To measure the chemical composition of a Near Earth Object

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Introduction. Scenarios for a Near Earth Object (NEO) rendezvous mission were discussed recently in Europe. Such a mission would address scientific questions about the initial conditions and evolutionary history of the solar nebula, as well as mitigation considerations to prevent impact with the Earth. In our opinion the measurement of the elemental composition and the distribution of volatiles in the shallow sub-surface are two of the key observations to be conducted, either from an orbiter or a lander. These measurements are also valuable for documentation (landing site candidates and sample context). This report is limited to the chemical composition, but we assume that remote and/or in-situ observations of physical characteristics, interior, morphology, mineralogy, and organic compounds will also be made as essential complements to achieve the mission scientific objectives.

Scientific Interest. The analysis of the bulk composition addresses three fundamental aspects of the scientific mission: (1) the formation of the asteroid or the comet; (2) the evolution of the object; (3) the relation between the parent body and collected meteorites on Earth.

Classification of an asteroid/comet can be based on its global composition (abundances of Mg, Si, Fe, Al, Ca, etc. along with its mineralogy), which bears the signature of the feeding zone where it formed. For example the K/U and K/Th ratios seem to increase with distance from the Sun (decreasing temperature). The hydrogen content is another measurable to study the distribution of volatiles in the Solar System.

The surface composition is also the result of the degree of evolution of the object and of the interactions with its environment. Building a compositional map of the major elements is necessary to identify and characterize the processes that influenced the asteroid along its history.

Finally, knowing the chemical composition will obviously help to relate the parent body to meteorites. Ideally the measurement of specific isotopes, including O, C and those produced by the exposure to the cosmic rays, such as ^{38}Ar or ^{21}Ne, can pinpoint to the family of meteorites, but such measurements are challenging with restricted resources.

Instrument Payload Options. To define the most appropriate instrument(s) in terms of scientific return and technical constraints, various solutions have been studied. For the orbiter this includes an X-ray spectrometer with a solar monitor, and a gamma-ray spectrometer with a neutron sensor. For a lander, it has been demonstrated that an active X-ray spectrometer gives outstanding results for very low resources. If mass is available in the frame of an ambitious mission, one can consider active experiments such as a laser-induced breakdown spectrometer, a mass spectrometer (needing sample manipulation, a laser ablation system, or an ion source), or evolved gas analyzers. It is very difficult however to baseline the use of active experiments from the orbiter (very close fly-bys) such as those on board the *Phobos* missions.

On the one hand the main constraints on the lander are related to the resources (mass, power, volume) and possibly the need for target contact/manipulation. On the other hand the difficulties from the orbiter are the sensitivity to prioritized chemical elements and the mapping resolution (e.g. of the order of 1/10 of the altitude for X-rays, and equivalent to the altitude for gamma-rays). Remote-sensing experiments have been evaluated from that perspective; It is possible to estimate the accumulation time needed to reach enough precision: of the order of 1 h for X-rays and several hours for gamma-rays above each pixel (defined by the spatial resolution, see above). In a classical orbital mission scenario these numbers translate into several weeks of observations (more than 1 month). Lessons learned from previous missions (*Apollo, Lunar Prospector, NEAR, Mars Odyssey, SMART-1*) are also taken into account: the difficulty to monitor the solar activity for the X-rays, the low signal to noise ratio for the gamma-rays. Previous experiments were successful when the ratio orbit-radius over body-radius was about 5-7 for X-rays and less than 2 for gamma-rays. All these points put strong constraints on the operations to measure properly the chemical composition of a NEO.