Europa Clipper Mission Concept: Exploring Jupiter's Ocean Moon

PAGES 165–167

The ice-covered world Europa—one of the four large Galilean satellites of Jupiter—may be the best place in the solar system to look for currently existing life beyond Earth.

Europa is about the same size as Earth's Moon, but its surface is much more dynamic. Its young, bright, icy landscape is crisscrossed by a network of cracks and ridges, interrupted by smooth bands, disrupted chaotic terrain, and just a handful of large craters [see *Greeley et al.,* 2004, and references therein].

Several lines of scientific evidence [see *McKinnon et al.,* 2009, and references therein] point to remarkable conclusions: Europa likely has a global ocean of liquid water under its icy surface, maintained by tidal flexing and heating due to its eccentric orbit about Jupiter, and that ocean could potentially be habitable by microorganisms.

For these reasons, future investigation of Europa is a top priority for planetary exploration, as expressed in the National Research Council's planetary science decadal surveys in both 2003 and 2011 [*National Research Council,* 2003, 2011] and as emphasized in NASA's fiscal year 2015 proposed budget. NASA's Europa Clipper mission concept could enable a leap in scientific understanding of this unique part of the solar system.

Previous Explorations

Observations of Europa by the twin Voyager spacecraft in the late 1970s first revealed the satellite's enigmatic linear features, but at only relatively low resolution, providing more questions than answers. The Galileo spacecraft, which orbited Jupiter from 1995 to 2003, obtained the first high-resolution images and spectra of a variety of Europa's surface terrain types (see Figure 1).

Images revealed iceberg-like, chaotic terrains, which seem to consist of icy crustal blocks that have been broken apart, rotated, translated, and tilted before being refrozen into new positions. Bull's-eye-like impact structures suggested that impact explosions were able to penetrate to an ocean some 20 kilometers below the surface. Surface geology lent credence to the idea that the floating icy shell could undergo solid-state convection today, driven by tidal flexing and heating.

Magnetometry from Galileo suggested that Europa has a magnetic field induced by the satellite's motion through Jupiter's field, creating eddy currents in a salty subsurface ocean. Charged particle irradiation of the surface is known to create oxidants, which, if transported to the subsurface ocean, could serve as a fuel for simple forms of life.

A Mysterious World

Even with these preliminary data sets, it is clear that Europa's youthful surface, potential subsurface ocean, and ongoing tidal flexing suggest that it is probably geologically active today. However, data return from the Galileo mission was limited, and the mission was not designed to detect subsurface water, so many mysteries remain [see *Prockter and Pappalardo,* 2014, and references therein].

For example, Galileo's Doppler gravity measurements imply a surface H_2O layer some 80–150 kilometers thick, but scientists do not know how much of that is liquid and how much is solid ice. There is not yet any definitive evidence of current geological activity [*Phillips et al.,* 2000], although recent observations using images from the Hubble Space Telescope [*Roth et al.,* 2014] suggest that vapor plumes currently may be venting water from Europa's interior.

Models for the formation of Europa's bizarre surface features are consistently maturing but remain inconclusive. Galileo spectroscopy indicates surface hydrated salts and radiolytic compounds, but specifics are uncertain. Fundamentally, it is not yet known if Europa has sufficient energy sources to sustain a biosphere, nor is it known if life within the interior ocean of Europa ever existed or still exists.

The Europa Clipper Mission Concept

A return mission to Europa is the only way to gather the critical data required to answer the highest-priority geophysical and astrobiological questions about this intriguing ocean world. Collecting a global data set in a systematic manner is the appropriate next step.

The Europa Clipper mission concept [*Pappalardo and Goldstein,* 2013], currently in formulation by NASA, could meet the science requirements and engineering challenges of a mission to Europa by flying past the moon repeatedly and observing with a payload specifically designed to address potential habitability. "Habitability" as defined in a solar system exploration context refers to the potential ability for a planetary environment to support microorganisms analogous to known terrestrial ones [e.g., *Chyba and Phillips,* 2001].

