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Ground-Based Optical Observations of Asteroids

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Abstract. Many physical parameters of asteroids can be inferred from remote measurements at optical wavelengths. These observations constitute the bulk of the information we have about these objects, and nicely complement the detailed physical studies which are made possible by in situ explorations of a few selected targets. The discovery of many binary systems for which mass determinations become possible, the identification of hydration features in asteroid spectra, including unexpectedly many M-types, the detection of space-weathering phenomena affecting S-type near-Earth objects, as well as improved estimates of sizes, albedos, and spin properties for many objects are among the major results obtained in recent years by means of remote-sensing techniques. These data can be used to infer important properties of the internal structures of the asteroids.

1. Introduction

Remote observations by means of ground-based instruments and orbiting detectors have been for a long time the unique source of information about all kinds of asteroids. Starting since the successful detection of Gaspra and Ida by the Galileo spacecraft, however, automatic space probes begun to provide a wealth of new information, including images at the highest possible resolutions and a wide variety of data by means of different detectors. At present, missions aimed at collecting and bringing back to Earth direct samples of asteroidal material are under way (Hayabusa mission) and this can possibly lead to another major step forward in our understanding of asteroids.

All this does not mean, however, that in the modern era of space missions remote observations are became obsolete. In spite of the spectacular results obtainable by means of space probes, short-distance observations cannot be expected to be performed but for a tiny sample of the whole asteroid population. The data obtained by space probes are invaluable to produce detailed understanding of a few selected bodies, but equally important is the fact that in situ exploration are a wonderful tool to confirm, reject or modify some previous interpretations of remote-sensing data. In this way, an improved reliability of the conclusions based on ground-based observations can be achieved, leading to a much better understanding of asteroidal bodies.

In turn, remote-sensing data are essential for a successful planning of space missions and for the identification of the most important targets, which are normally chosen according to criteria based on available observational evidence. Ground-based observations are also usually needed as an invaluable support during and after a space mission. In this sense, we can conclude that remote sensing and in situ exploration nicely complement each other in our attempt to improve our understanding of the origin, evolution and current physical properties of the asteroid population.

In what follows, I give a forcedly short summary of some recent results of ground-based observations of asteroids at optical wavelengths, using a wide variety of techniques. Several groups in different countries are at work, and the results of all these activities open new paths of investigation, and are the basis for further developments, both on the observational and on the theoretical side, in the next years. All the new ideas which are emerging will undoubtedly influence the concepts and designs of future space missions to asteroids.

This paper is organized in different Sections, each one being devoted to recent activities and results obtained by a different technique.

2. Photometry

Lightcurve photometry has been historically one of the main tools to derive physical information since the early times of modern asteroid science.

The main goals of these observations have been traditionally the measurement of the spin period and the derivation of the spin axis direction. In spite of the presence of problems of uniqueness of the solutions, lightcurve data have long been proven to be sufficient to derive reasonable estimates of the overall shapes of the objects at least in some favourable cases, when a sufficient number of lightcurves collected at different oppositions are available. A good example of this was the computation of the overall shape of 951 Gaspra before the Galileo fly-by (Barucci et al. 1992). Even before, a general model of the flattening and albedo spot was obtained for asteroid 4 Vesta by Cellino et al. 1987. This model has been largely confirmed by direct HST images collected ten years later (Thomas et al. 1997).

The situation in the field of lightcurve inversion has significantly improved in more recent years through the development of more sophisticated mathematical techniques (Kaasalainen, Mottola and Fulchignoni 2002).

An important contribution of lightcurve studies to the general understanding of asteroid internal structures comes from an analysis of the distribution of the rotation periods as a function of the objects' sizes. As extensively discussed by Pravec, Harris and Michalowski (2002) it turns out that practically all objects, down to sizes of a few km, have spin periods below the fission limit for rubble piles. This fact is interpreted as a major proof that asteroids are not monolythic down to sizes of less than 10 km.

Further recent developments in the field of asteroid photometry include the identification of asteroid binaries through discovery of multiple periodicities (Pravec et al. 2002; Merline et al. 2002). In some cases (like asteroid 2000 DP107) lightcurve photometry has confirmed binaries originally discovered by means of radar experiments (Ostro et al. 2002).

The most recent impressive result of lightcurve photometry has been the discovery of a bimodality in the spin axis orientation of several members of the Koronis family (Slivan et al. 2003). Such a finding can have potentially important implications for our understanding of family-forming events and for the determination of family ages.

3. Spectroscopy

Asteroid spectroscopy has been traditionally the most important tool to derive qualitative information on the likely surface composition of the objects. Recently, a major observational effort has been the SMASS II spectroscopic survey (Bus & Binzel 2002; Bus, Vilas & Barucci 2002). Among the major results of this survey, we can quote a new taxonomic classification based on reflectance spectra, and the discovery that asteroid families tend to be quite homogeneous in terms of spectroscopic properties. This fact has important implications for the collisional evolution models, as pointed out by Cellino et al. (2002).

Another important result in the field of family spectroscopy has been the identification of former members of the big Eos family, which are now trapped in the 9/4 mean-motion resonance with Jupiter, and are observed during the early stages of an evolution which will decouple them from the asteroid Main Belt (Zappalà et al. 2000).

