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Detection and Characterizationof Meteor Shockwaves Using Radar Observed Meteor Head Echo/Height Correlation

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1. Extended Abstract

All optically detectable meteors, as well as many of the stronger radio-detectable meteors, produce shockwaves prior to their terminal stage in the MLT (Mesosphere-Lower Thermosphere) region of the atmosphere, at altitudes between 75 km and 100 km [1]. The strengths of the meteor-generated shock waves depend on meteor atmospheric velocities and the values of the relevant Knudsen number. However, practical detection and determination of the altitude of formation of these shock waves have not been possible up to this point because of their rapid spatial and temporal attenuation, as well as the presence of radiative phenomena that extend to the meteor wake. Moreover, while shockwaves generated by bright meteors in MLT appear during the transitional flow regimes, good estimates of the relevant meteoroid parameters (such as velocity, shape, bulk density and size), and the altitudes at which shock waves are generated, remain elusive. This is largely because of the uncertainty introduced by the presence of ablation-amplified hydrodynamic shielding, which subsequently alters the considerations of the flow regime.

To address this, we consider measurement of the radar detectable meteor head echo (MHE) termination altitudes [2]. The size of MHE plasma radius depends upon altitude, and it scales with the atmospheric mean free path and meteoroid velocity. Thus the MHE termination altitudes are also strongly correlated with meteoroid parameters and the flow regime, and could be used to indicate the formation of the denser hydrodynamic shielding and flow fields around a meteor. Since these are precursors to the appearance of the shockwave, knowledge about these phenomena can be used to better predict the onset of shock fronts.

The formation of MHEs coincides with the sputtering regime in the free molecular flow, where the colliding atmospheric molecules directly impact the meteoroid surface and cause a large number of collisionally evaporated meteoric atoms to be ejected – some along the axis of meteor propagation with speeds of up to $1.5 \cdot v_{meteor}$ [3].The second and third order ionizing collisions of ejected meteoric atoms form fast scattering high energy electrons, some distance ahead of and around the meteor. Despite the retarding electrostatic barrier resulting from the initial charge separation between ions and electrons, the low plasma density causes the Coloumbic forces to be ineffective in controlling the departure rate of high energy ballistic electrons. This mechanism can be considered to initiate the formation of MHEs, depending on the rate of sputtering and evaporation.We demonstrate that the ablationally augmented appearance of the flow fields around a meteor during the MHE termination (as a precursor to the shock wave formation), results in strongly stratified density gradients in the plasma layer in front of and around the meteoroid, where Coloumbic forces are sufficiently strong as to prevent the large scale electron scattering associated with MHEs.

Consequently, we suggest that the radar-detectable MHE termination points can be used as reasonably accurate indicator of the meteor shock wave formation. Moreover, this can be used to accurately characterize the meteoroid properties, altitudes and flow regime parameters associated with shock wave formation.

2. References

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