Far-infrared multiwavelength polarimetry of HL Tau using SOFIA/HAWC+

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Introduction

SOFIA/HAWC+: First polarimetric observations
of a **protoplanetary disk** in the far-infrared

Emission of
aligned dust grains

Self-scattering of
thermal radiation

Polarization

Potential of polarization for analysis
of the magnetic field in protoplanetary disks

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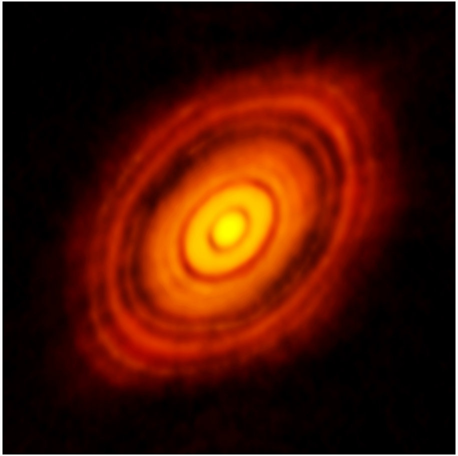
Potential of polarization for analysis of the magnetic field in protoplanetary disks



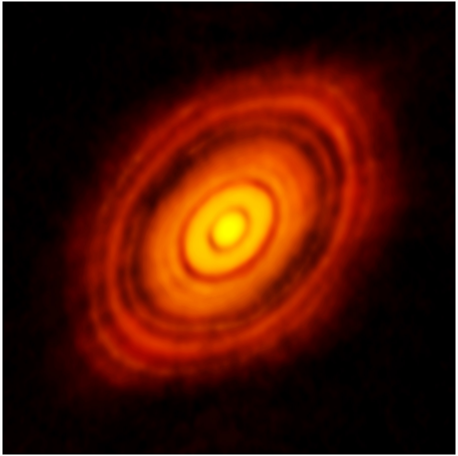
Credit: ALMA (ESO/NAOJ/NRAO)

Introduction

HL Tauri: Pre-Main-Sequence star in the Taurus molecular cloud

Surrounded by a protoplanetary disk, embedded in a circumstellar nebulosity

$i \approx 47°$ $\quad$ $PA \approx 138°$



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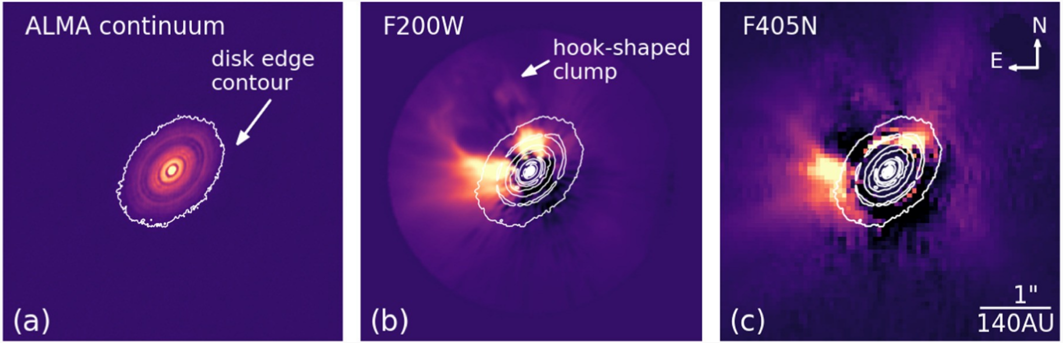
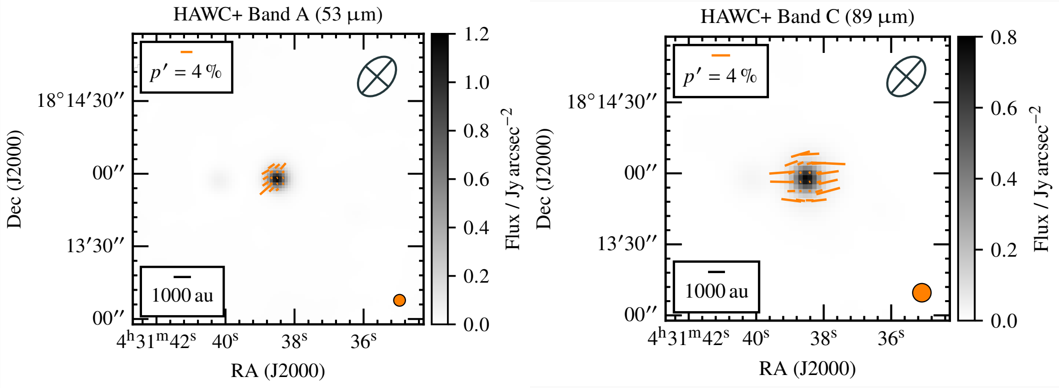


