

# Near-IR Polarimetry of Large Atmosphereless Bodies

## (1) Ceres & (4) Vesta

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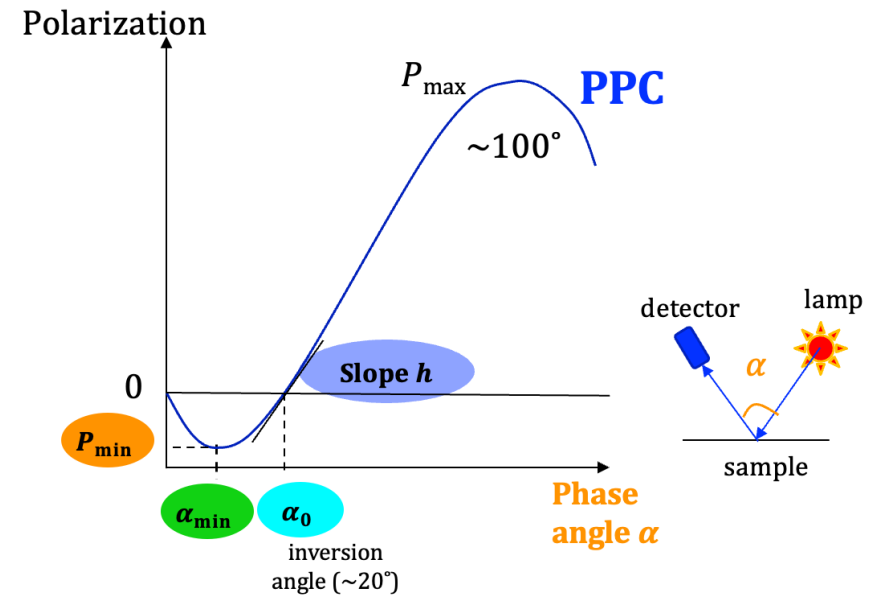
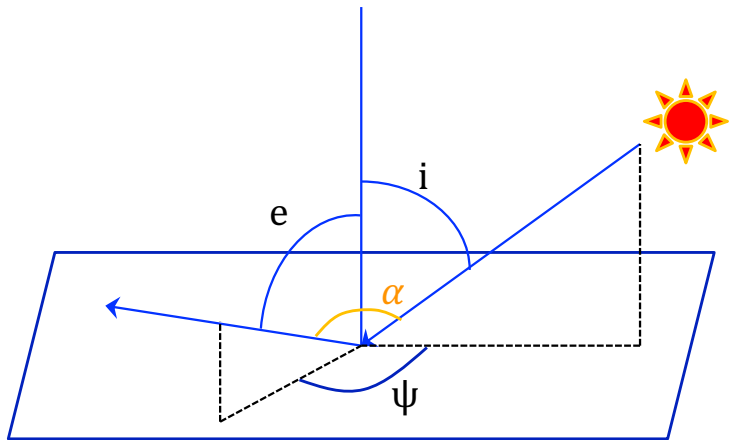
# Introduction - Asteroid polarimetry

- The “proper” polarization degree,  $P_r$ ,

$$P_r := \frac{I_{\perp} - I_{\parallel}}{I_{\perp} + I_{\parallel}}$$

$\parallel$  &  $\perp$ : parallel/perpendicular  
to the **scattering plane**  
cf. Rayleigh scattering:  $I_{\parallel} < I_{\perp}$

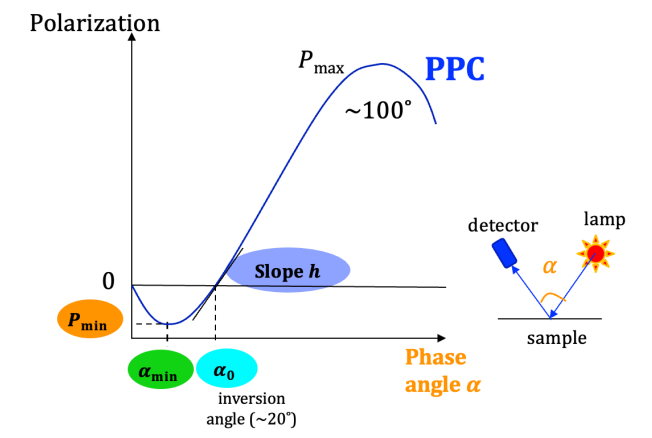
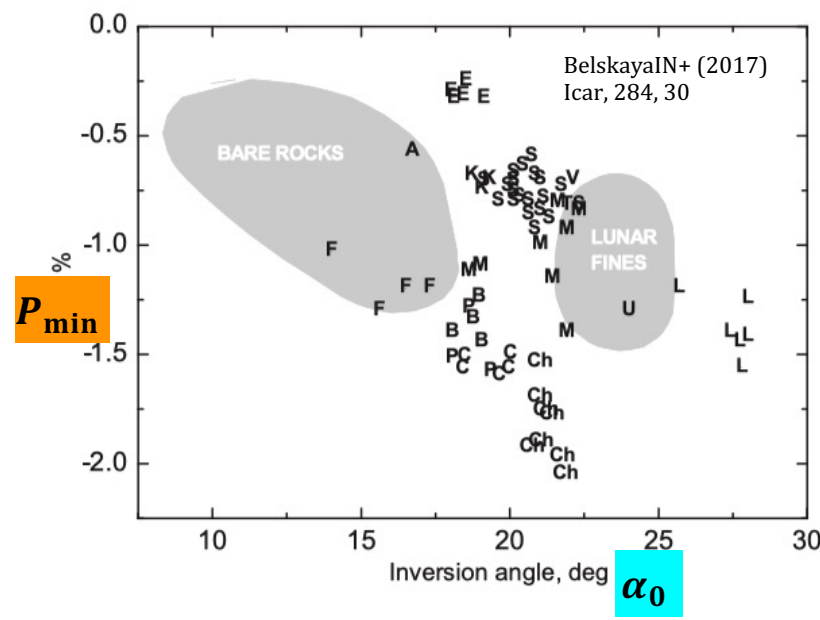
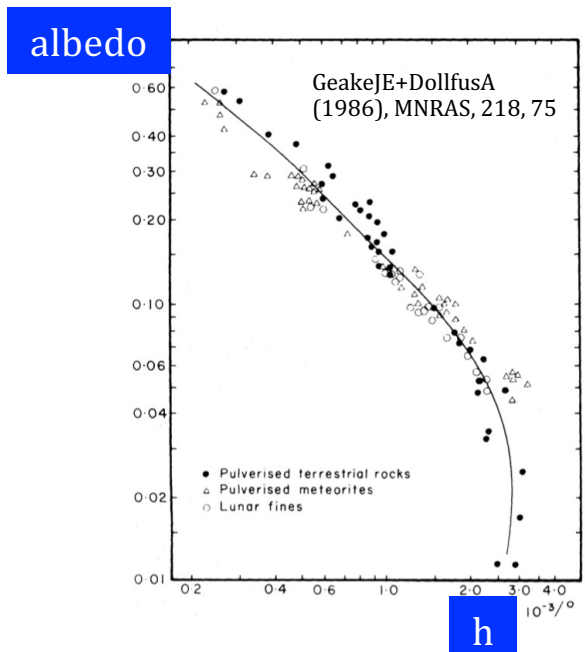
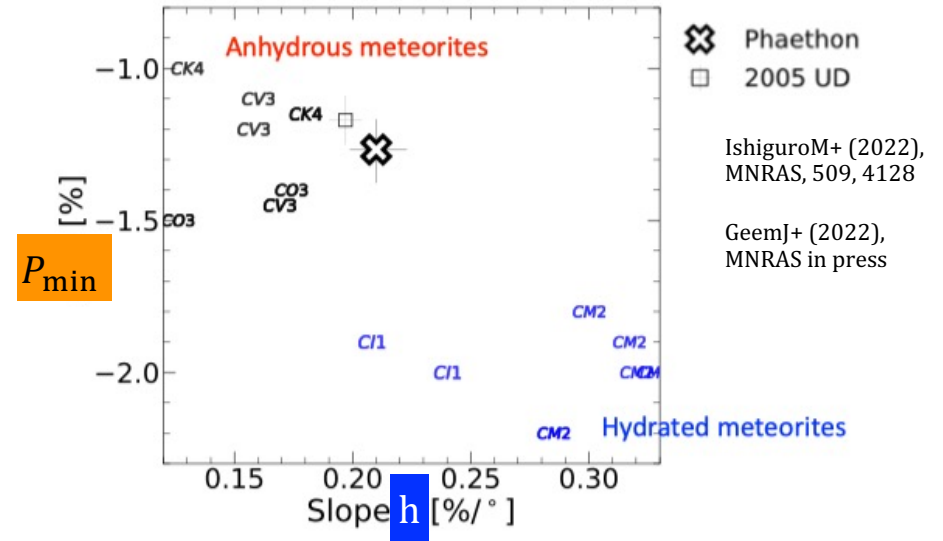
is known to be a function of phase angle ( $\alpha$ ) only (observation & Lab)



