Student questions: Larry Nittler colloquium on "A Trip to the Early Solar System: First Results from Returned Asteroid Ryugu Samples"

9/7/22

What effect is there on the strength or erosivity of asteroids that are tidally locked so only one side faces the sun and asteroids that rotate and become heated on multiple sides?
LN: Interesting question, but I am unaware of any tidally locked asteroids, so I can't really answer it.

Is there a correlation between albedo and asteroid class?
LN: Yes, C, D and M asteroids tend to be much darker than S asteroids which are darker than E asteroids.

What is Raman Spectroscopy and what did it measure in the Ryugu samples?
LN: Raman spectroscopy uses a laser to probe the structure of materials. Basically, some of the laser light excites vibrations in materials, losing energy in the process. This light gets reflected back into a detector but has a longer wavelength than the incident laser. Since vibration frequencies are specific to different phases, we can measure the wavelengths of the refelected light and (mostly) non-destructively learn about the material. It was used to study organic matter in Ryugu. Raman spectra of macromolecular organics provide information about how ordered or disoredered the material is, which further gives us information about how much it has been heated. The Ryugu organics show no sign of heating.

What was the importance of Olivine found in meteorites?
LN: Olivine is one of the most abundant silicate minerals in rocky planets. It is abundant in meteorites whose parent asteroids did not experience extensive aqueous alteration, but such alteration converts olivine to clay minerals. The significance of finding it in Ryugu samples is that it means there are tiny patches of Ryugu that escaped the pervasive alteration that it and CI chondrites experienced. By studying these patches and their surroundig mateiral we should be able to learna lot more about exactly how the alteration occurs.

Has there been any evidence (either spectroscopic measurements taken from orbit or in the samples) to suggest that amino acids are present within Ryugu's regolith?
LN: Yes! Initial analysis of the soluble organics revealed the presence of at least ten amino acids https://www.hou.usra.edu/meetings/lpsc2022/pdf/1781.pdf.

Since Ryugu is likely a rubble pile, is it possible to determine with any degree of certainty the exact nature of the parent body whose remains formed it, such as whether it was a differentiated planet/proto planet that was destroyed?
LN: We can tell that it was undifferentiated, since the Ryugu samples themselves are very primitive. We can also use the sample data to estimate things like when and at what temperature the extensive aqueous alteration occurred and use modeling to estimate how big the parent body originally was. I know there are people working on this. work is in progress.

What makes presolar stardust grains distinct from the carbon found in chondrite meteors and how can you tell the two apart in a lab?
LN: Most carbon in meteorites (and the Sun, Earth, Mars, comets, etc) shows a very narrow range of 12C/13C ratios (about 85-95), whereas the stardust grains show ratios ranging from ~2 to >10,000. By measrung the C isotope ratio we can identify the very rare presolar material.

Would the composition of meteors in other solar systems be more dependent on other factors, or would chondrite meteors be just as common in others as they are in ours?
LN: Interesting question. We would expect planet formation processes to be similar across different systems but there is a lot of randomness in the process and stars have different chemical compositions and it is not yet clear just how much this affects the compositions of planets (and their building blocks) around different stars. I am sure there would be a lot of system-to-sytem variabiltiyh but it would surprise me if there wasn't something "chondrite-like" in most forming planetary systems.

Why is it that the Ryugu samples were examined on silicon wafers?
LN: They were easily avaialble and work reasonably well in the SIMS instrument. That said, I prefer gold or indium substrates (they are cleaner) so we swqitched to gold as soon as we could.

Are the Pre-solar stardust grains made of the same material as the protoplanetary disc?
LN: Some are and some aren't. The most abundant presolar grains in meteorites are silicates that are similar to chemically (but not isotopically) to grains that formed in the disk. But presolar grains like SiC require carbon-rich conditions to form, so this mineral did not form in the disk and essentially every SiC grain we find is presolar.

The sample return seems like a very complex idea. Have there ever been failed returns of other samples in the past?
LN: Not that I am aware of; been pretty lucky I guess.

Why would there be elevated amounts of deuterium and nitrogen-15?
LN: These are thought to reflect unusual chemical reactions happening in space at very low temperatures. In fact, radio telescopes can measure H and N isotope ratios in molecules in comets and interstellar clouds, and have found similar enrichments. Note that the Earth itself is strongly enriched in both isotopes relative to the initial composition of the Solar System (which have been directloy emasured by a probe in Jupiter's atmosphere) so there are clearly processes that lead to such enrichments.

