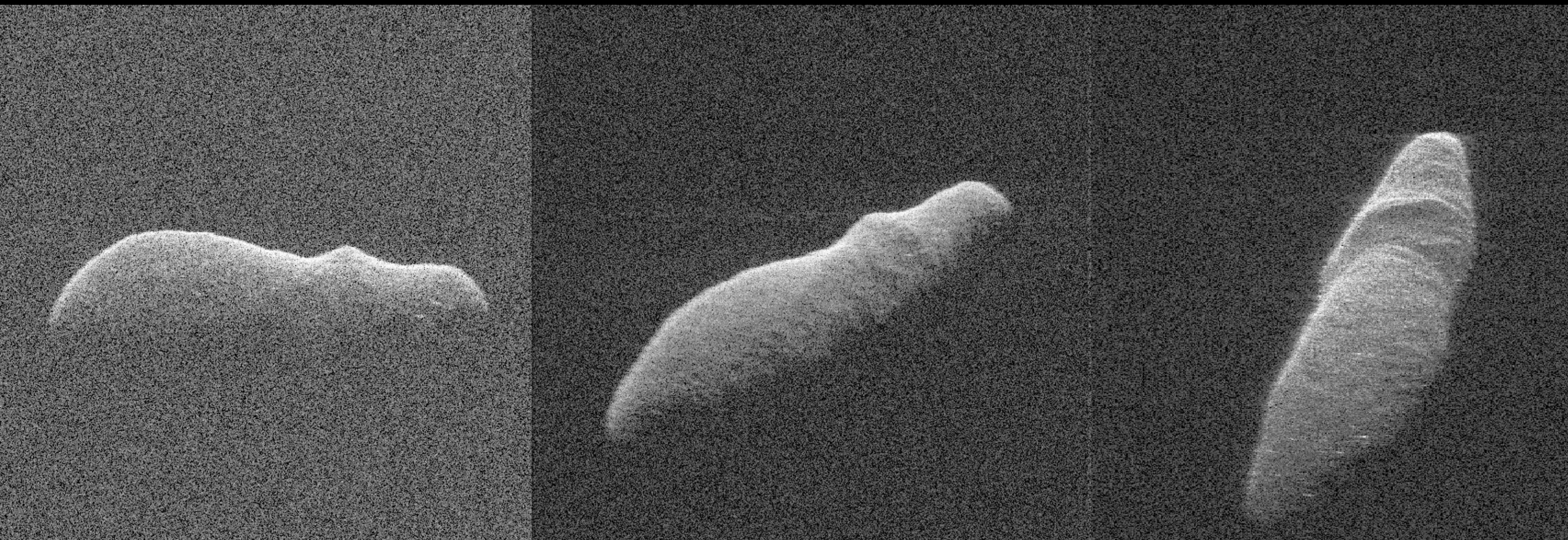
ICE & STONE 2020

Week 4: January 19-25, 2020

Presented by The Earthrise Institute



THIS WEEK IN HISTORY

JANUARY **19** 20 21 22 23 24 25

JANUARY 19, 2006: NASA's New Horizons mission is launched from Cape Canaveral, Florida. After a somewhat distant flyby of the main-belt asteroid (132524) APL in June 2006 and a gravity-assist encounter with Jupiter in February 2007, New Horizons encountered Pluto and its system of moons in July 2015 – providing our first detailed view of these objects in the process – and then the Kuiper Belt object (486958) Arrokoth in January 2019. New Horizons may be sent to an as-yet unidentified additional Kuiper Belt object and will eventually leave the solar system.

JANUARY 19, 2020: The main-belt asteroid (12712) 1991 EY4 will occult the 6th-magnitude star 23 Leonis. The predicted path of the occultation crosses the Kashmir region of northern India and northeastern Pakistan, northeastern Afghanistan, central Turkmenistan, southwestern Russia, central Ukraine, northeastern Poland, southern Denmark, northern Scotland, the southern tip of Greenland, and northern Quebec and east central Manitoba in Canada.

19 JANUARY **20** 21 22 23 24 25

JANUARY 20, 2016: Konstantin Batygin and Michael Brown publish their paper "Evidence for a Distant Giant Planet in the Solar System." In their paper Batygin and Brown propose that a hypothetical "Planet Nine" – a few times more massive than Earth – resides in the outer solar system a few hundred AU from the sun, basing their conclusions on dynamical studies of smaller objects that have been discovered in the outer solar system. To date, no "Planet Nine" has yet been detected, although searches are continuing. These outer solar system objects, and their relationship to this possible "Planet Nine," constitute the subject of a future "Special Topics" presentation.

NO CALENDAR EVENTS FOR JANUARY 21 AND 22.

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.

19 20 21 22 JANUARY 23 24 25

JANUARY 23, 1930: Clyde Tombaugh takes the first discovery photograph of Pluto from the Lowell Observatory in Arizona. Pluto is the subject of a future "Special Topics" presentation.

JANUARY 23, 1975: The near-Earth asteroid (433) Eros passes 0.151 AU from Earth, the closest it has approached Earth thus far since its discovery in 1898, becoming as bright as 7th magnitude in the process. Eros is the subject of this week's "Special Topics" presentation.

