REPORTS ON ASTRONOMY 2002-2005
Proceedings IAU Symposium No. XXVIA, 2006
O. Engvold (ed.)

doi:10.1017/S1743921306004418

IAU Division III
Commission 15: Physical Studies of Comets and Minor Planets

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Keywords. Comet, minor planet, asteroid, meteorite

1. Introduction

The report of Commission 15 was prepared primarily by the chairpersons of its two working groups: the Minor Planet Working Group and the Comet Working Group. In particular, the Minor Planet section was created by A. Cellino with a little help from E. Tedesco and the Comet section by T. Yamamoto with the assistance of D. Bockelée-Morvan, W. Huebner, A. Bhardwaj, D. Biesecker, L. Jorda, H. Kawakita, H. U. Keller, H. Kimura, A. Kouchi, and D. Prialnik. E. Tedesco was responsible for the Introduction, final editing, and merging of the two reports.

Scientific activity in the field has continued to grow in the past three years, as evidenced by publication of 700 papers in the refereed literature, compared with about 400 during the previous triennium. A comprehensive overview of so large a publication list cannot be accomplished in the space at our disposal. We have therefore chosen to highlight a representative subset of these publications to provide a snapshot of the current state of the field, and, as in the last several reports, without including a comprehensive bibliography. Instead, a complete list of the references used in creating this report, assembled by searching the ADS abstract service (http://adsabs.harvard.edu/abstract_service.html) to generate a list of refereed papers published between July 2002 and June 2005, inclusive, is available in the Archive section of the Division III Physical Studies of Comets and Minor Planets web site. This site can be reached (since it does not have a permanent home) via a link from the IAU home page.

2. Asteroids and TNOs

In this section, papers related to asteroid physical studies and their connections with comets and meteorites are briefly summarized.

This report is based upon a compilation of 339 refereed papers. Using a format similar to that used in previous transactions, the material is organized into a series of 12 arbitrary categories, corresponding to different observing techniques and/or physical properties being investigated. In many cases a given paper might logically be assigned to more than one category, due to unavoidable overlap between different topics. Note also that, following the example of the previous triennial report, Centaurs and TNOs are included in this Section, although they are obviously kept separate from the Asteroids.

As a general comment, we can say that the last three years have seen a number of very important achievements in the field of asteroid and TNO science. Studies of TNOs, in particular, are quickly developing, in spite of huge observational problems, taking profit of the availability of observing time at the largest existing telescopes. As for the asteroids, very spectacular results have been obtained by *in situ* explorations by space missions, and particularly by the NEAR-Shoemaker probe. Direct imaging, spectroscopy, photometry, polarimetry, thermal radiometry and radar experiments have produced impressive amounts of new data, and have triggered the development of theoretical advances. The increased recognition of the importance of the Yarkovsky effect, in particular, has been particularly important, and has contributed to a partial "change of paradigm" in the overall scenario of our theoretical understanding of the evolution of the asteroid population. These are only a few examples among many outstanding results obtained since the last IAU GA. A more analytical, but forcedly concise, list of contributions is given in the Subsections below. We did not attempt to mention all the published papers which were pertinent in each Subsection, because this would have been impossible, but we limited ourselves to a number of particularly relevant contributions, selected by the whim of the compiler (A. Cellino). It is also worth to be mentioned the fact that, for what concerns the asteroids, very useful reviews for all the topics discussed in the next Subsections have been published in the Asteroids III book, published during the lapse of time covered by this report. In particular, a very general overview of our understanding of the asteroid population and the likely perspectives in the field was given in the Bottke *et al.* (2002) introductory chapter. References to the Asteroids III chapters are also included in the Asteroid publications file available in the Commission web page.

2.1. *Size distributions, masses and densities*

New determinations of asteroid masses by means of observations of mutual close approaches have been published (Kuzmanowsky and Kovaçević, 2002; Kovaçević, 2005; Kochetova, 2004). An analysis of asteroid encounters suitable for the purposes of mass determination has been performed by Galád and Gray (2002). A general review of the current scenario for what concerns what we know about asteroid masses was given by Hilton (2002), while the current situation for density and porosity was discussed by Britt *et al.* (2002).

The problem of the determination of the asteroid inventory and size distribution of the asteroid population down to small sizes, beyond the limit of completeness of current surveys, is a hotly debated topic of investigation. Tedesco *et al.* (2005) developed a statistical asteroid model, aimed at simulating the asteroid population down to the size of 1 km, based on different extrapolations of the populations of family and non-family asteroids. On the observational side, dedicated surveys at thermal IR wavelengths (Meadows *et al.*, 2004) and in the visible (Yoshida *et al.*, 2003; Yoshida and Nakamura, 2004; see also Nakamura and Yoshida, 2002) have produced interesting results that are now being discussed.

2.2. *Photometry, shapes, and spin properties*

Disk-integrated photometry continues to be an active area of asteroid observations and is the basis for most of the research described in this Subsection. New observations were performed by Wang (2002), Tupieva (2003), Gil Hutton and Cañada (2003), Newburn *et al.* (2003), Wang *et al.* (2003), Tungalag *et al.* (2002, 2003), Shevchenko *et al.* (2003), Torppa *et al.* (2003), Galád *et al.* (2004), Michalowski *et al.* (2004), Almeida *et al.* (2004).

https://doi.org/10.1017/S1743921306004418 Published online by Cambridge University Press

A general review of the general subject of asteroid rotations was given by Pravec *et al.* (2002), while the distribution of asteroid rotations for objects of different sizes was discussed also by Donnison (2003).

Kaasalainen et al (2002a) reviewed current performances of light-curve inversion methods. Inversion of calibrated photometric data sparse in time was also discussed by Kaasalainen (2004). Models of twenty asteroids obtained from inversion of photometric data were presented by Kaasalainen *et al.* (2002b), and by Durech (2002) in the case of another one additional object.

Another important issue in asteroid photometry was discussed by Jurić *et al.* (2002), who made a comparison between the magnitudes of known asteroids actually measured by the SDSS survey, and the magnitudes predicted on the basis of their estimated absolute magnitude (H) values. Significant differences were found, meaning that currently published values of H are affected by significant errors, mainly at faint magnitudes.

Pravec *et al.* (2004) reviewed known cases of tumbling asteroids, namely objects rotating around a non-principal axis, and discussed possible biases affecting the discovery efficiency of different kinds of tumblers. Another independent analysis was also carried out by Mueller *et al.* (2002), based on the evidence coming from radar and photometric data of the near-Earth asteroid (4179) Toutatis. A search for time-scale variations in the light curve of the slow-rotator (1689) Floris-Jan by Toth (2004) gave negative results. Another, independent analysis of the photometric behavior of asteroid 288 Glauke by Kryszczynska *et al.*
(2003) gave also inconclusive results.

Equilibrium figures of spinning asteroids with self-gravity were studied by Holsapple (2004). Photometric signatures of highly non-convex and binary asteroids were discussed by Durech and Kaasalainen (2003).

Results of photometric observations devoted to dynamical family members were published by Yoshida *et al.* (Karin family), Alvarez-Candal *et al.* (Themis, Eos, and Maria families). Very important results concerning a bimodal distribution of the spin axis of the members of the Koronis family were published by Slivan (2002) and Slivan *et al.* (2003).

A comparison from light-curve extrema of asteroid 433 Eros photometrically observed over 30 years, and the actually known shape and rotation state of the object coming from the NEAR-Shoemaker space mission was carried out by Durech (2005).

In addition to classical photometry at visible wavelengths, important observations in the near-IR J,H,K bands have been obtained by the DENIS survey of the southern sky, and results for 8000 asteroids were published by Baudrand *et al.* (2004).

2.3. *Radar, thermal infrared, optical polarimetry, light-scattering phenomena*

A general review of the situation in asteroid radar astronomy was given by Ostro *et al.*, (2002). Based on previous radar observations, a refined model of the shape of (4179) Toutatis was carried out by Hudson *et al.* (2002). New radar experiments have then been carried out by Benner *et al.* (2004) for the asteroid (3908) Nyx, and by Ostro *et al.* (2003, 2004) for the asteroids 2002 AA29 and (25143) Itokawa, the target of the Japanese Hayabusa space mission. Radar observations of four additional near-Earth asteroids were also presented by Shepard *et al.* (2004). The results of the first Italian radar experiment were presented by Di Martino *et al.* (2003).

Radar observations of the near-Earth (6489) Golevka by Chesley *et al.* (2003) led to the first direct determination of a measurable Yarkovsky-driven drift in semi-major axis.

A significant effort was devoted by many authors to theoretical and observational projects in the field of asteroid radiometry. A review of the subject was given by Harris and Lagerros (2002), while the more specific topic of thermal IR observations from space was discussed by Price (2002). On the theoretical side, the possibility to develop detailed thermo-physical models of asteroid surfaces based mainly on thermal IR data was discussed by Mueller (2002). Practical applications to the case of asteroid (65) Cybele were presented by Mueller and Blommaert (2004). On the observational side, a wealth of new data were obtained by Delbò and Harris (2002), Delbò *et al.* (2003), Mueller *et al.* (2004), and Lim *et al.* (2005). Many observations, in particular, were devoted to near-Earth asteroids.

