

**Student questions: David Williams colloquium on “World of Fire (and Ice): Exploring
Jupiter’s Moon Io”
Dr. Williams’ answers in Blue.**

1/29/20

Question 1: You mentioned that there are no impact craters on Io, is that because of Jupiter's large gravitational pull that prevents smaller bodies from impacting Io?

No, it is because Io’s active volcanism covers over craters very rapidly, geologically. The resurfacing rate is ~1 cm/yr.

Question 2: Compared to the other moons of Jupiter, what is the significance of Io?

It is the most rocky, the most geologically active, and the best natural laboratory to study tidal heating.

Question 1: How does the radioactivity of the Jupiter's moon Io affect space exploration equipment?

Radiation from Jupiter itself (not Io), degrades spacecraft electronics after long exposure. Even quick flybys by the Galileo spacecraft resulted in radiation-induced computer errors, and failure of one of the Solid State Imager’s imaging modes.

Question 2: How often on average do volcanoes erupt on Jupiter's Moon Io?

Best estimates are that there are multiple volcanoes erupting on Io continuously.

Question 1: In earth, volcanoes result from the movement of tectonic plates. Taking into consideration that IO has no tectonics, what is the origin of its vulcanisms?

Tidal flexing in the asthenosphere and/or mantle creates a magma ocean, which feeds Io’s volcanoes.

Question 2: During the colloquium, David Williams mentioned that volcanoes in IO are almost if not the size of Arizona. Why are vulcanos massive in IO?

Without plate tectonics to move the crust above the hot spots (like Hawaiian islands on Earth), volcanoes erupt in one location and can get bigger and bigger. Also, the lower gravity of Io and the lack of an atmosphere enable bigger eruptions, all else equal.

Question 1: How does Jupiter's radiation affect probe instruments?

Radiation disrupts spacecraft electronics, causing upsets in the computers and, over time degradation of mechanical systems.

Question 2: Is tidal flexing similar to ocean waves on Earth?

Yes, similar to tides on Earth, only much great on Io, to flex its solid crust.

Question 1: What specific science questions do you hope to answer about Io with the IVO probe? Amplitude and strength of tidal activity, temperature of active eruptions, among others (see the slide set).

Question 2: What do volcanoes teach us about Io? What do we hope to learn by studying them? Volcanoes are mechanism whereby planets lose their interior heat, and act as windows into interior processes.

Question 1: I thought I saw on the slides that Io has an undifferentiated mantle. If that is the case, then is the current thought process that tidal forces from Jupiter are the reason?

Io's interior structure is not well determined. It is thought to have an Fe-FeS core, rocky mantle, mushy magma ocean in its asthenosphere, and a crust of silicate with solid and liquid sulfur and SO₂ zones.

Question 2: What type of rock are the mountain features on Io made up of?

To be as tall as they are, they must be silicate. Sulfur is not strong enough.

Question 1: Who is a professional I should contact to inquire about working with, or being educated on, the moons of asteroids?

Several asteroids are known to have moons, like Dactyl around (243) Ida. At present I am not aware of anyone at ASU who specializes in studying asteroidal moons. You might ask Prof. Steve Desch.

Question 2: I have known about the Kepler System for some time, I am unsure about the moons of this system, if there are any; are they potentially habitable?

I assume you mean some of the exoplanet systems discovered by the NASA Kepler spacecraft? That mission has discovered many thousands of exoplanet candidates, some within the habitable zones of their stars. Some of these could be habitable. This is an area of active research.

Question 1: Why is there so much volcanic activity on the surface of Io?

It is induced by tidal activity caused by the Laplace resonance of Jupiter, Io, Europa, and Ganymede.

Question 2: Compared to the other moons that orbit Jupiter, why are there little to no impact craters on Io?

Io's volcanism has buried them.

Question 1: Is volcanism relatively uniform across Io, and what does that tell us about its interior?

The coverage of Io by various flyby missions is incomplete, so it is unclear about the uniformity of volcanism. Available data suggests concentrations in some regions.

Question 2: Do we understand the origin of hotspots, and are they different on Io and Earth?

Each hot spot is an individual volcano. We don't know much about how their plumbing systems work.

Question 1: What are the biggest influences to the different eruption styles on Io and Earth?

On Io, Tidal heating, lower gravity, lack of an atmosphere, and presence of SO₂ and sulfur as the primary volatile gases in the magma. Earth has no tidal activity that causes volcanism, higher gravity, a thick atmosphere, and H₂O and CO₂ as volatiles.

Question 2: How big was the discrepancy between the data from Voyager and Galileo when you created the map for Io?

Voyager got some good coverage of parts of the subjovian hemisphere, whereas Galileo got better coverage of the antijovian hemisphere. But the filters used were different.

Question 1: I understand the difference between effusive and explosive volcanism, but I am confused about the difference between sulfur and silicate volcanism. In my head, the two are not mutually exclusive, for example, Vulcano in the Aeolian Islands had both sulfur and silicates present (right?). Yes! My question is what is the difference between sulfur and silicate volcanism?