# Introduction

➤ These simple curve gives information on

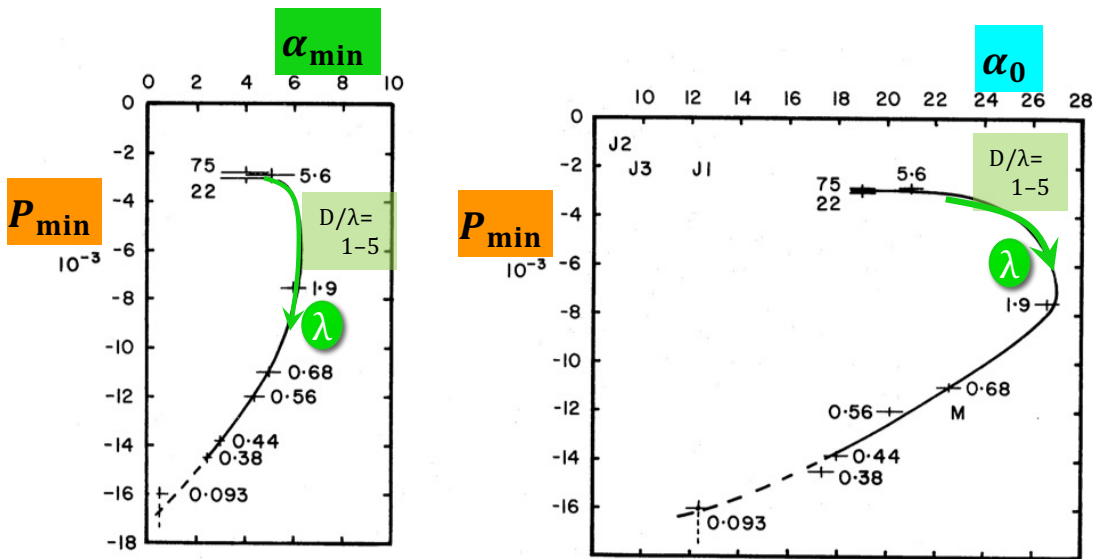
- albedo
- spectral type
- particle size
- hydrated minerals



# Introduction

- Among these, a *long-forgotten (?)* relation:
  - polarimetry as function of **size-parameter** ( $\frac{\pi D}{\lambda}$ )

numbers =  $D/\lambda$



GeakeJ+GeakeM (1990), MNRAS, 245, 46

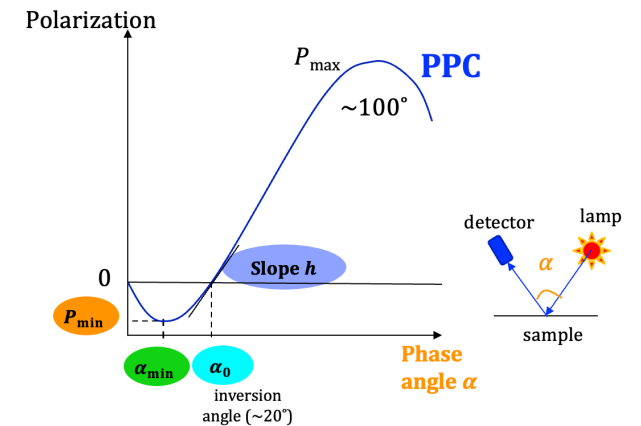
Particle size	V (0.55 μm)	I <sub>c</sub> (0.8 μm)	J (1.2 μm)	H (1.6 μm)	K <sub>s</sub> (2.2 μm)
20 μm	36	25	17	13	9
10 μm	18	13	8	6	5
5 μm	9	6	4	3	2

observation in this work

to small  $D/\lambda$

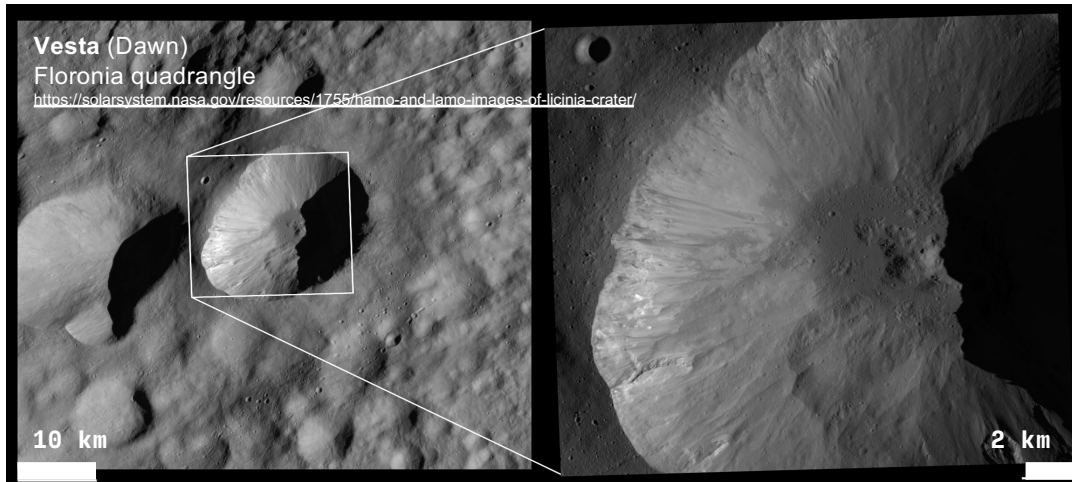
**Large asteroids are expected to be covered with fine particles ( $\lesssim 20 \mu\text{m}$  size) due to large gravity**

polarimetry [Le Berté T. & Zellner B. (1980), Icar., 43, 172]  
 and spectroscopy [Hiroi, T., Pieters, C. M., Takeda, H. (1994), Metic., 29, 394; Li, J.-Y. et al. (2011), Icar, 216, 640.; Martikainen, J. et al. (2019), MNRAS, 483, 1952.]

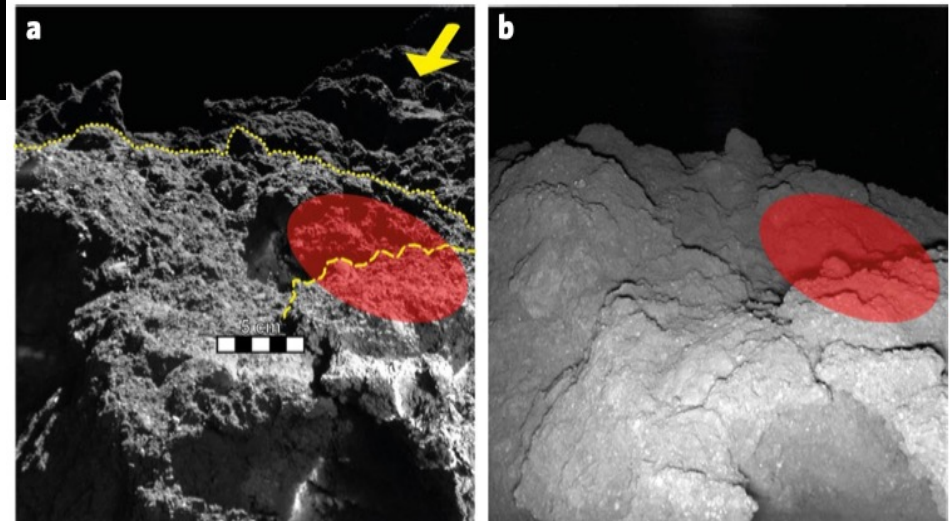


# Introduction

- ▶ Particle size measurement is very important yet difficult...



GrottM+ (2019) NatAs 3 971.



