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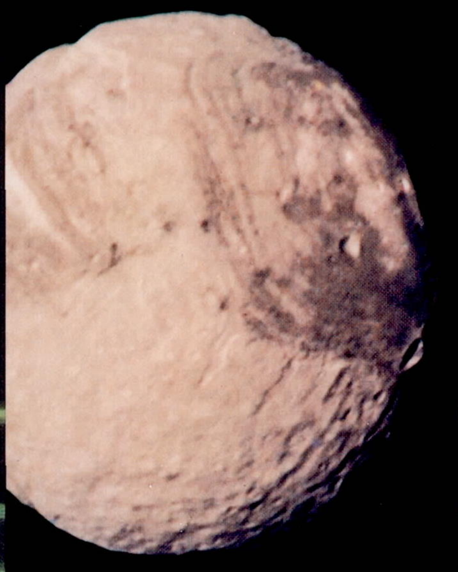
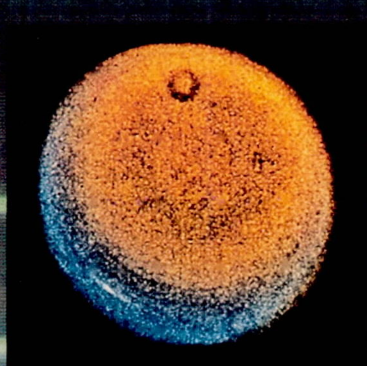
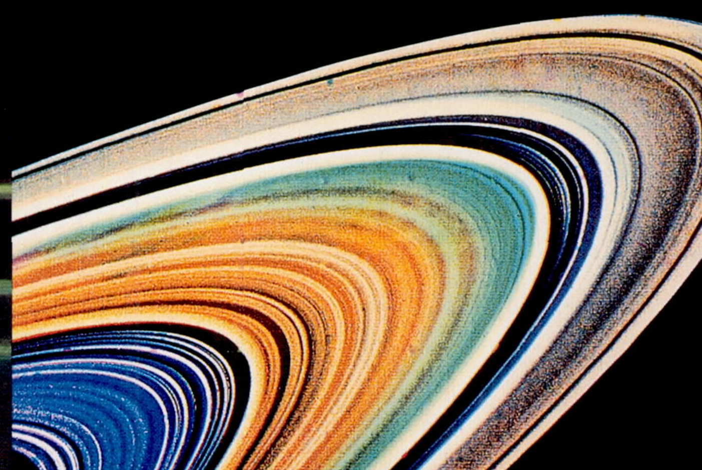
How We Get Pictures From Space

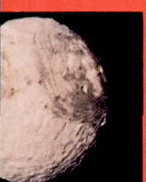
by Robert Haynes





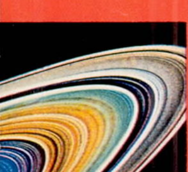


This false-color view of the Uranian ring system shows all nine known rings. Six 15-second narrow-angle images were taken: two each through green, clear, and violet filters. The images were averaged, then combined through computer enhancement. The final image shows that the brightest or epsilon ring at the top is neutral in color, with the fainter eight other rings showing color differences between them. Scientists will use this color information to try to understand the nature and origin of the ring material.



On Miranda, two types of terrain can be seen: cratered and grooved. The dark area was visible several days before the Voyager's *closest approach. Scarps, or cliffs, along the limbs have a rugged relief several kilometers high.*

The surface of Uranus is almost void of contrasting features. Here, however, a distinct cloud (lower left) is shown as a bright streak near the planet's limb. To gain this resolution, however, the image had to be so highly enhanced that faint blemishes on the camera lens appeared as donut-shaped features (as seen on the top and to the right of the image).



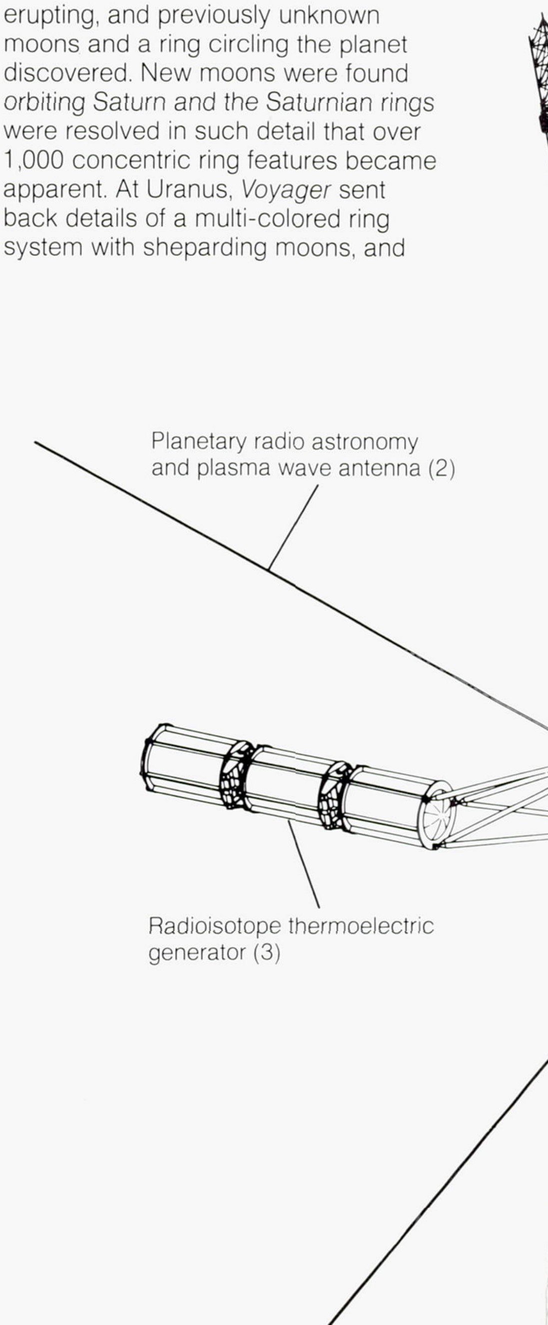
Voyager *sent this striking view of Saturn's rings 8.9 kilometers away from the planet, showing possible variations in the chemical composition from one part of the system to another. Besides the previously known blue color of the C-Ring and the Cassini Division, the picture shows additional color differences between the inner B-Ring and outer region (where the "spokes" form) and between these and the A-Ring.*

