20. POSITIONS AND MOTIONS OF MINOR PLANETS, COMETS AND SATELLITES (POSITIONS ET MOUVEMENTS DES PETITES PLANETES, DES COMETES ET DES SATELLITES)

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I. INTRODUCTION

An avalanche of discoveries pertaining to the satellite and ring systems of Jupiter and Saturn followed from the encounters of Pioneer 11 with Saturn, of Voyagers 1 and 2 with both Jupiter and Saturn, and from the passage of the Earth through the Saturn ring plane, all of which occurred during the triennium. The first comet discovery from a spacecraft also occurred during the same interval, a coronagraph experiment on the satellite P78-1 apparently catching a Kreutz sungrazer in the last hours before it impacted the Sun on 1979 August 30. Several successfully observed occultations of stars by the Uranian ring system, by minor planets, and possibly by satellites of Neptune and Pluto testify to efforts inspired by the Commission's Working Group on Prediction of Occultations.

Although there seems to be a general increase in interest in comets, particularly in their physical characteristics, arising from planning for the impending return of P/Halley, as well as from studies relating to experiments for future spacecraft missions, the burgeoning activity does not seem to extend to astrometric observations, even of rather bright comets. Part of the reason for this may be that such observations are no longer given the prominence they once enjoyed on the IAU Circulars. Initial observations of new and recovered comets still appear there, of course, but the bulk of the observations are now published in the Minor Planet Circulars/Minor Planets and Comets. The form of the MPCs has been modified recently in an attempt to give greater prominence to the observations of comets. But part of the problem is merely a relative one, in that the number of astrometric observations of minor planets has exhibited such a tremendous surge in recent years.

International meetings of interest to the Commission were the colloquium 'Asteroids', held in Tucson, Arizona, in 1979 March; and IAU Colloquium No. 61, 'Comets', held also in Tucson, in 1981 March. Publications derived from two international meetings held earlier also appeared during the triennium: IAU Symposium No. 81, 'Dynamics of the Solar System', held in Tokyo in 1978 May; and 'Natural and Artificial Satellite Motion', held in Austin, Texas, in 1977 December.

Commission 20 notes with regret the passing of the following members: P Herget (1908-1981), H Hirose (1909-1981), M Itzigsohn (18 -1978), J G Porter (1900-1981) and K Reinmuth (1892-1979). As founder-director of the Minor Planet Center and a former president of the Commission, Herget dominated the study of minor planets for several decades, applying his unique experience with automatic computing methods to rescue the subject following the disruption caused by World War II. As director of the Tokyo Observatory Hirose was for many years the leading figure in research on minor planets and comets in Japan; his first work on orbits and identifications was done more than half-a-century ago, and he was also actively involved in the Tokyo observational program. As leader of the La Plata program, Itzigsohn was responsible for the surge in observational and computational activity on minor planets in Argentina following World War II. As president of the subcommission on comets (later as chairman of the Working Group on comets) and as director of the Computing Section of the British Astronomical Association, Porter was responsible for the

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increase in the number and reliability of predictions for the returns of periodic comets during and after World War II; the first of the recent editions of the Catalogue of Cometary Orbits (1960) was produced under his guidance. As an early participant and for a quarter of a century the leader of the observing program at Heidelberg, Reinmuth holds the record for the number, almost 300, of discoveries of numbered minor planets.

Information for the sections of this report on Minor Planets, Comets, Satellites and Prediction of Occultations has been compiled by B G Marsden, Ľ Kresák, Y Kozai and G E Taylor, respectively. Due to unusual circumstances, the president of the Commission was unable to undertake the preparation of the Commission Report in final form. That responsibility has therefore fallen to the undersigned, who owes deep appreciation not only to the Working Group chairmen named above but to all individuals who provided information for the report. As in the past, Astronomy and Astrophysics Abstracts numbers are generally used for the references.

II. MINOR PLANETS

a) GENERAL

The Minor Planet Center has completed its first full triennium of operation at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, under the direction of B G Marsden. C M Bardwell was promoted to Associate Director in April 1981, and valuable assistance has also been variously provided by D W E Green and E Fogelin. As previously, the Minor Planet Circulars have been published in monthly batches. The steady increase from some 500 issues during 1979 to more than 800 during 1981 is a dramatic indication of the general surge of activity in the Commission in the area of minor planets. This surge involves astrometric observations and orbit computations in appropriate proportions: the machine-readable file of observations, which contained almost 230 000 entries when the first distribution of copies to interested users was made early in 1981, is now growing by some 10% per year, while the corresponding increase in orbital studies means that minor planets are now receiving permanent numbers at the unprecedented annual rate of more than 170.

The increasing rate of new numberings has also had a noticeable effect on the size of the annual volumes of Efemeridy Malykh Planet, which continue to be prepared at the Institute for Theoretical Astronomy in Leningrad by N V Ashkova, V A Isvekov, F B Khanina and V A Shor, under the direction of Yu V Batrakov. The 1982 volume contains 252 pages. Transfer to the BESM-6 computer enabled the production of the Efemeridy to be greatly automated. An important change, which greatly augments the scope of this publication, has been the presentation of high-precision orbital elements for all the minor planets for a new standard osculation epoch each year; although the opposition ephemerides are still given as before, many users are finding it convenient to calculate ephemerides more suited to their individual needs directly from the current osculating elements.

'Asteroids', the proceedings volume of the international colloquium organized by T Gehrels in Tucson in March 1979, is an excellent up-to-date general reference on the subject. Although there is an emphasis on physical studies, many of the contributions are relevant to the work of Commission 20, particularly the definitive compilation, by J G Williams, of proper elements and family memberships for minor planets 1-1796.

b) OBSERVATIONS AND ORBITS

The most consistently complete observational program continues to be that conducted by N S Chernykh and his four collaborators at the Crimean Astrophysical Observatory. The number of observations made is now in excess of 3000 per year, about 20% of them referring to numbered planets. As many as 1300 unnumbered objects have been recorded in one year, and about one-third of the minor planets receiving

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new permanent numbers result from this program.

The observing programs led by E Bowell at the Lowell Observatory and by A Mrkos at the Kleť Observatory are also especially worthy of note. Although the number of observations is rather less than in the Crimean program, the numbered planets are well covered, and more than 100 unnumbered objects are recorded in each program each year. A significant feature of these programs has been the immediacy with which the plates are measured; the resulting positions are generally published in the MPCs within a month or two of their being obtained. The Lowell program makes use of a microdensitometer, rather than a conventional measuring engine. Although the reduction process is more complex, a plate containing many objects can be measured more quickly, and tests show that the results are quite as accurate as those obtained by the conventional procedure.

Other wide-field programs currently yielding a substantial number of observations of faint or unnumbered minor planets are conducted by C Torres and his colleagues at Cerro El Roble, by H Kosai and K Hurukawa at the Tokyo Observatory's Kiso station, by F Börngen at Tautenburg, by C U Cesco and his associates at the Felix Aguilar Observatory's El Leoncito station, and under the general direction of Y-Z Zhang at the Purple Mountain Observatory. A large number of observations have also come from extensive international collaborations, notably by S J Bus, E Helin, J Gibson and C Kowal at Palomar and Siding Spring; and by H Debehogne, R R de Freitas Mourão, G De Sanctis, C-I Lagerkvist, L D Schmadel, J Schubart, H-E Schuster, R M West and V Zappalà at the European Southern Observatory, the Uppsala Southern Station, Kvistaberg and Marseilles.

