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DIVISION I: FUNDAMENTAL ASTRONOMY
(ASTRONOMIE FONDAMENTALE)

PRESIDENT: Nicole Capitaine
BOARD: Jean Chapront, John D. Hadjidemetriou, Wenjing Jin, Gérard Petit & Kenneth Seidelmann

Commission 4: Ephemerides
Commission 7: Celestial Mechanics and Dynamical Astronomy
Commission 8: Astrometry
Commission 19: Rotation of the Earth
Commission 31: Time

1. Introduction

Division I meetings have been organized for the first time during the XXVth General Assembly, providing opportunities for the members of the individual commissions of the division, and more generally for people interested in Fundamental Astronomy, to participate in scientific discussions on the most recent developments in this field. The SOC of these meetings was composed of Division I Board, enlarged with Vice-Presidents of Division I Commissions, Presidents of the current Division I Working Groups and with the upcoming Division I President, Toshio Fukushima, who was elected in March 2003. The first meeting (on 17 July) included three sessions devoted to scientific discussions and one session devoted to reports of the Division Working Groups. The second meeting (on 21 July) included one session devoted to the future organization of the Division. Besides organisation issues, the points that had been identified by the SOC as being the most important points to be discussed, were the "Implementation of the IAU Resolutions" and the "Precession and Astronomical Standards". At the opening of the first meeting, the memory of P. Bretagnon and Ch. de Veght, who had outstanding contributions to the topics to be discussed and passed away last year, was recalled.

This report includes the summary of the scientific presentations and discussions in these sessions. It also provides information about the future organization of the Division within the future revised by-laws of the IAU. The reports of Division I Working Groups can be found in the Reports in Astronomy (IAU Transactions, Vol XXVA, 2003, H. Rickmann ed.)

2. Session on the Implementation of the IAU Resolutions

2.1. Present status of the Implementation

Models for the implementation by N. Capitaine (Syrte, Observatoire de Paris, France)
The implementation of the IAU 2000 resolutions requires the adoption of (i) the IAU 2000 model (Resolution B1.6) to replace the IAU 1976/1980 precession-nutation for the motion of the Celestial Intermediate Pole (CIP) in the Geocentric Celestial Reference System (GCRS), (ii) a conventional model (Resolution B1.7) for high frequency motions

of the CIP in the International Terrestrial Reference System (ITRS) and (iii) the conventional relationship for defining UT1 (Resolution B1.8) as proportional to the Earth Rotation Angle (ERA) between the Celestial and Terrestrial Ephemeris Origins (CEO and TEO). Two equivalent ways of implementing these resolutions in the transformation from ITRS to GCRS can be used, namely (a) the new paradigm, based on a direct use of the CEO and the ERA and (b) the classical paradigm, based on the direct use of the equinox and GST, but using the CEO and the ERA indirectly. Implementation of the resolutions has required computation of expressions compliant with the new precession-nutation model, to be used in the ITRS/GCRS transformation once the relationship ERA (UT1) is adopted. Equivalent expressions have been provided in scientific papers published in 2002 and 2003 for all the models necessary to implement the IAU 2000 system, using either the CEO-based or the equinox-based transformations.

Status of the IERS implementation by D.D. McCarthy (U. S. Naval Observatory)
The International Earth rotation and Reference system Service (IERS) has implemented the IAU resolutions of the 24th General Assembly in its products. The IERS Conventions now provides an outline of the procedures to be used along with software consistent with those procedures. IERS Bulletins A and B have made the data required to implement the resolutions available since January, 2003. To assist users in the transition period between the previous system and that recommended by the 24th General Assembly, the IERS also continues to provide data consistent with the previous system. It also plans to make available a file of frequently asked questions to assist users in the transition between systems.

