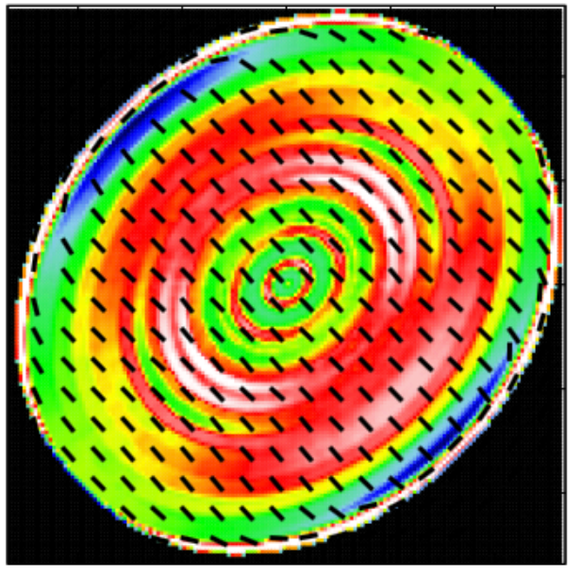
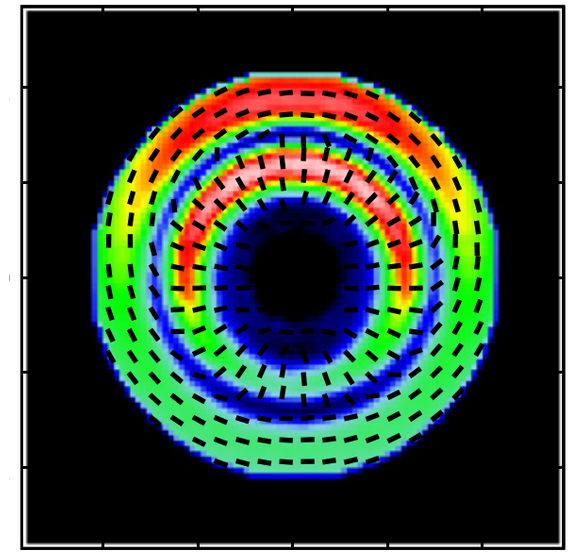
Measuring the grain size and finding the magnetic fields by ALMA polarization

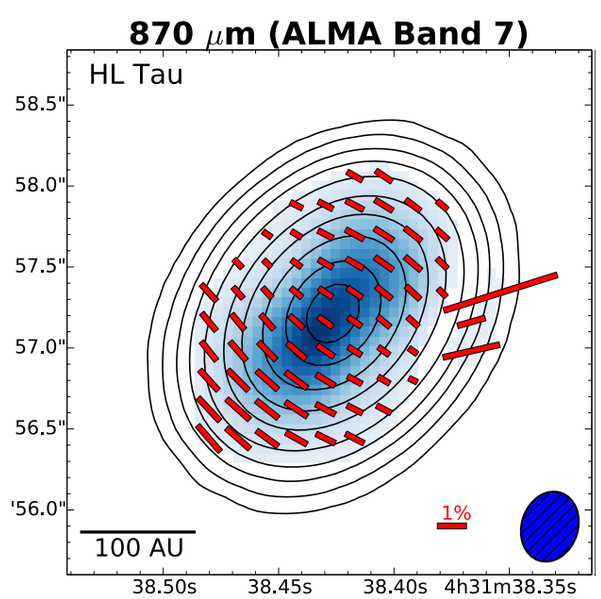
Inclined disk | **Lopsided disk**

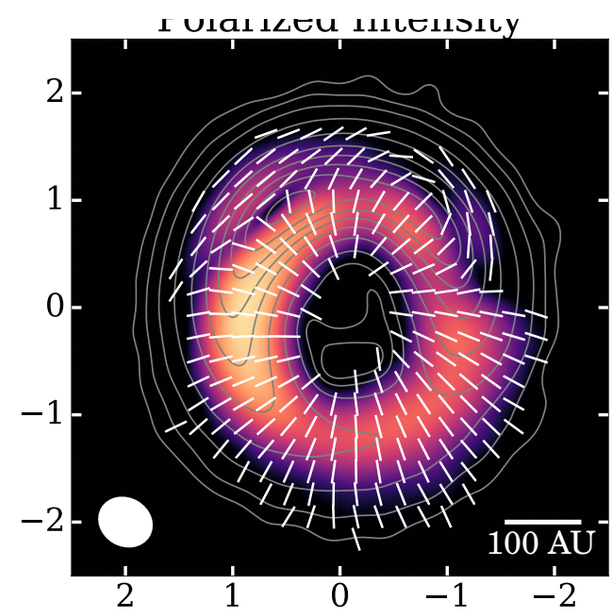
Theories





Observations



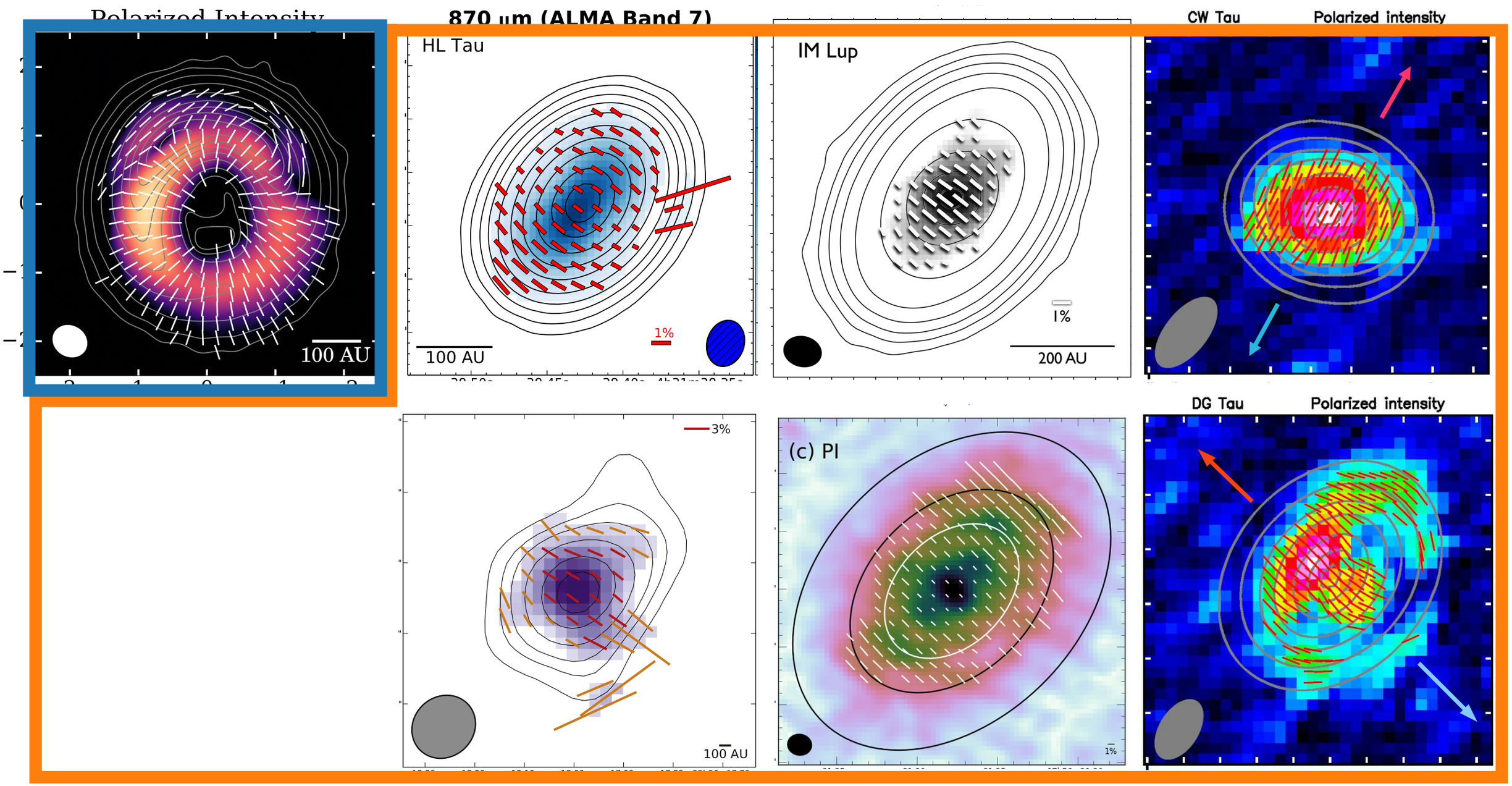


Kataoka et al. 2015, 2016ab,Stephens et al. 2017

Akimasa Kataoka (NAOJ)

T. Muto (Kogakuin U.), M. Momose, T. Tsukagoshi (Ibaraki U.), H.Nagai (NAOJ), M. Fukagawa (NAOJ), H. Shibai (Osaka U.), T. Hanawa (Chiba U.), K. Murakawa (Osaka-S.), C. Dullemond, A. Pohl (Heidelberg), S. Ohashi (RIKEN)

Millimeter-wave polarization of disks



HD 142527; Kataoka et al. 2016, HL Tau; Stephens et al. 2017, IM Lup; Hull et al. 2018, CW Tau and DG Tau; Bacciotti et al. 2018, Cepheus A HW2 ; Fernández-Lopez et al. 2016, HD 163296; Dent et al. 2019, HD100546; Pohl et al. in prep.

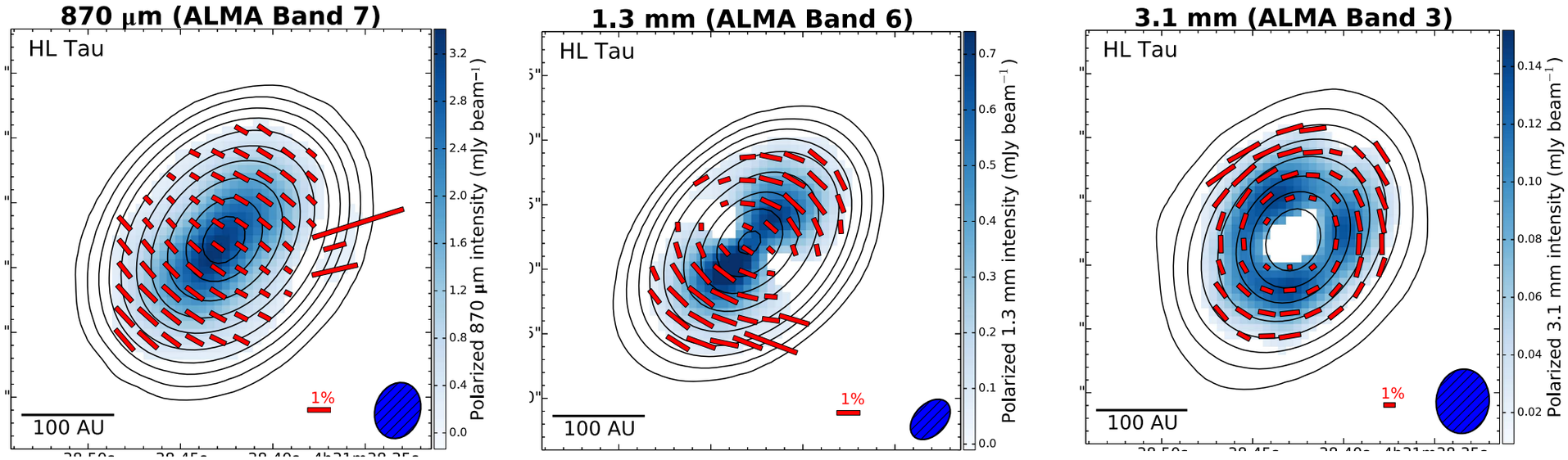
Inclined disks: vectors are parallel to the minor axis

Lopsided disks: radial inside, azimuthal outside

Millimeter-wave polarization of disks

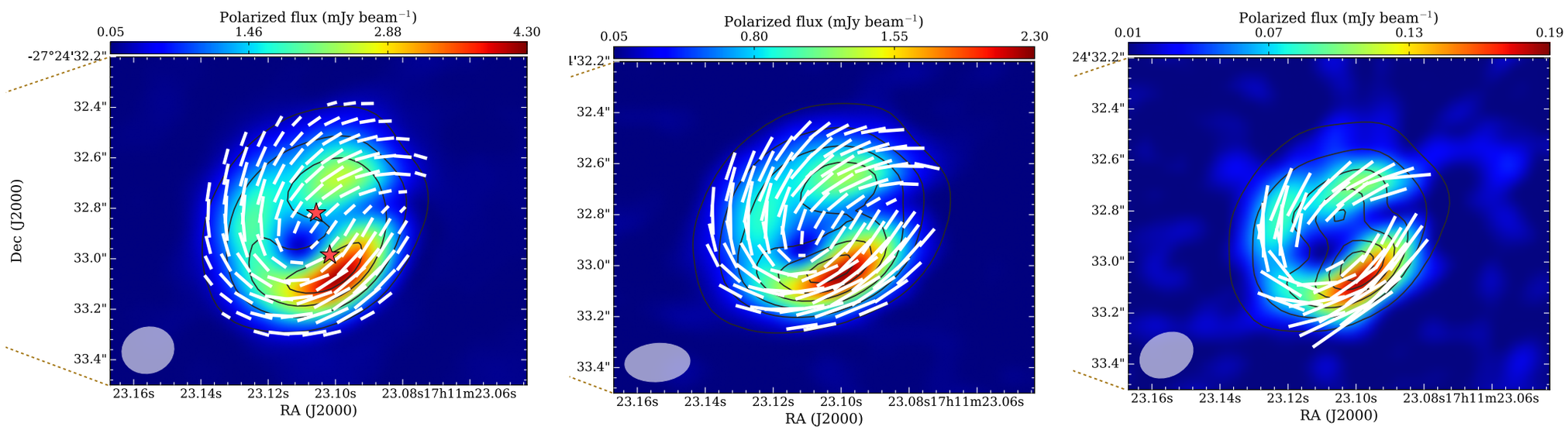
0.87 mm **1.3 mm** **3.1 mm**

HL Tau (Class I-II)



Kataoka et al. 2017, Stephens et al. 2017

BHB07-11 (Class I)