Conventional reflectors, such as those used in the programs under the direction of R E McCrosky at the Oak Ridge Observatory (formerly Harvard Observatory's Agassiz station) and by A C Gilmore and P M Kilmartin at the Mt John Observatory, frequently provide the important last-of-the-season observations of new discoveries. The brighter minor planets have been well observed at Nice (by B Milet), Bucharest (C Cristescu), Sydney (W H Robertson) and at several observatories in the USSR, as well as by amateur astronomers in Japan (T Seki, T Furuta, M Takeishi), England (B Manning and others), Australia (D Herald), West Germany (R Hempel and others) and East Germany (M Gressmann). A promising new source of observations is a real-time television survey being made at the Lincoln Laboratory's New Mexico installation (L G Taff).

C J van Houten and I van Houten-Groeneveld have now essentially completed the measurement of the additional plates from the Palomar-Leiden survey. The observations, which number more than 16 000, are to be included in the Minor Planet Center's machine-readable file. Several hundred new and improved orbits, mainly calculated by P Herget, will be published shortly.

Accurate positions have continued to be measured on request from older plates at the Goethe Link Observatory (under the general direction of F K Edmondson), the Turku Observatory (under the direction of L Oterma) and the Lowell Observatory (H L Giclas, Bowell). It has also been possible to get occasional accurate positions from the important collections at Johannesburg (via J Churms), and Budapest (West, Ľ Kresák).

In connection with the publication of the annual Efemeridy volume, Khanina and her associates at the Institute for Theoretical Astronomy have improved the orbits of the numbered minor planets at a rate of about 100 per year. Preliminary orbits and search ephemerides are computed by G R Kastel' for many of the objects observed in the program at the Crimean Astrophysical Observatory. A number of orbit improvements and integrations for numbered minor planets have been made by M A Dirikis at the Latvian State University, Riga.

Interest in finding identifications among unnumbered objects at different oppositions has remained at a high level. Such work is still carried out with significant success by hand, as it has been for many years, by O Kippes (Würzburg). Others, notably Herget (Cincinnati) and the Japanese amateurs T Urata and H Oishi, as well as Bowell, Marsden and Bardwell have generally used computer searches to find identifications. Williams (Jet Propulsion Laboratory) has led the effort to make searches for past images of specific objects on Palomar Schmidt plates. The resulting improved orbits have been determined generally by Herget, Urata, Nakano, Marsden and Bardwell. Schmadel (Astronomisches Rechen-Institut) has recently conducted a thorough search of the observations of unnumbered minor planets for previously unsuspected identifications with numbered objects.

In the report for the 1976-78 triennium it was noted that the number of lost numbered minor planets had been reduced to 23. Even more concerted searches for identifications have reduced this number further, so that now only eight objects are lost out of the total of 2495. The principal authors of the 15 recent successes are: L K Kristensen, Aarhus (452, 682, 730, 1537, 1538); Schmadel (843, 1370); Kippes (1037, 1198); Chernykh (1020); Marsden (612, 1229, 1316, 1465); and Bardwell (603).

c) THEORETICAL INVESTIGATIONS

C Froeschlé and H Scholl (25.098.004) have continued their work on the depletion of minor planets in the outer part of the belt. F A Franklin, M Lecar and D N C Lin (26.098.071; 27.098.135) have concluded that the depletion cannot have an entirely gravitational cause and have examined conditions for the production of the Kirkwood gaps. On the other hand, S F Dermott and C D Murray (29.098.010) have concluded that the gaps are formed by gravitational processes acting on individual objects. T A Heppenheimer (26.098.027; 28.042.042) also investigated the origin of the gaps, and he has extended the Brouwer-van Woerkom solution for determining proper elements. L Zaleski (26.098.115) made a statistical investigation of the formation of the belt, while V F Zheverzheev (25.098.056; 27.098.006) discussed the probability distribution of several parameters of the belt. Z Knezević (27.098.115) examined the statistical stability of the sample of numbered minor planets.

B Garfinkel (28.042.040) published the third paper in his series on the theory of motion of Trojans, and B Érdi (26.098.004) showed that the longitudes of perihelion of Trojans are twice as likely to circulate as to librate. R Bien (27.042.004; 27.098.074), continuing his earlier work on the Trojans, addressed the question of possible differences between objects of high and low inclination. C F Yoder (26.098.073) considered the general problem of the origin of Trojans, and M Delva and R Dvorak (26.042.012; 29.042.059) studied Trojans in terms of the elliptic three-body problem.

S G Zhuravlev (25.098.050; 28.098.022) examined the feasibility of using quasi-periodic solutions of the three-dimensional restricted problem as intermediaries in orbital theories for resonant planets and investigated the asymmetry of the Kirkwood gaps. G T Arazov and S A Gabibov (26.098.005) utilized the two-fixed-center problem to obtain an intermediary in the 2:1 case. Using Schubart's averaging model Bien (27.042.034) found stationary solutions at various resonances, and S I Ipatov (27.042.100) examined the evolution of resonant orbits in the planar restricted problem. A N Simonenko, L M Sherbaum and V G Kruchinenko (26.042.046; 26.098.072; 26.098.106; 28.042.029) investigated the evolution of orbits near the 3:1 resonance, and F A Karminskij (26.098.050) studied this resonance as it applies to objects observed in the P-L survey. T Kiang (27.098.134) continued his earlier work on the difference between the 2:1 and 3:2 resonances.

Y Kozai (27.098.109) introduced a new criterion for defining families of minor planets, namely, the semimajor axis, the projection of the angular momentum on Jupiter's orbit plane, and the minimum inclination as a function of the argument of perihelion. In an examination of the dispersion of members of Hirayama families, W-H Ip

(26.098.083) shed light on the general fragmentation processes in the minor planet belt. Williams and J Faulkner (Icarus 46, 390, 1981) made a detailed study of the positions of the secular resonances. Z Vrcelj (26.042.010) derived a new invariant relation in the elliptic restricted problem, with particular reference to the Sun-Jupiter-minor planet case; and D Olević and D Đurović (27.098.143) made a statistical study of Jacobi constants.

S Oikawa and E Everhart (25.098.006) investigated the long-term motion of (2060) Chiron, concluding that this object is more likely to be evolving toward, rather than away from, the inner part of the solar system; a similar investigation also was made by Scholl (26.098.074). On the other hand, R C Smith (27.098.082) considered the possibility that Chiron was ejected from the main belt of minor planets. Scholl (26.098.023) also summarized the dynamics of Apollo objects, and G W Wetherill (25.098.020; 25.098.039) continued his study of the likely processes involved in the formation of Apollo and Amor objects. M A Vashkov'yak (29.098.009) worked on the evolution of the orbits of more than 20 atypical minor planets, and Kresák (27.098.072) reviewed the general problem of dynamics of interplanetary bodies, with particular reference to the interrelation of comets and minor planets.

A P Mayo (25.098.069) derived analytical expressions for the perturbations of planetary orbits by the minor planet belt. J L Simovljevitch (26.042.034; 27.098.142; 29.098.062; 29.098.063) developed a procedure for estimating the effects of the mutual perturbations of two minor planets, while J Lazović and M Kuzmanoski (29.098.059; 29.098.060; 29.098.061) discussed the problems of close approaches of minor planets to each other.

