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

PRESIDENT:   E Roemer
VICE-PRESIDENT:   C J van Houten
ORGANIZING COMMITTEE:  Yu V Batrakov, M P Candy, Y Kozai, Ľ Kresák, L K Kristensen, B G Marsden, H Scholl, G E Taylor, D K Yeomans, Y Z Zhang

## I.  INTRODUCTION

Interest in minor planets and comets continued to grow during the triennium, sparked in part by the highly successful 1983 mission of the Infrared Astronomy Satellite (IRAS) as well as by activities associated with the return of P/Halley and the first spacecraft missions to comets.  A trial of the Astrometry Network of the International Halley Watch (IHW) on P/Crommelin was quite successful.  Yet with an increasing need for precise ephemerides, there continued to be concern for acquisition and timely reporting of astrometric observations of even the best known comets.

May 1983 saw the closest approach of a comet to the Earth since that of P/Lexell in 1770.  With the recovery of 1009 Sirene and the demonstration that the 1892 observations of 330 Adalberta were not valid, the number of lost numbered minor planets was reduced to six.

On the recommendation of Commission 20's Satellite Nomenclature Liaison Committee (SNLC), chaired by K Aksnes, and the Working Group on Planetary System Nomenclature (WGPSN), the IAU Executive Committee approved permanent designations and names for three more of the recently discovered small satellites:

|          |       |          |
|----------|-------|----------|
| 1979 J1  | J XV  | Adrastea |
| 1979 J3  | J XVI | Metis    |
| 1980 S28 | S XV  | Atlas    |

Although some decisions have been made by WGPSN concerning names for the F Ring guardians, 1980 S26 and 1980 S27, the orbits of these bodies are not yet considered by SNLC to be sufficiently well known to support assignment of permanent designations. Thus names for these objects remain provisional.

The Committee on Magnitude Ephemerides of Minor Planets and Satellites, chaired by E Bowell, has consulted broadly concerning the most suitable two-parameter equation for calculation of magnitudes of minor planets and satellites.  Because of closely related requirements involved in the reduction of photometric observations of minor planets made by IRAS, interaction with the group at the Jet Propulsion Laboratory that is managing the IRAS minor planet data reduction has been particularly important.  Among the decisions taken was that the two parameters are to be the absolute magnitude at zero phase angle and a quantity that describes the slope of phase curves.  The definitive IRAS data reduction will be based in part on recommendations of the committee.

The Comet Nomenclature Committee appointed at Patras made recommendations concerning naming of comets discovered from spacecraft (e.g., SOLWIND and IRAS), and for temporary designations of comets beyond the 26th in a given year.

A number of meetings of interest to members of the Commission have taken place during the triennium, and proceedings from most of them, as well as from some earlier meetings, have been published.  These include the Sixth European Meeting on Astronomy: Sun and Planetary System (Dubrovnik, Yugoslavia, October 1981); Workshop on the

Motion of Planets and Natural and Artificial Satellites, II (Embre, Brazil, December 1981); Workshop on Interstellar Comets (Edinburgh, April 1982); IAU Colloquium No. 74, Dynamical Trapping and Evolution in the Solar System (Chalkidiki, Greece, September 1982); IAU Colloquium No. 75, Planetary Rings (Toulouse, September 1982); Conference on Cometary Exploration (Budapest, November 1982); Colloquium on Asteroids, Comets and Meteors (Uppsala, June 1983); IAU Colloquium No. 77, Natural Satellites (Ithaca, New York, July 1983); IAU Colloquium No. 83, Dynamics of Comets (Rome, June 1984); and the IHW Astrometry Network Workshop (Garching, June 1984).

The passing of Harley W Wood (1911-1984) and of Gerald E Merton (1893-1983), both former members of Commission 20, is noted with regret.  Wood was a former director of the Sydney Observatory, an outstanding astrometrist, and a leader of the astronomical community in Australia.  Merton was associated for many years with the observation of comets and the determination of comet orbits, serving from 1945 to 1958 as director of the Comet Section of the British Astronomical Association.

The organization of this report follows that of earlier ones, with sections devoted to minor planets, comets, satellites, and prediction of occultations by minor planets and satellites.  Information for the several sections has been compiled by the director of the Minor Planet Center and by the chairmen of the Working Groups of the Commission.  I owe deep appreciation to B G Marsden, Ĺ Kresák, Y Kozai, and G E Taylor for their fine work.  I am also indebted to D W Dunham and P D Maley of the International Occultation Timing Association (IOTA) for additional information concerning prediction and observation of occultations by minor planets.  V A Shor and N A Belyaev provided information about work done in the USSR on minor planets and satellites, and on comets, respectively.  Thanks are also due to many individual members of the Commission who sent information about their own work and about other work being done at their institutions.  As in the past, references generally refer to citations in *Astronomy and Astrophysics Abstracts*.

## II.  MINOR PLANETS

a)  GENERAL
    The dramatically increased activity in observational and orbital work on minor planets, documented in the last triennial report, has been maintained during 1981-1984.  The two most direct indications of the activity are the *Minor Planet Circulars*, issued under the direction of Marsden at the Minor Planet Center, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts; and the *Efemeridy Malykh Planet*, published under the direction of Batrakov at the Institute for Theoretical Astronomy, Leningrad.  Bardwell and Green also participate in the production of the monthly batches of *Circulars*; and Ashkova, Izvekov, Khanina and Shor are involved in the preparation of the annual volumes of *Efemeridy*.

The production of *Minor Planet Circulars* seems to have reached a plateau at around 1000 pages per year.  The annual number of astrometric observations published has been close to 25 000.  Beginning in 1981, the observations have also been made available on magnetic tape.  Updated versions of the tape were issued in 1982 and 1984; the latter contained 305 636 entries, of which 69 416 involved minor planets that were then unnumbered.  Perhaps 20 percent of the new entries can be utilized in the computation of single-opposition elliptical orbits, and preliminary and improved such orbits are being published at a rate of around 1000 per year.  In some 10 percent of these cases observations are subsequently also being identified at other oppositions, and with the inclusion of older identifications the annual number of new multiple-opposition orbits published is in excess of 400, roughly half of which involve minor planets that are as a result being permanently numbered.  In addition to the printed publication in the *Minor Planet Circulars*, beginning in January 1984 orbits were also available over a "dial-in" computer service.  On contacting the Smithsonian Astrophysical Observatory's computer over a modem a user can obtain (essentially therefore in a form for subsequent machine-readable use) orbital

elements for numbered minor planets more recent than those in the current *Efemeridy* volume and unnumbered minor planets that have either been observed recently or at more than one opposition in the past.  There is also a feature for the automatic computation of eleven points of an ephemeris at a step-size from 0.1 to 20 days.

In April 1982 the Minor Planet Center issued a *Catalogue of Orbits of Unnumbered Minor Planets* (31.098.108).  The catalogue contained orbits for 2471 unnumbered objects, 211 of which were known to have been observed at more than one opposition, and fully half of the orbits were from observations made since September 1978. Except for the single-opposition orbits from the Palomar-Leiden survey (which would have doubled the number of entries), the catalogue was essentially complete for all cases where elliptical orbits could be determined.  By October 1984, however, the number of unnumbered objects for which elliptical orbits were available had increased to 4397!  This contrasts with the 3131 numbered minor planets, a total that had just doubled since the Minor Planet Center began operation in Cincinnati in 1947.  There were fewer than 600 elliptical orbits in the previous tabulation of data on unnumbered objects, published by the Minor Planet Center in 1961.

A companion publication, *Catalogue of Discoveries and Identifications of Minor Planets* (31.098.109), included references to the discovery observations of the 29 157 objects (again omitting the Palomar-Leiden objects) given provisional designations since 1925 (or pre-1925 'A'-type designations).  Although necessarily in abbreviated form, this was intended to be an update of Strobel's *Identifizierungsnachweis* of 1963.  The 8550 known identifications with numbered minor planets were also listed, identifications with other unnumbered minor planets having been given instead in the orbit catalogue.  By October 1984 the number of provisional designations had increased to 36 871, and 10 975 involved numbered minor planets.

The Institute for Theoretical Astronomy prepared and published the *Efemeridy* volumes for 1983, 1984 and 1985, and work on the 1986 volume was well underway. During the triennium, orbit improvements were made for more than 300 numbered minor planets.  As in previous years, valuable contributions have been made by Dirikis at the Latvian State University Observatory, Riga.  The increased rate at which new minor planets are now being numbered means that each *Efemeridy* volume is about 7 percent larger than its predecessor, and that for 1985 contains 320 pages.  The largest increase was for the 1984 volume, which included 308 newly-numbered objects. Several extended ephemerides are given for bright and unusual objects, but 60 percent of each volume is devoted to the standard eight-date opposition ephemerides.  The annual updating of the orbital elements to a new osculation epoch is a feature that continues to gain in importance, as increased numbers of users are thereby able to produce their own ephemerides.  On the other hand, the Institute for Theoretical Astronomy continues to provide daily ephemerides to the observatories participating in the special Leningrad program of observations of 20 selected minor planets.

b)  OBSERVATIONS AND ORBITS
     In connection with the Leningrad program, the Institute for Theoretical Astronomy reported the receipt during the triennium of some 2500 observations made at 30 observatories around the world.  Among the Soviet observatories involved in this program are those at Abastumani, Alma-Ata, Dushanbe, Goloseevo, Kazan, Kharkov, Kitab, Moscow, Nikolaev and Tashkent.  Commission 20 members elsewhere who have specifically mentioned in connection with this report their involvement with the program during this triennium are Quijano at San Fernando, Lomb at Sydney and Protitch-Benishek at Belgrade.  Beginning in January 1983 observations were made at San Fernando of 55 minor planets for the Hipparcos project.  Most regrettably, the Sydney Observatory was formally closed in late 1982; its astrometric camera and other astrometric equipment are being transferred to Macquarie University.

