ICE & STONE 2020

WEEK 48: NOVEMBER 22-28

Presented by The Earthrise Institute

48

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THIS WEEK IN HISTORY

NOVEMBER 22, 2020: The Apollo-type asteroid (7753) 1988 XB will pass 0.066 AU from Earth. The best visibility will be next week when it travels west-northwestward through Leo, Cancer, and Gemini and will be 15th magnitude. Close approaches by near-Earth asteroids are the subject of this week's "Special Topics" presentation.

NOVEMBER 25, 2005: JAXA's Hayabusa spacecraft performs a second brief touchdown on the near-Earth asteroid (25143) Itokawa and, although not realized at the time, successfully collects a few samples of soil material, which were eventually returned to Earth. The Hayabusa mission is discussed in a previous "Special Topics" presentation.

NOVEMBER 25, 2015: Then-U.S. President Barack Obama signs the U.S. Commercial Space Launch Competitiveness Act into law, which among other things allows and encourages the commercial utilization of resources from asteroids. The significance of this legislation, and other legal aspects involved with the extraction of resources from "small bodies," are discussed in a previous "Special Topics" presentation.

NOVEMBER 26, 1971: NASA's Mariner 9 mission, having recently arrived at Mars, takes the first close-up images of Mars' moon Deimos. These were the first close-up images of any "small body" within the solar system. The small moons of the various planets are the subject of a previous "Special Topics" presentation.

NOVEMBER 26, 2020: Comet 11P/Tempel-Swift-LINEAR will pass through perihelion at a heliocentric distance of 1.389 AU. This was one of the "lost" periodic comets examined by Brian Marsden in his 1963 study – discussed in previous "Comet of the Week" presentations – which was re-discovered by the LINEAR program in 2001. It returns under favorable viewing geometry in 2020, and has recently become bright enough for visual observations although thus far it remains reltively faint (14th magnitude at this writing). Additional information can be found at the "Comet Resource Center."

NOVEMBER 27

NOVEMBER 27, 1872: An extremely strong display of the Andromedid meteor shower is witnessed from Europe. The Andromedids are associated with Comet 3D/Biela – a previous "Comet of the Week" – which had been missed on some previous returns and apparently had completely disintegrated. The association between comets and meteor showers is the subject of last week's "Special Topics" presentation, and the association of the Andromedids with Comet Biela is discussed in that object's "Comet of the Week" presentation.

NOVEMBER 27, 1885: A very strong display of the Andromedid meteor shower is witnessed from Europe and elsewhere. During the shower, a Hungarian astronomer, Ladislaus Weinek, successfully takes the first known photograph of a meteor.

NOVEMBER 27, 2011: Amateur astronomer Terry Lovejoy in Queensland discovers Comet Lovejoy C/2011 W3, the first – and, so far, only – ground-discovered Kreutz sungrazer of the 21st Century. It is a future "Comet of the Week."

NOVEMBER 28

NOVEMBER 28, 2011: A team of astronomers led by Bruce Koehn of Lowell Observatory in Arizona discovers a small moon accompanying the asteroid (5261) Eureka, the first-known "Mars Trojan" asteroid, by means of photometric observations. The moons of asteroids, and Trojan asteroids in general, are the subjects of previous "Special Topics" presentations.

NOVEMBER 28, 2013: Comet ISON C/2012 S1 passes through perihelion at a heliocentric distance of 0.012 AU. There was hope that Comet ISON might become a "Great" comet, but instead it disintegrated as it passed through perihelion. It is this week's "Comet of the Week."

NOVEMBER 28, 2020: The main-belt asteroid (333) Badenia will occult the 7th-magnitude star HD 43246 in Auriga. The predicted path of the occultation crosses south-central Libya, north-central Algeria, northern Morocco, the north central Atlantic Ocean, the southeastern U.S. from New Jersey to southwestern New Mexico (including the city of Philadelphia), and the Mexican States of Sonora and Baja California.

