Exploring grain growth, radial drift, and magnetic fields by mm-wave polarization

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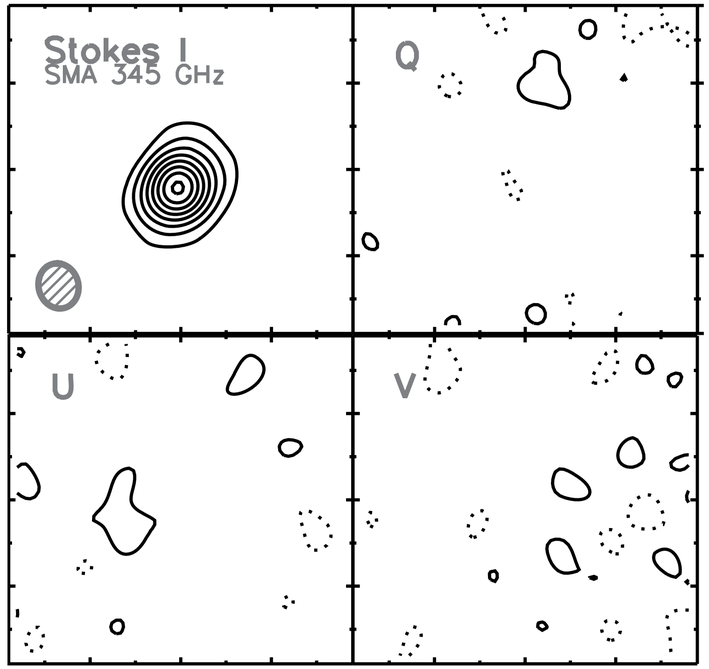
Millimeter polarization

- before ALMA -

HD 163296



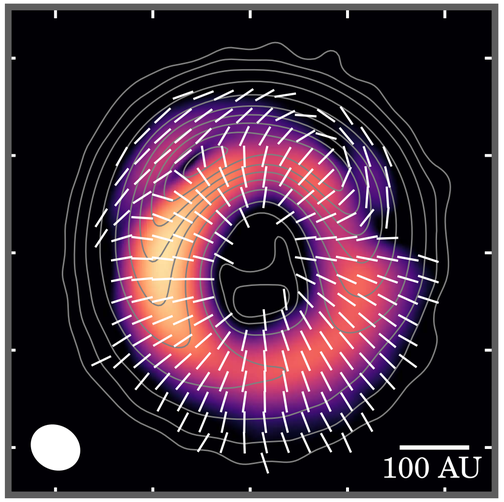
Hughes et al. 2009

upper limit ~ 1 %

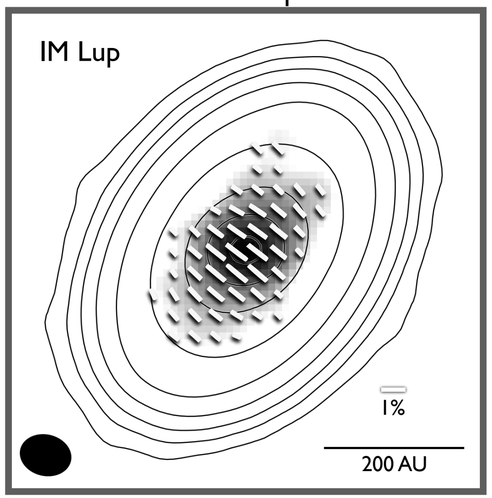
Non-detection on HD 163296, TW Hya. GM Aur and DG Tau (Hughes et al. 2009, 2013). 2 sigma detection on HL Tau (Stephens et al. 2014)

ALMA polarization (Class II disks)

