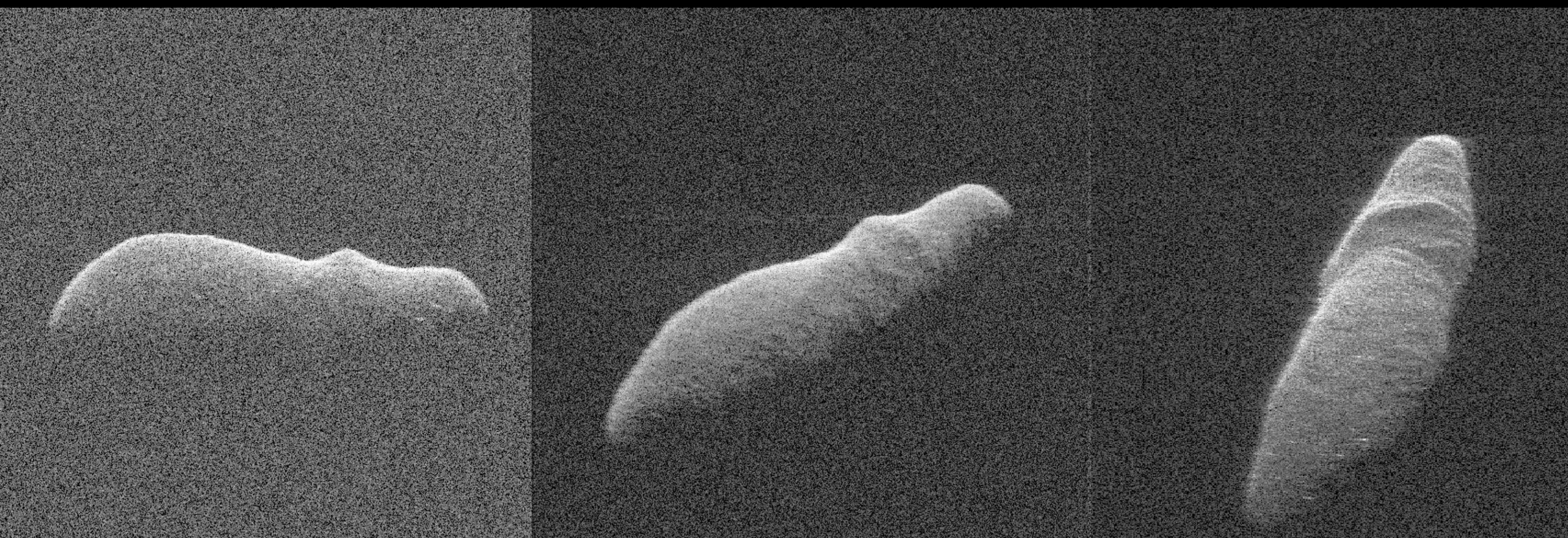
ICE & STONE 2020

Week 3: January 12-18, 2020

Presented by The Earthrise Institute



THIS WEEK IN HISTORY

JANUARY 12 | 13 | 14 | 15 | 16 | 17 | 18

JANUARY 12, 1910: A group of diamond miners in the Transvaal in South Africa spot a brilliant comet low in the predawn sky. This was the first sighting of what became known as the "Daylight Comet of 1910" (old style designations 1910a and 1910 I, new style designation C/1910 A1). It soon became one of the brightest comets of the entire 20th Century and will be featured as "Comet of the Week" in two weeks.

JANUARY 12, 2005: NASA'S Deep Impact mission is launched from Cape Canaveral, Florida. Deep Impact would encounter Comet 9P/Tempel 1 in July of that year and – under the mission name "EPOXI" – would encounter Comet 103P/Hartley 2 in November 2010. Comet 9P/Tempel 1 is a future "Comet of the Week" and the Deep Impact mission – and its results – will be discussed in more detail at that time.

JANUARY 12, 2007: Comet McNaught C/2006 P1, the brightest comet thus far of the 21st Century, passes through perihelion at a heliocentric distance of 0.171 AU. Comet McNaught is this week's "Comet of the Week."

