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

PRESIDENT: L. Kresák.
VICE-PRESIDENT: B. G. Marsden.
ORGANIZING COMMITTEE: F. K. Edmondson, P. Herget, E. I. Kazimirchak-Polonskaya, B. Morando, W. H. Robertson, E. Roemer, J. Schubart.

1. INTRODUCTION

(L. Kresák)

The present triennial report has been divided into sections corresponding to the three types of interplanetary bodies the dynamics of which constitutes the subject matter of Commission 20. The section on Minor Planets was compiled by P. Herget, that on Comets by E. Roemer and that on Satellites by B. Morando. The last two sections represent the reports of the Commission's Working Groups on these particular topics. The final editing was done by the President and the Vice-President. Most references are given by their *Astronomy and Astrophysics Abstracts* number. All the co-authors benefited from the wide response of commission members to the request for information and suggestions.

The highlights of the past triennium largely refer to the interface of dynamical studies with advances in the physics of minor planets, comets and satellites and with the accomplishments of space research. Rapidly expanding knowledge of the physical properties of these bodies has had a considerable impact on the choice of objects for detailed observation and orbit computation. The current investigation of planetary satellites by space probes and the prospects of early special missions to some comets and asteroids put rigorous requirements on the accuracy of orbits which, together with ground-based physical observations, will be decisive for the target selection. The requirements can only be fulfilled by a combination of high-precision positional observations (including the faintest objects detectable in the largest telescopes) with an elaborate theory of motion (including such problems as the non-gravitational effects on comets).

As an excellent example of international co-operation, the indispensable activities of three important centers of data processing and dissemination should be pointed out. The IAU Minor Planet Center at the Cincinnati Observatory, under the guidance of P. Herget, is doing a great deal of work on orbit computation and identifications of asteroids. This work is not only manifested by the increasing number of asteroids on the list of permanently numbered objects (127 new entries), but particularly by the rapidly increasing information on orbits of special interest. For example, one-half of the permanent numbers of the Earth-approaching asteroids and one-third of the permanent numbers of the Trojans were just assigned during this triennium. The Institute for Theoretical Astronomy in Leningrad, under the guidance of the late G. A. Chebotarev, has continued its extensive efforts in improving the orbits of the numbered planets (for about 270 objects) and supplying observers with extended annual ephemerides and lists of those objects that deserve special attention. Most of the rapid information relayed to observatories from the IAU Central Bureau for Astronomical Telegrams, operated by the Smithsonian Astrophysical Observatory in Cambridge under the guidance of B. G. Marsden, refers to comets, peculiar asteroids and natural satellites. The determination of preliminary orbits and ephemerides of new comets has been almost completely taken over by this center and the work thereby accelerated. A revised and extended edition of Marsden's *Catalogue of Cometary Orbits*, which appeared in 1975, lists 40 new comets and nearly 200 orbit improvements. The increasing harvest in the number of discoveries is featured by four new

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Apollo asteroids, including that of the highest inclination on record; nine new short-period comets; comet van den Bergh, 1974*g*, with the largest perihelion distance on record*; the brilliant comet Kohoutek, 1973*f*; and two new satellites of Jupiter. Although the lack of observing time on the largest telescopes is still a major problem, the situation seems to have improved somewhat and the reward has been great.

Among the international scientific meetings, two were of particular interest to our Commission: IAU Colloquium No. 25, 'The Study of Comets', held at NASA Goddard Space Flight Center, Greenbelt, Maryland, 28 October to 1 November 1974; and IAU Colloquium No. 28, 'Planetary Satellites', held at Cornell University, Ithaca, New York, 18 to 21 August 1974. Short reports of these meetings have been distributed in the nonperiodic *Circulars* of Commission 20, which were initiated as a tool for closer contacts among the commission members. Those contributed papers at IAU Colloquium No. 28 that most concern Commission 20 have appeared in *Celes. Mech.* 12, No. 1, 1975. The proceedings of IAU Colloquium No. 22, 'Asteroids, Comets, Meteoric Matter', held at the University of Nice in 1972, have been published by the Roumanian Academy of Sciences, with C. Cristescu, W. J. Klepczynski and B. Milet as editors. The Commission will co-sponsor IAU Colloquium No. 39, 'Relationships between Comets, Minor Planets and Meteorites', to be held in Lyons immediately before the IAU General Assembly in Grenoble.

During this triennium our research area has suffered a tremendous loss with the death of six prominent members of Commission 20: G. Van Biesbroeck (1880–1974), G. A. Chebotarev (1913–1975, a past President of the Commission), G. M. Clemence (1908–1974, retired 1973), S. Herrick (1911–1974), G. P. Kuiper (1905–1973) and E. Rabe (1913–1974). All of these members have made fundamental contributions to our present knowledge of minor planets, comets and satellites, as well as in other fields of astronomy; they will be badly missed by the scientific community.

2. MINOR PLANETS

(P. Herget)

A. *Introduction*

The outstanding feature of minor planet research during this triennium is the new program of radiometric, spectral, polarimetric and photometric observations by a group of young observers. This is providing greatly improved information on the physical characteristics of several hundred individual minor planets. Progress has also been furthered by: (a) the extensive observing program conducted by the Crimean Astrophysical Observatory and the Institute for Theoretical Astronomy (ITA) in Leningrad; (b) the observation of faint objects with relatively large telescopes at Harvard, Tucson and Wellington; (c) the measurement of selected objects on plates in the collection of the Goethe Link Observatory; and (d) greatly improved computer programs for the operations of the Minor Planet Center: plate reductions, special perturbations, differential corrections, ephemerides and preliminary orbits. Extensive reports have been received from ITA, E. Roemer (Tucson), B. G. Marsden (Harvard-Smithsonian), as well as less detailed reports from Indiana, Washington, Lick, Flagstaff, the Jet Propulsion Laboratory, Sydney, Heidelberg, Santiago, Bucharest, Nice, Madrid and San Miguel. The requirement of brevity in recording all of these is unfortunate.

