ICE & STONE 2020

WEEK 50: DECEMBER 6-12

Presented by The Earthrise Institute

#50

Authored by Alan Hale

COMET OF THE WEEK: LOVEJOY C/2013 R1

Perihelion: 2013 December 22.73, q = 0.812 AU

I've mentioned in some of the previous "Ice and Stone 2020" presentations that, until the appearance of Comet NEOWISE C/2020 F3 earlier this year, the northern hemisphere had not had what could be considered a "Great Comet" in well over two decades. We did have a moderately bright comet in early 2013, Comet PANSTARRS C/2011 L4, which became as bright as magnitude 1.5 when near perihelion in early March, although unfortunately the comet was only 15 degrees from the sun, and buried deeply in evening twilight, at the time. (It faded rapidly afterwards, and although it later exhibited a striking "anti-tail," by that time the comet had faded to 8th magnitude.) Later that year Comet ISON C/2012 S1 showed initial promise of becoming a spectacular object, but as I recount in that object's "Comet of the Week" presentation two weeks ago it disintegrated as it passed through perihelion, and there was nothing left of it after that.

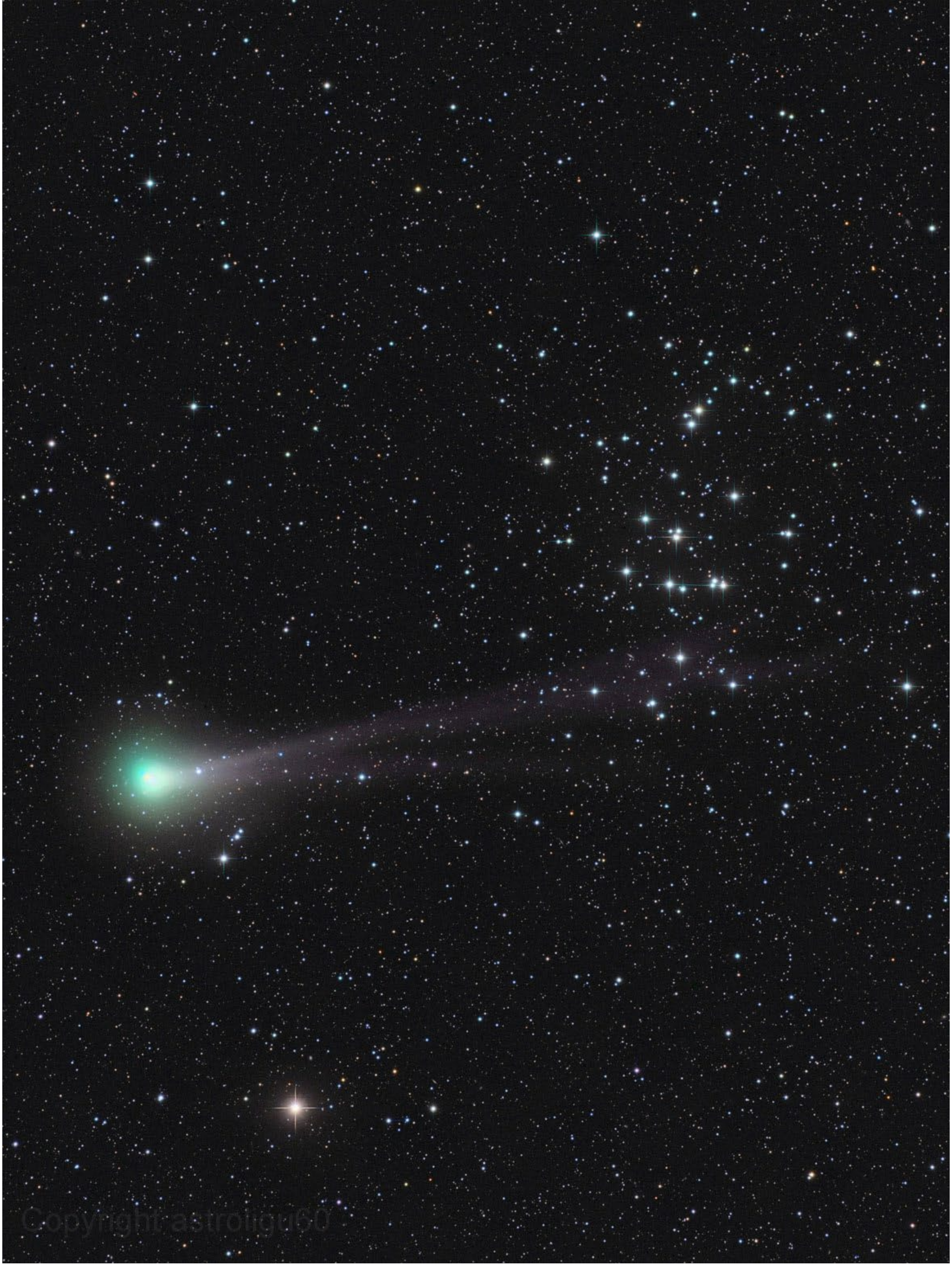
Comet Lovejoy from Montana on December 7, 2013, the morning my mother passed away. This image approximates the view the comet exhibited in binoculars. Courtesy John Ashley.

