Student questions: David Kring colloquium on "Testing the Inner Solar System Impact Cataclysm"

2/10/16

Question 1: Prior to the discovery of evidence that suggested otherwise, why was it commonly believed that comets were responsible for many of the impacts?

A: Comets are visually dramatic objects in the sky, whereas asteriods are dark, often invisible denizens of the Solar System. There was a not-very-scientific subjective preference for comets among some participants in the debate. Some early models also found it easier to disrupt the orbits of comets in the outer Solar System than it was to disrupt the orbits of asteriods between the orbits of Mars and Jupiter.

Question 2: Why would the series of events leading to Jupiter causing resonance in the astroid belt only occur once?

A: The giant planets are currently in a stable orbital configuration, so there is no force available to perturb those orbits. It is thought that they shifted roughly 4 billion years ago, because they were initially in a metastable orbital configuration.

Question 1: You mentioned an alternate hypothesis that stated that there was a large amount of impacts from 4.5 billion years to the drop-off event, and not just a cataclysmic event. What evidence does it have? I would imagine that if it were a valid alternative hypothesis, there would be some evidence in the impact crater ages to indicate the prolonged barrage rather than a relatively short period.

A: Initially, there was no evidence for a high impact rate between 4.5 billion years ago and the drop-off point (circa 3.8 billion years ago). Scientists, like other people, prefer simple answers. Thus, it was easier to imagine a constantly decreasing impact rater from 4.5 billion years ago to about 3.8 billion years ago. It was simply difficult for some scientists to imagine impact rates decreasing, then increasing, and then decreasing again.

Question 2: Is there a correlation with the inner solar system impact cataclysm with the beginnings of life on Earth. If there is, is it significant?

A: Our earliest isotopic evidence of life appears at the end of the impact cataclysm, so scientists have speculated that there is a connection. Two models are being explored: (1) That life originated between 4.5 and 3.8 billion years ago; that the record of that early life has been erased; and we only see the survivors of that period of bombardment; (2) That life could not get established early in Earth history, but was able to emerge after the bombardment ceased. In the latter model, life may have become established in the fractured rocks produced by that bombardment.

Question 1: I understand that it is not proven, but I'm not sure I fully understand exactly how an object(s) of high mass moving through the asteroid belt could cause Jupiter's orbit to shift, and to shift outwards from the Sun. My thought would be if any shoft, Jupiter's orbit would become smaller and not larger as the diagram in the presentation. From a physics stand point, what could have caused Jupiter's orbit to shift out becoming larger?

A: The process that disturbed asteroids does not involve mass passing through the asteroid belt. Rather, gravitational resonances are passing through the asteroid belt. A gravitational resonance is caused when an orbiting asteroid has an orbital period that gets an extra tug from Jupiter. Over time, those extra tugs cause the orbit to shift from a nearly circular orbit to an elliptical orbit. That process works today: it is why meteortites from the asteriod belt hit Earth. If Jupiter moved, then the location in the asteroid belt where the orbital periods obtain that extra tug would have also moved. Thus, a series of asteroids would have had their orbits modified, sending them into the inner solar system on elliptical orbits.

Question 2: How large of an object, or how high of a combined mass of objects, would there need to be passing through the asteriod belt in order to produce the results you found that Jupiter's orbit changed? Jupiter has such a large mass that it is widely accepted that it is the mass of Jupiter in the first place that caused the asteroid belt to form and not another planet, so just how massive would something have to be to influence Jupiter's orbit in such a way?

A: Again, a large mass passing through the asteroid belt is not what caused asteroids to hit the Earth and Moon. It was gravitational resonances, caused by Jupiter's shifting orbit, that caused asteroids to hit the Earth and Moon.

Question 1: Does it matter where you collect your samples on the moon? Will collecting from different areas affect your results?

A: To fully evaluate the geologic record of collisions on the Moon, we need samples from all geographic regions of the Moon and samples that represent all intervals of geologic time. For that reason, we have identified specific craters in different region of the Moon, with different ages, for future sample return missions.

Question 2: Could a bombardment on the moon, change the distance between the earth and moon?

A: The largest of the asteroid impact events I discussed could cause the Moon to rotate, but the impacts would not significantly affect the distance between the Earth and Moon. However, that distance was increasing during the period of bombardment for other reasons. I created a set of diagrams that show that increasing distance and have posted them in a collection of "Classroom Illustrations" that you can access. Go to http://www.lpi.usra.edu/exploration/training/resources/. Then click on "Earth-Moon Dynamics" under the "Classroom Illustrations" heading. The first three illustrations in that category are related to your question.

