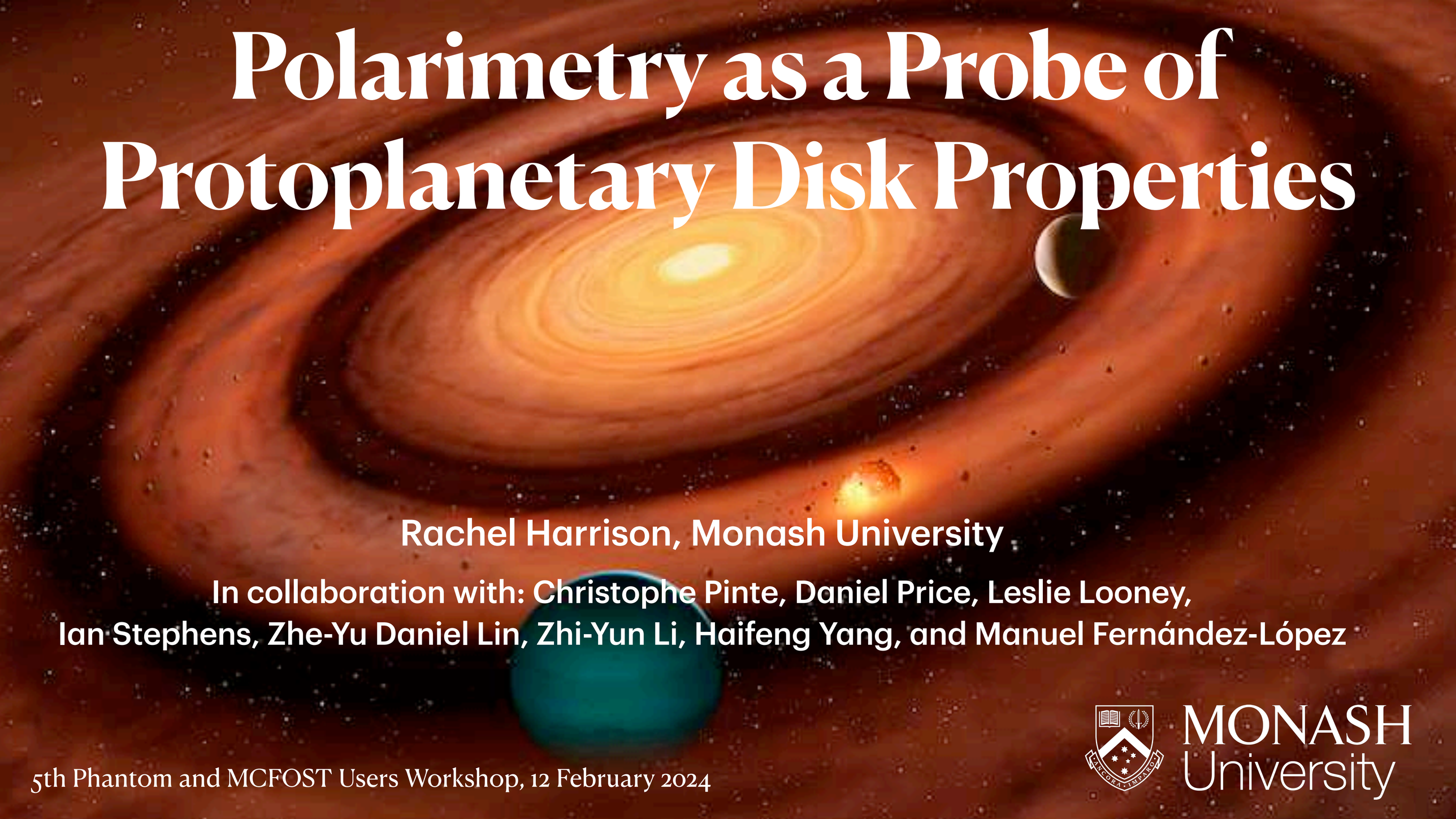
Polarimetry as a Probe of Protoplanetary Disk Properties

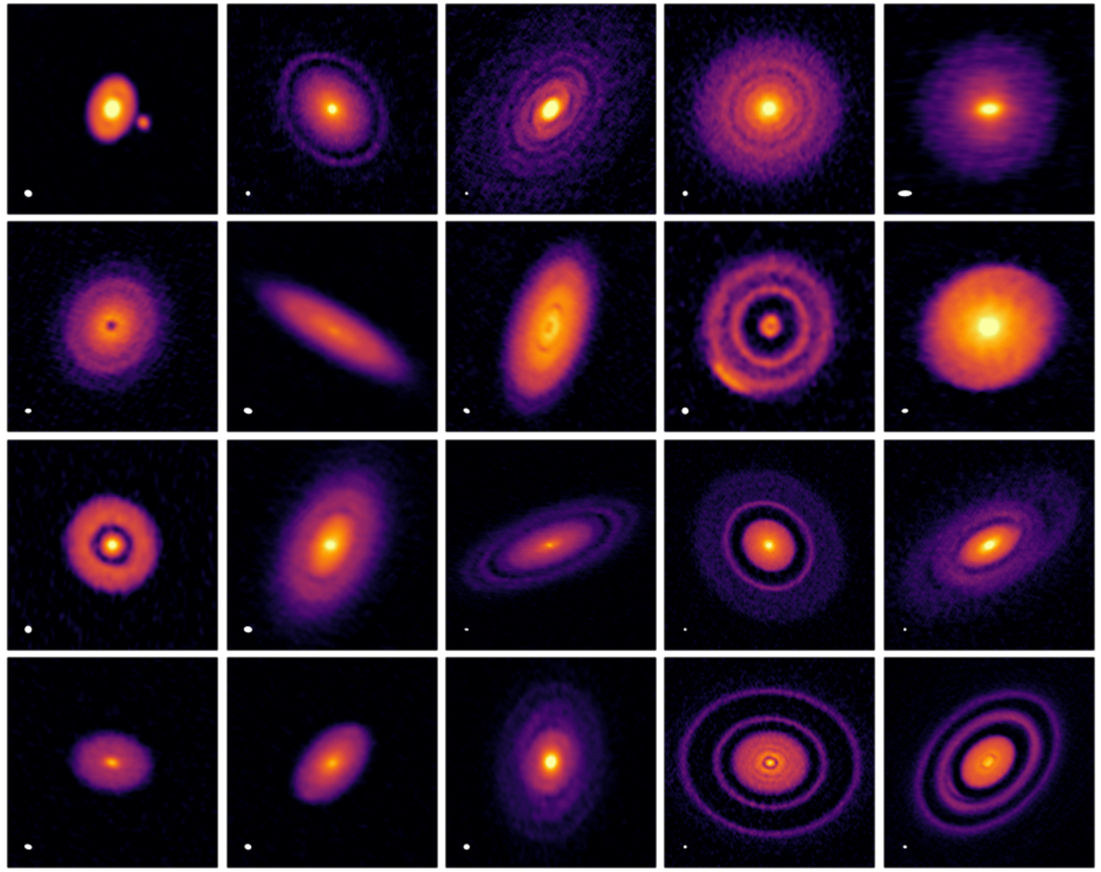
Rachel Harrison, Monash University

In collaboration with: Christophe Pinte, Daniel Price, Leslie Looney, Ian Stephens, Zhe-Yu Daniel Lin, Zhi-Yun Li, Haifeng Yang, and Manuel Fernández-López

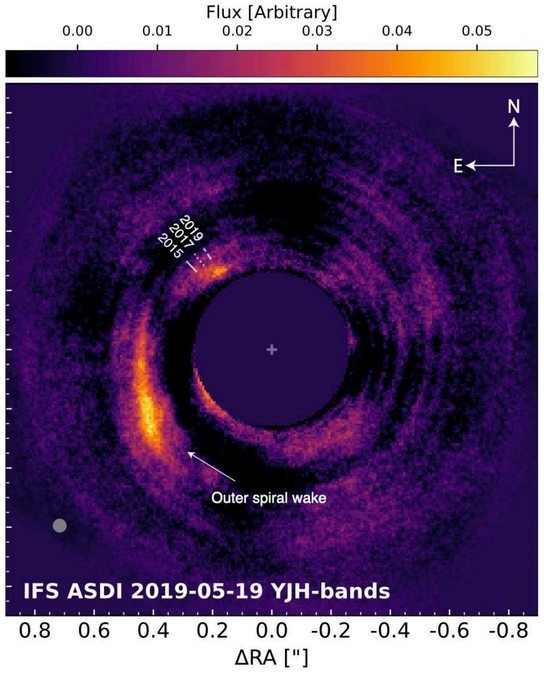


5th Phantom and MCFOST Users Workshop, 12 February 2024

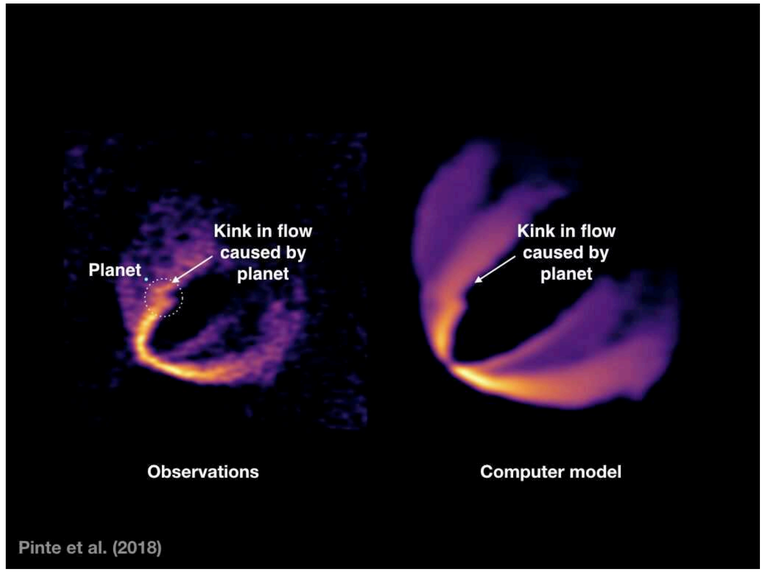
MONASH University



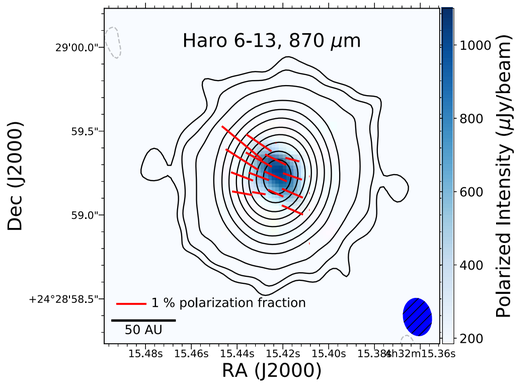
DSHARP Survey, Andrews et al. 2018

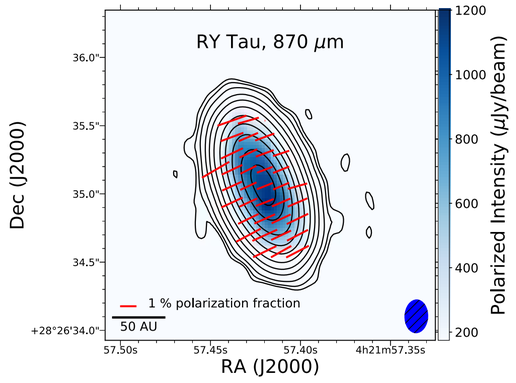


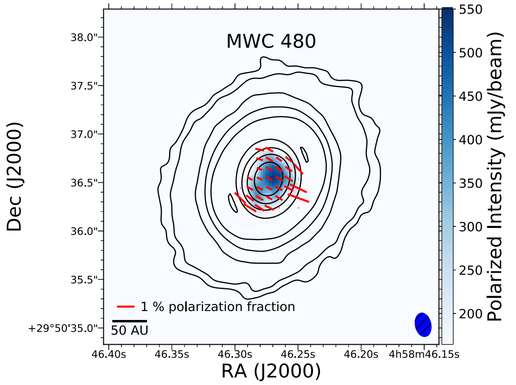
SPHERE observations of HD 169142, Hammond et al. 2023

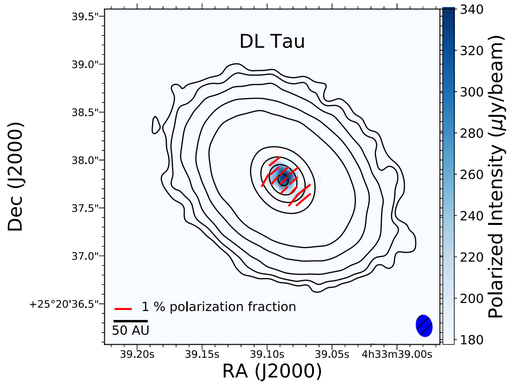


ALMA observations of CO J = 2-1 in HD 163296, Pinte et al. (2018)

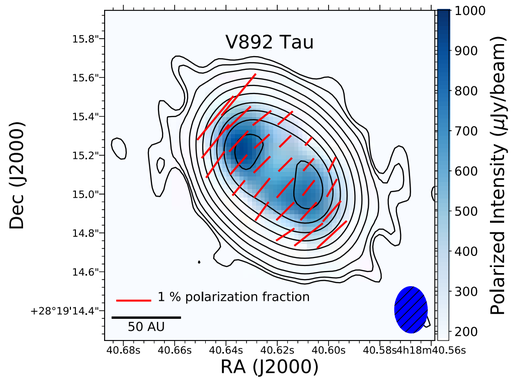


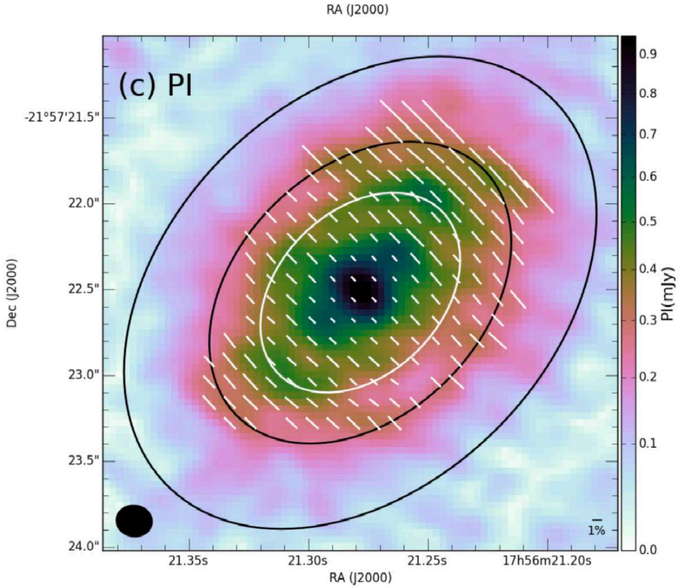




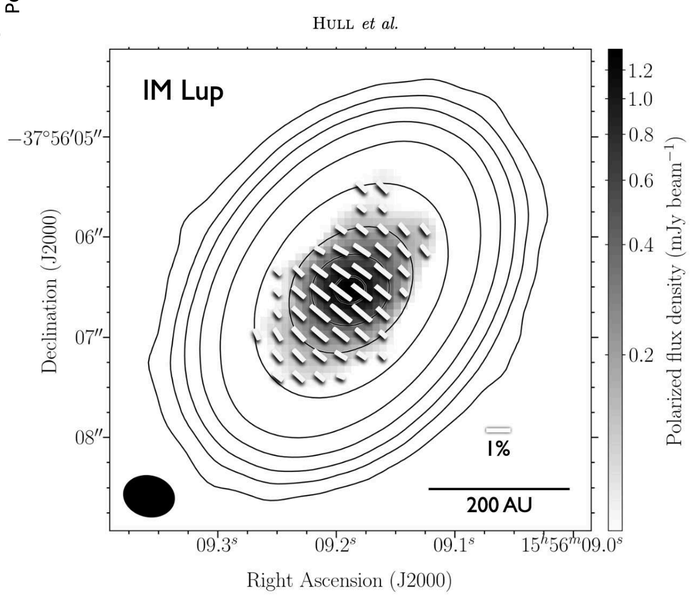


Haro 6-13, RY Tau, MWC 480, DL Tau, and V892 Tau, Harrison et al. 2024 (in review)



