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ON THE CALIBRATION OF THE POLARIMETRIC SLOPE - ALBEDO RELATION FOR ASTEROIDS: WORK IN PROGRESS

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ABSTRACT. Asteroid polarimetry is known to be an excellent tool to derive information on the geometric albedo of these objects. This is made possible by the existence of a relation between the albedo and the morphology of the curve which describes the variation of the degree of linear polarization of asteroid light as a function of the illumination conditions. A major problem is that the calibration of the commonly accepted form of the polarization - albedo relation includes numerical coefficients which are affected by fairly high uncertainties. Following some recommendations issued by IAU Commission 15, we are trying to improve the albedo - polarization relation by taking advantage of new polarimetric data obtained in dedicated observation campaigns. We present here some very preliminary results.

1. Introduction

The geometric albedo (usually indicated as p_V) of a Solar System body is, by definition, the ratio of its brightness measured by an observer in standard V light at zero phase angle, to that of an idealized flat, fully reflecting, diffusively scattering (Lambertian) disk with the same cross-section. In the above definition, the meaning of the phase angle is that of the angle between the directions to the Sun and to the observer, as seen from the observed body. Zero phase angle corresponds therefore to the ideal situation in which the object is observed at perfect solar opposition.

The geometric albedo is a very important physical parameter to characterize the surface properties of asteroids and other atmosphereless bodies in our Solar System. Based on its definition, it is clear that the albedo is strictly dependent on both the composition of the surface, and the optical properties resulting from the texture and roughness of the soil, and from the size distribution of the dust particles which are generally believed to cover asteroid surfaces, forming a layer of so-called regolith.

Moreover, knowledge of the geometric albedo is also needed to estimate the size of an asteroidal body, knowning its absolute magnitude. Some important, practical applications include the determination of the size of Potentially Hazardous Objects (PHO) found to have non-zero probability of impact with the Earth, *e.g.*, the PHO (99942) Apophis [1].

Unfortunately, the derivation of the albedo from astronomical observations is not an easy task. In most cases it is derived only indirectly, based on knowledge of the object's size derived by techniques such as thermal radiometry, provided the absolute magnitude

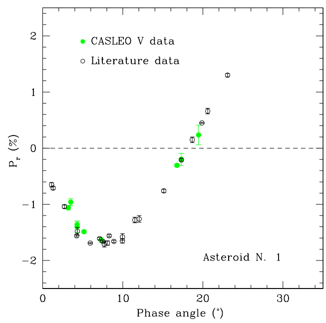

Figure 1. Phase-polarization curve for the dwarf planet (1) Ceres. Different symbols are used to indicate observations carried out by the authors using the 2.2 m telescope of the Complejo Astronomico El Leoncito in Argentina (filled circles) and data previously available in the literature (open circles).

of the object is known. Due to uncertainties on the derived size and the errors usually affecting absolute magnitude values [2], the resulting estimates of the albedo turn out to be generally quite uncertain, relative errors of the order of 60% being common.

On the other hand, we have at disposal another observing technique which can be used to derive the albedo of an object, without having to do any assumption on its size or absolute magnitude. This technique is polarimetry. In this paper, we briefly summarize the use of polarimetry in the field of asteroid investigations, and we present a few preliminary results of work in progress, which we are carrying out to improve the power and reliability of the polarimetric technique as a first-choice tool to derive asteroid physical parameters.

2. Asteroid Polarimetry

Since it consists of scattered sunlight, the radiation that we receive from asteroids at visible wavelengths is linearly polarized. According to a large body of observational evidence, both the degree of linear polarization, and the orientation of the plane of polarization, are functions of the phase angle at the epoch of observations. In particular, the plane of polarization is found to be parallel to the scattering plane (the plane containing the Sun, the asteroid and the observer) in a range of phase angles smaller than about 20 degrees. Beyond that value, the orientation of the polarization plane becomes perpendicular to the scattering plane. In asteroid polarimetry, it is customary to speak of *negative polarization* in the first situation, and of *positive polarization* in the latter one. The phase angle which marks the transition between the two regimes is usually called the *inversion angle*.