12 | JANUARY 13 | 14 | 15 | 16 | 17 | 18

JANUARY 13, 1950: Jan Oort's paper "The Structure of the Cloud of Comets Surrounding the Solar System, and a Hypothesis Concerning its Origin," is published in the Bulletin of the Astronomical Institute of The Netherlands. In this paper Oort demonstrates that his calculations reveal the existence of a large population of comets enshrouding the solar system at heliocentric distances of tens of thousands of Astronomical Units. This "Oort Cloud" is now believed to be the parent source of the long-period comets that visit the inner solar system, and this topic is discussed more thoroughly in this week's "Special Topics" presentation.

JANUARY 13, 2020: The 6th-magnitude star 11 Piscium will be occulted by the moderately large main-belt asteroid (75) Eurydike. The predicted occultation path crosses northeastern China, far southeastern Siberia, and the southern Kamchatka Peninsula.

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.*

12 13 **JANUARY 14** 15 16 17 18

JANUARY 14, 1970: A team of scientists led by Arthur Code at the University of Wisconsin utilizes the Orbiting Astronomical Observatory 2 (OAO-2) satellite to begin a series of observations of Comet Tago-Sato-Kosaka 1969g – the first time a comet had ever been observed from space. OAO-2's ultraviolet detectors detected the presence of a large cloud of hydrogen surrounding the comet's coma, the first detection of what is now called the "Lyman-alpha" cloud that is now known to accompany almost all comets visiting the inner solar system. Comet Tago-Sato-Kosaka – the first comet I ever observed – is a future "Comet of the Week," and the Lyman-alpha clouds, and spacecraft observations of comets in general, are the subjects of a future "Special Topics" presentation.

JANUARY 14, 2020: The main-belt asteroid (1834) Palach will occult the 7th-magnitude star HD 101517 in Crater. The predicted path of the occultation crosses primarily open waters of the central Pacific Ocean from north to south; the only land within the predicted path are some of the Hawaiian islands (eastern Moloka'i, western Maui, eastern Kaho'olawe, and the western "Big Island") and the western portions of the Arutua and Kaukura Atolls in French Polynesia.

12 13 14 **JANUARY 15** 16 17 18

JANUARY 15, 1951: Planetary scientist Gerard Kuiper publishes a paper in the proceedings of "Astrophysics: A Topical Symposium" proposing the existence of a large population of cometary bodies beyond Neptune. While Kuiper was not the first person to propose such a population, and the actual population is not quite the same as Kuiper envisioned, it is nevertheless referred to as the "Kuiper Belt" today. The Kuiper Belt will be the subject of a future "Special Topics" presentation.

JANUARY 15, 2006: NASA's Stardust spacecraft returns to Earth's vicinity and deploys a capsule into the atmosphere containing samples collected during its encounter with Comet 81P/Wild 2 two years earlier. Comet 81P/Wild 2 was the "Comet of the Week" two weeks ago, and the Stardust results were discussed there; meanwhile, Stardust would go on to encounter Comet 9P/Tempel 1 in February 2011.

12 13 14 15 **JANUARY 16** 17 18

JANUARY 16, 1985: Richard Binzel and Bonnie Buratti detect the first "mutual" event between Pluto and its moon Charon, in this case a transit of Charon across Pluto. These events continued for the next five years and constituted the final confirmation of the existence of Charon. They are discussed in a future "Special Topics" presentation.

12 13 14 15 16 **JANUARY 17** 18

JANUARY 17, 1786: French astronomer Pierre Mechain makes the first discovery of what is now known as Comet 2P/Encke. The comet was only followed for two days, and no valid orbit could be computed at the time. Comet 2P/Encke, which has the shortest orbital period (3.3 years) of any known comet and which returns to perihelion this coming June, is a future "Comet of the Week."

JANUARY 17, 1910: The Daylight Comet of 1910 passes through perihelion at a heliocentric distance of 0.129 AU.

JANUARY 17, 1982: John Schutt and Ian Whillans of the Antarctic Search for Meteorites (ANSMET) program discover a meteorite, now known as ALH A81005, in the Allan Hills region of Antarctica. The meteorite, roughly 3 cm in diameter, was found to have a chemical and isotopic composition very similar to the lunar rocks brought to Earth by the Apollo astronauts, and accordingly is the first meteorite found on Earth to be of lunar origin.

