IMPACTS INTO METHANE CLATHRATE AS A SOURCE FOR TITAN'S ATMOSPHERIC METHANE.

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Introduction: Methane forms lakes at polar regions, interacts with Titan's ice crust to form clathrates on the surface, and is the second most abundant component in Titan's dense atmosphere. However, methane in the atmosphere is lost via photolysis; its lifetime is estimated to be ~10–100 Myr [1, 2]. This is on the same order of estimated surface age using crater counts [3, 4], but shorter than the lifetime of other molecules in Titan's atmosphere [5]. Some mechanisms are needed to replenish atmospheric methane. While episodic outgassing from methane clathrate via cryovolcanic events may work [6], impacts have also been considered as a source of methane. For example, a Menrva-forming impact (400 km-diameter-basin) could potentially double the amount of methane in Titan's atmosphere [7]. Here, we consider the release of methane during impacts into a methane clathrate layer. We simulate impacts hitting a warm methane clathrate crust and find that the released methane may trigger the greenhouse effect and enhance the lifetime of methane in Titan's atmosphere.

Methods: We simulate impacts on Titan using the iSALE-2D shock physics code [8, 9, 10]. Since methane clathrate is expected on Titan's surface [6, 11], we consider a methane-clathrate layer on top of a water-ice basement. The lower thermal conductivity of methane clathrate [12] results in a higher temperature gradient near the surface. The temperature profile within the ice layer changes according to the thickness of the methane clathrate layer [11]. While we fix the surface temperature of 94 K, we consider 5, 10, and 15 km thick methane clathrate layers. Since methane clathrate is stronger than water ice [13], we use the strength model appropriate for methane clathrate [14]. Using an impact velocity of 10.5 km/s, an average impact velocity into Titan [15], we explore the release of methane from icy impactors ranging 2–40 km in diameter. Since these impactors differ in size by a factor of 20, we similarly vary the resolution from 50 m to 500 m. We assume there is a liquid water ocean beneath a combined 100 km thick layer of methane clathrate and water ice. For all icy materials, we use the ANEOS equation of state for water ice.

To estimate the amount of released methane, we emplace tracer particles in each cell of the simulations to track their temperature and pressure during the impacts. When the tracer particles within the methane clathrate layer exceed the dissociation curve of methane clathrate [12], we regard the methane as being released from the clathrate. Considering a typical structure of methane clathrate (1 mol of methane exists per every 5.75 mol water-ice [16]), we sum up those tracer particles and calculate the released methane mass.

Results: The mass of methane gas released via impact increases as the impactor size increases. Symbols in Figure 1 depict the released methane mass by a single impact as a function of impactor size. The larger impactor brings more energy than the smaller one at a given impact velocity. When the impactors are larger than 8 km in diameter, they have enough energy to release methane at the bottom of any methane clathrate thickness. Thus, the thicker methane clathrate cases supply more methane than the thinner cases. On the other hand, the released methane by the smaller impactors are less sensitive to the methane clathrate thickness as they have less energy. The impactor that formed Menrva is 20–30 km in diameter [17]; our results indicate that such an impactor produces < 10% of the current methane mass in Titan's atmosphere by itself [18], but other factors such as oblique impacts may increase the released methane mass.

Continuous impacts can be a source to release methane. To consider methane production rate via impact, we use the typical impact rate of comets on Titan [15]. Since impactors larger than 2 km are almost free from atmospheric ablation [19], we ignore any reduction in their size due to atmospheric entry. Using the impact rate and the approximation of released methane mass (lines in Fig. 1), the cumulative production rates are given in Figure 2. Limited increase in the cumulative methane production rate beyond 20 km-diameter indicates that the long-term contributions from larger impactors is minor. This is because the impact rate of larger bodies is 1–2 orders of magnitude lower than smaller bodies. If the impacts into Titan have continued over the age of the solar system (~4500 Myr), the total released methane would be 10^{16}–10^{17} kg, which is comparable to the current mass of methane in the atmosphere.

