Low-Altitude Radar Meteors and Bolide Langmuir Waves

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We introduce observational evidence obtained using the co-axial 430 MHz and 46.8 MHz radars at Arecibo Observatory for meteoroid flare processes that produce radar detectable scattering 1-2 kilometers from the point of the flare on the meteoroid trajectory through the atmosphere. While several such events have been observed, we concentrate on one particularly interesting event observed with both radars. For this ~90 km event, the head-echo at both frequencies is indicative of multiple fragments and of flaring based on the approach described by *Mathews et al.* [Extensive meteoroid fragmentation in V/UHF radar meteor observations at Arecibo Observatory, *Geophys. Res. Lett.*, *37*, L04103, 2010]. The UHF radar meteor head-echo yields evidence of two major fragments but did not show the flare while only the much less sensitive but wider-beam VHF radar observed the unusual non-thermal scattering as well as complex fragmentation and the flare. For this event the flare and the resultant non-thermal scattering were well defined in the Range-Time-Intensity results and together point to an apparent propagation speed of the process giving rise to the scattering of 50-100 km/sec. This is far too fast for shock waves thus pointing to intense plasma waves generated in the presumably "explosive" termination of a meteoroid fragment that produced the intense, well-defined radar flare-echo. We assume that the plasma "waves" generated by the explosive flare propagate in the trail-plasma "waveguide" and produce strong, highly non-thermal perturbations in the distribution of the trail-plasma thus engendering the observed strong VHF radar scattering from 1-2 km above the flare. We note convincing recent reports [Obenberger et al., Altitudinal dependence of meteor radio afterglows measured via optical counterparts, *Geophys. Res. Lett.*, *43*, 2016 and references therein] of transient HF/VHF radio emissions seen from the LWA1 (Long Wavelength Array prototype) and as identified as originating from along the trajectory of optical bolides observed by a network of meteor cameras. *Obenberger et al.* attribute these emissions to mode conversion to RF of Langmuir waves in the large gradients of the trail plasma. We agree with this assessment and, based on our non-thermal scattering results, further suggest that the meteoroid flaring generates these waves and also that the waves are contained within the trail-plasma waveguide thus limiting dissipation. Additionally, we show hybrid interferometric, compressed sensing imaging-radar observations of complex lower altitude fragmenting/flaring meteor events observed at the Jicamarca Radio Observatory. These observations suggest how meteoroid flare-plasmas evolve.