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A new calibration of the albedo–polarization relation for the asteroids

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ABSTRACT

We present a new calibration of the geometric albedo *versus* linear polarization relation for the asteroids. We use the classical relation $\log p_v = C_1 \log h + C_2$, where p_V is the geometric albedo and h is the slope of the phase–polarization curve. We have obtained new values for the C_1 and C_2 coefficients and their nominal uncertainties, by means of dedicated polarimetric observations of a number of asteroids for which the albedo is supposed to be known with good accuracy [Shevchenko and Tedesco. Icarus 2006;184:211–220]. The new calibration proposed in this paper represents the state of the art based on currently available data. However, the uncertainties on the derived calibration coefficients are still not negligible, and we suggest that alternative forms of the albedo–polarization relation should be explored in the future, possibly based on a bigger data set of polarimetric measurements.

1. Introduction

Polarimetry is a very useful technique to derive information on some physical properties of the minor bodies of our Solar System which are particularly difficult to determine by means of remote observations.

Among these properties, the geometric albedo is very important. On one hand, it is strictly related to the optical properties of an object's surface, and to the processes of single and multiple scattering of incident sunlight. On the other hand, the albedo is also related to important macroscopic properties including mineralogic composition, and is diagnostic of the likely thermal history of the bodies. It is known, for instance, that the most primitive samples of material which was present at the time of planetary accretion and is thought to have been least altered since that epoch, are found among low-albedo meteorites. Moreover, knowledge of the albedo, coupled with accurate photometric measurements at visible wavelengths, makes it possible to derive good estimates of the size of the objects. This fact can be particularly useful, for instance, for the physical characterization of potentially hazardous objects when they are discovered. A good example of this is given by the famous asteroid (99942) Apophis, which is well-known because it is one of the most interesting objects discovered in recent years, in terms of collision hazard with the Earth. Polarimetric observations of this object were performed at the VLT by Delbò et al. [4], showing that the albedo and size of such small objects can be derived by means of polarimetry,

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provided that Target of Opportunity time at sufficiently large telescopes is available.

In practical terms, however, most asteroid sizes and albedos have been mostly derived by means of other techniques, including primarily thermal radiometry. This technique is based on the measurement of the thermal flux of the objects at mid-IR wavelengths. Coupled with knowledge of the flux of scattered sunlight simultaneously emitted at visible wavelengths, and using suitable models of the distribution of surface temperature, thermal radiometry allows the observers to derive simultaneously the size and geometric albedo of the objects.

Thermal IR observations of asteroids have been mostly made by means of space-based observing facilities, including the IRAS, MSX, ISO, Spitzer and, more recently, WISE satellites. These observations have been extremely important for the derivation of the sizes of large numbers of minor bodies. The situation, however, is still not completely satisfactory for what concerns the determination of the albedo. In practical applications of the thermal radiometry technique, the measurement of the flux at visible wavelengths is usually not done at the same time of the IR observations, but it is mostly estimated for the given observation circumstances based on knowledge of the absolute magnitude of the object. The latter can be derived from sets of observations in V light obtained at different phase angles, and is commonly computed using the so-called (H,G) photometric system.

As a matter of fact, the thermal IR flux from an asteroid surface is only weakly dependent on its albedo. Therefore, estimates of the albedo by means of thermal radiometry are mostly indirect, being based on knowledge of the object's size (which is a more direct result of thermal IR observations), and assuming that the simultaneous flux at visible wavelengths can be reliably estimated from knowledge of the absolute magnitude of the object. Unfortunately, even disregarding the fact that the absolute magnitude itself is not properly a constant for a given object, but it depends on the aspect angle at the epoch when the object is observed (because the object's apparent cross-section visible at different epochs varies due to the effect of irregular shape and spin axis orientation), there are usually very big errors affecting the absolute magnitude values listed in the available catalogs [11]. Moreover, the choice of the most suitable thermal model to process IR data obtained for any given object, particularly for small bodies, is not trivial *a priori*, and observations at more than one single thermal IR band are needed to make a good choice. As a result of all the above-mentioned sources of uncertainty, the resulting albedo estimates turn out to be often fairly uncertain. From the classical relation (see, for instance, [6])

$$\log(D) = 3.1236 - 0.2H - 0.5\,\log(p_V) \qquad (1)$$

where D is the size, H is the absolute magnitude and p_V is the geometric albedo, it follows that, assuming the error on H to be negligible (an extremely optimistic assumption) the relative error on the albedo turns out to be twice the relative error on the size. In non-optimal cases (observations of small objects in only one IR band), the uncertainty on the size can reach values around 30%. The corresponding error on the albedo in such cases can therefore be of the order of 60%.

For this reason, polarimetry can be a very useful technique to complement and calibrate thermal radiometry for the purposes of albedo determination. Geometric albedos derived by polarimetry do not depend upon the absolute magnitudes of the objects. They can be derived directly from observations based on some known relation between the albedo and the degree of linear polarization of the sunlight scattered by an object's surface in different illumination conditions. Of course, we have here a couple of problems: not only we have to identify a suitable relation between polarimetric properties and the geometric albedo, and to express it in a convenient mathematical form. We also have to calibrate the relation, namely to determine accurate values of the numerical coefficients present in the adopted mathematical relation.