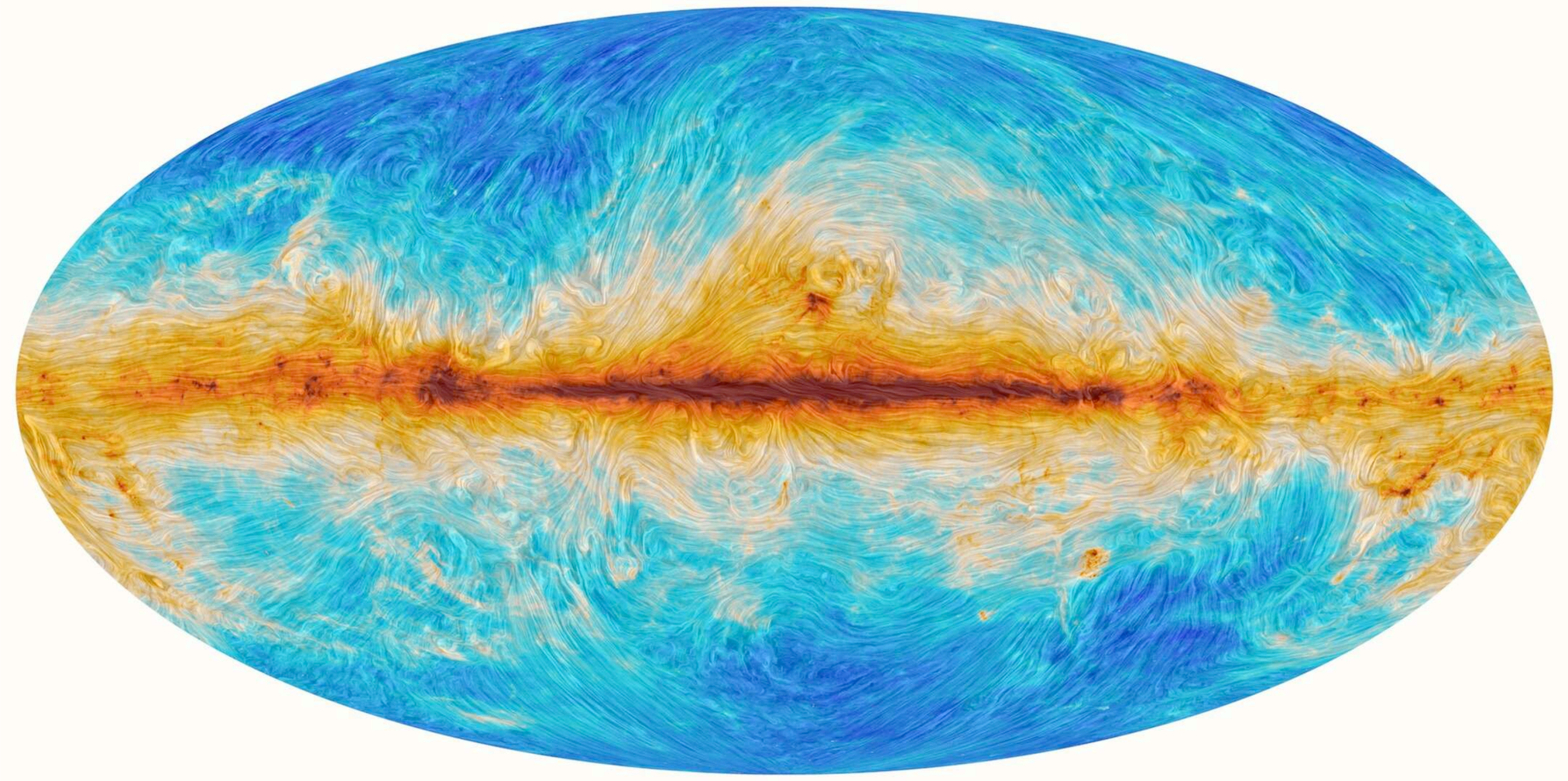


HD 163296, Dent et al. 2019



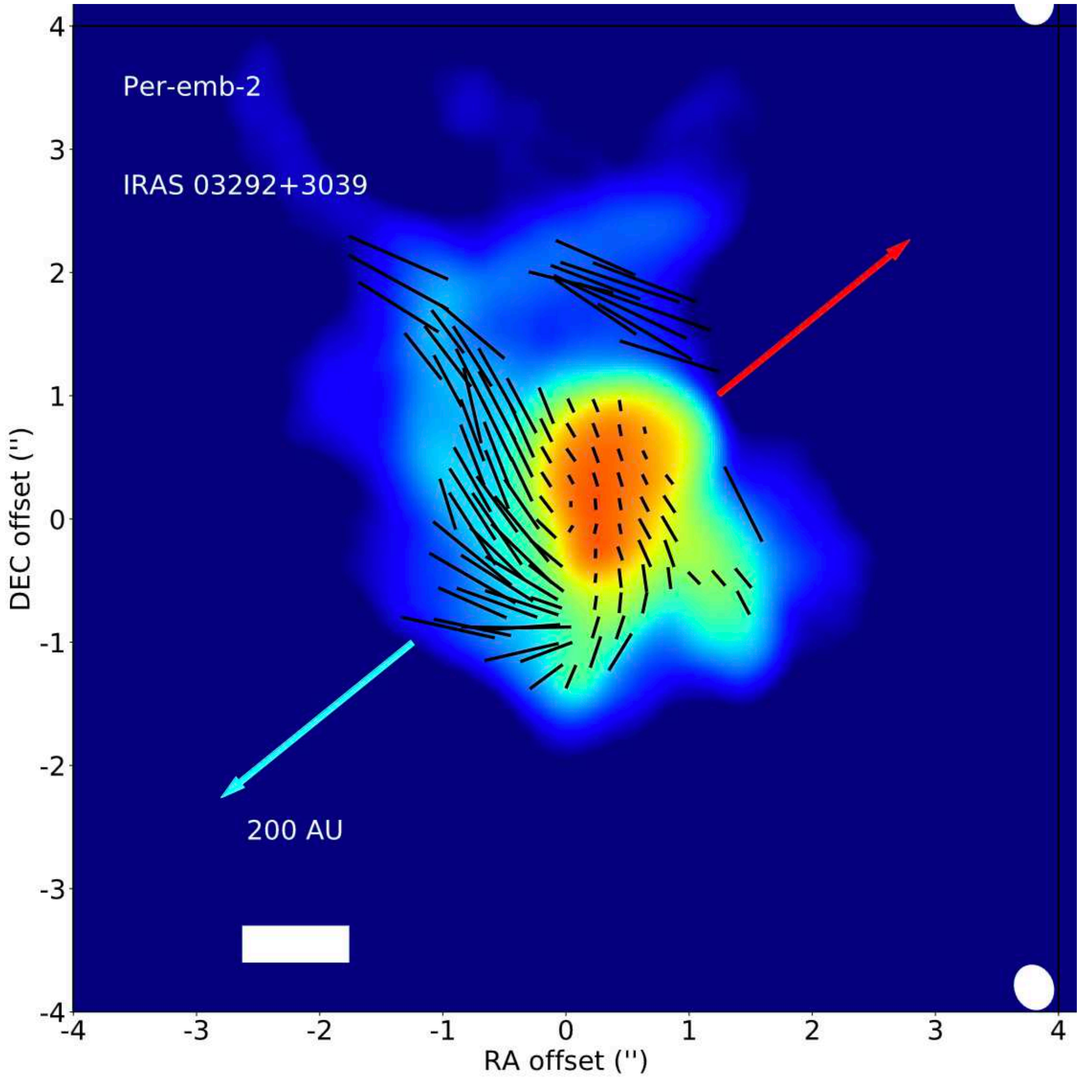
IM Lup, Hull et al. 2018

But what about magnetic fields???



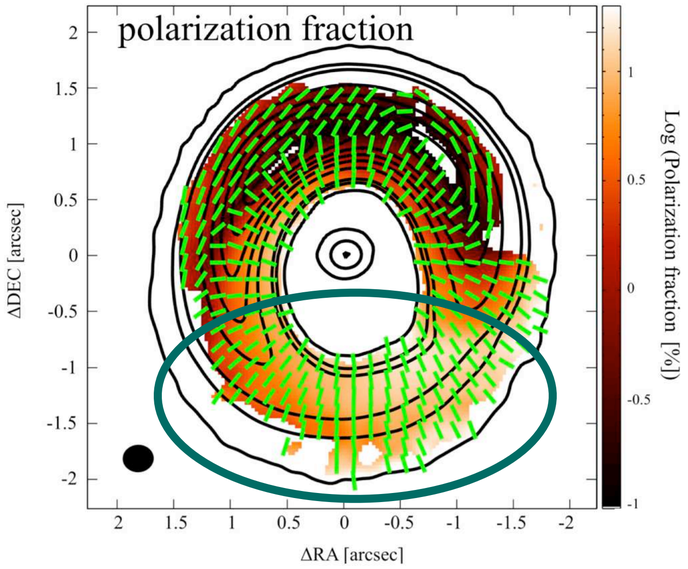
ESA, Planck Collaboration

But what about magnetic fields???

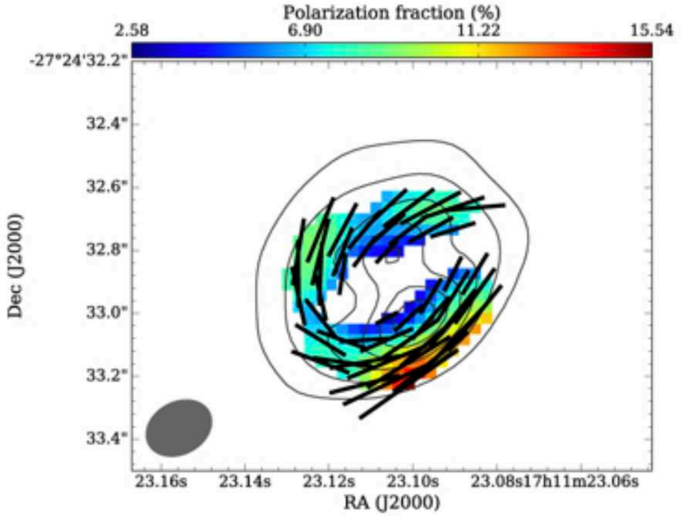


Cox et al. 2018

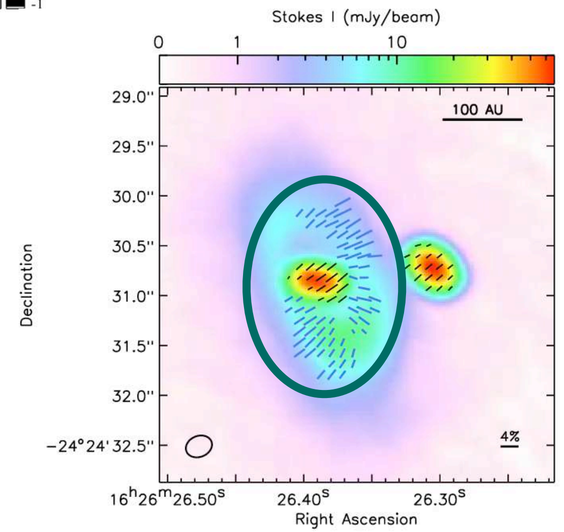
But what about magnetic fields???



HD 142527, Ohashi et



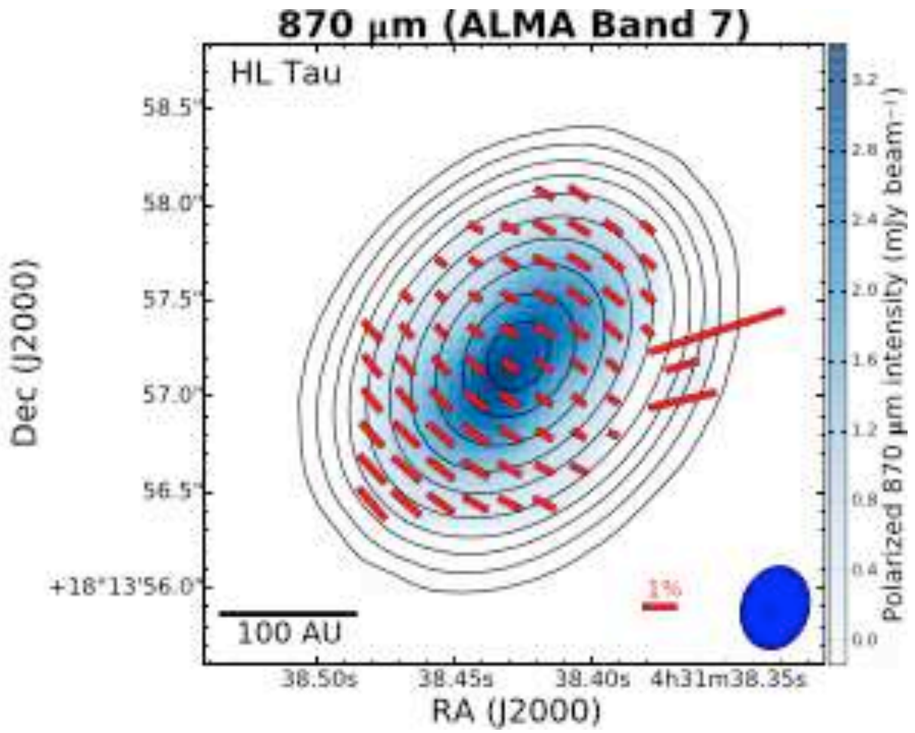
BHB 07-11, Alves et al.



