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EVOLUTIONARY DEVELOPMENT OF COMET TEMPEL-TUTTLE METEOROID COMPLEX

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Abstract

A new computer Technology has been developed which is based on the stochastic Model of the Formation and Evolution of meteoroid Complexes. The Technology take into account gravitational Perturbations and nongravitational Effects. The Results obtained are illustrated by Tempel-Tuttle Comet and its meteoroid Complex as an example

Studies of the formation and dynamics of meteoroid complexes have been performed until now within the undisturbed Keplerian motion as all computations revealed insignificant changes in the orbital element of fragments under the influence of nongravitational effects (Poynting-Robertson, Yarkovsky-Radzievsky and others) and secular planetary disturbances [1,2]. Now a computer technology has been developed [3] which is based on the stochastic model of fragments orbital formation and evolution for meteoroid complexes formed in nuclear disintegration of specific comets. The technology is developed according to a module principle. It allows its functions to be expanded and the algorithms applied to be replaced when necessary. A set of programs consists of a server and five software applications and is developed using the dynamic data exchange (DDE) technology [3].

To take into account gravitational pertirbations, a separate built-in module is being developed now. A module software is expected which will include the following components:

A- Gravitational disturbances in a N-body problem determined by numerical integration. RADAU program – Everhart's algorithm [4-6] is used for $N \geq 2$.

B- Perturbations from the major planet's gravity potential in the approach of small bodies. Analytical formulae are used of the developed intermediate non-Keplerian hyperbolic orbit which is based on the symmetric version of a generalized two-fixed centre problem and considers the central body oblateness [7]; the latter body is taken as the planet approached.

C- Perturbations from the Earth's gravity potential when a small body approaches it. Computations are made with formulae for the intermediate hyperbolic orbit based on a asymmetric version of a generalized two-fixed centre problem.

When a small body moves within the Solar System its trajectory may be divided into three parts:

1. the largest one, when a body is in a heliocentric orbit and experiences the greatest gravity perturbations from major planets. This orbital part is considered in the "A" component of our module. Everhart's algorithm is a special implicit one-step algorithm developed by the Runge-Kutta method. It is based on the right-side power expansion of independent variables of an equation of motion. A special method of optimal division into substeps is applied (Gauss-Radau subdivion). All the computations completed, the power expansion coefficients are specified in logical approximations.The integration step is controlled by the last term value in power expansion of independent variables. With this in view, two input parameters are introduced in the algorithm: one which sets the integration accuracy(LL) and another one which sets the order of step power expansion (NOR). A step is chosen automatically provided that the last term of power expansion be $<10^{-LL}$. Parameters are chosen according to the ratio $0.75<NOR<2LL$, NOR being chosen from a given sequence of predetermined numbers. RADA 27 (RADAU) program in a base version applies computer numeration with double accuracy and right-side expansion to the 27^{th} order.

2. If a small body finds itself in the sphere of the giant planet's influence, this body orbit may change abruptly when affected by gravity of the planet approached; this planet may, in some measure, even destruct a body (or destruct it completely as in case of Jupiter and comet Levy-Shomacker). Therefore it is essential to study motion in a time interval (be it small), when a small body approaches a major planet. The trajectory of a small body relative to the planet approached is often hyperbolic. As known, the spherical harmonics expansion of the giant planet gravity potential does not practically involve odd harmonics. So, it is expedient in computations to apply an intermediate hyperbolic orbit of the symmetric version of a generalized two-fixed centre problem [8-9] including perturbations from oblateness (the second harmonics in potential expansion) of the planet relative to which the intermediate orbit is constructed. The algorithms are developed and a computer realization of the four problems is performed:

    - Transition from heliocentric orbital elements of a small body to its planetocentric coordinates (x,y,z);
    - Calculation of intermediate orbital elements relative to the approached planet using planetocentric coordinates (x,y,z);
    - Calculation of planetocentric rectangular coordinates at any time moment from the previous intermediate orbital elements;
    - Transition from a planetocentric orbit back to a heliocentric one.

3. The third trajectory part of a small body seems to be essential when it approaches the Earth and there is a danger for our planet. In this case it is necessary to determine the real-time

trajectory of a hazardous object. In calculations the intermediate hyperbolic orbit may be useful from the non-symmetric version of a generalized two-fixed centre problem including perturbations from the second and the third harmonics in gravity potential expansion of the central body [10]. Algorithms describing the small body motion are developed and are being realized now.

