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Planets, Moons and Minor Bodies of the Solar System

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Abstract. A brief description is given of some recent researches carried out by Italian scientists relative to planets, moons and minor bodies of the Solar System. Among these, Mercury's Na exosphere, NEOs/NEAs, Trojans of outer planets, comets.

Key words. Solar System

1. Introduction

The Italian astronomical community active in Solar System researches probably has never been as productive as in recent years; significant results have been obtained in all different sectors, from theory to utilization of large ground telescopes to involvement in Space missions. How important is the national research in the international scenario can be appreciated by the index of the recent book Asteroid III (Bottke et al,. 2002) carrying the names of Italian authors, copied in a dedicated subsection of the references.

A thorough survey of the current status was prepared by a working group coordinated by the author at the request of the Istituto Nazionale di Astrofisica (INAF) in 2002. That document (Solar System and Extra-Solar Planets, C. Barbieri et al., 2002) contained also a section on Laboratory Astrophysics, one on Extra-solar Planets, and a full inventory of names and facilities. In the present paper, the presentation is restricted to some of the most significant results obtained since the writing of that report, by theoretical modeling or by observations from the ground of planets and their moons, comets and asteroids. Space activities, laboratory astrophysics and extra-solar planets will be covered by other communications.

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2. Planet Mercury

Observing this planet has always been very difficult because of its proximity to the Sun, and in particular large telescopes (including the HST) are essentially prevented from pointing it. Fortunately, the Telescopio Nazionale Galileo (TNG) has such fine mechanical characteristics that observations could be allowed, in an experimental program aimed to study the exosphere of the planet in the light of the Na yellow doublet. The program was proposed by an international team lead by C. Barbieri (with G. Cremonese and S. Verani from the University and Observatory of Padova, M. Mendillo, J. Baumgardenr and J. Wilson from Boston University, A. Sprague from Tucson Lunar and Planetary Laboratory, and R. Cosentino from the TNG). The unique advantages offered by the TNG are the exceptionally good optics, the excellent site and the very efficient high-resolution spectrograph (SARG), equipped for this project with a Na-D filter that allows the utilization of a 26 arc-sec long slit, well extending on both sides of the planetary disk (approximately 7"). Data were taken at the end of August, 2002, with the Sun still above the horizon, and immediately proved of good quality. A fuller discussion of the results is presented in Barbieri et al (2003). If further observing time will be granted in the forthcoming periods, the development of the Na exosphere with the solar cycle will be followed, providing a unique data base of the exospheric properties to missions to planet Mercury, namely Messenger (NASA) and Bepi Colombo (ESA).

3. Asteroids and NEOs Surveys

The two Schmidt telescopes in Asiago and Campo Imperatore have been rejuvenated with the main aim to search for NEOs and IEOs.

The search in Asiago (ADAS survey, nr. 209, Barbieri et al., 2002, http://planet.pd.astro.it/planets/adas/ http://planet.pd.astro.it/planets/adas/) is in collaboration with the DLR Berlin, who provided the SCAM camera. ADAS operated from December 2000 to March 2002, essentially in TDI mode, covering some 500 sq degree of sky along the celestial equator. With effective exposure times of 180 sec the limiting V magnitude is about 21. The inventory for that period is in Table 1 :

In March 2002 the telescope was closed for further improvements to the motors, cabling and encoders. These works on the telescope have been finished, and some observing in 2003 has been carried out. We are looking forward to a full restart of operation.

Table 2. CINEOS inventory (from Bernardi, 2003)

	Known	New	PHA
NEO Amors	11	1	2
Apollos	20	2	7
Atens	8	0	2
Total	39	3	11
Main Belt Objects	2501	473	
Unusual	0	2	
Total	2540	475	

Another important event took place in April 2003: the Catania Observatory CCD camera was installed on the telescope and started acquiring its first data. The camera is based on the Kodak KAF 4202 chip, 2048x2048 pixels, 9 micron/pixel. The field is smaller than that of the DLR SCAM camera (30' against 49'), but the smaller pixels allow a better sampling of the image (0".86/px instead of 1".4/px), and therefore a better photometry in good seeing conditions; furthermore, the camera is equipped with a BVRI filter wheel.

