

CHAPTER VI

REPORTS on DIVISION, COMMISSION, and WORKING GROUP MEETINGS

DIVISION I COMMISSION 4

EPHEMERIDES (*EPHEMERIDES*)

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VICE-PRESIDENT
PAST PRESIDENT
ORGANIZING COMMITTEE

George Kaplan
Catherine Hohenkerk
Toshio Fukushima
Jean-Eudes Arlot, John A. Bangert,
Steven A. Bell, William Folkner,
Martin Lara, Elena V. Pitjeva,
Sean E. Urban, Jan Vondrak

PROCEEDINGS BUSINESS SESSIONS, Session 1 of 27 August 2012

The triennial meeting of Commission 4 was attended by 16 people. All of the presentations from the meeting are provided on the commission website at

<http://www.iaucom4.org/c4docs.html>, so this report provides only summaries.

A minute of silence was observed in memory of the four members of the commission who were known to have passed away since the 2009 meeting: Shinko Aoki (1927–2011), Alan Fiala (1948–2010), George Krasinsky (1939–2011), and Nguyen Mau Tung (1926–2011).

George Kaplan, the president of the Commission, gave an overview of the activities of the commission over the 2009–2012 triennium. These included:

- Revising the terms of reference for the commission.
- Reorganizing the commission website (<http://www.iaucom4.org>), now located at the UK Hydrographic Office. Steve Bell is the webmaster.
- Submitting two reports for IAU Transactions.
- Organizing the Working Group on Standardizing Access to Ephemerides, to consider how best to ensure that software developers are able to access planetary/lunar ephemerides from multiple institutions in a simple and unified way. James Hilton is the chair and the working group's report is summarized below.
- Distributing ten "Commission 4 News" e-mails, containing news of scientific and organizational interest.
- Supplying letters of support for (1) sharing spacecraft navigation data important for planetary ephemerides and (2) establishing standard values of some solar system parameters for use by binary star and exo-planet researchers.

It was also mentioned that commission members had been active in organizing and participating in two *Journées* meetings in Europe, three AAS Division on Dynamical Astronomy meetings in the US, and two meetings on the future of the time scale UTC,

one in the US and one in the UK. The ephemeris-producing institutions represented within the commission continue to cooperate on various projects and publications.

Dr. Kaplan noted that a proposal to provide, on the Commission 4 website, a tabular comparison of the models, data, and numerical procedures used in three fundamental solar system ephemerides did not come to fruition, and that such a table should be a high priority during the next triennium. The ephemerides to be compared are produced by the Jet Propulsion Laboratory (JPL) in the US, the Institut de Mécanique Céleste et de Calcul des Éphémérides (IMCCE) in France, and the Institute for Applied Astronomy (IAA) in Russia.

The commission gained three new members during the triennium, and 17 prospective members of the IAU have requested membership. These additions together increase the size of the commission by 20%.

The new officers of the commission for the 2012–2015 triennium are: President: Catherine Hohenkerk (UK); Vice-President: Jean-Eudes Arlot (France); Organizing Committee (OC): John Bangert (US), Steven A. Bell (UK), Jose M. Ferrandiz (Spain), Agnès Fienga (France), William Folkner (US), Marina Lukashova (Russia), Elena Pitjeva (Russia), Mitsuru Soma (Japan), William Thuillot (France), and Sean Urban (US).

Summaries of the other reports presented at the meeting follow. **Working Group on**

Standardizing Access to Ephemerides

The Commission 4 Working Group on Standardizing Access to Ephemerides consists of James Hilton, USNO, US (chair); Jean-Eudes Arlot, IMCCE, France; Steve Bell, HM-NAO, UK; Nicole Capitaine, Paris Observatory, France; Agnès Fienga, Besançon Observatory, France; William Folkner, JPL, US; Mickaël Gastineau, IMCCE, France; Elena Pitjeva, IAA, Russia; Vladimir Skripnichenko, IAA, Russia, and Patrick Wallace, UK. The purpose of this working group is to provide guidance on a consistent format for distributing ephemerides of solar system bodies to the astronomical community. The working group recommends the use of the *binary* Planetary Constants Kernel (PCK) and Spacecraft and Planet Kernel (SPK) file formats used in SPICELIB, which is written and maintained by the Navigation and Ancillary Information Facility (NAIF) of the Jet Propulsion Laboratory. See

http://naif.jpl.nasa.gov/pub/naif/toolkit_docs/FORTRAN/. It is recommended that ancillary data such as body masses and initial conditions be stored in *text* PCK files.

Both SPK and binary PCK file structures are very similar; SPK is used for the positions of solar system bodies and binary PCK is used for body orientation. NAIF has agreed to some modifications of their standards to accommodate the Working Group's requirements:

- Add a new type to accommodate IAA-style (velocity-based) ephemerides;
 - Add new types to accommodate TCB-based ephemerides;
 - Add a new ID number (10 000 000) for TT–TDB or TCG–TCB time ephemerides;
- and
- Set aside type numbers 901–910 for experimental ephemeris types.

