NELIOTA

A Terrain-Dependent Dichotomy of Lunar Impact Flashes

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Abstract

In this study, we performed a comprehensive analysis of lunar impact flash (LIF) light curve shapes and their dependence on the lunar terrain by utilizing a large sample of 124 multi-frame LIFs detected by the NELIOTA project over the past nine years. By classifying these events based on their localization into mare, highland, and border regions, we identified a distinct behavioural dichotomy. Most notably, highland LIFs exhibit a significantly shallower and longer-lasting decay compared to mare flashes. This observed dichotomy demonstrates that the initial stages of the impact cratering process are fundamentally dependent on lunar lithology.

Introduction

The Moon serves as a unique natural laboratory for hypervelocity impact physics, as meteoroid strikes occur at speeds far exceeding the capabilities of laboratory replication. On airless bodies, these intense impacts produce luminous transient events visible in the optical and near-infrared spectra during the initial cratering stages. While lunar surface lithology, differentiated into high-albedo primary crust (highlands) and low-albedo basaltic plains (maria), is known to shape late-stage crater morphology, its influence on the initial impact stages and subsequent LIFs has previously remained elusive. To address this, we leveraged the extensive observations from the NELIOTA programme [1, 2, 3, 4], which has produced the largest publicly available LIF dataset to date.

