COMMISSION 15: PHYSICAL STUDY OF COMETS, MINOR PLANETS, AND METEORITES (L'ETUDE PHYSIQUE DES COMETES, DES PETITES PLANETES ET DES METEORITES)

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I. Introduction

The last three years have witnessed a growing interest in the physical properties of the small bodies in the solar system. Perhaps the most significant impetus to research on small bodies has been the imminent arrival of Comet Halley in the inner solar system. This famous comet, which was recovered in autumn 1982, has been the object of intense study during the past year as it has approached the sun and developed a tail. Much of the international, ground-based astronomical research on Halley has been coordinated through the International Halley Watch program. Spacecraft from several nations have been successfully launched (or soon will be, we hope) and are on their way to intercept the comet and make close-up observations and *in situ* measurements. The commencement of spacecraft study of small bodies marks a *new era* in comet/asteroid science and, in coordination with ground-based and Earth-orbital observations, will result in unprecedented new knowledge about the origin of the solar system and about solar system processes.

Although Halley is receiving the most attention, interest is also high in Comet Giacobini-Zinner, the vicinity of which will be probed by a diverted American spacecraft in September 1985. Upcoming spacecraft studies of comets through 1986 are described at the end of the comet section of this report. Asteroid exploration by spacecraft is also anticipated to begin in the near future. The trajectory of the NASA Gailieo Mission to Jupiter has been changed to permit close-encounter observations of the large main-belt asteroid 29 Amphitrite in December 1986; these observations will be conducted on a "best effort" basis only a few months after launch of Galileo. Interest is also high in Europe, the Soviet Union, and the United States in possible spacecraft missions to additional comets and asteroids during the 1990's. If these efforts are pursued, there will be a concomitant ground-based effort. The last three years have also witnessed extremely productive efforts to observe small bodies from Earth orbit. For example, the Infrared Astronomical Satellite discovered a comet in 1983, which made the closest approach to the Earth of any comet in centuries. IRAS made important discoveries and measurements of other comets and also assembled an immense database on infrared brightnesses of thousands of numbered and unnumbered asteroids. The planned launch of the Hubble Space Telescope next year highlights the continuing potential for applying extremely powerful instrumental techniques to the study of comets and asteroids from above the Earth's atmosphere.

A large number of conferences have been held during the past three years on comets, asteroids, and related topics. Among the conferences (many of them cosponsored by Commission 15) were the Tucson conference on comets (resulting in the major reference book *Comets*, L. Wilkening, ed.); conferences on international cometary exploration, modern observational techniques, comets and the origin of life, and ices in the solar system; two meetings in Uppsala on asteroids, comets, and meteors (the first one published as *Asteroids, Comets, and Meteors*, Lagerkvist and Rickman, eds.); a colloquium on dust; a conference on the galaxy and the solar system; a Chapman Conference on magnetic reconnection; a conference on "Physics and Dynamics of Solar System Minor Bodies" held in Dushanbe, USSR, which attracted 200

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representatives from various Soviet institutes; a symposium on the search for extraterrestrial life; plus a variety of other smaller meetings and workshops. The study of meteorites is an important adjunct aspect of Commission 15 work, inasmuch as meteorites are the products of the fragmentation and decay of asteroids and comets -- the chief meetings for the presentation of international research on meteorites are the annual meetings of the Meteoritical Society, the last two of which were held in Mainz and Albuquerque.

Activities of Commission 15 during the past three years have centered around co-sponsoring various meetings and fostering international communication about research on small bodies. The Commission, either by itself or in association with other Commissions, has worked on developing a file of asteroid lightcurve and rotation data, defining a series of standard comet filters, trying to improve the predictions of stellar occultations by small bodies, and developing an improved approach to predicting the magnitudes of asteroids.

Time and space constraints have not permitted us to develop a truly comprehensive report on the last three years of research on the physical properties of asteroids and comets. The field is very rapidly expanding, and our members have been pre-occupied with doing new research rather than with preparing exhaustive summaries of material available in the standard journals. Therefore, we apologize in advance for the somewhat uneven treatment of topics and for omitting many important publications. We have attempted, however, to highlight many of those areas that have been most intensively studied during recent years. The general format of the report follows that of previous years, beginning with topics in cometary physics and concluding with a summary of some asteroidal topics. We omit the traditional two pages on meteoritics, which is really a separate field larger than asteroid and cometary astronomy combined, and call readers' attention to such journals as Geochimica et Cosmochimica Acta, Meteoritics, and various letter journals for up-to-date information. The President of the Commission appreciates the efforts of the authors of the various sections below for their help in preparing reports with short advance notice. However, the President has made numerous changes and additions to the sections, so the listed authors should be regarded as major contributors to their section, but not blamed for defects or deficiencies.

II. Comets

PHYSICAL PROPERTIES OF COMETARY NUCLEI AND DUST - Z. Sekanina

Whipple (NATO Workshop on Ices in the Solar System, in press) has reviewed the history of the icy-conglomerate model for comet nuclei, emphasizing the rapid progress during the past decade. He suggests (Highlights in Astronomy 6, 323; BAAS 15, 805; Icarus, in press) that a pair of enormous outbursts several weeks apart, as displayed by P/Holmes and P/Tuttle-Giacobini-Kresak, may be triggered by near-tangent collisions between the components of a double comet. Sekanina (AJ 89, 1573) formulates a precession model for the nucleus of P/Kopff, indicating that its spin axis moves currently at a rate of about 20^{o} per revolution. He also argues (BAAS 16, 642) that a limited but growing body of evidence suggests that comet nuclei are generally far from being spherical.

A number of papers deal with the light variations of P/Halley at large solar distances (in 1982-84) and with implied constraints on the physical properties of the nucleus and on the processes on its surface (Belton BAAS 15, 804; Sicardy et al. A&A 121, L4; West and Pedersen A&A 121, L11 and 138, L9; Le Fevre et al. A&A 138, L1; Lecacheux and Le Febre IAUC 3957; Jewitt and Danielson BAAS 16, 636; Sekanina BAAS 16, 636). A majority view is that the photometry has not yet allowed one to determine the comet's spin rate unequivocally. As this report goes to press (Feb. 1985) there are many reports of light variations for Halley, with several favored periods, but no secure result as yet.

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Newburn and Reinhard (Adv. Space Res. 2, No. 12, 151) provide nominal model parameters for P/Halley. The comet's mass and lifetime are estimated by Delsemme and Yeomans (BAAS 16, 636). Also see Hughes (MNRAS 204, 1241) and Ferrin (A&A 135, L7); the latter concludes Halley will last ~40 more apparitions. Larson and Sekanina (AJ 89, 571; BAAS 16, 637) present a new image-processing algorithm to improve visibility of features in the head of P/Halley and suggest relatively high spatial densities of dust in its bright jets. Sekanina and Larson (BAAS 15, 651; AJ 89, 1408) introduce the concept of continuous emission of dust from small active areas on the nucleus to explain the evolution of spiral jets into envelopes seen on processed plates, summarize the results of modeling of these features, and determine the comet's spin vector. Whipple (Center for Astrophys. Preprint 1763) explains narrow dust jets in P/Swift-Tuttle as ejecta from small, less active sources embedded in larger, more active areas on the comet's nucleus.

Froeschle et al. (Asteroids, Comets, Meteors, p. 215), Froeschle and Rickman (Asteroids, Comets, Meteors, p. 225), Weissman and Kieffer (JGR, in press), Horanyi et al. (ApJ 278, 449), and Fanale and Salvail (Icarus, in press) propose new thermal outgassing models for comets. The problems addressed include the formation and purging of an insulating surface mantle, heat and vapor transport, rotation effects (diurnal and seasonal), implications for the nongravitational acceleration of the orbital motion, etc. Klinger (Asteroids, Comets, Meteors, p. 205) gives an overview of current trends in modeling the comet nuclei. Sekanina (Icarus 58, 81) concludes that the process of comet dissipation (disintegration before the eyes of observers) could be triggered by an eruptive dust-emission event weeks before demise. Mendis (NATO Workshop on Ices in the Solar System, in press) discusses the roles of dust mantles and dust halos in the nucleus outgassing.

Delsemme (NATO Workshop on Ices in the Solar System, in press) analyzes observational evidence that favors water ice as the dominant component of both new and old comet nuclei. Klinger (Icarus 55, 169) considers the activity of comets as a function of the phase of water ice (amorphous vs. crystalline). Smoluchowski (JGR 87, A422) draws attention to the roles of porosity and the abundance ratio CO_2/H_2O for heat transport in the nuclei. Cowan and A'Hearn (Icarus 50, 53) propose sudden exposure of CO or CO_2 to explain the outbursts of P/Schwassmann-Wachmann 1.

A large number of papers on Comet IRAS-Araki-Alcock (1983d), relevant to the problems of cometary nucleus, including reports and interpretations of its radar observations, were presented at meetings of the AAS Division for Planetary Sciences (cf. BAAS 15, No. 3 and BAAS 16, No. 3, Pt. 1). An extensive radar study of this comet was published by Goldstein et al. (AJ 89, 1745). Radar detection of P/Grigg-Skjellerup was reported by Kamoun et al. (BAAS 14, 753).