In this paper, we briefly review the above problems, and we describe the current results of a campaign of polarimetric observations that we are carrying out to obtain a new, updated calibration of the most common form of the albedo polarization relation which has been generally adopted by many authors in most papers available in the literature.

2. Asteroid albedo from polarization measurements

The light that we receive from asteroids and other atmosphereless bodies in our Solar System is in a state of partial linear polarization. This is a consequence of the physical mechanism of scattering of sunlight by the solid surfaces of the objects. Since a long time it has been known that (1) the plane of linear polarization is found to be either parallel or perpendicular to the scattering plane, namely the plane containing the Sun, the object and the observer; (2) the degree of linear polarization varies as a function of the phase angle at the epoch of any given measurement. The phase angle is defined as the angle between the directions to the Sun and to the observer as seen from the object. The relation between phase angle and linear polarization is most conveniently described by expressing the polarization state in term of the so-called P_r parameter. This is defined as the product $P\cos(2\theta)$, where P is the measured degree of linear polarization and θ is the angle between the position angle of the polarization plane and the position angle of a plane perpendicular to the scattering plane, as measured from the observer. Equivalently, P_r can also be expressed as the ratio

$$P_r = \frac{(I_\perp - I_\parallel)}{(I_\perp + I_\parallel)}$$

where $I_\perp$ and $I_|$ are the measured light intensities with the electric vector perpendicular and normal to the scattering plane, respectively. Note, that in the latter relation P_r has really the meaning of a degree of linear polarization, due to the fact that the plane of polarization is always found to be either perpendicular or parallel to the scattering plane. The advantage of using P_r instead of simply P is that P_r gives simultaneously information on both the measured degree of linear polarization (equal to its absolute

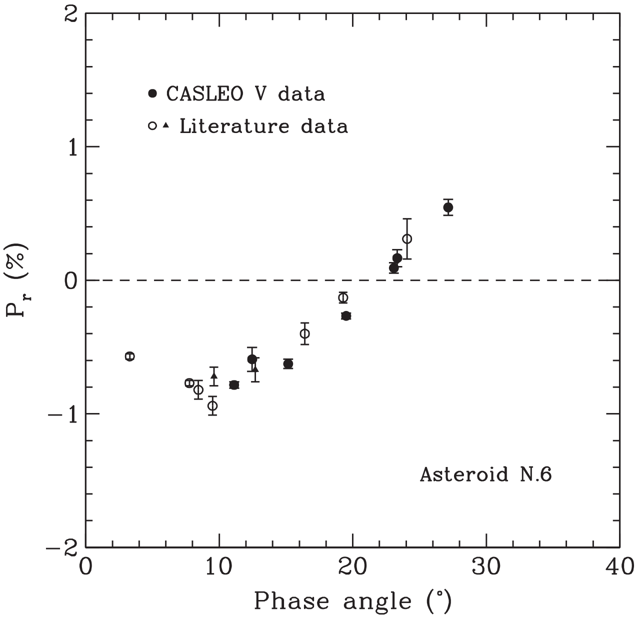

Fig. 1. The phase–polarization curve for asteroid (6) Hebe in *V* light. Displayed data include CASLEO observations (see Section 3) (full circles), literature data from the PDS website (APD file) (open circles), and data taken from Gil-Hutton and Cañada-Assandri [7] (triangles).

value) and on the orientation of the polarization plane (from its sign). Due to this fact, the authors commonly use the term "negative polarization" to indicate the situations in which the sign of P_r is found to be negative.

The general behaviour of the phase–polarization curve is shown, as an example, for the case of asteroid (6) Hebe which is fully representative of what is observed in all cases, in Fig. 1. From this figure it is easy to see the existence of a "negative polarization branch", namely an interval of phase angles for which P_r is found to be negative. The most negative value reached by P_r is commonly indicated as P_{min} in the literature. Beyond an *inversion angle* which is usually found to be around 20°, P_r becomes positive, and tends to increase much for increasing phase angles up to some maximum value P_{max} which is encountered at phase angles around 80–100°. Of course, this is not measurable by ground-based observations of main belt asteroids, since the maximum possible values of the phase angle for these objects are generally of the order of 30° due to obvious geometric constraints. Ground-based observations at larger phase angles are possible only for bodies which approach the Earth at much smaller distances, like the near-Earth objects (as an example, see [2]). A well known and important feature of the phase-polarization curves exhibited by all classes of asteroids is that the increase of P_r is mostly linear in a wide interval of phase angles around the inversion value. The slope of this linear increase is commonly indicated in the literature by the symbol h.

The general trend of the phase–polarization curve shown in Fig. 1 is exhibited by all atmosphereless Solar System bodies, but the details of this trend vary among different objects. In particular, the depth of the negative polarization branch and the steepness of the h slope appear to be related to the surface albedo. The relation which has been classically adopted in the literature (see, for instance [5]) is the following:

$$\log(p_V) = C_1 \log(h) + C_2 \tag{2}$$

where h is the phase–polarization slope mentioned above, and C_1 and C_2 are two calibration coefficients to be derived from observations. Another relation having the identical form, but linking p_V with another polarimetric parameter, P_{min}, has also been used, but it is generally known that it is less strict than the one expressed by Eq. (2).

