TEMPORAL AND SPATIAL RESOLUTION OF THE EARLY-TIME IMPACT FLASH: IMPLICATIONS FOR LIGHT SOURCE DISTRIBUTION. C. M. Ernst and P. H. Schultz, Brown University, Department of Geological Sciences, Box 1846, Providence, RI 02912 (Carolyn_Ernst@brown.edu).

Introduction: The impact flash can be challenging to observe in detail, due to its short duration. This is especially true at laboratory scales, where the entire flash may last under 1 ms and most of the significant changes occur on timescales of microseconds. While photodiodes can record the impact flash at very high time resolution [e.g., 1,2], the resulting observations are spatially integrated over the entire emitting source region; thus, the physical distribution of the light source cannot be determined from these data alone. Images can spatially resolve the flash, however most cameras have long exposure times relative to the flash duration. A single exposure often encompasses the entire flash; thus, the resulting image lacks the time resolution necessary to investigate the different components of the flash.

With advancing technology, newer cameras are capable of extremely short exposure times. Time series produced by such cameras allow the flash to be resolved both temporally and spatially. This study focuses on the earliest portion of the impact flash, from 0-20 µs. Time-resolved photodiode data and short-exposure, spatially resolved images are examined together in an in-depth investigation of the impact flash evolution. Here, the combination of these two datasets reveals the light source distribution and its evolution through time.

Experiments: A series of experiments designed to spatially and temporally resolve the impact flash was performed at the NASA Ames Vertical Gun Range (AVGR). An intensified CCD camera system capable of < 5ns gate widths took short-exposure images of the impact flash in the 600-900 nm wavelength range. In addition to the CCD camera, a high-speed photodiode (described in [3]) recorded the evolution of the total light intensity with a time resolution of 0.1 µs. Both instruments observed the impacts from an orientation above the target surface.

The CCD camera system does not allow multiple images to be captured during a single impact. In order to examine the evolution of the flash, a time series was produced by performing several impact experiments with nearly identical parameters, while acquiring images at various sequential time steps. Slight variations in impact velocity between experiments are unavoidable; however, these variations did not significantly affect the parameters of interest for this study.

The experiments occurred under near-vacuum conditions (< 0.5 Torr) at angles of 60º from the horizontal and at velocities between 1.6–1.9 km/s. The projectiles were 0.635 cm-diameter Pyrex spheres. One experiment used a 0.635 cm-diameter aluminum sphere. The targets in all cases were particulate pumice dust half-spaces.

Results: The images were analyzed in conjunction with light intensity curves measured by the photodiode. The photodiode data provide a time-resolved perspective of the entire flash, whereas the CCD images allow specific source regions of the flash to be pinpointed. The combination of these two datasets provides unique insight into the processes that control the evolution of the impact flash.

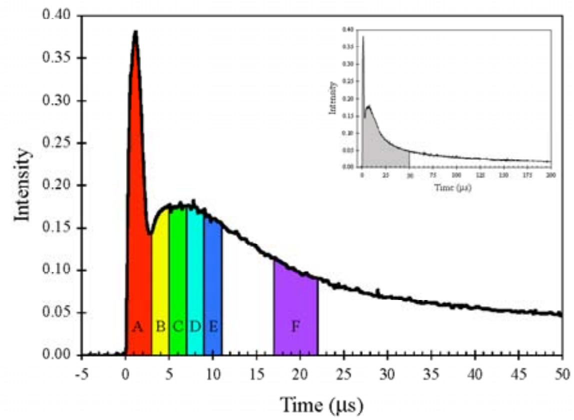

Figure 1. The location of the six short-exposure camera images (A-F) with respect to the photodiode light curve. The light curve out to 200 µs is shown for context, with the shaded region corresponding to the duration depicted in the main graph.

Because the CCD images are spatially resolved, higher intensity measurements imply higher temperature materials (methods to extract actual temperatures from the measurements are under development). Complications can arise when observing optically thin plumes; however, preliminary observations of the impact flash from above and from the side indicate that under these impact conditions, most of the early-time radiating material is located below the original target surface, lining the growing transient crater. Therefore, these sources can be considered to be optically thick.

Figure 1 shows the first 50 µs of the photodiode light curve of an impact at 1.9 km/s. The light curve out to 200 µs is shown in the upper right corner for context. The features of the light curve include an early-time spike, a subsequent rise to a broad, secondary intensity peak, and the gradual decay of the light intensity, as previously described [2,4]. The colored areas under the light curve correspond to the timing of the camera images (A-F). These images, spanning the first 22 µs after impact, are depicted in Figure 2. This time series is a composite of images taken during six impacts with velocities from 1.6 – 1.9 km/s. In addition to the time series, Figure 2 includes an integrated time exposure of the first 1 ms of a similar impact.