JANUARY 23, 1985: Steve O'Meara obtains the first visual observations of Comet 1P/Halley during its 1986 return with a 61-cm telescope at Mauna Kea Observatory in Hawaii. The comet was a stellar object near magnitude 19 ½ at the time, and these are the faintest visual observations ever recorded of a comet. The history of Comet Halley, and its 1986 return, are the subjects of future presentations.

19 20 21 22 23 JANUARY 24 25

JANUARY 24, 2020: The main-belt asteroid (1390) Abastumani will occult the 7th-magnitude star 41 Aurigae. The current predicted path of the occultation crosses the south-central U.S. from southeast to northwest, extending from southeastern Georgia through northern California, and then across the central Pacific Ocean, including the Majuro and Jaluit Atolls of the Marshall Islands.

JANUARY 24, 2056: The near-Earth asteroid (433) Eros will pass 0.150 AU from Earth, the next close approach to Earth and marginally closer than the approach in 1975.

19 20 21 22 23 24 JANUARY 25

JANUARY 25, 1983: The InfraRed Astronomical Satellite (IRAS) spacecraft is launched from Vandenberg Air Force Base in California. During its ten-month lifetime before its superfluid helium coolant ran out, IRAS discovered six comets plus the potential "extinct" comet (3200) Phaethon, an extensive dust tail accompanying comet 10P/Tempel 2, dust disks around several nearby stars, and many other discoveries which completely revolutionized much of our knowledge of the universe.

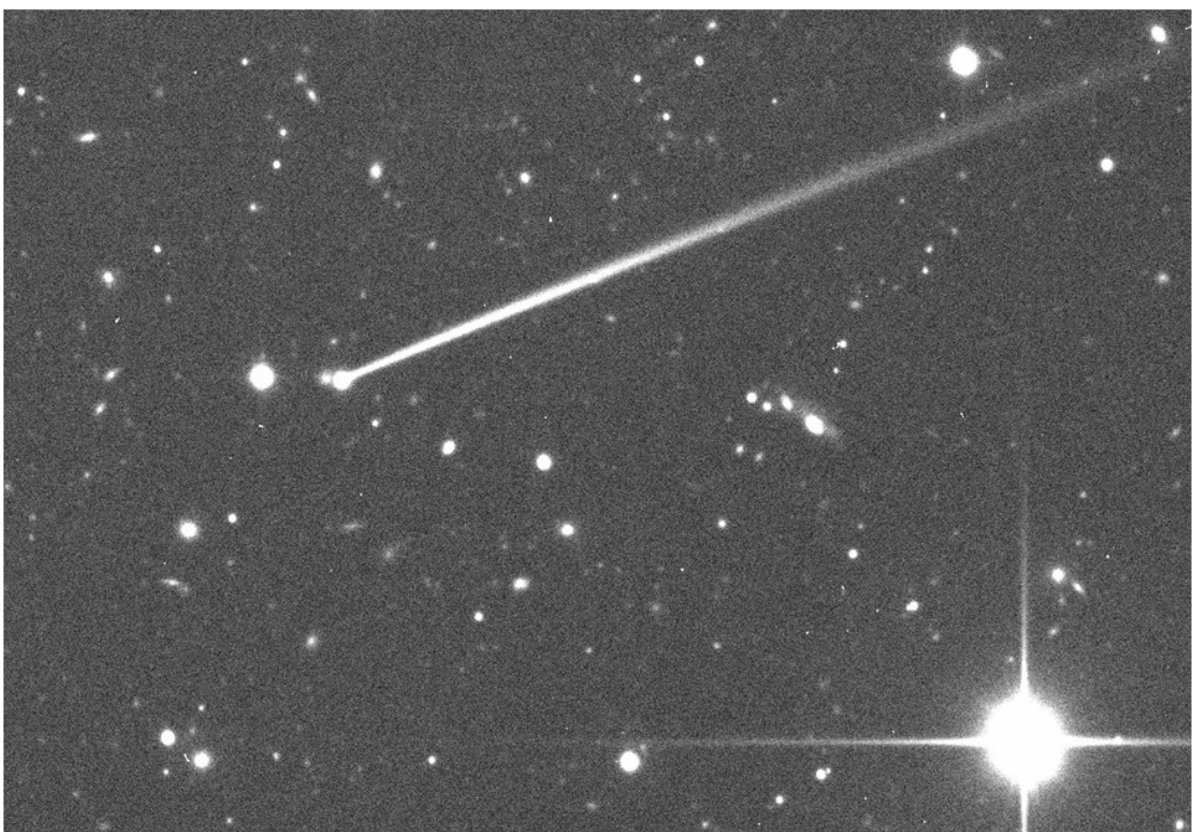
COMET OF THE WEEK: (6478) GAULT

Perihelion: 2020 January 2.79, q = 1.859 AU

It has been obvious for several decades that the dividing line between "comets" and "asteroids" is, in a word, nebulous, and some facets of this will be explored in future "Special Topics" presentations. One group of objects that are included within this discussion were initially referred to as "main belt comets," so called because they are objects traveling in near-circular orbits within the main asteroid belt that nevertheless have exhibited behavior typical of active comets. That term has now been largely supplanted by the term "active asteroids," which among other things recognizes that there are objects under this umbrella that orbit outside the main asteroid belt. The activity exhibited by some of these objects does genuinely seem to be due to the sublimation of volatiles that is typical of comets, but the activity exhibited by other such objects appears to be due to various other mechanisms. The entire subject of "active asteroids" is the topic of a future "Special Topics" presentation.