Among other projects devoted to bright minor planets is the continuing work by Kristensen at Aarhus on 51 Nemausa and the fundamental reference system; an

important impetus was provided by the occultation of 14 Psc in 1983 (34.096.015).
Johnston, Seidelmann and Wade (32.098.072) succeeded in obtaining high-quality astro-
metric observations from the thermal emission from 1 Ceres and 2 Pallas detected at
microwave frequencies using the Very Large Array in New Mexico; they remark in a
follow-up paper that an extended program of observations of this type--measurements
have already been made also of 4 Vesta and 10 Hygiea--could allow the equinox to be
located and provide a truly fundamental coordinate system for positions of radio
sources.

Duma and Kisjun (37.098.010) have refined the orbits of the first four minor
planets from meridian observations and discussed the effect of the inclination of
the true equator to that of the star-catalogue system.  Other specific orbital inves-
tigations not included in the publications sponsored by the Commission are a compu-
tation on 4 Vesta by Imnadze (34.098.012) and a relativistic examination of the
motion of 1566 Icarus by Shefer (33.098.042, 37.098.014).

Wide-field programs involving photographic observations of the fainter minor
planets and discoveries of new main-belt minor planets are in progress at Brorfelde
(Fogh Olsen and colleagues), El Leoncito (C U Cesco), Flagstaff (Bowell), Kleť (Mrkos),
La Silla (Debehogne, de Freitas Mourão, De Sanctis, Lagerkvist, Zappalà and several
others), Nanking (J-x Zhang), Nauchnyj (Chernykh), Perth (Candy) and Zimmerwald
(Wild); at the Lincoln Laboratory's New Mexico installation further real-time dis-
coveries have been made using a television device (Taff); and several real-time
discoveries (with rather crude astrometry) were made from the IRAS satellite (Davies,
Green; 37.103.014).  The Flagstaff (Lowell) project, which involves the use of a
microdensitometer to derive accurate positions, typically yields more than 5000
positions annually.  The Nauchnyj (Crimean Astrophysical Observatory) program pro-
duces perhaps half as many positions but sets the useful general magnitude (about
18.0) limit for programs of this type; more than 500 numbered planets and a compar-
able number of discrete unnumbered planets are observed each year.  The program with
the 0.46-m Palomar Schmidt (E Shoemaker, C Shoemaker) generally concentrates on fast-
moving objects, and the deeper limiting magnitude of the 1.2-m Schmidt imposes even
greater selectivity toward objects of unusual motion (separate programs by Helin and
Kowal) or is advantageous to the follow-up and recovery of specific objects (Gibson).
Useful observations of faint, new objects are also obtained from time to time with
the 1.3-m Tautenburg (Börngen) and 1.05-m Kiso (Kosai, Hurukawa) Schmidts.  The photo-
graphic follow-up and recovery programs for faint objects with the large to moderate
conventional reflectors at Oak Ridge (McCrosky) and Mt. John (Gilmore, Kilmartin)
and by Japanese (Furuta, Seki) and Italian (Colombini, Baur) amateurs also yield a
fair number of new discoveries.  There have recently been concerted attempts at CCD
astrometry with conventional reflectors, notably with the Flagstaff 1.7-m reflector
(Bowell), the Palomar 1.5-m reflector (Gibson) and the Steward Observatory's 0.9-m
reflector (the "Spacewatch" project) on Kitt Peak (Gehrels).

There is much fruitful interaction between all the above faint-object programs
and the Minor Planet Center, which assists with identifications and attempts to check
for errors before observations are published.  The Crimean program also operates in
close association with the Institute for Theoretical Astronomy, which puts consider-
able effort into calculating ephemerides for both numbered and unnumbered minor
planets and has involved during the triennium the computation of some 250 preliminary
orbits by Kastel'.  Kristensen makes orbit computations for the Brorfelde program;
Williams works closely with Palomar observers; and the amateurs Nakano, Oishi, and
Urata provide substantial computational support for all the Japanese observing pro-
grams.  Some of this interaction involves the suggestion and subsequent demonstration
of identifications, and this is an area in which Bowell, Bowman (Cincinnati), Kippes
(Würzburg), Kretlow (Wiesbaden), Landgraf (Lindau) and Schmadel (Heidelberg) have
also made useful recent contributions.

Much effort has been put into the measurement and analysis of positions of minor

planets from old plates.  Bowell has generously provided measurements on request
from the older Flagstaff plates (1929-1975), and Indiana students (under the direc-
tion of Edmondson and Owings) have continued to provide measurements from the Goethe
Link plates (1949-1966).  Oterma has in fact been able to complete the measurement
of all the unnumbered minor planets found in the course of the valuable Turku program
(1935-1957), and she continues to measure the positions of numbered minor planets
when there is a good reason for doing so.  Remeasurement of Budapest plates from the
Kulin program (1936-1942) is to begin at Belgrade in December 1984.

    The Palomar-Leiden survey (1960) has also finally been completed with the publi-
cation by van Houten, Herget and Marsden (1984, *Icarus* 59, 1) of 1198 orbits that
supplement or amend those in the 1970 version of the survey.  The completion of the
survey included an extension to 170 new objects found in the field originally used
only for calibration purposes, and in several instances the earlier class 4 orbits
(generally based on only four-day arcs) could be improved with the identification of
observations a month later.  Most of the class 4 orbits were in fact rederived using
positions measured from the second plate of each blink pair.  The total number of
objects in the survey is 2403, of which 2256 were still single-opposition objects as
of October 1984.  Van Houten-Groeneveld has continued her work in Leiden on the 1977
Trojan program (the plates for which were also taken by Gehrels with the Palomar
1.2-m Schmidt).  All fields have been blinked, and 80 percent of the fields have been
measured for positions.  Orbit computations will be possible for some 1600 objects,
of which 32 are evidently Trojans or Hildas; in a collaboration with the Minor Planet
Center, Bardwell has so far computed orbits for 166 objects.  Bus, now located in
Flagstaff, has completed the main phase of the March-April 1981 "UCAS" survey (organ-
ized from the California Institute of Technology) of faint minor planets with the
U K Schmidt.  Orbits have been calculated, mainly at the Minor Planet Center, for
1202 objects, of which some 200 have so far been identified at other oppositions.
For the remainder, the observed arcs range from nine to 40 days.  Except for one
fast-moving object, the minor planets followed for fewer than nine days are felt to
yield orbits that are too uncertain to be useful.  On the other hand, the important
next phase in this work will involve the extension of the existing orbits to observa-
tions in February and May 1981; it is hoped that this will yield several hundred high-
quality orbits, with arcs up to 85-90 days, and there will then be a very real possi-
bility of making deliberate searches for many of the objects at additional oppositions.

    With the help of long-term numerical integrations made a few years ago by Scholl
for some 2300 of the first 2357 numbered minor planets, the Minor Planet Center has
calculated the residuals for all the observations of the numbered minor planets.
Thorough analysis of the residuals is proving to be very time-consuming, but the
process of deleting, correcting or otherwise identifying observations showing large
residuals has so far been completed for minor planets 901 and onward.

    In the last report it was remarked that the number of lost numbered minor planets
had dropped from 23 in 1978 to eight in 1981.  Gibson recovered 1009 Sirene in 1982
quite close to the prediction by Kristensen.  A careful investigation by West, Madsen
and Schmadel (31.098.105) demonstrated that the (two) original observations of 330
Adalberta by Wolf in Heidelberg in 1892 were certainly imaginary, so this number and
name have been applied instead to another object, A910 CB, also discovered by Wolf.
Since 1982 there have been no further successes with the recovery (or elimination)
of lost objects, and they remain as follows: 473 Nolli, 719 Albert, 724 Hapag, 878
Mildred, 1026 Ingrid and 1179 Mally.

c)  THEORETICAL INVESTIGATIONS
    Garfinkel (31.098.038, 32.098.053, 32.042.063, 34.042.013) summarized and exten-
ded his theoretical treatment of the orbits of Trojans.  Also continuing his earlier
work on Trojans, B Érdi (30.098.008) used an asymptotic solution for the cylindrical
coordinates to obtain perturbations in the orbital elements and made a comparison
(33.098.027, 34.098.023) with Garfinkel's theory; with Varadi (034.098.059), he

investigated perihelion motion in the non-planar case.  Using numerical integration and Labrouste's procedure for isolating periodic effects, Bien and Schubart (34.098.021, 34.098.060) studied the long periods in the motion of Trojans and pointed out the importance of secular resonances for special Trojan orbits.  A simple theory of Trojans was devised by Giacaglia (34.098.136), and Hori (30.098.097) treated the 1:1 (mutual) commensurability case using canonical perturbation theory.  D'yakov and Reznikov (32.042.028, 37.098.012) integrated hypothetical Trojan orbits for various mass ratios of the primary and secondary bodies.  Zagretdinov (37.098.061) remarked on some regularities in Trojan motion, and Agafonova and Drobyshevskij (37.098.043) discussed the capture on Trojan orbits of objects ejected from the vicinity of Jupiter.

