Galileo, Death of a Satellite

Compiled by Joachim J. Kehr, October 2022 [1]

Werner Herzog, the eccentric German filmmaker (Fitzcarraldo) shared his participation in the "dying of the probe" in his biography "Jeder für sich und Gott gegen alle". [1]

With his fascination for extreme situations, he impressively described how almost all scientists and technicians who had worked on this great project over decades had come together to possibly say goodbye to the successful Galileo probe with a small champagne celebration, but he also foresaw that many would be sad. Herzog nevertheless was deeply moved that almost everyone present started crying very suddenly *at a time when the data could still be received undisturbed and displayed on the monitors in the control center.*

Of course, the time of the burn-up of the probe hitting Jupiter's atmosphere was calculated in advance and the one-way trip time of the data was 52 minutes from Jupiter to Earth, which meant that the probe was "dead" for 52 minutes before the data stream finally vanished too.[2]

The Galileo project

July 1, 1977, was the official beginning of the project, and the new Jupiter probe was given the sounding name Galileo after the famous Italian polymath. In 1610 he was probably the first person to see Jupiter and its four large moons with a self-made telescope and recognized them as satellites of the large planet because of the rapid changes in position.

But the initially very positive mood for the Galileo project was challenged because technical, financial, and above all political problems hit the project hard, and it was on the verge of being canceled several times. The first crisis came with the inauguration of Ronald Reagan, who became the new president in 1980. His government was fixated on the SDI ("star-wars") project and had no interest in planetary research, they wanted to dedicate the well-known Jet Propulsion Laboratory (JPL) in Pasadena, CA entirely to the service of missile defense in space or close it down! Image [3]

Nobody in the White House was interested in Galileo.

But now, under the leadership of prominent politicians, scientists, and the USAF a movement was formed, that promoted NASA's new mission and interested large sections of the population in the project. Galileo survived the political attacks and the probe's launch was scheduled for mid-1986.

Now the Challenger disaster occurred in January 1986, killing seven astronauts and bringing American space exploration to a standstill. The Galileo project also struggled to recover from this shock. It helped tremendously that the hardware and flight planning were 90% complete. The German partner attracted and obligated by a previously signed contract between the governments in Washington and Bonn also pushed for the realization of the project. Under this contract, Germany was responsible for the construction of the mission-critical propulsion module and promised to supply two scientific sensors and participate in five other instruments as well as mission operations support by the German Space Operations Control Center (GSOC) team for the German contributions.

Political-financial problems

In the aftermath of the Challenger disaster, there were more problems with the launch of Galileo. The combination space shuttle and high-energy Centaur stage to be transported with the attached Galileo in the shuttle cargo bay planned for launching Galileo was no longer feasible for safety reasons. However, finally, the weaker Interim Upper Stage (IUS) was accepted but extended the Galileo flight time to Jupiter to almost six years.

The spacecraft also had to fly past Earth twice and Venus once to gain speed. On the other hand, as a consolation for the long journey, Galileo was able to fly past two asteroids on the long way to Jupiter and explore such bodies up close for the first time — also an important first.

But many technicians and scientists in the US and Germany were frustrated by the 10-year delay in the Galileo project. Some experts left the teams, they retired or died - and their experience was lost.

And there was a third serious problem for Galileo, this time with the propulsion module from Germany because during tests in 1987 Messerschmitt-Bölkow-Blohm (MBB) technicians found that the 10 N nozzles tended to overheat and could fail completely. So the propulsion module had to go back to the manufacturer, where new more robust engines had to be installed. Otherwise, there might have been problems with attitude control and orbit changes of the space probe. Despite this, the new small 10 N engines were very sensitive and could only be activated at intervals, which used a little more fuel and required longer maneuvers. Nonetheless, in the 1980s, experts referred to the Galileo spacecraft as the 'Rolls Royce' of spacecraft. Such a complex electronic machine had never been built before for planetary research, containing 22 microprocessors and 85,000 computer components equivalent to 46 million transistor functions.

That was also way beyond the complexity of the Voyager probes, although their electronic systems already corresponded to that of approximately 2000 color T/Vs. NASA had entrusted the management of the Galileo project to JPL in Pasadena. In those years, special organizational and technical competence was accumulated in the support of many successful planetary probes - and with the Galileo project, above all, a lot of patience.

The Galileo Jupiter orbiter was built and tested under JPL control and JPL assigned the development of the atmosphere entry capsule to the Ames Research Center (ARC) near San Francisco, which had delegated the construction of the heat shield and the internal measuring equipment to Hughes Aircraft, where the Pioneer capsules for Venus exploration were built also.

