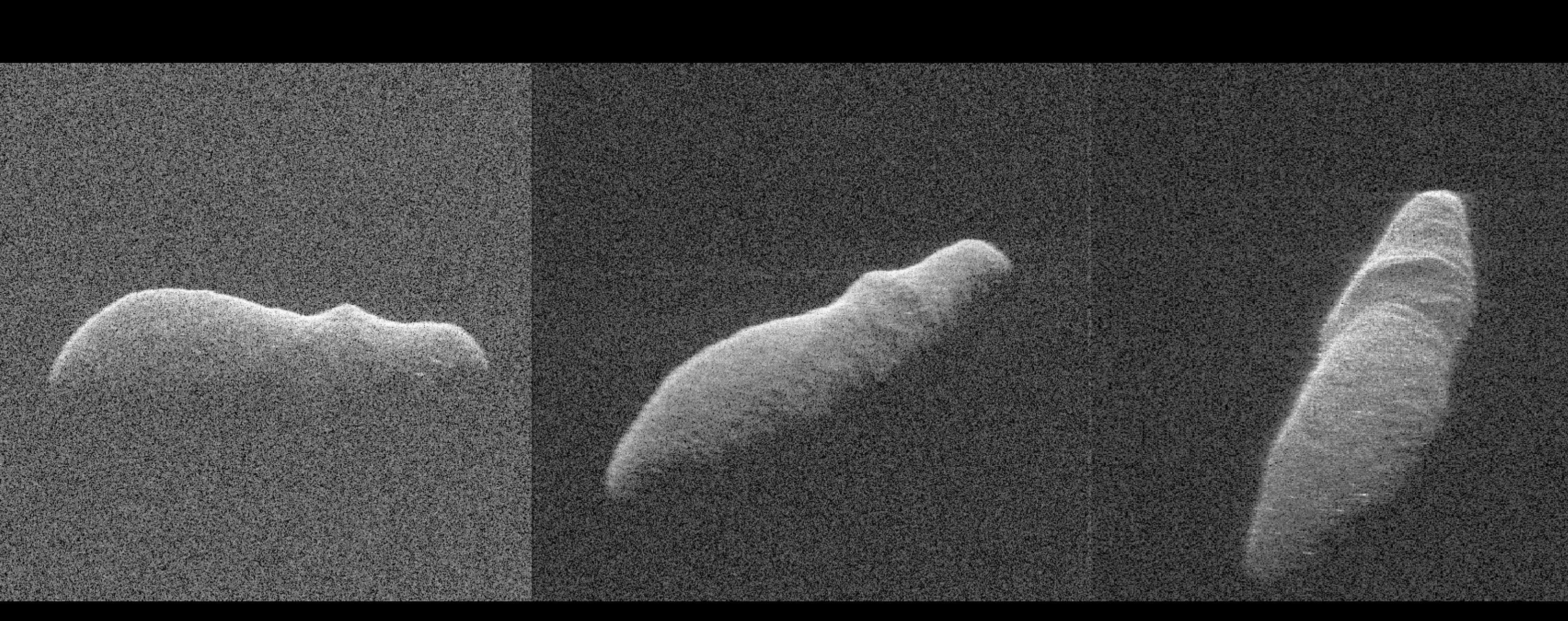
ICE & STONE 2020

Week 2: January 5-11, 2020

Presented by The Earthrise Institute



WELCOME TO ICE AND 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

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.

THIS WEEK IN HISTORY

JANUARY 5 | 6 | 7 | 8 | 9 | 10 | 11

JANUARY 5, 2005: The Kuiper Belt object now known as (136199) Eris is discovered by Mike Brown, Chad Trujillo, and David Rabinowitz on images taken in October 2003. Eris travels around the sun in a moderately-inclined and moderately eccentric orbit with a period of 558 years; it has one known moon (Dysnomia) and turns out to be slightly smaller than, but slightly more massive than, Pluto. When Eris' discovery was announced in August 2005 it brought to a head the matter of how to classify Pluto and other objects like it such as Eris; the following year these objects were assigned to the newly-created category of "dwarf planets." These objects are discussed in future "Special Topics" presentations.

JANUARY 5, 2020: The main-belt asteroid (1203) Nanna will occult the 7th-magnitude star HD 222455 in Pisces. The predicted path of the occultation crosses northwestern Mexico and central Texas and Louisiana.

5 | JANUARY 6 | 7 | 8 | 9 | 10 | 11

JANUARY 6, 1978: Paul Wild at the University of Bern in Switzerland discovers the comet now known as 81P/Wild 2. This comet, which was last week's "Comet of the Week," was found to have been perturbed into an inner-solar system orbit following a very close approach to Jupiter in 1974, and was the destination of NASA's Stardust mission which successfully returned samples to Earth in 2006.

JANUARY 6, 2010: The LINEAR program in New Mexico discovers what initially appeared to be a comet and which received the preliminary designation of P/2010 A2 and which is now formally known as 354P/LINEAR. The object was found to be traveling in a near-circular orbit within the inner main asteroid belt and is now believed to be the result of a collision between two asteroids (with the "tail" being the trail of dust debris following the collision). "Active asteroids" are the subject of a future "Special Topics" presentation.

JANUARY 6, 2019: NASA's OSIRIS-REx mission, in orbit around the near-Earth asteroid (101955) Bennu, detects the first of many "plume eruptions" of material off Bennu's surface. These events make Bennu an "active asteroid" – the subject of a future "Special Topics" presentation – and are consistent with the presence of hydrated clays on Bennu's surface, suggesting in turn that it might be a fragment of what had once been a comet.