Space missions produced also new, exciting results. In particular, thermal IR observations of 168 asteroids carried out by the MSX satellite were published by Tedesco *et al.* (2002), while Dotto *et al.* (2002) presented the results of the thermal IR flux of five asteroids observed by means of the ISO satellite.

Optical polarimetry is another important tool for deriving asteroid albedos (and hence, sizes), and it is also strictly related to the general phenomenon of light scattering. A general review of the subject was given by Muinonen *et al.* (2002). A method for obtaining an empirical interpretation of both photometric phase curves and phase – polarization curves was proposed by Kaasalainen *et al.* (2003), while Penttila *et al.* (2005) presented a new statistical analysis of the polarization – phase curves for asteroids and comets. Polarimetric observations of asteroids belonging to the S and E taxonomic classes were published by Belskaya *et al.* (2003).

2.4. *Imaging, disk-resolved images, and binary systems*

Due to the development of high-resolution observing techniques and the availability of very powerful instruments, in recent years it has been possible to resolve the images of an increasing number of asteroids. For instance, using the HST WF/PC, Storrs *et al.* (2005) were able to resolve the asteroids (9) Metis, (18) Melpomene, (19) Fortuna, (216) Kleopatra, and (624) Hektor.

A determination of the sizes and shapes of asteroids (15) Eunomia, (43) Ariadne, (44) Nysa, (63) Ausonia and (624) Hektor was also obtained by Hestroffer *et al.* (2002a) and Tanga *et al.* (2003) using the HST Fine Guidance Sensor. The obtained data were found to be marginally compatible with a binary structure in all cases but (63) Ausonia.

(216) Kleopatra, in particular, was a subject of considerable debate, in particular for what concerns a possible binary structure. In contrast with previous radar-based determinations of a single, dumb-bell shape for this asteroid, new ground-based adaptive-optics observations by Hestroffer *et al.* (2002b) pointed out a likely binary nature. Subsequent analyzes of HST-FGS images and disk-integrated photometric data led Hestroffer *et al.* (2002c) to point out some supposed inconsistencies of the nominal radar model of Kleopatra. According to a subsequent analysis by Takahashi *et al.* (2004) a binary model is the one that best fits the overall photometric data available at present, but there is not yet a conclusive evidence.

Baliunas *et al.* (2003) performed high-resolution multi-spectral images of the asteroid (3) Juno, and found evidence for the existence of a large crater on the surface.

Using speckle interferometry observations, Cellino *et al.* (2002) resolved nine additional main-belt asteroids, and obtained new constraints on the shapes and spin axis orientations for these bodies.

The discovery of new examples of asteroid binaries has continued during the last three years, by means of different techniques. An updated list includes (3782) Celle, a member of the Vesta family that was found by Ryan *et al.* (2004) to exhibit mutual eclipse events. Mutual eclipse events were also recorded by Michalowski *et al.* (2002, 2004) in the case of the well-known binary (90) Antiope. An improved solution for the orbit of the satellite of the asteroid (22) Kalliope was obtained by Marchis *et al.* (2003) based

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on new observations. In the same year, Margot and Brown (2003) concluded that the orbit of the Kalliope's satellite indicates that the bulk density of this M-type asteroid is hardly compatible with a mostly metallic composition. Finally, based on photometric observations, Pravec *et al.* (2002) found evidence of a likely binary system in the case of the NEA 1999 HF_1.

On the theoretical side, the formation of asteroid satellites in large impact events was numerically simulated by Durda *et al.* (2004), while the issue of binary systems stability was analyzed by Scheeres (2002).

We note also that deep optical imaging of the Geminid meteor stream parent body (3200) Phaeton was performed by Hsieh and Jewitt (2005) in order to find evidence of a possible cometary activity for this object, but the results were mostly negative.

2.5. *Spectra, taxonomy, composition and space weathering*

The last triennium was very important in the history of asteroid spectroscopy, due to the publication of impressive amounts of new data, which opened new perspectives in the field. Moreover, the subject of space weathering has also been particularly hot. Since it would be really impossible to mention all the papers produced on these subjects during the last triennium, we are forced to select arbitrarily only a small subset of the many excellent contributions published in many journals. We note first that some general reviews of the topics covered in this subsection were published in the Asteroids III book (2002) by Gaffey *et al.*, Bus *et al.*, Rivkin *et al.*, and Clark *et al.*

The Phase II of the Small Main-Belt Asteroids Spectroscopic Survey, including 1447 new asteroid spectra, was published by Bus and Binzel (2002a, 2002b). Moreover, another extensive spectroscopic survey by Lazzaro *et al.* (2004) produced spectra for 820 asteroids. This wealth of new data led Mothé-Diniz *et al.* (2003) to undertake a new analysis of the distribution of different taxonomic classes in the main belt.

Spectroscopic observations of asteroid families have been common in recent years. A review of the subject was given by Cellino *et al.* (2002). New observations were then presented for the Eunomia family by Nathues *et al.* (2005). From observations of some members of the Agnia and Merxia families, Sunshine *et al.* (2004) concluded that these families had differentiated parent bodies. (832) Karin, the largest remnant of the Karin family was also spectroscopically observed by Sasaki *et al.* (2004), who looked for possible presence of surface heterogeneity. A general reassessment of asteroid families based on spectroscopic data was also attempted by Mothé-Diniz *et al.* (2005).

The extension of the observed reflectance spectra to near-IR wavelengths is steadily continuing. Burbine and Binzel (2002) published near-IR spectra for 181 main belt asteroids. Rivkin *et al.* (2004) presented new near-IR spectra of the NEA (69230) Hermes, while near-IR spectra of 42 asteroids belonging to the taxonomic X complex were obtained by Clark *et al.* (2004a), while Clark *et al.* (2004b) obtained new spectra for a sample of E-type asteroids. Duffard *et al.* (2004) observed 19 V-type asteroids in the neighborhood of (4) Vesta. New observations for (1) Ceres and (4) Vesta were then published by Vernazza *et al.* (2005), while Hardersen *et al.* (2005) observed a sample of six M-type asteroids.

The spectroscopic properties of (4) Vesta, several Vesta family members, and V-type NEAs, and the outer belt V-type asteroid (1459) Magnya have also been the subjects of several studies. Among them, we quote Michtchenko *et al.* (2002), Hasegawa *et al.* (2003), and Hardersen *et al.* (2004), while Hendrix *et al.* (2003) analyzed available UV data for Vesta and interpreted them in terms of possible space weathering.

The likely content of Hydrogen in C-type asteroids was analyzed by Rivkin *et al.* (2003), who found evidence for a likely high water contents for asteroids belonging to the *G* class, which are then plausible candidate parent bodies for CM chondrites. The possible detection of water absorption on the reflectance spectrum of a *D*-type asteroid was discussed by Kanno *et al.* (2003).

Space weathering phenomena have been the subject of many studies. Among them, Strazzulla *et al.* (2005) presented the results of laboratory experiments on an H5 meteorite. Nesvorný *et al.* (2005) analyzed the possible evidence of space weathering from data coming from the SDSS survey. Jedicke *et al.* (2004) analyzed the colors of the members of some *S*-type families whose ages had been derived from models of their Yarkovsky drift in semi-major axis, and found a correlation interpreted in terms of a nice demonstration of the occurrence of space weathering. The effect of space weathering in disguising the relationship between *S*-type asteroids and ordinary chondrite meteorites was discussed by Clark (2004c). The general complexity of the phenomenon of space weathering, and the difficulties in achieving a full understanding of it, has been discussed by Chapman (2004).

Finally, the existence of significant color changes in many asteroids observed at different times by the SDSS survey, was interpreted by Szabó *et al.* (2004) as a proof of the existence of frequent albedo inhomogeneity in asteroid surfaces.

2.6. *Origins, impacts, families and evolutionary processes*

A great amount of work has been devoted to topics related to the origin and collisional evolution of asteroids, including theoretical and experimental studies of asteroid families, and the physics of catastrophic break-up phenomena. Moreover, a very big theoretical and observational effort has been devoted to study the effectiveness and the implications of the Yarkovsky effect. Also in the case of the topics covered in this Subsection, the number of very important papers published during the triennium is too large for allowing us to give a very complete summary of the obtained results. Again, some excellent review papers were published in the Asteroids III book (2002), including the chapters by Shukoyukov and Lugmair, Bendjoya and Zappalà, Zappalà *et al.*, Keil, Mc Sween *et al.*, Davis *et al.*, Scheeres *et al.*, Paolicchi *et al.*, Richardson *et al.*, Asphaug *et al.*, Holsapple *et al.*, Dermott *et al.*, Bottke *et al.*, Ivanov *et al.*

Papers related to the general subject of the origin, growth and thermal histories of asteroids were published by Merk *et al.* (2002), Scott and Wilson (2005), Greenwood *et al.* (2005), and Mousis and Alibert (2005), the latter paper being devoted in particular to the likely composition of ices incorporated in (1) Ceres. The evolution and current state of Ceres was also modeled by Mc Cord and Sotin (2005). The renewed interest for (1) Ceres and (4) Vesta (see also the previous Subsection) is certainly due to the planned launch of the DAWN mission.

