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Project VOYAGERS 1 and 2
BACKGROUNDER

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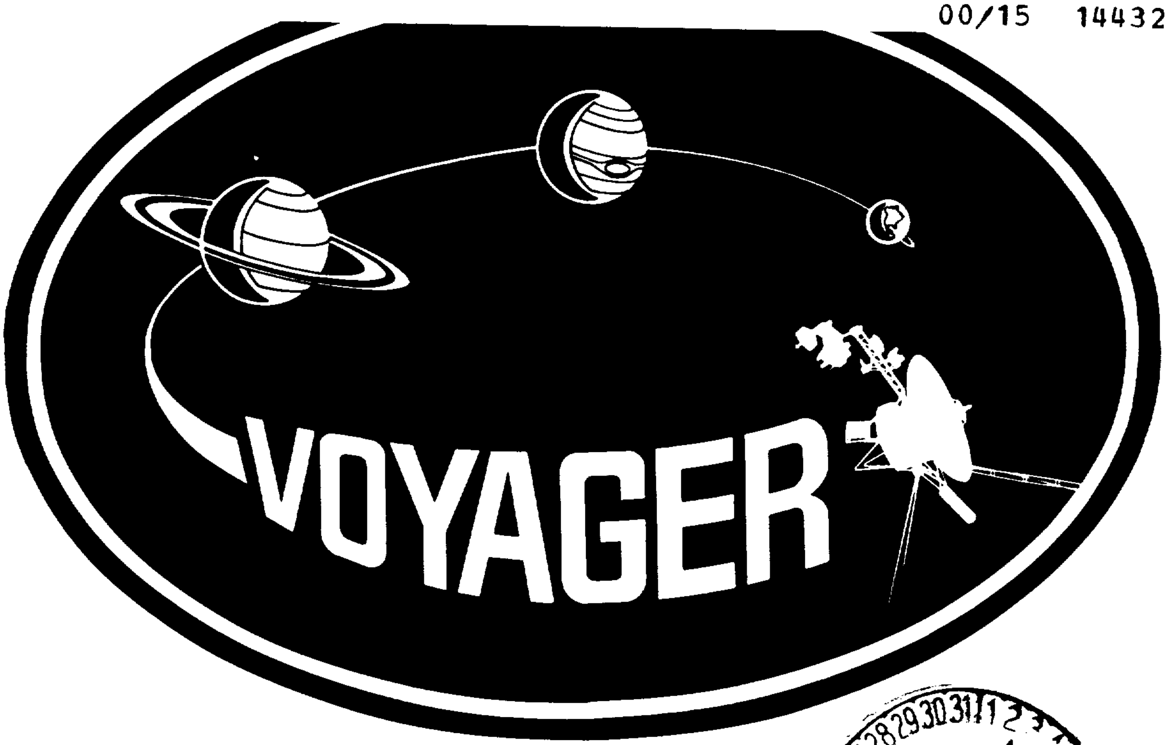

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THE VOYAGER SPACECRAFT

The two Voyager spacecraft are designed to operate at distances from Earth and the Sun greater than those of any previous NASA mission. Communications capability, hardware reliability, navigation and temperature control were among the major challenges. The spacecraft are identical. Each can meet the objectives of either mission and their various options.

Each Voyager at launch consisted of a mission module -- the planetary vehicle -- and a propulsion module, which provided the final energy increment necessary to inject the mission module into the Jupiter transfer trajectory. The propulsion module was jettisoned after the required velocity was attained. (For purposes of mission description, "spacecraft" and "mission module" will be used interchangeably. In describing the prelaunch configuration and launch phase, "spacecraft" will refer to the combined "mission module" and "propulsion module.")

The mission module after injection weighed 826 kilograms (1,820 pounds), including a 105-kg (231-lb.) science instrument payload. The propulsion module, with its large solid propellant rocket motor, weighed 1,220 kg (2,690 lb.). The spacecraft adaptor joins the spacecraft with the Centaur stage of the launch vehicle. It weighed 47.2 kg (104 lb.). Total launch weight of the spacecraft was 2,100 kg (4,630 lb.).

To assure proper operation for the four-year flight to Saturn, and perhaps well beyond, mission module subsystems were designed with high reliability and extensive redundancy.

Like the Mariners that explored the solar system's inner planets and the Viking Mars Orbiters, the Voyagers are stabilized on three axes using the Sun and a star (Canopus) as celestial reference points.

Three engineering subsystems are programmable for onboard control of spacecraft functions. (Only trajectory correction maneuvers must be enabled by ground command.) These subsystems are the computer command subsystems (CCS), the flight data subsystems (FDS) and the attitude and articulation control subsystem (AACS).

The memories of these units can be updated or modified by ground command at any time.

Hot gas jets provide thrust for attitude stabilization as well as for trajectory correction maneuvers.

A nuclear power source -- three radioisotope thermoelectric generators -- provides the spacecraft electrical power.

The science instruments required to view the planets and their moons are mounted on a two-axis scan platform at the end of the science boom for precise pointing. Other body-fixed and boom-mounted instruments are aligned for proper interpretation of their measurements.

Data storage capacity on the spacecraft is about 536 million bits of information -- the equivalent of about 100 full-resolution photos.

Dual frequency communication links -- S-band and X-band -- provide accurate navigation data and large amounts of science information during planetary encounter periods (up to 115,200 bits per second at Jupiter and 44,800 bps at Saturn).

Dominant feature of the spacecraft is the 3.66-meter (12-foot) diameter high-gain antenna which points toward Earth continually.

While the high-gain antenna dish is white, most visible parts of the spacecraft are black -- blanketed or wrapped for thermal control and micrometeoroid protection. A few small areas are finished in gold foil or have polished aluminum surfaces.

Structure and Configuration

The basic mission module structure is a 29.5-kg (65-lb.) 10-sided aluminum framework with 10 electronics packaging compartments. The structure is 47 centimeters (18.5 inches) high and 1.78 m (5.8 ft.) across. The electronics assemblies are structural elements of the 10-sided box.

The spherical propellant tank, which supplies fuel to hydrazine thrusters for attitude control and trajectory correction maneuvers (TCM), occupies the center cavity of the decagon. Propellant lines carry hydrazine to 12 small attitude control and four TCM thrusters on the mission module.

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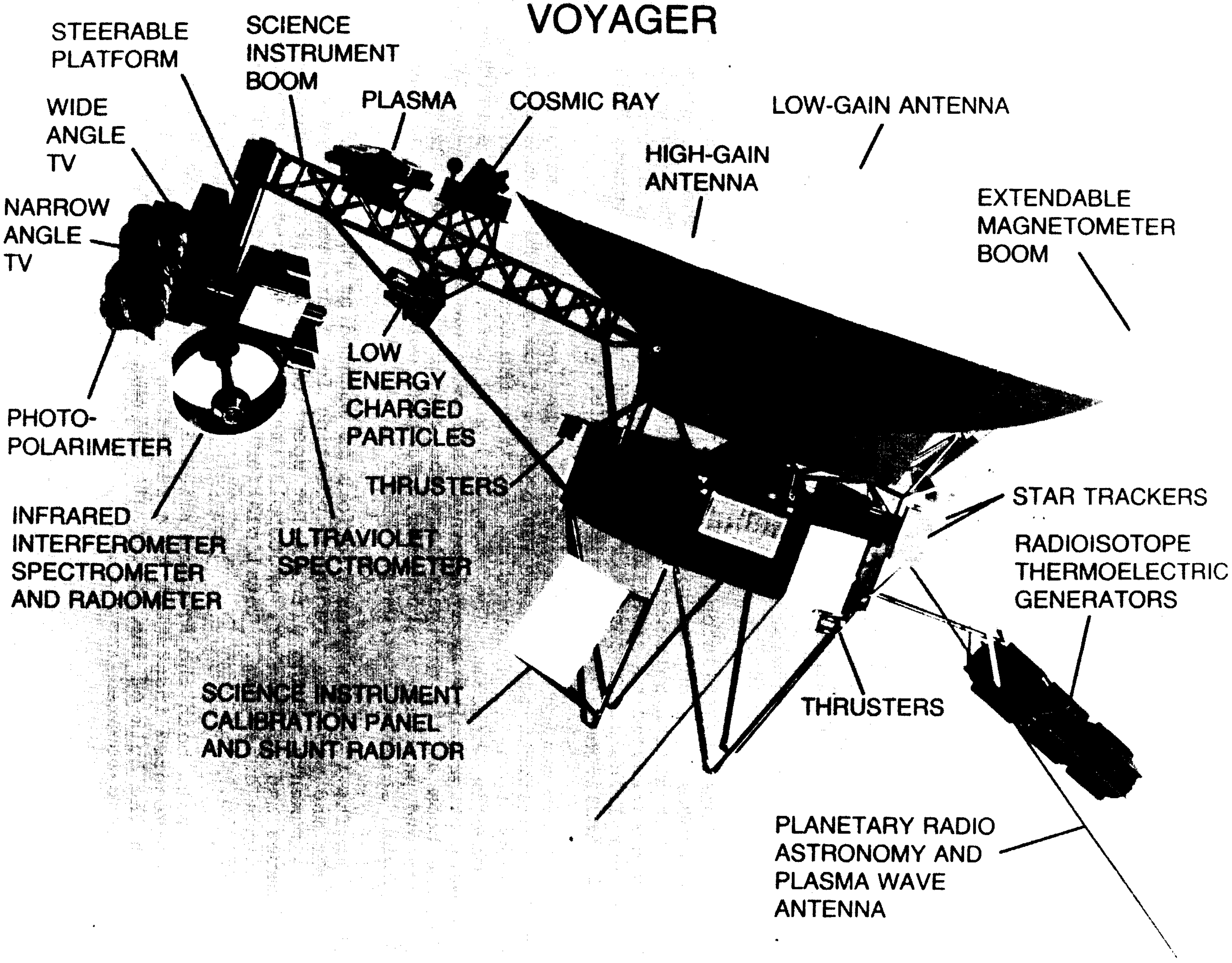
VOYAGER



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The 3.66-m (12-ft.) diameter high-gain parabolic reflector is supported above the basic structure by a tubular trusswork. The antenna reflector has an aluminum honeycomb core and is surfaced on both sides by graphite epoxy laminate skins. Attachment to the trusses is along a 1.78-m (70-in.) diameter support ring. The Sun sensor protrudes through a cutout in the antenna dish. An X-band feed horn is at the center of the reflector. Two-S-band feed horns are mounted back-to-back with the X-band subreflector on a three-legged truss above the dish. One radiates through the subreflector, transparent at S-band, to the high-gain dish. The other functions as the low-gain antenna.

Louver assemblies for temperature control are fastened to the outer faces of four of the electronics compartments. Top and bottom of the 10-sided structure are enclosed with multilayer thermal blankets.

Two Canopus star tracker units are mounted side-by-side and parallel atop the upper ring of the decagon.

Three radioisotope thermoelectric generators are assembled in tandem on a deployable boom hinged on an outrigger arrangement of struts attached to the basic structure. The RTG boom is constructed of steel and titanium. Each unit, contained in a beryllium outer case, is 40.6 cm (16 in.) in diameter, 50.8 cm (20 in.) long and weighs 39 kg (86 lb.).

The science boom, supporting the instruments most sensitive to radiation, is located 180 degrees from the RTG boom and is hinged to a truss extending out from the decagon and behind the high-gain antenna. The boom, 2.3 m (7.5 ft.) long, is a bridgework of graphite epoxy tubing. Attached on opposite sides of the boom at its mid-point are the cosmic ray and low-energy charged particle instruments. Farther out on the boom is the plasma science instrument.

The two-axis scan platform is mounted at the end of the boom and provides precision pointing for four remote-sensing instruments -- the ultraviolet spectrometer, infrared spectrometer and radiometer, photopolarimeter and a two-camera imaging science subsystem. Total platform gimballed weight is 107 kg (236 lb.).

With both the RTG and science booms deployed, the nearest boom-mounted instrument to a radiation source is 4.9 m (16 ft.), with the bulk of the spacecraft between the two. The closest platform-mounted instrument 6.7 m (21 ft.) away.

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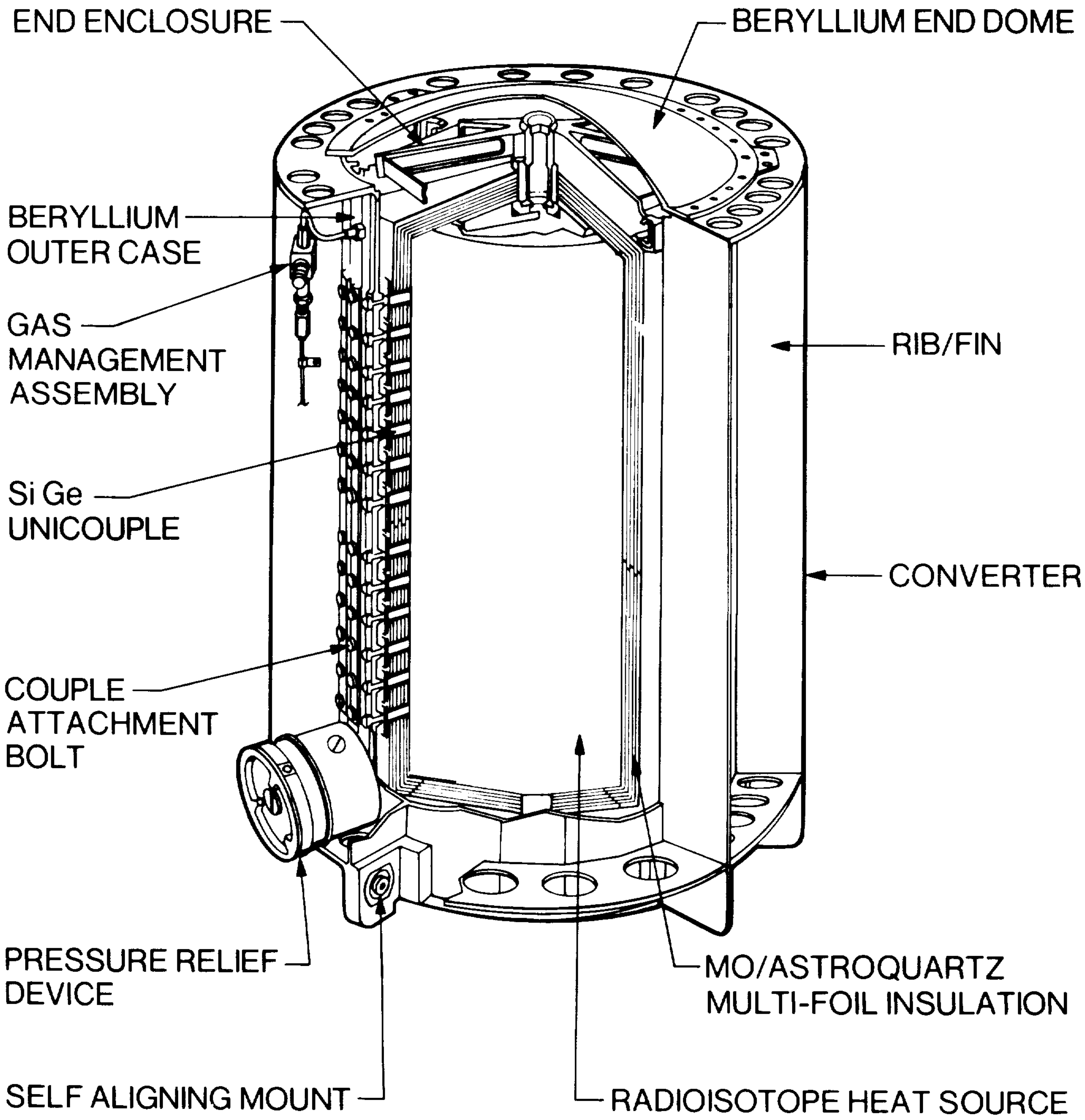
VOYAGER RADIOISOTOPE THERMOELECTRIC GENERATOR



A polarimetric calibration target, called a brewster plate, is mounted atop the mission module structure and aligned so that the photopolarimeter views the target during science maneuvers planned for the planetary phases of the mission.

