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STERNEO: SIMULTANEOUS NEAR-EARTH OBJECT OBSERVATIONS BY LAGRANGE POINT SATELLITES

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Extended Abstract—

The number of detected Near-Earth Objects (NEOs) is steadily increasing: by April 2021 the cumulative total of NEOs is exceeding more than 25,000 objects. However, the majority of discovered objects are small with diameters below 140 m and hence absolute magnitudes above H=23 mag. For such small objects it proves challenging to obtain reliable follow-up observations and orbital elements after their initial discovery. The relevance of the early high-precision orbit determination of an NEO, or even a potentially hazardous asteroid (PHA), is evident: high-quality (low uncertainty) orbital elements are critical for simulations of the future trajectory and collision probability estimates. The better the orbit is constrained the more time we have to take counter-measures and to mitigate a predicted collision with Earth.

We propose an observational method for a space-based astrometric survey for small NEOs and PHAs, and a space mission designed to employ this method that additionally provides advanced asteroid impact hazard mitigation capabilities. The "STERNEO" system, which is an acronym for simultaneous stereoscopic NEO observations, consist of two identical spacecraft (SC) situated near the Sun–Earth Lagrange points L4 and L5. There the SC perform a long-term survey (over a time-span of a decade or longer) to detect new NEOs, while they also serve to keep track of recently discovered objects, and contribute to obtain follow-up observations to improve the orbital elements of NEOs. The simultaneous observation of an NEO by both SC, favorably in combination with ground-based facilities, is a key feature for a complete NEO orbit characterization over short periods of time. A further advantage of locating the SC near the Lagrange points is that such a configuration permits and facilitates the survey for NEOs with orbits interior to Earth's, i.e. Aten and Atira class asteroids that are difficult to observe from ground-based facilities.

Observational method

The proposed method is based on the refinement of NEO orbital elements by simultaneous measurements from two observing stations [2,3]. It determines the NEO's spatial position (its heliocentric position vector) and Earth–NEO distance by virtue of a geometric triangulation, while a second set of simultaneous observations at a different time (possibly short-arc) then determines the NEO's heliocentric velocity vector and thus the missing parameters for a complete orbital characterization.

The method's main advantage is that it is capable of producing very accurate orbital elements with minimum effort necessary by using only two simultaneous measurements from two observers. It can also be employed for quick post-detection follow-up measurements, as well as frequent orbit update measurements. Moreover, the mathematical framework presented in [2] does not make any assumptions on the locations of the SC. The space-based telescopes are neither confined to the ecliptic plane nor to even share the same orbital plane. Their location in the vicinity of the Sun–Earth Lagrange points provides dynamically favorable conditions for a long-term survey with minimized fuel constraints for maneuvering.

However, there do occur unfavorable orbital configurations, mainly (1) at near-linear alignments of the SC and target NEO, i.e. when the triangle collapses to a straight line, or (2) when the line-of-sight of one SC is temporarily obstructed by the Sun. Figure 1 shows a sketch of the observation geometry and proposed counter-measures against a potential Earth-impacting asteroid.

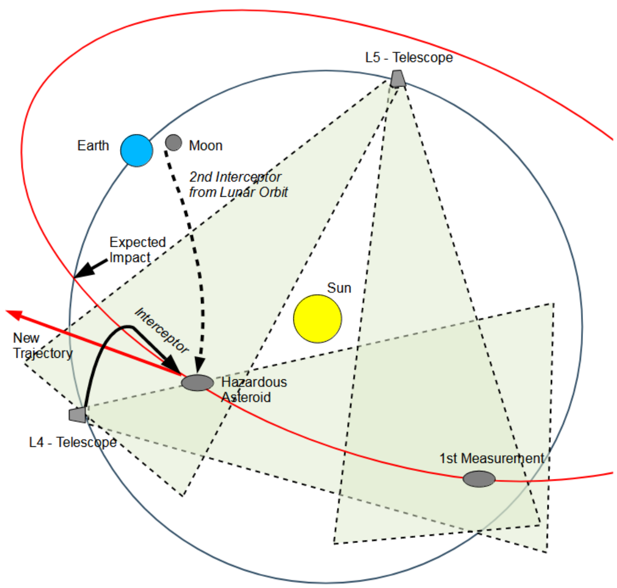

Figure 1: Concept drawing of detection and counter-measures (after [1]).

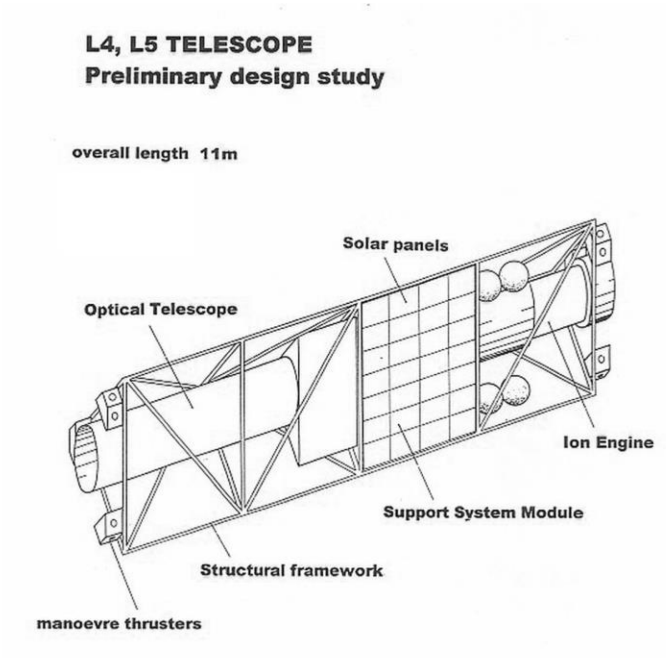

Figure 2: Preliminary telescope design (after [1]).