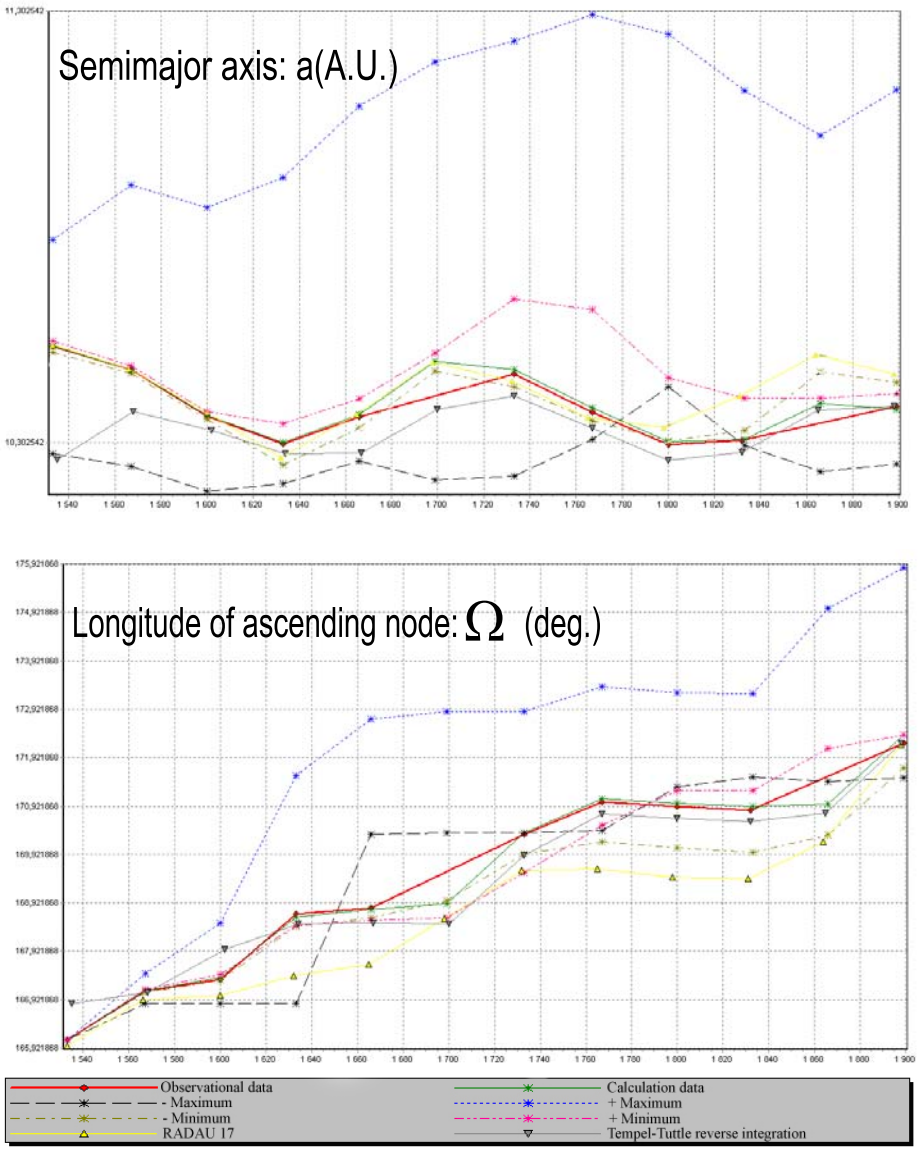


Fig.1 Evolution of Keplerian orbits of Tempel-Tuttle comet (1533), disintegration fragments and observational data

Now the first and the second elements have been realized to consider the effect of gravity disturbances on a small body motion in space. The results obtained are illustrated by Tempel-Tuttle comet and its meteoroid complex as an example.

In calculating the orbit of this comet during its appearance in 1533 is taken as a basis with the following orbital element values: a=10.524540, e=0.908110, i=161.806000, ω=166.100006, Ω=226,850998. The comet mass is taken to be 10^{-23} of the Sun's mass.

First the reliability factor of calculations and their disagreement have been studied from these input data.

Fig.1 presents some results of integrator modifications for a cometary orbit, orbits of fragments ejected with ±maximum and ±minimum deviations and formed in the parent body disintegration at a given cometary orbit point as well as observational data.

It is clear that evolution in the semimajor axis and the longitude of ascending node calculated from RADAU-17 and RADAU-27 for the orbit of Tempel-Tuttle comet in it appearances between 1533 and 1899 (i.e. during more than 350 years) are somewtat different.

RADAU-27 calculations are more close to observations. Observational data themselves fall within the calculation range for both integrator modifications.

Disintegration fragments of a comet for its appearance in 1533 with the maximum and minimum deviations of Keplerian orbital elements from the parent body orbit seem to bound the space area where this comet evolves.

To assess the data accuracy quantitatively, Table 1 shows the difference between calculated and observed values of Keplerian orbital elements of comet Tempel-Tuttle for years of its appearance.

Table 1

Data	Semimajor axis (A.U.)	Eccentricity	Orbital plane angle (deg.)	Angular perihelion distance from ascending node (deg.)	Longitude of ascending node (deg.)
03.01.1567	0.000408	-0.000008	-0.013236	-0.001859	-0.005114
17.06.1600	0.000443	-0.000008	-0.009495	0.044935	-0.016819
07.06.1633	0.003951	0.000100	-0.021280	-0.051093	-0.029182
26.05.1666	0.004791	0.000107	-0.020705	-0.024106	-0.028710
24.09.1733	0.009769	0.000221	0.006146	0.027766	0.007869
19.02.1767	0.010600	0.000231	0.000303	0.061898	0.042918
27.02.1800	0.007513	0.000185	-0.001053	0.070526	0.043456
30.12.1832	0.001867	0.000074	0.003970	0.072657	0.045603
05.07.1899	-0.007815	-0.000116	0.026870	0.165469	0.149473

One can see that RADAU-27 algorithm gives the best result for the first two comet returns, i.e. for about 70 years. In further evolution the error varies by the of magnitude but is not accumulated in time.

