# BRNO UNIVERSITY OF TECHNOLOGY
VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

## FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION
FAKULTA ELEKTROTECHNIKY
A KOMUNIKAČNÍCH TECHNOLOGIÍ

## DEPARTMENT OF FOREIGN LANGUAGES
ÚSTAV JAZYKŮ

# COMMUNICATIONS TECHNOLOGY AND THE NEW HORIZONS MISSION TO PLUTO
KOMUNIKAČNÍ TECHNOLOGIE A MISE NEW HORIZONS K PLUTU

**BACHELOR'S THESIS**
BAKALÁŘSKÁ PRÁCE

| | |
|---|---|
| **AUTHOR**<br>AUTOR PRÁCE | Daria Yarkina |
| **SUPERVISOR**<br>VEDOUCÍ PRÁCE | M. A. Kenneth Froehling |

**BRNO 2016**

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ
FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ

# Bakalářská práce

bakalářský studijní obor **Angličtina v elektrotechnice a informatice**
Ústav jazyků

***Studentka:*** Daria Yarkina ***ID:*** 164237
***Ročník:*** 3 ***Akademický rok:*** 2015/16

**NÁZEV TÉMATU:**

## Komunikační technologie a mise New Horizons k Plutu

**POKYNY PRO VYPRACOVÁNÍ:**

Pluto je vzdálený romantický svět a je stále považován za planetu pro mnoho lidí. Cílem této bakalařské práce je zmapovat literaturu na technologii komunikací, která slouží v misi New Horizons k Plutu, zejména v oblasti radioelektroniky, zvýrazněte schopnost kosmické sondy posílat signály miliardy kilometrů od Země a prezentovat své výsledky.

**DOPORUČENÁ LITERATURA:**

Robert S. Bokulic, A Decade of Advancements in Spacecraft Communications Technology at APL, Johns Hopkins APL Techncical Digest, Vol. 25, no. 4, 2004, pp. 286-294.

http://www.jhuapl.edu/techdigest/td/td2504/bokulic.pdf

Barrie W. Jones, Pluto: Sentinel of the Outer Solar System, Cambridge: Cambridge University Press, 2010 231 pp. ISBN 978-0-521-19436-5

***Termín zadání:*** 11.2.2016 ***Termín odevzdání:*** 27.5.2016

***Vedoucí práce:*** M. A. Kenneth Froehling
***Konzultant bakalářské práce:***

**doc. PhDr. Milena Krhutová, Ph.D.**, *předseda oborové rady*

# Abstrakt

Cílem této práce je ukázat, jaké komunikační technologie se používají v misi New Horizons k Plutu, poskytnout stručný popis cílů misi a položit důraz na schopnost posílat signály na velké vzdálenosti. Tato práce se také zabývá popisem a významem vědeckého zařízení v kosmické sondě. Dále následuje informace o přenosu dat a navigačním systému planetární sondy. Také jsou zmíněné účinnost využití Ka frekvenčního pásma a modernější technologie.

# Klíčová slova

Deep Space Network, komunikační technologie, New Horizons, Pluto, planetární sonda.

# Abstract

The aim of this work is to show what communications technology is used in the New Horizons mission to Pluto, provide a brief description of mission’s objectives and emphasize the ability to transmit signals over long distances. This work also deals with the description and the importance of scientific equipment in the spacecraft, followed by information about data transmission and the navigation system of the planetary probe. The relevance and effectiveness of using the Ka frequency band and more modern technologies are also mentioned.

# Keywords

Deep Space Network, communications technology, New Horizons, Pluto, space probe.

# Prohlášení

Prohlašuji, že svou bakalářskou práci na téma Komunikační technologie a mise New Horizons k Plutu jsem vypracovala samostatně pod vedením vedoucího bakalářské práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce.

Jako autor uvedené bakalářské práce dále prohlašuji, že v souvislosti s vytvořením této bakalářské práce jsem neporušila autorská práva třetích osob, zejména jsem nezasáhla nedovoleným způsobem do cizích autorských práv osobnostních a/nebo majetkových a jsem si plně vědoma následků porušení ustanovení § 11 a následujících zákona č. 121/2000 Sb., o právu autorském, o právech souvisejících s právem autorským a o změně některých zákonů (autorský zákon), ve znění pozdějších předpisů, včetně možných trestněprávních důsledků vyplývajících z ustanovení části druhé, hlavy VI. díl 4 Trestního zákoníku č. 40/2009 Sb.

V Brně dne ............................. ..................................

(podpis autora)

# Poděkování

Děkuji vedoucímu bakalářské práce M.A. Kennethu Froehlingovi za incpiraci, účinnou metodickou, pedagogickou a odbornou pomoc a další cenné rady při zpracování mé bakalářské práce.

V Brně dne .............................                                        ...................................

YARKINA, D. *Komunikační technologie a mise New Horizons k Plutu*. Brno: Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, 2016. 42 s. Vedoucí bakalářské práce M. A. Kenneth Froehling.

# Contents

# List of images

# Introduction

This bachelor’s thesis deals with communication technologies used in the New Horizons mission to Pluto. This paper focuses on the representation of the main objectives of this mission and describes some technical aspects of the spacecraft, which is the core of the mission.

New Horizons is an automatic interplanetary NASA station launched as a part of the "New Frontiers" program and intended for the exploration of Pluto and its natural satellite Charon. There is a little information about scientific equipment in the spacecraft as far as New Horizons considered as a scientific mission which involves ultraviolet, visible, and infrared imaging and spectroscopy, particle detection, and radio science. An understanding of how Pluto was formed might indicate future threats for Earth if a collision with a celestial body such as a comet occurs.

Prior to the launch of New Horizons, satellites of the United States were sent to all planets in our solar system except Pluto, that is why this mission is a realization of a certain ambition and victory in the space exploration race.[1] Moreover, until the Pluto encounter, this dwarf planet was the last unobserved planet in solar system, and that is why it is an achievement not only for the United States but for the whole of mankind.

Some features of the mission were created requiring a sophisticated telecommunication systems design. It was necessary to minimize power, as solar energy at such a long distance is a thousand times less than the irradiance received in Earth’s orbit. Therefore, an issue with the power consumption will be mentioned in this work and how this problem was overcome.

The aim of this work is to describe the methods and tools used for data transmission, describing the most significant scientific results already achieved, represent the main objectives of this mission and to compare them to the anticipated data.

---

[1] When New Horizons was conceived and launched, Pluto was still “officially” a planet.

# 1 Basic overview of the mission

## 1.1 Mission timeline

In the 1990s the idea of launching the space probe to Pluto became more and more attractive. There were several conceptual proposals to study Pluto until 2001, but for various reasons (such as financial problems, lack of cooperation between states, which could be possibly involved in the project and the excessive increase in the mass of the satellite) they were not destined to come true. In January 2001, NASA announced an opportunity for establishing a research mission to Pluto. The New Horizons project was selected from the five candidates and approved by NASA. From 2001 until 2005, a team led by Alan Stern and invited scientists from different institutions were developing design of the satellite, manufacturing a generator that had to support the power of all the equipment and scientific instruments.

The mission itself consist of five phases.

1. Preparation Phase

The initial stage, consisting of the preparatory steps and the creation of the necessary equipment, lasted for about five years. The designing of the spacecraft and equipment lasted until 2005, when the spacecraft passed final tests at the Kennedy Space Center. In September, New Horizons' spacecraft was transferred to Cape Canaveral for preparation for the launch aboard an Atlas V rocket.

2. Launch Phase

January 19, 2006 New Horizons finally was launched, despite a few postponements.

3. Pre-Encounter Phase

Three correction maneuvers were committed before the spacecraft headed for crossing the orbit of Mars on April 7, 2006. A stringent test of the probe's imaging capabilities during flyby took place on June 13, 2006 when the spacecraft passed by a small asteroid APL (previously called 2002JF56). It was possible to achieve the necessary conditions due to enough high angular velocity of APL relative to New Horizons. LORRI’s imaging and tracking capability for very distant objects was proved in September by using optical navigation

The probe's navigation and scientific systems had been tested in real conditions for the first time (the study of the Callirrhoe moon) before the Jupiter flyby, which occurred February 28, 2007 in order to use a gravitational slingshot. The orbits of Saturn and Uranus were crossed in June 2008 and March 2011, respectively. In early July 2013, LORRI camera from a distance of 880 million km took photos of Pluto and its largest moon Charon. LORRI’s excellent sensitivity and angular resolution made it possible to confirm that Charon was exactly in the predicted position relative to Pluto. The camera took pictures of Pluto and Charon at a much larger phase angle (the angle between the Sun and Pluto spacecraft) than can be achieved from Earth or its orbit. At the end of 2013 the probe was 1.2 AU from Neptune Trojan asteroid 2011 HM102, but no observations were made, especially due to the preparation activities for the Pluto encounter.