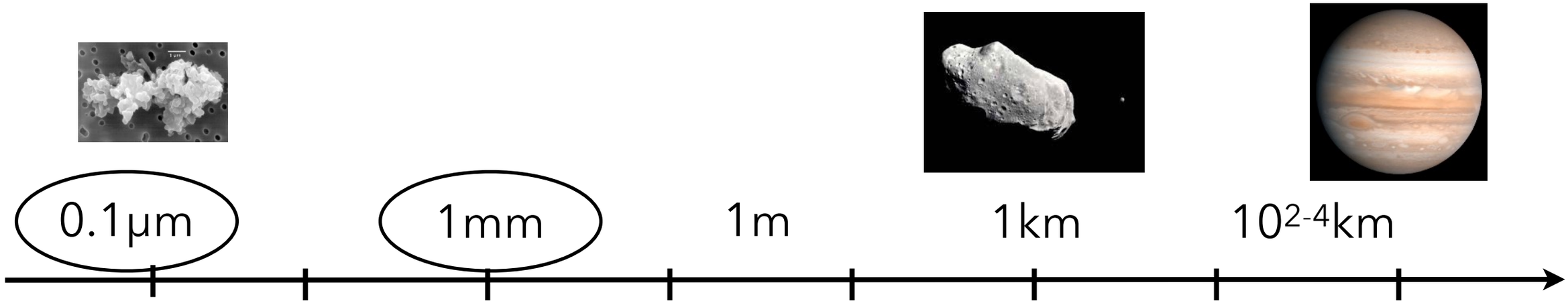
Alves et al. 2018

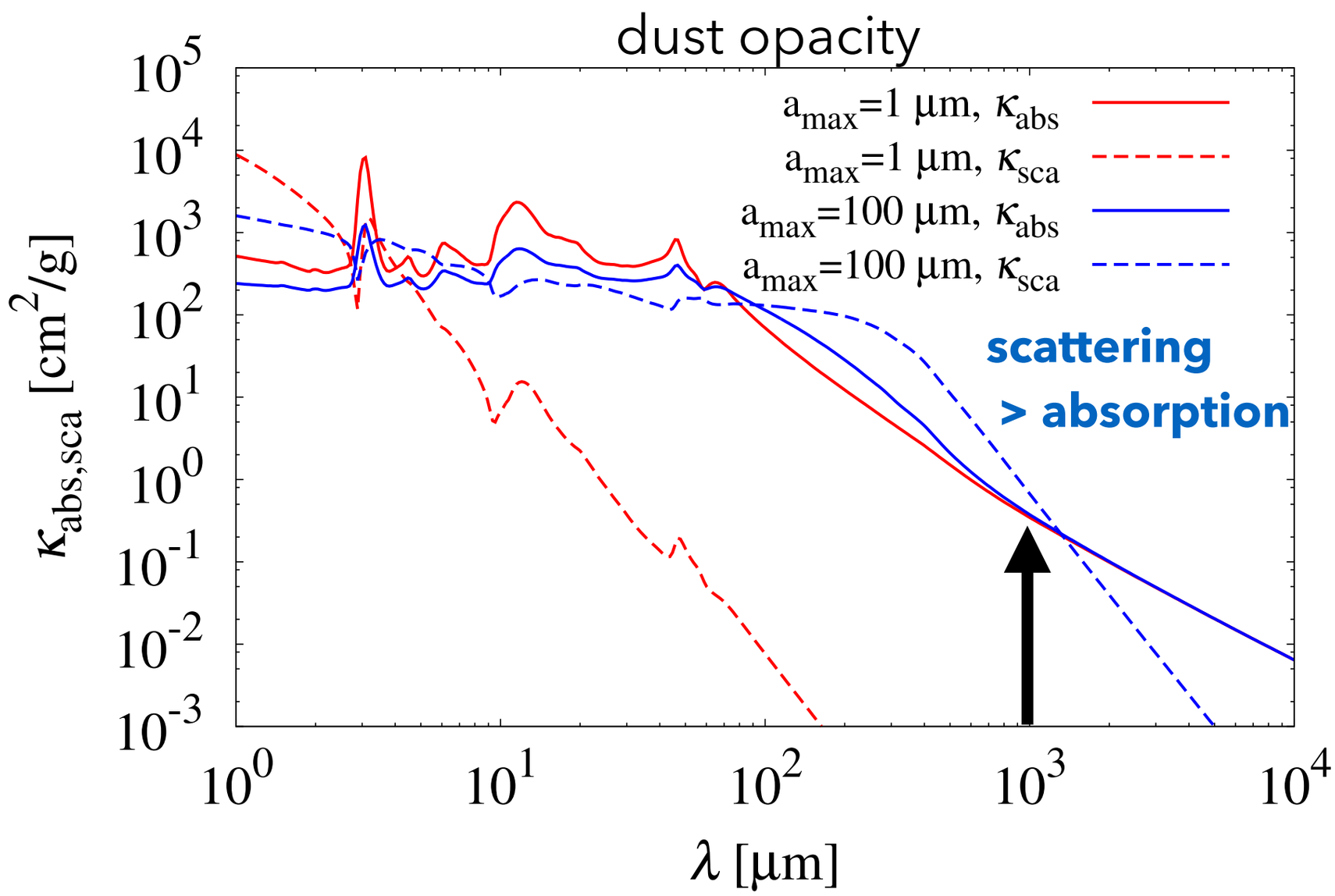
What's the origin of wavelength (in)dependence?

Talk outline

- Two pages to take a glance of recent ALMA polarimetric observations
- **Theories of polarization**
    1. Self-scattering
    2. Alignment
        - with B-fields, radiation, or (gas flow)
- Case studies
    - HL Tau: constraints on the grain size
    - HD 142527: different polarization due to the segregated grain population
    - HD 163296: evidence of dead zone

Grain growth is essential

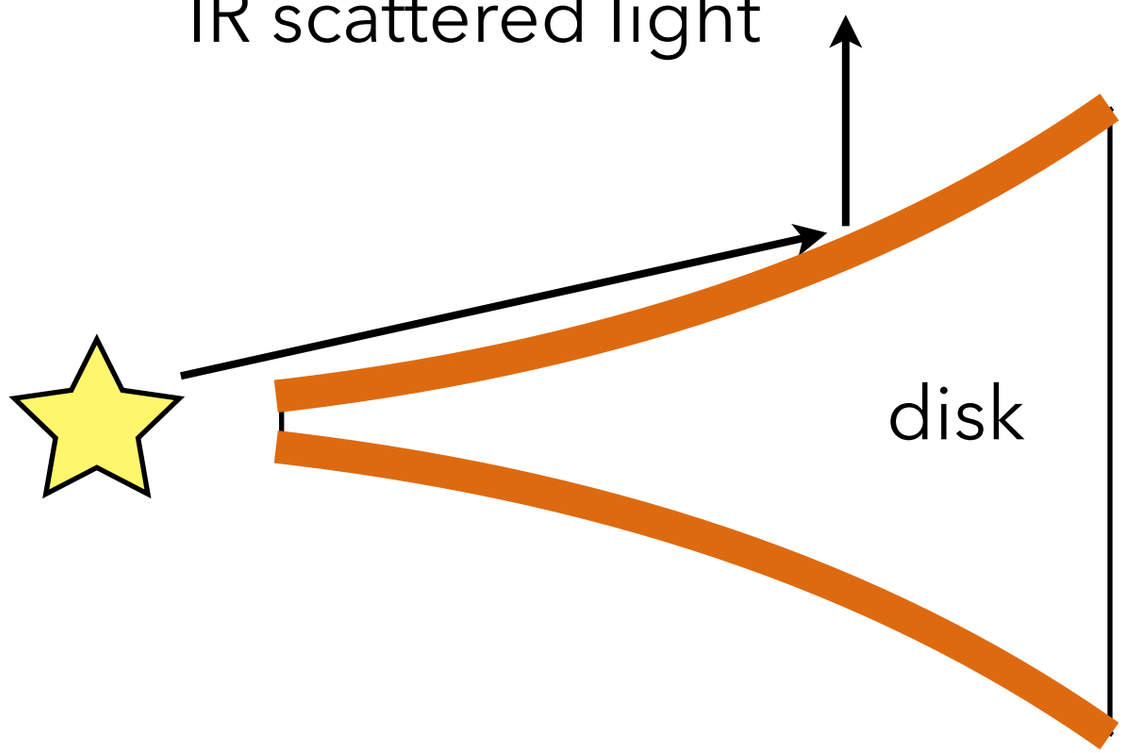




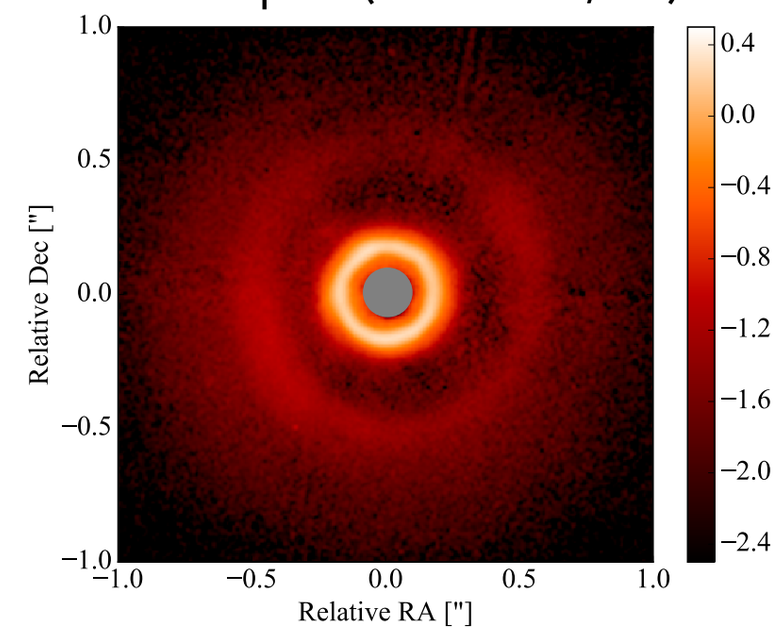
Light source of scattering

IR scattered light

Infrared



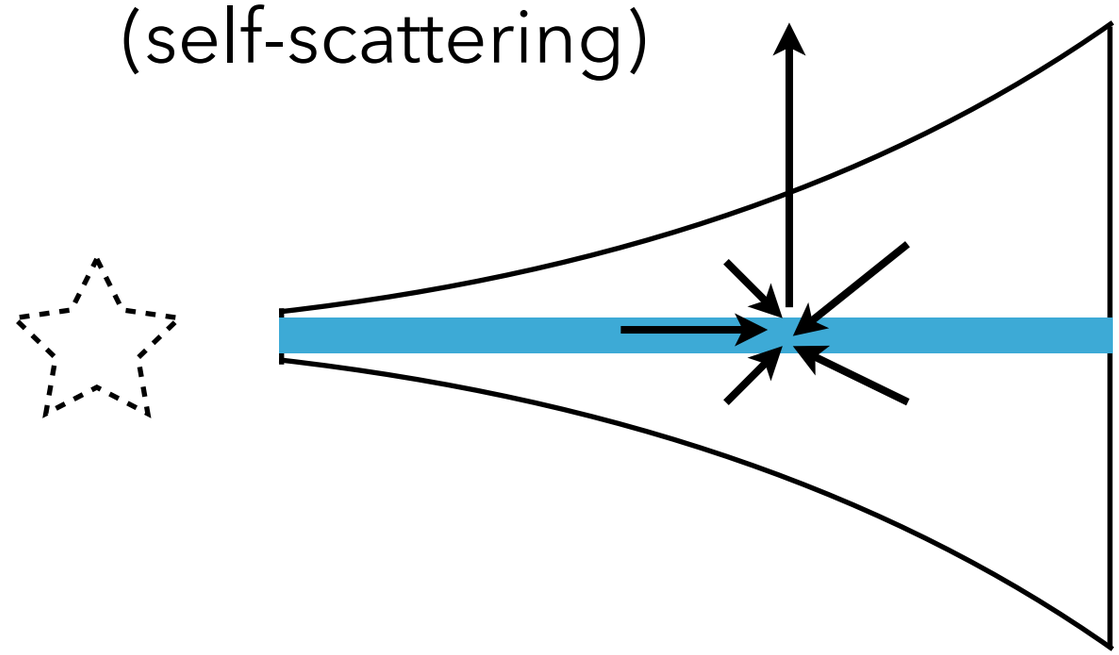
example (face-on, PI)



Pohl et al. 2017

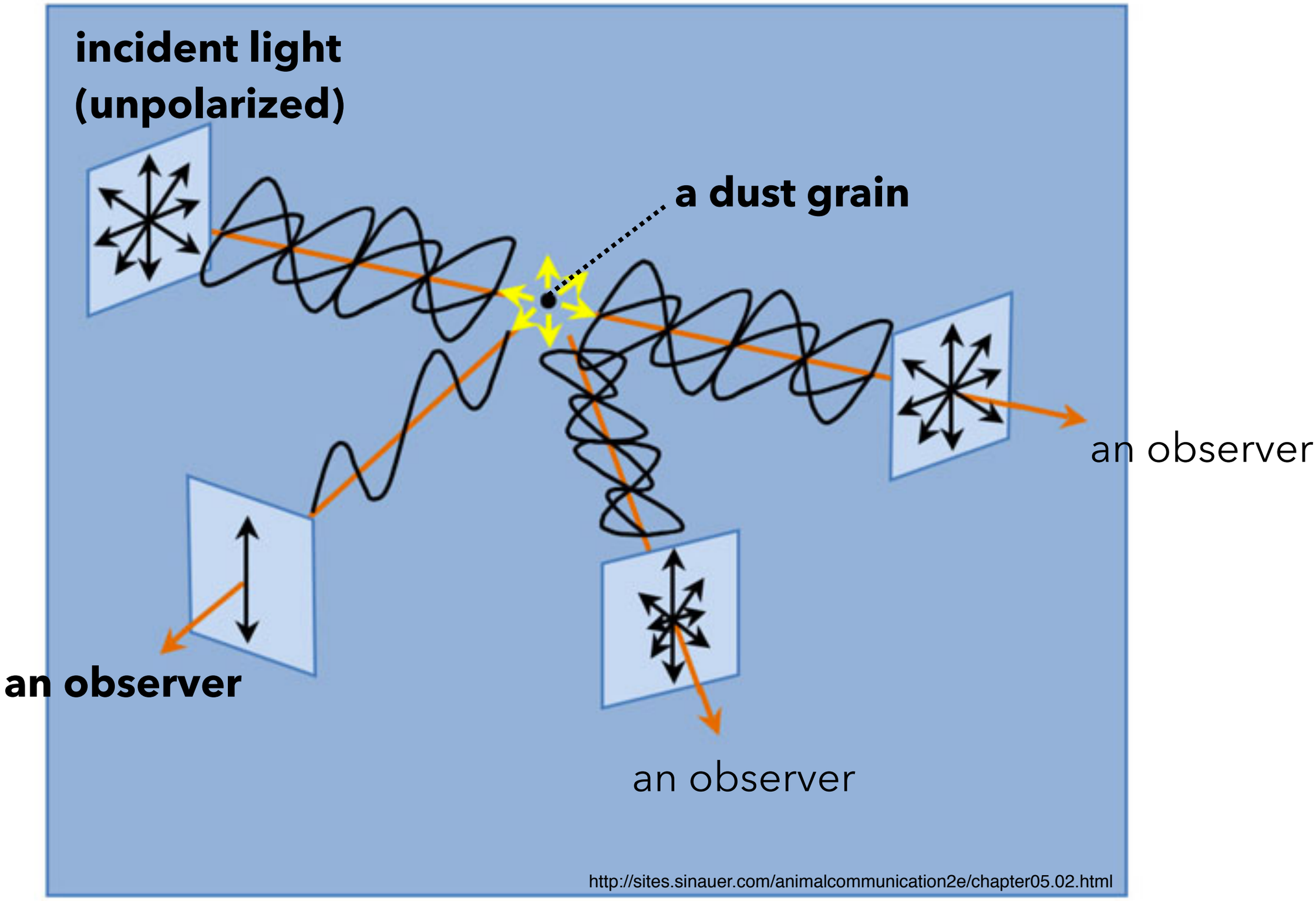
radio scattered light
(self-scattering)

millimeter

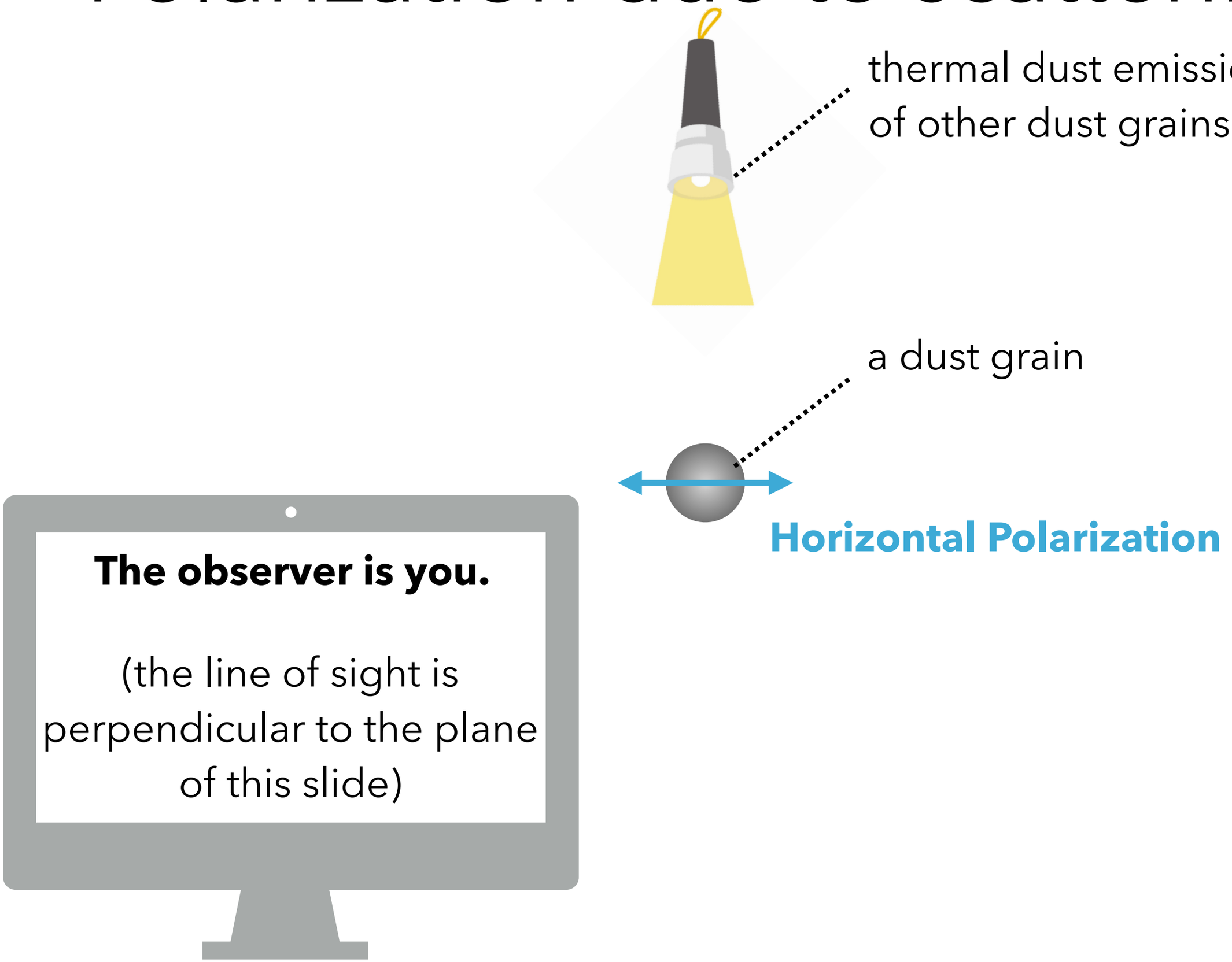


?