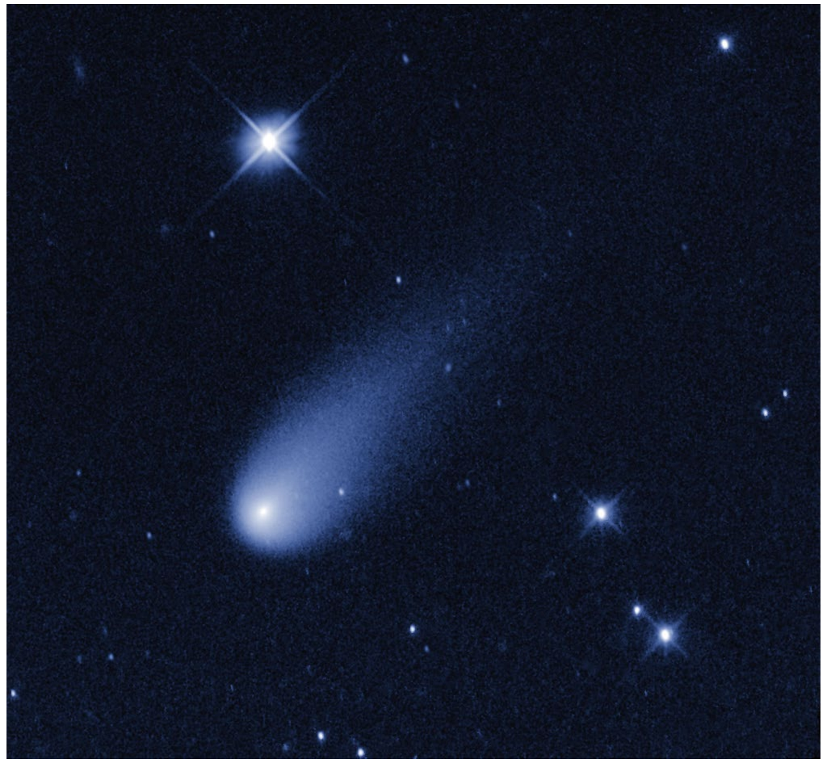
COMET OF THE WEEK: ISON C/2012 S1

Perihelion: 2013 November 28.78, q = 0.012 AU

Comet ISON on the morning of November 16, 2013, as photographed from near Setubal, Portugal. This approximates the comet's appearance in binoculars at that time. Courtesy Eric Cardoso.

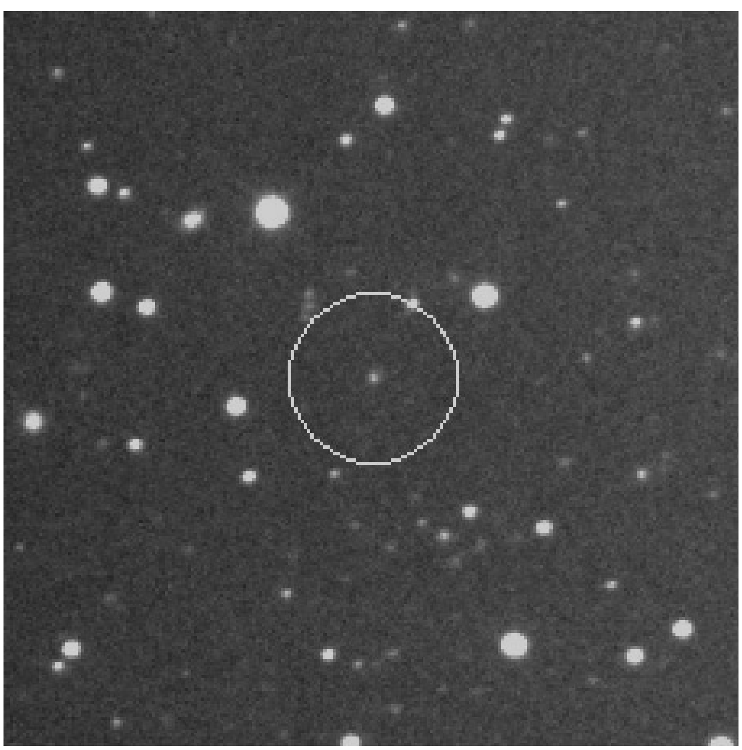
I mentioned in the "Special Topics" presentation on "Great Comets" that such objects come by about once a decade, on the average. Comet NEOWISE C/2020 F3, which appeared back in July, could perhaps be considered a borderline "Great" comet, but prior to that the last "Great Comet" for those of us in the northern hemisphere was Comet Hale-Bopp C/1995 O1, which was at its best during early 1997, well over two decades ago. The southern hemisphere, meanwhile, has had two "Great Comets" during the intervening years, Comet McNaught C/2006 P1 and Comet Lovejoy C/2011 W3 – both of which are either previous or future "Comets of the Week" – and in the unlikely event that Comet PANSTARRS C/2017 K2 – also a previous "Comet of the Week" – happens to become "Great" when it passes through perihelion in late 2022 it will also be exclusively visible from the southern hemisphere around that time. Those of us in the northern hemisphere can perhaps be forgiven for believing we were overdue for a "Great Comet" of our own.

What seemingly offered an excellent chance for a northern hemisphere "Great Comet" was discovered on September 21, 2012 by two amateur astronomers, Vitali Nevski of Belarus and Artyom Novichonok of Russia, who were conducting a survey program with one of the telescopes of the Russia-based International Scientific Optical Network (ISON) located at Kislovodsk, Russia. The comet was about 18th magnitude at the time, however pre-discovery images, including some that dated back almost a full year before the discovery, allowed for an early determination of a valid orbit. This showed that the comet was still fourteen months away from perihelion passage, which would occur at a very small perihelion distance. Excellent viewing geometry for the northern hemisphere after perihelion, including geometry favorable for forward scattering of sunlight, indicated a good potential for a "Great Comet." The orbit, in fact, bore a superficial resemblance to that of the Great Comet of 1680 – a future "Comet of the Week" – although it appears that there is no connection between the two objects.



Comet ISON as imaged by the Hubble Space Telescope on May 8, 2013. Courtesy NASA.

