KEY CHARACTERISTICS OF THE FE-SNOW REGIME IN GANYMEDE'S CORE. T. Rückriemen[1,2], D. Breuer[1] and T. Spohn[1,2], [1]German Aerospace Center, Berlin, Germany (tina.rueckriemen@dlr.de), [2]University of Münster (WWU Muenster), Institute of Planetology, Münster, Germany.

Introduction: Ganymede shows signs of an internally produced dipolar magnetic field ($|B_{dip}|$~719 nT) [1]. For small planetary bodies such as Ganymede the iron 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, 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 forms a dense Fe-rich fluid on top of a lighter Fe-FeS fluid creating 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 it needs to grow the snow zone across the core. With a 1D thermo-chemical evolution model, we investigate the key characteristics of the iron snow regime within Ganymede's core: the compositional density gradient evolving across the precipitation zone and the time period necessary to grow this zone across the entire core. Additionally, we determine the dipolar magnetic field strength associated with a dynamo in Ganymede's deeper fluid core.

Method: The 1D thermo-chemical evolution model of Ganymede's core includes profiles for the core and melting temperature. For the core temperature we choose an adiabatic temperature profile as well as a conductive temperature profile. In case of the latter one we also include the release of latent heat (in the snow zone) and the consumption of latent heat (in the deeper entirely liquid core). We calculate the melting temperature via an expression by [5]. Further, we determine a consistent pressure and density profile based on a 3rd order Birch-Murnaghan equation of state and a three-layer structural model [6]. The amount of solidifying iron within the snow zone is calculated by assuming thermo-chemical equilibrium (Lever rule). We further treat the subsequent redistribution of iron to the deeper fluid core. This process includes the continuous depletion of the snow zone in iron and the enrichment of the deeper fluid core in iron (as long as no inner core is present).

Results: We study the Fe-snow regime by varying three parameters: the inital sulfur concentration x_s (7-19 wt.%), the core heat flux q_{cmb} (2-6 mW/m^2) and the thermal conductivity k_c (20-60 W/mK) with our reference model being x_s=10 wt.%, q_{cmb}=4 mW/m^2, k_c=32 W/mK.

The compositional density gradient. We determine the density gradient within the snow zone at that point in time when the snow zone is present within the entire core. We find that for all tested models the average density gradient across the snow zone varies between 0.3 g/m^4 and 0.7 g/m^4 corresponding to a stable compositional density variation of 210 kg/m^3 and 590 kg/m^3, respectively. To identify the influence of the density gradient on the stability of the snow zone we appraised the minimum core heat flux, which is required to obtain double diffusive or even overturning convection (Fig. 1).

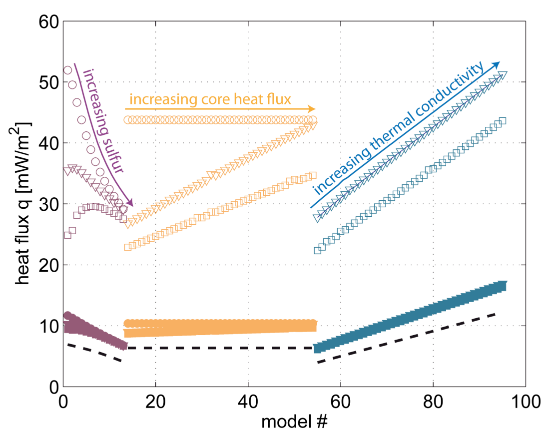

FIG. 1: Heat fluxes for all calculated models: heat flux conducted along adiabat (dashed line), double-diffusive convection (full symbols), overturning convection (empty symbols); circles: adiabatic core temperature profile, downward facing triangles: conductive profile without latent heat, squares: conductive profile with latent heat.

We find that for double diffusive convection the core heat flux must exceed values from 6 to 17 mW/m^2 depending on the model. For overturning convection the core heat flux has to be as high as 22-52 mW/m^2 to overcome the stable chemical gradient. Considering that the heat flux out of Ganymede's core typically does not exceed a value of 4 mW/m^2 [2], our results suggest that the snow zone is stable against large scale thermal convection.

The time period and magnetic field generation. We propose that the dynamo responsible for Ganymede's observed magnetic field is generated in the lower entirely fluid core as long as the snow zone grows. In Fig. 2 the time periods of dynamo action are plotted for all tested models. These vary from 230-950 Myr but can be also up to 1.9 Gyr for the most extreme case with x_s=19 wt.%, q_{cmb}=2 mW/m^2, k_c=32 W/mK.