A pair of 10-m (33-ft.) whip antennas are deployed from a position external to the top ring of the basic structure and looking "down" between the RTG boom outrigger members. The antennas, which form a right angle, are part of the planetary radio astronomy (PRA) instrument package and are shared with another instrument, the plasma wave science unit (PWS). The PRA and PWS assemblies are body-mounted adjacently. The antennas, beryllium copper tubing, are rolled flat in their housing prior to deployment by small electric motors.

The magnetic fields investigation experiment consists of an electronics subassembly located in one of the mission module electronics bays and four magnetometers -- two high-field sensors affixed to the spacecraft and two low-field sensors mounted on a 13-m (43-ft.) deployable boom. The boom, constructed of epoxy glass, spirals from its stowed position within an aluminum cylinder and forms a rigid triangular mast with one magnetometer attached to its end plate and another positioned 6 m (20 ft.) closer to the spacecraft. The mast itself weighs only 2.3 kg (5 lb.), less than the cabling running its length and carrying power to and data from the magnetometers. The boom housing is a 23 cm (9 in.) diameter cylinder, 66 cm (26 in.) long, supported by the RTG outrigger. The mast uncoils in helix fashion along a line between the rear face of the high-gain antenna and the RTG boom.

Basic structure of the since-discarded propulsion module was a 14-kg (97-lb.) aluminum semi-monocoque shell.

The cylinder, 1 m (39 in.) in diameter and 0.9 m (35 in.) long, was suspended below the mission module structure by an eight-member tubular truss adapter. The hollow of the structure contained the solid rocket motor which delivered the final powered stage of flight. The rocket, which weighed 1,200 kg (2,690 lb.) including 1,060 kg (2,340 lb.) of propellant, developed an average 68,000 newtons (15,300 lb.) thrust during its 43-second burn.

Mounted on outriggers from the structure were eight hydrazine engines which provided attitude control during the solid motor burn and prior to propulsion module separation and jettison. Hydrazine fuel was supplied from the mission module.

A pair of batteries and a remote driver module for powering the valve drivers to the thrust vector control engines were positioned on the outer face of the cylindrical propulsion module structure.

A 0.37 square m (4 sq. ft.) shunt radiator-science calibration target faces outward from the propulsion module truss adapter toward the scan platform. The dual-purpose structure is a flat sandwich of two aluminum radiating surfaces lining a honeycomb core. Through an arrangement of power collectors and emitter resistors between the plates, any portion of the electrical power from the RTGs can be radiated to space as heat. The outer surface also serves as a photometric calibration target for the remote sensing science instruments on the scan platform.

The shunt radiator, as well as the propulsion module truss adapter, remained part of the mission module when the propulsion module was jettisoned.

Steel alloy-gold foil plume deflectors extended from the propulsion module structure to shield the stowed RTGs and scan platform from rocket exhaust during engine firing.

The spacecraft adapter, an aluminum truncated cone, joined the propulsion module with the Centaur stage of the launch vehicle. The adapter, 0.71 m (30 in.) tall, was 1.6 m (63 in.) in diameter at the base (Centaur attachment), 1.0 m (39 in.) at the spacecraft separation joint and weighed 47.2 kg (104 lb.). The adapter remained with the Centaur rocket stage at spacecraft separation.

Launch Configuration

Some mechanical elements of the spacecraft must be rigidly restrained during the severe launch vibration environment. Following the launch phase appendages which had been latched securely within the Centaur stage nose fairing were deployed to their cruise positions.

The spacecraft pyrotechnic subsystem provided simple and positive deployment with explosive squibs. Devices stowed securely during launch and released for deployment by the pyrotechnic system were the science boom, RTG boom and magnetometer boom. Uncertainty concerning the full deployment and locking of the science boom on Voyager 2, first spacecraft launched, existed for several weeks.

The pyrotechnic subsystem also routed power to devices to separate the spacecraft from the launch vehicle, activated the propulsion module batteries, ignited the solid propellant rocket motor, sealed off the propellant line carrying hydrazine from the mission module to the propulsion module, jettisoned the propulsion module and released the Infrared Radiometer and Interferometer Spectrometer instrument's dust cover.

Communications

Communications with the Voyager spacecraft will be by radio link between Earth tracking stations and a dual frequency radio system aboard the spacecraft.

The "uplink" operates at S-band, carrying commands and ranging signals from ground stations to one of a pair of redundant receivers. The "downlink" is transmitted from the spacecraft at S-band and X-band frequencies.

The onboard communications system also includes a programmable flight data subsystem (FDS), modulation demodulation subsystem (MDS), data storage subsystem (DSS) and high gain and low gain antennas.

The FDS, one of the three onboard computers, controls the science instruments and formats all science and engineering data for telemetering to Earth. The telemetry modulation unit (TMU) of the MDS feeds data to the downlink. The flight command unit of the MDS routes ground commands received by the spacecraft.

Only one receiver will be powered at any one time with the redundant receiver at standby. The receiver will operate continuously during the mission at about 2113 MHz. Different frequency ranges have been assigned to the radio frequency subsystems of each spacecraft. The receiver can be used with either the high gain or low gain antenna. Voyager 2's primary receiver failed on April 5, 1978, and the spacecraft is operating on its backup receiver.

The S-band transmitter consists of two redundant exciters and two redundant RF power amplifiers of which any combination is possible. Only one exciter-amplifier combination will operate at any one time. Selection of the combination will be by onboard failure detection logic within the computer command subsystem (CCS), with ground command backup. The same arrangement of exciter-amplifier combinations makes up the X-band transmitting unit.

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One S-band and both X-band amplifiers employ traveling wave tubes (TWT). The second S-band unit is a solid-state amplifier. The S-band transmitter is capable of operating at 9.4 watts or at 28.3 watts when switched to high power and can radiate from both antennas. X-band power output is 12 watts and 21.3 watts. X-band uses only the high gain antenna. (S-band and X-band will never operate at high power simultaneously.)

When no uplink signal is being received, the transmitted S-band frequency of about 2295 MHz and X-band frequency of 8418 MHz originate in the S-band exciter's auxiliary oscillator or in a separate ultra stable oscillator (one-way tracking). With the receiver phase-locked to an uplink signal, the receiver provides the frequency source for both transmitters (two-way tracking). The radio system can also operate with the receiver locked to an uplink signal while the downlink carrier frequencies are determined by the onboard oscillators (two-way non-coherent tracking).

At present, only the 64-m (210-ft.) antenna stations of the Deep Space Network can receive the downlink X-band signal. Both the 64-m and the 26-m (85-ft.) antenna stations are capable of receiving at S-band.

The X-band downlink was not in use during the first 80 days of the mission -- until the Earth was within the beam of the spacecraft's high gain antenna.

Communications during launch, near-Earth and early cruise phase operations were confined to S-band and the low gain antenna. Exceptions occurred early in the flight when the spacecraft, on inertial control, pointed the high gain antenna toward Earth to support instrument calibration and an optical navigation high-rate telecommunications link test. During its calibration sequence, on Sept. 18, 1977, Voyager 1 took pictures of the Earth-Moon system.

The high gain antenna, with a 3.66-m (12-ft.) diameter parabolic reflector, provides a highly directional beam. The the low gain antenna provides essentially uniform coverage in the direction of Earth.

Under normal conditions after the first 80 days of the mission, all communications -- both S-band and X-band -- are via the high gain antenna. X-band is turned off, however, and the S-band transmitter and receiver are switched to the low gain antenna during periodic science maneuvers and trajectory correction maneuvers.

The S-band downlink is always on, operating at high power during maneuvers or during the cruise phase only when the 26-m (85-ft.) antenna DSN stations are tracking and at low power whenever X-band is on. At Saturn, both S-band and X-band transmitters will be on low power when gyros and tape recorder are on simultaneously.

Commanding the Spacecraft

Ground commands are used to put into execution selected flight sequences or to cope with unexpected events. Commands can be issued in either a predetermined timed sequence via onboard program control or directly as received from the ground. Most commands will be issued by the spacecraft's computer command subsystem (CCS) in its role as "sequencer of events" and by the flight data subsystem (FDS) as controller of the science instruments.

All communications between spacecraft and Earth will be in digital form. Command signals, transmitted at 16 bits per second (bps) to the spacecraft, will be detected in the flight command unit and routed to the CCS for further routing to their proper destination. Ground commands to the spacecraft fall into two major categories: discrete commands and coded commands.

A discrete command causes a single action on the spacecraft. For example, DC-2D switches the S-band amplifier to high power; DC-2DR, S-band amplifier low power; DC-2E, S-band radiates from high gain antenna; DC-2ER, S-band transmits low gain. Coded commands are the transfer of digital data from the computer command system or from the ground via the CCS to user subsystems. Subsystems receiving coded commands are flight data, attitude and articulation control, modulation-demodulation, data storage and power.

Ground commands back up all critical spacecraft functions which, in a standard mission, are initiated automatically by onboard logic. Command modulation will be off during science maneuvers and trajectory correction maneuvers unless a spacecraft emergency arises.

Downlink Telemetry

Data telemetered from the spacecraft will consist of engineering and science measurements prepared for transmission by the flight data subsystem, telemetry modulation unit and data storage subsystem. The encoded information will indicate voltages, pressures, temperatures, television pictures and other values measured by the spacecraft telemetry sensors and science instruments.

Two telemetry channels -- low rate and high rate -- are provided for the transmission of spacecraft data. The low rate channel functions only at S-band at a single 40 bps data rate and contains real time engineering data exclusively. It is on only during planetary encounters when the high rate channel is operating at X-band.

The high rate channel is on throughout the mission, operates at either S-band or X-band and contains the following types of data:

- Engineering only at 40 bps or 1,200 bps (the higher rate usually occurs only during launch and trajectory correction maneuvers) transmitted at S-band only.
- Real-time cruise science and engineering at 2,560, 1,280, 640, 320, 160 and 80 bps (40, 20 and 10 bps may be used for post-Saturn operations) transmitted at S-band only.
- Real-time encounter general science and engineering at 7.2 kilobits per second (a special 115.2 kbps will be available for brief periods at Jupiter for the planetary radio astronomy and plasma wave instruments) transmitted at X-band only.
- Real-time encounter general science, engineering and television at 115.2, 89.6, 67.2, 44.8, 29.9 and 19.2 kbps transmitted at X-band only.
- Real-time encounter general science and engineering, plus tape recorder playback, at 67.2, 44.8 and 29.9 kbps transmitted at X-band only.
- Playback recorded data only at 21.6 and 7.2 kbps transmitted at X-band only.
- Memory data stored in the three onboard computers -- CCS, FDS and AACS -- read out and played back at 40 or 1,200 bps transmitted at either S-band or X-band (treated as engineering data).

The numerous data rates for each type of telemetered information are required by the changing length of the telecommunications link with Earth and the possible adverse effects of Earth weather upon reception of X-band radio signals. The S-band cruise science primary telemetry rate is 2,560 bps. Lesser rates result in reduced instrument sampling and will be used only when the telecommunications link cannot support the higher rate.

In order to allow real time transmission of video information at each encounter, the flight data subsystem will handle the imaging data at six downlink rates from 115.2 to 19.2 kbps. The 115.2-kbps rate represents the standard full frame readout at (48 seconds per frame) of the TV vidicon. Under normal conditions, this rate will be used at Jupiter. Full frame, full resolution TV from Saturn can be obtained by increasing the frame readout time to 144 seconds (3:1 slow scan) and transmitting the data at 44.8 kbps. A number of other slow scan and frame edit options are available to match the capability of the telecommunications link.

The data storage subsystem can record at two rates: TV pictures, general science and engineering at 115.2 kbps; general science and engineering only at 7.2 kbps (engineering is acquired at only 1,200 bps, but is formatted with filler to match the recorder input rate). The tape transport is belt driven. Its 1/2-inch magnetic tape is 328 m (1,075 ft.) long and is divided into eight tracks which are recorded sequentially one track at a time. Total recycleable storage capacity is about 536 million bits -- the equivalent of 100 TV pictures. Playback is at four speeds -- 57.6, 33.6, 21.6 and 7.2 kbps.

Tracking the Spacecraft

To achieve the desired maneuver and flyby accuracies for a multi-planet/satellite encounter mission, very precise navigation is required.

To provide the standard Doppler tracking data, the S-band signal transmitted from Earth is received at the spacecraft, changed in frequency by a known ratio and retransmitted to Earth. It is possible to precisely determine the transmitted downlink frequency while measuring the Doppler shifted received signal, thereby measuring spacecraft velocity. This is called coherent two-way tracking. One-way tracking is when no uplink signal is received and the downlink carrier frequency is provided by an onboard oscillator. Noncoherent two-way tracking occurs when uplink and downlink carriers are operating independently.

(When both S-band and X-band transmitters are on, X-band frequency will always be 11/3 times the S-band frequency regardless of the frequency source -- spacecraft receiver, ultra stable oscillator or S-band exciter auxiliary oscillator.)

Distance or range to the spacecraft is measured in the coherent two-way configuration by transmitting a digital code (ranging modulation) on the uplink, turning this code around in the spacecraft and sending it back to the ground. By measuring the total elapsed time between transmitting and receiving the code at the ground station and knowing such factors as the speed of light, turnaround delay and relative velocities of the spacecraft and tracking station, it is possible to determine spacecraft range.

Dual frequency ranging (both S-band and X-band ranging on) will be conducted during planetary operations phases of the mission and during the cruise phases when the Deep Space Network's 64-m (210-ft.) antennas are tracking. Special three-way dual-frequency ranging cycles will be conducted while two or more ground stations on two continents are tracking the spacecraft.

All ranging modulation is turned off during science maneuvers, trajectory correction maneuvers and planetary occultations.

Power

The Voyager power subsystem supplies all electrical power to the spacecraft by generating, converting, conditioning and switching the power.

Power source for the mission module is an array of three radioisotope thermoelectic generators (RTGs), developed by the U.S. Department of Energy. The propulsion module, which was active only during the brief injection phase of the mission, used a separate battery source.

The RTG units, mounted in tandem on a deployable boom and connected in parallel, convert to electricity the heat released by the isotopic decay of Plutonium-238.

Each isotope heat source has a capacity of 2400 thermal watts with a resultant maximum electrical power output of 160 watts at the beginning of the mission. There is a gradual decrease in power output. The minimum total power available from the three RTGs ranges from about 423 watts within a few hours after launch to 384 watts after the spacecraft passes Saturn.

Spacecraft power requirements from launch to post-Saturn operations are characterized by this general power timeline: launch and post-launch, 235 to 265 watts; interplanetary cruise, 320 to 365 watts; Jupiter encounter, 384 to 401 watts; Saturn encounter, 377 to 382 watts; and post-Saturn, less than 365 watts.

