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Next Stop: Uranus

On January 24, 1986. the aging but still active *Voyager 2* spacecraft will become the first mission to fly by the seventh planet in our solar system. a giant, bluish-green, and often puzzling world called Uranus. Mission scientists predict that we will learn more about this distant planet in the six hours of closest encounter than we have in the roughly 200 years since Uranus was discovered. In this issue of *The Universe in the Classroom*, we summarize our current knowledge of the complex Uranus system and provide some background to help you evaluate and explain the Voyager results to your classes.

History

Uranus was the first planet to be discovered that was not known to the ancients. It was found on March 13, 1781 by an amateur astronomer (and professional musician) named William Herschel, using a homemade 6.2-inch telescope. At first Herschel thought he had merely discovered a new comet, but it soon became apparent that the new object behaved like a planet. After some debate it was named Uranus, after the god in Greek mythology who most closely personified the heavens. (Uranus was the father of the Titans and thus grandfather of Jupiter.)

As a result of his pioneering find, Herschel received a life-long stipend from the king of England and was able to continue building larger and larger telescopes and making a host of important discoveries. Among these was his spotting of two of Uranus's moons, Titania and Oberon, in 1787. (Uranus's satellites are the only ones in the solar system not named after figures in Greek and Roman mythology; instead they are named for characters in English literature. Oberon and Titania are the rulers of the fairies in Shakespeare's A Midsummer Night's Dream.)

Two further moons were discovered by the British astronomer William Lassell in 1851 and named Ariel and Umbriel, after characters in Alexander Pope's Rape of the Lock. (Ariel is also a figure in Shakespeares The Tempest.) Uranus's fifth moon was not discovered until 1948. when the noted American astronomer Gerard Kuiper used an 82-inch telescope in Texas to distinguish its faint light. It is called Miranda after another character in The Tempest.

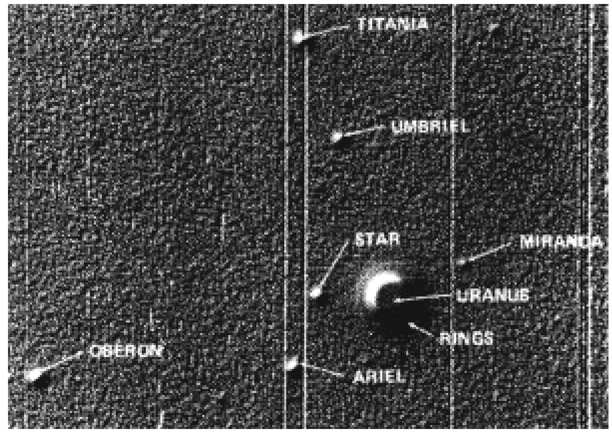
In 1977 a team of astronomers led by James Elliot of MIT discovered an extremely faint system of rings encircling Uranus. Flying aboard a jet aircraft equipped with a sizeable telescope, they found the rings by watching the Uranus system pass in front of a star. As expected, when the disk of the planet was in front of the star, the starlight was blocked (or eclipsed). Unexpectedly, the astronomers also saw several brief eclipses before and after Uranus was scheduled to cover the star. After careful analysis of their data, they surmised that the starlight was being alternately hidden and revealed by several thin, dark rings.

Uranus's Rings and Moons from Earth

This picture is the first visible-light image to show the rings of Uranus. It was produced in 1984 by Drs. Bradford Smith of the University of Arizona and Richard Terrile of NASA's Jet Propulsion Laboratory. They used the Carnegie Institution of Washington's 2.5-meter (100-inch) du Pont telescope high in the Chilean Andes, equipped with an electronic camera, to register the original image. The data recorded by the camera were then computer processed at the Jet Propulsion Laboratory to bring out details which would have been undetectable if the image had been recorded by conventional photographic means.

We view the Uranus system nearly pole-on now, because Uranus's spin axis is tilted by about 90 degrees relative to its orbit path and since it is in a part of its orbit where one pole is pointed almost directly toward the Sun and the inner planets (including Earth). The rings and satellites orbit around the plane above its equator, so we see them surrounding Uranus spread out like this. Notice that the ring system is more distinct at lower-right than elsewhere; this is because — unlike Saturn's rings — Uranus's are broader on one side than on the other.

JPL computer-processing created the false "three-dimensional'' effect, which helps make the very dark rings stand out clearly, even though they are close to the much brighter planet. The vertical lines are due to minor defects in the detector. (Photograph courtesy of NASA.)



Uranus: The Planet Uranus is one of the giant planets in the solar system, a designation it shares with Jupiter, Saturn, and its more distant neighbor, Neptune. It is a bluish-green globe about 51,000 kilometers (31,000 miles) in diameter, some four times the size of our Earth. In three dimensions, some 64 Earths could fit into the volume of the giant planet.