JANUARY 6, 2020: The main-belt asteroid (1400) Tirela will occult the 6th-magnitude star HD 39051 in Orion. The predicted path of the occultation crosses the southern U.S. (Louisiana, Texas, New Mexico, Arizona, and southern California, including just north of Los Angeles), the northern Pacific Ocean, the northern part of the Japanese island of Honshu, North Korea (just north of Pyongyang), and northeastern China (just south of Beijing).

5 6 **JANUARY 7** 8 9 10 11

JANUARY 7, 1976: From Palomar Observatory in California, Eleanor Helin discovers a fast-moving asteroid now known as (2062) Aten. This was the first-known asteroid to have an orbital period of less than one year, and is the prototype of what are now called the "Aten" asteroids. The Aten asteroids and the other classes of near-Earth asteroids constitute this week's "Special Topics" presentation.

JANUARY 7, 1985: The National Space Development Agency – now the Japanese Aerospace Exploration Agency, or JAXA – launches the Sakigake mission from what was then called the Kagoshima Space Center on the island of Kyushu. On March 11, 1986 Sakigake made a distant flyby of Comet 1P/Halley (7.0 million km).

5 6 7 **JANUARY 8** 9 10 11

JANUARY 8, 2014: A 90-centimeter-wide object enters Earth's atmosphere near a point above Manus Island in Papua New Guinea and disintegrates as a bright fireball. Analysis of the available data by Avi Loeb and Amir Siraj at Harvard University (and announced in April 2019) suggests that the object had an unusually high pre-entry orbital velocity (almost 60 km/sec) which in turn suggests that it was not gravitationally bound to the solar system and thus may be interstellar in origin. At this time these findings have not been confirmed.

JANUARY 8, 2025: The large near-Earth asteroid (887) Alinda will pass 0.082 AU from Earth – the closest approach it has made since its discovery in 1918 – and should reach 9th magnitude.

JANUARY 8, 2020: The discovery of asteroid 2020 AV2, found on January 4, 2020 by the Zwicky Transient Facility survey based in California, is announced by the Minor Planet Center. 2020 AV2 is tied for the shortest orbital period among known asteroids, and is the first-known asteroid with an orbit that lies entirely within the orbit of Venus. Its discovery is discussed within a Special Addendum to this week's "Special Topics" presentation.

5 6 7 8 **JANUARY 9** 10 11

JANUARY 9, 1992: David Rabinowitz with the Spacewatch program in Arizona discovers a slow-moving asteroid, now known as (5145) Pholus; it was found to have an orbital period of 92 years and a perihelion distance of 8.8 AU. Pholus was only the second-known such object, following the discovery of (2060) Chiron in 1977, but many more such objects have been discovered since then. Collectively these objects are referred to as "Centaurs," and they are covered in a future "Special Topics" presentation.

5 6 7 8 9 **JANUARY 10** 11

JANUARY 10, 2002: Comet 201P/LONEOS, discovered in September 2001 by the LONEOS program in Arizona, passes only 0.014 AU from Mars. This was the closest-known cometary approach to Mars at the time; that record has now been broken with the approach of Comet Siding Spring C/2013 A1 in October 2014 (and which is a future "Comet of the Week").

JANUARY 10, 2020: The main-belt asteroid (16054) 1999 JP55 will occult the 6th-magnitude star 50 Leonis. The predicted path of the occultation crosses central Honshu in Japan, northeastern China, central Russia, northern Finland, and north-central Sweden.

5 6 7 8 9 10 **JANUARY 11**

JANUARY 11, 1972: Elizabeth Roemer and Larry Vaughn recover the long-lost periodic comet 9P/Tempel 1. The comet, discovered in 1867, had not been seen since 1879, with the exception of a tentative image obtained by Roemer in June 1967 which was confirmed by the 1972 recovery. It is now safely "on board" and was the destination of NASA's Deep Impact mission in 2005 and visited again by the Stardust mission in 2011; it is a future "Comet of the Week."

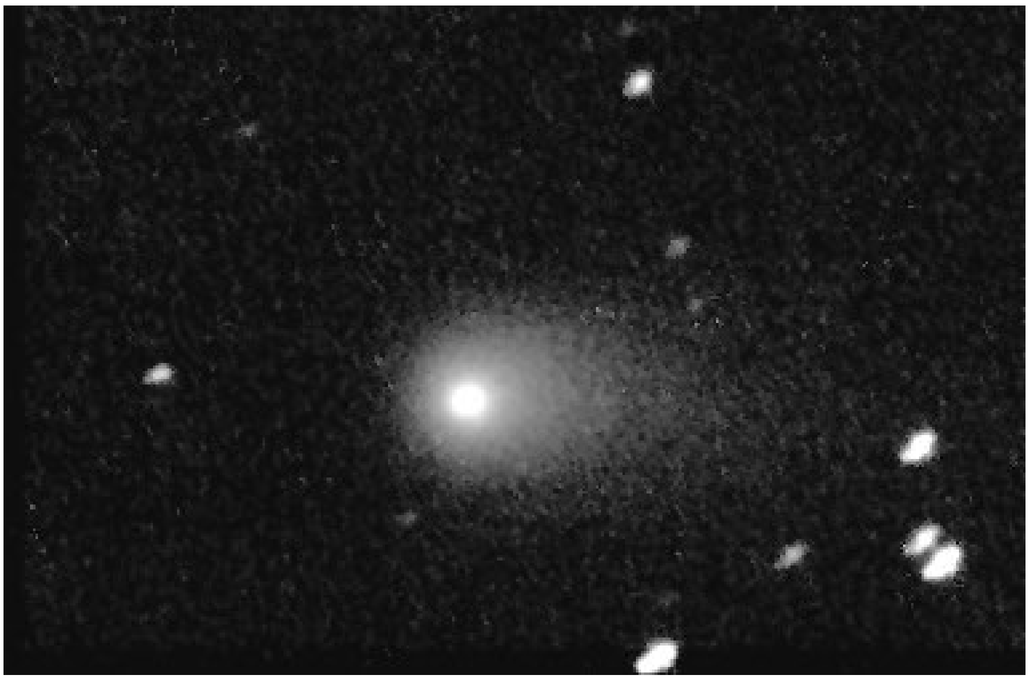
JANUARY 11, 2018: The Arkyd-6 satellite, designed and built by the private company Planetary Resources – now a subsidiary of ConsenSys – is launched from the Satish Dhawan Space Centre in India. Arkyd-6 is a technology testbed for future missions that will hopefully begin to carry out Planetary Resources' mission of resource extraction from asteroids. The subject of asteroid and comet mining is the topic of a future "Special Topics" presentation.