Question 1: If we could get samples from many different craters, and anaylized them isotopically, would that give us any new clues to the age of features on a planet?

A: Yes – The ages of large craters are important benchmarks for determinng that ages of nearby features on the Moon and also serve to calibrate relative crater counting ages that can be determined for features anywhere on the Moon.

Question 2: How will we try to date worlds beyond the solar system in the far future. Will crater counting be the end all be all?

A: Crater counting in our solar system works because we have a few known ages from the Moon. If we do not have a few ages to calibrate a crater counting system, it will be difficult to apply elsewhere.

Question 1: Your presentation included a slide of a meteor that was identified as coming from the highlands of the Moon. I assume we can identify the providence of the meteorite based on spectrscopic analysis of the surface of the Moon. What I don't understand is how we can do such spectroscopic studies when the lunar surface is so heavily covered in dust and debris from many thousands of impacts that may have scattered impactor material and lunar material in all directions and hoplessly confused/obscured the spectroscopic data?

A: First, let's discuss the difference between the word meteor and meteorite. A meteor is the optical effect produced when a fragment of an asteroid passes through the atmosphere. It is not a solid object, but only an optical effect. A meteorite is the word used for an object that has survived that atmospheric passage and landed on the surface. OK – now let's answer your question. Meteorites are linked to different planetary sources (such as the Moon, Mars, or asteriod-related bodies, such as Vesta) with chemical techniques. Each planet has a unique composition and the rocks generated on it will have unique compositions. The processes that produced a rock and the age of the rock are also clues to a meteorite's origin. In the cases of meteorites from the Moon, they have chemical compositions (such as Fe/Mn values) and isotopic compositions (such as oxygen isotope values) that are characteristic of lunar samples, but not other planetary sources.

Question 2: The careful piecing together of all these pieces of information makes for a fascinating story of how our ideas keep evolving about the solar system's formation. But doesn't the Giant Impact Theory on the formation of the Moon itself, and the idea of Theia, play some part in this story as well?

A: The giant impact hypothesis involves a different period of Solar System history, so it is not, currently, linked to the inner solar system cataclysm hypothesis.

Question 1: Is there a reason that certain areas on the moon tend to be more scientifically rich than others, for instance the angle of a certain quadrant towards the asteroid belt, or is the distribution generally random?

A: Some areas have been affected by many geologic processes, whereas others may have only been affected by a small number of geologic processes. More science can be accomplished in the complex geologic regions. This same strategy was used during the Apollo era. The first missions (Apollo 11 and 12) went to areas affected by mostly by volcanic eruptions of basalt. Later missions (such as Apollo 15 and 17) went to areas where there was a complex history of volcanism and impact cratering.

Question 2: Is there a website or journal that outlines the more recent findings in regards to the age of impact sites?

A: The relative ages of lunar craters are listed in an Lunar Impact Crater Database. To access that database, go to http://www.lpi.usra.edu/lunar/surface/. Scroll down the page to the section "Impact Craters." The last entry in that section is an updated 2015 database. If you are interested in the ages of terrestrial craters, the best database is http://www.passc.net/EarthImpactDatabase/. If you want a KMZ file with the locations of Earth's craters, go to http://www.lpi.usra.edu/exploration/training/resources/. Then click on "Earth's Impact Craters" and, then, select "Global Distribution of Earth's Impact Craters (KMZ file).

Question 1: Due to the extreme resurfacing processes that take place on Venus from the volcanism that occurs, is there any other way besides crater examinations that we could estimate the effect this impact cataclysm had on this inner planet?

A: Some planetary scientists have noted that the number of impact craters on Venus is unusually low compared to the surfaces of the Moon, Mercury, and Mars. They hypothesize that a intense period of volcanic activity buried older craters. For that reason, it is difficult to study geologic events prior to that period of volcanism, including the time of the inner solar system impact cataclysm.

Question 2: Since all of the solar system's planets are gravitationally tied to the sun and somewhat to one another, would Jupiter's orbit being altered have effected the growth and development of Earth in any significant manner or would the change have been negligable?

A: It affected the growth in minor way, by causing asteroids to hit the surface and, thus, increase the planet's mass slightly.

Question 1: Did the events explained in the Lunar Cataclysm hypothesis that took place on the lunar surface effect planet earth and their gravitational connection, and How?