There was, however, another comet around that same time, which although it was never expected to become, and did not become, anything close to a "Great Comet," nevertheless did become visible to the unaided eye and offered a bit of a consolation prize. This particular comet was discovered on September 7, 2013 by an amateur astronomer in Queensland, Terry Lovejoy, who among other things has pioneered the use of DSLR photography for discovering comets and who discovered six comets between 2007 and 2017, including Comet C/2011 W3 which will be "Comet of the Week" two weeks from now. At the time of Lovejoy's discovery this comet was located a few degrees east of the Great Orion Nebula M42 and was about 14th magnitude.

The comet brightened rapidly as it approached perihelion, and by early November it had already reached 6th magnitude. It passed closest to Earth, 0.40 AU, on November 19, and during late November and early December was near its peak brightness of 5th magnitude and exhibiting a tail a few degrees long in binoculars. It began a slow fading afterwards, being just fainter than 6th magnitude in early January 2014, then dropping to 8th magnitude by February and to 13th magnitude when I saw it for the last time in early June. The final astrometric observations were obtained in September.

I commented in the "Comet of the Week" entry for Comet 153P/Ikeya-Zhang P/2002 C1 that my father passed away three days after that comet's perihelion passage. It is only fitting that another bright comet should be in the sky when my mother, Ruth Elsa Perkins, did so at the age of 94 on December 7, 2013, right around the time that Comet Lovejoy was near its brightest. While my father's comet will be back to check up on us in a little over three centuries, it will be a bit longer for my mother's comet: according to orbital calculations, it should be back our way in a little over 8200 years.

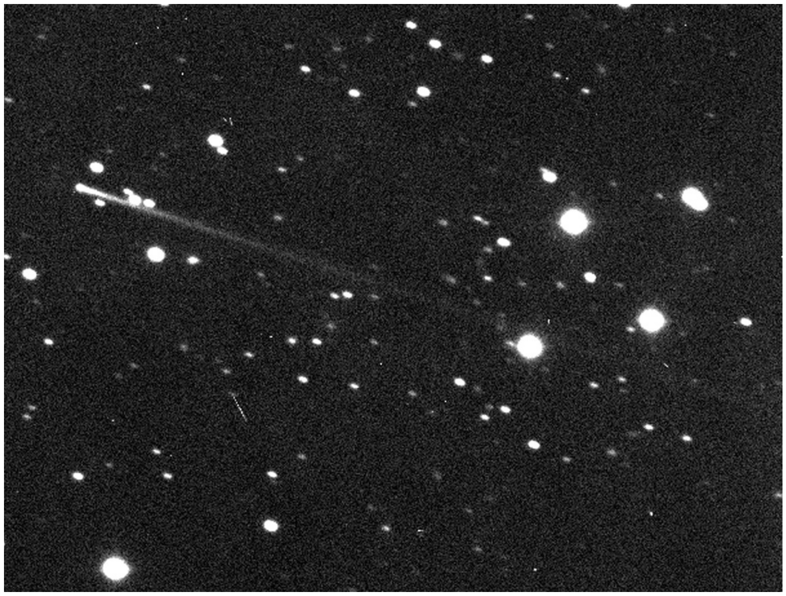
While in my mind I associate Comet Lovejoy with my mother's passing, there were some happier events taking place in my life as well. Both of my sons graduated from college while Comet Lovejoy was around, my older son Zachary in December 2013 and my younger son Tyler in May 2014 (by which time the comet had faded to magnitude 12.5 but I was nevertheless still following it). I am reminded that, as the various comets come into our sky, stay around for a while, and then head back out into the depths of space, the circle of life continues here on Earth.



Comet Lovejoy and the Beehive star cluster M44 on November 7, 2013, as imaged by a remotely-controlled telescope in New Mexico. Courtesy Rolando Ligustri in Italy.

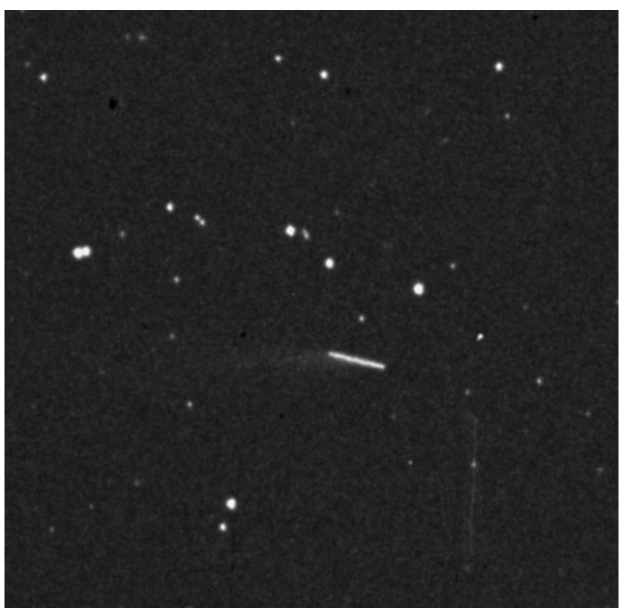
SPECIAL TOPIC: "ACTIVE ASTEROIDS"

