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DIVISIONS I, III / COMMISSIONS 4, 7, 8, 16, 20 / WORKING GROUP ON NATURAL PLANETARY SATELLITES

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TRIENNIAL REPORT 2009-2011

1. Introduction

The Working Group on the Natural Planetary Satellites has been created to promote the development of high-quality ephemerides. The Working Group encourages theoretical studies, coordinated observations, and makes all data available to the users through the NSDC web site (http://www.imcce.fr/nsdc).

2. Activities of the Working Group on Natural Planetary Satellites

The Working Group had continued its main activities: maintaining and feeding the astrometric database of observations of the natural planetary satellites NSDB and providing ephemerides of all known satellites. These ephemerides named MULTI-SAT are available at www.imcce.fr/sat (IMCCE) or at lnfm1.sai.msu.ru/neb/nss/nssephme.htm. (trilingual version of SAI) described by Emelianov and Arlot in Astronomy and Astrophysics, vol. 487, p.759. Ephemerides MULTI-SAT are continuously updated using the database. The accuracy of the ephemerides has been explored by Desmars et al. in Astronomy and Astrophysics, Volume 499, Issue 1, 2009, p.321. The accuracy of the MULTI-SAT ephemerides has been estimated for all the 107 outer planetary satellites by Emelyanov (2010, Planetary and Space Science, 58, p.411) over the 1975-2020 time interval. As it is shown in Emelyanov 2010 for a number of satellites new observations are of vital importance for maintaining the precision of the ephemerides at a level that would allow identification of satellites during the reduction of observations. For some satellites the precision of their ephemerides is of the order of the sizes of their orbits and such satellites can be considered to have been lost.

NASA's JPL maintains ephemerides for all of the natural planetary satellites and makes them available electronically through JPL's On-Line Solar System Data Service known as Horizons (at http://ssd.jpl.nasa.gov/) or in the form of Spice Kernels (SPK files) through NASA's Navigation and Ancillary Information Facility (NAIF).

Original ephemerides are also available from the Minor Planet Center for irregular satellites at http://cfa-www.harvard.edu/iau/NatSats/NaturalSatellites.html.

An European contract had linked several European laboratories for improving the natural satellites ephemerides for space projects purpose. A standardisation of the NSDB database will be made through this project in a near future.

The NSDB database of astrometric observations maintained by the working group has

been described by Arlot and Emelianov in Astronomy and Astrophysics, volume 503, p.631 and is accessible on the Internet: http://www.imcce.fr/nsdc or http://lnfm1.sai.msu.ru /neb /nss /nssnsdcme.htm. Efforts have been made in order to help the observers for the reduction of data through a software PRAIA (Platform for Reduction of Astronomical Images Astrometrically) proposed by Assafin et al. and described in Astronomy and Astrophysics, volume 515, p.A32. Similarly, a reduction procedure for mutual events of the main satellites of the giant planets has been proposed by Emelianov and Gilbert in Astronomy and Astrophysics, volume 453, p.1141.

A Summer School on astrometry has been organized in Antalya (Turkey) on September 5-10, 2011 in order to teach the astrometric reduction procedure and special lectures have been given on the reduction of observations of planetary satellites, either as by direct astrometric imaging or by photometric observation of phenomena (http://www.tug.tubitak.gov.tr/ aass/).

During the period 2008-2011, mutual events of the Galilean satellites and the main satellites of Saturn occur (in 2009) and campaigns of observations were organized. Only 25 observations of the Saturnian satellites events were made because of the conjunction Saturn/Sun but more than 500 observations of the Galilean satellites events were made through a worldwide network including many amateur astronomers. Studies have been made in order to know the interest of a new reduction of old observations of the natural planetary satellites. Plates made at USNO during the period 1967-1998 have been reduced using the UCAC2 catalogue after being scanned on the DAMIAN machine of the Royal Observatory of Belgium. Results have been published by Robert et al. in Monthly Notices of the Royal Astronomical Society, volume 415, p. 701.

In a workshop dedicated to the Gaia observations of solar system objects held in Pisa (Italy) in May 2011, it has been stated that the natural satellites will benefit of the new astrometric catalogue from Gaia for the astrometric reduction. Only 50 observations of each natural satellites until magnitude 20 will be provided by Gaia except the Galilean moons and Titan for which no observation is possible.