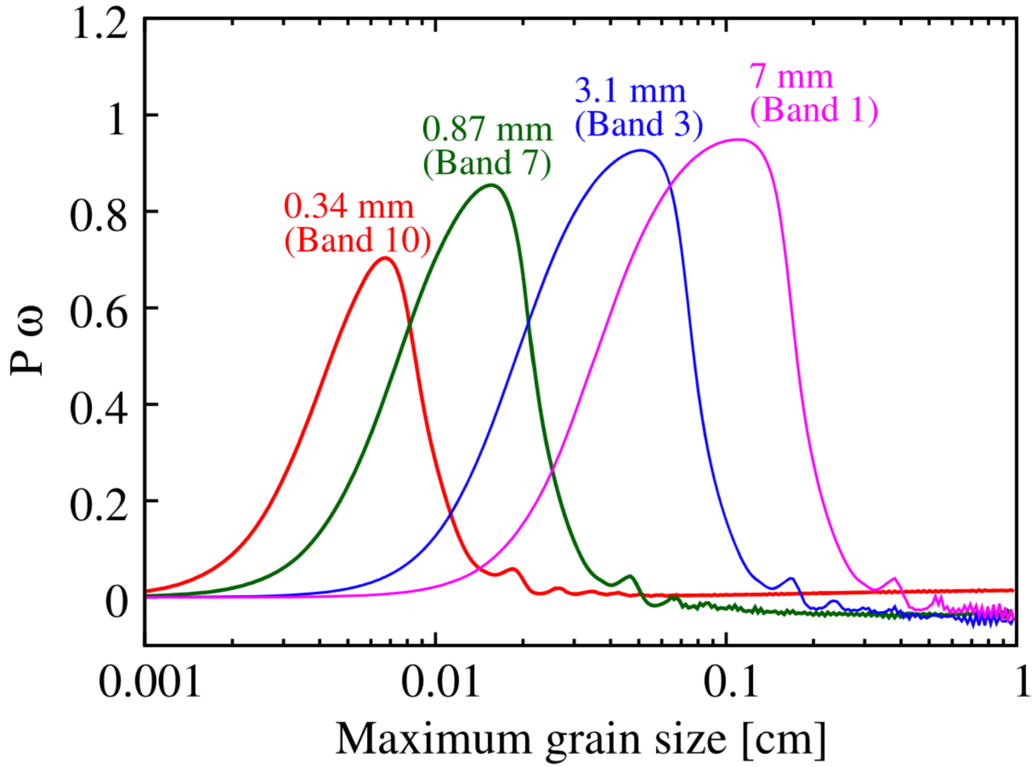
IRAS 16293, Sadavoy et

Figure 8. Magnetic field orientation for the ring around VLA

Dust Polarization from Scattering

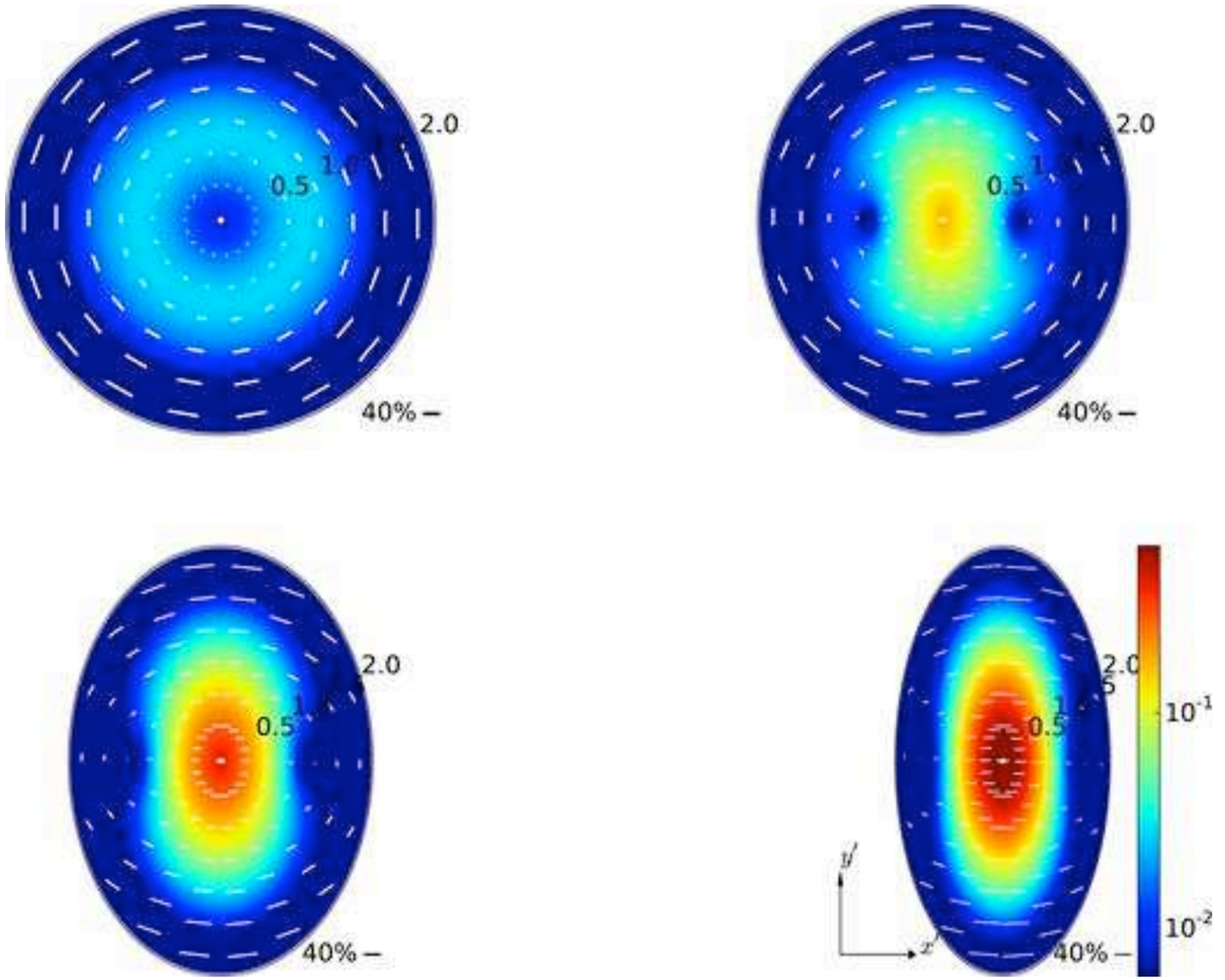


Kataoka et al. 2015, Stephens et al. 2017



Kataoka et al. 2015

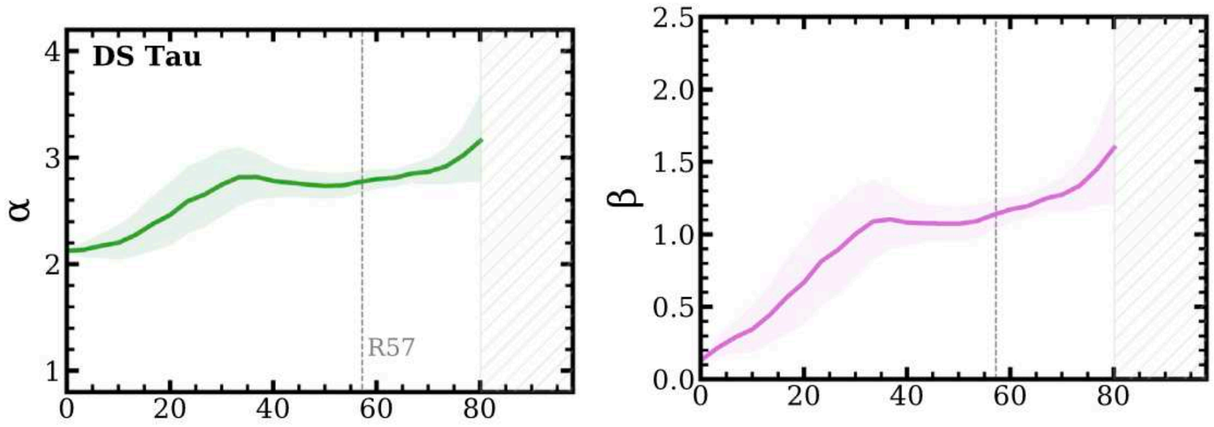
Scattering in Inclined Disks



Yang et al. 2016

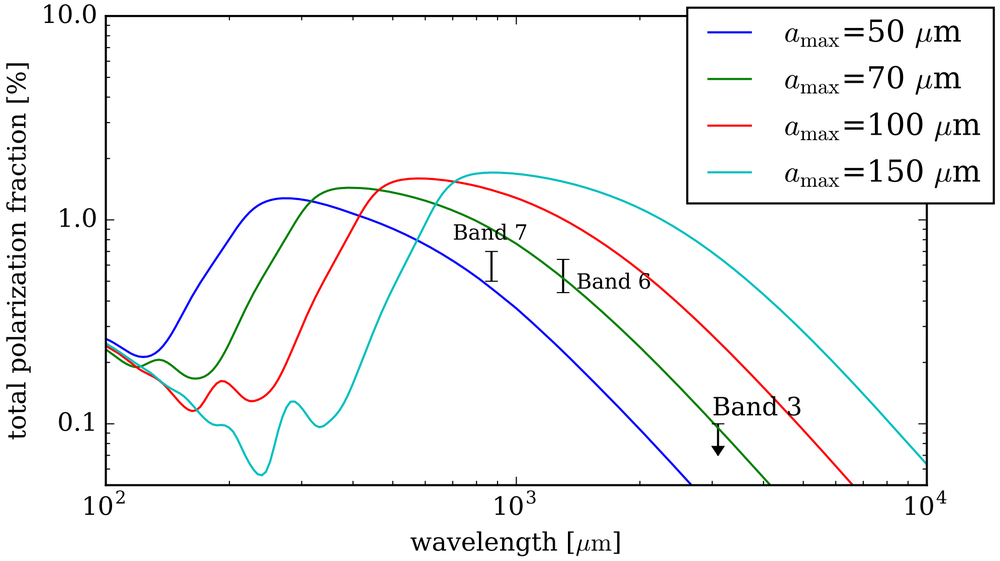
Measuring Dust Grain Sizes: Two Approaches

- Spectral index measurements
  - If dust is optically thin: $F_\nu \propto \nu^\alpha$
  - Opacity depends on frequency as $\kappa(\nu) \propto \nu^\beta$
  - $\alpha = 2 + \beta$
  - Implies grain radii ~1 mm



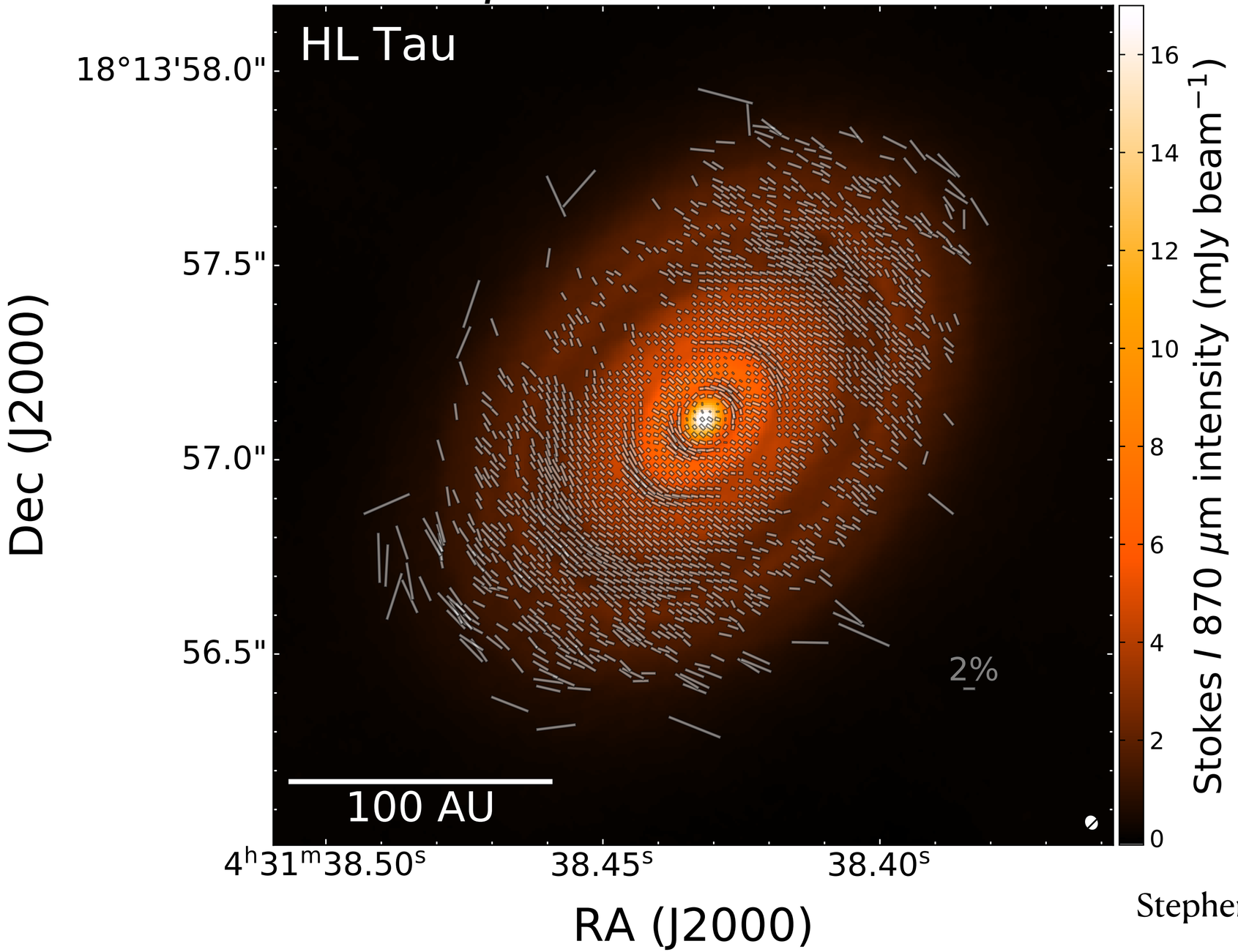
Long et al. 2020

- Scattering polarization measurements
  - Degree of polarization peaks when maximum grain radius $\sim \lambda/2\pi$
  - Polarization at mm and sub-mm wavelengths implies grain sizes ~0.1 mm

