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WORKING GROUP ON SATELLITES
(GROUPE DE TRAVAIL POUR SATELLITES)

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1. ASTROMETRIC OBSERVATIONS

1.1. Observations of the Galilean satellites of Jupiter

Direct observations of positions
Nikolaev Observatory (Ukraine)

During the period from July 1996 to Dec 1998, 189 photographic positions of the galilean satellites were obtained with the zonal astrograph (D=120 mm, F=2044mm). In the year 1998 the close approach of the satellite system with the star N 117881 from the HIPPARCOS catalogue was observed. The observations of 1996 were processed using PPM catalogue and the observations of 1997, 1998 in the ICRS using HIPPARCOS and ACTRC star catalogues. The results are not yet published, but are available upon request. Observations made since 1962 up to 1996 with the zonal astrograph were reprocessed and results are in preparation for publication. During the period from 1996 to 1998, 69 positions of the Galilean satellites were determined by photoelectric meridian observations with the Repsold meridian circle equipped by CCD-microscopes (F=2150 mm, D=150 mm).

Pulkovo Observatory

The astrometric observations of the Galilean satellites with the 26-inch refractor in 1996-1999 have been completed. The photographic plates NP-27 and CCD-camera ST-6 were used. Five plates were taken with 5 or 6 exposures on every plate. More than 1000 CCD exposures were made for the Galilean satellites and 5 sets of exposures to determine apparent distances between satellites. One pass of Europa near a star of the HIPPARCOS catalogue was observed with the CCD-camera.

Institute of Applied Astronomy (St Petersburg, Russia)

At the Teide Observatory (Instituto de Astrofisica de Canarias, Spain) in collaboration with Institute of Applied Astronomy, astrometric CCD observations of Galilean satellites relative to HIPPARCOS star 104297 in the time of the close conjunctions at Nov 12-14 1997 were made. Absolute positions of the satellite with an accuracy better than 20 mas were derived as well as a normal place for the position of Jupiter with 10 mas accuracy. Regular observations of close conjunctions of natural satellites with HIPPARCOS stars were initiated at the Teide observatory with the IAC-80 telescope (D= 82cm, F=900 cm). Until now, for Galilean satellites, 896 pairs of coordinates were obtained from October 26 to 28, 1998.

U.S. Naval Observatory

Photographic observations of the Galilean satellites were continued by D. Pascu with the 26-inch refractor at Washington through 1998. Observations will resume when a suitable substitute for the discontinued Kodak 103aG plate is found. At that time it is expected to remeasure the entire plate archive for the purposes of high precision plate reductions using Hipparcos and Tycho stars providing also precise positions for the planet as well as the satellites.

Photometric observations of occultations and eclipses

The PHEMU97 campaign of observations organized by Institut de Mécanique Mélèste–Bureau des Longitudes (IMC-BDL) provided more than 400 light curves of mutual events of the Galilean satellites. In France, observations were conducted at the Meudon (1m-reflector), Pic du Midi (1m-reflector) and Haute-Provence (80cm-reflector) observatories leading to 89 observations. In Italy, observations were made at the M.G. Fracastoro Station of Catania Astrophysical Observatory using the photon counting photometer of the 91-cm Cassegrain telescope: 80 phenomena were observed, 28 of which are suitable to provide elements useful to determine accurate astrometric positions. The lightcurve data of these events were sent to the IMC-BDL to be published in the PHEMU97 catalogue. Observations of mutual events were made in the observatories of Kazakh republic, Russia and Ukraine and were organized by the Sternberg Astronomical Institute, Moscow, Russia: 44 light curves were obtained for 31 mutual events of the Galilean satellites.

K. Aksnes et al. (Bull. Amer. Astron. Soc. 30, 1147, 1998) and A.A. Kaas et al. (Astron. J. 117, 1933, 1999) have derived astrometric data for the Galilean satellites from 213 light curves of 86 mutual events that occurred in 1990–1992. The data were drawn mainly from the PHEMU91 data set provided on the Web by IMC-BDL. These results and those from extensive data sets of mutual events in 1985 were compared with the E3 and E5 ephemerides developed by J. Lieske.