A similar undertaking has been made at Campo Imperatore (CINEOS survey, http://www.mporzio.astro.it/ cimperatore/WWW/cineos.html) in the framework of a cooperative agreement among INAF-OAR, IAS-CNR, INAF-OATo, and INAF-OAB. A NEO follow-up and recovery program is carried out in collaboration with the Spaceguard Central Node. Begun in 1996 and carried out for about one year, CINEOS was restarted in 2001 taking advantage of improved hardware and software equipment. The main goal of these surveys is the discovery of NEOs (Near Earth Objects), in particular Atens and IEOs (Inner Earth Objects). Small solar elongations are spanned during sunrise and sunset, while the middle of the night is devoted to the discovery at opposition and/or follow-up of known objects. With exposure times of 120-180 sec the limiting V magnitude is about 21. Table 2 reports the activity of CINEOS up to the end of November 2002.

Table 1. Observing Statistics till March 2003

Objects observed: 3175 , New Designations: 295
Total number of Positions: 17214, Number of Positions published by the MPC: 13805
New orbits: 198
Special asteroids discovered: 3 Trojans + 1 Hilda + 1 Hungaria
Marscrossers: 2002 AN_7, 2002 CS
8 Numbered Objects: 43511 Cima Ekar (2001 CP48), 46392 (2002 AO6), 48268 (2002 AK1), 51406 (2001 DL108), 55427 (2001 TF47), 55428 (2001 TN47), 57561 (2001 TA48), 57879 (2002 AD1)

4. Spectrophotometry, polarimetry, physical properties and origin

A large spectrophotometric program of main belt asteroids was started by Lazzarin and coworkers (2001), in particular to ascertain the presence of aqueous alteration on their surfaces, the effects of space weathering, and the link with the most common meteorites. Aqueous alteration requires liquid water to be effective, and so it can give information both on the thermal evolution of the asteroids and on the localisation of water sources in the asteroid belt. A great effort was done by an international collaboration to obtain data on the initial Rosetta targets. Although not any longer relevant to the mission, nevertheless the work enlarged our knowledge of the asteroid properties. In particular, Fornasier et al. (2003) derived a physical portrait of 4979 Otawara based on spectral and photometric data. The aim of this work was to investigate the composition and to evaluate its rotation pole orientation. The spectroscopic observations obtained at the Palomar 200" and IRTF telescopes covered the wavelength range 0.4 to 2.5μm. Two main broad bands could be identified: the band BI at $\lambda = 9570 \pm 50$Å, depth of 0.18 ± 0.01 and spectral slope of 0.0804% per 1000 due to olivine+pyroxene, and the band BII at $\lambda = 19780 \pm 50$Å, with a depth of 0.07 ± 0.01, due to pyroxene. The BII/BI area ratio = 45% definitely proves that Otawara belongs to S (IV) class, the S sub-type whose members are the most probable candidates as parent bodies for ordinary chondrites among the S-type asteroid population (Gaffey et al. 1993; Gaffey 2000, 2001). A good fit with the data has been obtained by a reddening model with the pμmresence of 0.05% nanophase iron (npFe0). Spectral slope and location of the 1μm and 2μm bands are consistent within the range of properties for ordinary chondrite meteorites (lines). All spectra are normalized to unity at 0.55μm. Moreover, new photometric data, obtained at the Asiago Observatory and at the TNG telescope, allowed confirmation of the fast rotational period of 2.707 ± 0.005 hours, and a first indication of the spin vector of Otawara. On the same line of aqueous alteration and space weathering effects, Lazzarin et coworkers have obtained one of the largest spectrophotometric surveys of NEOs using several telescopes, in particular at ESO. The spectra cover a wide spectral range, often uninterrupted from 0.4 to 2.5 μm, with good photometric precision. Following the Bus and Binzel classification with Principal Component Analysis (PCA) developed for the SMASSII data, in their data set the following types were found:

7 S, 2 Sa, 2 Sk, 3 Sq, 2 Sr,
1 Q, 3 K, 3 C, 1 B, 2 E, 3 Xe

The comparison with meteorites and the effects of space weathering are well ascertained in the sample.

