NORTHROP GRUMMAN

SPACE PRIMER

Front cover

All four satellites on the cover are built by Northrop Grumman.

The spacecraft in the upper left is the James Webb Space Telescope, the successor to the Hubble Space Telescope. Using the largest deployable telescope ever launched, the spacecraft will look deep into space to observe the universe billions of years ago when stars and galaxies were just beginning to form.

The Earth Observing System Aura, shown in the lower left, is studying the Earth's ozone, air quality and climate.

The Chandra X-ray Observatory satellite, shown in the upper right, is a highly sensitive X-ray telescope orbiting the Earth. It detects X-rays coming from very hot places in the universe such as exploding stars, galaxy clusters and black holes.

The lower right satellite is the National Polar-orbiting Operational Environmental Satellite System which will monitor the Earth and help improve weather forecasts.

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California Science Education Standards

Grade 5: Earth Sciences
5. The solar system consists of planets and other bodies that orbit the sun in predictable paths. As a basis for understanding this concept:
a. Students know the sun, an average star, is the central and largest body in the solar system and is composed primarily of hydrogen and helium.
b. Students know the solar system includes the planet Earth, the moon, the sun, eight other planets and their satellites, and smaller objects, such as asteroids and comets.
c. Students know the path of a planet around the sun is due to the gravitational attraction between the sun and the planet.

Grade 8: Forces
2. Unbalanced forces cause changes in velocity. As a basis for understanding this concept:
e. Students know that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction).

Grade 8: Earth in the Solar System
4. The structure and composition of the universe can be learned from studying stars and galaxies and their evolution. As a basis for understanding this concept:
a. Students know galaxies are clusters of billions of stars and may have different shapes.
b. Students know that the sun is one of many stars in the Milky Way galaxy and that stars may differ in size, temperature, and color.
c. Students know how to use astronomical units and light years as measures of distances between the sun, stars, and Earth.
d. Students know that stars are the source of light for all bright objects in outer space and that the moon and planets shine by reflected sunlight, not by their own light.
e. Students know the appearance, general composition, relative position and size, and motion of objects in the solar system, including planets, planetary satellites, comets, and asteroids.

Grades 9-12: Motion and Forces
1. Newton's laws predict the motion of most objects. As a basis for understanding this concept:
d. Students know that when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction (Newton's third law).
f. Students know applying a force to an object perpendicular to the direction of its motion causes the object to change direction but not speed (e.g., Earth's gravitational force causes a satellite in a circular orbit to change direction but not speed).
g. Students know circular motion requires the application of a constant force directed toward the center of the circle.

National Science Education Standards

Grades 5-8, Standard B: Motions and Forces
If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

Grades 5-8, Standard D: Earth in the Solar System
The Earth is the third planet from the sun in a system that includes the moon, the sun, eight other planets and their moons, and smaller objects, such as asteroids and comets. The sun, an average star, is the central and largest body in the solar system.

Gravity is the force that keeps planets in orbit around the sun and governs the rest of the motion in the solar system. Gravity alone holds us to the Earth's surface and explains the phenomena of the tides.

The sun is the major source of energy for phenomena on the Earth's surface, such as growth of plants, winds, ocean currents, and the water cycle. Seasons result from variations in the amount of the sun's energy hitting the surface, due to the tilt of the Earth's rotation on its axis and the length of the day.

Grades 9-12: The Origin and Evolution of the Universe
Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium. These and other processes in stars have led to the formation of all the other elements.

Introduction

This is an updated version of the Space Primer originally published in 1976. The intent of this book is to introduce the reader to the wonders and mysteries of the universe. The objects inhabiting our universe range from the very familiar area of the Earth and our moon to the strange quasars, pulsars, neutron stars, and black holes on the fringes of our perception.

Also included are discussions of the artificial satellites and spacecraft that humans have placed in our solar system and even in our galaxy. How satellites orbit the Earth and how we use them is another topic covered.

This book is aimed toward students in grades 5-12 and space novices interested in an introduction to this vast subject. It will not provide all the answers, but hopefully, it will stimulate interest to generate questions that can be answered by teachers, experts and books in local libraries.

Read, learn and enjoy!

Northrop Grumman gratefully acknowledges photos and data generously provided by NASA and other sources.

Table of Contents

The spiral galaxy M100 as seen from the Hubble Space Telescope. The M100 galaxy is similar to our Milky Way galaxy and is 56 million light years away.

The Universe

The universe includes everything that exists anywhere. The whole celestial cosmos consists of galaxies, stars, gas clouds and dust, which includes the planet Earth we live on and its closest star, the sun.

How was the universe formed? Astronomers and scientists still search for the answer, but the most popular scientific theory is called the "Big Bang" theory.

According to the theory, approximately 13 to 20 billion years ago, the whole universe was compressed in an incredibly small space. All the matter and energy in the whole universe was contained in this cosmic lump, until something set it off and it "blew up." In fact, galaxies and stars we're aware of today are still flying apart like fragments tossed into space.

For a long time, astronomers thought that the Milky Way and the stars it contains made up the entire universe. Then, in the 1920s, astronomer Edwin Hubble made several important discoveries using the largest telescope in the world at that time.

Looking through the powerful 100-inch Hooker telescope at Southern California's Mount Wilson Observatory, Hubble observed that some of the nebulae, appearing as smudges of light in the night sky, resolved into individual stars much farther from Earth than any previously known stars. Most of these "smudges" contained more stars than our own galaxy, the Milky Way, which contains at least 100 billion stars.

He discovered that the Earth and the sun are part of the Milky Way galaxy and determined the existence of countless other galaxies beyond ours. Today we know that there are at least as many galaxies in the universe as there are stars in the Milky Way.

While measuring the distances to some of the newly identified galaxies, Hubble made two more discoveries. First, wherever he looked he found that all galaxies were moving away from Earth.

Second, the farther away a galaxy was from Earth, the faster it was moving away. He also noted the galaxies were moving away from each other at a rate constant to the distance between them. He established the ratio for the proportional relationship between the velocity at which the galaxies are moving away and the distance to the galaxies. This ratio is known as the Hubble constant, named in his honor.

The universe includes everything that exists anywhere. The whole celestial cosmos consists of galaxies, stars, gas clouds and dust, which includes the planet Earth we live on and its closest star, the sun.

Credit: NASA/CXC/CfA/R.Kraft et al

A dramatic new Chandra image of the nearby galaxy Centaurus A provides one of the best views to date of the effects of an active supermassive black hole.

Albert Einstein, who had introduced his theory of relativity a few years earlier, had developed a model of space based on his theory. He claimed space was curved by gravity and therefore must be able to expand or contract. But he then questioned that assumption, believing it too far fetched, and revised his theory to indicate that space was static and immobile. However, soon after Hubble's findings became known, astronomers realized that his measurements served as evidence that we do live in an expanding universe…that if the universe was expanding outward, it must have originated from a central point and something must have caused the expansion to begin with, providing some scientific justification to the "Big Bang" theory.

By studying the stars as we see them today, we can find clues to the size, age and possible fate of the universe. The essential tools in this quest are large telescopes that allow us to look back in time. Take a moment to think about this…

BY STUDYING THE STARS AS WE SEE THEM TODAY, WE CAN FIND CLUES TO THE SIZE, AGE AND POSSIBLE FATE OF THE UNIVERSE.

Looking up at the moon, we really see it as it was one second ago, because it takes light about one second to travel from the lunar surface to Earth. Although light travels at the incredible speed of about 187,000 miles per second, it takes just over eight minutes for light to reach us from the more distant sun.

While this is already a very long distance for us to imagine, light from the closest star takes more than four years to reach Earth. For just about any star we see at night, the light has left its surface long before any one of us was born. On a clear night, the Large Magellanic Cloud, a close neighboring galaxy, is visible from the southern hemisphere without a telescope. However, the light that we see from this cosmic neighbor today has traveled for 170,000 years. This is the reason why telescopes, as they reach farther and farther out into space, are providing us with views further and further back in time.

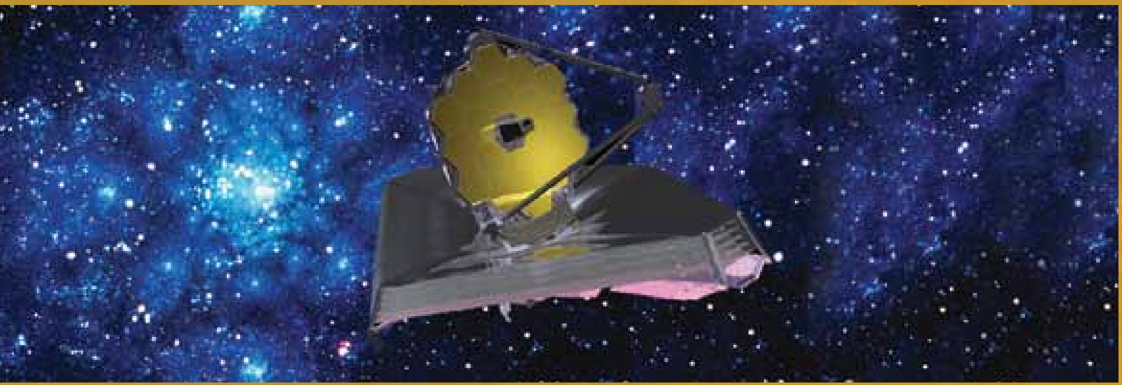
Because of these huge distances, astronomers usually measure distances in light years. A light year is the distance light travels in one year or about 5.9 trillion miles. Sometimes another unit called a parsec, equal to about 3.26 light years, is used when talking about very large distances. For smaller distances, astronomers use the distance from the sun to Earth as a unit of measurement. The average distance from the sun to the Earth is called an Astronomical Unit (AU). One AU is equal to about 93,000,000 miles.

Scientists measure the vast distances to the edges of the universe by making use of an effect called the Doppler shift. The light from an object turns bluer if the source is moving toward you rapidly, and redder as it moves away. Astronomers can measure the redness or blueness and tell how fast an object is moving relative to us and roughly how far away it is.

Measuring how fast some of the most distant galaxies are moving away from us requires very sensitive instruments and large telescopes. The ultimate measurements require telescopes placed in space such as the Hubble Space Telescope and the Chandra X-ray Observatory, that open new windows to the universe as they search for visible light coming from far distances, unaffected by the impact of Earth's protective atmosphere. Recent studies using the Hubble Space Telescope to more precisely measure the distances to remote galaxies, such as M100, suggest that the universe's age is only 7 to14 billion years.

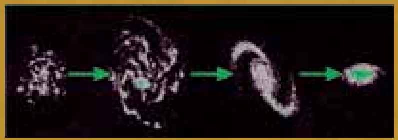
Even today, more than 80 years after Hubble's breakthrough discoveries, we are still learning about the universe. We can only imagine what new wonders we will discover with next-generation telescopes such as the James Webb Space Telescope.

The brightest galaxy visible from our Milky Way galaxy is the Large Magellanic Cloud, an irregular type, approximately 163,000 light years away.



As the successor to the Hubble Space Telescope, the James Webb Space Telescope will look beyond visible light to observe the outermost regions of the universe that can only be seen in infrared wavelengths. The Webb Telescope will allow astronomers to see deep into space and witness the birth and evolution of the first stars and galaxies.

Young galaxies have prominent spiral arms. Older galaxies have no spiral arms and become rounder as they age.



Most nearby galaxies seem to be spirals like our own Milky Way. We can see millions of galaxies.

The Galaxies

Galaxies are clusters of stars, gas clouds and interstellar matter that populate the universe. They come in different shapes. Three-fourths of the galaxies we can see are spiral shapes, like our own galaxy the Milky Way. A fifth of them are globular and egg-shaped, called ellipticals. The few remaining galaxies have no particular shape and are called irregulars.

From what we can tell, irregular galaxies are young, containing lots of star-building free gas and dust, and hot, bright, infant stars. Spiral galaxies are mature and middle-aged, with some starbuilding material, but also some older, dying stars. Elliptical galaxies, which seem to get rounder as they get older, have mostly dim, aged stars.

The brightest galaxy visible from our Milky Way galaxy is the Large Magellanic Cloud, an irregular type, approximately 163,000 light years away.

The Northrop Grumman-built James Webb Space Telescope, which will be launched in the next decade, will peer into the past and image galaxies and clusters of galaxies at greater distances than ever before. For the first time, scientists will be able to observe the formation of the first stars and galaxies in the universe billions of years ago. The Webb Telescope will also shed light on the size and shape of the universe.

Star Cluster NGC 2074 in the Large Magellanic Cloud

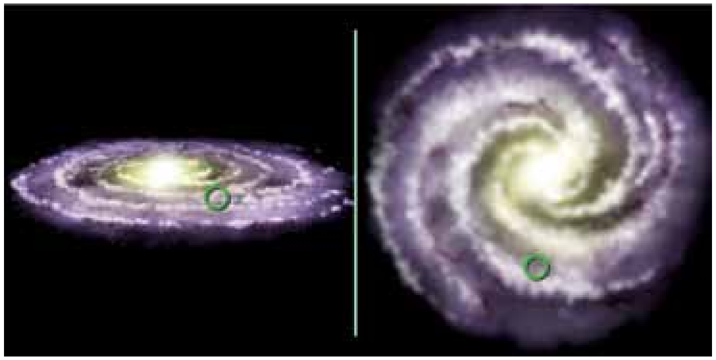
The Milky Way – Our Galaxy

The Milky Way consists of star clusters, evolving stars, collapsing or exploding matter, and clouds of dust and gas. If you have ever gone stargazing on a very clear night, you may have noticed a narrow, bright cloud of many stars stretching across the sky. This is the Milky Way – our galaxy.

The Milky Way galaxy is a relatively flat spiral structure, something like a pinwheel. It's about 100,000 light years across, so even though the sun circles the galaxy at about 500,000 miles per hour, 1,000 times faster than a jet plane, it still takes our sun 250 million years to go around once. Our galaxy has spiral arms, and our solar system is located in an arm about two-thirds of the way from the galactic center. The center of our galaxy contains mostly older stars. The spiral arms hold the youngsters and the stars being born.

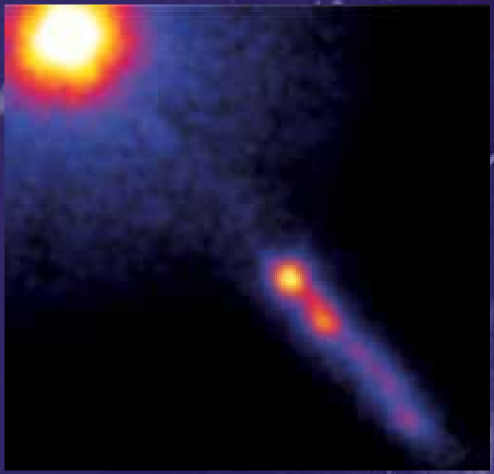
Our galaxy also contains great clouds of gas and tiny dust particles that surround some stars, hide some, and are the birthplace of others. There are wandering molecules, even the carbon-bearing organic molecules, which reinforce scientists' belief that life on Earth is not unique. Clumps of rock and gas that become comets and meteorites also move in the cold, dark void until they are captured by the gravitational pull of a star or planet.

