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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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Jan Thimo Grundmann(1), Stefano Mottola(2), Maximilian Drentschew(6), Martin Drobczyk(1), Ralph Kahle(3),
Volker Maiwald(4), Dominik Quantius(4), Paul Zabel(4), Tim van Zoest(5)

(1)DLR German Aerospace Center - Institute of Space Systems - Department of Satellite Systems
Robert-Hooke-Straße 7, 28359 Bremen, Germany
Email: jan.grundmann@dlr.de, martin.drobczyk@dlr.de

(2)DLR German Aerospace Center - Institute of Planetary Research - Department Asteroids and Comets
Rutherfordstraße 2, 12489 Berlin, Germany
Email: stefano.mottola@dlr.de

(3)DLR German Aerospace Center - Space Operations and Astronaut Training - Space Flight Technology Dept.
82234 Oberpfaffenhofen-Wesseling, Germany
Email: ralph.kahle@dlr.de

(4)DLR German Aerospace Center - Institute of Space Systems - Dept. System Analysis Space Segments (SARA)
Robert-Hooke-Straße 7, 28359 Bremen, Germany
Email: volker.maiwald@dlr.de, dominik.quantius@dlr.de, paul.zabel@dlr.de

(5)DLR German Aerospace Center - Institute of Space Systems - Department of Exploration Systems
Robert-Hooke-Straße 7, 28359 Bremen, Germany
Email: tim.zoest@dlr.de

(6)ZFT Zentrum für Telematik
Allesgrundweg 12, 97218 Gerbrunn, Germany
Email: maximilian.drentschew@telematik-zentrum.de

ABSTRACT

With the launch of MESSENGER and VENUS EXPRESS, 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 utilize 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 and SDO. These augment established solar observation capabilities at the Sun-Earth L1 Lagrangian point such as the SOHO spacecraft. Thus, three distinct classes of spacecraft operate or observe interior to Earth's orbit. All these spacecraft carry powerful multispectral cameras optimized for their respective primary targets.

MESSENGER is scheduled to end its six-year interplanetary cruise in March 2011 to enter Mercury orbit, but a similarly extended cruise with several gravity-assists awaits the European Mercury mission BEPICOLOMBO. Unfortunately, the automatic abort of the orbit insertion manoeuvre has also left AKATSUKI (a.k.a. Venus Climate Orbiter (VCO), Planet-C) stranded in heliocentric orbit. After an unintended fly-by, the probe will catch up with Venus in approximately six years. Meanwhile, it stays mostly interior to Venus in a planet-leading orbit.

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/m²sr in single 2 minute 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, completed in 2003 by the DLR Institute of Planetary Research and Kayser-Threde under ESA contract, proposed a dedicated steerable Ø20...35 cm telescope 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 rideshare on a Mercury orbiter and a dedicated low-thrust propulsion spacecraft to a heliocentric 0.5 AU orbit were studied. A similar-sized telescope is presently being developed for the ASTEROIDFINDER satellite of DLR.

Therefore, 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.

IN THE BEGINNING... THE EARTHGUARD I STUDY

Background

Small solar system bodies (SSSB) which are classified as a Near-Earth Objects (NEO) approach the Sun to 1.3 Astronomical Units (AU) or less. The Near Earth Asteroids (NEA) among them are divided into four classes:

- Amor class
    - semi-major axis > Earth's, a > 1 astronomical unit (AU)
    - perihelion > Earth's aphelion, q >1.017 AU, < 1.3 AU
- Apollo class
    - semi-major axis > Earth's, a > 1 AU
    - perihelion < Earth's aphelion, q <1.017 AU
- Aten class
    - semi-major axis > Earth's, a < 1 AU
    - aphelion > Earth's perihelion, Q >0.983 AU
- Atira class
    - semi-major axis > Earth's, a < 1 AU
    - aphelion < Earth's perihelion, Q <0.983 AU

A separate class definition exists for Potentially Hazardous Objects (PHO) which are larger than 140 m estimated diameter (Ø) and on an orbit which approaches the Earth's to within 0.05 AU or less. [1] Note that the thresholds for perihelia and aphelia of the '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. [2]

Due to the location of the Earth within the cloud of NEOs, geometrical observation conditions are rarely favorable, especially for objects that cross the Earth's orbit. Of these Earth-Crossing Asteroids (ECA), Apollo class objects have most of their mostly outside of the Earth's, and Aten class objects mostly within. Favourable observation conditions only exist while they are near aphelion, outside of the Earth's orbit *and* while the Earth passes on the inside, closer to the Sun. For ground-based observations, most of the celestial sphere is inaccessible due to the additional interference of the Sun and Earth's atmosphere, in the form of the bright day-time sky, and extinction close to the horizon. Only during brief periods of opposition, for which aphelion of the object of interest and conjunction with the Earth have to coincide, detection probability within the capabilities of given equipment is high. Atira class NEAs, also known as Inner-Earth Objects orbiting the Sun entirely Interior to Earths Orbit (IEO) are still harder to detect than Aten class objects. Only 10 of an estimated >1000 IEOs larger than Ø 100 m are presently known, all but one of them in borderline Aten-like orbits.

