Quantitative Grain Size Estimation on Airless Bodies from the Negative Polarization Branch:

The Case of Dawn Mission Targets, (4) Vesta and (1) Ceres using NHAO NIC

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Jooyeon Geem[2,3], Daisuke Kuroda[5], Hiroyuki Naito[6], Jungmi Kwon[7]

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Bach et al. (2022), StGal, 5, 4
Bach et al. (2024a), A&A, 684, 80
Bach et al. (2024b), A&A, 684, 81

Nayuta UM, 2024-07-31

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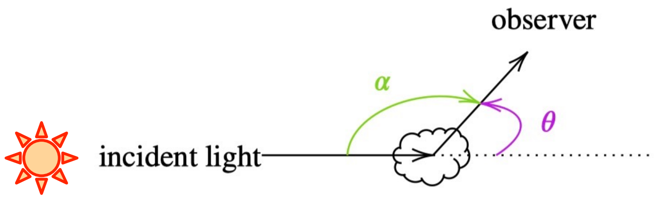
- Target selection
- Observations & Data reduction (Paper 0: Bach+22, StGal, 5, 4)
- Results (Paper II: Bach+24b, A&A, 684, 81)
- Discussions & Future work

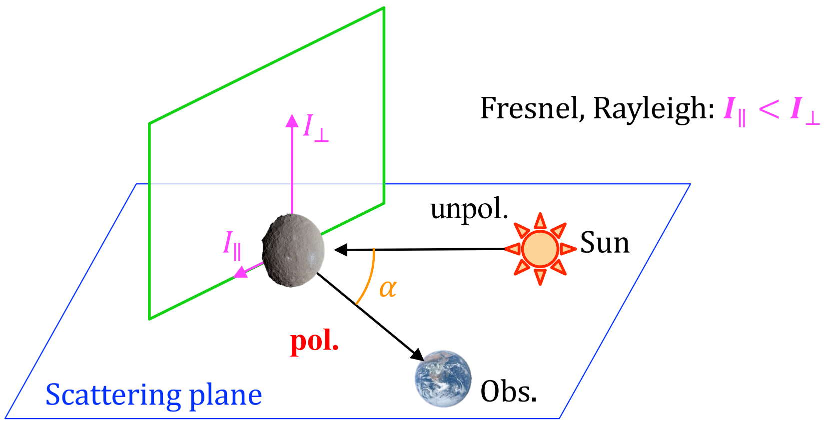
Bach et al. (20**22**), StGal, 5, 4
Bach et al. (20**24a**), A&A, 684, 80
Bach et al. (20**24b**), A&A, 684, 81

Intro: Polarimetry in Solar System

- Polarimetric <u>phase</u> curve (PPC)
  - Pol. as phase angle $P_r = P_r(\alpha)[\%]$
  - Phase angle α = 180° − scat. ang.



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



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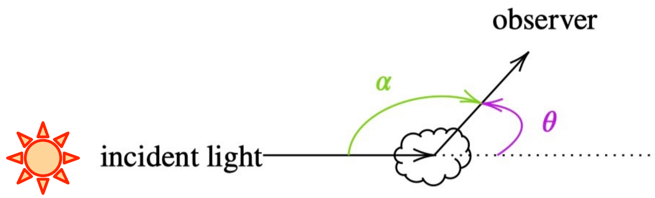
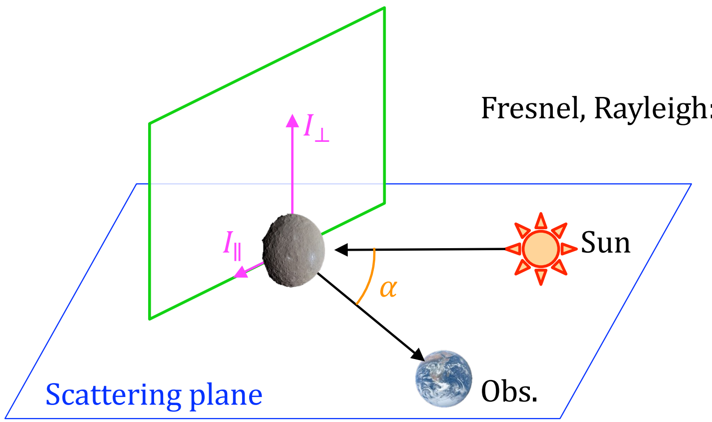
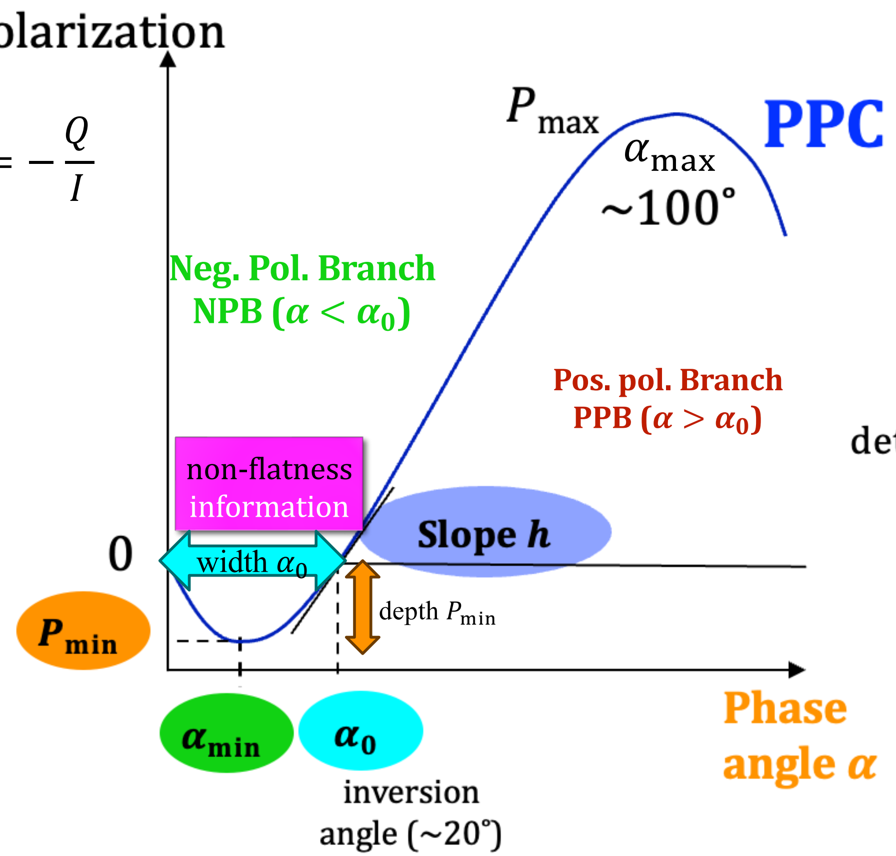
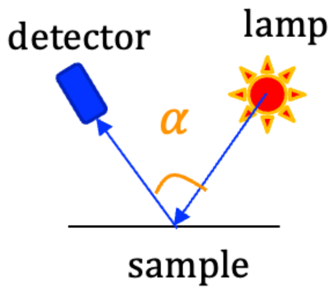


$$P_r = \frac{I_\perp - I_\parallel}{I_\perp + I_\parallel} = -\frac{Q}{I}$$

Fresnel, Rayleigh: $I_\parallel < I_\perp$

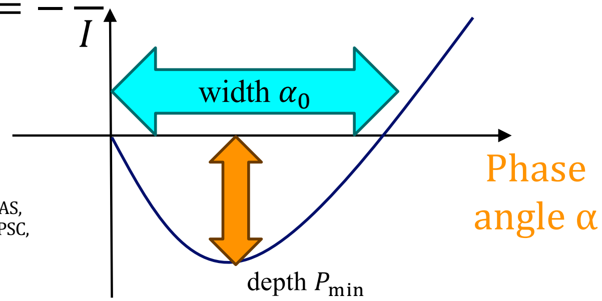






Motivation

$$P_{\mathrm{r}} = \frac{I_\perp - I_\parallel}{I_\perp + I_\parallel} = -\frac{Q}{I}$$