JANUARY 11, 2020: Comet 289P/Blanpain will pass 0.090 AU from Earth. The comet was lost from the time of its original discovery in 1819 until 2003 when it was re-discovered as an apparent asteroid, and even this identity wasn't confirmed until 2013. It is traveling northeastward through Cassiopeia and may possibly become bright enough for visual observations; if it does the Comet Resource Center will carry updated information about it.

COMET OF THE WEEK: MACHHOLZ C/2004 Q2

Perihelion: 2005 January 24.91, q = 1.205 AU

Beginning with French astronomer Charles Messier and his contemporaries in the mid- to late 18th Century, the vast majority of comets were discovered visually by amateur astronomers who regularly swept the skies looking for these objects. While this means of comet discovery began to be supplanted by photographic patrol programs in the early 20th Century, the visual hunters continued to Anhold their own for the next several decades. It was only when the CCD-based survey programs, which cover the sky extensively every month and are able to detect incoming comets when they are still too faint to be detected visually, became operational near the end of the 20th Century that visual comet discoveries essentially became a lost art. Only a handful of such discoveries have been made since the beginning of the 21st Century.

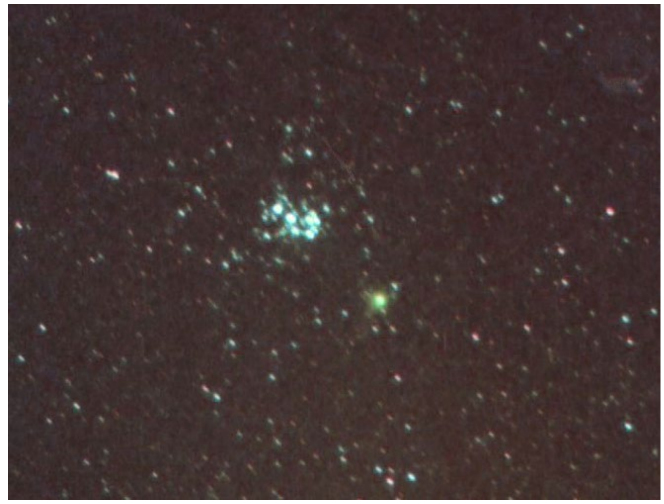


An image of Comet Machholz I took with the old Earthrise CCD system on September 23, 2004.

One of the most successful comet hunters of recent times is American amateur astronomer Don Machholz, a long-time resident of California who resided near San Jose and then relocated to Colfax (near Sacramento) in the early 1990s. Don, whom I have known personally for many years and consider a good friend, began his comet-hunting efforts at the beginning of 1975. If there is any one characteristic that embodies a successful comet hunter, it is perseverance, and Don truly exemplifies this: while the conventional wisdom is that a comet is discovered, on average, after 200 to 300 hours of searching, Don put in 1700 hours before making his first discovery in September 1978.

As of now Don has discovered a total of 12 comets. Most of these have been rather nondescript objects, however two of them are short-period comets that have turned out to be quite interesting: 96P/Macholz 1 (discovered in May 1986) has a very small perihelion distance (0.13 AU) and appears to be related to several inner-solar system phenomena including meteor showers and groups of small comets that have been detected by the SOlar and Heliospheric Observatory (SOHO) spacecraft; and 141P/Machholz 2 (discovered in August 1994) has been accompanied on some of its returns by various "companion" comets that have apparently come about as a result of fragmenting of its nucleus. This latter comet returns to perihelion, under relatively favorable viewing conditions, late this year.

Don discovered his 10th comet, and what would be his best one, on the morning of August 27, 2004, a discovery that took place almost ten years after his previous one and which, remarkably, took place in the

