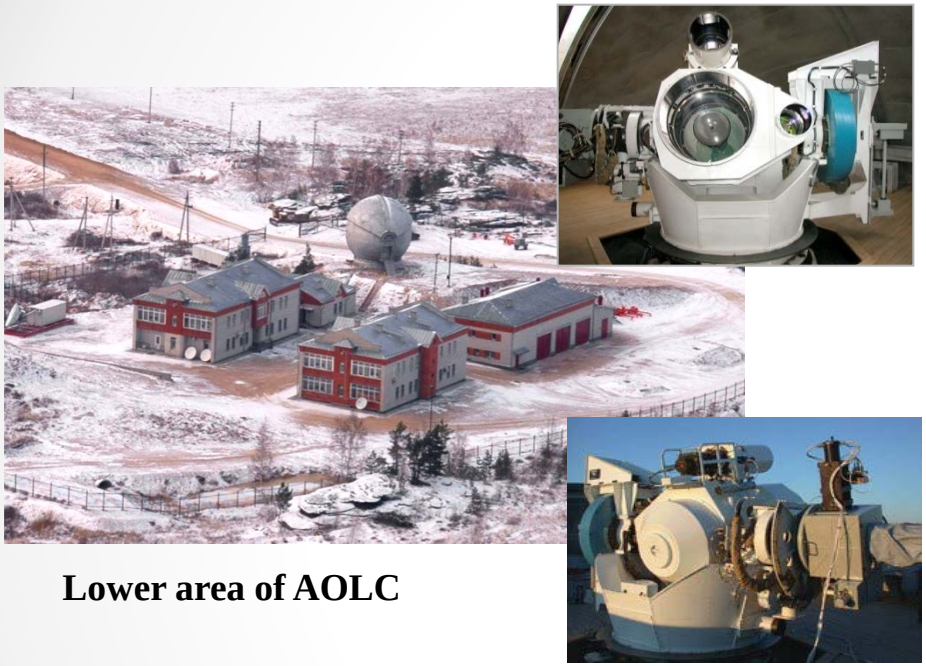
Open Joint Stock Company "Research-and-Production Corporation
"Precision Systems and Instruments", Moscow, Russia

Capabilities of observation facilities of Altay optic-laser center in the problem of space debris surveillance

Novgorodtsev D.D.*, *Aleshin V.P.*, *Grishin E.A.*, *Shargorodsky V.D.

Altay Optical Laser Center (AOLC)



Lower area of AOLC

Upper area of AOLC

AOLC – 1 Stage . 0.6 m aperture telescope with adaptive optics system

AOLC – 2 Stage (Under construction). 3.12 m aperture telescope with 3-conjugate adaptive optics system

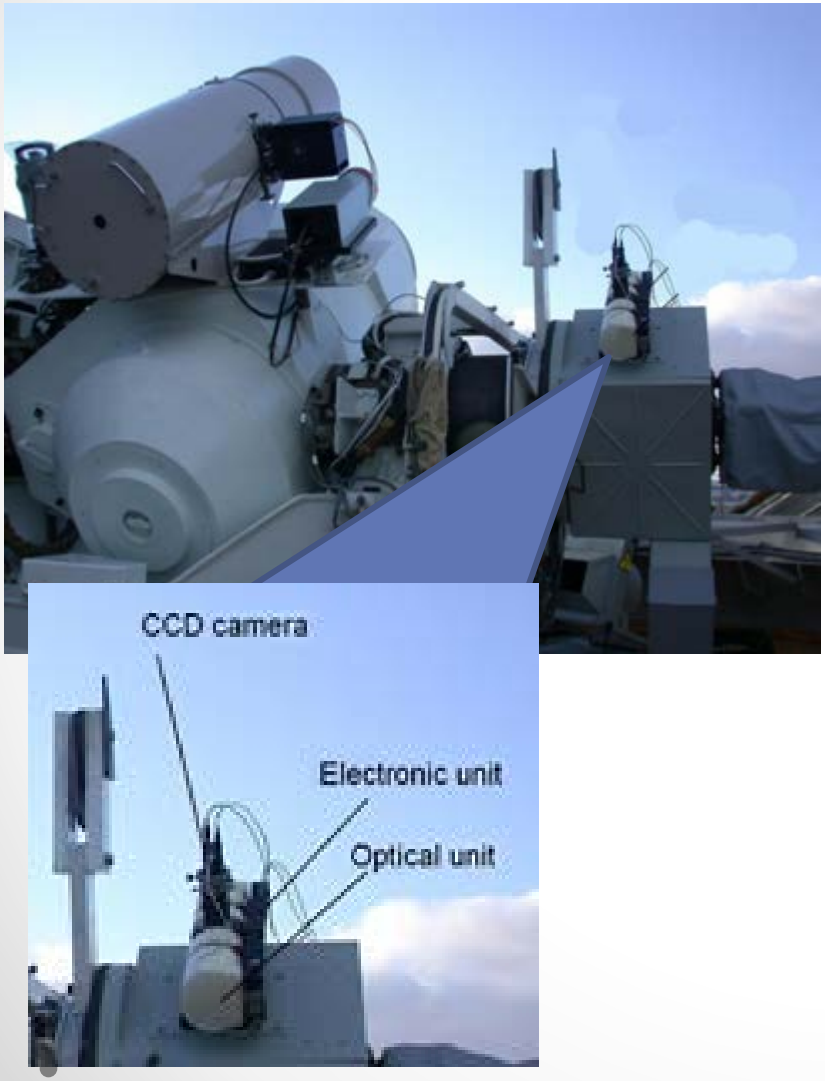
The main parameters of the Altay Optical Laser Center in the problem of technogenic space debris monitoring

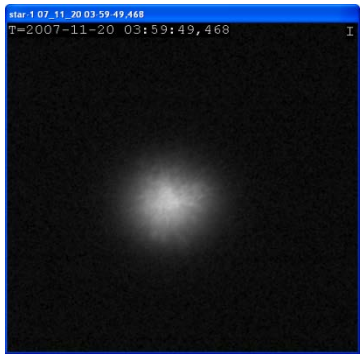
Range	Size of spacecraft		Size of the space debris components			Linear diffraction limits of resolution at a range L
	D=10 м	D=2 м	D= 0.2 м	D=0.05 м	D=0.01 м	
L= 200 км	0.5^{m} (10.3")	4.0^{m} (2.06")	9.0^{m} (0.2")	12.0^{m} (0.05")	15.5^{m} (0.01")	4.3 см (0.044")
L= 400 км	1.8^{m} (5.15")	5.3^{m} (1.03")	10.3^{m} (0.1")	13.3^{m} (0.03")	16.8^{m}	8.6 см
L=1000 км	4.0^{m} (2.06")	7.5^{m} (0.41")	12.5^{m} (0.04")	15.5^{m}	19.0^{m}	21.5 см
L=2000 км	5.5^{m} (0.56")	9.0^{m} (0.2")	14.0^{m} (0.02")	17.0^{m}	20.5^{m}	43 см
L=4000 км	6.8^{m} (0.28")	10.3^{m} (0.1")	15.3^{m}	18.3^{m}	21.8^{m}	86 см
L= 36000 км	11.8^{m}	15.3^{m}	20.3^{m}	23.3^{m}	26.8^{m}	770 см

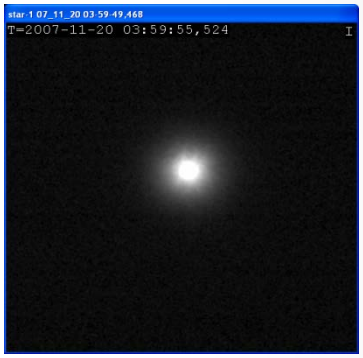
- space objects imaging

- space objects photometry and angular coordinates measurement

The adaptive optical system (AOS) of the Altai Optical Laser Center (AOLC)