A monograph, *Minor Planets*, by N. S. Samojlova-Yakhontova *et al.*, mainly covers the character of the research at ITA. Samojlova-Yakhontova also prepares an excellent annual summary of minor planet research, including a very complete bibliography. The annual ephemeris volume continues to appear each year from Leningrad, with minor improvements and a growing content, particularly with extended ephemerides in response to the requirements of observers. The Minor Planet Center has published 474 *Minor Planet Circulars* during this triennium.

* Already surpassed by comet Schuster 1976c (note added in proof).

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B. *New Results*

The infrared observations and analyses carried out by O. Hansen, C. R. Chapman, D. Morrison, B. Zellner and others have extended to much fainter minor planets than formerly, thus reducing the effects of observational selection. Two distinct classes of minor planets are indicated: (1) low albedo, chondritic surfaces, located mostly in the outer part of the minor planet belt around 3.0 AU; and (2) higher albedo with metallic surfaces and semimajor axes averaging 2.6 AU. The two classes have diameters roughly in the ratio of 1.6 to 1.0 at the same absolute magnitude. Larger diameters than formerly accepted are indicated for numerous dark objects. This work is well summarized in *Icarus* **25**, 104, 1975. The Minor Planet Center has computed nearly 400 definitive orbit improvements and accurate, extended ephemerides in support of these observing programs. This has exhibited a sampling of the quality of our total collection of more than 160 000 minor planet observations. Seldom is the rms residual from an orbit improvement below 2″, and in a few cases it is larger than 6″; the overall average is about 3.″3. This demonstrates that a special observing program will be necessary if there is to be a space mission to any particular minor planet.

One event of special interest was the prediction and recovery of 1932 HA = Apollo by Marsden and R. E. McCrosky, respectively. The result was admittedly fortuitous but nonetheless remarkable after 41 years. Another event was the occultation of κ Geminorum by Eros, although the predictions were of necessity highly uncertain. P. Herget used a standard differential correction program (with the position of κ Gem regarded as if it were an observation of Eros) to establish the usual Besselian occultation diagram. The hindsight conclusion is that κ Gem should have been observed as an unknown object, well in advance of the event, with the same system of reference stars as was used for Eros. Marsden not only made independent predictions but with B. O'Leary analyzed the results of observations made in New England. They can not be strongly conclusive because of the paucity of crucial observations, but a maximum dimension of 32 km seems confirmed.

C. *Observations and Orbits*

The ITA program for establishing an improved system of star catalogue corrections based on minor planet observations is now projected to continue until 1990. There are 21 000 observations on hand and more are being contributed by 35 observatories in 24 countries. V. I. Orel'skaya has enumerated the various sources of error which these observations contain, and experience at the Minor Planet Center corroborates that some observers need to apply much better checks to their plate-reduction methods, especially now that electronic computers are more readily available. ITA will provide the observers in this program with ephemerides at a one-day interval to serve as a standard of comparison.

Under the guidance of N. S. Chernykh, about 2000 oberservations per year have been obtained with the 40-cm astrograph in the Crimea, yielding 24 newly numbered planets. About 200 orbits were improved by F. B. Khanina, 20 by Orel'skaya and about 50 by M. A. Dirikis (Riga). G. R. Kastel' has computed many preliminary orbits and search ephemerides in support of the observing program.

At Tucson, Roemer has obtained more than 150 highly precise observations per year of very faint individual objects (down to magnitude 20.5), selected either because of unusual orbital characteristics, to reduce the 'critical list', or to provide a vitally needed extension to the observed arc of newly discovered objects. At Harvard, a similar program has produced 350 positions since 1972. Marsden supports these observers, as well as L. Kohoutek (Bergedorf), P. Wild (Berne), A. C. Gilmore and P. M. Kilmartin (Wellington), C. U. Cesco and J. Gibson (El Leoncito), T. Gehrels (Tucson), C. Kowal and E. Helin (Palomar), with appropriate orbit computations and predictions. He has computed orbits for 17 newly numbered objects and his predictions led to the recovery of the lost planets (998), (1265) and (1272). Using the 122-cm Palomar Schmidt, Gehrels obtained a series of plates in 1973 and 1974 in search of more Trojans. C. J. van Houten is continuing his scrutiny of the Palomar-Leiden

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Survey plates and making new measurements on the matching plate of each pair. About 200 new orbits may thus be added to the Palomar-Leiden Survey of 1960.

The Goethe Link Observatory has accurately measured another 1050 positions of specially requested observations, and the reductions are computed at the Minor Planet Center. To date 26 newly numbered planets have come from this observing program, although its initial purpose was to recover lost objects. At Flagstaff all minor planet positions to date have been published, and they may be accurately measured upon request. At Bucharest 1025 plates were obtained, and 1400 positions from 1963–68 were reduced at Nice and published. At Nice 1300 plates were obtained and 5000 positions derived, but computations at Cincinnati have shown that an unusually large portion of these are in error.

At Cerro El Roble the Maksutov astrograph has taken 98 plates, and recently 854 observations were completed, mostly of faint and unidentified objects. At Cerro Calán the Gautier astrograph is used for special objects, including (51) and (433). The U.S. Naval Observatory routinely observes all planets brighter than magnitude 12 and cooperated especially in the prediction of the Eros occultation; Eros was also observed with the PZT at the time-service substation in Florida. The Lick 51-cm double astrograph is available for occasional astrometric observations. At El Leoncito the 51-cm double astrograph is used on a systematic observing program. The retirement of J. A. Bruwer at the end of 1975 has apparently brought to an end the long and extensive program of astrometric observations at Johannesburg.