# Observation

- NHAO NIC, polarimetric-mode
- J/H/Ks simultaneous polarimetry
- (1) **Ceres**: 5 obs.
  - 2020-06-21, 2020-10-02, 2020-10-18, 2021-09-09, 2021-11-07
- (4) **Vesta**: 6 obs.
  - 2019-10-22, 2019-11-08, 2019-11-21, 2019-12-18, 2020-01-10, 2020-02-13

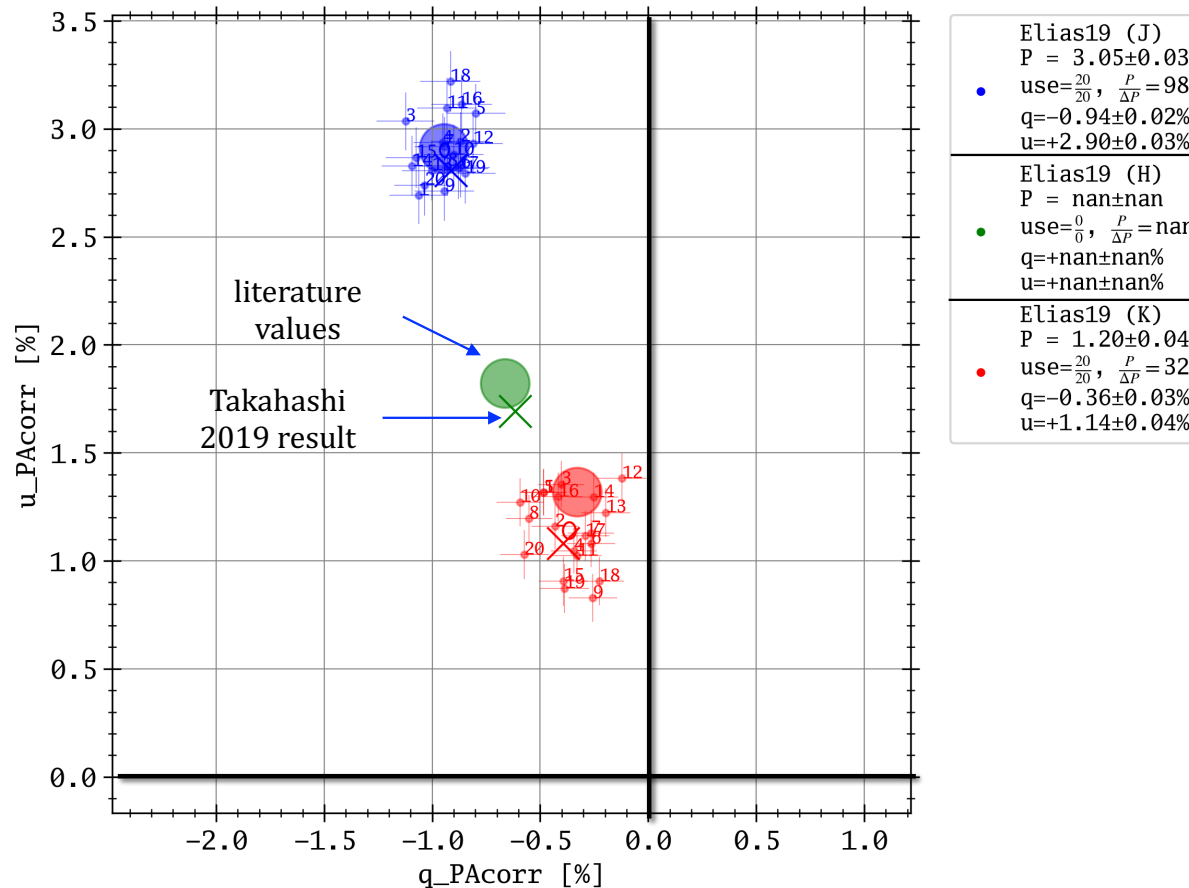


**World-~~First~~Second\*** Near-IR polarimetry  
of asteroid using NHAO NIC.  
Found regolith particle size using NIR polarimetry:

\* among peer-reviewed publications  
MasieroJ+ (2022), PSJ, 3, 90

IshiguroM+2011, ARNHAO, 21, 13  
TakahashiJ+2018, SAG, 1,17  
TakahashiJ+2019, SAG, 2(3)

# A Justification of Our Data Reduction



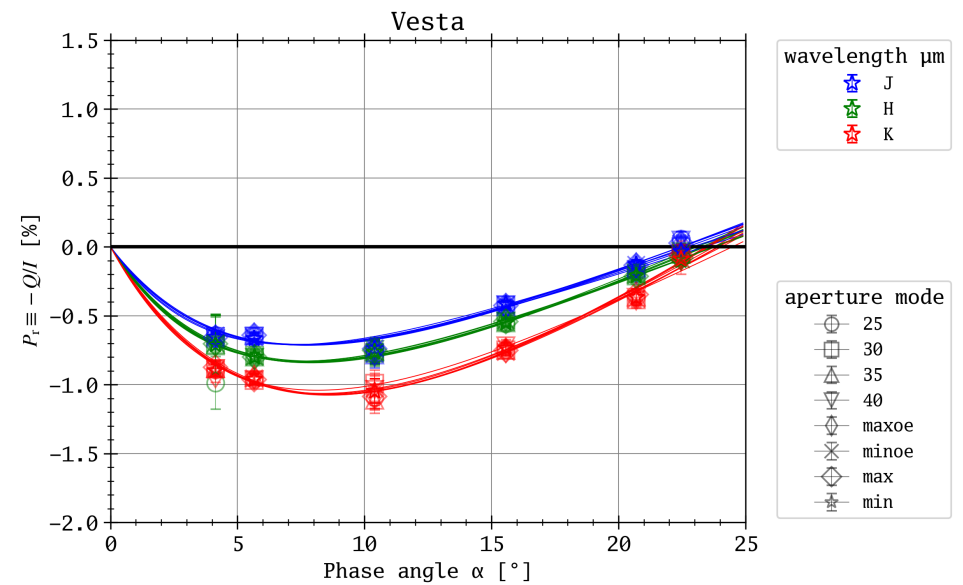
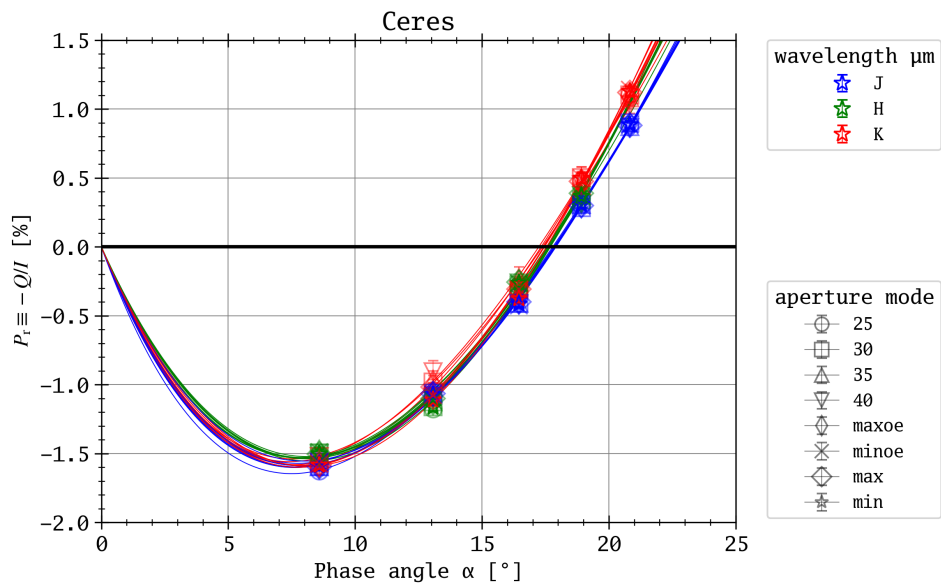
Strongly polarized standard star

H-data are all excluded as we put more stringent condition for "saturation" (if 5+ pixels are saturated, whole set is discarded)



# Results

- "*aperture mode*" means different photometric algorithms.
  - Note how consistent they are, *regardless of the algorithms*.



