ENS DE LYON

ricard@ens-lyon.fr
Yanick Ricard
ENS de Lyon
46 allée d'Italie, 69364 Lyon cedex 07

Lyon, December 25, 2014

Objet : Review of the Doctoral Thesis of Klara Kalousova

The manuscript of Klara Kalousova discusses the internal dynamic of icy satellites and particularly Europa's ice shell. The manuscript is very clearly written, with high quality graphics and illustrations. I was really impressed by its formal quality and the rigor of the mathematical developments. It is divided into four chapters.

The first chapter presents the observations relevant to Europa and explains the major problems related to these observations. The interpretations of the surface tectonics suggest that water is present inside the thick icy shell of the planet, however its presence is difficult to maintain as water is denser than ice and should rapidly sink through the ice by hydrofracturing, porous flow or Rayleigh-Taylor instabilities.

The second chapter develops the equations of two-phase flow with the formalism of Bercovici et al. (2001) or Sramek et al. (2007). Klara Kalousova does not simply re-use their equations but re-derive them with great care. As a minor point, I mention however that I suggested in Chambat et al. (2014) that the well known Hugoniot Rankine equation for momentum might miss a term. Klara Kalousova then performs a very rigorous dimensional analysis of the equations and present two numerical codes to solve these equations. These numerical codes are very carefully benchmarked in simple cases by comparison with previously published results of shocks, wave trains and thermal convection.

Having now introduced all the theoretical and numerical tools she needs, Klara Kalousova describes in the third chapter the evolution of the water-ice mixture in a temperate ice shell. She accurately studies the role of each parameter of her model and the quality of the numerical implementations in 1D and 2D situations (rheology, permeability, percolation threshold…). This chapter is really an example of all the tests, benchmarks and sensibility analysis through which a numerical model should always go. To summarize this chapter, it appears that the sinking of water through ice should always occur in a time of a few thousand years. As minor remarks, I was surprised by the comment that surface tension is "completely" negligible (although I would not have been surprised that it is neglected; furthermore the model ignores the grain-grain surface tension which is also present). There are simple analytical solutions of phase separation due to surface tension; does the code reproduce them? It is important to recognize that the ice grain size should itself be a function of the thermodynamic and stress-strain conditions. Except for a benchmark, a constant grain size, imposed a priori, may not be physically sounded.

The last section presents models with melting and freezing but without percolation of the fluid phase. This section and the previous one are thus two steps in the direction of a complete model with both phase change and porous flow. Taking into account the complexity of the whole project what Klara Kalousova has already done is remarkable and I do not doubt that she will in the future succeed in performing the last step. Like in the previous chapter, the presence of water is rapidly entrained toward the deep ocean by Rayleigh Taylor instabilities and the accumulation of partial melt at shallow depth seems unlikely.

In the last chapter, the tidal heating is taken from previous works and relates on the viscosity of the solid phase. This is really the only equation (7.2) of all the manuscript that Klara Kalousova does not derive from first principles. Although the fact that this equation has been used in various publications of international journals gives the impression of a solid result, it should have been discussed. A tide is nothing more that a propagating pressure field applied at the surface of a planet. Pushing the planet surface up and down induces matrix and liquid motions that dissipate according to 3.113 as a) matrix and b) liquid viscous dissipations, c) matrix and d) liquid compactions, e) matrix and liquid friction. Only the first term is somewhat parameterized by (7.2) and I do not clearly see why all the other terms should be negligible. This exercise (forcing a space and time periodic pressure on top of an homogeneous two phase medium) seems a feasible analytic task and would be a very useful one. Notice also that dissipation occurs even in pure water (this is why the experiment of joule-calorie equivalence was possible), in a fluid, turbulence (here neglected) works to reduce the eddy wavelengths so that “viscosity(strain rate)^2” remains finite even though “viscosity” tends to zero.

In addition to this dense manuscript, Klara Kalousova is the author of three articles in international journals: one on a topic not discussed in her PhD manuscript (Kalousova et al., Geophysical Journal International, 2012), and two other papers related to the material included in this PhD manuscript (Kalousova et al., Journal of Geophysical Research-Planets, 2014; Soucek et al., Geophysical and Astronomical Fluid Dynamics, 2014).

The high quality of Klara Kalousova research, her mathematical rigor and numerical skills, the papers that she already published, all proves the candidate's ability to conduct creative scientific work. She deserves to defend her PhD to get the title of Doctor of Charles University.

Yanick Ricard
Senior Scientist,
CNRS/ENS de Lyon