IMPACT DEVOLATILIZATION OF AMMONIUM SULFATE: IMPLICATIONS FOR THE ORIGIN OF N_2 IN TITAN'S ATMOSPHERE. S. Fukuzaki[1], Y. Sekine[1], K. Kurosawa[1], S. Sugita[1], T. Kadono[2], and T. Matsui[1], [1]Dept. of Complexity Sci. & Eng., Univ. of Tokyo (Kashiwanoha, Kashiwa, Chiba 277-8561, JAPAN, shofukuzaki@impact.k.u-tokyo.ac.jp), [2]Inst. of Laser Eng., Osaka Univ. (Yamadaoka, Suita, Osaka 565-0871 JAPAN)

Introduction: Titan has a thick atmosphere composed primarily of N_2 with a few percent of CH_4. One of the most puzzling aspects of Titan's atmosphere is the origin of N_2 because of the near absence of non-radiogenic noble gases (e.g., ^{36}Ar) in the atmosphere, highly suggestive of that the nitrogen was captured as NH_3 and other non-N_2-bearing compounds in the satellitesimals [1]. Although several studies have investigated the mechanism responsible for converting NH_3 to N_2 in the primitive atmosphere of Titan generated during the accretion [e.g., 2, 3], it is still unclear how and when the production of N_2 has occurred.

In this study, we assess the role of shock-induced devolatilization of Titan's icy crust and mantle by hypervelocity impacts of cometary bodies for the origin of N_2 in the atmosphere. Although the chemical compositions of Titan's crust and mantle are still uncertain, ammonium sulfate ($(NH_4)_2SO_4$) is considered as one of the major components when primordial NH_3 reacts with sulfate-rich water in the ocean during the accretion and the differentiation [4, 5]. We conduct laboratory experiments of hypervelocity impacts onto ammonium sulfate to investigate whether the conversion of ammonium sulfate to N_2 occurs or not. Then, we measure the efficiency of N_2 production as a function of peak shock pressure and discuss whether the impact devolatilization of Titan's crust can explain the present amount of N_2 in Titan's atmosphere.

Experimental: We conducted laboratory experiments of hypervelocity impact using a laser gun method [6]. The configuration of our experimental system is shown in Fig 1. A quadruple mass spectrometer (QMS; BGM-202, Qulee) was used for the gas analysis of shock-induced gas species. About 10 Pa of helium gas was introduced into the vacuum chamber as an internal standard for quantification of N_2 production. We used a gold (Au) foil (Nilaco, 99.95% purity) as an impactor, and isotopic-labeled ammonium sulfate powder compressed at 20 MPa (^{15}N>99%; ISOTEC) as a target for identification of the N_2 production. The porosity of the compressed target was measured to be less than 5%. We irradiated a laser pulse on the Au foil in the vacuum chamber. The laser pulse vaporized the very surface of the Au foil and generated a vapor plume. The Au foil was then accelerated by the reaction of the expanding vapor plume and collided onto the ammonium sulfate target. The impact velocity of the impactor was obtained with an empirical equation expressing the relationship among laser energy, density and thickness of the foil [6]. We used Au foils with thickness of 2.5 μm, 5 μm, and 10 μm to vary impact velocity. Laser beam diameter was ~800 μm that corresponds to the diameter of the impactor. The pulse width of the laser was 15 ns. The laser energy ranged from 9 to 34 J. Under these experimental conditions, the impact velocities ranged from 1.1 to 3.5 km/sec. Peak shock pressures in the target were calculated using a one-dimensional impedance match solution [7] and ranged from 9.0 to 43.4 GPa in our experiment. As shown below in this paper, this range covers most of the peak shock pressures achieved by hypervelocity impacts in Titan's history, e.g., impacts of circum-Saturnian satellitesimals [2], planetesimals from the feeding zone of Saturn [8], and comets from the Uranus, Neputune, and Kuiper belt regions [9].

Results: Here, we calculate the efficiency of N_2 production from the amount of $^{15}N_2$ (i.e., QMS signal at m/z = 30) released in each shot normalized by the volume of the impactor. Figure 2 shows that the efficiency of N_2 production as a function of the peak shock pressure (the lower horizontal axis). This figure indicates that N_2 production from ammonium sulfate begins around 10 GPa and that the efficiency of N_2 production linearly increases with the peak shock pressure.

