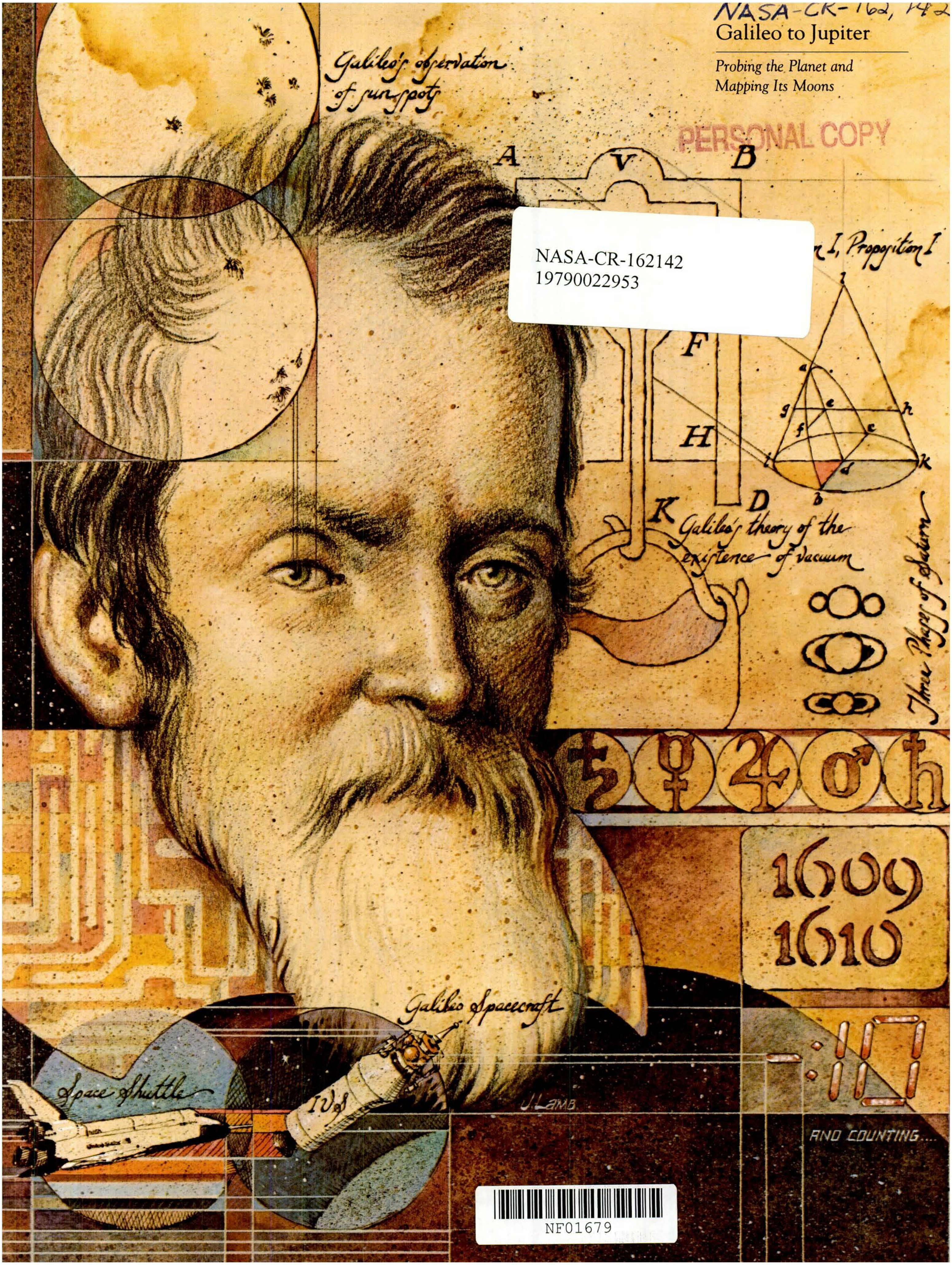
NASA-CR-162,142

Galileo to Jupiter

Probing the Planet and Mapping Its Moons



"On the seventh day of January in this present year 1610, at the first hour of night, when I was viewing the heavenly bodies with a spyglass, Jupiter presented itself to me; and because I had prepared a very excellent instrument for myself, I perceived (as I had not before, on account of the weakness of my previous instrument) that beside the planet there were three starlets, small indeed, but very bright."

Galileo Galilei was a pioneer of his time not only in science but also in scientific notation—for he documented his observations in Italian, rather than in Latin. This quotation is an English translation of Galileo's notes shown below.

Adi 7. di Gennaio 1610 Giove si vedeva col Cannone con 3. stelle fisse cosi . delle quali senza il cannone niuna si vedeva. à di 8. appariva cosi era dunque diretto et non retrogrado come pongono i calculatori.
Adi 9. si nugolò. à di 10. si vedeva cosi ciò è congiunto con la più occidentale si che la occultava quanto si può credere.
Adi 11. era in questa guisa et la stella più vicina à Giove era la metà minore dell'altra, et vicinissima all'altra dove che le altre sere erano le dette stelle apparite tutte tre di egual grandezza et trà di loro egualmente lontane; dal che appare intorno à Giove esser 3. altre stelle erranti invisibili ad ogn'uno sino à questo tempo.
Adi 12. si vedde in tale costituzione . era la stella occidentale poco minor della orientale, et Giove era in mezo lontano da l'una et dall'altra quanto il suo diametro in circa: et forse era una terza piccolissima et vicinissima à Giove verso oriente

The Man

On January 7, 1610 in Padua, Italy, Galileo Galilei happened to aim his newly developed spyglass at the planet Jupiter and discovered previously unknown worlds.

Galileo thought he was simply observing fixed stars, but their position aroused his curiosity; they lay in a straight line with Jupiter, two to the east and one to the west. For Galileo, that night was the beginning of what would be a long series of observations of these curious objects.

The next night, "led by what, I do not know," Galileo looked at the stars again. They were still visible, but to his amazement, they had changed position. Now all three stars were in a straight line on the west side of Jupiter. Galileo could not understand how the planet could have moved east of these stars when, the night before, it had been west of two of them. He feared that astronomers had miscalculated Jupiter's movement.

Galileo could hardly wait for the next night, but he was destined for disappointment, ". . . for the sky was covered with clouds in every direction." He had to wait another night.

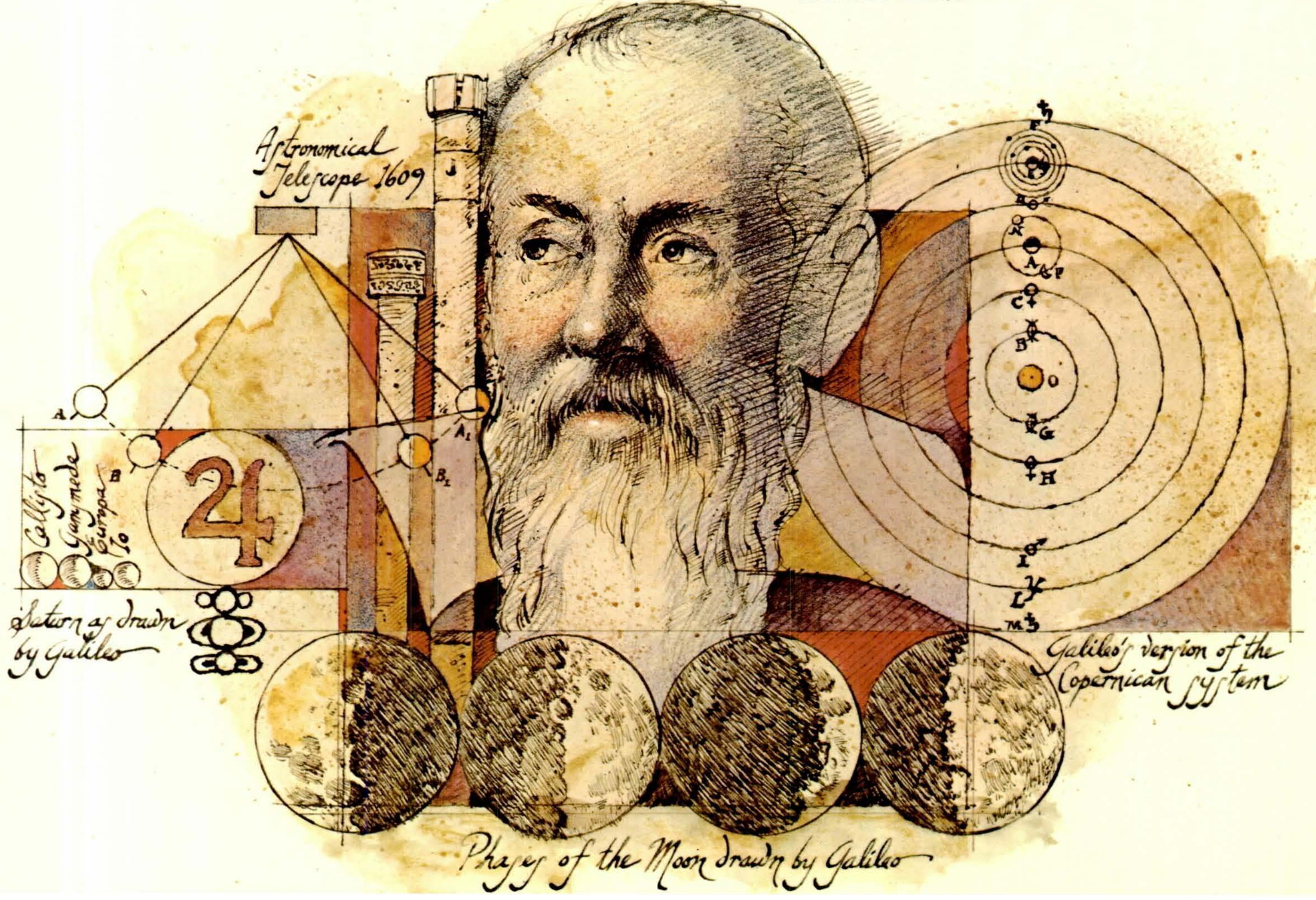
On January 10, Galileo could find only two of the stars, both on the east side of Jupiter. The third, he assumed, was hidden behind Jupiter. Galileo realized that the planet's movement could not possibly be so erratic. He decided at last that, contrary to everything he knew, the stars themselves must be moving.

On January 11, Galileo again saw only two stars, both on the east side of the planet. But the next night a new, extremely small star which Galileo was certain he had not seen before joined the others; two were on the east and one was on the west. Then on January 13, the fourth star, missing since January 8, reappeared; one star was on the east side of Jupiter and three were on the west. Two nights later, all four stars were on the west.

Galileo now realized that these stars were actually tiny planets, later called satellites, revolving around Jupiter. For the first time in history, man had seen the moons of a planet other than our Earth.

Galileo continued his observations through February. On March 10, he announced his discovery in the *Starry Messenger.* It created a sensation, spurring interest in astronomy as a science and providing support to the Copernican theory that the planets orbit the Sun.

The "stars" that Galileo saw are the four largest moons of Jupiter, now known as the Galilean satellites in honor of their discoverer. The satellites are named Io, Europa, Ganymede, and Callisto after four of Jupiter's lovers in Greek mythology. These are the satellites that will be closely investigated during the Galileo mission—a fitting tribute to the man.



