# Carbon Dioxide on the Surface of Iapetus, Its Stability and Production.

E. E. Palmer*[1] and R. H. Brown[1], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, *epalmer@lpl.arizona.edu

**Introduction:** Carbon dioxide was detected on Iapetus when Cassini entered the Saturnian system in December of 2004 [1]. Since then, Cassini VIMS has detected $CO_2$ on many of the Saturnian satellites [2]. The widespread presence of $CO_2$ in the Saturnian system is enigmatic because the surface temperatures of the moons of Saturn are above the sublimation temperature of $CO_2$ ice [3] and [4]

We address the following questions by looking at the $CO_2$ on Iapetus' surface: What is the source of $CO_2$ on the surfaces of Saturn's moons? Why are there such large quantities of $CO_2$?

**Carbon Dioxide on Iapetus:** Close analysis of Iapetus shows that $CO_2$ exists significantly in the dark material [2]. However, $CO_2$ has yet to detected by VIMS in the bright area, which is hard to detect becuase of the low signal from water ice at 4 um (Figure 1). If $CO_2$ is present, the amount would have to be small. In the transition areas between bright and dark material, it appears that this stark dichotomy remains; however, it is difficult to get a full pixel of only bright material due to the low resolution of VIMS cubes.

**Stability of Carbon Dioxide:** Previous work has shown that $CO_2$ is not stable at 10 AU from the Sun; even a 10 km layer of $CO_2$ would effectively be lost over the age of the solar system [3]. However, this analysis did not consider the effect of polar cold traps and gravitational binding energy.

To evaluate these factors, we created a computer model to calculated the surface temperature of Iapetus using energy balance between insolation, thermal conduction and latent heat due to sublimation. The $CO_2$ that sublimated was scattered ballistically around the moon. This results in accumulation of $CO_2$ at the winter pole, then a mass migration between the poles when the seasons change. During the migration 5% of the $CO_2$ reaches escape velocity and be lost from the system [4].

Gravitational binding energy and polar cold traps allow for an increase in the residence time of $CO_2$, but the effect is not large enough for $CO_2$ to remain on Iapetus' surface as ice. Our model shows a half life for carbon dioxide of ~200 years before it is lost from the system, such that over $10^{12}$ kg of $CO_2$ can be lost every solar orbit [4]. This suggests that $CO_2$ cannot be primordial, but must be produced in-situ.

**Carbon Dioxide Generation:** Carbon dioxide has been generated using water ice in labs by several research groups [5], [6], [7], [8], [9], [10], [11], [12], [13] and [14].

Specifically relevant to Iapetus was Mennella's work to identify a production mechanism for carbon monoxide and carbon dioxide in the interstellar medium. They found that CO and $CO_2$ could be produced from water and carbon by energetic ions and UV photolysis [10] and [11].

However, the material they used in these experiments was unusual in several regards: the carbon grains were very small, they were exposed to high amounts of hydrogen to create bonds before the experiment was started, and they were encased in water ice. These preconditions are relevant for the solar nebula but not as applicable to the surface of Iapetus.

We conducted UV photolysis experiments attempting to match the characteristics of the material expected to be found on Iapetus and other outer solar system bodies.

We created a simulated Iapetus regolith consisting of flash frozen de-ionized, degassed water using liquid argon. We mechanically crushed water ice into regolith-like particles (size < 100 um) in an argon atmosphere. We then mixed in amorphous 13C grains ($H_2O$:C of 500) that gave an albedo between .1 and .3 depending on the grain size and filled the sample chamber to a depth of approximately one centimeter.

Once the regolith was put in the chamber and cooled to the desired temperature (55K to 120K), we irradiated it with UV light from a deuterium bulb in a vacuum of $10^{-8}$ torr. This bulb produces a flux of photochemically active photons of ~$10^{14}$ photon $s^{-1}$ $cm^{-1}$.

*Results.* Using an SRS-100 RGA mass spectrometer, we detected an increase in mass 45 ($^{13}CO_2$), generated at a rate of 2 x $10^{12}$ pts $s^{-1}$, which indicates that carbon dioxide is being generated via UV radiation. Additionally, we see an increase in mass 29 ($^{13}CO$), carbon monoxide.

If we extrapolate this result and scale for the surface area of dark material on Iapetus and the lower flux, we calculate that ~ 1,000 kg of $CO_2$ is generated per year..

**Spectroscopy:** We are working to reproduce the $CO_2$ adsorption features seen by Cassini VIMS by doing bidirectional reflectance spectroscopy on our samples.

We chose not to use thin film samples for our spectroscopy because we wanted to ensure that trapping of $CO_2$ could occur at depths beyond the penetration depth of the UV light. One side effect, however, is that the amount of light reflected from our sample is very low.

A Nicolet Nexus 870 FT IR spectrometer with both the MCT-A* and InSb detectors was used to detect the trace amount of $^{13}CO_2$ that formed.