At Cincinnati, C. M. Bardwell has computed orbits for more than 100 newly numbered objects, including numerous new identifications. Permanent numbers have been assigned from (1814) to (1940). Seven of the new objects are Trojans, three are Hungaria-type, two are 2:1 librators [(1921) 1973 SE and (1922) 1949 HC] and six are Apollo-type – namely (1862) Apollo itself, (1863) 1948 EA, (1864) 1971 FA = Daedalus, (1865) 1971 UA = Cerberus, (1866) 1972 XA = Sisyphus and (1915) 1953 EA = Quetzálcoatl; although this last object, with a perihelion distance now of 1.05 AU is not now an Apollo object in the strict sense of the term, its perihelion distance was less than 1.00 AU before about 1940.

D. *Theoretical Investigations*

J. Schubart has succeeded in determining the masses of Ceres and Pallas, and along with H. Scholl, R. Giffen and C. Froeschlé the problems of commensurabilities have been studied (09.098.002; 09.100.019; 11.098.001; 12.098.008; 12.098.032). J. G. Williams has derived proper elements for 2822 planets (including planets from the Palomar-Leiden Survey) and he finds 44% of the sample to be members of 104 families. With F. A. Franklin, Marsden and Bardwell, he has identified several cases of libration about the 2:1 commensurability, although most of these orbits are uncertain. The same is true of the orbits considered by the late G. A. Chebotarev in a study of 1:1 librators and minor planets that might approach Jupiter very closely (10.098.023; 12.098.065). Chebotarev and the late M. J. Shmakova studied the structure and evolution of the asteroid belt (08.098.023; 10.098.019). E. A. Grebenikov and collaborators have developed methods for general group theories (10.098.034; 11.042.051).

3. COMETS

(E. Roemer)

A. *General*

This report is compiled from information contributed by 15 individuals who responded to the Circular Letter of the Commission President, supplemented from correspondence and personal contacts through the triennium and an incomplete literature search. Special appreciation is due to E. I. Kazimirchak-Polonskaya and G. R. Kastel', who communicated a comprehensive report on astrometric observations and studies related to cometary dynamics in progress in the U.S.S.R. during the triennium.

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Several meetings concerned in part with positions and motions of comets have been referred to by the President in his introduction to this report. Also of general interest are the annual reports on comets, prepared by B. G. Marsden, that appear in *Quart. J. Roy. Astron. Soc.*, most recently concerning the comets of 1973 (12.103.006). A second edition of Marsden's *Catalogue of Cometary Orbits*, updated to include orbital elements for 964 cometary apparitions from the year -86 to mid-March 1975, was issued from the IAU Central Bureau for Astronomical Telegrams in April 1975. Review articles by Marsden concerned 'Cometary Motions' (11.102.010) and 'Comets' generally (12.102.008).

The very efficient operation of the Telegram Bureau under Marsden's direction, with respect both to the telegram (telex) and mail *Circular* services, continues to be an important factor in obtaining timely observations of newly discovered or physically active comets. A parallel service is provided in the U.S.S.R. by the Kiev Comet Group, which issues the *Kiev Komet. Tsirk.* under the editorial supervision of S. K. Vsekhsvyatskij. Many sets of orbital elements and ephemerides for newly discovered objects are provided for the *Kiev Tsirk.* by Kastel', with the collaboration of N. A. Bokhan.

The Comet Medal of the Astronomical Society of the Pacific, awarded annually since 1969 in recognition of contributions of nonprofessional astronomers to the study of comets, was given in 1973 to Albert F. Jones, Nelson, New Zealand, and in 1974 to John E. Bortle, Stormville, New York. Unfortunately, the special encouragement given to work on comets by the Astronomical Society of the Pacific, for many years through the Donohoe Comet Medal, awarded to discoverers of new comets, and more recently through the A.S.P. Comet Medal awarded exclusively to amateurs for a variety of activities related to comets, has now been discontinued.

B. *Discoveries, Recoveries, Astrometric Observations*

The number of objects under observation during the triennium has been almost continually at record levels, and observational resources, particularly for the fainter objects, have at times been severely taxed. In 1973, a record 28 comets were under observation, including nine newly discovered ones, each a photographic discovery by a professional astronomer. Three of the new discoveries proved to be short-period comets. Five more new comets were discovered in 1974, including the long-period object of greatest known perihelion distance, comet van den Bergh, 1974*g*, with $q = 6.0$ AU. A single observation was made of another object that was rediscovered quite accidentally in February 1975. This object was one of six short-period comets discovered in 1975, four of them in a three-month interval early in the year. As it happened, five of the six were affected by delays either in announcement of the discovery or in publication of enough observations to derive an orbit, handicapping efforts to obtain observations for reliable predictions of future returns. Discovery of six long-period comets brought the discovery total for the year 1975 (to November) to 12! With reobservation of expected returning periodic comets and continuing observations of objects from previous years, the burden on the few observers who have access to telescopes large enough to follow objects to magnitude 20 and fainter is very great. Additional regular participation, particularly in the Southern Hemisphere, is very badly needed.

Two-thirds of the discoveries during the triennium were made by professional astronomers using wide-field telescopes on programs generally unrelated to comets. Discoveries were made with the Schmidt cameras at Palomar (6), Siding Spring (1), La Silla (2 comets, both found as the plates were being examined at the ESO headquarters in Geneva), Hamburg-Bergedorf (4), Budapest (1) and Haute Provence (1); and with the astrographs at the Crimean Astrophysical Observatory (1), El Leoncito (2) and Mt. John (1). It has been reported that 'Many new comets and asteroids are . . . being discovered' with the U.K. Schmidt at Siding Spring (*Observatory* **95**, 88, 1975), but no specific observations have been reported other than those of P/Longmore, 1975*g*. Additionally, amateurs made, or shared in, discovery of nine comets.

