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LCROSS: How We Crashed Into the Moon (On Purpose and for Science!)

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Editor's Introduction

How many people get to crash a spacecraft and still brag about it? In this first-person report from one of NASA's most interesting missions, LCROSS' Observation Campaign Coordinator describes for *Astronomy Beat* readers her experiences planning a mission to hit the Moon and then seeing the results, not only of the mission itself, but a coordinated international campaign of observations.

Artist rendering of LCROSS heading towards the Moon.

It's not everyday that you intentionally crash something into the Moon and then watch what happens, but on 9 October 2009 that's exactly what we did with the LCROSS (Lunar Crater Observation and Sensing Satellite) mission. LCROSS sent a big metal tube to impact the lunar surface. From the Science Operations Center (SOC) at NASA Ames Research Center in California we anxiously awaited the return of the data from the spacecraft. But how did such a dramatic mission get from the drawing board to reality?

A Piggy-back Mission

The story begins in January 2006, when NASA issued an unusual call for proposals. The agencyannounced that the upcoming launch of the Lunar Reconnaissance Orbiter (LRO) spacecraft had extra launch capacity, meaning that NASA could fit another (small) spacecraft to the Moon on the same rocket that would be launching LRO. Asecondary payload was a clever way to launch a second mission to the Moon without a lot of extra cost. The mission also had to have a rapid schedule since it had to launch when LRO launched (in a couple of years) or else you'd miss your ride to the Moon. NASA was very interested in learning more about the lunar poles, specifically wanting to know if lunar ice was trapped in the permanently shadowed regions. Armed with this information, NASA Headquarters put out a call for proposals for a small, fast-track, innovative mission that could address this high-priority question regarding ice on the Moon.

To respond to this call, teams were assembled and the ideas began flowing. Many of us had been thinking about mission concepts to study our Moon for quite some time, and this was a great opportunity to possibly bring at least one of those ideas to flight. There were many days (and nights) of creative brainstorming here at Ames and elsewhere, where scientists, engineers, and management came together to think of the best and most cost-efficient way to address the goal of searching for water ice on the Moon. This type of brainstorming work is one of my favorites, and one of the reasons I enjoy working at NASA. Final proposals were due on Valentine's Day 2006 — and LCROSS was among one of the concepts submitted. NASA Headquarters narrowed the choice to four mission concepts in March 2006, and in April 2006 LCROSS was officially selected for flight.

LCROSS & LRO launch.

The Mission Plan

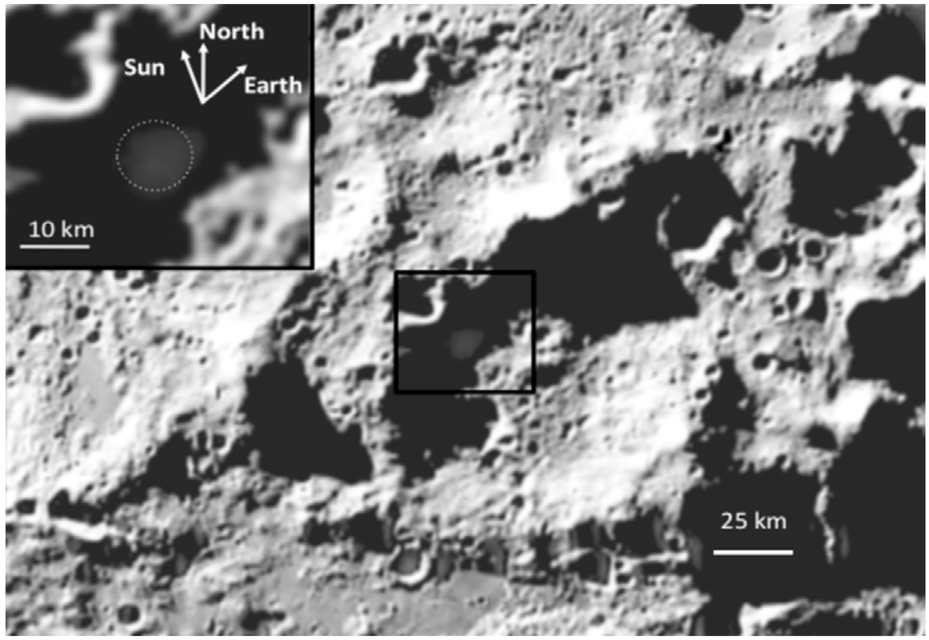
What did we have in mind? LCROSS proposed using the upper stage of the Atlas V Centaur launch vehicle as a 2,366-kg kinetic impactor. The impact was designed to create a large plume whose properties would be observed by a shepherding spacecraft as well as Earth- and space-based telescopes. And, indeed, when the mission flew in 2009, the 625-kg shepherding craft went right through the Centaur impact plume before impacting the Moon itself — justfour minutes after the Centaur.