A W Harris and J A Burns (26.098.013; 26.098.014) pointed out that if there is a real trend toward more rapid rotation among very small minor planets, many such objects must possess significant internal strength. L B Ronca and R B Furlong (26.098.114) also found that small objects are quite capable of maintaining irregular shape. S J Weidenschilling (29.098.038; 29.098.085) considered the general problem of rotation of minor planets, citing a case for the contact-binary nature of (624) Hektor (29.098.082). The likelihood that many minor planets possess satellites has continued to be promoted at length, notably by R P Binzel and T C Van Flandern (25.098.014; 27.098.139). While the claim might be somewhat acceptable theoretically (Harris, 26.098.032; J R Donnison, 25.098.025) the observational support remains far from convincing (H J Reitsema, 26.098.002; E K Hege, W J Cocke, E N Hubbard, J Christou and R Radick, 28.098.037; P D Maley, 28.098.088).

G Sitarski (26.098.065) demonstrated a method for including second-order terms in orbit-corrections problems, with special application to the case of (2101) Adonis, for which a similar solution was derived by G Schrutka and Dvorak (Sitzungsber Österreich Akad Wiss, in press). Dvorak and C Edelman (26.031.519) described a new filtering technique for orbit determination, while J Chapront and P Rocher (27.042.092; 27.098.014) considered the use of Chebyshev series in computing the motions of minor planets. T V Bordovitsyna, V A Shefer and B T Kharin (Astr Geodez 8, 54 and 81, 1980) demonstrated the use of Kustaanheimo-Stieffel transformations for the computation of special perturbations.

R L Branham (26.098.039; 27.043.003; 28.041.028) used observations of the minor planets (6), (7), (8), (9) and (15) to determine corrections to the FK4 equator and equinox, showing how an ideal program of observations might be conducted in order to obtain an optimal result; he also examined the general problem of the least-squares solution of ill-conditioned systems. V I Orel'skaya (27.041.026) continued her extensive work on a similar program, and Kristensen (28.041.014) has determined corresponding corrections from observations of (51) Nemausa. In connection with this work, P Hemenway (27.041.035) discussed the use of 'crossing-point' observations of minor planets.

III. COMETS

a) DISCOVERIES, RECOVERIES AND ASTROMETRIC OBSERVATIONS

During the interval 1979 January 1 - 1981 November 1, 14 long-period comets and 7 new short-period comets were discovered, and 21 previously known short-period comets were recovered. Half of the discoveries of long-period comets were made visually, confirming that the contribution of amateur comet searchers, as W A Bradfield, with three comet discoveries in the triennium, is still very important. Most of the discoveries of new short-period comets were made with large Schmidt telescopes (Siding Spring, Palomar) and most of the recoveries either with large Schmidts (La Silla) or large reflectors (Oak Ridge). It is noteworthy that for the first time in history a slight majority of the discoveries and recoveries came from the Southern Hemisphere: 11 to 10 in both cases. The annual number of comets which received provisional designations exceeded 20 for the first time in 1980.

These statistics refer only to well observed objects with determinate orbits, meeting the criteria for definitive designation. In addition, there were several unconfirmed discoveries or insufficiently observed objects. From among these, only 1979h Kowal was recorded on three nights; an approximate orbit by Marsden (26.103.521) indicated that it was very probably a short-period comet. Only two observations and, hence, no orbital elements are available for 1980p Helin-Dunbar (later identified as a ghost of α Leo), two comets found by C T Kowal (26.103.007), one by N S Chernykh (25.103.002), and one by P Stättmayer (IAU Circ 3638). While the IAU Telegram Bureau reacted immediately to each announcement, and follow-up observations were attempted at several observatories, no further observations were obtained of any of these objects. The need for early examination of each suitable wide-field plate must be emphasized, since in most of the cases cited a delay of several weeks was the main reason for loss of the comet.

The first comet discovered from a spacecraft, designated 1979 XI Howard-Koomen-Michels, was found by R Howard (IAU Circ 3640) in data belatedly available from the orbiting SOLWIND coronagraph developed and operated by N Koomen and D J Michels, Naval Research Laboratory, Washington. Although a range of solutions was consistent with the limited data on position and brightness of the head and tail, calculations by Z Sekanina (IAU Circ 3647) leave little doubt that the comet was a Kreutz sungrazer that actually impacted the Sun on 1979 August 30.

Detailed inspection of the Palomar Sky Survey plates by G Auner, J Dengel, H Hartl and R Weinberger (26.103.006; 27.103.012; 28.103.006) revealed three comet trails unnoticed earlier. One of these was identified by T Nomura (IAU Circ 3588) with P/Gunn, thus extending the observational history of this annual short-period comet by more than two revolutions. One rediscovery, that of P/Schwassmann-Wachmann 3, 1930 VI = 1979g, missed for 8 returns, deserves special mention. Being situated 24° from the predicted position, it was reported as a new comet by J Johnston and M Buhagiar (26.103.261). The corresponding error of 34 days in the time of perihelion passage was surprisingly large for a comet observed for nearly four months in 1930, during the second closest approach of a comet to the Earth in this century.

In 1979-81 two long-period comets became easy naked-eye objects (1979ℓ Bradfield: $4^{m}_{.}5$ and 1980t Bradfield: $3^{m}_{.}5$), and two short-period comets approached the naked-eye limit (P/Encke and P/Tuttle); yet there was no really spectacular object like 1976 VI West or 1973 XII Kohoutek. There was also no continuation to the series in 1974-77 of five discoveries of comets with perihelia outside the orbit of Jupiter. Undoubtedly the most interesting discovery was that of 1980b Bowell. This comet was located a mere 2° from Jupiter, and only the orbit determination by Marsden (27.103.661) showed that it was in fact 1.7 AU beyond that planet. It passed Jupiter at a distance of 0.23 AU in 1980 December, this being the closest approach of a comet to Jupiter included within an observed orbital arc. Inasmuch as the orbital inclination was the lowest of all known long-period comets, the perturbations were unusually

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strong, leading to the highest hyperbolic excess on record. This will result in an ejection from the solar system with a residual velocity of nearly 4 km/s. The discovery circumstances raised the problem, discussed by Marsden (28.103.221), of how to compute the preliminary orbit if a comet is discovered during an encounter with Jupiter.

The problems of rediscoveries of long lost comets were treated by N A Belyaev (25.102.003) and Kresák (Bull Astr Inst Czech 32, 321, 1981). According to the latter, ephemeris-aided searches appear feasible for only three lost one-apparition comets: P/Barnard 1, P/Swift and P/Giacobini. The awaited parent comet of the Perseid meteor stream, P/Swift-Tuttle, has not yet been recovered in spite of continuing searches, but the uncertainty in its revolution period leaves open the possibility of a recovery later in the decade. Extensive searches for P/Halley remained without success. Since the ephemeris should be reliable, the negative result imposes limits on the size and albedo of the nucleus.

Nearly 3000 astrometric observations of 54 different comets were published between 1979 January 1 and 1981 November 1 in the MPCs. About 55% of them were from earlier exposures, with nearly 600 positions measured by E Roemer on her 1967-76 Kitt Peak and Catalina plates representing a major contribution. Together with the results of six other observatories at Oak Ridge, Perth, Kleť, Geisei, Nice, and Cerro el Roble, with 100 to 200 positions each, it constitutes half of the data collected. The other half of the measurements was obtained at 80 different observatories distributed over the world. It is noteworthy that more than 20% of the observations were from the Southern Hemisphere and that this share was increasing, thus providing a stronger observational base for orbit determinations.