Four comet recoveries during the triennium were particularly noteworthy. P/du Toit 1, 1944 III, had been missed at its return in 1959 but was located by C. Torres early in 1975 on plates taken in search for it in March and April 1974 at Cerro El Roble. Corrections ranging between −2.6 and −4.8 days were required to predictions by G. Sitarski and by N. A. Belyaev,

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V. V. Emel'yaneko, and N. Yu. Goryajnova. P/Wild, 1960 I = 1973 VIII, was recovered by E. Roemer at its first predicted return. A correction of only $\Delta T = +0.75$ day was required to the prediction by Marsden, in spite of the fact that the comet had been observed for only three months in 1960. P/Churyumov-Gerasimenko, 1969 IV = 1975*i*, also was recovered at its first return by Roemer, in good agreement with predictions by Marsden and by Belyaev. The faint comet discovered by T. Gehrels with the Palomar Schmidt in February 1973 and designated 1973*d* was observed by R. E. McCrosky and C. Y. Shao with the 155-cm *f*/5 reflector at the Agassiz Station of the Harvard College Observatory, as well as by Roemer with the 229-cm *f*/9 reflector of the Steward Observatory, Tucson. With observations extending into March, identification was made by Marsden with P/Swift 1, 1889 VI, which had passed unobserved at eight perihelion passages between 1889 and 1973. This comet is now known as P/Swift-Gehrels.

On the other hand, P/Perrine-Mrkos, which has not been missed since its rediscovery by A. Mrkos in 1955, could not be found at its return in 1975 in spite of considerable effort expended in searches for it.

Continuing astrometric programs are underway at more than 30 observatories in the Northern Hemisphere, including 16 in the U.S.S.R. More than 200 observations of seven comets were made in 1972–74 by the mountain expedition of the Sternberg Institute to Zailijskij Ala-Tau ($\lambda = -5^h\,08^m$, $\varphi = +43^\circ\,04'$). New observing programs are underway at Lesniki (Kiev University), Gornotayezhnoye (Ussurian Sun-and-Cometary Station), and Pino Torinese, and a program is planned at Madrid. Only at the Agassiz Station at Harvard, at Tucson (University of Arizona), and at Tokyo have observations of objects fainter than about 17th magnitude been made on a regular basis. Such events as the appearance of Nova Cygni 1975, greeted with general enthusiasm, made serious inroads, however, on the large-telescope time assigned for ongoing observations of faint comets. Amateurs, particularly in Japan, Great Britain, and the U.S.A., continued to make important contributions.

The situation in the Southern Hemisphere is appreciably weaker, with ongoing programs at seven observatories and occasional contributions from three others. The role played by amateurs is correspondingly very important, with critical astrometric observations coming regularly from Australia (D. Herald, Canberra), New Zealand (where a Section on Comets and Minor Planets of the Royal Astronomical Society of New Zealand has recently been formed with the encouragement of A. C. Gilmore and P. M. Kilmartin), and South Africa (J. Hers, Johannesburg). Only occasionally during the triennium have observations become available for comets of 18th magnitude or fainter from Southern Hemisphere observatories.

Positions have been communicated by many observers on a more-or-less current basis for publication in the *IAU Circulars* or in the *Kiev Komet. Tsirk.* In addition, several other important series of observations have been published during the triennium. K. Tomita and H. Kosai have listed observations of nearly 40 comets made in the interval 1963–75 (12.103.009; *Tokyo Astron. Bull.* No. 238, 1975). Marsden and C. D. Vesely completed for publication the series of observations of comets made by G. Van Biesbroeck while he was at the University of Arizona, 1964–71 (*Astron. J.* **80**, 246, 1975; **81**, 1976 (in press)). S. Vaghi, V. Zappalà, *et al.* have published positions of comets observed at Pino Torinese, together with determinations of some orbits (11.103.124; 12.103.104).

The need for ongoing observations of newly discovered comets can hardly be overemphasized. For the periodic comets, extended observations are required for reliable enough determination of the orbital elements, particularly the semimajor axis, that recovery is possible at the next return. The recent orbital evolution, including close approaches to Jupiter and, eventually, nongravitational effects, can then be studied with some degree of confidence in the results. For long-period comets, one wants to determine a reliable value of the osculating $1/a$, and then the barycentric original and future $1/a$ as clues to the source and eventual fate of comets. In some instances it is possible to discern nongravitational effects from prolonged observations during a single apparition.

Adding to discoveries of distant comets in recent years, four new comets with $q > 3.0$ AU were discovered during the triennium, and comet Araya, 1972 XII, first observed in November 1972, was followed until October 1974. At distances of 4 to 7 AU, many months are required for a comet, often faint and difficult to observe because of remoteness from the sun, to traverse

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an appreciable arc of its orbit. Yet such important deductions can be made from characteristics of their orbits that observations of distant comets are urgently needed. As examples, Marsden and Z. Sekanina (10.102.038) have shown that comets of large perihelion distance, because of relative freedom from complicating nongravitational effects, can give valuable information regarding the immediate source of long-period comets. In particular, they found a remarkable concentration corresponding to an aphelion distance near 50 000 AU, i.e., only about a quarter of the distance deduced by J. H. Oort from the sample available in 1950. Also, studies of the capture processes by which comets come to move in orbits of short period (see Section E, below, for details) lead to the conclusion that large numbers of comets should be moving in orbits of intermediate eccentricity that pass in the vicinity of Jupiter and Saturn. Direct observation of such comets would be exceedingly interesting.

C. *Orbits of Short-Period Comets*

Some 30 workers have participated during the triennium in the computational work associated with provision of the best possible current ephemerides for periodic comets. Several phases are included in the work: (1) Calculations of orbits and ephemerides for newly discovered objects (nine short-period comets in the triennium); (2) Linking of the repeated returns of well-known periodic comets, including investigation of the long-term variations in nongravitational effects; and (3) Investigation of the orbital evolution of the observed short-period comets, including capture into, and ejection from, the orbits in which they are now observed.