JANUARY 17, 2017: The large Kuiper Belt object (and "dwarf planet") (136108) Haumea occults an 18th-magnitude star in Bootes. Several teams of astronomers across Europe report the star briefly disappearing and reappearing both before and after the actual occultation, revealing the presence of a thin ring – the first one known around a Kuiper Belt object. The Kuiper Belt is discussed in a future "Special Topics" presentation.

JANUARY 17, 2020: The 7th-magnitude star HD 48548 (in Gemini) will be occulted by the main-belt asteroid (412) Elisabetha. The predicted occultation path crosses southeastern Brazil, central Paraguay, southern Bolivia, northern Chile, and southern Peru.

12 13 14 15 16 17 **JANUARY 18**

JANUARY 18, 2000: The explosion of a large meteoroid in the atmosphere deposits fragments of the resulting meteorite on the frozen surface of Tagish Lake in northwestern British Columbia. Over 500 fragments, containing a total mass slightly in excess of 10 kg, have been collected. The Tagish Lake meteorite is a carbonaceous chondrite; these meteorites are the subject of a future "Special Topics" presentation.

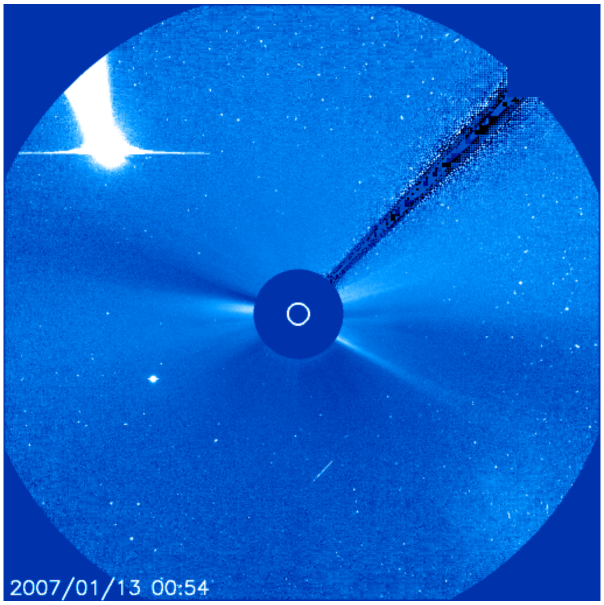
COMET OF THE WEEK: McNAUGHT C/2006 P1

Perihelion: 2007 January 12.80, q = 0.171 AU

After the LIncoln Near-Earth Asteroid Research (LINEAR) program based in New Mexico became operational in early 1998, the discovery rate for both asteroids (including, certainly, near-Earth asteroids) and comets exploded dramatically. This trend has continued on up to the present day with the various subsequent surveys that have come on-line, and this situation should remain for the foreseeable future.

Even with all the various surveys that have been going on, the sky coverage has not been 100% complete. One of the biggest gaps in the coverage involves the fact that essentially all of the initial surveys were based in the northern hemisphere, and thus those regions of the sky accessible only from the southern hemisphere remained largely uncovered. There had been a partial survey, of sorts, based at Siding Spring Observatory in New South Wales, that involved photographic plates taken with the 1.2-meter U.K. Schmidt telescope there. During the early- to mid-1990s astronomer Rob McNaught, a native of Scotland who had relocated to the Siding Spring area in 1984, was tasked to scan these plates specifically in search of near-Earth asteroids, and to perform any necessary follow-up work. Up until 1996 when the Australian government terminated funding for this program, it racked up a rather impressive list of discoveries not only of near-Earth asteroids but also of comets and supernovae. Perhaps the most notable discovery was that of the "asteroid" now known as (5335) Damocles in 1991; this was the first-known representative of the objects now called "Damocloids" that are discussed in a future "Special Topics" presentation.

Comet McNaught from the northern hemisphere's temperate latitudes before perihelion: the evening of January 11, 2007, from near Santa Fe, New Mexico. Photograph courtesy Peter Lipscomb.



Different views: LEFT: Comet McNaught in the LASCO C3 coronagraph aboard SOHO, January 13, 2007. The horizontal "spike" is an artifact due to saturation of the detectors. Image courtesy NASA/ESA. RIGHT: Comet McNaught in daylight, January13, 2007. This approximates the telescopic appearance I witnessed during my daytime observations. Photograph taken by Mark Vornhusen, from Gais Switzerland; licensed under Creative Commons.