Schubart (32.098.019, 32.098.054) found a numerical way of determining a proper inclination for a Hilda-type minor planet and characterized the orbits of the librating Hildas by this and two other parameters.  Froeschlé and Scholl examined the stochasticity of peculiar orbits in the 2:1 Kirkwood gap (29.042.038) and systematically explored three-dimensional motion near the gap (32.098.004).  Scholl (31.098.098) also reviewed earlier results on resonant motion and the possibilities of using resonant motion for mass determinations.  In a general study of stability near resonance, Hadjidemetriou and Ichtiaroglou (31.098.106, 34.098.020) found that small stability regions of doubly-symmetric periodic orbits may be present near the generally unstable second-order resonances and that two separate regions, one stable and the other unstable, exist near the first-order resonances.  The stability of real 2:1 and 3:2 objects was also discussed by Kiang (31.098.099, 34.098.057).  Gerasimov (32.098.081, 33.098.002) made a qualitative analysis of the 2:1 resonance and developed short-period terms using the von Zeipel method.  Kazantsev and Sherbaum (37.098.030, 37.098.033, 37.098.105) examined the boundaries of the a-e zones and the question of the asymmetry of the Kirkwood gaps.  The main resonance features of the minor-planet belt showed up in a computer simulation by D'yakov and Reznikov (37.098.011).  Veres (32.042.065) compared with a numerical integration the results of a twice-averaged solution from the restricted three-body problem.  Perozzi (34.098.058) suggested that the reported increasing mean values of eccentricities and inclinations away from the gaps is due to a lack of highly eccentric and inclined objects near the gaps.

Torbett and Smoluchowski (31.042.113, 34.042.065) examined the sweeping effect on the 2:1, 3:1, 5:2 and 7:3 resonances induced by dissipation of an accretion disk; in the case of the 3:2 resonance the resulting accumulation of objects and ejection of objects nearby resembles the real situation with regard to the Hildas.  Dermott and Murray (33.098.015) also concluded that the Kirkwood gaps were formed after the minor planets had dispersed from the near-coplanar disk in which they accreted, while Henrard and Lemaître (34.098.015) discussed in detail the production of Kirkwood gaps from a displacement of the Jovian resonances following the removal of an accretion disk in the early stages of the solar system.  Colombo and Franklin (31.098.039) examined motion around the second-order resonances 3:1 and 5:3.  Wisdom (31.042.038, 34.042.066) developed a mapping for motions near the 3:1 commensurability and suggested that there occur sudden increases in eccentricity that could easily account for the Mars crossers and possibly even objects that come close to the Earth.  The general problem of stability regions and the capture of minor planets was evaluated by Szebehely, Vicente and Lundberg (34.042.119, 34.098.018, 34.098.019).

Analysis by Milani and Nobili of the depletion problem (34.042.076, *Astr. Ap.* in press) showed the insignificance of collisions in the outer part of the minor-planet belt, confirming the absence there of families and small objects generally. Recognizing the destabilizing effect of Jupiter's eccentricity, they discovered three cases of minor planets with mean distances near 3.7 AU where the difference in perihelion direction of the object and Jupiter librates (in the planar problem) and noted the clear influence of coupling of perihelion direction and eccentricity for objects down to a distance of 3.4 AU.

In the course of a numerical integration of the Lagrange secular equations for 2 Pallas, Taylor (31.098.001) noted the dominance of periods of 15 000 and 190 000 years and the retrograde circulation of the longitude of perihelion in a period of 544 000 years. Chen and Tong (33.098.119, 34.042.043) developed an expansion for the gravitational potential of the minor-planet belt. Williams (37.098.006) pointed out that some three dozen minor planets perturb Mars by up to 5 m and thus that some of their masses should be determinable from Viking lander ranging data.

Three papers by Zhuravlev and Kiryushenkov (30.098.090, 31.098.004, 31.098.073) were concerned with the discovery of faint minor planets and comparison of the statistics of the population of bright and faint objects. Taff (34.098.110) discussed the optimization of searches for minor planets. Michel (30.098.100) made a computer simulation of the dispersion of orbital inclinations. Knezević (32.098.016, 34.098.095) discussed observational selection effects, particularly those involved with the inclinations. Beck (32.098.076) compared the eccentricity distribution of minor planets with an empirical rule by Plummer.

Carusi and Valsecchi (32.098.043) stressed the need for consideration of the classification of Hirayama families in terms of both dynamical and other physical parameters. Kozai (34.098.017) applied to the numbered minor planets his criterion for the definition of families and drew a distinction between compact families and loose families bounded by secular and mean-motion resonances. Yuasa (34.098.026) used secular-perturbation theory to estimate the ages of the families.

Farinella, Paolicchi and Zappalà (30.098.069, 31.098.092, 31.098.093) studied the distribution of rotation rates of minor planets in terms of a complex and size-dependent collisional history and concluded (33.098.010, 33.098.037, 33.098.116, 33.098.117, 34.098.024) that all objects have undergone catastrophic collisional events; they paid particular attention (30.098.106) to a class of elongated, rapidly rotating objects and enunciated (34.098.041) the open problems concerning Hirayama families. Fujiwara (30.098.096, 33.098.011) attempted to reconstruct the parent bodies of the Themis, Eos and Koronis families using data from laboratory impact experiments and concluded that the parent bodies of the families were completely fragmented. The dependence of rotation rates of main-belt objects on both size and type was also studied by Dermott, Murray and Harris (31.098.011, 37.098.007), and some of their results were considered by R. Halling (34.098.052) in terms of gravitational compaction of porous matter and Alfvén-Arrhenius accretion theory. Dobrovolskis and Burns (37.098.064) proposed that the relatively slow rotation rates of intermediate-sized objects could be due to angular momentum drain from impacts. Barricelli (32.098.080, 33.098.131) discussed the tendency for the smaller bodies to have slower axial rotation and allowed for the effect of possible satellites. On the basis of elongated photographic images, Wang and others (30.098.011) proposed that 9 Metis possesses a satellite, but a careful examination by many astronomers (32.098.059, 33.098.062) at a subsequent favorable opposition apparently disproved the satellite's existence.

Batrakov (31.021.047) reviewed methods of computation of perturbations, and Khotimskaya (31.042.036) demonstrated the application of a combination of the Myachin-Sizova method and a uniform polynomial approximation process for the positions of the perturbing planets. Sitarski (34.042.124) adapted his recurrent power-series method to incorporate general relativistic effects.

Duncombe and Hemenway (31.031.529, 34.098.135) continued their examination of the combination of Space-Telescope and ground-based observations to probe the systematic accuracy of the fundamental reference system, and the use of minor planets in the Hipparcos astrometric project was discussed by Söderhjelm and Lindegren (31.041.034).

Using results from a restricted circular $n$-body study, Vashkov'yak (30.098.035)

constructed families of integral curves describing the orbital evolution of 944
Hidalgo, 2060 Chiron, as well as Apollo-type and other unusual objects.  Landgraf
(33.100.019) determined the masses of Saturn and Uranus from observations of Hidalgo
and Chiron.

Levin and Simonenko (30.098.075, 33.098.036, 37.098.013) continued their work
on interrelations of minor planets, comets and meteoroids and the inconclusive evi-
dence for the cometary origin of most Apollo-Amor objects.  Yamada (32.098.011) con-
sidered the influence of encounters with the Earth and Venus on possible cometary
progenitors.  Galibina and Kastel' (33.098.004) examined over an interval of 10 000
years the particularly plausible case of relationship of 2212 Hephaistos and P/Encke.
Fox, Williams and Hughes (37.098.062) investigated the orbital evolution of the
Geminid parent 1983 TB.  Hedervari (33.098.088) made a statistical comparison of the
orbital inclinations of Apollo-Amor objects and short-period comets.  Sitarski (34.
098.061) and Ziolkowski (34.098.062) have tended to conclude that nongravitational
effects are present in the motions of some minor planets, but this claim has been
disputed by both Landgraf and Marsden.  Drummond (31.098.037) published a list of
theoretical meteor radiants for Aten, Apollo and Amor objects, while Babadzhanov
and Obrubov (33.098.092, 34.098.063, 37.098.101) considered variations in radiants
due to secular perturbations.