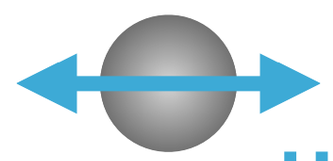
Polarization due to scattering



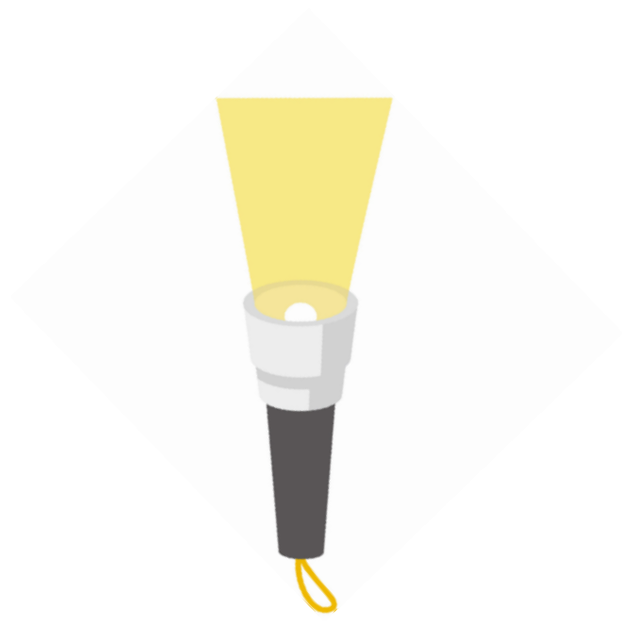
Polarization due to scattering



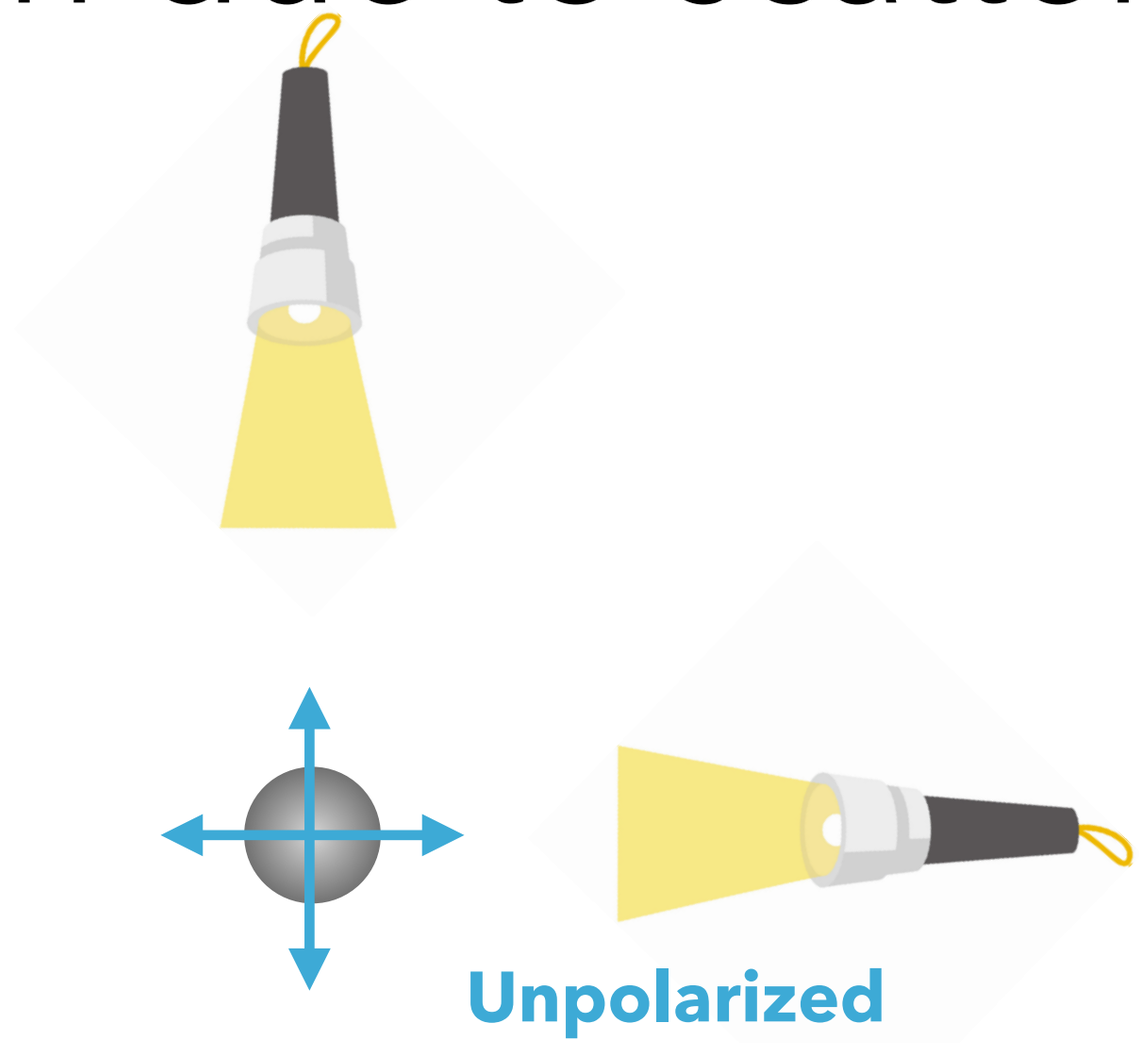
Polarization due to scattering



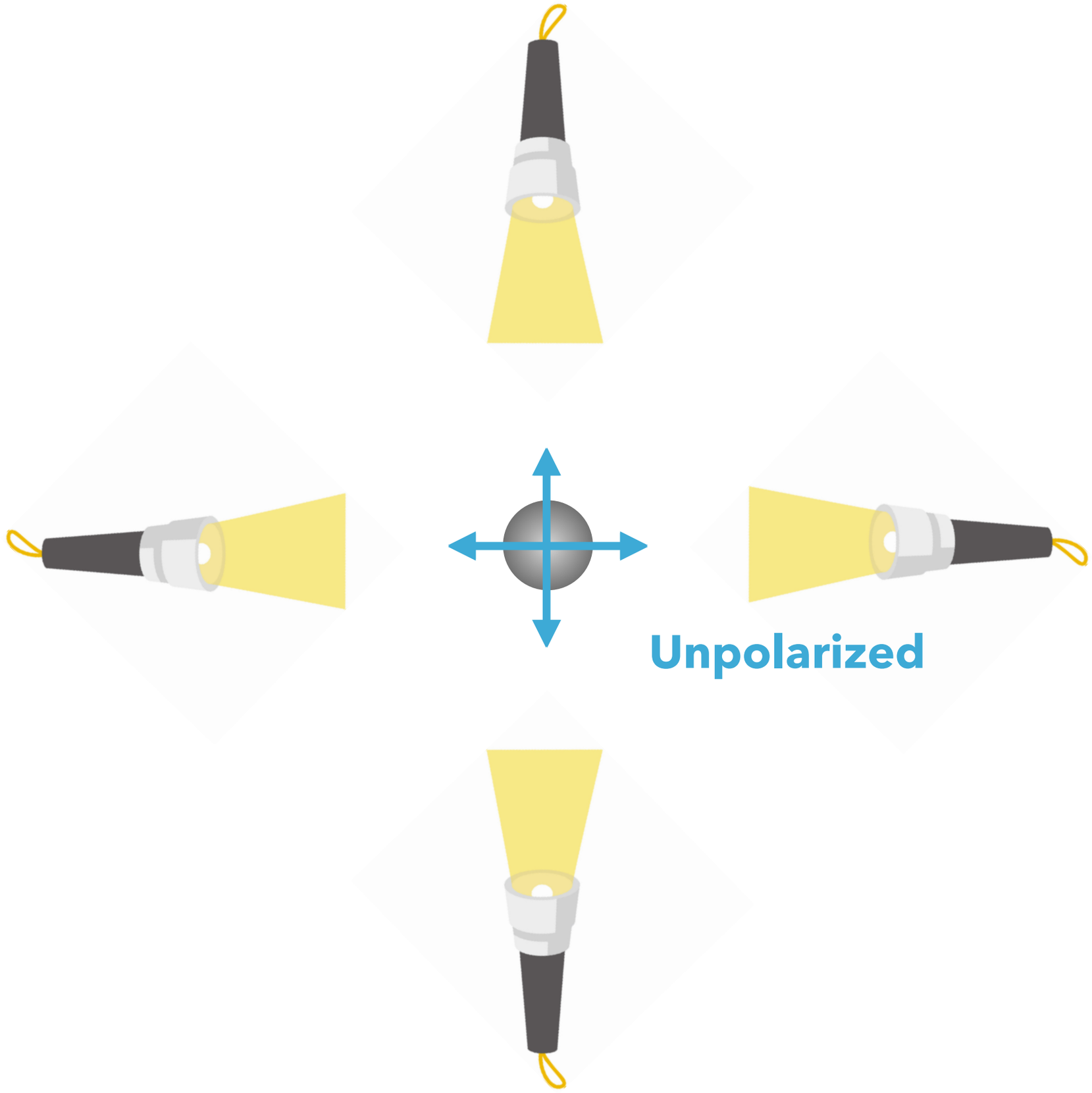
Horizontal Polarization



Polarization due to scattering

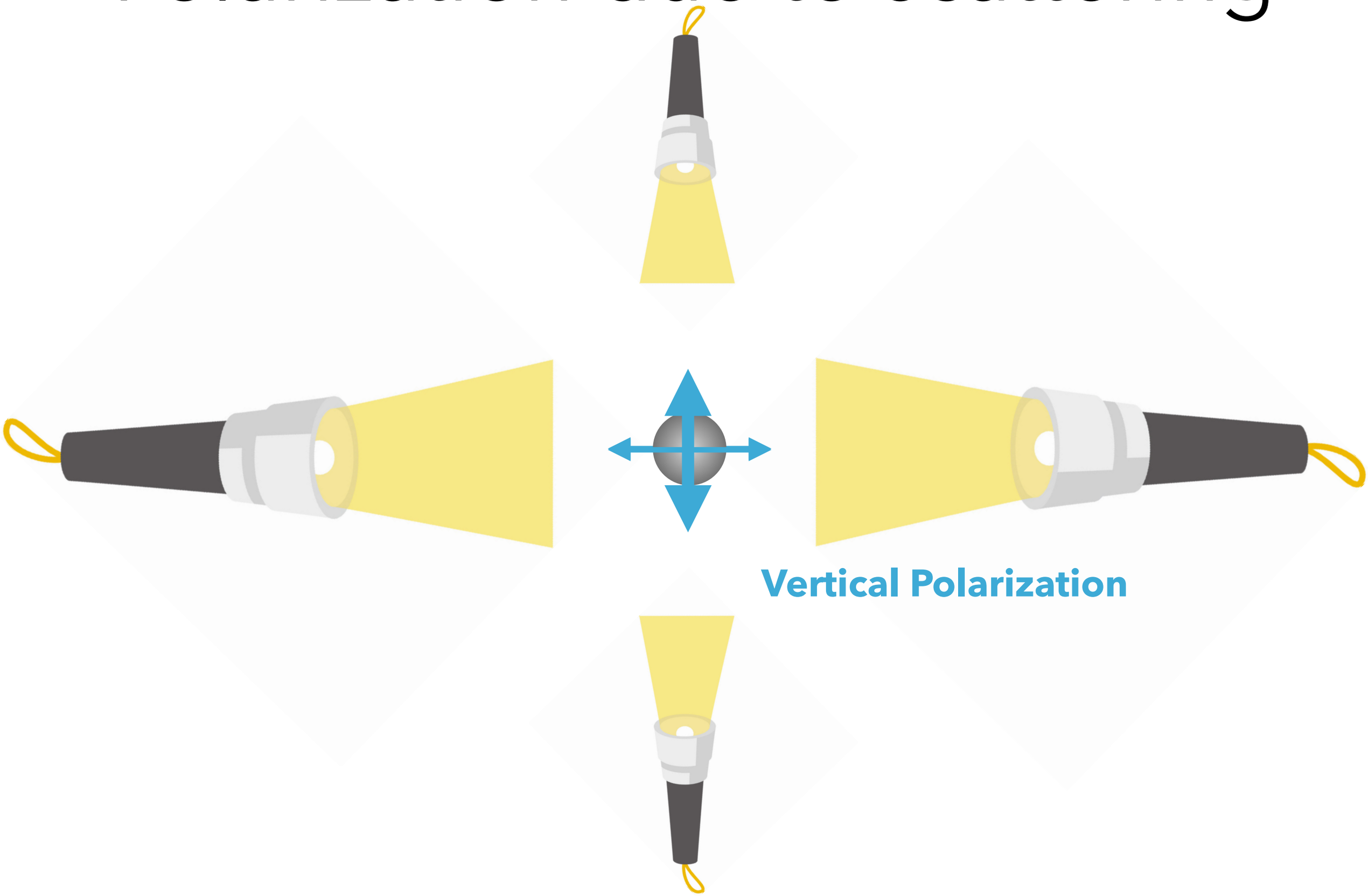


Polarization due to scattering

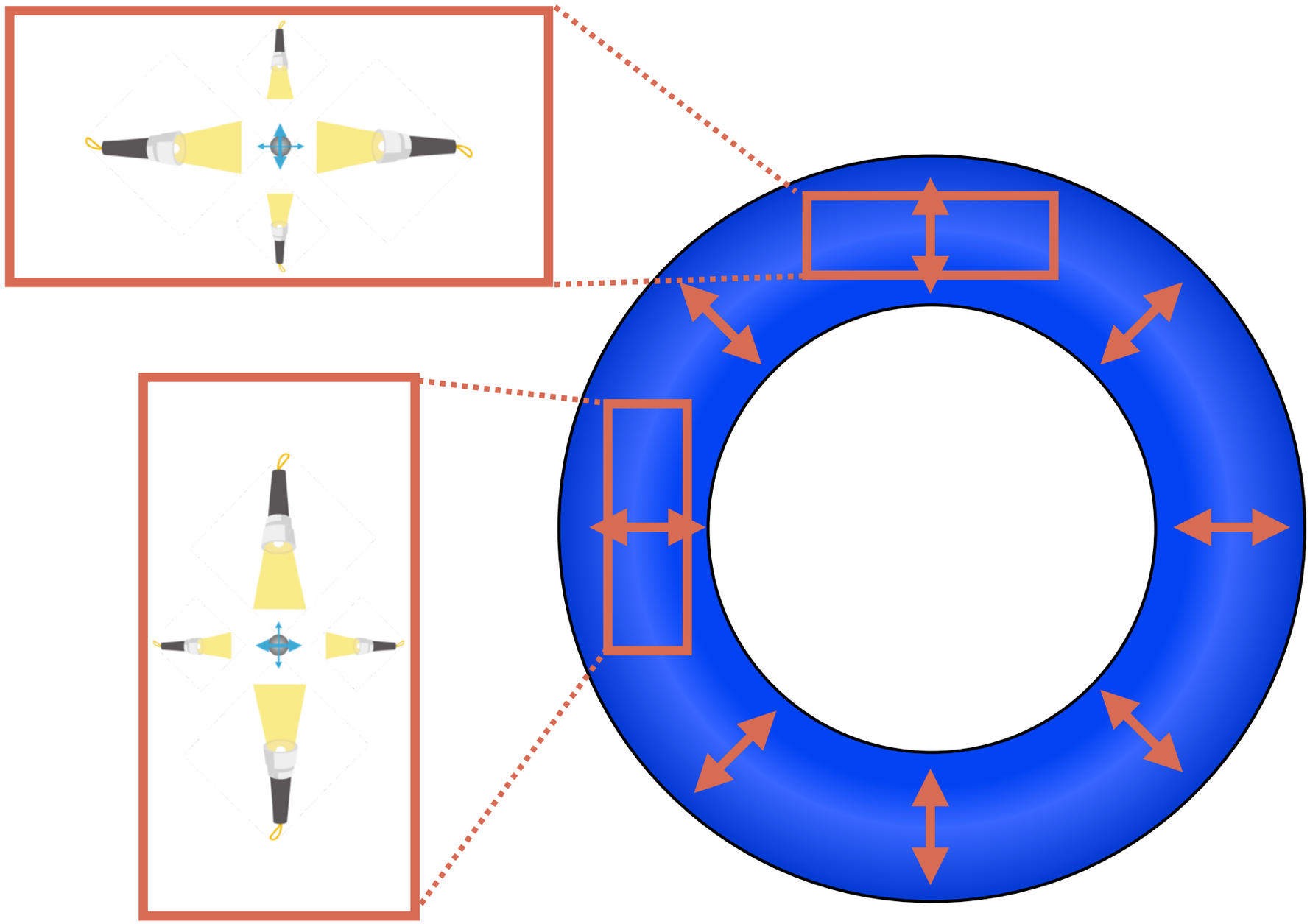


Akimasa Kataoka (NAOJ)