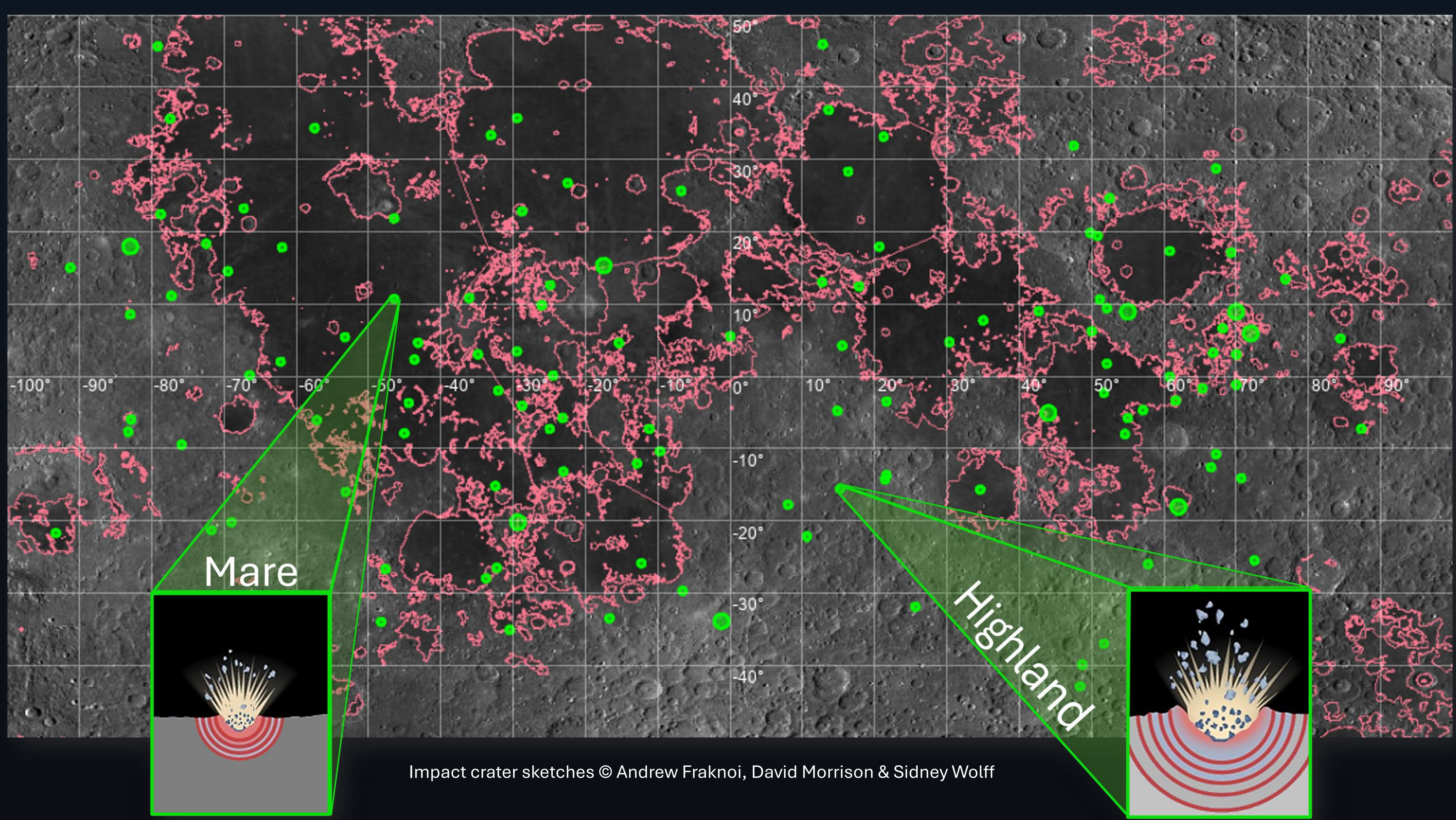

Fig. 1: NELIOTA multi-frame LIF sample (green ellipses, scaled according to their localisation accuracy) superimposed on a lunar map of the near side. Mare boundaries are highlighted by solid magenta lines.

Methodology & Results

To isolate the influence of target terrain, we analysed sporadic multi-frame LIFs, which inherently feature randomized impact velocities. We subsequently derived analytical expressions for two foundational ejecta cooling frameworks: the single-size molten droplet model [5] and the dual-size molten droplet model [6] fitting them to the observational data to estimate physical properties. Our findings reveal that while peak magnitude distributions are similar across the two terrains, their decay behaviours diverge significantly [7]. Highland flashes decay at a much slower rate $\left(\tau = 0.11^{+0.08}_{-0.05}\, s\right)$ than mare flashes $\left(\tau = 0.038^{+0.032}_{-0.018}\, s\right)$. Furthermore, the application of the dual-size model indicates that this extended emission duration is primarily driven by the coarse particles within the ejecta, which cool much more slowly than fine droplets.

