NEOMIR: A SPACE-BASED INFRARED MISSION FOR NEO DETECTION, CHARACTERISATION AND EARLY WARNING

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1. INTRODUCTION

The Planetary Defence Office in European Space Agency's Space Safety Programme is addressing the "... prediction and detection of the potential impact of a Near-Earth Object (NEO)".

To be able to provide advanced warning of future or imminent impacts of asteroids or comets, the first step is to observe the sky and discover these objects. This is performed by means of so-called NEO surveys; the next step typically consists of follow-up observations, to ensure that the discoveries are not immediately lost. A third step is, in general, the physical characterisation of the discovered and confirmed NEOs, typically by spectrophotometric and/or spectroscopic observations.

ESA's Planetary Defence Office's requirement on NEO detection is to discover all asteroids of visual magnitude 21.5 mag or brighter in any given night: this is equivalent to detecting objects bigger than 40 m typically 3 weeks before they impact. To fulfil this requirement, ESA is developing the first European observatory dedicated to NEO surveying, the Flyeye telescope, whose first light is expected by the end 2023. Currently, the two main survey programmes are the US-funded Pan-STARRS and Catalina sky surveys: however, they are only able to scan about 10% of the available sky every night.

Most current and planned NEO surveys are ground-based and carried out in the visible wavelength range. However, this approach has some limitations, such as (1) weather dependency, (2) that only a portion of the night sky is visible from any given location on Earth, (3) NEOs are difficult to detect at low galactic latitudes and (4) that visible-light surveys can only determine the motion and apparent magnitude of an object, but its physical properties (such as size) can only be inferred indirectly and therefore require additional observations for characterisation.

The first two points can be overcome by having, for example, a network of telescopes deployed in various locations of the planet. However, there is an intrinsic limitation to observing at very low solar elongations, which prevents the detection of potential impactors coming from the direction of the Sun (as in the case of the Chelyabinsk bolide). Additionally, accurate assessment of the impact risk requires knowledge of the size that can only be determined by other means (e.g. infrared or radar observations).

A space-based mission working in the thermal infrared (IR) and placed at the first Sun-Earth Lagrange point (L1) would overcome most of these issues: in fact, by scanning regularly an area not easily accessible from ground or other space-based NEO surveys, it will be capable of detecting and characterising new NEOs and — in the worst case of an imminent impactor — serve as an early warning system.

In October 2021, ESA conducted at its Concurrent Design Facility (CDF hereafter) an initial study to explore the viability of an NEO Mission in the InfraRed (NEOMIR hereafter) and its costs for development and operation. In what follows we will briefly present the status of the mission and the results on simulated data obtained so far.

2. MISSION OBJECTIVES

In 2005, the U.S. congress gave the mandate to NASA to discover by 2020 90% of the asteroids larger than 140 m in diameter. As of today, it is estimated that around 40% of them have been discovered and a further 30 years are needed to achieve the above mandate. To speed up the detection rate, NASA has been studying a space-based mission to detect NEOs in the IR since the early 2010s: the NEO Surveyor mission (hereafter NEOSM).

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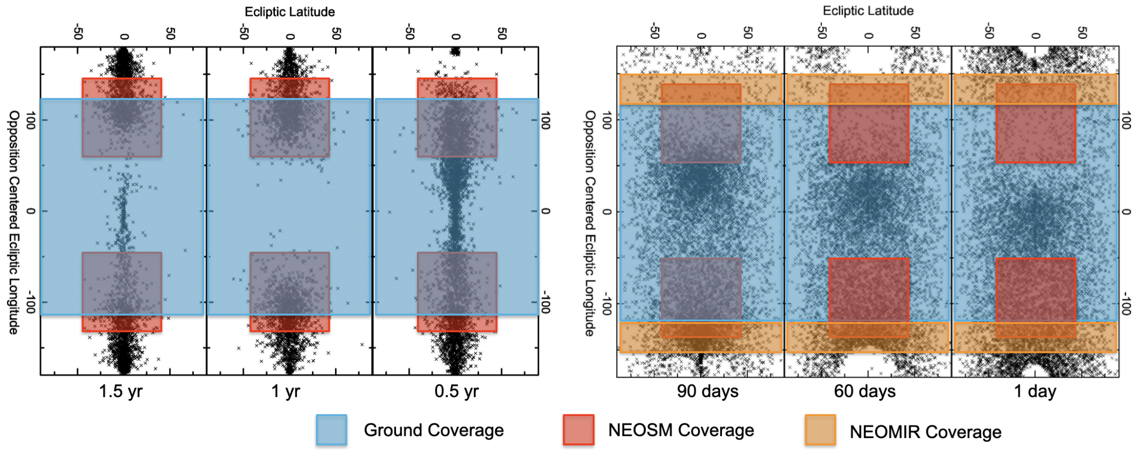