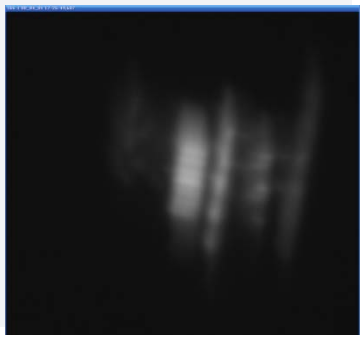




Without AOS

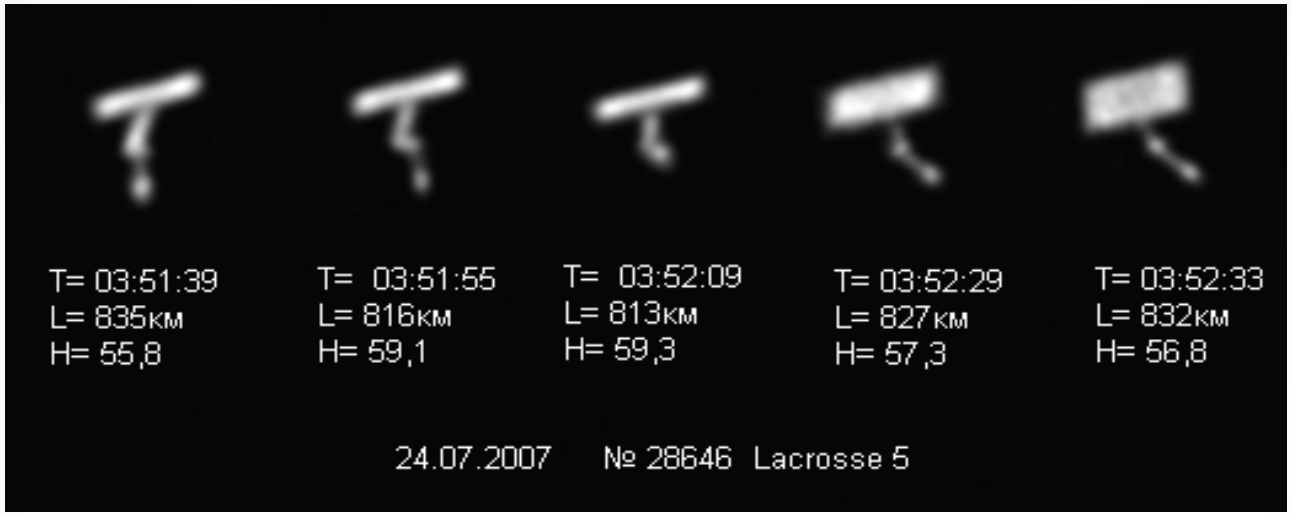
With AOS

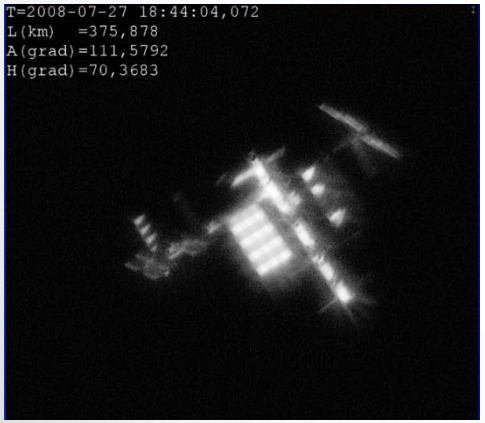
Star

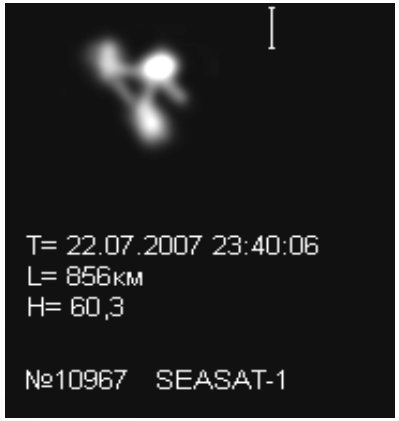


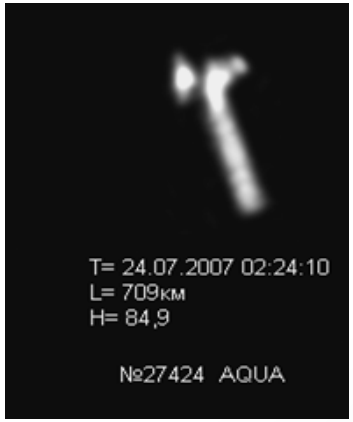
ISS

Samples images from AOS of AOLC

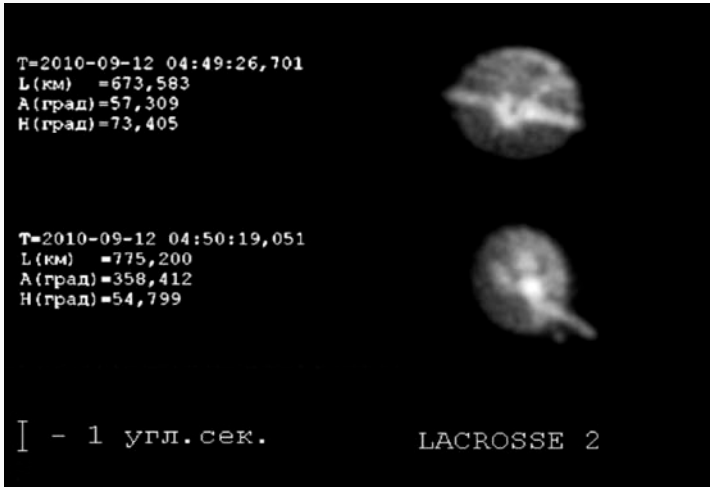


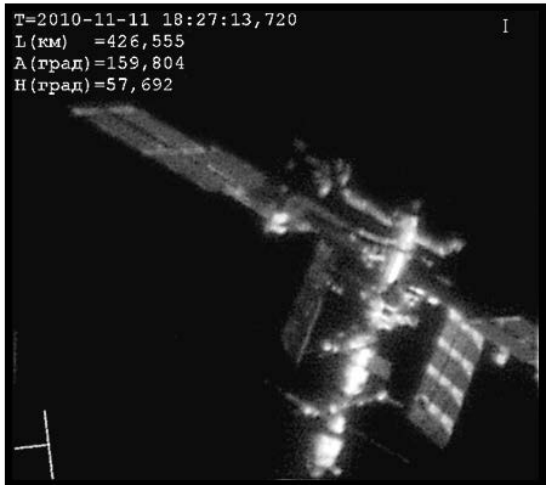


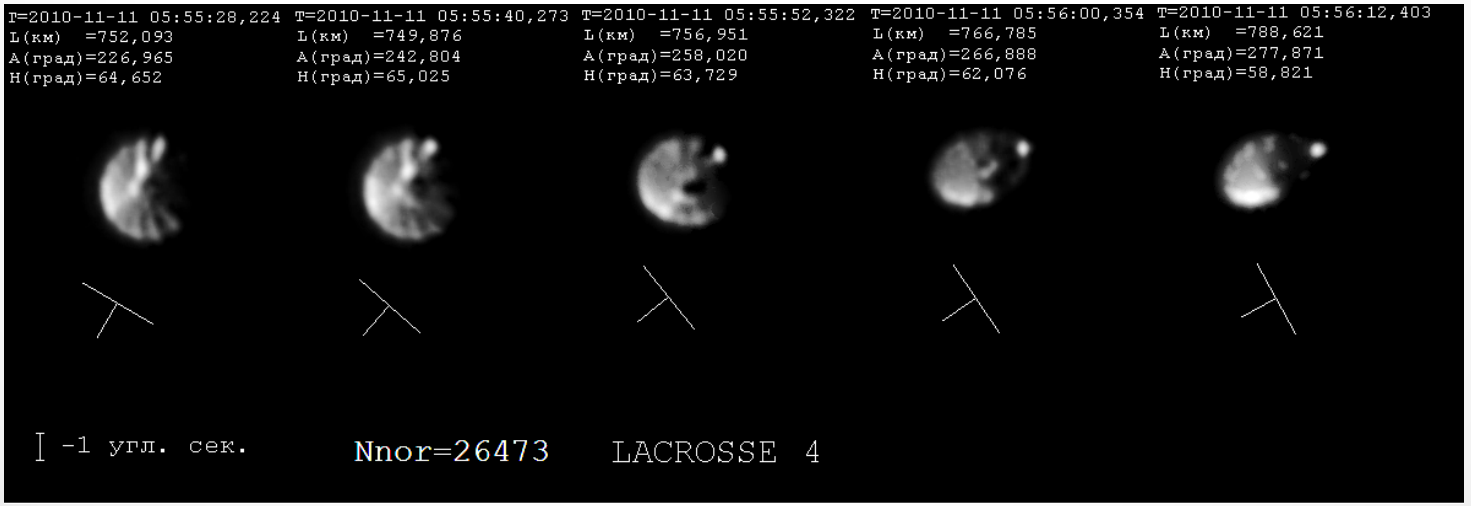




Samples images from AOS of AOLC







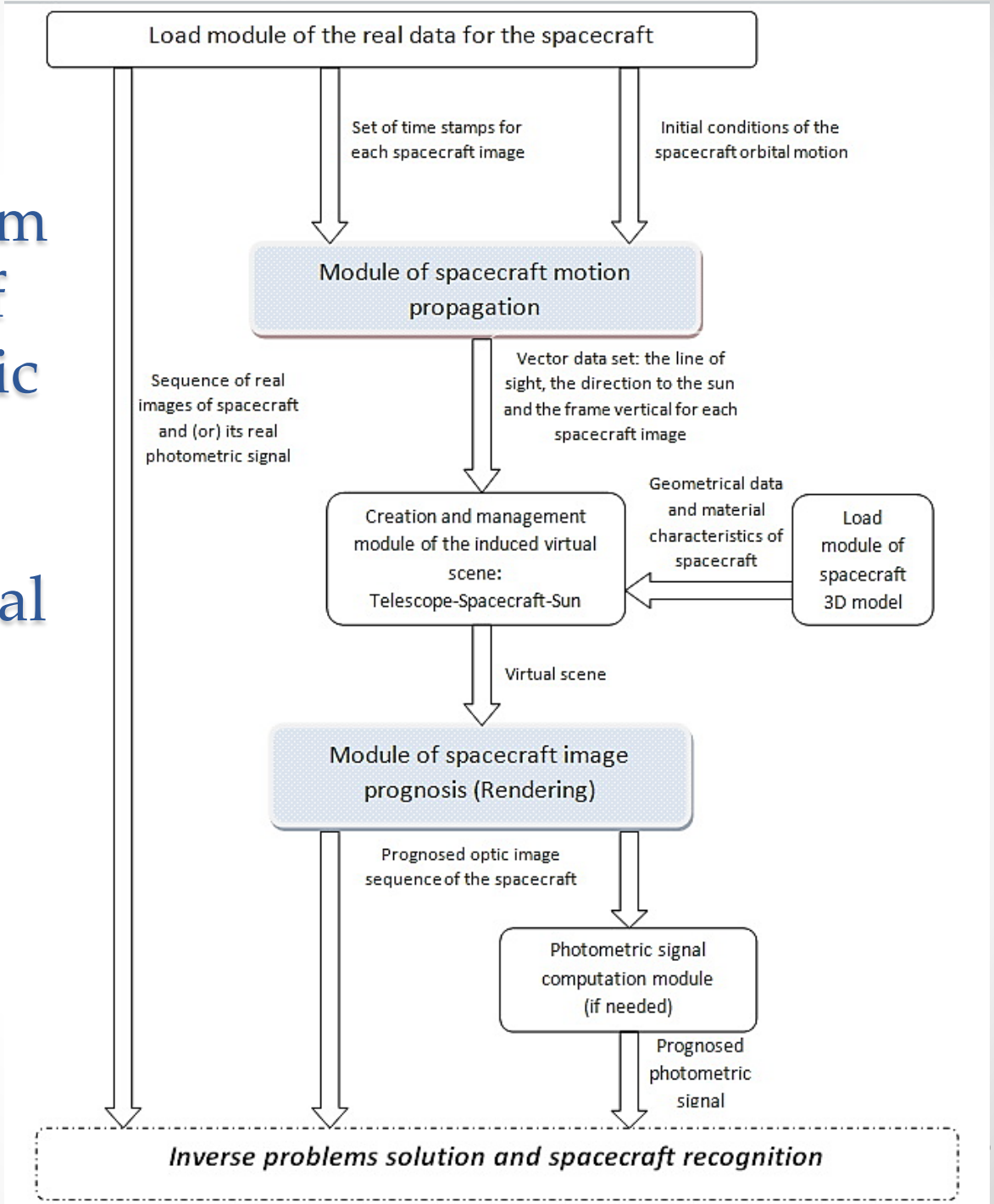
Principles of design of the interactive technical vision system of the Altai Optical Laser Center for spacecraft state monitoring