EARTHGUARD I

EARTHGUARD I was a mission proposal studied under an ESA contract by the DLR Institute of Planetary Research with Kayser-Threde in July 2002 to January 2003. The mission concept revolved around the idea of sending a NEO detection telescope to an inner solar system orbit to observe NEOs, ECAs, and IEOs in opposition where they are easiest to detect by observing geometry, and without additional interference due to Earth's atmosphere.

The space segment studied included two design options, a separate spacecraft or an instrument added to another space probe, depending on available launches and at the time planned missions:

- instrument-only option:
    - rideshare of the telescope mounted on an independent pointing platform on a space probe
    - flight to Mercury studied, based on BEPI-COLOMBO as then envisaged
- independent spacecraft option:
    - dedicated launch to ~0.5 AU heliocentric orbit
    - study focus on the use of advanced low-thrust propulsion in interplanetary space
        - e.g. solar sail from GTO rideshare with own kick stage

The EARTHGUARD I mission was to be equipped with a Ø 20…35 cm reflector telescope using a 2048^2 pixel resolution CCD camera augmented by 3 in-field star tracking sensors. A mission duration of 400 days was envisaged, and the detection of approximately 80% of all NEA's > Ø 1 km expected in this time. [3,4,5]

The IEO search component of Earthguard I evolved into the current AsteroidFinder project in the German national 'Kompaktsatellit' programme of the DLR Research & Development programmatic branch. [6] The Earthguard I telescope design study baseline was, for some time and with extensive modifications, held as a fall-back option for the more advanced concept to be used in AsteroidFinder.

DEEP SPACE PROBES AND CAMERAS IN THE REGION OF THE INFERIOR PLANETS

Background

The past decade has seen a renaissance of exploration of the inferior planets, Mercury and Venus. Currently, three missions equipped with various cameras and spectrometers operate in the interior solar system; Venus Express, MESSENGER, and Akatsuki. More planetary research missions are planned for this decade, including the ESA mission BepiColombo. Also, solar research missions equipped with cameras now venture into interplanetary space, for example the pair of STEREO spacecraft orbiting the Sun ahead and behind the Earth in very similar orbits to it, to provide a complete coverage of the Sun in cooperation with Earth-based observatories, Earth-orbiting satellites such as SDO, and solar probes stationed at the Sun-Earth Langrange point L1 such as SOHO.

Spacecraft and Cameras

The following planetary research space probes equipped with cameras and sensitive spectrometers are currently active on orbits significantly interior to the Earth's or in the advanced stages of planning:

- Venus Express [7]
    - Venus Monitoring Camera (VMC) [8]
        - 17.5° Field of View (FoV), 13 mm focal length (f.l.), *f*/5 wide-angle camera
    - Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) [9]
        - 64 mrad FoV, *f*/5.6 UV/VIS channel, 2 nm resolution
        - 64 mrad FoV, *f*/3.2 near to mid IR channel, 10 nm resolution
        - 0.45 · 2.25 mrad FoV, *f*/2 mid IR channel, 3 nm resolution
    - SPectroscopy for Investigation of Characteristics of the Atmosphere of Venus (SPICAV) [10]
        - 1 · 3.16° FoV, 118 mm f.l. UV channel, 0.55 nm resolution
        - 2° FoV, 40 mm f.l. VIS to near IR channel, 0.55 nm resolution
        - 180 mm f.l., *f*/4 mid IR channel
- MESSENGER
    - Mercury Dual Imaging System (MDIS) [11]
        - 10.5° FoV, 78 mm f.l., multispectral Wide Angle Camera (WAC)
        - 1.5° FoV, 550 mm f.l., *f*/22 multispectral Narrow Angle Camera (NAC)
    - Mercury Atmospheric and Surface Composition Spectrometer (MASCS) [12]
        - 0.04 · 1° FoV, 258 mm f.l., *f*/5 front-end telescope
        - resolution 0.6 nm UV/VIS, 4.7 nm resolution IR
- Akatsuki [13,14]
    - common FoV 12°
    - Ultraviolet Imager (UVI)
    - Lightning and Airglow Camera
        - 8 · 8 photodiode array, 50 kHz, filters for airglow and lightning emission lines
    - 1 µm Infrared Camera (IR1)
        - 84 mm f.l., *f*/4, multispectral near IR camera
    - 2 µm Infrared Camera (IR2)
        - 84 mm f.l., *f*/4, multispectral mid-IR camera (cf.[15])
    - Longwave Infrared Camera (LIR)
        - *f*/1.4, thermal IR camera, 240 · 240 bolometer array
- BepiColombo
    - Spectrometers and Imagers for MPO BepiColombo Integrated Observatory System (SIMBIO-SYS) [16]
        - 1.47° FoV, 800 mm f.l., *f*/8 High Resolution Imaging Channel (HRIC)
        - 5.3° FoV, 90 mm f.l., *f*/6 multispectral Stereo Channel (STC)
        - 0.25 · 64 mrad FoV, 160 mm f.l., *f*/6.4 Visible and Infrared Hyperspectral Imager (VIHI), 6.25 nm resolution
    - Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS) [17]
        - 4° FoV, 50 mm f.l., *f*/2 mid to thermal IR spectrometer, 90 nm resolution

