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Yutu Update

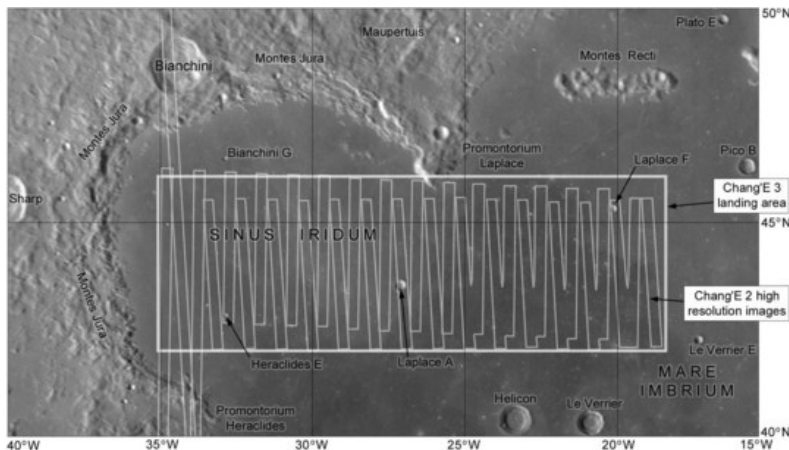
Posted by [Phil Stooke](#)

2014/04/10 03:08 CDT

Topics: [mission status](#), [the Moon](#), [Chang'E program](#)

We don't hear a lot at the moment about Chang'E 3 and Yutu, the Chinese lander and rover which were all over the news a few months ago. But I have been collecting news online and in person last month at the Lunar and Planetary Science Conference in Houston (or rather, north of Houston in The Woodlands, Texas), and now I will try to put it all together and address the current state of the mission.

First a word about the landing site. The target was said for years to be Sinus Iridum, and the actual site was in Mare Imbrium. Some commentators seemed to think this was significant, possibly indicative of a problem or a change of plan. In fact, the 'Sinus Iridum landing area' as outlined on Chinese maps was larger than Sinus Iridum and the landing site was well within it. Sasha Basilevsky, the veteran Russian planetary scientist who had worked with his Chinese counterparts on this, pointed out that it made sense to target the eastern end of the landing area because any delay could be accommodated by landing further west, as the Moon rotated under the spacecraft's fixed orbit plane. If the mission controllers planned to land in Sinus Iridum itself they could find themselves forced by a delay to land in the rugged highlands nearby, a much riskier option.



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[Chang'e 2 high-resolution image coverage of Chang'e 3 landing area in Sinus Iridum](#)



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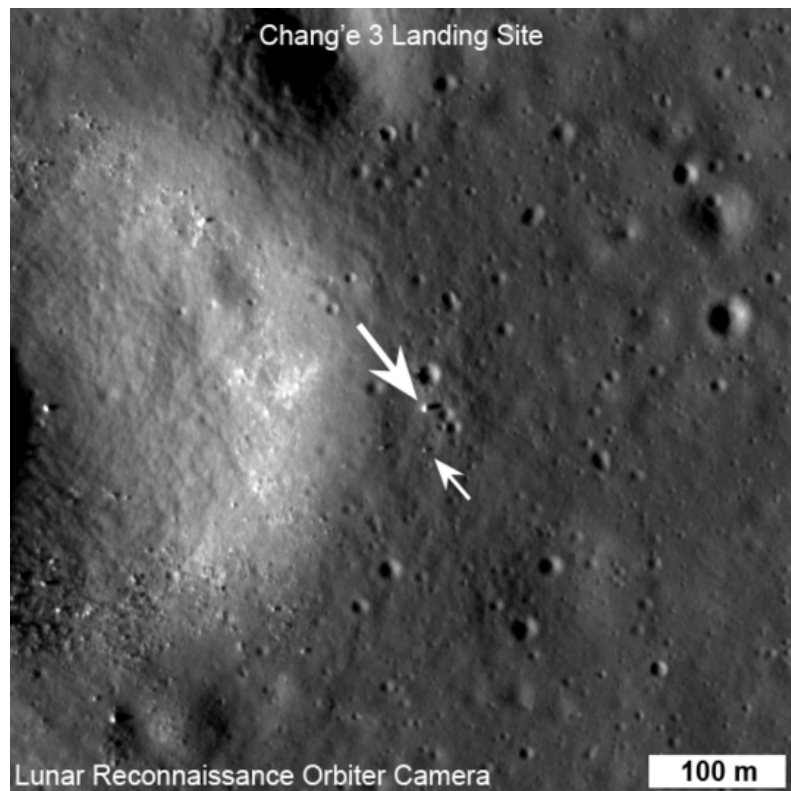
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This map shows the extent of the Chang'e 3 landing region, extending outside Sinus Iridum as well as inside it, and the areas where Chang'e 2 achieved imaging coverage at about 1.5 meters per pixel.