The southern hemisphere's gap in sky coverage was finally filled in 2004 when the Arizona-based Catalina Sky Survey, with funding from NASA, initiated the Siding Spring Survey, which utilized CCDs in a manner like those used by the northern hemisphere programs. The primary observers for the Siding Spring Survey were McNaught and Australian amateur astronomer Gordon Garradd, and up until the time that the NASA funding ran out in mid-2013 the Siding Spring Survey produced a large number of asteroid and comet discoveries. When his discoveries from the Siding Spring Survey are combined with those he made during the previous photographic survey, together with some discoveries he made on his own, McNaught has discovered a total of 82 comets which carry his name, the most of any human being.

McNaught discovered what would become the brightest comet from the Siding Spring Survey, and, indeed, the brightest comet of the 21st Century thus far, on August 7, 2006. Initially it was a rather dim object near 17th magnitude, and although it began to attract interest once orbital calculations revealed the small perihelion distance, it did not seem to be especially bright intrinsically, and thus there was not much reason for optimism of a bright display. The comet brightened somewhat rapidly, however, and I successfully picked it up visually at 14th magnitude in mid-September; when it disappeared into evening twilight two months later it had brightened to near magnitude 9.5.

By the latter part of December Comet McNaught was near conjunction with the sun, however since it was then north of the sun observers in the northern hemisphere, particularly those in far northern latitudes who experienced a longer time between sunset and comet-set and thus a darker sky in which to observe, began to pick it up at around 4th magnitude. It brightened rapidly from that point, being close to 2nd magnitude by New Year's Day 2007 and as bright as magnitude 0 or -1 a week later. While observers at the far northern latitudes got a moderately good show as the comet approached perihelion on January 12, those of us at more temperate latitudes had a much more difficult time seeing it, and at best could only detect it very close to the horizon in very bright twilight.

As Comet McNaught passed through perihelion it passed between the sun and Earth, thus exhibiting very large phase angles. A comet, especially one with a high dust content as Comet McNaught appeared to have, will accordingly experience an enhanced brightness due to the phenomenon of "forward scattering of sunlight," which anyone who has driven into a sunset with a dusty windshield has experienced. When it was at perihelion Comet McNaught was only 7 degrees from the sun but at a phase angle of 135 degrees, and for a few days was bright enough to be visible during daylight. Brightness measurements ranged from magnitude -4 to -6 and numerous observers reported naked-eye daytime sightings, and it was a relatively impressive object when viewed telescopically.

After perihelion the comet plunged southward, and by the 17th had become visible from the southern hemisphere during dusk. Over the next couple of weeks it was a spectacular object in the southern hemisphere's evening sky, being initially as bright as magnitude -2 although fading to magnitude 0 by the 22nd. It exhibited a bright dust tail at least 25 to 30 degrees long that showed a distinct curvature through a 90-degree angle, and that also exhibited numerous "synchronic bands" that various other dusty comets in the past have exhibited. While the comet itself was strictly a southern-hemisphere object at this time, the extremities of these "synchronic bands" could be seen from the northern hemisphere after dusk, although due to a spate of wintry weather at the time I never observed these. The origin of these "synchronic bands" in comets' tails is discussed in a future "Special Topics" presentation.

Following this spectacular performance the comet faded steadily, but remained visible to the unaided eye until early March. It passed within six degrees of the south celestial pole shortly after mid-May and remained visually detectable until July, which is also the last time that any astrometric observations were reported.

Comet McNaught is undoubtedly deserving of "Great Comet" status, although – other than its visibility in daylight when near perihelion – it was not an especially spectacular object from temperate latitudes in the northern hemisphere. The 21st Century's other "Great Comet" – Comet Lovejoy C/2011 W3 (which is a future "Comet of the Week") – was also strictly a southern hemisphere object. Those of us in the northern hemisphere patiently await our turn . . .

