MOON WATCH: CONTINUOUS MONITORING OF THE LUNAR SURFACE TO CONSTRAIN IMPACT FLUX.
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Introduction: The surface of the Moon is heavily cratered, recording a history of bombardment through the solar system. Though very large impacts are rare on the lunar surface today, there is evidence that small impacts occur regularly across the lunar surface. The LRO Camera (LROC) has measured a flux of impactors (>10 m in diameter) in monitored areas that is ~33% higher than anticipated and has observed secondary cratering processes that churn the top two centimeters of regolith on a timescale that is more than 100 times faster than previous models [1]. These measurements have altered our understanding of the current impactor flux with potentially significant ramifications for model ages of surfaces across the Earth-moon system as well as safety hazards faced by future robotic and human explorers.

One technique for measuring the current lunar flux is to monitor lunar impact flashes from Earth [e.g., 2-6]. These observations are complicated by atmospheric interference, the available resolution (both spatial and temporal) of instrumentation at great distances, and limitations in observable area to the near- side and during certain lunar phases. Placing an impact flash monitoring station on the Deep Space Gateway could mitigate many of these limitations and address three main questions in planetary and lunar science: 1) What is the current lunar impact flux? 2) What is the distribution of impactors across the lunar surface? 3) What is the range of meteoritic infall size?

Background Science: *Impact Flux.* Impacts large enough to damage future lunar infrastructure occur on the surface of the Moon frequently. Approximately 8 years of LROC Narrow Angle Camera (NAC) temporal pairs have revealed ~222 new craters with sizes from 1-75 m and ~47,000 new changes in surface reflectance (termed "splotches") that are likely caused by secondary impacts or small primary impacts [1]. So far, only ~9% of the Moon has been covered by this LROC temporal imaging, and thus these numbers may significantly underestimate the number of impactors that have struck the Moon over the course of the LRO mission.

Examination of impact craters on the lunar surface also reveals a putative leading-trailing hemisphere dichotomy in the impact flux [7]. This dichotomy is seen on other planetary bodies in the solar system as well. (e.g., the Galilean satellites [8]). Because they are limited to near-side observations, current observations of lunar impact flux (*e.g.*, the impact flash monitoring campaign led by Marshall Space Flight Center [*e.g.*, 9]) are not able to measure whether the number of impactors hitting the Moon is different on the leading versus trailing hemispheres. A monitoring campaign able to see more of the lunar surface could help to address this outstanding question.

Impact Flash. Following a hypervelocity impact, the energy from the projectile is converted into heat, light, and kinetic energy and deformation within the target material (e.g., damage accumulation and ejecta). 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 monitor the flash and determine the starting conditions of the observed impacts [10,11]. Time-resolved intensity curves are characterized by a rapid rise in luminous intensity to a peak value, followed by a more gradual decay in light (Fig 1). Laboratory experiments examine flash characteristics for impacts into a variety of target materials, including metals and geologic targets. For impacts into metal targets, the peak intensity of the flash occurs during the initial projectile penetration, with the signal quickly decaying [12,13]. 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 [e.g., 11,14]. Measurements of the flash in different wavelengths exhibit similar general shape characteristics, however the peak intensities and rise and fall time differ across as a function of wavelength.

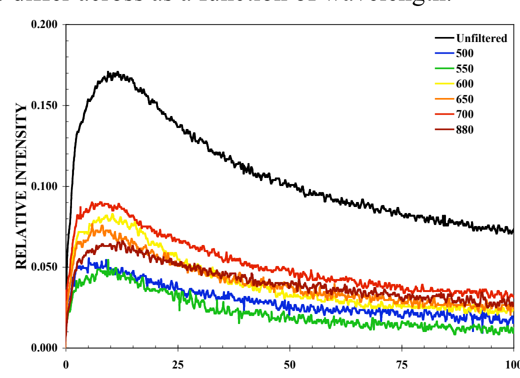

Fig 1. Light curves measured at different wavelengths for a typical laboratory experiment of a hypervelocity impact of pyrex into pumice performed at the NASA Ames Vertical Gun Range [14]. Note that this is for a laboratory experiment; lunar flashes are due to larger impacts and so would last longer than this example, probably on the order of 10s to 100s of ms.

Motivation for Flux Measurement Studies: A better understanding of impact flux is a goal of scientific investigations in the current Planetary Science Decadal Survey [15].

The lunar surface is often used as a baseline for age dating throughout the solar system, with methods largely based on the istopic model ages from returned samples, crater counts from imagery and the understanding of the lunar impact flux. However, the modern flux is highly uncertain, which can lead to large uncertainties in model ages from crater counting techniques.

Further, the safety of future crewed and robotic missions at the Moon (and across the inner solar system) may depend upon understanding the impact flux at small scales. For example, a better understanding of typical impactor size distributions during a given meteoroid stream may provide information to evaluate which are more or less dangerous to human activities. This, in turn, may provide important information about when astronauts should be taking extra precautions or seeking shelter.

A Mission Architecture to Monitor Current Lunar Impact Flux: The measurement strategy to monitor current impact flux on the Moon includes two main techniques: flash detection and measurement using a high-speed multi-band radiometer and flash locality determination using a combination of wide-field and high-resolution cameras.

The general conops includes continuous monitoring using the high-rate radiometer staring at the surface of the Moon. The signal will be continually buffered and data only saved when an event occurs. When an impact flash occurs, the rapid rise in intensity seen by the radiometer will trigger the cameras. Two separate camera types are envisioned. A wide-view camera would cover the full disk of the Moon and can be used to track where on the lunar surface the impact occurs generally. To provide operationally useful locations to orbiting cameras, a narrow angle, high-resolution, high-speed camera (or, perhaps an array of narrow-angle cameras) can image smaller portions of the disk detail. This will allow for a more resolved image of the impact plume as well as provide better targeting for follow-up observations by orbital assets (e.g., LROC).

The main data returned from this monitoring campaign would be the number of flashes and their time-resolved intensity, and the location of impacts on the lunar surface. This catalog would be useful in determining the recent and current impact flux and where the impacts are occurring on the surface (providing targets for cameras to view new impact craters). Measurements of flash intensity could be translated to energy and provide estimates of impactor size and speed. If resolved images of the impact plume are captured by the high-resolution camera, these data may also provide a method for determining impact trajectory and angle as well [*e.g.*, 9,17].

This setup requires a small footprint on the outside of the Gateway and no maintenance once installed. The mass and power needs are small. The system is designed to collect data without the need for humans in the loop. However, the data volume could be large depending on the resolution and frequency of data collected.

Conclusion: Understanding the impact flux is important to provide an understanding of the geologic record and assessing current inner Solar System exploration hazards. Providing information and catalogs of this current flux directly addresses questions in the decadal survey and has the potential to aid in future exploration of the Moon and aid in developing a better constraint for model ages of surfaces on the Moon and throughout the solar system. A relatively simple system of high-speed radiometers and cameras, requiring low resources and external footprint, can be designed to track this flux and return images and time-resolved light curves following lunar impacts.

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