Student questions: David Lawrence colloquium on "Using Gamma Rays and Neutrons to Measure the Elemental Composition of Planetary Bodies"

1/9/19

Question 1: What other projects with gamma rays are possibly being thought of that test outside of our solar system? A lot of the projects mentioned were within our solar system and I thought it would be interesting to know since voyager 2 did recently leave our solar system.
Aside from the astrophysics missions that I mentioned (e.g., lunar occultation mission to study galactic gamma-ray sources), there are no mission aimed at studying objects outside the solar system (at least by our group). The main reason is that you need a detector that is very close to a planetary body for a relatively long time (i.e., hours to days), and there are no planetary bodies outside the solar system that we know we can reach and orbit in order to make such measurements.

Question 2: Do the detectors (craft) have to be a certain size or can this technology also be used on spacecrafts that are manned?
There is a minimum size that gamma-ray and neutron sensors need to have in order to be able to detect the gamma rays and neutrons; this size is at least a few cm on a side. But they can be bigger. And there is no limitation to putting such sensors on manned spacecraft. In fact, the first orbital gamma-ray measurements ever made of a planetary body were of the Moon from the Apollo 15 and 16 missions. The gamma-ray detector was placed on a boom from the command module that orbited the Moon.

Question 1: Are there any plans to use gamma/neutron spectroscopy techniques on any of Jupiter's moons?
There are no current plans to operate gamma-ray or neutron detectors on any of Jupiter's moons. While many of Jupiter's moons would be attractive targets (e.g., Io, Europa, Ganymede, etc.), a major challenge for the Jupiter system is that there is a very strong flux of energetic particles around Jupiter due to its strong magnetic field (i.e., it has radiation belts just like the Earth, but much more intense). As a consequence, for the moons closest to Jupiter (Io, Europa), the large flux of energetic particles would create a very large background in any gamma-ray/neutron detectors, which are also very sensitive to energetic particles. However, we have investigated the possibility of making neutron measurements at Ganymede, which is a bit further from Jupiter than those other moons. There is some possibility that neutron measurements (using the appropriate detector) could work. We published a paper discussing this possibility. The reference for this paper is the following: Peplowski et al., "Operation of a ^{3}He proportional counter in the Ganymede radiation environment", Planetary and Space Science, (2011), doi:10.1016/j.pss.2011.07.002.

Question 2: Can these techniques be used on liquid bodies, such as the methane lakes on Titan, or does this only work on solids?
In principle, the technique can work on any type of material: solid, liquid, or gas. However, one still needs a source that creates the gamma rays and neutrons. The most convenient source in the solar system is galactic cosmic rays, and it turns out that they only hit the surface of solid bodies, not planetary bodies with liquid reservoirs like the Earth or Titan. And as I mentioned in the talk, gamma ray can be detected from gaseous bodies. However, there just haven't been any dedicated studies to date. Although, there have been many gamma-ray detectors that have been in Earth orbit, and one should look in those data to see if there are any Earth atmosphere gamma-ray lines. While I don't expect such a study to yield any major scientific discoveries, it still could be a useful exercise in understanding the production and detection of gamma rays in dense atmospheres.

Question 1: How long does it take until the neutrons can give an accurate reading of the planet body?
The time it takes to get an accurate reading depends on many factors, including how close the detector is to the body, what you are trying to measure (and with what precision), are you trying to get a 'whole-body' measurement, or are you wanting to get a map across the surface. Having said all that, the minimum amount of time to get a measurement would be on the order of an hour or two (say from a stationary lander or rover), and up to a few months to a year if you want to get a global, high-precision map of a planetary body from orbit.

Question 2: Would you get better results if you used a bi-directional receiver in a geostationary orbit over a omni-directional receiver in a synchonous orbit?
I'm not quite sure what this question means. With gamma-ray or neutron spectroscopy, there is not really a concept of a bi-directional receiver.

Question 1: I may have missed it in the lecture, but when looking at the scans that represented Fe and Th, there were large parts of the bodies that were unmarked. What would the theorized composition of the bodies be if they did not reflect on the image?
This must have been a misreading of the images. The maps that I showed of Fe and Th represented concentrations that ranged from the lowest amounts detected to the highest amounts detected. The color scale ranged from dark blue to bright yellow to represent these difference concentrations. There are large areas of the moon with low concentrations of both Fe and Th (mostly on the lunar farside) and these were represented by dark colors. These may have appeared to be 'unmarked', but they were just low concentrations.

