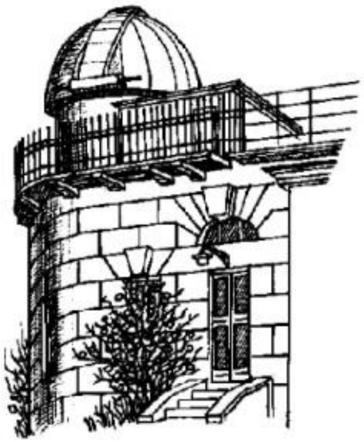
Determination of the small Solar system bodies orbital elements from astrometric observations with new OMT-800 telescope

V. Troianskyi, A. Bazyey, V. Kashuba, V. Zhukov

Astronomical observatory of
Odessa National University
Odessa, Ukraine

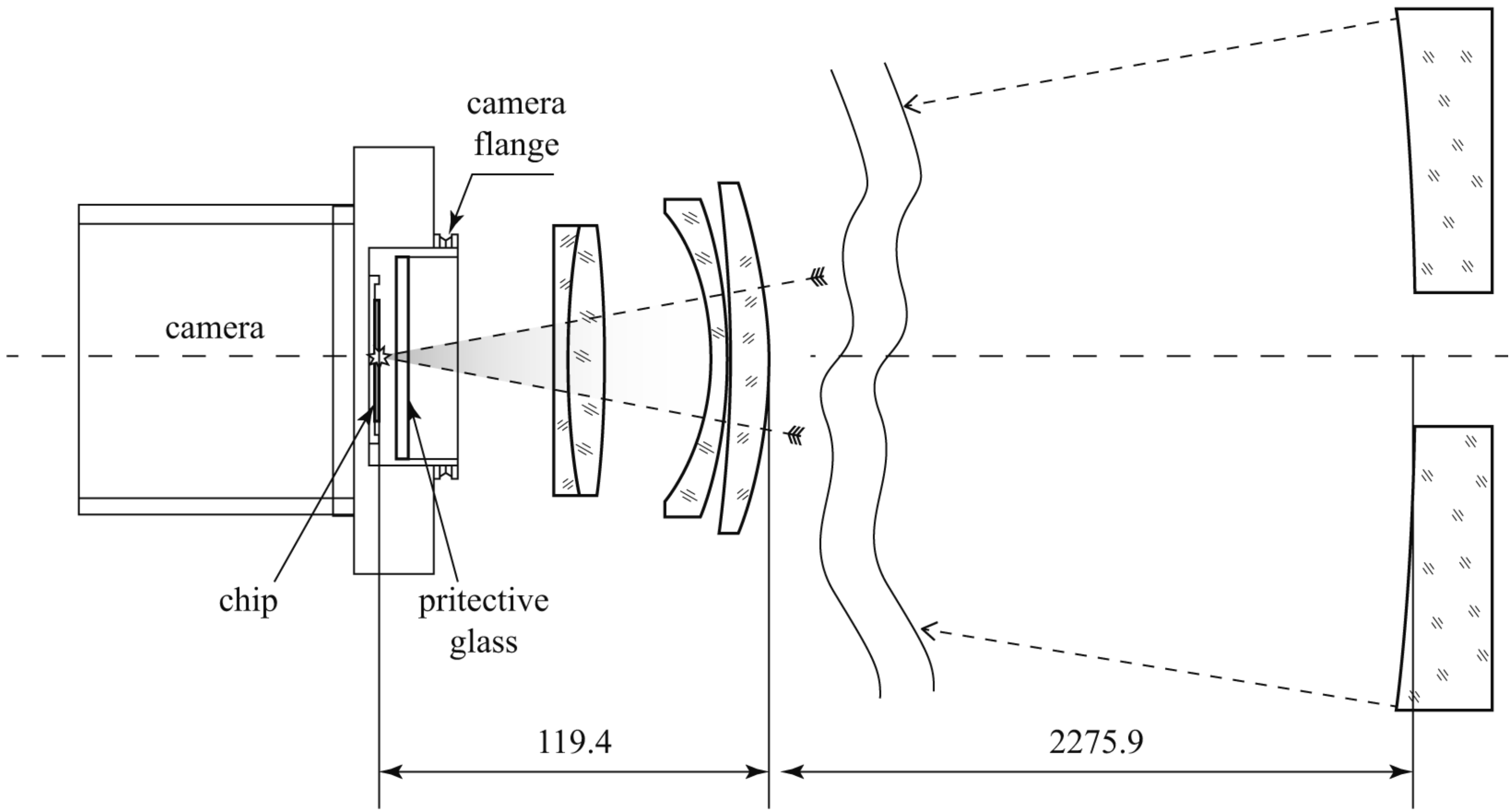


Gaia-FUN-SSO-3 Paris Observatory, 24-26 November 2014

Observational station Mayaki

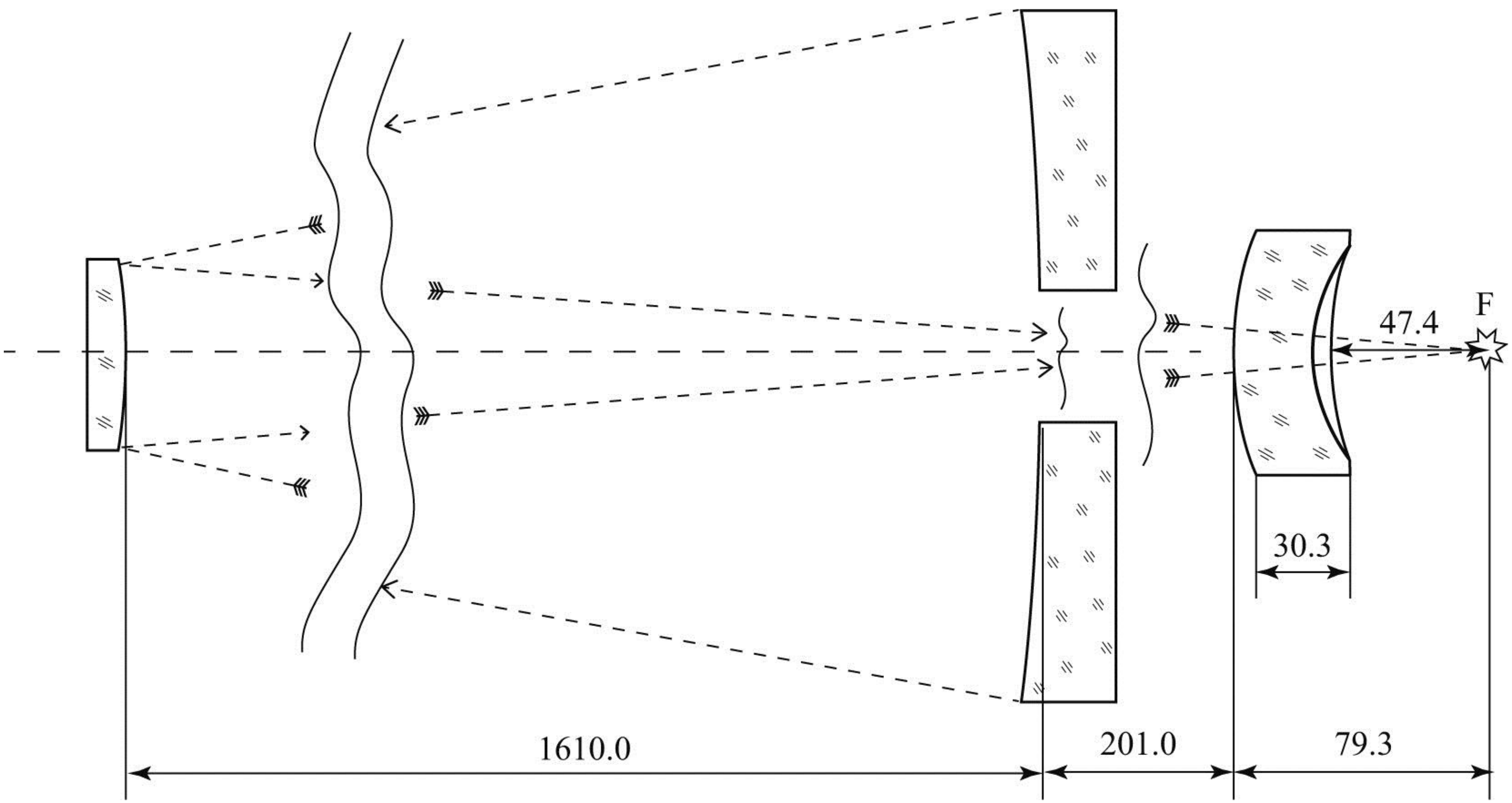
New OMT-800 telescope in Mayaki
800 mm f/2.67 reflector + CCD

The optical system of the telescope



Catadioprtic layout with modified Winn's corrector

The optical system of the telescope



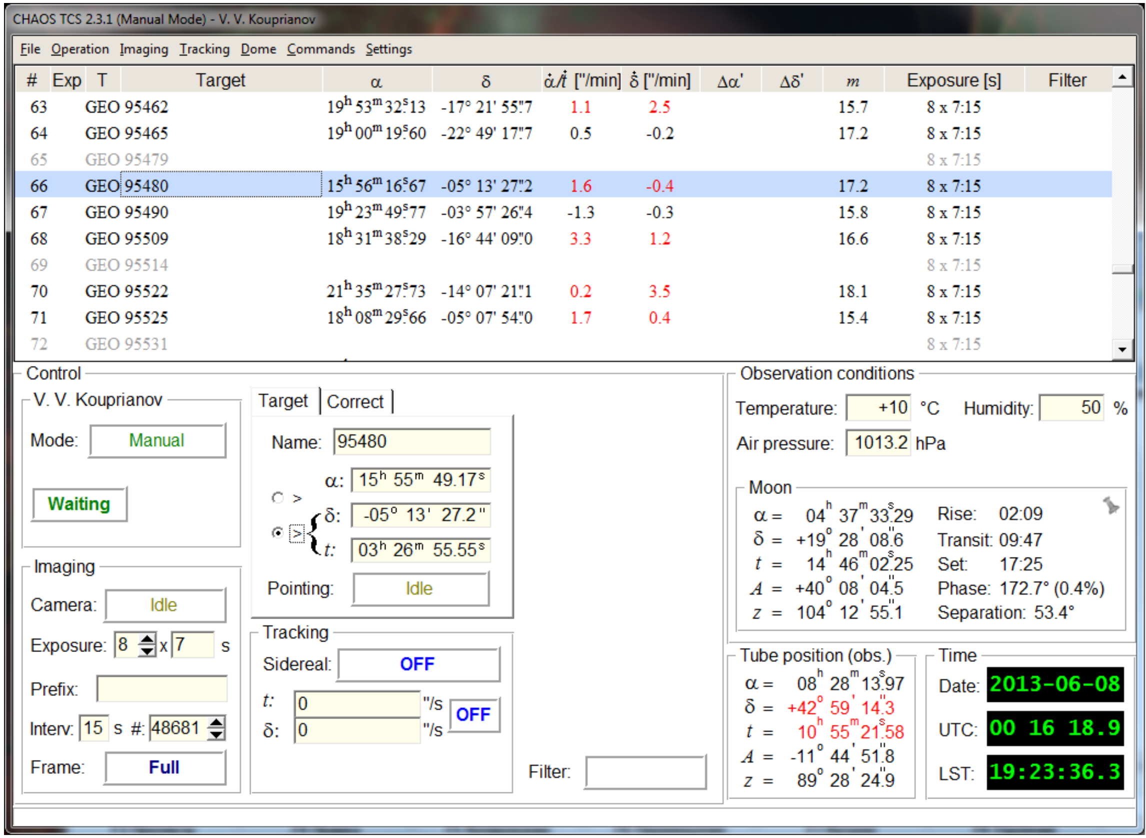
Alternative optical layout
with two-mirror Ritchey–Chrétien scheme

The main characteristics of OMT-800

Main mirror diameter, *mm*	**800**
Telescope effective diameter, *mm*	**755**
Telescope total optical length, *mm*	**2395.3**
Telescope effective focal length, *mm*	**2134.3**
Focal ratio	**1:2.67**
Mass of main mirror, *kg*	**75**
Focal length of main mirror at apex, *mm*	**2398.2**
Main mirror eccentricity square	**1.1986**
Max deviation of main mirror from the ideal surface, *nm*	**60**
Linear diameter of the field, *mm*	**49.14**
Angular diameter of the field, *arc min*	**78**
Spectral range of achromatization, *nm*	**486-820**

CHAOS telescope control software on the OMT-800 control workstation

- Automatic observations mode with a previously prepared schedule
- Observation of different types of objects in one in a one mixed schedule
- Tracking of moving objects with known velocities (v_α,v_δ or v_t,v_δ)
- Ability of using of tabular ephemeris, orbital elements of objects of the Solar system, orbital elements of major planets satellites relatively central planet.



