Apparent Encounters of the Outermost Satellites of Jupiter

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Abstract. Orbital parameters of any two planetary satellites may be refined from ground-based observations on the basis of differences in their astrometric coordinates. The higher accuracy of observations is reached at the periods of apparent encounters of satellites when two satellites fall within the same CCD frame. To obtain the difference in coordinates of satellites we do not need data from stellar catalogs. In addition, inaccuracies existing in planetary theories do not significantly influence the process of refinement of orbital parameters made on the basis of such observations. But for the outermost planetary satellites such events are very rare, while periods of apparent encounters are short. This paper presents the precalculated circumstances of the apparent encounters of the outermost satellites of Jupiter for the years 2005 through 2010.

Introduction

The refinement of the parameters of motion of natural planetary satellites is necessary for both studying the evolution of the Solar System and planning space missions to other planets. Progress in this matter depends on the accumulation of observational material and on the improvement in the accuracy of observations of satellites. The latter is determined not only by the improvement of optical instruments and photoreceivers but also by a search for new approaches to the problem. The use of spacecraft flying nearby the systems of planetary satellites is a very efficient way of receiving astrometric data. However, this way is very expensive and is not sufficiently informative because of the short duration of observational sessions. Observations with space telescopes are also difficult and as yet are very short. Observations in space, when used separately, are inadequate for determining the parameters of satellite orbits. In practice, to refine satellite orbits all available observational data are always used.

A search for new approaches to ground-based observations provides certain progress in accumulating astrometric data and improving the accuracy of observations of planetary satellites. The present paper is devoted to one such approach.

Advantages of ground-based observatons of planetary satellites during their apparent encounters

Ground-based observations of natural planetary satellites are necessary for refining the parameters of satellite orbits. As a result of observations, records of satellite images on a CCD frame against star field background are obtained. Processing of CCD frame consists in determining the differences in the linear coordinates of stars and satellite. Then celestial coordinates of the satellite are calculated, based on the celestial coordinates of the stars taken from suitable stellar catalog. Thus errors of coordinates of stars from the stellar catalog contribute to the satellite coordinates. Moreover, the measurements of star positions on CCD frame also bring in additional errors. The refinement of satellite orbits is based on the analytical dependence of the satellite coordinates upon parameters of its planetocentric motion. Another participant of the refinement process are heliocentric coordinates of the planet taken from the theory of planetary motion. This theory, in its turn, has certain degree of accuracy. Therefore both inaccuracy of planetary theory and that of formulas connecting the dynamical system of coordinates with the system of stellar catalog will affect the inaccuracy of orbital parameters of the satellite. Sometimes image field of CCD frame is so small that no sufficient number of stars falls within it, therefore celestial coordinates of the satellite cannot be determined.

All these errors and difficulties may be avoided if we measure the differences in the linear coordinates of two satellites in a photographic plate or a CCD image. These differences depend directly on the planetocentric coordinates of each satellite as well as on the topocentric vector of the planet. However, the error in the determination of this vector enters in the measured differences in satellites' coordinates with a small coefficient. This coefficient is equal to the ratio of the difference in planetocentric satellite coordinates to the length of the topocentric vector of the planet. For the outermost satellites of Jupiter the above-mentioned coefficient does not exceed 0.04, and in most cases it is even smaller. The coordinates of stars from stellar catalogs are used in this case only to determine the scale and orientation of the coordinate system in the image frame. Errors in the coordinates of stars have a considerably smaller effect on the accuracy of determination of satellites' mutual positions.

The gain in accuracy depends on the resolving power of the photoreceiver and on the apparent distance between two satellites. At least, when using an CCD matrix, the relative position of a satellite can be determined with an accuracy of about $0.05''$ (Shen et al. 2002; Vienne et al. 2001). At the same time, the accuracy of satellite position in the system of stellar catalog cannot be better than $0.1''$.

For these reasons, the measurements of the differences in satellite coordinates in photographic plates or CCD images appear to be preferable. The use of such data increases the accuracy of determination of orbital parameters of natural planetary satellites and, in the end, the accuracy of their ephemerides.

The differences between the apparent coordinates of a satellite and a planet are usually also determined from observations. The theoretical values of such differences are weakly dependent on inaccuracies in the theory of planetary motion. However, because of the high brightness of planet in comparison with the brightness of satellite and the photometric inhomogenety of its apparent disk, the accuracy of fixation of planet's position in a photographic plate or a CCD image appears to be insufficient.

There are examples when the orbital parameters of two satellites were well determined by measuring only the differences between their apparent coordinates. Such work had been done by one of the authors when determining the orbits of Phobos and Deimos (Emel'yanov et al, 1992). However, the most reliable results are obtained when all available observational material is used and certain weights are carefully attributed to observations.

Due to the circumstances described above, observations of planetary satellites prove to be effective when two or more satellites fall simultaneously in photoreceiver's field of vision. Such an opportunity depends on both the size of the field of view and on the apparent sizes of the satellite orbits. The practice of observations of the major satellites of Saturn and Uranus, as well as the Galilean moons of Jupiter, shows that the simultaneous location of several satellites in a photographic plate or a CCD frame is the rule rather than the exception. But when we observe outermost satellites of Jupiter, Saturn and Uranus using CCD detectors, this problem needs special consideration. For example, the eight outermost satellites of Jupiter, J6 - J13, are usually located at mutual apparent angular distances of about $50' - 150'$, only occasionally approaching at distances smaller than $15'$.