An extensive series of papers on cometary dust has appeared in the past three years. Campins et al. (Nature 301, 405) first reported spectrophotometric detection of water ice in a comet, Comet Bowell. Hanner (ApJ 277, L75) later reported detection of a similar absorption feature near 3 microns in Comet 1983ℓ, interpreting it as scattering by icy grains. Hanner et al. (AJ 89, 162, 170) also provide infrared data on P/Comets Stephan-Oterma, Swift-Gehrels, Kearns-Kwee, Gunn, and Grigg-Skjellerup, and on Comet 1981 XV. Sekanina (Adv. Space Res. 2, No. 12, 121) summarizes information on the properties of dust ejecta from P/Halley based on its 1910 and earlier apparitions. Sekanina and Farrell (AJ 87, 1836) model the striated dust tail of 1957 V and find two kinds of submicron-sized particles. Jewitt (Icarus 60, 373) presents the results of his comprehensive study of Comet Bowell (1980b), largely confirming Sekanina's earlier conclusions (AJ 87, 161). A large number of additional papers on dust in this comet are published as referenced by Jewitt, including the results of the IRAS observations (Walker et al. ApJ 278, L111). Sekanina's (AJ 87, 1059) study of the dust tail of Comet 1979 XI that collided with the Sun shows a possible effect of solar corona on the particle motions.

PHOTOMETRY AND SPECTROPHOTOMETRY BETWEEN 0.12 AND 1 μm - M.C. Festou

While the 1970's saw an increase of the spectral range inside which comet ejecta can be studied (access to near UV and vacuum UV, IR and radio emissions), the first years of the 1980's were characterized by the development of a new family of detectors, enhancing our ability to carry out important quantitative studies of the cometary phenomena. Monochromatic images are being obtained, fainter objects are being observed, and better spectral resolutions are being achieved. This technological breakthrough, together with the still increasing effort to observe comets, triggered by the impending return of Halley's comet, should soon yield a completely new picture of what a comet could be like. And more surprises are to be expected when the Space Telescope becomes available.

The photometric technique is used to monitor the gaseous output of the nucleus, using more or less broadband interference filters. A'Hearn et al. (AJ 86, 1559) found that Comet 1979 X was an exceptionally gassy object, while Millis et al. (AJ 87, 1310) found that Comet Stephan-Oterma was, on the contrary one of the dustiest (and showing a very strong brightening in the continuum near opposition). Numerous comets were observed by various groups in a more or less systematic way. The extensive work by Newburn and Spinrad (AJ 89, 289), to be confirmed by other studies, reveals that C_2 and CN production rates do not vary with the same heliocentric distance power law, and that C_2 radicals could be strongly deficient in the comet beyond 1.8 A.U. Two comets were observed by many astronomers using various techniques: Comet Iras-Araki-Alcock (IAA, 1983d) because of its proximity to the Earth, and Comet Bowell 1980b because of its exceptional activity far from the sun. Visible and IR photometric observations are not well understood, e.g., as shown by A'Hearn and Millis (ApJ 282, L43), Hanner et al. (Icarus, in press), and Jewitt et al (AJ 87, 1854).

The photometric technique can be complemented by polarimetric measurements (Michalsky, Icarus 47, 388) or by photopolarimetric measurements (to better isolate the continuum, Myers and Mordsieck, Icarus 58, 431), although the results are very difficult to interpret.

Spectrophotometry is now used more widely and allows a clean separation of emission features from the continuum as well as studies of the spatial extension of cometary emissions. Most studies deal with the determination of abundances, especially that of $O(^1D)$ atoms observed through their red forbidden lines (Spinrad PASP 94, 1008; Goraya et al., Moon & Planets 26, 3; Fink and Jonhson, AJ 89, 1565). The good detector sensitivity achieved in the near IR allowed the study of the spatial extension of OI and NH_2 emissions (Fink and Jonhson, ibid.) as well as the intensity ratios of various bands of NH_2 (Jonhson et al., Icarus 60, 351) and the CN red bands (Danks and Dennefels, AJ 86, 314; Jonhson et al., ibid.). A'Hearn et al. (AJ, in press) combined photometric and spectrophotometric observations of Comet Bowell in the 0.12-1 μm wavelength interval to study the strange behavior of that object.

Spectrophotometry was used to investigate the spectrum of comets in a few atypical cases: Johnson et al (ApJ 270, 759) recorded for the first time the spectrum of a comet in the 0.9-2.5 μm region at a resolution of 4-6 cm^{-1}, taking advantage of the very high gas prodution rate of Comet West around mid-March 1976 (this led to the first detection of the C_2 Ballik-Ramsay and Philipps bands). Comet IAA came very close to the Earth, thus allowing a detailed study of its inner coma. W. Cochran (Icarus 58, 440) made the first unambiguous observation of the green line of OI; Cosmovici and Ortolani (Nature 310, 122) may have detected new lines attributed to HCO, H_2S^+, DCO, S_2 and NH_4; however, the doscovery of S_2 was made by A'Hearn et al. (ApJ 224, L176) with the IUE long wavelength camera. The strange Comet P/Schwassmann-Wachmann 1 was the object of careful studies which led to the identification of CO^+ emission lines when the comet was either in a dormant state (Larson, ApJ 238, L47) or undergoing an outburst (Cochran et al., AJ 85, 474). The $^{12}C/^{13}C$

ratio was derived by Lambert and Danks (ApJ 268, 428) using a completely new set of C_2 lines.

Fabry-Perot interferometers are not often used; however, they offer the best way to isolate faint lines such as the Balmer alpha emission of HI atoms, thus providing an alternative way to observing the Lyman alpha line from space. Hydrogen production rates can then be deduced (Scherb, ApJ 243, 644; Shih et al., ApJ 279, 453).

The International Ultraviolet Explorer (IUE) telescope has been used to observe more than 20 comets in a few years. Numerous results were obtained and were reviewed by Festou et al. (2nd European Conference, ESA-SP 179) and Feldman (Science 219, 347). References relative to the exceptional input to cometary science that the IUE made are found in the two above-mentioned papers. For example, Feldman et al. (A&A 131, 394) conclude that IUE observations of the ultraviolet coma of Comet Austin (1982g) demonstrate a composition similar to that of the best previously observed comet by IUE, Bradfield (1979X). The derived water production rate varies with heliocentric distance with an exponent between -3 and -4, similar to the 3.7 found for Bradfield.

Theoretical investigations of comet spectra range from the (tentative) identification of new lines (CN, CN^+, and CS, Krisna-Swanny, A&A, 97, 110, CS^+, Singh, A&A 108, 369), fluorescence calculations (OH, Schleicher and A'Hearn, ApJ 258, 864; OH, Elitzur, ApJ 246, 354; CO, Krisna-Swanny, ApJ 267, 882; C_2, Krisna-Swanny and O'Dell, ApJ 251, 805; CN, Tatum, A&A 135, 183; CN, Festou and Zucconi, A&A, 134, L4, for the Comm. 15 comet filters) to the evaluation of the photodissociation lifetime of OD and OH radicals (Singh et al., Icarus 56, 184; Van Dishoeck and Dalgarno, Icarus 59, 305; Van Dishoeck, J. Chem. Phys. 79, 873). A high resolution atlas for fluorescence calculations was compiled by A'Hearn et al. (TR AP83-044, Univ. of MD) from high resolution spectra of the full solar disc obtained by various authors. Results are provided with a 0.005Å resolution in the 2,400-7,000Å wavelength range.

The occultation technique may become a very useful tool for deriving tidal depths in the continuum, although the technique is still quite difficult to master (Lecacheux et al., Icarus 60, 386; Combes et al., Icarus 56, 229; Larson and A'Hearn Icarus 58, 446), and occultations are difficult to predict (Taylor, A&A 135, 181); so are neutral species column densities (Smith et al., Icarus 47, 441).

Comet P/Halley was discovered by Jewitt and Danielson on Oct. 16, 1982, near magnitude 25. Since then, the comet has been studied using the broadband photometry technique. The recorded variability of the light reflected by P/Halley is, up to now, interpreted in terms of rotation of its nucleus (Felenbok et al., A&A 113, L1; Sicardy et al., ibid.; West and Pedersen, ibid.). As this report goes to press, Halley is showing a faint coma according to several preliminary reports, although it has not yet gotten brighter than 20th magnitude.

To complete this report, we note the additional contributions presented at various conferences (Tucson, 1981; Budapest, 1982; Uppsala, 1983; Nice, 1984). Reviews on the topics discussed here by M. A'Hearn and P. Feldman appear in the book Comets, (L.L. Wilkening, ed.).

COMA CHEMISTRY - W.F. Huebner

Reviews on chemical modeling have been published by Rh. Lüst (Topics in Chemistry 99, 73) who relates spectral observations to coma models, Mendis and Houpis (Rev. Geophys. Space Phys. 20 885) who discuss the effects of solar wind-coma interaction on chemistry, and A'Hearn (Chem. Eng. News, May 28, p. 32) who emphasize the complexity of photolytic reactions with water and also the newer species containing sulfur. A series of articles in which various aspects of comet chemistry are discussed are published in the Proceedings of the International Conference on Cometary Exploration: Cometary Exploration, Vol. I (Gombosi, ed.).