An important difficulty encountered in asteroid polarimetry has been just the derivation of a satisfactory calibration of the slope–albedo relation, i.e., the determination of the calibration coefficients C_1 and C_2. In practical terms, one needs to have at disposal a sample of objects for which both the albedo and the polarization properties are known with good accuracy. Unfortunately, the accurate measurement of the albedo for small Solar System bodies is a very difficult task. After the first pioneering work by Zellner et al. [14], Chapman et al. [3], Zellner and Gradie [15], in which the slope–albedo relation was first introduced and was tentatively calibrated using mostly samples of lunar material, for a long time the calibration of Eq. (2) has been most commonly based on the use of data sets of asteroid albedos derived by means of thermal radiometry, particularly based on IRAS data. This has led to some confusion, since the data reduction of asteroid observations by IRAS has been done at different stages. Different choices were made for the photometric system to be used to derive the values of absolute magnitudes (in visual light) which are needed to derive the albedo from radiometric measurements. The most updated reduction of IRAS asteroid data has been published by Tedesco [13].

In particular, the calibration of Eq. (2) proposed by Lupishko and Mohamed [9] was based on a mixing of albedos obtained from different reductions of IRAS data. This fact led Cellino et al. [1] to propose another, updated calibration using a self-consistent data set of radiometrically derived albedos.

The situation, however, is still very confused, with different authors adopting different calibrations in different papers. For this reason, IAU Commission 15 in 2006 set up a Task Group for Asteroid Polarimetric Albedo Calibration, to make a re-assessment of the situation and to propose a unique, updated calibration of the albedo–polarization relation.

It should be noted that the simplest possible idea, namely that of calibrating Eq. (2) by means of laboratory experiments making use of suitable materials, including meteorite samples, is not exempt from problems. This is due to the fact that, on one hand, experiments should be done in conditions ideally identical to those applicable to real asteroids, including regolith surface properties (and also temperatures), which are not easy to reproduce in the laboratory, because meteorites do not give us very detailed information on the structures and textures of the regolith layers covering the surfaces of their parent bodies. Moreover, the measurement of geometric albedo requires necessarily, due to the very definition of this parameter, photometric measurements in the laboratory to be done at zero phase angle illumination conditions. Unfortunately, observations at zero phase angle are not easy to be done in practice. The problem is that observing the scattered light at phase angles different from zero, even at quite small phase angles, can affect the determination of the albedo, due to the strongly non-linear opposition brightness surge which takes place at small phase angles in many cases, mainly for high-albedo surfaces ([10], and references therein).

For this reason, an ideal procedure should be based on the use of samples of real asteroids for which the albedo is indeed well known. Due to the problems and intrinsic uncertainties of the albedos derived from thermal radiometry, however, these same albedos are in principle not suitable for the calibration task. Of course, this is a severe problem, since most asteroid albedos have been derived from thermal radiometry.

A significant step forward to improve the situation has been done by Shevchenko and Tedesco [12], who published a list of asteroids whose albedos are expected to be quite accurate, because they were derived from knowledge of the absolute magnitude, coupled with very reliable determinations of the size, derived directly from the observation of stellar occultation events. In particular, the above authors considered a list of 57 objects for which only high-quality occultation events had been measured, leading to the best available determination of their sizes. For 18 of them, the estimated accuracy in the derived sizes is better than 5%. Moreover, the Shevchenko and Tedesco target list also includes four additional objects which have been visited *in situ* by space probes. Since the sizes of the asteroids in the Shevchenko and Tedesco list are known with good accuracy, and their absolute magnitudes are also supposed to be well known, their albedos were derived using Eq. (1). In this computation, the adopted value of the absolute magnitude H is potentially the most important source of error. Shevchenko and Tedesco [12] subdivided their sample into four categories, based on the expected quality of the adopted H value, and assigned to each of these categories a different expected albedo quality, ranging between a maximum expected relative error of about 3% up to a value of about 15%. We remind that, in an ideal situation, one should use for each object a value of H which not only must be obtained from an accurate analysis of the observed phase-brightness variation for the object, but it must also correspond to a geometric cross-section (aspect angle) equal to the one characterizing the observing circumstances at the epoch of the recorded star occultation event.

Having at disposal a list of asteroids for which the albedo is supposed to be known with good accuracy, the next step is obviously to obtain a sufficient coverage of their phase–polarization curves, in order to derive reliable measurements of the polarimetric slopes h. Some of the objects in the Shevchenko and Tedesco are very bright and have been extensively observed in the past using polarimetry. For most of them, however, only a few, if any, polarimetric data are available. For this reason, we have started an observing campaign aimed at obtaining new polarimetric data for all these asteroids. The preliminary results of this effort, which is still in progress, are presented in this paper.

3. Available data and new observations

Since several years, we have been carrying out polarimetric observations of asteroids at the Complejo Astronomico El Leoncito (CASLEO) in Argentina. Observations were done using the FOTOR photopolarimeter built at the Astronomical Observatory of Torino ([1], and references therein) and, more recently, using the CASPROF photopolarimeter developed at CASLEO [7]. Many targets have been repeatedly observed, and in recent observing runs high priority was assigned to the asteroids belonging to the Shevchenko and Tedesco [12] target list. The polarization measurements were made in the standard V band. In the case of some FOTOR observations, measurements in other colours were also obtained in several cases. A comprehensive analysis of all unpublished CASLEO data obtained in the most recent observing runs will be presented in a separate paper (Gil-Hutton et al. [8]). The subset of data used for the analysis presented in this paper will be made publicly available at the web page of the Astronomical Observatory of Torino, and will be also submitted soon to the public PDS web repository (http://pds.jpl.nasa.gov/).