Another major spectroscopic survey is in progress by M. di Martino (Torino, 2003) in collaboration with a group at Nice University using DFOSC at the 1.5m Danish telescope at La Silla. They have observed a sample of 34 Jupiter Trojans, a significant fraction of all Trojans observed to date.

5. Thermal Radiometry

Thermal radiometry is the most convenient technique to derive essential physical parameters like size and shape. Preliminary results have evidenced the fact that near-Earth asteroids exhibit often albedo values different with respect to the typical values of main belt objects of the same taxonomic type. The Torino team is involved in such studies of the thermal irradiance of asteroids at IR wavelengths. This research is carried out both at theoretical level, with the development of thermal models particularly suited for particular classes of objects, like the near-Earth population, as well as by means of observing campaigns. Observing time has been obtained at the Keck-1 telescope, and at the 3.6 m telescope of ESO. Moreover, the importance of carrying out nearly simultaneous multi-band observations, in order to avoid the problem of the varying projected cross-section of the objects due to their spin rate, has been clearly evidenced in these studies (see Delbó, M. and Harris, Alan W., 2002).

6. Polarimetric investigations

The Torino team is involved in the continuation of an observing program in the field of polarimetry. Polarimetric observations are carried out using the Torino photopolarimeter presently attached to the 2.15-m telescope of El Leoncito (Argentina). The PI of this project is A. Cellino. The goal is to obtain a better calibration of the IRAS data-base of asteroid sizes and albedos, and to obtain useful data for the development of improved theories of light scattering from planetary surfaces. Observations at very small phase angles are particularly important in this respect.

7. Origins of NEOs/NEAs

Cellino et al. (2002), underline that important improvements have been made in recent years in understanding their likely origins. Extensive observational campaigns are ongoing in order to assess their current inventory. From these studies we can hope to obtain a much better understanding of the different populations of minor bodies, their relationship with meteorites, and the overall history of the solar system. At the same time, NEOs are important also in terms of impact hazard. Both the purely scientific issues, and the more pragmatic point of view focused on the need of developing credible strategies of impact mitigation, require a major effort in order to improve the current knowledge of the physical properties of these objects. Zappala‘ et al. (2002) attempt to identify the most likely parent bodies of multi-km near-Earth asteroids (NEAs), in the framework of a scenario based on a few simple assumptions. (1) Multi-km NEAs are produced by collisional fragmentation of single parent bodies. (2) The fragments are injected into either the 3/1 mean-motion resonance with Jupiter or the v_6 secular resonance, or they achieve Mars-crossing orbits. (3) The collisional events responsible for the production of multi-km NEAs do not produce observable dynamical families. They showed that a limited number of potential parent bodies of multi-km NEAs compatible with the above assumptions do exist in the asteroid Main Belt. It is not clear whether these objects can likely explain the current inventory of known NEAs having sizes around 1-2 km. The results seem to indicate that the assumed scenario is not completely adequate to justify the number of observed NEAs larger than 2 km. This preliminary analysis must be complemented by a more precise analysis of the rates of occurrence of NEA-feeding events. If present results are confirmed, the conclusion that the origin of multi-km NEAs must be explained by different models, based on long-term dynamical diffusion produced by the interplay of collisional, gravitational, and nongravitational mechanisms in the Main Belt, plus a possible cometary contribution, will be strengthened.

8. Asteroid families

Dell'Oro et al.(2002) have carried out a statistical analysis of the mutual collisions among members of asteroid families during the very early times after family formation. The statistical properties of the collisions (probability, distribution of velocity, and so on) have been computed using an algorithm effective even in cases in which the longitude of the nodes and the longitudes of the perihelia of the orbits under consideration are not distributed uniformly. The results show the occurrence of a strong enhancement in the mutual collision rate among family members, immediately after family formation. Nevertheless, this episode lasts for a relatively short time, and it does not affect too severely the overall collisional evolution of the family. The early enhancement of mutual collisions, however, may influence the cratering record exhibited by the surfaces of family members, possibly laying the foundation for the early development of a surface regolith layer.

