ICE & STONE 2020

WEEK 30: JULY 19-25

Presented by The Earthrise Institute

#30

Authored by Alan Hale

THIS WEEK IN HISTORY

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

JULY 19, 2009: An unknown object, most likely an asteroid a few hundred meters across, impacts Jupiter, leaving a black "scar" in Jupiter's atmosphere that persists for the next one to two weeks; the "scar" was first noticed by amateur astronomer Anthony Wesley in New South Wales. The "scar" was reminiscent of those produced by the impacts of Comet Shoemaker-Levy 9 into Jupiter in 1994; that comet is last week's "Comet of the Week."

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

JULY 20, 1963: The path of a total solar eclipse crosses southern Alaska, central Canada, and the far northeastern continental U.S. Astronomers Francois Dossin and Bert Donn, observing from Maine, report their discovery of a probable comet near the sun that appears on several photographs they took during totality. "Eclipse Comets" are the subject of a previous "Special Topics" presentation.

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

JULY 22, 1960: American geologists Edward Chao and Eugene Shoemaker report their discovery of the mineral coesite at the site of the Barringer Crater (aka the Canyon Diablo Crater) near Winslow, Arizona, conclusively demonstrating its origin from an impact event. This was one of the first and best-established impact craters on Earth's surface, which are discussed in next week's "Special Topics" presentation.

JULY 22, 1994: Nucleus "W" of Comet Shoemaker-Levy 9 impacts Jupiter, the last of over twenty nuclei that impacted that planet over the previous week. This comet was last week's "Comet of the Week."

JULY 22, 2021: NASA's Double Asteroid Redirection Test (DART) mission is scheduled for launch. DART's destination is the binary Amor-type asteroid (65803) Didymos, where it will test asteroid deflection by impacting Didymos' moon, which has just recently been given the name "Dimorphos." The DART mission is discussed in a previous "Special Topics" presentation, while various deflection strategies are discussed in a future "Special Topics" presentation.

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

19 20 21 22 JULY 23 24 25

JULY 23, 1995: Shortly after midnight local time I discover an 11th-magnitude comet near the globular star cluster M70 in Sagittarius, and at around that same time an amateur astronomer in Arizona, Thomas Bopp, discovers the same comet. A little over a year and a half later Comet Hale-Bopp C/1995 O1 became one of the brightest comets of the second half of the 20th Century and was seen by more people than any other comet in history; up until this month it had been the most recent "Great Comet" for observers in the northern hemisphere. It is this week's "Comet of the Week."

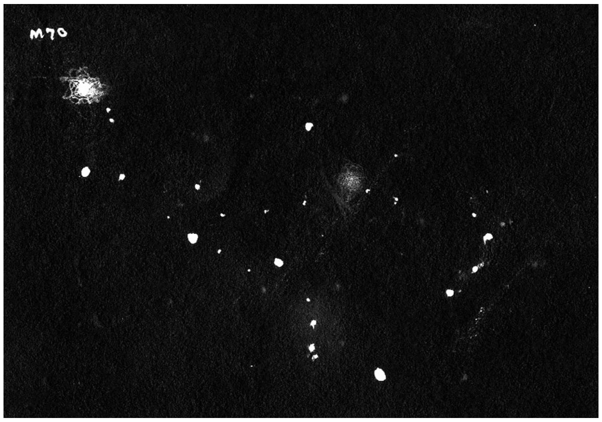
Previously unseen image of Comet Hale-Boop that I photographed the evening of April 9, 1997, from my then-residence in Cloudcroft NM.

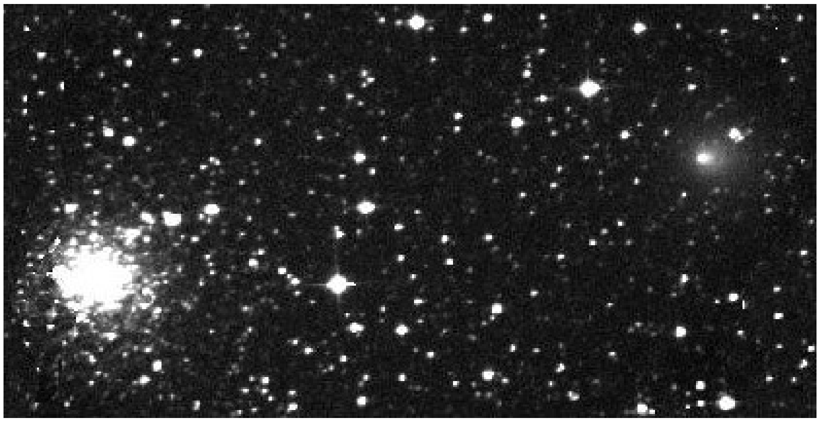
19 20 21 22 23 24 JULY 25

JULY 25, 2076: The outer solar system world (90377) Sedna will pass through perihelion at a heliocentric distance of 76.2 AU. Sedna and other objects in the outer solar system are discussed in a future "Special Topics" presentation.

