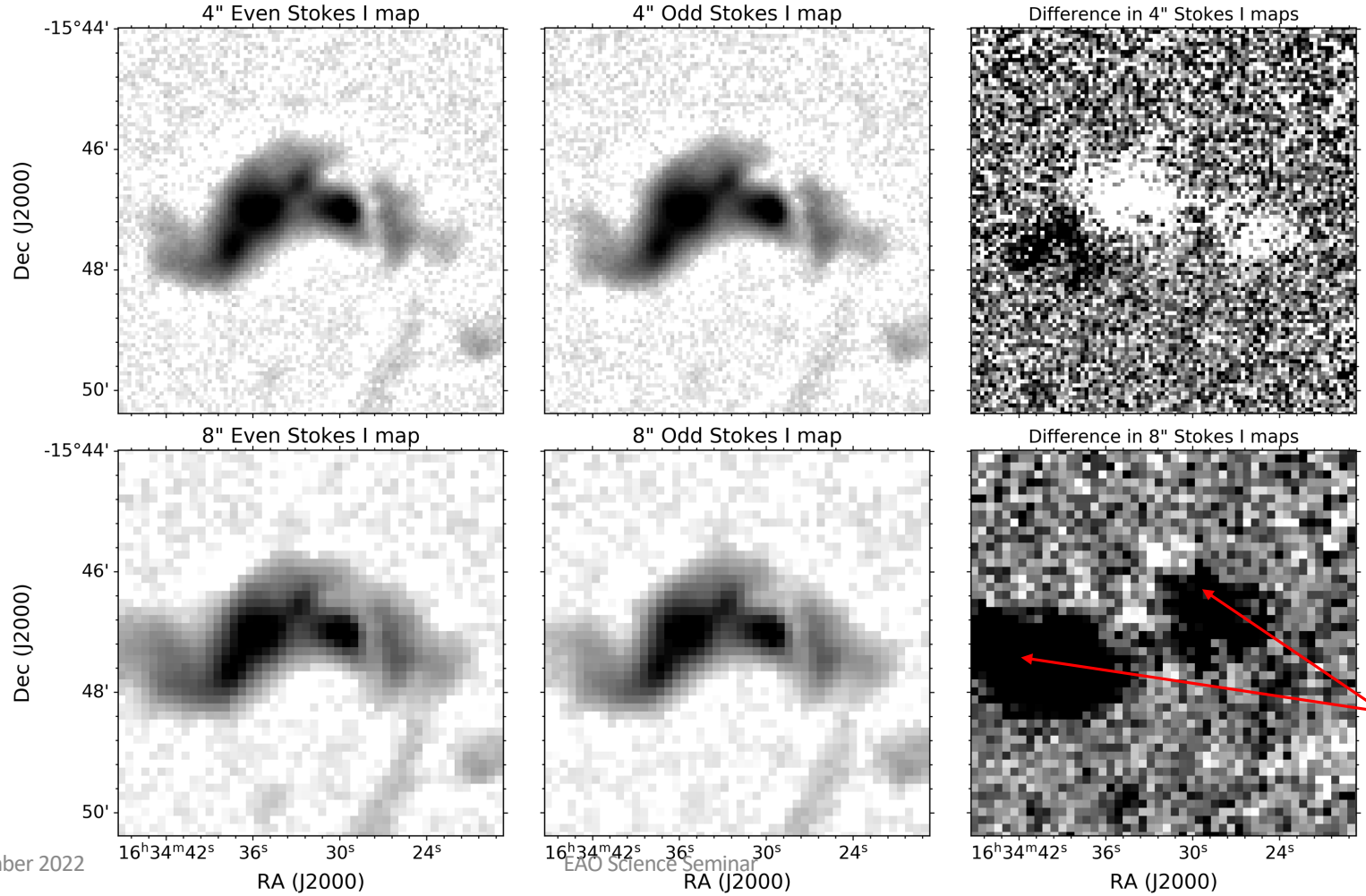
133 vectors

All vectors: 12” binned, p/dp > 2, I/dI > 10

L43 – Data Reduction

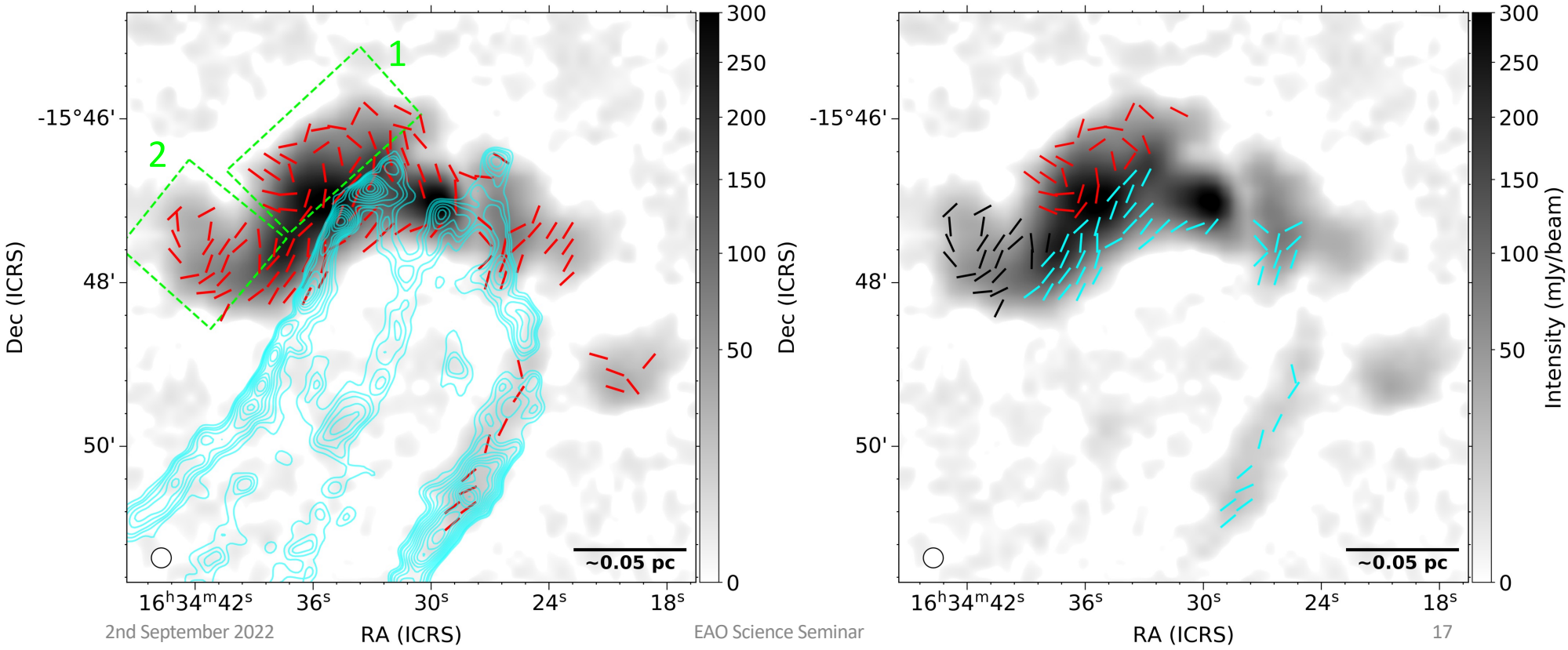
4” reduction

8” reduction with 8” auto masks

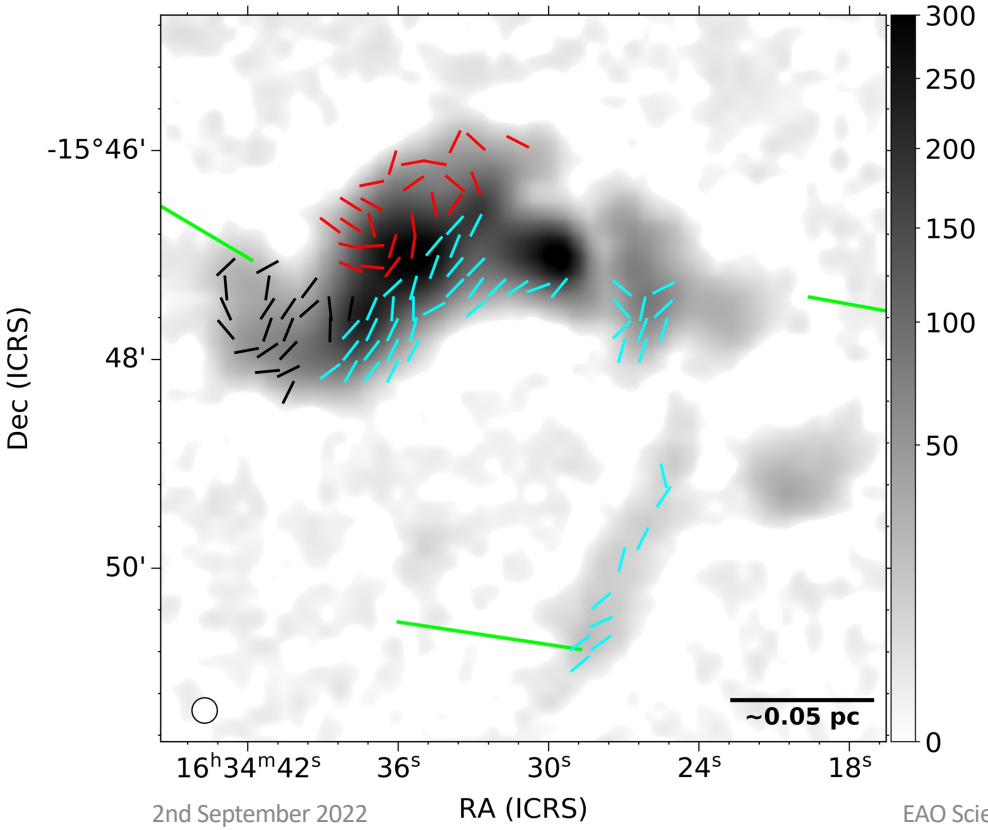


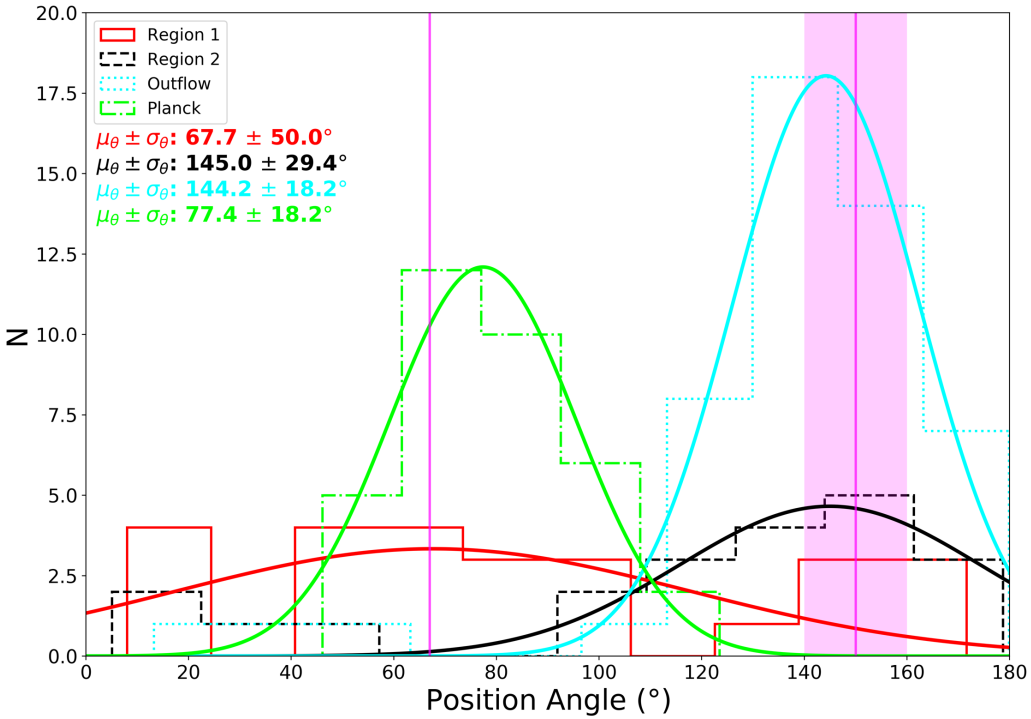
Areas of extra emission, may be factor of group selection

L43 – The Magnetic Field



L43 – The Magnetic Field





Calculation of Magnetic Field Strength

- Many methods to do this
  - Davis Chandresekhar Fermi Method