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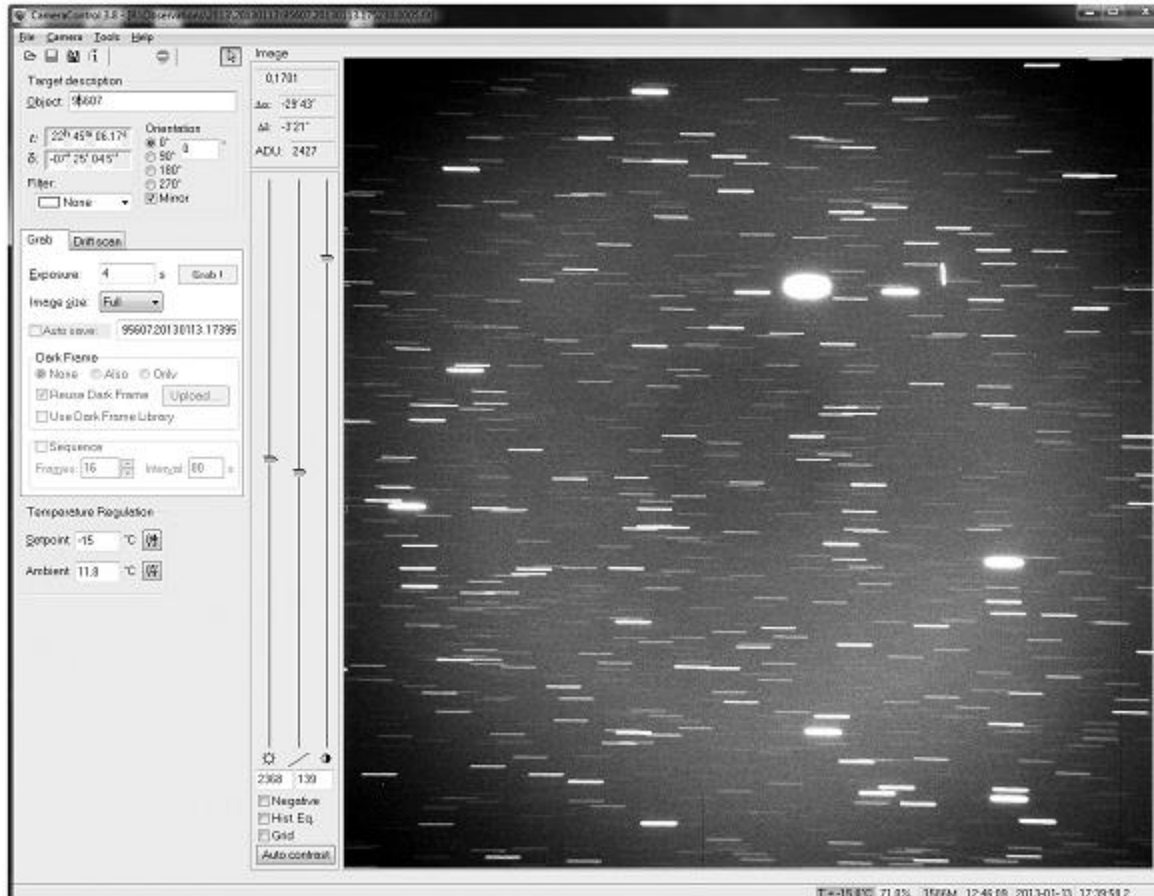
Camera Control software on the OMT-800 control workstation

- Good tool for quick searching of faint objects
- Control of camera cooler
- Various types of image previews
- Recording of FITS headers



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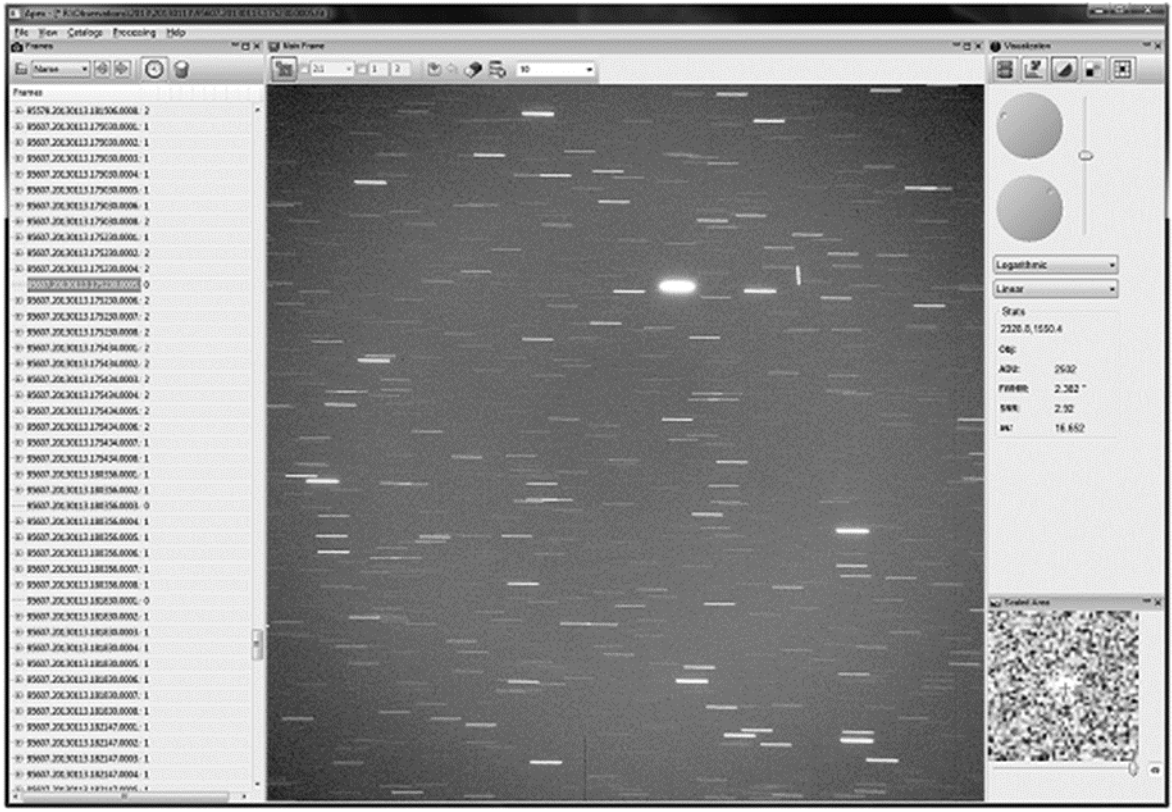
APEX II astronomical images processing software

- Modular architecture
- Instrumental calibrations
- Source measurement for accurate determination of position and photometrical profile of objects.
- Differential astrometry with data of Tycho-2 and UCAC4 reference catalogues
- Differential photometry
- Post-processing of several images for searching of new objects
- Reporting



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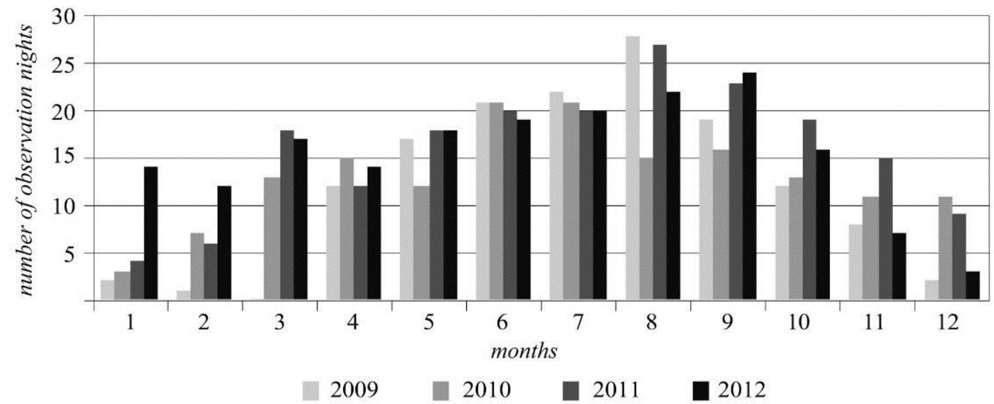
Capabilities of our telescope

