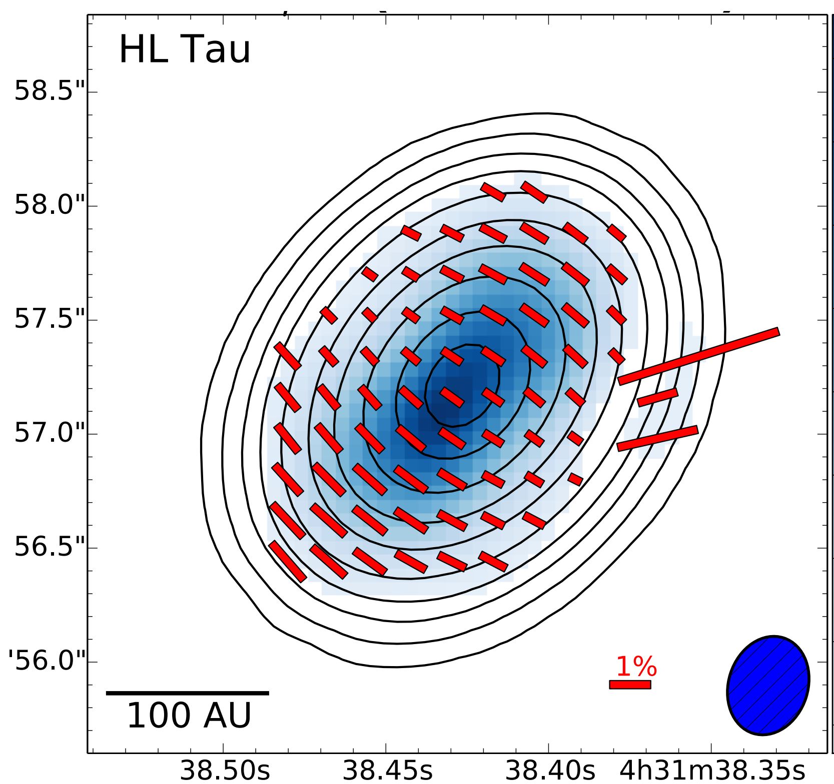
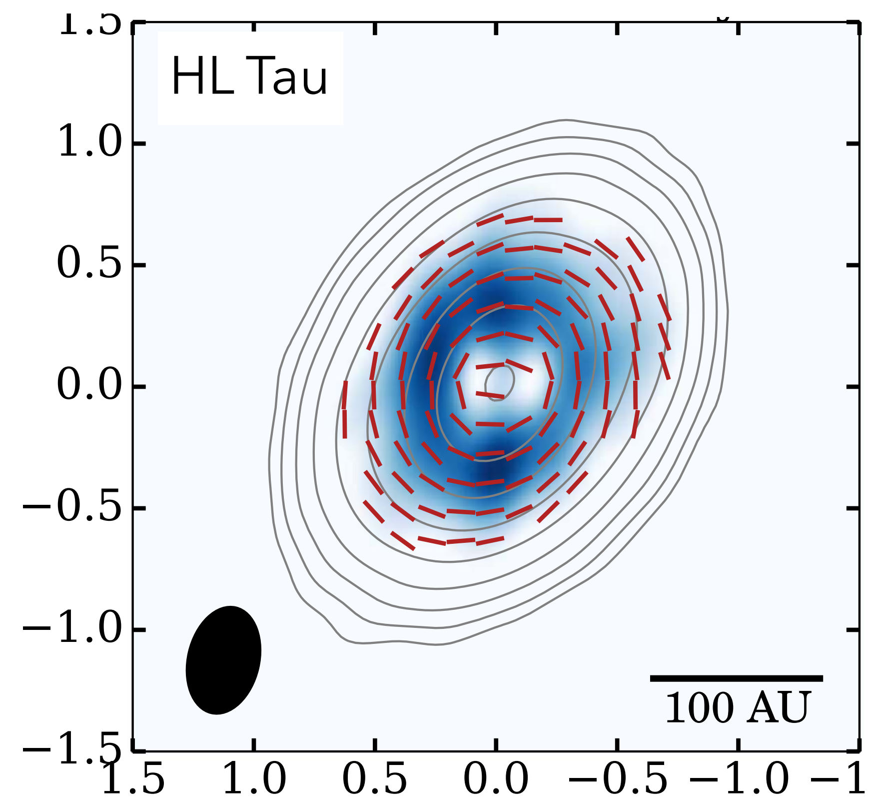
Investigating planet formation by FIR and sub-mm polarization observations of protoplanetary disks

ALMA Band 7 (870 μm)



Stephens et al. 2017

ALMA Band 3 (3.1 mm)



Kataoka et al. 2017

Scattering ↔ **Alignment**

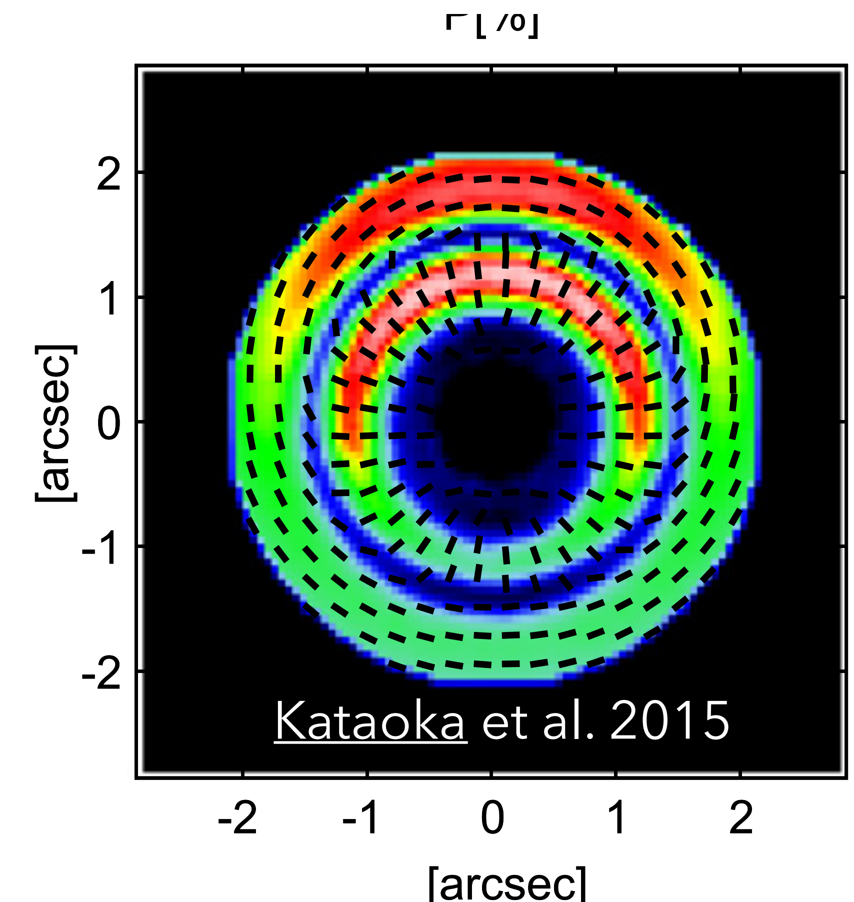
(Kataoka et al. 2015) (Tazaki et al. 2015)

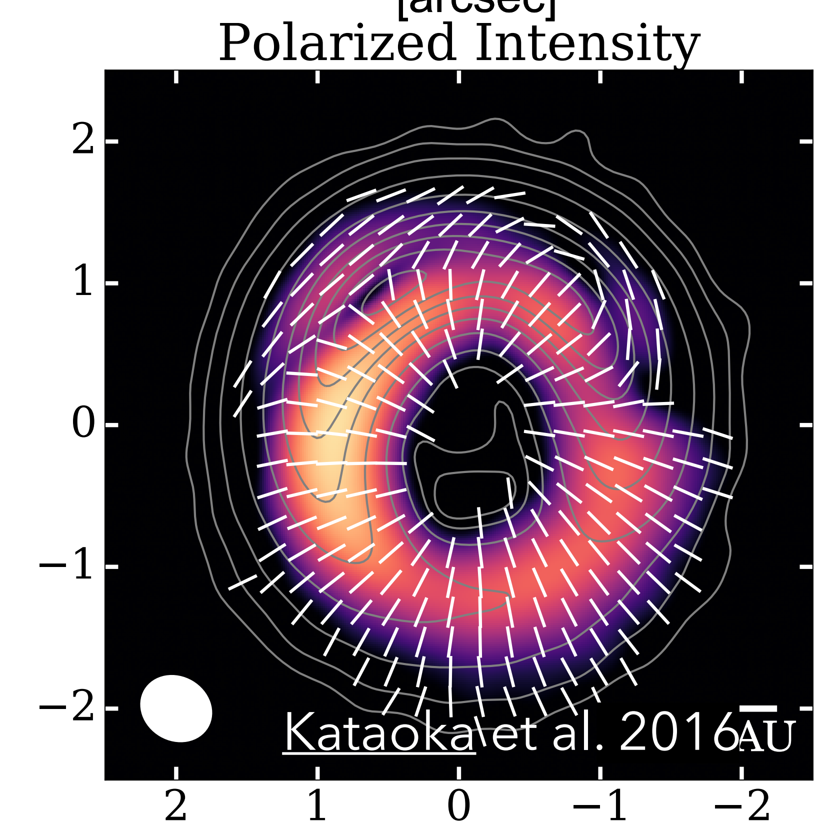
Akimasa Kataoka (NAOJ fellow, NAOJ)

T. Muto (Kogakuin U.), M. Momose, T. Tsukagoshi (Ibaraki U.), H.Nagai (NAOJ), M. Fukagawa (Nagoya U.), H. Shibai (Osaka U.), T. Hanawa (Chiba U.), K. Murakawa (Osaka-S.), Kees Dullemond, Adriana Pohl (Heidelberg)

