ON DETECTION OF SHOCKWAVES GENERATED BY OVERDENSE METEORS.

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Introduction: All optically detectable meteors, as well as many of the stronger radio-detectable meteors, produce shockwaves during the lower transitional flow regimes and 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 meteoroid atmospheric velocities and the values of Knudsen number in a given region. However, practical detection and determination of the altitude of formation of these shock waves (especially overdense meteors with electron line density, $10^{16} \leq q \leq 10^{19}$ electrons m^{-1} and diameters $d \geq 4$ mm up to small fireballs) have not been possible up to this point because of their rapid spatial and temporal attenuation in rarefied atmosphere, as well as the presence of radiative phenomena that extend to the meteor wake. Additional uncertainty is introduced by the presence of ablation-amplified hydrodynamic shielding and its overall dimensions [2,3], which subsequently alters the considerations of the flow regime. Moreover, good estimates of shockwave dependence on the relevant meteoroid parameters (such as velocity, shape, bulk density, composition and size), and the altitudes at which shock waves are generated, remain elusive.

Theoretical Approach: To resolve this, we consider VHF radar detectable Doppler shifted meteor head echoes (MHE) as a direct indicator of the formation of overdense meteor shockwaves. 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 $1.5v_{meteor}$ [2]. 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 (at higher altitudes) causes the Columbic forces to be ineffective in controlling the wide 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. The observed MHE strongly depends on the observing radar frequency and associated biases [4].

We propose that the altitude of specific overdense meteor shockwaves formation can be established by determining the heights where the VHF radar observed MHE radar cross section (RCS) (with assumed Gaussian electron distribution) corresponds to the size of the initial overdense meteor ablation amplified flow fields and the bow shock envelope, which are estimated to be between one and two orders of magnitude greater than the initial characteristic meteoroid dimensions [3,5,6,7]. The size of MHE RCS depends upon altitude [8], and it scales with the atmospheric mean free path and meteoroid velocity. Thus, MHE RCS, at altitudes where it becomes compatible to the dimensions of the cm-sized meteor flow fields and bow shock envelope [5,6,7] may be used to reliably determine the shock wave formation heights and constrain additional meteoroid parameters such as ablational efficiency and composition that affect the formation of the shock envelope around a meteor. Moreover, the altitudes where MHE RCS are compatible to the ablationally augmented flow fields around a meteor signify the existence of strongly stratified density gradients in the plasma layer in front of and around the meteoroid (as a direct precursor to the shock wave formation), where Columbic forces are sufficiently strong as to prevent the large scale electron scattering associated with MHEs at higher altitudes.

Conclusions: We suggest that the observation and statistical treatment of VHF radar-detectable overdense MHE RCS heights and related parameters, correlated with simultaneously captured specular radio echo observations of the same events from geographically separate locations, (at frequencies at or below 50 MHz) can be used as a reasonably accurate indicator of the meteor shock wave formation altitudes.

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