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

INTRODUCTION

The close-up pictures of Phobos and Deimos from the space probe Mariner 9 are probably the most spectacular single achievement in the field of Commission 20 during the triennium. For the first time we have seen the surface of a satellite other than the Moon, and accurate orbit data were an essential ingredient of this success.

The Pioneer 10 space probe, launched on March 2, 1972, safely passed through the asteroid zone from July to December on the way to Jupiter. Since this is a fly-by, it is not likely that close-up views of Jupiter's satellites will be obtained. These must await a Jupiter orbiter. Mariner missions to Jupiter and Saturn are being planned for 1977.

Alfvén's proposal for a manned landing on an asteroid has received wide attention, but the technical and financial problems are formidable. It seems more likely that there will be fly-by missions to a comet and two or three asteroids by the end of this decade. Plans are under discussion for an Explorer spacecraft to be launched in 1976 for a fly-by of Comet Grigg-Skjellerup.

Three new Apollo asteroids, 1971 FA, 1971 UA, and 1972 XA, were discovered, the first of this type since 1959. Two new Amor asteroids, 1972 RA and 1972 RB were also discovered. Discovery motion of 1972 RA was 0°7 per day and the apparent magnitude was 15. It was 0·15 A.U. from the Earth on October 7, 1972. 1972 RB had a motion of 1°4 per day and the apparent magnitude was 16 at the time of discovery. It was 0·10 A.U. from the Earth on August 28. The diameter is probably about 300 meters.

1685 Toro made a close approach in 1972 and was found to be in at least temporary resonance with the Earth.

329 Minor Planet Circulars were published, compared with 327 in the previous three years. 268 IAU Circulars were issued, compared with 209 in the previous three years.

The highest numbered asteroid is 1813 (MPC 3364). Other designations for this object are: 7589 P-L = 1967 DC = 1969 TT_5 = 1971 BA.

A development of particular concern to Commission 20 is the decision by authorities in South Africa to close the Republic Observatory. The Observatory Library is to be transferred to the Cape, and the 20-inch telescope is to be moved to the site of the new 'South African Astronomical Observatory' at Sutherland some 380 km from Cape Town. The future of the important minor planet observing program is uncertain. Dr. P. Herget has written to Dr. F. J. Hewitt, Vice-President, Council for Scientific and Industrial Research, Pretoria as follows:"... there have been more observations of more minor planets made at the Johannesburg Observatory (and the annexe at Hartbeespoort) than at any other observatory in the Southern Hemisphere in the whole history of astronomy. To destroy this treasure-trove of observations will surely bring you lasting and increasing condemnation as the years go on." Many other astronomers have individually protested against this action, and petitions have been sent by several groups (American Astronomical Society-Division on Dynamical Astronomy: a majority of those attending the Nice Colloquium; and the organizing Committee of Commission 26). Southern hemisphere observations are of crucial importance, so it

is gratifying to learn that Mrs. V. M. Blanco (B. F. Mintz) is starting a program of minor planet observing at Cerro Tololo, and it is to be hoped that the European Southern Observatory at La Silla and the U.S.S.R. Observatory at Cerro El Robles will expand their minor planet work.

The proceedings of the Leningrad comet symposium have been published: Leningrad, 1970 August 4–11, I.A.U. Symposium No. 45, *The Motion, Evolution of Orbits and Origin of Comets.*

The proceedings of the Tucson colloquium on minor planets have been published: Tucson, 1971, March 6–10, I.A.U. Colloquium No. 12, *Physical Studies of Minor Planets.*

I.A.U. Colloquium No. 22, *Asteroids, Comets, and Meteoric Matter* was held in Nice, 1972, April 4–6. 50 persons were in attendance, except for the opening and closing sessions which numbered about 90. The proceedings are being edited by B. Milet, W. Klepczynski, and C. Cristescu.

Contributions to this draft report have been received from: Aksnes, Bielicki, Böhme, Bruwer, Chebotarev, Cristescu, Dommanget, Edmondson, Everhart, Freitas Mourão, Gehrels, Giclas, Herget, Kresák, Kuiper, Marsden, Michkovitch, Milet, Oterma, Protitch, Rabe, Roemer, Schrutka-Rechtenstamm, Schubart, Sekanina, Sitarski, Strand, Strobel, Van Biesbroeck, Wilkins, J. G. Williams, and Wood. The draft report in the area of comets has been prepared by Dr. Elizabeth Roemer.

OBSERVATIONS

Australia. H. Wood reports that the Sydney Observatory has continued its work on minor planets with particular attention to observing long arcs for minor planets being used for purposes of fundamental astronomy. 1 Ceres, 2 Pallas, 3 Juno, 4 Vesta, 6 Hebe, 7 Iris, 11 Parthenope, 18 Melpomene and 433 Eros have been observed, several at more than one opposition.

Belgium. J. Dommanget reports that observations of minor planets and comets have been made by H. Debehogne using the Zeiss double astrograph (40/200 cm). Minor planets 1, 2, 3, 4, 6, 7, 11, 18, 39 and 40 have been observed in connection with the ITA Leningrad program (Mme Orel'skaya) to determine the corrections to the equator and equinox in modern fundamental catalogues. Debehogne has also made observations of minor planets and comets at Córdoba and Bosque Alegre (Argentina) using the 'Carte du Ciel' (32/350 cm) and large telescope (154/700 cm).

Brazil. Freitas Mourão reports that the 46-cm telescope of the Observatorio Nacional in Rio de Janeiro has been used to observe 9 minor planets (Ceres, Hebe, Laetitia, Irene, Metis, Melpomene, Pallas, Geographos, and Juno).

Czechoslovakia. L. Kresák reports that observations of minor planets down to the 15th magnitude have been made by M. Antal and L. Petrik using the 30-cm, f/5 Zeiss astrograph of the Skalnaté Pleso Observatory. Positional measurements of 1685 Torr have been made by A.Mrkos and R. Petrovičová at Klet'.

Finland. L. Oterma reports that a limited number of minor planet observations have been made by Mrs. Hilkka Rantaseppä-Helenius using the old anastigmatic telescope which is now mounted at Kevola (1^h31^mE, 60°25′ N).

France. B. Milet reports a very active program of minor planet and comet observations using the Zeiss double astrograph (40/200 cm) at l'Observatoire de Nice. Each year about 500 plates are taken and 5000 positions are measured. Use of a new moving plateholder to automate the method of Trépied-Metcalf has made it possible to observe minor planets to the 18th magnitude under the best conditions. Reduction of the observations of the 10 bright asteroids chosen by the I.T.A. Leningrad makes use of a program proposed by S. Arend, and the same program is used to reduce observations made at Bucharest. A different program is used for wide angle plates (8° × 8°) with as many as 10 asteroids. Milet is measuring 265 positions of asteroids on plates taken in 1972 with the 104 cm telescope at Byurakan.

