The software "IDA" for investigation of asteroid dynamics and its use for study of some asteroid motion

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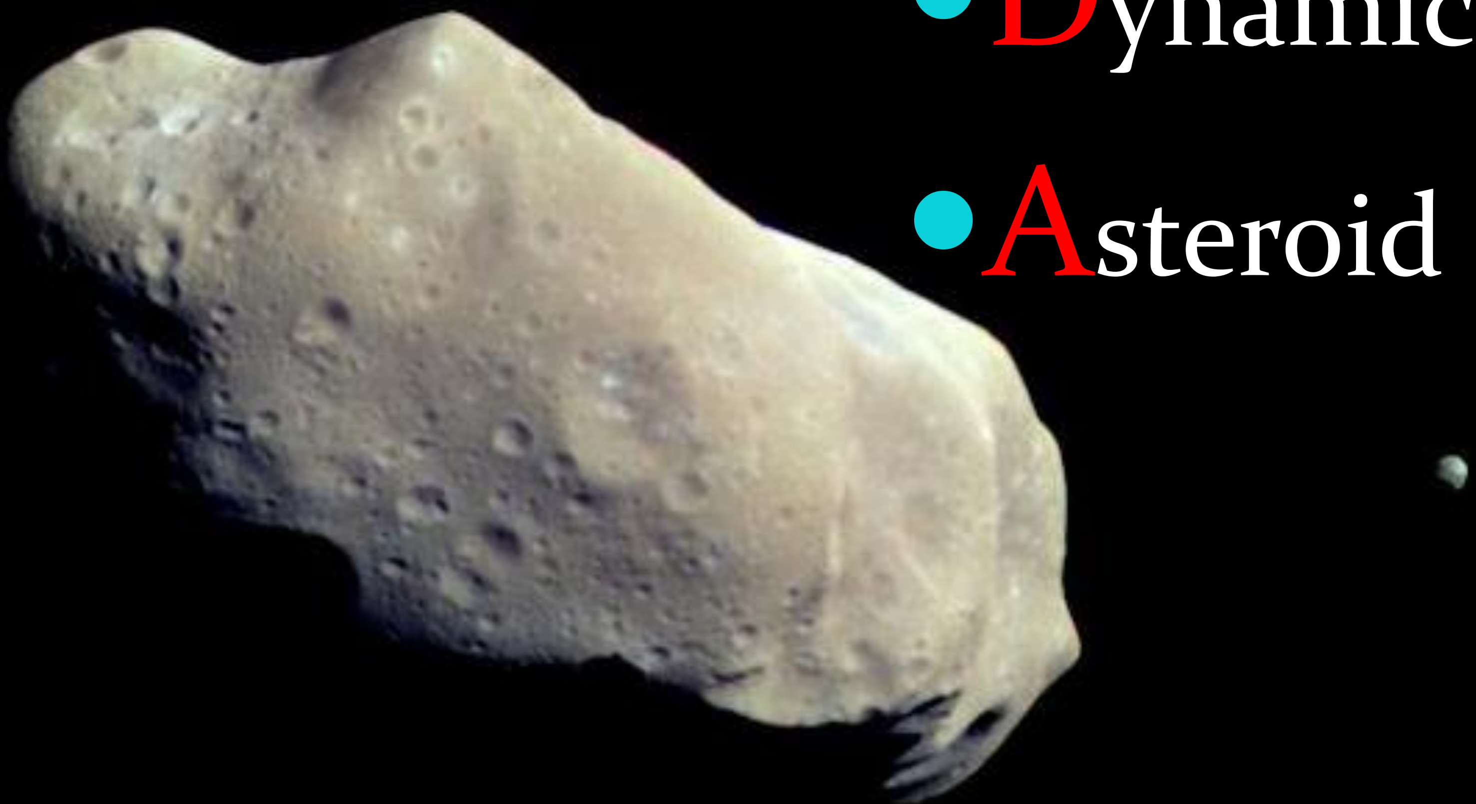
- Investigation of
- Dynamics of
- Asteroid



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 non-linear 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, λ_1, λ_2 are mean longitudes of asteroid and planet correspondingly, ω_1 is argument of pericenter of asteroid, Ω_1 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)