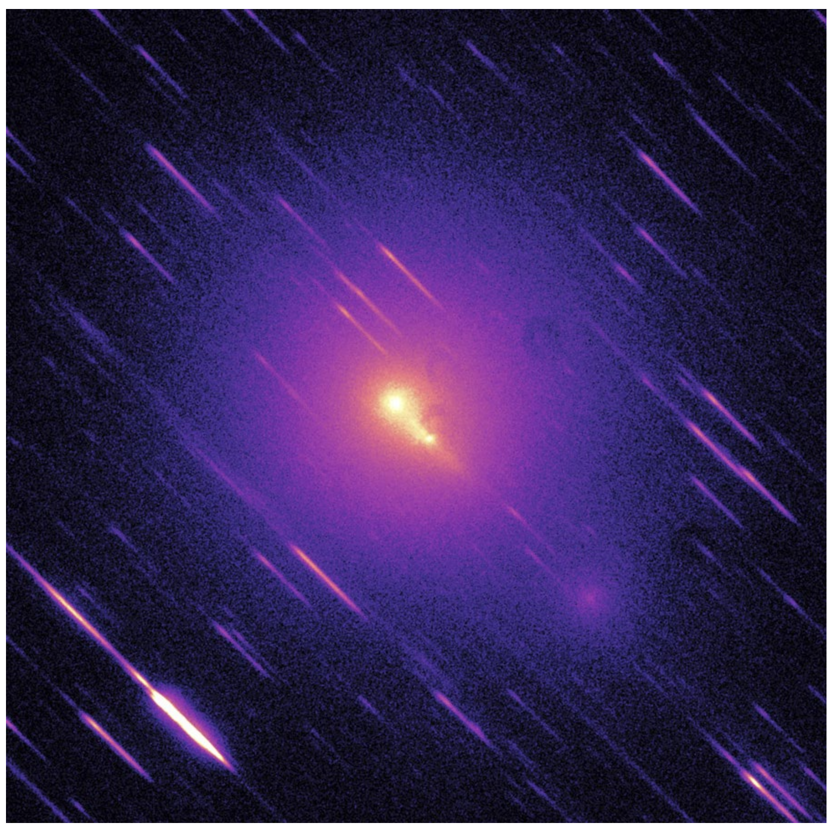
Two photographs of Comet Machholz as it passed by the Pleiades star cluster in early January 2005. Left: January 7, by Roy Royer in California. Used with permission. Right: A photograph I took on the evening of January 7 (January 8 UT). The comet's motion between the two photographs – slightly over two degrees per day – is obvious.

teeth of the comprehensive surveys that were already operating. The comet was around 11th magnitude when discovered, but brightened steadily over the coming weeks as it approached the sun and Earth, and by the latter part of November had become visible to the unaided eye from dark rural sites.

Comet Machholz was at its best in early January 2005, when it passed 0.35 AU from Earth on the 5th and passed two degrees west of the Pleiades star cluster (M45) – going from south to north – just a couple of days later. At that time the comet was slightly brighter than 4th magnitude and exhibited a coma half a degree in diameter; it also exhibited a faint ion tail up to two degrees long (visually) and a fainter, shorter dust tail.

After its passage by the Pleiades the comet remained detectable with the unaided eye until early March, at which time it was also passing five degrees from the North Celestial Pole. It continued fading after that, and I was able to follow it visually until the end of August, just beyond the one-year anniversary of its discovery.

Since that time Don has continued his visual comet hunting, and despite the competition from the comprehensive surveys he has managed to discover two more, a faint one in March 2010 and a somewhat brighter one as recently as November 2018. This latter one, which was independently discovered by two Japanese amateur astronomers using CCDs, is known as Comet Machholz-Fujikawa-Iwamoto C/2018 V1 and became slightly brighter than 9th magnitude as it approached perihelion in early December of that year. It was the first visual comet discovery in over eight years and shows that, perhaps, visual comet discovery may not entirely be a dead practice yet. Don, who is now 67 years old and who recently relocated to rural northwestern Arizona, continues to hunt for new comets, and, who knows? There conceivably could still be more Comets Machholz to come . . .



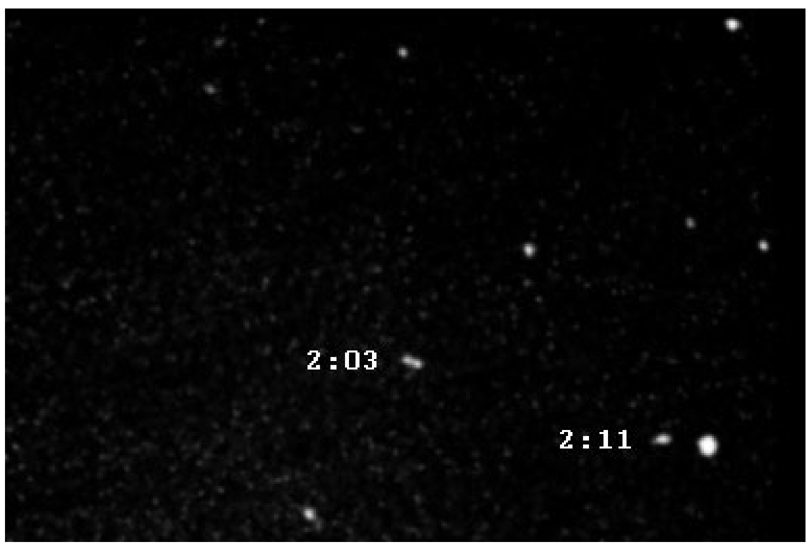
Ultraviolet image of Comet Machholz taken by NASA's GALaxy Evolution EXplorer (GALEX) spacecraft on March 1, 2005. The purple represents the hydroxyl molecule (OH) and the yellow represents the molecule CS. Image courtesy NASA/JPL-Caltech/University of Washington/Jeffrey Morgenthaler.

SPECIAL TOPIC: NEAR-EARTH ASTEROIDS

Last week's topic concerned the asteroids that occupy the so-called "main asteroid belt" between the orbits of Mars and Jupiter. The overwhelming majority of the first several hundred asteroids discovered, and, indeed, a large majority of the asteroids known today, reside in this region. However, as years went by and more and more asteroids kept being discovered, we started to find them in various other regions of the solar system. One of these regions, and which for obvious reasons is of high interest, is the inner solar system in and around the orbit of Earth, and the asteroids here are referred to – again, for obvious reasons – as the "near-Earth asteroids."

The first-known near-Earth asteroid was discovered in August 1898 and is now known as (433) Eros. It has a rather storied history, and will be the subject of its own "Special Topics" presentation in the near future. The next one was discovered in October 1911 by Johann Palisa at the Vienna Observatory in Austria and was given the number and name of (719) Albert; it had passed 0.21 AU from Earth four weeks before its discovery, but due to a short observing arc an accurate orbit could not be calculated and it was lost until it was re-discovered in May 2000. (It was subsequently identified on photographs taken in 1971, 1988, 1993, 1996, and 1997.)