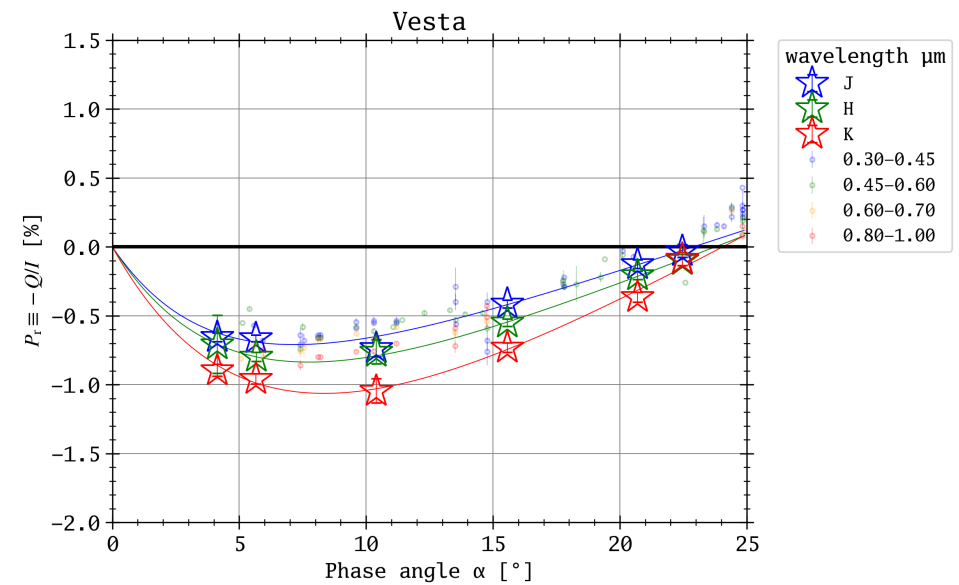
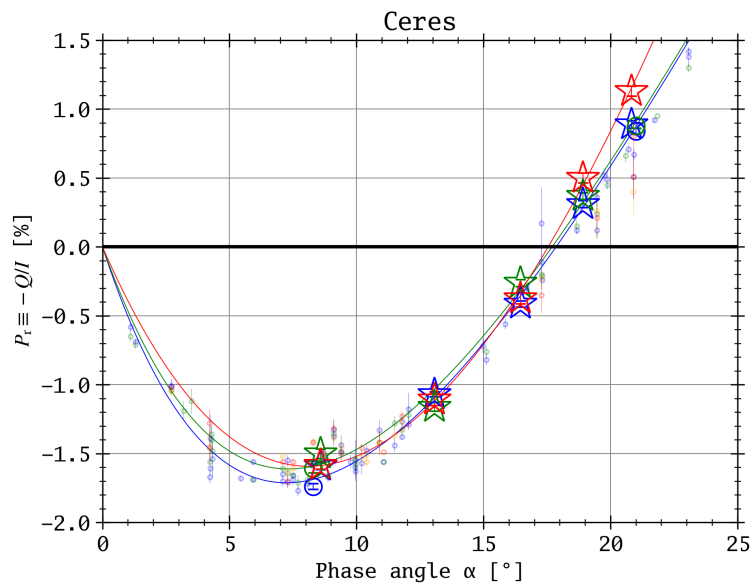
# Results

➤ **Ceres:** Two data (both at J/H) from another study coincides well

- max difference  $\sim 0.1\%$

MasieroJ+ (2022), PSJ, 3, 90

➤ **Vesta:** THE first result

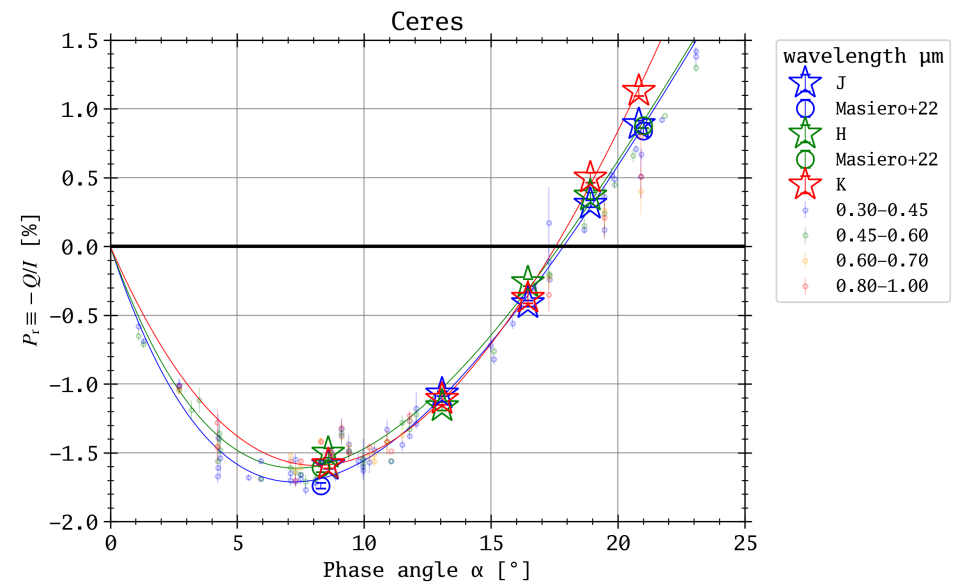
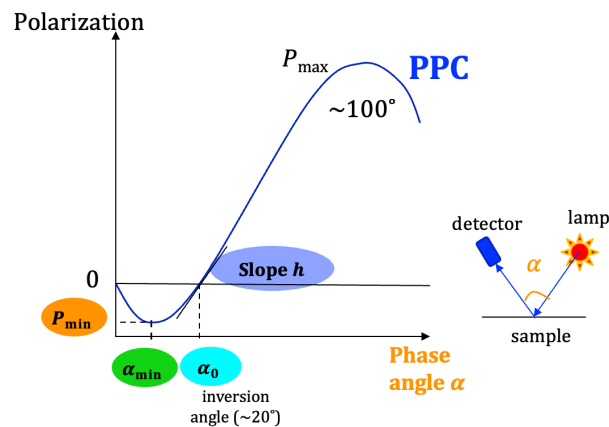


# Results - Ceres

➤ Phase curve at NIR  $\approx$  optical data

➤ parameters

- $h$  : slightly increases at longest  $\lambda$ ? (0.263  $\rightarrow$  0.258  $\rightarrow$  0.312 [%/°])
- $\alpha_0$  : virtually no change (17.9  $\rightarrow$  17.7  $\rightarrow$  17.5 °)
- $P_{\min}$  : virtually no change (-1.7  $\rightarrow$  -1.6  $\rightarrow$  -1.6 %)
- $\alpha_{\min}$  : virtually no change? (7.2  $\rightarrow$  7.3  $\rightarrow$  8.1 °)



# Results - Ceres

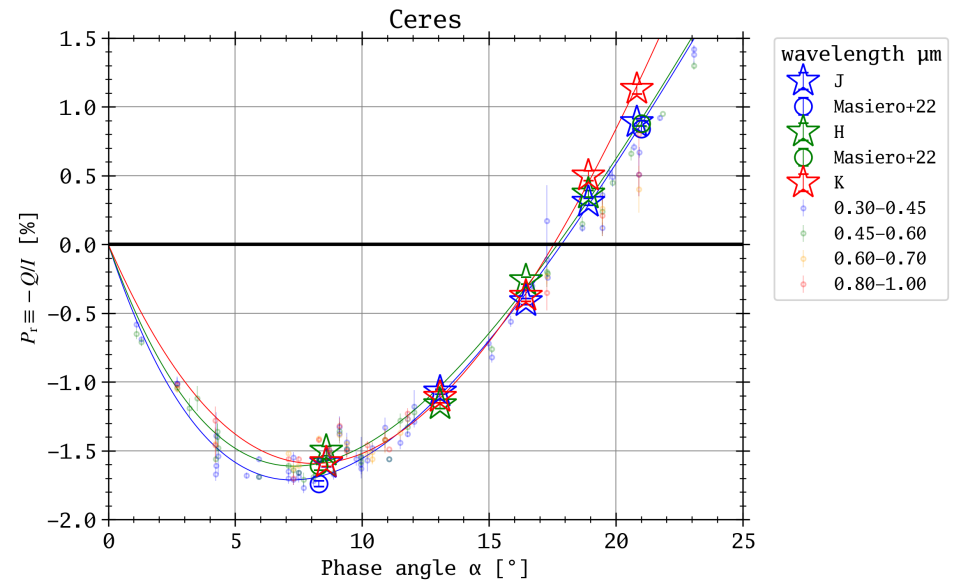
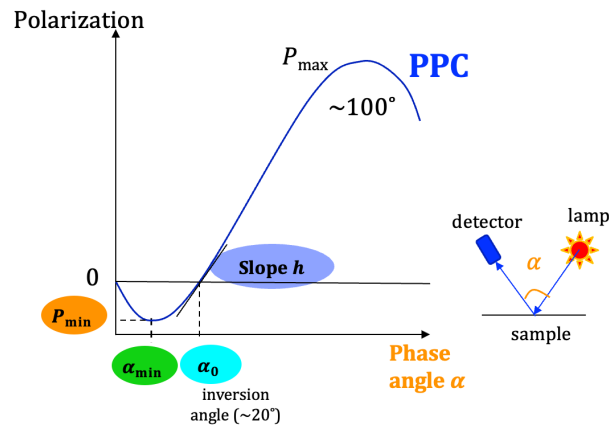
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➤ Consistent with previous work

Masiero+ (2022), PSJ, 3, 90.