  - Angular Dispersion Function
  - Velocity gradient technique

"Classical" DCF:

$$B_{pos} \approx 9.3\sqrt{n_{H_2}}\frac{\Delta V_{NT}}{\delta\theta}$$

$$\mathrm{M}_A = \frac{\sigma_{NT}}{v_A} = \frac{\sigma_\theta}{Q}$$

$$v_A = \frac{B}{\sqrt{4\pi\rho}}$$

$$\lambda = 7.6 \times 10^{-21}\frac{N_{H_2}}{B_{pos}}$$

L43 - Magnetic Field Strength

"Classical" DCF: $B_{pos} \approx 9.3\sqrt{n_{H_2}}\frac{\Delta V_{NT}}{\delta\theta}$

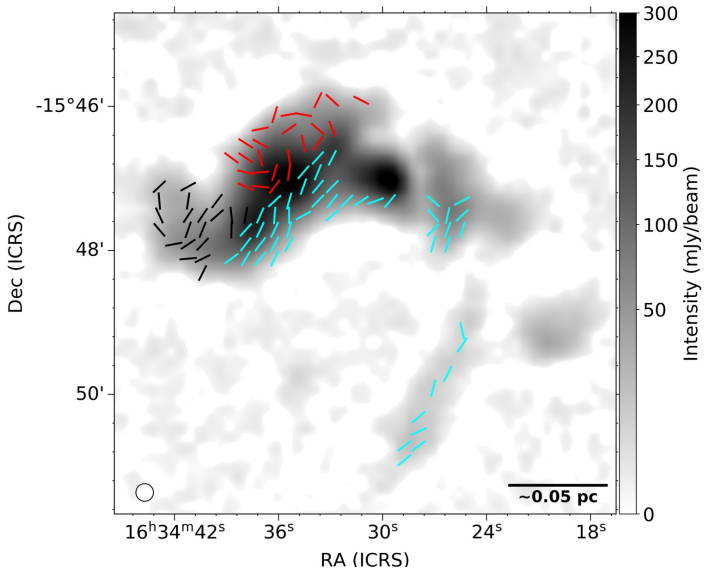
Region 1:

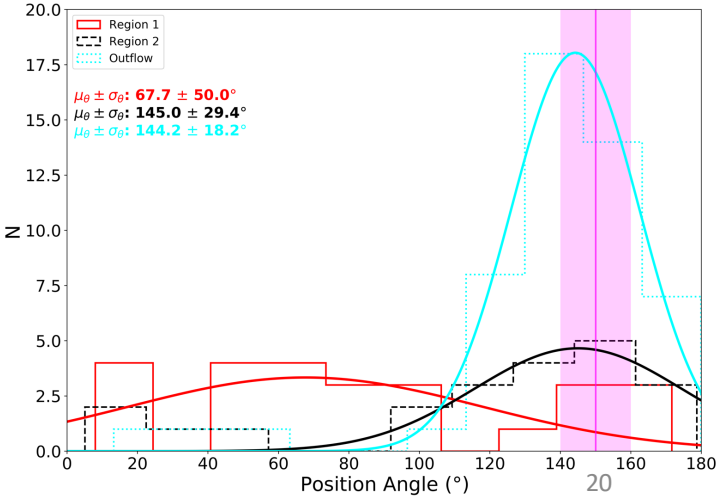
- $B_{pos} \approx 90 \pm 30\ \mu G$
- $\lambda \approx 0.7 \pm 0.5\ -2.0 \pm 1.5$
- $\mathrm{M}_A \approx 1.9 \pm 0.9$

Region 2:

- $B_{pos} \approx 30 \pm 10\ \mu G$
- $\lambda \approx 1.2 \pm 0.7\ -3.6 \pm 2.0$
- $\mathrm{M}_A \approx 4.0 \pm 1.4$

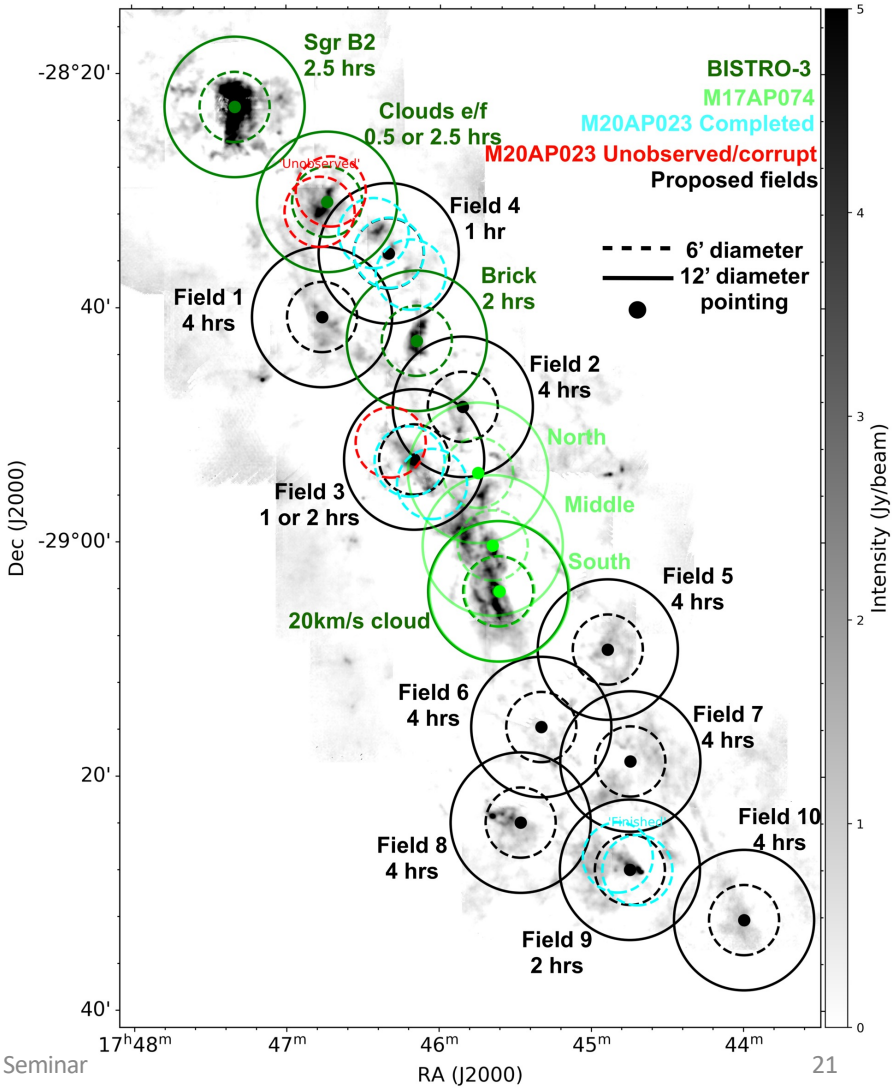
Lots of assumptions!
Large errors!





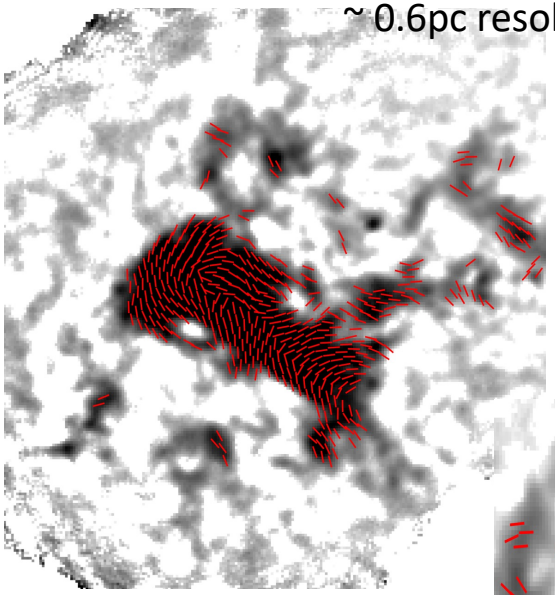
The Galactic Centre

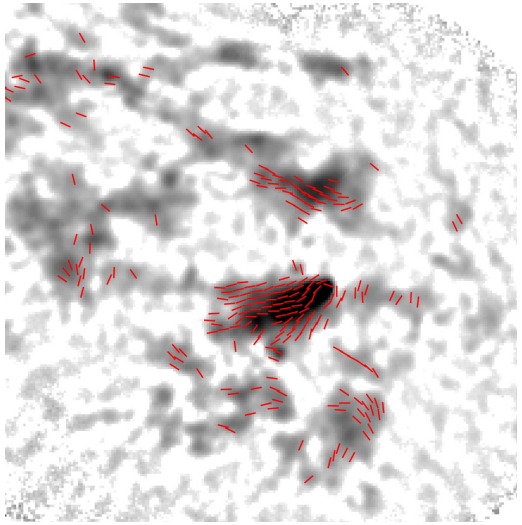
- Originally 4 proposed fields: Sgr B2, Clouds e/f, Brick and 20km/s Cloud, ~14 hrs each
- Change to ~4 hrs each and add 10 fields, synthesize with M20AP023 observations
- Will end up with a mosaic across the CMZ from Sgr B2 to Sgr C

