ICE & STONE 2020

WEEK 31: JULY 26-AUGUST 1

Presented by The Earthrise Institute

#31

Authored by Alan Hale

THIS WEEK IN HISTORY

JULY 28, 2014: The Pan-STARRS program in Hawaii discovers the centaur designated as 2014 OG392; it has an orbital period of 42.8 years and will pass perihelion in November 2021 at a heliocentric distance of 10.0 AU. An observational analysis published earlier this year indicates sustained cometary activity, however this report was published too late to be discussed in the "Special Topics" presentation on centaurs.

JULY 28, 2061: Comet 1P/Halley will pass through perihelion at a heliocentric distance of 0.593 AU. The viewing geometry of this return is not especially favorable, although the comet should briefly become rather bright; this is discussed in this comet's "Special Topics" presentation.

JULY 29, 1999: NASA's Deep Space 1 spacecraft passes by the Mars-crossing asteroid (9969) Braille. Deep Space 1 was a technology test bed mission and while software problems prevented any close-up images of Braille from being obtained, some more distant images were successfully taken. Deep Space 1 is discussed in a previous "Special Topics" presentation.

JULY 29, 2005: The IAU's Minor Planet Center officially announces the discoveries of the large Kuiper Belt worlds (and now "dwarf planets") now known as (136108) Haumea, (136199) Eris, and (136472) Makemake. Among other things, these discoveries forced a re-thinking of the definition of "planet," which is discussed in the "Special Topics" presentation on Pluto two weeks ago. These objects, and the Kuiper Belt as a whole, are discussed in a future "Special Topics" presentation.

JULY 30, 2020: The main-belt asteroid (503) Evelyn will occult the 7th-magnitude star HD 100974 in Leo. The predicted path of the occultation crosses southeastern New South Wales, the northern part of New Zealand's South Island, Pitt Island, and the southern part of Chatham Island.

COVER IMAGE CREDIT:

Front and back cover: In this 30 second exposure taken with a circular fish-eye lens, a meteor streaks across the sky during the annual Perseid meteor shower as a photographer wipes moisture from the camera lenses Friday, August 12, 2016 in Spruce Knob, West Virginia.

Courtesy NASA/Bill Ingalls

26 27 28 29 30 JULY 31 1

JULY 31, 2020: The main-belt asteroid (2365) Interkosmos will occult the 6th-magnitude star Theta Arietis. The predicted path of the occultation crosses the eastern Atlantic Ocean, the Brittany region of France, and southern England, including the northern parts of London.

26 27 28 29 30 31 AUGUST 1

AUGUST 1, 1729: The French scientist Nicolas Sarabat discovers a comet (new style designation C/1729 P1) that is visible to the unaided eye despite a perihelion distance of 4.05 AU. Intrinsically, this is the brightest comet ever recorded in history.

AUGUST 1, 1957: Comet Mrkos 1957d passes through perihelion at the heliocentric distance of 0.355 AU. Comet Mrkos was the second bright naked-eye comet to appear in 1957, and is a future "Comet of the Week."

AUGUST 1, 1980: An astronomer in Uruguay, Julio Fernandez, revives an idea, initially proposed in the late 1940s and early 1950s independently by Irish engineer Kenneth Edgeworth and American planetary scientist Gerard Kuiper, of a large population of bodies beyond Neptune's orbit, and proposes it as being the source of short-period comets in the inner solar system. The existence of this "Kuiper Belt" was observationally verified a little over a decade later, and is the subject of a future "Special Topics" presentation.

AUGUST 1, 2008: The path of a total solar eclipse crosses far northern Canada, northern Greenland, central Russia, western Mongolia, and northern China. During totality, observers in two locations (Russia and Mongolia) successfully record images of the small Kreutz sungrazing Comet C/2008 O1, discovered the previous day by the NASA/ESA SOlar and Heliospheric Observatory (SOHO) spacecraft. "Eclipse comets" are the subject of a previous "Special Topics" presentation (which includes an image of this comet), and Kreutz sungrazers are the subject of a future "Special Topics" presentation.

