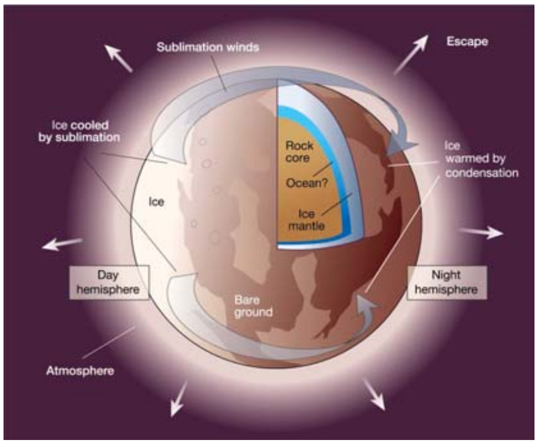
National Aeronautics and Space Administration

Exploring the Dwarf Planets

Exploring the Atmosphere of Pluto

Pluto radius… 1184 km
Pluto mass…. 1.3×10^{22} kg

Pluto temperature:
Closest to sun…. 55 kelvin (-218 C)
Farthest from sun… 33 kelvin (-240 C)



Pluto's atmospheric details. (Credit: NASA/JHUAPL)

Scale-height:

$$H = \frac{kT}{Mg}$$

k = 1.38×10^{-23} J/K
T = temperature in kelvin
g = acceleration of gravity at surface
M = mass of the molecule in kg

For Earth's atmosphere, T = 290 k, M=4.8×10^{-26} kg, g = 9.8 m/sec^2, then H = 8500 meters.

What this means is that each time you increase your altitude by 8500 meters, the density of the atmosphere decreases by a factor of 2.7 times.

Pluto's atmosphere consists of a thin envelope consisting of 90% nitrogen, and 10% methane, and traces of carbon monoxide gases. These are produced by the ices of these substances on its surface. As Pluto moves away from the Sun, its atmosphere gradually freezes out and falls to the ground. When Pluto is closer to the Sun, the temperature of Pluto's solid surface increases, causing the ices to sublimate into gas.

One way to compare the atmospheres of the planets is by calculating their scale heights. The scale height is the height above the surface such that 37% of the mass of the atmosphere is below this height. Mathematically, this is equal to

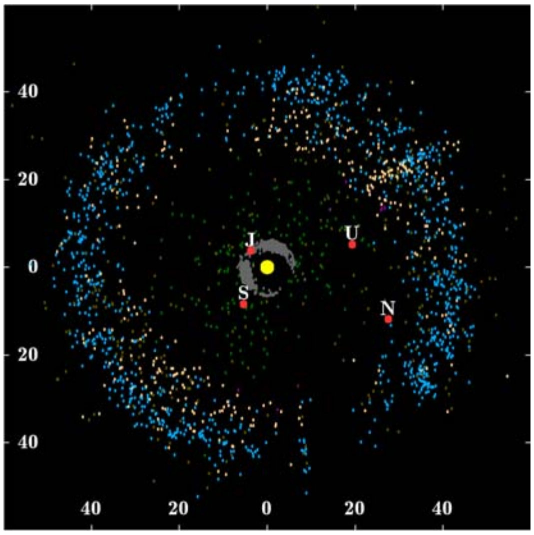
e^{-1}=1/2.7 of the material.

From the formula for H, you can see that as you make your planet more massive, the scale height 'thickness' of the atmosphere decreases. But if you have the same planet closer to the sun where it can be hotter, the thickness of the atmosphere can increase.

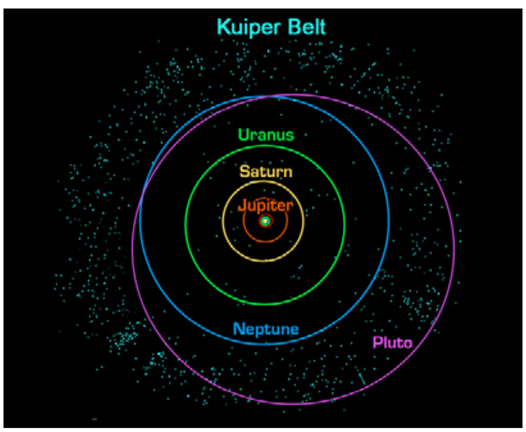
It is also the case that an atmosphere composed of low-mass molecules like hydrogen (smaller M) is much thicker than the atmospheres of heavier molecules (larger M) such as argon and carbon dioxide.

Things to think about: How does the scale height of Pluto's atmosphere change as it orbits the sun if the average atmosphere molecule mass (N_2) is 4.7×10^{-26} kg, and g for Pluto is 0.66 m/sec^2.

Mysteries of the Kuiper Belt



Objects of the Kuiper belt (blue). Plot displays the known positions of objects in the outer Solar System within 60 astronomical units (AU) from the Sun as of January 1, 2015. (Credit: SAO Minor Planets Center)



Location of the Kuiper belt.
(Image Credit: STScI/A. Feild)

At its fullest extent, including its outlying regions, the Kuiper belt stretches from roughly 30 to 55 AU, where 1 AU is the distance of our Earth from the sun. However, the main body of the belt is mostly located between 39.5 AU to 48 AU. Overall it more resembles a torus or doughnut than a belt. The presence of Neptune has a big effect on the Kuiper belt's structure because of orbital resonances. This causes the Kuiper belt to have gaps like the rings of Saturn, between 40 and 42 AU.