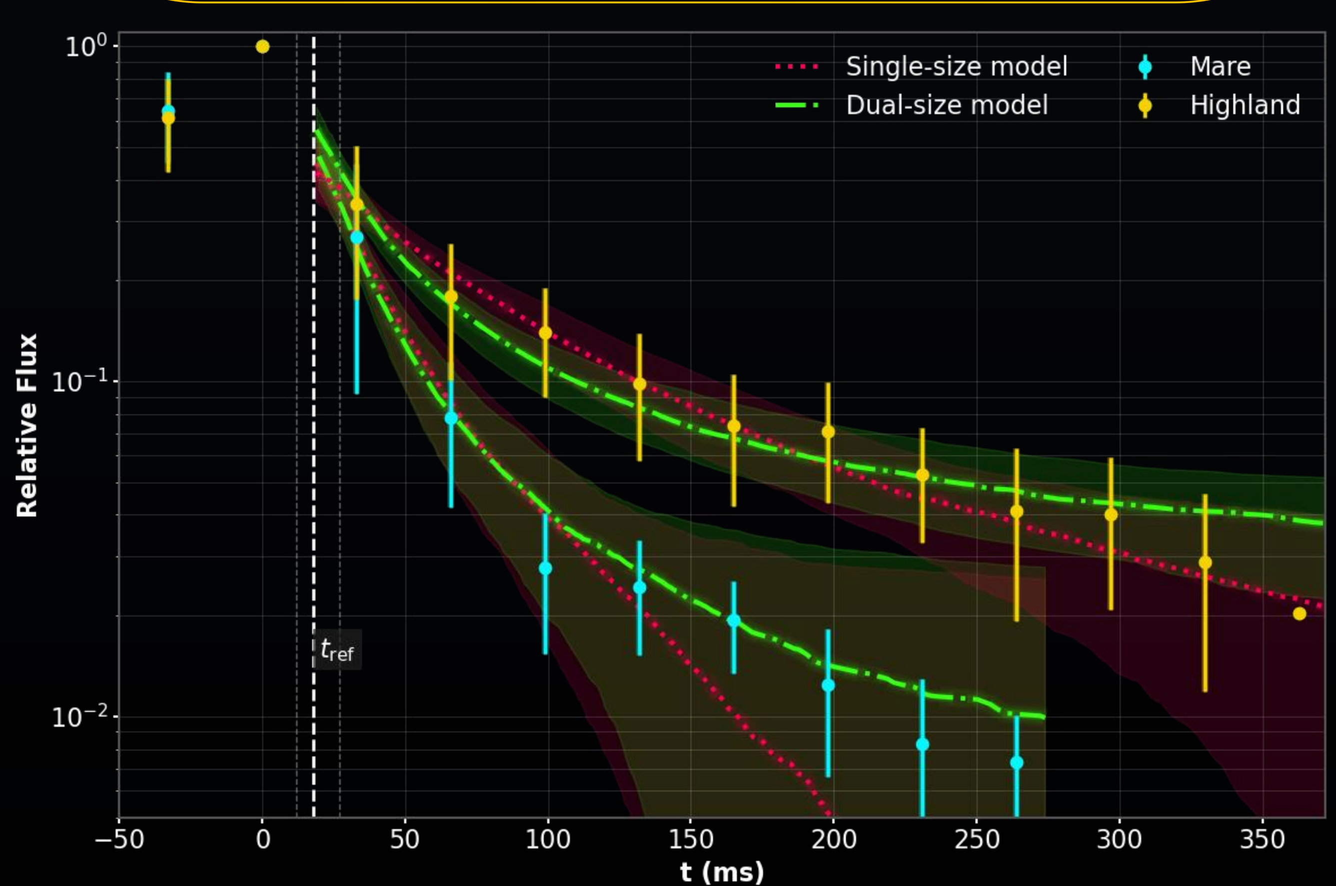

Fig. 3: Best-fit Markov chain Monte Carlo (MCMC) ejecta cooling models to the average (mare and highland) light curves

Discussion and Conclusions

The divergent observed light curves suggest a fundamental difference in the initial energy partitioning during an impact [7]. In mare regions, a significant fraction of the impact energy is likely consumed by the crushing and compaction of the denser consolidated basaltic rock, resulting in the rapid magnitude drop. Conversely, the highly porous regolith of the highlands facilitates a more gradual thermal release, generating the persistent thermal tails observed in our sample. Ultimately, these terrain-dependent findings provide a highly valuable predictive framework for upcoming monitoring campaigns, such as the ESA LUMIO CubeSat mission, which will observe the highland-dominated far side of the Moon.