One of the most dramatic examples of an "active asteroid" is an object discovered on May 12, 1988 – and provisionally designated as 1988 JC1 – by Carolyn and Eugene Shoemaker during the course of their photographic survey for near-Earth asteroids conducted from Palomar Observatory in California. After several observations over the next few years – including an accidental "re-discovery" from Catalina Observatory in Arizona in May 1995 – it received the permanent number (6478) in July 1995, and in July 1999 it was officially named "Gault" in honor of planetary geologist Donald Gault who was an expert in impact and cratering processes on planetary bodies. Gault is apparently a stony-type asteroid approximately 4 km in diameter; it orbits within the inner regions of the main asteroid belt in a low-eccentricity orbit (0.19) with an orbital period of 3.50 years.

For the first two decades following its discovery Gault apparently behaved as a seemingly "ordinary" asteroid. However, on January 5, 2019, an image taken during the course of the ATLAS survey in Hawaii showed that Gault was accompanied by a bright, straight tail-like structure over two arcminutes long. Several images taken elsewhere, including a Las Cumbres Observatory image that I took on January 8, confirmed this feature, and in fact I measured it as being slightly over four arcminutes in length.



The image which first indicated the activity on Gault, taken January 5, 2019, during the course of the ATLAS program in Hawaii. Courtesy Ken Weiland and ATLAS.

The confirming image I took with the 1-meter telescope of the Las Cumbres Observatory facility at the South African Astronomical Observatory on January 8, 2019.

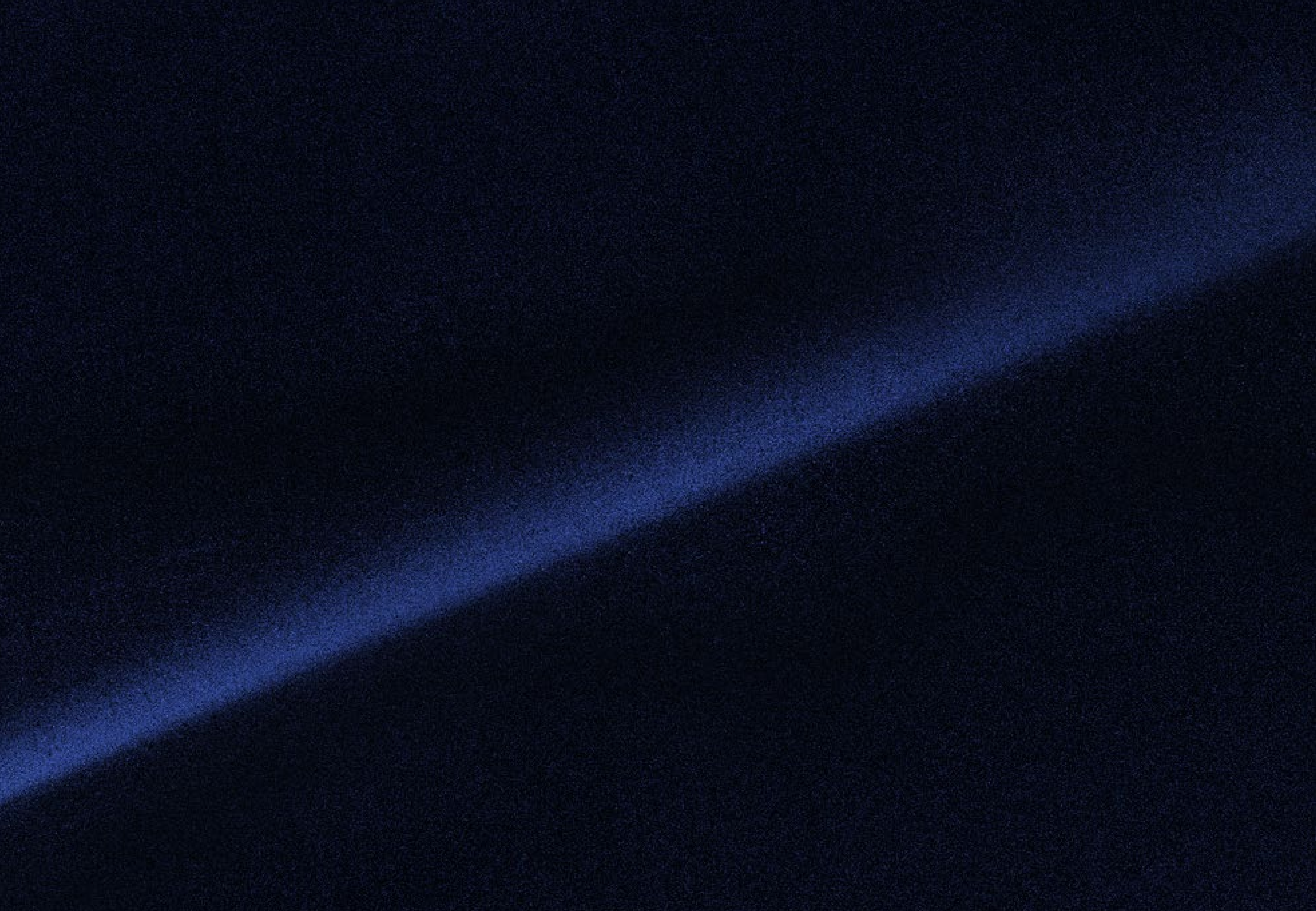
This "tail" remained relatively constant in appearance and brightness for the next few weeks, however in late January another tail, brighter than the first one, appeared to the north of the original tail and oriented about ten degrees in position angle relative to it. Numerous observatories around the world followed the development of this second tail, and in early February Gault was imaged with the Hubble Space Telescope.

