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System of Observation of Day-time Asteroids (SODA)

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In 2022 the national Russian "Milky Way" space safety program began, one of its topics is the asteroid-hazard problem. The "Milky Way - L1" project will solve two different scientific problems, both related to the Earth safety - detection of dangerous asteroids and prediction of space weather by monitoring the Sun activity and solar wind.
The SODA (System of Observation of Day-time Asteroids) payload goal is to detect “almost all” 10 m class sunward asteroids and ensure a warning time of 10 hours.
The main idea of the mission is to place one or two spacecraft (SC) equipped with ~30 cm aperture wide field telescopes into the vicinity of L1 point of the Earth-Sun system. Observations will be performed in a barrier mode. A computer controlled fast slewing pre-aperture flat mirror ensures very flexible and fast changes of observational modes.
The necessity of collaboration with night-time observational systems that are focused on the detection of NEOs in the near Earth space is emphasized.

Introduction

As it was demonstrated by the Chelyabinsk event on February 15, 2013, collisions of small (decameter-class) Near-Earth objects (NEOs) with the Earth pose a danger to inhabitants of our planet. These bodies are faint and can only be systematically detected in the near-Earth space. Moreover, half of these bodies approach the Earth from the day-time sky and can only be detected by special space-borne facilities.

A modern paradigm of the asteroid-hazard problem should address the detection of bodies with a size from 10 m, coming from all directions, including the day time hemisphere.

In 2022 the national Russian "Milky Way" space safety program began, one of its topics is the asteroid-hazard problem. One aspect of this program is addressing the asteroid problem, including 10 m class asteroids, according to the suggested definition of the asteroid-hazard problem. "Milky Way" has two segments regarding the problem under discussion:

Russian "Milky Way" space safety program

In the promising Russian Milky Way national program, two projects are devoted to the problem of detecting dangerous asteroids from 10 m in size:

- a ground-based network of wide-field optical telescopes searching for asteroids on the nighttime hemisphere;
- a space-based facility consisting of a spacecraft located in the vicinity of the SEL1 Lagrange point searching for day-time asteroids that can’t be observed by ground or with the near-Earth space telescopes.

We refer to this project as "Milky Way-L1" project.

The spacecraft (SC) for "Milky Way-L1" is designed by Lavochkin Association (LA). The "Milky Way-L1" payload is divided in two parts. The first payload named SODA (System of Observation of Day-time Asteroids) is responsible for detecting 10 m class asteroids coming from the Sun. It has been under development at the Institute of Astronomy RAS (INASAN). The second payload is responsible for observations of the Sun in different wavelengths from X-ray to IR, to measure the magnetic field and detect particles. The payload has been under development at the Space Research Institute of RAS

Detection zones

The size and form of detection zones for 10 m NEOs with a 30 cm space telescope located at SEL1 is illustrated in Figure 2. Boundaries zones are outlined by lines with given signal-to-noise ratios (SNR).

We propose other countries to consider building a second similar spacecraft to operate at SEL1 to utilize the triangulation technique advantages in cooperation with SODA.

The synergy of ground-based and space-born telescopes in the discovery of decameter class asteroids in near-Earth space seems to be very prospective [3]. The combined detection zones for 10 m NEO with a ground-based telescope (19m limiting magnitude) and SODA are shown in Figure 3. The SNR is shown by colored isophotes (green and blue) in 3 unit increments. The blue and pink dotted curves show SNR = 9 (quite reliable detection) for ground-based and SODA telescopes respectively.

The plot demonstrates that objects approaching the Earth along the Earth orbit have the shortest detecting distance (0.5 million km) and therefore the shortest warning time. Such objects are difficult to observe with ground-based telescopes because of the unfavorable phase angle and necessity to observe close to the horizon. For SODA the objects along the Earth orbit are close to the detection distance limit (~2 million km) of 10 m size NEOs for the 30 cm telescope.