There are about 1,300 Kuiper belt objects (KBOs) that are known beyond the orbit of Pluto. Most are located between 39 and 48 AU. These are called the 'Classicals'. The ones farther out than 48 AU are called the 'Scattered Disk population'.

Studies of thousands of stars with the Hubble Space Telescope have found very few 'eclipses' by small KBOs below about 10km. This means that most common KBOs are larger objects just barely detectable by Hubble…at least eventually.

It is estimated that there might be as many as 100,000 KBOs that are 100 km across or bigger that are yet to be discovered. There may also be billions of KBOs larger than 10 km yet to be detected.

The average distance between particles can be estimated by taking the reciprocal of the cube-root of the density of particles. For example, if the density is 1000 particles per cubic meter, the average distance between them is about $D = 1/1000^{1/3} = 0.1$ meters.

Things to think about: If the Kuiper Belt is a disk with radii of 39 AU and 48 AU, with a thickness of 10 million km, what is the average distance between KBOs if there are one billion of them in this volume of space? (Hint: 1 AU = 150 million km)

The Journey Beyond Pluto: What's Next?

This is an artist's impression of a Kuiper Belt object (KBO), located on the outer rim of our solar system at a staggering distance of 4 billion miles from the Sun. The Sun appears as a bright star at image center in this graphic, which represents the view from the KBO. The Earth and other inner planets are too close to the Sun to be seen in this illustration. The bright "star" to the left of the Sun is the planet Jupiter, and the bright object below the Sun is the planet Saturn. Two bright pinpoints of light to the right of the Sun, midway to the edge of the frame, are the planets Uranus and Neptune, respectively. The planet positions are plotted for late 2018 when the New Horizons probe reaches a distance of 4 billion miles from the Sun.

After its encounter with Pluto on July 14, 2015, the New Horizons spacecraft will have enough fuel left over to maneuver it into a trajectory to fly-by one more object. The challenge is to find a suitable target that just happens to be within the range of New Horizons after July, 2015!

The New Horizons team spent 45 days during the summer of 2014 searching for potential targets. To do this, they used data from the Hubble Space Telescope since 2011 to investigate the known Kuiper Belt Objects in the part of space where New Horizons would be. Five KBOs were identified, and after a careful study of their orbits and sizes, two potential destinations remained by October, 2014.

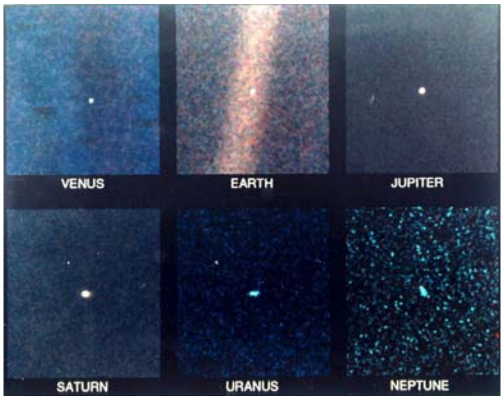
The first candidate, 2014 MT70, formerly called Potential Target 3 (PT3) has a diameter of approximately 47 miles (76 kilometers) and orbits at a distance of 44 AUs from the sun. New Horizons would arrive there in June 2019 and use 75% of its available fuel to get there.

The second candidate, 2014 MT69 (called PT 1), is a 37 mile (60 kilometer) wide body that orbits the sun at a distance 44.3 AUs. It would take less fuel (only 35% of the reserves) to reach it than 2014 MT70, and New Horizons could arrive there around January, 2019.

NASA will announce which target will be selected in August, and make the final course correction in October, 2015.

Things to think about: Search the Internet for images of the smaller moons of Jupiter, Saturn, Uranus and Neptune. Create a sketch of what you think 2014 MT69 or 2014 MT70 might look like, close-up. Describe why you selected the shape and features that you used.

The Solar System from Pluto: Looking Back



Images of the planets taken by the Voyager 1 spacecraft at the distance of 4 billion miles from Earth using a very small telescope that could not resolve the disks of the planets.

Transit of Venus, 2012 photographed by NASA Astronaut Tom Pettit.
(Credit: NASA/ESA)

Solar diameter = 1890 arcseconds
Venus diameter = 58 arcseconds

At the distance of Pluto in July, 2015 (7.5 billion km), the planets Mercury, Venus, Earth and Mars would be no farther than about 2 degrees from the sun. As for the rest of the planets, they would move back and forth along roughly the same line in the sky (called the Ecliptic) and never get farther from the sun that about 31 degrees (maximum for Neptune).

The maximum sizes of these planets from Pluto would be at the point where the distance to the planets from Pluto is the smallest. As seen from Earth, the maximum diameter of Mars is about 25 arcseconds (asec), while Neptune is about 2 asecs. As viewed from Pluto, our sun has a diameter of about 38 asecs. The other planets appear far smaller:

Earth: 0.3 asec	Mars: 0.2 asec
Jupiter: 4.3 asec	Saturn: 3.9 asec
Uranus: 6.3 asec	Neptune: 3.7 asec.

