Polarization
ALMA data analysis

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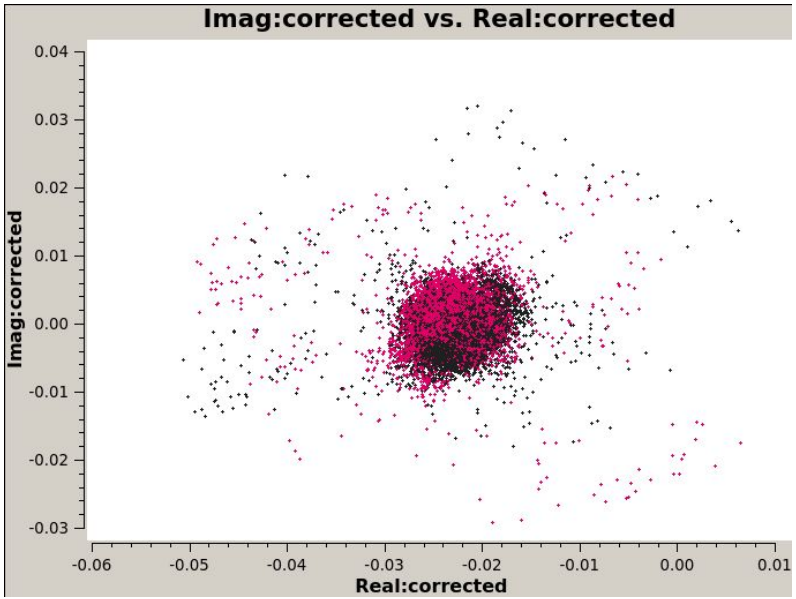
Goal

- Check Polarization calibration quality
  - Instrumental polarization
  - Flag the outliers in the scattered data
- Imaging calibration
- Playing `tclean` with some parameter changes
  - Robust parameters
  - Masking
  - Interactive vs non-interactive masking



Data

- Project code: 2019.1.00134.S
- Target source: HL Tau
- Band: Band 4 (140 GHz - 2.1mm)
- Lin et al. (2024) discussed the origin of polarization mechanism in HL Tau protoplanetary disk. It was reported that polarization angle distribution is approximately consistent with azimuthal in Band 4 while it becomes parallel to disk minor axis in higher bands.

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Panchromatic (Sub)millimeter polarization observations of HL Tau unveil aligned scattering grains