Collisional processes were studied and simulated by many authors. Housen *et al.* (2003) studied the phenomenon of impact cratering on porous asteroids. O'Brien and Greenberg (2003) computed new steady-state size distributions for collisional populations having size-dependent strengths. Theoretical expectations for cratering of the surfaces of the asteroids visited by space probes were performed by Jeffers and Asher (2003), and were found to be in agreement with the observations. Numerical models of the disruption of pre-fractured bodies were developed by Michel *et al.* (2004). Additional numerical experiments simulating the response of rubble piles to collisions were carried out by Richardson *et al.* (2005). The formation of binary systems in family-forming events was simulated by Durda *et al.* (2004). Cheng (2004) did an updated analysis of the collisional evolution in the asteroid belt, and another study on the same subject was later published by Bottke *et al.* (2005).

Asteroid families have been another field of intense activities. The important discovery of a bimodality in the spin properties of the members of the Koronis family was presented by Slivan (2002) and Slivan *et al.* (2003). This phenomenon was interpreted by Vokrouhlický *et al.* (2003) as an effect of thermal torques. Morbidelli *et al.* (2003) found evidence that the size distributions of families, previously believed to be very steep down to small diameters, might be much shallower, even more than that of non-family asteroids. On the other hand, an analysis of the color properties of the asteroids observed by the SDSS survey led Ivezić *et al.* (2002) to conclude that family members might be predominant in the main belt down to small sizes. The existence of short-lived asteroids in the 7/3 Kirkwood gap was interpreted by Tsiganis *et al.* (2003) as due to the Yarkovsky drift experienced by asteroids belonging to the nearby asteroid families of Eos and Koronis. The effect of close encounters with the largest asteroids present in the main belt were shown by Carruba *et al.* (2003) to be of limited importance as a possible mechanism of spreading of the semi-major axis distributions of family members. An evidence of aging of the proper elements of asteroid families, interpreted in terms of evidence of the presence of the Yarkovsky effect, was pointed out by Dell'Oro *et al.* (2004), who concluded that original families were on the average more compact than at present, by a factor of 2. A new analysis of families as the likely origins of the dust bands previously discovered by the IRAS satellite was performed by Nesvorný *et al.* (2003). A general discussion of the current situation in our understanding of the physical properties of asteroid families was done by Cellino *et al.* (2004).

Numerical simulations of the formation of families from catastrophic collision events were performed by Michel *et al.* (2002, 2003).

For what concerns the Yarkovsky effect, important papers were published by Morbidelli and Vokrouhlický (2003), who studied the Yarkovsky-driven origin of NEAs, and La Spina *et al.* (2004), who interpreted the available evidence coming from the spin properties of current NEAs as a proof of a Yarkovsky-dominated dynamical evolution. A general discussion of the role of the Yarkovsky effect was performed by Nesvorný and Bottke (2004), with interesting applications to the case of the dynamical evolution of the members of the very young Karin family.

Strictly related to the Yarkovsky effect is also the so-called YORP effect, acting on an asteroid's spin state. An updated discussion of the relevance of YORP was done by Çapek and Vokrouhlický (2004). According to Vokrouhlický *et al.* (2005), YORP is also probably necessary to fully explain the rotational properties of asteroid (433) Eros, recently visited by the NEAR-Shoemaker space probe.

Finally, Binzel *et al.* (2002) made a general assessment of the chances that we have in the near future to start to derive reliable and accurate information on the asteroids' interiors using all the available tools, including the next generation of space missions.

2.7. *Space missions*

One of the most spectacular achievements of recent years has certainly been the successful NEAR-Shoemaker mission to (433) Eros (and previously, to Mathilde). A general review of the obtained results was given by Cheng (2002), and the implications from the point of view of asteroid geology of the results of both the previous Galileo mission and the NEAR-Shoemaker probe were also discussed by Sullivan *et al.* (2002), while an analysis of the implications of the craters found on the surfaces of the visited asteroids was carried out by Chapman (2002).

Many other papers have been devoted during the triennium to a large variety of topics related to the data obtained by NEAR-Shoemaker. A concise list includes papers by Dombard and Freed (2002), Wasilewski *et al.* (2002), Cheng *et al.* (2002), Lucey *et al.* (2002), Robinson *et al.* (2002), Izenberg *et al.* (2003), Souchay *et al.* (2003), Anderson and Acuña (2004), Mantz *et al.* (2004), Korykansky and Asphaug (2004), Richardson

https://doi.org/10.1017/S1743921306004418 Published online by Cambridge University Press

et al. (2004), Li *et al.* (2004), Kracher and Sears (2005), Souchay and Bouquillon (2005), Colwell *et al.* (2005).

In addition to Near-Shoemaker, the Deep Space 1 encounter with asteroid 9969 Braille was another success. An analysis of the near-IR spectroscopic data obtained by this mission allowed Buratti *et al.* (2004) to reach interesting conclusions on the composition of this asteroid, which turned out to be similar to that of ordinary chondrites.

An analysis of the size, shape and spin axis orientation of asteroid (5535) AnneFrank, visited by the Stardust probe, was carried out by Duxbury *et al.* (2004).

The asteroid (25143) Itokawa, the target of the Japanese Hayabusa sample return mission, was also the subject of a number of investigations aimed at predicting in advance its most important physical properties. In this respect, papers were published by Dermawan *et al.* (2002), Ohba *et al.* (2003), Sekiguchi *et al.* (2003), Ishiguro *et al.* (2003), Kaasalainen *et al.* (2003), Vokrouhlický *et al.* (2004), Lederer *et al.* (2005).

An updated study of the composition of (243) Ida and its satellite Dactyl based on older Galileo data was performed by Granahan (2002).

We note also that a presentation of the planned DAWN mission to Ceres and Vesta was published by Russell *et al.* (2004).

2.8. *Asteroid–meteorite and asteroid-comet connections*

It has long been recognized that there are very important interrelations between classes of minor bodies of our Solar System that have been traditionally studied by different scientific communities.

The asteroids are now considered as the most important sources of meteorites. This particular subject was reviewed by Burbine *et al.* (2002), while the evidence coming from meteorites for understanding the accretion and the collisional evolution of their asteroidal parent bodies was discussed by Scott (2002). A similar analysis was also carried out by Consolmagno and Britt(2004). Evidence of fast delivery of meteorites to the Earth after a major asteroid collision was analyzed by Heck *et al.* (2004). The connection between (4) Vesta, the V-type asteroids and HED meteorites was discussed by Kelley *et al.* (2003), who found evidence for a common origin of (1929) Kollaa, (4) Vesta and the HEDs. Similar results were also obtained on the same subject by Nyquist *et al.* (2003). A more general analysis of the problem was later published by Cochran *et al.* (2004), while Treiman *et al.* (2004) found some possible evidence of hydration in Vesta from analysis of a quartz veinlet in an eucrite meteorite. Sephton *et al.* (2004) analyzed the Carbon and Nitrogen isotopic ratios in meteoritic organic material to derive indications on the geological history of the supposed asteroidal parent bodies. An interpretation of brachinites as being igneous rocks from a differentiated asteroid was proposed by Mittlefehldt *et al.* (2003).

The interrelations between asteroids and comets have been the subject of papers by Meng *et al.* (2004), mainly from the point of view of some cases of asteroids being the likely parent bodies of meteors showers. Hsieh *et al.* (2004) analyzed the case of the comet 133P/Elst-Pizarro, a typical asteroid-comet transition object.

2.9. *Near–Earth asteroids (NEAs)*

NEAs, their origin and evolution, and their relationship with impact hazards on Earth have been one of the most important fields of activity since several years. The general topic of the origin and evolution of NEAs was reviewed by Morbidelli *et al.* (2002a). Another review, devoted to make a summary of current knowledge of NEA physical properties, was given by Binzel *et al.* (2002).

One of the major fields of investigation has been the determination of the inventory, size and orbital distribution and steady supply of objects from the asteroid main belt.

Morbidelli *et al.* (2002b) developed a model of the albedo distribution of NEAs, needed to convert the observed magnitude distributions into real size frequencies. A new estimate of the bias-corrected NEA inventory, size frequency and impact hazard was then published by Stuart and Binzel (2004).

Studies of different physical properties of NEAs resulting from a variety of observing techniques were carried out by Krugly *et al.* (2002), Dandy *et al.* (2003), Yang *et al.* (2003), Kaasalainen *et al.* (2004), Binzel *et al.* (2004a, 2004b), Wolters *et al.* (2005), Marchi *et al.* (2005). A theoretical study of the evolution of NEA spin rates due to close encounters with the Earth and Venus was also carried out by Scheers *et al.* (2004).

Some studies were devoted to detailed physical analyses of the properties of single objects, like in the case of 2001 XR31, a possible unique example of an R-type NEA, according to Marchi *et al.* (2004).

Another blooming field of investigations has been that related to the impact hazard evaluation, and the effectiveness of current NEA searches. An analysis of the latter topic was carried out by Jedicke *et al.* (2003), who concluded that is very unlikely that the Spaceguard goal to achieve 90% completion in the discovery of NEAs larger than 1 km by 2008 can really be achieved. The more general topic of comet and asteroid impact hazard was discussed by Ipatov and Mather (2004), and Chapman (2004).