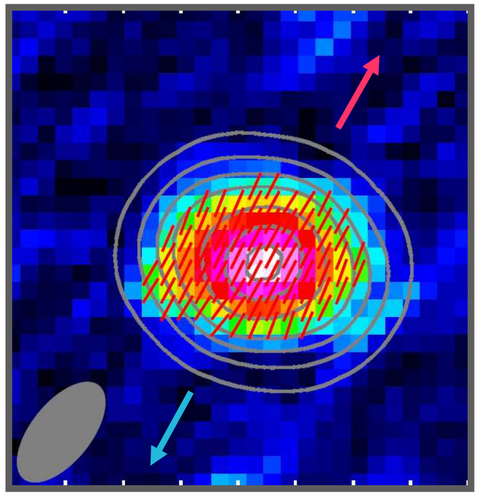
HD 142527



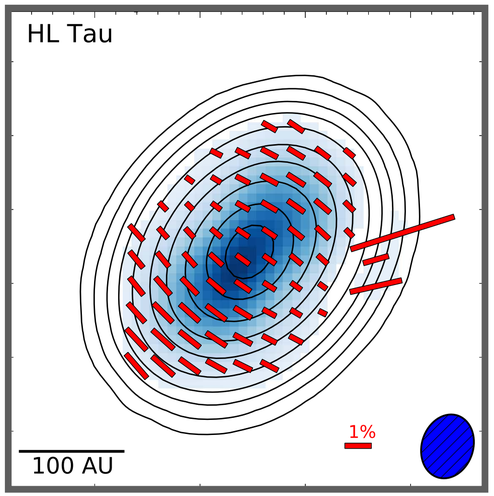
IM Lup



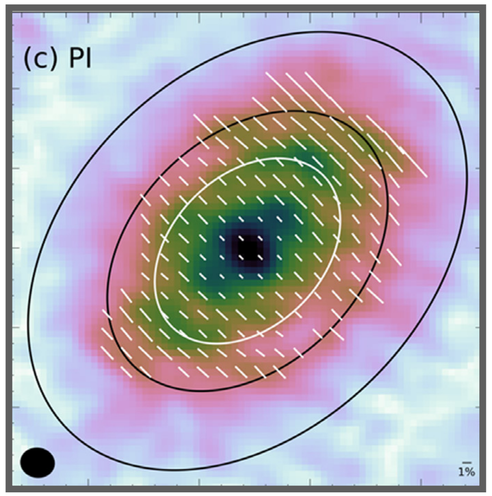
CW Tau



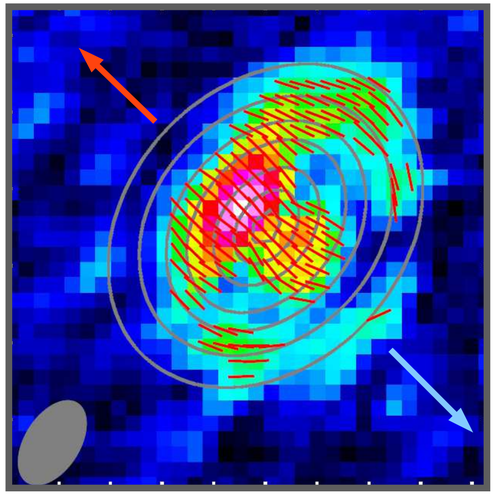
HL Tau



HD 163296



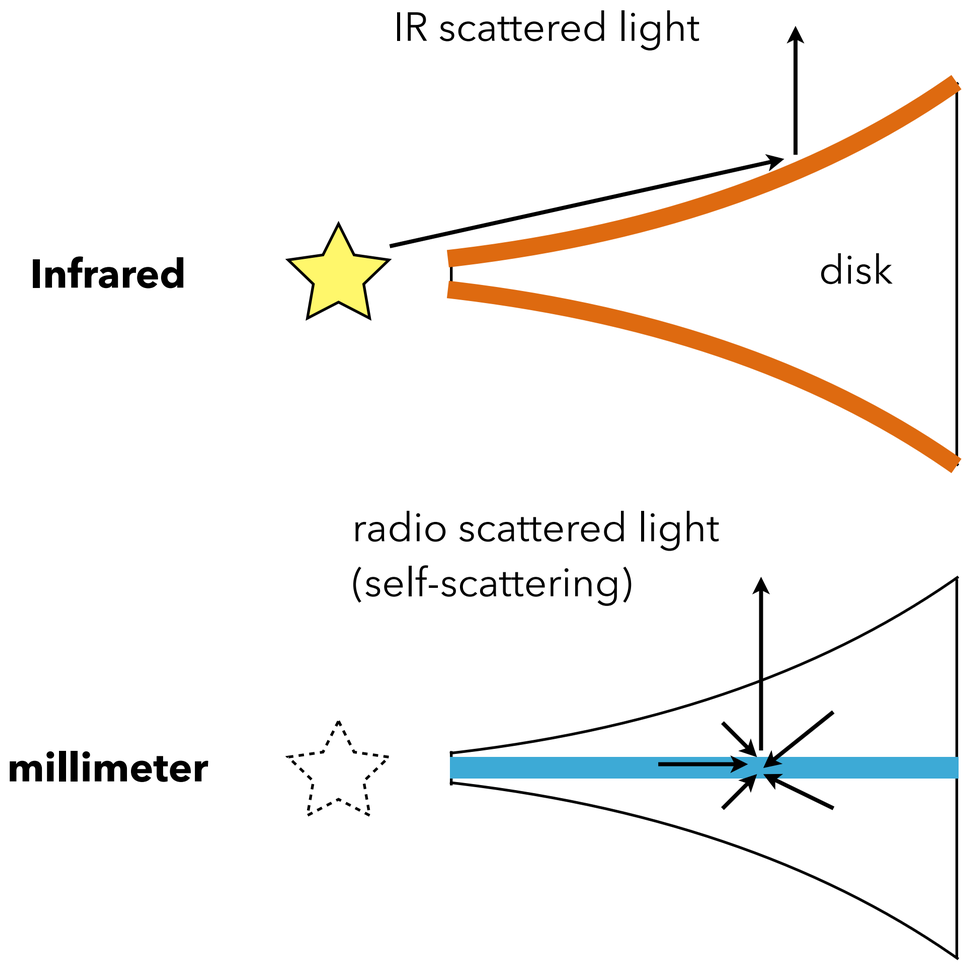
DG Tau



Kataoka et al. 2016, Hull et al. 2018, Bacciotti et al. 2018, Dent et al. 2019, Stephens et al. 2017, cf. Kataoka et al. 2017, Ohashi et al. 2018

