Geophysical Research Abstracts
Vol. 12, EGU2010-8995-1, 2010
EGU General Assembly 2010

Magnetic Field Generation on Super-Earths and Sub-Earths

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The last 15 years of astronomical observation have revealed a universe filled with planets. The observational techniques still limit the possibility to detect smaller, Earth-sized planets. New missions such as Kepler and Corot, next generation telescopes such as Darwin and TPF, and improved techniques in radial velocity measurements will lower this limit and make it possible to even detect Earth-sized planets in the near future. We study the ability of planets with different masses to generate a magnetic dynamo.

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 magnetic dynamos on those planets. 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 in comparison to non-pressure-dependent viscosity models.

We find using our parameterized 1D convection models that the low-lid insulates the core and thus affects the potential growth of an inner core and the ratio of CMB heat flux to critical heat flux. This on the other hand influences the generation of a magnetic dynamo, thermally and compositionally. The results, in particular for the compositional dynamo, depend on the melting curve, which can differ strongly in magnitude if different approaches are followed ([2], [3]). But we can show that thermodynamic constraints lead to the exclusion of [2] and therefore leave [3] as the most reliable melting curve at high pressures. In our model the scaling of thermodynamic core properties is tightly connected to the Grüneisen parameter.
Assuming an initially molten core as the consequence of accretion and core formation, we find that in the early evolution the low-lid reduces strongly the heat flow through the core-mantle-boundary, even though the melting temperatures (and thus the initial core temperatures), can be very high - up to 20'000K for 10-Earth-mass planets with pressures above 1200 GPa. Our results show that the thermally induced magnetic field generation is highly suppressed on Super-Earths, for plate tectonics and stagnant lid planets, as critical heat fluxes grow much faster that effective CMB heat fluxes. Compositional dynamos might also be suppressed as the inner core growth rate might become only very small, and the associated power is possibly even not strong enough to overcome ohmic dissipation thus inducing only small surface magnetic fields or no fields at all. We show that the mass-richer the planet, the more difficult it is to generate strong magnetic fields.

References

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