Since the first cave dweller ventured out to gaze up at the night sky, mankind has sought to know more about the mysterious images he saw there. Being limited by what he could see with his naked eye, this early star gazer relied on his intellect and imagination to depict the universe. He etched images in stone by hand, measured and charted the path of the wanderers he watched, and became as familiar with them as his limited technology would allow.

Although traveling down some wrong turns over the centuries, mankind began to overcome his limits one by one. The images he could see expanded dramatically when Galileo peered through the first telescope and saw the "cup handles" of Saturn. Bigger and more powerful telescopes were built, sharpening images still further and answering some of the continuing mysteries as well as unfolding new ones.

In the 1950s, mankind's view of the heavens reached beyond the obscuring atmosphere of Earth as unmanned spacecraft carried cameras and data sensors to probe moons and planets of the Solar System. Images these vehicles sent back to Earth made most previous visual planetary observations from the Earth's surface obsolete. Spacecrafts flew close to planets, orbited them, and some landed. They provided scientists with exceptionally clear and close views of planets and moons as far away as Saturn. In January 1986, the *Voyager 2* spacecraft flew close to the planet Uranus and returned the first close-up images of this distant wanderer to scientists on Earth. *Voyager* is now on its way to Neptune for close-up views in 1989 of an object we can barely see from Earth.

The knowledge humans have today of outer space would astound Galileo. Spacecrafts have sent back pictures to Earth-bound scientists of a cratered and moon-like surface on the planet Mercury and revealed circulation patterns in the atmosphere of Venus. From Mars, they have sent back images of craters, giant canyons, and volcanoes on the planet's surface. Jupiter's atmospheric circulation has been revealed, active volcanoes on the Jovian moon Io have been seen erupting, and previously unknown moons and a ring circling the planet discovered. New moons were found orbiting Saturn and the Saturnian rings were resolved in such detail that over 1,000 concentric ring features became apparent. At Uranus, *Voyager* sent back details of a multi-colored ring system with sheparding moons, and



measured a magnetic field that is tilted 55° from the planet's axis of rotation.

These discoveries and thousands of others like them were made possible through the technology of telemetry, which is the technique of transmitting measurements to distant locations.

Measurements made on board a spacecraft may be telemetered to a distant receiving station, such as a huge dish antenna on Earth. Telemetry includes the spacecraft technology for scanning objects in space and transmitting images to Earth.

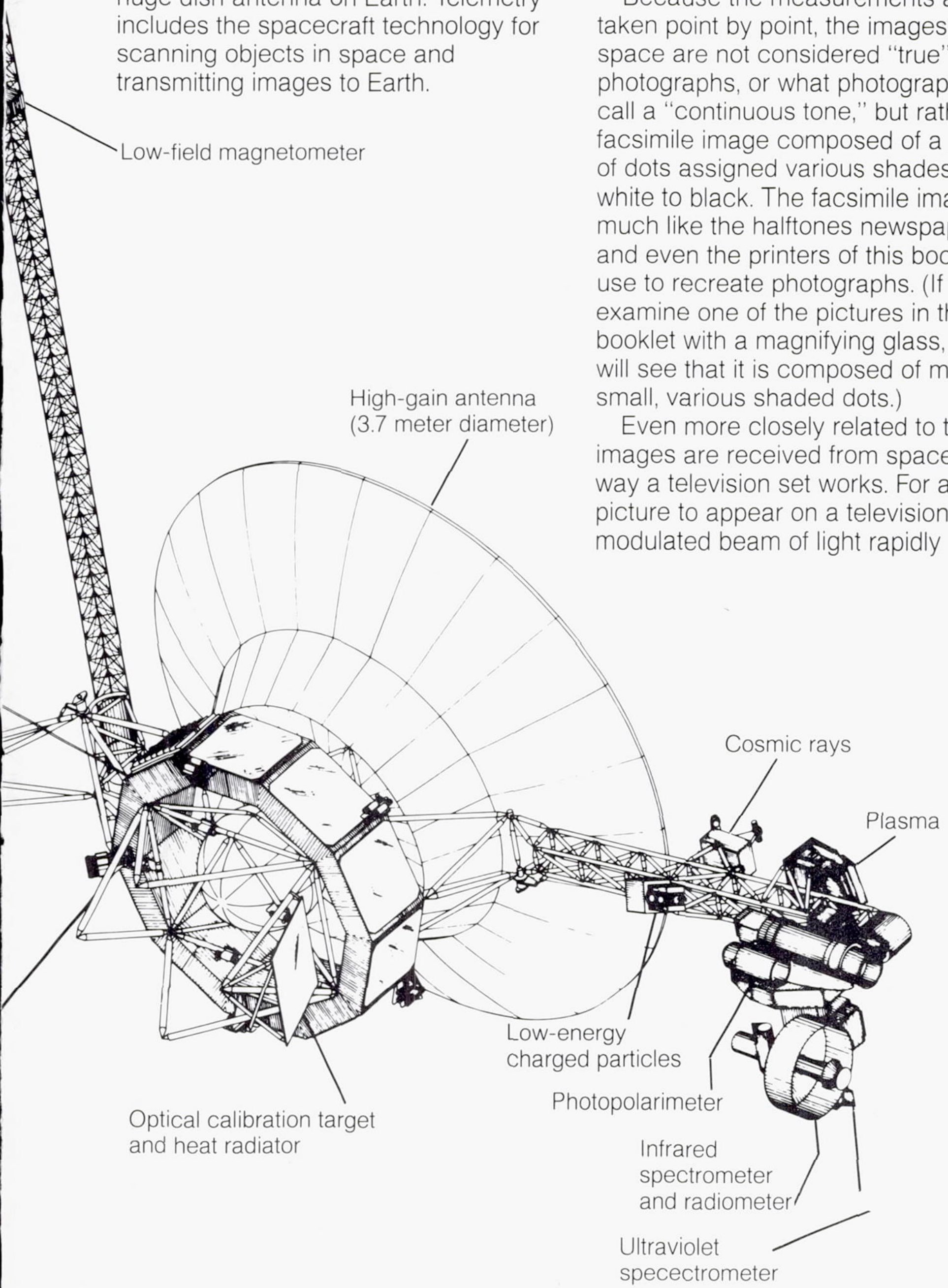
A scanning system on board the spacecraft measures reflected light from a planet or moon as it enters the spacecraft's optical system. A computer converts the measurements into numerical data, which are transmitted to a receiver on Earth by radio waves. On Earth, computers reassemble the numbers into a picture.