Telemetry measurements have been selected to provide the necessary information for power management by ground command, if needed.

Power from the RTGs is held at a constant 30 volts d.c. by a shunt regulator. The 30 volts is supplied directly to some spacecraft users and is switched to others in the power distribution subassembly. The main power inverter also is supplied the 30 volts d.c. for conversion to 2.4 kHz square wave used by most spacecraft subsystems. Again, the a.c. power may be supplied directly to users or can be switched on or off by power relays.

Command actuated relays control the distribution of power in the spacecraft. Some relays function as simple on-off switches and others transfer power from one module to another within a subsystem.

Among the users of d.c. power, in addition to the inverter, are the radio subsystem, gyros, propulsion isolation valves, some science instruments, most temperature control heaters and the motors which deploy the planetary radio astronomy antennas.

Other elements of the spacecraft use the 2.4 kHz power.

There are two identical 2.4 kHz power inverters -- main and standby. The main inverter is on from launch and remains on throughout the mission. In case of a malfunction or failure in the main inverter, the power chain, after a 1.5-second delay is switched automatically to the standby inverter. Once the switchover is made, it is irreversible.

A 4.8 kHz sync and timing signal from the flight data subsystem is used as a frequency reference in the inverter. The frequency is divided by two and the output is 2.4 kHz plus-or-minus 0.002 per cent. This timing signal is sent, in turn, to the computer command subsystem which contains the spacecraft's master clock.

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Because of the long mission lifetime, charged capacitor energy storage banks are used instead of batteries to supply the short term extra power demanded by instantaneous overloads which would cause the main d.c. power voltage to dip below acceptable limits. A typical heavy transient overload occurs at turn-on of a radio power amplifier.

Full output of the RTGs, a constant power source, must be used or dissipated in some way to prevent overheating of the generator units or d.c. voltage rising above allowed maximum. This is controlled by a shunt regulator which dumps excess RTG output power above that required to operate the spacecraft. The excess power is dissipated in resistors in a shunt radiator mounted outside the spacecraft and radiated into space as heat.

Computer Command Subsystem

Heart of the onboard control system is the computer command subsystem (CCS) which provides a semiautomatic capability to the spacecraft.

The CCS includes two independent plated wire memories, each with a capacity of 4,096 data words. Half of each memory stores reusable fixed routines which will not change during the mission. The second half is reprogrammable by updates from the ground.

Most commands to other spacecraft subsystems are issued from the CCS memory, which, at any given time, is loaded with the sequences appropriate to the mission phase. The CCS also can decode commands from the ground and pass them along to other spacecraft subsystems.

Under control of an accurate onboard clock, the CCS counts hours, minutes or seconds until some preprogrammed interval has elapsed and then branches into subroutines stored in the memory which result in commands to other subsystems. A sequencing event can be a single command or a routine which includes many commands (e.g., manipulating the tape recorder during a playback sequence).

The CCS can issue commands singly from one of its two processors or in a parellel or tandem state from both processors. An example of CCS dual control is the execution of trajectory correction maneuvers:

TCM thrusters are started with a tandem command (both processors must send consistent commands to a single output unit) and stopped with a parallel command (either processor working through different output units will stop the burn).

The CCS can survive any single internal fault. Each funtional unit has a duplicate elsewhere in the subsystem.

Attitude Control and Propulsion

Stabilization and orientation of the spacecraft from launch vehicle separation until end of the mission is provided by two major engineering subsystems -- attitude and articulation control (AACS) and propulsion.

Propulsion Subsystem

The propulsion subsystem consists of a large solid-propellant rocket motor for final Jupiter transfer trajectory velocity and a hydrazine blowdown system which fuels 16 thrusters on the mission module and eight reaction engines on the propulsion module.

The single hydrazine (N_2H_4) supply is contained within a o.71-m (28-in.) diameter spherical titanium tank separated from the helium pressurization gas by a Teflon filled rubber bladder. The tank, located in the central cavity of the mission module's 10-sided basic structure, contained 105 kg (231 lb.) of hydrazine at launch and was pressurized at 2,900,000 newtons per square meter (420 per square inch). As the propellant is consumed, the helium pressure will decrease to a minimum of about 900,000 N/psm (130 psi).

All 24 hydrazine thrusters use a catalyst which spontaneously initiates and sustains rapid decomposition of the hydrazine.

The 16 thrusters on the mission module each deliver 0.89 N (0.2-lb.) thrust. Four are used to execute trajectory correction maneuvers; the others in two redundant six-thruster branches, to stabilize the spacecraft on its three axes. Only one branch of attitude control thrusters is needed at any time.

Mounted on outriggers from the propulsion module are four 445 N-(100-lb.) thrust engines which, during solid-motor burn, provided thrust-vector control on the pitch and yaw axes. Four 22.2-N (5-lb-) thrust engines provided roll control.

The solid rocket, which weighed 1,220 kg (2,690 lb.) including 1,060 kg (2,340 lb.) of propellant, developed an average 68,000 newton (15,300 lb.) thrust during its 43-second burn duration.

Attitude and Articulation Control Subsystem

The AACS includes an onboard computer called HYPACE (hybrid programmable attitude control electronics), redundant Sun sensors, redundant Canopus star trackers, three two-axis gyros and scan actuators for positioning the science platform.

The HYPACE contains two redundant 4,096-word plated wire memories -- part of which are fixed and part reprogrammable -- redundant processors and input-output driver circuits. For a nominal mission, the memories will be changed only to modify predetermined control instructions.

Injection Propulsion Control

Because of the energy required to achieve a Jupiter ballistic trajectory with an 800 kg (1750 lb.) payload, the spacecraft launched by the Titan III E/Centaur included a final propulsive stage which added a velocity increment of about 2 kmps (4,500 mph).

The solid rocket motor in the propulsion module was ignited 15 seconds after the spacecraft separated from the Centaur and burned for about 43 seconds. Firing circuits to the motor were armed during the launch vehicle countdown.

The four 100-lb. thrust engines provided pitch and yaw attitude control and the four 5-lb. thrust engines provided roll control until burnout of the solid rocket motor. The hydrazine engines responded to pulses from the AACS's computer. Only two pitch-yaw and two roll engines at most were thrusting at any given time.

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Prior to solid rocket ignition and following burnout, only the smaller roll engines were required until the propulsion module was separated from the mission module. They were so oriented on the propulsion module that, by proper engine selection by the AACS, attitude control was maintained on all three axes.

Approximately 11 minutes after solid rocket burnout, the propulsion module was jettisoned. Several seconds earlier, the propellant line carrying hydrazine from the mission module to the propulsion module was sealed and separated.

Celestial Reference Control

The Sun sensors, which look through a slot in the high gain antenna dish, are electro-optical devices that send attitude position error signals to HYPACE, which, in turn, signals the appropriate attitude control thruster to fire and turn the spacecraft in the proper direction. Sun lock stabilizes the spacecraft on two axes (pitch and yaw).

The star Canopus, one of the brightest in the galaxy, is the second celestial reference for three-axis stabilization. Two Canopus trackers are mounted so that their lines of sight are parallel. Only one is in use at any one time. The star tracker, through HYPACE logic, causes the thrusters to roll the spacecraft about the already fixed Earth or Sun pointed roll axis until the tracker is locked on Canopus. Brightness of the tracker's target star is telemetered to the ground to verify the correct star has been acquired.

To enhance downlink communications capability, the Sun sensor is electrically biased (offset) by commands from the computer command subsystem to point the roll axis at or as near the Earth as possible. The Sun sensor can be biased plus and minus 20 degrees in both pitch and yaw axes.

Three axis stabilization with celestial reference is the normal attitude control mode for cruise phases between planets.

Inertial Reference Control

The spacecraft can be stabilized on one axis (roll) or all three axes with the AACS's inertial reference unit, consisting of three gyros.

Appropriate inertial reference modes are used whenever the spacecraft is not on Sun-star celestial lock. Such situations include: maintaining inertial reference from Centaur separation until initial celestial acquisition is achieved; purposely turning the spacecraft off Sun-star lock to do directed trajectory corrections or science instrument mappings or calibrations; providing a reference when the Sun is occulted; and providing a reference when concern exists that the Canopus or Sun sensor will detect stray intensity from unwanted sources -- planets, rings, satellites.

Each gyro has associated electronics to provide position information about two orthogonal axes (Gyro A: pitch and yaw, Gyro B: roll and pitch, Gyro C: yaw and roll). Normally, two gyros will be on for any inertial mode. The gyros have two selectable rates, one -- high rate -- for propulsion module injection phase; the other for mission module cruise and trajectory correction and science maneuvers.

Trajectory Correction Maneuvers

The Voyager trajectories were planned around eight trajectory correction maneuvers (TCM) with each spacecraft between launch and Saturn encounter. Mission requirements call for extremely accurate maneuvers to reach the desired zones at Jupiter, Saturn and the target satellites. Total velocity increment capability for each spacecraft is about 685 km/hr (425 mph).

Four maneuvers will be executed between Jupiter and Saturn. (See Voyager 1 Encounter Press Kit, NASA Release 79-23, for maneuvers accomplished and scheduled.)

TCM sequencing is under control of the computer command subsystem (CCS) which sends the required turn angles to the AACS for positioning the spacecraft at the correct orientation in space and, at the proper time, sends commands to the AACS to start and stop the TCM burn. Attitude control is maintained by pulse-off sequencing of the TCM engines and pulse-on sequencing of two attitude control roll thrusters. Position and rate signals are obtained from the gyros. Following the burn, reacquisition of the cruise celestial references is accomplished by unwinding the commanded turns -- repeating the turn sequence in reverse order. All TCMs are enabled by ground command.

Science Platform (Articulation Control)

Voyager's two television cameras, ultraviolet spectrometer, photopolarimeter and infrared spectrometer and radiometer are mounted on a scan platform which can be rotated about two axes for precise pointing at Jupiter, Saturn and their satellites during the planetary phases of the flight. The platform is located at the end of the science boom. Total gimballed weight is 107 kg (236 lb.).

Controlled by the AACS, the platform allows multiple pointing directions of the instruments. Driver circuits for the scan actuators -- one for each axis -- are located in the AACS computer. The platform's two axes of rotation are described as the azimuth angle motion about an axis displaced 7 degrees from the spacecraft roll axis (perpendicular to the boom centerline) and elevation angle motion about an axis perpendicular to the azimuth axis and rotating with the azimuth axis. Angular range is 360 degrees in azimuth and 210 degrees in elevation.

The platform is slewed one axis at a time with selectable slew rates in response to computer command subsystem commands to the AACS. Slew rates are: high rate, 1 degree per second; medium rate, 0.33 degree/s; low rate, 0.083 degree/s and a special UVS low rate, 0.0052 degree/s. Camera line of sight will be controlled to within 2.5 milliradians.

Temperature Control

The two Voyager spacecraft are designed to operate farther from Earth than any previous man made object. Survival depends greatly upon keeping temperatures within operating limits while the spacecraft traverses an environmental range of one solar constant at the Earth distance to four per cent of that solar intensity at Jupiter and less than one per cent at Saturn.

Unprotected surfaces at the Saturn range, nearly one billion miles from the Sun can reach 196 C (321 F) below zero -- the temperature of liquid nitrogen.

Both top and bottom of the mission module's basic decagon structure are enclosed with multi-layer thermal blankets to prevent the rapid loss of heat to the cold of space. The blankets are sandwiches of aluminized Mylar, sheets of Tedlar for micrometeroid protection and outer black Kapton covers which are electrically conductive to prevent the accumulation of electrostatic charges.

Also extensively blanketed are the instruments on the scan platform. Smaller blankets and thermal wrap cover eight electronics bays, boom and body-mounted instruments, cabling, propellant lines and structural struts. Only a few exterior elements of the spacecraft are not clad in the black film -- the high gain antenna reflector, plasma sensors, sun sensors and antenna feed cones.

Temperature control of four of the 10 electronics compartments is provided by thermostatically-controlled louver assemblies which provide an internal operating range near room temperature. The louvers are rotated open by bimetallic springs when large amounts of heat are dissipated. These bays contain the power conditioning equipment, the radio power amplifiers, the HYPACE and the tape recorder. Mini-louvers are located on the scan platform, cosmic ray instrument and and the Sun sensors.

Radiodisotope heating units (RHU), small non-power-using heater elements which generate one watt of thermal energy, are located on the magnetometer sensors and the Sun sensors. No RHUs are used near instruments which detect charged particles.

Electric heaters are located throughout the spacecraft to provide additional heat during certain portions of the mission. Many of the heaters are turned off when their respective valves, instruments or subassemblies are on and dissipating power.

JUPITER

Everything about Jupiter is enormous: when the solar system formed, most of the material that did not end up in the Sun went to make Jupiter. It is larger than the rest of the planets combined.

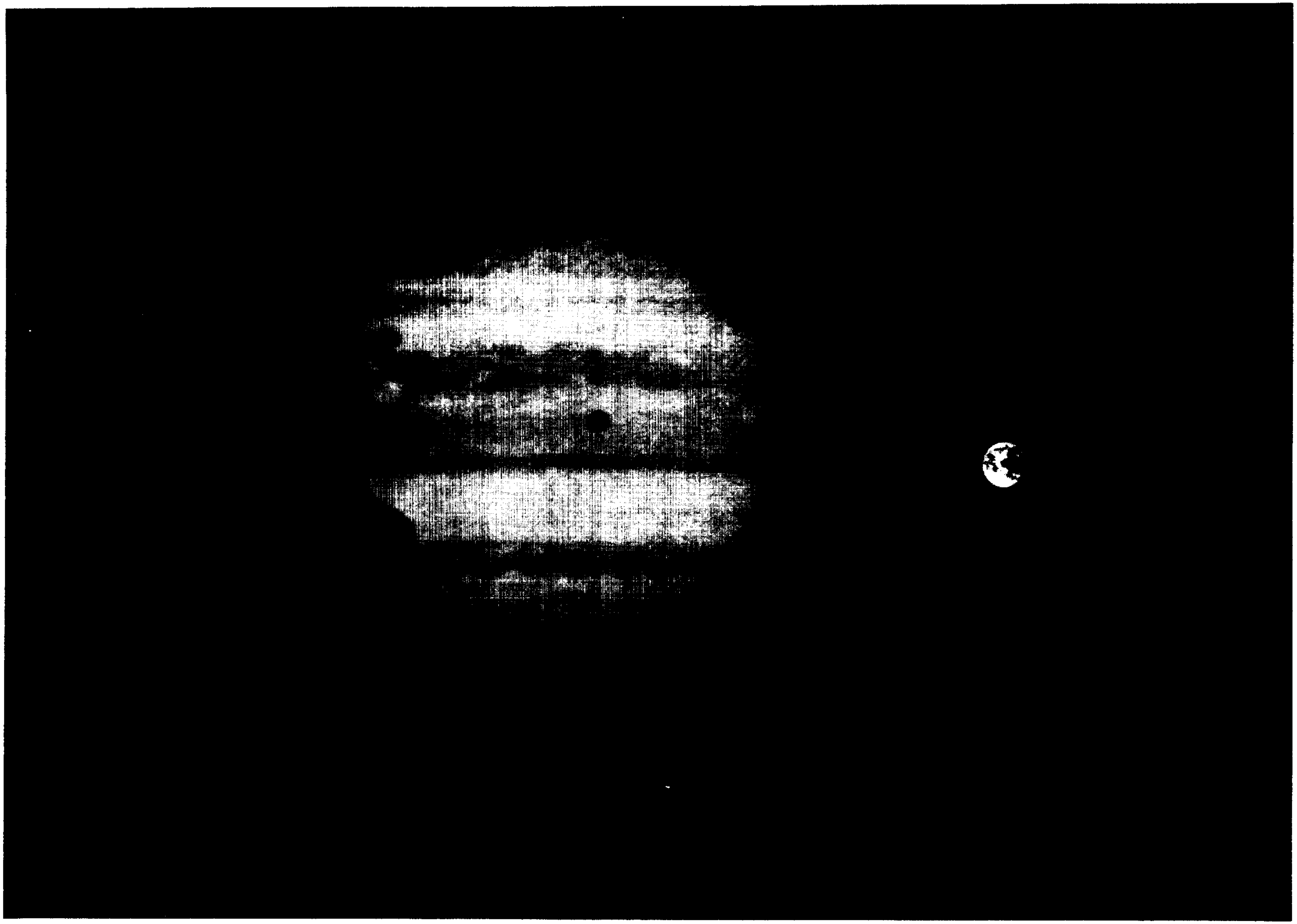
Jupiter is the fifth planet from the Sun. It completes one orbit every 11.86 Earth years.