1.2. Observations of the faint satellites of Jupiter

Goloseevo observatory (Ukraine)

In September 1998 CCD observations of JXIV (Thebe) and JV (Amalthea) were made with the 2-meter telescope and Two-Channel Focal Reducer in the Terskol observatory (North Caucasus) in collaboration with Max-Plank-Institut für Aeronomie, Katlenburg-Lindau, Germany. 29 positions of Thebe and 8 positions of Amalthea were obtained relative to the Galilean satellites of Jupiter.

Haute-Provence Observatory/IMC-BDL

In August and December, 1998, CCD observations provided 43 absolute positions of JVI, 23 of JVII, 53 of JVIII, 35 of JIX, 29 of JX, 27 of JXI, 18 of JXII and 16 of JXIII.

U.S. Naval Observatory

CCD observations were made for JV and JXIV by Pascu and Rohde with the 61-inch Astromeric Reflector at Flagstaff. These observations provide both astrometric and photometric data, and have been used by USNO, JPL and BDL for ephemeris developement (Wells, E., Flynn, B., Gradie, J., Johnson, R., Pascu, D., Stern, A., Thomas, P., Zellner, B.: 1996, Bull. Amer. Astron. Soc., 28, 1071).

1.3. Observations of the satellites of Saturn

Nikolaev Observatory (Ukraine)

During the period from July 1996 to Dec 1998, 26 photographic positions of the satellites of Saturn were obtained with the zonal astrograph (D=120 mm, F=2044mm) and 8 positions of Titan were determined with the Repsold meridian circle. *Pulkovo Observatory*

The major Saturnian satellites were observed with the26-inch refractor. 33 photographic plates were taken with 5 or 6 exposures on every plate during the period from July 1996 to June 1999. With the CCD camera installed at the 26-inch refractor 100 sets of images by 5 to 60 exposures on each of them. From these observations 44 mutual apparent distances were obtained. The internal errors of mutual distances are of 0.04 arcsec. After the processing of the photographic observations from 1994 to 1998, 244 mutual positions of the major Saturnian satellites were obtained as well as 205 positions relative to the planet. The internal precision of these observations is 0.12 arcsec.

Goloseevo observatory (Ukraine)

In September 1998 CCD observations of SII-SVII and SIX were made with the 2-meter telescope and Two-Channel Focal Reducer in the Terskol observatory (North Caucasus) in collaboration with the Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, Germany. After processing a part of these observations 10 positions of Phoebe were obtained relative to the stars of the USNO A-2.0 catalog with an internal precision of 0.35 arcsec. A series of photographic observations made in 1961–1984 is currently being processed and so far 360 positions of SIII-SVI and SVIII have been obtained relative to the stars of the PPM and ACT catalogues with an internal precision of 0.18–0.22 arcsec.

Bordeaux Observatory

Observations of Rhea, Titan, Hyperion and Iapetus were made with a CCD meridian circle (1024x1024) in scan mode, with a declination field of 28'. The mean internal precision of a single observation is about 0.05 arcsec in both coordinates for magnitudes $9 < V < 14$.

La Palma Observatory

CCD observations of the eight major satellites of Saturn were taken on La Palma using the Jacobus Kapteyn Telescope in 1990–1994 (D. Harper, C.D. Murray, K. Beurle, I.P. Williams, D.H.P. Jones, D.B. Taylor and S.C. Greaves, Astron. Astrophys. Suppl. 121, 65-69, 1997) and in 1995 and 1997 (D. Harper, K. Beurle, I.P. Williams, C.D. Murray, D.B. Taylor, A. Fitzsimmons and I.M. Cartwight, Astron. Astrophys. Suppl. 136, 257-259, 1999).

Brasopolis Observatory (Brazil)

(Observations from this observatory were taken using the 1.6 m Ritchey-Chrétien Reflector or the 0.6 m in a few cases).Astrometric positions of the first eight Saturnian satellites obtained from 138 photographic plates taken in 30 nights in 1982–1988 were reduced. The observed minus calculated residuals with the TASS 1.7 theory, give rise to standard deviations smaller than 0.3 arcsec. For Phoebe, 60 CCD frames taken in 10 nights in 1995–1997 were reduced using the USNO-A2.0 catalogue. The residuals (compared with Jacobson's ephemerides) had a standard deviation smaller than 0.5 arcsec.

