ICE & STONE 2020

WEEK 29: JULY 12-18

Presented by The Earthrise Institute

Authored by Alan Hale

THIS WEEK IN HISTORY

JULY 12, 2001: American astronomer Gary Melnick and his colleagues publish their discovery of water vapor around the old, evolved star CW Leonis, suggesting the presence of exocomets around that star. The subject of exocomets, including the importance of this discovery, is discussed in a previous "Special Topics" presentation.

JULY 12, 2126: Comet 109P/Swift-Tuttle, the parent comet of the Perseid meteors, will pass through perihelion at a heliocentric distance of 0.956 AU. A little over three weeks later the comet will pass 0.15 AU from Earth. 109P/Swift-Tuttle is a future "Comet of the Week."

JULY 14, 1996: European Southern Observatory astronomer Guido Pizarro takes the first of several photographs that show the presence of a cometary object discovered early the following month by Eric Elst. Comet Elst-Pizarro did not show a coma but did exhibit a distinct tail, and was found to be traveling in a low-eccentricity orbit entirely within the main asteroid belt. Dual-designated as "asteroid" (7968) and as "comet" 133P, Elst-Pizarro was the first-known example of a "main belt comet," more commonly referred to today as "active asteroids." These objects are the subject of a future "Special Topics" presentation.

JULY 14, 2015: NASA's New Horizons mission passes by Pluto and its system of moons. Pluto is the subject of this week's "Special Topics" presentation, and the New Horizons encounter is discussed in detail there.

JULY 15, 1862: American amateur astronomer Lewis Swift, who would become one of the top visual comet discoverers of the late 19th Century, discovers his first comet, which was independently discovered three days later by Horace Tuttle. Comet 109P/Swift-Tuttle, as this object is now known, is the parent comet of the Perseid meteor shower, and is a future "Comet of the Week."

JULY 15, 1965: NASA's Mariner 4 spacecraft passes by Mars and returns the first close-up photographs of the Martian surface. These revealed the presence of numerous impact craters, and significantly affected humanity's views concerning the possibility of Martian life.

JULY 15, 2020: The large main-belt asteroid (2) Pallas will be at opposition. It is currently traveling west-southwestward through the constellations of Vulpecula and Hercules and is visible in small telescopes near magnitude 9.5.

12 13 14 15 **JULY 16** 17 18

JULY 16, 1994: Nucleus "A" of Comet Shoemaker-Levy 9 impacts Jupiter, the first of over twenty nuclei that would impact that planet over the course of the subsequent week. The impacts had unexpectedly prominent effects on Jupiter's atmosphere and played a major role in our current understanding of the overall effects by impacts of small bodies. Comet Shoemaker-Levy 9 is this week's "Comet of the Week."

JULY 16, 2011: NASA's Dawn spacecraft arrives at and goes into orbit around the large main-belt asteroid (4) Vesta. Dawn would spend the next 13½ months orbiting Vesta and making detailed studies of it before departing for the large main-belt asteroid (and "dwarf planet") (1) Ceres. The Dawn mission is discussed in last week's "Special Topics" presentation, and Vesta itself is discussed in the Week 1 "Special Topics" presentation.

JULY 16, 2015: The Arkyd-3 Reflight CubeSat, a proof-of-concept satellite designed and built by the private company Planetary Resources, is deployed into Earth orbit from the International Space Station after arriving at the ISS three months earlier. Planetary Resources' efforts to establish asteroid mining operations are discussed in a previous "Special Topics" presentation.

JULY 16, 2020: Pluto is at opposition. It is currently traveling slowly west-southwestward through eastern Sagittarius and is visually detectable with larger telescopes near magnitude 14.5. Pluto is the subject of this week's "Special Topics" presentation.

12 13 14 15 16 **JULY 17** 18

JULY 17, 2020: The main-belt asteroid (904) Rockefellia will occult the 7th-magnitude star HD 161605 in Ophiuchus. The predicted path of the occultation crosses parts of southern Taiwan, the Hainan Peninsula of China, northern Vietnam, northern Laos, northern Thailand, southern Myanmar, far southern India, southern Somalia, and northern Kenya.

12 13 14 15 16 17 **JULY 18**

JULY 18, 2019: Retired University of Nebraska-Lincoln astronomer Edward Schmidt publishes the results of his study identifying as many as 21 possible analogs of the star KIC 8462852 (aka "Boyajian's Star"), i.e., stars with large and random drops in brightness possibly due to large clouds of exocomets. Boyajian's Star is discussed in a previous "Special Topics" presentation.

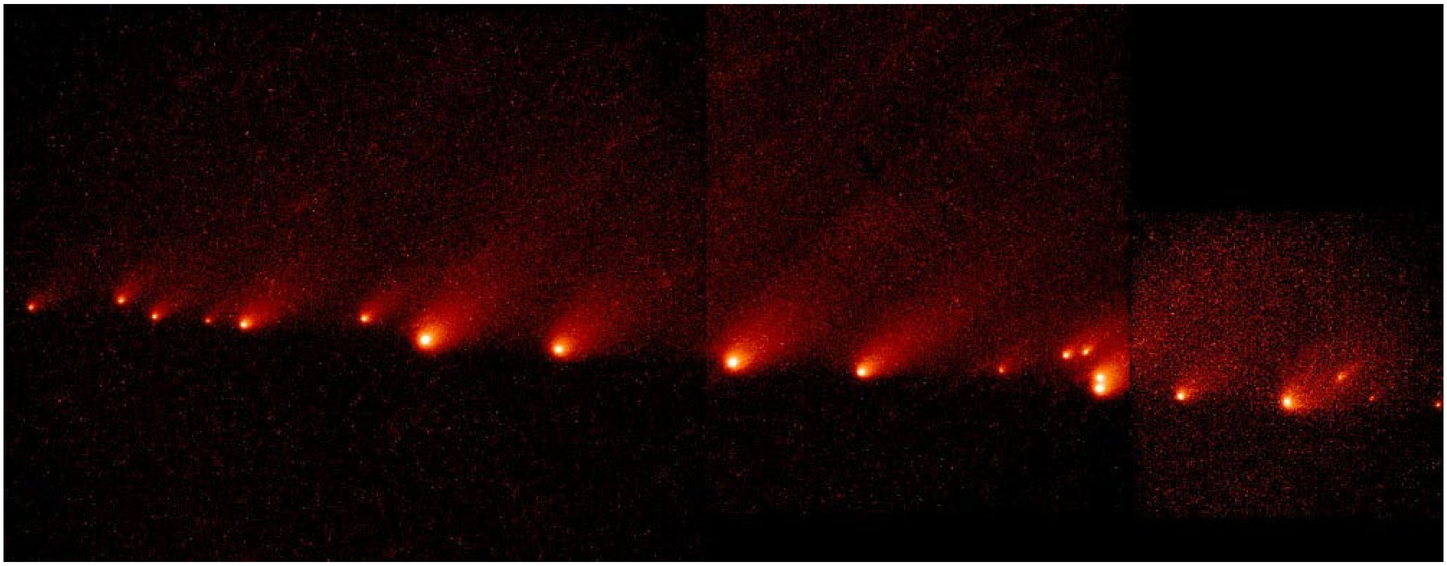
COVER IMAGE CREDIT:

Front and back cover: In this 30 second exposure taken with a circular fish-eye lens, a meteor streaks across the sky during the annual Perseid meteor shower as a photographer wipes moisture from the camera lenses Friday, August 12, 2016 in Spruce Knob, West Virginia.