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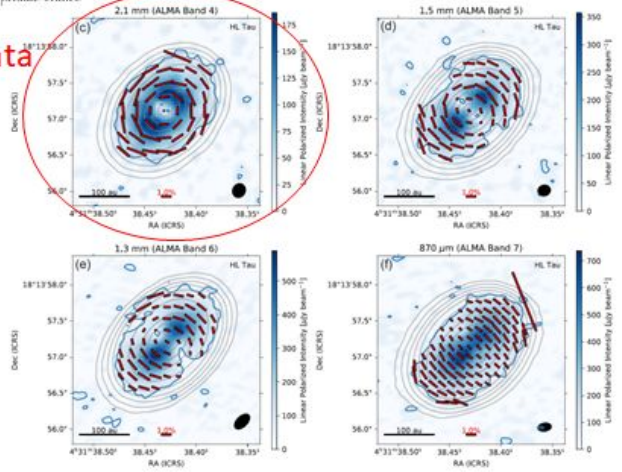
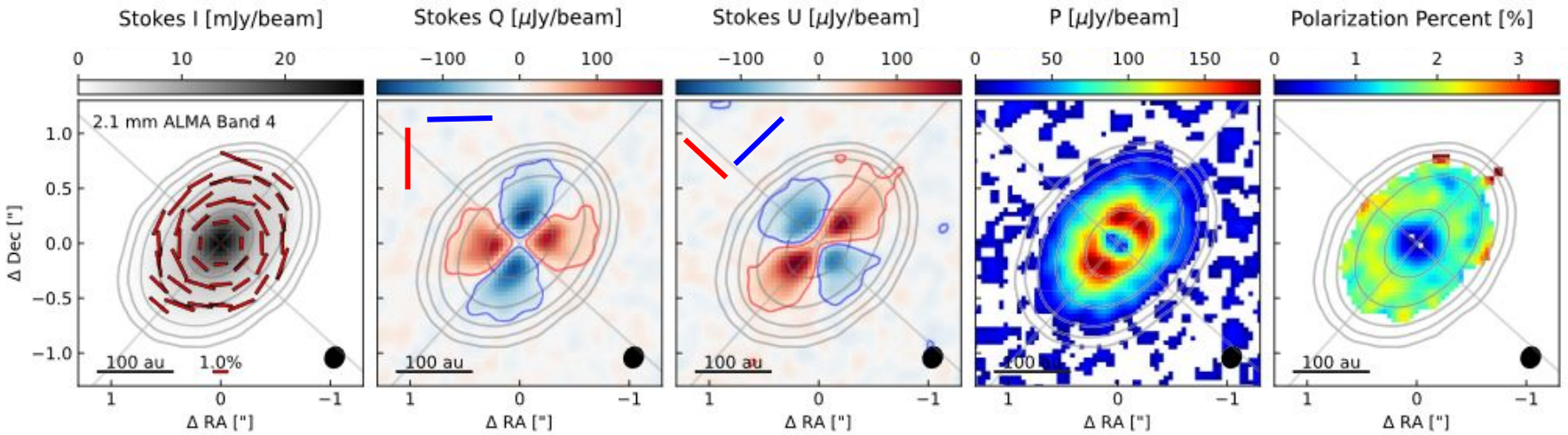
ABSTRACT

Polarization is a unique tool to study the dust grains of protoplanetary discs. Polarization around HL Tau was previously imaged using the Atacama Large Millimeter/submillimeter Array (ALMA) at Bands 3 (3.1 mm), 6 (1.3 mm), and 7 (0.87 mm), showing that the polarization orientation changes across wavelength λ. Polarization at Band 7 is predominantly parallel to the disc minor axis but appears azimuthally oriented at Band 3, with the morphology at Band 6 in between the two. We present new ~0.2 arcsec (29 au) polarization observations at Q-Band (7.0 mm) using the Karl G. Jansky Very Large Array (VLA) and at Bands 4 (2.1 mm), 5 (1.5 mm), and 7 using ALMA, consolidating HL Tau's position as the protoplanetary disc with the most complete wavelength coverage in dust polarization. The polarization patterns at Bands 4 and 5 follow the previously identified morphological transition with wavelength. From the azimuthal variation, we decompose the polarization into contributions from scattering (s) and thermal emission (t). s decreases slowly with increasing λ, and t increases more rapidly which are expected from optical depth effects of toroidally aligned scattering prolate grains. The weak λ dependence of s is inconsistent with the simplest case of Rayleigh scattering by small grains in the optically thin limit but can be affected by factors such as optical depth, disc substructure, and dust porosity. The sparse polarization detections from the Q-band image are also consistent with toroidally aligned prolate grains.

This data



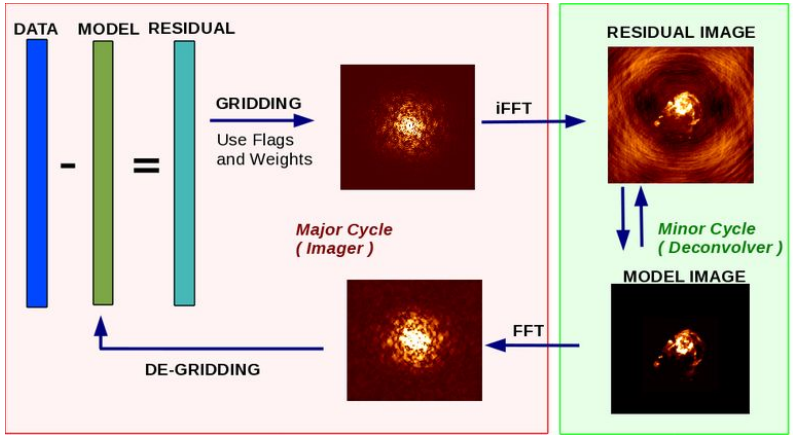
Polarization images from Lin et al. 2024



