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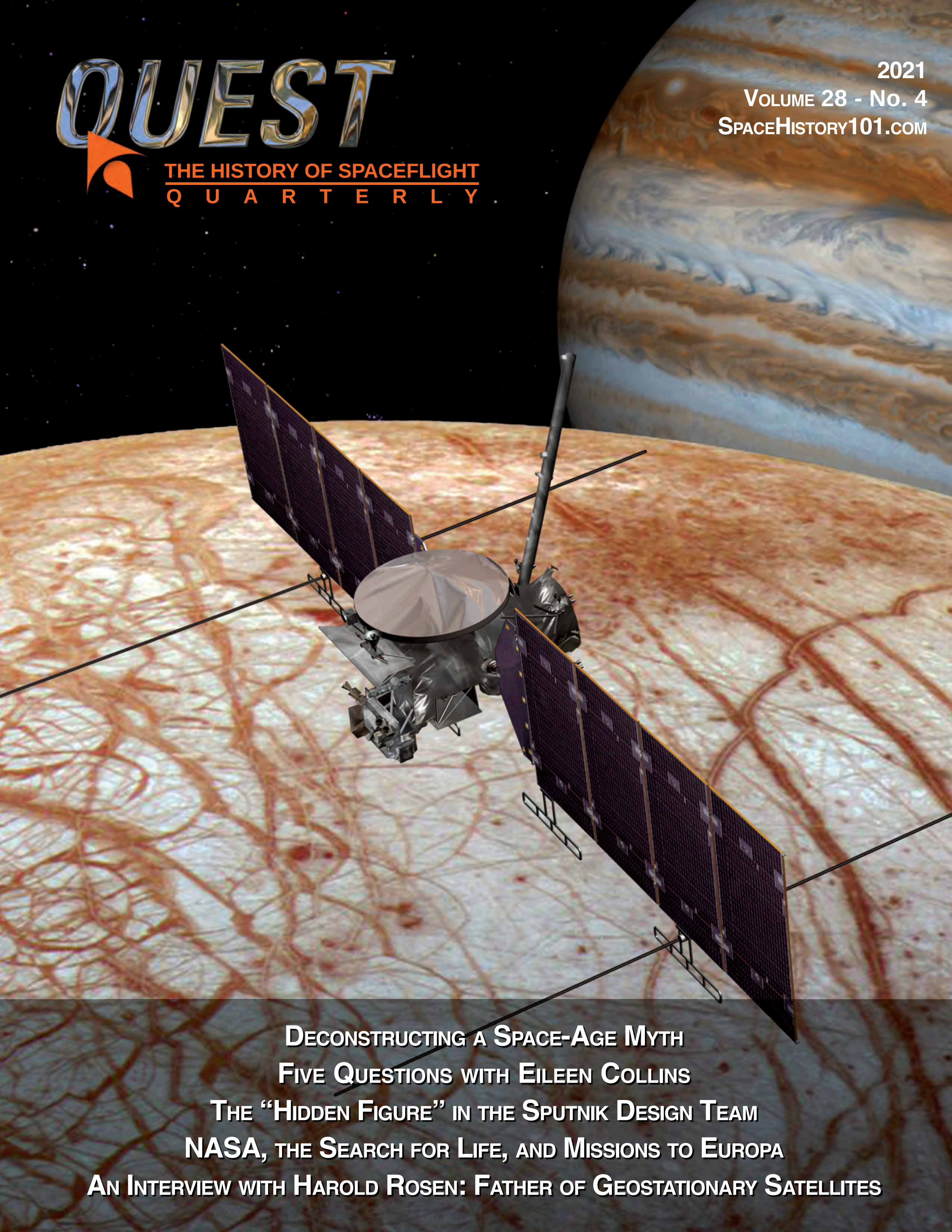

Deconstructing a Space-Age Myth

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The official illustration of *Europa Clipper* from about 2016 shows the mature configuration. The two long, high-frequency (HF) sounding radar antenna are parallel to the main body of the spacecraft, while the very-high-frequency (VHF) antennas for the radar are mounted on the solar panels. Integrating the panels and the radar proved challenging as the panels effectively become part of the antenna system. The cameras, spectrometers, and most other instruments are at the front of the spacecraft bus in this illustration. The high-gain antenna for communicating with Earth is on top, as is the magnetometer boom. Credit: NASA

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NASA, THE SEARCH FOR LIFE, AND MISSIONS TO EUROPA

By Michael J. Neufeld

In late 2024, the National Aeronautics and Space Administration (NASA) may launch *Europa Clipper,* a spacecraft designed to explore one of the Galilean satellites of Jupiter. The agency first began planning a Europa mission nearly three decades earlier, in 1996. The idea subsequently underwent a difficult evolution, including three outright cancellations. That the exploration of Europa survived at all has to be attributed to its primary objective: determining whether the moon, which apparently hides a deep ocean under its irradiated, icy crust, might be "habitable"—capable of supporting extraterrestrial life.

A long and circuitous origin is not unusual for US and European space science missions costing hundreds of millions or billions of dollars. Political and scientific consensus building is difficult, requiring the construction of coalitions in the scientific community and in the governments and legislatures involved, coalitions that need to be sustained and renewed, often for two or more decades. To succeed, a mission team must align science goals, science community enthusiasm, engineering development, and agency goals and programs, while navigating budgetary restrictions, changing technologies, and shifting political priorities.[1]

The origins and evolution of NASA Europa projects is thus a useful case study of American space science policy and mission formulation and how they are shaped by both science and politics. What makes this study particularly valuable to historians of science and space policy analysts is that it is primarily a twenty-first century story. It provides new insight on how the environment changed for NASA and the US space sciences since the year 2000, an era so recent it has been little studied by historians or political scientists. Sociologists and anthropologists have produced most of the scholarship on this era, but they study knowledge creation and group dynamics inside planetary science communities and spacecraft teams, not top-level policy.[2] Popular science writers have also discussed contemporary planetary exploration. Notable for the subject of this article is David W. Brown's *The Mission*, a very recent account of the origins of *Europa Clipper*. It does shed valuable light on the evolution of Europa mission concepts, primarily between 2004 and 2015, but it is written for a general audience and makes no pretense of trying to shape the scholarship on space science policy.[3]

In a 2014 article on the tortured emergence of the New Horizons mission to Pluto from 1989 to 2003, I posited a major change in the political environment around the year 2000, brought on by the introduction of competition in mission selection.[4] Those competitions brought new players inside and outside NASA into the business of proposing and building planetary spacecraft, notably the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland. This in turn increased political intervention in the budget process, shifting power away from NASA and the presidential administrations it reported to. The current study confirms those conclusions, but notes also the rise to commanding importance of the "decadal survey" in planetary exploration: a once-per-decade expression of the planetary science community's consensus recommendations about what missions to support. The first two planetary decadals in 2002/3 and 2011 both impelled and slowed the rise of an approved Europa mission. Equally critical was the intervention of a key member of Congress, Rep. John Culberson, who, unlike earlier congresspeople, was not motivated by the interests of his state or district. He simply wanted to make it possible to find life on Europa. His essential role in getting *Europa Clipper* funded, and pushing a *Europa Lander* to follow it, was in many ways an accident of history, a stroke of good fortune for those projects and for NASA. But his ability to force unrequested money onto NASA's budget under two presidential administrations is also a sign of the how much congressional intervention into the planetary sciences budget, and NASA's budget generally, has become the norm in the twenty-first century.

Europa Mission Origins

From January 1610, when Galileo discovered the four major satellites of Jupiter—Io, Europa, Ganymede, and Callisto—to 1979, when the *Voyager 1* and *2* spacecraft flew by them, little was known of Europa beyond its approximate size and mass, high albedo (reflectivity), and orbital characteristics. The smallest of the four Galilean satellites, Europa has a diameter of 3,122 km, slightly less than Earth's Moon. Its orbital period of 3.55 days is exactly half that of Io and twice that of Ganymede, as the three are locked in an orbital resonance. As a result of the constant gravitational interactions, the orbits of the three can never completely circularize. The slightly varying distance from Jupiter's great mass produces large tidal forces, injecting a lot of energy into their interiors, with the closest, Io, being most affected. Just before the *Voyager 1* flyby in March 1979, a prescient paper predicted Io's tidal heating, which was spectacularly borne out when the spacecraft imaged violent, ongoing volcanic activity on it.[5]

Voyager 1 passed at a great distance from Europa, so it was not until *Voyager 2* flew through the Jovian system in July 1979 that scientists at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, captured images that showed a complex array of streaks. Higher resolution confirmed that it was indeed a cracked ice ball with almost no impact craters. Based on the Moon and other solar system bodies, it was confidently expected that the frigid satellites of the outer solar system would be battered, ancient surfaces. The lack of cratering on Europa indicated that it must be resurfaced on a time scale of only tens of millions of years. Also enigmatic were the large number of linear ridges and cracks that covered the satellite. Both facts indicated that tidal flexure and heating, although less intense than it was on closer Io, could be a factor in shaping the ice shell covering Europa.[6]

In the wake of the Voyagers, scientists began discussing more seriously the possibility of an ocean under the ice shell that could be a habitat for life. New discoveries on Earth were expanding the range of what was considered habitable. By the mid-1970s it was clear that the extreme environments of Earth were host to a diverse range of microbes, including chemotrophs that derived their energy from chemical reactions, not sunlight-driven photosynthesis. In 1977, undersea explorers in the Pacific discovered the first "black smokers," deep-sea vents of volcanically heated water surrounded by specialized ecosystems of complex organisms, including crabs and giant tube worms, thriving at great pressures in total darkness. With no sunlight to power photosynthesis, the foundation of these communities are chemoautotrophic microbes that generate energy through the oxidation of inorganic sulfur molecules.[7]

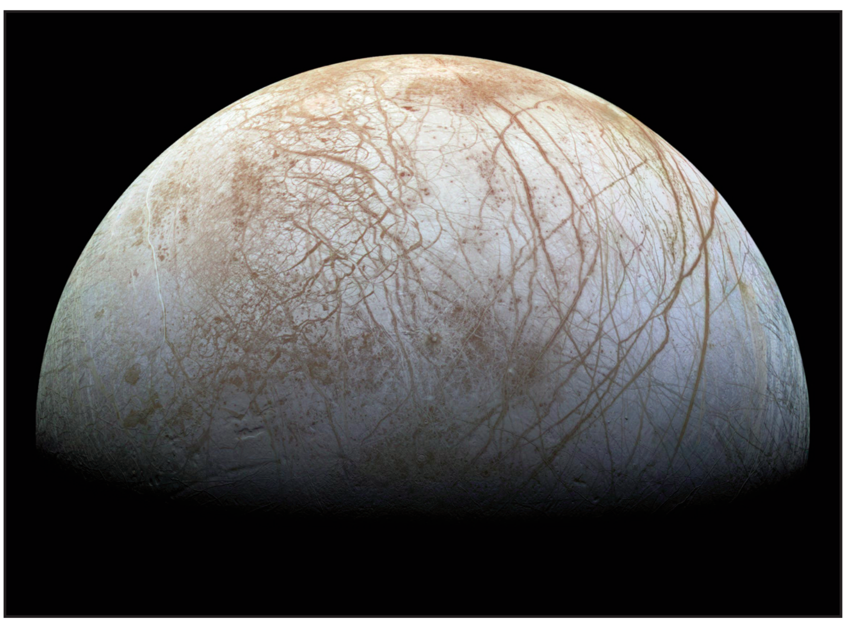

Figure 1: A mosaic of Europa, taken by the *Galileo* spacecraft, shows the extensive rifting of the icy surface and the virtual absence of impact craters. Credit: NASA

