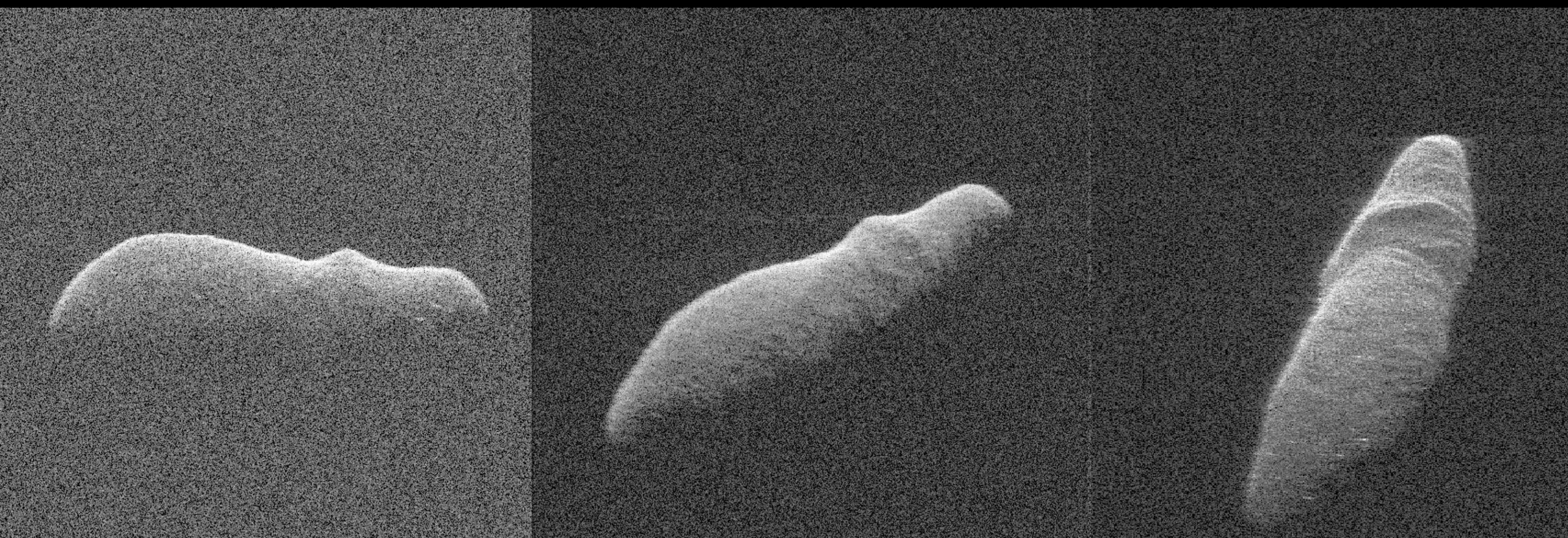
ICE & STONE 2020

Week 1: January 1-4, 2020

Presented by The Earthrise Institute



THIS WEEK IN HISTORY

29 30 31 JANUARY 1 2 3 4

JANUARY 1, 1801: On the first day of the 19th Century, Giuseppe Piazzi at the Palermo Observatory in Sicily discovers the first-known asteroid, now known as (1) Ceres. Ceres, a resident of the "main asteroid belt" between Mars and Jupiter, remains the largest-known asteroid (diameter 950 km), and is now formally designated a "dwarf planet." NASA's Dawn spacecraft arrived there in 2015 and remains in orbit around it. "Main belt asteroids" is the subject of this week's "Special Topics" presentation.

JANUARY 1, 2019: NASA's New Horizons mission encounters the Kuiper Belt object (486958) Arrokoth (unofficially known as "Ultima Thule" at the time). The New Horizons images revealed Arrokoth as being a "contact binary" object, i.e., what was originally two separate objects (one slightly larger than the other) now stuck together. The Kuiper Belt and contact binaries are subjects of future "Special Topics" presentations.

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JANUARY 2, 1905: Charles Perrine at Lick Observatory in California discovers the seventh known moon of Jupiter, now named Elara. It is about 86 km in diameter, and orbits around Jupiter at an average distance of 0.078 AU (11.7 million km) and a period of 260 days. Elara is a dark object and, like most of the outer moons of the giant outer planets, may be a captured asteroid.

JANUARY 2, 2004: NASA's Stardust spacecraft flies through the coma of Comet 81P/Wild 2, collecting samples (via an extremely lightweight and porous substance called "aerogel") for return to Earth two years later. Comet 81P/Wild 2 is this week's "Comet of the Week."

JANUARY 2, 2014: The very tiny asteroid 2014 AA, discovered the previous day by the Mt. Lemmon survey based in Arizona, enters Earth's atmosphere above the southern Atlantic Ocean and disintegrates. This is the second-known incident (of four thus far) of this kind; these are discussed in a future "Special Topics" presentation.

JANUARY 2, 2019: A strong signal of a comet transiting the star Beta Pictoris – which would have soon evaporated as it fell onto that star – is detected in data taken with NASA's Transiting Exoplanet Survey Satellite (TESS) mission. This was the first confirmed detection of an "exocomet." The details are discussed in a paper authored by Sebastian Zieba and Konstanze Zwintz of the University of Innsbruck in Austria and others; the subject of exocomets is discussed in a future "Special Topics" presentation.