Basics of interferometric imaging and robust parameter

`tclean` task in CASA

- CLEAN all Stokes parameters separately with ‘clarkstokes’ deconvolver
- Stokes Q, U, V can be negative



https://casadocs.readthedocs.io/en/stable/api/tt/casatasks.imaging.tclean.html

Robust parameter controlling visibility weighting – ranging from -2 to 2

robust = 2.0 (natural) : sensitive to extended emission and large beam size

robust = -2.0 (uniform) : small beam size but lower sensitivity

Example of imaging script

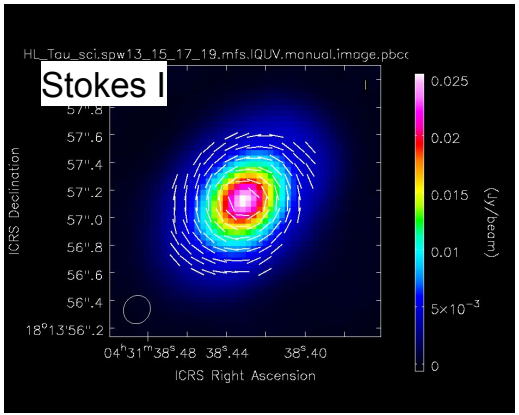
```
tclean(vis = ‘concat_S1.ms.TDM.cal’,
        imagename = 'HL_Tau_sci.spw13_15_17_19.mfs.IQUV.manual',
        field = 'HL_Tau',
        stokes = 'IQUV',
        spw = '0,1,2,3' ⟹ '0',
        outframe = 'LSRK',
        specmode = 'mfs',
        nterms = 1,
        imsize = [500, 500],
        cell = '0.041arcsec',
        deconvolver = 'clarkstokes',
        niter = 1000,
        weighting = 'briggs',
        robust = 0.5,⟹ [-2, 0.5, 2]
        mask = '',
        gridder = 'standard',
        pbcor = True,
        threshold = '0.011mJy',
        interactive = True
        )
```

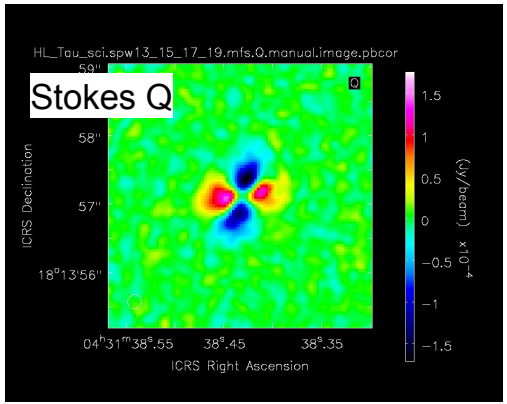
Reducing imaging time

casaviewer does not support Mac OS.
Mac users are forced to non-interactive imaging

