Polarization of HL Tau

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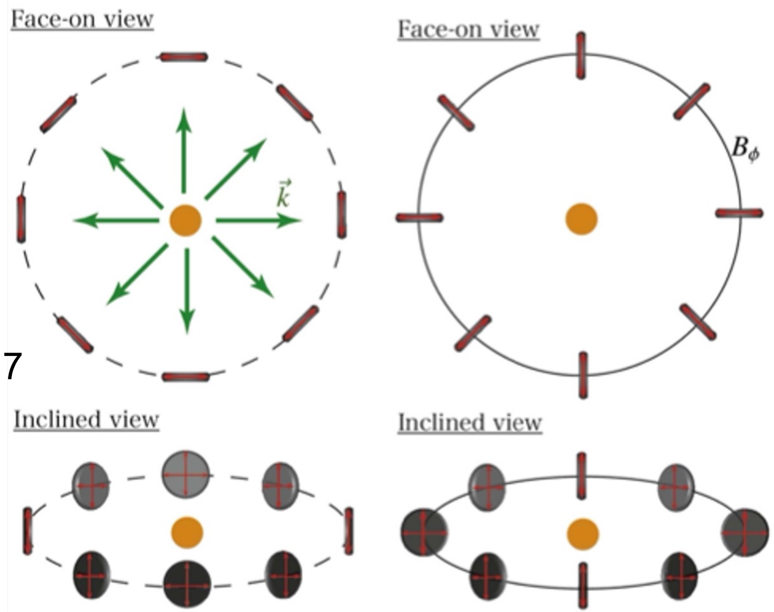
Introduction

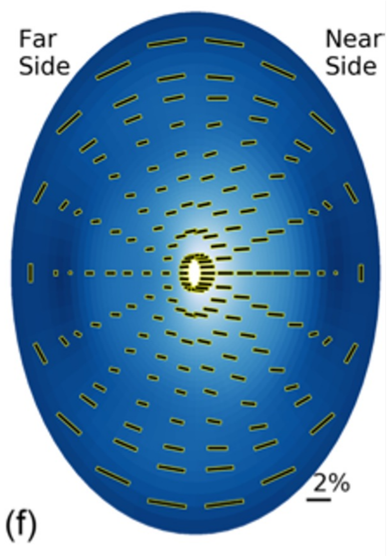
Polarization Mechanisms in Young Stellar Objects

Tazaki+'17



Grain alignment along radiation

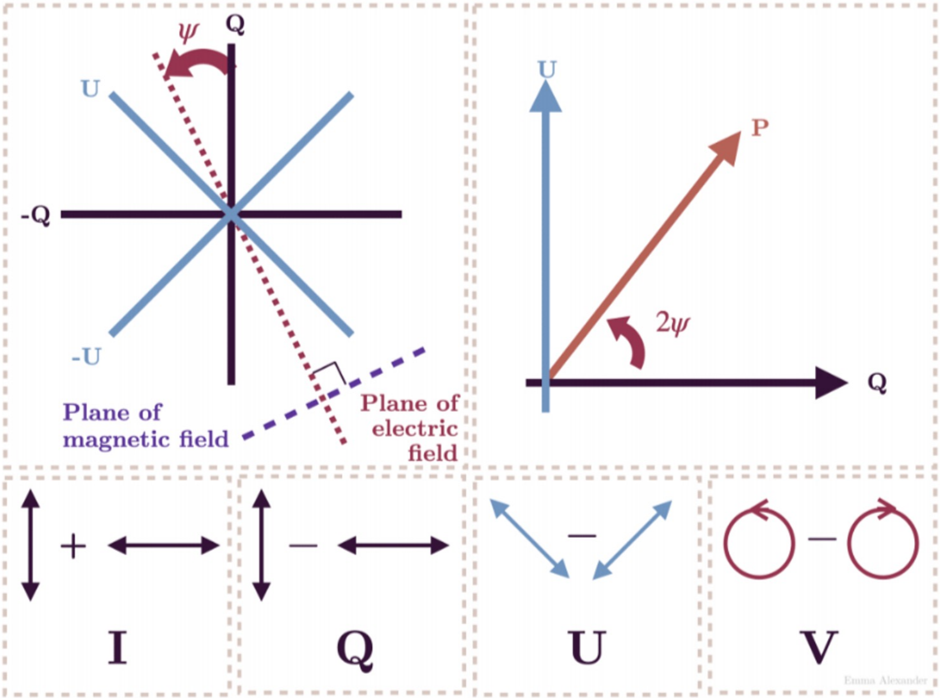
Grain alignment along magnetic fields



Yang+'17

Self-scattering
(90°-scattering is strongest)

Observable polarization signals



Polarization intensity:
PI = √(U²+Q²+V²)

Polarization fraction:
p = PI / I

Polarization direction:
ψ = 1/2 arctan (U/Q)

