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Novel Experimental Simulations of the Atmospheric Injection of Meteoric Metals

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Abstract

A newly-developed Meteor Ablation Simulator (MASI) is the first laboratory experimental set-up to study atmospheric ablation in a time-resolved manner under realistic heating rates. The MASI has been used to observe the absolute rates of ablation of Na, Fe, Mg and Ca from a number of meteoritic and synthetic cosmic dust particles. The comparison of the monolithic, single mineral simulations by the Leeds Chemical Ablation Model (CABMOD) to the MASI experimental data highlights the complexity of the process of melting and evaporation of IDP mineral assemblages, but also the usefulness of CABMOD for calculating elemental yields of volatile (e.g. Na), moderately refractory (e.g. Fe, Mg) and highly refractory (e.g. Ca) elements. This work confirms differential ablation in laboratory experiments for the first time, and provides confidence in CABMOD as an important tool for linking the cosmic dust input to a planetary atmosphere with a variety of atmospheric phenomena.

1. Introduction

There have not been may attempts to simulate micrometeoroid ablation in laboratory experiments. Most previous studies have focused on understanding the thermal processing of micrometeorites retrieved on the ground both from a textural and compositional perspective, in order to infer their origin [1]. More recent experiments using pyrolysis and gas-phase infrared spectroscopy have also attempted to quantify the yield of sulphur, CO_2 and H_2O in order to estimate the potential impact of micrometeoroids on planetary atmospheres [2].

The Chemical Ablation Model (CABMOD) [3], developed at the University of Leeds, estimates the ablation rate profiles of individual elements for a meteoroid with specified composition, mass, velocity, and entry angle. This model has been at the core of recent efforts to quantify the input of IDPs into the terrestrial atmosphere by reconciling observations including IR emission from the Zodiacal Cloud, the vertical fluxes of Na and Fe atoms in the upper mesosphere, and cosmic spherule accumulation at the surface [4]. The mass and velocity distribution of IDPs derived from High Performance Large Aperture radar observations [5] are very different from those inferred from orbital impact detectors and astronomical dust models [6]. This may reflect a bias of radars towards fast/large meteoroids; quantification of this effect requires a model such as CABMOD [7]. Therefore, in order to reduce uncertainties in ablation modelling it is necessary to set CABMOD on solid experimental ground.

2. Experimental

The MASI was designed to carry out controlled flash heating of IDP analogues over the range of atmospheric ablation temperatures, while the vaporisation rates of two elemental constituents are monitored using time-resolved atomic laser induced fluorescence (LIF). The instrument, shown schematically in Figure 1, consists of a vacuum chamber fitted with an electrical feed-through on which a tungsten ribbon is mounted as a filament. Samples of IDP analogues are deposited on the filament surface and then the chamber is closed and evacuated. The filament is resistively heated using a programmable power supply up to 3000 K. The temperature of the surface is measured using a 1 ms time response pyrometer camera and each experiment is recorded using a video camera to track the particle evolution on the surface of the filament.

A Nd:YAG laser operating at 250 Hz is used to pump two dye lasers, one tuned to the atomic Na and the other to either the Fe, Mg or Ca resonance transitions. The resulting LIF signals are collected through monochromators by orthogonal photomultipliers. These signals are proportional to the concentration of atoms in the gas envelope ablated from the particle, and hence to the particle mass loss rate. Different heating programs can be chosen, including ramps of different slopes, step functions, and modelled atmospheric ablation temperature profiles.

