

Pluto and its satellites from the new horizons spacecraft



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CAROLINE MOORE

Abstract

The New Horizons spacecraft has provided the first close-up study of Pluto and its satellites. Much more analysis is required of the data but the early findings have revolutionised our understanding of the Pluto system.

Discoveries such as the complexity of Pluto's surface, the current geological activity, the atmospheric hazes, lower-than-predicted escape rate and the largest known glacier in the solar system were completely unexpected.

Pluto's moon Charon has surprised with its dark red polar cap and tectonic belt and data from the smaller moons supports the hypothesis that they were formed out of the remnants from the collision that formed the Pluto-Charon binary.

Introduction

Since its discovery in 1930, with a semi-major axis of 39.5 AU, Pluto has been considered an icy oddity. Beyond the realm of the gas giants, Pluto did not fit into any known solar system architecture until 1992 when the existence of the Kuiper Belt (30-50 AU from the Sun) was confirmed by the discovery of the first Kuiper Belt object (KBO). Now more than 1,000 KBOs have been identified, including five dwarf planets, and it is estimated that more than 100,000 objects larger than 100 km orbit the sun within the belt. It's believed that the Kuiper Belt contains leftover remnants from the beginning of the solar system and that sending the New Horizons mission to explore Pluto, its moons and other KBOs would provide valuable insights into the formation of the solar system.

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The fastest spacecraft ever launched, New Horizons started its mission on 19 January 2006 and flew past Jupiter in February 2007 for a gravity boost which reduced journey time to Pluto by four years. It conducted a six-month-long reconnaissance flyby study of Pluto and its moons in summer 2015, culminating with the closest approach to Pluto on 14 July 2015. As well as the first mission to an ice dwarf planet, New Horizons is also the first mission since Voyager in the 1970s to an unexplored planet.

The official NASA science goals for the Pluto-system exploration element of the New Horizons mission were prioritised into three categories: 'required', 'important' and 'desired'. A key goal was mapping the surfaces of Pluto and Charon with an average resolution of one kilometre (the best the Hubble Space Telescope can do is a 500km resolution) and mapping the surface composition of the various geological regions of the two bodies. Another key goal was determining the composition, structure and escape rate of Pluto's atmosphere. The lower priority goals include measurement of surface temperature and a search for additional satellites or rings around Pluto. The full list of science goals appears in Appendix 1.

The seven instruments on New Horizons were selected to meet these science goals. They are the most capable suite of instruments ever launched on a first reconnaissance mission to an unexplored planet (now dwarf-planet). They include an imaging spectrometer to probe atmospheric composition and planet structure; a visible and infrared camera to obtain high-resolution colour maps and surface composition maps; a long-range telescopic camera for high-resolution surface images; particle spectrometers to measure charged particles in and around Pluto's atmosphere; a detector to measure

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masses of space-dust particles; and two copies of a radio science experiment to examine atmospheric structure, surface thermal properties and planet mass. The seven instruments are listed in Appendix 2.

Although considerably more work needs to be done to analyse the data received from New Horizons it is now clear that all NASA's science objectives have been met. On 14 July 2016, the anniversary of the fly-by in 2015, NASA published Principal Investigator, Alan Stern's, "top ten discoveries" so far from the Pluto element of the mission. They range from the unexpected complexity of Pluto and its moons to the lower than predicted escape velocity, and the ten have been used as a focus for this dissertation.

The geology of Pluto

Prior to New Horizons, the best images of Pluto's surface were obtained from the Hubble Space Telescope. A colour map released in 2010 isn't sharp enough to show any features, such as craters or mountains, but does show a degree of complexity and variegation with white, dark-orange and charcoal-black terrain. However, the evidence revealed by New Horizons of current geological activity was completely unexpected and the variety of landscapes on Pluto is also much greater than expected. Hummocky cratered uplands, washboard terrain (expanses of parallel ridges and troughs), chaotic blocky mountains, cellular and non-cellular nitrogen ice plains, pitted hummocky nitrogen ice plains and rugged dark highlands all feature.

A prominent feature of the encounter hemisphere (EH) is Sputnik Planum (SP), an 870, 000km² oval-shaped plain on the left side of the heart-shaped Tombaugh Regio. SP is most likely composed of volatile ices – N₂, CO and <https://assignbuster.com/pluto-and-its-satellites-from-the-new-horizons-spacecraft/>

CH₄, - and is the largest known glacier in the solar system. Computer simulations have been produced to show that the surface of SP is covered with icy, churning, convective 'cells' which recycle their surfaces every 500,000 years. The modest internal heat of Pluto causes great blobs of solid nitrogen to rise up, then cool and sink back down. This helps explain why no impact craters have been observed on SP which has a crater retention age of no greater than 10 million years.