A: The impact bombardment did not significantly affect the gravitational relationship between the Earth and Moon, but, as I describe above, the distance between the Earth and Moon was changing. To see that effect, go to http://www.lpi.usra.edu/exploration/training/resources/. Then click on "Earth-Moon Dynamics" under the "Classroom Illustrations" heading. The first three illustrations in that category show how the distance between the Earth and Moon changed.

Question 2: Are astroids and comets still hitting the lunar surface and other surfaces to help us more in our study?

A: Asteroids and comets still hit planetary surfaces, including the Earth and Moon. Most impacts are caused by asteroids. Those events are interesting for a lot of reasons, but they do not really shed much light on the events that occurred nearly 4 billion years ago.

Question 1: What could have caused such a massive and long term bombardment of the inner solar system?

A: A shift of Jupiter's orbit, which cause gravitational resonances to sweep through the asteroid belt, altering asteroid orbits so that they collide with Earth. Scientists are still debating the reason Jupiter's orbit shifted.

Question 2: Would you say that this bombardment could have been a direct cause to the Hadean period on Earth?

A: Potentially. The division between the Hadean and Archean on Earth is defined, in part, by the absence and presence of a rock record. Although we have a few mineral relicts from the Hadean, we do not have any large rocky surfaces. Those ancient rocks may no longer exist because they were destroyed by the impact bombardment.

Question 1: The Ordovician-Silurian mass exinction took place somewhere around 440 million years ago, has it been investigated as to whether this had any relation to the smaller scale bombardment that occured around 500 million years ago?

A: There are five major mass extinction events. Of those, the only one linked solidly to an impact event is the Cretaceous-Tertiary mass extinction event.

Question 2: I know you said for the moon that the same size impact object would have produced a larger crater earlier in the moon's history due to higher temperatures, is this true for the others planets in the inner solar system that were bombarded as well?

A: Yes.

Question 1: In what ways are models in suffient in proving or disproving a sharp peak in inner solar system bombardment?

A: Models do not really provide proof. Rather, models are useful because they help scientists explore different variables that may affect an outcome or suggest new measurements that can be used to test a hypothesis. The best science usually integrates models with measurements.

Question 2: What exactly are we seeing in other young star system that hints that early planetesimal orbital configurations are unstable?

A: The Spitzer Space Telescope detects variations in light that are consistent with dusty disks of debris around stars in the locations where planets may exist. Imagine, if you will, our own Solar System during the impact cataclysm. All of those impacts would have spread debris through space, making the plane of our Solar System dusty. That type of dust obscures a star and can also be hotter than empty space, two signatures that can be detected with telescopes.

Question 1: Was the Lunar cataclysm in any way responsible for the origin of life on earth?

A: Our earliest isotopic evidence of life appears at the end of the impact cataclysm, so scientists have speculated that there is a connection. Two models are being explored: (1) That life originated between 4.5 and 3.8 billion years ago; that the record of that early life has been erased; and we only see the survivors of that period of bombardment; (2) That life could not get established early in Earth history, but was able to emerge after the bombardment ceased. In the latter model, life may have become established in the fractured rocks produced by that bombardment.

Question 2: What are the chances of such cataclysm happening again?

A: The giant planets are currently in a stable orbital configuration, so there is no force available to perturb those orbits. It is thought that they shifted roughly 4 billion years ago, because they were initially in a metastable orbital configuration.

Question 1: You pointed out the landing site but it looked kind of small, how big is it and is there room for error if the flight pattern gets thrown off?

A: The Apollo 12 mission demonstrated the ability to land precisely on the Moon. Generally, we should be able to land within an area of 100 meters. Any landing plan has contingencies for landing errors.

Question 2: Serentatis is your main objective, but since SPA is known for probably being the oldest basin, wouldnt you want to try and sample that in other sections to make sure you get the best estimate, because how likely are you to use just Serentatis for all your information need with lunar and Solar System processes when there is such a small amount of sampling coming back?

A: The probability of obtaining a sample for determining the age of SPA is about the same in the Schrodinger basin (which is within the SPA basin) as in other regions of the SPA basin. Plus, a mission to the Schrodinger basin would provide an opportunity to study many more scientific issues.

Question 1: How do you determine which elements to test when trying to determine the age of a sample?

A: There are different radiometric clocks. Scientists choose the clock (and, thus, elements to analyze) based on the anticipated age of a rock and its composition. For example, the carbon isotope radiometric system works on very young samples (less than 50,000 years old) that contain carbon. The potassium-argon radiometric system works well on much older samples that have compositions common in evolved planetary crusts (like the highlands of the Moon or Earth's continents).