On June 13, 1983, the Northrop Grumman-built Pioneer 10 spacecraft became the first Earth-made object to leave our solar system and become a small speck in the Milky Way galaxy. Since then, the Northrop Grumman-built Pioneer 11 and Voyager 1 and 2 space vehicles have become explorers in interstellar space.

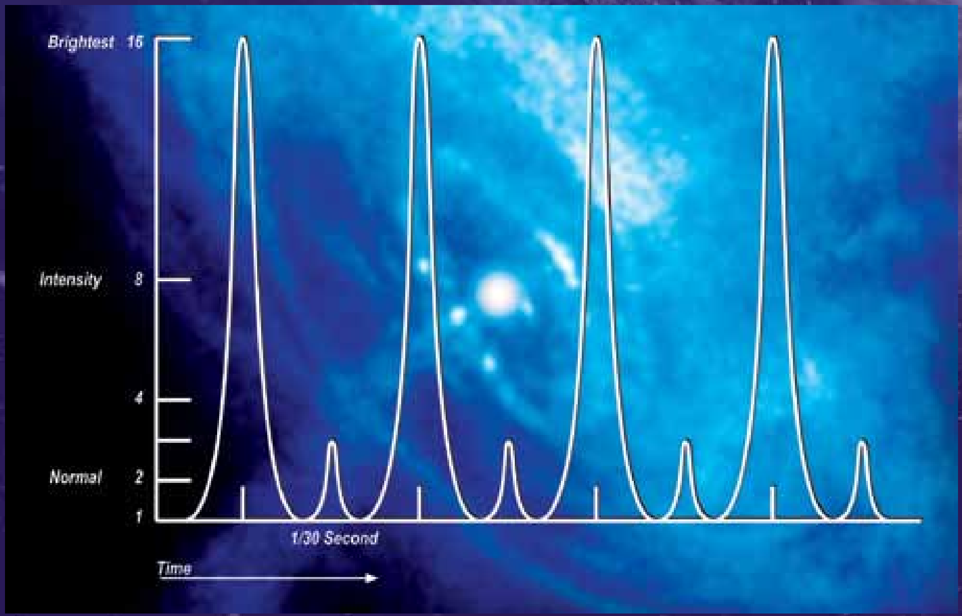


The Milky Way, showing its spiral structure and the position of our solar system in the galaxy.

The Milky Way, as seen from Earth. More than 100 billion stars are in the Milky Way.



In 1963, Dutch-American astronomer Maarten Schmidt discovered the large shift to the red in the spectrum of Quasar 3C273, one of the characteristics quasars have in common.



Every 1/30 of a second, the Crab Pulsar's light intensity becomes 16 times greater than its normal brightness.

Quasars and Pulsars

Quasars

Quasars (for "quasi-stellar radio sources") are the most powerful known energy sources in the universe. The amount of energy radiated from such a compact source and the rapid variations in brightness pose a challenge to astronomers' present understanding of the universe.

Most quasars emit strong radio waves. A hundred times brighter than the surrounding galaxies, quasars may be "snapshots" of galaxies being born.

Quasars seem to have the highest Doppler shifts (to the red) of any objects we have seen so far. One quasar has been observed to be moving away from us at 90 percent of the speed of light, making it the fastest and farthest object we can detect.

Pulsars

A pulsar is a rapidly spinning neutron star that has a mechanism to beam light, much like a lighthouse. This mechanism is only partially understood, but is connected with very strong magnetic fields spinning with the star. If the beam of the pulsar sweeps over the Earth as the neutron star rotates, the light from the pulsar appears to pulse on and off. Several hundred pulsars are now known, with periods ranging from seconds down to sub-milliseconds.

The first pulsar was discovered by Anthony Hewish and Jocelyn Bell at Cambridge's Radio Astronomy Observatory in 1967. A year later, a team of scientists at the National Radio Observatory in Puerto Rico discovered the most famous pulsar, the Crab Pulsar, lying in the Crab Nebula (M1), which is about 7,000 light years away in the constellation Taurus. The Crab Pulsar rotates about 30 times a second, emitting a double pulse in each rotation.

Neutron stars are the end stage of the evolution of massive stars. At the end of the star's life, a large amount of mass is ejected in an enormous explosion and what's left compresses together by gravity, rotating faster and faster, radiating energy at every turn.

Compressed stars like this are called neutron stars since almost all the atoms have been converted to neutrons. A pinhead-sized dot of neutron star material could weigh 1,000 tons!

The Stars

To the average person, a star is a tiny spot of light in the night sky. But the astronomer knows a star as a huge gas furnace, an independent source of energy.

The stars are really chemical factories. Out of hydrogen and helium (the two simplest atoms), they build all of the other known elements by nuclear fusion.

The stars are a varied lot. The super-giant stars are so huge it would take four million suns to fill them, yet neutron stars may be less than 10 miles in diameter. Bright blue stars are six times as hot as the sun, yet there are stars that give off little or no visible light. We can only "see" these stars by making radio and X-ray images of them.

Some stars gradually fade then grow brighter; others wink on and off. Some explode into brilliant novae or supernovae. A number of stars are very close, less than 10 light years away, with the more distant ones in our galaxy more than 80,000 light years away.

Alpha Centauri, a double star, and its companion, Proxima Centauri, are the stars nearest our solar system, 4.3 light years away. Double and triple stars are so close together that they rotate around each other, rather than being one large central body, like our sun, surrounded with smaller bodies, like the planets. Double and triple stars are the rule in our galaxy, but single stars, like our sun, are common exceptions.

One of the brightest stars we can see from Earth is 8.8 light years away. It is Sirius A, a white-hot star that has a small, dense white dwarf companion, Sirius B. Half a dozen other stars are within 10 light years of our solar system, all of them ordinary yellow-redstars a little cooler than the sun.

All stars are formed from giant clouds of gas and interstellar dust that collect together by gravity. How they grow and die depends on their size. Large stars radiate energy at a tremendous rate and burn out faster than a slow, steady star like our sun.

Stars similar to our sun become red giants — large, cool stars that have expanded so much that they become thinner than the air we breathe. After a few hundred million years, the star collects all its matter again, but so tightly that a teaspoonful of the star would weigh more than a ton. Now the star is a small white dwarf that just gets dimmer and dimmer.

Deep space probes use "star trackers" as a part of their navigation system. The second brightest star, Canopus, is generally used as the celestial reference. Although it is half as bright as Sirius, its declination (angle North or South of the celestial equator) is 53°, which makes it more usable as a reference coordinate with the sun than the 17° declination angle of Sirius.

Map of the Stars and Constellations

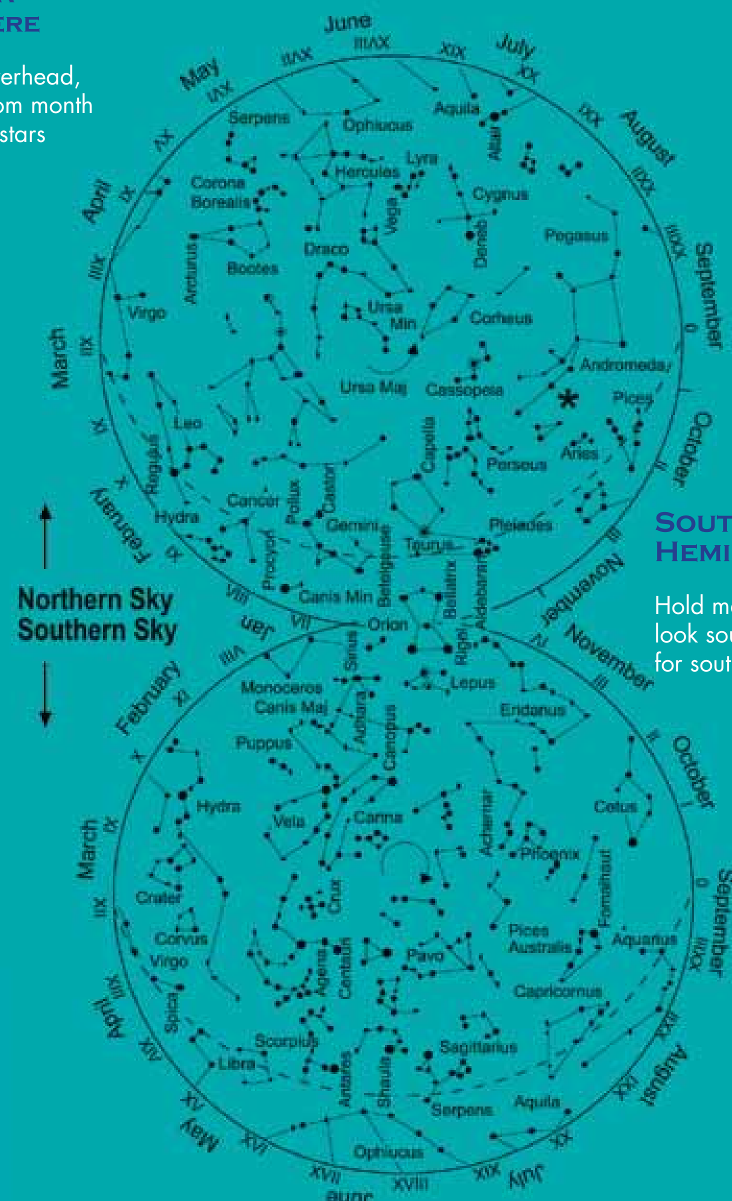
(Positions shown are for midnight)

Northern Hemisphere

Hold map overhead, look north from month for northerly stars

Southern Hemisphere

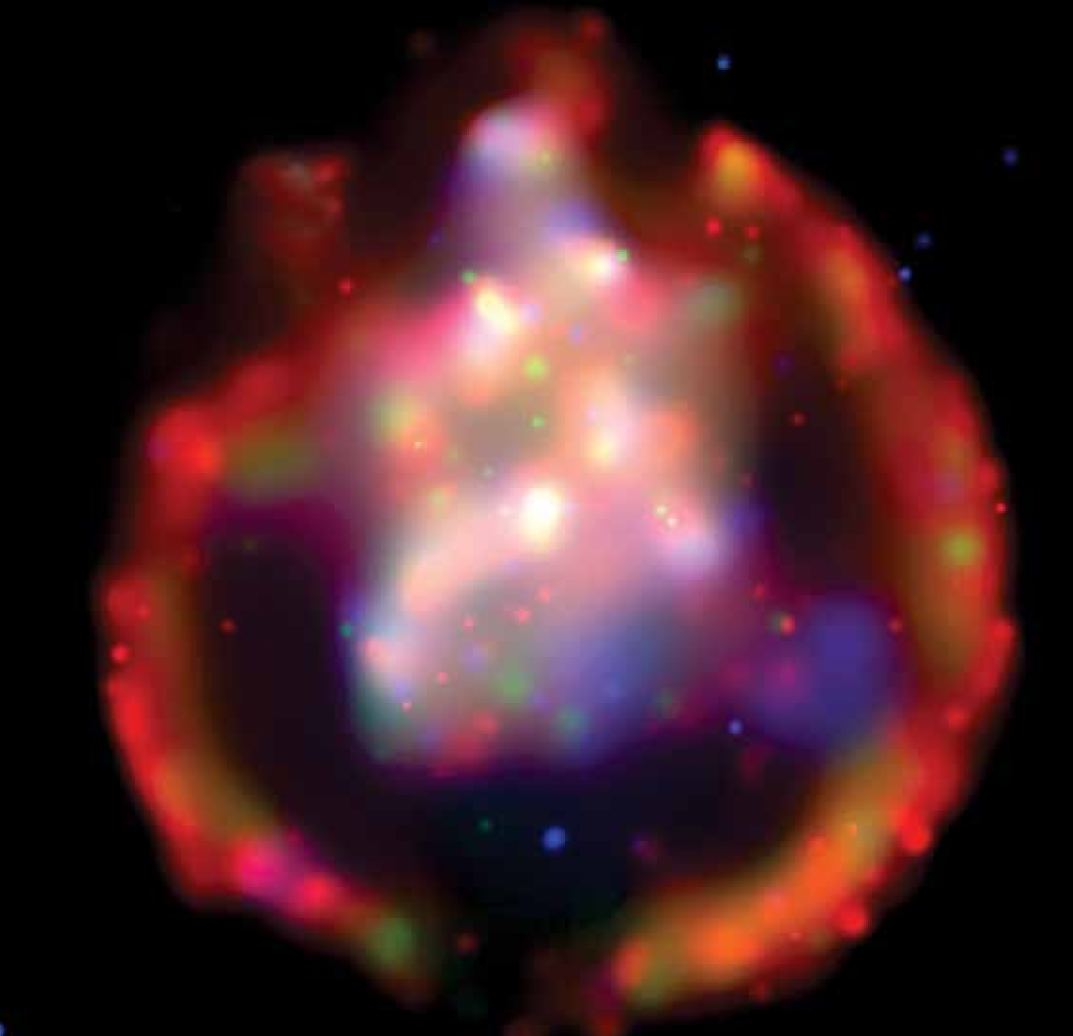
Hold map overhead, look south from month for southerly stars



About 6,000 stars are visible to the naked eye. The six brightest stars:

Sirius 8.8*	Arcturus 36.0*
Canopus 98.0*	Vega 26.0*
α Centauri 4.3*	Capella 46.0*

*Distance in light years from Earth.



This supernova appeared in 1987 in our neighboring galaxy, the Large Magellanic Cloud. This was the nearest and brightest such occurrence since 1604. As the brilliant star exploded, the remaining supernova was surrounded by inner and outer rings of material, diffuse gas clouds, and bright blue massive stars.

Novae and Supernovae

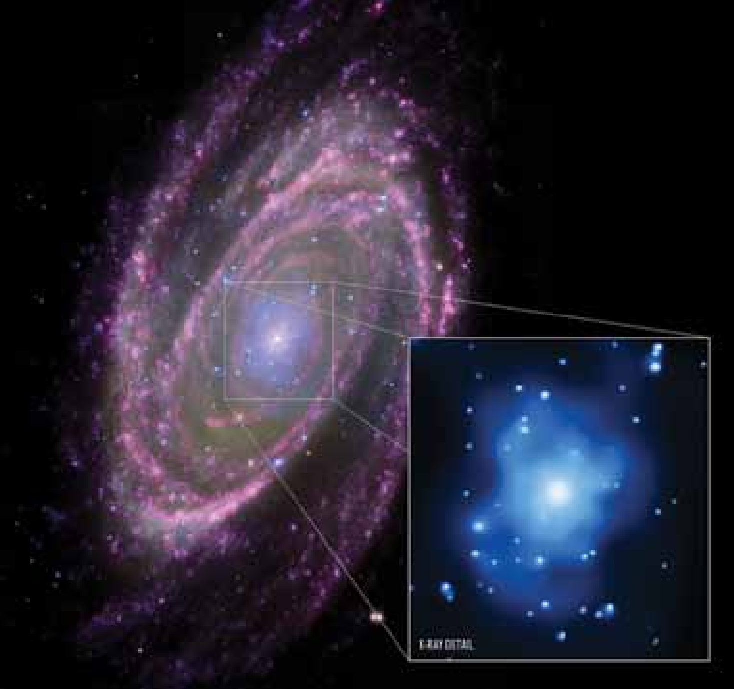
Stars smaller than our sun lead very humdrum lives, gradually just fading away. It's the stars with 10 to 100 times the mass of our sun that provide galactic fireworks. They can explode and become spectacular novae and supernovae or alternately grow brighter and dimmer.