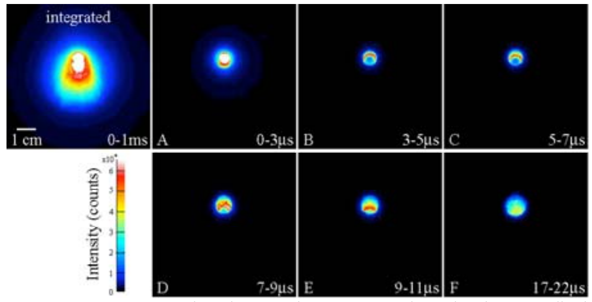

Figure 2. A composite time series representing the impact flash intensity for a Pyrex projectile impact into pumice dust at 60º, with a velocity between 1.6 and 1.9 km/s. The first image is an integrated image of the entire impact flash. The subsequent images (A-F) are much shorter exposures, as noted.

A false color intensity scale is used to better discern brightness changes in the images. The highest intensity source region occurred between 0-3 µs (image A). Image A encompasses the entire early-time spike feature, which is a result of the first contact between the projectile and the target [2]. This image represents the time of highest absolute intensity (for these low velocity, 60º impacts), consistent with this being the time of peak temperature [1], and stress [5].

The subsequent rise and arrival at the secondary intensity peak (Fig. 1) is covered by images B-E. Here, a well-defined, thin band of maximum relative brightness is visible through the projectile. This bright band moves at a speed consistent with the projected motion of the penetrating projectile; therefore, it likely represents light transmitted through the back of the projectile. As the projectile advances, it also leaves behind a growing source of heated material along its path.

By the time of the final exposure (image F, 17 µs after impact), the distinct intensity band has disappeared. At this time, the impact flash has reached its decay stage, representing the cooling of the heated target material [4]. In the time-exposed image, the region of highest intensity is located where the projectile illuminated on impact, and along the path of the advancing high intensity band. Based on these observations, the primary source of the early-time impact flash lies along the projectile/target interface, and it is observable primarily due to the transparency of the Pyrex projectile.

An (opaque) aluminum projectile was used to assess the effect of projectile transparency on the resulting flash intensity. Figure 3 compares 2 µs exposures of Pyrex and aluminum projectile impacts taken at similar times after impact (7µs and 8µs, respectively), along with their corresponding photodiode light curves.

The early-time intensity evolutions of the two impacts exhibit very different characteristics. The early-time spike feature is absent in the aluminum impact flash signal, the broad peak is much dimmer, and the rise to this peak is very different. By 45–50 µs, the intensity level and evolution of the two impact flashes are the same. By this time, the cooling of the heated target material controls the signal, independent of projectile opacity. This is to be expected, since the total amount of transferred energy should be approximately the same for these two impacts.

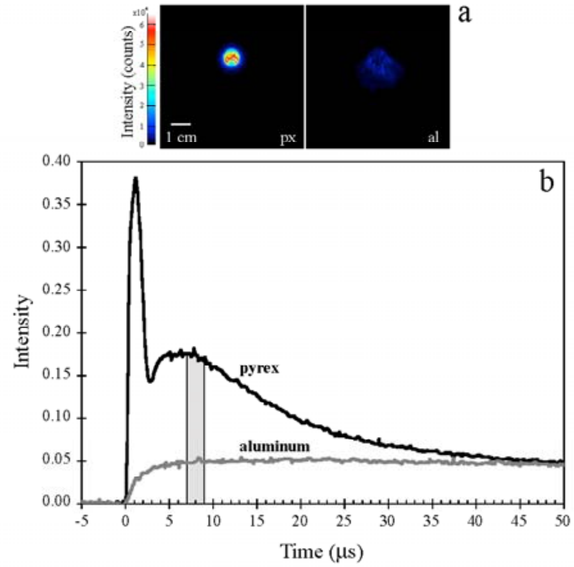

Figure 3. Comparison of Pyrex and aluminum projectiles. (a) Two µs exposures of Pyrex (px) and aluminum (al) impacts taken 7 and 8 µs after impact, respectively. (b) Comparison of the two light curves. The approximate time of exposure is shaded.

It is important to note that the evolution of the flash changes significantly with initial conditions. Higher velocities (5-6 km/s), oblique impact angles, projectile failure, and target properties all affect the characteristics of the resulting impact flash signal. These are all intriguing variables that will be investigated in future contributions.

Conclusions: The light source distribution of the impact flash can be determined using temporally and spatially resolved observations. Under these impact conditions, the early-time flash source is primarily located along the interface between the penetrating projectile and the target, and its visibility is greatly enhanced due to the transparency of the projectile. For impacts of opaque projectiles, this component of the impact flash would be relatively unobservable, since it is located behind the projectile when viewed from above, and below the target surface when viewed from the side.

Acknowledgements: This research was supported by the NASA Graduate Student Researchers Program (04-6011H).

References: [1] Kadono, T. and Fujiwara, A. (1996) *JGR, 101*(E11), 26097-109. [2] Ernst, C.M. and Schultz, P.H. (2002) *LPS XXXIII*, #1782. [3] Ernst, C.M. and Schultz, P.H. (2004) *LPS XXXV*, #1721. [4] Ernst, C.M. and Schultz, P.H. (2003) *LPS XXXIV*, #2020. [5] Dahl, J.M. and Schultz, P.H. (2001) *Int. J. Imp. Eng., 26*, 145-155.