The telescopes will employ a one-meter class mirror to reach limit magnitudes of 21 mag or fainter for typical exposure times below one minute. The CCD sensors will operate in the wavelength range from 0.4–4 µm, such that they cover the spectral bands of interest for the main taxonomic classifications of NEOs. Figure 2 displays a preliminary telescope design. Both telescopes would be launched together as payloads, requiring a launcher with payload capacity of about 12 tons to GTO. This is feasible with an Ariane 64 launch vehicle, or alternatively with a Falcon Heavy rocket. For the transfer from Earth to the Lagrange points the telescope SC use propulsion by ion-engines.

Robotic interceptor and deflection

In addition to the SC carrying the space telescopes, a second system component consists of a plurality of Autonomous Robotic Interceptors (ARI). These SC are launched separately from the telescope components to the Sun–Earth Lagrange point L4 and/or L5, while a backup unit remains in lunar orbit. The ARI modules are able to autonomously navigate to an identified hazardous NEO, perform rendezvous and commence with deflection actions. The ARI or interceptor module consists of two main components: (1) the mothership as main instrument carrier, and (2) the Semi-Robotic Interceptor (SRI), see Figure 3.

When the ARI has approached close enough to the target asteroid, the SRI is undocked, turns around by its rotation control thrusters and will land on the asteroid's surface. Meanwhile, the mothership is orbiting the asteroid and will determine the best time for blasting the explosive charge to deflect the hazardous object. After detonation, the mothership continues to measure the new trajectory of the asteroid. This scheme is visualized in Figure 4. In case the deflection maneuver fails, a second interceptor module would be launched from Earth or lunar orbit to complete the planetary defense mission successfully.

Related Work

There is a number of existing proposed missions as well as active and completed surveys with similar goals.

The Near Earth Object Surveillance Satellite [4] (NEOSSat), a Canadian microsatellite launched in 2013, had been specifically designed to search for and track NEOs inside Earth's orbit, mainly Aten and Atira objects. This was a single satellite in a ~800 km Earth orbit.

The Twinkle space mission [5] is an upcoming ~0.5 m space telescope designed for exoplanet and solar system surveys. It is to be launched into low-Earth orbit.

Another project, termed SODA [6], is dedicated to the detection of 10 m class objects that enter near-Earth space. According to the mission design up to two SC, equipped with 0.3 m telescopes, would be placed around the Sun–Earth Lagrange point L1 to incoming NEOs.

Former contributions have also suggested the combination of ground-based observations with the use of space telescopes. One example was to exploit the capabilities of the GAIA space observatory, that is operating from the Sun–Earth L2 point, and the ground-based GAIA follow-up network [7]. Simultaneous observations with LSST and the planned Euclid space telescope (again located at L2) has been proposed [8] aimed at improving the orbits of solar system bodies.

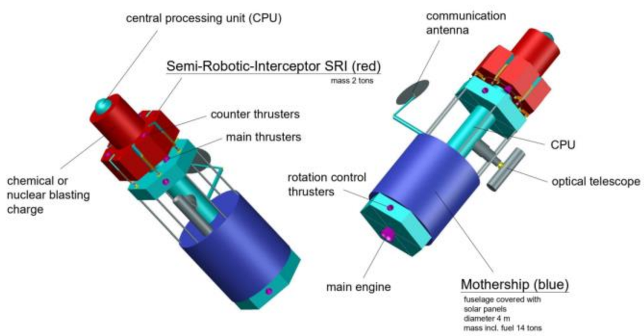

Figure 3: Concept design of ARI with mothership and detachable SRI carrying the explosive charge (after [1]).

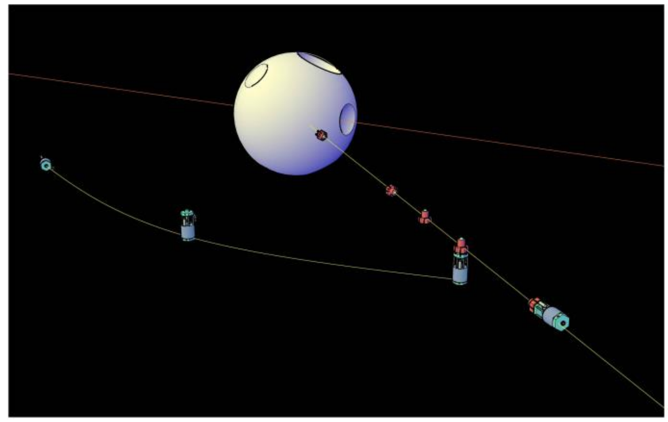

Figure 4: Concept of interceptor operating scheme (after [1]).

Conclusions

The novelty of the STERNEO mission lies in the fact, that two telescopes at the Sun–Earth Lagrange points L4/L5 are employed to provide triangulation of NEOs and to perform a long-term survey for hazardous objects., possibly in combination with ground-based facilities.

In parallel to the NEO detection and characterization capabilities, one or more Autonomous Robotic Interceptors are also deployed at the Lagrange points. These systems would be activated if a hazardous object is detected. The nearest one would independently and autonomously intercept the NEO and orbit it, while an explosive charge is detached to deflect the asteroid from its impact course.

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