In the last three years the suspicion that coma chemistry cannot be isolated from the physics of the coma has been confirmed. Energy balance in the coma, multi-fluid flow, gas-dust interaction, transition from collision dominated flow to free molecular flow, and interaction with the solar wind, all affect the density and velocity profiles of the various chemical species and therefore the coma chemistry (Houpis and Mendis, Moon & Planets 25, 95; Marconi and Mendis, Moon & Planets 27, 27 and 431; Huebner and Keady, Cometary Exploration, Vol. I, Gombosi, ed., 165; Marconi and Mendis, ApJ 273, 381). Although Beushausen and Jockers (Asteroids, Comets, Meteors, Lagerkvist and Rickman, eds., 317) do not discuss the effect of solar wind-coma interaction on the chemistry directly, the indirect effects on the ionization rate coefficients that they do discuss are important to the chemistry in the region of the contact surface. Similarly, effects of energetic neutral molecules on the coma were reviewed by Ip and Hsie (Cometary Exploration, Vol. I, Gombosi, ed., 265). H.U. Schmidt and Wegmann (Max Planck Inst. Astrophys.) model the chemical effects in the solar wind-coma interaction. Transition from collision-dominated flow to free molecular flow in the coma was modeled by means of escape probabilities by Huebner and Keady (A&A 135, 117); accelerations caused by radiation pressure on neutral species and the multiple collision random walk were calculated by Kitamura et al. (Icarus, in press) using the Monte Carlo procedure. Gas-dust interaction in the coma was discussed by Keller (Cometary Exploration, Vol. I, Gombosi, ed., 119). All these effects change the density and velocity profiles of species in the coma and thus the chemical reaction rates.

Festou (Adv. Space Res., in press) investigated the carbon abundance relative to the hydroxyl radical; his conclusion was the C/OH ratio varies greatly from comet to comet. Important to all chemical model calculations are the comparisons to observations as provided by Cucchiaro and Malaise (A&A 114, 102) for CN, C_2, and NH in Comet Bennett (1970 II), by Delsemme and Combi (ApJ 271, 388) for NH_2, $O(^1D)$, and CN in Comet Kohoutek (1973 XII), and by Weaver et al. (A&A 251, 809) for OH, H, and O in Comet Bradfield (1979 X). Festou and Feldman (A&A 103, 154) predict profiles for the forbidden oxygen lines at 5577Å and 6300Å.

New impetus to coma chemistry modeling came from the detection of several molecular species in Comet IRAS-Araki-Alcock (1983d). Altenhoff et al.(A&A 125, L19) probably detected H_2O and NH_3 in the cm wavelength range in a ratio approximately in agreement with chemical modeling. A'Hearn et al. (ApJ 274, L99) discovered S_2 in their UV spectra. Jackson (Howard U.) has modeled the sulfur compounds in comets.

The chemical composition of the nucleus has recently been investigated by Yamamoto et al. (A&A 122, 171). Related to this is the work of Irvine and Hjalmarson (Cosmochemistry and the Origin of Life, Ponnamperuma, ed., 113) who have investigated the chemistry in the formation of comet nuclei in interstellar clouds.

PLASMA TAILS AND THE SOLAR-WIND INTERACTION - M.B. Niedner, Jr.

The research performed in this field since mid-1981 significantly exceeds that of the previous reporting period, undoubtedly the positive influence of Comets Halley and P/Giacobini-Zinner, soon to be visited by spacecraft. Several excellent reviews emphasizing all or several aspects of the cometary/solar-wind interaction have appeared recently. Photographic observations of the plasma tail and physical interpretations were discussed in detail by Brandt (Comets, L.L. Wilkening, ed., 519) and Jockers (The Need for Coordinated Ground-based Observations of Halley's Comet, 193), whereas a somewhat more plasma physics-oriented (less observational) approach was adopted by Ip and Axford (Comets, L.L. Wilkening, ed., 588), Mendis and Houpis (Rev. Geophys. Space Phys. 20, 885), and Breus (Space Sci. Rev. 32, 361).

Reviews addressing more specific problems were those of Mendis - development and time dependence of cometary ionospheres (Comets, Origin of Life, 71); Niedner - data needs for plasma phenomena (Modern Obs. Tech. for Comets, 21); Niedner - disconnection events (DE's) and magnetic reconnection (Magnetic Reconnection, Geophys. Monograph 30, 79); Russell et al.- Venusian/cometary analogues (Comets, L.L. Wilkening, ed., 561); and Schmidt and Wegmann - plasma flow and magnetic fields (Comets, L.L. Wilkening, ed., 538). Published research papers are summarized below.

A. The Sunward Comet/Solar-wind Interaction

Mendis et al. (ApJ 249, 787) examined the access of solar wind to the nuclear surface at large heliocentric distances, concluding for water-dominated comets at $r > 5$ A.U. that the solar wind impinges directly on it, charging the nucleus to small positive potentials on the sunlit portion and to numerically large negative values on the nightside. Electrostatic levitation and blow-off of small, loose dust particles (created by cosmic ray damage to the nucleus) can occur, the process being partly modulated by the strong dependence of the nightside potential on the solar-wind speed. Houpis and Mendis (Moon & Planets 25, 95) studied the properties of the cometary bow shock and ionosphere for CO/CO_2-dominated comets as a function of heliocentric distance and proposed that Comet Humason, which had a prominent plasma tail and was irregularly active at large-r, could be explained by their model. Strazzulla et al. (A&A 123, 93) conducted laboratory tests of the irradiation of thin films of frozen gas with energetic (keV-MeV) particles, and suggested that erosion of ices by fast ion (solar wind) bombardment could explain cometary activity at large-r.

Gombosi et al. (ApJ 268, 889) examined the effect of charge exchange between fast solar-wind ions and cometary neutrals on the pressure balance budget and location of the standoff distance (contact surface); they concluded for a Halley-like comet at 1 A.U. that enough momentum is removed from the solar wind via charge exchange to place the standoff distance at several thousand km. Wallis (The Need for Coordinated Ground-based Observations of Halley's Comet, 171; Asteroids, Comets, Meteors, 303) discussed several aspects of ion formation and MHD modeling of plasma dynamics. The role of Alfven's critical velocity mechanism as an ionization source was studied by Formisano et al. (Planet. Space Sci. 30, 491), who proposed that a self-sustained beam discharge and Alfven's condition may only be met within 10^4 km of the nucleus. Beard (ApJ 245, 743) proposed the existence of a strong shock as the result of a neutral radical falloff made more rapid than ρ^{-2} by solar radiation pressure; the strong shock then causes rapid ionization via electron impact, thus explaining the rapid formation of ion tail rays. However, advocacy of such a steep falloff of neutrals, and especially the required large radiation pressures, is largely confined to Beard.

Marochnik (Moon & Planets 26, 353) proposed that unlike the case of Venus, where solar-wind magnetic fields penetrate the ionosphere as a result of instabilities along the ionopause, the cometary ionosphere is threaded by magnetic fields essentially at all times due to a continuous diffusion of fields across the ionopause. Ershkovich and Mendis (ApJ 269, 743) challenged this view, concluding that if deep field penetration does occur (and this was uncertain in their study), it is likely to be due to an instability (probably Kelvin-Helmholtz) of the ionopause. The response of a CO cometary atmosphere to the passage of interplanetary shocks and high-speed streams was examined in a numerical simulation by Beushausen and Jockers (Asteroids, Comets, Meteors, 317), who predicted that the increased charge exchange should result in the formation of an observable ion cloud similar to those seen in several comets.

B. Plasma Tails: Observation and Theory

Using photographs taken around the world, Jockers (Icarus 47, 397) studied the formation and kinematics of rays, waves, a large-scale disturbance, and other features in the plasma tail of Comet Kohoutek (1973XII) during the period 1974 January 19-21. His conclusions about the interaction of the comet with the solar wind and about the nature of tail disconnection events (DE's) disagree in part with earlier findings by Niedner and Brandt (ApJ 221, 1014; ApJ 223, 655), especially those concerning DE's, which Niedner and Brandt attribute to sector boundary crossings and magnetic reconnection, and around which they propose much of plasma-tail morphology is organized. Tail structure in the same comet (Kohoutek) was also briefly discussed by Jockers (Asteroids, Comets, Meteors, 327).

Le Borgne (A&A 123, 25) and Niedner et al. (Solar Wind V, NASA CP-2280, 737) pointed to the likely influence of a solar flare-generated interplanetary disturbance on a rapid 10^o turning of the plasma tail axis of Comet Bradfield (1979X) on 1980 February 6. Directional discontinuities seen in the tail of Comet Austin (1982g) were interpreted by Fulle and Pansecchi (Icarus 57, 410) as resulting from the interaction of the comet with probable (but unobserved) changes in the azimuthal component of the solar-wind velocity. Jockers and Balazs (Astronomy with Schmidt-type Telescopes, 237) obtained Schmidt camera objective prism spectra of Comet Austin (1982g) and noted the significantly greater strength of H_2O^+ emission at $\lambda6500$ compared to the CO^+ radiation at $\lambda4270$. Li et al. (Acta Astrophys. Sin. 3, 81) collected Shanghai Observatory photographic material of Comets Morehouse 1980III), Brooks (1911V), and Halley (1910II), and analyzed the data for plasma-tail structure and overall morphology.