Then disintegration has been simulated of comet Tempel-Tuttle at the perihelion (appearance of 1533, the above orbital elements). Eventually, the area boundaries are identified of meteoroid complex formation which fall within the ejection fragment orbits with ±maximum and ±minimum deviations (Table 2)

Table2

	+ max	**+min**	**-max**	**-min**
Semimajor axis (A.U.)	10,77270031	10,53750038	10,27639961	10,51159954
Eccentricity	0,910277009	0,908222973	0,905942976	0,907997012
Orbital plane angle (deg.)	161,8059998	161,8049927	161,8059998	161,8070068
Angular perihelion distance from ascending node (deg.)	166,1009979	166,1000061	166,098999	166,1000061
Longitude of ascending node (deg.)	226,8509979	226,8509979	226,8509979	226,8509979

Using these data, the evolution of a cometary orbit and meteoroid complex fragments was determined for the next 350 years for fragment masses of 1 g, 1 kg and 1 t. Fig.2 presents variations in the semimajor axis (a) and the longitude of ascending node (b) for meteoroid complex fragments (1g) of Tempel-Tuttle comet in its appearances from 1533 to 1989.

Calculations have shown that the influence of a meteoroid fragment mass on the evolution of Keplerian orbital elements is extremely low without close approaches. Particle mass changes from 1g to 1 kg result in modified calculations for the last 3-4th digits in a bit grid. Similar calculations have been also performed for other planets with a long-term life cycle and observational series: 1910 II (Halley), Giacobini-Zinner, Pons-Winnecke, Grigg-Skjellerup. So it is safe to say that the mass of cometary nuclear disintegration fragments does not effect the qualitative pattern of meteoroid complex orbital evolution. Quantitatively its influence is low too. Since substance eruption from the comet nucleus and not nucleus breakdown into some large parts is considered, most disintegration fragments forming meteoroid complexes of a certain comet are dust particles of some grammes in mass; larger fragments of 1 t in mass are infrequent, therefore the computations presented are quite practicapable.

We considered the contribution of gravity potential of all planets as a whole and some planets particularly to the orbital evolution of a meteoroid complex under investigation. As the Leonids and the parent comet are spaced rather compactly, the influence of gravity perturbations on isolated meteoroid complex fragments, the boundaries of which are governed by maximum and minimum deviations of orbital elements from cometary orbital elements, may be studied in terms of the comet itself as the largest body in a complex.

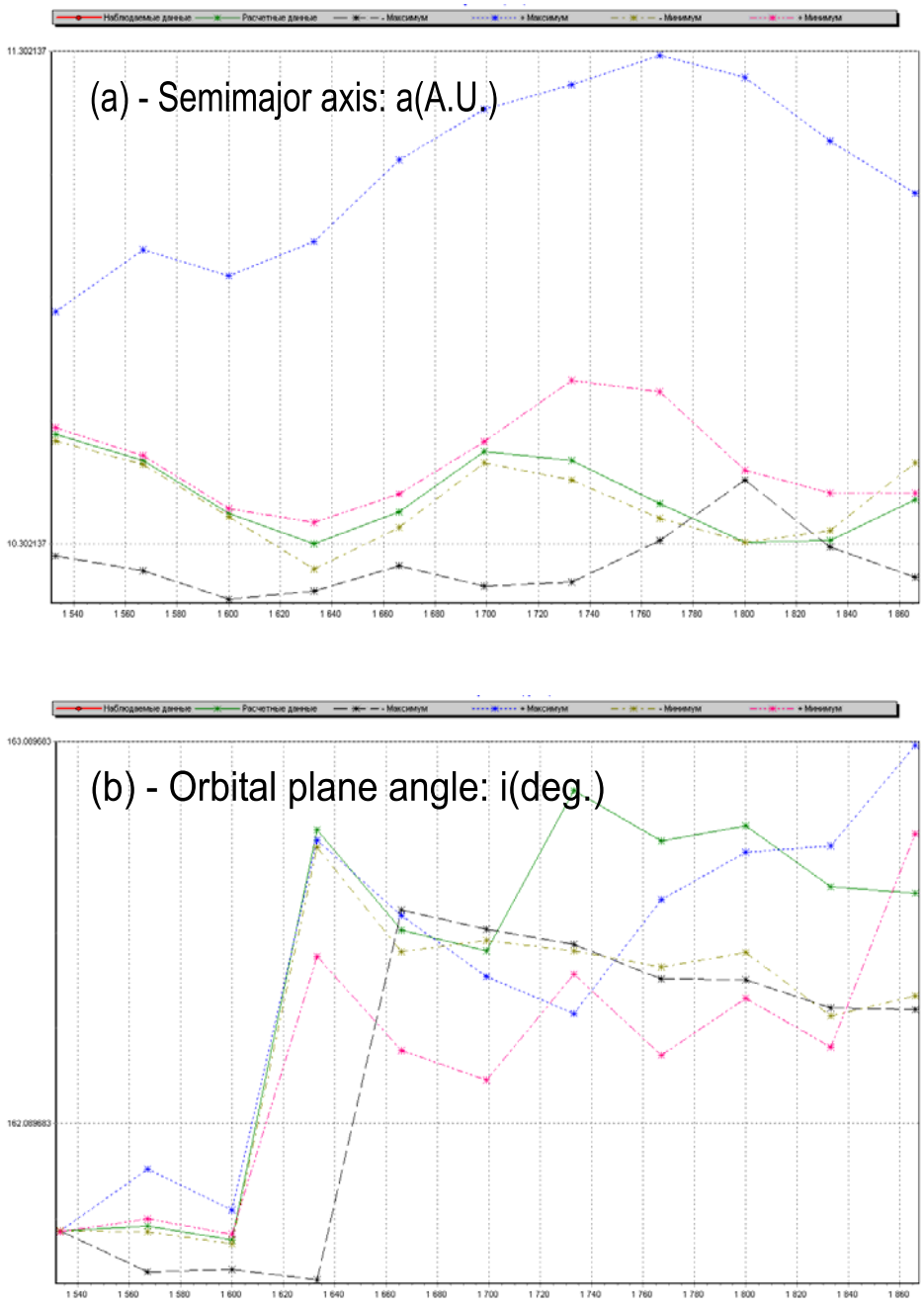


Fig.2. Evolution of Keplerian orbital elements of meteoroid complex fragments from 1533 to 1989