2.2. Implementation for the Almanacs *(Chair: J. Vondrak)*

Implementing the IAU 2000 resolutions in almanacs by J.A. Bangert (Astronomical Applications Department, U.S. Naval Observatory)
Almanacs provide practical astronomical data in an accessible form to satisfy the needs of a wide variety of user applications such as navigation, pointing a telescope, planning an observing session, or scientific research. Many users expect that the general content and format of the almanacs will remain the same from year to year. Thus, changes to the almanacs are made as infrequently as possible, and only after careful deliberation. The almanac makers implement a proposed change when the change (1) will result in more accurate information in the almanac, (2) is based on sound scientific underpinnings, and (3) will result in data or information relevant to the users of the almanac. The last criterion is the most important. The IAU 2000 resolutions must be considered in the context of these criteria before they are implemented in the almanacs. In addition, even under ideal circumstances there is a considerable lag between the time a resolution is adopted and the time that it is implemented in the almanacs. This lag is due to the time needed to develop, implement, and test new production software, and to the normal almanac publication schedule.

Changes in the Astronomical Almanac by G. H. Kaplan (Astronomical Applications Department, U.S. Naval Observatory)
The Astronomical Almanac must satisfy the needs of a variety of users around the world, who represent a wide range of interests and sophistication levels. The book, prepared jointly by the US and UK nautical almanac offices, is based to the greatest extent possible on IAU-endorsed and other internationally recognized standards. The IAU resolutions on reference systems and Earth rotation adopted in 1997 and 2000 represent a significant change in approach for both subject areas. To implement these resolutions in contents of The Astronomical Almanac, both the reference data and algorithms used must be changed, and some new tabulations added. Some of the required

modifications have already been made and others will be introduced into the editions now in preparation. The specific changes are described, along with issues for the future.

Implementation of the IAU resolutions in the French ephemerides by W. Thuillot (IMCCE, Observatoire de Paris, France)
Institut de mécanique céleste et de calcul des éphémérides (IMCCE), formerly Service des calculs et de mécanique céleste du Bureau des longitudes, is in charge, at Paris Observatory and under the auspices of Bureau des longitudes, of the making and the diffusion of the French ephemerides. Various ephemerides are provided as well by means of books as by means of on-line electronic facilities. The implementation of the IAU resolutions, together with the introduction of new dynamical models that we project, will then require important efforts. It appears that the improved models and the new constants must be adopted, therefore the use of new models of precession and nutation will be done at first. On the other hand, the changes in the systems of coordinates which will imply too hard disruptions to the general users will only be introduced in parallel with the usual systems.

Revisions of Japanese Almanacs by T. Fukushima (National Astronomical Observatory of Japan)
Japan publishes two kinds of national almanacs; the more precise and comprehensive one for the nautical use, the Japanese Ephemeris (JE) by the Maritime Safety Agency (MSA), and the more compact for the civil use, the Ephemeris Year Book (EYB) by the National Astronomical Observatory of Japan (NAOJ). As for JE, it is still in the same style and the same contents since the last major revision in 1984. The MSA will make no revision of the JE until all the required procedures for the changes are clear. As for EYB, we have already done a major revision from the edition of Year 2003. The contents of the revisions are (1) the change of base planetary/lunar ephemeris from DE200 to DE405, (2) the change of nutation theory from IAU 1980 to Shirai and Fukushima (2001), and (3) the change of geodetic datum from Tokyo datum to the new Tokyo datum, being almost the same as the latest ITRF.

The Russian astronomical yearbooks: modern state and IAU resolutions by M.L. Sveshnikov, N.I. Glebova, M.V. Lukashova, A.A. Malkov (Institute of Applied astronomy, RAS, St.-Petersburg, Russia)
IAA RAS produces several printed yearbooks. Their structure and contents are changed regularity to satisfy IAU resolutions and requirements of users. The current plan of implementing the IAU 2000 resolutions in Russian yearbooks is given. Future reform of yearbooks includes the replacement of planetary ephemeredes, precession-nutation model, stellar catalogue and transfer to the new CEO concept. It will be carried out during 2003-2006.

