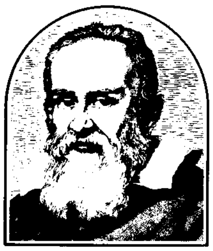
SECTION 4

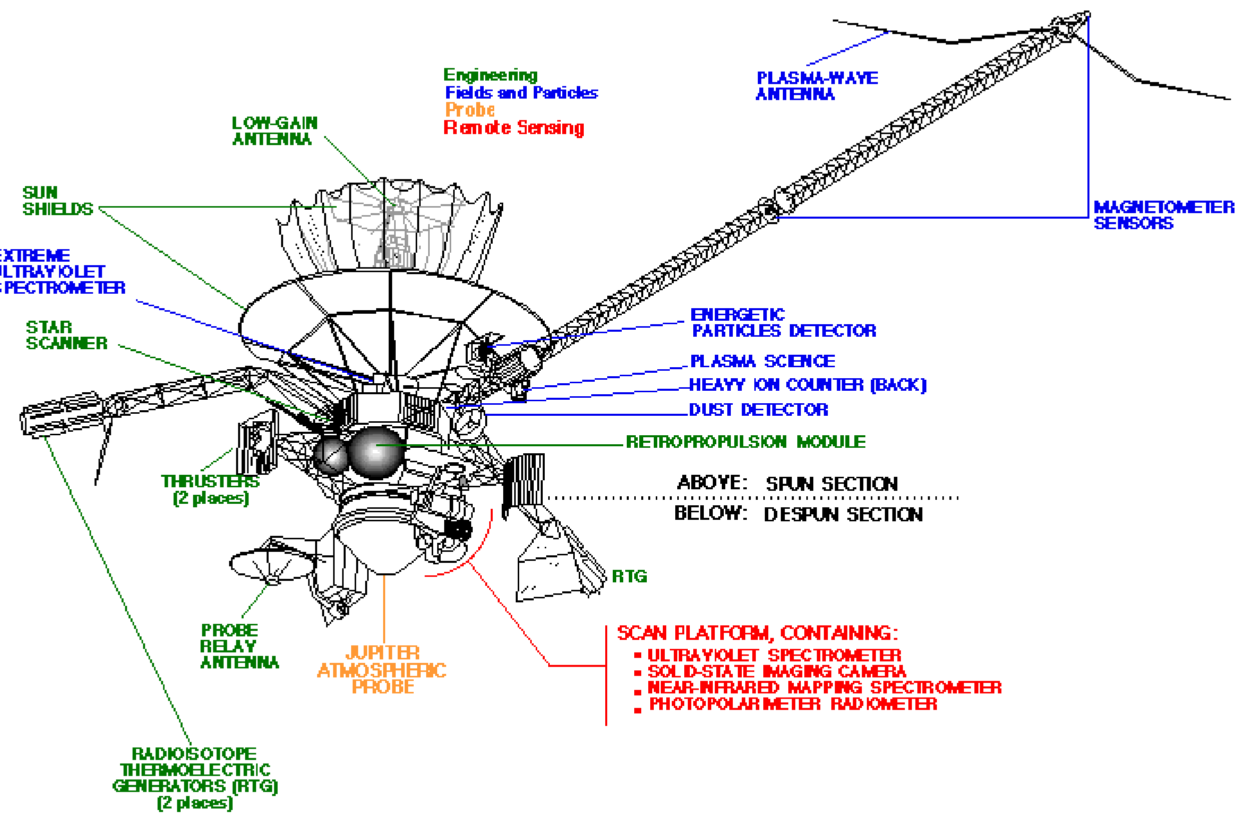


THE GALILEO ORBITER

The Galileo orbiter, built at JPL, combines features of spinner spacecraft (the Pioneers and Ulysses) and three-axis stabilized spacecraft (the Voyagers). The orbiter is an innovative "dual-spin" design. Part of the orbiter (containing the antennas and some instrument booms) rotates while another part (containing an instrument platform) remains fixed in inertial space. This means that the orbiter is a good platform for fields and particles experiments; they perform best when rapidly gathering data from many different directions. The orbiter is also a good platform for remote sensing experiments that require very accurate and steady pointing.