Great Britain. G. A. Wilkins reports that the program of predictions of occultations of stars by natural satellites has already led to successful observations of occultations by Io (Jupiter I) on 1971 May 14 and by Ganymede (Jupiter III) on 1972 June 7.

Roumania. Cristescu reports that 1500 plates were taken with the refractor (38/600 cm) for minor planet and comet observations. Beginning in 1971 the Metcalf method was used to observe

asteroids as faint as the 15th magnitude. 1036 accurate positions of bright minor planets (1, 2, 3, 4, 6, 7, 11, 18, 39 and 40) were published and 400 more positions are in press. Reductions were performed at l'Observatoire de Nice. Objects of special interest (433 Eros and 1036 Ganymed) were followed as long as possible. The light curve of 4 Vesta was determined by Cristescu using the 76 cm reflector at the Rosemary Hill Observatory of the University of Florida.

South Africa. Bruwer reports that the Franklin Adams telescope at Hartbeespoort was used to take 196 plates in 1970, 222 plates in 1971 and 180 plates in 1972 through October. A total of 801 minor planet positions were measured, most of them south of $-10°$.

United States

(1) Aksnes reports that he exposed 30 plates of the inner satellites of Jupiter, Uranus and Neptune using the new 102 cm *f*/7 reflector at the Florence and George Wise Observatory in Israel. Each plate contains up to 20 multiple exposures.

(2) Edmondson reports that plates taken in earlier years with the 25 cm astrograph at the Goethe Link Observatory were the source of 1748 accurate positions of minor planets measured in response to special requests during the period of this report. Reductions were done at the Minor Planet Center, and the results published in the MPC's. Mrs D. J. Owings also measured 302 accurate apparent magnitudes and calculated 446 absolute magnitudes in response to a request from T. Gehrels.

(3) Gehrels reports that he has continued his photographic program with the Palomar 122-cm Schmidt, and that he conducted an active photometric observing campaign on 1685 Toro in July and August 1972. His photometric and polarimetric programs are also continuing.

(4) Giclas reports that he has continued the Lowell Observatory program of observations of minor planets and comets using the 33 cm astrograph. Approximate positions of objects found during the course of the proper motion survey, together with both accurate and approximate positions from the early (1932–34) search plates, including accurate positions for especially requested objects, have been published in the MPC and IAU Circulars. When requested, accurate positions will be measured for all objects for which approximate positions have been published.

(5) Marsden reports that R. E. McCrosky and C. Y. Shao have initiated a program of astrometric observations of faint minor planets and comets with the 155-cm *f*/5 reflector at the Agassiz Station of the Harvard College Observatory. Objects as faint as the 20th magnitude have been recorded. Marsden has been doing special computational work in coöperation with Roemer's observational program to reduce the number of minor planets on the critical list.

(6) Roemer reports a significant increase in her observational activity on minor planets and comets, with a certain amount of time with the 229-cm telescope of the Steward Observatory supplementing 20–25 nights per year with the 154-cm reflector at the Catalina Station of the Lunar and Planetary Laboratory. Some 400 plates per year have been obtained, about equally divided between comets and minor planets plus faint satellites.

The satellite observing program includes: Phobos and Deimos; Jupiter VI, VII, VIII, IX, X, XI and XII; Saturn IX; the satellites of Uranus; and Neptune II.

The Minor planet observing list (Mostly magnitude 16 or fainter) includes: (a) Earth-orbit crossing (Apollo) asteroids; (b) Other small-*q* types, particularly those of large *i* or *e* (*limited* number of Hungarias); (c) Hildas, Trojans; cases of close approaches to other planets (e.g. 1011); resonant planets (e.g. 1362); (d) Objects selected from the critical list on the basis of: (1) Ephemeris sufficiently reliable to justify attempting long focus telescope observations. (2) Interesting orbit, and (3) Object too faint for observations with small telescopes. Marsden's cooperation in providing timely information on ephemerides (including realistic estimates of their uncertainties) and relative priorities has been singularly valuable.

Significant accomplishments include:

(a) Recovery in January 1972 of 1948 EA, an Apollo asteroid not seen since the discovery year, and observation through the mid-1972 opposition season.

(b) Observation of newly discovered Apollos 1971 FA and 1971 UA during both the discovery and the 1972 opposition seasons.

(c) Observations of 10 interesting unnumbered minor planets (1948 PC, 1967 CA, 1968 AA, 1968 UA, 1969 PC, 1969 QB, 1969 QP, 1969 QQ, 1970 BA, and 2008 P-L).

(d) Observations of 28 critical list objects (531, 1050, 1101, 1203, 1235, 1293, 1373, 1399, 1400, 1414, 1441, 1545, 1599, 1618, 1695, 1727, 1738, 1747, 1748, 1749, 1750, 1751, 1756, 1759, 1774, 1779, 1787, 1788). An attempt was made to observe 603 and 1380 but they were not found within 15′ of the ephemeris position.

(7) Strand reports that the U.S. Naval Observatory's program on observations of selected minor planets, with emphasis on Jupiter commensurates, continued with the 38 cm $f/6$ astrograph. Bright Hirayama family members were added to the observing program in 1971. In late 1970, the astrograph was stopped down to 23 cm and is now being permanently used as an $f/10$ instrument. A paper by R. S. Harrington and B. F. Mintz containing all positions obtained since the start of the program in 1950, through the spring of 1971, was published in *U.S. Naval Observatory Publications*, Vol. XXII, Part III (1972). Observations of 1620 Geographos were obtained in 1969 at Cerro Tololo Inter-American Observatory; coordination is continuing with this Observatory in the observation of minor planets.

U.S.S.R. Chebotarev reports that observations of minor planets were made in the U.S.S.R. mainly at the Crimean Astrophysical Observatory by the staff of ITA under the guidance of Mrs L. I. Chernykh. About a third of all numbered asteroids were photographed there and in addition 300–500 new planets were discovered each year, so that a total of 1500–2000 positions were obtained per year (03.098.018; 04.098.026; 06.041.001; 06.098.003; 06.098.036; 06.098.039; *Bull. ITA*, **13**, 132, 188, 130, 125; *Bull. Abastumani Obs.* No. 43). During the triennium 9 newly observed planets received permanent numbers: 1771, 1772, 1774, 1789, 1790, 1791, 1792, 1793, 1796.

The observatories in Alma-Ata, Abastumani, Kiev, Moscow, Nicolaev, Pulkovo, Tartu, Tashkent, Zvenigorod also took part in astrometric observations of asteroids (04.098.008; 04.098.022; 04.098.023; 04.098.025; 05.098.006; 06.098.033; 06.098.034; 06.098.035; 06.098.037; 06.098.038).

In 1968 at the Crimean Observatory and at the Observatory in Alma-Ata TV systems were used for the observation of Icarus (03.098.023; 05.098.001; 06.098.032).

The positions of the satellites of Mars (mainly Deimos) obtained in 1967 in Pulkovo, Golosejevo, Kazan, Moscow and Kiev were published (03.097.052; 03.097.053; 03.097.054; 06.097.001; 04.097.020; 02.097.064; 03.097.035). Twenty-one positions of Phobos and twenty-two positions of Deimos were obtained in 1971 by A. Sh. Khatisov with the 40 cm refractor of the Abastumani Observatory.

