# PRESENCE OF NONMETHANE HYDROCARBONS ON PLUTO.

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**Introduction:** Edgeworth-Kuiper belt objects are supposed to be the remnants of icy planetesimals and Pluto is one of the largest objects among them. However, Pluto is an exceptional object not only in the size, but also in the surface composition with the very volatile ices, such as nitrogen, methane and carbon monoxide [1-3]. Recently a few observations tried to search other hydrocarbons in the *L* bands [4], whose absorption is much stronger compared with the overtones in the *J*, *H*, and *K* bands. However, it is difficult to make precise spectroscopic measurements in the *L* band because of the strong and variable telluric extinctions. Here we report a high-resolved Pluto's *L* band spectra successfully derived by Subaru Telescope.

**Observation:** The spectroscopic observation of Pluto was carried out on 2002 May 28 UT using infrared camera and spectrograph on the Subaru telescope with its AO system. The typical seeing size was 0".3-0".4 during the observation and the total integration time was 2600 s. A nearby G3 V star SAO141540 was observed as a spectroscopic standard. Pluto was observed within 1.5 hours before / after the standard star and the difference of air mass was smaller than 0.035 throughout observations. After the bad-pixel correction, sky subtraction and flat-fielding, we obtained the one-dimensional spectra of Pluto by using NOAO Image Reduction and Analysis Facility aperture extraction package. For details refer to Sasaki *et al*., 2005 [5].

**Results:** The spectrum of Pluto is shown in Fig.1 along with the previous data [4] and a synthetic spectra calculated by Hapke's bidirectional model [6]. Our observation show lower reflectance around 3.45 μm and additional absorptions around 3.1, 3.2, and 3.35 μm. In order to reproduce the features, we incorporated some nonmethane hydrocarbons (NMHCs) and diluted $CH_4$. In Figs.2 and 3, $CH_4$ is assumed to be diluted in the solid molecular nitrogen, because the large fraction of diluted $CH_4$ was observed [2]. Assuming their mass ratio to $CH_4$ as 10 %, we computed the model spectra shown in Fig.2.

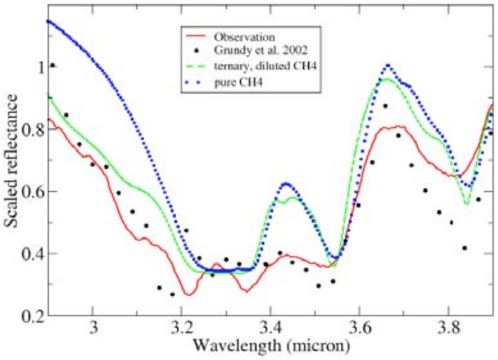

**Fig.1:** Reflectance spectrum of Pluto along with the previous low-resolution data [4] and synthetic spectra of intimate ternary mixture of $N_2$-$CH_4$-CO with the mass ratio 1:0.01:0.002. Our data was smoothed by a running average of 31 pixels, and all the data are normalized at 3.58 μm.

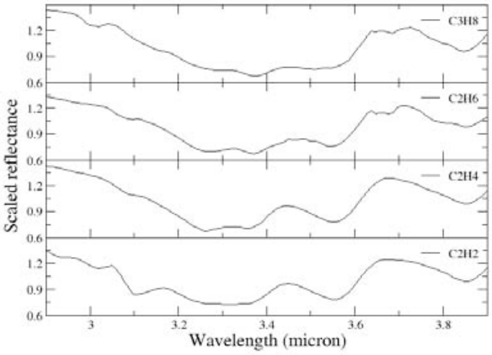

**Fig.2:** Modeled spectra including NMHCs as the forth component. The model parameters of the basic ternary mixture are the same as those in Fig.1.

The optical constants were measured by Quirico et al. [7]. Figure 2 indicate that $C_2H_4$ and $C_2H_6$ could be responsible for the absorptions around 3.2 μm and 3.35 μm. $C_2H_6$ also could reproduce the lower reflectance around 3.45 μm, while there was no clear absorption around 3.65 μm in the observed spectrum.

And $C_2H_2$ could reproduce the absorption around 3.1 μm. Therefore, we added $C_2H_6$ and $C_2H_2$ as new components in the model calculation. The resulting spectrum matches the observed spectrum quite well, as shown in Fig.3.

**Discussions:** In the previous studies, additional NMHCs have not been definitely identified in the *J*, *H*, or *K* bands. This discrepancy could be explained by a strong concentration of the NMHCs at the uppermost surface, which implies that they exist as a veneer. The veneer of NMHCs might be related to the lateral surface inhomogeneity of Pluto's surface [2, 8].