COMET OF THE WEEK: HALE-BOPP C/1995 O1

Perihelion: 1997 April 1.14, q = 0.914 AU





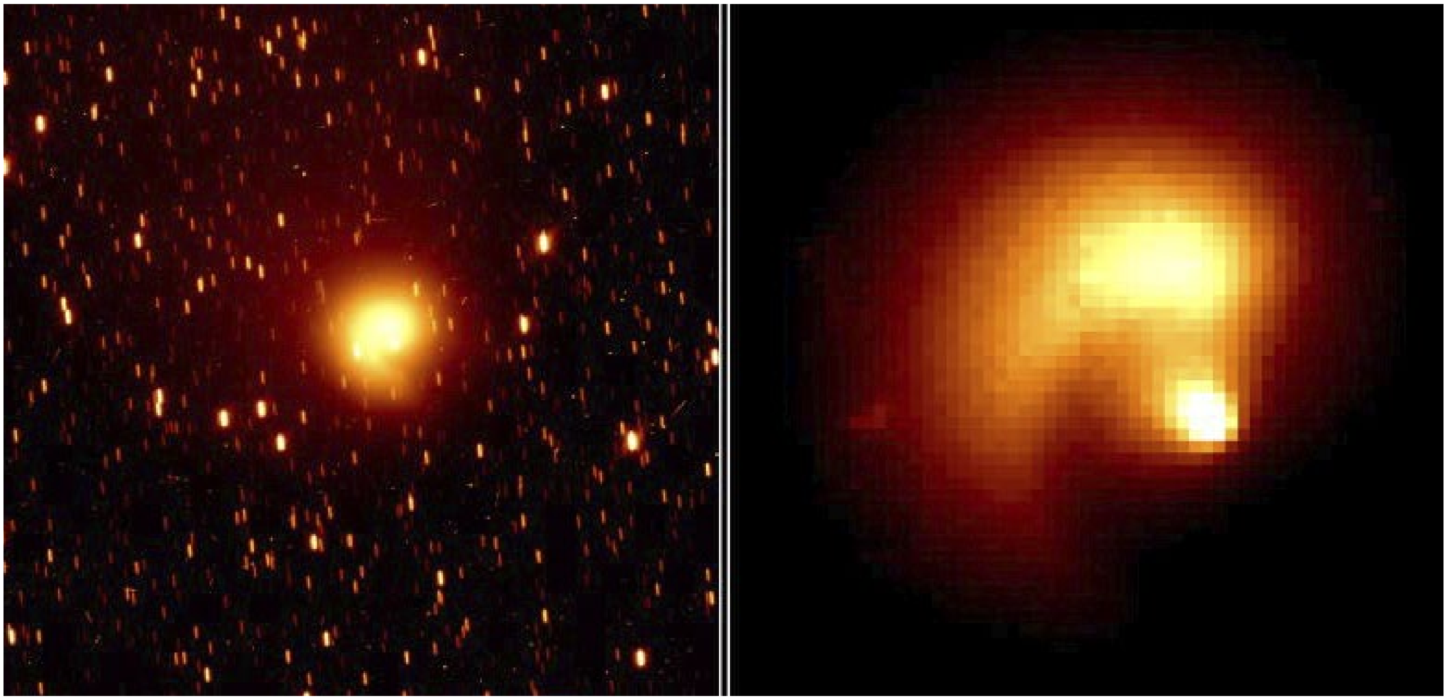
Comet Hale-Bopp at the time of its discovery. Left: Sketch I made of its appearance through the 41-cm "discovery" telescope shortly after midnight on July 23, 1995. Right: CCD image of the comet, with M70, taken the following night by Wayne Johnson with the Orange County (California) Astronomers' telescope in Anza, California. Courtesy Wayne Johnson and Orange County Astronomers.

This week's "Special Topics" presentation discusses, among other things, how the practice of discovering comets has changed over the years. Up until a couple of decades ago a rather large percentage of the known comets were discovered by amateur astronomers regularly scanning the skies with relatively small telescopes in deliberate search attempts, and several comet hunters scored multiple successes. Ever since I first began observing comets I had wanted to discover one, and I accordingly engaged in this practice myself, especially during the latter years of the 1980s, but as time went by and I continued to be unsuccessful in this quest, and as my career and family responsibilities began to increase, I began to grow discouraged, and in the early 1990s, after racking up 400 hours of unsuccessful hunting for comets, I gave up the effort. Then, three years later, I ended up discovering one accidentally. I'm not sure if there is a lesson there or not . . .

Pre-discovery image of Comet Hale-Bopp, from a photographic plate taken from Siding Spring Observatory in New South Wales on April 27, 1993. Reproduced with permission of the Australian Astronomical Observatory.

Throughout all that time, and afterwards, I continued my regular comet observing, and on the night of July 22-23, 1995, I had plans to observe the two comets I was then following, but while taking a break between them I decided to look at some deep-sky objects, and when I turned my telescope towards the globular star cluster M70 in Sagittarius shortly after midnight I noticed a diffuse 11th-magnitude object in the same field of view. Over the course of the next 40 minutes I could tell that this object was moving against the background stars. Meanwhile, in my neighboring State of Arizona, an amateur astronomer named Thomas Bopp was observing the sky with some friends in the desert south of Phoenix, and noticed the same diffuse object. Our respective discoveries were apparently within about five minutes of each other.

Comet Hale-Bopp was found to be located at the large heliocentric distance of 7.15 AU at the time of its discovery. For a comet at such a distance to be as bright as it was indicated a very high intrinsic brightness, and indeed, intrinsically it is the second-brightest comet ever seen in recorded history (only Comet Sarabat in 1729 was brighter). Once orbital calculations indicated that the comet



Images of Comet Hale-Bopp taken with the Hubble Space Telescope on September 26, 1995, showing jetting activity within the inner coma. Courtesy Hal Weaver/Paul Feldman/NASA.

was still over a year and a half away from perihelion passage, which would take place within 1 AU of the sun, it became apparent that a potential "Great Comet" was on the way. Rob McNaught at Siding Spring Observatory in New South Wales then located a pre-discovery image of Comet Hale-Bopp on a photographic plate taken at Siding Spring on April 27, 1993 – at which time the comet's heliocentric distance was 13.1 AU – and this helped establish that the comet was not a first-time visitor from the Oort Cloud, thus adding further grounds for optimism for a bright display.