So far as the trajectory of comet Tempel-Tuttle passes near the earth-type planets, Jupiter, Saturn and Uranus, just gravity potential of these planets will influence the orbital evolution of this comet and its meteoroid complex. It is quite clear that the larger the planet mass and the nearer the meteoroid stream are, the greater the gravity potential influence on the trajectory of this formation.

To assess the gravity potential of a planet in orbital evolution of a meteoroid stream, computer experiments have been carried out under the following conditions:

- the influence of all planets is taken into account;
- the influence of earth-type planets (Venus, Earth, Mars) is excluded;
- the influence of earth-type planets and Jupiter is excluded;
- the influence of earth-type planets and Saturn is excluded;
- the influence of earth-type planets and Uranus is excluded.

Table 3 gives input data on the basis of which the meteoroid complex evolution is performed (all data are for the epoch 1950.0)

Table 3

T	**01.01.1533 (B1)**	**17.06.1600 (B2)**	**07.06.1633 (B3)**
a(A.U.)	10.52454	10.36368	10.29873
E	0.90811	0.90476	0.90455
$i^{(o)}$	161.80600	161.79400	162.87900
$\omega^{(o)}$	166.10000	167.33900	168.65800
$\Omega^{(o)}$	226.85100	228.31100	229.54400

Consider some of the results obtained. Fig.3 (a, b) illustrates expected variations in the semimajor axis and the orbital inclination of a meteoroid complex (with a mean orbit corresponding to a cometary orbit) versus considered gravity perturbations of different planets.

Version B1.

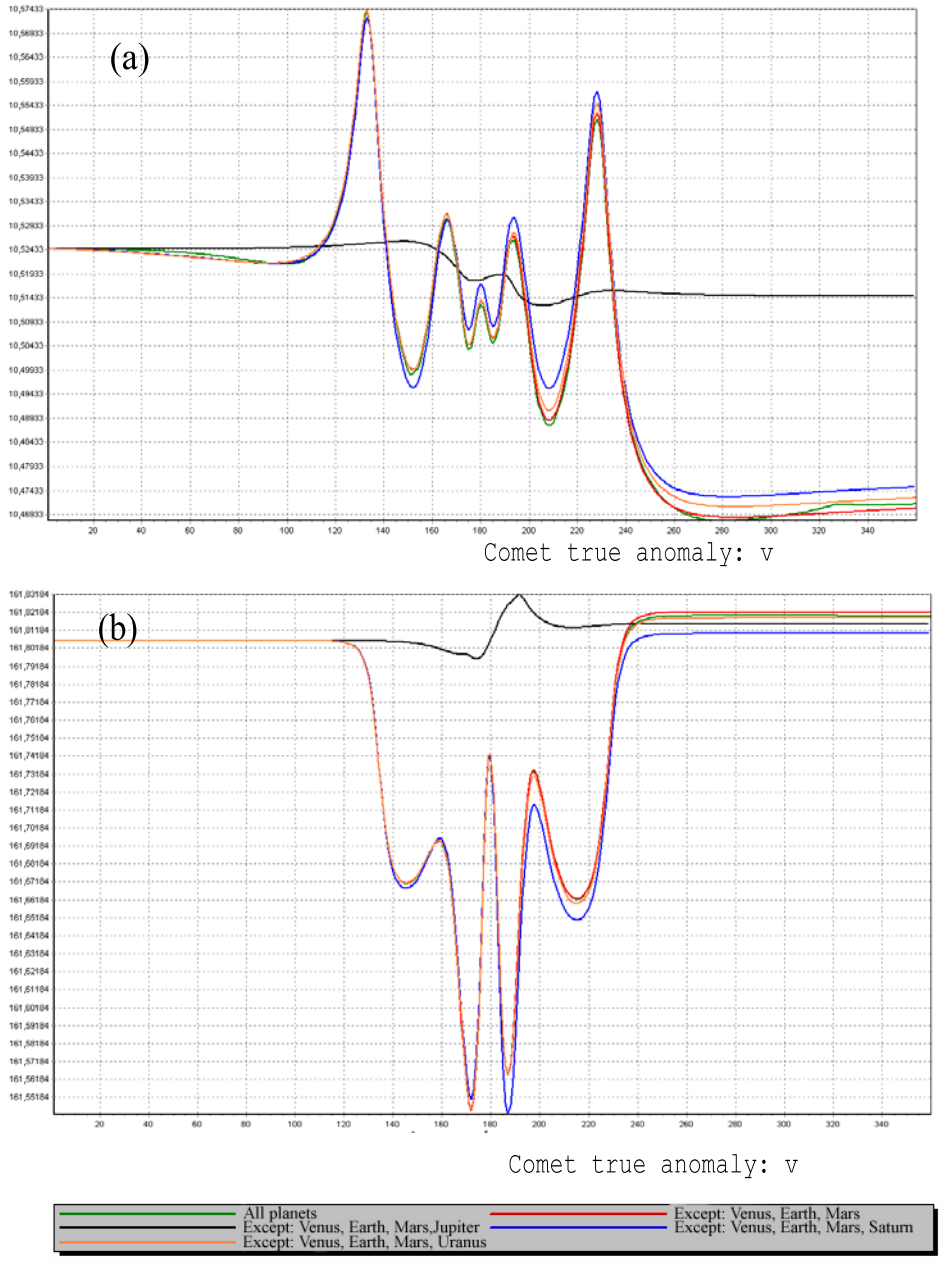


Fig.3 expected variations in the semimajor axis
and the orbital inclination of a meteoroid complex

For the results analyzed to be more qualitative, Fig.4 shows the space distribution of celestial bodies for version B1.