## III.  COMETS

a)  DISCOVERIES, RECOVERIES AND ASTROMETRIC OBSERVATIONS
      During the interval 1981 July 1 - 1984 June 30, 10 long-period comets and 7 new
short-period comets were discovered, and 27 previously known short-period comets were
recovered.  Two of these were accidental rediscoveries of poorly observed one-appar-
ition comets which had been classified as hopelessly lost since 1846 (P/Peters-
Hartley) and 1945 (P/du Toit-Hartley).  The latter consisted at recovery of two com-
ponents separated by nearly $1^{\circ}$, with major changes in relative brightness resembling
the behavior of P/Biela in 1852.  Two additional comets were found on the exposures
with the SOLWIND coronagraph from 1981 January 27 and 1981 July 20 (Sheeley, Howard,
Koomen and Michels, 32.102.060).  Both comets apparently belonged to the Kreutz group
and may have collided with the Sun, like 1979 XI. Two comets were found on the
Southern Sky Survey plates from 1975 May 4 and 1978 March 5 by Eberst and Tritton
(31.103.007), but the images were only sufficient to determine the approximate direc-
tion of apparent motion.  Two discoveries that received provisional designations
1983a and 1984b turned out to be plate defects.  A comprehensive search by Nakano
(1984 *Japan Astr. Circ.* 409) revealed that 10 objects observed in 1940-1981 and pro-
visionally designated as asteroids were in fact known short-period comets.  In one
case, 1967 EU = P/Smirnova-Chernykh, the observation predates the discovery by 8 years.

Many discoveries of long-period comets still come from systematic visual searches
in which amateur astronomers play a leading role.  A majority of the discoveries, and
many ephemeris-aided recoveries of short-period comets, are due to large Schmidt
cameras: 5 of the discoveries or independent rediscoveries of short-period comets to
the 1.2-m Schmidt at Siding Spring (Russell, Hartley) and as many as 13 routine
recoveries to the 1.2-m Schmidt at Palomar (Gibson).  Many critical observations from
the southern hemisphere are made with the 0.6-m reflector at Mt. John (Gilmore, Kil-
martin).  The only consistently conducted program with a large long-focus reflector
(1.5-m at Oak Ridge, McCrosky et al.) continued to produce astrometric observations
of comets down to magnitude 19-20, including many last observations important for
orbit determinations.

Two modern search techniques, which may affect comet discoveries very substan-
tially in the years to come, were implemented for the first time in 1982 and 1983.
Replacement of a photographic plate by a CCD detector made it possible to increase
the effective sensitivity by a factor of 100, and to shift the detection limit to
24-25 mag.  This technique was successfully applied to the recovery of P/Halley

(by Jewitt et al. at Palomar; confirmed by Belton and Butcher at Kitt Peak and by Baudrand et al. at Mauna Kea: 1982 *IAU Circ.* 3737, 3742, 3753) and of P/Giacobini-Zinner by Djorgovski, Spinrad, Will and Belton at Kitt Peak (1984 *IAU Circ.* 3937). An early recovery of both of these comets was especially desirable in connection with the planned spacecraft missions Vega, Giotto, Planet A and ICE.

The other novel search technique was implemented by the Infrared Astronomy Satellite (IRAS) launched on 1983 January 26 (Davies, Green, Stewart, Meadows and Aumann 37.103.014; IRAS *Asteroid Workshops* 2 and 3, JPL, 1984). During the 9 months of operation of the Fast Moving Asteroid Detector, 6 new comets (4 of long period and 2 of short period) were discovered, and 5 known comets were observed. The evaluation of the IRAS data files is still in progress, and other comets may await identification.

An effective method of ground-based faint comet searches, making use of a CCD in a scanning mode, was proposed and discussed by Gehrels (30.031.061, *MPC* 9198). The selection effects controlling comet discoveries and the observed distribution of comet orbits were analyzed by Hughes (31.102.007, 34.102.002), Radzievskij and Tomanov (33.102.005), Potapov (33.102.090) and by Kresák (32.102.013), who also suggested a method of optimizing the searches for newly captured short-period comets.

Two long-period comets passed remarkably close to the Earth in May and June 1983. The encounter distance of 1983d IRAS-Araki-Alcock, 0.031 AU on May 11, is the smallest on record since P/Lexell in 1770, and that of 1983e Sugano-Saigusa-Fujikawa, 0.063 AU on June 12, the fourth smallest in this century. Owing to the exceptional configuration, the former became the brightest comet of the triennium ($m_1 < 2$), but without any conspicuous tail. Two other comets, 1982g Austin and 1984i Austin, were barely visible with the naked eye ($m_1 \simeq 5$).

A large-scale worldwide astrometric program was initiated as a part of the International Halley Watch (Rahe and Newburn, 32.013.057). For more detailed information, see *Proceedings of the Astrometry Network Workshop*, ESO, Garching, 1984, and *IHW Newsletter* Nos. 1-5. The network, coordinated by Discipline Specialists Yeomans, West, Harrington and Marsden, consists of 176 members from 35 countries. P/Halley remained accessible mainly to large telescopes equipped with CCD detectors, a total of 44 positions having been obtained (mainly at La Silla) from the recovery up to conjunction with the Sun in 1984 June. The preparatory work included production of a special reference star catalogue, including a total of 16175 stars from various sources. During a very successful trial run on P/Crommelin, 283 astrometric observations were received from 34 observatories. In contrast to this, only eleven observations of the unique P/Encke have been reported from between the 1980 and 1984 perihelion passages, in spite of its observability all along its orbit (1984 *IAU Circ.* 3934, *MPC* 9175, 9254). Another comet of special interest was P/Giacobini-Zinner, in connection with the planned rendezvous of the ISEE 3/ICE spacecraft.

The astrometric observations of comets published in the *MPC*s, together with the observations published in the *IAU Circs.* and in a number of other publications since 1964 (and in some cases earlier), have now been included in the machine-readable files issued by the IAU Minor Planet Center. The 1982 version of the magnetic tape contained 13 385 cometary observations, while the 1984 version contained 16 567. Some 10 000 additional pre-1964 observations are also available in machine-readable form at the Center, but they require some attention before they can be incorporated with the more recent observations. Observations appearing on the *IAU Circs.* can now be otained directly in machine-readable form, as the current *Circulars* can themselves be acquired by "dialing in" over a modem to the new CBAT computer service. A brief statistical analysis of the astrometric observations of comets from 1964 to 1984 was presented by Marsden (IHW Astrometry Workshop, 1984). Helpful information on the use of the telegraphic code for reporting new discoveries and on the use of plate constants in astrometric reductions was summarized by Marsden and Roemer (32.012.009).

b)   ORBITS AND EPHEMERIDES

The fourth edition of Marsden's *Catalogue of Cometary Orbits* (33.002.052)
includes orbital information for 1109 apparitions of 710 different comets, with a
number of auxiliary tables.  Preliminary and improved orbits and ephemerides of comets
have been computed and published routinely by the Central Bureau for Astronomical
Telegrams/Minor Planet Center.  The *MPCs* also regularly contain predicted orbits and
ephemerides for returning periodic comets; a reduced-precision tabulation of prelim-
inary predictions from 1982 to 1999 was published by Marsden and Roemer (32.012.009-
Appendix).  The same paper includes a listing of "original" and "future" $1/a$ values
for 220 long-period comets, classified according to the anticipated accuracy.  More
details on the recent computations of 28 "original" and "future" orbits were given
by Everhart and Marsden (33.102.014).  A catalogue of Tisserand invariants of comets
with respect to Jupiter and Saturn was compiled and analyzed by Artem'ev, Kitaeva,
Mamedov, Markova and Radzievskij (31.021.045, 31.021.047), and a catalogue of their
perihelion directions and nodal positions by Tomanov (33.102.003).  The distribution
of the perihelion directions of short-period comets was discussed by Kazantsev and
Sherbaum (34.102.068).

From among the orbit improvements for short-period comets, the following link
a number of revolutions: P/Grigg-Skjellerup and P/Wolf-Harrington by Sitarski (32.103.
121 and 32.103.801), P/Ashbrook-Jackson and P/Wolf by Kazimirchak-Polonskaya (32.103.
363 and 32.103.901), P/Schwassmann-Wachmann 3 by Belyaev and Shaporev (34.103.701).
The orbit of P/Halley was very carefully updated by Yeomans (IAU Coll. 83, 1984),
Savchenko (33.103.928), Akim, Savchenko and Stepan'yants (37.103.910) and Landgraf
(IHW Astrometry Workshop, 1984), and its ephemeris uncertainty estimated by Sukhanov
and El'yasberg (*Kosm. Issl.* 21: 6, 1984) and by Zadunaisky (IAU Coll. 83, 1984).
Emel'yanenko (33.102.007) has analyzed the uncertainties in the time of perihelion
passages of long-lost short-period comets.  For one of them, P/Schorr, the predictions
have been improved by de Vegt, Kohoutek and Marsden (32.103.661) by remeasuring all
available photographic plates from 1918 and recomputing the orbit.

Nongravitational effects in the motion of individual short-period comets were
determined by Landgraf (33.102.047), Forti (34.103.003), Todorovic-Juchniewicz (34.
103.006) and others.  Gyrdymov and Evdokimov (33.103.001) and Batrakov and Chernetenko
(IAU Coll. 83, 1984) have suggested a correlation between these effects and solar
activity.  Marsden (IAU Coll. 83, 1984) reviewed all the previous work in the theory
and numerical evaluation of nongravitational effects, and presented a classification
of short-period comets according to the character of these effects.  Some of the
implications were also discussed by Belyaev and Ivanovskaya (IAU Coll. 83, 1984).