Question 2: It was mentioned that the sample group was extremely low. Then how was it determined that Schrodingers Basin for the best future samples?

A: I do not recall making the statement in the first statement, but let me try to answer the question. The National Research Council identified 35 scientific objectives. Students identified everywhere on the lunar surface where each of those objectives could be addressed, producing, in essence, 35 maps. When those maps were stacked together, it became obvious that many objectives could be addressed in some areas of the Moon, such as Schrodinger.

Question 1: What would have caused Jupitar to move in such a radical way?

A: Some scientsts suggest the giant planets formed in a metastable orbital configuration and that, after several hundred million years, shifted into a stable configuration. Other scienists suggest that Uranus and Neptune accreted much later than Jupiter and Saturn; when they finished growing that change the gravitational relationship between the planets, causing them to shift. Other scientists suggest there were one or more other planets that were ejected from the Solar System; when they were ejected, that changed the gravitational relationship between the planets, causing them to shift. Other reasons may appear as scientists try to solve the problem.

Question 2: Would you be picking large single impact craters to test for the mission or impact craters that might have had numerous impacts?

A: To address the largest number of scientific questions, we want to determine the ages of several of the largets imapct craters (such as Schrodinger and SPA), but we will eventually also want to measure the ages of smaller, usually younger, craters.

Question 1: What is your response to the hypothesis that the melt rocks sampled at the Apollo landings might have come from the Imbrium basin and that the melt ages are related only to that impact?

A: There are two lines of evidence that indicate that is not the case. (1) The impact melts have different geochemical fingerprints, suggesting they were produced by multiple impacting asteroids. (2) The analytical methods have improved substantially over the past 40 years, so that now discrete ages of different impact events have been measured, indicating there were multiple impacting asteriods, not one. This question is also why we measured impact melts in meteorites that come from all regions of the Moon, providing an even larger collection of non-Imbrium samples.

Question 2: Does the lack of melt rock samples older than 4.1 billion years hold any signifigance to the Inner Solar System Impact Cataclysm/Lunar Cataclysm? What is the liklehood that their ages were “reset” due to continuous impact cratering over the last 4 billion years?

A: There are a small number of melt rocks older than 4.1 billion years, although there are not very many of them. They indicate that older rocks can survive the bombardment. More importantly, there is a large number of rocks produced by other geologic processes that have ages older than 4.1 billion years, which also indicates that older rocks can survive the bombardment.

Question 1: After reading further into the giant impact hypothesis, some stated that the energy from that collision would cause a magma ocean to form, yet no evidence of this has been found on Earth. Has your research presented any new ideas to answer the lack of magma ocean evidence?

A: There may have been a magma ocean on Earth, but the scale of it may have differed from that of the Moon. While on the Moon, anorthositic highlands from the top of the lunar magma ocean survive, any rocky remnants of Earth's magma ocean were destroyed long ago by other geologic processes. On Earth, processes such as weathering, erosion, volcanism, and plate tectonics destroy older rocks, so the record of geologic processes on Earth is not as complete as it is on the Moon. That is one of the reasons for going to the Moon to collect more samples. We will learn more about the early Earth, but studying the ancient rocks that survive on the Moon.

Question 2: I'm sure you have heard this one as well, but if moon formed from the way you proposed, what about Venus's lack of a moon?

A: Do not confuse the giant impact hypothesis for the formation of the Moon (which I did not discuss) with the impact cataclysm hypothesis (which I did discuss). The impact cataclysm is an event that may have happened a few hundred million years after the Moon formed.

Question 1: With all the information we have now about the cause of the cataclysmic bombardment, how likely is it that we will have another in the future?

A: The giant planets are currently in a stable orbital configuration, so there is no force available to perturb those orbits. It is thought that they shifted roughly 4 billion years ago, because they were initially in a metastable orbital configuration.

Question 2: Before the idea of Jupiter causing resonance waves that moved the belt, what were some common theories on the cause of the cataclysmic bombardment?

A: Some scientists tried to determine if asteriods in the vicinity of Earth, left over from its accretion, could have caused the bombardment. Other scientists asked if comets from the outer solar system could have caused the bombardment.

Question 1: Have we been able to find evidence of these impact cataclysms in other solar systems?

A: The Spitzer Space Telescope has detected disks of rocky debris around other stars that may have been produced by the same processes.

Question 2: Does this tell us that the moon was once just an asteroid, or that it was actually once part of the Earth, and was divided from us millions and millions of years ago?