At launch, the orbiter weighed 2223 kilograms, including 118 kilograms of science instruments and 925 kilograms of usable rocket propellant. The overall length from the top of the low-gain antenna to the bottom of the probe measured 5.3 meters; the magnetometer boom extends 11 meters from the center of the spacecraft.

The Galileo Orbiter



Spacecraft Subsystems

The Galileo orbiter is composed of the following major engineering subsystems and science instruments.

Power Subsystem

Galileo uses two radioisotope thermoelectric generators (RTGs) to supply electrical power to run the spacecraft's devices. The radioactive decay of plutonium produces heat that is converted to electricity. The RTGs produced about 570 watts at launch. The power output decreases at the rate of 0.6 watts per month and was 493 watts when Galileo arrived at Jupiter.

Tele-communications

The problem with the high-gain antenna has made it necessary to communicate with Earth—data down and commands up—through a low-gain antenna. Instead of 134 kilobits per second through the 4.8-meter high-gain antenna, up to 160 bits per second will be sent to Earth from Jupiter.

Command and Data Subsystem

The Command and Data Subsystem (CDS) (really the "brain" of Galileo) has several functions. First, it must carry out instructions from the ground to operate the spacecraft and gather science data. Second, some portions of the CDS memory can serve as a storage place for science data. Third, the CDS must package the data for transmission to Earth. Finally, the CDS must be alert for and respond to any problem with any of the spacecraft subsystems.

Commands sent from Earth can be in the form of real-time (do this now) commands or as a sequence, a set of instructions for operating the spacecraft. Sequences are carefully constructed (with input from many scientists and engineers) and thoroughly checked before being radioed to the spacecraft. On Galileo, a sequence may control spacecraft operations for a period of hours to several months, depending upon how busy the period is.

In February of 1995, the capability to write probe data to the CDS memory was added via an inflight loading of new software. Doing so allowed the CDS to serve as a limited backup to the tape recorder for storage of the probe data. In the spring of 1996, data compression methods were added to the CDS software. These methods allow retention of the most interesting and scientifically valuable information, while minimizing or eliminating less valuable data (such as the dark background of space) before transmission. The final crucial function of the CDS is fault-protection activation. Fault-protection algorithms make the spacecraft semi-autonomous and able to act quickly to protect itself. There are occasions in the lives of most spacecraft when emergencies must be handled, and there is no time to wait for answers from the flight team on Earth.

Data Memory Subsystem	Data are either transmitted to Earth as they are gathered (called "real-time data"), or they are stored aboard for future playback. One place data can be stored is Galileo's Data Memory Subsystem (DMS), a four-track tape recorder that holds 900 megabits of data.
Attitude and Articulation Control Subsystem	The Attitude and Articulation Control Subsystem (AACS) is responsible for attitude determination (determining the orientation of the spacecraft in inertial space), attitude propagation (keeping track of the spacecraft orientation between attitude determinations), and attitude control (changing the orientation, instrument pointing, spin rate, or wobble of the spacecraft). Software in the AACS computer carries out the calculations necessary to do these functions. In the spring of 1996, the software was updated to include the ability to compress imaging and plasma wave data down to as little as 1/80th of their original volume.
Propulsion Subsystem	The Propulsion Subsystem consists of the 400-newton main engine and twelve 10-newton thrusters together with propellant, storage and pressurizing tanks, and associated plumbing. The fuel for the system is monomethyl hydrazine, which is burned using nitrogen tetroxide. The Propulsion Subsystem was developed and built by Daimler Benz Aerospace AG (DASA) (formerly Messerschmitt–Bolkow–Blohm) and provided by Germany, the major international partner in Project Galileo. The newton (N) is a unit of force used to measure, among other things, the thrust level of rocket engines. A thrust of 10 N would support a mass of about 1 kilogram (or 2.2 pounds) at the Earth's surface.