Thanks to the indefatigable efforts of Marsden and his associates at the IAU Minor Planet Center, remarkable progress has been made in data acquisition and handling, leading to assembly of a rapidly expanding file of astrometric observations of comets as well as of minor planets. The data on recent comets will soon be available in machine-readable form. Unfortunately, a simultaneous restriction of publication in the IAU Circulars to the discovery, recovery, and immediate-post-discovery observations, in force since 1978, seems to have had some negative impact (Marsden, IAU Circ 3531). The situation has improved recently, but is still unsatisfactory as regards short-period comets, for most of which less than 10 astrometric observations per apparition become available. To quote just the most striking examples, there seem to exist only two observations of P/Reinmuth 2 and P/Finlay, and three of P/Daniel and P/Harrington - in each case from a single observatory, often Perth. The situation is better with confirmatory post-discovery observations of new Northern comets, where the Oak Ridge observers, with guidance from R E McCrosky and Marsden, cooperate most effectively with the IAU Telegram Bureau. It must be emphasized that followup observations of all periodic comets are essential both for investigation of nongravitational effects in their motion and for satisfaction of the increasing demands on the accuracy of ephemerides by astronomers contemplating radio, radar, infrared or ultraviolet observations.

b) ORBITS AND EPHEMERIDES

Preliminary orbits and ephemerides for newly discovered comets were mainly computed by Marsden and appeared regularly in the IAU Circulars and in the MPCs. A parallel service, mostly using the same computations, was provided by the Kometnyj Tsirkulyar, edited by S K Vsekhsvyatskij in collaboration with D A Andrienko and K I Churyumov, and by the Japan Astronomical Circular, edited by M Takeishi. Dozens of orbit improvements were performed, in particular by Marsden and by S Nakano (Nakano wa Kangaeru noda, Nos. 344-407, 1979-81). Redeterminations of the orbits of 38 ancient and mediaeval comets, with several tentative identifications with periodic comets of Halley type, were published by I Hasegawa (26.103.001). R J Buckley (25.103.001; 26.103.005) improved the orbits of 23 nineteenth-century comets and other authors did the same for smaller numbers of objects. According to an orbit redetermination by W Landgraf (28.103.005) 1937 II Wilk, with P = 195 yr, falls into the middle of the gap between long- and short-period comets. As noted by Kresák (29.102.023), the long-period comets occupying the upper boundary of this gap exhibit a definite clustering of perihelion passages which is difficult to explain.

Our knowledge of the motions of short-period comets, and of the nongravitational forces acting on them, has been extended by a number of new solutions linking individual comet apparitions or integrating the motion of selected comets over centuries. The most comprehensive results include those on P/Pons-Winnecke by E A Reznikov (25.103.401), P/Daniel by L M Belous (26.103.441), P/Wolf and P/Ashbrook-Jackson by E I Kazimirchak-Polonskaya (27.103.151; Trudy Inst Teor Astr 18, 1981), P/Chernykh by Kazimirchak-Polonskaya and Chernykh (27.103.221), P/Halley and P/Olbers by H Q Rasmusen (27.103.705), P/Crommelin by E D Kondrat'eva (27.103.731), P/Schwassmann-Wachmann 3 by Belyaev and S D Shaporev (Byull Inst Teor Astr 15:4, 1981), P/Brooks 2 by I Yu Evdokimov and Yu V Evdokimov (Komety i Meteory 29, 73, 1981), P/Denning-Fujikawa and P/Schwassmann-Wachmann 2 by Nakano (Nakano wa Kangaeru noda 344, 1979 and 405, 1981), and P/Shajn-Schaldach and P/Whipple by E M Pittich (Bull Astr Inst Czech 32, 340, 1981).

Especially interesting is the case of P/Boethin. D Benest, R Bien and H Rickman (27.103.121) have found this comet to librate around the 1:1 resonance with Jupiter in a motion resembling an extremely distant satellite. It appears that satellite captures of short-period comets by Jupiter, in the sense of a temporary reduction of their jovicentric velocity below the parabolic limit, are relatively frequent events; A Carusi and G B Valsecchi (29.099.028) have identified 11 such cases in the recent history of 7 comets subject to low-velocity encounters with Jupiter. D K Yeomans and T Kiang (27.103.701; MNRAS 197, 633, 1981) integrated the motion of P/Halley back to -1404, using some unusually accurate old Chinese observations to constrain the comet's orbit. A good representation of all observations was obtained under the assumption of constant nongravitational forces, which would indicate slow aging and a relative stability of the spin axis. Extended ephemerides and other data relevant to the next return were published by Yeomans in his Comet Halley Handbook.

The third edition of Marsden's Catalogue of Cometary Orbits (25.002.022) lists 1027 apparitions of 658 different comets up to the end of 1978. A fourth edition is planned for early 1982. Of the special catalogs, that by Hasegawa (27.002.052) lists ancient, mediaeval and naked-eye comets and that by V P Tomanov (26.103.010) gives various orbital and physical characteristics of 118 short-period comets.

As regards computing techniques, G Sitarski (26.042.033) developed an efficient method for the integration of motion using recurrent power series, with automatic adjustment of the optimum step length at each step. Yu V Batrakov and E N Makarova (27.042.010) adapted the Encke method to a coincidence of initial perturbed and unperturbed velocities and accelerations, thus increasing its efficiency for handling large perturbations. P E Zadunaisky (26.042.019) developed a method for estimation of global errors propagated in the numerical solution of the N-body problem. The problem of the accuracy of the determination of short-period cometary orbits was treated by V V Emel'yanenko and N Yu Emel'yanenko (Opredelenie koordinat nebesnykh tel 19, Riga 1981). On the motion of P/Taylor, V V Emel'yanenko (Kometn Tsirk 273, 1981) showed how Jupiter's perturbations can improve the determinacy of the orbit - a case similar to that of P/du Toit-Neujmin-Delporte noted earlier by Marsden. This effect may become important in the searches for long-lost comets; Emel'yanenko suggests supplementing ephemerides of such comets with the evaluation of differential perturbations as a function of ΔT. Empirical formulae for estimating the accuracy of 1/a were derived by Kresák (26.102.006); they permit identification of those long-period comets for which improvements of the available orbital data appear feasible, and the prediction of the determinacy of 1/a in different stages of observation.

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Belyaev and Yu V Chernetenko (27.102.005) have compared Dubyago's and Marsden's methods for determining nongravitational effects in the motion of short-period comets, and found a good quantitative agreement. Statistical features of the nongravitational effects on long-period comets were investigated by P R Weissman (25.102.013), who showed that for $q < 0.5$ AU nongravitational effects can become comparable with the gravitational perturbations, the sign of the changes in a and q depending entirely on the sense of nuclear rotation. The long-standing problem of the variation in the nongravitational motion of P/Encke has been quantitatively explained by F L Whipple and Sekanina (26.103.422). A large precession rate of $\sim 1°$/yr for the spin axis was found to be induced by sublimation jet forces acting on a slightly elongated comet nucleus. The results of M K Wallis and A K Macpherson (29.102.025) on the outgassing jet thrust of snowball comets imply rather low limits on comet masses and densities. Relevant to these problems is also the theoretical paper by J A Burns, P L Lamy and S Soter (26.106.016) on radiation pressure, Poynting-Robertson drag and the Yarkovsky effect. The potential effects of a resisting medium on the evolution of cometary orbits were discussed by Tomanov (27.102.032).