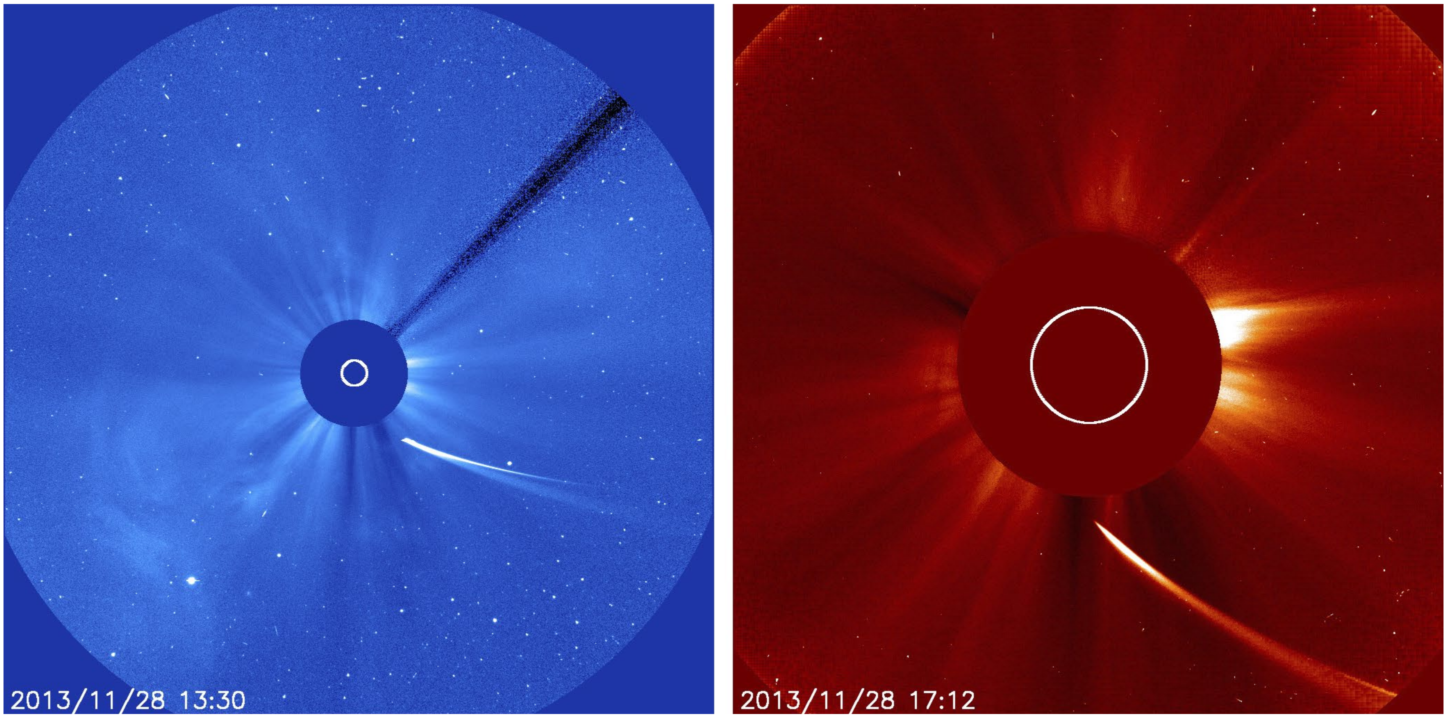
Initially Comet ISON brightened relatively rapidly, and was close to 15th magnitude when it was at opposition in early January 2013. From then until the time it disappeared into evening twilight in early June, however, its brightness remained relatively flat, which was not a good sign about a prospective future bright display. Also somewhat ominous was the fact that Comet ISON was a "new" comet making its first visit into the inner solar system from the Oort Cloud, and as discussed in the "Great Comets" "Special Topics" presentation, such objects often tend to under-perform compared to initial expectations.



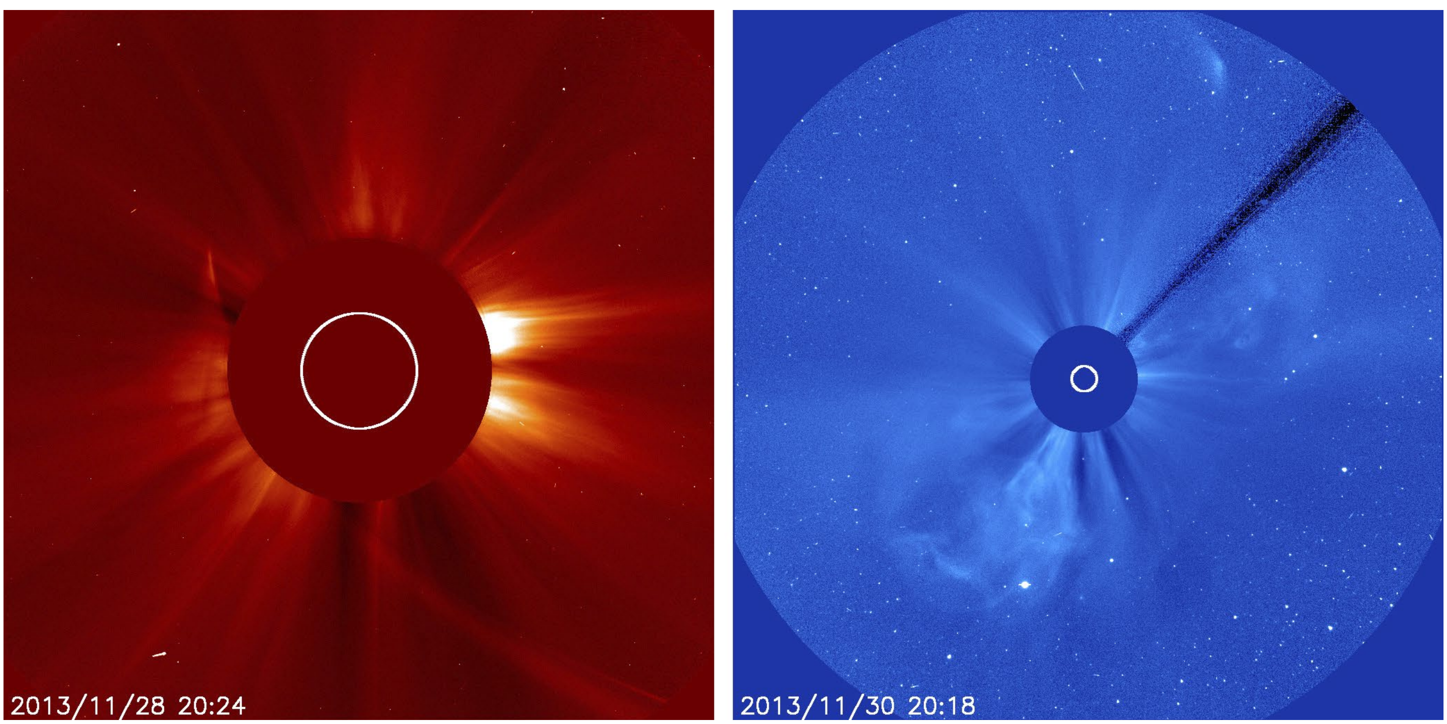
Discovery image of Comet ISON, taken September 21, 2012, with the ISON telescope at Kislovodsk, Russia. Courtesy Artyom Novichonok.

