Conceptual Study of Small Active Seismic Exploration Package on Moons and Small BodiesT. Kawamura[1], Y. Ishihara[2], K. Ogawa[3], T Tsuji[4], T. Kobayashi[5], R. Yamada[6], A. Araya[7], S. Tanaka[2], N. Takeuchi[7], [1]National Astronomical Observatory of Japan(e-mail: t.kawamura@nao.ac.jp 2-12 Hoshigaoka-cho, Mizusawa-ku, Oshu-city, Iwate, Japan 023-0861), [2]Institute of Space and Astronautical Science/Japan Aerospace Exploration Agency, [3]Kobe University, [4]Kyushu University, [5]University of Fukui, [6]University of Aizu, [7]Earthquake Research Institute.

Introduction: Seismic exploration is a powerful tool to probe inner structure of planetary bodies. Developing a seismic observation package that is compatible with small to middle size spacecraft will open a new window to investigate deep interior of planetary bodies including asteroids and small satellites such as Phobos. We have been designing and developing a seismic observation package with 3 axes seismometers, active seismic source and anchoring system. This was originally designed for Japanese Martian Moons eXploration (MMX) Mission. We were not selected for the nominal payload but the selection process of optional instruments is still ongoing. Here we will present the basic concept of our seismic observation package and describe each subsystem.

Seismometer: For the seismometer, we take advantage of the heritage of Japanese Lunar-A mission where short period seismometer was developed as the principal payload. The Lunar A SP seismometer is an electromagnetic sensor that includes a pendulum with a moving coil and a magnet fixed to the outer case[1]. Its performance is already verified and its Technology readiness levels (TRL) are high compared to other subsystems[2]. In our current design, we plan to have 2 horizontal and 1 vertical axes but other configurations such as a single vertical axis is also possible.

In addition to the previous design, we are developing a new feedback for higher sensitivity at lower frequencies. Current sensitivity of the SP seismometer decrease below 1 Hz but with new feedback, the sensitivity stays high down to 0.1 Hz[1]. This enables us to approach the frequency band of Phobos normal modes. Accessing to the normal modes of Phobos will help us probe the global structure of Phobos with single seismic station. In addition to this enlargement of the frequency band may enable us to detect surface waves. By not only detecting body waves but also surface waves expands our possibilities to probe subsurface structure with various seismic methods.

Active Seismic Source: One of the difficulties of seismic observation is that its achievement is strongly dependent on events that are detected with the seismometers. Thus in many cases, long observation periods are required to ensure the quality and number of events to be used in seismic analyses. This is not always possible with limited resources of space missions. Instead of requiring a long observation period, we propose to bring an active seismic source to explore structure under the landing site. Active seismic observation was already performed in previous space missions such as Apollo[3] or Rosetta[4]. These active experiment used either explosives or mechanical hammering as the seismic source which we can control the time, location and energy of the source. In addition to this, we are aiming to control the waveform of the seismic source. This is a well-developed method in terrestrial seismology known as ACROSS (Accurately Controlled Routinely Operated Signal System)[5]. On small bodies such as Phobos, the excitation force is limited to the surface gravity and how we improve the S/N ratio is an important issue. By controlling the waveform of the seismic source we can search for the reflected signal through cross correlation method. In addition to this, we can stack the signal to improve the S/N ratio. This will significantly improve the possibility to probe deep into the planetary body with relatively small excitation of the active seismic source. With surface excitation of 10^{-3} m/s^2, which is smaller than the surface gravity of Phobos with some margin, we expect that we can probe down to 200-800m depths depending on the surface physical properties.

Anchoring Mechanism: One of the major problems in planetary seismic observation is the coupling between the instruments and the ground. In low gravity condition, instruments can be decoupled from the ground more easily compared to the terrestrial case. This will be an important issue especially for active seismic source. The stronger the excitation is, the deeper we can explore with the experiment. In addition to this, stability of the waveform generated with the seismic source will be an important factor for cross correlation and stacking method. Thus, to have an efficient and stable excitation, we need to maintain well-coupled condition of the seismic source.

We will do this by installing the seismic source inside one of the feet of the installation system. This foot has a screw that drills into the regolith layer and anchors the instrument on the ground. The foot has a motor installed on the top and will penetrate into the regolith by 10 - 20 cm. Once the penetration is complete, the motor rewinds in the other direction and decouples the drill head including the seismic source to avoid the reverberation of the thermal shielding around the seismometer.

Mission plan for Martian Moons eXploration (MMX) Mission: MMX is a sample return mission to Phobos planned to be launched in 2024. It will be in quasi-stationary orbit at Mars/Phobos/Deimos system and will be touching down on Phobos twice to sample surface material. While nominal instruments mainly focus on remote sensing observations, we are proposing to use the touch down opportunities to install a geophysical station on Phobos. As a part of the geophysical station, we are developing a seismic observation package that will carry out active and passive observation during the mission. The seismometers and other subsystems will be installed in side Mission Survival Module (MSM) who is responsible for thermal shielding, power supply, and communication with the spacecraft. The seismometer will be deployed on the ground with MSM during the touch down phase.

The first target of the experiment will be a shallow structure up to 100 m where we expect to see physical and seismic property of porous regolith under very low gravity. The surface of Phobos is expected to be covered with thick regolith layer and most of the returned sample from the mission will be sampled from the regolith layer. Clarifying the structure and layering of the regolith layer will be informative to understand how much the returned sample is representative of Phobos. The second target will be the deep structure up to 1 km or more. This is to probe the non-contaminated region of the Phobos and search for indication of water ice inside Phobos. Existence of ice will be an important information to constrain the origin of the satellite. At the same time, we need to go down hundreds of meters for the water ice to be stable on Phobos[6] and seismic observation will provide a way to probe down to the deep inner structure where water ice may be stable.

Seismometer will be operated in two modes designed for active and passive observation. For active observation, seismometer will be operated in low gain mode so that it will not saturate with the seismic source near by. Since the distance between the seismometer and the seismic source is short we need a high sampling rate to resolve the travel time of direct wave. On the other hand, for passive observation, we switch to high gain-low sampling mode so that we can continuously monitor the surface seismic activity and detect seismic signals that may be very weak.

The seismic observation package is now under development for the selection and review for optional instruments. While the seismometer is very mature in terms of TRL, active seismic source and the anchoring system is still at a level of conceptual examination. We will be developing our first proto-type to test and fix our design. While the we are designing the instruments to meet the requirements of MMX, the system shall be made robust to be compatible with other space missions and we will continue to search for possibilities for launch opportunities.

References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

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