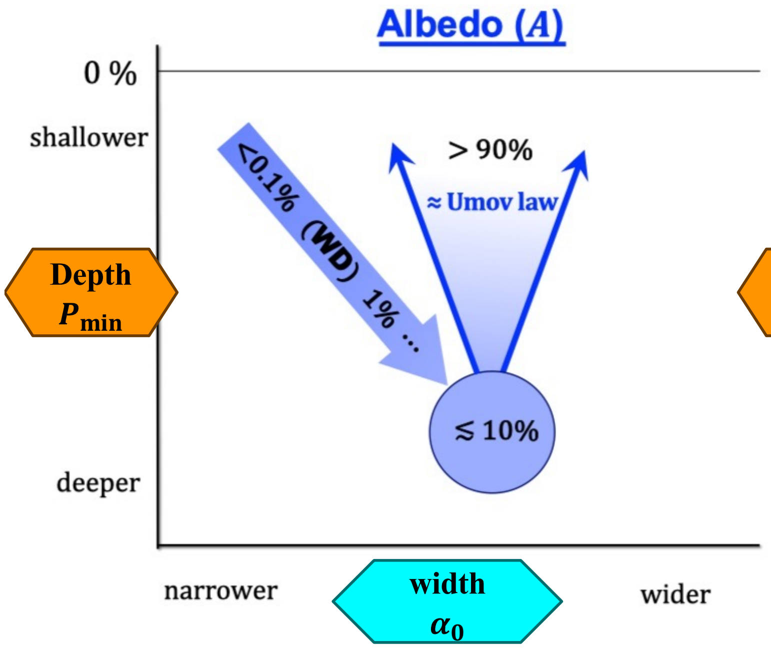


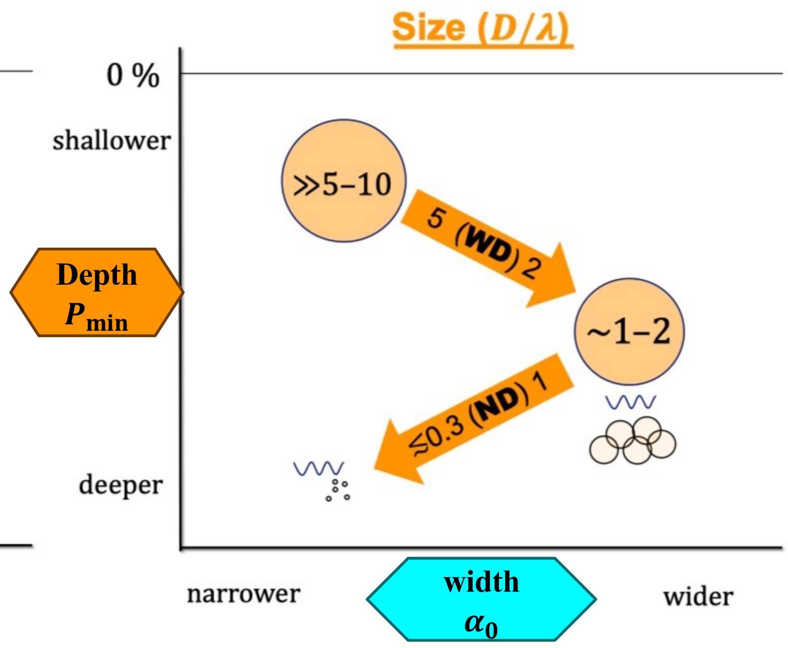
- We found two observables are important (Bach+24, A&A, 684, 80; Paper I):
  - Albedo
    - The **Umov law**
  - Size parameter (D/λ)

Umow 1905, Physikalische Zeitschrift, 6 (20), 674;
CellinoA+ 15, MNRAS, 451, 3473;
LupishkoD 18, SoSyR, 52, 98

Lyot 29, Dollfus 55, Gehrels+64 AJ, Clark 65 MNRAS, Kenknight+67 AJ, Geake+70 GeCAS, Dollfus 71 PSMP, Dollfus+71a A&A, Dollfus+71b A&A, Dollfus_71c LPSC, Dollfus+75 LPSC, Zellner+77a&b LPSC, Dollfus+77 RSTPA, Dollfus+79 Asteroids, Le Bertre+80 Icar, Geake+86 MNRAS, Lupishko+89 Icar, Dollfus+89 Asteroids II, Geake+90 MNRAS, Shkuratov+92 Icar, Shkuratov+ 94 E&MP, Volten+01 JGR, Shkuratov+02 Icar, Shkuratov+04 JQSRT, Shkuratov+06 JQSRT, Belskaya+05 Icar, Hapke 12 Book, Dabrowska+15 Icar, Nelson+18 Icar, Escobar-Cerezo+18 ApJS, Munoz+21 ApJS, Frattin+22 MNRAS, Spadaccia+22 A&A, Hadamcik+23 MNRAS, Sultana+23 Icar

And many (20+) more studies that we investigated but not directly used





Bach+24, A&A, 684, 80; Paper I

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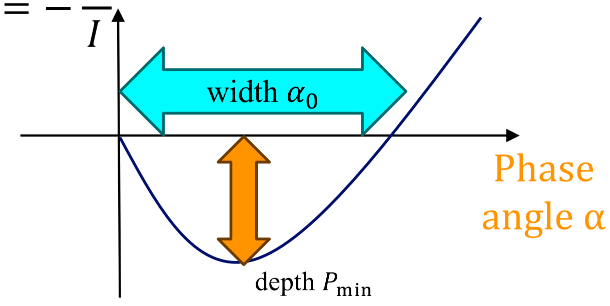

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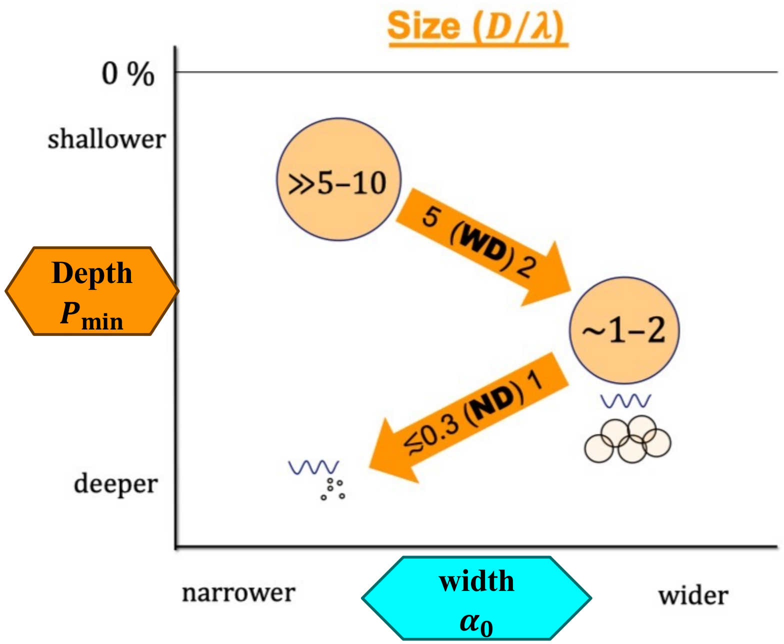