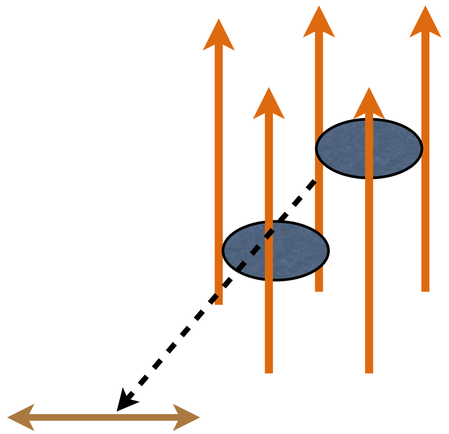
Polarization mechanisms

Self-scattering



Kataoka et al. 2015

Grain alignment



Linear polarization

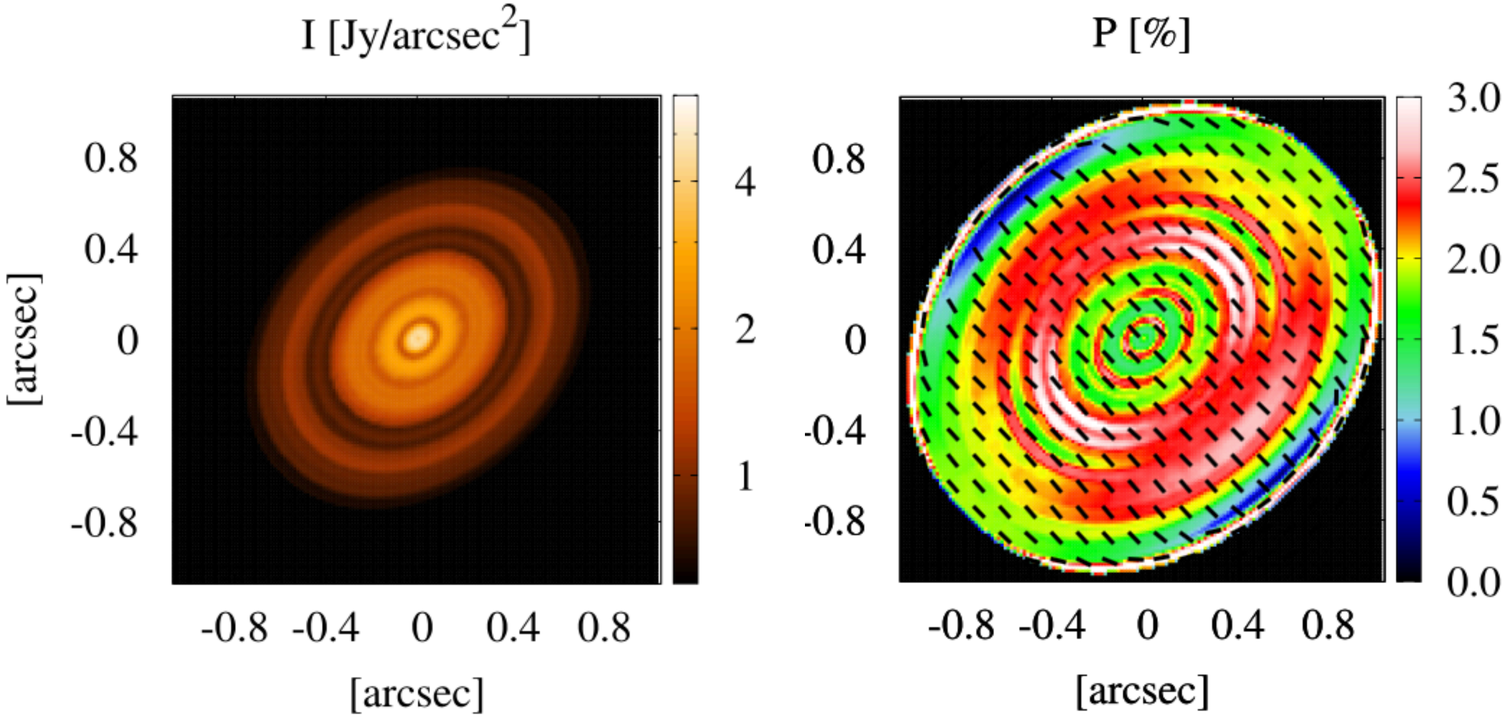
Direction

- B-fields
- radiation
- gas flow

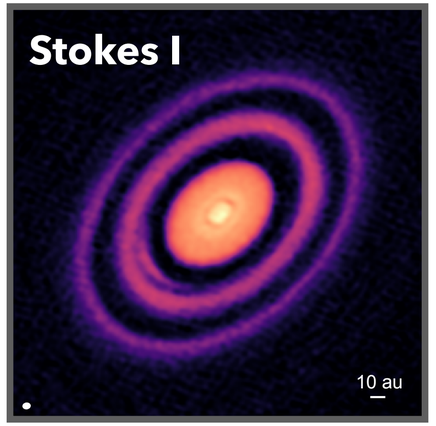
e.g., Cho and Lazarian 2007, Tazaki et al. 2017, Lazarian and Hoang 2007, Kataoka et al. 2019

Self-scattering polarization

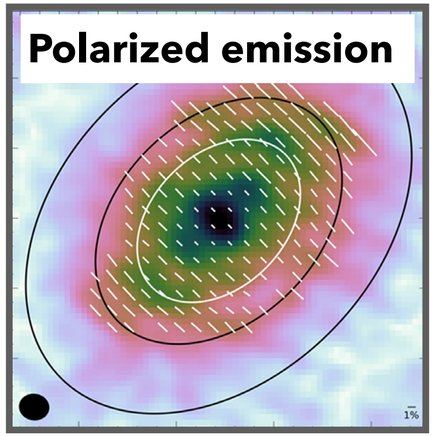
- **Polarization vectors are parallel to the disk minor axis.**
- **Grain size at the polarized regions would be ~ (λ/2π)**