A good example of the death of such a massive star is the supernova of 1054 A.D. This gigantic explosion could be seen in daylight from here on Earth. The Chinese and native Americans recorded this event. Today a cloud of gas and dust, called the Crab Nebula, which was thrown out by the explosion, surrounds the remnant of this star.

Clouds of matter like this, thrown out by supernovae throughout the galaxy billions of years ago, are the sources of the elements that make up the Earth… and even you! The brightness of a supernova explosion can be 100 million times that of our sun.

Stars smaller than our sun lead very humdrum lives, gradually just fading away.

This rock painting of the supernova of 1054 A.D. was found in Chaco Canyon, Arizona. Calculations show that the moon (crescent) and the supernova (star shape to left of moon) were very close in the sky when the supernova was at its brightest. The life-size hand indicates the site is sacred.



(Far Left)
This composite NASA image of the spiral galaxy M81, located about 12 million light years away, includes X-ray data from the Chandra X-ray Observatory (blue), optical data from the Hubble Space Telescope (green), infrared data from the Spitzer Space Telescope (pink) and ultraviolet data from GALEX (purple). The inset shows a close-up of the Chandra image. At the center of M81 is a supermassive black hole that is about 70 million times more massive than the sun.

Credit: X-ray: NASA/CXC/Wisconsin/D.Pooley & CfA/A.Zezas; Optical: NASA/ESA/CfA/A.Zezas; UV: NASA/JPL-Caltech/CfA/J.Huchra et al.; IR: NASA/JPL-Caltech/CfA

(Left)
The Northrop Grumman-built Chandra X-ray Observatory offers scientists the opportunity to collect, observe and analyze X-ray radiation, expanding our knowledge of the structure and evolution of the universe.

Black Holes

Einstein knew that the universal force of gravity affects even beams of light. He could imagine a gravitational pull so strong that even light could not escape. We call this a black hole.

Since even light cannot escape, looking for a black hole is like trying to find something you cannot see. Black holes are not large – they are stars shrunk to less than five miles across.

Luckily, we have other clues to the presence of black holes. As nearby matter is pulled into the black hole and its gravitational field strengthens, energy flies out of the doomed material. From this point on the edge of a black hole, radiation can still escape. We can pick it up as X-rays and gamma rays.

We have a good candidate for a black hole right here in our Milky Way galaxy. Its name is Cygnus X-1, and it's 3,000 light years away. NASA's Chandra X-ray Observatory spacecraft is helping us understand the evolution and location of black holes.

The largest black holes may feed just like the smallest ones, according to data from NASA's Chandra X-ray Observatory and ground-based telescopes. This discovery supports the implication of Einstein's relativity theory that black holes of all sizes have similar properties and will be useful for predicting the properties of a possible new class of black holes.

The conclusion comes from extensive observation of the spiral galaxy M81, which is about 12 million light years from Earth. In the center of M81 is a black hole that is about 70 million times more massive than the sun, and generates energy and radiation as it pulls gas in the central region of the galaxy inwards at high speed.

In contrast, so-called stellar mass black holes, which have about 10 times more mass than the sun, have a different source of food. These smaller black holes acquire new material by pulling gas from an orbiting companion star. Because the bigger and smaller black holes are found in different environments with different sources of material to feed from, a question has remained about whether they feed in the same way.

Using these new observations and a detailed theoretical model, a research team compared the properties of M81's black hole with those of stellar mass black holes. The results show that either big or little, black holes appear to eat similarly to each other and produce a similar distribution of X-rays, optical and radio light.

If these pint-sized cosmic vacuum cleaners are consuming all the matter and energy in sight, where does it all go?

Some scientists speculate that matter disappearing down the hole is changed to energy and pops up in another universe in a terrific explosion. This could explain why we sometimes see what appears to be whole galaxies exploding… another universe may be sending us all its substance via its black holes.

These scientists also think that our entire universe may pour into black holes, rather than following the oscillating universe theory and returning to the original cosmic lump. Will this be followed by another "Big Bang"?

The Solar System

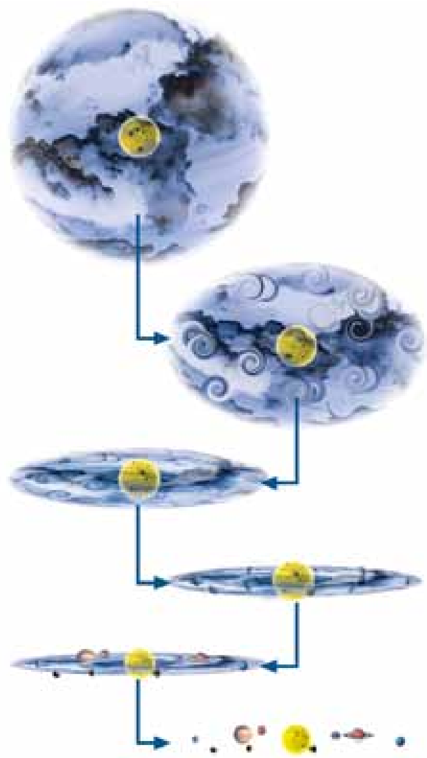
The solar system consists of the sun at the center (with 98 percent of the total mass), plus major and minor planets, their numerous satellites, tens of thousands of asteroids, and countless numbers of smaller objects, which occasionally signal their presence as comets, meteors or meteorites. All of these bodies qualify as members of the solar system, revolving in elliptical orbits about the sun, and unable to escape the solar gravitational pull.

According to scientific theory, some time ago, perhaps 10 billion years, a great ball of gas and dust (about 100 AU across) started to spin. Almost all of the material, about 98 percent, was drawn together by gravity at the center of the ball and became the infant sun.

The other two percent of the mass spun faster and faster, flattened and spread out around the new sun. Currents developed in the whirling disk, just as whirlpools and eddies develop in the ocean. These little whirlpools were pulled together by gravity, forming the planets and their moons.

Most of the bodies in the solar system move in a disk-shaped area around the sun. None of the planets have perfectly flat, circular orbits. All of the planets' orbits (except the Earth's) are inclined to the ecliptic, and are elliptical or oval-shaped. Inclination is the measure of the tilt of the other planets' orbits compared to the Earth's orbit. Eccentricity describes the difference between a planet's orbital path and a perfect circle. The closer the eccentricity is to zero, the closer the orbit is to a circle.

The boundaries of our solar system reach out hundreds of astronomical units beyond the sun. The heliosphere (region within the sun's influence) is filled with the solar wind, charged particles streaming out from the sun.



According to the protoplanet hypothesis of how the solar system was created, each little whirlpool was thought to condense into a large ball of gas, or protoplanet, which shrunk further into the planets we know today.

Physical Characteristics of the Planets

Planet	Radius at equator (miles)	Volume compared to Earth	Mass compared to Earth	Gravity compared to Earth	Rotation in Earth's time
Mercury	1,515	0.06	0.06	0.38	59 days
Venus	3,761	0.85	0.82	0.90	243 days
Earth	3,963	1.00	1.00	1.00	24 hours
Mars	2,110	0.15	0.11	0.38	24 1/2 hours
Jupiter	44,423	1,321.3	317.82	2.14	10 hours
Saturn	37,449	763.3	95.16	0.74	10 1/2 hours
Uranus	15,882	63.0	14.37	0.86	17 1/4 hours
Neptune	15,389	57.7	17.14	1.10	16 hours
Pluto	715	0.006	0.002	0.083	6 days

Orbital Characteristics of the Planets

Planet	Average distance from Sun (AU)*	Period of revolution in Earth's time	Inclinations of orbit to ecliptic	Eccentricity of orbit
Mercury	0.387	88 days	7.00°	0.206
Venus	0.723	225 days	3.39°	0.007
Earth	1.000	365 days	0.00°	0.017
Mars	1.524	687 days	1.85°	0.093
Jupiter	5.203	11.88 years	1.30°	0.048
Saturn	9.537	29.45 years	2.48°	0.054
Uranus	19.19	84.02 years	0.77°	0.047
Neptune	30.07	164.79 years	1.77°	0.009
Pluto	39.48	247.92 years	17.14°	0.249

*One AU (Astronomical Unit) = 93 million miles
Data courtesy of NASA and JPL

The planets in our solar system are shown in order outward from the sun. The Kuiper Belt is a large collection of ice bodies beyond the orbit of Pluto, relics from the original cloud of gas and dust that gave rise to everything in the solar system.

THE SUN – OUR STAR

Our sun is essentially a giant ball of about 90 percent hydrogen and 10 percent helium. The sun shines by using a nuclear fusion reaction. This reaction combines two hydrogen nuclei into one helium nucleus and changes the leftover matter into energy.

As the sun ages, the core gets richer and richer in helium and the surface has less and less hydrogen. Radiating at its present rate, the sun transforms 4.6 million tons of matter every second. This is an infinitesimal amount of the sun's total mass.

We don't have to worry about the sun wearing out for a few billion years. When that time comes, the loss of basic fuel will cause the sun to expand into a red giant star so large that all the planets out to Mars may lie within its influence. Long before this happens, the radiation falling on Earth will be so intense that no present-day life could survive.

After it has finished expanding, the sun will collapse again, this time to a pale, weak white dwarf. Should Earth survive this process, it will be a cold, dark, barren planet, for all living things depend on the sun's energy.

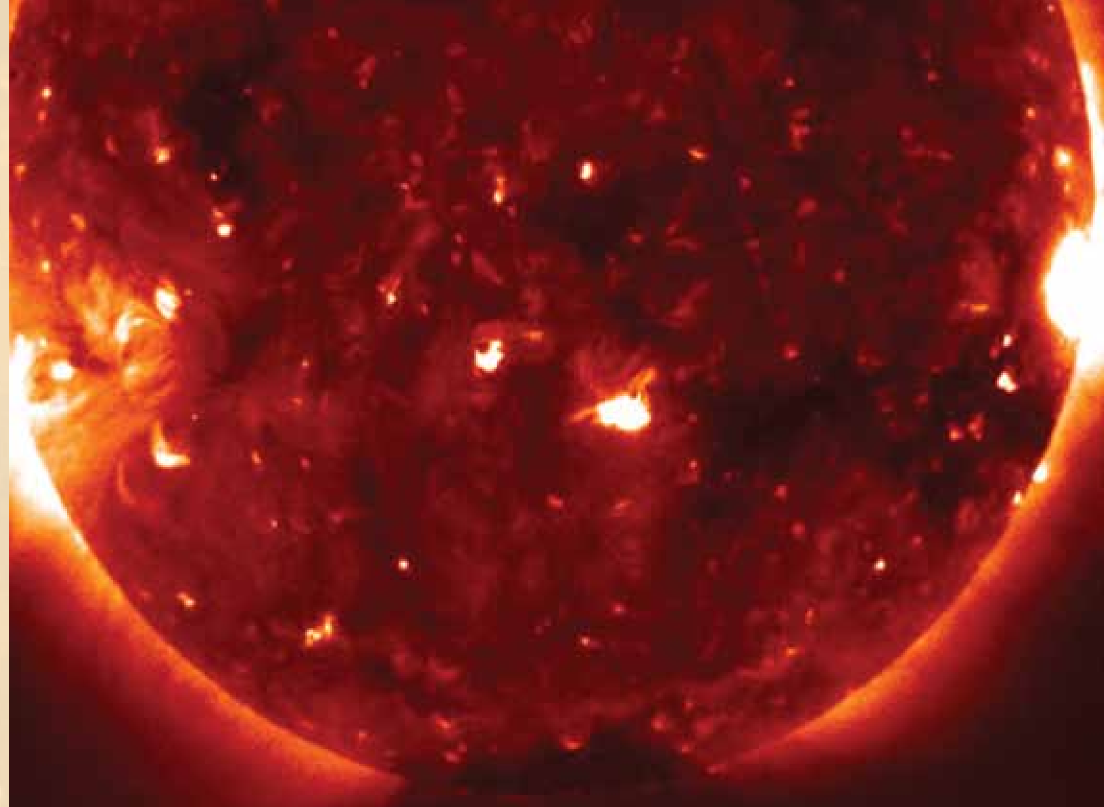
IF WE COULD FIND A WAY TO USE SOLAR POWER EFFICIENTLY, WE WOULD NOT HAVE TO WORRY ABOUT FUEL SHORTAGES UNTIL THE SUN DIES. SOLAR ENERGY HAS NO WASTE PRODUCTS OR POLLUTION.

If we could find a way to use solar power efficiently, we would not have to worry about fuel shortages until the sun dies. Solar energy has no waste products or pollution.

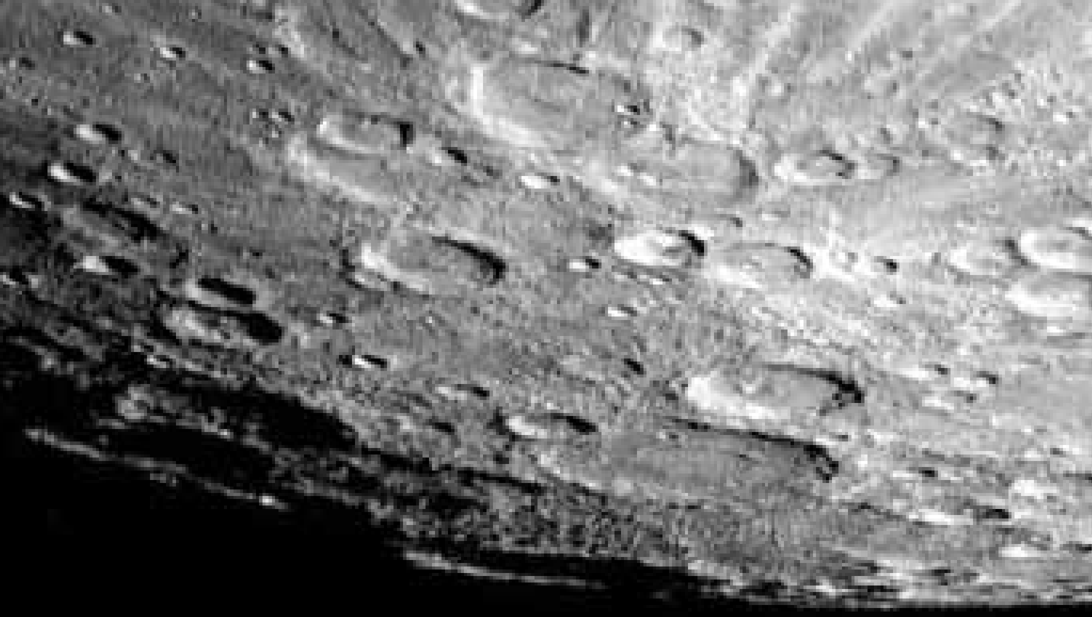
The most common users of solar power throughout the world are green plants. They can do things that we cannot do nearly as well. They store energy from the sun in molecular bonds by a process called photosynthesis. It's the sun's energy stored in these molecules that we use when we burn oil, wood or coal.

