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

PRESIDENT: G. A. Chebotarev.
VICE-PRESIDENT: F. K. Edmondson.
ORGANIZING COMMITTEE: S. Arend, P. Herget, H. H. Hirose, H. W. Wood.

INTRODUCTION

The Report in the part dealing with the minor planets and satellites has been compiled at the Institute of Theoretical Astronomy in collaboration of S. G. Makover (minor planets) and V. A. Shor (satellites). Contributions to this report have been received from S. Arend, H. Debehogne, J. Dommanget, P. Herget, S. Herrick, G. M. Jannini, B. G. Marsden, V. V. Michkovitch, B. Milet, Z. M. Pereyra, B. Popovič, E. Rabe, E. Roemer, J. Schubart, W. Strobel, C. Torres, H. Wood. The part on comets has been prepared by E. Roemer.

The main feature of minor planet research during this triennium has been the further application of modern electronic computing machines to the practice of computing. The time has gone when the computations of orbits and ephemerides were performed with the aid of logarithmic tables or with desk calculators. Therefore it is no wonder that all computational work in the field of the motion of minor planets is nowadays concentrated in a limited number of institutions provided with powerful up-to-date computing techniques, like the following.

(1) Institute of Theoretical Astronomy, Leningrad has used till recently a computer BESM-2 and now has at its disposal a new more powerful computer BESM-4.

(2) The Observatory of Cincinnati has used till recently a powerful computer NORC. Unfortunately this machine has been nowadays dismantled, but the observatory can perform some kinds of computations with an IBM-360 computer.

(3) Latvian State University, Riga, has made a large amount of computations with the computer BESM-2.

(4) University of California, Los Angeles, makes a large amount of computations with its own computer.

The four institutions mentioned above are computing nowadays more that 99% of orbits of all planets with permanent numbers as well as of many unnumbered planets.

The Minor Planet Center at the Cincinnati Observatory has continued issuing Minor Planet Circulars with data on minor planet observations made throughout the world, results of their orbit improvements as well as information on all new-numbered planets. By the 1st of October 1969, 2970 MPC's have been published. At the same date 1748 minor planets have received their permanent numbers.

The Institute of Theoretical Astronomy has continued issuing the yearbook *Ephemerides of Minor Planets* in which elements and ephemerides of all numbered planets are published. By the 1st of October 1969 the issue for 1970 has appeared and been distributed to all observatories.

OBSERVATIONS

The Institute of Theoretical Astronomy (I.T.A.) has carried out observations of minor planets at the Crimean Astrophysical Observatory with a Zeiss double astrograph 40×160 cm. These

observations, made under the guidance of Mrs L. I. Chernyh, have been made at a gradually increasing rate: 850 planetary positions were obtained in 1967 as compared with 2000 in 1969. Each position has been measured at the Observatory and reduced at the ITA. The large field of the telescope (10×10 degrees) enables the observer to find many planets not observed for a long time. About 700 unnumbered planets have been discovered. For 30 of these, elliptic orbits have been computed and some of them have already been reobserved in another opposition.

At the Uccle Observatory the observations of minor planets and comets have been performed on a large scale with the Zeiss double astrograph 40×200 cm under the guidance of S. Arend and J. Dommanget. Unfortunately the sky transparency has gradually declined owing to the neighbourhood of the large city of Brussels, which has badly influenced the observations.

At the Nice Observatory observations of minor planets continued with the Zeiss double astrograph 40×200 cm under the guidance of B. Milet. About 2000 positions have been obtained annually, and have been measured, and reduced with an electronic computer. Orbits have been computed for some newly discovered objects. Investigations of the brightness variation have been made for a number of planets, aiming at a determination of the periods of their rotation.

A large amount of research has been carried out at the Lunar and Planetary Laboratory, University of Arizona, Tucson. T. Gehrels and coworkers have made photometric observations of asteroids that had not previously been observed for light curves. The 36-inch reflector of the Steward Observatory and telescopes of the Kitt Peak Observatory have been used to obtain light curves for about 10 objects. Observations of polarization-phase relations of five bright asteroids have been compared with the results to be published by J. Veverka.

G. van Biesbroeck has continued his astrometric observations of comets, satellites and a few minor planets with the 154 cm reflector of the Catalina Station.

E. Roemer has continued astrometric observations, photographic photometry of comets, satellites and minor planets. Particular attention has been paid to observations of planets under the investigation of B. Marsden (see below).

Observations of planets with uncertain elements or an insufficient number of observations or not observed during the last ten years have been carried out at the observatories at Córdoba and Santiago.

Observations of ten selected minor planets (1, 2, 3, 4, 6, 7, 11, 18, 39, 40) for the determination of equinox and equator corrections of modern fundamental star catalogues have been obtained at different observatories (Bordeaux, Córdoba, Sydney, Uccle a.o.). These observations are for the greater part to be finished in 1969. The results of these observations have systematically been sent to the ITA for further reducing.