Courtesy NASA/Bill Ingalls

COMET OF THE WEEK: SHOEMAKER-LEVY 9 1993E

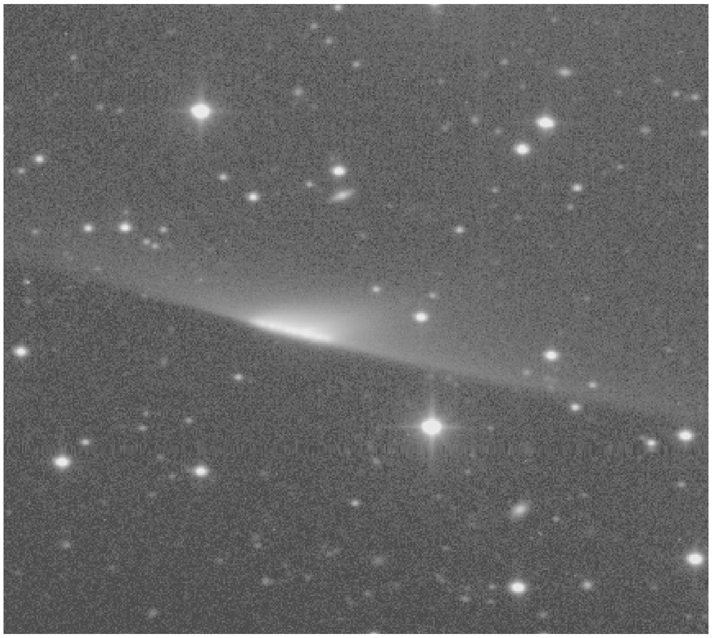
Perihelion: 1994 April 18.57, q = 5.380 AU



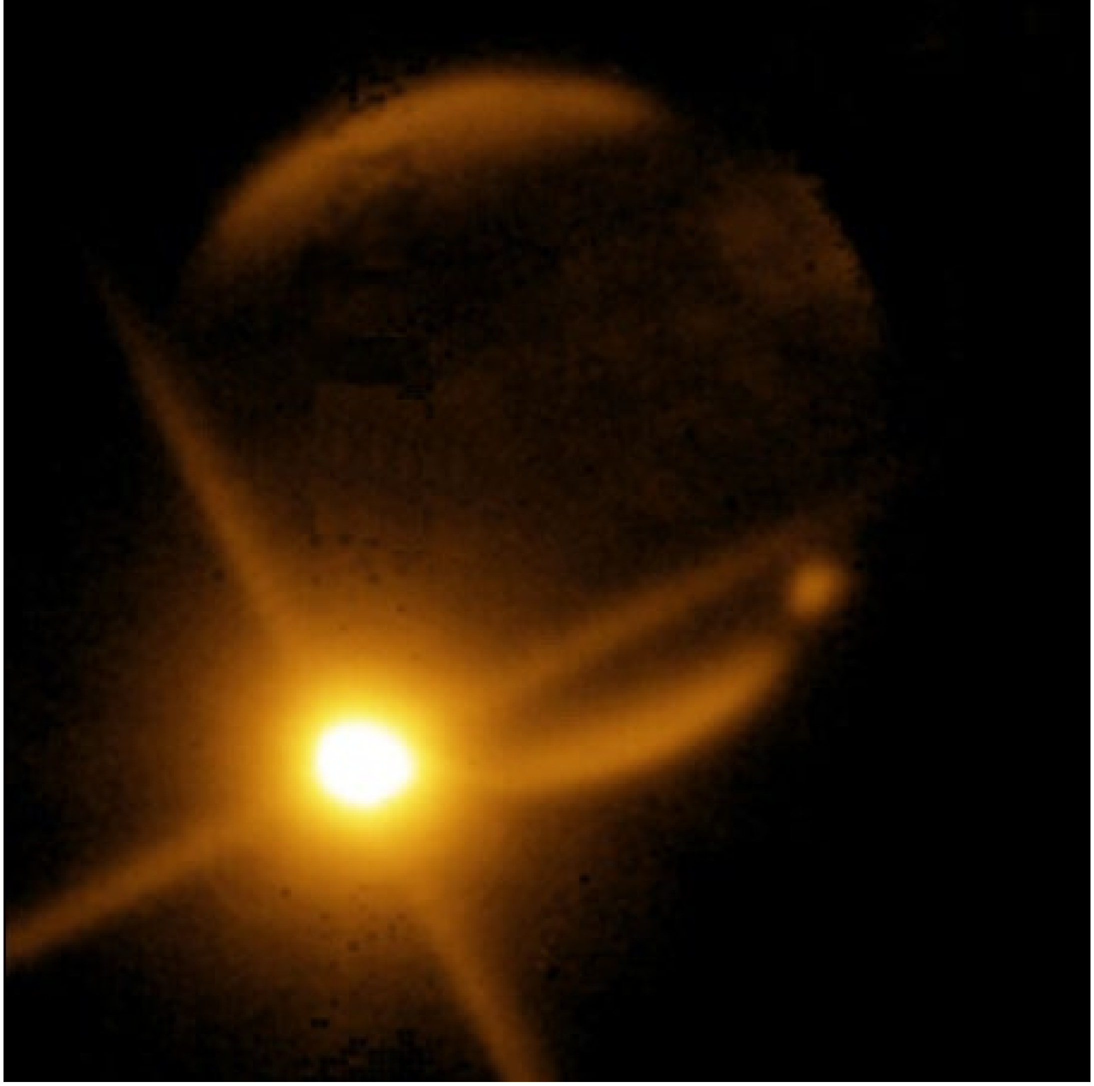
The individual nuclei of Comet Shoemaker-Levy 9, as imaged by the Hubble Space Telescope on May 17, 1994. Courtesy NASA.