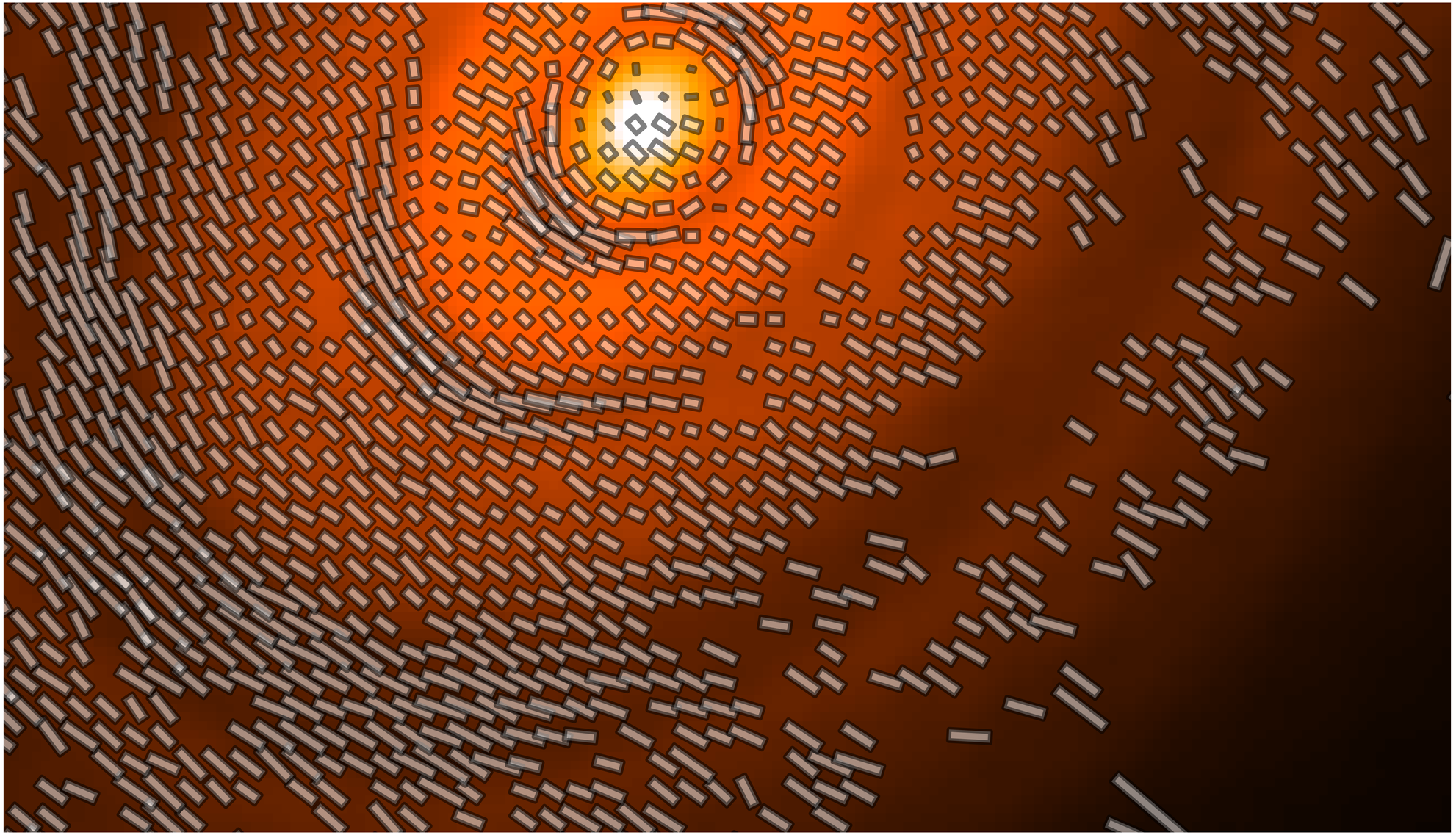


Kataoka et al. 2015

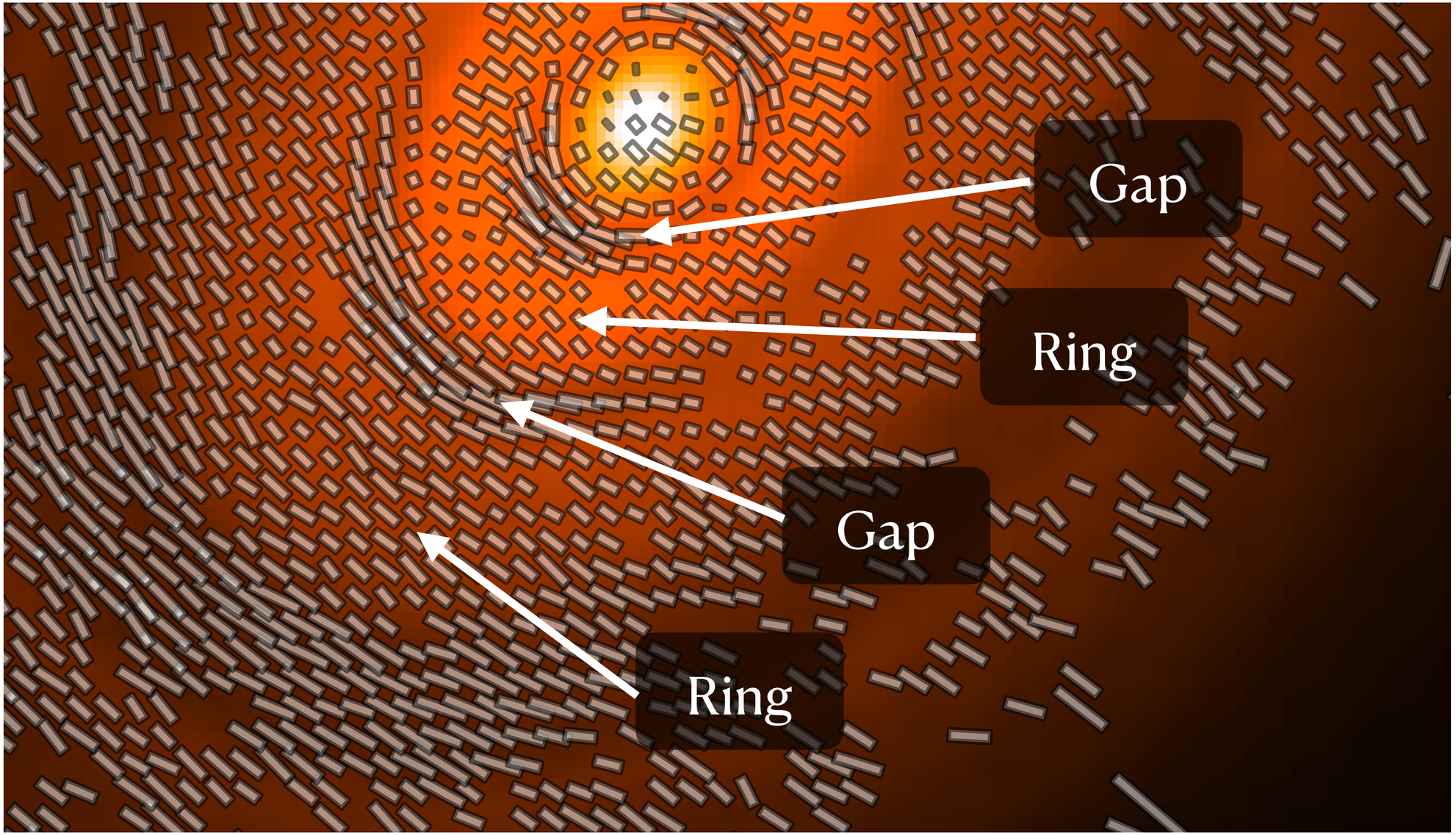
870 μm (ALMA Band 7)