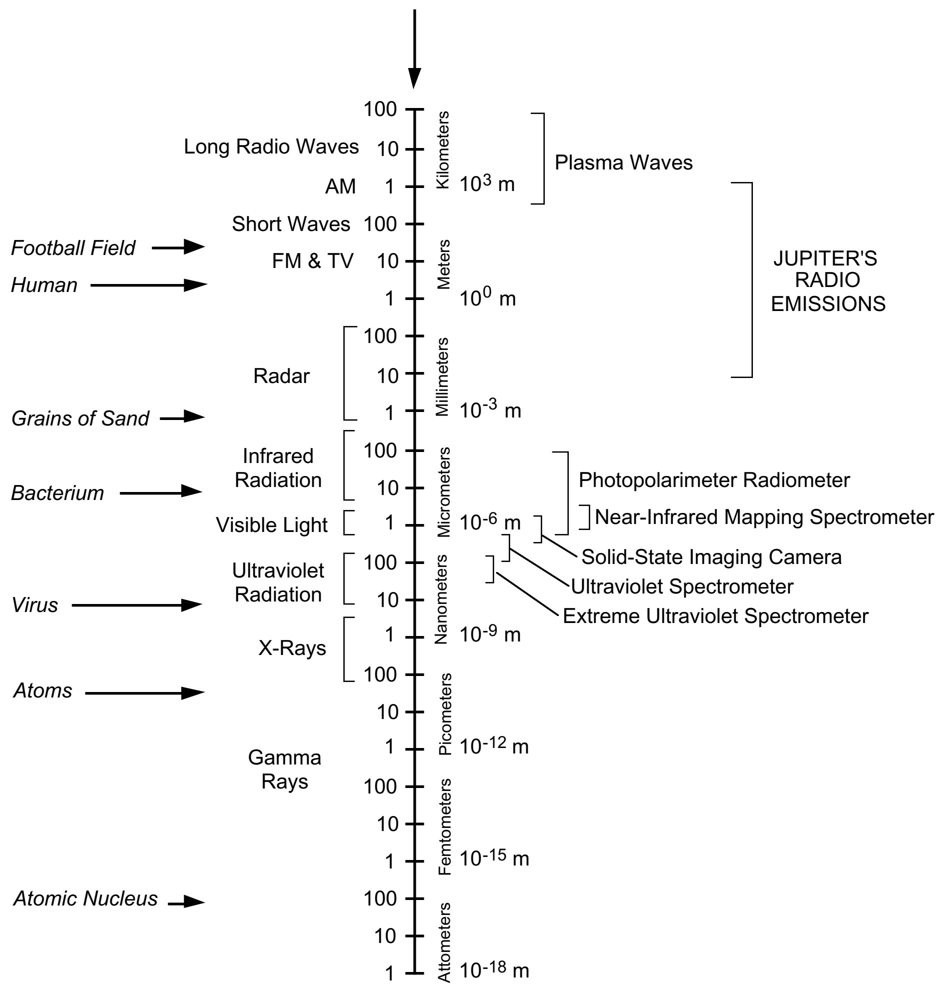
Scientific Investigations

There are 12 scientific experiments aboard the Galileo orbiter. The despun section is home to four remote-sensing instruments. These are mounted on a movable scan platform with their optical axes aligned so that they view a nearly common area. The spun section contains six instruments that investigate particles and magnetic fields. (An adjunct to the ultraviolet spectrometer—the *extreme* ultraviolet spectrometer—is also carried on the spinning section.) The remaining two investigations use the radio system of the orbiter with a special ultrastable oscillator.

