INVESTIGATING SUBGROUPS IN THE A1 DEEP MOONQUAKE CLUSTER USING SCATTERING TRANSFORMS. A. S. Khatib¹, N. C. Schnerr¹, V. Lekic¹, and R. C. Weber², ¹University of Maryland, College Park (akhatib1@umd.edu), ²Marshall Space Flight Center, Huntsville, AL

Introduction: The Apollo Lunar Surface Experiment Package (ALSEP) recorded lunar seismic activity continuously between 1969 and 1977 [1]. The seismic data contained signals of deep moonquakes, or repeating signals with distinct waveforms originating from distinct source regions in the lower mantle. Here we explore the ability of scattering transforms to characterize systematic differences in waveforms of events in the A1 deep moonquake cluster. Our goal is to exploit these differences by training an algorithm to (re)classify known deep moonquakes across clusters and their subgroups, and ultimately to identify new deep moonquakes clusters in the Apollo seismic data.

Background: The ALSEP comprised 4 seismic stations placed on the near side of the moon between 1969 and 1972, and continuously collected seismic data and transmitted it in real-time back to Earth until instrument shut-off in 1977 [1]. In that time, the network detected approximately 12,000 seismic events, the most numerous of which are deep moonquakes on the long period seismometers. Deep moonquakes (DMQs) are repeated lunar seismic events occurring at focal depths between 800 km and 1200 km [2]. These events originate from 319 source regions, or clusters, and are observed to have 13.5-day, 27-day, and 206-day periodicities, indicating that the build-up and release of tidal stresses caused by the interaction between the Earth, Moon, and Sun play a role in the DMQ source mechanisms [3]. DMQ events have been valuable for determining lunar interior structure, as their arrival times can be used to derive mantle P- and S-wave velocities [4] and other body waves, such as core reflections [5].

The identification and classification of events in the ALSEP data was initially conducted using visual inspection of day-long seismograms [1]. Computational advancements have enabled the application of new techniques that identified more DMQs: a combination of waveform cross-correlation and cluster analysis positively identified 5905 new moonquakes and 88 new DMQ nests [6], and a cross-correlation algorithm combined with an algorithm to de-glitch Apollo data resulted in 123 new events for the A1 DMQ cluster alone [7]. Challenges common to all techniques are the low signal to noise ratio of DMQ waveforms, and instrument glitches that create spikes and/or gaps in the data time series.

Methods: Wavelet scattering transforms [7] are an adaptation of traditional machine learning techniques like convolutional neural nets and are designed to analyze and classify high-dimensional data. In a scattering transform, an input signal is convolved with a family of complex wavelets that span all of frequency space; the modulus is taken of the convolution, which, when done iteratively to the second or third order, yield a set of coefficients that extract summary statistics carrying relevant information from the original data [8].

443 events of the A1 DMQ cluster were identified in the most recently updated lunar seismic event catalog [9, 10] and recorded on the Apollo 12 long period three-component seismometers. Each of the seismic records are filtered and the instrument response is removed to return the information in terms of acceleration. Scattering transforms will be calculated for each trace to the second order, which will extract information beyond just the power spectra of each time series. t-distributed stochastic neighbor embedding (t-SNE) will be used to cluster related events using their scattering transform coefficients. This presents an opportunity to identify any subgroups exist in the A1 DMQ cluster, or if all events identified through cross-correlation have no statistically significant differences in their coefficients.

Significance: Using wavelet scattering transforms to identify subgroups within the A1 DMQ cluster is the first step to analyzing possible subgroups and additional clusters within the rest of the DMQ clusters and identifying new DMQs in the Apollo seismic data. Reclassifying existing DMQs could help refine the locations from which these seismic events originate, and potentially identify new patterns in their frequency of occurrence, which would improve our understanding of the relationship between the DMQ source mechanisms and tidal stresses. Finally, scattering transforms could offer a powerful, automated approach to identifying new deep moonquakes in future seismic data returned from a Lunar Geophysical Network or seismometers deployed by Artemis astronauts.