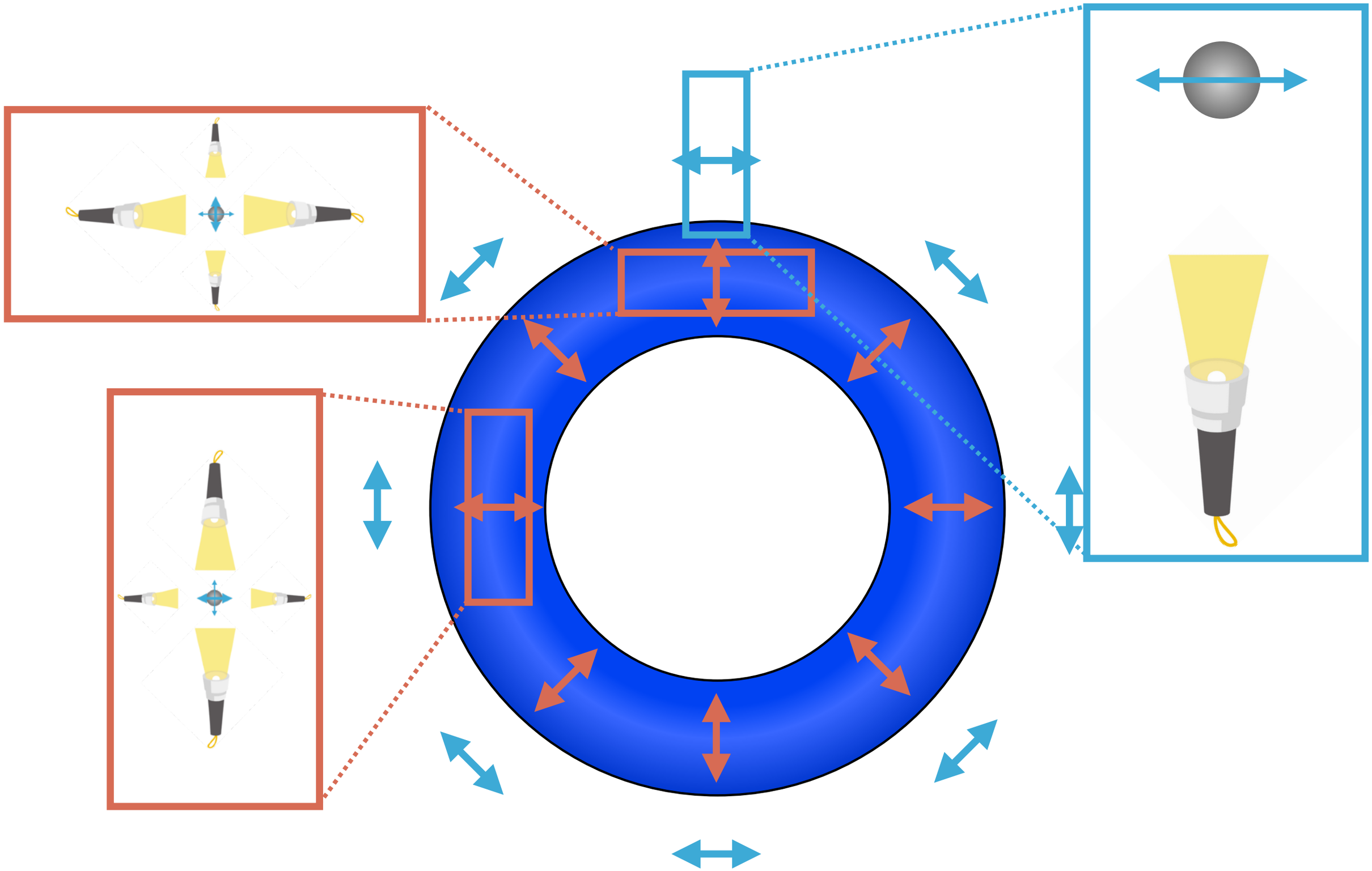
Polarization due to scattering



self-scattering in a protoplanetary disk

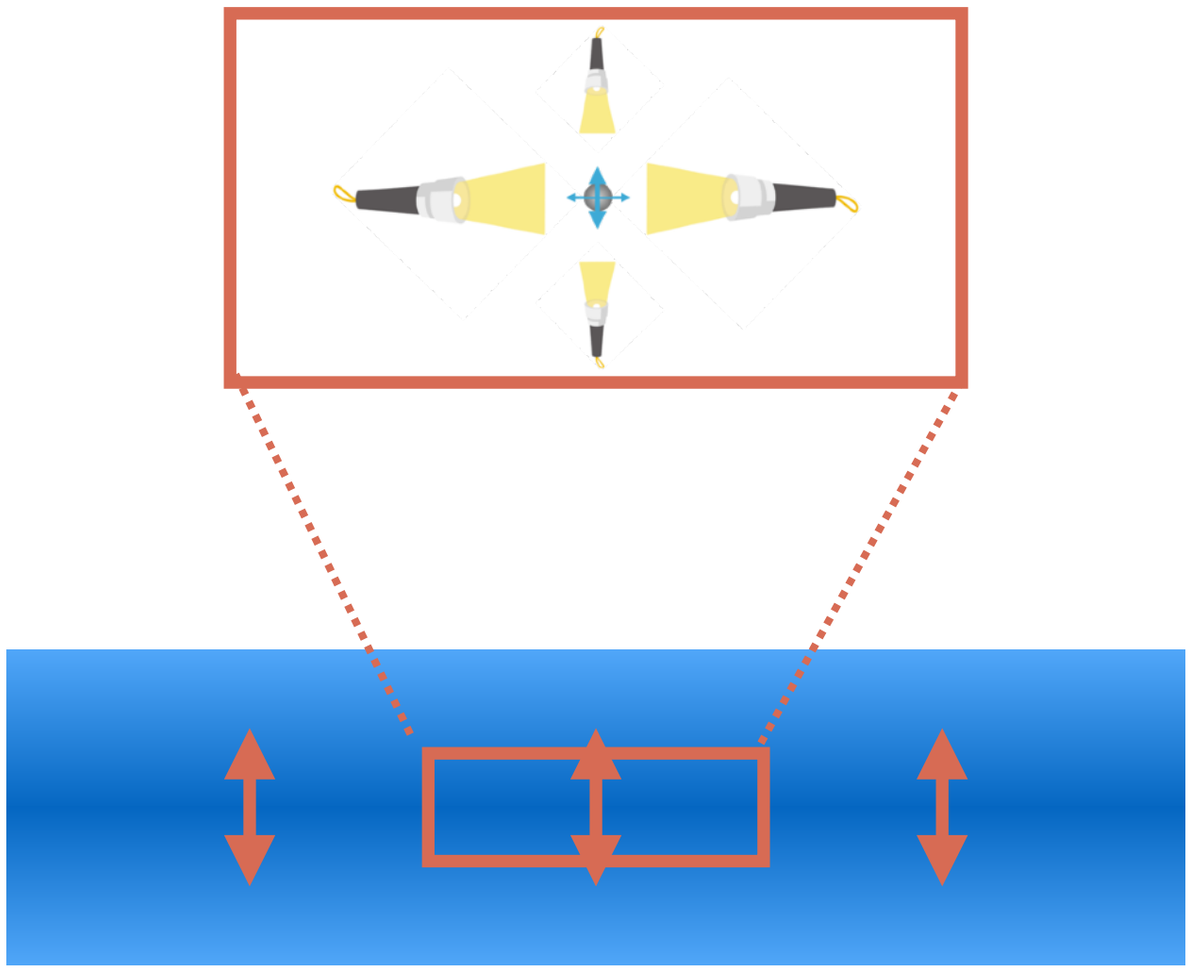


self-scattering in a protoplanetary disk



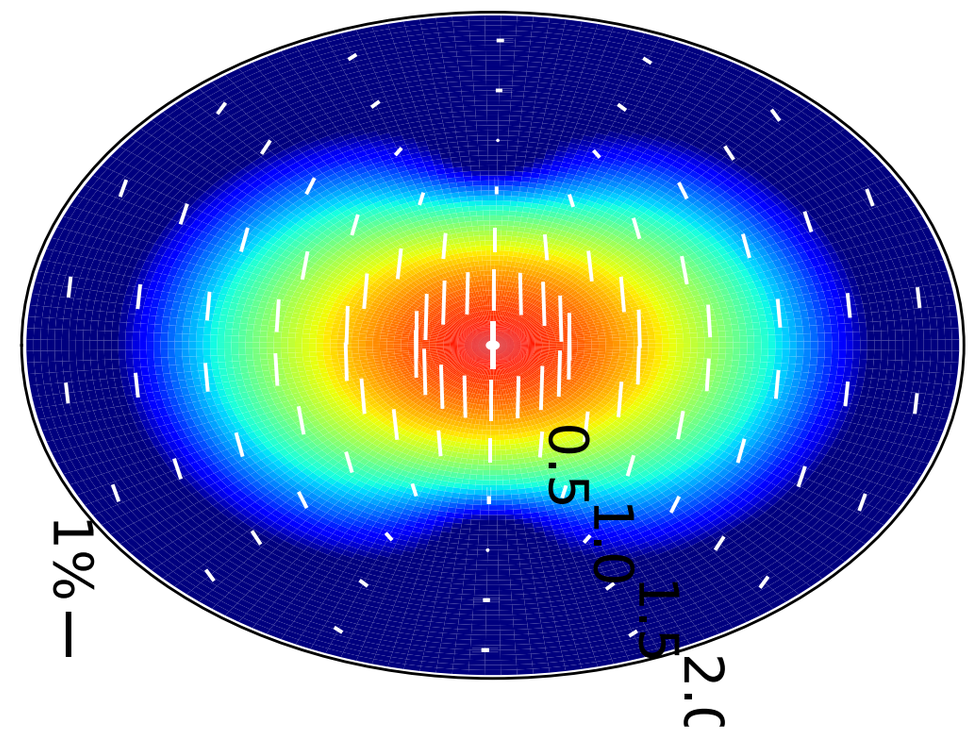
Akimasa Kataoka (NAOJ)

self-scattering in an inclined disk



(disk, edge-on view)