Note that there is a general similarity with respect to the FoV classes of the cameras used in many planetary spacecraft which suggests that Narrow-, Medium-, and Wide-Angle Cameras of approximately 1.5°, 5°, and 15° FoV are favoured, with 2 out of 3 usually present. The following table gives an overview of key camera parameters:

Tab. 1. Camera Parameters of Spacecraft in the Interior Solar System

spacecraft	instrument	FOV cross-track, °	FOV along-track, °	FOV cross-track, mrad	FOV along-track, mrad	focal length, mm	ƒ number, ƒ/n	sensor pixel, column	sensor pixel, line	pixel pitch, µm	A/D depth, bits	frame / sample rate, Hz	min. exposure time, s	max. exposure time, s	sensor temp., K	filter SW cut-off, nm	filter center, nm	filter LW cut-off, nm	filter band-width, nm	filter name / remark	min. SNR pixel
Akatsuki	Ultraviolet Imager (UVI)	12						1024	1024	13	12						283		15		120
Akatsuki	Ultraviolet Imager (UVI)	12						1024	1024	13	12						365		15		120
Akatsuki	Lightning and Airglow C	16						8	1	2000		0.05					542.5		125	O2 Herzberg I	10
Akatsuki	Lightning and Airglow C	16						8	1	2000		0.05					545.0		8	background	10
Akatsuki	Lightning and Airglow C	16						8	1	2000		0.05					557.7		8	OI airglow	10
Akatsuki	Lightning and Airglow C	16						8	1	2000		0.05					630.0				10
Akatsuki	Lightning and Airglow C	16						8	4	2000		50000					777.4		8	OI lightning	
Akatsuki	1 µm Camera (IR1)	12				84.2	4	1024	1024	17	16				260		900		10		100
Akatsuki	1 µm Camera (IR1)	12				84.2	4	1024	1024	17	16				260		900		40		100
Akatsuki	1 µm Camera (IR1)	12				84.2	4	1024	1024	17	16				260		970		40		100
Akatsuki	1 µm Camera (IR1)	12				84.2	4	1024	1024	17	16				260		1010		40		100
Akatsuki	2 µm Camera (IR2)	12				84.2	4	1024	1024	17	16				65		1650		30	Zodiacal IPD (	100
Akatsuki	2 µm Camera (IR2)	12				84.2	4	1024	1024	17	16				65		1735		40		100
Akatsuki	2 µm Camera (IR2)	12				84.2	4	1024	1024	17	16				65		2020		40		100
Akatsuki	2 µm Camera (IR2)	12				84.2	4	1024	1024	17	16				65		2260		60		100
Akatsuki	2 µm Camera (IR2)	12				84.2	4	1024	1024	17	16				65		2320		40		100
Akatsuki	Longwave Infrared Cam	12					1.4	240	240	37		60			313	8000	10000	12000	4000		
BepiColombo	SIMBIO-SYS HRIC	1.47				800	8	2048	2048	10		200					650		500	FPAN	200
BepiColombo	SIMBIO-SYS HRIC	1.47				800	8	2048	2048	10		200					550		40	F550	200
BepiColombo	SIMBIO-SYS HRIC	1.47				800	8	2048	2048	10		200					750		40	F700	200
BepiColombo	SIMBIO-SYS HRIC	1.47				800	8	2048	2048	10		200					880		40	F880	200
BepiColombo	SIMBIO-SYS STC	5.3	4.6			90	6	2048	2048	10		200	0.001				700		100	PAN	
BepiColombo	SIMBIO-SYS STC	5.3	4.6			90	6	2048	2048	10		200	0.001				420		20		
BepiColombo	SIMBIO-SYS STC	5.3	4.6			90	6	2048	2048	10		200	0.001				550		20		
BepiColombo	SIMBIO-SYS STC	5.3	4.6			90	6	2048	2048	10		200	0.001				700		20		
BepiColombo	SIMBIO-SYS STC	5.3	4.6			90	6	2048	2048	10		200	0.001				920		20		
BepiColombo	SIMBIO-SYS VIHI			64	0.25	160	6.4	256	256	40	14	25	0.01		220	400		2000	6.25	/pixel, hypersp	100
BepiColombo	MERTIS	4				50	2	160	120	35						7000		14000	90	/pixel, hypersp	100
BepiColombo	MERTIS	4				50	2	15	2	200						10000		40000			
MESSENGER	MDIS NAC	1.493				550.3	22	1024	1024	14	12	1	0.001	10	258.16	700	750	800	100	monochromati	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16	395	700	1040	600	2 - clear - pan(	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16	420	430	440	18	6 - violet	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16	465	480.4	485	8.9	3 - blue	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16	555	559.2	565	4.6	4 - green	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16	695	628.7	705	4.4	5 - red	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16		698.8		4.4	1 - far red	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16	745	749.0	755	4.5	7 - NIR	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16	825	828.6	835	4.1	12 - NIR	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16	895	898.1	905	4.3	10 - NIR	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16	945	948.0	950	4.9	8 - NIR	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16	980	996.8	1010	12.0	9 - NIR	200
MESSENGER	MDIS WAC	10.54				77.96		1024	1024	14	12	1	0.001	10	258.16	975	1010	1045	20	11 - NIR	200
MESSENGER	MASCS					257.6	5														
MESSENGER	MASCS UVVS	1	0.04			125		1	1	6000						115		180	0.6	FUV PMT	100
MESSENGER	MASCS UVVS	1	0.04			125		1	1	10000						160		320	0.6	MUV PMT	100
MESSENGER	MASCS UVVS	1	0.04			125		1	1	10000						250		600	0.6	VIS PMT	100
MESSENGER	MASCS VIRS	0.023				210		256	1	50	16					300		1050	4.7		100
MESSENGER	MASCS VIRS	0.023				210		512	1	50						850		1450	4.7		100
MESSENGER	visible-infrared spectrometer															300		1025		grating 100 grooves/r	
MESSENGER	visible-infrared spectrometer															950		1450		grating 100 grooves/r	
Venus Express	SPICAV SUV	1	3.16			118.13		384	288	23					270	118		320	0.55	/pixel	
Venus Express	SPICAV SIR	2						2	1	2400						250		1700	0.45	/pixel 0.45…1.12 nm/	
Venus Express	SPICAV SIR	2				40		2	1	2000	12		0.0007	0.1796	258.16	650		1050	0.42	/pixel 0.42…1.44 nm/	
Venus Express	SPICAV SIR	2				40		2	1	500	12		0.0007	0.1796	258.16	1050		1700	0.55	/pixel 0.55…1.5 nm/p	
Venus Express	SPICAV SOIR					180	4	320	256	30		10.0	0.000003	0.02	110		2500		11.65		
Venus Express	SPICAV SOIR					180	4	320	256	30		10.0	0.000003	0.02	110		3172		18.87		
Venus Express	SPICAV SOIR					180	4	320	256	30		10.0	0.000003	0.02	110		4500		38.18		
Venus Express	VIRTIS-M VIS			64	64		5.6	508	1024	19	16				155	250		1000	2	/pixel	
Venus Express	VIRTIS-M IR			64	64		3.2	270	438	38					70	950		5000	10	/pixel	
Venus Express	VIRTIS-M IR			64	64		3.2	270	438	38					70	900		1600	10	/pixel; 1st region	
Venus Express	VIRTIS-M IR			64	64		3.2	270	438	38					70	1200		2500	10	/pixel; 2nd region	
Venus Express	VIRTIS-M IR			64	64		3.2	270	438	38					70	2400		3750	10	/pixel; 3rd region	
Venus Express	VIRTIS-M IR			64	64		3.2	270	438	38					70	3600		4400	10	/pixel; 4th region	
Venus Express	VIRTIS-M IR			64	64		3.2	270	438	38					70	4300		5000	10	/pixel; 5th region	
Venus Express	VIRTIS-H (IR)			0.45	2.25		2.04	270	438	38					70	2000		5000	3	/pixel	
Venus Express	VIRTIS-H (IR)			0.45	2.25		2.04	270	438	38					70	2000		4400	3	/pixel; 1st region	
Venus Express	VIRTIS-H (IR)			0.45	2.25		2.04	270	438	38					70	3900		5000	3	/pixel; 2nd region	
Venus Express	VMC	17.5				13	7	1032	1024	9		1.62028	0.000504	32.4823		350	365	385	40	F3 (UV)	
Venus Express	VMC	17.5				13	5	1032	1024	9		1.62028	0.000504	32.4823		500	513	560	50	F4 (VIS)	
Venus Express	VMC	17.5				13	5	1032	1024	9		1.62028	0.000504	32.4823		950	965	990	70	F5 (NR1)	
Venus Express	VMC	17.5				13	5	1032	1024	9		1.62028	0.000504	32.4823		990	1010	1030	20	F6 (NIR2)	
Venus Express	STR (Star Tracker)	16.47				46		1024	1024			2				500		850			
Rosetta	STR (Star Tracker)	16.47				46		1024	1024			0.1				500		850			

