EARLY-TIME TEMPERATURE EVOLUTION OF THE IMPACT FLASH AND BEYOND. C. M. Ernst and P. H. Schultz, Brown University, Department of Geological Sciences, Box 1846, Providence, RI 02912 (Carolyn_Ernst@brown.edu).

Introduction: When a hypervelocity projectile impacts a target, a light flash is produced at the moment of first contact. Time-resolved light intensity curves can be used to determine the starting conditions of the observed impacts [1,2]. For impacts into metal targets, the peak intensity of the flash occurs during the initial projectile penetration, with the signal quickly decaying [3,4]. Impacts into particulate targets produce a source of blackbody radiators in addition to the initial flash. This source extends the resulting light intensity profile well beyond the time of initial contact.

A time-resolved temperature profile is an additional useful tool for analyzing the early-time evolution of an impact based solely on its emitted light. Observed thermal signatures indicate that the increase in light intensity to a peak value is dependent on an expanding radiating source area, not on an increasing temperature. Impact temperature profiles evolve differently for various angles and projectile diameters.

Experiments: Hypervelocity impact experiments were performed at the NASA Ames Vertical Gun Range (AVGR) in order to study the evolution of the impact flash and the resulting thermal plume. Two high-speed photodiode systems recorded the time-resolved light intensity. The first system, also used in previous studies [1,2], consists of a single photodiode with a spectral range of 350-1100 nm. The second system consists of six similar photodiodes that can be used in conjunction with bandpass filters (50–80 nm FWHM). This multi-channel photodiode/filter system was calibrated using a carbon arc blackbody thermogauge.

The systems viewed the impacts through windows in the ceiling of the target chamber. The single photodiode system was used as an unfiltered channel. Filters used with the multi-channel system were centered at 500, 550, 600, 650, 700, and 880 nm. The recorded intensity data have a time resolution of 100 ns.

Spherical Pyrex projectiles (0.318–0.476 cm in diameter (=a)) were launched at velocities between 4.50–6.10 km/s and at angles of 30º and 90º (measured from the horizontal). The impact targets were pumice dust, which was used to simulate loose, particulate regolith material. All experiments were performed in near-vacuum conditions (< 0.5 Torr). At levels below ~10 Torr, ambient pressure does not change the observed light intensity for macroscopic impacts [5]. This has been confirmed with these experiments.

Data: The seven channels of raw data collected for a 30º impact are depicted in Figure 1. For all of the recorded impacts, the characteristics of the unfiltered channel include an intensity peak that occurs 10–50 μs after impact (time = t_0) and lasts from 50–100 μs, and a long-duration decay signal (timing depends on initial a, θ, and v). Prior to this broad feature is a brief intensity spike lasting less than 2–3 μs. These features have been reported previously [1,2].

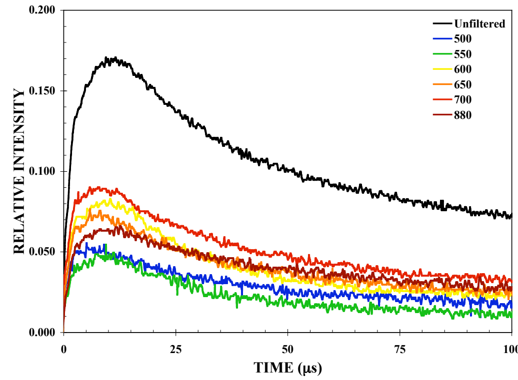

FIGURE 1. Seven channel raw intensity data from an impact of a 0.318 cm Pyrex sphere into a pumice dust target at 30º and 6.04 km/s. The unfiltered channel has the highest intensity and is shown in black. The filtered channels are represented by different colors.

Results: The filtered signals have the same overall shape as the unfiltered light curve but vary in relative intensity. Analysis yielded a thermal evolution curve for each impact based on ratios of the filtered channels. The calculated temperature profiles for several of the experiments are plotted in Figure 2. Curve fitting has been used to reduce the noise and this smoothes the appearance of the signals. The peak intensity times are indicated for each curve by diamonds.

Experiments with similar starting conditions (a, θ) yielded similarly shaped temperature profiles. The highest temperatures were observed at the time of first contact. Higher temperature levels occurred for the 30º impacts. This contrasts with other results [6,7] but most likely indicates a difference in the emitting source (blackbody versus vapor). Temperature then decreased with time for all cases, though more sharply for 90º impacts than for 30º impacts. The 30º profiles exhibit a gradual decrease in temperature out to a time of ~50 μs, where they begin to level off. The 90º profiles all exhibit very shallow slopes throughout the entire profile.

Source Area. Light intensity is dependent on the temperature of the radiating source as well as its surface area by the relation $I=A\sigma T^4$, where σ is the Stephan-Boltzman constant. Since the intensity and temperature of these impacts have been observed, the effect of source area on the light produced can be determined. The unfiltered intensity profile for the 30º impact from Figure 1 is plotted again in Figure 3. A theoretical intensity profile is also calculated from the known temperature evolution using an assumption that there was no source area growth to influence the light output ($I \sim T^4$).

