Research Article

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Project “Universat-SOCRAT” of Multiple Small Satellites for Monitoring of Natural and Technogenic Space Hazards

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Abstract: The new space project of M. V. Lomonosov Moscow State University on elaboration of multiple satellites for real time monitoring in the near-Earth space of radiation environment, natural (asteroids, meteoroids) and artificial (space debris) potentially dangerous objects, electromagnetic transients, such as cosmic gamma ray bursts, terrestrial gamma ray flashes, optical and ultraviolet bursts in the Earth atmosphere is presented.
It is intended to install on the satellites the following instruments for space monitoring of dangerous objects and hazards: spectrometers of electrons and protons, complex of instruments for study of transient electromagnetic phenomena including gamma ray spectrometer, detectors of ultraviolet and optical emission and wide-field optical cameras.
Successful implementation of the project for the first time in the world allows realization of a space system prototype for monitoring and preventing of space hazards for both ongoing and planned space missions, and also for aircraft flying in the upper atmosphere.
There are also discussed results of experiments on-board Lomonosov in view of good experience of wide field camera use for monitor observations in space. These results formed the base of scientific program for the new project Universat-SOCRAT.

Keywords: radiation environment, asteroids, space debris, electromagnetic transients

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1 Introduction

The natural and technogenic space environment causes serious risks for the implementation of space missions, both automatic and human. The risk is determined by the specifics of the planned missions, *i.e.* their duration, localization in outer space and orbital parameters.

The specific of natural conditions in outer space such as the variety of radiation field physical parameters, the features of ballistic trajectories of natural space objects, as well as the consequences of human activities in space, *i.e.* pollution of space with man-made debris cause, as a rule, real difficulties for environment modeling and for calculating of risks.

Monitoring in real time of space natural and man-made objects which can be assumed as potential threats is an optimal and effective way to reduce risks. In this way the project Universat-SOCRAT[1] is proposed for implementation. Under this project we plan to create a grouping of small satellites for real time monitoring in the near-Earth space of potentially dangerous hazards, *i.e.* the radiation environment; dangerous objects of the natural (asteroids, meteors) and technogenic origin (space debris), as well as electromagnetic transients (cosmic gamma-ray bursts, optical, ultraviolet and gamma ray flashes from the Earth's atmosphere.

The program of the new project Universat-SOCRAT is based on the results of experiments on the satellite Lomonosov and other satellites of Moscow State University intended on the study of extreme phenomena in the Earth's atmosphere and outer space (see, for example, Sadovnichii *et al.* (2013); Panasyuk *et al.* (2016a,b)) including the results of observations of high-altitude electromagnetic discharges, precipitation of magnetospheric electrons, gamma-ray bursts of astrophysical and solar origin, as well as observations of space debris by wide-field optical cameras first installed on a spacecraft (Lipunov et al., submitted to Space Science Reviews).

1 English abbreviation “Universat” means University Satellites. SOCRAT is the Russian abbreviation “The System of Alerting the Cosmic Radiation, Asteroid and Technogenic Hazards”

2 Potentially dangerous factors in the near-Earth space

2.1 Ionization radiation

One of the main goals of the elaborated multi satellite system is a real time monitoring of near-Earth radiation, which is dangerous for the satellite on-board systems and manned spacecraft crews. Mainly, there are energetic electron and proton fluxes of the Earth's radiation belts, as well as energetic particles of solar cosmic rays.

The necessity of such monitoring is caused by that fact that these fluxes even in geo-magnetically quiet conditions undergo by significant medium-term and long-term variations, which can not be described by existing quasi-static models of the Earth's radiation belts. On the other hand, modern satellite measurements are carried out only for a limited number of orbits and range of pitch angles, *i.e.* the angle between the particle velocity vector and the magnetic field line and can not give a global picture of the spatial and temporal variations of radiation in the near-Earth space.

2.2 Space debris, asteroids and large meteoroids

As of 2015, August 31, the total number of cosmic objects of technogenic origin that are located in outer space and cataloged in the databases “Warning System on dangerous situations in near-Earth space” amounted to 17 thousand 250 space objects. Of these, 1 thousand 362 space objects are operating spacecraft, and the remaining 15 thousand 888 space objects are space debris (Harris, 2015).