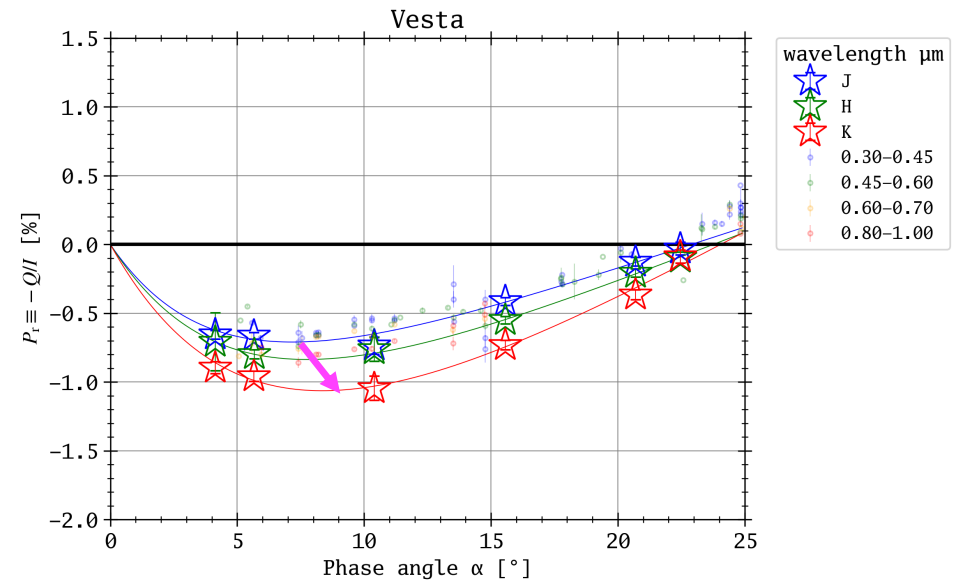
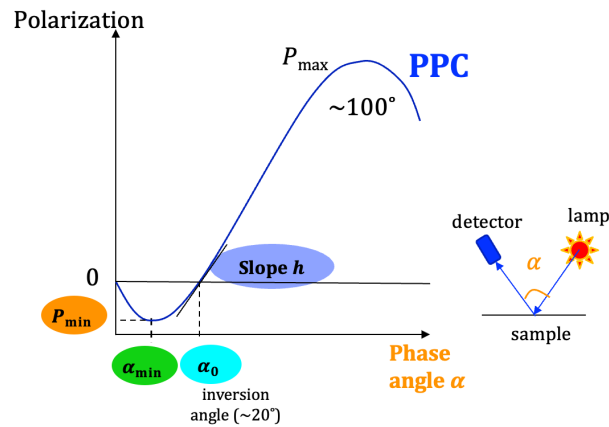
# Results - Vesta

➤ Phase curve at NIR  $\neq$  optical data

➤ parameters

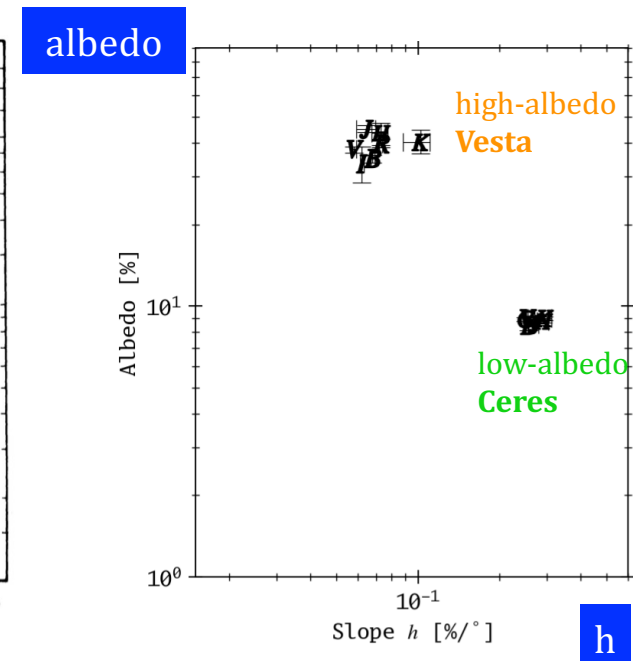
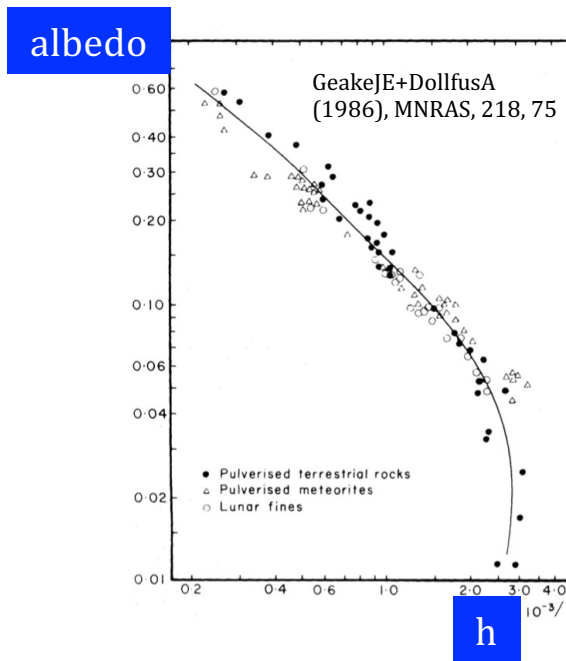
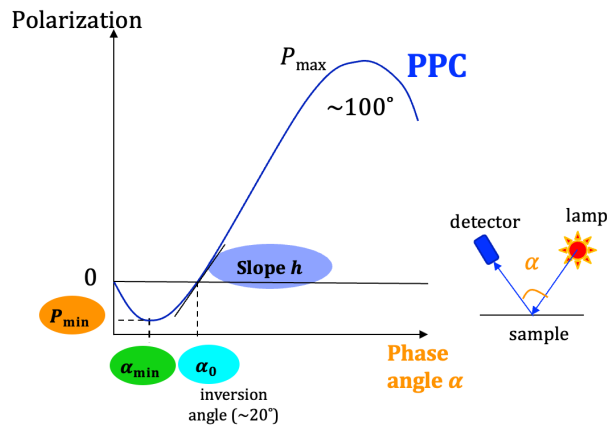
- $h$  : **increases** as wavelength (0.060  $\rightarrow$  0.071  $\rightarrow$  0.096 [%/°])
- $\alpha_0$  : **increases** as wavelength (22.9  $\rightarrow$  23.8  $\rightarrow$  24.1 °)
- $P_{\min}$  : **deepens** as wavelength (-0.7  $\rightarrow$  -0.8  $\rightarrow$  -1.1 %)
- $\alpha_{\min}$  : **increases** as wavelength (7.2  $\rightarrow$  7.7  $\rightarrow$  8.3 °)