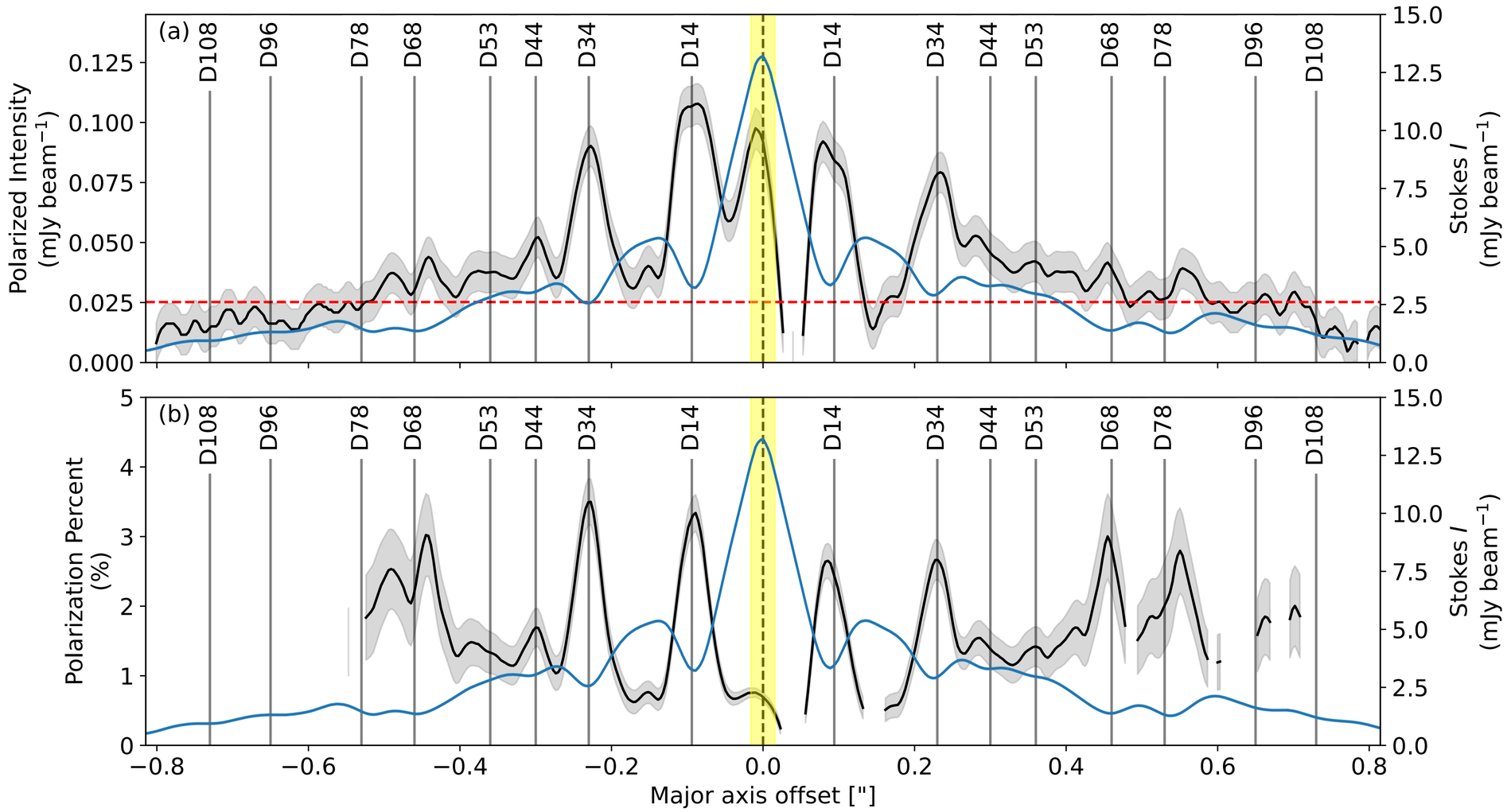
Stephens et al. 2023



Stephens et al. 2023

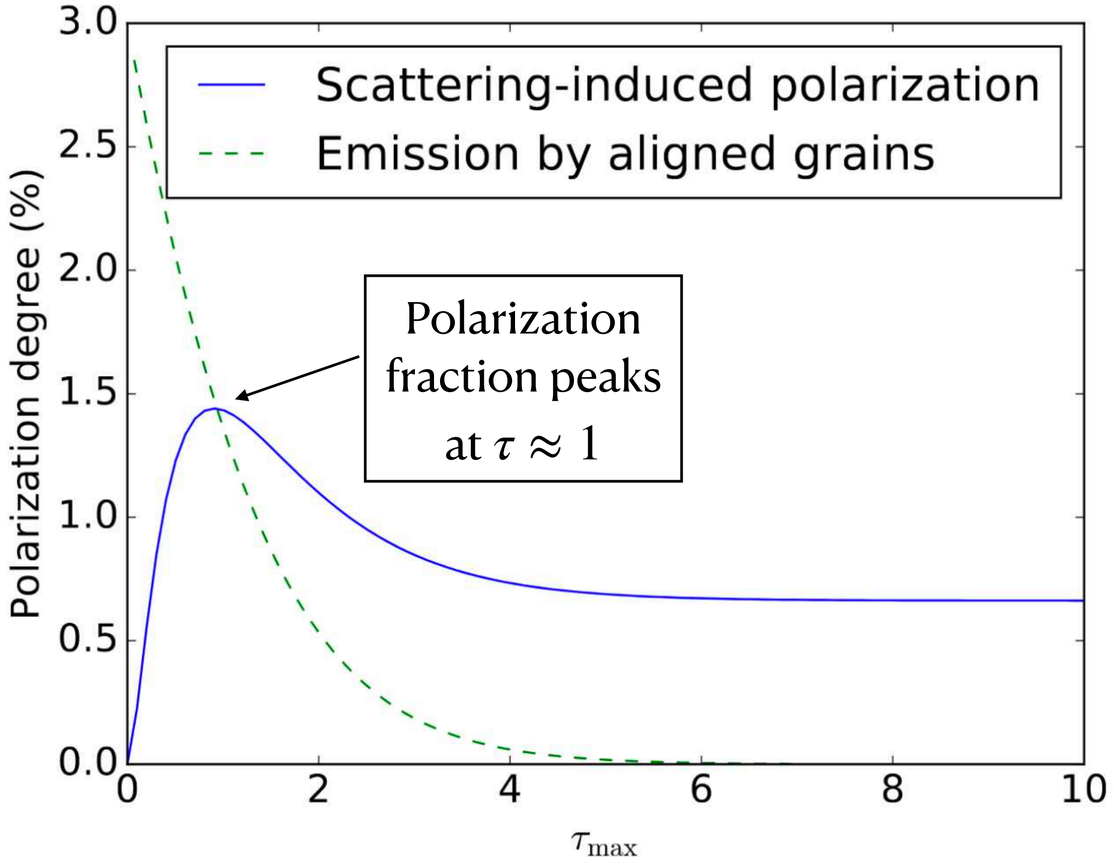


Stephens et al. 2023



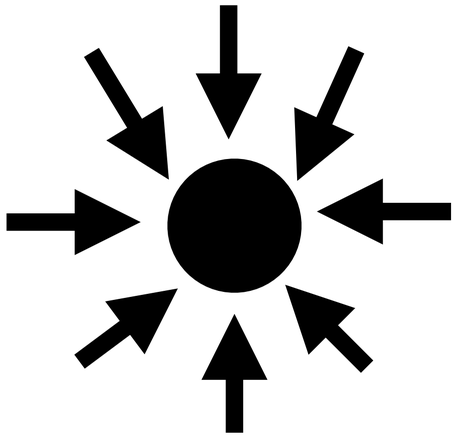
Stephens et al. 2023

Scattering Polarization and Optical Depth

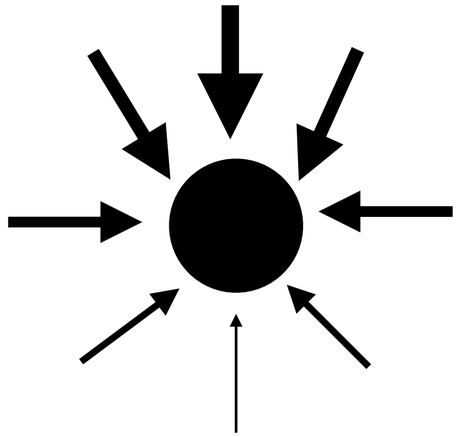


Yang et al. 2017

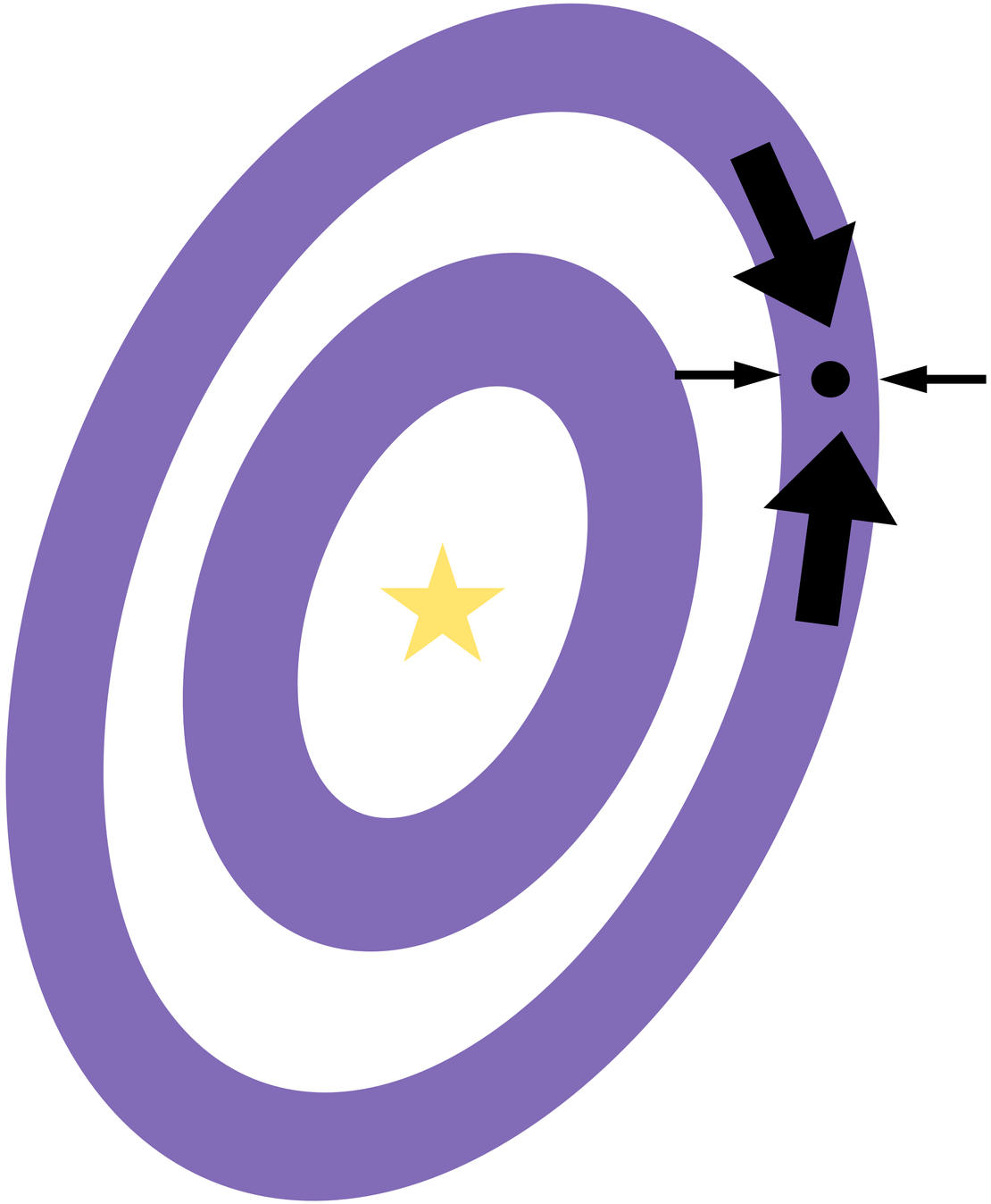
Net polarization from scattering depends on the radiation field a grain "sees":

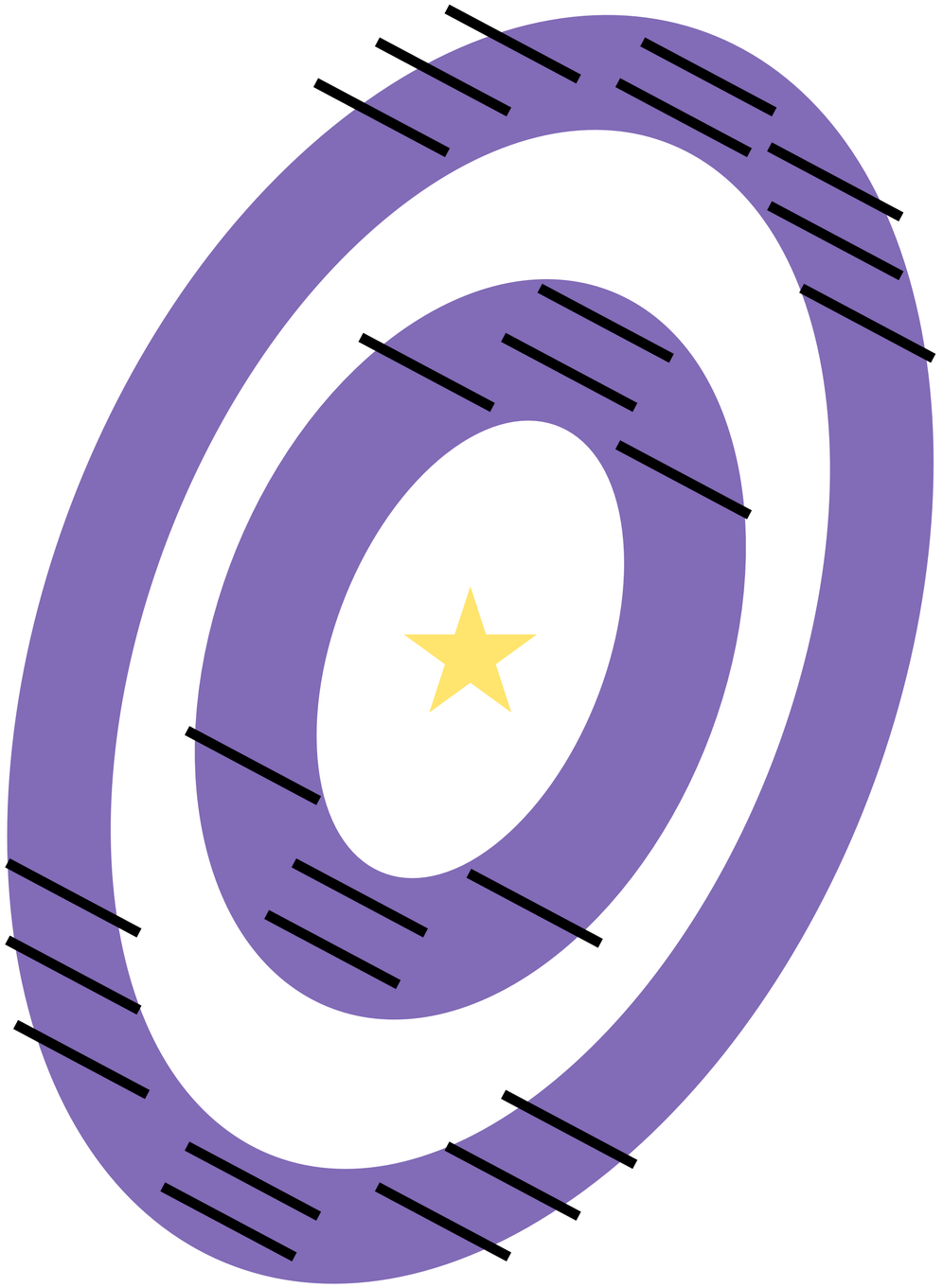


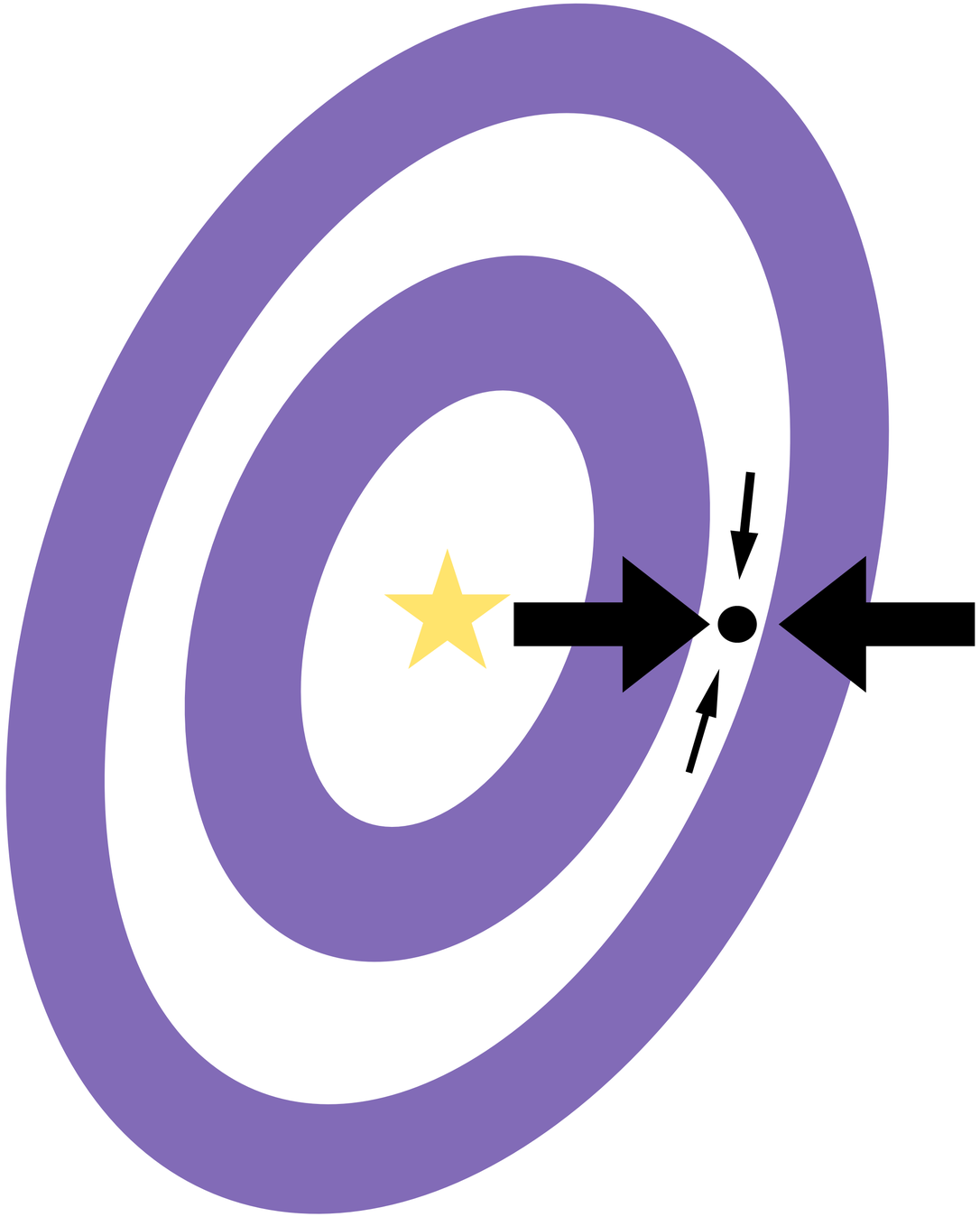
Isotropic radiation environment: little net scattering

