Near Infra-Red Polarimetry of Large Asteroids using NIC

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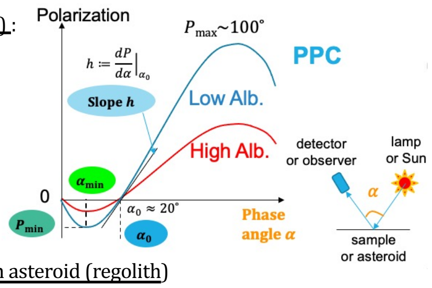
Scientific Backgrounds

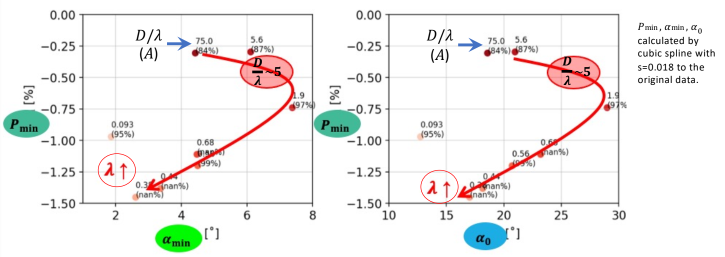
1. PPC (Polarization Phase Curve): Polarization ($P_r \coloneqq -\frac{Q}{I}$) as a function of phase angle.

2. Umow law [1]:
(1) $A \uparrow \Leftrightarrow |P_{\min}| \downarrow$ (shallower)
(2) $A \uparrow \Leftrightarrow h \downarrow$ (for $A \gtrsim 0.05$)
(3) $A \uparrow \Leftrightarrow P_{\max} \downarrow$
A = albedo



3. Observations: particle size on asteroid (regolith)
Large asteroids (including Vesta) **are expected to be covered with fine particles ($D \lesssim 20$ μm size)** due to large gravity [2-5].

4. Experiments: Particle size from experiments
$P_{\min}$ - $\alpha_{\min}$ and $P_{\min}$ - α_0 both showed **abrupt change when D/λ gets $\lesssim 5$** [6]



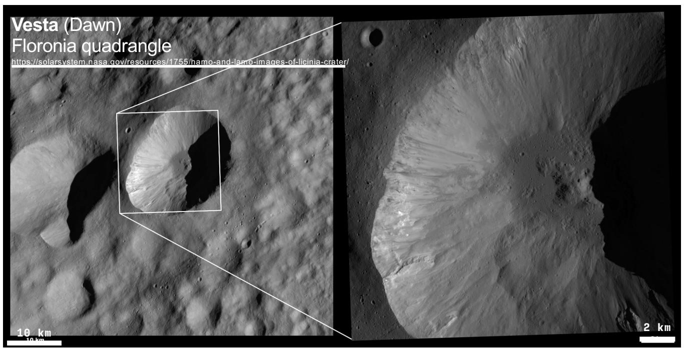
5. Motivation & Strategy
Observe the largest available asteroids, (4) Vesta and (1) Ceres, with **as long wavelengths as possible**. But if $\lambda \gtrsim 5$ μm, thermal radiation from the asteroid comes in, so we have to choose $\lambda \lesssim 3$ μm. Check from which λ the expected "abrupt" change in PPC happens. So far, there is **no refreed publication** which studied NIR polarimetry of asteroids.

size in wavelength values (D/λ)

observation in this work (J, H, Ks)

Particle size D	V (λ 0.55μm)	I_c (λ 0.8 μm)	J (λ 1.2 μm)	H (λ 1.6 μm)	K_s (λ 2.2 μm)
20 μm	36	25	17	13	9
10 μm	18	13	8	6	5
5 μm	9	6	4	3	2

to small D/λ



Observation

We found **NIC**[7-9] is a perfect instrument for our purpose, since it takes three (J, H, K_s) polarimetric images *simultaneously*, and thus sampling **three sizes (D/λ) at the same time**!

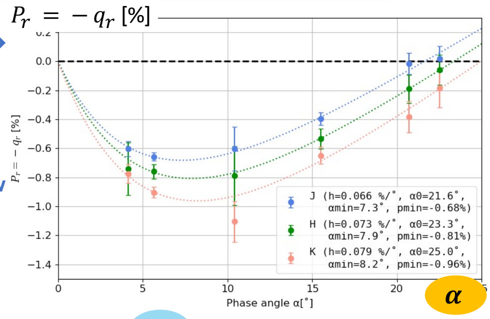
Mid UT (ISO 8601)	phase angle α [°]	EXPTIME [s]	AIRMASS	r_h [au]	r_o [au]	lunar elong. [°]	V mag
2019-10-22 15:41:39.1	10.4°	2	1.09-1.13	2.54	1.61	70	6.8
2019-11-08 15:37:37.7	4.1°	3, 5, 10, 30	1.42-1.67	2.55	1.57	60	6.5
2019-11-21 14:13:34.0	5.7°	2	1.12-1.24	2.55	1.58	120	6.6
2019-12-18 14:04:52.4	15.6°	2, 3	1.17-1.47	2.56	1.76	120	7.1
2020-01-10 13:38:53.7	20.7°	2	1.42-1.67	2.57	2.02	60	7.6
2020-02-13 09:39:28.4	22.5°	2	1.09-1.13	2.57	2.47	150	8.1