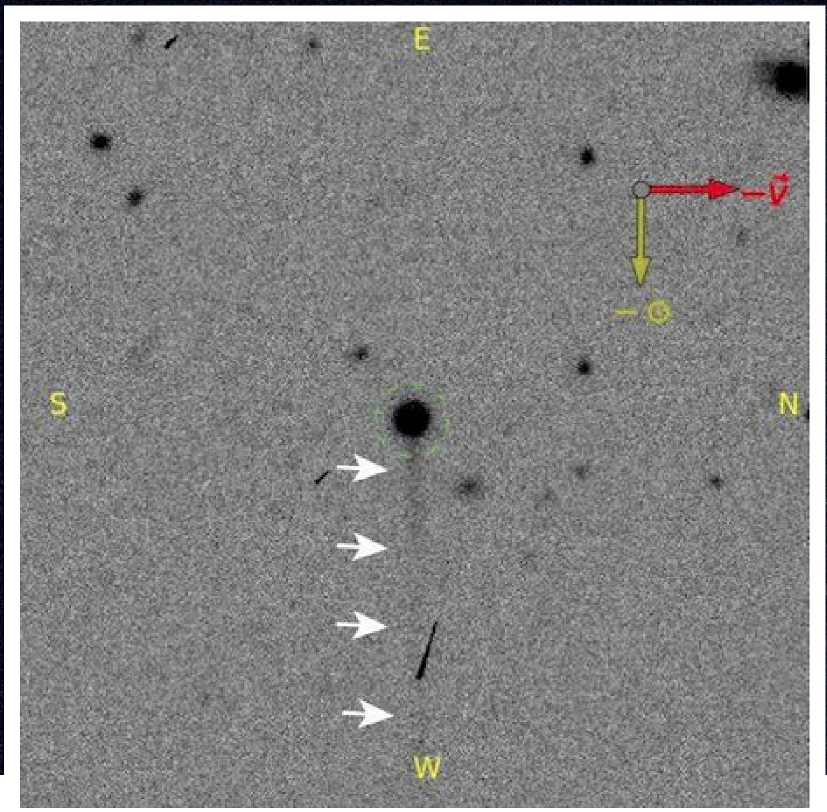
Analysis of all the data about Gault does not indicate the presence of any gaseous emissions but instead indicates that the tails are composed entirely of dust. The Hubble data in particular suggests that the dust was ejected in October 2018 as a result of a rapid rotation, with this rapid rotation being due in turn to a phenomenon known as 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. Ground-based infrared observations obtained in March 2019 indicate that Gault was changing color – from reddish to bluish – apparently due to sun-exposed red dust being spewed off by the rapid rotation and in turn exposing the bluer surface underneath.

On the other hand, a recent study conducted by a team led by Colin Chandler of Northern Arizona University of archived images taken by the Dark Energy Camera (DECam) at Cerro Tololo Inter-American Observatory in Chile has revealed that Gault has been more-or-less undergoing sustained activity since September 2013 – the activity shown in the images not being noticed at the times they were taken. This long period of sustained activity suggests at the very least that the mechanism driving the activity is complex, and may mean, in the words of Chandler and his colleagues, that "Gault represents a new class of object, perpetually active due to rotational spin-up."

Gault was near opposition, and about 18th magnitude, around the time its activity was observed in early 2019. It has recently passed through perihelion but, having been in conjunction with the sun last November, is still low in the dawn sky for observations but should be accessible within another couple of months. When at opposition in late September it should be close to 17th magnitude. For what it's worth, at the time of its next perihelion passage in early July 2023 Gault will be only one month past opposition and will be well placed for observation.