➤ First data



# Discussion

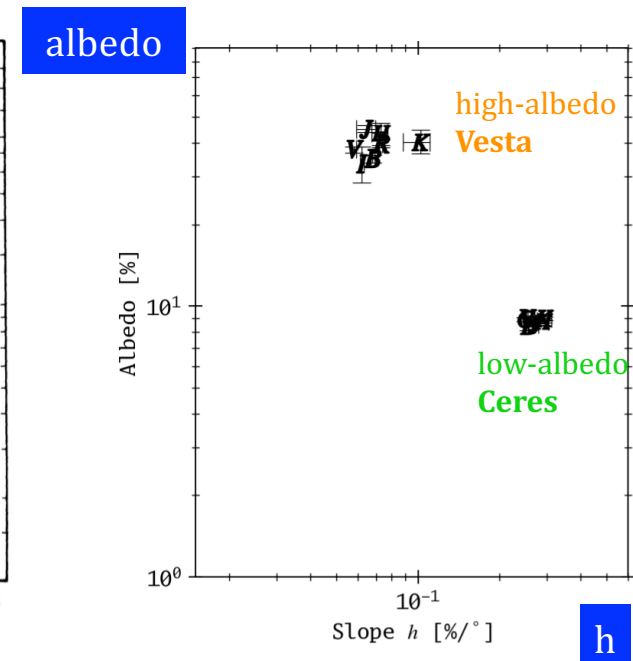
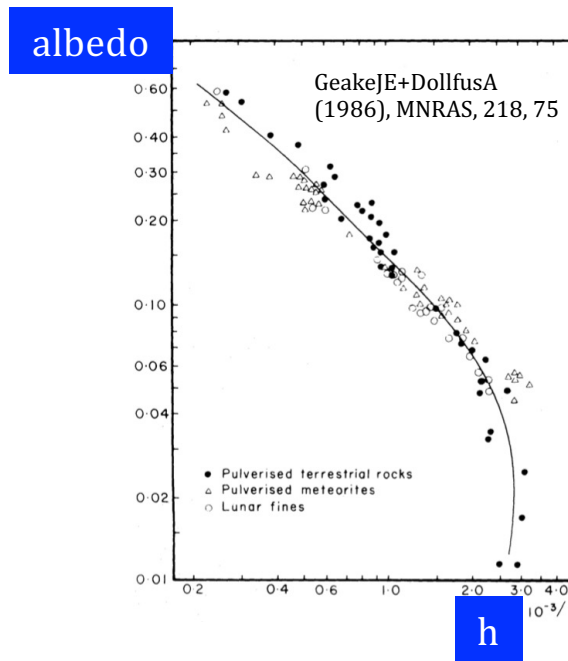
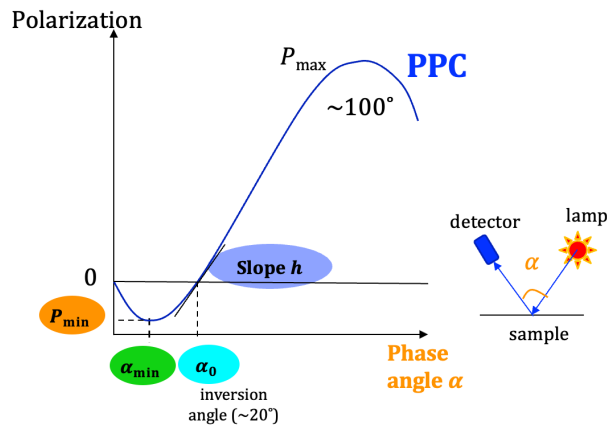
➤ Expected results are seen for slope  $h$



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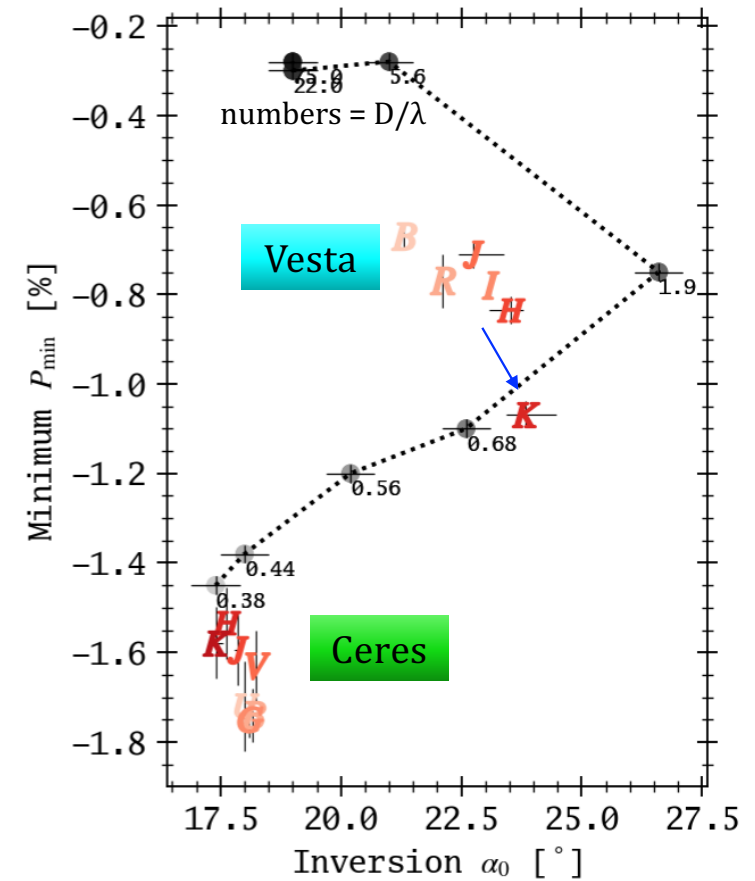
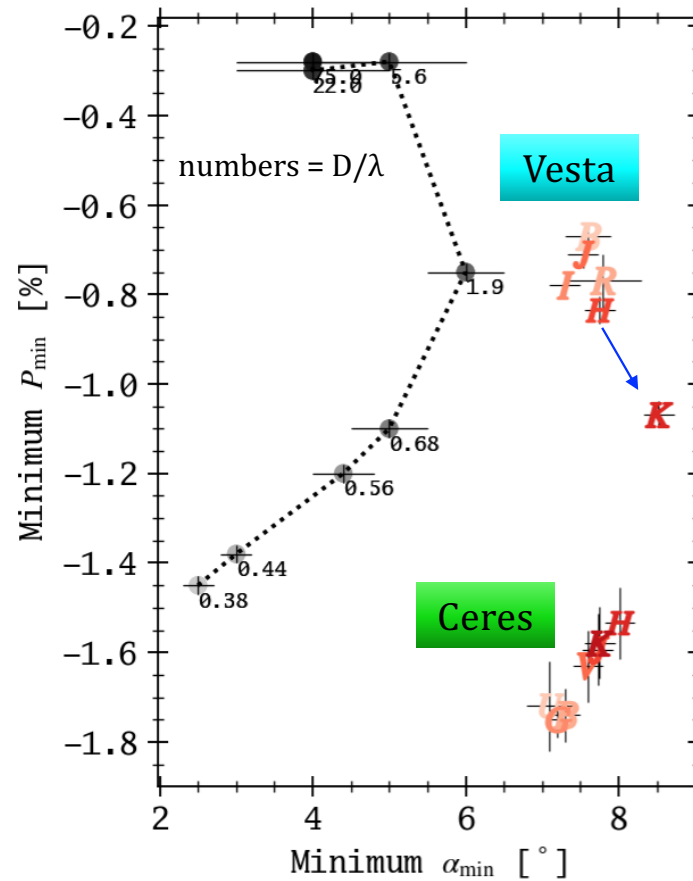
➤ Expected results are seen for slope  $h$

slope-albedo law holds in Near-IR too!



# Discussion

- New findings
  - Location for two are different may be because of compositional difference (V-type VS C-type).