LCROSS impacted into the Cabeus crater region near the south pole of the Moon on October 9th, 2009. Cabeus is a region of permanent shadow, which is believed to be important for trapping volatile materials on the Moon such as water ice. Thanks to the orientation of the Moon's orbit and the height of the crater walls, permanently shadowed regions exist at both poles of the Moon and are among the coldest regions in the Solar System. The temperature of the floor of the Cabeus Crater at the impact site has been measured at an astonishingly cold 45 K (-380 degrees F) by an instrument aboard LRO. The low temperatures of these permanently shadowed regions make these areas prime candidates for cold traps where volatile molecules can be stable for billions of years.

Cabeus also met several other site selection criteria. It was on the near-side of the Moon, so we could see it from Earth; it had a high hydrogen signature (indicating the possible presence of H_2O) as observed by both Lunar Prospector and LRO; it had a relatively smooth and flat terrain to help ensure the production of an observable plume upon impact; and it had a reasonable height between the crater floor and the horizon for the Sun (833 m). This last criterion meant that the ejected material from our crash could be illuminated by the Sun and could therefore be observed by many different instruments both in space and on the Earth.

Building the Spacecraft

As I mentioned, LCROSS was on the fast-track. We had about two years from the time we were selected until the time we had to be ready to fly, and had a cost cap of $79 million. That is not a lot of time (or money) in the world of spacecraft missions, and so we had to do business in a different way in order to meet the scheduling and cost constraints. The team was up for the challenge, though, and as a result came up with many innovative ways of working this mission. For example, eight of the nine instruments on the spacecraft were COTS (commercial off-the-shelf). This means that instead of designing and building all the instruments ourselves, we went to small companies and bought them, tested them here at Ames to make sure they were flight-qualified, returned them to the vendor for any repairs or modifications as needed, and in this way saved a lot of time and money.



Impact plume as seen from LCROSS visible camera. *(Schultz et al. 2010)*

The spacecraft itself was pretty innovative, too. In conjunction with our colleagues at Northrop Grumman, the spacecraft was designed around the ESPA (EELV Secondary Payload Adaptor) ring that was designed to connect a secondary payload (in this case LCROSS) to the launch vehicle. The ESPA ring is a big round piece of metal (analogous to a sewer pipe), and so the LCROSS spacecraft cleverly used this ring as the main structure and we attached multiple panels around the outside of the ring to hold the spacecraft components (one panel for communications, one panel for the payload, one panel for power, one panel for the instruments, etc.). This approach was simple, reliable, didn't require inventing new parts, and consequently was cost and time effective.


Lunar swingby, June 23, 2009 at about 2:30 a.m., Science Operations Center at NASA Ames (Colaprete, Ennico, and Heldmann).

The Night of Impact

Finally the night of lunar impact was upon us. The Mission Operations Center (MOC) here at Ames was fully staffed, and all three (3!) of us in the Science Operations Center (SOC) were ready to go. As part of the purposely small mission team, the three SOC members were Tony Colaprete (LCROSS PI and Payload Co-Lead), Kim Ennico (Payload Co-Lead), and myself, serving in the capacity of Observation Campaign Coordinator. Tony and Kim had the prime responsibility of watching the instrument data and telemetry stream back to Earth, monitoring the health of the instruments, and making instrument setting changes as needed. I was in direct communication with the myriad observatories and astronomer teams that were lined up to observe the LCROSS impacts.

I was listening to both Tony and Kim as well as the MOC activities in order to relay information to the astronomers in real-time about the spacecraft status, impact events, timing, etc., since it was absolutely critical that the telescopes were pointed at exactly the right place at exactly the right time for impact. We had rehearsed for this event over and over, practicing every aspect of impact night countless times, and so I felt very prepared for the actual event. In fact, in the SOC we remarked that the real thing felt just like another

Families camped out at NASA Ames to watch the lunar impacts.

rehearsal — that's how realistic and valuable all those simulations had been!

Impact was scheduled for approximately 4:30 a.m. local time, and so we were advised to not try and stay up all night but had scheduled a break for ourselves after the Centaur separated from the LCROSS Shepherding Spacecraft, but before lunar impact. During this time we were supposed to go and get some sleep, so that we would be ready and alert for the actual impact event. However, I'm not sure I got much sleep that night. Thousands of people had descended upon NASA Ames to watch the live broadcast that was being projected onto a huge screen on the Ames Parade Grounds in front of the NASA Lunar Science Institute. I saw pictures later of hundreds of families camped out for the night to watch this great event. Security was tighter than normal here at Ames, and so I stuck close to the SOC building during the night so I'd be sure not to get stuck in traffic on the other side of base with the thousands of well-wishers.

During our scheduled rest break, I went outside to my car where I had the seats folded down and a sleeping bag and pillow, just in case I was able to get a little bit of sleep. As soon as I got into the car I looked up and perfectly centered in the rear window was the bright, glorious Moon, hanging in the sky and illuminating the hangars and runways of NASA Ames. It was an amazing moment and I was glad to have that quiet time to reflect on this truly extraordinary mission. Our little LCROSS spacecraft was approaching that very same Moon at 2.5 km/sec, and soon would be impacting near the south pole. It was as if the Moon was reminding me that it was not just a projection on a computer screen upstairs in the SOC, but a real world waiting to be explored.

