Meteorite Controlled Ablation under Low Vacuum Studied Using Emission Spectroscopy: A Technique to Sample the Bulk Composition of Asteroids.

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Introduction: The ablation of meteoroids penetrating at hypervelocity in the Earth’s atmosphere is a complex process requiring a deep knowledge on the physics at work [1-2]. The meteoroid surface temperature increases while deepening into the atmosphere by the collisions experienced with atmospheric components. Progressive increase in the meteoroid surface temperature produces the differential ablation [3-4]. It takes place when the most volatile species being released earlier than the most refractory ones [4-5]. Emission spectroscopy is a powerful tool to infer the composition of meteoroids from the remote detection of the light produced by the luminous phase [4-5].

We have developed a simple experiment to simulate the ablation of a meteorite, or the development of an impact plume under low vacuum. We used a laser pulse to heat the surface of a meteorite, and we study remotely the temperature and chemical composition of the hot vapor. The elemental abundances and the temperature can be inferred from the study of the intensity of the lines of the main rock-forming elements.

Instrumental procedure: We performed the experiments in ICMAB-CSIC laboratories. We placed a H5 chondrite meteorite (Gao Guenie) into a vacuum chamber (10\textsuperscript{-2} mbar base pressure). A Quantel Brilliant B laser system, emitting 266 nm wavelength pulses of about 2 J/cm\textsuperscript{2} fluence and 4 ns duration at 10 Hz repetition rate, was used to produce the thermal pulses that heated the sample and produced the vapor plume (Fig. 1). The spectrometer was designed at the Institute of Spaces Sciences (CSIC-IEEC) in the framework of a JMT-R research project. A PHOTRON FASTCAM MINI UX50 monochromer with a Nikon 35mm f/1.8 DX G AF-S was used. In front of the lens a diffraction grating of 600 grooves/mm was used. The spectrometer provides a resolution of 0.317 nm/pixel.

Results and discussion: An example of emission spectrum of the vapor plume generated by the laser pulses is shown in Fig. 2. As an example, we have identified the main emission lines of the rock-forming elements (Fig. 3). The spectrum is characterized by the emission lines of several chemical elements released by the laser ablation of the meteorite. Most lines are exactly identical to the identified in meteor spectroscopy [2-3]. Them, this type of experiment can be useful to understand the ablation of meteoroids of different composition and mineralogy. Our current understanding of ablation is usually considering chondritic bodies, but achondritic materials are also common. On the other hand, different minerals have distinctive ablation temperatures. The chemical and mineralogical heterogeneity of meteoroids is probably behind the complexity of explaining luminous efficiencies that could be better studied under controlled experiments [6] Obviously our simple experiment cannot simulate the conditions behind a meteoroid entry at hypervelocity, but could help to quantify some key factors of meteor ablation [7]. Being Gao Guenie an impact melt breccia, it could be considered a good example of the materials forming an asteroidal surface [8]. Additional experiments could be envisioned in the future using different meteorites. We think that an emission spectrometer onboard an exploratory mission could be used to infer the chemical composition and temperature of an impact plume. An example could be the scientific interest to know compositional details for the crater excavation.

Figure 1. Image of the meteorite ablation plume under the action of the laser, seen through the chamber window.
made by the DART NASA mission in Dimorphos, the satellite of 65.803 Didymos binary asteroid [9]. This mission is the first kinetic impactor demonstration technique to improve our knowledge on our ability to change the motion of an asteroid in space.

Conclusions and future work: Our laser ablation experiment can be useful to simulate meteor ablation, to infer the composition of an asteroid using a laser-induced ablation technique, or even to study the composition of meteoroids impacting the surface of planetary and asteroidal bodies. The generated vapor plume can be studied remotely using a camera working as spectrometer thanks to a diffraction grating or a prism placed in front of the lens. The elemental abundances and the temperature can be inferred from the study of the intensity of the lines. Such emission lines will provide a direct measurement of the relative abundances of the main rock-forming elements. We plan to perform additional experiments using samples of different compositions to get additional insight into the technique.


Figure 2. First order of the emission spectrum of the ablation plume of the Gao Guenie chondrite obtained in 1/50 s

Figure 3. Calibrated emission spectrum showing the main emission lines. Some blended lines are marked: B1 (Fe I-42, Ca I-2, and Fe I-152), and B2 (ZnON fluorescence, Cr I and Mn I)