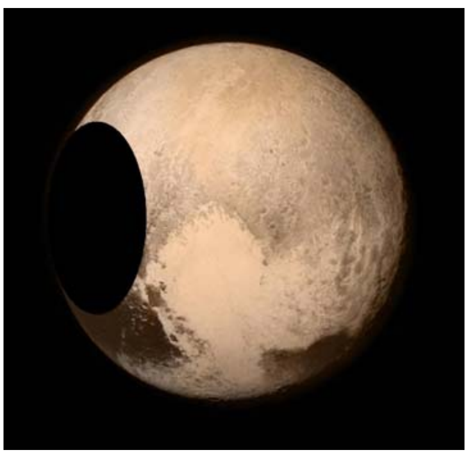
When each planet passes across the face of the sun, astronomers call this a transit. From Earth, the only planets we can see in transit are Mercury and Venus.

The previous Mercury Transit occurred on November 8, 2006 and the next one will happen on May 9, 2016. For Venus, the previous Venus Transit happened on June 5, 2012 and the next one will happen on December 10, 2117!

Things to think about: Draw a scaled diagram of what each of the planets would look like as they pass across the face of the sun as viewed from Pluto. Will the planets appear as colored disks with surface details, or as black disks? Explain.

Solar Eclipses from Pluto?

Because of the combination of our moon's diameter and distance, it subtends the same angle as our sun does from Earth. The two discs are nearly equal. This permits a total solar eclipse of the bright disk of the sun, revealing the faint corona. The image is of the total solar eclipse of November 13, 2012. (Credit: NASA/Cirtain)

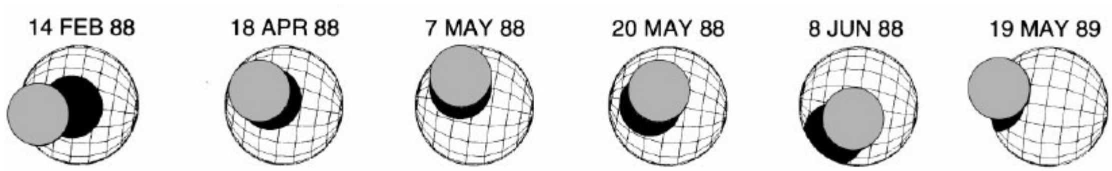


Approximate shadow size of Charon on Pluto for June 28, 2110.

From the surface of Pluto, the moon Charon would be about 8 times bigger than our own moon in the sky. It has an angular diameter of roughly 4 degrees as seen from the surface of Pluto. The Sun, meanwhile, appears much smaller, only about 1 arcminute in diameter. Every 124 years, and lasting for several years, Charon eclipses the Sun in step with its orbit period of 6.38 days. Because of the large size of Charon's shadow on Pluto, very large areas of Pluto can see the solar eclipse.

Pluto also has four smaller moons, and each of these also eclipses the sun at the appropriate times in Pluto's orbit. Nix's angular diameter is about 9 minutes of arc and Hydra's is about 7 minutes of arc. These are much larger than the Sun's angular diameter, so total solar eclipses are possible with these moons.

The next period of time when solar eclipses can occur on Pluto will begin October 2103, peak in 2110, and end January 2117. During this period, solar eclipses will occur at some point on Pluto every orbit of Charon. The maximum duration of any solar eclipse by Charon as seen from Pluto during this period is about 90 minutes.



Calculation of Charon eclipsing Pluto during 1988. From the surface of Pluto, solar eclipses would be observed under Charon's shadow. (Image credit: SwRI/Eliot Young in *The Astronomical Journal*, v. 117, pp 1063-1076)

Things to think about: Create a sketch from the surface of Pluto to show what the solar eclipses created by Nix and Hydra would look like.

Pluto: The Twilight World

The luminous energy of our sun is so great that even from the distance of Pluto, 7.5 billion kilometers, it is still bright enough to cast shadows!

The orbit of Pluto is not a perfect circle but an ellipse. This means that instead of having a constant distance to the sun, Pluto's distance changes from 7.3 billion kilometers to 4.4 billion kilometers. For part of its orbit, it is actually closer to the sun than Neptune (4.7 billion km)!

The brightness of our sun depends on the planet's distance according to the Inverse-Square Law which states that, as you double a planet's distance from the sun, the sun's brightness diminishes by a factor of $1/2^2 = 1/4$. If a planet is 40 times farther away from the sun than our Earth, sunlight will be $1/40^2 = 1/1600$ times dimmer.

This is a big problem for spacecraft powered by solar panels. It means that to create the same amount of electricity near Pluto where sunlight is 1600 times dimmer, you need solar panels that cover 1600 times as much area! That makes them very heavy, and this is why spacecraft use nuclear power (called Radioisotope Thermoelectric Generators or RTGs) instead of solar power.