Question 2: What does the "cold finger" do for the Megane?
The cold finger that was labeled on the MEGANE slide is a portion of the hardware that goes from the cryocooler to the Ge crystal. It is basically the thermal connection that enables the crycooler to pull out heat from the Ge crystal and cool it to cryogenic temperatures.

Question 1: Why do H neutron water-ice detections vary between the Lunar Prospector and Lunar Exploration Neutron Detector (LEND) dataset observations?
Interesting question as I did not show results from LEND. However, there are some results from the LEND instrument that are similar and consistent to what was measured with Lunar Prospector, and some that are different. For the results that are different, I attribute those differences to a poorer signal-to-noise in the LEND data.

Question 2: How does the Gamma-Ray and Neutron Spectrometer (GRNS) instrument vary from LEND?
LEND is just a neutron detector, where the detector was designed to try and collimate neutrons in order to get better spatial resolution. The various GRNS instruments were contained both gamma-ray and neutrons, and made no attempt to collimate either neutrons or gamma rays.

Question 1: What are the advantages of the dragonfly shape for the spacecraft?
I am not an expert in aerodynamics, but I expect that the shape of the Dragonfly rotorcraft is optimized both for reliability (i.e., multiple blades) and for operation in Titan's dense atmosphere.

Question 2: Other than because of Titan's thick atmosphere, why is Titan of specific interest?
It is expected to have a large variety of hydrocarbon type materials, as well as water ice. As a consequence, it is of interest for those that want to study planetary habitability.

Question 1: How much would the resolution of neutron spectroscopy data collected in a near-surface mission such as Dragonfly be improved over the resolution of orbital missions?
The spatial resolution for the Dragonfly neutron (and gamma-ray) measurements would be substantially better than that of orbital measurements because it would obtain measurements that are localized to the position of each landing spot of the rotorcraft. However, orbital gamma-ray/neutron measurements at Titan are not possible because its thick atmosphere prevents cosmic rays from reaching the surface. Thus, if one is to use gamma-ray/neutron spectrometers at Titan, one needs to bring along a source that created the neutrons and gamma-rays (i.e., a pulsed neutron generator).

Question 2: How deep into the surface can neutron spectroscopy read the composition of a planetary body?
Generally, tens of centimeters.

Question 1: It seems that there was quite a bit of talk on the creation of these instruments and usage, but I am wondering if there are many big steps taken into improvement and consolidation?
Yes, the design of these instruments does improve over time when one gets the opportunity to fly new missions. You tend to take use lessons learned from previous missions. For the parts that worked well, you do it again; for the parts that did not work as well, you find ways to improve it. And you also try to bring in new technologies to make better measurements as allowed by time and funding.

Question 2: What is your favorite achievement you or your team have accomplished in the field of nuclear spectroscopy?
There are many favorites. However, in some ways, my most favorite was getting the full map of thorium abundances at the Moon. I led the project to map thorium on the Moon with the Lunar Prospector data, and prior to that mission, there were only glimpses of what the thorium distribution looked like. The full map of thorium is very unlike any other quantity that we have mapped on the Moon, and I was the first person to have seen it. It was an awe-inspiring experience to know that this view of the Moon was shining out into space (and on the Earth) for much of the history of the solar system, and it wasn’t until 1998 that we were able to see what it actually looked like.

Question 1: Why are Iron and Thorium the two elements measured when detecting Gamma Rays on the moon and other planetary bodies?
I showed the iron and thorium measurements of the Moon because they provided good examples of what can be measured with gamma rays. However, there have been many different elements (Th, U, K, Fe, Si, Mg, Ca, Al, O, H, Cl, Na, S, C) measured with gamma rays and neutrons at different planetary bodies.

Question 2: Regarding the formation of Phobos and Deimos, if the two moons were once a part Mars, do you think by using Planetary Nuclear Spectroscopy we'll be able to see similar compositions of elements on the moons as there are on Mars or do think the process of them becoming moons could have altered their elements?
If Phobos and Deimos formed from the impact of a large body onto Mars, then it is likely they will have some similarities to Mars elemental composition. However, it is likely that in any large impact process, the proportion of some elements will have been altered; in addition, it is possible that under this scenario, the composition of the impactor may be mixed up with that of Mars. There are many possibilities, and ultimately one needs both people that carry out models of what might happen, and people gathering data to help constrain those models.