Discussion: Our results suggest that impacts into methane clathrate may enhance the lifetime of methane in Titan's atmosphere. The origin of methane on Titan is still unsolved. The current methane might have been released from Titan's core and formed methane clathrate layers [20, 21]. Subsequent impacts on Titan would have occurred into methane clathrate, releasing methane into the atmosphere. The shaded region in Fig. 2 illustrates the net loss rate of methane as derived in previous photochemical models [1, 2]. The methane released via impacts is lower than this rate, but our work indicates resupplying methane by the impacts can enhance the lifetime of methane gas by up to 10%.

Importantly, a single large impact may provide a significant influx of methane to Titan's atmosphere. The Menrva forming impactor produces a few percent of the current methane mass in Titan's atmosphere. However, our preliminary iSALE-3D run shows that 45 degree oblique impacts can release 2–3 times more methane than vertical impacts. While our estimates of released methane are based on the melting curve of methane clathrate, the damaged but unmelted methane clathrate that surrounds the crater may also release methane. In that case, the threshold to release methane is weakened and the total released methane mass might increase by an additional factor of 1–2. Additionally, if liquid methane exists within the regolith layer [7, 14, 22], this would also increase the amount of released methane. As such, we might underestimate the release of methane by up to an order of magnitude. Considering these effects, the Menrva forming impact could have resupplied a considerable amount of methane that might have triggered the greenhouse effect on Titan.

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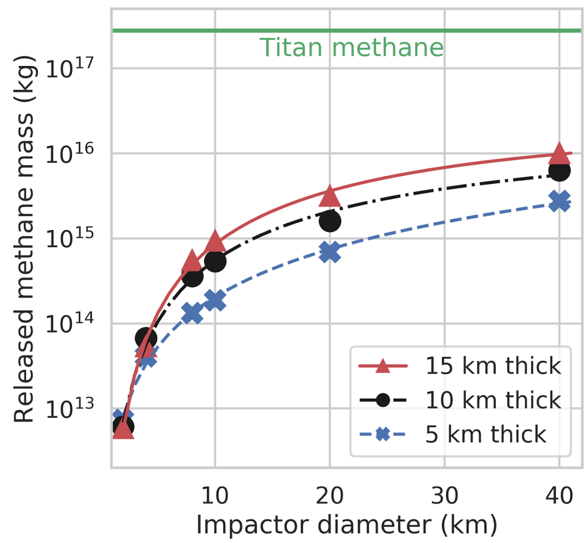

Figure 1. Released methane mass as a function of impactor diameter. Each symbol/color shows released methane from a single impact into different thickness of methane clathrate layers. The horizontal green line represents the current methane mass in Titan's atmosphere [18].

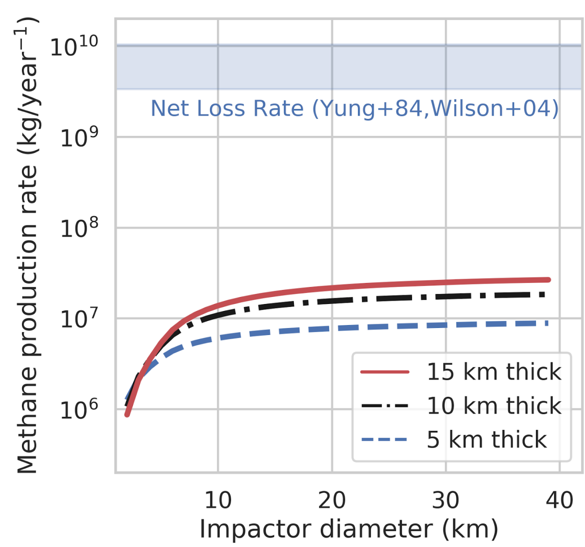

Figure 2. Cumulative methane production rate for impactors of different sizes (colored lines). The blue shaded region illustrates net loss rate due to photochemistry [1, 2].