These discoveries together made it possible to reconsider the so-called Goldilocks model of a habitable zone limited to the inner solar system, and to imagine communities of lifeforms in distant icy bodies where there was little or no sunlight, but other potentially habitable energy gradients and, most importantly, ample liquid water. Science-fiction author Arthur C. Clarke, having talked to scientists who had speculated about Europan life, popularized the idea in his post-Voyager *2001* sequel, *2010* (1982). The planetary science community at large was slow to abandon, however, physical models that suggested that the roughly 100 km of water in Europa's outer shell would freeze solid on a timescale much shorter than the age of the solar system. But opinion began to shift as calculations of tidal heating supported the possibility—as yet unproven—that it could sustain a subsurface ocean over the long term.[8]

It was not until mid-1996 that NASA and the scientific community got new closeup Europa images and data. The *Galileo* spacecraft entered orbit around Jupiter in December 1995. Although the spacecraft suffered from a crippled main antenna, the limited data it was able to transmit quickly surpassed that of *Voyager*, providing over 90 percent of the images and information about Europa presently available. While the first three orbits targeted Ganymede and Callisto, the spacecraft obtained several good images of the smaller moon. Two close flybys in December 1996 and February 1997 increased the already high public and scientific enthusiasm for Europa, as they revealed in greater detail the lack of cratering, endless patterns of ridges, "cycloidal" fault lines in regular wave form, and bizarre "chaos regions" of jumbled terrain. NASA supported an extended mission focusing on Europa from late 1997 to late 1999, and another such mission led to a close encounter at the beginning of 2000. The spacecraft operated until September 2003, when it was sent to burn up in the Jovian atmosphere to prevent it from accidentally crashing into and contaminating Europa or another satellite.[9]

Several 1996 and 1997 images of Europa electrified the science team and the public, as they showed jumbled and rotated ice blocks, as if the surface had partially melted and the blocks had floated around in an open sea—a condition difficult to imagine or sustain in a hard vacuum at temperatures of 130 K (-143 C) or less. Exposed liquid water would simultaneously boil and freeze. These images, which resembled ones of terrestrial pack ice, fueled scientific speculation about the ice layer being very thin. A heated controversy soon developed within the planetary science community between "thin shell" and "thick shell" advocates. Richard Greenberg and his team at the University of Arizona, notably Greg Hoppa, Randy Tufts, and Paul Geissler, made fundamental contributions to understanding the tidal forces on the Europan ice shell, which, if over an ocean, could cause vertical movements as much as 30 meters, generating significant heating in the ice. They were able to relate tidal stress fields to the patterns of faulting and ridging. Greenberg became convinced that the shell must be only a couple of kilometers thick and the many double and triple ridges must represent periodic opening and closings of faults, exposing open water. The thick shell advocates, led by James Head's group at Brown University, notably Robert Pappalardo, Louise Prockter, and Geoffrey Collins, argued that an ice layer that thin could not support the topographic relief of a kilometer or more seen in some ridges, or the few craters that were several kilometers in diameter. They argued for a shell averaging about 20-30 km, with convecting "diapirs" of warmer, softer ice rising within it to transport heat from the ocean to the surface. The community came to accept this as its consensus position by the early 2000s, although Greenberg has never reconciled himself to that model.[10]

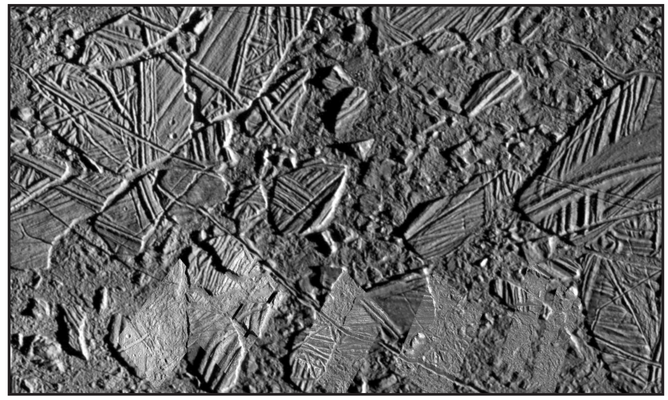

Figure 2: This image of Conamara Chaos, taken by *Galileo* in 1997, excited the science team. It shows kilometer-scale jumbled and rotated ice blocks often frozen in an undifferentiated matrix that looks like it partially melted. Credit: NASA

The crucial evidence for an ocean came from *Galileo*'s magnetometer. Close flybys detected a Europan field induced by Jupiter's extremely powerful magnetic field sweeping past the moon. The 3 January 2000 flyby confirmed the characteristics of the Europan field. In an influential paper, Margaret Kivelson of the University of California Los Angeles and her co-authors calculated that it was best explained by a subsurface conductor that matched the characteristics of a briny water ocean at least several tens of kilometers deep.[11]

The Rise and Rall of *Europa Orbiter*, 1996-2003

Years before all of *Galileo*'s data had been transmitted and digested, the earliest images had sparked the creation of the first proposed NASA mission: *Europa Orbiter*. In June or early July 1996, the agency's leader, Administrator Daniel Goldin, asked the question: "How quickly can we get a spacecraft to Europa to follow up on *Galileo* findings?"[12] There were two crucial contexts for this question: the evolution of extraterrestrial life studies, leading to NASA rebranding "exobiology" as "astrobiology," and Goldin's "faster, better, cheaper" campaign to transform the agency's planetary exploration program.

The emergence of astrobiology reflected both long-term changes in the study of extraterrestrial life and short-term agency needs. Over the long term, the discovery of terrestrial "extremophiles" and the new understanding of possible habitable zones opened up possibilities for extraterrestrial life beyond the familiar surface environments that had been exobiology's focus. In 1977, the same year the Galapagos Rift hydrothermal vent colonies were discovered, University of Illinois biologist Carl Woese announced that his chromosomal RNA research group had discovered that a number of exotic single-celled organisms, including thermophiles ("heat lovers") and halophiles (lovers of high salinity) were, in the words of historians Steven Dick and James Strick, "as different from [bacteria] as bacteria were from eukaryotes." In short, there was a third domain of life on Earth—a revolutionary discovery. The biological discipline eventually dubbed these organisms Archaea, indicating they were ancient lifeforms with origins in the earliest periods of the Earth's history. NASA-funded exobiology researchers began to include more terrestrial life studies.[13]

The renaming of the discipline took place in 1995. Post-Cold War budget cuts and Clinton Administration efforts to "reinvent" government led Goldin in January to initiate a review of the agency that did not exclude closing centers. The smallest, Ames Research Center in Northern California, was the most vulnerable. Center leadership and the Associate Administrator for Space Science, Wesley Huntress, concluded that Ames' expertise in extraterrestrial life studies provided it with a defining purpose. Huntress decided that rebranding these studies as astrobiology would help Ames and underline the evolution of the discipline. Later that year, he and Goldin announced the Origins Program, a creative repackaging of NASA cosmology, astrobiology, and exoplanet programs to make them more politically appealing. Origins got further impetus on 7 August 1996, when NASA held a news conference announcing that microfossils *may* have been discovered in a meteorite of Martian origin. Although that claim soon fell out of scientific favor, it bolstered the agency's political position and public profile. Thus, when the first *Galileo* Europa pictures were released six days after that news conference, the public, the media and the scientific community were already primed to see the Jovian satellite as an icy-crusted water world that might well hold life like that found in the Earth's deep oceans.[14]

The second context for the emergence of *Europa Orbiter* was Goldin's campaign to overhaul the agency's development of robotic spacecraft—best known by the slogan "faster, better, cheaper." The George H.W. Bush Administration had appointed him in April 1992 to shake up what it saw as a sluggish, underperforming bureaucracy. He survived the transition to President Bill Clinton in 1993 because of his reputation as a reformer, although he alienated many with his dictatorial style. Shortly after Goldin came into office, Huntress, then heading the Solar System Exploration Division of the Office of Space Science (OSS), told him about the nascent Discovery Program, which aimed to create small spacecraft for the inner solar system through competition. Since the 1970s, planetary exploration had come to be dominated by rare launches of big, expensive, JPL-built spacecraft like *Galileo*, thanks to limited budgets and increasingly ambitious missions. Reformers inside the planetary science community, notably Stamatios "Tom" Krimigis of Johns Hopkins APL, had pushed for more frequent missions with smaller spacecraft from a wider variety of institutions. Huntress agreed and felt that JPL, which had been assigned all NASA planetary missions since 1980, had become expensive, bureaucratic, and slow because it lacked competition. Thanks to a congressional compromise, the Discovery Program began in 1993 with two directed missions, one to Mars by JPL and one to an asteroid by APL, but thereafter would stage competitive selections. It became the poster child for Goldin's campaign for fast, risky, and innovative programs, and it was the starting point for the transformation of planetary exploration at NASA.[15]

While Discovery was an important context for the emergence of *Europa Orbiter* as a small, fast mission, it was *Pluto Express* that was directly influential on its early evolution. Discussions of how to get to Pluto began in 1989, in anticipation of *Voyager 2* flying by Neptune that August, completing its grand tour of the four gas giants of the outer solar system. The *Voyagers* could not reach Pluto, then still the ninth planet. In 1991, young engineers at JPL proposed a very light, relatively cheap spacecraft they called *Pluto Fast Flyby*. Goldin latched on to that idea immediately after he came into office, as it represented another example of the kind of innovation he wanted to foster. By 1996, it had evolved into *Pluto Express*, but was stuck in study mode, as Goldin and Huntress said the money was not available to formally propose it to Congress. When JPL was charged with studying a Europa mission in mid-1996, that spacecraft became the obvious starting point: *Pluto Express* was also designed as a small, cutting-edge vehicle for the frigid outer reaches of the solar system.[16]

A JPL team began studying how to morph it into *Europa Orbiter*. The few surviving documents do not discuss the choice of going into orbit around the moon, as opposed to multiple flybys, probably because it just seemed obvious at the time. It was axiomatic at NASA that the next stage after flying by a body was orbiting, allowing much longer observation. The scientific community also believed that good, consistent gravimetric data, using ground tracking of the spacecraft to map the moon's gravity field, could only come from a low, circular orbit. This data was the best way to meet the primary mission objective, to conclusively determine that there was an ocean. Such an orbit would also yield the best radar sounding data, a key method of establishing the character and perhaps the thickness of the ice shell. It would also enable global imaging and spectroscopic coverage at a uniformly high resolution.[17]

But that orbit posed two technological challenges that the Pluto spacecraft did not have, since it only flew by Jupiter to get a gravity assist. *Europa Orbiter* needed a large propulsion system to go into Jupiter orbit and later, Europa orbit. Secondly, orbiting the moon meant bathing the spacecraft in the trapped particle radiation of Jupiter's immense and powerful magnetosphere. The intense flux, primarily of electrons, was already a problem for *Galileo*, degrading the electronics and instruments and causing computer upsets that triggered spacecraft retreats into "safe mode." But *Galileo* flew in and out of the dangerous inner region of the Jovian magnetosphere, whereas *Europa Orbiter* would remain inside it once it entered orbit around the moon, a fundamental problem that would also challenge every subsequent mission concept that proposed circling the satellite. To have enough time to meet the mission's minimum scientific goals, the spacecraft would have to last at least thirty days, with the hope that it might make sixty to ninety. That meant using expensive, state-of-the-art, radiation-hardened avionics combined with shielding, which added mass. The more mass added, the larger the propellant load needed to slow the spacecraft into orbit.[18]