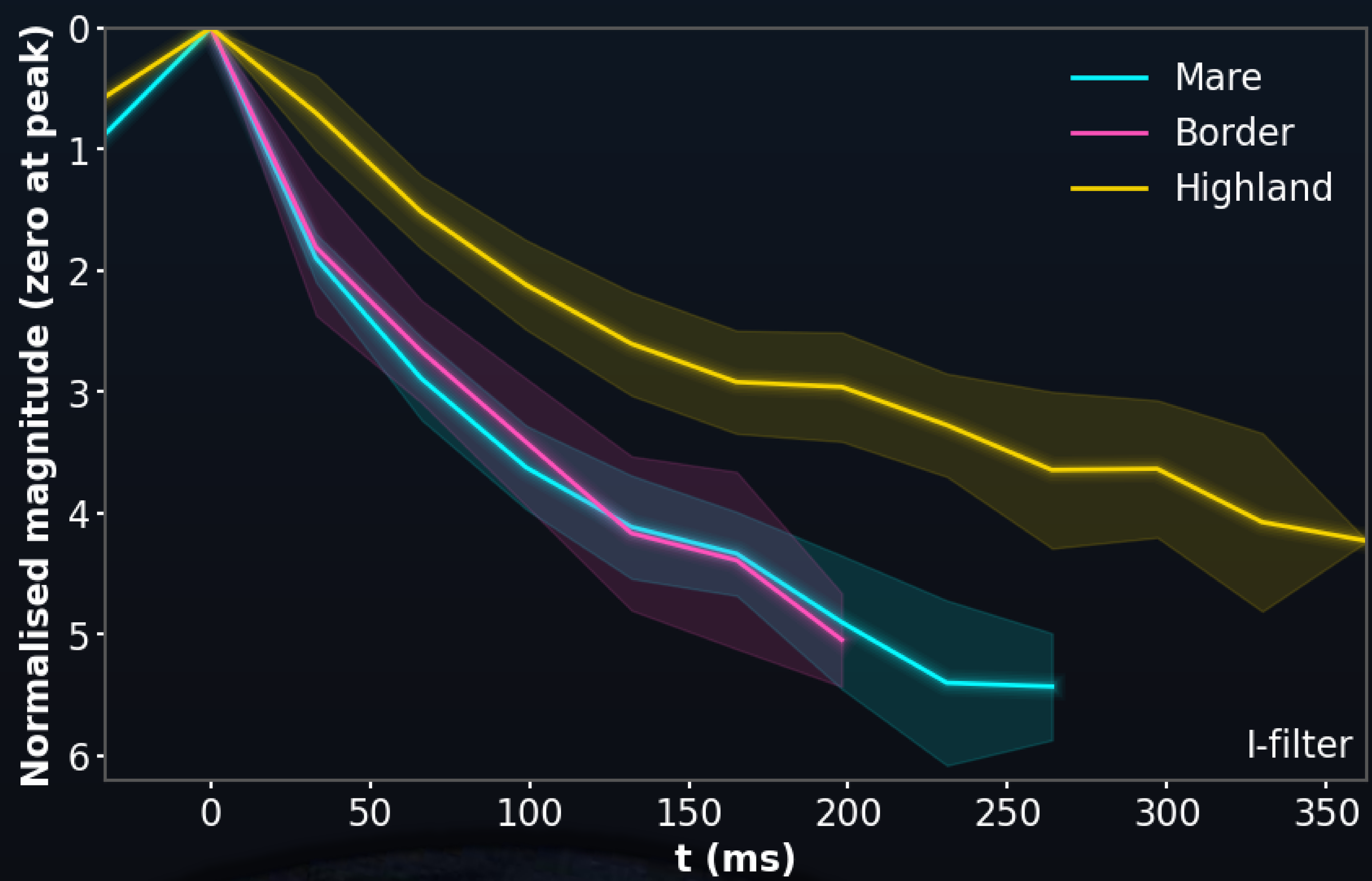

Fig. 2: Average LIF light curves (including rms) for each terrain type in the I filter

Expanding Collaboration: The NELIOTA-III Database

Building upon these discoveries, the NELIOTA-III project aims to broaden participation and foster global collaborations by expanding its official scientific database and welcoming contributions from external observers. Our newly established External Observers Database enables astronomers to submit their own LIF observations. These submissions will be linked to precise localizations of detected flashes on the lunar surface and may be associated with scheduled observing sessions. To ensure the highest standards of data quality, all datasets undergo rigorous administrative and expert review and validation prior to integration into the official NELIOTA scientific database, thereby expanding community participation while maintaining strict scientific integrity.

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Acknowledgments

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