Spectral index α, β

Spectral index is related to dust properties, especially **size of grain**.
Larger grain size gives smaller spectral index. (Draine, 2006)

$$F_\nu \approx F_{\nu_0}\left(\frac{\nu}{\nu_0}\right)^\alpha$$

$$F_\nu \approx \kappa_\nu\, B_\nu(T_d)\, \frac{M_T}{D^2} \quad \text{(optically thin)}$$

$$\approx \kappa_{\nu_0}\left(\frac{\nu}{\nu_0}\right)^\beta\, \frac{2kT_d}{c^2}\, \nu^2\, \frac{M_T}{D^2}$$

therefore $\alpha \approx \beta + 2.$

Kwon+’09

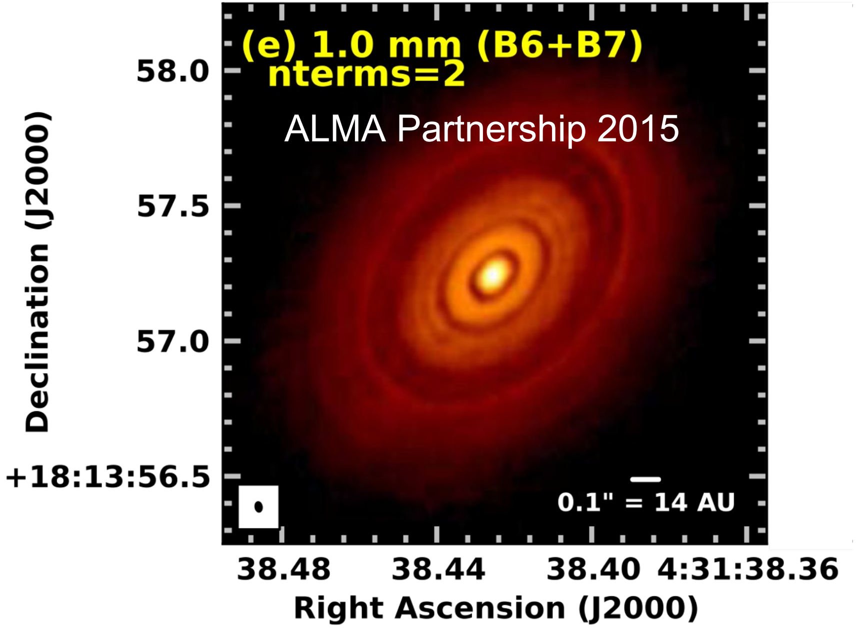
Large grains: Flux follows Rayleigh-Jeans law ($\propto \nu^2$), $\boldsymbol{\alpha}$ **~ 2,** $\boldsymbol{\beta}$ **~ 0**
Small grains: Flux follows Rayleigh scattering ($\propto \nu^4$), $\boldsymbol{\alpha}$ **~ 4,** $\boldsymbol{\beta}$ **~ 2**

Target HL Tau

HL Tauri is a Class I/II young stellar object in the constellation Taurus(황소자리).

Distance: 140pc
RA: 04h 31m 38.43s
Dec: 18d 13m 57.12s

Very well studied in multiple-wavelength polarized continuum emission using ALMA.



Data Reduction

Six measurement sets

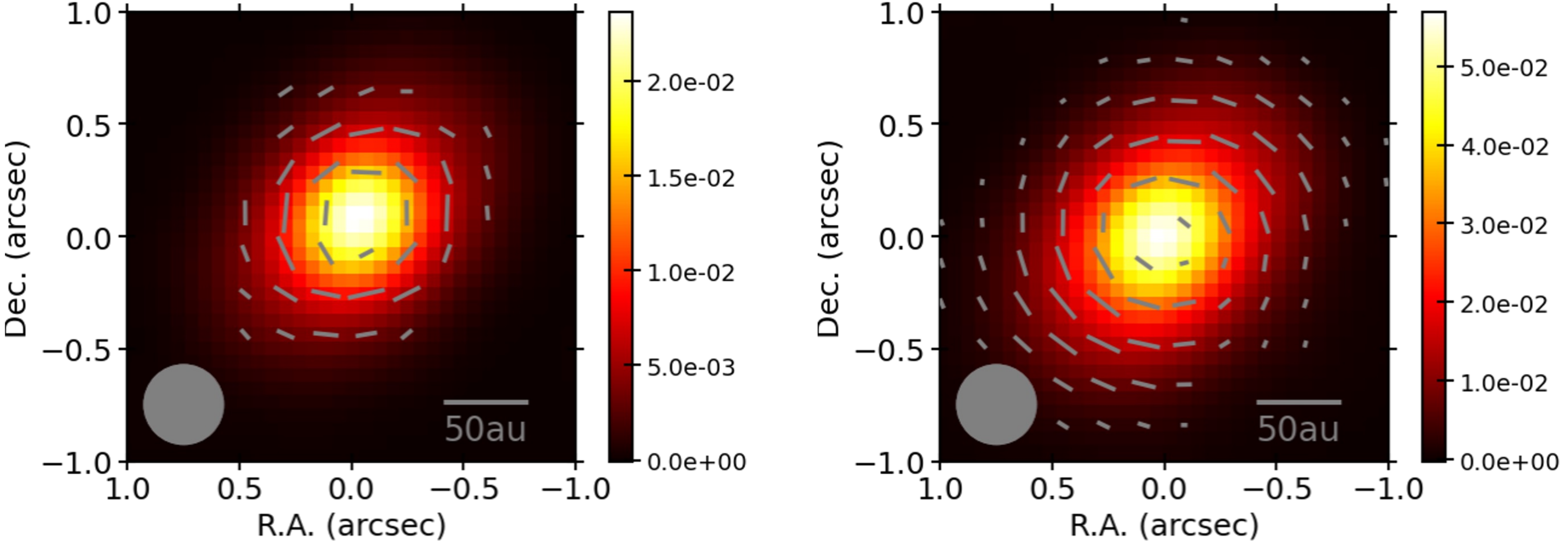
	Frequency (GHz)	Robust	Beam Size† (″ × ″)	UV distance (kλ)	3σ noise level (mJy/beam)
Band 3	97.5	–1.0	0.356×0.200	3.6 - 780	0.10
Band 4	145.0	0.5	0.312×0.260	**15.0** - 1,400	0.50
Band 5	203.0	1.5	0.320×0.279	8.5 - 1,920	0.75
Band 6	233.0	0.5	0.321×0.232	10.0 - 1,800	3.5
Band 7a	343.5	–1.0	0.343×0.259	14.2 - **770**	2.3
Band 7b	343.5	0.5	0.328×0.262	14.0 - 2,100	3.0

†This beam size is obtained with the common uv-distance range (**15-770 kλ**).
We smoothed the images to change all the beam sizes to **0.36”x0.36”**.