While human-made systems aren't as efficient as plants yet, Northrop Grumman-built solar panels can convert the sun's energy into electricity to power our satellites. Each cell on these panels is a tiny wafer of silicon that converts the sun's light into electrical energy.

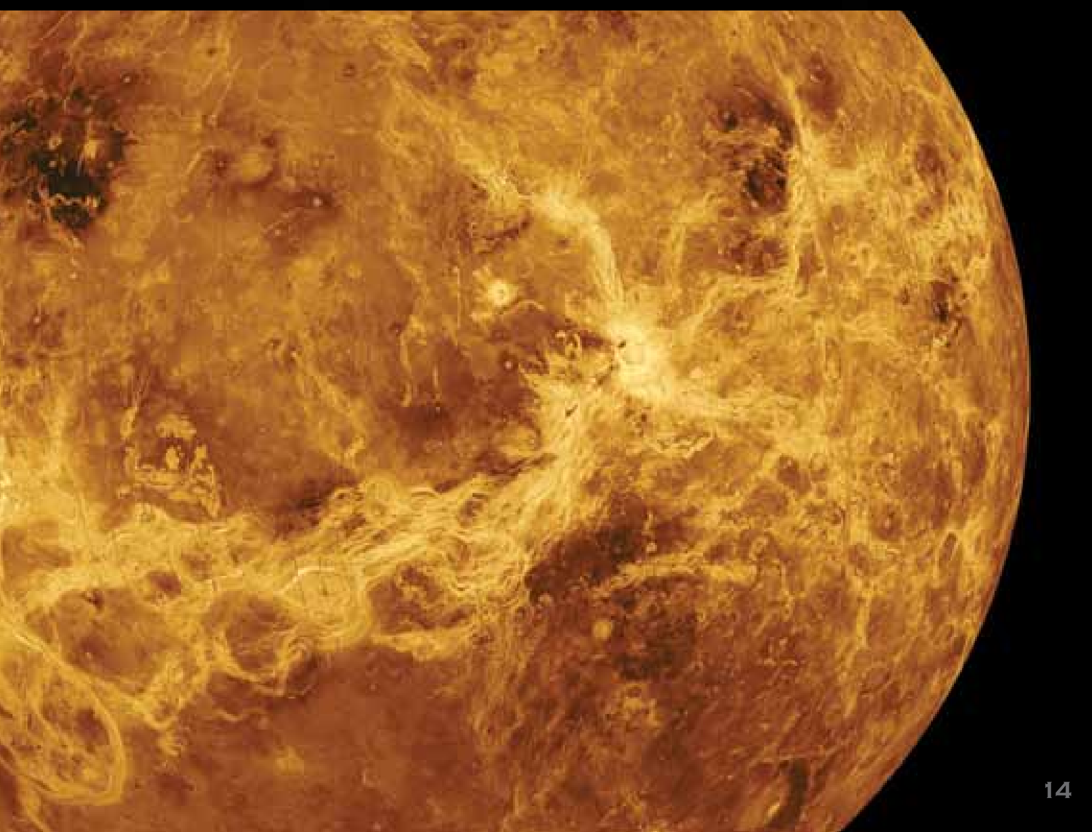
With today's technologies and processes, solar cells power objects ranging from wallet calculators to the Mars Rover.



The sun is heated to incandescence by thermonuclear reactions deep in its interior. Solar prominences can rise more than 100,000 miles above the solar disk.



Mercury was named for the wing-footed Roman messenger of the gods. In two flybys of Mercury in March and September 1974, the Mariner 10 spacecraft observed a cratered face much like the moon's and detected a nickel-iron core, much like Earth's. Mercury has no moons.



The Inner Planets

Mercury

Closest to the sun, Mercury is the second smallest planet. It has an orbital period of 88 Earth days and rotates on its axis once every 59 Earth days. The average surface temperature is 800°F on the bright side, and -280°F on the dark side. Radar astronomers recently have indicated that Mercury may have an ice cap at its north pole. Through a telescope Mercury looks like the moon, and, like the moon, has very little atmosphere that would slow down meteoroids approaching its surface. As a result, Mercury is home to craters such as Caloris Basin, roughly 800 miles in diameter.

Mercury also shares similar physical features with the moon such as large, wide impact craters and long steep cliffs cutting across its surface.

Mercury, Venus, Earth and Mars, the inner planets, are small and dense, have long days and few (if any) moons.

Venus

The brightest and closest neighboring planet to Earth, Venus is about the same diameter as Earth and has an orbital period around the sun of 225 Earth days. The planet rotates once every 243 Earth days in a clockwise (retrograde) direction, spinning in the opposite direction of its orbit around the sun. The atmosphere is mostly carbon dioxide with some sulfuric acid. On the surface, temperatures can reach 864°F, and the pressure is 90 times greater than on Earth.

The surface of Venus contains some impact craters similar to those found on Mercury, the moon, and Mars. The dense atmosphere surrounding Venus slows down most of the incoming smaller meteoroids that do not produce sizeable impact craters. The planet's surface also houses some unique features caused by volcanic activity: large circular mounds that look like pancakes and depressions displaying fracture rings.

(Lower Left)
Venus, Earth's closest neighbor, was named for the Roman goddess of love. Its dense, turbulent atmosphere is more than 90 percent carbon dioxide, with sulfuric acid in the upper clouds. Venus has no moons, and no magnetic field has been detected.

Earth

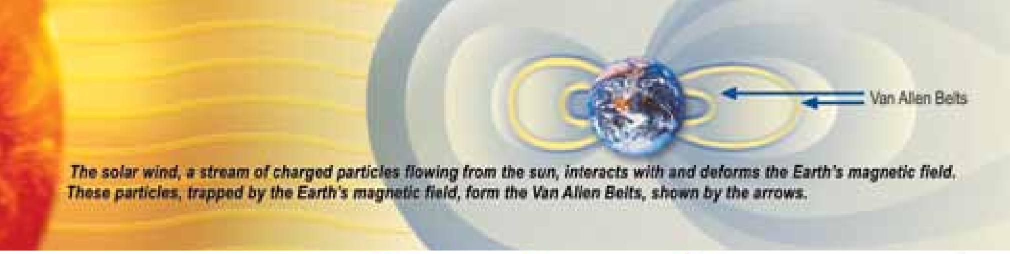
Earth is the only planet we know that supports life. If we look at Earth as a spacecraft with all of us as its astronauts, we travel 67,000 miles per hour around the sun every year. Close to the equator, we rotate about the Earth's axis at approximately 1,000 miles per hour every day.

The region of the Milky Way in which our sun is located revolves at 560,000 miles per hour around the galactic center. And our whole galaxy is moving, relative to other galaxies, at 220,000 miles per hour. So you can say that we really are "movers."

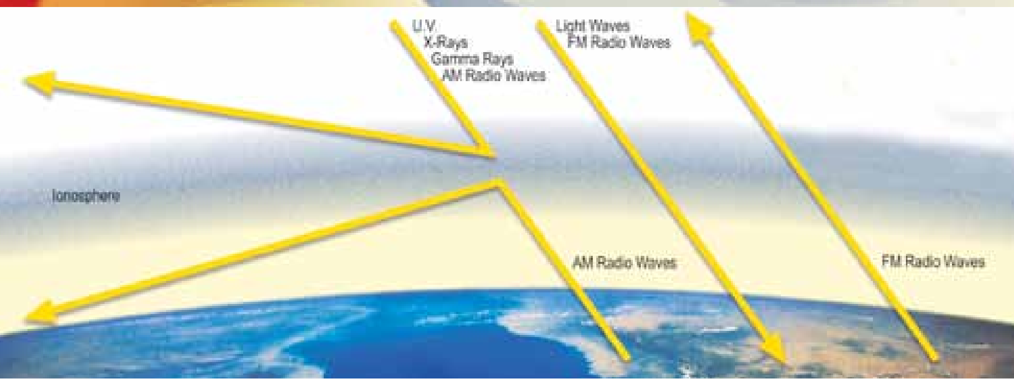
On "Spacecraft Earth," our atmosphere acts as a shield against harmful radiation and dangerous space debris. Our gravity holds the air and people on the spacecraft so that everything doesn't float away. Spacecraft Earth provides our food and water. The sun is our energy source; without it we would not be able to survive.

The blanket of our atmosphere shields us from many of the violent events happening around the Earth. But the atmosphere is a very thin blanket. If we shrunk the Earth to the size of a 3-foot-diameter beach ball, the atmosphere would be a layer only one-third of an inch thick. Yet this thin atmosphere and the Earth's magnetic field protect us from the solar wind, radiation and material floating in space.

Earth, the third planet from the sun, is unique (so far as is known) in having resident life forms. The Earth's atmosphere is primarily nitrogen and oxygen that, together with the presence of water, supports life on the planet.



The solar wind, a stream of charged particles flowing from the sun, interacts with and deforms the Earth's magnetic field. These particles, trapped by the Earth's magnetic field, form the Van Allen Belts, shown by the arrows.



We receive very little radiation from space. Gas molecules absorb X-rays, gamma rays and ultraviolet radiation. The ionosphere, a region of charged particles about 44 miles above the Earth's surface, deflects long (AM) radio waves. The only windows to space open to us are narrow bands of optical and FM radio wavelengths.

The solar wind consists of charged particles streaming out from the sun. When they encounter Earth's magnetic field, a shock wave is created. The particles then stream past the Earth and stretch out to form a long tail. Some of the particles enter the Earth's atmosphere at the North and South Poles.

The energy from the collision of these solar wind particles and the Earth's atmosphere cause the Northern and Southern Lights, or Aurora Borealis and Aurora Australis. The particles that become trapped by the Earth's magnetic field make up the Van Allen radiation belts. This pair of doughnut-shaped regions exist 1,900 and 12,500 miles above the Earth's surface.

Even though our atmosphere protects us, it can be a nuisance to scientists and astronomers. The atmosphere distorts light received by the large telescopes on Earth. It absorbs gamma rays and X-rays that are the products of some of the most exciting and violent events in the universe. To really observe space we must place telescopes outside our protective atmosphere.

The ozone layer surrounding Earth protects us from harmful ultraviolet rays from our sun. We have discovered temporal holes in this protective shield, primarily over Antarctica. The Northrop Grumman-built Total Ozone Mapping Spectrometer spacecraft helped us understand the activities of the ozone layer. The Earth Observing System Aura continues the mission of monitoring the ozone layer to assess causes of global climate changes.

Keeping Watch Over the Earth

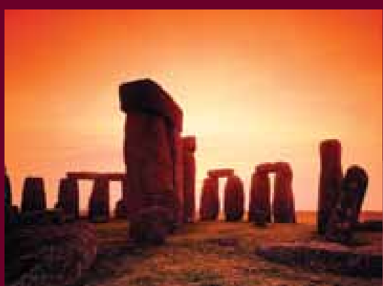
A family of Earth-observing satellites built by Northrop Grumman constantly sends critical data on the planet's water cycle and atmosphere to NASA scientists to more accurately forecast the effects of climate change.

From cyclones and severe storms to volcanic activity and wildfires, improved forecasts made possible through space-based weather and climate observation can have a significant impact on protecting lives, property and the environment.

This Apollo Moon Walk picture shows an Apollo astronaut on the lunar surface. Behind him is the Northrop Grumman Lunar Excursion Module (LEM) that landed him on the moon. The last 10 miles of his journey to the moon used the LEM's throttleable descent engine also built by Northrop Grumman.

This view of the main ruin of the Casa Grande in southern Arizona shows the small openings near the corners that may have been used by the Hohokam for making astronomical observations during the 1300s A.D.

Courtesy, Casa Grande Ruins National Monument



Many archaeologists believe the ancient stone circle of Stonehenge was used to observe the motions of the sun and the moon.

(Right)
The moon is not a hospitable location. It has nearly no atmosphere and shows minimal physical activity, but it is the Earth's only natural satellite. The moon rotates on its axis once every time it orbits the Earth; therefore, we always see the same part of the moon from Earth.

Our Moon

The moon is our closest neighbor, only 240,000 miles away. The moon rocks brought back by the Apollo astronauts were formed from lava. Sometime in the far past, the moon, like Earth, was probably seething with volcanic eruptions.

The moon rocks also tell us that the moon is about 4.5 billion years old, approximately the same age as the Earth. Scientists believe that the whole solar system was formed at about the same time.

Life does not exist on the moon's surface. The moon has nearly no atmosphere, so heat and radiation from the sun bombard its surface. In the heat of the day, the temperature can reach 260°F. At night, temperatures plunge to -315°F. But the moon's gravitational pull is one-sixth of that here on Earth, so golf balls can be driven a long way, and high jump records can be – well, astronomical!

Since early astronomers thought the dark areas on the moon were oceans, they called them maria (plural of mare, Latin for seas). These maria measure 80 to 1,200 miles in diameter. Meteorites have pounded the moon's surface, leaving behind craters up to 250 miles in diameter.

Lunar orbiting spacecraft have found that there are large, dense "lumps" beneath the lunar surface. They may be buried meteorites or underground lava flows. Their locations were mapped in the early 1970s by instruments on the Northrop Grumman-built Particles and Fields satellites that were placed in lunar orbit by the Apollo 15 and 16 astronauts.

The moon (along with the sun) causes tides here on Earth, not only in the ocean, but also on continents. The ground you stand on may rise and fall as much as 10 inches, depending on the position of the moon and sun. However, compared to the 8,000-mile diameter of the Earth, this small change is not noticeable.

Ancient people used the phases of the moon as an important tool to track the seasons. The moon's orbital period establishes one of our basic calendar units, the month, a name appropriately derived from the word moon. Stonehenge, in England, first established in the year 3000 B.C., is really a giant, ancient lunar calendar and eclipse predictor.

The Hohokam tribe of native Americans in Arizona built the Casa Grande (big house) in the center of their village around 1300 A.D. Several openings in its upper stories align with the sun and moon at certain points in their cycles. Perhaps it was used in part as an observatory. The Hohokam disappeared by 1450 A.D.