Because the measurements are taken point by point, the images from space are not considered "true" photographs, or what photographers call a "continuous tone," but rather a facsimile image composed of a pattern of dots assigned various shades from white to black. The facsimile image is much like the halftones newspapers, and even the printers of this booklet, use to recreate photographs. (If you examine one of the pictures in this booklet with a magnifying glass, you will see that it is composed of many small, various shaded dots.)

Even more closely related to the way images are received from space is the way a television set works. For a picture to appear on a television set, a modulated beam of light rapidly illuminates long rows of tiny dots, filling in one line then the next until a picture forms. These dots are called picture elements, or pixels for short, and the screen surface where they are located is called a raster. Raster scanning refers to the way the beam of light hits the individual pixels at various intensities to recreate the original picture. Of course, scanning happens very fast, so it is hardly perceptible to the human eye. Images from space are drawn in much the same manner on a television-like screen (a cathode-ray tube).

Although cameras on a spacecraft probing the Solar System have much in common with those in motion picture studios, they also have their share of differences. For one, the space-bound cameras take much longer to form and transmit an image. While this may seem like a disadvantage, it is not. The images produced by the slow-scanning cameras are of a much higher quality and contain more than twice the amount of information present in a television picture.

The most enduring image gatherer in space has been the *Voyager 2* spacecraft. *Voyager* carries a dual television camera system, which can be commanded to view an object with either a wide-angle or telephoto lens.



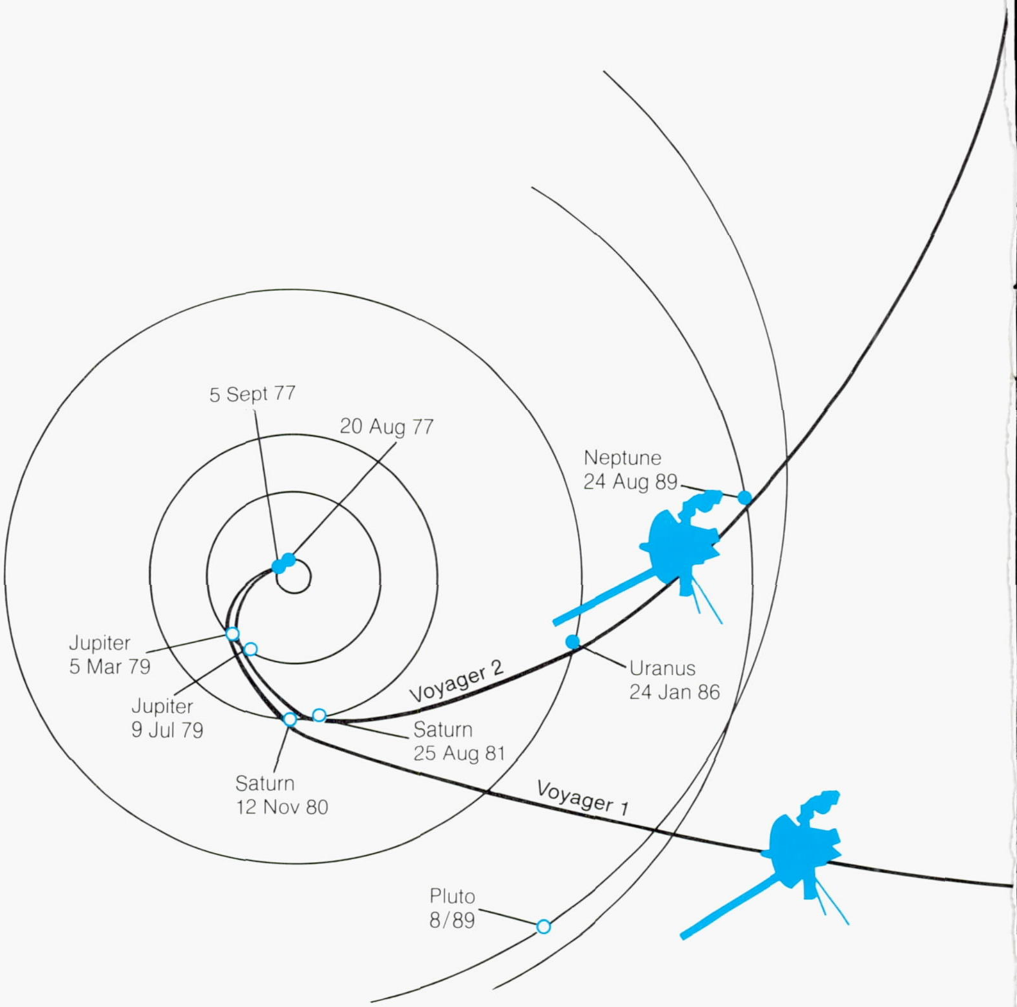
The Voyager *spacecraft weighs 795 kilograms. Of this, 113 kilograms are scientific instruments. The large dish antenna measures 3.66 meters in diameter. A gold-plated copper record of Earth greetings, sights, and sounds is attached to the craft inside a gold-plated aluminum canister, which has instruction symbols on its face. On the boom at the left are the nuclear power generators and above this boom is the 13-meter magnetometer boom. The boom to the right contains the optical equipment, including the camera and other sensors. Two 10-meter whip antennas, which study planetary radio astronomy and plasma waves, extend from the spacecraft's body below the magnetometer boom.*

