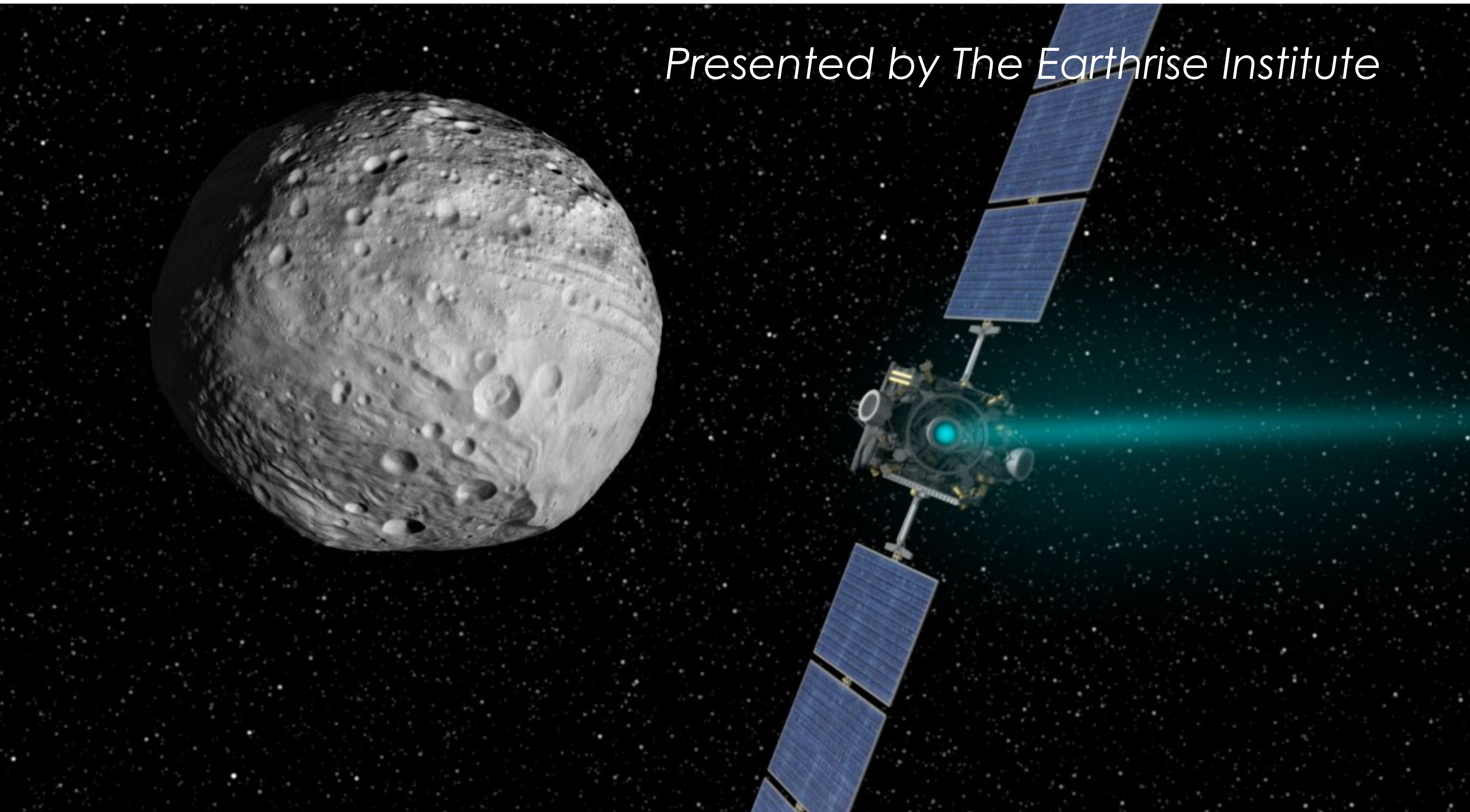
ICE & STONE 2020

Week 7: February 9-15, 2020



Presented by The Earthrise Institute

THE EARTHRISE INSTITUTE

Simply stated, the mission of the Earthrise Institute is to use astronomy, space, and other related endeavors as a tool for breaking down international and intercultural barriers, and for bringing humanity together. The Earthrise Institute took its name from the images of Earth taken from lunar orbit by the Apollo astronauts. These images, which have captivated people from around the planet, show our Earth as one small, beautiful jewel in space, completely absent of any arbitrary political divisions or boundaries. They have provided new inspiration to protect what is right now the only home we have, and they encourage us to treat the other human beings who live on this planet as fellow residents and citizens of that home. They show, moreover, that we are all in this together, and that anything we do involves all of us.

In that spirit, the Earthrise Institute has sought to preserve and enhance the ideals contained within the Earthrise images via a variety of activities. It is developing educational programs and curricula that utilize astronomical and space-related topics to teach younger generations and to lay the foundations so that they are in a position to create a positive future for humanity.

ALAN HALE

Alan Hale began working at the Jet Propulsion Laboratory in Pasadena, California, as an engineering contractor for the Deep Space Network in 1983. While at JPL he was involved with several spacecraft projects, most notably the Voyager 2 encounter with the planet Uranus in 1986. Hale eventually left JPL and returned to New Mexico where he earned his Ph.D. in 1992 with a thesis entitled “Orbital Coplanarity in Solar-Type Binary Systems: Implications for Planetary System Formation and Detection” which was published in the January 1994 issue of the Astronomical Journal), and which has since become one of the seminal papers in early exoplanet research, with over 200 citations to date.