Orbital elements referring to observed apparitions of the periodic comets are tabulated, with references, by Marsden in his annual reports on comets (12.103.006) and in the *Catalogue of Cometary Orbits*, 1975. Predictions for returning periodic comets are published regularly in the *IAU Circulars*, in the *Kiev Komet. Tsirk.* and in the *Handb. Br. Astron. Assoc.*

The large majority of returning periodic comets are recovered fairly routinely, even in rather unfavorable apparitions, in positions close to the predicted ones, usually while they are still quite faint. But surprises remain in the erratic behavior of some objects. The two large outbursts of light of P/Tuttle-Giacobini-Kresák during its apparition in 1973 raise questions as to what should be expected at its next return. Failure to recover P/Perrine-Mrkos at its return in 1975 has already been noted.

Principal contributors of current predictions have included Marsden, Sekanina, D. K. Yeomans, Kazimirchak-Polonskaya, L. M. Belous, Yu. V. Evdokimov, G. Sitarski, G. Schrutka, and several workers of the Computing Section of the British Astronomical Association. N. A. Bokhan and Yu. A. Chernetenko (11.103.102; 12.103.110) have carried on the precise work on P/Encke, and Kazimirchak-Polonskaya (*IAU Circ.* No. 2740, 1975) has continued and extended the calculations of M. Kamieński on P/Wolf. Schrutka and Marsden, H. J. Carr (*Handb. Br. Astron. Assoc.* for 1975), Belous (10.103.112; 12.103.101) and S. Nakano and Y. Banno (*Nihondaira Obs. Circ.* No. 586) have provided elements and current ephemerides for P/Westphal, 1852 IV, which faded out before its perihelion passage in 1913. This comet, of period about 62 y, is due at perihelion early in 1976. Belous (11.103.117; 12.103.102) has also studied the motion of P/Brorsen-Metcalf, 1847 V = 1919 III, linking the two apparitions on the basis of 62 observations. Kazimirchak-Polonskaya and Belous (11.103.115) have redetermined the orbit of P/Stephan-Oterma, 1867 I = 1942 IX. In nearly every instance full planetary perturbations and nongravitational effects have been taken into account.

A group that includes Emel'yanenko, Goryajnova and S. D. Shaporev has, under the guidance of Belyaev, recalculated the definitive orbits of short-period comets observed in only one apparition, and their motion for an interval of 200 y has been investigated. Current ephemerides have been published in the *Kiev Komet. Tsirk.*, *IAU Circulars*, and in the *Handb. Br. Astron. Assoc.* Included in the study were comets Swift 2, 1895 II; Giacobini, 1896 V; Metcalf, 1906 VI; Taylor, 1916 I; Schorr, 1918 III, Schwassmann-Wachmann 3, 1930 VI; du Toit 1, 1944 III, referred to above; and Churyumov-Gerasimenko, 1969 IV = 1975*i*. It appears that the main factor governing the discovery of new short-period comets is a major transformation of the orbit under influence of large perturbations from Jupiter that causes a reduction in the

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perihelion distance. Examples include comets Schwassmann-Wachmann 3 and Churyumov-Gerasimenko. Further conclusions have been given by Belyaev and Shaporev (*Probl. Kosmich. Fiz.* **10**, 1975).

Among the many orbital investigations by Marsden is one on the next return of P/Swift-Tuttle, the parent comet of the Perseid meteors (10.103.107). The formal prediction from the observations in 1862 gives the time of the next perihelion passage as mid-1981, but there is an uncertainty of something like ±2 y. Although it is not completely impossible that P/Swift-Tuttle is identical with comet 1737 II (in which case it will not return until 1992), the apparent absence of observations of the comet at its perihelion passages prior to 1862 suggests that few of those perihelion passages could have taken place between June and mid-October, and it is therefore possible to assign probabilities to the times when the comet might return.

Continuing their work on the effects of nongravitational forces on comets, Marsden and Sekanina (11.103.102) have studied the orbit of P/Encke from 1786 to the present. They find that, although the secular acceleration has been decreasing rather steadily in recent times, it had formerly increased to pass through a maximum around 1820.

K. A. Shtejns *et al.* (11.102.025) have also investigated the problem of taking into account the nongravitational effects in cometary motions. In parallel with this research, the orbital evolution of several short-period comets has been studied by integrations for an interval of 400 y (1660–2060): Neujmin 2 by Belyaev (*Trudy Kazan. Astron. Obs.* **39**, 1973); Borrelly by Belous (12.103.100); Giacobini-Zinner by Evdokimov (*Trudy Kazan. Astron. Obs.* **40**, 1974); Tempel-Tuttle by E. D. Kondrat'eva (*Trudy Kazan. Astron. Obs.* **41**, 1975).

Kazimirchak-Polonskaya and Chernetenko made a determination of the mass of Jupiter from large perturbations induced by Jupiter on P/Wolf in 1922 and on P/Kopff in 1954, using the method developed by Kazimirchak-Polonskaya (08.099.008).

The motion of both of these comets has also been investigated by Yeomans (11.103.119; *Publ. Astron. Soc. Pacific* 87, 635, 1975), who finds secular changes in the magnitude of nongravitational effects. In the case of P/Wolf, nongravitational effects were found to be negligible after the perihelion distance was increased from 1.6 to 2.4 AU as a consequence of the close approach to Jupiter in 1922. In the case of P/Kopff, Yeomans found a steady change from a secular deceleration of the comet's motion to a secular acceleration. This appears to be best explainable by the assumption that the rotation axis of the cometary nucleus passed through the orbit plane prior to midcentury.

The evolution of the orbits of two other recently discovered short-period comets, P/Tsuchinshan 1, 1965 I = 1971 VIII, and P/Tsuchinshan 2, 1965 II = 1971 X, and the possible relationship between them, has been investigated by Y. C. Chang *et al.* (11.103.136). They conclude that the similarity of the orbits in 1965 was only a coincidence.

T. Kiang (09.103.103) has found that the cause of the periodicity in the residuals in the perihelion time of Halley's comet lies in inherent properties of the 3-body configuration Sun-Jupiter-comet. The actuating factor in the residuals appears to be a nongravitational force of the same character as manifested in the motions of many other comets. In the case of Halley's comet, this force appears to have changed little over the last 22 revolutions.