DETECTION CAPABILITY OF EXISTING SPACE ASSETS FOR NEOS IN OPPOSITION

NEO Observation Feasibility Demonstration Scenarios

From the perspective of planetary probes, asteroid encounters and observations have long been a welcome bonus objective for the extended periods of interplanetary transfer. However, these asteroid observations have mostly been close and fast fly-bys. Observations in the context of Earth-based asteroid surveys and such as intended for EARTHGUARD I require continuous wide-area scanning and regular revisits for the purposes of transient object discovery, motion detection, classification, and tracking. Between these extremes lies the potential envelope of EARTHGUARD I -like technology demonstrations using existing in-space hardware or future interplanetary spacecraft:

- minimum scenario: one-off observation of a known bright object in opposition to the spacecraft
    - e.g. Ceres, Vesta, or large known NEA which happens to be within detection range
- maximum scenario: cruise-phase full asteroid survey implemented aboard the spacecraft

        - continuous mosaic imaging; on-board motion detection, processing & autonomy

Methods

To evaluate the general feasibility of the detection of NEOs from probes in the region of the inferior planets, the performance of the camera systems was studied based on published camera system parameters. Wherever data was lacking, information from comparable systems was substituted. The NEO target was assumed as a point source with the spectrum of a G0 star, seen from the orbit of Venus at 0.7 AU in opposition. A Signal-to-Noise (SNR) of 5 was assumed for object detection.