The well-known helical structures seen in the outer tail of Comet Ikeya-Seki (1964f) during 1965 October-November were interpreted by Krishan and Sivaraman (Moon & Planets 26, 209) as resulting from plasma instabilities excited in a tail containing twisted magnetic fields. Extending the earlier work of Podgorny et al. (Moon & Planets 23, 323), Dubinin et al. (Astron. Zh. 59, 1006; trans. in Sov. Astron. 26, No. 5, 608) used the motion of a plasma structure to derive the strength and topology of the magnetic field in the tail of Comet Halley (1910II). A major conclusion of both studies was that the field strength is greatest near the tail boundary (~75γ) and weakest near the tail center (~0γ) (cf. also Ioffe, Astron. Zh. 61, 121;trans. in Sov. Astron. 28, 72). Ershkovich (Moon & Planets 25, 521) pointed out several internal inconsistencies in Podgorny et al.'s method which vitiate the conclusion about a strong boundary/weak core magnetic model, and advocated the use of hypersonic pressure balance calculations to determine that the field strength in the distant tail is not more than ~$2\frac{1}{2}$ times the local interplanetary value. Podgorny et al. (Moon & Planets 27, 135) responded to Ershkovich's criticism and re-advocated their weak core tail model. Russell et al. (Comets, L.L. Wilkening, ed., 561) pointed out the essential correctness of Ershkovich's values based on Pioneer Venus Orbiter measurements of the Venusian magnetotail and the justifiable assumption that the Venus/solar-wind interaction is in many respects comet-like.

Ershkovich (Comets, Origins of Life, 105; MNRAS 198, 297) interpreted folding tail rays as drift motions in convectional electric fields; from the observed folding rates, he derived values for electrical conductivity in the tail plasma which are orders of magnitude less than classical values. Observations of generation rates as well as other tail ray properties were presented by Miller (BAAS 14, 752, 952; ibid. 15, 960).

Ershkovich et al. (ApJ 262, 396) and Niedner et al. (ApJ 272, 362) constructed a hypersonic pressure balance model of plasma tails which, given different values of the tail gas pressure as inputs, satisfactorily reproduced the observed and variable flaring behavior of Comet Bradfield (1974b). A major conclusion of the second study was that MHD instabilities should act to destroy magnetic flux conservation in the distant plasma tail.

Buti (ApJ 252, L43; Astrophys. Space Sci. 85, 35; ApJ 268, 420) studied the effect of high frequency electrostatic turbulence (in the solar wind) on the Kelvin-Helmholtz (KH) instability in cometary plasma tails. She found that hydromagnetic waves (KH) can either be stabilized or destabilized, depending on the direction of propagation of the electrostatic relative to the hydromagnetic waves. In addition, the stabilizing effect of a large tail magnetic field may explain why most waves are observed at large distances from the cometary head, where the expected tail field is small.

Ray (Planet. Space Sci. 30, 245) used KH theory to calculate growth rates for Comets Kohoutek (1973f), Arend-Roland (1956h), and Morehouse (1908c), and essentially agreed with the earlier results of Ershkovich and Heller (Astrophys. Space Sci. 48, 365) that the KH instability should have operated in these comets. Tupchienko and Yukhimuk (Geophys. J. 4, 135) considered the stability of the plasma tail/solar-wind interface and advocated the importance of the whistler mode.

Niedner (ApJ 48, 1) used the 72 plasma tail disconnection events (DE's) contained in his earlier DE catalog (ApJ 46, 141) to derive solar-wind sector boundary orientations and latitudinal extents far out of the ecliptic plane. The study offers a set of predictions to be tested by the International Solar Polar Mission, and emphasizes the unique value of comets as natural probes of the interplanetary medium.

C. Laboratory and Computer Simulations of the Comet/Solar-Wind Interaction

Although primarily concerned with deriving the magnetic field characteristics of Halley's tail from the observed motion of a plasma formation, Dubinin et al. (Astron. Zh. 59, 1006; trans. in Sov. Astron. 26, No. 5, 608) gave a brief summary of the earlier work of Podgorny and collaborators on laboratory simulation of the comet/solar-wind interaction. These simulations have shown that an induced magnetosphere and magnetotail are formed whose characteristics are similar to those predicted many years ago by Alfven (Tellus 9, 92).

Fedder et al. (Icarus, in press) ran 3-dimensional MHD computer simulations of the comet/solar-wind interaction, deriving large-scale plasma flow and magnetic field characteristics for various sets of input solar-wind conditions. Quiet-time models, characterized by a steady solar wind and IMF, yield magnetic field strengths in the head which are several times smaller than the large ($\gtrsim 100\gamma$) values reported by Schmidt and Wegmann (Comets, L.L. Wilkening, 538), and tail values ($\sim 10\gamma$) which are in agreement with Ershkovich's pressure balance and helical wave calculations. Fedder et al. found that a 90° change in the orientation of the IMF corresponding to a rotational discontinuity produced tail ray-like features similar to those seen in the simulations of Schmidt and Wegmann. A 180° reversal corresponding to a sector boundary produced a plasma depletion in the anti-sunward direction which Fedder et al. interpreted as a tail disconnection event (DE), in basic agreement with Niedner and Brandt's (ApJ 223, 655) sector boundary/magnetic reconnection model of DE's.

D. Plans for Ground-based, Wide-field Observations of Comets Halley and Giacobini-Zinner

The Large-Scale Phenomena (LSP) Discipline of the International Halley Watch (IHW) has organized a ground-based network of ≥ 90 observatories with wide-field imaging capability, in order to assemble as complete a photographic record as possible of the comet's rapidly variable plasma tail (e.g., DE's, helical waves, etc.). The network's period of maximum activity will be 1985 November - 1986 May, during which the comet is expected to be bright and possess a plasma tail. Image data obtained from the network will be permanently stored in various forms (digitized images, film copies, prints) in the IHW Archive. The philosophy and goals of the LSP network have been described in detail by Niedner et al. (The Need for Co-ordinated Ground-based Observations of Halley's Comet, 227) and by Brandt et al. (Astronomy with Schmidt-type Telescopes, 233). The LSP network is administered by J.C. Brandt (Code 680, NASA/GSFC, Greenbelt, MD 20771, USA), M.B. Niedner (Code 684.1, NASA/GSFC), and J. Rahe (Remeis Observatory, Bamberg, FRG).

An extension of the entire IHW's activities to include a shorter interval of coverage of Comet Giacobini-Zinner is presently being planned. The period of coverage will include the 1985 September 11 flyby of the comet by the International Cometary Explorer (ICE).

The history, research record, and overall raison d'etre of the Joint Observatory for Cometary Research (JOCR), a key station in the LSP Network, was discussed by Brandt (Modern Observational Techniques for Comets, 171), and Miller (Modern Observational Techniques for Comets, 169) gave a brief history of the wide-field photography of comets.

PHYSICAL STUDY OF COMETS IN THE USSR (INST. OF ASTROPHYSICS, DUSHANBE) - O.V. Dobrovolsky

The secular brightness decrease Δm of comets was shown to be statistically greater for comets with greater perihelion distances q and vice versa (O.V. Dobrovolsky, S.I. Gerasimenko, Kh.I. Ibadinov, C.R. Ac. Sci. Tadjik., No. 6). This is just the opposite of what D.W. Hughes and P.A. Daniels (Icarus 53, 444) expected but failed to find. However, this finding corresponds well to Shulman's (IAU Symp. No. 45, G.A. Chebotarev et al., 271) theory of evolution of nuclei with mineral crusts, even showing Shulman's bifurcation on the Δm - q diagram, and thus giving the first observational proof of the existence of dusty crusts on cometary nuclei. A comet catalogue has been composed, covering the last three centuries, of comets showing signs of nuclear splitting (O.V. Dobrovolsky, S.I. Gerasimenko, Bull. Inst. Astrophys. Dushanbe, No. 77).

There have been a variety of contributions to studies of cometary comas. The Na emission maximum far off the nucleus of Comet Mrkos (1957V) is explained by the cooling of dust grains in the vicinity of the nucleus by outflowing gas (S. Ibadov, C.R. Ac. Sci. Tadjik., 26, 90; Problems of Cosmic Phys., 18, 91). X-ray emission from dusty comas colliding with interplanetary dust is predicted to reach a measurable intensity at heliocentric distances $r \lesssim 1.0$ A.U. (S. Ibadov, C.R. Ac. Sci. Tadjik., in press). Comet head densities deduced from M. Beyers' visual observations exhibit unusual minima at r's corresponding to the orbital radii of planets (R.S. Osherov and M.Z. Markovich, C.R. Ac. Sci. Tadjik., No. 8). Cometary grains exposed to solar protons have been shown to become sources of negative ions involved in comet chemistry (O.V. Dobrovolsky et al., C.R. Ac. Sci. Tadjik., 24, No. 9 = Cometary Exploration, Vol. II, Gombosi, ed., Budapest).

An Invited Review on "Polarimetry of Comets" was presented by O.V. Dobrovolsky, N.N. Kiselev, and G.P. Chernova at a conference on "Polarimetric Methods in Astrophysics" held in October 1983 in Crimea. The wavelength dependence of polarization in the continuum studied by Kiselev et al. was found to be very flat in accordance with the results of J. Michalsky (Icarus 47, 388). A new result is that the phase angle of the polarization sign inversion turned out not to be at all wavelength dependent.

The high pressure C_2 bands (0,5) at 4680 Å and (0,7) at 5413 and 5435 Å were identified by V.F. Esipov and O. Mamadov in Comet Austin (1982g) on a 17 Sept. 1982 spectrogram; these bands are rare in cometary spectra. Some authors reported the C_2 Swan band vibrational temperature to be ~3250 K, and the continuum to appear bluer than the solar one (spectrophotometric gradient 2.08). The solar wind velocity at heliographic latitudes 33^o-43^o apparently is correlated with solar activity and with the relative acceleration of tail ions, deduced from Comet 1976 VI plates (Kh.I. Ibadinov, M. Rasulova, E. Pittich, Comets & Meteors, No. 38).