The variation of the degree of linear polarization as a function of phase is generally described by a curve which can be described by a few parameters. These parameters tend to have a range of values, being dependent on some properties of the asteroid surface. As an example, Fig. 1 shows the phase - polarization curve for (1) Ceres. It can be seen that, around the inversion angle, the curve is mostly linear, with the slope usually given the symbol h. The importance of h is that its value has long been known to be related to the geometric albedo p_V through an empirical relation [3]. The usual form of this relation, used by many authors, is the following:

$$\log(p_V) = C_1 \log(h) + C_2 \tag{1}$$

The big problem in asteroid polarimetry is currently that different values for C_1 and C_2 have been published by different authors [4, 5]. Moreover, the nominal uncertainties of these parameters, when published, turn out to be non-negligible. As a consequence, most of the uncertainty in the determination of asteroid albedos using the polarimetric technique is usually due to the uncertainty in the two calibration constants. Due to this reason, the Commission 15 of the International Astronomical Union has recommended that this problem should be solved, and has set-up a Task Force, dedicated to this purpose. The authors of this paper co-chair this Task Force.

3. Work in progress

The relation between polarization properties and surface albedo is eminently empirical. The basic physical mechanisms which are responsible for the observed polarimetric behavior are thought to be known today, with a major role being played by the so-called coherent backscattering mechanism according to several authors [6]. However, it has not yet been possible to develop an extensive analytical theory to predict all the observed details. Moreover, the discovery of objects exhibiting some uncommon polarimetric behavior (the so-called "Barbarians", after their prototype, (234) Barbara [7, 8]) adds further complexity. The issue of a better calibration of the h - albedo "law", therefore, cannot be solved without a wealth of new, accurate, polarimetric measurements. In particular, it is necessary in principle to obtain new polarimetric observations of objects for which the albedo is known with good accuracy. A list of such objects has been published [9], which includes asteroids whose sizes have been directly measured by *in situ* explorations by space probes, or by stellar occultation observations, and for which the absolute magnitude is also supposed to be known with sufficient accuracy.

For a few years, we have been carrying out polarimetric observations of the above objects using the 2.2 m telescope of the Complejo Astronomico El Leoncito, in Argentina. These new observations complement those already published by other authors in the past, and available in the literature. Our work is still in progress, since we are trying not only to find updated values of the C_1 and C_2 constants in Equation 1 based on more polarimetric data, but we are also exploring the possibility that equation 1 itself could be replaced by some more suitable mathematical representation of the albedo - polarization relation.

Here, we limit ourselves to provide a new, preliminary estimate of the C_1 and C_2 parameters. We find $C_1 = -0.98 \pm 0.07$ and $C_2 = -1.69 \pm 0.09$. These estimates are based on an analysis of the polarimetric slopes of 23 calibration objects recommended by [9]. Figure 2 shows the corresponding best-fit of our data by using Equation 1. As a comparison, we remind that the most recently published determinations of C_1 and C_2 gave the values of -0.98 ± 0.08 and -1.73 ± 0.07 [5] and -1.12 ± 0.07 and -1.78 ± 0.06 [4], respectively.

We stress again that the results shown in this paper are very preliminary, and will be possibly made obsolete by using a new, different form of the albedo - polarization relation, which might soon supersede Equation 1.

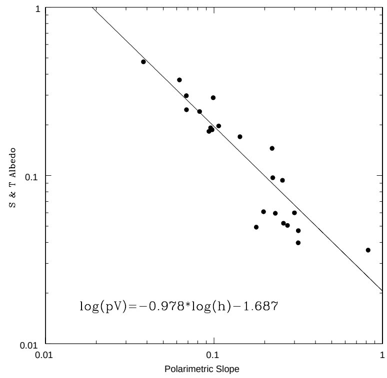

Figure 2. The resulting best-fit of current h - p_V data for a sample of 23 selected asteroids, using Equation 1. The S&T label on the y axis stands for Shevchenko and Tedesco (2006) [9]

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