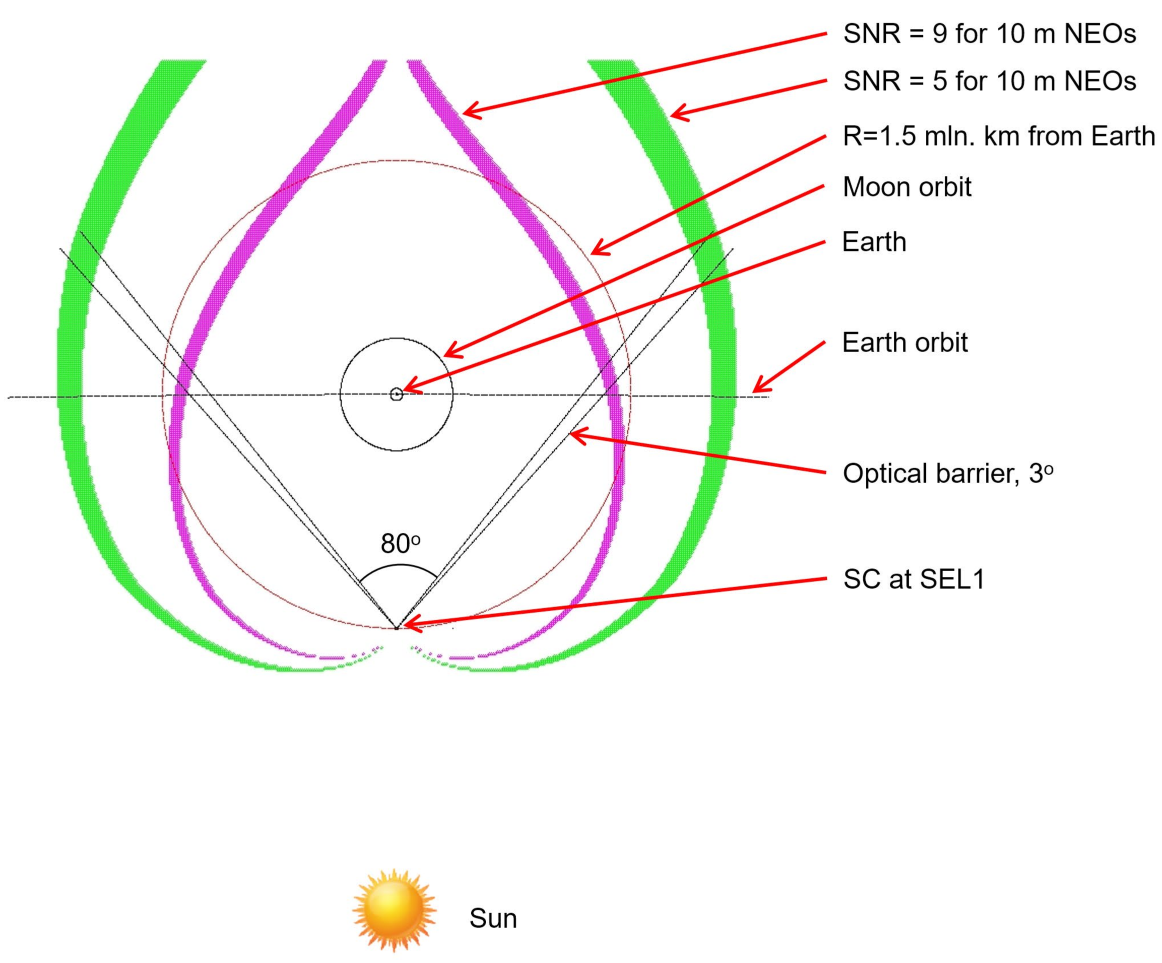

Figure 2. Detection zones of 10 m bodies for space-based SODA project at SEL1.

