Dynamics of icy crust of the Enceladus with tidal heating and asymmetric distribution of heat generation in the rocky core

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We investigate the dynamics of icy crust of the Enceladus, that is the sixth-largest moon of the Saturn, for understanding the diversity of the surface geology found from the planetary explorations. Especially, we have an interest in the ‘Tiger Stripes’ found around the south pole with heat release of 15.8 GW. The mechanism of formation of the Tiger Stripes is recognized as active terrains caused by thermal convection of icy crust driven by tidal heating. However, such active terrains caused by the tidal heating could not be explained by the tidal heating solely because they are only found around the south pole. Several researches concerning the convective dynamics of icy crust on the Enceladus have suggested some north-south asymmetries, for example in the thickness of icy crust or viscosity, but they have not been well-understood for the origin.

Here, to resolve the formation mechanism of Tiger Stripes, we propose the hypothesis on the north-south asymmetric distribution of heat producing elements in Enceladus’s rocky core. We assume that the more heat producing elements can be concentrated into the southern hemisphere. Since, regarding the formation mechanism of the Enceladus, the rocky core would not be likely to experience the large-scale melting events such as the magma ocean, the Enceladus still tends to maintain the chemical structure of the early distribution. Hence, the current chemical structure of rocky core may be heterogeneous, which can lead to north-south asymmetric distribution of heat generation. We test the hypothesis for using a numerical model of icy crust dynamics including tidal heating and north-south asymmetric distribution of heat generation in the rocky core. For tidal heating of the icy crust, we impose an analytical solution of tidal deformation considering viscoelasticity in a thin shell on the surface (e.g., Ojakangas and Stevenson, 1989). For north-south asymmetric distribution in heat generation in the rocky core, we set the temperature of the bottom of the icy crust as 273 K in the northern hemisphere, 283 K in the southern hemisphere.

Our results indicate that heat upwelling around the south pole and heat downwelling around the north pole when we assume tidal heating and north-south asymmetric distribution of heat generation. Rather, the asymmetric distribution of heat generation is more important for finding the more active dynamics around the south pole. A quantitative test indicates that the plume heat flow coming from the south pole region is about 300 GW, which is about 20 times as large as the observational constraints (15.8 GW). This suggests that the amplitude of heterogeneous heat generation is too large. Again, although the amplitude of heat transfer of plume in southern hemisphere is too large, the geographical distribution of plumes can form the north-south asymmetric distribution of heat generation. Therefore, this hypothesis provided here would be promising to reveal the origin of the hydrogen plumes on the Enceladus found by the Cassini mission.

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