The last planetary orbit of Neptune was crossed on August 25, 2014. January 2015 marked the beginning of Pluto’s observations from a far distance. The most remote correction of the trajectory in the history of astronautics at the time was made on March 10, 2015 when the probe was at a distance of 4,77 billion kilometers from the Sun and two days later New Horizons approached to Pluto at a distance less than 1 AU.

In early May, resolution of the images of Pluto from New Horizons exceeded the resolution of the best images of the object obtained by space telescope "Hubble". The New Horizons’ photos, which showed all the currently known satellites of Pluto were published. On June 30, 2015 the presence of methane ice on Pluto was confirmed by New Horizons using Ralph instrument. On July 4, 2015 satellite’s computer malfunctioned, which led to a communication loss with the flight control center for 81 minutes, but two days later experts from NASA assured that the computer malfunction could not affect the further course of the mission.

## 4. Science Phase

On July 14, 2015 the spacecraft flew within approximately 12,500 kilometers from the surface of Pluto exploring the whole Pluto system (including Pluto, Charon, Hydra, Nix, Kerberos and Styx). In general, the probe conducted observation only for 9 days and gathered about 50 Gbit of information during that time. On July 20, 2015 the transmission of the first package of images of the Pluto system to Earth from the flight trajectory was completed. Data transmitting will be conducted presumably until the end of 2016.

5. Post-mission Phase

The whole mission of New Horizons is expected to last until 2026. By that time, the fuel reserves will run out and RTG (a radioisotope thermoelectric generator) will not be able to provide New Horizons with energy until this is possible, it is expected that the probe will study the outer heliosphere and become the fifth probe working in this field.

## 1.2. Mission objectives

The New Horizons project was implemented to achieve three kinds of objectives: primary, secondary and tertiary. The primary objectives include a geological and morphological examination of Pluto and its moon Charon, mapping substance composition of their surfaces, Pluto's neutral atmosphere exploration.  According to Jones: “Failure to achieve any of these would be regarded as failure of the mission” [1] (Jones, Pluto: Sentinel of the Outer Solar System, 188).

Determination of time-variability of the surface and atmosphere of Pluto, Pluto's and Charon's stereoscopic image production, obtaining high-resolution mapping of the areas adjacent to their terminator (day-night border), conducting a search in the upper layers of the atmosphere for neutral molecules, such as molecular hydrogen H2, hydrogen cyanide HCN, CxHy and other hydrocarbon compounds, are considered as a secondary group of targets. Additionally, Charon’s atmosphere search, defining Bond Albedos of studied objects, exploration of Nix and Hydra should also be mentioned.

The tertiary tasks are the exploration of magnetic field presence on Pluto and Charon, explanation of the nature of the energetic particles environment in their vicinity, specifying the radius, mass, density and the parameters of the Pluto and Charon orbits, searching for new moons, and rings. After passing Pluto, New Horizons with its remaining fuel continues its flight studying the Kuiper belt, making a flyby of a Kuiper belt object (KBO) the next reasonable objective of its extended mission.

# 2 Science payload

The chief goal of the mission is collecting data and transmitting as much gained information as possible and for this reason, seven scientific appliances were installed in the probe. The science payload is represented by Alice, LORRI (Long Range Reconnaissance Imager), PEPSSI (Pluto Energetic Particle Spectrometer Science Investigation), Ralph, REX (Radio Science Experiment), SDC (Student Dust Counter) and SWAP (Solar Wind at Pluto). Alice and Ralph together are also called PERSI (Pluto Exploration Remote Sensing Investigation).

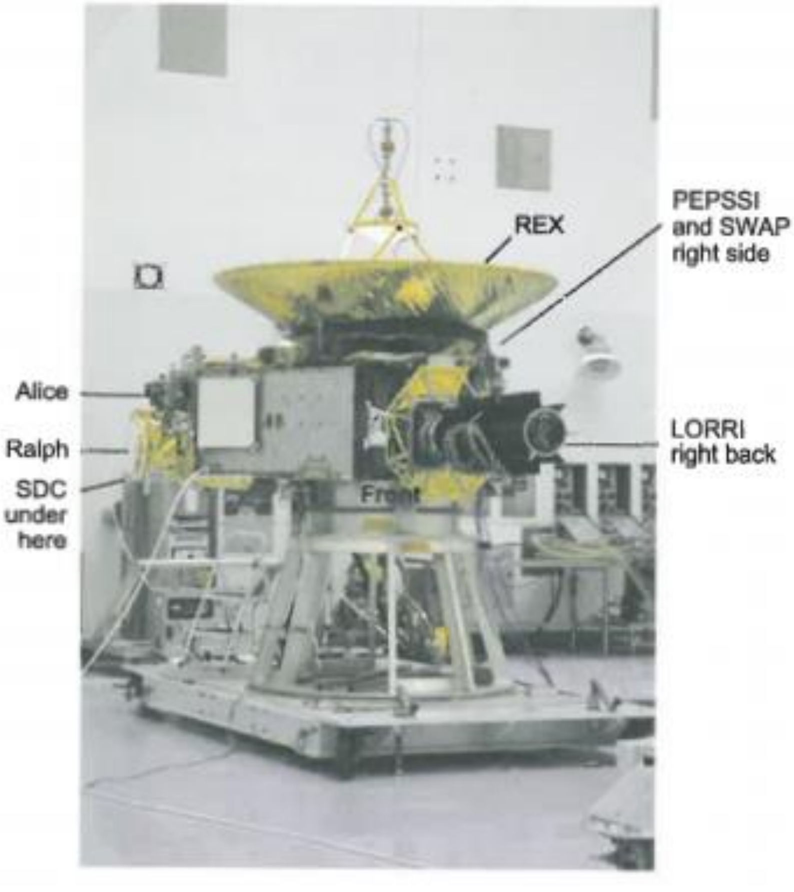

Figure 1: *The New Horizons scientific payload [1]*

## 2.1 Optical instruments

### 2.1.1 Alice

Alice is an ultraviolet imaging spectrometer that probes the Pluto atmospheric composition and temperature. The mapping spectrometer simultaneously separates light into components and generates an image at each wavelength. The instrument is able to find various important chemical substances in the atmosphere of Pluto. The spectroscope is designed to determine the relative content of substances found, showing for the first time a complete picture of the planet's atmosphere composition. Alice is involved in exploring for the Pluto- Charon ionosphere. The device is capable of determining the dependence between the density and temperature of the atmosphere and height above Pluto's surface.

### 2.1.2 LORRI

Long-Range Reconnaissance Imager (LORRI) is a digital sensor camera with a large telescope, adapted to operate in hostile conditions with ultralow temperatures. LORRI was installed on the New Horizons for expansion and backup of Ralph panchromatic imaging capabilities. The LORRI sensor camera provides hemispheric panchromatic maps of Pluto and Charon, terminator region and the far-side of hemisphere at a resolution exceeding 10 km/pixel, searches for atmospheric haze, satellites and rings. The scope of its objectives also includes panchromatic wide phase angle coverage and stereo images of Pluto, Charon, Nix, and Hydra and their orbital parameters. [2]

### 2.1.3 Ralph

In order to map and study the surfaces of Pluto and Charon, a high-resolution camera Ralph uses panchromatic and colour imagers and infrared compositional mapping spectrometer. Ralph is the only instrument which is capable of taking coloured images during the New Horizons mission.

Mapping spectrometer Linear Etalon Imaging Spectral Array (LEISA) and Multispectral Visible Imaging Camera (MVIC) are both valuable constituent parts of Ralph. LEISA is intended to observe congestions of various matters on the celestial body surfaces, operating at infrared wavelengths. MVIC's three panchromatic and four colour imagers allow NASA to obtain stereo images in high resolution with approximately 250 meters per pixel. [15]

## 2.2 Plasma instruments

### 2.2.1 Peppsi

It is widely known that Pluto's atmosphere is several times more considerable than Earth’s and escapes into space approximately by 75 kg every second. [15] Widespread particle collisions are one consequence of interaction of the solar wind with neutral atoms. It is assumed that under these circumstances, particles are being charged by the UV light and leaving the atmosphere. Pluto Energetic Particle Spectrometer Investigation (PEPPSI) is a plasma-sensing instrument, which was designed to detect neutral atoms leaving Pluto’s atmosphere and colliding with particles of solar wind.