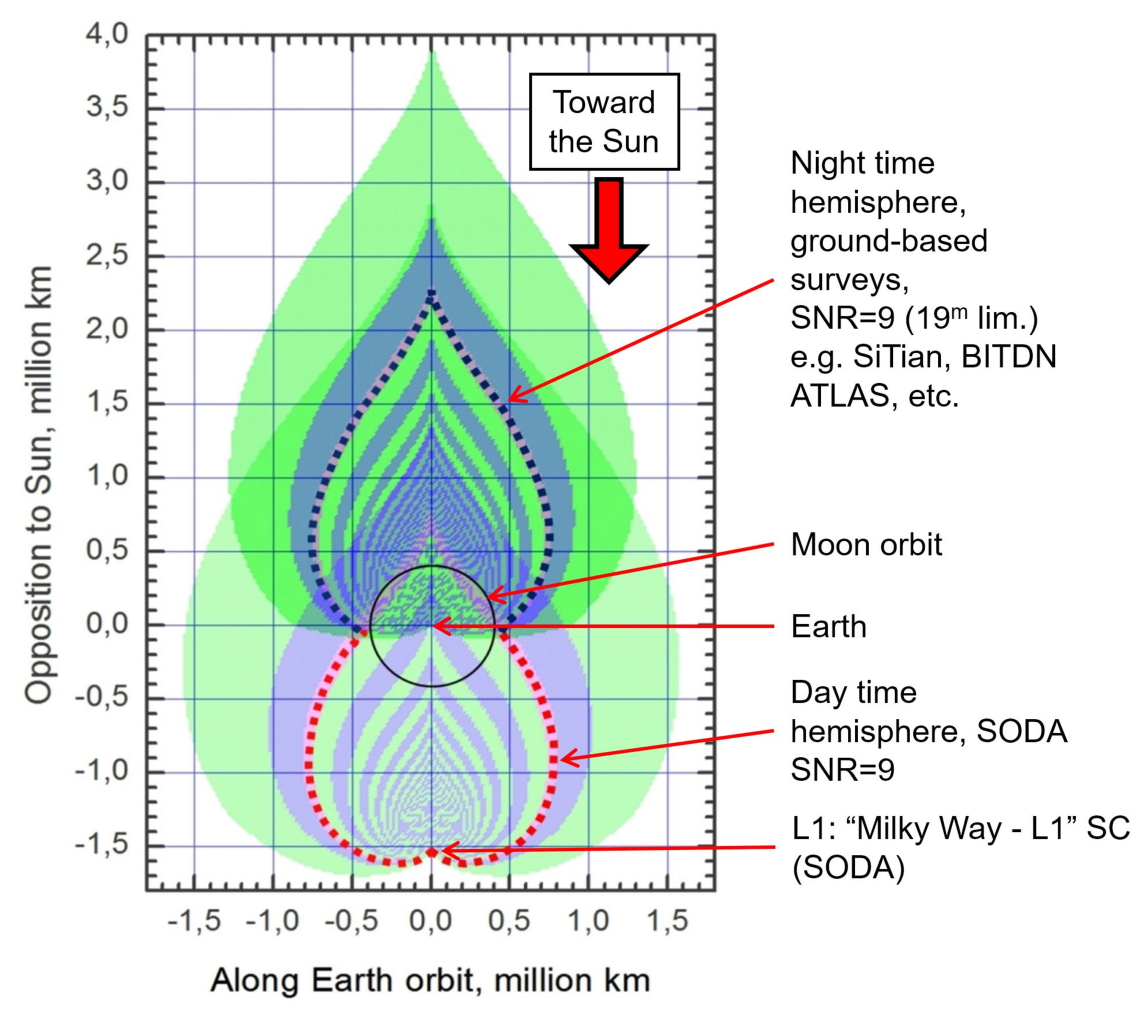

Figure 3. Detection zones of 10 m bodies with a ground-based telescope (19m limited mag.) and space-based SODA SC at SEL1.

SODA payload

The main practical goal of the SODA payload is to provide a warning of “almost all” sunward dangerous asteroids. The scientific goals are to experimentally validate existing models of small bodies in the Solar System and to search for a correlation between close flybys of asteroids near the Earth and meteor shower events.

The SODA payload is based on the results of the SODA conceptual design [1,2]. In Figure 1 the general scheme of observation for the two SC option is shown. The scientific payload consists of three or four wide field of view telescopes with a 30 cm aperture that operates in visible light. In the four telescope configuration, the cadence of a survey of a conical barrier around the Earth (Fig. 1) is 30 minutes (4 visits, each 9 s exposure frame is doubled for cosmic rays rejection).

