ICE & STONE 2020

WEEK 41: OCTOBER 4-10

Presented by The Earthrise Institute

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THIS WEEK IN HISTORY

OCTOBER 4, 2020: The main-belt asteroid (1679) Nevanlinna will occult the 7th-magnitude star HD 224945 in Pisces. The predicted path of the occultation crosses Newfoundland, part of the Maritime Provinces of Canada, the northeastern through the south-central U.S. (including Houston, Texas), north-central Mexico (including the northern regions of Monterrey, Nuevo Leon), and the southern Pacific Ocean.

OCTOBER 7, 2008: Twenty hours after its discovery by Richard Kowalski during the course of the Mount Lemmon Survey in Arizona, the tiny asteroid 2008 TC3 enters Earth's atmosphere above Sudan, explodes, and drops meteorite fragments – the Almahata Sitta meteorite – on the Nubian Desert. This is the first instance of an impacting asteroid being discovered in space while still inbound to an impact, and it is the subject of this week's "Special Topics" presentation.

OCTOBER 7, 2009: Astronomers using the Infrared Telescope Facility in Hawaii announce that the surface of the large main-belt asteroid (24) Themis appears to be completely covered with water ice. The significance of this discovery is discussed in a previous "Special Topics" presentation.

OCTOBER 8, 1769: Comet Messier C/1769 P1 passes through perihelion at a heliocentric distance of 0.123 AU. This was the brightest comet discovered by the 18th-Century French comet hunter Charles Messier and is a previous "Comet of the Week."

4 5 6 7 8 **OCTOBER 9** 10

OCTOBER 9, 1933: A brief but strong "storm" of Draconid meteors is seen over Europe. The parent comet of the Draconid meteors is Comet 21P/Giacobini-Zinner, which is a previous "Comet of the Week."

OCTOBER 9, 1946: Despite widespread cloudy weather and a full moon, a very strong shower of Draconid meteors is seen from the U.S. This was the first time that radar was used to observe a meteor shower, which is discussed more thoroughly in Comet 21P/Giacobini-Zinner's "Comet of the Week" presentation.

OCTOBER 9, 2009: NASA's Lunar Crater Observation and Sensing Satellite (LCROSS) mission impacts the lunar surface in a permanently-shadowed crater near the moon's south pole. Following the impact, water was detected in the resulting debris plume. The significance of the LCROSS mission is discussed in a previous "Special Topics" presentation.

4 5 6 7 8 9 **OCTOBER 10**

OCTOBER 10, 1846: Less than three weeks after the discovery of Neptune, British astronomer William Lassel discovers Neptune's large moon Triton. Triton orbits around Neptune in a retrograde orbit and is likely a captured object from the Kuiper Belt. The Kuiper Belt is the subject of a previous "Special Topics" presentation.

Present at the signing of the Outer Space Treaty are Soviet Ambassador Anatoly F. Dobrynin, UK Ambassador Sir Patrick Dean, US Ambassador Arthur J. Goldberg, US Secretary of State Dean Rusk, and US President Lyndon B. Johnson. The treaty was signed on January 27, 1967, in Washington and went into force later that same year. More than 100 nations have become parties to it. Courtesy of the United Nations.

OCTOBER 10, 1967: The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies – generally referred to as the "Outer Space Treaty" – enters into force. The effects of the Outer Space Treaty on the carrying out of resource extraction activities on the solar system's "small bodies" is discussed in a previous "Special Topics" presentation.

OCTOBER 10, 1969: Japanese amateur astronomer Akihiko Tago discovers a comet, which is independently discovered two days later by two other Japanese amateur astronomers, Yasuo Sato and Kozo Kosaka. In early 1970 Comet Tago-Sato-Kosaka 1969g became the first comet to be observed by an artificial satellite, and three weeks later became the first comet I ever observed. It is a previous "Comet of the Week."

COMET OF THE WEEK: DONATI 1858 VI

Perihelion: 1858 September 30.46, q = 0.578 AU

Among the many individuals who made important contributions to astronomy during the mid-19th Century was the Italian astronomer Giovanni Donati, who observed from the Observatory of Florence and who was Director of that institution from 1864 until his death (at age 46) in 1873. He made the first observations of a comet's spectrum, when in August 1864 he visually observed the spectrum of Comet Tempel 1864 II when that object was passing close to Earth. He is also credited with the discovery of five comets between 1855 and 1864.

Comet Donati over the Notre Dame cathedral in Paris, October 4, 1858. The bright star just to the left of the comet's head is Arcturus.