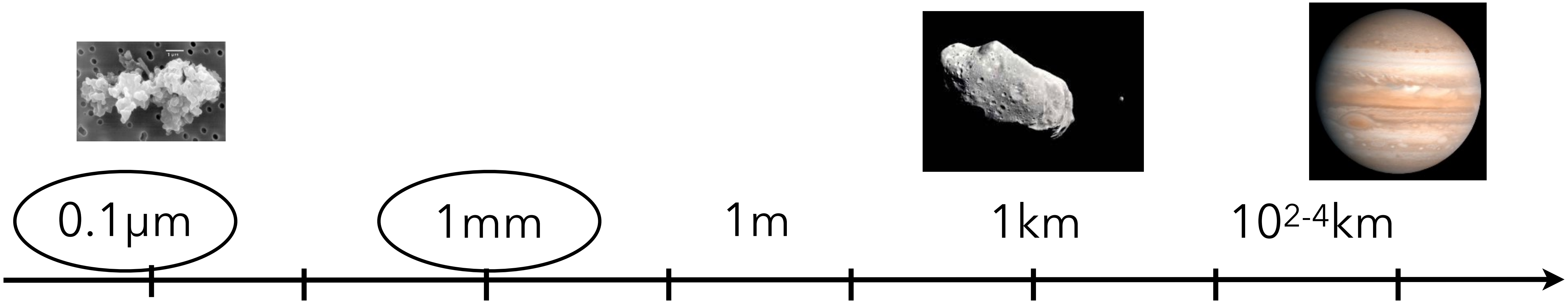
Millimeter Polarization

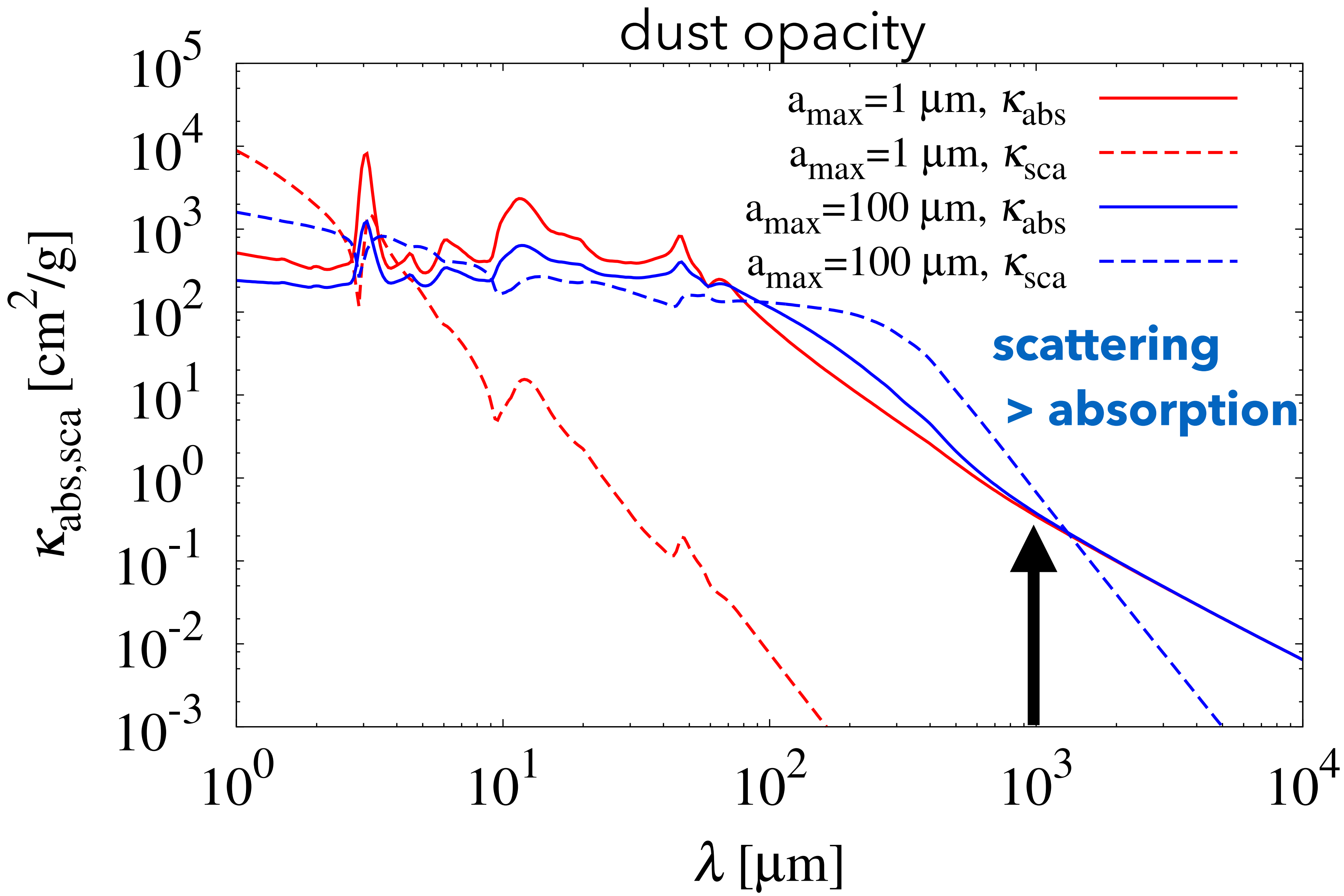
- **Old and new theories for explaining millimeter-wave polarization**
  1. Alignment with magnetic fields
  2. **Self-scattering of thermal dust emission**
  3. Alignment with radiation fields
- **Testing the theory with ALMA polarization observations**
  - HD 142527 - morphology of pol. vectors
  - **HL Tau - wavelength dependence**





Dust is big in disks

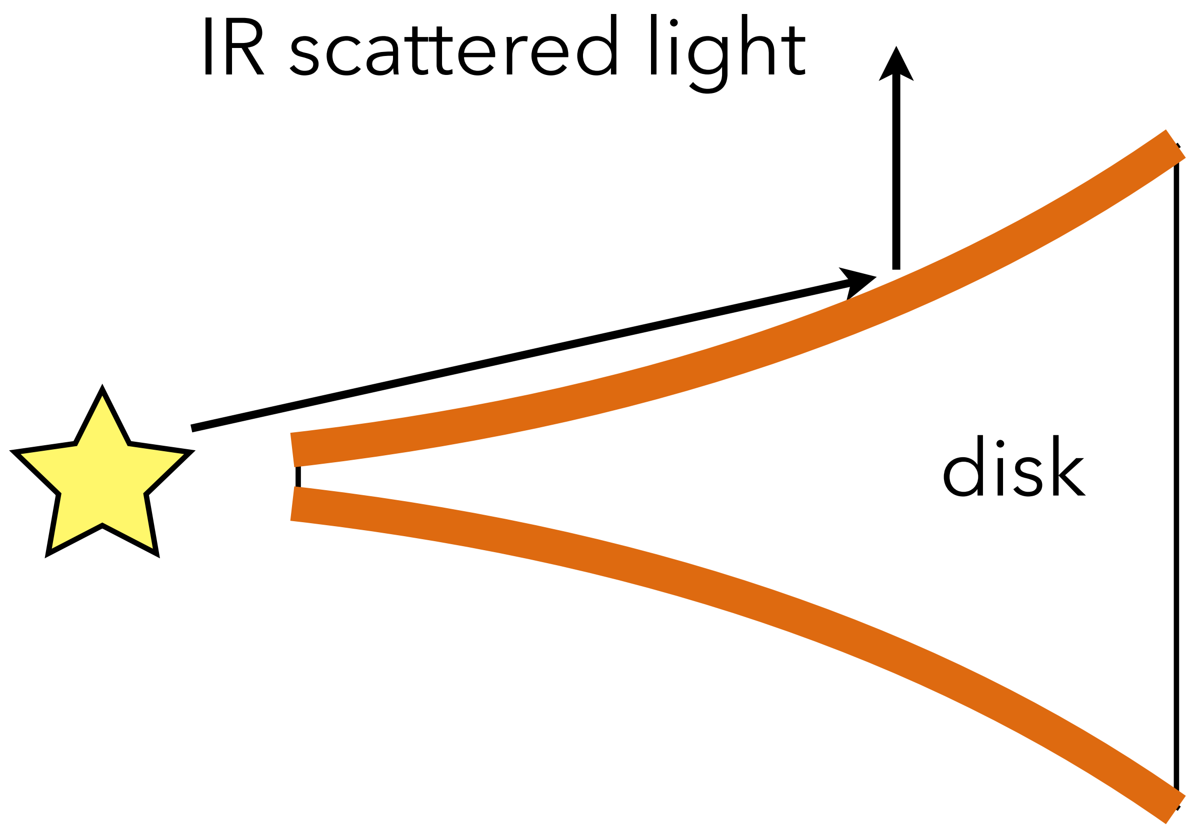


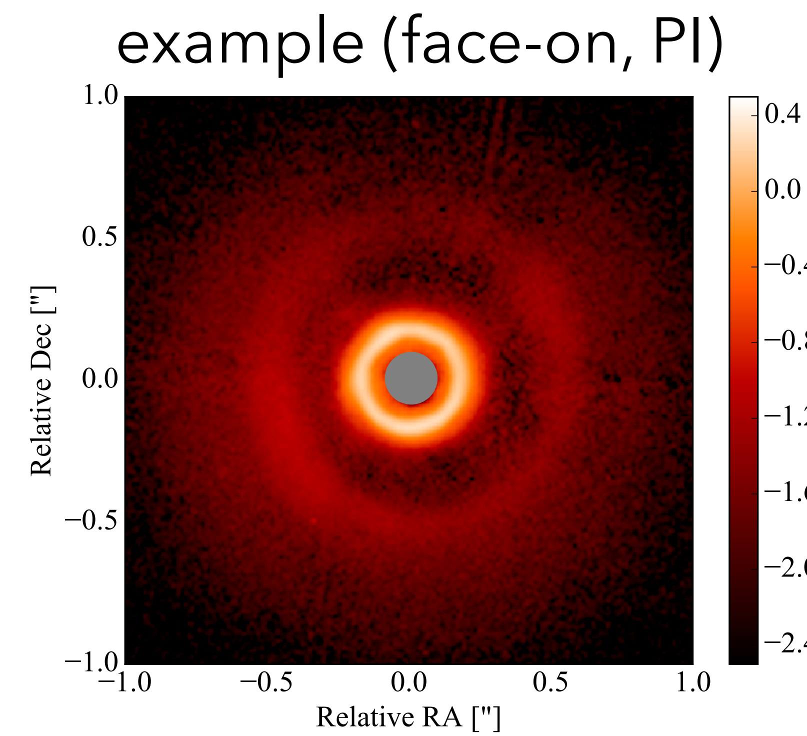


Akimasa Kataoka (NAOJ fellow)