At extrapolating the existing rate of low Earth orbit (LEO) clogging, even taking into account various efforts to reduce it, a “cascade effect” of the mutual collision of space debris objects and particles can arise in the medium term. In the long term it may lead to a catastrophic increase in the number of space debris objects on the LEO and, as a consequence, to the practical impossibility of further space exploration.

The problem of asteroid danger is actual also. A celestial body is considered as potentially dangerous if it crosses the Earth's orbit at a distance <0.05 AU (about 19.5 distances from the Earth to the Moon), and its diameter exceeds 100–150 m. Objects of this size are large enough to cause unprecedented destruction on the Earth land, or a huge tsunami if it fall into the ocean. Events of this magnitude occur about once every 10 000 years. Based on information received from the WISE Space Telescope, experts estimate the presence of 4700 ± 1500 potentially dangerous objects with a diameter of more than 100 meters (Mainzer *et al.*, 2014).

2.3 Electromagnetic transients

Another goal of the our project is monitoring and studying of electromagnetic transient phenomena in the upper Atmosphere, which are observed in different wavelengths, from radio to gamma ray ranges. These phenomena are global in nature and associated with electric discharges, occurring at altitudes of tens of kilometers in the upper atmosphere. The energy released in them is large enough to have a significant impact on radio communications, modify the physical parameters of the mesosphere, and also have a direct impact on the onboard systems of stratospheric suborbital aircrafts.

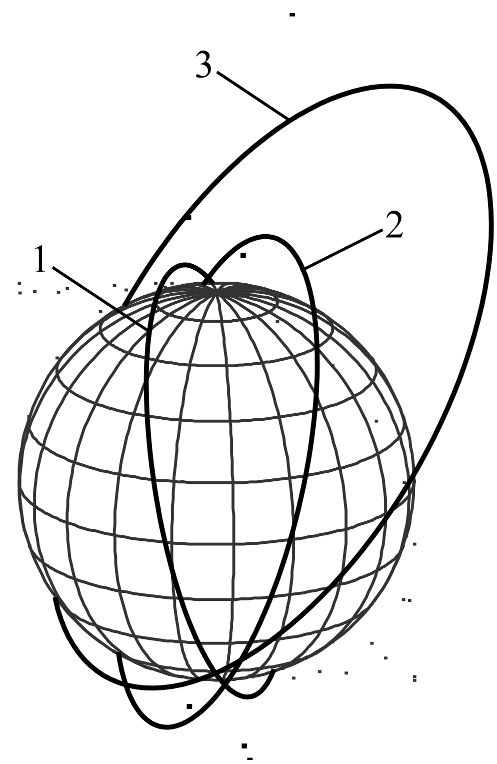

Figure 1. The mutual arrangement of multi-satellite group orbits. The numbers mark the orbits in the order presented in the above text.

3 Concept of multi-satellite space experiment for space hazard monitoring

Within the framework of the Universat-SOCRAT project several small spacecraft should be launched on specially selected orbits. In the minimal version, the group of satellites should consist of three spacecraft (Panasyuk *et al.*, 2015). One spacecraft of medium mass (small satellite) should be launched on a low solar-synchronous orbit with a height of about 500–650 km and an inclination of 97–98°. Two other satellites of lower mass (micro satellites) should be launched on an orbit close to circular with a height of about 1400–1500 km and an inclination of ~80° and on an elliptical orbit with an apogee of about 8000 km, a perigee of about 600–700 km and an inclination of 63.4°. The mutual arrangement of the orbits is shown in Figure 1.

The small satellite payload should include (Panasyuk *et al.*, 2017) instruments for monitoring of space radiation, a set of instruments for optical monitoring of hazardous objects, a set of instruments for studying of atmospheric phenomena in the optical range, a set of instruments for monitoring in gamma- range, and special unit for data collection. The payload should also include three-component magnetometer. The payload of each micro satellite should include instruments for space radiation monitoring, a compact gamma spectrometer, a wide field of view optical camera, an ultraviolet detector and an electronics unit for data collection.

