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## SEASONAL CHANGES ON PLUTO

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**Summary.** Due to the elongated orbit, Pluto's surface receives 2.8 times more heat at perihelion than at aphelion. This causes strong changes in its atmosphere and surface. It was previously believed that when Pluto is at aphelion, the entire atmosphere freezes and falls to the surface. However, refinements to the initial models suggest that Pluto has a noticeable atmosphere throughout the year. The last passage of the perihelion points by Pluto took place on September 5, 1989. And practically before this date, 12/16/1987, the moment of equinox came for Pluto. And now this dwarf planet is moving away from the Sun. The presence of a significant inclination of its axis of rotation to the plane of its orbit (over 122°) indicates very long polar nights and days for each of the hemispheres; they last almost 124 Earth years. When this dwarf planet passed the aphelion point of its orbit in 1865, a significant amount of gases were in a frozen state in both the southern and northern hemispheres. After this date, Pluto began to return to the Sun through the Southern Hemisphere. The frozen components of volatile chemical components then began to heat up, evaporate and migrate to the warmer Northern Hemisphere at that time. A significant part of them by 1900 had "moved" from the southern to the Northern Hemisphere. After the next equinox on December 16, 1987, the Southern Hemisphere began to deviate from the Sun. Its surface, which had been depleted of volatile ices by then, had already become quite well heated. Therefore, those gases that began to evaporate intensively from the Northern Hemisphere would not be able to quickly condense in the Southern Hemisphere. For this reason, newly formed gases began to replenish the part of the atmosphere illuminated by the Sun. This led to an increase in its pressure. Thus, due to seasonal changes in surface illumination, ice from volatile components will migrate across the planet. These components will evaporate in some places and condense in others. Seasonal variations in the thickness of their layer reach one meter. This should lead to significant changes in the color and brightness of Pluto. It is believed that by 2050 the Southern Hemisphere will be able to cool down so much that significant condensation of gas components will become possible. This will lead to the beginning of their migration from the Northern Hemisphere to the cold southern one. This situation will occur until the next equinox near the aphelion point in approximately 2113. Estimates show that seasonal changes in atmospheric pressure in such a model can reach up to 4 times. According to estimates based on data from the New Horizons spacecraft, Pluto's atmosphere will dissipate into space at rates per second of  $1 \times 10^{23}$  molecules for



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*nitrogen and  $5 \times 10^{25}$  molecules for methane. These values correspond to the loss of a layer several centimeters thick for nitrogen ice and a layer several tens of meters thick for methane ice over the entire time since the formation of planetary bodies in the Solar System. Those molecules that have enough speed to overcome Pluto's gravitational attraction escape into space and must be ionized there by solar ultraviolet radiation. When the solar wind collides with the resulting ions, an elongated tail of more than 100,000 km is created behind Pluto.*

Due to the elongated orbit, Pluto receives 2.8 times more heat at perihelion than at aphelion [4, 23]. This should cause strong changes in its atmosphere [3, 6-8, 24] (Fig. 1). Previously, it was believed that at aphelion the entire atmosphere should freeze and precipitate as ice on the surface layer. This was indicated by the significant dependence of the sublimation pressure of all its components on temperature. However, refinement of the initial models suggests that a noticeable atmosphere should persist on Pluto throughout the year [9].



**Fig. 1. The part of the image from space probe "New Horizons": Sunlight scattering through the Pluto' atmosphere, and it has blue color ([https://www.reddit.com/r/spaceporn/comments/oksi29/6\\_years\\_1\\_day\\_ago\\_new\\_horizons\\_flew\\_by\\_pluto/#lightbox](https://www.reddit.com/r/spaceporn/comments/oksi29/6_years_1_day_ago_new_horizons_flew_by_pluto/#lightbox)).**

Pluto's last perihelion passage occurred on September 5, 1989 [22]. And now this dwarf planet [16, 17] has begun to move away from the Sun. Therefore, the illumination of its surface has begun to decrease. It is clear that the significant, more than  $122^\circ$  inclination of its rotation axis to the orbital plane, significantly complicates the resulting picture. After all, such a large inclination indicates that very long polar nights and days last on a significant part of Pluto's surface.

According to the data obtained, almost before the moment of perihelion passage – December 16, 1987 – the moment of equinox came for Pluto [2]. It was at this moment that its north pole began to emerge from the polar night, which lasted about 124 Earth years.