9. Diameters by speckle techniques

A campaign of speckle-interferometry observations of main belt asteroids using the TNG Speckle Camera is currently in progress, under the coordination of A. Cellino at the Astronomical Observatory of Torino. Results for a first set of nine objects observed during the first successful observing run are in press on Icarus (Cellino et al., 2003). These observations are important because they give direct measurements of sizes and shapes, which are invaluable to calibrate the IRAS data-set of asteroid sizes and albedos, and to determine the volumes of the objects (needed for future estimates of average density).

10. HST studies and comparison with radar data

The Torino team, in collaboration with the Paris Observatory, has carried out an observing run of asteroids suspected to be binary, including five main belt objects and one Jupiter Trojan, using the Fine Guidance Sensor (FGS) of the HST. This interferometer is an ideal instrument to resolve the apparent projected disks of main belt asteroids. No evidence of binarity has been found for the sample of six considered targets, but detailed information about the size, overall shape and spin axis orientation have been obtained. This has made it possible also to test the shape model for (216) Kleopatra obtained by Ostro and coworkers from inversion of radar data. It turns out that the radar nominal-model, while being in global agreement with these data, doesn't adequately reproduce all of them. In particular the flattening seems to be underestimated by 20%. The HST/FGS observations should provide valuable constraints for determining a more refined shape model, since the model obtained from the radar data alone is subject to some uncertainty. Detailed shape models of large asteroids should provide valuable insights for explaining the collisional histories of the objects, and the formation and evolution of binary systems in general.

11. Moons of Jupiter

The dynamics, thermal evolution and interior structures of the four Galilean satellites are studied with numerical simulation by Musotto et al. (2002), using a realistic physical model that includes, besides Jupiter and the four satellites, also the Sun, Saturn, Uranus, Neptune, and the J_2 and J_4 terms of Jupiter's gravity field. The free libration of the Laplace angle, which plays a central role in the classical description of the tidal evolution of the Laplace resonance, was isolated from the simulated orbits. The amplitude and the period of the libration agree well with the values obtained by J. Lieske (1998). In addition, they also pointed out that tidal dissipation models need to take into account the large variations in Io's eccentricity due to Jupiter's oblateness. In fact, Io's eccentricity shows a variation on the orbital time scale (1.7 days) of about a quarter of its average value. To get a more accurate physical model, Io's rotation state was included in the overall gravity field. The numerical simulations integrate both the orbital and rotational dynamic with a simple two-dimensional model, without any assumption about synchronous rotation or Keplerian motion. The ultimate goal is to develop self-consistent models of Io's rotational dynamics that include tides: for the moment, a simple tidal model is included to couple the orbital and rotational dynamics to the tidal effects, but a more refined tidal and deformation model is being developed.

12. Trojans of the outer planets

Based on theoretical expectations (e.g. Marzari and Scholl, 1998, Marzari et al. 2002), a program of discovery of objects in the region around the Lagrangian points of Saturn, Uranus and Neptune was proposed by Barbieri and collaborators and approved in 2002 by the Astrovirtel European program. From the Astrovirtel archive, we selected all the ESO 2.2m WFI images which fell into a box of 30x30 around the Lagrangian points L4 and L5 of Saturn, Uranus, and Neptune. Among the software packages used in this work some are worth mentioning having being specifically developed for WFI frames:

wfpdred: this code has been written by a group of astronomers of the Observatory of Padova (Rizzi et al.) for entirely different purposes, but could be easily adapted to our needs; it assembles in a unique frame the 8 parts, in which the raw WFI images are divided;

fitsblink: this software has been written by a group of researchers from Ljubljana (Skvar et al.)who collaborate with the Padova group in this difficult search. It detects possible candidates as asteroids, because of their movements with respect to stars field. It also gives the possibility to recognize known asteroids by using a database containing all of them (this database is continuously updated via the MPC). The already known asteroids are marked on the display in a different way for easy visual recognition;

Amigo: a Fortran code (Marchi, 2002), which produces a distribution of asteroid's velocities as projected on the sky (namely velocity in RA and Dec) for any given direction of the line of sight at any date. Sometimes the separation of the different classes of objects is quite distinct. Therefore, by using this code for each image, we are able to quickly identify different regions in the RA-DEC velocity plane corresponding to different groups of asteroids, like Main Belt,

Jupiter's Trojans, Saturn's Trojans and so on. As a result we have already submitted to the MPC 55 reports, containing approximately 800 positions of 300 distinct asteroids. The faintest objects are around R = 23.7; there are also several fairly bright but not numbered objects (e.g. R = 15.9). Some objects were detected in U-band filters. The MPC has already awarded 57 designations.

