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Icy Satellite Surface – Exospheric - Magnetospheric Interactions, & What We've Learned from Cassini

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1. Introduction

The magnetospheric plasma interaction with the large Galilean and Saturnian icy satellites involves a fascinating coupling of different physics: including (i) surface ion implantation, radiation chemical processing of the surface ice, and sputtering, (ii) formation, redistribution, escape, and surface recondensitation of sputtered exospheres of radiolytic O_2 and CO_2, and (iii) the supply of ionized material to the surrounding plasma. I will review the fundamental processes involved, discuss the latest advances in understanding resulting from the discoveries of Cassini at Saturn and the questions raised.

2. Cassini Discoveries & Related Questions

Rhea & Dione O_2 - CO_2 Exospheres:

Cassini's Ion Neutral Mass Spectrometer (INMS) detected exospheres of O_2 and CO_2 during two low-altitude northern and southern Rhea flybys (97 and 72 km) on Mar 2, 2010 [1] and Jan 11, 2011, and a 99 km equatorial Dione flyby on Dec 12, 2011 [2]. Surface sputtering by bombarding magnetospheric ions and electrons is known to produce gravitationally bound exospheres of sputtered radiolytic O_2 at Europa and Ganymede [3], and CO_2 at Callisto [4]. Hence, the discovery of these same species at two large Saturnian icy satellites adds to growing evidence that physical processes leading to exospheres, in particular consisting of carbon dioxide and molecular oxygen, may be common on irradiated icy bodies in the universe.

What is the CO_2 source ?: Exospheric molecular oxygen is consistent decades of laboratory studies showing that O_2 (along with H_2, which easily escapes) a major radiation product sputtered from irradiated water ice [5, 6]. However, the source of CO_2 is more puzzling. While exospheric CO_2 at Rhea and Dione is consistent with the previous remote detection of a CO_2 exosphere at Callisto by Gallileo NIMS [4], and the, the lack of evidence for endogenic activity at Rhea and Dione [7, 8] such as outgassing from the interior, seems to imply a radiolytic CO_2 source. Although Cassini VIMS spectra indicate very pure water ice surfaces (close to 99% [9-11]), small surface CO_2 concentrations are ubiquitously detected in the ices of the Galilean and Saturnian satellites [9]. Such CO_2 could be synthesized through magnetospheric ion-induced radiolysis reactions involving dissociated H_2O and carbonaceous impurities [12]. Laboratory experiments are likely needed to clarify the details of this process.

Moons as Plasma Sources:

The Cassini Plasma Spectrometer (CAPS) detected positively charged pickup ions flowing from Rhea (possibly O_2^+ or CO_2^+) and Dione (likely O_2^+), during flybys through their plasma wakes (Rhea: Nov 26, 2005 and Aug 30, 2007 [1], Dione: April 7, 2010 [13]). The CAPS ion fluxes are consistent with the exospheric densities measure in situ by INMS after taking into account particle energies and fluxes, and known cross sections for all of the important photo and electron impact ionization and charge exchange channels. CAPS indications of outflowing plasma from the orbit of Tethys [14] may also be evidence of a source of material (such as O_2 or CO_2), or possibly an exosphere, at this moon.

What is the source of Negative Ions?: A surprise is the detection of negative pickup ions by CAPS, likely O^-, emanating from Rhea during the Nov 2005 encounter [1]. The ions trajectories trace back to low altitudes (or possibly the surface itself) on Rhea's night side [1]. However known formation mechanisms, e.g. dissociative electron attachment to O_2, or sputtering of O^- from the surface, have cross sections insufficient to account for the measured negative ion flux.