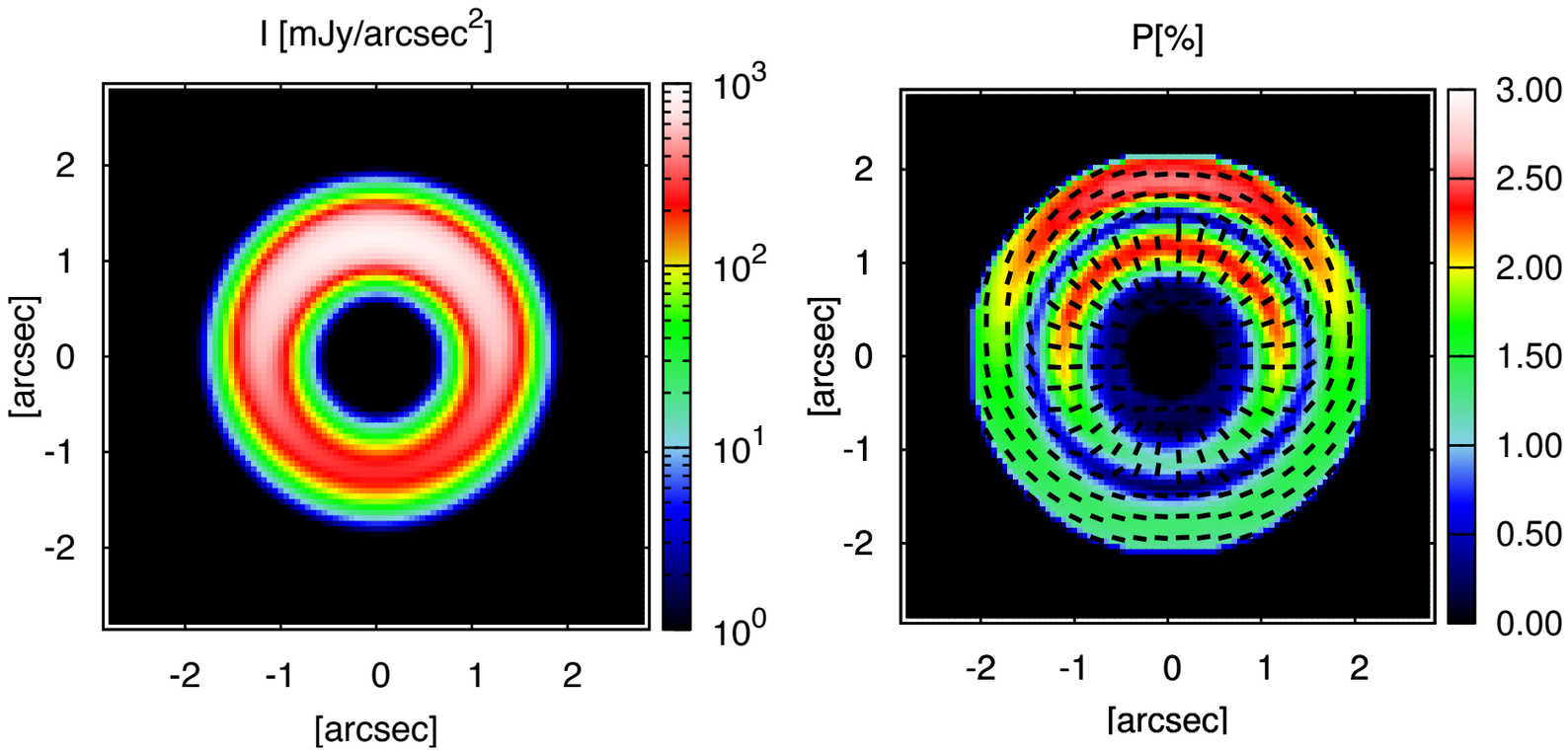
i=45°



Yang, Li, et al. 2016

See also Kataoka et al. 2016a

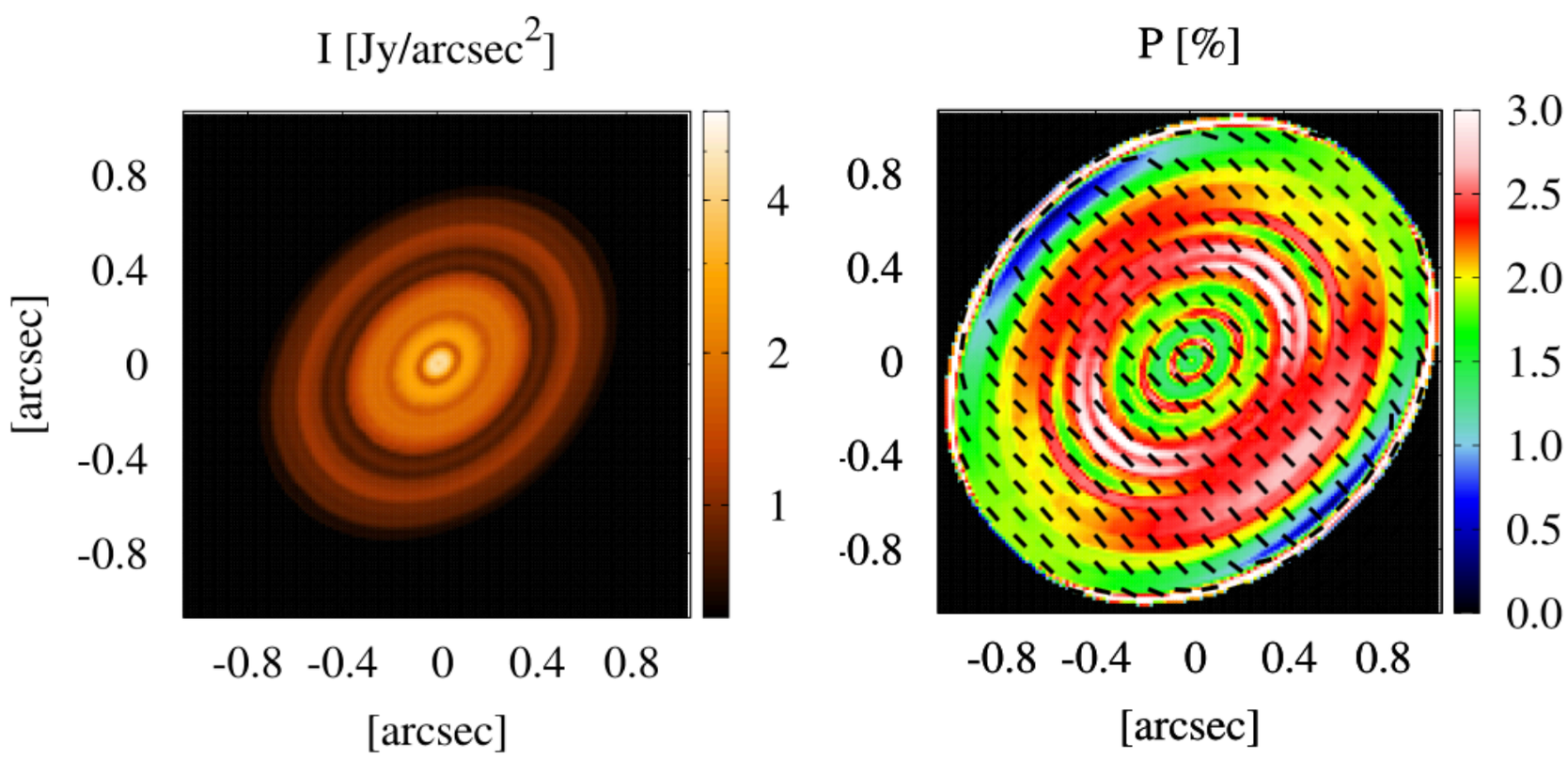
Radiative transfer calculations



Pol. vectors

Radial inside, azimuthal outside

Kataoka, et al., 2015



Parallel to the disk minor axis

Kataoka, et al., 2016a

see also Yang et al. 2016

Conditions of dust grains for polarization

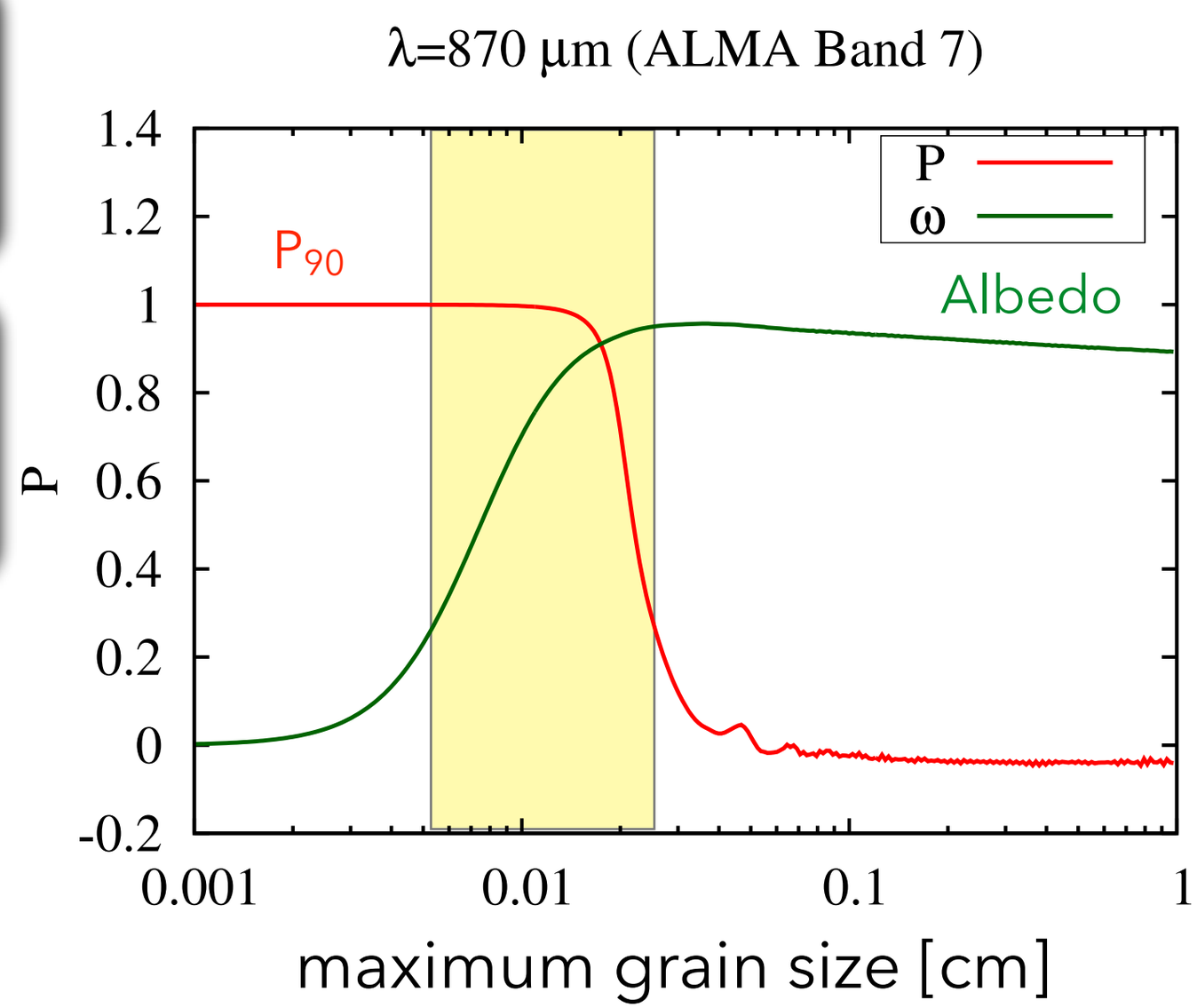
- For efficient scattering

  (grain size) >~ λ

- For efficient polarization

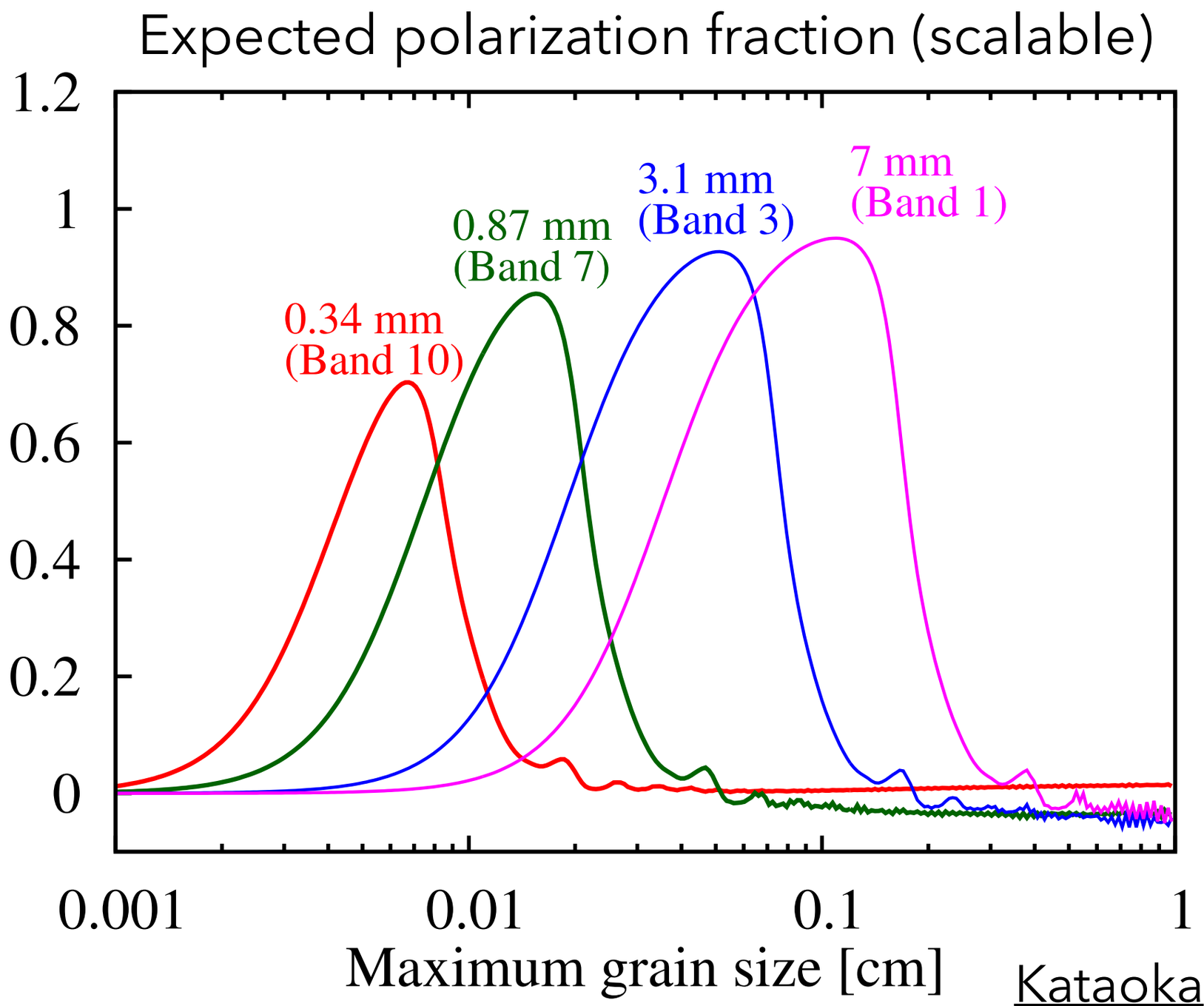
  (grain size) <~ λ

There is a grain size which contributes most to the polarized emission



If (grain size) ~ λ/2π, the polarized emission due to dust scattering is the strongest

Grain size constraints by polarization

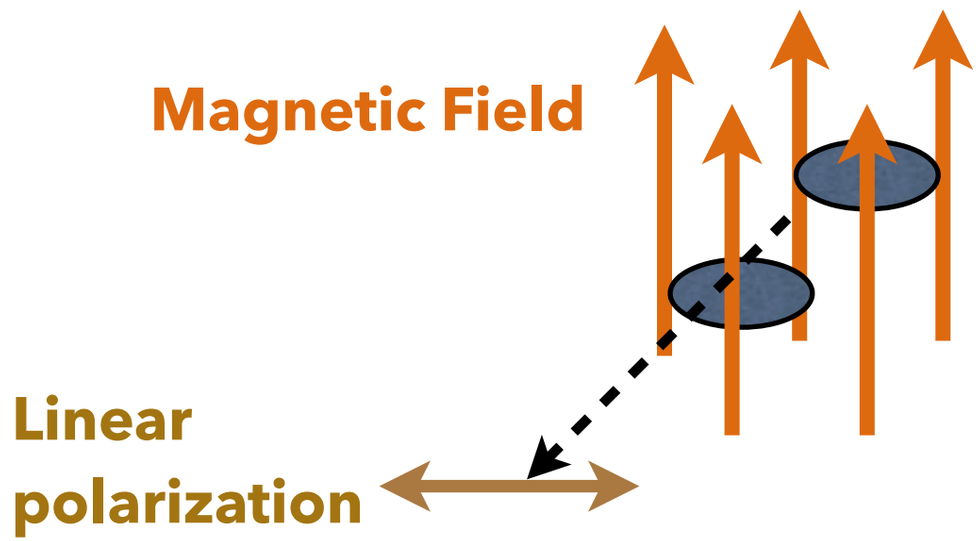


Kataoka, et al., 2015

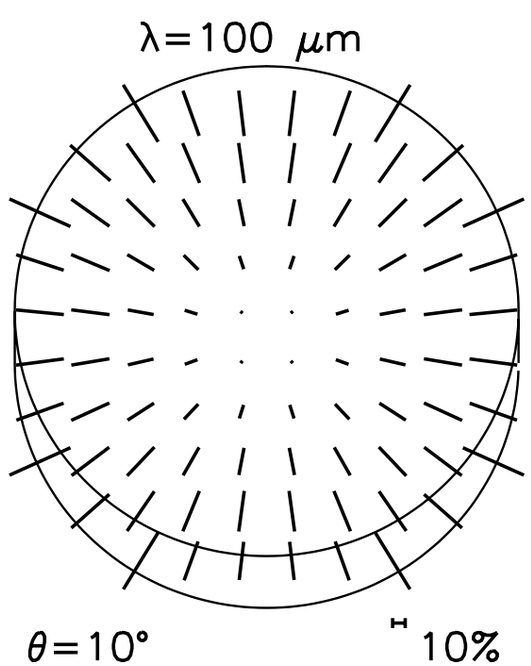
Multi-wave polarization → constraints on the grain size

Polarization mechanisms

1. Alignment of elongated dust grains with magnetic fields



e.g., Lazarian and Hoang 2007

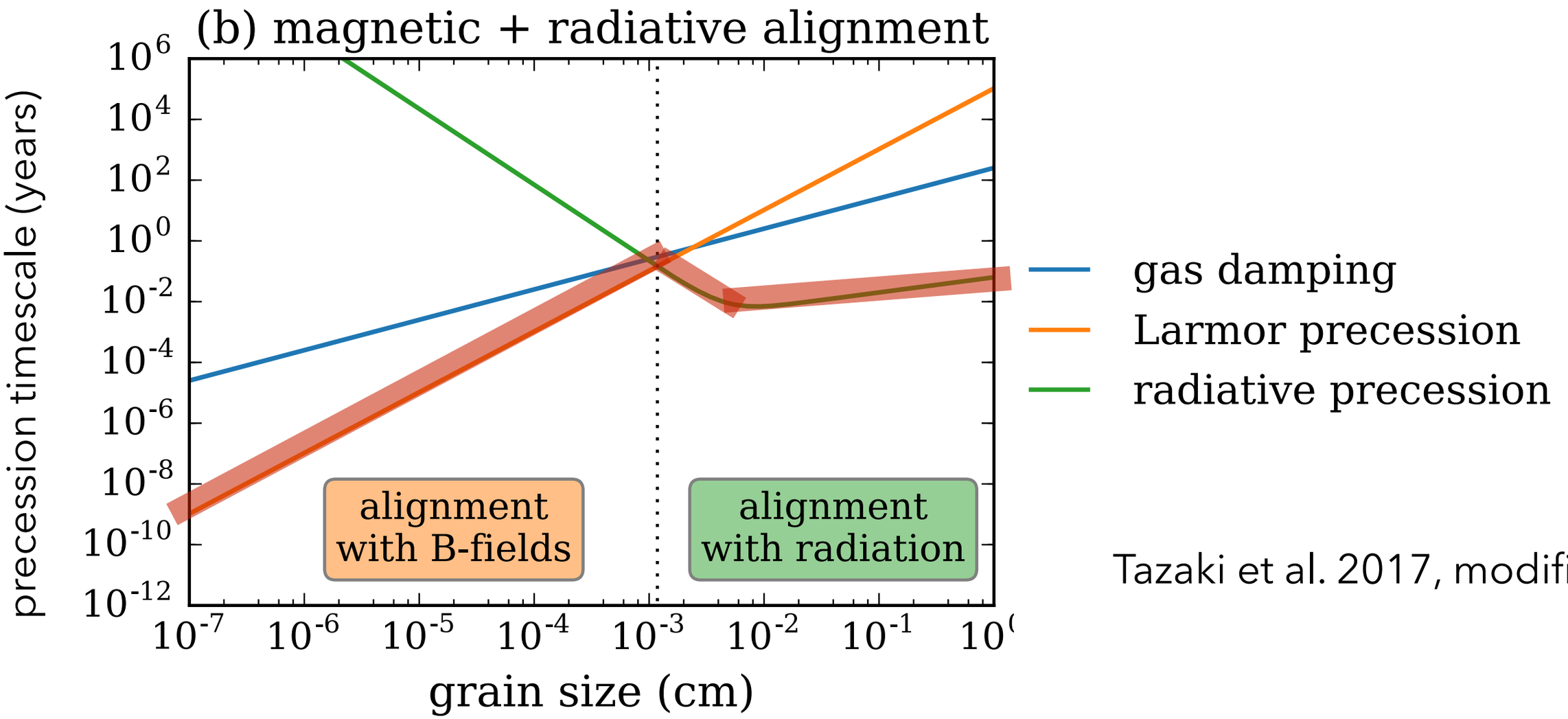


Cho and Lazarian 2007

If B-fields have toroidal components only,

it would produce radial polarization pattern.

