Comparing two proposed NASA missions to Jupiter's moon Io

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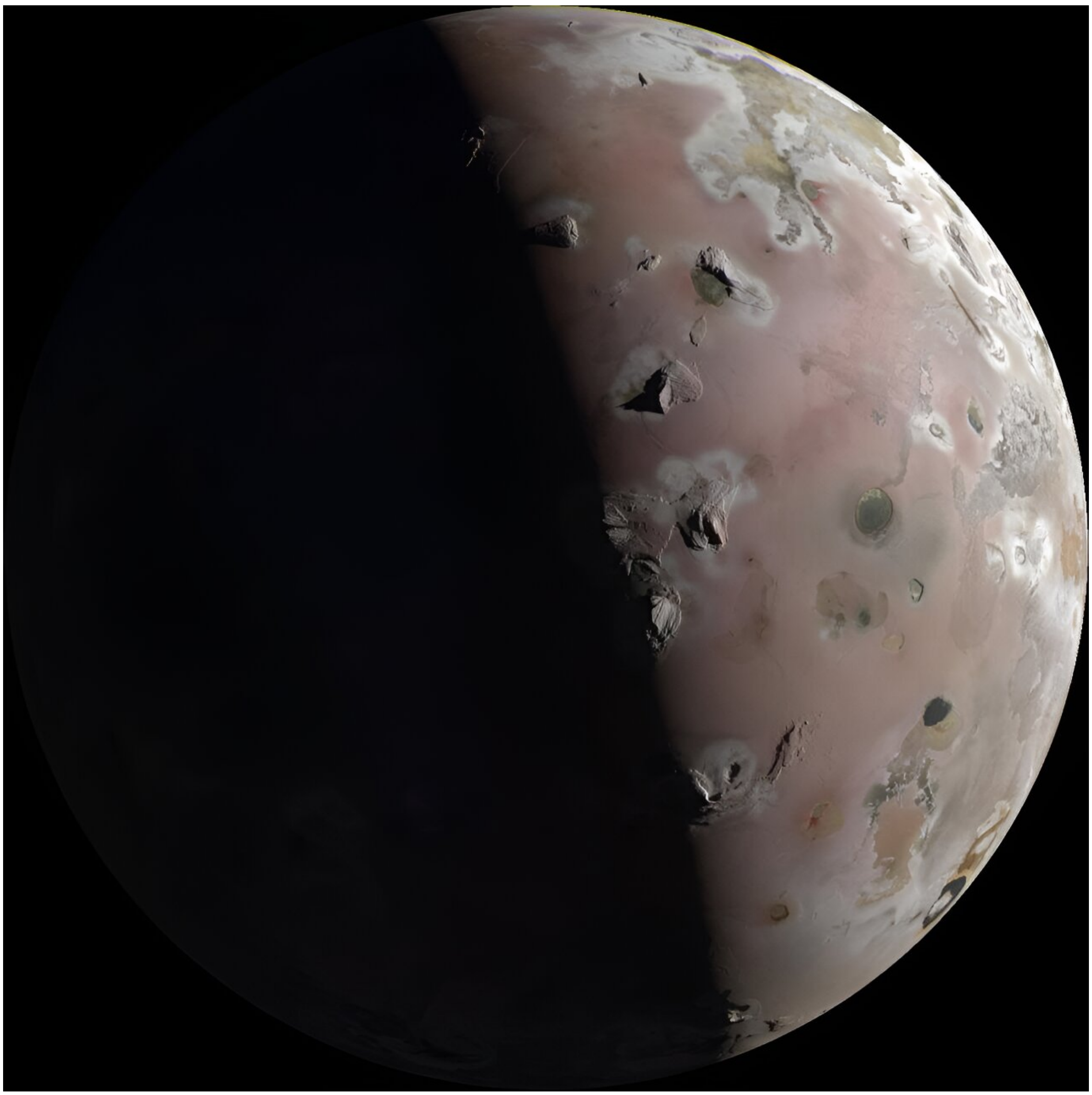


Juno captured this image of Io during Perijove 57. Juno's images of the volcanic moon are adding momentum to the calls for a mission to the moon. Is it time? Credit: NASA / SWRI / MSSS / Jason Perry

Thanks to NASA's Juno mission to the Jupiter system, we're getting our best looks ever at the gas giant's volcanic moon Io. Even as Juno provides our best views of the moon, it also deepens our existing questions. Only a dedicated mission to Io can answer those questions, and there are two proposed missions.