### 2.2.2 SWAP

The Solar Wind Analyzer around Pluto (SWAP) instrument measures the atmospheric escape rate from Pluto, solar wind velocity and density, low energy plasma fluxes, angular distributions and energetic particle fluxes at Pluto-Charon. “It is also capable of detecting particles from the solar wind near Pluto, to determine whether it has magnetosphere or not. Magnetosphere is the field around the planet produced by its internal magnetic field.” [1] (Jones, *Pluto*, 191)

## 2.3 The Venetia Burney Student Dust Counter

This is one of the devices which is remarkable because it is the first NASA instrument made, installed and operated solely by University of Colorado students. It was named in honour of Venetia Burney, the girl who named Pluto after its discovery in 1930. Dust Counter detects tiny pieces of celestial bodies which occurred after various collisions among them, calculates their concentration, mass, and speed along the trajectory of the New Horizons spacecraft.

Unlike all of the other instruments, the Venetia Burney Student Dust Counter was not part of the original New Horizons design and was added by NASA as an Education and Public Outreach experiment. For the first time ever, students have been given the opportunity to design, build, and operate an instrument for an interplanetary mission. [15]

## 2.4 REX

The Radio Science Experiment (REX) is incorporated physically and functionally within the communications subsystem to examine Pluto’s atmosphere. As the telecommunications system is redundant, there are two copies of REX on the spacecraft and both can operate simultaneously, increasing the stability of data transmission.

This technique of uplink radio occultation was used for Pluto's atmosphere research. Powerful NASA transmitters sent radio signals to the spacecraft and then REX detects the changes in signal phases caused by atmosphere through which the signal was sent. The time delay appears because radio waves bend in Pluto’s atmosphere in accordance with an average molecular weight of an atmospheric gas and temperature value. It is noteworthy that signals are sent from Earth, whereas in analogous research missions signals are sent by the spacecraft. [2]

# 3 Space communication systems

The radio transmissions principle lies in the fact that fluctuations of current in the transmitter antenna in surrounding space create electromagnetic waves which move at the speed of light reaching the receiver antenna and inducing alternating electrical current. This induced current is very weak, but if the receiver is set exactly at the resonance frequency of a radio wave, even the weakest impact can cause quite noticeable fluctuations in antenna. These changes are then amplified, analyzed and transmitted information is recovered.

The radio waves of various ranges in different ways pass through the Earth's atmosphere. For optimal space communication range should be from 1.5 to 30 centimeters. Beyond the scope of this range radio signals are significantly attenuated by the atmosphere, or may even be reflected.

Increasing the size of the receiving antenna makes it possible to gather more energy from electromagnetic waves and to catch the signal of the weaker transmitter. In space, the size of the antennas usually does not exceed the dimensions of the spacecraft. Although in recent years, engineers have found a way to circumvent this limitation by making antennas able to unfold. Antenna size is also important for another reason. The bigger diameter it has, the less divergent would be beam of radio waves.

If the orientation system fails, communication with the device will be interrupted. A case in point was the destruction of the Soviet interplanetary station "Phobos-1". In 1989, while approaching Mars it received an invalid command from Earth, resulting in a failure which occurred in the onboard computer. The spacecraft lost its orientation, solar panels turned away from the Sun and a parabolic antenna was not oriented towards Earth. Operators unsuccessfully tried to make contact with the station.

Thus, communication is the critical link in all interplanetary missions. Failure of other systems is often manageable to bypass, though sometimes a part of the scientific data is lost. In case of losing connection with Earth, spacecraft even operational in other systems ceases to exist for mankind. Therefore, the communication system has to be extremely reliable in every modern spacecraft or at least it should be duplicated.

The main parameter of any communications system is its data transmission rate. It is determined not only by the signal intensity, but also as the ratio of its amplitude to noises that interfere with reception. Noise appears in the receiver and transmitter equipment due to thermal motion of the atoms. In the space the noise is caused by relic microwave radiation left over from the Big Bang. Actually, it was discovered in 1964 by accident, in an attempt to get rid of the unknown noise in the new antenna, which was used for studying space communication's possibility.

The noise is filtered out statistically due to its random nature. It equally causes current movement in the antenna in one direction and then in another direction. On average, after a long period of time, its contribution will be zero. However, the weaker the signal is with respect to noise, the longer you need to keep receiving and averaging to filter noise. The poorer signal / noise ratio is, the longer it takes to transmit each bit of data. Trying to force transmission messages may result in higher amount of errors.

When designing the space communication system itis also necessary to take the motion velocity of the spacecraft into account, as the Doppler shift of radio frequency depends on it. If this effect is not taken into account, the receiving circuit cannot reach the resonance with the carrier frequency of the transmitter, and its sensitivity drops sharply. However, the Doppler frequency shift of the signal can accurately determine the speed of motion of the spacecraft along the line of sight.

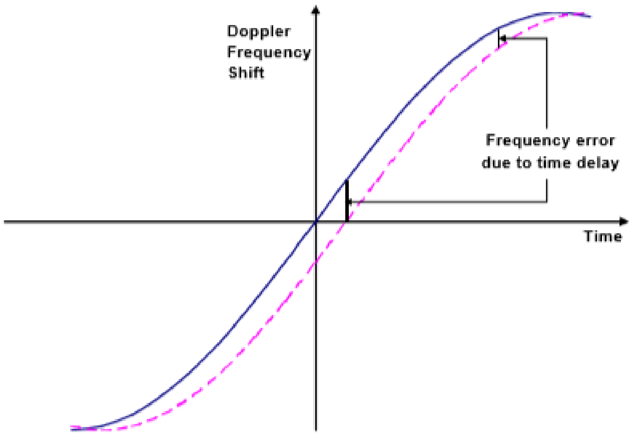

Figure 2 - *Typical Doppler shift profile as a result of Earth rotation for a distant spacecraft* [19]

Today mankind is limited in communication capabilities by the solar system. For interstellar distances terrestrial transmitter power must be billions of kilowatts (which is comparable with the total production of electricity in the world) in order to communicate with the New Horizons' class probe. [18]

## 3.1 Deep Space Network

Device support in interplanetary space is different from support in the Earth orbit. Interplanetary spacecraft during most of their missions have direct contact with the control centers on Earth, and in order to communicate with the device only a small number of ground stations with broad coverage is needed. New Horizons, like all deep space probes, have communications systems used for both control of the probe from the ground, via the uplink, and for return of telemetry from the probe, via the downlink. This technology also allows NASA to determine the probe's position in space.

The NASA Network uses only three complexes for deep space missions support, nevertheless, they include extra-large antennas, super-power transmitters and ultra-sensitive receivers. The communication between New Horizons and its operational-supporting team is going through The Deep Space Network (DSN). DSN is an international network of radio telescopes and communications equipment used for radio astronomical researches in the solar system and the universe, distance control of interplanetary spacecraft. DSN is part of the NASA Jet Propulsion Laboratory. On Earth, the Deep Space Network automatically collects all data sent from the New Horizons probe. There are three DSN antenna stations located in Goldstone (US), Canberra (Australia) and Madrid (Spain). They are based almost 120 degrees apart around the globe, so it provides sustained a signal despite Earth's rotation.

There are several analogues of this network such as ESTRACK, European Space Operations Centre (ESA), East Deep Space Communication Center in Russia, as well as Chinese and Indian centers of Deep Space Communication. [16]

## 3.2 Navigation system

In comparison with the majority of deep space probes, the New Horizons spacecraft communications system is a transceiver, while in most of other missions a conventional transponder is presented. The transceiver's remarkable feature lies in the fact that the uplink and downlink elements may reciprocate a common frequency reference, but the downlink signal is relatively independent with the uplink phase. This kind of communication system was implemented into the New Horizons project, because it is a perfect choice for the Radio Science Experiment that was conducted during Pluto-Charon encounter. It is the product of the evolutionary development of deep space communication systems.

A demanding function of the New Horizons communications system is the support of two-way Doppler velocity measurement for navigation usage. A collation of the uplink carrier frequency and the downlink carrier frequency is made systematically within the transceiver and the result is incorporated in the downlink telemetry.

