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Recent advances in asteroid polarimetry

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Abstract

Asteroid polarimetry has experienced important advancements in recent years. This includes the discovery of new classes of objects, a new assessment of the relation between geometric albedo and a variety of different polarimetric parameters, the first attempt to use *in situ* analyses of asteroid (4) Vesta to better understand the relation between local surface properties and disk-integrated polarimetric measurements, and the first applications of spectro-polarimetry to the physical characterization of the asteroids. The most recent results in the above topics are briefly summarized.

1. Introduction

Polarimetry is a powerful tool for the physical characterization of atmosphereless solar system bodies. For a long time, however, this technique has been rarely applied in a systematic way to the study of asteroids, due to the difficulty in obtaining several polarimetric measurements per object taken at different epochs, which are needed to successfully exploit the potential of this technique. Moreover, the lack of general physical models of light-scattering phenomena, capable to provide firm and detailed explanations of the variety of polarimetric data exhibited by bodies like the asteroids, has contributed for a long time to discourage many researchers, who considered asteroid polarimetry as a fairly exotic discipline.

The situation has started to change since the 80s and has been rapidly evolving in recent years. New teams of researchers made important efforts to increase the database of asteroid polarimetric data, and to improve our capability to use the results of these measurements as a primary source of information about physical parameters of asteroid surfaces that are very difficult to obtain by means of other techniques. This paper briefly summarizes the situation and presents the most recent advances in the field.

2. Polarimetry as the best technique to derive asteroid albedos

The determination of the geometric albedo is a very important tool for the physical characterization of asteroid surfaces. The geometric albedo, which quantities the reflectance of a planetary surface, is a fundamental parameter, being related to the composition and particle size distribution of the minerals present in the regolith, that is the most external surface layer. The determination of the albedo from polarimetric data is based on some known relations, first tested in laboratory experiments some decades ago, between the geometric albedo and some parameters that describe the polarimetric properties of different materials. In particular, what is observed in asteroid polarimetry is the variation of linear polarization as a function of the phase angle (the latter being the angle between the directions to the Sun and to the observer, as seen from the target body). Polarimetric data obtained at different epochs, corresponding to different phase angles, allow the observers to obtain the so-called phase - polarization curves, which are characterized by a common kind of general morphology, described traditionally by means of a small number of parameters, but with differences that are known to be a function of the albedo.

In the past, different authors have carried out analyses to establish quantitative relations between the parameters describing phase - polarization curves and the geometric albedo. The situation has long been quite confused, since there has never been a convergence to a unique approach, and due to the fact that the calibration of the adopted relations (like the so-called slope - albedo law) has been for a long time a difficult task, limiting the practical application of polarimetric studies to the derivation of asteroid albedos. As a consequence, most catalogues of asteroid albedos adopted in these years have been obtained by means of other techniques, primarily thermal radiometry.

In a recent paper, [1] have carried out a new extensive analysis of currently available polarimetric data and have proposed updated calibrations of different relations between different polarimetric parameters and the geometric albedo. According to these authors, several reliable relations can be successfully established, and can provide albedo determinations much more accurate than those obtained by means of thermal radiometry.

2.1 The ground truth from Vesta

The asteroid (4) Vesta, visited by the DAWN probe, is an ideal target to better understand the relation between albedo and polarization properties. The reason is that Vesta is the only one asteroid for which a clear variation of linear polarization as a function of rotation has been convincingly proven. After the detailed study of Vesta's surface by the instruments aboard DAWN, it is now possible to carry out analysis aimed at establishing the relation between physical properties of the surface, like albedo, texture and composition, and the disk-integrated polarimetric signal measured from the ground as a function of time, due to the rotation of the asteroid. This exercise has been attempted by [2], who have obtained the first indication about the "ground truth" in asteroid polarimetry.

3. The Barbarians

The discovery of the peculiar polarimetric properties of asteroid (234) Barbara dates back to 2006 [3]. Since then, a small number of other "Barbarian" asteroids have been discovered. Up to a couple of years ago, only a handful of Barbarians were known. The peculiar feature of Barbarians is an unusually large "negative polarization branch", namely an interval of phase angles at which the plane of linear polarization turns out to be parallel to the plane of scattering (the plane containing the Sun, the observer and the asteroid). More recently, it has been discovered that Barbarian asteroids are also peculiar for exhibiting very large abundances of the spinel mineral in their reflectance spectra [4]. This suggests that Barbarians might be among the most ancient and primitive solid bodies present in our solar system, having been accreted during the very early epochs of formation of the first planetesimals. Their rarity could be interpreted as being due to the fact that only a few objects belonging to this first generation of planetesimals have been lucky enough to survive the early processes that led to the removal of the vast majority of the planetesimals initially accreted between Mars and Jupiter.

An important recent discovery has been that one dynamical family of asteroids, named after the high-inclination asteroid (729) Watsonia, is composed of Barbarian asteroids [5]. This opens new possibilities for a better physical characterization and interpretation of Barbarians by means of polarimetric and visual and near-IR spectroscopy, with potential implications for our general understanding of the early phases of the solar system history.

4. Spectro-polarimetry

Recently, the first pioneering attempts to apply the technique of spectro-polarimetry to asteroid studies have started to give interesting results [6]. In addition to spectral reflectance and phase-dependent polarimetric data, spectro-polarimetry also provides another piece of information, namely the relation between the degree of linear polarization and wavelength. According to the first results, it seems that this new parameter can be used to distinguish between objects having different albedo. Moreover, the fairly complicated variation of the polarization gradient observed at different phase angles seems able to produce some important new constraint to modern models of light-scattering phenomena from planetary surfaces. If the first impressions will be confirmed, spectro-polarimetry might soon become the best and fastest technique for the physical characterization of asteroid surfaces, the most important limitation being that of the need of large telescopes to obtain useful data for faint objects.

5. Summary and Conclusions

Asteroid polarimetry is experiencing in these years a general Renaissance. The important results obtained in this field indicate that it is no longer possible to disregard the study of the polarimetric properties of small solar system bodies, since this is one of the major tools to be exploited for the purposes of physical characterization of these bodies, with immediate applications, as an example, to the topic of defense systems against the impact hazard posed by near-Earth objects. Moreover, polarimetry is also important for taxonomic classification purposes. A first interesting application will be a test of the future taxonomic classification that will be obtained by the Gaia mission. In particular, it will be interesting to see whether the sampling of the blue part of the reflectance spectrum perfomed by Gaia will be able to produce a distinction between asteroids belonging to the current B taxonomic class, and asteroids that were previously classified as F-class. These objects, which are now included in the modern B-class, are known to exhibit well-defined polarimetric properties that clearly distinguish them with respect to other low-albedo taxonomic classes ([7]).

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