JANUARY 2, 2020: The "active asteroid" (6478) Gault will pass through perihelion at a heliocentric distance of 1.859 AU. Gault is a future "Comet of the Week," and the subject of "active asteroids" is discussed in a future "Special Topics" presentation.

** Please note that words in blue type are clickable hyperlinks to additional content about the subject.*

29 30 31 1 2 JANUARY 3 4

JANUARY 3, 1918: The near-Earth asteroid (887) Alinda is discovered by Max Wolf at Heidelberg Observatory in Germany, the third-known near-Earth asteroid. It makes occasional approaches to Earth, including one to 0.082 AU in 2025. Near-Earth asteroids are the subject of next week's "Special Topics" presentation.

JANUARY 3, 2013: Comet Siding Spring C/2013 A1 is discovered by Rob McNaught during the course of the Siding Spring Survey in New South Wales. On October 19, 2014, Comet Siding Spring passed 1/3 of a lunar distance from Mars and became the first comet ever to be imaged from the surface of another planet. It is a future "Comet of the Week."

29 30 31 1 2 3 JANUARY 4

JANUARY 4, 2019: The asteroid 2019 AQ3 is discovered by the Zwicky Transient Facility (ZTF) program based at Palomar Observatory in California. 2019 AQ3 has an orbital period of 165 days and an aphelion distance of 0.77 AU (just beyond the orbit of Venus); the orbit is inclined 47 degrees with respect to the ecliptic. At the time of its discovery, 2019 AQ3 had the smallest orbit of any known asteroid, but that record has since been broken by another ZTF discovery, 2019 LF6.

JANUARY 4, 2020: The annual Quadrantid meteor shower will be at its peak. The Quadrantids have a peak Zenithal Hourly Rate (ZHR) in excess of 100 meteors per hour, making it one of the strongest of the annual showers; it does, however, have a very sharp and narrow peak. The predicted peak time in 2020 is around 8:20 UT, which is favorable for North America; the moon will be two days past its First Quarter phase and should not interfere too much with observations. The Quadrantids appear to be associated with the asteroid (and likely defunct comet) (196256) 2003 EH1.

COVER IMAGES CREDITS:

Front cover (top): The European spacecraft Giotto became one of the first spacecraft ever to encounter and photograph the nucleus of a comet, passing and imaging Halley's nucleus as it receded from the sun.
Courtesy of NASA/ESA/Giotto Project.

Front cover (bottom): Three radar images of near-Earth asteroid 2003 SD220 obtained by coordinating observations with NASA's 230-foot (70-meter) antenna at the Goldstone Deep Space Communications Complex in California and the National Science Foundation's (NSF) 330-foot (100-meter) Green Bank Telescope in West Virginia.
Courtesy of NASA/JPL-Caltech/GSSR/NSF/GBO.

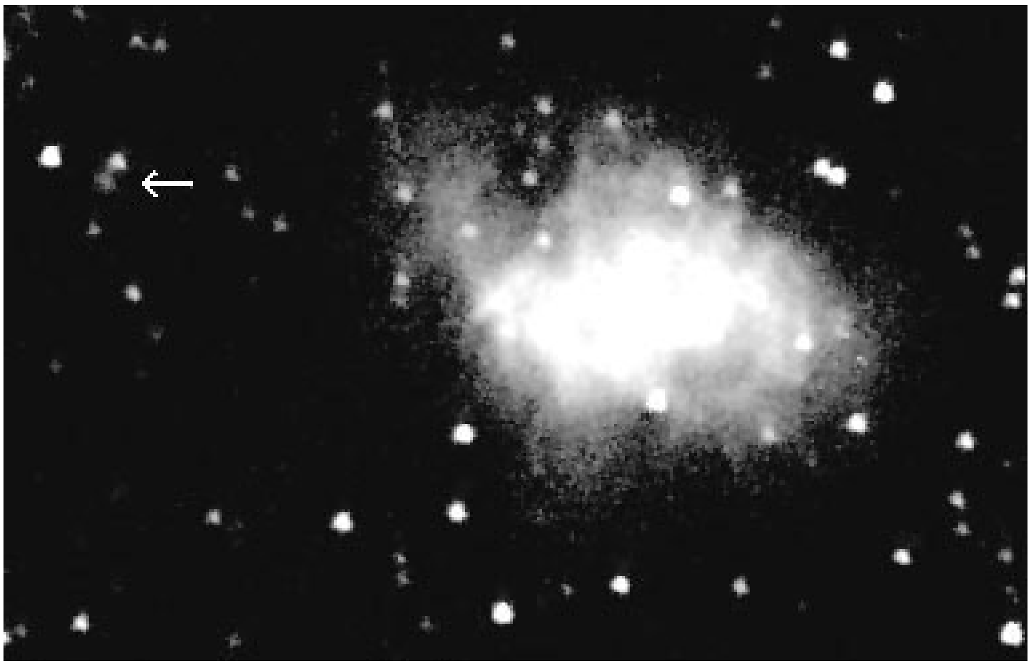
Back cover: This composite is a mosaic comprising four individual NAVCAM images taken from 19 miles (31 kilometers) from the center of comet 67P/Churyumov-Gerasimenko on Nov. 20, 2014 by the Rosetta spacecraft. The image resolution is 10 feet (3 meters) per pixel. Rosetta is an ESA mission with contributions from its member states and NASA.
Courtesy of ESA/Rosetta/NAVCAM.

