Student questions: Edwin Kite colloquium on "Powering Cry-Volcanos on Icy Moons"
2/17/16

Question 1: With what information is availible about Enceladus and its plumes, are there any estimates about how long the ring it makes can be maintained?
The mass of the E-ring is approximately the mass flux from Enceladus' eruptions of ice grains, multiplied by 8 years. Assuming that the ring is at steady-state mass, the lifetime of the individual ring particles is therefore 8 years (Ingersoll & Ewald, Icarus, 2011). The water vapor ejected by the eruptions does not condense into additional ice grains because the gas is so tenuous far away from the moon's surface.

Question 2: During and after the talk there were a lot of comparisons to other icy moons, particularly the similarities between Enceladus and Europa. How common are Enceladus' features amongst the other icy moons?
Miranda, Europa, and Ganymede all show features that appear to be either extinct of dormant "tiger stripes." Overall, although sub-ice oceans may be common among mid-sized icy satellites, most of the mid-sized icy satellites show little or no evidence for tectonic resurfacing. For example.

Question 1: How did you derive the equations for the daily water cycle in tiger stripes?
See equations A1 → A8 in
http://geosci.uchicago.edu/~kite/doc/Kite_and_Rubin_PNAS_accepted_Supplementary_Information.pdf .
Starting with conservation of volume in the slot, I first found the slot-wall distortion due to the time-varying tidal elastic stresses for a single slot, then added the "back-pressure" from water that didn't have enough time to be flushed out of the slot (or ingested into the slot) in order to reach equilibrium with the tides. Finally, I considered the effects of interacting slots.

Question 1: You said that the geysers drive the tectonics, but wouldn't the tidal stresses from interacting with Saturn's gravity drive the tectonics? How are the geysers powerful enough to do so?
The tides drive the whole system! But is the tidal energy deposited in the ice in the ice shell, the water in the ocean, or the water in the plumbing system within the ice shell? In the first two cases, the tides would drive the tectonics which would drive the geysers. But I think the third case is true, in which case the tides drive the geysers which drive the tectonics.

Question 2: Why did you not mention Venus when overviewing planets in our Solar System that undergo endogenic volcanism? The surface is very young with evidence of volcanism, although I am uncertain as to how recent that volcanism is.
The surface of Venus is a few hundred Myr old (based on crater statistics), resurfaced by lava. There is circumstantial evidence for <1-Myr-old volcanism (e.g. from regions with anomalous surface emissivity). I don't think this circumstantial evidence is convincing – more Venus missions are needed to confirm! If I included volcanically-dormant worlds I would have circled Earth's moon as well.

Question 1: What are ideal satellite conditions for conducting astrobiology research (you mentioned Cassini was moving too fast)?
Ideally you would insert a submarine into the ocean and look for the hydrothermal vents that are suggested by the nano-silica! Another option would be an Enceladus orbiter plus sample return (slow orbital velocity because Enceladus gravity is weak).

Question 2: Thinking about the slide with that massive equation, what instruments can help test the accuracy of that equation (observing the change in width, water levels, etc.)?
We might already have the data to test the model. Spitale et al. (Nature 2015) reports space-time variations in the erupted flux (in the talk I only discussed time variations), and these can be compared to different models. Nimmo et al. (Astronomical Journal 2014) shows that crack models do not work.

Question 1: Why do you think all the tiger stripes of enceladus are by the south pole and not by the north?
I don't know. One possibility (Nimmo et al. Nature 2006) is degree-one mantle convection, followed by true polar wander to a randomly-selected pole. But this solution raises as many questions as it answers …

Question 2: Has this happened on other planets or moons?
Possibly; Miranda (Uranus' moon) and Europa (Jupiter's moon) look similar, so maybe models

---

Question 1: Can other volitiles, such as amonia drasticly change the behavior of oceans below icy worlds?
Yes – ammonia acts as antifreeze and makes eruptions easier.

Question 2: How does a moon like Miranda compare to Europa, and does being farther out from the sun account for the chaotic terrain we see there?
Miranda has three roughly-rectangular coronae containing parallel depressions, whereas Europa's . I don't know of any reason why the distance from the sun (i.e., the surface temperature) would affect the surface disruption.

Question 1: Are your estimates of water production from these tiger stripes based in any way on modeling of the topographical build up of ice around the tiger stripes themselves?
No they are not. However, a full model should explain why the ridges would subside once they move away from the tiger stripes (I have not done this yet, and if I cannot do this then my tectonic-cycle model is wrong). The axial ridge close to the crest of the East Pacific Rise does subside as it moves away from the magma source, and this may be an Earth analogy.

Question 2: Could the location of the tiger stripes suggest there is a hot spot deep in the rocky core of Enceladus beneath this location, or are we certain the stripes are due solely to tidal friction?
Basically #2: the problem with #1 is that the ocean would even-out any thermal plume rising from the seafloor so that the heat flux from the seafloor would be smoothed out.

Question 1: What exactly is the Mimas test and how does it measure the energy sources?
Mimas, an inner moon of Saturn, is the same size as Enceladus, and roughly the same composition, with similar orbital eccentricity, but lacks tectonism or volcanism. If an energy-source hypothesis predicts the same level of volcanism on the two moons, then it cannot be correct.