By orbiting Jupiter rather than Europa directly, the Europa Clipper would spend most of its time outside of the high-radiation environment close to Jupiter that can be damaging to electronics. On each orbital pass, it would swoop as low as 25–100 kilometers from Europa, employing its remote sensing instruments to study the surface and subsurface while detecting particles from Europa's tenuous atmosphere and the moon's gravitational and magnetic fields in situ. After each close approach, the spacecraft would transmit its treasure trove of data back to Earth.

A key feature of the mission concept is that the Clipper would use gravitational perturbations from Europa—and from the icy Galilean moons Ganymede and Callisto—to deflect its trajectory, allowing the spacecraft to return to a different close approach point with each flyby. The flyby paths would create an intersecting web allowing remote sensing instruments to scan most of the surface over time.

Investigating Europa's Habitability

A NASA-appointed Science Definition Team has carefully honed the science goals and objectives of the Europa Clipper, ensuring that important questions can be answered while also permitting reactions to unexpected discoveries.

The main science goal for the proposed mission is to explore Europa to investigate its habitability. Within this scope, three key science objectives involve investigating Europa's ice shell and ocean, composition,

Fig. 1. Europa's surface geology hints at liquid water below. Regions of chaotic terrain such as Conamara Chaos may be the sites of partial melting of the moon's ice shell. This mosaic of Galileo images shows images with a resolution of 10 meters per pixel nested within contextual images (54 meters per pixel). Mosaic by Ryan Sicilia.

and geology. In turn, each objective has been mapped to example experiments and measurements that could realistically be performed by the Europa Clipper. These targets, in turn, helped the team of scientists and engineers conceptualizing the proposed spacecraft envision a sample set of instruments that would satisfy the science goal and objectives.

Questions that the Europa Clipper researchers hope to help answer include the following: Does the moon have an ocean, and, if so, how thick is the ice above it? Is material exchanged between the surface and the ocean? What are the chemistry and origin of non-ice materials on the surface and in Europa's tenuous atmosphere? Are there areas of recent or current geological activity, and what are their morphology and topography?

The initial example science payload consists of an ice-penetrating radar to search for water in the subsurface, an infrared spectrometer to identify molecular compounds, a stereo camera for mapping and topography, a neutral mass spectrometer to identify atmospheric constituents, a magnetometer along with Langmuir probes to measure the induced magnetic field to constrain the salinity and thickness of the ocean, and the spacecraft's radio system to undertake gravity measurements. Such a payload would enable the Europa Clipper to seek evidence of subsurface water, chemistry compatible with habitability, and active geological processes driven by tidal flexing and heating.

Preparing for a Future Lander Mission to Europa

A lander mission might someday follow up on initial discoveries at Europa. But with the limited knowledge we have today of the nature of Europa's surface at very small scales, designing a reliable mission to land on Europa would be challenging and risky.

In addition, currently, scientists do not know the most scientifically promising sites at which to land. Europa's surface needs to be scouted out first; thus, the Clipper concept has as a secondary goal: to characterize scientifically compelling sites for a future lander mission to Europa. This goal could be accomplished with the example science payload described above as augmented with two additional instruments. A high-resolution camera capable of obtaining images with a resolution of 50 centimeters per pixel would help in understanding the distribution of ice blocks and other potential landing hazards. In addition, a thermal instrument would help in characterizing the distribution of small-scale, icy blocks by measuring thermal inertia.

Mission Lifetime

The current baseline profile for the Europa Clipper mission concept is a launch aboard an Atlas V 551 rocket sometime in the first half of the coming decade. The transit time to Jupiter is about 6 years, using a Venus-Earth-Earth gravity assist (VEEGA) trajectory. However, if it launched aboard NASA's in-development Space Launch System, Clipper could arrive at Jupiter on a direct trajectory in less than 3 years. A nuclear power source is tentatively planned (several Multi-Mission Radioisotope Thermoelectric Generators (MMRTGs)), and the feasibility of a solar-powered spacecraft is also being evaluated.