Nongravitational hydrodynamic forces in splitting comets were investigated by Wallis (27.102.006). A test based on the assumption that the relative motions of the fragments are primarily due to jet forces from outgassing was devised and applied by Sekanina (25.102.015) to all unconfirmed observations of double and multiple nuclei, to identify the real events. Kresák (29.102.006) showed that tidal splitting probably occurs at every passage of a comet within the Roche zone of the Sun or a planet, that the tendency to non-tidal splitting does not depend on the dynamical age of long-period comets, and that only a few of the observed events are catastrophic. O V Dobrovol'skij (Komety i meteory 27, 3, 1980) presented a quantitative description of how splitting of comets can be produced by centrifugal forces acting on spinning asymmetric nuclei.

c) MODEL COMPUTATIONS, EVOLUTION AND ORIGIN

At close planetary encounters, which are frequent among short-period comets, tracing of manifolds of similar orbits represents an efficient tool both for constraining the motion of real comets and for mapping potential evolution in the regions of strong interaction. This approach has been applied by Rickman and M Malmort (A & A 102, 165, 1981) to P/Gehrels 3, notable for the longest satellite capture on record, and by Carusi, Kresák and Valsecchi (A & A 99, 262, 1981) to P/Oterma, notable for a temporary resonance with the smallest recorded aphelion distance. The latter case revealed evolutionary tracks ranging from a satellite capture for more than 100 years, through the maintenance of a small-aphelion orbit for more than 250 years, to immediate ejection after one synodic revolution - all within a range of $1.^{\circ}5$ in the mean anomaly of the same orbit. A variety of drastic transformations of nearly tangent orbits at close encounters with Jupiter was found in the modeling experiments of Carusi and Valsecchi (27.091.020; 27.099.061), who also showed that the Galilean satellites may appreciably affect the evolution (27.098.039). Captures of comets by Jupiter and general long-term orbital evolution were investigated by Kazimirchak-Polonskaya (25.102.008). Papers by the same author (25.102.009) and Tomanov (28.102.004; 28.102.053; 29.102.014) underline the role of the outer planets in delivering comets into the vicinity of Jupiter, thus controlling a multi-stage capture process that gives rise to short-period orbits

The perihelion distribution of short-period comets was investigated by R A Beck (28.102.002). V P Konopleva (27.102.045) has pointed out a substantial difference between the distributions of the minimum distances of the orbits of long-period comets from those of Jupiter and Saturn, respectively. She interprets this as a signature of the source of reduction of the revolution period, and as a definition of long-period comet families. P T Veleshchuk (28.102.048) has found a correlation between the inclinations and aphelion longitudes of comets with aphelia situated near the orbits of the planets. In the case of Uranus, the aphelion distribution was interpreted by Vsekhsvyatskij and A S Guliev (29.102.031) as the result of a

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volcanic origin of comets from its satellites. In support of this concept, Vsekhsvyakskij and A A Demenko (28.102.013; Astr Vestn 15, 159, 1981) add further arguments based on the distribution of orbital elements of short-period comets. On the other hand, V V Radzievskij (28.102.051; Astr Vestn 15, 32, 1981) and Tomanov (Opredelenie koordinat nebesnykh tel 56, Riga 1981) argue that the volcanic hypothesis is untenable from the dynamical point of view.

Another controversial problem is the distribution of aphelion directions of long-period comets. Most authors, as S Yabushita (25.102.021; 26. 102.003), Radzievskij (26.102.041), Tomanov (26.102.042) or I N Potapov and Tomanov (28.102.043), argue that their non-random clustering cannot be due to selection effects, and that it lends support to the interstellar origin of comets. Yabushita, Hasegawa and K Kobayashi (26.102.056) even find a double concentration, dividing long-period comets into the solar antapex group, the galactic group, and the background. T Nakamura (26.102.057) concludes that the irregularities in the inclination distribution are consistent with the interstellar origin of comets. However, J A Fernández (29.102.012) points out that high-inclination comets can more easily avoid strong perturbations by the planets and remain in the Oort cloud, which would explain the observed excess of such orbits. He also notes that a recent interstellar origin would imply a preponderance of small inclinations, unless the relative velocity of the interstellar cloud and the Sun was improbably low.

The effects of galactic perturbations on the orbits of long-period comets were found by Radzievskij (27.102.034) to induce a correlation between the distribution of their inclinations and aphelion directions, which finds some support in the observational data. A model of stellar motions in the solar neighborhood was constructed by K A Shteins and A L Salitis (Opredelenie koordinat nebesnykh tel 40, Riga 1981); the influence of star passages on the delivery of new comets into the inner solar system was quantitatively analyzed by Salitis (ibid. 28 and 35) and by Weissman (28.102.021), who showed that stellar perturbations would induce a progressive shrinking of the Oort cloud by stripping away its outer shells. Diffusion of comets in energy space was treated by Yabushita (27.102.025) using analytical methods; his relation between the number of perihelion passages and the average value of 1/a (27.102.001) is fairly consistent with the results of E Everhart's earlier modeling experiments. Modeling of the dynamical evolution of comets using Markov chains was developed by Rickman and Froeschlé (26.102.051) and applied to a sample of 60 000 test objects interacting with Jupiter. In the same sample, Froeschlé and Rickman (Icarus 46, 400, 1981) find a marked asymmetry of the 1/a distribution tails, in particular for tangent orbits.

Fernández and Ip (Icarus 1981) suggested a mechanism for the origin of comets as a part of the accretion of the protoplanets, with Neptune as the main contributor to the Oort cloud. The idea that the birthplace of comets was the Uranus-Neptune region and that a comet belt in this region may still supply the Oort cloud with new objects was developed by Fernández (28.102.010). By tracing the evolution of 500 model objects over 10^9 yr, he obtained a fair agreement with observation. His concept remedies the difficulties with a substantial depletion of the original comet population and, with prevailing high eccentricities, leads to a lower estimate of the present population (Fernández 28.102.001). Numerical experiments on the long-term orbital evolution of comets have also been performed by Nakamura (29.102.032). Dynamical interrelations between comets and asteroids as distinguished by orbital stability were discussed by Kresák (27.098.072). Kresák (ibid.) and Everhart (27.098.035) attempted a general taxonomy of orbits, with Everhart stressing the sharp division between stable and chaotic orbits of different forms.

It became apparent that model computations assuming unlimited physical lifetimes of comets cannot reproduce the real situation, since for some evolutionary paths it is the decay process rather than dynamical ejection which controls the survival of a comet as an observable object. The role of different destructive processes was

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investigated by Weissman (27.102.026). His model indicates that 65% of all long-period comets are eventually ejected from the solar system, 27% are disrupted, and 7% form insulating, nonvolatile crusts that render them unobservable. Lifetime limits were also taken into account in the investigation of statistical effects of planetary perturbations by Yabushita (25.102.004). Monte Carlo simulations of the orbital evolution of short-period comets by Froeschlé and Rickman (27.102.008) reveal a significant discrepancy with observations assuming infinite physical lifetimes; the authors conclude that for each active Mars-crossing comet there should be about 50 extinct cometary nuclei moving in similar orbits. The lack of such objects suggests that less than 5% of the extinct comets can survive as sizeable asteroid-like bodies, according to Rickman and Froeschlé (27.102.027). Criteria for discrimination of such objects were proposed, and known candidates for the transitional phases and their potential evolutionary paths specified, by Kresák (27.102.010). The problem was also reviewed by D W Hughes (27.102.045).

