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CALIBRATE THE POLARIZATION-ALBEDO RELATIONSHIP FOR NEOS BY COMBINING RADAR, POLARIMETRIC AND OPTICAL LIGHTCURVES DATA

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Extended Abstract—

We present here the result of an ongoing observation campaign in polarimetry, photometry, thermal radiometry, and radar aiming at calibrating the polarization-albedo relationship for Near-Earth Objects (NEOs) to provide a strong tool to measure the size of NEOs in an independent and complementary way to that of the thermal modelling method.

The degree of linear polarization, P_r of the sunlight scattered by an asteroid surface is primarily dependent on its albedo p_V [1]. There exists an anti-correlation where high albedo results in low polarization while low albedo provides high polarization. Polarization is also dependent on the solar phase angle α at which the target is observed. For asteroids, the state of linear polarization is described by the P_r parameter which is defined as the normalized difference between the intensity of the light having its polarization oriented perpendicular to the scattering plane and the intensity of the light having its polarization oriented parallel to the scattering plane (Fig. 1). If properly calibrated, this correlation would allow to determine the albedo easily and reliably, and thus the size, of a NEO from a single polarimetric measurement at phase angles larger than ~40°. Such a tool would be particularly important in the case of a newly discovered impactor.

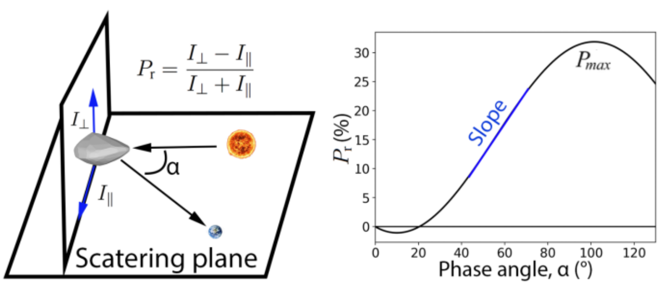

Figure 1: Left: Observation geometry with the sunlight scattered by the asteroid and then observed on Earth. The polarization is measured in the scattering plane ($I_\parallel$) and the plane perpendicular to the scattering plane ($I_\perp$). Right: typical variation of the polarization as a function of □. Pmax corresponds to the maximum value of polarization usually occurring between 80 to 120°.

If the albedo-polarization relationship has been calibrated for main-belt asteroids (MBAs) observed at low phase angles (α < 30°) [2], this relationship remains to be accurately calibrated for higher phase angles at which most of the NEOs can be observed. To date, only ~25 of the largest NEOs have been observed in polarimetry [3]. Almost half of these observations are 20 years old or older and the measurements are associated with large error bars, or no error bars at all, due to the technology available at the time. This lack of recent and high-quality observations provides a clear opportunity for new science, exploiting the fact that NEOs reach phase angles not possible for MBAs, thereby allowing for more comprehensive characterization.

We present here the first results of a multi-year observation campaign aiming to obtain polarimetric observation of over 30 NEOs, which will more than doubling the number of available measurements at phase angles larger than 40°, that are used to calibrate the polarization albedo relationship for NEOs at high phase angles. This calibration will allow to reduce the size uncertainty on newly discovered object by a factor of ~10 with one single polarimetric measurement at α > 40°. To complement the polarimetric observations, we are also regularly acquiring optical lightcurves and optical spectra and we make use of the radar observations of hundreds of NEOs accumulated by the Arecibo Observatory during its years of operation. This unique combination of data types allows for a more complete characterization of our targets. Polarimetric observations are conducted with the ToPol polarimeter [4] mounted on the Omicron-West 1-m telescope at the Calern Observatory, France for targets reaching V < 14.5. They are obtained at various solar phase angles to characterize the phase-polarization curve. Fig. 2 shows the already obtained polarization for 36 of our targets at various phase angles (up to 116°). The plot is color-coded using a weighted mean of the albedos retrieved from the literature.