Io is well-known as the most geologically active world in the solar system, and it's not even close. It has more than 400 active volcanoes. Io is the closest moon to Jupiter, and the planet's powerful gravity is largely responsible for Io's volcanoes.

As the planet pulls on Io, the friction creates tidal heating in the moon's interior. This creates magma and drives its volcanic eruptions. Sulfur compounds in the eruptions paint the moon's surface in shades of red, yellow, white, black, and green.

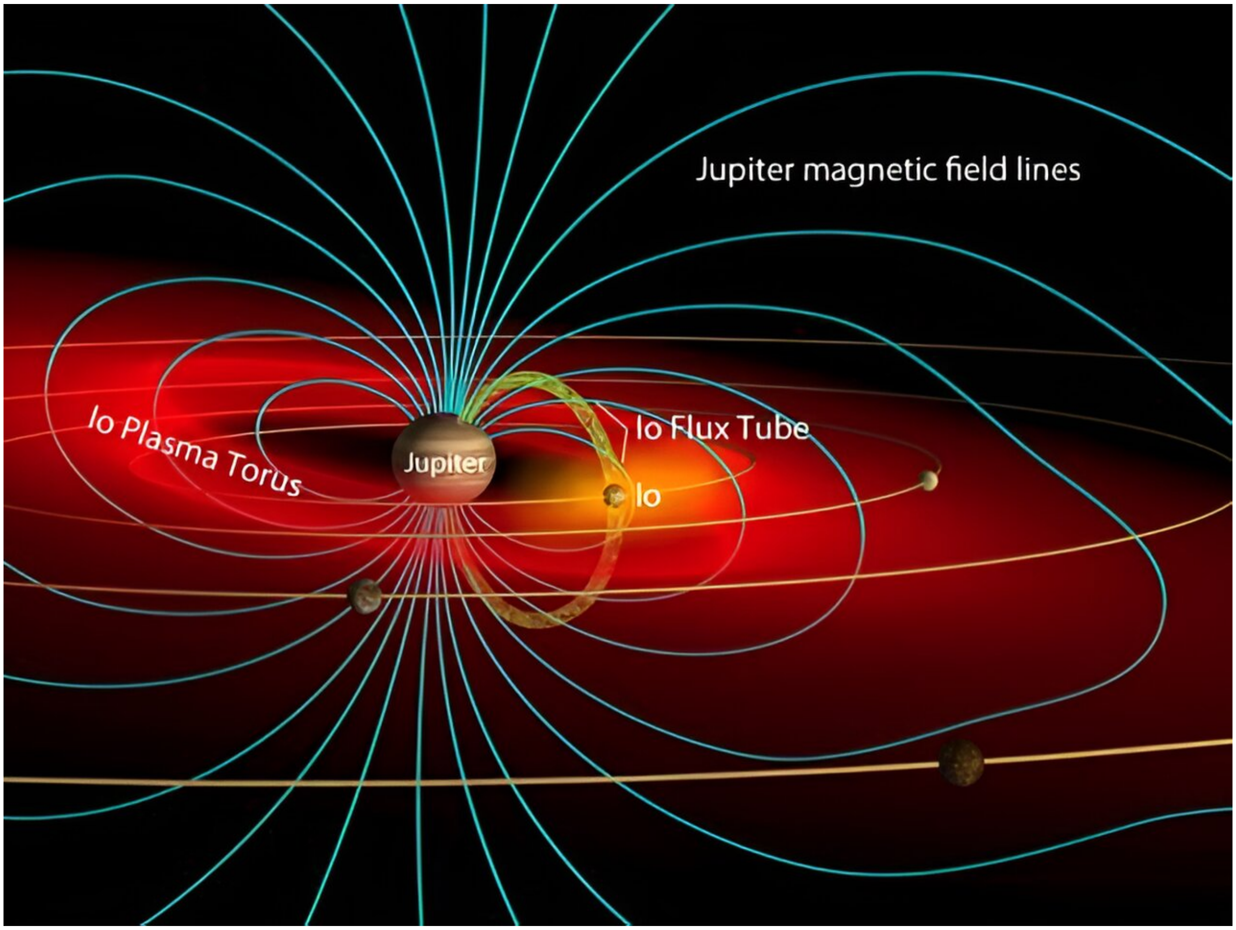
There's never been a dedicated mission to Io, only missions that captured images as they passed by, including Galileo, Voyager 1, Cassini, New Horizons, and Juno, NASA's current mission to Jupiter. But Io is intriguing and unique, and it can teach us a lot.