The aging process results in a progressive decrease of the absolute brightness of short-period comets, but this seems to be considerably slower than was believed earlier, as noted by J Svoreň (25.102.014). Analysis by Kresák (Bull Astr Inst Czech 32, 321, 1981) of the observing circumstances and prediction accuracy for the 30 lost short-period comets showed that only P/Biela and P/Brorsen, and possibly two or three other comets, have really disappeared. This suggests a mean active lifetime of typical short-period comets of about 400 revolutions. A similar figure of 200 to 500 revolutions was obtained by Fernández (29.102.012) by fitting the observed energy distribution of comets to his dynamical model. Yabushita and Hasegawa (29.102.017) have found a correlation between the energy and absolute brightness of comets, which they attribute to the aging process. Review papers on the problems summarized in this section were written by G Thiele, H Scholl, Bien, G Braun, and J G Schiffer (26.102.031 - 26.102.040).

IV. SATELLITES

a) DISCOVERIES

Several small satellites of Jupiter and Saturn were discovered during the triennium, the encounters of the Pioneer 11 spacecraft with Saturn in 1979 September and of the Voyagers with Jupiter in 1979 March and July and with Saturn in 1980 November and 1981 August, as well as the passage of the Earth through the Saturn ring plane in 1979-80 all affording unusual observational opportunities.

The three Jovian satellites 1979 J 1, 1979 J 2 and 1979 J 3, discovered from the Voyager spacecraft (26.099.177; 28.099.118; IAU Circ 3470, 3507, 3575) have orbital periods and semimajor axes in terms of the equatorial radius of Jupiter of $7^h\ 09^m\!.5$, $1.79R_J$; $16^h\ 11^m\!.35$, $3.105R_J$; and $7^h\ 40^m\!.5$, $1.89R_J$ respectively. Discovery of another satellite, 1981 J 1, was reported by D Pascu and P K Seidelmann (IAU Circ 3603); the suggested identity 1981 J 1 = 1979 J 2 has not yet been definitely confirmed. Discovery of a Jovian ring extending to $1.81R_J$ was reported by the Voyager 1 team (E C Stone and A L Lane 25.099.059; IAU Circ 3338).

Saturnian satellites 1979 S 1 through 1979 S 7, 1980 S 1 through 1980 S 33, and 1981 S 1 and 1981 S 2 had been reported through 1981 June 30 on the basis of observations from Pioneer 11 (IAU Circ 3417, 3454), by J D Mulholland (IAU Circ 3430), by Pascu (IAU Circ 3454), by B A Smith, H J Reitsema, and S M Larson (IAU Circ 3456, 3457, 3466, 3496), by D P Cruikshank (IAU Circ 3457), by A W Harris and J Gibson (IAU Circ 3463, 3466), by J Lecacheux et al. (IAU Circ 3457, 3463, 3484), by A Dollfus (IAU Circ 3474), by C Veillet (IAU Circ 3470), by P Lamy and N Mauron (IAU Circ 3466, 3574), by R Suggs (IAU Circ 3484), by the Space Telescope Wide Field/Planetary Camera Instrument Definition Team, which included Seidelmann, W A Baum and D G Currie (IAU Circ 3496), with the 1.54-m Danish telescope at ESO (IAU Circ 3593), and from Voyager 1 (IAU Circ 3532, 3539, 3602, 3603).

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Many identities exist among the separately designated Saturnian satellites, but details are obscured by limited intervals of observation and complications introduced by dynamical interactions. For example, the pair of co-orbiting satellites 1980 S 1 and 1980 S 3 are to be associated with the two satellites observed at the time of the 1966 ring plane passage (J W Fountain and Larson 22.100.012; K Aksnes and F A Franklin 22.100.505), but until the mutual interactions are better understood, the 1966 and 1980 observations cannot be linked. Larson et al. (Icarus 46, 175, 1981) have re-examined the 1966 observations in the light of data obtained in 1979-81. R S Harrington and Seidelmann (Icarus 47, 97, 1981) studied the dynamics of the satellites 1980 S 1 and 1980 S 3, concluding that the difference in longitude librates. Thus the satellites never approach extreme proximity, and the orbits appear to be stable for extended periods of time.

The two satellites 1980 S 26 and 1980 S 27, discovered from Voyager 1 (see S P Synnott et al. 29.100.057) are the outer and inner shepherding satellites of the F ring, first detected from Pioneer 11 (T Gehrels et al. 27.100.018). The satellite 1980 S 6, discovered by P Laques and Lecacheux (IAU Circ 3457; 28.100.020), librates about the leading triangular point of Dione, and 1980 S 13 and 1980 S 25 seem to be associated with the triangular points of Tethys (Harrington et al. IAU Circ 3583; see also Seidelmann et al. Icarus 47, 282, 1981). The orbit of 1980 S 28, also discovered from Voyager 1, lies close to the outer boundary of the A ring. Measurements from Voyager confirmed the existence interior to the C ring of a tenuous ring with numerous narrow features but indicated that this D ring (P Guerin 3.100.001) was too faint to have been detected from the Earth. The E ring (W A Feibelman and D A Klinglesmith 28.100.005) was the object of an intensive ground-based observational effort during the 1980 ring plane passages. The new observations (Dollfus and S Brunier 27.100.030; A Brahic et al. 28.100.061; Baum et al. 28.100.062; Reitsema et al. 28.100.063; Larson et al. Icarus 47, 288, 1981; Lamy and Mauron 28.100.070 and Icarus 46, 181, 1981) showed an extension to at least $8R_S$, with a density peak near the orbit of Enceladus. Also discovered from Voyager 1 was the faint, narrow G ring at $2.8R_S$.

Several groups looked for evidence of a Neptunian ring at the times of appulses to two stars in 1981 May. No evidence of a ring was found (W B Hubbard et al. Bull AAS 13, 728, 1981; J L Elliot et al. ibid. 13, 729, 1981; Reitsema et al. ibid. 13, 721, 1981), but Reitsema (IAU Circ 3608) reported a brief occultation event detected at two stations as evidence for a previously unsuspected satellite, 1981 N 1.

b) ASTROMETRIC OBSERVATIONS

Photographic astrometric observations of satellites have been made at a number of observatories during the triennium. The Galilean satellites as well as the Saturnian satellites S I - S VIII have been observed by Pascu, with the collaboration of R E Schmidt, with the 0.66-m refractor of the U S Naval Observatory. Some 250 observations were sent to the Jet Propulsion Laboratory for use in orbit improvements. The group led by Mulholland continued the astrometric program on the faint satellites of Jupiter, Saturn and Uranus with the 2.1-m reflector of the McDonald Observatory until impacted by loss of funding in late 1981. Results were published for Jupiter V and the Galilean satellites in 1976-78 (25.099.044), for Jupiter VI-XII in 1975-77 (25.099.077; 26.099.124) and for Saturn I-IX in 1975-76 (28.100.002). P A Ianna, F Levinson and P Seitzer (25.041.017; 25.100.042; 26.099.047; 28.100.003) used the 0.67-m refractor of the McCormick Observatory to observe the Galilean satellites of Jupiter and the eight bright satellites of Saturn. Ianna, in collaboration with L C Stayton and J R Rohde, is continuing the series of observations with the McCormick refractor and with the 0.66-m refractor at the Mt Stromlo Observatory.