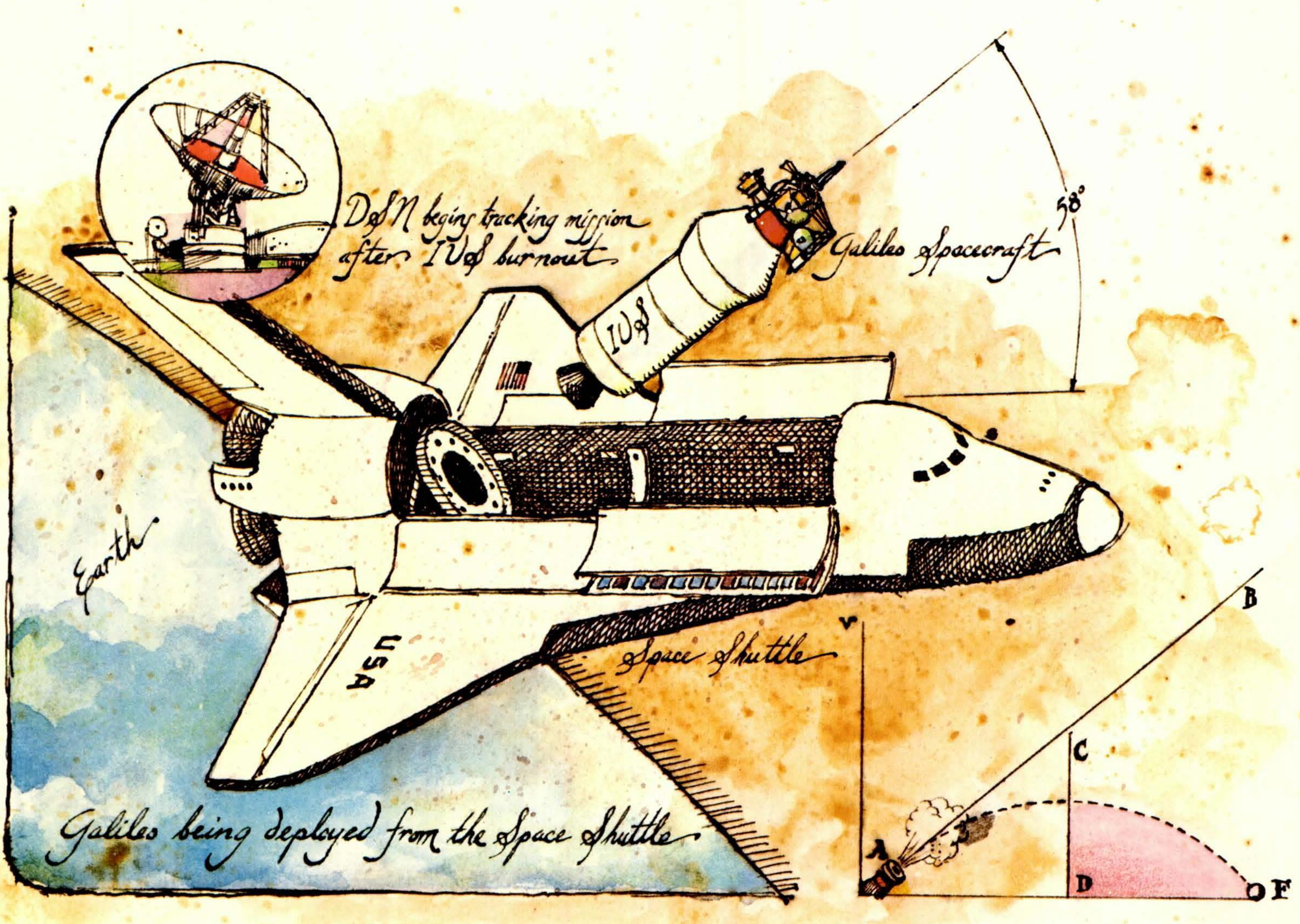
The Mission

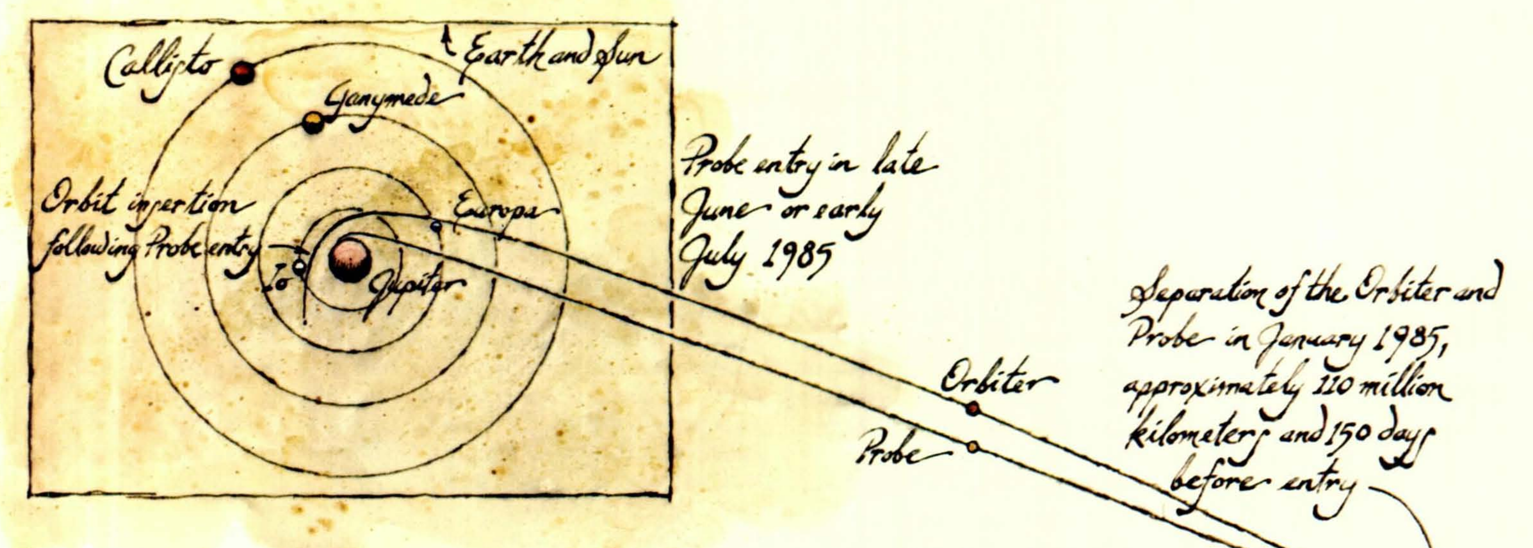
Twelve generations after Galileo Galilei looked through his telescope and discovered Jupiter's four largest satellites, Project Galileo will orbit a spacecraft around Jupiter and send a probe deep into Jupiter's atmosphere. The Galileo spacecraft will consist of an orbiter and an attached atmospheric entry probe. Project Galileo will make use of the best Jupiter launch opportunity during the remainder of this century to send a large amount of scientific equipment to Jupiter. The purpose of the mission is to seek important information about the origin and evolution of the solar system. Jupiter's primitive atmosphere is believed to be a sample of the original material from which stars are formed, still unmodified by nuclear process. Therefore, scientists are confident that the Jovian system—Jupiter and its satellites—will reveal important new insights into large-scale planetary phenomena which relate to our understanding of the evolution of the Sun's planets, including Earth.

Galileo is a project sponsored by the National Aeronautics and Space Administration. The Jet Propulsion Laboratory, Pasadena, California, has been assigned overall project management responsibility and, in addition, has responsibility for the Orbiter, mission design, and mission operations. NASA's Ames Research Center, Mountain View, California, is responsible for the Atmospheric Entry Probe built by Hughes Aircraft Company, El Segundo, California. The radioisotope power sources for the Orbiter are provided by the Department of Energy through the General Electric Company, Valley Forge, Pennsylvania.

Project Galileo is the first planetary mission to include major participation by another country; under sponsorship of the Bundesministerium für Forschung und Technologie (BMFT), the Federal Republic of Germany will design and produce a portion of the scientific instrumentation and the Orbiter's retropropulsion module (RPM). The RPM is built by Messerschmitt-Bölkow-Blohm GmbH.

NASA's Johnson Space Flight Center, Houston, Texas, and the Marshall Space Flight Center, Huntsville, Alabama, are responsible for the Space Shuttle transportation system and the





Inertial Upper Stage (IUS) that will be used to deploy Galileo.

Project Galileo is the first mission to use the new Space Shuttle as an interplanetary launch vehicle. The Shuttle, carrying the IUS and spacecraft, will be launched from NASA's Kennedy Space Center, Florida, in January 1982. When the Shuttle reaches Earth orbit, the crew will prepare Galileo for release. The IUS with the spacecraft attached to its forward end will be released from the Shuttle and aligned for the first of its rocket motor firings. Three motors will fire in sequence to send the Galileo spacecraft speeding from Earth orbit on a trajectory toward the planet Mars, beginning Galileo's 1000-day journey to Jupiter.

The spacecraft is aimed toward Mars to use the free gravitational pull of the Red Planet. This technique is known as gravity assist. Although previous spacecraft have used the gravity of Venus and Jupiter to gain velocity, Galileo will be the first spacecraft to use the gravity of Mars. Galileo will reach Mars in a little over three months. Newly developed techniques will be used to navigate Galileo at a speed of 58,600 kilometers per hour to within 275 kilometers above the surface of Mars. This course will give Galileo the needed force to bend its trajectory and send it on its way to Jupiter.

A long interplanetary cruise follows, during which Galileo will travel through the asteroid belt; however, the spacecraft will pass no closer than a few million kilometers to any of the catalogued asteroids. Arrival at Jupiter is scheduled for late June or early July 1985, three and one-half years after launch.

About 150 days before Galileo reaches Jupiter, an important operation takes place: the Probe must be separated from the Orbiter. The path of the spacecraft has been carefully controlled so that the Probe can be aimed at a specific region of Jupiter for arrival at an exact time. Moreover, the Probe must enter the atmosphere at a precise shallow angle. If it were to plunge in steeply, the deceleration and atmospheric heating would be so severe that the Probe would burn up like a meteor. Conversely, if the entry were at too shallow an angle, the Probe would ricochet off the top of the atmosphere, skipping back into space. The Probe has to be accurately aimed when it leaves the Orbiter because, once it has separated, its path cannot be changed. The Probe, which does not have an active attitude control system, spins at 5 revolutions per minute to maintain a stable attitude.

Jupiter and its largest satellite, Ganymede

After the Probe has separated from the Orbiter, the Orbiter's path must be changed so that it does not enter Jupiter's atmosphere. The Orbiter's large rocket motor ignites for the first time and puts the spacecraft on a new trajectory carrying it to the afternoon side of the planet. There it will be able to observe the entry of the Probe and receive data from it by radio. These data will be retransmitted immediately to Earth and also stored on magnetic tape within the Orbiter, to be replayed later if necessary.

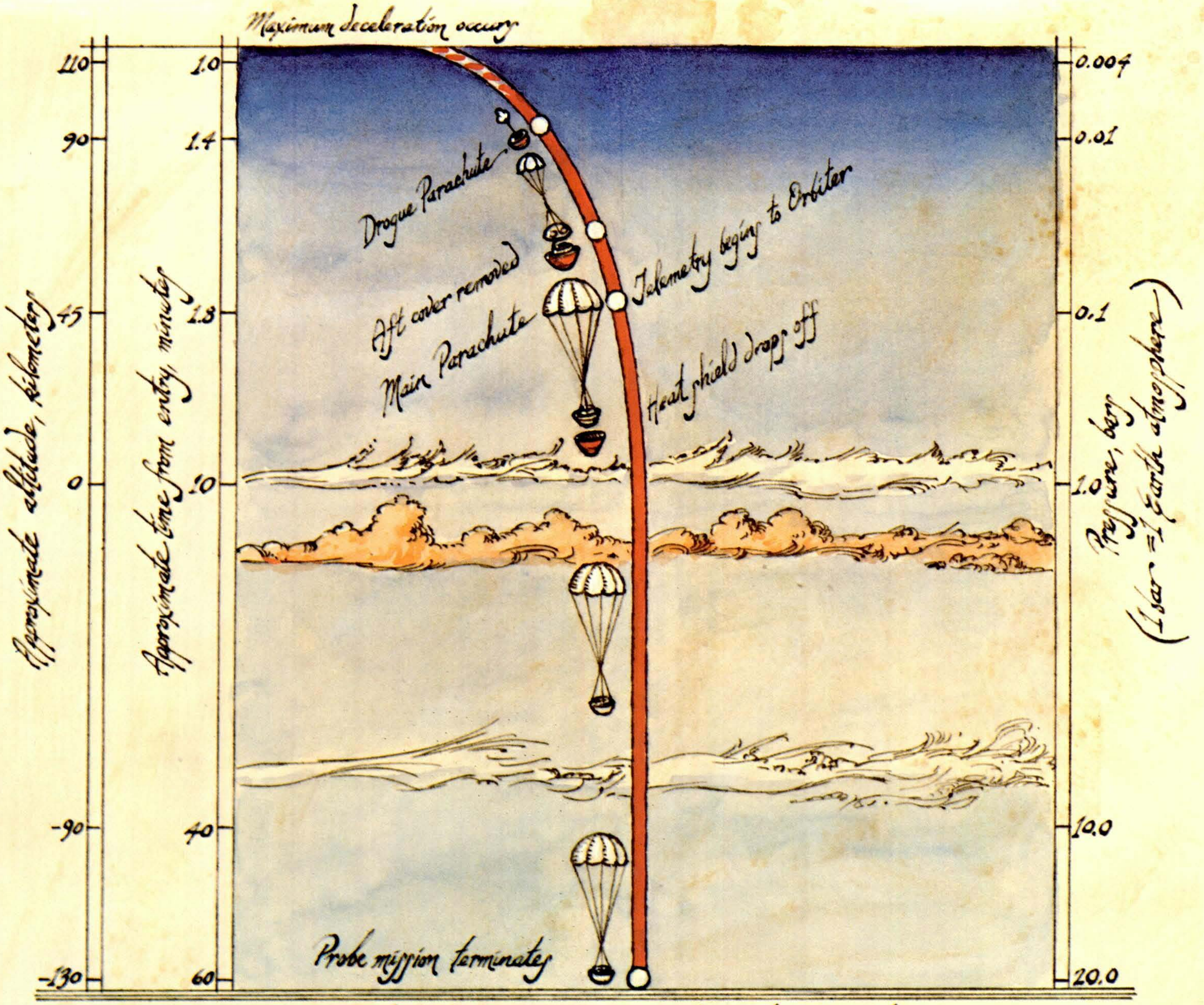
Jupiter's satellite Io and the shadow of Ganymede

The target entry point for the Probe will be selected within Jupiter's light-colored equatorial zone, between 1.0 and 5.5 degrees north or south latitude. Scientists believe that the topmost clouds there consist of ammonia. By entering through the highest cloud region, the Probe will be able to make diagnostic measurements of all the important cloud layers. The time at entry will be late afternoon on Jupiter.