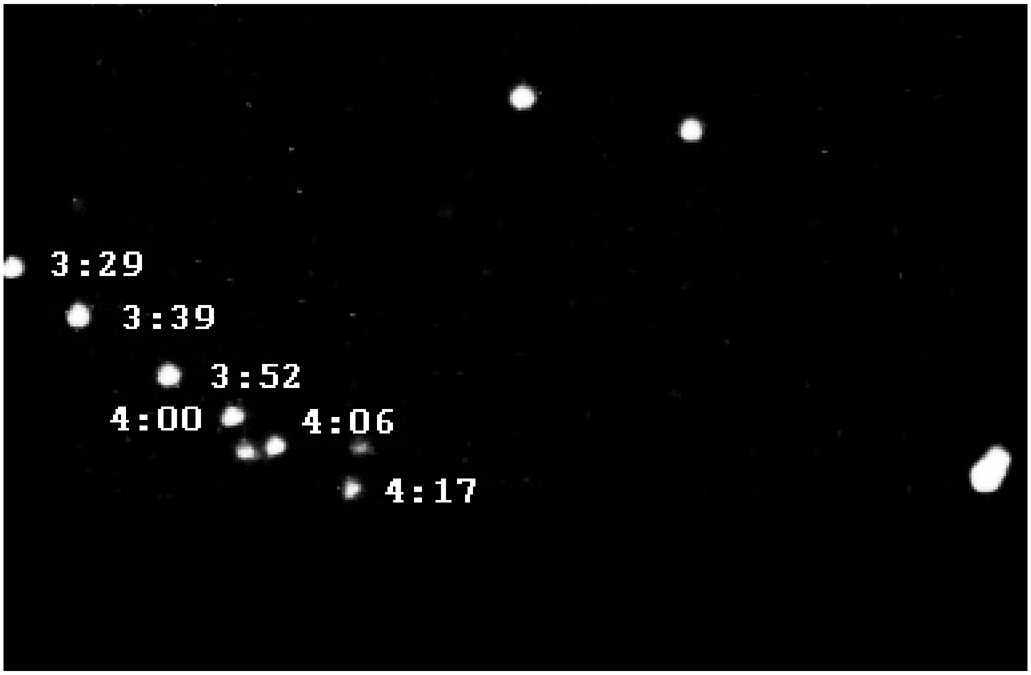
A third near-Earth asteroid, now known as (887) Alinda, was discovered by Max Wolf at Heidelberg Observatory in Germany in 1918, and a fourth, (1036) Ganymed, was discovered by Walter Baade at Bergedorf Observatory (also in Germany) in 1924. The 1930s saw the discoveries of several notable such asteroids: (1221) Amor, by Eugene Delporte at the Uccle Observatory in Belgium in March 1932; (1862) Apollo, discovered six weeks later by Karl Reinmuth at Heidelberg; (2101) Adonis, discovered by Delporte in February 1936; and (69230) Hermes, discovered by Reinmuth in October 1937. Apollo, which was lost until it was finally recovered in 1973, was the first known asteroid that came to within the orbit of Earth; Hermes, meanwhile, passed just 0.0050 AU (1.9 lunar distances) from Earth two days after discovery, a record known close approach which stood until 1989. It was only followed for four days, and was lost until its re-discovery in October 2003.



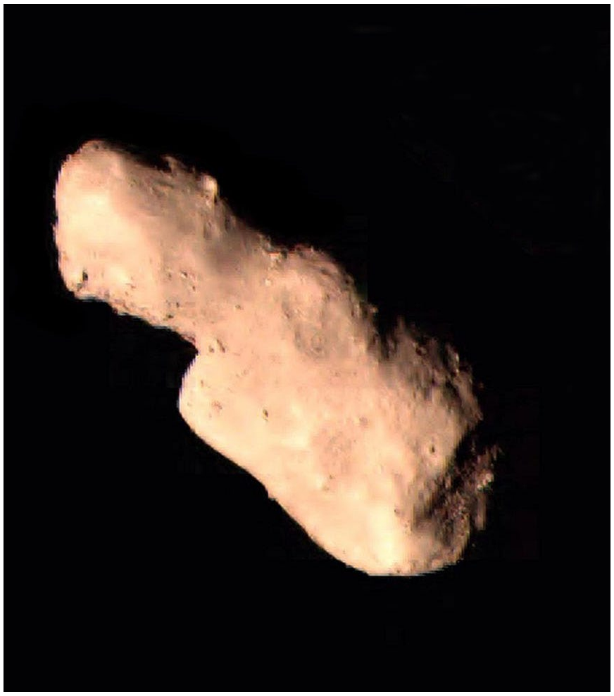
Two of the early known near-Earth asteroids during recent approaches to Earth. Left: (433) Eros on January 17, 2019, imaged with the Las Cumbres Observatory facility at McDonald Observatory in Texas. Eros is the bright "star" at lower left. Right: A time-tagged pair of "stacked" pair of images I took with the old Earthrise CCD system of (69230) Hermes on November 1, 2003 following its re-discovery the previous month. The asteroid's motion during the exposures is responsible for the apparent double images.

Over the next few decades various "fast-moving" near-Earth asteroids were occasionally discovered from time to time, almost every one of these receiving a fair amount of attention and fanfare. One of the most interesting such objects was discovered in June 1949 by Baade – now at Palomar Observatory in California – and was soon found to be traveling in an eccentric orbit (e = 0.83) with a perihelion distance of only 0.19 AU, slightly less than half of Mercury's average distance from the sun. Now known as (1566) Icarus, it has made some distinctly close approaches to Earth since then, including a highly publicized approach of 0.043 AU in June 1968 during which it became the first asteroid to be detected via radar and also started to introduce the concept of an impact threat into the public consciousness.