In addition to our CASLEO data, we also used data already available in the literature, in particular at PDS (the APD file available at URL http://starbrite.jpl.nasa.gov/pds/viewDataset.jsp?dsid=EAR-A-3-RDR-APD-POLARIMETRY-V6.0) and from the Gil-Hutton and Cañada-Assandri [7] paper.

Polarimetric slopes were obtained for a sample of 25 asteroids. In particular, only data obtained at phase angles larger than 13° were used for the determination of the polarimetric slope h, and of the inversion angle of the phase–polarization curve. Both h and the inversion angle were obtained from a weighted linear least-square fit of available data. In our computations of polarimetric slopes, we considered only objects for which at least three observations at phase angles larger than 13° were considered, but in the two cases of asteroids (404) and (431), for which we computed the polarimetric slope using only two good-quality polarimetric measurements. Of course, the associated uncertainties of the polarimetric slopes of these two objects were computed by considering the maximum error resulting from the nominal uncertainties in the two available P_r data, and turn out to be much larger than in the other cases in our sample.

The data and resulting fits for the objects of our sample are shown in Figs. 2–4.

4. Results and discussion

The overall results of our exercise are given in Table 1, in which we give, for each observed object belonging to the Shevchenko and Tedesco [12] list, the resulting polarimetric slope h with its associated error resulting from the least-squares fit of the data, the resulting inversion angle corresponding to the computed fit, the albedo derived by Shevchenko and Tedesco [12] based on the adopted

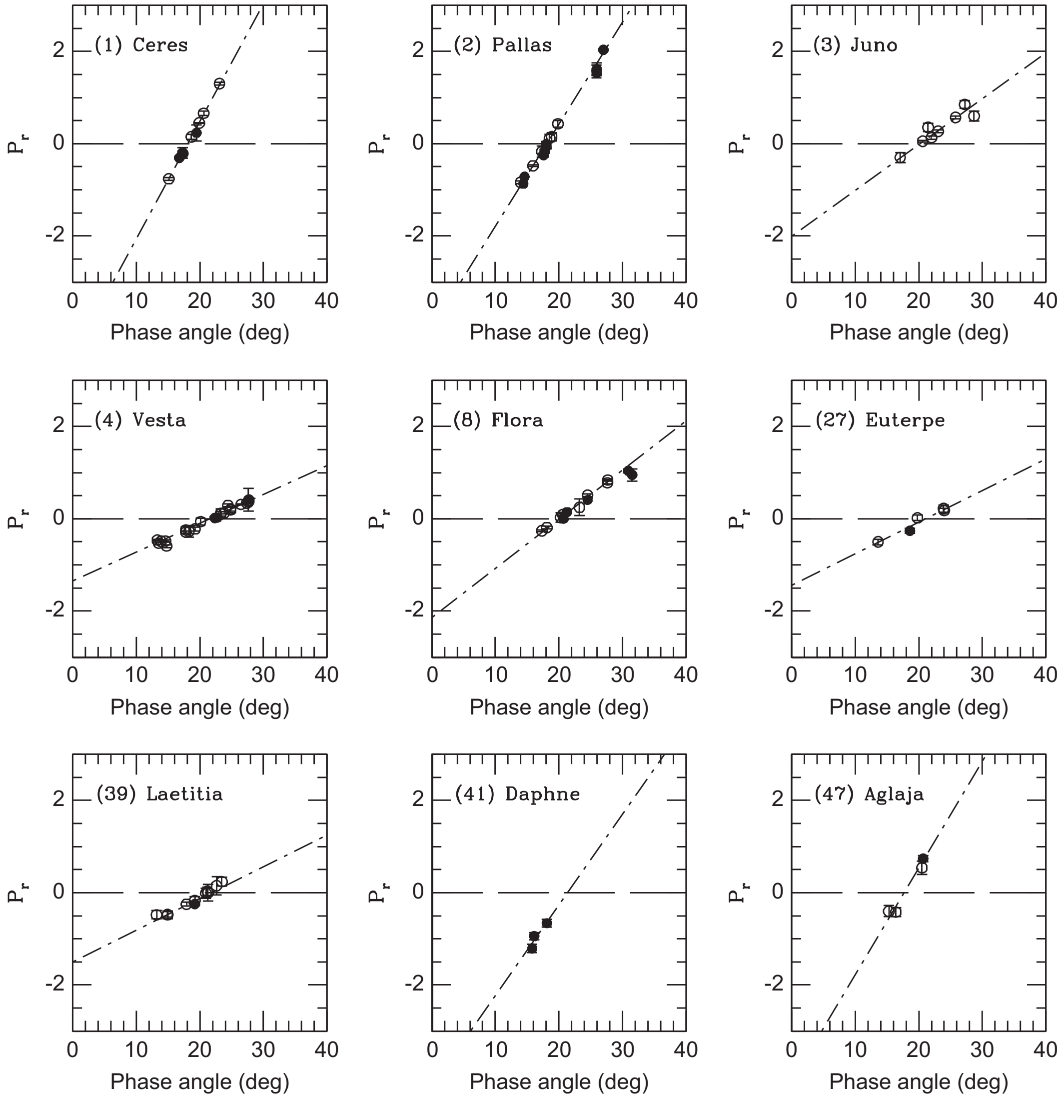

Fig. 2. Obtained polarimetric slopes h for asteroids. (1) Ceres, (2) Pallas, (3) Juno, (4) Vesta, (8) Flora, (27) Euterpe, (39) Laetitia, (41) Daphne and (47) Aglaja. Open symbols: data published in the literature. Full symbols: data obtained from new (and older) observations carried out at CASLEO. Only polarimetric measurements obtained at phase angles larger than 13° have been used to derive the polarimetric slopes shown in the plots.

