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Key characteristics of the Fe-snow regime in Ganymede's core

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Ganymede shows signs of an internally produced dipolar magnetic field ($|B_{dip}|\approx$719 nT) [1]. For small planetary bodies such as Ganymede the Fe-snow regime, i.e. the top-down solidification of iron, has been suggested to play an important role in the core cooling history [2,3]. In that regime, iron crystals form first at the core-mantle boundary (CMB) due to shallow or negative slopes of the melting temperature [2,3]. The solid iron particles are heavier than the surrounding Fe-FeS fluid, i.e. a snow zone forms, settle to deeper core regions, where the core temperature is higher than the melting temperature, and remelt again. As a consequence, a stable chemical gradient in the Fe-FeS fluid arises within the snow zone. We speculate this style of convection via sedimentation to be small scale, therefore it lacks an important criterion necessary for dynamo action [4]. Below this zone, whose thickness increases with time, the process of remelting of iron creates a gravitationally unstable situation. We propose that this could be the driving mechanism for a potential dynamo. However, dynamo action would be restricted to the time period the snow zone needs to grow across the core.

With a 1D thermo-chemical evolution model, we investigate key characteristics of the Fe-snow regime within Ganymede's core: the compositional density gradient of the fluid Fe-FeS within the snow zone and the time period necessary to grow the snow zone across the core. Additionally, we determine the dipolar magnetic field strength associated with a dynamo in Ganymede's deeper fluid core. We vary important input paramters such as the initial sulfur concentration (7-19 wt.%), the core heat flux (2-6 mW/m^2) and the thermal conductivity (20-60 W/mK) with the nominal model being: x_s=10 wt.%, q_{cmb}=4 mW/m^2, k_c=32 W/mK. We find, that heat fluxes higher than 6 or 22 mW/m^2 are required for double-diffusive or overturning convection to overcome the compositional density gradient within the snow zone, respectively. Since Ganymede's core heat flux does not exceed values of 4 mW/m^2 [2], we consider the snow zone to be stable against thermal convection. The time necessary to grow the snow zone across the core is between 230-1900 Myr. For representative models we calculate the temporal evolution of the surface dipolar magnetic field strength according to [5]. All models show surface dipolar magnetic field strengths during the evolution of the snow zone that match the observed value of $|B_{dip}|\approx$719 nT.

In conclusion, we find that the Fe-snow regime produces a stably-stratified liquid layer in the snow zone below which a magnetic field of observed strength can be generated. Such a chemical dynamo is restricted in time and stops as soon as an inner solid core starts to grow suggesting the absence of such an inner core in Ganymede. The present model further suggests a core with high initial sulfur concentration, because this leads to a late start and a long duration of the dynamo necessary to explain the present magnetic field.

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