THE LONG-TERM EVOLUTION OF PLUTO'S ATMOSPHERE AND ITS EFFECT ON CHARON'S SURFACE THOLIN FORMATION H. S. Shi[1], I. L. Lai[2] and W. H. Ip[1,3], [1]Institute of Space Science, National Central University, Taiwan (yagaga82@gmail.com), [2]Space Research and Planetary Sciences, University of Bern, Switzerland, [3]Institute of Astronomy, National Central University, Taiwan

Introduction: After the New Horizons' flyby observation of the Pluto-Charon system in July 2015, we have a better understanding of these far away objects.[1] Sputnik Planitia (SP) is one of the most important discoveries of this mission, which is located at the northern mid-latitude hemisphere in the antipodal position to Charon and contains a large quantity of ice.

In this work, we use a coupled treatment to compute the long-term evolution of Pluto's surface temperature and pressure. The time variation of the orbital parameters of Pluto was obtained by N-body integration and modified from the prior numerical results. Based on the energy balance equation, we build a Pluto thermal model with Clausius-Clapeyron equation and thermal conduction when Pluto revolves around the sun in its variable eccentric orbit with special attention to the sublimation process of the nitrogen ice stored in the SP over the past three million years. Furthermore, we also applied DSMC (Direct Simulation Monte Carlo) method to explore the corresponding escape dynamics of Charon's tholin-like materials which were seasonally transported from Pluto.

Pluto's Orbital Cycles Model: In order to build the long-term thermal model with the orbital evolution of Pluto, we computed the Pluto's orbital parameters which were modified from [2] to fit the current observational data. The variation of Pluto's orbital parameters in the past three million years [3] is shown in Figure 1. (a).

On the other hand, Figure 1 (b) illustrates the three unit components, x, y, z which represent the vector of Pluto's rotation axis. The reference frame is centered at Pluto's spring equinox with the x-axis pointing towards the sun and the z-axis being vertical to the orbital plane.

Thermal Model of Nitrogen Ice on Pluto: According to the New Horizons observations, Pluto's atmosphere is likely controlled by the seasonal sublimation of the SP's ice. [4] The Pluto thermal model is derived by a study of Leighton and Murray [5], which first described the sublimation of ice plays an important role in the thermal process of SP. The energy balance equation of surface can be written as: $F_0 (1-A_v)\, r_H^{-2} \cos\theta = \epsilon\sigma T^4 + Z(\mathrm{T})L(\mathrm{T}) + \kappa(\partial T/\partial z)$

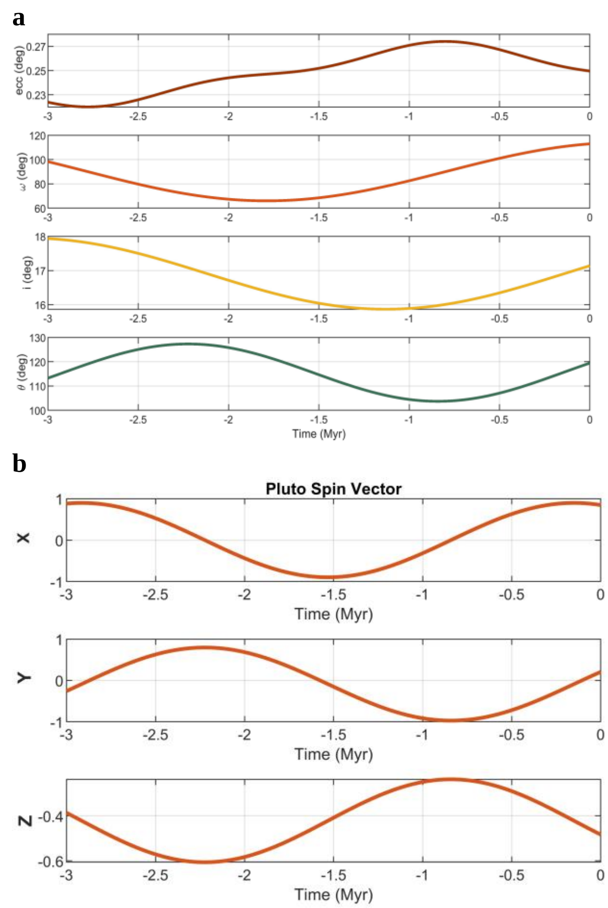

Figure 1. *(a)The variation of Pluto's orbital parameters over the past three million years. From the top to the bottom: eccentricity, argument of perihelion, inclination to the solar system and obliquity. (b) The x, y, z components of Pluto's spin vector in the past three million years based on the analysis of Dobrovolskis' work [2]*

The first term on the right hand-side represents the solar insolation on the surface of SP. Where F_0 is the solar constant, A_v is the visual geometric albedo, r_H is the heliocentric distance and θ is solar zenith angle. Figure 2 shows the solar flux which Pluto's and SP's surface receive in current epoch and Figure 3 shows the mean variation of SP's solar flux in the past three million years. The right-hand side represent the energy loss and conduction on SP. The first term $\epsilon\sigma T^4$ is the black body emission term. The second term describes the latent heat of sublimation by nitrogen ice on SP. The vapor pressure of nitrogen is controlled by the average solar insolation and infrared emissivity. It can be derived by [6] : $log_{10}P$ = 17.5901− 435.37/T − 3.88851$log_{10}T$ + 0.0063423T , where P is in pa and T is in Kelvin. The surface pressure of Pluto is very close to being in the vapor-pressure equilibrium of nitrogen gas, so the heat change of the nitrogen phase transition is zero in this model. [7] The last term is the thermal conduction which can be derived from the 1-D thermal conduction equation $\rho c(\partial T/\partial t)=\kappa\ (\partial^2 T/\partial z^2)$ with κ for thermal conductivity, ρ for density ,and c for specific heat capacity. Thermal inertia, I, is the key parameter to control the thermal conduction with unit $Jm^2K^{-1}s^{-1/2}$: $I = \sqrt{\rho c \kappa}$.

