MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES

SODA: a system to detect daytime asteroids of the "Milky way" project

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Abstract. The "Milky Way" space safety program is under development in Russia. A part of the program implies the launch of a special spacecraft aimed to detect decameter asteroids coming from the day sky (from the sunward hemisphere) as well as to predict space weather and monitor the Sun's activity. The spacecraft will be launched to the Sun–Earth L1 point. The payload SODA (System for Observation of Daytime Asteroids) is under development at INASAN. The SODA concept is based on the results of the previous, conceptual, phase of the project. We present a general outline of SODA and give some new features in more detail. IKI RAS is responsible for the second part of the spacecraft payload related to space weather and solar activity.

Keywords: telescopes; space vehicles: instruments; asteroids: general; Sun: solar-terrestrial relations

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1 Introduction

In recent years Roscosmos has been developing a new Russian system of ground-based telescopes and satellites called “Milky Way.” It is designed to ensure the safety of space activities in the near-Earth space.[1] The “Milky Way” system is going to be important for monitoring and warning about dangerous situations in the outer space near Earth and focuses on several problems: space debris, space weather, and asteroid hazard. The implementation of this project will help strengthen scientific potential in many fields, make more accurate forecasts, and respond to potential threats in space and from space.

A part of the program implies the launch of a dedicated spacecraft to the Sun–Earth L1 point with two scientific payloads.

The first payload, SODA (System for Observation of Daytime Asteroids), is aimed at detecting decameter asteroids approaching Earth from the daytime sky directions. It is now being developed at the Institute of Astronomy of RAS (INASAN) based on the results of the conceptual phase of the project.

The second payload concerns the observations of the Sun at wavelengths from X-rays to the infrared (IR) light, magnetic field measurements, and particle detection. The payload is under development at the Space Research Institute of RAS (IKI RAS).

2 Payload for detecting daytime asteroids

The asteroid hazard poses a threat not only from the large ($\geq$ 100 m) but also from the relatively small decameter ($\geq$ 10 m) bodies. Such small bodies can be systematically detected only in the near-Earth space (several mln km). The rate of the collisions with Earth of the bodies with a size of 1 m is 1 event per month, for the 5 m bodies it is once a year, and once every 10–15 years for the 10 m asteroids. Almost half of these objects comes from the daytime sky. Neither ground-based telescopes nor telescopes at low Earth and geosynchronous orbits are capable of observing such daytime bodies.

Shustov et al. (2015) have shown that the implementation of a system for close detection of asteroids arriving from the daytime sky requires the use of a space-based system. According to the SODA concept (Shugarov et al. 2018, 2021; Shugarov & Shustov 2022), several optical telescopes are placed in the vicinity of the Sun–Earth libration point L1. SODA is going to be the first system in the world to detect most of the 10-m class daytime asteroids in real time. It will provide the Russian Federation with exclusive access (currently there are no existing analogs) to a very significant