Haute-Provence Observatory/IMC-BDL

A series of 102 observations of the major satellites of Saturn was made in December 1998; 135 CCD images of Phoebe were obtained in August and December, 1998.

U.S. Naval Observatory

Photographic observations of satellites I-VIII of Saturn were continued by D. Pascu together with the Galilean satellites observations (cf. Sect. 1.1). In addition to the photographic program for the bright moons and planet, CCD observations were made for SXII, SXIII, SXIV, by Pascu and Rohde with the 61-inch Astrometric Reflector at Flagstaff.

1.4. Observations of the satellites of Uranus

Bordeaux Observatory

The Uranian satellites Ariel, Umbriel, Titania, and Oberon were observed together with the central planet.

Brasopolis Observatory (Brazil)

Astrometric positions of the five major Uranian satellites (Miranda, Ariel, Umbriel, Titania and Oberon) from 750 CCD frames carried out during 35 nights in 1995–1998 are presented (C.H. Veiga and R. Vieira Martins, Astron. Astrophys. Suppl., in press). The standard deviations are better than 0.05 arcsec for the four largest satellites and 0.08 arcsec for Miranda.

Goloseevo observatory (Ukraine)

The results of photographic observations made in 1990 with the reflector (D=600mm, F=7400mm) at Majdanak were processed with the HIPPARCOS catalog; thus 60 positions of the major satellites of Uranus were obtained.

U.S. Naval Observatory

CCD observations were made for UV by Pascu and Rohde with the 61-inch Astrometric Reflector at Flagstaff. These observations provide both astrometric and photometric data, and have been used by USNO, JPL and BDL for ephemeris developement.

D. Pascu and colleagues applied the Planetary Camera of the Hubble Space Telescope (HST) to observe the faint inner satellites of Uranus. The results for the eight brightest of the inner moons of Uranus were published in 1998. Mean motion corrections were determined for these eight moons, and an astrometric precision of 9 mas was achieved for 20th *V* magnitude Puck (Pascu, D., Rohde, J.R., Seidelmann, P.K., Wells, E., Kowal, C., Zellner, B., Storrs, A., Currie, D.G., and Dowling, D.M., 1996, Bull. Amer. Astron. Soc., 28, 1184; Storrs, A.D., Zellner, B., Wells, E.N., Buratti, B., Currie, D., Seidelmann, K., Pascu, D., 1996, Bull. Amer. Astron. Soc., 28, 1072; Pascu, D., Rohde, J.R., Seidelmann, P.K., Wells, E., Kowal, C., Zellner, B., Storrs, A., Currie, D.G., and Dowling, D.M., 1998, Astron. J. 115, 1190).

1.5. Observations of the satellites of Neptune

Bordeaux Observatory

Triton was observed together with the positions of Neptune.

Brasopolis Observatory (Brazil)

Photographic positions of Triton (53 positions taken in 1985, 1987 and 1988) and Nereid (8 positions taken in 1982, 1984 and 1985). The observed minus calculated residuals referred to Neptune (using Harris' ephemerides for Triton and a numerical integration for Nereid) have standard deviations of about 0.05 arcsec for Triton and 0.25 arcsec for Nereid (Veiga C.H., Vieira Martins R., Le Guyader Cl., Assafin M.: 1996, Astron. Astrophys. Suppl. 115, 319-324). CCD astrometric positions of Triton are given for the oppositions of Neptune for 1989 to 1997. In 1989–1994, 433 CCD positions of Triton distributed in 29 nights were obtained. When compared with Jacobson's ephemerides, the observed minus calculated residuals referred to Neptune have a standard deviation of about 0.11 arcsec (Veiga C.H., Vieira Martins R.: 1996, Astron. Astrophys. Suppl. 120, 107-109). In 1995–1997, 759 CCD positions of Triton were obtained during 35 nights. The standard deviation of the residuals were about 0.09 arcsec (Veiga C.H., Vieira Martins R.: 1998, Astron. Astrophys. Suppl. 131, 291-293). In 1993–1998, 229 CCD positions of Nereid were taken in 23 nights. Using a numerical integration method an orbit was fitted to all the published observations of this satellite in order to determine one state vector of this orbit. Compared with Jacobson's ephemerides the standard deviation is 0.16 arcsec (Veiga C.H., Vieira Martins R., Le Guyader Cl.: 1999, Astron. Astrophys. Suppl. 136, 445-451).

