COMMISSION 4

EPHEMERIDES
ÉPHÉMÉRIDES

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	P. Kenneth Seidelmann,
	E. Myles Standish,
	Sean E. Urban, Jan Vondrák

PROCEEDINGS BUSINESS MEETING on 24 August 2006

1. Introduction

This business meeting was held from 16:00 to 17:30. Toshio Fukushima and George Kaplan were welcomed as the next president and vice-president, respectively. The following, in no particular order, are the summary reports from the various offices. The full versions will be made available on the Commission 4 website at `<http://iau-comm4.jpl.nasa.gov/>`.

2. Institut de Mécanique Céleste et de Calcul des Éphémérides

2.1. *Recent developments and new ephemerides at IMCCE*

Institut de mécanique céleste et de calcul des éphémérides (IMCCE), formerly "Service des calculs et de mécanique céleste du Bureau des longitudes", is an institute of the Paris Observatory since 1998. It is responsible for computing the official French ephemerides on behalf of the Bureau des longitudes. Our activities include research in the areas of theoretical celestial mechanics, astrometry and planetology, as well as projects in dynamics and applied celestial mechanics with the goal of providing accurate ephemerides.

2.2. *The new dynamical models*

At IMCCE, during the last years, several new dynamical models have been developed. VSOP, the planetary ephemerides (Variations Séculaires des Orbites Planétaires) initially developed by Bretagnon, now improved (VSPO2002b) by Fienga and Simon who have used it to study the perturbations on inner planets by the asteroids. A new numerical planetary ephemerides named INPOP (Intégration Numérique Planétaire de l'Observatoire de Paris) has been produced.

New dynamical models of several planetary satellites systems have been derived. One model NOE (Numerical Orbit and ephemerides) is obtained by a recomposition of the quasi-periodic Fourier series produced from a frequency analysis coupled with digital filtering treatments. This has been used to model the motion of the Galilean satellites (ephemeris L1), and to obtain new ephemerides of the Martian (NOE-4-06) and Uranian (NOE-7-06) satellites. NOE-7-06 has been used to predict the mutual events of the Uranian satellites. A collaboration with the Sternberg State Astronomical Institute of Moscow led to the modelling of, and ephemeris production for 96 outer satellites of Jupiter, Saturn, Uranus and Neptune.

A new dynamical and physical model of the meteoritic streams has been studied.

2.3. *Ephemerides books*

IMCCE provides yearly ephemerides on behalf of Bureau des longitudes. Several books related to various Solar System objects and at different levels of accuracy are published.

The ephemerides of high precision, *Connaissance des temps* has been revitalized. Since 2003, half of the volume contains scientific texts concerning constants, timescale, reference systems and transformations of coordinates. The IAU 2000 precession and IAU 2000A nutation models are also included. Furthermore, the IAU recommendations have been implemented and Earth rotation angle, equation of the origins, Celestial Intermediate Pole coordinates, angle *s* are included. This volume still gives ephemerides for the Sun, the Moon, the planets, sidereal time and nutations. However, since 2005 the Chebychev coefficients are only used in the accompanying software (CD-ROM). The software also gives the positions of the main planetary satellites, only the differential coordinates, are tabulated, for use in identification. The software also computes topocentric coordinates, rise and set times.

A second yearly book *Guide de données astronomiques - Annuaire du Bureau des longitudes* aims to give ephemerides to medium precision. Data for the Sun, Moon, planets, as well as ephemerides for bright comets and asteroids, stellar occultations by the asteroids and the Moon, phenomena of the Galilean satellites and other phenomena. Since 2003, a scientific booklet is included each year on a topic by a specialist, for example the 2007 issue will contain the new equatorial origin (CIO) by N. Capitaine and B. Guinot.

Three booklets supplement the *Connaissance des temps* and are guides for observers; titled *Suppléments à la Connaissance des temps* giving (1) graphic configurations and dates of the phenomena of the Galilean satellites, (2) the graphic configurations of the first eight satellites of Saturn and (3) positional ephemerides of several faint satellites of Jupiter and Saturn.