Question 1: You mentioned the technique being used to study some fundamental physics problems. What would those be and why are they important?
One of the main problems of fundamental physics that we are studying is that of trying to measure the lifetime of neutrons.

Question 2: What kind of spectrometer is being proposed to send on the Dragonfly mission and why?
For the gamma-ray and neutron measurements, we are proposing to send a high-purity Ge detector (because of its superior performance), a scintillator gamma-ray detector (to provide, in part, redundant measurements), and two neutron sensors.

Question 1: How do planetary scientists know that their methods of compositional analyses of bodies are accurate?
Very good question, and keep asking those types of questions (and this is something we continually ask ourselves). The answer is that there are many different things we do to give us confidence that are measurements and analyses are accurate. The most straightforward way is to compare our measurements to other techniques that also measure elemental composition. For example, for our maps of the Moon, we compared our measurements to the locations where the Apollo astronauts collected samples and scientists on Earth compiled compositions from those locations. Another comparison technique we use is to compare the gamma-ray/neutron measurements with other remote sensing techniques, such as x-ray spectroscopy. For selected elements, a direct comparison can be made, and was done for the MESSENGER mission. We can also carry out models and simulations of the entire gamma-ray/neutron production process for bodies that we know and understand, and if we get a good match, we can then use those same models and simulations for bodies we don't understand as well. We then present our results to the scientific community, and they investigate our data to see if they are consistent (or not consistent) with other information that we know about the planetary bodies and that may be related to composition. If inconsistencies arise, such inconsistencies can provide clues to us where we might have problems with our analyses. In summary, answering this question is always an ongoing process for which we want to be continually improving.

Question 2: Are the gamma rays emitted as a result of the cosmic rays fired at all dangerous?
In principle, they could be as there could be some inherent danger to any radiation. However, generally speaking, the danger from gamma-rays tends to be less than that from more energetic particles (such as the galactic cosmic rays that produce planetary gamma rays in the first place). And the flux of planetary gamma rays, while large enough to be detected, is still relatively low. Compared to other hazards of space travel, I would estimate that the hazards from cosmic-ray-generated gamma rays is relatively small.

Question 1: The gamma-ray spectroscopy data plotted the counts of specific elements; is it possible to plot specific isotopes of those elements?
Good question. One of the sausage-making aspects of planetary gamma-ray spectroscopy is that all the gamma rays are actually produced by specific isotopes. The reason we talk about 'elements' is that almost all of the gamma rays that we can actually detect are from the dominant isotope from any element. Since the isotopic abundances from the same elements are generally present in planetary materials at the same proportion, it is fair to state that we are measuring 'elemental' abundances and not 'isotopic' abundances. However, one exception to this situation may arise for Psyche. If Psyche does indeed have up to 90% metal, this would imply it could have up to 80 to 90 wt.% iron abundances. In this case, some of the minor iron isotopes might have large enough concentrations that we can detect them with the gamma ray measurements. If this is the case, then the Psyche mission could provide us the first opportunity to really make remotely sensed isotopic measurements.

Question 2: In the data, how are naturally radioactive elements differentiated for ones impacted by cosmic rays?
The main way we can discriminate radioactive from cosmic-ray-generated elements is by their gamma-ray energies. Like all elements, the specific energies for radioactive elements are unique and provide a clear identification (e.g., radioactive thorium emits a strong gamma ray at 2.6 MeV; potassium emits a strong gamma ray at 1.46 MeV; no other elements emit gamma rays at these energies).

Question 1: For what reason would you choose one gamma ray/neutrino detector over another?
As I mentioned in the talk, there are many reasons why one would choose one detector over another, and the factors that come into play are available resources (mass, power, volume, cost) and the performance that is needed to obtain the needed and/or desired measurement.

Question 2: Why are volatiles on the polar caps of the moon and Mars so important?
For the moon, the volatiles at the poles have interest for both science and possible human exploration. One scientific interest is that the lunar polar volatiles are not likely native to the Moon, but probably arrived as a result of other bodies hitting the Moon such as comets and/or asteroid. If that is the case, then the lunar volatiles could be provide a time-history reservoir of volatiles from throughout the solar system. This is exciting because then one could study cometary materials without ever having to visit a comet, but just go to our near neighborhood at the Moon! In regards to human exploration, it is possible that such volatiles, if present at large enough concentrations, could be a resource that could support future human exploration both at the Moon and beyond.