Light source of scattering

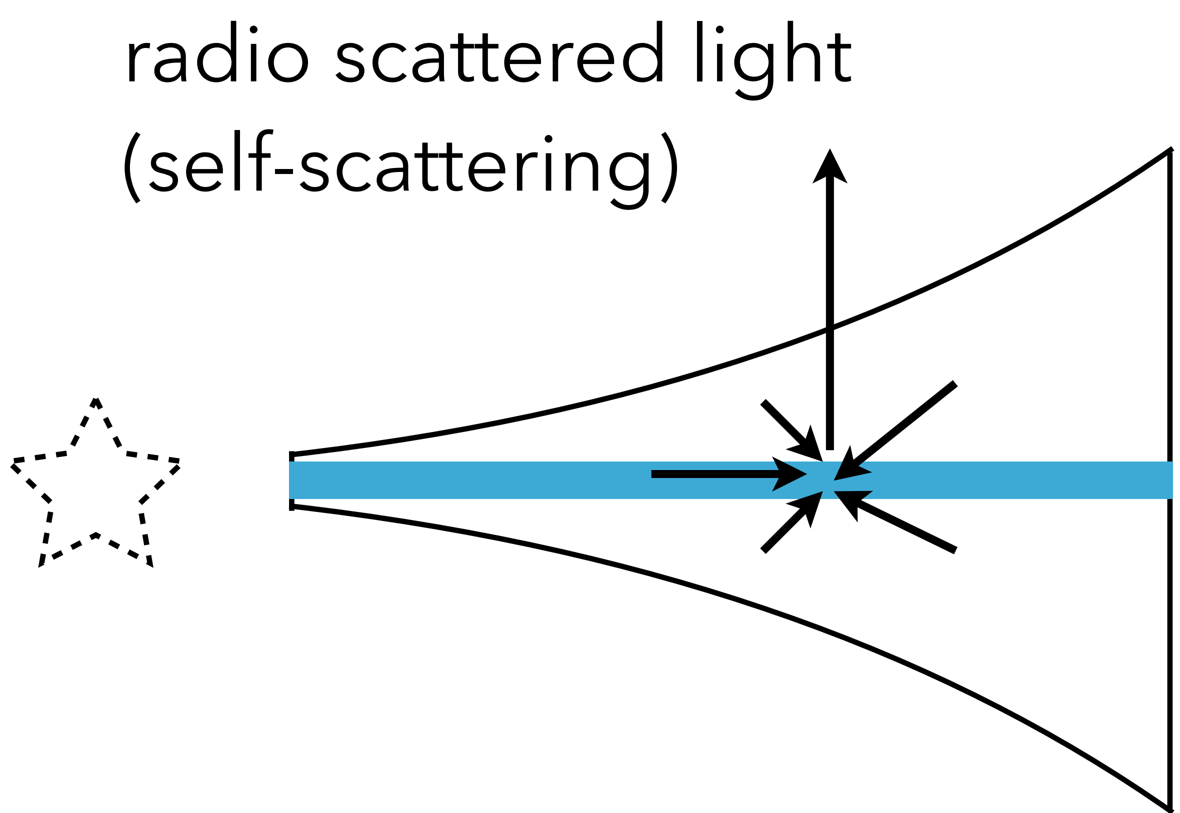
Infrared





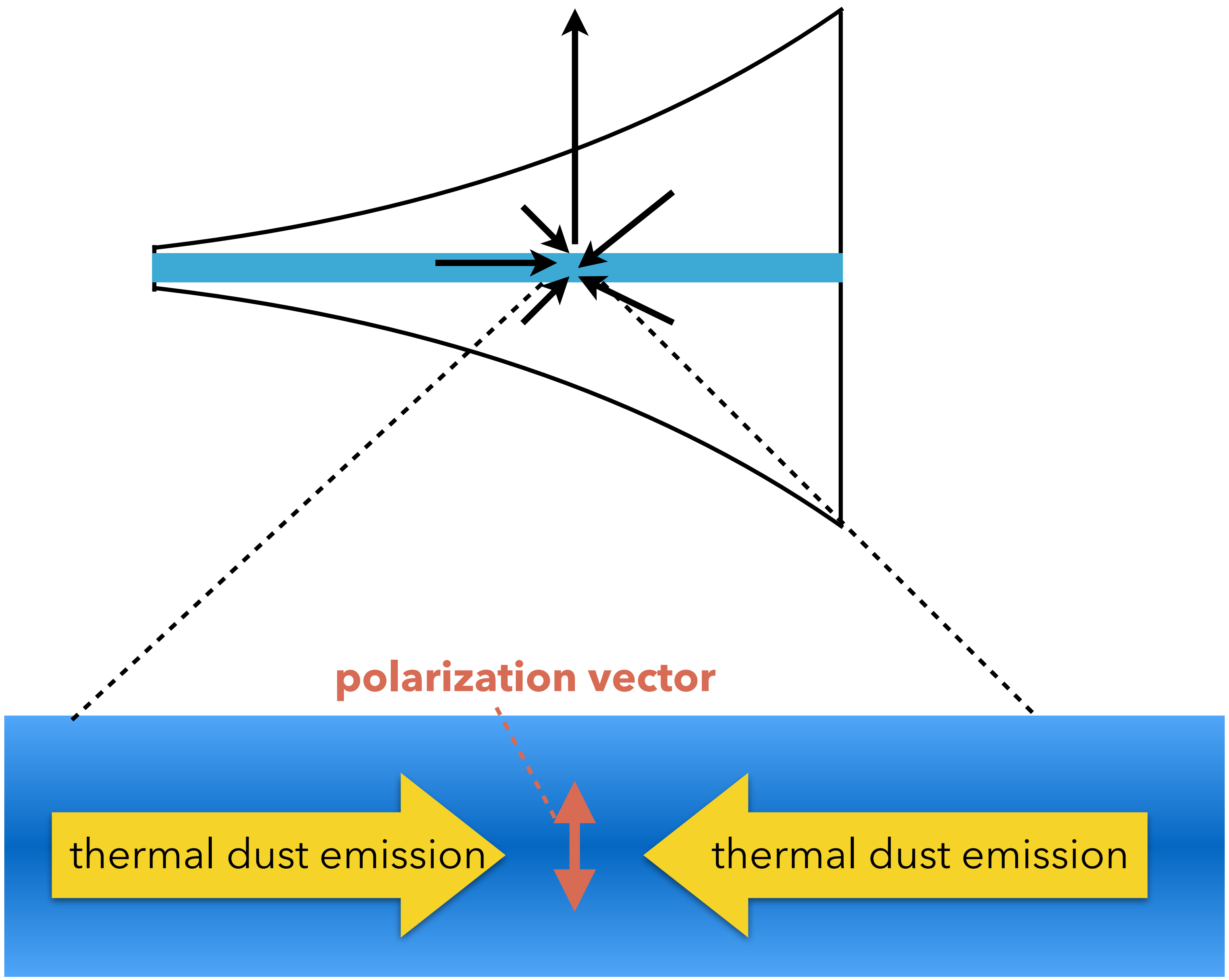
Pohl et al. 2017

millimeter

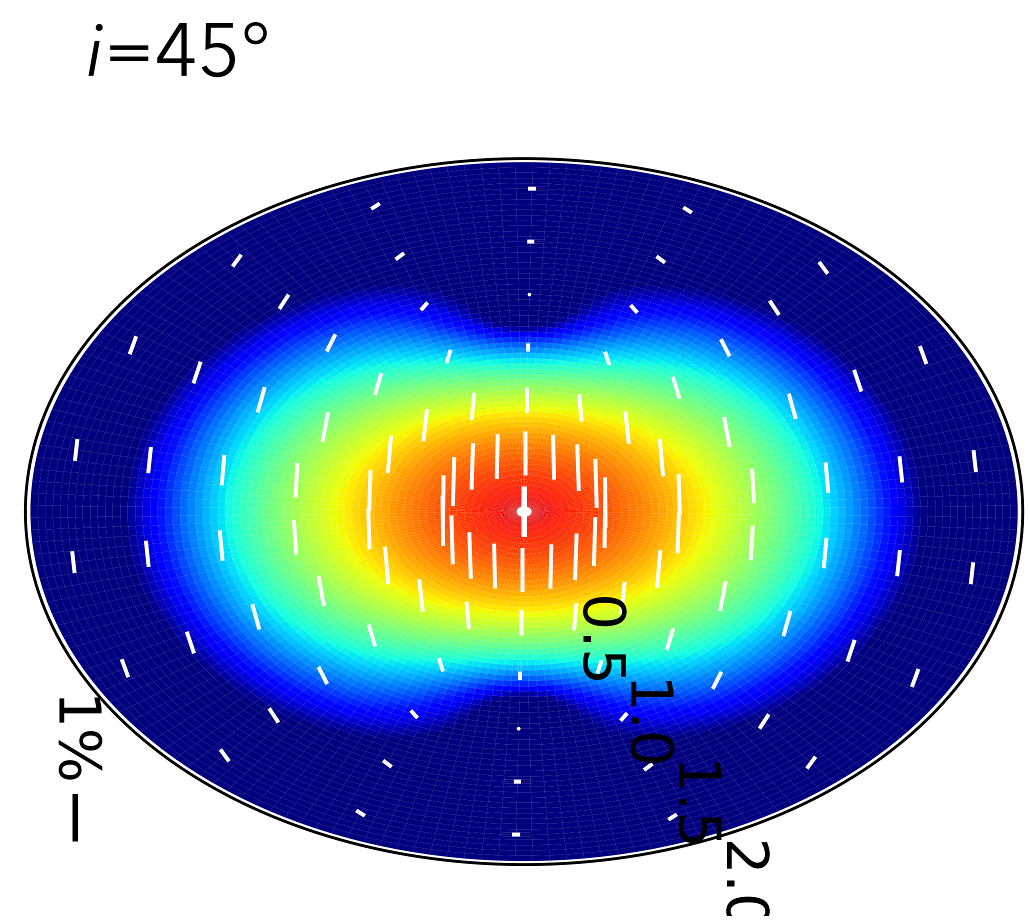


?

self-scattering in an inclined disk



(disk, edge-on view)



