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# Spectral Analyses of Lunar Seismic Events with LP-SP Combined Spectrum

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## Abstract

Source parameters of lunar seismic events are key pieces of information to understand their dynamics. In this study we examine spectral features of lunar seismic events by combining the long period and short period seismometer data from Apollo Passive Seismic Experiment. By combining the two data, we will study the spectral feature of lunar seismic events with broader frequency range. Thus it is expected to give us better-constrained source parameters compared to previous studies, which mainly used one component of the seismometers. As the preliminary analyses, we created the combined spectra for artificial impacts and estimated the corner frequency.

## 1. Introduction

Seismic activities of planets and satellites are one of the most important sources of information to know the states and dynamics inside the celestial bodies. Apollo Passive Seismic Experiment observed lunar seismic events for more than 5 years and provided us with important information of the Moon [1][2]. However, since the observation was limited, there are still questions left unsolved. In this study, we propose a new approach to investigate the source parameters of the seismic events through spectral analyses and try to give better constraints on source mechanism on the lunar seismic events.

## 2. Combined Spectrum

Estimations of source parameters of lunar seismic events were first done in Apollo era. Goins et al. (1981)[2] estimated seismic moment, stress drop, and seismic energy release through investigations of shallow and deep moonquakes. More recently, Lognonné et al (2009) [3] proposed source models for impacts, by taking into account the effect of ejecta. However, above 1 Hz, the result may contain large errors according the uncertainty of the estimations of corner frequencies. One limitation of the Apollo seismic observations was their frequency ranges. Apollo observation had 3 axis long period (LP) seismometer (center frequency: ~0.5Hz) and one vertical short period (SP) seismometer (center frequency: ~8Hz). Goins et al. (1981) mainly used LP data to for deep moonquakes and SP data for shallow moonquakes. Thus their estimation of corner frequencies are from limited frequency range and uncertainties in identifications of corner frequency may be large. For better identification of spectral features, especially corner frequencies, we used both LP and SP data in our calculation. Since there were both LP and SP seismometer for vertical axis, it is possible to combine the data from two seismometers and examine the spectral features of seismic events in broader frequency range. This was done by finding the most probable spectrum through least square fit with both LP and SP spectra. The example of the combined spectrum is shown in Figure 1. Comparison with the background noises shows that the seismic signals has power from about 0.35 – 8 Hz and it implies the detailed analyses from both LP and SP data is essential for better understandings of the spectral features.

## 3. Estimation of Source Parameters

To estimate the source parameters from the obtained spectrum, we compare the observed data from theoretically estimated spectrum. We assume that the observed spectrum consists of seismic signal, noise, and attenuation. The attenuation can be calculated when we assume the inner structure [4][5] and the seismic source. This can be written as

$$S(\omega) = S_0(\omega)\exp\left(-\frac{\omega t}{2Q}\right). \qquad (1)$$

$Q$ is the quality factor inside the moon and the $t$ is the travel time. For the noise, we took the data without seismic events and estimated the noise level. In this analysis, we used the data just before the seismic events as the noise. The spectral features of the lunar seismic events are most questionable but here, we use the analogy from terrestrial seismology and omega square model [6] for moonquakes and modified omega square model for impacts. The modification was from the difference in source function between moonquakes and impacts. The function is expressed as

$$S_0(\omega) = \frac{I\omega}{\left[1 + (\omega/\omega_c)^{n\gamma}\right]^{1/\gamma}} \qquad (2)$$

for impacts. Here, $I$ is the value proportional to the impact energy and $\omega_c$ is the corner frequency.

# 4. Results

As the preliminary result we fitted the model spectrum to the spectrum of artificial impacts. Figure 2 shows example of the artificial impact of Apollo 17 SIVB observed at Station 16. The spectrum calculated from the model gives good consistency with the observed spectrum. From the fit, the corner frequency is estimated to be 1.8Hz, which is higher than the previous estimation from LP data [2]. From the analogy with terrestrial seismology corner frequency is higher for low magnitude events. Thus it is possible that for small magnitude events, the corner frequencies are higher and we need to use SP data for their estimation.

# 5. Conclusions and Summary

We investigated the spectral feature of lunar seismic events with combined spectrum of LP seismometer and SP seismometer of Apollo Passive Seismic Experiment. This enables us to see the spectral feature in broader frequency range compared to previous studies and it is expected to give us better-constrained source parameters of the lunar seismic events. The analyses of artificial impact implies a corner frequency higher than previous estimation and it is suggest that we should study the spectral characteristics with both LP and SP data. Due to the much better expected sensitivity of the sensors, future missions, such as SELENE2 [7] and possibly US missions (e.g. ILN or LUNETTE) will allow us to study these effects with a much better resolution.

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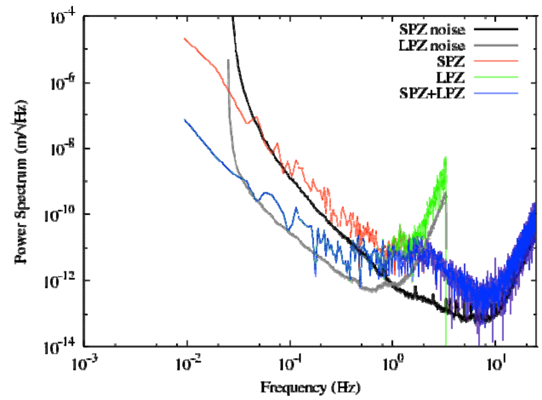


Figure 1 Combined spectrogram made from Apollo 17 SIVB impact observed at Station 16. By combining the two spectra, we can see the spectral feature in broader frequency range.

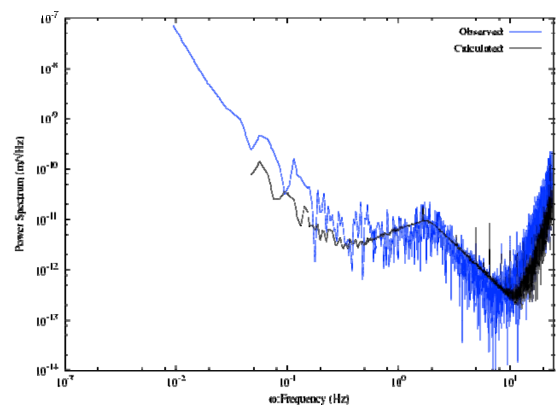


Figure 2 Observed spectrum (blue) and theoretically calculated spectrum (black). The corner frequency estimated from the fit is ~1.8 Hz.