TOMOGRAPHY OF AN ASTEROID USING A NETWORK OF SMALL SEiSMOMETERS AND AN ARTIFICIAL IMPACTOR.

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INTRODUCTION

In the frame of the R&T study of the French Space National Agency (CNES), the simulations of the normal modes of spherical models of asteroids have allowed the study of their seismic response [1]. In this paper, we use our previous results to provide constraints of a seismometer that would investigate a kilometer-sized asteroid. We then present: 1) the optimal frequency band required for seismological investigation of spherical kilometer-sized asteroids, and 2) the maximum accelerations that could be registered by a sensor on a such body. We also propose a set of specifications for a short period seismometer to image the internal structure of a spherical kilometer-sized asteroid.

SPECIFICATIONS FOR A SEISMOMETER TO STUDY A SPHERICAL 1 Km ASTEROID

MODEL OF ASTEROID AND OF SEISMIC SOURCE

A spherical layered model (without lateral heterogeneities) has been chosen (Fig 1b). Its diameter is 1km. As a seismic source, a projectile of 400 kg (impactor of the Don Quijotte mission [2]) impacts the asteroid at the north pole with a velocity of 10 km/s. We assume seismometers are located each 5° of epicentral distance (Fig 1a).

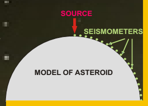


Figure 1a. Position of the seismometers and of the source

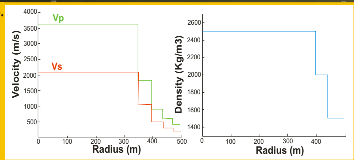


Figure 1b. Velocity and density profile of the model of asteroid.

MAXIMUM ACCELERATION

The computation of seismograms each 5° of epicentral distance on the model of asteroid has allowed the simulation of the curve of maximum accelerations as a function of the epicentral distance (Fig. 2). The amplitude of accelerations exhibits a decrease and a refocusing of the surface waves that varies as 1/sqrt(sin x) with x as the epicentral distance. The peak amplitude, 11 m/s² (in the Z component of the seimometer), is located at the source and at the antipode of the source.

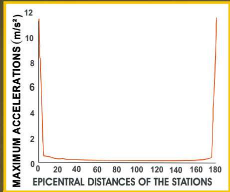


Figure 2. Maximum accelerations as a function of the epicentral distance

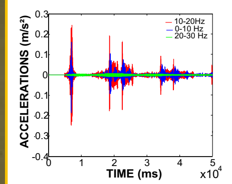


Figure 3. Seismograms at an epicentral distance of 45°, in several frequency bands

OPTIMAL FREQUENCY BAND

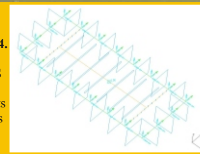
Maximum frequency : several seismograms have been computed with normal modes summed in different frequency bands. We observe (Fig. 3) that the maximum of signal occurs for frequencies up to 20 Hz. The biggest boulders observed on asteroids Itokawa and Eros are of 50m length (Chapman et al., 2002, Abe et al., 2006). If we want to prevent diffraction from these heterogeneities, a wavelength superior to 50m might be adopted. Then, the maximum frequency to consider sould be 50 Hz. **Minimum frequency**: the constraint on the minimum of frequency is known by the frequency of the gravest simulated mode. This value is ~1 Hz for our model of asteroid. Thus, we suggest an optimal frequency band of 1 Hz - 50 Hz for seismological investigations of a spherical kilometer sized asteroid.