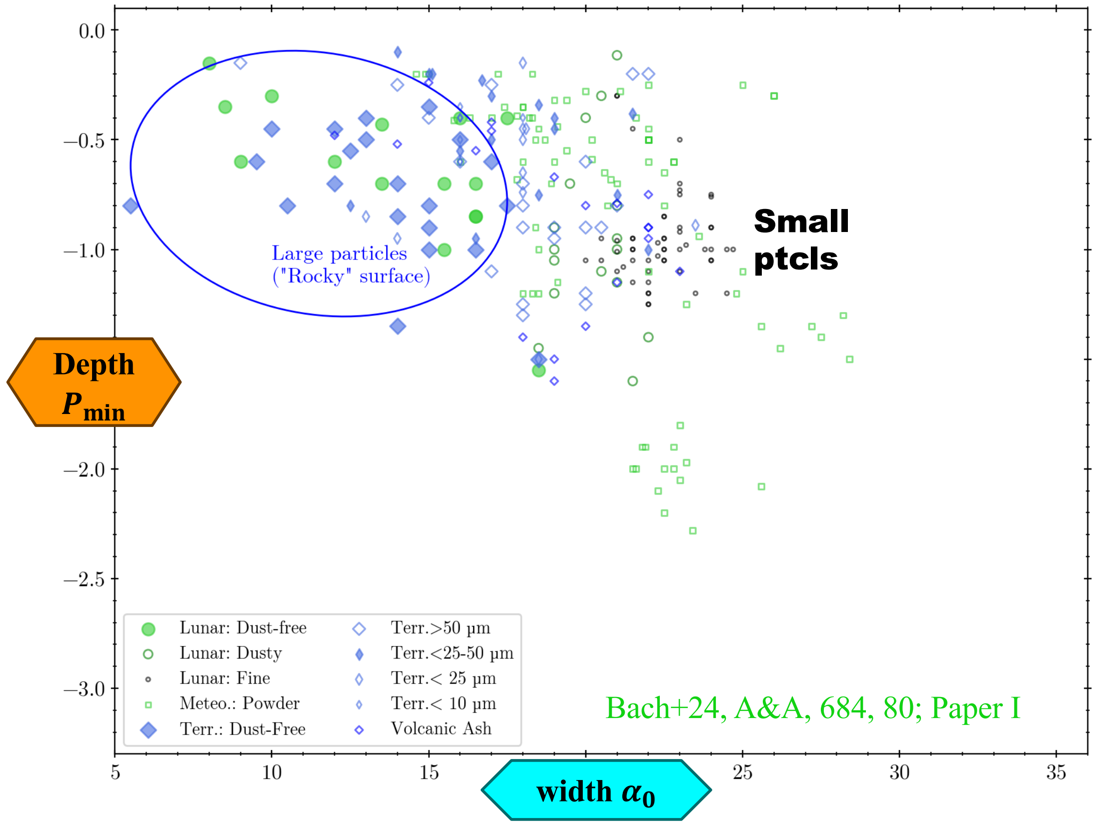

Motivation

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  - Albedo
    - The **Umov law**
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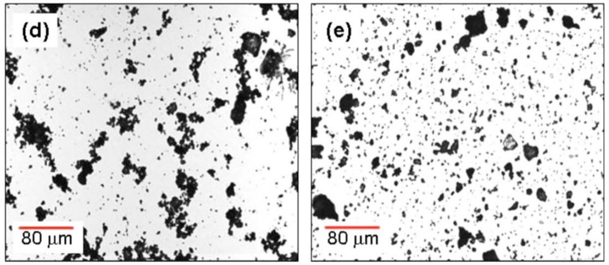
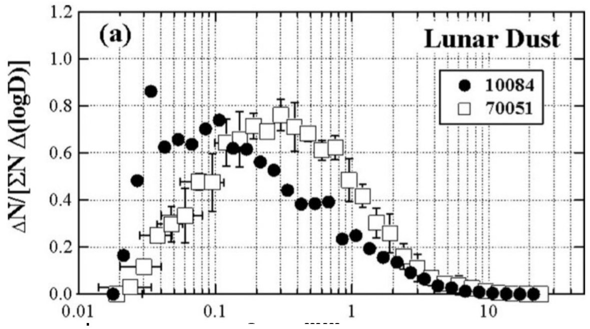
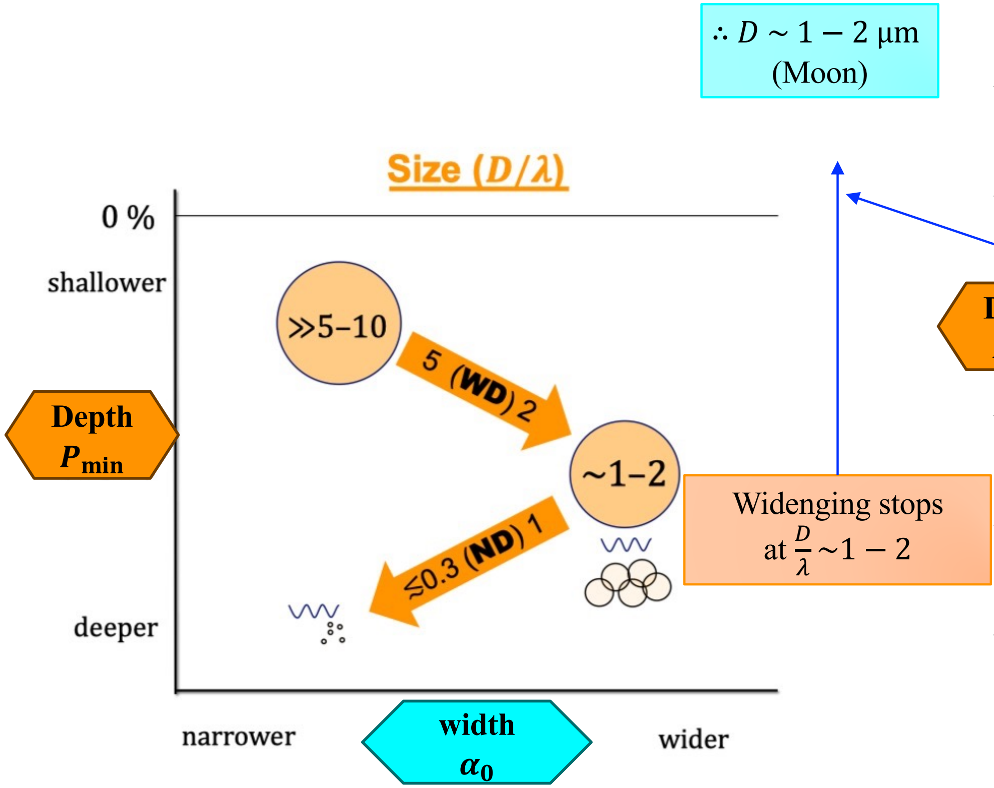
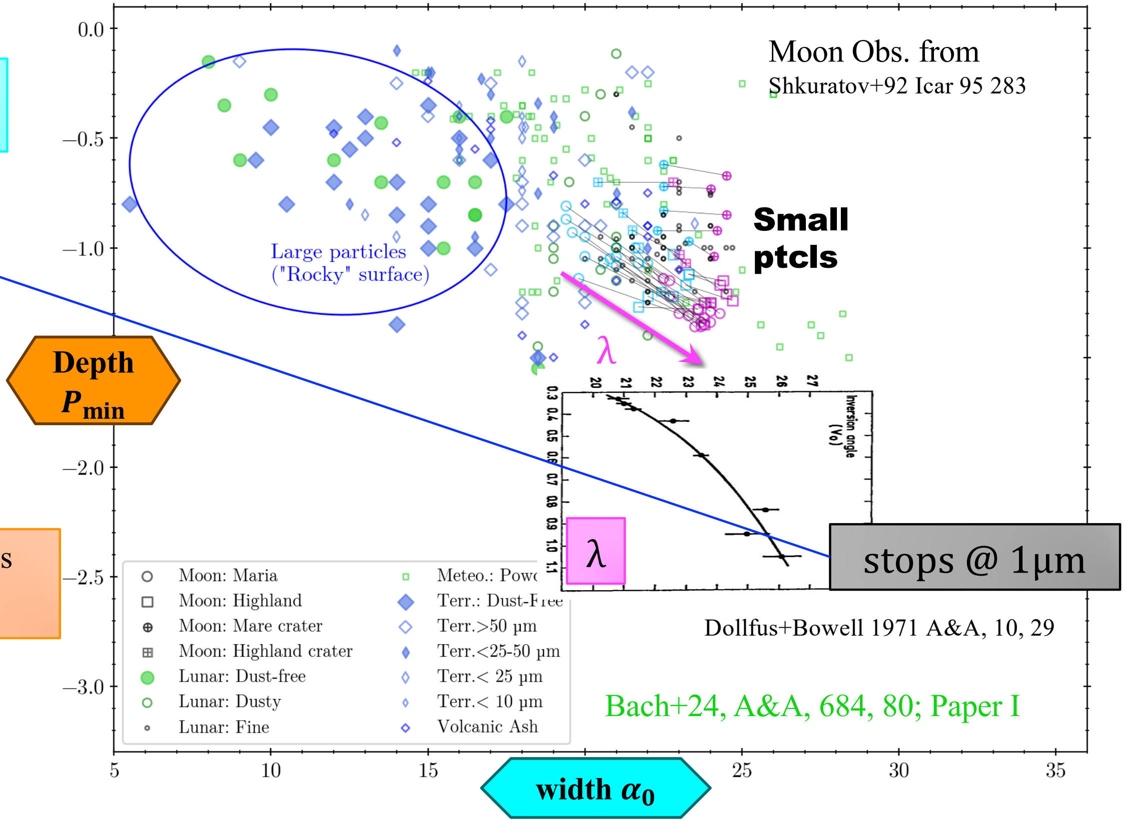