Yang, Li, et al. 2016

See also Kataoka et al. 2016a

Conditions of dust grains for polarization

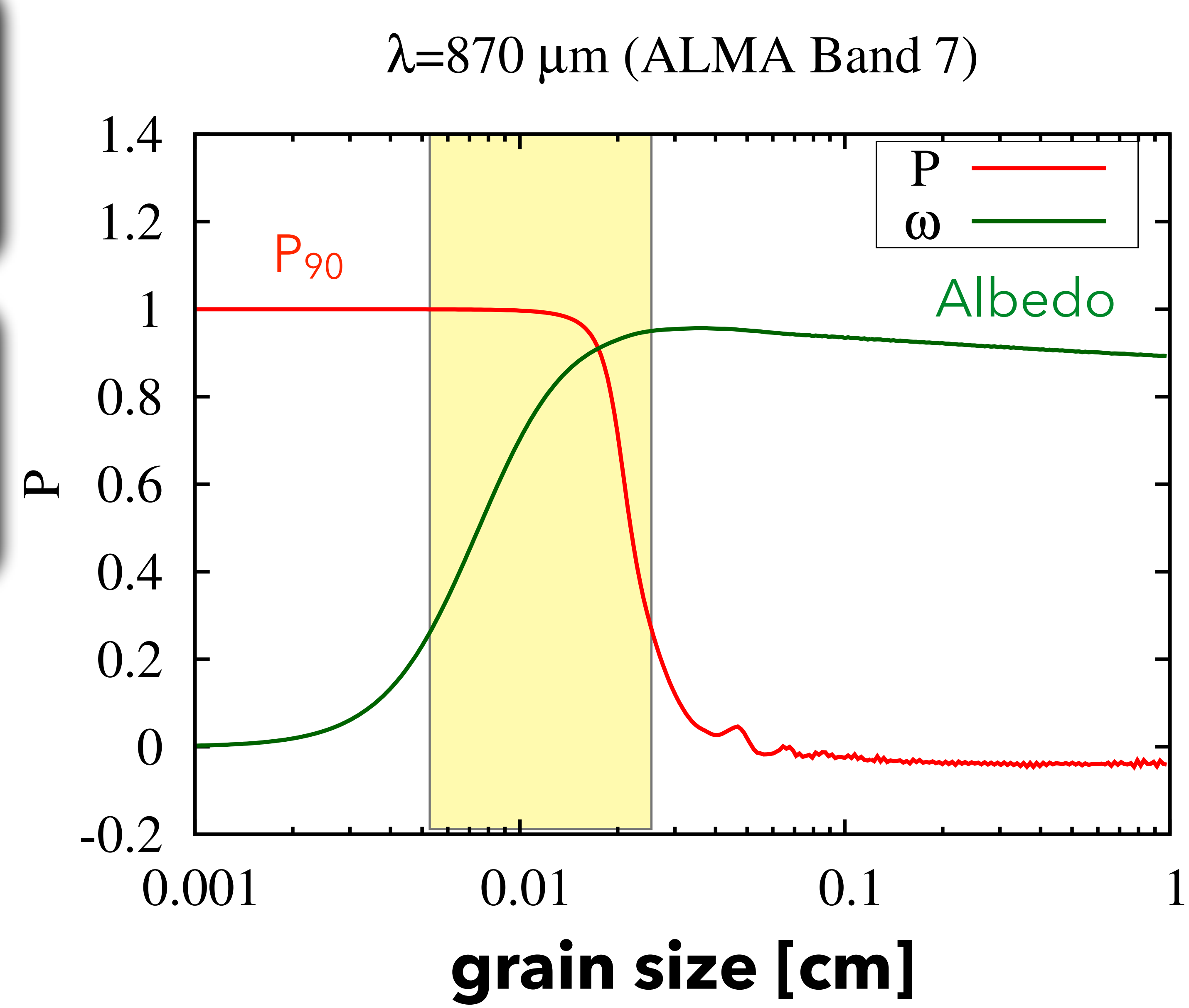
- For efficient scattering

  (grain size) >~ λ

- For efficient polarization

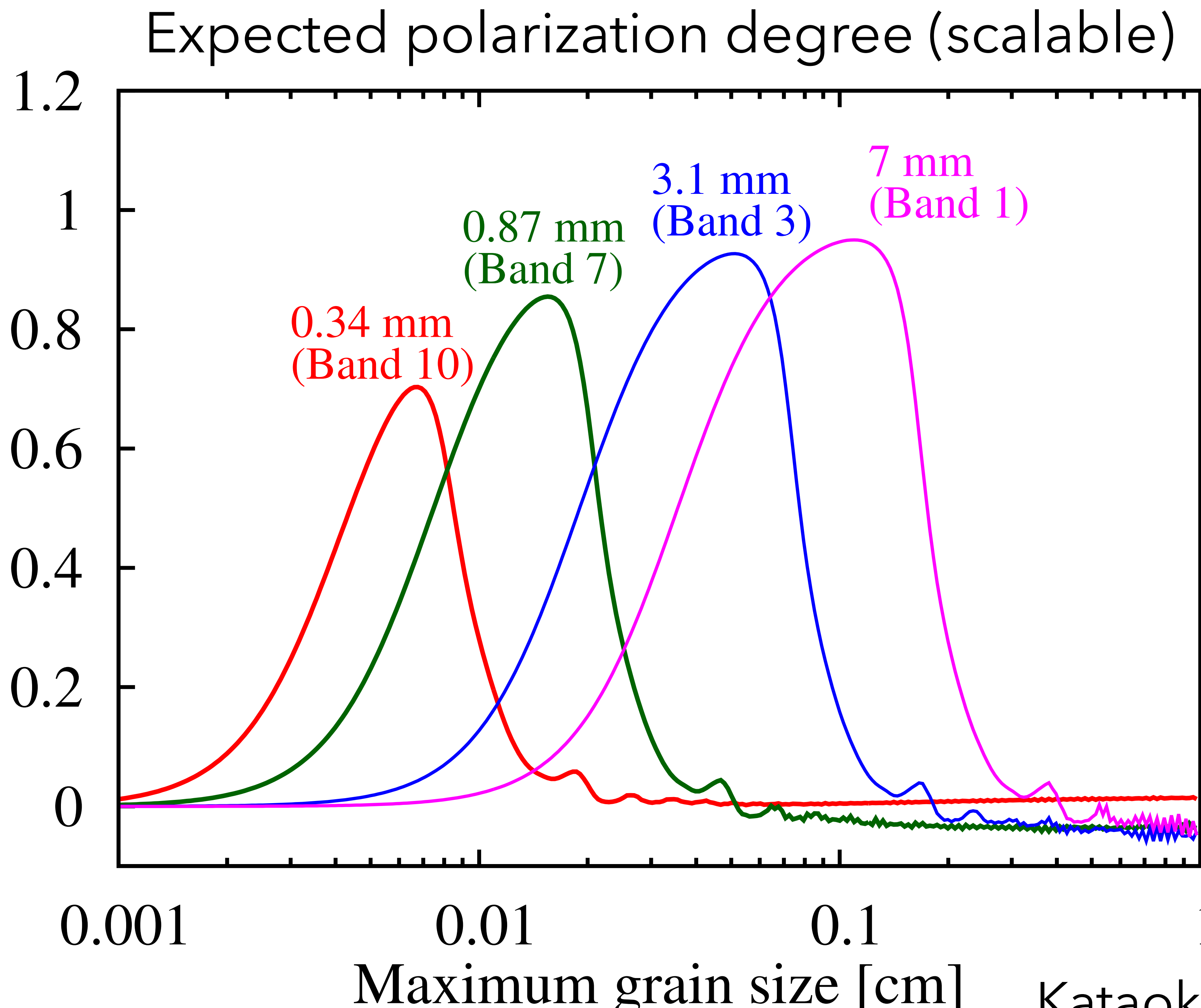
  (grain size) <~ λ

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

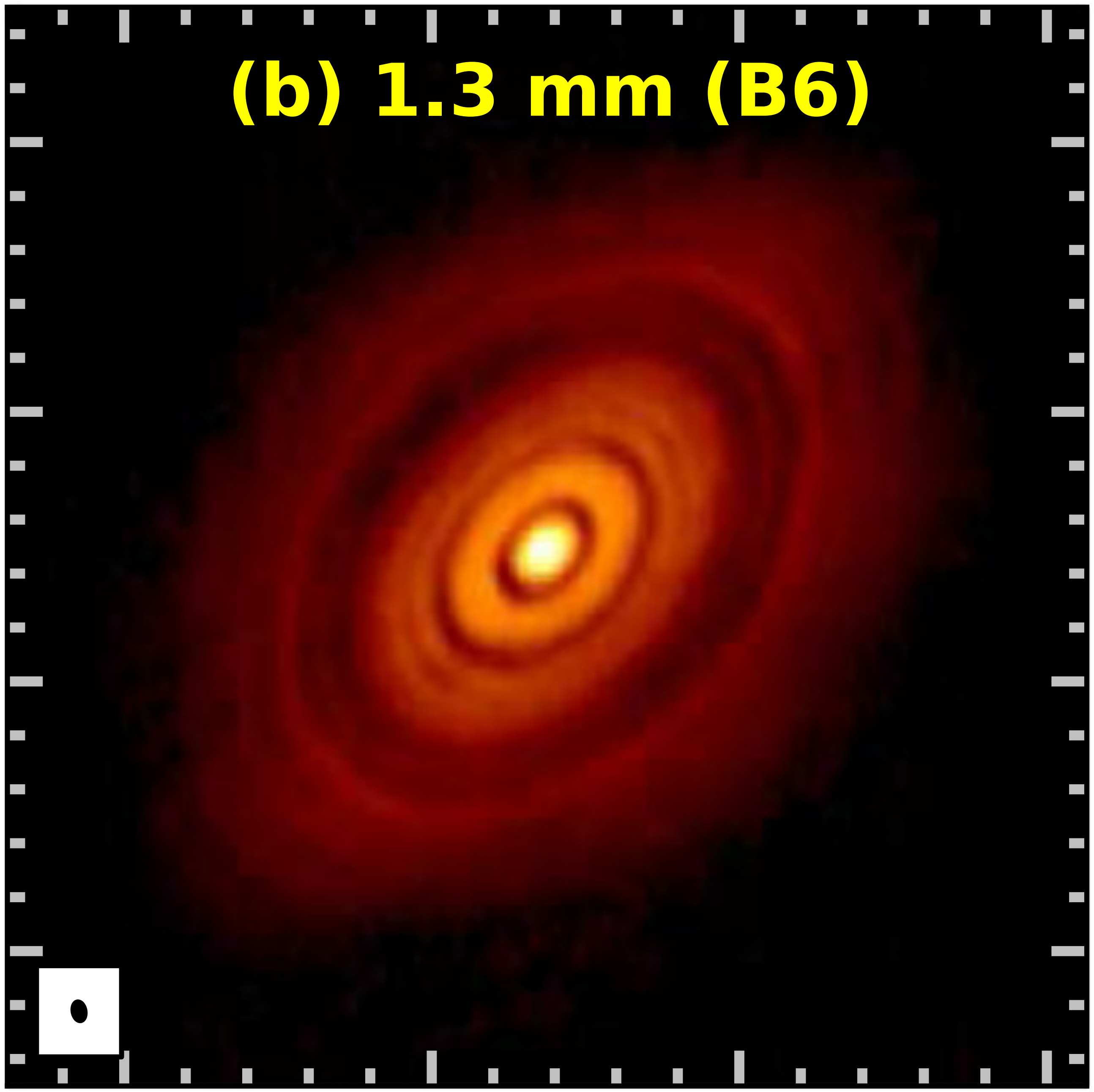
Grain size constraints by polarization

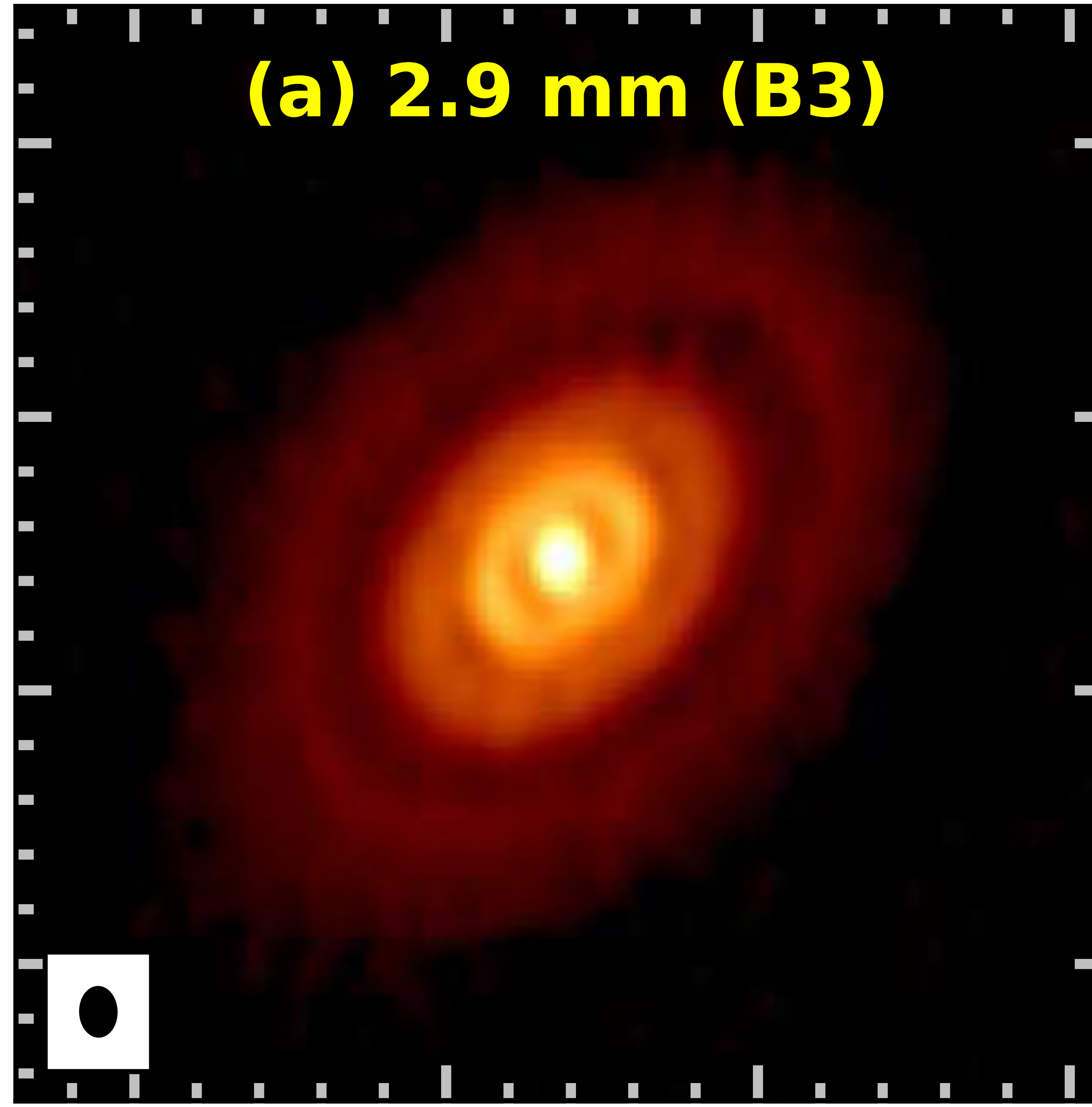