The challenges notwithstanding, NASA garnered enough political support from the President and Congress, thanks to the Mars rock and the *Galileo* images, to go forward with a "new start" in 1997. This was Washington, DC jargon for the insertion of a new space project into the president's budget request, which is typically released in February for the next fiscal year (in this case fiscal 1998, beginning 1 October 1997). Goldin and Huntress packaged three missions together as Outer Planets/Solar Probe (OP/SP). In addition to *Europa Orbiter,* the project included *Pluto Kuiper Express* (*PKE*), renamed to capture growing interest in the Kuiper Belt of icy bodies beyond Neptune, and *Solar Probe*. The latter had been paired with *Pluto Express* as the "Fire and Ice" missions in unsuccessful discussions with the Russians about providing launch vehicles. The logic of including Solar Probe was that it supposed to go to Jupiter too, in this case to use its gravity to throw the spacecraft into an orbit close to the Sun. As part of the rollout of OP/SP, in February 1997 the agency released the first description of what a Europa spacecraft might look like. It could include a small lander with a probe to melt through the ice, reflecting the excitement at the time about the possibility of a very thin ice shell.[19]

NASA Headquarters formed Science Definition Teams, made up of experts in the relevant scientific fields, to set research goals for all three OP/SP projects. In May 1998, *Europa Orbiter*'s committee defined its mandatory objectives as: "(1) determine the presence or absence of a subsurface ocean; (2) characterize the 3-D distribution of any subsurface liquid water and its overlying ice layers; [and] (3) understand the formation of surface features including sites of recent or current activity, and identify candidate sites for future lander missions." The desirable objectives were "(1) characterize surface composition, especially compounds of interest to pre-biotic chemistry; (2) map the distribution of important constituents on the surface; [and] (3) characterize the radiation environment in order to reduce uncertainties for future missions, especially landers."[20]

Landing on the surface was clearly very much on the minds of the committee, as it was likely the only way that evidence of ocean life, even just the chemical signatures of it, might be found. The 1998 NASA Space Science Enterprise Strategic Plan put a high priority on a Europa lander in the post-2005 period. As a result, JPL engineers continued advanced technology studies on ways to melt through the ice and put something into the ocean, even as scientific evidence of a thick shell grew, making such ideas improbable.[21]

Having clearly defined science goals and a federal budget allowed NASA to go forward with a combined Announcement of Opportunity (AO) in early 1999 for scientific instruments for the three missions. For Europa, the space agency got the backing of the Committee of Lunar and Planetary Exploration of the National Research Council, which concluded that, due to its astrobiological potential, "the future exploration of Europa

[has] a priority equal to that for the future exploration of Mars." According to scientists involved with Europa and Pluto research, the agency did select instrument teams, with principal investigators normally based in academia or NASA, but Headquarters never formally announced its decisions for those spacecraft. That reflected how quickly OP/SP's problems escalated.[22]

For *Europa Orbiter*, once project engineering began in earnest in 1998, the optimistic assumptions of two years earlier—a design based on the tiny, highly integrated *Pluto Express* and a launch to Jupiter as early as 2000—quickly went out the window. The earliest feasible launch opportunity became November 2003 and the spacecraft began growing in size and cost. Partly that reflected the unrealistic assumptions of the mid-nineties Pluto designs, with a target mass of 100 kg and only 7 kg of scientific instruments. *Europa Orbiter*'s instrument allotment eventually grew to a still-very-spartan 27 kg. But every other system added much more mass. By early 2000, the spacecraft was estimated at 1130 kg, and even *PKE*, which was to share common systems, was 447 kg. The difference was mostly the much larger propulsion system needed for *Europa*, plus extra radiation shielding.[23]

Galileo data made it increasingly apparent that the technological challenge of Europa's radiation environment had been underestimated. OP/SP was closely aligned with JPL's X-2000 program to invest in new technologies and software for planetary missions of the early 2000s. That included better radiation-hardened electronics, but X-2000's contractors struggled to meet deadlines and cost goals. An early specification was that *Europa Orbiter* had to withstand a dose of four megarads, half of it during a two-year tour of the Galilean satellites to get it into position for injection into Europa orbit, and the rest in the few months it was supposed to survive there. A study of whether "commercial off-the-shelf" electronics would work concluded that it would require a lot of shielding, meaning thick metal vaults that added too much weight. In short, expensive, radiation-hardened avionics from X-2000 were likely a necessity, plus shielding.[24]

John McNamee, named the Outer Planets/Solar Probe project manager in spring 1998, was also the project manager for *Mars Climate Orbiter* and *Mars Polar Lander* until their launch the following winter. When the two spacecraft were lost upon reaching the planet in September and December 1999, respectively, NASA endured a firestorm of public and political criticism. It ended Dan Goldin's "faster, better, cheaper" campaign; stung by the attacks, he became risk-averse. He dumped a lot of the blame on JPL, which took a serious hit to its reputation, at least temporarily.[25] The lab had to reexamine every flight program, which may explain why the Europa and Pluto science instrument selections were shelved.

McNamee, who had been saddled with very spartan budgets for the two Mars probes, pushed more conservative engineering designs on OP/SP, and after the failures, the pressure to be conservative increased. In practice, that meant mass gains and cost increases. Exacerbating the latter problem were rising launch expenses, caused by the delayed development of new launch vehicles, combined with *Europa Orbiter*'s weight growth driving it into the most powerful and expensive class of rockets. On top of that, new, more efficient radioisotope power systems, which converted the heat produced by decaying plutonium-238 into electricity, were faltering in development and growing in price. The older, entirely passive radioisotope thermoelectric generators (RTGs) did not produce enough power for the larger spacecraft.[26]

Over the course of 2000, OP/SP fell apart. In February, McNamee warned of the escalating budget problems for Europa and Pluto. *Europa Orbiter* would be postponed to the January 2006 Jupiter launch window because of launch vehicle and technical challenges. *Pluto Kuiper Express* was simplified and, while launch might be possible in late 2004, NASA Headquarters administrators warned in June that it could well be cancelled. Support for Pluto in the Clinton Administration's Office of Management and Budget (OMB) was weak, as excitement over the possibility of life on Europa had driven the creation of Outer Planets/Solar Probe in the first place. As a result, Headquarters had specified from the beginning that Europa should get higher priority and launch first. On 12 September Associate Administrator for Space Science Edward Weiler, who had taken over from Wesley Huntress in 1998, issued a "stop work order" for *PKE*. He was infuriated by the Mars 1999 failures and by the doubling of the combined Europa-Pluto runout cost from $654 million to $1.49 billion. Weiler blamed JPL for what he thought was deliberate underestimation to get "buy in" for a new start and then, after Mars 1999, for padding personnel and budgets out of engineering conservatism. He split away *Solar Probe*, which was really a space physics mission, leaving only *Europa Orbiter*. But he warned at the end of October that "it is not clear that the Agency can even afford" it.[27]

Meanwhile, the Pluto cancellation had prompted a wave of public and scientific protest. At the 31 October meeting of the scientific advisory committee to NASA's Solar System Exploration Division, to which Weiler spoke the above words by telephone, planetary scientists rebelled against this decision. A launch to Pluto was more urgent, in their view, because December 2004 was the last chance to use a Jupiter gravity assist to get there, otherwise it would have to wait almost a dozen years for the planet to come into position again. (As it turned out, there was one last chance in January 2006.) They also gave several scientific reasons why time was of the essence. A Europa mission, on the other hand, could be launched to Jupiter every thirteen months and the radiation technology challenge remained daunting. Stamatios Krimigis of APL proposed a competitive selection for a lower-cost Pluto mission, which led Weiler to ask APL for a quick study whether something could be done for under 500 million dollars.[28]

Dan Goldin had given Ed Weiler "until the end of the year to 'fix' the Outer Planets Program."[29] On 11 December, he wrote the Administrator advocating a Pluto competition, while "Europa [would be] put on a directed technology program and launches in ~2011 (Europa launch determined by $ available)." He gave a long list of reasons for prioritizing Pluto, many of them the scientists' arguments. He called it: "a far, far easier and 'cheaper' mission than Europa. I don't feel that a 2008 launch of Europa (by killing Pluto) is guaranteed. There is still some *unobtanium* in the system waiting to be 'discovered.'" Of the four arguments he gave against Pluto, the two most notable were that Europa was linked to the search for life, and: "Europa is the clear Administration and OMB priority, NOT Pluto."[30] Goldin approved it the next day. On 20 December, NASA released a draft Announcement of Opportunity for Pluto that would formally appear on 19 January 2001—not coincidentally the last full day of the Clinton presidency. The strategy appeared to be to get it out before the new George W. Bush Administration could stop it.[31]

While the administration changed, the budget examiners at OMB had not changed and still believed in the higher priority of Europa and its extraterrestrial life mission. In February, they cancelled the Pluto AO. Thanks to Krimigis, since 2000 the head of the APL Space Department, Senator Barbara Mikulski of Maryland intervened to force NASA to carry out the competition. The details of the Pluto battle have been treated elsewhere, but the bottom line is that in late 2001 Alan Stern of the Southwest Research Institute, allied with APL, beat JPL with a mission proposal called *New Horizons*. When the fiscal 2003 budget came out in early 2002, OMB again zeroed out Pluto. After the first planetary science decadal survey's recommendations were announced in summer 2002, putting a Kuiper Belt/Pluto spacecraft first on the medium missions list, Mikulski, a powerful member of the Senate Appropriations Committee, again inserted money. With the fiscal 2004 budget release in early 2003 the Bush Administration gave in and made it an official program.[32]

Weiler had asked for a planetary science decadal early in 2001, motivated in part by the Europa-Pluto controversy. The astronomy and astrophysics community had carried out such surveys since the 1960s through National Academy of Sciences' National Research Council. A panel of scientists would recommend, in a consensus report, which major astronomical instruments and space programs should be a priority in the next decade. Although National Academies committees had composed somewhat similar reports in other fields, including one on planetary exploration in 1994, the first formal space science decadal outside astronomy was in solar and space physics. Initiated in December 2000, it appears to have come from within the heliophysics community, rather than NASA. Weiler followed suit a month or so later, initiating a series of meetings and presentations that led to the July 2002 release of its recommendations. The single priority among large, non-Mars missions was a *Europa Geophysical Explorer* to "investigate the probable subsurface ocean of Europa and its overlying ice shell as the critical first step in understanding the potential habitability of icy satellites." It was an improved *Europa Orbiter*.[33]

Meanwhile, that project limped along at the Jet Propulsion Laboratory. In August 2000, due to the budget crisis, JPL had begun a thorough reevaluation of the project. An Independent Assessment Team reexamined the choice of orbiting Europa versus multiple flybys from Jupiter orbit, but concluded that the stated science goals could not be fully met with the latter. Proposals to save money and mass by changing spacecraft systems and instruments similarly compromised the science while saving little money. The team also reconsidered the decision to make a direct launch to Jupiter, as smaller rockets could put a larger spacecraft on trajectories using Venus and Earth gravity assists, at the cost of considerably lengthened transit times (about six or seven years versus two-and-a-half). While it did not save money, as the cost of operating the spacecraft over a longer time cancelled out the launch-vehicle savings, the group recommended such an approach as it increased "mass margins" in spacecraft development. However, it appears that this recommendation was not implemented, as a pair of 2002 documents mention a 2008 launch date, with arrival at Jupiter in 2011. By that point, the price for the mission had gone up to $1.2 billion.[34]

Earlier in 2002, however, the Bush Administration had deleted *Europa Orbiter* from the fiscal 2003 budget request in the name of saving money. Motivated no doubt by the mission's endorsement in the planetary decadal, Congress moved in fall 2002 to put the money back in.[35] But OMB cancelled *Europa Orbiter* again in early 2003, but for a different reason. A new administrator, Sean O'Keefe, had come into office with much more ambitious plans, ones that would put every other planetary spacecraft project in the shade.