In regards to Mars, the polar caps are a combination of both CO2 and water ice. For various reasons that I don't have time to get into, they also can provide both scientific and human exploration value.

Question 1: If we have a hypothetical water world planet, could we use neutron spectroscopy as a reliable method to constrain the water abundance, or if it's a hydrogen rich planet, could we estimate water abundance from the gamma rays striking the hydrogen atom in the water?
If we had a hypothetical water world planet, we would probably know that is the case from other types of remote sensing measurements. In that case, gamma-ray/neutron measurements might not be as interesting and useful as at other bodies where we didn't know the composition. In addition, such a water world would almost certainly have an atmosphere, in which case cosmic-ray-generated gamma-rays/neutrons would not be useful to obtain measurements because the cosmic rays would not reach the surface. In that case, one could do what we are proposing to do for Titan and bring the source with you.

Question 2: How much do thermal/epithermal neturon detectors improve our understanding of lighter elemental compositions over standard global circulation models and could we perhaps extrapolate this method and apply to extrasolar terrestrial and gas giant planets?
Thermal/epithermal neutron sensors are not a primary way of obtaining information about lighter elements and atmospheric information. However, Mars is an interesting case in that is has a very thin atmosphere. The atmosphere is sufficiently thin that cosmic rays do reach the surface, and the gamma rays and neutrons they generate escape back out the atmosphere and can be detected from orbit. Yet, the atmosphere is sufficiently thick that it does affect the gamma rays and neutrons on their way out, and there have been some studies that have used this attenuation to learn information about Mars' atmosphere.

Question 1: What makes a proposal for the Dragonfly mission to Titan the most competitive?
While I have my biases (it is just a really exciting mission to fly a drone on Titan), ultimately that question need to be answered by the NASA reviewers that will be examining both proposals in the final New Frontiers competition.

Question 2: The instrumentation for planetary nuclear spectroscopy seems to be advancing regularly. Are the statistical methods used on the data being advanced as well?
We are trying to make advances on all fronts. When one gets data, then you can apply various analysis techniques (including statistical methods) to try and improve the information return from the data. Sometimes, such techniques don't work out, and other times they do. As I mentioned in the talk, one of the techniques we have spent a considerable amout of effort on is to use spatial deconvolution (or spatial reconstruction) techniques to improve the final spatial resolution of the datasets.

Question 1: Besides measuring the elemental composition of planetary bodies, what other ways can gamma rays and neutrons be used on earth?
Gamma rays and neutrons are used in a large variety of fields ranging from environmental science, national security, health science, and more.

Question 2: How can we expect the MESSENGER and Spectrometer to advance over time?
If you mean the MESSENGER spectrometer (or gamma-ray/neutron spectrometer), it will not advance over time. Its pieces (or what is left of it) are scattered across the surface of Mercury, as the MESSENGER spacecraft hit Mercury in April 2015 at the end of its mission.

Question 1: Could a detector be used to find the composition of a comet? space dust?
If you can get the detector close enough to a comet, yet gamma-rays and neutrons could measure its composition. Proposals for such measurements have been made to NASA, but none yet have been selected. However, it is doubtful that space dust could be measured with gamma rays and neutrons. The reason is that there needs to be a minimal amount of dense material for the cosmic rays to collide in to, and I would expect space dust would be too thin (unless of course there was a very large and dense dust cloud).

Question 2: Can the detector only be used for solid bodies or can it be used for gaseous ones as well?
In principle, such measurements could be made at gaseous bodies. But for reasons I stated in the talk, such measurements might be less interesting.

Question 1: Is this method of gamma ray and neutron detection only viable for planetary bodies with thin to no atmosphere in an orbital mission?
No, as I mentioned in the talk if you bring along a neutron generator, you can also make measurements from the surface of a planet.

Question 2: An orbiter could use rising and setting around the body to determine how far away a gamma ray source is. Could this method for using the orbit be used by detecting other wavelengths and still be used to determine distance of the source object?
In principle, yes. However, for other wavelengths, there are other much easier techniques (e.g., telescopes) to detect where sources are located in space. The main challenge with gamma rays is that because they are so energetic and penetrating, it is very challenging to build any type of telescope that can focus gamma rays. Thus, occultation is an alternative technique to do the same job (i.e., pinpoint on the sky a source of gamma rays), but in a very different manner.