Can we tell which type of star the pre solar grains come from?
LN: Yes, by comparing with theeoretical models and in some cases astronomical observations, we think most of them come from "AGB stars" (one of the last stages of stellar evolution for stars like the Sun or up to a few times more massive).

What are some of the future tests going to look at for the samples?
LN: JAXA recently had its first international competition for allocating Ryugu samples now that the initial analysis period is done. They picked 40 teams to send samples to; you can see the huge range of topics people will be exploring with the samples here:

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When analyzing a microscopic image, is it possible to identify pre-solar grains, or does it need to be identified by chemical signature?
LN: It requires isotopic measurements.

What are the leading/favorited theories for the significantly low albedo on Ryugu?
LN: Some kind of "space weathering" effect (e.g., caused by interaction of the surface with high energy cosmic rays, the solar wind, and/or micrometeorites), but such processes are not well-understood for carbonaceous chondrite like materials. I expect to see a lot of upcoming experimental research to address this.

What could be the processes responsible for the presence of molecular carbonate in the phyllosilicates of Ryugu samples?
LN: This requires a lot more work before we can answer it but it may indicate that there were CO or CO2 ices originally present in the asteroid, and these reacted with organics during the aqueous alteration processing. I believe that people are planning some experiments to compare with the observations.

How representative to you think Ryugu is with respect to the asteroid population? In other words, do you expect to revise the fraction of CI chondrite-like asteroids based on your results?
LN: Excellent question but I don't know. It will be very interesting to see if Bennu is also CI-like.

Do you believe there are any asteroids or similar, other than Psyche, worthy of a mission on the same scale as Psyche?
LN: Absolutely. For example, the Lucy mission is already on its way to study some Jupiter Trojans (a type of asteroids trapped by gravity into orbiting the Sun along with Jupiter).

Assuming the giant impact lunar formation hypothesis is correct, where should we look to find asteroids that would allow us to determine the composition of Theia (the hypothesized impactor).
LN: A prioi, we have no way of knowing. But various researchers have argued that it should be like one type of asteroid or another based on chemical arguments (mostly regardigng differences and/or similiratiites of the Earth and Moon). Nothing is definitive yet.

Coming from minimal knowledge about science of asteroids, I'd like to ask, could the lack of water in Ryugu's composition be due to its porous characteristic?
LN: To be clear, Ryugu has lots of water, some 7% of its weight is in water molecules structurally bound in minerals. But it has less than seen in CI chondrites. I don't think this is related to the porosity, though it's an interesting thought. More likely, it's due to either CI meteorites picking up water when they are on Earth, or Ryugu surface samples losing some due to interaction with the space environment (e.g. bombardment by micrometeorites or high energy particles could in principle heat the samples enough that some water escaped.).

On a slide where the compostion of Ryugu was compared to solar composition, only H, He and Ne were not matching the solar levels (they were offset from the straight line). Considering H, He were the primary atmopshere constituents of Ryugu, could it be that this discrepancy is due to a photoevaporative mass-loss?
LN: Interesting thought, but no, Ryugu's parent body was almost certainly never big enough for its gravity field to have become strong enough to gain an atmosphere from the disk. Rather, the discrepancy reflects that only a little H (originally in the form of water ice) and far less noble gases can end up in these small rocky bodies.

Are there any measurements of pre-stellar stardust from other star systems apart from our own and, if so, how are they similar/dissimilar to pre-solar stardust?
LN: I am not sure I totally understand the question, but all of the presolar grains are by definition from other star systems (that existed before our own).

Do you expect to find pre-solar stardust (or dust from other star systems, if not) from Bennu's returned samples?
LN: Almost certainly, since they have been seen in all classes of carbonaceous chondrites.

What are the astrobiological implications of the carbon found in the meteorites?
LN: It shows us that organic molecules, including things like amino acids, are ubiquitous in space and present in the building blocks of planets. Thus, there are clearly raw materials for life and abiotic processes for producing pre-biotic molecules in small bodies and these bodies may thus provide the raw ingredients for life to the early Earth and other planets.