The WG thanks the Navigation and Ancillary Information Facility of JPL for their help and cooperation in adapting their PCK and SPK formats to the needs of the international community.

— James Hilton

Institute of Applied Astronomy, Russia

The Institute of Applied Astronomy (IAA) of the Russian Academy of Science deals with the construction of numerical ephemerides of the Sun, planets, and natural satellites. The

IAA uses these ephemerides for calculating data and issuing the Russian Astronomical Yearbook (AY), the Naval Astronomical Yearbook (NAY), and the Nautical Astronomical Almanac (NAA).

Ephemerides of planets and the Moon (EPM) have been constructed by the simultaneous numerical integration of equations of motion for all the major planets, the Sun, the Moon, asteroids, trans-neptunian objects, and the lunar libration over 400 years (1800–2200). The parameters of EPM2011 (65 for the lunar part and about 270 for the planetary part) have been fitted to 17 378 lunar laser ranging measurements 1970–2011, as well as about 680 000 planet and spacecraft observations 1913–2011 of different types. The numerical ephemerides of the main satellites of planets have been constructed taking into account the mutual perturbations of the satellites, the Sun, major planets, figures of the planets, and fitted to modern observations. (See presentation at Joint Discussion 7 at this General Assembly).

Since 2006, ephemerides for the AY, NAY, and NAA prepared at IAA take into account the IAU recommendations of 2000–2006, including new models of precession and nutation, a new algorithm for sidereal time, and catalogs referred to ICRS. The ephemerides are based on the equinox system, but there are also correction tables for transformation to the CIO-based system. IAA releases the ephemerides in electronic form also, using the DE405 planetary ephemerides in addition to its own ephemerides. PersAY, the Personal Astronomical Yearbook (<ftp://quasar.ipa.nw.ru/pub/PERSAY/persay.zip>), is an electronic version of AY. In addition to the tables of AY, it enables calculation of topocentric astronomical data for any time scale, any position of the observer, and at any time interval. The electronic version of NAA contains examples of 21 astro-navigation tasks. Currently, the next electronic version of NAA (Navigator) is being developed for release on a CD. Its structure consists of four basic parts: observation planning with planetarium; determination of ship and compass correction by astronomical observations; a description of some sections of the NA; and a detailed manual.

— Elena V. Pitjeva

Institut de Mécanique Céleste et de Calcul des Éphémérides, France

IMCCE is a laboratory of Paris Observatory with 60 permanent staff members. The missions are:

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

An important project is the development of the INPOP series of fundamental solar system ephemerides (see presentation at Joint Discussion 7 at this General Assembly). Distribution of various kinds of ephemeris data takes several forms. The yearly printed publications are:

- *Annuaire du Bureau des longitudes*, similar to *The Astronomical Almanac*
- *Connaissance des temps*, for high precision ephemerides (electronic version available); and
- *Ephemerides nautiques*, the French nautical almanac for the Navy.

Electronic ephemerides are provided through the Internet at <http://www.imcce.fr>. An ephemeris generator is provided, giving positional and physical ephemerides; also available are predictions of celestial phenomena, calendars, and an astronomical database. Specific web services are provided in the Virtual Observatory framework at <http://vo>.

imcce.fr/, using VO standard protocols, including a Sky Body Tracker facility, which identifies any solar system object in any field of view, an asteroid search application, and the *Miriade* ephemeris services.

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, further development of physical and satellite ephemerides, and new online tools for observers. A major revision of the *Annuaire du Bureau des longitudes* content was undertaken in 2011 and will be available for the 2013 edition.

— Daniel Hestroffer

Jet Propulsion Laboratory, California Institute of Technology, US

The Solar System Dynamics group at the NASA Jet Propulsion Laboratory is led by Donald Yeomans and continues to provide updated ephemerides for the planets, planetary satellites, asteroids and comets (see: <http://ssd.jpl.nasa.gov>).

Planetary ephemerides are developed by William Folkner, Petr Kuchynka and Ryan Park, with primary deliveries to support planetary missions such as MESSENGER to Mercury, the Cassini mission at Saturn, and the New Horizons mission to Pluto. The latest planetary ephemeris, DE425, was delivered to the Mars Science Laboratory project for precision landing on Mars in August 2012. A dedicated campaign of Very Long Baseline Interferometer observations of the Mars Odyssey and Mars Reconnaissance Orbiter spacecraft while in orbit about Mars was performed by James Border and the Deep Space Tracking systems group to tie the planetary ephemeris to the International Celestial Reference Frame to better than 0.1 milliarcsecond accuracy to meet the requirements for the Mars landing. Planetary ephemeris work is done in conjunction with lunar laser ranging analysis by James Williams and Dale Boggs in the Geodynamics and Space Geodesy Group.

