

COMMISSION 4: EPHEMERIDES (EPHÉMÉRIDES)

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I. Introduction

This report covers the period 1 July 1990 to 30 June 1993. The ephemerides that have been published during this period have in general made use of the IAU (1976) system of astronomical constants, apart from minor modifications introduced to allow a better fit to observations. The majority of the ephemerides are based on the fundamental ephemerides of the Moon and planets prepared by the Jet Propulsion Laboratory. At the 21st General Assembly of the IAU, the Working Group on Reference Systems produced nine resolutions, mostly aimed at ensuring that the definitions of the space time reference system will meet future demands as techniques improve.

II. International and National Ephemerides

1. The Fundamental System

The computation and publication of *Apparent Places of Fundamental Stars* (APFS) has continued at the Astronomisches Rechen-Institut, Heidelberg, Germany. The volume for the year 1994 was published in 1993. The number of copies was 750 of which 329 were distributed free to various astronomical institutions.

2. Reference Frame Studies

The Jet Propulsion Laboratory (JPL) have been working on the establishment of the Dynamical Reference Frame of the Lunar/Planetary Ephemerides, and on the determination of ties between the various reference systems.

Reference frame studies have included the establishment of the JPL Radio Frame and the Dynamical Reference Frame of the Lunar/Planetary Ephemerides, determination of frame ties, and development of the concept of the dynamical equinox as a reference point for the modern ephemerides and the connection of other coordinate systems to this reference point. Ties between VLBI and optical frames are being established via the observations of radio stars (in collaboration with French colleagues); a link has been determined between the VLBI and the ephemeris frame through a variety of methods, including differential spacecraft/quasar VLBI and ground ties.

3. Printed Ephemerides

The Bureau des Longitudes (BdL), Paris, France has published yearly the *Connaissance des Temps*, the *Ephémérides Astronomiques (Annuaire du Bureau des Longitudes)* and the *Ephémérides Nautiques*. BdL also published three supplements to *Connaissance des Temps*: Ephemerides of the satellites of Jupiter, Saturn and Uranus, that give the differential coordinates of the satellites and tables for the computation of the phenomena of the Galilean satellites; Phenomena and configurations of the Galilean satellites of Jupiter; Configurations of the first eight satellites of Saturn. Two main improvements were introduced in the Supplements to *Connaissance des Temps* after 1990; Ephemerides of the Martian moons and predictions of mutual phenomena for the Galilean satellites. Floppy discs containing satellite ephemerides are provided with the printed ephemerides.

The Hydrographic Department of Japan (JHD), Tokyo, Japan has continued to publish the *Japanese Ephemeris*, the *Nautical Almanac* and the *Abridege Nautical Almanac* for the years 1992, 1993 and 1994, with no major changes since 1985. The *Polaris Almanac* for Azimuth determination, the *Altitude and Azimuth Observation Almanac* for Antarctic Observation and the *Abstract* from the *Japanese Ephemeris* have also been compiled annually by JHD.

The Institute of Theoretical Astronomy (ITA), St Petersburg, Russia published the *Astronomical Yearbook* for 1993 and 1994. The 1994 edition onwards is in two parts. Part 1: The ephemerides of the Sun, Moon and planets. Part 2: The mean and apparent places of the stars. Part 1 is based on DE200/LE200.

The *Navy Astronomical Yearbook* and the *Air Navigation Astronomical Yearbook* were published for 1991 to 1993 and the *Astronavigation Almanac for 1991-1995*.

HM Nautical Almanac Office, Royal Greenwich Observatory, (HMNAO) and Nautical Almanac Office, US Naval Observatory (USNO) have continued their cooperative preparation and annual publication of *The Astronomical Almanac*, *The Nautical Almanac*, *The Air Almanac* and *Astronomical Phenomena*.

A new edition of *Sight Reduction Tables for Air Navigation*, (epoch 1995), was produced in collaboration by HMNAO, USNO and Defense Mapping Agency.

The Astronomy & Atmospheric Research Unit, Malaysia is creating an almanac and data facility using an IBM RISC 6000 workstation.

4. Electronic Dissemination of Ephemerides

Starting from 1992 BdL have established an ephemerides service on the French "Mintel Service" carried by the public telephone network.

To plan observing runs, astronomers using STARLINK now have access to information on sky brightness, Daylight and Moonlight Diagrams and Observers Calendar produced by HMNAO.

Recent trials with exporting the JPL planetary and lunar ephemerides on CD-ROM'S have been successful. These will soon become widely available. A new, improved ephemeris for all of the planets and the Moon will soon be integrated, extending over a number of millennia.

All JPL ephemerides are available for export via the JPL Navigation and Ancillary Information Facility.