Remote-Sensing Instruments

For Jupiter and its moons, the remote-sensing instruments will be acquiring data that may reveal the history of the Jovian system and its present composition and processes. The figure shows the wavelength ranges of the electromagnetic spectrum that these instruments will monitor during both encounters and cruise periods.

The Remote-Sensing Instruments Viewing Range in the Electromagnetic Spectrum



Solid-State Imaging Camera

The scientific objectives of the solid-state imaging (SSI) camera investigations have a wide scope: a study of satellite sciences, a study of the Jovian atmosphere, characterization of Jovian and satellite auroral phenomena, and an assessment of the rings of Jupiter. For the Galilean satellites Io, Europa, Ganymede, and Callisto, the imaging investigators hope to map a large portion of each surface to a resolution of 1 kilometer or better. In a few areas, features smaller than 100 meters will be distinguished. In addition, variations in color and albedo (reflectivity) will be mapped at a scale of about 2 kilometers. Scientists will look for changes on the surfaces over time. It is also planned to measure the shape and the location of the spin axis of each Galilean satellite.

The other smaller satellites will be studied throughout the orbital tour. Studies will also be made of Jupiter's rings. Small, new satellites may be found in or near the rings.

The SSI will be used to determine structure, motions, and radiative properties of the atmosphere of Jupiter. It will measure wind profiles by tracking how fast clouds move at various altitudes. Radiative properties of the atmosphere, which are important for understanding energy management, will be determined by measuring the scattering of light from specific features at various wavelengths and at various angles of illumination. Observations of auroral phenomena will be correlated with fields and particles measurements done with other instruments.

The SSI is an 800- by 800-pixel solid-state camera consisting of an array of silicon sensors called a "charge-coupled device" (CCD). The optical portion of the camera is built as a Cassegrain (reflecting) telescope. Light is collected by the primary mirror and directed to a smaller secondary mirror that channels it through a hole in the center of the primary mirror and onto the CCD. The CCD sensor is shielded from radiation, a particular problem within the harsh Jovian magnetosphere. The shielding is accomplished by means of a 1-centimeter-thick layer of tantalum that surrounds the CCD except, of course, where the light enters the system.

An eight-position filter wheel is used to obtain images of scenes through different filters. The images may then be combined electronically on Earth to produce color images.

The spectral response of the SSI ranges from about 0.4 to 1.1 micrometers. (A micrometer is one millionth of a meter.) Visible light has a wavelength covering the band of 0.4 to 0.7 micrometers.

The SSI weighs 29.7-kilograms and consumes, on average, 15 watts of power.

Near-Infrared Mapping Spectrometer

The near-infrared mapping spectrometer (NIMS) is a pioneering instrument for remote-sensing devices for planetary spacecraft. It combines spectroscopy and imaging in one instrument. The coldest part of the spacecraft is the NIMS radiator at 55 kelvin!

NIMS has two major objectives. The first objective is to look at the surfaces of the satellites of Jupiter to see what they're made of. The second objective is to study the atmosphere of Jupiter to determine such things as the characteristics of the Jovian cloud layers, the variations over time and space of the constituents of the atmosphere, and the temperature versus altitude profile.

For the satellites, the geological structures will be mapped to determine their mineral distributions. Resolutions of 25 kilometers per NIMS pixel or better are planned for the Galilean satellites Europa, Ganymede, and Callisto. NIMS will make distant observations of Jupiter's volcanic moon Io, at resolutions of 120 to 600 kilometers, to determine the moon's surface composition and to measure temperatures of the hot spots. NIMS will monitor Io's volcanic activity in every Galileo orbit. In addition, spectral analyses will be done for some of the smaller satellites and the planet's ring.