The lander had a hazard avoidance system never tried before in any lunar landing. As it descended it stopped at a height of about 100 m, hovering while camera images were analyzed onboard to find a smooth spot. The process worked well, but Basilevsky pointed out that if Chang'E 3 descended over the 400 m diameter crater just to its west the hazard avoidance system would probably not have prevented a landing in the crater, it would merely find a smooth spot in the crater. So this system would not prevent a rover from getting stuck in a crater.



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Chang'e 3 and Yutu seen from orbit

On December 25, 2013, Lunar Reconnaissance Orbiter spied Chang'e 3 and Yutu on the lunar surface. It was near sunset on the pair's first lunar day of operations. In its extended mission, Lunar Reconnaissance Orbiter is in an elliptical orbit whose altitude over the Chang'e 3 landing site is 150 kilometers, so its highest-resolution images have about 1.5 meters per pixel.

When Chang'E 3 landed on the Moon on 14 December last year it released its rover Yutu, the Jade Rabbit, and we were treated to [many images of the surroundings from both lander and rover](#). The lander has a panoramic camera system for mapping the landing site and observing the initial activities of the rover, as well as a descent camera which took spectacular video during the descent. It also has two astronomy instruments, an ultraviolet astronomical camera and an extreme ultraviolet imager to view Earth. These were not quite the first astronomy instruments on the Moon – Apollo 16 deployed a small ultraviolet telescope which imaged Earth and a few other targets, but as far as I can see not much was done with that limited dataset.

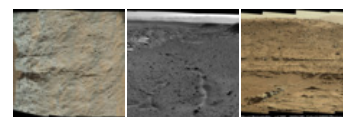
The rover, Yutu, has its own set of cameras. Like the Mars rovers it has hazard-avoidance cameras mounted low on its body, but only at the front – the Mars rovers have them at the back as well. None of the Yutu hazard camera images have been published, but a few were shown in a presentation at LPSC. It also has navigation cameras and panoramic cameras mounted on a mast. A near-infrared imaging spectrometer is mounted on the front of the rover body, and can view the ground in front of the rover in many wavelengths. An alpha particle x-ray spectrometer is mounted on an arm on the front of the rover for measuring elements in the surface, and it can be monitored by the hazard cameras. Lastly, a ground-penetrating radar makes use of two antennae projecting from the rear of the rover, working at different wavelengths to penetrate to different depths in the sub-surface.

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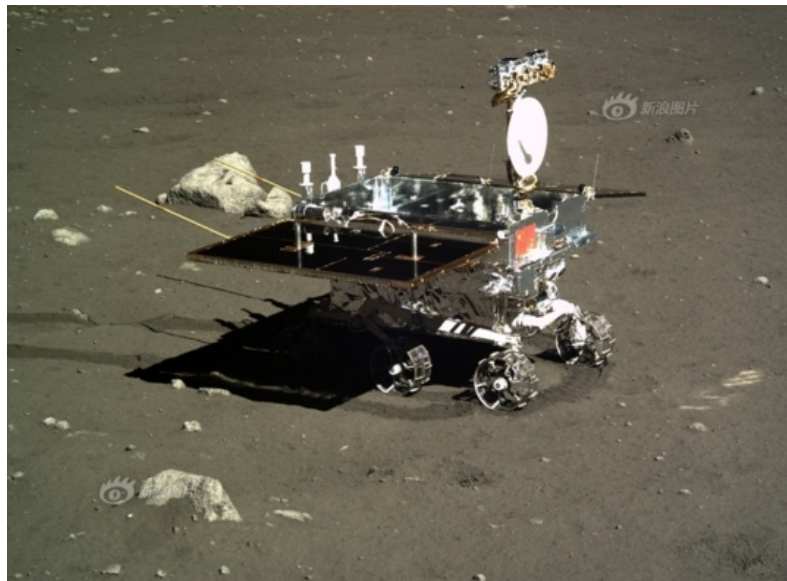
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Chinese Academy of Sciences