occultation-derived size and adopted H value, its nominal error according to the quality class assigned by the above authors, the resulting albedo, with its uncertainty, corresponding to the new calibration of the h-albedo calibration described below, and the corresponding relative error of the new albedo computation. We are aware that the quality of the adopted polarimetric data for (253) Mathilde is quite bad, as clearly shown in Fig. 4. It is evident that new and more accurate polarimetric data for this object are sorely needed. Due to the fact that the derived polarimetric slope for (253) Mathilde corresponds to the highest value in our samples, and this could in principle affect the resulting calibration of the slope–albedo relation, we have looked at the effect of removing this object from our data set. What we found is that the results described in what follows do not change appreciably. For this reason, we decided to keep the Mathilde data in our sample.

In this paper we have adopted the classical form of the slope–albedo relation described by Eq. (2). By using a least-squares fitting procedure based on the Shevchenko and Tedesco [12] albedo values and our obtained polarimetric slopes for the objects of our sample, we obtained the following new values for the calibration coefficients appearing in Eq. (2):

$$C_1 = -0.970 \pm 0.071$$

$$C_2 = -1.677 \pm 0.083$$

By removing the data for (253) Mathilde, the solution does not change (we find in this case $C_1 = -0.971 \pm 0.073$, $C_2 = -1.677 \pm 0.085$, completely equivalent to the nominal solution including Mathilde). A fit of our resulting calibration is shown in Fig. 5.

In Fig. 6, finally, we show the resulting polarimetric albedos for the objects of our sample resulting from our new calibration of the polarimetric slope–albedo relation, and the albedo derived for the same objects by Shevchenko