The equilibrium temperatures, sublimation rates, dielectric properties, and formation of refractory matrices were examined in the laboratory using models of crystalline water ice with different admixtures. Sublimation rates correspond well to the observed brightness decrease of comets (O.V. Dobrovolsky et al, C.R. Ac. Sci. Tadjik., 26, No. 1, 25). The majority of organic matrices showed densities as great as 0.04 g/cm^3 and compressive strengths as high as 0.1-0.2 kg/cm^2 (Kh.I. Ibadinov, S. Aliev, A. Rakhmonov, C.R. Ac. Sci. Tadjik., No. 9).

ORBITAL DYNAMICS AND EVOLUTION INCLUDING THE OORT CLOUD - D.K. Yeomans

This section briefly notes some of the important work on the dynamics of comets and asteroids as it pertains to their physics and origin. Works relating only to the dynamics of these objects is covered in the Commission 20 report. The dynamical and physical relationships between comets, large meteors, and meteorites are reviewed by Wetherill and ReVelle (Comets, L.L. Wilkening, ed., 297). They conclude that while many cometary meteoroids have measurable strength, almost all are weaker than any recovered meteorites. A possible connection between exhausted comets and Apollo-type asteroids was strengthened when Whipple noted the virtual coincidence of the orbital elements of 1983TB with the mean orbital elements of 19 Geminid meteors photographed with the super-Schmidt meteor cameras (I.A.U. Circular 3881).

Everhart (Comets, L.L. Wilkening, ed., 659) outlined the dynamical evolution of long and short-period orbits via stellar and planetary perturbations and noted that while the evolution of near parabolic comets with perihelion distances near the orbits of the major planets can account for short period comets with much smaller perihelia, there still remains the questions as to where comets originally formed, and whether the flux of near-parabolic new comets is sufficient to account for the number of observed short-period comets.

The dynamical aspects of cometary origin were investigated by Fernandez (AJ 87, 1318) with the result that a cometary origin in the Uranus-Neptune region produces the greatest current rate of cometary passages through the solar system as compared to cometary origins in the Jupiter region or at Oort cloud distances. Greenberg et al. (Icarus 59, 87) studied the origin of comets in the context of the accretional growth of Neptune and concluded that comets are probably physically unaltered planetesimals, not collisional fragments of larger bodies.

Everhart and Marsden (AJ 88, 135) continued their work on original and future reciprocal semimajor axes for cometary orbits. For 28 new osculating cometary orbits derived during the past few years, no convincing evidence could be found for original hyperbolic orbits. Using Monte Carlo techniques, Weissman (Highlights of Astronomy 6, 363) modeled the dynamical evolution of comets in the Oort cloud under the influence of stellar perturbations. The population of the cloud, depleted over the lifetime of the solar system, is estimated to be 1.0 to 1.5 x 10^{12} comets with a total mass of approximately 1.9 Earth masses. An alternative to the theory of a primordial and thermalized Oort cloud has recently been advanced by Clube and Napier (Highlights of Astronomy 6, 355) who suggest that passages of our solar system through galactic giant molecular clouds periodically removes the solar system's current cloud of comets and replaces it with comets captured from the giant molecular clouds.

Bailey, McBreen, and Ray (MNRAS 209, 881) suggest that the distribution of observed cometary orbits is consistent with a comet cloud that contains a very dense inner core containing most of the mass. This mass is $\leq$300 Earth masses for the more stable, centrally condensed models. Sekanina and Yeomans (AJ 89, 154) conducted a computer search for catalogued Earth-approaching comets and derived an average period between collisions of 33-64 million years. The constant rate of the close approaching comets in the last 300 years suggests a lack of long-period comets intrinsically fainter than absolute magnitude ~11. Fernandez (A&A 135, 129) believes that the small number of low-perihelion distance comets (none with $q < 0.34$ A.U.) is understood as a combination of the improbability of Jupiter encounters placing comets in such orbits plus the rapid physical sublimation of comets in such orbits.

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SPACECRAFT AND COMETS: 1985-1986 - J.C. Brandt

The direct exploration of comets will be spectacularly inaugurated in 1985 and 1986 with six missions -- five to Halley's Comet and one to Comet Giacobini-Zinner. In addition, other spacecraft will be used for remote observations. The combined effort should produce a large volume of scientific data and should begin a new era in our understanding of comets.

Table 1: KEY DATE SUMMARY

- Halley's Comet Recovered -- October 16, 1982
- International Cometary Explorer (NASA) "Launched" -- Dec. 22, 1983
- Comet Giacobini-Zinner Recovered -- April 3, 1984
- VEGA's (USSR) Launched -- December 1984
- Ms-T5 (Japan) Launched -- January 1985
- VEGA's Encounter Venus -- June 1985
- Giotto (ESA) Launched -- July 1985
- Planet A (Japan) Launched -- August 1985
- Comet G/Z-ICE Encounter -- September 11, 1985
- SMM & Pioneer Venus Observations Centered on Perihelion, Feb. 9, 1986
- Comet Halley Encounters -- 1986

VEGA-1	March 6
Planet A	March 7
MS-T5	March 8
VEGA-2	March 9
Giotto	March 13

- Astro 1 -- March 7 - 14, 1986

The pace of space-related events is indicated by the "Key Date Summary", as shown in Table 1. The International Cometary Explorer (ICE) was sent from the Earth-Moon system on December 22, 1983, on a trajectory to intercept Comet Giacobini-Zinner (G/Z). Two VEGA spacecraft have been launched by the USSR. They will intercept Halley's Comet after encountering Venus. MS-T5 and Planet A are to be launched by Japan, and they travel directly to Halley's Comet. Giotto is to be launched by the European Space Agency (ESA), and it travels directly to Halley's Comet. The encounters of Halley's Comet all occur during a short period in March 1986 with the comet near its orbital node, as dictated by launch energy considerations.

During the time period centered on perihelion, February 9, 1986, the comet is also near the sun on the sky as seen from Earth. Observations will be possible from Venus using the Pioneer Venus Orbiter and by the repaired Solar Maximum Mission (SMM) from Earth orbit. In addition, NASA plans to launch a Spartan payload to observe the comet during this time. Extensive Earth-orbital observations of Halley's Comet by the Astro I Mission are planned for an approximately one-week period in March of 1986. The intent is to provide coverage overlapping some of the times of encounter by the spacecraft carrying out direct exploration.

The ICE spacecraft will be targeted to pass 10,000 km tailward of the nucleus to explore the solar-wind interaction with Comet Giacobini-Zinner and the formation of its plasma tail. The ICE spacecraft was formerly the Third International Sun-Earth Explorer (ISEE-3) and carries instruments well-suited for probing the comet's plasma/magnetic field environment. In particular, we expect important results to be obtained for the magnetic field, plasma and radio waves, energetic electrons, and molecular ions. ICE has no imaging experiment.

The instrumental capabilities and other data relating to the spacecraft to Halley's Comet are summarized in Table 2. All of these spacecraft will be targeted

Table 2: SPACECRAFT TO HALLEY'S COMET

	USSR		ESA	Japan	
Characteristic	Vega-1	Vega-2	Giotto	MS-T5	Planet-A
Launch date	Dec. 1984	Dec. 1984	July 1985	Jan. 1985	Aug. 1985
Encounter date	3-6-86	3-9-86	3-13-86	3-8-86	3-7-86
Distance to nucleus, km	10,000	3,000	500	$4x10^6$	$2x10^5$
Flyby speed, km/sec	80	77	69	74	75
Sun distance, A.U.	0.79	0.83	0.89	0.81	0.80
Earth distance, A.U.	1.16	1.09	0.98	1.11	1.14
Spacecraft stabilization	3-axis	3-axis	Spin	Spin	Spin
Weight of experiments, kg	125	125	50	14	12
Number of experiments	13	13	10	3	2
Imaging (visible, IR, UV)	4	4	2	--	1
Mass Spectrometers (neutrals, ions, dust)	4	4	4	--	--
Dust detectors	1	1	1	--	--
Plasma instruments	5	5	4	3	1

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to pass on the sunward side of the nucleus. In addition to the plasma/magnetic field measurements, the dust and neutral gas environment will be measured. Imaging experiments are very important. A goal of Giotto and the VEGA's is to obtain images of Halley's nucleus. The imaging on Planet A will record the hydrogen cloud surrounding the comet.

III. Asteroids

LIGHTCURVES, ROTATIONS, COLLISIONS, AND PHASE RELATIONS - A.W. Harris & V. Zappalá

In the period 1981-1984, the number of main belt asteroids with rotation periods known to a statistically useful accuracy grew from about 215 to about 315. The number of Earth- and Mars-crossing asteroids with similarly known periods increased from about 15 to about 25. Approximately 60 papers reporting asteroid lightcurves were published in this time. The following researchers have been most active in reporting new lightcurve results:

Italy:	Zappalá; Di Martino (Torino Obs.); Barucci (Inst. Astrofisica, Roma)
Sweden:	Lagerkvist; Carlsson; Rickman (Uppsala)
Austria:	Schober (Graz)
Belgium:	Debehogne (Obs. Belg.); Surdej (ESO)
USSR:	Lupishko (Kharkov, Tadzhik)
China:	Zhou (Purple Mt. Obs.)
USA:	Harris (JPL); Binzel (U. Texas)

In addition, in the last year, several amateur astronomers in the USA, Britain, and Australia have begun producing high quality results with photoelectric photometers attached to telescopes in the 0.2-0.5m size range (cf. Ziegler, BAAS 16, 691; Minor Planet Bull. 11, 21). Such contributions by amateurs have been valuable, and promise to be even more so in the future, for supporting observations of asteroids observed by radar and/or by stellar occultations, since these objects tend to be large and within reach of modest aperture telescopes. In addition to the increasing availability of electronic and computer components at modest cost, the rise of amateur participation is a result of the formation of the International Amateur and Professional Photoelectric Photometry Association (IAPPP).