Pluto and its largest satellite Charon are both tidally locked which means that one hemisphere of Pluto is locked facing one hemisphere of Charon. They both spin and orbit in 6.4 days. Data from New Horizons shows that SP is almost exactly opposite Charon: the chance of this happening randomly is 5%. It is proposed that a subsurface ocean exists under SP and that over millions of years the planet has spun around, aligning the subsurface ocean and SP above it, almost exactly opposite the line connecting Pluto and Charon.

Along the west margin of SP there extends for hundreds of kilometres a discontinuous chain of mountains consisting of discrete angular blocks with apparently random orientations and sizes up to 40km across and 5km high (calculated by shadow length). Prior to New Horizons it was known that N₂, CO and CH₄ ices existed on the surface of Pluto, but once the images of these mountains were viewed it became clear that these ices could not support such high elevations and therefore water ices must be present. This has now been confirmed spectroscopically by New Horizons. Because water ice is buoyant with respect to N₂ and CO ice, some small blocks can be carried along by convective or advective motions and larger blocks can be

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undermined, shifted and rotated. Because of this it's possible, if the solid N₂/CO ice is sufficiently deep, that some of the smaller mountains observed may be floating within the plains, although the elevation of the largest mountains on the western margin of SP suggests that they are most likely "grounded" on the basement. It is not known why there are no mountainous terrains at the eastern edge of SP.

At a few locations at the eastern boundary of SP and the pitted uplands, smooth materials connect with SP along the floors of troughs 1.5 to 6km wide. High-phase imaging of the southernmost of these systems has shown clearly visible medial flow lines within the troughs, with the ice in the troughs sloping at an angle of 2-3 degrees over 50km. This implies glacial-like flow of the plains material into SP. At present it is unknown if the flowing ice carved the troughs.

Cthulhu Regio (CR) is a large dark area ranging from ~ 15°N to 20° S and bordering TR at 160°E and stretching almost halfway around the planet to 20°E . The region, comprised of a variety of geographical terrains, is covered by a thin dark mantle likely to be deposits of atmospheric Tholin. Tholin is a hydrocarbon formed by the action of sunlight on the methane in Pluto's atmosphere. The methane molecules link together in progressively longer chains and as they get heavier they form a haze which eventually settles to the surface.

Two broad quasicircular mounds, south of SP, might have an origin involving cryovolcanism. The smaller, Wright Mons, is 3-4km high and ~150km across, with a central depression at its summit at least 5km deep with a rim showing

concentric fabric. The larger, Piccard Mons, is similar but reaches ~6 km high and 225km across. If their origin is cryovolcanic it would entail materials much stronger than N₂, ice.

There are features on the EH which suggest prolonged tectonic activity. Numerous belts of aligned troughs and scarps, that can reach several hundred kilometres in length and several kilometres high, are often observed to cut across pre-existing landforms as well as branch into each other and these have been interpreted as extensional fractures in varying stages of degradation. The differing fault trends and states of degradation suggest several deformation episodes and prolonged tectonic activity. The great length of individual faults on Pluto, their scarp steepness and spectral evidence strongly suggest a thick water-ice lithosphere rather than a thin one or one made of any of Pluto's volatile ices.

Pluto displays a wide variety of crater morphologies and sizes vary from ~ 0.5 to 250km, not including any possible ancient basin underlying SP. Crater densities vary widely, from heavily cratered portions of CR to the apparently un-cratered SP. From the total cumulative crater size-frequency distribution it's been concluded that Pluto's surface, as a whole, dates back nearly to the time of the end of Late Heavy Bombardment (LHB)- perhaps 4 billion years ago. On the EH only the eastern portion of CR appears to approach the saturation crater densities expected of a terrain that has survived from the LHB itself. In contrast the water-ice mountains and the mounds mentioned previously are very young and no craters, down to a diameter of 2km, have been detected on SP. This implies a model crater retention age of no greater than 10 million years for SP and possibly much less.

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The atmosphere of Pluto

A major goal of the new Horizons mission was to explore and characterise the structure and composition of Pluto's atmosphere. Much more work is required to fully analyse the data obtained, but already understanding of Pluto's atmosphere has been revolutionised. Ground based stellar occultation had shown an atmosphere around Pluto composed primarily of N_2 , with trace amounts of CH_4 , CO and HCN , with complex surface interaction and an uncertain surface pressure of $\sim 3\text{--}60 \frac{1}{4}\text{bar}$ and a warm stratosphere at $\sim 100\text{K}$ above a much colder surface ($38\text{--}55\text{K}$).

