THE SMOKE TRAIN OF THE CHELYABINSK METEOROID.

N. A. Artemieva[1,2] and V. V. Shuvalov[2]. [1]Planetary Science Institute, artemeva@psi.edu. [2]Instiitute for Dynamics of Geospheres, RAS, Russia.

Introduction: A spectacular smoke train left by the Chelylabinsk meteoroid in atmosphere on February 15 of 2013 lasted much longer than its 10-sec bolide [1-3]. The train was easily visible in the skies above Ural Mountains at least half an hour and looked similar to a giant contrail. The leftovers of this train were observed in the upper atmosphere during the next 3 months by the US/Japan satellite sensors [4]. The paper describes numerical modeling of the smoke train during the first 3 minutes.

Numerical model and initial conditions: To model train evolution we use the multiphase hydrocode SOVA [5] which allows to describe interaction of particulates with the atmosphere. The train is presented either as a continuum (with the same equation of state as atmospheric gas) or as a swarm of particles with prescribed size-frequency distributions (in the size range of 0.1 µm - 10 cm). The total mass of the train is equal to the pre-atmospheric mass of the Chelyabinsk meteoroid (10^7 kg); the energy/mass distribution with altitude corresponds to the registered light curve [1]; particles are in thermodynamic equilibrium with the atmosphere and have no velocity at the beginning.

Evolution of the train: The train quickly expands at altitudes of 25-30 km (maximum energy release according to observations). Within 1 minute RT and KH instabilities create a wavy shape of the upper boundary and also cause splitting of the train into two. In 3 minutes the widest part of the train reaches an altitude of 70 km and looks like giant cumulus. Fragments larger than 1 mm are separated from the train and descend with free-fall velocity. Would these particles prevail, the train has an optical thickness <0.01 and is barely visible. Thus, condensates of ablated materials play a dominant role and are smaller than 1 mm as it was observed in other falls [6].

Plume formation could be an important mechanism allowing quick and global dispersion of extraterrestrial materials in planetary atmospheres (e.g., Shoemaker-Levy 9 [7], Tunguska [8]). However, after the Chelyabinsk fall plume formation has not been observed because of its small size (<20 m) and low entry angle (17°). Modeling of impacts with higher entry angles and higher energies shows that a plume is formed if the total energy is at least 4 times higher and the entry angle is steeper, ~45°.

Comparison with other events: Similar (albeit smaller) trains were observed after the Sikhote-Aline iron shower, the Carancas and the Tagish Lake falls. Conventionally observed contrails represent mm-sized condensation products (mainly ice) of aircraft engine exhaust at altitudes > 8 km. Noctilucent clouds consist of tiny (tens of nm) icy crystals and reside at much higher altitudes (~ 80 km).

References: [1] Brown P. et al. 2013. *Nature* 503: 238-241. [2] Borovička J. et al. 2013. *Nature* 503: 235-237. [3] Popova et al. 2013. *Science* 342: 1069-1073. [4] Gorkavyi N. et al. 2013. *Geophysical Research Letters* 40: 4728–4733. [5] Shuvalov V.V. 1999. *Shock Waves* 9: 381-390. [6] Klekociuk A.R. et al. 2005. *Nature* 436:1132-1135. [7] Boslough M.B.E. and Crawford D.A. 1997. *Near-Earth Objects*: 236-282. [8] Artemieva N. and Shuvalov V. 2010. Absract # 1268. 41st Lunar and Planetary Science Conference.