> **The impact's resulting plume will reveal the composition of the lunar subsurface, including the possible existence of hydrated minerals, ice crystals, and hydrocarbons.**

NASA's Return to the Moon

Nearly 40 years ago, the Lunar Excursion Module and Descent Engine built by Northrop Grumman for NASA landed the first Apollo astronauts on the moon. The lunar samples brought back by the astronauts revolutionized our understanding of the Earth-moon system, and gave rise to the "Giant Impact" theory of the moon's origin.

In 2009, a new mission called LCROSS (Lunar Crater Observation and Sensing Satellite) will send an unmanned spacecraft plummeting into one of the moon's polar regions to determine whether water ice exists in the moon's permanently shadowed craters, and if so, how much. The impact's resulting plume will reveal the composition of the lunar subsurface, including the possible existence of hydrated minerals, ice crystals, and hydrocarbons.

This information, along with other lunar imaging and data sent back to Earth by the LCROSS mission, will help determine potential resources and hazards as well as possible safe landing sites. NASA plans to return humans to the moon by 2020 and eventually set up a permanent base at one of the moon's poles.

THE LARGEST MARTIAN VOLCANO, OLYMPUS MONS, RISES 16 MILES ABOVE THE SURFACE. (EARTH'S HIGHEST MOUNTAIN, MOUNT EVEREST, IS ONLY 5-1/2 MILES HIGH.)

MARS

This bright red planet, tinted by its oxide-covered desert regions, revolves around the sun at about 1-1/2 times the Earth's distance from the sun. Its gravity is about one-third of the Earth's. Mars has little atmosphere, less than one percent as dense as that of Earth, consisting mostly of carbon dioxide. Its surface is pockmarked by the impact of thousands of meteorites, since the thin Martian atmosphere does not provide much protection from this bombardment.

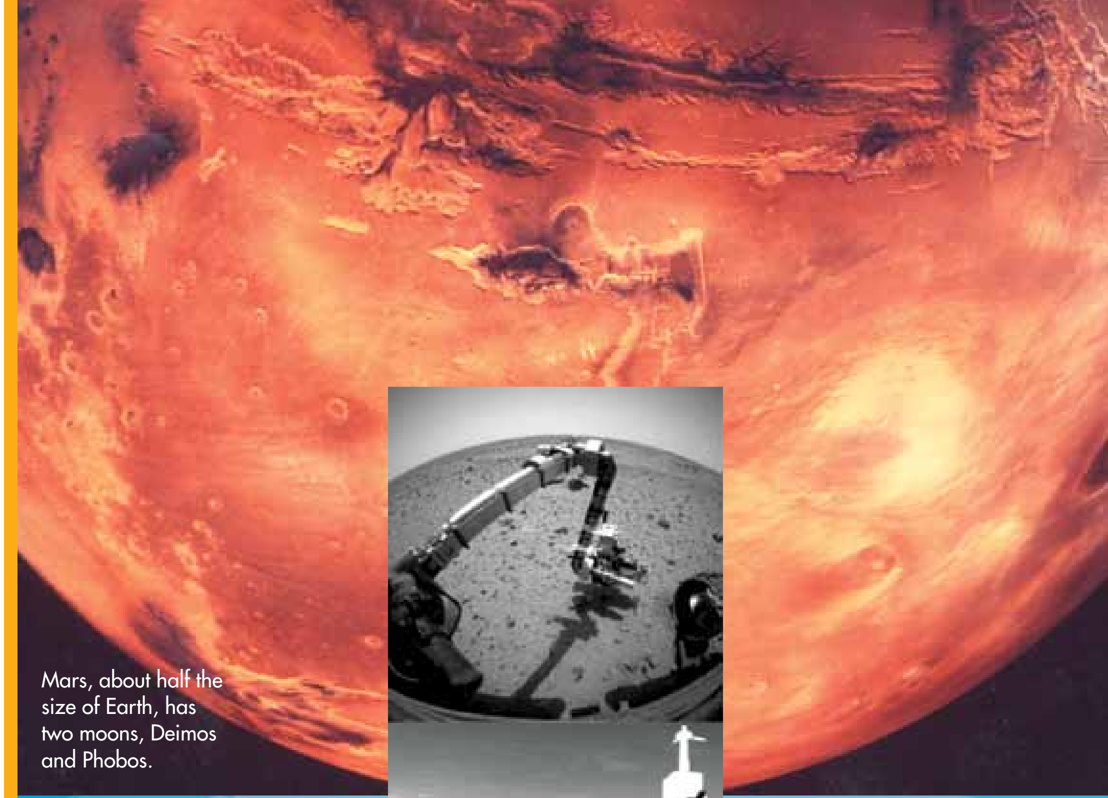
The surface temperature varies between -225°F and 63°F. Clearly visible polar ice caps cover four million square miles. Also observed are clouds of blue haze and yellow dust storms with wind velocities up to 120 miles per hour.

Surveys by orbiting spacecraft, like Mariner and Viking, have discovered some amazing things. They found a giant trough, called the Mariner Valley, almost four times deeper than the Grand Canyon and 150 miles wide. On Earth, this fault would stretch from San Francisco to Washington, D.C. Super volcanoes were also found. The largest Martian volcano, Olympus Mons, rises 16 miles above the surface. (Earth's highest mountain, Mount Everest, is only 5-1/2 miles high.) Lava flows spread over the Martian plains from these huge rock furnaces. Besides lava, volcanoes produced most, if not all, of Mars' water and carbon dioxide.

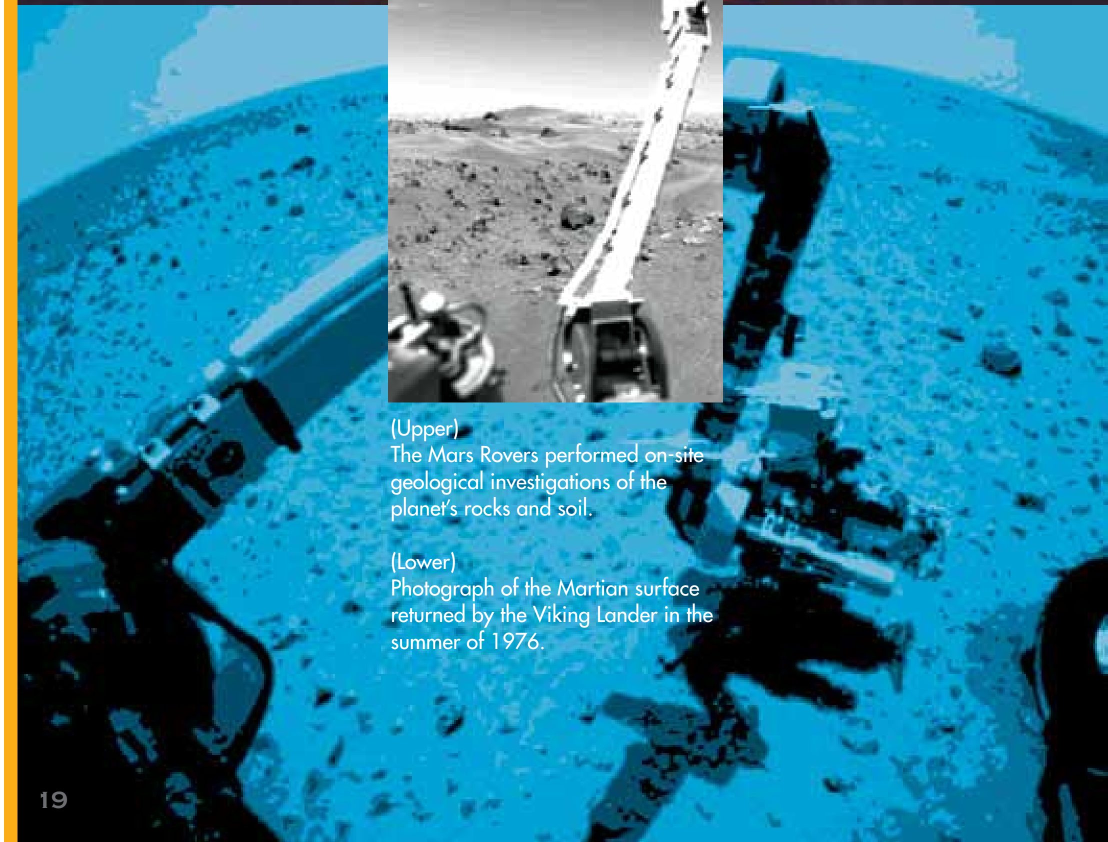
The Viking spacecraft mission had two parts: an orbiter to photograph landing sites and relay data, and a lander that would analyze the surface of the planet. In 1976, the Viking Biology Lander Instrument was the most complex space instrument flown, and at that time and location, no life forms were identified on Mars.

More than 25 years later, the Mars Exploration Rovers Spirit and Opportunity continued our exploration of Mars, searching the planet's surface for evidence of whether there was enough water in the planet's past to sustain life.

Almost all of Mars' water and most of the carbon dioxide are frozen in the polar caps, which recede and advance according to Martian seasons. Perhaps when the season is right, and Mars is close to the sun, the polar caps may melt and release all their water. So once every 50,000 years it might rain on Mars, and chances of life would be much better then.



Mars, about half the size of Earth, has two moons, Deimos and Phobos.



(Upper)
The Mars Rovers performed on-site geological investigations of the planet's rocks and soil.

(Lower)
Photograph of the Martian surface returned by the Viking Lander in the summer of 1976.

JUPITER IS ABOUT TWICE AS MASSIVE AS ALL THE OTHER PLANETS COMBINED. AS A RESULT, IT HAS THE LARGEST GRAVITATIONAL "PULL" IN THE SOLAR SYSTEM (EXCEPT FOR THE SUN).

(Right)
Artist's rendition showing the July 1994 impact of comet Shoemaker-Levy which was recorded by the NASA Galileo spacecraft as it approached Jupiter.

(Far Right)
The Northrop Grumman-built Pioneer 10 spacecraft was the first to take pictures of Jupiter.

The Outer Planets

The five outer planets – Jupiter, Saturn, Uranus, Neptune and Pluto (a dwarf planet) – are large balls of gas and have many moons (with the exception of Pluto which has three moons). These planets are not very dense and have very short "days."

Jupiter

Jupiter's day is shorter than other planets because it rotates fast, about once every 10 hours Earth time. The largest planet in our solar system, Jupiter orbits around the sun once every 11.86 Earth years. It has at least 63 moons, four of which are close to the size of our moon. The planet consists mostly of hydrogen and helium, with small amounts of methane, ammonia, water vapor, and a core of melted rock and ice.

Jupiter is about twice as massive as all the other planets combined. As a result, it has the largest gravitational "pull" in the solar system (except for the sun). The Pioneer 10 and 11 spacecraft used this huge gravitational pull for acceleration as they flew around the planet. It worked as a slingshot, increasing their speed and allowing them to break away from the gravitational pull of the sun and fly into interstellar space. On June 13, 1983, Pioneer 10 became the first Earth-made object to leave our solar system.

In July 1994, the NASA Galileo spacecraft was in a good position to record a comet impact on a planet for the first time in history. At that time the comet Shoemaker-Levy flew into the planet Jupiter. The impact resulted in a fireball five miles wide and hotter than the sun's surface.

Saturn, the second largest planet in the solar system, has the lowest density of all the planets. Saturn orbits at a distance of 9.5 AU from the sun. Saturn was named for the god of agriculture in Roman mythology.

Credit: NASA and E. Karkoschka (University of Arizona)

SATURN HAS AT LEAST 60 MOONS AND A COMPLEX RING SYSTEM THOUGHT TO HAVE FORMED FROM LARGER MOONS THAT WERE SHATTERED BY COMET AND METEOROID IMPACTS.

Saturn

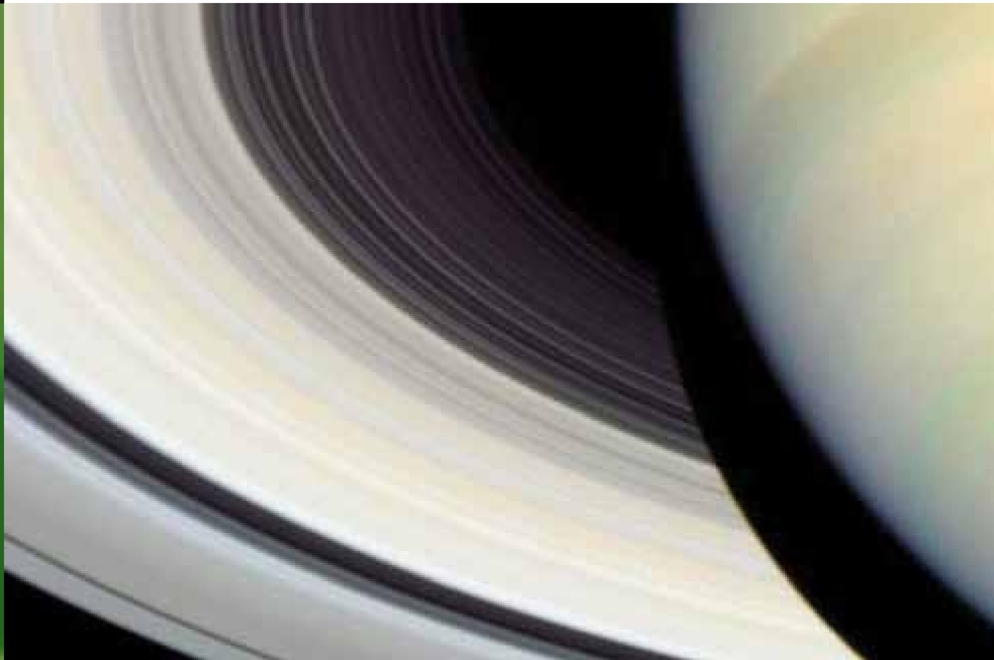
This is the second largest planet in our solar system. Like Jupiter, Saturn is mostly hydrogen and helium. Saturn has at least 60 moons and a complex ring system thought to have formed from larger moons that were shattered by comet and meteoroid impacts.