Upon arrival at Jupiter, encounters with Ganymede and Callisto would shape Clipper's orbit, placing it into a resonant orbit with Europa. Then it would make about 45 flybys of Europa over its proposed 3.5-year mission. Mission lifetime would be limited by radiation, but the mission radiation tolerance is designed to be twice the expected radiation dose to account for uncertainties; thus, survival of the spacecraft and instruments is expected well beyond the planned mission duration.

Whither Outer Solar System Exploration?

In the 2013 and 2014 federal budgets, Congress charged NASA with studying the Europa Clipper mission in detail. Although the planetary science budget is currently pinched very tightly, in its 2015 budget announcement, NASA for the first time announced plans to launch a mission to Europa sometime in the mid-2020s. However, the details and scope of such a mission remain uncertain.

Currently, outer solar system exploration by the United States is scheduled to end in 2017. By then, the Juno mission would have finished its investigation of Jupiter's interior, the New Horizons mission would have sailed past Pluto, and Cassini would have ended its spectacular mission at Saturn by plunging into that planet's clouds. Remarkable increases in scientific knowledge of the solar system are the legacy of the Voyagers, Galileo, and Cassini. Such missions have inspired students, teachers, scientists, and the general public for a generation. A future Europa mission such as the Clipper could keep that legacy alive.

If the Europa Clipper were to find evidence of habitable environments at Europa, it would greatly expand the possibilities for life beyond Earth. If plumes are currently erupting from Europa, lofting ocean material high above the surface, the Europa Clipper could even sample the ocean's contents.

In the more distant future, if life were to be found at Europa, it would revolutionize science in a way not seen since Galileo Galilei's paradigm-altering observations of Jupiter's moons in 1610. Exploration of Europa by the Europa Clipper would be the next step in a great scientific adventure.

References

Chyba, C., and C. B. Phillips (2001), Possible ecosystems and the search for life on Europa, *Proc. Natl. Acad. Sci. U. S. A., 98,* 801–804.

Greeley, R., C. Chyba, J. W. Head, T. McCord, W. B. McKinnon, and R. T. Pappalardo (2004), Geology of Europa, in *Jupiter: The Planet, Satellites and Magnetosphere,* edited by F. Bagenal et al., pp. 329–362, Cambridge Univ. Press, New York.

McKinnon, W. B., R. T. Pappalardo, and K. K. Khurana (2009), Europa: Perspectives on an ocean world, in *Europa,* edited by R. T. Pappalardo et al., pp. 697–710, Univ. of Ariz. Press, Tucson.

National Research Council (2003), *New Frontiers in the Solar System: An Integrated Exploration Strategy,* Natl. Acad. Press, Washington, D. C.

National Research Council (2011), *Visions and Voyages for Planetary Science in the Decade 2013–2022,* Natl. Acad. Press, Washington, D. C.

Pappalardo, R. T., and B. Goldstein (2013), The Europa Clipper: Update to CAPS, report, Comm. on Astrobiol. and Planet. Explor., Natl. Res. Counc., Washington, D. C., 4 Sept.

Phillips, C. B., et al. (2000), The search for current geologic activity on Europa, *J. Geophys. Res., 105,* 22,579–22,598, doi:10.1029/1999JE001139.

Prockter, L. M., and R. T. Pappalardo (2014), Europa, in *Encyclopedia of the Solar System,* 3rd ed., edited by T. Spohn et al., Academic, Amsterdam, in press.

Roth, L., J. Saur, K. D. Retherford, D. F. Strobel, P. D. Feldman, M. A. McGrath, and F. Nimmo (2014), Transient water vapor at Europa's south pole, *Science, 343,* 171–174.

—Cynthia B. Phillips, SETI Institute, Mountain View, Calif.; and Robert T. Pappalardo, Jet Propulsion Laboratory, California Institute of Technology, Pasadena; email: robert.pappalardo@jpl.nasa.gov