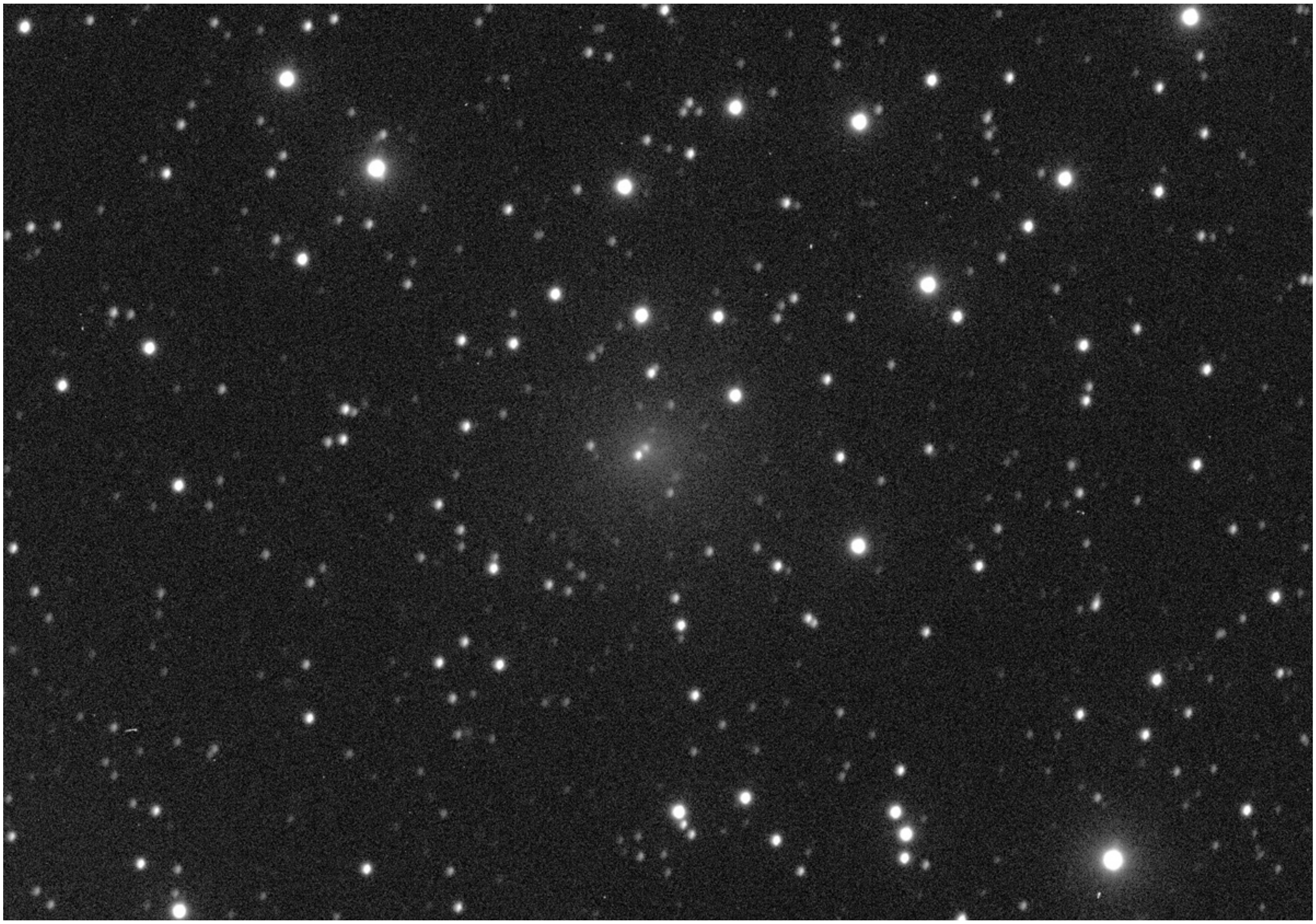
COMET OF THE WEEK: NEOWISE C/2020 F3

Perihelion: 2020 July 3.68, q = 0.295 AU

A photograph I took of Comet NEOWISE during evening sky on July 21, 2020. I had hoped to photograph the comet the following night – the 25th anniversary of my discovery of Comet Hale-Bopp – but was clouded out.