Throughout "Ice and Stone 2020" we have primarily been concerned with the objects we call "comets" and the objects we call "asteroids," which collectively are "planetesimals" left over from the formation of the solar system. From an observational perspective, "asteroids" are stellar in appearance whereas "comets" are diffuse and fuzzy, while from a physical perspective "asteroids" are primarily made up of metals and silicate materials whereas "comets" are primarily made up of "volatile" substances like ices of water and gases like carbon monoxide and carbon dioxide. As is often true in many facets of nature, there is no clear dividing line between what constitutes an "asteroid" versus what constitutes a "comet," and as was discussed in the "Special Topics" presentation five weeks ago, many apparent asteroids may in fact be "extinct" comets. There are quite a few other objects that exhibit characteristics of both comets and asteroids, and the issue of what to call them sometimes comes down to what they were called when they were first discovered.



Comet 133P/Elst-Pizarro, imaged with the 1.5-meter telescope at the European Southern Observatory in Chile. Courtesy European Southern Observatory.

One of the earliest examples of such a "dual-natured" object was discovered on November 19, 1949, by Albert Wilson and Robert Harrington during the course of the first Palomar Observatory Sky Survey conducted with the 1.2-meter Schmidt telescope. On both the blue- and the red-sensitive photographic plates it exhibited a distinct comet-like tail, although it did not exhibit a coma. Unfortunately, it was only photographed on three additional nights over the course of the subsequent week, and at best exhibited only a marginal cometary appearance on those photographs. There was not enough data to compute a valid orbit, with only a preliminary parabolic orbit being entered into the orbit catalogs, although the general consensus was that "Comet Wilson-Harrington" was very probably a short-period object.



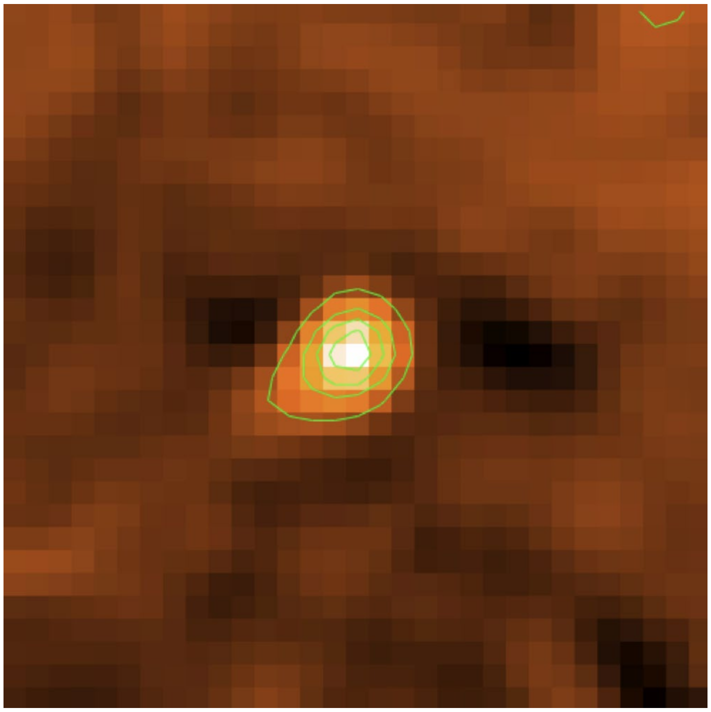
The blue-plate discovery image of Comet 107P/Wilson-Harrington, taken with the 1.2-meter Schmidt telescope at Palomar Observatory on November 19, 1949 during the course of the first Palomar Sky Survey. The image is trailed during the 12-minute time exposure, but the tail can be detected extending towards the left. Courtesy National Geographic Society/Digitized Palomar Sky Survey.

There the matter stood until 1992, when Ed Bowell at the Lowell Observatory in Arizona was engaged in a project to find pre-discovery images of currently-known near-Earth asteroids on Palomar Sky Survey photographs. One of these was an object that had been discovered in November 1979 by Eleanor Helin with the 46-cm Schmidt telescope at Palomar, which had passed 0.09 AU from Earth three weeks earlier and which, after being recovered in 1988, had been assigned the asteroidal number (4015). The Sky Survey images of this object that Bowell identified were seen to show a cometary tail, which Brian Marsden at the IAU's Minor Planet Center recognized as being none other than the "lost" "Comet Wilson-Harrington." It turns out to have an orbital period of 4.3