E Bowell (IAU Circ 3602, 3603) reported observations of J VI, S VIII and S IX with the 0.33-m astrograph at the Lowell Observatory. H Debehogne et al. (26.099.064; 27.097.012; 27.099.060; 27.099.086; 27.099.087; 28.099.006; 29.099.054; 29.099.055) published observations of the Galilean and some other bright satellites made

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with the GPO 0.40-m astrograph at ESO and with the 0.4-m astrograph of the Royal Observatory, Uccle. Observations of Phoebe made at ESO under Debehogne's direction also were published (IAU Circ 3612).

At Pulkovo Observatory 189 plates for the Galilean satellites and 156 plates for Saturnian satellites I-VIII were taken between 1978 January and 1981 May with the 0.65-m refractor. In the same interval 93 plates for the Galilean satellites and 85 plates for the Saturnian satellites S II - S VI and S VIII were taken with the normal astrograph. Some 41 plates for the Galilean satellites were taken with the short-focus double astrograph. At Nikolaev 44 plates for the Galilean satellites and 60 plates for the Saturnian satellites S III - S VI were taken with the zone astrograph. At Tashkent 107 plates for the Saturnian satellites S I - S VI, 144 plates for the Uranian satellites U I - U IV, and 27 plates for N I, Triton, were taken in the interval 1978-81. At Engelhardt Observatory, Kazan, routine observations of the Saturnian satellites have been made with the 0.40-m astrograph.

Observations made in the USSR have been published during the triennium as follows: for satellites of Mars made at Kiev in 1973 (Ref Zh Astr 1.51.115, 1981), for Galilean satellites made at the Pulkovo Observatory with the normal astrograph in 1974-76 (27.099.017) and in 1977-78 (Izv GAO No 199, 1981), at Nikolaev in 1975 (Ref Zh Astr 3.51.199, 1979), and for Saturnian satellites made at Nikolaev in 1973-76 (Ref Zh Astr 3.51.200, 1979) and at Engelhardt Observatory in 1973-75, 1978, and 1980 (Ref Zh Astr 12.51.137, 1980; 12.51.138, 1980; 3.51.82, 1981).

Astrometric observations of the satellites of Uranus were made at Pic du Midi (Veillet and G Ratier 28.101.003) and with the 1.88-m reflector of the Tokyo Observatory (K Tomita and M Sôma 26.101.035).

The satellite of Pluto was observed with the 1.55-m reflector of the U S Naval Observatory, Flagstaff, the 4.0-m telescope at Cerro Tololo, the 2.1-m reflector of the McDonald Observatory, the 1.60-m Mégantic reflector, and the C-F-H 3.6-m reflector on Mauna Kea equipped with a speckle interferometer. The new results have been discussed by Harrington and J W Christy (27.101.010; 29.101.011) and by D Bonneau and R Foy (28.101.032). The best value of the orbital radius (19 700±300 km) implies an inverse mass of the system of $(1.34\pm0.07) \times 10^8$. Mutual phenomena may begin with the 1983 apparition, and should certainly be observable in 1984.

Astrometric plates are now measured with microdensitometers, instead of coordinate comparators, at a number of observatories. J-E Arlot (27.099.080) explained how the positions of Galilean satellites were measured at the CDCA in Nice with the PDS 1010A microdensitometer controlled by a PDP 11/40 computer.

c) MOTIONS OF THE SATELLITES OF JUPITER

Analysis of the motions of the Galilean satellites remains an important problem in celestial mechanics, and was the subject of a book by S Ferraz-Mello (27.003.054). J L Sagnier treated the problem by an analytical method in his doctoral dissertation (1981). The great inequality terms, together with libration terms of the first three satellites were derived by D T Vu (29.099.005) following Sagnier's formulation. J H Lieske (27.099.018) provided improved ephemerides based on his new theory (1977) together with analysis of over 4800 Earth-based observations. The estimated error is less than 200 km. Lieske (25.099.045) also derived simplified expressions for the poles of the satellites with an error of $< 0^\circ.01$, and published (29.099.065) a catalog of eclipses of the Galilean satellites for 1610-2000. M Tsuchida, Ferraz-Mello and R Biancale compared photographic observations of the Galilean satellites with Sampson's theory as improved by Lieske. For modern observations, 1968-77, the geocentric differences are of the order $0''.08$ while for older ones, in 1913-28, they are $0''.14$.

P Nacozy, R McKenzie, Ferraz-Mello and M Sato (26.099.202) made numerical inte-

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grations after removing short-periodic terms by numerical averaging to obtain long-term motions of the Galilean satellites. W Thuillot (26.099.062) determined parameters for the satellites of Jupiter by computing satellite orbits by numerical integrations for 88 days in 1975 and comparing them with Pascu's observations. W Wiesel (27.099.024; 29.099.064) discussed secular effects of orbital and solar resonances.

Vu explained the new ephemerides published by the Bureau des Longitudes for Jupiter's satellites, including the Galilean ones, in Supplements to Connaissance des Temps for 1980 and 1981. Positions for the Galilean satellites are expressed by Chebyshev polynomials computed directly from Sampson's theory, rather than from his tables. Positions for satellites relative to Saturn, also expressed by Chebyshev polynomials, are included in the Supplements.

J-F Lestrade (28.042.065) applied Laplace's idea, using the true longitude as the variable, to derive the motion of Jupiter VI. L E Bykova (27.099.016) determined the mass of Jupiter from the motion of its outer satellites. T S Boronenko (Astr Geod 8, 97, Tomsk 1980) developed analytical theories of the motions of J VI, J VII and J X up to the sixth order with respect to the eccentricities and the inclinations; the theories represent available observations within 2". T V Bordovitsyna and Bykova (25.003.025) published a monograph presenting theories of the motion of J VI and J VII as well as ephemerides for 1979-2000.

d) MOTIONS OF SATELLITES OF OTHER PLANETS

A T Sinclair (22.097.504) gave new orbits and J A Burns (22.097.508) discussed the dynamical evolution and origin of the satellites of Mars at the colloquium marking the centennial of the discoveries at the U S Naval Observatory. Other studies of the tidal evolution and origin of the Martian satellites include those of D M Hunten (25.097.007), T C Van Flandern (26.097.180), K Lambeck (26.097.031), A Cazenave at al. (27.097.005; 29.097.035) and F Mignard (29.097.001). J Veverka and Burns (27.097.185) reviewed dynamics and origin, as well as physical properties, in their excellent review chapter devoted to the satellites of Mars.

A new analytical theory of the motion of Mimas and Tethys was developed by W H Jefferys and L M Ries (26.100.033; 29.100.901) using the algebraic manipulation language TRIGMAN. They expect that the theory can provide positions with 10 km accuracy. L E Rose (26.100.003) derived a new orbit of Saturn IX by numerical integrations, fitting 133 observations for 1904-1969 with a mean residual of 1".52 and determining the mass of Saturn. Bec-Borsenberger developed an analytical theory of Phoebe based on her literal series derived for the main problem of the lunar theory. She also made numerical integrations using constants by Rose, compared the results with observations in 1898-1976, and improved the constants for use in the analytical theory. She then extended the integrations up to 1990 and computed an ephemeris in polynomial form for use by the Bureau des Longitudes.

I G Chugunov (Ref Zh Astr 6.51.211, 1980; 1.51.77, 1981) developed theories of the motion of Saturn's satellites that take into account the non-sphericity of the planet, effects of the ring, the Sun, and the mutual actions of the satellites. All terms exceeding 10^{-6} are retained in the solution. Orbital elements of the satellites were improved by using 10 000 observations. A group of scientists at Tomsk State University also has been developing numerical and analytical theories for the Saturnian satellites. A theory for Phoebe has been completed.