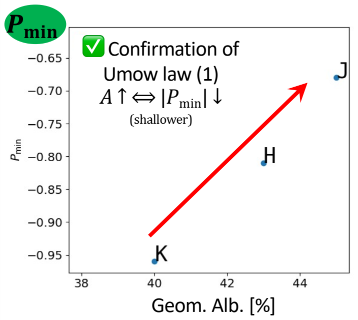
Columns: **MidUT** = Median of the observation for each night; **phase angle** = the Sun-target-observer's angle; **EXPTIME** = The exposure times used for each night's observation; **AIRMASS** = The minimum and maximum airmass values for each night; r_h = heliocentric distance; r_o = geocentric (observer-target) distance; **lunar elong.** = Lunar elongation angle; **V-mag** = V-band magnitude.
All values, except for EXPTIME, are queried from NASA/JPL/HORIZONS web service (https://ssd.jpl.nasa.gov/horizons.cgi#top).

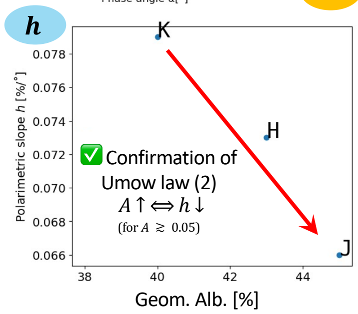
Results & Discussions

The PPC of (4) Vesta →
- Linear-exponential function fitting (J, H, K_s): $P_r = A(e^{-k\alpha}-1) + B\alpha$

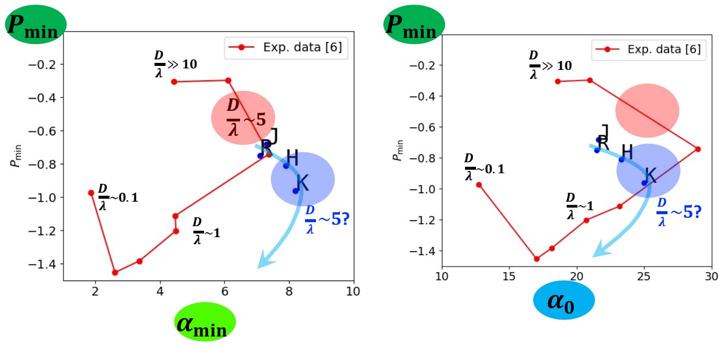
↓ Confirmation of Umow
(1) $A \uparrow \Leftrightarrow |P_{\min}| \downarrow$ (shallower)
(2) $A \uparrow \Leftrightarrow h \downarrow$ (for $A \gtrsim 0.05$)







Abrupt change when D/λ gets $\lesssim 5$?
Using archived optical polarimetry data[10], R band (0.60-0.70 μm) is the most reliable among them. Plotting R & JHK bands simultaneously, we find "abrubt change" in the $P_{\min}$ - $\alpha_{\min}$ and $P_{\min}$ - α_0



Comparing our R-J-H-Ks data points with the previous experimental works, we suggest the abrupt change may indicate the criterion **$D/\lambda \sim 5$ happens near the H and Ks bands**. Therefore, λ ~ 2 μm, and we find the particle size on asteroid (4) Vesta, **$D \sim 10$μm**. This is not a lower/upper bound, but an exact value.

If the experimental work is applicable to the realistic asteroidal materials, this is a **novel and very reliable measurement of particle sizes on an asteroid**. Further experimental studies and NIR polarimetry on large asteroids may be required to understand the particle size determination on asteroidal regoliths, such as the determination of the critical D/λ value (we used ~ 5) depending on materials and porosity. If our results of "abrupt change" is a true feature, theories to describe it must also be developed.

Conclusion

We conducted the near infrared polarimetric observation of a large asteroid (4) Vesta. As expected from the experimental studies, **we confirmed Umow laws**. So far, *near infrared polarimetry of asteroids has never been published* to any peer-reviewed journal to our best knowledge. Furthermore, we may have detected the "abrupt change" in the polarimetric phase curve of asteroid due to the size parameter (size/wavelength), which has only been confirmed in laboratory experiments. If we assume the critical size parameter where such abrupt change occurs in experiments can be applied to asteroids, we can conclude the **particle size on asteroid (4) Vesta is about 10 μm**.

References

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