Following conjunction with the sun Comet ISON began emerging into the morning sky, and was first imaged low in twilight, during mid-August, appearing at around 14th magnitude. It had brightened to 13th magnitude when the first visual observations were made around the beginning of September, and it brightened somewhat steadily from that point, being close to magnitude 9½ and exhibiting a bright telescopic tail a few tens of arcminutes long by early November. It soon became apparent, however, that the brightness increase was solely due to the decreased distance from Earth, meaning that there had been no increase in the comet's intrinsic activity during that time. (To hearken back to the "Special Topics" presentation on "Great Comets," Comet ISON's value of "n" was essentially zero.) The prospects for a "Great Comet" display from Comet ISON were looking less and less likely . . .

Around the end of the second week of November Comet ISON started to undergo some outbursts, to about 5th magnitude, and although it thereafter faded slightly from this, by



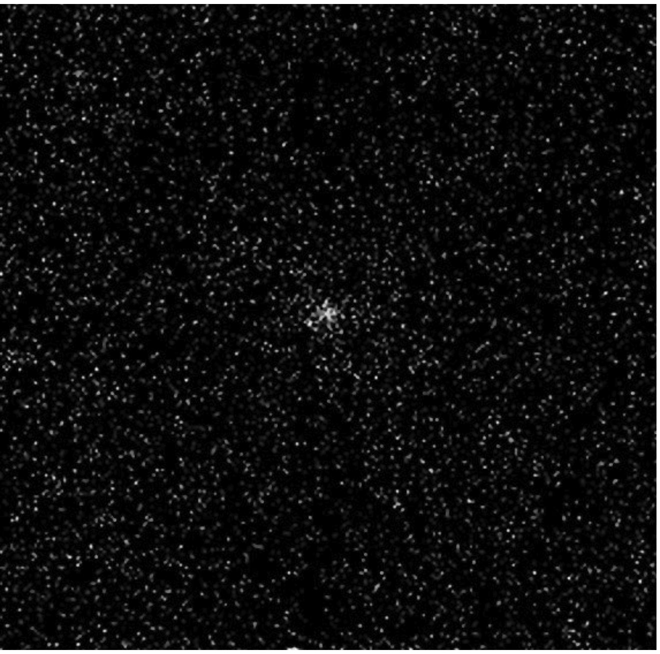
Comet ISON as it appeared in images from the LASCO coronagraphs aboard SOHO as it approached perihelion on November 28, 2013. The Universal Time date/times are in the lower left corner. Left: C3, five hours before perihelion passage. Right: C2, 1½ hours before perihelion passage. Both images courtesy NASA/ESA.

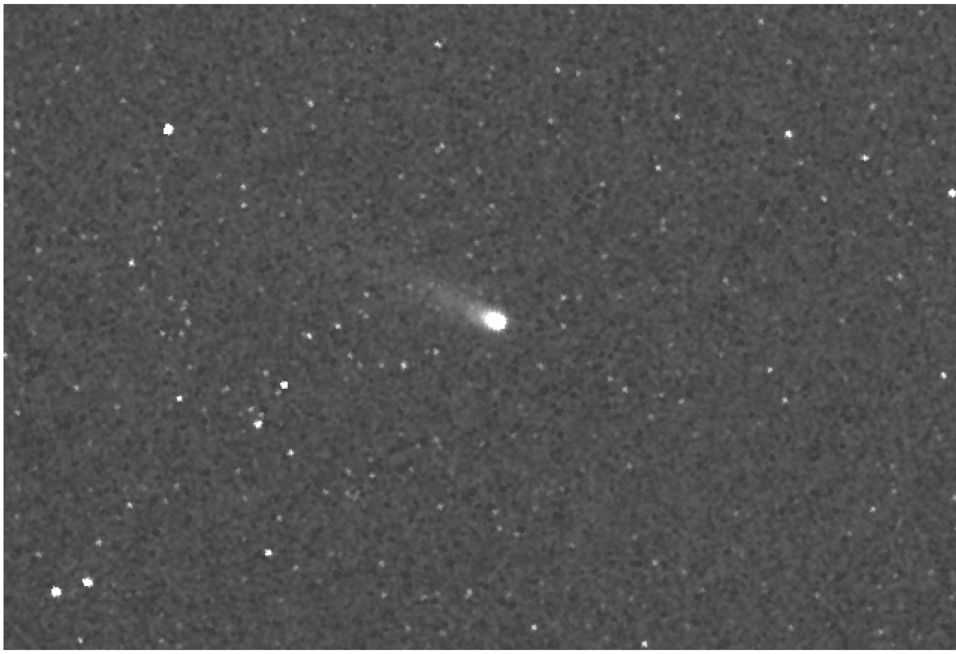


The remnant of Comet ISON as it appeared in the LASCO coronagraphs aboard SOHO after perihelion. Left: C2, two hours after perihelion passage. Right: C3, a little over two days after perihelion. The remnant is near the upper right corner. Both images courtesy NASA/ESA.