Planetary satellite ephemerides are developed by Robert Jacobson and Marina Brozović. They revised the ephemerides of Phobos and Deimos using a dynamical model that included tidal effects and the Phobos figure acceleration due to its forced libration. Their support of the Cassini Project continued with improvements in the ephemerides of the regular as well as irregular Saturnian satellites using Earth-based astrometry and Cassini imaging data. They produced new ephemerides for the irregular Jovian, Uranian, and Neptunian satellites. As part of the work on the irregular satellites, they carried out a campaign of astrometric observations of those bodies at the Palomar Observatory and, in the course of that campaign, discovered two new Jovian irregulars. At the request of the New Horizons project, they developed ephemerides for Pluto's satellites including the two discovered in 2011 and 2012.

Small-body orbits and ephemerides are developed by Steven Chesley, Paul Chodas, Jon Giorgini, and Alan Chamberlin. All available small-body observations are processed with orbits and ephemerides updated and distributed on the Horizons system. Typically, Horizons (<http://ssd.jpl.nasa.gov/?horizons>) provides over 100 000 ephemeris products per day to the international user community. Near-Earth Objects are a special topic, with emphasis on potential Earth-approaching or Earth impacting asteroids (e.g., 2008 TC3). Comprehensive information is provided on near-Earth orbit and physical characteristics, interactive orbit diagrams, discovery statistics, Earth close approaches, Earth impact probability computations, and information on those objects that are particularly accessible for future, round-trip human exploration spaceflight missions. Information on the Near-Earth Object Program is maintained on the web site <http://neo.jpl.nasa.gov/>.

— William M. Folkner

Her Majesty's Nautical Almanac Office, UK

Over the last three years, HMNAO has received significant support from the National Hydrographer's group within the United Kingdom Hydrographic Office, particularly in the area of new staff, thereby ensuring the continuity of the office. In particular, Dr. Julia Weratschnig joined the office in November 2009 and Mr. James Whittaker joined in February 2012. Two more staff will join the office at the end of October 2012, bringing the complement up to seven. The collaboration with the US Naval Observatory (USNO) Astronomical Applications Department has grown stronger, celebrating its centenary during 2011, and an exchange program has been established allowing staff to gain experience and share knowledge and expertise.

The joint publications with USNO and those published by HMNAO have continued, the only change being for *The UK Air Almanac*, which is now available for download only. *The Astronomical Almanac* 2009 became fully compliant with the IAU resolutions passed in 2006 and further changes relating to the definition of dwarf planets are in progress. HMNAO staff members have given a number of talks to raise HMNAO's profile within the UKHO and beyond. HMNAO also hosted a meeting in London entitled "Astro-Navigation Solutions for the Future" which brought together many of the parties interested in celestial navigation in the United Kingdom. In view of the possible denial of GNSS, this meeting confirmed the need for celestial navigation as an independent backup to GPS, the continuing requirement for *The Nautical Almanac* and the promotion of *NavPac*, HMNAO's celestial navigation software. It also established the need for better training tools for celestial navigation and star identification including the use of new technology on mobile devices.

— Steven A. Bell

United States Naval Observatory, US

Production of the annual astronomical and navigational almanacs continued as a collaborative effort between the U.S. Nautical Almanac Office and H.M. Nautical Almanac Office (UK). A number of significant changes were made to *The Astronomical Almanac*, including a new table of exoplanets and host stars, a table of the ICRF2 defining sources, and a reorganization of material made necessary by the 2006 IAU definition of a "planet" in the solar system. The third edition of the *Explanatory Supplement to the Astronomical Almanac*—a major update of the previous (1992) edition—was published in late 2012. The Naval Observatory Vector Astrometry Software (NOVAS) in Fortran, C, and a new Python edition was updated to version 3.1 (2011), and the Multiyear Interactive Computer Almanac (MICA) for Windows and Mac OS X computers was updated to version 2.2.2 (2012). Research activities included work on the theory of bodily tides, the long-term orbital evolution of Phobos and Deimos, and a comparison of the three major, generally available solar system ephemerides. The fourth and final release of the USNO CCD Astrograph Catalog (UCAC) was completed in 2012, and the successor to the UCAC project, the USNO Robotic Astrometric Telescope (URAT), commenced observations. The Flagstaff Astrometric Scanning Transit Telescope (FASTT) program was expanded to include the first 5600 numbered asteroids, and completed more than 440 000 observations by mid-2012.

— John. A. Bangert (report presented by James Hilton.)

Comments by the Incoming President

Incoming president Catherine Hohenkerk thanked the outgoing president and members of the OC for their work over the past triennium. She looks forward to working with the new, somewhat enlarged, OC and welcomed all the new members of the Commission.

Ms. Hohenkerk noted that the IAU reorganization may affect how the commissions work and interact with their divisions. She hopes that the recommendations of the WG on Standardizing Access to Ephemerides might be put into action during the new triennium. She is committed to keeping the Commission 4 website up-to-date and relevant. She can be reached at iaucom4@ukho.gov.uk.

Report submitted 29 November 2012

George Kaplan, Past President