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Enceladus' Plume Composition

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Abstract

Apparent changes in the plume volatile composition measured by the Cassini Ion Neutral Mass Spectrometer as a function of the flyby speed have resulted in a more complete understanding of the plume's volatile and granular compounds. We present a baseline volatile makeup and suggest the existence of condensed high-molecular weight organic compounds in the plume mixture as well.

1. Introduction

Waite et al. [1] reported a plume composition for Cassini Enceladus flyby E5 that was dominated by water with an admixture of CO_2, CO, NH_3, CH_4, H_2CO and a host of organic species, reminiscent of the volatile composition of a comet (Table 1). The comet analogy was bolstered by a fortuitous measurement of D/H in water of 3×10^{-4}. However, Waite et al. noted a change in composition with flyby velocity that warranted further study.

2. Elemental Composition

A subsequent flyby at low velocity (E7) reinforced the notion of apparent changes in the plume composition as a function of the spacecraft velocity (Fig. 1). This figure shows that as the speed of the flyby increases the oxygen content goes down, and the carbon and hydrogen content goes up. Nitrogen does not demonstrate a clear dependence. We explain these changes as follows: 1) the oxygen decreases due to reaction with raw titanium vaporized from the antechamber walls by high-speed ice grains acting on water vapor; (This enabled the determination of the D/H in water.) 2) the increase in carbon comes from the surface induced dissociation of organic macromolecules (> 100 Da) or condensed organic materials ("grains"), which we detect as smaller organic fragments. The organic-bearing particles have been reported among E-ring particles originated at Enceladus [2] and should be sampled by the INMS.

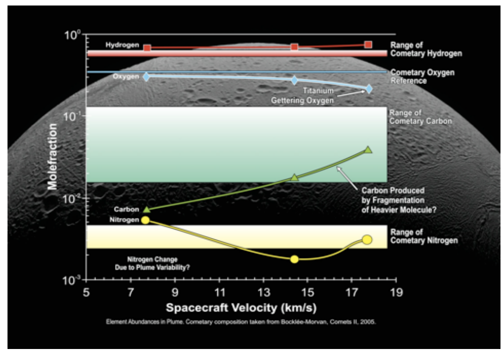

Figure 1: Apparent changes in elemental abundances of plume volatiles with flyby speed.

3. Mass Spectra and Speciation

Evaluation of the compositional differences between the low and high velocity data sets in Table 1 yields a number of interesting observations. The most immediately obvious difference is that a majority of the species show a significant reduction in the values presented for E7. Hydrocarbon and oxygenate species are universally depleted ranging from a factor of two to ten. Surprisingly, the CO_2 measured at E7 does not agree with the notion that CO is a direct product of CO_2 dissociation at high velocity. Another intriguing difference between the E5 and E7 case is a change in the structure of the mass spectrum in the mass range 24-27, not shown due to space limitations. At high velocities the peak at 26 Da extends above that at 27 Da, a clear indication of C_2H_2 and/or C_2H_4. The prominence of the signal at 27 Da in the low velocity E7 spectrum, however, marks the first definitive detection of HCN, previously an unconfirmed constituent caught in the ambiguity of signal in this region. This also implies that C_2H_2 and C_2H_4 are preferentially created as velocity increases. E7 shows the first reasonable evidence of native H_2 in the plume gas, which may hint at geochemical processes below Enceladus' surface. We consider this observed abundance of H_2 a tentative detection, however, for two reasons: 1) the extent of titanium-water reactions at this velocity cannot be determined empirically and 2) the Cassini spacecraft made use of its hydrazine (N_2H_4) thrusters for attitude adjustments during E7.

Table 1. Plume composition of selected compounds for high-speed flyby (E5) and low-speed flyby (E7)

Species	E5 mixing ratio	E7 mixing ratio
H_2O	**0.90 ± 0.01**	**0.92 ± 0.03**
CO_2	**$0.053 \pm (1 \times 10^{-3})$**	**$8.0 \times 10^{-3} \pm 3 \times 10^{-3}$**
CO	**[0.044]**	**< 0.015**
H_2	**[0.39]**	**$<0.034 \pm 0.01$**
H_2CO	**$3.1 \times 10^{-3} \pm (1 \times 10^{-3})$**	**$< 3.2 \times 10^{-4}$**
CH_3OH	**$1.5 \times 10^{-4} \pm (6 \times 10^{-5})$**	**$3.0 \times 10^{-5} \pm 2 \times 10^{-5}$**
C_2H_4O	**$< 7.0 \times 10^{-4}$**	**$* < 1 \times 10^{-4}$**
C_2H_6O	**$< 3.0 \times 10^{-4}$**	**$* < 6 \times 10^{-5}$**
H_2S	**$2.1 \times 10^{-5} \pm (1 \times 10^{-5})$**	**$3.0 \times 10^{-5} \pm 1 \times 10^{-5}$**
^{40}Ar	**$3.1 \times 10^{-4} \pm (3 \times 10^{-5})$**	**$* < 4 \times 10^{-5}$**
NH_3	**$8.2 \times 10^{-3} \pm (2 \times 10^{-4})$**	**$8.0 \times 10^{-3} \pm 3 \times 10^{-}$**
HCN	**$< 7.4 \times 10^{-3}$**	**$7.0\times10^{-3} \pm 3 \times 10^{-3}$**
CH_4	**$9.1 \times 10^{-3} \pm (5 \times 10^{-4})$**	**$2.1 \times 10^{-3} \pm 9 \times 10^{-4}$**

The mixing ratios presented in Table 1 represent the range of possible abundances based on multiple modeled composition mixes which fit the data sets equally well. In some cases this leads to large uncertainties or upper limits. Values in the E5 column are taken directly from Waite et al. [1]. Brackets around CO and H_2 mixing ratios represent the directly observed abundances of these species, which were then subsumed into the reported mixing ratios for CO_2 and H_2O respectively. Composition analysis of the E7 flyby included the same list of candidate species as that used for E5 described in Waite et al. supplement [1]. Entries preceded by an asterisk (*) indicate upper limits for species whose spectral signatures were not evident in the E7 data above noise levels.

6. Summary and Conclusions

The scientific implications for the measured volatile composition are presented in a companion presentation by Zolotov et al. In summary, the composition of Enceladus' plume appears comet-like in major volatile content with a D/H ratio in water of 3×10^{-4}, and indications of macromolecular organic species seen before at comet Halley [3] and with the Stardust mission [4], and also observed with Cassini CDA instrument [2]. However, possible presence of H_2 among plume gases is consistent with past or present aqueous processes in the rocky core also consistent with the detection of salts in the E-ring and plume particles [5].

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