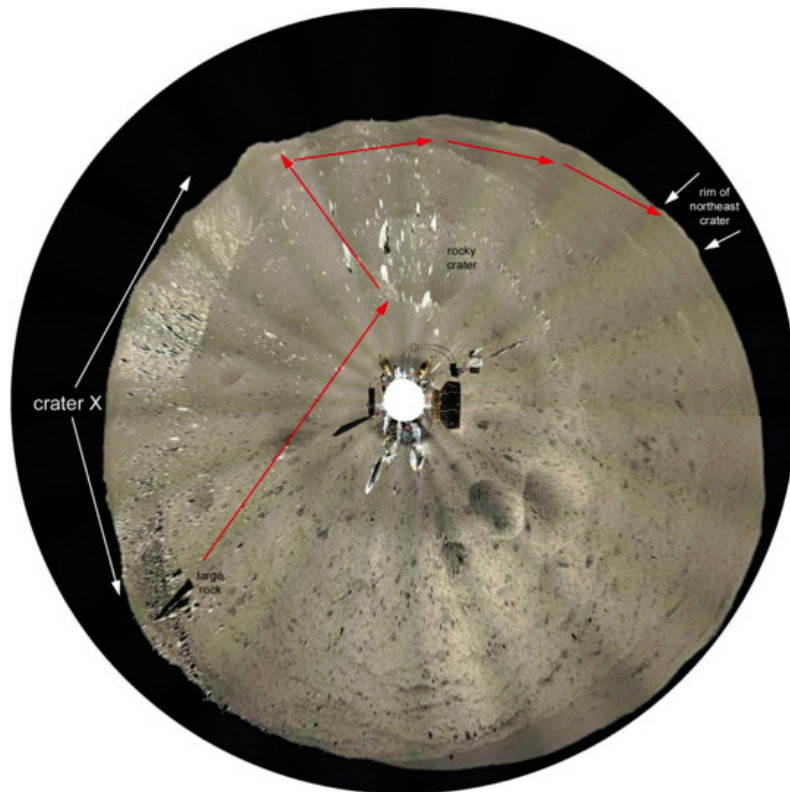
Yutu on the Moon, December 16, 2013

During the first lunar day, from December 14 to 25, 2013, the rover drove around the lander on the side best lit by the Sun, and [both of them imaged the other at several locations](#). Yutu tested all of its instruments, and all seemed to be working well. It took a short break through the hottest part of the day, but the controllers in China decided this was not really necessary and they started up again soon. This was a reminder of the extreme temperature variations on the Moon. The Apollo crews always left the surface well before lunar noon, but NASA's old Surveyor spacecraft and the Soviet Union's Lunokhods survived their noon heating (I'm not sure if any of the other Soviet landers lasted through local noon, but I think not). Those older machines were built in a different age, and modern microelectronics and chips may be more vulnerable to temperature extremes. At the end of the day the rover stopped about 18 meters southwest of the lander.

Then night fell. Yutu protected its delicate cameras by folding its camera mast down into the body of the rover and covering it with one solar panel, while the other was tilted down to face the sunrise on the next lunar morning. Reports suggested the orientation (tilt and heading) of the rover was critical, so much so that it scuffed the soil with its wheels to optimize its tilt. Some images of the lander showed it tilting both of its panels, one raised, the other lowered, to maximize power in late afternoon or early morning. The lander could not protect the panoramic cameras on its mast, but they were not needed after the first day and they were allowed to succumb to the cold lunar night. Why not needed? They had already mapped the landing site, and the rover was expected to spend its later lunar days out of range, behind ridges or even beyond the horizon, so the lander would have nothing much to look at.