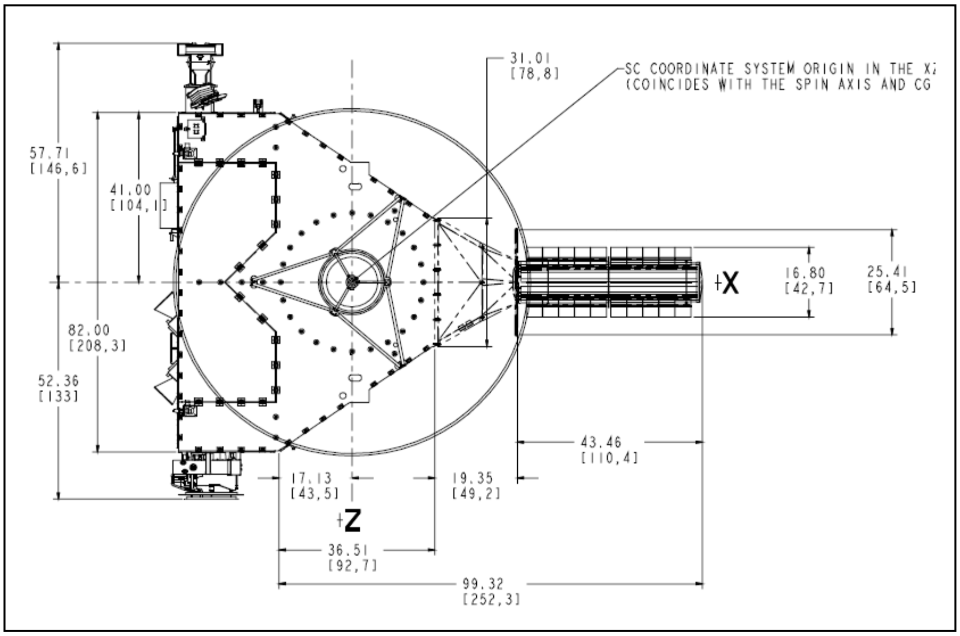
If you want to explore what the lighting conditions are where you live that mimic Pluto's noontime sunshine, visit NASA's *PlutoTime* website at

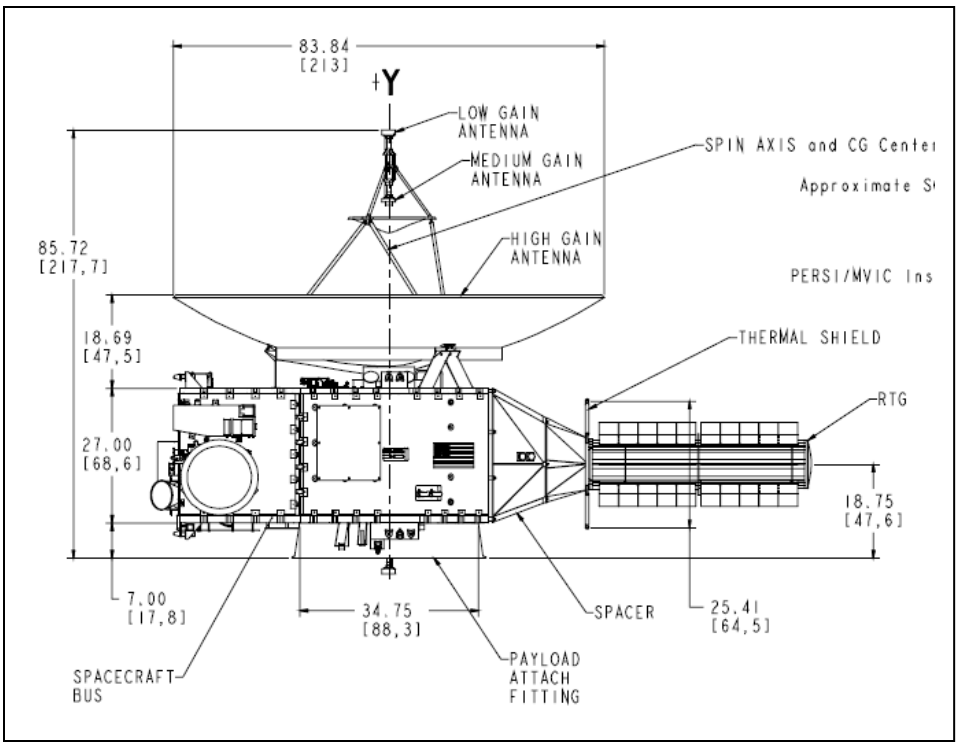
http://solarsystem.nasa.gov/plutotime/

Just input your location and the program will predict at what time you should go outside and see what your world looks like with Pluto's illumination!

Things to think about: The distance from Earth to the sun is 150 million km. From the closest and farthest distances to Pluto from the sun, by what factors is sunlight dimmer on the surface of Pluto during each of these times? If the solar panel on your roof measures 10 meter^2 to generate 2000 watts and costs $6000, how big would the same system be near Pluto to generate the same amount of power?

The New Horizons Spacecraft: Close-up





These two drawings show the major parts and dimensions of the spacecraft. The top drawing looks down on the spacecraft through the radio dish (large circle). The bottom figure is a side view of the spacecraft.

The dimensions are recorded between the arrowed segments. For instance the length of the RTG unit on the right-hand side of the spacecraft is given in inches as 43.46, and in metric units in brackets as 110.4 centimeters.

