# THE UPPER BOUND FOR $CO_2$ TRANSPORT ON IAPETUS: NARROWING IN ON THE NATURE OF $CO_2$ IN THE DARK MATERIAL.

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**Introduction:** Iapetus, two-faced in its surface composition and brightness, is positioned in the outskirts of the Saturnian system. Further beyond its orbit lie Phoebe and the recently discovered Phoebe ring, which are prime candidates for the origin of the dark material in the exogenic models [1]. Regardless of the origin, Buratti *et al*. [2] discovered a signature of $CO_2$ in the dark material; subsequent studies have mapped its distribution, finding the 4.26 micron absorption band depth to strengthen approaching the boundary between the dark and light material [3-5]. In addition to $CO_2$, nano-phase hematite, amorphous carbon, and trace amounts of water ice have also been suggested to be the major constituents [2,3]. The detection of $CO_2$ in the dark material is problematic due to its instability at Saturn's solar radius, which was first shown by Lebofsky [6]. Palmer and Brown [7] have shown that $CO_2$ remains for longer time scales when considering the effect of gravity, which could possibly permit formation of a seasonal or residual polar cap.

Possibilities for the nature of $CO_2$ in the dark material include adsorption on the surface, in solid inclusions within water ice, complexed, clathrate hydrate, solid ice [2,7] in a mineral form such as siderite, or some combination of the preceding list. In the case of adsorbed carbon dioxide, the source for the $CO_2$ could indeed be a reservoir beneath the dark overburden at the interface between the carbon-enriched overburden and the water-rich ice beneath. Cosmic rays could then produce the $CO_2$, creating a subsurface reservoir that then diffuses out slowly and adsorbs on the surface at night. The extensive possibilities for kinetics make a model that explores $CO_2$ sublimation from the dark material highly problematic and case-limited.

As Figure 1 demonstrates, visual evidence from *Voyager 1 & 2* suggests that a $CO_2$ polar cap was not present during the flybys in 1980 and 1981. Specifically, a polar cap of dry ice, as suggested by previous authors [7,8], would provide albedoes in the range 0.7-0.9 similar to the martian $CO_2$ residual caps [9]. If ballistic transport were the mechanism for polar cap formation, then the surface ice would be even brighter and purer than martian polar cap albedoes that are darkened by regional and global dust storms. A typical model would begin with the source flux of $CO_2$ evaporating from the dark material; however, since the exact nature of the $CO_2$ transport is not known (the possibilities of which affect the kinetics), the best way to bind this set is to work the problem in reverse. Therefore in this study, we assume that no polar cap exists on the surface at present, an assumption supported by observational evidence at near-equal obliquities. Since the evaporation rate for a pure $CO_2$ cap is more easily quantifiable, we can determine the maximum possible evaporation flux of $CO_2$ from the dark material required such that no polar cap can form in an effort to eliminate some of the possibilities for the nature of the $CO_2$ detected by *Cassini* VIMS [2].

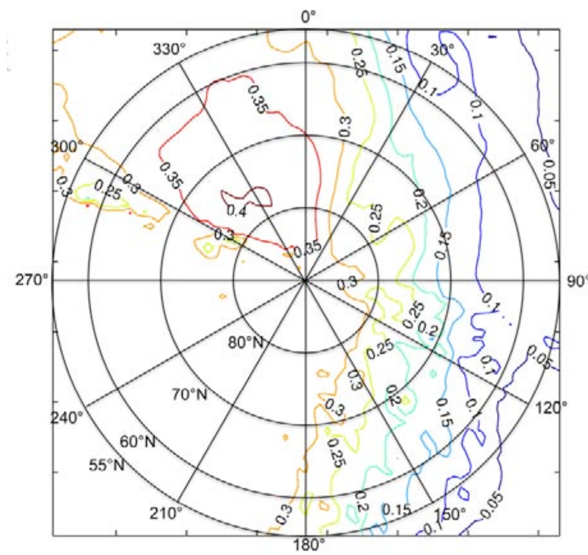


**Figure 1.** Bolometric Bond albedo for the northern pole of Iapetus from Blackburn *et al*. [10].

**Methods**: Consider the possibilities for a solitary carbon dioxide molecule on the surface of Iapetus for any given second (Fig. 2). A carbon dioxide molecule could be destroyed by UV, sublimate, or remain stable on the surface. If it sublimates, then it either makes a hop or reaches escape velocity and leaves the system. If it hops, then it also faces the possibility of destruction or ends up back on the surface; thus, this process is recursive. We found that molecules sublimating at the summer temperatures of the poles could make a maximum hop of 16 kilometers, which still places them within what we consider the polar region (i.e. a molecule originating at the pole moves about 1° latitude). Since there is a finite surface area by which to sublimate, a recursive algorithm is not necessary as the evaporative fluxes are fixed.