Alan Hale’s research interests include the search for planets beyond the solar system, including those which might have favorable environments for life; stars like the sun; minor bodies in the solar system, especially comets and near-Earth asteroids; and advocacy of spaceflight. He is primarily known for his work with comets, which has included his discovery of Comet Hale-Bopp in 1995. In recent years he has worked to increase scientific collaboration between the U.S. and other nations.

Besides his research activities, he is an outspoken advocate for improved scientific literacy in our society, for better career opportunities for scientists, and for taking individual responsibility to make ours a better society. He has been a frequent public speaker on astronomy, space, and other scientific issues He has been involved with the Icarus Interstellar project and previously served on the Advisory Board for Deep Space Industries.

Alan Hale lives in the Sacramento Mountains outside of Cloudcroft, New Mexico with his partner Vickie Moseley. He has two sons, Zachary and Tyler, both of whom have graduated from college and are now pursuing their respective careers. On clear nights he can often be found making observations of the latest comets or other astronomical phenomena.

COVER IMAGES CREDITS:

Front cover (top): Image of C/2014 Q2 (Lovejoy), a long-period comet discovered on 17 August 2014 by Terry Lovejoy. This photograph was taken from Tucson, Arizona, using a Sky-Watcher 100mm APO telescope and SBIG STL-11000M camera. Courtesy John Vermette.

Front cover (bottom): Artist’s impression of NASA’s Dawn spacecraft arrival at the giant asteroid Vesta on July 15, 2011. Courtesy NASA/JPL-Caltech.

Back cover: Composite image taken by JAXA’s Hayabusa-2 spacecraft just before touchdown on the Ryugu asteroid to collect a sample in 2019. Courtesy JAXA, Chiba Institute of Technology, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Meiji University, University of Aizu, AIST).

THIS WEEK IN HISTORY

FEBRUARY 9, 1986: During its most recent return Comet 1P/Halley passes through perihelion at a heliocentric distance of 0.587 AU. Comet Halley's 1986 return is a future "Comet of the Week," and its entire history is the subject of a future "Special Topics" presentation.

FEBRUARY 10, 1907: August Kopff at Heidelberg Observatory in Germany discovers the asteroid now known as (624) Hektor, the third known "Jupiter Trojan" asteroid. The subject of Trojan asteroids is discussed in a future "Special Topics" presentation.

FEBRUARY 10, 2015: Eric Mamajek and his colleagues publish their paper in the Astrophysical Journal wherein they conclude that a recently-discovered nearby dwarf star (WISE 0720-0846, unofficially known as "Scholz's Star") passed through the Oort Cloud 70,000 years ago, likely triggering a shower of long-period comets that are still inbound. Scholz's Star and other stellar passages through the Oort Cloud are discussed in next week's "Special Topics" presentation.

FEBRUARY 10, 2020: The main-belt asteroid (191) Kolga will occult the 4th-magnitude star Nu Serpentis. The predicted path of the occultation crosses the southeastern U.S. from far eastern Colorado through South Carolina.

FEBRUARY 10, 2020: The main-belt asteroid (55099) 2001 QK137 will occult the 5th-magnitude star Nu Cancri. The predicted path of the occultation crosses New Zealand's North Island and southern Australia from east to west.

FEBRUARY 11, 2003: The LINEAR program in New Mexico discovers the asteroid now known as (163693) Atira, the first confirmed example of the Atira-type asteroids, i.e., those whose orbits lie entirely interior to Earth's orbit. The Atira asteroids and other near-Earth asteroids were discussed in a previous "Special Topics" presentation.

FEBRUARY 11, 2020: The large main-belt asteroid (4) Vesta will occult the 5th-magnitude star HD 19270 in Aries. The predicted path of the occultation passes over far southeastern Canada, specifically Nova Scotia and Newfoundland, and then portions of northern Europe, including Northern Ireland, northern England, Scotland, Denmark, southern Sweden, northern Poland, Lithuania, Latvia, Belarus, and far western Russia.

FEBRUARY 12

FEBRUARY 12, 1936: Eugene Delporte at the Royal Observatory of Belgium in Uccle discovers the near-Earth asteroid now known as (2101) Adonis, the second known Apollo-type asteroid. Adonis – which was discussed with other near-Earth asteroids in a previous "Special Topics" presentation – had passed just 0.015 AU from Earth a week earlier and was followed for two months but was then "lost" until it was recovered in 1977. There is some evidence that it may be an "extinct" cometary nucleus.

FEBRUARY 12, 1947: A brilliant daytime meteor appears over far eastern Siberia and falls to Earth near the Sikhote-Alin Mountains. The Sikhote-Alin meteorite was one of the largest observed meteorite impacts of the 20th Century and over 23 tons of fragments have been identified; these are primarily composed of iron. Sikhote-Alin and other large meteorite impacts are discussed in a future "Special Topics" presentation.

