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Finding the Small Moons of the Outer Planets: A Satellite Revolution

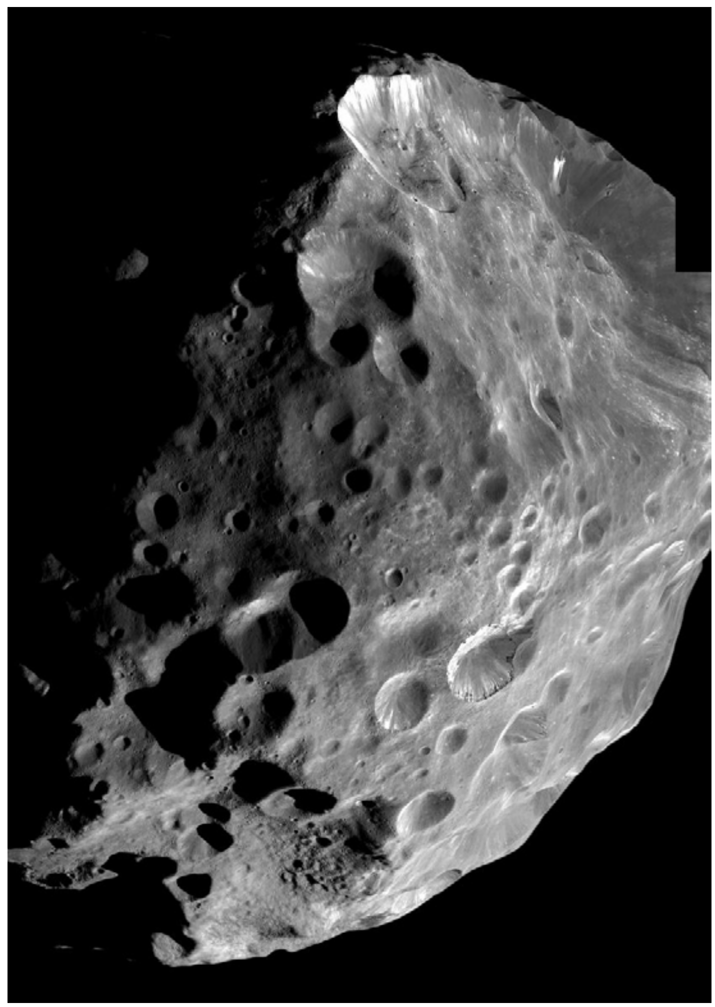
Scott S. Sheppard
Carnegie Institution of Washington

Editor's Introduction

At the present moment, astronomers know 166 moons orbiting the planets and 6 moons around the dwarf planets in our solar system. For a long time, new moons could only be discovered if they reflected a significant amount of sunlight (because they were close or large) or got in camera range of one of our visiting spacecraft. But recently, the pace of discovery has really accelerated. We asked one of the leading satellite discoverers, Scott Sheppard, to fill us in on what has changed and what kinds of new worlds are being discovered.

The orbital history of a satellite can be very complex, but, ultimately, understanding where satellites came from can tell us about the formation and evolution of the Solar System. My branch of astronomy started in 1610 when Galileo Galilei used one of the first telescopes to discover the four large satellites of Jupiter, which are now called the Galilean satellites in his honor. The discovery of these satellites, which had the audacity to orbit Jupiter, lead Galileo to support the ideas of Nicolaus Copernicus — that is, that the Earth is not the center of the universe.

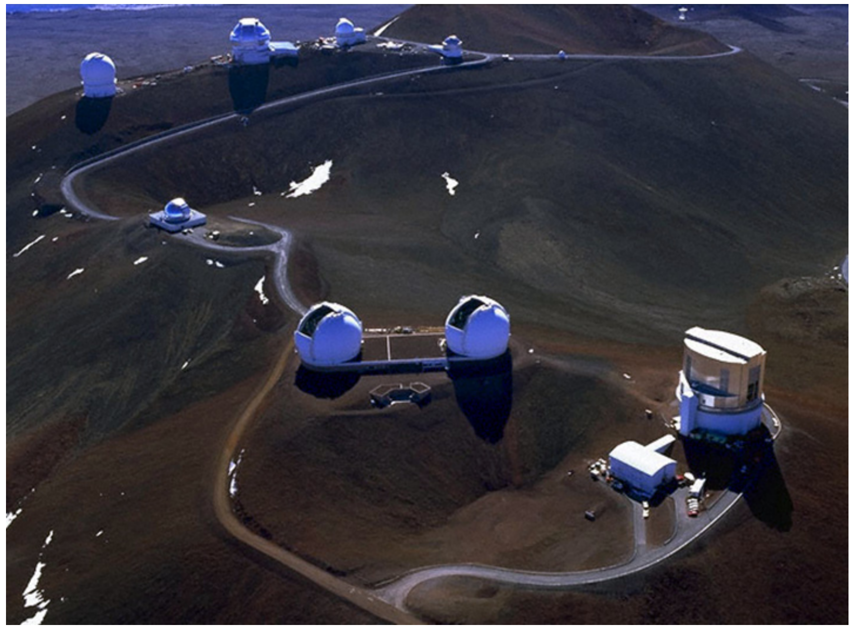
Until the late 1990's, only around 60 satellites were known to exist in our Solar System. Many smaller inner satellites were found near the giant planets by the Voyager spacecraft. Satellites that have more distant orbits from their planet cannot be discovered