Planetary scientists want to know more about the moon's geological processes. Io is considered a high heat flux world, and scientists want to learn more about its tidal dissipation. Studying Io can also tell us more about primitive planetary bodies that were once more volcanic, which Earth likely was early in its history.

Io can also tell us more about volcanogenic atmospheres, which can play a vital role in shaping a planet's environment. This 2020 paper draws a link between Earth's volcanic activity and the Great Oxygenation Event, a critical period when oxygen accumulated in Earth's atmosphere. A better understanding of the link between volcanic activity and atmospheric evolution will help us better understand exoplanets and habitability.

Scientists know that the Galilean moons exchange material with Jupiter's atmosphere and magnetosphere. They also know that material ejected from Io's volcanoes can reach the surfaces of the other moons. Some of it can be turned into plasma by Jupiter's powerful magnetosphere, forming Io's plasma torus. They're curious about this mass exchange in the Jupiter system and how it's shaped the moons.

These are the reasons for a dedicated mission to Io.



This schematic of Jupiter's magnetic environments shows the planet's looping magnetic field lines, Io and its plasma torus, and Io's flux tube. Credit: John Spencer / Wikipedia CC-BY-SA3.0 with labels by the author

In 2010, scientists at the University of Arizona and Johns Hopkins University's Applied Physics Laboratory first proposed the Io Volcano Observer (IVO) as part of NASA's Discovery Program. IVO was proposed as a low-cost mission to explore Jupiter's volcanic moon. It was proposed again in 2015 and in 2019. In 2020, IVO was selected with two other missions for further study but ultimately lost out to the DAVINCI+ and VERITAS missions to Venus.

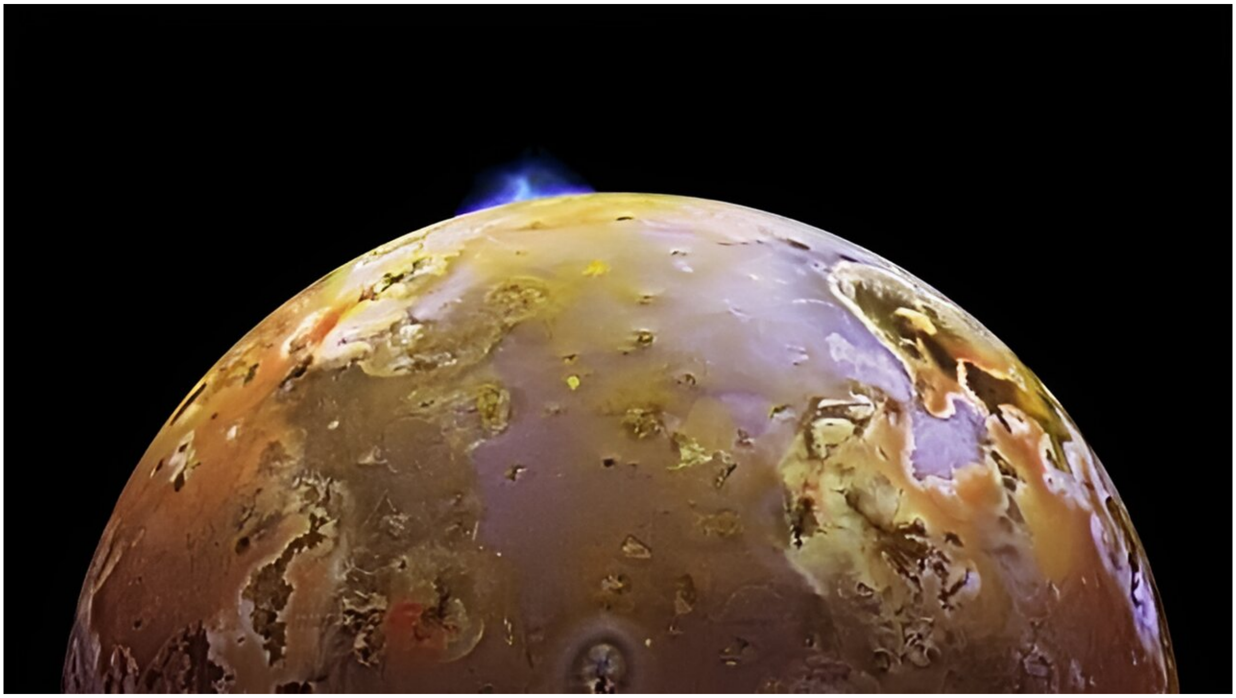
Now, there's another proposal for the Io Volcano Observer, but this time, it's under NASA's New Frontiers Program. The new proposal shows that the desire for an Io-focused mission won't go away. Instead, it's gaining steam.