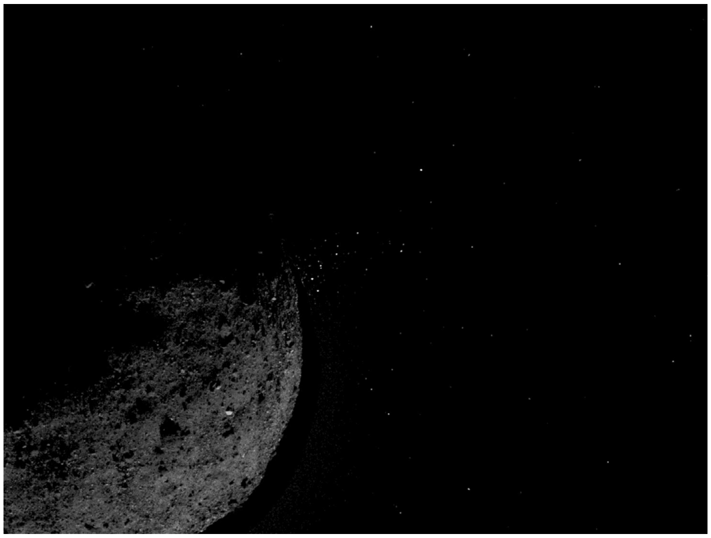
years, a perihelion distance of almost exactly 1.0 AU, and an eccentricity of 0.62. As indicative of its "dual nature" the object was later assigned the short-period comet number 107P, and its "cometary" name and its "asteroidal" name are both Wilson-Harrington.

Wilson-Harrington appeared entirely asteroidal when it was re-discovered in 1979, and in fact with the exception of the photographs taken at the time of its original discovery in 1949 it has never exhibited any kind of cometary activity, although it has been carefully examined when circumstances have permitted it. The cause of the activity in 1949 remains a bit of a mystery, although a brief episode of cometary outgassing seems to be the most likely explanation. It will next pass somewhat close to Earth on October 31, 2039, when it will approach to slightly within 0.11 AU, and perhaps it will be amenable to detailed studies at that time.

One of the most interesting objects that illustrate the nebulous borderline between "asteroid" and "comet" was reported in early August 1996, when Eric Elst with the Royal Observatory in Uccle, Belgium found images of an apparent comet on photographs taken in mid-July by Guido Pizarro with the 1-meter Schmidt Telescope at the European Southern Observatory in Chile. The object, about 18th magnitude, did not show a coma but did exhibit a distinct tail several arcminutes long, which persisted for several weeks. It was found to be traveling in an orbit entirely typical of main-belt asteroids, i.e., an orbital period of 5.6 years, a perihelion distance of 2.63 AU, and a low eccentricity of 0.17, however in light of its persistent tail



A coma and dust tail on (3200) Phaethon, in a composite image obtained with the STEREO-A spacecraft on June 21, 2009. Courtesy NASA/Jing Li and David Jewitt (UCLA).



A composite of two images of (101955) Bennu taken by OSIRIS-REx's Navigation Camera on January 19, 2019, showing one of the plume ejection events. Courtesy NASA/ University of Arizona.

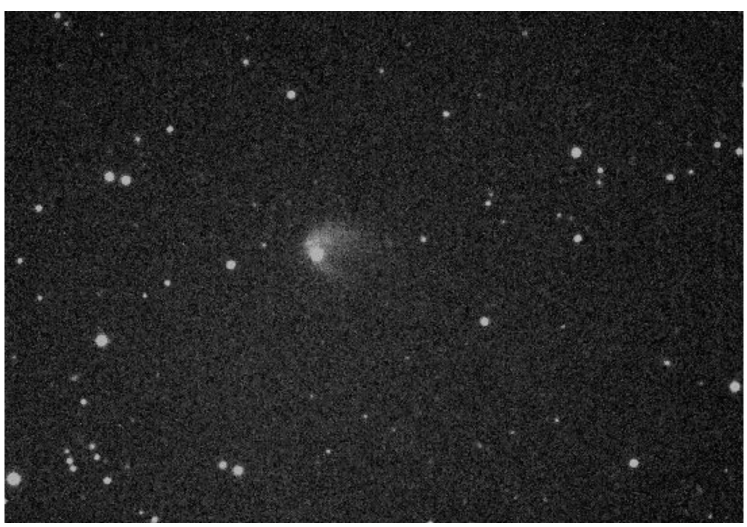
it was assigned both an asteroid number, (7968), and a short-period comet number, 133P, and the name Elst-Pizarro.
Elst-Pizarro had passed perihelion in April 1996 a few months before its discovery, however when it was recovered near opposition late the following year its appearance was completely stellar. Nevertheless, since that time it has exhibited a comet-like tail on several occasions around the times of subsequent perihelion passages, and thus it appears that Elst-Pizarro's cometary activity is due to the sublimation of ices just as in the case of regular comets, but it happens to be traveling in an orbit more representative of main-belt asteroids.

Elst-Pizarro's status as the only known "main-belt comet" changed in late 2005 when a second such object was discovered by Michael Read with the Spacewatch program in Arizona. At around that same time David Jewitt and Henry Hsieh at the University of Hawaii were engaged in a special search for cometary activity in asteroids when they detected a third such object, which had originally been discovered – as an "ordinary" main-belt asteroid – by the LINEAR program in New Mexico in late 1999. Since that time several more such objects have been discovered, and at least some of these have exhibited cometary activity on multiple occasions. It would appear, then, that these are genuine comets that reside permanently within the main asteroid belt.