2.3. Experiences and problems *(Chair: P. Wallace)*

An other look at non-rotating origins by G. H. Kaplan (Astronomical Applications Department, U.S. Naval Observatory)
As an alternative to the usual quantities used for positioning the CEO, a simple vector differential equation for the position of a non-rotating origin on its reference sphere is developed. The equation can be easily numerically integrated to high precision. This scheme directly yields the ICRS right ascension and declination of the CEO, or the ITRF longitude and latitude of the TEO, as a function of time. This simplifies the derivation of the main transformation matrix between the ITRF and the ICRS. This approach also yields a simple vector expression for apparent sidereal time. The directness of the

development may have pedagogical and pratical advantages for the vast majority of astronomers who are unfamiliar with the history of this topic.

FAQS as an educational device by C. Ma (GSFC, USA)
FAQs have become common on the worldwide web as an introduction to a specific topic. An initial set of FAQs on the recent IAU resolutions has been prepared for linking from relevant web sites. The content, future refinement and expansion, and distribution is discussed.

2.4. Discussion on the Implementation of the IAU Resolutions

The presentations in this session showed that procedures, models and software are available to users for the implementation of the IAU 2000 resolutions. Such an implementation has already been done in IERS products and will be done in almanacs in a near future. However, an important educational effort is needed to inform a wider astronomical community about the new system recommended in IAU 2000 Resolutions and official recommendations are required in order that the almanacs implement the new IAU resolutions based on a common an approved terminology.

3. Session on Precession and Astronomical Standards

3.1. Improved Precession models and Parameters *(Chair: G. Kaplan)*

New precession formulae by T. Fukushima (National Astronomical Observatory of Japan)
We modified Williams' formulation (Williams 1994) of the 3-1-3-1 rotation matrix to express the precession and the precession-nutation matrices with respect to the ICRF in a robust form. By using the latest determination of the planetary precession of DE405 in the inertial sense (Harada and Fukushima 2003) and one of the recent nutation theories (Shirai and Fukushima 2001), we determined the luni-solar precession from the VLBI observation of celestial pole offsets during 1979 to 2000. We also determined the best estimate of the geodesic precession and nutation. As by-products, we obtained the new determinations of (1) the mean equatorial pole offset at J2000.0, (2) the speed of general precession in longitude at J2000.0, (3) the mean obliquity of ecliptic at J2000.0, and (4) the dynamical flattening of the Earth.

Expressions for IAU 2000 precession quantities by N. Capitaine[(1)], P.T. Wallace[(2)] and J. Chapront[(1)] ([(1)] Syrte, Observatoire de Paris, France, [(2)] H.M. Nautical Almanac Office, RAL, United Kingdom)
We discuss precession models consistent with the IAU 2000 precession-nutation and a range of products that implement them. We first present the expressions for the currently used precession quantities, in agreement with the MHB corrections to the precession rates, that appear in the IERS Conventions 2000. We then discuss a more sophisticated method that we used to develop P03 precession expressions that are dynamically consistent. We obtained expressions for the precession of the ecliptic based on most recent theories for the Earth and the Moon and the most precise numerical ephemerides. We then used these new expressions for the ecliptic together with the MHB corrections to precession rates to solve the precession equations for providing a new solution for the precession of the equator that is dynamically consistent and compliant with IAU 2000. A number of perturbing effects have first been removed from the MHB estimates in order to get the physical quantities needed in the equations as integration constants. We also discuss the most suitable precession quantities to be considered in order to be based on the minimum number of variables and to be the best adapted to the most recent models and observations.