Battlestar Galactica: Jupiter Icy Moons Orbiter (JIMO), 2003-2005

When Dan Goldin arrived at Headquarters in 1992, he dismissed large, complicated and expensive robotic spacecraft as "Battlestar Galacticas," after the monstrous spaceship in a television science-fiction show.[36] He applied that label to *Cassini* in particular, a Saturn orbiter launched in 1997 that paralleled *Galileo*'s mission at Jupiter. There were supposed to be no more spacecraft of Cassini's size in the new "faster, better, cheaper" world he was creating. But, as we saw, the Mars 1999 failures derailed that campaign, and *Europa Orbiter* grew from a small, innovative spacecraft into a large, heavy, and expensive one.

The Discovery Program, the primary vehicle for creating small planetary spacecraft, survived the crisis of Goldin's program, and it survived Goldin, who resigned in November 2001. While costs grew with increasing engineering caution, Discovery successfully embedded competition inside NASA's mission selection process, opening planetary spacecraft projects to institutions outside JPL, above all APL. That was confirmed by the battle over *New Horizons*. With the funding pushed through by Mikulski, the agency also created a mid-sized competitive planetary program, New Frontiers, with the Pluto spacecraft being the first in line. New Frontiers projects were initially capped at about half-a-billion dollars. "Flagship missions," as NASA labelled the largest class of spacecraft since the 1990s, were one to several billion dollars. Yet *Jupiter Icy Moons Orbiter* was far larger than that. It really was a Battlestar Galactica.

In December 2001, the Bush Administration made Sean O'Keefe NASA Administrator. He had been deputy director of the Office of Management and Budget since January. Beyond straightening out the space agency's budget processes, which had led to massive overruns in the *International Space Station* program, he had one big idea: put nuclear reactors in space. O'Keefe was the son of an engineering officer in the nuclear navy, and was Secretary of the Navy in the last year of the George H.W. Bush presidency, so it was very much a personal passion. But he tapped into the enthusiasm of NASA engineers who missed the ambitious plans of the 1960s, which included a nuclear rocket program terminated in the mid-seventies. Under O'Keefe, the space nuclear reactor became a technology in search of a mission.[37]

Since there were no ambitious human spaceflight plans at the time beyond the shuttle and station, the planetary decadal's recent endorsement of Europa as a flagship mission became the focus of the nuclear project. After an "Eight Day Study" in August 2002, Ed Weiler's Office of Space Science funded three assessments of a Jupiter Icy Moons Tour, apparently using electric rocket engines (which use electrical fields to expel ions and electrons at very high exhaust velocities but very low thrust) to carry out a mission more ambitious that *Europa Orbiter*. The latter was already to fly by Ganymede and Callisto to shape its orbit around Jupiter prior to orbital insertion at Europa. A large ambitious spacecraft could investigate all three more thoroughly, and with enough power, could fly in and out of orbit around each of them, ending at Europa, where the radiation would be the strongest. JPL studied a nuclear-electric spacecraft versus non-nuclear options and, not surprisingly, O'Keefe picked the far-more-capable reactor one. He directed JPL in November to produce, "in 10 weeks, a project plan, an acquisition strategy and plan for an industry RFP [Request for Proposal], so that a *JIMO* project could be recommended to the Administration for submission in the FY04 budget request to Congress." JPL and Headquarters staff briefed O'Keefe on 31 January 2003, and he approved.[38] The very next morning, the Space Shuttle *Columbia* burned up on reentry, killing seven astronauts, which would ultimately contribute to the project's short life by forcing the Bush Administration to reevaluate NASA's priorities.

Because *JIMO* was sustained by the Administrator's enthusiasm, and that of rocket engineers and space advocates, however, the expense and difficulty of building a huge spacecraft based on radically new technology was mostly ignored in the first eighteen months of its existence. Congress quickly jumped on the *JIMO* bandwagon. It had not finished the fiscal 2003 budget on time—now a normal occurrence—so it approved a new start immediately and appropriated twenty million dollars for the rest of that fiscal year. On 18 March, Weiler signed the order launching the Prometheus Project, as the overarching nuclear program was now entitled, which allowed JPL to formally constitute the project office. John Casani, a legendary JPL engineer from the earliest days of planetary exploration, came out of retirement to be Project Manager. He shared the excitement of many over the creation of a nuclear technology that could fundamentally change human space capability.[39] The aerospace industry, for its part, salivated at the prospect of a multi-billion-dollar program, quite unlike most planetary spacecraft, which cost a few hundred million and were often built in-house at JPL or APL.

Jupiter Icy Moons Orbiter grew into a gigantic vehicle with a mass of 36,000 kg and a length of 43 m. It would have a science payload an order of magnitude larger than anything built before: a 1500 kg Mission Module with 470 kg of instruments and tens of kilowatts of power, whereas *Europa Orbiter* meager 27 kg of instruments ran on 27 watts (the power of a small light bulb). To figure out what to do with all that capability, NASA tasked the Europa Science Definition Team in March 2003 to produce a new report. In February 2004, it gave the overarching goal as: "Explore the icy moons of Jupiter and determine their habitability in the context of the Jupiter System." The three areas of focus would be "Oceans, Astrobiology, and Jupiter System Interactions." One quarter of the mission module (375 kg) could be devoted to some kind of small Europa lander. Studies determined that one could get a probe that could operate for three to fourteen days on batteries. A seismometer could produce key information on the ice shell and spectrometers could explore the chemistry of the surface ice and look for the presence of organic chemicals.[40]

The planetary science community's recollections of *JIMO* vary considerably today. To Bob Pappalardo, then at the University of Colorado and now Project Scientist for *Europa Clipper*, the project "seemed ridiculous to the [science] community." However, there was "doublethink, in 1984 terms…of realizing it's ridiculous, but at the same time saying, oh well…let's think about what it would be like if we had all this power to run a spacecraft."[41] His friend and ally in the Europa ice shell debate, Louise Prockter, now a senior scientist at APL, remembers *JIMO* only positively. It was "this incredibly exciting, giant nuclear-powered spacecraft," which was supposed to be just the first of "whole fleet" to the outer solar system. She argues that the *JIMO* science definition process helped

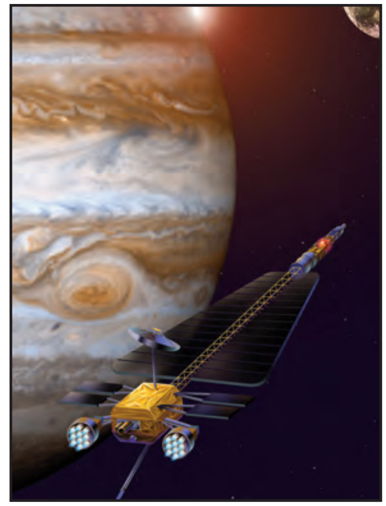

Figure 3: Artist's concept of the gigantic Jupiter Icy Moons Orbiter. The electric rocket engines in the foreground are powered by a nuclear reactor at the far end of the boom. A series of panels would have been necessary to radiate away the reactor's heat.
Credit: NASA

build the outer planets scientific community.[42] Curt Niebur, then the JIMO Program Scientist at NASA Headquarters and now the Discovery and New Frontiers Program Scientist there, recalls it as "a bit of wild ride…. It was the complete antithesis of every kind of planetary science mission we'd ever done," with size, power and data rates:

> two to three orders of magnitude beyond what Planetary had ever worked with. And it was challenging to communicate to the people that were big proponents of this [project] that you can't just flip a switch on the planetary exploration community when it's been going in one direction for 50 years, to miniaturize, to reduce their resource needs, and then expect them to just do a 180 and fully embrace and execute on something like this. It's

sociologically difficult, and it's technically difficult as well.[43]

To Ellen Stofan, then an independent planetary scientist and now the Under Secretary for Science and Research at the Smithsonian, "*JIMO* came out of nowhere" as it was not discussed in the decadal survey process. "It was a great mission," but "just so far beyond" what could be afforded "in any kind of budgetary constrained environment."[44]

An interesting non-scientist perspective comes from John Casani, the JIMO/Prometheus project manager, now retired again. He claims that the program was "doomed to fail…because they [the scientists] were excluded from the process of selecting the mission, and they thought it was something that…O'Keefe…just shoved down their throat, and that they were going to have to bear the expense of it, because the money to develop it was going to come out of science projects." Casani admires O'Keefe for his emphasis on technology development and dislikes what he sees as the domination of the agency's robotic program by scientists and their decadal process. "I think the science community, in some ways, has hijacked the program…you know, the 'S' in 'NASA' does not stand for 'science.' It stands for 'space.'" He thinks balance has been lost as the robotic program is only about science and not about technology development or public engagement.[45] Yet the agency has never lost interest in either technology or publicity and, as we have seen, some scientists were excited by the program and were not opposed to a nuclear-powered spacecraft if the money was available. That was the question that hung over *JIMO* and Prometheus from the beginning, was it affordable?

When the program was initiated, the estimate was three billion dollars over the first five years, and nine billion up to a projected *JIMO* launch in 2012. These figures already raised red flags in the science community. But O'Keefe was determined to push it through and told Casani to go on, whatever the cost. The Prometheus nuclear project never fit very comfortably in the Office of Space Science and in early 2004 O'Keefe transferred the primary responsibility to the Office of Exploration Systems, which was responsible for future human spacecraft. Admiral Craig Steidle headed it. Casani says that the JPL Director, Charles Elachi, told him: "don't give him [Steidle] a number until you've got it good and handled—till you're pretty sure you know what it's going to be…because you're going to get stuck with it.…I had…my number, it was $14 or $15 billion."[46]

The transfer of Project Prometheus was part of a shake-up and reorganization of NASA Headquarters after the *Columbia* disaster. Taking advantage of the *Spirit* rover Mars landing, President George W. Bush announced his Vision for Space Exploration on 14 January 2004: the Shuttle would be retired after the space station was complete and the human program would be redirected to the Moon and Mars. O'Keefe subsequently reorganized NASA Headquarters into mission directorates. The science component of *JIMO* would remain the responsibility of the new Science Mission Directorate (SMD), which combined OSS, the Office of Earth Science, and the Office of Biological and Physical Research.[47]

Thanks to O'Keefe's protection, Prometheus continued relatively undisturbed in 2004. After over a year of working with NASA, in March the Energy Department assigned the space nuclear reactor development to its Naval Reactors office, which was responsible for Navy ship and submarine units. On 5 August, NASA and Naval Reactors formalized the alliance with a memorandum of understanding. The next month, following two rounds of aerospace industry studies, the agency awarded the spacecraft contract to Northrop Grumman for $400 million through 2008.[48]

Yet the technical challenges remained daunting. Bruce Campbell, a National Air and Space Museum geophysicist specializing in planetary radar, recalls a briefing by an engineer from Energy, who explained the challenge of dissipating the waste heat of the powerful, 200-kilowatt *JIMO* reactor. That unit was at the end of a long boom and behind a shield to keep the radiation away from the spacecraft. Along the boom was a massive, arrow-shaped radiator array with pipes circulating liquid sodium at hundreds of degrees C. When the speaker described the jitter from that fluid circulation, Campbell concluded right then that JIMO was unworkable as a science platform. Curt Niebur thinks that was a solvable technical problem, but "what concerned me most about *JIMO* was we were piling extreme technical challenge upon extreme technical challenge…[We realized that] this has become so complex that getting it to…the 99 percent reliability level that we require is going to make it even more complex. And that's when the downward spiral began." The budget estimate soon reached sixteen billion dollars. *JIMO*, now renamed *Prometheus 1*, was so huge it would have to assemble itself in orbit after three separate launches on a heavy-lift rocket that did not yet exist—another five billion dollars.[49]

Then O'Keefe announced in December 2004 that he was leaving to become a university president. Perhaps he was influenced by budget talks with OMB, which had already targeted the project for major cuts. In February 2005, the Bush administration's fiscal 2006 budget "indefinitely delayed" *Prometheus 1*. NASA's budget increased, but only enough to support the new Constellation Program to take humans to the Moon and Mars. As Administrator, Bush named rocket engineer Michael Griffin, who soon directed Prometheus to focus on a small reactor to support human exploration. That idea did not last six months. Pressed by the budget realities of getting the Shuttle flying again, completing the station and funding new human spacecraft and launch vehicles, Griffin cancelled Prometheus entirely at the beginning of the next fiscal year—1 October 2005. In two-and-a-half years, it had already expended $463 million—enough to pay for a small planetary mission.[50]

With hindsight, it is apparent that JIMO/Prometheus was doomed from the outset. Sustained primarily by the technological enthusiasm of O'Keefe, aerospace engineers, space advocates, and some members of Congress, the project was so ambitious that it bordered on utopian. It resembled the US's nuclear-powered airplane boondoggle of the 1950s in its gigantomania. Instead of starting with a small demonstration project, *Prometheus* began with a powerful reactor and a complex and difficult mission. It was a wild pendulum swing from Dan Goldin's "faster, better, cheaper." *Prometheus* was able to use the planetary science decadal's endorsement of the search for life on Europa to keep scientists onboard and strengthen congressional support, but it gradually became clear that it was primarily an excuse for a massively expensive technology project. Barely two years after the end of *Europa Orbiter*, another mission to the Jovian moon had gone under. It would be an uphill battle to get a new one started.