Saturn's largest irregular satellite as viewed by the Cassini spacecraft in June 2004. Phoebe appears to have a surface that is very rich in volatile (easier-to-evaporate) materials, unlike other small objects observed up close in the main belt of asteroids between Mars and Jupiter.
Credit: NASA/JPL/Space Science Institute.

efficiently with current spacecraft, since cameras with a wide field of view are required to survey the much larger space covered by these more distant orbits.

In the late 1990's, technology had advanced to the point that sensitive wide field-of-view digital detectors were now available on large ground based telescopes. This modern technology was far superior over earlier photographic plates, and made new discoveries possible in many fields of astronomy. For solar system observations, the digital detectors were first focused on finding Kuiper Belt objects beyond Neptune (see *Astronomy Beat* #17). But in 1997 a team led by Brett Gladman used a wide-field camera to find a few small outer satellites of Uranus. Our group, based at the University of Hawaii, wanted to learn more about Jupiter's satellite population.



The telescopes atop Mauna Kea in Hawaii. Many of the outer satellites of the giant planets were discovered using one of three telescopes on Mauna Kea. The University of Hawaii 2.2 meter telescope is in the middle top of the picture, the 3.6 meter Canada-France-Hawaii telescope is in the upper left and the Japanese 8.2 meter Subaru telescope is in the lower right. *Credit: Richard J. Wainscoat.*

Surprising Discoveries

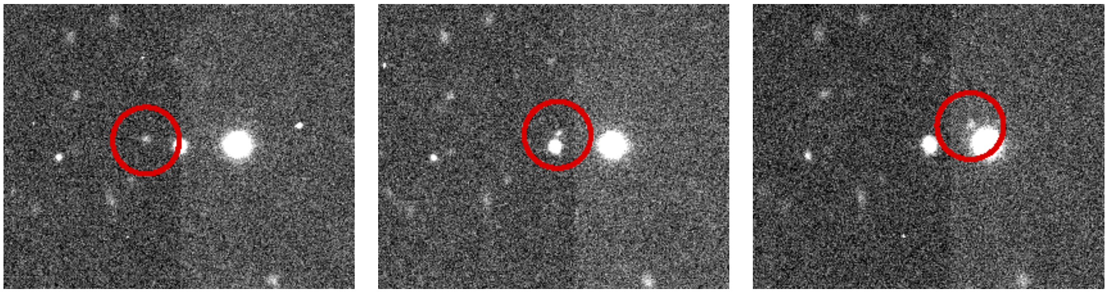
When we first turned our telescope with its wide-field digital detector towards Jupiter, we would have been happy to just find one new satellite. At that time, there was no reason to believe that Jupiter had any significant population of small satellites. Also, no outer satellites smaller than about 10 km had ever been detected around any planet, though several earlier photographic surveys had attempted to probe this faint regime. It was thought that friction with an early disk of gas and dust around the giant planets may have preferentially removed all the smaller outer satellites.

As we began our observations at the University of Hawaii's 88-inch (2.2-meter) telescope on Mauna Kea, things didn't go so well. Bad weather prevented us from observing objects as faint as we desired. But after fourteen straight grueling nights, we finally got the perfect conditions we needed and made about ten satellite discoveries in one night! By the end of our satellite survey a few years later, we had found over fifty new satellites of Jupiter, as well as tens of satellites around Saturn, Uranus and Neptune. There is still a large population of even smaller satellites around all the giant planets to be discovered, but most of these await further advances in astronomical instrumentation in order to find them efficiently.

The Two Types of Satellites

The gas giants Jupiter and Saturn and ice giants Uranus and Neptune all have tens of known satellites each, and these can be classified into one of two categories: regular and irregular. The regular satellites of the giant planets are close to their planet and they have nearly circular orbits. They orbit their planets near the planes of their equators and in the same direction that the planet rotates. These satellites are thought to have formed around their respective planet through accretion in a disk of gas and dust that surrounded the planet during its formation, similar to how the planets formed in a disk of gas and dust around the young Sun.