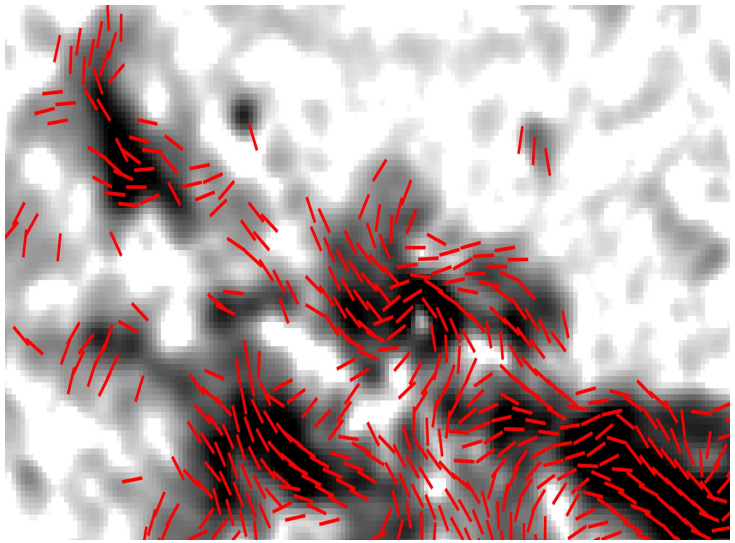


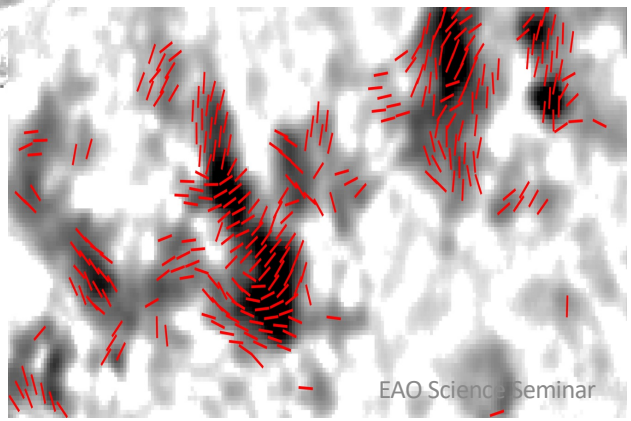
Ordered large-scale fields

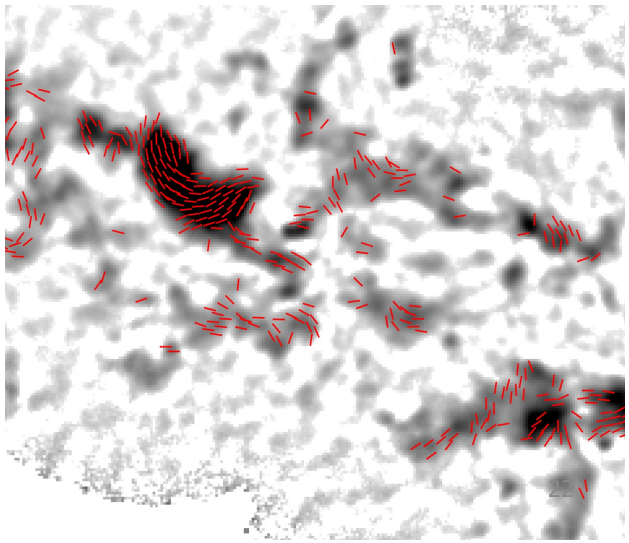
- D ~ 8300 pc
- JCMT beamsize ~ 15”
  ~ 0.6pc resolution





