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APOPHIS Express, a unique opportunity for visiting asteroid Apophis in 2029

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Abstract

The purpose of the paper is to present a novel design for a space mission headed towards the near-Earth asteroid (99942) Apophis and taking advantage from its close Earth flyby in April 2029.

During its 2029 pass, Apophis will be easily visible from the Earth and it can be expected that its terrain model and most of its physical properties will be well determined from ground based observations. However, the characterization of its interior will not be achievable from purely terrestrial remote observations, even with such short distance approach. Such a characterization is however essential for planning any mitigation operation of this particular Potentially Hazardous Asteroid (PHA), should it be necessary in a distant future. It will also provide informations that could be generalized to any PHA.

This can be done only through a dedicated space mission, delivering a set of instruments, softly laid down on the asteroid surface. These instruments can be used for drilling, sounding the interior (like Consert on Rosetta). Some devices such as a laser reflectometer would be essential for long term orbit tracking.

The mission scheme that is proposed in this paper consists in a very fast mission, less than one month, from the launch to the delivery of a scientific payload on Apophis' surface, with a possible sample return option. From a few days before its close approach to the Earth to its departure from the Earth vicinity, Apophis would be followed by a spacecraft carrying a set of scientific modules.

In March 2029, just a few weeks before Apophis is coming close to the Earth, a mission is launched into a highly eccentric orbit, the direction of the line of apsis being towards the incoming asteroid with an apogee altitude higher than 1 million kilometers. It will take about 3 weeks to reach the region that will be crossed by Apophis just a few days before its close encounter. From there, a ΔV of about 6 km/s is requested to cancel the relative velocity with respect to Apophis, and thus allow delivering a scientific payload at its surface after achieving the rendez-vous.

In the paper, we present some possible scientific scenarios depending on the capacities of the selected launcher.

1. Introduction

During its 2029 pass, the PHA asteroid (99942) Apophis will be easily visible from the Earth and it can be expected that its geometry and most of its physical properties will be well determined from ground-based observations. However, the characterization of its interior will not be achievable from purely terrestrial observations. Such a characterization is essential for planning any mitigation operation, should it be necessary in the future.
This can be done only through a dedicated space mission delivering a set of instruments to probe the interior of Apophis after being softly laid down on its surface.

2. Traditional Mission Scheme

To rendez-vous with a celestial body such as an asteroid or a planet orbiting the Sun, it is usual to place the probe on an orbit for which the initial conditions are an optimal combination of the velocity of the Earth and the Infinite Velocity. This has been established in 1925 by Walter Hohmann and is still of common use.

Applied to a rendez-vous with Apophis before its close approach in April 2029, a suitable mission scheme could be a launch in May 2028 for an arrival in February 2029. The Infinite Velocity from Earth would be 3.7 km/s and the arrival velocity to Apophis 1.6 km/s, so a total ΔV around 5.2 km/s.

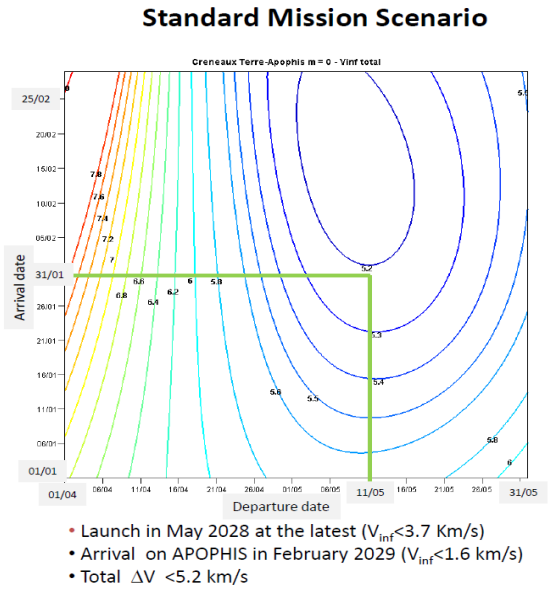

Fig.1 Earth-Apophis Launch/Arrival diagram for Hohmann transfer

Solar Electric Propulsion could also be envisioned but it would take even longer to reach Apophis.

3. APOPHIS Express Mission Scheme

The mission scheme that is proposed in this paper consists in a very fast mission, less than one month, from the launch to the delivery of a scientific payload on Apophis surface, with a possible sample return option. From a few days before its close approach to the Earth to its departure from the Earth vicinity, Apophis would be followed by a spacecraft carrying a set of scientific modules.

In March 2029, just a few weeks before Apophis is coming close to the Earth, a mission is launched into a highly eccentric orbit, the direction of the line of apsis being towards the incoming asteroid with an apogee altitude higher than 1 million kilometers. The plane of the orbit would be the plane defined by the incoming hyperbolic branch of Apophis' orbit with respect to the Earth. The inclination of this plane with respect to the equatorial plane is about -30°, Apophis approach being in the Southern hemisphere.

It will take about 3 weeks to reach the region that will be crossed by Apophis just a few days before its close pass. From there, a ΔV of about 6 km/s is requested to cancel the relative velocity with respect to Apophis and thus allow delivering a scientific payload at its surface. This ΔV will be delivered by the Apogee Kick Module (AKM).