$$Y(t)=\frac{2}{t}\int_0^t \frac{\dot{\delta}(s)}{\delta(s)}sds$$

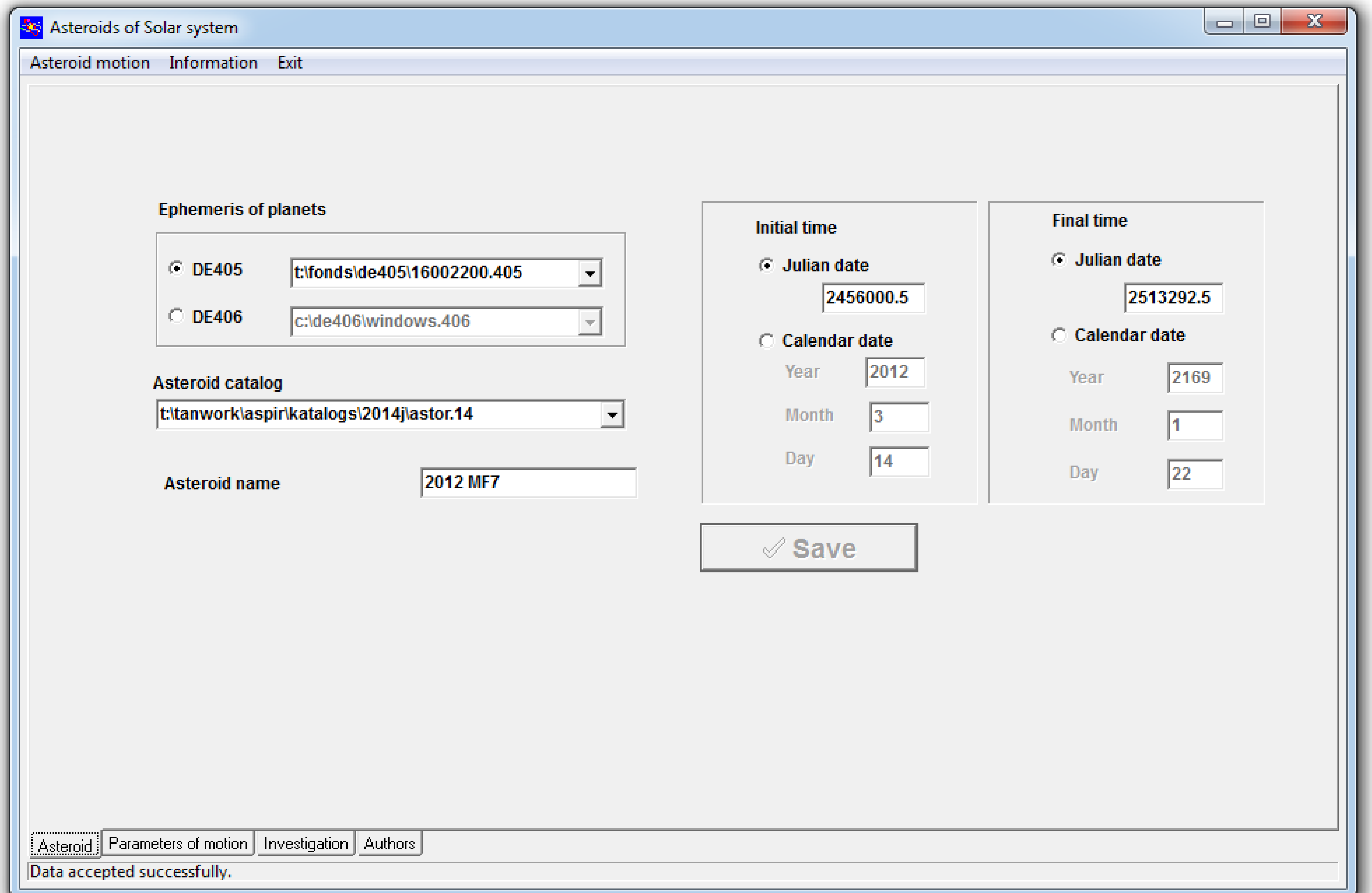
$$\bar{Y}(t)=\frac{1}{t}\int_0^t Y(s)ds$$

- 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 $\bar{Y}(t)$ increases linearly and reaches values $\bar{Y}(t)$ > 2.
- For quasi-periodic (regular) orbits with linear divergence of close trajectories $\bar{Y}(t)$ oscillates around 2, and for stable orbits harmonic oscillator type $\bar{Y}(t)$ = 0.

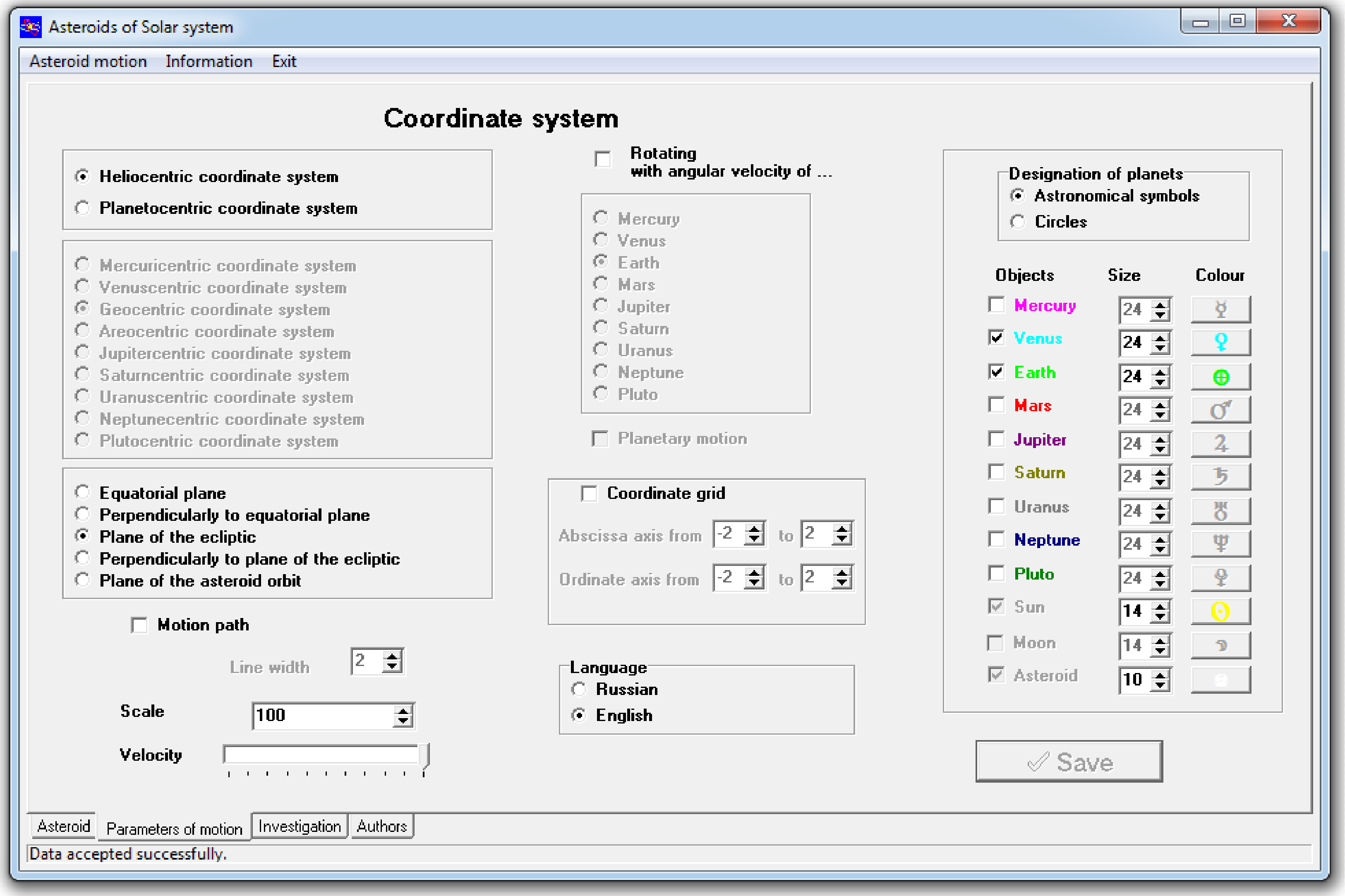
The structure of the application suite “IDA”