Alignment direction



Tazaki et al. 2017, modified

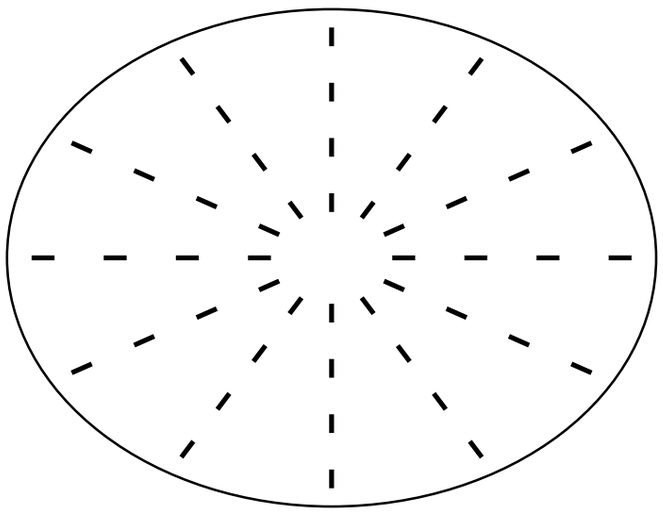
Note: radiation for alignment is NOT the stellar radiation but those at λ ~ 100 μm

Small grains: magnetic-field alignment

large grains: radiation-field alignment

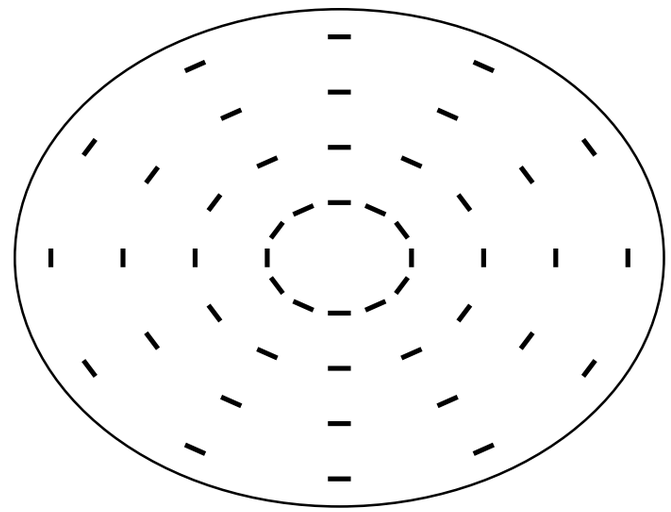
Short summary

alignment with B-fields

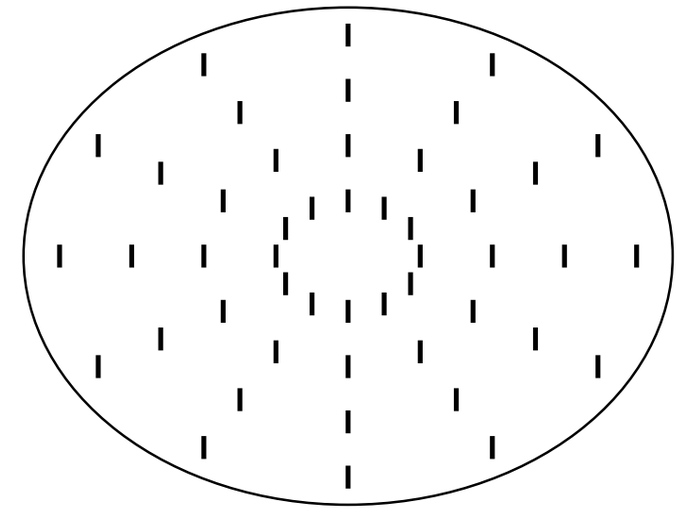


- **depends on magnetic field components**

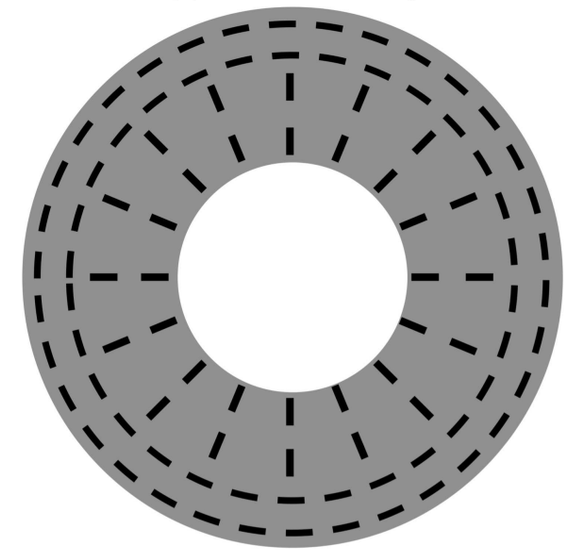
alignment with radiation



self-scattering



(a) self-scattering

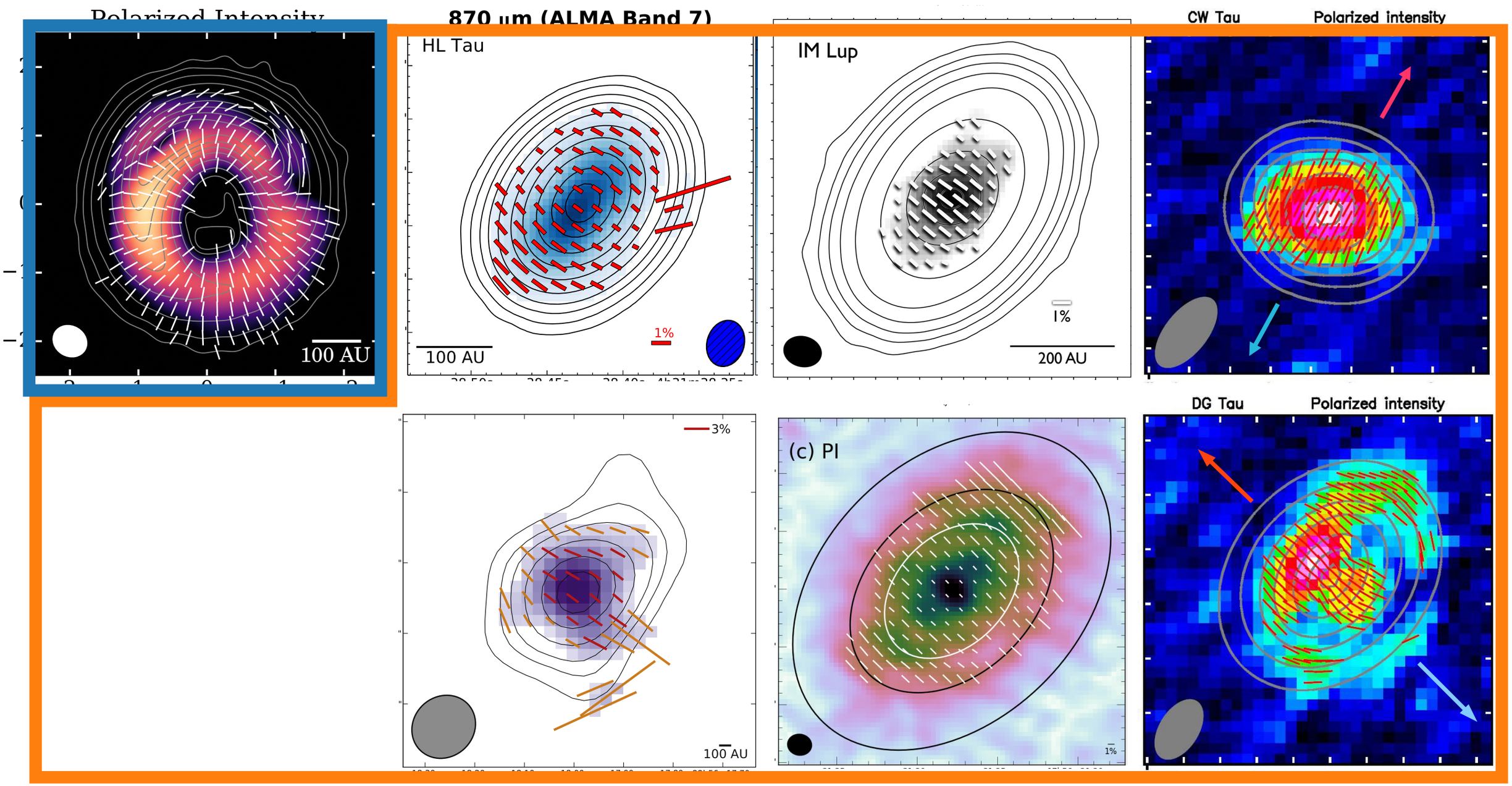


(alignment with gas flow)

wavelength independent ⟷ **wavelength dependent**

Kataoka et al. 2017, submitted, Ohashi et al. 2018

Millimeter-wave polarization of disks



HD 142527; Kataoka et al. 2016, HL Tau; Stephens et al. 2017, IM Lup; Hull et al. 2018, CW Tau and DG Tau; Bacciotti et al. 2018, Cepheus A HW2 ; Fernández-Lopez et al. 2016, HD 163296; Dent et al. 2019, HD100546; Pohl et al. in prep.

Inclined disks: self-scattering at 870 μm

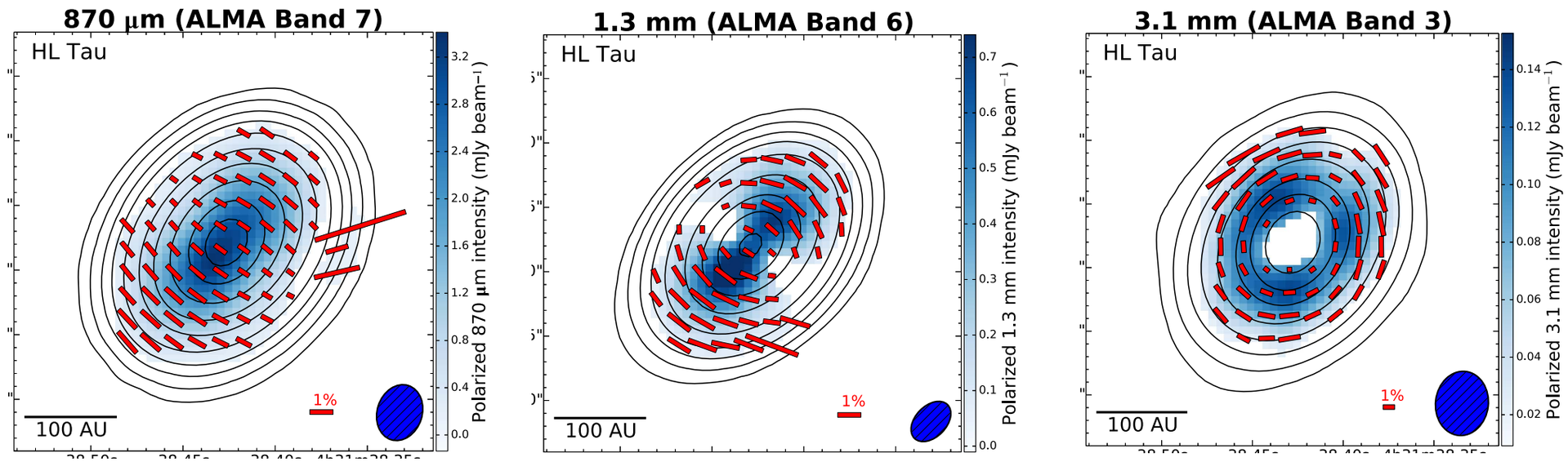
a lopsided disk: self-scattering at north and alignment at south

Millimeter-wave polarization of disks

0.87 mm **1.3 mm** **3.1 mm**

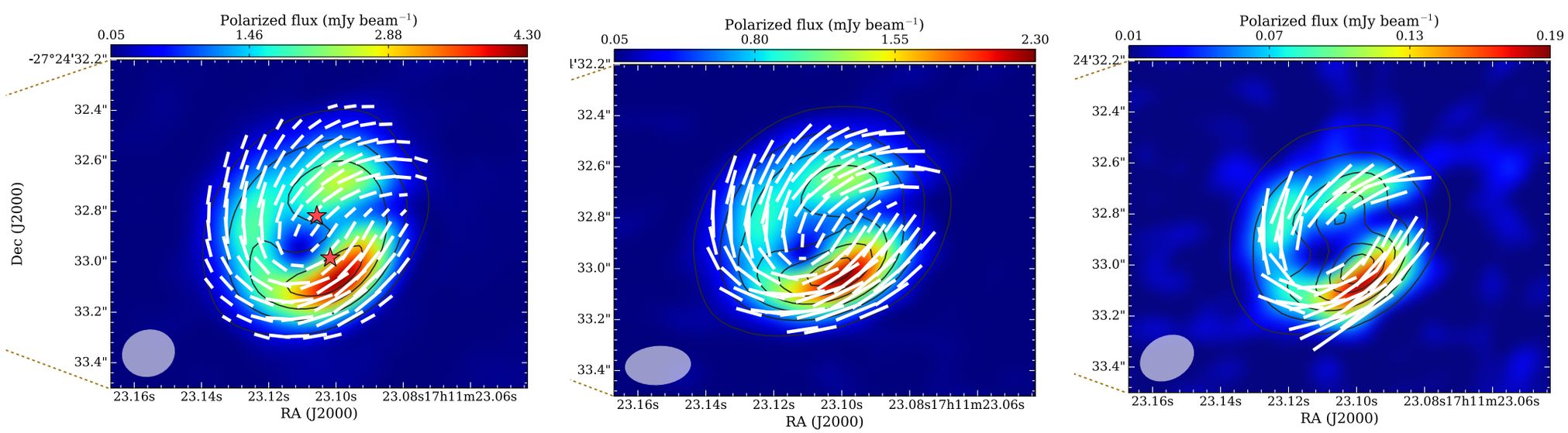
Self-scattering + alignment

HL Tau (Class I-II)



Kataoka et al. 2017, Stephens et al. 2017

BHB07-11 (Class 0)



Alves et al. 2018

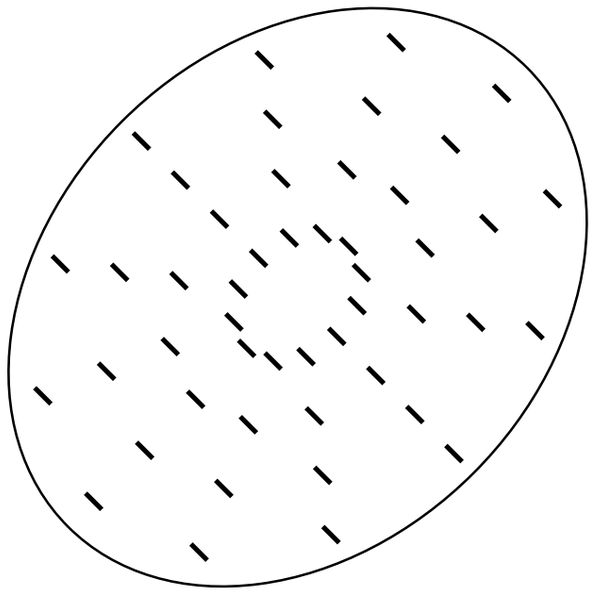
Alignment only

Talk outline

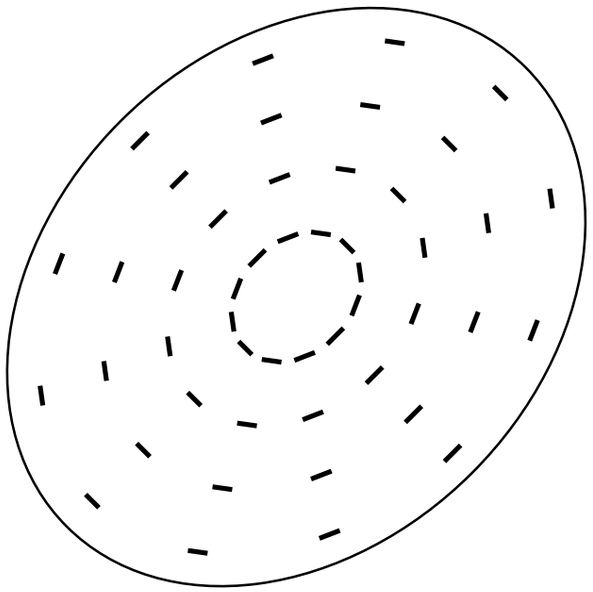
- Two pages to take a glance of recent ALMA polarimetric observations
- Theories of polarization
    1. Self-scattering
    2. Alignment
        - with B-fields, radiation, or (gas flow)
- **Case studies**
    - HL Tau: constraints on the grain size
    - HD 142527: different polarization due to the segregated grain population
    - HD 163296: evidence of dead zone