Since NIMS measures infrared radiation from the atmosphere of Jupiter, it will contribute to compositional studies, the nature of clouds, motions, and energy balances. NIMS will be able to monitor ammonia, water vapor, phosphine, methane, and germane and to look for previously undetected molecules. Phosphine, which is formed in the deep interior (more than 1000 kilometers deep below the clouds at temperatures near 1000 kelvin) and is rapidly destroyed at observable altitudes, is a tracer of huge upwellings of gas from deep inside the planet. NIMS will map the abundance of phosphine over a wide range of latitudes and longitudes. The goal is to understand the major deep-seated circulation patterns that power the "near-surface" meteorology (planet-girdling cloudy zones, drier belts, and localized cyclonic storm systems such as the Great Red Spot).

The NIMS instrument is sensitive from 0.7 to 5.2 micrometers, overlapping the wavelength range of SSI. The telescope associated with NIMS is all reflective (uses mirrors and no lenses) with an aperture of 229 millimeters. The spectrometer of NIMS uses a grating to disperse the light collected by the telescope. This method is often used by instrument makers rather than use of the familiar prism. The dispersed spectrum of light is focused on detectors of indium antimonide and silicon.

The NIMS weighs 18 kilograms and uses 12 watts of power on average.

Photopolarimeter/ Radiometer

The photopolarimeter/radiometer (PPR) will be used to measure the intensity and polarization of sunlight, in the visible portion of the spectrum, that is reflected from—scattered from—the Jovian satellites and Jupiter. The PPR is in many respects three instruments combined into one: a polarimeter, a photometer, and a radiometer.

The polarimeter detects three spectral bands. Polarization is an important property of light (a fact known to the wearers of some types of sunglasses) and can reveal information about the nature of the object from which the light comes.

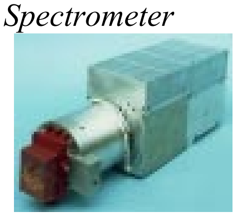
The photometer uses seven narrow spectral bands in the visible and near-infrared wavelengths. The bands in which to make these measurements have been carefully selected. For example, locations are covered where methane and ammonia strongly absorb light.

The PPR has seven radiometry bands. One of these uses no filters and observes all the radiation, both solar and thermal. Another band lets only solar radiation through. The difference between the solar-plus-thermal and the solar-only channels gives the total thermal radiation emitted. The PPR will also measure in five broadband channels that span the spectral range from 17 to 110 micrometers. The radiometer provides data on the temperatures of the Jovian satellites and Jupiter's atmosphere.

The design of the instrument is based on that of an instrument flown on the Pioneer Venus spacecraft. A 10-centimeter-aperture reflecting telescope collects light, directs it to a series of filters, and, from there, measurements are performed by the detectors of the PPR.

The PPR weighs 5.0 kilograms and consumes about 5 watts of power.

Ultraviolet Spectrometer/ Extreme Ultraviolet Spectrometer



The Galileo ultraviolet spectrometer investigation consists of two instruments: the ultraviolet spectrometer (UVS) and the extreme ultraviolet spectrometer (EUV). The UVS works on the wavelengths just shorter than visible light, operating from 113 to 432 nanometers. The EUV is a modified flight spare of the Voyager ultraviolet spectrometer and covers the range of 54 to 128 nanometers.

The UVS/EUV will study properties of Jupiter's atmosphere and aurora, the surfaces and atmospheres of the Galilean satellites, and the doughnut-shaped cloud of ionized plasma in Io's orbit. Absorption and reflectance spectra from the atmospheres of Jupiter and its satellites, characteristic of certain atoms and molecules, will be combined with the study of airglow emissions (emissions that occur because of sunlight and electron impacts).

The reflective properties of satellite surfaces in the ultraviolet help scientists to determine the composition and physical state of the materials that comprise the surface. One can look for ice and frost or deduce the sizes of grains.

Volcanic eruptions on Io are believed to be the source of the Io torus. Temperatures of the sulfur and oxygen ions in this plasma torus can be more than 10 times the temperatures at the surface of the Sun. These ultraviolet observations will help provide a picture of Io’s evolution and its relationship with Jupiter’s magnetic field.