The comet was followed extensively for the remaining months of 1995, and it remained quite active, occasionally exhibiting small outbursts in its nuclear region, and studies indicated that the activity was being driven by sublimation of carbon monoxide. After being in conjunction with the sun at the beginning of 1996 it emerged into the morning sky in February, being about 9th magnitude at the time. The comet brightened steadily throughout the course of 1996, becoming faintly visible to the unaided eye shortly before mid-year (at which time its heliocentric

Photograph of Comet Hale-Bopp in the evening sky of April 1, 1997, right around the time it was brightest.

Photograph of Comet Hale-Bopp in the morning sky of March 21, 1997, right around the time it was brightest.

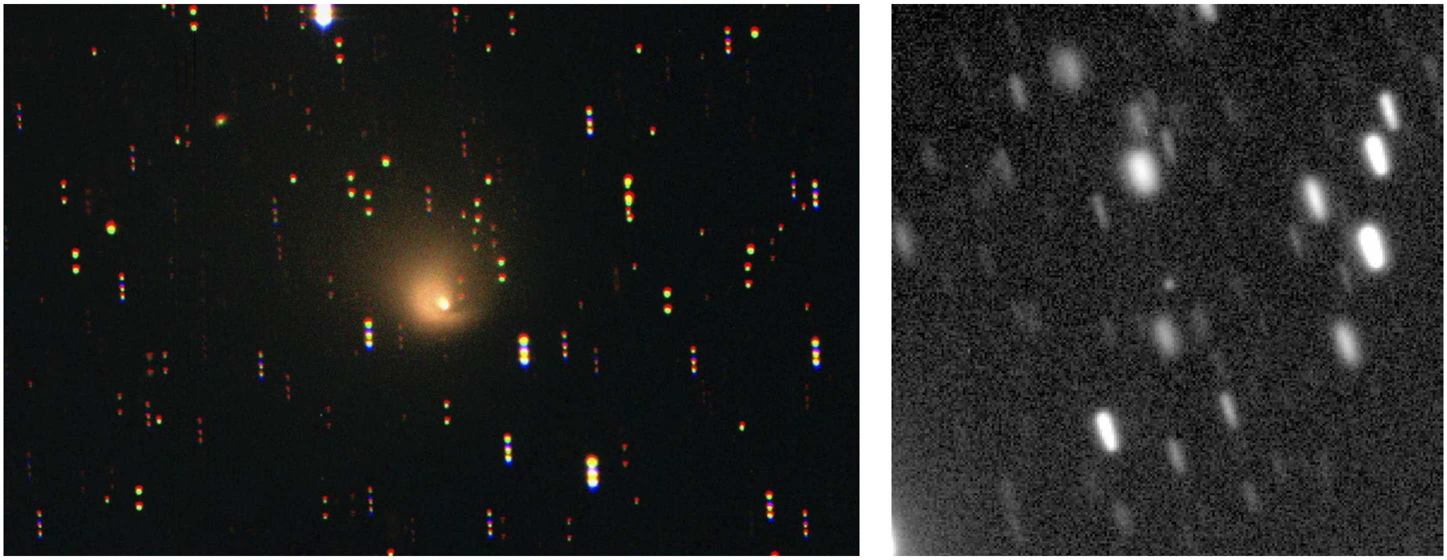
distance was a little over 4 AU) and being close to magnitude 3.5 at the very end of the year when it was again passing through solar conjunction.

After emerging back into the morning sky in early January 1997 Comet Hale-Bopp brightened rapidly as it made its final approach to perihelion, reaching 1st magnitude in late February and magnitude 0 in early March, when it was successfully observed during the total solar eclipse on March 9 that crossed Mongolia and Siberia. It was nearest Earth (1.32 AU) on March 22, at which time it was also in conjunction with the sun but well north of it, and thereafter became primarily visible in the northwestern evening sky after dusk. During the last couple of weeks of March and first couple of weeks of April the comet reached a peak brightness of magnitude -1 and exhibited a prominent dust tail close to 20 degrees long as well as a prominent ion tail roughly 15 degrees long.

Following perihelion passage the comet traveled southward and began fading, and was lost to the northern hemisphere during the latter part of May. By this time it had become accessible from the southern hemisphere, and was around 2nd magnitude during June (albeit low in the west after dusk). After another conjunction with the sun in early July the comet was again briefly visible from mid-northern latitudes as a 5th- and then 6th-magnitude object low in the southern sky, but dropped permanently below the southern horizon from northern temperate latitudes during the latter part of November. It remained accessible from the southern hemisphere from that point on, with the final naked-eye observations being reported right around that same time. I saw it for the last time on May 26 from New South Wales when it was 9th magnitude, and the last visual observations that I'm aware of were made in early July 2000 – shortly after it had passed directly over the Large Magellanic Cloud – when it was around 14th magnitude. Larger telescopes continued to follow it well after that time, and the comet apparently remained active until 2010, at which time its heliocentric distance was almost 30 AU. The final images as of this writing were taken on August 13, 2013, by Karen Meech and Olivier Hainaut with the European Southern Observatory's Very Large Telescope in Chile; at that time its heliocentric distance was 36.4 AU and it appeared as a very faint, stellar object close to 24th magnitude.

Especially with the long lead time that allowed for detailed observation planning, Comet Hale-Bopp

Left: "Ripple" structure within the inner coma of Comet Hale-Bopp, caused by rotation of the comet's nucleus. Courtesy Alireza Mehrani of the Adib Astronomical Society, Esfahan, Iran. Right: Photograph of Comet Hale-Bopp that I took from Siding Spring Observatory, New South Wales, June 9, 1997.



Images of Comet Hale-Bopp as it receded from the inner solar system. Left: a composite of images obtained between February 27 and March 2, 2001. Courtesy European Southern Observatory. Right: The last image taken to date of Hale-Bopp, obtained with the European Southern Observatory's Very Large Telescope on August 13, 2013, when the comet's heliocentric distance was 36.4 AU. Courtesy Karen Meech and Olivier Hainaut.

