How Galileo explored the Jovian system fifteen years ago

Ever since the famous astronomer Galileo Galilei improved his telescope making it possible to look further into space, people have been staring through telescopes into the far distance in search of new worlds. In January 1610 Galilei discovered the four biggest satellites of Jupiter: Io, Europa, Ganymede and Callisto, later to be known as the Galilean moons. About fifteen years ago the eponymous NASA spacecraft ‘Galileo’ entered an orbit around Jupiter to discover the Galilean moons once again. But this time from a much smaller distance and with a larger set of tools than ever before.

ON THE WAY TO JUPITER
The Galileo spacecraft (figure 1) was launched on the 18th of October 1989 on board the space shuttle Atlantis. Galileo was originally designed to fly directly to Jovian orbit but due to new constraints on shuttle operations after the Challenger accident, a direct flight to Jupiter became impossible. The new flight plan included the use of gravitational assist flybys of Venus and Earth to get the spacecraft on its way to Jupiter and its moons. This new plan significantly increased the time to get to Jupiter, but made it possible to pass by and examine several other bodies.

ASTEROID ENCOUNTERS
As Galileo used the gravity of Venus and the Earth to get to Jupiter, it passed by Venus, twice by our home planet and two times through the asteroid belt between Mars and Jupiter. During this six-year trip Galileo had time to test its equipment on the Venusian atmosphere and explore several comets and asteroids.

Galileo flew through the asteroid belt for the first time in October 1991. Here it performed the first ever asteroid encounter by passing Gaspra from about 1,600 kilometers at a speed of 8 kilometers per second. Almost two years later it passed the asteroid belt for the second time. Yet another discovery was to be made when a small moon in an orbit around the asteroid Ida was found. In figure 2 a picture is shown taken by Galileo of Ida and its moon Dactyl which was the first ever known moon of an asteroid discovered. Ida’s moon was about 1.4 kilometers in diameter, comparable to the size of the TU campus.

Almost at the end of its journey to Jupiter, in July 1994, Galileo was used to make direct observations as fragments of comet Shoemaker-Levy 9 crashed into Jupiter. Earth-based telescopes had to wait as they turned into view as Galileo used its instruments to capture footage of the up to 2km in diameter comet fragments impact into Jupiter with a speed of 60 kilometers per second.

MAIN ANTENNA FAILURE
To send the measurement data all the way back to Earth a big umbrella shaped high-gain antenna was mounted on the spacecraft. Galileo passed the Earth for the first time in 1991 where the large dish was planned to open for long range communication as it flew towards the asteroid belt. In figure 3 the spacecraft is illustrated as three of the antenna ribs got jammed in the process and Galileo’s high-gain antenna failed to fully deploy. Engineers tried thermal cycling the antenna, rotating the
spacecraft up to its maximum spin rate of 10.5 rpm and turning the deployment motors on and off repeatedly over 13,000 times, but nothing seemed to work. Fortunately Galileo had an additional low-gain antenna for transmitting data to Earth which made scientists able to retrieve the data. This was done by arraying several 70-meter-wide Deep Space Network antenna’s and upgrading the sensitivity of their sensors. This allowed scientists to capture almost all the information originally planned.

THE PROBE MISSION
In July 1995, the Galileo spacecraft began its first exploration in the Jovian system. Onboard the spacecraft was Galileo’s atmospheric entry probe which was finally to be released on a solo flight into the clouds of Jupiter (figure 4). The probe plunged into Jupiter’s atmosphere five months later with a speed of 48 kilometers per second and in less than two minutes it was slowed down to subsonic speed, protected by its heat shield. Fifteen kilometers from the cloud layer the probe deployed its 2.5m parachute and dropped its heat shield, as illustrated in figure 5. From there it traveled another 155 kilometers into the depth of Jupiter, to finally melt and eventually vaporize by the intense heat of the Jovian atmosphere. During this 58 minute descend the probe measured pressure, temperature, atmospheric composition, radiative flux and its distance to lightning strikes and energetic particles for every altitude. This data was directly sent to the Galileo spacecraft which in turn sent it back to Earth.

The air measured by the probe was much dryer and more turbulent than predicted. Also the temperature was higher, fewer clouds were observed and lightning was measured only in the distance. Later, scientists would discover that the area the probe had entered was a so called ‘hot-spot’. Hot spots are vast cloudless areas in the Jovian atmosphere wherein the heat can escape from the depth without much absorption.

JUPITER’S MOONS
Fifteen and a half years ago, after traveling in our solar system for more than six years, the Galileo spacecraft first entered Jovian orbit. On 7 December 1995 Galileo slowed down using its main engine as the smallest error could send it sailing past the planet. After hours of anxious waiting, mission controllers confirmed that the spacecraft was safely in orbit and Galileo began its primary mission: the study of the four biggest moons in the Jovian system. In the first two years several flybys were made on all four moons and from December 1997 to the end of the millennium the mission was focused on the icy moon Europa which might have an ocean, the thunderstorms on Jupiter and the blistering volcanoes of Io.