A task to form prognosis of trans-atmospheric images and corresponding photometric signal consists of two subtasks:

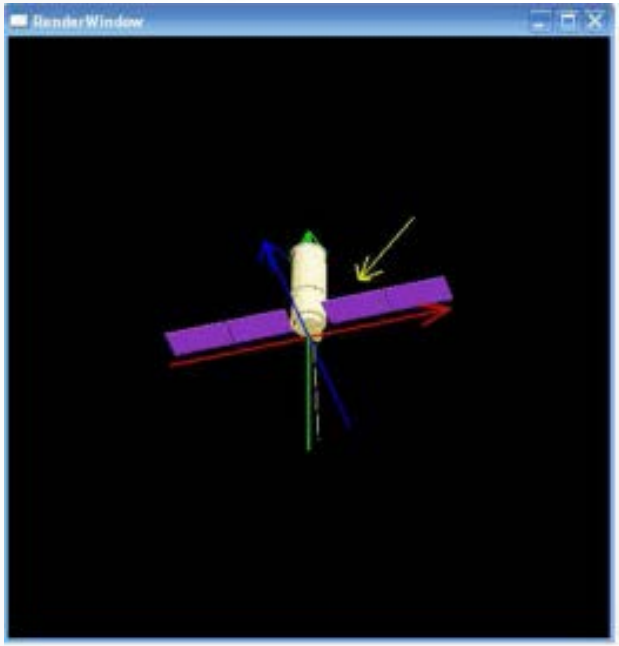
a) propagation of spacecraft orbital motion and computation of the appropriate centre of mass orientation vectors (line of sight, vertical of the frame, direction to the sun, etc.);

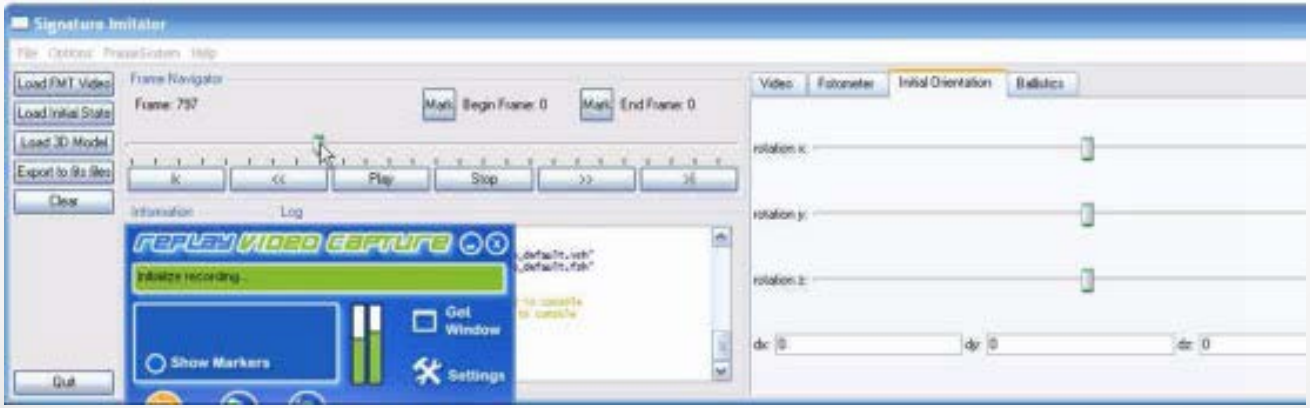
b) formation of trans-atmospheric images (by physically adequate rendering) based on the ballistic data set from the first subtask .

Design of program for prognosis of trans-atmospheric images and corresponding photometric signal

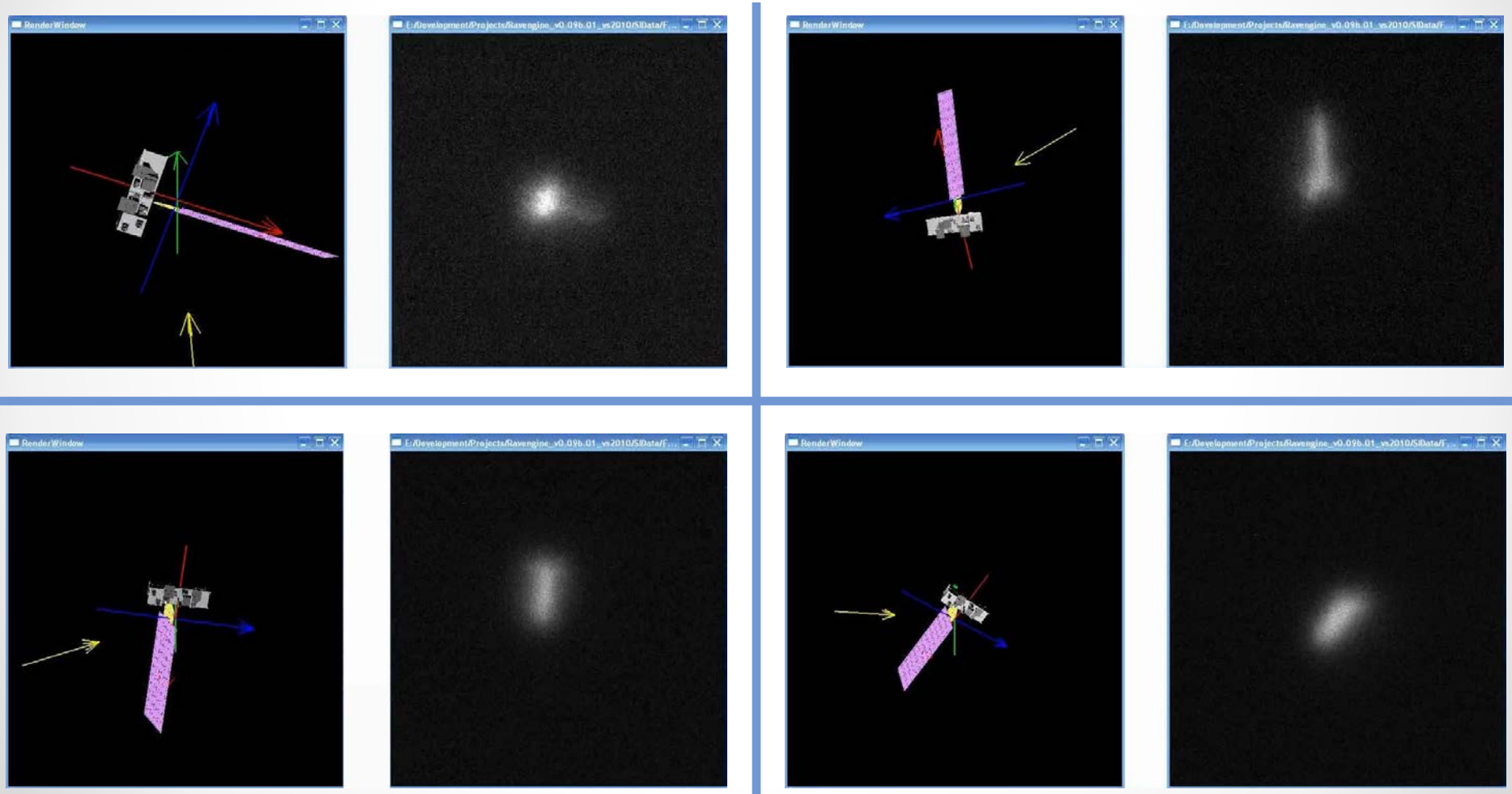


An example of interactive search of spacecraft orientation



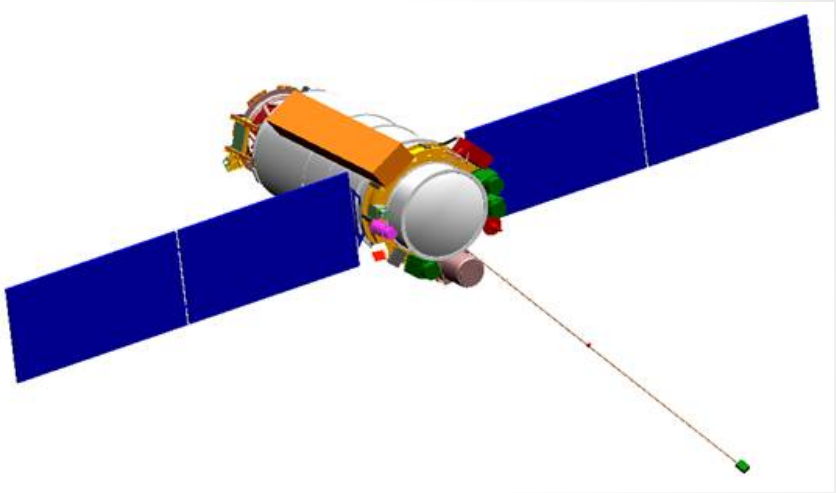


Simultaneous display of real AOS video sequences and sequences of prognosis images (example: AQUA – *stabilized spacecraft*)



Analysis of the emergency with the spacecraft "Koronos-Photon"