Kataoka, et al., 2015

Multi-wave polarization → constraints on the grain size

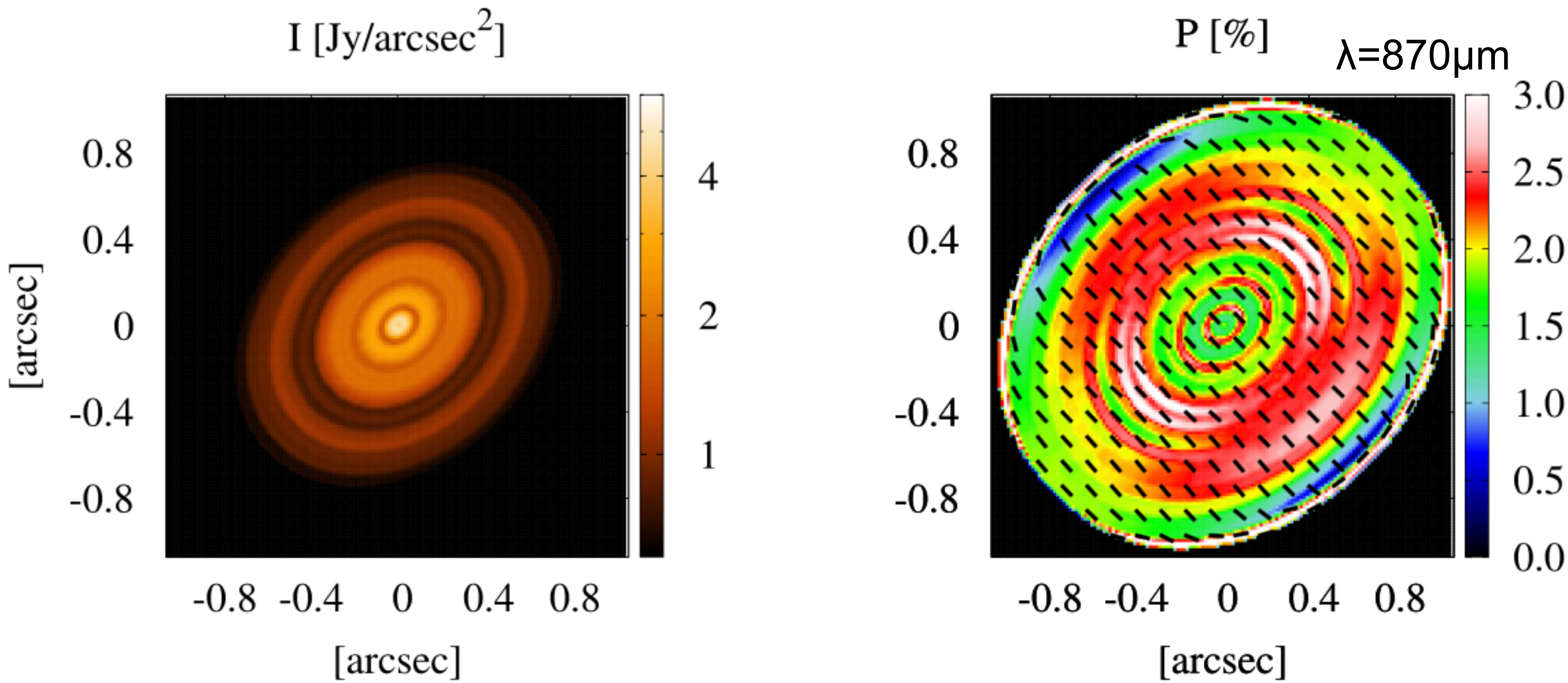
HL Tau - continuum





ALMA Partnership, 2015

HL Tau pol. - prediction

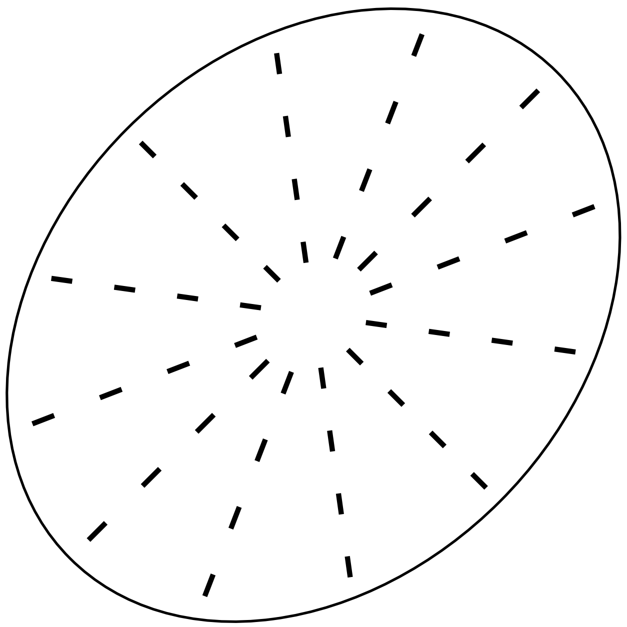


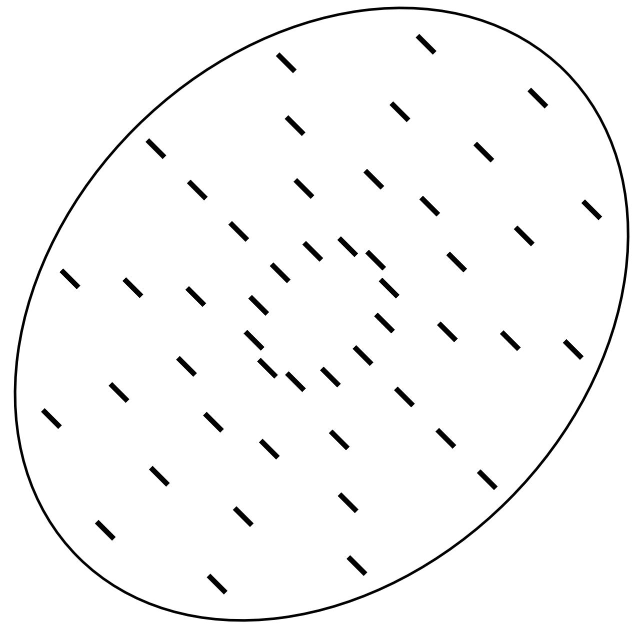
- i = 47° (ALMA Partnership 2015)
- The polarization vectors are parallel to the minor axis

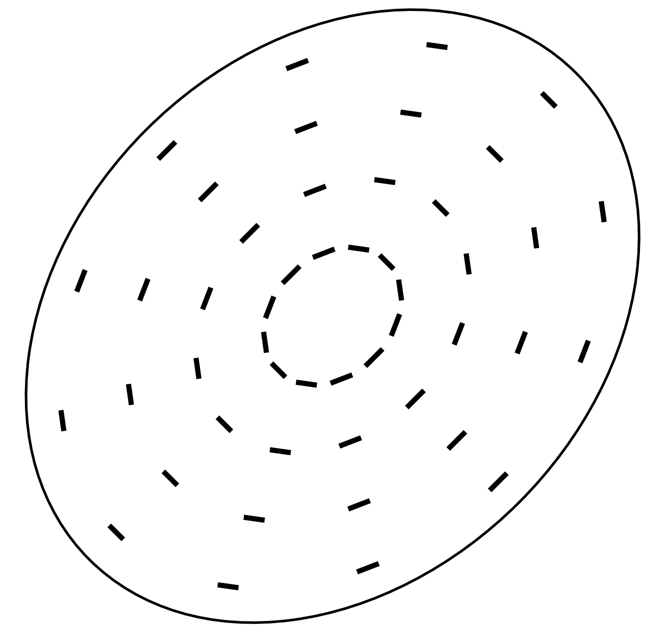
Kataoka, et al., 2016a (see also Yang et al. 2016)