The Slow Rise and Sudden Death of *Jupiter Europa Orbiter*, 2005-2011

In his May 2005 testimony to the Senate Appropriations Committee, Griffin delivered, a "stinging critique" of *JIMO*, in the words of one journalist, but he explicitly endorsed a Europa mission "in a year or two as part of our science line, but we would not, again would not, favor linking that to a nuclear propulsion system." Supporting a new spacecraft to Europa drew praise from the scientific community. It certainly excited the Outer Planets Assessment Group that Curt Niebur had helped organize in late 2004 as *JIMO* fell apart. Its purpose was to provide scientific guidance on future projects to that region of the solar system.[51]

Immediately before or after Griffin's comments, the Science Mission Directorate issued a *Solar System Exploration Roadmap* that put Europa as its planetary flagship mission priority for 2005-10, in line with the decadal. SMD also ordered a "45 Day Study" of a *Europa Geophysical Explorer*. It directed Venus and/or Earth gravity assists for the trajectory to Jupiter, presumably to see how much payload would be gained over a direct launch. As a result, the instrument allotment in the study came out at 150 or 180 kg, including a much larger radar sounding antenna than was the case for *Europa Orbiter*. The plan also called for a small lander, like that conceived for *JIMO*. JPL used internal funds for a follow-up study from November 2005 to February 2006. Calling the spacecraft concept *Europa Explorer,* the report writers argued that the minimum radiation survival time in Europa orbit could be increased from thirty to ninety days, thanks to better radiation-hardened electronics combined with selective shielding.[52]

The goodwill between NASA and the planetary scientists evaporated, however, when the fiscal 2007 budget request came out in February 2006. SMD got a small increase, but it allocated no money for Europa. Sustaining existing missions consumed the budget, notably the increasingly expensive *James Webb Space Telescope*, the planned successor to the *Hubble Space Telescope*. Money could not come from elsewhere, as NASA had large, unfunded costs to put the shuttle back in service and needed money to finish the space station, Griffin asserted. Moreover, the agency had to develop the new vehicles for Constellation, which he had focused on a Moon landing by 2019. Despite Bush's 2004 Vision, the president and his administration did little to increase the agency's budget to pay for it.[53]

The NASA five-year plan released at the same time cut three billion dollars from the science budget over that period, primarily by greatly decreasing the rate of growth. That implied that a *Europa* new start before 2011 was unlikely unless Congress intervened. "Scientists are in an uproar," stated one *Space News* article; another was titled "Angry Scientists Confront NASA Officials." Some testifying before the House spoke in favor of small spacecraft over flagships, which had the unintended effect of undercutting *Europa*—the projected spacecraft weighed over 7,000 kg fueled. The largest space advocacy organization, The Planetary

Society, launched a Save Our Science campaign and several sympathetic congresspeople said they would try to increase SMD's appropriation. Republican Rep. John Culberson of Texas, notably, spoke out strongly, in one of the first times he became publicly visible on the topic of Europa and space science. In the end, there was some redistribution of funds inside NASA's budget, but no significant increase and no new start for *Europa* in 2006.[54]

In order to put the project on a stronger footing, JPL recruited Bob Pappalardo from the University of Colorado to be the lead scientist for Europa. It also proposed a Europa alliance to APL, in a move to neutralize rivalry and bolster the support of Maryland's congressional delegation, notably Sen. Mikulski. According to JPL Director Elachi, he also appreciated APL's technical capability at a time when JPL's workforce was taxed with other missions. After initial two-way discussions and consultation with NASA Headquarters, the two institutions signed a memorandum of agreement on 15 September 2006, giving the Hopkins laboratory 20 to 25 percent of Europa work. (While APL was roughly the same size as JPL, around 5000 people, it mostly worked for the navy; its Space Department was considerably smaller than JPL.) This alliance was a testimony to how much competition had changed NASA planetary exploration since the mid-1990s. Missions were no longer just assigned to the Pasadena center and APL was no longer just the annoying upstart that had stolen the Pluto mission. It was now a major player in NASA space science.[55]

That same year, James Green, a magnetospheric physicist at the Goddard Space Flight Center in the Maryland suburbs of Washington, DC, took over SMD's Planetary Science Division (as Solar System Exploration had been renamed). He came into office thinking that he would make Europa a new start fairly quickly. It did not turn out that way. Not only was SMD going through a period of restricted growth, the Webb telescope's overruns and delays posed a continuing problem, and the launch of *Mars Science Laboratory* (*MSL*), which would eventually land the *Curiosity* rover on the red planet, had to be delayed two years, costing hundreds of millions more. Even without these budgetary woes, there was still the Europa mission's price tag. In March 2007 NASA reported to Congress that it would cost two to four billion dollars.[56]

In order to keep the project going, Green and Curt Niebur funded a four-way competition in 2007 for outer-planets proposals. As Niebur explains it:

> It was time to do more in-depth studies, but nobody was willing to just say: let's study a Europa mission, because there was still a lot of bad memories from *JIMO* and from *Europa Orbiter*. So instead, what Jim [Green] and I put together was, we'll sort of do a competition, then. We'll study a Titan mission, because we were getting data back from *Cassini* showing Titan was extremely cool. We'll do one for Europa, and we'll do one for Ganymede. And then at the last minute, given the results we were seeing about Enceladus and the surprises there, we added Enceladus to the mix as well.[57]

The latter was a small satellite of Saturn that was apparently spewing out water from its south polar region, indicating that it too might have a subsurface ocean. The *Cassini* spacecraft had reached Saturn at the end of 2004 and it dropped off the European Space Agency's *Huygens* probe, which landed on the giant moon Titan in January 2005. As a result, the Saturnian moons were now in competition with Jovian ones for the next outer planets flagship mission.

The four teams delivered their reports in August 2007, four months after New Horizons Principal Investigator Alan Stern became associate administrator for science. In December, he decided that Europa and Titan would compete in a second round of more detailed studies. The two survivors also expanded to incorporate parts of the Ganymede and Enceladus missions, plus significant participation by the European Space Agency (ESA) and possibly also Japan. One of the proposals in the ESA's ongoing competition for a large science mission was Laplace, a Jupiter system tour ending in Ganymede orbit. That suggested a natural synergy: both it and NASA's spacecraft would fly through the Jupiter system and examine several moons before ending up in orbit around Ganymede and Europa, respectively. The JPL-led Europa spacecraft became the *Jupiter Europa Orbiter* (*JEO*); the ESA spacecraft *Jupiter Ganymede Orbiter*. NASA and ESA labeled the combined effort the Europa Jupiter System Mission. The competing Titan Saturn System Mission, led by APL with JPL participation, included Enceladus flybys plus an ESA Titan lander and balloon (Titan is the only satellite with a major atmosphere).[58]

Based on SMD's future budget, which was still saddled with the large *Webb* and *MSL* overruns, Stern instructed the teams to cap NASA mission cost at $2.1 billion, not including foreign contributions. That meant potentially painful cutbacks in the Europa and Titan designs. But Stern resigned in March 2008 when NASA

Administrator Griffin overruled his cuts to the Mars program. Griffin pulled Ed Weiler, who had become director of the Goddard Space Flight Center in 2004, back to Headquarters for a second stint as associate administrator. (Astronaut Mary Cleave had held the position 2004-2007.) Weiler, seeing perhaps the limits Stern's number put on the science, told Green and Niebur to let the teams to determine the "sweet spot" between cost and science return, with launch dates around 2020. The result was that both the Europa and Titan projects came in around three billion dollars for NASA. With the stretched-out timelines, that decision pushed the major costs well into the next decade and put the winner in contention for the next planetary decadal survey in the early 2010s.[59]

In February 2009, NASA announced that JEO was the winner and could be launched in tandem with the European spacecraft. According to Louise Prockter, the Europa science lead for APL, the team was worried that their project was not nearly as exciting as the Titan one, although they had the astrobiology focus and the 2003 decadal endorsement on their side. According to Niebur, the Titan proposal was a little too complex and risky, with its three elements, two of them European. *Jupiter Europa Orbiter* could fly separately even if the ESA spacecraft failed or was cancelled (it had not yet been officially selected). Over the course of the 2008 studies, the Europa team also focused on reducing complexity and risk in their proposal, states Niebur. It probably did not hurt that JPL already had been studying Europa missions for twelve years.[60]

From 2009-2011, both space agencies funded their teams to keep developing their spacecraft concepts preparatory to a formal budgetary commitment. But on the US side, the next planetary decadal survey, which began committee meetings in 2009, loomed as critical to JEO's future. In September 2010, it became a "pre-project," meaning that it was only one step away from "phase A," the official start of the program. But in March 2011, the National Academy of Sciences published the baseline survey recommendations for 2013-2022. The result shocked the Europa team, who assumed that they would again be first among flagships. Instead, the top recommendation was the *Mars Astrobiology Explorer-Cacher*, which was to cache samples on the surface for later return to Earth. It eventually became the Mars 2020 project that landed the *Perseverance* rover in 2021. *Jupiter Europa Orbiter* was second priority, but came in for criticism: "its cost… is so high that both a decrease in mission scope and an increase in NASA's planetary budget are necessary to make it affordable." The survey's outside cost estimators put it at $4.7 billion, far above the roughly $3.5 billion estimated by the JPL/APL team, something Pappalardo questions to this day.[61]

A key difference between the two decadals was that in the first, Mars had been a separate category not competing with other missions, based on the way the planetary program was organized at the time. On this occasion, the agency requested one list. *JEO* was saddled with the apparently unacceptable cost, making Mars the preferable option. By the time the decadal survey came out, the Great Recession was pummeling the federal budget, Webb telescope overruns continued to worsen, and Obama's NASA Administrator, former astronaut Charles Bolden, was implementing Administration priorities to cut planetary science in favor of the climate-change-focused Earth sciences. Jim Green, then the head of the NASA planetary division, recalls that, in the fiscal 2012 budget request that came out just before the decadal's announcement, "I lost $370 million in one fiscal year…Which was about 23 or 24 percent of my total budget."[62]

For JEO, the one-two punch of the decadal and SMD's money woes meant that number-two priority was no priority. And the bitter pill for the team included instructions to downsize and rethink the whole JEO concept. The aftereffects for Green were also unpleasant. The joint Europa Jupiter System Mission was dead, but the budget cuts plus the decadal's Mars recommendation meant that NASA also had to pull out of Europe's