Deep Space Network (DSN) obtains Doppler measurements on a regular basis, later these data are delivered to the New Horizons Mission Operation Center and processed along with the spacecraft generated frequency comparisons to produce an innovation in the set of Doppler measurements, equivalent to those that would have resulted from the use of a transponder. Therefore, the navigation method is completely analogous to the two-way method, whereas the handling of the Doppler measurements does not include any knowledge of the probe position and movement or the light-time between the ground station and New Horizons. As the Ultrastable Oscillators (USO) are the spacecraft frequency reference of the probe and potentially may lead to offset and drift, it became necessary to avoid these deviations which occurred due to these effects, using Doppler measurements.  As a consequence of this processing, the frequency of the oscillator can be precisely determined. Only two unknown quantities remained: the Doppler velocity and the spacecraft frequency reference. However, the Doppler measurement is provided by the DSN and the correlation calculation of frequency is made in the spacecraft, which makes it possible to determine the Doppler velocity and the USO frequency. Measurement of the spacecraft oscillator frequency has been a routine process since the probe was launched in January 2006. [13]

# 4 Spacecraft’s construction

## 4.1 Power consumption

The flight is supported by a radioisotope thermoelectric generator (RTG). Sensors installed on the RTG recorded a temperature of about 245 degrees Celsius during the launch of the probe. According to data, when New Horizons reached Pluto, the temperature of the RTG decreased to 208 degrees Celsius.

RTG emits a palpable infrared and thermal radiation. Nearly 4,000 watts of heat energy is produced during the combustion of the fuel generator. The device uses only 25 watts to maintain the internal temperature. RTG’s electrical power is about 245 watts, which can also be used to maintain the desired temperature in the machine. The rest of the generated heat and power is radiated into space.

Some elements of the machine perform better when they are out of range of RTG heat radiation. Therefore, they are mounted at the opposite sides of the probe in order to maximize the distance of the radiation source to the electronics and instruments. New Horizons is also equipped with thermal protection placed around the RTG, ensuring the protection and smooth functioning of some of the research instruments on board.

The fundamental action of the generator is based on the radioactive fuel decay process and heat emission. At the beginning of the mission, 11 kg of plutonium dioxide were loaded on board and RTG power output was 245 watts. However, by July 2015 RTG produced only 200 watts. This power reduction is not critical, since a decreasing amount of fuel leads to total weight loss and less force is required to maintain the desired speed. Harmonious work of all probe systems and their interaction depend on the power distribution unit (PDU) that implements effective functioning of major systems using 96 connectors and more than 3,200 wires. [14]

## 4.2 Antenna system

Antenna gain is the combined expression of directivity and energy conversion efficiency of the antenna in comparison with a suitable reference antenna. It is defined as the ratio of the intensity of radiation (power radiated per solid angle) of the antenna in a particular direction to the radiation intensity of the reference antenna (in the same direction). Gain without any certain direction is valid for the direction of maximum radiation. It is usually expressed on a logarithmic scale in decibels. Antenna gain is closely related to its directionality. As long as an antenna is a passive element, its gain is achievable solely at the expense of increasing the directivity (contrary to, for example, gain amplifier). Therefore, a high-gain antenna is necessarily more directional (radiating in a narrower beam) than the low-gain antennas or an antenna with the same losses. In the design of the spacecraft's antenna system low-gain, medium-gain and high-gain antennas are used.

The probe's antennas undergo the impact of extremely low temperatures during the mission. The RF performance of the high-gain antenna during and after Pluto and KBO encounters is critical for the science and communications mission requirements. The signals must not overlap each other, as far as the antennas work with various radio frequencies, and the antennas' construction should allow for clear visibility. Production costs have to be minimized and materials used in the antenna system have to be as lightweight as possible, but durable and resistant to extreme changes in temperature.

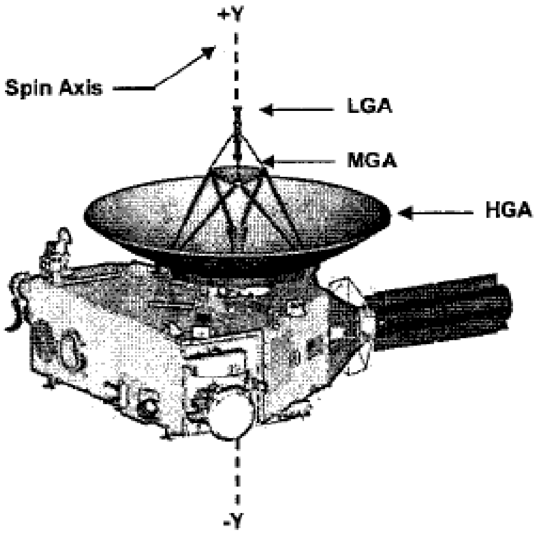

Figure 3: *Forward side of New Horizons observatory* [12]

The whole antenna system is aligned with the Y-axis (shown in Figure 3.) and designed to support low- and high-data-rate communications from both a spinning and three-axis stabilized position. Based on the path duration of the considered mission, most of the time the satellite is in the spin-stabilized rotation mode along the Y-axis that allows antenna assembly to be pointed towards the ground. This arrangement of antenna plates can receive commands and manage required maintenance from the DSN at any time. The path may be subjected to adjustment, except in cases when the apparatus uses scientific tools and changes its direction according to their needs. “The antenna system includes both a forward antenna system (aligned with the +Y axis of Figure 3) and a hemispherical Low Gain Antenna (LGA) mounted below the spacecraft in order to achieve an omni-directional low-gain communication capability and aligned along the –Y axis. The forward antenna assembly consists of the +Y hemispherical-coverage LGA and two co-aligned parabolic antennas.” [4] (Fountain, *The New Horizons Spacecraft*, 19)

A spacecraft's low-gain antenna(LGA) provides wide-angle coverage at the expense of gain. Coverage is nearly omnidirectional, except for areas that may be shadowed by the spacecraft body. For inter planetary space missions, especially in the inner solar system, low-gain antennas often are designed to be usable for relatively low data rates, as long as the spacecraft is within relatively close interplanetary range (typically a few astronomical units, and the Earth-to-spacecraft transmitter is powerful enough). For example, an LGA can be used on a mission to Venus, but a spacecraft exploring Pluto and KBO must use a high-gain antenna (HGA) because of the distances involved. An LGA sometimes is mounted on top of a HGA's subreflector. [17]

The medium gain antenna (MGA) has increased angle (up to 4°) for an operation between +Y-axis and Earth, allowing it to control the satellite at distances up to 50 AU. Two low gain antennas are capable of operating only at distances up to 1 AU. Hence, they are not involved in data transmission at the moment, providing the necessary support for the device during the early phases of the mission.

Out of all of the above-mentioned antennas, the greatest interest to us is the HGA antenna, because the distance of its operation is much higher than others, which means that this antenna is used throughout most of its time. The high-gain antenna with a diameter of 2.1 meter is made according to the Cassegrain scheme and has an angle of 0.3 degrees of disclosure and a gain of 41.9 dB. The outgoing signal is amplified by a 12-watt travelling wave tube (TWT), which (along with backup) is mounted on the spacecraft body below the HGA’s dish. Transmitting device control permits the simultaneous usage of both tubes, which allows nearly double the downlink’s rate. Tests of such a transmitting method were found successful at the beginning of the mission and now are considered as an operational option (only in cases where sufficient power reserve is present).

The construction of the New Horizons’ high gain antenna is dictated by the -200°C to +80°C operational temperature range that the antenna system will be exposed to during the life of the mission. The lowest operational temperatures were expected for Pluto and KBO encounters, while the highest temperatures occurred early in the mission, when the launch required turning the HGA directly to the Sun. In order to meet critical science and communication mission requirements, the mechanical alignment of the HGA’s axis of maximum gain must be maintained for a high degree of accuracy over this temperature range. In order to realize these requirements, composite materials serve as the basis for the HGA mechanical design. Composite materials are more expensive and complex in application, but they offer a dimensionally stable mechanical design over the expected temperature range, as well as a high rigidity and low mass solution required for the launch. “The fabrication of the HGA reflector utilizes a 0.019-meter-thick composite sandwich lay-up with a Korex honeycomb core. The secondary reflector assembly consists of MGA and HGA sub-reflectors and is a composite laminate shell lay-up.” [3] (DeBoy, *The New Horizons mission to Pluto: Advances in telecommunications system design*, 546)