For the second time during the course of "Ice and Stone 2020" I have found it appropriate to swap out my originally intended "Comet of the Week" for a comet currently appearing in our skies. For the past three weeks Comet NEOWISE has been putting on a splendid show in the northern hemisphere's nighttime sky, the best cometary display that those of us in the northern hemisphere have seen in over two decades. I consider it a borderline "Great Comet."

In some of the previous "Special Topics" presentations I have discussed NASA's Wide-field Infrared Survey Explorer (WISE) spacecraft, which was launched on December 14, 2009, and which then spent the next ten months surveying the entire sky at four different infrared wavelengths. During that time it made many important discoveries of astronomical objects both within and beyond the solar system; among these were 17 comets as well as the first-known "Earth Trojan" asteroid, 2010 TK7. (Trojan asteroids are the subject of a future "Special Topics" presentation.) After WISE's solid hydrogen coolant ran out in October 2010 it remained a healthy spacecraft, with two of its infrared detectors (at the shorter wavelengths) still active, and after a period of hibernation WISE was reactivated in 2013 and, under the mission name NEOWISE (for "Near Earth Object Wide-field Infrared Survey Explorer"), was tasked with the primary mission of surveying the sky for potentially threatening objects in Earth's vicinity. Since then it has discovered



Comet NEOWISE on April 25, 2020, as imaged by the Las Cumbres Observatory facility at Siding Spring Observatory in New South Wales.

approximately 200 Earth-approaching asteroids as well as 15 additional comets.

NEOWISE discovered its most recent comet on March 27, 2020, at which time it was located near a declination of -49 degrees in the southern constellation Carina and about 16th or 17th magnitude. It brightened rapidly and by mid-April was close to 13th magnitude, and in fact I succeeded in observing it a couple of times very low in my southwestern evening sky before it dropped below my horizon. Observers in the southern hemisphere were able to follow it for almost another two months, and it had brightened further to almost 7th magnitude by the time it disappeared into evening twilight in early June.

From June 22 through 28 Comet NEOWISE traversed the southwestern quadrant of the field of view of the LASCO C3 coronagraph aboard the NASA/ESA SOlar and Heliospheric Observatory (SOHO) spacecraft. Initially around 4th magnitude when it first appeared, the comet brightened steadily and was close to 2nd magnitude, and exhibiting an ion tail as well as a distinct (albeit foreshortened) dust tail, by the time it exited the LASCO field early on the 28th. Although the comet was then located on the far side of the sun as seen from Earth, the stage was now set for its impending appearance in the northern hemisphere's skies.

The first ground-based observations were reported as early as July 1, at which time Comet NEOWISE was very deep in twilight. I saw it on the morning of July 3 – the day of perihelion passage – and despite being at an elongation of only 13.5 degrees it was readily visible in 10x50 binoculars as an object of 1st magnitude, already with a distinct tail. Over the course of the following week the comet continued climbing higher into the morning sky, and although it did start to fade slightly, its higher location above the horizon made it an easy naked-eye object. On the morning of July 11 I could easily see it as a 2nd magnitude object with a prominent dust tail several degrees long.

After passing through conjunction with the sun (24 degrees north of it) in mid-July Comet NEOWISE moved over into the northern hemisphere's evening sky, and continued to climb higher into a darker sky. While it continued to fade slowly, its better

A composite image of Comet NEOWISE prepared by Michael Jaeger in Austria, of six images from the LASCO C3 coronagraph aboard SOHO taken on June 25 and 26, 2020. Courtesy NASA/ESA.