Institute of Applied Astronomy (St Petersburg, Russia)

In collaboration with the Teide observatory (Instituto de Astrofisica de Canarias, Spain) the series of CCD observations of Triton in the times of close conjunctions with HIPPARCOS stars with the telescope IAC-80 (D= 82 cm, F=900 cm) were made in Apr 30 - May 8, 1999 and 317 pairs of coordinates were obtained.

Goloseevo observatory (Ukraine)

The results of photographic observations made in 1987 with the reflector (D=600 mm, F=7400 mm) at Majdanak were processed with the HIPPARCOS catalogue, and 4 positions of Triton were obtained.

U.S. Naval Observatory

D. Pascu and colleagues applied the Planetary Camera of the Hubble Space Telescope (HST) to observe the faint inner satellites of Neptune. Observations were obtained in 1997. While these observations are difficult to calibrate, preliminary reductions indicate a somewhat greater precision (Pascu, D., Rohde, J.R., Seidelmann, P.K., Wells, E.N., Hershey, J.L., Zellner, B.H., Storrs, A.D., Currie, D.G., Bosh, A.S., 1998, Bull Amer. Astron. Soc. 30, 1144; Pascu, D., Rohde, J.R., Seidelmann, P.K., Wells, E.N., Hershey, J.L., Zellner, B.H., Storrs, A.D., Currie, D.G., Bosh, A.S., 1998, Bull. Amer. Astron. Soc. 30, 1101).

1.6. Miscellaneous

The data base NSDC of astrometric positions of planetary satellites has now a bibliographic database linking the data to the paper describing the observations. The data base received new observations which were added on the ftp server. All observations are not yet reachable through the interactive software NSDB.

Some observational and reduction methods used for work on natural satellites were presented by Vieira Martins R., Veiga C.H. and Assafin M. in the Proceedings of IAU Symposium 172 (S. Ferraz Mello, B. Morando and J-E. Arlot eds, Kluwer Academic Press, 419-422, 1996), by Veiga C.H. and Vieira Martins R. in the proceedings of the PHESAT95 Workshop on the observation of the phenomena of the satellites of Saturn in 1995 (Ann. Phys., Coll. C1, Supp. 1, J-E. Arlot and M. Stavinschi, eds., 21, C1-163-167, 1996) and by Vieira Martins R. and Veiga C.H. in the Proceedings of the XXth Annual Meeting of the Sociedade Astronomica Brasileira (August 1994), 11-19, Brazil (1996).

Review papers on the CCD long focus observations were published such as: Pascu, D. (Ann. Phys., Coll. C1, Supp. 1, J.-E. Arlot and M. Stavinschi eds, 21, C1-109-115, 1996); Pascu, D. (1996) in the proceedings of IAU Symposium 172; Pascu, D., Rohde, J.R., Seidelmann, P.K., Wells, E., Kowal, C., Zellner, B., Storrs, A., Currie, D.G., and Dowling, D.M. (1997) in the Proceedings of IAU Coll. 165 (I.M. Wytrzyszczak, J.H. Lieske and R.A. Feldman, eds., p. 517).

A paper on the impact of Hipparcos catalogue on planetary satellites observations was published: Pascu, D., Fienga, A. and Arlot, J.-E., 1997, Bull. Amer. Astron. Soc. 29, 1103.

2. THEORETICAL WORKS AND COMPARISONS TO OBSERVATIONS

2.1. Satellites of Mars

Jet Propulsion Laboratory

R.A. Jacobson reports that the verification of the current JPL Phobos ephemeris with imaging observations from the Mars Global Surveyor spacecraft in 1998 indicated that no ephemeris update was needed.