about November 21 – just one week away from perihelion passage – it had brightened back to 4th magnitude. By this time, however, its elongation was getting to be quite low, and it disappeared into the dawn sky within a few days.

While Comet ISON was not observable from the ground on the day of perihelion, November 28 – which happened to be Thanksgiving Day here in the U.S. – it was readily detectable in the LASCO coronagraphs aboard the SOlar and Heliospheric Observatory (SOHO) spacecraft. Initially it was rather bright, about magnitude -2, in the C3 field-of-view, and then in C2, but it was also clearly starting to fade by the time it disappeared behind the C2 occulting disk. When it reappeared from behind the occulting disk it was nothing more than a smeared-out trail of debris – it had clearly disintegrated as it passed through perihelion. A dusty remnant remained within C3 for the next three days, and then for another three days it remained detectable with one of the cameras aboard the STEREO-A spacecraft, but there was clearly no "comet" left to speak of.





Comet ISON as seen from spacecraft orbiting other planets. Left: Image by the HIRISE camera aboard the Mars Reconnaissance Orbiter (MRO) on September 29, 2013. Right: Image by the Wide Angle Camera aboard the MESSENGER spacecraft in orbit around Mercury on November 20, 2013. Both images courtesy NASA.

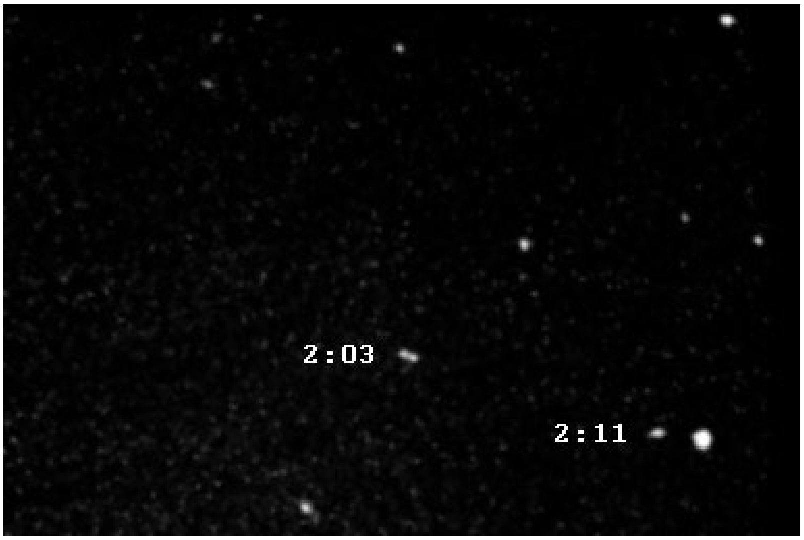
The only question that remained was whether or not this remnant would still be visible once it had traveled far enough away from the sun to be accessible in the pre-dawn sky. Attempts to observe it became possible after the first week of December, but nothing was ever detected, and even the Hubble Space Telescope failed to detect anything on December 18. Whatever was left of Comet ISON had completely evaporated.

While clearly a major disappointment as far as any dramatic display was concerned, Comet ISON was nevertheless an intensely studied comet scientifically, and in fact it presented the best opportunity to date to study a fresh comet making its first visit in from the Oort Cloud. While inbound to perihelion it passed close to both Mars (0.07 AU) and Mercury (0.24 AU), and while doing so it was imaged by spacecraft in orbit (Mars Reconnaissance Orbiter (MRO) around Mars, and MESSENGER around Mercury), becoming the first comet ever to be observed from the vicinity of another planet. Data from MRO suggests that the comet's nucleus was probably no more than 800 meters in diameter, quite a bit smaller than initially believed, and this small size undoubtedly played a significant role in the comet's failure to survive perihelion.

For those of us in the northern hemisphere, the wait for our next "Great Comet" continued for another 6½ years before finally ending earlier this year. Hopefully we will not have to wait another two decades before another one . . .

SPECIAL TOPIC: CLOSE ASTEROIDAL ENCOUNTERS

In the Week 2 "Special Topics" presentation I discussed the history and recognition of near-Earth asteroids, and described some of the early observed encounters by these objects. What could perhaps be considered the most remarkable of these asteroids was a 10th-magnitude fast-moving object discovered on October 28, 1937 by Karl Reinmuth at Heidelberg Observatory in Germany. Two days later Reinmuth's object passed just 0.0050 AU (1.9 lunar distances) from Earth, by far the closest known approach of an asteroid to Earth at that time. Unfortunately, only four days of observations – some of these being images from pre-discovery photographs taken elsewhere up to three days earlier – were available, which was not enough from which to calculate a valid orbit, and thus Reinmuth's object was lost. He nevertheless named it Hermes, after the fleet-footed messenger of the gods in Greek mythology, and this name was accepted by the general astronomical community.