An unexpected and very important discovery has been the identification of spectroscopic bands diagnostic of hydration in the reflectance spectra of a large fraction of M-type asteroids (Rivkin et al. 2002). Since hydration is not thought to be compatible with the traditional interpretation of M-type asteroids as metal-rich stripped cores of differentiated parent bodies, these observational findings lead us to reconsider our interpretation of M-type asteroids, although other pieces of evidence, like radar data, confirm that at least in some cases we actually deal with metal-rich bodies.

Finally, a major step forward in our understanding of the origin of Ordinary Chondrites from S-type asteroids, a long debated subject, came from the discovery by Binzel et al. (2001) that S-type near-Earth asteroids tend to "fill the gap" between typical spectra of ordinary chondrites and spectra of S-type asteroids observed in the Main Belt. The interpretation is that such a diversity of spectral behaviour is likely due to different times of exposure to space-weathering phenomena. NEAs have short dynamical lifetimes, and they may be in many cases collisional debris only recently injected into resonant orbits leading them into the inner Solar System. If this is true, their surfaces may be on the average much younger than objects observed in the Main Belt. On the other hand, even if the supply of NEAs takes place over much longer time scales (dynamical diffusion, Yarkovsky effect) it is still true that the collisional lifetimes of small asteroids like the NEAs observed by Binzel et al. (2001) are shorter than those of bigger asteroids like those that are observed in the Main Belt. Thus, NEA surfaces are expected to be on the average younger and less weathered.

4. Polarimetry

Asteroid polarimetry has been used in the past to infer information about the likely properties of surface regolith, and to derive asteroid albedos and sizes (Dollfus et al. 1989) through analysis of the phase - polarization curves.

Since some years, a long-term observational campaign is carried out at the Complejo Astronomico El Leoncito (Argentina), in order to determine the albedo of relatively small asteroids (diameters below 50 km) whose sizes and albedos had been previously determined based on IRAS radiometric observations. The reason is that there is an apparent difference between the distribution of IRAS-derived albedos for objects of different sizes, and it is not clear if this is a real phenomenon, or it is an artifact of the limits in sensitivity of the IRAS detectors. Preliminary results of the polarimetric campaign show evidence of a small systematic difference between IRAS and polarimetric albedos, although important discrepancies have been found only in a couple of cases (Cellino et al. 1999, and Cellino et al. in preparation).

In addition to the above mentioned results, some observational effort is also currently devoted to the possible identification of a polarimetric "opposition effect", although the data collected so far are not yet conclusive. What seems certain, is that merging the evidence coming from polarimetric data and photometric phase curves can be important to derive improved understanding of the light scattering on asteroid surfaces (Muinonen et al. 2002; Kaasalainen et al. 2003).

5. High-resolution imaging

One of the major step forward in asteroid science in recent years has certainly been the discovery of a relevant number of binary systems. Here, we deal with results obtained by means of conventional observations at optical wavelengths, then I will not mention binary discoveries obtained by means of radar experiments (for this, see Ostro et al. 2002).

A review of binary discoveries by means of high-resolution imaging is given by Merline et al. (2002). It is clear that binaries give us unprecedented chances to derive asteroid masses, through measurements of the orbits of the binary components.

More in general, technical improvements of the detectors, and the availability of increasingly larger telescopes are steadily shifting down the size limit for which asteroids are essentially point-like sources. This certainly opens new perspectives to asteroid science. In addition to Adaptive Optics observations, also the more traditional speckle interferometry technique has been recently applied to the determination of asteroid sizes and shapes (Cellino et al. 2003).

6. Astrometry

Astrometry, with the determination of asteroid orbits, is the oldest tool of asteroid science. In recent years we have seen a huge enhancement of the asteroid discovery rate, mainly as a consequence of surveys devoted to the discovery of potentially hazardous objects (Stokes, Evans & Larson 2002). On the other hand, another independent achievement has been the development of improved dynamical models and algorithms for the computation of asteroid proper elements (Knežević, Lemaître & Milani 2002). A consequence of this, is that now we have huge data-sets of asteroid proper elements which can be used to identify asteroid families. An example of a discovery made possible by this, is the discovery of the small and apparently very young Karin family (Nesvorný et al. 2002).

7. Conclusions

The results shortly described in the above Sections show that asteroid science is currently very active, and major step forward in the understanding of the asteroid populations have been done or are imminent.

The impressive body of observational evidence obtained by means of remote observations at optical wavelengths shows that these observations are and will be absolutely needed for further advancements. Some problems are also present and deserve a careful attention in the near future. An example is the significant discrepancy between the asteroid inventory at small sizes, as resulting from visible observations from the ground (SDSS, Yoshida) and from thermal infrared observations from space (Tedesco & Désert 2002). Of course, this is a critically important point, since the inventory and size distribution of the objects are primary constraints for any attempt at modelling the overall collisional evolution of the asteroid population.

Some other contradictory evidence comes from the NEAR in situ exploration of asteroid 433 Eros. In particular, it seems that this object is a largely consolidated body (Cheng 2002), and this can be a problem in the framework of recent ideas about the internal structures of the asteroids (gravitational aggregates down to small sizes, as mentioned in the Section devoted to asteroid Photometry).

Solving these problems will require further observations, both from remote instruments and in situ.

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