Both sulfur and silicate can be the primary liquid rock, or magma, that erupts onto the surface. Sulfur can also be a volatile gas in silicate magma. On Earth, pure sulfur eruptions are much more rare. Mostly it is a gas in silicate eruptions.

Question 2: How can Europa and Io be so proximate (relatively speaking) and yet have such different surface temperatures? Is it more based on proximity to Jupiter, composition, age, or a different factor?

It is caused by composition of the moons. Io is rocky with no water, plus active volcanism, whereas Europa is a water-rich icy world.

Question 1: Io is considered to be the youngest surface in the solar system due to the large amounts of volcanic activity constantly resurfacing the moon; why don't we see cratering on the surface in regions where there are plumes and no longer active volcanoes?

There could be and likely are small craters preserved in inactive regions. We just haven't had the imaging resolution or coverage to detect them.

Question 2: Because the Galileo space craft's umbrella malfunctioned, would that keep other space crafts from using the same idea; or would modifications be made to allow future missions to use the same design?

I think all missions since Galileo have avoided HGAs that open like an umbrella, based on the problem that occurred on Galileo.

Question 1: Why did you start studying volcanism?

Volcanology was the first geology class I took at ASU in grad school, and I became fascinated with them at that time.

Question 2: Will Io ever "cool down"?

If the tidal activity it currently undergoes to cease (for whatever reason), then the volcanism would end

Question 1: Do tidal forces affect any other moons to the extent they affect Io? You mentioned Europa as another planet that experiences high tidal forces. Why are the two moons so radically different? Wouldn't they have formed in relatively the same area?

Presumably they formed in their current locations. It is the difference in compositions that causes the two moons to be different: Io is rocky, Europa is icy. The lower tidal heating at Europa's distance from Jupiter is still large enough to cause melting of the ice to make the subsurface ocean, and the ridged plains of its crust.

Question 2: How applicable are the measurements/discoveries that we get from Io to other exoplanets/moons that experience tidal forces? Do the physical makeup of the other bodies matter more than the tidal forces or is it a factor of both?

Both factor in. The idea is that understanding Io (and Europa) will inform us on exoplanets in other solar systems where similar tidal activity occurs.

Question 1: What is the oldest feature on the surface of Io, and how old is it?

Without impact craters to count or samples to radiometrically date, it is impossible to tell. But we think some of the old mountain blocks represent the oldest material at the surface.

Question 2: Besides sulfur, silicates, and SO₂, what is the mineralogy of Io's surface composed of primarily?

That's it! We don't know any better, but we think the silicates are dominated by olivine and the pyroxenes. Need a new mission to find out!

Question 1: What is the most challenging mission you have been a part of and why?

Probably Galileo at Io, because Io is a tough place to acquire data and Galileo's instruments were pretty primitive compare to what is available now.

Question 2: Does Io's surface appear to move relative to the hotspots?

No.

Question 1: What is required for there to be over turning in the Lokian lava lakes?

Disruption in the frozen lava crust by convective activity in the molten lava underneath.

Question 2: These lava overturns, how large(thick) are they and would there be a possibility that io make have piles in the mantle and cause convection that could over turn the upper crust?

We do not know. It's possible.

Question 1: The volcanism that is happening on IO is the most intense in the solar system, how do these events that only happen on IO relate to the volcanism that happens here on Earth?

Volcanism on Io is more akin to ancient volcanism on Earth back in the Hadean, some theorize.

Question 2: Would it be in the interests of Scientists to make a "cheap" satellite device, that is meant to be used for 3 months, that would orbit IO to gather data that otherwise could not from just flying by multiple times to prolong the life of the spacecraft?

Yes, a short-lived CubeSat in Io orbit could collect data not possible by a flyby mothership.

Question 1: What criteria were you using when deciding on your map units for the map of Io?

Morphology (shape of the surface), texture, albedo (brightness), and color (composition).

Question 2: What is the next planet or moon you want to work on after Io?

I am working on Pluto now, then (16) Psyche.

Question 1: What causes or allows the volcanic eruptions on Io to be so expansive?

Lower gravity and lack of an atmosphere on Io.

Question 2: What can studying Io tell us about our own planet?

Insights into Earth's volcanism, both in the present and the past.

Question 1: Is the tidal heating responsible for the seemingly accelerated reshaping of Io's surface, appear to be changing its rate in any discernible respect?

Volcanism induced by tidal activity resurfaces Io at a high rate, ~1 cm/yr, higher than any place beyond Earth.

Question 2: As a researcher, what is some of the most pertinent, sought-after data to be collected by a space probe or spacecraft like *Voyager I* or the *Galileo* when performing flybys?

Images with a variety of spatial resolutions, compositional information from spectrometers, topographic, gravity, magnetic field information (for objects without atmospheres).