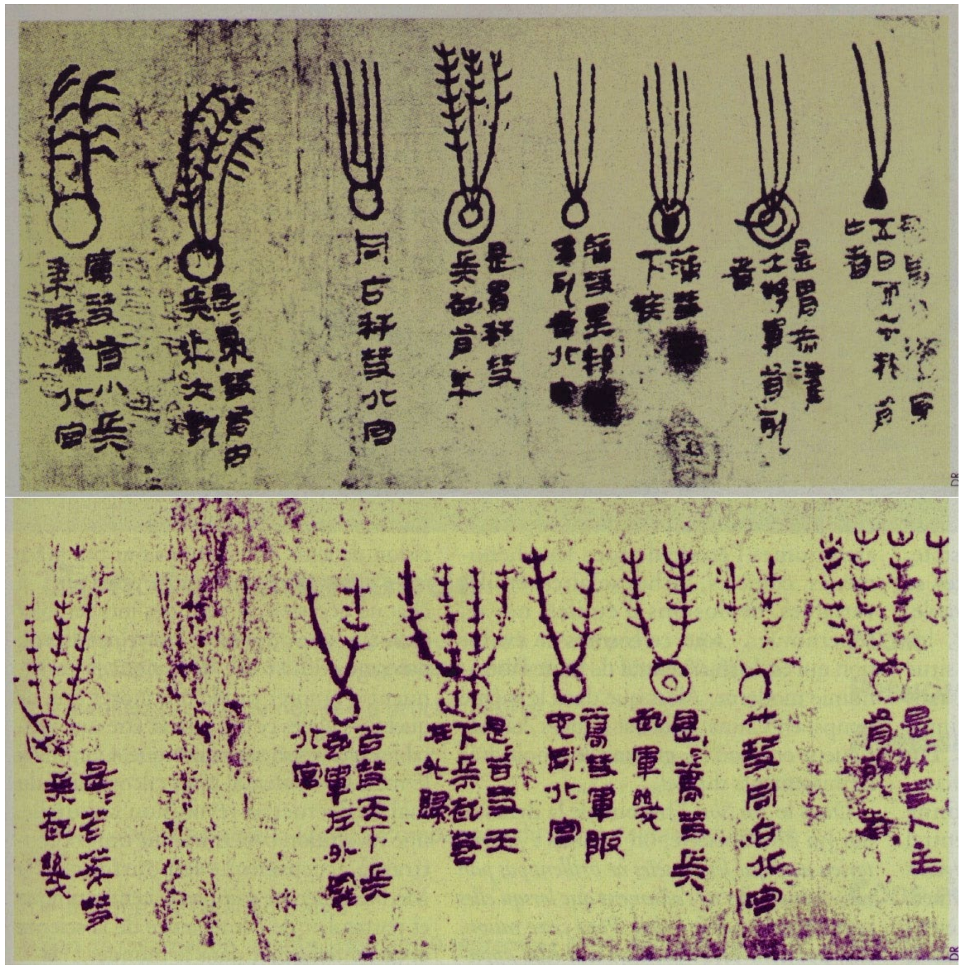
was a scientific boon. Although it never came close enough to Earth for an accurate determination, most studies indicate that Hale-Bopp has a nucleus roughly 40 km in diameter – among the largest on record. Physically, the coma was as large or larger than the sun, and ultraviolet images taken with the Solar Wind ANisotropies (SWAN) telescope aboard the SOlar and Heliospheric Observatory (SOHO) spacecraft indicate that its Lyman-alpha hydrogen cloud was 2/3 of an AU across. Numerous substances, including several first-time detections of various organic compounds as well as material also found in interstellar dust clouds, were detected within Hale-Bopp, and studies suggest that it – and presumably most if not almost all other long-period comets as well – initially formed in the other solar system between Jupiter and Neptune. One especially interesting scientific result was that the deuterium-to-hydrogen ratio in Hale-Bopp's water is about twice that of Earth's seawater – a result consistent with that of some other comets but inconsistent with some others, and which has important implications for Earth's natural and biological history. This subject is addressed further in a future "Special Topics" presentation.

Comet Hale-Bopp was also very popular with the general public as well, and it can be safely said that it was viewed by more people than any other comet in history. It found its way into numerous movies and episodes of television programs, and quite a few songs about it were written as well – I discuss some of these in a previous "Special Topics" presentation. My life was certainly interesting throughout this time, as I found myself being asked for numerous interviews and public speaking engagements. One of the most memorable events was a private comet-viewing session at the U.S. Naval Observatory in Washington, D.C. with then-U.S. Vice President Al Gore and his wife.

With over 20 years' worth of astrometric observations available, it is conceivable that some reasonably valid statements can be made about Comet Hale-Bopp's past and future. A 2017 study by Rainer Kracht and Zdenek Sekanina suggests that the comet would have previously returned around 2251 B.C.; while it could well have been a bright object at that time, there are no records from that era that can conclusively be tied to it. If Kracht and Sekanina's predicted perihelion time in early December of that year is accurate, then the comet would have passed very close to Jupiter a little over a year previously, possibly being perturbed from being a first-time visitor from the Oort Cloud into the 4600-year orbit that it occupied thereafter. Meanwhile, in April 1996 while approaching its most recent perihelion Comet Hale-Bopp passed 0.77 AU from Jupiter, which cut its orbital period almost in half. While this should perhaps not be taken too seriously, Kracht and Sekanina predict the next perihelion passage as taking place around August 6, 4393. Regardless of whether or not that prediction is accurate, the comet should certainly be returning sometime within that general timeframe, and presumably should once again be a bright object as it was in 1997. Provided that there is still a human civilization on Earth at that time – and perhaps "Ice and Stone 2020" participating students could have something to say about that – any humans living during that time can once again appreciate the lovely object in their nighttime sky, and it might very well be known by its present name, in turn giving me a type of immortality that few individuals in history have ever achieved.