Carusi, Kresák, Perozzi and Valsecchi have integrated the motion of all known
short-period comets back to 1585 and forward to 2406.  The main results are summarized
in an atlas of long-term orbital evolutions (*IAS Int. Report* 12, Rome, 1984); the
methods are explained and a preliminary general evaluation is presented in two sep-
arate papers (IAU Coll. 83, 1984).  One of the interesting conclusions is that P/Van
Biesbroeck and P/Neujmin 3 are apparently fragments of a single comet which split
apart a few years before a close encounter with Jupiter in 1850 (*IAU Circ.* 3940,
1984).  Contrary to the earlier views of Öpik (06.102.025) and others, similar geneti-
cally associated pairs or groups of detached components seem to be totally absent
among the known long-period comets, as demonstrated by Kresák (31.102.052) and Lind-
blad (IAU Coll. 83, 1984).  The only exception is the Kreutz group, with 11 members
known at present.  The dynamical criteria of orbital similarity between different
types of interplanetary objects were discussed by Kresák (31.102.012).

The motion of seven comets that spent some time near the 2:1 resonance with
Jupiter (P/Lexell, P/Tempel-Swift, P/Wirtanen, P/Kohoutek, P/West-Kohoutek-Ikemura,
P/Haneda-Campos and P/Wild 2) was integrated by Vaghi and Rickman (31.102.048) to
evaluate the role of a repeated encounter mechanism.  Integrations of the motion of
the two comets librating around the 1:1 resonance (P/Boethin and P/Slaughter-Burnham)

extending over two millennia have been carried out and analyzed by Benest, Bien and Rickman (34.103.009). The same authors have also studied the capture of P/Boethin by Jupiter (31.103.741, 34.103.240). By backward integration of the motion of all known short-period comets with high values of the Tisserand invariant, Carusi and Valsecchi (31.102.026, 31.102.046) have identified a number of temporary satellite captures, which apparently represent a rather frequent phenomenon. Carusi, Kresák and Valsecchi (31.042.130) have shown that a limiting value of the invariant, $2\sqrt{2}$, splits the comets into two families, those that can be ejected on hyperbolic orbits but cannot be captured into satellite orbits, and those for which the situation is reversed.

Rickman and Karm (31.102.047, 32.103.016) have developed a method for identifying close planetary encounters using unperturbed Keplerian orbits. An application to all known short-period comets enabled them to estimate the frequency of such events. A quick method for estimating the perturbing effects at close encounters, suited to maximize the yield of Monte Carlo simulation experiments, was devised by Rickman and Froeschlé (33.102.042). An interesting possibility of assessing the previous orbital evolution of Earth-approaching comets from the observed structure of meteor streams associated with them was proposed by McIntosh and Hajduk (34.104.003) and by Hajduk (IAU Coll. 83, 1984).

The current status of orbit determinations was reviewed by Kazimirchak-Polonskaya and Belyaev (IAU Coll. 83, 1984). The RADAU integrator, which has proven very efficient and accurate for the integration of comet orbits, was tested and compared with other integrators by Everhart (IAU Coll. 83, 1984). The local and propagated errors of numerical integrations were discussed by Milani and Nobili (IAU Coll. 83, 1984), and the subtle dynamical and observational effects inherent in the underlying data by Sitarski (34.098.061). Todorovic-Juchniewicz (34.102.026) has determined the perturbing effects of the three largest minor planets on 53 comets. Optimum targets for future space missions from among the short-period comets were identified and evaluated by Yeomans (IAU Coll. 83, 1984).

c) MODEL COMPUTATIONS, EVOLUTION AND ORIGIN

Potential evolutionary tracks from different reservoirs into the Jupiter family of comets were reviewed by Carusi and Valsecchi (IAU Coll. 83, 1984). Transitions between different types of cometary orbits starting in the Oort cloud were discussed by Everhart (32.102.032) with emphasis on the connecting links between individual regimes of chaotic motion, and by Kresák (31.102.042) with emphasis on the stepwise capture at low-velocity encounters with the outer planets. Modeling experiments on low-velocity encounters with Jupiter revealed distinct families of evolutionary patterns of widely different occurrence rate (Carusi, Kresák and Valsecchi, 31.042.130; Carusi and Valsecchi, 31.102.045), which are substantially different from the symmetrical patterns appearing at higher velocities (Carusi, Kresáková and Valsecchi, 32.103.831, 34.103.221). A family of temporary satellite captures by Jupiter, of the type of P/Gehrels 3, was investigated in detail by Rickman and Malmort (31.102.049). Statistical results of computer simulations of 1000 close encounters of minor bodies with each of the four outer planets were presented by Carusi and Valsecchi (31.102.046).

While the concept of stepwise capture clearly implies temporary binding of cometary perihelia to individual outer planets, there is little consensus as to the irregularities in the distribution of their aphelion distances. Some authors attribute them to the existence of comet families produced by eruptions on these planets, their satellites, or even transplutonian planets (Vsekhsvyatskij, 33.102.064; Vsekhsvyatskij and Demenko, 32.102.070, 33.102.010; Vsekhsvyatskij and Guliev, 33.101.026, 33.102.027; Guliev, 32.102.066, 34.102.063); but others present dynamical and statistical arguments against (Kresák, 33.101.026; Tomanov, 33.102.001, 33.102.045, 33.102.063, 34.102.049).

Bogart and Noerdlinger (31.102.051) and Khanna and Sharma (34.102.043) have

re-examined the distribution of the orientations of the orbits of long-period comets, and concluded that there is a significant relation to the galactic plane and to the solar apex. Lüst (IAU Coll. 83, 1984) has shown that there are major differences in this respect between dynamically old and new comets. All of these authors and Kresák (32.102.013) have pointed out local anisotropies, which limit the use of an ellipsoidal analysis. The aphelion clustering of new comets is attributed by Biermann, Huebner and Lüst (34.102.072) to recent star tracks through the Oort cloud, and Delsemme (IAU Coll. 83, 1984) considers two additional possibilities: the presence of an unseen companion of the Sun, and a grazing incidence of a giant molecular cloud 3 to 30 million years ago. Babenko (34.102.009) finds the observed distribution of binding energies of new comets inconsistent with the expected stellar perturbations in perihelion distance. Nakamura (37.102.061) has checked the random character of the sequence of perihelion passages of long-period comets over two centuries.

Shteins and Salitis (37.102.012) have developed the theory of diffusion of comets, including a method of computation of the distribution of velocity perturbations by passing stars (Salitis, 33.102.006). Numerical simulations of this process have been performed and analyzed by Yabushita, Hasegawa and Kobayashi (32.102.002); Scholl, Cazenave and Brahic (32.102.004); Weissman (32.107.008, 33.102.034, IAU Coll. 83, 1984); Mignard and Remy (IAU Coll. 83, 1984). Galactic perturbations on the Oort cloud of comets were investigated by Byl (34.102.042). Fernández (31.102.041, 31. 102.043) and Weissman (Protostars and Planets II, Tucson, 1984) have followed the dynamical evolution from different birthplaces to check the plausibility of different theories of comet origin. The possible processes of comet formation were reviewed by McCrea (32.012.059) and Greenberg (IAU Coll. 83, 1984).

The main arguments against the classical concept of the Oort cloud as a primordial part of the solar system concern its potential survival time, and its adequacy to replenish the inner cometary zone. The long-term stability of the cloud was questioned especially due to the tidal forces experienced during encounters with molecular clouds, and these clouds were also suggested as a source of episodic replenishment by new comets (Napier and Staniucha, 31.107.001; Napier, 31.102.044, 32.102.084, IAU Coll. 83, 1984; Clube, 32.102.082, 34.102.036, IAU Coll. 83, 1984; Clube and Napier, 33.102.033). This, however, would require dense clouds of extremely low encounter velocity and small velocity dispersion (Valtonen and Innanen, 31.102. 006), or assistance of an unseen companion of the Sun (Valtonen, 33.102.023). Present quantitative data about the molecular clouds are not sufficient to be sure about the destruction rate of the Oort cloud; Weissman (33.102.034) finds it low, and estimates the total depletion of the Oort cloud over the history of the solar system at 85%. Some authors agree with the disruptive effects of the molecular clouds but not with the replenishing ones, and suggest a substantial inner concentration of comets in the region of the outermost planets or not far beyond. This would be sufficiently stable against disruption and could regenerate the outer envelope (van den Bergh, 32.107.038; Bailey, 33.102.019, 34.102.003). The inner concentration may include 99% of the total mass of the cloud and feed the inner planetary zone only at the time of close star passages (Hills, 30.102.049). Bailey (34.102.038) also suggests three methods by which the concentration could be detected: by the total gravitational effects on other bodies, by the infrared emission, and by monitoring of selected stars for occasional occultations. The presence of an inner concentration would alleviate the problem of a source from which enough objects could be perturbed into short-period orbits (Fernández and Ip, 33.102.058, 34.102.039; Fernández, IAU Coll. 83, 1984). The nature of the concentration, together with the limited knowledge of the size distribution of comets, is the main source of uncertainty in present estimates of the total mass of the comet population (Biermann, 31.102.054; Weissman, 33.102.013, IAU Coll. 83, 1984).