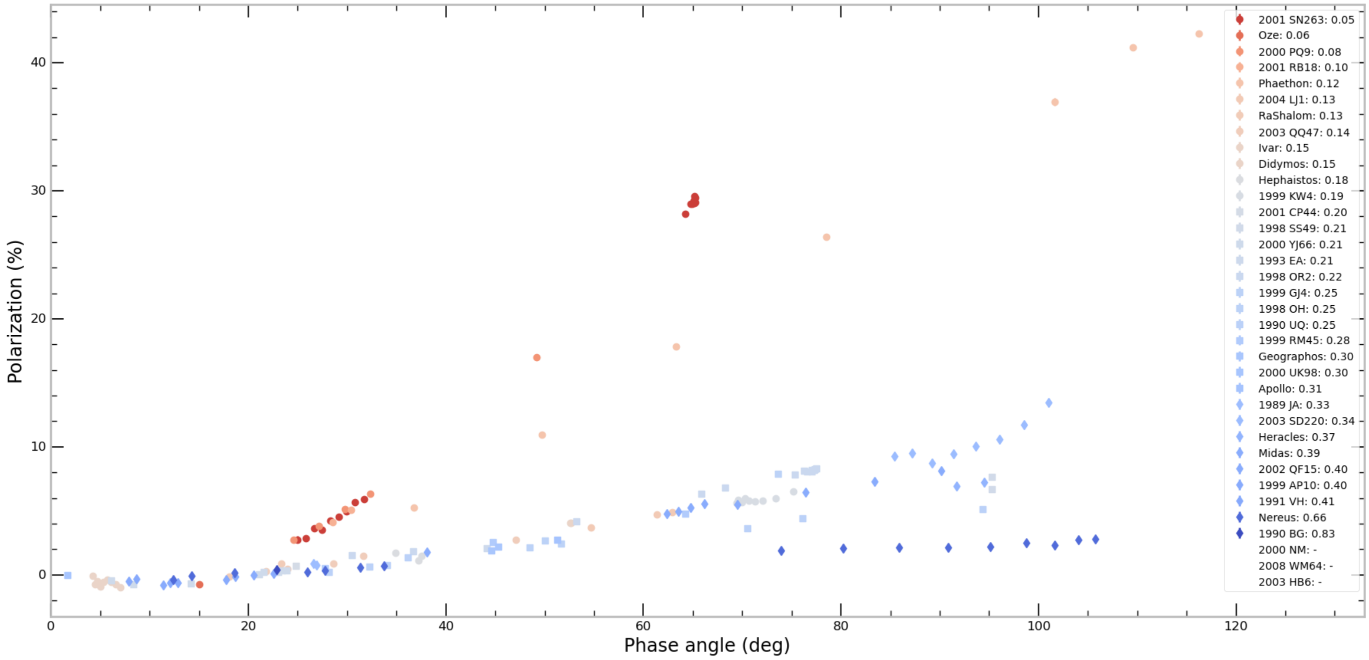

Figure 2: Plot of all our obtained polarimetric data. The corresponding current albedo for each asteroid is indicated in the legend.

To calibrate the albedo-polarization relation, we do not only need good polarimetric measurements, but also reliable albedo determinations. The determination of the albedo of an asteroid is a difficult task that primarily relies on assumptions/calibrations/models that are imperfect. Thus, measured albedos are often associated with large uncertainties (that are most of the time underestimated). These large uncertainties on albedo translate into large uncertainties on the size estimation of the targets. In terms of prediction of the consequences of a possible impact, such large uncertainties on the size can lead to a large uncertainty on the estimation of ground damages. Currently, the most common method to determine the albedo of an asteroid is thermal modelling. However, most of the time, assumptions must be made relative to the asteroid properties. The largest source of error in the albedo estimation of an asteroid through thermal modeling is the value of the absolute magnitude *H* (i.e., the magnitude that would display an asteroid if observed at a distance of 1 au from the Sun, 1 au from the Earth, and at 0° of phase angle) [5]. This dependence on the *H* magnitude can be detrimental for albedo determination of NEOs when data are only available at high phase angle. Indeed, to obtain a reliable *H* magnitude, an object must be observed at low phase angle as the *H* magnitude is defined at zero degree of phase angle. For objects without data at such low phase angles, the uncertainty on the *H* magnitude can be up to 1 mag resulting in an uncertainty on the albedo of ~70%. The determination of the geometric albedo based on polarimetric measurements does not depend on the *H* magnitude. Moreover, in contrast to thermal modeling, our method works best at high phase angles. This makes albedo determination through polarimetry an important complementary and independent method from thermal modelling.

