Outgassing Experiments on Carbonaceous Chondrites and Their Implications for Titan's Secondary Atmosphere.

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Introduction: Titan is the only known moon in the Solar System with a substantial atmosphere of N_2 and CH_4, however, its origin and evolution are not well understood. Titan's present amount of atmospheric CH_4 was predicted to be destroyed photochemically on very short timescales compared to the age of the Solar System suggesting a resupply mechanism is necessary [1]. Cassini provided new insights into the origin of Titan's atmosphere by measuring abundances of primordial noble gases and found that instead of being incorporated during formation, Titan's atmosphere is likely linked to its interior [2, 3]. Recent theoretical modeling works of Titan's atmosphere and interior [4, 5] suggests that its atmosphere could have originated in part by outgassing of primordial organics in its interior. If this theory holds true, volatiles like methane could be outgassing from Titan's interior to sustain its current observed abundances.

Insoluble organic matter (IOM) found in carbonaceous chondrites may serve as an analog for the organic material in Titan's interior and provide experimental constraints on the outgassed component of its atmosphere [4]. By heating carbonaceous chondrite samples and measuring the abundances of their released volatiles, specifically methane, we may be able to connect what we see in the lab to species in Titan's atmosphere today.

Meteorite Sample: In this study, we use samples of the Murchison meteorite, a CM carbonaceous chondrite fall. The Murchison contains substantial amounts of IOMs.

Methods: We prepared two different sample sizes using the Murchison meteorite, one being our small grain sample, < 20µm, and the other being our normal grain size distribution sample, 20-100µm. We heated 3 mg of powdered Murchison respectively with the small and the normal grain samples and placed them in an alumina combustion boat. We then heated the samples in a furnace that is connected to a turbomolecular pump, which brings the entire system to a base pressure of 10^{-5} torr at room temperature. The samples are then heated from room temperature to 1200° C. We continuously monitored the partial pressures of 10 outgassed volatile species (H_2, C, N, CH_4, H_2O, CO/N_2, H_2S, Ar, CO_2, S/O_2) with a Residual Gas Analyzer (RGA) mass spectrometer.

We experimented with two different heating schemes: steady and stepped. For our steady heating scheme, we gradually heated our samples to 1200° C with a heating rate of 3°C/min. For the stepped heating scheme, we used only the normal grain size distribution samples and gradually heated them up to 400°, 600°, 800°, and 1000° C with a heating rate of 3°C/min, then held them at these respective temperatures for 5 hours. We also held at 200° C for each experiment for 12 hours before the 5 hour hold so we could get rid of any water absorbed on our samples.

Although we conduct each heating experiment under high-vacuum conditions, slight contamination may still be possible. Therefore, we heated a blank alumina crucible and preformed the same heating scheme before each experiment to collect the background signals to properly calibrate our experimental data.

To account for the background subtraction is quite simple. We took the sum of the partial pressures from the background data and subtracted that from the sum of the partial pressures from our continuous heating data. The equation below ultimately determines the background-subtracted partial pressures [6].

$$P_{Total} = \Sigma_i P_{i,\ heating} - \Sigma_i P_{i,\ Background}$$

We also corrected our data for ion fragmentation and atmospheric absorption. For ion fragmentation for a certain species, we subtract the species' partial pressure from the partial pressures of other species that contribute to its mass signal, then multiply that by the percentage of each other species' contribution. In addition, to correct for the possibility of terrestrial atmospheric adsorption onto the samples, we assume that the signal at 40 amu is due entirely to atmospheric argon adsorbed onto the samples. Below is an example of the type of calculation needed for ion fragment corrections [6].

$$P_{CH4} = P_{16\ amu} - (0.10P_{CO2}) - (0.02P_{H2O}) - (4.96P_{Ar})$$

We constructed two versions of plots for both the steady and step heating schemes. One using the more stringent correction for the partial pressure of methane, by subtracting the highlighted $4.96P_{Ar}$, and one neglecting this correction.

Results and Discussion: For the steady heating scheme, we can neglect the signal due to N_2 because it is negligibly small ($< 10^{-10}$ Torr) (**Fig. 1**, **Fig. 2**). One can see that the only difference between Fig. 1 and Fig. 2 is the signal for CH_4.