COMET OF THE WEEK: 81P/WILD 2

Perihelion: 2003 September 25.93, q = 1.590 AU

Comet 81P/Wild 2 was discovered on January 6, 1978, by Swiss astronomer Paul Wild, who photographically patrolled the skies for several decades from the University of Bern. Throughout that time he discovered numerous asteroids and supernovae, as well as eight comets; he has the interesting distinction of having discovered at least one comet during each of the decades of the 1950s, 1960s, 1970s, 1980s, and 1990s.

This particular comet was found to be traveling in a short-period orbit with a perihelion distance of 1.49 AU and an orbital period of 6.17 years. Most interestingly, calculations soon showed that it had passed less than 0.01 AU from Jupiter in September 1974, and prior to that had been in a much larger orbit with a perihelion distance of 4.95 AU and an approximate orbital period of 44 years. Meanwhile, an approach to Jupiter (1.01 AU) in June 1986 has changed the 1978 orbit slightly, to a present perihelion distance of 1.6 AU and an orbital period of 6.4 years.



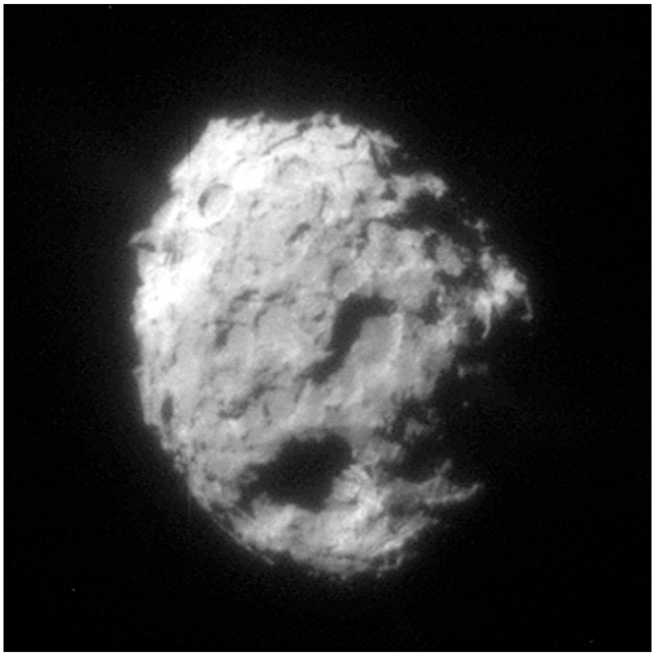
An image I took with the old Earthrise CCD system on April 28, 2003, showing Comet 81P/Wild 2 passing by the Crab Nebula M1 in Taurus. This was one of the last images taken of the comet prior to conjunction with the sun, and I was personally asked by representatives of the Stardust mission to provide astrometric positions from this image that proved crucial in navigating the spacecraft to its destination; for a while this image was featured on the homepage of the Stardust web site.

In 1978 the comet remained visually detectable for several months and reached a peak brightness near 11th magnitude. It has continued to be visually detectable at every return since then, although the viewing geometry is sometimes unfavorable; indeed, its 2003-04 return was very unfavorable, with the comet's being in conjunction with the sun around the time of perihelion passage. Meanwhile, during the best return it has had thus far, in 2010, it reached a peak brightness of magnitude 9 ½ and I could faintly detect it with ordinary binoculars.

In part because of a small orbital inclination (3 degrees) which makes it an energy-efficient destination for spaceflight, as well as its pre-discovery encounter with Jupiter which suggests it may be a "pristine" object newly arrived within the inner solar system which in turn makes it an interesting scientific target, 81P was often considered an early destination for a spacecraft mission. In 1995 it was selected as the destination comet of NASA's Stardust mission, which was launched from Cape Canaveral, Florida on February 7, 1999. After its launch Stardust completed two full orbits within the inner solar system, which included a flyby of the small main-belt asteroid (5535) Annefrank on November 2, 2002, and on its third orbit it passed 237 km from the nucleus of Comet 81P on January 2, 2004.

Comet 81P on April 10, 2010, during the course of the best return it has had thus far since its discovery. This image approximates the visual appearance it exhibited through my 41-cm reflector. Image courtesy Uwe Wohlrab in Germany.

Via means of a very lightweight, porous substance known as "aerogel" which had been invented by Jet Propulsion Laboratory scientist Peter Tsou, Stardust collected over one million samples of dust particles during its passage through Comet 81P's coma. When Stardust passed by Earth on January 15, 2006 it deployed a capsule containing these samples into the atmosphere, where it plummeted to the surface and was then successfully retrieved from the U.S. Army's Utah Test and Training Range southwest of Salt Lake City.



The nucleus of Comet 81P, photographed by Stardust on January 2, 2004. The nucleus is a near-spherical object with an approximate diameter of 5 km. Image courtesy NASA.

Analysis of the samples retrieved from Stardust has revealed that the comet formed in the region of the Kuiper Belt beyond Neptune and that there was an unexpected amount of mixing between materials in the inner and outer solar system. Various organic compounds, as well as the silicates olivine and pyroxene, have been identified within the samples, and in 2009 a team led by Jamie Elsila of the Goddard Space Flight Center in Maryland announced the presence of the amino acid glycine, which is utilized by life here on Earth.