SPECIAL TOPIC: DISCOVERIES AND SURVEY

Up until a few centuries ago, all the comets that were seen by human beings were "discovered" via the unaided eye. It is unlikely that there were ever any search efforts for these objects, rather, when they appeared they essentially revealed themselves to the people who were alive at that time. Probably the closest thing to any "search effort" was conducted by the court astronomers of the various Chinese dynasties, who were primarily tasked with watching the skies for anything unusual. They kept relatively detailed records of the comets they observed, indeed, much of what we know about comets that appeared prior to about the year 1600 comes from these records. It should perhaps be kept in mind that for a comet to become noticed to naked-eye observers it probably needs to be at least as bright as 3rd or 4th magnitude.



Pictures of comets as drawn by ancient Chinese astronomers, from the Mawangdui Silk, circa 300 B.C.

After the invention of the telescope in the early 17th Century it was inevitable that, eventually, such an instrument would be used to discover comets. The first such discovery took place on November 14, 1680 when a German astronomer, Gottfried Kirch, discovered what would later become the Great Comet of that year (and a future "Comet of the Week"). As the subsequent decades passed more and more comets began to be discovered with telescopes.

What were apparently the first systematic search efforts for comets began during the mid- to late 18th Century and were conducted by French astronomer Charles Messier – best known for the catalogs of deep-sky objects he compiled in order to avoid mistaking them for comets – and his contemporaries like Pierre Mechain and Jacques Montaigne. Caroline Herschel, sister of Uranus discoverer William Herschel, discovered eight comets in the late 18th Century, and another French astronomer, Jean Louis Pons, dominated comet discoveries during the first three decades of the early 19th Century. Among the many successful comet hunters of the late 19th and early 20th Centuries, those with the most discoveries include Lewis Swift, Edward Barnard, William R. Brooks, and Charles Perrine in the U.S., and Alphonse Borrelly and Michel Giacobini in France.

The most successful visual comet hunters of the early to mid-20th Century were William Reid in South Africa and Leslie Peltier in the U.S. In 1940 a Japanese amateur astronomer, Minoru Honda, discovered his first comet, and then discovered eleven more up through 1968 (as well as several novae in subsequent years); inspired by their countryman, Japanese amateur astronomers began to devote significant energy towards discovering comets, and dominated the field during the 1960s and 1970s and well into the 1980s, and it was not unusual for comets to have two or three Japanese names assigned to them. During the recent past the most successful visual hunters have been Don Machholz (11 comets between 1978 and 2010) and David Levy (9 comets between 1984 and 2006) in the U.S. and William Bradfield (18 comets between 1972 and 2004) in South Australia; all three of these individuals have previous and/or future "Comets of the Week."

In addition to all the above-named individuals, there have been numerous others who have swept the sky looking for comets, and who have perhaps one or two comet discoveries to their credit. From time to time there have been the occasional "accidental" discoveries, i.e., a comet that is detected while the discoverer is examining something else; my own discovery of Comet Hale-Bopp C/1995 O1 – this week's "Comet of the Week" – is a distinct example of this.

All of the earliest known asteroids were also discovered visually, although the first-known one, (1) Ceres, was an accidental discovery. Unlike comets, which can usually be noticed right away due to their large and diffuse comae, asteroids are much more difficult to identify since they appear starlike and can only be detected by their motion against the background stars. Nevertheless, some astronomers were reasonably successful at this endeavor, with the most successful one being Austrian astronomer Johann Palisa, who discovered 122 asteroids between 1874 and 1923.

By the late 19th Century astro-photography was starting to come into its own, and asteroids were starting to show up on photographic plates so often that one astronomer of that era referred to them as the "vermin of the skies." Among the more successful asteroid discoverers who utilized photography was the German astronomer Max Wolf, who discovered 248 asteroids between 1891 and 1932.

A comet discovery from the first Palomar Sky Survey: the blue print discovery photograph of Comet Minkowski 1950b (bright object in lower left) on May 19, 1950. Courtesy National Geographic Society/Digitized Palomar Sky Survey.

The first comet to be discovered via photography was found by American astronomer Edward Barnard on October 13, 1892, who accidentally discovered it on a 4-hour exposure he took of a Milky Way star field near the star Altair in the constellation Aquila. The comet – about 12th magnitude at the time of its discovery – was found to be of short period, however it was lost until it was re-discovered in 2008 by Andrea Boattini with the Catalina Sky Survey – see below – and it is now known as Comet 206P/Barnard-Boattini.

Beginning in the late 19th Century various observatories around the world engaged in photographic patrol programs for comets and asteroids, and many of these made quite a few discoveries of these objects. One of the more notable of these was the one conducted at Lowell Observatory in Arizona beginning in 1929 and which utilized wide-field photographic plates; as discussed in last week's "Special Topics" presentation this was specifically instituted to look for Percival Lowell's "Planet X" and it was during the course of this survey that Clyde Tombaugh discovered Pluto the following year. The survey continued for another decade afterwards, and netted many asteroid discoveries as well as two comets, although both of these were not recognized until many months after the fact and had become lost. Both of these comets have now been identified with periodic comets discovered during the relatively recent past.

One interesting variation of the various observatory-run survey programs was a visual survey for comets conducted at Skalnate Pleso Observatory in then-Czechoslovakia (present-day Slovakia) from the mid-1940s to the late 1950s. The program resulted in several comet discoveries during that period, with one of the individuals involved, Antonin Mrkos, discovering 11 comets. His brightest one, Comet Mrkos 1957d, is a future "Comet of the Week."