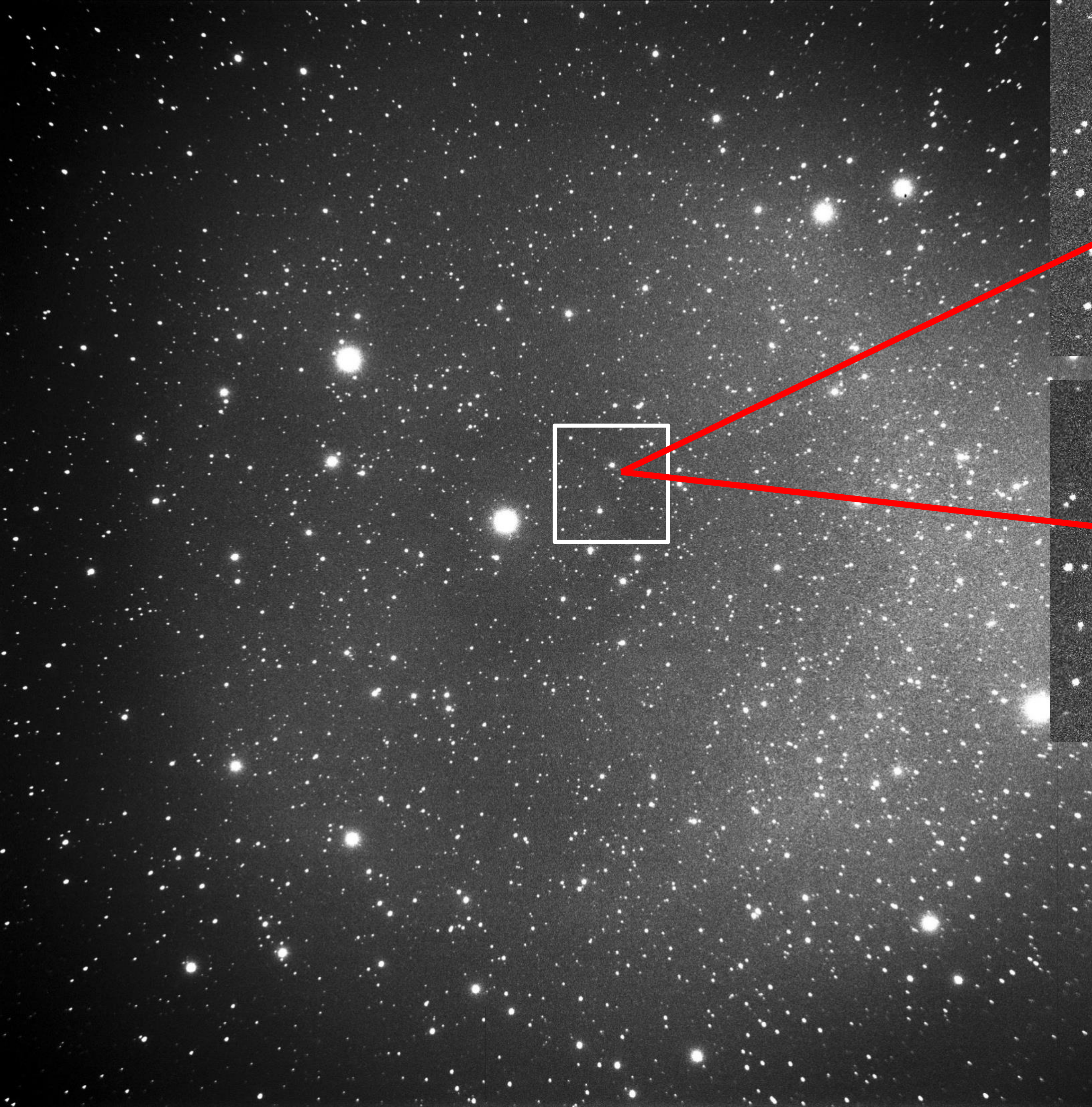
- Observations of artificial satellites in geostationary and geosynchronous orbits
- Observations of Near Earth Asteroids
- Observations of small Solar System bodies
- Differential photometrical observations of stars and stellar fields
- Observations of exoplanet transits

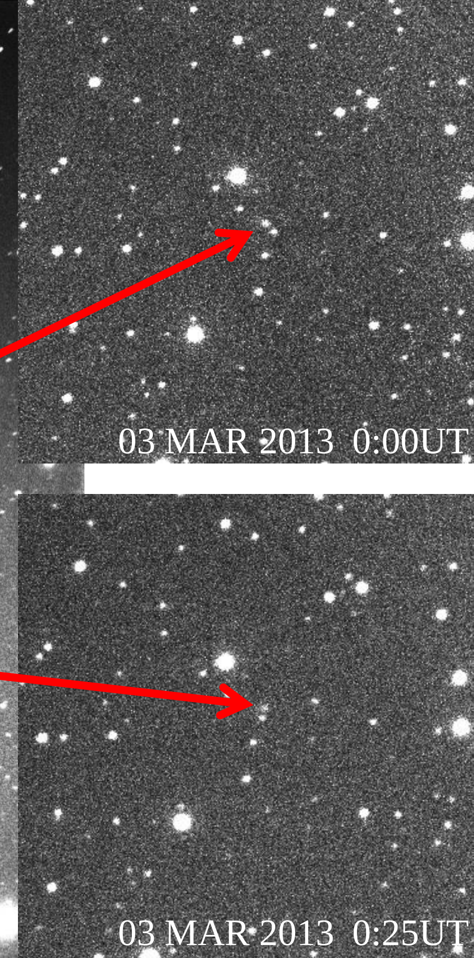
Advantages of our telescope

Statistics on clear nights at Mayaki station
for the last 4 years



- The possibility of observing the mixed programs
- High performance automatic observations
- Ability operational observing time-dependent processes (gamma-ray bursters, novae)
- Observations of objects with declination up to -35˚and magnitude up to 21^m.





The image is made with OMT-800 March 3, 2013, 0:00UT with 10 sec exposure.
The arrows shows the image of comet C/2012 S1 ISON.
The next fragment of the shot made 25 minutes later is shown at the bottom right

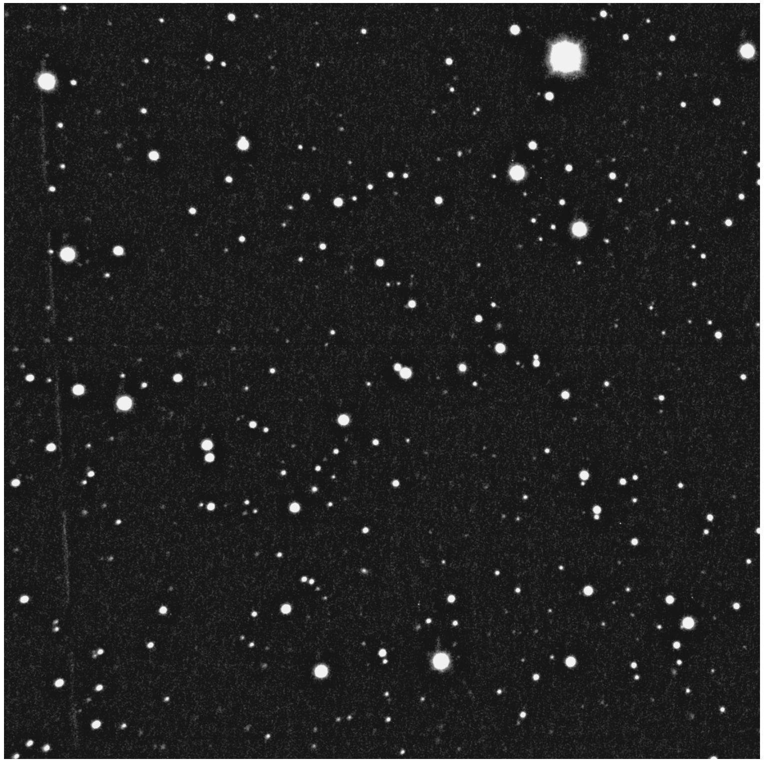
M33 galaxy
Sum of 3 exposure
of 10 seconds.
MaximDL processing

Great Orion Nebula
M42
10 seconds exposure
MaximDL processing

The Andromeda Galaxy M31
Sum of 10 ten-second exposures.
MaximDL processing

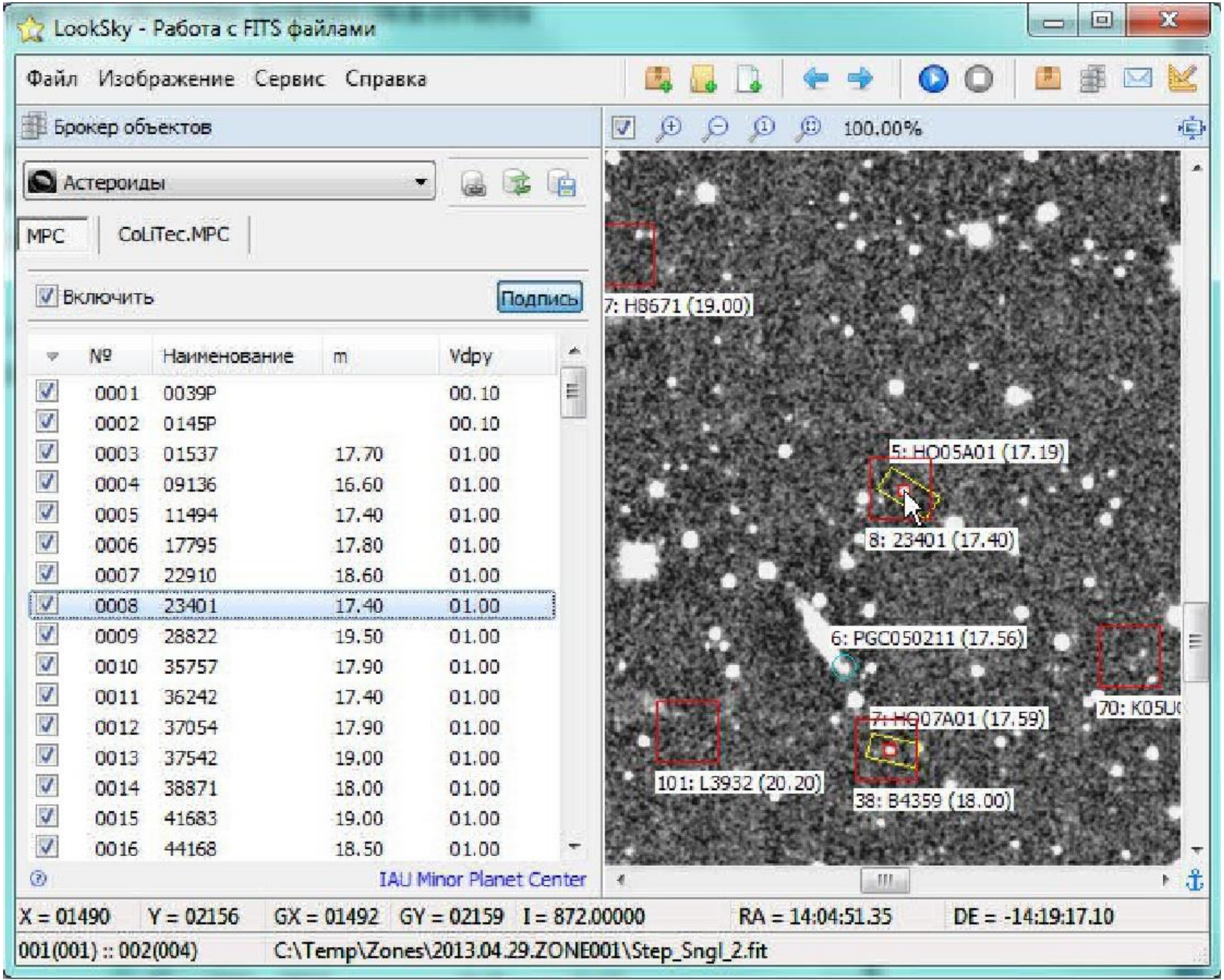
CoLiTec software for automatical searching of asteroids on series of CCD frames