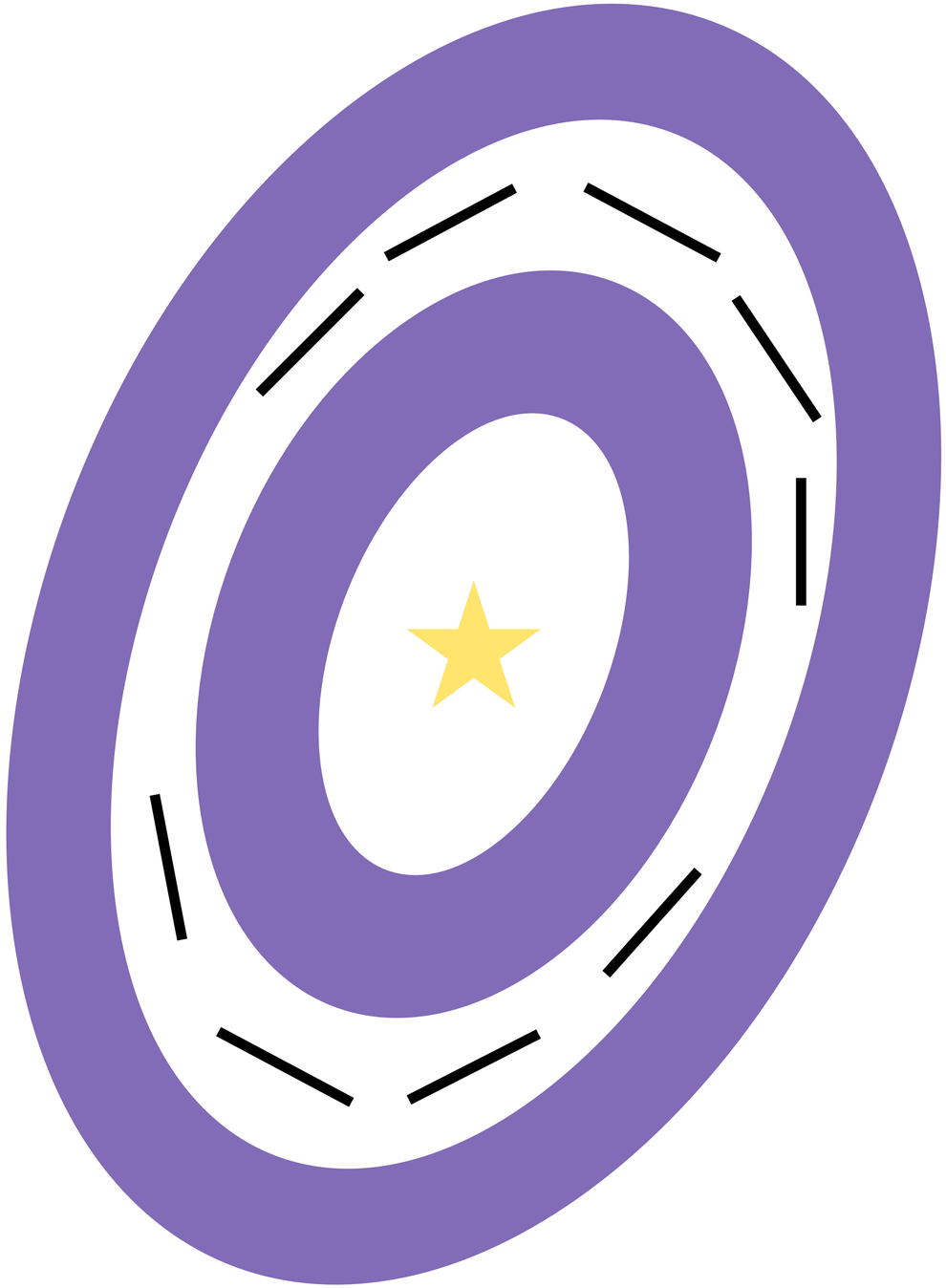


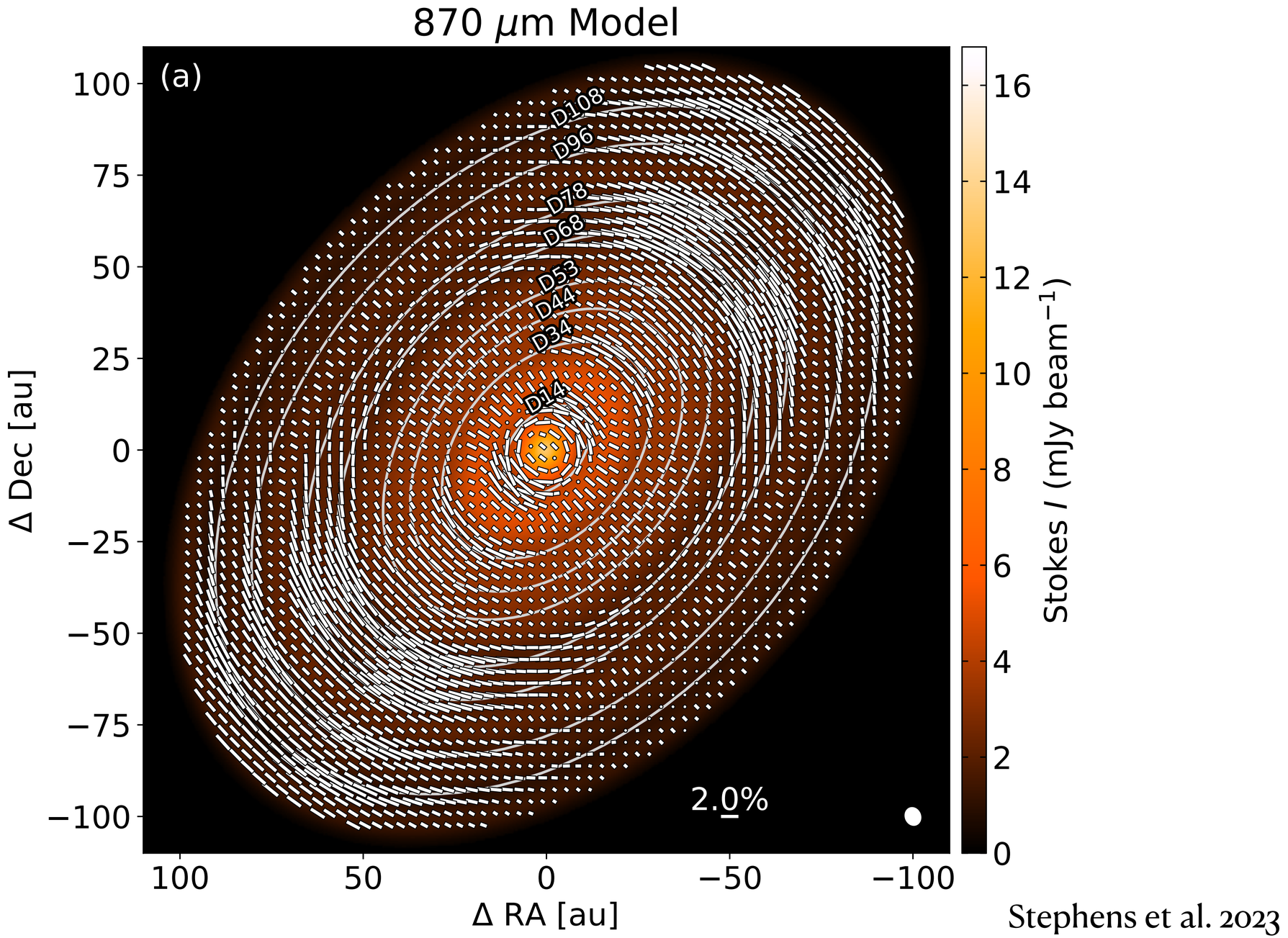
Anisotropic radiation environment: net scattering