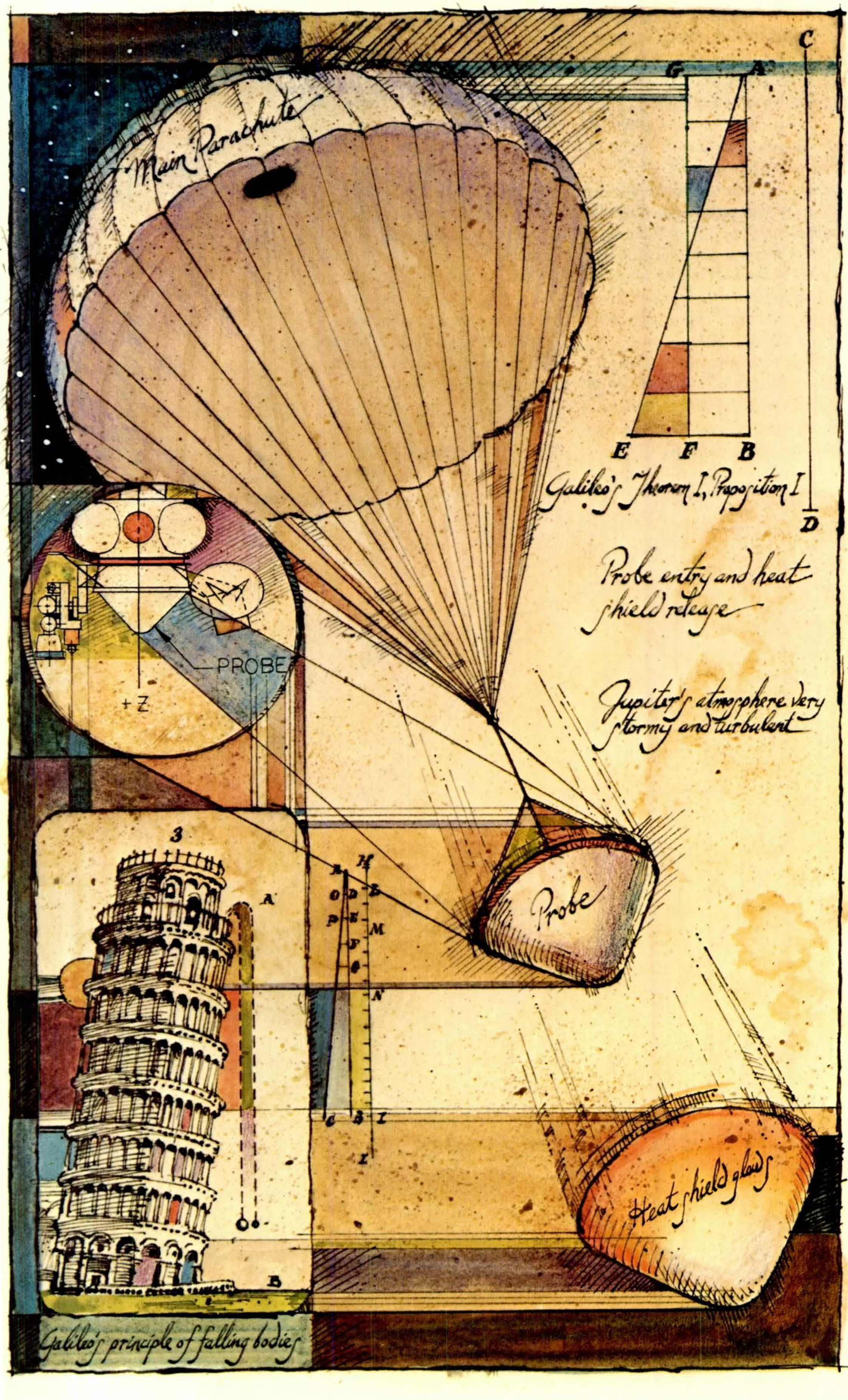
The sequence of operations of the Probe itself is straightforward. It is hurtling toward Jupiter at a speed of 48.2 kilometers per second (a speed of more than 100,000 miles per hour). As it enters the atmosphere, there is a rapid deceleration. The Probe slows down at a rate so rapid that it experiences a force almost 400 times that of Earth's gravity. The Probe's protective heat shield glows brightly with the fierce heat generated by the encounter with the atmosphere. But within a few seconds the worst conditions have passed; the Probe has slowed to a speed at which a parachute opens, the heat shield is jettisoned, and the descent module containing the science instruments descends more slowly into the atmosphere. Having performed its atmospheric entry protection function, the heat shield falls free into the ever thickening atmosphere below.

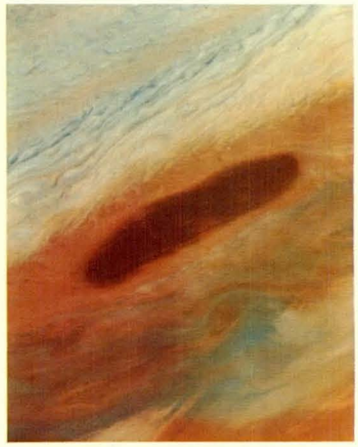
As the Probe drifts down, spinning on its parachute at 5 revolutions per minute, it transmits scientific measurements to the Orbiter, hurtling high above the atmosphere. The Probe is expected to send its data for about 60 minutes. Forty minutes after entry, the Probe will have penetrated to a depth in the atmosphere where the pressure is approximately 10 times the pressure at sea level on Earth. This is believed to be below the lowest water cloud layers. At this point, the temperature is about 73°C. By 60 minutes, the Probe will have penetrated to a depth where the atmospheric pressure is 15 to 20 times that at sea level on Earth. Below this level, the Probe is not expected to survive—silenced by a combination of increasing temperature and weakening radio signals.

Immediately after the Probe's mission is completed, the Orbiter will burn its large rocket motor for almost 50 minutes to enter into an elongated elliptical orbit around Jupiter. Either before the Probe entry period or immediately after the orbit insertion rocket firing, the Orbiter will fly by the innermost Galilean satellite, Io. As the Orbiter flies by Io, it will study the satellite and use its gravity to reduce the amount of fuel required for the spacecraft to go into orbit. The Orbiter will move outward



Probe Entry and Descent Into Jupiter's Atmosphere





Large brown oval in Jupiter's clouds which may be an opening to lower cloud layers from Jupiter's cloud tops from a distance of about 320,000 kilometers to a distance of about 19.5 million kilometers. It travels along this path for 100 days and, when it attains its greatest distance from Jupiter, the Orbiter fires its large rocket motor for the third and final time. This raises the closest point of its orbit to 900,000 kilometers from Jupiter's cloud tops. The Orbiter will then use the gravity of the Galilean satellites to "tour" the Jovian system; using the same navigation techniques as the Mars flyby, Galileo will fly close to one of the large satellites on each revolution around the planet. The timing and positioning of the encounters are selected to change the spacecraft's orbit about Jupiter, enabling future encounters to be made with a minimum expenditure of rocket propellant.

The surfaces of the Galilean satellites will be scrutinized. Some encounters will be so close—within one-tenth the radius of the satellites—that details as small at 30 to 50 meters will be recognizable. This is between 10 and 100 times more detail than that seen by the Voyager spacecraft. The adaptability of the mission also permits Galileo to inspect the polar regions of the satellites. The Orbiter will circle Jupiter at least 11 times, encountering a Galilean satellite on each orbit.

The orbital tour part of the mission will take 20 months. If the spacecraft survives for this period, as is expected, an extended mission could then look at the dawn regions of Jupiter and continue to study the satellites or explore the general environment of the planet far above and below its equator.

Because Galileo will orbit Jupiter for an extended period of time, it will provide information that could not be obtained by earlier spacecraft such as Pioneers 10 and 11 and Voyagers 1 and 2, which were designed for single rapid flybys.

Project Galileo will be

☆ The first mission to send an entry probe into the atmosphere of an outer planet.

☆ The first mission to send an orbiter around an outer planet.

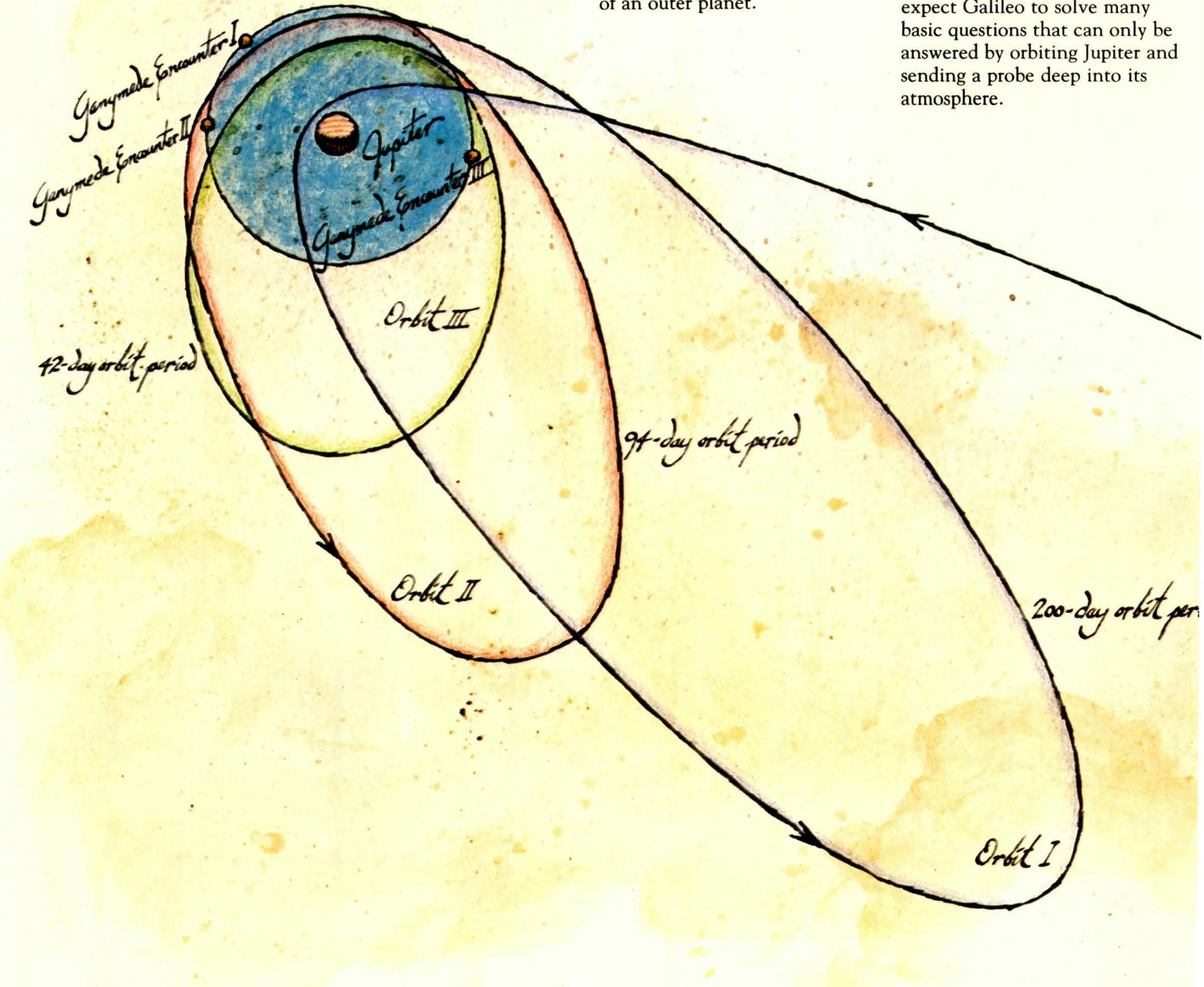
☆ The first mission to use the gravity assist of the Galilean satellites to navigate the Jovian system.

☆ The first mission to use the Space Shuttle and Inertial Upper Stage to deploy a planetary spacecraft.

☆ The first mission to use a dual-spin spacecraft for an outer planet mission.

☆ The first mission to use the gravity-assist technique at Mars.

Following the reconnaissance conducted by Pioneers 10 and 11 and the exploration by the two Voyager flyby spacecraft, Project Galileo is the next step in the exploration of Jupiter. Scientists expect Galileo to solve many basic questions that can only be answered by orbiting Jupiter and sending a probe deep into its atmosphere.

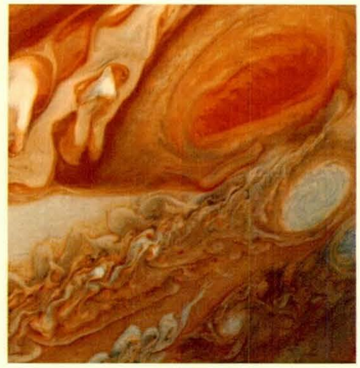


The Planet

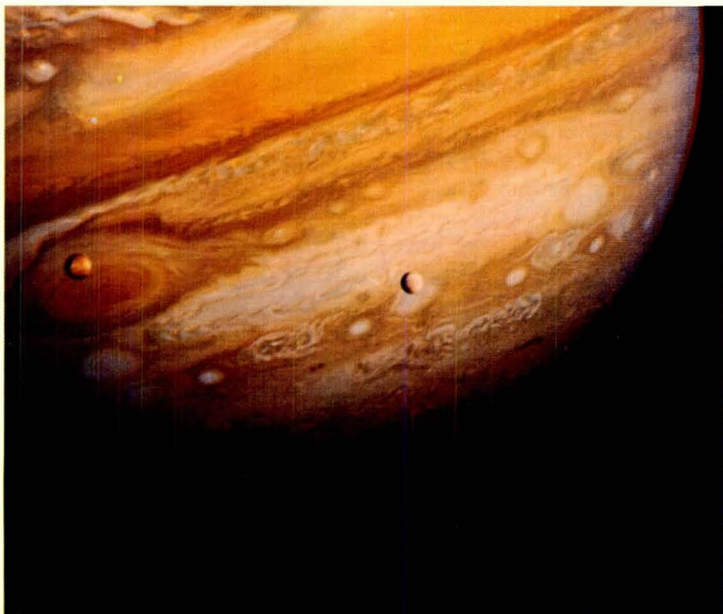
More than one-half billion kilometers beyond Earth's orbit, the giant planet Jupiter dominates the outer solar system; except for the Sun, Jupiter contains two-thirds of all the matter in the entire system.