The Galilean satellites of Jupiter were observed by M. Divinsky in Golosejevo, L. I. Chernykh in Crimea and T. P. Kiseleva in Pulkovo. A few plates of Saturn VII, VIII and IX were taken by T. M. Smirnova with the 40 cm refractor of the Crimean Astrophysical Observatory (06.041.001). A good series of observations of Saturn II, III, IV, V, VI was performed in 1972 (*Bull. ITA*, **13**, 132).

Yugoslavia. Protitch reports that the Belgrade Observatory has continued to observe bright minor planets and comets accessible to their astrographs: Zeiss (16/80 cm) and Askania (10/100 cm). However the difficulty of obtaining good quality photographic plates in reasonable quantities hampers their work. In addition to the minor planet observations, the 65/1000 cm refractor was used to take plates of the Galilean satellites of Jupiter, and to participate in observing the occultation of Beta Sco by Io. The name Simonida had been proposed to the Minor Planet Center for 1675, discovered at Belgrade.

ORBITS AND EPHEMERIDES

France. Milet reports that observations from Bucharest and Nice have been combined to increase the number of positions available for calculation of residuals, and to compute provisional orbits to eliminate errors of identification in those cases where numerous observations are available.

Great Britain. Wilkins reports that predictions of lunar occultations of minor planets are now prepared with a view to possible determination of their diameters from photoelectric observations. The search for predictions of occultations of stars by minor planets is being extended to cover all minor planets whose diameters are believed to exceed 50 km, and for which accurate ephemerides

are available. The ITA Leningrad has prepared special ephemerides for this program. The search for possible occultations of stars by natural satellites of planets is being carried out on a limited scale. These have already led to successful observations of two occultations mentioned in a previous section.

Roumania. Cristescu reports that attempts to improve orbits of minor planets, either in cooperation with Nice (Cristescu) or independently (V. Ionescu Vlasceanu) are in progress.

United States

(1) Aksnes reports that he has computed preliminary orbits for several newly discovered asteroids (1971 UA, 1972 FA, 1972 FC, 1972 FD and 1972 FE). Of these, 1971 UA has the smallest aphelion distance of any known asteroid. At the time of discovery its very fast motion led to the suspicion that it might be orbiting the earth. It is not always possible from a short arc of observations to distinguish between the orbit of a distant earth satellite and that of a fast moving asteroid.

(2) Herget reports that C. M. Bardwell has found more than 100 new identifications, many of which were the basis for newly numbered planets. He also established the recovery of 155 Scylla, which had been lost since its discovery in 1875. He improved the elements of 1101 Clematis, based on identifications by O. Kippes and himself, and showed that the supposed resonance in the Hecuba gap is invalid. He derived preliminary orbits for 33 newly discovered objects, including five new Trojans. Preliminary orbits and ephemerides were also provided through collaboration with T. Gehrels and C. J. van Houten during a search survey with the 122-cm Palomar Schmidt in March 1971.

(3) Marsden reports that although the emphasis of his work has been on objects with orbits of particular interest, orbits and ephemerides have also been calculated for some 60 recently discovered, unnumbered minor planets. Observations obtained at second and third oppositions have been utilized to improve the orbits in about a dozen cases. His collaboration with Roemer has been mentioned previously.

The accidental discovery of two new Apollo-type objects, 1971 FA and 1971 UA, has inspired interest in making specific searches for earth-approaching objects, and T. Gehrels has taken a number of appropriate plates with the 122-cm Palomar Schmidt. At the same time, the possibility of recovering previously observed Apollo- and Amor-type objects has been considered, and Roemer succeeded in picking up 1948 EA and 1968 AA on the basis of predictions by Marsden, as mentioned previously. Attempts to recover Apollo itself (1932 HA) in 1971 were unsuccessful.

Subsequent to the publication of the 1970 report (p. 189, lines 9–10 from the bottom) it was found that the residuals in the motion of 944 Hidalgo were more probably due to the error in the adopted mass of Saturn than to non-gravitational forces.

(4) Rabe reports that the ephemeris of 433 Eros for the close approach in 1974–75 has been prepared in cooperation with C. Bardwell and H. J. Carr. It is based on a new numerical integration and a new differential correction from 67 normal positions from 1926 through 1968. For the mass of Earth + Moon, the value 1/328 899 has been used. The ephemeris is available with a 1-day interval, from 1974 June 2 through 1975 March 28.

(5) J. G. Williams reports that he has been calculating proper elements for the catalogued and Palomar-Leiden asteroids, using his own theory of secular perturbations. Of the 3558 orbits processed, about 2800 have sufficiently accurate orbits to use for the identification of families.

U.S.S.R. Chebotarev reports that the main feature of minor planet research in the U.S.S.R. during the period of this report was further application of electronic computers in the practice of computing.

As in earlier years the Institute of Theoretical Astronomy regularly published the yearbook *Ephemerides of Minor Planets.* Four yearbooks (02.098.015; 04.098.010; 06.098.006 and *Ephemerides of Minor Planets for 1973*) were issued during this triennium. Nearly all ephemerides obtained were computed on electronic computers (BESM2, BESM4 or Minsk 2) taking into account perturbations of major planets, the programmes being compiled by N. W. Ashkova, E. I. Kazimirchak-Polonskaya, M. J. Shmakova and V. A. Shor. Ephemerides obtained elsewhere were also computed by means of numerical integration on electronic computers.

Beginning with 1971 issue the format of the yearbook changed somewhat: each ephemeris gives

now the positions for 8 dates, covering 70-days interval, so that the observers will be able to follow faint planets at least during two months around opposition.

At the same time the publication of extended ephemerides of bright planets had to be discontinued, but at the request of observers these ephemerides will be published again (for 1972 in MPC 3277-3296 and later in *Ephemerides*).

In accordance with wishes expressed at the XIV Congress of IAU a reference to the elements on which the ephemerides are based is given: the year of the Ephemeris-Volume in which the elements were introduced is published in the last column of the table 'Opposition dates'.

The close-approach ephemerides as well as favorable-elongation ones for some unusual planets will now be published regularly in the yearbooks.

The improvement of orbits was carried out in a very intensive manner. S. G. Makover had chosen for improvement minor planets with very uncertain elements, insufficient number of accurate observations and some of them not observed for a long time. He used approximate observations and a simplified method for the improvement of orbits (04.098.024). In all other cases only accurate observations were utilized. F. B. Khanina (ITA) carried out 365 orbit improvements (04.098.006; 04.098.007 and *Bull. ITA*, **13**, 160): M. A. Dirikis (Latvian State University) nearly 70. V. I. Orel'skaya improved the orbits of ten planets, selected for the determination of systematic errors of star positions. All the orbit improvement methods were programmed for the BESM4. The normal places were not formed. V. I. Orel'skaya continued her work on the collection and checking the observations of ten minor planets mentioned above, selected for the determination of equinox and equator corrections of the Catalogue of Faint Stars. About 18000 positions were collected, obtained both at the observatories of the U.S.S.R. and abroad. Some observatories (Bordeaux, Nice, Besançon) sent rectangular coordinates of the asteroids and they were reduced at ITA. But it should be mentioned that determination of elements of orientation is rather difficult as all the observations have to be referred to one Fundamental Catalogue (FK4 for instance) and there is no means at present to do it accurately for the Southern Hemisphere stars.

