Student questions: SESE postdocs colloquium:

Carver Bierson: "Why is Io Rocky and Ganymede Icy?"

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Answers by Carver in blue.

How is the fierce volcanic activities in Io affecting its planet's orbit? Is there any known or discovered instability in its orbiting?

The volcanoes themselves don't directly change Io's orbit. However the tidal heating that drives those volcanoes is deeply tied to Io's orbit. Tidal heating in general takes energy from a moons orbit to produce heat. Over time this reduces the eccentricity of the orbit (making it more circular). Once an orbit is perfectly circular there is no more tidal heating. Io, Europa, and Callisto are in a special configuration (called a Laplace resonance) where they steal energy from Jupiter's rotation to keep their eccentricity high. They do this by having their orbital periods as integer multiples of each other, so as Io orbits four times, Europa orbits twice, and Callisto once. It turns out this configuration is extremely stable and so may have existed for all of solar system history.

What are the possible triggers to the fierce volcanic activities in Io, does this has more to do with the dynamics of its deep materials or more of external influences?

Earth's heat flow (the amount of heat moving from the interior to the surface) is ~0.1 W/m^2. For Io it is ~2 W/m^2, twenty times more than Earth. That heat comes from tidal heating (see my previous answer). The only way Io can move that much heat from the interior is to have constant eruptions of volcanic material. This is often called a "heat pipe" model of heat flow in comparison to the Earth which uses plate tectonics to move heat to the surface.

Is it more common to see moons formed like Io, or like Ganymede? Thank you!

Io is a really unique world. It is the only large rocky moon in the outer solar-system. The most similar satellite would probably be Earth's moon but that hasn't been volcanicly active in billions of years. Ganymede on the other had has a similar composition (70% rock 30% ice) to many other moons like Callisto, Titan, Triton, and even Pluto. Each of these worlds has aspects that make them unique (Titan has an atmosphere for some reason) but they also all seem to have been formed our of roughly the same mix of material.

How does the information gathered from the Europa Clipper mission help to answer your questions about Io/Ganymede?

Europa Clipper will (hopefully) get measurements of the chemistry and isotopic composition of Europa's ice shell with its mass spectrometer. Each of these different pathways of losing ice has its own impact on that chemistry and isotopic composition. I will also note that this is an excellent question but to answer it deeper than this requires diving into the isotopic fractionation and that would be a very long answer.

What are some of the specific isotopic traces we need to look for from the Europa Clipper mission to tell us about how the ocean on Europa formed and how exactly will that help tell us about whether Io had an ocean?

The short answer is we are working on this. I have made predictions from my work about what the isotopic difference should be between Europa and Callisto. Now we need more predictions from the other models (like ice sublimation) so we can compare the two.

How and why would one of Jupiter's moons dehydrate its center?

Warning: I am not a geochemist so this might not be 100% correct. Some rocks (like serpentine) have water bound in their chemical structure. When those rocks get heated (by tidal heating or radioactive decay) the rock chemistry changes and the water is released. This is a really important process in subducting slabs on the Earth because that released water helps melt the surrounding rock. On Europa **maybe** that released water made it to the surface to form its ocean. I don't think many planetary scientists think this formed the whole ocean but we also don't know how much it contributed.

You said there where three possibilities for how the water that froze hot on them, how do we figure out which one really happened and what does the mean in terms of their formation?

Testing these ideas is hard. I am trying to put together predictions for each of these models that can be tested by Europa clipper.

Would the ice present on particles forming Jupiter's moons have changed phase or been stored elsewhere during accretion and reappeared as ice later on?

In the low pressure of space H2O is either going to be ice or vapor, you need some pressure to keep it liquid. So the H2O that was accreted onto the satellites was almost certainly ice (you have to be Jupiter size to accrete gas). Once on the satellites it can melt alternating between ice and liquid. Today it is thought that Europa, Callisto, and Ganymede all have liquid water oceans under their ice shells.

You mentioned that taking isotopic composition of the ice on Europa would help us understand how Jupiter's moons' oceans formed. How, though? What kind of results would be definitive, and how would Europa Clipper measure the required data?

Great question, still working on the details of this. I am published some predictions and now we need predictions from other models to test against. Europa clipper is planning on carrying a mass spectrometer that will be able to measure the chemistry of Europa's ice shell.

You mentioned that the inner portion of the proto-Jovian disk is warmer than the outer portion; if it is warmer how are volatiles or water not lost?

They were lost, but it takes time to lose all of them. It becomes of question of how long does a bit of material spend in the hot part of the disk before being accreted versus how long does it take to lose all of your ice. The bigger you are the longer it takes to warm up and the faster you move in the disk. Because of this previous researchers have suggested that anything larger than about a meter would not lose its ice before being accreted onto Io or Europa.

How excited are you and your team for a mission such as the future Europa Clipper and how could data from this type of mission improve our understanding of the icy moon?

I'm not on Europa Clipper but I wish I was :). That said I am super excited for the results. I think the biggest leaps in understanding will be learning what is happening in Europa's ice shell. Are there pockets of water? Is the ice convecting? Is there something like plate tectonics?

Wouldn't an atmosphere keep the water on the planet rather than be an efficient way of removing it from the moon's surface?

All atmospheres leak to space. How fast they leak (lose mass) depends on the gravity holding them down and their temperature. Hotter atmospheres have faster moving particles that escape easier. Io and Europa (particularly as they were forming) were small low gravity worlds by comparison to say the Earth. They were also in a hot disk that heated the atmosphere. This is a perfect recipe for fast atmospheric escape. As the atmosphere loses mass the ocean "boils" (going from liquid to vapor) to try and buffer the loss. In the end you keep losing water till its all gone (or nearly so in Europa's case).