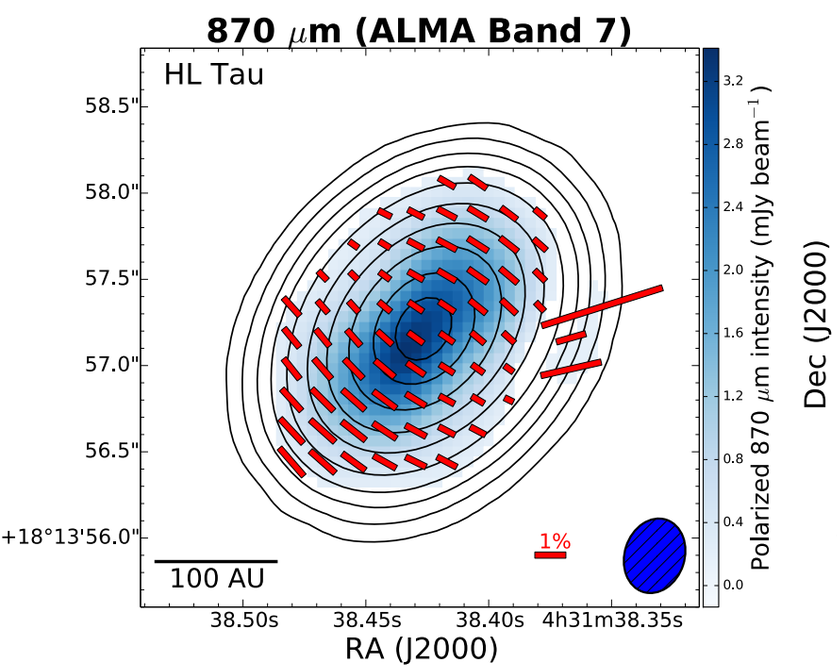
Case study - HL Tau

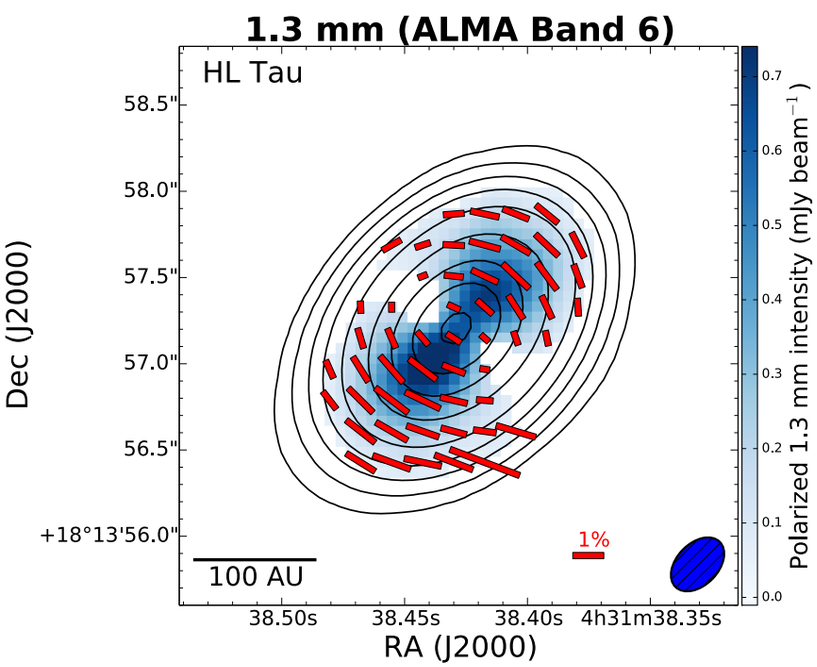
self-scattering



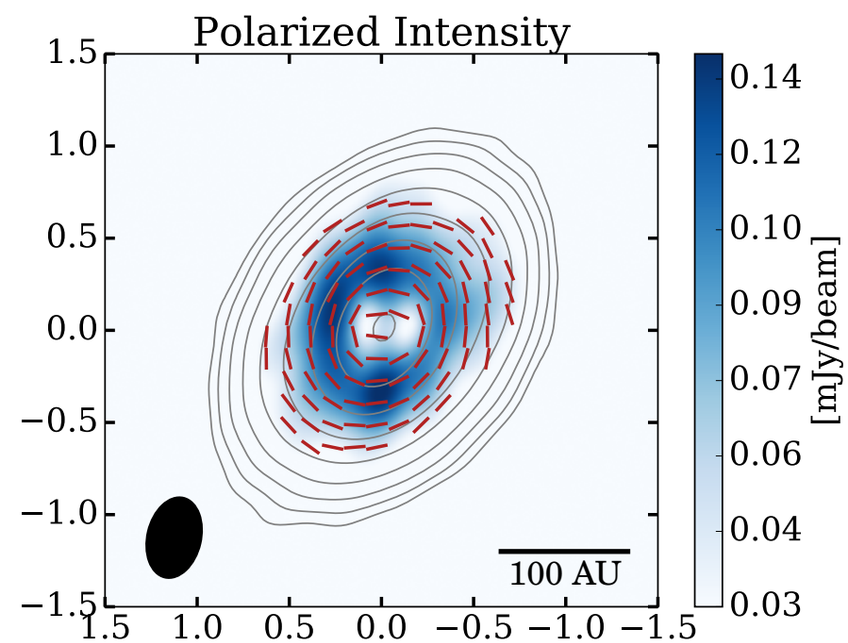
alignment with rad./gas





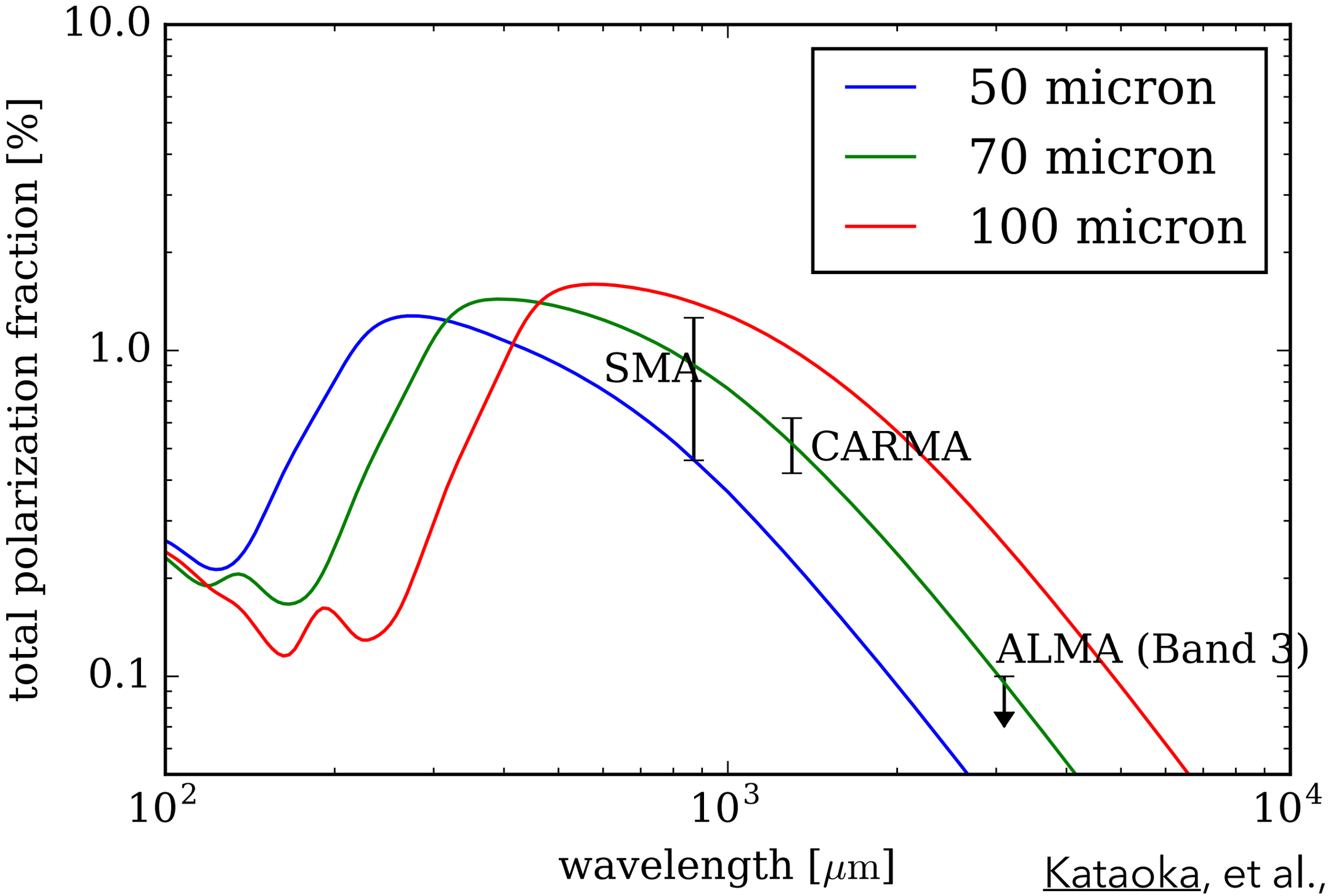


Stephens,…, Kataoka, et al. 2017



Kataoka et al. 2017

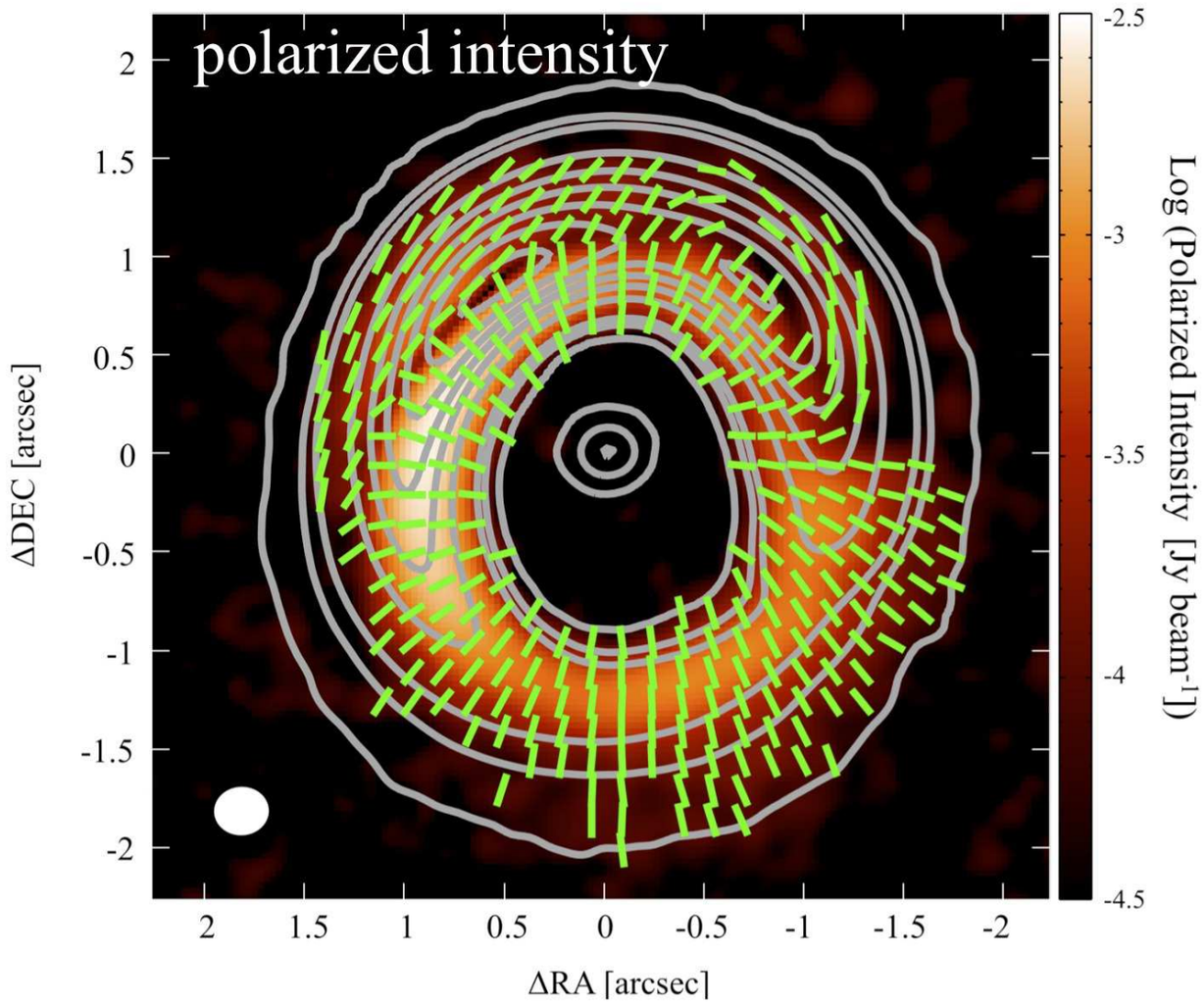
What can we learn? - grain size

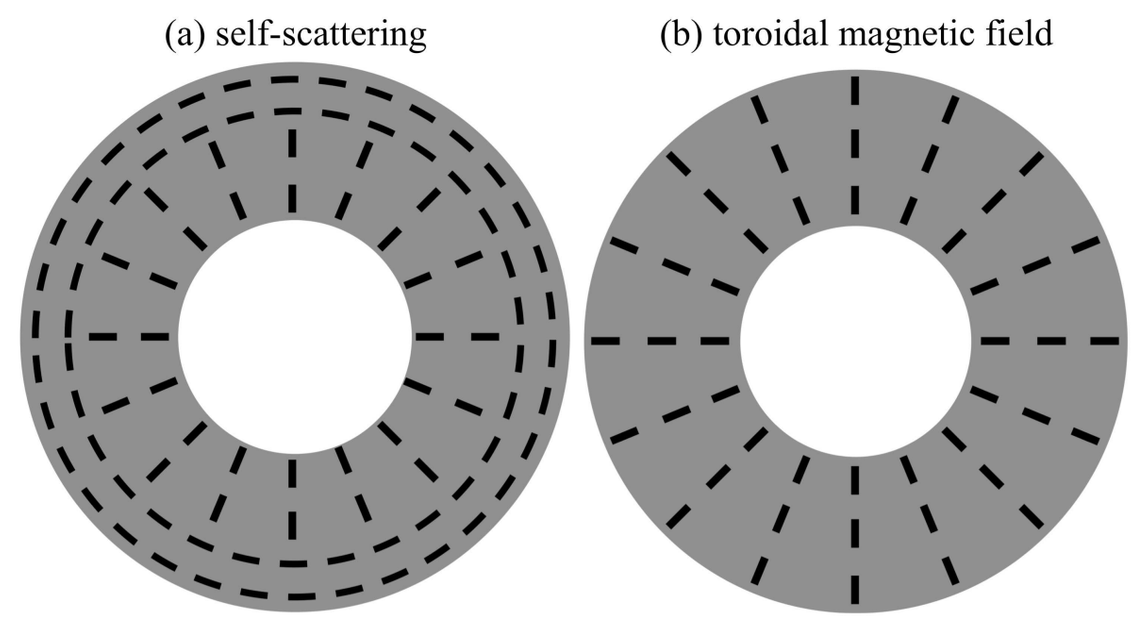


Kataoka, et al., 2017

The maximum grain size is ~ 70 μm

Case study - HD 142527

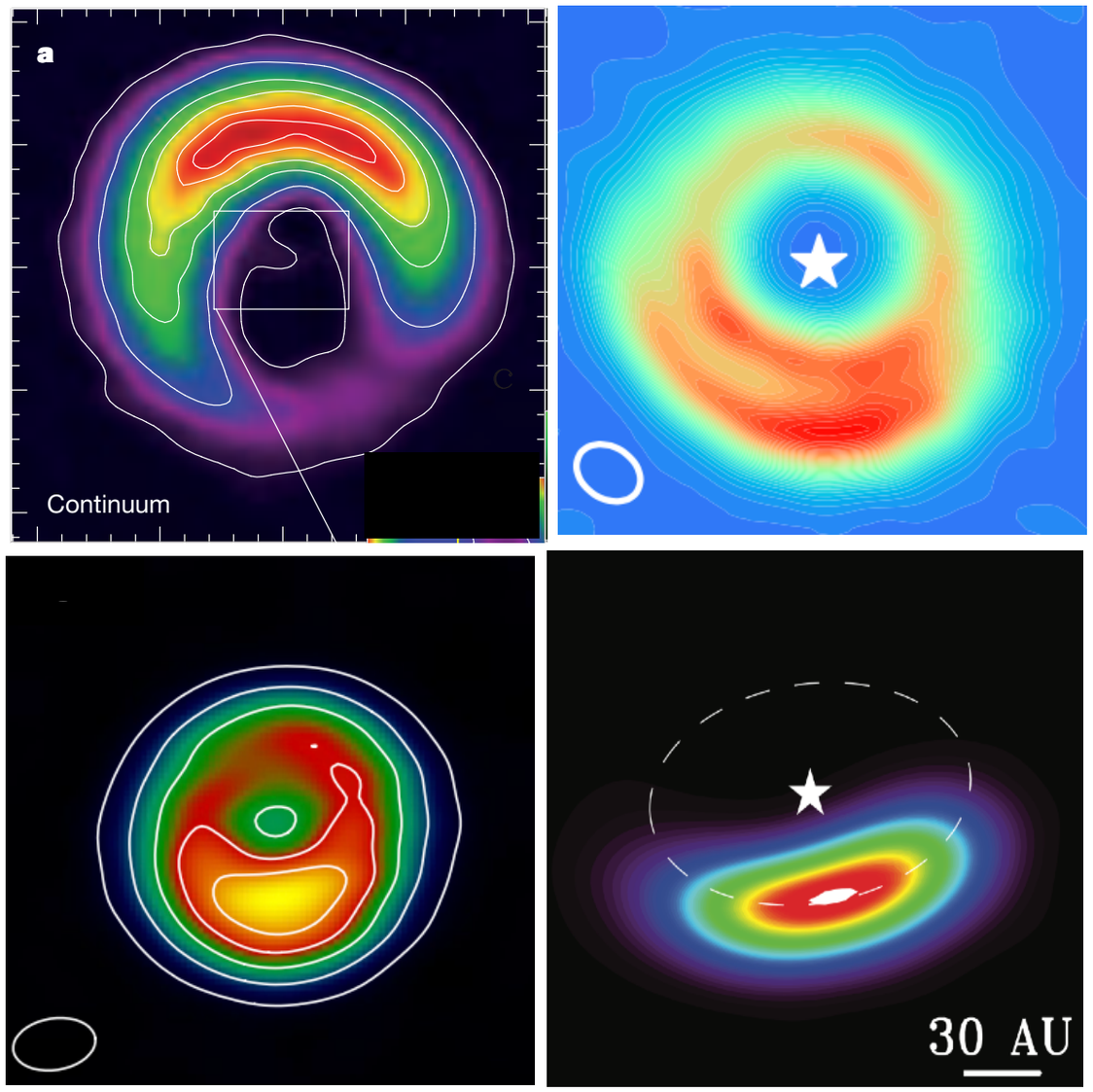




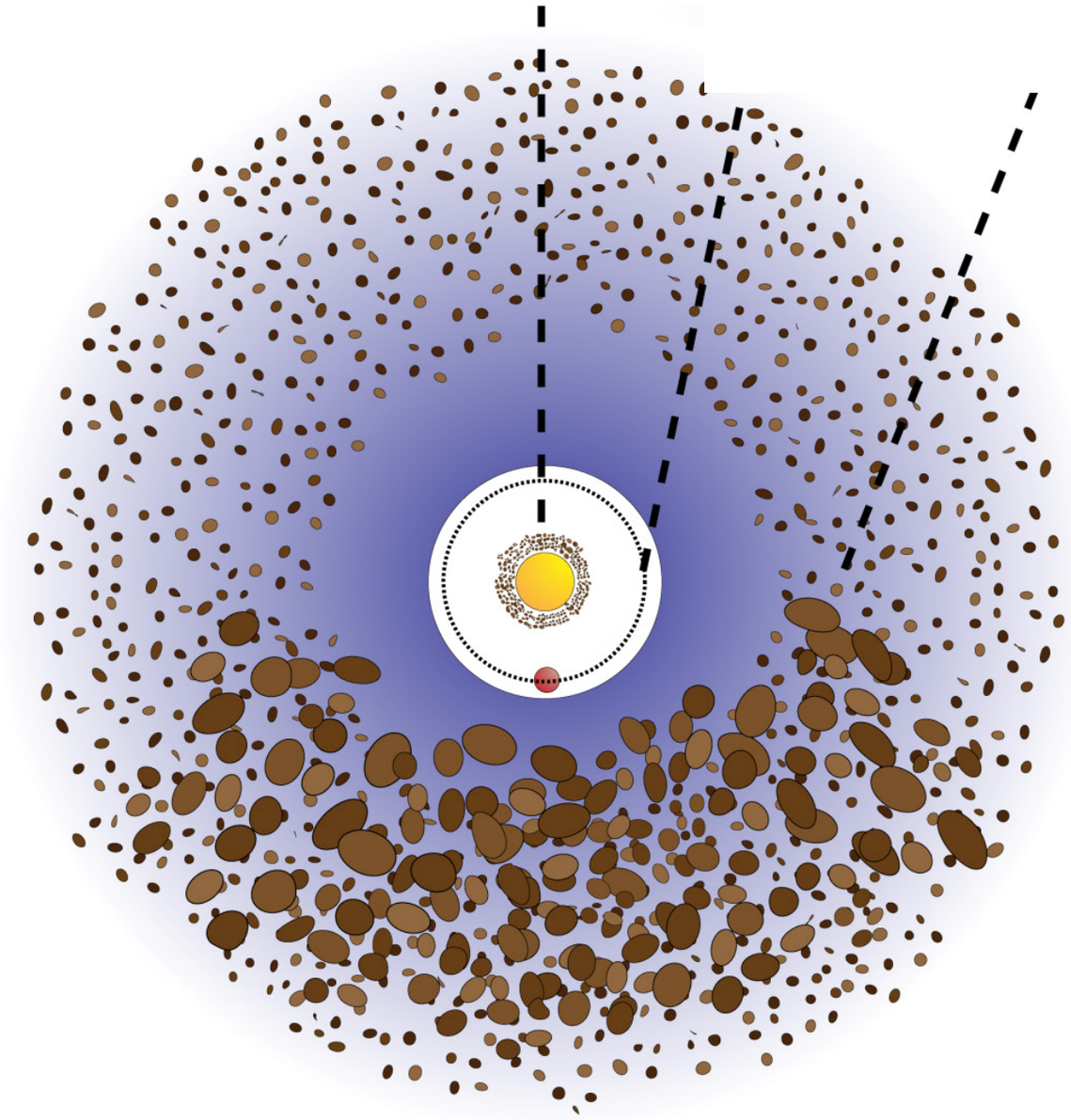
Ohashi, Kataoka et al. 2018

- Morphological discussion
  - **North**: consistent with **self-scattering**
  - **South**: not consistent with either of self-scattering, alignment with radiation, nor with gas flow -> **B-field alignment.**

Consistent with dust trapping



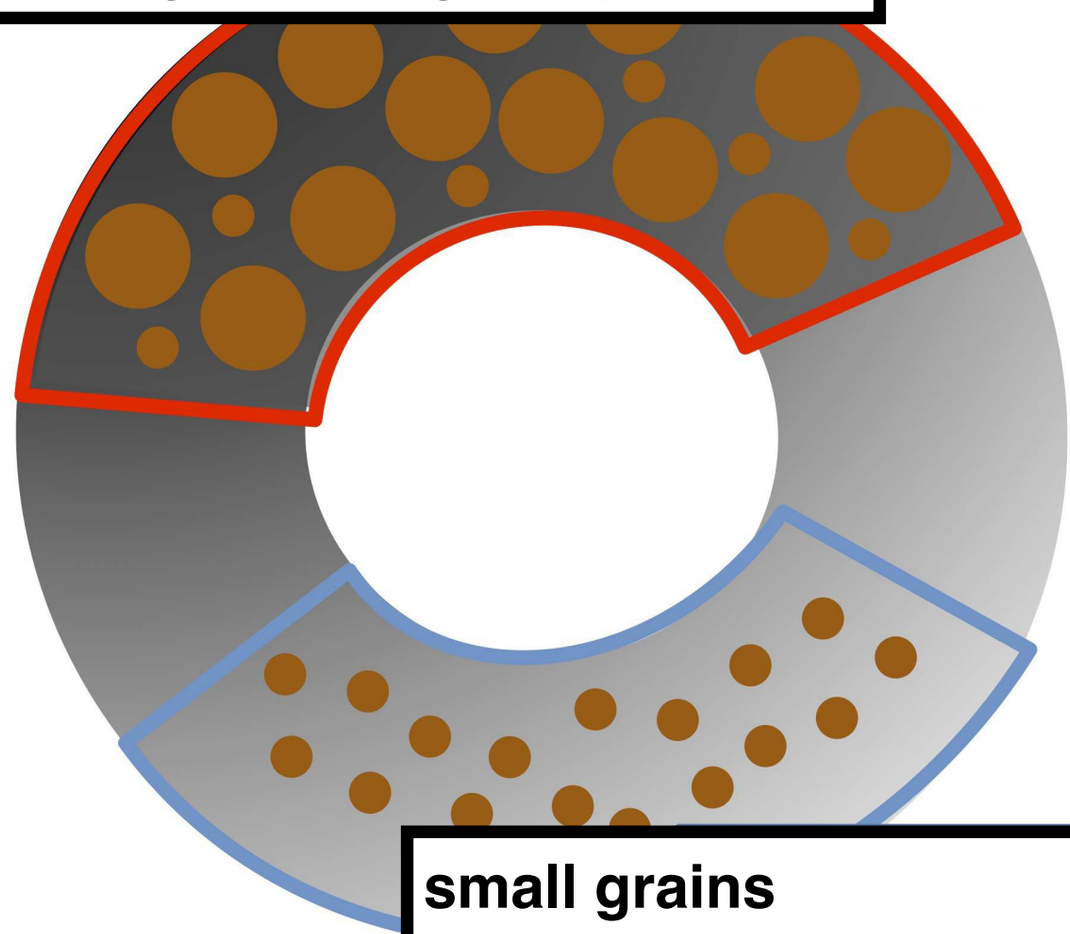
Casassus et al. 2013, van der Marel 2013, 2016, Perez et al. 2014