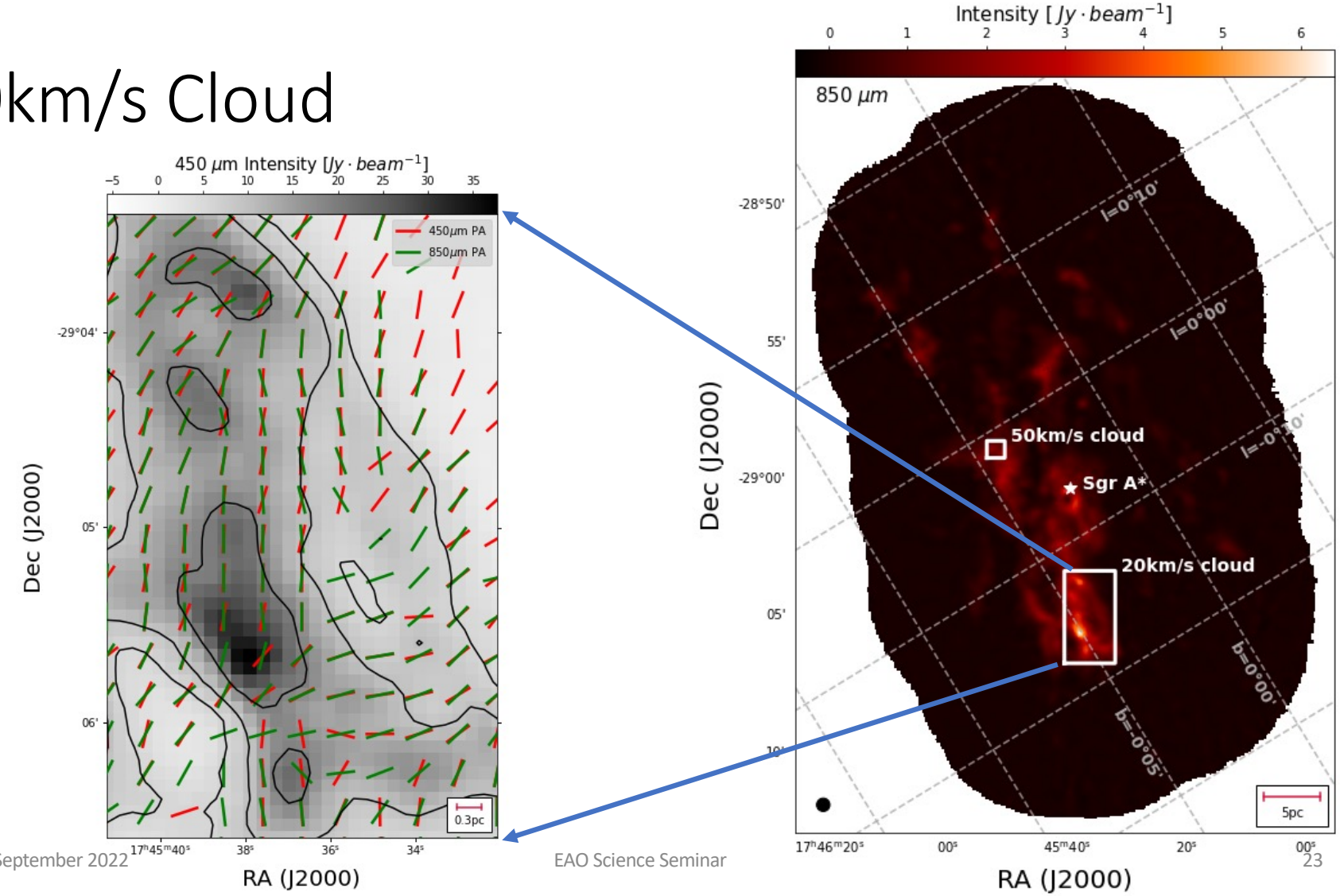






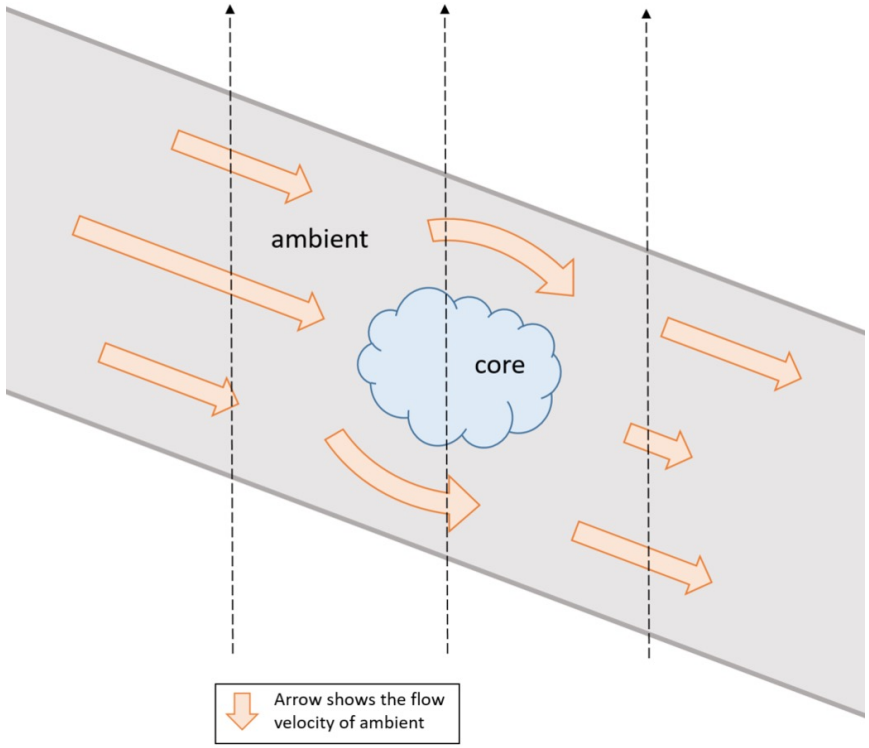
Field strengths on order of 10s of mG

20km/s Cloud


450 μm Intensity [Jy · beam⁻¹]
450μm PA
850μm PA
0.3pc
Dec (J2000)
RA (J2000)
Intensity [Jy · beam⁻¹]
850 μm
50km/s cloud
Sgr A*
20km/s cloud
5pc
l=0°10'
l=0°00'
b=0°00'
b=-0°05'
Dec (J2000)
RA (J2000)

20km/s Cloud

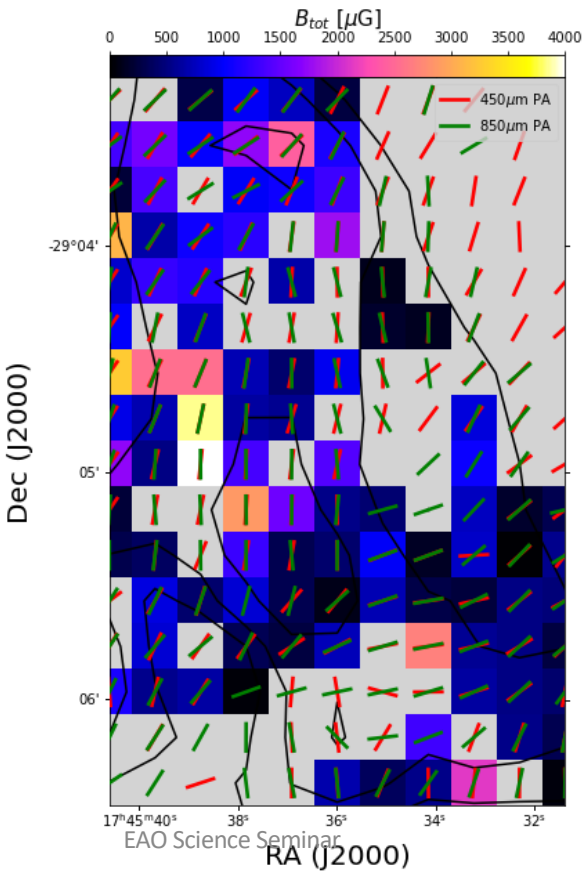
- From CHIMPS data, multiple component CO profiles
- Hypothesis – an ambient material (moving close to 20km/s) and a core



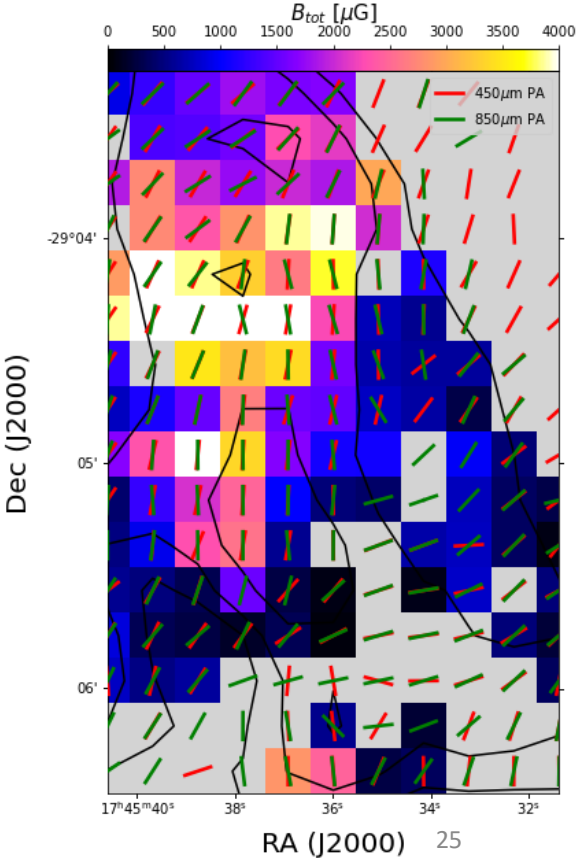
20km/s Cloud

- Field strengths on order of mG
- Finds that on this large scale, magnetic field does support against gravity