FEBRUARY 12, 2001: After orbiting the near-Earth asteroid (433) Eros for one year, the Near-Earth Asteroid Rendezvous (NEAR) Shoemaker spacecraft performs the first-ever soft landing by a spacecraft onto an asteroid. Following its landing NEAR Shoemaker continued transmitting for two more weeks before it was shut down. Eros, including the NEAR Shoemaker mission, is the subject of a previous "Special Topics" presentation.

FEBRUARY 13

FEBRUARY 13, 2020: The main-belt asteroid (112) Imphigenia will occult the 7th-magnitude star HD 73210 in Cancer (just southwest of the "Beehive" Cluster M44). The predicted path of the occultation crosses northern Brazil, southern Venezuela, northern Columbia, northern Panama, south-central Nicaragua, and parts of the southern coast of Mexico before crossing open waters of the central Pacific Ocean.

9 10 11 12 13 **FEBRUARY 14** 15

FEBRUARY 14, 1977: As a result of a prediction by Brian Marsden, Charles Kowal at Palomar Observatory in California recovers the near-Earth asteroid (2101) Adonis after it had been "lost" for 41 years. Adonis will pass 0.036 AU from Earth on February 7, 2036.

FEBRUARY 14, 1980: The Solar Maximum Mission (SMM) is launched from Cape Canaveral, Florida. After suffering an attitude control failure later that year, SMM was repaired by Space Shuttle astronauts in 1984. SMM discovered ten comets, all Kreutz sungrazers, from 1987 up until the time it re-entered Earth's atmosphere in 1989. Kreutz sungrazers, including SMM's discoveries of these objects, are discussed in a future "Special Topics" presentation.

FEBRUARY 14, 1996: The first-known centaur, (2060) Chiron (also known as Comet 95P/Chiron), passes through perihelion – 18 ½ years after its discovery – at a heliocentric distance of 8.454 AU. Centaurs are the subject of this week's "Special Topics" presentation.

FEBRUARY 14, 2000: The Near-Earth Asteroid Rendezvous (NEAR) Shoemaker spacecraft arrives at the near-Earth asteroid (433) Eros and goes into orbit around it. NEAR Shoemaker would spend the next year orbiting Eros before performing a soft landing onto its surface.

9 10 11 12 13 14 **FEBRUARY 15**

FEBRUARY 15, 1997: Jim Scotti with the Spacewatch program in Arizona discovers the "asteroid" now known as (10199) Chariklo. Chariklo is the largest-known centaur and is now known to be accompanied by at least two rings. Centaurs are the subject of this week's "Special Topics" presentation.

FEBRUARY 15, 2011: The Stardust spacecraft, which had previously flown through the coma of Comet 81P/Wild 2, collected samples, and delivered those to Earth, encounters Comet 9P/Tempel 1. This comet, which had earlier been visited by the Deep Impact mission in 2005, is a future "Comet of the Week."

FEBRUARY 15, 2013: The tiny asteroid (367943) Duende passes just 0.00028 AU from Earth (4.3 Earth radii above the surface). Duende had been discovered a year earlier by the La Sagra Sky Survey based in Spain, and this encounter holds the current record for closest approach to Earth by a previously-discovered asteroid.

FEBRUARY 15, 2013: A brilliant daytime meteor passes over the city of Chelyabinsk in southwestern Russia and explodes. Although there are no fatalities, numerous people were injured. The Chelyabinsk meteorite is estimated to have been about 20 meters in diameter with an original mass of several thousand tons; the largest individual fragment recovered has a mass of 650 kg. This is the largest meteorite impact event of the 21st Century thus far, and it and similar events are covered in a future "Special Topics" presentation.