Precession expressions consistent with the IAU 2000A model. Consideration about the EOP and a conventional ecliptic by W. Thuillot, P. Bretagnon[1], A. Fienga and J.L. Simon (IMCCE, Observatoire de Paris, France)

Since the adoption of an accurate nutation model, the IAU encourages the development of new expressions for precession consistent with the new model. We present here the new precession quantities given in Bretagnon *et al.* (2003). These expressions are issued from the analytical solution of the rotation of the rigid Earth SMART97 (Bretagnon *et al.* 1998) which provides together precession and nutation. These expressions include the new value of the precession rate of the equator in longitude. As the SMART97 series are close to the Souchay *et al.* (1999) series used to build the new model, they are consistent with the IAU 2000 Precession-Nutation Model. We give the differences between our expressions and the Lieske *et al.* ones (1977) improved in the IERS Conventions 2000 and show that those differences are superior to the precision of the low-precision model IAU 2000B. We also give the derivatives of our expressions with respect to the precession constant and to the obliquity in order to compute the corrections of the precession quantities given by future improvements of these constants. Following Bretagnon *et al.*'s model for Earth rotation (1998, 2003), we show that the celestial pole offsets as well as polar motion can be included with precession and nutation in a global modeling of the Earth rotation, thanks to the Euler angles and we discuss the use of such angles in IERS publications. In the end, we propose the definition of a conventional ecliptic plane close to the mean ecliptic J2000 and with a non-rotating origin.

Future directions in precession and nutation by J. Hilton (U.S. Naval Observatory)

The IAU 2000A precession-nutation theory is computationally expensive, requiring over one thousand evaluations of sine and cosine functions required to evaluate IAU 2000A just once. In response to this another precession-nutation theory, IAU 2000B, was adopted at the same time. However, IAU 2000B has a reduced precision and was designed to cover only a limited time span around the epoch J2000.0. At the same time, applications such as the Multiyear Interactive Computer Almanac (MICA), are being developed that require long coverage periods and the ability to reach the accuracy of modern day observations. To address this deficiency future precession and nutation theories will need to do one or more of the following: (a) make a serious effort to optimize the code; (b) reduce its precision to match the accuracy with which the Earth orientation can accurately be determined; (c) no longer separate terms that are so close together in frequency space that their individual contributions cannot be determined at the level of accuracy of the observations; (d) move from representation as an analytic theory to a numerically integrated representation.

3.2. Astronomical standards *(Chair: V. Dehant)*

The sources and uses of astronomical constants by E.M. Standish (Caltech/JPL)

We discuss the use of ephemerides based upon the independent variable, "Teph", and compares it with the use of ephemerides based upon the recent IAU-defined "TCB". Teph has been used over the past three decades for the ephemerides created at JPL, CfA, and IPA; it has been referred to, somewhat erroneously, as "ET" and or "TDB" in the past. Teph and TCB are mathematically equivalent; they are both relativistic coordinate times. Proper use of a Teph-based ephemeris should give results identical to those obtained using a TCB-based ephemeris. However, care must be taken in some circumstances, such as navigating a spacecraft in orbit around a remote planet while timing the dynamics on an earth-based clock. This paper discusses such situations.

[1]Pierre Bretagnon, died on November 17, 2002

3.3. Discussion on precession and astronomical standards

Presentations in this session showed that a physically consistent precession should have to be considered in the near future based on an improved precession of the ecliptic. An IAU Working Group is needed to recommend a new precession model resulting from comparisons of the recent available models. Discussion about astronomical standards makes it clear that a strong coordination is required between the various sources of standards (IAU, IERS or IAG values) in order to improve consistency between the standards for astronomical or geophysical uses. An effort should be done in that sense by the representatives of these bodies in various Committees.

4. Division I Organization

The last session of Division I meetings has been devoted to a large discussion on the future of Division I commissions and working groups within the future revised by-laws of the IAU. According to the discussions that have been held during the scientific sessions and during the session devoted to the reports of the Division I Working Groups, Division I Board proposed to continue the Working Groups that have very specific tasks and to establish two new Working Groups: one on "Precession and ecliptic" (Chair: J. Hilton, USA) and the other on "Nomenclature for Fundamental Atronomy" (Chair: N. Capitaine, France). This proposal was presented by the upcoming President, Toshio Fukushima, at the end of the Joint Discussion 16 "The International Celestial Reference System: Maintenance and future realizations" (on 22 July) during which the future of the Working Group ICRS, considering a possible distribution of its tasks to some Division I Commissions, has been discussed.

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President of the Division