[1] URL:https://tass.com/science/1792063?ysclid=lz5maokqlw391262954

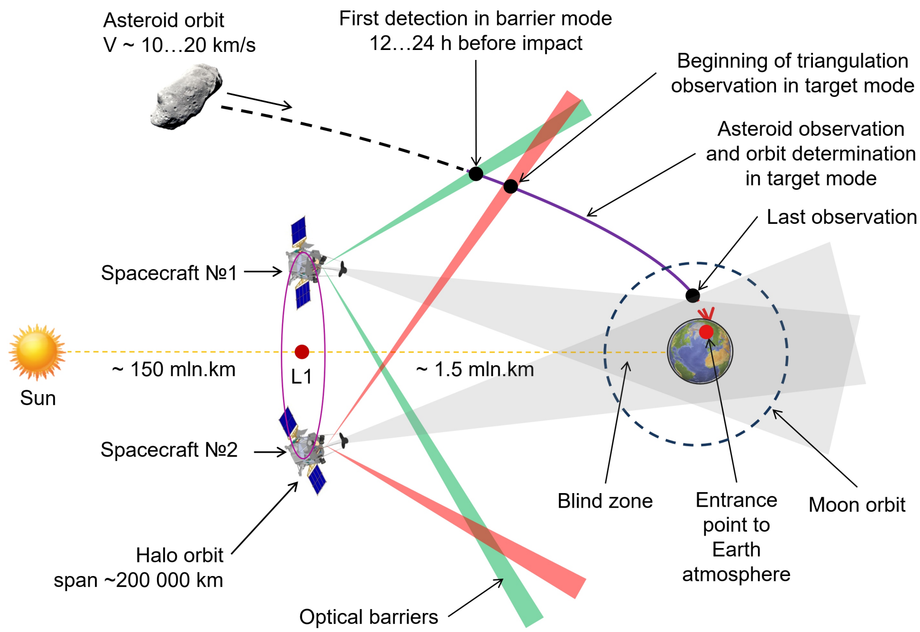

Fig. 1. SODA scheme of operation at the L1 point of the Sun-Earth system.

share (up to 50%) of information about dangerous asteroids that might collide with or fly near Earth in the coming decades.

SODA has a possible additional useful outcome. The probability that an asteroid collides with a spacecraft in the near-Earth space is extremely low; however, many small asteroids are often formed as a result of a collision of larger asteroids. Therefore, they may have a tail of small unobservable debris, since collisions always produce many small fragments. When such an asteroid with a tail crosses the near-Earth space, we may preliminary state that the probability of damage to spacecraft due to the collisions with small particles of the asteroid's tail is subject to study and it may not be negligible.

In Fig. 1 the general scheme of the SODA operation for the two spacecraft option is shown. Each spacecraft is going to be equipped with three telescopes to provide the required survey efficiency. Each telescope will observe a part (slightly above 120°) of the conical barrier around the Earth every 3 minutes. Both the target mode and the barrier detection mode can by implemented with the same telescope using a fast repointing pre-aperture mirror.

An asteroid moving from the Sun crosses the optical barrier approximately one day before its closest approach to Earth. For a typical asteroid it takes about 30 minutes to cross the barrier. This means that an asteroid is going to be observed about

8 times while crossing the barrier. The data will be transmitted to the ground center, where a preliminary orbit is to be calculated. This is sufficient to classify the object as dangerous or not. If the asteroid is classified as an object of special interest, the ground center sends a command to the SODA payload to observe the object in the target mode every 3 minutes. The last observation can be done at an angular distance between the asteroid and Earth of $\sim 5°$.

The spacecraft is based on the proven Russian satellite bus Navigator, which has successfully been operating at L2 for the Spektr-RG mission. It is going to be put into orbit around L1 by a medium-class launch vehicle Soyuz-2. The total payload mass is estimated as 500 kg, and the spacecraft should not exceed 2000 kg. The lifetime of the spacecraft should be at least 5 years.

A permanent low-speed radio channel in the X-band will be used to rapidly transmit the most critical (selected) scientific data to the Ground Center. This requires placing receiving stations at the Earth eastern and western hemispheres. A high-speed X-band radio communication channel will be installed to transmit a complete set of scientific data to the Ground Center when possible.

For asteroids on collision orbits, SODA provides the issuance of a 10-hour warning (on average) before the impact as well as the asteroid entry point into the Earth atmosphere with an accuracy of 10–200 km. In the most complicated cases the system guarantees a warning no later than 4 hours before the impact. This is not enough for mitigation actions such as evacuation of the population. However, in the coming decades evacuation is not necessary and may even be harmful for most impactors of 5–20 m in size. On average, the expected number of fatalities from the 5–20 m sized asteroids is not very high. A hasty evacuation may lead to greater losses than the absence of evacuation but with civil defense actions.

The warning time of 10 hours provided by SODA is sufficient for:

- emergent call to all services (police, ambulance, etc.) to be in full readiness;
- putting infrastructure facilities to safe mode;
- early completion and cancellation of public events;
- notifying the civilians about the need to comply with certain civil defense measures, if such notification is deemed appropriate.