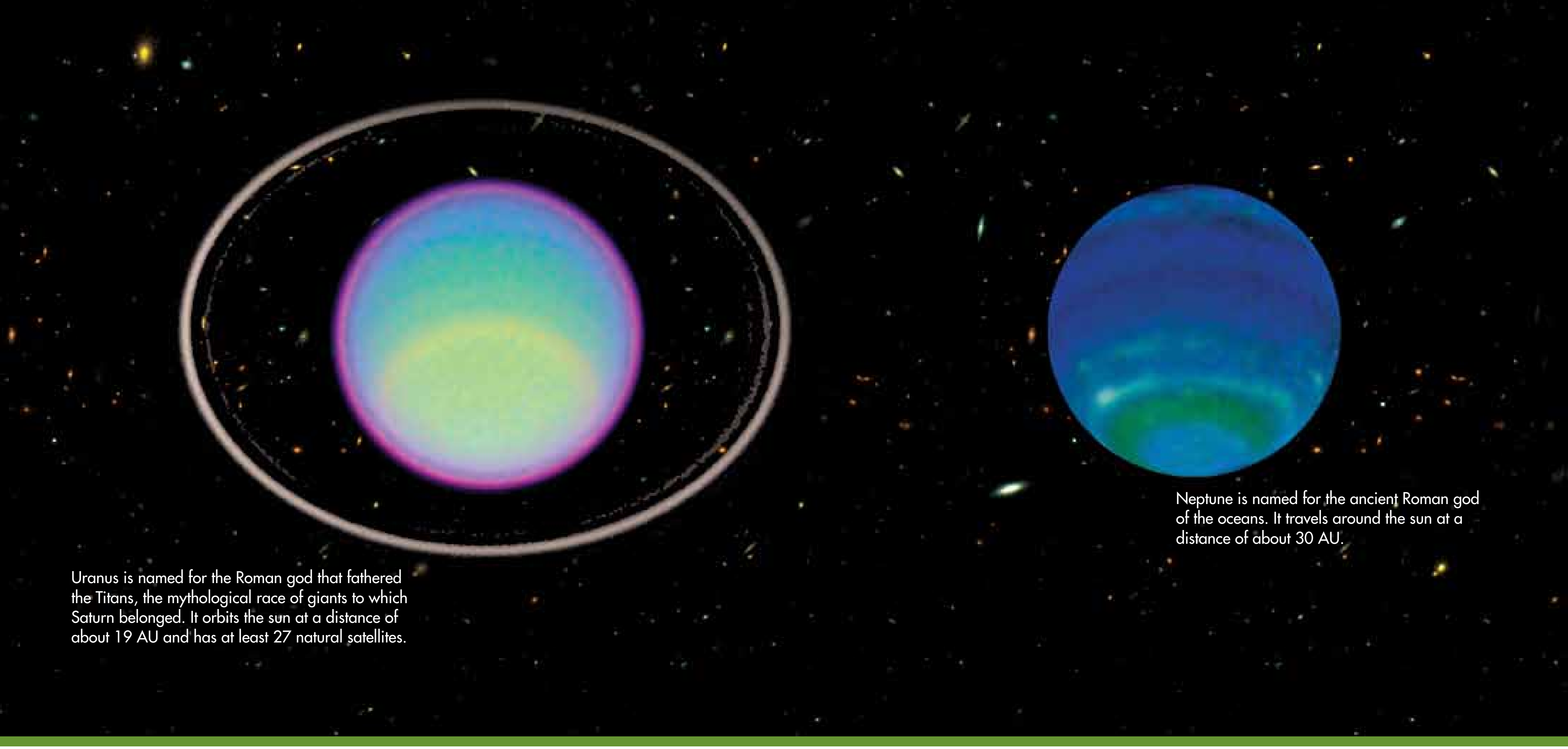
The temperature of the atmosphere is about -288°F. Wind speeds on the surface can reach up to 500 miles per hour. Titan, the largest moon, is 3,200 miles in diameter with an atmosphere of nitrogen and methane that is 1 1/2 times denser than Earth's.

The rings of Saturn surround the planet at its equator and do not touch the planet. As Saturn orbits the sun, the rings always tilt at the same angle as the equator. Saturn's seven rings consist of thousands of narrow ringlets made up of billions of pieces of ice. These range from ice particles the size of dust to chunks of ice measuring more than 10 feet in diameter.

Saturn's major rings are extremely wide with the outermost ring measuring close to 180,000 miles across. However, Saturn's rings are so thin that they cannot be seen when in direct line with Earth. The rings vary in thickness from about 660 to 9,800 feet, with a space separating the rings from each other. Each of these gaps is about 2,000 miles or more in width, with some of the gaps between the major rings containing ringlets.

Credit: NASA, ESA and E. Karkoschka (University of Arizona)





Uranus is named for the Roman god that fathered the Titans, the mythological race of giants to which Saturn belonged. It orbits the sun at a distance of about 19 AU and has at least 27 natural satellites.

Neptune is named for the ancient Roman god of the oceans. It travels around the sun at a distance of about 30 AU.

Uranus

Uranus, the third largest planet in our solar system, orbits the sun about once every 84 Earth years. Nine rings that are quite different from the ones around Saturn surround the planet. The rings did not form at the same time as Uranus; they may be remnants of a moon that broke up.

The surface of Uranus consists of blue-green clouds made up of tiny crystals of methane. Its atmosphere is about -355°F and is composed of approximately 83 percent hydrogen, 15 percent helium, 2 percent methane, and tiny amounts of ethane and other gases.

Neptune

Two astronomers, John Couch Adams and Urbain Le Verrier, discovered this planet in 1846. It travels around the sun once every 165 Earth years. Like Uranus, its bluish-green atmosphere consists of methane, hydrogen, helium and ammonia. Neptune, surrounded by four faint rings, has at least 13 moons. Wind speeds of up to 700 miles per hour blow the thick layers of clouds covering the planet, making the "surface" temperature extremely cold (about -353°F).

The clouds farthest from Neptune's surface consist mainly of frozen methane. Scientists believe that Neptune's darker clouds, which lie below the clouds of methane, are composed of hydrogen sulfide.

Pluto

Pluto is a dwarf planet 39 AU from the sun. Percival Lowell originally predicted the existence of this planet in 1905, later confirmed photographically by Clyde Tombaugh in 1930. The name Pluto was chosen so the first two letters would remind the world of Percival Lowell, even though he was not its discoverer. The planet rotates round the sun once every 248 Earth years. At -380°F, its surface is believed to be covered by frozen methane.

In 1978, astronomers at the U.S. Naval Observatory substation in Flagstaff, Arizona, detected a satellite of Pluto and named it Charon. This satellite has a diameter of about 750 miles. In 2005, a team of astronomers studying images from the Hubble Space Telescope discovered two previously unknown moons of Pluto. The satellites, later named Hydra and Nix, are up to 100 miles in diameter and lay well outside the orbit of Charon.

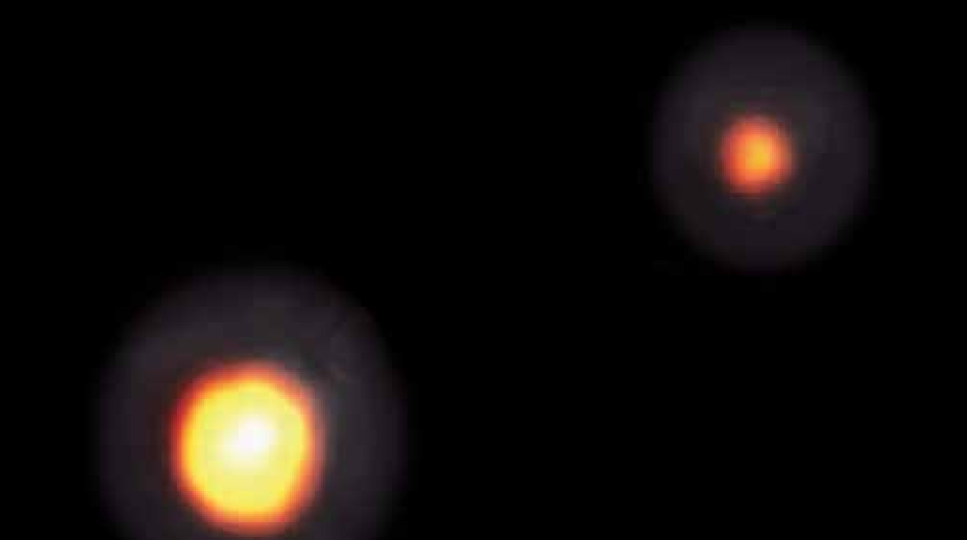
Pluto's orbit lies in the Kuiper belt along with similar icy bodies known as Kuiper Belt Objects. Due to its small size and irregular orbit, many astronomers questioned whether Pluto should be grouped with planets such as Earth and Jupiter since it seemed to share more similarities with Kuiper Belt Objects.

In 2006, this debate led the International Astronomical Union, the recognized authority in naming heavenly objects, to formally classify Pluto as a dwarf planet.

DUE TO ITS SMALL SIZE AND IRREGULAR ORBIT, MANY ASTRONOMERS QUESTIONED WHETHER PLUTO SHOULD BE GROUPED WITH PLANETS SUCH AS EARTH AND JUPITER SINCE IT SEEMED TO SHARE MORE SIMILARITIES WITH KUIPER BELT OBJECTS.

NASA, ESA, H. Weaver (JHU/APL), A. Stern (SwRI), and the HST Pluto Companion Search Team

Two new moons, later named, Hydra and Nix, were discovered around the distant planet Pluto in 2005 by the Hubble Space Telescope.



Earlier view of Pluto taken by the Hubble Space Telescope in 1994 shows a rare image of tiny Pluto with its moon Charon, which is slightly smaller than the planet.

Asteroids

An estimated 100,000 rock fragments called asteroids currently exist, widely ranging in shape and size from 1 to 500 miles across. Their orbits around the sun lie mainly between those of Mars and Jupiter, with distances from the sun of 2.2 to 3.2 AU. One asteroid, Vesta, is sometimes visible to the naked eye.

It is possible that originally several large asteroids existed and collided during the 4.5 billion years the solar system has existed, making the fragments that now fill the region.Some of the meteors that burn up in our atmosphere, and the meteorites that strike Earth's surface, are very likely asteroids that have passed too close to Earth and could not escape the planet's gravitational pull.

Scientists speculate that a major meteorite impact on the Earth 65 million years ago kicked up so much dust and debris that it effectively blocked out the sun. This potentially killed off plant life and the dinosaurs that relied on the plants for food.

Comets

Comets are the vagabonds of the solar system. Many of them make only one trip past our sun and never return. Others, like the famous comet Halley, return periodically.

Although some comets look big and bright as they pass Earth, there's almost nothing to them. A comet is a lump of rock and frozen gas, often just a few miles in diameter. As the comet approaches the sun, the sun's heat thaws the frozen gases that form a large cloud (coma) around the rocky nucleus. The solar wind blows this cloud away to form the comet's tail.

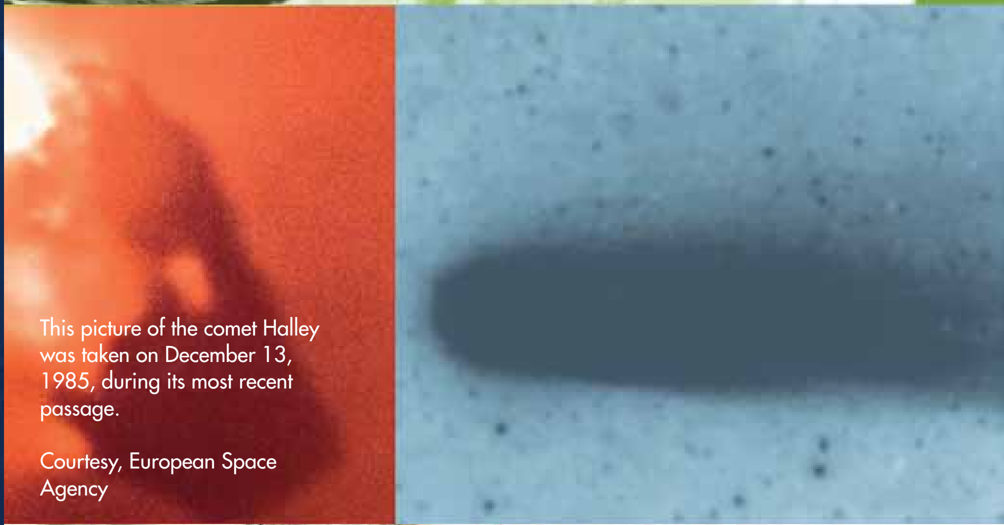
A comet's tail points away from the sun and consists of gas and dust being carried off, just as sand grains held in the palm of your hand will be carried away by a strong wind. With each pass by the sun, comets lose a little mass (about 1/1000th part of itself) and eventually fade away.

Comet Halley was first sighted in the year 240 B.C. and returns every 76.1 years. The most famous recording of a passage of comet Halley is on the Bayeux Tapestry.

The Kuiper Belt, a region of space beyond the orbit of the planets Neptune and Pluto, contains an estimated population of 200 million comet-like objects. Astronomer Gerard Kuiper predicted the existence of those objects in 1951, later confirmed in 1992 by the detection of a 150-mile wide body called 1992 QBI. Since then, 29 candidate comet nuclei have been identified, some by the Hubble Space Telescope.

(Right) The famous Bayeux Tapestry records the events of the Norman invasion of England in 1066 A.D. One section clearly records the visit that year of the comet Halley.

Gaspra was the first asteroid to be encountered by a spacecraft, Galileo, in 1991. Pioneer 10 was the first spacecraft to traverse the asteroid belt on its way to Jupiter. Scientists were worried that it might be bombarded by thousands of tiny particles. But it turns out that the belt is surprisingly empty of the microasteroids. Perhaps the larger chunks, with their greater gravitational attraction, have swept the belt clean of the dust-sized grains.



This picture of the comet Halley was taken on December 13, 1985, during its most recent passage.

Courtesy, European Space Agency

Artificial Satellites and Spacecraft

Since the launch of Sputnik in October 1957, humans have been pushing the frontiers of exploration further into the galaxy. We have orbited thousands of artificial Earth satellites, put dozens of new spacecraft in our solar system, and (to date) have put four new objects in the Milky Way galaxy (Pioneers 10 and 11, Voyagers 1 and 2). These spacecraft left our solar system and are now traveling into interstellar space.

In the 20th century, humans discovered a way to explore the final frontier of space. In the following chapters we will try to explain how and why we did it and look into the future to see where it may lead in the 21st century.