Kataoka, et al., 2016a, see also Yang et al. 2016



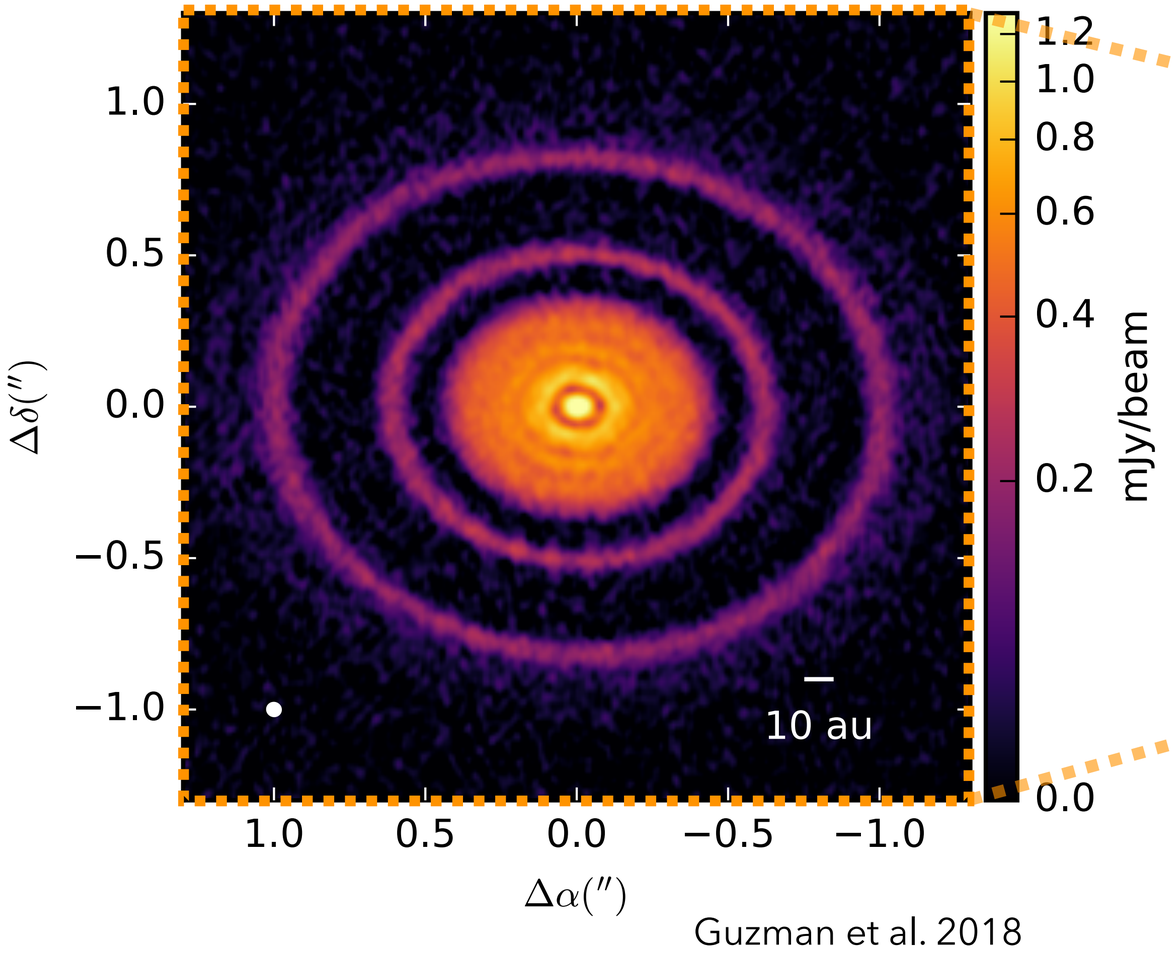
Isella et al. 2018



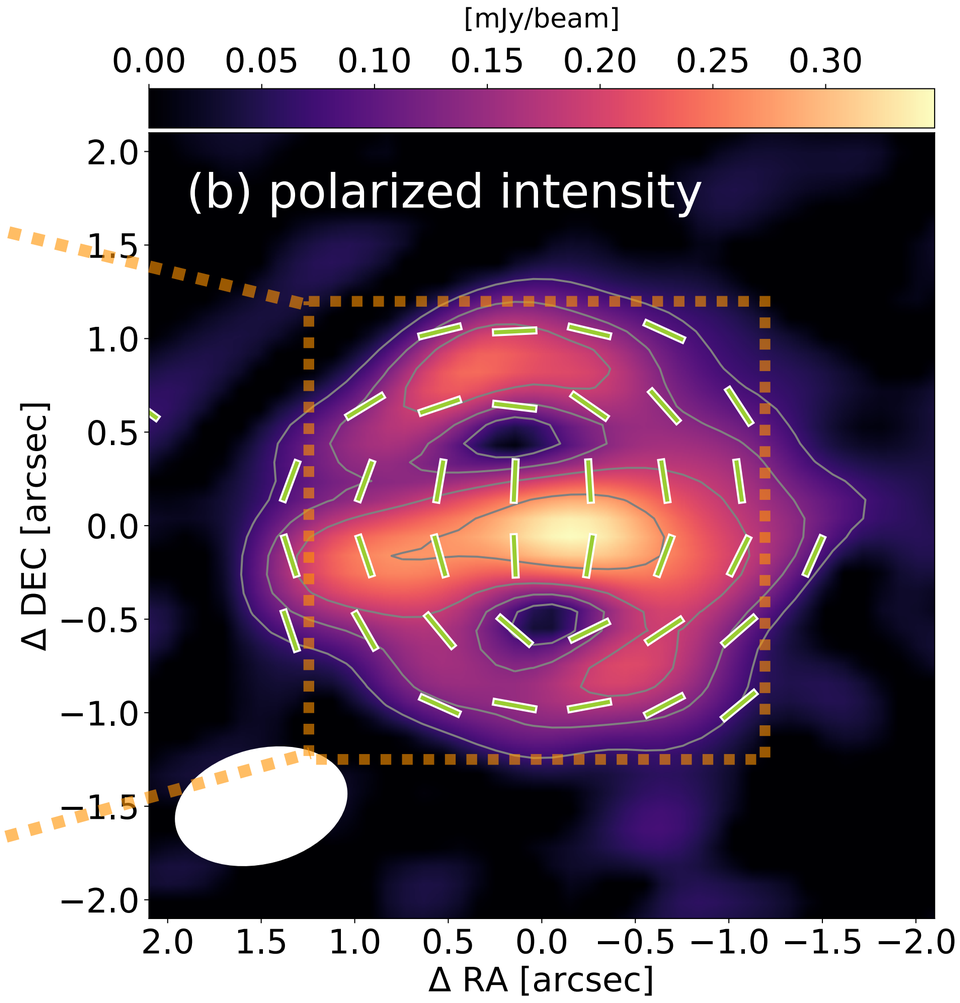
Dent et al. 2019

See Satoshi Ohashi's talk

AS 209 - polarization from a ring



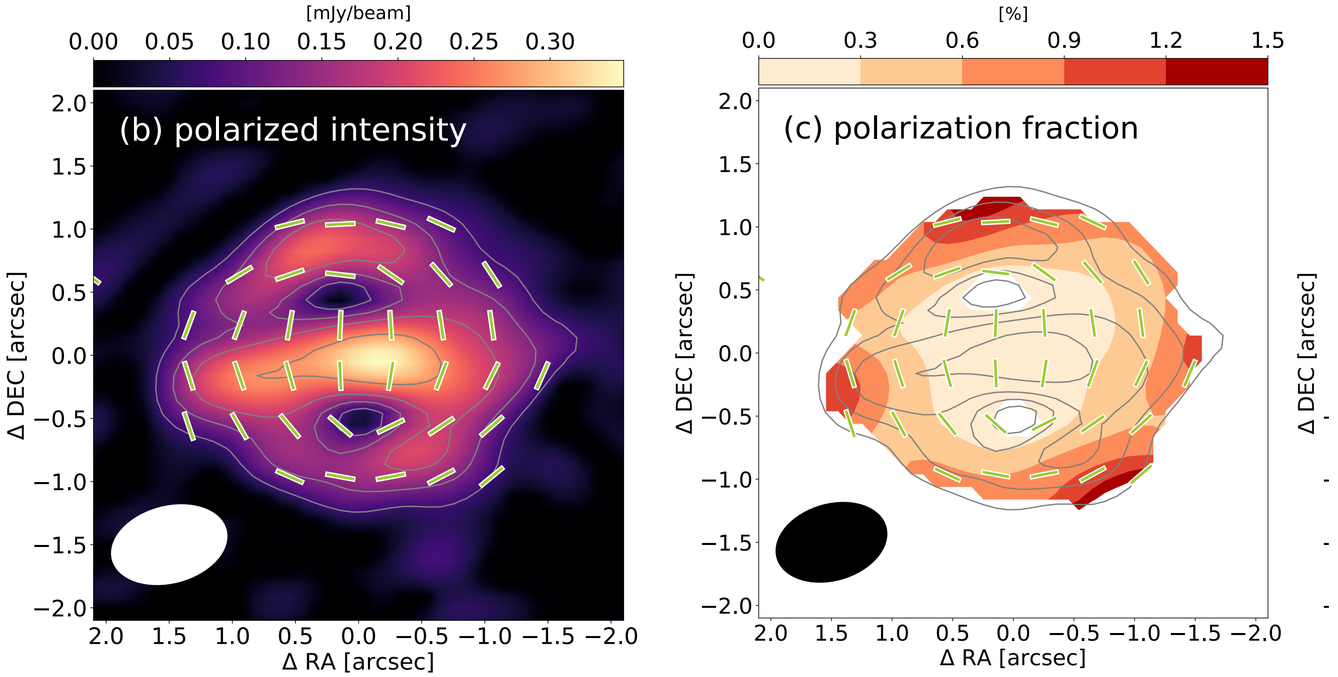
Guzman et al. 2018



ALMA Band 7, continuum polarization

Mori, Kataoka, et al. submitted

AS 209 - polarization from a ring



(beam size) : $0.''94 \times 0.''62$ (~114 × 75 au)

- **Inner regions:**
  - the vectors are parallel to the disk minor axis.
  - Polarization fraction is ~0.2%
- **Outer regions:**
  - the vectors are in the azimuthal direction
  - Polariztation fraction ~ 1%

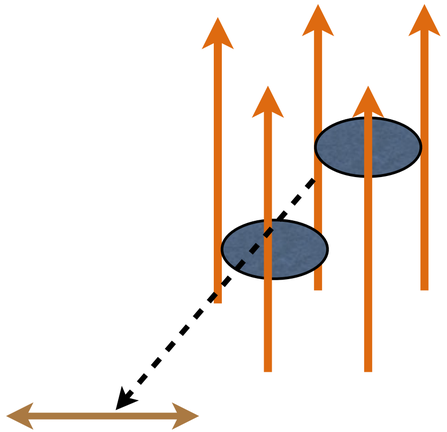
Inner part: self-scattering

Ourter part: ??

Mori, Kataoka, et al. submitted

Origin of azimuthal polarization

Grain alignment



Linear polarization

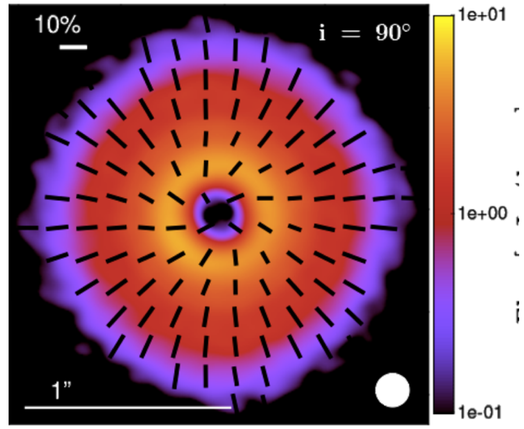