A day on Jupiter is complete in 9 hours, 55 minutes and 30 seconds. This extremely rapid rotation causes the planet to be flattened at the poles. Equatorial radius is 71,600 km (44,500 mi.), and the polar radius is 67,000 km (42,000 mi.).

Jupiter has 13 known satellites. A 14th may have been seen recently by Charles T. Kowal of Caltech, who also found the 13th in 1974. The four largest satellites were discovered by the first man to aim a telescope at Jupiter -- Galileo Galilei in 1609-10. Galileo's discovery that Jupiter has satellites provided evidence that the Copernican theory of the solar system was correct and that Earth is not the center. The four satellites discovered by Galileo (grouped together and called the Galilean satellites) are Io, Europa, Ganymede and Callisto. They range in size from the planet Mercury to the Moon. All will be studied by the Voyagers.

Jupiter is composed primarily of hydrogen. Indeed it is so massive that very little of its original material could have escaped in the 4.6 billion years or so since it formed. The second most abundant element in Jupiter is helium. The ratio of hydrogen to helium on Jupiter probably is about the same as in the Sun. The solar ratio is roughly one atom of helium for 10 molecules of hydrogen.

Several other substances have been identified spectroscopically in the Jovian atmosphere: ammonia, methane, water, ethane and acetylene. The presence of hydrogen sulfide has been inferred. These are minor components, relative to hydrogen and helium.



Earth and Jupiter to scale.

The currently popular model of Jupiter's structure begins with a small iron silicate core only a few thousand kilometers in diameter. The core is inferred because cosmic abundances of the elements include small amounts of iron and silicates. The temperature there is thought to be about 30,000 degrees Kelvin (54,000 degrees Fahrenheit).

Surrounding the suspected core is a thick layer in which hydrogen is the most abundant element. The hydrogen is separated into two layers, both liquid but in different states. The inner layer, about 46,000 km (29,000 mi.) radius, is liquid metallic hydrogen, which means that the hydrogen is electrically conductive like ordinary metals. That form of hydrogen has not been observed in laboratories since it requires immense heat and pressure. On Jupiter it is thought to exist at temperatures around 11,000 degrees Kelvin (20,000 degrees Fahrenheit) and at pressures about 3 million times Earth's sea-level atmosphere.

The next layer -- liquid hydrogen in its molecular form -- extends to about 70,000 km (44,000 mi.). Above that layer, reaching to the cloud tops for another 1,000 km (600 mi.) is the atmosphere.

If the model is correct, Jupiter has no solid surface, but exists as a rapidly spinning ball of gas and liquid almost 779 million km (484 million mi.) from the Sun.

One of the puzzles about Jupiter is the fact that it radiates about two and a half times the amount of heat that it receives from the Sun. Early models postulated nuclear reactions inside the planet or heat from gravitational contraction. These ideas are no longer believed likely.

Since a liquid is virtually incompressible, however, and since Jupiter is too small and too cold to generate nuclear reactions, scientists now believe the excess heat being radiated by the planet is left over from the primordial heat generated when the planet coalesced out of the solar nebula. As NASA's Dr. John Wolfe writes, "Jupiter cannot be radiating heat because it is contracting; on the contrary, it is contracting because it is slowly cooling."

The visible surface of Jupiter consists of bands of clouds, alternating dark and light, from the equator to about 50 degrees latitude, as shown on page 27. These bands appear to be convection cells that are stretched by Coriolis forces created by the planet's rapid rotation. By convention, the light features are called zones and the dark ones belts. The light zones appear to be regions of greater altitude and cooler temperatures than the dark belts. Gas warmed by the planet's internal heat rises and cools in the upper atmosphere and forms clouds of ammonia crystals suspended in gaseous hydrogen. At the top of the zones, the cooler material moves toward the equator or the poles, is deflected in an east-west direction by Coriolis forces and then sinks back to lower altitudes. A similar but much smaller mechanism on Earth causes the trade winds.

One of the most prominent features on Jupiter is the Great Red Spot. It has been observed almost constantly since its discovery 300 years ago by Giovanni Domenico Cassini. Its width is almost always about 14,000 km (9,000 mi.), but its length varies between 30,000 km (19,000 mi.) and 40,000 km (25,000 mi.).

The Great Red Spot appears to resemble an immense hurricane on Earth -- although it is much larger and has lasted much longer than any terrestrial storms.

Other spots have been observed in the Jovian atmosphere that are similar to but much smaller than the Great Red Spot. They, too, appear in the equatorial regions but have relatively short lifetimes. The one most recently observed lasted just under two years.

Above about 50 degrees latitude, the bands disappear and the Jovian atmosphere becomes turbulent and disorganized. It appears to contain many small convection cells such as those that create the belts and zones of the lower latitudes.

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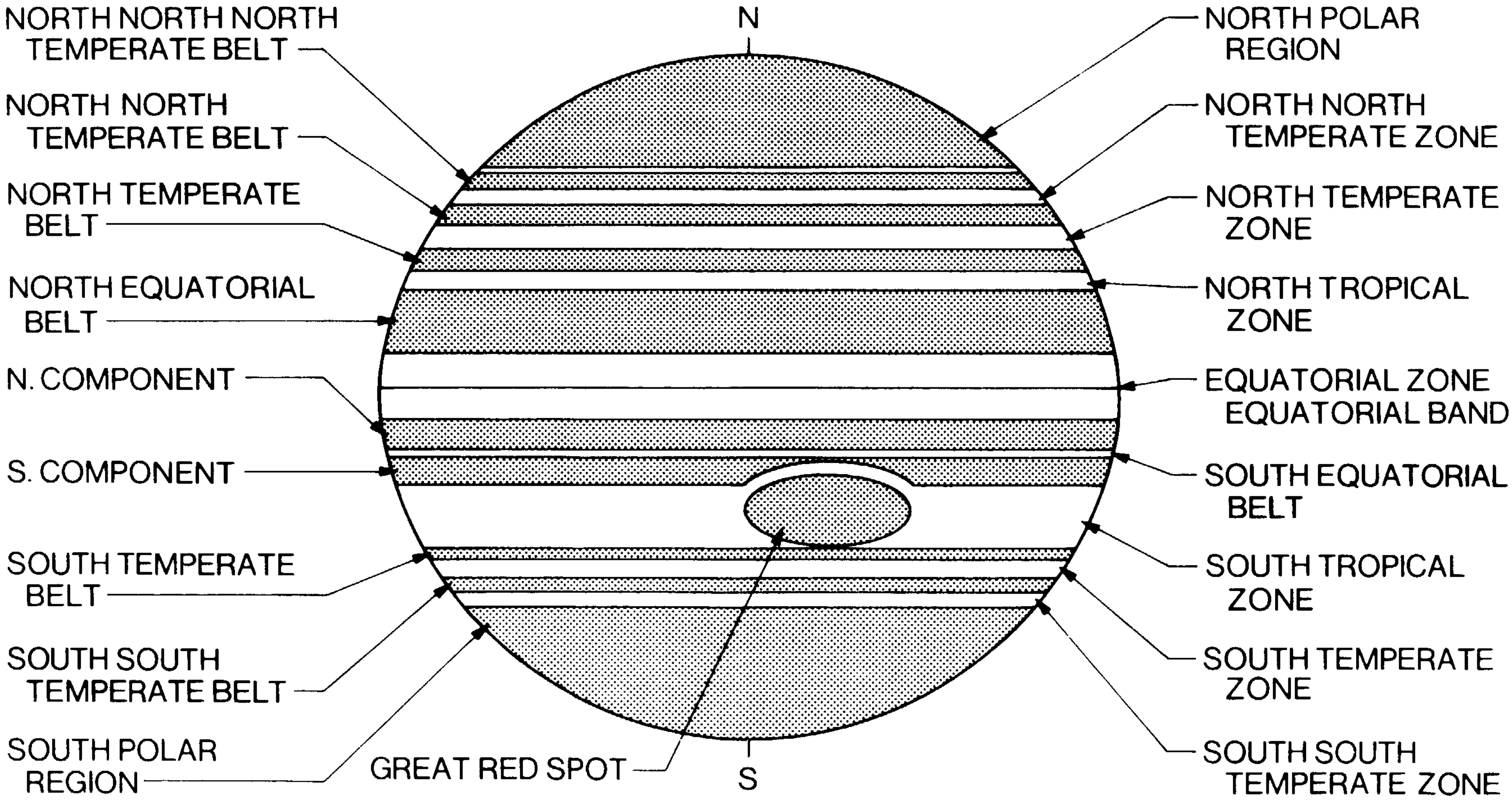
MAJOR FEATURES OF JUPITER



Radio astronomers found evidence for a magnetic field around Jupiter during observations in the 1950s when they discovered radio-frequency emissions coming from the planet. The emissions are confined to two regions of the spectrum -- with wavelengths measured in tens of meters (decametric) and in tenths of meters (decimetric). The decimetric contribution comes primarily from nonthermal mechanisms that depend on the planet's magnetic field. This "synchrotron radiation" comes from electrons that move near the speed of light.

The satellite Io appears to have some link with the decametric radiation, since the bursts seem to occur when Io crosses the face of Jupiter.

While the Jovian magnetic field is essentially dipolar (north and south, like Earth's), its direction is opposite Earth's (the needle of a compass on Jupiter would point south). The axis of the field is offset about 10.8 degrees from the rotational axis and the center of the axis is offset from the center of the planet by about one tenth of a Jupiter radius. At the planet's cloud tops the field ranges between three and 14 gauss (Earth's magnetic field at the surface averages about one half gauss).

The shape of Jupiter's magnetic field is about the same as Earth's with some significant differences. The movement of energetic particles near the equator is intense, but at higher latitudes falls off dramatically. There is apparently an electric-current sheet along the magnetic equator that traps and holds particles there.

The five inner satellites of Jupiter affect distribution of charged particles. As the satellites orbit Jupiter they sweep particles out of their way and at the same time their surfaces are altered by the impinging particles.

Jupiter's outer magnetosphere is highly variable in size, possibly due to changes in the solar-wind pressure. Both Pioneer spacecraft flew in and out of the magnetosphere several times on their inbound legs. The first crossed the magnetopause -- outer edge of the region -- at about 100 Jupiter radii (R_J) and crossed again as close as 50 R_J. Earth's magnetosphere would shrink that much only in the event of the largest solar magnetic storms.

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High-energy electrons have also been observed in another unexpected place -- ahead of the bow shock wave in interplanetary space. Scientists believe high-energy particles in Jupiter's magnetosphere reach such velocity that they can escape. Reexamination of records from Earth satellites turned up the fact that these electrons had been observed for many years. They were believed, however, to be of cosmic origin. Now scientists think they spin down the solar magnetic field lines and intersect Earth, since their peaks occur every 13 months when Earth and Jupiter are connected by the spiral lines of the interplanetary magnetic field.

Jupiter's satellites fall into three groups -- the large inner bodies, then a group of four that are small and a final group, also four in number, that are far distant and have retrograde orbits.

The five inner satellites are Amalthea (the smallest, about 240 km or 150 mi. in diameter); Io, larger than Mercury; Europa, Ganymede and Callisto.

Io is about 3,640 km (2,260 mi.) in diameter. It displays some of the most bizarre phenomena in the solar system. The density of Io is about the same as that of the Moon, indicating a rocky composition. Io has a layer of ionized particles about 100 km (60 mi.) above the surface; the satellite has a tenuous atmosphere. Measurements indicate the atmosphere is about one billionth as dense as Earth's. Io is surrounded by a yellow glow -- an ionized cloud of sodium. Also detected in this tenuous extended atmosphere are hydrogen, potassium and sulfur. The surface of this Jovian moon has a unique spectrum, probably due to a combination of sulfur and salts deposited long ago through hydrothermal outgassing. Io also has reddish polar caps of unknown composition.

Europa, smaller than Io, has a diameter of 3,050 km (1,900 mi.). Europa appears to be a rocky body like Io and scientists say this is probably because it heated early in its history to a temperature high enough to drive off the volatiles. However, its white highly reflective surface is almost entirely covered with ice and frost.

Ganymede is one of the largest satellites in the solar system. Its diameter is 5,270 km (3,270 mi.). Ganymede may be mostly liquid water -- a planet-sized drop of water with a mud core and a crust of ice. The surface is not pure ice, however. It is mixed with darker material of unknown composition.

Callisto has a diameter of 5,000 km (3,110 mi.). It is darker than the other Galilean satellites, apparently because of absence of ice or light-colored salts. It may have suffered the least change of all the big satellites since formation billions of years ago. Scientists believe it is probably half water and may contain so little rock that radioactive heating has not melted or differentiated it.

The outer satellites, in order of increasing distance from Jupiter, are: Leda, Himalia, Lysithea, Elara, Ananke, Carme, Gasiphae and Sinope. All the outer satellites appear to be very different from the inner group. They may be former asteroids captured by Jupiter. Or they may be the remains of broken-up satellites. Their orbits are fairly highly inclined (25 to 28 degrees from the equatorial plane) and the outermost four pursue retrograde paths.

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SATURN

Saturn is the farthest planet from the Sun known to the ancients. Not until Sir William Herschel discovered Uranus in 1781 did anyone know of the existence of a trans-Saturnian planet.

Saturn is unique in the solar system. It is the only planet less dense than water and, until the recent discovery of Uranus' rings, was thought to be the only planet with rings.

The rings were discovered in 1610 when Galileo Galilei aimed the first astronomical telescope at Saturn. Even Galileo didn't realize what they were. He reported seeing "cup handles" in his less-than-adequate telescope. Forty-five years later, in 1655, Christian Huygens described the rings' true form.

Saturn has a volume 815 times greater than Earth's, but a mass only 95.2 times greater. It is the second largest planet. Saturn's equatorial radius is 60,000 km (37,300 mi.). The polar radius is considerably smaller -- 53,500 km (33,430 mi.). The dynamic flattening, caused by Saturn's rapid rotation and increased by its low density, is the greatest of any planet yet measured.

