A historic first in solar system exploration

Rosetta spacecraft becomes first manmade probe to orbit a comet

By Don Barrett
8 August 2014

On August 6, the Rosetta spacecraft entered into orbit around Comet 67P/Churyumov-Gerasimenko. It is the first manmade probe to complete such a maneuver, enabling the study of the comet at close range for months as it approaches the Sun.

Comets are rare among the celestial objects visible to ancient man because they brazenly disturb the apparently unchanging order of the night sky, appearing and disappearing in a way that seemed to defy understanding.

Their nature was subject to speculation for millennia: Aristotle, who viewed the heavens as perfect and orderly, described a previous brilliant appearance of Halley’s comet as an emanation of the Earth, associated with windy conditions. The Bayeux tapestry records the 1066 appearance of this same comet as the harbinger of the defeat of Harold, Earl of Wessex, by William the Conquerer at the Battle of Hastings.

The beginnings of scientific descriptions of comets would await the great awakening of the Enlightenment in Europe. Kepler demonstrated in 1609 that detailed observations of the orbits of planets around the Sun could be most simply described by the geometric figure of the ellipse, with their motion described by simple mathematical laws. Isaac Newton would demonstrate half a century later that this otherwise arbitrary shape was the result of a much more central phenomenon: the attraction of the planets by the Sun with a force that varied as the inverse square of their distance

Edmund Halley was an acquaintance of Newton. In 1684, he was astounded to discover that Newton had worked out this more fundamental model of gravity and the shapes of orbits almost 20 years earlier. He arranged for Newton to publish these results, which formed the basis of the monumental volume, the *Philosophiae Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy), which would revolutionize physics.

Almost immediately, Halley began using Newton’s model of orbits to calculate how cometary appearances could fit within this framework. He rapidly determined that they travelled about the Sun in extremely elongated ellipses, unlike the planets’ more circular paths. By 1705, he would publish an analysis showing that the comets of 1456, 1531, 1607, and 1682 were in fact the same object, returning to the inner solar system on a periodic basis. He would not live to see the return of this comet in 1758 (he would have been 102, and died 16 years previously), but the fame of a successful prediction led to his name being associated with the comet, and inaugurated the tradition of naming comets after those who either discovered them or connected historic appearances to a consistent orbit.

The 1800s led to the connection of meteor showers with the passage of the Earth through the orbital paths of comets, which implied that comets generated debris which would over time share their orbit. Comets came to be seen as small rocky bodies containing quite a bit of ice, which would evaporate and liberate dust as comets approached the Sun and were heated by it.

In 1950, astronomer Fred Whipple first described comets as we understand them today: as bodies of mostly ice, containing considerable dust – as a “dirty snowball.”

The first spacecraft to fly by a comet were the Soviet probes Vega 1 and 2, the first arriving at Halley’s Comet on March 6, 1986 at a distance of 9,000 km. It was followed eight days later by the European probe Giotto, which passed 15 times closer.

The enormous difference between planetary orbits, including that of the Earth, and cometary orbits, requires substantial fuel to adjust the orbit of a spacecraft to synchronize with a comet. As a result, these early probes made no effort to do so, and travelled by Halley’s central nucleus at the vast speed of about 70 km/s (156,000 mph). Even the smallest dust particles impact with enormous destructive potential at this velocity. The Giotto survived its closer encounter but was knocked about by dust impacts and the mirror that reflected light to its protected camera was scoured to the point of uselessness. The close encounter period of flybys like these lasts mere seconds, making systematic close-up studies impossible.

Over the intervening 28 years, several spacecraft have encountered comets, but all as difficult, speedy flybys. The Deep Impact spacecraft even hit comet Tempel 1 with an 815 lb impactor on July 4, 2005, and studied the resulting surface explosion from the main spacecraft during a high-speed flyby.