A model of a possible Tsunami event caused by the impact of a 1.1 km NEA was developed by Ward (2003).

The need of achieving a much better knowledge of the physical properties of NEAs for developing any credible strategy of mitigation of the impact hazard is well known. In this respect, Walker and Huebner (2004) discussed the possibilities to obtain seismological data on NEAs by means of dedicated space missions, while Cellino *et al.* (2004) discussed the opportunity to have a satellite dedicated to measure NEA sizes by means of thermal-IR observations. The possibility to probe the internal structure by means of radio reflection tomography was discussed by Safaeinili *et al.* (2002).

The use of purely kinetic energy impacts from retrograde orbits as a possible tool to deflect a possible Earth impactor was proposed by Mc Innes (2004).

2.10. *Trojan asteroids*

Trojans play an increasingly important role in modern asteroid science. A general review of the subject was given by Marzari *et al.* (2002), who mainly focused on the origin and evolution of these objects, while Barucci *et al.* (2002) focused specifically on the physical properties of Trojans, compared with those of Centaurs and TNOs.

During the last triennium, Jupiter Trojans were spectroscopically observed by Dotto *et al.* (2004), who focused their attention on Trojan asteroid families, Emery and Brown (2004), and Bendjoya *et al.* (2004), who found first evidence for one or two Trojans exhibiting blueish reflectance spectra. Emery and Brown (2003) performed near-IR spectroscopy of 20 objects, and derived some new constraints on the surface compositions.

Radiometric observations of Jupiter Trojans were also performed by Fernández *et al.* (2003).

Spectroscopic observations of Mars Trojans were carried out by Rivkin *et al.* (2003).

2.11. *Miscellaneous asteroid–related publications*

Cremonese *et al.* (2002) made an analysis of the likely detections of asteroids by the Planck space mission at millimetric and sub-millimetric wavelengths. According to their results about 400 objects should be detected.

Foot and Mitra (2003) carried out a very speculative analysis concerning the possibility to find evidence of mirror matter (an entirely new form of matter whose existence is predicted by some theories) from analyzes of the crater size distributions in some asteroids, like (433) Eros.

2.12. *Centaurs and Trans–Neptunian objects*

The situation in the field of the physical studies of distant objects in the outer Solar System resembles the analogous situation encountered in the early history of modern asteroid science. The availability of large telescopes and efficient detectors, coupled with the recognized importance of Centaurs and TNOs to understand the history and evolution of our Solar System, is triggering a burst of activities. Barucci *et al.* (2002) reviewed the knowledge of the physical properties of these objects at the time the Asteroids III book was published, but since then many new results have been obtained.

Boenhardt *et al.* (2002) presented the first results of an observing campaign of TNOs and Centaurs in BVRI colors using the ESO VLT telescope. In particular, results for 28 objects were discussed. Optical observations of 13 TNOs were carried out by Sheppard and Jewitt (2002), while multi-color observations of 24 Centaurs were presented by Bauer *et al.* (2003). Bauer *et al.* (2002) presented observations of the peculiar Centaur object 1999 UG_2, while the Centaur C/NEAT (2001 T4) was optically observed by Bauer *et al.* (2003). First results of TNO visible spectroscopy using the ESO VLT were presented by Lazzarin *et al.* (2003) and by Doressoundiram *et al.* (2003). Spectra of two of the largest TNOs were also obtained by Marchi *et al.* (2003). The possible determination of TNOs distances and sizes from star occultations was discussed by Cooray (2003) and Denissenko (2004). Ortiz *et al.* (2003) reported the results of photometric observations of six TNOs. Size estimates for seven TNOs by means of bolometric observations were presented by Altenhoff *et al.* (2004). Some indication for a possible aqueous alteration of the surfaces of two Plutinos was found by de Bergh *et al.* (2004) based on visible and near-IR spectra. Visible and near-IR spectra for eight TNOs and four Centaurs were also obtained by Delsanti *et al.* (2004). A direct measurement of the size of the large TNO (50000) Quaoar was obtained by Brown *et al.* (2004), using the High Resolution Camera of the HST. Based on spectrophotometric observations, Sheppard and Jewitt (2004) found some evidence that the TNO 2001 OG_{298} is a contact binary. The orbit and albedo of another TNO binary system, (58534) 1997 CO_{29}, were determined by Noll *et al.* (2004). The final results of their ESO VLT program of TNO observations started in 2001, were presented by Fornasier *et al.* (2004). Jewitt (2005) presented the results of a multi-color investigation of twelve "Damocloids", objects considered to be likely inactive Halley-type comets. An unexpectedly high albedo for the TNO 2002 AW_{197} was found by Cruikshank *et al.* (2005) based on thermal IR observations using the Spitzer space telescope.

Stern (2002) discussed the evidence for a collisional mechanism affecting TNO colors. Evidence for the existence of a collisional family in the Kuiper belt was also discussed by Chiang (2002).

Allen *et al.* (2002) discussed a possible explanation of a lack of TNOs beyond 50 AU from the Sun.

3. Comets

In this section, papers related to physical studies of comets are briefly summarized. The comet section is based upon a compilation of 361 refereed papers. The material is organized into a series of nine subsections covering a wide range of cometary science including the origin of comets in relation to the formation of the solar system. A section is devoted to the exploration of comets by the Stardust and Deep Space 1 missions. The

https://doi.org/10.1017/S1743921306004418 Published online by Cambridge University Press

Deep Impact mission carried out a first "active" experiment on 9P/Tempel 1 on 4 July, 2005. The scientific results of the Deep Impact is not reported here because of the period covered in this report. The Rosetta mission is now on the way.

We note that COMETS II, a comprehensive book on cometary science, was published in 2004 by the efforts of editors M.C. Festou, H.U. Keller, and H.A. Weaver and 88 collaborating authors. This book was dedicated to Dr. Fred L. Whipple, who passed away on 20 August, 2004. The comet community was saddened to hear of Michel Festou's death on 11 May, 2005, at the age of 60, just at the time of Comets II publication.

3.1. *Comet nuclei*

Size and shape: The ongoing observational effort dedicated to the determination of the size and shape of cometary nuclei from ground-based observations in the visible, in the thermal infrared and at radio wavelengths yielded new data during the last three years. The radii of comets 103P/Hartley 2, 126P/IRAS (Groussin *et al.*, 2004), 48P/Johnson (Jewitt and Shepard, 2004), 143P/Kowal-Mrkos (Jewitt *et al.*, 2003) and C/1999 S4 LINEAR (Altenhoff *et al.*, 2002) have been measured. Two recent surveys in the visible were published by Lowry *et al.* (2002) and Meech *et al.* (2003). An observing campaign to support the Deep Impact mission and involving several Earth- and space-based observatories allowed the determination of the size and elongation of comet 9P/Tempel 1 (Fernandez *et al.* 2003, Belton *et al.* 2005, Lisse *et al.* 2005).

Ground-based observations have been complemented by detailed observations of the nucleus of comets 19P/Borrelly and 81P/Wild 2 by the Deep Space 1 and Stardust space probes. The analysis of the images yielded an accurate determination (with an accuracy of about 50-100 m) of their size and shape (Oberst *et al.* 2004, Duxbury *et al.* 2004). In both cases, no evidence was found for building blocks (cometesimals). The nucleus of comet 19P/Borrelly is prolate and very elongated while that of comet 81P/Wild 2 is close to an oblate spheroid with radii 1.65x2.00x2.75 km. The difference could come at least partially from erosion processes (A'Hearn 2004).

A database of cometary nucleus sizes allowing statistical analyses is now available in the literature. The index q_S of the cumulative size distribution is of particular interest because it depends on the collisional history of the population of bodies. Values of $q_S = 1.6 \pm 0.1$ and 1.45 ± 0.05 have been measured by Lowry *et al.* (2002) and Meech *et al.* (2003) from their restricted samples. Based on reliably measured radii of 65 ecliptic comets and 13 nearly isotropic comets, Lamy *et al.* (2004) estimated $q_S = 1.9 \pm 0.3$ with a depletion for objects with radii lower than 1.5 km. For their sample, Meech *et al.* (2003) found a similar index for the objects with radii greater than 2 km. This index is different from that measured for large (> 100 km) KBOs, which indicates that the size distribution of objects in the Kuiper belt has different slopes at different sizes (Meech *et al.* 2003, Lamy *et al.* 2004).

Rotational properties: The study of the rotational properties of comets both from observations and modeling remains the subject of a large number of articles.

The spin period of comets was measured for comets 48P/Johnson (Jewitt and Shepard 2004), 9P/Tempel 1 (Belton *et al.* 2005), 6P/d'Arrest (Gutierrez *et al.* 2003), C/1996 B2 Hyakutake (Schleicher and Woodney, 2003) and 143P/Kowal-Mrkos (Jewitt *et al.* 2003). A possible change in the spin period of 6P/d'Arrest has been claimed by Gutierrez *et al.* (2003). Possible directions of the spin axis have been derived for comets 9P/Tempel 1 (Belton *et al.* 2005), C/1996 B2 Hyakutake (Schleicher and Woodney, 2003), 19P/Borrelly (Schleicher *et al.* 2003) and 81P/Wild 2 (Duxbury *et al.* 2004, Vasundhara and Chakraborty 2004). A change of about 10 degrees in the direction of the spin axis of 19P/Borrelly between 1911-1932 and 1994-2001 has been measured by Schleicher *et al.*

(2003). An updated review of the best known rotational parameters can by found in an article by Samarasinha *et al.* (2004). Finally, the nucleus of 2P/Encke has been found by Belton *et al.* (2005) to be in a short-axis mode excited spin state from the analysis of light curves and dust coma morphology. This is the second nucleus after that of comet 1P/Halley to be in an excited spin state.

