ON THE MECHANISM OF EARLY RAPID REMOVAL OF ELECRONS FROM POSTADIABATICALLY EXPANDING OVERDENSE METEOR TRAINS.

R. E. Silber[1], E. A. Silber[2], M. Gritsevich[3,4], M. L. Niculescu[5], W. K. Hocking[6]
[1]Department of Earth Sciences, The University of Western Ontario, London, Ontario, N6A 3B7, Canada (e-mail: reynold.silber@uwo.ca), [2]Department of Earth, Environmental and Planetary Science, Brown University, Providence, RI, USA, 06912 (e-mail: elizabeth_silber@brown.edu), [3]Department of Physics, University of Helsinki, Gustaf Hällströmin katu 2a, P.O. Box 64, FI-00014 Helsinki, Finland (email: maria.gritsevich@helsinki.fi), [4]Institute of Physics and Technology, Ural Federal University, Mira St. 19, 620002 Ekaterinburg, Russia, [5]INCAS - National Institute for Aerospace Research "Elie Carafoli", Flow Physics Department, Numerical Simulation Unit, Bucharest 061126, Romania, [6]Department of Physics and Astronomy, University of Western Ontario, London, Ontario, N6A 3K7 Canada

Introduction: The dynamics of meteoroid motion in the atmosphere and the related chemical processes between the ablationally formed thermalized meteor train and the ambient atmosphere have been subject of numerous studies [e.g. 1,2,3]. However, largely neglected aspect of meteoroid's interaction with the atmosphere involves cause and effects of meteor generated shockwaves and the small scale physico-chemical processes occurring in, and on the boundary of, the extreme environment of the high temperature adiabatically formed meteor trail in the initial stages of the expansion ($t \leq 0.1$ s). Overdense meteors (electron line density, $10^{16} \leq q \leq 10^{19}$ electrons m^{-1} and diameters $d_m \geq 4$ mm up to small fireballs) are in the size regime of the meteoroids capable of generating 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 [4]. Short lasting high temperature driven reactions that take place on the boundaries of the postadiabatically expanding meteor train within the first 0.1 s after its formation and subsequent rapid and intense electron removal remain poorly understood. A comprehensive background on the topic can be found in [5]. In this work, we examine the combined physico-chemical effects of meteor-generated cylindrical shock waves on the ambient atmosphere in the MLT region, and the subsequent hyperthermal chemistry on the boundaries of overdense meteor trains to address the physico-chemical processes accompanying the initial evolution of the high temperature meteor train. This study has been motivated by the recent observational evidence [6] that suggest slower thermalization times of the postadiabatically formed meteor trains which is conducive for hyperthermal chemistry.

Theoretical and Modeling Approach: A theoretical approach was applied to approximate the temperature of the ambient atmosphere near the meteor train, which is heated by the passage of the overdense meteor cylindrical shock wave. This was accomplished by considering the meteor velocity and energy deposition, and evaluating the pressure ratios between the ablation amplified shock front and the ambient atmosphere (see [5] for further details about this treatment). We have modeled hypersonic meteor flow in the MLT region using a simplified model without ablation, incorporated into the computational fluid dynamics (CFD) software package ANSYS Fluent. The computation was performed using O_2 and N_2 as the only major species, at an altitude of 80 km. A spherically shaped meteoroid is assumed to have velocity of 35 km/s (M_{80km} = 124.6). Two meteoroid sizes were modeled, d_m = 2.5 cm and d_m = 10 cm. Further details about the model are given in [5].

Discussion and Conclusion: The cylindrical shock waves produced by overdense meteors are strong enough to heat the ambient atmosphere to temperatures of ~6000 K in the near field and subsequently dissociate oxygen and minor species such as O_3, but insufficient to dissociate N_2.This substantially alters the considerations of the chemical processes taking place at the meteor train boundary. We demonstrate that ambient O_2 that survives the cylindrical shockwave, along with small quantities of O_2 that originates from the shock dissociation of O_3, participate primarily in high temperature oxidation of meteoric metal ions, forming metal ion oxide. For the case of overdense meteor trains, the subsequently formed meteoric metal oxide ions are predominantly responsible for the initial intense and short lasting electron removal from the boundary of the expanding meteor train, through a process of fast temperature independent dissociative recombination. This altitude dependent process is typically completed within 0.1- 0.3 s, which in good agreement with the results suggesting substantially slower cooling of meteor wakes [6]. The rate of this process is also strongly dependent on the second Damköhler number. The full scope of implications of this work is presented in [5].

References: [1] Boyd I.D. (2000) *Leonid Storm Research*. Springer, p. 93. [2] Gritsevich M. (2009) *AdSpR*, 44, 323. [3] Plane J.M. (2012) *ChSRv*, 41, 6507. [4] Bronshten V.A. (1983) *Physics of meteoric phenomena*. Dordrecht, D. Reidel. [3] Popova O. et al. (2001) *Meteoroids 2001*, 231. [5] Silber E.A. et al. (2017), *MNRAS*, doi: 10.1093/mnras/stx923. [6] Jenniskens P. et al. (2004) *AsBio*, 4(81).