Seasonal Variability:

The INMS and CAPS measurements suggest that the Rhea and Dione exospheres are seasonal, modulated by O_2 and CO_2 surface adsorption at high winter latitude surfaces, with transient sublimation near the equinoxes [2]. INMS detected similar gas densities at Rhea northern latitudes [5(±1) and ~2(±1) $\times 10^{10}$ O_2 and CO_2 m^{-3}] and Dione's equator [2(±1)$\times 10^{10}$ m^{-3} for both species], but much lower densities in the Rhea southern latitudes [0.35(±0.3) and <0.7 $\times 10^{10}$ O_2 and CO_2 m^{-3}]. The results are consistent with a gas source currently residing in the north of both moons due to sublimation of O_2 and CO_2 adsorbed during the recently ended (as of the Aug 2009 equinox) northern winter. Monte Carlo seasonal exosphere simulations [2] yield good agreement with both the spatial distribution of the gas seen by INMS, and the north-south difference at Rhea. CAPS also detected ~3 times more pickup ions during the 2007 Rhea flyby than in 2005 (corresponding to ~3.4 and 10 $\times 10^{22}$ ions/sec produced globally, respectively, assuming O_2^+), despite the ~10 times greater distance of Cassini from Rhea's surface in 2007 (5736 vs 502 km in 2005). The CAPS results are therefore consistent with an increase in time of the exospheric abundance toward the northern spring equinox.

How much O2 & CO2 are stored in polar cold traps ?: The Monte Carlo exosphere model cannot simulate the observed persistence of the northern source gas source 2 – 3 years past equinox, *unless* the cold polar surface temperatures (down to ~20 K possible at end of winter) are also assumed to persist during this period. A possible explanation is the persistence of high-latitude topographically shadowed regions, which may act as localized cold traps. Diffusion of adsorbed O_2 and CO_2 into the surface regolith may lead to the buildup and retention of these species at depth, not unlike ice cold trapping in permanently shadowed terrains of the Moon and Mercury [15]. Work is now underway to model the temperatures and O_2 and CO_2 versus surface location and depth on a simulated topography, to estimate the distribution and quantities of these volatiles that may be stored in the Rhea and Dione polar surfaces. Molecular oxygen diffusion in ice regolith is a process relevant at Europa where O_2 migrating from the surface could feed active chemistry in the subsurface ocean [16-18]. Moreover, just as the phenomenon of ice cold trapping on the moon has significance for future habitability [19], the potential role of polar cold trapping of carbon dioxide and molecular oxygen in shadowed regions is a highly interesting possibility for the same reason.

Acknowledgements

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References

[1] B. D. Teolis *et al.*, Science **330**, 1813 (2010).
[2] B. D. Teolis, and J. H. Waite, in *LPSC*Woodlands, Tx, USA, 2012).
[3] D. T. Hall, P. D. Feldman, M. A. McGrath, and D. F. Strobel, Astrophysical Journal **499**, 475 (1998).
[4] R. W. Carlson, Science **283**, 820 (1999).
[5] B. D. Teolis, J. Shi, and R. A. Baragiola, Journal of Chemical Physics **130**, 134704 (2009).
[6] B. D. Teolis *et al.*, Science (Supporting Online Material) **330**, 1813 (2010).
[7] K. Stephan *et al.*, Icarus **206**, 631 (2010).
[8] K. Stephan *et al.*, Planetary and Space Science **61**, 142 (2012).
[9] D. P. Cruikshank *et al.*, Icarus **206**, 561 (2010).
[10] D. P. Cruikshank *et al.*, Icarus **175**, 268 (2005).
[11] R. N. Clark *et al.*, Icarus **193**, 372 (2008).
[12] E. E. Palmer, and R. H. Brown, Icarus **212**, 807 (2010).
[13] R. L. Tokar *et al.*, Journal of Geophysical Research **39**, L03105 (2012).
[14] J. L. Burch *et al.*, Nature **447**, 833 (2007).
[15] D. A. Paige *et al.*, Science **330**, 479 (2010).
[16] K. P. Hand, C. F. Chyba, R. W. Carlson, and J. F. Cooper, Astrobiology **6**, 463 (2006).
[17] C. F. Chyba, Nature **403**, 381 (2000).
[18] C. F. Chyba, and K. P. Hand, Science **292**, 2026 (2001).
[19] P. Spudis, The Space Review: essays and commentary about the final frontier **740**, 1 (2006).