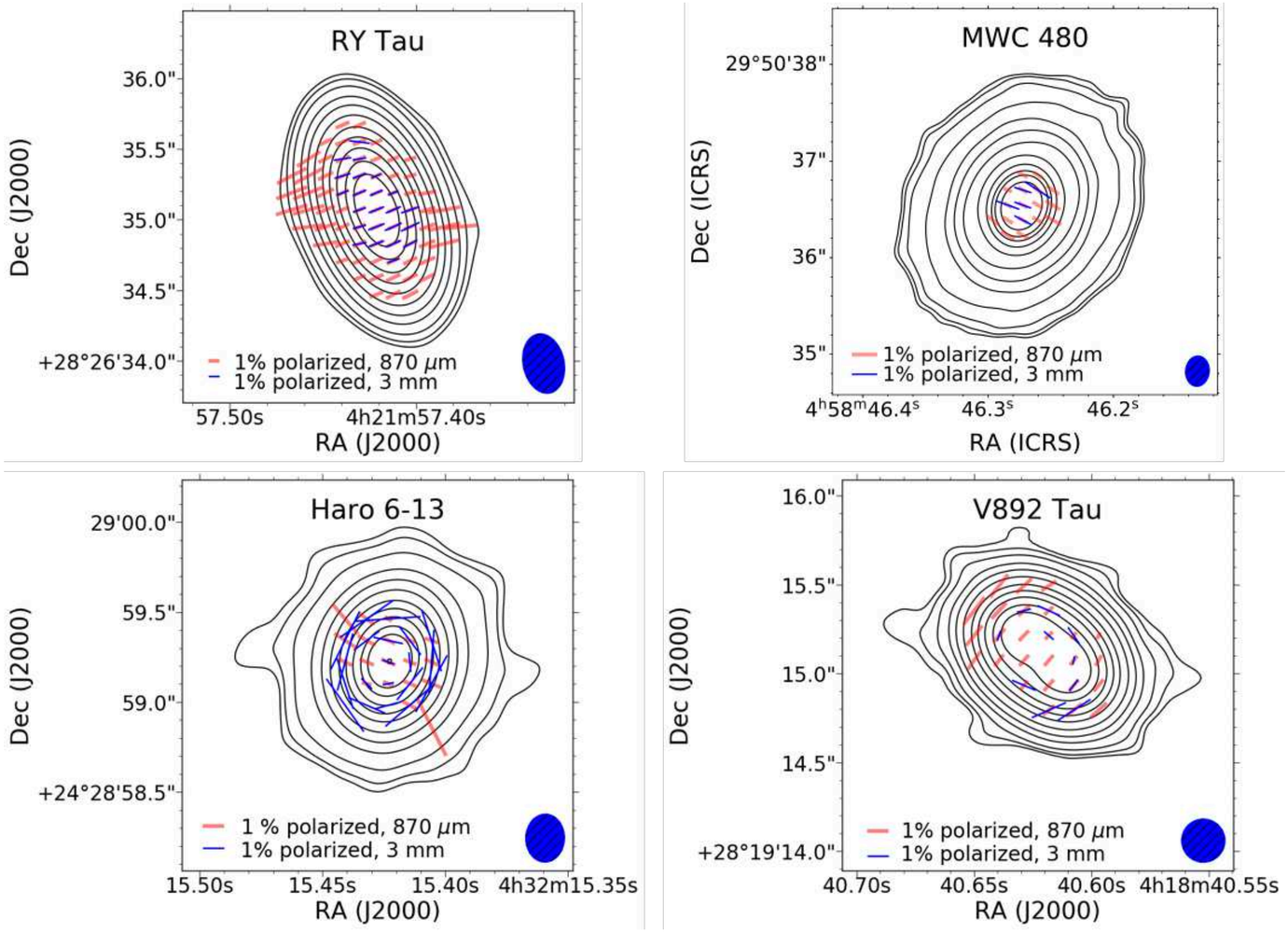






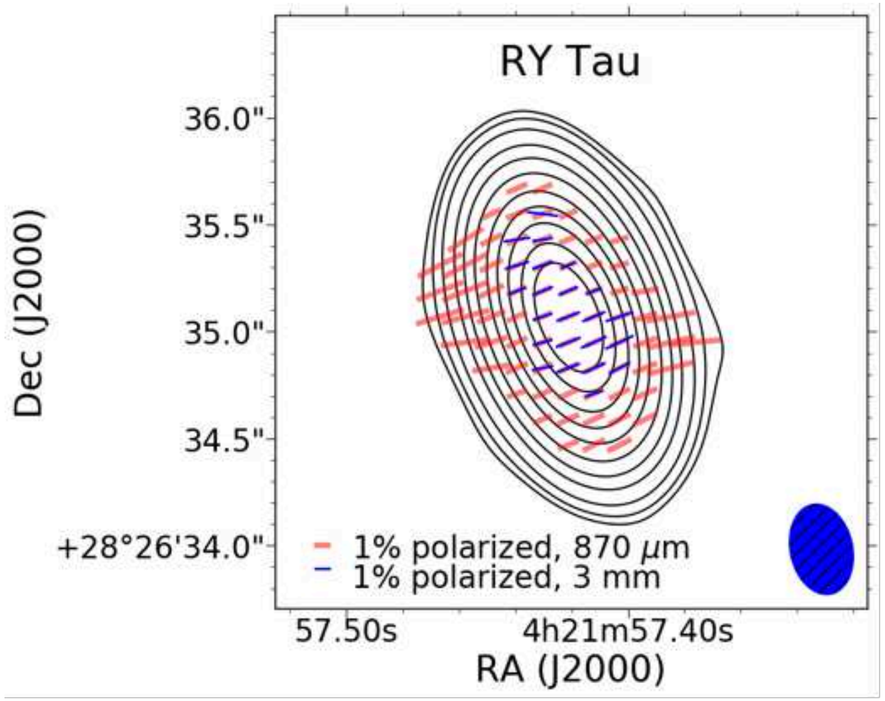
Stephens et al. 2023

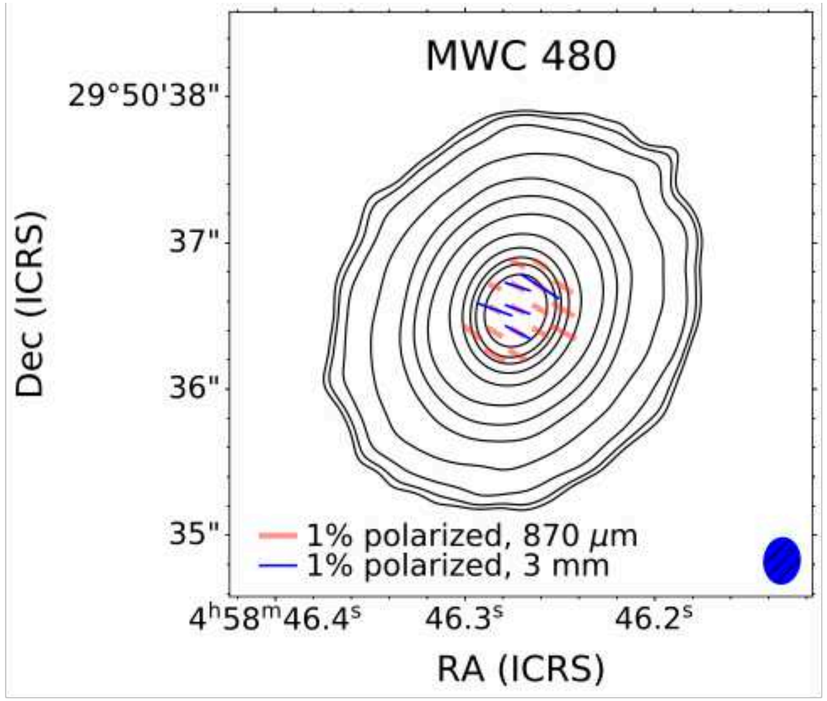
Dual-wavelength Disk Survey



Harrison et al., submitted to ApJ

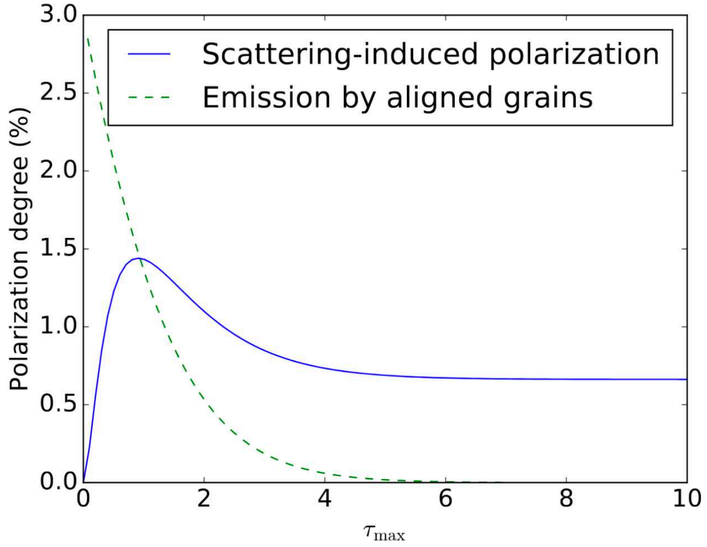
Scattering at Multiple Wavelengths



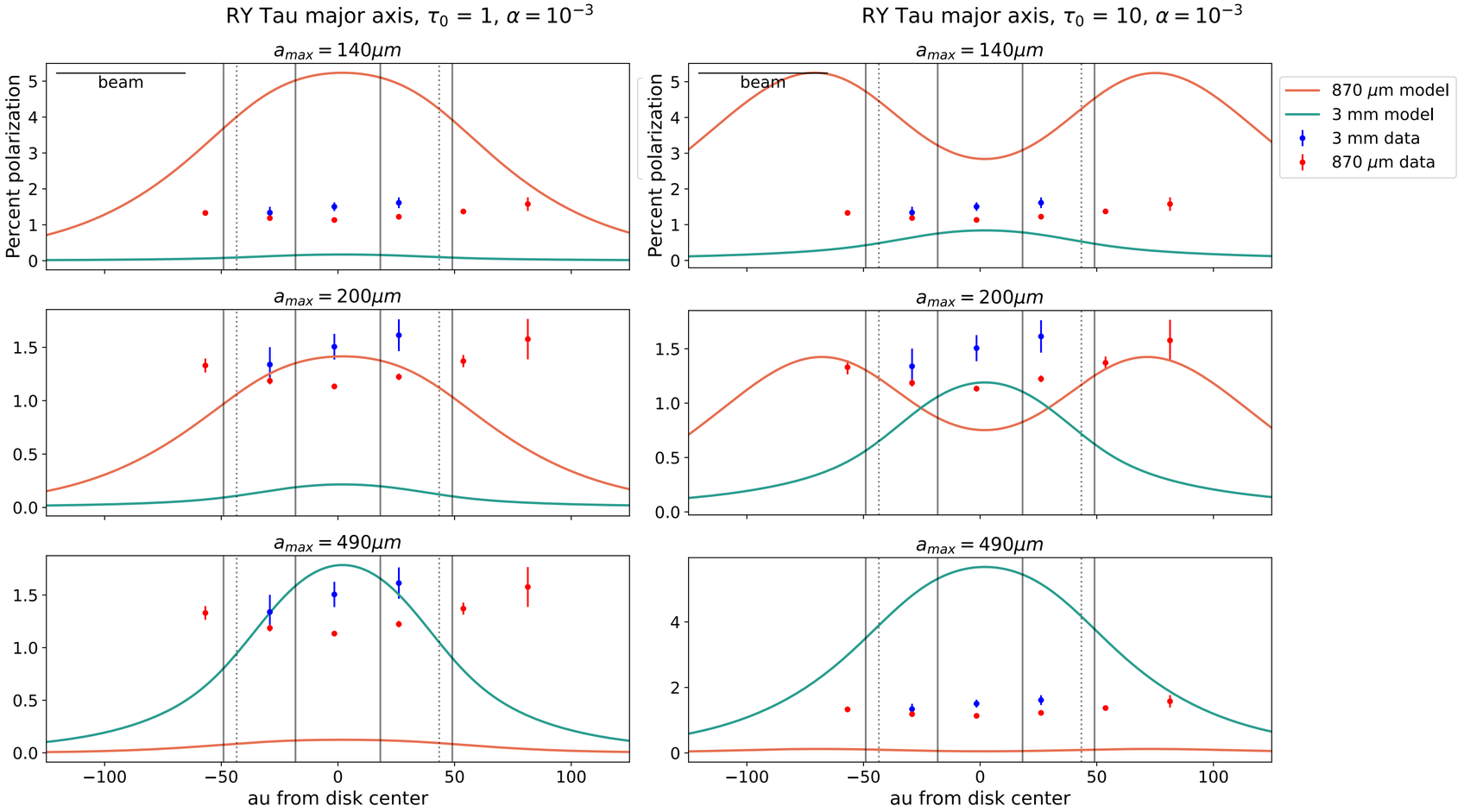


Harrison et al., submitted to ApJ

Optical Depth: Single-Population Model

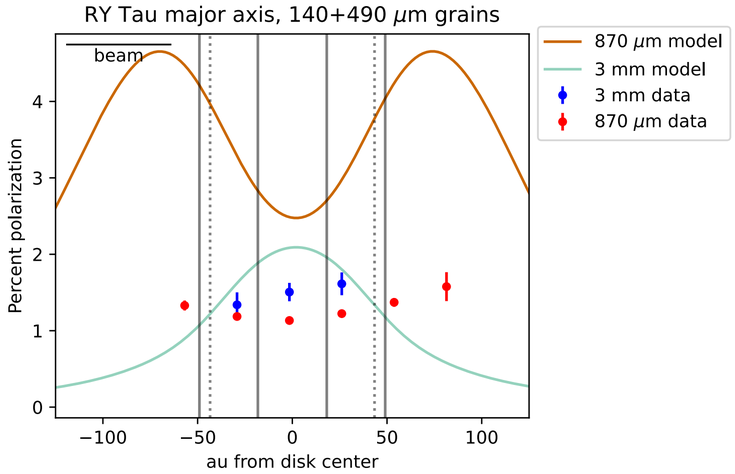


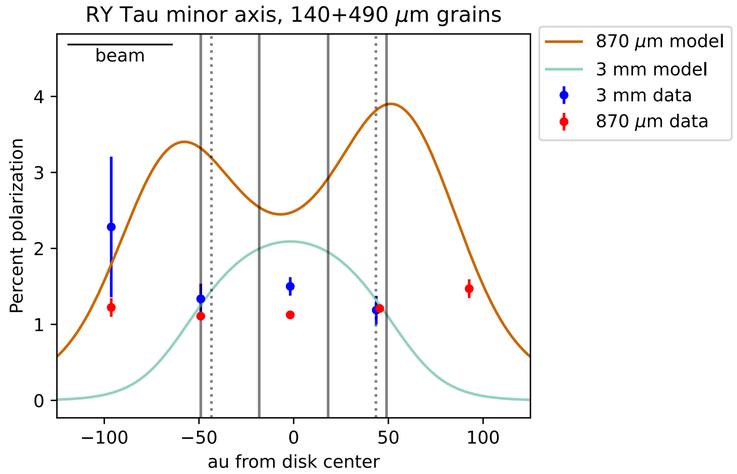
Yang et al. 2017

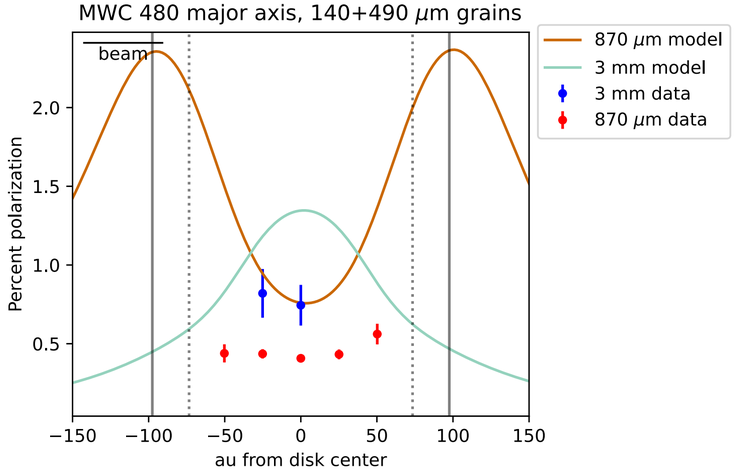


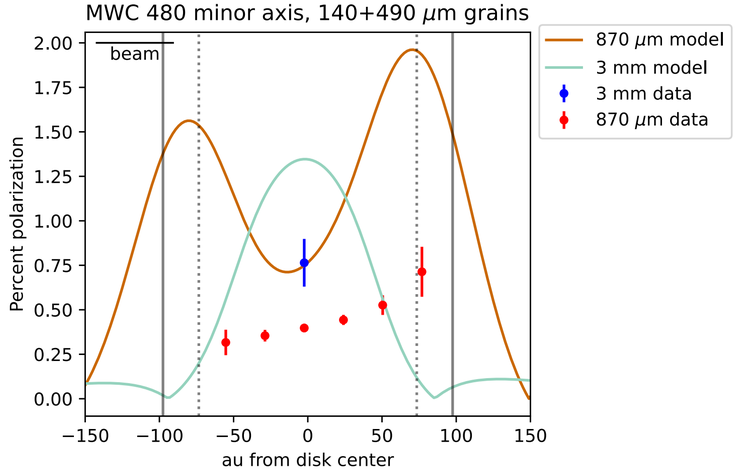
Harrison et al., submitted

Vertical Dust Settling: Two-population Model



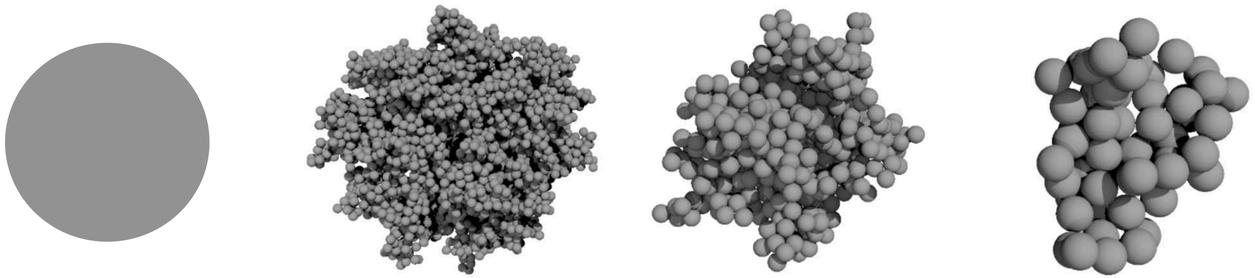




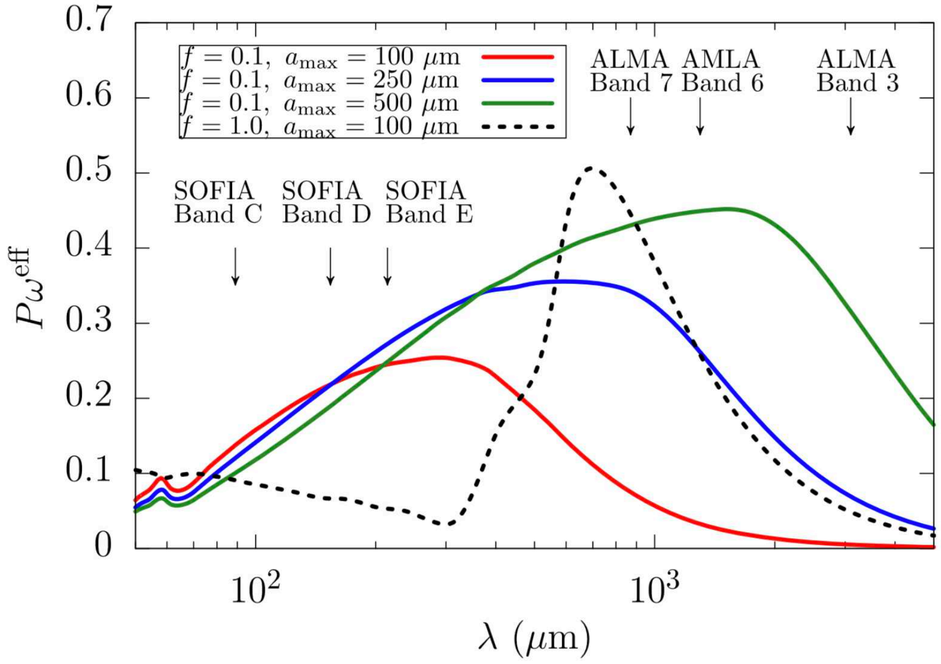


Harrison et al.,
submitted to ApJ

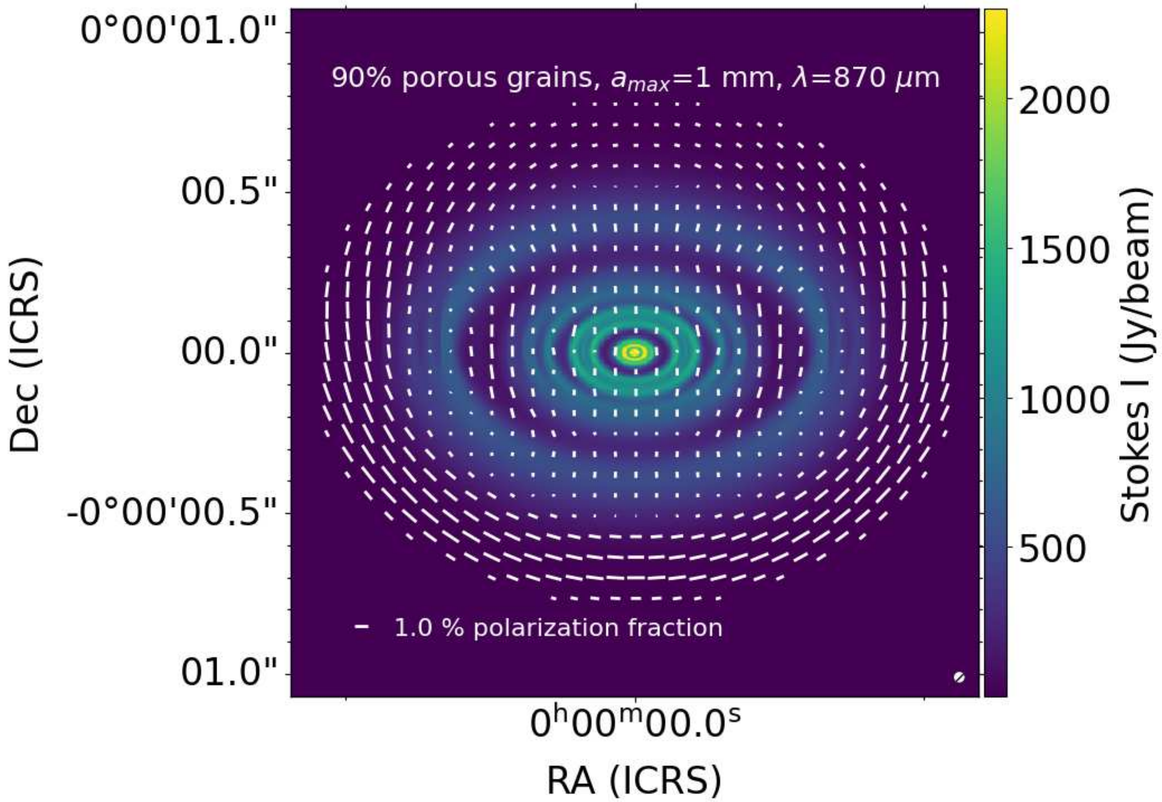
Scattering from Porous Dust Aggregates

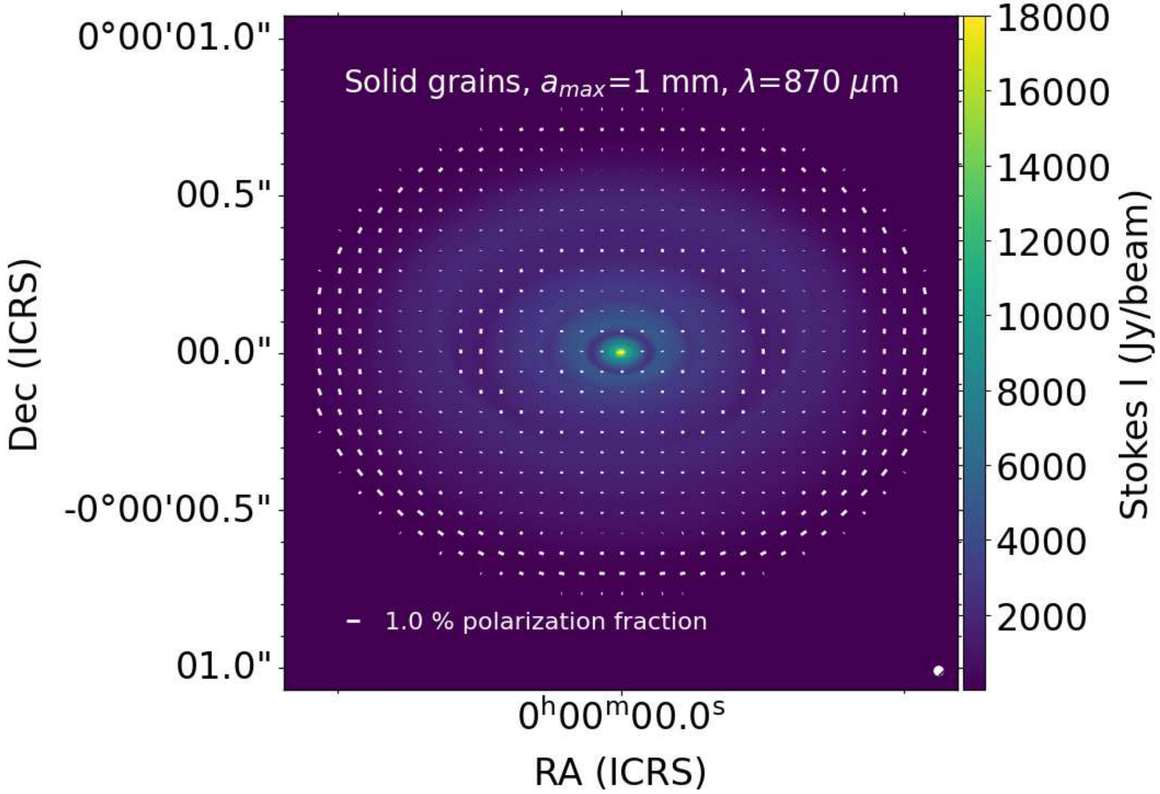


Less porous → More porous

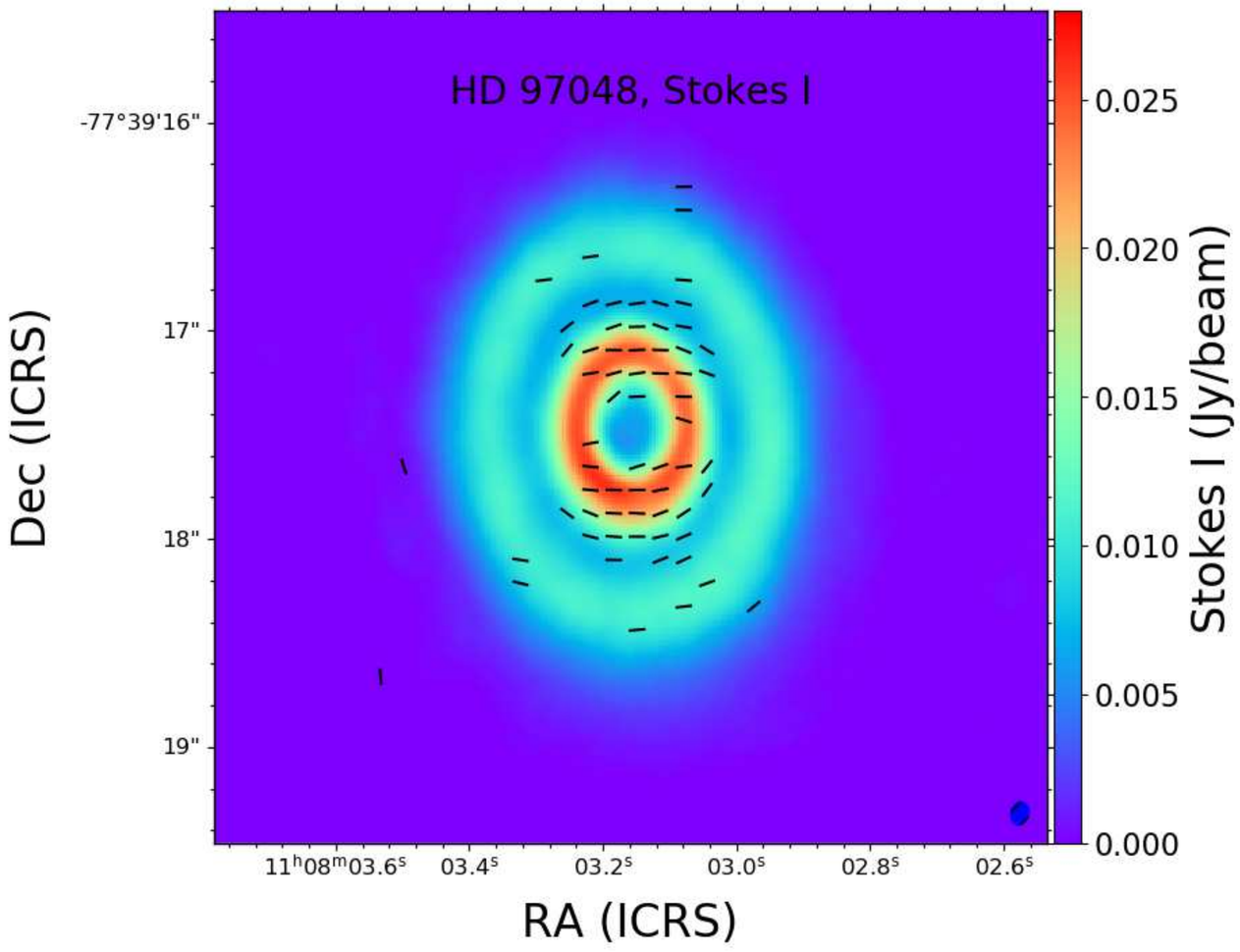


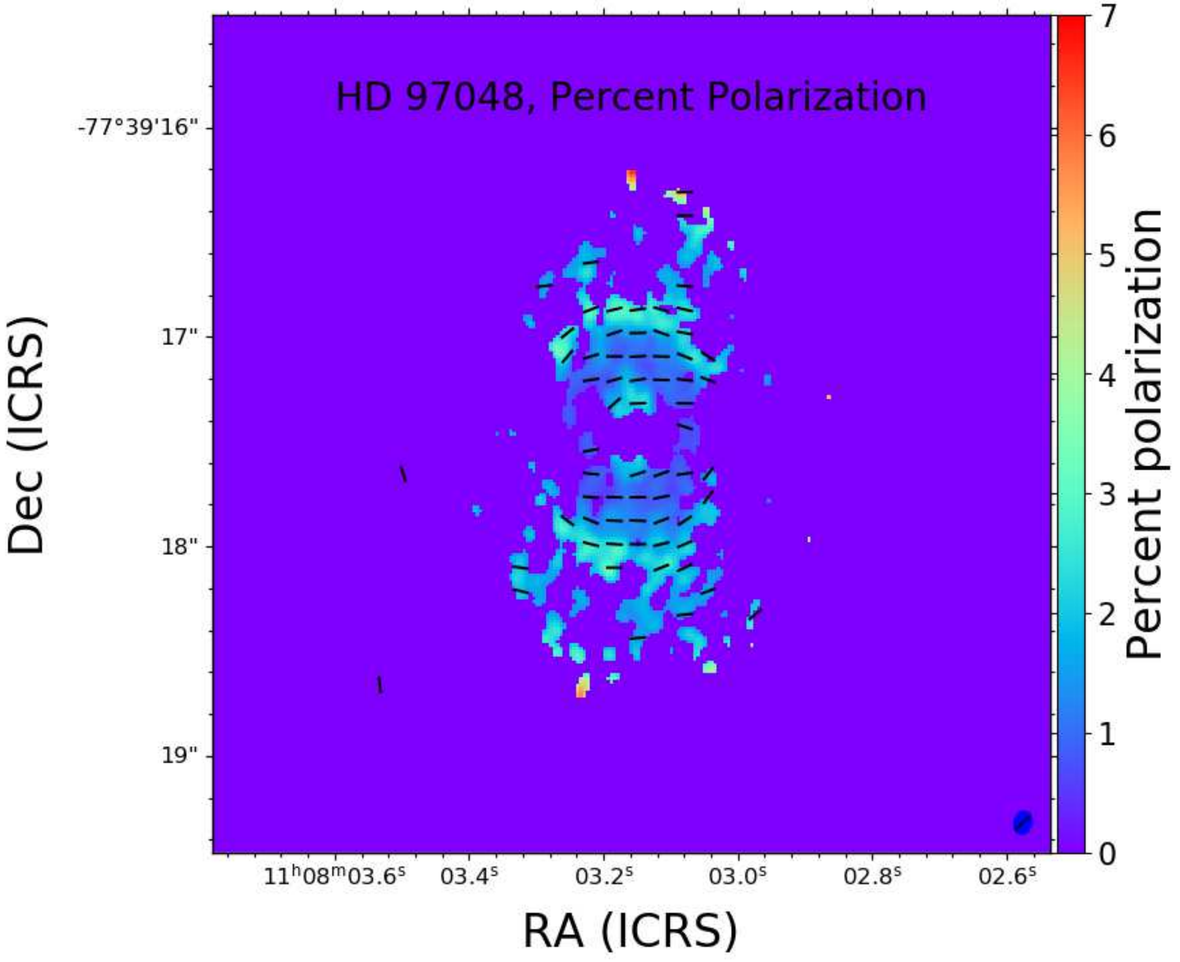