A day on Saturn's equator is only 10 hours, 14 minutes -- 18.5 minutes longer than a day on Jupiter. Saturn completes one orbit of the Sun in 29.46 Earth years. The average distance of Saturn from the Sun is 9.5 A.U.* Saturn receives only about 1/100th the Sun's intensity that strikes Earth.

Saturn, like the other outer giants, bears some resemblance to Jupiter -- enough that they are often coupled together as the Jovian planets. Like Jupiter, Saturn apparently has no solid surface, but changes gradually from a thin outer atmosphere through progressively denser layers to the core, which may be a small chunk of iron and rock.

*An astronomical unit (A.U.) is the mean distance from the Sun to the Earth -- 149,600,000 km (92,960,000 mi.).

Earth and Saturn to scale.

When scientists discuss the planet's atmosphere, they generally restrict their attention to a region where pressure varies from 1,000 Earth atmospheres to one 10-billionth atmosphere (10^{-10}).

Like Jupiter, the principal constituents of the Saturnian atmosphere are thought to be hydrogen and helium. Three molecules have definitely been detected in Saturn's atmosphere: hydrogen (H_2), methane (CH_4) and ethane (C_2H_6). Radio observations provide indirect evidence for ammonia (NH_3) at atmospheric levels inaccessible to optical measurements. No other molecular or atomic species has been detected.

Also, like Jupiter, Saturn is believed to be composed of materials in about the same ratio as the Sun, formed into the simplest molecules expected in a hydrogen rich atmosphere.

Saturn appears to radiate nearly twice as much energy as it receives from the Sun. In the case of Jupiter, that radiation has been explained as primordial heat left over from the time, about 4.6 billion years ago, when the planet coalesced out of the solar nebula. The same may be true for Saturn. Convection is the most likely transport mechanism to carry heat from the interior of the planet to the surface.

Saturn has cloud bands similar to Jupiter's, although they are harder to see and contrast less with the planetary disc. Photographs confirm that Saturn's bland appearance is real. The blandness may be a result of lower temperatures and reduced chemical and meteorological activity compared with Jupiter or a relatively permanent and uniform high altitude haze.

The principal features of Saturn's visible surface are stripes that parallel the equator, as shown on page 35. Six dark belts and three light zones have been seen continuously over 200 years of observations.

Spots have been observed in the upper atmosphere of Saturn. Unlike the Great Red Spot of Jupiter they are not permanent nor are they easily identifiable. The spots that have been observed have lifetimes up to a few months. Sometimes they are light, sometimes dark. They are confined to a region within 60 degrees of the equator and typically are a few thousand kilometers across. They may be comparable to hurricanes on Earth.

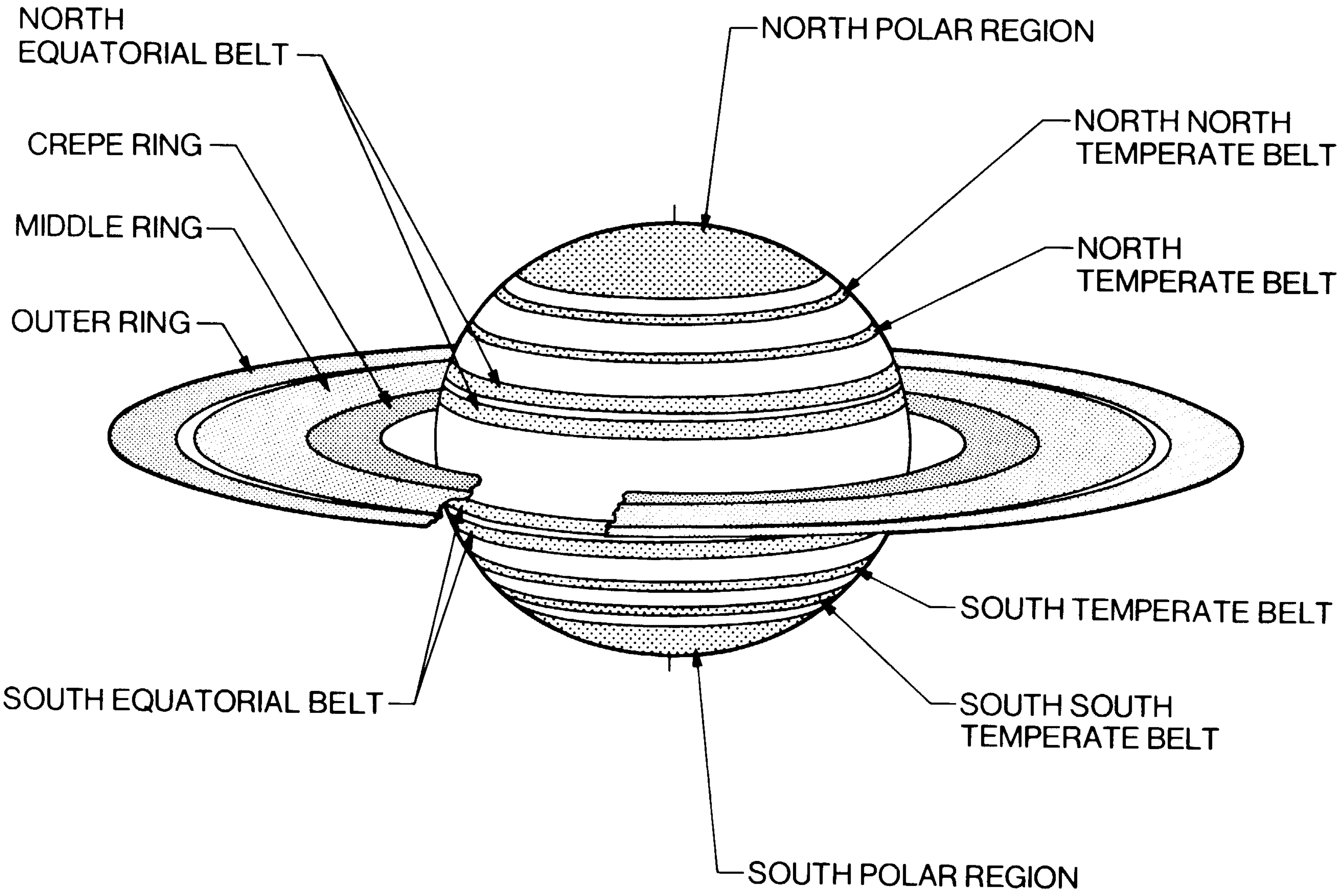
Saturn has 10 known satellites. The most recent discovery was Janus, found in 1966 by Audouin Dollfus. Janus has been seen in only a few photographs. It appears to travel in the plane of Saturn's rings and near them. Its low albedo and proximity to the rings make Janus difficult to observe except when the rings are edge-on to Earth and recent studies indicate that at least two separate satellites are masquerading under the name of Janus.

The largest known satellite in the solar system is Saturn's satellite Titan. Titan has a diameter of 5,800 km (3,600 mi.) and is known to have an atmosphere. In 1944, the late Dr. Gerard Kuiper detected a methane atmosphere on Titan. Titan's atmospheric pressure may be comparable to Earth's. Other molecules identified include ethane and probably acetylene and many scientists believe there is also a major undetected gas present. The most likely candidate is nitrogen. Some scientists believe organic compounds may be present on the surface of Titan, leading some to suggest it as a possible abode of some primitive life forms.

Iapetus is another Saturnian satellite that draws scientific interest. Its brightness varies by a factor of about five as it rotates on its axes, indicating that one face is bright and the other dark. The light face appears to be covered with ice but the composition of the dark face is unknown.

Saturn's rings have been a curiosity to astronomers since their discovery. Their origin is unknown but a number of hypotheses have been put forward. They might be the remains of some early satellite broken up by gravitation or remnants of the primordial material that somehow became trapped in orbit. The age of the rings is not known.

MAJOR FEATURES OF SATURN



The rings lie in Saturn's equatorial plane, which is tipped 27 degrees to the orbital plane of Saturn. Although it is certain the rings are not a solid sheet, little else is known about their composition and structure. Spectroscopy shows that they are made primarily of water ice or ice-covered silicates.

The individual particles probably vary from less than a millimeter (0.04m.) to more than 10 m (32.8 ft.), but most are a few centimeters in size -- about as big as a snowball.

Three distinct rings can be seen. The inner or "crepe" ring begins about 17,000 km (11,000 mi.) from the planet's visible cloud surface and extends for 15,000 km (9,000 mi.) to 32,000 km (20,000 mi.). The second ring begins at that point and extends for 26,000 km (16,000 mi.) to a distance of 58,000 km (36,000 mi.) from the planet. There, a phenomenon known as Cassini's Division breaks the rings' continuity. Cassini's Division is 2,600 km (1,600 mi.) wide.

The outer ring begins 60,000 km (38,000 mi.) from the equator of Saturn and appears to end 16,000 km (10,000 mi.) farther away at a distance of 76,000 km (47,000 mi.).

Cassini's Division is real. It is explained by a phenomenon in celestial mechanics. Any particle at that distance would have an orbital period of 11 hours 17 1/2 minutes, just half the period of the satellite Mimas. The particle would be nearest Mimas at the same place in its orbit every second time around. This repeated gravitational perturbation would eventually move the particle to a different distance.

Accurate measurements of the ring thickness are not possible, but limits have been placed. They appear to be somewhere between 1 and 4 km (0.6 to 2.5 mi.).

Until recently there was no evidence that Saturn has a magnetic field. Neither decimetric nor decametric radio emissions had been observed -- the kind of "radio noise" from Jupiter that was evidence for its magnetic field. But radiometric observations from the Earth-orbiting satellite IMP-6 have provided indirect evidence for a magnetic field. If a magnetic field is present, it is probably distorted by the rings. Direct measurement of any magnetic field and associated trapped radiation is one of the primary goals of the Voyager mission.

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PLANETARY ATMOSPHERIC AND SURFACE DATA

Jupiter

Major atmospheric constituents are hydrogen and helium.

Minor constituents include methane, ammonia, acetylene, ethane and phosphoric acid. Hydrogen has been detected in the exosphere.

There is a thin layer of ammonia clouds with tops at about 106 degrees K (-269 degrees F) and about 0.2 atmospheres and base at about 150 degrees K (-189 degrees F) and about 0.6 atmospheres.

Pressure near the main cloud tops is about 1.5 atmospheres.

Main cloud top temperature is about 200 degrees K (-99 degrees F).

Beneath the clouds, temperatures and pressures rise rapidly.

It is not known whether Jupiter has a solid surface.

Saturn

Major atmospheric constituents are hydrogen and perhaps helium.

Minor constituents include methane and ammonia.

Temperature at tropopause is about 77 degrees K (-321 degrees F).

Pressure at tropopause is about 0.17 atmospheres.

It is not known whether Saturn has a solid surface.

Effective temperature is about 97 degrees K (-285 degrees F).

Beneath the clouds, temperatures and pressures rise rapidly.

Uranus

Major atmospheric constituents are hydrogen and perhaps helium.

Minor constituent is methane.

Effective temperature is 57 degrees K (-356 degrees F).

The atmosphere is very deep and higher temperature and high pressures certainly exist at depths.

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COMPARISON TABLE

PARAMETER	EARTH	JUPITER	SATURN
Radius (Equatorial)	6,378 km (3,963 mi.)	71,400 km (44,366 mi.)	60,000 km (37,300 mi.)
Satellites	1	13	10
Year	1	11.86	29.46
Day	23h 56m 04s	9h 55m 30s	10h 14m
Mass	1	317.9	95.2
Density (Water = 1)	5.5	1.3	0.7
Mean Distance From Sun	1 A.U.	5.2 A.U.	9.5 A.U.

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THE SATELLITES OF JUPITER

NAME		DIAMETER (km- mi.)		SEMIMAJOR AXIS (km-mi.)		PERIOD (Days)
Amalthea	V	240	150	181,300	112,650	0.489
Io	I	3,640	2,660	421,600	261,950	1.769
Europa	II	3,050	1,895	670,900	416,400	3.551
Ganymede	III	5,270	3,275	1,070,000	664,900	7.155
Callisto	IV	5,000	3,105	1,880,000	1,168,000	16.689
Leda	XIII	2-14	1.3-8.5	11,110,000	6,903,500	240
Himalia	VI	170	110	11,470,000	7,127,000	250.6
Lysithea	X	6-32	3.7-20	11,710,000	7,276,000	260
Elara	VII	80	50	11,740,000	7,295,000	260.1
Ananke	XII	6-28	3.7-17	20,700,000	12,862,000	617
Carme	XI	8-40	5-25	22,350,000	13,176,000	692
Pasiphae	VIII	8-46	5-28.5	23,300,000	14,478,000	735
Sinope	IX	6-36	3.7-22	23,700,000	14,725,000	758

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THE SATELLITES OF SATURN

NAME	DIAMETER (km-mi.)		SEMIMAJOR AXIS (km-mi.)		PERIOD (Days)
Janus	300 (est.)	187	168,700	105,000	0.815
Mimas	400	300	185,800	120,000	0.942
Enceladus	550	390	238,300	148,000	1.370
Tethys	1,200	745	294,900	183,200	1.888
Dione	1,150	715	377,900	235,000	2.737
Rhea	1,450	900	527,600	328,000	4.518
Titan	5,800	3,600	1,222,600	760,000	15.945
Hyperion	300 (est.)	187	1,484,100	922,000	21.276
Iapetus	1,800	1,120	3,562,900	2,214,000	79.33
Phoebe	200 (est.)	125	12,960,000	8,093,000	550.45
(Phoebe's motion is retrograde)					