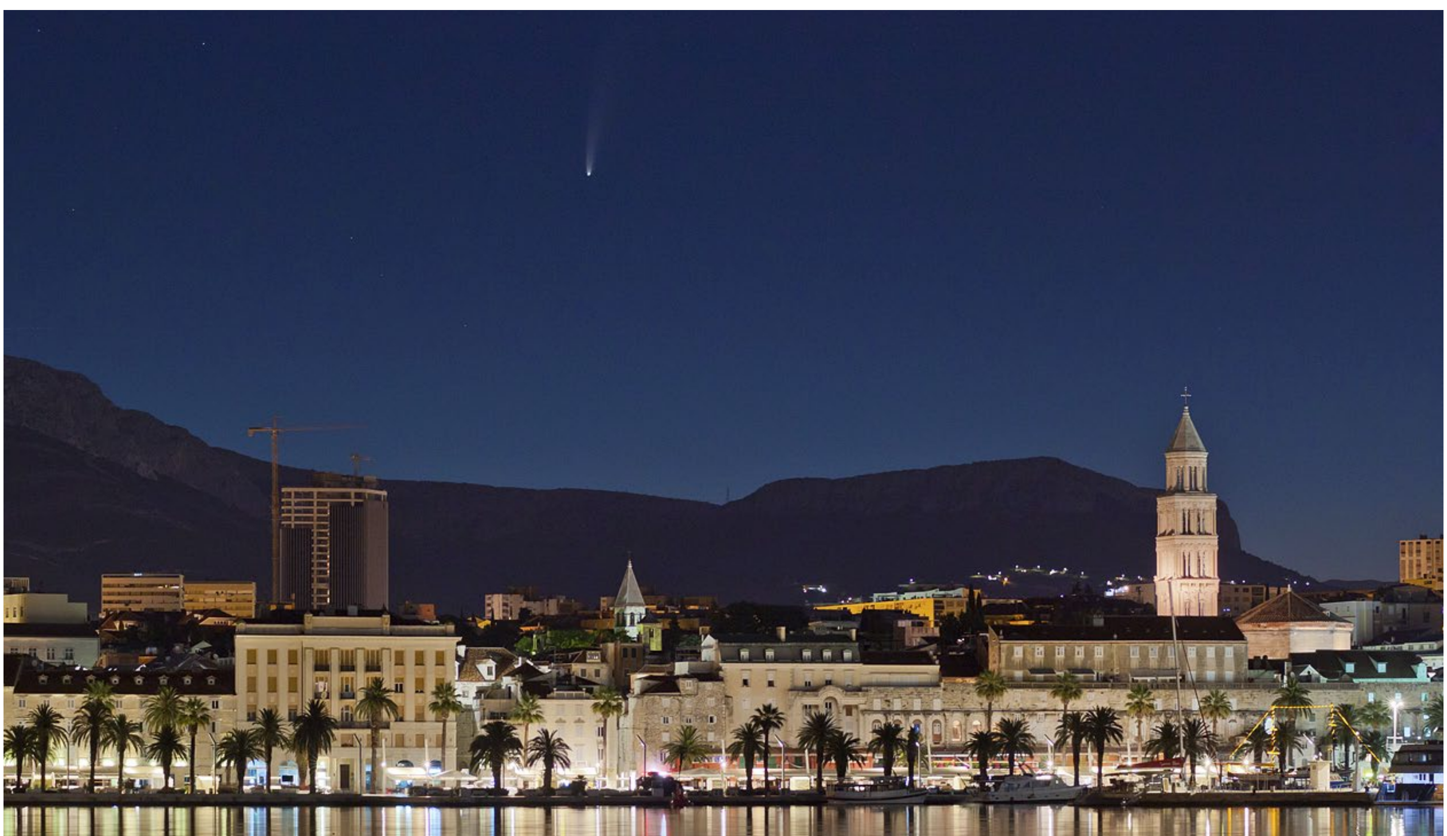
visibility allowed it to remain a prominent object for observation, and when it was closest to Earth (0.69 AU) on July 23 – the 25th anniversary of my discovery of Comet Hale-Bopp – it was readily visible to the unaided eye near 3rd magnitude and sporting both a prominent dust tail (which to my unaided eye appeared 12 degrees long the previous night) as well as a distinct ion tail. The dust tail has exhibited the so-called "synchronic bands" (discussed in a future "Special Topics" presentation), and meanwhile shortly after perihelion passage spectroscopic observations of the comet revealed an unusually large amount of sodium within its coma.