The system is mounted on a science platform that can be tilted in any direction for precise aiming. Reflected light from the object enters the lenses and falls on the surface of a selenium-sulfur vidicon television tube, 11 millimeters square. A shutter in the camera controls the amount of light reaching the tube and can vary exposure times from 0.005 second for very bright objects to 15 seconds or longer when searching for faint objects such as unknown moons.

The vidicon tube temporarily holds the image on its surface until it can be scanned for brightness levels. The surface of the tube is divided into 800 parallel lines, each containing 800 pixels, giving a total of 640,000. As each pixel is scanned for brightness, it is assigned a number from 0 to 255.

This range (0 to 255) was chosen because it coincides with the basic way a computer operates. In a computer, information is read in units called "bits" and "bytes." A bit contains one of two possible values, and can best be thought of as a tiny on-off switch on an electrical circuit. A byte, on the other hand, contains the total value represented by 8 bits. This value can be interpreted in many ways, such as a numerical value, an alphabet character or symbol, or a pixel shaded between black and white. As each bit is set either "on" (a value of 1) or "off" (a value of 0), the value of the byte increases or decreases in multiples of 2 (2×2×2×2×2×2×2×2, or 2^8 or 256). Keep in mind, 8 binary digits, in sequence, represent a doubling of numerical value. The Binary Table on the right shows how bits are arranged according to their value.

Each byte, therefore, can contain a "binary" value from 0 to 255, with 0 being one of its possible 256 values. If 0 represents pure white, and 255 pure

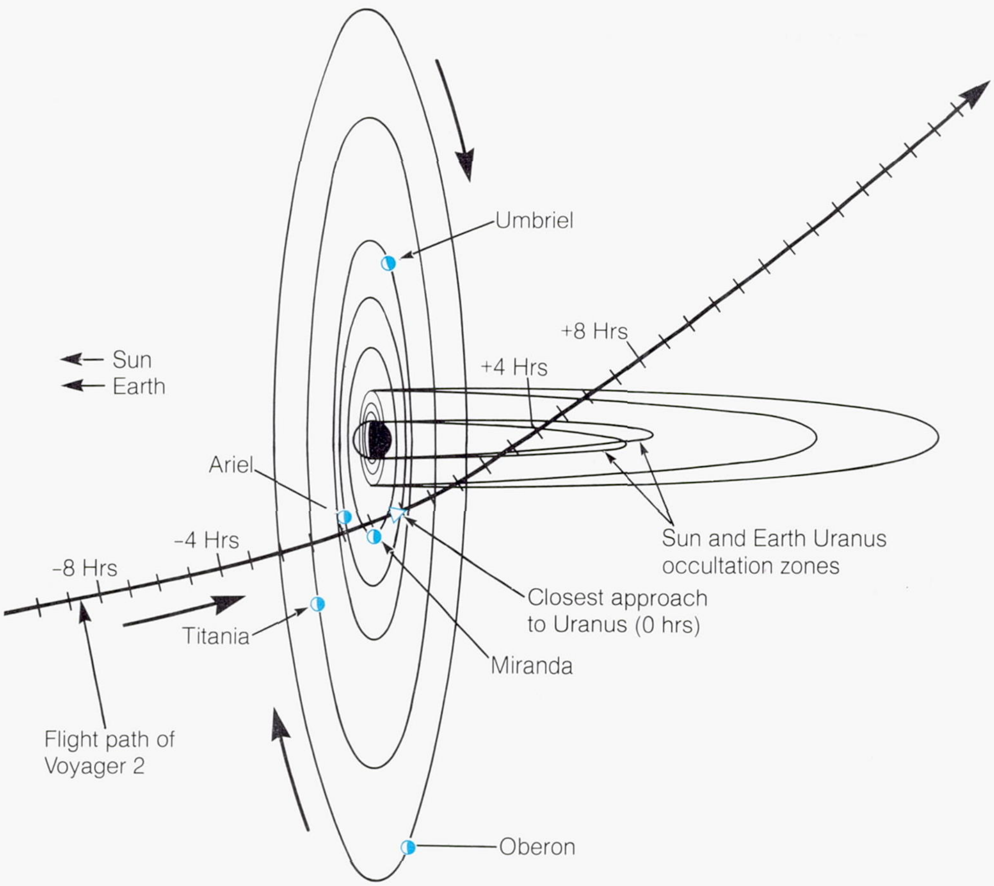


The Voyager *missions began August 20, 1977, from Cape Canaveral, Florida. Two probes launched 16 days apart were to explore the outer planets, returning images and data. Both explored Jupiter and Saturn and their moons, but* Voyager 1 *veered up out of the ecliptic plane to return data on fields and particles it encounters, while* Voyager 2 *flew on to encounter Uranus. It sent back striking images of this planetary system which is barely visible from Earth.* Voyager 2 *is now on its way to Neptune and should arrive in late 1989.*