It is conceivable that the population of "main-belt comets" is even larger than it currently appears. Based upon infrared observations obtained in 2009, the surface of the large main-belt asteroid (24) Themis appears to be almost entirely covered with water ice, although no evidence of sublimation of this ice has ever been detected. During recent years a team of Russian astronomers led by Vladimir Busarev has reported that some larger main-belt asteroids, including (145) Adeona, (704) Interamnia, and (779) Nina, have exhibited spectroscopic evidence for water ice sublimation, although so far none of these objects have shown direct physical evidence for such activity. Even the largest main-belt asteroid, (1) Ceres, has exhibited spectroscopic evidence for ice sublimation, and the Dawn spacecraft which has been in orbit around Ceres since early 2015 detected such evidence as well, although this was in the form of a temporary and extremely thin atmosphere that appears to be generated on occasion by strong solar activity.

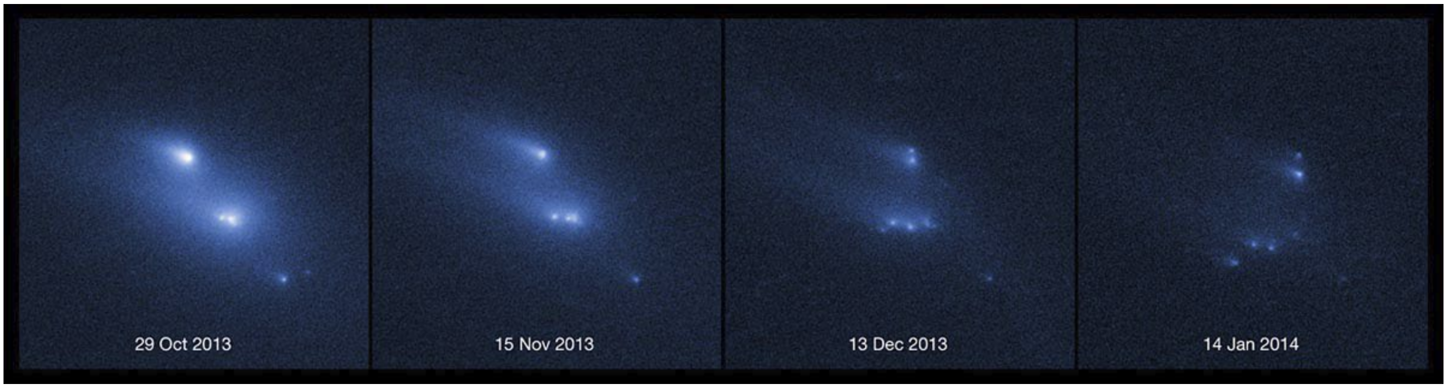
Hubble Space Telescope image of "Comet" 354P/LINEAR taken January 29, 2010. The "head" is the detached small asteroidal object to the lower left of the "tail." Courtesy NASA/ESA/David Jewitt.

Not all apparent cometary activity in asteroids can be attributed to water sublimation, however. A striking example is offered by the Apollo-type asteroid (3200) Phaethon, which was discovered by the InfraRed Astronomical Satellite (IRAS) spacecraft in October 1983 and found to be traveling in an elongated orbit with a period of 1.43 years and a perihelion distance of only 0.14 AU – the smallest for any asteroid known at that time. Fred Whipple soon pointed out that Phaethon has the same orbit as the Geminid meteor shower, and there has been a fairly strong consensus that Phaethon is indeed the parent object of the Geminids. It has made several relatively close approaches to Earth since that time, including one to 0.069 AU in December 2017, however despite close scrutiny it has never exhibited any cometary activity via ground-based observations.
Phaethon has nevertheless now shown cometary activity when close to perihelion passage when it is not observable from the ground. In June 2009 researchers noted that in near-sun images taken with the STEREO-A spacecraft it exhibited a coma and a tail-like extension, and it has done so again when near perihelion in 2012 and 2016. An analysis by David Jewitt and his colleagues at UCLA has demonstrated that these are indeed dust-ejection events, however since any volatile substances that Phaethon might have possessed would have been cooked off by its repeated close passages by the sun, these events are likely due to sun-baked fracturing of its crust with the resulting dust then being swept off the surface due to solar radiation pressure. Phaethon could thus be described as a "rock comet" as opposed to a more conventional comet where the activity is driven by sublimation of ices. Jewitt and his colleagues have pointed out, incidentally, that the dust released from Phaethon during these episodes is too small by at least a factor of ten to account for the observed strength of the Geminid meteor shower, so it is entirely conceivable that it might have been a more conventional comet in the past.



The main-belt asteroid (596) Scheila on December 13, 2010, showing the "coma" resulting from an apparent impact event. Courtesy Martin Mobberley in England.