Meanwhile, the demise of the Siding Spring Survey in 2013 means that the southern hemisphere's gap in sky coverage has returned. A handful of small-scale surveys operated by amateur astronomers have filled in the gap a bit, but at this time there is nothing approaching the coverage provided by the Siding Spring Survey. When the LINEAR program's "Space Surveillance Telescope" becomes operational in Western Australia – currently scheduled for 2021 – that coverage should begin to return, and when the presently-under-construction Large Synoptic Survey Telescope (LSST) in Chile becomes operational a year or two later that coverage should be complete.

Photograph of Comet McNaught taken by its discoverer, Rob McNaught, on January 19, 2007, from Siding Spring Observatory. The tail's distinct curvature and the numerous "synchronic bands" are prominent. Courtesy Rob McNaught.

SPECIAL TOPIC: THE OORT CLOUD

When examined from the standpoint of orbital characteristics, comets appear to come in one of two broad categories: short-period and long-period. Short-period comets, as this term implies, have relatively short orbital periods and often have been observed at numerous returns, while long-period comets, obviously, have long orbital periods and usually have only been observed once. The dividing line between these two is a matter of arbitrary definition, but typically 200 years has been the figure most often utilized when discussing cometary orbits.

In addition to their respective orbital periods, there are other differences between short-period and long-period comets, at least when examined as overall groups. (As in any population, there are individual exceptions from time to time.) One such difference involves the inclinations of their orbits: short-period comets, especially those with orbital periods of ten years or less, usually travel in low-inclination direct orbits, whereas the orbits of long-period comets come with just about any inclination – up to an including 90 degrees, i.e., perpendicular to the ecliptic – and are just as likely to be retrograde, i.e., traveling in the opposite direction from Earth (inclinations between 90 degrees and 180 degrees), as direct (inclination between 0 degrees and 90 degrees). Accordingly, unlike the short-period comets (as well as the planets and the asteroids), long-period comets can come from anywhere in the sky.

The origins of comets have long been an object of high interest. The origin of short-period comets will be the subject of a future "Special Topic" presentation, but as for long-period comets . . . As early as the 1930s the Estonian astronomer Ernst Opik hypothesized that there existed a large cloud of long-period comets in the far outer regions of the solar system. In the mid-20th Century a Dutch astronomer, Jan Oort, calculated the "original" orbits – i.e., the orbits before gravitational perturbations from any of the planets were encountered – of a large sample of long-period comets, and found that a significant percentage of them had their aphelia at distances of several tens of thousands of AU. From this, Oort concluded that a large spherical cloud of comets surrounds the solar system at these distances, and that this cloud supplies the solar system's population of long-period comets. Oort published his findings in January 1950, and this population of comets has been referred to as the "Oort Cloud" ever since.

The existence of the Oort Cloud not only explains the origins of long-period comets, but also explains how we continue to see long-period comets appearing in our skies after the 4.6-billion-year lifetime of the solar system. If the Oort Cloud has existed since the early days of the solar system, comets would remain there indefinitely until "kicked in" to the inner solar system, or else ejected from the solar system altogether, by outside influences. Even now it is estimated that up to one trillion comets may still reside within the Oort Cloud, and obviously that number would have been much higher when the solar system was younger.

After a comet has been "kicked in" towards the sun, once it encounters the planets it will experience gravitational perturbations from them, especially from Jupiter if it is anywhere near. Depending upon the strength and direction of these perturbations, the comet's orbit will accordingly be changed; some comets will be placed into shorter period orbits, perhaps of a few thousand years, while other comets will be placed into hyperbolic orbits and will be ejected from the solar system altogether. Comet Hale-Bopp, for example, was found to be arriving in an orbit with a period of somewhat over 4000 years, and thus could not have been making its first visit from the Oort Cloud; it is conceivable that its previous return was a first-time visit and it was then placed into its present orbit by a close approach to Jupiter at that time.

Detailed studies of various first-time visiting comets from the Oort Cloud suggest that, in the billions of years they have spent in the "deep freeze" of near-interstellar space, their nuclei become covered by a thin "crust" of organic materials, likely produced by bombardment by cosmic rays. As the comet approaches the inner solar system on its first visit some of its more volatile substances may begin sublimating at relatively large heliocentric distances which in turn may suggest a rather high intrinsic brightness and thus a bright display if the perihelion distance is small enough, however once these volatiles are dispersed the comet's activity may appear to begin to begin "shutting down" until this organic crust is broken by the warmer temperatures at smaller heliocentric distances. The result may be a disappointing display based upon the projections made from the comet's initial appearance. Comet Kohoutek 1973f – which will be a future "Comet of the Week" – is a prime example of this; initially it was projected to be a potential "Comet of the Century," but its actual performance, while still relatively decent, was far less spectacular than this and engendered widespread disappointment amongst the

Graphical representation of the Oort Cloud. Licensed image via Creative Commons.

general public. One of the early signs that Comet Hale-Bopp might indeed put on a spectacular performance was the fact that it was found not to be a first-time visitor from the Oort Cloud.

