The software "IDA" for investigation of asteroid dynamics and its use for study of some asteroid motion Galushina T., Bykova L., Letner O., Baturin A. Tomsk State University Russia

Investigation of

• Dynamics of

Asteroid

Solving problems

- construction of numerical model of asteroid motion with account chosen perturbed factors;
- asteroid orbit improvement according to positional observations;
- construction of initial probabilistic domain by linear and nonlinear methods;
- study of evolution of initial probabilistic domain;
- revealing of close encounters and possible collisions of investigated asteroid with planets, the Moon and Pluto;
- estimation of asteroid collision probability with planets and the Moon;
- revealing of commensurabilities of mean motions of asteroid and planets;
- estimation of predictability time of asteroid by average MEGNO parameter;
- demonstration of asteroid and planets motion in different coordinate frames on computer screen.

2012 MF7

- The collision probability of this object with the Earth in June 2046 is about 10⁻⁴.
- *D* = 15 m

The algorithms

- Perturbed two body problem in the heliocentric coordinate frame related to equator 2000.0
- Perturbations from major planets, Pluto, the Moon, Ceres, Pallas, Vesta, the Earth and the Sun oblateness, the solar pressure and relativistic effects from the Sun.
- Fundamental ephemeris DE405, DE406 or DE408.
- Everhart method
- Least squares method, earth-based and space positional observations
- Linear or non-linear methods of construction of initial probabilistic domains

- Revelation of close encounters of clones with planets bases on calculation of minimum of square distance function which approximated by Lagrange cubic expression relatively time.
- The impact probability is estimated as relation of collided clone number to all ones.
- The resonance argument $\beta = k_1 \lambda_1 k_2 \lambda_2 (k_1 k_2) \omega_1 (k_1 k_2) \Omega_1$
- The resonance band $\alpha = k_1 n_1 k_2 n_2$
- *n*₁, *n*₂ are mean motions, λ₁, λ₂ are mean longitudes of asteroid and planet correspondingly, ω₁ is argument of pericenter of asteroid, Ω₁ is longitude of the ascending node of asteroid, *k*₁, *k*₂ are integers.

MEGNO (Mean Exponential Growth of Nearby Orbit) parameter represents the time-weighted integral form of the Lyapunov characteristic number (LCN)

$$Y(t) = \frac{2}{t} \int_{0}^{t} \frac{\dot{\delta}(s)}{\delta(s)} s ds$$

$$\overline{Y}(t) = \frac{1}{t} \int_{0}^{t} Y(s) ds$$

- δ is the tangent vector, which measures the evolution of the initial infinitesimal deviation between the solution of motion equations and a very close orbit.
- For chaotic orbits with the exponential divergence of close trajectories \$\overline{Y}(t)\$ increases linearly and reaches values \$\overline{Y}(t) > 2\$.
- For quasi-periodic (regular) orbits with linear divergence of close trajectories $\overline{Y}(t)$ oscillates around 2, and for stable orbits harmonic oscillator type $\overline{Y}(t) = 0$.

The structure of the application suite "IDA"

- subsystem "Assol" allows to study orbital evolution for nominal orbit and to demonstrate the asteroid and planets motion on a computer screen;
- subsystem "Observations" intends to asteroid orbit improvement according positional observations and construction of initial probabilistic domain by non-linear methods;
- subsystem "Distribution" developed for the visualization of distribution of observations along an asteroid orbit;
- subsystem "Clone ensemble" allows to construct an initial probability domain by the linear method;
- subsystem "Evolution" designed for the study of the orbital evolution of an ensemble of asteroid clones ;
- subsystem "Megno" intends to estimate of predictability time of asteroid motion by means of average MEGNO parameter.

Subsystem "Assol"

Asteroids of Solar system				
Asteroid motion Information Exit				
Ephemeris of planets C DE405 t:\fonds\de405\16002200.405	Initial time	Final time Julian date		
C DE406 c:\de406\windows.406	2456000.5	2513292.5		
Asteroid catalog	C Calendar date Year 2012	Year 2169		
t:\tanwork\aspir\katalogs\2014j\astor.14 Month 3 Month 1				
Asteroid name 2012 MF7	Duy 14	Day 22		
	√ Save			
Asteroid Parameters of motion Investigation Authors Data accepted successfully.				

Subsystem "Assol"

Asteroids of Solar system				
Asteroid motion Information Exit				
Coordinate system				
 Heliocentric coordinate system Planetocentric coordinate system 	Rotating with angular velocity of Mercury Venus	Designation of planets C Astronomical symbols C Circles		
 Mercuricentric coordinate system Venuscentric coordinate system Geocentric coordinate system Areocentric coordinate system Jupitercentric coordinate system Saturncentric coordinate system Uranuscentric coordinate system Neptunecentric coordinate system Plutocentric coordinate system 	© Earth C Mars C Jupiter C Saturn C Uranus C Neptune C Pluto	Objects Size Colour Mercury 24 ♀ ダ ✓ Venus 24 ♀ ダ ✓ Earth 24 ♀ ⊕ Mars 24 ♀ ♂ Jupiter 24 ♀ 2		
 Equatorial plane Perpendicularly to equatorial plane Plane of the ecliptic Perpendicularly to plane of the ecliptic Plane of the asteroid orbit 	Coordinate grid Abscissa axis from -2 € to 2 € Ordinate axis from -2 € to 2 €	Saturn 24 € 5 Uranus 24 € 8 Neptune 24 € 9 Pluto 24 € 9		
☐ Motion path Line width	Language O Russian © English	Moon 14 € 0 Moon 14 € 0 Masteroid 10 €		
Velocity		✓ Save		
Asteroid Parameters of motion Investigation Authors Data accepted successfully.				