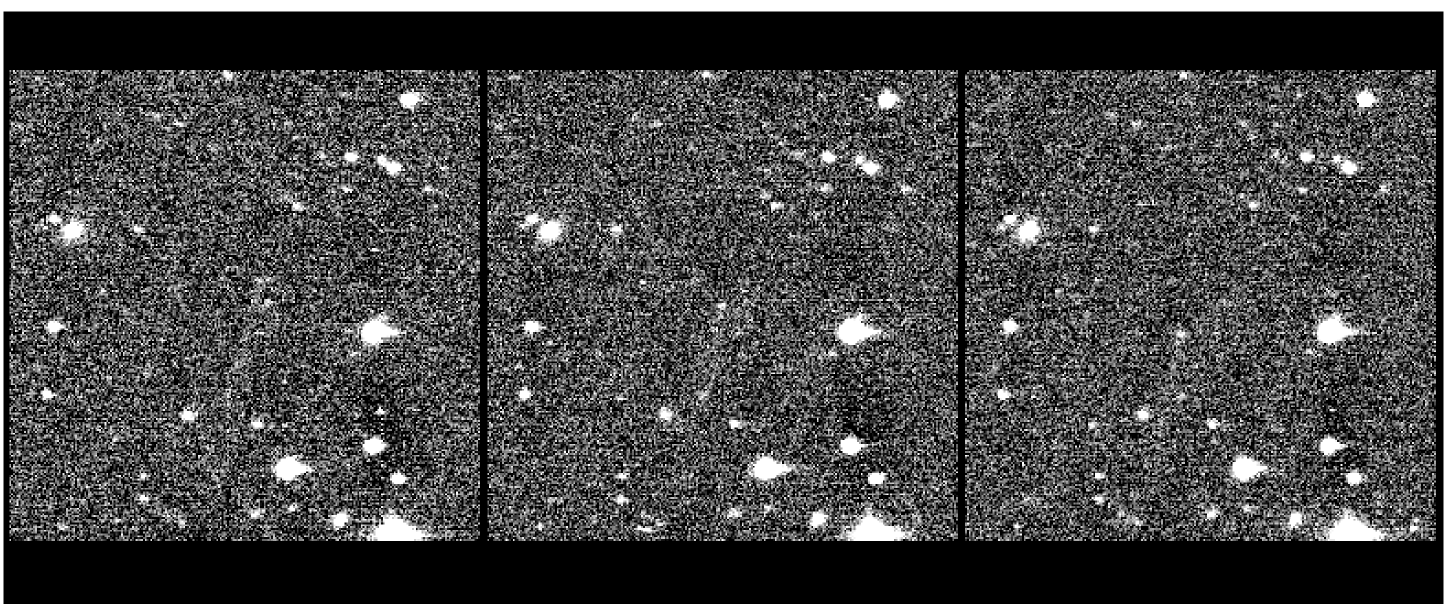
A Schmidt telescope is an instrument invented in 1930 by German-Estonian optician Bernhard Schmidt specifically designed to take wide-field photographs of large areas of the sky. One of the earliest and most productive Schmidt telescopes was one with a 1.2-meter aperture constructed at Palomar Observatory in California in the late 1940s, and in an effort partially funded by the National Geographic Society between 1949 and 1955 this instrument carried out a detailed survey of the entire sky visible from California. Many asteroids and over a dozen comets were discovered during the course of this "Palomar Sky Survey," and the digitized version of the survey images remains one of the most useful tools in astronomy today. A southern hemisphere version of the Palomar Sky Survey was conducted with a similar-size Schmidt telescope located at Siding Spring Observatory in New South Wales during the 1970s, and a second-generation Palomar Sky Survey was conducted with the Schmidt telescope at Palomar from the mid-1980s to the mid-1990s; both of these surveys also produced numerous asteroid and comet discoveries.

These and other Schmidt telescopes at various observatories around the world have been utilized for survey efforts on a rather frequent basis, and indeed the Palomar Schmidt has yielded numerous asteroid and comet discoveries over the years, including the first-known centaur, (2060) Chiron, in 1977. (See the "Special Topics" presentation on centaurs.) A smaller Schmidt telescope, with an aperture of 46 cm, has also been constructed at Palomar, and planetary geologist Eugene Shoemaker conducted a survey program with this instrument from 1982 to 1994 that netted 32 comet discoveries as well as numerous asteroids; one of the comets was Shoemaker-Levy 9 – last week's "Comet of the Week" – which impacted Jupiter in 1994. Astronomer Eleanor Helin conducted a similar survey program with this same telescope during that same timeframe and also made discoveries of several comets and asteroids.

The invention of the charge-coupled device, or CCD, which utilizes electronic computer chips instead of film for its recording surface, in the late 1960s has revolutionized just about every facet of astronomy. CCDs, which are far more efficient than photographic emulsions and thus can reach fainter magnitudes in a much shorter span of time, began to be utilized for astronomy in 1980, and the recovery of Comet 1P/Halley in 1982 with a CCD attached to the 5.1-meter Hale Telescope at Palomar Observatory was an early and powerful demonstration of their capabilities.