The Cassegrain telescope of the UVS has a 250-millimeter aperture and collects light from the observation target. Both the UVS and EUV instruments use a ruled grating to disperse this light for spectral analysis. This light then passes through an exit slit into photomultiplier tubes that produce pulses or “sprays” of electrons. These electron pulses are counted, and these count numbers are the data that are sent to Earth.

The UVS is mounted on the scan platform and can be pointed to an object in inertial space. The EUV is mounted on the spun section of the spacecraft. As Galileo spins, the EUV observes a narrow ribbon of space perpendicular to the spin axis.

The two instruments combined weigh about 9.7 kilograms and use 5.9 watts of power.

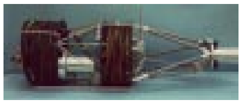
Fields and Particles Instruments

As a set, the fields and particles instruments are designed to study numerous phenomena within the magnetosphere of Jupiter.

Plasma (as in the Io torus) is a very important ingredient of the magnetosphere. The sources of the plasma are being investigated. Which particles come from the ionosphere of Jupiter, which from the solar wind, and which from the satellites?

The plasma interactions with the satellites and particularly the parameters of the Io torus are of interest. The Jovian radiation belts and other structures of the magnetosphere will also be under scrutiny. And it is possible that a plasma wind will be found to flow out from Jupiter at the magnetotail.

Magnetometer



A basic set of measurements for fields and particles science is the determination of the strength and direction of the magnetic field within the magnetosphere.

The magnetometer (MAG) uses two sets of three sensors. The three sensors allow the three orthogonal components of the magnetic field section to be measured. One set is located at the end of the magnetometer boom and, in this position, is about 11 meters from the spin axis of the spacecraft. The second set, designed to detect stronger fields, is 6.7 meters from the spin axis. The boom is used to remove the MAG from the immediate vicinity of the spacecraft to minimize magnetic effects from the spacecraft. However, not all these effects can be eliminated by distancing the instrument. The rotation of the spacecraft is used to separate natural magnetic fields from engineering-induced fields.

Another source of potential error in measurement comes from bending and twisting of the long magnetometer boom. To account for these motions, a calibration coil is mounted rigidly on the spacecraft and puts out a reference magnetic field during calibrations.

The strength of a magnetic field is measured in units of “tesla.” The magnetic field at the surface of the Earth has a strength of about 50,000 nT. (The letter “n” stands for the prefix “nano,” which indicates one thousand millionths of a tesla, or, in scientific notation, 10^{-9} tesla.) At Jupiter, the outboard (11-meter) set of sensors can measure magnetic field strengths in the range from ±32 to ±512 nT while the inboard (6.7-meter) set is active in the range from ±512 to ±16,384 nT.

The MAG experiment weighs 7 kilograms and uses 3.9 watts of power.

Plasma Instrument

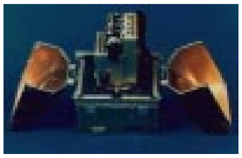
As remarked before, plasma consists of electrically charged particles—ions, which carry a positive charge, and electrons, which carry a negative charge. Usually, the number of ions in a plasma equals the number of electrons, so the plasma as a whole is electrically neutral, but ions and electrons travel different paths within the magnetosphere. The plasma instrument (PLS) measures the energies and directions of approach of ions and electrons comprising the plasma. PLS also uses a mass spectrometer to identify the composition of the ions.

Information from PLS helps determine the temperature of the plasma and the manner in which the particles are distributed in space. This information in turn helps scientists understand particle dynamics in the magnetosphere, for example, where particles are being lost and where particles are being energized.

The PLS uses seven fields of view to collect charged particles for energy and mass analysis. These fields of view cover most angles from 0 to 180 degrees, fanning out from the spin axis. The rotation of the spacecraft carries each field of view through a full circle. The PLS will measure particles in the energy range from 9 volts to 52 kilovolts.

The PLS weighs 13.2 kilograms and uses an average of 10.7 watts of power.