Park+08 JAE 21 266



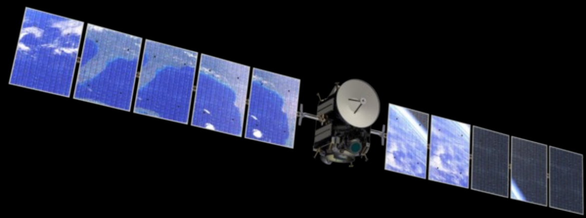




Targets

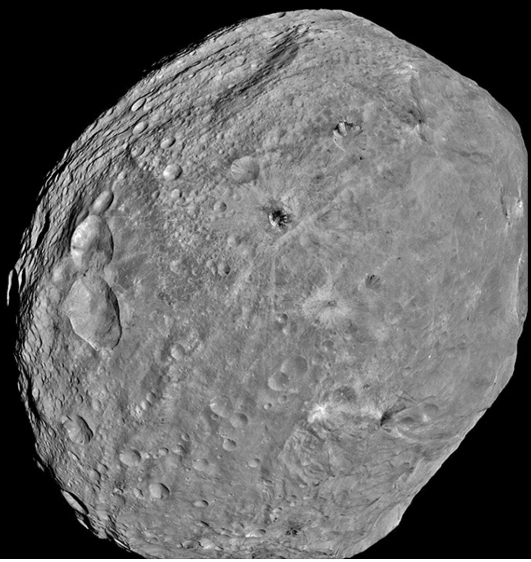
Criteria:

- Brightest
- Most studied
- Likely to contain small ($\lesssim$ 20μm) particles

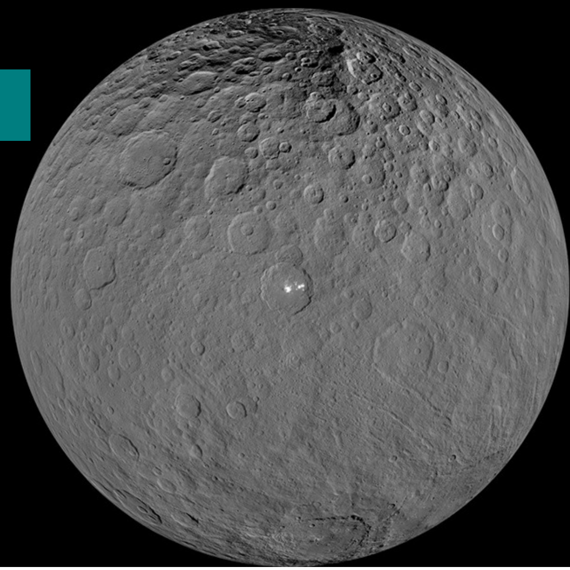


(4) Vesta

560 × 450 km



"Airless Bodies"



(1) Ceres

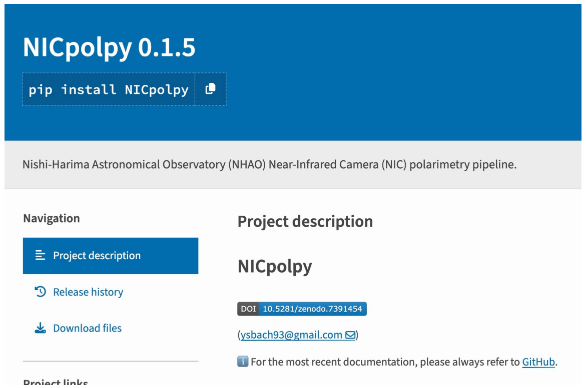
960 × 890 km

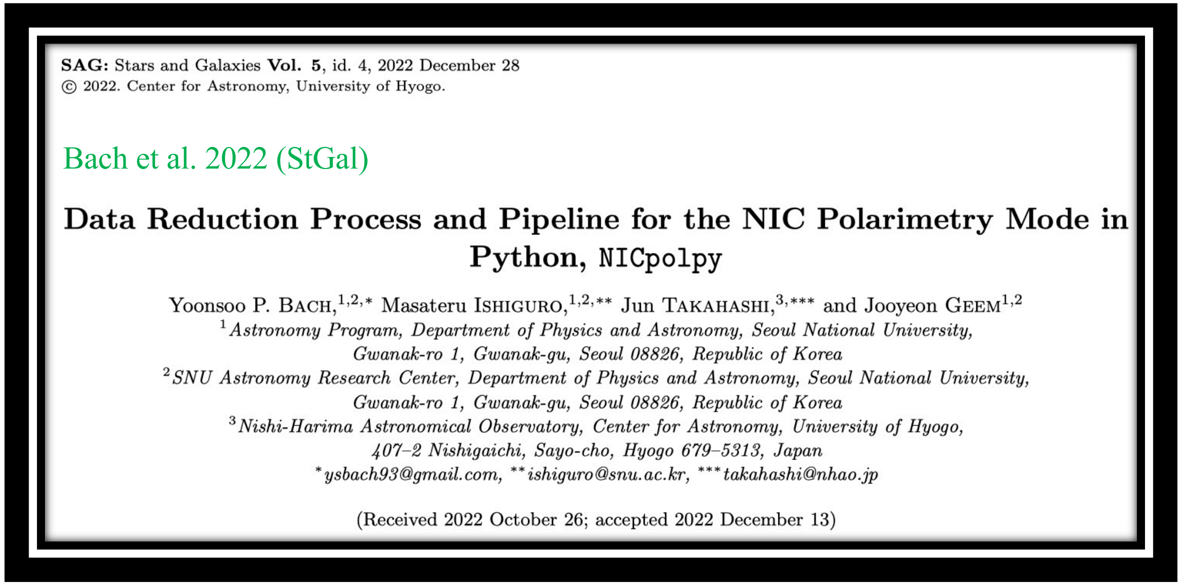
Observation

- NHAO NIC, polarimetric-mode
  - J, H, Ks-band simultaneous pol.
- (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