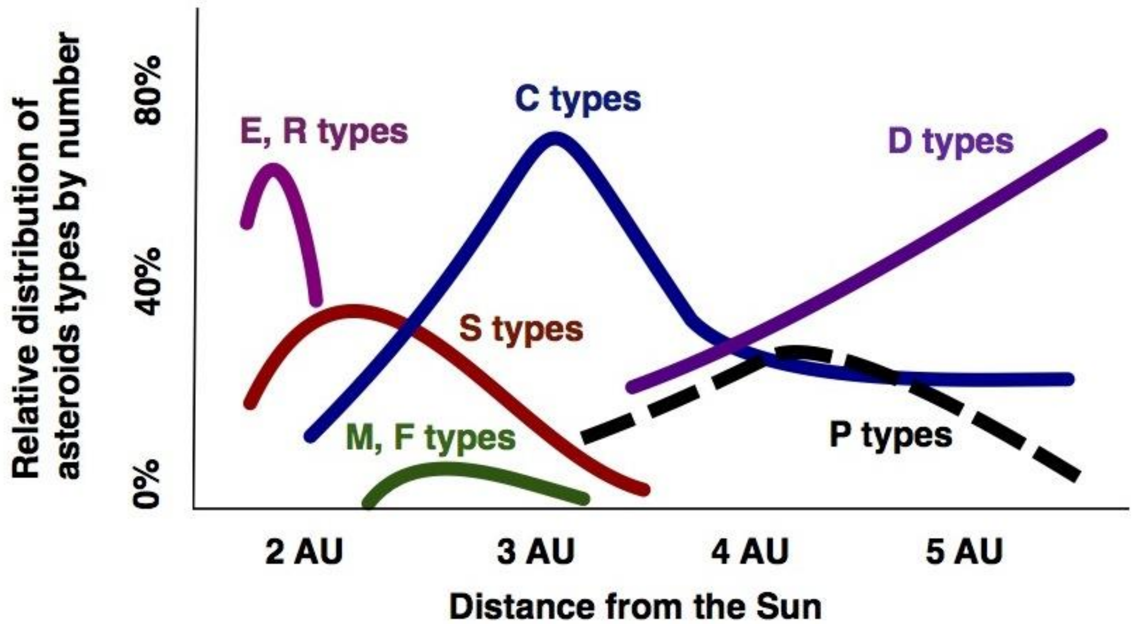
What other factors affect meteorite albedo besides composition?
LN: Space weathering (interaction with the space environment including solar wind particles, galactic cosmic rays, and micrometeorite impacts) can change the albedo of planetary materials (for example, exposed material on the Moon's surface gets darker over time), but the effect is also compositionally dependent and may affect carbonaceous chondrite type materials differently than others.

Are there any immediately noticeable physical differences between the two samples (Chamber A & C) returned from Ryugu?
LN: No.

Why did they use Tantalum as the material for the impactor - are there physical or chemical reasons, or both?
LN: I don't know, but I imagine it's both (i.e. something particular about its physical properties, plus the fact that it is a very rare element that is not of particularly high scientific interest on its own).

The plot of distance vs distribution of asteroid types started at 2AU, why weren't closer asteroids shown?

LN: The plot starts at ~1.5 AU, which is where Mars orbits, so the graph shows the full asteroid belt. Closer asteroids (like Ryugu) have been gravitationally perturbed into their current orbits, so they are pretty much a mix of most asteroid types from the main belt.



Do explosions on asteroids like the artificial crater affect our future ability to study things like the morphology of those asteroids?

LN: I don't think so, such small impacts only have a small local affect. But in principle, if we went back to Ryugu some time in the future we might see new impact craters that have formed since Hayabusa2 was there.

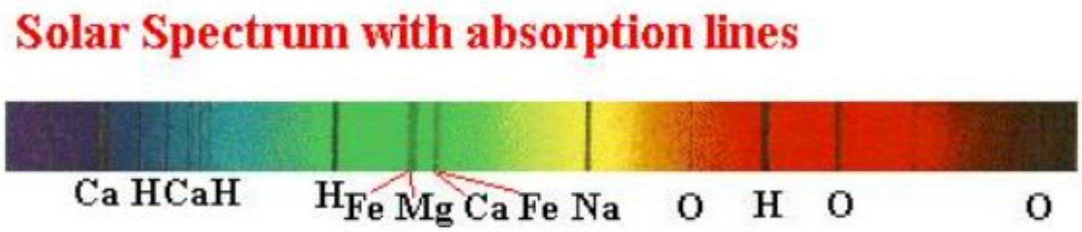
How common an occurrence are moons around asteroids or other non-planetary objects?