On Jan. 8, 2003, NOAO released the announcement of the discovery of 2001 QR322, the first Trojan of Neptune, librating around L4 with low eccentricity (approximately 0.035) and a libration amplitude lower than 40 deg. Its inclination is around 1.3, and its diameter is about 230 km. On one side, it is unfortunate that our American colleagues detected the first Neptune Trojans ahead of us; on the other, the discovery lends further weight to our idea for this search. For more details, see Barbieri et al. (2003, this conference).

13. Mass Transfer among the Moons of the outer planets

A theoretical study of the mass transfer between the moons of the outer planets has been carried out by Marchi et al (2002a, b). This process has been applied to several pairs of satellites in order to explain some surface characteristics that some satellites show. The most important applications of our model regard the origin of the Cassini Regio on Iapetus (a Saturn' satellite) and the anomalous crater distribution on Triton (a Neptune's satellite). In both cases our model is able to produce a good fit with the observation. Regarding Iapetus and Hyperion, the percentage of fragments that reaches Iapetus ranges from 19 to 43% (Cassini Regio 100m depth), the mass transfer duration is of the order of 106 y, the impact velocities are in the range 1-3 km/s. The mass transfer affects mainly the leading side, the impact density distribution has an elliptical shape with maximum on the apex but with non negligible penetration in the trailing side. For Proteus-Triton, the mass transfer efficiency is strongly dependent on the orbital configuration (0- 80%), but in any case the transfer duration is less than 3000 y, and the mean impact velocities are in the range 10-15 km/s. The cumulative distributions of craters fit very well with that observed for diameters larger than approximately 5 km, however, the largest craters seem to require heliocentric impactors. A spectroscopic analysis of Triton was started in order to look for constraints of the origin of its crater distribution and whether or not it can be due to mass transfer. The observations were carried out in October 2002 with NTT, with a strategy that allowed for the first time to obtain separately spectra of the leading and of the trailing faces (Marchi et al., 2003, this conference). Although the data are still under analysis, significant differences on the surface of Triton were found.

14. Centaurs, KBOs, TNOs

The existence of the Kuiper belt was originally postulated to explain the origin of the short period comets (P¡10 y), whose number and orbital characteristics (in particular the low inclinations) could not be accounted for with the sole capture by the giant planets of the long period comets coming from the Oort's cloud with random inclinations. The Kuiper belt, located from 40 to 500 AU, having many objects with diameters exceeding hundreds of km, could therefore be the remnant of the outer solar nebula. Details on present researches and results are given in the accompanying paper by E. Dotto (2003, this conference).

15. Comets

On the theoretical side, I. Bertini, in Padova is studying an original model of surface layers of cometary nuclei. This is done using an innovative point of view, involving microscopic constituent particles. The aim of the work is to model the surface of a fresh comet nucleus, building an ensemble of mixed particles, made of ices and dust, using observational physical constrains, and to study the development of this ensemble when ices sublimate under the solar radiation action. This model wants to deepen the knowledge about physical mechanisms in these objects (e. g. the formation of an insulating mantle made of dust material depleted in its volatile compounds) and to reproduce some observational quantities, such as dust and gas production rates in order to predict and to help cometary observations, especially those of ROSETTA. This project is a collaboration with Prof. Nicholas Thomas (University of Bern).