Binary Table

Bit of Data	8	7	6	5	4	3	2	1	
Sequence Value	128	64	32	16	8	4	2	1	
Binary Value	0	0	1	0	1	1	0	1	
Byte Value	0	+ 0	+ 32	+ 0	+ 8	+ 4	+ 0	+ 1	= 45

Sequence Value		128	64	32	16	8	4	2	1
Brightness Values		Binary Values							
0	(white)	0	0	0	0	0	0	0	0
9	(pale gray)	0	0	0	0	1	0	0	1
62	(gray)	0	0	1	1	1	1	1	0
183	(dark gray)	1	0	1	1	0	1	1	1
255	(black)	1	1	1	1	1	1	1	1



Previous planetary encounters for the Voyager *spacecrafts were almost leisurely excursions. At Saturn, for example, the spaceship encountered one planetary feature at a time, exploring it before focusing on the next, until it had photographed all it could. However, at Uranus the planetary system is tilted almost 90° to the planetary plane. For this reason* Voyager *has been compared to a dart tossed at a bull's-eye, passing the center, the outer rings, and virtually everything at the same time. This meant cameras had to scan many areas very quickly to catch even scant glimpses of features, because the spacecraft wouldn't have a second chance.*

black, then the values between will represent subtle shades of gray.

When the values for all the pixels have been assigned, they are either sent directly to a receiver on Earth or stored on magnetic tape to be sent later. Data is stored when radio communications between the Earth and the spacecraft are temporarily blocked, such as when *Voyager* passes behind a planet or moon. For each image, and its total of 640,000 pixels, 5,120,000 bits of data must be transmitted (640,000 × 8). When *Voyager* flew close to Jupiter, data was transmitted back to Earth at a rate of more than 100,000 bits per second. This meant that once data began reaching the antennas on Earth's surface, information for complete images was received in about 1 minute for each transmission.

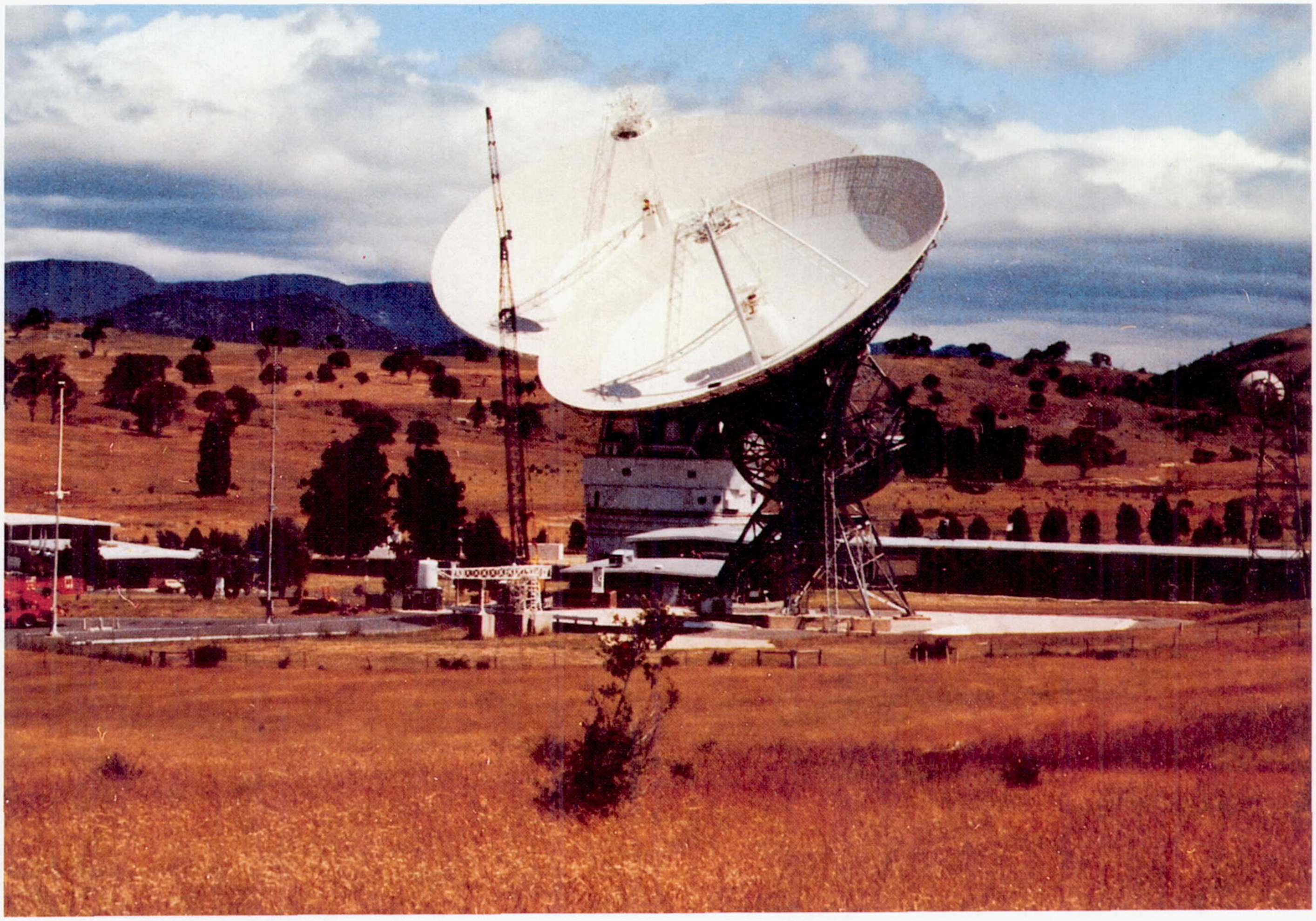
As the distance of the spacecraft from Earth increases, the quality of the radioed data stream decreases. However, by lowering the rate at which *Voyager* transmits its data, controllers reduce to an acceptable level the amount of noise that will arrive mixed with the signal.