For navigation, IMCCE publishes annually a nautical almanac, *Ephémérides nautiques* and ephemerides for air navigation in the *Ephémérides aéronautiques*.

2.4. *Electronic ephemerides*

Ephemerides are available on-line at the web site of IMCCE at `<http://www.imcce.fr>`. Several improvements to the data and their organization have been done since 2003. The main changes are the introduction of web services with the objectives to provide "self-defined" data and to make these services interoperable. IMCCE has thus been able to join a working group dedicated to the development of software and databases in the Virtual Observatory framework. Their first product SkyBoT (Sky bodies Tracker) has been developed in collaboration with the Centre de données de Strasbourg in France (CDS). This software deals with dynamical models of all the known asteroids and the main natural satellites. It provides weekly updated ephemerides (1949-2009) for identification of solar system objects in star fields and to data mining. Access the software at `<http://www.imcce.fr/webservices/skybot/>` using query forms or in other user software, or, via the CDS's Star Atlas Aladin at `<http://aladin.u-strasbg.fr/aladin.gml>` which gives graphic identification from any of the archives, thanks to the interoperability between the CDS and the IMCCE servers.

3. Report of United States Naval Observatory

This report covers activity in the Astronomical Applications (AA) Department since the XXVth General Assembly in Sydney. The AA Department employs 14 scientists in three divisions: The Nautical Almanac Office (NAO), the Software Products Division (SPD), and the Science Support Division (SSD). The SSD was established in January 2004 as the department's research arm. S. Urban was appointed Chief of the NAO in June 2004. M. Efroimsky joined the staff on a permanent basis in March 2005. G. Kaplan, who was Chief of the SSD, retired in October 2005, and was rehired into a part-time position the following month. A. Fredericks joined the SPD staff in December 2005. R. Miller retired from the NAO in January 2006, and was replaced by E. Barron. The same month, J. Hilton moved from the SSD to the NAO.

Hilton served as chair of the Division I Working Group on Precession and the Ecliptic and as a member of the Inter-Division Working Group on Cartographic Coordinates and Rotational Elements. Urban chaired the Commission 8 Working Group on the Densification of the Optical Reference Frame. Kaplan served as a member of the Division I Working Group on Nomenclature

for Fundamental Astronomy. J. Bangert served as a member of the Standards of Fundamental Astronomy (SOFA) reviewing board.

Publication of *The Astronomical Almanac* and *The Astronomical Almanac Online*, *The Nautical Almanac*, *The* (U.S.) *Air Almanac*, and *Astronomical Phenomena* continued as a joint activity between Her Majesty's Nautical Almanac Office of the United Kingdom and the NAO. *The Astronomical Almanac* for 2006, released in January 2005, was the first edition to incorporate fully the resolutions on reference frames, Earth rotation models, and time scales adopted by the IAU in 1997 and 2000.

U.S. Naval Observatory Circular 179, *The IAU Resolutions on Astronomical Reference Systems, Time Scales, and Earth Rotation Models: Explanation and Implementation*, was published in October 2005. It is available in print form, and as a PDF file at `<http://aa.usno.navy.mil/publications/docs/Circular_179.html>`.

A major upgrade of the *Multiyear Interactive Computer Almanac*, MICA version 2.0, was completed and released in July 2005. The software is available in two editions for computers running Microsoft Windows and Apple Mac OS operating systems.

Use of the Astronomical Applications Department Web site (`<http://aa.usno.navy.mil/>`) continued to grow during the reporting period, hosting as many as 45000 user sessions per day. The site now contains approximately 1200 pages and numerous interactive calculators.

A new version of the Naval Observatory Vector Astrometry Subroutines (NOVAS) that implements the 1997 and 2000 IAU resolutions is under development, with release anticipated in late 2006 or early 2007.

An active research program is underway within the department. Research topics include gauge functions in celestial mechanics, solid-body tides in orbit theory, asteroid ephemerides and determination of asteroid masses, determination of orbital parameters of one satellite from observations taken from another, and development of instruments to fully automate celestial navigation and surveying.