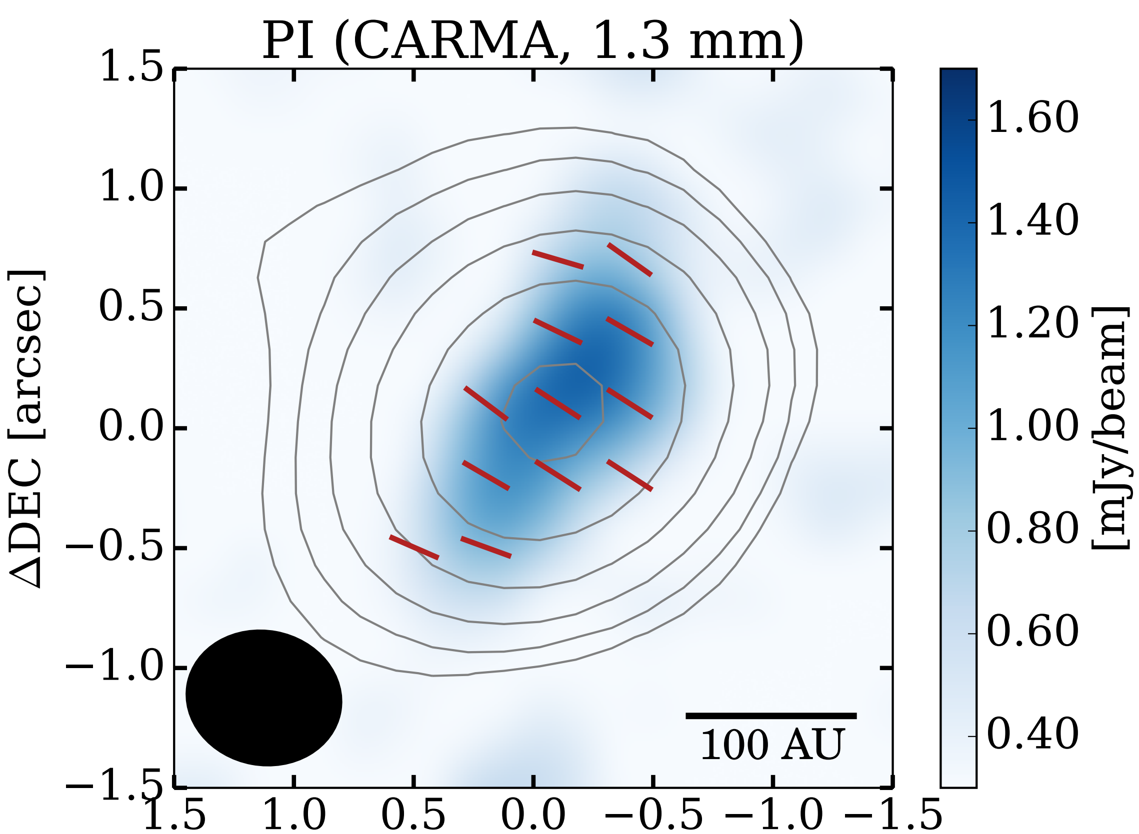
Polarization mechanisms

alignment with B-fields | **self-scattering** | **alignment with radiation**

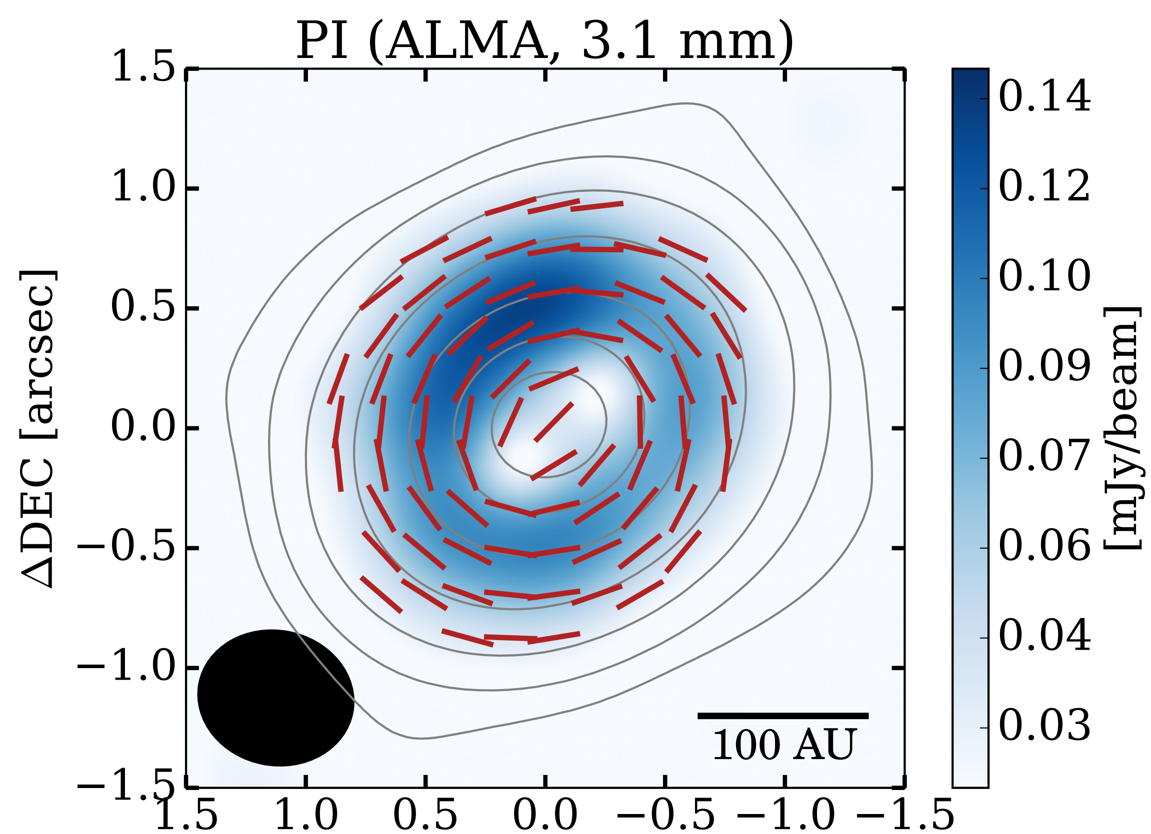








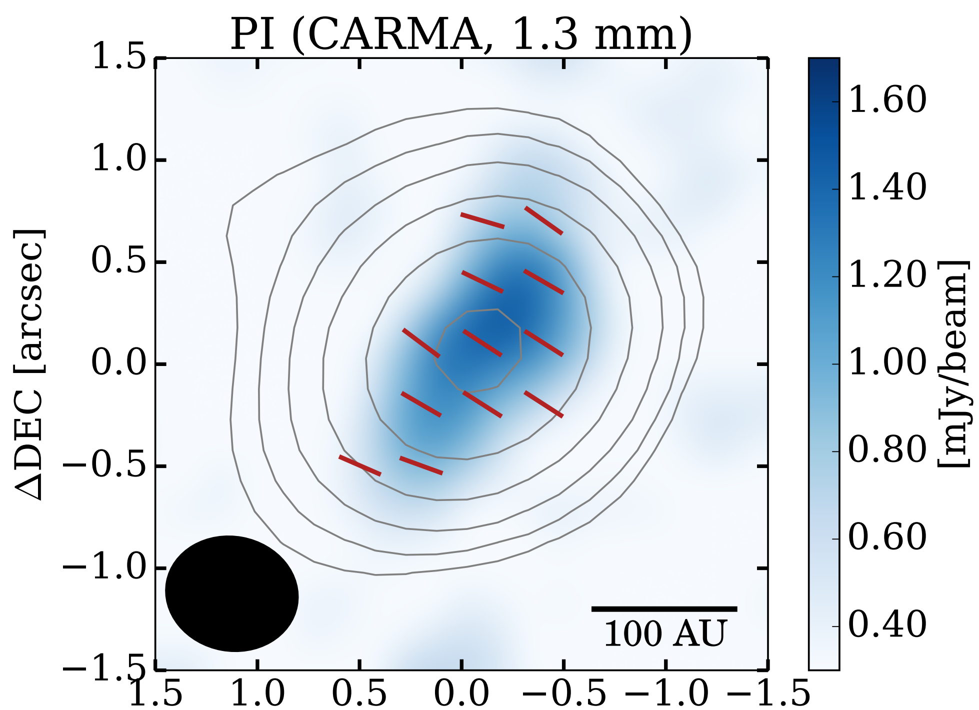
self-scattering

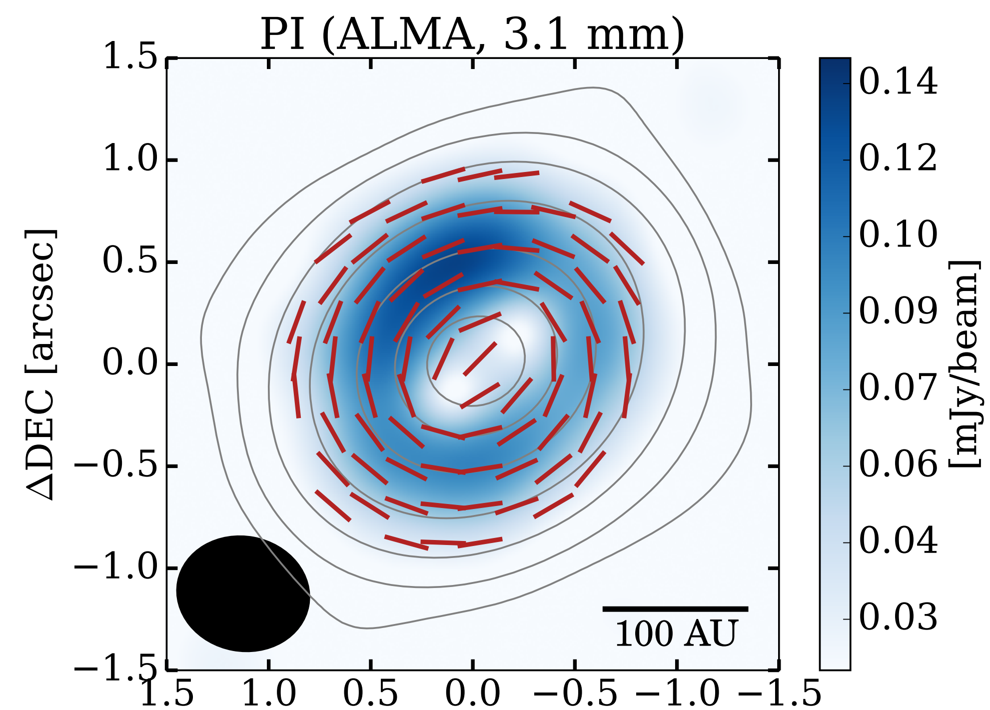


alignment with radiation

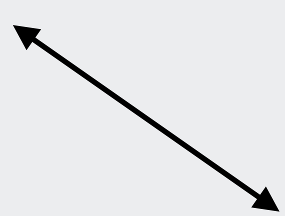
Kataoka, et al., 2017

Total polarization fraction





integrating



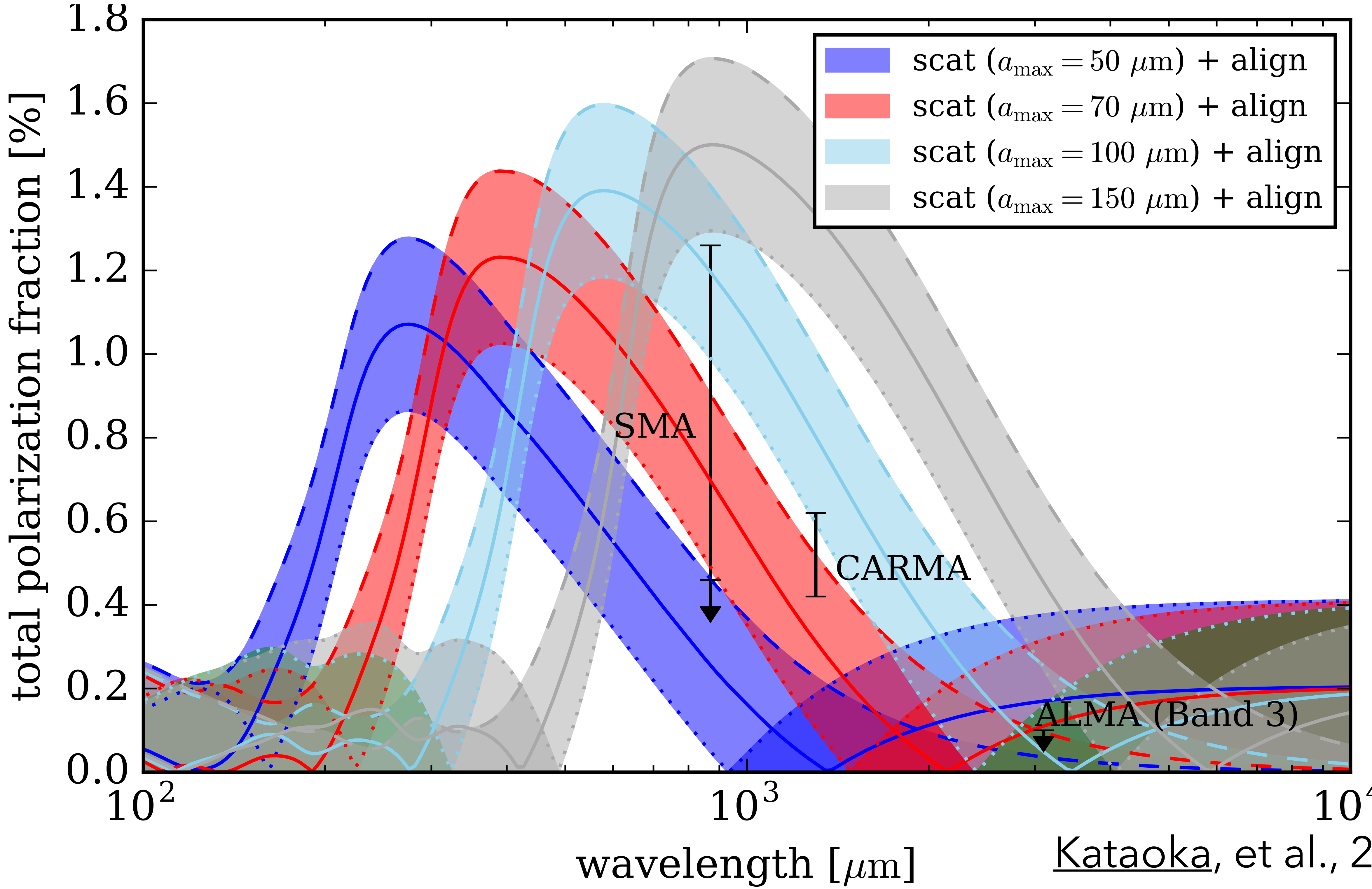
0.5%

weak polarization

<0.1%

We can extract the self-scattering components

HL Tau polarization



Kataoka, et al., 2017

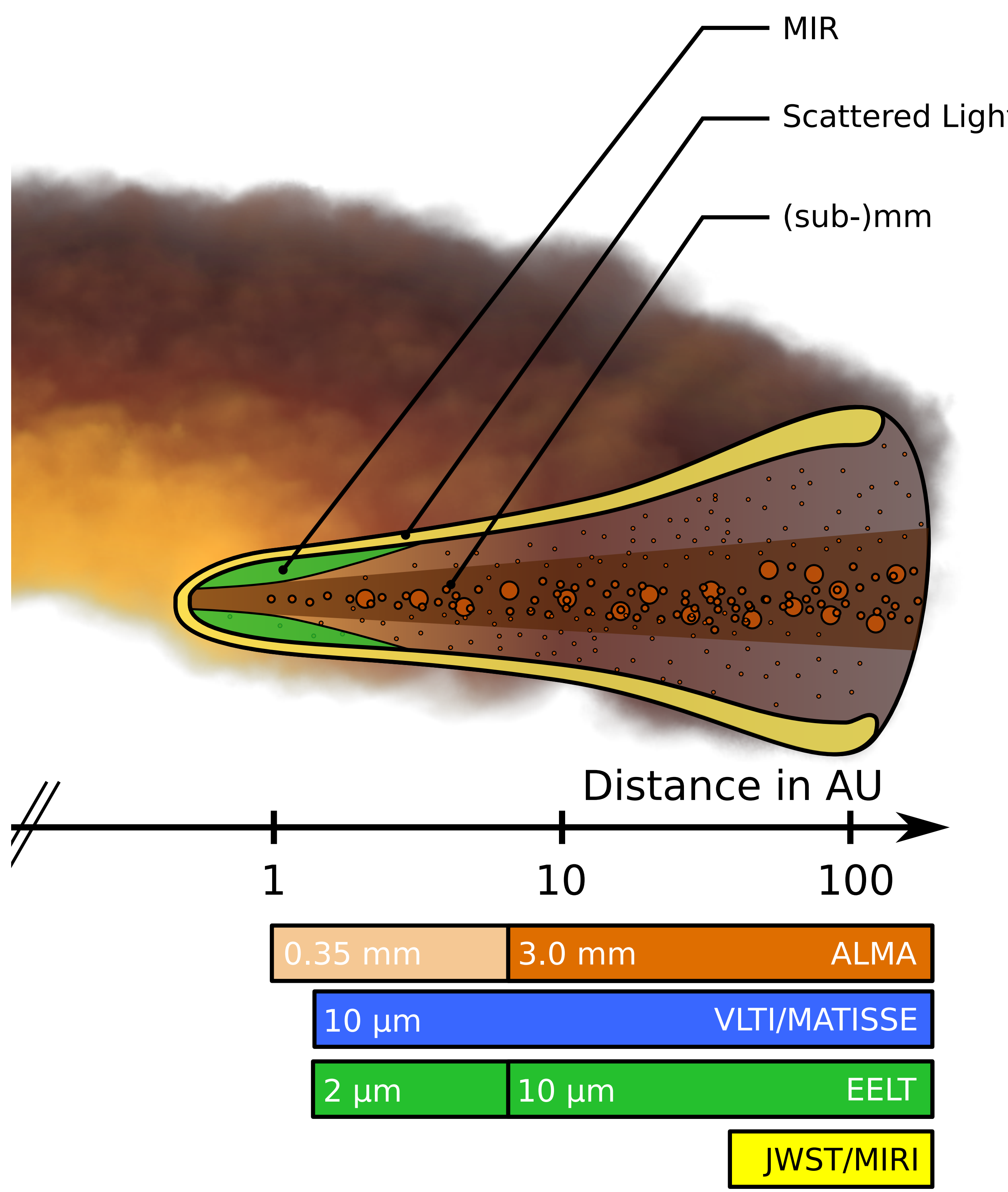
The maximum grain size is ~ 70 μm

What can we do at MIR?

SPICA / SAFARI_Pol Fact Sheet

A polarimetric camera with
3 simultaneous bands 100, 200 & 350 µm
on the same FOV : 2,6’ x 2,6’ @ 0,6 f#λ sampling

	100µm	200µm	350µm