At this time Comet NEOWISE – still visible to the unaided eye near 3rd magnitude – remains in the western sky during the evening hours as it travels southward, and is now starting to become accessible again to observers in the southern hemisphere. It continues to travel southward over the coming weeks and should continue fading before disappearing into evening twilight around mid-October.

Above: Comet NEOWISE as imaged on July 5, 2020 by the Wide-field Imager for Solar PRobe (WISPR) instrument aboard NASA's Parker Solar Probe. Courtesy NASA/Johns Hopkins APL/Naval Research Lab/Parker Solar Probe/Brendan Gallagher. Below: Photograph I captured of Comet NEOWISE during the morning sky, July 11, 2020.

Comet NEOWISE: A Global Star

Above: Comet NEOWISE captured July 21, 2020 in Joshua Tree National Park, California. Copyright Kalpa11, licensed via Creative Commons. Below: The comet seen over Split, Croatia on July 9, 2020. Copyright Goran Leš, licensed via Creative Commons.



Top left: Comet NEOWISE photographed in the early morning hours of July 7, 2020 from Landers, California. Copyright Dbot3000, licensed via Creative Commons. Top Right: A closeup of the comet observed on July 09, 2020 as recorded from Ray's Astrophotography Observatory in Texas. Copyright Raman Madhira, licensed via Creative Commons. Below: Captured before sunrise from Pulsnitz, Germany, the comet's tail is seen in detail on July 14, 2020. Copyright Stefan Ziegenbalg, licensed via Creative Commons.

Above: A 4-second exposure of Comet NEOWISE viewed from San Francisco, California. Copyright Darshan Shankar, licensed via Creative Commons. Below: The comet shines in the predawn skies over Deer Valley Utah on July 9, 2020. Courtesy of NASA.

Above: Comet NEOWISE imaged via noctilucent clouds over Anglesey, Wales and Puffin Island on July 11, 2020. Copyright Brwynog, licensed via Creative Commons. Below: The comet visible in the early morning sky over Odessa, Ukraine on July 10, 2020. Copyright Andrey Nikolenko, licensed via Creative Commons.

Special Topic: Terrestrial Impact Craters

Meteor Crater in Arizona, observed from Earth orbit. Courtesy NASA/U.S. Geological Survey.

The "Special Topics" presentation six weeks ago on "Lunar and Planetary Impacts" discussed how the Italian astronomer Galileo Galilei noticed craters on the moon the first time he turned his recently-made primitive telescope towards that object. Indeed, almost any kind of optical aid, be this in the form of binoculars or a small telescope, will reveal that the moon's surface is covered with craters. Although the mechanism that produced those craters was debated for quite some time, as discussed in that presentation it has become quite clear that the lunar craters are overwhelmingly caused by impacts of objects from space.

That being the case, one might accordingly expect Earth to also be covered with impact craters, since with almost 13 times the moon's surface area it presents a much bigger target. Quite obviously, this is not what we see. One reason, although not the primary one, is that the earth's atmosphere prevents many of the smaller impacting objects from reaching the surface. As happened during impact events like Tunguska and Chelyabinsk (discussed in the "Special Topics" presentation four weeks ago) the stresses that objects of this size encounter during their passages through the atmosphere often cause them to disintegrate and explode while still several km above the surface. While these airburst explosions may wreak catastrophic consequences for life in the near vicinity – and was indeed demonstrated by the aforementioned events – since there is no actual "impact" onto the surface there is accordingly no crater. The lack of an impact crater at the site of the Tunguska event remained one of the stronger mysteries associated with that event for quite some time.

Even with the earth's atmosphere, larger objects will still nevertheless reach and impact the surface. Since somewhat over 70% of the earth's surface is covered by ocean water, a similar percentage of impacting objects would impact the oceans, and while this might slow down and prevent some of the smaller objects from impacting the ocean floor, we might still nevertheless expect a non-trivial part of the ocean floor to have impact craters. At the same time we would also expect the land surface area to be substantially covered by craters. Once again, this is not what we see.