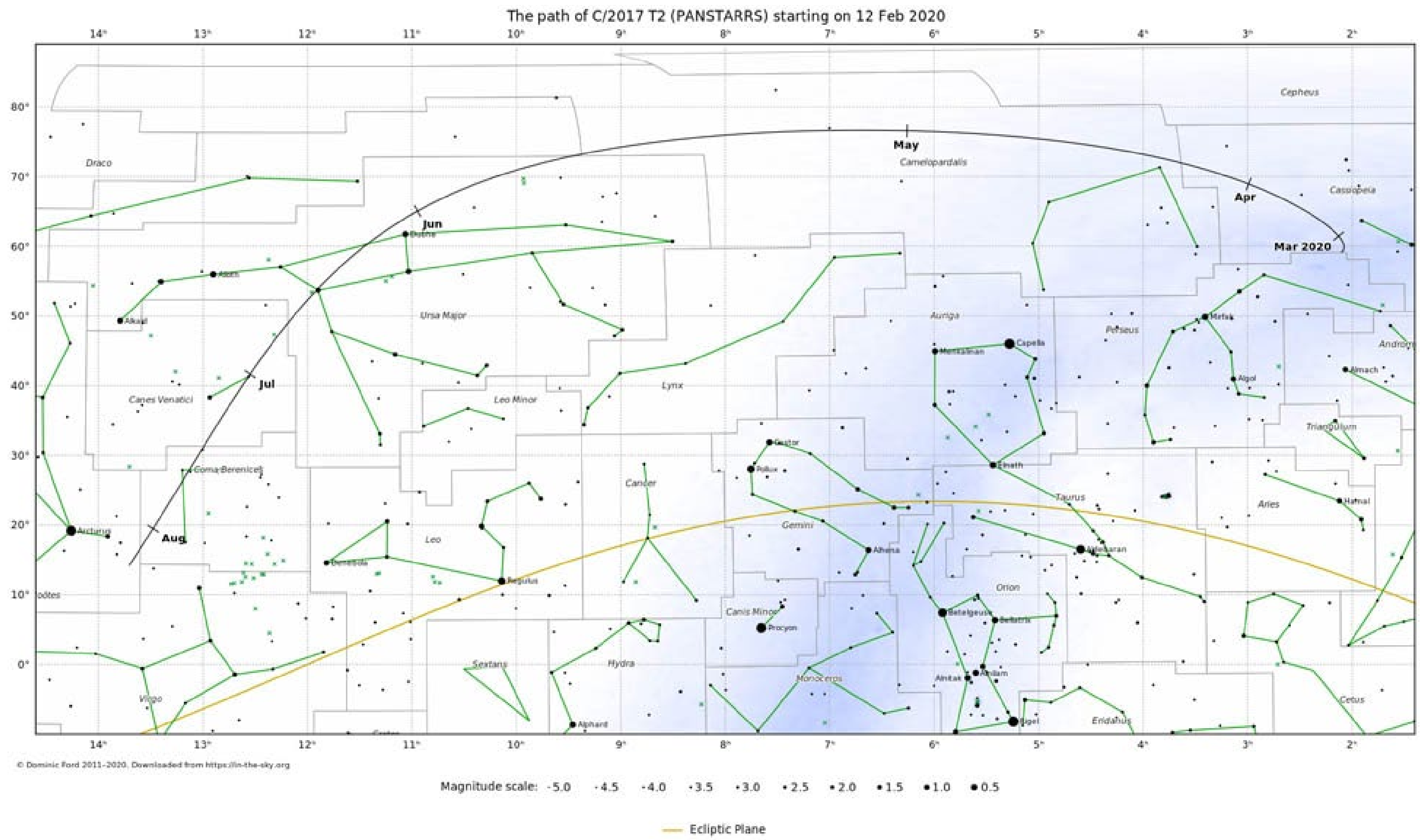
COMET OF THE WEEK: PANSTARRS C/2017 T2

Perihelion: 2020 May 4.95, q = 1.615 AU

Comet PANSTARRS and the "Double Cluster" (NGC 869 and 884) in Perseus on January 26, 2020. Courtesy Danilo Pivato in Italy.

After devoting my "Comet of the Week" last week to the first comet I ever observed, it seems appropriate to devote this week's "Comet of the Week" to the brightest comet that is currently visible in our nighttime skies, and which is easily accessible for observations, at least from the northern hemisphere. The full moon early this week might affect observations initially, but by the latter part of the week, and later, the comet should be easy to see.

The comet in question is a discovery of the Panoramic Survey Telescope And Rapid Response System (Pan-STARRS) program based at Mount Haleakala in Hawaii, the most prolific of the current near-Earth asteroid survey programs. Pan-STARRS originally comprised a 1.8-meter telescope that first went on-line in 2010, and has recently been joined by a second telescope of the same size. Pan-STARRS made its first comet discovery in October 2010 and has since gone on to find many, many more; at this writing its count of comet discoveries stands at 203, although this will clearly continue to increase. Most of the Pan-STARRS comet discoveries are very faint objects – 20th magnitude or fainter -- and stay that way, but a relative few do become somewhat bright, usually many months, or even a year or two, after their discovery. The brightest Pan-STARRS comet thus far is C/2011 L4, which became as bright as magnitude



Path of Comet PANSTARRS through the constellations in the sky, February – August 2020. From In-the-Sky.org.

1.5 when it passed through perihelion in March 2013, although its elongation from the sun was quite small at the time and it was not an especially easy object to see.

Pan-STARRS discovered this comet as far back as October 2, 2017, over 2 ½ years before its perihelion passage, and in fact pre-discovery images back to September 15 were later identified. At the time of its discovery the comet was located at a heliocentric distance of 9.25 AU and was a rather faint object near 19th magnitude. It has brightened steadily since then, and after being in conjunction with the sun in May 2018 was widely imaged during the last few months of that year and first few months of 2019, being at opposition in mid-November 2018 and brightening from about 16th magnitude to 15th during that period.

After being in conjunction with the sun again in mid-May 2019 Comet PANSTARRS began emerging into the morning sky during July when it was near 14th magnitude, and shortly thereafter it began to be picked up visually. It has brightened steadily since then, being at opposition in early December and being closest to Earth (1.52 AU) on December 29. Although now receding from Earth it is still approaching perihelion in early May, and thus it remains moderately bright near 10th magnitude; it should at least maintain this brightness, and perhaps might even brighten slightly, over the next few weeks.

During this week the comet is located in eastern Cassiopeia just a few degrees northwest of the "Double Cluster" in Perseus. Over the next few weeks it travels to the north-northeast and then curves more directly northeastward; it passes just three degrees east of the star Epsilon Cassiopeiae (the easternmost star of the "W") in mid-March and then traverses the obscure constellation of Camelopardalis and comes to within 14 degrees of the North Celestial Pole around the time it is at perihelion in early May. It then starts heading southeastward as it crosses into Ursa Major, and passes one degree northeast of the bright galaxies M81 and M82 around May 23 and then crosses diagonally – northwest to southeast – across the "bowl" of the Big Dipper during the first half of June. Afterwards it travels through the constellations of Canes Venatici and Coma Berenices – passing through the eastern regions of the distant Coma Cluster of Galaxies in mid-July – and then through Bootes and (by late August) into Virgo. By that time it will be getting low in the western sky after dusk and will presumably have noticeably faded.