- 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.

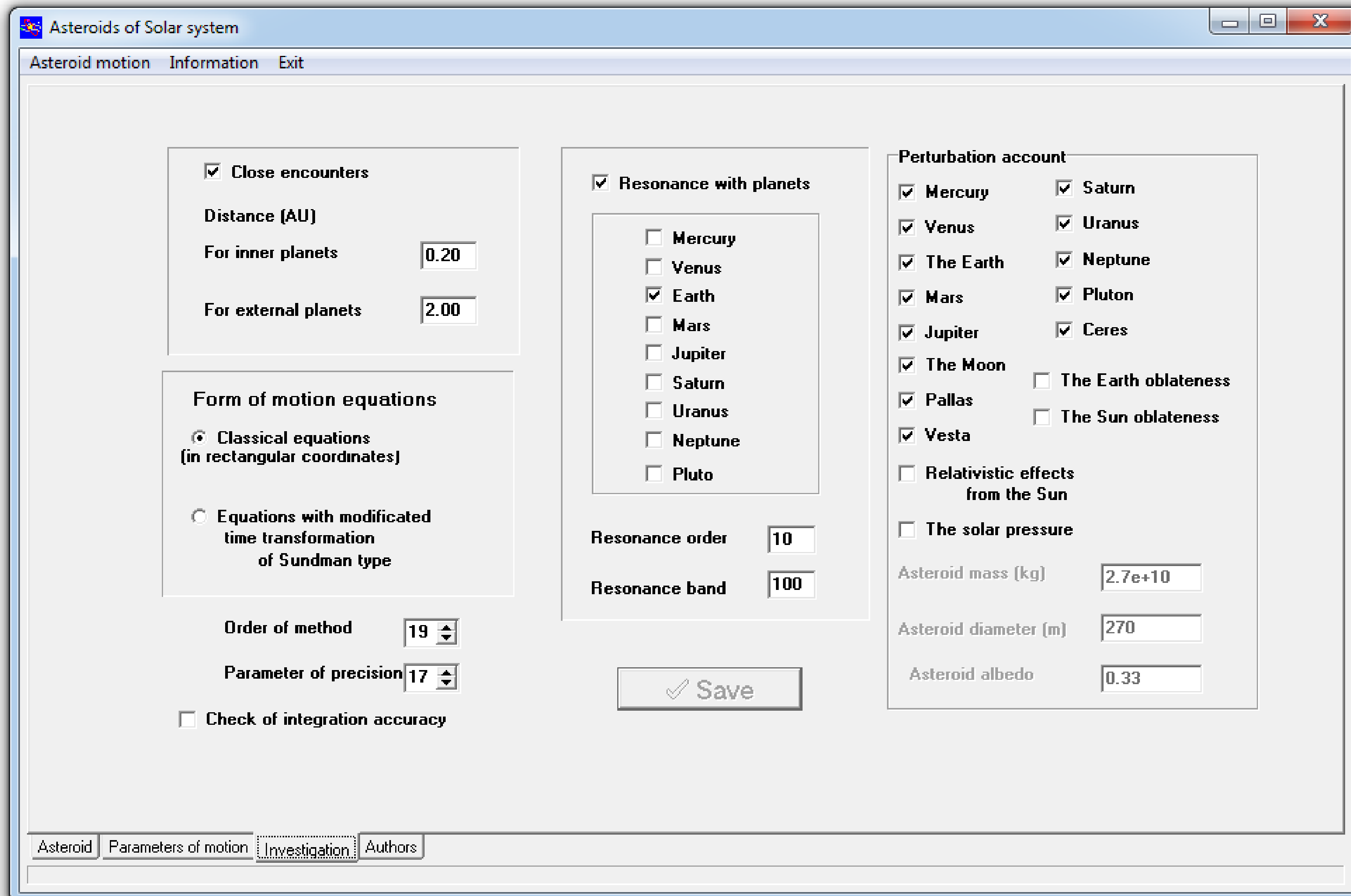
Subsystem "Assol"



