EARTHGUARD-I

A Space-Based NEO Detection System

Executive Summary

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INTRODUCTION

Since early July 2002 a Phase-A study under contract to ESA has been carried out with the goal of defining a mission to search for Near Earth Objects (NEOs) which are difficult or even impossible to detect from groundbased locations. Based on long-term orbital evolution studies of known NEOs it is expected that a significant fraction of the NEO population has orbits that are mostly or completely inside the Earth's orbit - the so called Atens and Inner-Earth Objects (IEOs). Due to their short orbital periods of less than one year their encounter frequency is high, and so is their potential impact risk.

The EARTHGUARD-I study resulted in a design for a telescope, including a turntable with one degree of freedom, sensor electronics and a data processing unit, which could be accommodated on a planned spacecraft such as the BepiColombo Mercury Orbiter, or a dedicated spacecraft which would cruise to a heliocentric orbit of around 0.5 AU utilizing advanced low-thrust propulsion, either solar sailing or solar electric (ion) propulsion.

In the course of this study several observation strategies have been numerically simulated in order to estimate the efficiency of the discovery process. We studied the effects of varying 1) the solar elongation of the scan centers, 2) telescope aperture sizes, 3) different orbits and 4) different mission durations.

BACKGROUND

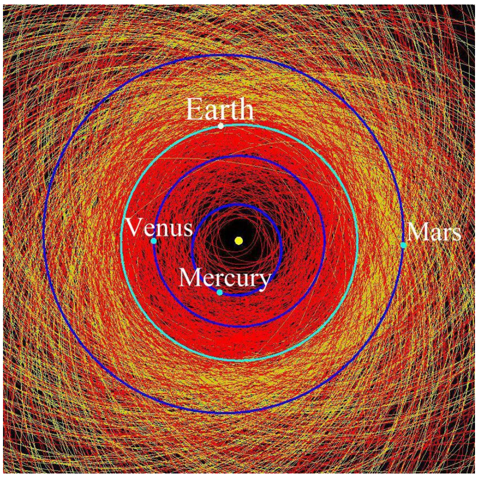
The 50 000-year old Meteor Crater in Arizona

Collisions between planets and asteroids and comets are a natural phenomenon that can be considered a relic of the planet-building phase of our Solar System some 4.5 billion years ago. We are now becoming aware that our highly networked society is vulnerable to devastation from the same phenomenon that led to the creation of the Earth in the first place. Groundbased NEO surveys are designed to maximize the discovery rate, regardless of orbital type, and spend most of their time scanning in dark-sky directions more than 90° from the Sun.

There is good theoretical evidence, however, to suggest there may be a population of asteroids in orbits that lie entirely within the Earth's orbit, the so-called "inner-Earth objects" (IEOs) or Apohele asteroids. As a result of perturbation of their orbits by the inner planets they may become Earth crossers but remain virtually undetectable from the Earth. Only with the help of a space-based search telescope observing at small angular distances from the Sun can we hope to close the gap left by the groundbased surveys and facilitate a complete and reliable assessment of the terrestrial impact hazard.

MISSION OBJECTIVES AND SCIENTIFIC REQUIREMENTS

Our major goal is to make an accurate assessment of the total population of asteroids with orbits inside that of the Earth. To date 636 NEAs of all orbital categories with diameters of 1 km or more have been discovered. Simple statistical techniques applied to the known population lead to an estimate of around 900 NEAs in this size category in total, compared to the current consensus from independent estimates of 1000 ± 200. By analogy, therefore, we anticipate that our primary goal can be met, to within an uncertainty of some 20%, if EARTHGUARD-I discovers some 50% of the total number of asteroids with orbits inside that of the Earth in this size category, together with some information on their size distribution. The corresponding scientific requirements are:



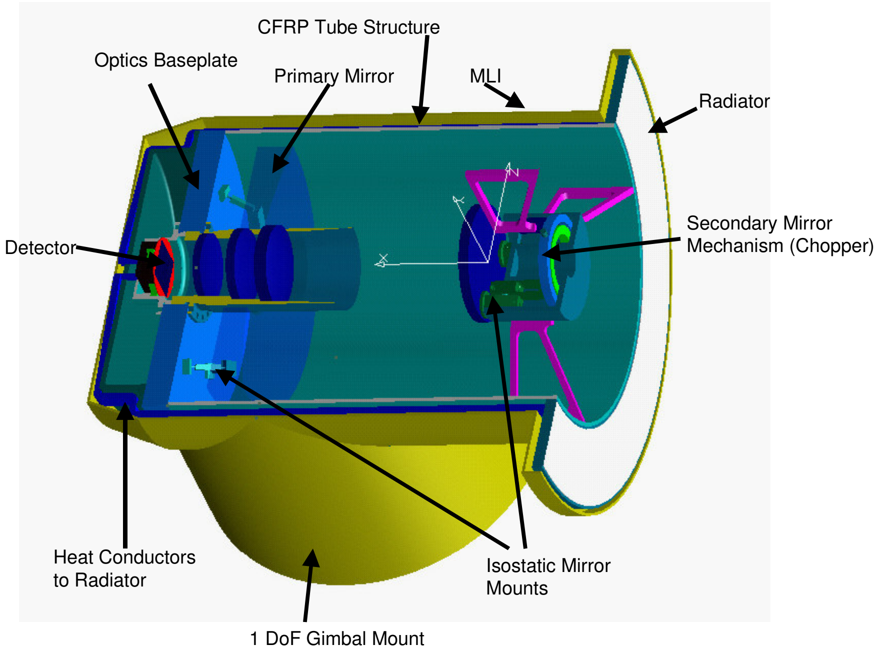
Orbits of known near-Earth asteroids. Graphic by S. Manley, from "Target Earth" by D. Steel (2000, Reader's Digest, N.Y.).