5. Computerised Ephemerides

The US Naval Observatory (USNO) has produced *MICA*, a high-precision almanac for microcomputers. This menu-driven program provides positions of the Sun, Moon, planets and catalogue objects for 1990 to 1999 inclusive. Versions are available for machines running MS-DOS and for Apple Macintoshes. *MICA* can be obtained from National Technical Information Service, Springfield, VA 22161, USA.

The USNO has also completed a new version of the Satellite Almanac. This MS-DOS program is available on a floppy disc and provides accurate ephemerides for all planetary satellites for the period 1990-1999.

At HMNAO a software package based on the data and algorithms published in *Compact Data for Navigation and Astronomy* called NAVPAC is being prepared. The package fits onto a single floppy disc. The program is interactive and the data used by the program is displayed on the monitor screen where it may easily be updated. The program has also been carefully error trapped. It is intended to market the product with the next edition of the book.

At present the first version of the *Astronomical Yearbook Part 1*, has been prepared by ITA on a floppy disc.

The program system EPHRAT has been elaborated for the ephemeris maintenance of the observations of various radio sources (stars, major planets, Sun, Moon, including surface details and the Galilean satellites of Jupiter) on RATAN-600. The system for prediction of occultations of stars by objects of the solar system has been also elaborated, in Proceedings of the 1st Spain-USSR Workshop on Positional Astronomy (1991).

The CERES software package, which can generate various ephemerides of minor planets and comets, was produced for IBM PC's and compatibles, see Proceedings of the 2nd Spain-USSR Workshop on Positional Astronomy (1992).

The Ephemeris Service of the Institute of Applied Astronomy, Russia, (IAA), has produced a programming system ERA, which is designed to solve a wide range of problems that require automation of computations involving ephemerides. The object is to create a PC-based "work station" for both theoretical and observational astronomers who have to deal with ephemerides and problems in dynamical astronomy. It may also be used as a teaching aid. The system, which is extremely versatile, would now benefit from independent testing by those astronomers in Commission 4 who are qualified to suggest standards for the dedicated computer language, and make proposals for further developments and improvements to the program package.

6. Ephemerides for Special Purposes.

The following ephemerides have been produced by BdL and published in the *Notes Scientifiques et Techniques du Bureau des Longitudes*: Ephémérides de petites planètes de 1989 à 1996 (S018, S022, S023, S031, S032, S039, S040, S041) – Détermination d'orbites de comètes de 1989 à 1994 (S019, S020, S027, S033, S034, S042) ELP 2000/85: Une solution au mouvement de la Lune couvrant la période historique (S021) – Construction d'une éphémérides de Phobos issue de la théorie ESAPHO (S024) – Modélisation des phénomènes mutuels (S030), fonction perturbatrice astéroïdale et méthodes de perturbation en mécanique céleste (S035, S037).

Ephemerides of 48 Hipparcos minor planets for 1992 and for 1993 have been published by Bec-Borsenberger in *Astron. & Astrophys. Suppl. Series*, **93**, 1992 and **98**, 1993.

The following ephemerides and reference materials have been prepared by ITA and published in Russia: The astronomical data for all types of calendars, "The ephemerides for comparing and setting instruments" for astronomical observatories, ephemerides for observations of solar eclipses for observatories and expeditions, the ephemerides for occultations of stars by the Moon, "The instructions on definition of azimuth of reference point by the Moon's observations", the ephemerides of approaches of fifteen selected minor planets to FK5-stars were computed for the period 1991-2000.

7. Special Publications

The *Explanatory Supplement to the Astronomical Almanac*, edited by PK Seidelmann, was published by University Science Books.

US Naval Observatory Circular No.176, "Central Solar Eclipses of 1992", by JA Bangert, AD Fiala and WT Harris was published. This is the last of the eclipse circulars to be published by USNO.

The Canon of Lunar Eclipses 1500BC - AD3000 by Bao-Lin and Fiala AD, containing 10990 lunar eclipses, was published in 1992 by Willmann-Bell.

III. Observational Data for Improving the Ephemerides

The services of the International Lunar Occultation Centre have continued since 1981. The number of the timing data collected at the Centre was 34,646 from 35 countries during the years 1990 to 1992. Reports containing all the reduced data as well as the station coordinates are published annually. Nos. 9 to 11, listing observations in the years 1988 to 1990, were published in the period.

Observations of the 1991 July 11 total solar eclipse was made by JHD in Mexico for the purpose of examining the values for the position of the Sun listed in the current ephemeris and the reduction was completed. The result is published in Report of Hydrographic Researches, No. 29 (1993).

At HMNAO DB Taylor has continued to improve the orbits of the satellites of Saturn and has begun reducing and analysing La Palma CCD observations of the five major satellites of Uranus to improve their ephemerides.

JPL is actively involved in the development of models, ephemerides and the determination of the associated constants to be used as standards by the astronomical community.