What could perhaps be considered the most successful search program for comets and near-Earth asteroids during the photographic era, i.e., before the advent of CCD-based comprehensive survey programs in the late 1990s, was conducted by renowned planetary geologist Eugene Shoemaker from 1982 to 1994. Usually once a month he and his wife Carolyn would spend a week at the 46-cm Schmidt telescope at Palomar Observatory in California taking photographs near the ecliptic, which Carolyn would then scan for interesting objects. The Shoemakers tallied a significant number of near-Earth asteroid discoveries, and 32 comets, during the course of this program, making Carolyn the record-holder for most comet discoveries by a woman. Throughout the course of their program the Shoemakers were joined by various members of a team; one of these was the well-known amateur astronomer David Levy, visual discoverer of several comets, who joined the Shoemaker team in 1989 and remained with them for the duration of the program.

On the night of March 23-24, 1993, the second night of a planned observing run at Palomar, clouds began to interfere, but rather than shut down for the night the team decided to use some light-damaged film. They succeeded in taking a handful of photographs of a region of sky around Jupiter (then near opposition) before being completely clouded out shortly after midnight, and upon scanning one of the last-taken sets of photographs two days later Carolyn discovered what she called a "squashed comet" – a diffuse 13th-magnitude object which, instead of a circular coma with perhaps a tail attached, appeared as a straight bar approximately one arcminute long. The team was able to get confirmation of the object from James Scotti with the Spacewatch program in Arizona, who reported the comet as appearing as a "train" of several discrete nuclei, each with their own tails, and with a broad



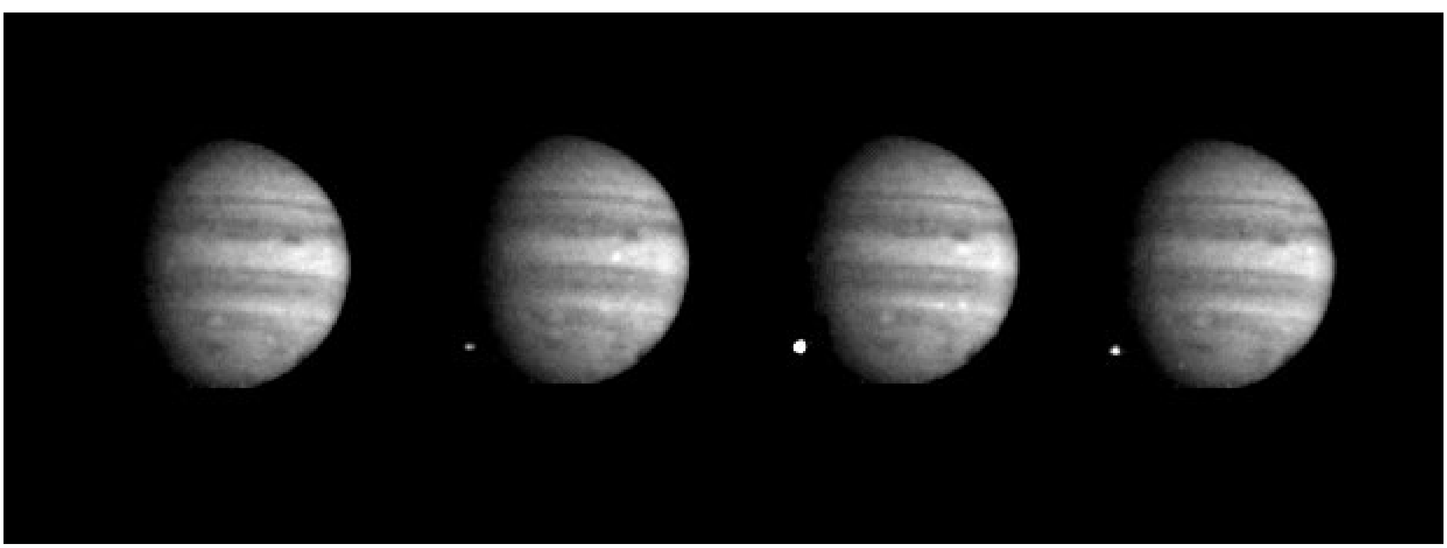
Comet Shoemaker-Levy 9, as imaged with the 0.9-meter Spacewatch telescope in Arizona on March 30, 1993. Courtesy James Scotti.



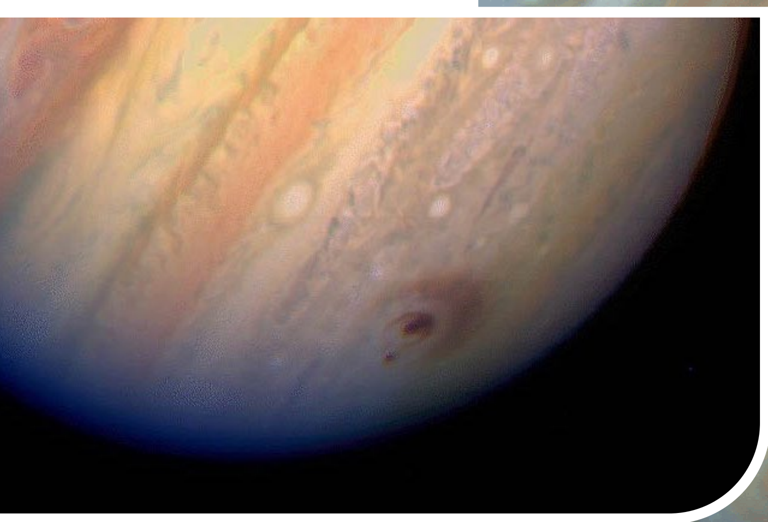
Infrared image of the impact of nucleus "G" on July 18, 1994, taken by Peter McGregor from Siding Spring Observatory in New South Wales. Image courtesy Mount Stromlo and Siding Spring Observatories.