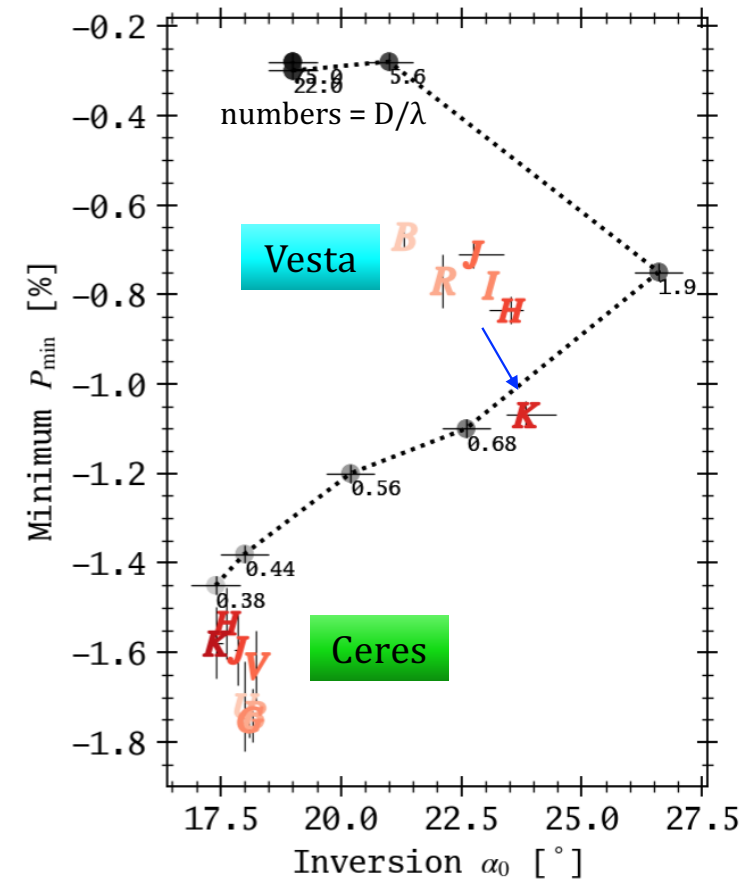
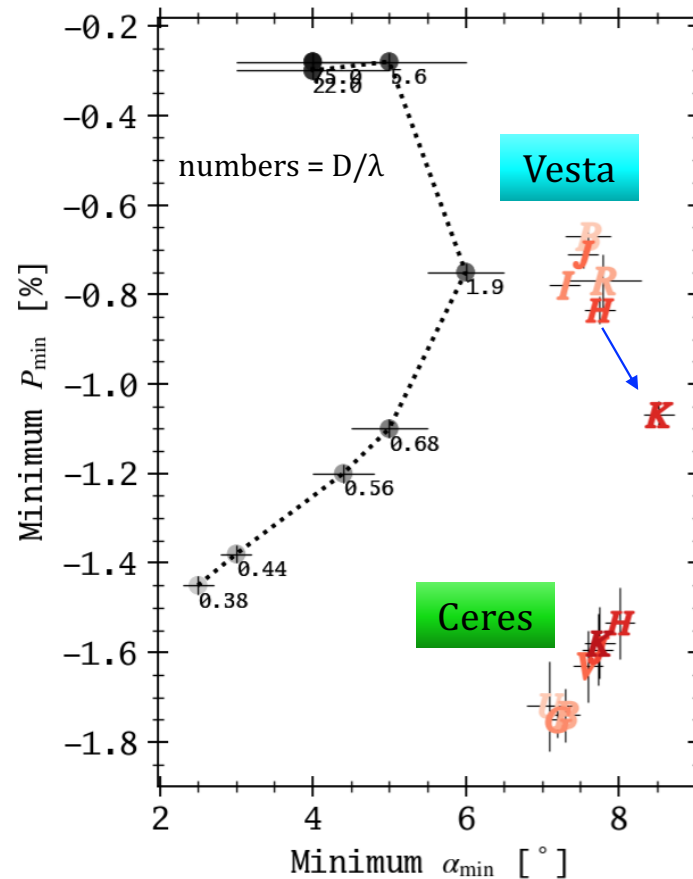
# Discussion

## ➤ New findings

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### ◦ Ceres:

- No change.
- Likely  $D/\lambda \gg 5$  for all  $\lambda$
- ( $D \gg 5 \lambda_K \sim 10 \mu\text{m}$ )
- or already  $D \ll 5 \lambda_U \sim 1.5 \mu\text{m}$ .



# Discussion

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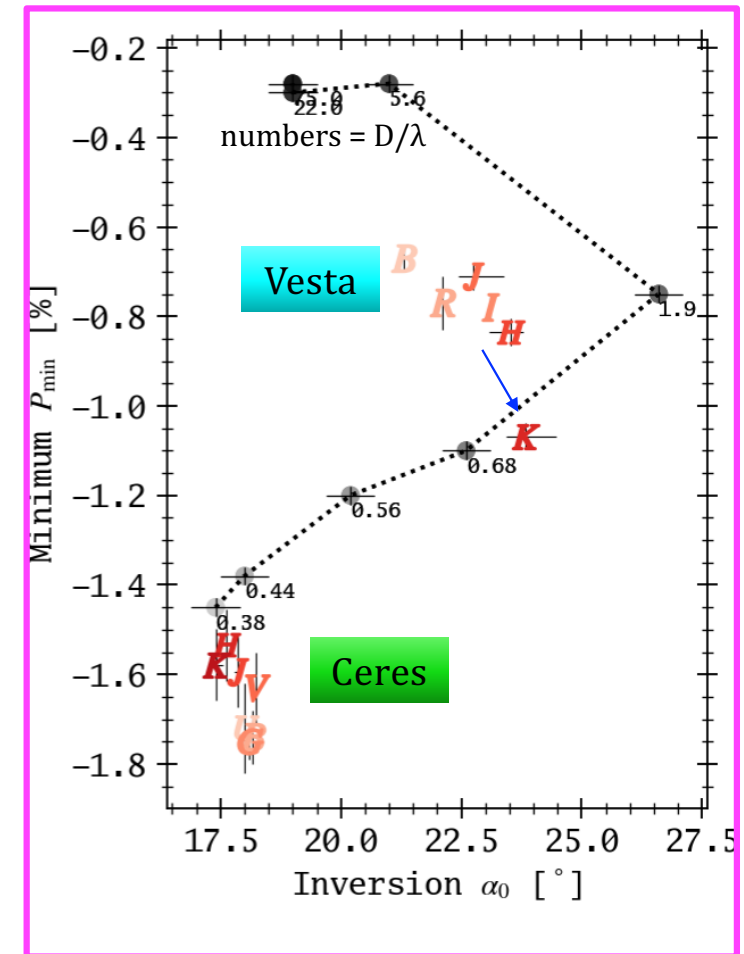
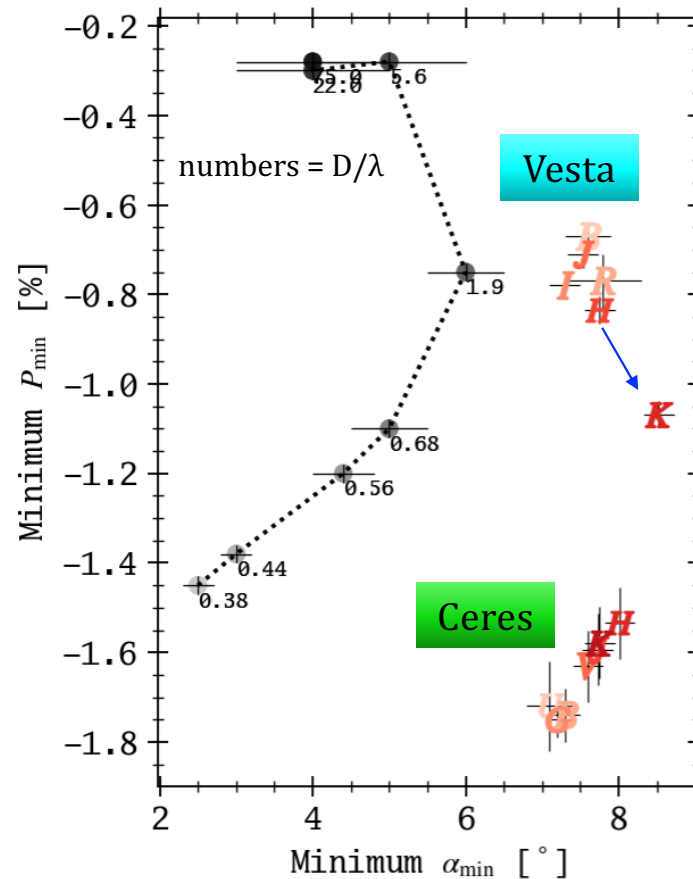
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- $D \sim 10 \mu\text{m}??$