1 exposure
of 10 seconds



Processing of 8 exposures
of 10 seconds

CoLiTec LookSky Software



First report and results in Minor Planet Center for CoLiTec MPS 544817-545650

```
COD 583
CON V. Troianskyi [v.troianskyi@onu.edu.ua]
OBS V. Kashuba
TEL 0.80-m f/3 reflector + CCD
ACK AsteroidsSurvey
NET UCAC4
MEA V. Troianskyi
AC2 v.troianskyi@onu.edu.ua, v.kashuba@onu.edu.ua
     AA01A02  C2014 10 05.08044 02 47 35.73 +15 35 08.6          13.9 V      583
     AA01A02  C2014 10 05.09421 02 47 35.26 +15 35 07.2          14.0 V      583
     AA01A02  C2014 10 05.10785 02 47 34.81 +15 35 06.0          14.0 V      583
     AA01A02  C2014 10 05.12068 02 47 34.39 +15 35 04.7          14.6 V      583
     AA03A02  C2014 10 05.08044 02 45 39.11 +16 15 48.5          16.1 V      583
     AA03A02  C2014 10
     AA03A02  C2014 10
     AA03A02  C2014 10
     AA09A02  C2014 10
     AA09A02  C2014 10
     AA09A02  C2014 10
     AA14A02  C2014 10
     AA14A02  C2014 10
     AA14A02  C2014 10
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2014 NOV. 16 M.P.S. 544817

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Syuichi Nakano and Andreas Doppler, Associates
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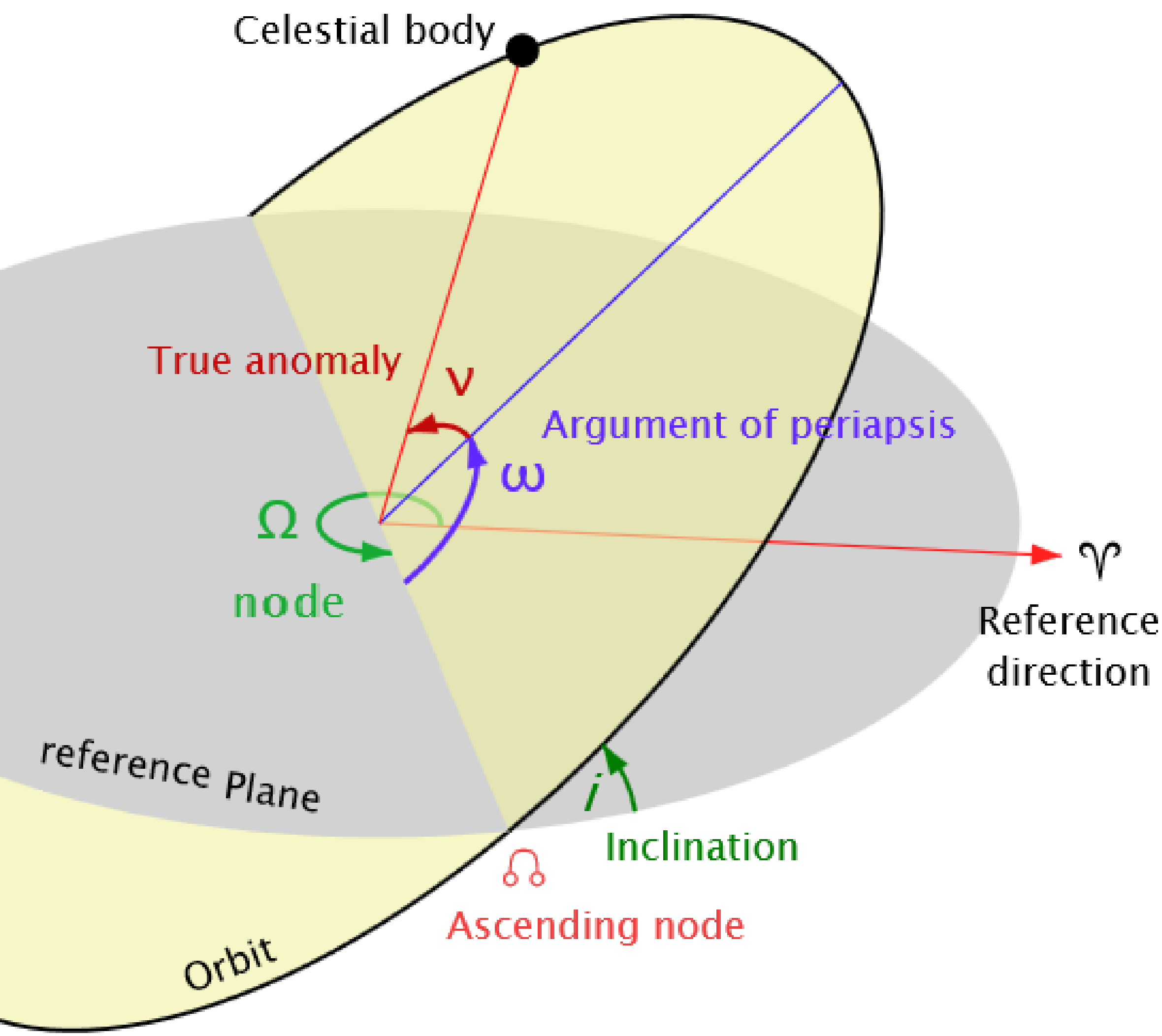
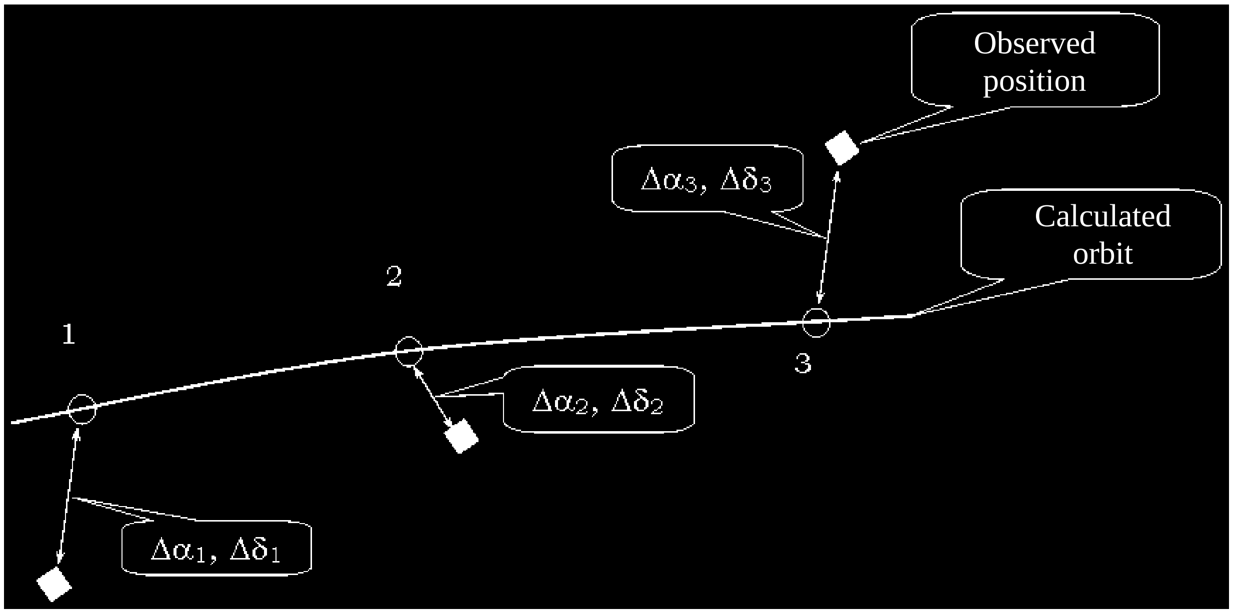
Object	Date UT	α_{2000}	δ_{2000}	Mag.	N	Obs.
1988 PF_1	2014 11 09.40252	01 18 11.503	+18 05 17.37	18.2 i		F51
1988 PF_1	2014 11 09.41554	01 18 11.338	+18 05 13.69	18.2 i		F51
1988 PF_1	2014 11 09.42854	01 18 11.186	+18 05 09.80	18.2 i		F51
1988 PF_1	2014 11 09.44154	01 18 11.027	+18 05 06.01	18.2 i		F51
1988 PF_1	2014 11 11.82837	01 17 56.86	+17 53 57.7	18.9 w		C41
1988 PF_1	2014 11 11.87227	01 17 56.57	+17 53 44.5	19.1 w		C41
1988 PF_1	2014 11 11.87438	01 17 56.56	+17 53 45.3	18.6 w		C41
1988 PF_1	2014 11 12.39927	01 17 54.802	+17 51 28.12	18.4 r		F51
1988 PF_1	2014 11 12.41224	01 17 54.717	+17 51 24.51	18.5 r		F51
1988 PF_1	2014 11 12.42530	01 17 54.634	+17 51 20.94	18.4 r		F51
1988 PF_1	2014 11 12.43782	01 17 54.554	+17 51 17.47	18.4 r		F51
1991 JN	2014 11 10.36980	02 12 45.293	+06 01 22.65	20.6 i		F51
