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Interior and surface evolution paths of rocky exoplanets

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Abstract

In this study, the thermal and chemical evolution of rocky exoplanets is modelled, using a Monte-Carlo method to study the influence of randomly selected values for unknown parameters like composition-related or thermal parameters. Evolution scenarios can be diverse depending on the parameter assumptions for small-massive planets (with masses of up to few Earth masses).

1. Introduction

Thousands of exoplanets have been discovered in the past decade, revolutionizing our way of scientific thinking both in the direction of formation and evolution of planets, as well as in the direction of exotic places where life may evolve and flourish in non-Earth-like environments. However, identification of possible atmosphere bio-signatures or models of the evolution of exoplanets are typically based on Earth models - which is a natural first step to understand processes on possibly habitable planets, especially since we are more prone to detect exo-life (if it exists) on Earth-like planets than on other planets due to our detection bias.

Several studies for example extrapolated Earth models to other planet properties (e.g. mass, radius, core size, see Fig. 1 from [1]) to predict how basic planetary processes (like mantle convection or plate tectonics) are affected by these parameters. However, even if a planet is discovered with a density hinting at a rocky planet, it may be quite non-Earth-like for example in terms of composition, mineralogy, core formation, volatile content, etc. Within the range of uncertainties and with the current observation techniques, it is impossible to differentiate remotely between a planet like Earth with continents and oceans at the surface, or a dry one-plate planet, or an ocean planet, or other, exotic planets.

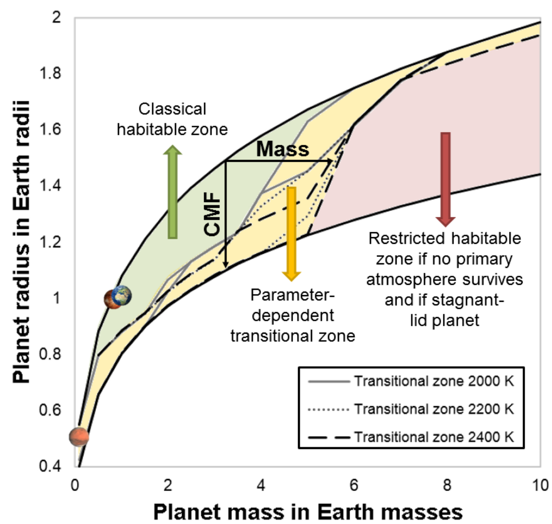

Figure 1: Sketch of a mass-radius diagram indicating the mass-radius range, where the classical HZ definition can be applied (green area), the range where the HZ may be restricted due to limited outgassing (red area) and the transitional regime in-between (yellow area) for planets of Earth-like composition and structure without plate tectonics. From [1]

It is therefore necessary to study how the evolution of a planet may be affected by the unknown planet's properties as well as its formation and evolution history, and to better understand possible restrictions for surface or subsurface habitability.

2. Convection simulations

The evolution of the mantle of rocky exoplanets is modelled using the truncated anelastic compressibility approximation (for specifics on the code implementation, please look at [2]). For given planet mass and pre-defined mantle composition, radial profiles are derived for the thermodynamic properties depending on an adiabatic temperature profile.

The composition of the mantle has a strong influence on the mantle convection (and possibly plate tectonics initiation or maintenance), as well as on the crust and atmosphere evolution (for example via volatile-dependent melting temperatures and melt compositions). The influence of the mineralogy of the mantle (depending for example on the Fe/Si and Mg/Si ratio as well as on volatile contents) and initial parameters (as for example initial upper mantle and core temperatures and radioactive heat sources) on convective behavior, surface processes and outgassing of greenhouse gases such as CO_2 and H_2O [3] is investigated.

3. Preliminary results

Thermal initial parameters can strongly influence the efficiency of mantle convection and therefore have a major effect especially on outgassing results.

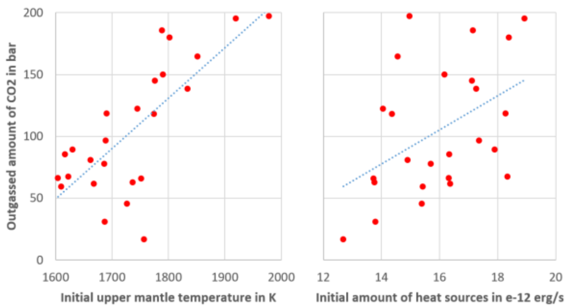

Figure 2: Example outgassed amount of CO_2 depending on initial upper mantle temperature (left) and initial amount of radioactive heat sources (right).

Figure 2 shows an example outgassing result for a rocky planet of 1.3 Earth masses with an Earth-like core-mass fraction and assuming here a pure silicate mantle and pure iron core. A clear increasing trend can be observed between outgassing efficiency and initial upper mantle temperature (influencing the entire adiabatic temperature), whereas a less strong but still increasing trend can be observed with respect to the initial amount of radioactive heat sources.

Further investigations will include for example the influence of composition (e.g. magnesium number in mantle minerals), initial mantle volatile content, non-linear partitioning of volatiles into the melt, and volatile influences on melting temperature.

4. Summary and Conclusions

Monte-Carlo models of possible planet post-formation thermal states and planet compositions are used in this study to predict the range of possible evolution trends for specific rocky planets. Initial parameters for the thermal profile as well as radioactive heat sources have a strong influence on outgassing of greenhouse gases and therefore possible surface habitability (see also [4]). The mass in addition strongly affects the convective behavior in the interior and therefore also the effectiveness of outgassing.

Monte-Carlo models with randomly chosen parameters for planet properties and initial values as reported here can be used to obtain a statistical probability of specific surface processes (e.g. sufficient greenhouse outgassing at the outer boundary of the habitable zone, [1]). This can be used to help identifying exoplanets of higher (or lower) interest to expensive follow-up observations.

Acknowledgements

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References

[1] Noack, L. et al.: Volcanism and outgassing of stagnant-lid planets: Implications for the habitable zone, PEPI, in review.

[2] Noack, L. et al.: Modeling the Evolution of Terrestrial andWater-rich Planets and Moons, JSysMea, 2016.

[3] Boissinot, P.: Evolution of the atmosphere of Mars, Master thesis (in French), U Nantes, 2017

[4] Dorn et al.: Maximum interior outgassing of exoplanets, GRL, in preparation.