L. Kresák (10.102.003) has investigated the brightness of short-period comets when observed at extreme distance, inferring that at heliocentric distances greater than 3.2 to 3.5 AU these comets are made visible effectively by sunlight reflected only from the nucleus. A list of revised standard magnitudes is given for use in search ephemerides when the comets are near the threshold of detectability.

D. *Orbits of Nearly Parabolic Comets*

Work is progressing at the Astronomical Institute of Warsaw University, in cooperation with some other institutions and with M. Bielicki as coordinator, on the catalogue of definitive orbits of all nearly parabolic comets observed between 1750 and 1970. Orbital elements are being redetermined, using standardized methods in handling the observational material and in carrying out the computations. Bielicki has requested to receive observational data that may not have appeared in a journal of wide circulation.

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Marsden and Sekanina (10.102.038), on redetermining the orbits for most of the long-period comets of perihelion distance greater than 2.2 AU – a distance beyond which the $1/a$ values are not likely to be significantly affected by nongravitational forces – have established that the 'Oort effect' of small 'original' $1/a$ values is, for these comets, very much more pronounced than in Oort's 1950 sample. They suggest that the reason is that, after a first approach to the Sun, most of the remaining volatile material in a cometary nucleus is trapped in water, which would be frozen solid at the heliocentric distances involved. On its second and subsequent returns to perihelion such a comet would be faint and tend to look asteroidal and thus not be likely to be recognized.

In addition to new definitive orbits for several dozen large-q and other comets determined by Marsden and Sekanina in the course of their study, new orbits have been determined recently for the following comets: 1892 VI, 1911 V, 1911 VI, 1914 II, 1937 V, 1948 IV, 1955 III, 1955 V, 1959 I, 1964 IX, and 1968 IV. Participants in this work included F. Buchinger, T. Jastrzebski, V. N. Klevetskij, M. Marinković, L. A. Markelov, K. P. Ölsböck and G. Schrutka. Vesely and Marsden completed the work on 1911 VI left unfinished by Van Biesbroeck at his death (12.103.132); the work on 1892 VI and 1911 V, also begun by Van Biesbroeck and finished by Vesely and Marsden, is in press (*Astron. J.* **81**, 1976).

Results of new orbit determinations have been incorporated regularly in the tables of elements given by Marsden in his annual reports on comets (e.g., 12.103.006), and many have already been included in the *Catalogue of Cometary Orbits*, 1975.

E. Everhart, F. Banks and W. Orvis have provided the corrections from osculating $1/a$ to barycentric original and future $1/a$ for recently observed comets. These corrections have been listed annually in Marsden's reports on comets.

E. *Theoretical Investigations*

Investigations have continued, mainly in the U.S.S.R., on the effect of stellar perturbations on the motions of comets in the distant cloud and on statistical regularities that might be impressed on the system of long-period comets, possibly reflecting the Sun's peculiar motion with respect to nearby stars. (K. A. Shtejns; V. V. Radzievskij and V. P. Tomanov, 09.102.019 and *Astron. Vestn.* **9**, 1, 1975; Tomanov, 09.102.020).

Sekanina (*Icarus* **26**, 1975 in press) has investigated the possible existence of a cloud of interstellar comets in the neighborhood of the Sun, using the fact that no comet with a strongly hyperbolic orbit has yet been observed, to deduce an upper limit for the space density of interstellar comets. He finds, further, that the theoretical distribution of the semimajor axes of interstellar comets is such that a strong hyperbolic excess must be present in the orbits of a majority of interstellar comets regardless of the dynamical characteristics of the comet cloud – except when the cloud is moving along with the Sun and the distribution of individual velocities has a very low dispersion, which effectively reduces to the problem of an Oort-type cloud.

It appears valid to state as a general conclusion that as comets are diffused gradually inward from an Oort cloud through multiple planetary encounters, any anisotropies that might have been present originally should be lost (P. C. Joss, 09.102.015). Nevertheless it is well known that there are large-scale irregularities in the spatial distribution of long-period comet orbits. Kresák (*Bull. Astron. Inst. Czech.* **26**, 92, 1975) has extended earlier work by J. Holetschek, P. Bourgeois and J. F. Cox, Everhart, and E. M. Pittich to verify that these irregularities can be explained by effects of observational selection on a random distribution. In particular, Kresák finds that the bias in the statistics of long-period comet orbits is closely related to the perihelion distance, an aspect not previously investigated in an adequate way.

Considerable effort continues to be dedicated to investigation of the origin of the short-period comets. Everhart (09.102.012), B. E. Lowrey (09.102.021) and Vaghi (09.102.005; 10.102.017) confirm and extend earlier conclusions that the observable short-period comets cannot be produced directly from observable long-period comets solely by perturbations of Jupiter, either through single close encounters or by repeated smaller perturbations. The conclusion that the process of capture is an evolutionary one in which the outer planets – Jupiter, Saturn, Uranus, and Neptune – all contribute is becoming increasingly convincing.

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Although long-period comets with perihelia near Jupiter can evolve directly into observable short-period comets, it appears likely that there are many short-period comets in Trojan or 'horseshoe'-type orbits and in orbits of moderate inclination and eccentricity between Jupiter and Saturn. Everhart (*IAU Colloq.* **25**) concludes that long-period comets cannot have been formed within the planetary system but must approach from great distance. It is possible that some of the short-period comets could have been formed inside the orbit of Neptune, but it is certain that others have the same distant source as the long-period comets. The hypothesis that all comets approach the solar system initially on near-parabolic orbits, from which some can be diffused eventually into short-period orbits, appears to offer the least difficulties.