GANYMEDe’S MAGNETIC FIELD
In its first two orbits around Jupiter, Galileo flew by Jupiter’s biggest moon: Ganymede (figure 6). With 5262 kilometers in diameter it is the biggest moon in our solar system and even bigger than Mercury. As Galileo passed by Ganymede it discovered that the moon possesses its own substantial magnetic field, the first satellite known to have one. A magnetic field often implies an iron-rich core. As the electric conductivity of liquid iron is very high, it is mostly suitable for magnetic field generation.

Next to its Solid State Imager to take beautiful pictures, the spacecraft was equipped with a Near-Infrared Mapping Spectrometer or NIMS. The NIMS was able to detect the composition of materials on the surface of the moon using near-infrared light. With use of the NIMS Galileo detected a silicate and water-ice mantle and the discoveries also showed evidence of an underground salt-water ocean about 200km under the crust.

A QUIET PLACE CALLED CALLISTO
Callisto is the furthest away from Jupiter of all four Galilean moons. Its surface is heavily cratered and it seems not to be affected by subsurface processes like plate tectonics or volcanism. As the Galileo spacecraft measured Callisto’s dimension-
less moment of inertia during close flybys, it discovered that Galileo might also have a salty ocean 60 to 200 km beneath its crust. These properties together with its low radiation level make Galileo the most suitable place for a human base for future exploration of the Jovian system.

POSSIBLE EXTRATERRESTRIAL LIFE ON EUROPA
After two years of collecting data on the four Galilean moons, the Galileo spacecraft was set to focus on the moons Europa and Io. As Galileo passed by Europa, it took measurements of a thin, almost pure oxygen atmosphere and a water-ice surface of about minus 170 degrees Celsius. The icy surface of the moon contains dark streaks crisscrossing the entire globe, called lineae. A closer look at these cracks as shown in figure 7, reveals that the edges of each side of the crust have moved relative to each other similar to tectonic plates on Earth.

The smoothness of Europa and magnetic measurements done by Galileo have led to the hypothesis of a salt-water ocean beneath the approximately 100 km thick ice crust. This ocean would be kept warm by a gravitational effect called ‘tidal heating.’ As the gravity of Jupiter and other moons pulls on the ice of Europa, friction occurs and causes heat. Therefore, Europa’s warm under-ice ocean could plausibly serve as a suitable place for extraterrestrial life.

MASSIVE ERUPTIONS ON IO
Io is the most geologically active object in the solar system with over 400 active volcanoes. This geological activity is also caused by tidal forces from Jupiter as the gravity of the other Galilean moons force Io into an eccentric orbit. Therefore Jupiter’s gravity force on Io varies tidally and as that happens the rocky crust of Io moves in huge waves along the surface which can reach up to 100 m high, similar to the tides on Earth, but with rock instead of water. The huge amount of friction causes the silicate rock to melt and magma to erupt onto the surface. Large lava flows have been observed by Galileo as it passed by and as pressure builds up, volcanoes can blow sulfur dioxide, ash and liquid silicate up to 200 km into space producing large umbrella shaped plumes. These eruptions form deposits on the surface and paint Io in red, black and white as showed in figure 8.

PROTECTING THE GALILEAN MOONS FOR ITSELF
As Galileo approached Io several times, it had to pass through Jupiter’s intensive radiation belts. The radiation severely affected the spacecraft and in 2001 the Solid State Imager’s sensor eventually stopped producing usable data. Even without taking pictures, Galileo still explored the Jovian system for two more years making use of the still working instruments. In a system where extraterrestrial life might possibly be found, the Galileo team could not take the risk of contaminating one of the moons with microscopic life, from Earth. Because Galileo almost ran out of fuel and to protect future missions, Galileo ended its fourteen year mission in 2003 crashing, melting and finally evaporating in the Jovian atmosphere.

FUTURE JOVIAN EXPLORATION
Several spacecraft have passed by the Jovian system. Before Galileo, Pioneer Ten and Eleven flew by Jupiter in the early seventies. A few years later Voyager One and Two passed by the Jovian system as they were on their way to the borders of the solar system. In December 2000, the Cassini-Huygens spacecraft joined Galileo on its way to Saturn, to observe the extreme weather on Jupiter together and seven years after that, New Horizons used the gravity of Jupiter for a swing-by trajectory to Pluto.

As scientists are still not finished with the fascinating phenomena in the Jovian system, new missions are planned to visit Jupiter. In August this year the Juno spacecraft was sent to space on board an Atlas V rocket for a six year mission to observe Jupiter’s atmosphere once again. But this time from a much smaller distance, with a more powerful radiation shield and a larger set of tools than ever before.

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SPACE DEPARTMENT
The Space Department promotes astronautics among the students and employees of the Faculty of Aerospace Engineering at Delft University of Technology by organizing lectures and excursions.