1991 JN	2014 11 10.38188	02 12 44.530	+06 01 08.01	20.4 i		F51
1991 JN	2014 11 10.40616	02 12 42.936	+06 00 38.77	20.6 i		F51
1991 VO_8	2014 11 11.45235	02 54 28.970	+15 14 23.64	19.6 i		F51
1991 VO_8	2014 11 11.46603	02 54 28.121	+15 14 24.35	19.6 i		F51
1991 VO_8	2014 11 11.49321	02 54 26.383	+15 14 25.15	19.6 i		F51
1995 ST_{28}	2014 11 11.32764	02 04 20.56	+11 13 08.3	19.4 r		I41
1999 VS_{46}	2014 11 10.25543	01 54 24.87	+05 17 29.7	17.7 R		H15
1999 VS_{46}	2014 11 10.26645	01 54 23.88	+05 17 41.6	17.3 R		H15
1999 VS_{46}	2014 11 11.40077	01 52 45.000	+05 36 56.20	18.6 i		F51
1999 VS_{46}	2014 11 11.41306	01 52 43.896	+05 37 08.70	18.6 i		F51
1999 VS_{46}	2014 11 11.41437	01 52 43.776	+05 37 10.04	18.7 i		F51
1999 VS_{46}	2014 11 11.42527	01 52 42.803	+05 37 21.12	18.7 i		F51
1999 VS_{46}	2014 11 11.42659	01 52 42.681	+05 37 22.47	18.7 i		F51
1999 VS_{46}	2014 11 11.43744	01 52 41.707	+05 37 33.61	18.7 i		F51
1999 VS_{46}	2014 11 11.43877	01 52 41.592	+05 37 34.84	18.6 i		F51
1999 VY_{95}	2014 11 12.71649	02 53 31.50	+19 44 20.1	19.7 V		D00
1999 VY_{95}	2014 11 12.73802	02 53 29.96	+19 44 20.4	19.5 V		D00
1999 VY_{95}	2014 11 12.74877	02 53 29.17	+19 44 21.5	19.5 V		D00
1999 VL_{231}	2014 11 10.20744	22 17 18.594	−13 27 30.35	21.9 w		F51
1999 VL_{231}	2014 11 10.21973	22 17 19.279	−13 27 25.82	21.8 w		F51
1999 VL_{231}	2014 11 10.23201	22 17 19.943	−13 27 21.99	21.8 w		F51
1999 VL_{231}	2014 11 10.24430	22 17 20.598	−13 27 17.60	21.8 w		F51
1999 XM_{141}	2014 11 08.296319	02 42 56.27	−18 52 54.7	19.5 R	K	448
1999 XM_{141}	2014 11 08.323121	02 42 51.29	−18 52 44.6	20.3 R	K	448
1999 XM_{141}	2014 11 08.353210	02 42 45.71	−18 52 33.1	20.5 R	K	448
1999 XM_{141}	2014 11 09.327587	02 39 51.06	−18 45 38.5	19.6 R	K	448

Search parameters of motion of the object (Orbital elements, the position vector)



Preliminary determination of the position vector for the three positional measurements by Gauss and Laplace method

Clarification prior position vector in all dimensions

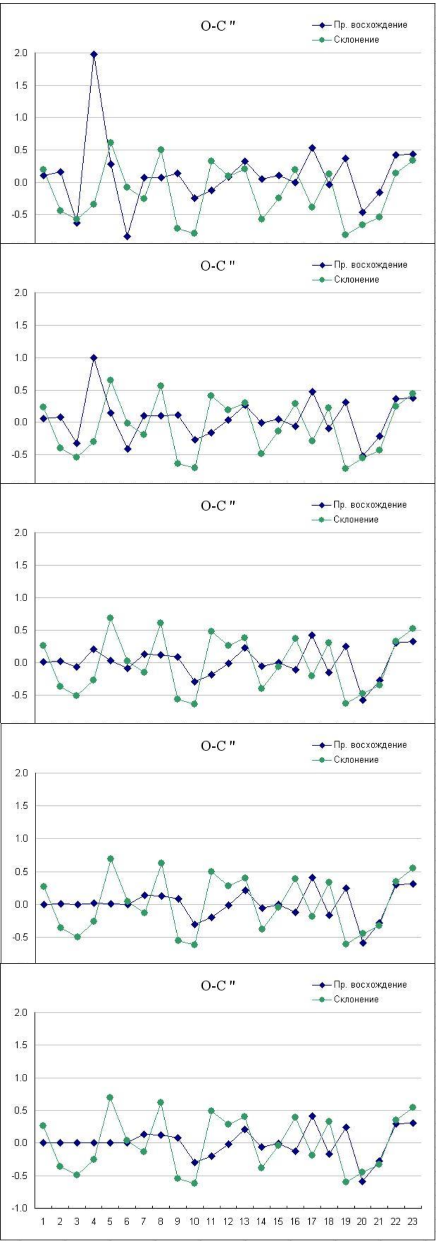


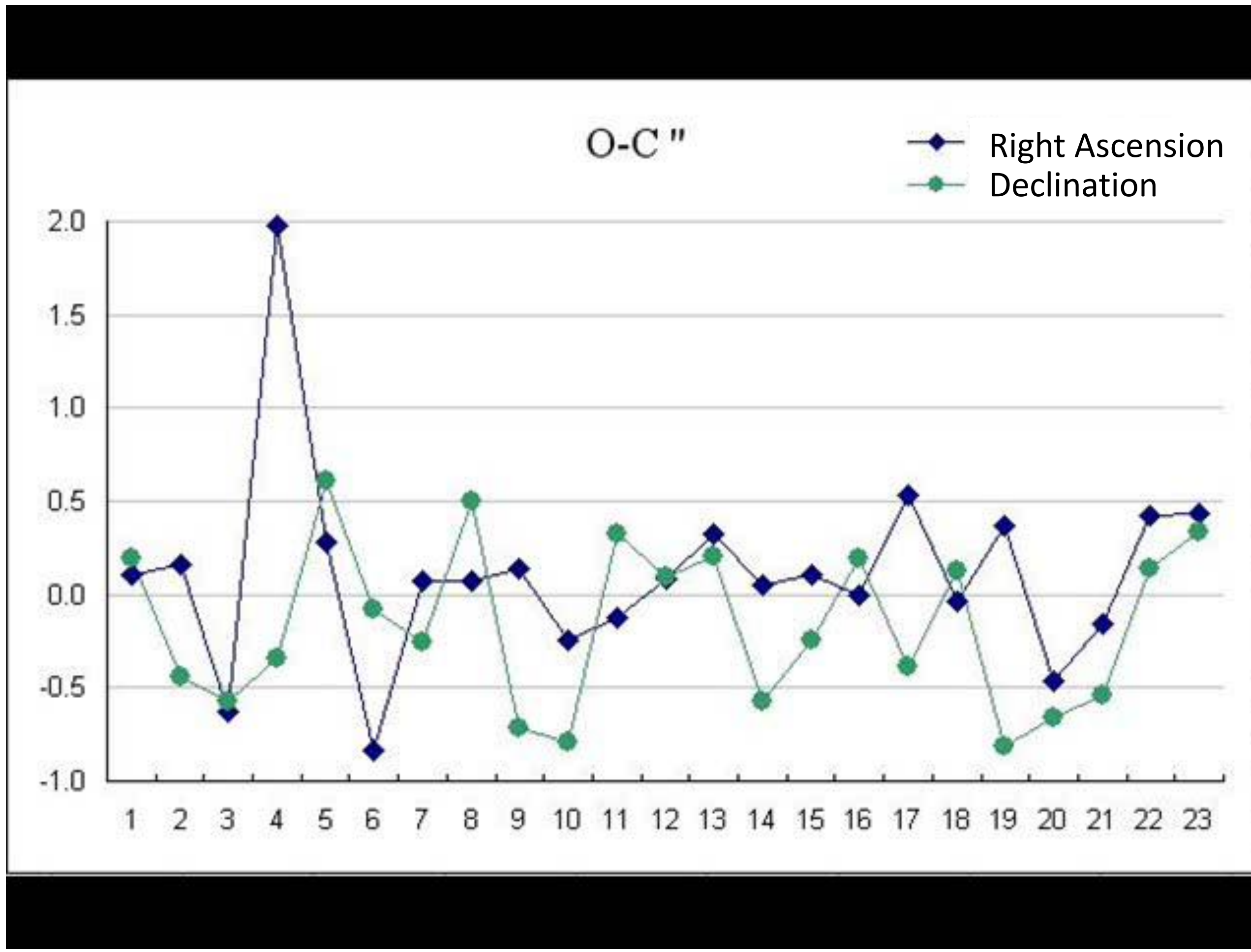