Direction

- **B-fields**
- radiation
- gas flow

e.g., Cho and Lazarian 2007, Tazaki et al. 2017, Lazarian and Hoang 2007

- **B-field alignment**
  - Polarization vectors are perpendicular to the B-field direction
  - To reproduce the azimuthal polarization, we need radial B-fields

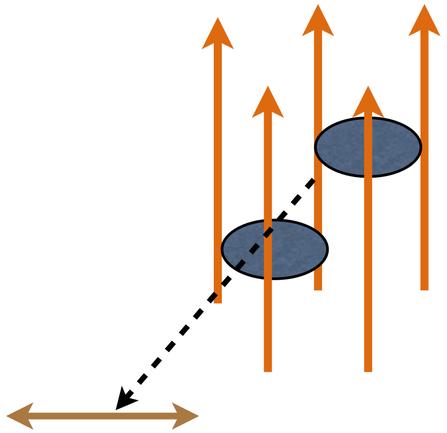
Expected polarization pattern from toroidal (azimuthal) B-fields



Bertrang et al. 2017

Origin of azimuthal polarization

Grain alignment



Linear polarization

Direction

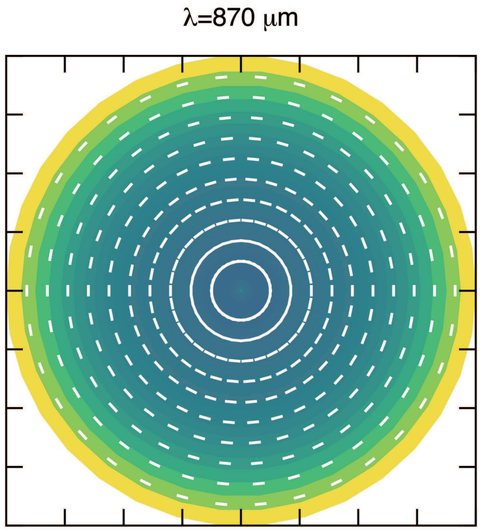
- B-fields
- **radiation**
- gas flow

e.g., Cho and Lazarian 2007, Tazaki et al. 2017, Lazarian and Hoang 2007

- **radiation alignment**
  - Polarization vectors are perpendicular to the radiation gradient
  - Usually azimuthal (or circular) polarization is expected

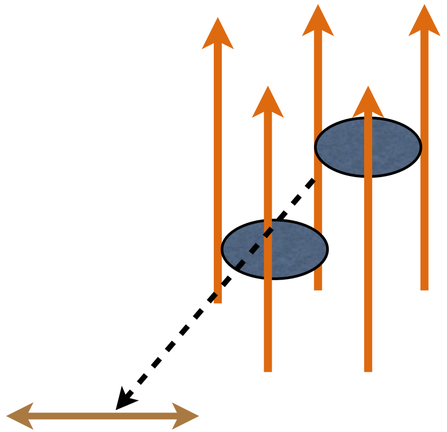
Expected polarization pattern from radiation alignment

