Interpretation of Lunar Topography: Impact Cratering and Surface Roughness

Thesis by

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The impact theory applies a single process to the entire series,correlating size variation with form variation in a rational way... In fine, it unites and organizes as a rational and coherent whole the varied strange appearances whose assemblage on our neighbor's face cannot have been fortuitous.

—G. K. Gilbert, 1893

She died early, but thus saved upon herself the marks of youth. She is not an aged, decrepit world, since the dead do not age; she is an embalmed mummy, and by her outer appearance we can judge the appearance of other worlds at the beginning of Creation.

—E. J. Öpik, 1916

The origin of the principal morphological features on the lunar surface—the circular or subcircular craters ranging from centimeters to hundreds of kilometers in diameter—remains a controversial subject. On the one hand the countless number of craters attests to an intense bombardment of the moon by interplanetary debris over eons of time. But on the other hand there is ample evidence for extensive volcanic activity that many workers argue has been active either directly or indirectly as a major crater-forming process. Undoubtedly, both exogenic and endogenic processes have been in action and the controversy now revolves around the relative significance of the two agents for crater formation.

—D. E. Gault, 1970

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I have been extraordinarily lucky during my time at Caltech to have had friends and mentors who support my broad range of interests and who have, at times relentlessly, insisted that I see them through. The last seven years have been a time of great professional and personal growth for me, as a scientist, an aspiring historian of science, and a communicator, and for that I have a great many people to acknowledge.

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I also have Caltech theater to thank for landing me the amazing opportunity to produce *The PHD*

Movie with Jorge Cham, a lucky break in many ways that has opened my eyes to the possibilities of science communication. I was incredibly shy as a child, and I still cannot quite believe that I see a role for myself as a communicator, but working with Jorge has taught me to keep creating, to accept and learn from feedback, and to trust my instincts. I am so grateful for everything I've learned from Jorge and from everyone else involved in the movie and PHD TV, including (but not limited to) Laurence Yeung, Crystal Dilworth, Alex Lockwood, Matt Siegler, Roser Segura Flor, Vahe Gabuchian, Zachary Abbott, and Zach Tobin. Thank you!

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The MIT Shakespeare Ensemble has a tradition of reciting a quote from *A Midsummer Night's Dream* just before the curtain goes up, and I think it's only fitting that I continue that tradition now, so here goes: "Take pains, be perfect. Adieu!"

Abstract

This work seeks to understand past and present surface conditions on the Moon using two different but complementary approaches: topographic analysis using high-resolution elevation data from recent spacecraft missions and forward modeling of the dominant agent of lunar surface modification, impact cratering. The first investigation focuses on global surface roughness of the Moon, using a variety of statistical parameters to explore slopes at different scales and their relation to competing geological processes. We find that highlands topography behaves as a nearly self-similar fractal system on scales of order 100 meters, and there is a distinct change in this behavior above and below approximately 1 km. Chapter 2 focuses this analysis on two localized regions: the lunar south pole, including Shackleton crater, and the large mare-filled basins on the nearside of the Moon. In particular, we find that differential slope, a statistical measure of roughness related to the curvature of a topographic profile, is extremely useful in distinguishing between geologic units. Chapter 3 introduces a numerical model that simulates a cratered terrain by emplacing features of characteristic shape geometrically, allowing for tracking of both the topography and surviving rim fragments over time. The power spectral density of cratered terrains is estimated numerically from model results and benchmarked against a 1-dimensional analytic model. The power spectral slope, β, is observed to vary predictably with the size-frequency distribution of craters, as well as the crater shape. The final chapter employs the rim-tracking feature of the cratered terrain model to analyze the evolving size-frequency distribution of craters under different criteria for identifying "visible" craters from surviving rim fragments. A geometric bias exists that systematically over counts large or small craters, depending on the rim fraction required to count a given feature as either visible or erased.

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List of Acronyms

HPF Hartmann Production Function

LOLA Lunar Orbiter Laser Altimeter

LRO Lunar Reconnaissance Orbiter

LROC Lunar Reconnaissance Orbiter Camera

MESSENGER MErcury Surface, Space ENvironment, GEochemistry, and Ranging

MLA Mercury Laser Altimeter

MOLA Mars Orbiter Laser Altimeter

NAC Narrow Angle Camera

NLR NEAR Laser Rangefinder

PSD Power Spectral Density

PSR Permanently Shadowed Region

SLA Shuttle Laser Altimeter

USGS United States Geological Survey

WAC Wide Angle Camera