It would only be a matter of time before CCDs would be utilized for search efforts for asteroids and comets. The earliest CCD chips were quite small and thus couldn't cover a very large field, although their efficiency and short exposure time made up for this. The first CCD survey program was Spacewatch, the brainchild of astronomer Tom Gehrels (who had utilized the 1.2-meter Palomar Schmidt telescope to make discoveries of several comets and near-Earth asteroids), which went on-line at Kitt Peak Observatory in Arizona in late 1983 with a 0.9-meter telescope. Initially Spacewatch was pretty much limited to recoveries of expected periodic comets, but with the installation of a larger chip in late 1989 it began discovering faint near-Earth asteroids almost right away. Spacewatch found its first comet – the first ever discovered via CCD – on September 8, 1991, a very faint periodic object now known as Comet 125P/Spacewatch. The Spacewatch program continues operating today, and has undergone numerous upgrades including larger and more efficient computer chips as well as the addition of a 1.8-meter telescope; it has racked up quite a few discoveries, including the Apollo-type asteroid now known as (35396) 1997 XF11 which, as discussed in a previous "Special Topics" presentation, created quite a stir when orbital calculations were indicating a very close approach to Earth in 2028.

The impacts of the fragments of Comet Shoemaker-Levy 9 into Jupiter in July 1994 generated a lot of public interest in the potential threat due to impacts by comets and asteroids, and among other things led to the chartering of a commission led by Eugene Shoemaker – one of that comet's co-discoverers – and tasked with recommending appropriate courses of action to counter that threat. The Shoemaker Commission's strongest recommendation was the development of comprehensive survey programs to search for and identify potentially threatening objects



The first CCD-discovered comet. Discovery images of Comet 125P/Spacewatch (very faint moving object in center), taken September 8,1991. Courtesy James Scotti.

The brightest Pan-STARRS comet discovery thus far: Comet PANSTARRS C/2011 L4, with the day-old crescent moon, on the evening of March 12, 2013, from Cerrillos, New Mexico. Photograph courtesy Peter Lipscomb.

well in advance, and with CCD imaging starting to come into its own, along with the continuing improvements in computer technology, the time was ripe for the first such survey efforts to become operational.

The first comprehensive survey was the LIncoln Near-Earth Asteroid Research (LINEAR) program, developed by Grant Stokes at Massachusetts Institute of Technology's Lincoln Laboratory and which utilized funding from the U.S. Air Force to develop the large computer chip used for the imaging. The chip was placed on a 1-meter Ground-based Electro-Optical Deep Space Surveillance (GEODSS) telescope located at Lincoln Laboratory's Experimental Test Station near the northern end of White Sands Missile Range in New Mexico, and after tests that were conducted in mid-1996 and again in 1997 – during which approximately twenty near-Earth asteroids were discovered – LINEAR went fully on-line in March 1998.

At that time the field of near-Earth asteroid discovery changed almost overnight, as LINEAR began reporting discoveries of such objects on almost a nightly basis. Before long, almost all other discovery programs were rendered all but obsolete, and LINEAR dominated the field for the next several years, although eventually additional survey programs (discussed below) became operational and began making their own discoveries. LINEAR also dominated the discoveries of comets and main-belt asteroids as well, and by the time it was shut down at the end of 2012 LINEAR had discovered over 200 comets, over 2400 near-Earth asteroids, and over 140,000 main-belt asteroids. Among its discoveries were the first bright naked-eye comet of the 21st Century, Comet C/2001 A2 (a previous "Comet of the Week"), and the first confirmed Atira-type asteroid – (163693) Atira – in February 2003.

Following the termination of the initial survey LINEAR's efforts turned toward testing of a 3.5-meter Space Surveillance Telescope on an adjacent site at White Sands Missile Range for a few years during the mid-2010s, during which time it discovered a handful of additional comets and near-Earth asteroids. This instrument is currently scheduled to be deployed to Exmouth, Western Australia, and to become operational in 2021, and although its primary mission is the search for artificial space debris, it will likely discover more comets and near-Earth asteroids in the process.

Another early comprehensive survey effort was the Near-Earth Asteroid Tracking (NEAT) program developed by Eleanor Helin. An early incarnation of NEAT went on-line in late 1995 and utilized a 1-meter GEODSSS telescope based at Mount Haleakala in Hawaii, and over the next 3½ years it discovered approximately 30 near-Earth asteroids, two comets, and the first-known long-period "Damocloid" object, 1996 PW. (These objects are discussed in a future "Special Topics" presentation.) After this initial effort was terminated in mid-1999 a more comprehensive version became operational in mid-2000 which involved both a 1.2-meter GEODSS telescope at Haleakala as well as the refitted 1.2-meter Schmidt telescope at Palomar. During the subsequent six years NEAT discovered several hundred near-Earth asteroids and over fifty comets.

One other productive early comprehensive survey effort was the Lowell Observatory Near-Earth Object Search (LONEOS) program, which utilized a 0.6-meter Schmidt telescope located at Lowell Observatory's

Anderson Mesa station outside of Flagstaff, Arizona, and which initially went on-line in 1993, expanded its capability in 1998, and terminated in 2008. During its years of operation LONEOS discovered approximately 22,000 main-belt asteroids, almost 300 near-Earth asteroids, and 40 comets.