2.2. Galilean satellites of Jupiter

Jet Propulsion Laboratory

A determination of the orbits (precessing ellipses) of the four inner satellites from the original Voyager imaging observations, astrometric observations through 1997, and the Galileo imaging observations (Jacobson 1997: Bull. Amer. Astron. Soc. 29, 1098) will be completed and published later. A fit of numerically integrated Galilean satellite orbits to astrometric observations (1967–1996), Voyager imaging observations, mutual events (1973, 1979, 1985, 1991), eclipses (1967–1996), and Galileo data (1995–1999) is an ongoing project presented in Bull. Amer. Astron. Soc. 30, 1147).

H.M. Nautical Almanac Office (Rutherford Appleton Laboratory, U.K.)

D.B. Taylor reports that Hipparcos observations of Europa (J2) and Titan (S6) and Tycho observations of Ganymede (J3) and Callisto (J4) are analysed to give checks on the latest JPL ephemerides of Jupiter and Saturn (L.V. Morrison, D. Hestroffer, D.B. Taylor and F. van Leeuwen, Proc. of ESA Symposium 'Hipparcos-Venice '97', ESA SP-402, 1997).

Institute of Applied Astronomy (St Petersburg, Russia)

From the preliminary analysis of the results of astrometric observations of Galilean satellites (1962–1997) which were made and re-reduced in Nikolaev Observatory (Ukraine) it was shown that the reduction greatly improved the accuracy of the observations (the single observation error is 0.12–0.15 arcsec), and this series appears to be quite informative for astrometry, particularly for improving ephemerides of Jupiter. Corrections to elements of Jupiter in the DE403 ephemeris were obtained. These results were confirmed by analysis of observations made by the Carlsberg meridian circle.

Photometric light curves obtained in the observational campaigns PHEMU85 and PHEMU91 were processed. Astrometrical data in the form of dates of contacts of apparent disks (or apparent disks with umbra and semi-umbra for eclipses) as well as moments of maxima of the light curves were derived.

A numerical model for Galilean satellites was developed and compared with Lieske's theory on the time span 1962-1997. Model provides as rectangular coordinates of the satellite so partials with respect to initial state vector, masses of Jupiter and satellites, and coefficients of gravitational harmonics.

IMC-BDL

The series of observations made by D. Pascu at USNO were re-reduced using the Hipparcos catalogue. Absolute R.A. and declination of the Galilean satellites were obtained and positions of Jupiter were deduced in order to correct the elements of the orbits of the planet itself (Fienga A. , Arlot J.E. and Pascu D., Proc. of ESA Symposium 'Hipparcos-Venice '97', ESA SP-402, 1997).

2.3. Satellites of Saturn

Jet Propulsion Laboratory

R.A. Jacobson reports a fit of a numerically integrated Phoebe orbit to astrometric (1904–1996) and the Voyager 2 imaging observations (Astron. Astrophys. Suppl. 128, 7, 1998).

H.M. Nautical Almanac Office (Rutherford Appleton Laboratory, U.K.)

D.B. Taylor reports the analysis of the observations of Titan (cf. above).

2.4. Satellites of Uranus

Jet Propulsion Laboratory

A redetermination of the minor satellite orbits from the original Voyager imaging observations and 1994 HST observations was made (Astron. J. 115, 1195, 1998). A fit of numerically integrated orbits for the newly discovered Uranian satellites, Caliban and Sycorax, to observations (pre-discovery to 1998) was published (Jacobson: Meeting of the Amer. Astron. Soc. Division on Dynamical Astronomy, Estes Park, Colorado, 1999).

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H.M. Nautical Almanac Office (Rutherford Appleton Laboratory, U.K.)

D.B. Taylor (Astron. Astrophys. 330, 362-374, 1998) compiled a catalogue of all available published and unpublished Earth-based observations of the 5 major satellites of Uranus. A numerical integration was fitted to observations (Earth-based and Voyager astrographic data) in the time interval April 1977 to October 1995. The physical parameters of the system were determined. The masses of the 4 outer satellites are found to be sensitive to the weights used for the spacecraft data. Details of the determination of the starting conditions for the ephemerides of the 5 major satellites is given in NAO Technical Note No.72 (1998). Included in this numerical integration were the observations taken with the Jacobus Kapteyn Telescope on La Palma in 1990 and 1991 (D.H.P. Jones, D.B. Taylor and I.P. Williams, Astron. Astrophys. Suppl. 130, 77-80, 1998).