Asteroid detection is carried out using a barrier technique and dangerous objects are tracked until they approach the Earth. For asteroids on collision orbits, the SODA system provides a 10-hour warning (on average) before impact as well as a prediction of the entry point of the asteroid into Earth's atmosphere with an accuracy of 10…200 km in the two SC configuration. In a single SC configuration, the accuracy along the asteroid’s orbit is much poorer.

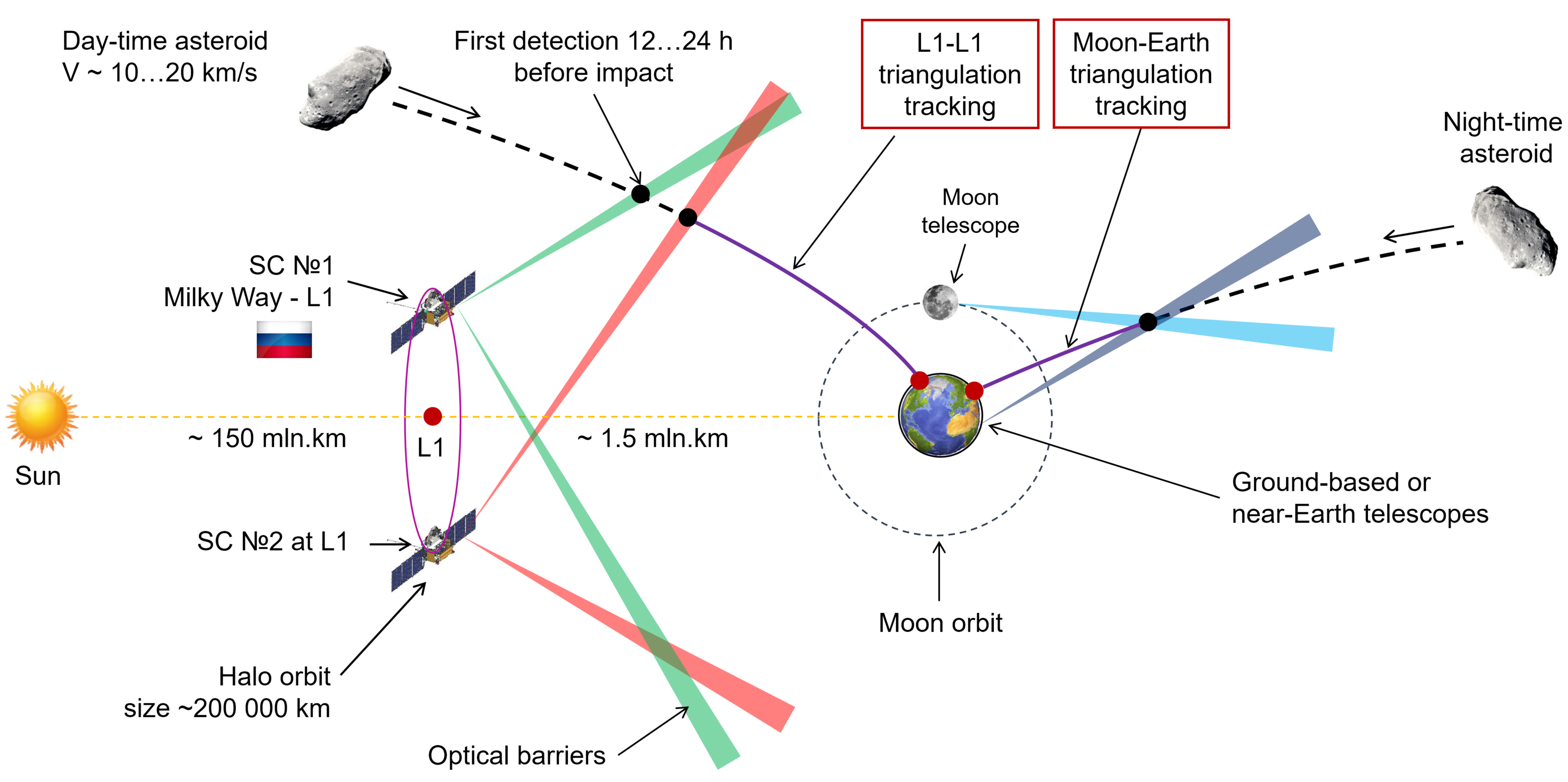

Figure 1. Scheme of operation to use triangulation mode in near-Earth space.