Comet nuclei can reach excited spin states under the effect of the reactive torque created by anisotropic outgassing. All the models assume that the nucleus is a rigid body. Neishtadt *et al.* (2003) modeled the temporal evolution of the rotational parameters for the particular case of a nucleus with two equal moments of inertia. They find a linear increase with time of the angular momentum which could lead to breakups in some cases. They also confirmed that for localized active areas, the angular momentum tends to be aligned with the comet-Sun vector at perihelion. The subject is also addressed by Gutiérez *et al.* (2003b), who perform numerical simulations of the long-term evolution of the spin state of small active nuclei. Mysen (2004) developed a similar model for a tri-axial ellipsoidal nucleus. He used a more realistic thermal model and an expansion of the Hamiltonian in spherical harmonics to model the long-term evolution of the rotational parameters. Mysen (2004) described the stability of spin states as a function of the comets' axes ratios and found that 67P/Churyumov-Gerasimenko has the most stable spin state of his sample. Gutierrez *et al.* (2003) performed simulations for a small active comet on the orbit of 46P/Wirtanen. They used a direct numerical integration of the Euler equations for several irregular shapes and activity patterns. Gutierrez *et al.* (2003) found changes in the spin period of up to 10 hrs and displacement of the angular momentum of up to several tens of degrees during a single perihelion passage. They also found that the spin period must increase dramatically before the nucleus can reach an excited spin state. The model of Rodionov *et al.* (2002) is more realistic because it also accounts for the phenomena occurring in the Knudsen layer above the surface.

Surface properties: Measurements of the albedo of the comet nuclei consistently show values in the range 0.02-0.06. Fernandez *et al.* (2004) and Lisse *et al.* (2004) measured a mean geometric albedo of 0.04-0.07 for comet 9P/Tempel 1 from two different ground-based datasets. Surface properties of comets 19P/Borrelly and 81P/Wild 2 determined from the Deep Space 1 and Stardust probes are described in the Section presenting spacecraft observations.

Activity processes: Understanding the activity of comet nuclei is a challenge which triggered several works. Refined thermo-physical models have been used and their results compared to observational constraints.

Capria *et al.* (2003) use a thermal evolution model of the nucleus to compute surface temperatures and production rates for comet 46P/Wirtanen, the old (and discarded) target of the Rosetta mission. Cohen *et al.* (2003) developed a quasi-3D model (neglecting lateral heat conduction) for a spherical nucleus composed of dusty water ice. Predictions of their model includes the water production rate, the distribution of erosion at the surface of the nucleus and the surface temperature for a comet on the orbit of 46P/Wirtanen. Lamy and Groussin (2003) pointed out that the water production curve of comet 46P/Wirtanen could be explained by large variations of the active surface fraction caused by the formation of a temporary crust. De Sanctis *et al.* (2003) developed a sophisticated thermal model to try to explain the surface temperature and production rate of comet 19P/Borrelly observed by Deep Space 1. They find that the crust formation caused by the accumulation of dust particles at the surface is highly latitude-dependent. Their model could reproduce the formation of a dust layer covering most of the nucleus surface. Yelle *et al.* (2004) suggest that the thin dust jets observed by Deep Space 1 could be created by geysers in hypersonic flows emanating from subsurface cavities.

Davidsson & Skorov (2002) and Skorov *et al.* (2002) develop a model of porous nucleus surface and consider gradual absorption of solar radiation by the surface layers. They showed that the energy can be deposited in a surface layer of 20 particle radii. They also found that the local sublimation rate is lower by a factor of 2-7 than what it would be for a pure surface model, which lead to the conclusion that the actual active surface fraction of comet nuclei could be much larger than those estimated from previous thermal models. Davidsson & Skorov (2004) investigate the flow of gas molecules through the outer layers of the nucleus, including back-scattering from the coma. A self-consistent model of heat and mass transfer in the outer layers of a comet nucleus coupled with the inner coma is developed by Skorov *et al.* (2004). The comet nucleus topography and its effect on gas release and dust mantle evolution is investigated by Huebner (2003). Ivanova & Shulman (2003) show that craters on the surface of the nucleus increase the sublimation rate due to the concentration of solar radiation by the conical hole. Uneven erosion of the nucleus is considered by Cohen *et al.* (2003).

Podolak *et al.* (2002) consider sublimation of H_2O and HDO ice from the outer layers of the nucleus, which suggests that, on parts of the cometary orbit, the relative sublimation rates may differ from the D/H ratio in the nucleus itself. The formation of a crater structure on the surface of comet nuclei by meteoroid impacts is studied by Shulman & Ivanova (2003), who calculate the probability for simultaneous existence of several craters on the same nucleus.

Internal properties: In contrast to their surface properties, our knowledge of the interior of comet nuclei remains scarce and inaccurate. The bulk density of comet 19P/Borrelly has been estimated to be lower than 0.3 g cm^{-3} by Davidsson and Gutierrez (2004) from a detailed modeling of the observed non-gravitational forces. Farnham and Cochran (2002) found a density of 0.3-0.8 cm^{-3} for this comet using a model simpler than that of Davidsson and Gutierrez (2004). However, for comets in general, the density must be greater than 0.4 g cm^{-3} to ensure the stability of a strengthless body against centrifugal disruption (Samarasinha *et al.* 2004). Images of the surface of comets 1P/Halley, 19P/Borrelly and 81P/Wild 2 are compatible with a high porosity and moderate tensile strength material (Keller *et al.* 2004, A'Hearn 2004, Britt *et al.* 2004).

Fragmentation: Fragmentation of cometary nuclei due to tidal forces and thermal stress continues to be subject of investigation. Ip (2003) shows that a large fraction of short-period comets and scattered Kuiper belt objects may have been fragmented by close encounters with the outer planets. Fragmentation in relation to sungrazers are described in the Section presenting sungrazing comets.

Early evolution: The presumed pristine nature of cometary material is questioned by Choi *et al.* (2002), who show that Kuiper belt objects are likely to lose ices of very volatile species during early evolution, and by Stern (2003), who argues that comets can no longer be regarded as wholly pristine. The possible presence of liquid water in the early evolution of comets is considered by Merk & Prialnik (2003). The thermal conductivity of porous material in terms of microstructural parameters, allowing for heat transport by pore filling vapor, is investigated by Keller & Spohn (2002).

3.2. *Gas coma*

A large numbers of papers have been published on the gas coma, emphasizing new observations or theoretical modeling. Several comets made spectacular apparitions in 2002–2005 (e.g. C/2002 T7 (LINEAR), C/2001 Q4 (LINEAR)), but many papers concern comets which were observed in the preceding years, as C/1995 O1 (Hale-Bopp), C/1996 B2 (Hyakutake) and 153P/Ikeya-Zhang. The targets of the space missions Deep Space 1, Stardust and Rosetta were observed for preparing or supporting the missions.

Many papers report on compositional measurements. The study of chemical diversity among comets is indeed of great interest to obtain clues to the origin of cometary material and to study the role of aging and differentiation processes at or below the nucleus surface. Composition measurements obtained by IR long-slit spectroscopy are reported for comets C/1996 B2 (Hyakutake) (Magee-Sauer *et al.* 2002, Dello Russo *et al.* 2002, DiSanti *et al.* 2002), 153P/Ikeya-Zhang (Kawakita *et al.* 2003, Dello Russo *et al.* 2004), and other comets (Dello Russo *et al.* 2005). Relative abundances concerning CO, CH_4, HCN, C_2H_2 and C_2H_6 are inferred. Gibb *et al.* (2003) present the abundance of methane in eight Oort cloud comets and show that there is no correlation between CH_4 and CO abundances. Bonev *et al.* (2004) show that OH ro-vibrational lines near 3 μm resulting from prompt emission can be used as a proxy for measuring water production rates and determine effective g-factors of these lines. Kawakita *et al.* (2004, 2005) and Dello Russo *et al.* (2005) present measurements of the nuclear spin temperature of CH_4, NH_3 and H_2O, respectively. Kawakita *et al.* (2003, 2005) present upper limits on the CH_3D/CH_4 ratio.