Another open question is the effect of limited physical lifetimes of comets on the distribution of their binding energies. Current physical theories of cometary nuclei predict relatively slow fading rates, which cannot account for the $1/a$ distri-

bution anomalies (Yabushita, 34.102.005, 34.102.051; Bailey, IAU Coll. 83, 1984;
Weissman, IAU Coll. 83, 1984). Observational identification of the cases of extinc-
tion of comets during their apparitions (Kresák, 37.103.029; Sekanina, 37.102.073)
suggests rather short lifetimes of long-period comets. There is also a major dis-
crepancy between the observed and expected rate of brightness decrease of short-
period comets (Hughes and Daniels, 33.102.021) and a significant difference between
the mass distributions of long- and short-period comets (Hughes and Daniels, 31.102.
003). Unfortunately, the underlying data are strongly biased by observational selec-
tion. The problem of comet fading and survival times was reviewed by Kresák (IAU
Coll. 83, 1984).

Until recently it was widely believed that the ultimate fate of almost all comets
is a total disintegration at the time of extinction. A real breakthrough was presen-
ted by the recent discovery of several Apollo and Amor minor planets moving in comet-
like orbits (1982 YA, 1983 LC, 1983 SA, 1983 VA, 1983 XF, 1984 BC, 5025 P-L), and of
one (1983 TB) which may be the missing parent body of the Geminid meteor stream
(Whipple, 34.104.033; Williams, Fox and Hunt, IAU Coll. 83, 1984; Fox, Williams and
Hughes, 37.098.062). In the latter case the meteoric debris have physical properties
quite similar to those of active comets, in spite of a definitely asteroidal aphelion
distance of only 2.40 AU. While the orbits of the new comet-like planets are not yet
known with an accuracy that permits a large extrapolation, perturbation integrations
do not reveal any significant differences from active comets (Benest, Bien and Rick-
man, IAU Coll. 83, 1984). Comparative long-term integrations for the minor planets
2212 Hephaistos and P/Encke were carried out by Galibina and Kastel' (33.098.004),
and the existence of a family of Encke-like orbits was discussed by Clube (32.102.082)
and Napier (34.102.040). Sitarski (34.098.061) and Ziolkowski (34.098.062) have
found indications of weak nongravitational effects in the motions of three Apollo
planets (1566 Icarus, 1685 Toro, 1862 Apollo) and one main-belt object (1162 Larissa),
but the findings have been disputed by both Landgraf and Marsden. Various aspects
of the comet-minor planet relationship were discussed by Degewij and Tedesco (32.102.
033), Hughes (32.102.083), Kresák (32.098.039, 33.098.035) and Rickman (IAU Coll. 83,
1984).

Close encounters and collisions of comets with the Earth were statistically
evaluated by Sekanina and Yeomans (37.102.003). Their estimate of 2 to 3 impacts
per $10^7$ years is only 20% higher than the previous estimate by Kresák (21.098.042),
the difference being apparently due to updating the statistics by the inclusion of
the recent encounters with comets 1983d and 1983e. They also confirm the cutoff in
the absolute magnitude distribution of long-period comets; this may be responsible
for considerable overestimates of the total population of the Oort cloud through over-
correction for undiscovered faint objects. The collision rate of comets is similar
to the repetition rate of episodic terrestrial catastrophism, as revealed by the
global-scale geochemical anomalies and mass extinctions (Shoemaker, 33.105.230).
However, the latter also agrees with the frequency of solar system passages through
the mid-plane of the Galaxy and its encounters with the giant molecular clouds (Clube
and Napier, 31.107.003, 37.102.047; Clube, 34.102.036). The impact rates of comets
are appreciably smaller than those of the minor planets. Weissman (*Geological Soc.
of America Spec. Paper* 190, 15, 1982) estimates the share of Earth cratering at 10%
for long-period comets, 20% for short-period comets and 70% for Apollo-type minor
planets. Zimbelman (37.102.004) concludes that 3% to 9% of the large craters (d >
10 km) on terrestrial planets are due to long-period comets, and that the crater
production rate is quite similar throughout the planetary system. The influx of
comets and minor planets on the Earth is also discussed by Hughes (31.102.023).

A study of cometary impacts on the Sun by Weissman (34.102.011) has shown that
there is no dynamical explanation for the very small perihelion distance, $q = 0.35\ R_\odot$,
of comet 1979 XI, and suggests that the problem may be errors in the measured posi-
tions or in the solution for the orbital elements. Whipple (33.102.031) suggests
that the violent outbursts of P/Holmes in 1892 and P/Tuttle-Giacobini-Kresák in 1973

were due to collisions of a cometary satellite with its primary.  His scenario pre-
sumes a grazing encounter followed by destruction of the satellite at the next peri-
comet passage.

The cloud of particulate material discovered by IRAS around Vega and some other
main sequence stars may represent an analogy to the inner Oort cloud, and the lack
of warm dust closer to each star suggests that planets may have formed and swept out
the dust, as suggested by Weissman (*Science* 224, 987, 1984).  The possibility of
comets revolving in double and multiple star systems was discussed by Dvorak (IAU
Coll. 83, 1984).

## IV.  SATELLITES

### a)  ASTROMETRIC OBSERVATIONS

Rohde, Ianna, Stayton and Levinson (31.099.089) published astrometric observa-
tions for satellites of the outer planets made in 1978-1979, 1980 and 1981 at the
Leander McCormick Observatory, a total of 1032 pairs of spherical-equatorial coordin-
ates and 1316 intersatellite positions being reported.  Debehogne and Houziaux (32.
099.111) gave positions for the Galilean satellites observed in April 1979 at ESO.
Ianna's group is continuing their astrometric observations of brighter satellites of
Jupiter, Saturn, Uranus and Neptune at the McCormick Observatory and with the Yale-
Columbia refractor at Mt. Stromlo.  Bocşa started astrometric observations of Jupiter
and its Galilean satellites, photographing the five bodies with the 0.38-m astrograph
at Bucharest Observatory; observations made in 1982 have been reported.

Harrington and Walker (37.101.021) reported positions of satellites of Uranus
and Neptune relative to their respective planets during oppositions of 1979, 1981,
1982 and 1983.  Their plates were taken with the 1.55-m reflector in Flagstaff, the
planet being occulted with neutral density spots for magnitude compensation.  The
positions of the satellites of Uranus were sent to the Jet Propulsion Laboratory for
use in planning for the 1986 flyby mission.

Pascu made photographic observations of satellites of Mars, the Galilean satel-
lites of Jupiter, and Saturnian satellites I through VII with the 0.66-m refractor
and with the 1.55-m reflector at Flagstaff.  Pascu, Seidelmann, Baum and Schmidt
(32.031.546, 34.091.048) observed Jupiter XIV, Saturn XII, XIII and XIV and the
satellites of Uranus and Neptune using the Space Telescope Wide-Field Planetary
Camera Ground-Based CCD system on the 1.55-m reflector.

Veillet and Martins (*IAU Circ.*3940, 1984) reported their observations of Saturn
XII and the Tethys Lagrangian satellites, S XIII and S XIV on 1984 April 12-19 with
the Danish 1.5-m reflector at ESO and gave the following data for the orbital separa-
tions: S XII-Dione = $+74^\circ\!.6$ (36 measurements), S XIII-Tethys = $+61^\circ\!.3$ (11 measurements)
and S XIV-Tethys = $-65^\circ\!.0$ (25 measurements), the standard deviations being roughly $0^\circ\!.6$.

The following observations made in the USSR were published: observations of the
Galilean satellites in 1976-1978 with the normal astrograph at Pulkovo by Bronnikova
and Kiseleva (32.099.151); observations of the Galilean satellites and bright satel-
lites of Saturn in 1976-1979 at the Nikolaev Observatory by Voronenko and Gorel' (32.
099.007); observations of the Galilean satellites in 1977-1978 at the Engelhardt
Astronomical Observatory by Nefed'ev and Chugunov (37.099.072); observations of the
Saturnian satellites in 1977-1978 at the Engelhardt Observatory by Chugunov (37.100.
060), and those in 1980 and 1981 by Kitkin and Chugunov (32.100.012, *Izv. AEO* No. 48,
96, 1984); observations of the Galilean satellites in 1975 at the Goloseevo Observa-
tory (Kiev) by Levitskaya (31.099.051); observations of Deimos in 1978 at Goloseevo
Observatory by Major and Sereda (*Ref. Zh. Astr.* 3.51.115, 1984).

