**Introduction:** There are several competing models for the formation of Saturn’s mid-sized icy moons. In a primordial accretion model, the moons would all have similar ages, while a ring-based formation model [1-3] generates moons one at a time, which then migrate away from Saturn. Hence, ring-based formation implies that the order of the moons, in terms of distance from Saturn, also represents a gradient in their ages. In fact, ring-based models show that the innermost moon, Mimas, would be of order a billion years younger than the outermost mid-sized moon, Rhea [4]. By characterizing the cratering records of these two moons, along with the populations already analyzed on Tethys and Dione [5-7], we can test whether the relative surface ages are consistent with the age implications of the ring-based formation model versus primordial accretion.

When considering surface age dating, it is important to note that the surface ages of the moons may not reflect their formation ages due to resurfacing processes that remove/modify craters. It is also possible that one or more of the mid-sized moons was disrupted and reassembled after a large impact [8], which would affect any initial gradient in age. There are also large uncertainties in crater-based dating of the mid-sized moons as their crater populations show evidence of planetocentric (Saturn-orbiting) impactors, for which the size-frequency distributions are not well-known [5-7]. However, relative ages between the moons are likely more robust as long as all of the moons have been subjected to the same population of impactors. A further complication in the Saturn system is the influence of secondary and sesquinary impact sources.

To mitigate these complicating factors, we assess both the circular and elliptical crater populations on Mimas and Rhea, as we have previously done for Tethys and Dione [6-7,9]. Elliptical craters are useful for detecting differences in the impactor populations among the moons. We present the results of our investigations of Mimas, Tethys, Dione, and Rhea (for which work is on-going), which seem to favor the ring-based formation model and capture clear differences in impactor populations across the moons.

**Methods:** For this study, we use the Mimas and Rhea basemaps generated by the Cassini team as well as individual high-resolution images (~250 m/pix) from the Cassini ISS-NAC instrument [10]. We utilize the ArcGIS mapping software along with the CraterHelper Tools extension [11] and the USGS ISIS3 software [12] to process the ISS-NAC images.

First, we conduct the elliptical crater mapping primarily using the USGS basemaps for each moon. All craters that appear vaguely elliptical are measured so that our dataset is sufficiently robust. At Mimas, we map from 60° S to 90° N, at all longitudes, using higher-resolution north polar data not included in the basemap. Our preliminary mapping extent for Rhea ranges from 60° S to 60° N and spans all longitudes. We use a simple cylindrical projection for the equatorial regions and reproject into a polar stereographic view as the mapping area gets closer to the polar terrains. The crater’s measured ellipticity is calculated by taking the ratio of the major axis (measured diameter in CraterHelper Tools) and the minor axis. Craters with ellipticities ≥1.2 are classified as elliptical. We also measure the orientation of the long axis of the elliptical crater.

For the regional crater studies, we focus on the high-resolution imagery from the ISS-NAC instrument across 5 main regions on Mimas’ surface. We are currently evaluating the imaging dataset for the regional study of Rhea. We map and categorize all craters within the study area. Morphologies such as elliptical, polygonal, irregular, and circular are used to classify the crater shapes. We generate crater size-frequency distributions (SFDs) for the circular craters using established methodologies [13,14].

**Figure 1:** Mollweide projection of Mimas with elliptical crater locations/orientations plotted on top. Light yellow craters represent craters with orientations that are more oriented in the East/West direction, as on Tethys/Dione.

We compare the SFDs of observed craters with the Case B production function [15]. Case B was developed to explain the crater record of Triton, which is thought to be heavily influenced by planetocentric debris at Neptune. Outer solar system moons that were mainly...
cratered by heliocentric material follow a different trend (Case A in [15]). Past work has shown that Case B provides a better fit to Saturn’s mid-sized moons [6,7], but there are deviations that likely represent differences in the extent and nature of planetocentric material at Saturn and Neptune, adding uncertainty to ages derived from the fit between observed craters and the production function.

**Results/Discussion:** We counted 134 elliptical craters on Mimas, distributed across the surface [Figures 1,2]. We observe two signals in the data: a group of elliptical craters located in an equatorial band that exhibits a slight preference for east-west long axis orientations (yellow in Fig. 2) and a group of north-south oriented elliptical craters in the (north) polar region (teal in Fig. 2). When compared to elliptical craters on Tethys and Dione, we find nearly an order of magnitude fewer craters on Mimas and the north-south group is not observed on the other moons (See discussion section of [7]).

For the regional study, we focused on the area in and around the Herschel impact basin as well as regions near the North Polar and the Trailing Hemisphere. Based on our crater counts, the age sequence (from oldest to youngest) is the North Polar terrain, the region exterior to Herschel and the trailing hemisphere, which share similar crater densities, Herschel’s ejecta blanket, and the interior of Herschel. The crater densities of the two older regions on Mimas’ leading and trailing hemispheres are very similar, without the asymmetry between leading and trailing hemispheres that is expected from a heliocentric impactor source, [16,17]. The lack of asymmetry and the substantially better fit to the data using the Case B production function, we conclude that planetocentric impactors play an important role in cratering Mimas, which is consistent with our findings at Tethys and Dione [6,7,18].

**Preliminary Conclusions:** Analysis of elliptical and non-elliptical impact crater distributions on Mimas provide evidence for a surface dominated by planetocentric impacts. The regional crater densities on Mimas are comparable to those on Tethys and Dione, when crater diameters are scaled to the appropriate satellite, but we observe nearly an order of magnitude fewer elliptical craters on Mimas. Taken together, these results suggest Mimas experienced fewer impacts that formed elliptical craters but not fewer impacts overall. Either the conditions at Mimas are somehow less conducive to forming elliptical craters or the impact population that formed elliptical craters on Tethys and Dione differs strongly. Sesquinaries/secondaries may also play a larger role at Tethys and Dione. Interestingly, there are also clear differences between the elliptical crater patterns at Mimas when compared to the other moons. Specifically, there is a north-south clustered group far from the equator – a unique characteristic of Mimas’ elliptical crater population.

Due to uncertainties in the planetocentric impactor flux at Saturn and Neptune, the relative surface ages of the moons are more robust than the model ages derived from fits to the Case B production function. In general, we find that regions associated with Herschel are systematically younger than other regions on Mimas. We also find that Mimas’ terrains are younger than the terrains on Tethys, which are younger than the terrains on Dione. Rhea, thus, becomes a critical data point to determine whether the moons’ surfaces are showing a signature of ring-born formation.

Further characterizing the planetocentric impactor sources and fluxes will improve our ability to date the moons. Rhea mapping is currently underway, which will be an additional critical component in building a holistic framework about the bombardment sources within the Saturn system.


**Figure 2:** Mimas’ equatorial (yellow) elliptical craters have long axis orientations with a slight preference for E-W, while the polar group (teal) has a strong N-S preference.