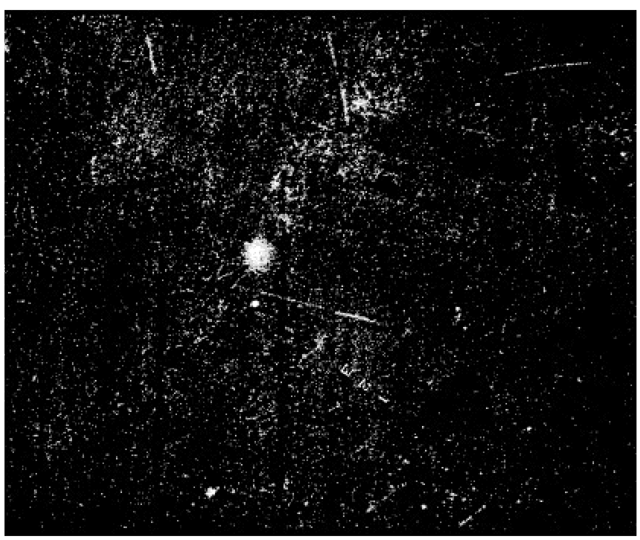
Donati discovered what would be his best comet on the evening of June 2, 1858, at which time it was 7th magnitude and located near the "head" of the constellation Leo. It traveled slowly northward from that point and brightened, and by the end of August was nearing conjunction with the sun, some 25 degrees north of it; meanwhile, by that time it was close to 3rd magnitude and exhibiting a short, bright tail. Throughout September it remained visible – from the northern hemisphere – both in the northwest after dusk and in the northeast before dawn as it traveled eastward through Ursa Major south of the Big Dipper, brightening to 2nd magnitude by mid-month and to 1st magnitude or brighter, with a 20-degree-long tail, by month's end.

Having passed through perihelion at the end of September and being closest to Earth (0.54 AU) on October 10, Comet Donati was at its best during the first half of October, being a striking object in the evening sky as bright as magnitude 0 and exhibiting a bright, curved dust tail up to 60 degrees long as well as a shorter and dimmer ion tail. As it traveled southward and began fading it ceased being accessible from mid-northern latitudes by the latter part of that month, however by this time it had started to become visible from the southern hemisphere. It remained visible to the unaided eye until the latter part of November, and was followed telescopically until early March 1859, by which time it had entered southern circumpolar skies.

The practice of astro-photography was just starting to come into existence in the mid-19th Century, and

A rendition of Comet Donati on the evening of October 5, 1858, painted by British artist William Turner of Oxford, England.

Comet Donati has the distinction of being the first comet ever photographed, when a British portrait painter and photographer, William Usherwood, managed to record an image of it on September 27; unfortunately, no copies of this photograph are known to exist. On the following night George Bond at Harvard College attempted several photographs through the Observatory's 38-cm refractor, and on a six-minute exposure managed to record "only the nucleus and a little nebulosity" in the inner coma. It would be another two decades before astro-photography in general, and photography of comets in particular, started to come into its own, and part of this process is covered in last week's "Comet of the Week" presentation.



The inner coma region of Comet Donati as it appeared on a six-minute exposure taken with Harvard College Observatory's 38-cm refractor by George Bond on September 28, 1858. From Pasachoff et al. (1996).

Comet Donati was widely observed, especially from the northern hemisphere, around the time of its peak display in early October 1858, and by all accounts was a strikingly beautiful object with its long and curved dust tail. It appears in quite a bit of the literature and news stories of the time and was painted by various artists, and future U.S. President Abraham Lincoln reportedly viewed it when he was a candidate for the U.S. Senate on the evening before one of his famous debates with Stephen Douglas. As Comet Donati and various other "Comets of the Week" throughout "Ice and Stone 2020" – including the recent Comet NEOWISE C/2020 F3 – demonstrate, the appearance of a bright and beautiful comet in the nighttime sky can have a profound emotional effect on those of us here on Earth fortunate enough to view them.

Special Topic: 2008 TC3 and the Almahata Sitta Meteorite

The "Special Topics" presentation three weeks ago discussed actions that we might take should we detect an asteroid that appears will impact Earth. The first and foremost task is the collection of as much data as possible in order to refine the orbit and the likelihood of an actual impact, and if this continues to indicate that an impact is definite (or, at the very least, likely) then the discussion turns to what actions can be taken to eliminate or mitigate the threat posed by the object in question. For small objects that may not be discovered until they are already on their final impact trajectory there may not be much that can be done as far as eliminating the threat is concerned, however the data-gathering process can at least identify the "when" and "where" of an impact so that appropriate actions can then be taken to minimize destruction and loss of life.