Here (a) is a three-dimensional model when a comet is at its orbital point with the true anomaly of 125^0; (b) is the same for 175^0.

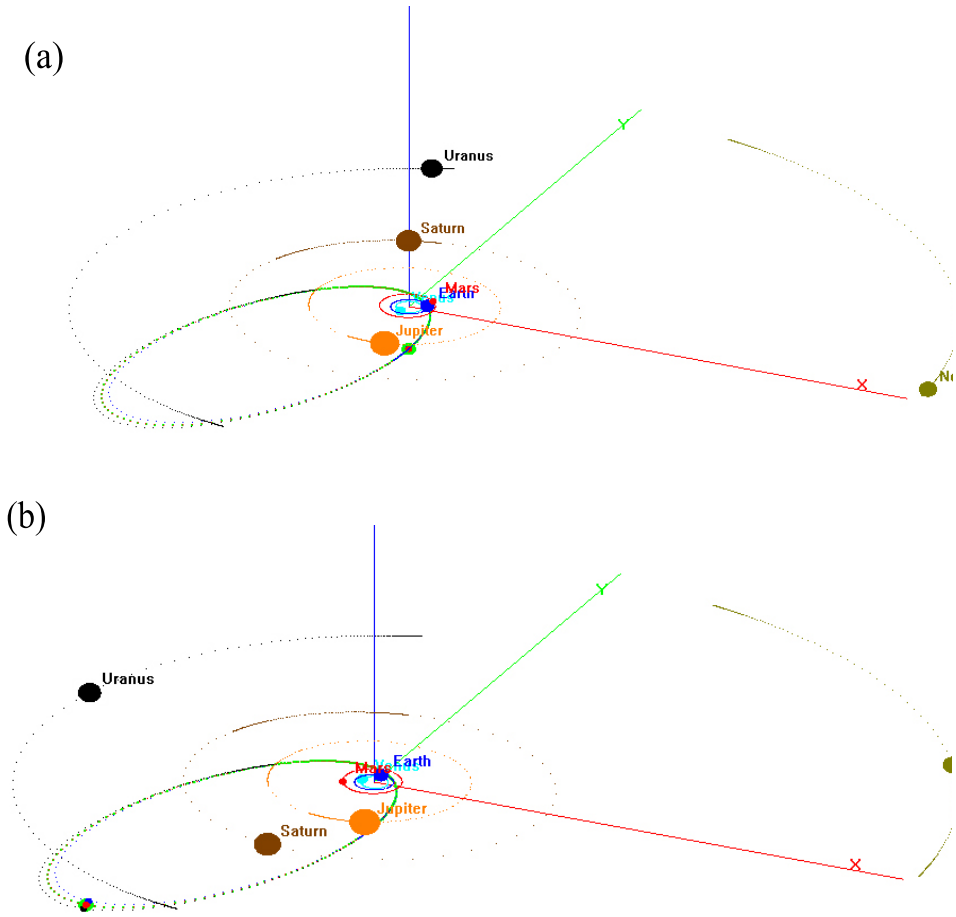


Fig 4. Three-dimensional model of celestial body distribution in space

It appears from the comparison of Fig. 3 and Fig.4 that in orbital motion within the true anomaly (110^0-250^0), the comet itself and the stream following it experience perturbations primarily from Jupiter.

Fig.4a shows that an abrupt jump in the semimajor axis values (Fig.3a) observed within the true anomaly (120^0-140^0) is stipulated by the comet approach with Jupiter. Fig.3b shows that in the absence of Jupiter's gravity potential the evolution of inclination seems to be a straight line

with insignificant spikes at aphelion. Changes in inclination within this range (170^0-200^0), are most probably caused by Saturn's gravity potential (Fig. 4b), though a comet is far distant from the planet.

Similar results for versions B2 and B3 represented in Figs.5-8.