Results

Intensity & Polarization angle map

Color: Stokes I (Jy/beam)
Segment length ∝ PI



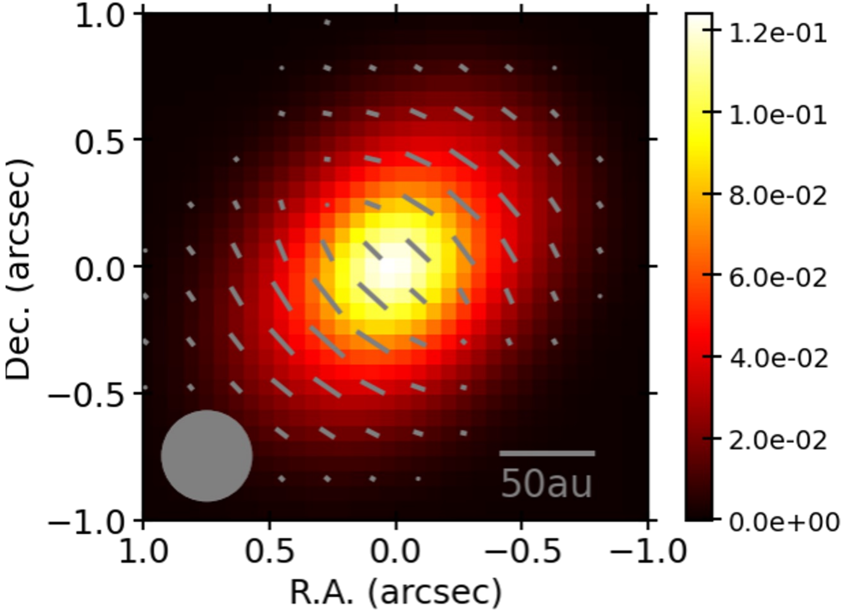
Circular pattern

Band 3

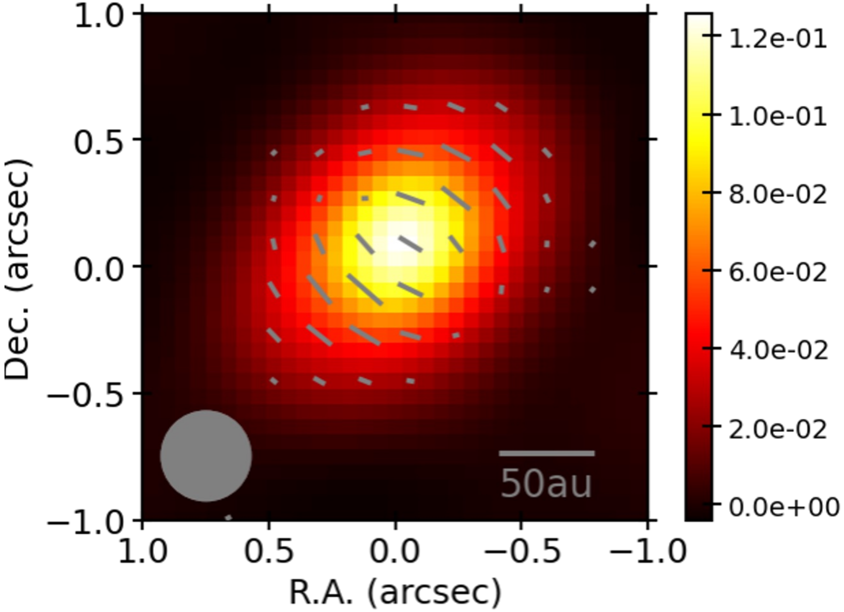
Band 4

Intensity & Polarization angle map

Color: Stokes I (Jy/beam)
Segment length ∝ PI



Band 5

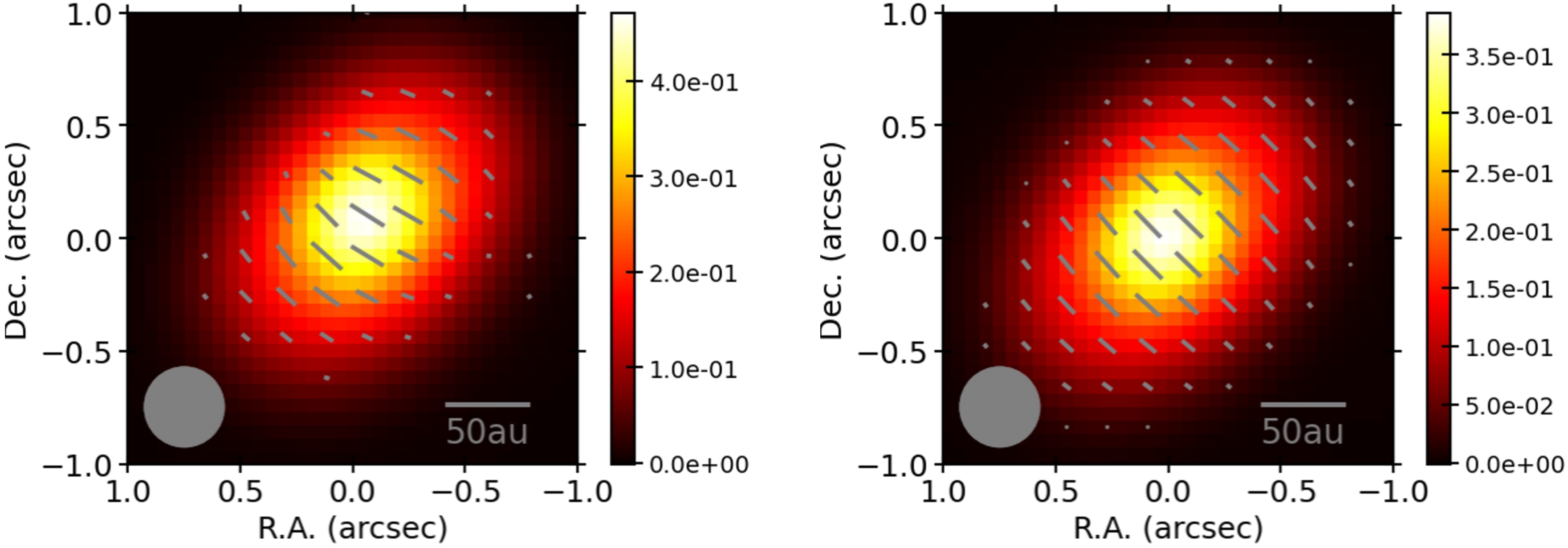


Band 6

NE-SW (minor axis)

Intensity & Polarization angle map

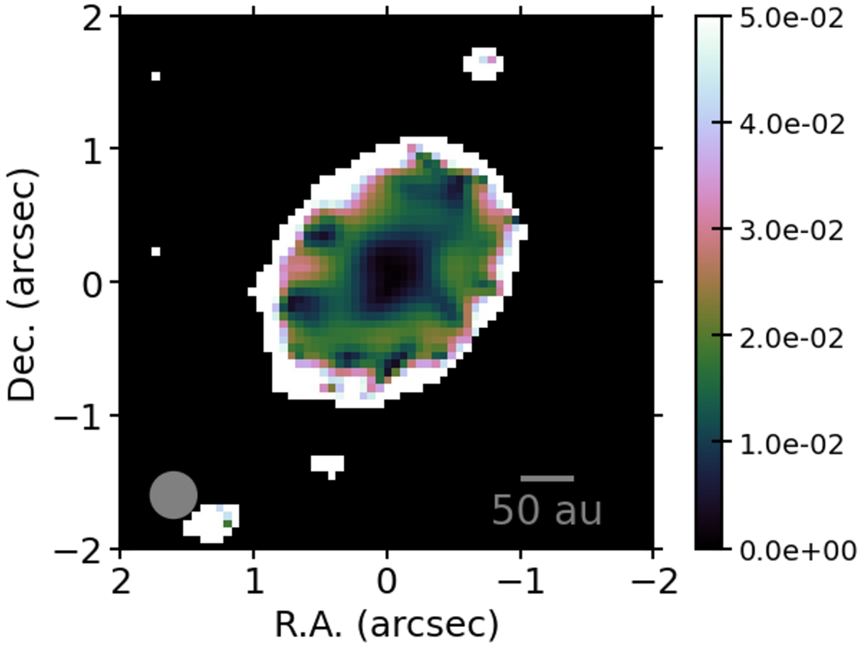
Color: Stokes I (Jy/beam)
Segment length ∝ PI



