Can we live on exoplanets? Overview of 'Topography of (exo)planets' (Landais er al. 2019)

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1.Introduction

Are there any rocky exoplanets that we can inhabit?

- Their climates depend mainly on their atmospheric composition, stellar flux, and orbital parameters.
- Topography also plays an important role in atmospheric circulation.
- The surface habitability relies on the presence of the three elements: the atmosphere, ocean, and land.

The topographystatistical models.

Landais,Schmidt & Lovejoy 2019 reported the first unifying statistical similarity between the topographic fields of the Earth, Moon, Mars, and Mercury. All these topographies seem to be well described by a mathematical scaling framework called multifractals.

They propose a general statistical theory to describe and generate realistic synthetic topographies of rocky exoplanetary bodies.

2.Method

Multifractal Framework

A fractal describes self-similar structures, independent of scale. Multifractals extend this concept to account for varying degrees of roughness and heterogeneity across scales. Simulations were conducted using universal multifractal models. Parameters:

H: Controls how roughness varies with scale.
C1: Measures spatial heterogeneity near the mean.
α: Quantifies how rapidly properties diverge from the mean.

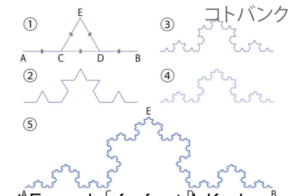

Fig 1:Example of a fractal: Koch curvel

Spherical Mapping

Multifractal fields are applied to spherical coordinates using harmonic expansions, enabling realistic planetary simulations.

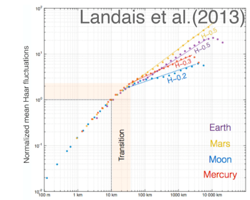

Fig 2:a log-log plot of the mean normalized variation in altitude

3.Results

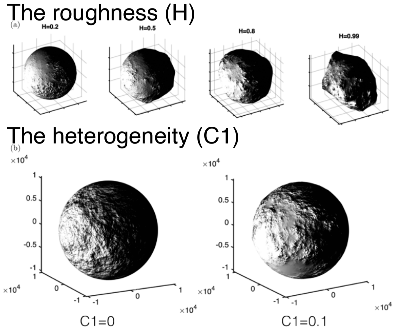

Fig3:The results of a multiple fractal simulation on a sphere, generating topography for different values of H and C1.

Landais et al.(2013)

- When H is low, it is rough on the small scale and smooth on the large scale.
- When H is high, it shows significant variation on the large scale and smooth on the small scale.
- When C1 is low, the roughness is uniform throughout.
- When C1 is high, smooth and rough areas appear alternately.

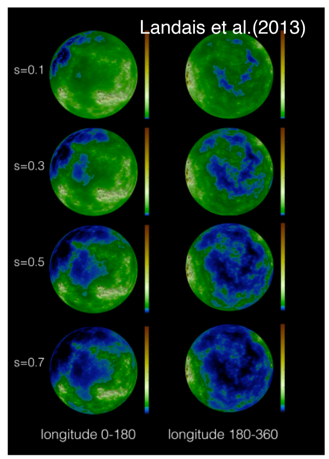

Fig 4:Synthetic multifractal topography as a function othe surface proportion of the ocean s(the Earth/Mars-like planet H= 0.5, α = 1.9, and C1 = 0.1).

- The largest continent or ocean typically occupies nearly the maximum possible area.
- At extreme s values (e.g., s=0.1 or s=0.9), land and ocean distributions fragment into smaller structures.
- At middle levels (e.g., s=0.5), stable and large-scale structures for both land and ocean are more likely to form.

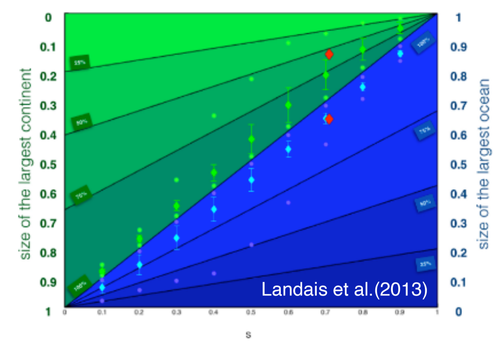

Fig 5:The ocean/continent relationship. The diamonds indicate the mean.

- The simulation results are consistent with the observed ocean ratio on Earth.
- Scenarios disconnected large-scale oceans or continents are statistically improbable.

4.Conclution

- Despite geological differences, the topographies of Earth, Moon, Mars, and Mercury exhibit a unified statistical similarity.
- Multifractal models successfully simulate realistic topographies for rocky exoplanets.
  - Realistic synthetic topographies of Earth-like planets were generated using multifractal simulations.
  - At middle socean levels (s≈0.5), large-scale structures such as dominant continents or oceans emerge.
  - The land-ocean interface is critical for evaluating habitability, as stable climates are associated with balanced land-sea distributions and smooth topographies.

5.References

Demory B.-O. et al., 2013, ApJ, 776, L25
Landais F et al.(2019), Monthly Notices of the Royal Astronomical Society 484, 787–793.
Landais F., Schmidt F., Lovejoy S., 2019, Icarus, 319, 14
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