Comet PANSTARRS appears to be rather bright intrinsically, and it is unfortunate that it does not come close to either the sun or Earth. It also appears to be a first-time visitor from the Oort Cloud, and as was discussed in an earlier "Special Topics" presentation, such objects tend to under-perform when compared to initial expectations. However, the only way to determine how bright Comet PANSTARRS might

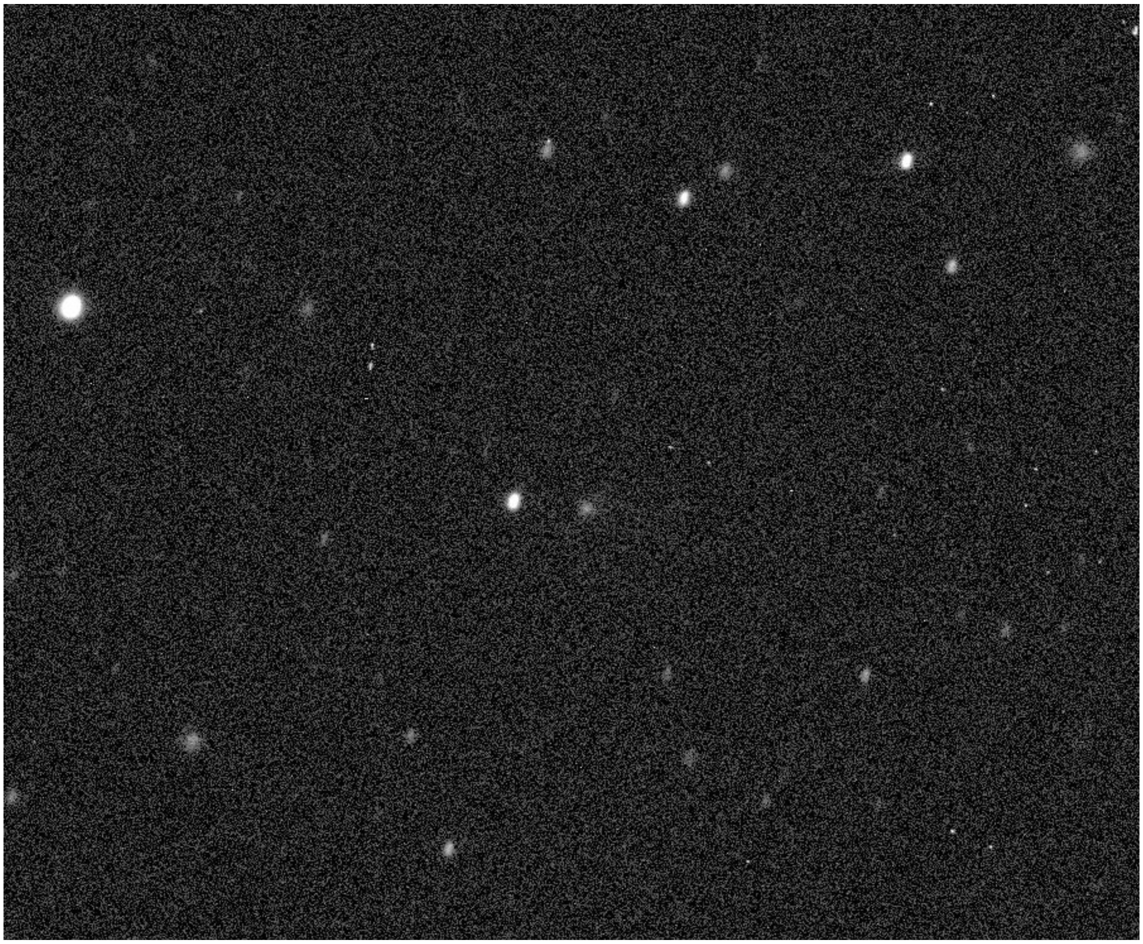
Comet PANSTARRS on February 2, 2020 – the 50th anniversary of my first comet observation – as imaged by the Las Cumbres Observatory facility at McDonald Observatory in Texas.

become is to observe and study it as it makes its passage through the inner solar system. The Comet Resource Center at the Earthrise web site will contain regular updates as to its actual performance.

Although there aren't any especially bright comets currently known that will be coming to perihelion within the near future, there are a few somewhat bright ones that will be appearing within the next few months. Comet 2P/Encke, which has the shortest orbital period of all known comets, passes through perihelion in late June and will be visible from the southern hemisphere afterwards, and will be featured as a "Comet of the Week" around that time. Two long-period comets, both discovered by the ATLAS program based in Hawaii this past December, could become interesting within the near future: Comet C/2019 Y1 is currently around 12th magnitude but could become somewhat brighter around the time it passes through perihelion in mid-March, and Comet C/2019 Y4, while currently a relatively faint object of 16th magnitude, passes through perihelion at the end of May at the small heliocentric distance of 0.25 AU and, at least theoretically, could become fairly bright. Both of these comets appear to be members of comet "groups," suggesting that they might be fragments of comets that have split; this is the subject of a future "Special Topics" presentation. As with Comet PANSTARRS, the Comet Resource Center will carry information about these and other various comets as they make their respective appearances.