Band edges	75—125µm	150—250µm	280—420µm
# of pixels	32 x 32 (x 2)	16 x 16 (x 2)	8 x 8 (x 2)
Pixel size	5" x 5"	10" x 10"	20" x 20"
Band centre beam FWHM	9"	18"	32"
PS sensitivity 5σ/1h/FOV (unpolarised)	21µJy	42µJy	85µJy
PS sensitivity in Stokes (Q,U) 5σ/1h/FOV (polarised)	30µJy	60µJy	120µJy
PS sensitivity 5σ/10h/1deg^2 (unpolarised)	0.16 mJy	0.32 mJy	0.65 mJy
PS sensitivity in Stokes (Q,U) 5σ/10h/1deg^2 (polarised)	0.23 mJy	0.46 mJy	0.92 mJy
Surface brightness sensitivity 5σ/10h/1deg^2 (unpolarised)	0.09 MJy/sr	0.045 MJy/sr	0.025 MJy/sr
Sensitivity to map Stokes parameters (Q,U) at 5% level 5σ/10h/1deg^2	2.5 MJy/sr	1.25 MJy/sr	0.7 MJy/sr



Current understandings

1μm 10μm 100μm 1mm

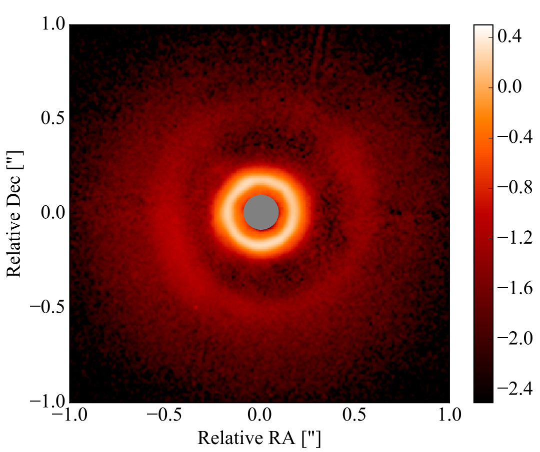
scattering of photons of central star

Alignment with B-field?

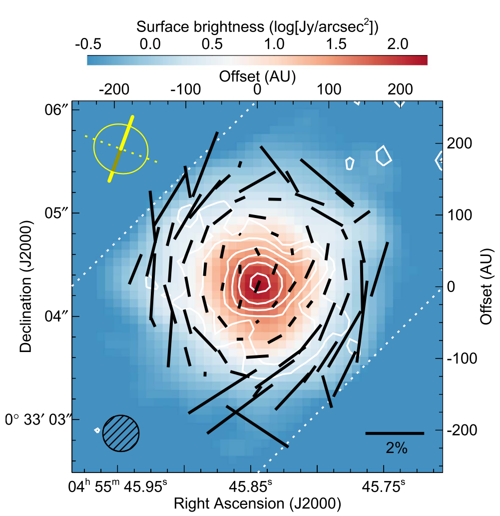
Alignment with rad-fields

scattering (?)