In our experiments, we did not set up a cold trap outside of the UV light source to accumulate $CO_2$ (something that happens on the night side of Iapetus), but instead irradiated the entire sample expecting $CO_2$ to bind with either water ice grains or carbon grains and remain long enough to be detected.

*Results.* We found that water ice grains do not appear to trap or adsorb enough $CO_2$ to be detected at the 1% level. This may be due to the continued flux of UV light that would break down any $CO_2$ in about one hour in our lab.

However, there is indication of some trapping of carbon dioxide in samples with a high carbon ratio. We found a 3.7% absorption feature at 4.385 um (Figure 2), the asymmetric stretch feature for $^{13}CO_2$ [15]. This may be due to a lag deposit of carbon forming and the $CO_2$ binding with carbon grains. Further work is needed to identify the trapping mechanism that allows this to occur. Additionally, we detected a small feature (2% band depth) at 4.415 um, but have not identified it.

**Conclusion:** Our laboratory experiments show that $CO_2$ can be produced in-situ with components that are common in the outer solar system, a simple mixture of water and carbon-rich meteoritic dust. Further, this can be done at low temperature and with solar UV light. It is likely that ion radiation is also capable of driving these reactions. Finally, because carbonaceous material is commonly found on the surface of outer solar system bodies, it is likely that $CO_2$ is being generated, and possibly trapped, throughout the outer solar system. We suggest that the $CO_2$ signatures found on Saturn's moons may not be primordial but photolytically generated.

**References:** [1] Buratti, B. J., et al. (2005) APJ. 622, L149-L152. [2] Clark, R., et al. (2008) Icarus. 193, 372-386. [3] Lebofsky, L. A. (1975) Icarus. 25, 205-217. [4] Palmer, E. E., Brown, R. H. (2008) Icarus. 195, 434-446. [5] Allamandola, L. J., et al. (1988) Icarus. 76, 225-252. [6] Ehrenfreund, P., et al. (1997) Astronomy and Astrophysics. 328, 649-669. [7] Gerakines, P. A., et al. (1996) Astronomy and Astrophysics. 312, 289-305. [8] Hudson, R. L., Moore, M. H. (2001) JGR. 106, 33275-33284. [9] Loeffler, M. J., et al. (2005) Astronomy and Astrophysics. 435, 587-594. [10] Mennella, V., et al. (2006) APJ. 643, 923-931. [11] Mennella, V., et al. (2004) APJ. 615, 1073-1080. [12] Moore, M. H., Hudson, R. L. (1998) Icarus. 135, 518-527. [13] Sandford, S. A., et al. (1988) APJ. 329, 498-510. [14] Strazzulla, G., Palumbo, M. E. (1998) Planetary and Space Science. 46, 1339-1348. [15] Warren, S. G. (1986) Appl. Opt. 25, 2650-2674.

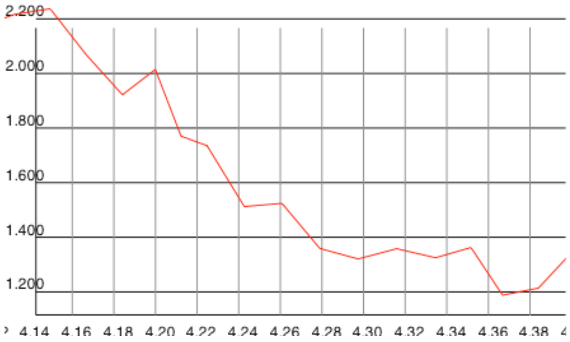

**Figure 1** - Sample VIMS spectrum of 15 pixels taken near the polar region, coadded to reduce noise. There is no $CO_2$ feature detectable at 4.26 um

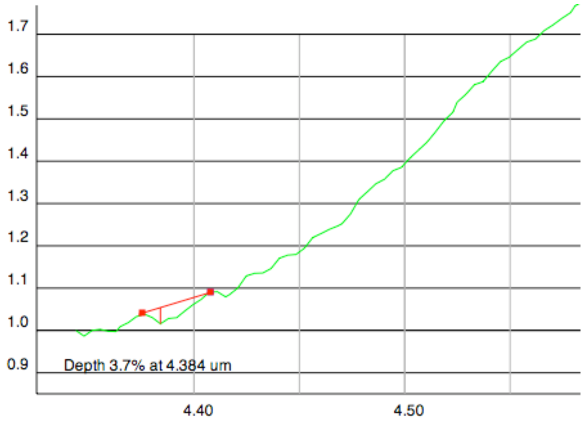

**Figure 2** - Carbon lag deposit - The center of the $^{13}CO_2$ ice feature is at 4.385 um (Warren 1986). We detected a 3.7% absorption feature indicative of $^{13}CO_2$ ice in our sample. There is another feature at 4.14 um at a 2% band depth; however, we have not identified it.