THE CONTRIBUTION OF RADIOGENS TO THE THERMAL BUDGET OF ENCELADUS. R.-S. Taubner[1], J. J. Leitner[1,2], M. G. Firneis[1,2]. [1]Institute of Astronomy, University of Vienna, Türkenschanzstraße 17, A-1180 Vienna (a0605269@unet.univie.ac.at), [2]Research Platform: ExoLife, University of Vienna

Introduction: Since the NASA/ESA/ASI Mission Cassini Huygens revealed several new facts on the interior of Enceladus we know that Enceladus has a density of 1608.3 ± 4.5 kg m^{-3} and a GM of 7.2085 ± 0.0068 km^3 s^{-2}. Furthermore the data imply a rock fraction m_{rock}/m_{total} of 0.61 [1].

Enceladus' south polar endogenic emission is 15.8 ± 3.1 GW [2], which is significantly (272 %) higher than a recent estimate of 5.8 ± 1.9 GW [3]. Several heating mechanisms have been studied like the secondary spin-orbit libration model [4] or tidal heating which among others was examined by Meyer and Wisdom [5]. The latter might be the main heating process if Enceladus possesses indeed a subsurface ocean.

Another mechanism is radiogenic heating which seems to contribute only to a small part to the global heating, but cannot be neglected due to Enceladus' high rock fraction.

If we assume that the abundance of the radionuclides ^{232}Th, ^{235}U, ^{238}U, and ^{40}K in the rocky material of Enceladus is similar to that of chondrites, we could estimate the actual radiogenic heating rate. A previous estimate of this rate amounted to 0.32 GW [1] by using values for the concentrations and decay energies assessed in the years 1954 and 1971 [6]. Furthermore, we assumed the age of Enceladus to be 4.56590 ± 0.00085 Gyr, which corresponds to the age of Calcium-aluminum-rich inclusions (CAIs) of 4567.2 ± 0.6 Myr [7] and the assumption that the icy Saturnian satellites formed between 1.0 ± 0.2 to 1.6 ± 0.4 Myr after the production of CAIs [8].

Model: The radiogenic heat rate H_0 can be estimated by

$$H_0 = m_{rock} \times \Sigma (C_i \times H_i) , \qquad (1)$$

with m_{rock} as the mass of rocks in Enceladus, C_i as the concentration of a certain radioactive element, and H_i as the heat of decay released when 1 kg of the corresponding radionuclide decays completely [9]. We used two different assumptions for the concentration and the heat release of the radionuclides ^{232}Th, ^{235}U, ^{238}U, and ^{40}K (see Tab. 1): assumption 1 (A1, [10]) was corresponding to chondritic meteorites and assumption 2 (A2, [11]) for average CM (a group of Carbonaceous chondrites) radionuclide abundances.

Results: We calculated a radiogenic heating rate of H_0 = 0.4279 ± 0.0004 GW for A1 and H_0 = 0.2665 ± 0.0003 GW for A2. Both values are close to 0.32 GW estimated by Porco et al. in [1].

	^{232}Th	**^{235}U**	**^{238}U**	**^{40}K**
C_i (kg kg^{-1}) in [10]	5.50×10^{-8}	6.3×10^{-9}	2.20×10^{-8}	1.10×10^{-6}
H_i (J kg^{-1}) in [10]	1.65×10^{13}	1.86×10^{13}	1.92×10^{13}	1.72×10^{12}
C_i (kg kg^{-1}) in [11]	5.21×10^{-8}	8.60×10^{-9}	2.64×10^{-8}	6.60×10^{-7}
H_i (J kg^{-1}) in [11]	1.03×10^{13}	1.16×10^{13}	1.20×10^{13}	1.99×10^{12}

Tab. 1. Concentration and heat release of certain radionuclides by [10], [11]

Discussion: The considerations about the radiogenic heat release of Porco et al. [1] were based on data which only includes values for the elements Th, U, and K. In contrast, our scenarios include values of the specific radioisotopes ^{232}Th, ^{235}U, ^{238}U, and ^{40}K, but although our model was more detailed we obtained similar results. This confirms the general theory that current radiogenic heating by long-lived radionuclides contributes only a small part of the measured heating on Enceladus.

Minor changes of the estimated radiogenic heating rate might occur in the future if there have to be modifications in the values for the density and/or the rock fraction due to possible new data of Cassini.

Furthermore, we did not take short-lived radionuclides into account, like ^{26}Al or ^{60}Fe. This scenario was already simulated by Schubert et al. [11] for the first 20 Myr after Enceladus' formation. They concluded that in this period a possible subsurface ocean could have originated due to melting of ice from primarily short-lived radionuclides and that it "can remain above freezing through the action of long-lived radioactivity and tidal dissipative heating for the roughly 4.5 Gyr interval between the formation of Enceladus and the present day".

Equilibrium tidal heating leads to a heat release similar to that of current radiogenic heating [5]. Whereas, with Enceladus having a global subsurface ocean or a possibly localized sea, the ice shell would be decoupled "from the silicate interior and permits larger shear velocities and greater tidal heating" [12].

This viscoelastic tidal heating scenario was already examined by Ross and Schubert in 1989 [13]. They calculated the dissipation in a homogenous Maxwell model (one-layer model) to be as large as 920 GW, but the assumed material properties (primarily the viscosity) were not realistic. In the more recent past, Roberts and Nimmo estimated for a multilayered, viscoelastic Enceladus that "an ice shell with constant viscosity of 3 $\times 10^{13}$ Pa s, and rigidity of 4 GPa will dissipate … 6.4 GW if there is a 500 m ocean between the solid layers" [14]. Even if a value of 6.4 GW is still too small to explain the observed south polar endogenic emission of 15.8 GW, it is yet a step in the right direction.

The mechanisms going on in Enceladus' interior are very complex and intertwined. So, for example, without radiogenic heating – primarily in the early times of Enceladus – a still liquid subsurface ocean and consequentially intensified tidal heating in such a way might not be possible today. However, it is also conceivable that we are just witnesses of periodically appearing bursts of intense activity stored inside Enceladus over long time scales [2]. Nevertheless, every mechanism envisaged above might not be able to release such a high heat measured by Cassini on his own, but as already indicated a composite of all of them might be the answer to the still unknown heating source of Enceladus.

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