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COMMISSION 4 EPHEMERIDES

ÉPHÉMÉRIDES

COMMISSION 4 WORKING GROUP

Div. I / Commission 4 WG **Standardizing Access to Ephemerides**

TRIENNIAL REPORT 2009–2012

1. Introduction

The Commission 4 Organizing Committee began its work for the 2009-2012 triennium by revising the commission's terms of reference, which serve as our "mission statement." The new terms of reference are:

(*a*) Maintain cooperation and collaboration between the national offices providing ephemerides, prediction of phenomena, astronomical reference data, and navigational almanacs.

(*b*) Encourage agreement on the bases (reference systems, time scales, models, and constants) of astronomical ephemerides and reference data in the various countries. Promote improvements to the usability and accuracy of astronomical ephemerides, and provide information comparing computational methods, models, and results to ensure the accuracy of data provided.

(*c*) Maintain databases, available on the Internet to the national ephemeris offices and qualified researchers, containing observations of all types on which the ephemerides are based. Promote the continued importance of observations needed to improve the ephemerides, and encourage prompt availability of these observations, especially those from space missions, to the science community.

(*d*) Encourage the development of software and web sites that provide astronomical ephemerides, prediction of phenomena, and astronomical reference data to the scientific community and public.

(*e*) Promote the development of explanatory material that fosters better understanding of the use and bases of ephemerides and related data.

There are two broad kinds of work that the commission supports. The first is the computation of fundamental solar system ephemerides, that is, using gravitational theory along with observations of many types to determine the orbits of bodies in the solar system. The second kind of work uses these fundamental ephemerides to compute practical astronomical data, such as the geocentric or topocentric coordinates of the Sun, Moon, planets and stars for any given time; the prediction of times of astronomical phenomena, such as the times of rise, set, and transit, and eclipse phenomena; the parameters that describe the apparent orientation and illumination of solar system objects at specific

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14. ABSTRACT

The Commission 4 Organizing Committee began its work for the 2009-2012 triennium by revising the commission's terms of reference, which serve as our ?mission statement.? The new terms of reference are: (a) Maintain cooperation and collaboration between the national offices providing ephemerides, prediction of phenomena, astronomical reference data, and navigational almanacs.(b) Encourage agreement on the bases (reference systems, time scales, models, and constants) of astronomical ephemerides and reference data in the various countries. Promote improvements to the usability and accuracy of astronomical ephemerides, and provide information comparing computational methods, models, and results to ensure the accuracy of data provided.(c) Maintain databases, available on the Internet to the national ephemeris offices and qualified researchers, containing observations of all types on which the ephemerides are based. Promote the continued importance of observations needed to improve the ephemerides, and encourage prompt availability of these observations, especially those from space missions, to the science community.(d) Encourage the development of software and web sites that provide astronomical ephemerides, prediction of phenomena, and astronomical reference data to the scientific community and public.Promote the development of explanatory material that fosters better understanding of the use and bases of ephemerides and related data.

15. SUBJECT TERMS

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times; and various quantities that allow knowledgeable users to transform coordinates or vectors between standard reference systems.

Fundamental solar system ephemerides are now being produced by three groups, at JPL, IAA, and IMCCE (see institutional reports below). Session 2 of the 2010 *Journées* conference in Paris was devoted to a discussion and comparison of these ephemerides. In 2010, the commission Organizing Committee, with the concurrence of Division I, established a Working Group on Standardizing Access to Ephemerides, to facilitate the use of these products. A short report on its work is given immediately below.

2. Working Groups

The Working Group on Standardizing Access to Ephemerides consists of James Hilton (USNO, USA), chair; Jean-Eudes Arlot (IMCCE, France); Steve Bell (HMNAO, UK); Olga Bratseva (IAA, Russia); Nicole Capitaine (Paris Observatory, France); Agnès Fienga (Besançon Observatory, France); William Folkner (JPL, USA); Mickael Gastineau (IMCCE, France); Elena Pitjeva (IAA, Russia); and Vladimir Skripnichenko (IAA, Russia). The purpose of this working group is to to provide a common software interface to all of the fundamental solar system ephemerides, based on a consistent distribution format. It is hoped that this will facilitate the use of the three sets of ephemerides now being regularly produced, as well as others in the future, allowing users to easily switch among them. The working group has tentatively decided to support the Spacecraft and Planetary Kernel (SPK) file format used in the SPICE Library written and maintained by the Navigation and Ancillary Information Facility (NAIF) of the Jet Propulsion Laboratory. This decision is dependent on NAIF providing a detailed specification of those portions of the SPK file format needed for the ephemerides and producing a standalone routine for reading SPK files.