The cost of the Galileo project totaled approximately $1.5 billion, significantly more than planned, but not surprising given the many changes, disruptions, and delays. The budget increased significantly for the conversion of the probe and the heat protection when the new trajectory was determined, which had to boost Galileo to Venus, i.e. much closer to the sun than planned. Originally, the Galileo construction was aimed to avoid excessive cooling and heating cycles, now it had to endure heating by a much closer sun without being damaged.

In the end, Germany's participation decided in 1977, required also a much longer support of the mission. The construction of the propulsion system and the delivery of three scientific instruments including mission support amounted to about 220 million DM [$150 million].

The antenna problem

Galileo finally lifted off Cape Kennedy from launch complex 39B on October 18, 1989. After the successful rendezvous with Earth in December 1990, the Galileo probe swung out into the outer planetary system for the first time to meet the small asteroid Gaspra. But first, the unfolding of the 3.8 m large High Gain Antenna (HGA) was expected on April 11, 1991, which until then had been folded up like an umbrella behind a protective shield on top of the space probe so that it would not heat up too much by the sun during the Venus flyby.

Artist conception of stuck antenna [5]

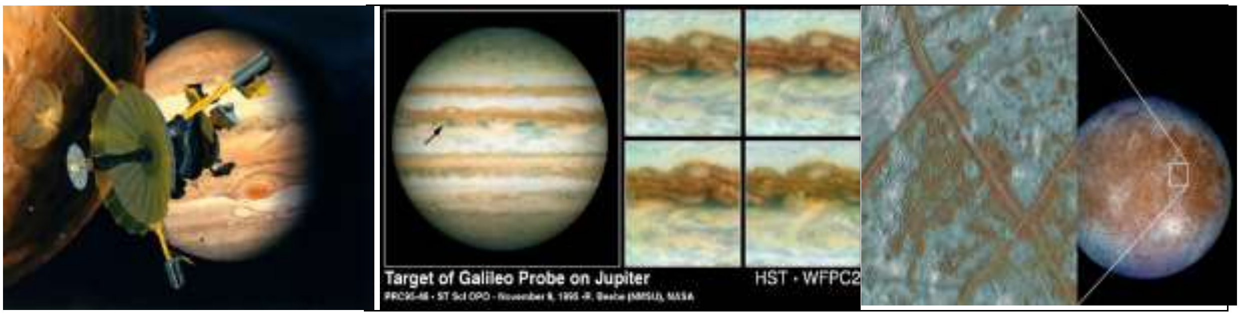
But after the command to open the parabolic wire mesh, there was no confirmation signal, the antenna was stuck in a half-open position. Three of the 18 ribs were soon found to be stuck on top of the central pylon. That was fatal news because without the large antenna, the entire Galileo mission was at stake. The high-speed transmission of the sensor data and, above all, the transmission of images from Jupiter to Earth was only possible with the large directional high-gain antenna. The shock was followed by confusion, then the technicians at JPL became hectic, with one emergency conference following the next. After analysis of the problem, remedial actions for the failure had to be worked out—a preliminary action plan was developed: The antenna was first heated up in direct sunlight over the next few months to be subjected to a drastic cooling cycle afterward. But nothing changed, the expansion or contraction of the metal elements under changing temperature extremes did not help. Even hours of hammering with the small antenna motors and shaking the space probe by igniting the position nozzles was to no avail, the vibrations did not loosen the stuck ribs of the antenna. Tests with a spare antenna at JPL showed very similar results, although this type of foldable reflector had already proven itself on NASA's TDRS satellites.

It was concluded that the lubricant on the upper ring structure had evaporated due to the long storage of the space probe caused by the launch delays. The multiple truck transportations of the Galileo probe over the US continent probably also contributed to this malfunction because the spacecraft was always transported in the same position, supporting a "cold welding" phenomenon.

Even the expected shock impulses to the spacecraft when the entry-probe would be released or the ignition of the main engine to insert Galileo into Jupiter orbit no longer promised a solution to the problem. Some managers wanted to send a data relay satellite after the Galileo probe, which could relay radio signals to Earth. Abandoning the entire Jupiter mission and reducing the mission to a few asteroid flybys was also briefly considered.

But those were just vague ideas, born out of disappointment and helplessness over the fatal situation. Finally, the experts had to accept that the Galileo high-gain antenna could no longer be unfurled, and the first scenarios were designed to fine-tune the planned Jupiter mission using only the small Low Gain Antenna (LGA-1) located on top of the HGA. Given the very low data rate of max 100 bps, the image sequence of the Jupiter rotation and the cloud streams in the atmosphere had to be canceled. But the studies of the four large moons of Jupiter should still be possible with the crippled probe, and the researchers were adapting their plans accordingly. Before that, however, everything had to be done to carry out the mission of the entry probe and to transmit its important measurements directly from the Jupiter clouds to Earth.