A: The Moon is not an undifferentiated asteroid. It is chemically distinct from most asteroids and has a composition that is linked to, albeit different from, that of the Earth.

Question 1: Are there any other pyroclastic vents of interest in the area near the one you plan to study?

A: The Schrodinger basin has one of the largest pyroclastic vents on the lunar farside.

Question 2: You outlined the plan for one sample return mission. Are there any future plans to visit the same area or will that depend on the data that you collect during the mission?

A: In some scenarios, multiple missions would go to multiple areas of the Moon. In a scenario currently being investigated, three different missons would explore different regions of the Schrodinger basin – which is a very big structure on the lunar farside.

Question 1: Is there reason to believe that the cataclysmic impact theory was related to the emergence of life on Earth?

A: The question is being investigated because of the coincidence in time. The first isotopic evidence of life appears at the end of the bombardment, so scientists wonder if they are connected.

Question 2: Is it possible that the lunar meteorite samples could have been falsely dated due to the heat generated by passing through the atmosphere?

A: Only thin (less than 1 millimeter) layer on the outside of a meteorite is heated. The interior is unaffected by passage through the atmosphere.

Question 1: How did the lunar cataclysm event affect the early evolution of life on earth?

A: We do not yet know. Our earliest isotopic evidence of life appears at the end of the impact cataclysm, so scientists have speculated that there is a connection. Two models are being explored: (1) That life originated between 4.5 and 3.8 billion years ago; that the record of that early life has been erased; and we only see the survivors of that period of bombardment; (2) That life could not get established early in Earth history, but was able to emerge after the bombardment ceased. In the latter model, life may have become established in the fractured rocks produced by that bombardment.

Question 2: How are you able to tell that the impact craters are from asteroids from the inner or outer belt?

A: Astronomers looking at light reflected from asteroids have concluded that the compositions of asteroids in the outer belt are different those those in the inner belt. They have also suggested that carbonaceous chondritic meteorites are good analogues for outer belt asteroids, while ordinary and enstatite chondritic meteorites are good analogues for inner belt asteroids. Each of those classes of meteorites have different chemical compositions and leave different chemical traces in any impact melts they generate in a crater. Thus, by analyzing the impact melts, we can determine the types of asteroids that produced them and where they may have been derived.

Question 1: In your talk today there was a slide that showed the ages of meteors that were dated on I think it was other larger meteors. Why do you think there was no ages found between around 3.5 Ga and 2.5 Ga approximately?

A: There were very few collisions occuring in the asteriod belt during that interval of Solar System history.

Question 2: Thinking about the graviational residents that moved through the solar system and moved Jupiter, any ideas on what this/these objects are that could move a whole planet?

A: The gravitational resonances did not move Jupiter. Rather, they swept through the asteroid belt when Jupiter moved. Scientists are still debating why Jupite moved.

Question 1: The two lunar missions that were outlined in the presentation, the rover and human landing missions, how far along in the process are those?

A: Both mission concepts that were described were human-assisted sample return missions. They involve astronauts in the Orion vehicle or a Deep Space Habitat in orbit above the lunar surface and a robotic rover on the lunar farside. In one mission concept, there was a single lander. In the other mission concept, there were three or four landers. These missions are in tht "concept" phase. Landing sites and traverses have been mapped out. Orbits have been studied. And some of the engineering needed to design and build the spacecraft have been done. Also, importantly, the Orion crew vehicle was successfully tested with a launch and landing in December 2014.

Question 2: You hinted that the inner solar system cataclysm suspiciously occurred right before the very first signs of life appear in our fossil records. Is there a main idea as to how the two are linked? Is it the thought that maybe life came here from another place via asteroid or something, or that the cataclysm created the right environment for life to begin, something else entirely, or even a combination of multiple possibilities?

A: Our earliest isotopic evidence of life appears at the end of the impact cataclysm, so scientists have speculated that there is a connection. Two models are being explored: (1) That life originated between 4.5 and 3.8 billion years ago; that the record of that early life has been erased; and we only see the survivors of that period of bombardment; (2) That life could not get established early in Earth history, but was able to emerge after the bombardment ceased. In the latter model, life may have become established in the fractured rocks produced by that bombardment. In both models, it is usually assumed life originated on Earth and was not brought to Earth.

Question 1: If there is no correlation between asteroid diameter and impact events (ie: more often bigger asteroids colliding with the Moon followed by smaller asteroids in later bombardments), and there is a thin correlation between impact events and asteroids in the asteroid belt from the outer belt to the inner belt, can you give us any insight into any other possible correlations between asteroid diameter and collision event that might have come up in your models?