$$\Delta\alpha = (\alpha_{t0})_i - (\alpha_{tc})_i$$
$$\Delta\delta = (\delta_{t0})_i - (\delta_{tc})_i$$

$$\alpha_t = \alpha_t(x_2, y_2, z_2, \dot{x}_2, \dot{y}_2, \dot{z}_2)$$
$$\delta_t = \delta_t(x_2, y_2, z_2, \dot{x}_2, \dot{y}_2, \dot{z}_2)$$

$$\Delta\alpha = \frac{\partial\alpha_i}{\partial x_2}\Delta x_2 + \frac{\partial\alpha_i}{\partial y_2}\Delta y_2 + \frac{\partial\alpha_i}{\partial z_2}\Delta z_2 + \frac{\partial\alpha_i}{\partial \dot{x}_2}\Delta \dot{x}_2 + \frac{\partial\alpha_i}{\partial \dot{y}_2}\Delta \dot{y}_2 + \frac{\partial\alpha_i}{\partial \dot{z}_2}\Delta \dot{z}_2$$
$$\Delta\delta = \frac{\partial\delta_i}{\partial x_2}\Delta x_2 + \frac{\partial\delta_i}{\partial y_2}\Delta y_2 + \frac{\partial\delta_i}{\partial z_2}\Delta z_2 + \frac{\partial\delta_i}{\partial \dot{x}_2}\Delta \dot{x}_2 + \frac{\partial\delta_i}{\partial \dot{y}_2}\Delta \dot{y}_2 + \frac{\partial\delta_i}{\partial \dot{z}_2}\Delta \dot{z}_2$$

Clarification of the position vector - minimizing the residuals O-C





The accuracy of calculating of the orbit in comparison with Jet Propulsion Laboratory or Minor Planet Center

e= 0.55932

0.55927 (MPC)

a=2.23491 a.u.

2.23418 a.u. (MPC)

w=161.953 °

161.925 ° (MPC)

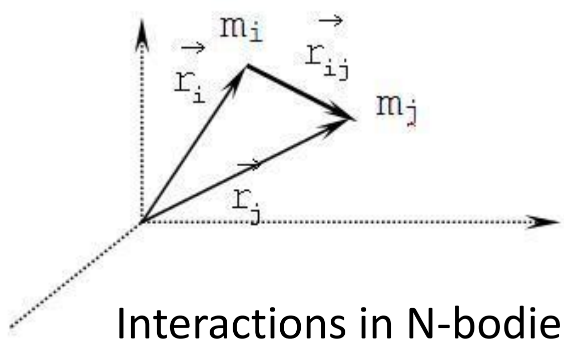
W=228.015 °

228.062 ° (MPC)

i=47.226 °

47.287 ° (MPC)

Equations of motion



Interactions in N-bodies problem

$$m_i \ddot{x}_i = -k^2 \sum_{j=1}^{n'} m_i m_j \frac{x_i - x_j}{r_{ij}^3},$$

$$m_i \ddot{y}_i = -k^2 \sum_{j=1}^{n'} m_i m_j \frac{y_i - y_j}{r_{ij}^3},$$

$$m_i \ddot{z}_i = -k^2 \sum_{j=1}^{n'} m_i m_j \frac{z_i - z_j}{r_{ij}^3}.$$

We have 3N second order differential equations. That is, the problem is reduced to a system of 6N order. To solve this system should have a 6N initial conditions and, accordingly, 6N integrals of motion.

Integration of orbits with Everhart's method

Everhart E. // A New Method for Integrating Orbits // Bulletin of the American Astronomical Society. 1973.

А.А. Базей, И.В. Кара // Применение методов Эверхарта 15, 17, 19, 21 порядков для вычисления траектории движения небесных тел в околопланетном пространстве // Вісник Астрономічної школи.