Although Jupiter never became as hot as a star and never ignited internal nuclear fires, it does have its own internal heat source. Groundbased observations and measurements made by instruments on board the Pioneer spacecraft indicate that Jupiter emits into space about twice as much heat as it receives from the Sun. Some scientists believe that this heat is "fossil heat," left over from the formation of the planet and now leaking out of the deep interior.

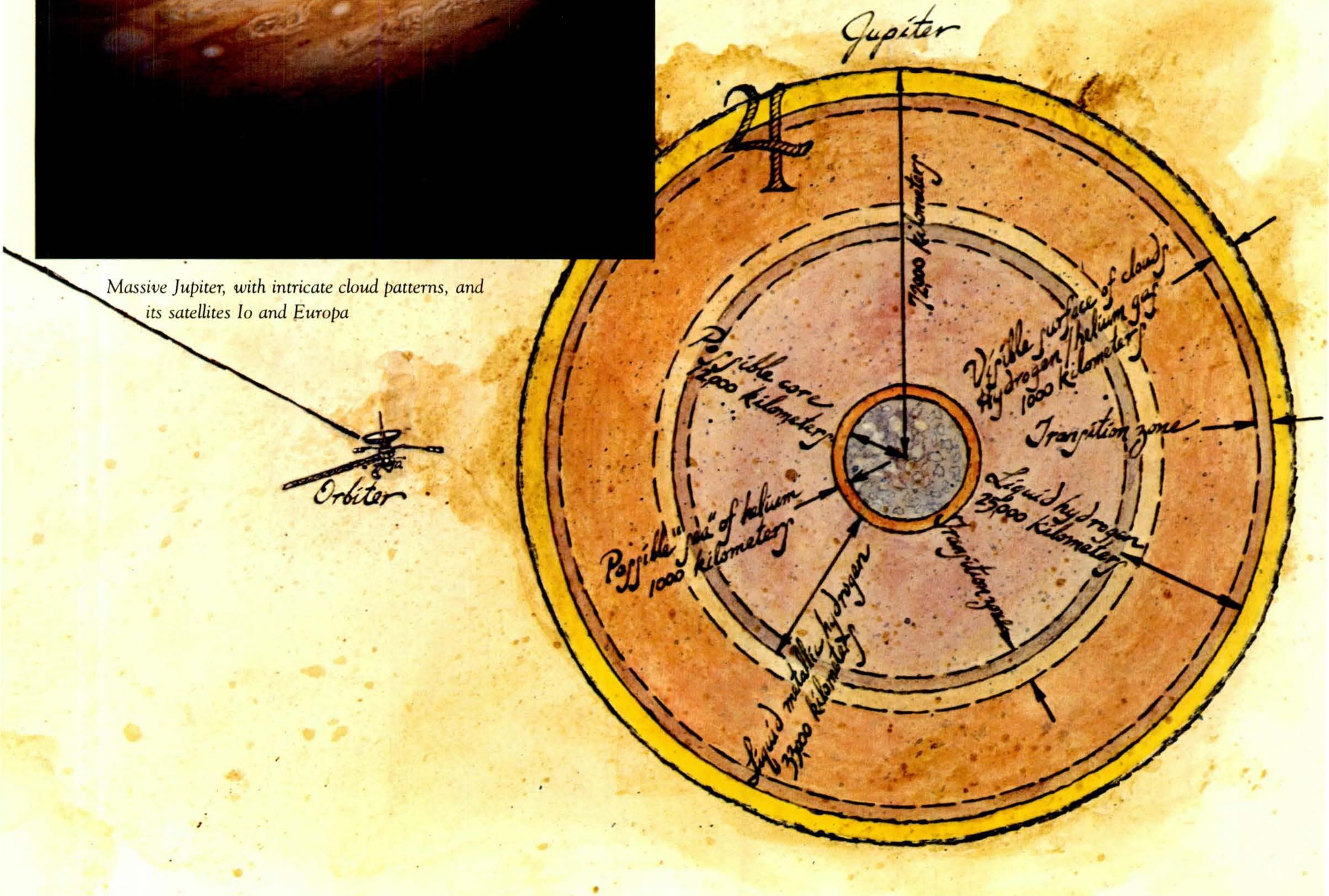
Jupiter differs significantly from Earth. Jupiter is a great, rapidly spinning ball composed primarily of hydrogen and helium, which scientists think represent the basic materials from which the Sun and all the planets were formed. Although its diameter is 11 times that of Earth, Jupiter spins very quickly, making one rotation on its axis in just under 10 hours. While Earth consists of rocky materials with a core of iron-rich matter, Jupiter is a planet of liquefied light gases with perhaps a small rocky core. (Small on Jupiter's scale, that is! The core could contain as much material as 10 to 100 Earths.)



Jupiter's Great Red Spot and turbulent clouds nearby



Massive Jupiter, with intricate cloud patterns, and its satellites Io and Europa



The Satellites

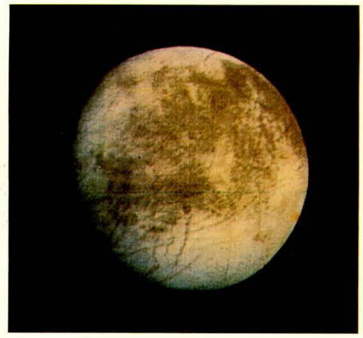
Jupiter's 13 known satellites that make the Jovian system resemble a small solar system fall into three distinct groups. An outer group of small satellites moving in unusual orbits possibly consists of captured asteroids. They are known as irregular satellites because their orbits are tilted at high inclinations to the equator

4-image mosaic of Io

of Jupiter, and the satellites move around Jupiter in the direction opposite to the planets' movement around the Sun.

Another group closer to Jupiter also consists of small satellites, possibly captured asteroids as well, that move around Jupiter in the same direction the planets move around the Sun. These satellites are also irregular because their orbits are tilted at high inclinations to the equator of Jupiter.

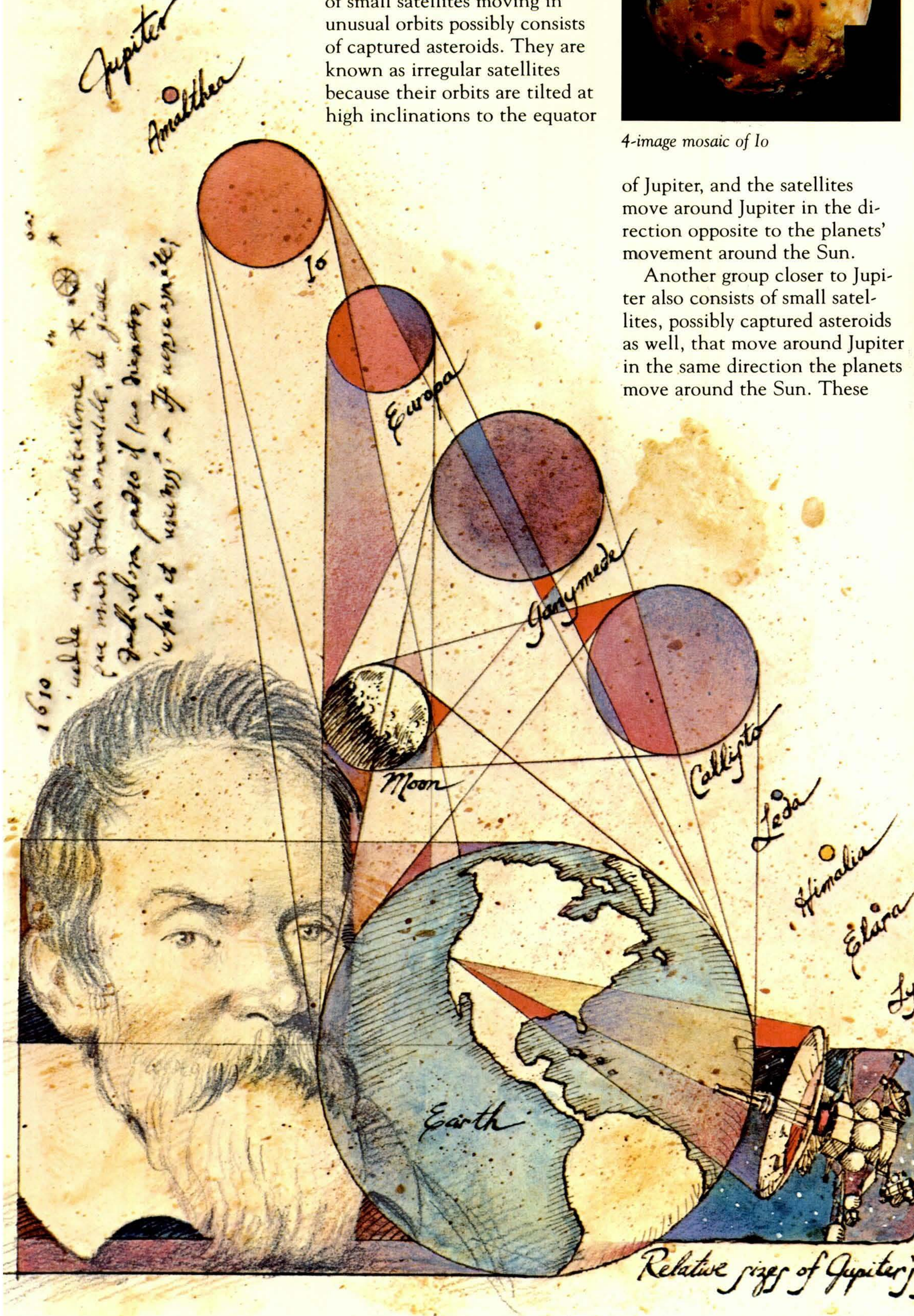
The innermost group consists of the small satellite Amalthea orbiting closest to Jupiter and the four large satellites discovered by Galileo. All five innermost satellites move in regular, almost circular orbits close to the plane of Jupiter's equator in the same direction the planets move around the Sun. But the Galilean satellites—Io, Europa,



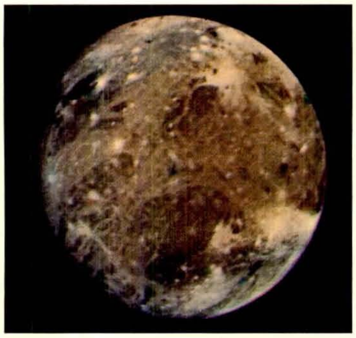
Europa

Ganymede, and Callisto—are by far the most interesting of Jupiter's 13 known satellites. These large satellites range in size from slightly smaller than Earth's Moon to slightly larger than the planet Mercury.

More is known about Jupiter's Galilean satellites than about any other satellites of the outer planets. They are large enough to appear as measurable discs from Earth and were photographed by the Voyager spacecraft that flew by Jupiter in 1979.



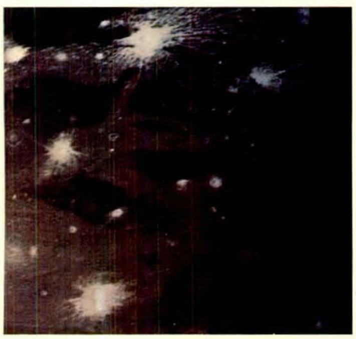
The satellites show a wide variety of basic characteristics and surface appearances. Water and other volatiles have apparently played a major role in the evolution of Jupiter's satellites. Europa, Ganymede, and Callisto all show evidence of water frost



Ganymede

on their surfaces, and Ganymede and Callisto are believed to be composed of up to 50 percent water, mixed with rocky material.

Io is the most geologically active planet yet observed in the solar system, with more than half a dozen active volcanos observed erupting during Voyager 1's flyby. Europa's frosty surface is covered with huge fracture-like patterns. Ganymede has a surface cratered like our Moon, but shows fractures and faults suggesting that its surface was once a mobile, geologically active place, possibly displaying



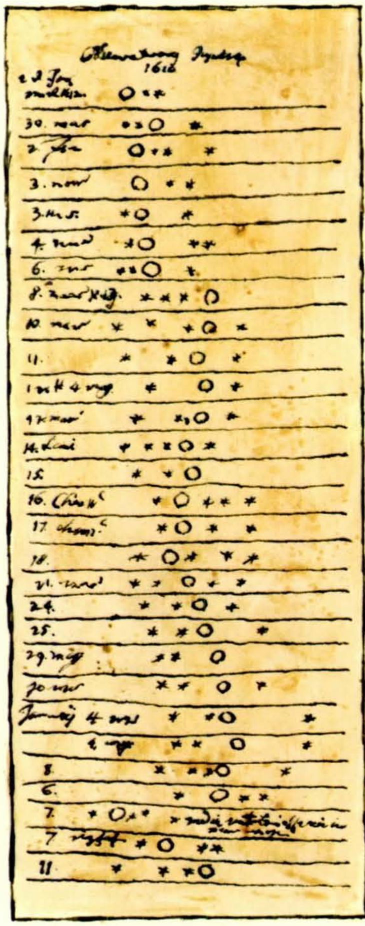
Icy impact craters on Ganymede

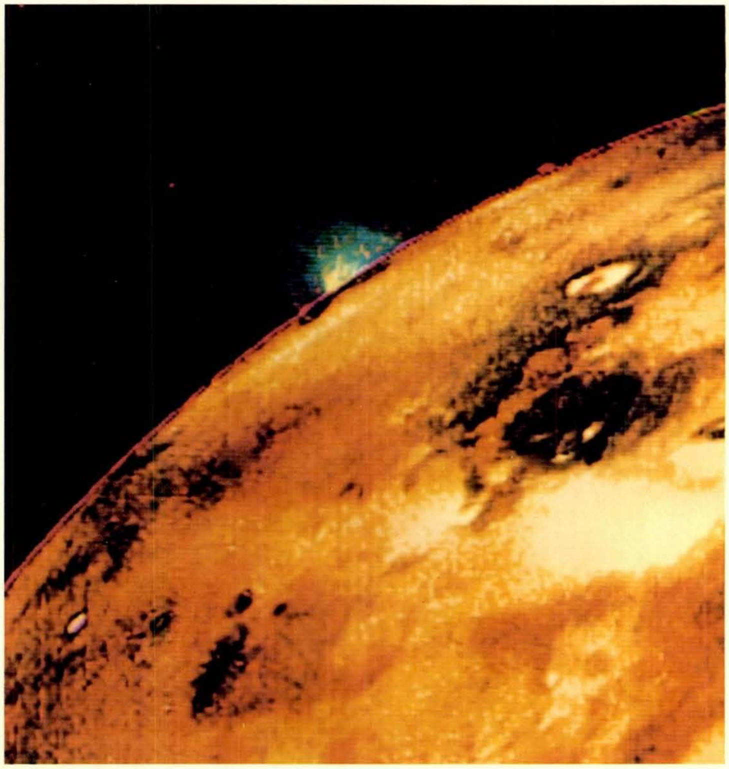
features similar to terrestrial plate tectonics. Callisto shows the oldest surface of the Galilean satellites, with a dense crater population suggesting that its surface has remained intact since the final stages of accre-

Callisto

tion over 4 billion years ago. Remains of huge basin-like structures may record asteroidal scale impacts which came close to breaking through Callisto's early icy crust.