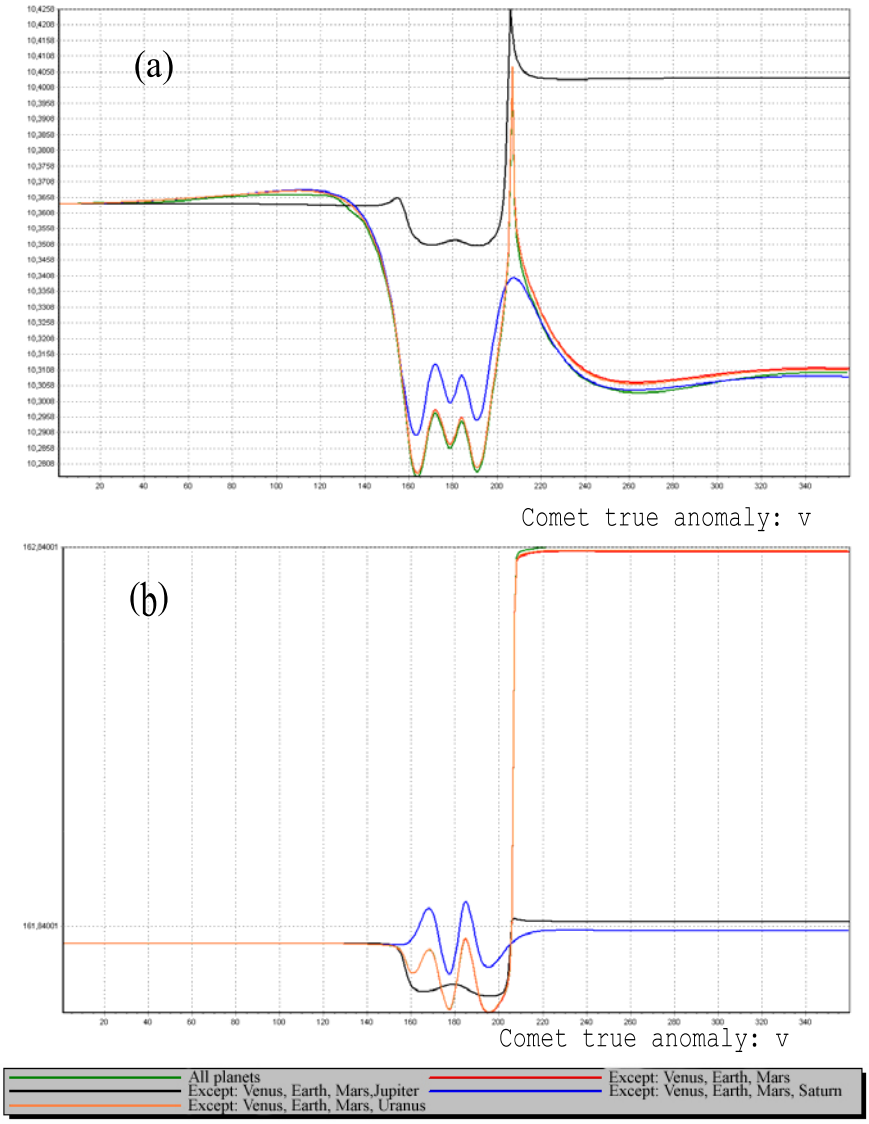


Fig.5. Variations in meteoroid complex semimajor axis (a) and inclination (b) depending on gravity perturbations of various planets. Version B2.