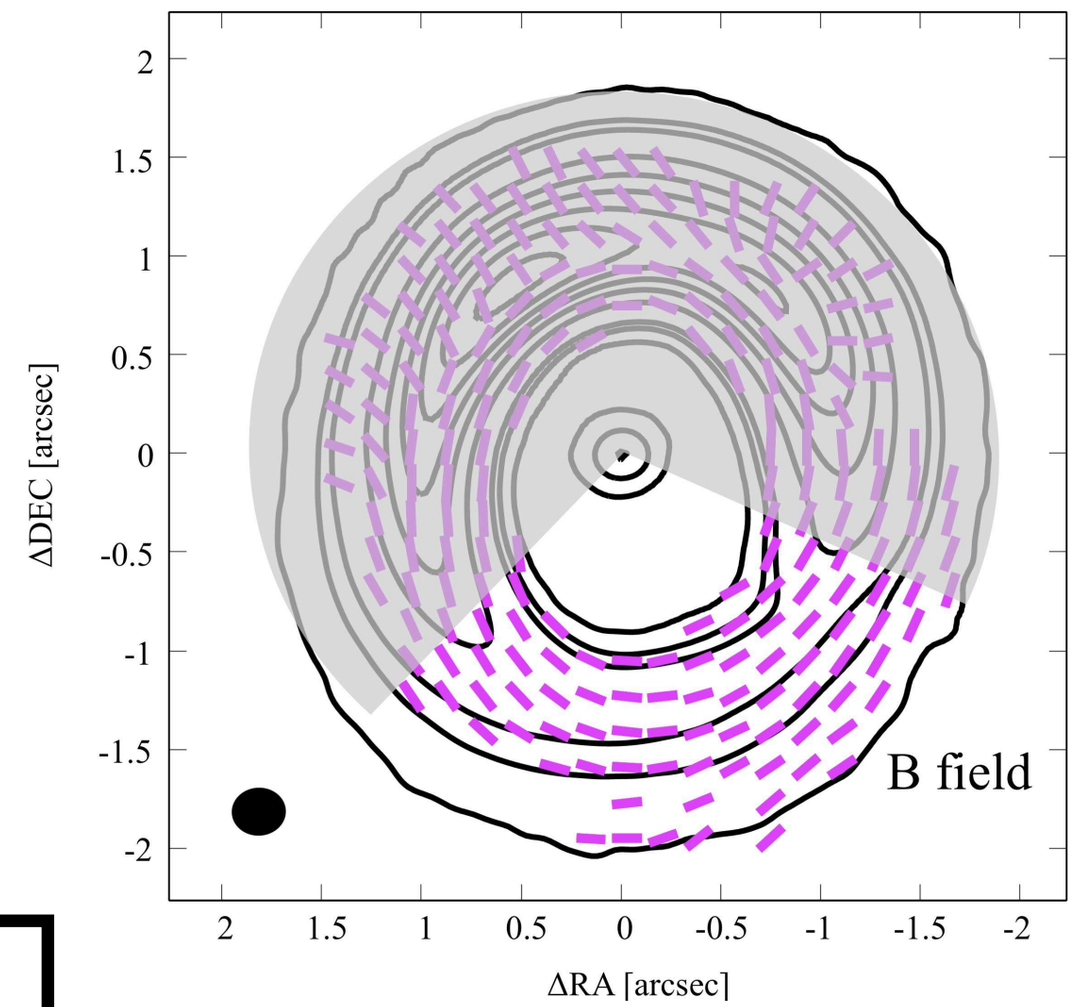
Birnstiel et al. 2013, van der Marel 2013

Consistent with dust trapping

large grains
- emit scattering
- strong wavelength dependence

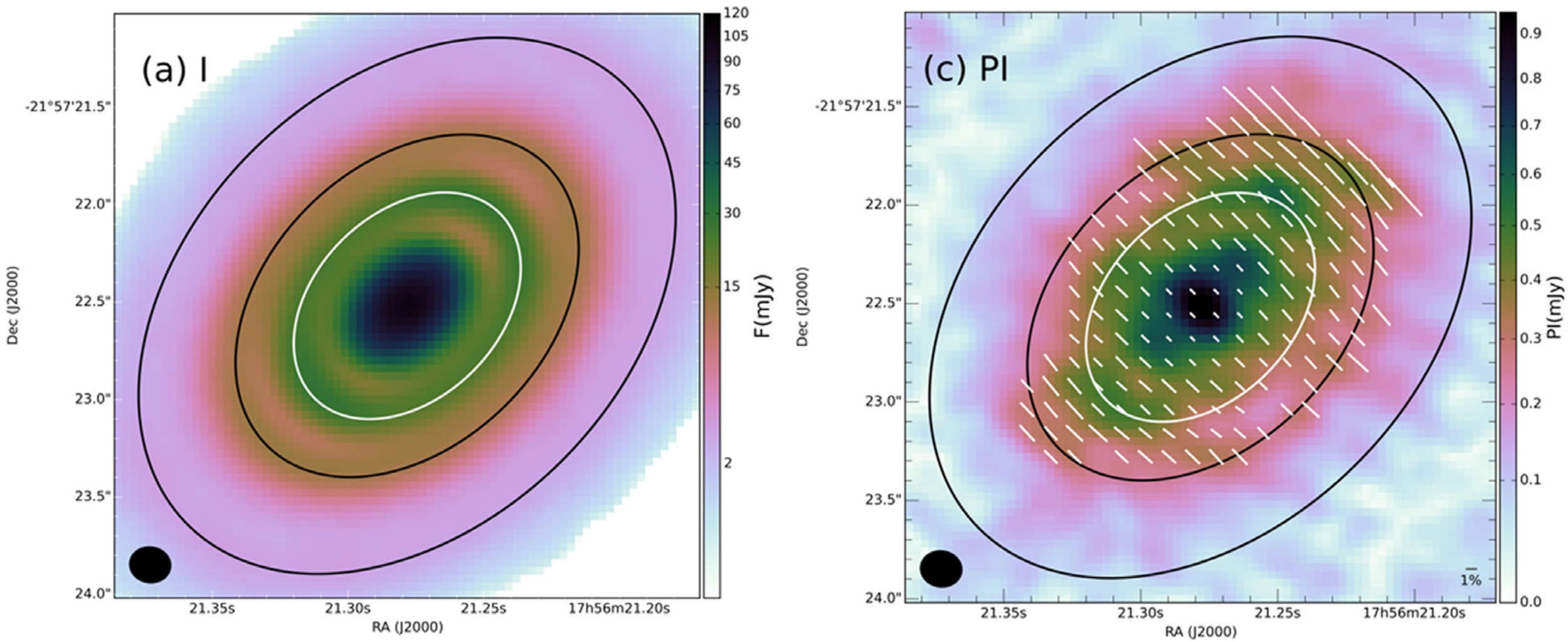


small grains
- too small to emit scattering
- aligned with B-fields
- No wavelength dependence



Ohashi, Kataoka, et al., 2018

Case study - HD 163296



Dent et al. 2019

Summary

- **Theories of millimeter-wave polarization**

  1. Self-scattering - **wavelength dependent**. Parallel to the minor axis.

  2. Alignment

     - **Large grains may be aligned with radiation while small grains with magnetic fields**

- **Case studies - ALMA polarization observations**

  - HL Tau: **constraints on the grain size - 70 μm**

  - HD 142527: different polarization due to the segregated grain population - **magnetic fields are toroidal at south**

  - HD 163296: **evidence of dead zone**