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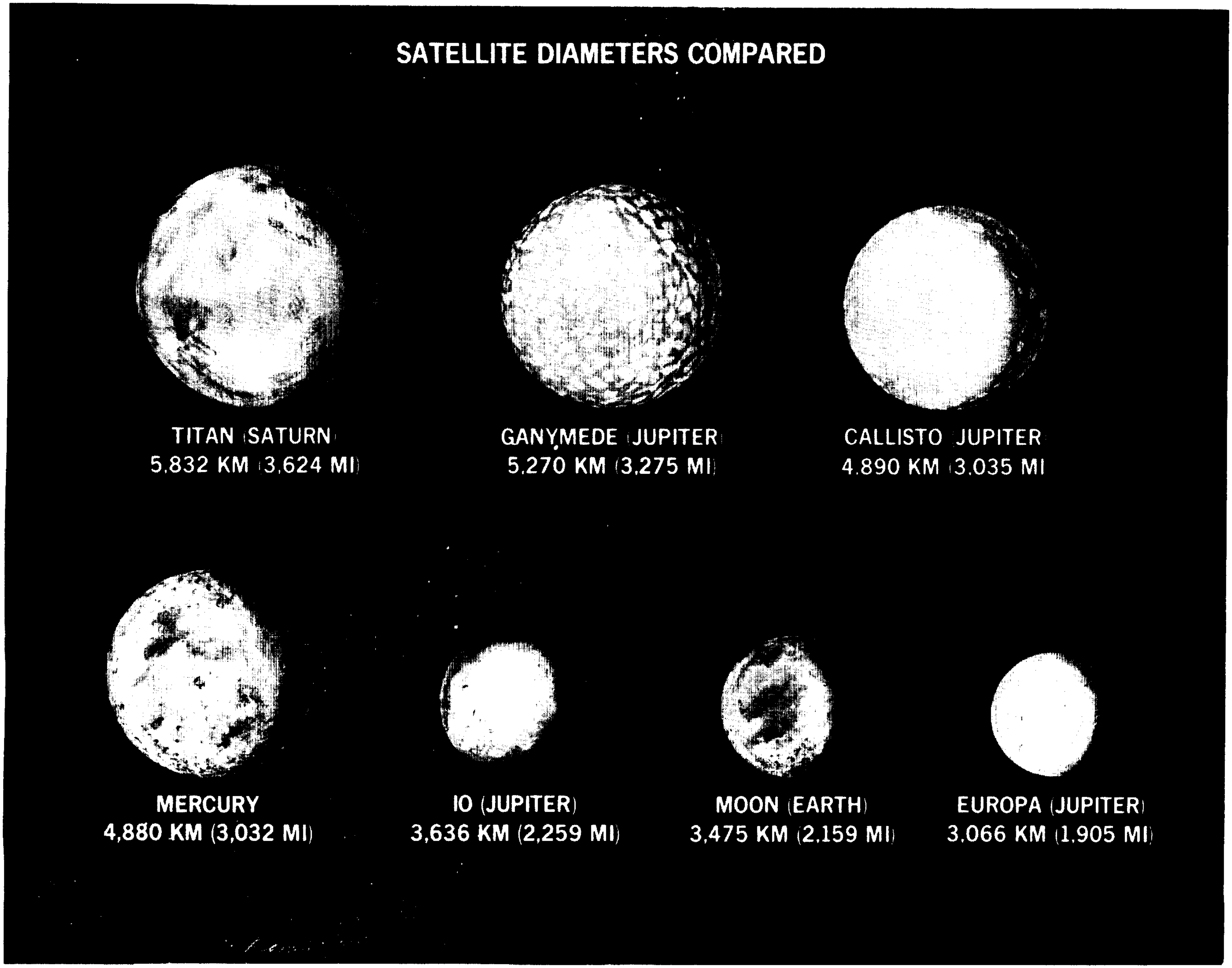
SATELLITE DIAMETERS COMPARED
TITAN (SATURN)
5,832 KM (3,624 MI)
GANYMEDE (JUPITER)
5,270 KM (3,275 MI)
CALLISTO (JUPITER)
4,890 KM (3,035 MI)
MERCURY
4,880 KM (3,032 MI)
IO (JUPITER)
3,636 KM (2,259 MI)
MOON (EARTH)
3,475 KM (2,159 MI)
EUROPA (JUPITER)
3,066 KM (1,905 MI)

VOYAGER SCIENCE

The Voyager mission to Jupiter and Saturn will address fundamental questions about the origin and nature of the solar system. Understanding interplanetary space and the other planets should give scientists a greater knowledge of Earth.

According to current theoretical models of the origin and evolution of the solar system, a gaseous nebula composed of solar material -- gases and dust of various elements -- collapsed to form the Sun. Some of the material remained behind and began to coalesce to form the planets, their satellites, the asteroids, comets and meteors. Temperature, pressure and density of the gas decreased with distance from the Sun. Formation of the planets is believed to have resulted from accretion of the nebular material. Observed differences in the planets are accounted for in these theories by variations in material and conditions at the places where they formed. Thus, knowledge gained at each planet can be related to others and should contribute to an overall understanding of the solar system as well as our own planet Earth.

Missions to Mars, Venus, Mercury and the Moon have contributed greatly to the body of knowledge. Each planet has its own personality, significantly different from others because of its unique composition and relationship to the Sun. Individual as they are, the inner planets are related as bodies that originated near the Sun and that are composed mainly of heavier elements. They are classified as "terrestrial planets," since the Earth is approximately representative.

Scientists have known for a long time that Jupiter, Saturn and the other outer planets differ significantly from terrestrial planets. They have low average densities; only hydrogen and helium among all the elements are light enough to match observations to date. Jupiter and Saturn are sufficiently massive (318 and 95 times Earth's mass, respectively) to insure that they have retained almost all their original material. They are, however, only relatively pristine examples of the material from which the solar system formed. While almost no material has been lost, the planets have evolved over their 4.6-billion-year lifetimes and the nature and ratio of the materials may have changed. If that 4.6-billion-year evolution can be traced, scientists will obtain a clearer picture of the early state of their region of the solar system.

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Voyager Science Investigations

The scientific investigations of the Jupiter-Saturn mission are multipurpose taking data in a variety of environments. For example, the ultraviolet spectrometer studies planetary and satellite atmospheres and also interplanetary and interstellar hydrogen and helium. The magnetic fields experiment will examine the magnetospheres of the planets and also search for the transition between solar and galactic regions.

It is difficult to separate "planetary" from "interplanetary" instruments and investigations. There is, however, another grouping.

First, the optical scanners, mounted on the spacecraft's scan platform, have narrow fields of view and must be accurately pointed. They collect radiant energy (light, for example) from their targets and create images or spectral information that permit scientists to understand the physical form or chemical composition of the planets and satellites. Investigations in this group include the imaging science instruments (TV), infrared interferometer-spectrometer and radiometer, ultraviolet spectrometer and photopolarimeter.

The second family of investigations senses magnetic fields and fluxes of charged particles as the spacecraft passes through them. These instruments are fixed to the body of the spacecraft and have various fields of view. Their data taken together will give information on planetary magnetic fields (and indirectly, interior structure), on Sun-planet and planet-satellite interactions and on cosmic rays and the outer reaches of the solar plasma. These investigations are plasma, low energy charged particles, cosmic ray and magnetic fields.

A third family is planetary radio astronomy and plasma-wave investigations whose long antenna whips listen for planetary emissions, like those from Jupiter.

A radio investigation uses S-band and X-band links between spacecraft and Earth to gather information on planetary and satellite ionospheres and atmospheres and spacecraft tracking data to chart gravitational fields that affect Voyager's course.

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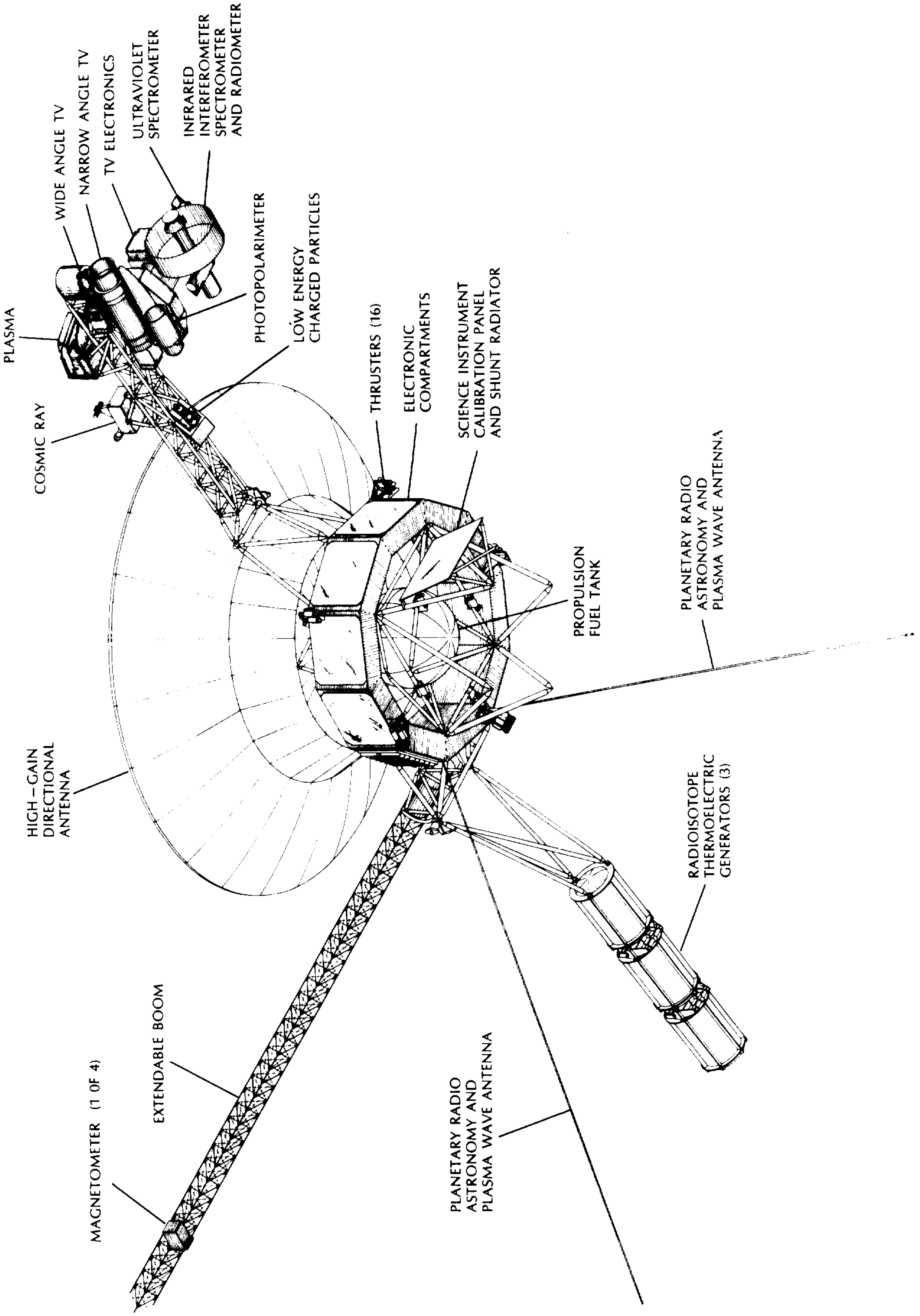
WIDE ANGLE TV
NARROW ANGLE TV
TV ELECTRONICS
ULTRAVIOLET SPECTROMETER
INFRARED INTERFEROMETER SPECTROMETER AND RADIOMETER
PLASMA
PHOTOPOLARIMETER
LOW ENERGY CHARGED PARTICLES
COSMIC RAY
THRUSTERS (16)
ELECTRONIC COMPARTMENTS
SCIENCE INSTRUMENT CALIBRATION PANEL AND SHUNT RADIATOR
PLANETARY RADIO ASTRONOMY AND PLASMA WAVE ANTENNA
PROPULSION FUEL TANK
HIGH-GAIN DIRECTIONAL ANTENNA
RADIOISOTOPE THERMOELECTRIC GENERATORS (3)
EXTENDABLE BOOM
MAGNETOMETER (1 OF 4)
PLANETARY RADIO ASTRONOMY AND PLASMA WAVE ANTENNA

Cosmic-Ray Investigation

The cosmic-ray investigation has four principal scientific objectives:

- To measure the energy spectrum of electrons and cosmic-ray nuclei;
- To determine the elemental and isotopic composition of cosmic-ray nuclei;
- To make elemental and isotopic studies of Jupiter's radiation belts and to explore Saturn's environment, whose possible radiation belts have not yet been positively detected from Earth;
- To determine the intensity and directional characteristics of energetic particles as a function of radial distance from the Sun, and determine the location of the modulation boundary.

The cosmic ray investigation uses multiple-solid state detector telescopes to provide large solid-angle viewing. The low-energy telescope system covers the range from 0.5 to 9 million electron volts (MeV) per nucleon. The high-energy telescope system covers the range from 4 to 500 MeV. The electron telescope system covers the range from 7 MeV.

The cosmic-ray instrument weighs 7.5 kg (16.5 lb.) and uses 8.25 watts of power, including 2.8 watts for supplementary heaters.

Dr. Rochus E. Vogt of the California Institute of Technology is principal investigator.

Low-Energy Charged-Particle Investigation

Scientific objectives of the Low-Energy Charged Particle Investigation include studies of the charged particle composition, energy-distribution and angular distribution with respect to:

- Saturn's magnetosphere (exploratory) and Jupiter's magnetosphere (detailed studies);

- Interactions of charged particles with the satellites of Jupiter and Saturn and possibly with the rings of Saturn;
- Measurements of quasi-steady interplanetary flux and high-energy components of the solar wind;
- Determination of the origin and interstellar propagation of galactic cosmic rays (those that come from outside the solar system);
- Measurements of the propagation of solar particles in the outer solar system.

The investigation uses two solid state detector systems on a rotating platform mounted on the scan platform boom. One system is a low energy magnetospheric particle analyzer with large dynamic range to measure electrons with energy ranging from 15,000 electron volts (15 KeV) to greater than 1 MeV; and ions in the energy range from 15,000KeV per nucleon to 160 MeV per nucleon.

The second detector system is a low-energy particle telescope that covers the range from 0.15 MeV per nucleon to greater than about 10 MeV per nucleon.

The Low-Energy Charged-Particle Investigation weighs 7.5 kg (16.5 lb.) and draws 9.46 watts including 4.66 watts for supplementary heaters.

Dr. S. M. (Tom) Krimigis of the Applied Physics Laboratory, Johns Hopkins University, is principal investigator.

Magnetic Fields Investigation

The magnetic field of a plane is an externally measurable manifestation of conditions deep in its interior.

The magnetic fields instruments on Voyager 1 and 2 will determine the magnetic field and magnetospheric structure at Jupiter and Saturn; they will study the interaction of the magnetic field and the satellites that orbit the planets inside that field and will study the interplanetary-interstellar magnetic field.

Four magnetometers are carried aboard Voyager. Two are low-field, three-axis instruments located on a boom to place them as far from the spacecraft body as possible. This allows separation of the spacecraft's magnetic field from the external field that is to be measured. The other two magnetometers are high field, three-axis instruments mounted on the spacecraft body.

The boom-mounted, low-field instruments will measure the magnetic fields in the range from 10p tesla (0.010 gamma) to 50u tesla (50,000 gamma). (Fifty-thousand gamma equals one-half gauss, about the average magnetic field strength at the surface of Earth.)

The high-field instruments cover the range from 25n tesla (25 gamma) to 2m tesla (20 gauss). While the highest field strengths measured by the Pioneer spacecraft at Jupiter were about 1.4m tesla (14 gauss) scientists expect that localized, stronger fields may be associated with the planets or some of their satellites.

Total weight of the magnetic fields investigation is 5.6 kg (12.3 lb.). The instruments use 2.1 watts of power.

Dr. Norman Ness of NASA's Goddard Space Flight Center is principal investigator.

Infrared Spectroscopy and Radiometry Investigation

The IRIS instrument is designed to perform spectral and radiometric measurements of the Jovian and Saturnian planetary systems and targets of opportunity during the cruise phase of the mission.

Scientific objectives for IRIS are:

- Measurement of the energy balance of Jupiter and Saturn.
- Studies of the atmospheric compositions of Jupiter, Saturn, Titan and other satellites.
- Temperature structure and dynamics of the atmospheres.
- Measurements of composition and characteristics of clouds and aerosols.

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- Studies of the composition and characteristics of ring particles (at Saturn) and the surfaces of those satellites the instrument will observe.

The instrument provides broad spectral coverage, high spectral resolution and low noise equivalence radiance through use of Michelson interferometers. These characteristics of the instrument, as well as the precision of the radiometer, will allow scientists to acquire information about a wide variety of scientific questions concerning the atmospheres of the planets and satellites, local and global energy balance and the nature of satellite surfaces and the rings of Saturn.