For the Uranus encounter, scientists and engineers devised a technique that allowed *Voyager* to transmit more than 200 images each day. To do this, they reprogrammed the spacecraft en route. Instead of having *Voyager* transmit the full 8 bits for each pixel, its computers were instructed to send back only the differences between brightness levels of successive pixels. This reduced the number of data bits needed for an image by about 60 percent. By slowing the transmission rate, noise did not interfere with the image reception, and by compressing the data, a full array of striking images were received. The computers at NASA's Jet Propulsion Laboratory restored the correct brightness to each pixel, producing both black-and-white and full-color images.

The radio signals that a spacecraft such as *Voyager* sends to Earth are received by a system of large dish antennas called the Deep Space Network (DSN). The DSN is designed to provide command, control, tracking, and data acquisition for deep space missions. Configured around the globe at locations approximately 120° apart, DSN provides 24-hour line-of-sight coverage.

Stations are located at Goldstone, California; Madrid, Spain; and Canaberra, Australia. The total DSN, managed by NASA's Jet Propulsion Laboratory in Pasadena, California, consists of three 64-meter (210-ft) diameter dish-shaped antennas, five 34-meter (111-ft) diameter antennas, and three 26-meter (85-ft) antennas. As antennas at one station lose contact, due to Earth's rotation, antennas at the next station rotate into view and take over the job of receiving spacecraft data. While one station is tracking a deep space mission, such as *Voyager*, the other two are busy tracking spacecraft elsewhere in the sky.

During *Voyager*'s contact with Saturn, the DSN recovered more than 99 percent of the 17,000 images transmitted. This accomplishment



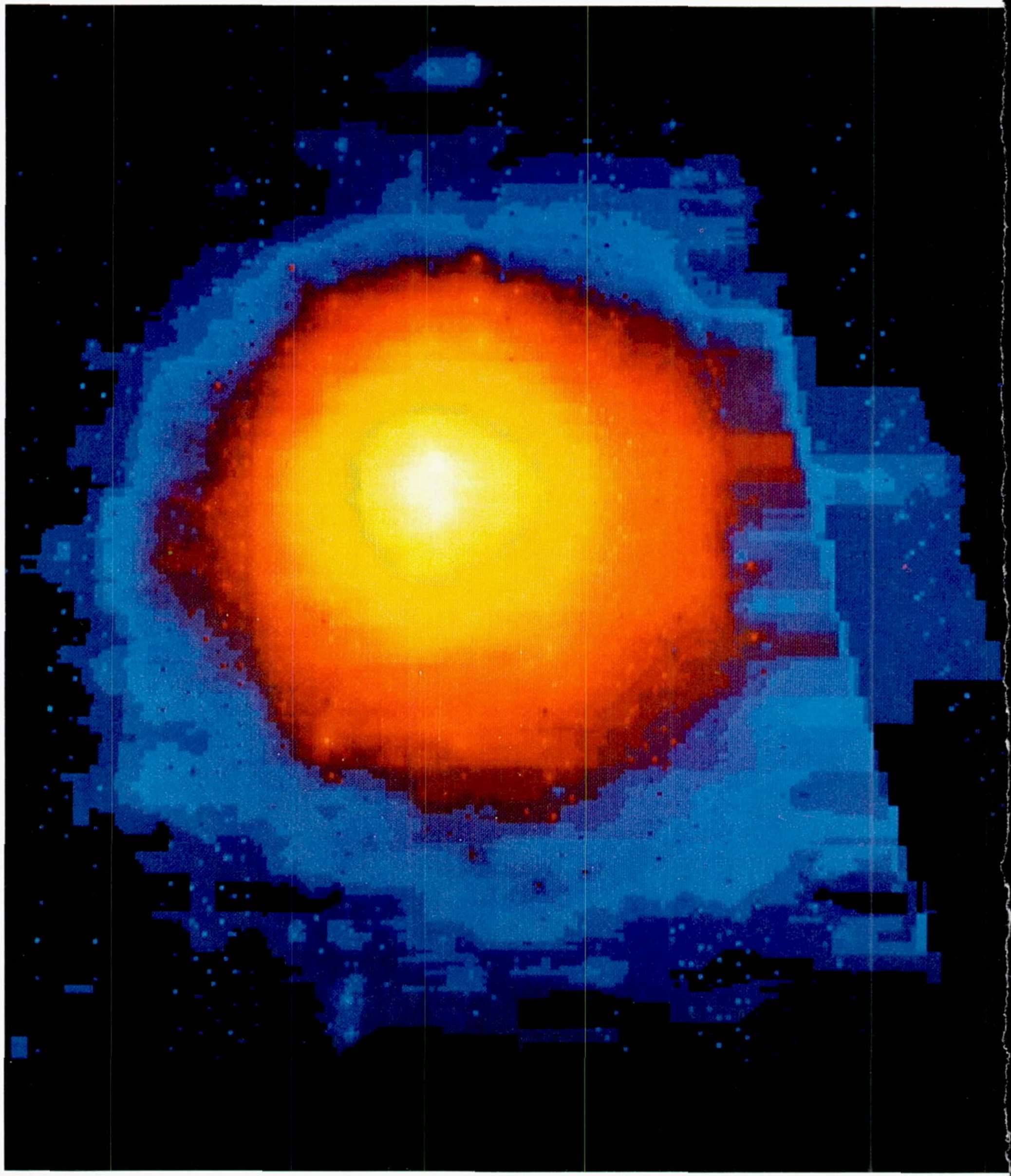
NASA's Deep Space Network consists of huge dish antennas like these positioned at three receiving stations around the globe. The stations in Goldstone, AZ; Madrid, Spain; and Canaberra, Australia, track the spacecraft as it speeds through deep space. The farther the spacecraft travels away from Earth, the weaker its signal becomes. To compensate for this weaker signal, the antennas are electronically "arrayed" so that two or more antennas focus on receiving the same signal. Arraying not only increases the apparent strength of the signal, but also gives valuable information about the spacecraft's speed and distance.