Various physical studies of long-period comets – including, certainly, Hale-Bopp – indicate that they were formed in the region of the solar system between Jupiter's and Neptune's present-day orbits. As these (and other planets) formed their gravitational perturbations would have "kicked out" the long-period comets into their present position in the Oort Cloud; they would have also "kicked in" other comets into the inner solar system, some to bombard Earth and the other forming inner planets and others to impact the sun, and they would have ejected other comets from the solar system. The entire process was certainly stochastic and non-uniform, and would accordingly explain why the Oort Cloud does not appear to have a homogenous, uniform

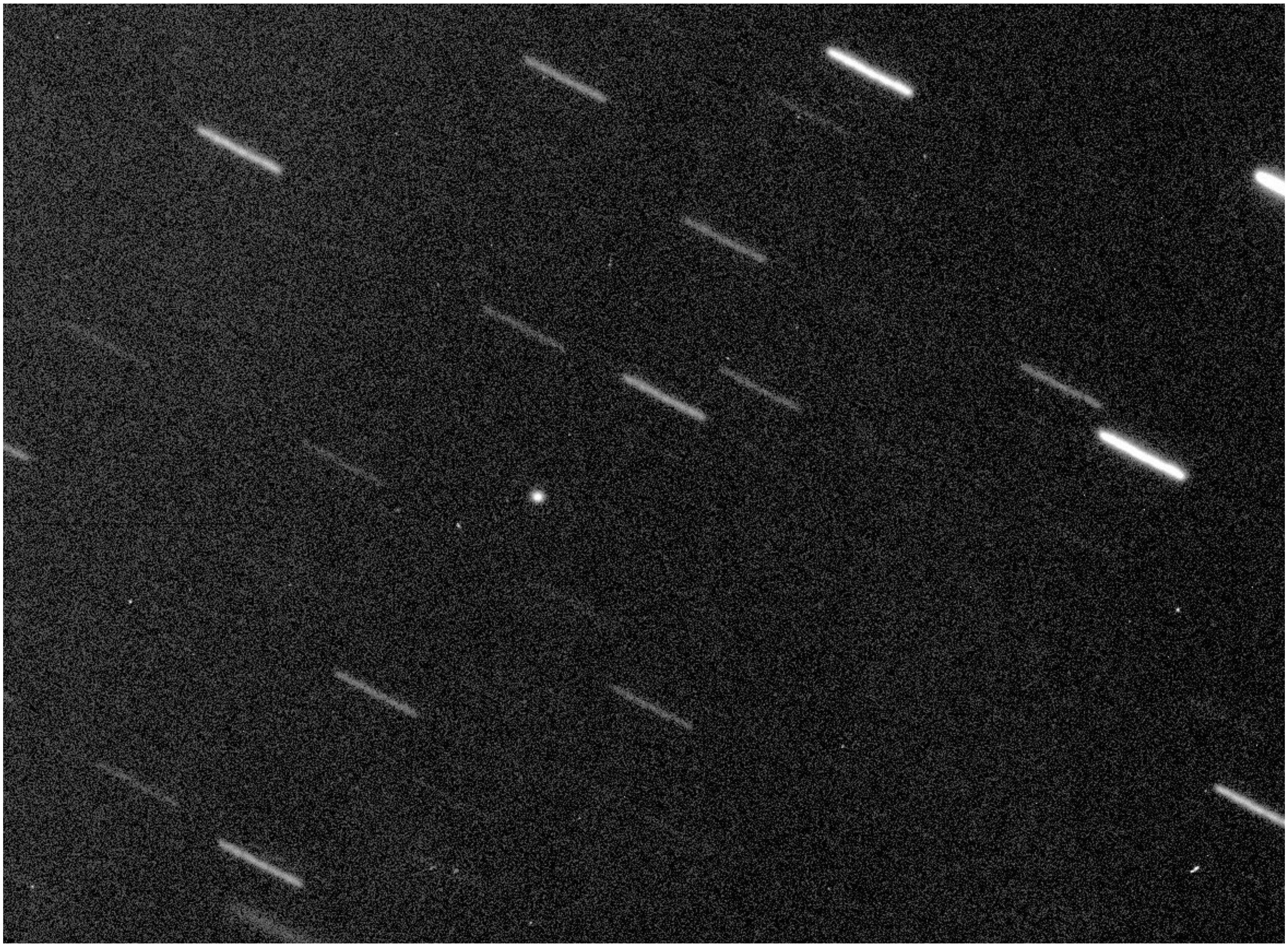
structure. While the outer regions of the Oort Cloud – perhaps 20,000 to 50,000 AU – do appear to be spherical in structure, there is evidence that the inner regions – sometimes called the "Hills Cloud," after astronomer Jack Hills who proposed its existence, and which would occupy the first few thousand AU of the Oort Cloud – are flatter and comprise more lower-inclination comets.