The Minor Planet Center at the Cincinnati Observatory has continued as in former years its works on the maintenance of a complete punched card file of all minor planet observations.

ORBITS, EPHEMERIDES

As in former years the Institute of Theoretical Astronomy has regularly published the yearbook *Ephemerides of Minor Planets*. The ephemerides computed either in the ITA or elsewhere have been published in this edition. For instance in the 1970 issue of the yearbook ephemerides of 1356 planets have been published including 389 sent from Cincinnati, 98 from Riga and 7 from other places. Beginning with 1971 issue the contents of the yearbook will be partly changed. At present an ephemeris of each planet consists of 6 lines in steps of 10 days and covering on the whole 50 days. In future each ephemeris is expected to consist of 8 lines covering altogether 70 days. Such a change will be made meeting the request of some observatories with powerful telescopes able to observe faint planets at least during two months around opposition.

At the same time the publication of extended ephemerides of bright planets will be discontinued.

Every year the ITA improves the orbits of about 150 planets (F. B. Hanina, S. G. Makover). V. I. Orelskaya has continued her work on the collection and reduction of observations of ten

selected minor planets. By the 1st of October 1969 about 7500 observations have been collected at the following 18 observatories: Bordeaux, Bucharest, Cape, Cordoba, Golosejevo, Copenhagen, Leiden, Moscow, Nice, Nikolajev, Poznan, Pulkovo, Santiago, Sydney, Tashkent, Tsingtao, Uccle, Zo-Se.

The Cincinnati Observatory and the Minor Planet Center (under the guidance of P. Herget) have made the following contribution: All the ephemerides until 2000 AD of the minor planets which were on the selected list have been completed on microfilm and several copies have been deposited at the ITA and some other institutions. The programs for computing preliminary orbits and for computing plate reductions have been rearranged for an IBM-360 computer. The Schubart-Stumpff N-Body program for computing perturbed planet orbits was in use. C. M. Bardwell has continued his work on the improvement of orbits and testing of identifications. E. Rabe began his work on the improvement of orbits of planet 1011 Laodamia and 1362 Griqua aiming at the improvement of the calculated masses of Mars and Jupiter.

S. Herrick and coworkers (University of California) have given much care in producing elements and ephemerides for the minor planets 1566 Icarus, 1580 Betulia, 1620 Geographos and 1685 Toro. In the period 1967–70 about 20 ephemerides have been published. S. Herrick has completed his two-volume book *Astrodynamics* which is expected to appear in 1970. Some of the original features include his work on universal variables, on the updating of the astrodynamic constants, on perturbed variation techniques in the method of variation of parameters and a new universal, singularity-free solution for an orbit through two positions.

B. Popovič (Belgrade) is preparing a monograph on the theory of the motion of planetoids and comets, using only the heliocentric position and velocity as orbital elements.

M. A. Dirikis (Latvian State University) has completed the improvement of orbits of about 120 planets, including all Trojans, 887 Alinda, 944 Hidalgo. Ephemerides of all these planets have been calculated regularly.

E. Rabe (Cincinnati), G. Zech (Heidelberg) and J. Lieske (Yale) have improved the orbit of 433 Eros using all available observations, and have obtained new values of the mass of the Earth-Moon system. Similar work on the planet 1221 Amor has been done by J. Schubart (Heidelberg). In all four cases the values of the Earth-Moon system appeared to be in a good mutual agreement as well as with those obtained by radar. Schubart has computed an ephemeris of 1221 Amor for 1972. The observations of the planet in this year are of great importance, since after 1972 the observing conditions of the planet will not be favorable for a long time.

B. G. Marsden (Smithsonian Astrophysical Observatory) has calculated new orbits for several numbered and unnumbered planets. The planets selected were ones with high orbital eccentricity (greater than 0·35) or with unusually small or large mean distances (less than 2·0 a.u. or greater than 3·5 a.u.). Five of these planets were reobserved by E. Roemer, including two members of Hilda group and the lost Trojan 1949 SB.

Another reason for doing this work was to verify that the program prepared for computing the orbits of periodic comets (where there are some additional difficulties due to large perturbations by Jupiter and to the effects of nongravitational forces) was working correctly. Two minor planets caused some difficulties: 887 Alinda, until it was realized that, with its frequent approaches to the Earth, this planet provides a dynamical test of the correctness of the radar value of the astronomical unit; and 944 Hidalgo, where it seems likely that the slight systematic trends remaining in the residuals are due to nongravitational forces.