ADEQUAT SENSORS TO BE DEPLOYED ON A 1 Km ASTEROID, AND SYSTEM DESCRIPTION

SYSTEM CONCEPT

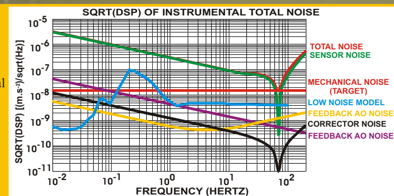
The proposed mission outline consists in a main spacecraft, an impactor (such as Don Quijotte or Deep Impact) and a set of micro penetrators. Each micro penetrator includes a high g accelerometer, a MEMS seismometer, a power and a telecom subsystem, enabled to live a few days. The system concept for the NEO mission would be as follows. (1) Deployment in advance of the set of micro penetrators: a few time before the impact, several micro penetrators would be deployed by an autonomous sub-spacecraft. Their telemetry would be on, so their penetration into the NEO regolith would be monitored. (2) A few seconds to minutes after the micro penetrators deployment, the main shock of the impact occurs on the asteroid. The data recorded will be used to allow a tomography of the inner of the asteroid. (3) After the shock, MEMS sensitivity is tuned to record potential thermal cracks activity in the asteroid. The mission finishes when the power source is exhausted or when the contact is lost.

Figure 4. MEMS finite elements models



Such mission would allow an important scientific return, complementary to radar sounding as foreseen in the Deep Interior NASA mission. As a matter of fact, it would provide a direct velocity profile, complementary to a dielectric profile provided by a sounding radar.

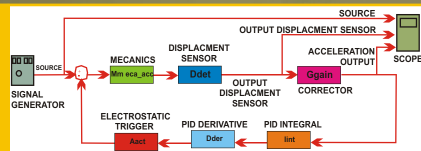
Figure 5. Instrumental noise modeling (and sub systems)



PRELIMINARY STUDIES

Preliminary trade-studies have been conducted to design such micro penetrators. The first trade that has been conducted was to choose between COTS geophones and MEMS seismometers developed by French DoE for its own needs. The MEMS development was chosen as more mass and power effective (Fig. 4, 5 and 6). The adaptation to our needs included a mechanical study to assess 0 g performances, shock resistance and thermal sensitivity. It included also the design of a feedback loop in order to assess the instrument electronics constraints, and the possibility to tune the sensitivity of the instrument along its various phases of life.

Figure 6. MEMS feedback modeling



ON GOING WORK

The next phase of the work has been funded by CNES for Y2007. We intend to follow two main tracks : **(1) Refinement of the requirements:** we will use more precise model, along with the spectral element method to issue an improved version of the requirements. The direct problem will be further analyzed, as well as the inverse problem (structure information can be retrieve from a small seismometers network deployed at the surface of a given model). (2) **Sensor development**: on a technological point of view, we will focus our study on the following tasks (a) improvement of the capacitive sensor electronics, (b) realization of an electronics breadboard to evaluate the performances of the seismometers, and (c) preliminary breadboarding of a power and telecom system to support the sensors.

CONCLUSION

We have computed the maximum accelerations and optimal frequency band on the surface of an elementary asteroid model. This study allows us to suggest a value of 11m/s² for the maximum acceleration, and an optimal frequency band of 1Hz-50Hz. These values have helped to issue a first set of requirements for a mission dedicated to the exploration of the interior of an asteroid, thanks to the deployment of a seismometer network. However, it should be mentioned that these values may significantly vary because seismic responses of asteroids are strongly dependant of their asphericity. Thus, synthetic seismograms of more complex models (a three-dimensional model of the shape of the asteroid Eros) will be simulated by the spectral element method [3]. Work is on-going on both requirement and technological sides.

REFERENCES: [1] Blitz, C. et al, (2006) EGU Annual meeting, abs. EGU06-A-06034; [2] Ball, A. J. et al, (2004) In Mitigation of Hazardous Impacts Due to Asteroids and Comets (eds., Belton, M.J.S. et al.), p. 266-291; [3] Komatitsch, D. et al, (2005) In Seismic Earth: Array Analysis of Broadband Seismograms (eds., Levander, A. et al.), p. 205:227.[4] Chapman, C, et al, (2002) Impact history of Eros: craters and boulders. Icarus, 155, 104-118, 2002. Credit:NASA/JPL-Caltech/T. Pyle (SSC)