Uranus is more than 19 times farther from the Sun than our Earth, taking about 84 Earth years to circle our star. Its average distance from the Sun is 1.8 billion miles, so large that when Herschel discovered the planet it almost doubled the size of the known solar system.

As a result of its remoteness, the amount of sunlight reaching Uranus is very small indeed — only about 1/400th the intensity of the sunlight we enjoy on Earth. This is a question of more than just academic interest, since the darkness will make it more difficult for Voyager's cameras to take photographs than it was at Jupiter or Saturn. Because we see planets only by the sunlight they reflect back to us, Uranus is always a faint object in our sky. In a recent issue of Sky & Telescope magazine James Elliot calculates that the total amount of light astronomers have seen observing Uranus since 1781 is less than the light produced simply by turning on an average flashlight for one second.

One of the most interesting features of Uranus's motion is that the planet is rotating "on its side.'' The planets in our solar system generally circle the Sun in a flat plane. If you imagine passing a thick (cosmic) sheet of paper through the Sun's equator, the orbits of the planets would be found more or less in that sheet. In addition to their motion about the Sun, the planets also spin on their axes, producing day and night. These axes are generally perpendicular to the plane of the solar system. Venus, for example, has an axis that points almost straight up and down; Earth's axis is tilted by 23 degrees. giving us our varying seasons.

Uranus's axis is tilted by about 90 degrees from the vertical, meaning its axis lies more or less in the plane of the solar system — Uranus spins on its side. Right now Uranus's south pole is pointing almost directly at the Sun and its north pole is in complete darkness. As the planet slowly circles the Sun, the part facing the Sun gradually changes. In 42 years, it will be the north pole that receives the feeble rays of the distant Sun and the south pole that is shrouded in darkness.

We are not sure why Uranus rotates on its side. One idea is that early in the history of the solar system, one large chunk of forming matter or a number of smaller chunks collided with Uranus and tipped it over. But it is not easy trying to reconstruct events that occurred billions of years ago (and billions of miles away).

Astronomers are also not sure how fast Uranus spins about its sideways axis — current estimates suggest about 16 Earth hours, but this number is very uncertain. We hope Voyager will soon give us the definitive answer to this question — and many others.

The Rings

Uranus's rings have been observed with the starlight-blocking (or occultation) technique 13 more times since they were discovered in 1977. We now know that there are at least nine narrow rings encircling the planet. They are not easy to see even with sophisticated modern techniques. First of all, the whole system is very narrow — probably no more than 10,000 km (6000 miles) from the inner edge to the outer edge. By contrast, Saturn's main ring system is 70,000 km wide and some of its outer rings stretch another 100,000 km farther from the planet. Uranus's rings themselves vary in width from just 2 kilometers for the innermost rings, to almost 100 kilometers for the widest part of the ring.

A second reason Uranus's rings are so hard to make out is that they are very very dark, reflecting little of the sparse sunlight they receive. For example, the outermost ring (called the epsilon ring) reflects only 5 percent of the light it receives. Furthermore, the rings all lie within 26,500 kilometers (16,500 miles) of the planet's comparative!y much brighter cloudtops. making their feeble light even more difficult to distinguish.

Astronomers have learned a bit more about the rings by studying not their visible light, but the faint heat rays (infrared) they emit. Once again, however, the close-up Voyager photos will help us sort out just how many rings there are and what their detailed properties might be.

One noteworthy and fundamental puzzle is just how the rings, which are made up of many smaller particles orbiting together, maintain their thin structure without spreading out. One suggestion is that tiny moons on either side of each ring act as "shepherds'' holding the ring particles in their narrow orbits. Voyager investigators will be on the lookout for evidence of these shepherding satellites during the flyby.

Uranus Characteristics

Diameter	= 51,000 km (32,000 miles)
Distance from Sun (average)	= 2.9 billion km (1.8 billion mi)
Mass	= 14.6 x Earth's mass
Density (average)	= 1.2 gm/cc
Orbital period (year)	= 84.01 Earth years
Rotation period (day)	= 16 hours (uncertain)
Force of gravity at "surface"*	= 88% of Earth's

* "Surface'' here means the cloudtops; Uranus may not have a solid surface at all.

Uranus's Satellites

The accompanying tab!e gives our best (pre-Voyager) estimates for the characteristics of Uranus's five known satellites. Overall, they appear some 2000 times fainter to us than the faintest star that can be seen with the naked eye, so it should not be surprising that we don't know a great deal about them. All are cold worlds, with the surface temperature never exceeding minus 190 degrees centigrade. They vary in size from a chunk about the size of an asteroid to a world less than half of the size of our Moon. (It is interesting that Uranus is the only giant planet without a large moon; Jupiter, Saturn, and Neptune each have one or more satellites that are comparable in size to our Moon.)