Results for Spacecraft Cameras

The following list gives a brief overview of the capabilities and possible NEO detection feasibility demonstration scenarios for the respective spacecraft and cameras which are marked by light green lines in Tab.1:

- VENUS EXPRESS
    - Venus Monitoring Camera (VMC) - Fig.1
        - filter: F4 (VIS) - 513 nm, 50 nm bandwidth
    - even large NEOs would need to come exceptionally close to become detectable
    - sensor large, but shared between 4 instrument channels
    - no useful potential for Earthguard I -like technology demonstrations
    - observation of very bright comets may occasionally become possible
- MESSENGER
    - Mercury Dual Imaging System Narrow Angle Camera (MDIS NAC) - Fig. 2
        - filter fixed monochromatic - 750 nm, 100 nm bandwidth
    - due to the limited time of exposure ≤ 10 s, even large NEOs would need to come very close to become detectable
    - large, > 100 km mainbelt asteroids can be detected
    - a limited Earthguard I -like technology demonstration is feasible
- AKATSUKI
    - 1 μm Infrared Camera (IR1) - Fig. 3
        - filter: 900 nm, 40 nm bandwidth
    - 2 μm Infrared Camera (IR2)
        - filter: Zodiacal IPD - 1650 nm, 30 nm bandwidth
        - stated point source sensitivity: 13 mag H-band in single exposure, 2 min integration
    - long integration, wide FOV & many similar-bandwidth filters are available
    - large NEOs would need to come close to become detectable
    - large, > 100 km mainbelt asteroids can be detected
    - the spacecraft is in a long cruise period to a re-encounter with Venus at ~0.7 AU
    - Zodiacal InterPlanetary Dust (IPD) observations were part of the cruise to Venus
    - extended Earthguard I -like technology demonstration is feasible
        - taxonomy may be included for a subset of the detectable objects
- BEPICOLOMBO
    - Spectrometers and Imagers for MPO BepiColombo Integrated Observatory System High Resolution Imaging Channel (SIMBIO-SYS HRIC) - Fig. 4
        - filter: panchromatic
    - sub-km class NEOs can be detected - if long exposures ~100 s are possible
    - 10 km class objects can be detected throughout the main belt - if long exposures possible
    - Earthguard I -like observations could be conducted as a regular cruise component,
        - survey patterns or region of interest adapted to the small FOV, e.g. Trojans
        - limited taxonomy potential due to filter bandwidth and imaging channel contrast
        - \- if on-board data reduction implementation is feasible

SSSB Detection Limit Size-Distance Functions for Spacecraft Cameras

The following figures show the minimum size of detectable objects with respect to the distance from the spacecraft under the conditions given above, for the cameras as previously listed:

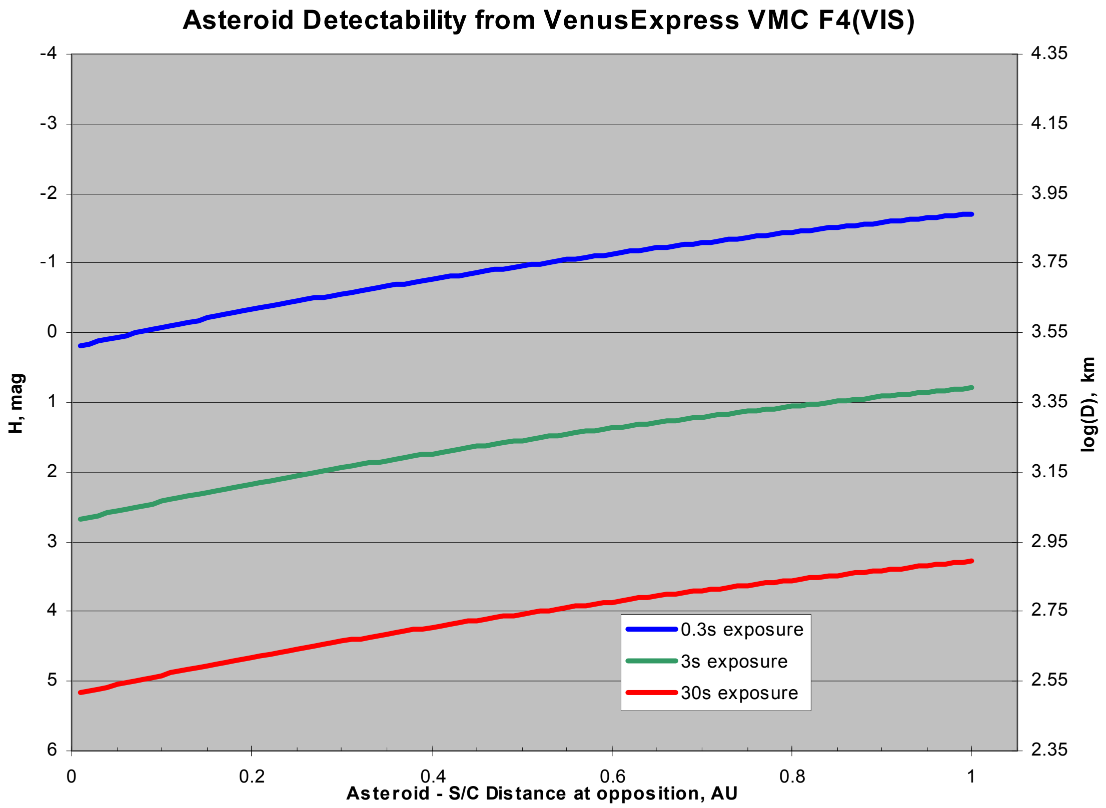

Fig. 1. Detection Limit Size-Distance Functions for the VENUS EXPRESS VMC channel using the F4(VIS) filter

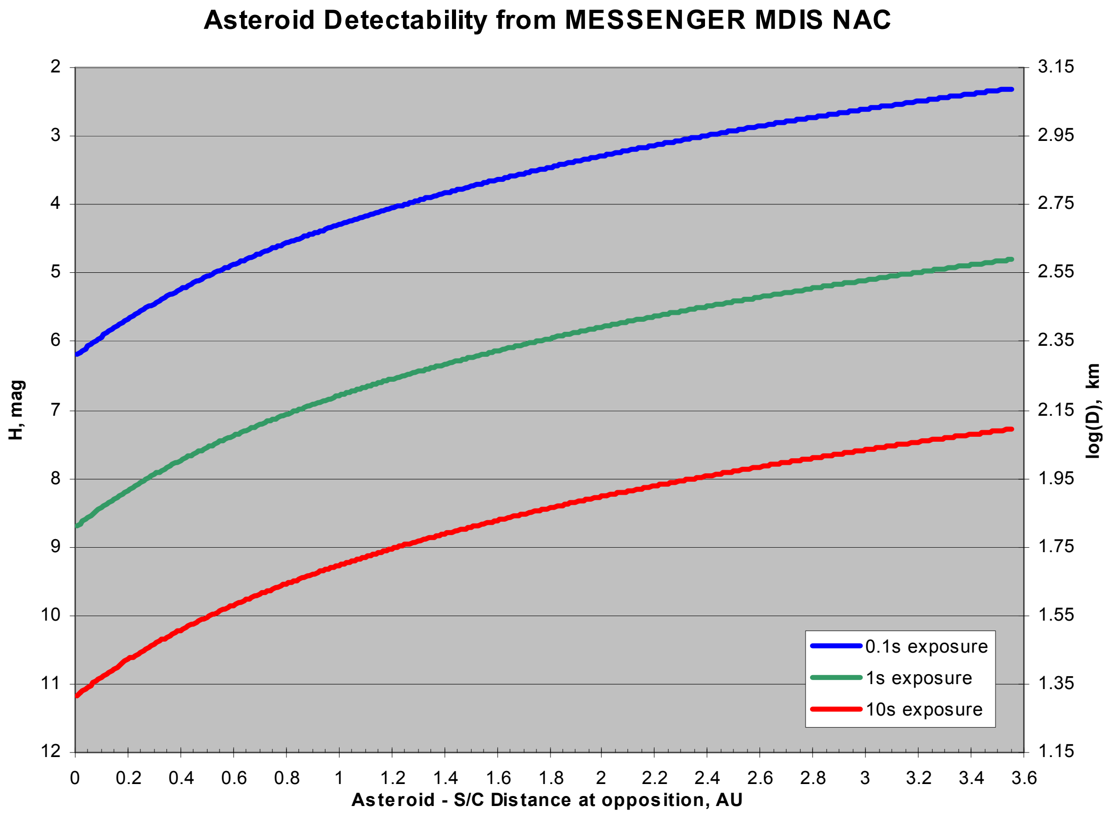

Fig. 2. Detection Limit Size-Distance Functions for the MESSENGER MDIS Narrow-Angle Camera

