The Size-Ellipticality Relationship of Lunar Craters

Introduction

Asteroid impacts have significantly shaped the geography and environments of terrestrial bodies in the solar system. Because of their significance in shaping terrestrial bodies like Earth, it is important to understand these events (Collins et al. 2011). Given the rarity of impact events, it is helpful to study the craters that impacts leave behind as they can provide a more readily available source of information on how to understand these events. The Earth’s tectonic plate movement recycles the Earth’s crust; this means that much of the Earth’s crater history has been erased. Because the Moon has no tectonic plates (Heiken et al. 1991), the moon better preserves the history of asteroid impacts which can give a window into Earth’s past. In this paper, we explore the relationship between the size and shape of lunar craters. Elliptical impact craters are still relatively unstudied (Collins et al. 2011), this paper serves to detail some of the features of them with the hope that this will gain us a better understanding of these structures.

A crater is a geologic formation that occurs as the result of an impact of an asteroid or comet with a planetary body. Asteroid impacts have been responsible for significant events in our solar system’s history such as the disruption of Mars's magnetic field, the extinction of the dinosaurs, and the formation of the moon itself (Drummond et al. 2016, During et al. 2022, Asphaug et al. 2021). Thus, it is important to study asteroid impacts to better understand these events. Craters have elliptical shapes as a function of the angle of impact, the material properties of the impacted material, and the projectile size (Elbeshausen et al. 2013, Collins et. al. 2011). For our research, we will be using the database presented in Robbins’ 2019 paper.

The previous work done by Collins et. al. (2011) discussed the relationship between crater size and ellipticality based on differing models of how elliptical craters are formed. Their conclusions were that ellipticality of craters is primarily influenced by the material properties of the surface impacted and the angle of incidence of the asteroid during impact. However, they discuss how these dynamics build to the conclusion that large impact craters are more likely to be elliptical due to their impact dynamics (Collins et. al. 2011). In this paper we seek to confirm this assertion through observation of lunar structures by comparing the ellipticality with the size of the craters from the Robbins’ dataset.

Methods

The primary point of our paper investigates the relationship between the major axis diameter of the craters from the data and the ellipticity of the respective craters. In order to properly plot the craters for whom a proper ellipse fit was created we first filtered out the craters which did not have a valid ellipse fit or estimated size from the dataset.

In order to confirm the results of the Collins 2011 paper which asserted that large craters (diameter 100 km or more) were more likely to be elliptical than smaller craters based on impact dynamics (Collins et al. 2011, p. 6), we separated the crater data into two subsets. Small craters, with a major axis diameter less than 100 km in size, and large craters with a major axis diameter >= 100 km in size. We then found the mean ellipticity for each of these populations and added it to the graph. The third standard deviation of each of these populations is also shown as the error bars on these values as a way of allowing the viewer to assess the statistical likelihood of various values.

We have also included two cutoff values on the graph. The diameter cutoff value is set to 100 km and represents the dividing value between what is considered a small and a large crater. This value is based on assessments discussed in the Collins paper. The ellipticality cut off describes the dividing line between ‘circular craters’ and ‘elliptical craters.’ The value is set to 1.16 which means that the major axis diameter of the ellipse fit should not exceed 116% of the size of the minor axis diameter. We chose this value to be a reasonable determination of circularity but it should be noted that this value is similar to the ellipticality cutoff discussed in the Collins paper of 1.2 (Collins et al. 2011, p. 6).

Results

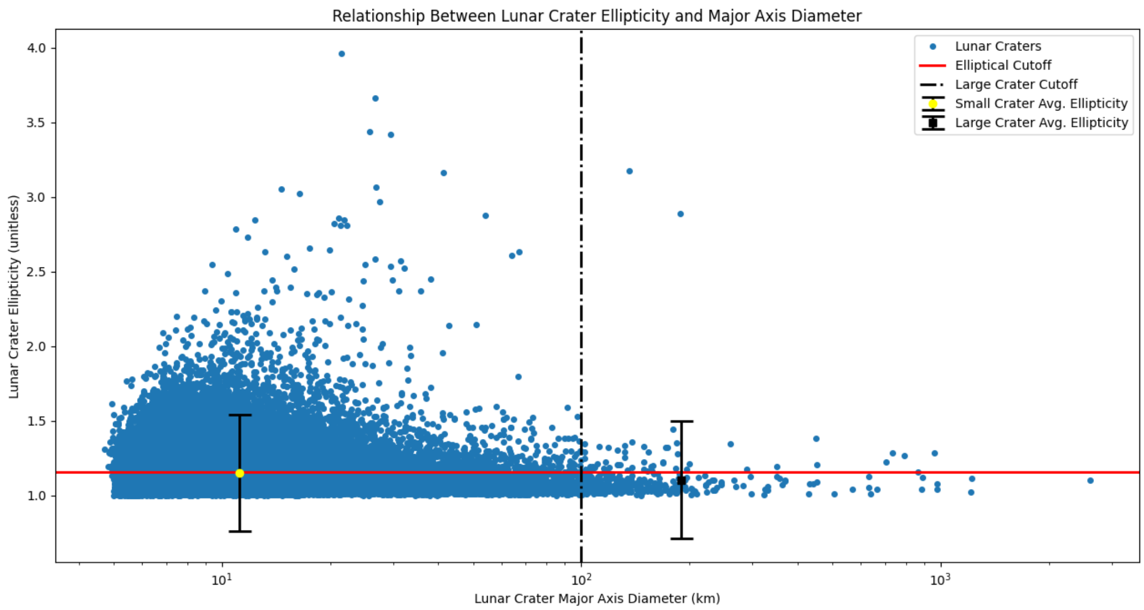

Figure 1: This graph shows the relationship between a lunar crater's ellipticity and its major axis diameter for 83,053 craters. The major axis diameter has been calculated from an ellipse fit, calculated by Robbins et. al (2019). The elliptical cutoff (horizontal, solid red line at y=1.16) is the value at which craters show significant ellipticity and cannot be accurately described by a circular fit, by our calculations. The large crater cutoff (vertical, dot dashed black line at x=100 km) is the major axis diameter at which Collins et. al. (2011, p. 6) defined as the maximum diameter for small craters.

As one can see in *Figure 1,* small craters (defined as less than 100km by their major axis diameter) have a greater range of ellipticity values than large craters. Looking at the yellow and black error bar on the left side of the graph, one can see that the mean ellipticity for small craters is higher than that of large craters (right side black error bar), but the range of values three standard deviations from the mean is similar for both groups.

Additionally it can be seen that the majority of lunar craters have major axis diameters less than 100 km. While there are 83,053 craters on this graph, many of the data points aren't visible as they are clustered and overlapped in the lower corner of the graph. While we attempted multiple methods to reduce the effects of overplotting such as random downsampling of points and reducing opacity, these points were so heavily clustered that any such attempts would result in the obfuscation or erasure of large or highly elliptical craters

Conclusion

From the Collins (2011) paper we would expect to find that large craters tend to be more elliptical than small craters. However as we can see from the results large craters have a lower maximum ellipticality than the small craters and the two sizes of craters have no statistically significant, within three standard deviations, difference between the average ellipticality for each of these populations. This seems to be in contradiction with the Collins paper. We recommend that more research should be conducted to validate a size-ellipticallity relationship, possibly considering impact cratering on other bodies other than just the moon.

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