Other projects underway at USNO, and of interest to Commission 4, include the USNO CCD Astrograph Catalog (UCAC; `<http://ad.usno.navy.mil/ucac/>`) and observations of solar system bodies made with the Flagstaff Astrometric Scanning Transit Telescope (FASTT; `<http://www.nofs.navy.mil/about_NOFS/telescopes/fastt.html>`).

4. Ephemeris astronomy at Institute of Applied Astronomy

4.1. *Almanacs*

Apart from Ephemerides of Minor planets (which are not described here), IAA continues to regularly publish *The Astronomical Yearbook* of Russia, *The Nautical Astronomical Yearbook* and biennially *The Nautical Astronomical Almanac* for ships at long-run sailing.

The Astronomical Yearbook of Russia includes geocentric apparent places of the Sun, Moon, major planets, 779 bright stars and some information on current astronomical phenomena, such as solar and lunar eclipses, planet configurations and so on (686 pages for 2007) and follows the recommendations of IAU whenever possible.

The *Explanatory Supplement to Astronomical Yearbook* (in Russian) has recently been published. It includes a summary of modern trends in ephemeris astronomy and the new theories of the major planets, relativistic time scales, precession-nutation models, relativistic theory of reference systems, and the CIO. A bibliography of over 500 references is included.

In the navigation almanacs, the IAU 2000 resolutions concerning the CIO are deliberately not implemented to ensure continuity.

4.2. *Scientific work*

The work on the publications is done by the Laboratory of the Astronomical Yearbook. Research work to support the published ephemerides is the duty of the Laboratory of Ephemeris Astronomy which is also involved in other research studies. Here the main aim is to attain the highest accuracy, and so the recommendations and standards of IAU or IERS are not always rigorously followed.

In the recent years it was decided that the published ephemerides should be generated after fitting their dynamical models to available high-accuracy observations. The current stage of this approach is given in brief.

The ephemerides, EPM, of the major planets for *The Astronomical Yearbook for the Year 2007* have been fitted (Pitjeva) to the all observations on `<http://ssd.jpl.nasa.gov/iau-comm4>`, the Commission 4 website. The current version, EPM2006, accounts for the gravitational interaction of the 9 major planets, the Sun, the Moon, 301 biggest asteroids, the perturbations from the asteroid ring of smaller asteroids, and for the perturbations from the solar oblateness. The planetary part has resulted from a least squares adjustment to observational data totaling 437883 observations (1913–2005) including radiometric observations of the planets, spacecraft, and astrometric observations of the outer planets and their satellites.

The lunar ephemerides are obtained by integrating the equations of lunar orbital and rotational motion simultaneously with the equations of planet motion described above. The parameters are estimated from the analysis of LLR observations from 1970–2004 (15599 time delays). About 60 parameters were adjusted, including the lunar Love numbers the tidal lag of the lunar body tides and harmonics of the lunar potential.

As the data are published with 1 mas truncation errors, the published planetary ephemerides coincide with those based on DE405, while for the lunar ephemerides, the differences exceed the truncation error.

The EPM ephemerides are available from `<ftp://quasar.ipa.nw.ru/incoming/EPM2004>` in the form of Chebyshev's polynomials.

Soon the contents of the *Astronomical Yearbook* will be expanded by including ephemerides of the main satellites of the major planets. This involves, integrated simultaneously, the numerical ephemerides of these satellites and the equations of motion of satellite systems and accounting for their mutual perturbations. At present work has been done for four Galilean satellites, eight satellites of Saturn, and five satellites of Uranus.

For the Earth and major planets the theories of their rotation are to be constructed by numerical integration, presenting the results in the form of Chebyshev's polynomials.

A numerical theory of rotation of the deformable Earth with the fluid core was constructed and fitted to VLBI observed position of the Celestial Pole and Universal Time UT1 (Goddard Space Flight Center series of 1984–2004). The numerical theory provides a better fit than using the adopted IAU 2000 theory of precession-nutation. For the case of Mars, constructing the analogous numerical theory based on the observations of Martian landers is in progress.