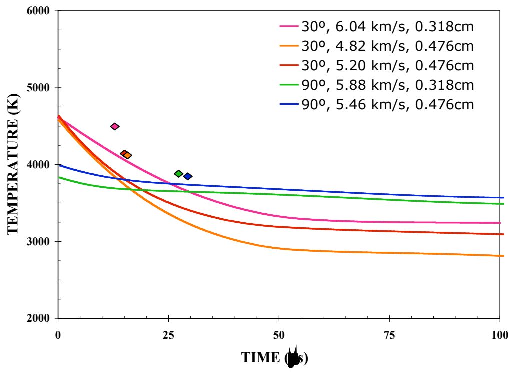

FIGURE 2. Temperature evolution profiles for impacts with different θ, v, and a. Diamonds represent the time locations of the intensity peaks. The peak temperatures occur at t_0. Impacts at 30º and 90º exhibit distinct temperature trends with time.

If there were no growth of the radiating area, the shape of the observed intensity profile would follow that of the temperature profile. The theoretical curve, however, is not able to reproduce the long-duration peak in the observed intensity profile. Therefore, the evolution of radiating surface area with time is necessary to explain the recorded shape. Since the observed peak temperature occurs at time t_0 and steadily decreases after that point, the measured intensity increase to the peak can only be explained by an expanding source area. This may occur by increasing the number of radiating particles or by expanding the area of the thermal plume exposed to the detectors.

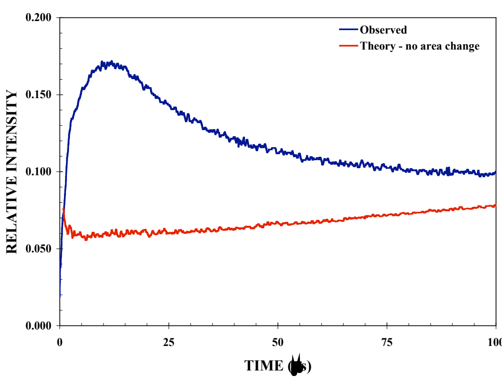

FIGURE 3. An observed intensity profile for an experiment at 30º, and a theoretical intensity profile calculated assuming no change in radiating source area. The theoretical curve cannot match the shape of the observed intensity peak, thus the radiating surface area must evolve over time.

The intensity and temperature data were used to calculate the actual surface area of the radiating material. The resulting area evolutions are plotted in Figure 4. Diamonds indicate the peak intensity time for each of the area profiles. The radiating surface area initially increases faster for the 90º impact than for the 30º impact. By the time the 90º intensity profile reaches its peak, the source area has already undergone most of its growth. When the 30º data reaches its peak, the source area has yet to undergo the majority of its growth. This illustrates an important angular dependence of the radiating source. After 100 μs, both the intensity and temperature decrease as the emitting particles cool and no new radiating material is added. At this point in the light evolution, intensity decay rates depend on projectile and target properties that affect the exposure of the radiating material in the transient cavity [2].

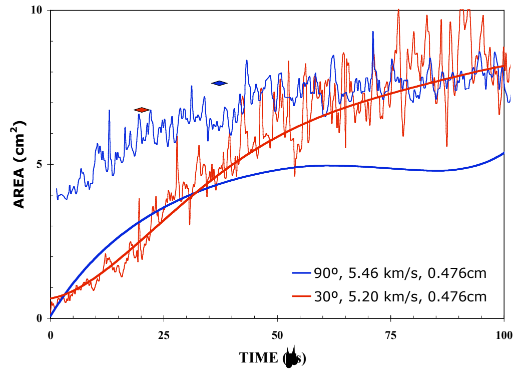

FIGURE 4. Evolution of the radiating source area for impacts at 30º and 90º. Diamonds represent the time locations of the intensity peaks. The 90º source area has undergone most of its growth by the time the intensity reaches its peak whereas the 30º source undergoes most of its growth after the peak.

Implications: Observations of the evolution of the impact flash and resulting thermal plume can be used to probe the early-time impact process and may be used to address issues such as the effect of shear heating in laboratory scale impacts. Frictional shear heating occurs at the contact between the projectile and the target surface and appears to increase for more oblique impacts [6]. Studies of the evolution of the impact flash and the thermal plume for impacts of different initial conditions (a, θ, v, and target) can help to address the role of shear heating in oblique impacts. These results can be applied to interpret both natural (Leonid meteors hitting the Moon) and man-made (NASA's Deep Impact mission) impacts. Results also can be compared to computer simulations, since simulations must be able to reproduce what is seen in the laboratory and what is seen in larger-scale impacts.

Conclusions: The flash produced during macroscopic impacts into pumice targets is a prolonged phenomenon that extends well beyond the initial penetration of the projectile into the target surface. Observations of the impact flash and the thermal plume provide useful information about the initial impact conditions. If both light intensity and temperature are recorded over time, the surface area of the radiating source can be studied. Together, this information can be integrated to gain a better understanding of the early-time impact process.

References: [1] Ernst, C. M. and P. H. Schultz (2002) *LPS XXXIII*, #1782. [2] Ernst, C. M. and P. H. Schultz (2003) *LPS XXXIV*, #2020. [3] Kadono, T. et al. (1994) *ASP Conference Series*, 63, 273-279. [4] Eichhorn, G. (1976) *Planet. Space Sci.*, 24, 771-781. [5] Gehring, J.W. and R. L. Warnica (1963) *Proc. 6th HVIS, 2, 627-682*. [6] Schultz P. H. (1996) *JGR*, 101 E9, 21,117-21,136. [7] Sugita, S. et al. (1998) *JGR*, 103 E8, 19,427-19,441.