With the objects that make up the Oort Cloud forming in the regions of the solar system that are relatively cold and where volatile substances would be plentiful, the large majority of these objects would be expected to be comets. However, it is conceivable that some asteroids might have been ejected into the Oort Cloud as well, and recent studies indicate that these might constitute perhaps up to 2% of the Oort Cloud's population. The apparent "asteroid" 1996 PW never exhibited any cometary activity despite having an orbital period of close to 4000 years, and likewise the recent object A/2018 V3 also never exhibited any cometary activity despite its high-eccentricity long-period orbit. Although both of these objects appear not to be in their original orbits and thus have apparently been around the sun before, they may very well be representatives of a population of asteroids within the Oort Cloud.

Long-period comets: TOP: Comet Kohoutek 1973f – a first-time visitor from the Oort Cloud – on January 7, 1974. Photograph courtesy Dennis di Cicco. BOTTOM: A photograph I took of long-period comet Hale-Bopp – which was not a first-time visitor from the Oort Cloud – on April 1, 1997.

It is obvious that objects at heliocentric distances of tens of thousands of AU are only weakly held by the sun's gravity, and there is likely a steady "drainage" of these objects into interstellar space. At the same time, outside gravitational influences will sometimes provide the impetus that "kicks" the Oort Cloud objects into the inner solar system. Tidal influences by the outer galaxy as a whole are likely one contributor to this process, especially around those occasions when the sun (and accompanying solar system) crosses the equatorial plane of the Galaxy, which take place on approximate intervals of a few tens of millions of years.