A "stacked" pair of CCD images of (69230) Hermes that I took 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.

If Hermes was ever to be seen again, it would have to be accidentally re-discovered. That event finally happened on October 15, 2003, when Brian Skiff with the LONEOS program in Arizona discovered a relatively bright fast-moving object that was soon identified as being none other than the long-lost Hermes. This re-discovery allowed for a valid orbit to be computed, after which it was assigned the number (69230); it is an Apollo-type asteroid with an orbital period of 2.13 years, a perihelion distance of 0.62 AU, and an eccentricity of 0.62. The calculated orbit also indicated that Hermes had been imaged in 2000, 2001, and 2002 by the various survey programs but had not been recognized; it had also made occasional close approaches to Earth during the intervening decades, including an extremely close approach of 0.0042 AU (1.7 lunar distances) in April 1942, but had been missed on all occasions. Its next close approach will be one of 0.028 AU on April 25, 2040.

Hermes' record for the closest-known asteroidal approach to Earth would stand for over five decades. It was finally broken on March 31, 1989, when Henry Holt and Norman Thomas – working with the Shoemakers' survey program with the 46-cm Schmidt telescope at Palomar Observatory in California – discovered the asteroid now known as (4581) Asclepius; nine days before its discovery Asclepius had passed 0.0046 AU (1.8 lunar distances) from Earth. Since it was already outbound it was well observed for the next two months and then recovered the following year, and thus before long its orbit was well enough known for it to be numbered.

It was around this time that the first of the CCD-based survey programs, Spacewatch (based at Kitt Peak National Observatory in Arizona), was starting to become operational. While Spacewatch is not as comprehensive in its sky coverage as the later surveys have been, what regions of the sky it did survey it did so very "deeply," i.e., to very faint magnitudes. It accordingly began finding tiny asteroids passing very close to Earth, including 1991 BA (0.0011 AU, or 0.43 lunar distances) on January 18, 1991; 1993 KA2 (0.0010 AU, or 0.39 lunar distances) on May 20, 1993; and 1994 XM1 (0.0007 AU, or 0.27 lunar distances) on December 9, 1994. Each of these asteroids was no more than 5 to 10 meters in diameter.

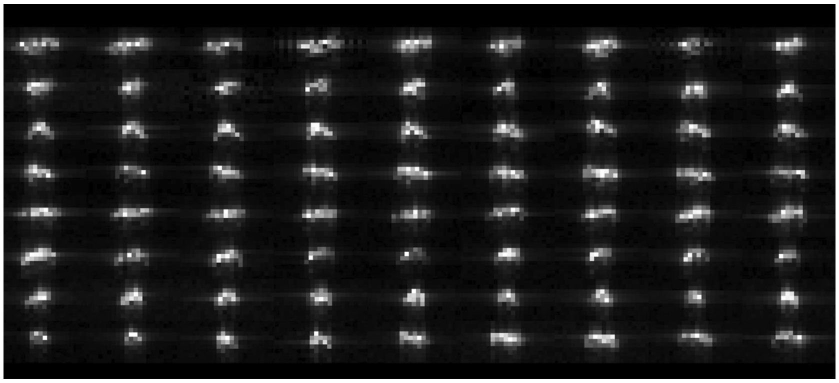
It has become clear with the advent of the comprehensive survey programs that asteroid encounters such as these are just the "tip" of the proverbial "iceberg." Tiny objects such as these passing very close to Earth are nowadays routinely discovered on a continuous basis, and for example already this month two asteroids with a "miss distance" less than one lunar distance has been discovered. The closest approaches have been 2008 TC3 and the three other objects discussed in that object's "Special Topics" presentation, all of which entered Earth's atmosphere and disintegrated and two of which left retrievable meteorite fragments, but several others have come almost as close; the closest such approach took placed less than two weeks ago, when on November 13, 2020 the tiny asteroid 2020 VT4 passed just 380 km above Earth's surface fifteen hours before its discovery by the ATLAS survey in Hawaii. The IAU's Minor Planet Center maintains a continuously-updating list of recently-discovered (and other) asteroids that have either made very close approaches in the recent past or will do so within the near-term future.

Artist's conception of an asteroid passing by Earth. Courtesy NASA/JPL-CalTech.

The vast majority of these close-approaching objects are one-time tiny visitors that travel on back into interplanetary space, and that pose no significant threat to Earth if they do happen to come back. However, the primary rationale for the various survey programs is to find potentially threatening objects – which are larger – with enough lead time to predict future approaches and to take appropriate actions if those become necessary. The processes by which this is done are described in a previous "Special Topics" presentation.