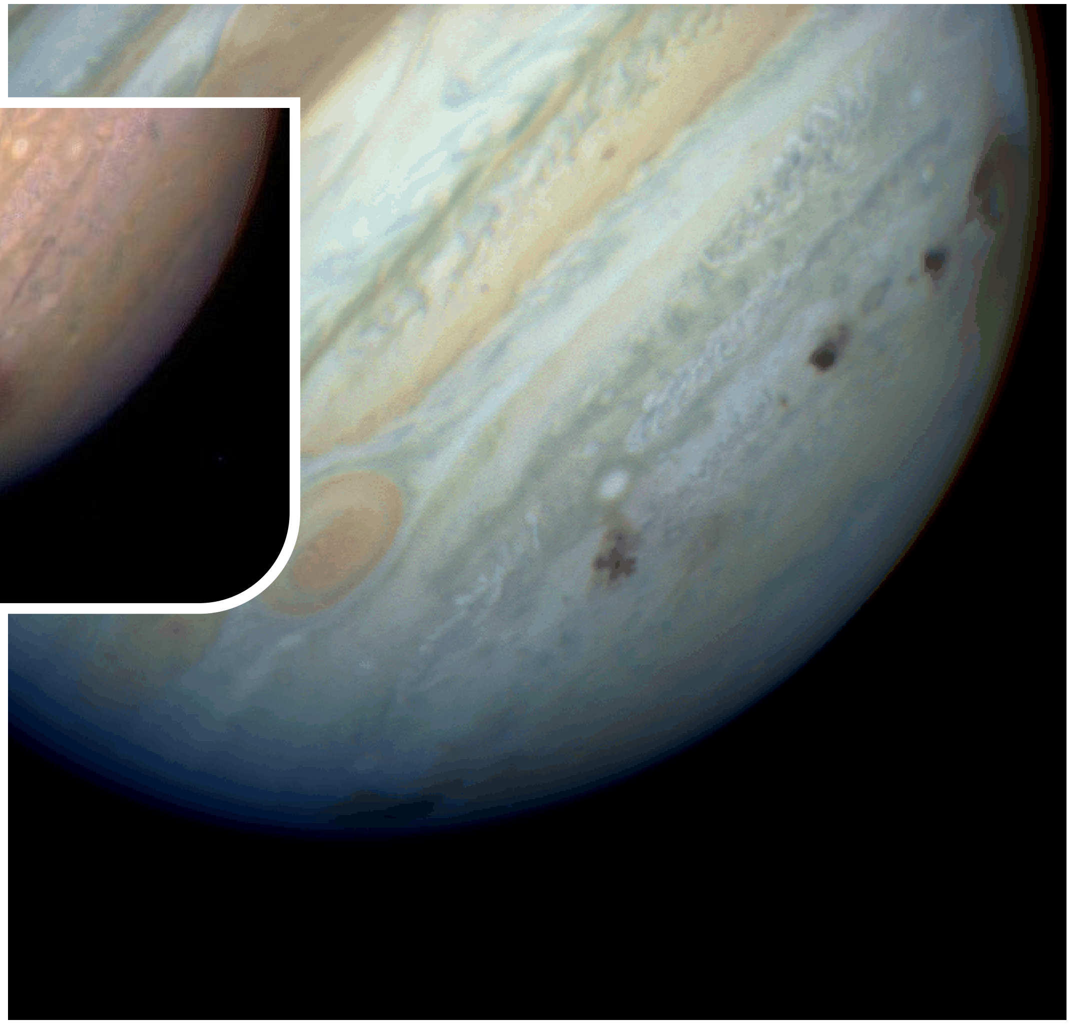
fan of material extending well off to either side of this "train." A few nights later images taken from Mauna Kea by Jane Luu and David Jewitt showed at least 17 separate nuclei, in their words "strung out likes pearls on a string."

The comet was located approximately four degrees from Jupiter and moving in roughly the same speed and direction as that planet. Orbital calculations proved quite problematical for some time, but eventually it became clear that the comet was actually in an elongated orbit around Jupiter as opposed to the sun – a phenomenon that was first identified in the early 1980s but never exhibited in so dramatic a fashion. The calculations soon showed that on July 7, 1992, the comet had passed just 43,000 km above the top of Jupiter's atmosphere, close enough such that the tidal forces from Jupiter's



Sequence of images of the impact of nucleus "W" on July 22, 1994, from the Galileo spacecraft. Courtesy NASA.





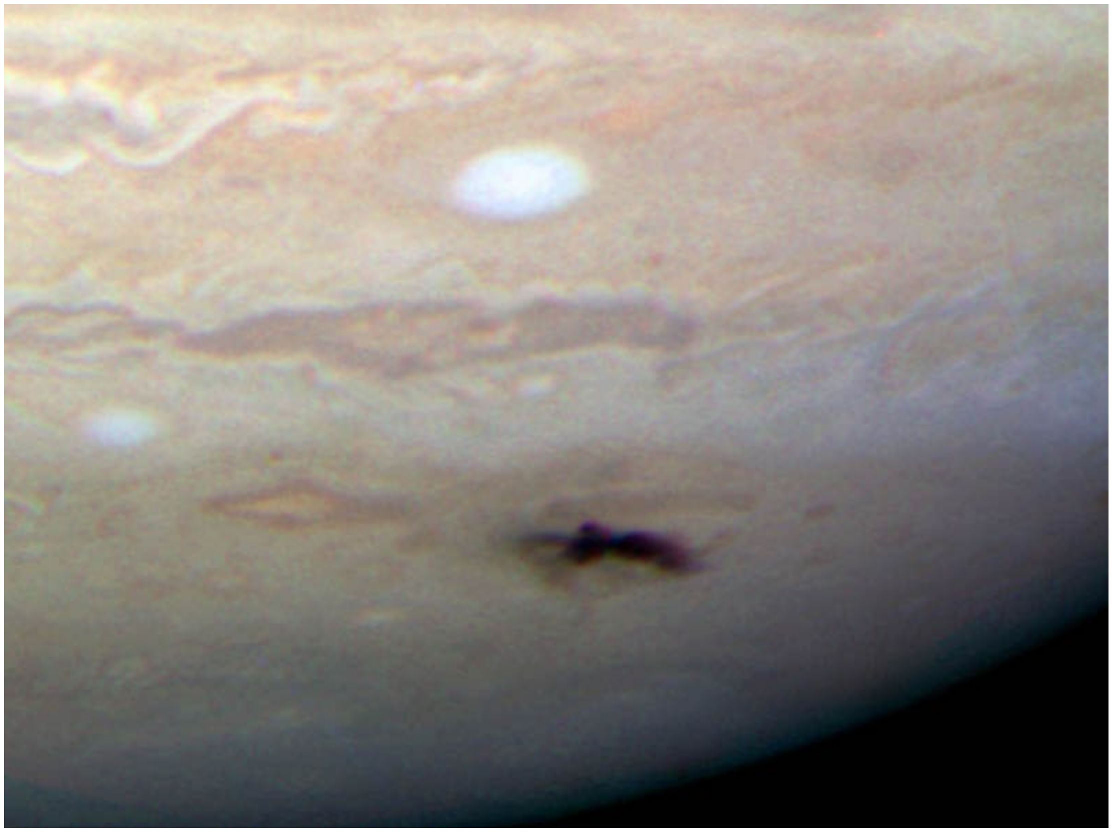
Hubble Space Telescope images of Comet Shoemaker-Levy 9 impact "scars." Left: Impact "scar" of nucleus "G;" the "scar" is larger than Earth. Right: Multiple impact "scars." Both images courtesy NASA.

gravity were stronger than the internal strength of the comet's material, thus ripping it apart into over 20 fragments. It turned out that Swedish astronomer Gonzalo Tancredi had taken photographs of Jupiter's vicinity in March 1992 for the deliberate purpose of searching for comets, but these didn't reveal any sign of Comet Shoemaker-Levy 9 down to 21st magnitude, suggesting that – not unexpectedly – it had brightened dramatically as a result of its splitting during its close approach to Jupiter.