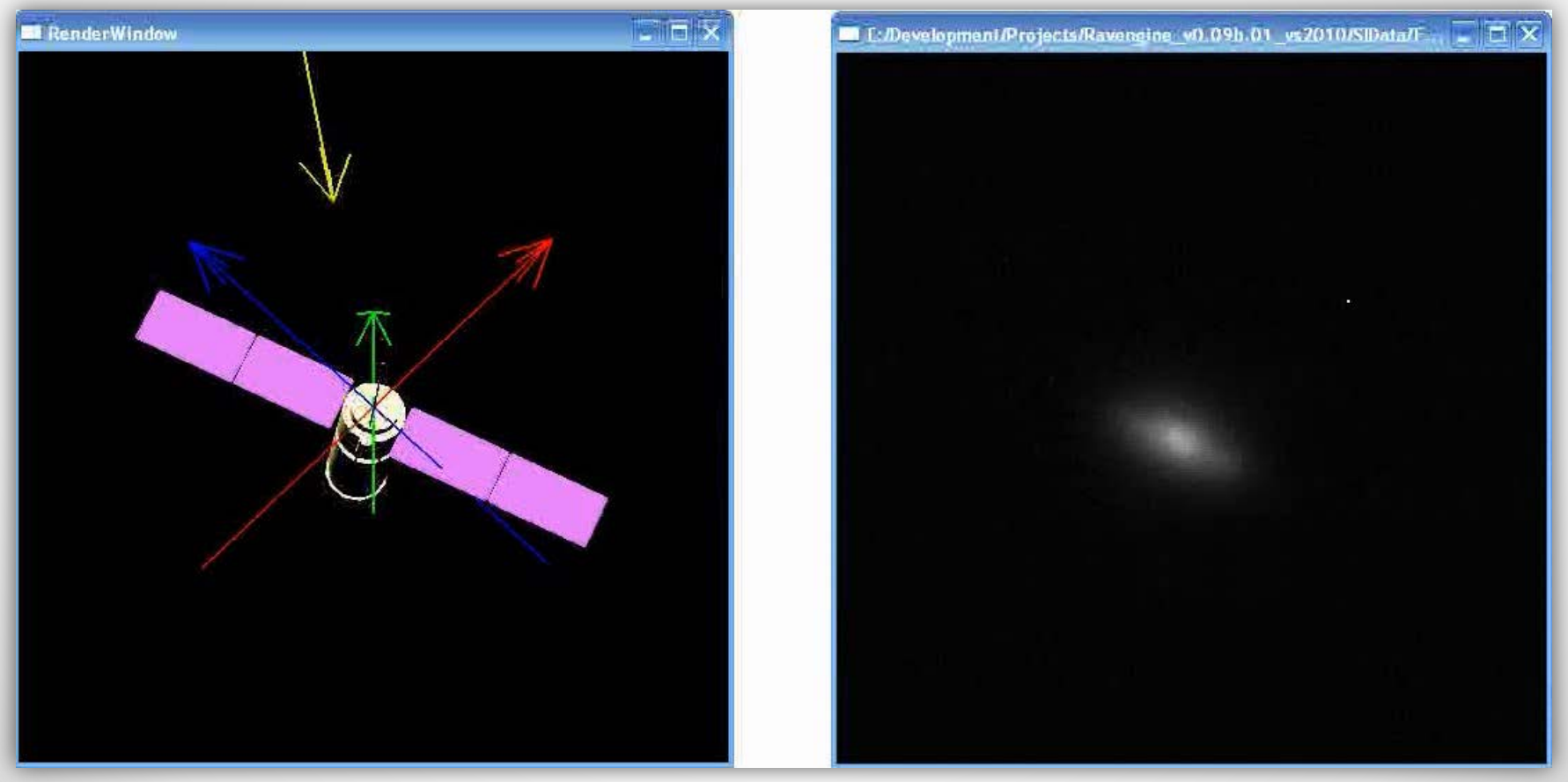
This unit was designed for astrophysical studies of the Sun. The orientation of the spacecraft in working order was determined by the Sun - measuring devices aimed at the Sun, the solar panels are orthogonal to a vector from the spacecraft towards the Sun. The orbit of the spacecraft is sunsynchronous. The spacecraft came into an emergency state in December 2009. The treatment of observation sessions on 16, 17 and 22 June, 2010, allowed us to determine the orientation of the spacecraft and the degree of deviation of solar panels from the direction to the Sun.



A priori 3D shape

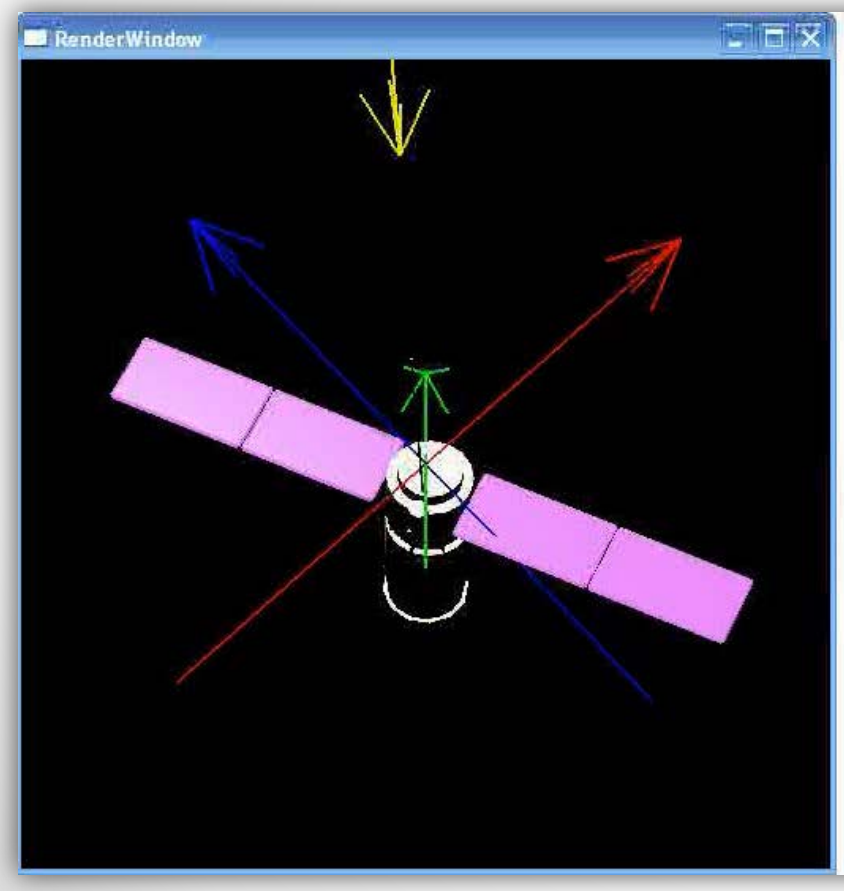
Analysis of the emergency with the spacecraft "Koronos-Photon"

Simultaneous display of real AOS video and sequences of prognosis images "Koronos-Photon" on 16.06.2010



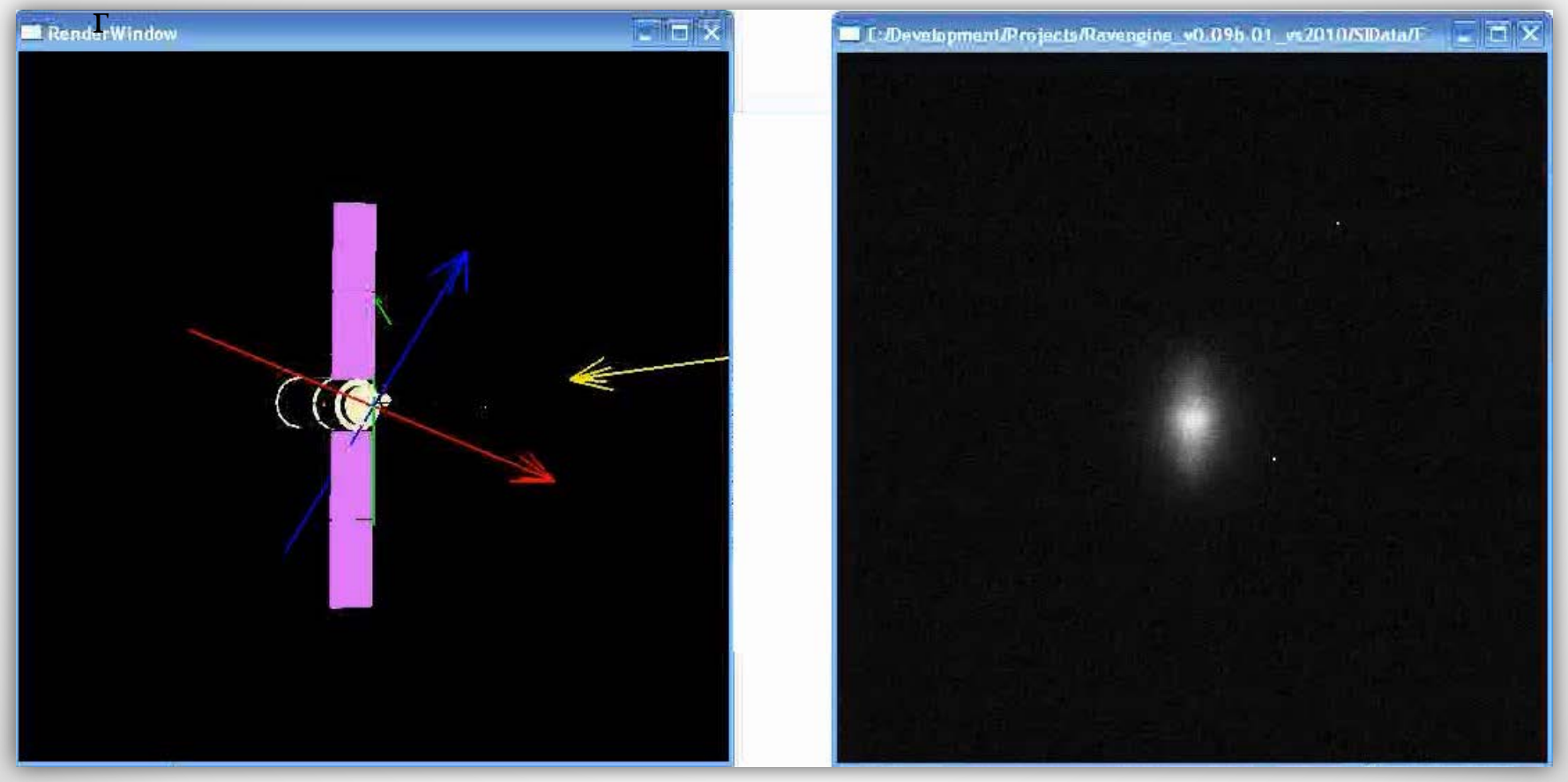
Analysis of the emergency with the spacecraft "Koronos-Photon"

