PLUTO AND CHARON: THE NON-ICE SURFACE COMPONENT D. P Cruikshank[1], S. J. Clemett[2],W. M. Grundy[3], S. A. Stern[4], C. B. Olkin[4], R. P. Binzel[5], J. C. Cook[4], C. M. Dalle Ore[1,6], A. M. Earle[5], K. Smith-Ennico[1], D. E. Jennings[7], C. J. A. Howett[4], I. R. Linscott[8], A. W. Lunsford[7], A. H. Parker[4], J. Wm. Parker[4], S. Protopapa[9], D. C. Reuter[7], K. N. Singer[4], J. R. Spencer[4], C. C. C. Tsang[4], A. J. Verbiscer[10], H. A. Weaver[11], L. A. Young[4], C. K. Materese[12], S. A. Sandford[1], H. Imanaka[1,6], M. Nuevo[12], B. Schmitt[13], E. Quirico[13], S. Philippe[13], T. Hiroi[14], and the *New Horizons* COMPOSITION Team. [1]NASA Ames (Dale.P.Cruikshank@nasa.gov), [2]NASA Johnson, [3]Lowell Observatory, [4]Southwest Research Inst., [5]MIT, [6]SETI Inst., [7]NASA Goddard, [8]Stanford U., [9]U. Maryland, [10]U. Virginia, [11]Applied Phys. Lab., [12]NASA Ames and BAER Inst. [13]IPAG France, [14]Brown U.

Introduction: The surface of Pluto displays an array of colors ranging from yellow to red to brown, while the surface of Charon is largely gray with a north polar zone of red color similar to regions on Pluto. Pluto's surface shows layers of intensely colored material in tilted blocks and fractured geographical units, suggesting episodes of formation or deposition of that material interspersed with episodes of emplacement of material having little or no color. The ices identified on the surfaces of these two bodies (N_2, CH_4, CO, C_2H_6, H_2O on Pluto, and H_2O and NH_3 on Charon)[1,2] are colorless, as are nearly all ices in a powdery state. It thus remains to identify the composition and mechanism(s) of formation of the non-ice colored material. Rocky material is an unlikely candidate because the low mean density of Pluto (ρ= 1.860 g cm^{-3}) and Charon (ρ= 1.702 g cm^{-3})[3] and the expectation that they are differentiated bodies indicate that their surfaces and mantles are ice. A consensus has emerged around the concept of *in situ* formation of a macromolecular carbonaceous material generated by energetic processing of the ices on the surface, with CH_4 and N_2 being the principal components with contributions from CO, to the chemistry on Pluto. The incident energy can be solar ultraviolet light, galactic cosmic rays, energetic components of the solar wind, or various combinations, depending on the characteristics of Pluto's local space environment and the extent of its atmosphere over time. The chemistry of the surface of Charon and the polar distribution of its red material is less clear.

Macromolecular carbonaceous solids relevant to Solar System bodies have been produced in the laboratory for many years using CH_4, H_2O, and other simple molecular starting recipes (usually in the gas phase) and irradiated by UV and charged particles[4-7]. In addition to their use in modeling planetary atmospheric aerosols, these materials, termed tholins, have proven valuable in modeling the spectra of the solid icy surfaces of numerous Solar System bodies[8,9]. They generally display a range of color closely similar to those on Pluto. Tholins also result from the irradiation of the same starting components in the ice phase, and are similarly colored.

Chemical Analysis: Laboratory experiments producing refractory tholins particularly relevant to Pluto explored the chemistry of both UV and low-energy electron bombardment of a mix of Pluto ices (N_2:CH_4:CO = 100:1:1)[10,11]. The initial analyses of these Pluto ice tholins (at room temperature) by GCMS, IR spectroscopy, and XANES showed the presence of urea, carboxylic acids, aldehydes, amines, alcohols and ketones, plus some nitriles and numerous high-mass (Da>100) molecular complexes. There is a greater degree of N incorporation in the solids from the electron irradiated tholin (N/C ~ 0.9) than in the UV tholin (N/C ~ 0.5). Here we report on additional analysis of the electron tholin by the two-step laser desorption technique[12].

UV fluorescence images of the tholin indicate a large aromatic component (Fig. 1), also demonstrated in the mass spectrum obtained by ionization by the 266 nm laser of the desorbed plume (Fig. 2).