Based on the existing observational data, one of the models of seasonal changes in Pluto's atmosphere was built [14, 15, 19-21]. When passing the aphelion

point of the orbit in 1865, a significant number of gases was in a frozen state in both the southern and northern hemispheres. Shortly before this moment, the moment of the next equinox came on Pluto. And after that, Pluto began to return to the Sun through the southern hemisphere. The frozen components of volatile chemical components began to heat up, evaporate and gradually migrate to the warmer [25] at that time northern hemisphere. Calculations showed that by 1900 a significant part of them had "moved" from the southern to the northern hemisphere.

After the moment of the next equinox (16.12.1987), the southern hemisphere began to deviate from the Sun. However, its surface, depleted by this time of volatile ices, was already quite well warmed up. And provided with non-volatile water ice, significant thermal inertia still does not allow it to cool down quickly. Therefore, those gases that began to evaporate intensively from the northern hemisphere will not be able to condense relatively quickly in the southern hemisphere. And the newly formed gas components will replenish the atmosphere illuminated by the Sun. This effect leads to an increase in its pressure.

Thus, due to seasonal changes in surface illumination, ice [26] from volatile components will migrate around the planet [10, 11, 18, 28, 29]; these ices will evaporate in some regions and condense in others. According to some estimates, seasonal variations in the thickness of their layer reach a value of about one meter [9, 27]. This fact should lead to noticeable changes in the color and brightness (Fig. 2) of Pluto [5].



Fig. 2. **Image of Pluto according to the data of the space probe "New Horizons"** (<https://newatlas.com/new-horizons-xray-red-charon/45437/>)

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It is believed that in 2035-2050 the surface in the southern hemisphere will be able to cool down so much that significant condensation of gas components will become possible. This will lead to the beginning of their migration to the cold south from the northern hemisphere, where at that moment the polar day will prevail. This situation will occur until the next equinox near the aphelion point in approximately 2113. However, the northern hemisphere will never be able to completely get rid of volatile ices. After all, as a result of their evaporation from the warmer part of the surface of Pluto, a small atmosphere will be able to persist even near the aphelion point. Estimates show that in such a model, seasonal changes in atmospheric pressure values can reach up to 4 times. The minimum pressure values should have been in the 1970-1980s; and Pluto should reach its maximum atmospheric pressure around 2030. During this time, the temperature will vary within a few degrees [9].

According to estimates based on the results of the “New Horizons” spacecraft, Pluto's atmosphere will dissipate into space at rates per second for nitrogen of  $1 \times 10^{23}$  molecules and for methane of  $5 \times 10^{25}$  molecules. These values correspond to the loss of a layer several centimeters thick for nitrogen ice and a layer several tens of meters thick for methane ice over the entire time since the formation of planetary bodies in the Solar System [4].

Before the measurements made by the “New Horizons” spacecraft, the temperature values in the upper layer of Pluto's atmosphere were considered somewhat higher. These values gave a fairly high rate of dissipation of atmospheric components [13]. The rates of its loss were previously estimated at 4-5 orders of magnitude higher; and they reached up to 50-500 kg of nitrogen per second. At such speeds, a layer of hundreds or even thousands of meters thick could evaporate from Pluto's surface layer during the existence of the planetary system [12]. Under such conditions, the relative rate of atmospheric loss from Pluto would be greater than for all large planets [13]. Pluto has nothing to replenish its nitrogen reserves: calculations have shown that the fall of meteoritic bodies onto its surface is insufficient for this [12]. Those molecules that have enough speed to overcome Pluto's gravitational attraction escape into outer space, and there must be ionized under the action of solar ultraviolet. When the solar wind collides with the resulting ions, it will slow down, deflect slightly, pick up atmospheric ions and carry them with it, forming an elongated tail behind Pluto. Therefore, behind Pluto, a kind of cavity with a length of more than 100 thousand km remains in the solar wind stream; however, it is filled with relatively cold nitrogen ions. This was detected using the solar wind particle parameter meter installed on the New Horizons spacecraft during its flight through this cavity. The region of interaction of Pluto's atmosphere with the solar wind on the sunward side is located at a distance of almost 6 Pluto radii (about 7 thousand km); and on the opposite side, the

interaction region exceeds 400 Pluto radii (over 500 thousand km). The obtained estimates belong to the zone in which the speed of the solar wind has slowed down by about 20% [1].

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