The world's astronomers had the unexpected opportunity to test this process in October 2008 with the discovery of the asteroid 2008 TC3, the first time an impacting asteroid was detected while still in space. With an approximate diameter of only four meters 2008 TC3 did not pose any significant impact threat and in fact, as expected, it exploded and broke apart when it entered Earth's atmosphere, but the opportunity to see how the overall process would work in "real time" helped enormously in seeing how the procedures we have now work and in stimulating improvements to those procedures in case a more serious threat presents itself in the future.

Richard Kowalski with the Mt. Lemmon Survey in Arizona discovered 2008 TC3 on October 6, 2008, with the discovery image being taken at 6:40 UT (11:40 P.M. local time October 5). The object was about 19th magnitude at the time, and images taken over the next hour were enough to show that it was likely

Peter Jenniskens of NASA's SETI Institute approaches a meteorite fragment of 2008 TC3 in the Nubian Desert of northern Sudan. Courtesy Muawia Shaddad/Peter Jenniskens.

located near Earth, and the IAU's Minor Planet Center shortly thereafter placed it on its Near-Earth Object Confirmation Page, making other observers around the world aware of its presence. Several astrometric observations, mostly from Australia, obtained over the next few hours were enough to provide a valid orbit, and the MPC announced the discovery at 14:59 UT. This first published orbit was already enough to indicate that 2008 TC3 would be impacting Earth – although not surviving passage through the atmosphere – at 2:46 UT October 7, i.e., twenty hours after its initial discovery, and that the impact point would be over northern Sudan.

Trailed image of 2008 TC3 entering the earth's shadow at 1:45 UT on October 7, 2008, taken by the La Sagra Sky Survey in Spain. Courtesy La Sagra Sky Survey.

Over the next eleven hours the MPC issued two dozen orbital updates as additional observations flowed in, primarily from observers in Europe. The last observations were obtained around 1:45 UT, by which time 2008 TC3 had brightened to 13th magnitude, however shortly thereafter it entered Earth's shadow and was lost from view.

As predicted, 2008 TC3 entered the atmosphere as a bright meteor over northern Sudan at 2:46 UT – 5:46 A.M. local time – and exploded approximately 37 km above the ground. Eyewitness accounts, some from hundreds of km away, report it as being a brilliant fireball, and it left a long-lasting train of debris and ionized air in the dawn sky. The European weather satellite Meteosat 8 in geostationary orbit over the region recorded it as a bright flash as it disintegrated.

There was hope that some meteorite fragments from the 2008 TC3 atmospheric impact might have reached the ground, and in early December a coordinated research effort led by Peter Jenniskens from the SETI Institute in California and Muawia Shaddad at the University of Khartoum, and involving several students and staff from that University, began scouring the barren Nubian Desert in search for them. Within three days the team had collected 15 fragments, and overall some 600 fragments with

The persistent "train" left by the passage of 2008 TC3 through the atmosphere above northern Sudan, October 7, 2008. Courtesy Mohamed Elhassan Abdelatif Mahir/ Muawia Shaddad/Peter Jenniskens.

The search for meteorite fragments of 2008 TC3 in the Nubian Desert of northern Sudan. Left: A member of the search team scours the desert floor. Right: Members of the search team point to a fragment. Images courtesy Muawia Shaddad/Peter Jenniskens.

a total combined mass of 10.5 kg have now been collected. The meteorite fragments have collectively been named the Almahata Sitta meteorite, that name (which translates as "Station Six" in Arabic) referring to a train station in northern Sudan.

Analysis of the Almahata Sitta fragments indicates that the overall meteorite is a rare achondritic stony type known as an "ureilite," which in general are relatively dark-colored and primitive. Tiny structures known as "nanodiamonds" which are produced by impacts and/or other shock events, have been found within the Almahatta Sitta fragments, suggesting that it came about as a result of a collision between two asteroids. Somewhat surprisingly, 19 different amino acids were detected within the fragments as well.

While 2008 TC3 remains the most comprehensive case study of an asteroid's being detected prior to impact, three other similar events have occurred during the years that have elapsed since then. The first of these occurred at the very beginning of 2014, when on January 1 Richard Kowalski – once again – discovered the small fast-moving asteroid that was designated 2014 AA. Kowalski obtained seven astrometric measurements over a span of 69 minutes, which were enough to show that atmospheric entry would occur early the following day. There were no known ground-based eyewitnesses to the asteroid's entry, but infrasound detectors monitoring the Comprehensive Nuclear Test-Ban Treaty detected signs of its occurrence in the central Atlantic Ocean approximately 2000 km north of Brazil. 2014 AA is estimated to be the same approximate size as 2008 TC3 and thus did not survive its passage through the atmosphere.