3. Selected works performed during the triennum

The accuracy of astrometric observations and the improvement of the dynamics of the satellites systems allow now to get information on the physical nature of the satellites. The comparison with physical data from space probes or from large ground based telescopes appears to be fruitful.

3.1. *all satellites: observations and theoretical studies*

A publication gathering astrometric observations of planetary satellites, close approaches and occultations of stars by asteroids and mutual events in the systems of planetary satellites with the 26-in. refractor of Pulkovo observatory in 1995-2006 was made by Kiseleva et al. in Planetary and Space Science, Volume 56, Issue 14, p.1908. Another publication gathers many observations made with the transit circle of Bordeaux observatory during 1997-2007 by Arlot et al. in Astronomy and Astrophysics, Volume 484, Issue 3,2008, p.869. A theoretical study on Tidal dynamics of extended bodies in planetary systems was published by Mathis and Le Poncin-Lafitte, in Astronomy and Astrophysics, Volume 497, Issue 3, 2009, p.889. Astrometric corrections for geometric distorsion were proposed by Peng et al. (2010, Chinese Science Bulletin, 55, p.791 and Sci Sin Phys Mech Astron, 2011, 41, p.1126) and applied to Phoebe.

3.2. *The Martian satellites*

New ephemerides available at JPL were published by Jacobson in AJ 139, 2010, p.668. A paper on the origin of the Martian moons has been published by Rosenblatt in Astronomy and Astrophysics Review, Volume 19, article id.44. Mars Express data have been used for improving the values of the masses of these moons and their ephemerides: results are published by Rosenblatt et al. in Planetary and Space Science, volume 56, p.1043.

3.3. *The Galilean satellites*

Predictions of mutual events occurring in 2009 has been published by Arlot in Astronomy and Astrophysics, Volume 478, Issue 1, 2008, p.285-298. Some results of the former campaigns of observations of the mutual events have been published:

- the 1997 campaign: by Emel'Yanov and Vashkov'yak in Solar System Research, Volume 43, Issue 3, p.240
- the 2003 campaign: by Emelyanov in Monthly Notices of the Royal Astronomical Society, vol. 394, Issue 2, p. 1037; by Arlot et al. in Astronomy and Astrophysics, Volume 493, Issue 3,2009, p.1171;
- the 2009 campaign: by Zhang et al. in Astronomy and Astrophysics, volume 532, p.A36; by Emelyanov et al in Solar System Research, Volume 45, Issue 3, p.264; by Marino et al. in Astronomia, n3, p. 18.

Tidal effects on Ganymede have been explored by Bland et al. in Icarus, Volume 200, Issue 1, p. 207 (2009). The rotation of Io with a liquid core was studied by Henrard and published in Celestial Mechanics and Dynamical Astronomy, Volume 101, Issue 1-2, p.1 (2008). The analysis of a large set of astrometric data and comparison to a complete theory of the motion of Io including tides led to a thermal equilibrium of Io as published by Lainey et al. in Nature, Volume 459, Issue 7249, p. 957 (2009).

3.4. *The satellites of Saturn*

A new catalogue of improved astrometric observations was published by Desmars et al. in Astronomy and Astrophysics, Volume 493, Issue 3,2009, p.1183. The predictions of the events of the satellites of Saturn during the 2009 equinox has been published by Arlot and Thuillot in Astronomy and Astrophysics, vol. 485, 2008, p.293.

An updated Phoebe's orbit has been published by Shen et al. in MNRAS, Online Early and CCD astrometric observations of Phoebe made in 2005-2008 published by Qiao et al. in MNRAS, Volume 413, Issue 2, pp. 1079-1082. JPL continuously improves the ephemerides through Cassini data as presented at the 41st and 42nd annual meetings of the AAS DDA.

An Analytical description of physical librations of saturnian coorbital satellites Janus and Epimetheus has been published by Robutel et al. in Icarus, Vol.211, p. 758. Numerical exploration of resonant dynamics in the system of Saturnian major satellites has been made by Callegari and Yokoyama in Planetary and Space Science, Volume 58, p.1906. A Theory of the rotation of Janus and Epimetheus was made by Noyelles in Icarus, Vol.207, p.887 and by Tiscareno et al. in Icarus, Vol.204, p.254.