In this program, we are proposing to improve, or determine for the first time, the albedo of the objects that we are observing in polarimetry. The main technique used for albedo determination is thermal infrared observations. We are obtaining new thermal radiometry observation with the SpeX instrument in LXD mode at IRTF and analyzing archive observations from NEOWISE/Spitzer to perform ThermoPhysical Model (TPM). Radar data from the Arecibo Observatory (see Fig. 3) or new observation at Goldstone will also be used as many of our targets have been or will observed at Goldstone at very high SNR allowing for high resolution imaging. Radar imaging provides a direct measurement of the asteroid size. To obtain a full determination of the size trough Goldstone observations, information on the pole orientation is needed. This information will be obtained through extensive photometric observations. The photometric observations obtained at different phase angles will also provide a better determination of the *H* magnitude also needed for accurate TPM [5]. We will thus obtain independent measurements of the albedo, size, and *H* magnitude which are all related through the relation $D = 10^{(3.1236-0.5\log(pV)-0.2H)}$. Finally, for some targets, combining photometric and radar observations might allow to obtain full 3D shape models and precise determination of their size. The lightcurves are obtained using the TRAPPIST-South and -North 0.6-m telescopes [6] located at the La Silla Observatory, Chile, and the Oukaïmeden Observatory, Morocco, respectively. Together with the rotation period from lightcurves, the radar data allow us to better constrain the size of our targets. For certain targets, the lightcurves and delay-Doppler radar images are also used with the SHAPE software [7] to derive the spin axis orientation and to reconstruct a shape model. We are also looking for large-scale features present on the radar images and the shape model that could be linked to rotational variation of the degree of linear polarization.

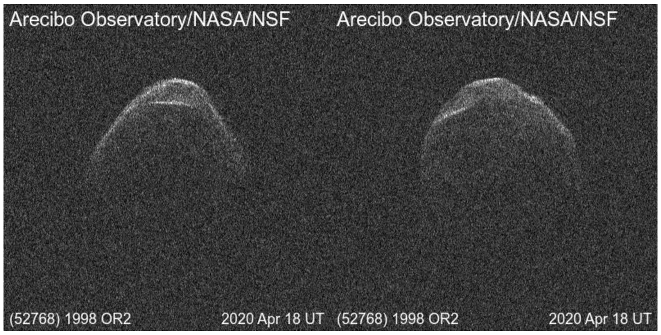

Figure 3: Delay-Doppler images of 1998 OR2 obtained by the Arecibo telescope in 2020.

[1] Belskaya, I. et al. Asteroids IV 151–163 (2015).

[2] Cellino, A. et al. Monthly Notices of the Royal Astronomical Society 451, 3473–3488 (2015).

[3] Lupishko, D., & Vasilyev, S. NASA Planetary Data System, EAR (2019).

[4] Devogèle, M. et al. Monthly Notices of the Royal Astronomical Society 465, 4335–4347 (2017).

[5] Masiero, J. et al. The Planetary Science Journal 32-42 (2021)

[6] Jehin, E. et al. The Messenger 145, 2–6 (2011).

[7] Magri, C. et al. Icarus 186, 152-177 (2007).