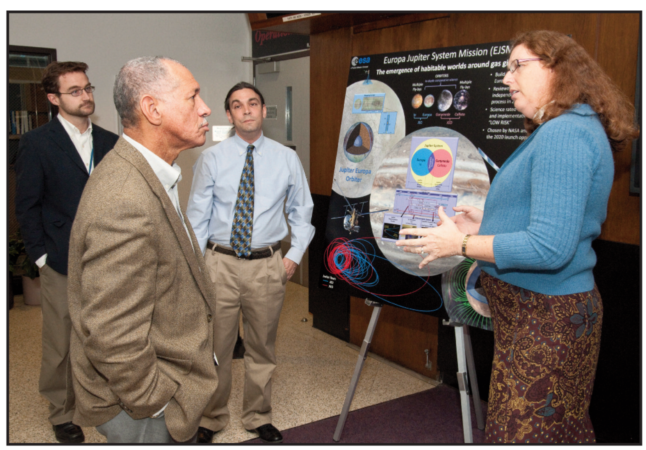

Figure 4: JEO Project Manager Karla Clark (right) briefs NASA Administrator Charles Bolden (second from left) at JPL on the Europa Jupiter System Mission, 29 October 2009. Behind them are standing Kevin Hand (left), later the Project Scientist for Europa Lander, and Robert Pappalardo (third from left), Project Scientist for *JEO* and later for *Europa Clipper*. Credit: JPL/NASA

Figure 5: James Green, director for Planetary Science in SMD, helps kick off the "Seeking Signs of Life" Symposium on 14 October 2010, in Arlington, Virginia. Credit: NASA

ExoMars program. "ESA was very upset with me…I feel horrible about it still." He and two colleagues had to fly to Paris and tell their Europeans counterparts about the latest NASA betrayal produced by political decisions made over their heads (it certainly was not the first). ESA made a deal with the Russians to launch *ExoMars* and the *Jupiter Ganymede Orbiter* was reformulated as the *Jupiter Icy Moons Explorer* (*JUICE*), which incorporated two Europa flybys before focusing on Callisto and Ganymede. It was confirmed as a mission in May 2012. But *Jupiter Europa Orbiter* was dead. It was back to the drawing board for the third time in ten years.[63]

The Divergent Fates of *Europa Clipper* and *Europa Lander*, 2011-2020

In the decadal's aftermath, Jim Green and Curt Niebur fought to keep a Europa mission alive. In April 2011, after convincing Ed Weiler not to cancel it altogether, they funded a one-year JPL-led study of three options: a Europa orbiter, a multiple flyby spacecraft (which would stay in Jupiter orbit like *Galileo*), and a lander. The estimated cost had to be under $2.25 billion. As part of the process, the Europa Science Definition Team reviewed the scientific strengths and weaknesses of each option. Niebur gives the scientists a lot of credit for doing the hard work of throwing out "nice to have" objectives and focusing on what was important—understanding the moon's structure and its potential habitability. By the time the study was completed in 2012, it was clear that, at $2.8 billion, a lander was too expensive. The stripped-down orbiter came in cheapest at $1.7-1.8 billion, whereas the "multiple-flyby" mission was $2.1 billion, with the Pappalardo-led team hoping they would eventually get both. The final report, dated 1 May 2012, recommended the more expensive flyby option as having "the greatest science return per dollar." Further studies were carried out over the next few months, before NASA felt ready to reveal the findings in open meetings. The favored concept was now called *Europa Clipper*, and the study team also recommended solar panels instead of radioisotope thermoelectric generators, as it would free up mass for a high-resolution camera and more instruments.[64]

Rethinking both the mission profile and the power system was a Europa spacecraft design revolution. Every mission concept that had advanced so far had some kind of nuclear power source and ended in Europa orbit. Although the scientific advantages of the latter remained—a global data set at the same resolution and gravity science that would best determine the thickness of the ice shell and the depth of the ocean—several things drove this profound rethink. First and foremost, not orbiting ameliorated the radiation problem, as the spacecraft dipped in and out of the intense zone of the Jovian radiation belts. This significantly reduced the risk of mission loss and lengthened the spacecraft's lifetime, allowing it to collect more data. It also eliminated the additional propulsion system mass needed to get into orbit.

These advantages were long known from multiple JPL studies of both the flyby and solar options, so what changed? Technological advances over the two decades of studying and restudying the Europa challenge was a significant factor. Better radiation-hardened computer chips and improved solar cell performance in conditions of extreme cold and intense radiation made a lighter, solar-powered vehicle more feasible. *Juno*, a JPL spacecraft to study Jupiter itself, rather than its moons, was a major influence. Chosen in 2005 as the second New Frontiers medium-priced planetary mission (after *New Horizons* to Pluto), it was launched in 2011 and would reach the planet in 2016. It was the first outer-planets spacecraft to not use a nuclear power source; its solar cells provided a baseline for the Europa flyby study. While *Europa Clipper* officially remained powered by RTGs until mid-2014, further examination of the engineering tradeoffs, and also of the limited US supply of plutonium 238, confirmed the recommendation to go solar.[65]

As for the flyby decision, *Cassini* was important. It had made multiple Titan passes since 2005, allowing a buildup of radar, imaging and spectroscopic coverage of Saturn's largest moon. It undermined the traditional assumption that orbiting the body was the only way to ensure global coverage. The operational challenges of orbiting Europa were an additional factor, notably for Jim Green. Sounding radar creates copious amounts of data that is virtually incompressible through software routines, meaning that it requires either massive solid-state memory storage or real-time transmission. While a flyby spacecraft could record data in manageable chunks and then transmit it during the weeks between passes by Europa, an orbiter would have to transmit data twenty-four hours a day to ensure receipt before radiation killed the spacecraft. That would monopolize the largest tracking dishes of the Deep Space Network and exhaust the science and engineering teams. Green recalls the impact of such a frantic, short-lived mission on the *Mars Phoenix* lander team in 2007.[66]

The emergence and consolidation of a viable, lower-cost Europa concept in 2012 did not alter resistance in OMB and NASA Headquarters to taking on another flagship mission, albeit one half the price of JEO. The reductions in the space science budget plan for 2011-2015 left no room to pay for it. Moreover, billions of dollars of overruns on the Webb Telescope and the Mars Science Laboratory made flagship missions so unpopular with Obama's OMB and NASA chief Bolden that NASA banned the term from its official jargon for a while.[67] It would take three years of intervention by Rep. John Culberson to overpower their resistance.

His first effective budget maneuver came in fiscal 2013. Federal budget legislation remained unfinished months after the year's official start on 1 October 2012, reflecting the effective collapse of "regular order" in the budget process. Continuing resolutions kept the government open until March 2013, when a compromise bill finally passed both houses. It included the $75 million for Europa studies Culberson had inserted into the House version of the bill that funded NASA—the president's budget request a year earlier was zero. The space agency was confronted with disbursing the money with only seven months left in the fiscal year. The Planetary Science Division funded scientific instrument teams to develop key technologies and Jim Green also contacted the European Space Agency, promising up to $100 million over several years for US participation in *JUICE* instrument development. In early 2014, Green also funded a study of what kind of Europa mission a one-billion-dollar budget could buy. The answer apparently was not enough to make it scientifically defensible. Meanwhile, the fiscal 2014 budget request had already zeroed out Europa again—Culberson inserted $80 million.[68]

A lawyer and conservative Republican who represented the northwestern suburbs of Houston since January 2001, Culberson was ideologically opposed to much federal spending. But he had been an amateur astronomer and space science enthusiast since childhood. In January 2003 he joined the House Appropriations Committee and was assigned to the Commerce, Justice, and Science (CJS) Subcommittee, which controlled the House markup of NASA's budget. He received a coveted invitation to watch one of the Mars rover landings in early 2004 and subsequently made frequent visits to the Jet Propulsion Laboratory. A *JIMO* enthusiast, he was disillusioned by its cancellation. He began inserting language in the Appropriations Committee reports asking the agency to fund Europa studies, only to see it ignored. Federal agencies are not required to obey these reports but must spend specific appropriations written into the bill. He also wrote into legislation that NASA's Science Mission Directorate

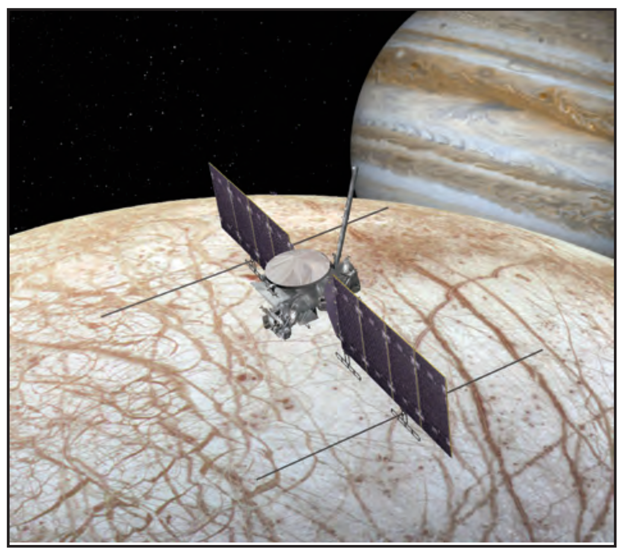

Figure 6: The official illustration of *Europa Clipper* from about 2016 shows the mature configuration. The two long, high-frequency (HF) sounding radar antenna are parallel to the main body of the spacecraft, while the very-high-frequency (VHF) antennas for the radar are mounted on the solar panels. Integrating the panels and the radar proved challenging as the panels effectively become part of the antenna system. The cameras, spectrometers, and most other instruments are at the front of the spacecraft bus in this illustration. The high-gain antenna for communicating with Earth is on top, as is the magnetometer boom. Credit: NASA

must adhere to the recommendations of decadal surveys.[69]

Frustrated again after the 2011 survey effectively put Europa on the back burner, the next year he began to insert specific dollar amounts into annual appropriations bills. His ability to do so was aided by his collegial, bipartisan approach inside the Appropriations Committee and his stance as a protégé of Rep. Frank Wolf of Virginia, who became the CJS subcommittee chair after the Republicans won back the House in November 2010. Four years later, Culberson would succeed him.[70]

To ensure that his interventions would be sustained when the House and Senate bills were reconciled in the conference committee, Culberson also cultivated relationships with members of the Senate Appropriations Committee, notably Richard Shelby (R-Alabama). The Obama Administration's cancellation of the Constellation Program in early 2010, and with it the human Moon landing, had gone over poorly in the Senate. Democratic and Republican senators from states benefitting most from human spaceflight, such as Florida, Alabama, Texas, and Utah, forced the Administration to revive the Orion lunar spacecraft and create a new version of its shuttle-derived, super-heavy-lift booster, now called the Space Launch System (SLS). While its primary purpose was to send humans to the Moon and beyond, Culberson immediately saw that it could propel a large spacecraft to Jupiter directly, obviating the need for time-consuming gravity assists from the Earth and Venus. That provided yet another rationale for funding SLS and strengthened his alliances in the Senate.[71]

Figure 7: Rep. John Culberson, R-Texas, chairs a hearing on the FY 2018 NASA budget request, 8 June 2017, at the Rayburn House Office Building in Washington, DC. Credit: NASA