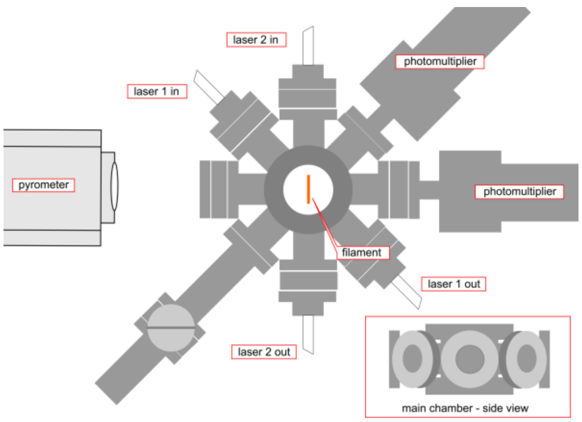

Figure 1: Top view of the MASI

3. Results

Figure 2 is a comparison of the elemental ablation profiles predicted by CABMOD and measured by MASI. The general features of *differential* ablation – sequential evaporation of Na, Fe, Mg and Ca – are correctly predicted by the model. However, the measured ablation profiles of Na and Fe are broader than predicted – clear evidence for these elements evaporating from different minerals contained in the meteorite matrix.

4. Summary and Conclusions

The new ablation simulator is an important tool for testing and refining the ablation models which are central to predicting where different meteoric elements are injected into a planetary atmosphere. This is crucial information for modelling the atmospheric impacts of cosmic dust. Modifications have been introduced in CABMOD to better match the Na velocity and mass-specific experimental profiles, which has implications for meteor radar detectability of slow and light particles. Most recently, the input of cosmic dust to the terrestrial atmosphere has been determined to be 43 ± 14 t d^{-1}, or which around 18% ablates [4].

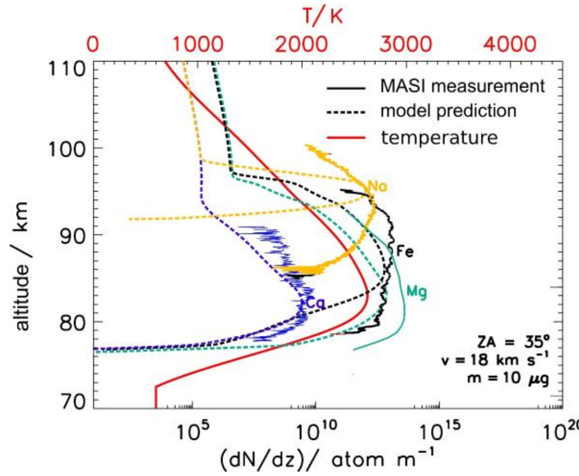

Figure 2: Comparison of CABMOD predictions (dashed lines) with MASI measurements of ablating of Na, Fe, Mg and Ca from Allende meteoritic particles, radius ~64 µm, entry velocity = 18 km s^{-1}

Acknowledgements

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References

[1] Toppani, A., Libourel, G., Engrand, C., Maurette, M.: Experimental simulation of atmospheric entry of micrometeorites. Meteor. Planet. Sci., 36, 1377-1396, 2001.
[2] Court, R. W., Sephton, M. A.: The contribution of sulphur dioxide from ablating micrometeorites to the atmospheres of Earth and Mars. Geochim. Cosmochim. Acta, 75, 1704-1717, 2011.
[3] Vondrak, T., Plane, J. M. C., Broadley, S., Janches, D.: A chemical model of meteoric ablation. Atmos. Chem. Phys., 8, 7015-7031, 2008.
[4] Carrillo-Sánchez, J. D., Nesvorný, D., Pokorný, P., Janches, D., Plane, J. M. C.: Sources of Cosmic Dust in the Earth's Atmosphere. Geophys. Res. Lett., 43, 11,979–911,986, 2016.
[5] Janches, D., Heinselman, C. J., Chau, J. L., Chandran, A., Woodman, R.: Modeling the global micrometeor input function in the upper atmosphere observed by high power and large aperture radars. Journal of Geophysical Research: Space Physics, 111, A07317, 2006.
[6] Nesvorný, D. *et al.*: Cometary Origin of the Zodiacal Cloud and Carbonaceous Micrometeorites. Implications for Hot Debris Disks. Astrophys. J., 713, 816, 2010.
[7] Janches, D. *et al.*: Radar Detectability Studies of Slow and Small Zodiacal Dust Cloud Particles. I. The Case of Arecibo 430 MHz Meteor Head Echo Observations. Astrophys. J., 796, 41, 2014.