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Autonomous active seismology on small body: science and implementation on the MARCO-POLO-R Mission

Seismic EGGS

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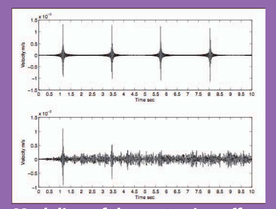
BACKGROUND

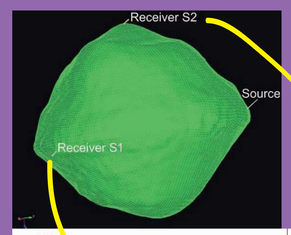
Small bodies like asteroids and comets can be strongly affected by the seismic waves generated by impacts, as the maximum acceleration of these waves are expected to exceed the local gravity. This phenomena, called seismic shacking (Richardson et al., 2004, 2005), remains however far to be understood, as no space mission has today deployed seismometers on a small body. Their detailed internal structure remains therefore unconstrained, as well as the seismic propagation properties, especially in term of diffraction in monolithic asteroids or transmission in rubber piles asteroids.
The MARCO-POLO-R project, if selected by ESA, could be the first to seismically explore a small body. It is targeted to a binary asteroid of slightly less than 800 m in diameter. We suggest that the mission deploy on this asteroid 3 fully autonomous surface modules (EGGS) weighing 1kg each, carrying 150g of explosive and equipped with 3 axis geophones. A total mass of 5kg for the entire experiment on the spacecraft is then the target.

SIMULATION: Active sourcing

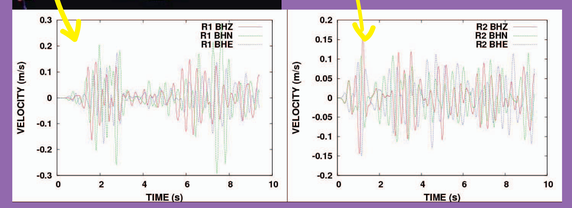
Estimation of amplitude from active source for spherical model:
- point force equivalent to 16 x 10^3 Ns (5kg at 3.2km/s or 5 kg blast)
- 50Hz cutoff (~ 10^-4m/s ground velocity)

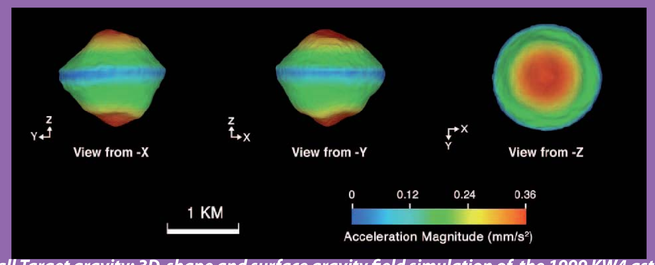


Modeling of the scattering effects by normal modes summations



Estimation of amplitude from active source for 3D model and SEM seismic waves modelling (Blitz, 2009)

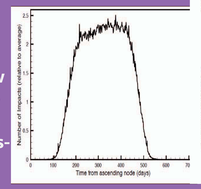


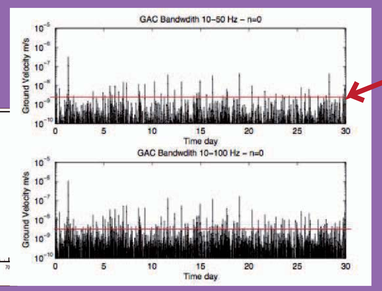


Typicall Target gravity: 3D-shape and surface gravity field simulation of the 1999 KW4 asteroid (Ostro et al, 2006, Scheeres et al., 2006), weight MARCO-POLO-R Mission equivalent target.

EXPERIMENT Philisophy

As on the Moon (Lognonne et al, 2009), the background noise is associated to the steady impacts of micrometeorites. But even if the expected sensitivity of the sensors is compatible with the detection of several impacts per week, the experience is not supposed to last more than 48 hours. This is the estimated required time to fire two of the three EGGS in a stabilized window. During this time, all the landed and survival EGGS will send continuous Datas through a low power UHF/VHF link to the spacecraft in order to export them back to Earth. Therefor, the seismic experiment is Active but with a Passive survey.





SENSITIVITY ISSUE

* Nominal explosion ~10^-4 m/s @ 50Hz
  - OK for body waves sounding the interior
  -will return constrains on the possible rubble piles structure
  -but coupling issues might occur when direct surface waves will reach the pod
  -subsurface sounding by cross-correlation of the diffracted surface waves (e.g. Larose et al, 2005)

* 1 gr impact at 5 km/s (3200 smaller) ~ 3.10^-8 m/s @ 50Hz
  -OK for surface waves
  -will return constrains on the shallow layers

* 1 mg impact at 5 km/s (1000 smaller) ~0.3.10^-10 m/s @ 50Hz
  - Feasibility of cross-correlation techniques for extraction of the green function of one pod with respect to the other

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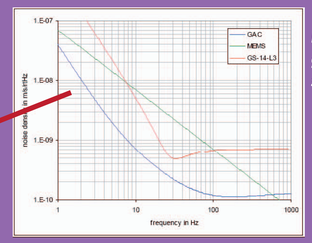
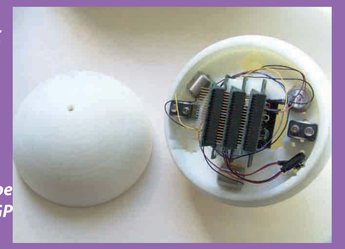
TECHNICAL ISSUE

The two main challenges for the seismic mission are to have sensitive and light sensors and to deploy the latter in a way allowing pertinent seismic measurements of the surface vibrations. Instead of a design based on seismic coupling by harpoon or spike, the EGGS have been designed to play the role of test particules, comparable to the small boulders of the regolith, in order to measure the typical local acceleration when surface explosion (or impacts) are affecting the asteroids. Due to the small size of the asteroid, the seismic wave bandwidth is high (e.g.10-500 Hz) and therefore comparable to those of resource seismic exploration on Earth. We plan therefore to use proprietary geophones developed by Schlumberger called GAC. Initially designed for harsh environment, the later have been qualified to the vibration levels of a space mission (ECSS Standard ESA-PSS-802, plus three dB margin), and an ongoing qualification program is in progress to achieve their qualification for the other environment specifications.

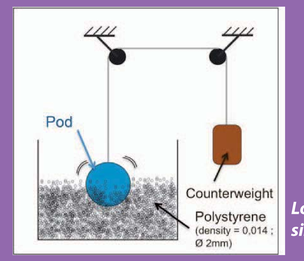


Noise of the Schlumberger GAC geophone compared to other sensor types.



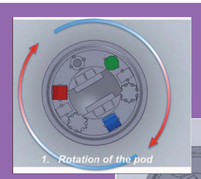
3-Axis G-Pod prototype developped at IPGP

LOW-GRAVITY COUPLING TECHNIQUE

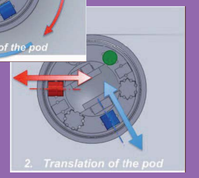


Low gravity and dust simulation testbench

Procedure experimentally tested to try to improve the coupling between an EGG and the asteroid by actuating the seismic geophones sensors with small acoustic signals.



Vibration axis proposed by the geophones used as actuators



Dust and eperimental EGG motion during a vibrating phase