After our short break we returned to duty and everything went according to plan. The spacecraft camera images continued to show us getting closer and closer to the Moon as the Centaur descended towards the lunar surface, zooming in on the impact location. The impact of the Centaur occurred right on time, and all instruments were returning data as expected. Astronomers at the telescopes were collecting data at the same time, as were multiple observing assets in space. After four fabulous minutes, the shepherding spacecraft also impacted the Moon as planned which was confirmed by the abrupt loss of signal. The mission had been executed flawlessly! Cheers abounded in the Mission Operations Center and by countless others watching the activities.

In the Science Operations Center, we cheered briefly but then got straight back to work. Our duties were not over and we had a series of time-critical tasks to complete immediately following impact. We were scheduled to give a press conference at 7:30 a.m. PT, less than three hours after the impacts. People were going to want to know how things went and see some data, so Tony and Kim got busy looking at as much of the spacecraft data as they could. They worked to pull out some interesting bits to show in a few hours (not an easy task given all the data was returned just minutes earlier from the Moon). I was busy working with the astronomers who were sending me some of their images and spectra that had been collected literally just moments ago. We worked frantically to try and assess the data and generate slides we could show at the press conference. But what a good situation to be in, flooded with data that were just waiting to reveal some of the secrets of the Moon!

Results

And the Moon certainly did not disappoint us. Following the press conference we took a few hours to go home to shower and change our clothes — and then the Science Team reconvened at NASA Ames to take a first thorough look at the data. It was at this meeting that we all realized the full extent of the treasure trove of information that was awaiting analysis. The images were spectacular. The floor of Cabeus crater had been

The LCROSS (gold) and LRO (silver) spacecraft stack before launch.

imaged in the near-infrared for the first time ever. The mid-infrared cameras clearly showed the heat signature of the impact. The visible camera provided unprecedented information on the lunar lighting conditions and impact location. The near-infrared spectra had oh so many absorption bands just waiting to be identified, and the ultraviolet-visible spectra had numerous emission lines to be analyzed. Needless to say we were very excited and thrilled — and very much looking forward to doing the scientific analysis to decipher all of the datasets.

Since the impact, the Science Team has worked hard on this incredibly rich dataset for many months. Scientific analysis requires careful and thoughtful work to reduce the data, understand the data, and interpret the results. The first fruits of this labor were six articles in *Science* magazine about the LCROSS results on 22 October 2010. LCROSS was also the cover story for that issue of *Science*. We showed that the Moon does indeed harbor water ice in the Cabeus region on the order of 5% by weight. We learned that there is much more than just water ice, though; numerous other volatile species such as H_2S, NH_3, SO_2, C_2H_4, CO_2, CH_3OH, and CH_4 are likely also present. We learned that the floor of Cabeus is likely a very porous material and this regolith material was lofted far above the lunar surface in the impact plumes observed by the spacecraft. The data analysis is still ongoing; there is still much to be learned from this dataset collected over just four minutes.

I am very grateful to have had the opportunity to be a part of such a unique and rewarding project. The rapid pace of the work had the ancillary benefit of training many people about how to execute a spacecraft mission from concept inception through flight and data analysis, which is a very valuable training tool. It is my hope that NASA can continue to explore our Solar System and beyond by tapping into the ingenuity and skill of the present workforce, and that we continue to utilize extraordinary opportunities such as LCROSS to train and inspire the future generation of scientists and explorers.

About the Author

Dr. Jennifer Heldmann is a Research Scientist in the Division of Space Sciences and Astrobiology at NASA Ames Research Center in California. She graduated from Colgate University with a Bachelor's degree in Astrogeophysics, earned her Master's degree in Space Studies at the University of North Dakota, and a Doctorate degree in Planetary Science from the University of Colorado. Her research focuses on studies of the Moon, Mars, and Earth. She studies recent water on Mars through spacecraft data analysis, numerical modeling, and fieldwork in Mars-analog environments. Heldmann is also interested in the Moon with a focus on improving our understanding of the lunar poles.

Resources for Further Information

The LCROSS mission site is:
http://lcross.arc.nasa.gov/mission.htm

The Lunar Reconnaissance Orbiter mission site is:
http://lunar.gsfc.nasa.gov/

A video recording of the LCROSS mission results, made at the SETI Institute, can be found at:
http://www.youtube.com/watch?v=39kwTtI6cgU

A video recording of a talk on LCROSS results by the author in August 2010 at the North East Astronomy Forum is at:
http://www.cloudynights.com/item.php?item_id=2495

For a general listing of educational resources about the Moon, see:
www.astrosociety.org/education/family/resources/moonguide.html ✦