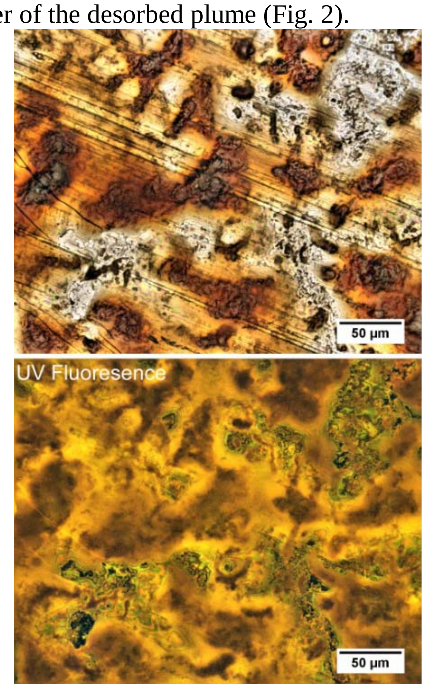

Fig. 1. Top frame: electron microscope image of the Pluto ice tholin deposited on Al foil, and in the bottom frame a UV fluorescence image at the same scale.

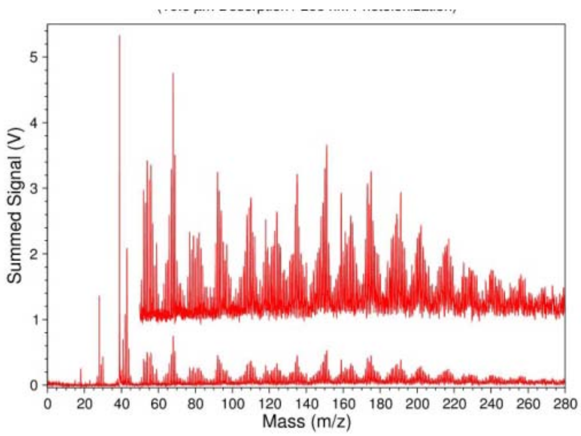

Fig. 2. Mass spectrum of Pluto ice tholin with 266 nm ionization.

Fig. 3 shows the mass spectrum from ionization of the plume by the 118 nm laser, and shows the presence of numerous small molecules, including, significantly, NH_3. NH_3, radicals, and possibly biradicals are trapped in the complex network of small aromatic units that are linked by aliphatic bridging units of several C atoms, resulting in a high degree of cross linking, analogous to the insoluble inorganic matter (IOM) in carbonaceous meteorites[13].

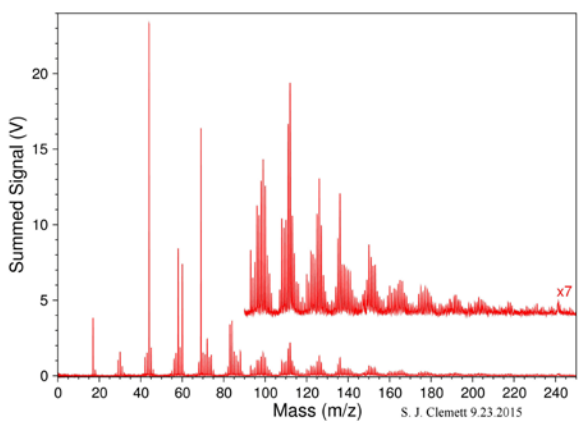

Fig. 3. Mass spectrum of Pluto ice tholin with 118 nm laser ionization.

The spectral reflectance of Pluto ice tholin was measured at RELAB (Brown Univ.); the normalized reflectance is shown in Fig. 4, and demonstrates the strong rise in reflectance toward longer wavelengths in the extended region (300-1000 nm). While the red slope of the pure tholin does not match exactly the color curves of various regions on Pluto measured from Earth-based telescopes[14], the material native to Pluto is not expected to be identical to that made under restrictive conditions in the lab.

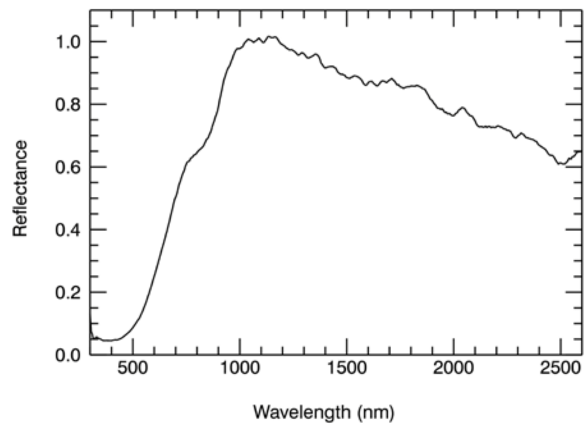

Fig. 4. Normalized reflectance spectrum of Pluto ice tholin measured at RELAB.

Ultimately, the complex refractive indices of Pluto ice tholin will be measured to enable inclusion of this material in radiative transfer models of the spectra of Pluto and Charon. That work is in progress.

Conclusions: A complex organic residue produced in the lab by radiolysis of a mix of ices known to exist on Pluto exhibits colors similar to those found on Pluto and in a region of Charon, and thus represents a reasonable first approximation to the chemical composition of the non-ice component of those surfaces.

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