PLANETARY SURFACE DATING WITH CRATERSTATS3 – A NEW OPEN SOURCE IMPLEMENTATION IN PYTHON.

G. G. Michael. Albrechtstr. 83, 12167 Berlin, Germany.

Introduction: *Craterstats* is a software tool for analyzing crater count data in the context of a planetary surface chronology model. It was first developed in 2007 to replace an older piece of software used at the Freie Universitaet for crater dating [1], known as *Kranch*, which was written in HP BASIC and took its data input in the form of hand digitized measurements from photographic plates. The new program was coded in IDL with the aim of exactly reproducing the analysis of the old measurements while also being able to process new data produced by GIS software. Subsequent changes to enable better comparison between different chronology models and data presentations, as well as to introduce new calculations to account for resurfacing effects eventually led to a restructuring as *Craterstats2* in 2010. Since then, notable updates have included adaptations to allow:

Fitting of the differential form of polynomial-style cumulative production functions, removing the necessity to make so-called *resurfacing corrections*, making the analysis both simpler and mathematically cleaner [2].

Compensation of exponential binning bias. When working with binned data representing a decreasing exponential function, a bias arises when plotting against the bin centre since, statistically, more craters occur close to the left edge of the bin than its right. The consequence is that points are plotted higher than would be the case for a continuous function. The effect becomes larger as the bin width increases, and makes a difference of a few percent in model ages for root-2 binning. Where the slope of the production function is known (even approximately), the effect can be compensated out [2].

Poisson timing analysis. Following a workshop on *Issues in Crater Studies and the Dating of Planetary Surfaces* (Laurel, Maryland) where the problem of calculating errors for chronology models fitted to binned data was discussed at length, a new approach was introduced which evaluates the model exactly – without binning or fitting. The method describes the surface age probabilistically, and remains valid for those cases where the number of craters is low or even zero, when the binning/fitting method becomes inadequate [3].

μ-notation. At the same workshop, we discussed the importance of distinguishing the error arising from the Poisson process of crater formation, which may in some cases be rather small, from the uncertainty of correctness and calibration of any particular chronology model, which may remain considerably larger and is not easily quantifiable. We denote this latter uncertainty by the function μ in a quoted age estimate, e.g. $\mu 10.9^{+2.8}_{-2.4}$ Ma, with the plus/minus values representing only the stochastic error [3]. Provided that the model is broadly valid – that we are counting primary craters that accumulate with time – the stochastic errors maintain meaning in distinguishing the relative age of surfaces even when the model calibration is less well known.

New implementation: *Craterstats3* is designed to replicate the output of the previous version as closely as possible. As before, it produces plots in cumulative, differential, Hartmann, and R-plot styles [4] with possible overlays of crater counts, isochrons, equilibrium functions and epoch boundaries, as well as chronology and impact rate functions (Fig. 1). Data can be shown with various binnings or unbinned, and age estimates made by either cumulative fitting, differential fitting, or Poisson timing evaluation. Numerical results can be output as text for further processing elsewhere. A number of published chronology systems are already set up for use, but new ones may be added by the user.

The software is written as a Python package with a command line interface, the intent being to create an archived reference implementation of the calculation components of the software. Some example command lines are shown in Figure 1 with the plots they generate. The package is designed to be easily integrated into other software, which could allow the addition of a graphical interface or the inclusion of some *Craterstats* functions into a GIS.

Installation instructions and the source code can be found at: https://github.com/ggmichael/craterstats. Note that the installation procedure is likely to be revised in the near future.

The methods of the companion program for spatial randomness analysis of crater populations provided with *Craterstats2* were recently generalised for analysis of regions covering a significant fraction of a curved surface body [5]. It is intended to provide a future Python parallel of this program based on this generalisation.