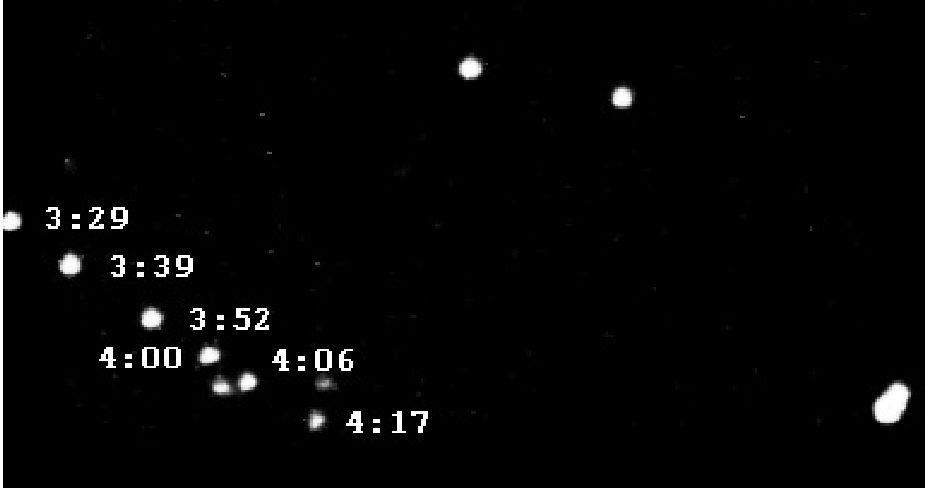
Because of the discoveries that have already been made, predicted close approaches to Earth by already-known asteroids take place all the time. Throughout any given year a few of these usually become bright enough to detect visually with small- to moderate-size telescopes, and throughout "Ice and Stone 2020" I have indicated such events in the weekly "This Week in History" write-ups. One such event takes place this week: the Apollo-type asteroid (7753) 1988 XB (discovered in December 1988 by a Japanese amateur astronomer, Yoshiaki Oshima, and with an orbital period of just under 1.8 years), which will pass 0.066 AU from Earth on this Sunday, November 22. It is approaching Earth from the sunward side and will be best visible next week when it is visible in the morning sky and near 15th magnitude.

At this time, the closest predicted approach by a previously-discovered asteroid took place on February 15, 2013, when the small asteroid now known as (367943) Duende – which had been discovered a year earlier by the La Sagra Sky Survey, based in southern Spain and operated by a group of Spanish amateur astronomers – passed just 0.00028 AU (0.11 lunar distances) from Earth; this was just 27,700 km above the earth's surface and within the orbital distance of geosynchronous satellites. The flyby was best viewed from the eastern hemisphere where the asteroid became as bright as 7th or 8th magnitude, and meanwhile the Earth's gravitational influences perturbed Duende's orbit such that it went from being an Apollo-type asteroid to an Atira-type asteroid. By a most remarkable coincidence, the meteor explosion over Chelyabinsk, Russia – discussed in a previous "Special Topics" presentation – took place that very same day, but there is no relation between the two events.



A series of radar images of (367943) Duende during its close approach to Earth on February 15, 2013, obtained with NASA's Deep Space Network tracking antenna at Goldstone, California. Courtesy NASA.

One group of asteroids that is especially interesting in the overall discussion of Earth encounters are the "Potentially Hazardous Asteroids," or PHAs, defined as having an absolute magnitude of 22 – corresponding to an approximate diameter of 100 to 200 meters – or brighter, and having a minimum approach distance to Earth's orbit of 0.05 AU or smaller. (An asteroid's absolute magnitude is defined as the apparent magnitude it would have if located 1.0 AU from the sun and Earth at a phase angle of 0 degrees – an impossible physical configuration, but calculable mathematically.) For obvious reasons, these are the objects most likely to impact Earth at some point in the future, and are most likely to present a threat if



The Potentially Hazardous Asteroid (4179) Toutatis, which has made several close approaches to Earth since its discovery in 1989. Left: A series of "stacked" CCD images I took on September 22, 2004, when it was located 0.048 AU from Earth. Right: Close-up image taken by China's Chang'e 2 spacecraft during its flyby of Toutatis on December 13, 2012. Courtesy China National Space Administration.

they were to do so – thus, they are the asteroids that most warrant keeping a close watch on. (Comets that fit these criteria can also be considered as "potentially hazardous objects.") As of now, slightly over 2100 PHAs have been identified. Duende, incidentally, is not among this group; with an absolute magnitude of 24 – corresponding to a size in the neighborhood of 50 meters – it is not large enough to be considered a global threat, although it could wreak damage over a local scale were it to strike Earth at some point.

The following table gives the predicted close approaches of known PHAs to within 0.02 AU of Earth over the remainder of this decade, i.e., through the end of 2029 (extracted from the list maintained by the Minor Planet Center):

Asteroid	Approach Date	Distance (AU)
1999 RM45	2021 March 2	0.0196
(231937) 2001 FO32	2021 March 21	0.0135
2008 MP1	2021 July 8	0.0106
(7482) 1994 PC1	2022 January 18	0.0132
2014 HK129	2022 December 20	0.0172
2010 XC15	2022 December 27	0.0052
2006 HV5	2023 April 26	0.0162
2011 GA	2023 October 15	0.0174
1998 HH49	2023 October 17	0.0079
2008 OS7	2024 February 2	0.0191
2011 HJ7	2025 May 12	0.0168
2009 FF	2025 September 11	0.0175
(152637) 1997 NC1	2026 June 27	0.0172
(137108) 1999 AN10	2027 August 7	0.0027
(153814) 2001 WN5	2028 June 26	0.0017
2011 LJ19	2028 July 27	0.0127
(440212) 2004 OB	2028 September 30	0.0150
(35396) 1997 XF11	2028 October 26	0.0062
(99942) Apophis	2029 April 13	0.0003
(418416) 2008 LV16	2029 November 24	0.0188

