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Probes to the inferior planets—A new dawn for NEO and IEO detection technology demonstration from heliocentric orbits interior to the earth's?

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ABSTRACT

Recent years have seen a renewed interest in exploration of the interior of the solar system. A number of missions are currently under way, in planning as well as in space, with the primary goal to expand our knowledge on the planets Mercury and Venus. Chemical propulsion missions to Mercury in particular require an extended cruise phase prior to arrival at their destination, usually involving multiple planetary fly-by manoeuvres and many revolutions in heliocentric orbit. The difficulties in discovering and tracking small objects interior to Earth's orbit, mainly due to unfavourable viewing geometry as well as atmospheric interference, have long been noted by the solar system science and planetary defence communities. Space probes in the interior of the solar system are in a position to observe objects near or interior to Earth's orbit in favourable opposition geometry. They are also usually free from planet-related interference, at least while in cruise, and often can be while in planetary eclipse.

Dedicated search and survey missions to look for Near and Inner Earth Objects (NEO, IEO) from the vicinity of Earth or low Earth orbit are being planned. In this article, the ad-hoc available as well as near-term planned in-situ capabilities of the optical instrument payloads of space probes to Venus and Mercury are compiled from publications by the respective instrument teams. The small-object detection capabilities of cameras and spectrographs in opposition geometry are estimated by a common method, using data from comparable instruments to supplement missing information where necessary. The on-board cameras are classified according to their small-object detection potential in a technology demonstration of asteroid detection from a heliocentric orbit substantially interior to Earth's.

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1. Introduction

With the launch of MESSENGER [1] and Venus Express [2], a new wave of exploration of the inner solar system has begun. Noting the growing number of probes to the inner solar system, it is proposed to connect the expertise of the respective spacecraft teams and the NEO and IEO survey community to best utilise the extended cruise phases and to provide additional data return in support of pure science as well as planetary defence.

Several missions to Venus and Mercury are planned to follow in this decade. Increased interest in the inferior planets is accompanied by several missions designed to study the Sun and the interplanetary medium (IPM) from a position near or in Earth orbit, such as the STEREO probes [3] and SDO [4]. These augment established solar observation capabilities at the Sun–Earth L1 Lagrangian point such as the SOHO [5,6] spacecraft. Thus, three distinct classes of spacecraft operate or observe interior to Earth's orbit. All these spacecrafts carry powerful multispectral cameras optimised for their respective primary targets.

MESSENGER has meanwhile ended its 6½-year interplanetary cruise on March 18th, 2011, to enter Mercury orbit, but a similarly extended cruise with several gravity-assists awaits the European Mercury mission BepiColombo [7]. Unfortunately, the automatic abort of the orbit insertion manoeuvre in December 2010 has also left Akatsuki (a.k.a. Venus Climate Orbiter (VCO), Planet-C) [8–10] stranded in heliocentric orbit. After an unintended fly-by, the probe has in November 2011 been manoeuvred to catch up with Venus in 2015 or 2016. Meanwhile, it stays mostly interior to Venus in a planet-leading orbit. [11]

In addition to the study of comets and their interaction with the IPM, observations of small bodies akin to those carried out by outer solar system probes are occasionally attempted with the equipment available. The study of structures in the interplanetary dust (IPD) cloud has been a science objective during the cruise phase of the Japanese Venus probe Akatsuki from Earth to Venus. IPD observations in the astronomical H-band (1.65 μm) are supported by its IR2 camera down to 1.5 μW/m^{2}sr in single 2 min exposures. In the same setting, point sources of 13 mag can be detected. Obviously, a number of large asteroids exceed this threshold.

The Earthguard-I study [12–14], completed in 2003 by Kayser-Threde and the DLR Institute of Planetary Research under ESA contract, proposed a dedicated steerable telescope in the size range 20–35 cm and CCD camera payload on a probe to the inner solar system, to detect Near-Earth and Inner-Earth Objects (NEOs, IEOs) in favourable opposition geometry. A ride-share on a Mercury orbiter and a dedicated low-thrust propulsion spacecraft to a heliocentric 0.5 AU orbit were studied. A similar-sized telescope was under development for the Asteroid-Finder [15], a low Earth orbit small satellite project of DLR. The Canadian small satellite NEOSSat [16] carries a smaller telescope for a shared space situational awareness and IEO search mission; it is currently awaiting launch as a secondary payload. Four large spacecraft concepts, using visible light or mid-infrared telescopes in low-elongation or opposition mode, have recently been studied, also with the goal to broaden the target base for a manned NEO mission [17]; the NEOCam [18] proposal has been selected for a technology development study phase in 2011. A NEO survey using the Deep Impact fly-by bus is currently being proposed. [19] After its primary mission of guiding an impactor vehicle to comet 9P/Tempel [20], this spacecraft now has already been re-purposed once for the EPOXI mission including such diverse topics as a close fly-by of 103P/Hartley, long-distance observations of 2009 P1 Garradd over 1.4 AU, and the observation to characterise known exoplanets lightyears away. [21] A NEO survey would constitute a second re-use of flying hardware [22], an approach that may seem obvious given the effort required to develop any mission proposal into a flying spacecraft but nevertheless is uncommon even for Earth-orbiting spacecraft. [23]

In the following, the technical feasibility of a number of asteroid observation scenarios involving spacecraft and targets interior to Earth's orbit is assessed based on the latest available spacecraft information and asteroid population models. A rough estimate of the required effort in terms of ground-based spacecraft operations and on-board resources is given for selected representative scenarios. Given the number of dedicated IEO survey missions currently under study or in development, the focus is on near-term pathfinder scenarios using spacecraft which are already in space or expected to be launched soon.

1.1. Relevant small solar system bodies

Small solar system bodies (SSSB) which are classified as Near-Earth Objects (NEO) approach the Sun to $q_{NEA} = 1.3$ Astronomical Units (AU) or less. The Near Earth Asteroids (NEA) among them are divided into four classes according to the relationship of their orbital parameters perihelion q_A, semi-major axis a_A, and aphelion Q_A with the corresponding parameters of Earth's orbit, $q_\oplus = 0.983$ AU, $a_\oplus = 1$ AU, $Q_\oplus = 1.017$ AU.

- Amor class: $a_\oplus < a_A$; $Q_\oplus < q_A < q_{NEA}$
- Apollo class: $a_\oplus < a_A$; $q_A < Q_\oplus$
- Aten class: $a_A < a_\oplus$; $q_\oplus < Q_A$
- Atira class: $a_A < a_\oplus$; $Q_A < q_\oplus$

A separate class definition exists for Potentially Hazardous Objects (PHO) which have an absolute magnitude $H \leq 22.0$, therefore inferred to be larger than 140 m estimated diameter (Ø), and are on an orbit which approaches the Earth's to within 0.05 AU or less. [38] Note that the thresholds for perihelia and aphelia of the four 'A' NEA classes do not imply automatically that a close approach geometry exists. Also, the fraction of comets (NEC, PHC) is very small in NEOs [24].

Due to the location of the Earth within the cloud of NEOs, geometrical observation conditions are rarely favourable, especially for objects that cross the Earth's orbit. Of these Earth-Crossing Asteroids (ECA), Apollo class objects have orbits mostly outside the Earth's orbit,