LN: I don't know, but I think they are fairly common. NASA DART mission is going to crash a space probe into an asteroid moon in November https://en.wikipedia.org/wiki/Double_Asteroid_Redirection_Test.

Have any meteorites been found that cannot be traced to originate from near-Earth or the asteroid belt?

LN: Most meteorites do not have fireball reconstructions but those that do come from the asteroid belt and thus we assume that most do as well. That said, we definitely could have some from other places (we know we have lunar and martian meteorites); the question is how to recognize them. A few meteorites have been suggested to come from Mercury. They probably didn't, but we have a good idea now how to recognize one if it did. We have very tiny meteorites (interplanetary dust particles) that are collected by aircraft in the stratosphere and there is some evidence that many of these come from beyond Neptune.

Carbonaceous chondrites have bulk compisition similar to the sun. How to prove this, and how do we determine the material composition of the sun?
LN: We can measure the composition of the Sun's photosphere by analyzing spectral lines – that is, atoms in the photosphere absorb some of the light coming from below, so when you look at the solar spectrum you see lots of black lines where elements absorb. By analyzing these (and adding a lot of physics) you can calcualte how much of the various elements there are. And when we do this, we see that most elements are in the same relative abundances as CI chondrites and Ryugu.



With a rubble pile as porous as Ryugu, should we expect the inside rubble to be different from the surface without differentiation?
LN: Good question. Since the surface materials show no signs of differentiation and the rubble pile should be more or less a random collection of stuff broken off a larger body, we don't expect much heterogeneity, but we absolutely do not know for sure. It is entirely possible that whatever smashed into the parent body to break it up in the first place was chemically different and some of it survives in the interior of Ryugu.

Even without exposure to air, did ablation affect the chamber the sample was held in during the retrieval and potentially heat up the sample?
LN: JAXA says the samples stayed very cold and this is supported by their analysis which show no signs of heating.

Were the differences between the sun an Ryugu in density of non-volatile elements due in large part to the production of those in the sun?
LN: The Sun and Ryugu are pretty much identical in non-volatile elements. The Sun is enriched in highly volatile elements (like noble gases, H, N), because they don't like to condense into rocks. The Sun itself is burning hydrogen into helium in its deep interior but none of that material will show up on its surface for another ten billion years or so.

How do grains from other stellar systems get moved so far without being destroyed?
LN: Good question! The answer is that apparently they were lucky. From astronomical observations we ewxpect most dust grains formed in stars to get destroyed by shock waves from supernova explosiona, but some clearly escaped this fate. Note that these are very rare – at most ~100 parts per million of bulk meteorites.

What is the implication of finding non-crystalline CO3 in Ryugu samples rather than crystalline CO3?
LN: To be clear, the Ryugu samples also contain abundant crystalline carbonate grains like dolomite. These are believed to have formed during the aqueous alteration that Ryugu experienced, but the source of the C is not totally clear. It could be from the organic matter or

from CO or CO2 ices that were originally present (or all of the above). The significance of the molecular CO3 is both that it is something about which we know very little and that it may be a "snapshot" in time of the carbonate formation process.

I'm extremely curious about the anomalously low albedo of Ryugu. What could be the cause of this, if not composition - is it possible that there is some phenomenon that increases the optical maturation rate of Ryugu's surface?
LN: Me too! We don't know but we also don't really understand space weathering effects on carbonaceous chondrite like materials (most work in the past has been on how space affect lunar samples and S asteroids, which are chemically very different).

What was it that made us originally assume that carbonaceous chondrites were directly related to c-asteroids if we still do not know that this is true?
LN: The fact that they were dark and rather spectrally featureless made people think they may have a fair amount of C in them, but the connection was mainly based on the fact that we know the C chondrites have to come from somewhere and C asteroids seem like the most likely bet.

Is there any significance of the carbonate anomalies in the carbon isotope samples?
LN: I am not sure what anomalies are referred to here. I answered a couple other questions about the molecular carbonate.

Why do CI chondrites lack chondrules compared to other carbonaceous chondrite groups?
LN: We don't know! It might mean they formed in a different part of the disk where chondrule formation (which we do not understand) did not take place.

What is the significance of finding molecular carbonate rather than crystalline carbonate in the C-XANES spectra of Ryugu?
LN: See above.