Krasnopolsky estimated that a 500-m thick $N_2$ layer has been lost from the surface of Pluto since the formation of the Pluto-Charon system [9]. Although $N_2$ could be the dominant form of nitrogen in the outer protoplanetary disk, it is unlikely that such pristine N2 survived the accretional heating and formed such a thick layer near the surface. It seems implausible that Pluto has a deep internal reservoir that can produce $N_2$ from more refractory nitrogen compounds and supply it to the surface along with $CH_4$ and CO.

Owen & Bar-Nun suggested that the likely maximum value for the initial $N_2$ / CO ratio cannot account for the currently observed $N_2$ dominance on Pluto [10]. Because the slightly different volatility of $N_2$ and CO led to efficient concentration of $N_2$ in the surface frost through sublimation-recondensation, the composition of surface frost could be generally different from the underlying reservoir layer [11]. Our obsrvation may provide some additional constraints on the models for atmosphere-surface interaction and / or the atmospheric escape.

$C_2H_2$ and $C_2H_6$ have been found in the comets of Oort-cloud comets [12], but detection of $C_2H_4$ has not reported to date. The $C_2H_6$ / $CH_4$ ratio estimated from Fig.3 is consistent not only with Oort-cloud comets but also with the value of the short-period comets [13] and the upper limit for interstellar materials [14]. Moreover, the $C_2H_2$ / $CH_4$ ratio approximately agrees with the values for Oort-cloud comets [9]. The observed 3.2 and 3.35 μm features could be ascribed to cometary $C_2H_6$, not $C_2H_4$, and $C_2H_2$ may be responsible for the absorption at 3.1 μm.

NMHCs could be secondary products generated from methane through photochemical reactions in Pluto's tenuous atmosphere and the subsequent precipitation to the surface [15]. And, we do not rule out the possibility that the observed features were associated with NMHCs produced by in-situ surface reactions induced by cosmic-ray irradiation to the original ternary mixture [16]. The relative mass ratio to the parent methane, derived from our observations, could be a key to understanding the gardening process on Pluto, such as the poorly known dust flux and vertical mixing timescale.

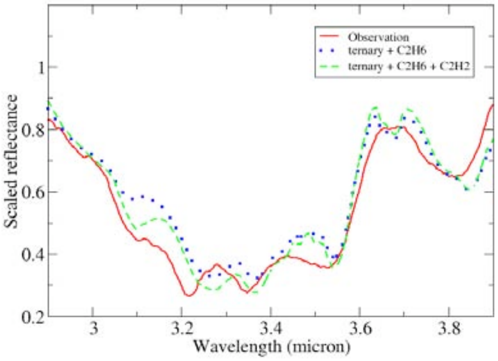

**Fig.3:** Reflectance spectrum of Pluto with the modeled spectra. The ternary mixture are the same as that in Fig.1. Mass ratio of $C_2H_2 : C_2H_6 : CH_4$ is 1 : 1 : 10.

**References:** [1] Cruikshank, D. P. *et al.* (1997) in *Pluto and Charon,* 221. [2] Doute, S. *et al.* (1999) *Icarus, 142,* 421. [3] Nakamra, R. *et al.* (2000) *PASJ,52,* 551. [4] Grundy, W. M. *et al.* (2002) *AJ, 124,* 2273. [5] Sasaki, T. *et al.* (2005) *ApJ, 618,* L57. [6] Hapke, B. (1993) *Theory of Reflectance and Emittance Spectroscopy.* [7] Quirico, E. (1999) *Icarus, 139,* 159. [8] Young, E. F. *et al.* (2001) *AJ, 121,* 552. [9] Krasnopolsky, V. A. (1999) *JGR, 104,* 5955. [10] Owen, T. and Bar-Nun, A. (1996) *Icarus, 116,* 215. [11] Young, L. A. *et al.* (2001) *Icarus, 153,* 148. [12] Mumma, M. J. *et al.* (1996) *Science, 272,* 1310. [13] Mumma, M. J. *et al.* (2000) *ApJ, 531,* L155. [14] Boudin, N. *et al.* (1998) *A&A, 331,* 749. [15] Krasnopolsky, V. A. and Cruikshank, D. P. (1999) *JGR, 104,* 21979. [16] Moore, M. H. and Hudson, R. L. (2003) *Icarus, 161,* 486.