Due to the high completeness of the detection of daytime asteroids flying from the Sun, in coming decades SODA is going to provide almost sufficient information about sunward asteroids that pose a real threat. The coordinated work of all state departments and municipal services will ensure significant reduction of the consequences of an asteroid impact on Earth.

3 Payload for monitoring the solar wind and the Sun

The heliophysical situation, e.g., the state of solar activity and near-Earth interplanetary environment, is determined primarily by the processes occurring on the Sun. Monitoring tasks include providing regular information on both the current heliophysical situation and the heliophysical factors that allow reliable predictions of its condition. The regular remote monitoring of the Sun disk and corona in various spectral ranges (optical, UV, X-ray, IR) as well as local observations of the properties of the interplanetary medium (solar wind) directly affecting the Earth are required.

The necessary observations of the Sun include the short-wave solar radiation from the full disk, the solar magnetic field both on the entire disk and in individual active regions, images of the photosphere, chromosphere, and corona in a number of characteristic spectral lines. Based on this information, a forecast of solar activity would be made. The monitoring of the interplanetary environment at the Sun–Earth libration point L1 would allow us to determine the specific characteristics of the solar wind and interplanetary magnetic field that directly affect the Earth and quantify their effect on the ionosphere and magnetosphere, including the strength of a magnetic storm.

The space segment of the Sun and interplanetary environment monitoring is key to successful prediction of the heliogeophysical situation. Currently, the space weather forecast in Russia relies mainly (and completely in terms of the monitoring data of the interplanetary environment) on the data from foreign spacecraft; however, access to this data may be restricted at any time. In this regard, the development of Russian spacecraft with appropriate instruments for space weather and Sun monitoring is of particular importance.

The optimal location for the instrumental complex of solar wind and Sun monitoring is the vicinity of the libration point L1. For space weather monitoring this type of orbit is the only one, since it provides continuous observations of the interplanetary space at a fixed distance from the Sun, which is impossible on other types of orbits. In the case of solar monitoring this option is also preferable, since it ensures uninterrupted measurements, unlike near-Earth orbits.

Currently, IKI RAS selects scientific instruments for this project. Space weather monitoring requires a spacecraft to be close to the Sun–Earth line, a halo orbit with a span (radius) of 200 000 km has been chosen. Such an orbit is suitable for the asteroid detection payload, since a small span of the orbit allows it to minimize the amount of missing objects flying very close to the spacecraft, as in the Solar system there are practically no asteroids with highly eccentric orbits. A spacecraft with two payloads would allow us to solve steadily and in parallel both the asteroid hazard and space weather forecast problems for about 10 years.

4 Possible international cooperation

The efficiency of asteroid monitoring at L1 can be significantly increased if two spacecraft operate simultaneously. The triangulation tracking mode provides an increase in the accuracy of determining the impact region coordinates on Earth by 1–2 orders of magnitude. Also it would improve the detection completeness due to cross-compensation of the blind zones of each spacecraft and provide better redundancy.

For the Russian “Mily Way” program, the plan is to build one spacecraft. Discussions to build another similar spacecraft to operate at L1 are underway with the Chinese partners. The international coordination with ground based telescopes and radio radars would allow additional observations of the dangerous asteroids discovered by SODA.

5 Summary

The Chelyabinsk event has changed our priorities regarding the asteroid and comet hazard. We understand that it is necessary to create special space-based facilities to detect decameter-size bodies coming from the sunward hemisphere (daytime sky). A combination of the space-based (SODA) and ground-based projects is a proper way to provide a realistic real-time warning system against the decameter-size impactors.

The national “Milky Way” space safety program is under development in Russia. The spacecraft orbiting at L1 with a span of 200 000 km would allow us to solve steadily and in parallel both the asteroid hazard and space weather forecast problems for about 10 years. International collaboration is welcome for both the space and ground segments of the “Milky Way” space safety program.

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