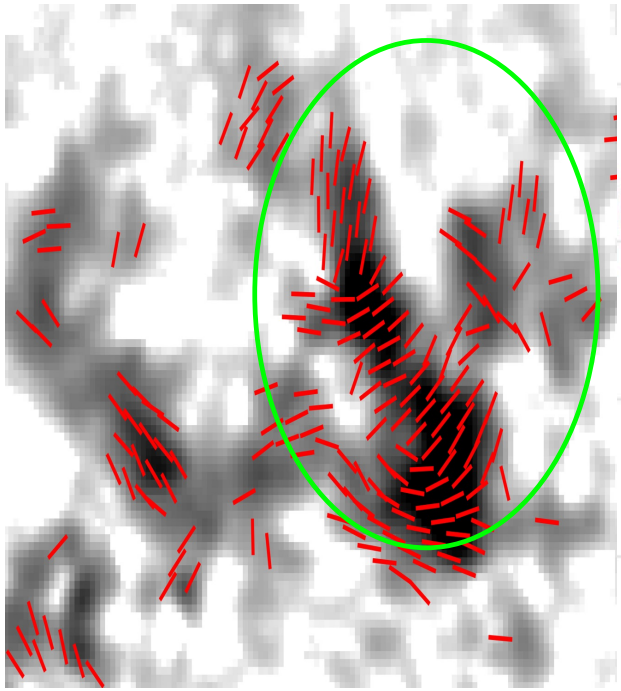
“core”