An important contribution has been made by S. J. Weidenschilling (*Astron. J.* **80**, 145, 1975), who has reexamined in general terms the problem of close encounters of small bodies with planets. With some simplifying assumptions the probabilities of collision or ejection from the solar system can be expressed as functions of the relative velocity only, rather than of the orbital elements. The results are in agreement with those of L. W. Bandermann and R. D. Wolstencroft, but not with those of E. J. Öpik. It appears that Weidenschilling's findings will have direct application to certain problems that arise in study of the evolution of comet orbits.

Evolution of comets into short-period orbits is also an active area of investigation in the U.S.S.R., as indicated in Section C, above. Kazimirchak-Polonskaya (*IAU Colloq.* **25**) has compiled a review of the research on close approaches of comets to Jupiter and of the studies of the secular evolution of orbits performed in the U.S.S.R. during the past half-century. Numerous examples are given of various types of gross transformations of cometary orbits in the sphere of action of Jupiter and the capture of real comets from orbits with aphelion distances comparable with those of Saturn, Uranus and Neptune. The capture process appears to be a complex, multistep evolution that requires consideration of stellar perturbations and of the theory of diffusion of long-period comets (Shtejns).

The capture of fictitious comets by Neptune from near-circular trans-Plutonian orbits and from interstellar space has been investigated numerically by Kazimirchak-Polonskaya (*IAU Colloq.* **25**), who confirms that under appropriate circumstances even a hyperbolic cometary orbit can be transformed into a retrograde orbit of short period with perihelion near the orbit of the Earth. She also found an example of capture that led to a stable satellite orbit situated between the orbits of the two real satellites of Neptune.

4. SATELLITES

(B. Morando)

A. *New Satellites of Jupiter*

One of the most interesting developments of the triennium is the discovery, by C. T. Kowal at Palomar, of certainly one and probably two new satellites of Jupiter. Of photovisual magnitude 20, J XIII was found on plates obtained with the 122-cm Schmidt telescope on three consecutive nights in September 1974. Very fortunately, the object could then also be recorded on a pair of exposures (using an image tube) with the Steward Observatory's 229-cm *f*/9 reflector at Kitt Peak some ten nights later, and as a result K. Aksnes and B. G. Marsden were reasonably confident that the object was indeed a satellite and that it belonged to the group of direct satellites J VI, J VII and J X. Five additional observations made during the following three months by Kowal and by E. Roemer with the Steward Observatory's reflector enabled the orbit computation to be refined ($a = 0.0743 \pm 0.0007$ AU, $e = 0.147 \pm 0.003$, $i = 26^\circ\!.72 \pm 0^\circ\!.05$; see *Astron. J.* **80**, 460, 1975), and further observations could be made during the 1975 opposition by Kowal, Roemer, and also with the 208-cm reflector at the McDonald Observatory.

The probable fourteenth satellite, of photovisual magnitude 21, was picked up with the 122-cm Schmidt telescope on three consecutive nights in September-October 1975. Roemer was again able to observe this object a few nights later, but the object's proximity to Jupiter

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during the following dark of the Moon precluded any further observations, for by early December the object had become too faint, its position too uncertain and its motion too close to the sidereal rate for identification. The orbit determination leaves little doubt that the object is indeed a satellite, but it is not possible to decide whether its orbit is direct or retrograde. Presumably this object will eventually be rediscovered at some opposition in the future.

B. *Observations and Related Analyses*

A world-wide campaign was organized to make observations of the very favorable mutual occultations and eclipses of Jupiter's Galilean satellites in 1973–74. Predictions had been prepared by S. W. Milbourn and J. V. Carey, R. T. Brinkmann, Aksnes and J. E. Arlot (*Handb. Br. Astron. Assoc.* for 1973; 09.099.069; 10.099.015; 10.099.026; 11.099.201).

The photoelectric campaign, organized on the initiative of Brinkmann and R. L. Millis (09.099.014), has provided light curves of more than 100 events; these observations have been filed in the data bank established at the Lowell Observatory. Early analyses by R. E. Murphy and Aksnes (*Nature* **244**, 559, 1973) and by J. R. Vermilion *et al.* (12.099.229) of a few grazing occultations of Europa by Io had suggested the presence of a bright north polar cap on Europa. The light curves of these occultations were considerably deeper than predicted. Later, Aksnes and F. A. Franklin (*Center for Astrophys. Prepr.* No. 339, 1975) showed that most of this discrepancy was probably due to latitude errors of up to 400 km in the ephemerides of Io and Europa given by Sampson's theory. Although the light-curve analyses have not yet been completed, the results by T. Nakamura (11.099.217), Arlot *et al.* (12.099.226), Aksnes and Franklin (*Astron. J.* **80**, 56, 1975) and T. C. Duxbury *et al.* (*Icarus* **25**, 1, 1975) show that accurate information about the positions and radii of the Galilean satellites can be derived from observations of mutual events.

Astrometric observations of the natural satellites of the giant planets have been resumed at the McDonald Observatory after a lapse of almost 20 y. This work is being conducted by J. D. Mulholland, with the collaboration of P. J. Shelus and R. I. Abbot. The list of objects observed includes Jupiter VI–XIII, Saturn I–IX, Uranus I–V and Neptune I and II. A special effort is made to secure observations of difficult objects. Some aspects of this work are reported in *Astron. J.* **80**, 723, 1975.

At the University of Arizona, Roemer has continued to make observations of satellites with the Steward 229-cm reflector and also with the 154-cm *f*/13.5 reflector at the Catalina Station of the Lunar and Planetary Laboratory. In addition to the observations of J XIII mentioned above, she obtained observations of J X and J XI in September 1974, of Phoebe in January 1974 and of Nereid on ten nights during 1973–75.

With the 155-cm reflector at Harvard Observatory's Agassiz station, Aksnes and co-workers obtained more than 100 plates of satellites, mostly of Saturn I–IX, between December 1972 and April 1974.

In 1971 and 1972, observations of the Galilean and Saturnian satellites were made by C. F. Peters with the 60-cm reflector at the Table Mountain Observatory (10.099.067).