- Detect asteroids with diameters larger than about 100 m that are impossible or difficult to observe with groundbased NEA search telescopes. Requires space-based telescope with limiting V-band mag of 18.5, situated ideally in Mercury orbit, and automatic detection of moving objects.
- Determine orbital types (IEOs, Atens, Apollos, etc). Requires derivation of preliminary orbital parameters from repeated observations of object positions.
- Facilitate follow-up observations of interesting objects by other telescopes or EARTHGUARD-I itself. Requires scanning and linking strategies aimed at providing orbital parameters of sufficient accuracy to allow objects to be located again up to a few months later.
- Make crude size estimates. Requires estimation of absolute magnitude (H-value) from measured brightness and knowledge of the orbit.

TELESCOPE DESIGN

The baseline optical design of the telescope consists of an adapted Ritchey-Chretien telescope with a refractive three element field corrector. This type of design is a reliable and technically mature classical approach with the following characteristics:

- Axial symmetry of the design
- All mirror elements are axial symmetric and the optical surface has only a moderate level of asphierization
- All lens elements of the field corrector are classical spherical lenses from available radiation resistant glasses.



EARTHGUARD-I Telescope Design

The required image performance can be easily achieved by this design. In addition, the design allows the field of view to be shifted (chopping) for image stabilization during the integration time by tilting the secondary mirror.

The mechanical design consists of a CFRP tube as optical bench. Emphasis was put on studying the secondary mirror mechanism that provides a coma-free chopping functionality for optimized image performance.

The telescope is supported by a rotation stage. A rotary stage built previously for the Cosmic Dust Analyzer on the CASSINI spacecraft perfectly meets the requirement for the EARTHGUARD-I payload. Only minor mechanical and thermal modifications of this item - that has already been qualified and flown - were required to derive an overall technical baseline for the payload design. The thermal design of the telescope will allow installation on a number of different platforms. Budgets derived on the basis of this design comply with the requirements. No critical item was identified.

The design approach based on well known mature technologies and technical concepts inherits a low design and development risk in terms of schedule and performance.

The focal plane incorporates the science detector (a 2kx2k CCD) and 3 star tracking sensors. The signal from the star trackers is used to control the autonomous image stabilization system. The data processing unit, which is based on a DSP design, is responsible for the near real-time detection of light sources in the fields, for the discrimination of spurious detections and for the identification of moving-object candidates.

OBSERVATION STRATEGY AND SIMULATIONS

The survey strategy is designed to maximize the number of detections of NEOs and to ensure a reliable determination of their orbits. In the survey mode, the turntable-mounted telescope repeatedly scans strips in the sky (typically 2° wide and about 50° long) located along great circles in the vicinity of the ecliptic. By stepping the spacecraft around the Sun-pointing axis, coverage in ecliptic latitude is achieved. Further, due to the orbital motion of Mercury, the spacecraft Sun-pointing axis drifts by about 4°/day in longitude. With this strategy, a twofold advantage is pursued: 1) on average NEOs will be detected many times on subsequent scans before they leave the scanned region (or before the scanned region drifts away), therefore allowing a preliminary orbit determination. 2) The drift of the spacecraft axis ensures that the full range of longitudes is observed several times during the mission lifetime.

Moving-object candidates are identified by the on-board software by correlating the positions of all light sources in consecutive frames of the same field. Cosmic-ray hits and other artifacts are discriminated by acquiring double exposures in rapid succession. By transmitting only the co-ordinates of candidate objects (instead of the full image data), the telemetry requirements of the experiment are rather moderate, amounting to about 1 kBs.

The simulated mission scenarios were rather idealized, nevertheless the following general conclusions about survey performance can be drawn:

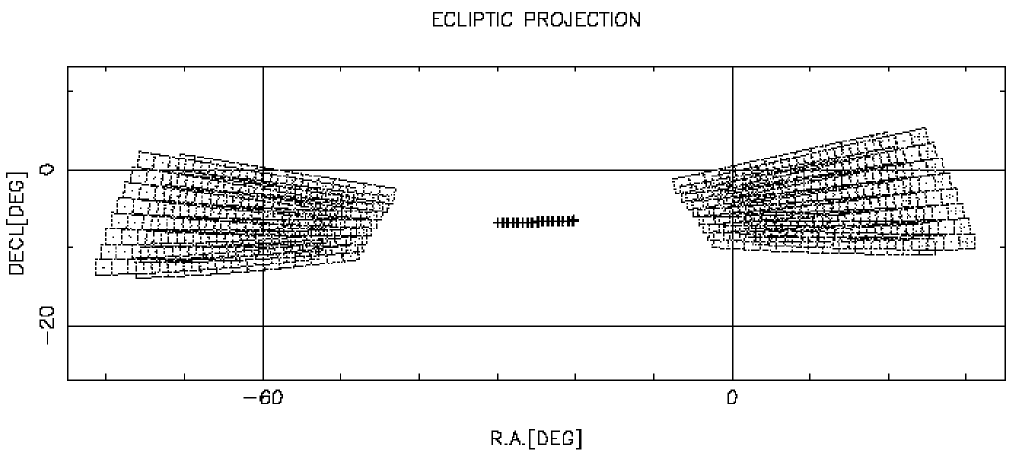
1) Observations from both orbits (Mercury and R=0.5 AU) result in a large number of discoveries for all NEO groups, and allow the determination of reliable orbits for a good fraction of them, therefore achieving the scientific goal of the experiment.

2) Increasing the telescope size (from 20 cm to 25 cm) increases the detection rate by 25%-30%.

3) Increasing the mission duration from 1 year to 3 years increases the detection count and the orbital determinations roughly by a factor 2.

4) Scans centered around 90° elongation generally appear to produce somewhat better results compared to opposition scans. It must be stressed, however, that this conclusion is bound to depend on actual mission constraints.

5) Using a small amount (e.g. 5%) of EARTHGUARD-I observation time in observatory mode for follow-up of selected objects could significantly improve the number of objects for which reliable orbits are obtained.



Simulated successive scans around the opposition (anti-Sun) point for the Mercury-orbit option. The track of the opposition point is shown in the center of the figure. The coordinate system is heliocentric, with 0 declination in the ecliptic plane. Crosses mark the beginning of the scans.

PAYLOAD SUMMARY

The total mass of the telescope, turntable (one degree-of-freedom), sensor and data processing unit is 15 kg, including a 20% contingency. The peak power is currently estimated at 22 W (20% contingency included).

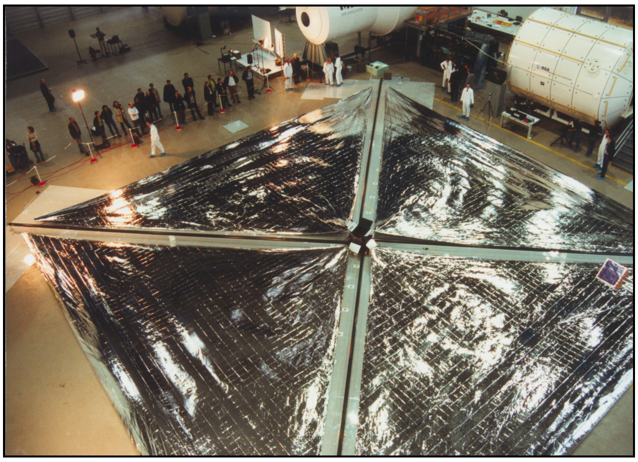
ALTERNATIVE, DEDICATED MISSION OPTIONS

Besides the piggy-back option on BepiColombo, dedicated mission scenarios were investigated in which a spacecraft is sent to a heliocentric orbit with a semimajor axis of 0.5 AU. Due to the high Δv requirement to access this orbit, two low-thrust propulsion options with a high specific impulse were investigated:

- Solar Sail Propulsion (SSP), and
- Solar Electric (Ion) Propulsion (SEP).

For both options a preliminary mass budget and mission scenario were derived. It was concluded that the mass in the case of the SEP option will exceed the capability of an ARIANE 5 piggy-back launch, whereas the solar sail option will allow a launch-mass of 350 kg to be inserted into GTO. There a kick-stage will provide the Earth escape impulse and the solar sail will be deployed in order to generate the necessary Δv for the interplanetary transfer. Solar sail technology is currently being developed by ESA and DLR in cooperation with Kayser-Threde. A fully functional, deployable ultra light-weight solar sail structure was successfully tested on ground in 1999 under simulated zero-g conditions.

A 80m x 80m solar sail structure could carry a mini-spacecraft of approximately 140 kg, leaving up to 20 kg for the science payload. This sailcraft would allow a low-thrust spiral transfer to a circular, heliocentric 0.5 AU orbit within 2.9 years. An operational lifetime of three years in the final orbit is considered to be feasible.



20m x 20m Deployable Solar Sail Structure (ESA and DLR)

CONCLUSIONS AND RECOMMENDATIONS

EARTHGUARD-I will greatly enhance our knowledge of the Near Earth Object population and potential impactors on Earth. The piggy-back option aboard BepiColombo offers a cost-effective opportunity to transport this telescope to a near-Sun orbit. This vantage point allows the detection of Earth-threatening asteroids which are difficult or even impossible to detect from the ground.

The EARTHGUARD-I telescope will strengthen ESA's and Europe's lead in the area of Near Earth Objects and the hazard they pose to Earth, and facilitate ESA's compliance with Resolution 1080 (1996) of the Council of Europe ("on the detection of asteroids and comets potentially dangerous to humankind").