The primary reason that Earth's surface is relatively free

Left: The largest meteorite fragment recovered from the impacting object that produced Meteor Crater in Arizona. Copyright Mariordo Mario Roberto Duran Ortiz, licensed via Creative Commons. Above: Ground-level view of the Odessa Crater. Copyright Fredlyfish4, licensed via Creative Commons.

of impact craters is that Earth's surface is geologically active. Due to plate tectonics, the continental plates not only drift upon the earth's semi-liquid mantle, portions of the crustal plates are often subducted underneath other plates. As a result, the earth's surface has constantly been re-worked throughout its natural history. Furthermore, weathering processes like wind erosion, water erosion, and glaciation act to erode craters away within geologically short periods of time.

The first impact crater on Earth's surface to be unequivocally recognized as such is in Arizona near the town of Winslow, and is roughly 1200 meters in diameter and 170 meters deep. Although undoubtedly known to the native peoples who had lived in the area for centuries, the crater was "discovered" by settlers in the 19th Century, and for the most part was believed to be volcanic in origin, especially since a large field of volcanoes lies just over 60 km to the west. Several iron meteorites found in the area led an American mining engineer, Daniel Barringer, to believe that the crater might indeed be due to an impact, and he staked a mining claim to the crater and its vicinity in the hope of drilling down to find the primary parent body. These efforts

Pingualuit Crater – formerly known as Chubb Crater – in northern Quebec. The interior lake is Lake Pingualuk. Courtesy NASA/Denis Sarrazin.

One of the more easily recognizable impact craters on Earth's surface: Wolfe Creek Crater in Western Australia. Courtesy Dick and Pip Smith/Australian Geographic.

failed, however, and although Barringer continued to believe that the crater was created by an impact, this remained a minority scientific opinion well into the 20th Century.

Finally, in 1960 American geologist Eugene Shoemaker – then working on his Doctoral thesis – together with geologist Edward Chao identified the mineral coesite – a form of silicon dioxide that can only be formed naturally at very high pressures and temperatures – at the site of the crater. Volcanic activity cannot do this, but the pressures and temperatures generated during an impact can, and thus with this evidence in hand Shoemaker and Chao were able to demonstrate conclusively that the crater was created by the impact of an object from space.

The crater today is primarily known as "Meteor Crater," although it is more formally known as "Canyon Diablo Crater" or as "Barringer Crater." Studies have since indicated that it was formed approximately 49,000 years ago, by an iron meteorite perhaps 50 meters in diameter. Although this did leave some of the fragments that were later found within the crater's vicinity, the bulk of it probably disintegrated upon impact, which would explain Barringer's failure to find the parent body. Erosion since the time of the impact is believed to have caused the crater's rim to have lost some 20 meters of height and at the same time to have been filled by roughly 30 meters of sedimentation at its floor, but overall it still retains a distinct "crater" shape.

The effects of erosion are perhaps well demonstrated by a crater of similar age located near Odessa, Texas. The Odessa Crater is roughly 160 meters in diameter and is believed to have been caused by an iron meteorite – numerous fragments of which have been found in the area although, as in the case of the Arizona Meteor Crater, the primary body apparently disintegrated upon impact – that struck roughly 63,500 years ago. Although perhaps 30 meters deep when first formed, it has now filled in to the point where it is only about 5 meters deep at its lowest point, and in all honesty I was hard put to see much of a crater at all when I visited there several years ago.