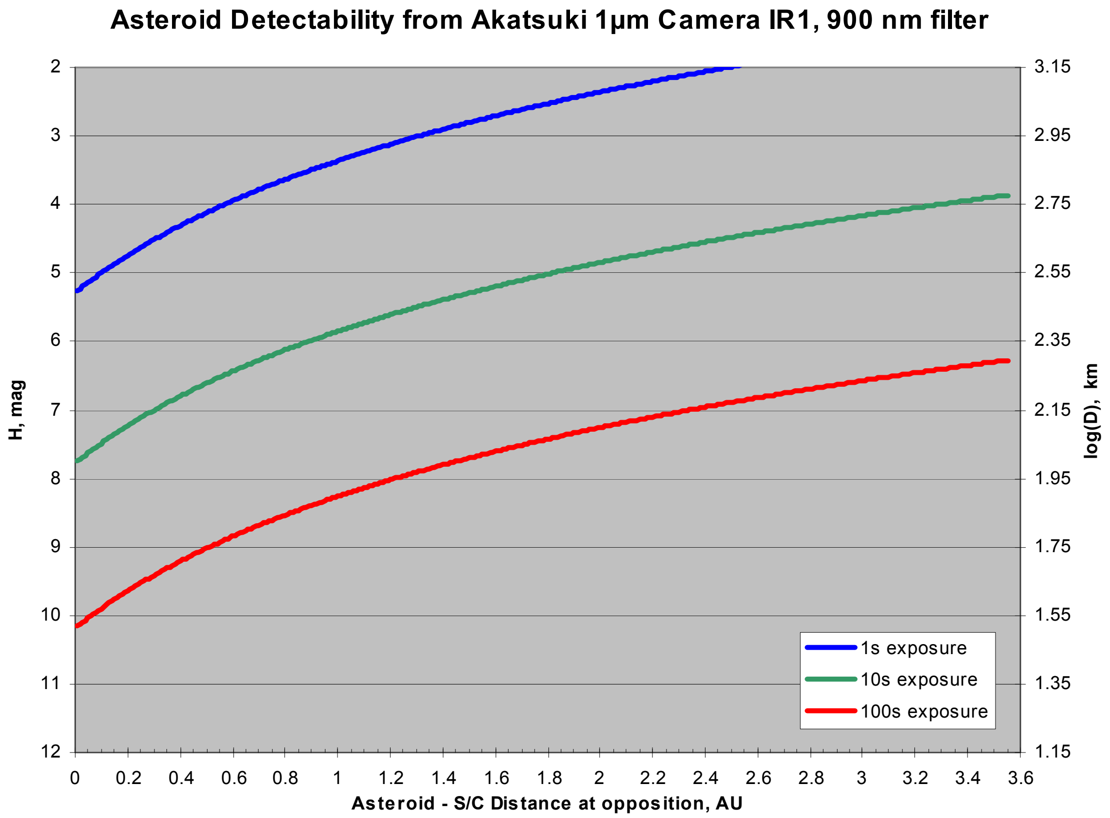

Fig. 3. Detection Limit Size-Distance Functions for the AKATSUKI 1µm Camera IR1 using the 900 nm filter

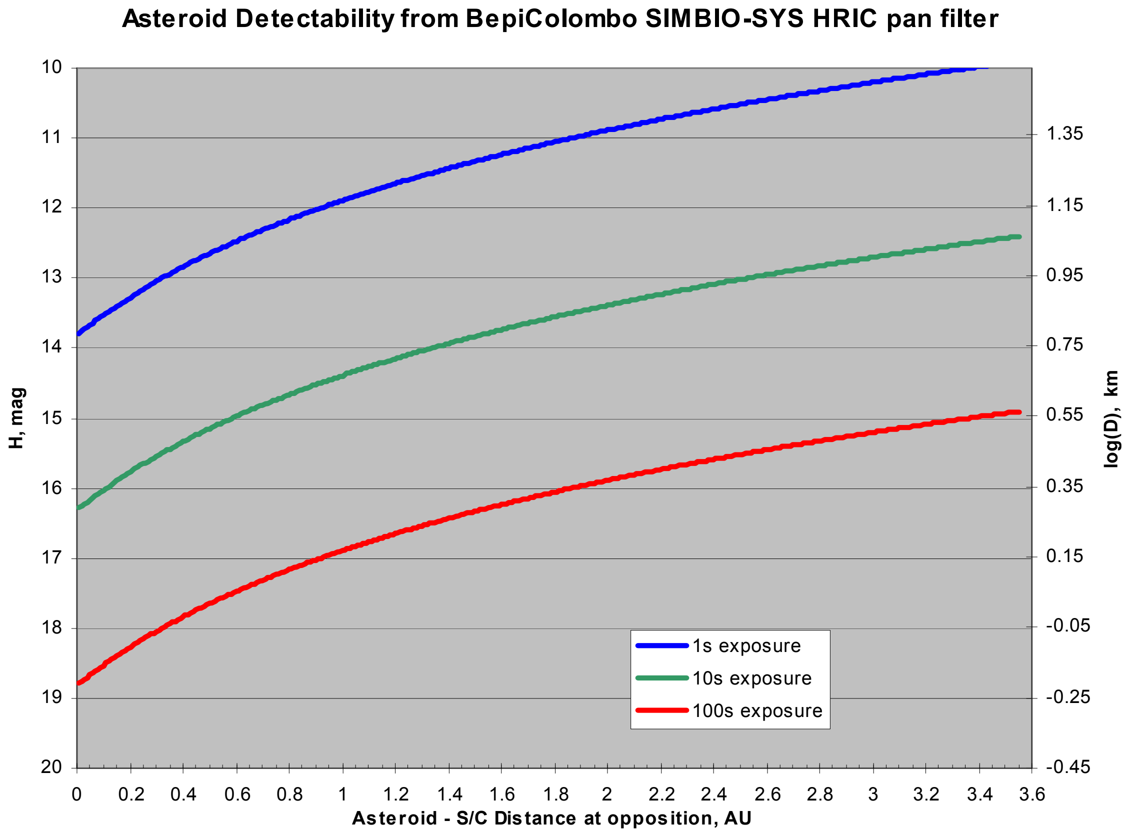

Fig. 4. Detection Limit Size-Distance Functions for the BEPICOLOMBO SIMBIO-SYS HRIC (panchromatic)