The Rotational modeling of Hyperion was explored by Harbison et al. in Celestial Mechanics and Dynamical Astronomy, Vol.110, p.1. Very Long Baseline Array Astrometric Observations of the Cassini Spacecraft at Saturn were published by Jones et al. in AJ, Vol.141, article id. 29 (2011) and may be useful for satellites studies.

3.5. *The Outer satellites of Jupiter and Saturn*

Discoveries occurred during the past triennium: new satellites of Jupiter S/2010 J 1 and S/2010 J 2 by Jacobson et al. in 2011 (Central Bureau Electronic Telegrams 2734, 1). A

new analytical solution of the equations describing secular and long-period solar perturbations of mean orbits of outer satellites of giant planets was published (M.A.Vashkov'yak, N.M.Teslenko. Astronomy Letters, 2009, Vol. 35, pp. 850-865; M.A.Vashkov'yak. Solar System Research, 2010, Vol. 44, No. 6, pp. 527-540). A paper on the history of the Irregular Satellites of the Giant Planets was published by Nicholson et al. in The Solar System Beyond Neptune, M. A. Barucci, H. Boehnhardt, D. P. Cruikshank, and A. Morbidelli (eds.), University of Arizona Press, Tucson, p.411. Another paper on the origin of the Irregular satellites of Jupiter (capture configurations of binary-asteroids) was published by Gaspar et al. in Monthly Notices of the Royal Astronomical Society, Volume 415, Issue 3, p. 1999.The photometric model parameters for the 97 new outer satellites of Jupiter, Saturn, Uranus, and Neptune have been determined by N. V. Emel'yanov and Ural'skaya 2011 (Solar System Research, 45, 377385) from the magnitudes accompanying the results of astrometric observations published in Minor Planet Circulars (MPC).

A paper on the rotation of the outer irregular satellites was published by Melnikov and Shevchenko in Icarus, Volume 209, Issue 2, p. 786 (2010). A precise modeling of Phoebe's rotation was published by Cottereau et al. in Astronomy and Astrophysics, Volume 523, id.A87 (2010) and a paper on the Rotational Behavior of Nereid was published by Alexander et al. in The Astronomical Journal, Volume 142, Issue 1, article id. 1 (2011).

3.6. *The satellites of Uranus*

Mutual events have occurred in the Uranian system in 2007 and the list of events together with possibilities of observations were published by Arlot and Sicardy in Planetary and Space Science, Volume 56, Issue 14, p.1778. The Observation of an eclipse of U-3 Titania by U-2 Umbriel on December 8, 2007 made with ESO-VLT was published by Arlot et al. in Astronomy and Astrophysics, vol. 492, 2008, p.599. A Photometric and astrometric analysis of a mutual event between the Uranian satellites Miranda and Oberon was published by Birlan et al. in Astronomische Nachrichten, Vol.329, p.567.

Updated ephemerides of the irregular Uranian satellites were published by Brozovic and Jacobson, 2009, AJ 137, p.3834.

3.7. *The satellites of Neptune*

The orbit of Nereid based on astrometric observations was recalculated and published by Emelyanov and Arlot in Monthly Notices of the Royal Astronomical Society, Online Early. The origin of Triton was explored in a paper by Nogueira et al. published in Icarus, Volume 214, Issue 1, p. 113-130.

Observations of the faint Halimede, Psamathe, Sao, Laomedeia and Neso were used for new ephemerides (Brozovic, M., Jacobson, R. A., Sheppard, S. S., 2011, AJ 141, p.135).

3.8. *The Pluto system*

New results on Pluto'system were presented at the meeting Nix and Hydra: Five Years after Discovery, at STScI, Baltimore, MD. A new satellite P4 or S/2011 (134340) was discovered and publications are in preparation.

3.9. *The satellites of asteroids*

These objects are in fact binary or triple objects, the center of mass of the system being not inside the largest object. Nowadays a lot of binary (or triple) systems have been discovered. No data base of astrometric observations is available yet and no ephemeris is published.