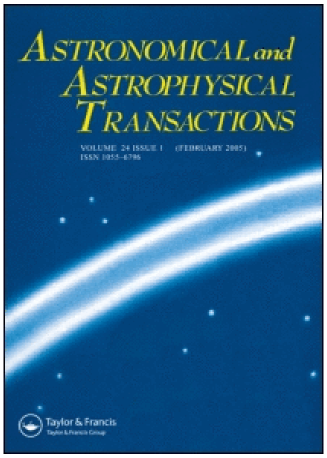

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TRITON SURFACE EVOLUTION

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Recent physical data of the Triton surface characteristics are given, with particular reference being made to the factors determining the mechanisms of that satellite's surface evolution. It is suggested that the photolysis, caused in Triton's ice surface by short-wave Solar radiation, should be considered as the basic mechanism responsible for the evolution of the surface of the satellite. Photodissociation of the $CH_4 + h\nu \rightarrow CH_3 + H$-type is discussed. Ethane C_2H_6 is shown to be the basic substance resulting from the above mentioned photodissociation and subsequent reaction involving CH_3 molecules. The time required for full photodestruction of CH_4 ice on Triton surface has been calculated, as well as the surface temperature of the satellite. Some other issues are touched upon.

Keywords: Solar system; Planets; Triton; Surface evolution

Triton, Neptune's satellite, is one of the most interesting bodies of the Solar system. Its diameter is known to be $D \approx 2700$ km (Hamilton, 1997). Triton appears to have quite a thin nitrogen atmosphere. The atmospheric pressure at its surface temperature is $T = 38.6$ K. The mean density of the matter is $\rho \approx 2.066\,\mathrm{g\,cm^{-3}}$. According to the data provided by Voyager-2, the surface of Triton revealed geyser – like eruptions emitting gaseous nitrogen and dark particles.

It was also shown (Burns, 1990, and others) that CH_4 ice is one of the prevailing substances at Triton's surface. Besides this, it contained other frozen compounds, such as carbon monoxide, carbon dioxide, water, ammonium and others.

There is, however, another important problem, namely, a problem of the physics of the Triton surface evolution. This process is sure to depend on a number of external and internal factors, such as (1) the degree of Triton's geological activity, (2) the chemical composition of its surface, (3) the thickness and chemical composition of its atmosphere, and (4) the distance between Triton and the Sun.

The geysers in Triton's surface evidence for a high degree of geological activity of the satellite. This assumption is supported by periodic changes (reddening) of the surface colour (Buratti *et al.*, 1998). On the other hand, observations made by different scientists definitely proved the presence of methane ice at Triton's surface, which means that there are hardly any global geological transformations or cataclysms, including visible surface warming, occurring on Triton. A comparatively thin atmosphere but with scarce clouds is transparent for the optic range of the Solar electromagnetic radiation. Besides, the Solar UV radiation in

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the range of 1450–3800 Å may also easily reach Triton's surface, and this is naturally due to the inability of Triton's atmospheric nitrogen to absorb the UV radiation of this particular range. The long distance between the Sun and Triton ($r \approx 30$ a.u.) certainly affects and reduces the influence of the Solar radiation upon Triton's surface, but, on the other hand, it was proved (Grinberg, 1984) that photodissociation of one CH_4 molecule requires an UV photon of an energy slightly over $E_{hv} > 4.51$ Ev. Therefore, we supposed that one of the most probable mechanisms of Triton surface evolution is the surface photolysis occurring under the influence of the Solar electromagnetic radiation.

Let us now calculate the mean temperature of Triton's surface using the equation offered by Moroz (1967):

$$\theta_m^4 = \frac{1}{4}\frac{1-A}{\delta}\frac{Q}{r_m^2}, \tag{1}$$

where θ is the surface mean temperature, A is the visual albedo ($A = 0.21$ for Triton), δ is the Stefan–Boltzman constant, Q is the Solar constant and r_m is the average distance between Triton and the Sun. We calculated $\theta_m = 48.6$ K. A difference between our calculated mean temperature value for Triton's surface and that found by Hamilton seems to be due to the fact that we used an average value for the Triton to the Sun distance. But such averaging is quite reasonable if we take into consideration Triton's orbital motion in the Neptune–Triton system.

Photoprocessing of Triton's surface will consist in the photodissociation of the ice molecules exposed to the Solar short-wave radiation. Considering the chemical composition of the satellite's surface, we propose the following photochemical reaction as the most probable one:

$$CH_4 + hv \rightarrow CH_3 + H \tag{I}$$

This reaction produces a free radical CH_3 and atmospheric hydrogen. Having a short half-period of life (0.002 sec), the free radical CH_3 will unavoidably react with other compounds, which may result in the formation of C_2H_6, CH_3CN, CH_3OH, CH_4NH_2, CH_3CCH on Triton's surface. However, the high extent of the frozen methane spreading over Triton's surface suggests an idea, although a cautious one, that C_2H_6 seems to prevail at the surface.