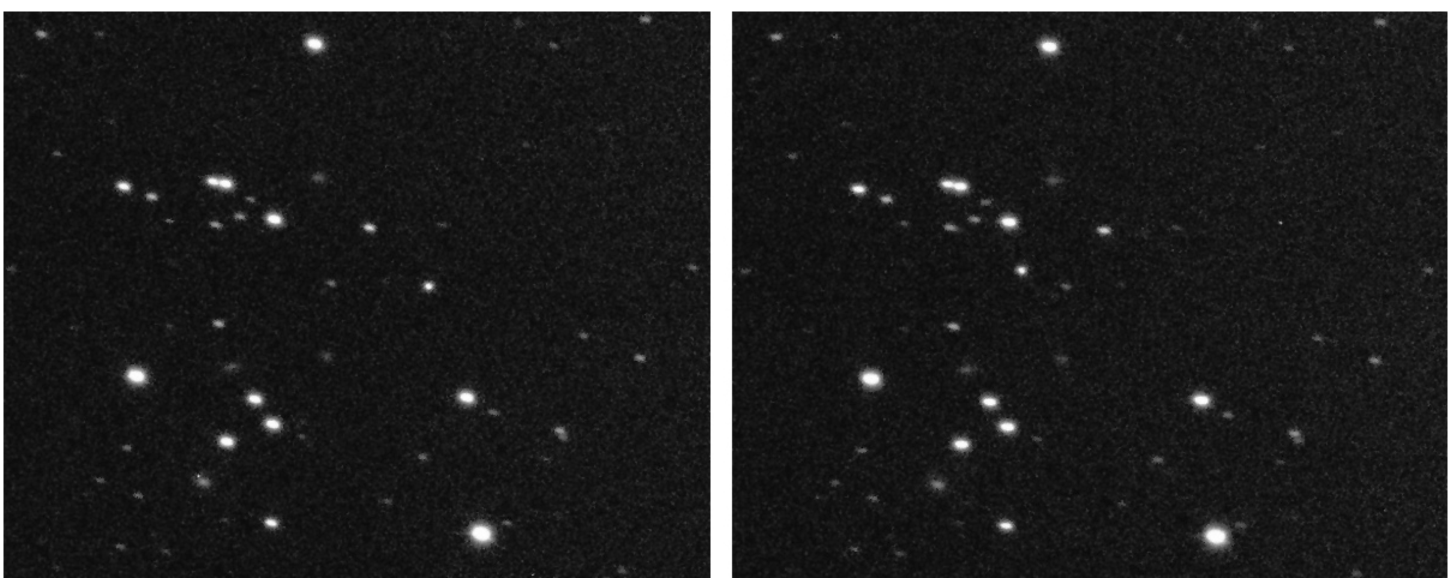
The next-to-last entry on this list is the famous approach by (99942) Apophis that is discussed in detail in a previous "Special Topics" presentation; it will pass 31,000 km above Earth's surface, within the orbit of geosynchronous satellites. The encounter will best be seen from the eastern hemisphere, from where it should become as bright as 3rd magnitude as it transits across the nighttime sky. As discussed in that same "Special Topics" presentation, the approach of (35396) 1997 XF11 in October 2028 was originally calculated to be much closer, and the overall story of how those predictions evolved played a significant role in the process by which predictions are made today.

Composite image of Elon Musk's Tesla Roadster, with Earth in the background. Courtesy Space Exploration Technologies (SpaceX).

I have attempted to keep the above list somewhat manageable, but as we go to larger "miss distances" and longer timeframes the list of Earth-approaching objects quickly gets longer and longer. In the "Special Topics" presentation on "Close Cometary Encounters" I give a list of some "active asteroids" and potential "extinct" comets (currently classified as asteroids) that will be passing somewhat close to Earth over the next two decades.

At least one near-Earth "asteroid" is of artificial origin: this is Elon Musk's Tesla Roadster, which was included as a payload for the test launch of Space Exploration Technologies' (SpaceX) Falcon Heavy rocket from the Kennedy Space Center at Cape Canaveral, Florida on February 6, 2018. The Tesla Roadster was placed in an Apollo-type orbit with an orbital period of 1.52 years and an eccentricity of 0.26, and despite its origins from Earth it does not approach Earth again until January 11, 2047, at which time it will pass by at a distance of 0.032 AU.

Earth is certainly not the only planet that experiences close encounters by asteroids, and as discussed in several previous "Ice and Stone 2020" presentations we have seen the results of recent impacts into Jupiter as well as the evidence of impact craters, including very recent ones, on the moon and on Mars. Many asteroids make close passages by other planets as well as Earth: for example, by the end of the 21st Century Hermes will come to within 0.1 AU of Venus four times and Mars once, and also within 0.02 AU of the main-belt asteroid (4) Vesta on one occasion. The closest Mars-approaching asteroid that we've seen is 2007 WD5, discovered by the Catalina Sky Survey in Arizona, that – according to the best available orbit – passed just 0.00015 AU (19,000 km, or 6.5 Mars radii) above the Martian surface on January 30, 2008. If there should come a point in the future when there are human colonies on Mars, or other worlds of the solar system, among their many other concerns they will still have to deal with the potential threat of impacting objects from space.



Two images of Elon Musk's Tesla Roadster taken ten minutes apart on February 9, 2018 by Tim Lister with the Las Cumbres Observatory's facility at Cerro Tololo Inter-American Observatory in Chile. The identity of the Tesla (a moving "star") is left as an exercise for the reader.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