- 2009. - Т.6, № 2. - С.155-157.

The coordinates of the major planets and the Moon, obtained from numerical theory Solar system DE431 (JPL, 2013)

IPN Progress Report 42-196 • February 15, 2014

The Planetary and Lunar Ephemerides DE430 and DE431

William M. Folkner,* James G. Williams,† Dale H. Boggs,†
Ryan S. Park,* and Petr Kuchynka*

Gravitational potential of Celestial body

$$U_x = \left\{ -\frac{\mu}{r^2} \sum_{\ell=0}^{\infty} (\ell+1) \left(\frac{a}{r} \right)^{\ell} \sum_{m=0}^{\ell} P_{\ell,m}(\sin\phi) \left[C_{\ell,m} \cos m\lambda + S_{\ell,m} \sin m\lambda \right] \right\}$$

$$U_y = \left\{ \frac{\mu}{r^2} \sum_{\ell=1}^{\infty} \left(\frac{a}{r} \right)^{\ell} \sum_{m=0}^{\ell} \frac{\partial P_{\ell,m}(\sin\phi)}{\partial \phi} \left[C_{\ell,m} \cos m\lambda + S_{\ell,m} \sin m\lambda \right] \right\}$$

$$U_z = \left\{ \frac{\mu}{r^2} \sum_{\ell=1}^{\infty} \left(\frac{a}{r} \right)^{\ell} \sum_{m=1}^{\ell} m \frac{P_{\ell,m}(\sin\phi)}{\cos\phi} \left[-C_{\ell,m} \sin m\lambda + S_{\ell,m} \cos m\lambda \right] \right\}$$

μ – gravitational constant (GM)
a – equatorial radius of the celestial body
$C_{l,m}$,$S_{l,m}$ – the coefficients of the gravitational field
r,φ,λ – spherical coordinates of the asteroid
$P_{l,m}$ – associated Legendre functions

Accounting 343 most massive Small bodies selected JPL

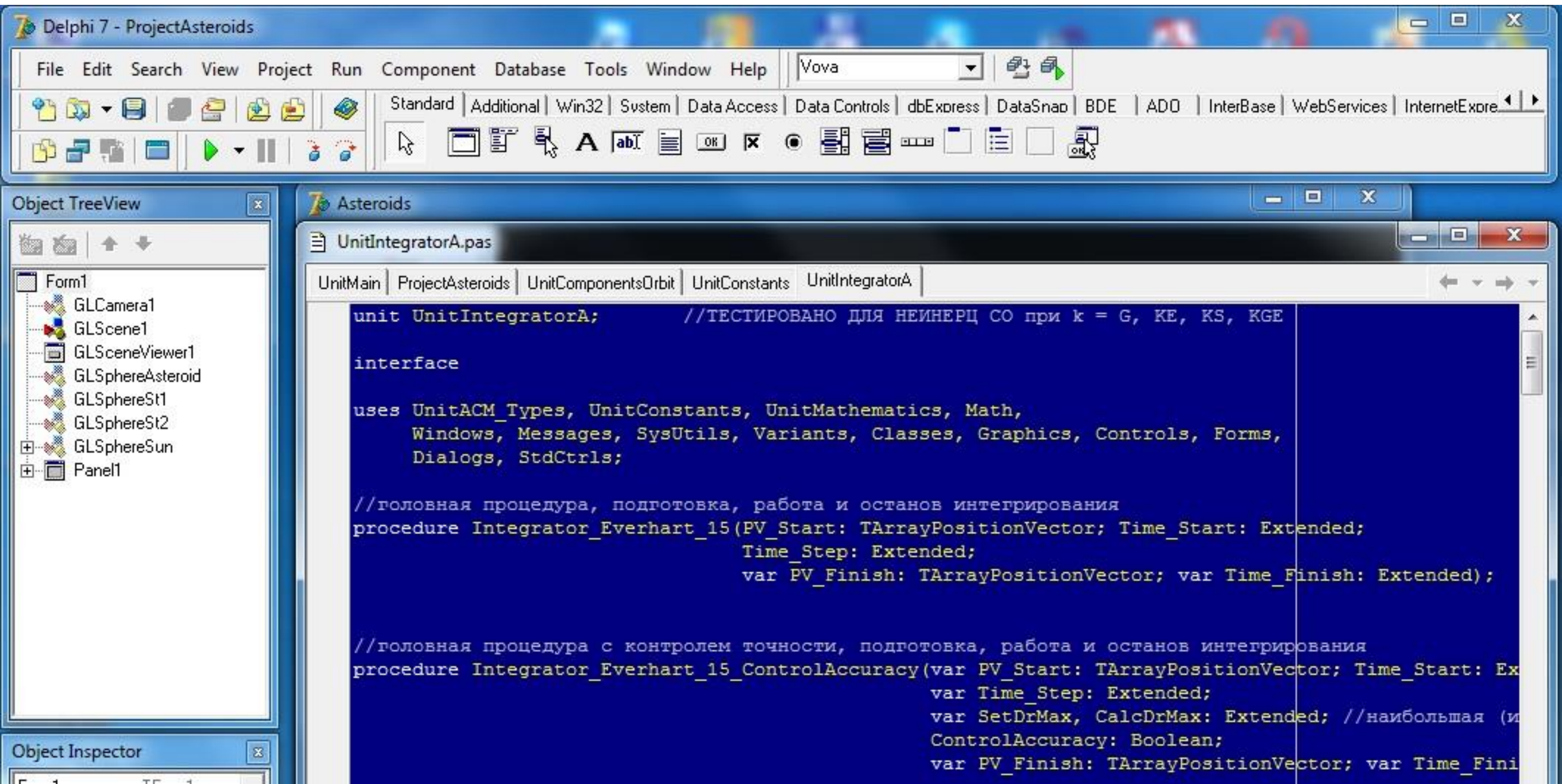
Table 12. Mass parameters of asteroids (1 of 7).

Number	Name	GM, au^3/day^2	$GM_{ast}/GM_{\odot}$	GM, km^3/s^2
1	Ceres	0.140047655617234400E–12	4.73E–10	62.809393
2	Pallas	0.310444819893871300E–13	1.05E–10	13.923011
3	Juno	0.361753831714793700E–14	1.22E–11	1.622415
4	Vesta	0.385475018780881000E–13	1.30E–10	17.288009
5	Astraea	0.374873628455203200E–15	1.27E–12	0.168126
6	Hebe	0.831241921267337200E–15	2.81E–12	0.3728
7	Iris			
8	Flo			
9	Me			
10	Hy			
11	Par			
12	Vic			

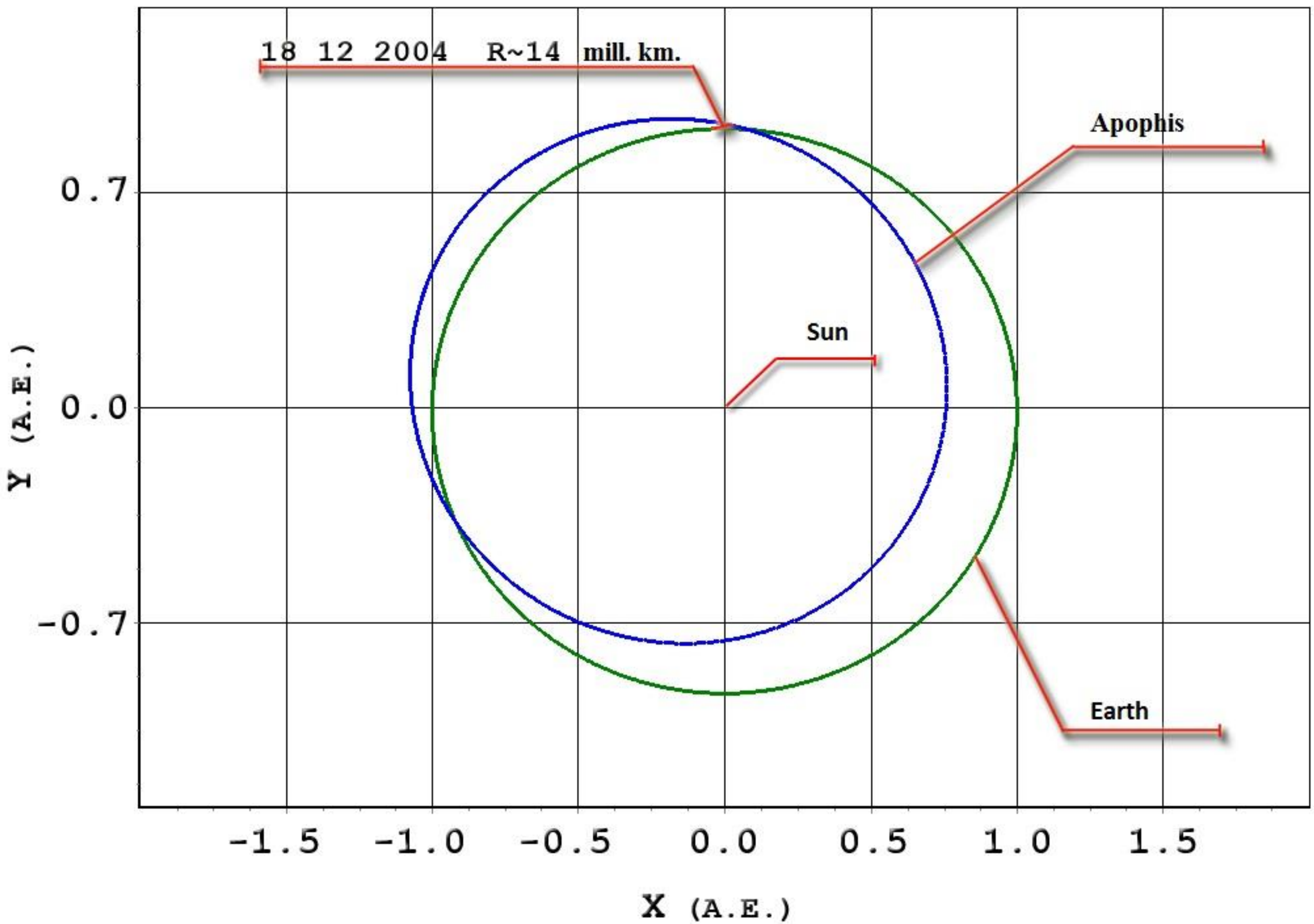
Table 13. Initial positions (au) and velocities (au/day) of the asteroids with respect to the Sun at Julian day (TDB) 2440400.5 (June 28, 1969) in the ICRF2 frame (1 of 15).