4 Experience of wide field camera use for monitor observations on board Lomonosov satellite

The Lomonosov spacecraft payload includes two identical units of wide-field optical cameras SHOK-1 and SHOK-2 (see Figure 2). Both units are connected directly to the central electronics unit BI, through which communication is carried out with the satellite on-board systems and other payload instruments. These cameras are of the same type, that are used in the ground robotic telescopes network MASTER to search for optical transients, including cosmic gamma ray bursts (GRB) (Lipunov *et al.*, 2010).

Each camera is made from the Nikkor lens and CCD Kodak KAI-11002. The cameras have a sensitivity of 9–10^m of stellar magnitude. Each camera is directed in such a way that its field of view is within the field of view of one of the gamma ray detectors also installed on Lomonosov satellite. Continuous recording of images with a time resolution

Figure 2. Wide field optical camera units from Lomonosov satellite scientific payload.

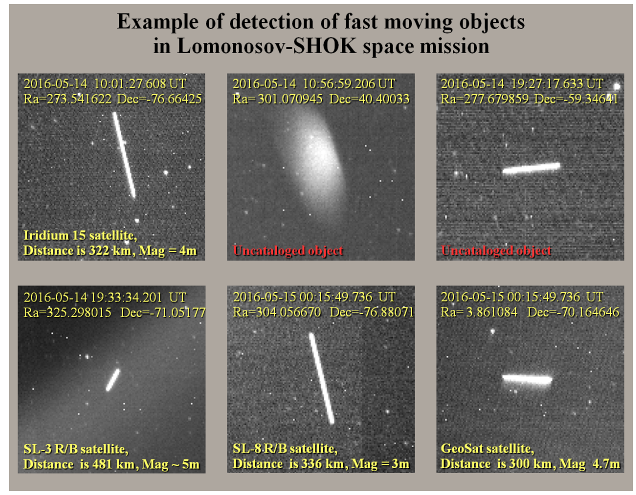

Figure 3. Examples of identification of fast moving objects with the use of wide field cameras on-board Lomonosov satellite.

of 0.2 s is realized in this instrument. In the case of GRB alert, *i.e.* trigger from Lomonosov gamma ray burst monitor BDRG (Svertilov et al., submitted to Space Science Reviews) or from the UBAT X-ray telescope of UFFO instrument (Park et al., submitted to Space Science Reviews), data are fixed for 1 min before and 2 min after the trigger. Due to the alignment with the BDRG gamma ray detectors, this makes it possible to detect GRB by both instruments simultaneously and obtain an optical image both directly at the time and before the burst. Also, the selected time intervals of data fixation overlap typical times between the precursor and the burst.

It is also possible to fix images from wide field cameras by a trigger from the Earth, *i.e.* by the bursts, fixed by the global GCN network. Cameras can also perform observations in the mode of searching for optical transients by their own trigger. In this case, each subsequent image is automatically compared with the previous one and if the brightness changes or a new object appears, then the camera’s field of view is fixed. This mode can be used not only for observations of astrophysical phenomena such as supernovae, nova etc., but also for studying of space debris, meteor hazard, etc.. Examples of identification of fast moving objects with the use of wide field cameras on the Lomonosov satellite are given in Figure 3.

5 Space debris and asteroid monitoring in the Universat-SOCRAT project

The successful launch of the first in the history of Russia of wide-field robotic optical system MASTER-SHOK on April 28, 2016 as part of the space observatory Lomonosov payload confirmed the correctness of the chosen principles of space monitoring and image automatic processing.