Comet 81P/Wild 2 most recently passed perihelion in July 2016, reaching 11th magnitude in the process, and it should reach a similar brightness around the time of its next perihelion passage in December 2022. It remains in the same basic orbit that it is in now until an approach of 0.11 AU from Jupiter in August 2058 increases its perihelion distance to 1.75 AU and its orbital period to 6.6 years.

SPECIAL TOPIC: MAIN BELT ASTEROIDS

In 1766 a German astronomer, Johann Titius, reported a curious mathematical relationship between the orbits of the planets in the solar system, which was popularized six years later by another German astronomer, Johann Bode; it is usually referred to as "Bode's Law" although sometimes it is called the "Titius-Bode Law." In essence, if one starts with zero, then adds three and doubles that and every subsequent number, then adds four to each number in the sequence and divides the results by ten, the "law" reproduces rather well the semimajor axes of the solar system's planets that were known at the time.

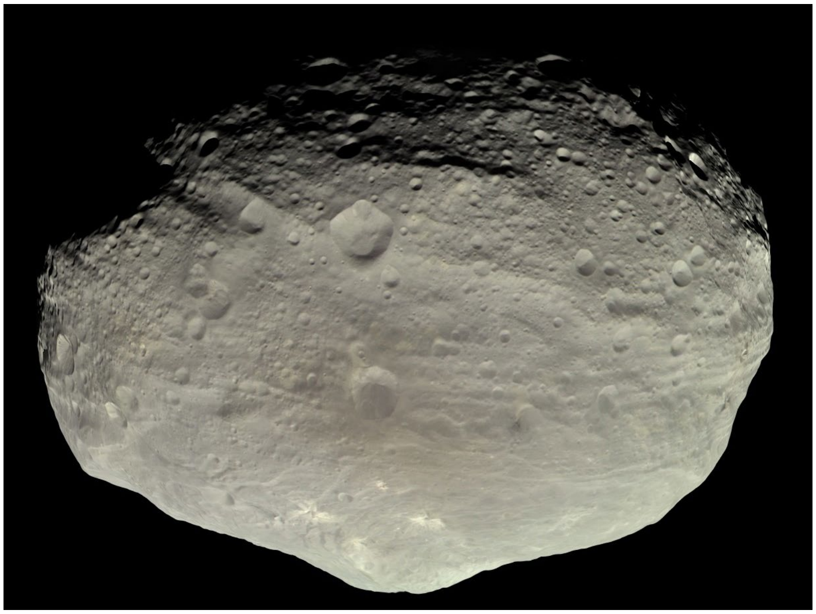
Planet	Bode's Law distance (AU)	Actual average distance (AU)
Mercury	0.4	0.39
Venus	0.7	0.72
Earth	1.0	1.00
Mars	1.6	1.52
--	2.8	--
Jupiter	5.2	5.20
Saturn	10.0	9.58

When Uranus was discovered by the British astronomer William Herschel in 1781 it fit in rather well with the scheme, with a "predicted" average distance of 19.6 AU and an actual average distance of 19.22 AU. It broke down with Neptune, however ("predicted" average distance of 38.8 AU vs. actual average distance of 30.11 AU), and the consensus nowadays is that there is no physical basis for this "law," although since gravitational resonances do appear within systems of orbiting objects it is conceivable that Bode's "Law" could be a crude symptom of this and thus may not be entirely due to coincidence.

The obvious "gap" at 2.8 AU is quite noticeable, and many astronomers of that era were convinced that an as-yet undiscovered planet existed at that location. In 1800 several of these individuals, who were later informally dubbed the "celestial police," met in Lilienthal, Germany, to map out strategies for searching for this object. Before this effort could get underway, however, it was pre-empted by the Director of the Royal Observatory in Palermo, Sicily, Giuseppe Piazzi, who, on January 1, 1801 – the first day of the 19th Century – discovered a star-like object that moved from night to night. Piazzi followed his object for the next six weeks before he was stopped by illness, and shortly thereafter it was lost in sunlight as it approached conjunction with the sun. Through heroic orbital calculations performed by the German mathematician Karl F. Gauss the object was recovered in the morning sky on the last day of 1801.

Piazzi's object was eventually given the name Ceres, the Roman goddess of agriculture – and, incidentally, the patron goddess of Sicily. With an orbital period of 4.6 years and an average distance of 2.77 AU Ceres fits in nicely with Bode's "Law," and at least some astronomers felt that the "missing" planet had been found. Its relative faintness – never brighter than 7th magnitude – in turn suggested that it is quite small, however, and some astronomers of the era were unconvinced that it was all there was to the story. On March 28, 1802, one of the "policemen," the German astronomer Heinrich Olbers, discovered a second object – since named Pallas – that appeared to confirm this. Another "policeman," Karl Harding, discovered a third object – since named Juno – on September 1, 1804, and Olbers discovered a fourth – since named Vesta – on March 29, 1807.

There were no additional discoveries for quite some time thereafter, and the general consensus as the time was that, collectively, these four objects represented the "missing" planet. But then, in 1845, a German amateur astronomer, Karl Hencke, after 15 years of unsuccessful searching discovered a fifth object, now named Astraea, and then a sixth object – named Hebe – two years later. Other astronomers of the time began to get in on the action, and pretty soon similar objects were being discovered all the time; by the end of the 19th Century several hundred had been found. By this time the practice of astro-photography was coming into its own, and so many of these objects were appearing on the photographic plates that one astronomer of the era dubbed them the "vermin of the skies." With the advent of the comprehensive CCD-based survey programs near the end of the 20th Century thousands were being detected every month, and nowadays over half a million of them have had valid orbits computed.