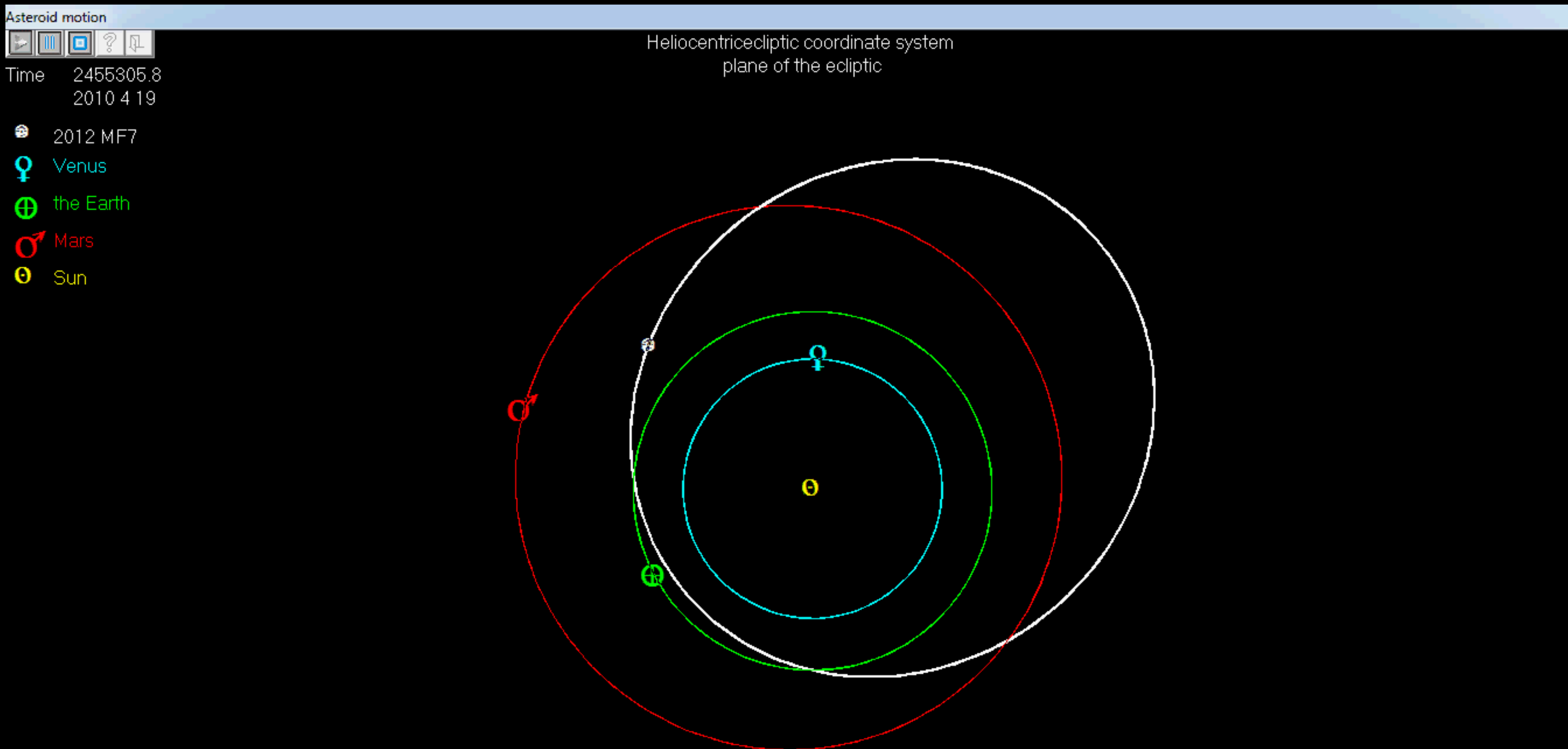
Subsystem "Assol"



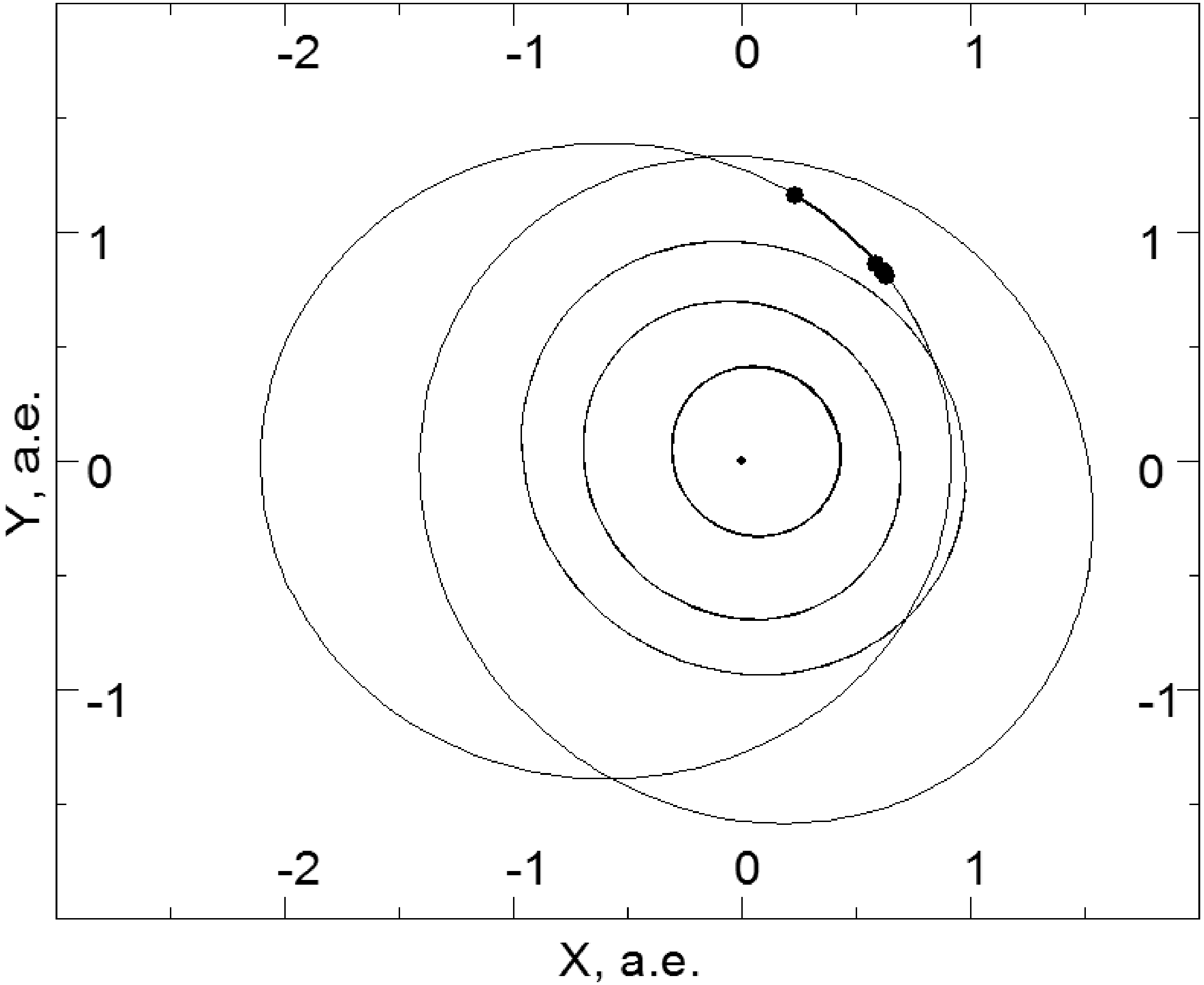
Subsystem "Assol"