Two versions of the IRIS instrument are being prepared for possible use on the spacecraft. The first, known simply as IRIS, was designed for use at the Jupiter and Saturn planetary systems. It is an improved version of the IRIS instrument which flew to Mars on Mariner 9 in 1971-72. The second, known as the Modified IRIS, or MIRIS, was designed later to be able to perform farther out in the solar system at Uranus. Either instrument can be flown on the spacecraft because the principal mechanical and electrical interfaces are identical. In general, the MIRIS instruments will be flown on both Voyager spacecrafts if they are completed in time because they offer advantages at Jupiter and Saturn as well as at Uranus. The accompanying table compares the characteristics of the two instrument versions.

IRIS Instruments
Comparison of Characteristics

	IRIS	MIRIS
Michelson Interferometer Spectral range	2.5-50 μM	1.4-10, 15-200 μM
Radiometer Spectral Range	0.3-2.0 μM	0.3-1.2 μM
Noise Equivalent Radiance (Wcm^{-2} SR^{-1}/cm^{-1})	$7x10^{-10}$	$7.5x10^{-12}$
System Operating Temperature	200°K	140°K
Field-of-view	0.25°	0.15°
Weight	18.6 kg	30.2 kg
Power, watts	20.1	14.0

Dr. Rudolf A. Hanel of Goddard Space Flight Center is principal investigator.

Photopolarimetry Investigation

A great deal of information about the composition of an object can be learned from the way that object reflects light. The Voyager spacecraft's photopolarimeter will observe how light reflected from Jupiter, Saturn and their satellites is polarized by the chemicals and aerosols in the atmospheres and on the surfaces.

The photopolarimeter will measure methane, molecular hydrogen and ammonia above the cloud tops. It will study aerosol particles in the atmospheres of the planets and satellites; the textures and compositions of the surfaces of satellites; size, albedo, spatial distribution, shape and orientation of particles in Saturn's rings; measure optical and geometric thickness of the rings; and observe the sky background to search for interplanetary and interstellar particles.

The instrument is made up of a 15-cm (60 in.) Cassegrain telescope, aperture sector, polarization analyzer wheel, filter wheel and a photomultiplier tube detector. The filter wheel carries eight filters ranging from 2,350-Angstrom to 7,500-Angstrom wavelength; three linear polarizers (0 degrees, 60 degrees and 120 degrees) plus "open" or blank. The instrument's field of view can be set at 3.5 degrees, 1 degree, 1/4 degree and 1/16 degree.

The photopolarimeter weighs 4.4 kg (9.7 lb.) and uses 2.6 watts average power.

Dr. Charles F. Lillie of the University of Colorado's Laboratory for Atmospheric and Space Physics is principal investigator.

Planetary Radio Astronomy Investigation

The Planetary Radio Astronomy investigation consists of a stepped frequency radio receiver that covers the range from 20 kHz to 40.5 mHz and two monopole antennas 10 m (33 ft.) long, to detect and study a variety of radio signals emitted by Jupiter and Saturn.

Scientific objectives of the investigation include detection and study of radio emissions from Jupiter and Saturn and their sources and relationship to the satellites, the planets' magnetic fields, atmospheric lightning and plasma resonances. The instrument will also measure planetary and solar radio bursts from new directions in space and will relate them to measurements made from Earth.

Jupiter emits enormous bursts of radio energy that are not clearly understood. They appear to be related to the planet's magnetosphere, its rotation and even to passage of the satellite Io. The energy released in the strongest bursts is equivalent to that of multi-megaton hydrogen bombs.

The receiver is designed to provide coverage in two frequency bands -- one covering the range from 20.4 kHz to 1,345 kHz, the second from 1,228.8 kHz to 40.5 mHz. The receiver bandwidth is 1 kHz in the low-frequench range and 200 kHz in the high- frequency band. There are three signal input attenuators to provide switchable total attenuation from 0 to 90 decibels.

The instrument weighs 7.7 kg (17 lbs.) and draws 6.7 watts of power.

Principal investigator is Dr. James W. Warwick of the Department of Astro-Geophysics, University of Colorado.

Plasma Investigation

Plasma, clouds of ionized gases, moves through the interplanetary region and comes from the Sun and from stars. The plasma investigation uses two Faraday-cup plasma detectors, one pointed along the Earth-spacecraft line, the other at right angles to that line.

Scientific objectives of the plasma investigation are:

- Determine properties of the solar wind, including changes in the properties with increasing distance from the Sun;
- Study of the magnetospheres that are intrinsic to the planets themselves and that corotate with the planets independent of solar wind activity;

- Study of the satellites of Jupiter and Saturn and the plasma environment of Io;
- Detection and measurement of interstellar ions.

The Earth-pointing detector uses a novel geometrical arrangement that makes it equivalent to three Faraday cups and determines macroscopic properties of the plasma ions. With this detector, accurate values of the velocity, density and pressure can be determined for plasma from the Earth (1 A.U.) to beyond Saturn (10 A.U.). Two sequential energy scans are employed to allow the instrument to cover a broad range of energies -- from 10 electron volts (eV) to 6,000 electron volts (6 KeV). Significant measurements can be made between subsonic and supersonic speeds in cold solar wind or hot planetary magnetosheath.

The variable energy resolution allows scientists to detect and sort out ions that flow with the solar wind at the same time they are measuring the solar wind's properties.

The instrument has a large (180-degree) field of view at planetary encounters and a 90-degree field of view in the solar wind. No electrical or mechanical scanning is necessary.

The other Faraday cup, a side-looking or lateral detector, measures electrons in the range of 10 eV to 6 KeV and should improve spatial coverage for any drifting or corotating positive ions during planetary encounters.

The instrument was designed primarily for exploring planets' magnetospheres. It is capable of detecting hot subsonic plasma such as has been observed in the Earth's magnetosphere and is expected from ions originating in the McDonough-Brice ring of Io. The instrument's large angular acceptance allows detection of plasma flows well away from the direction of the Sun, such as plasma flows that corotate with the planet.

The plasma instrument weighs 9.9 kg (21.8 lb.) and draws 9.9 watts of power.

Dr. Herbert Bridge of the Massachusetts Institute of Technology is principal investigator.

Plasma Wave Investigation

Scientific objectives of the plasma wave investigation are measurements of thermal plasma density profiles at Jupiter and Saturn, studies of wave-particle interactions and study of the interactions of the Jovian and Saturnian satellites with their planets' magnetospheres.

The plasma wave instrument will measure electric-field components of local plasma waves over the frequency range from 10 Hz to 56 kHz.

The instrument shares the two extendable 10-m (33 ft.) electric antennas provided by the planetary radio astronomy experiment team. The two groups use the antennas in different ways. The plasma wave investigation uses the antennas to form a Vee-type balanced electric dipole, while the radio astronomy investigation uses them as a pair of orthogonal monopoles.

In the normal format, the plasma wave signals are processed with a simple 16-channel spectrum analyzer. At planetary encounters, the system will provide a spectral scan every four seconds.

The plasma wave system has a broadband amplifier that will use the Voyager video telemetry link to give electric field waveforms, with a frequency range from 50 Hz to 10 kHz, at selected times during planet encounters.

The investigation is designed to provide key information on the wave-particle interaction phenomena that control important aspects of the dynamics of the magnetospheres of Jupiter and Saturn. Wave-particle interactions play extremely important roles at Earth and scientists understand that at least the inner magnetosphere of Jupiter is conceptually similar to that of Earth despite the vast difference in size and in energy of the trapped particles.

In addition, the satellites of Jupiter and Saturn appear to provide important localized sources of plasma and field-aligned currents and they should significantly affect the trapped-particle populations.

The instrument weighs 1.4 kg (3.1 lb.) and draws 1.6 watts of power.

Dr. Frederick L. Scarf of TRW Defense and Space Systems is principal investigator.

Radio Science Investigation

The spacecraft's communications system will be used to conduct several investigations by observing how the radio signals are changed on their way to Earth.

By measuring the way signals die out and return when the spacecraft disappears behind a planet or satellite and then reappears, the radio science team can determine the properties of planetary and satellite atmospheres and ionospheres.

The radio signals also allow scientists to make precise measurements of the spacecraft's trajectory as it passes near a planet or satellite. Post-flight analyses allow determination of the mass of a body and its density and shape.

The rings of Saturn will also be explored by the radio science team by measuring the scattering of the radio signals as they travel through the rings. This will provide measurements of ring mass, particle size distribution and ring structure.

The investigation uses the microwave receivers and transmitters on the spacecraft as well as special equipment at the Deep Space Network tracking stations. The spacecraft transmitters are capable of sending 9.4, 20 or 28.3 watts at S-band, and 12 or 21.3 watts at X-band. The spacecraft antenna is a 3.67 m (12 ft.) parabola and is aimed by special maneuvers performed during planet occultations.

Dr. Von R. Eshleman of the Center for Radar Astronomy, Stanford University, is the Leader of the Radio Science Team.

Imaging Science Investigation

The Voyager imaging system is based on those flown aboard Mariner spacecraft, with advancements and changes dictated by the specific requirements of flybys of Jupiter, Saturn and their satellites.

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Science objectives for the imaging science investigation include reconnaissance of the Jupiter and Saturn systems, including high-resolution photography of atmospheric motions, colors and unusual features (such as the Great Red Spot and similar smaller "spots"), vertical structure of the atmospheres of the planets, comparative and detailed geology of satellites, satellite size and rotation and detailed studies of the rings of Saturn.

Two television-type cameras are mounted on the spacecraft's scan platform: a 200mm focal-length, wide-angle camera with 4,000-Angstrom to 6,200-Angstrom sensitivity and a 1,500mm focal-length, narrow-angle camera with a 3,200-Angstrom to 6,200-Angstrom range.

The discs of Jupiter and Saturn will exceed the field of view of the narrow-angle camera about 20 days before closest approach. At that time, resolution will be about 400 km (250 mi.). For several days before and after closest approach, scientists will have several simultaneous imaging opportunities:

- Photography at high resolution of planets whose angular diameters are many times larger than the field of view;

- Close encounters (some comparable with Mariner 10's Mercury flybys) with the major satellites. For example, all four Galilean satellites (Jupiter's largest) will probably be photographed at resolution better than 4 km (2.5 mi.);

- More distant photography of several additional satellites;

- High-resolution photography of Saturn's rings.

To exploit such a variety of opportunities, it is necessary for the spacecraft to return large quantities of imaging data. The camera-spacecraft system has been designed to return imaging data over a wide range of telemetry rates in real time. Data can also be recorded on board the spacecraft for later playback to Earth -- during occultation by Jupiter, for instance.

Each camera is equipped with a filter wheel whose eight individual filters have a variety of uses:

The wide-angle camera's filter wheel contains one clear filter, one each in violet, blue, green and orange wavelengths, a seven-Angstrom sodium-D filter for special observations near Io and other satellites and two 100-Angstrom filters at the wavelength of methane absorption for study of the distribution of methane in the atmospheres of Jupiter, Saturn, Titan and Uranus.

The narrow angle camera's filter wheel carries two clear filters, two green and one each of violet, blue, orange and ultraviolet.

Voyager will be the first imaging system with narrow-band capability to directly observe distribution of atomic and molecular species. The seven-Angstrom sodium-D filter is the narrowest bandwidth filter ever flown with this kind of camera.

Because the Voyager spacecraft will pass the planets and satellites at high velocities and must take pictures in dimmer light than Mariner missions to the inner planets, image smear conditions are more severe than on previous flights. To overcome these problems, the camera's preamplifiers have been redesigned to lower system noise and and to incorporate a high gain state. Both changes are meant to provide high quality images with minimum smear.

During the several months before closest approach, the narrow-angle cameras will photograph Jupiter and Saturn regularly and often to provide information on cloud motions. These pictures will be taken on a schedule which would permit scientists to make motion pictures in which the planet's rotation has been "frozen" so that only the cloud motions are apparent. Resolution during the period will range from about 1,600 km (1,000 mi.) to about 400 km (250 mi.). Once the planet grows larger than the narrow angle camera's field of view, the wide-angle camera will begin its work. The narrow-angle camera will then repeatedly photograph portions of the planets that warrant special scientific interest. Both cameras will be shuttered simultaneously during these periods so scientists can relate small scale motions to larger patterns.

Because of the nature of the planetary flybys the cameras will not be able to concentrate on a single target for hours at a time. As each satellite moves it will present an everchanging appearance to the cameras. The planets' clouds will also be in constant motion. Therefore, observational sequences are structured to provide repeated images at differing intervals for each target. Additionally, large amounts of multicolor imaging data will be obtained for the planets and satellites.

The camera system weighs 38.2 kg (84 lb.) and uses 41.7 watts of power including 8.6 watts for instrument and scan platform supplementary heaters.

Dr. Bradford A. Smith of the University of Arizona is the leader of the Imaging Science Team.

Ultraviolet Spectroscopy Investigation

The ultraviolet spectrometer looks at the planets' atmospheres and at interplanetary space.

Scientific objectives of the investigation are:

- To determine distributions of the major constituents of the upper atmospheres of Jupiter, Saturn and Titan as a function of altitude;
- To measure absorption of the Sun's ultraviolet radiation by the upper atmospheres as the Sun is occulted by Jupiter, Saturn and Titan;
- To measure ultraviolet airglow emissions of the atmospheres from the bright discs of the three bodies, their bright limbs, terminators and dark sides;
- Determine distribution and ratio of hydrogen and helium in interplanetary and interstellar space.

The instrument measures ultraviolet radiation in 1,200-Angstrom bandwidth in the range from 400 to 1,800 Angstroms. It uses a grating spectrometer with a microchannel plate electron multiplier and a 128-channel anode array. A fixed position mirror reflects sunlight into the instrument during occultation. The instrument has a 0.86-degree by 0.6-degree field of view during occultation and a 0.86-by 2-degree field of view for airglow measurements.

The ultraviolet spectrometer weighs 4.5 kg (9.9 lb.) and uses 2.5 watts of power.

Dr. A. Lyle Broadfoot of Kitt Peak National Observatory is principal investigator.

INVESTIGATION	PRINCIPAL INVESTIGATOR	INSTRUMENTS AND FUNCTIONS
Imaging Science	Team Leader, Dr. Bradford Smith, University of Arizona	Two TV cameras with 1500mm, f/8.5 and 200mm, f/3 optics, multiple filters, variable shutter speeds and scan rates. Wide-angle field of view, 56x55 millirad (about 3 deg. square). On scan platform.
Infrared Spectroscopy and Radiometry	Dr. Rudolf Hanel, Goddard Space Flight Center	Spectrometer-radiometer measuring temperatures and molecular gas compositions, with narrow 1/4-deg field of view producing measurements every 48 sec. on scan platform.
Ultraviolet Spectroscopy	Dr. A. Lyle Broadfoot, Kitt Peak National Observatory	Grating spectrometer measuring ion, atomic, and small-molecular gas abundances, spectral range 400-1600 Angstroms, on scan platform.
Photopolarimetry	Dr. Charles Lillie, University of Colorado (Cruise Phase) Dr. Charles Hord, University of Colorado (Encounter Phase)	200mm telescope with variable apertures, filters, polarization analyzers and PMT detector, on scan platform.
Plasma	Dr. Herbert Bridge, Massachusetts Institute of Technology	Dual plasma detectors, one aligned toward Earth-Sun and one perpendicular, with detection ranges from 10eV to 6 keV.