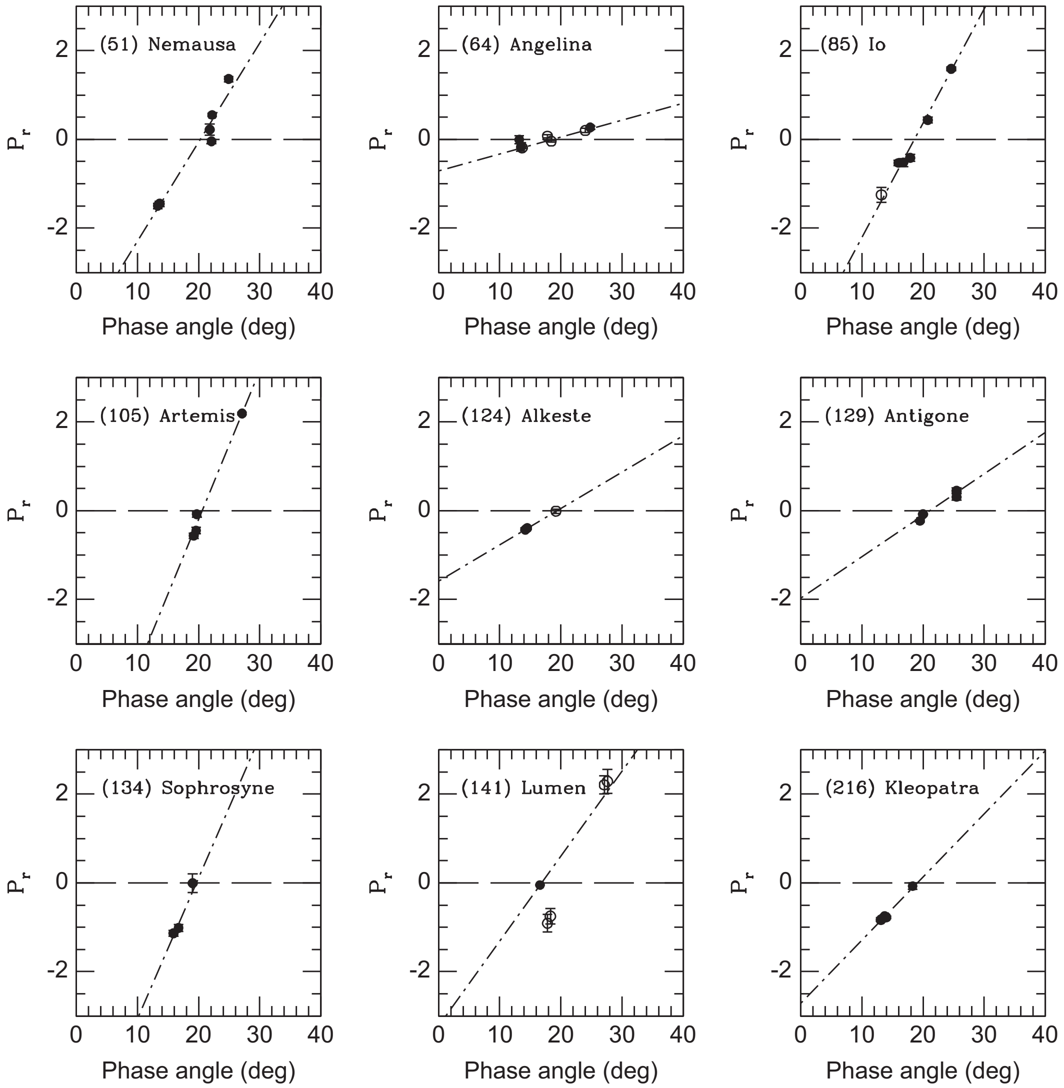

Fig. 3. The same as Fig. 2, but for the asteroids (51) Nemausa, (64) Angelina, (85) Io, (105) Artemis, (124) Alkeste, (129) Antigone, (134) Sophrosyne, (141) Lumen and (216) Kleopatra.

and Tedesco [12] based on knowledge of the sizes and absolute magnitudes.

When looking at the error bars in the polarimetric albedos shown in Fig. 6, one immediately notes that they tend to be increasingly large for increasing albedo. This fact is a consequence of the adopted form for the slope–albedo relation. By assuming in fact the expression given in Eq. (2), and doing a formal computation of the associated error of p_V, that we will call $\sigma(p_V)$, due to the errors in h, C_1 and C_2, that we will call $\sigma(h)$, $\sigma(C_1)$ and $\sigma(C_2)$, respectively, it is easy to see that one obtains that

$$\sigma(p_V) = p_V\sqrt{(\ln h)^2\sigma^2(C_1) + \left(\frac{C_1}{h}\right)^2\sigma^2(h) + (\ln 10)^2\sigma^2(C_2)} \quad (3)$$

which shows that $\sigma(p_V)$ turns out to be directly proportional to p_V. On the other hand, the same is true also for the Shevchenko and Tedesco [12] albedos derived from knowledge of the size and absolute magnitude, since the above authors quantify the expected errors of their albedo determinations in terms of relative error, depending on the assumed quality of the adopted value of absolute magnitude. For this reason, it can be seen from the plot that low albedo objects tend in any case to have smaller absolute values of their associated errors.

The newly obtained values for the C_1 and C_2 coefficients turn out to be closer to the older Lupishko and Mohamed [9] results ($C_1 = -0.983 \pm 0.082$, $C_2 = -1.731 \pm 0.066$) than to the more recent Cellino et al. [1] values ($C_1 = -1.118 \pm 0.071$, $C_2 = -1.779 \pm 0.062$). The most important consequence is that, if one looks at Fig. 5, at small values of polarimetric slope h, the corresponding albedo turns out to have more moderate values than in the case of the Cellino et al. [1] calibration. In this respect, the new calibration seems to give more realistic albedo values. For instance, in the case of the asteroid (64) Angelina, the nominal albedo value derived using the new calibration presented in this paper turns out to be 0.50, much closer to the Shevchenko and Tedesco value of 0.47 than the value of 0.64 which would result from application of the Cellino et al. [1] calibration.