Let us now try to evaluate the energetic exposition of Triton's surface, implying here a full spectral range of the Solar electromagnetic radiation (ignoring the energy of charged particles of the Solar wind). The Solar radiation power is

$$P_\Theta = \sigma\varepsilon A T^4, \tag{2}$$

where σ is Stefan–Boltzman's constant, ε is the radiating ability of the grey body (0.9 in this work), A is the radiating surface area ($A_0/2$ in this work), and T is the temperature of the radiating body (6000 K in this work). Now, transferring from the power to energy $W_\Theta = P_\Theta t$ (where t is the time) and considering the Sun-to-Triton distance, we obtain

$$E = \frac{(W_\Theta/S)}{r^2}, \tag{3}$$

where S is Triton's surface area and r is the heliocentric distance of the satellite. By making calculations for $S/2$ we obtain $E = 0.16 \times 10^8\,\mathrm{j\,m^{-2}}$ or $0.1 \times 10^{27}\,\mathrm{Ev\,m^{-2}}$.

Keeping in mind that it is basically the UV photons of the Solar radiation that participate in the CH_4 dissociation process and considering the absorption nature of methane, the amount of the Solar energy ensuring photolysis of Triton's surface can be evaluated as $E_1 \leq 4 \times 10^{29}\,\mathrm{EV\,m^{-2}}$.

It was proposed (Quiri *et al.*, 1999) that CH_4 is a hard solution in an ice N_2 matrix. Meanwhile Bonn *et al.*, (1994) using laboratory experiments, supposed that the relative content of frozen CH_4/N_2 in the surface is 1.3×10^{-3}. If these assumptions are fine, then, transferring to the measures of length and ignoring the latitude–longitudinal distribution of the ice massifs on Triton, we can conclude that there is 1.33 mm of CH_4 ice per each meter of the N_2 ice layer.

Therefore, we can evaluate the time required for photodissociation CH_4 ice, taking into account the structure and mean atom-to-atom distance in a CH_4 molecule which is 1.09 Å between the C and H atoms. With the radius of Triton as 1350 km, we calculated the total amount of CH_4 molecules covering the surface in the form of a 4 mm thick layer. We got the number $n = 3.2 \times 10^{40}$.

Let us now define the principle of photoprocessing of Triton's surface in order to calculate the time of full photo dissociation of the CH_4 layer. This principle can be formally defined as a step-by-step, layer-by-layer photodestruction of CH_4 ice by short-wave Solar radiation, at a rate of one CH_4 molecule layer per second. Assuming the thickness of one layer equal to 3.3 Å, and using previously calculated energetic exposition of Triton surface and other related values, we divide the total number of CH_4-molecule layers into the diurnal number of destroyed layers, to derive minimal time of full photodissociation of the 4 mm thick CH_4 ice layer. This time, T_F is equal to 138.9 Earth days. The products of reaction (I) will immediately form new chemical compounds, like ethane, in the upper layers. The energy of the Solar radiation will be more intensively used for photoprocessing of the new by formed chemical compounds. Triton's synchronous rotation will introduce certain corrections into the value of T_F. Therefore, the final estimate of T_F can be made as $T_F = 180$ Earth's days. As the half-period of CH_3 life is short, it can be stated with a high degree of confidence, that within 180–200 Earth's days, a layer of C_2H_6 must form on Triton's surface.

But this is still to be proved by observations, though, as we know, the presence of CH_4 ice is regularly observed on the surface.

This is, therefore, evidence of some complicated multi-stage processes occurring on Triton's surface and comprising photodissociation of CH_4 ice + C_2H_6 ice formation + CH_4 ice reproduction. This latter component of the process provides for the permanent presence of CH_4 ice on Triton's surface. The CH_4 ice can be reproduced as a result of joining of carbon and hydrogen atoms and subsequent condensation of new CH_4 molecules on Triton's surface. The carbon atoms may be provided by the dark particles from the geyser-like eruptions, the free nitrogen atoms and subsequent condensation of new CH_4 molecules on Triton's surface. The carbon atoms may be provided by the dark particles from the geyser-like eruptions.

The free nitrogen atoms can be produced by the (I) type photochemical reactions. It should be noted here that two elementary (I) – type photochemical reactions and subsequent formation of C_2H_6 can produce only two free hydrogen atoms, while each dark particle ejected into Triton's atmosphere can produce thousands of carbon atoms. This may cause a certain delay in the CH_4 reproduction. The above described multi-stage process will actually appear as cyclic, with Triton's surface being covered alternately with ethane (C_2H_6) and methane (CH_4). This will, in turn, cause changes in the spectral characteristics of this satellite cyclic change of the surface color (darkening), temperature, albedo, etc. Thus, for instance, the temperature may size by 1.4 K.

We have given a very generalized report, a kind of scheme, of Triton's surface photoprocessing. The real physical phenomena, the surface evolution, is much more complicated and diverse, particularly considering the fact that the C_2H_6 photodissociation products contribute noticeably to the cyclic changes of the surface physiochemical characteristics. It is worth noting that the exposure of unirradiated CH_4 ice on the surface will occur owing to (a) geological mechanisms, (b) atmospheric erosion, and (c) impacts of meteorites. We have not discussed the role of frozen nitrogen in the process of evolution of Triton's surface. Nevertheless, the considerable amounts of the CH_4 ice and its visible photoprocessing with short-wave Solar radiation allows us to hope that the suggestions we have made are quite justified. Short-term cyclic changes on Triton's surface may be, to our mind, a part of a whole century-old process of evolution of the satellite's surface.

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