The orbit of 2012 MF7



Subsystem "Distribution"

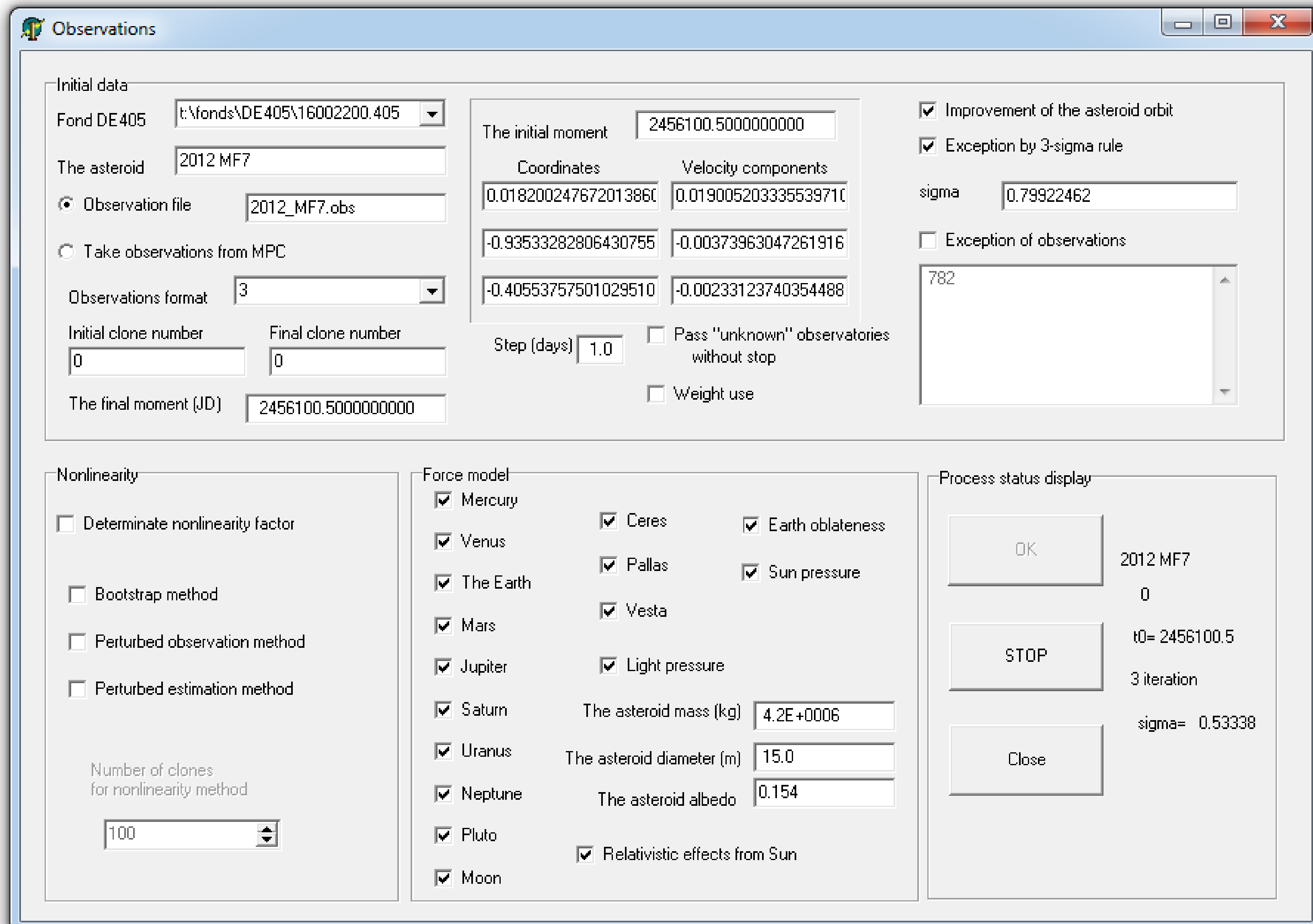


2012 MF7

$N = 27$

$\Delta t = 29$ days

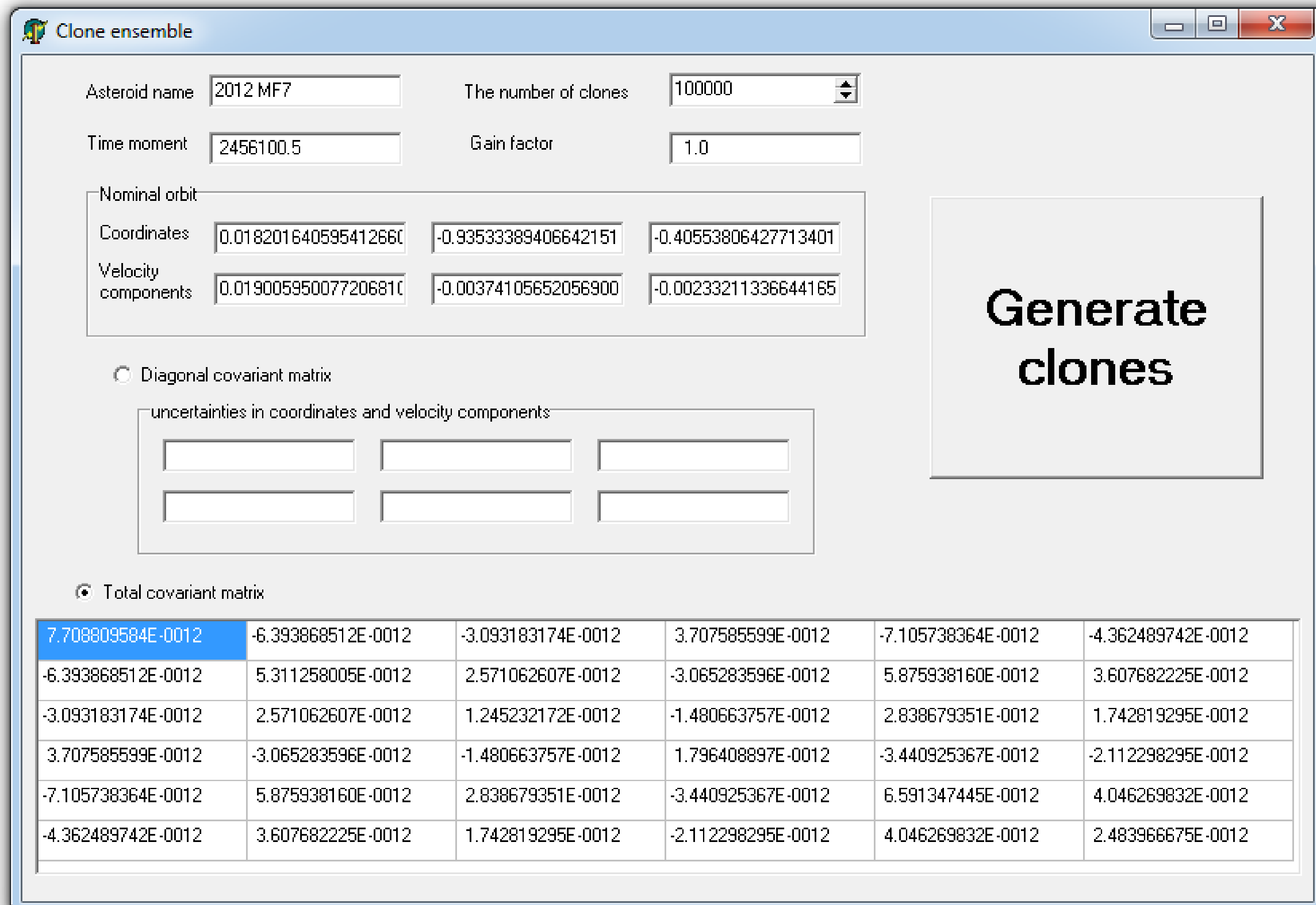
Subsystem "Observations"



The results of orbit improvement of the asteroid 2012 MF7