Tazaki et al. 2017



Origin of azimuthal polarization

Grain alignment



Linear polarization

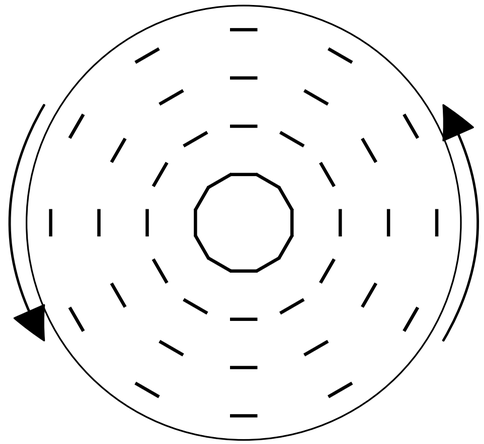
Direction

- B-fields
- radiation
- **gas flow**

e.g., Cho and Lazarian 2007, Tazaki et al. 2017, Lazarian and Hoang 2007

- **Gas-flow alignment**
  - Polarization vectors are perpendicular to the gas flow onto dust grains
  - Usually azimuthal (or circular) polarization is expected

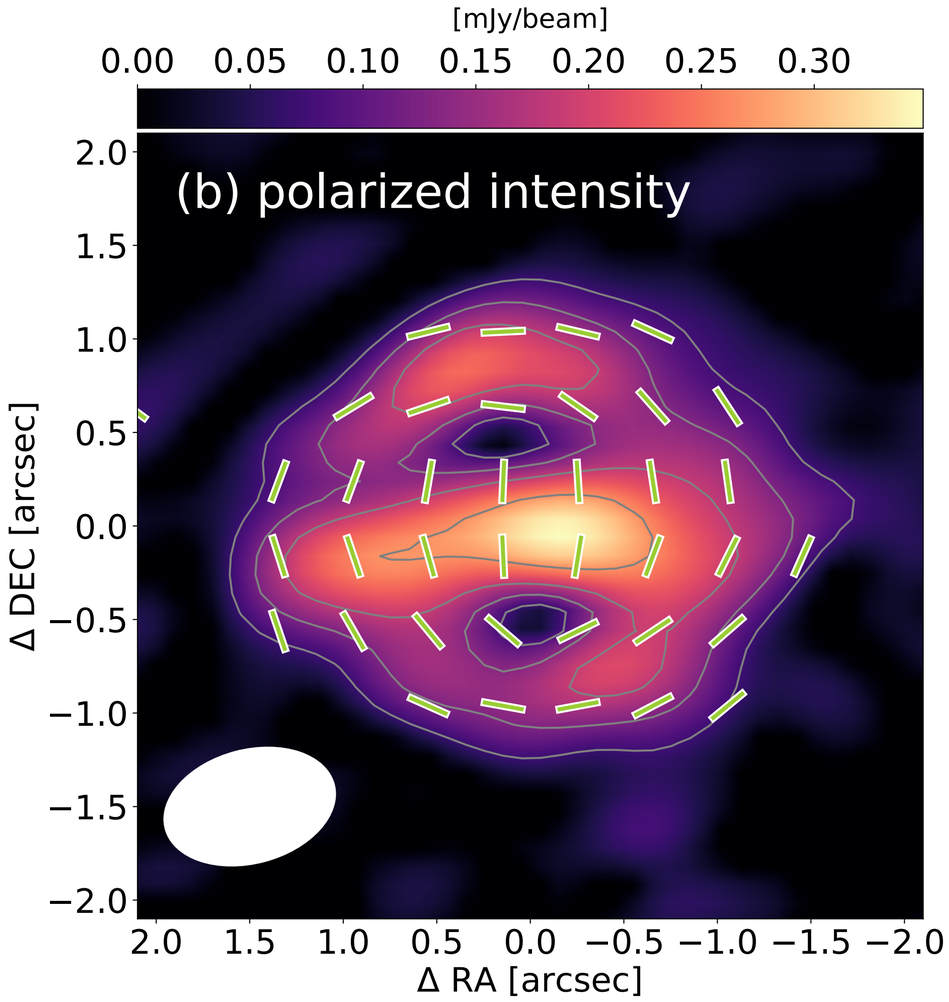
Expected polarization pattern from gas-flow alignment



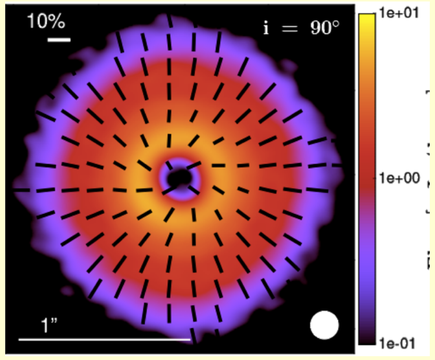
Kataoka et al. 2019

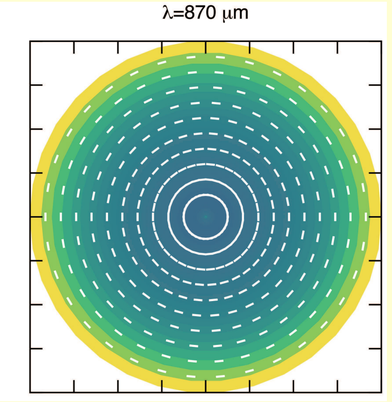
Origin of azimuthal polarization

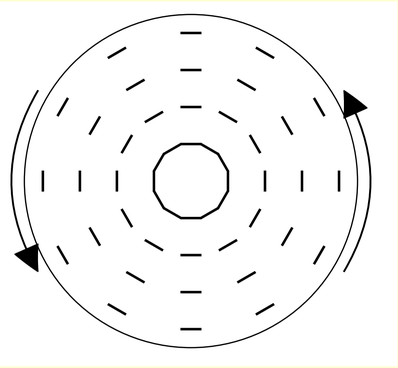
Observations



Models

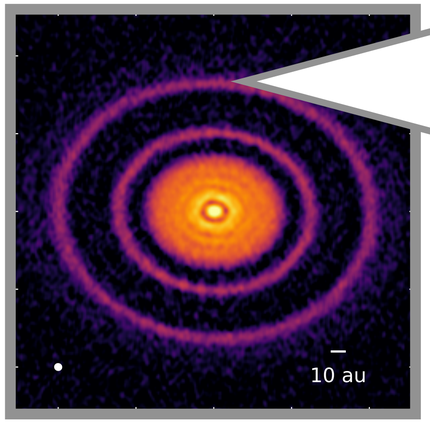






B-fields	Radiation	Gas-flow
✗	✔	✔
no	**yes**	**yes**

How can we distinguish between radiation and gas-flow?