4.3. *Software*

The practical preparation of the almanacs, as well as their ephemeris support is carried out by a technology developed by IAA staring in 1982. The approach is based on using a high-level problem-oriented language SLON designed specially for ephemeris and dynamical astronomy. The corresponding programming, version ERA-7 (`<ftp://quasar.ipa.nw.ru/incoming/era/>` for the 16-bit version) is more advanced both in the functional diversity and in the descriptive power of SLON. The system has been thoroughly tested by a number of practical tasks and has proved its efficiency.

In particular, it provides the user with (a) a unified method of constructing numerical dynamical theories of any body of the Solar system (orbital and rotational motion) and presenting them as Chebyshev polynomials, (b) easy processing of observables thus improving the parameters, and (c) providing a toolkit for updating the constructed numerical ephemerides using Least Squares or by Kalman filtering.

5. HM Nautical Almanac Office, Rutherford Appleton Laboratory

This is the report of HM Nautical Almanac Office (HMNAO) covering the period since the XXVth General Assembly in Sydney. After seven and a half years operating under commercial conditions within CCLRC at the Rutherford Appleton Laboratory (RAL), HMNAO has been transferred to the UK Hydrographic Office (UKHO), an agency of the UK Ministry of Defence (MoD).

HMNAO consists of three staff who are funded by the royalties generated by the sales of the almanacs produced by the office and jointly with the US Naval Observatory and also from the

sales of its services. These funds were insufficient to take on and train new staff. As RAL were also unable to provide any support, financial assistance was sought from the Royal Navy/UK MoD. Having satisfied themselves HMNAO's services were needed, the UK MoD requested UKHO to access the viability of taking on the office. Having generated a satisfactory business plan, HMNAO was handed over to UKHO on April 1st 2006. This entire process took the better part of 4 years requiring considerable staff input.

Joint publications with the US Naval Observatory, in particular, *The Nautical Almanac* and *The Astronomical Almanac* have been produced on schedule. A fully navigable pdf version of *The Nautical Almanac* has been produced and extensive changes have been made to *The Astronomical Almanac* to implement the resolutions relating to reference frames, times scales and earth orientation from the previous two IAU's. Improvements have also been made to the calculation and provision of satellite data and phenomena in Section F, to Section K and the provision of lunar eclipse diagrams in Section A.

A new edition of *Navpac and Compact Data 2006-2010* has been produced including some new features. To emphasise its use by the Royal Navy, a joint launch of this product with the Admiralty Manual of Navigation (BR45) was arranged.

Catherine Hohenkerk has served on the IAU Working Group on Nomenclature for Fundamental Astronomy and has given talks at the Journées meetings in Paris (2004) and Warsaw (2005) on the application of this topic to *The Astronomical Almanac*. She has taken an active role on the Software for Fundamental Astronomy (SOFA) board. HMNAO now hosts the SOFA Center web site. She has taken a leading role in the major changes to Section B in the 2006 edition and has also received the USNO Superintendent's Award 2005 for her services to *The Nautical Almanac*. Steve Bell attended the IAU Colloquium 196 on New Views of the Solar System and Galaxy.

Significant effort has gone into the generation of new web site material. Transit information was provided for the 2004 transit of Venus and a new eclipse web site http://www.eclipse.org.uk has been generated giving solar and lunar eclipse information for the period 1500 CE to 2100 CE. A mass participation project for Einstein Year was launched in collaboration with the Institute of Physics to observe the first sighting of new crescent moon involving a web site http://crescentmoonwatch.org. This received significant media coverage. Steve Bell has given several talks around the UK on this subject.

Don Taylor has been involved in work relating to the astronomical application of map projections and the compilation of time zone and daylight saving time rules for web services. He has also continued his worked on solar perturbations for the satellites of Uranus and integration software for cometary ephemerides.

6. Closing remarks

It was agreed that the Almanac Offices and ephemeris producers, the Commission as a whole, should aim to be more pro-active in the next triennium.

George A. Krasinsky
president of the Commission