Question 1: Does the constant flexing of Io at 1000 meters every 1.8 Earth days generate heat for the moon since it is farther from the Sun in comparison to Earth's moon?

Yes, that tidal heating powers Io's volcanism.

Question 2: Is it possible that parts of the Galileo spacecraft survived after it plummeted into Jupiter and if so does this pollute the planet?

No, it was traveling so fast that friction with Jupiter's atmosphere caused the spacecraft to vaporize.

Question 1: What was the reason behind the malfunction of the Galileo Orbiter's umbrella?

The mission was redesigned multiple times because of problems with the Space Shuttle system in the 1980s, and the spacecraft was trucked back and forth across the country. Engineers think that movement cause bending in the antenna such that it jammed while opening.

Question 2: With the missions going to Io and the Galilean moons, do you think it will be possible to have a lander mission on Io in the future?

Likely not in the near future, but yes, a short-lived lander should be possible from an engineering perspective.

Question 1: If technology permitted do you believe we will ever have economic interest to visit the moons of Jupiter?

At present it is unclear if there is a usable economic commodity on Io that would be worth exploitation.

Question 2: Do you believe that using GIS on this project helped you visualize the topography, or did it just give a more understandable visualization to the public?

Yes, absolutely!

Question 1: Is it possible that Europa's salt ocean could potentially have life?

Yes.

Question 2: Does Io have tectonic plates and if so what is the rate that they move at compared to Earth's tectonic plates?

Io has no plate tectonics. It loses heat through a 'heat pipe' model.

Question 1: Why don't all Jupiters moons have craters?

Active volcanism on Io has erased all of its impact craters. Europa has a few, and Ganymede has many, but tectonic resurfacing has also erased many on those icy moons.

Question 2: Why does IO create a gaseous torus material around it?

The Io plasma torus results from the ionization of volcanic gasses from Io, from interaction with Jupiter's powerful magnetic field.

Question 1: What potentially useful resources are there on Io, and would there ever be any interest in exploring its geology for this purpose?

Currently this is unknown.

Question 2: What potential for life is there on Io given is extreme volcanism produced by tidal forces?

Very, very unlikely that life as we know it could exist on Io.

Question 1: Are there any other significant sources of heat besides tidal heating on Io?

Probably radioactive decay of isotopes, but this is much smaller.

Question 2: How variable is the thickness of Io's crust, given that the height of some of the mountains is so extreme and variable, and accounting for mountain roots?

This is not well understood. The crust is estimated to be ~30 km thick (based on the tallest mountains), but it is not well constrained.

Question 1: Would a future lander/rover mission to Io be feasible, or are the conditions there hostile to current materials used for making such machines, like on Venus?

A short lived lander/rover might be feasible.

Question 2: Could any of the Galilean moons suitable for establishing colonies in the future? We all have heard about Europa's contention for the presence of life but I have read some reports about Ganymede being a potential candidate for human colonies.

Ganymede is probably the best option because it is the largest, has the highest gravity, and generates its own magnetic field to offer some protection.

Question 1: Could landers or other terrestrial exploratory machines compensate for Io's tidal flexing with current possible engineering technology?

No.

Question 2: Can the volcanoes on Io be dated from the data gathered from previous flyby missions, is there a different technique needed to do so, or is it even possible to date those volcanoes?

An in situ measurement or sample return would probably be required.

Question 1: Does the extreme non-spherical form of an asteroid affect the orbit of their moons, compared to the moons' motion of planets?

Potentially, yes.

Question 2: What kind of shielding is used to counteract the radiation on the satellites?

JPL has developed rad-hardened electronics. Also, we put the electronics within a vault of aluminum inside the spacecraft body.

Question 1: Do we have a theory on the origins of Io?

Probably formed in the jovian system, but it is unclear when the Laplace resonance arose.

Question 2: Are the volcanic eruptions coming mainly from the core or the mantle?

Either asthenosphere or deep mantle

Question 1: What other bodies in our solar system do you wish you could study?

All of them!

Question 2: Does the tidal flexing act like shaking an etch a sketch or a sand box and clean the surface completely off of craters?

More like squeezing a rubber ball (it heats up!). The erupted volcanic materials bury the craters.

Question 1: What would looking at the changes in Io's surface features over time tell us about it?

How and what types of volcanism reoccur the most.

Question 2: Did you notice any significant data degradation from Galileo in the later orbits because of the radiation field? And if so, is that a concern for future missions?

The camera did degrade over the course of the mission, but most of the images returned were useful.

Question 1: Do you worry that with an increased focus on finding life in space, there will be less funding for exploring objects such as Io, where the conditions seem to be less suitable to life?

Yes, this is very much a concern!

Question 2: You mentioned Io is the most geologically active site in our solar system besides Earth, what knowledge have we gained from Io that we can apply to our understanding of Earth?

Nature of volcanism, both now and in the past.