The number of observations obtained in the U.S.S.R. has significantly increased. At the Pulkovo Observatory, by means of a short-focus astrograph, a normal astrograph and a 66-cm refractor, some 800 positions of eight of Saturn's satellites and 200 positions of the Galilean satellites have been obtained since 1972. In addition, 14 positions of Phobos and 22 positions of Deimos were obtained at the opposition in 1973. The observers were T. P. Kiseleva, N. V. Fatchikhin, N. M. Bronnikova and A. A. Kiselev.

At the Nikolaev Observatory, G. K. Gorel' obtained 160 positions of the Galilean satellites and took more than 20 plates of Saturn's satellites. At Abastumani, 60 positions of Phobos and 114 positions of Deimos were obtained by A. Sh. Khatisov and G. N. Salukvadze in 1973. At the same observatory differential positions were measured of Ganymede with respect to the star SAO 186658 during the occultation in 1972 (11.099.213). The satellites of Jupiter and Saturn were also photographed in Tashkent.

In 1974 C. Cristescu remeasured the plates of Jupiter's satellites obtained by G. Petrescu at

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the Bucharest Observatory in 1934 and at the Paris Observatory in 1936. All the plates were measured at least twice.

Arlot has made a detailed analysis of the observations of the Galilean satellites in relation to Sampson's theory (*IAU Colloq.* 28; Thesis, University of Paris). S. Ferraz-Mello, using all the photographic observations made since 1930, has found a deviation of the timescale defined by the motions of the satellites from Ephemeris Time; the deviation can be expressed by 0.006 (t-1900.0) minutes (where t is in years). Using the best available observations (those of Petrescu in 1934 and of D. Pascu in 1968) Ferraz-Mello also showed that the errors due to the periodic terms in the tables are of the order of $0''.1$.

E. A. Whitaker and R. J. Greenberg (10.101.011) have remeasured all the available plates showing Uranus V and established that this satellite has both a pronounced orbital eccentricity and inclination (to the plane of the other satellites).

Last but not least, Duxbury has reported that the observations of the Galilean satellites made by Pioneer 10 will lead to data that can be used for the purposes of improving ephemerides.

C. *Theoretical Work*

The motions of the satellites of Jupiter and Saturn are being extensively investigated. D. T. Vu and J. L. Sagnier have studied Sampson's theory of the motions of the Galilean satellites of Jupiter (11.099.221). Vu is now programming the algorithms of Sagnier's theory in view of its application to the planetary problem in general, and to the Galilean system in particular. At the Jet Propulsion Laboratory (JPL), J. Lieske has also been working on Sampson's theory (10.099.005; 11.099.206; *IAU Colloq.* 28). Sagnier is completing his planetary theory and Galilean resonance theory (09.099.032; *IAU Colloq.* 28).

Ferraz-Mello has developed a theory of the motions of the Galilean satellites to the second order of the inclinations and eccentricities. Integro-differential equations that appear in the perturbation problem and nonlinear equations in the angular variables have been solved by Krasinsky's method (*IAU Symp.* 62). Ferraz-Mello has also compared classical observational data with Sampson's theory when the masses used are those determined at JPL from Pioneer 10 and 11. He shows that it is impossible to reconcile the value of one of the free-oscillation coefficients in the longitude of Ganymede with the JPL mass of Callisto (*Revista Soc. Astron. Brasil*, in press).

A numerical study of the Galilean system is being made by P. E. Nacozy (University of Texas at Austin) and M. Sato (University of São Paulo).

E. N. Lemekhova, at the Institute for Theoretical Astronomy (ITA) in Leningrad, continued to improve the parameters and to make a comparison with the parameters in Marsden's theory of the Galilean satellites. Peters has made an analysis of the ephemerides of the Galilean satellites (10.099.066).

The motions of the outer satellites of Jupiter have been studied at Tomsk University by T. V. Bordovitsina and L. E. Bykova (10.099.088; 10.099.089). Corrections to the mass of Jupiter have been obtained from the motions of satellites VI, IX and X (10.099.090; *Trudy Tomsk. Univ.* **251**, 84, 1973). The results are in good agreement with other modern determinations.

Ross' theory of Jupiter VI has been compared with numerical integration by R. Dvorak and B. Morando, and similar work is underway for Jupiter VII. A. Bec and Morando are contemplating the construction of an analytical theory of the motion of Jupiter VI using programs prepared for lunar theory.

A. T. Sinclair has attempted to understand the origins of the commensurabilities among the satellites of Saturn and Jupiter. It appears that those in the Saturn system can be satisfactorily explained by the action of tidal forces, but this explanation does not work for the Jupiter system (08.100.018; 11.100.201; *Monthly Notices Roy. Astron. Soc.* **171**, 59, 1975). He also gives a new theory for the motion of Iapetus, fitted to recent observations and using analytical expressions for the short-period perturbations and a numerical integration for the motion of the orbital plane (12.100.214). Another paper by Sinclair is on the orbits of Tethys, Dione, Rhea and Titan (*H. M. Nautical Almanac Office Techn. Note* No. 36, 1974).

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A new analytical theory for the motion of pairs of satellites in mean-motion resonance is being constructed and applied to Enceladus and Dione by W. H. Jefferys and L. M. Ries (*Astron. J.* **80**, 876, 1975).

Greenberg has completed a study of the Laplace relation among the satellites of Uranus and has been analyzing commensurabilities among the apsidal precession periods of the satellites of Saturn and Uranus (*Monthly Notices Roy. Astron. Soc.* **170**, 295, 1975; **173**, 121, 1975).

V. A. Shor (ITA) has continued his research on the motions of the satellites of Mars. From observations during 1877–1971 he obtained a new system of parameters for Struve's theory of these satellites. The theory has been compared with ground-based observations made in 1973 and with the data acquired during the Mariner 9 experiment (*IAU Colloq.* **28**).

L. KRESAK
President of the Commission

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