Another interesting object is the Apollo-type asteroid (101955) Bennu, the current home of NASA's OSIRIS-REx mission (discussed in last week's "Special Topics" presentation). Between early January and mid-February 2019 – during which time Bennu was near perihelion – OSIRIS-REx detected eleven different plume ejection events of dust grains and larger particles off Bennu's surface. While the complete explanation for this activity is perhaps not entirely certain at this time, various studies suggest



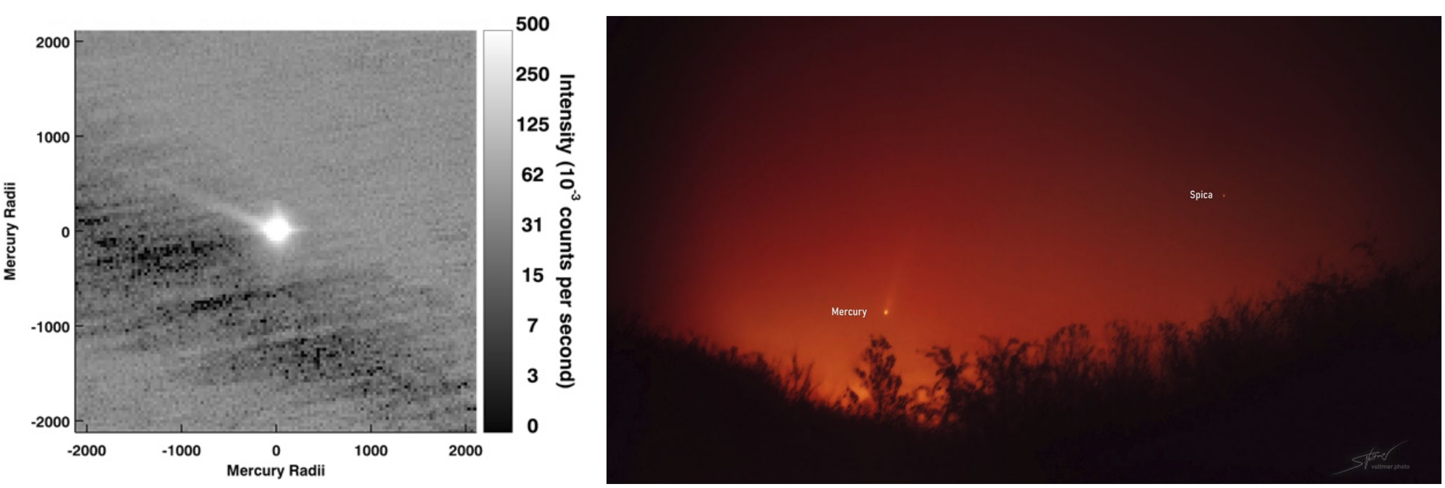
A sequence of images of "Comet" Catalina-PANSTARRS P/2013 R3 taken by the Hubble Space Telescope in late 2013 and early 2014, showing the process of disintegration. Courtesy NASA.

that, while Bennu does appear to contain a non-trivial amount of water, the most likely causes of the activity are actually thermal fracturing of its surface (similar to, although smaller in scale than, the apparent cause of Phaethon's activity) as well as meteoroid impacts, including ricochets from those impacts.

In January 2010 the LINEAR program in New Mexico discovered an apparent comet, originally designated as P/2010 A2, that appeared to consist entirely of a tail without an apparent "head." Detailed studies afterward, including with the Hubble Space Telescope, showed a small apparent asteroid near the front end of this tail, although detached from it, and analysis indicates that we were witnessing the result of an impact between two small asteroids, with the "tail" being the debris field created from this event. The object was found to be traveling in a near-circular orbit in the inner portion of the main asteroid belt with a period of 3.5 years, and after being recovered (without any tail or other cometary features) in 2017 has nevertheless been assigned the cometary designation 354P/LINEAR.

An even more interesting event took place later in 2010, when on December 11 Steve Larson with the Catalina Sky Survey in Arizona reported that the large main-belt asteroid (596) Scheila, which had been discovered by the German astronomer August Kopff in February 1906 and which had been an "ordinary" asteroid ever since – was over a magnitude brighter than expected, and moreover was accompanied by an extended coma roughly 2 by 5 arcminutes across. This coma dispersed over the next few weeks, and a spectroscopic analysis indicated it was made up entirely of dust, i.e., there was no evidence of any gases present. Researchers concluded that the coma and overall outburst was caused by the impact of a small (35-meter) asteroid onto Scheila itself. A similar event seems to have occurred in early 2015, when on March 17 David Tholen, Scott Sheppard, and Chad Trujillo detected a faint comet-like tail extending from the large main-belt asteroid (493) Griseldis in images taken with the 8.2-meter Subaru Telescope at Mauna Kea. This feature, too, dispersed not too long thereafter, and also appears to be due to an impact event. Neither Scheila nor Griseldis has exhibited any additional signs of cometary activity since their respective outbursts.