Figure 1. Simulated population of Earth impactors as a function of time to the impact date (see [2]). Coverage obtainable from ground-based surveys as well as the proposed space-based missions NEOSM and NEOMIR are overlaid.

NEOSM is currently in phase B and, if further approved, is scheduled for launch in 2028. The main mission and spacecraft design characteristics of NASA's NEOSM are reported in [1]: many of them are considered as baseline for the NEOMIR study.

The instrument performance is expected to allow NEOSM to discover NEOs larger than 140 m at as far as 1 au. The survey cadence is designed to perform self-follow-up of its detections and to reach the goal of discovering $> 90\%$ of the 140 m NEOs during the 5 years nominal mission lifetime.

NEOSM is designed with the primary goal of discovering larger NEOs while they are still far away. This is also evidenced by the plots reported in Fig. 1: these are simulations of the population of impactors from [2], i.e. asteroids on collision course with Earth, and their location as a function of time before the impact date. The plots show that the vast majority of the NEOs will be in the field of regard that NEOSM will cover six months or more before impacting the Earth. However, the situation changes when the "cloud" of impactors gets closer to Earth: many of them are at higher ecliptic latitudes, and lower solar elongation.

NEOMIR is designed with the main aim of discovering the smaller NEO population that can only be observed when the asteroids get closer to Earth, and serve as an early warning in the worst case of an impactor. This is achieved by:

1. covering a different field of regard: NEOMIR will point closer to the Sun and at all Ecliptic latitudes, where NEOSM will not observe;

2. shorter exposure times and higher cadence of revisit, ensuring that faster and therefore closer NEOs crossing the field of regard are not missed.

3. MISSION REQUIREMENTS

In the visible wavelength spectrum, only the sunlight reflected by an asteroid can be detected. Without taking into consideration instrumental effects, the signal observed depends mainly on few target parameters: size, shape, albedo, rotation state, phase angle and distance of the asteroid to the observer and the Sun. Observing at low elongation in the visible is challenging because only a small portion of sunlight is reflected.

On the other hand, every asteroid will have an intrinsic temperature that mostly depends on its distance from the Sun. The surface temperature of an NEO will typically be in the range 200-400 K: a black-body of 300 K has its peak thermal emission at 9 μm, i.e. in the so-called thermal infrared wavelength spectrum.

Another advantage of observing in this domain is that most stars will not be visible, hence sensibly reducing the confusion between asteroids and field stars. However, the absence of stars complicates the determination of accurate astrometry. This can be solved by having a second IR channel observing the same field-of-view as the 9 μm channel but at shorter wavelengths, e.g. 5 μm, where stars are still visible and available catalogues can be used to improve the pointing knowledge.

Taking the NEOSM optics design and performance as baseline for the NEOMIR study, the following assumptions were made during the CDF study:

- in order to complement NEOSM, NEOMIR shall cover a different field of regard. In particular, it shall be able to point closer to the Sun (down to 30°, as opposed to the 45° of NEOSM) and at any ecliptic latitude.