What was even more exciting was that calculations began to reveal that when the comet fragments next returned to Jupiter's immediate vicinity – during the third week of July 1994 – each of them would impact the planet. For the first time, humanity would have the opportunity to witness a comet striking a planet. The one downside was that the impacts would occur on the side of Jupiter facing away from Earth, although due to Jupiter's rapid rotation the impact sites would rotate into view within a few minutes. One observer that would have a direct view of the impacts was the Galileo spacecraft, at that time en route to Jupiter (where it would arrive in late 1995) and located 1.6 AU away.

After being hidden behind the sun for the last several months of 1993 the comet reappeared in the morning sky towards the end of that year, and throughout the first six months of 1994 the nuclei slowly spread apart as they approached Jupiter. The first fragment – nucleus "A" – struck Jupiter on July 16, and although nothing was detected visually, ground-based observers using infrared telescopes almost immediately detected a bright flash at the expected location on Jupiter's limb behind which the impact would have occurred. Meanwhile, the Hubble Space Telescope detected a short-lived plume extending up from Jupiter's limb which then spread out into a characteristic mushroom-cloud shape. A few minutes later, when the impact site rotated into view it was clearly marked by a large black "scar" situated on Jupiter's cloud bands.

For the next six days, until the last fragment – nucleus "W" – made its impact into Jupiter on July 22, the world watched as nucleus after nucleus struck the planet. Even some of the nuclei that had supposedly "disappeared" during the intervening month produced observable impact events, and meanwhile the largest fragment – nucleus "G," which struck on the 18th – produced an impact flash bright enough to saturate the ground-based detectors and left an impact "scar" that was significantly larger than Earth.



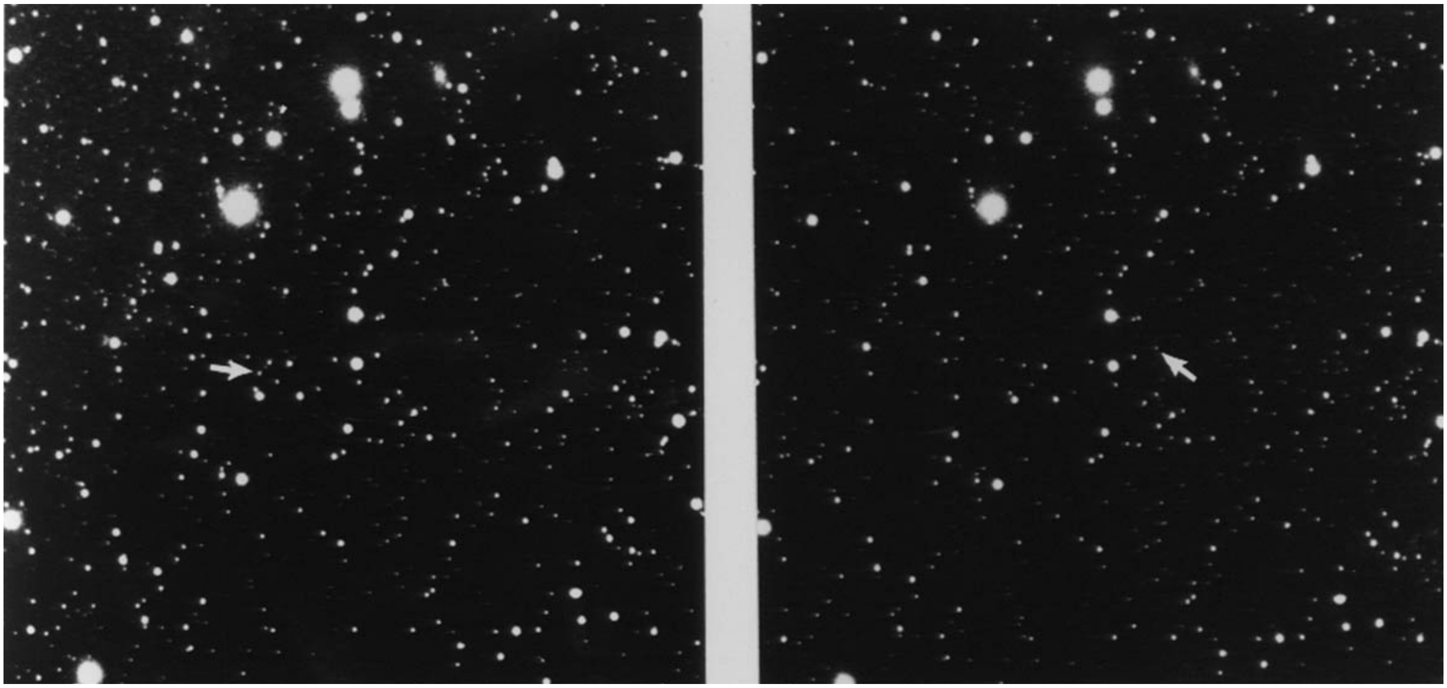
Impact "scar" on Jupiter, as imaged by the Hubble Space Telescope on July 23, 2009. The actual impact had taken place four days earlier. Courtesy NASA.

It turns out that these "scars" – which were easily detectable even with small backyard telescopes – were created when a fragment, traveling at a relative speed of 55 km per second, struck the atmosphere and disintegrated, briefly heating up the surroundings to temperatures exceeding the surface of the sun. The plumes that were ejected upwards included material from the disintegrated comet as well as material excavated up from the atmosphere, and reached a height of roughly 3000 km above the top of the atmosphere before quickly spreading out over a large area and settling down onto the tops of the clouds. The "scars" persisted for several weeks, although they eventually began to smear out due to Jupiter's atmospheric winds, and when Jupiter reappeared in the morning sky near the end of 1994 following conjunction with the sun the various "scars" had smeared out into a dark band that encircled the planet. This faded steadily over the subsequent weeks and months, although I could still faintly detect it in July 1995, a full year after the impacts.