3+ year of data reduction

→ Published **NICpolpy**





SAG: Stars and Galaxies Vol. 5, id. 4, 2022 December 28

Bach et al. 2022 (StGal)

Data Reduction Process and Pipeline for the NIC Polarimetry Mode in Python, NICpolpy

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[2] *SNU Astronomy Research Center, Department of Physics and Astronomy, Seoul National University, Gwanak-ro 1, Gwanak-gu, Seoul 08826, Republic of Korea*
[3] *Nishi-Harima Astronomical Observatory, Center for Astronomy, University of Hyogo, 407–2 Nishigaichi, Sayo-cho, Hyogo 679–5313, Japan*
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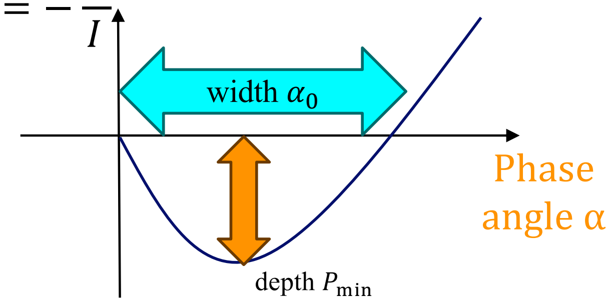
(Received 2022 October 26; accepted 2022 December 13)

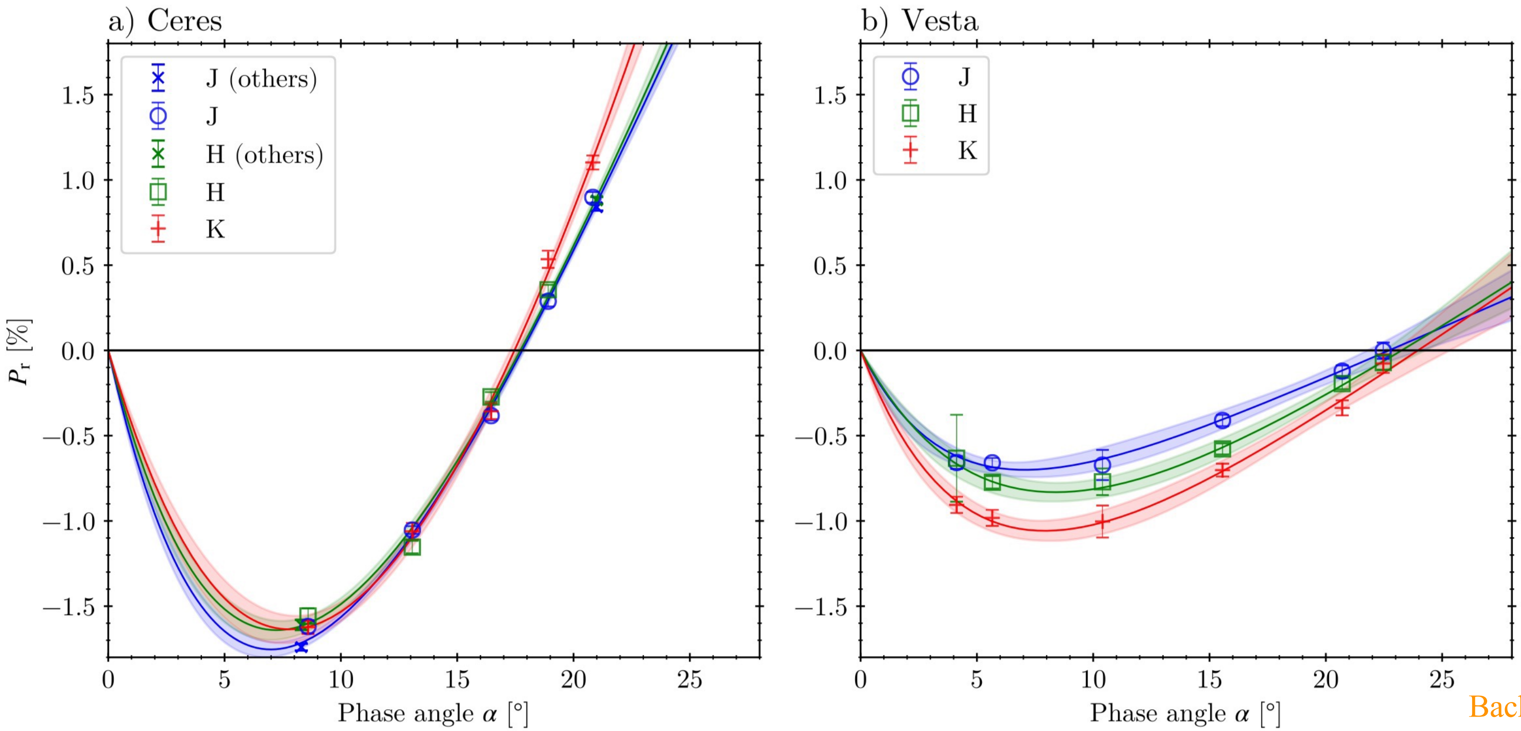
PPC

- **Ceres**: Matches well with Palomar
- **Vesta**: First NIR pol of V-type

200" (5.1-m) telescope (WIRC+Pol)
(*Masiero et al. 2022 PSJ*)
The first NIR pol. for asteroids (!?)

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





Bach+24b A&A, 684, 81; Paper II

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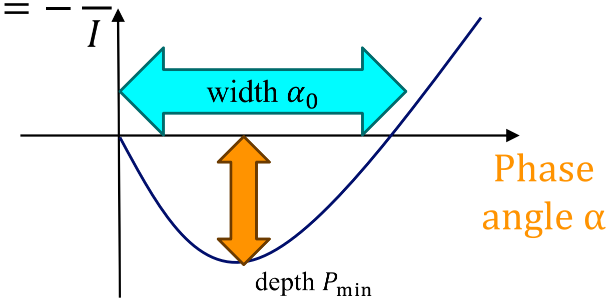

