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Polarimetric evidence of close similarity between members of the Karin and Koronis dynamical families ☆

A. Cellino [a,*], M. Delbò [b], Ph. Bendjoya [c], E.F. Tedesco [d]

[a] INAF, Osservatorio Astronomico di Torino, strada Osservatorio 20, 10025 Pino Torinese, Italy
[b] Laboratoire Cassiopée, Observatoire de la Cote d'Azur, BP 4229, 06304 Nice cedex 4, France
[c] UMR 6525 H. Fizeau, UNS-CNRS-Observatoire de la Cote d'Azur, Campus Valrose, 06108 Nice cedex 2, France
[d] Planetary Science Institute, Tucson, AZ, USA

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ABSTRACT

We present the results of a campaign of polarimetric observations of small asteroids belonging to the Karin and Koronis families, carried out at the ESO Cerro Paranal Observatory using the VLT-Kueyen 8-m telescope. The Karin family is known to be very young, having likely been produced by the disruption of an original member of the Koronis family less than 6 Myr ago. The purpose of our study was to derive polarimetric properties for a reasonable sample of objects belonging to the two families, in order to look for possible systematic differences between them, to be interpreted in terms of differences in surface properties, in particular albedo. In turn, systematic albedo differences might be caused by different times of exposure to space weathering processes experienced by the two groups of objects. The results of our analysis indicate that no appreciable difference exists between the polarimetric properties of Karin and Koronis members. We thus find that space-weathering mechanisms may be very efficient in affecting surface properties of *S*-class asteroids on very short timescales. This result complements some independent evidence found by recent spectroscopic studies of very young families.

1. Introduction

The Karin family is an extremely young cluster of objects with an estimated age of less than 6 Myr ago (Nesvorný et al., 2006). Since it is located, in the space of orbital proper elements, inside the big Koronis family, it is extremely likely that the Karin family was produced by the collisional disruption of a parent body that was originally a member of the Koronis family. Karin members should be therefore second-generation fragments deriving from the body that produced the Koronis family more than 1 Gyr ago. The much longer estimated age of Koronis is based on the Galileo probe observations of the cratering record on (243) Ida and its small satellite Dactyl.

We remind that Koronis members belong to the populous *S* taxonomic class, that according to many authors is believed to include the parent bodies of Ordinary Chondrites (Chapman, 1996a,b; Clark et al., 2002). We also remind that the Koronis family does not represent an exception to the general observational evidence that families are quite homogeneous in compositions, since the reflectance spectra of members of the same family are generally found to be very similar (Cellino et al., 2002).

If the above inferences are correct, a comparative analysis of the properties of Karin and Koronis members is in principle an ideal tool to study the observable effects of different times of exposure to space weathering processes affecting the surfaces of objects of nearly identical composition.

According to current knowledge, the effect of exposure to space weathering effects on *S*-class asteroid surfaces is twofold. On one hand, the spectral reflectance properties tend to progressively change, leading to an overall reddening of the spectrum, and to a relative decrease in depth of the silicate absorption feature around 1 μm in wavelength. A preliminary spectroscopic analysis of a sample of objects belonging to another very young family, Iannini, suggested that the characteristic timescale for space weathering evolution of spectral reflectance might be of the order of 570 ± 220 Myr (Willman et al., 2008). Spectroscopic observations of several members of the Karin family gave in the past controversial results. In particular, available data seemed to indicate that these objects tend to exhibit a less reddish spectral trend with respect to typical *S*-class asteroids (Chapman et al., 2007). At the same time, however, it was found also that the 1 μm absorption band might be quite shallow, more than would be expected for fresh surfaces not heavily modified by space-weathering mechanisms.

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* Corresponding author. Address: INAF – Osservatorio Astronomico di Torino, strada Osservatorio 20, I-10025 Pino Torinese (TO), Italy. Fax: +39 11 8101930.
E-mail addresses: cellino@oato.inaf.it (A. Cellino), delbo@oca.eu (M. Delbò), Philippe.Bendjoya@unice.fr (Ph. Bendjoya), eft@psi.edu (E.F. Tedesco).

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More recently, a more comprehensive spectroscopic survey of members belonging to some among the youngest families identified so far, including those of Datura, Lucascavin and Karin, led Vernazza et al. (2009) to conclude that the reddening of the surfaces of asteroids belonging to the *S* class is an extremely rapid process, occurring during the first 10^6 years since family formation.

The present paper focuses on another expected effect of exposure to space weathering, namely a progressive decrease of the albedo of the surface. As in the case of spectral reddening, this additional effect is thought to occur as a result of separation and deposition of nanophase iron (Hapke, 2001; Noble et al., 2001). The albedo of asteroid surfaces may be determined by means of polarimetric observations. A comparison of the observable polarimetric properties of Karin and Koronis members, therefore, can be very interesting. If the space weathering process would act relatively slowly, one should expect to find evidence of systematic differences between the polarimetric properties of objects having ages of 6 Myr and 1 Gyr, respectively. On the other hand, if the space-weathering mechanism is capable of modifying very efficiently the geometric albedo, reaching some kind of saturation over very short timescales, as suggested by the spectroscopic results quoted above, and also confirmed by some laboratory experiments (Brunetto and Strazzulla, 2005; Brunetto et al., 2006), no strong differences should be expected for the two samples. Since we cannot be sure that the process of detectable reddening and that of detectable modification of polarimetric properties should have necessarily identical timescales, it is very interesting to investigate the polarimetric properties of different members of the Koronis and Karin families, and to compare them. This is exactly the subject of this paper.