Composition measurements based on radio observations are published in a few papers. Crovisier *et al.* (2004) present the first detection of ethylene glycol in a comet, observed in archive millimeter spectra of comet Hale-Bopp. In another paper, Crovisier *et al.* (2004) present upper limits obtained on the abundance of a number of species in comet Hale-Bopp, including deuterated species. The detection of acetaldehyde CH_3CHO is reported. Irvine *et al.* (2003) and Rodgers *et al.* (2003) present measurements of the HNC/HCN ratio in comets C/2000 WM1 (LINEAR) and 153P/Ikeya-Zhang and show that it increases with decreasing heliocentric distance, suggesting a thermally-controlled process for the origin of HNC. Bockelée-Morvan *et al.* (2004) publish composition measurements in 19P/Borrelly. Importantly, the H_2O molecule has now been detected in several comets through its fundamental 557 GHz line using the SWAS (Bensch *et al.* 2004) and Odin (Lecacheux *et al.* 2003) space telescope. Observations of $H_2^{18}O$ show that the $^{16}O/^{18}O$ ratio is terrestrial (Lecacheux *et al.* 2003). Finally, Crovisier *et al.* (2002) publish the whole set of observations of the OH radical performed at the Nançay radio telescope from 1982 to 1999, which includes 53 comet apparitions.

The visible and UV windows allow to observe several radicals (OH, CN, C_2, C_3, CS ..), atoms (C, O, H) and ions in cometary atmospheres which provide key diagnostics on comet outgassing and chemical diversity. Many papers report on the relative production rates of these radicals and heliocentric dependence, and on their spatial distribution. Seasonal effects are observed (e.g., Schleicher *et al.* 2002 for C/1996 B2 (Hyakutake); Farnham and Schleicher 2005 for 81P/Wild 2) as well as spatial asymmetries (Lara *et al.* 2004 in C/2000 WM1). Measurements in space mission targets 19P/Borrelly (Weaver *et al.* 2003, Farnham and Cochran 2002), 81P/Wild 2 (Schulz *et al.* 2003, Farnham and Schleicher 2005) and 67P/Churyumov-Gerasimenko (Weiler *et al.* 2004, Schulz *et al.* 2004) are reported and comparison between multiple apparitions are presented. Rauer *et al.* (2003) present the monitoring of several radicals performed at ESO in comet Hale-Bopp from 2.8 to 12.8 AU from the Sun and show that the production rate of CN and its radial distribution are consistent with HCN being the major parent of CN. On the other hand, in several comets, Arpigny *et al.* (2003) and Jehin *et al.* (2004) report a $^{14}N/^{15}N$ ratio in CN twice lower than the terrestrial value and the value measured in HCN. Cochran (2002) obtains a very stringent upper limit on the N_2^+/CO^+ ratio in comet 153P/Ikeya-Zhang. Harris *et al.* (2002) report wide field imaging of OH in comet Hale-Bopp and evidence for strong acceleration in the outer coma. Oliverson *et al.* (2002) report observations of CI 985 nm forbidden line in comet Hale-Bopp. The possible sources of this emission are discussed in detail by Saxena *et al.* (2002). Jackson *et al.* (2004) show that several unidentified lines in comet 122P/de Vico can be attributed to CS_2, based on laboratory spectra. In the UV, using the Far Ultraviolet explorer (FUSE), Weaver *et al.* (2002) report a sensitive search for argon in several comets, which shows a Ar/O depletion of 13 with respect to the solar value. Interestingly, H_2 produced by the photodissociation of water is detected by FUSE, as well as new electronic bands of CO (Feldman *et al.* 2002). Clairemidi *et al.* (2004) suggest a tentative identification of pyrene in comet 1P/Halley from the analysis of spectra obtained with the TKS spectrometer aboard Vega spacecraft.

The study of extended sources in cometary coma is the topic of several papers. DiSanti *et al.* (2003) show that, in contrast to found in comet Hale-Bopp, the dominant source of CO in comet Hyakutake is the nucleus. Brooke *et al.* (2003) suggest that most of the CO in the coma of comet Hale-Bopp is produced by an extended source. Gunnarsson *et al.* (2003) analyses the CO radio observations of Hale-Bopp made at large heliocentric distances and suggest that part of the CO is released from icy grains. Lifetimes of porous icy grains at large heliocentric distances are published in Gunnarsson (2003). Note that icy grains are detected spectroscopically in the coma of C/2002 T7 (LINEAR) at 3.52 AU from the Sun by Kawakita *et al.* (2004). Cottin *et al.* (2004) and Fray *et al.* (2004) show that the degradation of formaldehyde polymers can explain the extended spatial distribution of H_2CO observed in comet 1P/Halley. The origin of sodium in cometary atmospheres is also strongly debated. Comets Hale-Bopp and 153P/Ikeya-Zhang showed a steep heliocentric dependence in Na production, suggesting that Na is produced by thermo-desorption from grains (Furusho *et al.* 2003, Watanabe *et al.* 2003).

Models: Modeling of coma processes has been an active field between 2002 and 2005. A few papers concerning molecular excitation have been published. Kim (2003) examines C_2H_6 excitation to model its infrared emission. The excitation of CH_3D is modeled by Kawakita and Watanabe (2003). Lovell *et al.* (2004) study the effect of collisions with electrons to the excitation of HCN. Bensch and Bergin (2004) present a model for water excitation and prospectives for observations of cometary water with the Herschel Space Observatory and SOFIA. Reylé and Boice (2003) and Kim *et al.* (2003) present fluorescence models of S_2 to analyses HST observations. Bardhwaj and Haider (2004) model the production of OI 630nm forbidden emission in comets. Concerning coma chemistry, Glinski *et al.* (2004) examine oxygen and hydrogen chemistry in the inner coma and show that O_2 should be present at the 1% level. Deuterium chemistry is examined by Rodgers and Charnley (2002): for most molecules, the deuterium fractionation is unchanged in the coma. Coma gas dynamics is investigated in several papers. Combi (2002) presents a model for comet Hale-Bopp and compares it to observations. Crifo *et al.* (2003) present Navier-Stokes and Monte-Carlo simulations of the circumnuclear coma for aspherical nuclei and show excellent agreement between the two methods even for low production rates. An advanced physical model of the inner coma environment handling complex nuclear shapes and composition heterogeneity is presented by Rodionov *et al.* (2002).

3.3. *Cometary dust*

Dust comae and tails: Lisse (2002) study the role of dust mass loss in the evolution of comets using an ongoing optical/thermal infrared photometric imaging survey of comets. A long-term dust activity of comet C/1995 O1 (Hale-Bopp) was monitored at the European Southern Observatory by Weiler *et al.* (2003). Lara *et al.* (2003) observed dust in comet C/1999 T1 (McNaught-Hartley) with optical and near-infrared bands. The dust coma of comet C/1999 H1 (Lee) was observed between 0.6 and 1 μm and modeled with Mie theory for perfect compact spheres by Lara *et al.* (2004). The dust environment of comet 67P/Churymov-Gerasimenko, which is the new target for the Rosetta mission, was studied by Fulle *et al.* (2004), Schulz *et al.* (2004), and Moreno *et al.* (2004). Lara *et al.* (2004) investigated the dust coma of comet C/2000 WM1 (LINEAR) during its closest approach to Earth. Lisse *et al.* (2004) discuss the dusty coma characteristics of two comets, 126P/IRAS and 2P/Encke, based on infrared data of ISO/ISOPHOT and Midcourse Space Experiment. Schleicher and Woodney (2003) present inner-coma imaging of comet C/1996 B2 (Hyakutake) to study its dust coma morphology. Schulz *et al.* (2003) monitored the dust coma morphology and activity of comet 81P/Wild 2, the target of the Stardust mission. Vasundhara and Pavan (2004) investigated the dust morphology of comet 81P/Wild 2 measured in the I- and R-band images of the dust coma. Schleicher *et al.* (2003) observed dust in comet 19P/Borrelly at multiple apparitions to study a seasonable variation in dust morphology.

Moreno *et al.* (2003) developed a numerical method to compute brightness of cometary dust tails and applied the model to red continuum images of comet C/1999 T1 (McNaught-Hartley). Andrienko and Mishchishina (2003) studied stabilities of dust trajectories in the comae of comets by hydrodynamical modeling. Gas-dust jet formation in comets was simulated in laboratory experiments by Ibadinov and Rahmonov (2002).

Chen *et al.* (2004) study the charging characteristics and equilibrium potential of dust grains in comets.

Qian *et al.* (2002) observed an outburst of comet C/1995 O1 (Hale-Bopp) and estimated the mean radii of dust grains in two ejecta during the outburst. The dust tail of comet C/1999 J2 (Skiff) was observed at the large heliocentric distance of 7.24 AU by Korsun and Chörny (2003). Pansecchi and Scardia (2005) observed a ray-shaped structure in the dust tail of comet C/2004 F4 (Bradfield).

Dust composition: Biesecker *et al.* (2002) identified the presence of two populations in sungrazing comets by analyzing the lightcurves of their dusty comae. The two populations of dust particles are interpreted as olivine dust aggregates and pyroxene dust aggregates by Kimura *et al.* (2002). Bemporad *et al.* (2005) ascribe an additional Lyman alpha component of the sungrazing comet C/2100 C2 measured by SOHO Ultraviolet Coronagraph Spectrometer to sublimation of pyroxene dust grains released from the comet.