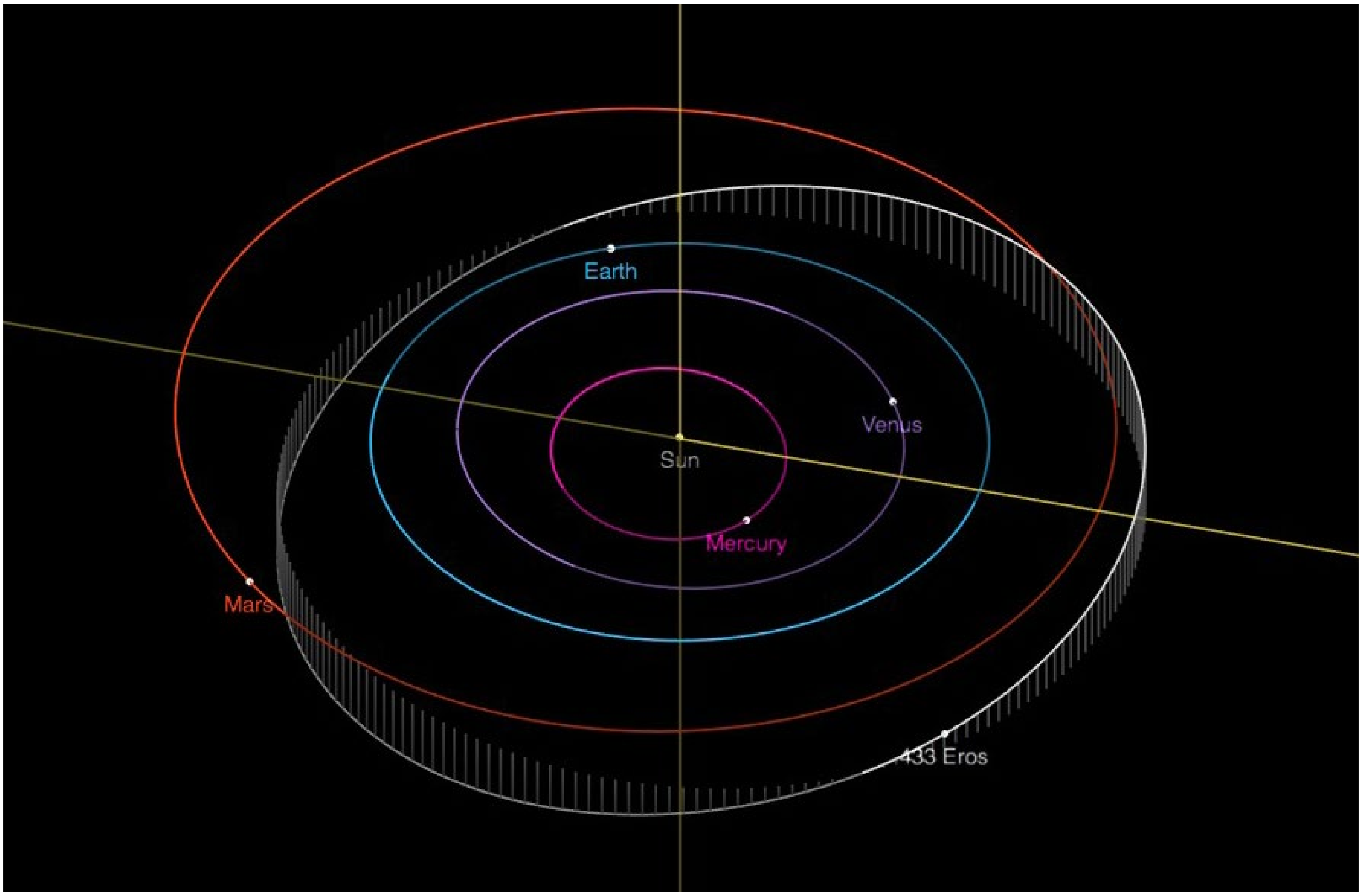
Hubble Space Telescope image of Gault obtained February 5, 2019, showing the two tails. Courtesy NASA, ESA, Karen Meech and Jan Kleyna (University of Hawaii) and Olivier Hainaut (European Southern Observatory)





DECam image from September 28, 2013 showing tail activity on Gault. Image courtesy Chandler et al. (2019)

SPECIAL TOPIC: (433) EROS

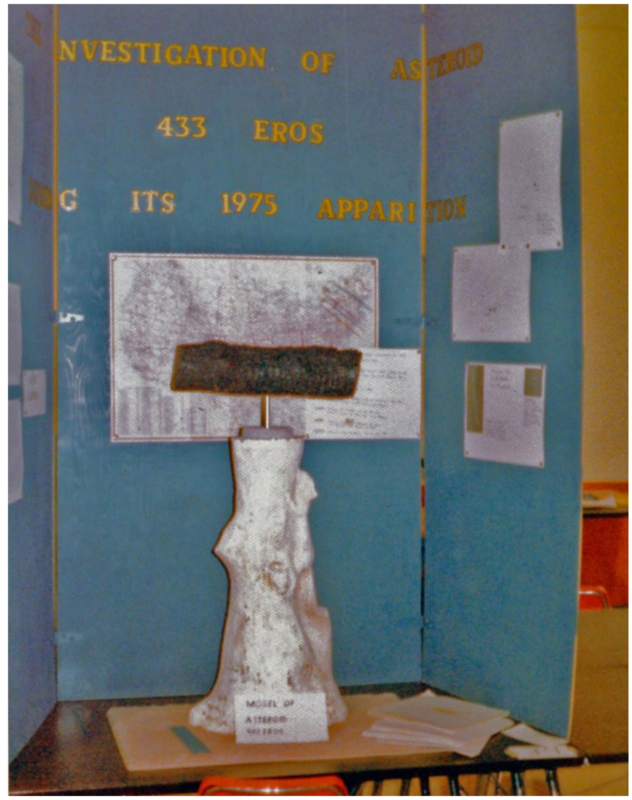


3-D graphical representation of Eros' orbit. The positions of Eros and the planets are indicated for January 19, 2020. Courtesy JPL Solar System Dynamics.

Two weeks ago I devoted the "Special Topics" presentation to the subject of near-Earth asteroids. Up until almost the end of the 19th Century all of the over 400 asteroids that had been discovered up to that time orbited within the "main asteroid belt" between Mars and Jupiter, and the astronomers of that era were quite surprised when an asteroid was found that could approach quite closely to Earth. As I discussed in that presentation, during the century and a quarter that has elapsed since then we have discovered that a rather large population of asteroids exists in near-Earth space, and in other regions of the solar system as well.