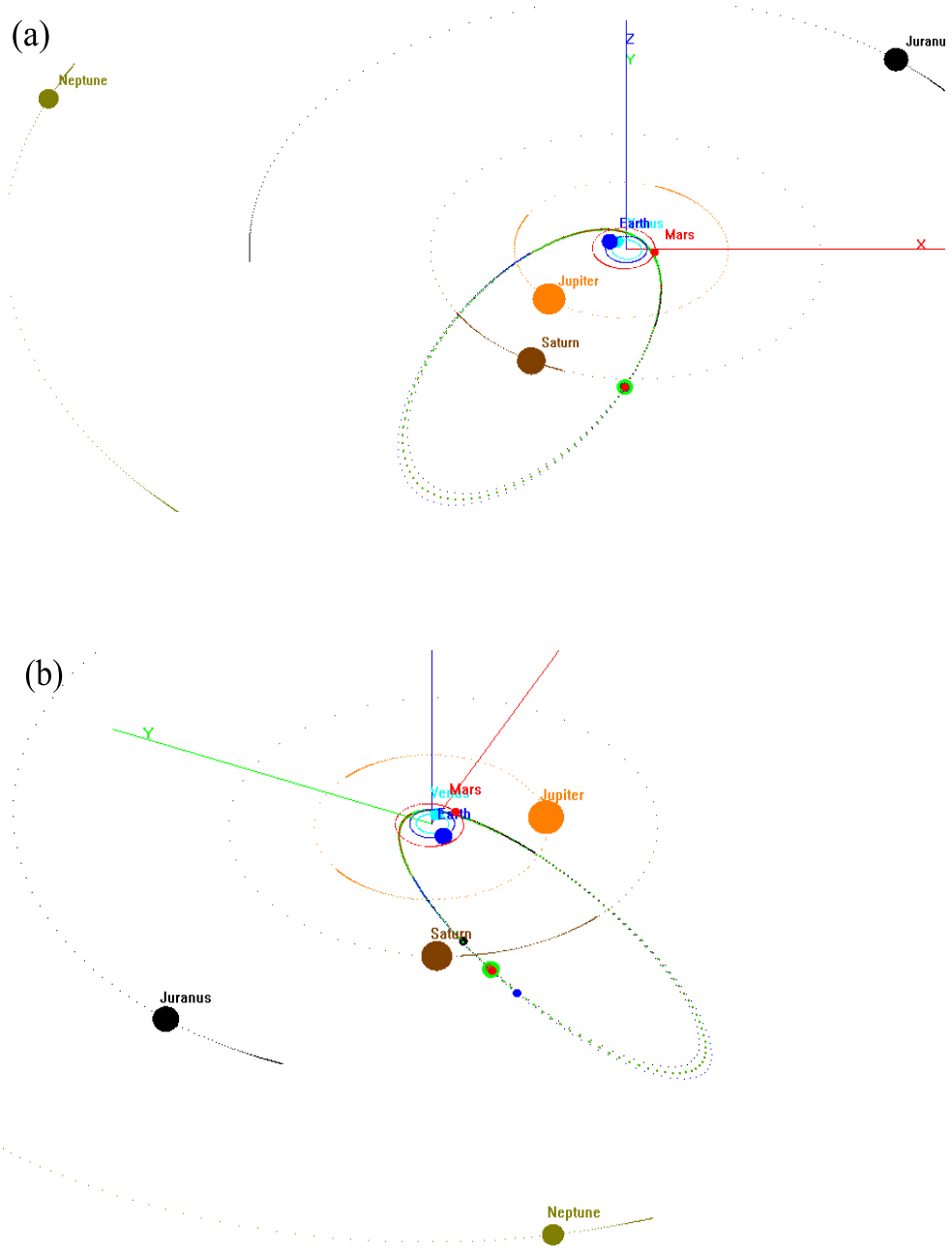


Fig. 6. Three-dimensional model of celestial body distribution in space. Version B2. A comet is at a point with the true anomaly: a-150^0; b-203^0.

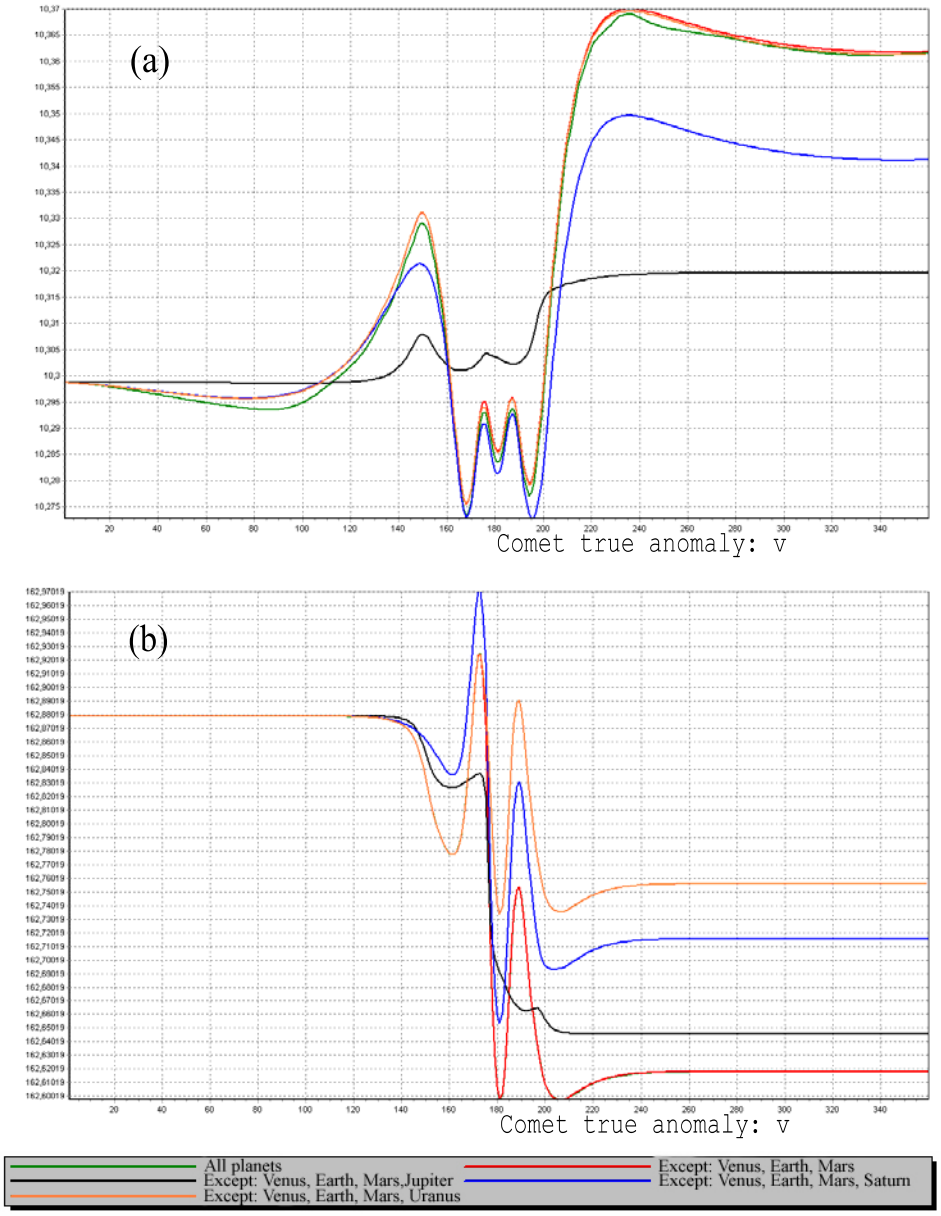


Fig. 7. Variations in meteoroid complex semimajor axis (a) and inclination (b) depending on gravity perturbations of various planets. Version B3.