To use the advantages of the outermost planetary satellites' observations during their apparent encounters, these observations should be planned in advance. To do this, we should know the intervals of time when images of any two satellites will fall within one CCD image. So we need special ephemerides describing the circumstances of apparent encounters of the outermost planetary satellites.

Table 1: Parameters of satellites taken into consideration.

Satellite	Semi-major axis apparent at mean opposition, arcmin	Mean opposition magnitude, V0
J6 - Himalia	62.7	14.6
J7 - Elara	64.2	16.3
J8 - Pasiphae	129.2	17.0
J9 - Sinope	131.0	18.0
J10 - Lysithea	64.1	18.2
J11 - Carme	128.0	17.5
J12 - Ananke	116.4	18.7
J13 - Leda	61.1	19.5
J17 - Callirrhoe	131.9	20.7
J18 - Themisto	41.1	21.0
J19 - Megaclite	130.2	21.7
J20 - Taygete	127.8	21.9
J23 - Kalyke	129.0	21.8
J24 - Iocaste	116.4	21.8
J27 - Praxidike	115.7	21.2

Ephemerides of apparent encounters of the outermost satellites of Jupiter in 2005 - 2010

In this paper the following task was set: to find those intervals of time during which at least two outermost satellites of Jupiter will be at an apparent angular distance not exceeding the given one. For these intervals we calculated apparent angular distances between satellites for the beginning of each day.

Only those satellites were taken into consideration which are brighter than 22th mean opposition magnitude. Thus, among all known outermost moons of Jupiter we selected those included in Table 1.

The ephemerides were calculated for the full interval of time from 2005 to 2010. The periods when apparent angular distance between Sun and Jupiter is less than 30 degrees were excluded. We consider two satellites to be in close encounter if the apparent angular distance between them is less

Table 2: Division of the ephemerides in the tables.

Table no.	Time interval
Table 3	31.10.2004 - 13.09.2005
Table 4	30.11.2005 - 14.10.2006
Table 5	30.12.2006 - 15.11.2007
Table 6	31.01.2008 - 17.12.2008
Table 7	04.03.2009 - 20.01.2010
Table 8	10.04.2010 - 31.12.2010

then $15'$.

Calculated ephemerides are presented in Tables 3 - 8 where apparent angular distances between two satellites for the beginning of each date are given. Each line contains ephemerides for a single moment of time. Each column (beginning from the 7th) corresponds to a pair of satellites. One column may contain data for different pairs of satellites if their close encounters do no coincide in time. Numbers of satellites, whose apparent angular distances are calculated, are given in the first line of the column segment. For each date, phase of the Moon and apparent angular distance between Moon and Jupiter are also given. Ephemerides were divided into six parts, according to periods of Jupiter's observability and placed into tables as mentioned in Table 2.

These tables are available in electronic form by
http://lnfm1.sai.msu.ru/neb/nss/AAv1/index.htm.

Tables' columns contain the following data. The first column gives the date in a form YYYY MM DD, where YYYY denotes year, MM is a month number, DD is a day. Second column gives Modified Julian Date in a form JD* = JD-2450000.5. Then follows phase of the Moon: 0.00 is a New Moon, 1.00 is a Full Moon, 0.50 is a First or Last Quarter. Next column contains angular distances between Moon and Jupiter (in degrees). Following columns give mutual angular distances between pairs of satellites (in arcminutes). Numbers of satellites, to which apparent angular distances relate, are given in the first line of the column segment.

The algorithm of using these tables is following. First, select the date of planned observations and look for the corresponding line in the table. To find out whether Moon will hamper your observations, give a look at columns containing the lunar phase and Moon separation from Jupiter.

If observational conditions are acceptable, move along the line looking at the apparent angular distances between pairs of satellites. For each such value move upwards along the column. In the first line of column segment you will see the numbers of both satellites for which these distances are given. Choose only those distances, which do not exceed field of vision of your observational instrument. For both satellites found by their numbers define their right ascensions and inclinations. This may be done by means of existing programs for calculating ephemerides accessible via the Internet. In particular, such services are offered by Institute of Celestial Mechanics and Calculation of Ephemerides in Paris (http://www.imcce.fr) and by JPL (http://ssd.jpl.nasa.gov/horizons.html). Satellite positions may be defined only for 1-3 moments of time, since during the night satellites do not shift at more than $10'$.

One should take into consideration that the accuracy of ephemerides of apparent encounters is restricted to the accuracy of satellite coordinates determination. For satellites J6 - J13 the accuracy of ephemerides is high enough. At least, it is not worse than $0.3'$. As to satellites J17, J18, etc., not many observations of these small satellites have been accumulated so far, so the accuracy of their ephemerides is lower. For this reason, circumstances of those encounters in which these satellites are involved were defined less reliable.

Ephemerides of satellite encounters were calculated on the basis of right ascension and inclination values obtained using JPL's HORIZONS System program available via the Internet (http://ssd.jpl.nasa.gov/horizons.html).

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