# 5 RF communications

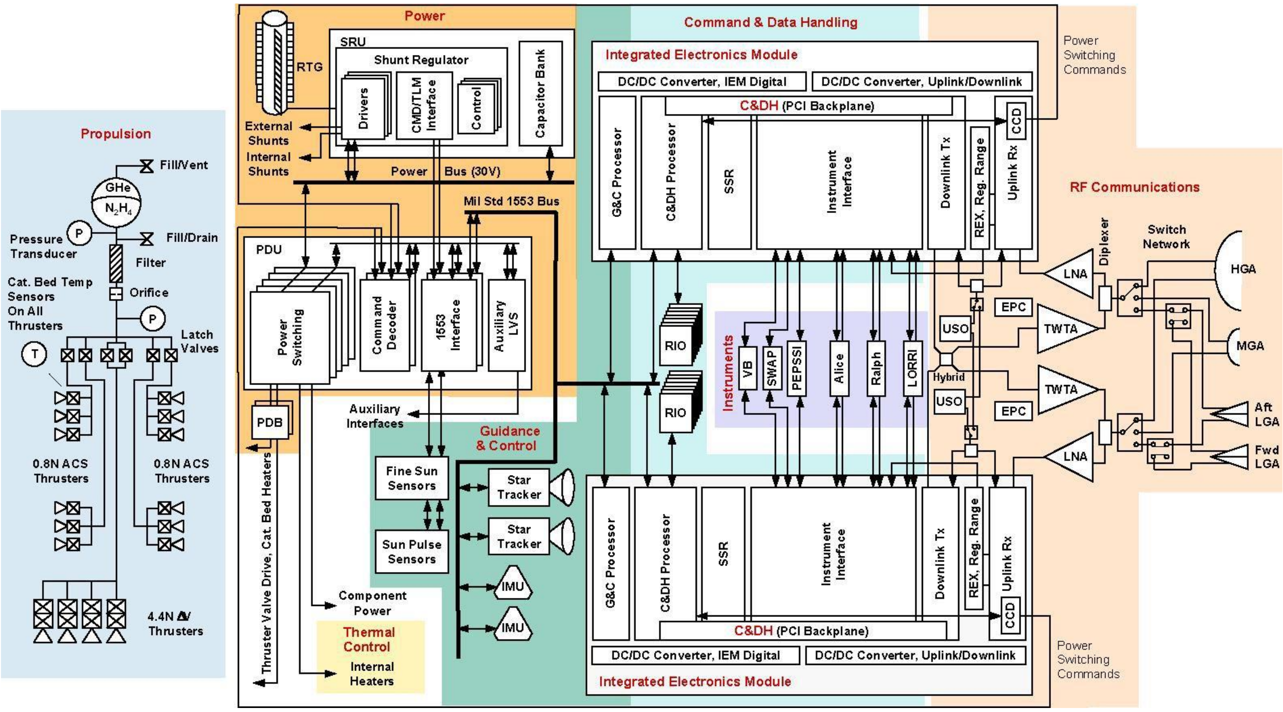

Figure 4 - *Communications system block diagram.* [4] *Figure 4 shows that the whole communications system includes RF switch network, an antenna assembly, TWTAs, USOs, hybrid coupler, and the uplink and downlink cards situated in the IEMs.*

## Integrated Electronics Module (IEM)

Integrated electronics module is a key part for holding all core spacecraft electronics subsystems. There are two IEMs in the spacecraft's system. Both of them are responsible for the functioning of the command and data handling (C&DH) system, the telemetry interface function, the solid state recorder (SSR), the instrument interface circuitry, and the receiver and exciter sections of the telecommunications system, and also the DC/DC converters that power them. The usage of IEMs provides a possibility of mass and cost reduction, moreover, it allows to make system's improvements in the future. [5]

According to Figure 4, there is a C&DH processor in one of the IEMs, that can be used as the controlling unit and the guidance and control processor in the other IEM can be responsible for operation of the guidance and control system. In order to improve system reliability, they are cross-strapped below the block level. A redundancy of instruments' interfaces enables redundant circuits to be accessed from the instrument interface card in each IEM. The cross-strapping allows each C&DH processor to access any of the redundant 1,553 buses providing the data pathways to the inertial measurement units, star trackers, fine sun sensors and sun pulse sensors. [4]

### USO

The New Horizons Ultrastable Oscillator (USO) is a significant item of the RF telecommunication system, ensuring accuracy of the reference frequency (30 MHz) for the uplink, downlink, and stability of the radio science experiment (REX) and providing down-conversion to an intermediate frequency. [5] There are two USOs in the satellite, moreover, each of them is an unaltered version of an oven-controlled crystal oscillator with low output phase noise emission. The cross-strapping of a power splitter, transfer switch and both of the USOs is necessary in order to retain redundancy in the Uplink and Downlink Cards in the event of a USO failure. The first time USO was used for deep space exploration in Voyager mission in the late 1970s, providing stability for radio occultation experiments.

### TWTA

A traveling-wave tube (TWT) is a device, which is intended to amplify microwave radio frequency signals in electromagnetic spectrum. It works on the principle of power absorption from the beams of electrons extending through and it belongs to the certain "linear beam" type of a vacuum tubes.

Traveling-wave-tube amplifier is an instrument producing high-power radio signals and obtained by coupling traveling-wave tube, protection circuits and regulated power supply (converts unregulated AC into a constant DC). TWTAs, which are incorporated in the New Horizons' RF communication system, made by Thales, Inc. The power of downlink provided by TWTA is located between data rate and beamwidth performance and power dissipation (measure of the rate at which energy is dissipated, or lost, from an electrical system). The life time of each TWTA's filaments is estimated for approximately 260,000 hours. The expected time for Pluto downlink is less than 45,000 hours. That is why even usage of a single TWTA can satisfy mission requirements. [4]

## Hybrid Coupler

A hybrid coupler is a one of the so-called passive devices widely used in telecommunications and radio and its power is equally divided between two output ports.

It is seen in Figure 4 that the hybrid coupler is connected to the outputs of downlink exciter and inputs of TWTA. This position enables each exciter to work with each TWTA and provides improved reliability. Furthermore, by powering the appropriate TWTA, Mission Operations team can change downlink polarization state (Right/Left Hand Circular) avoiding the necessity to change the IEM for usage of the other exciter. Because of this the post encounter downlink data rate can be nearly doubled – in the case of using both TWTAs and one exciter it is possible to transmit a dual-polarized downlink signal (Right & Left Hand Circular).

## Radio Science Experiment (REX)

The REX Instrument is considered to be the part of the RF telecommunications system. REX attempts to define the Pluto and Charon atmosphere and to make a measurement of surface temperatures through records of changes in the periodically received uplink signal during the encounter. A fixed downconversion mode is provided by the Uplink card.

There are two tools specific to REX on the Radiometrics Card with the Regenerative Ranging System: an analog-to-digital converter and an Actel Field Programmable Gate Array (FPGA). According to Weaver: "FPGA takes samples of the intermediate frequency receiver output and generates wideband radiometer and narrowband sampled signal data products." [2] (Weaver, *Overview of the New Horizons Science Payload, 85*)

A wideband intermediate frequency output from the uplink receiver is connected to the REX circuitry, and the receiver is commanded to a fixed-conversion mode. Before processing every RF input goes through three stages: frequency shifting, filtering, and decimation (down conversion). Consequential reduction of power consumption of a certain system is directly related to the usage low power digital design by the uplink command receiver. The digital receiver developed for New Horizons consumes approximately 4 W. “The uplink card also provides critical command decoding, ranging tone demodulation, X-band carrier tracking, and a regenerative ranging subsystem. This will enable New Horizons to determine spacecraft range to a precision of less than 10 m (1s) from near-Earth ranges to beyond 50 AU, or achieve mission range measurement accuracy for integration times orders of magnitude shorter than those for sequential ranging.” [5]

Two types of measurements are made using REX. Blocking of the uplink signals by Pluto starts at the moment when the probe goes into the occultation and REX filter saves its output. It allows us to determine the changes in phase and amplitude the uplink signal under the influence of different layers of Pluto’s atmosphere. At this period of time, integration, sampling, and comparison are conducted at the intermediate frequency input in the REX's full bandwidth in order to determine the effective antenna noise temperature and to map the physical temperature of Pluto. The best performance of REX can be reached by decreasing the New Horizons system noise temperature (additive noise in the receiving system of thermal origin), by the careful selection of crystal resonators in the USO and tight control of spurious signals in the intermediate frequency receiver. [5]

## Downlink Exciter Card

The downlink exciter card computes and inserts navigation counts into the frame data for supporting of the noncoherent Doppler tracking capability. Moreover, it is used to transmit beacon tones during the spacecraft hibernation flight period. IEMs' downlink cards are connected by the instrumentality of the hybrid coupler to the inputs of the traveling wave tube amplifiers (TWTA), which were designed to enhance the downlink signal. The redundancy principle suggests that any TWTA can be associated to any downlink card. Considering that both TWTA outputs are attached to antennas via the RF switch assembly, there is a capability of concurrent transmission of two mutually opposite directed signals (a right hand circular (RHC) polarized signal and a left hand circular (LHC) polarized signal). This type of effective communication is conditional upon satisfactory spacecraft power. When signals are received on the ground, the DSN merges them in order to strengthen the received signal-to-noise ratio and by that increase the data rate almost by 90 percent comparing to the usage of a single TWTA. "The resulting downlink data rate (which includes 2db of margin in the link calculation) is shown in Figure 5. The downlink system will guarantee that the entire Pluto data set (estimated to be 5 Gbits after compression) in 172 days with one 8-hour pass per day using the DSN 70m antennas. If there is sufficient power, such that both TWTAs can be used, the time to downlink the data set can be reduced to less than 88 days." [4] (Fountain, *The New Horizons Spacecraft*, 21)