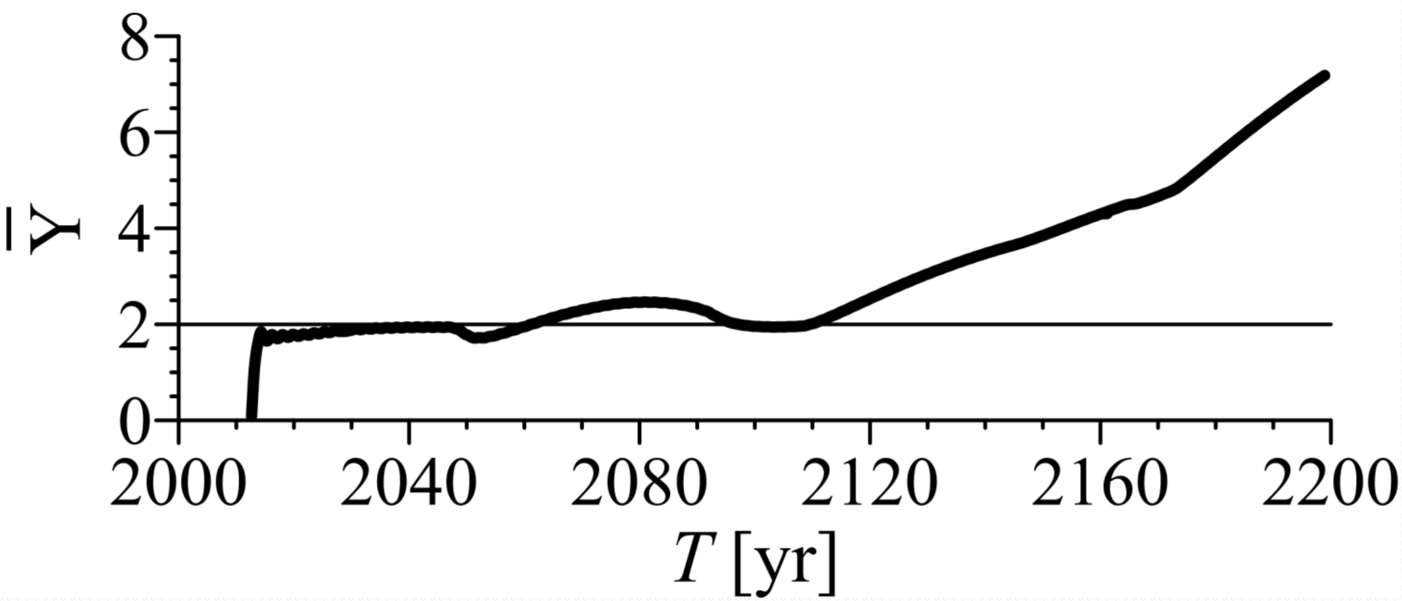
Parameter	Value
t_0	22.06.2012
$\mu(A)$	$2.3 \cdot 10^6$
$\sigma,''$	0.53
χ	$9.6 \cdot 10^{-3}$
Δr, AU	$3.8 \cdot 10^{-6}$
Δv, AU/day	$3.3 \cdot 10^{-6}$
a, AU	1.9715678
e	0.3866357
$i,^\circ$	1.4812566