Guzman et al. 2018

gas rotation

gas headwind

polarization

≈

(central star)

Laboratory frame

dust velocity

gas velocity

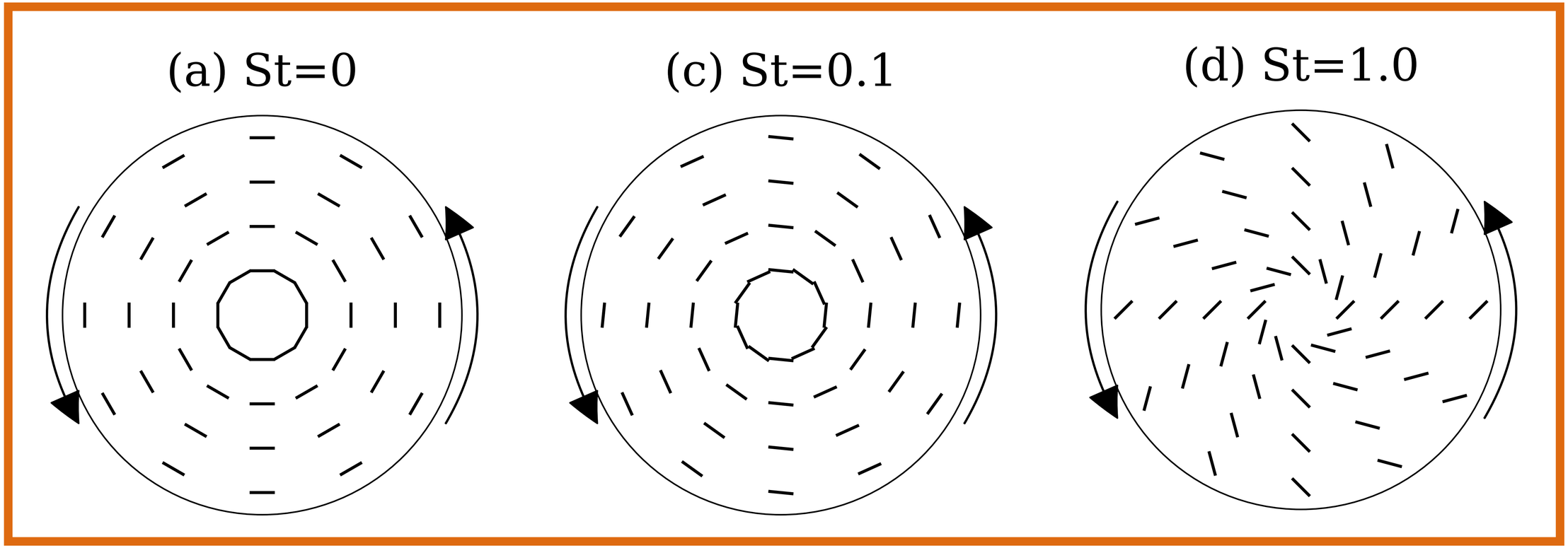
(azimuthal)

(radial)