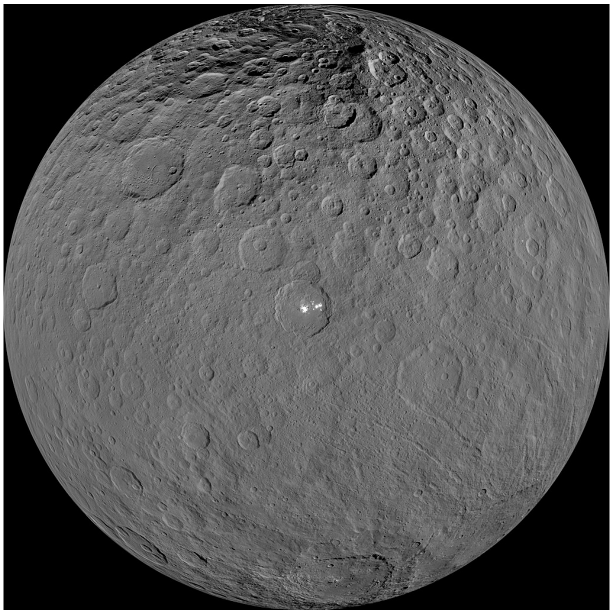
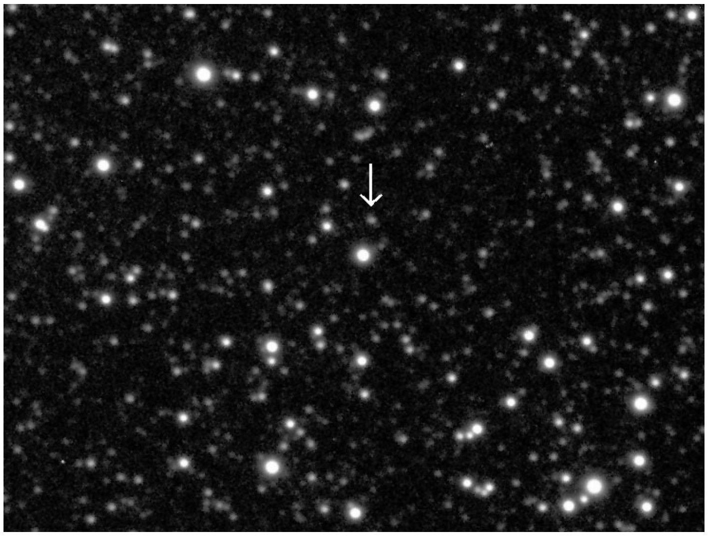
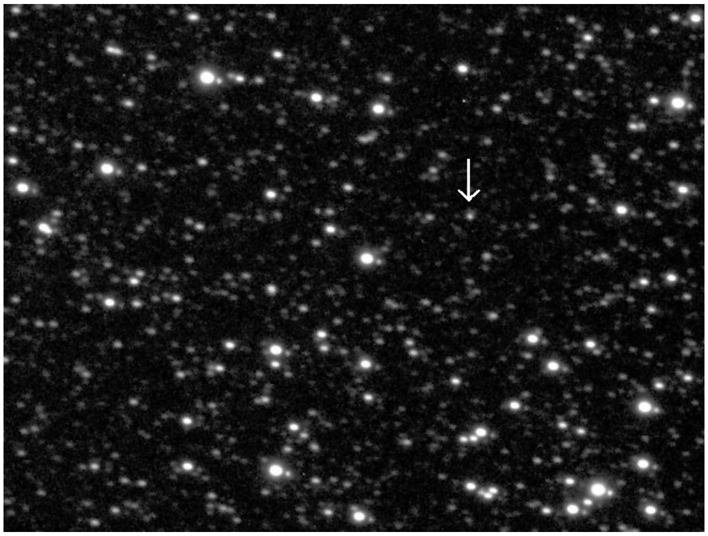


Image taken of Vesta (left) on July 24, 2011 and a montage of images taken of Ceres (right) released on September 20, 2017, by the Dawn spacecraft. The bright spots in the crater (named Occator) on Ceres are likely salt deposits (sodium carbonate plus other salts) left behind after the sublimation of briny surface water. Both images courtesy NASA.

Due to their stellar appearance these objects are normally referred to as "asteroids" (from Greek words meaning "star-like"), although a slightly more formal term is "minor planets." The overwhelming majority of known asteroids reside in what is normally called the "main asteroid belt" between the orbits of Mars and Jupiter. The large majority of known asteroids are quite small, usually only a few km in diameter (and there surely must be many more that are smaller than this but just too faint to detect); Ceres, meanwhile, remains the largest main-belt asteroid with a diameter of 950 km. Vesta, although somewhat smaller than Ceres with an average diameter of 525 km, has a more reflective surface than Ceres and is the brightest of the main-belt asteroids, occasionally becoming bright enough to be viewed with the unaided eye (5^{th} to 6^{th} magnitude).