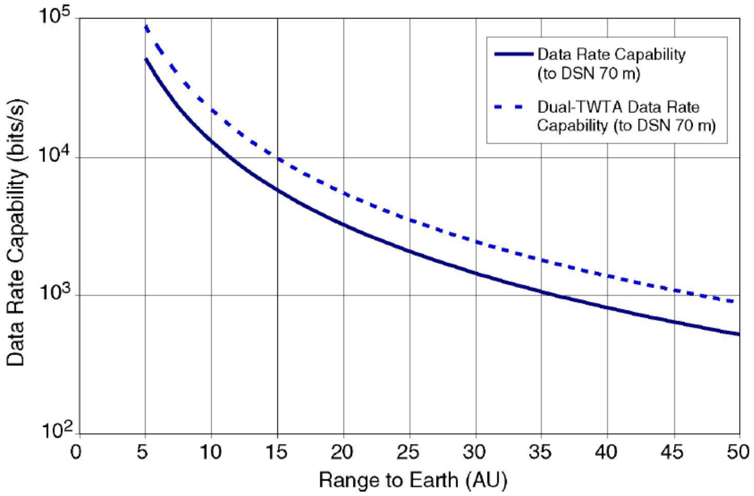

Figure 5 - *The RF system provides downlink telemetry above 1 kbit/s at Pluto and above 700 bits/s at 50 AU. A mode using both the redundant TWTAs simultaneously and combining the signals on the ground increases the data rate such that over 9 kbit/s can be transmitted at 50 AU.* [4]

## Uplink Card

The Uplink Card provides the command reception capability as well as a fixed down conversion mode for the uplink radio science experiment. Additionally, it maintains "command decoding, ranging tone demodulation, X-Band carrier tracking and a regenerative ranging subsystem. The non-coherent Doppler tracking and ranging system developed by APL is also largely implemented on the Uplink Card, capable of Doppler velocity measurements better than 0.1mm/s." [4] (Fountain, *The New Horizons Spacecraft*, 19)

Some features of deep space RF systems such as the primary RF carrier tracking, command detection, and the digital receiver system’s turnaround ranging channel performance requirements are identical to those of previous missions' systems CONTOUR RF transceiver systems and small deep space transponder (SDST). [24]

The New Horizons' uplink card design enhanced its performance and flexibility thanks to the usage of digital processing techniques and achieved considerably lower power consumption than previous systems. "The Uplink Card consists of three separate printed circuit boards (PCB) mounted to an aluminum heat sink. On one side, a multilayer contains the circuits required for the RF, intermediate frequency, analog, and digital portions of the X-band carrier tracking receiver, ranging tone demodulation, and the wideband intermediate frequency channel. RF downconverter board, which consists of a temperature stable microwave substrate, various microstrip circuits, and the circuitry required to complete the first RF downconversion stage in the uplink card is attached to this polyimide PCB. On the other side, the other multilayer contains the required circuits for the command detector unit (CDU) and the critical command decoder (CCD).

Performance highlights include the following: total secondary power consumption of 2.5 W (including the integrated on-board command detector unit (CDU) and critical command decoder (CCD)), built-in support for regenerative ranging and REX, carrier acquisition threshold of -157 dBm, high RF carrier acquisition and tracking rate capability for near-Earth operations (2800 Hz/s down to -100 dBm, 1800 Hz/s down to -120 dBm, 650 Hz/s down to -130 dBm), ability to digitally tune to any X-band RF channel assignment (preprogrammed on Earth for this mission) without the need for analog tuning and tailoring, use of an even 30.0 MHz ultrastable oscillator (USO) as a frequency reference, a noncoherent AGC system, and best lock frequency telemetry accuracy to 0.5 Hz at X-band and best lock frequency settability plus stability error < +/- 0.1 ppm with zero temperature effects (all relative to USO frequency).

These results highlight the major performance parameters of the operational and functional RF uplink system. One of the key benefits of moving to a more-digital system is increased operational flexibility. Once in place, successive design iterations in future missions may include in-flight reconfiguration of RF channel assignments, and carrier tracking loop optimization for near-Earth, deep space, and interstellar operational modes. A secondary benefit is the ability to leverage from increasing gate array densities and processing unit speeds, thus contributing to further mass, size, and power savings. Finally, further reduction in hardware assembly steps due to lower parts count and fewer solder connections increases the reliability of these systems." (DeBoy, *The RF telecommunications system for the New Horizons mission to Pluto*)

# 6 Results obtained by April 2016 and their importance

On 18 March, 2016 Science magazine published some of the data obtained in July 2015. This chapter covers some of the key aspects of the mission’s research, and also allows me to assess the progress towards achieving the desired objectives. All present findings concerning Pluto’s and Charon’s atmospheres and surfaces were obtained within a few hours of the closest approach of New Horizons to Pluto on 14 July 2015.

## Atmosphere

On the basis of data obtained by ground-based stellar occultation in 1988 and subsequently studied with later occultations by spectra at near-infrared and microwave wavelengths and with models of increasing sophistication the expected profile of the atmosphere has been formed.

It was anticipated that one of the main components of the Pluto’s atmosphere is nitrogen ($N_2$) with additional elements such as methane ($CH_4$), carbon monoxide (CO), and hydrogen cyanide (HCN) with complex surface interaction. According to forecasted temperature of Pluto’s surface with an expected range from -235.15 °C to -218.15 °C (with surface pressure of nearly 3 to 60 Pa), its surface should have been colder than the approximate temperature of stratosphere -173.15 °C.

1) During the encounter LORRI, MVIC, and Linear Etalon Imaging Spectral Array (LEISA) imaging clearly have revealed optically thin hazes extending to altitudes of at least 200 km.
2) The formation of higher hydrocarbons and other species such as acetylene ($C_2H_2$) and ethylene ($C_2H_4$) had been predicted due to photochemical models and later proven and observed through the Alice solar occultation data (ultraviolet reflectance spectra also show the absorption signatures of $C_2H_2$ and $C_2H_4$).
3) The escape rate of Pluto’s atmosphere is proven to be considerably less than anticipated, nevertheless, later it may leave its signature on Charon. [21]

## Surface composition

By virtue of the ground-based spectroscopic observations some constituents of Pluto’s surface have become known. It applies to highly volatile cryogenic ices of nitrogen ($N_2$) and carbon monoxide

(CO), also including less volatile methane ice ($CH_4$), $H_2O$ and ethane ($C_2H_6$) ices and more complex tholins that are inert at the temperatures of the Pluto's surface. The term "tholin" refers to "a reddish organic substance, found on the surface of icy bodies in the outer solar system, and formed by the exposure of simple organic compounds, such as ethane and methane, to ultraviolet radiation". [23] The presence of ices of $H_2O$ and ammonia ($NH_3$) has also been observed on Charon's surface.

On Pluto, the colour images show nonvolatile tholins coating an ancient equatorial belt with a lot of craters. In order to erase all impact craters, a flat, thousand-kilometer plain must be able to refresh its surface rapidly enough. Infrared observations of this region show volatile ices including $N_2$ and CO. $H_2O$ ice is not detected there, but it does appear in neighboring regions. $CH_4$ ice is abundant at Pluto's high northern latitudes and is present on crater rims and mountain ridges at low latitudes.

Pluto's various processes that are modifying its surface over time scales ranging from seasonal to geological become possible due to the existence of volatile ices. These ices are easily mobilized even at the extremely low temperatures prevalent on the surface of Pluto (around -233.15 °C). Pluto's regional albedo contrasts (a measure of brightness) are among the most extreme for solar system objects.