The Division I – Division III Working Group on Satellites continues to maintain ephemerides of all planetary satellites at http://www.imcce.fr/sat and at http://lnfm1.sai.msu.ru/neb/nss/nssephme.htm. When used with an astrometric database, these ephemerides allow observed positions of the giant planets to be determined from observations of their satellites. Satellite ephemerides are also provided by JPL and by the Minor Planet Center for the irregular satellites of the giant planets.

Commission 4 members are also active in the Division I Working Group on Numerical Standards for Fundamental Astronomy, the Division I Board of the Standards of Fundamental Astronomy (SOFA), and the Division I – Division III Working Group on Cartographic Coordinates and Rotational Elements. Details can be found in the Division I report.

3. Reports of the Institutions

3.1. *Real Instituto y Observatorio de la Armada (ROA), Spain*

The Ephemerides Department of the Spanish Naval Observatory publishes the following printed publications:

- *Efemérides Astronómicas*: a yearly publication containing: data for eclipses, transits and other astronomical phenomena; ephemerides of solar system bodies; and apparent places of 194 stars. The ephemerides are computed from JPL DE405/LE405 fundamental ephemerides and USNO/AE98.
- *Fenómenos Astronómicos*: a biennial publication containing data for the general public. Most of the data is extracted from *Efemérides Astronómicas*.
- *Almanaque Náutico*: the Spanish nautical almanac, containing necessary data for celestial navigation.

In addition, ROA regularly issues a nautical almanac in electronic format, valid for a ten year period, and maintains a web site with interactive computation of astronomical phenomena and other astronomical information (http://www.armada.mde.es/roa/).

— submitted by Teodoro López Moratalla

3.2. *Institut de Mécanique Céleste et de Calcul des Éphémérides (IMCCE), France*

The ephemerides service of IMCCE has three main missions:

- performing research activities on the motions of the solar system objects;
- making the French official ephemerides on behalf of Bureau des longitudes; and
- providing calculations on request for professionals, space agencies, and the public.

During the reporting period, J. Berthier was assigned responsibility for the Service des éphémérides, and D. Hestroffer was appointed head of the IMCCE to succeed W. Thuillot. Various planetary ephemerides solutions (planets, Moon and the Sun) are used at the operational service des éphémérides; the ones developed at IMCCE are the VSOP model (Secular Variations of Planetary Orbits) and the INPOP model (Planetary Numerical Integration of Paris Observatory). The latter is an original 4-D theory based upon a high precision model for planets and the Moon, fitted to space observations, and developed in support of the Gaia mission. INPOP06 and INPOP08 have been published in the past (Fienga *et al.* 2008, A&A, 477, 315; Fienga *et al.* 2009, A&A, 507, 1675). Publication of INPOP10 with TCB–TDB is pending, based on LLR data, new radio-science data, and a new model for asteroid perturbations (Fienga *et al.* 2011, CMDA, in press).

For the natural satellites, the NOE model (Numerical Orbit and Ephemerides) is used for the Martian satellites, the Galileans and the main Uranians (Lainey *et al.*, A&A 2006, 456, 783; Arlot *et al.* A&A 2006, 456, 1173). An estimation of the propagation of the ephemerides error is provided (Desmars *et al.* A&A 2009, 499, 321). The ephemerides web server (Multi-sat ephemerides) is made in collaboration with the Sternberg Astronomical Institute in Moscow.

Distribution of the ephemerides is done by yearly publications, dedicated CD-ROM, and electronic ephemerides on the web. The yearly printed publications are:

- *Connaissance des temps*, since 1679, for high precision ephemerides;
- *Annuaire du Bureau des longitudes*, since 1795, for the general public; and
- *Ephemerides nautiques*, the French nautical almanac for the Navy.

An electronic version is available for the *Connaissance des temps*.

Electronic ephemerides are provided through Internet at http://www.imcce.fr (approximately 5 Mhits per month). In addition to these positional ephemerides, ephemerides for the physical observations of the planets and small bodies are also provided. Publication of occultations of planets and stars by the Moon has been suspended, because the ILOC (Japan) has stopped computing such data and predictions provided by IOTA are not compatible with our editorial calendar constraints. Stellar occultations by asteroids are provided. Specific web services are provided in the Virtual Observatory framework using VO standard protocols, metadata and VOTable for exchange of self-defined information. The Sky Body Tracker facility identifies any solar system object in any field of view. The asteroid search application, based upon pre-calculated ephemerides for $> 500,000$ asteroids (taken from the Astorb database, Lowell Observatory), has been extended to cover the time span 1889–2060; it is updated daily and interfaced with Aladin Sky Atlas V7. Implementation to include all natural satellites and comets is in progress.

Several developments are foreseen over the next triennium for the ephemerides service, including upgrade of the software accompanying *Connaissance des temps*, improving

access to the Miriade system (http://vo.imcce.fr/webservices/miriade) for distributing VO compliant data, and distribution of physical ephemerides. A major revision of the *Annuaire du Bureau des longitudes* content was undertaken in 2011.