ALMA at 1.3 mm
(ALMA Partnership et al. 2015)

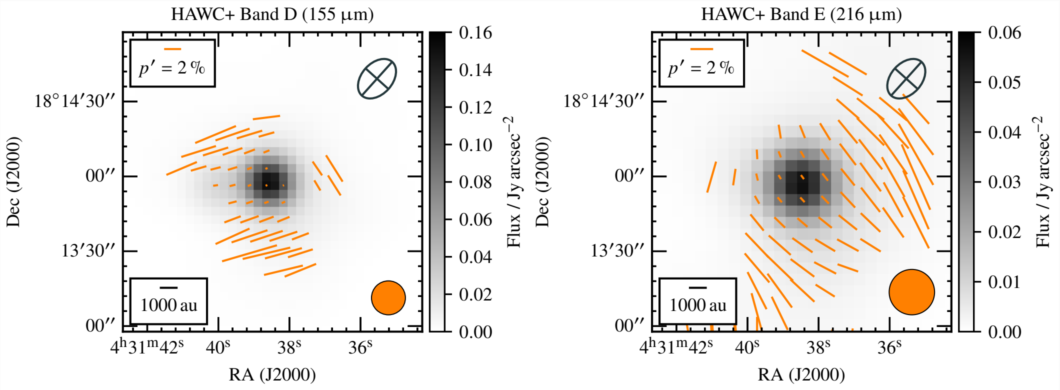
JWST at 2 µm and 4 µm
(Mullin et al. 2024)

Polarization maps



$I/\sigma_I > 100 \qquad p'/\sigma_p > 3$

Polarization maps



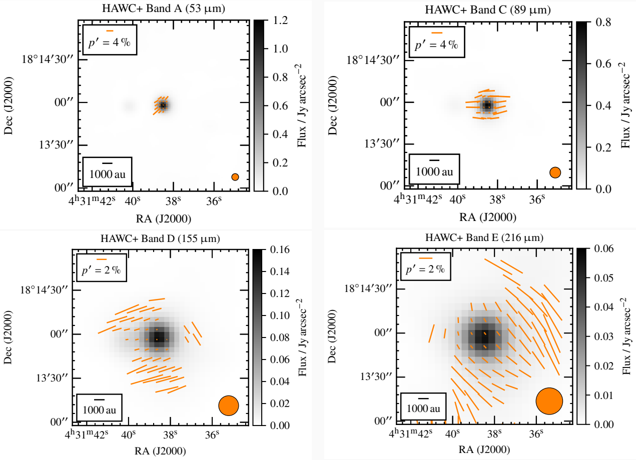
$I/\sigma_I > 100 \qquad p'/\sigma_p > 3$

Bands A, C, D

Polarization vectors parallel to major disk axis

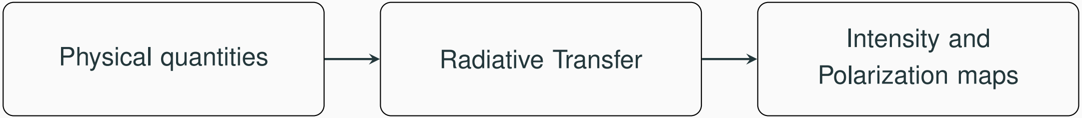
Band E

Polarization vectors parallel to minor disk axis



Radiative transfer modeling

3D Monte Carlo radiative transfer code POLARIS (Reissl et al. 2016)[1]



[1] publicly available at portia.astrophysik.uni-kiel.de/polaris/

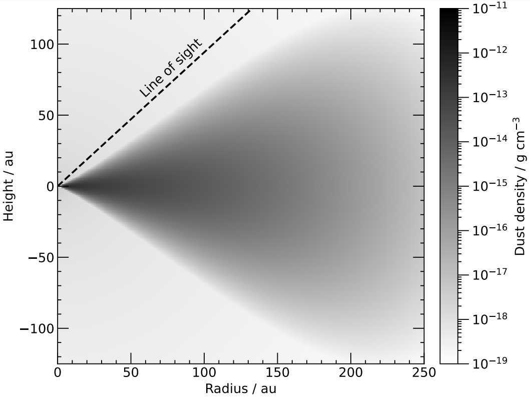
Radiative transfer modeling

Disk density distribution (Andrews et al. 2009):

$$\rho_{\rm disk} = \rho_0^{\rm disk} \left(\frac{r}{R_{\rm in}}\right)^{\alpha} \exp\left[-\left(\frac{r}{R_0^{\rm disk}}\right)^{2+\alpha+\beta}\right] \times \exp\left[-\frac{1}{2}\left(\frac{z}{h_0 (r/R_0^{\rm disk})^{\beta}}\right)^{2}\right]$$