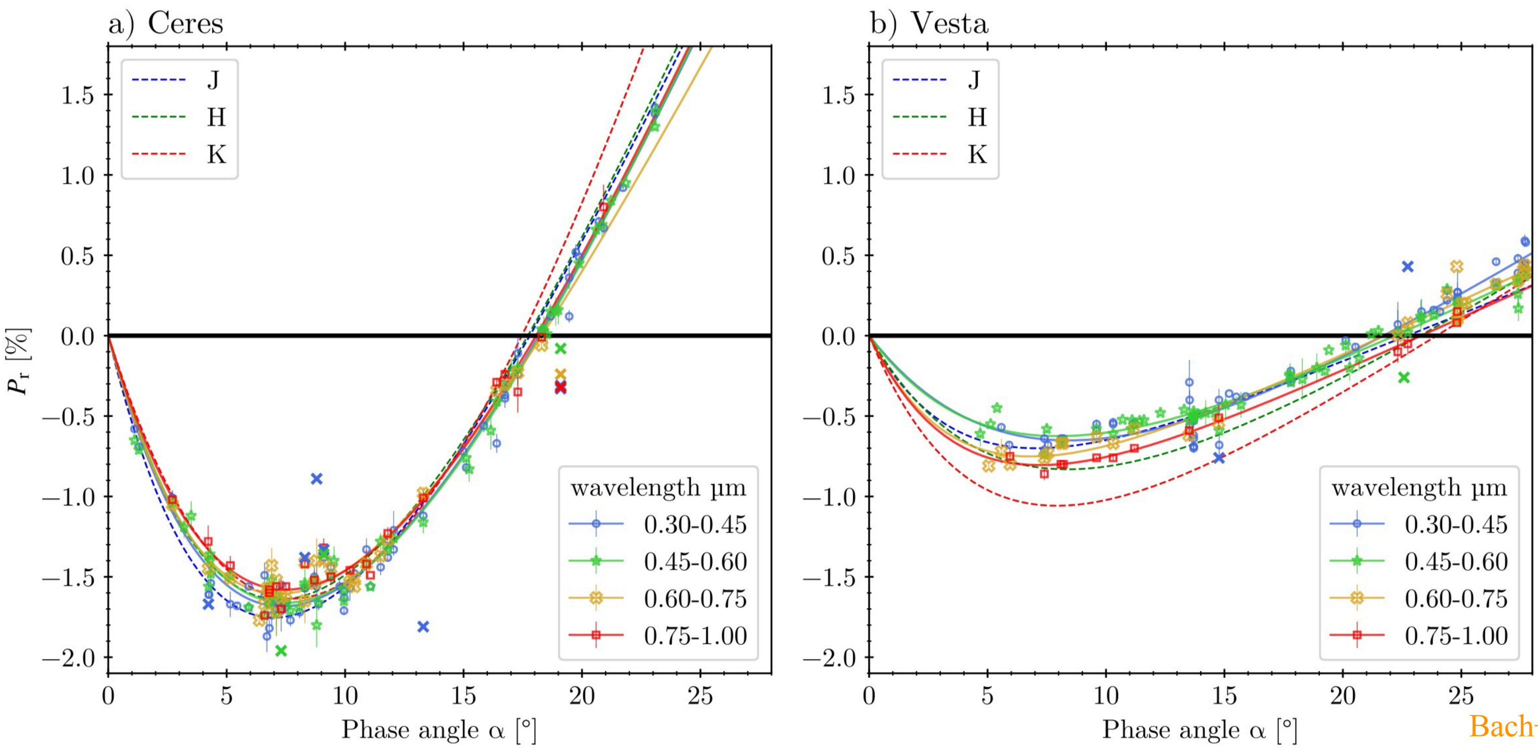

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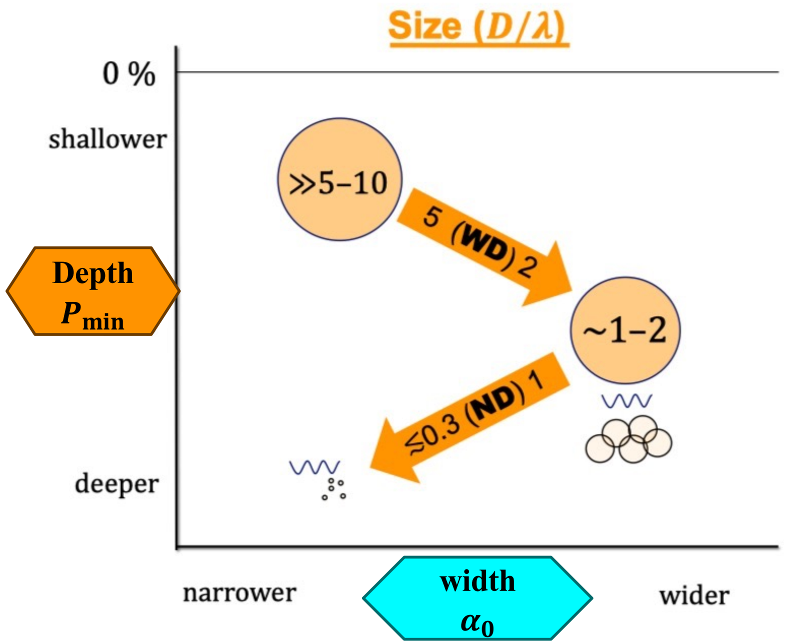
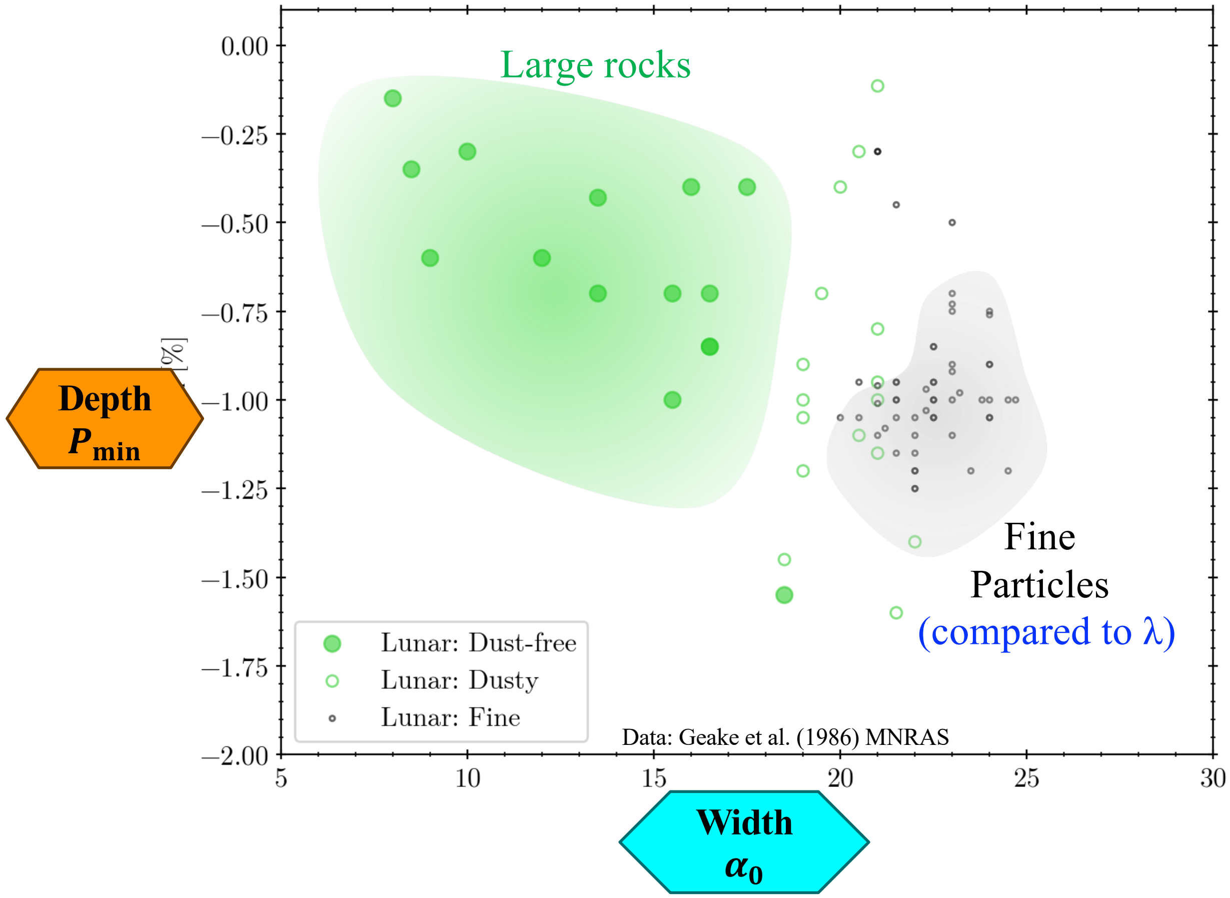
Case of Vesta