Galileo Mission phases



Galileo Prime Mission (Dec. 1995/1997)

The Galileo mission was successful despite the technical problems the probe performed much longer than could possibly be expected. In the seven years up to 2002, the robot probe completed four flybys of the four large moons of Jupiter with astonishing results.

In the first two years of Galileo's Prime Mission phase starting with Jupiter's orbit insertion on Dec. 8, 1995, eleven orbits around the planet with ten targeted flybys of three of its large moons were planned. The identification of these 'encounters' consisted of the first letter of the respective moon and the continuously counted orbit number. Galileo's first flyby after entering Jupiter's orbit led to Ganymede in June 1996 and was designated G1. Then G2 followed in September and flyby C3 in November, i.e. the first flyby of Callisto.

With E4 and E6 in the winter of 1996/97, the first flybys of the second-innermost moon, Europa, took place, resulting in particularly high-resolution images that still contained details of only a few tens of meters in size. They revealed the complex nature of the ridges and regions of chaos on the surface of this icy moon. Then there were further Ganymede passages (G7/G8) and two Callisto visits (C9/C10) and in November 1997, at the end of the primary mission, another flyby of Europe (E11). During the first two years of Galileo's activities in its Jupiter orbit, the probe made 11 targeted flybys of the three outer moons of the planet with distances of 262 - 3100 km. They produced highly impressive image results as well as other interesting measurements.

Galileo's Europe Mission (1998/1999)

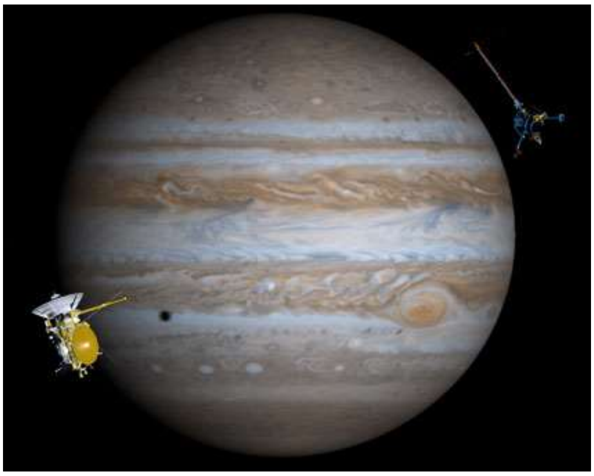
As Galileo was still working very well and there was enough data storage capacity and enough fuel available, after the end of the prime mission for the years 1998 and 1999 the Galileo Europa-Mission (GEM) was added (see GEM timeline in the annex below).

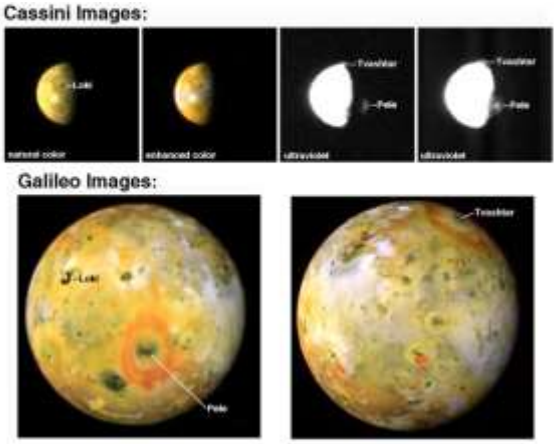
This moon, Europa, has been selected as the second major research object of the Galileo mission given the fantastic close-up images and concrete evidence of a possible ocean beneath its icy crust. Up until the beginning of the year 2000, the space probe flew past this moon ten times. With the beginning of the GEM, however, technical difficulties increased, and the radiation belt passages took their toll on the electronics.

Galileo Millennium Mission (2000/2002)

Then, from February 2000 onwards, JPL proclaimed the "Galileo Millennium Mission" (GMM), which brought about another ten flybys of Jupiter's moons by the end of 2002.

In a reliability marathon, the American-German probe showed superior technical and electronic operating qualities. The GMM began on February 22, 2000, with a perfect Io passage at a minimum distance of only 199 km, and the two Ganymed flybys in May and December also ran smoothly. The last encounter in December 2000 was particularly interesting because the new, big Cassini space probe was at that time passing straight through the Jovian system on its way to Saturn. For the first time, two instrument carriers were in the vicinity of Jupiter and its four moons at the time allowing cross-reference measurements and track propagation events - a premiere of a special kind, which was used extensively for the acquisition and comparison of scientific data and was also celebrated after its success (see GMM timeline in the annex below).