required the use of a technique known as "antenna arraying." Arraying for the Saturn encounter was accomplished by electronically adding signals received by two antennas at each site. Because of the great distance Uranus is from the Earth, the signal received from *Voyager 2* was only one-fourth as strong as the signal received from Saturn. A new arraying technique, which combined signals from four antennas, was used during the Uranus encounter to allow up to 21,600 bits of data to be received each second.

The DSN was able to track *Voyager*'s position at Saturn with an accuracy of nearly 300 kilometers (about 200 miles) during its closest approach. This accuracy was achieved by using the network's radiometric system, the spacecraft's cameras, and a technique called Very Long Baseline Interferometry, or VLBI. VLBI determines the direction of the spacecraft by precisely measuring the slight difference between the time of arrival of the signal at two or more ground antennas. The same technique was used at Uranus to aim the spacecraft so accurately that the deflection of its trajectory caused by the planet's gravity would send it on to Neptune.

When the DSN antennas receive the information from the spacecraft, computers at the Jet Propulsion Laboratory store it for future use and reassemble it into images. To recreate a picture whose image has been sent across the vacuum of space, computers read the data bit by bit, calculating the values for each pixel and converting the value into a small square of light. The squares are displayed on a television screen that duplicates the vidicon screen on the spacecraft: a grid 800 lines by 800 pixels, or 640,000 pixels for the full image. The pixels are lighted up one at a time until the screen is full. The resulting image is a black-and-white facsimile of the object being measured.

Color images are composed using the same telemetric technology as for black-and-white images. However, instead of transmitting just one image, three images are sent in rapid succession for each picture. Measurements are taken through colored filters: one through blue, one through green, and one through orange. Filters have varying effects on the amount of light being measured. For example, light that passes through a blue filter will favor the blue values in the image making them appear brighter or transparent, whereas red or orange values will appear much darker than normal. On Earth the three images are given the appropriate colors of the filters through which they were measured and then blended together to give a "true" color image.



This image of the coma of Comet Halley was sent to Earth from the Pioneer Venus *spacecraft and was compiled from more than 20,000 separate vertical ultraviolet scans. The coma, or cloud of gases surrounding the nucleus, is 20 million kilometers in diameter. Concentric areas show decreasing brightness from the comet's center outward. Data was collected and beamed to Earth on February 2-5, 1986.*

In January 1986, Voyager 2 *made its closest encounter with the planet Uranus. It returned never-before-seen close-up views of a planet barely visible from the Earth's surface.*

An important feat the interplanetary spacecraft must accomplish is focusing on its target while traveling at extremely high speeds. *Voyager* hurtled past Uranus at more than 40,000 miles an hour. To get an unblurred image, the cameras on board had to steadily track their target while the camera shutters were open. The technique to do this, called image-motion compensation, involves rotating the entire spacecraft under the control of the stabilizing computers. The strategy was used successfully both at Saturn's moon Rhea and at Uranus. Both times, cameras tracked their targets without interruption.

Once the image is reconstructed by computers on Earth, it sometimes happens that objects appear nondescript or that subtle shades in planetary details such as cloudtops cannot be discerned by visual examination alone. This can be overcome, however, by adding a final "enhancement" to the production. The process of computer enhancement is like adjusting the contrast and brightness controls on a television set. Because the shades of the image are broken down into picture elements, the computer can increase or decrease brightness values of individual pixels, thereby exaggerating their differences and sharpening even the tiniest details.

For example, suppose a portion of an image returned from space reveals an area of subtle gray tones. Data from the computer indicates the range in brightness values is between 98 and 120, and are all fairly evenly distributed. To the unaided eye, the portion appears as a blurred gray patch because the shades are too nearly similar to be discerned. To eliminate this visual handicap, the brightness values can be assigned new numbers. The shades can be spread further apart, say five shades apart rather than the one currently being looked at. Because the data is already stored on computers, it is a fairly easy task to isolate the twenty-three values and assign them new ones: 98 could be assigned 20, 99 assigned 25, and so on. The resulting image is "enhanced" to the naked eye, while the information is the same accurate data transmitted from the vicinity of the object in space.