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Case of Vesta

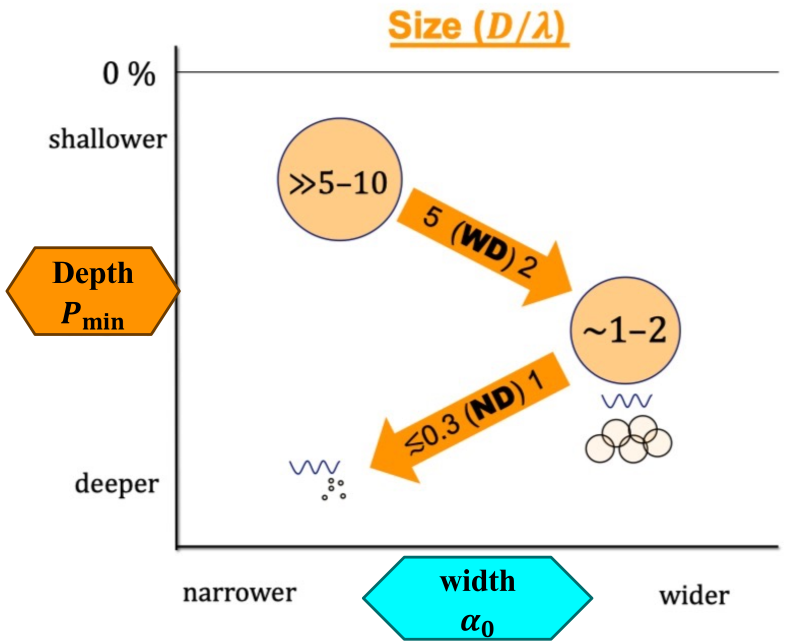
- P_{min} - α_0 change for Vesta
- Particle size:

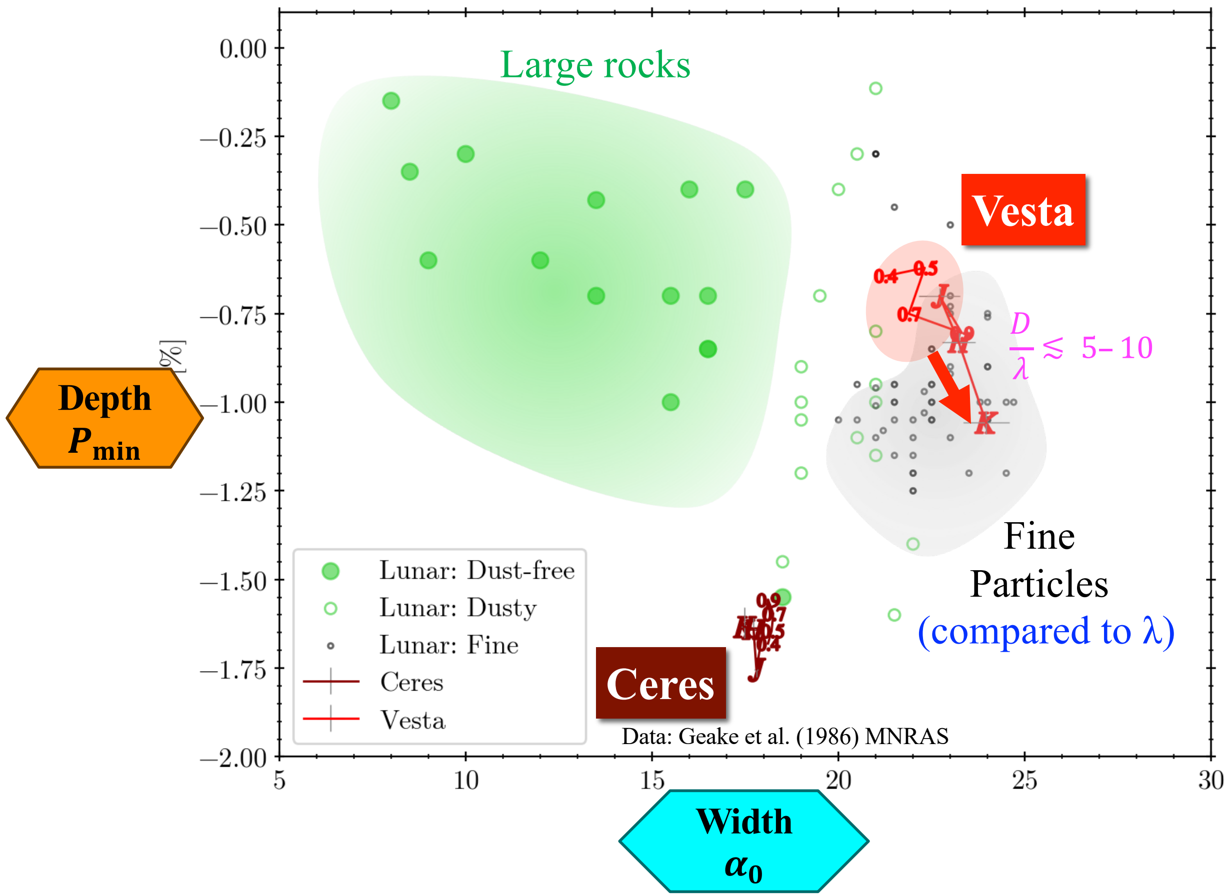
$$\frac{D}{\lambda} \sim 5-10 \quad (\lambda \sim 2\mu\text{m})$$

$$D \sim 10-20\ \mu\text{m}$$

Bach+24b A&A, 684, 81; Paper II

First quantitative estimation of D from multi-λ pol to NIR





Bach+24b A&A, 684, 81; Paper II

Consistent with
- Optical pol.: Le Berte & Zellner 1980
- Spectra : HiroiT+94, LiJY+11, MartikainenJ+19

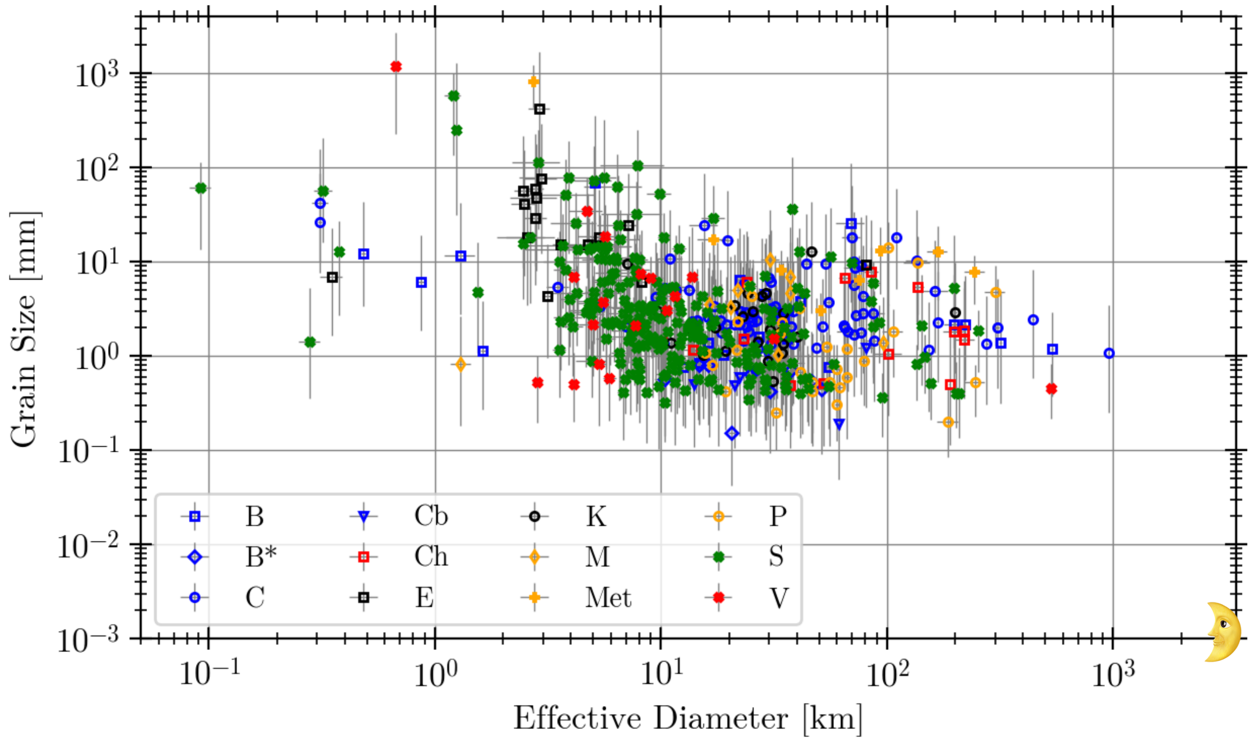
Discussions – Importance

An independent way to measure particle size D

- **Compensates** **thermal modeling** based estimations.