The New Horizons trajectory allowed near simultaneous radio (using REX) and solar (using ALICE) occultations. The spacecraft passed almost diametrically behind Pluto, as viewed from Earth, with ingress near the centre of the anti-Charon hemisphere and egress near the centre of the Charon facing hemisphere. The atmospheric structure at altitudes 0 to 50km was retrieved from REX. A strong temperature inversion at both ingress and egress was found for altitudes below $\sim 20\text{km}$, consistent with measurements taken from Earth. However new evidence of horizontal variations in temperature was discovered from two notable differences between the REX profiles at entry and exit. First, the temperature inversion at entry is greater than that at exit; the derived mean vertical gradient in the lowest 10km of the inversion is $6.4 \pm 0.9 \text{ K km}^{-1}$ at entry but only $3.4 \pm 0.9 \text{ K km}^{-1}$ at exit. Second, the temperature inversion at entry ends abruptly at an altitude of $\sim 4\text{km}$, marking the top of a distinctive boundary layer. The temperature inversion at exit, however, appears to extend all the way to the surface, with no evidence for a boundary layer at this location. These differences in

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temperature structure cannot be accounted for by night-time radiative cooling or daytime solar heating within the atmosphere because the radiative constant of Pluto's atmosphere is approximately 700 Pluto days.

From REX data, surface pressure has been estimated at $11 \pm 1 \frac{1}{4}$ bar at entry and $10 \pm 1 \frac{1}{4}$ bar at exit. Analysis of stellar occultation data from 2012 and 2013 yielded essentially the same result indicating that the mass of Pluto's atmosphere has not changed significantly in recent years.

REX data shows that at occultation exit, temperature adjacent to the surface is 45 ± 3 K: this may be indicative of a surface material less volatile than N_2 , ice because a surface covered in N_2 , ice would have a temperature of 37.0 K to remain in vapour pressure equilibrium with the measured surface pressure of Pluto. At occultation entry, close to the region SP, the mean temperature in the lowest 4 km above the surface is 37 ± 3 K - close to the saturation temperature of N_2 ,. It is suggested that this layer of cold air could arise directly from sublimation of the N_2 , ices in SP. Calculations have shown that it would take approximately two years for downward heat conduction in the overlying temperature inversion to establish and an inversion that extends to the ground. So the observed boundary layer would have vanished on this timescale without the resupply of cold N_2 ,: further confirmation of SP as a sublimation source.

Models indicate that photochemistry in Pluto's upper atmosphere is similar to that of Titan and Triton. Methane is processed into heavier hydrocarbons by far-ultraviolet sunlight and also solar Lyman α photons. The solar occultation results show that the upper atmosphere is much colder than

previously thought. The observed N_2 opacity at high altitudes was lower than expected. The absorption of sunlight in the 57-64nm wavelength range by N_2 at high altitudes (850 to 1400km) constrains the temperature of the upper atmosphere to be approximately 70K. The mechanisms by which Pluto's upper atmosphere is being cooled are not yet understood.

The existence and complexity of Pluto's hazes, as detected by LORRI and MVIC, was unexpected. Extensive, optically thin hazes extend to altitudes of > 200 km. Distinct layers are present which vary with altitude but are contiguous for over 1000km. In the highest resolution images from MVIC about 20 haze layers are resolved. The haze is unexpectedly blue, suggesting a composition of very small particles thought to be tholin-like in composition from the scattering properties observed. The layers in the haze are possibly the result of internal gravity waves driven by sublimation forcing orographic forcing.

Pluto has a much lower than predicted escape rate. Prior to New Horizons the escape rate to space of N_2 was calculated to be in the region of 2.8×10^{23} molecules s^{-1} based on estimates of Pluto's surface pressure and radius, as well as CH_4 and CO mixing ratios. However these calculations did not take into account the cooling of the upper atmosphere. It's now calculated that the escape rate for N_2 is 1×10^{23} molecules s^{-1} . The escape rate calculated for CH_4 is 5×10^{23} molecules s^{-1} which is much closer to estimates prior to New Horizons and also 500 times faster than that of N_2 . If these rates for N_2 and CH_4 are stable over a single Pluto orbit and over the age of the solar system, the equivalent thickness of N_2 and CH_4 surface ice lost to space would be approx. 6cm and 28m respectively.
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This relatively small amount of N_2 loss is consistent with an undetected Charon atmosphere but appears to be inconsistent with the erosional features seen on Pluto's surface. This suggests that N_2 escapes in the past may have been occasionally higher. The loss of methane is a suggested origin for Charon's north polar red colour, involving "varnishing" of the winter poles over millions of years through cold-trapping and polymerisation of escaping hydrocarbons from Pluto.