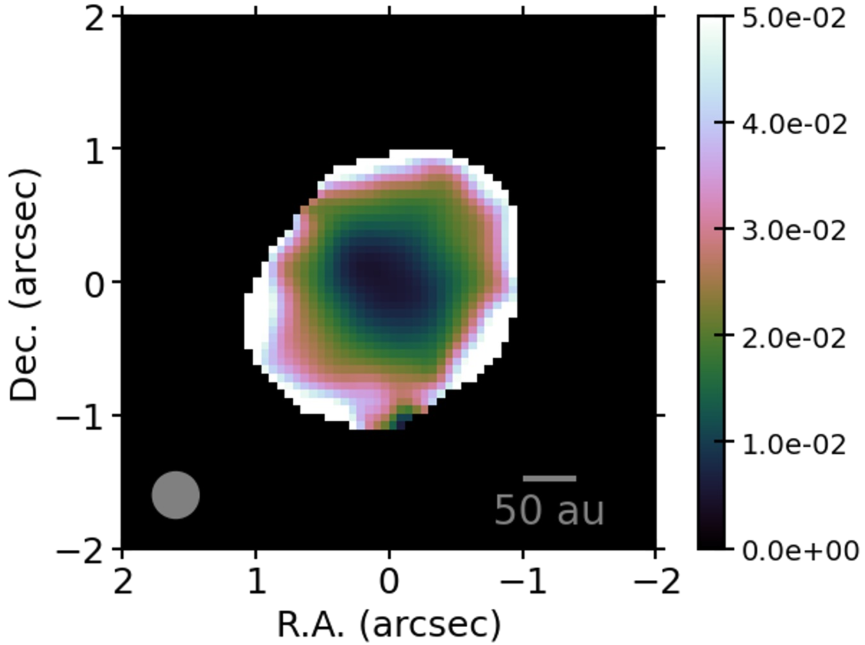
Band 7a NE-SW (minor axis) **Band 7b**

Polarization Fraction

$$p = \frac{PI}{I} = \frac{\sqrt{Q^2+U^2+V^2}}{I}$$



Band 3

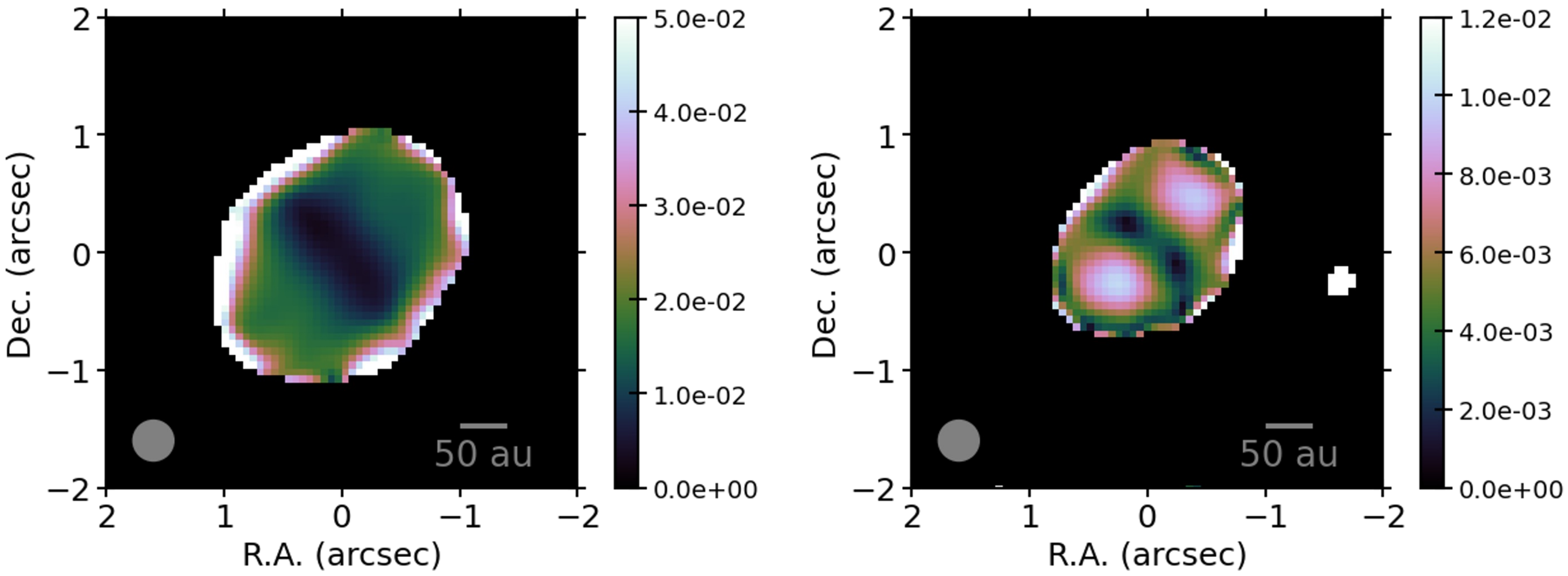


Band 4

Ring-like distribution

Polarization Fraction

$$p = \frac{PI}{I} = \frac{\sqrt{Q^2+U^2+V^2}}{I}$$

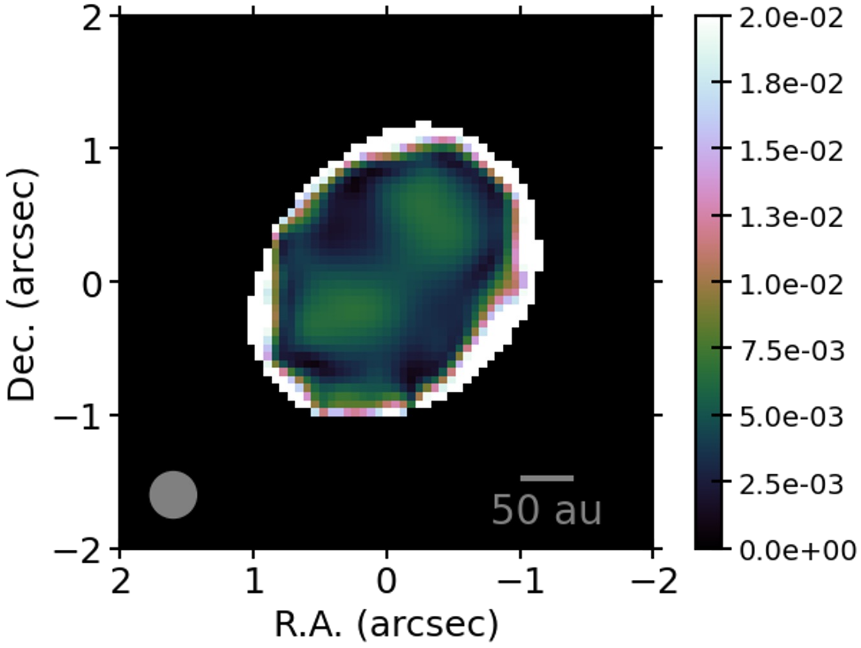


Double-peak distribution