S. Arend, H. Debehogne and J. Dommanget (Uccle Observatory) have computed orbits of planets discovered at the Observatory. Moreover they have made a set of investigations connected with the problem of reducing of astrophotographs. Debehogne has studied a question on the influence of the number of reference stars on the accuracy of the result by different methods of reducing. Dommanget has been occupied with the derivation of formulas for reducing the astrophotographs for the cases when the field of the telescope reaches as much as 45° or 90°. Debehogne has studied the influence of second order terms caused by an error of optical center determination. He has also made a program for rapid identification of plate reference stars.

1566 ICARUS

This planet was in 1968 in a close approach to the Earth ($\Delta = 0{\cdot}04$ a.e.). Accurate ephemerides have been prepared by S. Herrick *et al.* (University of California) and I. I. Shapiro (Massachusetts Institute of Technology). The planet was discovered by E. Roemer at the Catalina station on June 11. Near the date of close approach the planet was moving so fast, that usual photographic methods of observations were hardly suitable. Therefore a special photoelectric observational method was used at the Crimean Astrophysical Observatory, the planet image on a background of stars having been taken from a screen of a television device. About 300 observations of the planet were published, made at 20 observatories. P. Tiffany (University of California) has started to improve the planet's orbit using all old observations as well as all 1968 observations. Some observatories have made a set of photoelectric observations for the determination of the planet's brightness, colour and polarization. A rotational period of approximately 1.13 hours has been suggested. T. Gehrels has made an extensive series of photopolarimetric observations of the planet.

The most striking event in the field of research of the minor planet's motion during the triennium considered has been an attempt at making radar observations of Icarus. This attempt turned out to be successful owing to the recent improvement of Icarus's orbit made by Herrick who used old observations and two observations of 1968 June 11. I. Shapiro *et al.* successfully obtained radar observations from June 13 till June 15. R. Goldstein (Jet Propulsion Laboratory, Pasadena) made a series of radar observations of Icarus from June 14 till June 16. J. Lieske and G. Null (JPL) have made a new improvement of Icarus's orbit using 154 astrometric observations of the planet obtained in 1949–68 and 7 radar observations. This improvement has been made to verify the predictions of general relativity and to estimate the dynamical oblateness of the Sun, the mass of Mercury and some other parameters.

In August 1969 the planet 1620 Geographos was in close approach to the Earth. An extensive program of observations of the planet has been made.

GENERAL

Under the guidance of N. A. Bohan (Institute of Theoretical Astronomy) a library of standard subprograms for the computer BESM-4 has been elaborated. Each of these subprograms is intended for the solution of separate tasks connected with the theory of motion of minor planets and comets. The library is to be used for the composition of complex programs, each of them consisting of a short unifying program and a set of standard subprograms.

E. I. Kazimirchak-Polonskaja has worked out a new method for the integration of the equations of planetary motion, which is considered to be a combination of the methods of Numerov and Subbotin and therefore may be named the Numerov-Subbotin method. In this method only two approximations are needed for receiving the accurate solution, as compared with several in the Cowell method. The method has been programmed for the computer BESM-4.

V. F. Mjachin has elaborated a new method for the simultaneous integration of the equations of celestial mechanics based on ideas of Taylor and Steffensen. In this method a planet's coordinate is expanded into a series containing not high differences, but high order derivatives. The method is particularly convenient for integration with a variable step.

N. S. Chernyh has made an attempt for the determination of the mass of Jupiter from a study of the motion of the planet 10 Hygiea. Annual reviews of minor planet problems have been prepared by N. S. Yahontova.

G. A. Chebotarev and M. Shmakova have written a paper on the statistics of minor planet orbits. The existence of three main zones in the minor planets belt has been shown, each of them having its own physical peculiarities. The existence of "flat" and "spherical" components of the belt has been shown. G. A. Chebotarev, N. A. Beljaev *et al.* have investigated the motion of some minor planets (Thule, Hilda group, Trojans, planets with large eccentricities) for a period of 400 years

(1660–2060). It has been shown that the concentration of planet perihelia near the perihelium of Jupiter takes place only in some epochs.

J. Schubert (Heidelberg) has studied long-periodic effects in the motion of Hilda-type planets. He intends to continue his research on minor planets with a commensurable mean motion. He is studying the long period effects of 334 Chicago and of 279 Thule. One of his graduate students is investigating the possibility to determine the mass of Jupiter from selected planets of the Hilda- and Thule-type.

E. Rabe (Cincinnati) has studied the elliptic restricted problem (periodic solutions and their stabilities for motions of the Trojan type, but for appropriate mass ratios different from the one in the actual Jupiter-Sun case).

V. V. Michkovitch (Belgrade) as well as H. Debehogne and J. Dommanget have studied the problem of the determination of the shortest distance between two asteroid orbits with small mutual inclination.