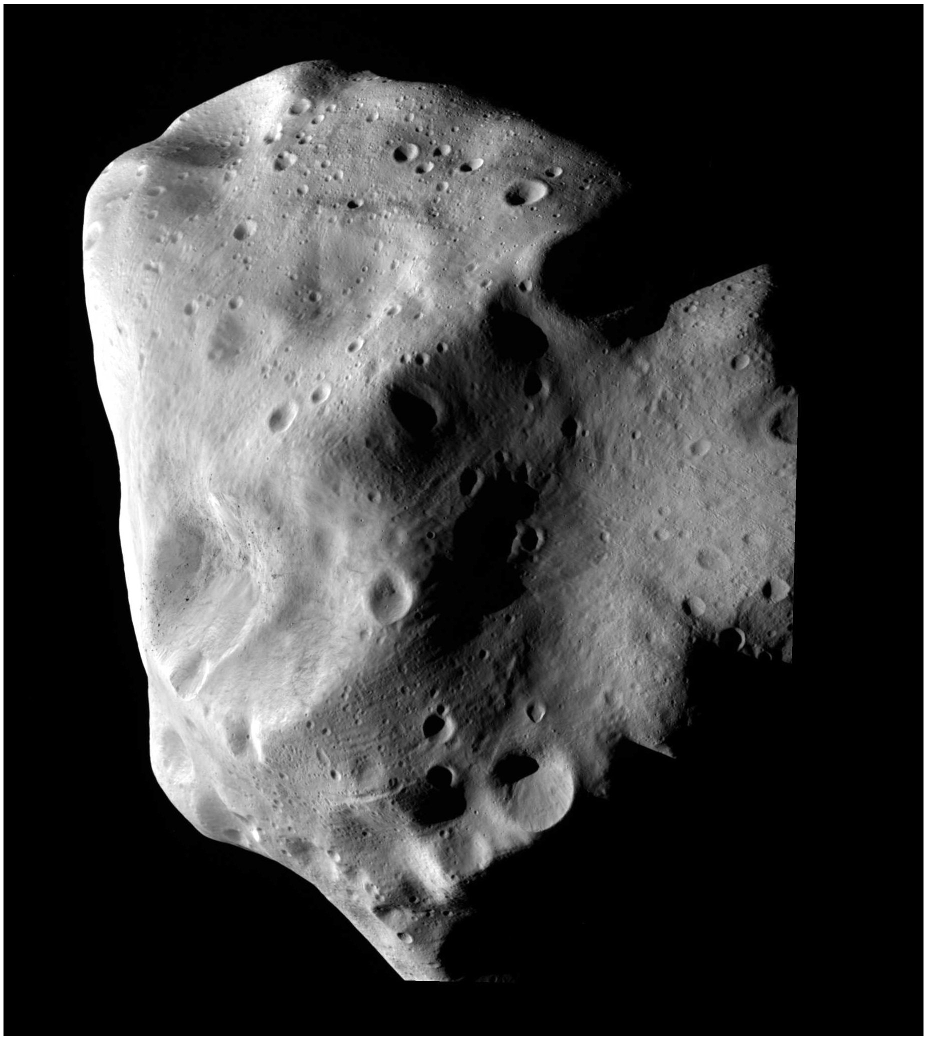
Physical studies of the asteroids indicate that they vary widely in composition. Some contain substantial amounts of metals and are quite dense; others are made up more of silicates and are accordingly less dense, and others are little more than "rubble piles" of rather low density. Quite a few of them contain significant amounts of organic materials, and some of them also contain substantial amounts of water (although this water would not be free-standing but rather is contained within the form of hydrated clays and other similar materials). They are not massive enough to have any kind of atmosphere, with the exception of Ceres which has on occasion exhibited indications of trace amounts of an atmosphere, most likely due to sun-driven sublimation of water ice on its surface as well as the interaction of coronal mass ejections with that ice.





Two images of asteroid (4151) Alanhale taken two hours apart on June 6, 2019 with the Las Cumbres Observatory telescope at Cerro Tololo Inter-American Observatory in Chile. A fainter asteroid, (75591) 2000 AN18, also appears in the two images; its identification is left as an exercise for the reader. (See solution toward end of document.)

An early idea, apparently originally suggested by Olbers, is that the asteroids are remnants of a planet that once existed between Mars and Jupiter but that exploded or otherwise disintegrated (perhaps as a result of an impact by another large object). This idea is no longer seriously considered, and the overwhelming consensus today is that the asteroids are "leftover" planetesimals from the formation of the solar system, with the gravitational perturbations from nearby Jupiter preventing a planet from forming in this region. (In this case, the asteroids would be a planet that "never was.") The overall mass of the asteroids within the main belt is only 0.05% the mass of Earth, but this was likely significantly larger in the distance past; erosion via collisions, ejection from the solar system, and impacts into the other planets would have substantially decreased the population of asteroids over the billions of years since the planets formed.