Question 1: What is the minimum spacial resolution used to isolate individual craters on either the Moon or an asteroid?
It depends on the size of the crater you want to measure.

Question 2: Why are the poles of a moon the best places to search for enhanced hydrogen?
Because the Moon axis of rotation is nearly perpendicular to its orbital plane. As a consequence, the center of many lunar polar craters (also Mercury polar craters), never see the sun. Because of this, they get and stay very cold. When any water (or hydrogen) is delivered to the Moon by comets or asteroid, it can hop around the Moon. Most of such water will be lost to space, but some small fraction will hop into one of those cold polar craters and stick. If this process happens over a long enough time (or if it happens quick from some large impact), then these polar craters can build up increasing amount of hydrogen and other volatiles.

Question 1: Why is there so much water ice on Mercury relative to the moon?
The short answer is that we don't know. There are a number of different theories as to why this may be the case, and there are many different papers that investigate these options. A couple of years ago, I wrote a paper that, among other things, summarizes some of these different theories. It is: Lawrence, D. J. (2017), "A tale of two poles: Toward understanding the presence, distribution, and origin of volatiles at the polar regions of the Moon and Mercury", Journal of Geophysical Research: Planets, 122, 21–52, doi:10.1002/2016JE005167.

While there is no conclusive proof yet, I am partial to the idea that Mercury may have had a recent impact that deposited a large amount of water at its poles, and there just hasn't been enough time for the water to slowly leak away. In contrast, it may be that for the Moon, it has had no recent impacts and so what water that was there has been gardened away (or mostly lost by other processes). But in the end, we really don't know. More data is needed, and likely one would need to land in craters on the Moon and/or Mercury to possibly find out for sure.

Question 2: How does Thorium serve as a tracer for Lunar crustal evolution?
This is a good question, and a long story. But the basic idea is that thorium is what is called an incompatible element. When molten materials are undergoing crystallization, incompatible elements do not easily go into the crystal lattice, so they end up getting concentration in whatever residual melt is left. On the moon, it is thought that this residual melt (or whatever it is – note that I am a physicist/nuclear scientist trying to talk about planetary formation and mineralogy – a dangerous combination) ended up concentrated between the top crust and underlying materials. The full story is much more complicated (and we still don't understand the full story), but however it plays, thorium as one of the many incompatible elements provides information about how the moon crystallized and changed over time.

Question 1: What are the limitations to getting elemental data from planets farther than Saturn?
The main limitations are building a spacecraft that can travel to those planets (and moon) and spend enough time around them to get good measurements.

Question 2: Is it likely that we will compare data taken from Earth and the Moon to data taken from Psyche?
We most certainly make such comparisions. In fact, we will compare the data we get from Psyche from all prior measurements we have made with gamma rays and neutrons. One of the things we have learned from prior measurements is that every time we explore a new planetary body, we are surprised and need to adjust our thinking.

Question 1: From looking at the "heat maps" of different elemental abundances derived from the neutron and gamma ray fluxes on the Moon, Mercury, etc., how was the 2D spatial information obtained if the spacecraft was only ever on the same orbital path? For example, if the obiter is going from East to West over the surface and flies close to a "hot spot" of neutron or gamma ray flux, how do you determine if the hot spot is to the North or South of the orbiter? (With the knowledge that the instruments themselves provide no spatial information).
Good question. I did not explain how the orbits of those missions worked. For most of our orbital gamma-ray and neutron measurements, the spacecraft had a polar orbit where it traveled from the north to the south pole and back again. During that time, the planet rotates underneath. So every time the spacecraft makes another pass, it traveling over a different portion of the surface. On the Moon, a typical orbit gets full coverage in two weeks. Because the number of detected gamma rays and neutrons is so low, to build up the maps we needed many two-week periods to get the maps that I showed (the duration of the Lunar Prospector mission around the Moon was 18 months).

Question 2: As a follow up to the previous question, is it feasible and would it be useful to use a swarm of cubesats, with lower-tech, cheaper versions of the same instruments, on varying orbits instead of a single orbiter?
No one has yet done that, but it is not a crazy idea. The place where such an idea might be most useful could be for small asteroids. Although, a fair amount of work is needed to know how such a concept might work, and if it is really feasible.