SHOCK SYNTHESIS OF PREBIOTIC MOLECULES II: PROBING THE TEMPERATURE OF CREATION USING IMPACT FLASH SPECTRA.

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Introduction: During hypervelocity impacts, an intense, short-lived flash known as a hypervelocity impact self-luminous plume (or ‘impact flash’) is produced (Figure 1). These impact flashes have been observed on the lunar surface [1 - 5] and can be studied to acquire information on the target and impactor composition, as well as impactor mass and size [6 - 11]. Prior experiments carried out revealed that the intensity of light emission from a hypervelocity impact increases rapidly with impact velocity [12 - 20]. The intensities of the atomic lines and molecular bands in an impact flash (produced from both the projectiles and targets) can also be used to determine the temperatures reached during impact [21 - 27].

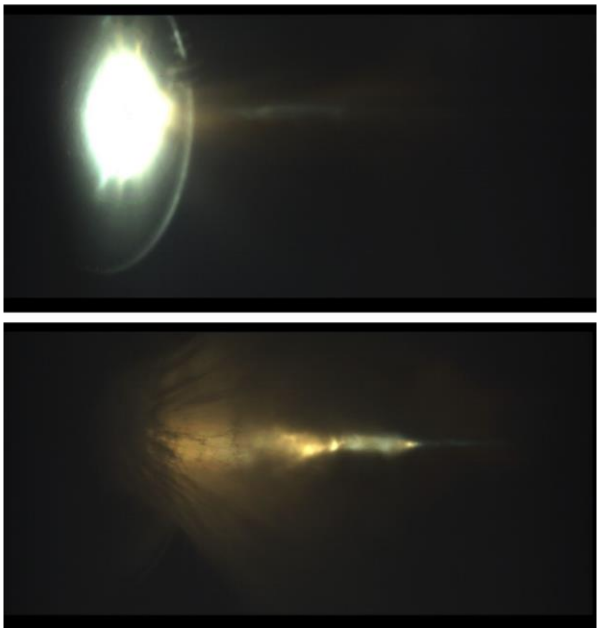

Figure 1: Pictures of a hypervelocity impact flash from a 1 mm stainless steel projectile impacting an ice mixture target at 6.03 kms^{-1}. The target mixture consisted of CO_2 ice, $(NH_4)_2SO_4$, NaCl and water ice. *Top:* impact flash, *Bottom:* subsequent picture frame (~0.5 ms later, post-impact) showing the ejecta and residual light trail.

Herein the impact flash spectra for impacts onto ice mixtures (representative of the icy worlds of the outer Solar System) were recorded to experimentally measure the peak temperatures achieved during impact to quantify the temperatures needed to shock synthesize organic compounds [28, in these proceedings].

The *Stellar AccRetion-Mapping with Emission Line Tomography* (STAR-MELT) Python package, developed by the University of Dundee, involves the analysis of emission line tomography of time-resolved, high-resolution spectra of young stars. Here, STAR-MELT was utilized, in conjunction with conventional analyses, to identify spectral peaks and their relative intensities in order to determine the temperatures reached during the impact process.

Materials & Methodology: The University of Kent’s two-stage LGG [29] was used to horizontally accelerate the projectile prior to impact, while an *Ocean Insight Red Tide USB-650 Fibre Optic* spectrometer was used to record the impact flash.

Experimental Methodology: A 3.0 mm diameter aluminium sphere projectile was fired onto an ice target mixture at 6.03 kms^{-1}. The target mixture consisted of 20 g NaCl dissolved in 1 L deionised water and placed in a sterilized stainless-steel container. The target mixture was frozen to -120 °C, with the temperature increasing to approximately -50 °C during the evacuation process of the LGG target chamber (to 50 mbar), prior to firing. A manual focus, 50 mm, F1.2, Nikon *NIKKOR* lens was aligned with the front viewport of the LGG target chamber and focused onto the end of a 1 mm internal diameter core of a fibre optic cable connected to the spectrometer for maximal optical throughput. The *OceanView* spectrometer software was subsequently used to record the spectra.

Analytical Methodology: Five consecutive spectra were acquired during firing to ensure the impact flash was recorded. The ‘dark’ spectra were then averaged and subtracted from the ‘signal’ spectrum to reveal the impact flash spectrum (Figure 2). Once the impact flash spectrum was acquired, the emission lines can be automatically extracted and identified using STAR-MELT, which matches the spectral lines to a compiled reference database of lines. Line profiles are fitted and quantified, and the relative intensities of the atomic and molecular emission lines/bands can be precisely measured. The difference in the relative peak intensities for specific atomic and/or molecular species allows for the temperature to be determined following a Boltzmann distribution calculation.

Results: Preliminary results demonstrate that the impact flash was successfully recorded using this methodology, with the Na atomic lines clearly visible at approximately 589 nm and 819 nm, as shown in Figure 2. The relative intensities of the Na atomic emission lines were used to determine a peak temperature of ~2200 K from the Boltzmann distribution calculation.

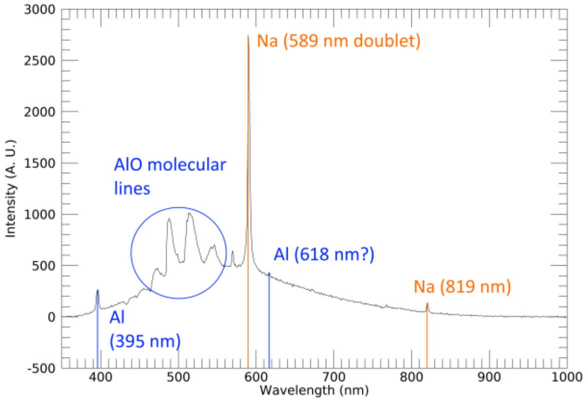

Figure 2: Impact flash emission spectrum from a 3 mm Al projectile impacting a target composed of NaCl and water ice at 6.03 kms^{-1}. The Na atomic lines labelled were used for the peak temperature determination.

Discussion: The results from these preliminary experiments demonstrate that the impact flash spectrum can be successfully recorded and used to determine the peak temperatures reached during impact. In doing so, the temperatures required for impact shock synthesis of complex organic compounds to form can be constrained, as insufficient energy will prevent bond-breaking processes and the overcoming of chemical reaction activation barriers.

The findings from the photodiode experiments presented in Tandy *et al.* (2020) [30] show that the impact flash from different ices and ice mixtures using 3 mm projectiles accelerated to ~6 kms^{-1} varies depending on the projectile size and impact speed but, does not last longer than ~2 ms. Therefore, the spectrum recorded during this experiment is actually the 'envelope' of the flash spectrum as it changes throughout the impact process.

Conclusions & Future Work: This initial study demonstrates that peak temperatures during the impact process can be measured by studying the flash produced. This can greatly assist in the study of impact shock synthesis phenomena by constraining the temperatures required for synthesis to occur. Funding is being sought for a second-generation spectrometer system with higher spectral and temporal resolution, and high-speed spectrometers will be developed to allow for more precise measurements of atomic and molecular emission lines of interest and overlapping lines/bands (such as the 590 nm Na doublet), potentially revealing additional molecular features important to the understanding of the unique, shock-induced chemistry. Coupled with the STAR-MELT Python package currently being developed by the School of Science and Engineering at the University of Dundee, and the high-speed pressure sensing system [31, in these proceedings] developed at The University of Kent, this opens a whole new dimension in interpreting the outcomes of impact events as we can successfully measure temperatures experimentally in situ.

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