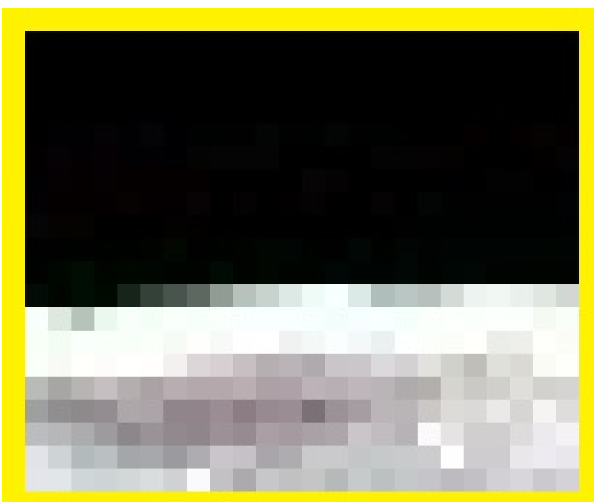
The drawings were created by mechanical engineers based on the work by scientists and other engineers who designed the instruments and other flight hardware.

The total mass of the spacecraft fully-fueled was 478 kilograms (1,054 pounds).

Things to think about: From the dimensions and clues given in the two drawings, what is the volume in cubic meters of the triangular spacecraft body, not including the portion labeled 'spacer' or the RTG unit? (Hint: Consider the spacecraft as a collection of squares, rectangles, triangles and their individual 3-D volumes)

The Transmission of Images from Pluto.

The top image shows a 800x600 pixel digital photo of the full moon in black and white. The small yellow box on the top edge of the moon is a 22x26 pixel piece of this image shown enlarged below.



To send this image to Earth, the brightness of each of the pixels is sent as a string of numbers called data words. The enlarged piece of the larger picture contains 22x26 = 572 pixels, so a string of 572 binary numbers has to be sent to Earth just for this little piece of the image. The full image requires 480,000 numbers to be transmitted.

Each data word is a 12-bit binary number that indicates how bright the pixel is from 000000000000 or '0', which is black to 111111111111 or '8191' which is white. This is often referred to as a 'grey scale level'. For example, the spacecraft might send a string of binary digits for Pixel 234 and Pixel 235 as

….000000000000111111111111….

This will be translated as Pixel 234=0 and Pixel 235=8191, meaning that when you reconstruct the image from the data you assign Pixel 234 as 'black' and Pixel 235 as 'white' on the greyscale. Color images are created from three of these images; one each for the Red, Blue and Green intensity data.

Things to think about: From the distance of Pluto, the New Horizon spacecraft can transmit data at a rate of 1,000 bits per second. Each image contains 1024x1024 pixels, and each pixel is coded with 12-bits of intensity data. How long will it take to transmit to Earth one of these uncompressed images? How long will it take if the image is compressed to 2.5 megabits before sending?

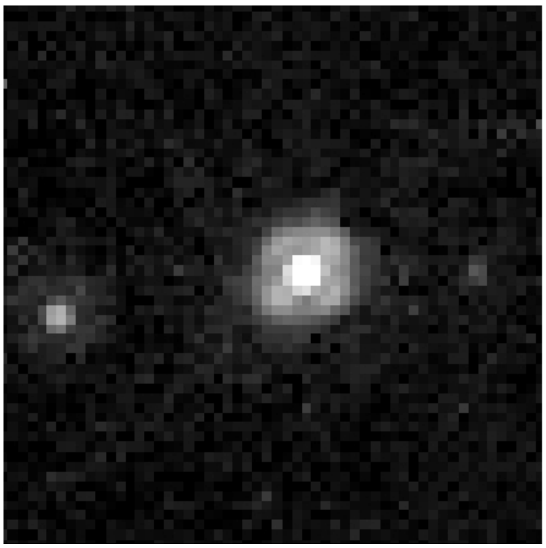
Exploring Dwarf Planet Haumea

Discovered:	**Mike Brown, 2004**
Size:	**1,920 km x 1,540 km x 990 km**
Mass:	**4 billion billion tons**
Orbit Size:	**51.48 AU x 34.95 AU**
Orbit period:	**284.1 years**
Temperature:	**32 k (-241 C)**

Haumea is rotating so rapidly that it has become elongated into a football-shape! This shape means it is mostly a rocky body with a thin surface of ice, otherwise it would be either much rounder (if all rock), or much more elongated (if more ice).

Up to 80% of the surface material may be pure crystalline water ice. Hydrogen cyanide, silicate clays, and inorganic salts such as copper potassium cyanide may also be present.

The lack of any compounds such as methane suggests a collision occurred in the past. The heat from the collision vaporized these compounds. A very bright feature on the surface may be fresh ice or snow at the site of a large impact crater.



This is an actual image of Haumea and its two small moons Hi'iaka (left) and Namaka (right) taken by the Hubble Space Telescope. The moons are believed to have been formed from the collision that formed Haumea itself.

Haumea is one of the five known dwarf planets, which also includes Ceres (938 km), Pluto (2,368 km), Eris (2,326 km) and Makemake (1,434 km).

Dwarf planets are all round and orbit our sun, but they are too small in mass, and have such weak gravity, that they have not swept out all of the orbital debris in their vicinity unlike the eight 'true' planets.

Things to think about: Astronomers sometimes use a single number to represent the diameter of an object that is not perfectly round. How many different diameter definitions can you come up with for Haumea?