— submitted by Daniel Hestroffer and J. Berthier

3.3. *United States Naval Observatory (USNO), U.S.A.*

This report covers activity in the Astronomical Applications (AA) Department since the XXVIIth General Assembly in Rio de Janeiro. The AA Department employs 13 scientists in three divisions: the Nautical Almanac Office (NAO), the Software Products Division (SPD), and the Science Support Division (SSD). J. Bartlett was appointed chief of the SPD in late 2010.

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 of Her Majesty's Nautical Almanac Office (HMNAO) of the United Kingdom and the NAO. This activity is governed by a formal memorandum of understanding between the parent organizations. Major changes in *The Astronomical Almanac* include updated and improved computations of the lunar librations (2011 edition) and revisions of Sections E and G required to accommodate Pluto's new status as a "dwarf planet" (2013 edition).

A major revision of the *Explanatory Supplement to the Astronomical Almanac*, produced in collaboration with P. K. Seidelmann (University of Virginia) and numerous contributors, was completed and should be available for purchase in 2012.

Version 3.0 of the Naval Observatory Vector Astrometry Software (NOVAS) in C and Fortran editions was released in December 2009, followed by version 3.1 in March 2011 (http://aa.usno.navy.mil/software/novas/novas_info.php). The first Python edition of NOVAS, which is based on version 3.1 of the C edition, was released in June 2011. NOVAS fully implements recent IAU resolutions in positional astronomy, including the latest reference system definitions and models for precession and nutation.

Version 2.2.1 of the *Multiyear Interactive Computer Almanac* (MICA) was released in April 2010, to be followed by version 2.2.2 in early 2012. MICA is available for computers running Microsoft Windows and Apple Mac OS operating systems.

The department operated two public Web sites during the reporting period. The main site (http://aa.usno.navy.mil/) underwent a full content review and update in 2011. *The Astronomical Almanac Online* (http://asa.usno.navy.mil/), updated annually, is maintained jointly with HMNAO and mirrored at both organizations.

A modest research program in positional astronomy, dynamical astronomy, and navigation continued within the department. Research topics included the spin theories of Mercury and Iapetus, the theory of bodily tides, relativistic celestial mechanics, and new methods of celestial navigation.

Other projects underway at USNO and of interest to Commission 4 include the USNO CCD Astrograph Catalog (UCAC), and observations of solar system bodies made with the Flagstaff Astrometric Scanning Transit Telescope (FASTT). Additional information on these projects can be found at http://www.usno.navy.mil/USNO/astrometry/.

— submitted by John A. Bangert

3.4. *Institute of Applied Astronomy (IAA), Russia*

Fundamental ephemerides: During the period 2009–2012, the regular publication of *The Russian Astronomical Yearbook* has been continued. Planetary and lunar ephemerides

are based on the numerical model EPM2004. Ephemerides for planetary configurations, eclipses and occultations, as well as the ephemerides of the Moon (as Tchebyshov polynomials), the mutual phenomena of the Galilean satellites of Jupiter, and the configurations of eight satellites of Saturn are updated and located at http://quasar.ipa.nw.ru/PAGE/EDITION/ENG/newe.htm. The P03 precession and IAU 2000A nutation theories have been introduced. Fundamental catalogues FK6 and HIPPARCOS have been used for the calculation of star positions. The matrix for conversion from the ICRS to the CIRS is also given.

Special ephemerides: *The Naval Astronomical Yearbook* (NAY) (annual issues for 2010–2013) and biennial *The Nautical Astronomical Almanac* (NAA-2) (issues 2011–2012, 2013–2014) were published. The basic purpose of producing the Almanac is to increase the applicability of the NAY data, at the same accuracy, but in a smaller physical volume. The explanation is given in both Russian and English.

Software: Constructing numerical dynamical models, fitting the ephemerides to observations, as well as preparation of the ephemerides for publication are all carried out within the framework of the universal program package ERA — Ephemerides for Research in Astronomy (ftp://quasar.ipa.nw.ru/incoming/era/). The electronic version of *The Personal Astronomical Yearbook* (PersAY) for 2010–2015 was constructed. It is intended for calculation of the ephemerides published in *The Astronomical Yearbook*, including the topocentric ephemerides for any observer. A demonstration version of PersAY for interval 2010–2011, based on the fundamental ephemerides DE405/LE405 and EPM2004, is available at ftp://quasar.ipa.nw.ru/pub/PERSAY/persay.zip. The electronic system *Navigator* for the solution of basic naval astronavigating tasks is available at http://shturman.ipa.nw.ru/.