In addition to the large satel-





Volcanic eruption on Io

lites, Voyager observed tiny elongated Amalthea (about the size of the state of California) and discovered a faint ring inside Amalthea's orbit, making Jupiter the third planet (the others being Saturn and Uranus) with a narrow ring system.

In-depth studies cannot be done during the short period of observation available in single flyby missions of the Pioneer or Voyager type. However, the Orbiter will repeatedly fly by the Galilean satellites, closely observing them from various angles. The Orbiter will inspect their surfaces, measure their magnetic and gravitational fields, study their atmospheres and ionospheres, and find out precisely how the satellites interact with the magnetosphere, where protons, heavy ions, and electrons pulsate wildly.

January, 1610
Notebook entries of Galileo reporting his observations of Jupiter and several of its satellites

The Magnetosphere

Except for the Sun, Jupiter is the strongest source of radio signals in our sky. When astronomers first detected these radio signals from Jupiter in 1955, they were certain that the planet must have a magnetic field and trapped charged particles that generated the radio waves. This region occupied by the magnetic field and particles is called a magnetosphere. In 1973, the first spacecraft to fly by Jupiter, Pioneer 10, provided our first closeup view of Jupiter's magnetosphere. Pioneer 10 revealed the dynamic and very complex nature of the Jovian magnetosphere, but provided only limited understanding of its behavior. Pioneer 11 and Voyagers 1 and 2 provided additional information. Galileo will make comprehensive observations for at least 20 months, showing how this dynamic magnetosphere changes.

The magnetic field of Jupiter is approximately 20 to 30 times stronger than the magnetic field of Earth. Because of its strong magnetic field and large distance from the Sun, Jupiter's magnetosphere is considerably larger than Earth's magnetosphere. If we could see the Jovian magnetosphere from our Earth, it would appear close to the size of the Moon in the sky, despite our great distance from Jupiter.

Jupiter's magnetosphere has three distinct regions: an inner region, a middle region, and an outer region. The inner region is doughnut-shaped, with the planet in the hole of the doughnut. It is similar to Earth's magnetosphere but more intense, containing several shells where protons and electrons of enormous energies concentrate. These shells are similar to the Earth's Van Allen radiation belts. Jupiter's small innermost satellite, Amalthea, and three large satellites—Io, Europa, and Ganymede—travel through the inner region.

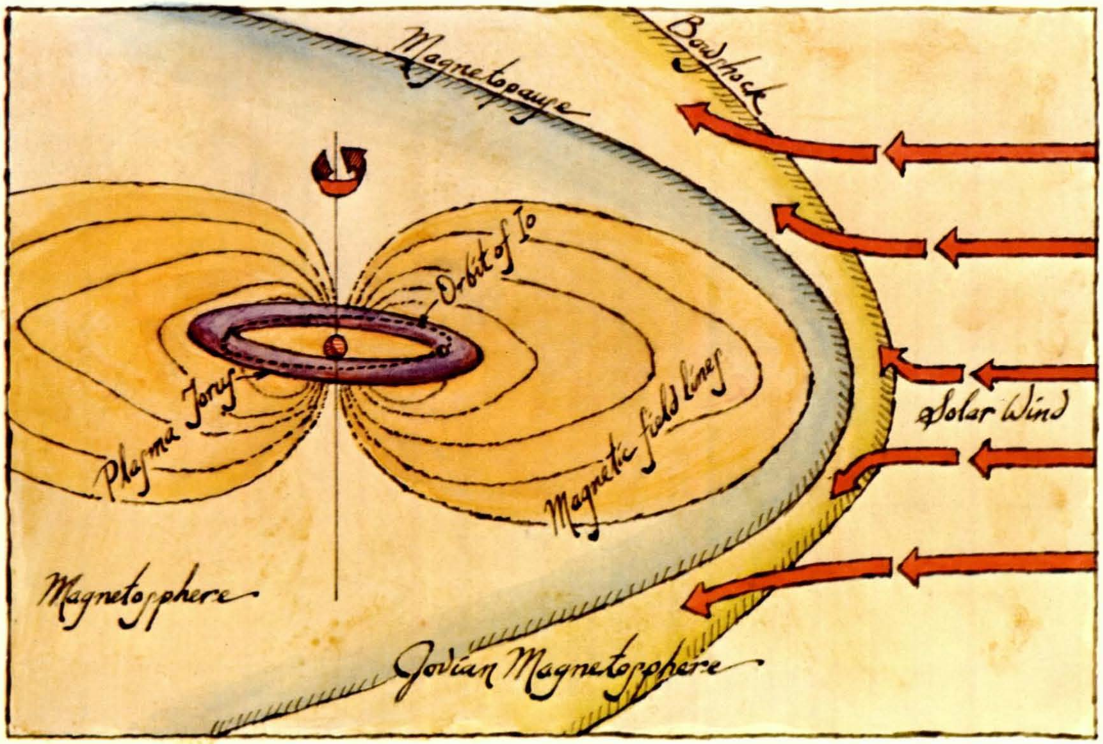
The middle region of the magnetosphere does not have a counterpart around Earth. It consists of a sheath of electrically charged particles being whirled around rapidly by the rotation of Jupiter's magnetic field. These particles strongly distort the intrinsic magnetic field of Jupiter.

The outer region is the transition zone between the middle region of the magnetosphere and the solar wind, where a blizzard of electrons and protons streams across space from the Sun. The solar wind interacts with the magnetic field of Jupiter, often forcing the Jovian field back toward the planet, squeezing the magnetosphere as though it were a great air-filled bag. Leaks develop, from which high-energy particles "squirt" across the solar system. Some of these particles have been detected at Earth and at Mercury by orbiting and interplanetary spacecraft.

The energetic particles in Jupiter's magnetosphere appear to have several sources. Some originate from the planet's ionosphere; others appear to be injected into the magnetosphere from the surface of the satellites. Io, in particular, is believed to interact with the Jovian magnetic field to produce energetic electrons, while volcanic activity and bombardment of Io's surface with energetic particles are believed to be responsible for releasing sodium, potassium, and sulfur ions into the magnetosphere. These atoms and ions form neutral clouds around Io and a doughnut-shaped torus of ions circling Jupiter in the plane of the magnetic equator.

Investigations of this complex region of plasma where ionized gas consists wholly of charged particles are important in understanding not only the magnetosphere of Earth but plasmas in general. Since most of the intensely energetic processes of the universe take place in plasmas, their study is important to future energy research, particularly in fusion power. The dynamic magnetosphere of Jupiter provides us with a laboratory for the study of astrophysics.

Galileo will provide even further understanding of this strange environment, with instruments to measure magnetic fields, detect the various particles, and find out how the particles interact with the satellites and the magnetic fields.



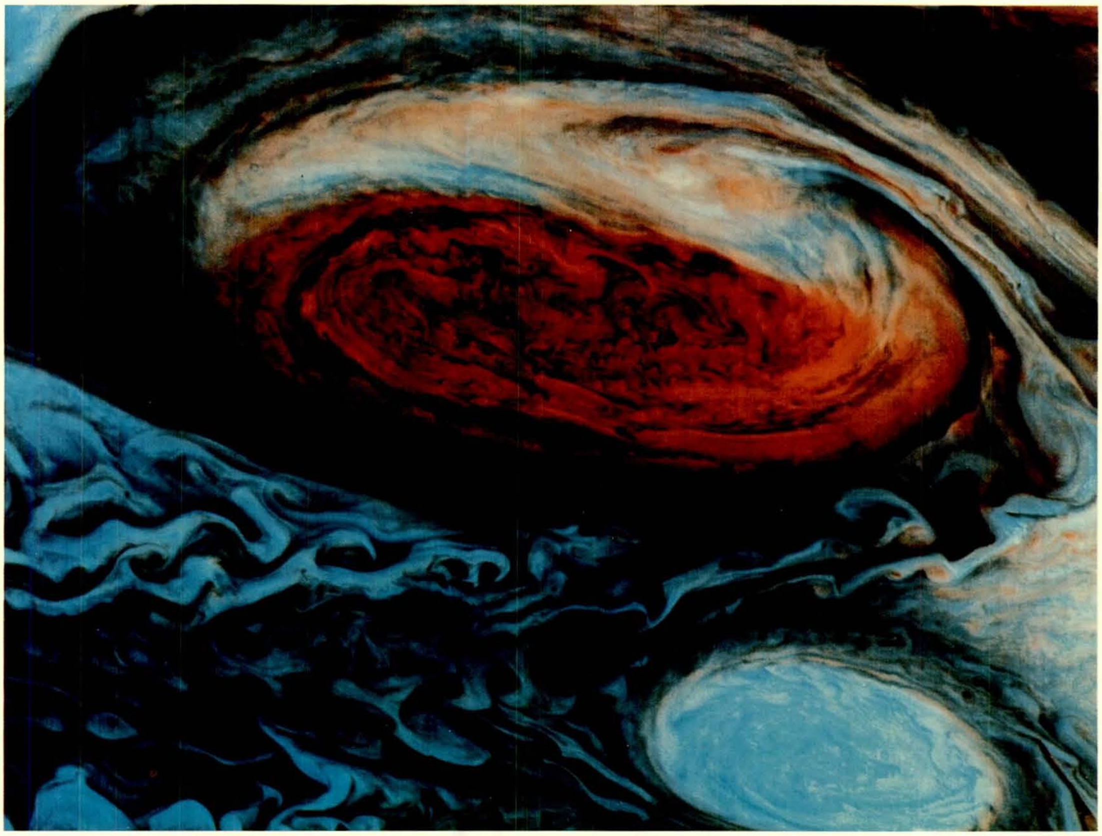
The Weather

The great ball of liquid hydrogen and helium forming the bulk of Jupiter is topped by a thin shell of atmosphere. This is where Jupiter's weather systems swirl in enormous storms. There are colored clouds, cyclones and anticyclones, and rainstorms. While Earth's weather is driven primarily by heat from the Sun, that of Jupiter derives most of its energy from the planet's internal heat combined with the circulation driven by its high speed of rotation.

The surface of Jupiter as seen through a telescope is a vast sea of clouds, providing a spectacular display of turbulent motions and billowing cloud tops. While some of the whirling cloud masses resemble terrestrial hurricanes, others stretch out in stripes around the planet. The systems often change extensively within a few days; but, because there is no solid surface on the planet, some Jovian weather systems last for many years. One of them, the Great Red Spot, has appeared like a baleful red eye on the planet for centuries. Its origin is not clearly understood. Much larger than Earth, the Great Red Spot appears to move around the planet at a different speed from the surrounding clouds. The Great Red Spot is thought to be a violent 30,000-kilometer-long storm system with clouds rising about 8 kilometers above the surrounding clouds.

Equatorial and temperate regions of Jupiter are marked by bands paralleling the equator that can be seen with even a small telescope. Prior to Voyager 1, the light zones were thought to be rising masses of atmosphere; the dark bands were thought to be masses sinking deeper into the atmosphere. Voyager pictures and movies of Jupiter revealed that the motions of the atmosphere in these bands and zones are much more complicated than previously thought. All regions of the planet appear to be in continuous, complicated swirling motion with many areas of shear and turbulence.

Meteorologists are intrigued by the processes taking place in Jupiter's atmosphere and need many observations over a period such as that provided by the Galileo mission to explain the driving forces. Understanding long-term weather systems and climatic changes on our planet is a basic and economically vital challenge in terrestrial science. Repeated observations of the giant, long-lasting storms on Jupiter (and other planets with atmospheres) and the multilayered cloud formations surrounding the planet are expected to help meteorologists understand the evolution of Earth's climate and long-term weather systems. Measurements of Jupiter's atmosphere and extensive observations of cloud formations such as the Great Red Spot will provide new links to this understanding.



Great Red Spot with color exaggerated to enhance cloud detail

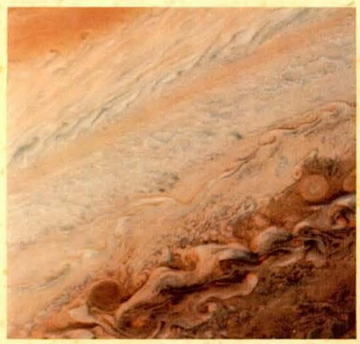
The Probe

The Galileo Probe, similar in concept to the Pioneer Venus Large Probe, consists of a deceleration module and a descent module. Since this represents the most challenging atmospheric entry mission undertaken by NASA, a highly conservative design is required for the deceleration module's main component—its heat shield. Many tests were made at Ames facilities to make sure that the heat shield material can withstand entry at high speed into Jupiter's atmosphere.