Question 2: When the ocean material is ejected into the air in the plumes, how long will it stay in the atmosphere before dissipating?
A lot of the material escapes into orbit around Saturn. The rest crashes back on to the surface on ballistic timescales. There is essentially no atmosphere.

Question 1: Are each of the tiger stripes about equally volcanically acitve, or is there variation between them?
About equally active.

Question 2: Will future imaging missions be able to target Enceladus at specific intervals of its elliptical orbit in order to further prove that the most active volcanism occurs when is farthest from Saturn in its orbit?
The Cassini mission has done this already – Hedman et al. Nature 2013

Question 1: In regards to the initiation of the volcanism, is there the possibility of the minerology and the phases of the ice and water having any significance to the bouyancy of the underlying water ocean?
I assume you mean the mineralogy/phases of H_2O? The pressure inside Enceladus' ice/water layer is too low to stabilize high-density phases of ice such as Ice III.

Question 2: What are the, if any, prevailing theories regarding the initiation of cyrovolcanism on Enceladus?
It's complicated! Start with Crawford & Stevenson (Icarus, 1988) (http://adsabs.harvard.edu/abs/1988Icar...73...66C) and follow the citation trail! Rudolph & Manga (2009) http://adsabs.harvard.edu/abs/2009Icar..199..536R is also good.

Question 1: How accurate is the mimas test to confidently rule out everything except tidal heating?
It's a circumstantial, heuristic argument, not a decisive test.

Question 2: As far as I understood, you believe the tiger stripes are from the tension and compression and they let loose a supersonic plume, but how wide do they get, why don't they close, and why do we not see giant gaps all the way down in the pictures if they do not close?
In my model the peak slot width is a few meters. They don't close because of back-pressure from the water (the water cannot be squeezed out of the slots quickly enough for the slots to respond fully to the tidal stresses in 0.7 days, i.e. ½ an orbit). Cassini's highest-resolution images of Enceladus have a pixel size bigger than that.

Question 1: What percentage of the ejecta falls back to the surface and what percentage travels into space?
This has not been measured directly. We know some proportion does fall back to the surface because snow has been mapped in a pattern that matches that expected for (rotationally-modified) suborbital flight from the vents – e.g. http://meetingorganizer.copernicus.org/EPSC-DPS2011/EPSC-DPS2011-1358.pdf.

Question 2: Do we really expect enough ejecta to be released within the next decade or two, before spacecraft fly there, to cease all further release?
The problem is clogging up of the vents with frost, not exhaustion of the reservoir. I think that my model resolves this problem.

Question 1: If Enceladus orbit is elliptical and Saturn causes Enceladus to be oblong at times, would there be any danger of Enceladus breaking up?
For a cohensionless (strengthless) body the disruption limit is the Roche radius, which differs for each planet, inside of which we find rings but no large moons. Enceladus orbits well outside the Roche radius.

Question 1: You stated that Cassini took a shower in Enceladus's plumes at 18 km/s, which destroyed the organics. What would be the optimal cruise speed to collect samples without destroying them?
Much less than 7 km/s (Stardust encounter velocity). 2-3 km/s is probably sufficiently slow.

Question 2: I'm currently trying to design a cubesat mission to Enceladus and I'm having a hard time choosing only one science intrument to include on the satellite. If you could choose one scientific instrument for an Enceladus cubesat, what would you select?
Very Tricky! If you have 12U (interplanetary cubesat standard) then I would try minituarizing the mass spectrometer proposed for E.L.F. (Enceladus Life Finder) by Prof. Lunine and also for TANDEM (Titan AND Enceladus Mission). Descriptions of these missions and instruments can be found by googling.

Question 1: How important is it to have a global ocean compared to local ones when regarding these types of eruptions on Europa and Enceladus?
A moon with a local ocean deforms less under tidal forces than a moon with a global ocean, so a moon with a local ocean will have weaker turbulent dissipation and thus a lower power output. Any eruptions that initiate on such a moon are thus more likely to shut down.

Question 1: What kind of salts are in the oceans?
Definitely sodium (this has been directly detected). The other cations and anions are theoretically estimated using models of water-rock reactions, e.g. by Prof. Zolotov in his paper http://onlinelibrary.wiley.com/doi/10.1029/2007GL031234/full

---

Question 1: If the tiger stripes are related to plate tectonics, have we tried measuring the speed at which they move yet and if so, how fast?
Impossible with Cassini's instruments – we need either a radio-ranging station on a surface lander, or a interferometric synthetic aperture radar similar to those Prof. Shirzeai uses. My model predicts horizontal movement at >1 cm/yr.

Question 1: Hello - You had mentioned there have been three close fly-bys of Enceladus. Were all of these performed by Cassini?
Three close passes dedicated to gravity measurements. Many more close imaging passes. All by Cassini.

Question 2: Are there any plans to visit Enceladus with an orbiter in the near future?
Plans exist -
http://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb_059320.pdf - but are not yet funded.