The set of instruments for optical monitoring of hazardous objects on-board small satellite should consist of two wide-field optical cameras (mini-telescopes) and a scanning telescope with an input window diameter of 120–250 mm and an operating field of view of up to 100 square degrees. Such a wide field cameras successfully passed the flight tests on-board the Lomonosov satellite (Lipunov et al., submitted to Space Science Reviews). Parameters of wide-field cameras are: field of view ~20×40°, 12 megapixels, CCD matrix 24×36 mm. Data from each camera is analyzed by a processor that provides a detailed recording of the video (5 frames per second) triggered by a gamma detector or other instrument detected GRB. Processor also samples video fragments related to spacecraft, space debris, asteroids and other objects. Successful implementation of observations means the necessity of orientation stabilizing for the exposure time up to 3 minutes with an accuracy of at least 5” relative to the fixed stars and knowledge of the telescope orientation at the time of the exposure beginning not worse than 60’. Wide field optical cameras should be also included in the micro satellite payload.

The Universat-SOCRAT multi satellites should provide monitoring observations in the real time. For this purpose it is proposed to use other spacecrafts (for example, spacecraft of the Globalstar or Gonetz system, or telecommunication satellites in the geostationary orbit). Thus, a mini-observatory located on a small spacecraft will allow a round-the-clock all sky monitor up to 20^m. The system will discover automatically dangerous asteroids, report to ground robots of M.V. Lomonosov Moscow State University Global System MASTER and automatic systems of the Center for the Study of Small Planets of the International Astronomical Union.

As a ground support for the MASTER-Cosmos space complex, the Global Network of Telescopes-Robots MASTER will be used (Lipunov *et al.*, 2010; Kornilov *et al.*, 2012). It is a modern system of the latest generation of astronomical robotic telescopes with the capabilities of a fully autonomous or remote mode of outer space scanning. Now there are 8 double telescopes-robots located on 5 continents and islands. A total of 14 tubes are involved, which provide the world's fastest sky survey to $19–21^m$ on fixed objects.

The unique software of MASTER detects and determines in real time the parameters of the moving objects in the Solar system. It allows to get full information about all objects in each image in 1–2 minutes after reading from the CCD camera, including identification of moving objects and determination parameters of their motion. As a result, potentially dangerous asteroids 2015 UM67, 2014 UR116, 2013 UG1, 2013 SW24, 2014 EL45, 1998 SU4, 2011 QG21 and comets C2015 K1 (MASTER) and C2015 G2 (MASTER) are opened automatically to 2016.

Physical and technical parameters of MASTER-Cosmos system are presented in the Table 1.

The MASTER-Cosmos system is able to detect in real time, that is, during the time of image obtaining, all uncataloged objects to the stellar magnitude, depending on the angular velocity of object motion. Corresponding values are presented in the Table 2.

Table 1. Physical and technical parameters of MASTER-Cosmos system.

type of optical system	mirror-lens (catadioptric)
aperture, mm	120–250
focusing distance, mm	330
field of view	9°
field of view linear size, mm	
90%	52
80%	60
Spectral sensitivity, mcm	0.4–0.9
focus length, mm	59
length of optical system, mm	300
mass, kg	10

Table 2. Sensitivity of MASTER-Cosmos system.

Type of object	Detectable stellar magnitude
unmoving objects	up to 20^m
objects with velocity about 120”/h (typical velocity of asteroids and high-apogee satellites and its fragments)	up to 19^m
objects with velocity <1000”/h (potentially dangerous asteroids)	up to 18^m

It follows from the foregoing that a cosmic body about 50 meters in size can be detected at a flight time of 3–7 days. The MASTER Cosmos system provides detection, automatic capture and tracking of such objects. By this, the accuracy of coordinate determining in one dimension is better than 2.5” (when processing in real time).

6 Conclusion

The successful realization of the project will make it possible for the first time in the world to create a prototype of a space system for monitoring and helping to prevent space hazards for both ongoing and planned space missions, including high-altitude atmospheric aircraft.

During the project realization, the following tasks should be solved:

– real-time estimation radiation environment in near-Earth space for evaluation of the radiation risks of space missions and the producing of alert signals for decision accept on their control;
– verification of modern computational models of radiation fields in the near-Earth space;
– real-time control of potentially dangerous objects of natural and technogenic origin in the near-Earth space;
– control of electromagnetic transients in the upper Earth atmosphere and space (GRBs, Solar flares).

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