Triangulation tracking of NEO in the near-Earth Space

Orbit accuracy determination of NEOs in the near-Earth space could be improved significantly (up to 1-2 orders of magnitude) by using the triangulation tracking technique. This option requires two or more SC. Besides better orbit determination accuracy it improves the completeness of detection due to cross-compensation of blind zones of each SC (Fig. 1) and provides better system redundancy.

A small telescope on the Moon proposed as part of the future International Lunar Research Station (ILRS) will allow triangulation tracking mode on the night-time hemisphere in cooperation with ground-based surveys (Fig. 1).

Conclusion

We believe that the combination of space-based (SODA) and ground-based projects, as well as international cooperation both in space and on the ground, is a proper way to build an efficient and realistic warning system against small decameter-size impactors.

In the coming decades, 10 m class asteroids pose the highest probability of collision with Earth. Due to the very high completeness of day-time asteroid detection, SODA will provide almost complete information on sunward asteroids that pose a real threat in a human-life time scale (decades).

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SODA and another missions at L1

It is interesting to compare SODA with other prospective telescopes for NEO detection and monitoring from the libration point SEL1.

The NEO Surveyor (NASA) project attracts the attention of many researchers since this powerful observatory is scheduled for launch soon (2027). The mission is designed to discover and characterize near-Earth asteroids and comets with an IR telescope [4]. The major goal of NEO Surveyor is to complete the catalog of large >140 m NEOs operating together with LSST and other ground telescopes within 15 years. Additionally it will improve discovery completeness of NEOs larger than 50 m. The cadence of the survey is about 1 day, which is too long if we have to detect all NEOs crossing the boundary of near-Earth space from the daytime sky, as they appear in near-Earth space for only a very short time (a few days at maximum).

The cadence of the survey for SODA is short (4 visits in 30 minutes). SODA is properly aimed to discover >90 % of 10 m class asteroids in the near-Earth space. We may state that NEO Surveyor and SODA space missions at SEL1 complement each other and are not competitors.

The cost of the NEO Surveyor mission is about 1 billion USD. The cost of the SODA project is expected to be much lower, while the project still keeps very significant scientific and practical outcomes for the asteroid hazardous problem concerning day-time asteroids.

ESA’s planned NEOMIR mission will be located at SEL1, the mission goal is to provide an early warning for >20 m asteroids [5]. NEOMIR will monitor objects in a ring-like region of 30-70 deg around the Sun which is impossible to observe from the ground. NEOMIR will detect the heat emitted by asteroids themselves, which isn’t drowned out by sunlight.

Based on the 2024 NEORMIR project presentation, the telescope has FoV of 1.7x7 deg and a spectral range of 6-10 μm. The NEOMIR telescope survey will allow monitoring of the ring area with a cadence of 11-17h (4 visits). Such a cadence is well suitable to detect asteroids at longer distances similar to NEO Surveyor, but in the region much closer to the Sun. In this scenario, NEOMIR will complement NEO Surveyor.

The weak point of NEOMIR in comparison to SODA is that it will search for new objects only within the conical ring around the Sun (30-70 deg), while SODA will detect nearly all bodies coming from the day-time hemisphere (2 π sr) toward the Earth. Also, the cadence of NEOMIR is about 25 times slower than SODA, which may result in missing some bodies. Finally, NEOMIR is not fully compliant with our new paradigm, that the asteroid-hazard problem should be addressed to all bodies from 10 m in size.

The price of the NEOMIR mission seems to be similar to NEO Surveyor (1 billion USD), i.e. much more expensive than SODA.

As a result, we may conclude, that SODA and NEOMIR will complement each other. For some fraction of decameter class objects (>20 m) coming from the day-time hemisphere, NEOMIR will provide a longer warning time than SODA, while SODA will provide very high (>90 %) detection efficiency for all bodies larger than 10 m, coming from the daytime hemisphere, but with a shorter warning time of less than 1 day.