Simultaneous display of real AOS video and sequences of prognosis images "Koronos-Photon" on 17.06.2010



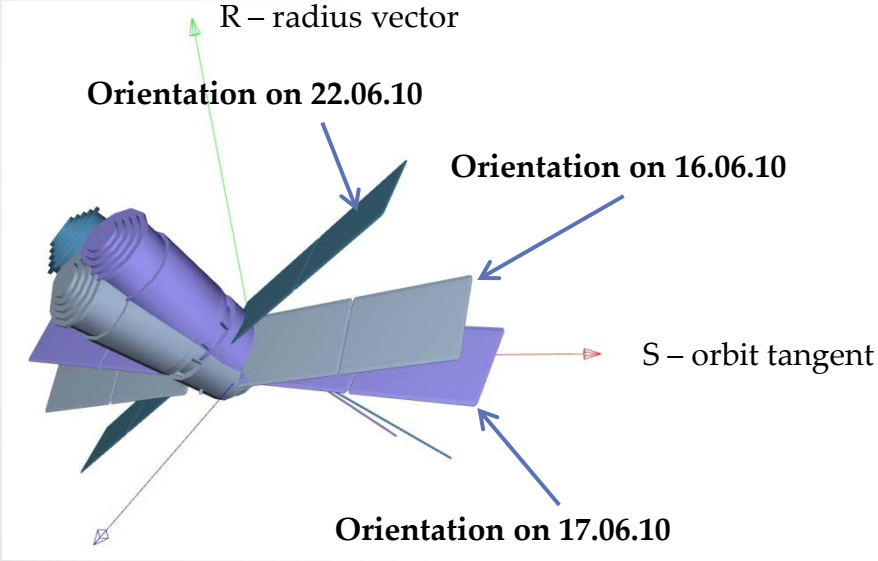
Analysis of the emergency with the spacecraft "Koronos-Photon"

Simultaneous display of real AOS video and sequences of prognosis images "Koronos-Photon" on 22.06.2010



Analysis of the emergency with the spacecraft "Koronos-Photon"

Orientation evaluations in orbital system:

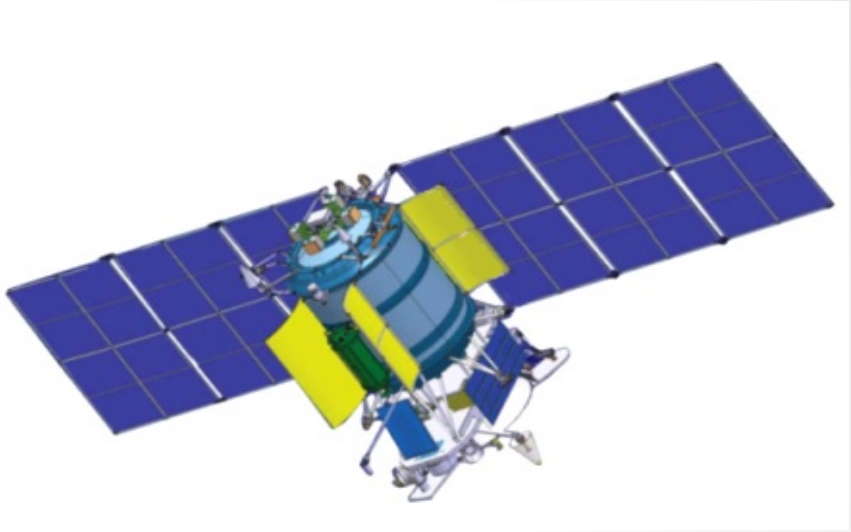


W - binormal

1. For all the observation sessions, normal of solar panels deviated from the direction to the Sun of more than 30 - 60 degrees.
2. Rotation of the spacecraft during the observation session in the orbital coordinate system was not observed (angles of rotation of the spacecraft during the observation session is in range of 1-3 degrees).

Analysis of the emergency with the spacecraft "GEO-IK 2"

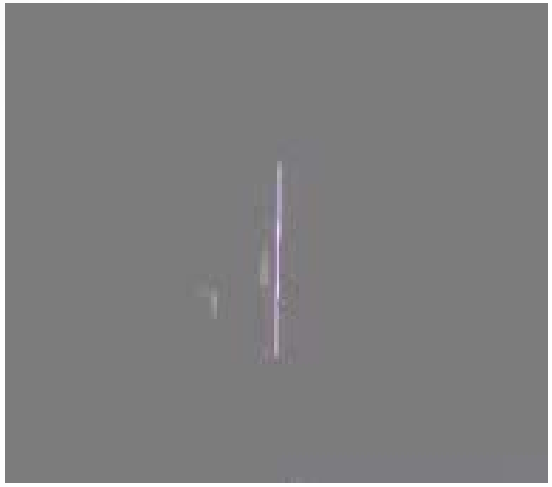
The spacecraft was designed to solve the problems of space geodesy, but was not parked in the expected orbit. By hypothesis, the spacecraft got rotation as a result of attempts to transfer to a new orbit

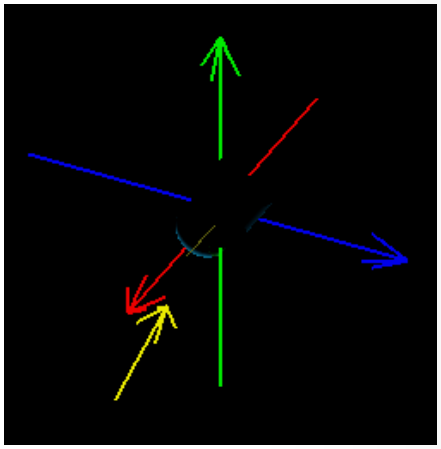


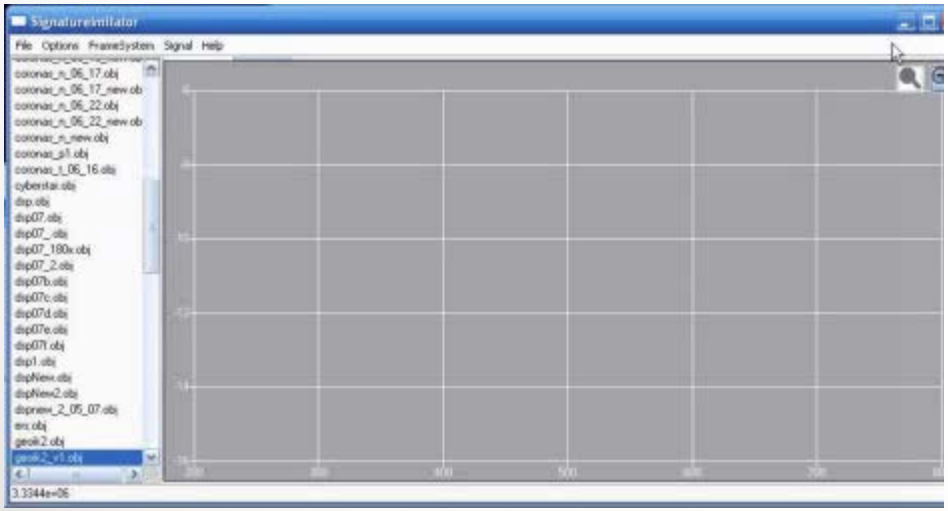
A priori 3D shape

Analysis of the emergency with the spacecraft "GEO-IK 2"

Example of the modeling photometry.



