Compositional convection in a Fe-FeS core of the Moon T. Rückriemen, D. Breuer, and T. Spohn Deutsches Zentrum f. Luft und Raumfahrt (DLR), Berlin, Germany (tina.rueckriemen@dlr.de)

Introduction: Since the Apollo era it is well known that the Moon's crust is remanently magnetized [1]. Paleomagnetic studies suggest that a dynamo operated in the Moon's core for a substantial amount of time from at least 4.25 Ga to potentially 1.3 Ga ago [e.g. 2,3,4,5]. One possible mechanism for magnetic field generation is thermo-chemical convection driven by core crystallization [6,7]. Most thermo-chemical core evolution models concentrate on bottom-up core crystallization in iron-rich Fe-FeS cores ($x_s \leq 20$ wt.%). However, given that the Moon's core features low pressures the core might start to crystallize iron at the top for a considerable range of iron-rich core sulfur concentrations [8]. A consequence is the emergence of a snow zone with settling iron crystals on top of a deeper liquid core that convects due to the remelting of those iron crystals [9,10]. In this so-called iron snow regime the lifetime of the thermo-chemical dynamo in the deeper core is determined by the time it takes for the snow zone to grow across the entire core. Those lifetimes can vary depending on several parameters, e.g., the core sulfur concentration, but are generally found to be short and may not be substantially longer than 1 Gyr [10].

Furthermore, it has been suggested that the bottom-up core freezing shifts to top-down crystallization with increased sulfur concentration in the outer core [6]. As soon as this shift has occurred, dynamo activity probably shuts down rapidly since the dynamo region vanishes quickly for a growing snow zone.

We want to build upon existing thermo-chemical studies and further explore which core crystallization scenario we find for a given core sulfur concentration. Moreover, we investigate the lifetimes of an iron snow dynamo in the Moon's core as well as the timing of the shift from bottom-up to top-down crystallization.

Model: We employ a 1D thermo-chemical evolution model of the Moon that includes the evolution of the mantle and the core. Mantle evolution is modeled according to the approach by [11] and [12], where the energy transport in the mantle is treated by parametrized stagnant lid convection. The evolution of the core in the bottom-up mode is handeled as in [13]. The top-down core crystallization follows the approach by [10]. In the case of bottom-up crystallization, the temperature follows an adiabat in the well-mixed outer core and is set to the liquidus at the inner core boundary. For the iron snow scenario the temperature in the snow zone follows a conductive profile, whereas the temperature in the deep convecting core is adiabatic. The temperature at the interface between snow zone and deeper core is at the liquidus. Both crystallization models include the energy contributions from latent heat, gravitational heating, and secular cooling. The liquidus for the iron-rich Fe-FeS alloy is taken from [14].

Results: We find that the iron snow regime occurs for a broad range of core sulfur concentrations from 7 wt.% to 20 wt.%. Bottom-up freezing occurs only for sulfur concentrations less than 3 wt.% while between 3 wt.% and 7 wt.% the core freezes neither at the bottom nor at the top but somewhere in between.

It can be shown that for a lunar core starting to crystallize in the iron snow regime (top down) the resulting dynamo lifetimes are strikingly short (< 19 Myr) and may not explain the oberserved magnetitzation. Also slower core cooling for instance due to an increased reference mantle viscosity (i.e., assuming stiffer mantle material) cannot prolong the dynamo lifetime. For these cases, only the onset of core freezing is retarded.

Alternatively, assuming a low sulfur content, the lunar core can start with bottom-up core freezing that later transitions to top-down freezing. For example, this transition occurs 726 Myr after the onset of inner core freezing if the core has an initial core sulfur concentration of 1 wt.%. Those roughly 700 Myr can explain the lifetime of the lunar dynamo up to 3.56 Ga ago and possibly a few hundred million years longer assuming an early thermal dynamo before the start of crystallization. However, this scenario cannot explain the recently extended lifetime up to 1.3 Ga.

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