Institute of Applied Mathematics (Moscow, Russia)

On the basis of orbital data about the two new Uranian satellites S/1997 U1 (Caliban) and S/1997 U2 (Sicorax), the orbit evolutions have been studied by M. Vashkoviak. The limits of eccentricities and inclinations as well as the periods of pericentres and nodes revolutions have been obtained. This analysis was accomplished with a general solution of the twice averaged Hill problem.

Minor Planet Center

Orbit calculations have been performed in 1998 for the Uranian satellites S/1997 U1 and S/1997 U2 by B.G. Marsden, G. Williams, and K. Aksnes (IAU Circ. 6834, 6869, 6870).

2.5. Miscellaneous

R.A. Jacobson reports that he continued to improve the JPL satellite observation processing software system and provided ephemerides for all of the natural satellites except the newly discovered S/1986 U 10. Ephemerides are available on line via the JPL Horizons system (Giorgini et al. 1996: Bull. Amer. Astron. Soc. 28, 1158). He has also been supporting the Galileo Galilean satellite gravity science work (Anderson et al. 1998: Bull. Amer. Astron. Soc. 30, 826; Science 280, 1573; Science, 281, 2019).

3. RINGS AND INTERPLANETARY DUST

D.P. Hamilton in collaboration with A.V. Krivov (Icarus 123, 503-523, 1996) developed the analytical theory for the circumplanetary dust dynamics taking into account the planetary oblateness, radiation pressure, Lorentz force acting on a grain with a constant charge moving in the magnetic field of dipole and the solar gravity represented by the tidal term. The applications of this theory were the motion of grains in Martian dust belts along the orbits of Phobos and Deimos, Saturn's E ring, the motion of the outer Jovian satellite Elara and of its dusty ejecta.

A.V. Krivov, L.L. Sokolov and V.V. Dikarev, (Cel. Mech. Dynam. Astron. 63, 313-339, 1996) investigated the dynamics of Mars-orbiting dust. The equations of motion of particles governed by radiation pressure and Mars' oblateness in Lagrangian non-singular elements were deduced and solved, both analytically and numerically.

A.V. Krivov and D.P. Hamilton (Icarus 128, 335-353, 1997) modeled the presumed dust belts of Mars having combined theoretical results described above with up-to-date impact models. They used a new numerical code to construct a three-dimentional, time-dependent, and size-dependent distribution of dust material. The normal and edge-on optical depths of the Phobos and Deimos tori were estimated to lie in the interval from 10^{-8} to 10^{-5}.

A.V. Krivov and A. Jurewicz (Planet. Space Sci., 1999) studied the statistics, spatial distributions, and volume densities of the impact ejecta from Phobos and Deimos in the vicinities of these moons.

V.V. Dikarev and A.V. Krivov (Astronomicheskii Vestnik 32(2), 147-163, 1998) investigated the dynamics of the particles of Saturn's E ring with allowances for perturbations caused by radiation pressure, planetary oblateness, the Lorentz force determined by three zonal harmonics of the planetary magnetic potential, and plasma drag. A collective model of the E ring was constructed.

V.V. Dikarev (Astron. Astrophys. 346, 1999) considered the motion of an E ring grain carrying variable charge and being subject to the plasma drag force as well as the radiation pressure and planetary oblateness.

M. Banaszkiewicz and A.V. Krivov (Icarus 129, 289-303, 1997) argued that Hyperion may act as a reasonably effective source of dust in the saturnian system. Eventually the dust ejected (e.g. due to hypervelocity impacts of interplanetary grains or dust particles coming from the outermost moon Phoebe) from Hyperion and subject to the perturbations due to Titan's gravity, solar radiation pressure and plasma drag force, can either collide with Titan, spread into the inner part of the saturnian system, or escape to the interplanetary space.

J.E. Arlot
Chairperson of the Working Group