Research work: The updated Ephemerides of Planets and the Moon — EPM2010 (Pitjeva E., Bratseva O., Panfilov V., 2011, Proc. Journées 2010, 49) differ from the previous versions by the addition of perturbations from the ring of Trans-Neptunian objects (TNO), a corrected model of the dissipative effect of the lunar rotation, new values of the planetary masses adopted at the last IAU GA, an improved mass for Mercury from the Messenger mission, improvements in the reductions of observations, and an extended database of observations. Ephemerides were constructed by the simultaneous numerical integration of the equations of motion for all the major planets, the Sun, the Moon, the largest 301 asteroids, 21 TNOs, and the lunar libration, taking into account the perturbations from the solar oblateness, the asteroid belt (consisting of the remaining smaller asteroids), as well as the ring of the TNOs at a mean distance of 43 au. The 400-year integration (1800-2200) was performed in the barycentric system of coordinates for the epoch J2000.0. The free parameters of EPM2010 were determined from 16131 lunar laser ranging measurements (1970–2010), as well as more than 635000 planetary and spacecraft observations (1913–2010) of different types. A direct estimate of $GM_\odot$ and its annual rate of change have been obtained: $GM_\odot = (132712440032.7 \pm 0.7)$ km^{3}sec^{-2}, $\dot{GM}_\odot/GM_\odot = (-5.0 \pm 4.1) \cdot 10^{-14}$ (Pitjeva E.V., Pitjev, N.P., 2012, Solar System Research, n.1).

The differences between the time scales TT and TDB were also constructed for the EPM2004 and EPM2008 ephemerides. Access to these ephemerides, as well as those of Ceres, Pallas, Vesta, Eris, Haumea, Makemake, and Sedna, using the new program package Calc_Eph, is available via ftp://quasar.ipa.nw.ru/incoming/EPM.

Numerical ephemerides of the satellites of Mars and the main satellites of the outer planets have also been developed, fit to modern observations.

— submitted by Elena V. Pitjeva and Marina V. Lukashova

3.5. *Her Majesty's Nautical Almanac Office (HMNAO), U.K.*

For the last triennium, HM Nautical Almanac Office (HMNAO) has remained at the UK Hydrographic Office (UKHO) in Taunton. Initially, HMNAO was part of the UKHO Operations Division but now resides within that of the National Hydrographer, improving our links with our military and international customers. During this time, the office has taken on a new staff member, Dr. Julia Weratschnig, welcome evidence of succession planning for the office, bringing the total number of staff to four. She has taken on the preparation of The UK *Air Almanac*, now a free PDF download, *Astronomical Phenomena*, and is currently taking a leading role in the updating of Section G of *The Astronomical Almanac*, "Dwarf Planets and Small Solar System Bodies," in accordance with the resolutions reclassifying Pluto and Ceres at the 2006 GA.

In line with the requirements of the UK government's Central Office of Information directives on streamlining web sites and improving their accessibility, five web sites operated by HMNAO have been amalgamated into one, which can now be accessed at http://astro.ukho.gov.uk/. A significant amount of work on improving the accessibility of these web sites has also been undertaken. A new edition of *NavPac and Compact Data 2011–2015* has been released in tandem with web-based registration and downloading of updates.

This year, 2011, marks the centenary of our collaboration with the Astronomical Applications Department of USNO. Schedules have been maintained for all the joint publications of both offices as well as those produced solely by HMNAO. Indeed, Volume 1 of *Rapid Sight Reduction Tables*, AP3270, is being added to the body of joint publications (the corresponding U.S. publication is *Sight Reduction Tables for Air Navigation*, Pub. 249). To mark the strong ties between the USNO and HMNAO, an exchange scheme for staff from both offices to gain experience of each others' methods of working and to exchange expertise has been inaugurated. Eric Barron from USNO spent part of August at the UKHO looking at future directions for providing new services and products over the Internet. Further evidence of the fruitful collaboration is a comprehensive technical note describing the new process for calculating lunar librations in *The Astronomical Almanac*, using JPL rotational ephemerides, prepared by members of both offices and by Dr. Andrew Sinclair, formerly head of HMNAO.

Catherine Hohenkerk is now chair of the SOFA board and members of the HMNAO support a number of IAU activities. Don Taylor continues to work from Rutherford Appleton Laboratory working on technical notes on lunar librations and map projections.

— submitted by Steven A. Bell

4. Closing remarks

The commission appears to have a bright and active future. There is some uncertainty in how the almanac-producing institutions will respond to a change in the definition of Coordinated Universal Time (UTC), if that is approved by the International Telecommunications Union in 2012. Such a change would not represent a major obstacle to Commission 4 affiliated institutions, but would rather require some decisions on how best to provide data to users in the future. I expect that if the change is made, this will be a continuing point of discussion in the next triennium. Similarly, the institutions that are computing the fundamental solar system ephemerides will have to respond to a potential change in the definition of the astronomical unit, although this has been well discussed over the past several years and the path forward seems clear.

George H. Kaplan *President of the Commission*