The asteroid that would create this paradigm shift was discovered on August 13, 1898, by Gustav Witt at the Berlin Observatory in Germany – on a photograph that he had taken of the asteroid (185) Eunike for astrometric purposes – and independently that same night by Auguste Charlois at Nice Observatory in France. Calculations soon revealed that it is traveling in a small, moderately elongated orbit (eccentricity 0.223) with a period of only 1.76 years (21 months) that brings it to 1.133 AU from the sun at perihelion and out to 1.783 AU – somewhat beyond the orbit of Mars – at aphelion. These calculations also revealed that it could approach the Earth moderately closely on occasion, indeed it had passed only 0.152 AU from Earth in January 1894, 4½ years before its discovery. (It was actually only two months past aphelion when discovered.) The newly-discovered asteroid was given the name Eros, after the Greek god of love.

Eros was soon found to be exhibiting short-term periodic variations of its brightness, which are indicative of rotation and of its being oblong in shape. By 1913 Solon Baley at Harvard had determined an accurate rotation period, now firmly established as being 5 hours 16 minutes. Its physical dimensions have now been accurately determined as being 34 km by 11 km by 11 km, and when oriented such that we are seeing it "pole-on" its brightness can vary by as much as 1.5 magnitudes.



The display of my High School Science Fair project on Eros, circa March-April 1975.

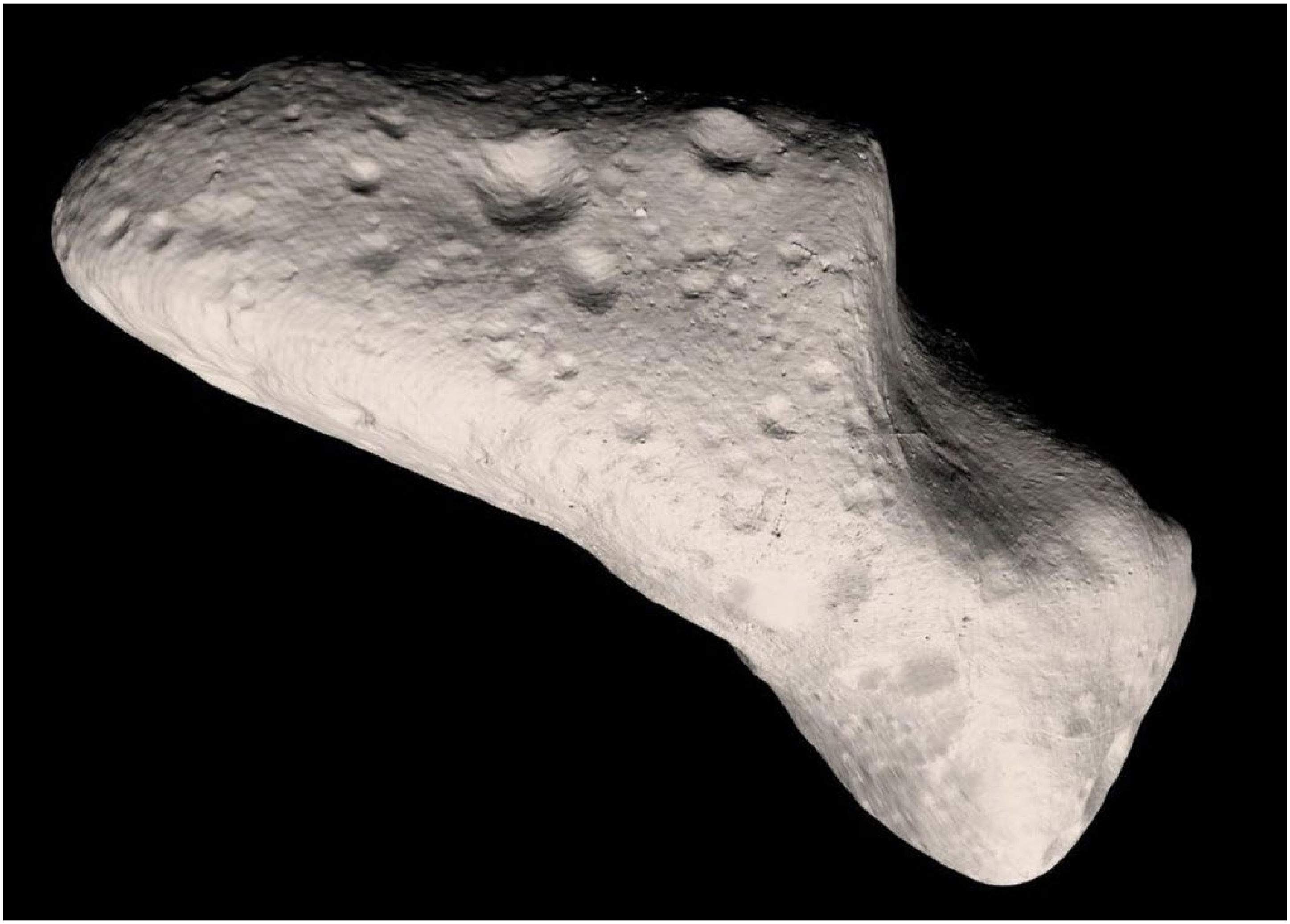
During the first few decades after its discovery Eros would play a key role in our understanding of the overall universe. It comes close enough to Earth such that observers stationed at different locations can determine a measurable parallax, and thus an accurate distance to it. By applying Kepler's Third Law, and Isaac Newton's Law of Universal Gravitation (from which Kepler's Third Law can be derived), it can then be possible to determine an accurate estimate of the total mass of the Earth/moon system, and – even more fundamentally – an accurate measurement of the exact size of an Astronomical Unit. This in turn establishes a solid foundation for the determination of distances for objects in the solar system, and also for parallax measurements and resulting distance determinations for nearby stars. These are the first "rungs" of the "cosmic ladder" by which it is then possible to determine distances to objects throughout the entire universe.

