— a potentially safer option when it comes to gene-fixing therapeutics, although the treatment would need to be administered repeatedly. It would also mean that researchers could alter a treatment as they gain a better understanding of the disease. "If you use RNA therapy," Zhang says, "you can upgrade."

His team's RNA editor is based on a naturally occurring enzyme that rearranges the atoms in A to resemble I instead. The researchers fused the enzyme to a disabled version of the CRISPR system — one involving an RNA-targeted enzyme called Cas13, instead of the usual DNA-binding Cas9. With the help of a sequence-specific guide RNA molecule, they successfully corrected disease-causing mutations 23–35% of the time, with low incidences of off-target activity.

In the base-editing method pioneered by Liu's team last year, the researchers engineered a naturally occurring enzyme and tethered it to a dud Cas9, which allowed them to convert C to T. But there is no equivalent enzyme found in nature for the opposite conversion in DNA. So the researchers started with an RNA-editing enzyme similar to the one Zhang's group used.

The team guided the evolution of bacterial cells through seven generations, and used some protein engineering in the lab, to produce an enzyme that would recognize and manipulate DNA. The enzyme was able to rearrange atoms in adenine to change it into an inosine, which the cell reads as a guanine. The system then tricked the cell into inserting a cytosine into the unmodified DNA strand (see 'Changing bases').

COVERING THE BASES

"It represents a heroic effort," says Dana Carroll, a genome-engineering researcher at the University of Utah in Salt Lake City, noting that the directed-evolution approach was something of a shot in the dark. "I wouldn't have had the guts to try what they did," Carroll says. "My hat's off to David Liu."

The ability to make four types of single-base conversion — A to G, G to A, C to T and T to C — "will be extremely valuable for precise therapeutic and agronomic editing", says Caixia Gao, a plant geneticist at the Chinese Academy of Sciences' Institute of Genetics and Developmental Biology in Beijing.

It could also prove useful in drug discovery and for DNA-based data storage (see *Nature* **537,** 22–24; 2016), says Marcello Maresca, a gene-editing researcher at AstraZeneca in Gothenburg, Sweden.

The development of any other base editors will require enzymes that do not occur in nature, even for conversions in RNA. But that kind of obstacle has not stopped Liu before. "We'll keep trying until the community has developed all possible base editors," he says. ■

1. Gaudelli, N. M. *et al. Nature* http://dx.doi.org/10.1038/nature24644 (2017).
2. Cox, D. B. T. *et al. Science* http://dx.doi.org/10.1126/science.aaq0180 (2017).
3. Komor, A. C., Kim, Y. B., Packer, M. S., Zuris, J. A. & Liu, D. R. *Nature* **533,** 420–424 (2016).

SPACE EXPLORATION

India gears up for second Moon mission

The Chandrayaan-2 orbiter, lander and rover signal India's lunar ambitions.

BY T. V. PADMA

In a large shed near the headquarters of the Indian Space Research Organisation (ISRO) in Bangalore, a six-wheeled rover rumbles over dark grey rubble in a landscape designed to mimic the Moon's rocky surface. This test and others scheduled for the next few weeks are crucial steps in India's quest to launch a second mission to the Moon next March.

The country's much-anticipated Chandrayaan-2 comes almost a decade after India began its first journey to the Moon, in 2008. "It is logically an extension of the Chandrayaan-1 mission," says Mylswamy Annadurai, director of the project at ISRO. The spacecraft comprises an orbiter that will travel around the Moon, a lander that will touch down in an as-yet undecided location near the Moon's south pole, and a rover.

India's maiden Moon trip was a significant achievement for its space programme, but ended prematurely when ISRO lost contact with the orbiter ten months into the planned two-year mission. However, an instrument on a probe that reached the Moon's surface did gather enough data for scientists to confirm the presence of traces of water.

Chandrayaan-2 will attempt more ambitious technical manoeuvres. For the first time, ISRO will try to steer a lunar craft to a controlled, or soft, landing. The agency has had to develop advanced systems that can guide the lander to a touchdown and successfully deploy the rover.

Lunar missions are also being planned by China, Japan and other countries. Like those efforts, India's explorations are designed to improve understanding of the Moon's environment, which would help if governments or private entities decide to establish a human settlement there. One poorly studied phenomenon is floating lunar dust. Without an atmosphere like Earth's, the surface of the Moon is buffeted by solar wind and ultraviolet radiation, creating a layer of charged ions called a plasma sheath in which dust particles can levitate.

If humans colonize the Moon, this dust will be a big challenge, says planetary scientist Penny King of the Australian National University (ANU) in Canberra. It gets into everything, from astronauts' suits to machinery and equipment, where it causes damage, she says. "Understanding how it moves around is pretty critical." ISRO says the Chandrayaan-2 orbiter and lander will carry a first-of-its-kind instrument, called the Radio Anatomy of Moon Bound Hypersensitive ionosphere and Atmosphere (RAMBHA), to measure the density of the plasma and how it changes over time.

The spacecraft's other instruments will help scientists to study other aspects of the Moon's environment and how it has evolved. Chandrayaan-2's lander will take the first thermal measurements of the lunar surface near a polar region, says Annadurai, who is also director of ISRO's Satellite Centre in Bangalore. In three to four weeks, ISRO will begin final tests to integrate all of the mission's components.

> ***"A nice part of the Indian space programme is that they manage to do things so cheaply."***

The budget for the mission is just 6.03 billion rupees (US$93 million), including the rocket and launch. Chandrayaan-2 will be carried into space on one of the agency's three-stage rockets, a Geosynchronous Satellite Launch Vehicle Mark II, taking off from a spaceport on the island of Sriharikota in the Bay of Bengal. "A nice part of the Indian space programme is that they manage to do things so cheaply," says ANU astrobiologist Charles Lineweaver. "If it succeeds, maybe everyone else will see that their mission didn't really need that extra bell or whistle." ■

Additional reporting by Nicky Phillips.