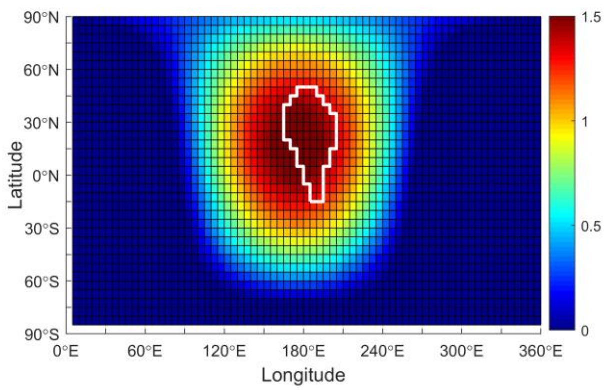

Figure 2. *The solar flux distribution map of Pluto at Sputnik Planitia noon in current epoch.(Units: W/m²)*

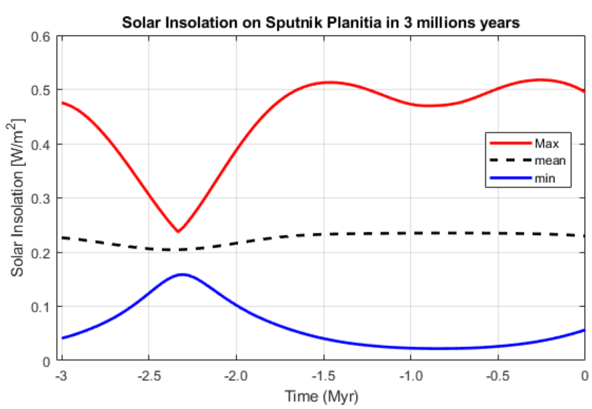

Figure 3. *The mean solar flux of SP in each epoch over the past three million years*

DSMC in Pluto-Charon System: Because of the large variation of Pluto's orbit, the seasonal influence of exobase will be significant. By using a DSMC calculation, we can calculate the gas transport between Pluto and Charon. Figure 4 shows the Jean's escape on a exobase of 2750 km from the center of Pluto. The motion of gas particle is by the gravitational force of Pluto and Charon.

Figure 5. shows the number density distribution of escaping CH_4 molecules on the rotational frame of Pluto-Charon system. We assume an escape rate of 5x10[25] molecules/s. The collisions between gas molecules only occur near the exobase of Pluto. Therefore, the gas molecules travel as a vortex-like stream line on the rotational frame. Due to the gravitational effect, there is a higher density region on the trailing side of Charon. The DSMC result also shows 3.6% of escaping CH_4 molecules will impact with the surface of Charon.

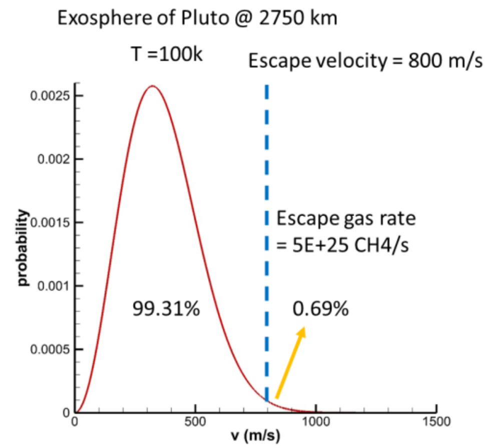

Figure 4. *An example of Jean's escape on the upper atmosphere of Pluto.*

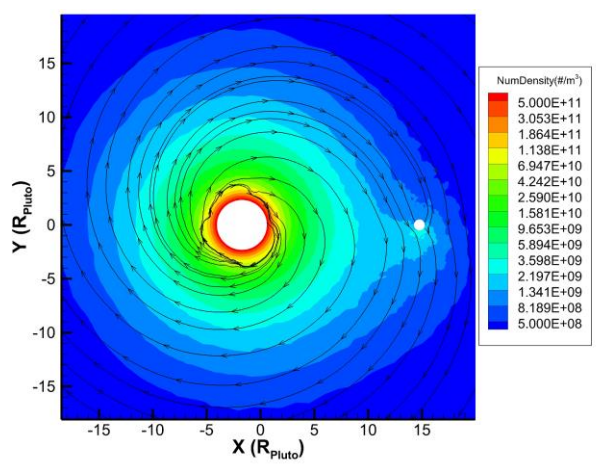

Figure 5. *CH_4 gas distribution and flow line on XY-plane with an exobase of 2750.*

References: [1] Stern, S. A. et al. (2015) *Science, 350* (6258) [2] Dobrovolskis A. R. et al., (1997) *Pluto and Charon*, 159-190 [3] Stern, S. A. et al. (2017) *Icarus, 287*, 47–53 [4] Gladstone, G. R. et al. (2016) *Science, 351* (6279) [5] Leighton R. B. and B.C. Murray (1966) *Science, 153* (3732) [6] Huebner, W. F. et al. (2006) *ISSI Scientific Reports SR-004* [7] Young, L. A. (2012) *Icarus, 221*, 80-88