V. N. Boyko (Leningrad University) studied the precision of determination of the equinox and equator corrections and the systematic errors of fundamental systems on the basis of a hypothetical series of observations of asteroids Ceres and Vesta (04.041.028).

M. A. Dirikis investigated the evolution of orbits of three minor planets with great eccentricities over a 1000 year period.The same method was then applied to a set of fictitious planets near the commensurability 1:2 with Jupiter in order to study this gap (in *IAU Symp.* **45**).

I. V. Galibina determined the secular perturbations of four minor planets 279, 1162, 1180 and 1202 and some comets using the method of Gauss-Halphen-Goryachev modified by P. Musen. All computations were performed by means of the electronic computer Minsk 2. The results of the investigation have shown that this method can be applied to minor planets as they very seldom approach the major planets. But it is unreasonable to apply the above method to comets because it does not consider the possibility of their close approach to major planets and consequently does not reflect the evolution of cometary orbits (04.042.018).

G. A. Chebotarev and his collaborators continued and extended statistical investigations of minor planet orbits. During the current period the papers (03.098.014; 03.098.016; 03.098.017) as well as the paper of G. A. Chebotarev and M. J. Shmakova on the structure of the entire asteroidal belt (06.098.002) were issued. As usual annual reviews of minor planet problems have been prepared by N. S. Samoilova-Yakhontova (03.098.015; 04.098.005; 06.098.001 and *Bull. ITA*, **13**, 137).

GENERAL

Belgium. Dommanget reports that Debehogne has continued his work on various astrometric problems, part of which was reported at the Nice Colloquium. Debehogne has also developed a program for the IBM 360/40 to calculate special perturbations using the complete formulas.

Brazil. Freitas Mourão reports that he is doing theoretical work on methods of plate reduction in collaboration with Debehogne.

Czechoslovakia. Kresák reports that he has been working on comet-asteroid relationships, and selection effects in the Palomar-Leiden Survey, especially the sources of differences from the orbits of brighter asteroids and the reality of the jetstream within the Nysa family.

Germany. Schubart reports that 4 papers were published by H. Scholl and himself on the subjects of: Minor Planets on Commensurable orbits with Jupiter; Mass of Jupiter Derived from Observations of 153 Hilda, 279 Thule, and 334 Chicago; The Planetary Masses and the Orbits of the First Four Minor Planets; and Asteroid Masses and Densities. The latter two papers contain the first results about the mass of Ceres from perturbations on Pallas and Vesta.

Poland. Bielicki reports that he is continuing his work on orbital motion of small bodies.

United States

(1) Everhart reports that he has papers in press on 'Trojan and Horseshoe Orbits associated with Jupiter and Saturn', 'Predictor-Corrector Equations of High Order used to Integrate Orbits', and 'Integration of Perturbed Orbits by Time Series Expansion'.

(2) Rabe reports that he has continued his work on the elliptic restricted Trojan problem, and a possible relationship between Trojans and Comets of the Jupiter group. His paper on 'The Use of Asteroids for Determination of Masses and other Fundamental Constants' is in the Tucson Symposium volume.

Yugoslavia. Michkovitch reports that he has published a 'Review of Periods of Quasi-identical Oppositions' of all numbered minor planets. In collaboration with J. Simovljević and J. Lazović he has been studying the problems of approximations of quasi-coplanar orbits of minor planets.

SATELLITES

In addition to the observations of satellites reported in a previous section, the following reports have been received.

Great Britain. Wilkins reports that a new theory of the motions of the satellites of Mars has been completed by Sinclair and compared with all available data (*M.N.R.A.S.* **155**, 249–274, 1972). This study confirmed that the secular accelerations of the satellites are very much less than the values originally proposed by Sharpless. The results of the analyses are in good accord with subsequent determination of other parameters of the system from the motions of the Mariner spacecraft. The conditions for the capture of the satellites of Saturn into stable librating configurations have been examined and explanations of some aspects of the present system put forward (in press).

United States

(1) Aksnes has prepared several computer programs for ephemeris computations of the satellites of the outer planets for use in the planning of U.S. space missions to these planets. This work also led to a set of new initial conditions for Jupiter VIII–XII. He also modified Brouwer's artificial satellite theory to make it applicable to the low-eccentricity and low-inclination orbits of most natural satellites. This theory was used by G. Born and T. Duxbury to improve the orbits of Phobos and Deimos using TV-imaging data obtained by the space probe Mariner 9.

(2) Herget reports that Publications of the Cincinnati Observatory, No. 23, contains definitive orbits of the outer satellites of Jupiter (J VIII to J XII), residuals of all observations, and ephemerides until 2000 A.D. It also contains ephemerides of Comet Schwassmann-Wachmann 1 until 2000 A.D.

U.S.S.R. Chebotarev reports that sets of elements of Phobos and Deimos were calculated at twenty oppositions, covering a time span from 1877 to 1971 and the comparison of the longitudes of Phobos with the theory developed by H. Struve was carried out. The results obtained appear to be in good agreement with the hypothesis of the secular acceleration of Phobos though its value should be smaller than reported by B. Sharpless (04.097.069; 06.097.015).

The work on the refinement of parameters of the theory of Galilean satellites elaborated by B. Marsden has been continued at ITA. The comparison of the theory with observations during the

period 1961–1971 was performed. The O–C differences of this time interval do not exceed a few dozens of seconds of arc (E. Lemekhova). A number of publications are concerned with the investigation of motion of the outer satellites of Jupiter (05.099.018; 05.099.019; *Astron. Tsirk.*, No. 695, 696). The motions of Jupiter VI and VII were investigated by means of numerical methods, taking into account the perturbations of the Sun and Saturn, and the new sets of elements have also been determined. The new set of elements of Jupiter VI represents 435 observations during the time interval 1894–1970, the mean error being 2″.1.170 observations of Jupiter VII during 1905–65 are given with the mean error 2″.5. The ephemerides of the satellites have been computed ahead to 2000. A series of theoretical investigations concerned with the motions of the satellites of Mars (06.097.025; 04.097.062) and Jupiter V (02.099.035; 02.099.059; 03.042.020) was published during the triennium.

COMETS

E. Roemer

Introduction

The following report is compiled from the responses of seventeen Commission members to inquiries by or on behalf of the President, supplemented by an incomplete literature search and personal communications received independently by the Chairman of the Working Group on Orbits and Ephemerides of Comets. The organization is along the general lines of the Report of the Working Group presented at Brighton and published in *Trans. IAU* **XIVB**.