Starting in the early 1970s, geologist Eugene "Gene" Shoemaker and planetary astronomers Tom Gehrels and Eleanor "Glo" Helin – all somewhat independently of each other – initiated systematic searches for near-Earth asteroids, primarily utilizing the wide-field Schmidt photographic telescopes at Palomar, and before much longer the discovery rate of these objects began to climb rather rapidly. A most dramatic discovery came on January 7, 1976, when Helin discovered the first-known asteroid – now known as (2062) Aten – that has an average distance from the sun less than that of Earth's orbit and thus an orbital period of less than one year.



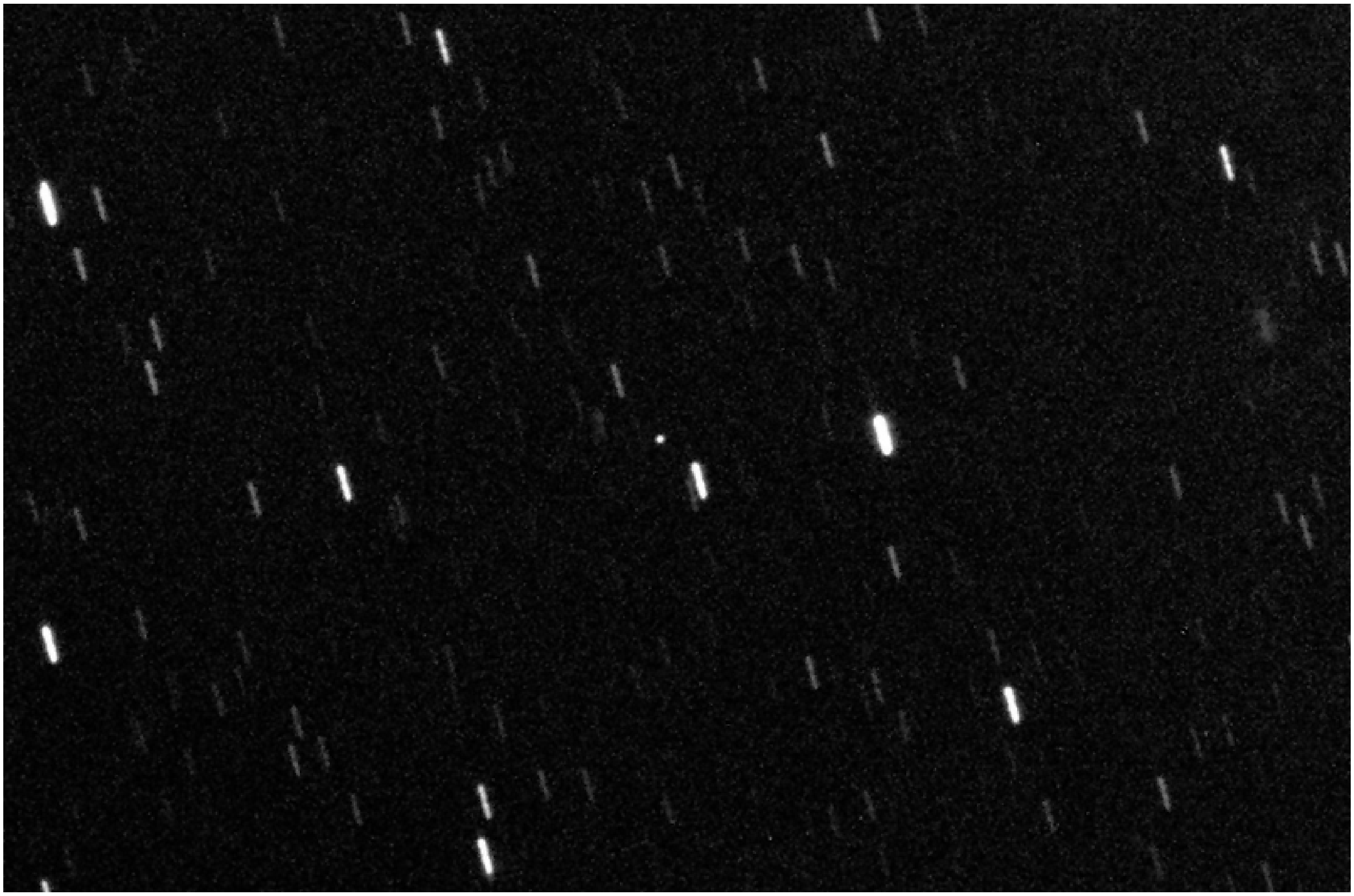
Two views of the Apollo asteroid (4179) Toutatis. Above: A series of time-tagged images taken with the old Earthrise CCD system during a very close approach to Earth in September 2004. Below: Close-up image taken by the Chinese Chang'e 2 spacecraft on December 13, 2012. Image courtesy China National Space Administration.



The first CCD-based survey program for near-Earth asteroids, called Spacewatch, was initiated by Gehrels in the early 1990s at Kitt Peak National Observatory in Arizona, and the discovery rate of these objects subsequently increased further. Then, the impacts of Comet Shoemaker-Levy 9 – discovered during the course of Shoemaker's photographic survey program, and which will be a future "Comet of the Week" – into Jupiter in July 1994 emphasized in a major way the threat that near-Earth asteroids (and comets as well) pose to our Earthly civilization and accordingly stimulated a wide public interest in this subject. A special commission chartered by the U.S Congress and chaired by Shoemaker was tasked to find the best ways to address this issue, with the report (which was delivered in 1995) finding that comprehensive survey programs that could accordingly detect the majority of threatening objects well in advance would be a prudent way to proceed.

