EPSC Abstracts
Vol. 5, EPSC2010-806, 2010
European Planetary Science Congress 2010

Detection of an O_2 and CO_2 atmosphere at Rhea

B. D. Teolis (1), J. H. Waite (1), B. A. Magee (1), P. F. Miles (1)
(1) Southwest Research Institute, San Antonio, Texas, USA (ben.teolis@swri.org)

Abstract

We present the discovery of a tenuous oxygen-carbon dioxide atmosphere at Saturn's icy moon Rhea by the Cassini Ion Neutral Mass Spectrometer (INMS). The atmosphere is generated mainly by the bombardment of Rhea's trailing hemisphere by Saturn's co-rotating heavy-ion plasma. This first of its kind in-situ detection of an oxidizing extraterrestrial atmosphere is consistent with remote sensing observations of other icy solar system bodies such as Europa and Ganymede, and suggestive of a reservoir of radiolytic O_2 and other oxidants in Rhea's ice. The presence of CO_2 is evidence of radiochemical co-processing of oxidants and organics in Rhea's surface.

1. Observations

On 2 March, 2010 the Cassini spacecraft carried out a close flyby of Rhea, with a trajectory pointed inbound toward Saturn just 92 minutes prior to solar eclipse, and with the point of closest approach at 97 km altitude almost directly over the north pole and day-night terminator. The INMS: a quadrupole mass analyzer equipped with an antechamber and electron-impact ionizer for in-situ collection and detection of neutral gas; was operated during the flyby with the antechamber inlet pointed favorably (at an angle of 44 degrees) to Cassini's trajectory, enabling detection of neutral species. As shown in Fig. 1, signals of O_2 and CO_2 were detected in mass channels 32 and 44 amu at a maximum density of $5 \pm 1\ 10^{10}$ molecules per m^3. The CO_2 and, to a lesser extent, the O_2 were seen to peak after closest approach, on Rhea's dayside.

2. Radiolysis Source

The tenuous radiolytically generated O_2 atmospheres detected by the Hubble Space Telescope at the Jovian icy satellites Europa and Ganymede [1], as well as numerous laboratory experiments showing the evolution of O_2 from irradiated ice [2], have long suggested the possibility of oxygen atmospheres around the Saturnian satellites. Rhea, as well Saturn's icy moon Dione, are especially interesting due to the presence of O_3 in their surface ices: a trait that they share with Ganymede [3]. Ganymede's surface (as well as those of Europa and Callisto) also contains trapped radiolytic O_2 [4], which has been shown in laboratory experiments to lead to O_3 as a byproduct, along with eventual O_2 ejection from the surface through sputtering [2]. Together with the detection of O_3 in Rhea's surface, the discovery of an O_2 atmosphere is consistent with surface radiolysis, and suggestive of a reservoir of O_2 trapped in the surface ice.

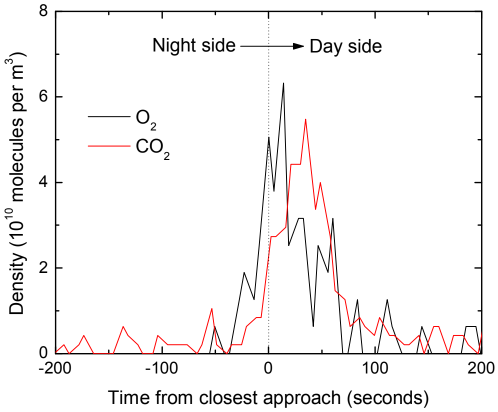

Figure 1: The signals (converted to density) at mass 32 (O_2) and 44 (CO_2) amu measured by INMS versus time from clostest approach to Rhea.

Based on measurements from the Cassini Plasma Spectrometer (CAPS) and Magnetospheric Imaging Instrument of the Saturnian ion and electron plasma, and laboratory estimates of O_2 production and desorption from ice irradiated with different projectiles and energies, we have estimated the expected production of O_2 from different radiation sources. As shown in table 1, a principal oxygen source is bombardment of water group ions in Saturn's co-rotating plasma, which sweeps past Rhea along its orbit while preferentially bombarding its trailing hemisphere. The oxygen is therefore produced preferentially on the trailing hemisphere. This is an interesting finding given that the magnetospheric electrons deposit approximately 8 times more energy into the surface than the water group ions (table 1). However, the available laboratory data suggests that electrons are relatively inefficient at generating O_2, with yields of the order 10^{-5} [5] or 10^{-6} O_2 per eV [6], compared to heavy ions which can have yields of the order 10^{-3} O_2 per eV depending on stopping power, ion range and temperature [2, 7]. At the energy range of Saturn's co-rotating water group species (loosely defined here as < ~10 keV), arriving ions are stopped quickly on impact with the ice, and deposit their energy close to the material surface, where according to experiments [2] O_2 synthesis is most favored due to easy surface escape of radiolytic hydrogen atoms. The total expected production rate of ~2.5 x 10^{24} O_2 molecules per second is consistent with the observation by CAPS of a concentration of O_2^+ ions in the region of Rhea's orbit. Martens *et. al.* [8] have implied based on modeling that, if Rhea is the source of these ions, a source of the order 10^{23} - 10^{24} O_2 per second would explain the observed O_2^+ densities, which is compatible with our estimate.