In accordance with the expressed wish of G. A. Chebotarev, a somewhat condensed version of the report prepared by E. I. Kazimirchak-Polonskaya concerning work on comets in the U.S.S.R. during the triennium is presented in a separate section.

1. *General*

Several meetings that pertained at least in part to dynamics of comets were held during the triennium 1970–72. Most important of these was IAU Symposium 45, 'Motion, Evolution of Orbits, and Origin of Comets', organized by the Institute of Theoretical Astronomy of the Academy of Sciences of the U.S.S.R., and held in Leningrad in August 1970. Contributions of more than 80 investigators, including over 50 from the Soviet Union, were organized under six broad categories: (1) Observations and ephemerides, (2) General methods of orbit theory, (3) Motions of the short-period comets, (4) Physical processes in comets, (5) Origin and evolution of comets, and (6) Relationship with meteors and minor planets. The proceedings, edited by G. A. Chebotarev, E. I. Kazimirchak-Polonskaya, and B. G. Marsden, were published in 1972.

IAU Colloquium 12, 'Physical Studies of Minor Planets', held at the University of Arizona, Tucson, in March 1971, included consideration of possible interrelations between comets, asteroids, meteors, and meteorites. Contributions were published in 1971 as SP-267 of the U.S. National Aeronautics and Space Administration. IAU Colloquium 22, 'Asteroids, Comets, Meteoric Matter', convened in April 1972 at the invitation of Observatoire de Nice.

Two special meetings devoted to topics relevant to space missions to comets were sponsored by NASA. The reports presented in April 1970 at a meeting in Tucson designed to develop general scientific background were edited by G. P. Kuiper and E. Roemer and published by the Lunar and Planetary Laboratory, University of Arizona, on behalf of NASA, under the title 'Comets: Scientific Data and Missions'. The 38 participants included 4 from outside the United States.

The 'Proceedings of the Cometary Science Working Group', which met at the Yerkes Observatory in June 1971, were published at the end of that year as a contractor's report of the Research Institute of the Illinois Institute of Technology, with D. L. Roberts as editor.

'Comet Notes', which include brief descriptive information of comets under current observation and notes of expected periodic comets, were written by E. Roemer for *Publ. astr. Soc. Pacific* through late 1971. Beginning in 1972 they appear in the new journal of that society, *Mercury*. B. G. Marsden has compiled the reports on comets that appear annually in *Q.J.R. astr. Soc.* Included

is a tabulation of newly determined or improved orbital elements, intervals of observation, notes of unsuccessful searches, photometric parameters, and the like, as well as a brief description of each cometary apparition.

Very efficient operation of the IAU Central Telegram Bureau, under the direction of Marsden, at the Smithsonian Astrophysical Observatory, has been an important factor in assuring early verification and observation of newly discovered or physically active comets. Marsden has often provided orbits and ephemerides for newly discovered objects, but results of computations elsewhere are as welcome as previously. In some instances observations have been insufficient for an orbit determination, and trial orbits computed under a variety of assumptions by Marsden have been helpful in reobservation of an interesting object. Comet Gehrels, 1972 k which has turned out to be a periodic comet of particularly interesting orbit, was recaptured through such efforts in spite of being as faint as 19th magnitude.

A new *Catalogue of Cometary Orbits*, prepared by Marsden, was issued in 1972 as a special publication of the Bureau. Compilation was facilitated by availability of the card files used by J. G. Porter in producing the 1961 catalog. Through Marsden's efforts, comprehensive information is now collected in machine-readable form. With rapid and inexpensive reproduction practicable from data prepared by computer, it seemed no longer necessary to wait for resolution of those questions regarding optimum form of representation of nongravitational effects that had been topics for discussion at Prague and Brighton, or for completion of programs of systematic rediscussion of observations and redetermination of orbital elements now in progress (see G. Sitarski, M. Bielicki in *Symp.* **45**). It is expected that updated editions of the orbit catalog can be published as progress warrants.

The Comet Medal of the Astronomical Society of the Pacific, designed to recognize the contributions of non-professionals to observation and investigation of comets, was inaugurated in 1969 with the first award to R. L. Waterfield. Subsequent recipients have been T. Seki (1970), H. Q. Rasmusen (1971), and Max Beyer (1972).

2. *Discoveries, recoveries, astrometric observations*

Discoveries in 1970 and early 1971 were dominated by finds of Japanese amateurs, as they have been for several years. But P/Gunn, 1970 *p*, and four of the new comets of 1972 were found incidental to other programs being carried out with the Palomar Schmidt, or, most recently, with the Michigan Schmidt at the Cerro Tololo Interamerican Observatory. Although the objects found with the powerful photographic telescopes are usually appreciably fainter than those found by amateurs, they include unusually interesting objects: short-period comets (which seem very frequently to have a close approach to Jupiter in their recent pre-discovery history), and objects of extraordinarily large perihelion distance – of the type found during the deep photographic surveys of the 1950's.

Recoveries of returning periodic comets of sound observational history are now almost invariably made with large, long-focus reflectors at magnitudes in the range 19–21, in excellent accord with accurate predictions. If geometrical circumstances permit, observations are generally continued until comparable faintness is reached on recession from the sun. Three important recoveries of comets not seen since the discovery apparition were made during the triennium by C. Kowal with the Palomar Schmidt: P/du Toit-Neujmin-Delporte (1941 VII = 1970 XIII), P/Jackson-Neujmin (1936 IV = 1970 IX), and P/Shajn-Schaldach (1949 VI = 1971 *e*). In each case the prediction was by Marsden.

P/Tempel 1, observed previously in 1867, 1873, and 1879, was recovered by Roemer early in 1972 as a consequence of a remarkably accurate prediction that derived from work of G. Schrutka, J. Schubart, and Marsden. A single observation in 1967 was confirmed by the 1972 recovery as referring to P/Tempel 1.

Astrometric observations with instruments that reach to magnitude 16–17 are in generally satisfactory state, with active participation of at least 25 observatories, including five in the Southern

Hemisphere. More than 100 observations of comets have been made during the triennium at each of several of the observatories, and more than 200 observations at a few of them. It is a matter of deep concern, however, that the participation of the Republic Observatory, Johannesburg, apparently will be seriously limited in the future. A number of amateurs also contribute positions and photometric determinations of professional quality for the brighter comets.

The situation with the long-focus reflectors is much more precarious, as is reflected by the statement in Marsden's report on comets in 1971 (Q.J.R. Astr. Soc.): "...the total number of comets under observation during 1971 was as large as twenty, although twelve seem to have been observed only by Elizabeth Roemer, University of Arizona..." Z. Pereyra, Córdoba, and K. Tomita, Tokyo, also have occasional access to large reflectors, and it is gratifying to report that R. E. McCrosky and C. Y. Shao have been able to make important observations in recent months with the 155-cm $f/5$ reflector at the Agassiz Station of the Harvard College Observatory. With baked Kodak IIIa-J plates and automatic offsetting they have sometimes been able to reach objects as faint as magnitude 20.