Several attempts have been made to separate Charon, a possible satellite of
Pluto, from the planet.  For example, Reitsema, Vilas and Smith (34.101.019)

reported that images obtained with a CCD detector attached to the 1.54-m Catalina
telescope of the University of Arizona on 1980 February 3 showed an elongation caused
by the satellite.  Analysis of the data separated the planet and satellite components,
yielding a Pluto/Charon brightness ratio of 5.5.  Hege et al. (32.101.002) and Hege
and Drummond (*IAU Circ.* 3986, 1984) have applied the technique of speckle interfer-
ometry to observations of the Pluto-Charon system and reported corrections to the
ephemeris of Harrington and Christy (29.101.011).  Speckle interferometric observa-
tions have also been reported by Hetterich and Weigelt (34.101.007).  Mulholland and
Binzel (37.101.020, *A.J.* 89,1759, 1984) discussed the expected eclipse phenomena,
which had not yet started in 1983.

b)  MOTIONS OF SATELLITES
     Mutual phenomena of Galilean and Saturnian satellites have been used to improve
their orbital elements.  Aksnes et al. (37.099.008) gave astrometric data derived
from photoelectric observations of mutual occultations and eclipses of the Galilean
satellites in 1973 and 1979/1980 and of four Saturnian satellites in 1980, with
accuracy approaching 0".01.  Orbital elements based on these data and derived by using
radii of satellites measured by the two Voyager spacecraft are in generally good
agreement with other recent analyses.  Some of the observations used were reported
by Arlot et al. (32.099.001).  Dourneau (32.100.007) observed two mutual events of
Saturnian satellites, S III partially occulting S IV on 1980 April 5, and S V parti-
ally eclipsing S III on 1980 April 20, finding that the two events occurred, respect-
ively, about 1 min and 3 min in advance of the predictions by Aksnes and Franklin
(1978).  It was concluded that a small difference could exist between observed and
theoretical longitudes for S III, Tethys, which was involved in both events.

     Aksnes and Franklin (*Ctr. for Ap. Preprint* No. 1987, 1984) gave predictions for
nearly 300 observable mutual eclipses and occultations of the Galilean satellites
expected between 1985 May and 1986 April.  Predictions for the 1985-1986 events were
given also by Arlot (*Astr. Ap.* 138, 113, 1984).

     Arlot, Morando and Thuillot (*Astr. Ap.* 136, 142, 1984) rediscovered an important
set of old observations of the Galilean satellites that form a part of the eclipse
observations collected by Delambre; some 845 mutual phenomena of Io between 1775 and
1802 are included in their list.  Lieske (34.099.028) examined the Delisle manuscript
and the Pingré book and recorded and reduced the observations listed there.  He now
has more than 6800 eclipse observations of the Galilean satellites before 1800 and
over 16 000 prior to 1982 and has shown the usefulness of such observations for the
adjustment of the theory, particularly for the correction of the mean motions.

     Tsuchida, Ferraz-Mello and Biancale (31.099.090) discussed the accuracy of photo-
graphic observations of the Galilean satellites of Jupiter in the interval 1913-1928
and showed that the residuals are generally very small, 0".06 to 0".08 in the mutual
distances.  Arlot (31.099.038) calculated new constants for the Sampson-Lieske theory
of motion of the Galilean satellites by using a set of 8856 photographic observations;
comparison was made with observations of mutual phenomena in 1979.

     Thuillot and Vu (34.099.112) reported the development of a first approximation
of an analytical theory for the Galilean satellites using Sagnier's method, the
results being reduced to numerical tables of longitude, radius vector and latitude
for easy comparison with Sampson's or Lieske's tables.

     Rocher (33.099.052) computed ephemerides of Jupiter's satellites, J VI and J VII,
for the years 1981-1990 by a numerical integration method and by fitting observational
data analogous to that used by Bordovitsyna and Bykova (1978).

     Boronenko and Schmidt (Tomsk University) continued to work on a theory of the
motion of distant satellites using the Lie transformation technique; they plan to
apply it to Jupiter VI, VII, X and Saturn IX.

Bec—Borsenberger and Rocher (32.100.083) collected the topocentric observations of Phoebe (S IX) from 1904 to 1981 and obtained initial integration constants adjusted with these observations.  They then made a numerical integration up to 1990, taking into account perturbations by the Sun and Titan, and computed an ephemeris for the ten years 1981-1990.  Bykova and Shikhalev (37.100.019) analyzed observations of 1898-1981 and derived new orbital elements of Phoebe which represent observations with a mean error of 1".5.

Zhang and Liu (32.100.104) surveyed the theory of motion of Hyperion (S VII). Taylor (*Astr. Ap.*, in press, 1984) used astrometric observations of Hyperion from 1967 to 1982 to derive values of parameters of Woltjer's theory for a best fit to the modern data.  He found, however, that there are significant inadequacies in the theory.  Accordingly, Sinclair and Taylor have tried to fit a numerical integration of the motions of Titan, Hyperion and Iapetus to the modern data, obtaining a much better fit to the Hyperion data and a good determination of various physical parameters of the system.

Yoder et al. (33.100.047) presented a simple analytical theory describing the 1:1 orbital resonance and applied it to the Saturnian co-orbiting pair, 1980 S1 (S X) and 1980 S3 (S XI).  These small satellites can approach within 15 000 km, but they are prevented from passing each other by their mutual gravitational interactions. Long-term stability was also discussed, and a tie was established between the 1966 and 1980 observations of the two satellites.

Chugunov (32.100.016, 33.100.060, 33.100.061, *Ref. Zh. Astr.* 11.51.65, 1983; *Ref. Zh. Astr.* 12.51.73, 1983; *Ref. Zh. Astr.* 4.51.266, 1983; *Ref. Zh. Astr.* 4.51.120, 1984; *Ref. Zh. Astr.* 6.51.179, 1984) determined new orbital elements and masses of Saturnian satellites S I - S VI as well as the mass of Saturn and the values of J2 and J4 by using 28 500 observations.

Thuillot (34.099.032) proposed a new method to derive compact sets of ephemerides of various phenomena of the Galilean satellites by calculating a Chebyshev representation; 15 coefficients give a representation of each type of phenomenon for one satellite for one year with a precision better than 51 seconds.

The Bureau des Longitudes, Paris, publishes each year in the *Connaissance des Temps* the positions of the planets and the four Galilean satellites of Jupiter developed into Chebyshev polynomials, and in its *Supplements* the configurations and phenomena of the Galilean satellites, the positions of the first eight satellites of Saturn, and the positions of J VI, J VII, J VIII, J IX and S IX developed also into Chebyshev polynomials.

Veillet (33.101.004) gave 112 positions of Miranda relative to Uranus in 1980-1981 and confirmed an inclination which agrees with the value found by Whitaker and Greenberg from observations in 1948-1972.  However, the eccentricity derived is very small.  A more extended study, using Van Biesbroeck's data from 1948-1949 as well as all published positions of Miranda (300 points), confirmed all the orbital elements obtained except for those linked to the eccentricity, for which the value found was 0.0021±0.0005.  The masses of Ariel and Umbriel were derived by using the values of J2 and J4 derived from the apsidal precession rates of the rings and the nodal precession rate of Miranda.

Veillet (32.101.005) used a series of observations of Nereid made with the Danish-ESO 1.5-m reflector in 1981 April, together with two unanalyzed plates taken at the McDonald Observatory in 1977 and 1978 to determine orbital elements of Nereid and the mass of Neptune.

c)   THEORETICAL STUDIES OF SATELLITE MOTIONS
     Most theoretical studies of satellite motions have been devoted to the question

of dynamical evolution of the orbits, considering such topics as capture mechanisms and the effect of resonances.

Tanikawa (33.042.024) proved the impossibility of the capture of retrograde satellites in the frame of the circular planar restricted problem of three bodies. Huang and Innanen (34.042.037) explored numerically the stability and capture region for retrograde jovicentric satellites in the frame of the restricted three-body prob-lem and derived the value of the Jacobian constant for the greatest probability of temporary capture.

Szeto (34.097.008) examined the role of tidal dissipation within the Martian satellite system and assessed theories of origin through calculations of collision probabilities between Phobos and Deimos in the distant past.  An accretion model is preferred over capture, although no such model consistent with the likely carbonaceous chondritic composition of the Martian satellites has yet been established.

Henrard (33.099.020) reexamined Yoder's scenario (25.099.047) for the capture into resonance of the first three Galilean satellites by introducing a more refined dynamical model for resonance and tidal effects.  Gailitis (32.099.099) showed that the limited energy of the radial motion has preserved Io from a runaway type of melting as the energy-momentum balance relates tidal heating to orbital expansion as in Yoder's secular equation.

Sinclair (34.100.023) critically reviewed the hypothesis that the origin of the resonances among the Saturnian satellites is due to orbital evolution caused by tidal dissipation within the planet.  He concluded that the hypothesis provides a plausible explanation for the origin of the Mimas-Tethys resonance, but it is unsatisfactory for Enceladus-Dione, since their resonance now has little effect on the relative evolution rate of these satellites.

Poirier, Bolah and Chambon (34.100.014) investigated tidal dissipation in a viscoelastic homogeneous sphere having the orbital and physical characteristics of the icy inner satellites of Saturn and found that tidal dissipation with current orbital eccentricity cannot account alone for the surface activity observed on Encel-adus if it is composed of water ice.  Lissauer, Peale and Cuzzi (37.100.051) argued that the angular momentum transfer between Enceladus and Janus could have sufficiently enhanced the eccentricity of Enceladus' orbit for tidal heating to have melted the interior of Enceladus if Janus were ever locked into a stable 2:1 orbital commensur-ability with Enceladus.  The rapid time scale for dynamical evolution of the ring and inner satellites as presently situated remains a major problem.

Farinella et al. (33.100.089) proposed that the peculiar orbital motion of Hyperion, characterized by a strong orbit-orbit resonance with Titan, was responsible for the ineffectiveness of the process of repeated reaccretion from narrow rings of collisional fragments proposed for the other satellites.  The irregular shape of Hyperion thus stands in contrast to the regular figures of the other small satellites of Saturn.