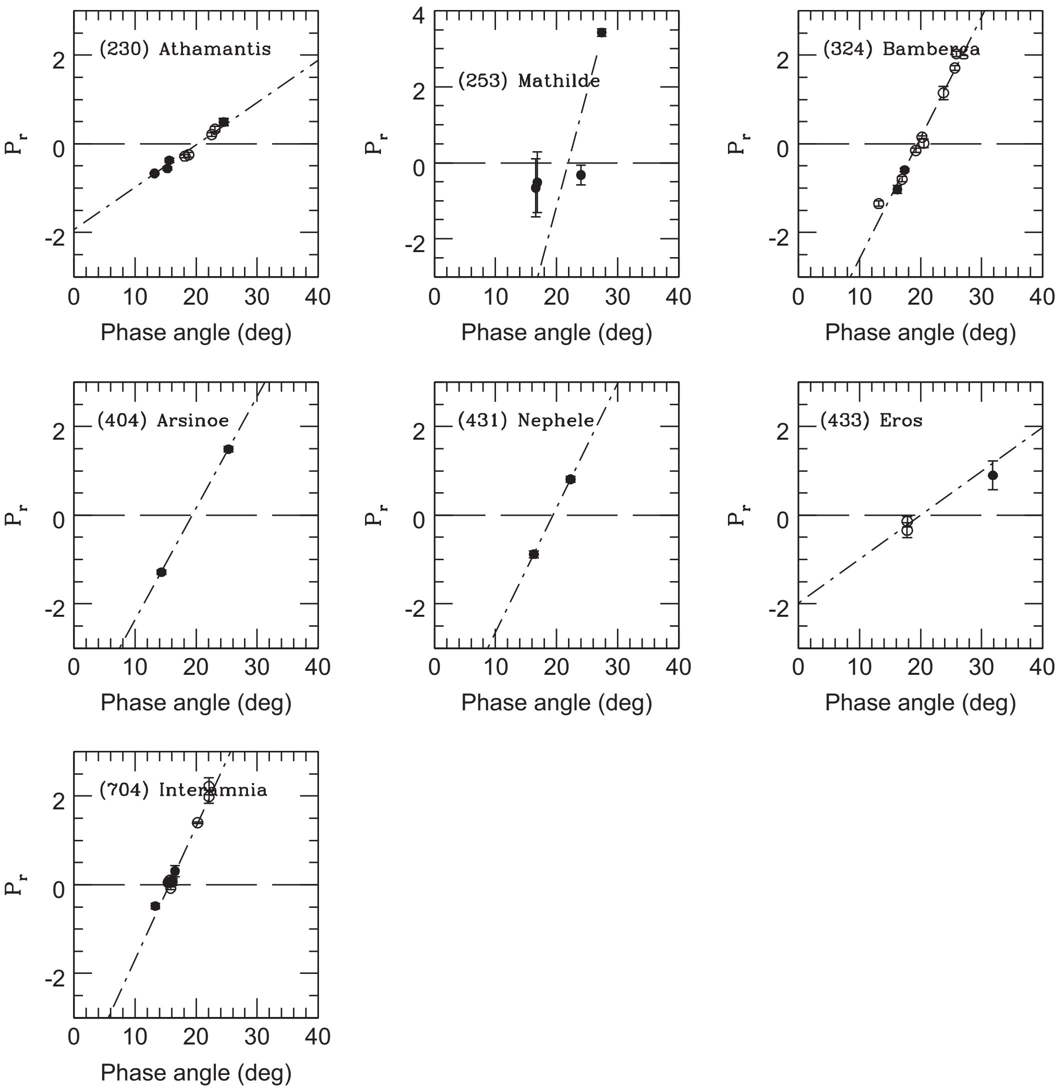

Fig. 4. The same as Fig. 2, but for the asteroids (230) Athamantis, (253) Mathilde, (324) Bamberga, (404) Arsinoe, (431) Nephele, (433) Eros, and (704) Interamnia.

It can also be interesting to note that, using the new calibration coefficients, the albedo of the potentially hazardous asteroid (99942) Apophis turns out to be 0.28 ± 0.08, a slightly lower albedo than the 0.33 ± 0.08 value found by Delbò et al. [4] using the Cellino et al. [1] calibration. This corresponds to a diameter of 280 ± 60 m, assuming for H the value of 19.7, suggested by Delbò et al. [4]. If this is correct, (99942) Apophis should be just a little larger, but still within the interval of uncertainty of the value given by Delbò et al. [4].

One should also note that, although the relative uncertainty in the albedo values computed from available polarimetric slopes turns out to be of the order of 20%, which looks fairly reasonable, it is still true that the points in the slope–albedo plot shown in Fig. 5 are quite scattered, and the resulting fit seems not completely satisfactory. We think that this may be the effect of the interplay of several possible explanations: on one hand, we are aware that our sample is still limited, and we should and will try and get a larger number of observations for these and other objects of the Shevchenko and Tedesco list, in order to obtain for them more accurate values of h. Another possible explanation is the error which affects the albedo values obtained by Shevchenko and Tedesco [12] due to uncertainty in the adopted absolute magnitude values (see Eq. (1)). A third possibility is that the generally adopted form of the albedo–polarization relation expressed by Eq. (2) might be not fully adequate. This is in our own opinion the most likely possibility, and it is also the most exciting one, because it opens new perspectives for the research in this field. On one hand, the relation between the polarimetric slope h and the geometric albedo might be possibly different, and a better formulation might produce smaller residuals. On the other hand, one should also explore the possibility that the use of polarimetric slope h alone is not sufficient to build the best possible relation between the albedo and polarimetric properties.

We are just now exploring new ways to derive from observed P_r-phase curves some better relations with the albedo, but the results of this effort, which constitutes the next step of our current project aimed at improving the

Table 1
For each object considered in our analysis, identified by its number, the columns give the number N_{obs} of observations adopted to derive the results, the computed polarimetric slope h with its nominal $1-\sigma$ uncertainty, the inversion angle α_{inv}, the Shevchenko and Tedesco [12] albedo, the albedo p_V resulting from the new calibration proposed in this paper, and its relative error (in %), respectively.