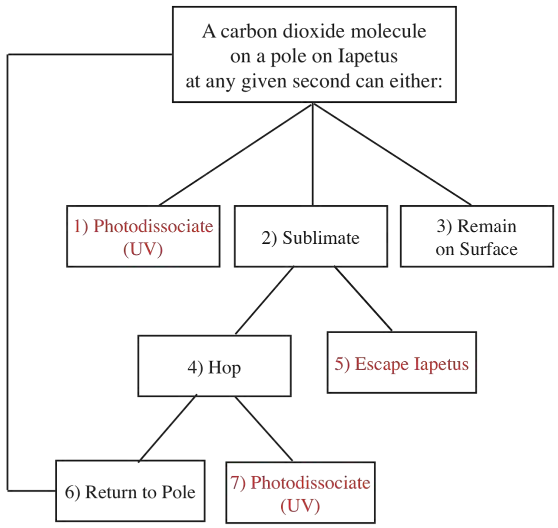


**Figure 2.** Possibilities for a carbon dioxide molecule on one of Iapetus' poles.

Since it is difficult to estimate (7) in Figure 2, i.e. the percentage of molecules undergoing a transit that are photodissociated in flight, we assume it is negligible for the purposes of this exercise, which is reasonable considering the average flight time for a molecule at the poles (1.7 x $10^3$ s) and the photochemical time scale for $CO_2$ (1.7 x $10^7$ s) differ by almost exactly four orders of magnitude [7]. The lost rate from the polar cap system can then be expressed as the sum of (1) and (5). Therefore, the source rate into the polar regions must be less than or equal to the loss rate for no polar cap to exist.

The photodissociation rate from ultraviolet light $J_P$ can be calculated from the following formula [11-15]:

$$J_P = \eta \int_{1nm}^{227nm} \Phi(\lambda)\sigma(\lambda)d\lambda \quad (1)$$

where $\sigma$ is the radiometric cross section of $CO_2$ and $\Phi$ is the solar flux reaching Iapetus' surface, both of which are dependent on the wavelength $\lambda$ of light; and $\eta$ is the number density. For the escape rate, we use the velocity distributions determined from Section III and classify molecules that have left Iapetus by those that have achieved the escape velocity of Iapetus (591 m $s^{-1}$) or greater. To estimate sublimation rates, we use the traditional Hertz-Knudsen-Langmuir equation.

*Thermal Model:* We used the thermal model for Iapetus established by Rivera-Valentin *et al.* [16], which incorporates as inputs the bolometric Bond albedo from Blackburn *et al*. [10] and the thermal inertial map from Rivera-Valentin *et al.* [16] for accurate temperature simulations. Since this study concerns the sublimation of $CO_2$, our thermal model also includes latent heat loss using a heat of sublimation for $CO_2$ of 590 x $10^3$ J $kg^{-1}$ [17].

**Results**: We ran our polar cap sublimation code for one full solar orbit of Saturn to produce four maps for each obliquity: 1) sublimation map, 2) escape map, 3) UV photodissociation map, and 4) total loss map. All loss rates are expressed in kg $m^{-2}$ $orbit^{-1}$. The list of obliquities checked included the current (14.7°), minimum (4.3°), and maximum (19.3°), as Iapetus varies its inclination with respect to Saturn on a three thousand year cycle [18]. Once the flux rate leaving the polar regions is known, it must be compared to possible source rates given different kinetic possibilities, which include all listed in the introduction section. We developed accumulation maps over one solar orbit of Saturn of the possibilities of $CO_2$ transport by adding a ballistic transport model that investigates the statistical likihoods for landing zones after one hop. We will present these results, which define strict upper bound limits on the nature of the $CO_2$ that sublimates from the dark material.

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