Pauwels (34.100.005) studied the Rhea-Titan secular resonance as a special case of secular orbit-orbit resonance.  Taking into account both masses, it was shown that in the Rhea-Titan case, the resonance is dominated by the effect of the large difference between the proper precession rates of the lines of apsides of the two satellites.

Sinclair (*Astr. Ap.* 136, 161, 1984) examined the effects of orbital resonances on satellites in tadpole or horseshoe orbits relative to Mimas, Enceladus, Tethys or Dione and concluded that a tadpole companion of Enceladus would be the most highly perturbed.  Although the perturbations would not cause instability, they might prevent the initial formation of a satellite in such an orbit.  Tadpole companions of Mimas

would have large forced eccentricities, which would probably prevent the simultaneous existence of horseshoe orbits.  He also examined the effects of tidal forces, which were found to cause a small displacement of the L4 and L5 equilibrium points.

d)  DYNAMICS OF RINGS
      Study of the dynamical processes that cause the complex structural features of rings, such as those manifested by the narrow elliptic rings of Uranus and the F ring of Saturn, as well as the spokes in the Saturnian rings, has been an extremely active field during the triennium.  Reviews have been published by Goldreich and Tremaine (32.091.025) and by Cuzzi (37.091.052).  IAU Colloquium No. 75, held in Toulouse in September 1982, was devoted entirely to the subject of planetary rings.  The proceedings of the colloquium, containing contributed papers and also the discussion, have been edited by Brahic and published in 1984 under the title *Anneaux des Planetes/ Planetary Rings* by Cepadues-Editions on behalf of CNES, the French space agency.  A second book, based on a set of review papers selected from among those presented at Colloquium No. 75, has been edited by Greenberg and Brahic and published in 1984 under the title *Planetary Rings* in the Space Science Series of the University of Arizona Press.  The material in this second book has been carefully reviewed and refined, and reflects the results of investigations published in 1983.  Since full lists of literature citations are given in both books, mention is made here of only a few of the most recent studies.

      Borderies, Goldreich and Tremaine (34.042.039) extended their investigations of the evolution of eccentric rings under the influence of differential precession due to the oblateness of the planet, self-gravity, viscous forces due to interparticle collisions, and eccentricity excited by shepherding satellites.  They concluded that uniform precession can be enforced by self-gravity, the resulting configuration being both secularly and dynamically stable, that due to viscous forces the line of the apse at the inner ring edge is not exactly aligned with the line of apsides at the outer edge, the apse shift being detectable in the α- and β-rings of Uranus, and that the mean eccentricity is determined by a balance between viscous damping and excitation by shepherding satellites.

      Lissauer (37.100.002) has studied ballistic mass transport in Saturn's rings, developing an analytic model that includes the effects of angular momentum advection. He showed that net material movement due to angular momentum advection is comparable to that caused by direct ballistic transport.

      Seidelmann, Harrington and Szebehely (37.100.052) studied the dynamics of Saturn's E ring, which extends from three Saturn radii, the orbit of Mimas, to at least eight Saturn radii, just inside the orbit of Rhea.  Although the brightness profile has a peak at the orbit of Enceladus, there are apparently not corresponding peaks at the orbital distances of Tethys or Dione.  It is known that there are satellites at the Lagrangian points of Tethys and Dione within the E ring.  Thus the E ring is not constrained by satellites, but rather co-exists at the same orbital distances as satellites, which have other satellites at their Lagrangian points.  A discussion of preliminary numerical and analytical investigations of the motions of the ring particles is given.

V.  PREDICTION OF OCCULTATIONS

a)  IDENTIFICATION OF EVENTS
      The number of minor planets whose orbits have been investigated by Taylor for occultations has risen to approximately 200.  Ephemerides for Ceres, Pallas, Juno and Vesta were provided by H M Nautical Almanac Office, and an ephemeris of Nemausa was supplied by Kristensen and Møller.  Ephemerides of all other minor planets were generated at the Royal Greenwich Observatory from osculating elements supplied by Shor, Institute for Theoretical Astronomy, Leningrad.  All these ephemerides have been searched against a combined AGK3 + SAO star catalogue by Taylor, who issued

predictions for suitable occultations in *Bulletins* circulated to members of the Working Group. Predictions up to the end of 1985 have been issued in this manner. Predictions for 1984 and 1985 have also been issued by Wasserman, Bowell and Millis (34.096.012) and by Millis et al. (37.096.017). Supplementary calculations have been carried out by D W Dunham, International Occultation Timing Association, and issued, along with other data, in IOTA's *Occultation Newsletter*. Tabulations of possible events involving minor planets have appeared annually in the *Handbook of the British Astronomical Association*, in the January issue of *Sky and Telescope*, and in several other publications.

Searches for occultations of faint stars (not AGK3 or SAO) have been intensified, particularly for occultations by Uranus, Neptune and Pluto (Mink and Klemola, *A.J.*, in press). Searches for occultations by comets are now being made on a routine basis, particularly those involving P/Halley. Predictions are given by Taylor (37. 103.914), and by Bowell and Wasserman (*IHW Newsletter*, No. 5, 1984).

Since star positions based on the AGK3 and SAO catalogues commonly involve errors of 0.6-0.8 arcsecond and more at the current epoch, these catalogues are not suitable as a basis for precise predictions. It has been the practice to engage in "last-minute" astrometry as the basis for refinement of the expected ground tracks. However, in a substantial number of cases, the actual paths of occultation events are far from contact with the Earth. At least semi-precise (to 0.3-0.5 arcsecond) measurements of positions of stars involved in events predicted on the basis of the AGK3 and SAO star catalogues would permit weeding out of the obvious non-events at an early stage. This work could be done at leisure, requires relatively modest equipment, and would have the valuable effect of conserving resources for the high-precision last-minute astrometry for the more certain events.

b) "LAST-MINUTE" PREDICTION IMPROVEMENT
Experience with "last-minute" astrometry during the report period has tended to reinforce the view that only the AGK3R and SRS (or Perth 70) catalogues, each with a density of about one star per square degree, contain stellar data accurate enough at current epochs to provide a suitable reference frame for this demanding work. The astrograph field must be large enough to include several of these stars, yet also have a plate scale adequate for accurate measurements. Schmidt cameras do not yield satisfactory results because of the number of stars needed to determine the higher-order plate constants; the AGK3R and SRS catalogues are not dense enough to give the needed coverage. Good results have been obtained with the 13-inch astrograph at the Royal Greenwich Observatory (Taylor). But the best and most consistently satisfactory results during the report period were those obtained with the 0.5-m Carnegie double astrograph at the Lick Observatory (Klemola), due in part to the wide field and favorable plate scale of that telescope. Long-focus instruments, such as the 1.55-m astrometric reflector at the U S Naval Observatory, Flagstaff, and the 1-m reflector and 26-inch Clark refractor at the University of Virginia (McNamara), also gave good results when the positions of secondary reference stars were measured from Lick plates. In general, better accuracy was achieved when several exposures were measured.

The photoelectric transit telescope at Bordeaux, France, has proved to be an alternate source of accurate data for improving predictions of minor planet occultations. The observations can be made farther in advance of events, since star and minor planet are not limited to the same field. Both objects must be brighter than 13th magnitude, and both must cross the meridian in a dark cloudless sky during several nights of the few weeks preceding the event.

Arrangements have been made with Candy at Perth for astrometry involving stars in the southern hemisphere, but at least one more southern astrometric station is needed.

c)   OBSERVATIONS AND DIAMETERS

     An historical review and report on the status of observations of occultations
by minor planets through the end of 1981 was given by Maley (33.098.020).  Millis
et al. (34.098.104) have given a brief overview of recent progress and of prospects
for the future.

     Events well enough observed since those listed in the previous report of the
Commission to permit the derivation of useful diameter information include the
following:

|  |  |  |
|---|---|---|
| 375 Ursula | 1982 Nov. 15 | 6 chords: Texas, Utah<br>R L Millis et al., 37.098.032 |
| 93 Minerva | 1982 Nov. 22 | 20 chords: Arizona, Michigan<br>L H Wasserman et al., 34.098.106 |
| 106 Dione | 1983 Jan. 19 | 10 chords: The Netherlands, Germany, Denmark<br>L K Kristensen, 37.098.100 |
| 52 Europa | 1983 Apr. 26 | 6 chords: Texas, New Mexico, Arizona |
| 2 Pallas | 1983 May 29 | 130 chords: USA<br>D W Dunham et al., 34.098.105 |
| 51 Nemausa | 1983 Sept. 11 | 55 chords: USA<br>E W Dunham et al., *A.J.* 89, 1755, 1984 |
| 9 Metis | 1984 Feb. 19 | 10 chords: Denmark, Germany<br>L K Kristensen, *Astr. Raumfahrt* 1984 May-June, p. 76 |
| 230 Athamantis | 1984 May 11 | 4 chords: Australia |
| 47 Aglaja | 1984 Sept. 16 | 13 chords: USA |

Papers presenting results from earlier occultation events were published by Kristensen
(29.098.073) and Millis et al. (33.098.009).  A progress report on accurate determin-
ations of diameters of minor planets was given by Taylor (33.098.109).


                                    E Roemer

                                    President of the Commission