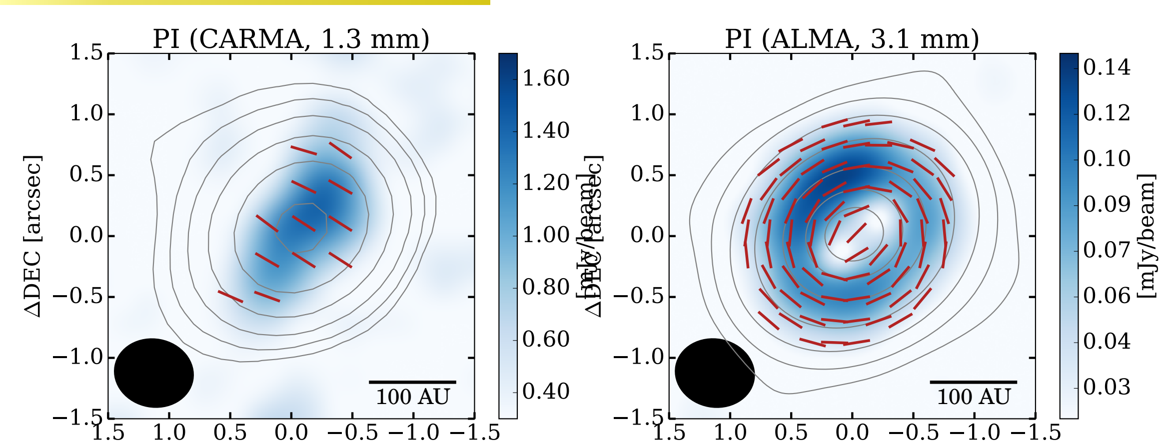
scattering



Pohl, et al., 2017

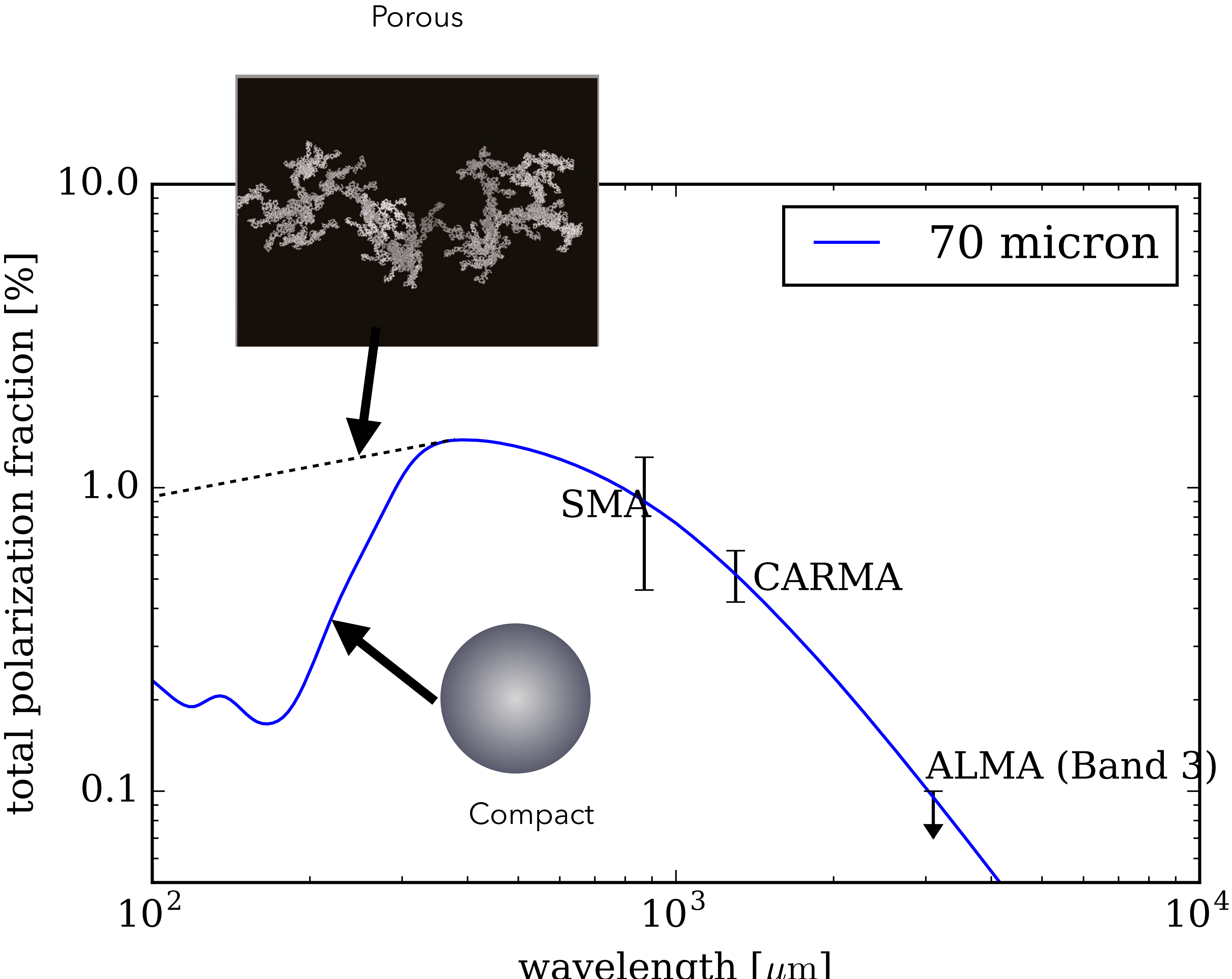


Li, et al., 2016

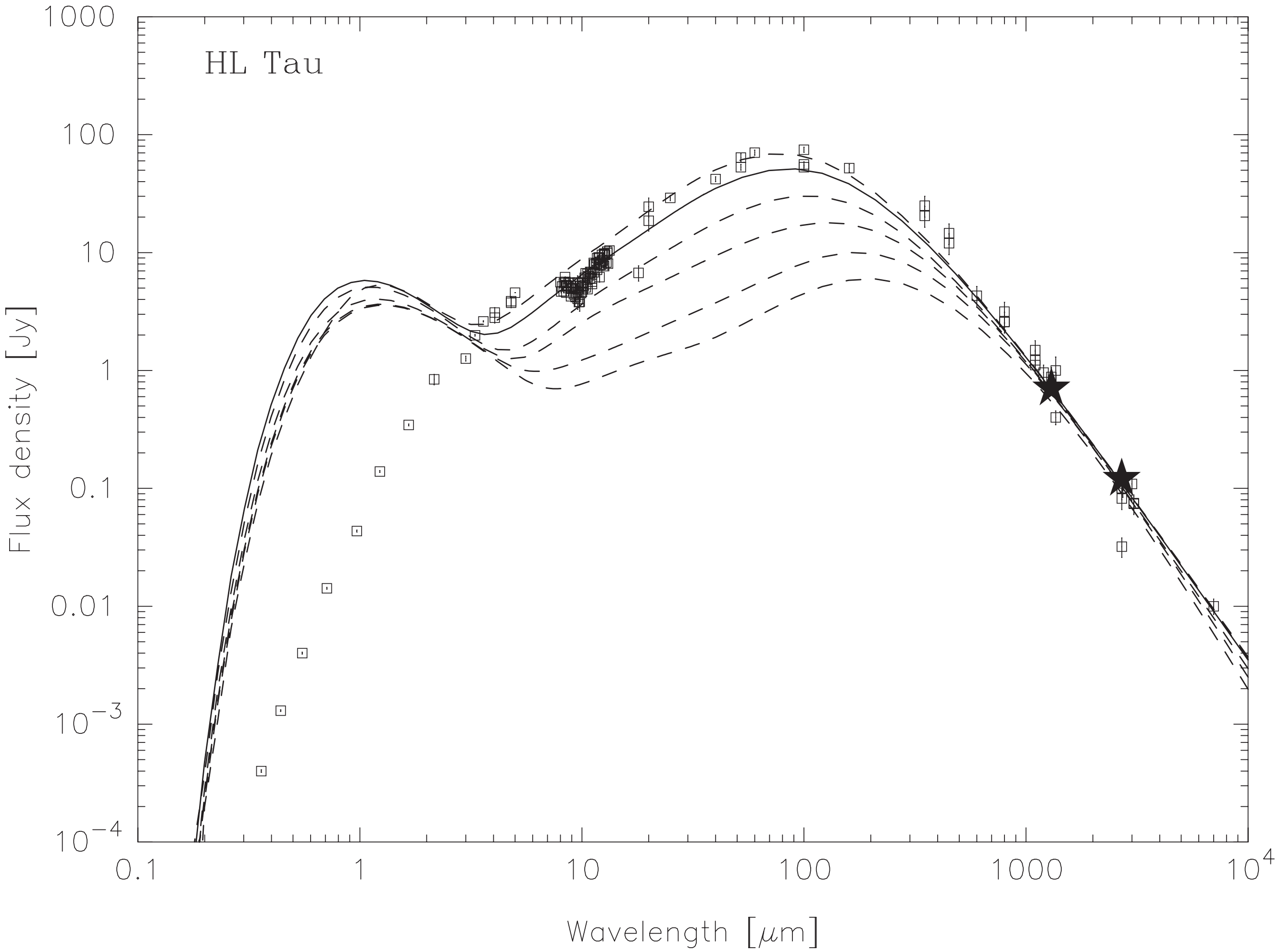


Kataoka, et al., 2017

Science: scattering is efficient at MIR?



Case study: HL Tau



~ 50 Jy at 100 micron

1% polarization:

→500 mJy

0.1% polarization

→50 mJy

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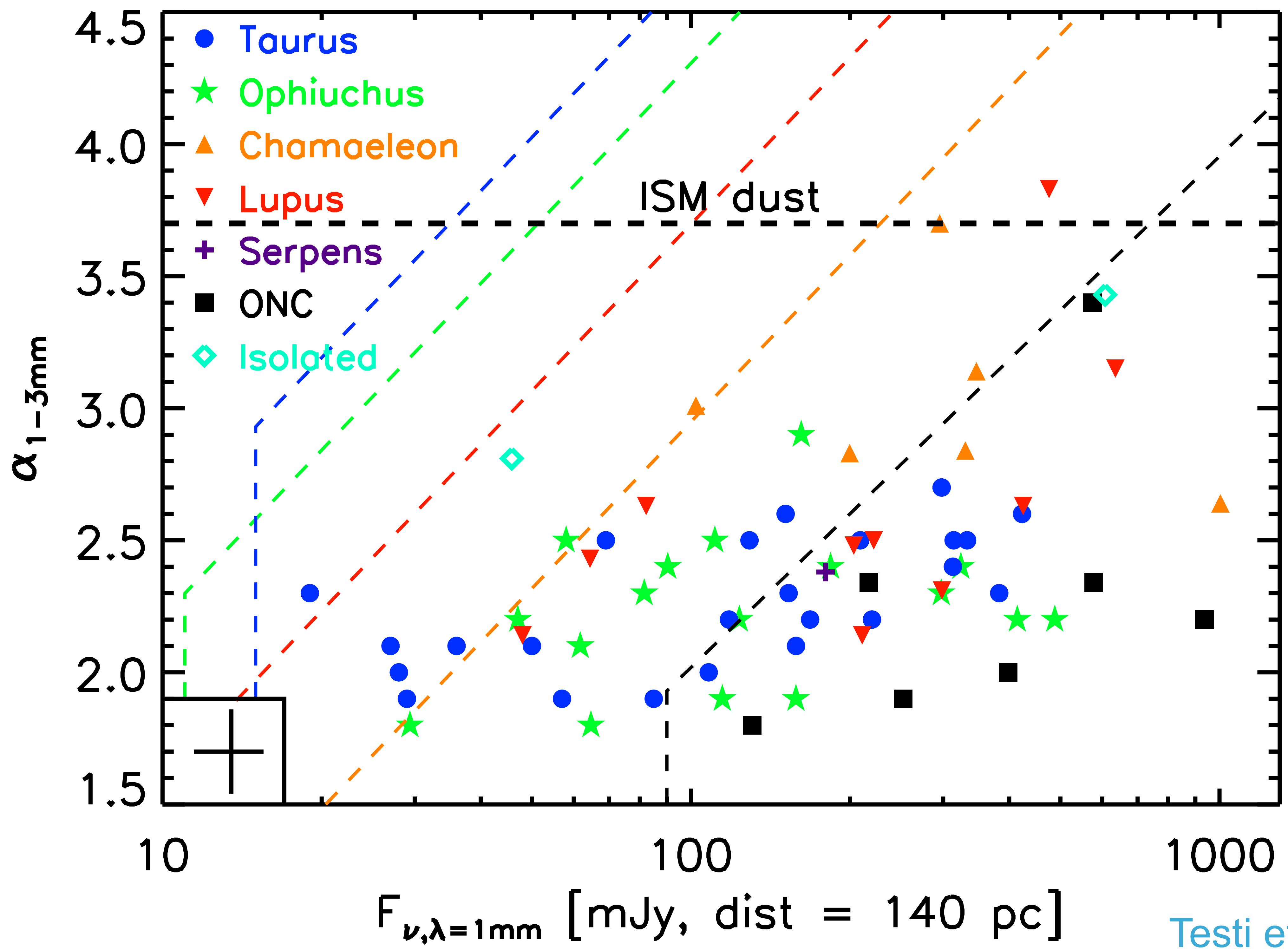
Conclusions

- We have observed **polarization of HL Tau** with ALMA
  - 3.1 mm polarization vectors are dominated by explained by the grain alignment, while 1.3 mm pol. vectors by the self-scattering.
  - The maximum grain size is constrained to be ~70 μm

(Kataoka et al. 2016a ApJ, Kataoka et al. 2017 ApJL)

- Possible science goals of MIR polarimetry of protoplanetary disks
  - HL Tau
    - Detection of MIR polarization of HL Tau -> porous dust aggregates
    - Non-detection of MIR polarization of HL Tau -> compact dust aggregates
  - Other disks
    - If scattering is observed, it would represents disks with small grains - may be young. This is complementary with ALMA observations.
    - If we can detect polarization due to alignment of grains with B-fields, this would be the unique way to study the magnetic fields in disks

Dust opacity of protoplanetary disks



Testi et al. 2014

Grain size is ~ millimeter (or larger)