Pluto's large moon Charon's $H_2O$ ice–rich surface is unlike other outer solar system icy satellites and it clearly reveals reddish tholin colouration around its northern pole. Moreover, it becomes clear that some patches rich in $NH_3$ ice are tremendously localized. Charon's polar reddening and its latitudinal distribution can be explained by a thermally controlled production processes. The existence of highly localized patches of ammonia ice on its surface assumes relatively recent emplacement. [20]

## Geology

The New Horizons spacecraft has uncovered the complexity of Pluto's and Charon's geology. There is an ongoing surface geological activity on Pluto's observable hemisphere. This activity mostly centered on a vast basin represented by a thick layer of volatile ices that seems to be involved in convection and advection, with a crater retention age no greater than almost 10 million years. Surrounding terrains show active glacial flow, apparent transport and rotation of large floating water-ice blocks of crust, and pitting, the latter likely caused by sublimation erosion and/or collapse. "More enigmatic features include tall mounds with central depressions that are conceivably cryovolcanic and ridges with complex bladed textures. Pluto also has ancient cratered terrains up to ~4 billion years old that are extensionally faulted and extensively mantled and perhaps eroded by glacial or other processes. Charon does not appear to be currently active, but experienced major extensional tectonism and resurfacing (probably cryovolcanic) nearly 4 billion years ago. Impact crater populations on Pluto and Charon are not consistent with the steepest impactor size-frequency distributions proposed for the Kuiper belt.'' [22]

Information gained by means of New Horizons has already greatly transformed our understanding of how Pluto's atmosphere and geological processes work, even with much data remaining to be reduced and analyzed.

# 7 Relevance of the used technologies

## 7.1 X-band and Ka-band

New Horizons is an excellent example of the deep space mission. It comprises common but essential constituents: the probe itself, the scientific payload and the supporting equipment, which is located on Earth (Deep Space Network).

As technologies develop, only equipment which is located on Earth can be updated and improved. For instance, such an improvement was introduced in maintenance of NASA’s Galileo and the Voyager deep space missions. However, it is impossible to change anything on the New Horizons’ spacecraft which has been in space for approximately 10 years.

Communication between the spacecraft and the Deep Space Network is carried out by transmitting radiowave signals to antennas on Earth. The speed at which we can obtain necessary data depends on the distance between transmitter and receiver. This was a difficult problem that the designers of New Horizons had to overcome. In fact, the higher microwave frequencies are used, the less time is needed for signal transmission. Time reduction for New Horizons mission was very important.

At the starting point of the space exploration, missions such as Mariner 4 which flew past Mars in 1964 used "S-band" (an IEEE standard for radio waves with frequencies that range from 2 to 4 GHz, crossing the conventional boundary between Ultra High Frequency and Super High Frequency at 3.0 GHz [8]). In 1977 Voyager used the higher frequency "X-band" (the frequency range is specified by the IEEE at 8.0 to 12.0 GHz, Portions of the X band are assigned by the ITU (International Telecommunications Union) exclusively for deep space telecommunications. [6]), allowing Voyager to transmit significantly more data than Mariner 4. X-band is still used by most of spacecraft (including New Horizons) but there is a tendency to use higher frequencies. Moreover, the first mission using "$K_a$-band" was launched in 2009, only two years after New Horizons had left Earth.

$K_a$-band is a frequency range of wavelengths used mainly for satellite radio communication and radars. According to IEEE, this range extends from 40 to 26.5 GHz of the electromagnetic spectrum (corresponding to wavelengths of 1.13 to 0.75 cm) [7]. The name comes from a range of mixture of

English and German words "short" (Kurz) and "above", which indicates the position of the $K_a$-band above the K-band (18 - 26.5 GHz) [9].

If New Horizons had been able to use $K_a$-band, it would have potentially been able to transmit three-to-four times more data or return a similar amount of data more quickly than the year it would take to uplink all the measurements made at Pluto. But there is only a small chance of such an outcome, because the design of the spacecraft is complicated and this might not have led to such large improvements. One small implementation in a certain area can influence the entire spacecraft design and mission plan.

As for the actual instruments it is harder to know how things could have been different. A camera known as the wide-angle camera which used a telescope that was built as a spare part for Voyager is involved in Cassini–Huygens mission. This camera was designed in the early 1970s, it became a part of a spacecraft designed in the 1990s, and it is still sending high quality scientific images 40 years later that provides an opportunity to explore the nature of Saturn and its moons.

In the same way, Galileo spacecraft was launched in 1989 and carried science equipment such as the Heavy Ion Counter (HIC) which was in effect a repackaged and updated version of some parts of the flight spare of the Voyager Cosmic Ray System [10]. That is why the several year-old equipment does not appear to be a vital problem. [11]

## 7.2 Optical deep space communication as an alternative to RF communication

As it is already clear, the data rate of deep space missions is sufficient, but not nearly as fast as the average person are accustomed to (i.e. while using high-speed Internet). As was previously mentioned, conversion of X-band technology to Ka-band can improve data transmission. However, there is a relatively new method of laser communications, which is now being developed and tested worldwide. A prerequisite for the development of new technology is the imperfection of the current ones as well as the ever-increasing demand for data from planetary probe spacecraft. Present missions are also nearing its limitation in terms of the increasing complexity of the design. Increasing the size of antennas makes it more challengeable to embed them in the probe’s construction due to limits in size and weight. Enlargement of the spacecraft’s weight, in its turn, leads to an increased amount of fuel needed and higher costs for launching such a probe. Due to these reasons, it is not recommended to increase the power of the transmitter leading in electric power production complications; moreover, an issue with excessive undesired heat waste occurs as a result of inefficiencies in the transmitter's energy conversion elements.

The advantage of optical communications comes from the operational frequencies of signals, which are significantly higher than in the case of radio signals. Nowadays, usage of X-band is designated for deep-space communications and it is planned to substitute this with Ka-band in future missions. Optical communication, in its turn, theoretically can provide incomparable higher frequency than both of them, which makes it possible to surpass the existence of impeding practical factors like receiver sensitivities or atmospheric losses. RF systems are affected by attenuation of atmosphere due to weather notably at $K_a$-band, and they are capable of penetrating cloud cover, unlike optical systems. [27]

Optical communication is also capable of solving the problem with inefficient signal spread in space. It is offered to consider a hypothetical situation, showing the distribution of the signal toward the Earth from Voyager spacecraft working in X-band and the laser from a distance of about Saturn.

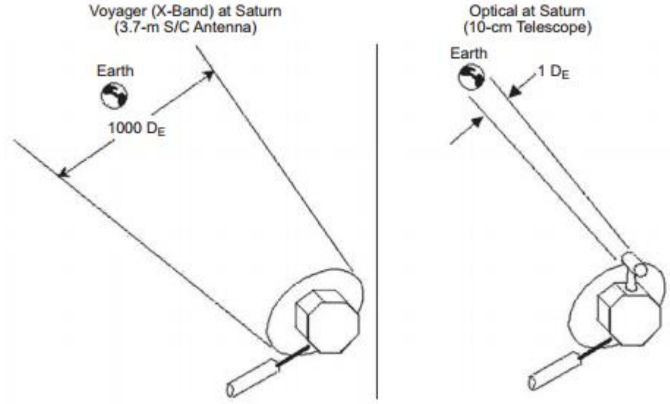

Figure 6 - *Comparison of RF and optical beam spreads from Saturn.* [25]

This figure shows how much more efficient usage of optics is. By comparing two situations, it becomes clear that the signal sent from the Voyager is a thousand times more divergent in space (due to diffraction impact). On the one hand it is an advantage, since it gives more opportunities for the spacecraft maneuvering and requires for less rigorous pointing. On the other hand, calculating the data from the assumption that optical wavelength and frequency are 1 μm and 300 THz respectively, 10-cm telescope provides a much more concentrated signal using lasers, than the

Voyager’s 3.7 m antenna. Overcoming the distance from Saturn to Earth, laser’s coverage will be quite commensurate with the diameter of Earth, while the coverage of the Voyager’s signal is 1000 times greater. According to Hemmati: “The wavelength-squared advantage over X-band is approximately 90 dB, although quantum effects and practical implementation considerations limit current realistic gains to about 60 Db”. [25] (Hemmati, *Deep Space Optical Communications, 4*) This example perfectly illustrates the advantages of laser technology and its potential.

Don Cornwell, director of the Advanced Communications and Navigation Technology Division at NASA headquarters told Space.com [26]: "If we wanted to do a Google map of the entire surface of Mars, it would take nine years to bring back all the data with the current radio-frequency system" when Mars is at its closest. "The laser communication system that we're talking about is 40 times more bandwidth, which means that you could bring back that Google map of the complete Martian surface in nine weeks instead of nine years".

# Conclusion

The New Horizons mission is just as important for the development of science as the study of the ocean floor in the Mariana Trench, or the rock formation of the Kola Superdeep Borehole. All this is quite exciting. Such information cannot be described in words and we cannot give it just a strictly practical sense. I am convinced that we must study everything that surrounds us, with all means available. Because people need to know what is around them in the solar system and should be aware of those parts in which we have not been yet. New Horizons is a relatively inexpensive, but very important mission that when completed will help us to cast a new light on our solar system, and understand how it was formed next to the various celestial bodies.