For a long time it had been thought that impact events like these were very rare, however in the aftermath of the Shoemaker-Levy 9 impacts researchers suspect that some historical reports of short-lived dark spots on Jupiter may have been due to impacts. Indeed, on July 19, 2009 an amateur astronomer in New South Wales, Anthony Wesley, reported the appearance of such a black spot, and it soon became clear that this was in fact due to an impact, although the consensus is that it was caused by an unknown asteroid a few hundred meters across. There have been several smaller impacts detected since then, the most recent of these having occurred on August 7, 2019; these have appeared as brief flashes of light and didn't leave any "scars," suggesting that they were caused by relatively small objects. Meanwhile, astronomers have identified "chains" of craters on Jupiter's moons Ganymede and Callisto, suggestive of multiple impact events like those produced by Comet Shoemaker-Levy 9.

The ultimate lesson of the Shoemaker-Levy 9 impacts for many people was in the sheer energy of the impacts. The largest impact – from nucleus "G" – appears to have liberated close to six million megatons of energy, and all this from a rather small object; the total diameter of the original comet was probably no more than about 5 km. While Jupiter was the target this time, it could be Earth next time, and with the recent realization that the K-T extinction event that marked the demise of the dinosaurs was likely due to an impact, public awareness about the threat due to impacts climbed rapidly. The U.S. Congress commissioned Eugene Shoemaker to chair a commission to examine this issue and provide appropriate courses of action; the report that the Shoemaker Commission delivered to Congress and to NASA in June 1995 concluded that identification of threatening objects was the top priority, and this has in large part led to the comprehensive survey programs that first became operational in the late 1990s and that are continuing today – and that are discussed in next week's "Special Topics" presentation.

SPECIAL TOPIC: PLUTO



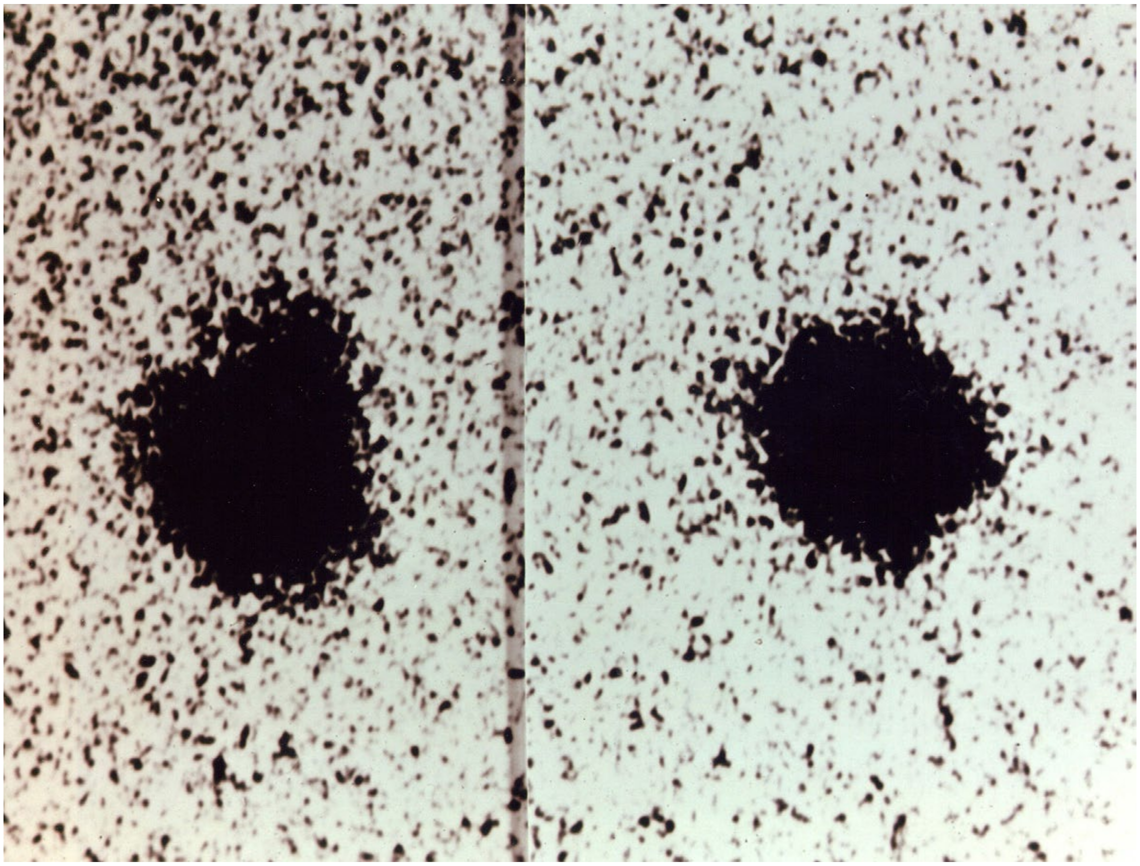
The discovery images of Pluto, taken from Lowell Observatory in Arizona on January 23 (left) and January 29 (right), 1930. Pluto is arrowed. Courtesy Lowell Observatory.

The discovery of the planet Uranus by British astronomer William Herschel in 1781 essentially doubled the size of the then-known solar system. During the years after Uranus' discovery astronomers began to notice small discrepancies in its orbital motion, and at least two individuals – a young British astronomer named John Adams, and a French mathematician, Urbain Le Verrier – concluded that these might be due to perturbations by an unknown planet orbiting the sun beyond Uranus, and attempted to calculate where in the sky such a planet might be located. Adams' calculations, which were rather imprecise to begin with, were essentially ignored by astronomers in England, however Le Verrier was able to have his predictions communicated to Johann Galle and Heinrich d'Arrest at the Berlin Observatory in Germany, who in turn found the planet we now call Neptune within an hour of searching and within one degree of Le Verrier's predicted position.

While Neptune's discovery seemed to take care of most of the discrepancies in Uranus' orbital motion, there still seemed to be some minor discrepancies left over, and some astronomers concluded that there might still be another planet beyond Neptune. One such person was the wealthy American amateur astronomer Percival Lowell, who built his namesake observatory near Flagstaff, Arizona in 1894 and who popularized the idea that Mars had been inhabited by a dying civilization and had accordingly built a worldwide network of "canals." Lowell calculated positions for a so-called "Planet X" and initiated search efforts from Lowell Observatory in 1906 which he continued up until his death ten years later; it turns out that his object did show up on a couple of his search photographs but he didn't recognize them at the time.