How satellites orbit Earth

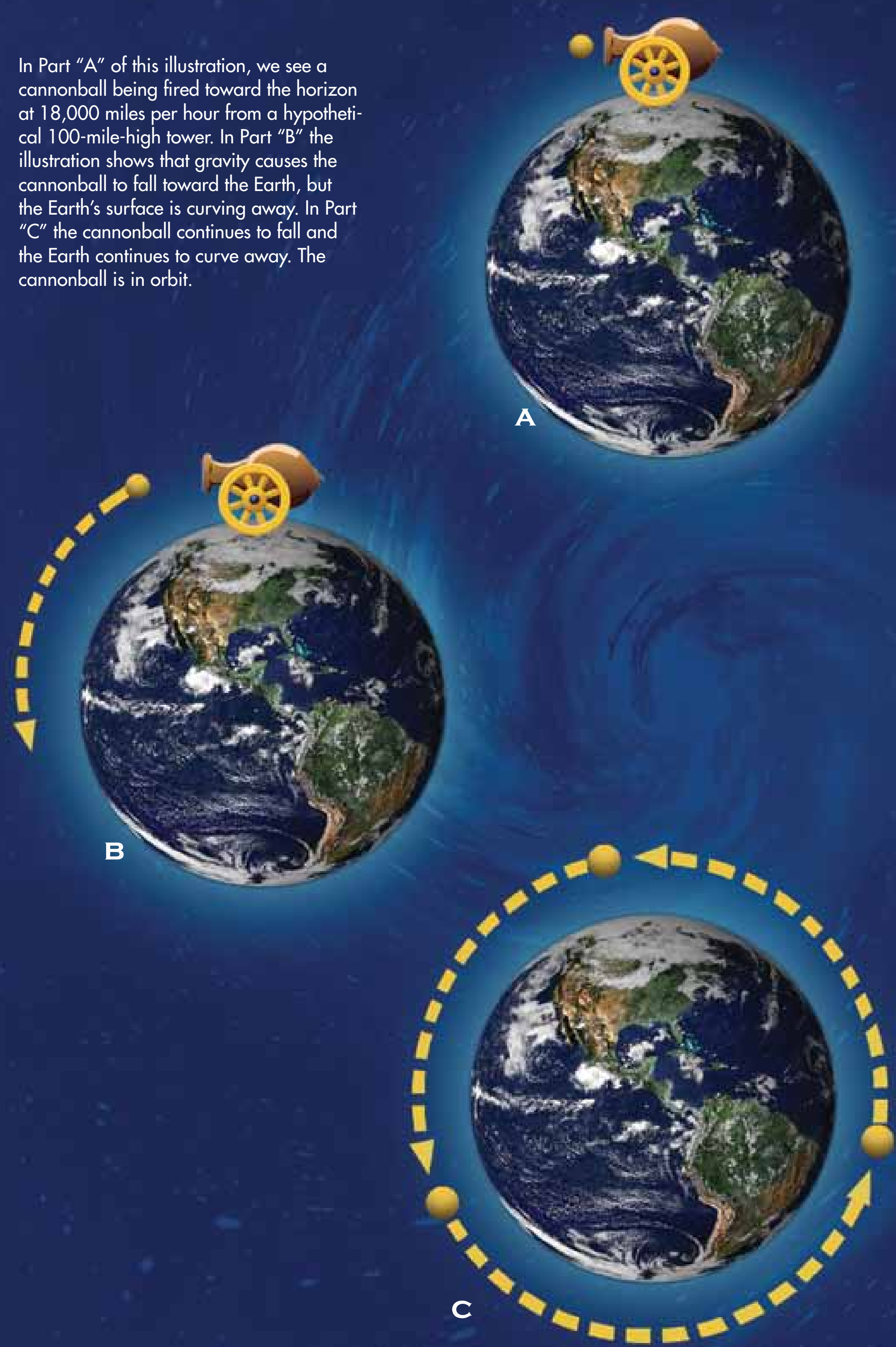
Today we take it for granted that a rocket launch from Cape Canaveral in Florida or Vandenberg in California will put a satellite in orbit around the Earth. But how does this satellite stay in orbit?

To describe the process of orbiting a satellite, let's imagine we could build a tower 100 miles high. (We know this isn't possible but use it as an example to demonstrate a principle.) Place a cannon on top of this tower and aim it toward the horizon. Fire a cannonball at approximately 18,000 miles per hour. As gravity pulls the cannonball toward the Earth, the Earth's surface curves away. The cannonball continues to fall; the Earth continues to curve away. The cannonball is in orbit (sometimes called "free fall"). Since we don't have any 100-mile-high towers, we use rockets to put the satellite in orbit.

Satellites in low-earth orbit, at a few hundred miles altitude, are subjected to "drag" forces by the Earth's atmosphere. This causes them to eventually reenter the Earth's atmosphere and burn up (like meteors).

Different satellite orbits can support different missions. For example, polar-orbiting satellites (North-South orbits) can scan the Earth more efficiently. The Earth rotates beneath the orbiting satellite, allowing continuous viewing for Earth resources monitoring. Detecting the depletion of the ozone layer and effects of pollution are two examples of resource monitoring.

One special orbit is the "geosynchronous" orbit. At 22,300 miles above the equator, an orbiting satellite circles the globe once every 24 hours and thus appears stationary when viewed from Earth. This unique orbit is extremely useful for communications satellites. Since the satellite appears to remain in one location above the Earth, it does not have to be "tracked" by complex tracking equipment. Ground stations, therefore, can be relatively simple and inexpensive, like home satellite dishes.



In Part "A" of this illustration, we see a cannonball being fired toward the horizon at 18,000 miles per hour from a hypothetical 100-mile-high tower. In Part "B" the illustration shows that gravity causes the cannonball to fall toward the Earth, but the Earth's surface is curving away. In Part "C" the cannonball continues to fall and the Earth continues to curve away. The cannonball is in orbit.

Communication satellites such as the Tracking and Data Relay Satellite System provide communications links between NASA's orbiting satellites (as well as the Space Shuttle) and the Earth.

How we use satellites

People often ask why do we have to go to space, why do we need satellites? Well, let's discuss that for a while, putting aside the huge space-related technology advancements that have given us PCs, advanced electronics, computer games, laser surgery, CAT scans and all the other technology benefits.

There are four areas where we are dependent upon space assets to maintain our lifestyle here on Earth:

- **Communications**
- **Navigation**
- **Observation**
- **Science**

Let's look at each of these areas:

Communications

This is undoubtedly the area where we have received the most significant benefits from space assets.

Since communications satellites started linking the world in the 1960s, the world has become a smaller place. The 1964 Tokyo Olympic Games were the first major events broadcast worldwide, in color, live, by satellite. Remote areas around the globe can access information broadcast from satellites. A three-minute telephone call from Los Angeles to London in 1964 cost $12; today that same call costs less than 50 cents! Space communications systems are the cornerstone of the global commerce.

NASA's first spacecraft, the Northrop Grumman-built Pioneer 1, launched in October 1958, could handle 1-1/2 lines of data every second. Today's satellites can handle all the data in 20 volumes of an encyclopedia in one second!

People can now receive hundreds of channels of TV programs in their homes, relayed from satellites 22,300 miles above the Earth to small satellite dishes on their roof or windowsill.

Navigation

A rapidly increasing use of a specialized form of space communications is a navigation aid called Global Positioning System (GPS). By tracking signals from the orbiting satellites, GPS can tell you where you are on Earth to an accuracy of about 50 feet and even more accurately with specialized equipment. It is often used when driving across country. Long distance trucking companies and ocean freighters use GPS to achieve significant savings by planning the most favorable schedules and minimizing fuel consumption.

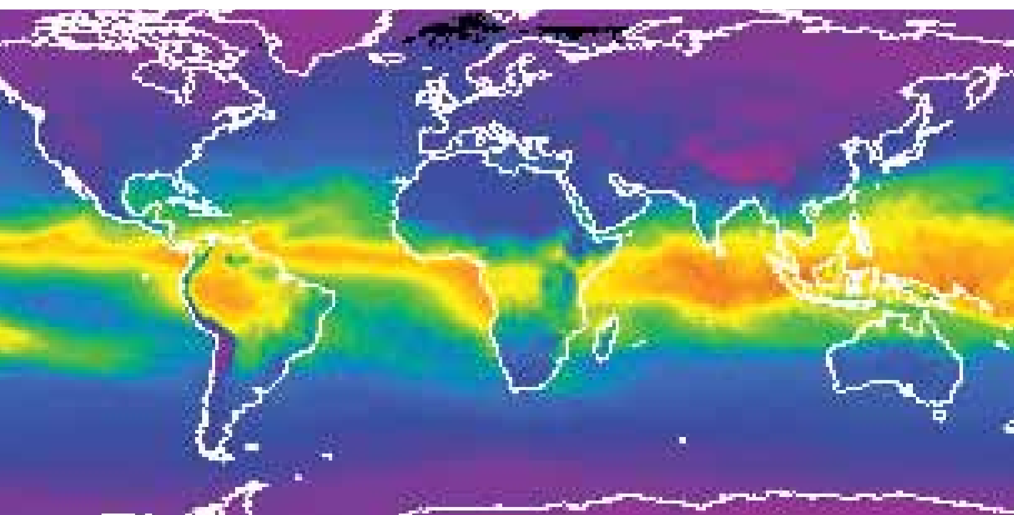
GPS also is being used to track minute Earth movements in areas of major earthquake faults. This could potentially help us predict future earthquakes.

Observation

Another major use of space is observation. From the ultimate "high ground" of space, satellites can constantly monitor the Earth for a variety of reasons. They can see whether anyone is violating the international nuclear test ban treaty by exploding nuclear weapons on Earth or in space. They can instantly spot any ballistic missile launches and warn of their approach and destination.

Environmental satellites can check the health of crops and forests around the world, and identify pollution in rivers, lakes and oceans. They can provide long-range weather forecasts that will help predict severe storms. Those weather maps you see in newspapers and on television news programs come from satellites circling the Earth.

With the Earth Observing Systems Aqua and Aura satellites, the health of Earth's water cycle, atmosphere and ozone layer can be monitored and measured. Assessments of ozone depletion, like the hole observed over Antarctica, can help us take steps to prevent future depletion.



Earth Observing System (EOS) Aqua, built by Northrop Grumman and launched in 2002, is helping us better understand global environmental changes. From its polar, sun-synchronous orbit, it constantly monitors the Earth's water cycle, including evaporation from the oceans, water vapor clouds, precipitation, soil moisture, sea and land ice, snowcover, and water surface temperatures.

Since its launch on July 23, 1999, the Northrop Grumman-built Chandra X-ray Observatory has been NASA's flagship mission for X-ray astronomy, taking its place in the fleet of "Great Observatories." Chandra's superb sensitivity allows the detection of X-rays from the dawn of the modern universe, when the first massive black holes and galaxies were forming.

Earth Observing System (EOS) Aura, a polar, sun-synchronous orbiting satellite built by Northrop Grumman and launched in 2004, studies the composition, chemistry and dynamics of the Earth's atmosphere as well as the planet's ozone, air quality and climate.

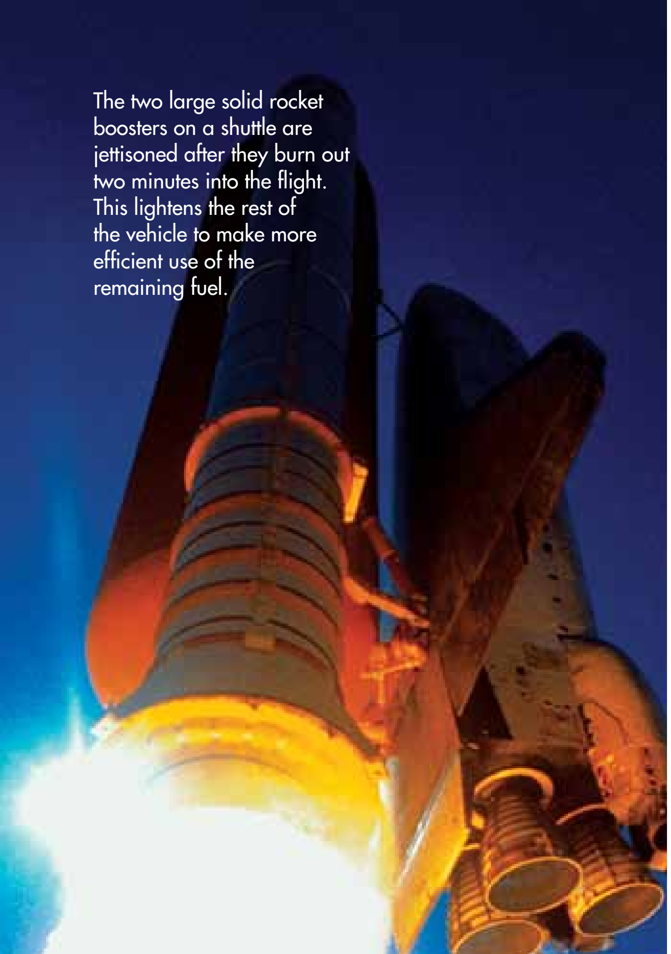
The National Polar-orbiting Operational Environmental Satellite System (NPOESS) is being built by Northrop Grumman for the Dept. of Defense (U.S. Air Force), Dept. of Commerce (NOAA), and NASA. The system will gather global environmental data and speed it to weather forecasters, military commanders, civilian leaders and scientists worldwide.

As the successor to the Hubble Space Telescope, the James Webb Space Telescope will look beyond visible light to observe the outermost regions of the universe that can only be seen in infrared wavelengths. JWST will allow astronomers to see deep into space and witness the birth and evolution of the first stars and galaxies.

Science

Let's not forget the main reason we went to space in the first place — science. As mentioned previously in this book, scientists studying the origin of our universe have to view the high-energy end of the electromagnetic spectrum from space. This is because gamma rays and X-rays are absorbed by the Earth's atmosphere. Even visible light from the stars is distorted by the Earth's atmosphere, so astronomers at the major observatories are limited in their observations.

NASA's orbiting observatories have none of these limitations and are helping to advance scientific discoveries. The Hubble Space Telescope and the Northrop Grumman-built Chandra X-ray Observatory are two facilities helping astronomers understand the origins of our universe. The Spitzer Space Telescope has joined them in their search. For a decade, the Northrop Grumman-built Compton Gamma Ray Observatory supported this scientific observation to help us understand where we came from, and perhaps even tell us where we are going.



The two large solid rocket boosters on a shuttle are jettisoned after they burn out two minutes into the flight. This lightens the rest of the vehicle to make more efficient use of the remaining fuel.

How Rockets Work

Sir Isaac Newton, the English mathematician who lived from 1642 to 1727, derived three laws of motion that have been the foundation of the structure of mechanics. Newton's third law…"For every action there is an equal and opposite reaction"… covers the basic principle of how rockets work.

To try a simple experiment that demonstrates how a rocket works, blow up a balloon, then hold the neck closed. Now let go of the balloon and it will fly around the room. The air molecules escaping from the balloon react with the balloon, causing it to move forward. That is an example of "action… and equal and opposite reaction."

This is essentially the same way a rocket engine operates. When the rocket is ignited, the propellant burns. The hot gases produced expand and go out the bottom (or nozzle) of the rocket, and the rocket moves in the opposite direction. Since oxygen is required for combustion and there is no oxygen in space, rockets must carry fuel and an "oxidizer" to provide a source of oxygen to support combustion.

Since a rocket must carry all of its propellant with it, the rocket gets lighter and travels faster as the propellant is burned. Engineers design space launch vehicles with multiple stages, like three rockets one on top of the other. This way, when the first stage finishes, it is dropped, leaving less "dead weight" for the second stage to carry.

The same occurs when the second stage finishes, and the third stage continues to put the spacecraft into orbit. The third stage is then jettisoned. Currently, this is the most cost effective way of getting satellites into orbit.

(Left)
A balloon filled with air and then released demonstrates the principle of rocketry, according to Newton's third law of motion on action and reaction.

(Far Left)
The American scientist, Robert Hutchings Goddard (1882-1945), designed the first liquid-fueled rocket.