The first of these comprehensive large-scale survey programs, the LIncon Near-Earth Asteroid Research (LINEAR) program developed by Lincoln Laboratory at the Massachusetts Institute of Technology and utilizing optical sensors developed by the U.S. Air Force, was based at White Sands Missile Range in New Mexico and went on-line in early 1998. Almost immediately the discovery rate of near-Earth asteroids exploded, with several being found every month. Since then various additional survey programs, with improved detection technology, automated motion-detection software, and other capabilities, have come on-line, and today dozens of near-Earth asteroids are discovered every month, most of these being rather small objects typically a few tens of meters in diameter. These various programs are discussed more thoroughly in a future "Special Topic."

Based upon their orbital characteristics, near-Earth asteroids are generally divided into four classifications. "Amor" asteroids have perihelion distances greater than Earth's aphelion distance but less than 1.3 AU, while "Apollo" asteroids have perihelion distances interior of Earth's orbit. A subset of the Apollo asteroids are the "Aten" asteroids, that have orbital periods of less than one year. A further subset of these are the



The Amor asteroid 2019 HC, imaged with the Las Cumbres Observatory facility at the South African Astronomical Observatory on April 16, 2019, slightly over 11 hours after its discovery by the ATLAS survey in Hawaii. Nine days later 2019 HC passed 0.21 AU from Earth.

"Atira" asteroids – named after the first confirmed member of the class, (163693) Atira, discovered by LINEAR in February 2003 – that have orbits entirely interior to that of Earth. Because of gravitational perturbations – including, certainly, by Earth – it is possible that an asteroid can shift from one of these classes to another; indeed, (99942) Apophis, which will pass just 31,000 km above Earth's surface on April 13, 2029, will shift from being an Aten asteroid to an Apollo asteroid in the process.

Near-Earth asteroids are, in general, smaller than their known counterparts in the main asteroid belt. The largest one, (1036) Ganymed, is approximately 35 km in diameter, and the second-largest, (433) Eros, is an oblong object 34 km by 11 km in size. Due to the comprehensive surveys, over 90% of the near-Earth asteroids larger than 1 km in diameter are now believed to have been discovered. As mentioned above, most of the objects being found by surveys today are significantly smaller, on the order of tens to hundreds of meters across.

The primary reason, of course, for the high interest in these objects is the potential threat they pose via impacts, and the "early warning" being provided by their discoveries at this time is a substantial aid in estimating and reducing that threat. This specific topic, including how the threat estimation works, will be a future "Special Topic." The smaller asteroids that are being found today present their own issues; while they may not present a threat on a global scale, they can still do so on a regional scale, however their small size makes them difficult to detect unless they are near Earth. The Atira asteroids also present issues, since they usually remain at small solar elongations and are usually only detectable when near aphelion – which even under the best of circumstances must take place at a relatively small elongation. For what it's worth, at this time the Atira asteroid with the smallest known orbit is 2019 LF6, which has an orbital period of only 151 days, a perihelion just inside Mercury's orbit and an aphelion just outside Venus' orbit. Its orbital inclination of 30 degrees makes it slightly easier to detect than it otherwise would be.

With all the near-Earth asteroids that are now known and that are being discovered, close approaches to Earth happen on almost a daily basis, although most of the asteroids involved are quite small and require large telescopes to be detected. Lists of approaching asteroids, both those that are previously known as well as those that have just been discovered, are maintained at, among other places, the Minor Planet Center's web site. Some of the brighter and/or more notable predicted approaches taking place this year include:

Asteroid	Approach distance (AU)	Date (2020)	Peak magnitude
(52768) 1998 OR2	0.042	April 29	11
(85184) 1991 JG1	0.150	May 4	15
(242450) 2004 QY2	0.163	July 8	14
(85275) 1994 LY	0.115	August 24	14
(159402) 1999 AP10	0.081	October 19	13
(7753) 1988 XB	0.066	November 22	15
*(162173) Ryugu	0.061	December 29	17

*Site of Hayabusa2 mission

When possible and appropriate, I will attempt to include observations of these – and any bright new discoveries – as exercises for "Ice and Stone 2020."

A handful of near-Earth asteroids have been visited by spacecraft, beginning with (433) Eros which was orbited by NASA's Near-Earth Asteroid Rendezvous (NEAR) Shoemaker mission in 2000-01. This mission, and others, including two that are ongoing at this time and more that are planned for the future, will be discussed in future "Special Topics" presentations.

ABOUT THE AUTHOR: ALAN HALE

Alan Hale was born in Tachikawa, Japan, in 1958 (as the son of a U.S. Air Force officer) but moved with his family later that year to Alamogordo, New Mexico, where he spent the remainder of his childhood years. He attended the U.S. Naval Academy, where he graduated with a Bachelor's Degree in Physics in 1980.

Hale began working at the Jet Propulsion Laboratory in Pasadena, California in 1983, as an engineering contractor for the Deep Space Network. While at JPL he was involved with several spacecraft projects, most notably the Voyager 2 encounter with the planet Uranus.