In January the sun rose at Mare Imbrium. Yutu awoke first – its heading was optimized for solar power early in the day. The lander awoke a bit later. [Everything was fine except for the lander cameras which had been expected to fail](#). The rover drove south a bit more and west towards a large rock which was said to be a geological target. This was about where the news dried up, so the remainder of this post is pulled together from many sources and may not be completely accurate.

We know that all of the science instruments on Yutu were used, and a map shown at LPSC illustrated the science measurement locations. It seems the big rock was bypassed. Perhaps it was too steep-sided for the APXS to be deployed properly on it, or too high for optimal viewing geometry for the NIR spectrometer. Instead, the rover drove northeast, back towards the lander. The LPSC map showed the projected route passing the lander on its west side and approaching a rocky-rimmed crater just north of the lander. The smaller rocks around its rim might have been better suited to analysis by the rover's instruments.



Chinese Academy of Sciences / Phil Stooke

Yutu's planned future route

But the rover did not arrive at the crater, or even reach the lander. It stopped as it was getting close to the lander, apparently because the electronics associated with moving its wheels and solar panels, so probably an important central control unit, failed at that point. I don't know when it stopped, but the map shown at LPSC is instructive. It shows the daily stops between drives (the rover was only operated when in direct contact with China, for at most half a day at a time), and counting them suggests the fault occurred in the middle part of the day, possibly due to excessive heating which might have been exacerbated by dust buildup on the rover body. But this is conjecture, as I don't know that each stop occupied only one day.

At any rate, it soon became apparent that the rover could neither move nor fold itself up to protect against the cold of the night. Enormous efforts were made to overcome this, to no avail. As night approached [the problem was made public](#), most memorably by [the rover's Twitter alter-ego itself](#). Meanwhile the lander continued operating, and I'll come back to that later. Sunset, and possibly the end of Yutu's short life, came on 25 January. After a seemingly interminable wait the sun rose again, and a few days later on 12 February [both lander and rover woke up](#). Yutu was more robust than expected. All its instruments, even the fragile cameras, were fine, but [it couldn't move](#). I don't know if the lack of movement extends to the robotic arm with the APXS. The instruments may work, but future science would be very limited if the NIR spectrometer and the ground-penetrating radar are limited to always making the same observation.

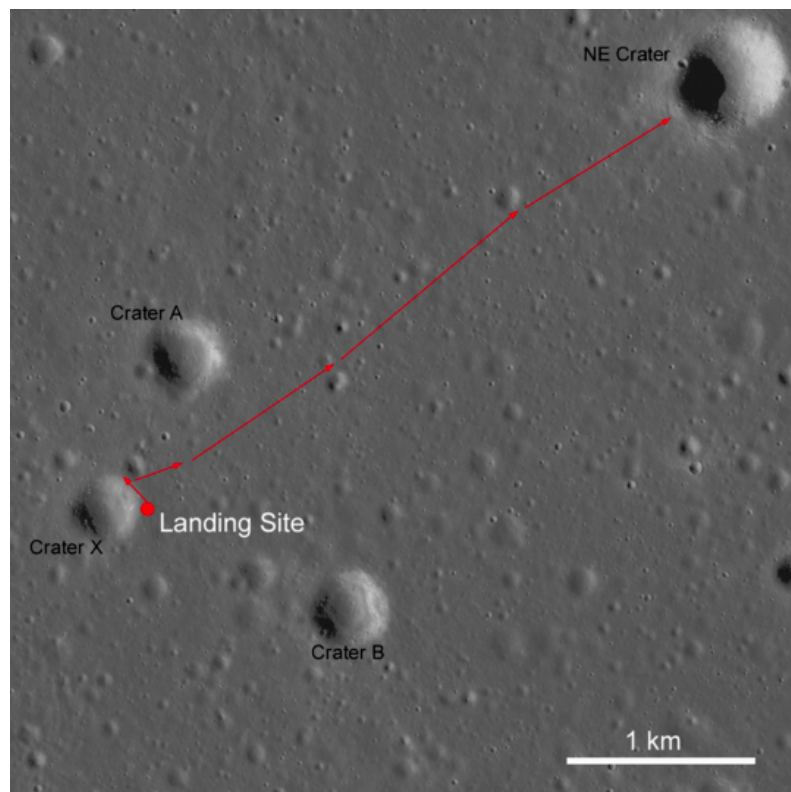
The rover [shut down near sunset on 23 February](#) and woke up again on 13 March, three days after sunrise, but this time much more feebly. Nevertheless, intervention from Earth, I think in the form of a computer re-boot, again restored full operation. The rover was supposed to survive for three days and nights, so now it had exceeded that. Night fell late in March, and now we are ready for another sunrise and another attempt to revive the rover. Engineers will be interested in how long it can survive, and how various components fail, to help plan future missions. But it seems very likely that Yutu will do no more science.