The past 25 years of space travel and exploration has generated an unprecedented quantity of data from planetary systems. Images taken in space and telemetered back to Earth have greatly aided scientists in formulating better and more accurate theories about the nature and origin of our Solar System. Data gathered at close range, and from above the distorting effects of Earth's atmosphere, produce images far more detailed than pictures taken by even the largest Earth-bound telescopes.

In mankind's search to understand the world as well as the universe in which he lives, he has in one generation reached farther than in any other generation before. He has overcome the limitations of looking from the surface of his own planet and traveled to others. Whatever yearning drew that first star gazer from the security of his cave to look up at the night sky and wonder still draws men and women to the stars.

ORIGINAL PAGE
COLOR PHOTOGRAPH

Brief History of Pictures By Unmanned Spacecraft

Name	Year	Mission
Pioneer 4	1959	Moon: measured particles and fields in a flyby, entered heliocentric orbit
Ranger 7	1964	Moon: 4,316 high-resolution TV pictures of Sea of Clouds; impacted
Ranger 8	1965	Moon: 7,137 pictures of Sea of Tranquility; impacted
Ranger 9	1965	Moon: 5,814 pictures of Crater Alphonsus; impacted
Surveyor 1	1966	Moon: 11,237 pictures, soft landing in Ocean of Storms
Surveyor 3	1967	Moon: 6,315 pictures, first soil scoop; soft landed in Sea of Clouds
Surveyor 5	1967	Moon: more than 19,000 pictures; first alpha scatter analyzed chemical structure; soft landed in Sea of Tranquility
Surveyor 6	1967	Moon: 30,065 pictures; first lift off from lunar surface, moved ship 10 feet, soft landed in Central Bay region
Surveyor 7	1968	Moon: returned television pictures, performed alpha scatter, and took surface sample; first soft landing on ejecta blanket beside Crater Tycho
Lunar Orbiter 1	1966	Moon: medium and high-resolution pictures of 9 possible landing sites; first orbit of another planetary body; impacted
Lunar Orbiter 2	1966	Moon: 211 frames (422 medium and high-resolution pictures); impacted
Lunar Orbiter 3	1967	Moon: 211 frames including picture of Surveyor 1 on lunar surface; impacted
Lunar Orbiter 4	1967	Moon: 167 frames; impacted
Lunar Orbiter 5	1967	Moon: 212 frames, including 5 possible landing sites and micrometeoroid data; impacted
Mariner 2	1962	Venus: first succesful planetary probe; determined planet mass and measured high temperatures; close fly by
Mariner 4	1964	Mars: pictures of cratered moon-like surface, measured planet's thin mostly carbon dioxide atmosphere; fly by
Mariner 5	1967	Venus: found dense magnetic field and dense atmosphere; fly by
Mariners 6 and 7	1969	Mars: verified atmospheric findings: no nitrogen present, dry ice near polar caps; both fly bys
Mariner 9	1971	Mars: 7,400 pictures of both moons and planet's surface; fly by
Mariner 10	1973	Venus: ultraviolet images of atmosphere, revealing circulation patterns; atmosphere rotates more slowly than planetary body; fly by Mercury: pictures of moon-like surface with long, narrow valleys and cliffs; fly by

ORIGINAL PAGE
COLOR PHOTOGRAPH

Name	Year	Mission
Pioneer 10	1972	Jupiter: first close-up pictures of Great Red Spot and planetary atmosphere; first spacecraft to leave Solar System (5 am PDT, June 13, 1983) carries plaque with intergalactic greetings from Earth
Pioneer 11 (Pioneer Saturn)	1973	Jupiter: pictures of planet from 42,760 km (26,725 mi) above cloudtops; only pictures of polar regions; used Jupiter's gravity to swing it back across the Solar System to Saturn Saturn: pictures of planet as it passed through ring plane, within 21,400 km (13,300 mi) of cloudtops new discoveries were made; spacecraft renamed Pioneer Saturn after leaving Jupiter
Pioneer Venus 1	1978	Venus: first full-disc pictures of planet; studied cloud cover and planetary topography; orbited
Pioneer Venus 2	1978	Venus: multiprobe, measuring atmosphere top to bottom; probes designed to impact on surface but continued to return data for 67 minutes
Viking 1	1975	Mars: first surface pictures of Mars; landed July 20, 1976
Viking 2	1975	Mars: first color pictures; showed a red surface of oxidized iron; landed September 3, 1976, and some equipment remained operating until November 1982
Voyager 1	1977	Jupiter: launched after Voyager 2 but on a faster trajectory; took pictures of Jupiter's rapidly changing cloudtops; discovered ring circling planet, plasma cloud covering Io, and first moons with color: Io, orange; Europa, amber; and Ganymede, brown; fly by Saturn: pictures showed atmosphere similar to Jupiter's, but with many more bands and a dense haze that obscured the surface; found new rings within rings; increased known moon count to 15; fly by
Voyager 2	1977	Jupiter: color and black-and-white pictures to complement Voyager 1; time-lapse movie of volcanic action on Io; fly by Saturn: better cameras resolved ring count to more than 1,000; time-lapse movies studied ring spokes; distinctive features seen on several moons; 7 new satellites were discovered; fly by Uranus: first encounter with this distant planet; revealed detailed surfaces of moons, resolved rings into multicolored bands showing anticipated sheparding moons; discovered planetary magnetic field; fly by Neptune: encounter scheduled for 1989

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