Data from MacLennan & Emery (2022) PSJ
Figure from Bach, Y. P. (2023) PhDT
Methodology - see
Gundlach & Blum 2012 & 2013

Thermal modeling



Discussions – Importance

An independent way to measure particle size D

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Methodology - see
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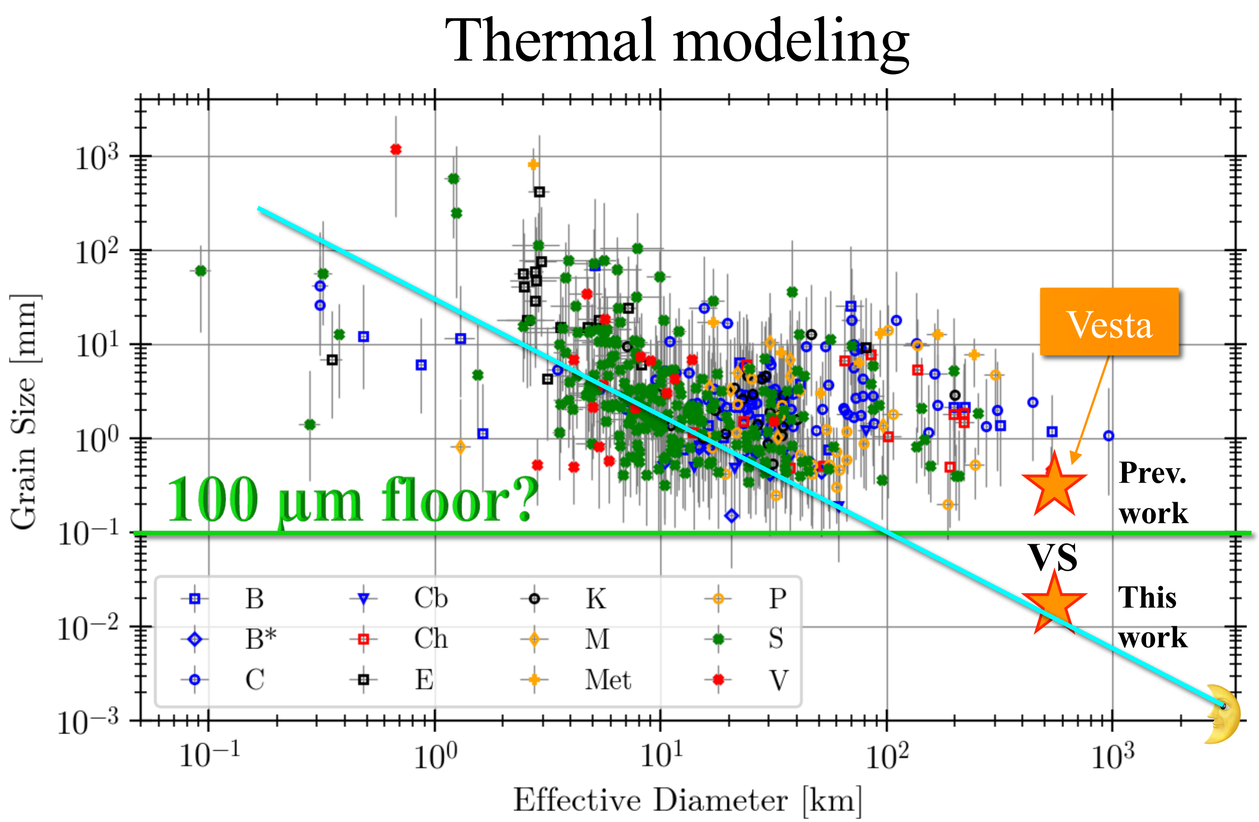
- 100μm floor VS 10-20μm on Vesta?
  - Bug found in M&E22
    - (priv. comm. MacLennan 2023)
  - Our result is consistent with their updated results!

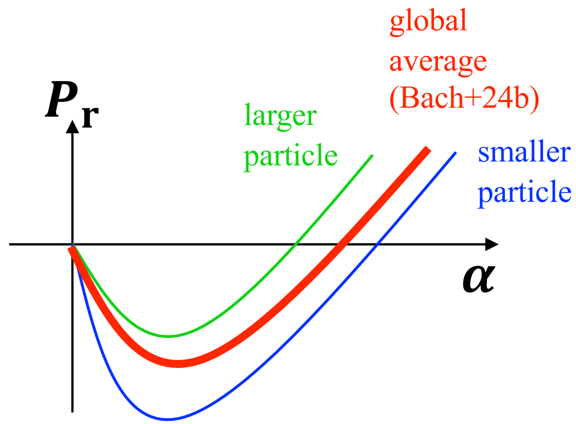


- Summary:
  - First application of NIR polarimetry to **quantify** grain size.
  - Vesta $D \sim 10 - 20$ μm
  - Ceres: further discussion needed (e.g., h value)
- Future: Disk-resolved NIR pol for Vesta

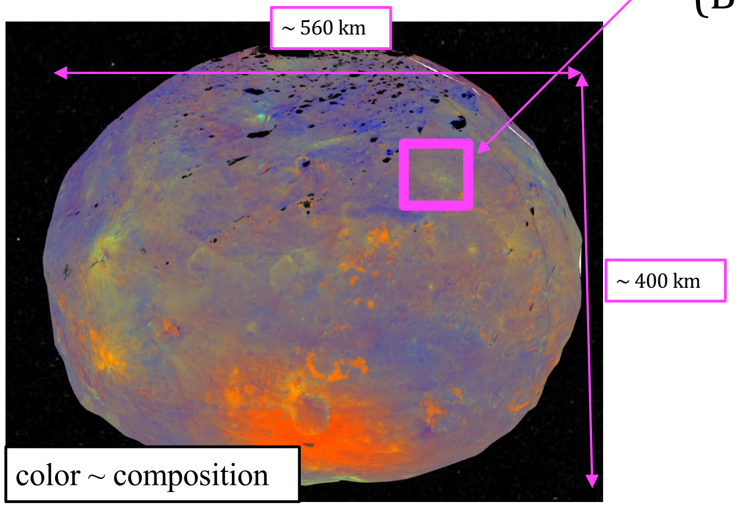
Future Works – Vesta

[1] Reddy V. et al. (2012) Science

- Disk-resolved NIR polarimetry
  - Vesta is one of the "most heterogeneous asteroids"[1]
  - Albedo already known (Dawn mission)
  - With Pol. map, we may discuss grain size map (size VS craters, compositions, etc)



Subaru IRCS with AO188 (K-band)
(Best expected resol. = 70 km)



https://trek.nasa.gov/vesta/#

Vesta K-band P_r

Small particle high albedo region	Large particle high albedo region
Small particle low albedo region	Large particle low albedo region

2023B proposal rejected
Planning to submit 2025A