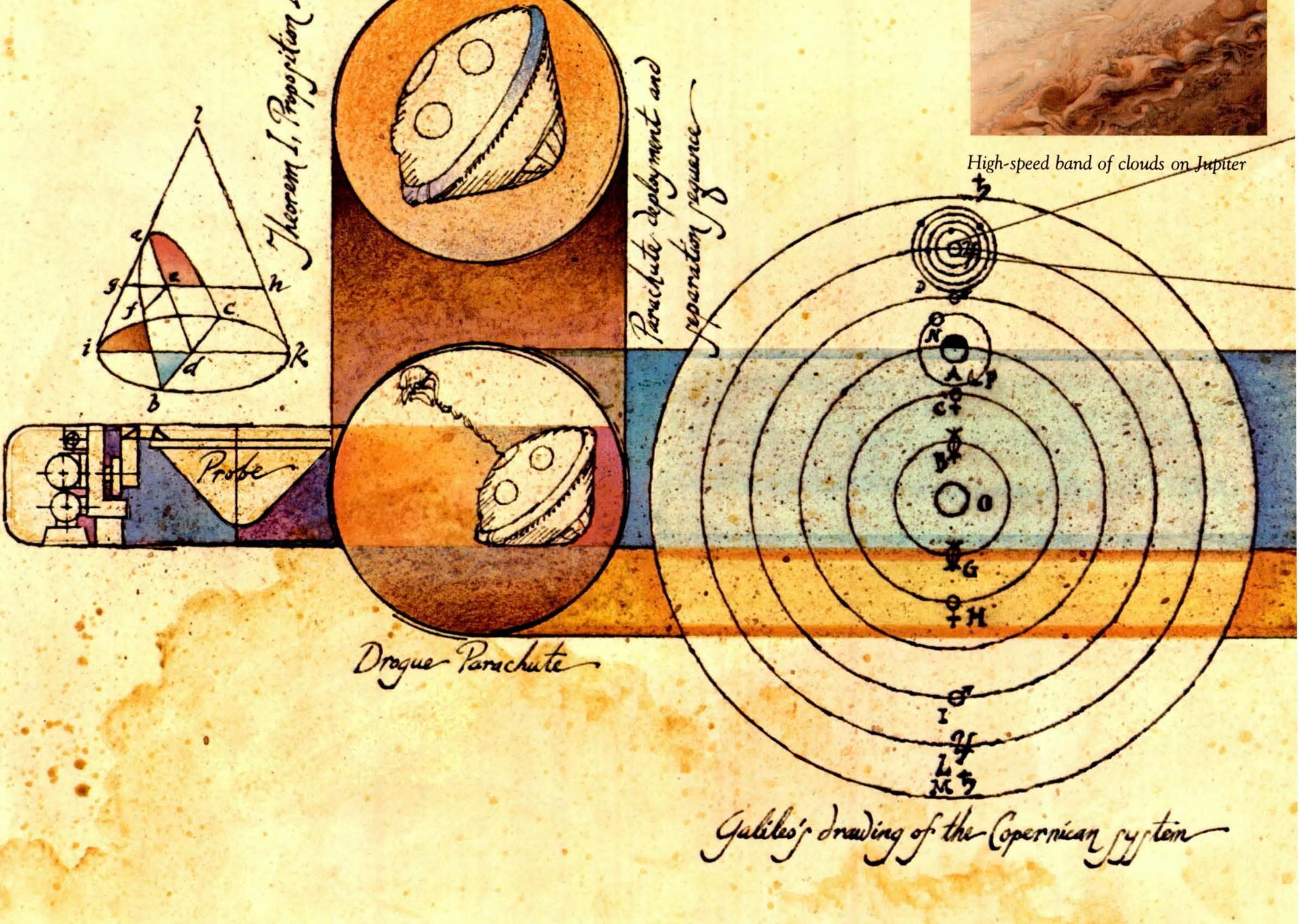
The atmospheric pressure in the region where the Probe is expected to make measurements ranges from one-tenth to at least 10 times that of Earth. The Probe will pass through this area within 60 minutes.

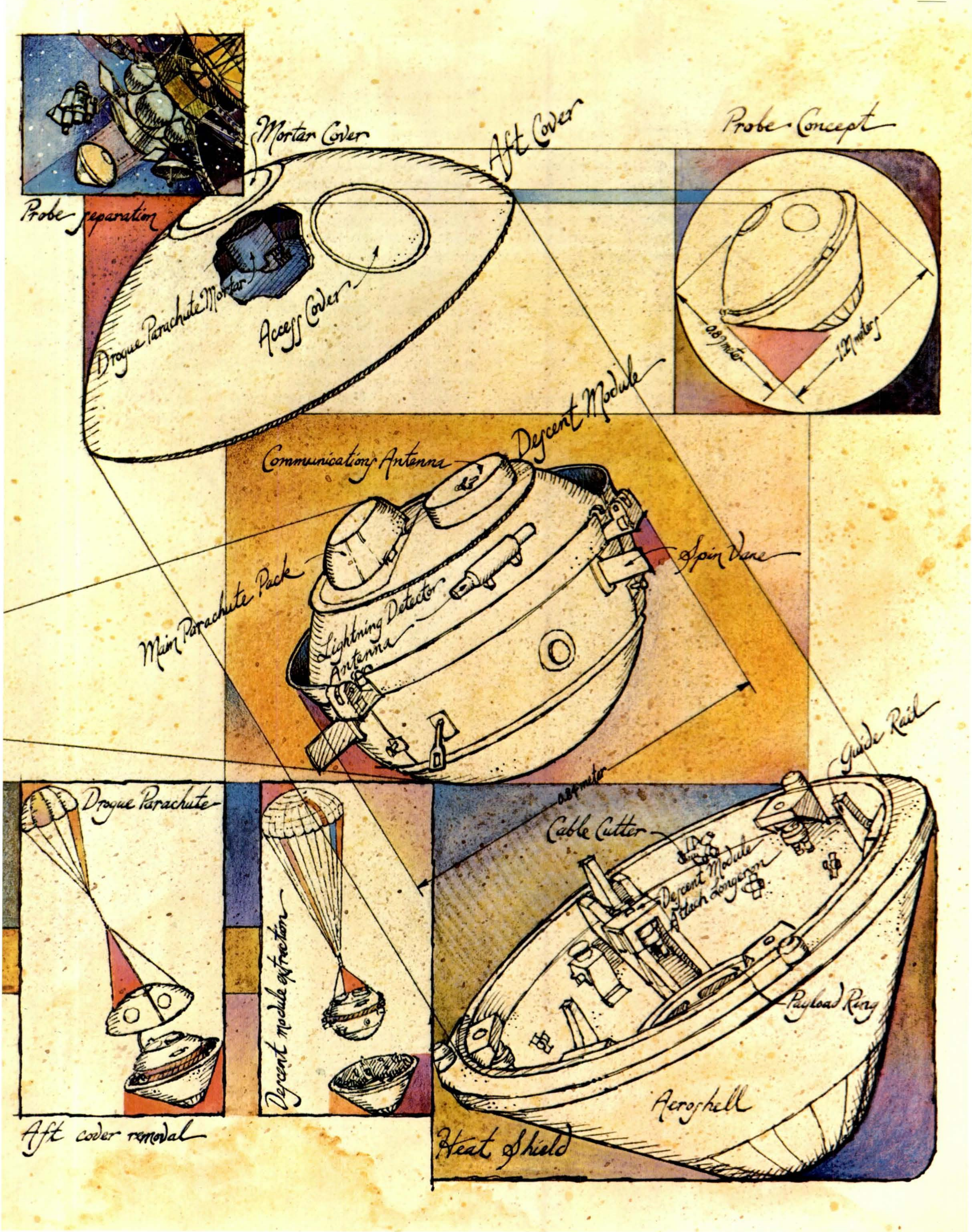
The Probe's instruments are carried inside the descent module which also houses the supporting systems: power, electronics, and thermal control. To equalize the pressure within the Probe despite changes of pressure at different depths of Jupiter's atmosphere, a vented probe design was chosen. Thus, the pressure inside the Probe is always the same as the pressure outside. As a result, structural weight is low. This is important because so much of the Probe's weight—about 44 percent—is taken up by the heat shield. The rest has to be shared among instruments, systems, and structure. Low-weight structure means that more instruments can be carried. The Probe is powered by a lithium battery which is dormant during interplanetary flight and then, upon command by a g-switch just prior to entry, energizes all instruments and subsystems.

Special antennas mounted on the rear of the Probe were designed to transmit data to the Orbiter for the longest period practical under the hostile conditions deep within the Jovian atmosphere.



High-speed band of clouds on Jupiter




Probe separation
Mortar Cover
Aft Cover
Probe Concept
Drogue Parachute Mortar
Access Cover
Descent Module
Communications Antenna
Spin Vane
Main Parachute Pack
Lightning Detector Antenna
Guide Rail
Cable Cutter
Descent Module Attach Longeron
Drogue Parachute
Descent module extraction
Payload Ring
Aeroshell
Aft cover removal
Heat Shield

The Orbiter

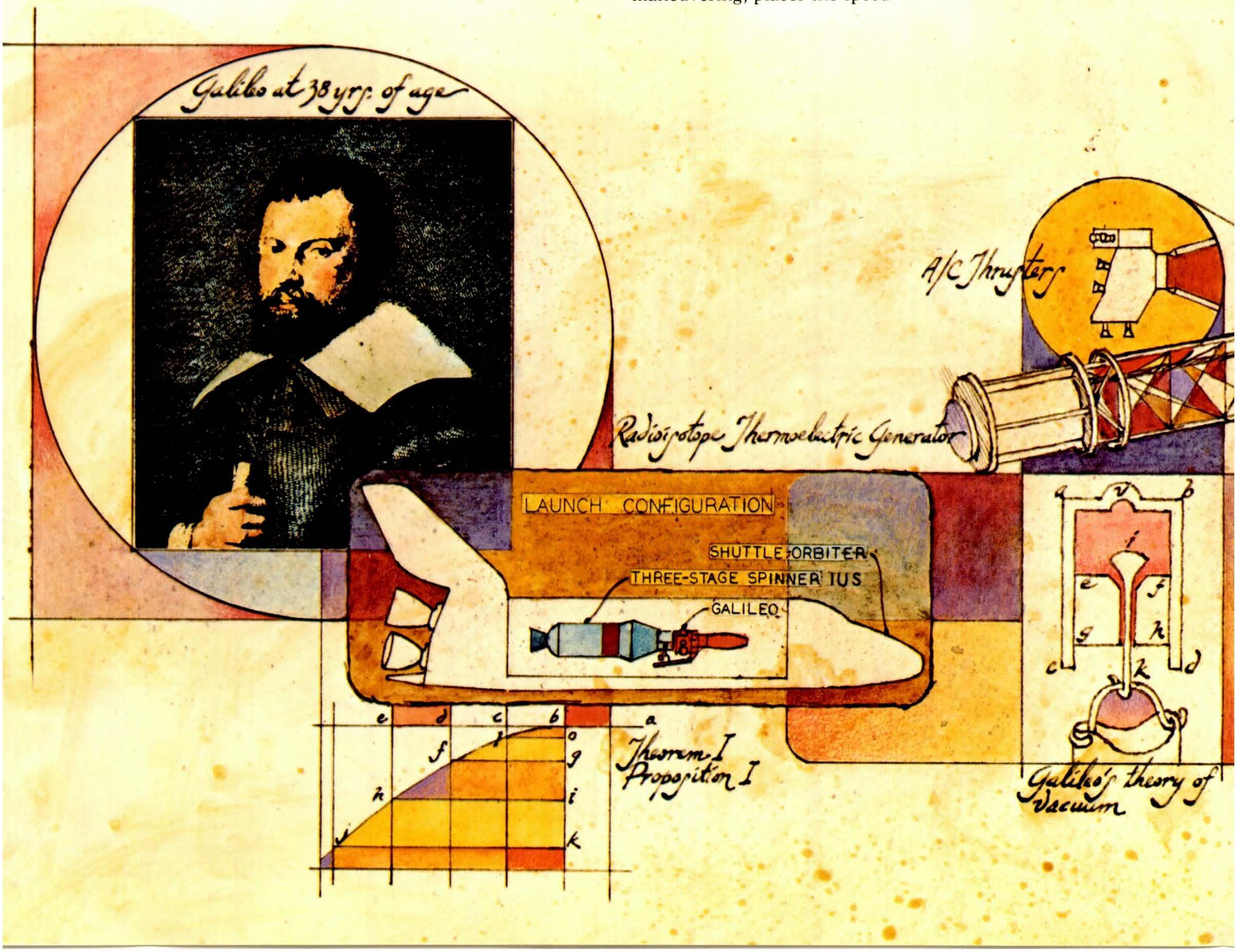
The Orbiter is a large spacecraft that incorporates many of the advanced technologies from previous interplanetary missions. It consists of two major parts, one of which can be despun while the other is spinning. The dual nature maximizes the effectiveness of two groups of experiments. To investigate the magnetosphere of Jupiter, scientists require a spinning spacecraft to sweep the viewpoint of the instruments around in space several times per minute. By contrast, the imaging of Jupiter and its satellites requires a stable platform from which instruments can be accurately pointed. The two parts can spin together during interplanetary cruise and maneuvers. A command from Earth despins the imaging part of the spacecraft when required.