Band 5 **Band 6**

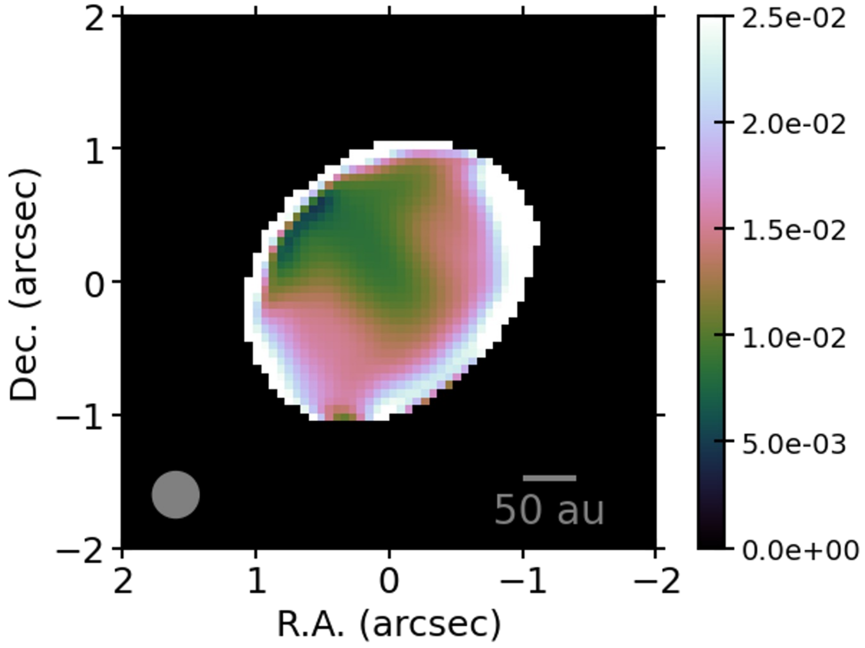
Polarization Fraction

$$p = \frac{PI}{I} = \frac{\sqrt{Q^2+U^2+V^2}}{I}$$



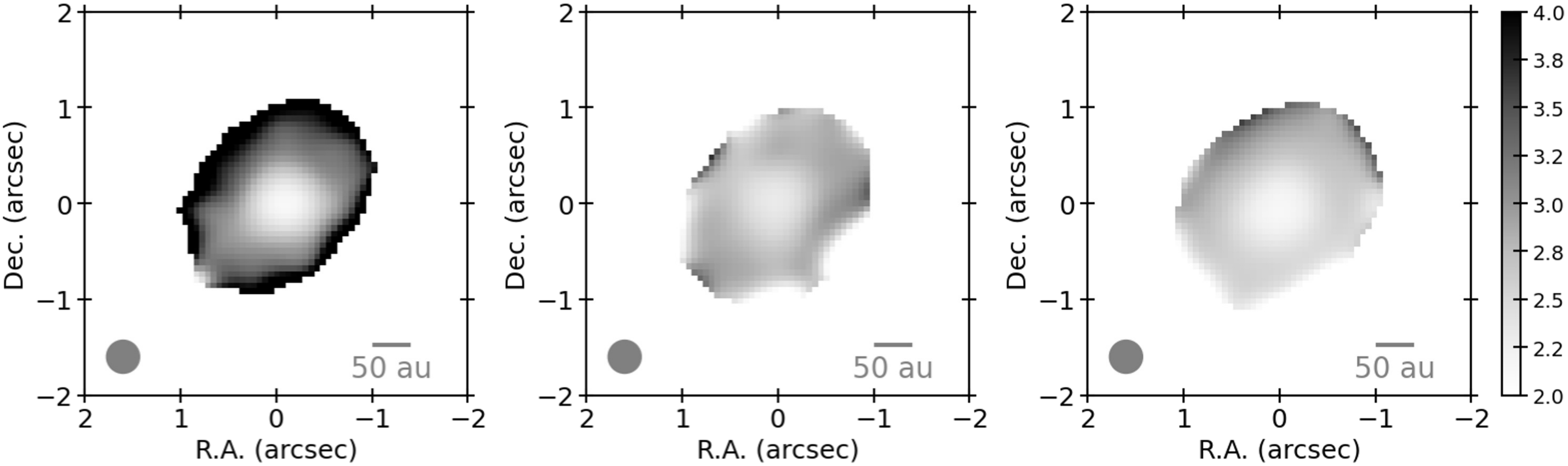
Band 7a

Double-peak distribution



Band 7b

Spectral index α of Band 3-4, Band 4-5, Band 5-7a



Band 3-4 **Band 4-5** **Band 5-7b**

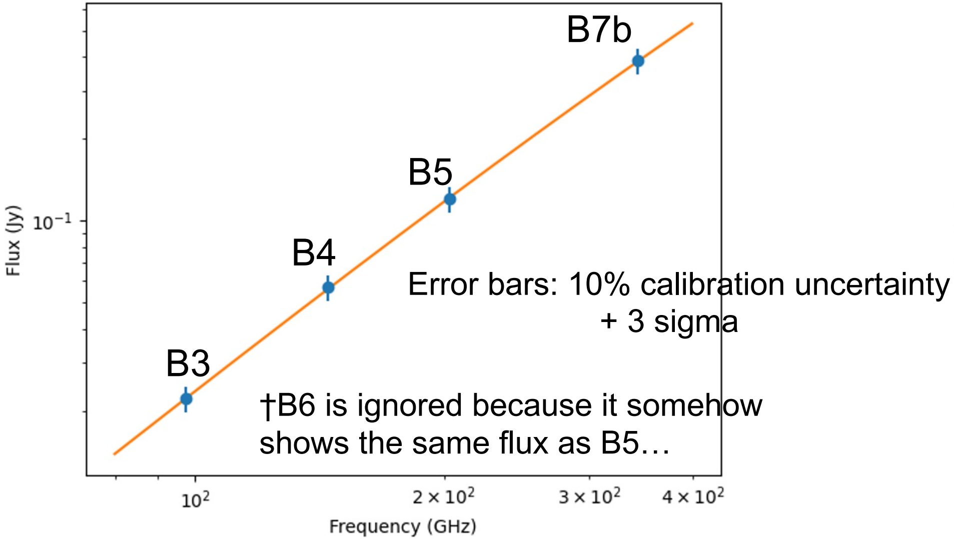
α~2 at the center, while α~3 in the outer region

