LUNAR SEISMIC IMPACT CLUSTERS - EVIDENCE FOR THE PRESENCE OF "METEORITE STREAMS"; J. Oberst and Y. Nakamura, Institute for Geophysics, The University of Texas at Austin, Austin, Texas 78751.

Introduction. We are performing an in-depth analysis of the meteoroid impacts detected by the Apollo seismic station network. Here, we focus on clusters of impacts detected by the network. In particular, we raise the question whether "meteorite streams" (showers of meteoroids that can survive a terrestrial atmospheric entry and may be represented in our meteorite collections) exist.

Statistical Methods for Detection of Impact Clusters. We took various measures to improve detection of clustering within the background noise of sporadic impacts. First, we considered separately the impact events of low- and high seismic amplitude. We have shown that both groups mostly represent different meteoroid families (1). Hence separate consideration of both groups may considerably improve recognition of clusters within each of these groups.

Various tests were used to verify the statistical significance of clustering. The simplest test is to count the number of impacts detected within certain time intervals and to compare this number with the average number of impacts expected to occur in these intervals. A shortcoming of this method is that the expected average impact rates must be known for given intervals. Unfortunately, the impact rate for both large and small impacts strongly varies with the time of the lunar day. A test which overcomes this problem is the Anderson-Darling statistics (2,3). The Anderson-Darling statistics analyzes a sequence of impact events and gives the probability for this sequence to be caused by a random process. An a priori knowledge of the average impact rate is not needed. The test is often used in earthquake statistics for detection of earthquake swarms, foreshocks and aftershocks.

Further, we take advantage of the long duration of the lunar seismic experiment. Showers of meteoroids may be intercepted by the moon repeatedly in different years. This suggests that observations of impacts at the same seasonal times of the year may be "stacked" (added) in order to improve recognition of possible yearly showers. Since showers may be missed in years in which the front side of the moon (where the seismic stations are located) does not face the shower, we must simultaneously consider impact times with respect to both time of the year and lunar phase (see (1), Figures 2, 3, and 4 for details). Using nearest-neighbor statistics (4) clustering in this two-dimensional grid can be identified.

Results. Several clusters are detected, most of which correlate well with the fall times and radiants of known meteor showers. An extraordinary cluster represented by an unusual number of large-amplitude impact events is detected in June 1975 (5). We therefore suggested earlier that this cluster contains stony material; i.e., the cluster represents a "meteorite stream" (1). Nevertheless, the seismic data do not rule out the possibility that these meteoroids represent very large, but fragile, objects which would not survive the terrestrial atmospheric entry, and thus would not be represented in the meteorite collections. However, our hypothesis received strong support when we found that the "Farmington" meteorite with its exceptionally young radiometric exposure age of $t < 25{,}0000$ years shows a fall time and a radiant in agreement with the fall time and direction of approach of the lunar meteoroids (6). Hence, the meteorite may well be a former member of this lunar meteoroid shower.

Another hitherto unrecognized candidate of a "meteorite stream" encountered the moon in

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January 1977. This small cluster contains 8 large-amplitude impact events detected by all stations in the network over a period of a week (Figure 1). Compared with the above mentioned cluster these impacts are even more likely to represent encounters with meteorites for the following two reasons. (a) The shower appears to approach from the antapex of the earth-moon system. This radiant is quite unusual for cometary meteor showers, but is often observed in the case of meteorite falls (7). (b) Since the meteoroids approach from the antapex, their encounter velocity must be very low, because they must catch up with the full orbital speed of the earth-moon system. In order to generate large-amplitude seismic signals in spite of a low encounter velocity the meteoroids must be either especially massive, very dense, or both.

Implications. If the lunar meteoroids in the second case are indeed of a type represented in our meteorite collections, a problem arises. Most meteorites show radiometric exposure ages $t \geq 10^6$ years, which is in contrast to the common view that showers of meteoroids, can remain coherent only for a time on the order of $t \leq 10^4$ years. It is not likely that these meteorites represent species of a short exposure age ($t \approx 10^4$ years), as in the case of "Farmington", since meteorites of such short exposure ages are exceedingly rare. Must we therefore discard the possibility of the detected objects being meteorites?

Meteorite swarms in orbits that are in resonance with the orbit of Jupiter may offer a solution to this paradox. Such meteorite swarms may remain coherent for a much longer time than is commonly believed to be possible (8). Hence, our identified meteorite swarm, if residing in a resonant orbit, may be quite old and our interpretation that the lunar meteoroids represent a "meteorite stream" is no longer in conflict with the high meteoritic exposure ages.

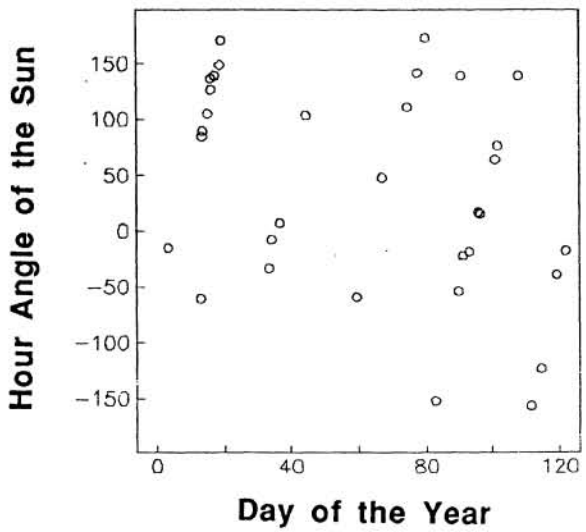

Figure 1: Large-amplitude meteoroid impacts detected in 1977 in a small section of the time-of-year time-of-the-month (lunar day) space (see (1) for a sample of a complete section). Note that in this plot a group of meteoroids impacting the moon from a common orbit will show up as a linear cluster of events centered around the direction of approach of the meteoroids. This is the case for the impact cluster in discussion, upper left corner, which occurred around day 20 (January) at an hour angle of the sun from 80 to 180 degree (from lunar late afternoon to midnight).

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