Following a protracted legal battle with Lowell's widow, Lowell Observatory resumed the search for "Planet X" in 1929 and hired a 23-year-old amateur astronomer from Kansas, Clyde Tombaugh, to conduct the actual search. Tombaugh's job was to take large-field photographs of regions of the night sky in pairs separated by a few nights, and then to compare these pairs of photographs using a device called a "blink comparator" to search for moving objects. On the afternoon of February 18, 1930, while comparing two photographs taken on January 23 and 29 of that year, he spotted a slow-moving 15th-magnitude stellar object relatively close to the predicted location of Lowell's "Planet X," and after verification of the object's existence and motion over the next couple of weeks Lowell Observatory announced the discovery on March 13, 1930, the 149th anniversary of Herschel's discovery of Uranus.

Lowell Observatory received numerous suggestions



The discovery images of Charon. Charon is the "bump" to the upper right of the image of Pluto on the left photograph, taken June 22, 1978. Courtesy U.S. Naval Observatory.

for a name for the newly-discovered world, but soon settled on "Pluto," which had been suggested by an 11-year-old schoolgirl from Oxford, England named Venetia Burney. Pluto, the Roman god of the underworld, seemed an appropriate name for a world located in the distant outer reaches of the solar system, and it was not lost on the Lowell staff at the time that the first two letters of the name "Pluto," i.e., "PL," are the initials for Percival Lowell.

Being as distant as it is, and as dim as it is, very little information could be gleaned about Pluto for quite some time. Not much could be discerned about its physical nature, although the general assumptions were that it was perhaps approximately the size of Earth. The orbital period has been calculated as being 248 years, with an inclination of 17 degrees, unusually large for a planet. Furthermore, although Pluto's average distance from the sun is 39.5 AU, it has a distinctly non-circular orbit, with an eccentricity of 0.25; for 20 years of its orbit it is actually closer to the sun than Neptune. Such was the situation between 1979 and 1999, with perihelion passage at a heliocentric distance of 29.66 AU taking place on September 5, 1989. Meanwhile, detailed studies of Pluto's brightness behavior revealed small periodic brightness variations which suggested a rotational period of 6.4 days.

Continued studies of Pluto over subsequent decades, including a couple of near-miss occultations of background stars, suggested that it is smaller than was originally believed, and estimates of its diameter and mass kept being revised downward. The big breakthrough finally came on June 22, 1978, when U.S. Naval Observatory astronomer James Christy was examining photographs of Pluto that had been taken for astrometric purposes, and noticed that a small "bump" regularly appeared in the images of Pluto but not in the images of surrounding stars. Christy concluded that he had found a moon orbiting Pluto, and with its appearances indicating an orbital period of approximately 6.4 days this in turn suggested that it was in synchronous orbit around Pluto. Christy named this putative moon "Charon," after the ferryman across the River Styx in Greek mythology.

The discovery of Charon allowed a rather precise determination of Pluto's mass (from Newton's Law of Universal Gravitation), which has been found to be only 1/6 of the moon's mass. Furthermore, due to a fortuitous alignment of Charon's orbit around Pluto with respect to Earth, in early 1985 Pluto and Charon began a series of mutual occultation events – i.e., each object regularly passing in front of and then behind the other – that lasted for the next five years. In addition to allowing final confirmation of Charon's existence, these events also allowed accurate size measurements to be made of both objects: Pluto's diameter is slightly under 2400 km (a little over 2/3 of the moon's diameter), and Charon's diameter is just over 1200 km – just over 1/3 of the moon's diameter and almost exactly half of Pluto's diameter.

A photograph of me (center) in my graduate school days (circa 1989-90) in the conference room in the NMSU Astronomy Department. At left is Clyde Tombaugh, discoverer of Pluto, and at right is James Christy, discoverer of Charon.

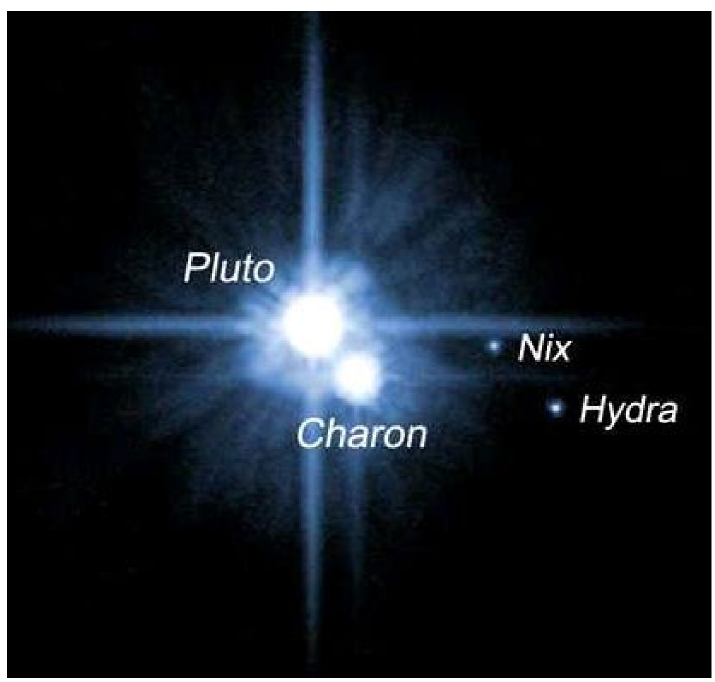
In hindsight, Pluto is clearly nowhere near massive enough to have caused any discernible changes in Uranus' orbit, and the fact that it was discovered fairly close to Percival Lowell's predicted location for "Planet X" can be nothing more than a coincidence. The Voyager 2 encounter with Neptune in 1989 allowed for a more precise determination of that planet's mass, and the revised value alone eliminates the minor discrepancies that existed earlier.

On June 9, 1988, Pluto occulted a 12th-magnitude star in the constellation Virgo. Both the star's disappearance and reappearance were gradual rather than abrupt, thus providing the first direct evidence that Pluto has at atmosphere, albeit a relatively thin one. Studies since then have shown that the atmosphere is primarily made up of nitrogen and smaller amounts of methane and carbon monoxide. Since Pluto was then fairly close to its perihelion passage there has been some speculation that the atmosphere is temporary and is being produced by solar heating – what little there is at such a distance – sublimating its surface materials. Since the atmosphere is still persisting today, three decades beyond Pluto's perihelion – as revealed by Pluto's occultation of a 13th magnitude star in August 2018 – the situation is apparently more complex than that, and it will likely be another few decades – as Pluto continues to recede from perihelion – before this can be sorted out.