OBJECTS AND OBSERVATION REGIONS OF SPECIAL INTEREST

From the interior of the respective planet orbits, co-orbital and L4/5 Trojans become more easily detectable. Also, the structure of the Interplanetary Dust (IPD) may be investigated, including its perturbations caused by the planets. Of particular interest with respect to planetary defence are observations of known PHAs to augment ground-based assets by the different perspective available, or to continuously refine the PHA orbit during periods of invisibility from Earth. As an example, the following table and figure show selected opposition encounters of three known PHAs with space probes currently in the interior solar system, and their orbits. *Note* that the orbit of Akatsuki was propagated from the last available state before the failed Venus orbit insertion. It is therefore known to be inaccurate, but nevertheless believed to represent the general characteristics of the actual current orbit which are similar to the Venus-leading Earthguard I design option using a separate spacecraft. [3] The orbit of Venus is virtually identical to that of Venus Express. BepiColombo is not shown for clarity. The characteristics of its possible envisaged trajectories depend on the actual launch date, but are similar to MESSENGER in general, with the addition of propelled cruise phases. Both present ample geometrical opportunities for observation of regions and objects of special interest in opposition due to the short orbital periods, especially of the revolutions mainly inside of Venus towards Mercury rendezvous.

Tab. 2. Spacecraft opposition encounters with selected PHA of interest and Fig. 5 colour code

Probe	Asteroid	Closest Approach
MESSENGER	Toutatis	24/09/2009
	1999RQ36	21/09/2005
	Apophis	28/11/2006
Venus Express	Apophis	08/10/2008
Akatsuki	Apophis	18/08/2018

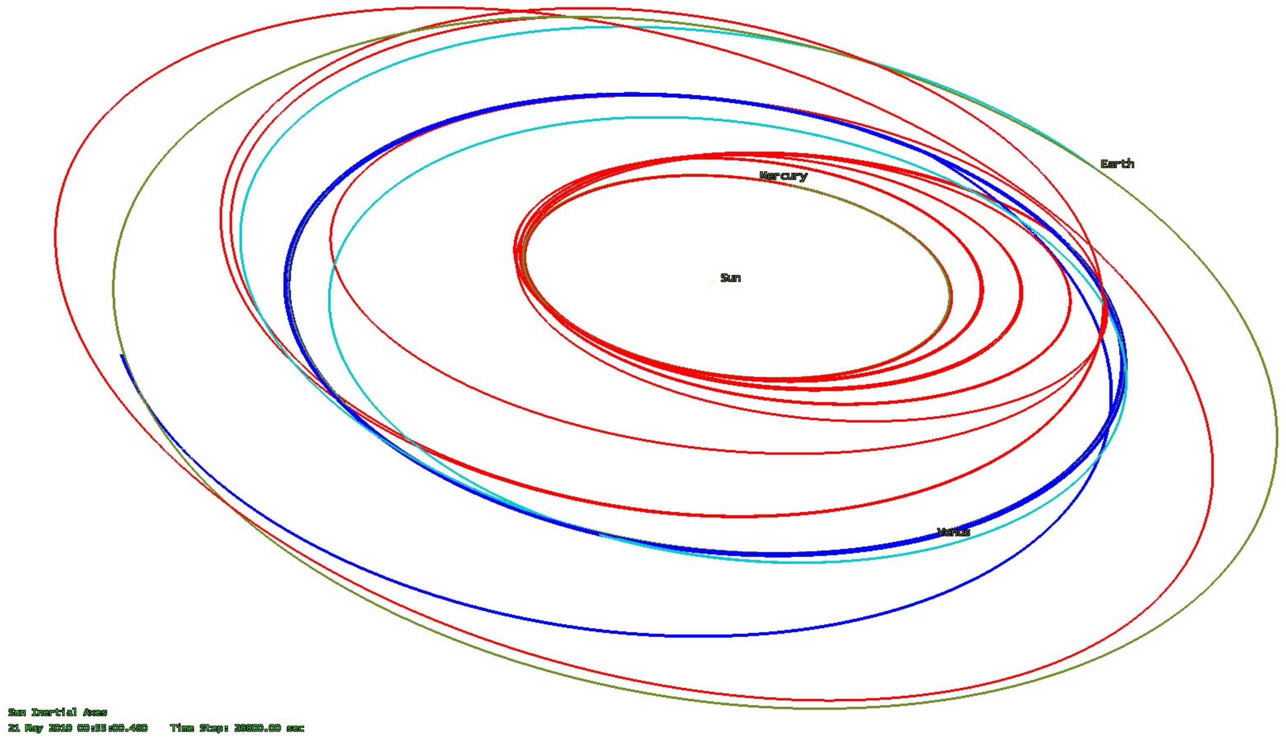

Fig. 5. Orbit geometry of space probes currently in the interior solar system

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