Results: Interactive

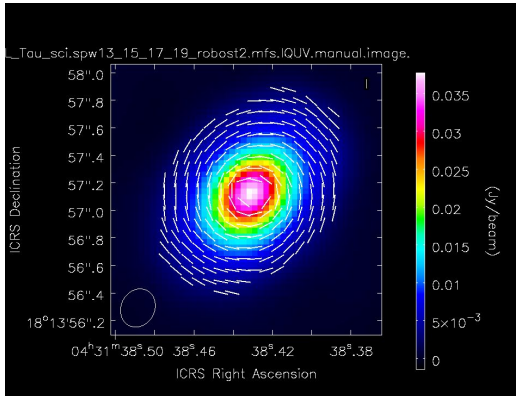
robust = 0.5

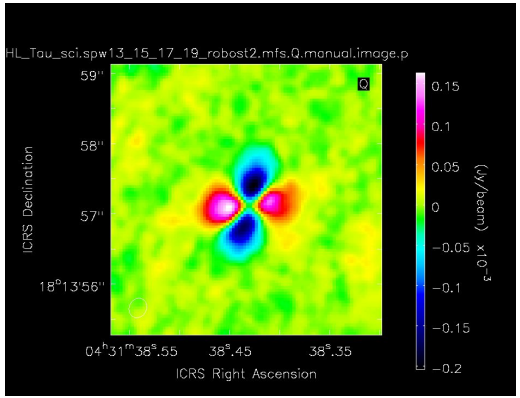




beam size: 0.19 arcsec

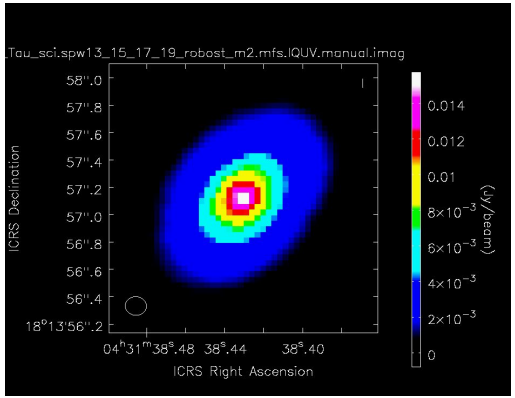
robust = 2.0

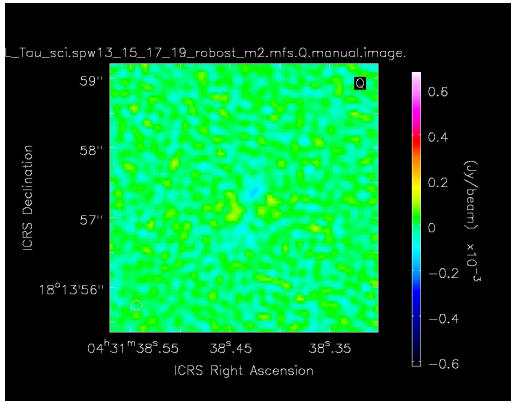




beam size: 0.24 arcsec

robust = -2.0

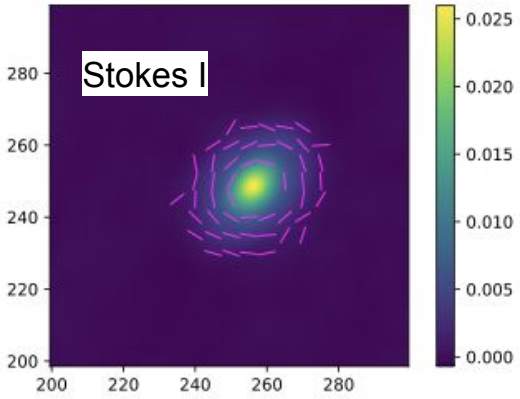


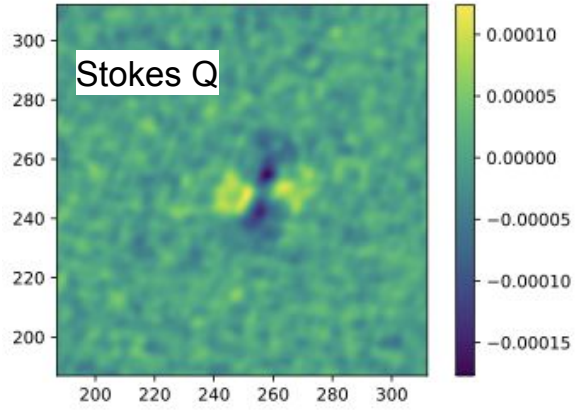


beam size: 0.13 arcsec