If the Voyager exploration of Jupiter and Saturn is any indication, we may well discover previously unknown satellites around Uranus during our brief visit. In fact, three astronomers at MIT have already predicted the existence of another satellite inside the orbit of Miranda (the innermost known moon) from the detailed study of the motion of the rings. We shall see how well their prediction comes out.

One major challenge of the Voyager flyby involves the orientation of Uranus's moons Voyager is approaching the planet from the general direction of the Sun — the same direction Uranus's south pole now faces. The satellites, on the other hand, orbit about the equator of the planet. This means that as Voyager approaches its rendesvous, the orbits of the satellites will present a kind of bullseye to our spacecraft. Just like a bullet can only pierce a target in one place, so Voyager can only select one point in that bullseye to fly through. (When Voyager passed by Jupiter and Saturn, it flew more along the plane of the satellites' orbits and was able to explore several moons in succession.) To get the best views of both the planet and some satellites. Voyager scientists have programmed the spacecraft to fly closest to the small inner moon Miranda. The plan calls for Voyager to pass within 29,000 kilometers (18,000 mi) of Miranda and within 81,000 km (51,000 mi) of

Uranus's cloudtops. However, Voyager's cameras will be trained on all the other moons as well, even if the views will not be quite as detailed as our images of Miranda.

Uranus's Satellites

		Miranda	Ariel	Umbriel	Titania	Oberon
Distance from planet	km	130,000	192,000	267,000	438,000	586,000
	mi	80,000	119,000	166,000	272,000	364,000
Diameter	km	500	1,300	1,100	1,600	1,630
	mi	310	800	680	990	1,010
Revolution period (in Earth days)		1.4	2.5	4.1	8.7	135

[For comparison, Earth's Moon is 385,000 km (239,000 mi) from our planet, 3,475 km (2,160 mi) in diameter, and has a revolution period of 27.3 days.]

The Voyager Mission

Voyager 2, one of the most successful planetary missions in history, was launched in August of 1977. It flew by Jupiter in July 1979 and Saturn in August 1981. Only expected to last 4 years, the spacecraft is now in its 8th year of operation. Although a number of its components have failed or are beginning to show signs of wear, the many backup systems and the ingenuity of NASA engineers have kept the craft in sufficiently good shape that it is expected to go on after its Uranus encounter to a 1989 flyby of Neptune.

When Voyager arrives at Uranus, after a 2.8 billion kilometer (1.7 billion mile) journey from Saturn, the giant planet will become the most distant object ever visited by a human craft. The spacecraft picked up speed at each of its two previous stops — engineers used the gravity of Jupiter and Saturn to whip the craft around like a stone in a slingshot and speed it on its way. Project scientists calculate that without this "gravitational assist'' it would have taken the craft 30 years to get from Saturn to Uranus, instead of the little more than 4 years it took.

When it encounters Uranus, Voyager will be so far away from the Earth that receiving complex scientific data from the spacecraft becomes a tremendous technical challenge. At Jupiter, Voyager was able to transmit over 115,000 bits of information each second; at Uranus, the rate will drop to 21,600 and NASA will be calling on an additional large radio antenna in Australia to help its Deep Space Network with catching every bit of information we can.

There are many other challenges involved in doing "on site'' astronomy from 2 billion miles away. To give one further example, we should remind ourselves that the Uranus environment is so dark that long exposures will be required for useful photography. However, Voyager will be flying through the Uranus system at a speed of about 40,000 miles per hour. This means that during a 10-second exposure, the spacecraft will travel 100 miles and would smear the images of the objects it passes closest to. To make matters even more complicated, it will be impossible for scientists on Earth to exert minute-to-minute control over the gathering of data or to make quick changes based on what the first photographs reveal. At Uranus's distance from Earth at the time of encounter (about 2 billion miles), radio messages take 2 hours and 45 minutes to travel from one world to the other.

Thus project engineers have had to program and reprogram Voyager's onboard computers to execute all the maneuvers necessary for gathering data and compensating for the equipment that is no longer working well. To take long-exposure photographs despite Voyager's enormous speed, the entire spacecraft will be rotated "backwards'' to allow it to compensate for its motion through the Uranus system and thus, in essence, to hold its camera still. By using several new programming and message compression techniques, Voyager engineers managed to squeeze more than 200 pictures per day into the mission schedule during the encounter.

The Future

If all continues to go well, *Voyager 2* will come within 20,000 miles of the 8th planet, Neptune, in August 1989 and perhaps even send back photographs of this distant outpost. After that, the craft will begin its long journey into darkness. In the late 1990's it may encounter the heliopause — the region where the influence of the Sun's wind becomes so weak that, in a sense, you are at the edge of the solar system. After that, it will be in interstellar space — the vast almost empty gulfs that separate stars. Traveling in the general direction of the bright star Sirius, the spacecraft will probably continue coasting for millions of years without coming near either a planet or a star.

We will cover the results of the *Voyager* flyby of Uranus in a future issue of *The Universe in the Classroom*.

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