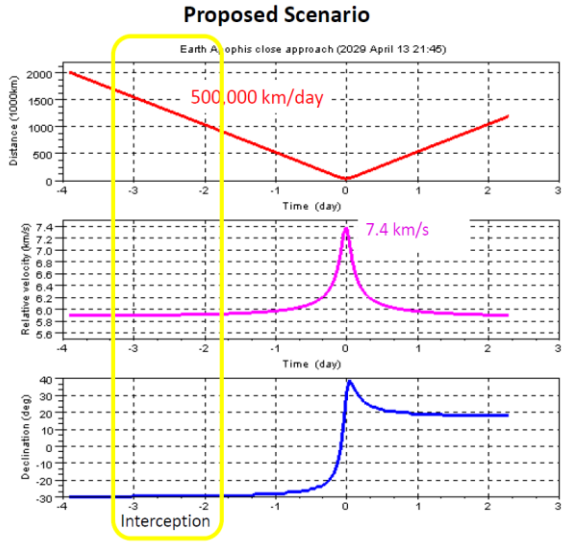

Fig.2 Distance, velocity and elevation of Apophis during its 2029 flyby

The main conclusions that can be drawn from Fig.2 are that the distance between Apophis and the Earth is decreasing by 500,000 km a day before the flyby, the relative velocity is about 5.85 km/s until the day before the flyby and the elevation of Apophis from the Earth is 30°S.

4. Mission sequences

The payload that is delivered by the launcher would be made up of a stack of modules (depending on the available mass):

- An Apogee Kick Motor (AKM)
- A Service Module (SM)
- An Orbiter Module (OM)
- The Apophis Lander (AL)
- and optionally a Reentry Capsule (RC)

¤ The AKM will be ignited close to the apogee of the initial orbit in order to deliver a ΔV of about 6km/s (sum of the Vinf of Apophis and velocity at apogee of the orbit). This will place APOPHIS Express on a trajectory intersecting the Apophis incoming branch.

¤ The Service Module is the interface between the ground operation center and the individual modules.

¤ The Orbit Module is supposed to observe Apophis from the side opposite to the Service Module. It could be a CubeSat or nanosatellite size module and provide observations of Apophis. It could carry a transponder (like CONSERT in the ROSETTA mission) in connection with the Service Module and/or with ground stations.

¤ the Lander would carry scientific instruments and possibly a reentry capsule. In order to follow Apophis in the long term (up to its next apparitions), a Laser Reflector, similar to the ones laid on the Moon, could be included in the landing payload.

Assuming that the apogee altitude of the delivery orbit is 1,000,000 km, it would be reached after a 20 days cruise and the rendez-vous with Apophis will be executed 2 days before its closest approach.

The sequence of events is summarized in the following graphics.

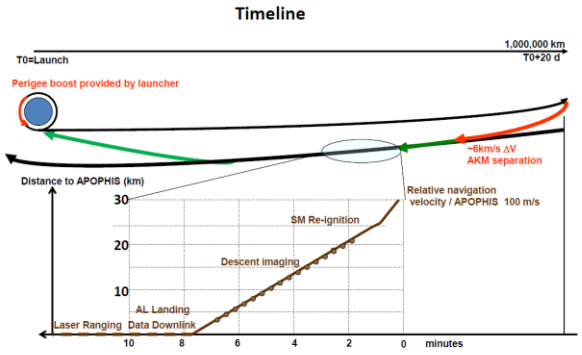

Fig.3 From the launch to the surface

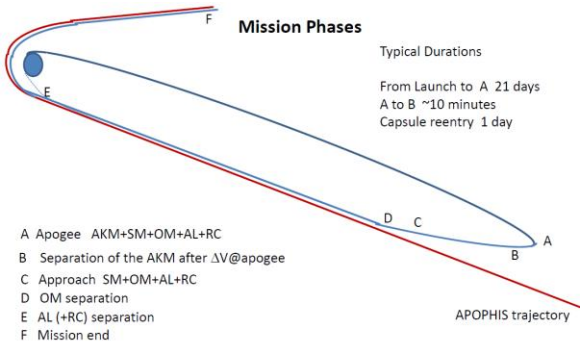

Fig.4 Complete Mission Scheme

5. Launch options

The delivery orbit of APOPHIS Express is not a classical one. Specific studies have to be realized in order to provide reliable figures. From the publicly available launcher manuals, the following rough order of magnitude can be stated for a delivery on a 1Mkm apogee altitude orbit

Launch Options (based on publically available data)

Launcher	Delivery capacity @ 1 Mkm	Gross mass after AKM separation	Estimated allocation (2) for Instrumentation
Soyuz-Fregat	2000kg	296kg	56kg
AR 62	2500	320	60
AR5 ECA	6200	920	174
AR64	7500	1060	201
AR64-VINCI (1)	7500	1370	260

All masses in kg

(1) AKM Specific Impulse 435s except for AR64-VINCI (465s)
(2) Based on HERA mass budget (19% of the total mass available for the scientific P/L

Considering that about 85% of the delivered mass is absorbed by the Apogee Kick Motor, the useful mass allocation for the set of modules would range between 50 kg (ARIANE 62) and 140 to 200 kg for the more powerful ARIANE versions.

Obviously, the ambitions for APOPHIS Express are highly depending from the selected launcher.

6. Conclusions

The APOPHIS Express basic scenario that is presented here provides many advantages compared to traditional ones:

- It is of shorter duration, so the operation costs are lower
- The distance between the Earth and the modules is much lower (~Mkm instead of

~100Mkm) which makes the communication system simpler
- The launch date is about one year later, allowing for a more comfortable development plan

Nevertheless this scenario should not be considered as a self-consistent one. At least for the choice of the landing site, precursor observations are necessary. They should be provided by ‘traditional’ missions that are presently under study in various space agencies. Irrespective of the present mission scenario proposition, the establishment of an Inter Agency coordination group for these Apophis missions would be highly useful.

Even if it has been recently established (March 2021) that asteroid Apophis does not present any hazard for at least one century, it is important to collect all possible scientific information about it. They can be vital for our descendants.