Geophysical Research Abstracts
Vol. 17, EGU2015-10569, 2015
EGU General Assembly 2015

Enceladus-Mimas paradox: a result of different early evolutions of satellites?

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Summary: Thermal history of Mimas and Enceladus is investigated from the beginning of accretion to 400 Myr. The following heat sources are included: short lived and long lived radioactive isotopes, accretion, serpentinization, and phase changes. We find that temperature of Mimas' interior was significantly lower than of Enceladus. Comparison of thermal models of Mimas and Enceladus indicates that conditions favorable for starting tidal heating lasted for short time ($\sim 10^7$yr) in Mimas and for $\sim 10^8$ yr in Enceladus. This could explain Mimas-Enceladus paradox.

1. Numerical model: In our calculations we use numerical model developed by Czechowski (2012) (see e.g. description in [1]). The model is based on parameterized theory of convection combined with 1-dimensional equation of the heat transfer in spherical coordinates:

$$\rho c_p \frac{\partial T(r,t)}{\partial t} = \mathrm{div}(k(r,T)\ \mathrm{grad} T(r,t)) + Q(r,T),$$

where r is the radial distance (spherical coordinate), ρ is the density [kg m^{-3}], c_p [J kg^{1} K^{-1}] is the specific heat, Q [W kg^{-1}] is the heating rate, and k[W m^{-1} K^{-1}] is the thermal conductivity. $Q(r,t)$ includes sources and sinks of the heat. The equation is solved in time dependent region [0, R(t)]. During accretion the radius $R(t)$ increases in time according to formula: $R(t) = at$for t_{ini}<$t <\quad t_{ac}$, and $R(t) = R_{sat}$ for $t >\quad t_{ac}$, i.e. after the accretion (see e.g. [2]), where t_{ini}denotes beginning of accretion and t_{ac} denotes duration of this process.

If the Rayleigh number in the considered layer exceeds its critical value Ra_{cr} then convection starts. It leads to effective heat transfer. The full description of convection is given by a velocity field and temperature distribution. However, we are interested in convection as a process of heat transport only. For solid state convection (SSC) heat transport can be described by dimensionless Nusselt number *Nu*. We use the following definition of the *Nu:*

Nu= (True total surface heat flow)/(Total heat flow without convection).

The heat transport by SSC is modelled simply by multiplying the coefficient of the heat conduction in the considered layer, i.e.:

k_{conv} =*Nu k*.

This approach is used successfully in parameterized theory of convection for SSC in the Earth and other planets (e.g. [3], [4]).

Parameterization of liquid state convection (LSC) is even simpler. *Ra* in molten region is very high (usually higher than 10^{16}). The LSC could be very intensive resulting in almost adiabatic temperature gradient given by:

$$\frac{dT}{dr} = \frac{g\alpha_m T}{c_{pm}},$$

where α_m and c_{pm} are thermal expansion coefficient and specific heat in molten region, g is the local gravity. In Enceladus and Mimas the adiabatic gradient is low and therefore LSC region is almost isothermal.

2. Results:

Comparison of thermal models of Mimas and Enceladus indicates that conditions favorable for starting tidal heating (interior hot enough) lasted for short time ($\sim 10^7$yr) in Mimas and for $\sim 10^8$ yr in Enceladus. This could explain Mimas-Enceladus paradox.

3. Conclusions: The Mimas-Enceladus paradox is probably the result of short time when Mimas was hot enough to allow for substantial tidal heating. The Mimas-Tethys resonance formed later when Mimas was already cool. (see also [1, 4]) The full text of the paper will be published in Acta Geophysica [5].

Acknowledgements: The research is partly supported by National Science Centre (grant 2011/ 01/ B/ ST10/06653).

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