Energetic Particles Detector



The energetic particles detector (EPD) is designed to measure the numbers and energies of ions and electrons whose energies exceed about 20 keV. (An electron volt, eV, is the unit of energy equal to the energy that an electron acquires in falling through an electrical potential of 1 volt.) The EPD can also measure the direction of travel of such particles and, in the case of ions, can determine their composition (whether the ion is oxygen or sulfur, for example).

The EPD uses silicon solid-state detectors and a time-of-flight detector system to measure changes in the energetic particle population at Jupiter as a function of position and time. These measurements will tell us how the particles get their energy and how they are transported through Jupiter's magnetosphere.

The EPD weighs 10.5 kilograms and uses 10.1 watts of power on average.

Plasma Wave Subsystem

Particles of plasma are bound to the magnetic field. Motions within the plasma can perturb the surrounding magnetic and electric fields. Changes with time of the electric and magnetic fields within plasma are called "plasma waves." There are a great many different sorts of waves that affect a plasma or are excited by a plasma. Some of these waves can cause particles to be lost from the magnetosphere. The Plasma Wave Subsystem (PWS) is designed to measure the properties of varying electric fields over the frequency range from 5 hertz to 5.6 megahertz and of varying magnetic fields from 5 hertz to 160 kilohertz—and to identify the plasma waves present.

An electric dipole antenna (a simple antenna of the form that one often sees to improve radio reception on Earth) will study the electric fields of plasmas, while two search coil magnetic antennas will study the magnetic fields. The electric dipole antenna is mounted at the tip of the magnetometer boom. The search coil magnetic antennas are mounted on the high-gain antenna feed. Nearly simultaneous measurements of the electric and magnetic field spectrum will allow electrostatic waves to be distinguished from electromagnetic waves.

The PWS weighs 7.1 kilograms and uses an average of 9.8 watts.

Dust Detector Subsystem

"Dust" is a term used by astronomers to describe small grains of matter found not only in planetary systems but also in interstellar space, often mixed in with interstellar clouds of gas. Dust can be a natural part of the magnetosphere, or it can come from Jupiter, the satellites, or even from external forces like Comet Shoemaker–Levy 9.

The Dust Detector Subsystem (DDS) will be used to measure the mass, electric charge, and velocity of incoming particles. The masses of dust particles that the DDS can detect go from 10^{-16} to 10^{-7} grams. The speed of these small particles can be measured over the range of 1 to 70 kilometers per second. The instrument can measure impact rates from 1 particle per 115 days to 100 particles per second. These particles will help determine dust origin and dynamics within the magnetosphere.

The DDS weighs 4.2 kilograms and uses an average of 5.4 watts of power.

Engineering Experiment

Heavy Ion Counter

The heavy ion counter (HIC) experiment was originally included on the payload as an engineering experiment. It was to measure and monitor very high-energy heavy ions (such as the nuclei of oxygen atoms) hitting the spacecraft.

These measurements would then provide basic information on a form of radiation that can cause random changes in a spacecraft's electronics and perhaps provide the basis for the design of better radiation resistant electronics for future missions. However, HIC data would be useful to scientists as well. For example, the heavy ions observed by the HIC during solar flares have been analyzed to determine the composition of the Sun.

The HIC is really a repackaged and updated version of some parts of the flight spare of the Voyager Cosmic Ray System. The HIC detects heavy ions using stacks of single-crystal silicon wafers. The HIC can measure heavy ions with energies as low as 6 MeV and as high as 200 MeV per nucleon (that would be 6400 MeV for sulfur's mass of 32 nucleons). This range includes all atomic substances between carbon and nickel.

The HIC and the EUV share a communications link and, therefore, must share observing time.

The HIC weighs 8 kilograms and uses an average of 2.8 watts of power.

Radio Science

There are two scientific experiments that use Galileo's radio telecommunications system. "Radio science" has been used for several decades within the space science community to denote experiments conducted in this manner. The two categories of radio science that will be done at Jupiter are celestial mechanics and radio propagation.