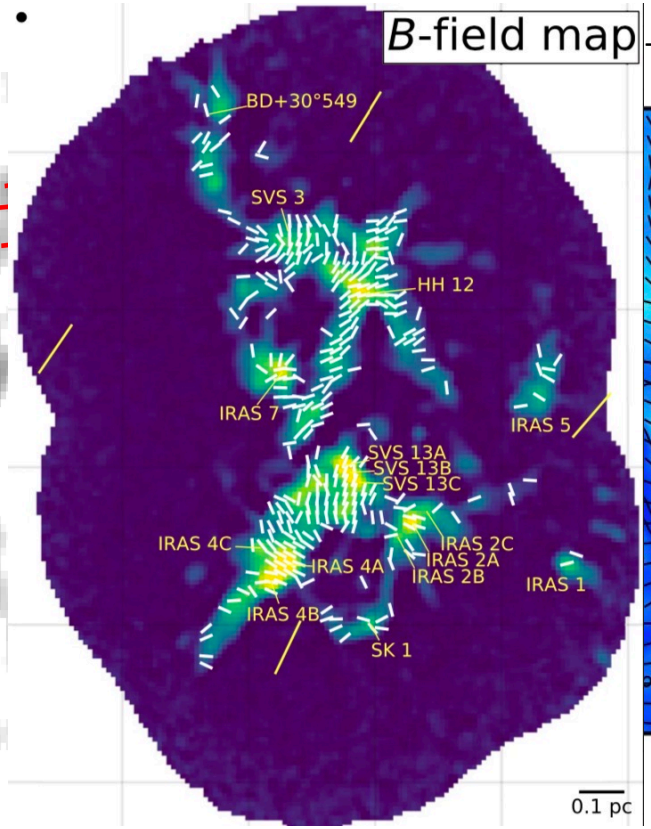


ambient

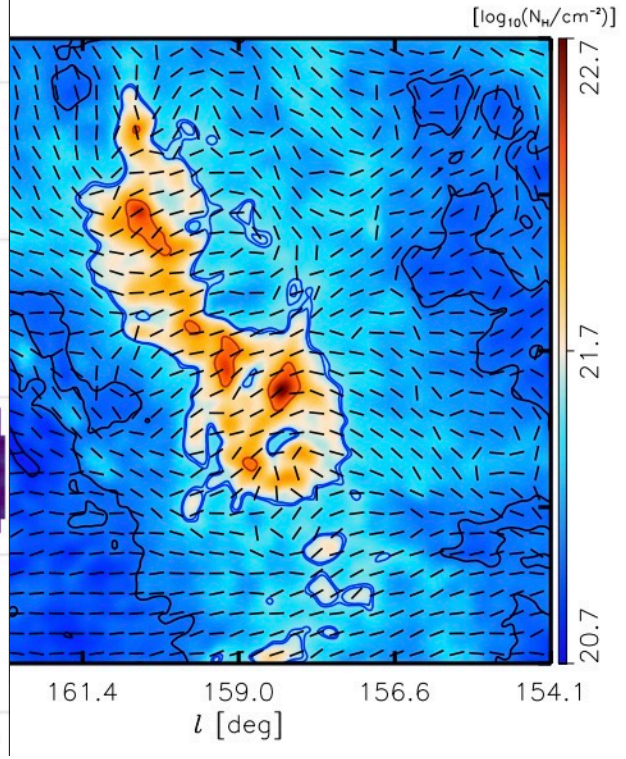


Ordered large-scale fields





-Field map of Perseus region

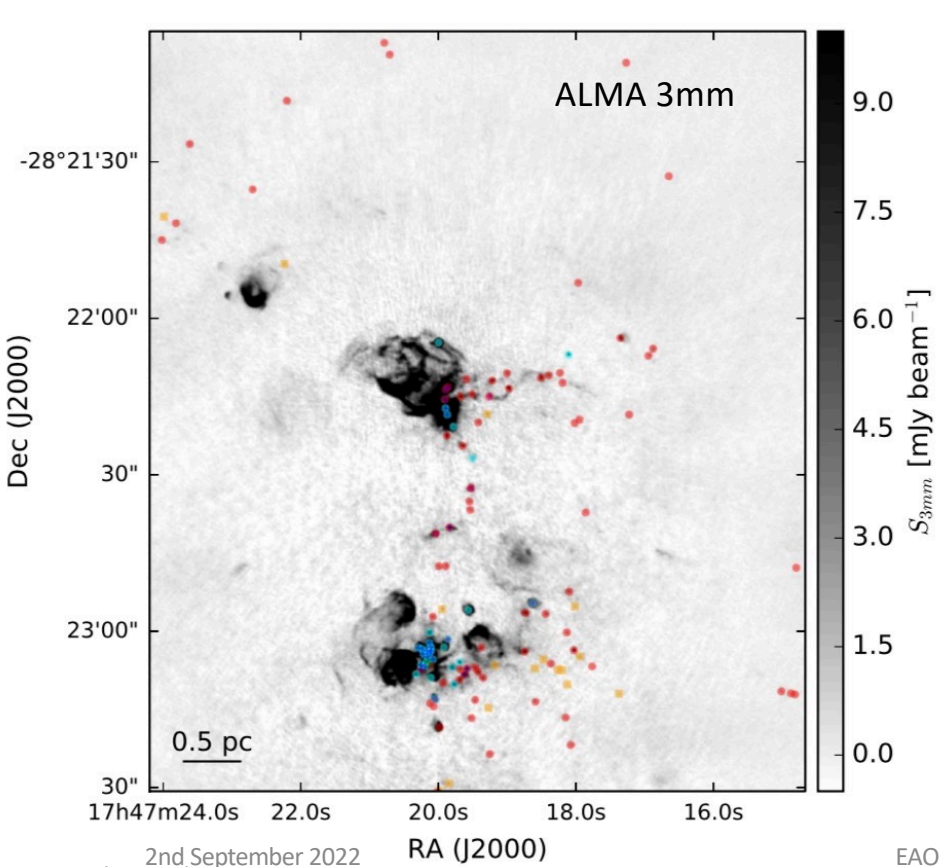


Planck Collaboration, 2016, A&A, 586, 138

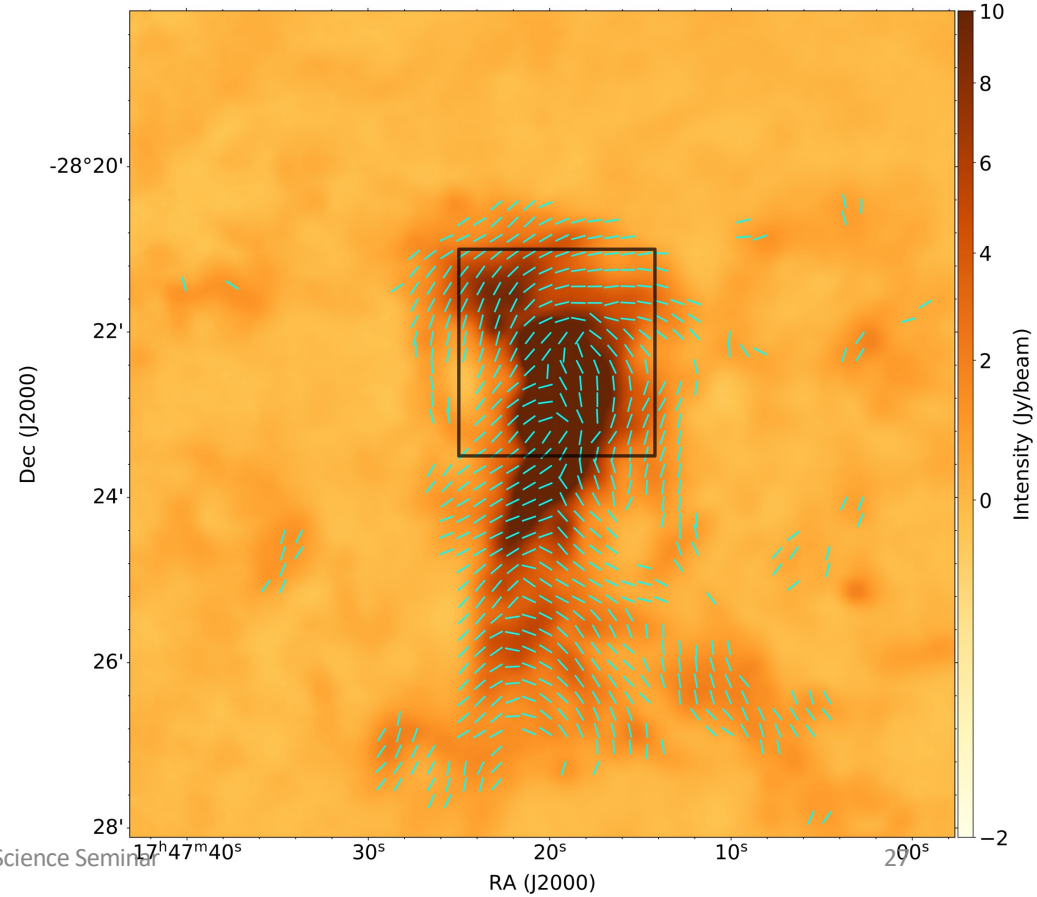
15” resolution at 8300 pc (~0.6pc)

10’ resolution at 300 pc (~0.9pc)

