Geophysical Research Abstracts,
Vol. 10, EGU2008-A-02641, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-02641
EGU General Assembly 2008

The proposed icy mineralogy package (XRD/XRF) for TandEM.

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Introduction: Understanding the geology of Titan's crust, and its interaction with the atmosphere, requires determination of the mineralogy and chemistry of surface materials which can only be achieved unambiguously using a combination of X-ray diffraction (XRD) and X-ray fluorescence (XRF). Here we describe an icy mineralogy package (IMP) consisting of a miniaturised XRD/XRF instrument designed primarily with Titan (and the TandEM proposal [1]) in mind; however, the instrument is not predicated upon an *a priori* knowledge of surface mineralogy and consequently is applicable with little modification to any solar system body (rocky or icy). Further details of the scientific background is presented in ref. [2].

Instrument design: Two design concepts are currently under study, which differ in the complexity of the sample handling system, and the range of Bragg angles which may be observed. Both are focusing cameras, one (IMP senior) working in transmission, and the other (IMP junior) working in back-reflection. IMP jnr is intended for deployment on a static surface probe with no sample acquisition capability, collecting a single diffraction pattern through a window in the probe's underside. IMP snr is intended for deployment on a balloon with a sample collection arm able to deliver scoops of surface material to a rotating specimen stage. The latter may therefore be used to analyse many samples at geographically dispersed points.

In each case X-rays are generated by a radioisotope source, ^{55}Fe for IMP jnr and both ^{55}Fe and ^{241}Am for IMP snr, which have half-lives of 997±4 days and 432.2±0.7

years, respectively. The use of radioisotopes for XRD has been described previously [3-7]. From ^{55}Fe we intend to use the strongest X-ray line at 5.895 keV (λ = 2.103 Å) and from ^{241}Am the Lβ_1 line at 17.764 keV (λ = 0.699 Å): the collimated beam will be monochromated and focused by a synthetic multilayer optical element (a Göbel mirror). The advantage of using a secondary ^{55}Fe source is that X-rays of this wavelength will shift all Bragg peaks in the diffraction pattern to larger angles, allowing better resolution of substances with very large unit cells – i.e., Bragg peaks at low 2θ angles (clathrate hydrates, salt hydrates, and sulfuric acid hydrates). Longer wavelength X-rays will be more strongly absorbed along the ray path, but more strongly scattered by the sample than shorter wavelengths. Diffracted X-ray are to be detected using a curved silicon microstrip covering an angular 2θ range of $\sim$60°. The transmission geometry allows us to observe low-angle Bragg peaks which are not detectable in back-reflection. Using ^{55}Fe, the strong triplet from ice Ih at d-spacings of 3.46, 3.69, and 3.92Å occurs at Bragg angles of 31 - 36°; these peaks can just be resolved in back-reflection with a low-angle incident beam.

Combined XRF: X-ray fluorescence (excited by the radioisotope source) will provide accurate elemental abundances and constrain the identification of mineral species from the observed powder XRD data. Carbon, nitrogen and oxygen fluoresce at very low energies, but these emissions can be detected using a lithium drifted silicon detector - Si(Li) - with an ultrathin window.

Summary: The proposed IMPs will be able to identify any crystalline substances present on Titan's surface at $>$ 1 wt % levels, and quantify their relative abundance [8,9], as well as, in principle, estimate the abundance of any amorphous material. The focusing geometry maximises the flux and resolution obtainable from radioisotope sources and also has the advantage of illuminating a relatively large sample volume (compared to other mini-XRD designs); this improves the measured powder statistics. Most of the mass, and all of the power use is confined to the detector system (which is cooled passively by Titan's atmosphere) and data rates will be very small. The robustness of the technique renders it the method of choice for unambiguous determination of Titan's surface mineralogy.

References: [1] Coustenis, A., et al. (2008) paper submitted to *Astrophys. Instr. Methods*. [2] Fortes, A. D. et al. (2008) *LPSC 39, abstract #1183.* [3] Bugenis, C., et al. (1968) *Rev. Sci. Instr. 39, 1754.* [4] Gregory, J. C., & T. A. Parnell (1972) *IEEE Trans. Nucl. Sci. NS-19, 224-232.* [5] Lobov, S. I., et al. (1969) *Nature 222, 767.* [6] Preuss, L. E., et al. (1967) *J. Appl. Phys. 38, 3404.* [7] Toothacker, W. S., et al. (1967) *Nature 216, 255.* [8] Rietveld, H. (1969) *J. Appl. Cryst. 2, 65-71.* [9] Hill, R. J. & C. J. Howard (1987) *J. Appl. Cryst. 20, 467-474.*