Charon

The EH of Charon has two prominent features: a tectonic belt of ridges and canyons in the equatorial region and a dark reddish cap to the North pole.

The tectonic belt is more than 200km wide in places and consists of scarps, ridges and troughs which are almost parallel. There are two long, narrow, steep-sided depressions (chasmata). Serenity Chasma is > 50km wide and ~5km deep and Mandjet Chasma reaches ~7km deep. Both chasmata are similar to extensional rifts visible on several mid-sized icy satellites such as Saturn's Tethys. It's assumed that the tectonic belt is the result of substantial, aligned tectonic extension of Charon's icy crust. The fact that several large craters are visible on the chasmata implies that the extension is geologically old.

North of the tectonic belt there is rugged, cratered terrain. Mountains of 20km can be seen in the limb profiles. The crater density at large sizes on the northern terrain implies a surface age older than ~4 billion years. The Northern hemisphere is capped by dark reddish region named Mordor

Macula (MM), the extent of which does not correlate with any specific terrain
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boundary or geological feature. Layer This is an unusual feature because polar caps on other bodies tend to be bright, not dark, due to some kind of reflective ice or frost. Because the red-stained areas of Pluto look similar to MM it was originally thought that they might have similar origin. It's now known that Pluto's red-staining is due to atmospheric tholins and since Charon has no atmosphere the origin could not be the same. It's now proposed that the tholins on Charon are made from methane escaping from near-by Pluto. The methane sticks to the winter pole where the temperature is lowest and the ultraviolet light received at night is sufficient to start to link the methane molecules together. As daytime comes, the molecules are heavy enough to remain on the surface and sunlight completes the process of polymerisation to form tholins.

South of the tectonic belt the surface is smoother, comprised of seemingly continuous plains named Vulcan Planum. Tectonic resurfacing is one possible origin of these plains. Areas of relatively low crater density and at least one pancake-shaped unit might imply cryovolcanic resurfacing.

The spatial distribution of tectonic features across Charon is not consistent with the types of patterns predicted from tidal or de-spinning stresses. This may point to Charon having had an ancient subsurface ocean that subsequently froze producing the extensional features and possibly allowing the eruption of cryovolcanic magmas.

The small moons of Pluto

When the New Horizons mission was green-lighted only the dwarf planets

Pluto and Charon were known. Then in 2005 the two small moons Nix and <https://assignbuster.com/pluto-and-its-satellites-from-the-new-horizons-spacecraft/>

Hydra were discovered by the Hubble Space Telescope, followed by the even smaller moons, Kerberos and Styx, in 2011 and 2012 respectively. It had been expected that New Horizons would detect additional satellites but no other moons larger than approx. 1.7 km in diameter are present at orbital radii between 5,000 and 80,000 km.

The general hypothesis is that Pluto and its satellites were produced by the collision of Pluto with a similar Kuiper Belt object and it was hoped that New Horizons would provide information on whether this was the case. Several findings have helped to reinforce this hypothesis. First, the small moons are highly elongated, suggesting they formed and grew by the agglomeration of small objects, but, due to their size, their gravity was not sufficient to pull the material into a spherical shape. Indeed, from New Horizons images Kerberos appears to have a double-lobed shape suggesting the merger of two bodies. The shapes are consistent with the hypothesis that they all formed in the remnant disk produced by the collision that formed the Pluto-Charon binary.

Second, it has been found that all four satellites have high geometric albedos, ranging from 0.56 ± 0.05 to 0.83 ± 0.08 . In contrast, the majority of 'small' KBOs have geometric albedo of ~ 0.1 . This is further evidence that the moons were formed from the remnant disk rather than being captured gravitationally from the general Kuiper Belt population. Third, 11 craterlike features have been identified on Nix, and 3 craterlike features on Hydra. Crater densities have been calculated which exceed the values found on the older regions of Pluto and Charon and suggest that the surfaces of Nix

and Hydra date back to at least 4 billion years ago. This fact again supports the formation hypothesis.

From the high surface albedo of the moons, it's strongly suggested that, like Charon, they are covered with water ice. Unlike Pluto and Charon, which rotate synchronously, the small moons are not synchronous and rotate much faster than expected with rotation periods ranging from 0.43 days to 5.31 ± 0.10 . In addition, the rotational poles of the small moons are almost at right angles to the common rotational poles of Pluto and Charon. These rotation speeds and axes have not been observed in other regular satellite systems and imply that tidal spinning has not played a major role in the moons' rotational histories. A future study will determine whether chaos has played a part.