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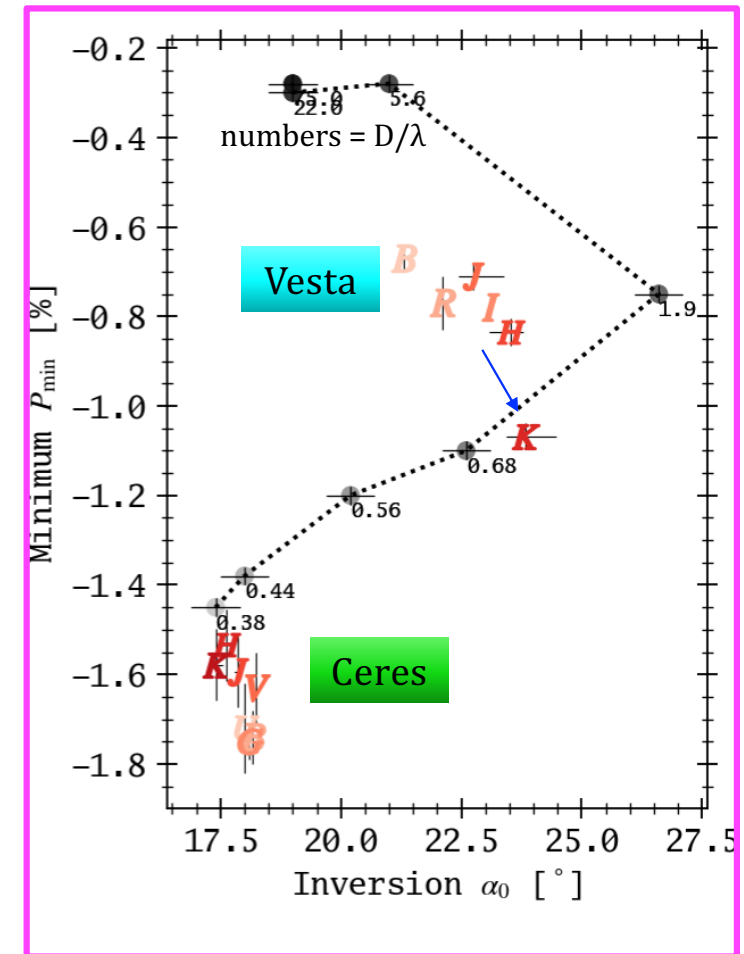
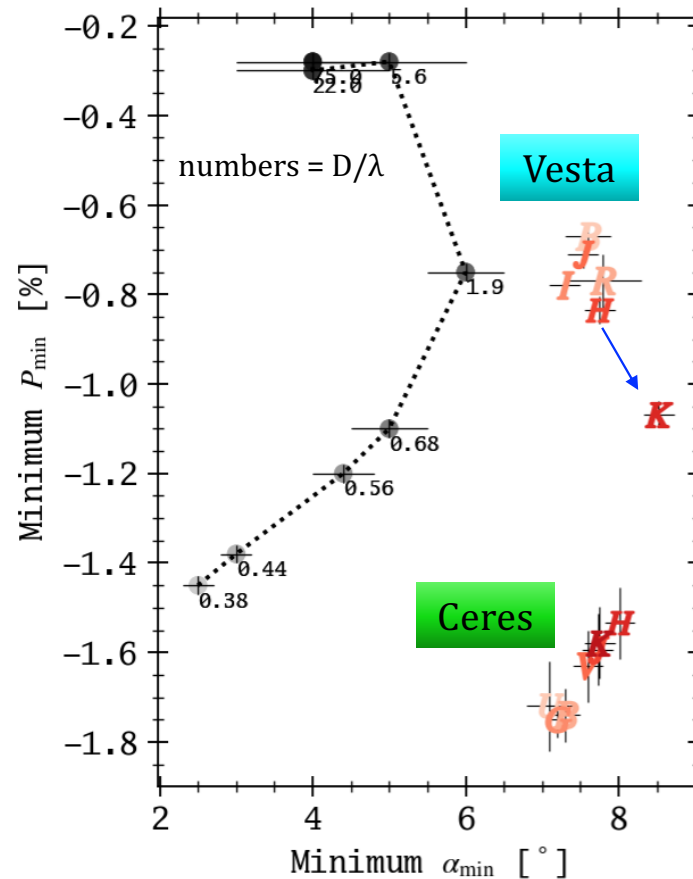
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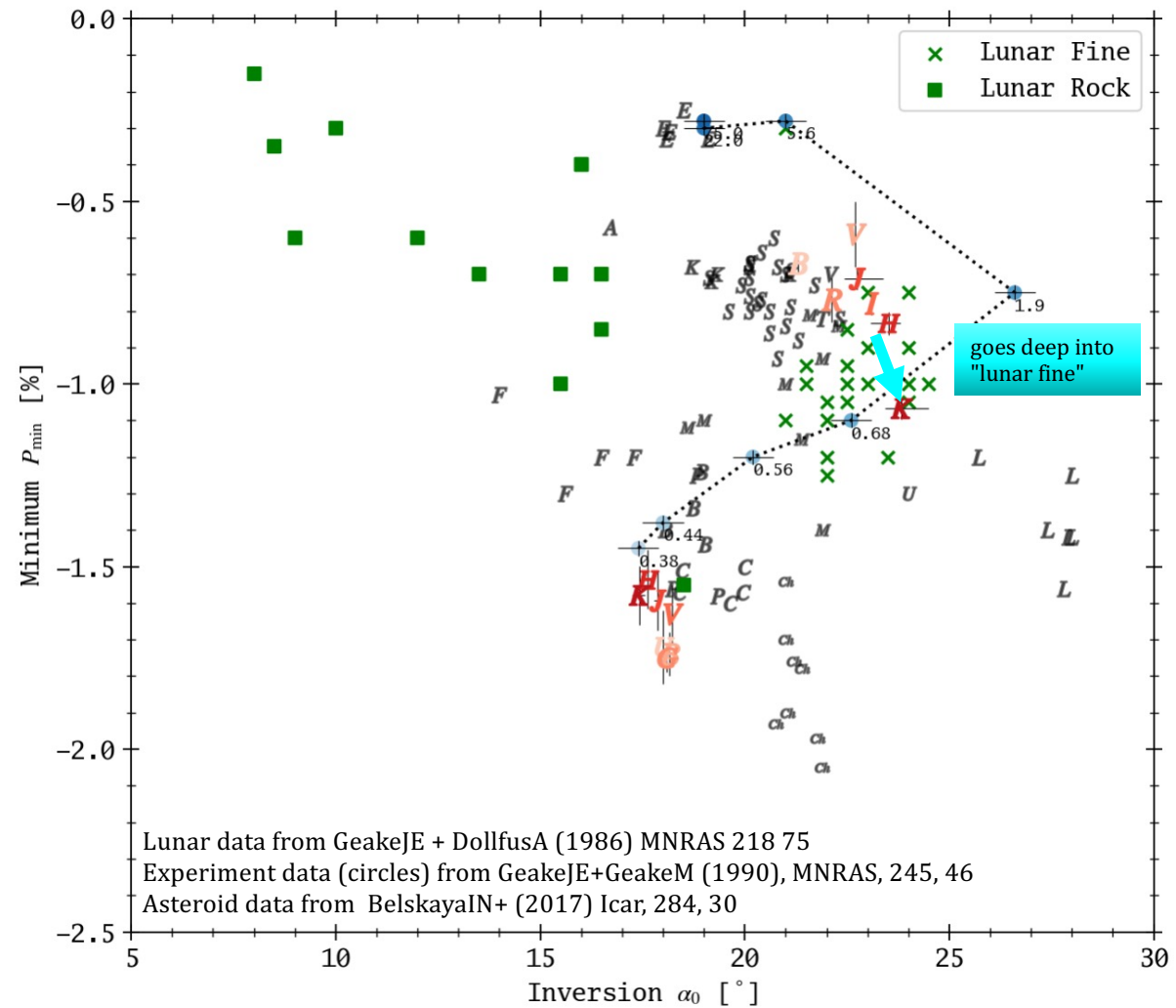
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# Conclusion

- Nearly world-first NIR polarimetry of asteroids
- The **first** observation to see the polarimetric behavior at small  $D/\lambda$  in **Vesta**.
  - Vesta:  $D \sim 10 \mu\text{m}$ ?
  - Ceres: inconclusive
  - **Strong point**: This is not a lower/upper bound, but quite an exact value.
- Further investigation needed:
  - Is the lab experiment applicable to real asteroids?