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IN REVIEW



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Astrodynamics enables Mars, comet exploration

by Ryan Park

The Astrodynamics Technical Committee advances the science of trajectory determination, prediction, and adjustment, and also spacecraft navigation and attitude determination.

On Aug. 6, after a decade-long cruise, the European Space Agency's **Rosetta** spacecraft arrived at Comet 67P/Churyumov-Gerasimenko, making it the first spacecraft to rendezvous with a comet. Since its launch in March 2004, Rosetta performed a four-gravity assist interplanetary transfer to the comet (Earth-Mars-Earth-Earth, or EMEE), including two asteroid flybys en route. Rosetta deployed the **Philae lander** in late 2014, which searched for organic molecules on the comet's surface. Rosetta is planned to orbit the comet for about a year and will perform various in situ observations of the comet.

NASA's Mars Atmosphere and Volatile Evolution mission arrived in Mars orbit on Sept. 22. **MAVEN** will study the planet's upper atmosphere, ionosphere and interactions with the sun and the solar wind.

The Indian Space Research Organisation's **Mars Orbiter Mission** arrived at Mars two days after MAVEN's orbit insertion. MOM is India's first interplanetary mission as well as Asia's first spacecraft to orbit Mars. MOM showcases India's rocket

launch system, spacecraft-building, and science instrument and operations capabilities.

While both spacecraft took advantage of the same Earth-Mars interplanetary transfer opportunity, MAVEN launched directly into its transfer, while MOM used a series of orbit-raising maneuvers prior to commencing the transfer.

Also at Mars, the Comet Siding Spring made an extremely close flyby of the planet on Oct. 19. With a total of five orbiters in operation at the planet, program officials had to consider precautionary measures, including orbit timing adjustments, to avoid potential damage from the comet's dust particles. Early knowledge of this flyby also provided a unique observation opportunity for all Mars assets.

China's **Chang'e 3** was launched on Dec. 1, 2013, on a Long March 3B rocket from the Xichang Satellite Launch Center in the southwestern province of Sichuan. Chang'e 3 used a direct transfer to enter a 100-kilometer-altitude circular orbit around the moon on Dec. 6, and finally landed its 1,200-kilogram lander on Mare Imbrium on Dec. 14. NASA's Lunar Atmosphere and Dust Environment Explorer, which had arrived earlier in 2013, ended its mission on April 18 by performing a controlled crash into the far side of the moon.

On May 29, two-way communication with the International Sun-Earth Explorer 3 spacecraft was re-established by the **ISEE-3 Reboot Project team of volunteer citizen-scientists**. ISEE-3, which was launched on Aug. 12, 1978, was the first spacecraft to be placed in a halo orbit at the Sun-Earth L1 point. It was renamed the International Cometary Explorer in 1982 and became the first spacecraft to fly by a comet. Although significant effort was made to place the spacecraft back into a halo orbit, the spacecraft's propulsion system had failed due to a loss of the nitrogen gas used to pressurize the fuel tanks. On Aug. 10, the spacecraft passed about 15,600 kilometers above the lunar surface. It is now in a heliocentric orbit and will return to the vicinity of Earth in 17 years.

Finally, the Seventh Global Trajectory Optimisation Competition was hosted by the Politecnico di Torino and Università di Roma "La Sapienza." The objective of the competition was for teams to design trajectories for a **mothership** (launching from Earth), as well as trajectories for three electric-propulsion daughter craft whose goal was to rendezvous with as many asteroids as possible (candidate targets included 16,000 main belt asteroids) and then rejoin the mothership. Propellant mass was the tiebreaker for solutions visiting the same number of asteroids. The winning solution came from a team from the Jet Propulsion Laboratory, with 36 asteroids. ▲

ESA/Rosetta/MPS



Rosetta's OSIRIS camera — the Optical, Spectroscopic and Infrared Remote Imaging System — captured this image of Comet 67P/Churyumov-Gerasimenko.



Artist's concept of comet C/2013 A1 Siding Spring.

NASA/JPL-Caltech.