Celestial Mechanics

The celestial mechanics experiments use the radio system to sense small changes in the trajectory of the spacecraft. The spacecraft's radio transmitter sends a signal at a well-known stable frequency. Any change in speed that the spacecraft experiences will cause the frequency of the radio signal received on Earth to change. The amount of change is dependent on the change in speed of the spacecraft, relative to Earth. When the spacecraft passes close to Jupiter or one of the Galilean satellites, that body pulls on the spacecraft, causing its speed to change. The amount of change in speed depends not only upon the mass of the body and the distance of the spacecraft from that body but also on how that mass is internally distributed. Thus, by measuring the change in frequency of the Earth-received radio signal, the mass and internal structure of Jupiter or one of the Galilean satellites can be estimated.

The results should allow us to make a better selection of models for the interior of the satellites. This is possible because Galileo will approach the satellites much closer than did any earlier spacecraft, so that gravitational effects will be stronger and easier to observe. Arrival Day data have already confirmed that Io has a giant iron core. (See the Arrival at Jupiter section for more of the latest science news on Io.)

Radio Propagation

The spacecraft radio signal will be used to investigate Jupiter's neutral atmosphere and ionosphere, Io's ionosphere, and to search for ionospheres on the other Galilean satellites (Europa, Ganymede, and Callisto). This is done during radio occultation experiments, when the Galileo orbiter passes behind the planet or satellite as viewed from Earth.

The radio signal propagating from the spacecraft to Earth experiences both refraction and scattering in the atmosphere of the occulting body. (The atmosphere will bend and slow the radio signal by the process of refraction; additionally, the atmosphere will diffuse the electromagnetic waves of the signal by the process of scattering.) This causes changes in the frequency and amplitude of the signal received at a DSN tracking station on Earth. Analysis of these changes will yield information about the atmospheres and ionospheres of the Jovian system.

Anticipated results include profiles of electron number density versus radius in the ionosphere—and profiles of refractive index, pressure, and temperature versus radius in the neutral atmosphere. Of particular importance will be the multiplicity of measurements of Jupiter's ionosphere at a variety of latitudes and magnetic longitudes.

The 18-month tour of the Jovian system includes 8 occultations of the Earth by Jupiter and more than 10 occultations of the Earth by the four Galilean satellites.

Principal Investigators for the Orbiter's Scientific Experiments

Instrument	Investigator/ Team Leader	Objectives
Remote Sensing (despun)		
SSI	Michael Belton, National Optical Astronomy Observatories	Galilean satellites, high resolution, atmospheric small-scale dynamics
NIMS	Robert Carlson, Jet Propulsion Laboratory	Surface/atmospheric composition thermal mapping
PPR	James Hansen, Goddard Institute for Space Studies	Atmospheric particles, thermal/reflected radiation
UVS/EUV	Charles Hord, University of Colorado	Atmospheric gases, aerosols, etc.
Fields and Particles (Spinning)		
MAG	Margaret Kivelson, University of California, Los Angeles	Strength and fluctuations of magnetic fields
EPD	Donald Williams, Johns Hopkins Applied Physics Laboratory	Electrons, protons, heavy ions
PLS	Lou Frank, University of Iowa	Composition, energy, distribution of ions
PWS	Donald Gurnett, University of Iowa	Electromagnetic waves and wave particle interactions
DDS	Eberhard Grün, Max Planck Institut für Kernphysik	Mass, velocity, charge of submicrometer particles
Engineering Experiment		
HIC	Edward Stone, California Institute of Technology	Spacecraft charged-particle environment
Radio Science		
Celestial Mechanics	John Anderson, Jet Propulsion Laboratory	Masses and internal structures of bodies from s/c tracking
Propagation	H. Taylor Howard, Stanford University	Satellite radii and atmospheric structure from radio propagation