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Low-lid formation on Super-Earths and implications for the habitability of Super-Earths and Sub-Earths

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The last decades of astronomical observation have opened the new interdisciplinary field of extra-solar planetary research. Up to this date more than 380 extra-solar planets, or short exoplanets, were detected. Our own solar system consists of terrestrial planets that are less massive than Earth. But most exoplanets found so far are by many factors larger than Jupiter, as detection techniques still highly limit the possibility to detect smaller planets. With observational technology steadily improving researchers are confident to be able to reduce the mass observation limit for exoplanets.

But still, in the close future we will be able to mainly detect and spectroscopically analyse Super-Earths with masses much larger than Earth. The question raised is, if we can at all expect to find habitable conditions on such objects – or do habitable planets have to be under a maximum planetary mass?

Habitability is a highly undefined term, as life itself is poorly constrained. We are solely investigating how some key habitability factors such as plate tectonics and magnetic field generation react on planetary mass, to gain a first insight into the habitability of extra-solar worlds. For this we [1] investigate the thermal evolution and convection of planets with Earth-like composition and structure of sizes ranging from 0.1 to 10 Earth masses (Mearth). Important is that we include the pressure dependence of viscosity into our parameterized 1D boundary layer and spherical 2D/3D models, with the scope to understand how the pressure-viscosity coupling changes the convection in the mantles of Super-Earths, and less massive planets, which we termed Sub-Earths. We then look how this influences the rise of plate tectonics and the emergence of magnetic dynamos on those planets, whilst in this work focussing on the magnetic field generation. We observe that the pressure dependence of viscosity becomes an important factor for the mantle convection of planets with masses larger than 1Mearth - resulting in a sluggish convection regime in the lower mantle for Earth-sized planets. Depending on activation volume, we observe with growing planetary mass the formation of a conductive lid over the core mantle boundary (CMB), termed low-lid, where convection velocities cease and where heat transport is only due to conduction. The sluggish convection and the formation of the low-lid reduce the convective vigour throughout the mantle. This leads to much lower core-cooling rates and convective velocities throughout the lower and the upper mantle in comparison to non-pressure dependent-viscosity models. We furthermore observe that scaling laws for convective velocities and stresses used by ([2], [3]), trying to understand the propensity of plate tectonics on Super-Earths, cannot be used for pressure-dependent viscosity models, which are however necessary to model Super-Earths. Therefore implications for the propensity of plate tectonics of Super-Earths cannot be made without an inclusion of pressure-dependent viscosity into mantle dynamics.

Our results show that the thermally induced magnetic field generation is highly suppressed on Super-Earths. Compositional dynamos might also be suppressed as the inner core-cooling rate is only very small, thus inducing only small surface magnetic fields. This could lead to a higher radiation environment on the surfaces of Super-Earths and to potential stronger atmospheric loss, both factors reducing the habitability of Super-Earths. Therefore any future lack of findings of biomarkers on Super-Earths might indicate that surface-habitable worlds cannot be too massive.

References

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