The planetary ephemerides at JPL continue to improve as the result of new and improved observational data. Since the masses of the Jovian planets and Pluto are now well determined from the Voyager Mission, these no longer introduce significant uncertainties into the outer planet orbits. Accurate photoelectric observations of the outer planets from La Palma and Bordeaux have now been taken for the past decade, including since 1989, observations of Pluto. Recent radar ranges to Mercury, Venus and Mars have significantly extended the observational coverage for those planets, providing a greater measure on their mean motions. Venus topography, determined from the Magellan Mission at Venus, is being used to reduce the uncertainties normally introduced into the Venus radar ranges. Improved modelling of the perturbations of the asteroids upon the orbits of Mars and the Earth reduces the

deterioration of the orbits of these two planets. It is expected that the information available from all of the navigational tracking files from outer planet encounters will soon be incorporated into the ephemeris data set.

JPL continues to maintain ephemerides for all of the natural planetary satellites including the small satellites discovered from the Voyager imaging observations. The ephemerides are periodically updated as new observations become available. The most recent work was the generation of new ephemerides for the major Saturnian satellites based on a fit of numerical integration to observations from 1971 to 1991. Currently under investigation are upgrades to the ephemerides for the Martian and Galilean satellites and the minor Jovian and Saturnian satellites.

Development of Galilean satellite ephemerides in support of NASA's Galileo Mission continues. Earth based observations of eclipse timings, photographic data, radar data and mutual event observations are being combined with Voyager optical observations to produce the new ephemerides.

The analysis of lunar laser ranging (LLR) data, now consisting of over 8,000 normal points, from 1969 to 1993, has influenced a broad spectrum of studies including astronomy, ephemeris development, lunar science, geodynamics, relativity and gravitational physics. As the major focus here, the lunar ephemeris benefits from recent accurate ranges, which show a post-fit scatter of ~ 3 cm. Solutions using these data improve the lunar ephemeris; determine the mutual orientations between the equator, lunar orbit, and ecliptic planes; determine the mass ratio Sun/(Earth+Moon); improve the precession and nutations of the Earth's pole; monitor Earth rotation; determine Earth station and lunar reflector locations; improve lunar physical librations; and test theories of relativity. The determination of the tidal secular acceleration of the Moon has improved, and the separate contributions of the Earth's diurnal and semi-diurnal tides can now be distinguished. The sensitivity to lunar physical librations has provided improved values for the lunar moment of inertia combinations $(C-A)/B$ and $(B-A)/C$, third-degree gravitational harmonics, Love number k , and rotational dissipation. The lunar and planetary orbits are integrated simultaneously with the lunar physical librations. The partial derivatives of the orbits and physical librations are also integrated numerically. Modelling improvements have been made for small tidal effects which displace the stations and change the rotation of the Earth.

A new foundation of ephemeris calculations has been elaborated by ITA. A new numerical model of the barycentric motion of the Sun, major planets, Moon and major axes of inertia of the Moon has been constructed, which reproduce very accurately the DE200/LE200 ephemeris. A highly accurate method, using truncated Chebyshev series, to integrate and approximate objects positions and velocities has been developed. The errors for the approximation to the radius-vector do not exceed 1mm over a time span of 10 years.

The theoretical considerations and the accuracy estimations for the method of determining planetary positions from photographic observations of planetary satellites have been completed.

The method of calculation of ephemerides for mutual events between close planetary binaries, including shadow effects has been developed.

ITA has coordinated the work on the astrometric observations of the Sun, major and minor planets and the satellites of major planets, by providing the observers with the necessary observational information and by processing the observations.

From the analysis of 30,000 meridian observations of the inner planets the correction to Newcomb's constant of precession and the value of non-precessional motion of the FK4 equinox were taken out by the comparison with the long-term numerical ephemerides of the major planets and the Moon (EPMBB). Also estimates of the constancy of G and an upper limit on the solar dynamical oblateness were obtained. This work appeared in a joint paper by Krasinsky and Pitjeva of IAA, and Sveshnikov and Chunayeva of ITA, 1993, *Celest. Mech.*, **55**, 1-23.

IV Working Group Activities

The IAU Working Group on Astronomical Standards, lead by T Fukushima, has been organised into sub-groups on Constants, Procedures, Time and Electronic Distribution. A report is expected at the next General Assembly.

The International Earth Rotation Service has issued a new IERS Standards (1992). IERS Technical Note 13, edited by DD McCarthy.

The IAU/IAG/COSPAR Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites published its latest report in *Celestial Mechanics and Dynamical Astronomy*, Davies, ME et al, 1992, **53**, 377-397. The Working Group continues to gather relevant data and information and is working on the contents of the next report that will be presented at the 22nd General Assembly.