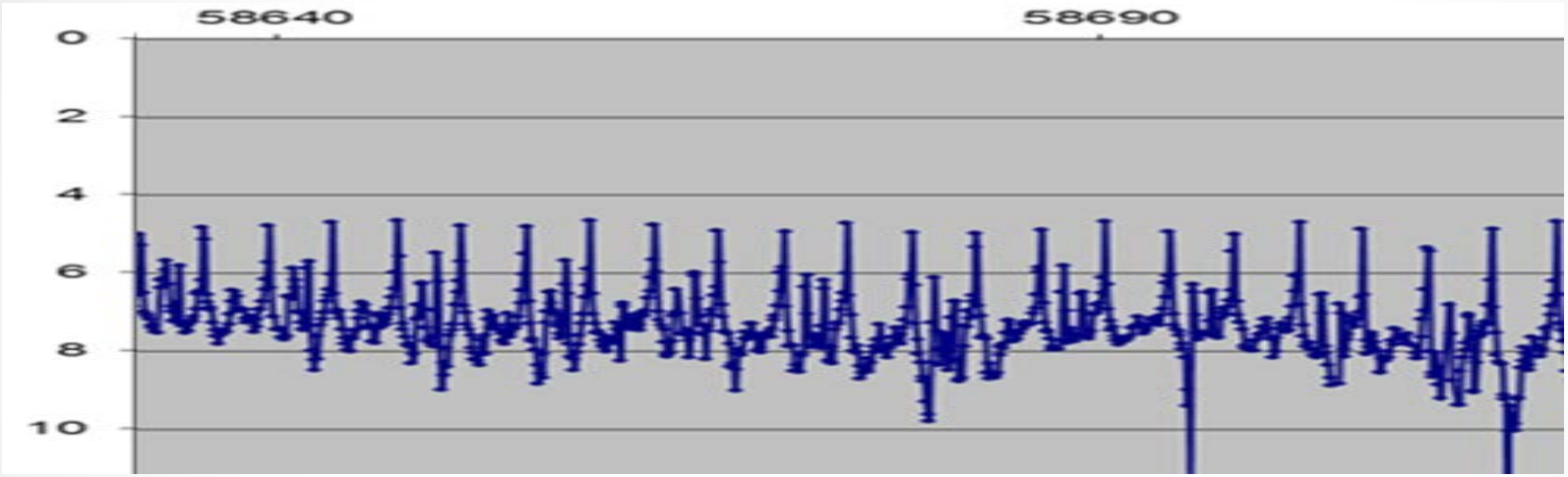




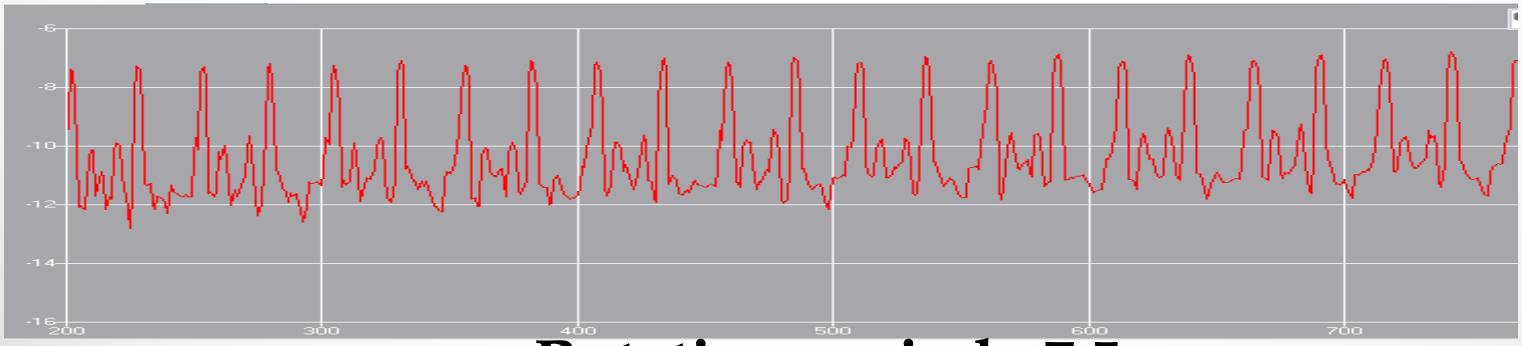
The phase angle of the observations (the angle between the vectors from the spacecraft center of mass to the Sun and to the telescope) was over 120 degrees

Analysis of the emergency with the spacecraft "GEO-IK 2"

The measured photometry of GEO-IK 2 on 03/22/2011



The modeled photometry for the most probable hypothesis of rotation



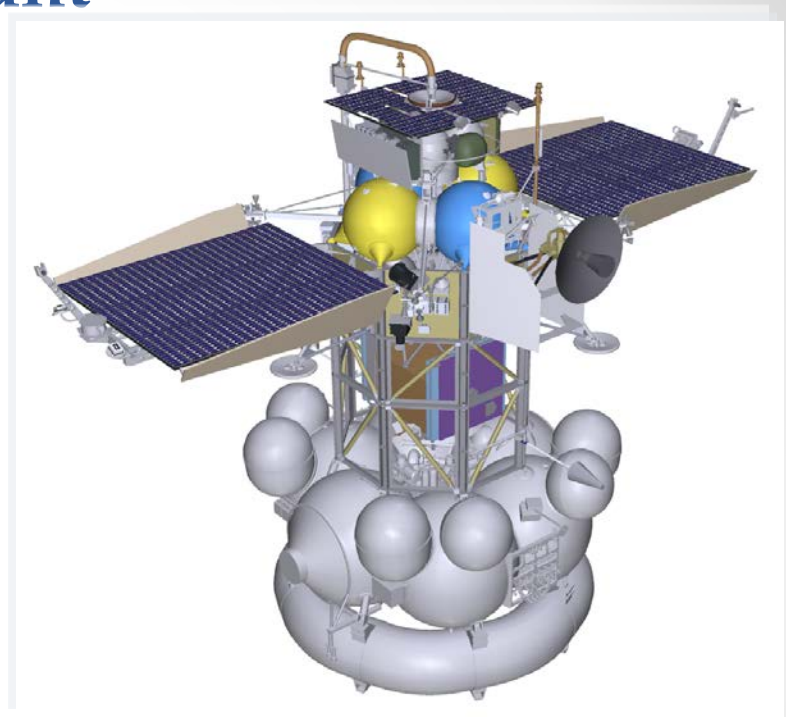
Rotation period ~7.5 s

Analysis of the emergency with the spacecraft "Phobos-Grunt"

It was launched on 9 November 2011, but subsequent rocket burns intended to set the craft on a course for Mars failed, leaving it stranded in low Earth orbit.

Efforts to reactivate the craft were unsuccessful, and it fell back to Earth in an uncontrolled re-entry on 15 January 2012.

Further we present data obtained through the observations of the spacecraft "Phobos-Grunt" and its interactive interpretation in the period from 29 November to 25 December, 2011



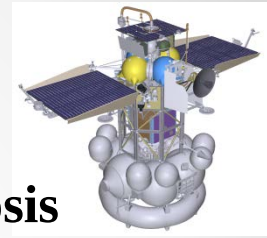
A priori 3D shape

Analysis of the emergency with the spacecraft "Phobos-Grunt"

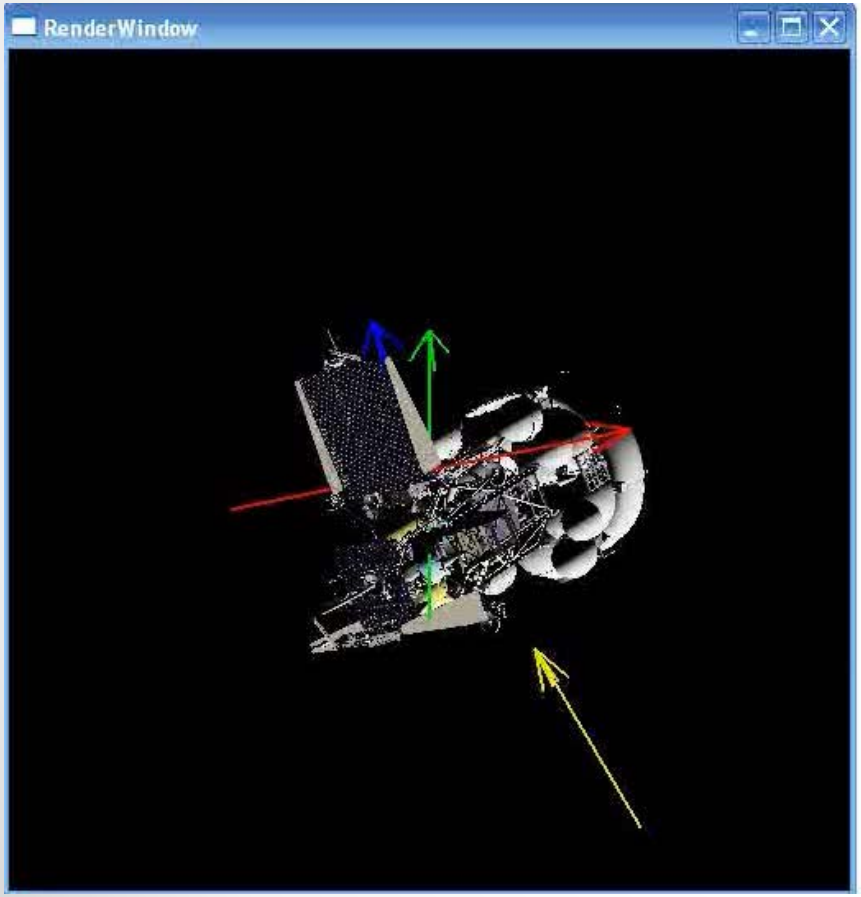
Parameters of observation sessions and resulting estimations of the spacecraft orientation

Observation date and time (Moscow region)	Number of frames	Minimum range (km)	Maximum elevation (deg)	Atmosphere turbulence	Sun direction	Orientation
29.11.11 14:45:26	1167	235	74	middle	r: -0.636 s: -0.697 w: 0.329	ϕ_r: 121° ϕ_s: -12° ϕ_w: 251°
01.12.11 14:33:48	1578	227	84	strong	r: -0.610 s: -0.764 w: 0.206	ϕ_r: 107° ϕ_s: -173° ϕ_w: 77°
23.12.11 04:29:17	1261	276	70	middle	r: 0.202 s: 0.263 w: -0.943	ϕ_r: 164° ϕ_s: 13° ϕ_w: 44°
24.12.11 04:14:50	2634	265	77	light	r: 0.174 s: 0.354 w: -0.918	ϕ_r: 99° ϕ_s: 21° ϕ_w: 28°
25.12.11 03:58:08	1199	259	82	middle	r: 0.146 s: 0.441 w: -0.885	ϕ_r: 45° ϕ_s: 31° ϕ_w: -303°
25.12.11 05:30:53	1791	256	78	light	r: 0.252 s: 0.396 w: -0.882	ϕ_r: -116° ϕ_s: 39° ϕ_w: 238°

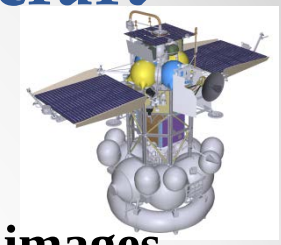
Analysis of the emergency with the spacecraft "Phobos-Grunt"