Culberson could force NASA to spend money on Europa it had not asked for, but in order for it to become a new start—a formal program—Jim Green in the Planetary Science Division had to find a way to get his agency leaders to go to OMB and argue for it. In December 2013, he got "a gift." Curt Niebur called to tell him that astronomer Lorenz Roth and his team had discovered, in *Hubble Space Telescope* data, the spectral signature of water vapor spewing from Europa. Those plumes—similar to those that had generated excitement about Saturn's moon Enceladus—were further proof of subsurface water and probably a global ocean. It also opened the possibility of direct sampling by flying through a plume, as *Cassini* had done at Enceladus. Green told Niebur: "we've got to make a big deal out of this." They organized a last-minute NASA press conference at the American Geophysical Union meeting in Washington, DC, where Lorenz was giving his paper. The event made a small media splash and gave Green "the hook I didn't have before…to sell it in this [Headquarters] building." On 20 February 2014, he presented his case to Administrator Bolden and the Associate Administrator for SMD since 2011, John Grunsfeld. Green featured the plumes and a recent discovery that lakes inside the Europan ice shell likely explained chaos regions called *maculae* (spots). He convinced Bolden and Grunsfeld to spend money on developing a mission concept and selecting scientific instruments for it. Perhaps because these new results had already been discussed with OMB, the president's budget request released at that time included $15 million for Europa in fiscal 2015. Once again, Culberson went to work and by the time the budget was passed nearly a year later, the appropriation was $100 million.[72]

With that kind of money and political backing, and now with Bolden's support, the Office of Management and Budget finally accepted *Europa Clipper* as a new start. In May 2015, the agency announced the winners of the instrument selection, and in June the project officially went into "phase A": mission formulation. Of course, Culberson overrode fiscal 2016's request, $30 million, by arranging the appropriation of $175 million. That bill also specified that *Europa Clipper* must launch on an SLS in 2022 and include a lander. The next fiscal year, 2017, the bill required a separate lander to be launched on an SLS in 2024, and Culberson added $225 million to the president's budget request. In fiscal 2018, now under the Donald Trump Administration with James Bridenstine as NASA Administrator, the agency for the first time asked for a nine-figure Europa budget, but

Table 1: Europa Mission Funding Request and Congressional Appropriations, FYs 2013-2019
(Dollars in Millions)

	Fiscal Year							
	2013	2014	2015	2016	2017	2018	2019	Totals
Funding requested by NASA	$0	$0	$15	$30	$50	$425	$265	$785
Funding enacted by Congress	$75	$80	$100	$175	$275	$595	$740	$2,040
Increase in the amount Congress funded versus what NASA requested	$75	$80	$85	$145	$225	$170	$475	$1,255

Table 1: NASA Office of the Inspector General, "Management of NASA's Europa Mission," Report No. IG-19-019, 29 May 2019, 3. https://oig.nasa.gov/docs/IG-19-019.pdf

Culberson exceeded that too. At the end of 2018, he lost his re-election, but the fiscal 2019 budget he helped shape specifically allocated $195 million for a *Europa Lander* out of a total of $740 million. The bill did allow the projected launch dates to slip to 2023 and 2025, due to SLS delays. Table 1 shows Europa's highly unusual funding history as a result of his interventions. In just seven years, the agency got one-and-a-quarter billion dollars more than it had asked for.[73]

As for a lander, although it had been deemed too expensive in 2012, NASA did fund a follow-on study. A landing vehicle had always been the logical successor to an orbiter or flyby. Direct analysis and sampling of the surface ice is almost certainly necessary if better evidence for the habitability of the Europan ocean, perhaps even life, can be found. But if orbiting the moon is incredibly challenging, landing there is even more so. It requires a lot of extra rocket propellant to slow down to near zero velocity, and the lander would have to be designed for a wide variety of icy terrain, as little would be known about potential dangers until at least the initial results of *Europa Clipper* were received. *Europa Lander* advanced considerably in design in the late 2010s as a result of all the money Culberson provided. In order to reduce its projected $3.2 billion price tag, JPL engineers and scientists decided to eliminate a separate communications orbiter (the lander would send signals directly back to Earth) and limited it to battery power alone (instead of an RTG) for a projected twenty-day mission. Its primary science goal became the search for "biosignatures"—chemical indications of the likely presence of life in the ocean below—rather than determining the presence or absence of life, which requires much more elaborate instruments and has proven to be difficult on Mars. Together, these measures saved an estimated half billion dollars.[74]

But *Lander* always seemed premature to those who were not its advocates. A 2019 NASA Inspector General report noted that, even if Congress were to supply the money for both *Clipper* and *Lander* to proceed, the engineering and scientific manpower of JPL was already overtaxed with *Clipper*, Mars 2020 and other ongoing projects. Even accounting for the APL partnership, there was no capacity for Lander. After Culberson lost his re-election, it was put on hold, but thanks to the large 2019 appropriation, the team resumed work. In fiscal 2020, the now Democrat-run House Appropriations Committee continued its support for *Clipper* and *Lander* and launching both on the SLS, while slipping the launch dates to 2025 and 2027, respectively. Nonetheless, *Lander* remained a "pre-project"—not an approved NASA program—and it seems likely to stay that way at least until the next decadal survey of planetary science delivers its report in 2022.[75]

In fiscal 2021, Congress finally dropped the Culberson-imposed commitment to an SLS launch for *Clipper*, after rejecting previous NASA appeals. The rocket's numerous delays and limited availability

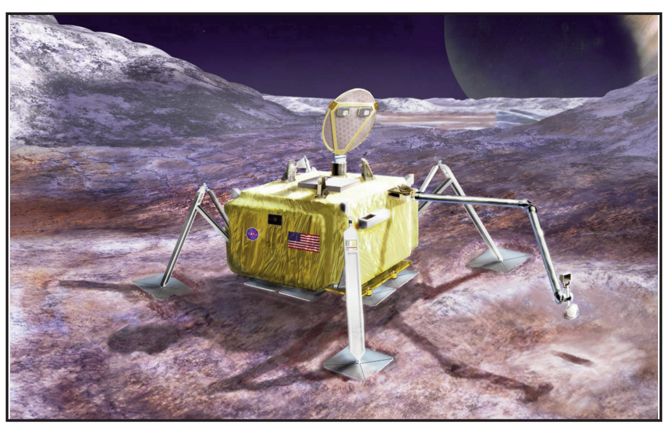

Figure 8: Artist's concept of *Europa Lander* after the redesign of 2016. Credit: NASA

because of the demands of the Artemis human Moon program were already a problem. But when engineering studies of launch vibration brought into question SLS's compatibility with *Europa Clipper*, that provided a face-saving excuse to open the door to launching on a commercial rocket, possibly as soon as October 2024. Such a launch would necessitate a much longer transit time for gravity assists from the Earth and Mars, but could save more than a billion dollars and be reliably scheduled.[76]

Regardless of how that turns out, with the decision to allow *Clipper* to go forward in 2015, followed by approvals of "Phase B" in 2017 and "Phase C" in 2019, a mission to Europa finally became a reality.[77] It had taken a quarter century, and three outright cancellations, to get there.

Conclusions

What does the evolution of Europa missions tell us about the forces shaping NASA's planetary science program in the late twentieth and early twenty-first centuries? First, there never would have been a Europa mission without the fascination, widely shared by scientists, politicians and the general public, for the idea of extraterrestrial life. This was already a direct or indirect motivator for NASA's Mars exploration programs,[78] but the *Voyager* and *Galileo* imagery of Europa, the discovery of terrestrial hydrothermal vent communities, and the rise of an astrobiology focusing on extremophiles and exotic habitats, rather suddenly made the Jovian moon into objective number two in the solar-system life search. That is why Administrator Dan Goldin initiated *Europa Orbiter* in 1996/97, why two decadal surveys put Europa at or near the top of its mission lists, why the technology-driven *Jupiter Icy Moons Orbiter* exploited Europa's astrobiological interest to justify itself, and why *Jupiter Europa Orbiter*, and then *Europa Clipper* and *Lander*, got funded, to a greater or lesser degree. Extraterrestrial life was the primary reason why John Culberson steered so much money to the last two. In interviews, he emphasizes his lifelong interest in space science and in the discoveries of "black smoker" hydrothermal vent colonies on Earth. But *Clipper* project scientist Bob Pappalardo thinks Culberson also wanted to see Europan life discovered in his lifetime, which is why he pushed *Lander* to follow immediately after *Clipper*.[79]

Second, the history of Europa missions confirms that the introduction of competitive mission selection in the late 1990s fundamentally altered the way in which the NASA planetary program operated. For most of the eighties and nineties, NASA Headquarters had simply assigned projects to JPL as the agency's center for robotic missions beyond Earth. The NASA Administrator and the Associate Administrator for Space Science had to convince their political masters in OMB and the White House to spend the money, but they effectively controlled what projects would be assigned. This is the way *Europa Orbiter* began in 1996/97. But the Discovery Program and Goldin's "faster, better, cheaper" campaign were already disrupting that pattern. Soon afterward, *Outer Planets/Solar Probe* fell apart and an APL-built *New Horizons* emerged as the first in a new, competitive, medium-sized mission series. When APL became an important player in Discovery and New Frontiers competitions, it increased political intervention into the planetary program by Sen. Barbara Mikulski, setting an example for others in Congress. In that context, JPL offered a Europa alliance to APL in 2006 to forestall a competitive fight, bolster Mikulski's support for a struggling project, and enlist the Hopkins laboratory's significant technical capability. At about the same time, JPL Director Charles Elachi restructured his laboratory from an organization designed to mostly do one or two flagship missions at a time to a place capable of competing for multiple Discovery and New Frontiers spacecraft.[80] The JPL-APL Europa alliance was unusual, as the two were often rivals, but it was a direct product of that environment.

Third, it is no coincidence that, in the first decade of the twenty-first century NASA initiated formal decadal surveys in the planetary sciences (and in other disciplines). In an era of competed projects and congressional intervention, decadals promised to deliver scientific consensus decisions about what objectives were most important—judgments that were at least nominally independent of NASA and the political process. Weiler's request for the first planetary decadal survey arose in part from the battle over Pluto versus Europa. As the result of NASA's failure to implement the Europa flagship mission called for in the 2002/3 survey, Culberson wrote into legislation that the agency must follow the decadals. Of course, when he wanted to appropriate money for a lander project, he conveniently interpreted the 2011 survey's Europa number-two priority as including such a mission, although it had nowhere been explicitly called out as such.[81]

Fourth, the Europa mission story illuminates the changing role of Congress in planetary exploration.

Conventional, district-based concerns about money and jobs for local institutions have always shaped political intervention in NASA's programs. But with planetary missions assigned directly to JPL, there was little room for specific congressional action, once the presidential administration and Congress had agreed on the overall objectives and budget levels. But once APL became a competitor as a result of the Discovery Program and Pluto, Mikulski intervened to defend its projects from postponement or cancellation. According to Louise Prockter, the senator was enthused by the space sciences and remembered how she had been steered away from science as a girl, but there is also no doubt that jobs and money for Maryland were central considerations.[82] Mikulski used her power to protect NASA Goddard Space Flight Center and the Space Telescope Science Institute, both in the state, as well. As a result of the new environment, Goddard became a player in the planetary program too.

John Culberson obviously does not fit the traditional model, however, since his Houston district had nothing to gain from sending money to APL, JPL, or the companies that supplied components or launch vehicles for planetary spacecraft. He was and is a space enthusiast. *Europa Clipper* probably would still be stuck in study stage without the appropriations he inserted against the wishes of the Office of Management and Budget of both Democratic and Republican administrations. His long tenure on the Commerce, Justice, and Science subcommittee of House Appropriations was crucial. It took him several years to learn how to create iron-clad legislation and to develop the seniority and relationships that allowed him to enlist Republicans and Democrats on his subcommittee, on the Appropriations Committee, and in the full House and Senate. He forged a relationship with Sen. Richard Shelby, who championed the SLS rocket. He may have learned from Shelby and other senators who overrode the Obama Administration's human spaceflight policy early in the 2010s. The question arises, however, as to whether his example tells us anything about the changed environment for planetary exploration after the year 2000, as perhaps Culberson was nothing but a stroke of luck for Europa advocates. A congressperson without district interest steering a billion extra dollars to a project is an example that may not soon be repeated, but it certainly demonstrates that congressional intervention in NASA's planetary program (and in other parts of the agency's budget) has become normal.