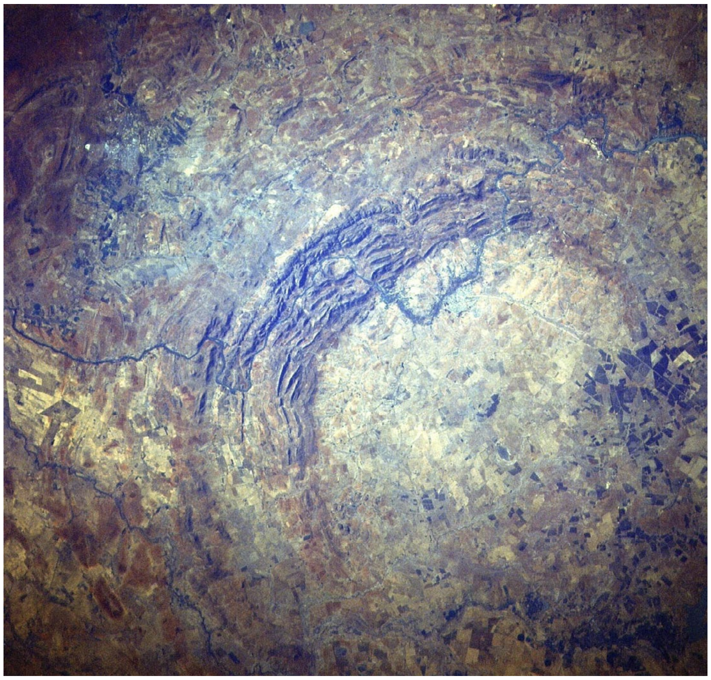
At this time 190 confirmed impact craters have been identified on Earth's surface, and information about these is provided by the Earth Impact Database (EID) maintained by the Planetary and Space Science Centre at the University of New Brunswick. There are various other features on Earth's surface that have been, or are, suspected of being impact craters, and there are lists of these as well, including one that has been maintained by the Impact Field Studies Group at the University of Tennessee-Knoxville.

While some of the craters in the EID are easily recognizable as such, others, such as the Odessa Crater, are more subtle. Some of the craters are lakes filled with water, for example, Pingualit Crater – formerly known as Chubb Crater – in northern Quebec. Some of the craters are subterranean, perhaps the best-known example being the Chicxulub Crater off the northern shore of the Yucatan Peninsula in southern Mexico and which is the apparent site of the impact event that produced the K-T extinction (see the "Special Topics" presentation on that topic).

For some of the listings in the EID the word "crater" is a bit of a stretch. In such cases, the actual impact crater itself has long eroded away, but some geological features remain which indicate that an impact had indeed happened there; the more appropriate term here would be "impact structure." The two oldest "craters" listed in the EID, both of which are a little over two billion years old, are good

View from the rim of the largest of the Wabar Craters in Saudi Arabia, taken in 1994. Courtesy U.S. Geological Survey/Jeff Wynn.

examples of this: the Vredefort Crater in South Africa – which, with an original diameter of over 300 km, is the largest "crater" listed in the EID – is gone, although a central dome-like structure remains; and the Suavjarvi Crater in Russia which, with an estimated original diameter of 16 km, is much smaller, while a 3-km-wide lake remains near its center. There is some evidence that Lake Mistassini in Quebec may be the remnant of an impact crater, although it has not been confirmed as such; with a diameter of some 600 km and an estimated age of a little over two billion years it would rank as one of the largest and oldest craters on Earth if it can be verified as such.



Remains of the Vredefort Crater in South Africa, as seen from Earth orbit. Courtesy NASA.

A handful of craters listed in the EID appear to have ages of less than 10,000 years, i.e., within the span of human history. The Kaali craters in Estonia, the Henbury craters in Australia's Northern Territory, and the Campo del Cielo crater field in Argentina – which has produced two of the largest meteorites found on Earth's surface, as discussed in a previous "Special Topics" presentation – all date from approximately 4000 years ago, and events described within the stories of the indigenous peoples in these areas can possibly be interpreted as referring to the actual impacts. The Wabar Craters in southeastern Saudi Arabia may even be younger; while some evidence suggests the craters are a few thousand years old, other evidence – including the fact that, in the sandy desert, they have filled in substantially since they were "discovered" in 1932 (the largest crater being 12.5 meters deep then and only two meters deep in 1994) – suggests a much younger age, only about 250 years at most. A bright fireball reportedly seen from Riyadh in the mid- to late-19th Century – the year has been reported as either 1863 or 1891 – and heading southeast is roughly consistent with this.

It is entirely conceivable that future impacts could produce craters on Earth's surface, although as discussed above and in other "Special Topics" presentations all the relatively recent events have resulted in airburst explosions a few km above the ground, with blast effects and, at most, some meteorite fragments affecting the surface. The ultimate goal of the comprehensive survey programs discussed in last week's "Special Topics" presentation is, of course, to prevent – or at least mitigate – such occurrences by identifying potentially impacting objects ahead of time.

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