- Closer NEOs will move faster, thus shorter exposure times will be required. Early analysis show that 60

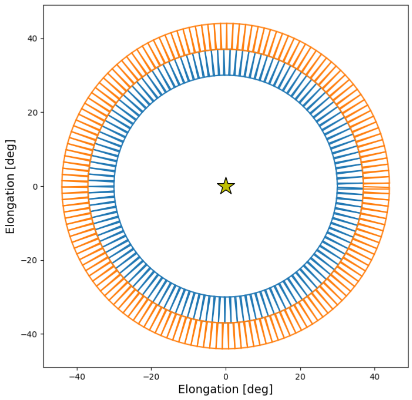

Figure 2. Annuli at 30°-44° elongation around the Sun. In this example, the FoV is 1.7° by 7°. Each ring has to be observed at least 4 times, and the NEO detected 3 times to be considered "measurable" for astrometric purposes.

s is a good compromise. In particular, given the 3"/ pixel resolution and that the PSF will be undersampled, any object moving at less than 3"/min will not trail, but also objects as fast as 10"/min will be easily detected (if bright enough).

- An NEO moving at 10"/min relative speed would cross the FOV (assumed to be 7° wide) in 42 h. This imposes a maximum revisit time if we want to avoid missing any NEO crossing our field of regard.
- Similar to NEOSM, it is assumed to require a dither pattern by moving/tilting an optical element, in order to reduce the idle time to around 1 s. Thus, a single exposure time will be around 9 s, so that each visit will last 60 s.

Given the reduced integration time, NEOMIR will still be able to detect NEOs as small as 20-25 m at 0.1 au, i.e. at least 3-4 weeks before a possible impact. In the worst case that the NEO will cross the NEOMIR field of regard at a geocentric distance equivalent to the Earth-to-SEL1 distance, the warning time will be at least 2 days.

The initial survey design is reported in Fig. 2: NEOMIR will scan a region of the sky around the Sun such that any NEO passing this "ring" will be detected. The ring will need to be observed at least 4 times in less than 42 h, so that no NEO slower than 10"/min can cross this "ring" undetected.

4. DETECTION CAPABILITIES

In order to evaluate the performance of the observational strategy, we analysed the orbits of 3000 synthetic impactors as provided by S. Chesley [3] by propagating them using a simple Keplerian model from one year prior to the actual impact date. We then included in subsequent steps only the NEOs that crossed the NEOMIR field of regard (assumed to be 30°-60°) at a distance $\leq$ 0.5 au and we computed their IR flux using a thermal model whose only changing parameters where the phase angle and the distances to the Sun and observer, while keeping constant others — e.g. all impactors being 50 m in diameter, having same spherical shape and thermal constant, etc.

For this initial analysis, we assumed the same sensitivity as NEOSM, i.e. 50 μJy in the 4-6 μm band and 150 μJy in the 6-10 μm band. We finally checked if, giving the survey design, they could be detected at least 3 times before they get out of the NEOMIR field of regard.

Our simulations show that 869 out of the 3000 synthetic impactors passed the filtering criteria. However, only 700 of them were actually bright enough to be potentially detected by NEOMIR. Of this 700, we were able to detect 610 - on average, 29 days before impact. The missed impactors were mostly due to NEOs crossing the field of regard when very close to the S/C, thus the survey cadence do not allow to have at least 3 detections. However, it is expected that they would be much brighter, and thus an alternative algorithm (e.g. streak detections) could be employed: this will be the subject of further studies.

5. CONCLUSIONS

The CDF study demonstrated the an NEO Mission in the InfraRed dedicated to the detection of NEOs, and specifically of impactors to function as an early warning system, is viable and would fall in a typical ESA's medium-class mission cost cap.

NEOMIR is currently in the so-called phase 0 and two industrial parallel studies are expected to start in March 2023. The mission was further supported at the last ministerial meeting (Nov. 2022) and sufficient funds are available to study the mission until phase B1. The current plan is compatible with a launch date around 2030.

The preliminary results on the mission capabilities show that it would have ~87% of chances of detecting an impacting NEO coming from the Sun direction, as small as 50 m with a typical 4 weeks notice.

Moreover, a science advisory group supported by ESA has been formed: its aim is to provide recommendations to both industry and ESA during the entire mission study. The first topic identified as critical and currently under study is the estimation of the zodiacal light background, especially at small elongations typical of NEOMIR targets.

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