Culberson's story provides one final insight into how the planetary exploration has operated in the period examined—and before it. In my article about Pluto missions, I argued that JPL lacked APL's independence from NASA Headquarters since the California laboratory was part of the agency. If the Pluto program had stayed at JPL, it would have been cancelled because it could not easily make an end-run around Headquarters and OMB, as APL did with Mikulski. That may still be true for Pluto, but in the case of Europa, both John Culberson and Charles Elachi state that the congressman was getting his budget numbers primarily from the JPL Director, although the president's budget request for that fiscal year was official agency policy. Elachi noted that, since JPL is the only non-civil-service NASA center—it is a branch of the California Institute of Technology on contract to the agency—the director does have a certain amount of leeway that other center directors lack. Perhaps not as much as APL or other external organizations, but he and his predecessors were able to use that modicum of independence to sometimes make end-runs around Headquarters.[83]

Further research is needed into how NASA's science programs operated in the past two decades. Only a handful of programs have been studied—primarily Mars, Pluto, and the *Hubble Space Telescope*—and congressional records have scarcely been touched. Meanwhile, the Europa story is far from over. *Clipper* needs to be completed and successfully launched and *Lander* is being discussed in the planetary decadal process currently underway. The European *JUICE* mission is supposed to launch in 2022, reach Jupiter in 2029, and make at least two Europa flybys. Many exciting discoveries lie ahead, providing rich opportunities for further work in the history of the space sciences.

About the Author

Dr. Michael J. Neufeld is a senior curator in the Space History Department of the Smithsonian National Air and Space Museum and served as its chair from 2007 to 2011. Dr. Neufeld has authored numerous scholarly articles and books including: *The Rocket and the Reich: Peenemunde and the Coming of the Ballistic Missile Era* (1995), *Von Braun: Dreamer of Space, Engineer of War* (2007), and *Spaceflight: A Concise History* (2018). In 2017, he received the Smithsonian Distinguished Scholar award, the highest research honor of the Institution. He is the lead curator of a new exhibition gallery, *Destination Moon*, due to open in late 2022.

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Notes

1 Robert W. Smith, et al., *The Space Telescope: A Study of NASA, Science, Technology and Politics* (Cambridge: Cambridge University Press, 1989); Arturo Russo, "Europe's Path to Mars: The European Space Agency's Mars Express Mission," *Historical Studies in the Natural Sciences 41*, 123-78; Michael J. Neufeld, "First Mission to Pluto: Policy, Politics, Science and Technology in the Origins of New Horizons, 1989-2003," *Historical Studies in the Natural Sciences 44*, 234-76.

2 See for example, Janet Vertesi, *Shaping Science: Organizations, Decisions, and Culture on NASA's Teams* (Chicago: University of Chicago Press, 2020), and Lisa Messeri, *Placing Outer Space: An Earthly Ethnography of Other Worlds* (Durham, NC: Duke University Press, 2014). The two collaborated on "The Greatest Missions Never Flown: Anticipatory Discourse and the 'Projectory' in Technological Communities," *Technology and Culture 56* (2015), 54-85. For much of the history I detail here, sending a spacecraft to Europa fits into their category of the idealized but seemingly unattainable exploration project that serves to sustain scientific communities and advocacy. One of their cases is Mars Sample Return, which came into direct competition with Europa in the 2010 planetary decadal. Both eventually emerged from that as actual, sustained missions.

3 David W. Brown, *The Mission: A True Story* (New York: Custom House, 2021). My research was carried out in parallel to Brown's, and I got his book only after I had already drafted this article. He barely discusses *Europa Orbiter* (1996-2003), goes lightly over *Jupiter Icy Moons Orbiter* (2002-2004), and does not cover *Europa Lander* or anything after mid-2015, but details the rise and fall of *Jupiter Europa Orbiter* and the emergence of *Europa Clipper* (2005-15) much more extensively than I can, uncovering much new information. Where he had access to documents or participant perspectives I did not have, I cite him below.

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5 C. Alexander, R. Carlson, G. Consolmagno, R. Greely and D. Morrison, "The Exploration History of Europa," in Robert T. Pappalardo, William B. McKinnon, and Krishnan Khurana, with the assistance of Renée Dolson, eds., *Europa* (Tucson: University of Arizona Press in collaboration with Lunar and Planetary Institute, 2009), 3-26, here 3-10.

6 Alexander, et al., "The Exploration History," 10-11; Kevin Peter Hand, *Alien Oceans: The Search for Life in the Depths of Space* (Princeton: Princeton University Press, 2020), 35-36; Henry C. Dethloff and Ronald A. Schorn, *Voyager's Grand Tour: To the Outer Planets and Beyond* (Old Saybrook, CT: Konecky and Konecky, 2003), 158-60, 169-70. On the history of Jet Propulsion Laboratory in this period see Peter J. Westwick, *Into the Black: JPL and the American Space Program, 1976-2004* (New Haven: Yale University Press, 2007).

7 Steven J. Dick and James E. Strick, *The Living Universe: NASA and the Development of Astrobiology* (New Brunswick, NJ: Rutgers University Press, 2004), 105-09.

8 Alexander, et al., "The Exploration History," 11-12; Arthur C. Clarke, *2010: Odyssey Two* (New York: Ballantine Books, 1982), 277, 285-88, 291; Peter Weller, NASA News Release 82-45, "Jupiter's Moon Europa Could Support Life in Oceans," 14 December 1982, NASA History Division (hereinafter NHD), NASA Headquarters, Historical Reference Collection (hereinafter HRC) 10117; Robert Pappalardo, oral history interview (hereinafter OHI) by the author and Matthew Shindell, Washington, DC, 28 October 2018.

9 Michael Melzer, *Mission to Jupiter: A History of the Galileo Project* (Washington, DC: NASA, 2007), 231-39, 253-67, https://history.nasa.gov/sp4231.pdf (accessed 16 December 2020); Alexander, et al., "The Exploration History," 13-14, esp. the table of encounters on 13.

10 NASA Press Release 96-164, 13 August 1996, "Jupiter's Europa Harbors Possible 'Warm Ice' or Liquid Water," and NASA Press Release 97-66, 9 April 1997, "New Images Hint at Wild and Wet History for Europa," both in NHD, HRC 10117; Paul Schenk, "Oceans, Ice Shells and Life on Europa, The *Planetary Report, 22,* no. 6 (November/December 2002), 10-15; "Galileo's Greatest Hits—The Scientists' Choices," *The Planetary Report*, 23, no. 5 (Sept./Oct. 2003), 12-18, esp. Torrance Johnson photo caption on 17; Alexander, et al., "The Exploration History," 18-20, and several other chapters in that volume, notably, Paul M. Scheck and Elizabeth P. Turtle, "Europa's Impact Craters: Probes of the Icy Shell," 181-98; NASA Europa Clipper website, "Daytime Temperatures on Europa," 8 January 2019, https://europa.nasa.gov/resources/114/daytime-temperatures-on-europa/ (accessed 16 December 2020); Pappalardo OHI, 28 October 2018: Louise Prockter, OHI by author, Washington, DC, 12 December 2018; Richard Greenberg, *Unmasking Europa: The Search for Life on Jupiter's Ocean Moon* (New York: Copernicus Books, 2008).

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Evidence Points to Possible Water World Under Europa's Icy Crust," 25 August 2000, both in NHD, HRC 10117; M. G. Kivelson, K. K. Khurana, and M. Volwerk, "Europa's Interaction with the Jovian Magnetosphere," in Pappalardo, McKinnon and Khurana, eds. *Europa*, 545-70; David W. Brown, "How Do You Find an Alien Ocean? Margaret Kivelson Figured it Out," *New York Times*, 8 October 2018, https://www.nytimes.com/2018/10/08/science/margaret-kivelson-europa.html? (accessed 16 December 2020).

12 R. Gershman, R. Oberto, R. Stoller. "Europa Orbiter Study Status," 18 July 1996, JPL Archives (hereinafter JPLA), D-47160, 2. The first images of Europa were taken on 27 June after the Ganymede flyby: Alexander, et al., "The Exploration History," 13. The images were not released to the public until 13 August, see NASA Press Release 96-164. An email about *Europa Orbiter* from one day before the flyby, the first document about the project in the JPL Archives system, may mean that Goldin asked the question even before the images had been taken: Gershman to Dawson, 26 June 1996, JPLA, D-66331.

13 Dick and Strick, *Living Universe*, 18-20, 105-30, quote on 107.

14 Ibid., 19-20, 176-205; Wesley T. Huntress, OHI by Wright, NHD, HRC 18948; Torrence Johnson talk on Europa, 9 September 1995, JPLA, D-66332; NASA Press Release 96-166, 13 August 1996, "Statement of Administrator Daniel S. Goldin on the Release of New Galileo Spacecraft Images of Europa," in NHD, HRC 10117.

15 See the references in note 2, plus Howard E. McCurdy, "Learning from History: Low-cost Project Innovation in the U.S. National Aeronautics and Space Administration," *International Journal of Project Management 31* (2013), 705-11; Amy Page Kaminski, "Faster, Better, Cheaper: A Sociotechnical Perspective on Programmatic Choice, Success, and Failure in NASA's Solar System Exploration *Program," in Exploring the Solar System: The History and Science of Planetary Exploration*, edited by Roger D. Launius (New York: Palgrave Macmillan, 2013), 77-101; Michael J. Neufeld, "The Discovery Program: Competition, Innovation, and Risk in Planetary Exploration," in *NASA Spaceflight: A History of Innovation*, edited by Roger D. Launius and Howard McCurdy (NY: Palgrave Macmillan, 2017), 267-90.

16 Neufeld, "First Mission," 234-58.

17 Gershman email to Dawson, 26 June 1996, and Gershman, Oberto, and Stoller. "Europa Orbiter Study Status," 18 July 1996; Ellen Stofan, OHI by Michael Neufeld, 11 March 2019, 4. For an explanation of the Europa gravimetry conducted with *Galileo*, see Hand, *Alien Oceans*, 73-76. The lack of documentation probably reflects that it started as a very small study by a few people. But note that email is almost impossible to access at JPL and other institutions. From an archival standpoint, it represents myriad problems of privacy which, when combined with the restrictions of ITAR (International Traffic in Arms Regulations) as they apply to space technologies, make documents not already classed as public difficult to access. JPL's policy is to allow no copying of materials by researchers. If the document is actually in the JPL archives database and accessible to researchers, one can take notes in person at JPL, but has to request copies of specific pages, which then need to be cleared. Practically speaking, those clearances either take a long time or never get done. One advantage of doing research on topics after the mid-1990s is that most public documents are available on the JPL and NASA technical report servers, but getting beyond those publicly available documents is difficult. When I have found them in the servers, I have put in the links below.

18 Gershman, Oberto, and Stoller. "Europa Orbiter Study Status."

19 Neufeld, "First Mission,", 258-60; Paul Hoverston, "Plans in the works for mission to Europa," 24 February 1997, *Florida Today Space Online*, copy in NHD, HRC 10117. The latter file also has a version of the same story from *USA Today* with a line drawing.

20 Chris Chyba, Europa Orbiter SDT Chair, to Jay Bergstralh, NASA HQ, 18 May 1998, quoted in Jan M. Ludwinski, et al., "The Europa Orbiter Mission Design," paper presented at the International Astronautical Congress, Melbourne, Australia, 28 September—2 October 1998, IAF 98-Q.2.02, https://trs.jpl.nasa.gov/bitstream/handle/2014/20516/98-1507.pdf?sequence=1&isAllowed=y (accessed 16 December 2020).

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