Meanwhile, another intrinsically bright Comet PANSTARRS discovered in 2017, C/2017 K2, is also on its way in, and does not pass perihelion until late 2022. It has the potential to become a rather bright object, although it will not be especially well placed for observation around the time it is brightest, and – unfortunately for those of us in the northern hemisphere – will only be accessible from the southern hemisphere at that time. It will be a future "Comet of the Week."

Las Cumbres Observatory image of the inbound ATLAS Comet C/2019 Y1 on January 25, 2020, from Haleakala Observatory in Hawaii.



Las Cumbres Observatory image of the inbound ATLAS Comet C/2019 Y4 (small fuzzy object in center) on January 24, 2020, from Teide Observatory in the Canary Islands.

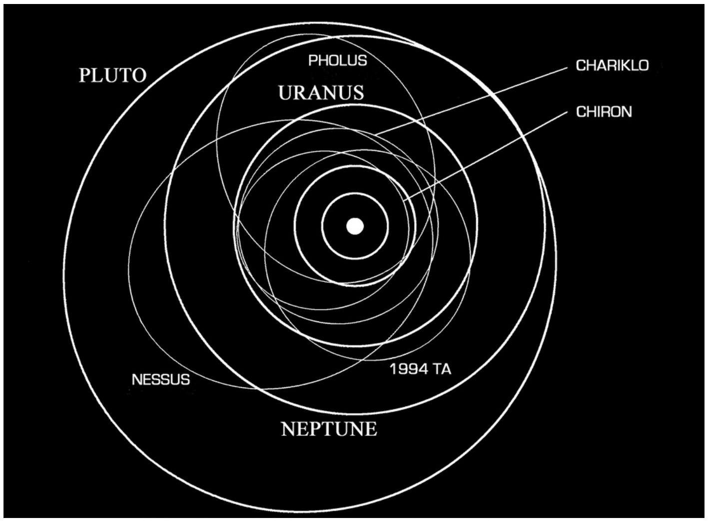
SPECIAL TOPIC: CENTAURS

Chiron, with its coma, as imaged with the 4-meter reflector at Kitt Peak National Observatory on March 9, 1992. Courtesy Karen Meech and Michael Belton.

In previous "Special Topics" presentations I have focused on asteroid populations in the "main asteroid belt" between Mars and Jupiter, and on asteroids in near-Earth space. If, however, as is now widely believed to be the case, asteroids are among the "leftovers" of the planet formation process, we would accordingly expect asteroids to exist in other regions of the solar system as well.

Between the early 1970s and mid-1980s astronomer Charles Kowal utilized the large 1.2-meter Schmidt telescope at Palomar Observatory in California on a monthly basis, ostensibly to search for objects in the outer solar system. During the course of this program he discovered several near-Earth asteroids, a handful of comets, numerous supernovae in other galaxies (including one of the brightest such objects of the entire 20th Century), and two outer moons of Jupiter. Perhaps his most significant discovery, though, was a stellar-appearing 18th-magnitude object that appeared on Schmidt photographs he took on October 18 and 19, 1977. The object was traveling at the very slow rate of only three arcminutes per day – roughly similar to that of Uranus – which suggested that it was probably located at a similar distance from the sun.

Kowal was soon able to locate images of the object on Schmidt photographs that he had taken in September 1969. With this available data Brian Marsden was able to calculate that Kowal's object was traveling in an orbit with a moderate eccentricity and an orbital period of approximately 50 years, and in fact was not too far past aphelion at the time of Kowal's discovery. It would have been at perihelion in the mid- to late 1940s, and shortly thereafter several images of it were found on photographs taken during that era, including a Palomar Schmidt photograph taken in August 1952 as part of the Palomar Sky Survey. William Liller and Lola Chaisson of Harvard



Graphical representation of the orbits of Chiron and a few of the other early known centaurs. . The innermost planetary orbits shown are those of Jupiter and Saturn.

Observatory were also able to identify an image of the object taken from Harvard as far back as April 24, 1895, around the time of its previous perihelion passage.

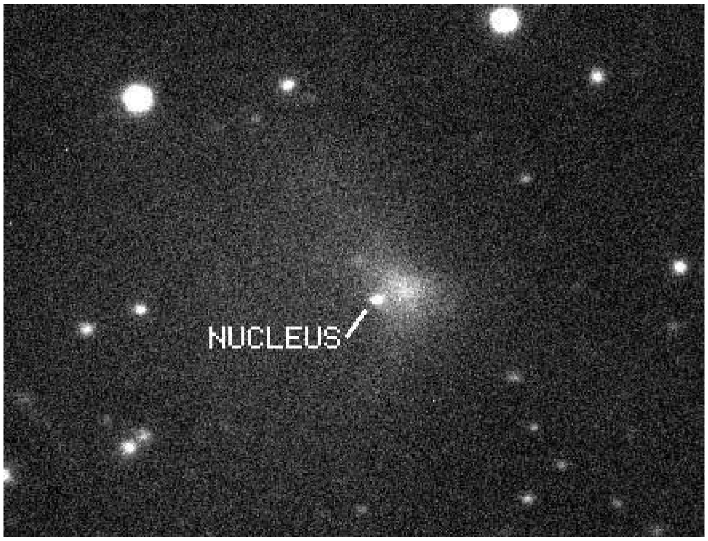
Marsden was now able to calculate that Kowal's object was traveling in an orbit with an eccentricity of 0.38, an orbital period of 50.7 years, with its heliocentric distances ranging from 8.45 AU – somewhat inside the orbit of Saturn – at perihelion to 18.9 AU – close to Uranus' average distance – at aphelion. Its heliocentric distance at the time of discovery was 17.8 AU, and it would not reach perihelion until February 1996, over 18 years after Kowal's discovery. Originally assigned the asteroidal designation 1977 UB, it was soon assigned the number (2060), and Kowal named it "Chiron," the mythological centaur who was the son of Kronus (Saturn) and grandson of Ouranos (Uranus) – the two planets between which it orbits – and the instructor of many of the Greek heroes. According to the Roman poet Ovid, Chiron is supposedly represented by the southern constellation Centaurus.

