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Natural satellites dynamics from observations

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Dynamics of the natural satellites has to be studied with the most accuracy for several reasons. First, it is necessary to prepare the missions of the space probes exploring the system of the satellites. For example, with the coming of the Cassini mission, the dynamics predictions of Saturn's satellites are becoming very important. Second, the researches of the recent state of the Solar system lead to the discoveries of its new members and new properties of the known planets and satellites. Third, the mass distribution in the Solar system and its motion properties serve as a source of great information for the reconstruction of the past and for the prediction of the future of the Solar system.

The motion of the natural satellites is affected by numerous perturbations. This motion is one of the most complex in celestial mechanics. There are theoretical problems related to the satellite motion which are not solved. There are some systematic discrepancies between the parameters obtained from different observational sources and by different authors. For example, let us look through the values of planet parameters obtained from the observations of the satellites of Mars.

Authors	fm km^3s^{-2}	$J2$ 10^{-6}	$J3$ 10^{-6}	$J4$ 10^{-6}
Christensen and Balmino, 1979	42828.4	1959.2	+29.6	−10.2
Sinclair, 1989	42839.5	1951.7	−26.4	−33.1
Emelyanov et al., 1993	42837.6	1950.4	+13.5	−35.2

In this table f — the constant of gravity, m — the mass of Mars, $J2$, $J3$, $J4$ — the coefficients of planet gravity potential expansion.

The properties of satellite motion raise some particularities in the stu2dy of natural satellite dynamics. Let a satellite be observed in the time interval from t_1 to t_2 with a precision of satellite position that is of σ in the orbital longitude. The precision σ_e of the ephemeris in the longitude in the time moment t_e will be evaluated by

$$\sigma_e = \frac{\sigma}{t_2 - t_1}(t_e - t_2).$$

This leads to important conclusions. The advantages of one data set with respect to another one depend not only on the precision of observations but implicitly on the time interval of observations. To build an adequate model of satellite motion one must use the most large data base of observations. Continuation of observations with the former precision remains to be useful. Any new observations even more precise ones are used as the supplement to the previous data base. The use of more precise observations made once does not lead always to the more precise ephemerides. For example, the set of observations of the satellites of Mars made by the spacecraft Mariner 9 in 1971–1972, Viking 1, 2 in 1976–1980, and Phobos 2 in 1989 with the real precision of 20 km leads to the same precision of ephemerides as the ground–based observations made from 1877 to 1988 with the modest precision of $0.4''$ in the apparent coordinates.

This particularity implies the composition of a data base of all observations made in the world. It is reasonable to make some unique data base accessible to all researchers. The Institut de Mécanique Céleste et de Calcul des Ephémérides in Paris is in charge of support of the Natural Satellites Data Base (NSDB) with the help of some members of the IAU Working Group on Natural Satellites mainly from Sternberg Astronomical Institute in Moscow and CNPq Rio de Janeiro Observatory in Brasil. The problem is to suggest all observers to send their results to this data base in real time or after the publication.

In other circumstances we deal with the ephemerides of natural satellites. The creation of the ephemerides is a very complicated process. It includes various theories of the satellite motion and a lot of methods of the data processing. To make the satellite motion prediction more reliable it is reasonable to develop several independent sources of the natural satellites ephemerides in the world.

To provide the process of natural satellites observations with an independent and suitable service of the ephemerides a special software was developed in Sternberg Astronomical Institute in Moscow and proposed to be transferred over the observatories [1].

Very accurate astrometric data can be get from the photometry of the mutual events in the natural satellites. Light curves have to be processed to obtain an astrometric result of such observations. In contrast to the usually accepted method of deduction of the apparent topocentric relative coordinates of satellites an original approach was proposed and developed in our paper [2]. To facilitate the use of the photometric data we reduced them to the planetocentric rectangular coordinate differences of satellite pairs for one instant of time from each observed light curve. The advantages of this approach consist in the fact that after processing the photometric data one will have to deal only with the planetocentric satellite motion to fit the satellite orbit to observations.

The most exact data are received from measurements of coordinates of one satellite relative to other. The accuracy of determination of mutual coordinates of satellites is improved with decrease of their apparent angular distance. The apparent encounters of outer satellite of Jupiter are very rare. We have pre–calculated these events to profit by this circumstance [3].

Saturn's inner satellites have poorly determined ephemerides because they have rarely been observed only during the ring plane crossings ("RPXs" for short) when the usually bright rings become faint. The epochs of these events are separated in time by 14 years. All small satellites were discovered either during the RPXs in 1966 and 1980 or during the Voyager spacecraft encounters in November 1980 and August 1981.

The August 1995 HST images revealed at least 19 unidentified moving objects. Most of these images were linked with three different objects.

Saturn co-orbital satellites Janus and Epimetheus have very interesting dynamics. The satellites move on horseshoe-shaped orbits when viewed in a reference frame rotating at the average mean motion of two satellites. The time period for a complete libration around the horseshoe is 8.01 years. The values of the libration period and the distance of mutual approach are very sensitive to the masses of the satellites. In other way new observations of the satellites lead to a more precise determination of the mass. Unfortunately satellites Janus and Epimetheus are difficult to be observed being very faint objects and moving very closely to the bright A ring of Saturn. The only favorable opportunities to obtain the positions of the satellites occur during the RPXs.

The solution find by Nicholson et al. [4] was to exploit the strong planetary methane and hydrogen absorption at λ 2.0 $-$ 2.4 μm. Thus using the infrared camera, the light of the bright planet may be eliminated. Saturn's rings, however, remain bright in this spectral region. It was a good idea to use the disk of Saturn to occult or to eclipse the bright ring and to observe the satellites as they passed through superior conjunction. The relative positions of the Earth, Saturn, and the Sun restrict the useful windows. Such a situation occurs only on four occasions during Saturn's 29-year orbital period. Nevertheless this offers additional points for the 8-years period of libration. We have published [5] the predictions and circumstances of these events observable from August 20, 2004 to June 1, 2005.

One of the most surprising results from the 1995 Saturn RPX campaign of observations was enigmatic peregrinations of Prometheus. From the satellite dynamics it was discovered that Prometheus lagged some 19° behind its predicted position based on the ephemerides derived from Voyager 1 and Voyager 2 observations. The simplest scenario consistent with the observed lags involves a horseshoe encounter with an unknown small co-orbital satellite.

An exciting enigma arises from the motion of the Galilean satellites of Jupiter as the famous acceleration of Io. The Jupiter–Io problem is very complicated for two reasons: the motions of the three inner satellites (Io, Europa, and Ganymede) are interlocked through strong mutual perturbations, and the tidal response of Jupiter is totally unknown. In apparent contradiction to the lunar tidal theory, which predicts decreasing mean motion it was found through comparisons with observations that the mean motions of these three satellites are increasing very slowly with time. This result implies that Io is now spiralling slowly inward, losing more orbital energy from internal dissipation than it gains from Jupiter tidal torque.

We expect new exciting and useful results from further developing the models of natural satellites motion. New methods of observations as well as more sophisticated theories are wanted.

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