The Effect of Flyby Velocity on the Composition of the Enceladus Gas Torus as Measured by Cassini INMS .

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Introduction: The observations of the Enceladus gas plume by the Cassini Ion Neutral Mass Spectrometer indicate changes in the H_2O, CO_2, CO, H_2, and unsaturated hydrocarbons as a function of the flyby velocity. To first iorder this can be interpreted as molecular fragmentation produced by impact of the molecules on the walls of the Titanium antechamber that serves as an inlet to the mass spectrometer. In the remainder of the abstract we discuss how these fragmentation effects have: 1) enabled the determination of the D/H ratio of the water ice in Encaldus' interior, and 2) indicated the existence of organic molecules larger than 100 amu (the INMS mass range) that make up a "dusty' component of the gas and dust emanting from the plume of Enceladus.

Determination of the D/H ratio of the Enceladus water ice: The determination of the D/H ratio of water vapor using a low resolution mass spectrometer, such as the INMS quadrupole, are problematic due to the overlap of fragmentation products and isotopologues of the water and interfering species such as methane and ammonia. On the other hand the determination of the D/H ratio is an important indicator of the temperature conditions present during the formation of the ice amd thereby tell us about the likely position of ice formation in the protosolar nebula.

What we noticed at Encelaus was that the amount of water vapor and molecular hydrogen varied in an inverse fashion depending on the velocity of the flyby (see Figure 1). The presence of icy grain impacts in the antechmaber during the flyby sugssested a mecahnism whereby the ice grains impacted the Titanium antechamber releasing unoxidized Titanium that then reacted with the water vapor from Enceladus in the antechamber forming molecular hydrogen, which could be measured unambiguously with regard to D/H ratio. (See table below and reference [1].)

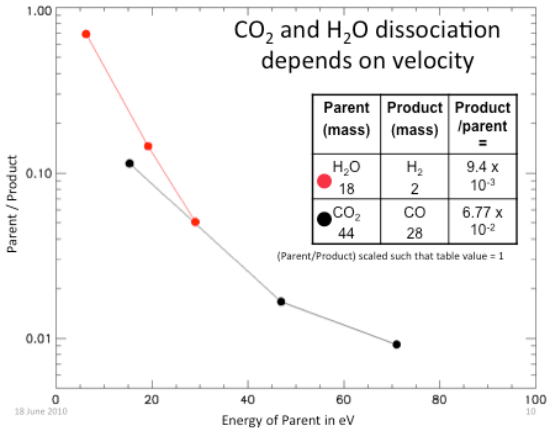

Figure 1: H_2O, CO_2, CO, and H_2 versus flyby velocity

Stable Isotopes

Object Name	D/H	$^{18}O/^{16}O$	$^{12}C/^{13}C$
Enceladus	2.9 (+1.5/–0.7) x 10^{-4}	2.1 (+0.4/–0.2) x 10^{-3}	84±13
Comets	3.1 (+0.4/–0.5) x 10^{-4} (a)	1.93±0.12 x 10^{-3} (a)	90±10 (b)
Protosolar	2.1±0.4 x 10^{-5} (d)		
Earth	1.56 x 10^{-4} (c)	2 x 10^{-3} (c)	89 (c)

(a) Balsiger, H. et al. D/H and $^{18}O/^{16}O$ ratio in the hydronium ion and in neutral water from in situ ion measurements in comet Halley, *J. Geophys. Res.* **100**, 5827-5834, (1995).
(b) Wycoff, S. et al. Carbon isotope abundances in comets. *Astrophys. J.* **535**, 991-999 (2000).
(c) Lodders, K., and B. Fegley. *A Planetary Scientist's Companion*. Oxford University Press, New York (1998).
(d) Geiss, J. and G. Gloeckler, Abundances of deuterium and helium in the protosolar cloud, *Space Sci. Rev.* **84**, 239-250 (1998).

Higher order organic molecules: Similar trends in composition change with velocity for both the elemental composition (se Figure 2) and for the unsaturated molecules (see Figure 3) suggest that gragmentation and Titanium sublimation processes are effecting other volatiles and icy grains from the Enceladus plume.

Figure

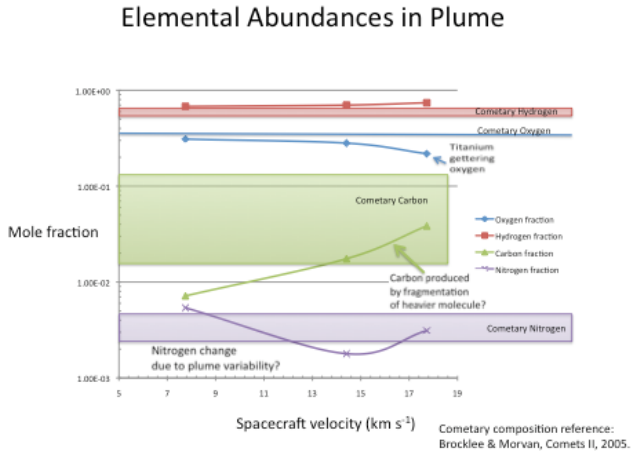

Figure 2: Change in elemental composition with flyby velocity.

Most notably the increase in CO and unsaturated hydrocarbons with flyby velocity suggested that the fragmentation of a larger organic molecule beyond the mass range of INMS on the wasllls of the antecahmber (Figure 3) . furthermore, the indentity of these

fragments was consistent with an extended CO source postulated at comet Halley and for the existence of PAHS as observed in the Stardust sample.

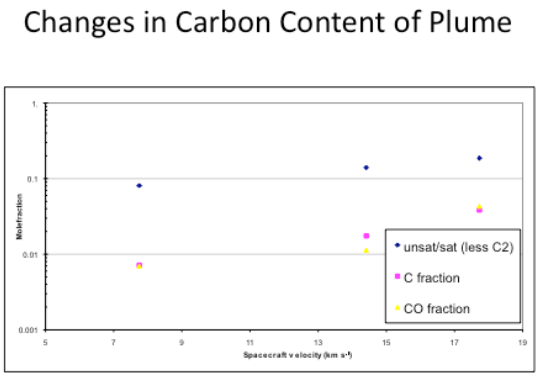

Figure 3: Changes in carbon content as a function of flyby velocity.

References

[1] Waite et al., Liquid water on Encaldus from observations of ammonia and ^{40}Ar in the plume, Nature, 460,487-490, July 23, 2009.

Fragmentation of heavy organics

1. The carbon content increases with velocity suggesting a fragmentation of carbon compounds beyond the INMS mass range (100 amu) may be dissociating upon impact with the antechamber.
2. CO increases in concentration with velocity along with methanol and formaldehyde, which suggests that one of the fragmentation components may be similar to the organics polymers observed in Halley and other comets (ref. Cottin et al., *Ap. J., 556*, 417-420, 2001 or Mitchell et al., *Icarus, 98*, 125-135, 1992.
3. Unsaturated hydrocarbons also increase with velocity suggesting that a secondary fragmentation component may be due to PAHs, which have also been inferred from comet observations (ref. Formenkova, *Space Sci. Rev., 90*, 109-114, 1999.