A: To clarify, there is a relationship between the size of an asteroid and the size of the crater it can produce. There was not, however, any mechanism that hit the Moon with an unusually great number of larger (or small) asteriods. Large and small asteroids seemed to hit the Moon in the same proportion that exists in the asteriod belt. The only way scientists know to do that is for there to be a gravitational mechasism, like sweeping resonances, that delivers asteriods of all sizes equally to the inner Solar System.

Question 2: The HERACLES mission, in my opinion, was very ambitious and I believe most scientists and science enthusiasts would like to see humans return to the Moon. In the mission concept you shared the lunar rover appeared to have a rocket device able to achieve lunar orbit (to a certain precision) from the surface of the Moon. How much of the technology necessary to achieve this mission already exists? And at what stages are these asteroid- and lunar-related missions currently?

A: Most of the technology needed for the misson was developed and flown during Apollo. However, most of the people involved in those missions have retired (or died). Thus, we need to retrain young engineers and scientists how to fly these types of missions again. The longer we wait to fly these types of missions, the more difficult (and costly) it will be to train the necessary workforce.

Question 1: Would you be able to summarize some of the consequences of the heavy bombardment for the Hadean Earth; how would these have changed if comets would have been the source of the impacts and not asteriods, as it is belived now?

A: Long ago, scientists thought comets were needed to deliver Earth's water during the late heavy bombardment, because they contain more water than asteroids. I (and many others) have shown that water already existed on Earth before the late heavy bombardment. So, one of the major differences between asteroid and comet impacts has disappeared.

Question 2: In the talk today you mentioned that at one point comets were thought to have created the majority of the impacts in the cataclysm, is there any evidence that in the latest data that could prove this to be the case once again?

A: The existing data suggests asteroids were the dominant type of impactor.

Question 1: Would missions to other inner solar system terra planets to study their geology help to confirm or deny the inner solar system cataclysm.

A: Missions that return samples to Earth so that scientists can measure the ages of large, ancient impact craters and determine the types of objects that made those craters will further test the hypothesis.

Question 2: With the knowledge that asteroids played a large role in the inner solar system cataclysm (which is usually a role played by comets), how does that change our view of asteroid activity/impacts in the past?

A: Interestingly, the ratio of asteroid/comet impacts inferred for the cataclysm is virtually the same as that today.

Question 1: You had mentioned that students were making a direct impact on NASA regarding this topic - could you go into more detail about that? What student groups?

A: We host a NASA-sponsored Exploration Science Summer Intern Program for graduate students at the LPI and JSC. Details are posted at http://www.lpi.usra.edu/exploration_intern/.

Question 2: When you described the mixing of the asteroid belt did you mean the mixing of the larger asteroids with the smaller ones?

A: The phrase mixing in the asteroid belt is used to refer to asteroids in one part of the belt colliding with asteroids in another part of the belt. If asteroids maintain their orbits, those types of collisions do not occur. However, the same gravitational processes to cause some asteroids to change orbit (and hit the Earth) also cause them to cross the orbits of other asteroids. When that occurs, there can be a collision between asteroids that were originally in different parts of the asteroid belt. Some meteorites contain evidence of those types of collisions. We will find fragments of one type of asteroid in a larger meteoritic fragment from another asteroid.

Question 1: At one point in the talk you mentioned resetting the moon in some fashion. I believe in relation to impacts that occur on its surface. In what way is it “reset”? Something along the lines of so many impacts occur the top portion of the Moon's surface is coverred with new material?

A: Impact events reset the ages of rocks when those rocks are melted. For example, if an asteriod hits an area that formed 4.5 billion years ago and melts a portion of that region, the age of the melted rock will correspond to the age of the impact event. If the impact event occurred 3.9 billion years ago, then the age of the melted rock was reset from 4.5 to 3.9 billion years.

Question 2: In the video you showed the orbiter carries humans. What is the importance in having a manned orbit for such a mission? Are there complications that can occur that require humans to be on board?

A: Astronauts may be able to drive the rovers easier than we can from Houston, because there is not much of a communication time-delay. However, there is another way to look at the issue. We need to test the Orion crew vehicle if we want to use it for exploration beyond the Moon. While we are testing the Orion crew vehicle in the vicinity of the Moon, it makes sense to do good science at the same time. Lots of tests are planned in the vicinity of the Moon, because it is relatively close to Earth (3 days away). Once we have developed the technology and experience of working there, then missions to more distant destinations can be planned.