Subsystem "Assol"

🐝 Asteroids of Solar system	
Asteroid motion Information Exit	
Image: Close encounters Distance (AU) For inner planets For external planets 2.00 For external planets 2.00 Form of motion equations (° Classical equations (in rectangular coordinates) C Equations with modificated time transformation of Sundman type	Perturbation account ✓ Mercury ✓ Saturn ✓ Venus ✓ Uranus ✓ The Earth ✓ Neptune ✓ Mars ✓ Pluton ✓ Jupiter ✓ Ceres ✓ The Moon The Earth oblateness ✓ Pallas The Sun oblateness ✓ Vesta The Sun oblateness ✓ The solar pressure Asteroid mass (kg)
Order of method 19 + Parameter of precision 17 + Check of integration accuracy	Asteroid diameter (m) 270 Asteroid albedo 0.33

Asteroid Parameters of motion Investigation Authors

The orbit of 2012 MF7



Subsystem "Distribution"



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Subsystem "Observations"

Observations		
Initial data Fond DE405 t:\fonds\DE405\16002200.405	The initial moment 2456100.500000000	 Improvement of the asteroid orbit Exception by 3-sigma rule
Observation file 2012_MF7.obs	Coordinates Velocity components 0.018200247672013860 0.019005203335539710	sigma 0.79922462
C Take observations from MPC	-0.93533282806430755 -0.00373963047261916 -0.40553757501029510 -0.00233123740354488	Exception of observations
Initial clone number Final clone number	Step (days) 7.0 Pass "unknown" observatories without stop	
The final moment (JD) 2456100.500000000	🔲 Weight use	▼
Nonlinearity Force mo	rcury	Process status display
Determinate nonlinearity factor Ven The	nus Pallas V Sun pressure	0K 2012 MF7
Bootstrap method Perturbed observation method Mar	IV Vesta rs	0 t0= 2456100.5
Perturbed estimation method	turn The asteroid mass (kg) 4.2E+0006	3 iteration
Number of clones	anus The asteroid diameter (m) 15.0	Close
	to IV Relativistic effects from Sun	
IV Moo	on	

The results of orbit improvement of the asteroid 2012 MF7

Parameter	Value
t_0	22.06.2012
$\mu(A)$	$2.3 \cdot 10^{6}$
$\sigma,''$	0.53
X	$9.6 \cdot 10^{-3}$
Δr , AU	$3.8 \cdot 10^{-6}$
Δv , AU/day	$3.3 \cdot 10^{-6}$
a, AU	1.9715678
е	0.3866357
i,°	1.4812566

Subsystem "Clone ensemble"

Clone ensemble					
Asteroid name	012 MF7	The number of clones	100000		
Time moment	2456100.5	Gain factor	1.0		
Nominal orbit				1	1
Coordinates	0.018201640595412660	-0.93533389406642151	-0.40553806427713401		
Velocity components	0.019005950077206810	-0.00374105652056900	-0.00233211336644165	Ger	nerate
Total covariant r	ties in coordinates and velo matrix	ocity components			
7.708809584E-0012	-6.393868512E-0012	-3.093183174E-0012	3.707585599E-0012	-7.105738364E-0012	-4.362489742E-0012
-6.393868512E-0012	5.311258005E-0012	2.571062607E-0012	-3.065283596E-0012	5.875938160E-0012	3.607682225E-0012
-3.093183174E-0012	2.571062607E-0012	1.245232172E-0012	-1.480663757E-0012	2.838679351E-0012	1.742819295E-0012
3.707585599E-0012	-3.065283596E-0012	-1.480663757E-0012	1.796408897E-0012	-3.440925367E-0012	-2.112298295E-0012
-7.105738364E-0012	5.875938160E-0012	2.838679351E-0012	-3.440925367E-0012	6.591347445E-0012	4.046269832E-0012

Subsystem "Megno"



• The average MEGNO parameter evolution for asteroid 2012 MF7

Subsystem "Evolution"



2012 MF7: close encounter with Venus (a), the Earth (b) and Mars (c), evolution of semimajor axis (d), eccentricity (e) and inclination (f)

The data about passing clones through gravitation sphere of the Earth

Date	$d_{min},$ km	N, %	$N_{col}, \%$
06.2037	11843	0.288	0
06.2042	43243	0.001	0
06.2044	71430	0.005	0
06.2046	826	0.761	0.036
06.2048	163047	0.001	0
06.2050	191683	0.001	0
06.2051	58078	0.001	0
06.2053	31498	0.023	0
06.2055	772	0.203	0.002
06.2056	238224	0.001	0
06.2057	2150	0.003	0.001
06.2060	89319	0.007	0

Conclusion

- Thus this report contains description of software "IDA" which developed for study of asteroid dynamics.
- The application suite consists from several subsystems which allow to carry out the comprehensive study of asteroid motion.
- The opportunities of software have been demonstrated on example of asteroid 2012 MF7 motion investigation.

Thank you for attention!







• The maximum distance of clones from nominal particle for asteroid 2012 MF7



• 2012 MF7: the projection of probability domain on equator plane in 2037 (a), 2039 (b) and 2042 (c) years