Discussion

Grain size from SED

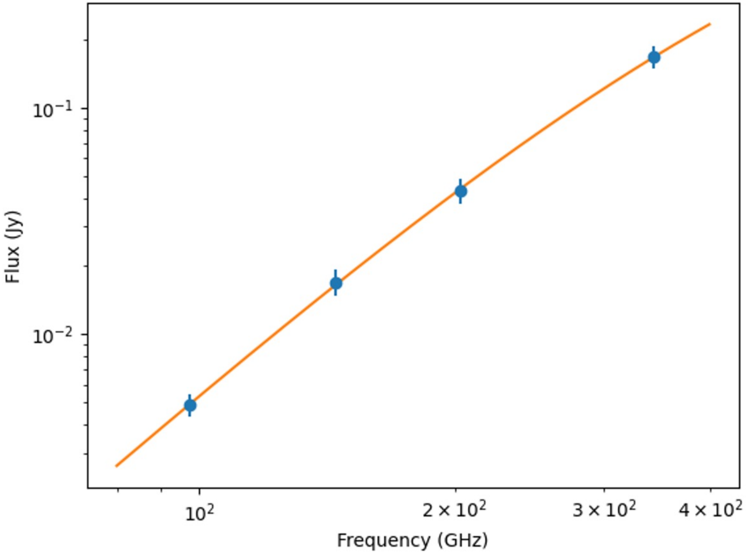
$$F_\nu = (B_\nu(T) - B_\nu(T_{bg}))(1 - e^{-\tau_0(\nu/200\ \mathrm{GHz})^\beta})\Omega$$