Chiron is a relatively large object, with an estimated diameter in the vicinity of 200 km. During the years after its discovery it exhibited periodic brightness variations which indicated a rotational period of 5.9 hours. Around the time it passed through perihelion in 1996 Chiron reached a peak brightness of 15th magnitude and was detectable visually in moderate-sized telescopes.

For the next decade and a half after Chiron's discovery it pretty much had the outer solar system to itself, at least in terms of known objects of its size. Then, in early 1992, David Rabinowitz with the Spacewatch program in Arizona discovered an object (which was independently found around the same time by Eugene and Carolyn Shoemaker at Palomar), dubbed 1992 AD, that is traveling in an orbit similar to Chiron's: an orbital eccentricity of 0.57, a period of 92 years, and a perihelion distance of 8.78 AU. Pre-discovery images from 1977 were soon identified, which allowed it be assigned the number (5145) and, in keeping with the precedent established by Kowal, Rabinowitz gave it the name "Pholus," the mythological centaur who befriended Heracles.

In April 1993 Rabinowitz discovered a third object, 1993 HA2 (now known as (7066) Nessus) with an orbital period of 123 years and a perihelion distance of 11.89 AU, and in October 1994 Jun Chen and David Jewitt at Mauna Kea in Hawaii discovered a fourth one, 1994 TA, with an orbital period of 70 years and a perihelion distance of 11.7 AU. Once the comprehensive surveys became operational a few years later more and more such objects began to be discovered, and it is now clear that an entire population of them exists in the outer solar system. Collectively they are now referred to as "centaurs," and while there is no precise definition of what exactly constitutes a "centaur," today approximately 500 of them are now known. It is likely that their total population is at least in the tens to hundreds of thousands.

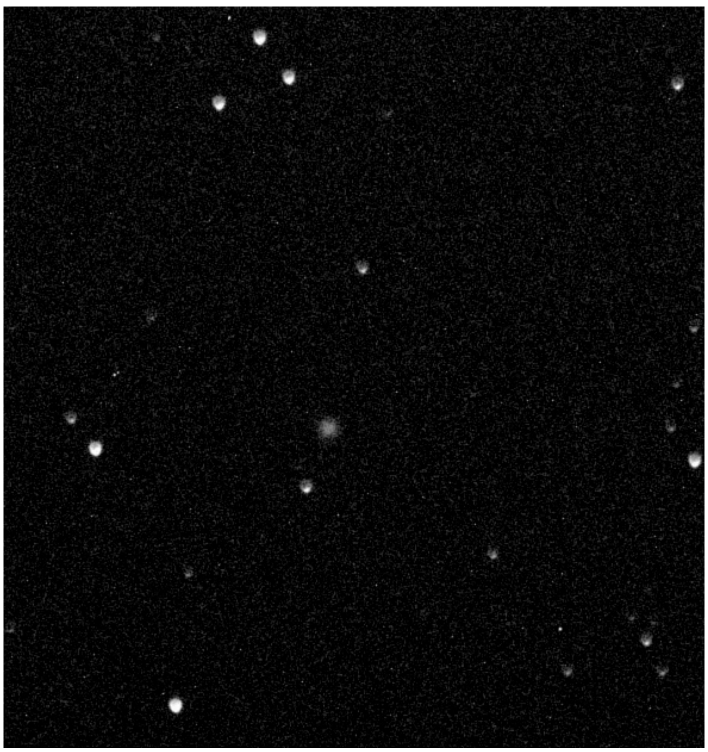
Ever since Chiron's discovery, its physical nature – and, more recently, the physical nature of other centaurs – has been a matter of much debate and speculation. At first Chiron behaved more or less like a "normal" asteroid, but as it approached perihelion it started to depart from this. In early 1988 it was over a half-magnitude brighter than expected, and by late that year this difference had grown to a full magnitude. At the same time, the brightness variations that it had long exhibited had all but vanished, suggesting



(60558) Echeclus (also known as Comet 174P/Echeclus) while in outburst on April 2, 2006, as imaged with the 1.8-meter Vatican Advanced Technology Telescope at Mt. Graham Observatory in Arizona. Courtesy Guy Consolmagno, Stephen Tegler, and colleagues.

the possibility of a cloud of obscuring material. Then, on April 10, 1989, Karen Meech and Michael Belton detected a coma around Chiron in images taken with the 4-meter telescope at Kitt Peak National Observatory in Arizona. (Subsequent measurements elsewhere indicated that this coma extended as far as 130,000 km from Chiron itself.) Finally, in January 1990 Schelte "Bobby" Bus of Lowell Observatory in Arizona and his colleagues detected the presence of gaseous emissions from Chiron.