The heavy load borne by so few observers equipped to follow faint comets has as a consequence some difficulty in keeping measurements and reductions current. In addition to the volume of observations and the individualized preparations for them (some 400 plates of comets and minor planets on more than 40 nights per year for E. Roemer, in addition to university duties), complications arise in the reductions. The limited field and faintness of the objects observed combine to preclude use of reference stars from such sources as the SAO Star Catalog, AGK zones, or the Yale catalogs. At least 1/3 of the reductions have to be dealt with by individualized methods, because of difficulties of one kind or another. The lack of currency is a matter of deep concern not only to those who need the positions, but also to those who are struggling to produce them.

The importance of pressing observations to faint limits lies not only in extending the observed arc, but particularly that comets may still be observed at less favorable returns. As an example, P/Tsuchinshan 1, 1971*f*, was never brighter than 20th magnitude at its first predicted return in 1971–72. The possible connection with P/Tsuchinshan 2 and history of approaches to Jupiter make this comet of more than ordinary interest. Continuity of observation at successive returns is important in investigation of secular changes in nongravitational effects – in which there are still some surprises! And in case of missions of space vehicles to comets, early optical recoveries will be particularly critical. The successful observation of P/Encke at *aphelion* in August–September 1972 also is a matter of some interest.

It would seem that the most satisfactory solution would arise from broader participation in the long-focus observations. This would also serve to minimize the possibility of total loss of critical observations through bad weather, or some other local circumstance.

3. *Orbits of short-period comets*

More than 20 workers are known to be engaged in investigations of the motion of various individual short-period comets. At least one high-quality prediction for the return of each expected object seems now to be regularly available. Almost invariably all significant gravitational perturbations have been taken into account, the starting orbit is often one derived from linking several previous apparitions, and, increasingly frequently, some account has been taken of nongravitational effects.

Particular note may be taken of several special investigations:

T. Kiang (*Mem. R. Astr. Soc.* **76**, 27, 1972) has reinvestigated the past motion of Halley's comet, redetermining the perturbations over the past 28 revolutions and carrying out a parallel re-examination of the Chinese records. The project was aimed at improvement of catalog values of the perihelion times.

G. Schrutka (*Ann. Sternw. Wien* **30**, Nr. 2) has finished a rediscussion of the observations and study of the orbit of P/Tempel-Swift. He is currently engaged in a study of the motion of P/Westphal, from observations in 1852 and 1913, in preparation for the return expected in 1975–76. A provisional ephemeris is available.

In connection with studies of nongravitational effects, Marsden has re-examined predictions for several 'long-lost' comets, finding in particular the possibility of a close approach of P/Biela to the earth in November 1971. He is inclined to take the fact that the comet was not recovered as further increasing the probability that this comet no longer exists. Marsden comments that P/Brorsen, Tempel-Swift, and Neujmin 2 may also have disappeared, but notes the fact, mentioned above, that P/Tempel 1 was recovered and well observed in 1972.

Consideration is being given in the U.S.A. to two modest missions to comets, a spacecraft of the IMP class to P/Grigg-Skjellerup in 1977, and one of the HELIOS type to P/Encke in 1980. Studies are in progress at the Goddard Space Flight Center.

4. *Orbits of nearly parabolic comets*

G. Sitarski, M. Bielicki (refs. *Symp.* **45**), P. Rybka, and K. Ziolkowski have undertaken jointly the preparation of a 'Catalogue of Orbits of One-Apparition Comets', including re-examination of observations and improvement of orbits. Criteria, methods, and programs for testing of observations for accuracy and improvement of orbits, including effects of perturbations, have been worked out and tested, and collection of 20th century observations is in progress.

G. Van Biesbroeck has continued his work in computing definitive orbits of nearly parabolic comets, selection of objects being made in consultation with Marsden. Orbit improvements have been finished for nine objects during the triennium, and work is in progress on Comet Brooks, 1911 V, for which more than a thousand observations are available. The resulting elements have been incorporated in the lists in Marsden's annual reports on comets (*Q. J. R. Astr. Soc.*), and details are published in *Comm. Lunar and Planetary Laboratory*.

A number of improved orbits have also been determined by Marsden, sometimes in collaboration with Sekanina; elements have been included in the tables in the annual reports.

Everhart has determined corrections applicable to the osculating $1/a$ to obtain values corresponding to original and future orbits for a list of comets supplementary to that given by Everhart and Raghavan (03.102.005). A tabulation, with figures corresponding to epochs actually used by the computers of osculating orbits, is included in the report on comets for 1971 (*Q. J. R. Astr. Soc.* **13**, 415, 1972).

Marsden and Sekanina have looked into the more general question of determination of $1/a$ for original and future orbits when effects of nongravitational forces are included. They conclude that it is often impossible to decide whether an individual comet originated in the solar system or not, though in general, allowance for nongravitational terms tends to make original orbits more elliptical than they otherwise would be.

P. C. Joss (04.102.022) has reported on a method for calculating the mean evolution of long-period orbits over many perihelion passages that applies to long-period orbits of perihelion distances $\leqslant 1$. This is a part of a study of orientation-dependent effects implicit in dynamical evolution of comets of the Oort cloud.

A new investigation of the effects of stellar perturbations on eccentric orbits of long-period comets has been made by S. Yabushita (*Astron. Astrophys.* **16**, 395, 1972).

5. *Theoretical investigations*

O. Havnes (*Symp.* **45**) has summarized his investigations of the effects on the semimajor axes of short-period comets undergoing close encounters with Jupiter. He finds a general diffusion toward larger orbits and loss of comets into hyperbolic orbits, the distribution being substantially altered on a time scale of a few hundred years.

E. Everhart (*Symp.* **45**) has looked into effects of ellipticity of Jupiter's orbit on capture into short-period orbits through single, random close encounters of long-period comets with Jupiter. He finds no effect on either rate of capture or distribution of longitudes of perihelion. In another study (*Astrophys. Letters* **10**, 131, 1972) he finds that short-period comets can evolve from near-

parabolic orbits of small inclination and perihelion distance near the orbit of Jupiter. He is continuing work on the general problem of the origin of comets.

S. Yabushita (*Astron. Astrophys.* **16**, 471, 1972) has carried out a related investigation, considering the effect of planetary perturbations on orbits of near-parabolic comets of large perihelion distance.

E. Rabe (*Symp.* **45**, *Colloq.* **12** and **22**) has examined orbital characteristics of comets passing through the 1 :1 commensurability with Jupiter. In particular he has discussed the temporary Trojan capture of P/Slaughter-Burnham and the possibility of origin of some Jupiter family comets from the Trojan clouds.