As part of a deliberate search effort for additional moons of Pluto utilizing the Hubble Space Telescope, a team of astronomers led by Alan Stern and Hal Weaver discovered two such objects, since named Nix and Hydra, on May 15, 2005. The same basic team, although now led by Mark Showalter, discovered a fourth moon, now named Kerberos, on June 28, 2011, and a fifth one, now named Styx, on June 26, 2012. All of these objects are relatively small – Nix and Hydra being about 50 km in diameter, and Kerberos and Styx being only 16 to 19 km across – and they all orbit well outside of Charon's orbit.

The primary tool of our understanding of Pluto and its moons is NASA's New Horizons mission, which was launched from Cape Canaveral, Florida on January 19, 2006. Following a distant flyby of the main-belt asteroid (132524) APL in June 2006 and a gravity-assist flyby of Jupiter in February 2007, New Horizon flew through the Pluto system on July 14, 2015, passing 12,500 km from Pluto and 28,800 km from Charon. In order that the time of the encounter could be fully devoted to the taking of images and data measurements, the recorded images and data were stored on-board and then transmitted to Earth over the subsequent 15 months.

The New Horizons data showed that Pluto's surface is primarily made up of nitrogen ice. At least parts of the surface are geologically active – likely due to some form of cryovolcanism – and indeed a large "heart"-shaped feature on the surface that has been named Sputnik Planitia apparently has no impact craters, indicating a young age geologically (i.e., less than ten million years old), with more recent studies indicating an age as low as 180,000 years. Pluto internal structure appears to be differentiated, i.e., with a rocky core and a mantle made of water ice; there may be a subsurface ocean of liquid water perhaps 100 km deep. Charon, meanwhile, also appears to show signs of cryovolcanism, and with the exception of a dark region named Mordor Macula



The discovery image of Pluto's moons Nix and Hydra, taken with the Hubble Space Telescope on May 15, 2005. Courtesy NASA.

Image of Pluto taken by the New Horizons spacecraft during its flyby through the Pluto system on July 14, 2015. The bright "heart"-shaped region below center is Sputnik Planitia. Image courtesy NASA.

does not exhibit very much in the way of impact craters. Unlike Pluto, Charon does not appear to have much in the way of an atmosphere.

Pluto's overall small size that has been revealed by scientific studies over the past few decades has forced a rethinking on what should and what should not be considered a "planet." Pluto, in fact, is in the "trans-Neptunian" region of the solar system where the "Kuiper Belt" originally proposed in the mid-20th Century was believed to exist, and the discovery of other objects in this region of the solar system beginning in 1992 began to bring this discussion up. (The Kuiper Belt as a whole is the subject of a future "Special Topics" presentation.) The first several Kuiper Belt objects that were discovered were relatively small objects on the order of 100 to 200 km in diameter – i.e., significantly smaller than Pluto – and thus for a while there remained a sharp distinction in size between Pluto and these objects. On the other hand, several of these objects have orbital periods roughly the same as that of Pluto, and indeed along with Pluto are in what is called a "2:3 resonance" with Neptune, i.e., they orbit the sun twice for every three orbits that Neptune makes. It is in fact this resonance that makes any collisions with Neptune impossible, even though Pluto does cross within Neptune's orbit. Resonances like these are discussed

Image taken of the moon Charon by the New Horizons spacecraft during its flyby through the Pluto system on July 14, 2015. The dark region near the top is Mordor Macula. Image courtesy NASA.

in a future "Special Topics" presentation.

Beginning in the early 2000s, however, Kuiper Belt objects approaching the size of Pluto began to be discovered. Matters reached a head in 2005 with the discovery of the Kuiper Belt world now known as Eris, which is just slightly smaller than Pluto in terms of physical diameter but which is somewhat more massive than Pluto. A couple of other Kuiper Belt worlds of similar size were also discovered and/or announced that same year. If Pluto is a "planet," then these other worlds are "planets" as well, and since there appears to be a gradual continuum in size downward from these, what is and what is not a "planet" devolves into an arbitrary exercise in where to draw the line.

On the concluding day of its General Assembly

A backlit image of Pluto taken by the New Horizons spacecraft as it was departing. The glow is caused by layers of haze in Pluto's atmosphere. Courtesy NASA.

that was held in Prague, Czech Republic, in August 2006, the remaining attending members of the International Astronomical Union voted for a definition of "planet" that contains the criteria: a) the object is in orbit around the sun; b) the object has enough mass to be in a state of "hydrostatic equilibrium," or, in other words, has enough mass to be gravitationally forced into a roughly spherical shape; and c) the object has "cleared the neighborhood" around its orbit. By this definition, neither Pluto nor Eris nor any of the other large Kuiper Belt objects are "planets." Instead, the IAU created a new category of object, called "dwarf planet," for objects that fulfill the first two criteria, and to date this category includes Pluto, Eris, a handful of other large Kuiper Belt objects, as well as the largest of the "main-belt" asteroids, (1) Ceres. One aftermath of this decision is that Pluto has now been assigned an "asteroidal" number, (134340).

This definition by the IAU has been controversial since then, with some astronomers as well as various members of the general public being opposed to it. Indeed, it can be argued that the criterion of an object "clearing the neighborhood around its orbit" is itself somewhat arbitrary, since if taken to extremes neither Earth nor even Jupiter fulfills it. Nevertheless, the definition remains to this day, and in all honesty since any definition is going to involve some arbitrariness there perhaps isn't a better one available.

In my own opinion, the term "planet," as it has been used by humanity ever since the ancient Greeks first used it to describe "wandering stars," is an outdated concept, as the solar system as we know it today is far more complex than that. For example, Earth and Saturn are both "planets" even though in physical terms they are very dissimilar objects, whereas Titan, which is physically larger than Mercury and is quite similar to Earth in physical terms – to the point of having at atmosphere thicker than Earth's – is not a "planet." (The fact that Titan is a moon of Saturn can be argued as being an arbitrary distinction, since both it and Saturn orbit around the system's center of mass, which itself is what orbits the sun.) Pluto remains a fascinating object regardless of whatever arbitrary label is or is not placed upon it. Finally, there are the thousands of currently known "exoplanets" – with more being discovered all the time – that have been discovered orbiting around other stars (and thus failing the first of the IAU's "planet" criteria). Many of these worlds appear to have physical characteristics quite unlike anything in our solar system, however they are large, are presumably spherical, and orbit their respective parent stars just like the "planets" in our solar system orbit the sun.

In that spirit, then, perhaps the best solution is to eschew labels like "planet" altogether, and instead treat each object we discover as a separate world, worthy of recognition and study in its own right.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