Exploring Dwarf Planet Makemake

Discovered:	**Mike Brown, 2005**
Diameter:	**1,434 km**
Mass:	**3 billion billion tons**
Orbit Size:	**52.84 AU x 38.59 AU**
Orbit period:	**309.1 years**
Temperature:	**32 k to 44 k (-241 to -229 C)**

Like Pluto, Makemake appears red in the visible spectrum, and significantly redder than the surface of Eris. The spectrum shows the presence of methane ice on its surface, which is similar to Pluto and Eris. This methane, however, must be present in the form of large grains at least one centimeter in size. It contains far less nitrogen ice than found on Pluto, suggesting that over billions of years this ingredient has been lost.

The surface of Makemake cannot be easily discerned by the most powerful optical telescopes because it is so far away and not very big. This magnified image only shows it as a blob of light. Even its round disk cannot be seen very clearly.

The faint light from Makemake can be gathered by telescopes and spread out into a spectrum. When studied at high magnification, this spectrum reveals the fingerprints of molecules like methane, ethane and other organic compounds. The reddish color of Makemake and other dwarf planets is due to deposits of compounds called tholins on the surface.

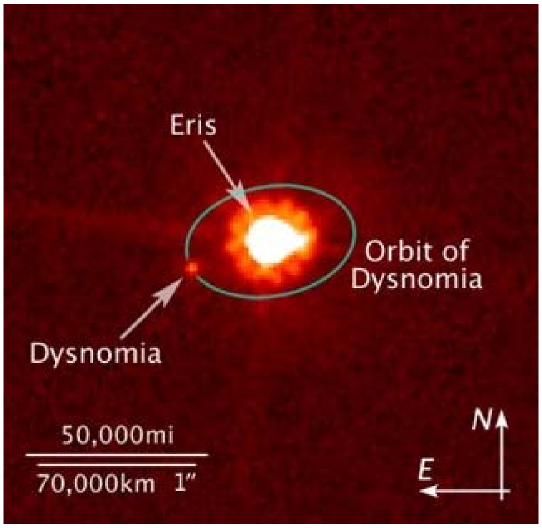
Makemake, with a diameter of 1,434 km, is one of the five known dwarf planets, which also includes Ceres (938 km), Pluto (2,368 km), Eris (2,326 km) and Haumea (1,240 km).

Things to think about: From the measured diameter, what is the mass of Makemake if it consisted of water ice with a density of 917 kg/m^3 ? Suppose it consisted only of common granite rocks with a density of 2700 kg/m^3, what would its mass be?

Exploring Dwarf Planet Eris

Discovered:	**Mike Brown, 2005**
Diameter:	**2,326 km**
Mass:	**17 billion billion tons**
Orbit Size:	**97.65 AU x 37.91 AU**
Orbit period:	**558.0 years**
Temperature:	**30 k to 55 k (-243 to -218 C)**

Due to its mass and size being similar to Pluto's, Eris is probably an object with a rocky core and an icy mantle. Its surface has a similar reddish color to Pluto's and methane ice has been detected spectroscopically. Like Pluto, methane ices on the surface of Eris may create a brief atmosphere during the planet's closest approach to the sun (perihelion) and then re-freeze in the winter (aphelion).



Mass Calculation: The mass of Eris can be calculated from the orbit details of its moon Dysnomia, (diameter 684 km), which orbits Eris every 15.774 days (1.36×10^6 seconds) at a distance from the center of Eris of 37,350 km (3.735×10^7 meters). From the formula,

$$M = \frac{4\pi^2 R^3}{GT^2}$$

where G = Newton's constant of gravity (6.66×10^{-11} kg $\sec^2/m^3$) and for Dysnomia's orbit R = 3.735×10^7 meters and T = 1.36×10^6 seconds, we get M = 1.67×10^{22} kg or about 17 billion billion tons.

Eris, with a diameter of 2,326 km, is one of the five known dwarf planets, which also includes Ceres (938 km), Pluto (2,368 km), Makemake (1,430 km) and Haumea (1,240 km). These objects are all round and orbit our sun, but are too small to have swept out all of the orbital debris in their vicinity unlike the eight 'true' planets.

Things to think about: From the measured mass and diameter, what is the average density of Eris? If water ice has a density of 917 kg/m^3 and common granite rocks have a density of 2700 kg/m^3, what would be your best guess about the composition of Eris?

Answers to Problems

In the following answers, the rules for Significant Figures will be applied. Answers will be given to correspond to the smallest number of significant figures in the numerical information and applied after the computation is completed. Example: (1.346 x 1.23) x 3.45 = 5.711751 but with SF applied to 3 SF you get the final answer of 5.71.

11 - Exploring the Atmosphere of Pluto - How does the scale height of Pluto's atmosphere change as it orbits the sun if the average atmosphere molecule mass (N_2) is 4.7×10^{-26} kg, and g for Pluto is 0.66 m/sec^2. **ANSWER:** At closest: T = 55 k so H = $(1.38\times10^{-23})(55)/(4.7\times10^{-26})(0.66)$ = 24 kilometers. At farthest: T = 33k so H = 24.5 x (33/55) = 15 kilometers.

