IN-SITU GEOPHYSICAL EXPLORATION OF ASTEROID APOPHIS. N. Murdoch[1], R.F. Garcia[1], A. Cadu[1], A. Wilhelm[1], M. Drilleau[1], A. Sournac[1], A. Stott[1], V. Dehant[2], F. Bernauer[3], C. Schmelzbach[4], S. Stähler[4], H. Igel[3], G. Lecamp[5], L. Ferraioli[4], O. Karatekin[2], P. Lognonné[6], D. Giardini[4], D. Scheeres[7], and D. Mimoun[1]

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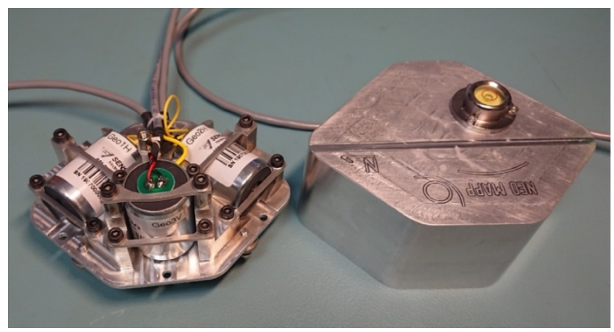
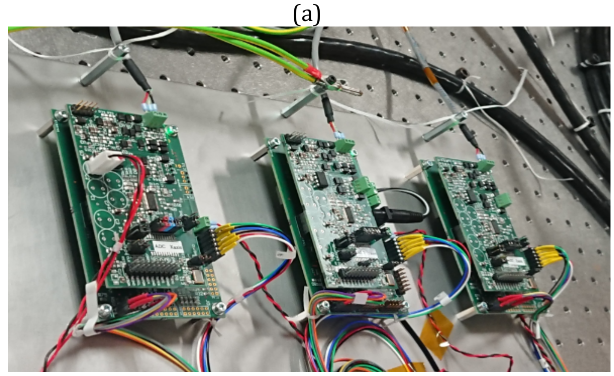
Introduction: The Apophis 2029 encounter with the Earth offers the ideal scenario for an in-situ geophysical investigation of the asteroid. Ground rotation and translation sensors are complementary instruments that can be used in-situ (on the surface) to infer the mechanical properties and internal structure of planetary bodies at different scales. An accelerometer can be used to constrain the physical properties of the asteroid surface by measuring the interactions between a surface package and the asteroid during landing and rebounding [1-3], and could also be used to measure strong seismic signals. An in-situ rotation sensor can probe the deep interior of the asteroid by measuring the variations of the instantaneous asteroid rotation and potential vibration modes of the asteroid. Such dynamic effects can be induced by tidal interactions during a close planetary encounter, such as the Apophis flyby of the Earth [4]. A short period seismometer measures ground motion and can be used to determine the seismic response of the asteroid and image the sub-surface structure [5]. Such a seismometer could record the tidal force-induced seismicity during the Apophis Earth fly-by but can also record other types of low amplitude seismic signals (thermal, impacts, …; [6-7]). Such investigations of an asteroid's physical properties and internal structure provide information that is critical for planetary defense (to understand the damage that may cause upon impact, and to evaluate mitigation strategies), and for understanding the evolutionary history of asteroids.

In the framework of two European Commission Horizon 2020 projects (NEO-MAPP and PIONEERS), we are developing two complementary in-situ geophysical instruments, designed specifically to fit inside a small asteroid surface package and function in the challenging environment of the asteroid surface.

Compact seismometer: This seismometer consists of three geophones that will each measure the ground motion along one axis, and dedicated analogue and digital electronics that are developed at ISAE-SUPAERO (Fig 1). The commercial sensors contain no active electronics and are designed to withstand extreme environments (e.g., terrestrial boreholes). During the Apophis Earth flyby tidal-induced quakes are predicted to have signals in the frequency range 1-100 Hz with amplitudes above 10^{-4} ms^{-2} $Hz^{-1/2}$. Our compact seismometer can image an asteroid's internal structure by measuring ground motion generated by such tidal quakes, but can also record other natural seismic sources (micro-meteoroid impacts, thermal cracking, … [6-7]) or artificial sources (such as the Hayabusa SCI-2 impactor [8]).



(a)



(b)

Figure 1. (a) Compact seismometer containing three geophones. (b) Breadboard of the acquisition electronics, developed at ISAE-SUPAERO as part of the NEO-MAPP project.

Compact 6 Degrees of Freedom instrument: The PIONEERS 6 Degrees of Freedom (DoF) instrument combines MEMS accelerometers and fiber optic gyroscopes and makes precise absolute measurements of the small body's rotational dynamics. The instrument is capable of measuring variations of asteroid rotation during the Apophis Earth flyby that are estimated to have signal amplitudes above 10^{-6} rads^{-1} Hz$^{-1/2}$ in the frequency range 10^{-5} – 10^{-3} Hz [9]. This instrument can also precisely measure the landing dynamics in order to probe the mechanical surface properties [1-3] and can be used for active seismic experiments (experiments with an active source such as the Hayabusa SCI-2 impactor [8]). In addition, this 6 DoF instrument can function as an IMU for a lander deployed on the surface and improve its navigation during its trajectory from the orbiter to the asteroid surface.

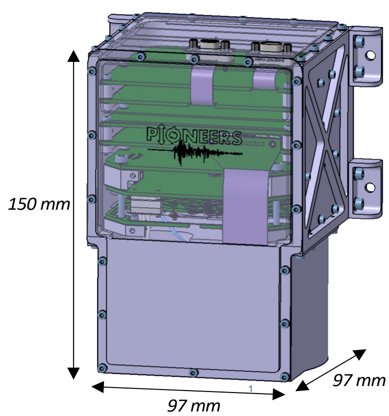


Figure 2. The 6 Degrees of Freedom PIONEERS instrument.

This presentation will discuss the design, status, performance and complementary nature of these two compact geophysical instruments that would be ideal for inclusion in a small lander to a target like asteroid Apophis. The proximity of the Apophis Earth flyby may allow for the precise determination of the asteroid's rotational dynamics with ground-based radar measurements [10]. We will discuss the synergistic measurements that can be performed, and how such ground-based radar measurements can be used to cross-validate the in-situ measurements made by the 6 DoF sensor. In addition, the high-rate measurements of the PIONEERS instrument may also provide new insights of the dynamics of the asteroid close to the Earth fly-by.

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