Subsystem "Clone ensemble"



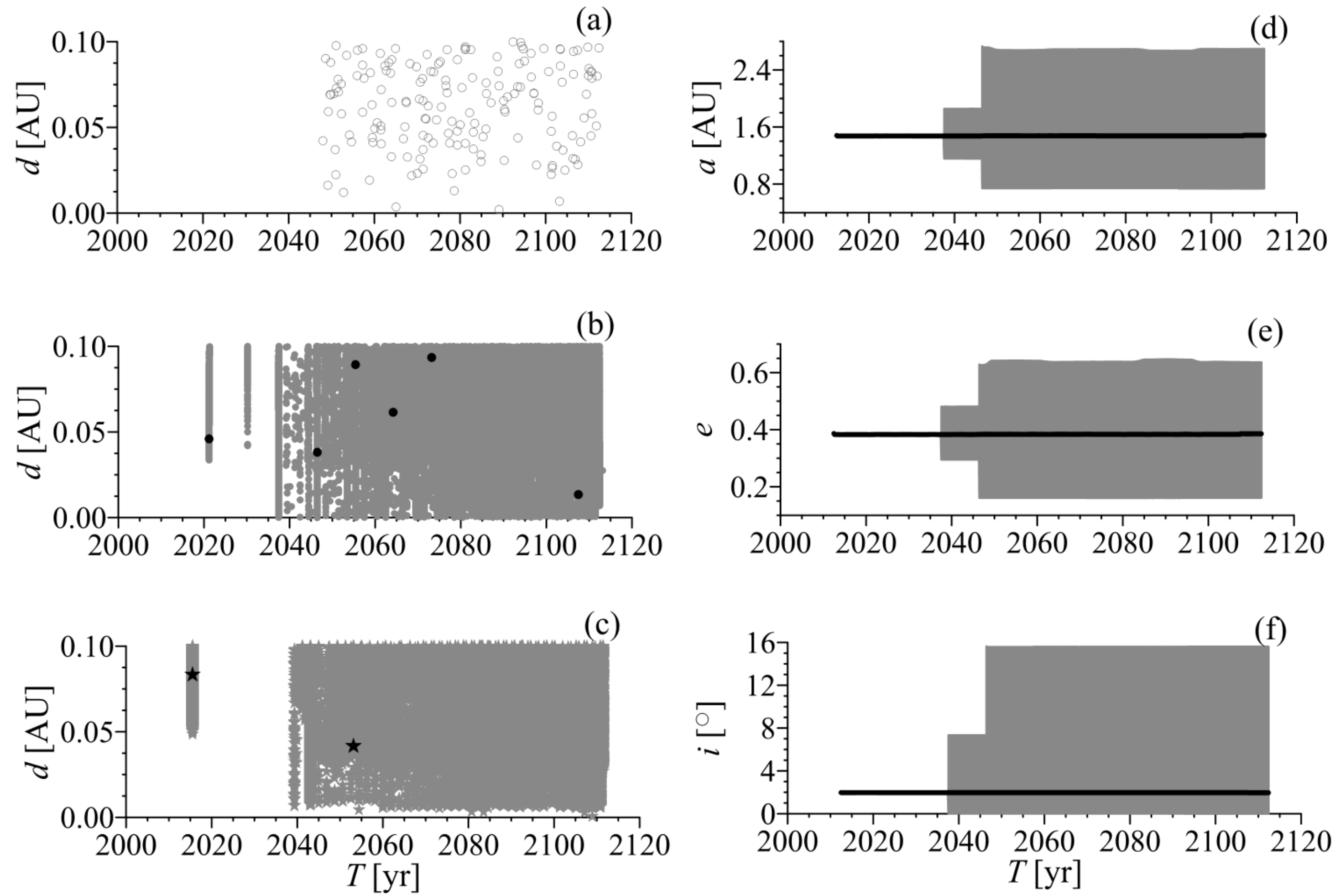
7.708809584E-0012	-6.393868512E-0012	-3.093183174E-0012	3.707585599E-0012	-7.105738364E-0012	-4.362489742E-0012
-6.393868512E-0012	5.311258005E-0012	2.571062607E-0012	-3.065283596E-0012	5.875938160E-0012	3.607682225E-0012
-3.093183174E-0012	2.571062607E-0012	1.245232172E-0012	-1.480663757E-0012	2.838679351E-0012	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
-4.362489742E-0012	3.607682225E-0012	1.742819295E-0012	-2.112298295E-0012	4.046269832E-0012	2.483966675E-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)