1	Ceres	x,y,z	1.438681809676469747	–2.204373633189407045	–1.326397853361325874
		v_x,v_y,v_z	0.008465406136316316	0.004684247977335608	0.000466157738595739
2	Pallas	x,y,z	0.203832272462290465	–3.209619436062307152	0.623843179079393351
		v_x,v_y,v_z	0.008534313855651248	–0.000860659210123161	–0.000392901992572746
3	Juno	x,y,z	0.461207259670432135	–3.006098959780790114	–0.580164049296942208
		v_x,v_y,v_z	0.008395458298285176	0.003111908045571209	0.000273059675893248
4	Vesta	x,y,z	0.182371836377417107	2.386628211277654010	0.924596062836265498
		v_x,v_y,v_z	–0.010174496747119257	0.000041478190529952	0.001344157634155624
5	Astraea	x,y,z	2.489297359488491956	1.036395265106434982	0.210563198822894787
		v_x,v_y,v_z	–0.005569115604615741	0.007959732929200320	0.003113959705731406
6	Hebe	x,y,z	1.339049495814490065	1.442775542206668815	0.079273672077323748
		v_x,v_y,v_z	–0.008775983793258694	0.009426820472364830	0.003535716141864189

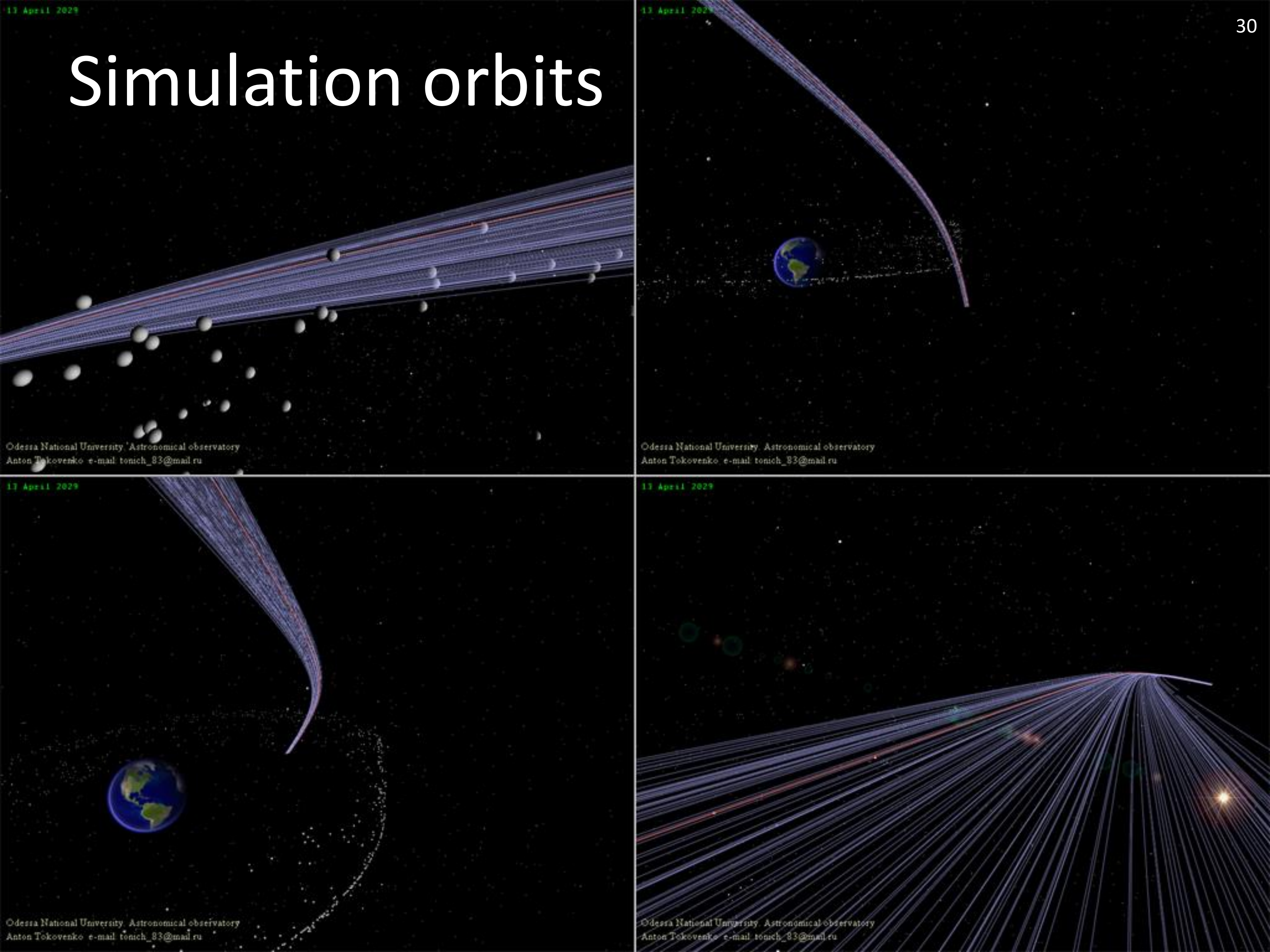
Method of mathematical modeling in the "Delphi7" we got a change in Kepler orbit of the planets, asteroids and their chosen companions on an arbitrary time interval.



Orbits asteroid Apophis 99942

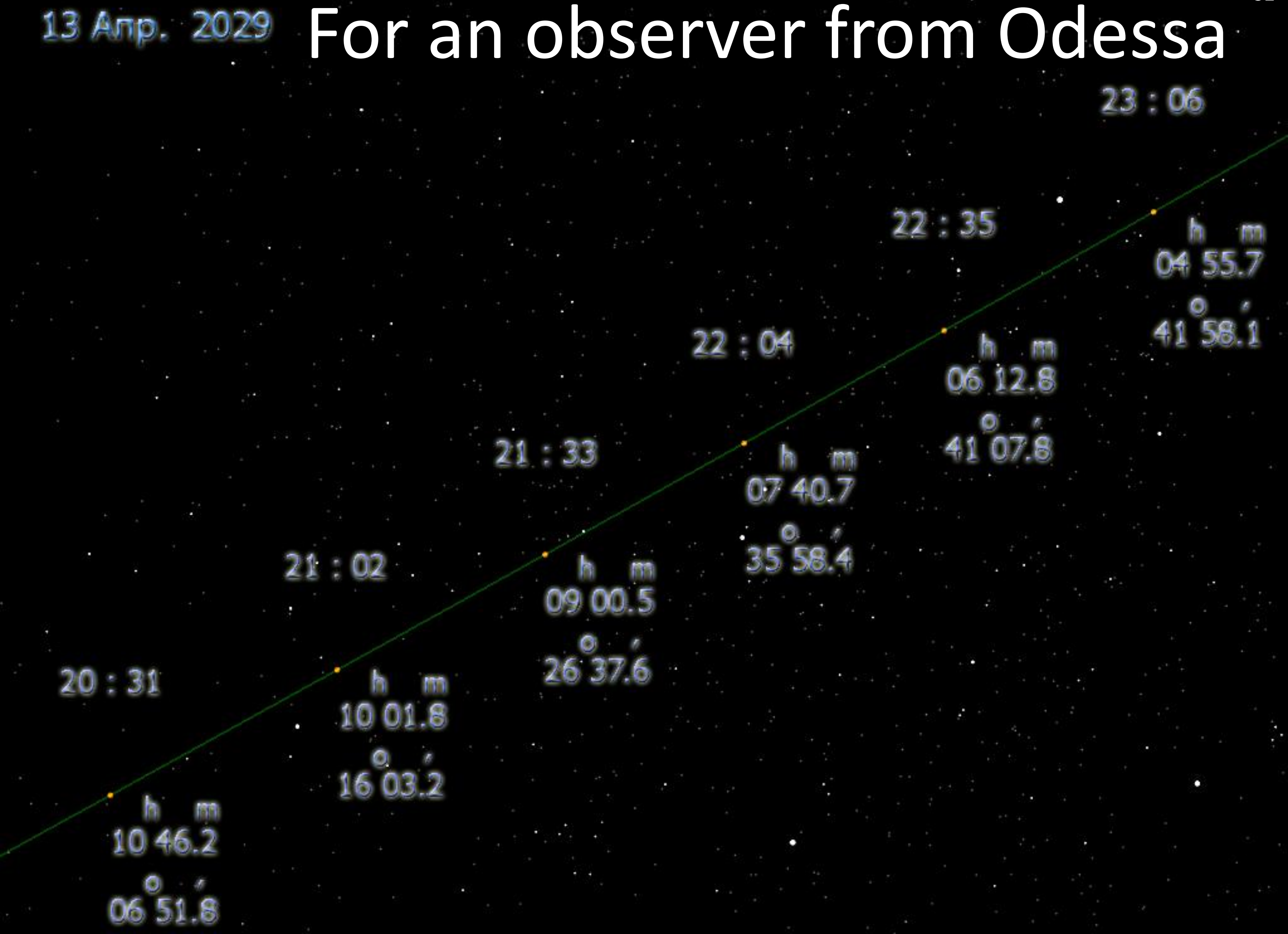


Simulation orbits

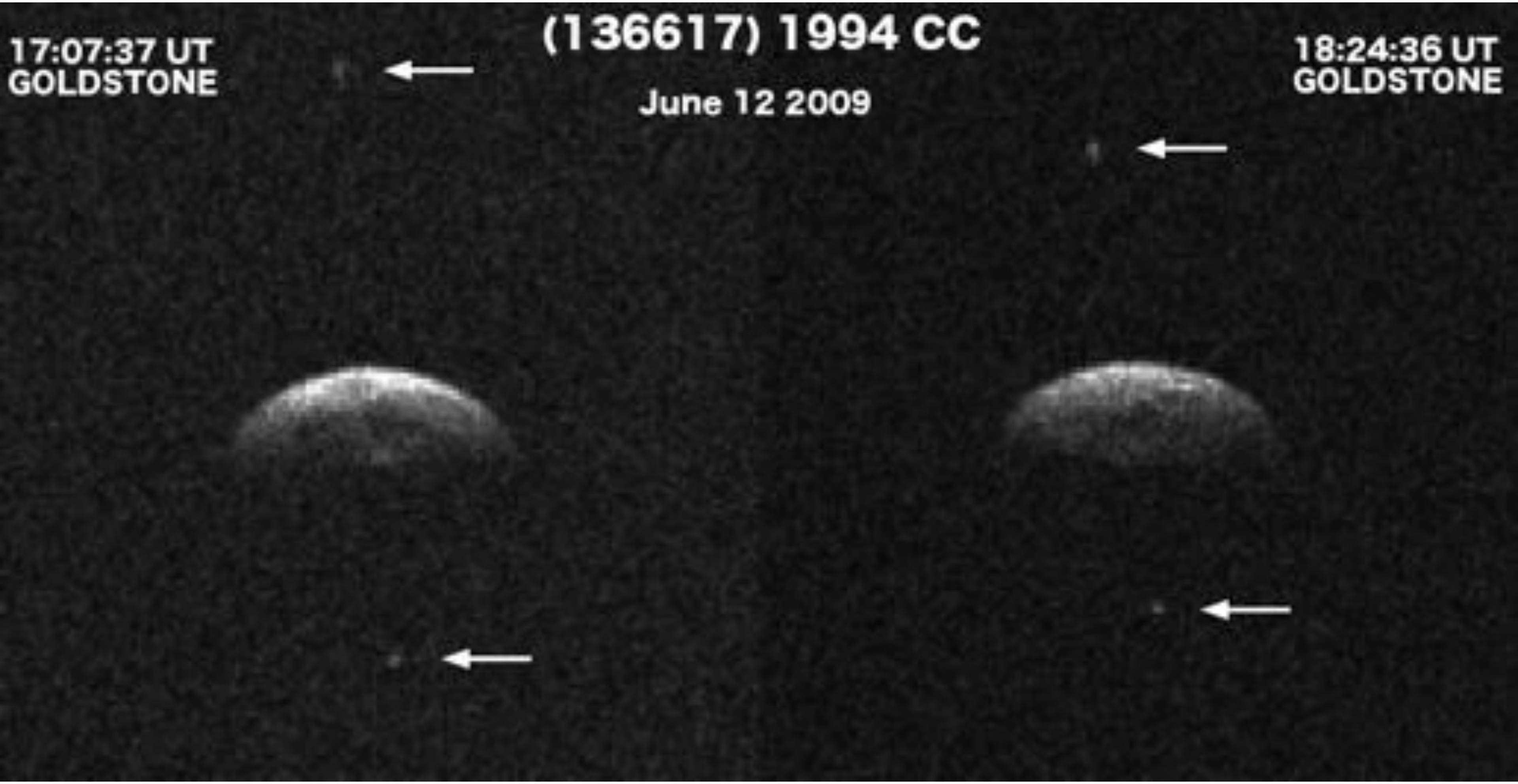



Time: 2029 03 15 04:00
Distance to Earth: 15733758 km
Distance to Moon: 16023080 km
Heliocentric Speed: 26.4 km/s
Geocentric Speed: 6.5 km/s
Odessa National University. Astronomical observatory
Anton Tokovenko e-mail: tonich_83@mail.ru

For an observer from Odessa

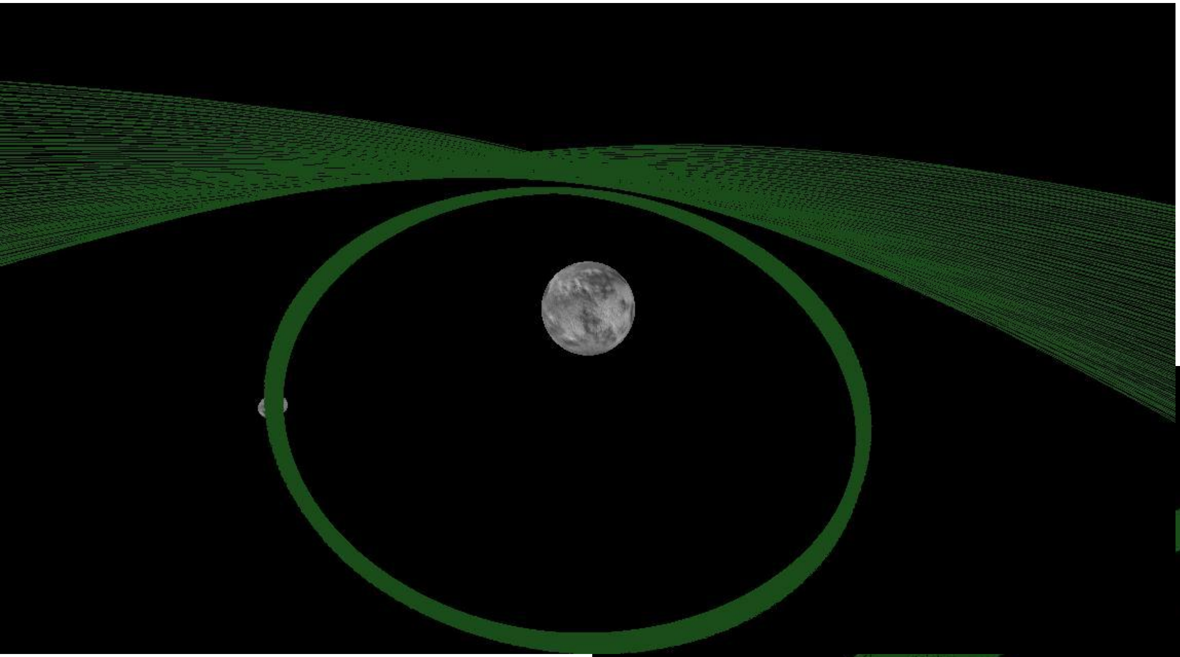


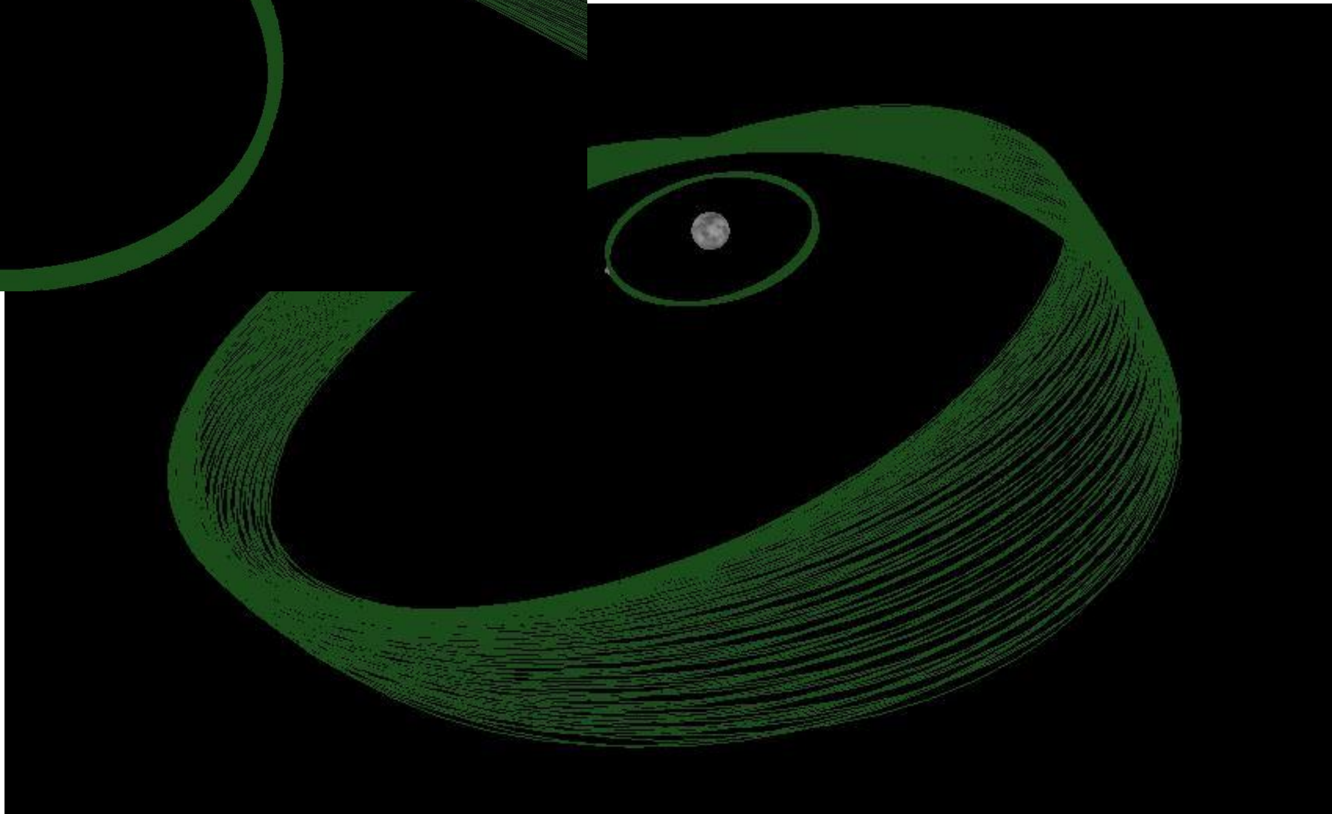
(136617) 1994 CC *(Apollo)*



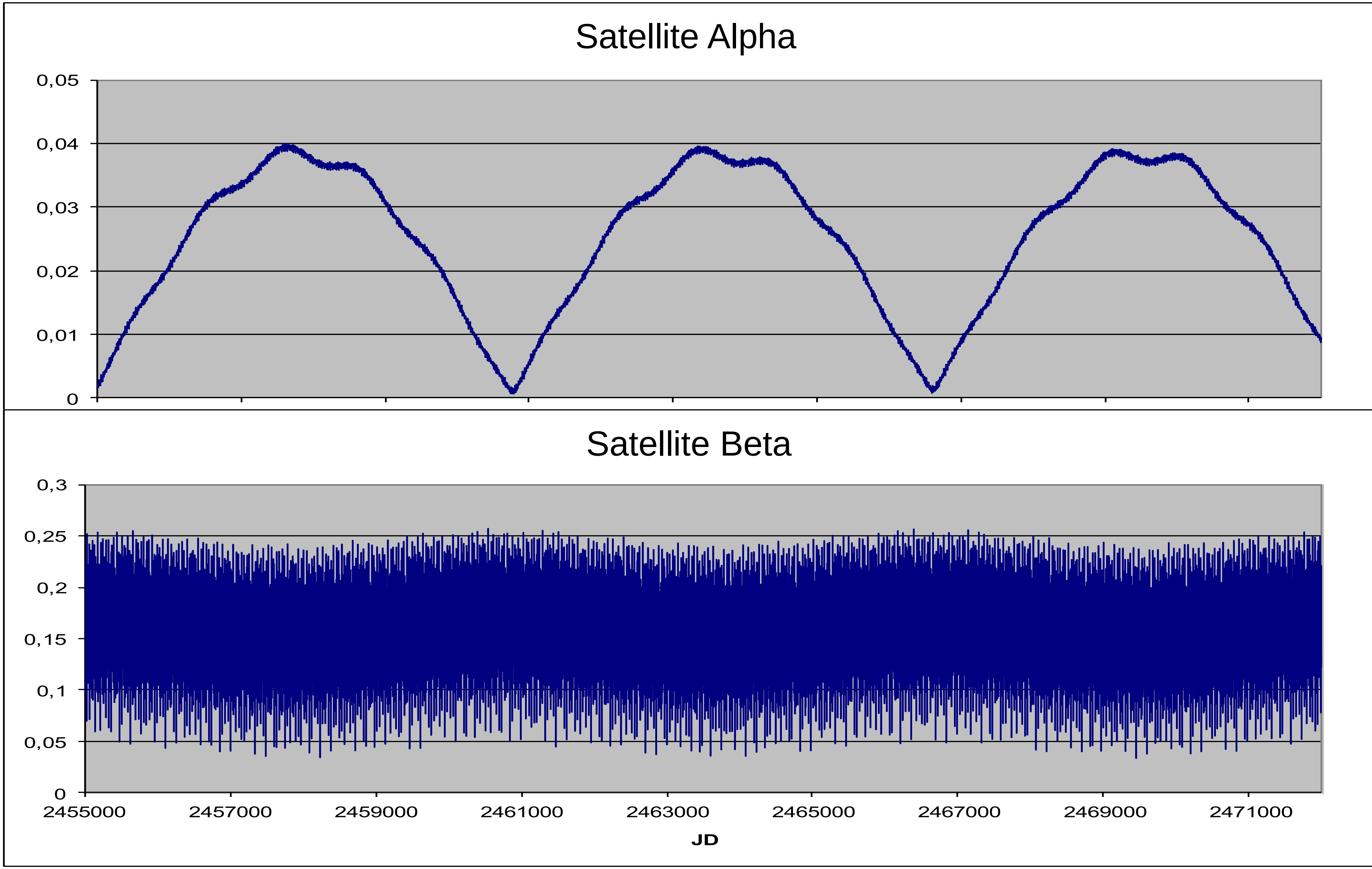
Radar imaging at NASA's Goldstone Solar System Radar on June 12 and 14, 2009, revealed that near-Earth asteroid 1994 CC is a triple system. Image Credit: NASA.

Evolution orbits satellites (136617) 1994 CC



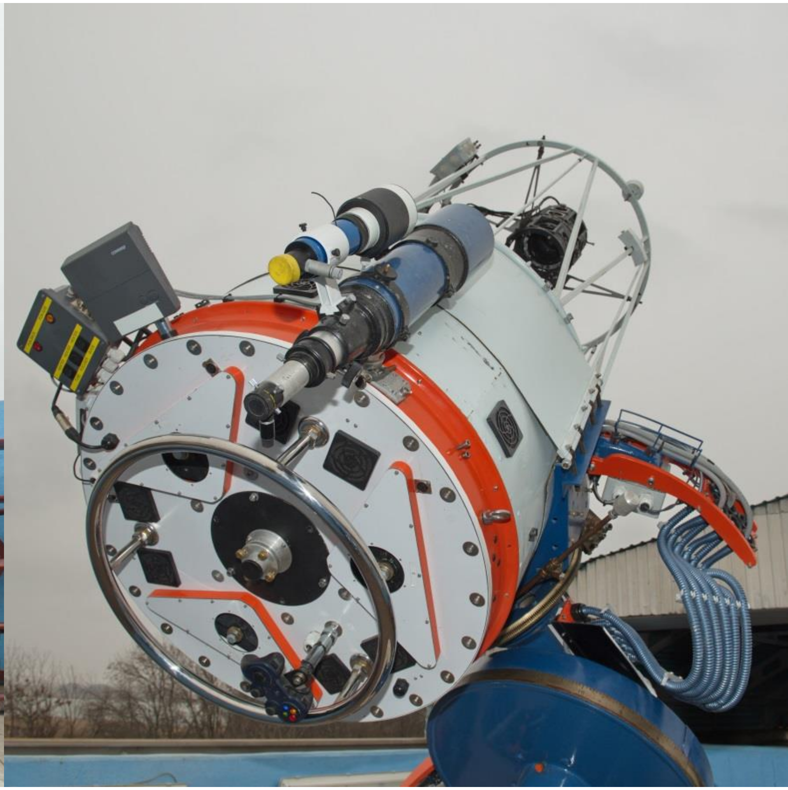


Evolution of the eccentricity of the asteroid satellites



Thanks for attention !!!

Questions



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