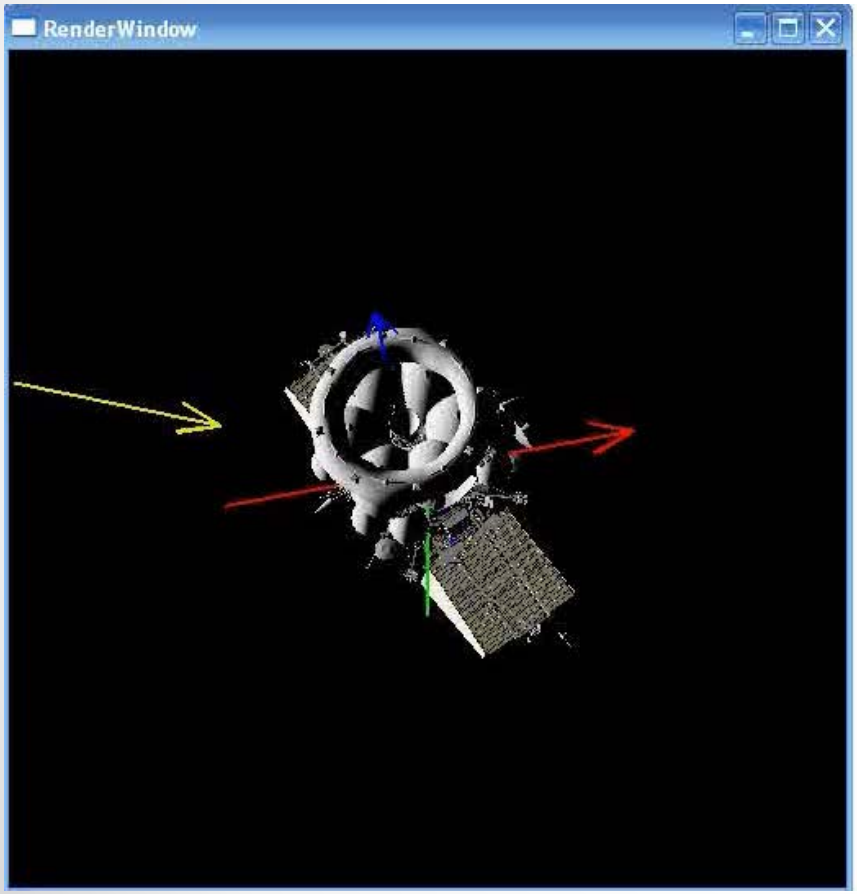
Simultaneous display of real AOS video and sequences of prognosis images "Phobos-Grunt" on 29.11.2011

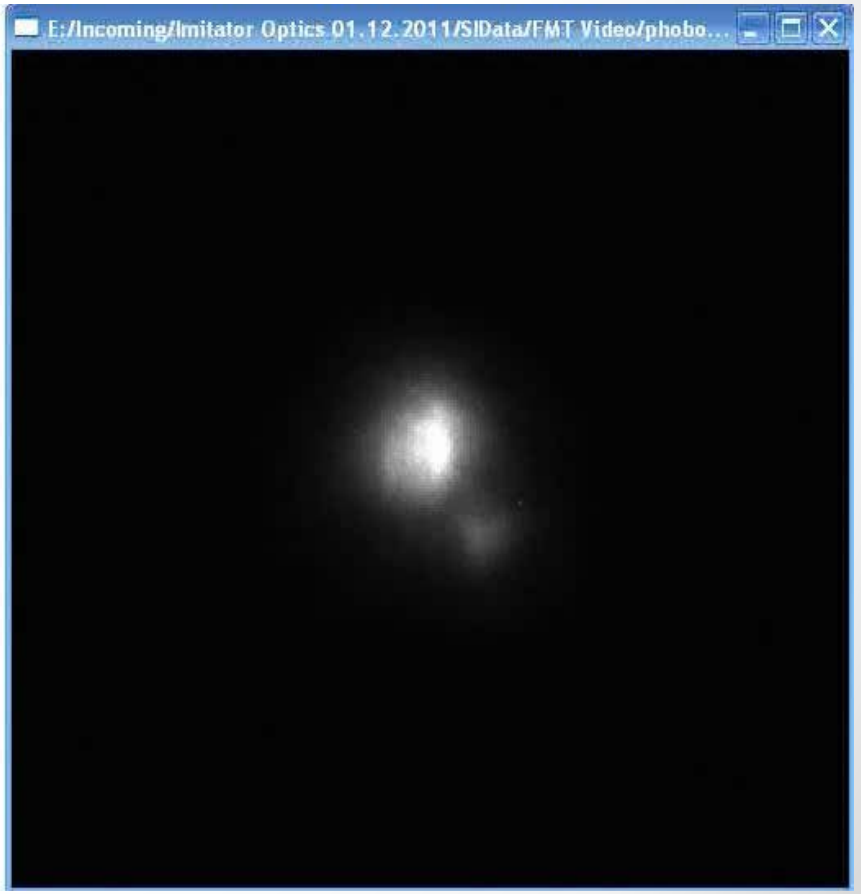


Analysis of the emergency with the spacecraft "Phobos-Grunt"



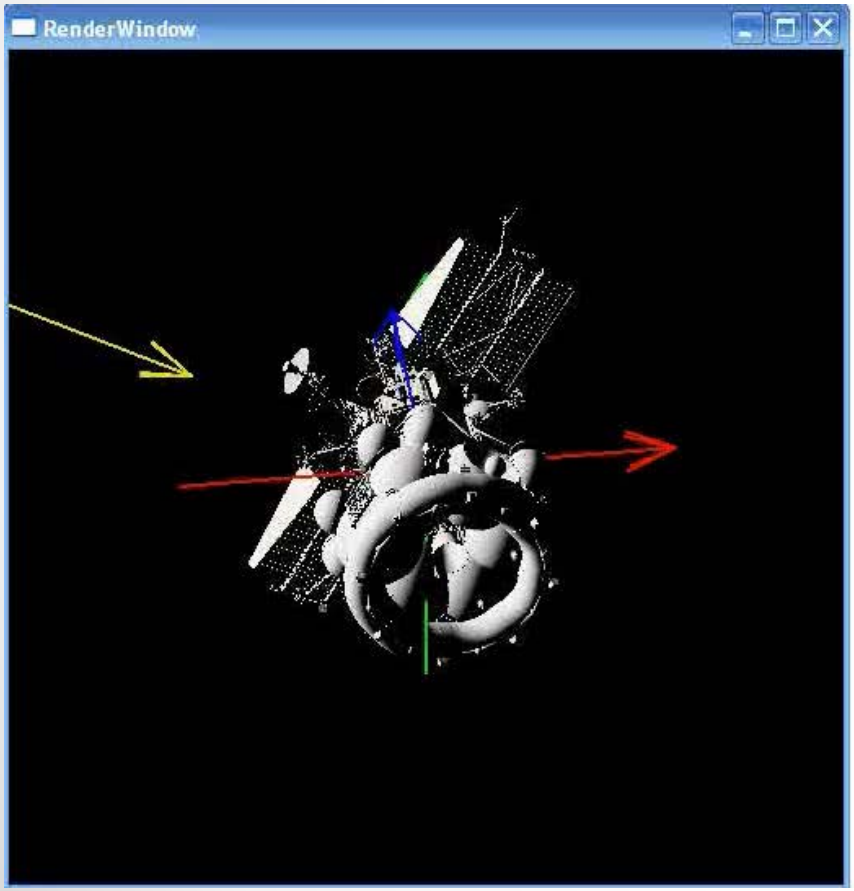
Simultaneous display of real AOS video and sequences of prognosis images "Phobos-Grunt" on 24.11.2011



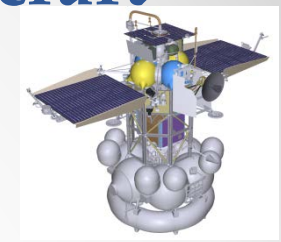


Analysis of the emergency with the spacecraft "Phobos-Grunt"

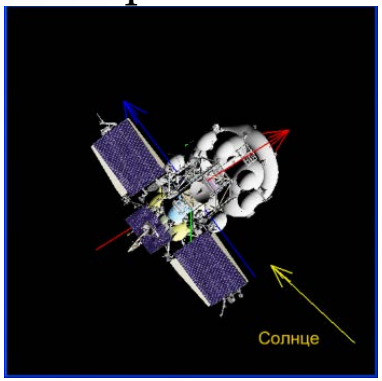
Simultaneous display of real AOS video and sequences of prognosis images "Phobos-Grunt" on 25.12.2011

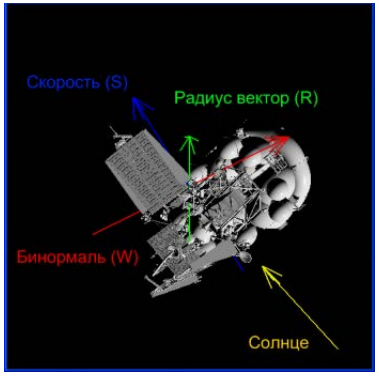


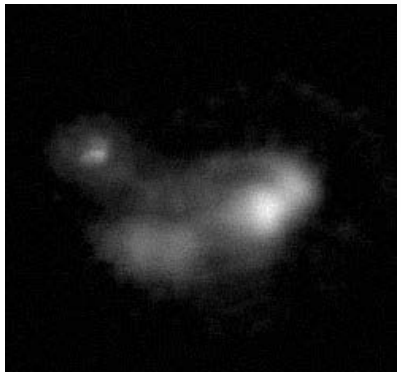
Analysis of the emergency with the spacecraft "Phobos-Grunt"



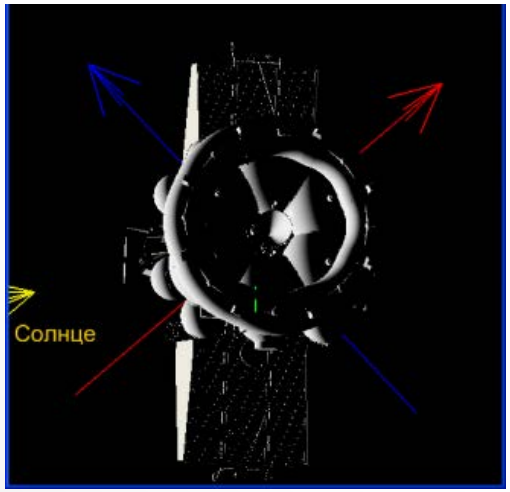
1.One of the solar panels on November 29th , 2011 is not observed:

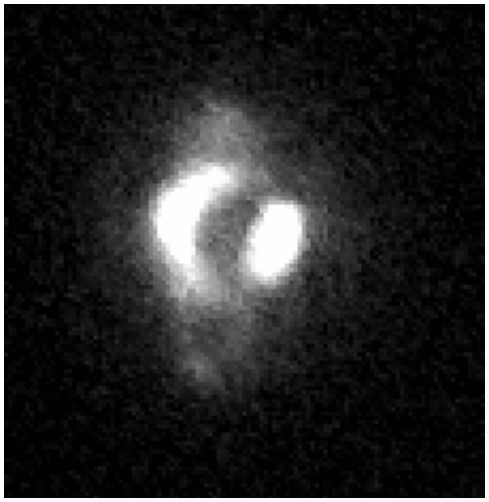




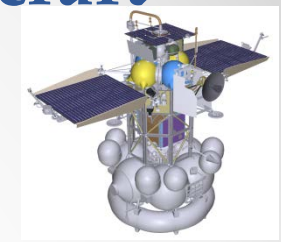


2. On December 25th, 2011 in observation session two panels were observed in the deployed state :

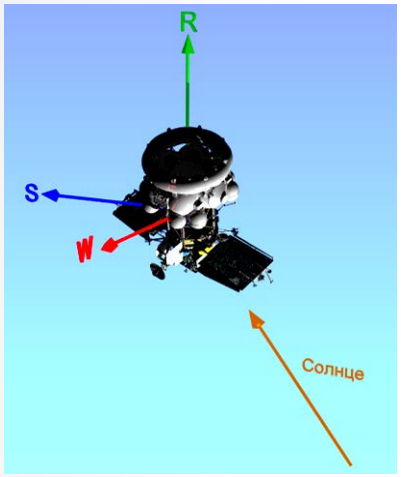




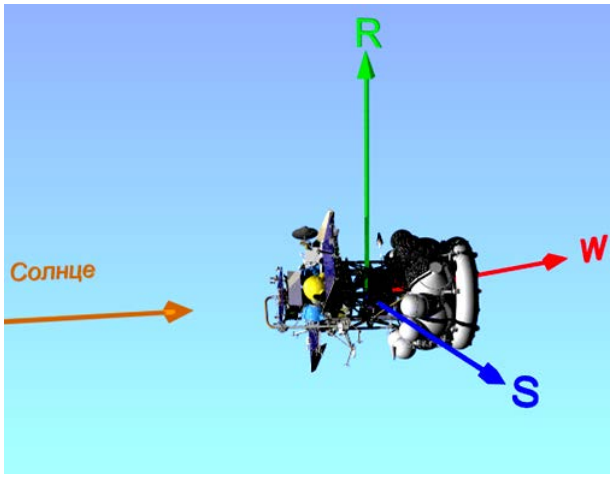
Analysis of the emergency with the spacecraft "Phobos-Grunt"



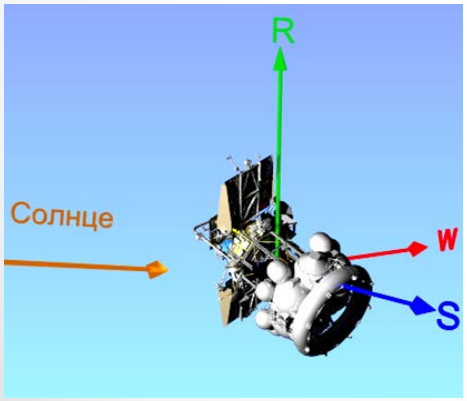
Probable orientation of the spacecraft "Phobos-Grunt"



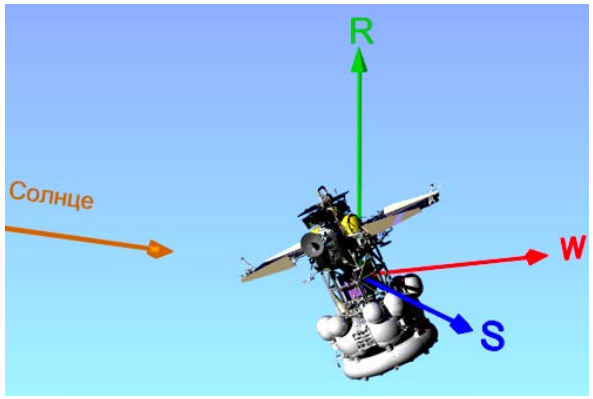
29.11.2011 at 11:45:26 UTC



23.12 .2011 at 01:29:18 UTC



24.12.2011 at 01:14:50 UTC



25.12.2011 at 02:30:53 UTC

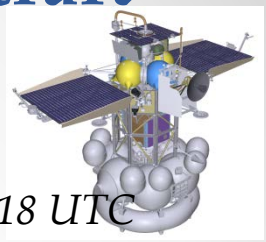
Orbital coordinate system (OCR):

R – the radius vector

S - the tangent to the orbit in the direction of the velocity vector

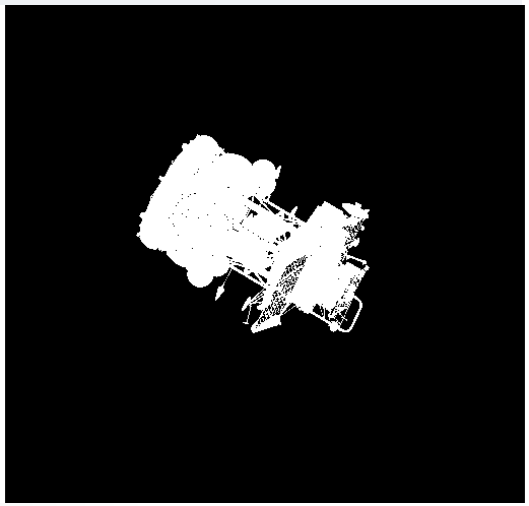
W – binormal supplementing the **R** and **S** up to the right-hand triple.

Analysis of the emergency with the spacecraft "Phobos-Grunt"

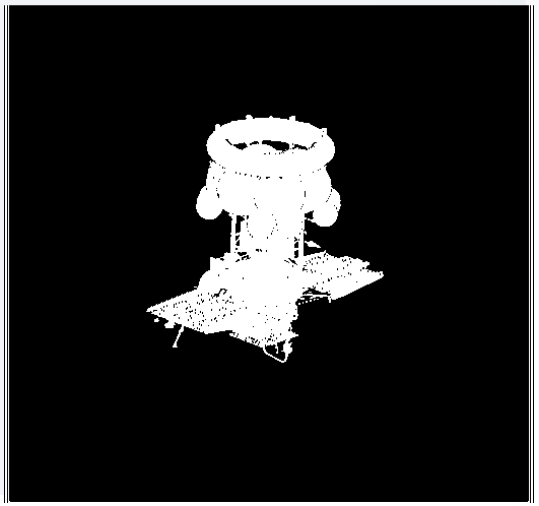


Estimated middle values of the spacecraft "Phobos-Grunt"

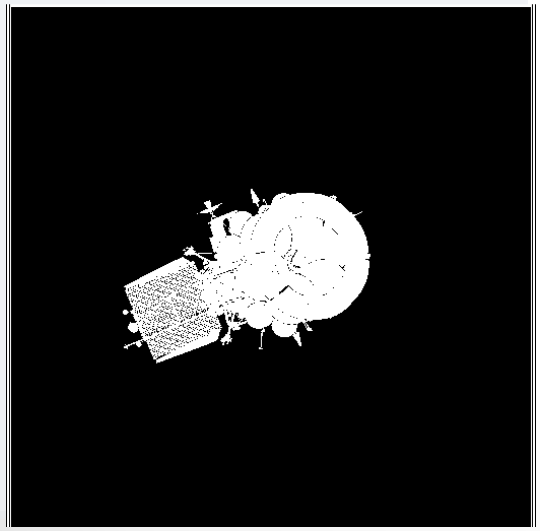
Middle 17.1 м² *29.11.2011 at 11:45:26 UTC*



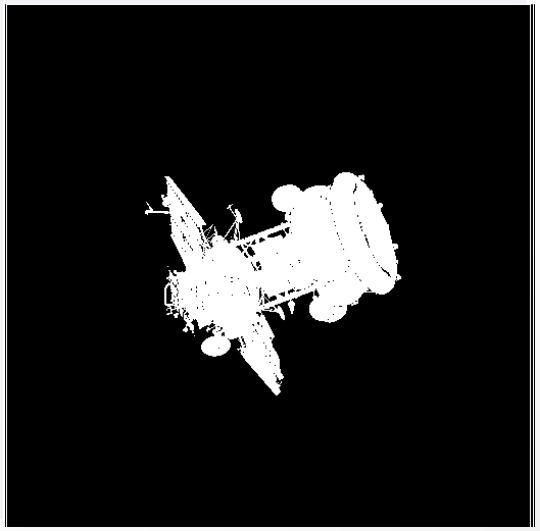
Middle 19.3 м² *23.12 .2011 at 01:29:18 UTC*



Middle 17.4 м² *24.12.2011 at 01:14:50 UTC*



Middle 18.9 м² *25.12.2011 at 02:30:53 UTC*



Conclusions:

1. The Altai Optical Laser Center in its present state is able to bring a considerable contribution to solving a problem of space surveillance. Creation of a second stage of AOLC significantly increases the effectiveness of Space Situational Awareness (SSA).
2. The use of adaptive optics in conjunction with the prognosis of trans-atmospheric spacecraft images allows the analysis of emergency situations and to evaluate the orientation of spacecraft in the most complicated cases of its slow motion relative to the center of mass. A developed software complex for monitoring a spacecraft state has shown its high efficiency in the analysis of observations in the case of particular emergencies with the real spacecraft.
3. Quite effective in terms of computations algorithms and programs for prognosis of optical information are implemented on the basis of modern methods of physically adequate modeling of the optical images (rendering).
4. Observation sessions were performed to evaluate the emergency situations with the spacecraft "Coronas - Photon", "Phobos-Grunt", "GEO IK 2".

Acknowledgments

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Thank you for your attention!

Questions?

Examples of AOS Images