L. Kresák (*Symp.* **45**; *Bull. astr. Inst. Czech.* **23**, 1, 1972) in a discussion of the dividing line between cometary and asteroidal orbits, proposes use of a simplified form of the Jacobi integral in the Sun-Jupiter-comet system as a useful criterion. In a further investigation (*Colloq.* **22**) amplifying on topics raised in Marsden's (04.102.024) discussion of the dynamical relationships between comets and minor planets, he has examined effects of resonance with Jupiter in the system of short-period comets. In particular he calls attention to an interesting group of faint, diffuse comets in temporary libration about the 2 :1 resonance gap.

Other lines of investigation have been directed toward physical interpretation of nongravitational parameters in terms of structure and behavior of the nucleus. According to studies by Marsden and Sekanina (06.102.014), most comets show a decrease with time in the magnitude of nongravitational effects, but a few show an increase. This has led Sekanina (see also *Colloq.* **12**, and *Symp.* **45**) to propose two alternate models for the nucleus, (1) a core-mantle model, in which a non-volatile portion might survive, perhaps as an observable Apollo- or Amor-type minor planet, and (2) a free-ice model, in which the comet would eventually disappear completely. In a separate investigation Sekanina has found, however, that reduction of aphelion distances through nongravitational effects turns out to be a rather ineffective process, a point of difficulty in a cometary origin for some earth-approaching asteroids. Sekanina has also looked into effects of precession of the axis of nuclear rotation as a possible explanation for a change of sign of the tangential nongravitational term for one or two comets. Dynamical discontinuities in the motion of several comets have been attributed by Marsden and Sekanina to collisions with Harwit's interplanetary boulders, which, they suggest, may themselves be of cometary origin.

The question of splitting and outbursts of comets as indicators of nongravitational effects has been considered by E. M. Pittich (06.102.001; *Symp.* **45**). He concludes that solar radiation or tidal effects by the sun or Jupiter are more likely causes of splitting and outbursts than collisions with small asteroids.

Marsden, Sekanina, and Yeomans (*Astron. J.* 1973) have together determined nongravitational parameters for some 25 comets, rather more than half the total number with three or more apparitions. The results have been used to examine the variation of nongravitational effects with heliocentric distance using a new law, based on the vaporization rate of water snow, and derived incidental to A. Delsemme's studies of the 'icy-halo' model of comet nuclei.

REPORT ON RESEARCH IN THE U.S.S.R.

The following review of work on cometary dynamics in the Soviet Union is condensed from the comprehensive report of E. I. Kazimirchak-Polonskaya:

Cometary investigations in the U.S.S.R. during the period 1970–1972 are classified as follows: (1) Cometary observations and ephemeris service; (2) Analytical methods for the calculation of planetary perturbations on cometary orbits; (3) Numerical methods and programs for electronic computers used in investigations of cometary motions; (4) Construction of numerical theories of cometary motion taking into account all planetary perturbations and nongravitational effects; (5) Investigation of the physical structure of cometary nuclei and atmospheres affecting determination of nongravitational forces; (6) Encounters of comets with minor planets and resultant disturbances of the cometary motion; (7) Determination of the mass of Jupiter from large perturbations on cometary orbits in Jupiter's sphere of action; (8) Calculation of definitive original and future orbits

of nearly parabolic comets; (9) Diffusion and disintegration of comets; (10) Investigation of orbital evolution of short-period comets of the Jupiter and Saturn families and of minor planets with cometary eccentricities, on a time scale of centuries and millennia; (11) Study of great orbit transformations of fictitious comets in the spheres of action of Uranus and Neptune. The capture theory in connection with the diffusion theory; (12) Researches on the stability, form, size, and formation of the Oort cometary cloud; (13) Origin of comets; (14) Production of meteor streams by cometary nuclei. Statistics of the orbits of meteor streams and comets.

Sponsorship of IAU Symposium 45 proved to be very fruitful from various points of view, including establishment of closer contacts between observers and investigators of cometary motion in all countries, which facilitated access to unpublished material.

The observations and ephemeris service of comets in the USSR have been revitalized. In 13 observatories more than 600 observations of 13 comets have been obtained. The ephemerides of a number of comets were calculated. General laws and variations of cometary brightness, as well as underlying causes were studied (see Vsekhsvyatskij; Andrienko *et al.*; Chernykh; Churyumov and Gerasimenko, all in *Symposium* **45**).

V. I. Skripnichenko (*Symp.* **45**) demonstrated that Hansen's method of partial anomalies makes it possible to obtain an analytical solution for comets moving in orbits with high eccentricities. He applied this method to the calculation of general perturbations by Saturn on P/Tuttle. V. M. Chepurova (*Symp.* **45**) developed an intermediate orbit for studying hyperbolic jovicentric motion of a comet in Jupiter's sphere of action, where the effect of Jupiter's oblateness may become significant, and successfully performed calculations for certain comets.

The development of methodology and compilation of programs for electronic computers at the Institute for Theoretical Astronomy followed two directions. (A) V. F. Myachin and O. A. Sizova (*Symp.* **45**) were the first to use the Taylor formula directly as a method of numerical integration of the n-body problem with calculation of derivatives of the coordinates according to the generalized Steffenson rule. This method, used with the BESM-6 electronic computer, is the most precise of all numerical methods based on the predetermined part of the Taylor series. It is used with a variable number of derivatives and also with a variable step. (B) E. I. Kazimirchak-Polonskaya, N. A. Bokhan, and N. A. Belyaev (see refs. in *Symp.* **45**) compiled three sets of programs for three different methods of integration (in special coordinates, Herrick's, and Cowell's methods) with variable step. These were used to construct numerical theories of cometary motion taking into account all planetary perturbations and nongravitational effects, and to investigate the evolution of the small bodies of the solar system for 400 yr (1660–2060). The papers of T. K. Nikolskaya (*Byull. I.T.A.* **13**) supplement the methodological investigations.

The application of methods and sets of programs compiled by Belyaev, Bokhan, and Kazimirchak-Polonskaya enabled the Soviet astronomers to investigate the motion of P/comets Borrelly, Faye, Giacobini-Zinner, Encke, Tempel-Tuttle, Ashbrook-Jackson, and Stephan-Oterma over long intervals of time (Belous; Belyaev and Khanina; Evdokimov; Kondrat'eva; Shmakova, all in *Symp.* **45**; Kastel' (06.103.100); Merzlyakova (in press). For comets Borrelly and Giacobini-Zinner a secular deceleration of motion has been detected.

Inspired by the compilation of a new cometary catalogue by B. G. Marsden, the scientists of Leningrad, Kazan, and Tomsk started to work on the construction of numerical theories of motion of P/comets: de Vico-Swift, Pons-Winnecke, Westphal, Brorsen-Metcalf, Herschel-Rigollet, and on the calculation of definitive orbits of one-apparition comets: Schwassmann-Wachmann 3, Swift 2, Denning 2, and others. Bokhan is conducting the research on the motion of Encke's comet.

The method and the double-precision program for integrating the equations in special coordinates makes possible accurate calculation of the transformation of cometary orbits in the sphere of action of the major planets.