An improvement of the orbital elements of Hyperion was reported by Y Hatanaka (25.100.039), who used his own observations made with the 0.65-m refractor at Tokyo. J D Anderson et al. (27.100.023) and G W Null et al. (29.100.014) derived the mass of Saturn, the values of J_2, J_4 and J_6, and the masses of Rhea, Titan and Iapetus from Pioneer 11 tracking data.

Veillet (29.101.018) determined a new orbit of Miranda by using all the observations since its discovery. Terms with period 12.2 yr, very close to the circulation period of the near commensurability between Miranda, Ariel and Umbriel, had to be included to represent the observations.

Pluto and the irregular satellite system of Neptune was the subject of a study by Harrington and Van Flandern (25.101.025), who performed numerical experiments to set limits on encounter circumstances of a massive body with Neptune. In addition to the new observations and orbital calculations for the Pluto satellite referenced in section IV.b. above, a discussion of possible origin of Charon was published by Mignard (29.101.016).

e) RINGS

The Jovian ring discovered by Voyager 1 was found by Voyager 2 to consist of three components. Amazing complexities of the Saturnian rings, including hundreds of ringlets, braided structure of the F ring, transient spokes crossing the B ring, and a very faint and narrow G ring were detected during the two Voyager encounters in 1980 November and 1981 August (Smith et al. 29.100.056; see also J K Beatty S & T 62, 430, 1981) Besides observational data referenced above in section IV.a., overviews, comparisons and speculation concerning origin of the ring structures surrounding Jupiter, Saturn and Uranus have been published by R Smoluchowski (25.100.010; 26.099.002), S F Dermott et al. (27.099.006), and Burns et al. (29.099.077). Ip (27.091.018; 27.091.019) reviewed physical studies and orbital dynamics of planetary rings, first on the basis of ground-based observations and then incorporating the new spacecraft data. Burns et al. (26.100.034) examined the effects of satellite and solar perturbations and planetary precession on the 'thickness' of the Saturnian rings, concluding that such effects are inadequate to explain the many-particle-thick nature of the rings commonly accepted as required by optical and radio observations.

New observations of the Uranian rings were obtained by a number of groups during occultation events on 1979 June 10, 1980 March 20 and August 15, and 1981 April 26. Papers on the structure and dynamics of the Uranian rings were published by P Goldreich and S Tremaine (25.101.001; 26.101.024; 29.101.014), Dermott et al. (26.101.001), Dermott and C D Murray (28.101.035), P D Nicholson et al. (29.101.025), G A Steigmann (25.101.002), and J C Bhattacharyya et al. (26.101.034). According to Elliot et al. (29.101.009; 29.101.012) the Uranian rings seem to be coplanar ellipses precessing uniformly according to the harmonics of the Uranian gravitational potential. The ellipticity of Uranus, ϵ = 0.022±0.003, is consistent with the reanalysis of the Stratoscope II images by Franklin et al. (27.101.012); J_2 corresponds to a planetary rotation period of $15^{h}.5$.

V. PREDICTION OF OCCULTATIONS

The number of minor planets whose orbits have been investigated by G E Taylor for occultations has now risen to over 180. Kristensen and Møller supplied a precise ephemeris for Nemausa, and ephemerides for Ceres, Pallas, Juno and Vesta were provided by H M Nautical Almanac Office. Ephemerides for all other minor planets were generated at the Royal Greenwich Observatory from osculating elements supplied by V Shor. These ephemerides have been searched against a combined AGK3 + SAO star catalog by Taylor, who issued predictions for suitable occultations in Bulletins circulated to members of the Working Group. Predictions have been issued in this way for occultations through 1982 and also for two important occultations by Pallas in 1983 May. Supplementary calculations have been carried out by D W Dunham, International Occultation Timing Association (IOTA), with contributions from D Wallentinsen and others. Information concerning both observations and predictions has been published in IOTA's Occultation Newsletter. Tabulations of possible events involving minor planets have appeared annually in the Handbook of the British Astronomical Association and in the January issues of Sky and Telescope.

Longer range predictions for Ceres, Pallas, Vesta and Hygeia for 1981-89 were published by Taylor (Astr J 86, 903, 1981). L Wasserman and Bowell (28.021.024) described an automated method for identifying occultations of catalog stars; a list of predictions for occultations by minor planets in 1982-83 was in press (Astr J). Predictions for occultations by Uranus in 1981-84 and by Neptune in 1981-84 were published by A R Klemola, D J Mink and Elliot (29.096.005; 29.096.004). And a valuable review chapter on stellar occultation studies of the solar system was published by Elliot (26.096.009), who described the prediction and observational techniques, the physical processes involved in occultations, and early results concerning radii of minor planets, as well as planetary atmospheric characteristics and rings.

Great progress has been made during the triennium in predictions, on the one hand, attributable mainly to improved orbital elements, to which Herget made substantial contributions, and in observational resources, on the other hand, largely due to the deployment in the USA of portable photoelectric equipment mounted on mobile telescopes. Last-minute astrometry, the real key to observational success, is usually available for stars in the Northern Hemisphere. The most urgent need is to obtain fast, accurate astrometry from a few observatories in the Southern Hemisphere.

Further papers deriving from observations of the occultation of ϵ Geminorum by Mars in 1976 were published by R G French and Elliot (25.096.010), W B Hubbard (25.096.009) and Taylor (29.097.065). Four occultation events by Uranus or its rings were observed during the triennium, making a total of eight such events now observed. Publications relating to these events have been referenced above in section IV.e. The appulse of Neptune to two stars in 1981 May, mentioned in section IV.a. above, provided evidence from two-channel photoelectric photometry at each of two stations for a previously unsuspected satellite (Reitsema IAU Circ 3608). An occultation of a 13th magnitude star by Pluto's satellite was observed by A R Walker (28.096.001). The resulting minimum diameter for Charon is consistent with findings from speckle interferometry by Bonneau and Foy (28.101.032) and by S J Arnold et al. (26.101.029).

Additions to the list of minor planet occultation events observed successfully numbered 17 during the interval 1979 January to 1981 October. Several events were observed only visually, the number of chords was too few, or the chords were too badly distributed across the disk of the minor planet to provide optimum diameter information. The best observed events included the following:

51 Nemausa	1979 Aug 17	27.096.006; 27.096.012; A & A Sup 44, 375, 1981 2 chords: USSR
65 Cybele	1979 Oct 17	Ref Zh Astr 1.51.209, 1981; 3 chords: USSR
3 Juno	1979 Dec 11	29.096.003; 29.098.008; 15 chords: Wisconsin, California, Hawaii, China
78 Diana	1980 Sept 4	7 chords: Texas, Oklahoma
216 Kleopatra	1980 Oct 10	9 chords: Washington (USA), British Columbia
134 Sophrosyne	1980 Nov 24	5 chords: California
48 Doris	1981 Mar 19	3 chords: Washington (USA), British Columbia
18 Melpomene	1981 Aug 7	IAU Circ 3650: 2 chords: Australia, Hawaii
88 Thisbe	1981 Oct 7	IAU Circ 3642, 3652; 11 chords, all on the S half of the MP: Colorado, Wyoming, Minnesota

Papers presenting results from earlier occultation events were published by Wasserman et al. (25.098.023), Dunham and G Mallén (26.098.009) and R M Williamon (27.098.020).

E ROEMER
Vice-president of the Commission

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