OPEN TOOLS FOR CRATER ANALYSES. S.J. Robbins[*,1], J.D. Riggs[2]. [*]stuart@boulder.swri.edu, [1]Southwest Research Institute, 1050 Walnut Street, Suite 300, Boulder, CO 80302, [2]Northwestern University.

Introduction: Impact crater studies began decades ago and craters were analyzed with relatively simple, straightforward methods and tools. The development of individual researchers' own analysis tools and methods is common in many branches of science, but it is also important that some of those tools and methods be standardized. Standardization allows for repeatability, openness, and ultimately can lend credibility to all efforts in the field. However, standardization of tools that are *not* open-sourced and are treated entirely as a black box by the end user can lead to problems. For instance, the now common CraterStats and subsequent CraterStats2 software [1] is often used by the planetary science community, but it is written in commercial IDL software (with a free run-time environment) and, over the years, different researchers have raised questions about the way some of the analysis in that software is done.

To try to bring together the best of both worlds – standardized tools with open source code – we have been working towards Python implementations of the crater analysis tools presented in [2]. Additionally, we have been developing other software in Python, including (a) tools to measure the polygonality of impact craters, and (b) tools to determine the significance of a paucity of intermediate-sized impact craters in a population (*e.g.*, the absence of any craters >50 km on Mimas, except the ~135 km Herschel). When completed, each tool will be placed on the open platform GitHub and carry the GNU public license. The benefit of coding in Python is that Python is also an open language, freely available to download and install, and works on most computer platforms. Additionally, Python is fast becoming the language of choice in many sciences, and, as a result, it has numerous libraries specifically written for math and science. At the August 2019 conference, we will discuss our progress towards these tools and demonstrate them.

The SFD_{EDF}: In [2], the authors demonstrated a new method for creating the crater size-frequency distribution. Instead of a simple binning, they represented each crater as a Gaussian or other probability distribution (PDF), and then summed those individual PDFs, arguing it is a better statistical representation of the data. Because the sum of those PDFs form an empirical distribution function (EDF), they called the result a SFD_{EDF}. Additionally, they presented a bootstrap technique requiring CPU-intensive Monte Carlo sampling to calculate the uncertainty envelope. They also presented different methods for fitting power laws that are more statistically sound than common least-squares techniques. Due to the complexity of calculating the SFD_{EDF} and its uncertainty, it is not nearly as straightforward to produce as an SFD, and so the authors promised to provide computer code to do so. Unfortunately, we were unable to fulfill that specific promise for user-friendly code at the time.

Our alpha version of a Python implementation is extremely straightforward, only requiring a list of crater diameters. It produces the SFD_{EDF}, its uncertainty, and includes on the graph a rug plot – a small tick mark on the *x*-axis to indicate where original craters in the sample were.

There are numerous options that the user can include in the calculation if desired, all available as command-line arguments to modify the built-in defaults. We also plan to allow the code to export a table of the results so that the end user can graph it themselves in their software of choice. In current form, the fitting component is a separate code, but we are experimenting with merging the two so that both can be displayed on the same output graph.

Polygonal Craters: At the 2018 Crater meeting, [3] presented work towards identifying and measuring the polygonality of impact craters, for some craters on various solar system bodies display straight edges rather than a quasi-continuous curve. A further subset of bodies, including Ceres, appear to be enhanced in those polygonal craters. However, the authors demonstrated that there was no formal definition of what constituted an "edge" of a crater, with different papers adopting different definitions and measuring edges by hand. This raises significant questions about reproducibility and replicability, and discussion at that meeting suggested that a straightforward computer algorithm might be developed to better define and quantify a crater "edge" based on a manual rim trace.

Figure 1 demonstrates work towards that effort. After projecting the crater rim into a physical unit (*e.g.*, km) to correct for map projections, the code effectively walks around the crater rim trace looking for edges and hinges. Where two edges meet does not necessarily mean there is a hinge. The tunable parameters for this code include: How long an edge must be to be considered a straight edge, how little that edge can vary from a straight heading to be considered a straight edge, and the minimum angle change over what physical distance is needed between edges to be considered a hinge. In the Figure 1 example, five edges and three hinges were identified. The arc between 9:00 and 11:00 exceeds the maximum angular change to be considered an edge, and the hinge near 4:00 is over too large of a distance to be considered a valid hinge, for the example parameters chosen for this Figure.

We are now working to test this code on a variety of impact craters and develop empirical parameter bounds based on published literature for our three tunable parameters. We expect to release this tool along with a short manuscript about our results.

Significance of Missing Craters: After *New Horizons*' flyby of MU_{69}, the crater population was shown to have numerous crater-like features of the ~100s m size, but then no intermediate craters between that and the largest structure $D \sim$ 7–8 km. With relatively few impact features overall, this raised the question about how significant an absence of intermediate-sized craters actually is: Should one expect to see craters between the largest and next-smallest, and if so, to what level of significance?

