National Aeronautics and Space Administration

Radar detection of cm-sized exoatmospheric meteoroids

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Objectives

Our first objective was to expand on techniques used in radar observations of the near-Earth asteroids (NEAs) and Earth-orbiting space debris particles in order to detect meteoroids from the most active meteor streams such as Orionids, Leonids, Geminids, Ursids, Quadrantids, eta Aquarids, and Perseids [1]. Our second objective was to estimate the size-frequency distribution of the particles in each stream. Our third objective was to produce an unbiased (from the atmospheric passage) meteoroid speed distribution by measuring Doppler offsets of the detected particles. Our fourth objective was to estimate the radar scattering properties of the meteoroids and to establish how uniform they are within each meteor stream and if they differ between different streams.

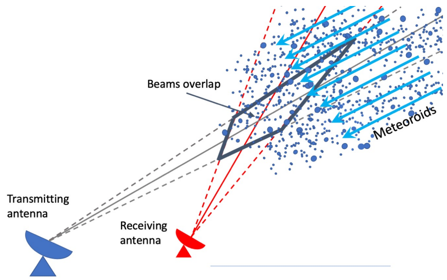

Figure 1. Bistatic radar experiment design. Both the transmitting and the receiving antennas are pointed to have their beams intersect at a certain distance, from several hundred to a few thousand km, in the direction of meteor stream radiant. The incoming meteoroids are parallel to the radar line of sight. They can be detected during the short time it takes them to cross the length of the overlap between the two antenna beams (area marked in bold).

Approach and Results

Our observations require two antennas, one for transmitting and one for receiving (**Figure 1**). The antennas point toward the meteor stream radiant (point in the sky from which meteors appear to emerge). We successfully observed the eta Aquarids in 2021 May and the Perseids in 2021 August. The eta Aquarids are associated with comet 1P/Halley, and their velocity is ~65.5 km/s with respect to Earth [2]. As such, we expected to detect their signatures, in a form of transient spikes, at ~3.74 MHz in Doppler frequency assuming that the antennas pointed parallel to the incoming particles. **Figure 2** shows a histogram of candidate events in the echo power spectra obtained on 2021 May 6. This was the first evidence of exo-atmospheric meteoroids and direct measurements of their velocities. We observed Perseids with the same setup on two days in August. The Perseids are associated with comet 109P/Swift-Tuttle, and their velocity is ~57–59 km/s with respect to Earth [2,3]. We expected to detect Perseids at ~3.37 MHz. **Figure 3** shows a histogram of spikes in the echo power spectra obtained during observations on 2021 August 11. We noticed a spike in the number of events at 3.273 MHz (57.4 km/s) in all collected data sets. We strongly believe these features represented meteoroids, likely sub-mm in size.

Background

To date, all meteoroid flux measurements come from either optical (direct lunar or atmospheric Earth impacts) or atmospheric radar observations of meteors. Results depend on models that convert the energy of meteor ionization trail or optical flash into the mass and/or size of the impacting particle. Similarly, measurements of meteoroid speeds depend on models accounting for gas drag. The innovative aspect of this task is that we propose to use planetary radar to detect meteoroid particles outside the atmosphere, in the near-Earth space, and thus avoid the usual observational and modeling biases.

Significance/Benefits to JPL and NASA

Meteoroids provide insight into their cometary and asteroidal parent bodies and into the dynamical evolution of grains in the solar system. Study of meteoroids aligns with the US National Space Policy objective to track and characterize near-Earth Objects. Large meteoroids pose a known hazard to spacecraft (physical damage, momentum transfer, electrical anomalies) and any direct measurement of their flux is of interest to Earth-orbiting spacecraft and human missions.

Our project was affected by hardware issues at the DSN antennas, so we did not obtain most of the planned data. However, we obtained first unbiased measurements of the line-of-sight velocities of meteoroid particles for the eta Aquarids and Perseids. These findings can provide insights into meteor stream formation and dust evolution.

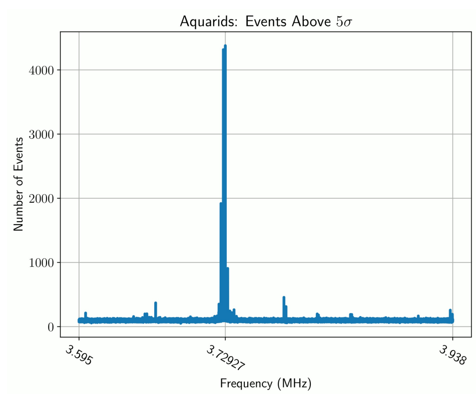

Figure 2. Candidate detections (above 5σ from the noise floor) of meteoroids from the eta Aquarid meteor stream on 2021 May 06 11:05:22-13:15:33 UTC. The spike with events at ~3.73 MHz corresponds to 65.3 km/s. The smaller spikes are likely noise.

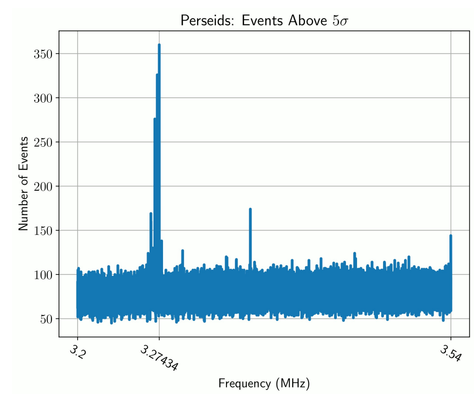

Figure 3. Candidate detections (above 5σ from the noise floor) of meteoroids from the Perseid meteor stream on 2021 Aug 11, 12:00:18–13:44:27 UTC. The spike with events at ~3.27 MHz corresponds to 57.4 km/s.

References

[1] Jürgen Rendtel, "2021 Meteor Shower Calendar," *International Meteor Organization*, https://www.imo.net/files/meteor-shower/cal2021.pdf; [2] Peter Jenniskens," The established meteor showers as observed by CAMS," Icarus 266 (Mar, 2016): pp. 331-354.; [3] Eugene Mroz, Denis Vida, Paul Roggemans, "Comparison of two meteor trajectory solvers on the 2020 Perseid shower," eMeteorNews 6 (Jan 2021), pp. 39-43.

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