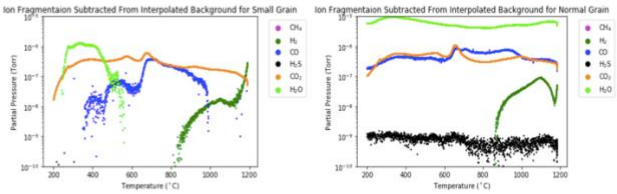

Fig.1 Both plots are for a stringent steady heating scheme. The plot on the left is for our small grain sample and the plot on the right is for our normal grain sample. These plots incorporate the $4.96P_{Ar}$ correction.

We can also see that in **Fig. 2**, CH_4 seems to be more prevalent in the small grain sample and appears right after 600° C and then reappears from 1000°-1200° C. For the normal grain, it only appears around 600° C and a little at 200° C.

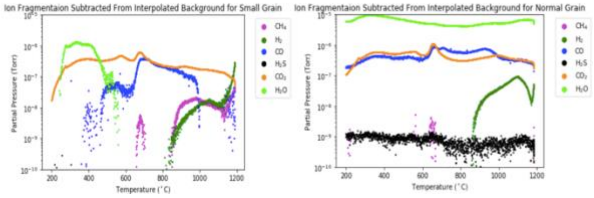

Fig. 2 These plots represent the less stringent steady heating scheme. The plot on the left is for the small grain sample and the plot on the right is for the normal grain sample. These plots neglect the $4.96P_{Ar}$ correction.

For the stepped heating scheme, we can see there is no methane outgassed for different hold temperatures with the stringent method, but does appears in the less stringent method (**Fig. 3**, **Fig.4**).

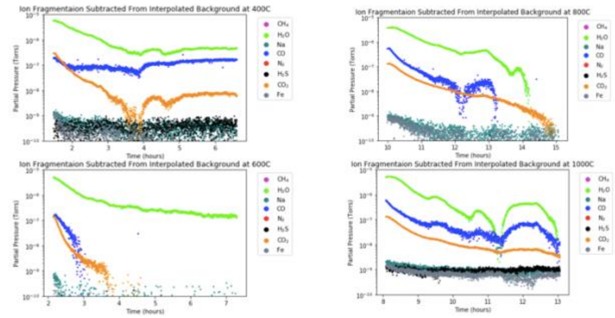

Fig. 3 Stepped heating scheme for the stringent method. Top left: 400°C, bottom left: 600° C, top right: 800 ° C, bottom right: 1000°C.

For the less stringent plots, one can see that methane does not appear until 800° C plot and the 1000° C plot (**Fig. 4**).

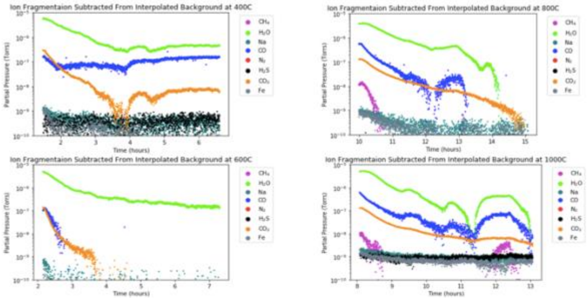

Fig. 4 Stepped heating scheme for the less stringent method. Top left: 400°C, bottom left: 600° C, top right: 800 ° C, bottom right: 1000°C. Signals for methane are present at higher temperature holds.

For both the steady heating scheme and stepped heating scheme, the most abundant species are H_2O, CO_2, and CO.

The steady heating scheme shows that using different grain sizes affects the amount of outgassed species. This may suggest that there is a correlation between grain size and abundances of particular outgassed species from carbonaceous chondrites.

The lack of CH_4 in our plots could be explained by our conservative atmospheric corrections (**Fig. 1** & **3**). While if we remove the additional atmospheric corrections using m/z 40, methane outgassing is consistently seen at around 800-1000° C. This makes us question what corrections are considered to be an overcorrection. Titan's interior would likely reach this temperature [5], so outgassing of methane from primordial organic matter is possible to replenish its atmospheric methane.

Conclusion and future work: The source of methane in Titan's atmosphere has been a mystery. By continuing our work with carbonaceous chondrites, we may provide more evidence of methane outgassing from Titan's interior.

For future studies, we intend to conduct additional experiments with the Murchison meteorite by changing the grain sample size from normal grain to small grain for the stepped heating scheme. Additionally, we will monitor 15 amu's signal in subsequent experiments because CH_3 (mass 15 amu) is the main fragment of CH_4 and this mass has less interference from other abundant species like H_2O and CO_2. We also intend to use a gas chromatograph mass spectrometer (GCMS) for this work so we can identify methane. It is also our goal to experiment with other carbonaceous chondrites so we can compare our findings across a range of diverse samples.

References:

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