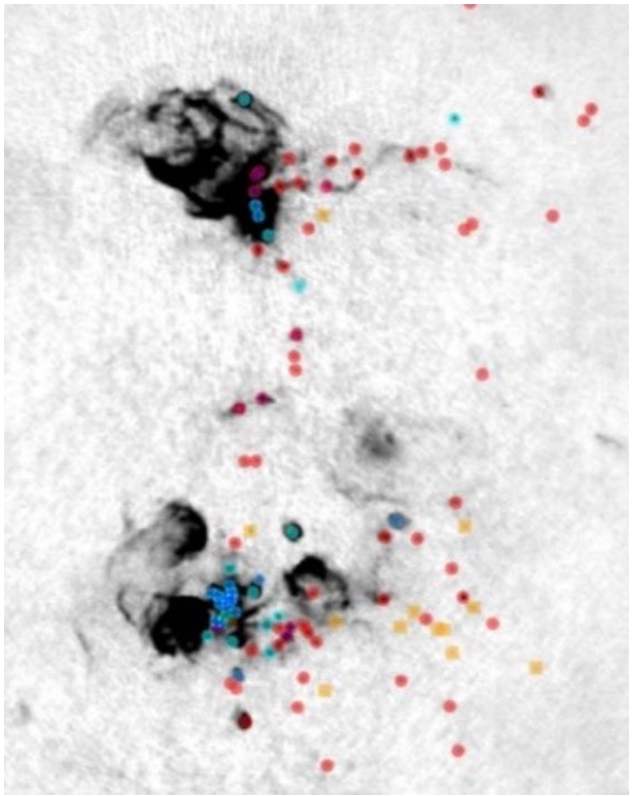
Sgr B2



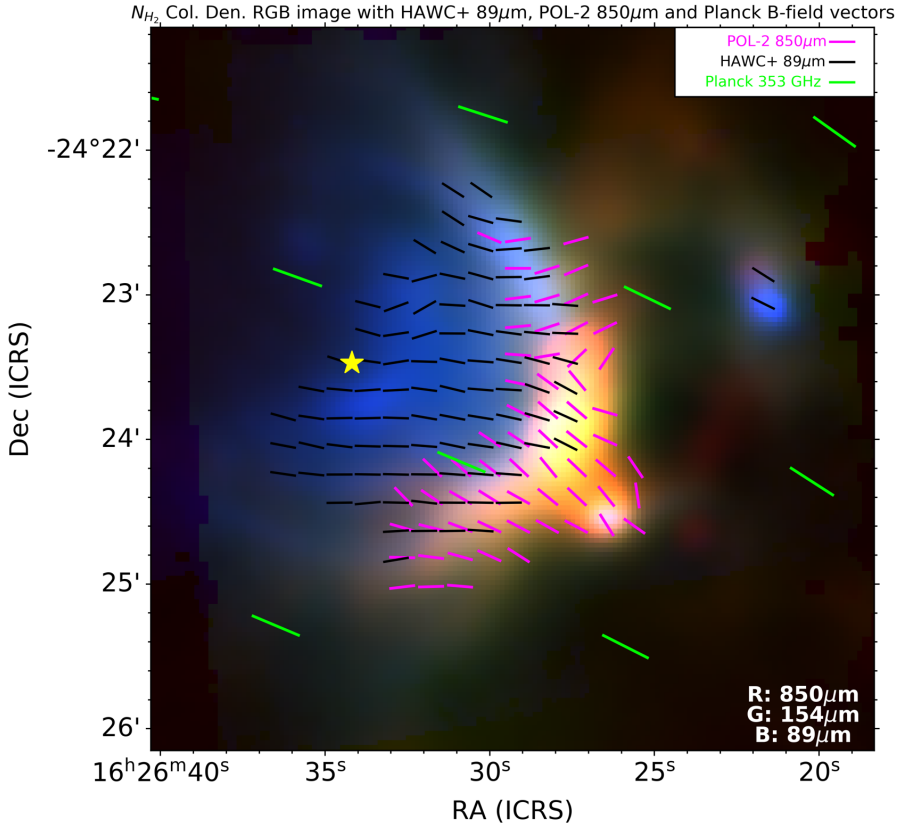
Ginsburg et al. 2018, ApJ, 853, 171



H II Regions



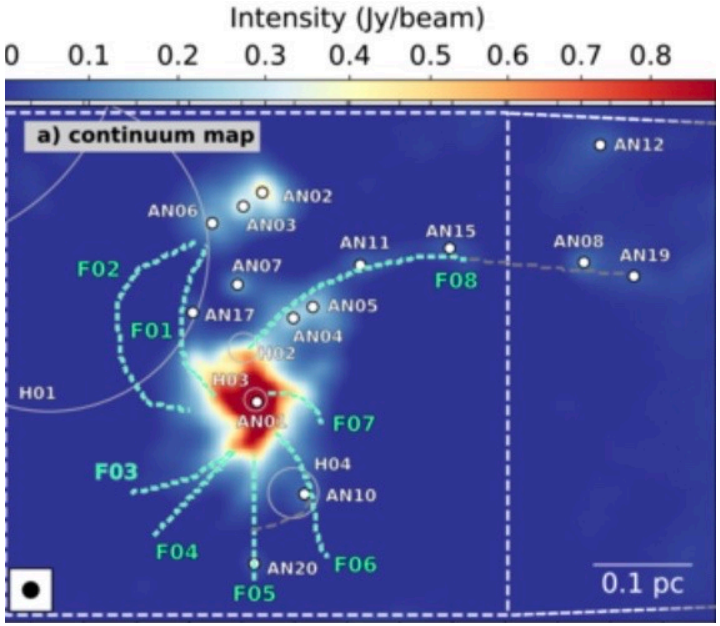
JCMT resolution ~ 0.6pc
ALMA 3mm resolution ~ 0.06 pc

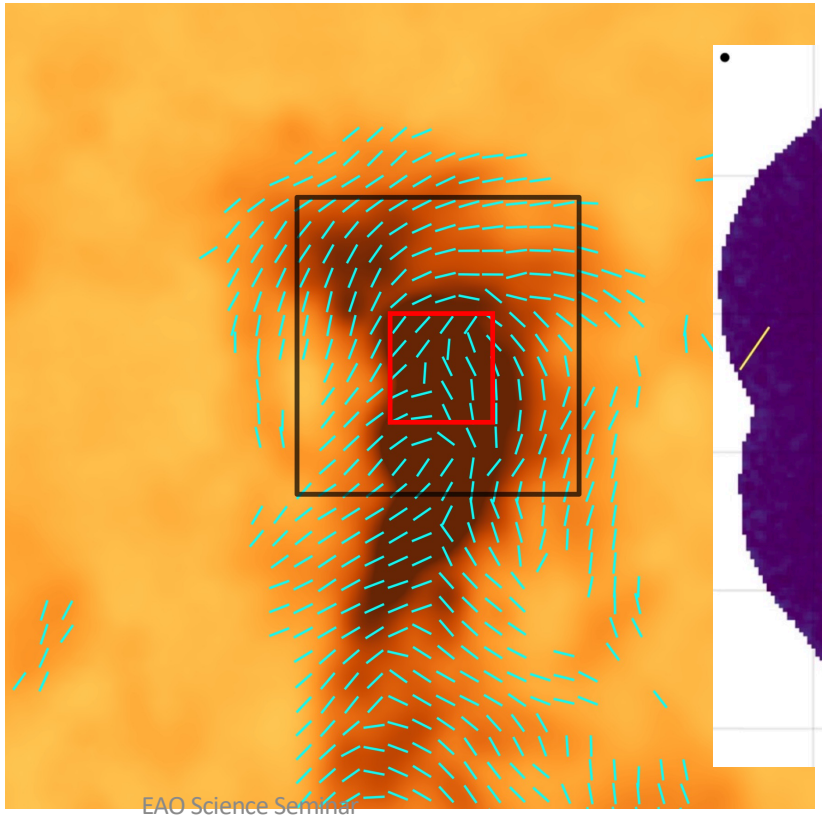


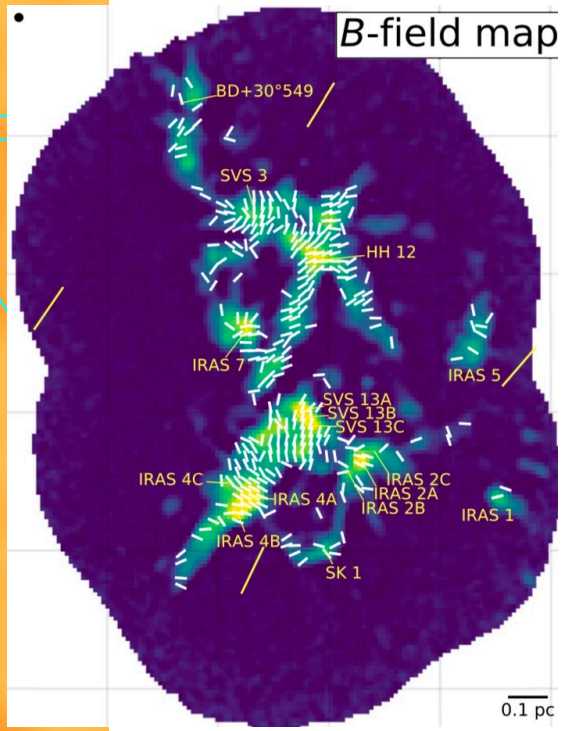
Planck resolution ~ 0.4pc
JCMT resolution ~ 0.01 pc

Filamentary structures in Sgr B2

ALMA Scales







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Conclusions/Summary

- BISTRO-1/2 have already provided interesting results about magnetic fields in nearby, small-mid size star-forming regions
  - Misalignment of B-field with protostellar outflows
  - B-field perpendicular or parallel to filaments depending on density or material flow
  - B-fields contributing to the energy budget of clouds on par with kinetic and gravitational energies
- BISTRO-3 aims to expand on these results in the smallest and most massive star-forming regions
  - L43 shows B-field potentially aligned with outflow cavity walls and B-field is losing out to turbulence and gravity
  - Large, structured magnetic fields in the Galactic Center – can infer global magnetic field strengths of cloud as well as smaller scale magnetic field roles based on comparison with nearby regions and Planck/POL-2

Thank you!!!