12 - Mysteries of the Kuiper Belt - If the Kuiper Belt is a disk with radii of 39 AU and 48 AU, with a thickness of 10 million km, what is the average distance between KBOs if there are one billion of them in this volume of space? (Hint: 1 AU = 150 million km). **ANSWER:** Volume = $\pi(48^2 - 39^2)$(10 million/150 million) = π(2304 - 1521)(0.066AU) = 160 cubic AUs. Density of particles = 1 billion/160 = 6.2×10^6 KBOs per cubic AU. The average distance is then $1/(6.2\times106)^{1/3}$ = 0.0055 AUs. This is a distance of about 820,000 km, or about 3 times the Earth-Moon distance.

13 - The Journey Beyond Pluto: What's Next? - Search the Internet for images of the smaller moons of Jupiter, Saturn, Uranus and Neptune. Create a sketch of what you think 2014 MT69 or 2014 MT70 might look like, close-up. Describe why you selected the shape and features that you used. **ANSWER:** These objects are about 60 km across and are in the outer solar system where icy objects are common. For example, the moon of Saturn called Prometheus is about this size and there is a clear image of it taken by Cassini. It is potato-shaped and lightly cratered.

14 - The Solar System from Pluto: Looking Back - Draw a scaled diagram of what each of the planets would look like as they pass across the face of the sun as viewed from Pluto. Will the planets appear as colored disks with surface details, or as black disks? Explain. **ANSWER:** They will appear as black disks because they will be located exactly between the sun and Pluto when they cross and so will not appear illuminated by the sun. If you draw a circle 10 cm in diameter representing the sun (38 asec in diameter), the diameters of each of the planets to this scale will be Earth (0.3 asec)= 0.8 mm, Mars (0.2 asec) = 0.5 mm, Jupiter (4.3 asec) = 11 mm, Saturn (3.9 asec) = 10 mm ,Uranus (6.3 asec) = 17 mm, Neptune (3.7 asec) = 10 mm.

15 - Solar Eclipses from Pluto? - Create a sketch from the surface of Pluto to show what the solar eclipses created by Nix and Hydra would look like. Nix's angular diameter is about 9 minutes of arc and Hydra's is about 7 minutes. Sun=1 arcminute. **ANSWER:** Draw a circle 1 cm in diameter to represent the sun. On this scale, Nix will be a circle 9 cm in diameter and Hydra will be 7 cm in diameter.

16 - Pluto: The twilight world. - The distance from Earth to the sun is 150 million km. From the closest and farthest distances to Pluto from the sun, by what factors is sunlight dimmer on the surface of Pluto during each of these times? If the solar panel on your roof measures 10 meter^2 to generate 2000 watts and costs \$6000, how big would the same system be near Pluto to generate the same amount of power? **ANSWER:** Pluto's distance changes from 7.3 billion kilometers to 4.4 billion kilometers. Closest: (150 million/4.4 billion)^2 = 1/860 farthest (150 million/7.3 billion)^2 = 1/2400. A solar panel system at closest distance would have to have an area 860x10 m^2 = 8600 m^2 and cost 860x\$6000 = \$5.16 million. At the farthest distance it would cover an area of 24000 m^2 and cost \$14.2 million.

17 - The New Horizons Spacecraft: Close-up - From the dimensions and clues given in the two drawings, what is the volume in cubic meters of the triangular spacecraft body, not including the portion labeled 'spacer' or the RTG unit? (Hint: Consider the spacecraft as a collection of squares, rectangles, triangles and their individual 3-D volumes). **ANSWER:** The spacecraft looks like an equilateral triangle with a rectangle attached to its base, and the tip of the triangle cut off. From the top view, the rectangular base measures 82 inches (208 cm) long and by using the drawing scale its width is about 24 inches (61 cm) and from the side view it has a depth of 27 inches (68.6 cm) for a volume of 208cm x 61cm x 68.6 cm = 870,000 cm3. The triangular piece with part of its tip cut off near the RTG is a bit trickier to estimate. It is an equilateral triangle with a side length of 82 inches (208 cm). The area of an equilateral triangle is

