Lunar Cratering Asymmetries. J. Gallant[1] and B. Gladman, [1]University of British Columbia, Dept. of Physics and Astronomy, 6224 Agricultural Road, Vancouver BC, V6T 1Z1, CANADA. E-mail : jgallant@phas.ubc.ca

Introduction: Much work has been done regarding the spatial and size distribution of craters found on the lunar landscape. Recently there has been a renewal of interest studying asymmetries found in the crater field. Our study calculates the lunar crater distribution currently being produced by the near-Earth Object (NEO) distribution as its bodies strike the Moon. By using computationally intensive, but straightforward, integration methods and a realistic impactor population based on present estimates of the NEO orbital distribution, our goal is to calculate the expected level of crater non-uniformity on the lunar surface.

Background: The idea of non-uniform lunar crater coverage is nothing new; one needs only to compare the near side to the far side to see asymmetry in the mare-filled basins. Wood [1] used the idea of Earth as a gravitational lens idea to investigate the source of crustal asymmetries and concluded the concept was viable. Though state-of-the-art at the time, the numerical setup and initial conditions imposed on the system were very basic and somewhat artificial. A purely-theoretical argument, downplaying the Earth's lensing ability, was introduced by Bandermann and Singer [2]. Their study found that a focusing effect causing a nearside/farside asymmetry would be so minor as to be of little significance.

Research involving lunar cratering asymmetries had few contributors over the following three decades, most notably Horedt and Neukum [3], who derived equations for asymmetric crater frequency over a synchronously rotating satellite's surface, and Pinet [4], who examined a range of geocentric orbital parameters for lunar impactors and found a qualitative match to the observed lunar surface.

Recent work has re-opened the question of lunar cratering asymmetries. Examination of the spatial distribution of rayed (and thus likely young) craters gave evidence for a higher density on the Moon's leading hemisphere[5][6], with an amplitude 150% that of the trailing hemisphere. This seems to be in agreement with a simple dynamical estimate [7], given that the Moon orbits the Earth at 1.0 km/sec and thus sweeps up more impactors (capable of generating a crater larger than a given diameter) on its leading than trailing hemisphere. A recent numerical study [8] re-examined the hypothesis of an increased nearside crater production due to gravitational focusing by the Earth. It concluded that on average, the cratering rate is approximately a factor of four greater on the near side than on the far side. As with previous studies, the orbital distribution of possible impactors is artificial and not based on an observed NEO population. We present here the results of more extensive simulations which use the NEO orbital model derived in Bottke et al. [9] as the impactor source population. This distribution (de-biased from observational surveys) has a realistic distribution of radiant directions and encounter speeds with the Earth/Moon system.

Numerical Setup: The Bottke et al. NEO orbital distribution was filtered to keep only candidate impactors with perihelion distances $q \leq 1$ AU and aphelia $Q \geq 1$ AU. This ensured that any object chosen for an Earth/Moon flyby would be Earth crossing. Each of the remaining 16,307 particles were then duplicated into the 4 possible encounter configurations (i.e. pre and post-perihelion for both ascending and descending nodes). A test particle (TP) was randomly selected (weighted by its encounter probability with Earth) and its orbital intersection with Earth's orbit placed at a common reference point. A disk of radius 0.005 AU was populated with 100,000 test particles whose orbits were very close to the chosen reference particle. These 100,000 particles all began 0.02 AU from Earth.

Calculations: 1.7 million such flybys were conducted for the purpose of this study. The 100,000 particles were integrated forward in time using the SWIFT rmvs3 integrator in the 4-body model of Earth, Moon, TP , and Sun. The duration of the flyby was 3 times the time required for the disk to reach the Earth. Impacts with Earth or the Moon were recorded, and further calculation yielded a list of latitudes and longitudes for the impacts on both the Terran and lunar surfaces, allowing us to study what the spatial distribution of craters should be that are currently forming on the Moon and Earth. Our initial calculations assume that the moon's orbital inclination relative to the ecliptic and spin obliquity are zero, although we will relax this in future.

Numerical Results: Our results are based on a sample of 18,472 lunar impacts identified in the simulations. We have measured their locations on the lunar surface relative to the sub-Earth point.

Firstly, when comparing the near side to the far side, our simulations suggest that the level of asymmetry between the near and far side is no more than 1% (and the near-side/far-side ratio is statistically indistinguishable from unity). This result, based on the current Earth-Moon separation, is based on a realistic impactor orbital distribution, and we shall in future examine the variation with the Earth-Moon orbital separation. The asymmetry is much less than previously found in [8], but in agreement with previous analytic work [2].

In agreement with rayed crater counts ([5],[6]), we find a higher percentage of impacts strike the leading hemisphere of the Moon. Where [5] found a factor of 1.5 more rayed craters in the lunar leading hemisphere, our simulations give only 53% of lunar impacts on the leading hemisphere. If we confine our comparison to the regions from 70-290 degrees longitude and from -42 to +42 degrees latitude (the region studied in [5]), then the leading/trailing impact ratio in our simulations is 1.12. However, we must account for the impact speeds (which are calculable from our simulations) and correct the crater sizes by the effect of a likely higher impact speed onto the leading hemisphere, which would increase the asymmetry when computed versus a limiting crater diameter.

Conclusions: The bombardment of the Moon at the current epoch is relatively uniform across its surface. The high encounter speeds orbital inclinations of many of the Earth-crossing NEOs cause the gravitational focussing of the Earth to be of little importance. However, there are enough low-speed encounters from the NEO population that the orbital speed of the Moon cannot be entirely neglected; this produces an expected cratering rate enhancement on the Moon's trailing hemisphere. We will continue to refine our work in order to quantitatively compare the expected crater density with the observations of young craters on the Moon.

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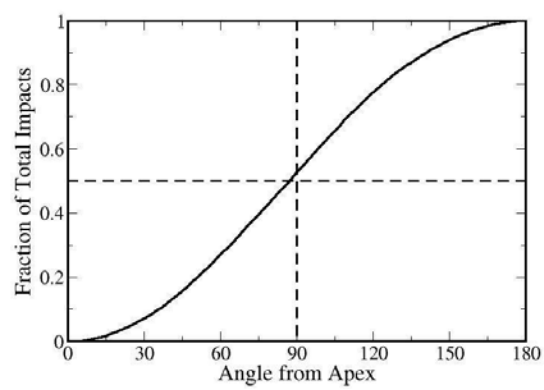

FIGURE: Cumulative fraction of lunar impacts as a function of angular distance from the apex of the Moon's orbital motion (the leading hemisphere has angles <90 degrees here). The calculations show that there is only a mildly larger leading hemisphere (although our statistical sample is large enough to rule out leading/trailing equality at the 10-sigma level). This enhanced leading-hemisphere impact flux must then be translated into an asymmetry in craters larger than a given limiting diameter using the impact speed and size distribution, which is expected to slightly increase the fraction of craters on the leading hemisphere.