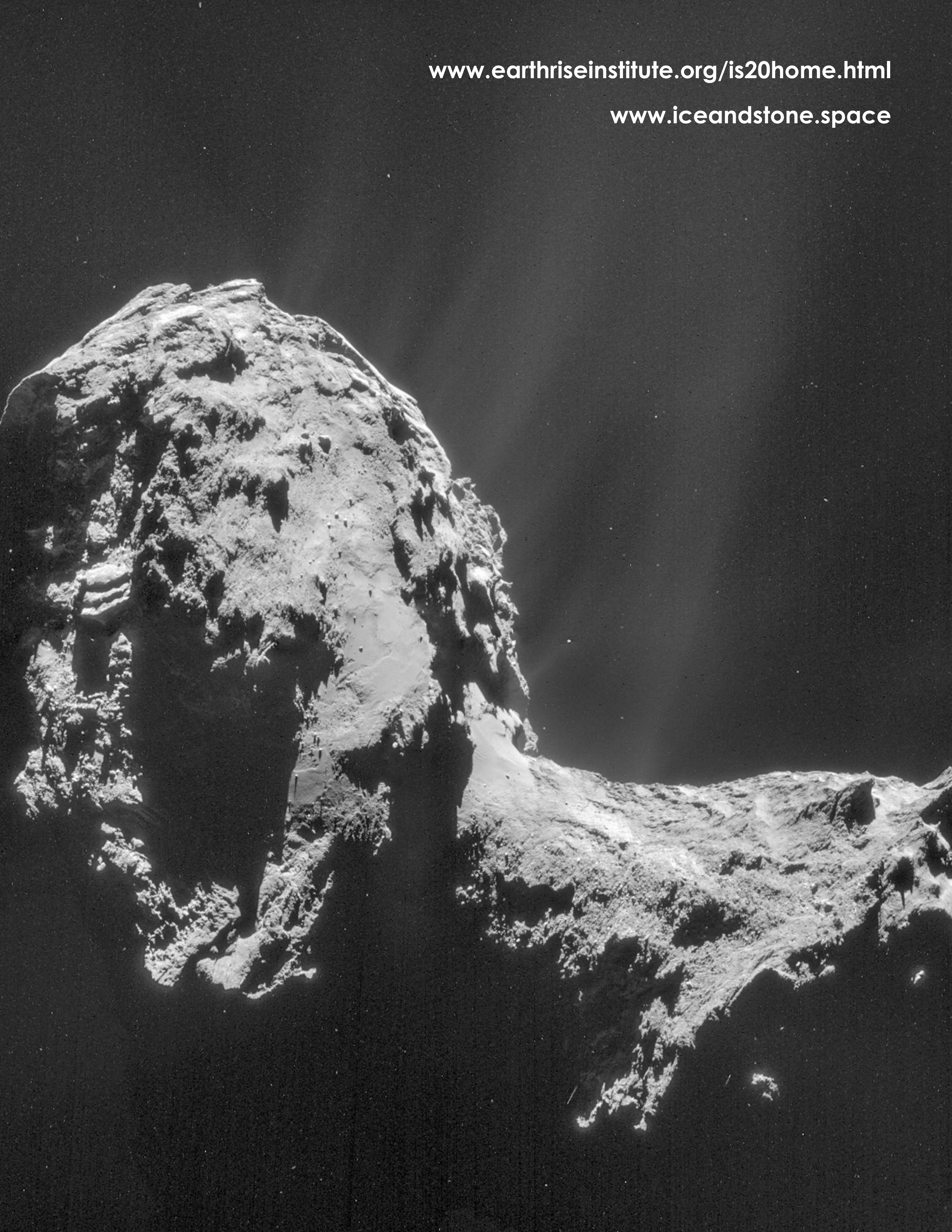
During the course of their respective travels around the Galaxy, the sun and



The long-period apparent "asteroid" A/2018 V3, imaged with the Las Cumbres Observatory facility at Cerro Tololo Inter-American Observatory in Chile on August 12, 2019.

various other stars will occasionally pass somewhat close to each other. If and when another star might pass through the Oort Cloud, its gravitational influences would likely "kick in" an unusually large number of comets into the inner solar system – producing a much larger number of comets appearing in Earth's skies and also a much higher frequency of impacts from these "comet showers." (Due to the travel times involved, these events would take place a few million years after the star's passage through the Oort Cloud.) This subject, including discussions of specific stars that have either passed through the Oort Cloud during the – astronomically – recent past or will do so in the – astronomically – near future, will be discussed more thoroughly in a future "Special Topics" presentation.

A variation of this particular theme is provided by the hypothetical object dubbed "Nemesis." In the mid-1980s some published paleontology research suggested that "mass extinctions" on Earth seemed to occur at approximately 26-million-year intervals, and some astronomers accordingly suggested that these could be due to a very distant companion of the sun that periodically passed through the Oort Cloud and sent large numbers of comets inward towards the inner solar system and Earth. Since it had not yet been detected, this so-called "Nemesis" could either be a very low-mass M-type star or perhaps a "brown dwarf" (a stellar object not massive enough to sustain nuclear fusion in its interior; no such objects were known at that time, although many have been discovered since then). More recent studies have cast doubt on the alleged 26-million-year periodicity of mass extinctions, and meanwhile – despite careful searches – no signs of any "Nemesis" have been detected, including in data taken by the Wide-field Infrared Survey Explorer (WISE) spacecraft during the early 2010s (although some nearby low-mass stars and brown dwarfs have been detected, and it is entirely conceivable that other such objects may be discovered in the future). At this time, "Nemesis" is no longer considered a viable hypothesis, although some very interesting objects have indeed been found in the outer solar system and will be discussed in a future "Special Topics" presentation.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