Mid-infrared spectra were obtained in a number of comets to study the 10-μm silicate thermal emission. Harker *et al.* (2002, 2004) analyze a large set of Hale-Bopp data and show that the silicate crystalline-to-amorphous ratio spans the range 1.5–3.7, while the silicate-to-amorphous carbon ratio is in the range of 8.1-13.3. Wooden *et al.* (2004) present measurements in C/2001 Q4 (NEAT) and show that the crystalline/amorphous silicate content in this comet is similar to that in comet Hale-Bopp, the silicate-to-amorphous carbon ratio being lower. Sitko *et al.* (2004) analyze silicate emission in several comets and show that there is a correlation between band strength and grain temperature. Comet 81P/Wild 2 displayed a 10μm silicate feature about 25% above the continuum, similar to several other Jupiter-family comets, but much lower than that seen in a number of Oort cloud comets (Hanner *et al.* 2003).

Several papers present laboratory experiments aimed to understand the nature and origin of cometary silicates. The mid-infrared spectral evolution of amorphous metastable eutectic magnesiosilica smokes and its implication for silicates in cometary dust were studied by Rietmeijer *et al.* (2002). Thompson *et al.* (2003) performed laboratory experiments on annealing of amorphous $MgSiO_3$ to study the processing of crystallization that might happen to primordial cometary dust.

Scattering properties: Hanner (2003) review light-scattering and thermal-emission properties of cometary dust from observational point of view. Hadamcik and Levasseur-Regourd (2003) present their polarimetric observations of solar radiation scattered by cometary dust between 1990 and 2001. Müller *et al.* (2002) define a procedure for estimating the optical thickness of a cometary dust coma. Das *et al.* (2004) studied the relation between size distributions of cometary dust and the dynamical ages of comets by analyzing polarimetric data with Mie theory.

Hadamcik and Levasseur-Regourd (2003) performed imaging polarimetry of comet C/1995 O1 (Hale-Bopp) over a large range of phase angles. Schulz and Stüwe (2002) inferred a splitting of the nucleus of comet C/1999 S4 (LINEAR) from their optical observations of the dust coma. Imaging and polarimetry of the comet during its disruption were used to constrain the physical properties of scattering dust particles by Bonev *et al.* (2002) and Hadamcik and Levasseur-Regourd (2003). Kiselev *et al.* (2002) found no difference of polarization between split comets and normal comets through their polarimetric database. Grynko *et al.* (2004) derived the phase curves of brightness and polarization at forward scattering regions for comet 96P/Machholz 1 from the SOHO/LASCO C3 coronagraph data. Jewitt (2004) accurately measured the coma polarization of comet 2P/Encke that is much higher than previously reported.

Vilaplana *et al.* (2004,2005) attempted to model observationally determined light-scattering properties of cometary dust. Kimura *et al.* (2003), Kimura and Mann (2004), Kolokolova *et al.* (2004), and Mann *et al.* (2004) present a model of fractal dust aggregates simulating the composition of Halley's dust and the morphology of interplanetary dust particles to reproduce simultaneously all of the observed light-scattering properties of cometary dust.

3.4. *X-ray emission*

The discovery of X-ray emission in 1996 from C/1996 B2 comet Hyakutake created a surprising new class of X-ray emitting objects. The original discovery and subsequent detection of X-rays from several other comets have shown that the soft ($E < 1$ keV) X-ray emission is a fundamental property of comets (Lisse *et al.* 2004, Krasnopolsky *et al.* 2004). In the last few years, Chandra and XMM-Newton X-ray observatories have measured spectrum of cometary X-rays that are dominated by line emission from high charge states of O, C, N, Ne, Mg, ions, which result mainly due to charge exchange collision of highly ionized solar and ions and cometary gas (Cravens, 2002, Krasnopolsky *et al.* 2002, Kharchenko *et al.* 2003, Beiersdorfer *et al.* 2003, Krasnopolsky *et al.* 2004). It is shown that most of cometary X-rays come from inside the bow shock and its morphology depends on gas production rate (Wegmann and Dennerl, 2005, Wegmann *et al.* 2005). The observed cometary X-rays spectra and intensity can be used to study the solar wind composition and its variations (Krasnopolsky *et al.* 2004, Bodewits *et al.* 2004, Wegmann *et al.* 2005).

3.5. *Chemistry, Plasma and Tail*

Interaction of solar wind with comets results in a host of phenomena that start from beyond the bow shock in the sun-ward direction and go way beyond the plasma tail in anti-sunward direction. During the last three years papers have been published dealing with disturbances in solar wind due to comet-solar wind interactions (Wegmann, 2004), ion pick-up processes (Katoh *et al.* 2003, Wimmer-Schweingruber *et al.* 2003), interaction of coronal mass ejection with comets (Jones and Brandt, 2004), tail disconnection events (Snow *et al.* 2004), diamagnetic cavity boundary (Israelevich *et al.* 2003), and reconnection events in cometary tails (Konz *et al.* 2004). A new MHD model of comet-solar wind interaction has also been developed (Benna *et al.* 2004).

Detections of doubly ionized carbon in the tail of comet Kudo-Fujikawa (Povich *et al.* 2003) and cometary ions trapped in a coronal mass ejection (Gloeckler *et al.* 2004) were noteworthy observations.

Since comets are watery bodies, studies on electron impact excitation (Makarov *et al.* 2004, Faure *et al.* 2004) and ionization of water (Bhardwaj, 2003) are important for understanding the physical and chemical processes in the coma (Haider and Bhardwaj, 2005). Several papers were published that discuss ion chemistry (Glinski *et al.* 2004, Haider and Bhardwaj 2005, Stoeva *et al.* 2005).

3.6. *Sungrazing comets*

The prodigious discovery of sungrazing comets continues with the Solar and Heliospheric Observatory (SOHO) mission. The Large Angle Spectrometric Coronagraph (LASCO) has discovered close to 1000 of them as of June, 2005, in under 9.5 years of observing. The vast majority of these are members of the Kreutz family, but about 100 of them have been noted as belonging to one of 4 new comet groups. These new groups all have lower inclinations than the Kreutz family and the perihelion distances for all of them are of order 0.05 AU, so the moniker sungrazer may not be appropriate. The most numerous is the Meyer group, and that with the fewest members is the second (II) Kracht group. Of most interest are the Marsden and first Kracht groups, which have been clearly associated with not only each other, but also 96P/Machholz, the Quadrantid meteor stream (and 2003 EH1), and the southern delta Aquarid meteor stream (Ohtsuka *et al.* 2003). Notably, several of the Marsden family comets were not only discovered, but may have also been recovered by LASCO. If so, then elliptical orbits with periods between 5.5 and 6.0 years are appropriate.

The bulk of the research on sungrazers remains centered around the Kreutz family, with the majority of this investigating the fragmentation history and processes of the family. Sekanina and Chodas (2002) found that non-tidal fragmentation post-perihelion, possibly aided by fissuring at perihelion, yields the best orbital solutions for many of the brightest Kreutz comets. Bemporad *et al.* (2005) presented observations showing a series of fragmentation events, and the eventual destruction, of one of the smaller sungrazers just hours prior to perihelion passage. The age of the Kreutz comet system has been estimated to be <1700 years (Sekanina and Chodas, 2004). Several attempts to understand the Kreutz lightcurves, with their peaking and fading prior to perihelion have been reported (Kimura *et al.* 2002, Sekanina 2003). Sungrazing comets have also been postulated to be a significant source of inner heliosphere pickup ions, ions which were initially neutral and upon being ionized, are 'picked up' by the solar wind (Bzowski and Królikowska 2005).

Fragmentation of sungrazers is investigated by Sekanina (2003). Kulikova & Chepurova (2004) perform a computer simulation of the disintegration of comet Tempel-Tuttle into meteoroid bodies. The potential consequences of collisions between comets and other small bodies on cometary brightness is discussed by Gronkowski (2004).

3.7. *Cometary material origin*

New observational constraints on cometary material origin were obtained. The ortho/para ratios and/or spin temperature of H_2O, NH_3 and CH_4 have been measured in a few comets at different heliocentric distances, They are all consistent with a spin temperature of 25–30 K (Kawakita *et al.* 2004, 2005, Dello Russo *et al.* 2005), suggesting that these species formed at 30 K. The upper limit on the CH_3D/CH_4 ratio also argues for formation at 30 K (Kawakita *et al.* 2005). The detection of ethylene glycol in comet Hale-Bopp, a species present in star-forming region, strengthens the link between cometary and interstellar material. The strong deficiency of N_2 with respect to CO measured by Cochran (2002) in comet 153P is puzzling. Iro *et al.* (2003) explain this deficiency by the formation of clathrates hydrates in the solar nebula which preferentially trapped CO. According to this model, strong deficiencies in noble gases are expected. From the CO abundance in comets and the assumption that water ice condensed in amorphous form,

https://doi.org/10.1017/S1743921306004418 Published online by Cambridge University Press

Notesco and Bar-Nun (2005) suggest that icy grains which agglomerated to form comet nuclei were formed at 25 K. Notesco *et al.* (2003) study the trapping of Ar, Kr and Xe in water amorphous ice at various temperatures to interpret noble gases abundance measurements. Gail (2002) investigates the chemistry in the Solar Nebula, taking into account radial mixing, and suggests that cometary CH_4 and C_2H_2 were formed in the inner solar nebula as a by-product of carbon oxidation. The metamorphosis of silicates in proto-planetary disks is investigated by Gail (2004) and it is proposed that cometary crystalline silicates formed by thermal annealing of amorphous silicates in the inner hot solar nebula, and were radially transported in the comet formation zone by turbulence. In contrast, Scott *et al.* (2005) suggest that crystalline silicates were formed by heating in nebular shocks.