In a new paper still subject to peer review, a group of mostly American scientists present their case for the New Frontiers IVO. It's titled "Comparing NASA Discovery and New Frontiers Class Mission Concepts for the Io Volcano Observer (IVO)" and its available on the *arXiv* preprint server. The first author is Christopher Hamilton from the Lunar and Planetary Laboratory, University of Arizona.

The IVO NF would address our scientific questions by reaching three goals, according to the authors:

- Determine how and where tidal heat is generated inside Io;
- Understand how tidal heat is transported to the surface of Io;
- Understand how Io is evolving.

The original IVO proposal had the spacecraft encounter Io 10 times in four years after reaching the moon in 2033. It would've carried five instruments, with a sixth under consideration. The IVO would've crossed Io from pole to pole, passing over the equator at an altitude of between 200 and 500 kilometers (124 and 310 miles.)



The Jovian moon Io as seen by the New Horizons spacecraft. The mission's camera caught a view of one of this moon's volcanos erupting. A new mission to Io could have a spacecraft fly right through one of these plumes to sample it. Credit: NASA Goddard Space Flight Center Scientific Visualization Studio

The closest approaches were carefully designed to give the spacecraft the best observations of the moon's magnetic field, gravity field, and libration amplitude. The approaches also would've allowed for both sunlit and dark views of volcanoes, allowing the spacecraft to study the composition of lava. The polar perspective would've provided new views of heat emanating from the moon that were unavailable to Galileo and unobservable from Earth.

The new IVO NF proposal maintains the polar orbit of the original IVO but improves it in several ways. Universe Today talked with lead author Christopher Hamilton about the new proposal. His remarks have been lightly edited for clarity.

The first change in the new proposal concerns the number of flybys, which would increase from 10 to 20.

"10 flybys for the original Discovery-level IVO mission would fill important gaps in image coverage that remain unfilled after the Voyager and Galileo era," Hamilton said. So why double it?

"The new tour not only doubles the image coverage of Io's surface with high-resolution imaging but also enables more flybys of active volcanoes, like Loki, Loki Patera, and Pillian Patera," Hamilton said. "These are highly dynamic volcanic systems that include active lava lakes and explosive eruptions—one pass over the volcanic systems is simply not enough to constrain their time-variability and eruption dynamics."

Like Earth's moon, Io is tidally locked to Jupiter, with one side more readily available for study than the Jupiter-facing side. But Jupiter's effect on Io is much stronger than Earth's effect on the moon. "However, tidal interactions between Jupiter and Io are much stronger, exciting tides in solid rock with an amplitude of about 100 m (328 feet), which is taller than the Statue of Liberty!" Hamilton said.

These tidal interactions drive Io's powerful volcanism. "However, studies of the past decade have suggested that this heat has also melted a layer within Io to form a subsurface ""'magma ocean,'" Hamilton said.