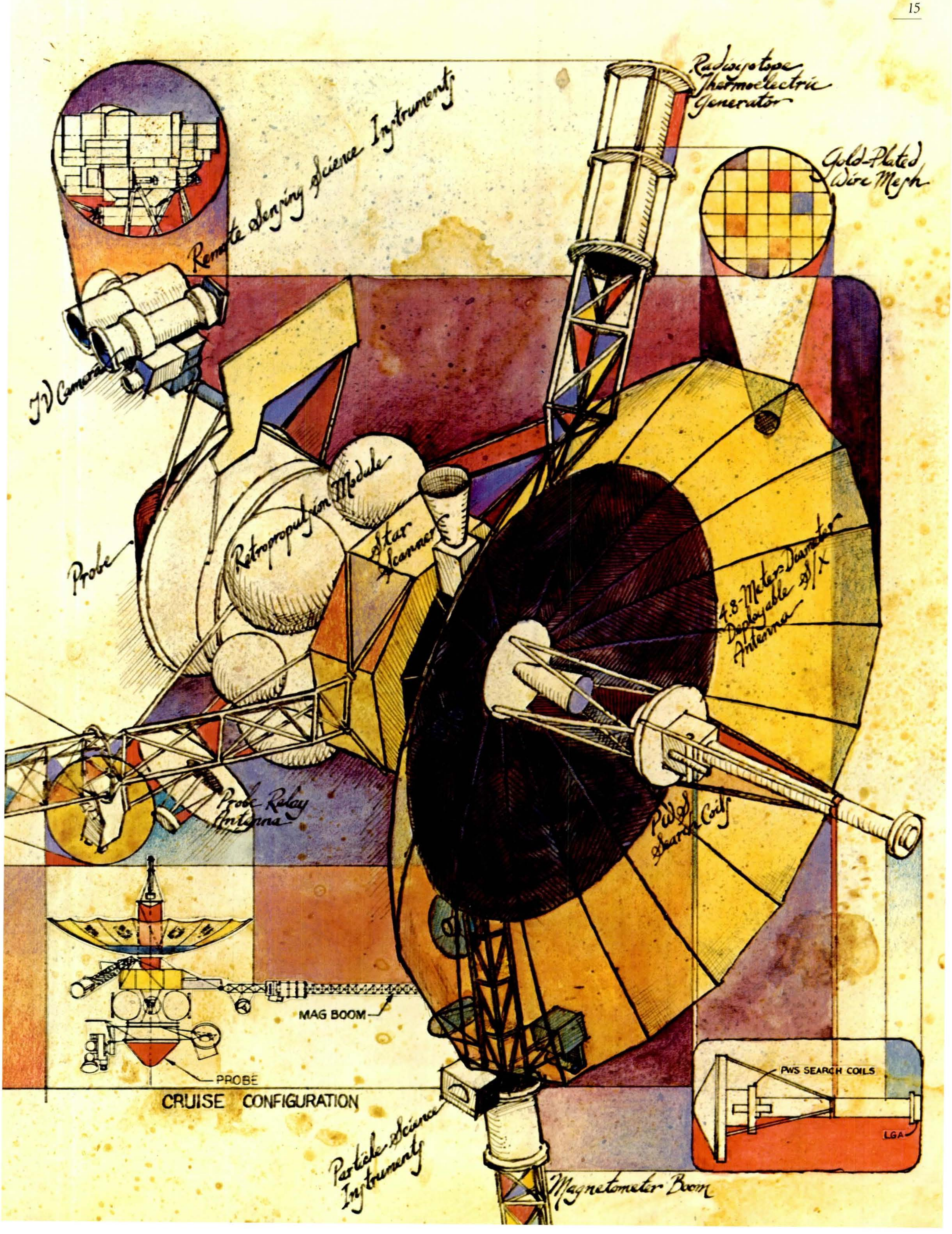
A large, 5-meter-diameter antenna is folded for launch and extended, umbrella fashion, when the spacecraft is on its way to Jupiter. The large antenna is needed to transmit data gathered by the Probe and the Orbiter across the enormous distance to Earth.

The spacecraft carries a propulsion system designed and built by the Federal Republic of Germany as part of that nation's contribution to this international venture in interplanetary exploration. This part of the spacecraft, known as the retropropulsion module, provides for attitude and trajectory correction maneuvering, places the speeding spacecraft into orbit around Jupiter, and is used when needed to trim that orbit.

The electrical power units designed for Galileo use a process which changes heat from nuclear radioisotopes into electricity to power the spacecraft and its instruments. These units are called Radioisotope Thermoelectric Generators (RTGs).

Important engineering challenges were met in designing Galileo: for example, interfacing with the Shuttle and its Inertial Upper Stage and with the German propulsion unit, developing a new command and data system, perfecting the dual-spin technology, and incorporating the Probe so that it can be released to follow a precise path to Jupiter.




Radioisotope Thermoelectric Generator
Gold-Plated Wire Mesh
Remote Sensing Science Instruments
TV Cameras
Retropropulsion Module
Probe
Star Scanner
4.8-Meter-Diameter Deployable S/X Antenna
Probe Relay Antenna
PWS Search Coils
MAG BOOM
PROBE
CRUISE CONFIGURATION
PWS SEARCH COILS
LGA
Particle Science Instruments
Magnetometer Boom

The Purpose

The purpose of the Galileo mission to Jupiter is to find out more about the chemical composition and physical state of the atmosphere of Jupiter; to study the surfaces, chemical composition, and physical state of the Galilean satellites; and to study the magnetic field of Jupiter and determine how the energetic particles behave within it.

The Probe is designed to

☆ Determine how pressure, temperature, and density of Jupiter's atmosphere vary from the region above the clouds to the level at which the pressure is about 10 times that at sea level on Earth, believed to be below the bottom layer of water clouds.

☆ Determine the composition of Jupiter's atmosphere and find out how the constituents vary at different levels within each cloud layer.

☆ Determine the exact location and structure of Jupiter's different cloud layers and learn the nature and extent of the cloud particles.

☆ Measure how much energy flows outward through the atmosphere from inside Jupiter, and inward from the Sun, and how these flows balance.

☆ Determine the characteristics of Jupiter's upper atmosphere above the clouds.

The Orbiter is designed to

☆ Inspect the surfaces of the Galilean satellites to determine their composition and to study in detail the state of these surfaces and their character.

☆ Define the shape and other characteristics of the outer magnetosphere of Jupiter (particularly the distant "tail" region where the Jovian field stretches out by interaction with the solar wind) and observe the changes to the boundary regions as the solar wind gusts hit it.

☆ Find out how energetic particles are squirted from the magnetosphere into interplanetary space.

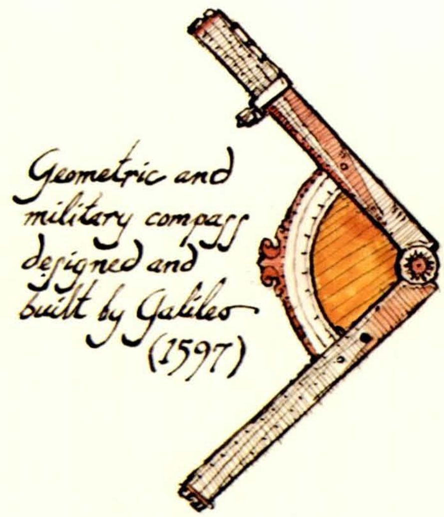
☆ Determine how trapped particles are distributed within the magnetosphere, how long they remain within it, and what finally happens to them.

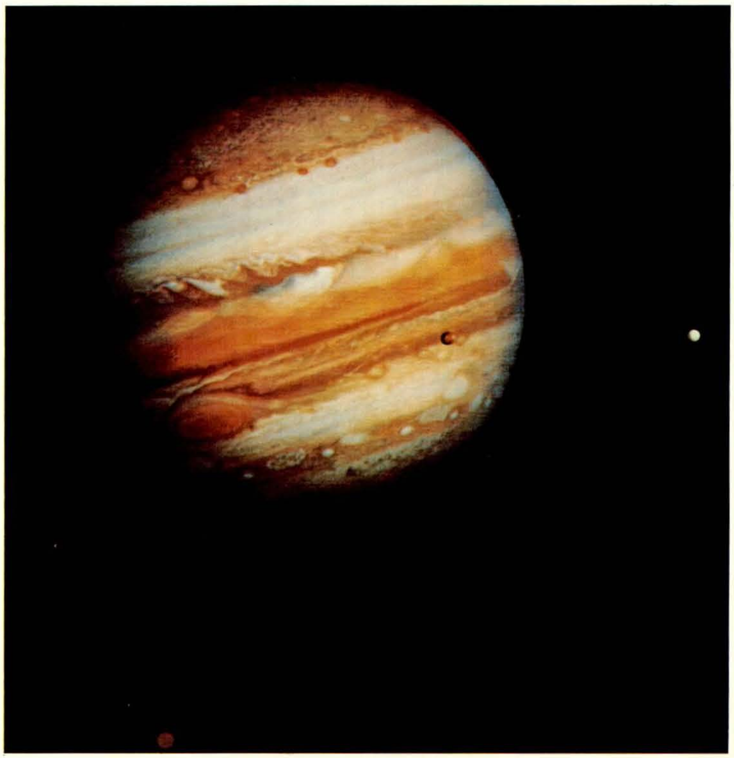
☆ Investigate the interactions that take place between the Galilean satellites and the magnetosphere.

☆ Measure the magnetic and gravitational properties of the satellites to determine their geophysical characteristics.

☆ Study the atmospheres and ionospheres of the satellites to find out such things as how the atmospheric gases originate and how they leak into space.

☆ Observe various properties of Jupiter's atmosphere such as temperature, composition, density, and cloud formations to find out how they are interrelated.





Jupiter and three of its satellites: Io can be seen against the face of Jupiter, Europa to the right, and Callisto to the bottom left

The Experiments

More than 475 scientists, including 90 from foreign countries, submitted proposals to participate in Project Galileo; over 100 scientists were selected to form the science teams.

To meet the science objectives of its mission, the Probe instruments will make local measurements of Jupiter's atmospheric structure and composition, its cloud structure, and its radiative flux balance. In addition, the Probe instruments will search for lightning discharges.

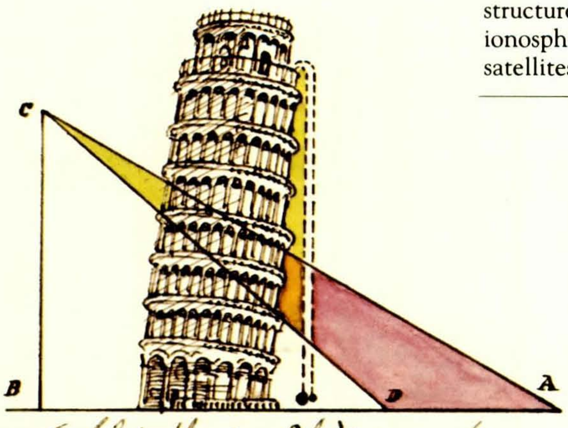
While the Probe will make most of its measurements within the atmosphere of Jupiter, the Orbiter will look at the planet from a distance. The Orbiter will carry several remote-sensing instruments mounted on a nonspinning platform so that they can be pointed at selected areas of Jupiter and its satellites by command. In addition, the Orbiter will carry several magnetospheric instruments on the spinning section in order to investigate the complex fields and particles in the magnetosphere of Jupiter.

Radio signals from the Orbiter will be used to perform celestial mechanics and radio science experiments, to investigate Jupiter's atmosphere, and to study the interiors and ionospheres of the Galilean satellites.

In addition to the experiment groups, radio teams, and imaging team, there are 15 interdisciplinary scientists to work with the data from several experiments and to provide a broad link among the many disciplines involved in Project Galileo.