Galileo's fiery end

All Galileo sensors gradually developed problems leading to electronic dropouts caused by intense radiation. All that remained was to focus on a graceful termination of the mission, which was fixed for September 21, 2003, staging a fiery crash of the terrestrial ambassador into the clouds of Jupiter—a fitting exit for a spacecraft that had wrested so many secrets from the planet and its moons during a fantastic mission, despite the main antenna not deployed.

After 14 years of very successful research work, one of the most impressive and fruitful planetary research missions in the history of space exploration came to a furious end.

Right up to the last minute, Galileo radioed back interesting data about the nature of the radiation belts near Jupiter and its atmosphere.

Despite the crippled HGA antenna, Galileo transmitted more than 30 gigabytes of image data and other measurements to Earth during the transfer flight to Jupiter and during its 34 orbits around Jupiter, which is 95% of the data originally expected. The biggest contribution was the 14,000 images of the planet, its ring system, various small moons, and especially the images of the four large satellites Io, Europa, Ganymede, and Callisto. There were also countless particle, radiation, and field measurements from the other sensors. The scientists only had to do without the planned image and film sequences of the cloud movements in Jupiter's atmosphere and detailed spectra of the gas envelope due to a lack of data transmission capacities.

When appreciating Galileo's success, the interesting results of the entry probe, which was separated on December 7, 1995, during the prime mission when the space probe arrived at the giant planet should not be forgotten. Penetrating through Jupiter’s atmosphere for the first time a measuring device delivered data on the cloud cover of one of the large gas planets and gave the researchers a direct insight into the chemical and physical conditions as well as of the rapid increase in temperature and pressure with depth speeding towards Jupiter’s “surface”.

During the approach to Jupiter, Galileo also provided the first close-up images of two of the asteroids orbiting the sun between Mars and Jupiter (Gaspra and Ida).

But after 14 years of mission, Galileo's attitude control fuel was almost gone, and the robot's electronics had suffered badly over the years from the intense bombardment in Jupiter's radiation belts. Too many dropouts and malfunctions made meaningful work with the robot very difficult.

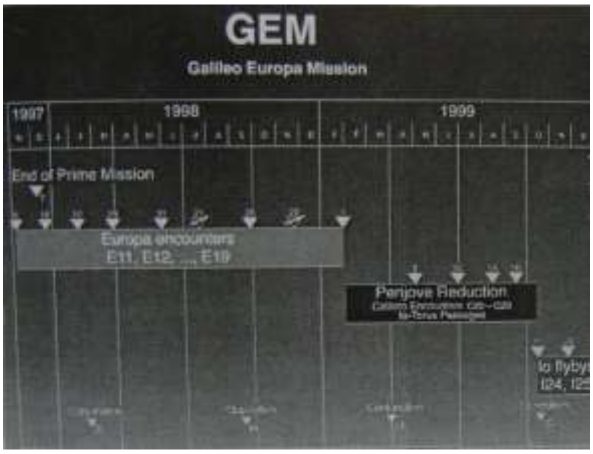
So, the Galileo orbiter on September 21, 2003, finally shot toward the planet at a flat angle at 48 km/s and plunged into the high cloud layers, only to burn up a little later. The official end of mission (EOM) was on September 21, 2003, at 18:57:18 UTC.

The burn-up of the spacecraft in the clouds of Jupiter was not only the symbolic end of a major space mission but this final maneuver was also intended to prevent Galileo from crashing uncontrolled onto one of Jupiter's moons one day in the distant future. Since these satellites, or the oceans that may exist under their surfaces consisting of ice shells - especially in the case of the second inner moon Europa - have recently been regarded as carriers of simple life forms, their contamination with terrestrial bio-organisms, which may have survived on the Galileo probe, had to be avoided. [4]

Galileo burns up in the Jupiter atmosphere. Image [6]

Annex

Timeline of the Galileo Mission [4]



References

[1] Joachim J. Kehr DLR-GSOC was appointed as German mission operations representative for Galileo at JPL 1980/81

[2] Galileo brochure JPL: JPL 400-15 7/79

[3] Werner Herzog „Jeder für sich und Gott gegen alle“ Hanser-Literaturverlag

ISBN 978-3-446-27399-3, August 2022

[4] Most of the text and GEM, GMM timelines translated and edited by J. Kehr from the book “Galileo, Cassini, Giotto” Wolfgang Engelhard ISBN 3-8171-1764-7, Verlag Harri Deutsch

[5] Wikipedia Galileo Project https://en.wikipedia.org/wiki/Galileo_project

[6] https://spaceflightnow.com/galileo/030921galileogone.html

October 2022, Joachim J. Kehr, Editor Journal of Space Operations& Communicator

https://opsjournal.org