Central region



T	τ_0	β
55 ± 16 K	0.8 ± 0.4	0.5 ±0.1

Outer region



T	τ_0	β
25 ± 2.6 K	0.7 ± 0.1	1.3 ± 0.1

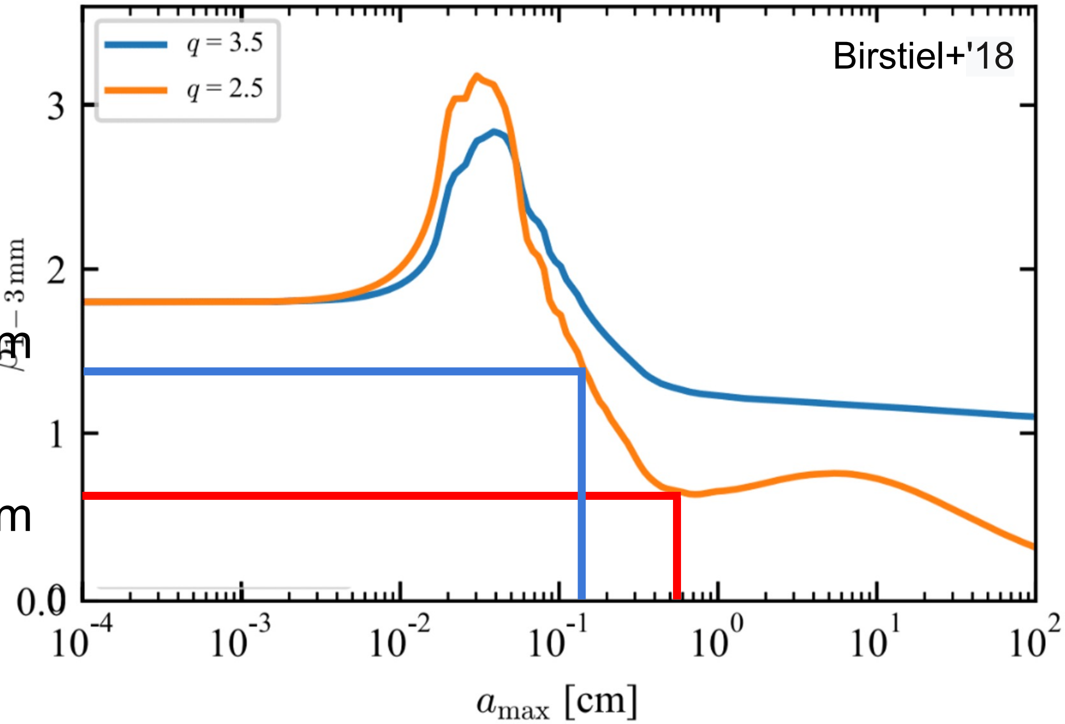
Grain size from SED

Central region

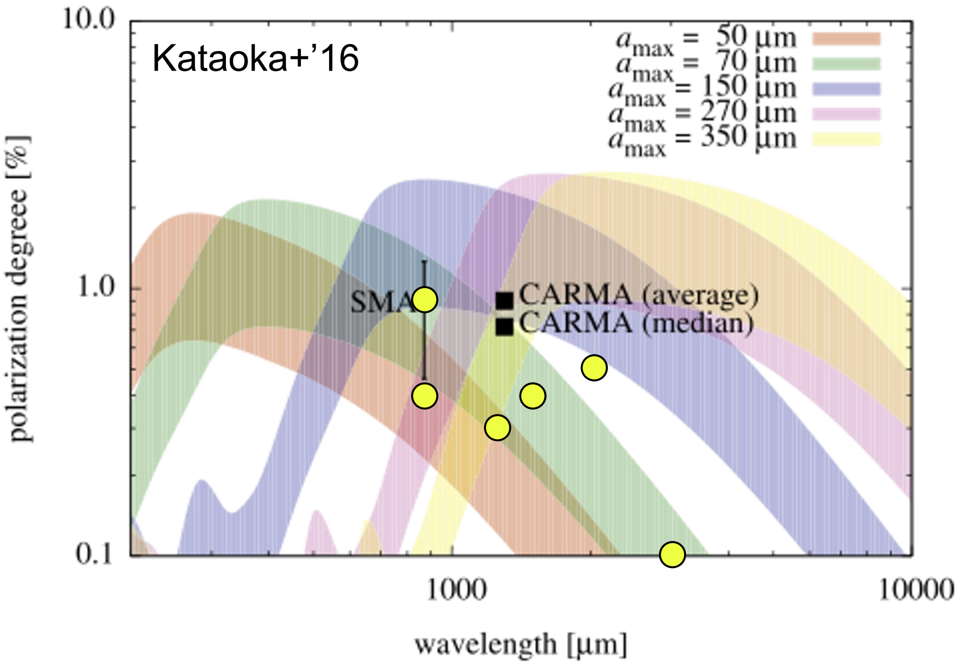
~ 4-5 mm

Outer region

~ 1-2 mm



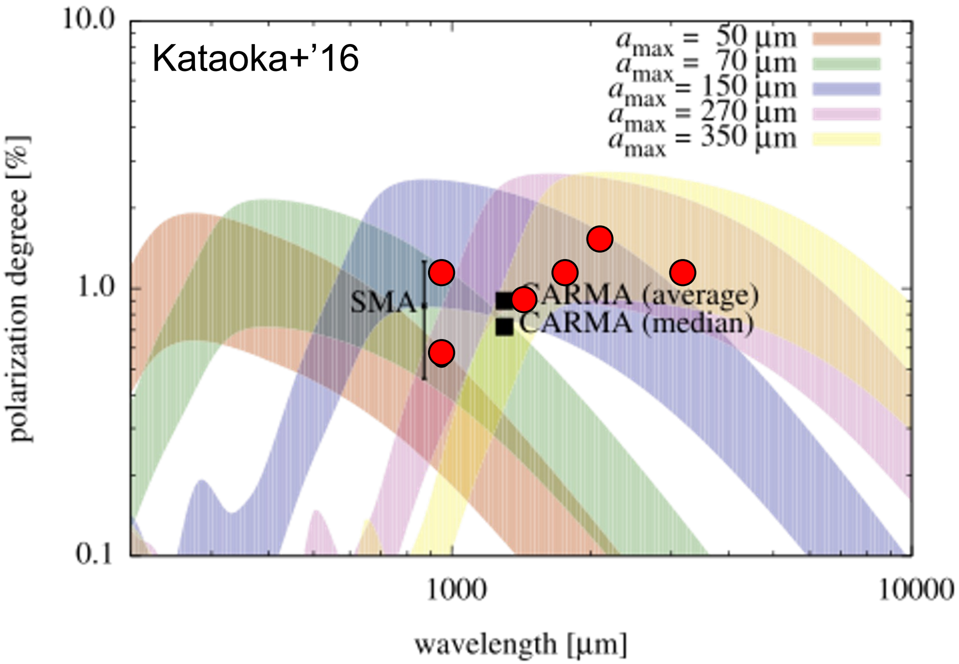
Grain size from polarization



	Wavelength (μm)	Center PF
Band 3	3,000	0.1%
Band 4	2,000	0.5%
Band 5	1,470	0.4%
Band 6	1,280	0.3%
Band 7a	870	0.4%
Band 7b	870	0.9%

Estimated grain size from polarization in Center: 70μm(0.07mm)

Grain size from polarization



	Wavelength (μm)	Outer PF
Band 3	3,000	1.3%
Band 4	2,000	1.5%
Band 5	1,470	1.3%
Band 6	1,280	0.9%
Band 7a	870	0.6%
Band 7b	870	1.3%

Estimated grain size from polarization in outer region: 270μm(0.27mm)

Discrepancy between SED and polarization

SED provided the sizes of 1 - 5 mm.
Polarization fraction provided the sizes of 0.1 - 0.3 mm

Possible reasons:

- Circular patterns cancel polarization at the center.
- Polarization may be more sensitive to surface smaller grains.
- PF model depends on dust properties (Yang & Li 2020).

Summary

Summary

We reduced data of the Class I/II YSO HL Tau to study the usage of polarization. The main results are followings.

- Polarization direction appears circular patterns at Band 3&4, alined to NE-SW at Band 5,6 and 7
- Polarization fraction map shows ring structure at Band 3&4, double-peak structure at Band 6&7a. (Weak in band 5&7b)
- Spectral index is 2 (central), ~3 (outer region).
- Grain size estimated from polarization fractions is 70 μm (central), 270 μm (outer region).
- Grain size estimated from SEDs is 4~5 mm (central), 1~2 mm (outer region).

Thanks!