Rest frame of the dust grain

gas velocity against dust

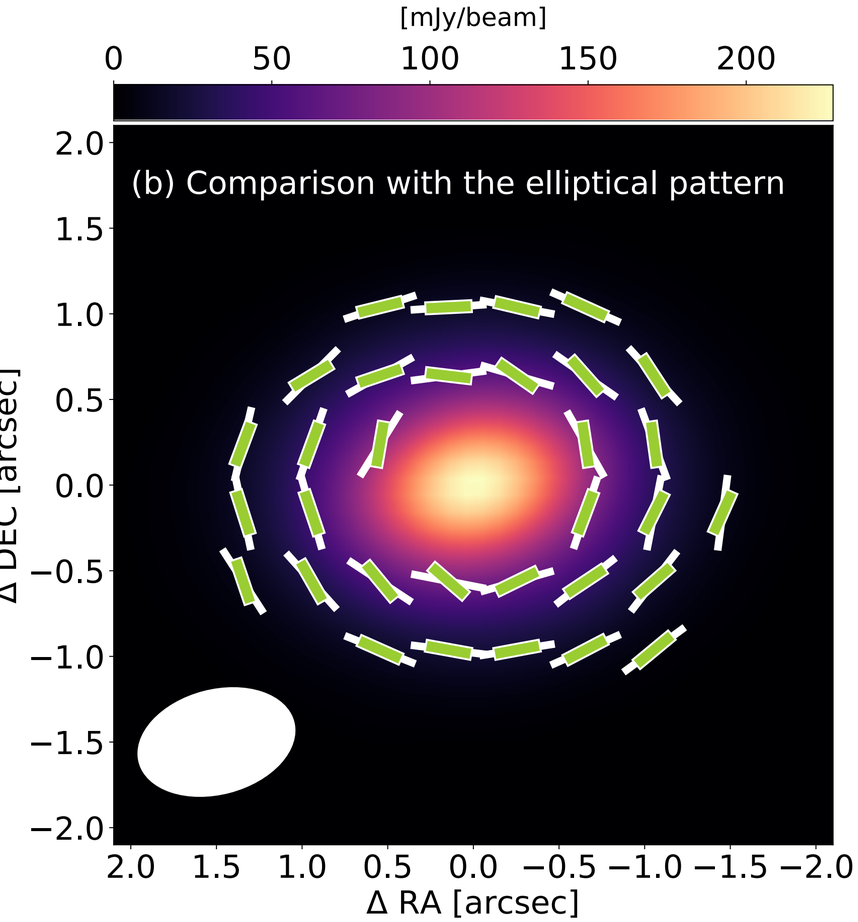
Gas-flow alignment polarization

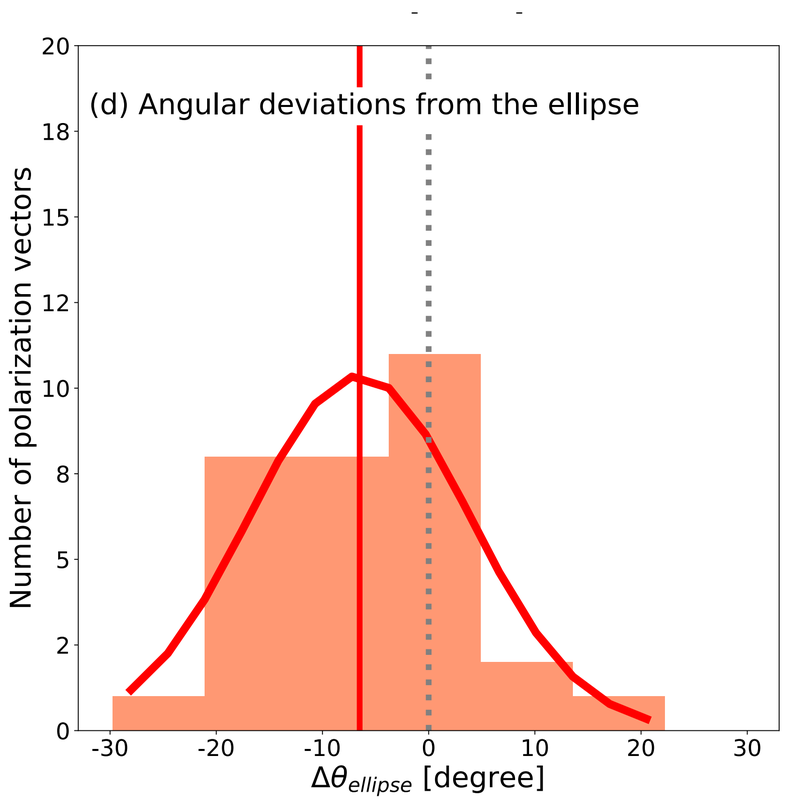


We would observe systematic rotation of polarization vectors from the azimuthal direction

Kataoka, et al. 2019

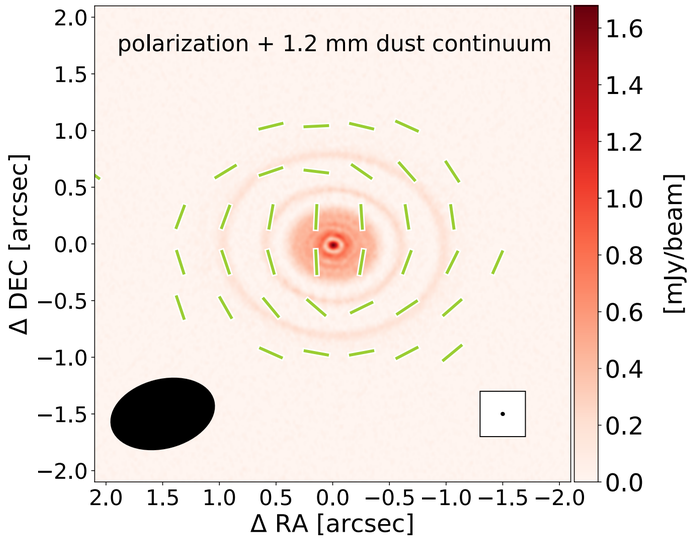
AS 209 - polarization from a ring





$$\Delta\theta = -4.5 \pm 1.6\ ^\circ$$

Where does this correspond?

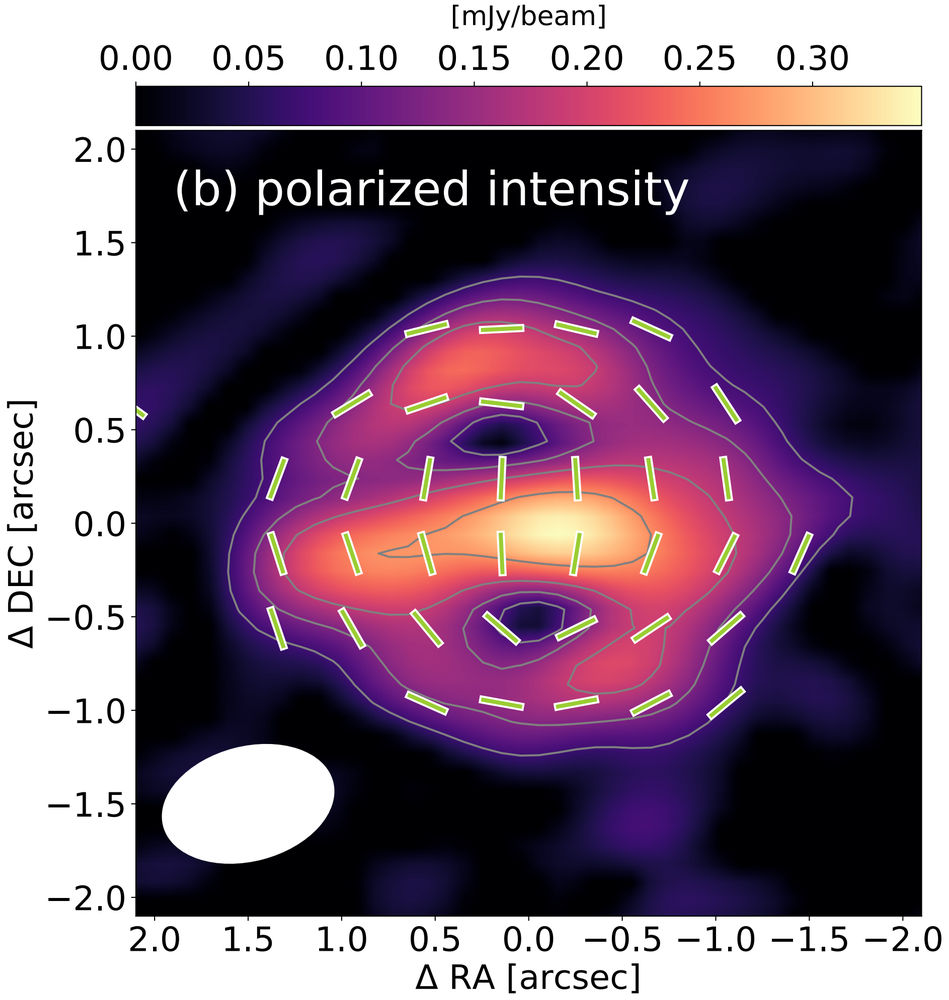


From the outermost ring

Slight deviation from the azimuthal direction -> gas-flow alignment?

Summary

- **ALMA polarization observations of AS 209 disk**
  - **Inner part: parallel to the minor axis**
    - likely due to self-scattering
    - grain size would be ~50 μm - 500 μm
  - **Outer part: azimuthal pattern**
    - Alignment with gas-flow is the most likely scenario
    - Grains are being accumulated?



Mori, Kataoka, et al. submitted