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Cessation of early Martian dynamos due to subcriticality

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Mars has no active dynamo action at present, but likely had one in the early stage of its history. Clarifying why and how ceased is a challenging question. Several different scenarios have been proposed so far, here we explore the possibility that the dynamo stopped operating due to its subcritical nature. The presence of a strong magnetic field modifies the convective structure, mainly due to a balance between Lorentz and Coriolis forces. This modification can guarantee dynamo action at smaller Rayleigh numbers, where a weak seed field may simply decay, i.e. it can lead to a subcritical situation. Former studies suggested that the subcritical regime is rather narrow, indicating that it may therefore not play an important role for the cessation.

Here we show that a more appropriate model for the early Martian dynamo yields a much wide subcritical regime than previously reported. Even today Mars may not have developed a solid inner core so that the early dynamo was purely driven by secular cooling. The thermal temperature gradient in the conductive state is steepest at the core-mantle boundary (CMB), and hence the convection is strongly affected by the respective thermal boundary condition. Constant heat flux rather than constant temperature conditions should be used here. These more realistic conditions favor a strong magnetic field which in turn leads to much larger convective length scales than for a weak or non-existing magnetic field. This strongly modified convection allows to lower the Rayleigh number significantly below the point where a weak seed field would start to grow. This increased extend of the subcritical regime makes it more likely that this effect may have played a role in the shutdown of the early Martian dynamo.