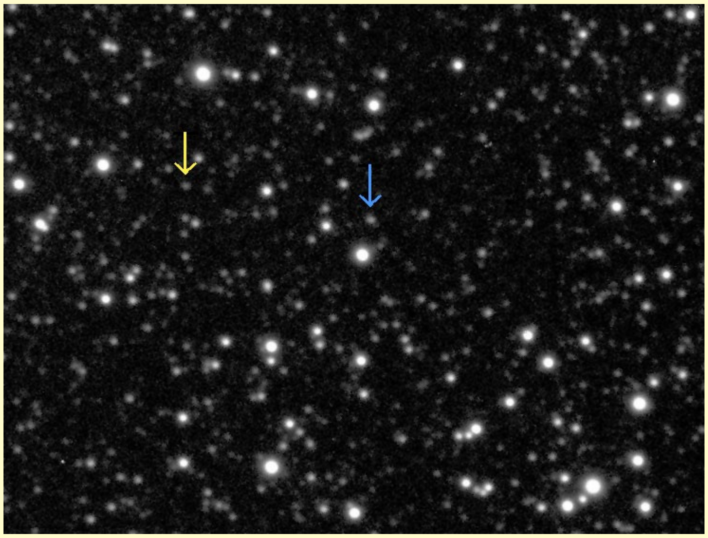


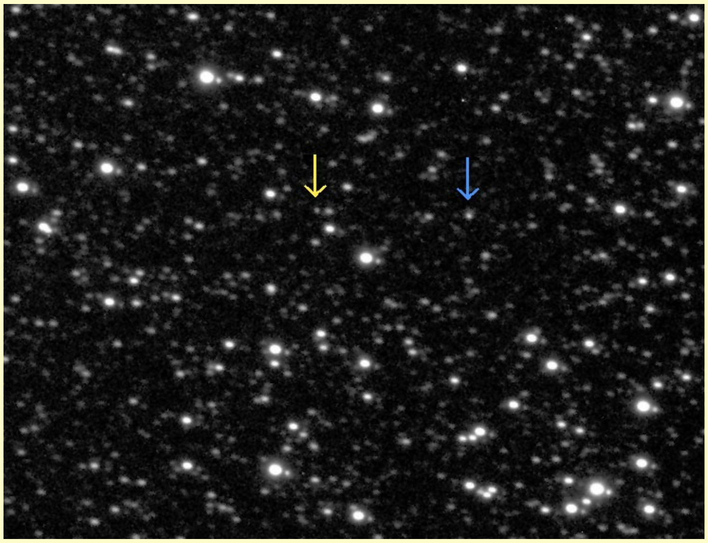
Main-belt asteroid (21) Lutetia, photographed by ESA's Rosetta mission on July 10, 2010. Image courtesy ESA.

Contrary to the images portrayed within popular media, the asteroid belt is not a region of space that is hazardous for spacecraft to navigate. Indeed, the volume of space is so large that the average distances between asteroids are on the order of hundreds of thousands of km. (To be sure, collisions between asteroids do occur from time to time, but – at least for somewhat large asteroids – over timescales of millions of years.) For a spacecraft to pass by an asteroid requires detailed planning and precise calculations, but nowadays most spacecraft missions to the outer solar system will involve a flyby of one or more main-belt asteroids if any can be found that are in the general vicinity of the expected trajectory.

The first asteroid to be visited by a spacecraft was (951) Gaspra, which was encountered on October 29, 1991, by NASA's Galileo mission while it was en route to Jupiter. As of this writing a total of nine main-belt asteroids have been visited by spacecraft. Two of these have been orbited, both of these by NASA's Dawn mission which was launched in September 2007: Vesta from July 2011 until September 2012, and Ceres, ever since March 2015 (although the mission itself was forma-2017 and Dawn ran out of its hydrazine fuel in November 2018). These various encounters will be discussed in more detail in a future week's "Special Topics" presentation.

At any given time, many of the main-belt asteroids are bright enough to be visually detected with moderate-size telescopes. During 2020, Ceres is at opposition on August 28, when it will be 8th magnitude and traveling through southern Aquarius; Pallas is at opposition on July 15, when it will be 10th magnitude and traveling through western Sagitta and eastern Hercules; and Juno is at opposition on April 3, when it will be 10th magnitude and traveling through western Virgo. Vesta does not have an opposition in 2020, but is currently 8th magnitude and traveling through northeastern Cetus, having been at opposition in November 2019; at the end of 2020 it will be 7th magnitude and traveling through central Leo as it approaches its next opposition in March 2021 (during which it will reach 6th magnitude). "My" asteroid, (4151) Alanhale, is at opposition on August 11, around which time it will be traveling through northeastern Capricornus but won't be any brighter than magnitude 17.





SOLUTION: Movement of asteroids (4151) Alanhale (blue arrows) and (75591) 2000 AN18 (yellow arrows) can be seen in these two images.

ABOUT ICE & STONE 2020

It is my pleasure to welcome all educators, students, and anybody else who might be interested, to "Ice and Stone 2020." This is an educational package I have put together to cover the so-called "small bodies" of the solar system, which in general means asteroids and comets, although this also includes the small moons of the various planets as well as meteors, meteorites, and interplanetary dust. While these objects may be "small" compared to the planets of our solar system, they are nevertheless of high interest and importance for several reasons, including:

a) they are believed to be the "leftovers" from the formation of the solar system, so studying them provides valuable insights into our origins;

b) we have learned that this process isn't over yet, and that there are still objects out there that can impact Earth and threaten our existence upon it; and

c) we have also learned that many of these objects contain valuable resources that we can utilize should humanity expand out into the solar system.

"Ice and Stone 2020" will cover various facets of our knowledge about these objects. I do not intend this to be a substitute for formal classroom educational courses, however, I do intend this to supplement the material in such courses, and to act as a resource for additional information.