INVESTIGATION	PRINCIPAL INVESTIGATOR	INSTRUMENTS AND FUNCTIONS
Low-Energy Charged-Particle	Dr. S. M. Krimigis, Johns Hopkins, Applied Physics Laboratory	Dual rotating solid-state detector sets, covering various ranges from 10 keV to more than 30 MeV/nucleon.
Cosmic Ray	Dr. R. E. Vogt, California Institute of Technology	High-energy, low-energy, and electron telescope systems using arrays of solid-state detectors, several ranges from 0.15 to 500 MeV/nucleon.
Magnetic Fields	Dr. Norman Ness, Goddard Space Flight Center	Two low-field triaxial flux-gate magnetometers located roughly 10 m (33 ft.) from spacecraft on boom, two high-field (20 gauss) instruments mounted on spacecraft.
Planetary Radio Astronomy	Dr. James Warwick, University of Colorado	Two 10-m (33 ft.) whip antennas and two-band receiver (20.4-1300 kHz, 2.3-40.5 mHz), detecting planetary radio emissions and bursts and solar stellar bursts.
Plasma Wave	Dr. Frederick L. Scarf TRW Space and Defense Systems	Uses 10-m (33 ft.) planetary radio astronomy antennas with step-frequency detector and waveform analyzer to measure plasma waves, thermal plasma density profiles at Jupiter and Saturn, satellite/magnetosphere interactions, wave particle interactions.

INVESTIGATION	PRINCIPAL INVESTIGATOR	INSTRUMENTS AND FUNCTIONS
Radio Science	Team Ieader, Dr. Von R. Eshleman, Stanford University	Uses spacecraft S-band/X-band links in planet, satellite and Saturn ring occultations to perceive changes in refractivity and absorption. Celestial mechanics information calculated from tracking data.

TRACKING AND DATA ACQUISITION

Tracking, commanding and obtaining data from the spacecraft are part of the mission assigned to the Jet Propulsion Laboratory (JPL), Pasadena, Calif. These tasks cover all phases of the flight, including telemetry from launch vehicle and spacecraft, metric data on both launch vehicle and Voyager, command signals to the spacecraft and delivery of data to the Mission Control and Computing Center (MCCC) at JPL.

The Tracking and Data System (TDS) will include elements of the world-wide NASA JPL Deep Space Network (DSN), Air Force Eastern Test Range (AFETR), the NASA Spaceflight Tracking and Data Network (STDN) and the NASA Communications System (NASCOM).

During the launch phase of the mission, data acquisition was accomplished through use of the near Earth facilities--the AFETR stations, downrange elements of the STDN, instrumented jet aircraft and a communications ship. Radar-metric data obtained immediately after liftoff and through the near Earth phase was delivered to and computed at the AFETR Real time Computer system facility in Florida so that accurate predictions could be transmitted to Deep Space Network stations giving the locations of the spacecraft in the sky when they appear on the horizon.

Tracking and communications with the Voyagers from injection into Jupiter transfer trajectory until the end of the mission are being carried out by the Deep Space Network (DSN).

The DSN consists of nine deep space communications stations on three continents, a spacecraft monitoring station in Florida, the Network Operations Control Center in the MCCC at JPL and ground communications linking all locations.

DSN stations are located strategically around the Earth--at Goldstone, Calif.; Madrid, Spain; and at Canberra, Australia. Each location is equipped with a 64-m diameter (210 ft.) antenna station and two 26-m (85 ft.) antenna stations.

The three multi-station complexes are spaced at widely separated longitudes around the world so that spacecraft beyond Earth orbit--and, for the Voyager mission, the planets Jupiter and Saturn--are never out of view. The spacecraft monitoring equipment in the STDN station at Merritt Island, Fla., covered the prelaunch and launch phases of the mission. A simulated DSN station at JPL, called CTA-21, provided prelaunch compatibility support.

In addition to the giant antennas, each of the stations is equipped with transmitting, receiving, data handling and interstation communication equipment. The downlink includes supercooled lownoise amplifiers. The 64-m antenna stations in Spain and Australia have 100-kw transmitters. At Goldstone, the uplink signal can be radiated at up to 400 kw. Transmitter power at all six 26-m stations is 20 kw.

The downlink is transmitted from the spacecraft at S-band (2295 mHz) and X-band (8400 mHz) frequencies. The uplink operates at S-band (2113 mHz) only, carrying commands and ranging signals from ground stations to the spacecraft.

Only the 64-m antenna stations can receive the X-band signal and can receive at both frequencies simultaneously. The 64-m stations will provide continuous coverage during planetary operations and periodically during the cruise phase for maneuvers, spacecraft recorder playbacks and dual-frequency navigation sequences. A 26-m antenna subnet will provide continuous coverage--shared by the two spacecraft--throughout the mission.

Various data rates for each type of telemetered information are required by the changing length of the telecommunications link and the possible adverse weather effects at ground stations on reception of X-band radio signals.

Nerve center of the DSN is the Network Operations Control Center at JPL which provides for control and monitoring of DSN performance. All incoming data is validated at this point, while being simultaneously transferred to the computing facilities of the Mission Control and Computing Center for real time use by engineers and science investigators.

Ground communications facilities used by the DSN to link the global stations with the control center are part of a larger network, NASCOM, which connects all of NASA's stations around the world. Data from the spacecraft are transmitted over high speed circuits. Telemetry at rates up to and including 115.2 k.b.p.s. will be carried in real time on wideband lines from Goldstone and Madrid. The Canberra stations will send encounter data in real time at rates up to and including 44.8 k.b.p.s. Higher downlink rates will be recorded at the station and played back to MCCC at 44.8 k.b.p.s.

Simultaneously with the routing to the MCCC of the spacecraft telemetry, range and range rate information will be generated by the DSN and transmitted to the control center for spacecraft navigation. To achieve the desired maneuver and encounter accuracies, very precise navigation data is required. Navigation information includes S-X ranging, DRVID (differenced range versus integrated Doppler) and multi-station tracking cycles.

Commands are sent from the MCCC to one of the DSN stations where they are loaded into a command processing computer, automatically verified for accuracy and transmitted to the proper spacecraft at 16 bps. Commands may be aborted, if necessary. Manual control and entry of command data at the station is possible in the event of a failure in the high speed data line from the control center.

For all of NASA's unmanned missions in deep space, the DSN provides the tracking information on course and direction of the flight, velocity and range from Earth. It receives engineering and science telemetry and sends commands for spacecraft operations on a multi-mission basis.

Concurrent with the four-year or longer Voyager mission, the network is supporting the extended mission activities of the Viking Project with two Landers on Mars and two Orbiters circling the planet; maintaining post-Jupiter communications with Pioneers 10 and 11; and complementing West Germany's space communications facilities on two Helios Sun-orbiting missions. The DSN also supported a Venus exploration mission by two Pioneer Venus spacecraft -- a planetary orbiter and five atmospheric probes -- launched in May and August, 1978, and planetary science activities in December 1978.

All of NASA's networks are under the direction of the Office of Tracking and Data Systems. JPL manages the DSN. The STDN facilities and NASCOM are managed by NASA's Goddard Space Flight Center, Greenbelt, Md.

The Goldstone DSN stations are operated and maintained by JPL with the assistance of the Bendix Field Engineering Corp. The Canberra stations are operated by the Australian Department of Supply. The stations near Madrid are operated by the Spanish government's Instituto Nacional de Tecnica Aerospacial.

MISSION CONTROL AND COMPUTING CENTER

The Mission Control and Computing Center (MCCC) at the Jet Propulsion Laboratory is the focus of all Voyager Project flight operations. It is through the center's computer systems that data from the Voyagers pass, are processed and presented to the engineers and scientists for analysis. Through the extensive and varied displays of the computers in the MCCC, the flight analysts observe and control the many ground processing functions and the spacecraft.

The MCCC is housed in two JPL buildings containing its computer systems, communications and display equipment, photo processing lab and mission support areas. The various areas are outfitted to satisfy the diverse needs of the Voyager mission operations team--requirements of the mission controllers, spacecraft performance analysts and science investigators.

The MCCC contains several computer systems designed to receive the incoming Voyager data, process it in real time, display it and organize it for further processing and analysis. After the data have been received as radio signals by the Deep Space Network (DSN) stations located around the world, they are transmitted to Pasadena and into the MCCC computers, where the processing begins. Software developed by the MCCC, operating in these computers, performs the receiving, displaying and organizing functions. Computer programs generated by other elements of the Voyager Project further process the data.

Commands causing the spacecraft to maneuver, gather science data and perform other complex mission activities are introduced into the MCCC computers and communicated to a station of the DSN for transmission to the appropriate spacecraft.

The MCCC is composed of three major elements, each with its own computer system. They are the Mission Control and Computing Facility (MCCF), the General Purpose Computing Facility (GPCF) and the Mission Test and Computing Facility (MTCF).

The MCCF consists of three IBM 360-75 processors and supports the Voyager command, data records and tracking systems. The 360-75s provide the means through which commands are sent to the spacecraft. They also are used to process and display tracking and data and provide the data management capability to produce plots and printouts for the day to day determination of spacecraft operating conditions. The 360-75s also produce the final records of data for detailed analysis by the science community.

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The GPCF, with three UNIVAC 1108 computers, supports the Voyager Project's navigation and mission sequence systems. The 1108s also are used to develop prediction programs and detailed spacecraft engineering performance analysis. Computer terminals located in the mission support area allow project analysts to execute their programs and obtain results displayed on TV monitors, or on various printers and plotters.

The MTCF provides telemetry data processing for the science and engineering information transmitted from the Voyagers. Within the MTCF are the telemetry system, imaging system and photo system. The telemetry system uses three strings of UNIVAC and Modcomp computers to receive, record, process and display the data as requested by analysts in the mission support areas. The imaging and photo systems produce the photographic products from data generated by Voyager's TV cameras. Pictures of Jupiter, Saturn and their moons will be analyzed by scientists housed in the mission support areas. Scientists will be provided both electronic and photographic displays.

MCCC, like the DSN, also supports the other flight missions, Viking, Pioneers 10 and 11, Helios and the Pioneer/Venus orbiter.

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Kennedy Space Center

Lee R. Scherer	Director
Walter J. Kapryan	Director of Space Vehicle Operations
George F. Page	Director, Expendable Vehicles
John D. Gossett	Chief, Centaur Operations Division
Creighton A. Terhune	Chief Engineer, Operations Division
Jack E. Baltar	Centaur Operations Branch
Donald C. Sheppard	Chief, Spacecraft and Support Operations Division
James E. Weir	Spacecraft Operations Branch
Floyd A. Curington	Voyager Project Engineer

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Department of Energy

Douglas C. Bauer	Director, Nuclear Research and Applications
Bernard J. Rock	Assistant Director for Space Applications
James J. Lombardo	Chief, Power Systems Branch
Thaddeus G. Dobry	Chief, Flight Safety Branch
Norman Thielke	Chief, Heat Source Branch
Alfred L. Mowery	Chief, Technical Support Branch

VOYAGER SUBCONTRACTORS

Following are some key subcontractors who provided instruments, hardware and services:

Algorex Data Corp. Syosset, N.Y.	Automated Design Support for Flight Data Subsystem
Boeing Co. Seattle, Wash.	Radiation Characterization of Parts and Materials
Fairchild Space and Electronics Co. Germantown, Md.	Temperature Control Louvers
Ford Aerospace and Communications Corp. Palo Alto, Calif.	S/X-Band Antenna Subsystem; Solid-State Amplifiers
Frequency Electronics, Inc. New Hyde Park, N.Y.	Ultra Stable Oscillators
General Electric Co. Space Division Philadelphia, Pa.	Radioisotope Thermoelectric Generators
General Electric Co. Utica, N.Y.	Computer Command Subsystem; Flight Control Processors

General Electric Co. Space Systems Organization Valley Forge, Pa.	Attitude Control and Articulation Subsystem
Hi-Shear Corp. Ordnance Division Torrance, Calif.	Pyrotechnic Squibs
Honeywell, Inc. Lexington, Mass.	Canopus Star Trackers
Hughes Aircraft Co. Aerospace Group Culver City, Calif.	Radiation Characterization of Parts and Materials
Lockheed Electronics Co. Industrial Technology Division Plainfield, N.J.	Data Storage Tape Transport
Martin Marietta Aerospace Denver, Colo.	Attitude Control Electronics; Propulsion Subsystem
Motorola, Inc. Government Electronics Div. Scottsdale, Ariz.	Modulation-Demodulation Subsystem; Radio Frequency Subsystem
Rocket Research Corp. Redmond, Wash.	Rocket Engine and Thruster Valve Assemblies
SCI Systems, Inc. Huntsville, Ala.	Computer Command Subsystem Memories
Teledyne Microelectronics Los Angeles, Calif.	Hybrid Memories for Flight Data Subsystem
Texas Instruments Dallas, Tex.	Data Storage Electronics
The Singer Co. Little Falls, N.J.	Dry Inertial Reference Units (Gyroscopes)
Thiokol Chemical Corp. Elkton Division Elkton, Md.	Solid Rocket Motor
Watkins-Johnson Co. Palo Alto, Calif.	S/X-Band Traveling Wave Tube Amplifiers
Xerox Corp. Electro-Optical Systems Pasadena, Calif.	Power Subsystem
Yardney Electronics Corp. Denver, Colo.	Flight and Test Battery Assemblies

Science Instruments

Massachusetts Institute of Technology Cambridge, Mass.	Plasma Subsystem
University of Colorado Boulder, Colo.	Photopolarimeter Subsystem
University of Iowa Iowa City, Iowa	Plasma Wave Subsystem
Xerox Corp. Electro-Optical Systems Pasadena, Calif.	Imaging Science (TV) Electronics
Kitt Peak National Observatory Tucson, Ariz.	Ultraviolet Spectrometer
Johns Hopkins University Applied Physics Laboratory Baltimore, Md.	Low-Energy Charged Particles Subsystem
Goddard Space Flight Center Greenbelt, Md.	Magnetometers; Cosmic-Ray Subsystem
Texas Instruments Dallas, Tex.	Modified Infrared Interferometer, Spectrometer and Radiometer
Martin Marietta Aerospace Denver, Colo.	Planetary Radio Astronomy Subsystem
Astro Research Corp. Santa Barbara, Calif.	Magnetometer Boom; Planetary Radio Astronomy Antennas
TRW Defense and Space Systems Redondo Beach, Calif.	Ultraviolet Spectrometer Electronics
Matrix Corp. Acton, Mass.	Plasma Subsystem Electronics
General Electrodynamics Corp. Dallas, Tex.	TV Vidicons

CONVERSION TABLE

Multiply	By	To Get
Inches	2.54	Centimeters
Centimeters	0.3937	Inches
Feet	30.48	Centimeters
Centimeters	4.7244	Feet
Feet	0.3048	Meters
Meters	3.2808	Feet
Yards	0.9144	Meters
Meters	1.0936	Yards
Statute Miles	1.6093	Kilometers
Kilometers	0.6214	Miles
Feet Per Second	0.3048	Meters Per Second
Meters/Second	3.281	Feet/Second
Meters/Second	2.237	Statute Miles/Hour
Feet/Second	0.6818	Miles/Hour
Miles/Hour	1.6093	Kilometers/Hour
Kilometers/Hour	0.6214	Miles/Hour
Pounds	0.4563	Kilograms
Kilograms	2.2046	Pounds

To convert Fahrenheit to Celsius (Centigrade), subtract 32 and multiply by 5/9.

To convert Celsius to Fahrenheit, multiply by 9/5 and add 32.

To convert Celsius to Kelvin, add 273.

To convert Kelvin to Celsius, subtract 273.

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