Table 1: Estimated O_2 production from different radiation sources.

Radiation Source	Energy Deposition (10^{26} eV / sec)	Estimated O_2 Production (10^{22} O_2 / sec)
corotating W^+ (< 8 keV)	11.7	180
W^+ (> 8 keV)	4.7	13.4
H^+	10.8	9.3
electrons	145	0.15-111*
solar UV	8.1	4.2

* The high uncertainty for electrons reflects the inconsistency of yields reported in the literature, and the lack of yield measurements above very low energies (100 eV).

The presence of carbon dioxide in Rhea's atmosphere is consistent with possible trace indications of surface CO_2 by the Cassini Visual and Infrared Mapping Spectrometer [9], as well as the observations of atmospheric [10] and surface CO_2 at several Jovian and Saturnian icy satellites [9]. Possible sources for CO_2 at Rhea include radiolysis reactions between surface water, oxygen and organics present is the surface ice and/or carbonaceous materials deposited by micrometeorite bombardment. Alternatively, the CO_2 may have a primordial origin endogenic to Rhea's ice. Estimates of expected CO_2 source rates are inherently more difficult than O_2 given the uncertainties in the source mechanisms and laboratory experiments, but efforts in this regard are currently in progress.

3. Atmospheric Modelling & Escape

Preliminary atmospheric modeling of the O_2 density distribution suggests that day-night maximum-minimum temperatures of roughly 110 and 40 K produces a dayside shift in atmospheric density profile similar to the shift indicated by INMS (Fig. 1). The dayside atmosphere has a larger scale height than the nightside due to the increased temperature, i.e., the warmer temperatures expand the atmospheric gas to the altitude of Cassini's trajectory in this hemisphere. We note that CO_2 is less volatile than O_2, and thus the nightside could act as a cold trap for CO_2 condensation onto the surface, possibly explaining the almost non-existent CO_2 signal inbound on the night-side (Fig. 1).

Comparing the model results to the densities observed by INMS, we estimate atmospheric global O_2 and CO_2 abundances of ~6 (CO_2) and ~11 (O_2) x 10^{29} molecules at Rhea, and Jeans escape rates of 12 (O_2) and ~3 (CO_2) x 10^{22} molecules per second. The O_2 Jeans escape rate is below the production, suggesting a role for other mechanisms such as electron impact ionization and photo-dissociation, which dominate escape at Europa and Ganymede. However, the lower plasma densities and surface temperatures at Rhea may imply a more prominent role for phenomena such as sputtering of adsorbed gas, in particular on the night side cold surfaces.

References

[1] Hall, D.T., Feldman, P.D., McGrath, M.A., and Strobel, D.F..: Astrophys. J., Vol. 499, pp. 475-481, 1998.

[2] Teolis, B.D., Shi, J., and Baragiola R.A.: J. Chem. Phys., Vol. 130, pp. 134704, 2009.

[3] Noll, K.S., Roush, T.L., Cruikshank, D.P., Johnson, R.E., and Pendleton, Y.J.: Nature, Vol. 388, pp. 45-47, 1997.

[4] Spencer, J.R., Calvin, W.M., and Person, M.J.: J. Geophys. Res., Vol. 100, pp. 19049-19056, 1995.

[5] Sieger, M.T., and Orlando, T.M.: Nature, Vol. 394, pp. 554-556, 1998.

[6] Orlando, T.M., and Sieger, M.T.: Surf. Sci., Vol. 528, pp. 1-7, 2003.

[7] Bar-Nun, A., Herman, G., Rappaport, M.L., and Mekler, Y.: Surf. Sci., Vol. 150, pp. 143-156, 1985.

[8] Martens, H.R., Reisenfeld, D.B., Williams, J.D., Johnson, R.E., and Smith, T. D.: Geophys. Res. Lett., Vol. 35, pp. L20103, 2008.

[9] Clark, R.N.., *et. al.*: Vol. 193, pp. 372-386, 2008.

[10] Carlson, R. W.: Science, Vol. 283, pp. 820-821, 1999.