The Rosetta probe is the first cometary probe to solve the problem of orbital synchronization within the limited funding now available to basic science. In place of a substantial reserve of fuel to adjust its orbit, its mission team instead relied on a complex trajectory which would bring the probe around the solar system five times, encountering the Earth three times and Mars once, using their gravity on each encounter to adjust the orbit closer to that of its target.

The final transfer orbit carried the spacecraft far from the Sun, approaching the orbit of Jupiter. Without expensive nuclear power sources, the probe instead was designed to hibernate for almost three years until its orbit brought it again close enough to the Sun to waken and rely on its solar panels for power.

Comets are now understood to represent primordial material left over from the formation of the Solar System, condensed at distances considerably farther away than the outermost planets. From this permanent pool, some occasionally are disturbed to begin a long trip into the inner solar system. For most, this is a one-time trip, ending with a return to the distant reaches. Some, however, pass close enough to one of the planets to alter their orbits to remain within the solar system, with orbital periods from a few years to a few hundred years. Over time, close approaches to the Sun deplete them of their reserve of volatile ices. They may become too faint to be discovered, or may even entirely disassociate.

Comet 67P/Churyumov-Gerasimenko was discovered in 1969 by Klim Churyumov and Svetlana Gerasimenko of the Academy of Sciences of the Republic of Tajikistan in the USSR. The comet was found in photographs taken by them at a state observatory in Kazakhstan. The scientific development of these two previously backward territories was made possible largely by the powerful impulse and resources provided by the Russian Revolution– both facilities have seen enormous reverses in the aftermath of the collapse of the USSR.

Comet 67P is a short period comet which orbits the Sun in only 6.5 years (Halley's period is 75 years). At its closest approach, it still remains about 35 percent farther from the Sun than the Earth. At its far point, it approaches Jupiter's distance. Unlike many comets, it orbits the Sun in a plane similar to that of the other planets, allowing the use of their gravity to deflect a probe as part of the approach and synchronization of a probe's orbit.

Perhaps most importantly, a study of its orbit showed that its current orbit is of recent origin: in February 1959 it passed close to Jupiter, which brought it substantially closer to the Sun. Prior to then, it approached the Sun to only about twice the distance of Mars, keeping its material in "cold storage." With only nine close approaches to the Sun since then, it is thought to contain relatively undisturbed primordial volatile ices – at least compared to other periodic comets. It would be almost impossible to organize, given the financial constraints of space exploration, a mission to a comet making its first approach into the inner solar system: the complex approach necessary for the Rosetta mission has taken ten years!

Over the coming months, the Rosetta probe will orbit ever closer to the nucleus of the comet, coming ultimately to within 30 km. It will monitor the comet constantly with 11 scientific instruments, which will photograph and study the comet's composition and dynamic evolution in great detail as the pair approach the Sun. The comet is currently evaporating only about a liter of water of ice per second. As it approaches the Sun, that quantity will grow by a factor of hundreds, and the comet will grow a tail. The Rosetta probe, without the worry of hitting debris at high speeds, will get a close-up view of the whole process.

In November, the Rosetta probe will deploy a separate lander, called Philae, which will approach the nucleus of the comet and attempt to land on it. The gravity of the small cometary nucleus, only 4 km across, is too small to rely on for a secure attachment. The spacecraft will press against the ice of the nucleus with rocket thrust, while attempting to drill two ice screws into the ice. A harpoon attached by a line to the lander will also be fired in the ice to tether the lander.

The lander may operate for weeks or months, and its own suite of nine scientific instruments will make observations impossible even from the close distance of the Rosetta orbiter.

Nine countries are formally involved in the construction of the Rosetta/Philae mission: the subsidiary components of the mission undoubtedly involve dozens of others. Scientific exploration on this scale is inherently a vast social undertaking, involving the participation of thousands of workers across the globe.

Less than a century from the understanding of the general nature of comets, the organized labor of man has accomplished a rendezvous with a comet and continued orbit around it. The coming months will bring a profound increase in our understanding of these long-observed denizens of the solar system.