At the beginning of each week "Ice and Stone 2020" will unveil new "presentations" about different aspects of our solar system's "small bodies." Specifically, each week will feature:

a) "This Week in History" -- a brief summary of important events in the study of "small bodies" during that particular week in history. This will include such events as spacecraft encounters, asteroid flybys, important discoveries, and notable publications and announcements, each of which will include a short summary. Some of the events are those that will be taking place in the future.

b) "Comet of the Week" -- a short discussion of an important comet that was visible during that corresponding week in the past. These could be comets that were especially bright, or that are scientifically important in some way. A small number of these are comets that are expected to be visible during 2020 or in later years.

c) "Special Topic" -- each week will feature a moderately in-depth discussion of some topic related to the study of "small bodies." Some representative topics include: main-belt asteroids, near-Earth asteroids, "Great Comets," spacecraft visits (both past and future), meteorites, and "small bodies" in popular literature and music.

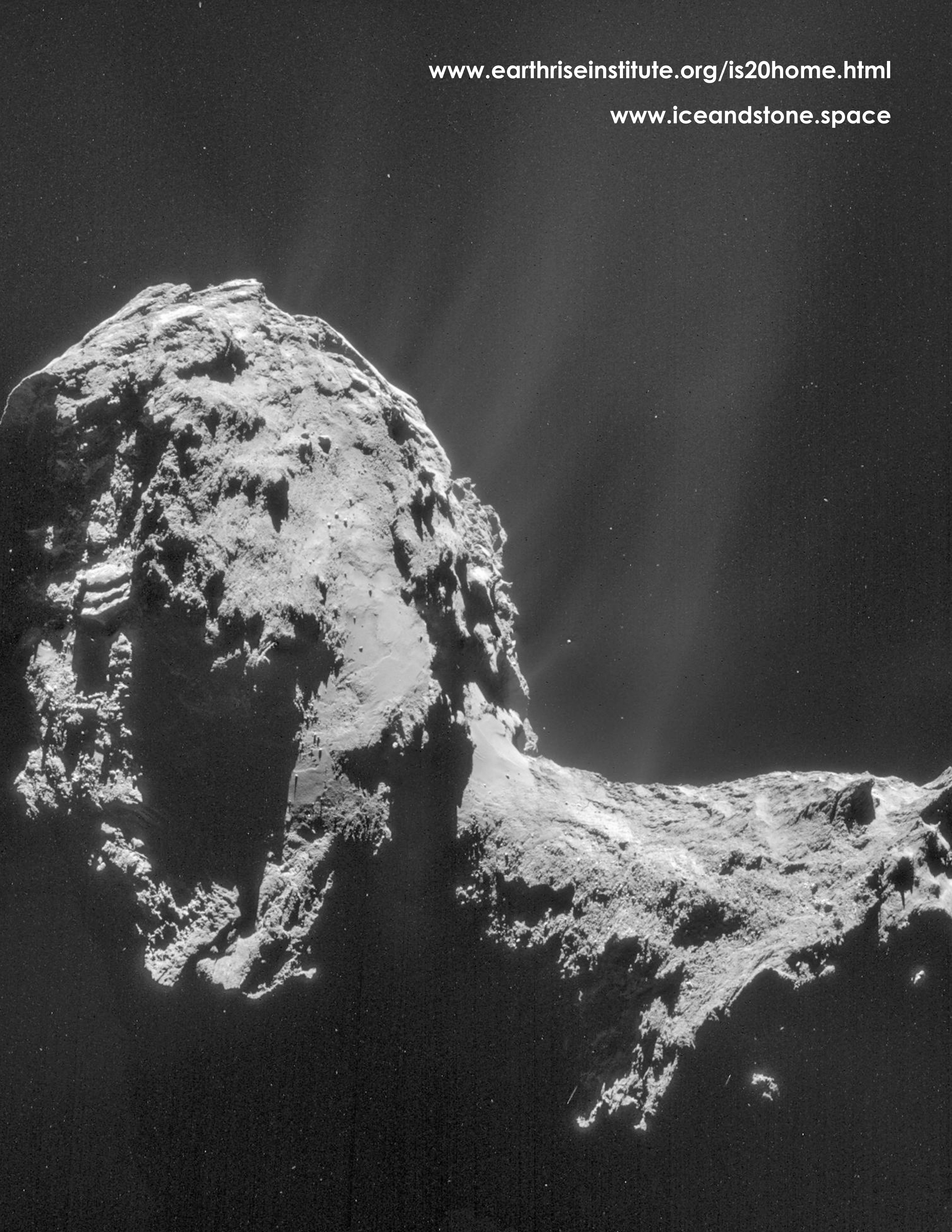
The Earthrise Institute is pleased to be partnering with various organizations in "Ice and Stone 2020." We especially acknowledge RocketSTEM, which will be hosting our presentations and assist in putting together lesson plans around them. The Las Cumbres Observatory, a worldwide network of automated telescopes placed at some of the top observing sites in the world, will be available for participants who might wish to image some of the objects that are visible.

2020 marks some very special anniversaries for me. It was 50 years ago, on February 2, 1970, that I saw my very first comet -- which, coincidentally, also happened to be the first comet ever observed from space. And it was 25 years ago, on July 23, 1995, that I discovered the comet that brought me worldwide recognition and forever changed my life.

As I begin to approach the later years of that life it is my intent with "Ice and Stone 2020" to share both the knowledge and the joy that I have gained throughout that life with the future generations of humanity, all over the world, so that they can use that knowledge -- however they see fit to do so -- to build a worthy future.

Alan Hale

Founder, The Earthrise Institute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