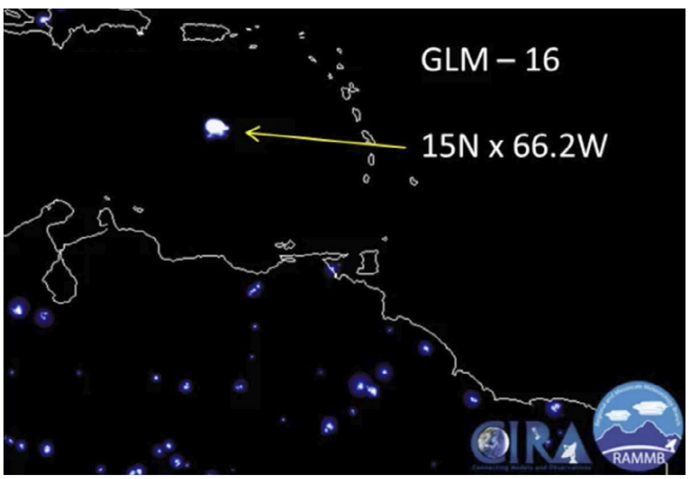
Richard Kowalski holds a fragment of the Almahatta Sita meteorite that came from the asteroid 2008 TC3 that he discovered. Courtesy Richard Kowalski/Full Moon Photography.

Kowalski also discovered the asteroid in the third such incident, 2018 LA, on June 2, 2018. It was followed for four hours before entering the atmosphere later that same day over southern Africa, and indeed several eyewitnesses on the ground reported a bright fireball over Botswana five hours after the last reported astrometric observation. Although, like the previous two objects, 2018 LA did not survive its passage through the atmosphere, it did drop meteorite fragments, and a search expedition led by Alexander Proyer from the Botswana International University of Science and

Left: Frame grab from a security camera video taken by Barend Swanepoel in Botswana on June 2, 2018, showing the fireball of 2018 LA's atmospheric entry. Right: The meteorite fragment of 2018 LA retrieved from the Central Kalahari Game Reserve in Botswana. Courtesy Peter Jenniskens.

Technology three weeks later successfully found the first fragment in Botswana's Central Kalahari Game Reserve. This fragment has a mass of 18 grams and although no formal analysis has been released yet, a preliminary examination suggests it may be an achondrite.

The most recent incident took place on June 22, 2019, when the ATLAS program in Hawaii discovered the tiny asteroid 2019 MO. ATLAS only followed it for half an hour, however pre-discovery observations obtained two hours earlier by one of the nearby Pan-STARRS telescopes were then identified. Eleven hours after the last ATLAS observation 2019 MO entered the atmosphere over the Caribbean Sea south of Puerto Rico, and while there does not seem to have been any ground-based eyewitnesses to the fireball, it does show up on a frame taken by NOAA's GOES-16 geostationary weather satellite. As with the previous three entering small asteroids 2019 MO disintegrated upon atmospheric entry, but does seem to have dropped meteorites, as NOAA's NEXRAD radar detected echoes from falling fragments. Any such fragments would now be resting on the ocean floor over four km below the surface.



Frame grab from the Geostationary Lightning Mapper aboard NOAA's GOES-16 weather satellite, showing the fireball from the entry of 2019 MO over the Caribbean Sea on June 22, 2019. Courtesy SkySentinel/NOAA/CIRA/ Colorado State University.

The discoveries of these four objects all within the relatively recent past suggests that our capabilities of detecting incoming objects are improving, and that our procedures for predicting where and when a potential impact will occur work. While we are certainly missing quite a few of the 2008 TC3-sized objects that do enter the atmosphere, it should be remembered that these are very tiny objects that even a few lunar distances away are too dim to be detected with telescopes we now have. Fortunately, as these objects demonstrated, other than producing bright fireball displays and dropping meteorite fragments on the ground they do no pose any kind of a threat. The larger objects, like those that produced the Tunguska and Chelyabinsk events – discussed in a previous "Special Topics" presentation – do remain a threat, at least over localized areas, and in theory at least these can be detected with enough lead time to provide for evacuation procedures if necessary. However, the object that entered over Chelyabinsk – which was four or five times the size of 2008 TC3 – approached Earth from the daytime side, and such objects are, for obvious reasons, not detectable beforehand. Perhaps at some point it might be considered worthwhile to have satellite platforms interior of Earth's orbit looking outwards for such objects – with the "whys" and the "hows" perhaps being determined by today's "Ice and Stone 2020" participants.

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