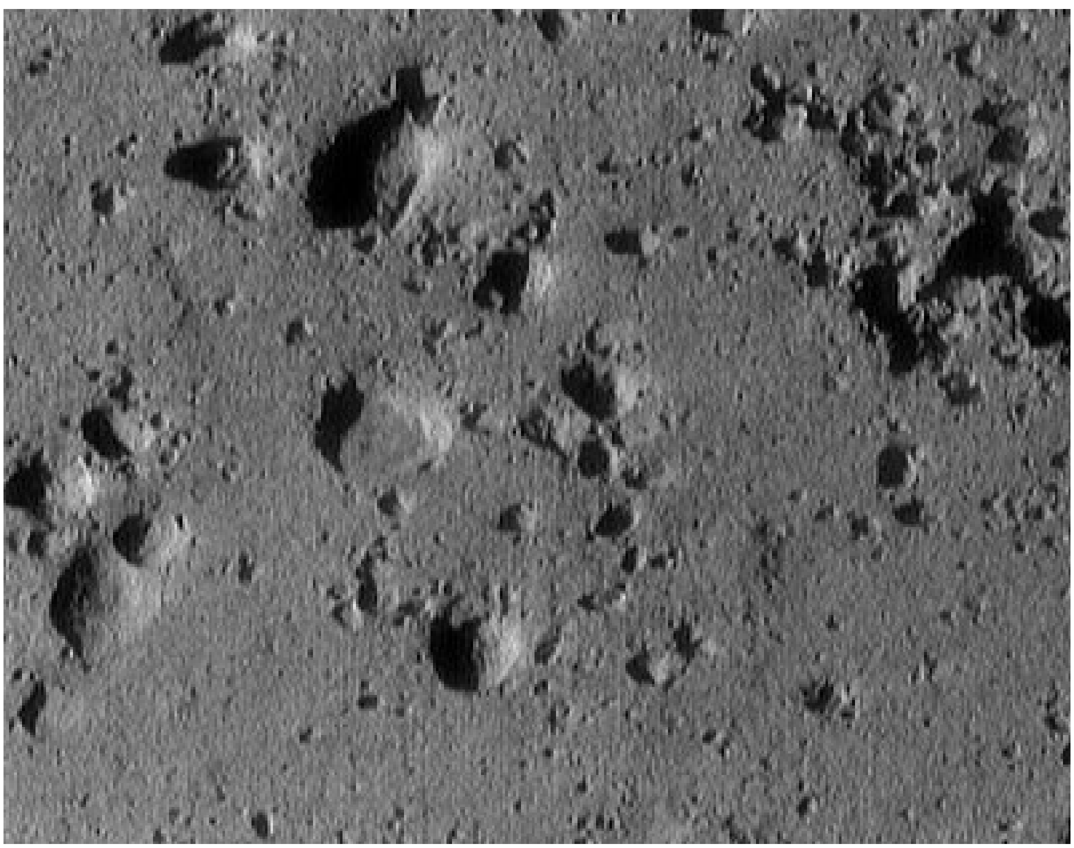
Eros made a moderately close approach to Earth (0.315 AU) in December 1900, and Arthur Hinks of Cambridge University was able to use parallax measurements obtained then to make a reasonably accurate determination of an AU. When Eros made its first post-discovery near-Earth encounter of 0.174 AU in January 1931, British astronomer Harold Spencer Jones (who would soon become Astronomer Royal, the Director of the Royal Observatory in Greenwich) was able to refine the determination of the exact size of an AU to a rather high degree. This determination remained the defining value of an AU until radar measurements in the late 1960s, and then spacecraft measurements, superseded it. The exact value of an AU has now been determined to be 149,597,870.7 km (92,955,807.3 miles).

On January 23, 1975, Eros passed 0.151 AU from Earth, the closest it has come to our planet since its discovery, and in the process it became as bright as 7th magnitude. That encounter allowed for the most accurately-determined values of the rotational period as of that time, as well as of the determination of Eros' physical dimensions. On the very evening after its closest approach Eros occulted the 4th-magnitude star Kappa Geminorum, one of the earliest and most-publicized events of this nature; the occultation was successfully observed from locations in Massachusetts and Connecticut and among other things this event provided valuable lessons in the art of predicting such occurrences.

The 1975 approach of Eros to Earth was an important event to me personally, as in a very real sense it produced my "breakout" astronomical study. I was in my Junior year of High School (11th Grade) at the time, and under the mentorship of local amateur astronomer Phil Simpson – who passed away a year and a half ago – I was able to gain access to the local school district's observatory (which housed a 32-cm reflector) and, at his suggestion, carry out several scientific observations of Eros. These included a measurement of its rotation period via observations of its brightness variations, a determination of its brightness parameters, and I even took a stab at predicting the path of the occultation of Kappa Geminorum. I entered my investigation into the Science Fair competition, and to my rather excited delighted, won First Place in the Earth and Space Science Division at the Local, Regional, and State Science Fairs as well as various other rewards. More importantly, I was able to meet Herb Beebe, then-chairman of the Astronomy Department at New Mexico State University (and who was one of the judges at the Regional Fair); our ensuing conversation turned into a longstanding friendship which in turn played a non-trivial role in my decision over a decade later to enter graduate school at NMSU. Incidentally, the display of my Science Fair project featured a log, spray-painted black and mounted on top of a birdbath pedestal, to portray Eros; this was to demonstrate both Eros' elongated shape and its overall dark surface.