Among the more recent publications of lightcurves and related information are: Schober, A&A Suppl. 48, 57; Schober and Schroll, A&A 107, 402; Debehogne et al., A&A 108, 197; Piironen, A&A 112, 172; Debehogne et al., A&A Suppl. 50, 277; Pavlovski et al., Publ. Astron. Obs. Sarajevo 1, 225; Lagerkvist and Rickman, Moon & Planets 27, 107; Zhou et al., Acta Astron. Sinica 23, 349; Zappalá et al., Icarus 52, 196; Barucci and Dipaoloantonio, A&A 117, 1; Schober, A&A 117, 362; Schober and Schroll, A&A 120, 106; Harris and Young, Icarus 54, 59; Lagerkvist and Kamel, Moon & Planets 27, 463; Surdej et al., A&A Suppl. 52, 203; Cunningham, JRASC 77, 121; Lupishko et al., Vestn. Khar'kov Univ. 232, 54; Schober, A&A Suppl. 53, 71; Schroll and Schober, A&A Suppl. 53, 77; Carlsson and Lagerkvist, A&A Suppl. 53, 157; Debehogne et al., Icarus 55, 236; Binzel and Tholen, Icarus 55, 495; Hahn, Asteroids, Comets, Meteors, 35; Poutanen, Asteroids, Comets, Meteors, 45; Lupishko et al., Soviet Astron. Lett. 9, 358; Di Martino and Cacciatori, A&A 130, 206; Harris et al., Icarus 57, 294; Harris et al., Icarus 58, 377; Ziegler and Florence, BAAS 16, 691; Di Martino and Cacciatori, Icarus 60, 75; Ostro et al., Icarus 60, 391.

A systematic photoelectric survey on very small asteroids has been started at the Univ. of Texas (Binzel and Mulholland, Icarus 56, 519); it is important to investigate the spin evolution of small, faint bodies thought to be collisional fragments of catastrophic impacts, for which there are still severe observational biases in the available database. A similar project is in progress in Italy (Barucci and Di Martino, A&A Suppl. 57, 103). Worldwide campaigns were devoted to lightcurve photometry of selected objects (Schober and Kristensen, Sun and Planetary System, 305; Birch et al., Icarus 54, 1; Tedesco et al., Icarus 54, 23; Tedesco et al., Icarus 54, 30). The unusual fast rotation of M-type asteroids (Lagerkvist and Rickman, Sun and Planetary System, 287; Zappalá et al., A&A Suppl. 50, 23; Surdej et al., A&A Suppl. 54, 371) and the extremely slow rotation of some small asteroids (Harris and Young, BAAS 14, 724; Schober et al., A&A 115, 257) are confirmed (see below).

A Commission 15 Working Group (A.W. Harris, H.J. Schober, E.P. Tedesco, and V. Zappalá) is preparing a detailed data-file on all the existing observations. A preliminary list of rotational properties is already completed and is at disposal of the scientific community; a general lightcurve catalogue is also in preparation (Lagerkvist et al., Asteroids, Comets, Meteors, 27). The latest published list of known rotations, including references, is by Harris and Young (Icarus 54, 59).

New observations have shown recently ambiguity for some rotational periods previously considered to be of high reliability (Zappalá et al., Icarus 56, 319; Schober, A&A 105, 419), and a careful re-analysis of the available data is planned, because of the potential bias on statistical studies. For example, Zappala et al. (A&A 130, 208) have re-observed 21 Lutetia, originally thought to have a spin period of 6.133h, and have found it to be 8.17h. They attribute the incorrect earlier period to confusion caused by the high phase angle at the time of the marginally redundant earlier observations.

Several papers have been published in recent years reporting statistical analyses of the rotation data available (e.g., Farinella et al., A&A 104, 159; Paolicchi et al., Sun and Planetary System, 291; Golubeva and Shestopalov, Sov. Astron. 27, 583; Lagerkvist, Asteroids, Comets, Meteors, 11; Dermott et al., Icarus 57, 14; Binzel, Icarus 57, 294). The results that appear to be agreed upon are that the largest asteroids rotate with a mean period of ~8 hours with a dispersion about the mean which is not significantly different from that expected of a stochastically produced distribution (i.e., Maxwellian in three dimensions). In the size range of ~50 to ~150 km, it appears that there is a significantly longer mean period, ~10 hours. Dobrovolskis and Burns (Icarus 57, 464) suggest that this might be due to loss of angular momentum in collisions due to escape of ejecta thrown in the direction of rotation. Since preferential escape of forward thrown ejecta requires that the ejecta velocity be of the same order as the escape velocity from the asteroid, the mechanism is only effective in the size range of ~100 km diameter. Other possibilities exist, such as variation in the population index of asteroids in different size ranges, but these have not been explored in detail. Among asteroids smaller than ~50 km, the mean rotation period is again ~8 hours, but the dispersion becomes broader than expected for a Maxwellian distribution, becoming even bi-modal at the smallest sizes. Since essentially all known rotations of asteroids of D <10 km are of Earth- or Mars-crossing objects, it is not clear whether this result applies only to that class of asteroids, or to main-belt asteroids as well. A survey of small main-belt asteroids by Binzel and Mulholland (Icarus 56, 519) suggests that it does, but more data is required to reach a firm conclusion. Among the Earth- and Mars-crossing asteroids, the bi-modal distribution in spin rates may indicate that at least some of these bodies are extinct comets, since comets appear to have a bi-modal split in their rotation rates, including a very long-period group (Whipple, Comets, 227). Among asteroids in the main belt of D < 50 km, there appears to be an excess of slowly rotating asteroids, with periods greater than a day, up to 6 days. These slow spins can be explained as being due to tidal friction between an initially more rapidly spinning asteroid and a massive satellite, with the system eventually becoming synchronous, as in the Pluto/Charon system (Farinella et al., op cit.). Because of the limited power of tidal friction on small, solid bodies, evolution to synchronous is expected only if that state is reached before the satellite recedes beyond ~10-15 radii from the primary. Thus, only periods up to ~6 days can be explained this way. Two asteroids, 288 Glauke (Harris, Sky & Tel. 65, 504) and 1220 Crocus (Binzel, Icarus, in press) have apparent periods much

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longer than 6 days (~60 and ~30 days, respectively). Both exhibit large amplitudes (>0.5 mag.), and the periods appear firmly established. The only explanation which has been offered for these extremely long periods is that they are periods of precession of the spin axes of rather oblate asteroids induced by the presence of massive satellites orbiting about them. The true rotation rates would be considerably shorter. In the case of 1220 Crocus, Binzel observed a smaller amplitude period of ~8 hours when the long period variation is near its minimum level, suggesting that this is the true rotational variation, visible only when the asteroid is seen close to its equatorial aspect.

The plausibility of binary systems among asteroids has been analyzed from different points of view (Lambert, Proc. Southwest Reg. Conf. 7, 127; Scaltriti et al., Sun and Planetary System, 277; Showalter et al., BAAS 14, 725; Zappalá et al., Icarus 53, 458; Schober, Astrophys. Space Sci. 99, 387; Cellino et al., BAAS late paper, 1984). In particular, models of equilibrium figures with mass ratio different from one were studied (Leone et al., A&A 140, 265). As described above, Harris (BAAS 15, 828) suggested that the very slow rotation of small asteroids can be explained with forced precession due to a satellite: a puzzling oscillation found in the period of Ceres has also been proposed to be due to a precession phenomenon (Zappala et al., BAAS late paper, 1984).

Lightcurve data also yield information on the shapes, pole orientations, and phase relations of asteroids, but to obtain such results, one must impose model constraints on the data. One requirement is to separate the effects of solar phase angle from that of the viewing aspect (latitude on the asteroid of the viewing direction). The group led by M. Fulchignoni in Rome has studied in the laboratory the brightness variations of irregular models under various viewing conditions to attempt to separate these effects. For example, they have studied the effects of changing aspect and phase angle on the amplitude of variation for a wide variety of shapes and variable albedo models (Barucci and Fulchignoni, Asteroids, Comets, Meteors, 101). Harris (Icarus 57, 251) has called attention to the fact that the geocentric line of sight to the asteroid is an unrealistic approximation for the effective viewing direction when the solar phase angle is non-zero. A better approximation is the phase angle bisector, the line which bisects the Earth and sun lines to the asteroid. By referencing the aspect (latitude on the asteroid) to this line, one makes a better separation of the effects of viewing aspect and phase relation as the geometry of the Earth and sun change. Work has progressed on improving the magnitude-aspect method of shape and pole determination (Zappalá, Moon & Planets 24, 319; Zappalá and Scaltriti, Sun and Planetary Systems, 303; Zappala, Moon & Planets 24, 319; Zappalá and Knĕzević, Icarus 59, 436) so that it now appears to be comparable to the method of photometric astrometry (Taylor and Tedesco, Icarus 54, 13; Tedesco and Taylor, BAAS 16, 700; Taylor, Icarus, in press) in accuracy. An important work which remains is to combine the two methods, since they are complementary in that the former is better for objects whose poles lie near the ecliptic plane, whereas the latter is better for objects which are more nearly pole upright. Both yield accurate results only if the amplitude of variation at some aspect is fairly large. Efforts are also progressing on understanding the potential of speckle interferometry for the same purposes (Drummond et al., BAAS 14, 725; Drummond et al., Steward Obs. Preprint 523), and future work is planned on comparisons with other techniques (Drummond and Hege, BAAS 16, 647).