Envelope density distribution:

$$\rho_{\rm env} = \rho_0^{\rm env} \left(\frac{R}{R_{\rm in}}\right)^{\gamma} \exp\left[-\left(\frac{R}{R_0^{\rm env}}\right)^{2+\gamma}\right]$$

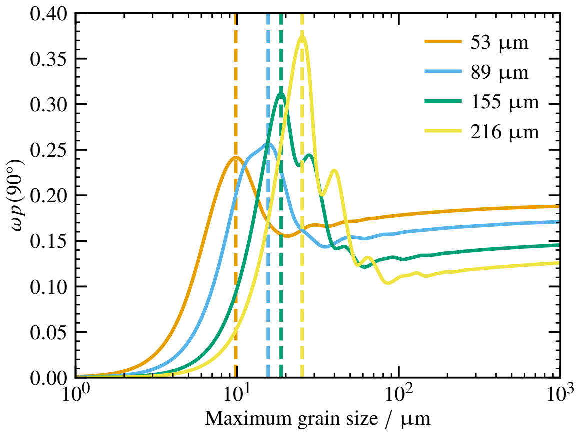


Astronomical silicate (Draine 2003)

Grain size distribution:

$$\mathrm{d}n(s) \propto s^{-3.5}\mathrm{d}s$$

Maximum grain size: 25 µm

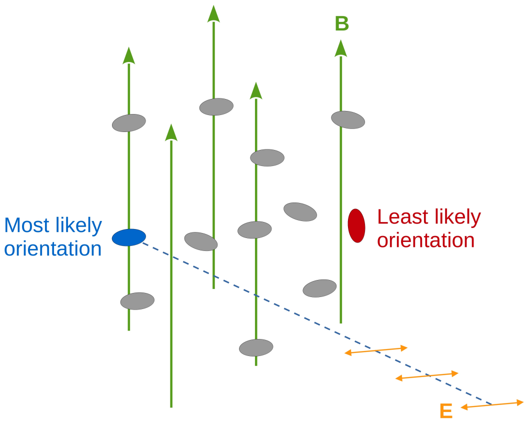


Radiative transfer modeling

Relation between field strength and density (Crutcher 1999):

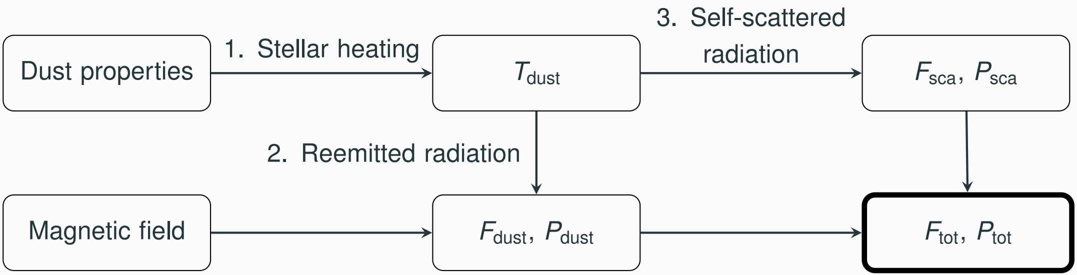
$$B = B_0 \left(\frac{\rho}{\rho_0^{\text{disk}}} \right)^{\kappa}$$

- ✓ Projected PA of the field
- ✗ Tilt angle from line of sight
- ✗ B_0



Radiative transfer modeling

3D Monte Carlo radiative transfer code POLARIS (Reissl et al. 2016)[1]