Eros would enter the news again near the end of the 20th Century, as it was the destination of NASA's Near Earth Asteroid Rendezvous (NEAR) mission – later renamed "NEAR Shoemaker" in honor of renowned planetary geologist Eugene "Gene" Shoemaker, who was killed in an auto accident in July 1997. NEAR Shoemaker was launched from Cape Canaveral,





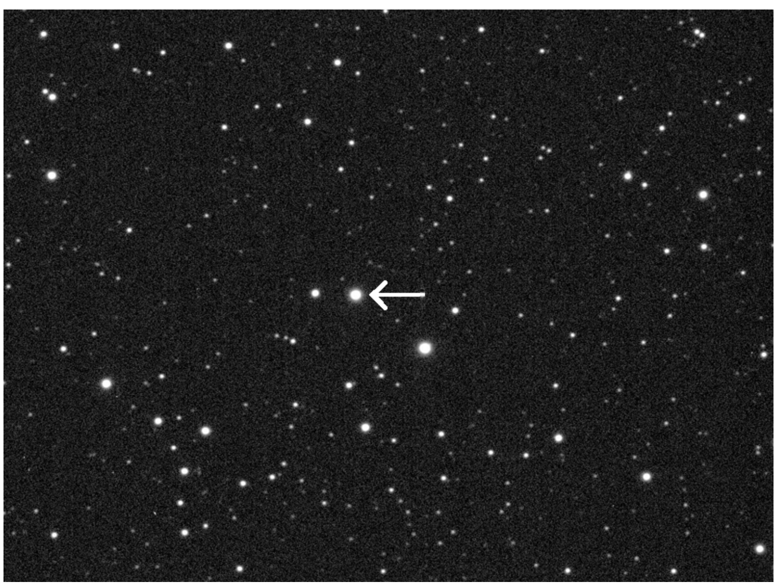
Images of Eros taken by NEAR Shoemaker. ABOVE: February 14, 2000, near the time of orbital insertion. RIGHT: View from 250 meters above the surface, taken during the touchdown descent on February 12, 2001; the field of view is approximately 12 meters across. Both images courtesy NASA.

Florida on February 17, 1996, and after an encounter with the main-belt asteroid (253) Mathilde on June 23, 1997 and a gravity-assist flyby of Earth on January 23, 1998, it was planned for arrival at and orbital insertion around Eros in January 1999. Unfortunately, an aborted engine burn in December 1998 forced a one-year postponement of this, although NEAR Shoemaker was able to make a distant flyby of Eros (3800 km) later in December.

NEAR Shoemaker arrived at Eros in February 2000 and successfully went into orbit around it on February 14. For the next twelve months NEAR Shoemaker orbited Eros in a variety of distances and orbital configurations, in the process extensively photographing and mapping the surface and making numerous scientific measurements. Among many other features, the images show one large crater, since named Charlois Regio, that appears to be due to an impact that took place about one billion years ago; this event appears to be responsible for the many of the large boulders strewn across Eros' surface as well as the lack of small craters over a significant percentage of the surface. After one year, and as its supply of maneuvering fuel was beginning to run out, NEAR Shoemaker descended to Eros surface on February 12, 2001 and performed a soft landing onto the surface – becoming in the process the first spacecraft to make a successful soft landing onto an asteroid or other small body. It continued transmitting data for two more weeks before it was shut down.

Since that time Eros has made two additional somewhat close approaches to Earth: one of 0.179 AU on January 31, 2012 and the other being 0.209 AU on January 15, 2019. It does not approach Earth again for quite some time, although due to its relative closeness and large size it is often nevertheless detectable without much difficulty under appropriate conditions; for example, it will be 13th magnitude, and accessible in the morning sky, when at perihelion in early November this year, and will be 12th magnitude when it is next at opposition, in mid-June 2021, at which time it will be three months away from aphelion.

Eros will next approach Earth again on January 24, 2056, when it will pass 0.150 AU from our planet – marginally closer than its 1975 approach. I would be 97 years old at the time, and when I pointed this out to some of my science-minded friends when I was in High School one of them jokingly replied that perhaps I could do another Science Fair project on it then. I suppose we will have to see about that . . . But, perhaps, the students of that era could perform their own investigations of Eros when it makes its approach. And, perhaps, some of them might even be able to do so by journeying out to it and making observations from its surface . . .



Two images of Eros I took around the time of its 2019 approach to Earth. LEFT: Las Cumbres Observatory (facility at McDonald Observatory in Texas) image taken on October 10, 2018. RIGHT: slightly out-of-focus DSLR photograph taken on November 27, 2018. The line of stars known as "Kemble's Cascade" and the open star cluster NGC 1502 are at the upper left.

www.earthriseinstitute.org/is20home.html

www.iceandstone.space