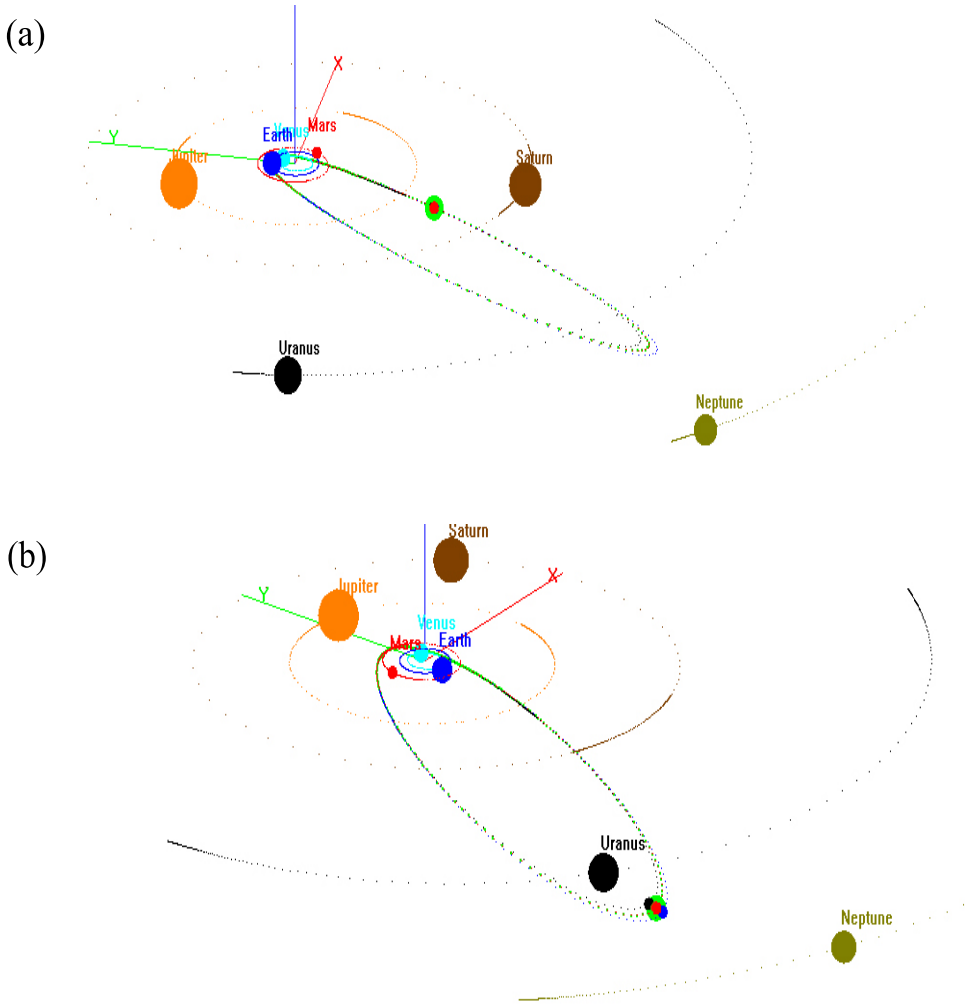


Fig.8. Three-dimensional model of celestial body distribution in space.
Version B3. A comet is at a point with the true anomaly: a-140^0; b-174^0.

When comparing calculation results (Version B2), presented in Figs.5 and 6, it can be seen that within the true anomaly (140^0-200^0) interval the comet and its meteoroid complex are mainly affected by two planets (Saturn and Jupiter) and this produces changes in the elements shown (Fig.5).

Within the true anomaly interval 200^0-210^0, Saturn's gravity potential manifests itself (Fig.6b) and as a result, there are peaks in diagrams (Figs.5a,b). At the true anomaly of 220^0 Saturn's influence decreases and the semimajor axis stabilizes but at higher values than before aphelion passage. Figs.5b and 6 demonstrate that variations in the cometary orbital and meteoroid inclination to the ecliptic plane are caused by perturbations coming from Saturn and Jupiter.

It is interesting to note that in Version B3 (Figs.7 and 8), just as in previous versions, the true anomaly interval from 120^0 to 240^0 is the range of sizable fluctuations in orbital elements for the formation studied. In the other interval (0^0-120^0) - (240^0-360^0) the involved value variations are of a linear character, they grow for the semimajor axis and drop for the inclination after aphelion passage.

In the true anomaly 180^0-200^0 range a meteoroid stream and a comet must have been affected by Uranus (Fig.8b), however, this planet gravity perturbation is insufficient to change the comet's semimajor axis but can change the inclination angle (Fig.7b).

Fig.7a graphically demonstrates that within the whole true anomaly 120^0-240^0 range first Jupiter and then Saturn have a strong impact on variations in the semimajor axis, whereas a spatial object distribution (Figs. 8a, 8b) does not correspond to this conclusion. The analyzed numerical values of orbital element variations have shown that in cometary returns from 1533 till 1600 a semimajor axis tends to lower values after aphelion passage (Figs. 3a and 5a). In 1633 (Fig. 7a) its values increase but do not reach the initial value 10,52454 A.U., so within this time interval the orbit form changes towards a more round ellipse. At the same time the inclination in 1533 changes slightly (Fig.3b), in the year 1600 at the point of true anomaly 200^0 there is an abrupt 1^0 dump towards increasing (Fig. 5b), by 1633 the inclination again decrease but by $0{,}26^0$ only (Fig. 7b).

Eventually, the inclination angle has changed by $0{,}8^0$ relative to the initial value. The values presented are in good agreement with comet Tempel-Tuttle observations for this time interval.

In authors'opinion this technology may be profitably applied for studying meteoroid complexes through long-term or short-term periods which are scientists interested in.

Comparison of the results obtained and the data processed correctly for both the parent comet and its meteoroid complex fragments observed on the Earth as a meteor stream allows us to reproduce the existence pattern of these objects in retrospective and to forecast the entry of fragments, including those which cross the Earth's orbit, into a certain space region.

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