The original IVO's 10 orbits, with its magnetometer instrument, would have confirmed or excluded this hypothesis. The new proposal will carry an improved version of this instrument, and with more orbits, it could answer questions about Io's magma ocean.

"IVO-NF would also carry a fluxgate magnetometer and with the repeat passes, carefully timed to measure Io's induced magnetic field at different times in its orbit, would greatly reduce the uncertainty in estimating a potential magma ocean's depth," Hamilton said.

The current uncertainty is ±10 km, but IVO NF would reduce it to ±3 km. This "would revolutionize our understanding of Io's interior and the links between tidal heating and volcanism," Hamilton told Universe Today.

"Both IVO and IVO-NF are great missions, but doubling the number of flybys more than doubles the scientific return from an Io mission!" Hamilton said.

IVO-NF would also approach Io much closer than the original IVO. The original mission called for an altitude of 200 and 500 kilometers (124 and 310 miles) above Io's surface. IVO-NF would begin its mission with high-altitude fly-bys, but as the mission progressed and objectives were reached, it would come much closer.

"With 20 flybys, IVO-NF can be more daring, flying closer to Io's surface and even flying through its volcanic plumes to determine the chemistry of its erupted products in unprecedented detail," Hamilton told Universe Today.

Initial flybys would be at about 200 km, "but as the mission progresses and Baseline objectives are achieved, we will be able to lower the altitude of later flybys over active volcanoes like Pele Patera," Hamilton said.

"Nonetheless, we would image and analyze these volcanoes first, making use of repeat coverage to further constrain the safety of the close approach, and take precautions like reorienting the spacecraft's solar panels so that they fly through the plume side-on rather than exposing the full cross-sectional area," Hamilton told Universe Today.

"Plume flythroughs for Io would also open the door to other sampling opportunities for plumes on Saturn's active moon, Enceladus."

"This may seem dangerous, but even at altitudes of 50 km, there would be very few particles," Hamilton said. But before the spacecraft comes that close, it'll use its Surface Dust Analyzer to understand the hazard.

This instrument was added to the IVO-NF as a top priority. It will measure surface dust composition and the composition of nanograins in the volcanic plumes. Overall, it will give scientists a better understanding of Io's dust environment and inform them if it's safe to approach within 50 km.

According to Hamilton, we're experiencing a renaissance in exploring the Jovian system.

"This is an important time in Planetary Exploration, and exploration of the Jupiter System is undergoing a renaissance, with Juno, Europa Clipper, and JUICE examining Jupiter, Europa, and Ganymede at the same time," Hamilton told Universe Today.

Io is a critical part of Jupiter's moon system. It's at the heart of the orbital resonance configuration between Io, Europa, and Ganymede, and the resonance drives geological activity on all three moons, including volcanism, tectonic activity, and the formation of surface features.

"Juno has filled some important gaps left after the end of the Galileo mission (1995–2003), but IVO and IVO-NF would be the first to have an instrument suite that is optimized specifically for Io," said Hamilton.

To the intellectually curious, everything in nature is worthy of study and deeper understanding. An extraordinary world like Io is certainly no exception, with everything it has to tell us about itself, its sibling moons, and even about the early Earth and moon.

"Our paper makes the case that Io is a priority target for exploration that should be considered in the next New Frontier Announcement of Opportunity," Hamilton told Universe Today. He acknowledges that the original IVO mission at the Discovery level is possible, but the IVO New Frontiers mission would accomplish a lot more and would more thoroughly address our outstanding questions about Io.

"A larger mission to Io via New Frontiers would more than double the scientific return of the mission and would offer the best approach to understanding not just Io, but the Jupiter System as a whole, and the origins of high-heat flux worlds like the early Earth, early moon, and other terrestrial planets in the solar system and beyond," Hamilton concluded.

More information: Christopher W. Hamilton et al, Comparing NASA Discovery and New Frontiers Class Mission Concepts for the Io Volcano Observer (IVO), *arXiv* (2024). DOI: 10.48550/arxiv.2408.08334

Provided by Universe Today