On the observational side, two main works can be cited. G.P Tozzi in Florence carries out a program to the study of the solid component of the coma. In particular, in collaboration with L. Kolokolova of the University of Florida, he tries to characterize the dust of various comets, to check if differences exist between Oort clouds and Kuiper belts comets. With this method, from at least 6 narrow or broad band images obtained in regions free from gas emission, it is possible to obtain the index of the power law distribution of the size, the minimum and maximum sizes of the dust and its optical constants. The last would give hints on the dust composition. Particularly successful have been the observations of comet C/2000 WM1 (LINEAR) that passed at 0.32 AU from the

Earth on Dec. 2001. The observations consisted in contemporary observations with three ESO telescopes: the 1.5D/DFOSC in the visible, the NTT/SOFI in the near-IR and the 3.6m/TIMMI2 in the thermal IR. The high spatial resolution allowed to detect, beside the normal cometary dust, two sublimating components; one with scale length L of 10000 km and the other with L 1000km. While the long L component has the same red color of the normal dust, the short L component has a completely different color, bluish-neutral. This may be the first clear detection of ice or ice covered particles lifted by sublimating gas. A program of high resolution spectroscopy of comets is being conducted with SARG/TNG and other telescope by G. Cremonese (Padova) and T. Capria (Rome), with the collaboration of a Japanese team. The aim of the program is to catalogue known and unknown emission lines, compare them with the lines already listed in existing catalogues, and possibly identify unknown lines. In the visible range of the spectrum, emission lines of daughter molecules and ions can be found, and many of them are still unidentified. The comet C/2002 C1 Ikeya-Zhang was observed with SARG during the night 19-20 of April and spectra with two different setups were taken (Capria, et al., 2002). In the first case, a narrow band filter was used to isolate the sodium emissions with a long slit and R = 43000. The data show very interesting cometary sodium emissions in the coma (Cremonese, et al., 2002). The second setup used a short slit covering the spectral range of 4620-7920 with R=57000. Their first objective is to catalogue all the emission lines that can be seen in the spectra. After this first phase, theyll proceed to the identification of these lines, comparing them with lists of lines measured in laboratory and/or already listed in the existing catalogues, possibly identifying unknown lines. A fluorescence model has been applied to the NH2 bands (Kawakita et al., 2001) obtaining a spin temperature of the ammonia around 31 K.

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References

Barbieri, C. et al. 2002, Solar System and Extra-Solar Planets, INAF
Barbieri, C. et al. 2003, MSAIt, 74, 432
Bernardi, F., 2003, PhD Thesis, Univ. di Roma Tor Vergata, Apr. 2003
Capria, M. T., et al. 2002, ESA SP-500: Asteroids, Comets, and Meteors: ACM 2002, 693
Cellino, A., et al. 2003, Icarus, 162, 278
Cellino, A., Zappala, V., & Tedesco, E. F. 2002, Met. and Plan. Sci., 37, 1965
Cremonese, G. et al. 2002, IAUC, 7914, 2
Delbó, M. & Harris, A. W. 2002, Met. and Plan. Sci., 37, 1929
dell'Oro, A. et al. 2002, Icarus, 156, 191
Fornasier, S. et al. 2003, A&A, 398, 327
Fornasier, S., 2002, PhD Thesis, Univ. di Padova and Univ. de Paris VII, Dec. 2002
Hestroffer, D. et al. 2002, A&A, 392, 729
Hestroffer, D. et al. 2002, A&A, 391, 1123
Lazzarin, M. et al. 2001, "Piazzi 2001", Palermo June 2001.
Licandro, J. et al. 2002, EM&P, 90, 495
Marchi, S. 2003, PhD Thesis, Univ. di Pisa, Feb. 2003
Marchi, S. et al 2003, A&A, 408, L17
Marchi, S. et al. 2002, ESA SP-514: Earth-like Planets and Moons, 151
Marchi, S. et al. 2002, A&A, 381, 1059
Marchi, S. et al. 2001, A&A, 374, 1135
Marzari, F. et al. 2002, ApJ, 579, 905
Musotto, S. et al. 2002, AGU Fall Meeting Abstracts, 506
Musotto, S. et al. 2001, BAAS. 33, 1063
Zappalà, V., Cellino, A., & Dell'Oro, A. 2002, Icarus, 157, 280