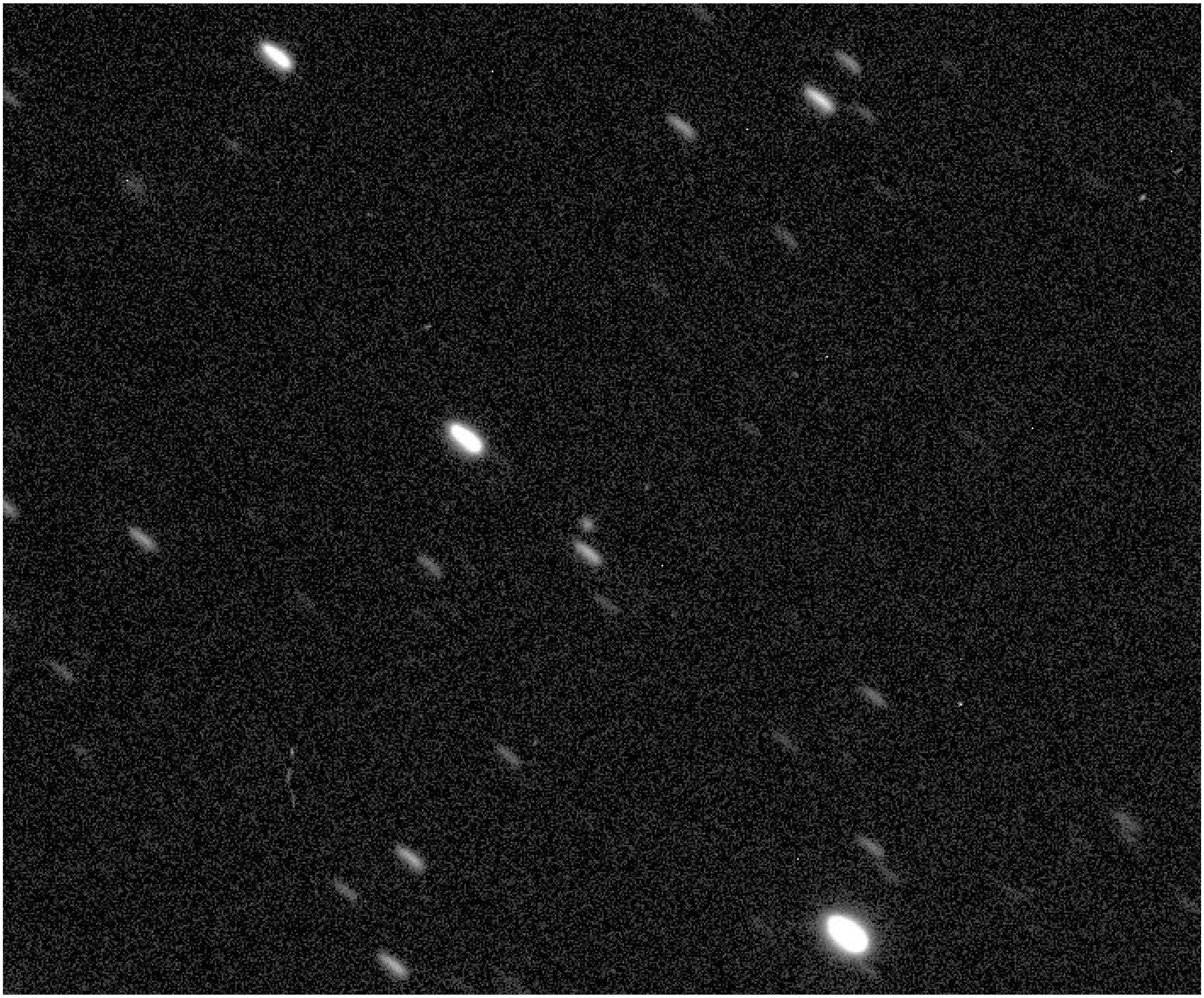
Following that encounter Hale left JPL and returned to New Mexico, enrolling in the Astronomy department at New Mexico State University. He earned his Master's Degree in 1989 and his Ph.D. in 1992 with a thesis entitled "Orbital Coplanarity in Solar-Type Binary Systems: Implications for Planetary System Formation and Detection." It was published in Astronomical Journal and has since become one of the seminal papers in early exoplanet research, with over 200 citations to date. Upon earning his doctorate he initially worked at The Space Center (now the New Mexico Museum of Space History) as its Staff Astronomer and Outreach Education Coordinator. In 1993 he founded the Southwest Institute for Space Research (now the Earthrise Institute). As an adjunct faculty member of the New Mexico Museum of Space History he developed and taught several of their astronomy-related educational activities. In early 2019 he taught classes for the International Space University's Southern Hemisphere Space Studies Program in Australia.

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 and his participation in the International HalleyWatch in 1986. In recent years he has worked to increase scientific collaboration between the U.S. and other nations, including Iran, Zimbabwe, and Lebanon.

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.

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. On clear nights he can often be found making observations of the latest comets or other astronomical phenomena.

SPECIAL ADDENDUM: LATE BREAKING NEWS



Asteroid 2020 AV2, imaged by the Las Cumbres Observatory facility at McDonald Observatory in Texas on January 7, 2020.

ASTEROID DISCOVERED INSIDE ORBIT OF VENUS

While, strictly speaking, it is not a "near-Earth" asteroid, an important asteroid has been discovered since I first put up this presentation. On January 4, 2020, the Zwicky Transient Facility survey, based at Palomar Observatory in California, discovered an 18th-magnitude object which was formally designated as 2020 AV2 when its discovery was announced on January 8. According to calculations 2020 AV2 is traveling in a moderately low-eccentricity orbit (0.18) with an orbital period of only 151 days -- tying it for the shortest period among known asteroids -- and an aphelion distance of only 0.654 AU, which is inside the orbit of Venus (perihelion distance 0.718 AU). 2020 AV2 thus becomes the first-known asteroid that orbits the sun entirely within the orbit of Venus.

Its overall brightness indicates that 2020 AV2 is approximately 1 to 2 km in diameter, unusually large for a previously-unknown asteroid in near-Earth space, but the fact that its elongation from the sun never exceeds much over 40 degrees undoubtedly has contributed to its not being found before now. There must certainly be other asteroids with similar orbits, but for the time being they will remain difficult to detect and discover.

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