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COMMISSION X2 **SOLAR SYSTEM EPHEMERIDES**

EPHEMERIDES DU SYSTEME SOLAIRE

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TRIENNIAL REPORT 2015-2018

1. Introduction

The commission was created in 2015, based on approval of a proposal to merge the functions of the previous Commission 4 on Ephemerides and Commission 20 on Positions and Motions of Minor Planets, Comets and Satellites.

The main purpose of the SSE commission is to support the development of high precision ephemerides, and the products/services that disseminate them, for all solar system bodies: planets, dwarf planets, asteroids, comets, trans-neptunian objects, natural satellites (of planets and asteroids). The ephemerides will include position, velocity, and orientation for bodies other than Earth.

2. Developments within the past triennium

Working in conjunction with the Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE), a more accurate model for the rotation of Mars was developed and published (Jacobson et al. 2018). The defining longitude has been changed to the position of the Viking 1 lander, that can be accurately determined with respect to inertial space from radio range and Doppler tracking data (Konopliv et al. 2016) and has also been imaged by several instruments on spacecraft in orbit about Mars. The defining longitude is consistent with the previous reference of crater Airy-0 to the accuracy of optical images of the crater (Kuchynka et al. 2014).

With increased interest in Phobos and Deimos, including observations from the ESA Mars Express spacecraft and the planned MMX mission from Japan, the orientation models of Phobos and Deimos required significant updates. These models have been developed and published for use by the WGCCRE (Jacobson et al. 2018, Stark et al. 2017).

The arrival of the Juno mission to Jupiter in 2016 has provided initial data to significantly improve the ephemeris of Jupiter (Bolton et al. 2016). The final days of the Cassini mission to Saturn in 2017 included several months with low altitude orbits that have produced data expected to improve the orbit and orientation model for Saturn.

Analysis of pulsar timing data from 2004-2015 for detection of stochastic gravitational waves has shown dependence on the current uncertainty in the orbit of the Sun with respect to the local inertial reference frame (Arzoumanian et al. 2018). This is limited by accuracy of the ephemerides of Jupiter, Uranus, and Neptune.

Several extreme Kuiper belt objects have been detected and found to have correlated longitudes of perihelion (Trujillo & Shepard, 2014). These may be explained by a body more massive than the Earth in an orbit with longitude of perihelion 180 degrees opposite to the known objects with semi-major axis more than 500 au (Batygin & Brown, 2016). Searches for this body are underway, along with searches for possible constraints on its mass and position from its effect on the orbit of Saturn (Fienga et al. 2016), although the effects of the main Kuiper belt objects on the orbit of Saturn must also be taken into account (Pitjeva & Pitjev, 2017).

Searches for Earth-crossing asteroids continue to improve. Notably the first interstellar object visiting the solar system was discovered, 1I/2017 U1, Oumuamua (Meech et al 2017).

3. Future Activities

The ephemerides and orientation models of Jupiter and Saturn will be significantly improved with further acquisition of data from the Juno project and final analysis of the Cassini data. The orientation models, especially the precession rates, will be used to estimate the planetary moments of inertia that will be used in combination with gravity fields and other observations to constrain models of the interior structure of Jupiter and Saturn.

With two planned missions to the major Jupiter satellites, JUICE (ESA) and Europa Clipper (NASA), and one mission under study to Titan, commission X2 will work with the WGCCRE to develop improved models for the Jupiter and Saturn satellite orientations.

The coordinate system for the Moon is currently based on longitude reference to the mean-Earth point. This point is not uniquely defined. A small working group will be formed, coordinated with the WGCCRE, to propose a well-defined coordinate system, possibly based on a no-net rotation constraint on the coordinates of lunar laser retroreflectors derived fro the planetary ephemeris DE421 that has been used for most lunar imaging data reduction for the last decade.

The anticipated released of the first GAIA catalog with proper motions, Data Release 2, in 2018, will allow improvements in accuracy for historic observations of many solar system body observations. One particular goal will be improvement in the ephemerides of Uranus and Neptune from re-processing of astrometric observations from the early 1900s that can be combined with Voyager data to aid pulsar timing searches for gravitational waves.

GAIA observations of asteroids expected in the coming triennium will allow improvements in the ephemerides of most asteroids by more than an order of magnitude.

A proposal for a symposium on Solar System Astrometry, Dynamics, and Ephemerides was submitted in cooperation with the commission X2 organizing committee. If approved, this will be held in 2019 as a forum to discuss these ongoing results and plan for future developments.

William Folkner

vice president of the Commission

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