While MU_{69} may have formed the initial motivation for this work, the question can be asked for other solar system bodies. For example, Saturn's smallest regular spherical satellite, Mimas, has an absence of craters $D \sim$ 51–134 km, and it is not clear from any established tool in the crater community whether this dearth of craters is statistically meaningful. At the time of this abstract submission, we have not yet solved this problem, but we are working towards it and expect to provide an update at the August meeting and make available a simple tool that an individual can use to help determine the significance of such gaps.

References: [1] Michael (2013). doi: 10.1016/j.icarus.2013.07.004. [2] Robbins *et al*. (2018). doi: 10.1111/maps.12990. [3] Zeilnhofer & Barlow (2018), PCC #9 Abstract #1801.

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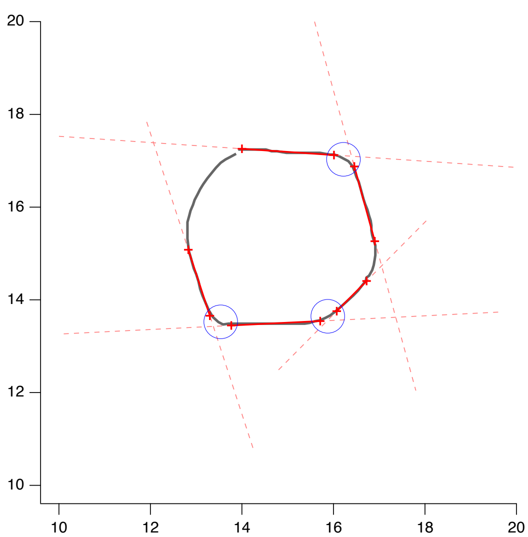

Figure 1: Example polygonal crater centered near 15° latitude and longitude. The rim trace is shown in dark grey. Identified edges are shown in solid red with + end caps. Identified hinges are shown as blue circles. The edges have been projected out via thin, dashed red lines.

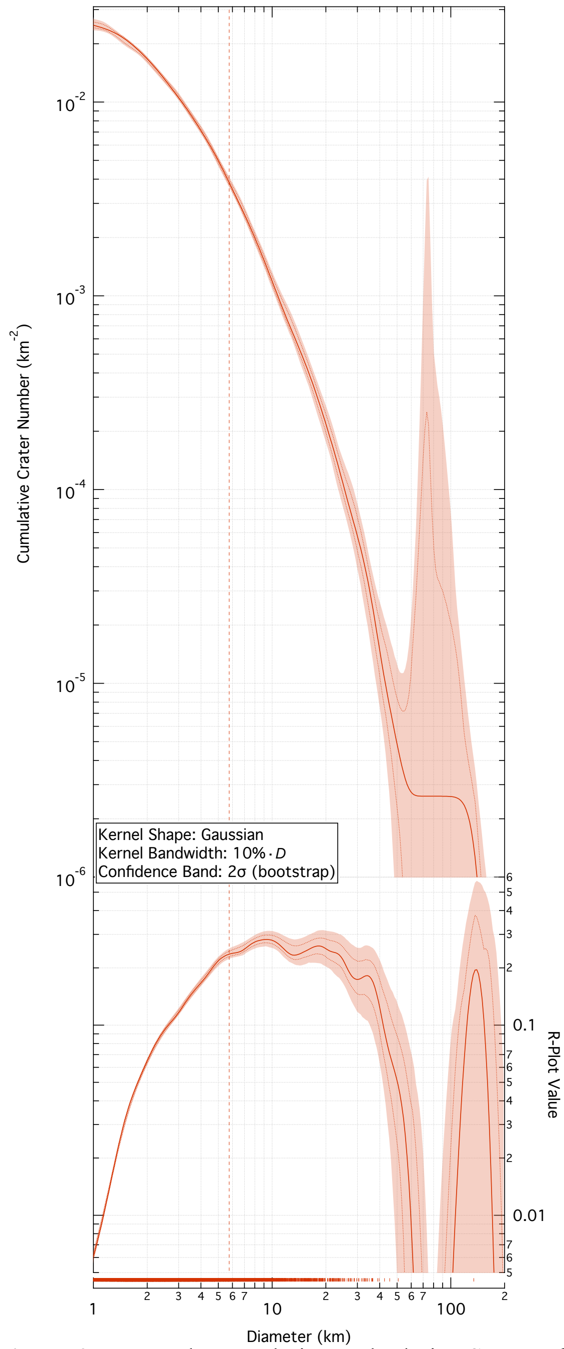

Figure 2: Example cumulative and relative SFD_{EDF} for Mimantean craters, showing on the rug plot the largest crater is $D \sim$ 135 km, and the next-largest $D \sim$ 51 km. The $CSFD_{EDF}$ shows an extremely large uncertainty in the missing data range, while the $RSFD_{EDF}$ shows an almost disconnected distribution. The questions we are investigating are: Is that confidence misleading, or is real and we should expect craters in the range $D \sim$ 51–135 km, and what is the significance of their absence?