References: [1] Neukum G. (1983) http://ntrs.nasa.gov/search.jsp?R=19840027189 [2] Michael G. G. (2013) Icarus 226, 885–890. [3] Michael G. G. et al. (2016) Icarus 277, 279–285. [4] Arvidson R. E. et al. (1979) Icarus 37, 467–474. [5] Riedel C. et al. (2021) Journal of Geophysical Research: Planets 126, e2020JE006693.
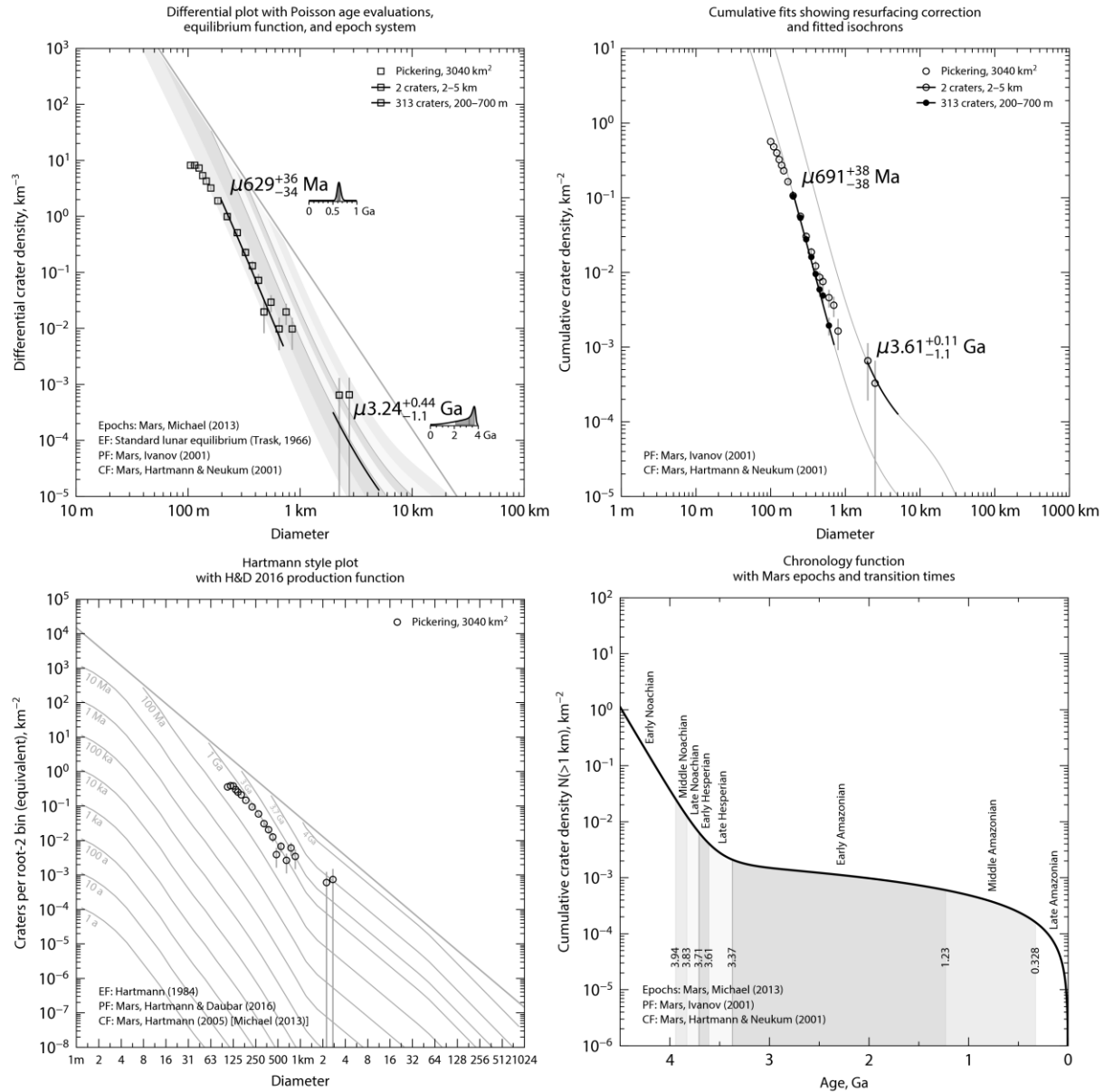
```
python craterstats.py -cs 3 -ep 2 -ef 1 -title Differential plot with Poisson age evaluations, -subtitle equilibrium
function, and epoch system -p source=craterstats/sample/Pickering.scc -p type=poisson,range=[2,5],offset_age=[2,-2] -p
range=[.2,.7]

python craterstats.py -pi 1 -cs 3 -title Cumulative fits showing resurfacing correction -subtitle and fitted isochrons -p
source=craterstats/sample/Pickering.scc,psym=1 -p type=c-fit,range=[2,5],isochron=1 -p range=[.2,.7],resurf=1,psym=10

python craterstats.py -pi 4 -cs 6 --equilibrium 2 -title Hartmann style plot -subtitle with H&D 2016 production function
 -isochrons 4s,3.7s,3s,1,.1,.01,.001,1e-4,1e-5,1e-6,1e-7,1e-8,1e-9 -p source=craterstats/sample/Pickering.scc,psym=1

python craterstats.py -pi 5 -ep 2 -cs 3 -title Chronology function -subtitle with Mars epochs and transition times
```

Figure 1. Example plots generated by *Craterstats3* with command lines used to generate them