Another source of apparent cometary activity in asteroids is demonstrated by two "comets"



Images of Mercury, taken through special filters that isolate the light of sodium atoms, that reveal Mercury's sodium tail. Left: Image taken by the STEREO-A spacecraft on February 8, 2008. Courtesy NASA/Boston University – Center for Space Physics. Right: Ground-based image taken November 10, 2020 by Sebastian Voltmer in France. Courtesy Sebastian Voltmer.

An image I took of (6478) Gault with the 1-meter telescope of the Las Cumbres Observatory facility at the South African Astronomical Observatory on January 8, 2019.

discovered by the Hawaii-based Pan-STARRS program in 2013 (although other similar objects have also been discovered), P/2013 P5 and P/2013 R3 (the latter object being independently discovered by the Catalina Sky Survey in Arizona). Both objects were found to be spewing streams of dust by rapidly-rotating asteroids being spun up by sunlight via the Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect, which is caused by scattering of sunlight impinging on planetary surfaces and by emission of thermal radiation. Both objects travel in orbits typical of main-belt asteroids: P/2013 P5 is in a near-circular orbit in the inner asteroid belt with a period of 3.24 years and, having been observed as recently as 2018 and in fact would have passed through perihelion again this past October, has been assigned the periodic comet designation 311P/PANSTARRS, while P/2013 R3, which traveled in a larger orbit with a period of 5.3 years, apparently completely disintegrated in early 2014 and has not been detected since then.

An interesting variation of the apparent YORP-effect driven cometary activity is provided by the main-belt "asteroid" (6478) Gault, which exhibited a distinct comet-like tail in late 2018 and early 2019. Although this does appear to be another example of a YORP-effect "comet," a search of old images has revealed that Gault has exhibited this tail-like feature at least a far back as September 2013, suggesting there may be more to its story. Gault is a previous "Comet of the Week" and that overall story is discussed more completely in that presentation. For what it's worth, Gault, which was at opposition back in late September, has not exhibited any unusual activity or appearance this year.

All of the objects described in this presentation illustrate that there is no firm distinction between a "comet" and an "asteroid," and that there are quite a few objects that exhibit characteristics of both. Indeed, for a rather extreme example, sodium atoms from Mercury's surface and its (very thin) atmosphere are pushed away by sunlight (in the same manner as dust grains are pushed away from cometary nuclei by sunlight), and in images taken with special filters that isolate the light of sodium atoms Mercury is accompanied by a distinct tail that gives it the superficial appearance of a comet. This phenomenon was predicted in the mid-1980s and was first detected in 2001.

For my own observational purposes, I consider any "small body" that has exhibited distinct physical cometary activity at some point, including objects like (596) Scheila and (493) Griseldis, as a "comet," although I draw the (admittedly arbitrary) line at Mercury. Collectively, all of these objects illustrate that our solar system is a complex place, and each of the objects have their own unique story to tell.

THIS WEEK IN HISTORY

DECEMBER 6 | 7 | 8 | 9 | 10 | 11 | 12

DECEMBER 6, 1997: Jim Scotti with the Spacewatch program in Arizona discovers the Apollo-type asteroid now known as (35396) 1997 XF11. This asteroid created a major stir the following year when orbital calculations indicated a very close approach to Earth would be occurring in October 2028, and even though subsequent calculations with more data moved the "miss distance" out much farther, the process itself forced a re-thinking of how potential future close encounters are approached. The story is discussed in a previous "Special Topics" presentation.

DECEMBER 6, 2020: JAXA's Hayabusa2 mission returns to Earth with its collection of soil samples that it collected from the near-Earth asteroid (162173) Ryugu, from which it departed 13 months ago. After releasing a capsule containing these samples that is then expected to be retrieved from the Woomera Test Range in South Australia, Haybusa2 will depart Earth's vicinity for an eventual flyby of the Apollo-type asteroid (98943) 2001 CC21 in 2026. The Hayabusa2 mission is discussed in last week's "Special Topics" presentation.

6 | DECEMBER 7 | 8 | 9 | 10 | 11 | 12

DECEMBER 7, 1968: NASA's Orbiting Astronomical Observatory 2 (OAO-2) satellite, the first successful space telescope, is launched from Cape Canaveral, Florida. In January 1970 OAO-2 made the first observations of a comet from space – Comet Tago-Sato-Kosaka 1969g, a previous "Comet of the Week" and the first comet I ever observed – and detected the Lyman-alpha hydrogen cloud that is now known to accompany almost all comets passing through the inner solar system.

DECEMBER 7, 2020: The large main-belt asteroid (16) Psyche will be at opposition. It is currently traveling westward through Taurus and is close to 9th magnitude. Psyche is primarily metallic in composition and potentially important in the mining of asteroids, and is also the destination of NASA's Psyche mission currently scheduled for launch in August 2022. These aspects of (16) Psyche are discussed in previous "Special Topics" presentations.

6 7 **DECEMBER 8** 9 10 11 12

DECEMBER 8, 2251 B.C.: According to calculations by Zdenek Sekanina and Rainer Kracht, Comet Hale-Bopp C/1995 O1 passes through perihelion (during its previous return) at a heliocentric distance of 0.907 AU. The comet would have been well placed for observation, passing 0.65 AU from Earth and potentially becoming as bright as magnitude -2. This may have been the comet's first visit to the inner solar system from the Oort Cloud, and it would have passed within 0.01 AU of Jupiter on the way in and captured into the shorter-period orbit that it occupies today.