SATELLITES

In connection with the launchings of space vehicles to Mars and Jupiter already started or planned for the near future we should focus our attention on improvement of the orbits of natural satellites of the planets especially close to their primaries. Such improvements should be based on a large series of highly accurate observations. Unfortunately only a small number of observers devote their energies to these fields. In this connection the fruitful activity of the U.S.A. astronomers should be noted. E. Roemer has obtained a good series of plates of the Martian satellites in 1969. D. Pascu (Naval Observatory) has obtained in 1968 a large series of plates of the Galilean satellites of Jupiter with the McCormac reflector. G. van Biesbroeck has continued his astrometric observations of planetary satellites (emphasis made on Neptune II = Nereid and Saturn IX = Phoebe), with the Catalina reflector. E. Roemer with coworkers has regularly observed the satellites Jupiter VIII to Jupiter XII and Saturn IX; it is intended to add Jupiter VI and VII to the program.

A large series of observations of Jupiter V has been performed by P. V. Sudbury (University of Manchester, England) with the 74-inch reflector of the Kottamia Observatory (U.A.R.). In the U.S.S.R. a small series of observations of the Martian satellites have been made in 1967 (Pulkovo, Golosejevo, Kazan a.o.). Observations of Saturn IX are planned at Córdoba.

During the triennium considered theoretical investigations have been successfully developed. G. A. Wilkins has continued his fruitful investigations of the orbits of the Martian satellites with particular reference to the investigations of tidal friction effects. S. N. Vashkovjak (Moscow) has developed a new analytical theory of the Martian satellites, taking into account not only secular but also periodic perturbations due to Mars' oblateness and the Sun. At the ITA work on the refinement of the elements of the orbits of these satellites has been continued (V. A. Shor and N. I. Glebova).

P. V. Sudbury has obtained a new system of elements of Jupiter V based on all old observations made in 1892–1949 and some new ones made in 1967 by himself (see above). V. N. Kiryushenkov (Moscow) elaborated an analytical theory of Jupiter V.

A. Bec (Bureau des Longitudes) has elaborated a numerical theory of the motion of the outer satellites of Jupiter and has determined Jupiter's mass from the motion of Jupiter IX. P. Herget has completed his large work on the orbits of Jupiter's outer satellites VIII to XII. He obtained precise orbits by process of numerical integration, improved the orbital data, based on all observations available and has computed ephemerides until 2000 AD. M. Charnow, P. Musen and J. L. Maury have published a paper on the application of Hansen's method to Jupiter X, containing new elements and a table of the general perturbations of the satellite. S. Herrick has continued his work on Jupiter IX and Jupiter XII. R. R. Allan (London) has studied the evolution of the Mimas-Tethys commensurability in the system of Saturn's satellites. J. R. Gill and B. L. Gault have determined a new orbit of Triton based on observations made in 1877–1958. G. A. Chebotarev has investigated a problem related to the stability of the motion of natural satellites in the solar system.

PROPOSALS

(1) The Institute of Theoretical Astronomy requests the discussion and approval of its suggestions regarding a new form of the *Ephemerides of Minor Planets*, to start with the 1971 issue.

(2) B. G. Marsden has pointed out that the recent practice of including extended ephemerides for Earth-approaching minor planets in the *Ephemerides of Minor Planets* should be strongly encouraged. It is hoped that the number of planets that will be given this special treatment will be increased so that the list includes eventually all those with highly eccentric orbits (greater than 0·35 say) and not necessarily the best observable during the two month interval around opposition.

(3) E. Roemer states that the uncertainty regarding the accuracy of the ephemerides is still the prime deterrent against the inclusion of additional minor planets on her observing list. The very limited fields of large reflectors means that an O–C of 5′ may well make plates unmeasurable. The date of the last observation presently printed with the ephemerides, does not really give the information we need. It would be more practicable to print with the ephemerides a reference to the elements on which the ephemeris is based, perhaps the year of the "Ephemerides" in which the elements were introduced.

(4) T. Gehrels proposes revision to the present photometric system of asteroids. The proposal is that the UBV photometric system must be adopted. The new values are 0.10 magnitudes fainter, nearly the same difference for all asteroids, which is a small change in view of the precision of the asteroid magnitudes. However fundamentally the change is important, because the UBV system now widely used. A new list photoelectric magnitudes of nearly all numbered asteroids will be submitted before Brighton meeting.

(5) The Institute of Theoretical Astronomy states with satisfaction that the number of observation of minor planets published formerly often in an approximate form is now being reduced rapidly. Taking into account that only accurate observations are of value for computers the Institute appeals to all observatories having modern measuring tools and computing facilities to publish in the future only accurate observations of minor planets. This proposal is concerned not only to planets having permanent numbers, but also to unnumbered ones.

(6) The President proposes to create a new Working Group dealing with the natural satellites' motion.

G. CHEBOTAREV
President of the Commission

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