Tazaki et al. 2019, 2022

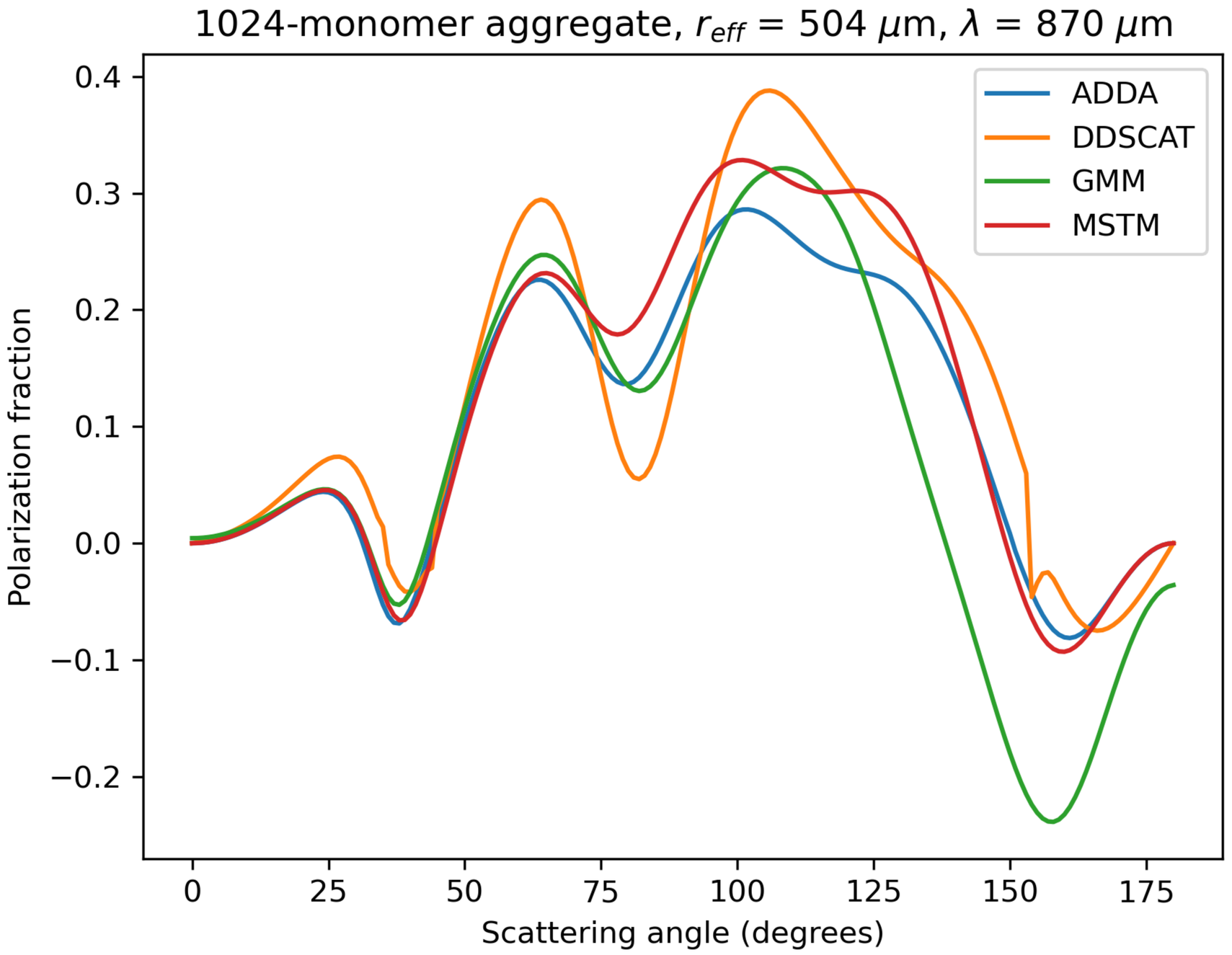

90% porous grains, a_{max}=1 mm, λ=870 μm
1.0 % polarization fraction
0°00'01.0"
00.5"
00.0"
-0°00'00.5"
01.0"
Dec (ICRS)
0h00m00.0s
RA (ICRS)
2000
1500
1000
500
Stokes I (Jy/beam)


Solid grains, a_{max}=1 mm, λ=870 μm
1.0 % polarization fraction
0°00'01.0"
00.5"
00.0"
-0°00'00.5"
01.0"
Dec (ICRS)
0h00m00.0s
RA (ICRS)
18000
16000
14000
12000
10000
8000
6000
4000
2000
Stokes I (Jy/beam)


MCFOST


HD 97048, Stokes I
-77°39'16"
17"
18"
19"
Dec (ICRS)
11h08m03.6s
03.4s
03.2s
03.0s
02.8s
02.6s
RA (ICRS)
0.025
0.020
0.015
0.010
0.005
0.000
Stokes I (Jy/beam)


HD 97048, Percent Polarization
-77°39'16"
17"
18"
19"
Dec (ICRS)
11h08m03.6s
03.4s
03.2s
03.0s
02.8s
02.6s
RA (ICRS)
7
6
5
4
3
2
1
0
Percent polarization


1024-monomer aggregate, r_{eff} = 504 μm, λ = 870 μm
ADDA
DDSCAT
GMM
MSTM
Polarization fraction
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
0
25
50
75
100
125
150
175
Scattering angle (degrees)

Grand Unified Theory of Dust Polarization