2. Asteroid polarimetry

The basic idea of our analysis is to derive phase–polarization data for objects belonging to the Karin and Koronis families, in order to look for some possible systematic difference between the behavior of the members of the two groups. If present, such differences may be interpreted in terms of different properties of the surfaces of the members of the two families. In particular, we have tried to obtain polarimetric data in ranges of phase angles which may be useful to derive evidence of some systematic difference in surface albedo.

For those who are not familiar with asteroid polarimetry, we remind that the light we receive from asteroids is in a state of partial linear polarization. The observations show that the polarization plane is normally found to be, with very good approximation, either parallel or perpendicular to the Sun–asteroid–Earth plane (the scattering plane), depending on the value of the phase angle. The results of polarimetric observations are usually expressed using the P_r parameter, defined as the ratio

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

where $I_\perp$ and $I_\parallel$ are the intensities of the components of scattered light with the electric field vector oscillating in the planes perpendicular and parallel to the scattering plane, respectively. If we indicate as θ the angle between the position angle of the linearly polarized beam and the position angle of the plane perpendicular to the scattering plane at the epoch of the observation, we can also write that the relation between the measured degree of linear polarization P and the P_r parameter is given by:

$$P_r = P\cos(2\theta)$$

The advantage of using P_r, is that, according to its definition, the absolute value of P_r gives directly the degree of linear polarization, while its sign specifies the orientation of the polarization plane (either parallel or normal to the scattering plane).

The polarimetric properties of asteroids are generally described through an analysis of the variation of P_r as a function of different illumination conditions, described by the value of the phase angle. The latter is defined as the angle between the directions to the Sun and to the observer, as seen from the asteroid. Typical phase–polarization curves of asteroids are characterized by an interval of phase angles for which P_r has negative values, the so-called negative polarization branch. The extreme value P_{min} of the negative branch is normally reached between 8 and 10 degrees of phase. P_r changes sign at an *inversion angle* usually occurring around 20 degrees of phase. Around the inversion angle, the variation of P_r as a function of phase is usually well described by a linear relation, and its slope computed at the inversion angle is conventionally indicated as h. A classical result of laboratory experiments and astronomical observations is that there is a relation between the slope h and the surface albedo. Another, though less strict, relation exists also between albedo and P_{min}. These relations are conventionally expressed in very simple mathematical form, as

$$\log(p_V) = C_1 \log x + C_2$$

where x is either h or P_{min}, and the values of the two constants C_1 and C_2 vary accordingly. The most recent calibration of the albedo–polarization relation (namely the values to be used for the two coefficients in the above formula) has been published by Cellino et al. (1999), and we will use it in our present analysis. We note that older calibrations exist in the literature, and are still used by several authors. This is a source of confusion, and it is clear that one urgent goal in asteroid polarimetry is to converge to a unique and updated choice of the calibration coefficients. IAU Commission 15 has appointed a Working Group of specialists with the goal of solving this problem as soon as possible, but it is clear that many new observations are needed to fulfil this task.

Summarizing, polarimetry provides information on some properties of surface regolith which can hardly be obtained by means of other techniques. In particular, polarimetry is one of the best available techniques for the determination of the geometric albedo, mainly for small objects, with particularly useful applications to near-Earth objects (Cellino et al., 1999, 2005a,b; Delbò et al., 2007). The polarimetric behavior is also thought to be related to other properties, including the typical sizes of regolith particles (Dollfus et al., 1989), and/or the distances of light scatterers in the crystalline structure of the surface material, and its refractive index (Masiero et al., 2009). The major problem in asteroid polarimetry is that it is not easy to develop a comprehensive analytical theory based on current knowledge of light scattering properties, to quantitatively explain in details the whole body of observational evidence. Some of the commonly exploited relations between polarimetric properties and physical parameters are still at least partly empirical, although important advances have been done in recent years on the theoretical side (Muinonen et al., 2002a; Shkuratov et al., 2002). According to these studies, the most important phenomenon determining the observed polarimetric properties of atmosphereless Solar System bodies is coherent backscattering.

On the other hand, it is well established that asteroids belonging to different taxonomic classes exhibit differences in the details of their phase–polarization curves, and this is interpreted in terms of corresponding differences in regolith particle properties, including primarily albedo (Penttilä et al., 2005). It is thus very interesting in principle to compare the polarimetric properties of bodies having likely the same mineralogical composition, but having been exposed for very different times to space weathering effects that are known to produce observable effects on the properties of regolith particles, including spectral reflectance and albedo.