The upper horizontal axis of Fig. 2 represents the impact velocity of a water-ice impactor onto a water-ice target that generates the corresponding peak shock pressure in the target to the lower axis. On the other hand, typical impact velocities of the satellitesimals in Saturnian subnebula, the planetesimals from the feeding zone of Saturn, and comets from Uranus, Neptune, and Kuiper belt regions onto Titan are estimated as 2-4 km/sec (blue area in Fig. 2) [2], ~8 km/sec (gray area), and ~11 km/sec (yellow area) [9], respectively. Our experimental results suggest that the N_2 production from ammonium sulfate in Titan's crust and mantle may be highly inefficient in impacts of the satellitesimals. However, the N_2 production may takes place efficiency in impacts of both planetesimals from the feeding zone of Saturn and cometary bodies.

Discussion & Conclusions: Using our experimental data, we estimate the total amount of N_2 produced by cometary impacts over 4.5 Gyr and then compare with the amount of N_2 in the present Titan's atmosphere. The total amount of N_2 production for 4.5 Gyr is calculated from the efficiency of N_2 production by devolatilization of ammonium sulfate, the impact rates and size distributions of comets, and the content percentage of ammonium sulfate in the crust. We use the efficiency of N_2 production obtained from our experimented data at 43 GPa of peak shock pressure, corresponding to an impact with 10.3 km/sec of water-ice onto water-ice target. The impact rates and size distribution of comets are derived from the expressions by Zahnle, Lunine, and their coworkers [10, 11]. Previous studies also calculated the content of ammonium sulfate in the crust to be 12 vol% [4, 5]. Using these values, the total amount of N_2 production for 4.5 Gyr is estimated as $\sim 7.5 \times 10^{20} - 3.0 \times 10^{21}$ [mol] , corresponding to ~2.5 – 10 times that in the present atmosphere (i.e., 3×10^{20} [mol]). The observations of the isotopic composition of N_2 in Titan's atmosphere by the Huygens suggest that several times the present amount of N_2 might be lost over geologic time [1]. Therefore, the estimated value of N_2 production in our study implies that almost all the present amount of N_2 could have been derived from the devolatilization of Titan's crust by cometary impacts.

Refferences: [1] Niemann H.B. et al., *Nature*, 438, 2005, [2] McKay C.P. et al., *Nature,* 332, 1988, [3] Atreya S.K. et al., *Science,* 201, 1978, [4] Fortes A.D. et al., *Icarus.*, 188, 2007, [5] Grindrod P.M. et al., *Icarus*, 197, 2008, [6] Ohno S. et al., *GeoRL.*, 35, 2008, [7] Melosh H.J. *Impact Cratering*, 145pp, 1989, [8] Mousis O. et al., *Icarus,* 156, 2002, [9] Zahnle K.J. et al., *JGR.* 100, 1995, [10] Zahnle K.J. et al., *Icarus*, 163, 2003, [11] Lunine J.I. et al., *Icarus,* 175, 2005

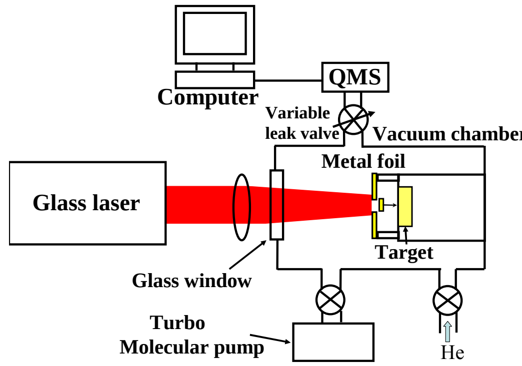

Figure 1. A schematic diagram of our experimental system. It consists of a Glass laser, a vacuum chamber, a turbo molecular pump and a quadruple mass spectrometer (QMS).

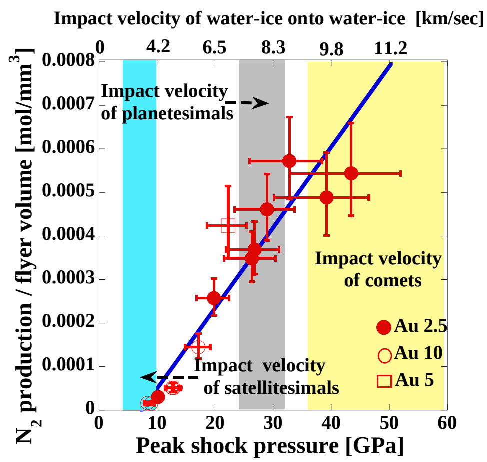

Figure 2. The amounts of shock-induced N_2 production normalized by the volume of the flyers as a function of the peak shock pressure achieved by the impact. The solid and open circles and squares represent the results using gold foil with the thickness of 2.5 μm, 10 μm, and 5μm, respectively. The fitting line of the experimental data is given by the least square method. The blue, gray, and yellow areas are impact velocity of satellitesimals, planetesimals, and comets respectively. See the text for upper axis of this figure.