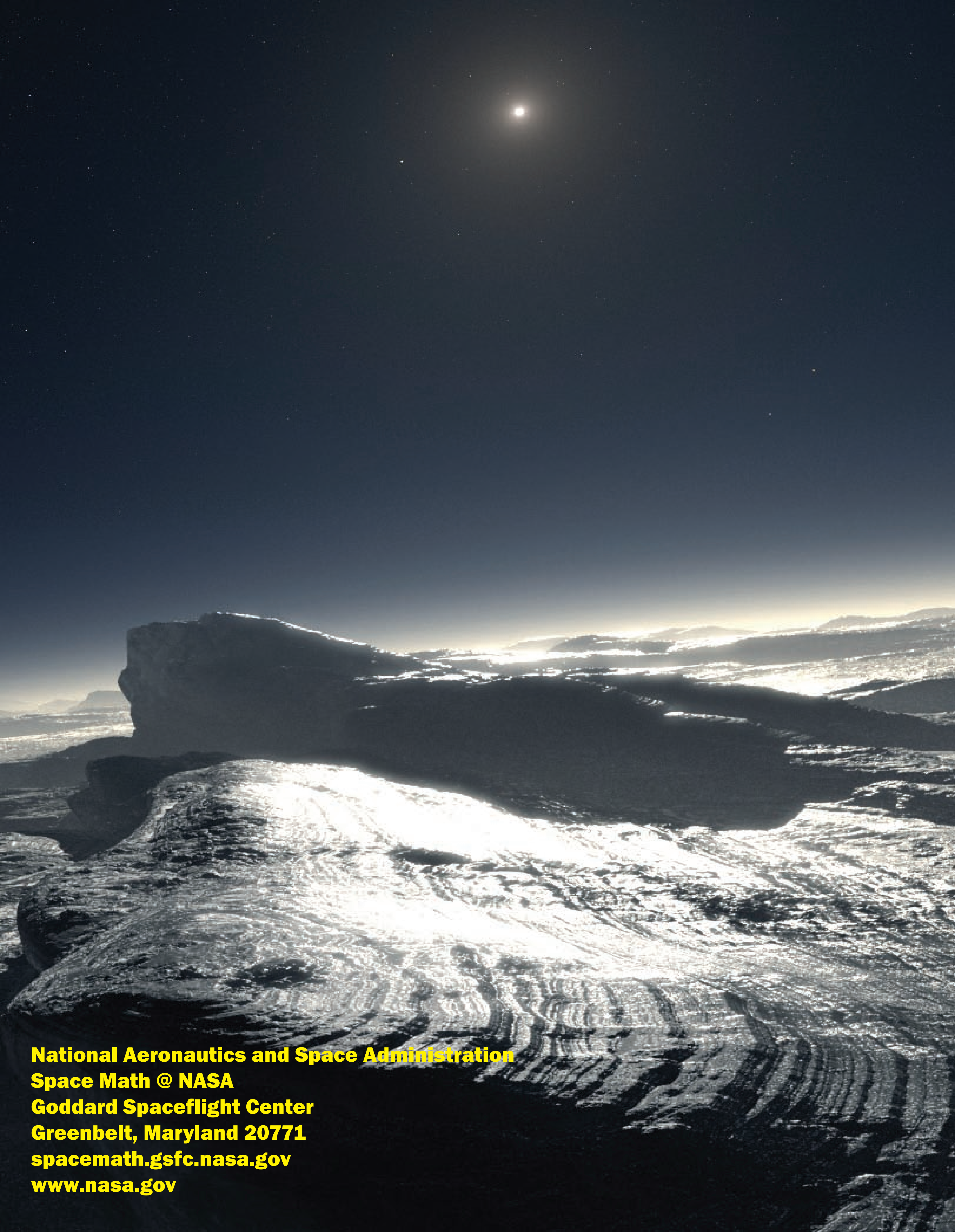
$s^2 \frac{\sqrt{3}}{4}$ where s = 208 cm, so A = 18,700 cm^2, but the tip of this triangle has been removed. This tip is another smaller equilateral triangle with a side length from the drawing that is about 59 cm, so its areas is 1,500 cm^2. So the clipped triangular face of the spacecraft has an area of 18,700 - 1,500 = 17,200 cm^2. The width of the spacecraft is 68.6 cm, so the volume is 1,180,000 cm^3. When this is added to the volumes of the base rectangle we get 2,050,000 cm^3. Since one cubic meter is 1 million cm^3, the volume of the spacecraft is about 2.1 cubic meters.

18 - The Transmission of Images from Pluto. - From the distance of Pluto, the New Horizon spacecraft can transmit data at a rate of 1,000 bits per second. Each image contains 1024x1024 pixels, and each pixel is coded with 12-bits of intensity data. How long will it take to transmit to Earth one of these uncompressed images? How long will it take if the image is compressed to 2.5 megabits before sending? **ANSWER:** Total pixels = 1024x1024 = 1,049,000. Total bits = 12 x 1,1049,000 = 12,600,000. At 1,000 bits/sec it will take 12,600 seconds or 3.5 hours. With compression to a 2,500,000 bit file, it will take 2,500 seconds or 42 minutes.

19 - Exploring Dwarf Planet Haumea - Astronomers sometimes use a single number to represent the diameter of an object that is not perfectly round. How many different diameter definitions can you come up with for Haumea? **ANSWER:** Average diameter: (1920+1540+990)/3 = 1,480 km. Radius based on volume of equivalent sphere. $4/3\pi R^3$ = 1920x1540x990=$2.93x10^9$ km^3 so R = 882 km, and diameter = 1,770 km.

20 - Exploring Dwarf Planet Makemake - From the measured diameter, what is the mass of Makemake if it consisted of water ice with a density of 917 kg/m^3 ? Suppose it consisted only of common granite rocks with a density of 2700 kg/m^3, what would its mass be? **ANSWER:** Radius = 1434/2 = 717 km. Volume = 4/3 $(3.14)(717000)^3$ = $1.54x10^{18}$ m^3. Density = $3x10^{21}$ $kg/1.54x10^{18}m^3$ = 2,000 kg/m^3. It probably contains about as much ice as a granite-like material.

21 - Exploring Dwarf Planet Eris - From the measured mass and diameter, what is the average density of Eris? If water ice has a density of 917 kg/m^3 and common granite rocks have a density of 2700 kg/m^3, what would be your best guess about the composition of Eris? **ANSWER:** Radius = 2326/2 = 1163 km. Volume = 4/3 $(3.14)(1163000)^3$ = $6.59x10^{18}$ m^3. Density = $1.7x10^{22}$ $kg/6.59x10^{18}$ m^3 = 2600 kg/m^3. It is probably mostly a granite-like material with very little ice.



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