Thus, Kazimirchak-Polonskaya has eliminated the discontinuity that has hitherto existed in the theory of the motion of P/Wolf, constructed by M. Kamieński for two isolated intervals, 1884–1918 and 1925–1967, with mean square error $\varepsilon < 2''$. The discontinuity in the theory during the revolution of 1918–1925 was due to the close approach of the comet to Jupiter in 1922 ($\Delta_{\min} = 0{\cdot}12$ A.U.);

based on the elements for 1918, Kamieński represented the normal places of P/Wolf in 1925 with $\varepsilon = \pm 67''.6$, and until now this error could not be reduced. Kazimirchak-Polonskaya, on the base of the same set of elements of 1918, represented observations in 1925 with $\varepsilon = \pm 3''.9$. In her paper presented at *IAU Colloquium* No. **22** (1972) she reduced this error to $\pm 2''.9$.

K. A. Shtejns, I. E. Zal'kalne and L. Lautsenieks (05.042.022; 05.102.015; 05.103.110; 06.042.055) determined the minimal distance between orbits of comets and asteroids and investigated the collision frequency of comet with minor planets, as well as the perturbing influence of minor planets on cometary orbits (05.103.110; 06.102.015; Shtejns and Zal'kalne, *Symp.* **45**). Kazimirchak-Polonskaya together with Zal'kalne (*IAU Colloq.* No. **22**, 1972) was the first to investigate the possible encounters of 1735 minor planets with P/Wolf during the revolution of 1918–1925. It was found that Hidalgo had the closest approach, encountering the comet in the sphere of action of Jupiter in 1922 at a minimum distance of 0·7 A.U. The perturbing influence of Hidalgo proved to be almost negligible.

Kazimirchak-Polonskaya (*Symp.* **45**) formulated the conditions for determining the mass of Jupiter from large cometary perturbations in its sphere of action and applied the method to the passage of P/Wolf through Jupiter's sphere of action in 1922. The resulting value was $1/1047{\cdot}345\, M_{\odot}$.

Soviet astronomers also continued their researches on the calculation of nearly parabolic cometary orbits. L. E. Nikonova and Bokhan (*Symp.* **45**) have compiled an appropriate set of programs. O. Rudyn (05.042.038) proposed a new method for calculating the perturbations of the perihelion time. L. M. Belous (04.103.109) and O. N. Barteneva (06.103.131) calculated the definitive orbits of comets Bester 1948 X and Pajdušáková-Mrkos 1948 V. Barteneva has also determined the original and future orbits of nearly parabolic comets Cunningham 1941 I, Arend-Roland 1957 III, Pajdušáková-Mrkos 1948 V and Kresák-Peltier 1954 XII (04.103.107; 04.103.108; 06.103.132). Research in this direction will be pursued.

Many Soviet astronomers associate cometary diffusion theory with the problem of capture and origin of comets. Shtejns (*Symp.* **45**) has continued to develop the theory, investigating the diffusion of comets from parabolic into nearly parabolic orbits. He considers the orbital diffusion to be related to the disintegration of comets. O. V. Dobrovol'skij (*Symp.* **45**) proposed new estimates of cometary disintegration and made critical remarks on the modern diffusion theory.

Investigation of secular patterns in the evolution of cometary orbits and of the role of major planets in this evolution is one of the central subjects of I.T.A. research, developed at the initiative of Kazimirchak-Polonskaya. She has considered (06.102.011; *Symp.* **45**) all main types of large transformations of real cometary orbits in the sphere of action of Jupiter, allowing as well for appreciable perturbations from Saturn. Enormous transformations of orbits of fictitious comets in the spheres of action of Uranus and Neptune were included in the study. An example of cometary capture by Neptune was shown at *IAU Colloquium* No. **22**. Two deductions were made: (1) The outer planets (Jupiter-Neptune) are powerful transformers of cometary orbits, largely controlling the course of orbital evolution; (2) the diffusion theory, in conjunction with the modern theory of capture, eliminates all contradictions between observations and the classical capture theory, permitting consideration of both long- and short-period comets as part of a unified cometary complex. G. A. Chebotarev, Belyaev, and Eremenko (*Symp.* **45**) investigated the evolution of orbits for a group of asteroids with cometary eccentricities and have demonstrated the secular stability of their orbits. Belyaev (*Symp.* **45**; 05.103.120), Churyumov and Gerasimenko demonstrated that orbit changes following large perturbations by Jupiter led to discovery of comets Faye and Churyumov-Gerasimenko 1969 IV. Chebotarev (*Byull. I.T.A.* **13**) proposed to search for transplutonian planets with the aid of periodic comets. I. V. Galibina (04.042.018) investigated the orbital evolution of the comets which had no close approaches to major planets for a period of 4000 years, demonstrating their stability. Chebotarev (06.042.033) discussed general problems of celestial mechanics and development of cometary astronomy.

E. M. Nezhinskij (*Symp.* **45**; 06.102.013), V. A. Antonov and I. N. Latyshev, and V. S. Safronov (see *Symp.* **45**) investigated the characteristic features of the Oort cometary cloud and its probable origin. Nezhinskij attempted to estimate the rate of destruction of the Oort cloud by stellar pertur-

bations, determining that the lower limit for its half-life is $1{\cdot}1 \times 10^9$ yr. Antonov and Latyshev determined the form of the Oort cloud as the Hill surface of the galactic field. Safronov developed the idea of formation of the cometary cloud as a result of ejection of bodies from the solar system incidental to accumulation of the giant planets.

Entirely different ideas of the origin of comets were pursued by other investigators. V. G. Fesenkov concluded that processes in interstellar space, as well as the structure of nebulae – including the numerous small condensations around newly formed stars – suggest a relationship to the formation of the cometary cloud surrounding the Sun. Chebotarev (*Symp.* **45**; 06.042.033) accepts the existence of the Oort cloud, representing the evolution of cometary orbits on a cosmogonic scale by means of Shtejns' diffusion theory and the conclusions of Kazimirchak-Polonskaya concerning the role of major planets as powerful transformers of cometary orbits. S. K. Vsekhsvyatskij (03.102.014 and *Symp.* **45**) in applying the theory of eruptive origin to comets and other small bodies affirmed the relevance of the process of cosmic volcanism coupled with tremendous internal energy of giant planets. The papers of V. V. Radzievski and V. P. Tomanov (04.102.019), and M. A. Mamedov (05.102.018; 06.102.016; 06.102.017) are also dedicated to the problems of cometary origin.

Some Soviet astronomers conduct investigations on the border of cometary and meteoric astronomy, studying the rate of ejection of dust by long-period comets (Lebedinets, *Symp.* **45**; 06.102.021); investigating the production of meteor streams from cometary nuclei (Katasev and Kulikova, *Symp.* **45**); and conducting studies on the statistics of meteor streams and comets (Lebedinets, Korpusov and Sosnova, *Symp.* **45**).

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https://doi.org/10.1017/S0251107X00024688 Published online by Cambridge University Press