At the very least, New Horizons allowed us to get a photo of the last planet in the solar system, which we previously did not have. The New York Times has published a melancholy review, entitled “Reaching Pluto, and the End of an Era of Planetary Exploration”. Perhaps the flight to Pluto really marks a sunset of the planets’ discovery era in our solar system for years to come. Operating with up-to-date data, it is believed that Pluto formed much earlier than our planet and has passed all the same cycles of "development" as Earth, before its appearance at the edge of the solar system.

Space missions are mainly limited by costs and are designed for certain reconnaissance activities. If they do not support the available technology, then as a rule, they do not get selected for launch. NASA could have made New Horizons more effective by including more instruments, or more powerful by loading more fuel into it to enable it to downlink more data with the higher speed. However, this decision could have resulted in a mission delay, the loss of unique data and pioneer status. The bottom line, however, is that the exploration of the solar system continues. Furthermore, humankind continues a journey that started in 1894 in the Lowell Observatory in Arizona with the beginning of searching for the ninth planet.

# References

[1] JONES, Barrie William. *Pluto: Sentinel of the Outer Solar System*. New York: Cambridge UP, 2010. Print.

[2] WEAVER, H. A., GIBSON, W. C., TAPLEY, M. B. and YOUNG, L. A. *Overview of the New Horizons Science Payload*. Space Science Reviews. 2008. Vol. 140, no. 1-4, pp. 75-91. DOI 10.1007/s11214-008-9376-6. Springer Science + Business Media

[3] DEBOY, Christopher C., Christopher HASKINS, Dennis DUVEN, Ronald SCHULZE, J. Robert JENSEN, Mark BERNACIK a Wes MILLARD. *The New Horizons mission to Pluto: Advances in telecommunications system design.* Acta Astronautica [online]. 2005, vol. 57, 2-8, pp. 540-553. DOI: 10.1016/j.actaastro.2005.03.051. http://linkinghub.elsevier.com/retrieve/pii/S0094576505001086

[4] FOUNTAIN, Glen. *The New Horizons Spacecraft*. Southwest Research Institute, 2007. *The New Horizons Spacecraft*. SwRI-Boulder's Departments of Space Studies and Space Operations, 02 Feb. 2007. Web. <http://www.boulder.swri.edu/pkb/ssr/ssr-fountain.pdf>.

[5] DEBOY, C.C., et al. *The RF telecommunications system for the New Horizons mission to Pluto*. In: <i>2004 IEEE Aerospace Conference Proceedings [online]. IEEE, 2004, pp. 1463-1478. DOI: 10.1109/AERO.2004.1367922. [online] http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1367922

[6] Wikipedia, 2015, X band. [online]. 2015. [Accessed 20 November 2015]. https://en.wikipedia.org/wiki/X_band

[7] Wikipedia, 2015, Ka band. [online]. [Accessed 20 November 2015]. 2015. https://en.wikipedia.org/wiki/Ka_band

[8] Wikipedia, 2015, S band. [online]. [Accessed 20 November 2015]. 2015. https://en.wikipedia.org/wiki/S_band

[9] Itwissen.info, 2015, K-Band: K band :: ITWissen.info. 2015. [online]. [Accessed 7 November 2015]. http://www.itwissen.info/definition/lexikon/K-Band-K-band.html

[10] Wikipedia, 2015, Galileo (spacecraft). [online]. 2015. https://en.wikipedia.org/wiki/Galileo_(spacecraft)

[11] ARRIDGE, Chris. *New Horizons is an old spacecraft – but it will transform our knowledge of Pluto*. Phys.org [online]. 2014. http://phys.org/news/2015-07-horizons-spacecraft-knowledge-pluto.html

[12] SCHULZE, R.C. a S. HILL. *The new horizons high gain antenna: reflector design for a spin-stabilized bus at cryogenic temperatures*. 2004 IEEE Aerospace Conference Proceedings [online]. IEEE, 2004, pp. 966-974. DOI: 10.1109/AERO.2004.1367697. http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1367697

[13] JENSEN J. a G. WEAVER. *The In-Flight Frequency Behavior of Two Ultra-Stable Oscillators Onboard the New Horizons Spacecraft*. ResearchGate, 2007. [Online]. https://www.researchgate.net/publication/229054140_The_In-Flight_Frequency_Behavior_of_Two_Ultra-Stable_Oscillators_Onboard_the_New_Horizons_Spacecraft.

[14] Pluto.jhuapl.edu, *New Horizons. Power*, 2015. [online]. http://pluto.jhuapl.edu/Mission/Spacecraft/Systems-and-Components.php. [Accessed 07 December 2015].

[15] Pluto.jhuapl.edu, 2015, *New Horizons*. 2015. [online]. [Accessed 7 November 2015]. http://pluto.jhuapl.edu/Mission/Spacecraft/Payload.php

[16] Deepspace.jpl.nasa.gov, 2015, *About*. 2015. [online]. [Accessed 14 November 2015]. http://deepspace.jpl.nasa.gov/about/#

[17] Angelo, Joseph A. Encyclopedia of Space and Astronomy. Facts On File Science Library. New York, NY: Facts On File, ©2006. Accessed March 25, 2016. http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&an=229631.

[18] "Космические радиолинии | Вокруг света", Vokrugsveta.ru, 2007. [Online]. http://www.vokrugsveta.ru/vs/article/5956/. [Accessed 12 March 2016].

[19] BOKULIC, R. S., and JENSEN, J. R., *Tone-Based Commanding of Deep Space Probes Using Small Aperture Ground Antennas*, in Proc. 5th Int. Symp. on Reducing the Cost of Spacecraft Ground Systems and Operations, Pasadena, CA (Jul 2003)

[20] GRUNDY, W. M. et al., *Surface compositions across Pluto and Charon. Science* [online]. 2016. Vol. 351, no. 6279. [Accessed 13 April 2016].

DOI 10.1126/science.aad9189. http://science.sciencemag.org/content/351/6279/aad9189American Association for the Advancement of Science (AAAS)

[21] GLADSTONE, G. R. et al. *The atmosphere of Pluto as observed by New Horizons*. Science [online]. 2016. Vol. 351, no. 6279. [Accessed 10 April 2016].

DOI 10.1126/science.aad8866.

http://science.sciencemag.org/content/351/6279/aad8866American Association for the Advancement of Science (AAAS)

[22] MOORE, J. M. et al., *The geology of Pluto and Charon through the eyes of New Horizons*. Science [online]. 2016. Vol. 351, no. 6279, pp. 1284-1293. [Accessed 13 April 2016].

DOI 10.1126/science.aad7055.

http://science.sciencemag.org/content/351/6279/1284American Association for the Advancement of Science (AAAS)

[23] American Heritage® Dictionary of the English Language, Fifth Edition. S.v. "tholin." Retrieved April 11 2016 from http://www.thefreedictionary.com/tholin

[24] HASKINS, C.B. and W.P. MILLARD. *X-band digital receiver for the New Horizons spacecraft*. In: 2004 IEEE Aerospace Conference Proceedings (IEEE Cat. No.04TH8720) [online]. IEEE, 2004, pp. 1479-1488

DOI: 10.1109/AERO.2004.1367923. ISBN 0-7803-8155-6 http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1367923

[25] HEMMATI, Hamid, 2006, *Deep space optical communications*. Hoboken, NJ: Wiley-Interscience.

[26] LEWIN, Sarah, Staff Writer, 2015, NASA's Laser-Communication Tech for Spacecraft Zaps Forward. *Space.com* [online]. 2015. [Accessed 9 March 2016].

http://www.space.com/30452-nasa-laser-communications-system-spacecraft.html

[27] WILLIAMS, W. Dan, 2007, RF and Optical Communications: A Comparison of High Data Rate Returns from Deep Space in the 2020 Timeframe. *Ntrs.nasa.gov* [online]. 2007. [Accessed 9 March 2016]. http://ntrs.nasa.gov/search.jsp?R=20070017310&hterms=rf+optical&qs=N%3D0%26Ntk%3DAll%26Ntt%3Drf%2520and%2520optical%26Ntx%3Dmode%2520matchallpartial%26Nm%3D123%7CCollection%7CNASA%2520STI%7C%7C17%7CCollection%7CNACA

[28] Wikipedia, 2016, New Horizons. [Online]. [Accessed 07 March 2016].

https://en.wikipedia.org/wiki/New_Horizons