The lander is a different story. Its astronomical instruments are apparently working fine. The telescope had already obtained more than 22,000 images by mid-March, making it by far the most productive of all the mission's instruments. Chang'E 3 is expected to survive for a year. A few results have been released, pictures of star fields. As far as I can tell, many of the observations have been of variable stars, so the thousands of observations would be monitoring certain stars to follow their brightness variations, not covering the sky with thousands of images. The images, or some of them, are being shared with the International Lunar Observatory Association, a Hawaii-based organization trying to set up its own lunar observatory.

ILOA signed an agreement with the Chinese Academy of Sciences and China's Space Agency, giving it access to Chang'E 3 data in exchange for Chinese access to ILOA's first lunar telescope, an experimental instrument intended to fly on the first Moon Express lunar flight in 2015. Moon Express is one of the front-running Google Lunar XPrize contenders, currently intending to land in the southern mid-latitudes of the lunar near side late in 2015. A larger observatory will be built for ILOA and flown to a south polar site a couple of years later. ILOA's

plans don't stop there. It is currently working with the Golden Spike Company to fly a human mission to tend its observatory in the 2020s. Lunar astronomy may be a big thing in the next few years.

If Yutu had remained operational, where would it have gone? [JianNan Zhao of China's Planetary Science Institute in Wuhan discussed this at LPSC](#). In a previously released paper and in the LPSC abstract he identified a crater 3 km northeast of the landing site and just visible on the horizon from the lander. This was about as far as the rover team expected to be able to drive, and this crater might have dug deep enough to excavate an older lava flow from beneath the lava Chang'E 3 landed on. That older lava flow was exposed at the surface a few kilometers further north but probably too far away to reach. At the conference Zhao said that an intermediate goal was to drive to the north rim of the big crater (400 m across) just to the west of the lander. He referred to it as 'crater X' (no Chinese sources so far have attached placenames to the features around the site, just a few labels like 'crater X', which has also been called 'west crater' by the LRO camera team). So a future route can be sketched out: the rocky crater north of the lander, the north rim of crater X, and then the northeast crater.



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Yutu's planned future targets

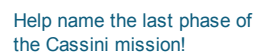
Had Yutu not lost its mobility, this is what its future path may have looked like.

Will Yutu ever move again? It doesn't look promising. But perhaps the lessons learned from this mission will help a companion rover, Chang'E 4, to survive longer and drive further in a year or two. Meanwhile, I have made a map of the path of Yutu, as complete as I can make it at the moment. This is based on Chinese maps from the first lunar day, near the lander, and another Chinese map shown at LPSC. That information has been modified from my own examination of the wheel tracks in images, including a vertical projection of tracks from the middle of day 2 which was also shown at LPSC.



The rover location is from [the LROC images](#) and it slightly updates the Chinese map shown at LPSC. Round dots are stops between drives, and square symbols are science locations shown on the Chinese map. The dates shown for each stop are my estimates but they may not be correct, as we have almost no reliable information to go on. The rover is shown to scale (approximately) but I don't know its orientation.

Curiosity update: Initial reconnaissance of the Kimberley, sols 585-595



6/7