Frequencies of Interplanetary Launch Dates From Earth for Minimum Fuel Use

Planet	Optimum Launch Date Occurrence
Mercury	116 days
Venus	18 months
Mars	2 years
Jupiter	13 months
Saturn	1 year
Uranus	1 year
Neptune	1 year
Pluto	1 year

Interplanetary Space Missions

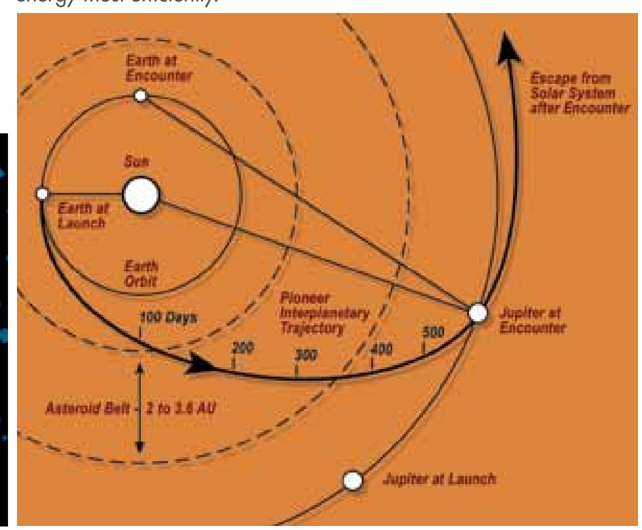
Planning an interplanetary space mission is a complex process that can only be done with the aid of computers. To conserve rocket fuel, which is expensive and heavy, we need to take advantage of the Earth's velocity around the sun (67,000 miles per hour counterclockwise). The other planets orbit in the same direction, but at different speeds. Therefore, the trajectory from Earth to the planet that uses minimum rocket energy is a long, looping curve, not a straight line.

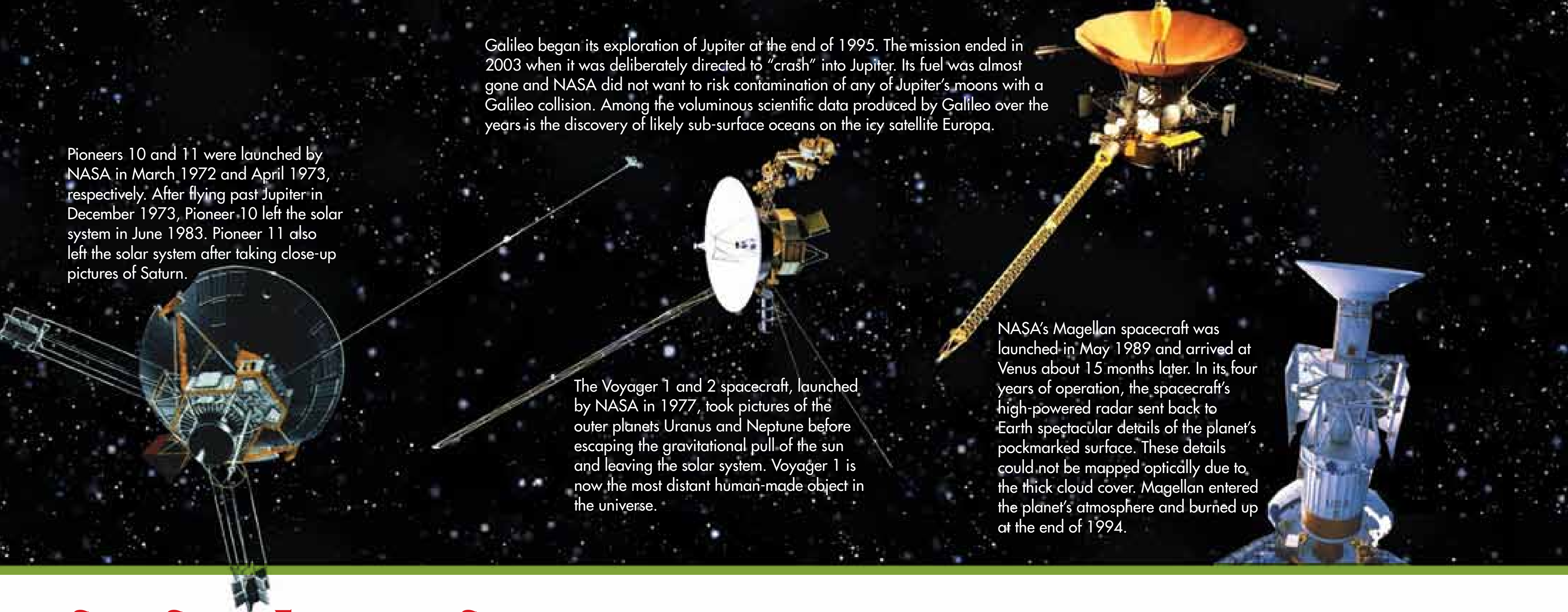
Engineers feed data about the orbits of Earth and target planet into a computer to get the launch times when the spacecraft's route will be the shortest. These times are not when the planets are the closest together.

The interval between optimum launch periods is different for most of the planets. For example, launch opportunities from Earth to Mars come only once every two years.

When Pioneers 10 and 11 set out for Jupiter, they were launched in tangential paths. This means that the spacecraft left by running more or less parallel to Earth's orbit to intercept Jupiter's orbit going in roughly the same direction as that planet.

This Pioneer trajectory to Jupiter uses the spacecraft's available energy most efficiently.





Galileo began its exploration of Jupiter at the end of 1995. The mission ended in 2003 when it was deliberately directed to "crash" into Jupiter. Its fuel was almost gone and NASA did not want to risk contamination of any of Jupiter's moons with a Galileo collision. Among the voluminous scientific data produced by Galileo over the years is the discovery of likely sub-surface oceans on the icy satellite Europa.

Pioneers 10 and 11 were launched by NASA in March 1972 and April 1973, respectively. After flying past Jupiter in December 1973, Pioneer 10 left the solar system in June 1983. Pioneer 11 also left the solar system after taking close-up pictures of Saturn.

The Voyager 1 and 2 spacecraft, launched by NASA in 1977, took pictures of the outer planets Uranus and Neptune before escaping the gravitational pull of the sun and leaving the solar system. Voyager 1 is now the most distant human-made object in the universe.

NASA's Magellan spacecraft was launched in May 1989 and arrived at Venus about 15 months later. In its four years of operation, the spacecraft's high-powered radar sent back to Earth spectacular details of the planet's pockmarked surface. These details could not be mapped optically due to the thick cloud cover. Magellan entered the planet's atmosphere and burned up at the end of 1994.

Solar System Explorers – Spacecraft

Since the early days of the space program, starting in 1958, we have been launching spacecraft that break away from the Earth's gravitational pull to explore the moon and other planets in our solar system. More than 80 have been launched to date.

The sophistication of these spacecraft varies significantly — from the complex Apollo vehicles that landed humans on the moon to explore and bring back moon rocks to Earth for analysis to fly-by photographic missions to the planets. Somewhere in between were the 1976 Viking Lander missions to the planet Mars. The Landers put robotic biological laboratories and weather stations on the surface of Mars. Through these explorers, humankind has been able to learn more about our neighbors and the origin and evolution of the solar system.

Using the gravitational pull of the huge planet Jupiter, four of these solar system explorers have been able to accelerate and escape the gravitational pull of the sun. These four spacecraft, now beyond our solar system, are the newest objects in our galaxy.

To discuss the major achievements of this planetary exploration program you have to start with Pioneer 10, built by Northrop Grumman and originally designed for a 2-1/2 year mission.

Launched in March 1972, this spacecraft took the first closeup pictures of the planet Jupiter and some of its moons in December 1973. Using the gravity boost "slingshot" acceleration of the planet, it sped to 83,000 miles per hour. It became the first human-made object to leave our solar system and travel beyond Neptune and Pluto.

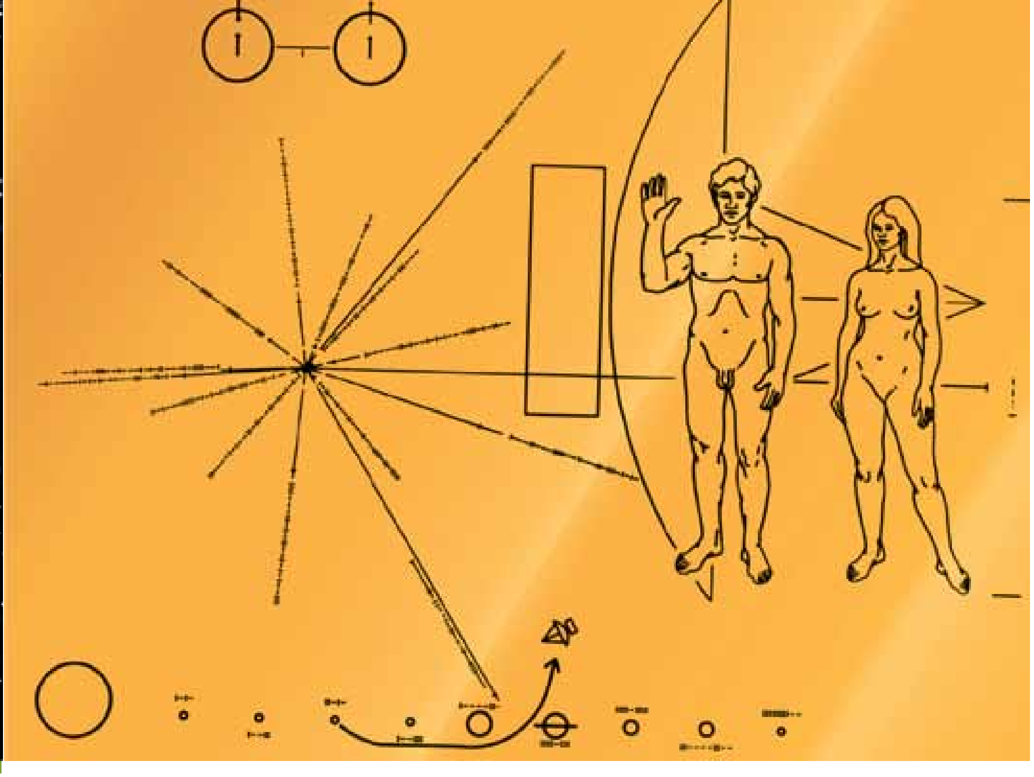
Pioneer 10's last signal was received in January 2003, more than 30 years after its launch. At the time, it was 7.6 billion miles from Earth.

Pioneer 11 was launched in April 1973. After swinging around Jupiter, it traveled to Saturn and took the first pictures of that planet, its moons and unique rings. Pioneer 11 also is now in interstellar space.

Other outer planet photographic mission explorers that have left our solar system are the Voyager 1 and 2 spacecraft, both launched in 1977. Voyager 1 took pictures of the planet Uranus, and Voyager 2 sent back spectacular photographs of the planet Neptune before leaving our solar system.

One of the more spectacular missions to the inner planets was the Magellan mission to the planet Venus. Launched by the space shuttle in 1989, Magellan arrived at Venus in the summer of 1990. For the next four years, its high-powered radar pierced the constant Venus cloud cover and mapped more than 98 percent of the planet's surface.

Exploration of the outer planets was performed in 1995 when spacecraft Galileo arrived at planet Jupiter for an extensive mission. This mission included the deployment of a probe toward the "surface" of Jupiter. (Since Jupiter is a ball of gas, it does not have a clearly defined surface such as Mars, Earth or the moon.)



(Left)
The Pioneer Plaque – A Cosmic Message in a Bottle

An illustrated plaque, affixed to both Pioneer 10 and 11, carries a message to possible alien civilizations about who we are, what we are and where we are. Designed by the late Dr. Carl Sagan, the plaque shows the figures of a man and woman (the types of people who created Pioneer), next to a silhouette of the spacecraft. The man's hand is raised in a gesture of good will. Brackets on the far right represent height of the woman compared to the spacecraft. Across the bottom are the planets ranging outward from the sun, showing Earth's location in the galaxy and the spacecrafts' trajectory. The radial pattern of nearby pulsars relative to our sun is shown on the left to further help locate our galaxy. Hydrogen, the most common element in the universe, is illustrated in the upper left and represents the key to understanding universal measurements of time and dimension.

Is There Other Life in the Universe?

If only one star in a million of the estimated 10 billion trillion stars in the universe has a planet that could support life, then there are 10 thousand trillion such planets. If only one in a million of those planets actually has an intelligent civilization at this time, there are still 10 billion civilizations out there, right now.

So why are we not talking to and visiting with these aliens from around the universe? As you probably guessed, the speed of light gets involved.

Statistics show it's likely that civilizations, if spread evenly throughout the universe, are about 1,000 light years from each other. Let's assume that tomorrow we find out a civilization exists 1,000 light years away. We send them a radio message to introduce ourselves. But it will take 1,000 Earth years for them to receive the message and another 1,000 years for us to receive their reply. Will they still be listening? Will we?

It's even worse if we try to visit them. Current top spacecraft speeds are 30,000 to 40,000 miles per hour. At that speed it would take us more than 21,000,000 years to reach them. Even if it were possible to travel at the speed of light, 2,000 years would pass before the return to Earth.

Discouraging but maybe not impossible. Planets capable of supporting life could be just a few light years away, and future generations might find ways of covering that distance.

Eventually the Earth will not be able to support human life. The sun is cooling down and at some point will be unable to support life on Earth (but don't be alarmed; we are talking about billions of years from now).

It's possible that before the Earth becomes uninhabitable a few intrepid scientists will find another place in the cosmos where life can be supported for billions of years more. Necessity is the mother of invention, and scientists and engineers are very good inventors.

Conclusion

Look at the immense strides we have made since the Wright Brothers first flew at Kitty Hawk in 1903. Today air travel is commonplace throughout the world. Spaceflight has also become routine. Humans are permanently orbiting the Earth in the International Space Station. We have left human footprints in the gray dust of the moon, and robotic rovers have explored the surface of the planet Mars. We even have spacecraft heading for the stars. If humans have done so much in 100 years, what can we do in a million years?

To realize our potential we must continue to move forward. Author James Michener, an enthusiastic space advocate, once said:

A nation that loses its forward thrust is in danger, and one of the most effective ways to retain that thrust is to keep exploring possibilities.

During the Apollo moon program we had a strong national pride. Our nation received international respect for our accomplishments, and students were interested in math and science.

We have the opportunity to build on what we learned from those days and move forward. We can go back to the moon and establish a permanent human base. We can send humans to Mars who will leave their footprints in the red dust of our neighboring planet. All of this will help us to explore, understand and utilize space.

It's just possible that somewhere in a grade school in this country, at this time, is a student very interested in math and science who will take those first steps on Mars!

Twenty years from now you will be more disappointed by the things you didn't do than by the ones you did do. So throw off the bowlines. Sail away from the safe harbor. Catch the trade winds in your sails. Explore. Dream. Discover.

— Mark Twain