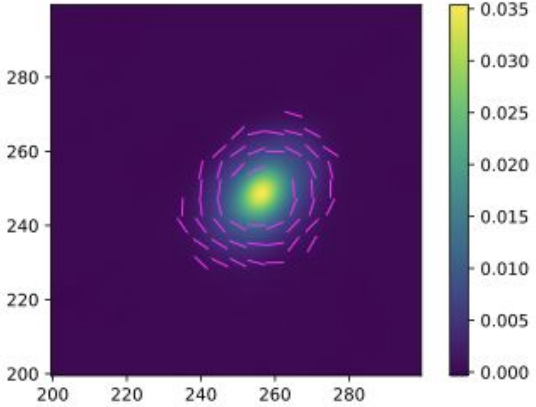
Results: Non-interactive

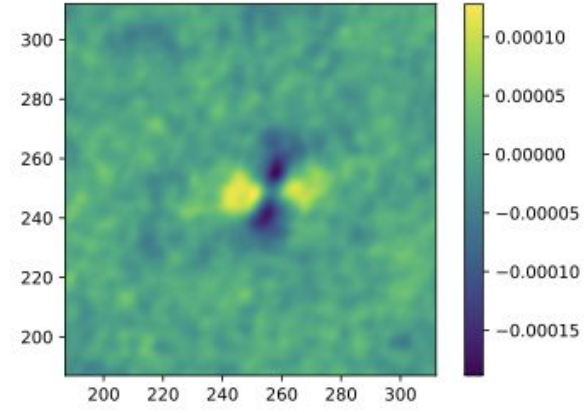
robust = 0.5
1 RMS = 458 uJy/beam



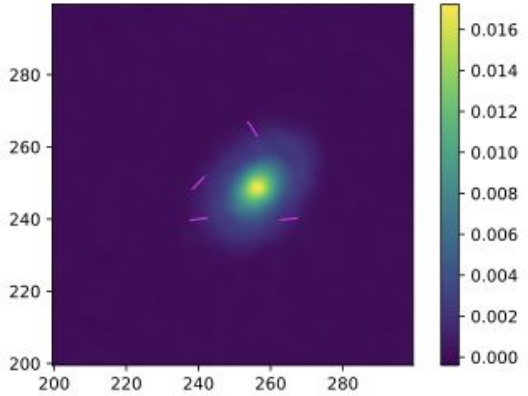


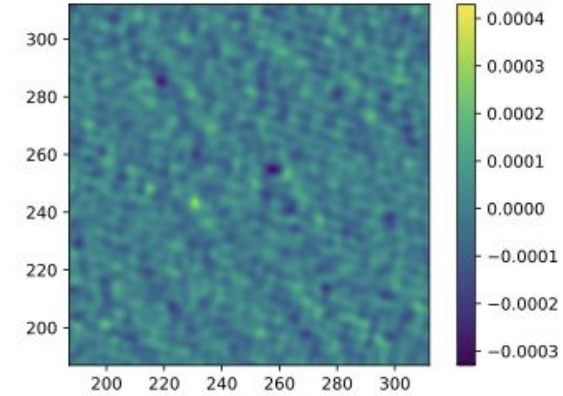
robust = 2
1 RMS = 733 uJy/beam



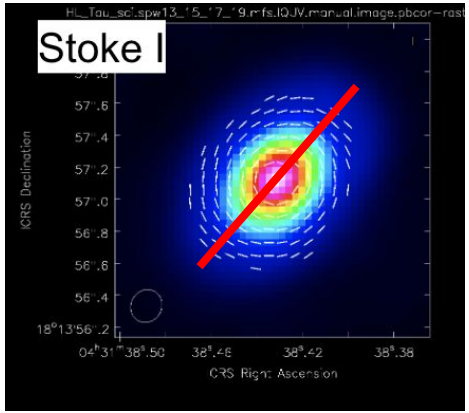


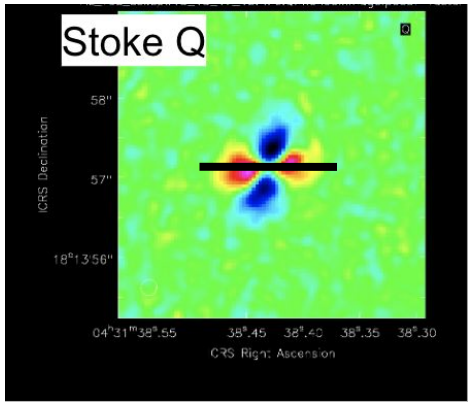
robust = -2.0
1 RMS = 296 uJy/beam

