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# Topography of exoplanet

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## Abstract

Current technology is not able to map the topography of rocky exoplanets, simply because the objects are too faint and far away to resolve them. Nevertheless, indirect effect of topography should be soon observable thanks to photometry techniques, and the possibility of detecting specular reflections. In addition, topography may have a strong effect on Earth-like exoplanet climates because oceans and mountains affect the distribution of clouds. Also, topography is critical for evaluating surface habitability. We propose here a general statistical theory to describe and generate realistic synthetic topographies of rocky exoplanetary bodies. In the Solar system, we have examined the best-known bodies: the Earth, Moon, Mars, and Mercury. It turns out that despite their differences, they all can be described by multifractal statistics, although with different parameters. Assuming that this property is universal, we propose here a model to simulate 2D spherical random field that mimics a rocky planetary body in a stellar system. We also propose to apply this model to estimate the statistics of oceans and continents to help to better assess the habitability of distant worlds.

## 1. Introduction

Efforts to detect and study exoplanets in other solar systems were initially restricted to gas giants [1] but multiple rocky exoplanets have now been discovered [2]. Their climates depend mainly on their atmospheric composition, stellar flux and orbital parameters [3]. But topography also plays a role in atmospheric circulation [4] and is an important trigger for cloud formation [5]. Furthermore, the presence of an ocean filled with volatile compounds at low albedo is of a prime importance to the climate [6]. Last but not least, surface habitability relies on the presence of the three elements linked by topography: the atmosphere, ocean and land [7]. The effect of exotopography should be observable by the next generation of ground and spaceborne telescopes targeting transiting exoplanets [8].

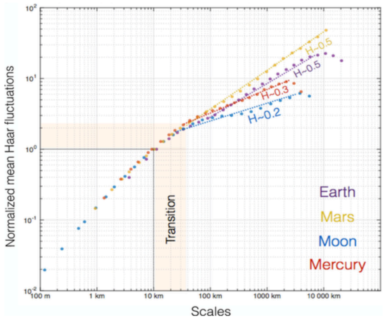

Figure 1: Mean fluctuations of topography of the Earth, Mars, Moon, and Mercury, as a function of scale [10, 11]. All data sets are normalized in order to be equal to 1 at the scale 10 km. The normalization does not modify the scaling behavior but emphasizes the transition occurring at around 10 km.

## 2. Method

We used the multifractal theory [9] to describe the topography at all scales from the planetary scale down to several meters. It allows to comprehend realistic texture with (i) scaling symmetry: the topography is statistically identical at all scales and (ii) intermittent: the topography is spatially variable with rough and smooth area. We demonstrated that all known bodies of our Solar System are reasonably described by this theory the Earth, Moon, Mars, and Mercury [10]. Figure 1 shows the roughness for the 4 bodies (described here as the mean Haar fluctuation) as a function of scale. They all follow a linear law in a log-log plot, as expected by scaling law. A transition occurs around 10 km, most probably due to the elastic thickness of the crust [10]. The multifractal parameters alpha and $C_1$ are also investigated. We develop a new algorithm to generate spherical synthetic topography, in agreement with the observed data [11].

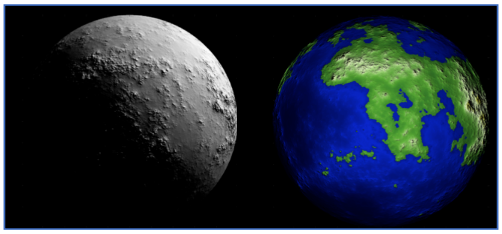

Figure 2: Examples of synthetic exoplanet topography [11].

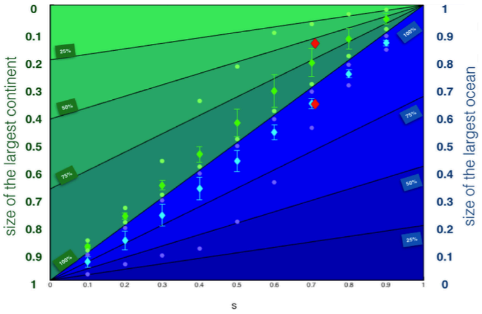

Figure 3: The ocean/continent relationship [11]. The size (as proportion of the total planet surface) of the largest continent (blue) and ocean (green) for different values of sea level s, defined as the quantile of the global topographic distribution. The diamond indicates the mean size with one standard deviation bars, whereas the circles indicate the minimum and maximum value in each case. The blue and green lines correspond to proportions of the remaining area covered by continents and ocean. These results are based on 500 synthetic topography simulations of an Earth-like planet (H = 0.5, alpha = 1.9, $C_1$ = 0.1). The red diamonds are for the Earth.

## 3. Results

Examples of synthetic topography are provided on figure 2. We investigate the interface between ocean, atmosphere, and land (see fig. 3). From our results, on average the size of the largest ocean or continent is always close to the maximum available size (near the 90 % line). The congruent part of the surface covered by ocean (or land) is split up into smaller but more numerous islands (or lakes), as also observed on the Earth. There are some extreme cases, where the largest continent is very small. Interestingly, this case happens more for small sea levels. If s=0.1, the extreme case can even reach 25%, meaning that the largest ocean only covers 25% of the ocean surface, 75% are thus covered by smaller lakes. The symmetric situation occurs for s=0.9: the largest continent only covers 25% of the land, 75% are thus covered by small islands. The Earth corresponds to the average situation since all the major oceans are connected through the thermo-haline circulation. From this study, we can exclude the situation of two large unconnected oceans, representing a global sea surface > 50%. The same for two large unconnected continents, representing a global sea surface > 50%. As a summary, the interface between land and sea, so important for habitability, can be statistically constrained by this model.

## 4. Conclusion and perspectives

Multifractal simulations on spheres are able to statistically reproduce the morphology of planetary bodies, and even potentially small bodies such asteroids and comets. We provide a 3D visualization of some examples with varying parameters (https://data.ipsl.fr/exotopo/ ). In addition, a data set of synthetic spherical topographies can be downloaded by the reader (http://dx.doi.org/10.14768/20181024001.1). Future work should incorporate these statistical constraints to recover the topography from real exoplanet observations.

## References

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