The conclusion was inescapable: Chiron is a comet, albeit a very large and most unusual one. In recognition of this "dual nature," in 1995 the IAU assigned it the short-period comet designation 95P, although to avoid any kind of confusion it retains the name "Chiron" as opposed to the name of its discoverer.



(60558) Echeclus (also known as Comet 174P/Echeclus) while in outburst on December 12, 2017, imaged with the Las Cumbres Observatory facility at McDonald Observatory in Texas. Echeclus is the small diffuse object just below and left of center.

Since then, a handful of other centaurs have been observed to exhibit cometary activity. Three of these, in fact, were exhibiting such activity around the time of their respective discoveries, and accordingly received short-period comet designations shortly thereafter; one of these, 167P/CINEOS, has the distinction of being the comet with the largest known perihelion distance, 11.79 AU. Comet Tenagra C/2013 C2 also has a Centaur-like orbit (orbital period 64 years and perihelion distance of 9.13 AU) and can also be considered a likely member of this class; this object underwent a three-magnitude outburst in February 2015 six months before its perihelion passage.

One of the most interesting "cometary" centaurs is (60558) Echeclus, originally discovered in March 2000 by Jim Scotti with the Spacewatch program; it has an orbital period of 35 years and a perihelion distance of 5.82 AU, and in fact was only a couple of years past perihelion at the time of its discovery. For the next few years its behavior was entirely "asteroidal," however in late 2005, when it was located at a heliocentric distance of 13.1 AU, Paul Weissman and Young-Jun Choi detected a cometary coma around it in images taken with the 5.1-meter Hale Telescope at Palomar. Despite its large distance this coma was detectable visually at 14th magnitude in early 2006, and meanwhile in early April images taken with the Vatican Advanced Technology Telescope at Mt. Graham Observatory in Arizona showed that this coma had become detached from the nucleus itself.

Echeclus – which received the short-period comet designation 174P in the wake of this outburst – subsequently returned to "normal" not too long thereafter, but since then has undergone three more such outbursts, the most recent (and brightest) of which was in December 2017 when it was 2 ½ years past perihelion and located at a heliocentric distance of 7.3 AU. Based upon the behavior it has exhibited thus far, it is entirely possible that it may continue to exhibit occasional outbursts up through it time it passes through aphelion in late 2032, and beyond.

At least one other centaur, (52872) Okyrhoe, has exhibited spectroscopic and photometric behavior that is suggestive of weak cometary activity, and two other ones, (8405) Asbolus and (10199) Chariklo, have shown spectroscopic evidence for the presence of water ice (perhaps due in part to a recent impact crater in the case of Asbolus). On June 3, 2013, meanwhile, Chariklo occulted a background star, and this event revealed that it is accompanied by two small thin rings, possibly created through a collisional event. Incidentally, Chariklo, which was discovered by Scotti in 1997, has a diameter slightly larger than 250 km and is the largest-known confirmed centaur.

Some centaurs, among them Pholus and Nessus, have surfaces that are very red in coloration. The consensus is that this is due to the presence of organic compounds, known as "tholins," that are generated by intense cosmic ray bombardment on objects that have never experienced significant solar heating. This would in turn suggest that other centaurs, for example Chiron, that do not exhibit this

Artist's conception of the rings around (10199) Chariklo. Courtesy European Southern Observatory/Luis Calcada/Nick Risinger

coloration have experienced significant solar heating at some point. There is some evidence, in fact, that Chiron may have spent time in the inner solar system as a short-period comet sometime in the moderately distant past.

Dynamical studies indicate that the orbit of Chiron, and indeed the orbits of centaurs in general, are "chaotic" in a mathematical sense, i.e., they are unstable over timescales of several millennia. Although this was probably not Kowal's original intention, given that the centaurs of Greek mythology were, in general, wild and unruly creatures, the practice of calling these objects "centaurs" and giving them the names of individuals of this group seems rather appropriate.

In physical terms, centaurs are essentially indistinguishable from objects in the Kuiper Belt, which also exhibit a range of physical characteristics and colorations. Given this and all the other available information about them, it now seems rather clear that the centaurs are a link in the evolutionary progression between Kuiper Belt objects and short-period comets. It seems rather likely, in fact, that most, if not almost all, centaurs are dormant cometary nuclei, with some of them, for example Chiron, being active now and/or at some point in the past, and others, for example Pholus and Nessus, never having yet come close to the sun and thus never having been active. At least some of the centaurs that we are detecting today may eventually become the short-period comets that our descendants may be observing in the centuries and millennia to come.

Indeed, a study published last year by a team led by Gal Sarid at the University of Central Florida concludes that a dynamical "gateway" between centaurs and short-period comets exists just beyond Jupiter's orbit. A small handful of objects appears to occupy this "gateway" at the present time, by far the most prominent of these being the comet known as 29P/Schwassmann-Wachmann 1. This most unusual comet, which was discovered almost a century ago, is a future "Comet of the Week."

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