



Constraints on planetary habitability from interior modelling

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The most interesting planetary bodies outside the Solar System regarding the search for life are potentially rocky extrasolar planets. Some of them may feature surface conditions that allow for liquid water, which is the elementary prerequisite for life as we know it. The amount of greenhouse gases, like e.g. carbon dioxide (CO₂), plays an important role for the determination of the surface temperature, hence the habitability of an extrasolar planet. The amount of greenhouse gases is strongly influenced by their outgassing from the interior.

In this study, we investigate under which conditions the planetary interior structure and dynamics allow for the build-up of planetary atmospheres which may lead to habitable surface conditions. We investigate the evolution of a secondary atmosphere for Earth-sized planets with different interior structures (i.e. iron-silicate mixing ratios) by applying a two-dimensional model of interior dynamics [1], which allows for the calculation of the production of partial melt [2]. From this, we estimate the amount of CO₂ outgassing for Earth-sized planets with different core and mantle radii after adapting the total CO₂ outgassing in 4.5 Gyr for a Venus reference simulation to the present-day atmosphere of Venus. We furthermore investigate the possible influence of plate tectonics on outgassing and the likelihood of plate tectonics depending on the interior structure of the planet.

We find that the size of the iron core has a large impact on the production of partial melt, hence on the possible outgassing of CO₂, which is due to the pressure-dependence of the melting temperature of silicate rocks: for planets with a large core the planetary mass is larger than for a planet with a small iron core, leading to larger melting temperatures in the upper mantle. Therefore only little outgassing from the interior can be expected. However, for the determination of the outer edge of the habitable zone it is typically assumed that enough greenhouse gas CO₂ is available in the atmosphere to lead to liquid water at the surface – independent of the interior of the planet [3]. Our results on the other hand suggest that the outer boundary of the habitable zone may be constrained by the production of partial melt in the interior for planets with a large iron core and a thin silicate mantle. However, if plate tectonics initiates, several tens of bars of CO₂ can be outgassed in a short time also for planets with a large iron core. In this case the outer boundary of the habitable zone would not be limited by outgassing as is the case for stagnant-lid planets. It is, however, questionable if planets with a very thin mantle are able to initiate plate tectonics.

References

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