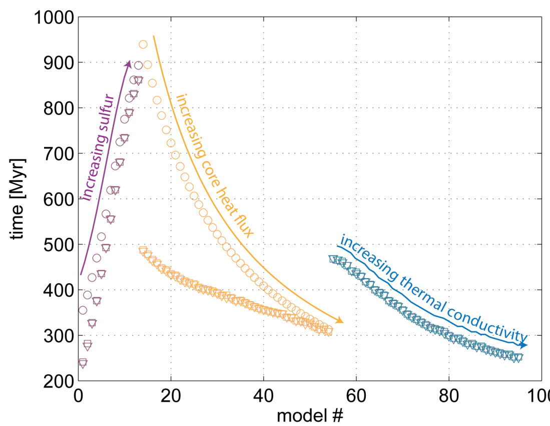

FIG. 2: Duration of dynamo action for all calculated models. For meaning of symbols see figure caption 1.

For some representative models we calculate the evolution of the dipolar magnetic field strength at the surface of Ganymede within the respective time periods. The magnetic field strength is calculated via a scaling law by [7], which is applicable given the buoyancy flux at the top of the dynamo region [personal communication U. Christensen]. To obtain the field strength at the surface we consider the decay of the dipolar component with $(R_{dynamo})^3/(R_p)^3$ and the fact that the volumetrically averaged field strength within the core is bigger than that at the core-mantle boundary (factor ≈ 7) [7]. We further estimate the magnetic Reynolds number, which should at least exceed a value of 50 for a self-sustained dynamo to occur [7]. All models show magnetic field strength at some point during the evolution of the snow zone that match the measured present day value of Ganymede's dipolar magnetic field ($|B_{dip}|$~719 nT) (Fig. 3 and 4).

Conclusions: We find that the Fe-snow regime in Ganymede's core leads to a stably-stratified snow zone below which we propose the existence of the dynamo region. This dynamo is restricted to the time-period the snow zone needs to grow across the core. Representative models of the present study show that they can match the observed magnetic field strength of Ganymede. We favor cores with high initial sulfur concentrations, because those lead to a late start (low melting temperatures) and a long duration of the dynamo (see Fig. 2). Our model suggest that the existence of Ganymede's magnetic field requires the absence of a solid inner core. It will be the subject of future work to couple the present model to an overall thermal evolution model.

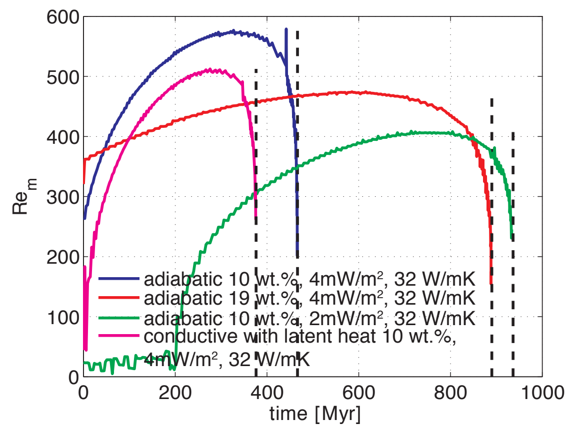

FIG. 3: The magnetic Reynolds number as a function of time. Note, t=0 Myr corresponds to the onset of solidification at the CMB, i.e. onset of Fe-snow; black dashed lines represent time, where snow zone is present in the entire core.

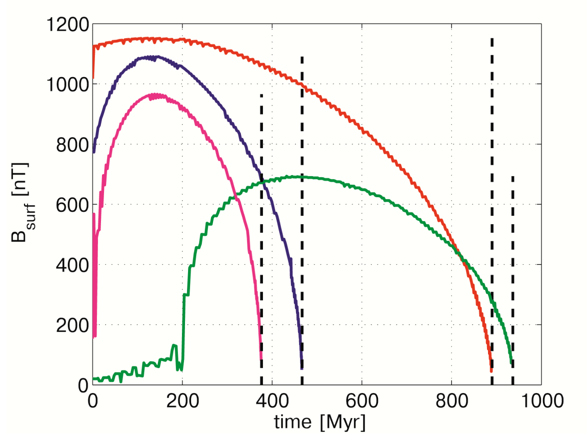

FIG. 4: The surface dipolar magnetic field strength as a function of time (for color reference see Fig. 3). Note, t=0 Myr corresponds to the onset of solidification at the CMB, i.e. onset of Fe-snow.

References: [1] Kivelson, M et al. (1996), Nature, 384(6609), [2] Hauck II, S. et al. (2006), JGR, 111(E9), [3] Williams, Q. (2009), EPSL, 284(3), [4] Christensen, U. and J. Wicht (2007), Treatise of Geophysics, Elsevier, [5] Buono, A. and Walker, D. (2011), GCA 75, [6] Rivoldini, A., T. et al. (2009), Icarus, 201(1), [7] Christensen, U., and J. Aubert (2006), GJI, 166(1)