The classic work of H.N. Russell in 1906 has been reconsidered in the light of our present knowledge that most of the rotational light variation of asteroids is due to shape rather than albedo. Ostro and Connelly (Icarus 57, 443) have considered the idealized case of geometric scattering from a body viewed equatorially to deduce a recipe for inverting the lightcurve to obtain a convex profile of the mean cross-section of the asteroid. The idealizations made require caution in interpreting results. Most important, the work serves to give a feeling for the best viewing conditions under which observations for shape studies should be made, and

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to understand the uncertainties of shapes and poles determined under more general conditions but which require model assumptions in their results.

Torino Observatory started an international observing campaign, which should produce a considerable amount of new pole positions in a few years. Several results have already been published on rotation axis determinations (Zhou and Yang, Acta Astron. Sinica 22, 378; Burchi and Milano, Moon & Planets 28, 17; Lupishko and Belsksaya, Asteroids, Comets, Meteors, 55; Magnusson, Asteroids, Comets, Meteors, 77; Barucci, A&A Suppl. 54, 471; McCheyne et al., Icarus 59, 286; Binzel, Icarus 59, 456; Zappalá and Knezevič, Icarus 59, 436). Pole coordinates will also be derived from the program on equilibrium shapes of the P.S.I. group in Tucson (Chapman et al., BAAS 14, 728; Chapman et al., BAAS 15, 829; Chapman et al., BAAS 16, 708). When the program is completed in about a year, we also expect to have decisive evidence supporting or negating the existence of triaxial quasi-equilibrium figures expected for "rubble-pile" structures.

A considerable amount of work, both observational and theoretical, has been devoted to the study of phase relations and scattering laws. Most theoretical work to date has been restricted to the case of a spherical body, thus again the laboratory work of Fulchignoni and co-workers (e.g., Barucci et al., BAAS 16, 700) is important for comparing results to real observations of non-spherical objects. Hapke (JGR 86, 3039; JGR 86, 3055; Icarus 59, 41) and Lumme and Bowell (AJ 86, 1694; AJ 86, 1705) have developed theories which attempt to define the disk integrated brightness of a body of uniform albedo as a function of phase angle, accounting for such effects as single particle phase function, surface roughness, porosity, and single scattering albedo. Theoretical studies of phase relations have been carried out in the Soviet Union, as well (e.g., Golubeva and Shestopalov, Astron. Zh. 60, 602; Akimov, Vestn. Kharkov Univ. 204, 3; Shevchenko, Astron. Vestn. 16, 209). In addition, the group led by Lupishko has observed a number of asteroids very extensively to measure the phase relations in detail (e.g., Lupishko et al., Astron. Vestn. 15, 25; Pis'ma Astron. Zh. 7, 437; Astron. Vestn. 16, 101; Vestn. Kar'kov Univ. 232, 54). It is only through such detailed observations covering all observable phase angles that we will be able to test the various theoretical models proposed.

In addition to attempts to define asteroud phase relations theoretically, work is underway to define a function purely empirically for the purpose of prediction of magnitude vs. phase angle (e.g., Lumme et al., Proc. Nord. Astron. Mtg.; BAAS 16, 684). This function is especially required for use by IAU Commission 20 in the publication of asteroid ephemerides. However, it will also be useful for interpretation of thermal infrared data (e.g., IRAS asteroid observations), and can serve as a paradigm for judging individual asteroid phase relations as "normal" or unusual.

It is now widely believed that collisions at high relative velocities (several km/s) have been the main process responsible for the evolution of the physical properties of asteroids since their origin. Special efforts have been made to analyze how these collisions have affected the rotational properties and, more generally, how we can recognize among the present asteroids the outcomes of different types of impacts.

Determining the mass ratio of the probable largest collision for target asteroids of different sizes during the solar system's lifetime, Farinella et al. (Icarus 52, 409) concluded that, if the results of laboratory impact experiments can be scaled up to asteroidal sizes, then all the asteroids have undergone collisional events capable of overcoming the material's solid-state cohesion. Such events do not always lead to complete disruption of the targets, and also self-gravitation can easily cause a reaccumulation of the fragments for targets exceeding a critical size, which appears to be of the order of 100 km. It follows that in the intermediate size-range (100 to 300 km) the formation of gravitationally bound "rubble piles", having low strength, is fairly frequent (cf. Davis et al., Asteroids, T. Gehrels, ed., 528), and the collisional angular momentum transfer can be large enough to produce objects with triaxial equilibrium shapes or to cause fission into binary systems. Asteroids smaller than about 100 km are mostly multi-generation fragments, while for diameters larger than 300 km, the collisional process yields nearly spheroidal objects covered by deep regolith layers. These conclusions are in accord with a comparative analysis of the asteroid shapes with those of collisional fragments produced in laboratory experiments (Catullo et al., A&A 138, 464; Capaccioni et al., Nature 309, 832).

The analysis of the collisional outcomes can be applied to study the origin of dynamical Hirayama families (Zappalá et al., Icarus 59, 261). In particular, we can separate the families according to their mass and relative velocity distributions, identifying "asymmetric" families, whose minor members were asymmetrically ejected on one side of the largest collisional remnant, and "dispersed" families, for which the disruption event was nearly isotropic and the largest asteroid is roughly at the center of the fragment mass distribution. The influence of the parent body's self-gravitation in most cases was crucial (Fujiwara, Icarus 52, 434), and in particular it could amplify the effects of ejection asymmetries. These ideas are supported by the available data on families, even though the current family identification schemes have several problems both from the point of view of celestial mechanics and from that of the clustering techniques (cf. Carusi and Valsecchi, A&A 115, 327). Davis et al. (BAAS 16, 697; Icarus, in press) use the characteristics of the major families, as well as the apparent preservation of the presumed ancient basaltic crust on Vesta, to constrain the collisional evolution of the asteroids. In some contradiction to earlier work and the recent work of Farinella et al. *mentioned above*, Davis et al. *find the collisional evolution to have been* quite modest since early epochs. The original abundance of asteroids may have been only a few times greater than that of today, which may also be consistent with the number of intermediate-sized asteroids having high angular momenta (Farinella et al., Icarus 52, 409).

There are clear hints that the results of laboratory experiments cannot be fully extrapolated for asteroids without a better physical understanding of the rupture mechanism. Davis et al. (loc cit) pointed out the difficulty of applying a scaling law passing from centimeter to multi-kilometer-sized targets, and have proposed that there is increasing strength for increasing body size due to hydrostatic self-compression; this can explain the unexpectedly large fragment-to-parent body mass ratios observed in the Hirayama families with respect to outcomes of laboratory experiments. Theoretical (Paolicchi et al., Hvar Obs. Bull. 6, 163) and experimental (Matsui et al., Lun. Planet. Sci. XIII, 475; Waza and Matsui, Lun. Planet. Sci. XIV, 838; Bianchi et al., A&A 139, 1) studies of fragmentation processes have been made and are in progress for a general understanding of the physical and rotational properties of the break-up outcomes. The surprising abundance of objects with very long lightcurve periods remains an open problem, despite the mechanisms of angular momentum drain (Dobrovolskis and Burns, Icarus 57, 464) and tidal evolution within binary systems (Harris, BAAS 15, 828; Binzel, BAAS 16, 698) mentioned above, which could play a role in its solution.

Another important puzzle is presented by the bimodal distribution of rotational periods of the Apollo-Amor asteroids. Moreover, Apollo-Amors seem on the average to be more irregularly-shaped than both laboratory fragments and small main-belt asteroids (cf. Capaccioni et al., Nature 309, 832). Catullo et al. (A&A 138, 464) have compared lightcurve amplitude distributions for several groups of asteroids with equivalent shape parameters for fragments generated by high-velocity impact experiments. They find that main-belt asteroids smaller than 100 km diameter match the experimental distribution well. Large asteroids are lacking in extreme amplitudes, suggesting equilibrium configurations due to self-gravity. But Apollo-Amor asteroids have an excess of unusually elongated objects: the interpretation of this latter fact is unclear. Could we be observing two classes of Apollo-Amors, one of "asteroidal" and one of "cometary" origin?

COMPOSITIONS, PHYSICAL PROPERTIES, RELATIONS TO METEORITES - C.R. Chapman

Detailed infrared spectra of 2 Pallas are interpreted by Larson et al. (Icarus 56, 398) in terms of a mineral assemblage similar to CI and CM meteorites, but subjected to greater aqueous alteration and with an admixture of another component. An earlier study of 1 Ceres, especially of the 3 micron region, by Lebofsky et al. (Icarus 48, 453), suggests a hydrated clay mineralogy for that body. In addition to water of hydration, Lebofsky et al. claim to see a feature due to water ice on Ceres, which would have profound implications if true. Results of the most recent survey of 3-micron water features, and relationships to carbonaceous chondrite mineralogy, are reported by Feierberg et al. (BAAS 16, 692).