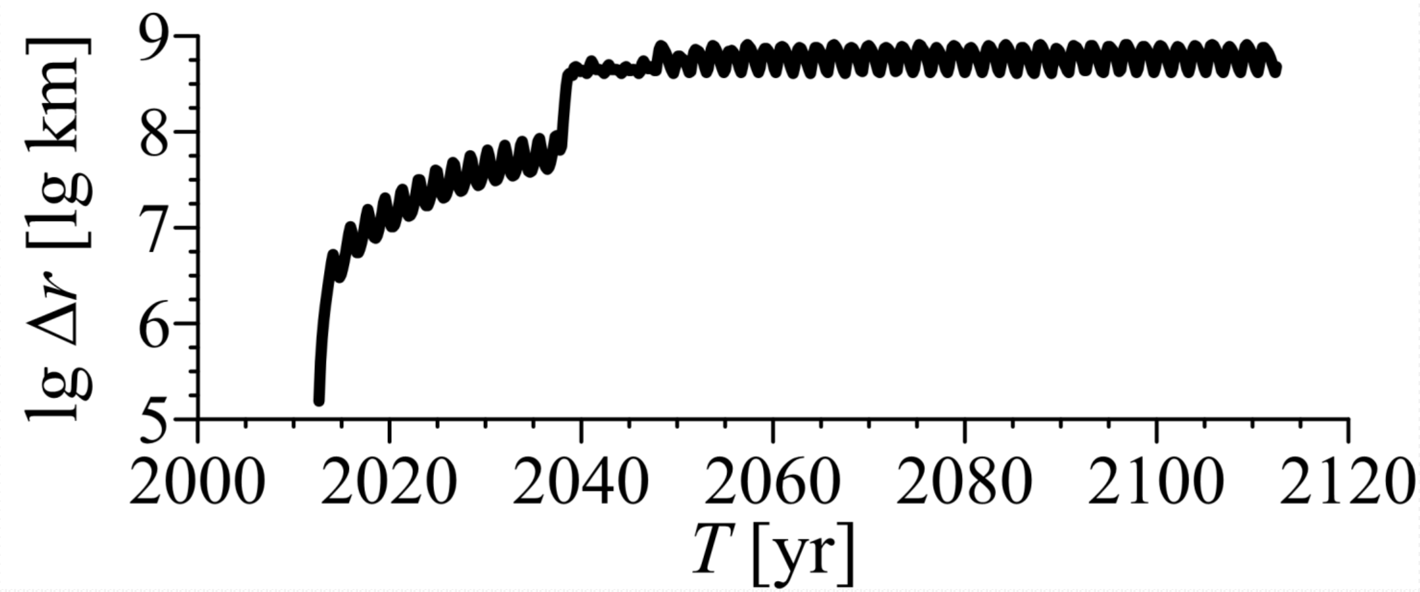
The data about passing clones through gravitation sphere of the Earth

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

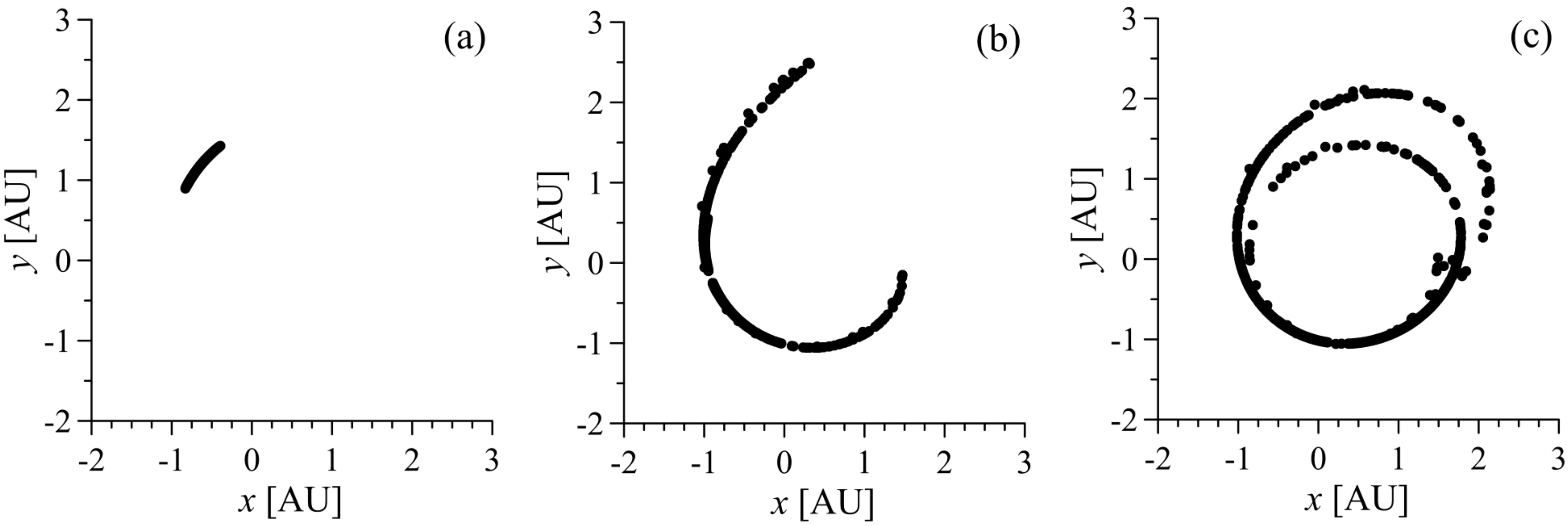
Conclusion

- 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