DECEMBER 8, 1845: The German amateur astronomer Karl Hencke discovers the main-belt asteroid now known as (5) Astraea. This was the first asteroid to be discovered in almost four decades, and its discovery soon led to many other asteroids being discovered, and eventually to the realization that our solar system contains a large population of such objects. The story of the discovery of the asteroid belt is the subject of the Week 1 "Special Topics" presentation.

DECEMBER 8, 2018: Images of the main-belt asteroid (6478) Gault taken by the ATLAS program in Hawaii begin to show that it is accompanied by a comet-like tail. This feature would develop significantly over the next few weeks, and meanwhile examination of old images of Gault revealed that it has exhibited this tail as far back as September 2013. This tail activity makes Gault an "active asteroid," the subject of this week's "Special Topics" presentation. Gault itself is a previous "Comet of the Week."

DECEMBER 8, 2019: The interstellar Comet 2I/Borisov passes through perihelion at a heliocentric distance of 2.007 AU. This was the first confirmed example of a comet from interstellar space passing through the solar system, and it is a previous "Comet of the Week."

DECEMBER 8, 2020: The nucleus of the unusual Comet 29P/Schwassmann-Wachmann 1 – a recent "Comet of the Week," and currently in a state of outburst – is predicted to occult a 14th-magnitude star in Aries. The predicted path of the occultation crosses western Russian, southern Sweden, and Scotland.

6 7 8 **DECEMBER 9** 10 11 12

DECEMBER 9, 1805: The comet now known as Comet 3D/Biela passes 0.037 AU from Earth, becoming an easy naked-eye object of 4th magnitude or brighter in the process. Comet Biela, a previous "Comet of the Week," appears to have completely disintegrated during the mid-19th Century.

DECEMBER 9, 2023: Comet 1P/Halley will be at aphelion, at a heliocentric distance of 35.143 AU, after which it will begin heading back into the inner solar system for its next perihelion passage in July 2061. Comet Halley is the subject of a previous "Special Topics" presentation, and its most recent return in 1986 is a previous "Comet of the Week."

6 7 8 9 10 DECEMBER 11 12

DECEMBER 11, 2010: Steve Larson with the Catalina Sky Survey in Arizona reports that the main-belt asteroid (596) Scheila is a magnitude brighter than expected and is accompanied by a coma. This coma was apparently the result of an impact by a smaller asteroid, and in the meantime has caused Scheila to be considered as an "active asteroid," the subject of this week's "Special Topics" presentation.

6 7 8 9 10 11 DECEMBER 12

DECEMBER 12, 1970: NASA's Orbiting Geophysical Observatory 5 (OGO-5) satellite detects a Lyman-alpha hydrogen cloud around Comet 2P/Encke, the first detection of such a feature around a short-period comet. Comet Encke, which returned earlier this year, is a previous "Comet of the Week," and Lyman-alpha hydrogen clouds are discussed in previous "Ice and Stone 2020" presentations.

DECEMBER 12, 1992: Comet 109P/Swift-Tuttle 1992t, the parent comet of the Perseid meteor shower, passes through perihelion at a heliocentric distance of 0.958 AU. Comet Swift-Tuttle is last week's "Comet of the Week."

DECEMBER 12, 2003: A team of astronomers led by Matthew Povich and John Raymond publishes their paper describing observations of Comet Kudo-Fujikawa C/2002 X5 and relating these to the likely existence of comets in other planetary systems. These observations are discussed in more detail in a previous "Special Topics" presentation on exocomets.

DECEMBER 12, 2020: The recently-discovered Comet Erasmus C/2020 S3 will pass through perihelion at a heliocentric distance of 0.398 AU. Comet Erasmus had brightened to close to 6th magnitude by the time it disappeared into the dawn sky early this month, and will be located 11 degrees west of the sun during the total solar eclipse on December 14; it possibly may be bright enough to detect during totality. Solar eclipse comets are discussed in a previous "Special Topics" presentation.

DECEMBER 12, 2020: The main-belt asteroid (498) Tokio will occult the 4th-magnitude star Omicron Virginis. The predicted path of the occultation crosses southern Greenland, portions of the Norwegian and Barents Seas, the southern part of Yuzhny Island, and parts of central Siberia.

COVER IMAGE CREDIT:

Front and back cover: Astronaut Ron Garan, Expedition 28 flight engineer, tweeted this image from the International Space Station on Aug. 14 with the following caption: "What a 'Shooting Star' looks like from space, taken yesterday during Perseid Meteor Shower." The image was photographed from the orbiting complex on Aug. 13 when it was over an area of China approximately 400 kilometers to the northwest of Beijing. The rare photo opportunity came as no surprise since the Perseid Meteor Shower occurs every year in August.

Courtesy NASA/Ron Garan

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