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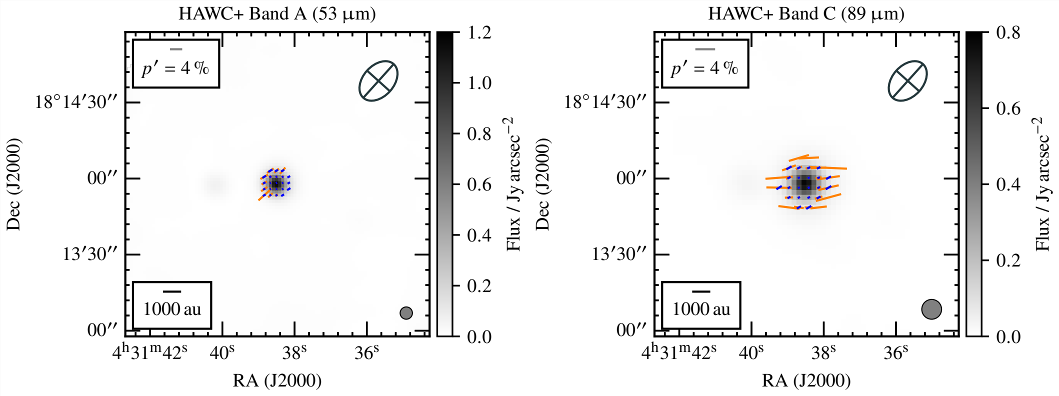
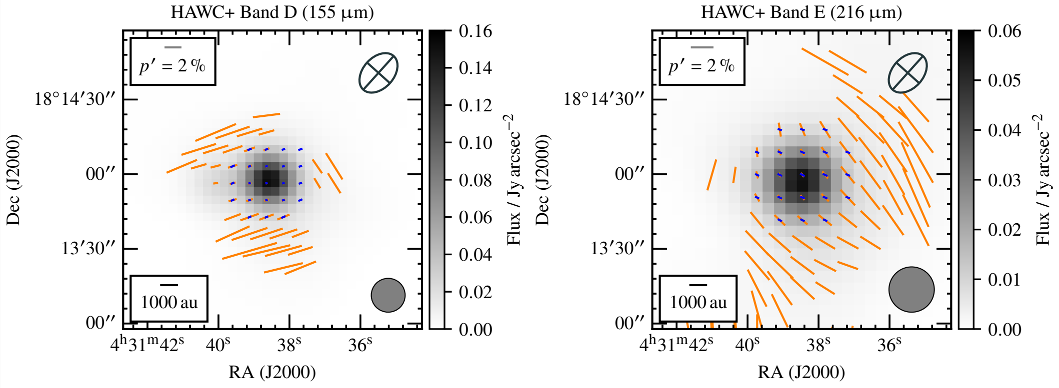
Polarization maps

Observations + Simulations



Polarization maps

Observations + Simulations



Results

Bands A, C, D

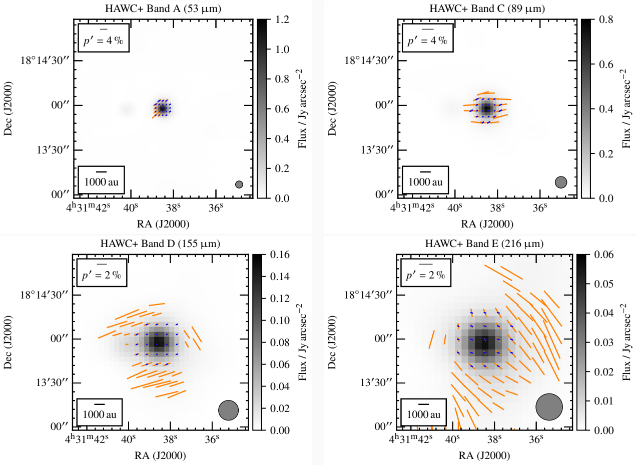
Polarization due to emission of aligned dust grains

→ Magnetic field perpendicular to disk midplane

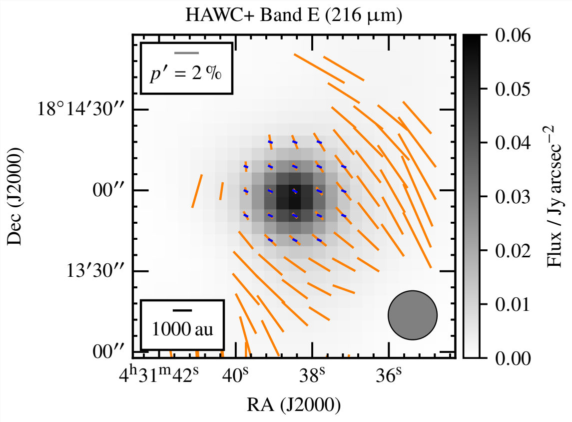
Band E

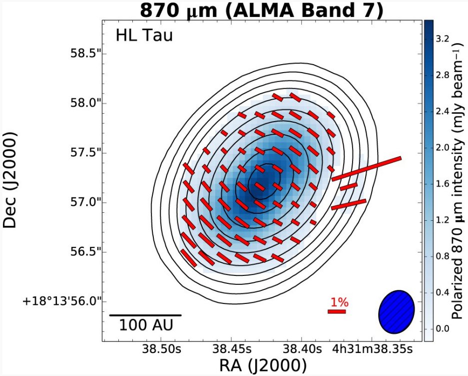
Polarization due to self-scattering of thermal radiation

→ Dust grain size up to 25 µm



ALMA polarization observations





(Stephens et al. 2017)

Summary

SOFIA/HAWC+: First polarimetric observations
of a protoplanetary disk in the far-infrared (HL Tau)

Bands A, C, D

Polarization due to emission of aligned dust grains
Magnetic field lines perpendicular to the disk midplane

Band E

Polarization due to self-scattering of thermal radiation
Dust grain size up to 25 µm

References

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