Instrument/ Experiment	Function	Principal Investigator and Affiliation
	Probe	
Atmosphere structure instrument	Provides information about temperature, density, pressure, and molecular weight to determine the structure of Jupiter's atmosphere.	Alvin Seiff NASA Ames Research Center
Neutral mass spectrometer	Measures the composition of the gases in Jupiter's atmosphere and the variations at different levels in the atmosphere.	Hasso B. Niemann Goddard Space Flight Center
Helium abundance interferometer	Measures with high accuracy the ratio of hydrogen to helium in Jupiter's atmosphere.	Ulf von Zahn Bonn University Federal Republic of Germany
Nephelometer	Determines the sizes of cloud particles and the location of cloud layers in Jupiter's atmosphere.	Boris Ragent NASA Ames Research Center
Net flux radiometer	Measures energy being radiated from Jupiter and the Sun, at different levels in Jupiter's atmosphere.	Robert W. Boese NASA Ames Research Center
Lightning and radio emission instrument	Measures electromagnetic waves being generated by lightning flashes in Jupiter's atmosphere; detects the light and radio transmissions from those flashes.	Louis J. Lanzerotti Bell Laboratories/ University of Florida Klaus Rinnert (Co-Investigator) Max-Planck-Institut für Aeronomie Federal Republic of Germany
Energetic particle detector	Measures energetic electrons and protons in the inner regions of the Jovian radiation belts and determines their spatial distributions near the edges of the belts.	Harald M. Fischer University of Kiel Federal Republic of Germany

Instrument/ Experiment	Function	Principal Investigator and Affiliation
	Orbiter: Spinning Section	
Magnetometer	Measures magnetic fields and the ways they change near Jupiter and its satellites; measures variations caused by the satellites interacting with Jupiter's field.	Margaret G. Kivelson University of California at Los Angeles
Plasma instrument	Provides information on low-energy particles and clouds of ionized gases in the magnetosphere.	Louis A. Frank University of Iowa
Energetic particles instrument	Measures composition, distribution, and energy spectra of high-energy particles trapped in Jupiter's magnetic field.	Donald J. Williams NOAA Space Environment Laboratory Tom Krimigis (Co-Investigator) Johns Hopkins, APL Berend Wilkin (Co-Investigator) Max-Planck-Institut für Aeronomie
Plasma wave instrument	Investigates waves generated inside Jupiter's magnetosphere and waves radiated by possible lightning discharges in the atmosphere.	Donald A. Gurnett University of Iowa
Dust-detection instrument	Determines size, speed, and charge of small particles such as micrometeorites near Jupiter and its satellites.	Eberhard Gruen Max-Planck-Institut für Kernphysik Federal Republic of Germany
Celestial mechanics	Uses the tracking data to measure the gravity fields of Jupiter and its satellites; searches for gravity waves propagating through interstellar space.	John D. Anderson (Team Leader) Jet Propulsion Laboratory
Radio propagation	Uses radio signals from the Orbiter and Probe to study the structure of the atmospheres and ionospheres of Jupiter and its satellites.	H. Taylor Howard (Team Leader) Stanford University



Galileo's theories of bodies in motion

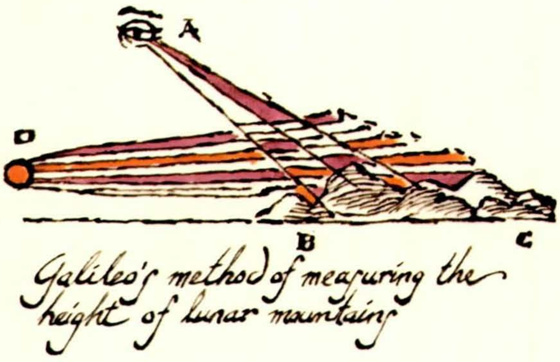
Instrument/ Experiment	Function	Principal Investigator and Affiliation
	Orbiter: Nonspinning Section	
Solid state imaging	Provides images of Jupiter's atmosphere and its satellites.	Michael J. S. Belton (Team Leader) Kitt Peak National Observatory
Ultraviolet spectrometer	Studies composition and structure of the upper atmospheres of Jupiter and its satellites.	Charles W. Hord University of Colorado
Near infrared mapping spectrometer	Provides spectral images and reflected sunlight spectra of Jupiter's satellites, indicating the composition of their surfaces; measures reflected sunlight and thermal emission from Jupiter's atmosphere to study composition, cloud structure, and temperature profiles.	Robert W. Carlson Jet Propulsion Laboratory
Photopolarimeter radiometer	Measures temperature profiles and energy balance of Jupiter's atmosphere; measures Jupiter's cloud characteristics and composition.	James E. Hansen Goddard Institute for Space Studies

Interdisciplinary Scientist	Affiliation
Fraser P. Fanale	Jet Propulsion Laboratory
Peter J. Gierasch	Cornell University
Donald M. Hunten	University of Arizona
Harold Masursky	U.S. Geological Survey
Michael B. McElroy	Harvard University
David Morrison	University of Hawaii
Glenn S. Orton	Jet Propulsion Laboratory
Tobias Owen	State University of New York, Stony Brook
James B. Pollack	NASA Ames Research Center
Christopher T. Russell	University of California at Los Angeles
Carl Sagan	Cornell University
Frederick L. Scarf	TRW
Gerald Schubert	University of California at Los Angeles
Charles P. Sonett	University of Arizona
James A. Van Allen	University of Iowa

The Signals

As Galileo travels to Jupiter and explores the Jovian system, a worldwide network of tracking stations, known as the Deep Space Network (DSN), will send commands to Galileo and receive data from the spacecraft. Deep Space Stations are located 120 longitudinal degrees apart in California, Spain, and Australia. Each location includes a 64-meter-diameter antenna and a 34-meter-diameter antenna. The Galileo spacecraft will remain within the field of view of at least one of these stations at all times.

From Jupiter, Galileo's data will be transmitted across distances so great that the radio signals will travel at the speed of light for approximately 40 minutes to reach Earth. The giant DSN antennas will receive Galileo's radio signals and route them through the ground-based communications systems to Mission Control at the Jet Propulsion Laboratory in Pasadena, California. Mission Control is the focal point for Galileo spacecraft command operations and mission performance evaluation.



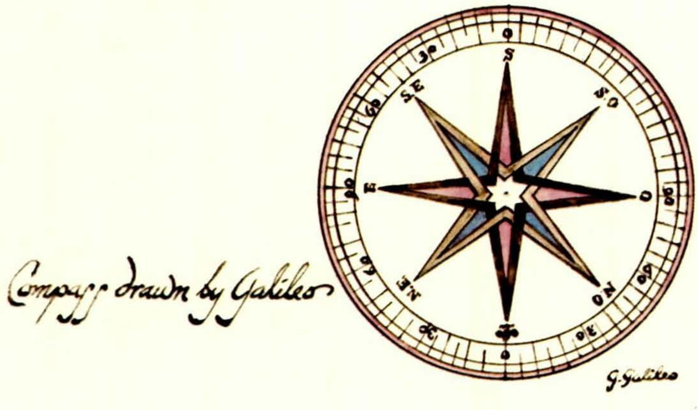
Giant DSN antenna at Goldstone, California

The Dream

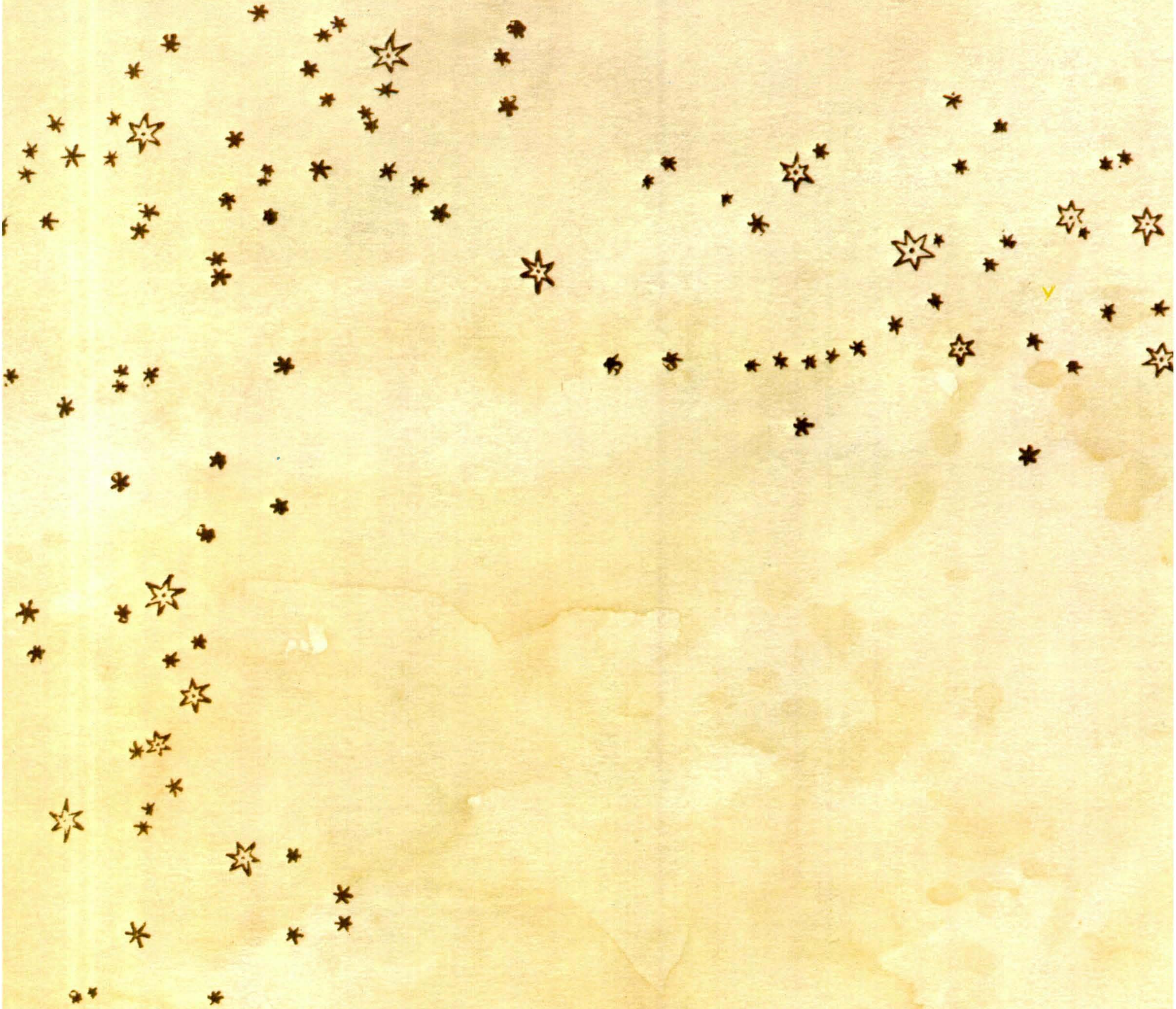
Over 350 years ago, Galileo saw Jupiter's four largest satellites with his newly invented spyglass. The significance of Galileo's discovery was recognized by the great German mathematician Johannes Kepler, who wrote the following words to his friend Galileo in April 1610:

"There will certainly be no lack of human pioneers when we have mastered the art of flight. . . . Let us create vessels and sails adjusted to the heavenly ether, and there will be plenty of people unafraid of the empty wastes. In the meantime, we shall prepare, for the brave sky-travellers, maps of the celestial bodies—I shall do it for the moon, you Galileo, for Jupiter."

(from *Conversation With the Starry Messenger*)



All photographs of Jupiter and its satellites were taken by Voyager 1.



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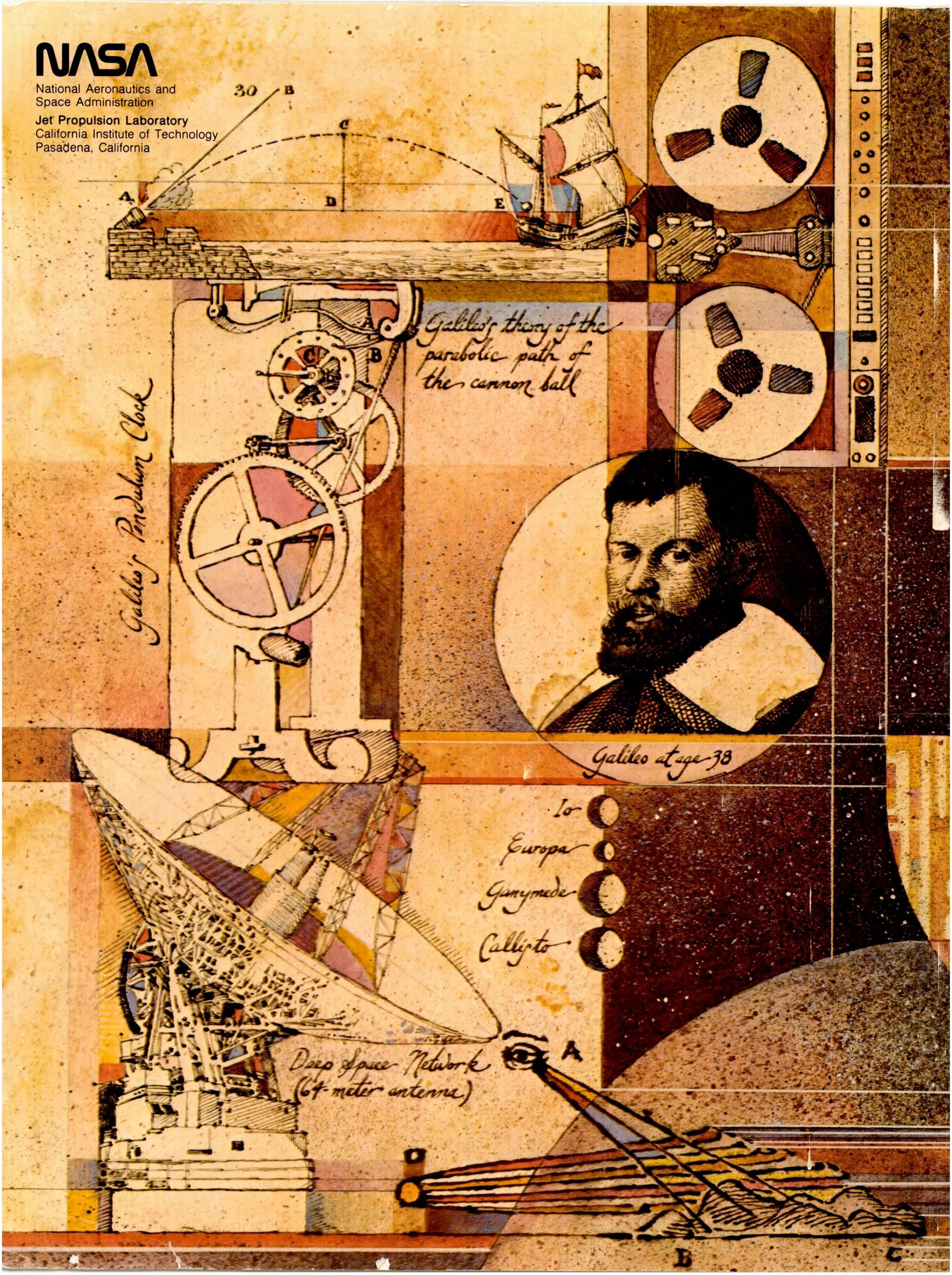
NASA

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California



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