What may be the first silicate emission features observed for asteroids in the 8-13 micron spectral range were detected by Feierberg et al. (Icarus 56, 393) for 19 Fortuna and 21 Lutetia; comparable features were absent for several other asteroids.

A continuing question of great importance is whether the S-type asteroids are mineralogically similar to the undifferentiated ordinary chondrites or, instead, they are similar to differentiated stony-iron meteorites. Feierberg et al. (ApJ, 257, 361) interpret mid-IR spectra as implying ordinary chondrite-like mineralogies. Gaffey et al. (Icarus 60, 83; BAAS 16, 698) have studied 8 Flora in exhaustive detail and find that this particular S-type object shows variations in its spectrum as it rotates that are inconsistent with ordinary chondrite mineralogy. Gaffey strongly feels that a differentiated (stony-iron) mineralogy is required and generalizes this particular result as suggesting that most S-types are differentiated. This may be incompatible with the radar work of Ostro et al. (see below), who find that Flora has one of the lowest radar reflectivities of asteroids observed by radar, which probably means that it is incompatible with the large fraction of surficial metal that Gaffey believes is there. Inasmuch as the continuing 8-color spectrophotometry program (see below) has turned up few objects (except those already in Earth-approaching orbits) with colors more like ordinary chondrites than the S-types, it is becoming less and less clear how we can derive so many meteorites from such uncommon main-belt asteroids, unless we interpret many (or at least some) S-types as being ordinary chondrites. The alternative, namely that comets are the parent bodies of ordinary chondrites, is incompatible with current views of condensation temperatures in the region of comet formation. Also, earlier dynamical difficulties with extracting sufficient material from the inner main belt to account for the abundance of ordinary chondrites are evaporating in the face of new work (see below). It is hoped that a major input to this controversy about S-types can be made by the Galileo spacecraft, which may make near-infrared spectral maps and take high resolution images of the surface of 29 Amphitrite in late 1986. Some additional information may be derived from the more intensive studies of S-type asteroids in the infrared, which have been initiated by Brown (see Bell et al., BAAS 16, 692).

It has long been suspected that certain S-like asteroid spectra (some asteroids with these spectra were originally termed R's) could imply an olivine-rich assemblage, which would be of great interest since olivine-rich meteorites are believed to be derived from the mantles or mantle-core interfaces of strongly-heated and geochemically differentiated parent bodies (cf. Greenberg and Chapman, Icarus 57, 267). Definitive spectra of 246 Asporina and another main-belt asteroid by Cruikshank and Hartmann (Science 223, 281) shows the diagnostic signature of olivine with an absence of pyroxene. These are members of a small group of A-type asteroids that are presumably all olivine-rich and pyroxene-poor. JHK photometry of asteroids (e.g., Veeder et al., AJ 87, 834; AJ 88, 1060) continues to supplement visible and near-IR colorimetry in the taxonomic classification of asteroids, including the A-types (Veeder et al., Icarus 55, 177).

A major contribution to asteroid research has been made by the 8-color spectrophotometry program conducted by Tholen, Tedesco, and Zellner. Although the final publication of data on nearly 600 asteroids is still due this year, preliminary interpretation of these data, and of associated radiometry, by Gradie and Tedesco (Science 216, 1405) has identified -- with much better precision than earlier studies -- a well-ordered sequence of predominant taxonomic types of asteroids with semi-major axis. There is a progression of seven distinct peaks in the distribution of types with distance from the sun, in the order E, R, S, M, F, C, P, and D (from 1.0 to 5.2 A.U.), although the distributions do overlap substantially. An important element of this work has been the clear identification of additional sub-types of asteroids previously thought to be C's or M's (e.g., the P type, which has C-like albedos but M-like colors). Tholen, in his 1984 thesis, has further refined the taxonomy of low-albedo asteroids; he adds "T" as intermediate between C and D, "G" as an unusual C-like type, and "B" as intermediate between C and the bluish F-types. The chief conclusion from the preliminary interpretations so far is that the asteroids truly are likely to preserve, in an ordered way, the primordial variation in solar nebular condensates with solar distance. Perhaps one or more types (e.g., the E's) have been implanted from orbits originally closer to 1 A.U.

Further observations of asteroids by Earth-based radar have been made, with the numbers of observed objects now large enough to permit some tentative correlations with such properties as size and taxonomic type (Ostro et al., BAAS 16, 692). Radar studies of 1685 Toro (Ostro et al., AJ 88, 565) suggest that its mean effective diameter is about 3.3 km, that its surface has a porosity comparable to the moon's, and that it is much rougher than the moon on 10-100 meter scales. A comprehensive report on radar observations of 2100 Ra-Shalom has also been presented (Icarus 60, 391).

There has been increasing success during the triennium in measuring asteroid diameters and shapes from studies of stellar occultations, despite the considerable logistical efforts required for success. For example, Millis et al. (AJ 89, 592) deduce a mean diameter for 375 Ursula of 216±10 km from a November 1982 event observed at six sites. Ten chords were measured by Millis et al (Icarus 61, 124) for 93 Minerva, yielding a diameter of 170 km, in good agreement with the radiometric value. The occultation of a naked-eye star by 2 Pallas in May 1983 resulted in the observation of more than 100 chords, providing by far the most refined profile of an asteroid to date; the southern cap of Pallas was missed, however, due to cloudy weather throughout the southern United States and northern Mexico.

It remains to be seen how fruitful speckle interferometry will prove to be in addressing the questions about asteroid sizes, shapes, and possible satellites. For example, Drummond et al. (Steward Obs. Preprint 525) have withdrawn an earlier suggestion that speckle data showed a satellite for 532 Herculina, and now propose a triaxial shape for that body with a superimposed albedo spot. Drummond and Hege (BAAS 16, 697) have also withdrawn the suggestion that speckle data imply the existence of a satellite of 2 Pallas, which was not detected during the widely observed 1983 stellar occultation by that body. Speckle measurements of elliptical shapes have been reported for 29 Amphitrite and 3 Juno by Baier and Weigelt (A&A 121, 137). An important test of the speckle method has been reported for the well-observed, highly elongated object 433 Eros (Drummond et al., Icarus 61, 132).

The Infrared Astronomical Satellite (IRAS) observed a large number of asteroids during its 300-day mission. These data are currently being cataloged for future scientific analysis. Preliminary reports on asteroid results were presented by Tedesco et al. and Aumann and Walker (BAAS 16, 689). Of particular interest was the discovery of zodiacal "dust bands", apparently related to collisions in the asteroid belt (cf. Sykes and Greenberg, BAAS 16, 690) or perhaps the Hirayama families.

Froeschlé and Scholl (Asteroids, Comets, Meteors, 115) reviewed the dynamical evolution of the asteroid belt, including possible depletion mechanisms for the Kirkwood gaps. Gravitational perturbations may be able to remove existing bodies in the gaps but not in times on the order of 10^4 years. Gonczi, Froeschlé, and Froeschlé (Asteroids, Comets, Meteors, 137)studied the motion of small grains, in the early solar system evolving under the gravitational effect of the sun-Jupiter system and the Poynting-Robertson drag effect. Their numerical experiments suggest that, if in a given resonance gap there was no preexisting large body, no grains could remain in the gap to form larger bodies.

A number of programs are directed toward the discovery of unusual objects, especially Earth-approachers. Among the important discoveries of asteroids during the period was the object 1982 DB, which is the most accessible of the near-Earth objects known, requiring a delta-V of only 4.45 km/sec (Helin et al., Icarus 57, 42). Another important discovery (by IRAS) was 1983 TB, which Whipple has proposed to be the probable parent of the Geminid meteors (see also Fox et al., MNRAS 208, 11P, and the discussion in Comets section above). The possibility that 1984 BC may be an extinct comet has been raised by Helin et al. (BAAS 16, 691); it apparently has a low albedo and a reddish, D-like spectrum. A recent summary of the population of Earth-crossing asteroids has been presented by Helin (Minor Planet Bull. 11, 19). There are 60 Earth-crossers now known, although the total population of such bodies to visual magnitude 18 is probably about 1000.

Considerable interest has been generated concerning the small Earth-crossing asteroid 2201 Oljato due to unusual colors apparently observed by McFadden (see McFadden et al., Icarus 59, 25, for a presentation of reflectance spectra for 17 Earth-approaching objects). The possibility that Oljato is a nearly extinct comet has been raised, although no diagnostic evidence of well-known cometary emission features exists. There has also been reported a possible connection between events on Venus and the proximity of this object. These unresolved questions are summarized by McFadden et al. (BAAS 16, 691).

There has been considerable work on the important question of how meteorites may be derived from the asteroids. Levin and Simonenko (cf. Bull. Inst. Theo. Astron. 15, 20) believe that there is good evidence that Apollo-Amor objects represent the last parent bodies of most or even all classes of meteorites, whether comets or main-belt asteroids were the predecessors. Greenberg and Chapman (Icarus 55, 455) argue, however, that the observed distribution of meteorite classes can be derived through well-understood cratering processes on main-belt asteroids; they suggest that Earth-approaching asteroids play a minor role. The greatest advance during the period comes from the work by Wisdom (Meteoritics 18, 422), who suggests that "chaotic" behavior in the evolution of orbits of asteroids near the 3:1 Jupiter commensurability results in Earth-crossing orbits; Wetherill (Meteoritical Society Presidential Address, Albuquerque, 1984, in press) thinks this may provide the long-sought-for mechanism of getting ordinary chondrites from the main belt to the Earth.

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