Number	N_{obs}	h	α_{inv}	S&T albedo	$p_V(h)$	%
1	9	0.2549 ± 0.0002	18.09	0.0936 ± 0.005	0.079 ± 0.017	21.4
2	18	0.2211 ± 0.0002	18.10	0.145 ± 0.004	0.091 ± 0.020	21.9
3	10	0.0974 ± 0.0008	20.17	0.187 ± 0.006	0.201 ± 0.051	25.3
4	23	0.0623 ± 0.0001	21.53	0.370 ± 0.022	0.311 ± 0.085	27.5
8	13	0.1066 ± 0.0002	20.02	0.197 ± 0.012	0.185 ± 0.046	24.9
27	5	0.0685 ± 0.0006	21.10	0.298 ± 0.045	0.283 ± 0.076	27.0
39	11	0.0686 ± 0.0006	21.84	0.246 ± 0.015	0.283 ± 0.076	27.0
41	3	0.1968 ± 0.0070	21.39	0.0609 ± 0.004	0.102 ± 0.023	22.6
47	4	0.2311 ± 0.0034	17.67	0.0596 ± 0.002	0.087 ± 0.019	21.8
51	6	0.2232 ± 0.0016	20.31	0.0970 ± 0.006	0.090 ± 0.020	21.9
64	7	0.0381 ± 0.0003	18.54	0.474 ± 0.047	0.501 ± 0.151	30.1
85	6	0.2583 ± 0.0012	18.61	0.0520 ± 0.004	0.078 ± 0.017	21.4
105	4	0.3351 ± 0.0011	20.56	0.0470 ± 0.005	0.061 ± 0.013	20.6
124	3	0.0821 ± 0.0001	19.31	0.240 ± 0.036	0.238 ± 0.062	26.1
129	4	0.0933 ± 0.0008	21.07	0.183 ± 0.018	0.210 ± 0.054	25.5
134	3	0.3159 ± 0.0143	19.63	0.0398 ± 0.001	0.064 ± 0.014	21.2
141	5	0.1912 ± 0.0135	16.86	0.0493 ± 0.005	0.105 ± 0.025	23.5
216	6	0.1425 ± 0.0005	19.08	0.170 ± 0.010	0.139 ± 0.033	23.6
230	8	0.0954 ± 0.0002	20.30	0.192 ± 0.019	0.206 ± 0.052	25.4
253	5	0.6058 ± 0.0798	21.92	0.036 ± 0.001	0.034 ± 0.008	23.3
324	10	0.2730 ± 0.0010	19.47	0.0505 ± 0.003	0.074 ± 0.016	21.2
404	2	0.252 ± 0.020	19.48	0.0451 ± 0.008	0.080 ± 0.018	22.8
431	2	0.282 ± 0.050	19.42	0.122 ± 0.019	0.072 ± 0.020	27.2
433	5	0.0991 ± 0.0009	20.05	0.29 ± 0.009	0.198 ± 0.050	25.2
704	11	0.3002 ± 0.0007	15.64	0.0600 ± 0.002	0.068 ± 0.014	20.9

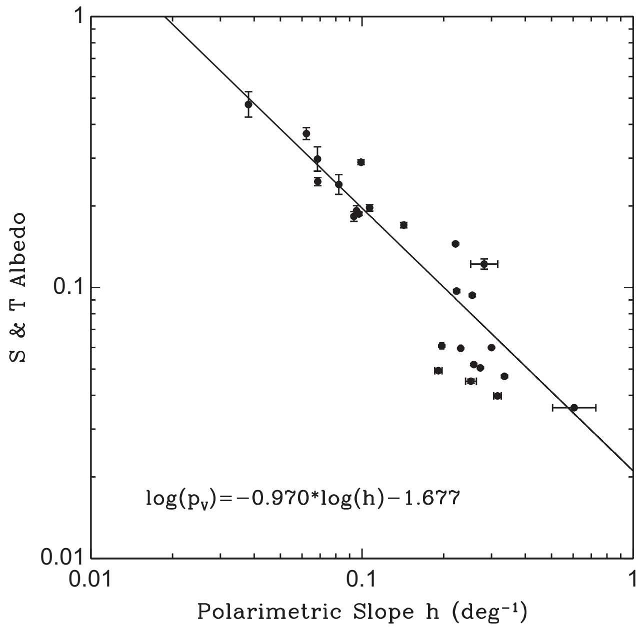

Fig. 5. Fit of the $\log(p_V)=C_1\log(h)+C_2$ relation, using the data set analyzed in the present paper.

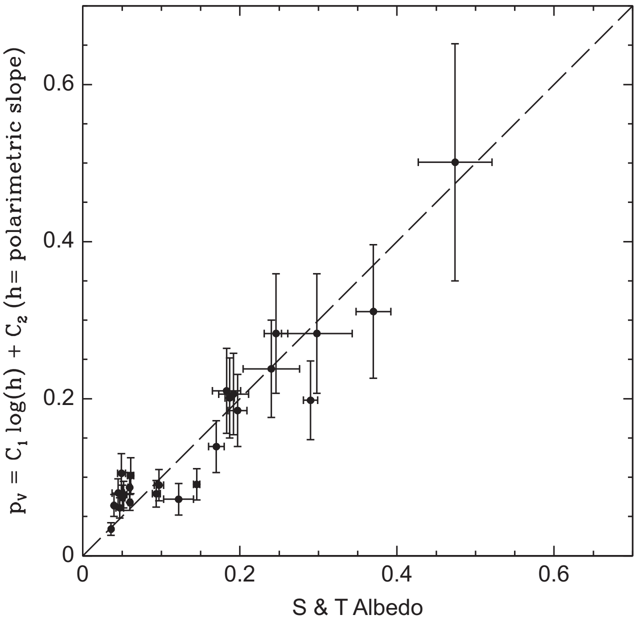

Fig. 6. This figure shows for the objects of our sample listed in Table 1 the resulting plot of the new polarimetric albedo obtained from the new calibration of Eq. (2) presented in this paper and the albedo value derived by Shevchenko and Tedesco [12] for the same objects.

state of the art in asteroid polarization studies, will deserve a separate paper, which will also include the results of new imminent observing runs. For the moment, however, we think that the results we have obtained so far by adopting the "classical" h–p_V relation are already interesting, although we are aware that more observations, which we will continue to do in the future, will be necessary to obtain better and larger data sets of polarization data needed to strengthen the results of this work, which is still in progress.

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