In contrast, the irregular satellites of the giant planets are found very far from their planet and have eccentric and highly inclined orbits. Many of the irregular satellites also orbit the planet in the opposite direction of the planet's rotation. The irregular satellites cannot have formed around their planet with their current orbits, and were therefore likely captured objects. Before capture they were probably asteroids, Kuiper Belt objects, or part of some reservoir of small objects that is now extinct. Most known irregular satellites are between 1 and 200 km in size. One exception is Neptune's moon Triton, which is larger than Pluto, but very similar in composition. Triton is thought to have



The discovery images of Jupiter's satellite Carpo. They were taken about 30 minutes apart on February 26, 2003 with the Canada-France-Hawaii Telescope. The motion of the satellite clearly stands out compared to the steady state background of stars and galaxies.

formed in a way similar to Pluto, but was captured as a satellite of Neptune very early in the Solar System's history.

How to Capture a Satellite

Only the four giant planets have known outer satellite populations. The likely reason is that the capture process requires something that the terrestrial planets did not have. Objects may temporarily orbit a planet for a few hundred years (as Comet Shoemaker-Levy 9 did Jupiter), but because of the reversibility of Newton's equations of motion, some form of energy dissipation is required to permanently capture a body. In the present epoch, a planet has no known efficient mechanism that can permanently capture satellites. Thus outer satellite capture must have occurred near the time of planet formation, when the Solar System was not as organized as now.

Three viable mechanisms have been proposed for the capture of irregular satellites. Such capture could have occurred efficiently towards the end of the planet formation epoch, when giant planets may have had an extended planetary atmosphere or a disk of dust and gas around them. Friction with this material would have dissipated energy and allowed a small satellite to be caught into orbit. Another capture method involves the "Hill sphere" around a planet, the distance where a moon can orbit and not be "taken away" by the gravity of the Sun. As planets grew in the early solar system, their Hill spheres got larger and smaller bodies in the area could be permanently captured if a planet's Hill sphere grew significantly over a short period of time.

A final satellite capture mechanism would have been the result of the higher probabilities for the collision or collisionless gravitational interaction of small bodies near a planet's Hill sphere in the early solar system. At that time, a large number of small solar system bodies had not yet been incorporated into the planets or tossed out of the solar system. These asteroid and comet type objects would have likely had collisions or gravitational interactions with each other within the Hill spheres of the planets. During these Hill sphere interactions, some small bodies could have lost the right amount of orbital energy to be permanently captured by the planet as a satellite. These interactions are currently the best explanation for capture since they would be relatively independent on the mass of the planet.

Because these outer irregular satellites were captured during the Solar System's early years, they can give us insight into the formation and evolution process of the planets. Amazingly, the gas giants Jupiter and Saturn and the ice giants Uranus and Neptune all have a system of irregular satellites which have similar sizes, populations and dynamics — even though the four planets have different masses and formation

Scott Sheppard observing at the 6.5 meter Magellan telescope in Chile.

scenarios. Thus these planets likely captured their irregular satellites in a similar manner and any theories that attempt to explain the differences of Uranus' and Neptune's characteristics compared to Jupiter and Saturn's must take these similarities into account. Thus, these new discoveries bring interesting challenges for those astronomers who work on the details of how our solar system developed in its youth.

About the Author

Scott S. Sheppard is a research scientist at the Carnegie Institution of Washington's Department of Terrestrial Magnetism (DTM) in Washington, D.C. He obtained his Ph.D. in astronomy from the University of Hawaii where he learned the art of small body discovery in the outer solar system from Kuiper Belt legend David Jewitt. Scott's research interests are in the origin and evolution of planetary systems. To this end, Scott studies small bodies in our solar system in order to understand how the planets formed and migrated. Along with Chad Trujillo, Scott recently discovered a high inclination Neptune Trojan asteroid. Along with physical observations of these bodies, this gives observational support to the idea that Neptune was on a much more eccentric orbit in the distant past. The Trojans appear to share a similar origin with the outer satellites of the giant planets.

Resources for Further Information:

Scott Sheppard's web site on the outer solar system satellites can be found at:
http://www.dtm.ciw.edu/sheppard/satellites/

A list of the known satellites in the solar system, with the dates of discovery and the discoverers, is at:
http://ssd.jpl.nasa.gov/?sat_discovery

An interesting book on the satellites in the solar system is: Davide Rothery's *Satellites of the Outer Planets: Worlds in Their Own Right*, 2nd ed. 1999, Oxford U. Press. ✦