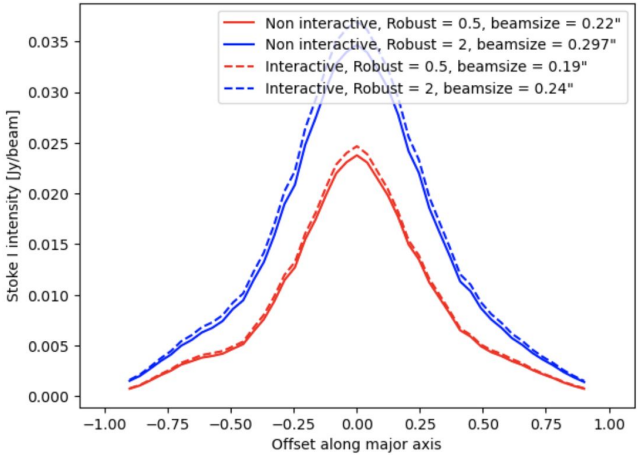


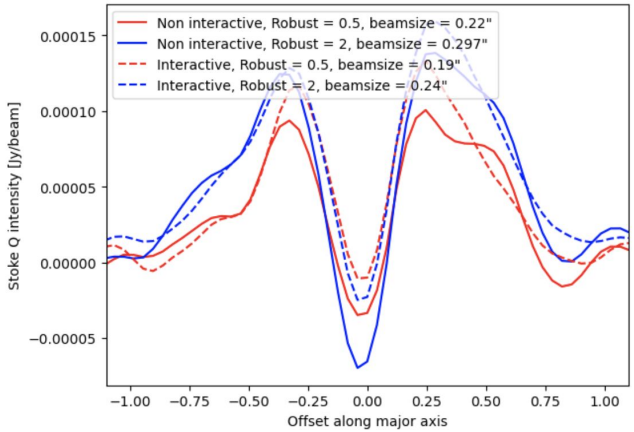


Comparison

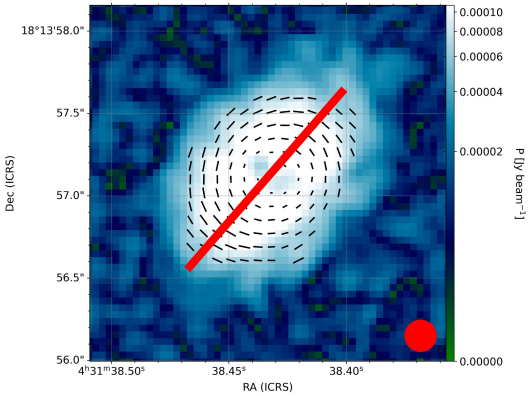


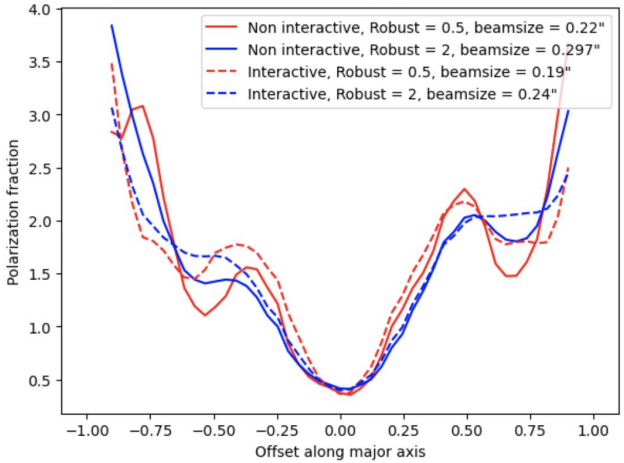






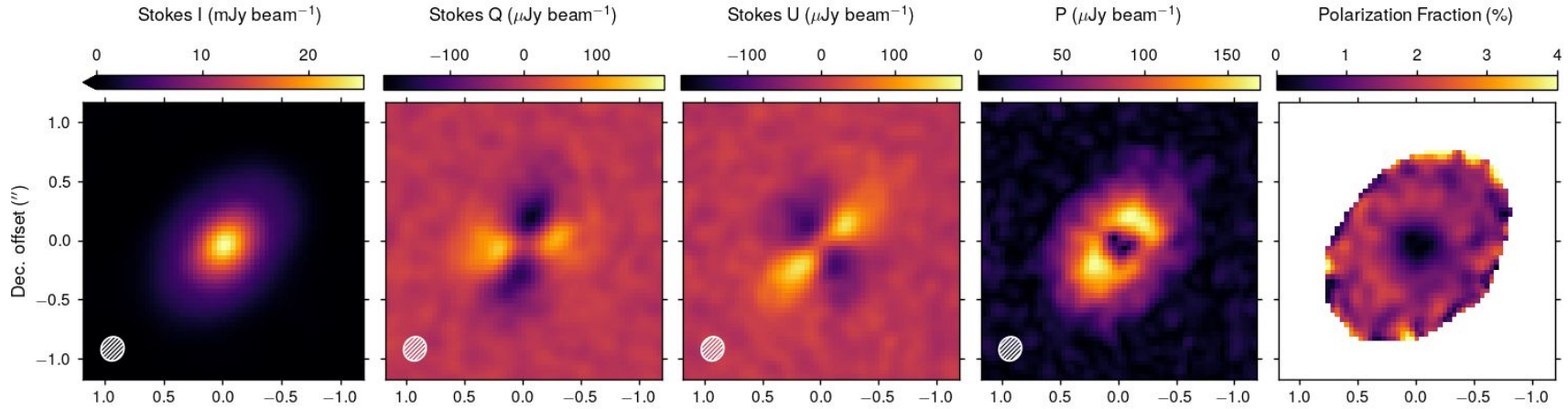
Polarization fraction



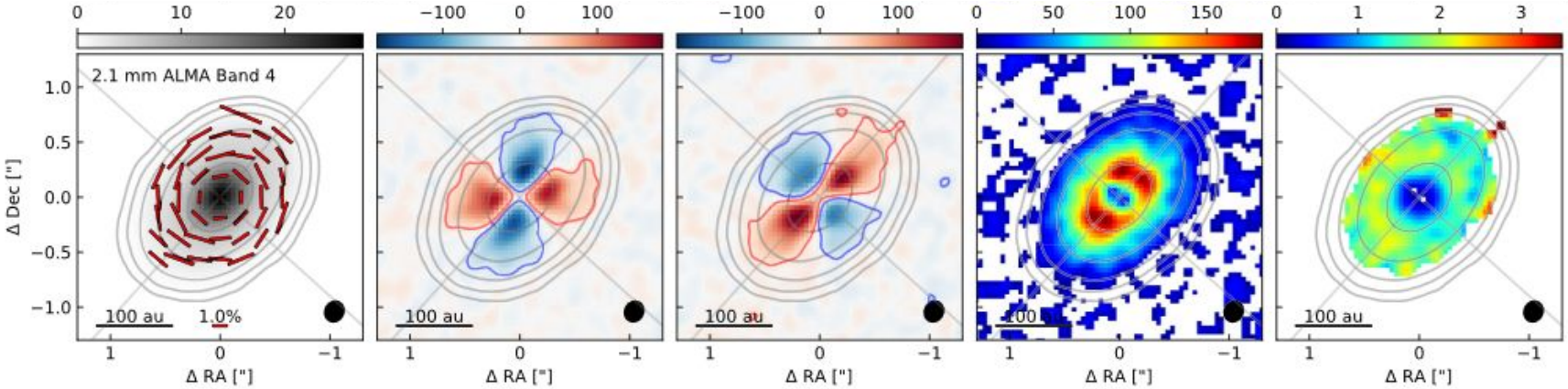


Our work vs Lin et al. 2024

Our CLEAN maps

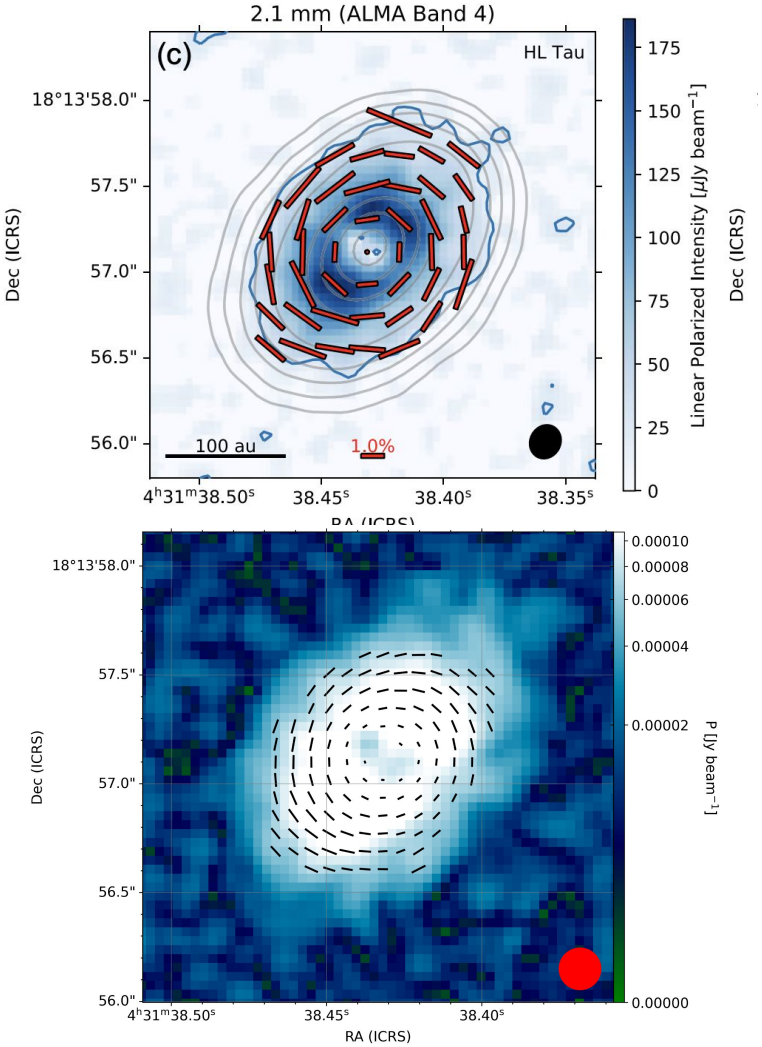


Clean maps from Lin et al. (2024)



Our work vs Lin et al. 2024

Data	Paper	Our work
Beam	0.21X0.19	0.22X0.20
Stokes I RMS	31 uJy/beam	~ 60 uJy/beam
Stokes I Peak	27.53 mJy/beam	~ 24.6 mJy/beam
Stokes Q/U RMS	7.7 uJy/beam	~ 17 uJy/beam
I_pol peak	186 uJy/beam	~192 uJy/beam



Summary and conclusion

- Understanding the reduction & imaging process of ALMA polarization data
- `tclean` with different robust parameter (-2.0, 0.5, 2.0)
  - Larger beam size for larger robust values
- interactive/non-interactive modes
  - No significant difference appears
- Comparison with Lin et al. 2024
  - Similar quadruple emission pattern for Stokes Q and U
  - Consistent azimuthal polarization pattern: Evidence of grains aligned their longest axis along toroidal B field