3.8. *Laboratory experiments relating cometary ice and connection to ISM*

Laboratory experiments relevant to cometary ices and organic materials have been reviewed by Schutte (2002), Ehrenfreund *et al.* (2002), and Colangeli *et al.* (2004).

Effect of UV and/or cosmic ray bombardments on the formation of organic molecules in mixed ice has been continued over the last few years. A number of new molecules are identified by Muñoz Caro and Schutte (2003), Bernstein *et al.* (2003), Gerakines *et al.* (2004), Muñoz Caro *et al.* (2004), and Hudson and Moore, (2004). Gudipati *et al.* (2003) showed that UV-irradiated ices and the room-temperature residues have remarkable photo-luminescent properties in the visible. Leto and Baratta (2003) studied the UV-induced amorphization of water ice crystal (ice Ic) at 16 K. To explain the so-called "extended source" of some molecules, degradation of large molecules (polyoxymethylene, hexamethylenetetramine, and HCN polymers) by UV photolysis and heating have been performed by Fray *et al.* (2004a, 2004b) and Cottin *et al.* (2002).

A series of experiments on the hydrogenation of CO by the addition of low temperature atomic H have been performed by Watanabe and Kouchi (2002) and Watanabe *et al.* (2003, 2004). Successive hydrogenation of CO at 10 K was found to be efficient for the formation of H_2CO and CH_3OH on dust grains under the condition of molecular clouds. Gas trapping experiments in amorphous water ice have been continued by Notesco *et al.* (2003) and Notesco and Bar-Nun (2005). Ehrenfreund *et al.* (2003) started microgravity experiments to study the physics and chemistry of icy particles in astronomical environments. Durda *et al.* (2003) made impact experiments of porous foam targets to investigate the disruption of comet nucleus. Grey *et al.* (2002) studied the hypervelocity oblique impacts onto polycrystalline water ice at 253 K to understand the crater formation.

3.9. *Spacecraft observations*

Deep Space 1: The NASA Deep Space 1 mission encountered comet 19P/Borrelly on 22 September 2001 and provided images of its nucleus (Boice *et al.* 2002). The geological terrains and surface features have been described and analyzed by Britt *et al.* (2004). The surface of the nucleus of comet 19P/Borrelly is complex and exhibits a variety of terrains with different albedos and surface roughness. Because comet 19P is a dynamically "old" comet, the surface features are likely due to sublimation processes and erosion. (1) "Mesa terrains" are flat plateaus about 100 m above the surrounding terrains. They are located near the pole, where most of the activity seem to originate. They are interpreted as inactive areas with sublimation occurring along the walls of the area. Such areas could be created when an unidentified "geological event" would create a crack or a hole into the crust which would grow up when the sublimation of fresh ice would begin at the edges. "Smooth terrain" are located below the big mesa area. (2) "Mottled terrain" is a mixture

https://doi.org/10.1017/S1743921306004418 Published online by Cambridge University Press

of pits and low (about 100 m) hills. It may have experienced some erosion due to the inhomogeneous sublimation of ices. (3) “Dark spots” are located mostly at the ends of the comet. They could possibly correspond to ancient terrains which have experienced a long exposure to space weathering. Finally, there are indications of compressional stress through a set of ridges 1-2 km long and 200 m above the surrounding terrain. No impact crater larger than 200 m could be identified. The geometric albedo of comet 19P/Borrelly derived from the Deep Space 1 images is 0.029 ± 0.06 (Buratti *et al.* 2004). However, large variations (from 0.012 to 0.05) are observed across the surface (Buratti *et al.* 2004, Oberst *et al.* 2004).

Spectra acquired with the SWRI near-infrared imaging spectrometer provide informations on the nucleus surface color and temperature (Soderblom *et al.* 2004). A single absorption band at 2.39 μm is present in the spectra and resembles features seen in nitrogen-bearing organic molecules (Soderblom *et al.* 2004). Images of the close environment of the comet show a prominent jet which is co-aligned with the rotation axis. From a combination of fitting the nucleus light curve from approach images and the nucleus' orientation from stereo images at encounter, the rotational parameters of comet Borrelly nucleus were inferred and are consistent with a simple rotational state (Soderblom *et al.* 2004).

Results from Deep Space 1 ion measurements in the coma of comet Borrelly are discussed by Nordholt et al (2003) and Young *et al.* (2004). Tsurutani *et al.* (2003, 2004) detected plasma clouds created by cometary dust impacts on the spacecraft.

Stardust: Stardust, NASA's fourth Discovery mission, successfully encountered 81P/Wild 2 on 2 January 2004, with a closest approach of 237 km. Stardust was launched on 7 February 1999 with the primary goal of collecting particulate coma samples from comet Wild 2 for return to Earth. At the encounter, four other in situ investigations were operated, including the Comet and Interstellar Dust Analyzer (CIDA), the Dust Flux Monitor Instrument (DFMI), Navigation Camera (NavCam) and two-way Doppler and spacecraft attitude control system as Dynamic Science. The collected samples are scheduled to return by direct reentry in a capsule on 15 January 2006. These samples will be made available to the scientific community for detailed study for decades to follow. The first results of Stardust have been published in 2004 in special issues of Science and the Journal of Geophysical Research.

The images of comet 81P/Wild 2 acquired by Stardust show a wealth of geological features quite different from that of 19P/Borrelly. This comet is likely to have a fresh surface almost unchanged (at a few meter level) since its nucleus came from the Kuiper belt (A'Hearn 2004). Two kinds of depressions (of up to 2 km in size) have been identified on the images: (i) the “pit halo” type of depression is surrounded by an irregular rough region, and (ii) the “flat floor” type of depression with nearly vertical walls. There are indication that the latter corresponds to a weak inactive porous crust (Brownlee *et al.* 2004). Some craters are likely to be of impact origin (Brownlee *et al.* 2004). There is no crater smaller that 500 m. Like for comet 19P, a few flat mesa areas about 100 m above the surrounding terrain have also been observed. However, they are much smaller than that identified on the 19P images, which is not consistent with 81P being less altered than 19P by erosion (Brownlee *et al.* 2004). Small pinnacles have also been observed across the surface, but the mechanism of formation of such structures is still unknown (Brownlee *et al.* 2004). Contrary to 19P, 81P appears to be a rather homogeneous body (Brownlee *et al.* 2004). The nucleus of comet 81P/Wild 2 has a low geometric albedo of 0.03 (Brownlee *et al.* 2004). Unlike for comet 19P, small rare albedo spots have been detected (Brownlee *et al.* 2004).

Tsou *et al.* (2004) report the dust environment of comet 81P/Wild 2 measured by Stardust during its encounter with the comet. The results on the direct measurements of dust grains at the comet during the Stardust flyby were presented by Tuzzolino *et al.* (2004) and Green *et al.* (2004). Anderson *et al.* (2004) infer an impact of a large dust particle with a mass in the range of 20 to 40 mg on the spacecraft based on their analyses of radio Doppler data at X band and spacecraft attitude control data obtained during the encounter. The organic component of dust particles in comet 81P/Wild 2 was identified from the Stardust CIDA data by Kissel *et al.* (2004).

Rosetta: The Rosetta spacecraft was launched by the European Space Agency (ESA) from Kourou in French Guyana in February 2004. The target comet is 67P/Churyumov-Gerasimenko. It will be reached in May 2014 where the rendezvous begins at almost 4 AU from the sun. Rosetta will stay with the comet at least to its perihelion. Shortly after meeting the comet the lander Philae will be released to make observations and measurements on the comets surface. On its way to the comet rendezvous Rosetta will pass the Earth 3 times and Mars once. In addition the Rosetta spacecraft will flyby asteroids (2867) Steins and (21) Lutetia in 2008 and 2010, respectively. The spacecraft and instruments onboard were successfully commissioned during the year 2004. The spacecraft and all its instruments work well. In February 2005 the first Earth flyby took place. Most instruments received their first data. In June 2005 a campaign was started to observe comet P/Tempel 1 around the impact date of the Deep Impact mission.

Deep Impact: The Deep Impact spacecraft was launched by the National Aeronautics and Space Administration (NASA), U.S.A. by a Delta II rocket in January 2005. The target comet was 9P/Tempel 1. The spacecraft consists of two parts: a larger "fly-by" spacecraft and a smaller "impactor", which was released from the "fly-by" spacecraft to collide with comet Tempel 1. The impact experiment was successfully carried out on 4 July, 2005. The observations on board include imaging of the nucleus and ejecta, temperature mapping of the nucleus surface and high-dispersion infrared spectroscopy to detect volatile molecules. Many observations from the Earth and from space were also carried out during the period before and after the collision of Deep Impact with comet 9P/Tempel 1. The papers describing the results of the observations will be reported in the next IAU C15 Triennial Report, which covers the period when those papers are published.

Acknowledgements

The President wishes to acknowledge the contributions of the individuals named in the Introduction to the timely creation of this report.

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President of the Commission