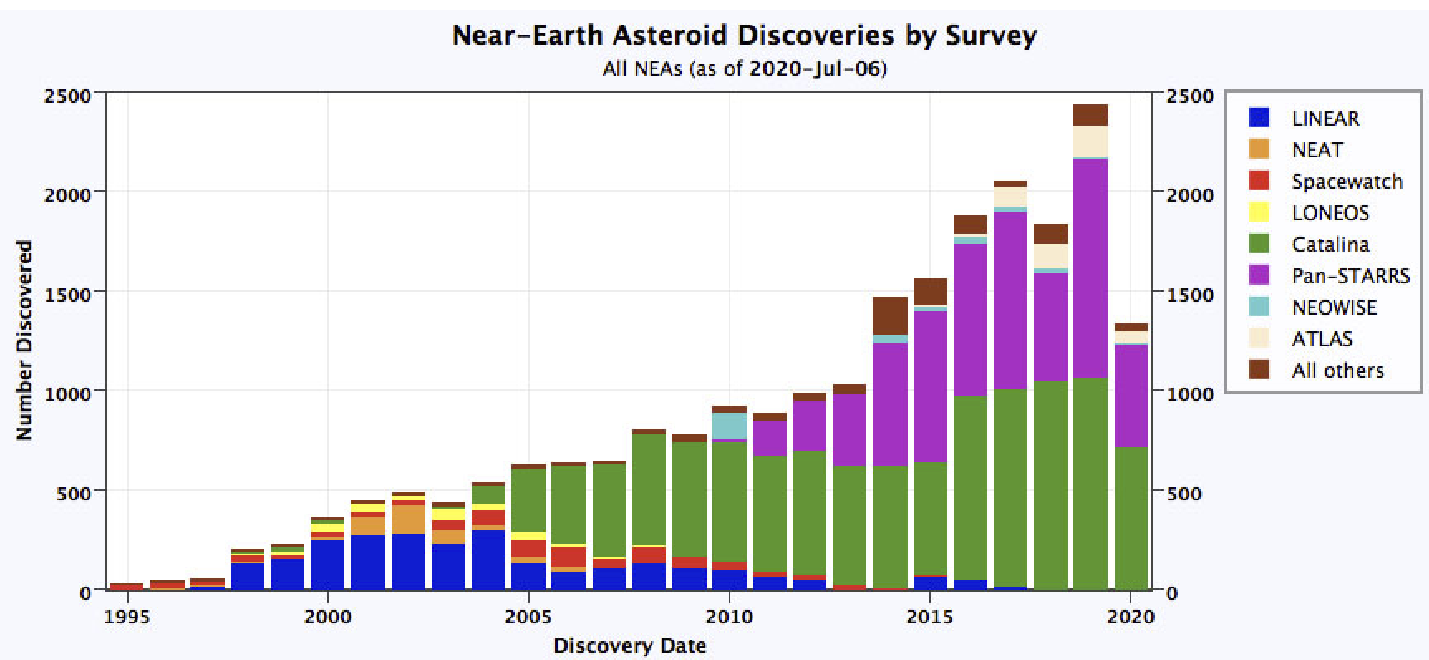
For the past decade and a half, one of the most productive survey programs is the Catalina Sky Survey based in Arizona which, after some earlier smaller efforts in the mid- to late 1990s, became fully operational in 2004. The Catalina survey utilizes a 0.7-meter telescope located on Mount Bigelow near Tucson, and the Mount Lemmon Survey, which operates under the same management, utilizes a 1.5-meter telescope on that peak. As of now the Catalina and Mount Lemmon surveys have discovered several thousand near-Earth asteroids and over 200 comets.

Between 2004 and mid-2013 (at which time funding was terminated) the Catalina survey program also managed the Siding Spring Survey that was based at the namesake observatory in New South Wales. During that time it was the only comprehensive survey program based in the southern hemisphere, and it discovered several hundred near-Earth asteroids and slightly over 100 comets, three-fourths of these being made by Rob McNaught. Two of the survey's most important discoveries were Comet McNaught C/2006 P1 – a previous "Comet of the Week" – which was the 21st Century's first "Great Comet," and Comet Siding Spring C/2013 A1 – a future "Comet of the Week" – that passed extremely close to Mars in October 2014. Following the survey's termination there has not yet been another comprehensive survey program in the southern hemisphere.

The most comprehensive survey program operating at this time is the Panoramic Survey Telescope And Rapid Response System (Pan-STARRS) program run by the Institute for Astronomy at the University of Hawaii and based on Mount Haleakala. Pan-STARRS, which became operational in 2010, utilizes a 1.8-meter telescope (as well as a second telescope of the same size that has been operational since 2015) and since then has discovered several thousand near-Earth asteroids and over 200 comets. What can be considered as Pan-STARRS's most important discovery is the interstellar object 1I/'Oumuamua in 2017, which is the subject of a future "Special Topics" presentation.

Two other productive survey programs that are operating at this time are the Asteroid Terrestrial-impact Last Alert System (ATLAS) program based in Hawaii and the Zwicky Transient Facility (ZTF) program based in California. ATLAS, which went on-line in 2015, utilizes two 50-cm telescopes, one based at Haleakala and the other based on Mauna Loa, and has to date discovered over 450 near-Earth asteroids and 48 comets, including Comet ATLAS C/2019 Y4, a previous "Comet of the Week." The ZTF program, which utilizes the again-refitted 1.2-meter Schmidt telescope at Palomar, became operational in early 2018, and although it looks for transient phenomena both within and outside the solar system, has discovered a handful of comets and near-Earth asteroids, including the three Atira-type asteroids with the smallest-known orbits (2019 AQ3, 2019 LF6, and 2020 AV2, the last of these being the first-known asteroid to travel entirely within the orbit of Venus).

Over the recent years several smaller-scale survey programs have also been successful at discovering



The annual number of near-Earth asteroids discovered by the various surveys between 1995 and July 2020. (The numbers for "Catalina" include the Mount Lemmon and Siding Spring surveys.) Courtesy JPL/Alan Chamberlin.

What may the last comet ever to be discovered visually: Comet Machholz-Fujikawa-Iwamoto C/2018 V1, imaged with the Las Cumbres Observatory facility at Teide Observatory in the Canary Islands on November 15, 2018.

comets and near-Earth asteroids. There have also been a couple of space-based survey programs, which, like the ZTF, have searched for phenomena both within and outside the solar system. During the ten months it was operational in 1983 the InfraRed Astronomical Satellite (IRAS) spacecraft discovered six comets, including the Earth-grazing Comet IRAS-Araki-Alcock 1983d – a previous "Comet of the Week" – and a few near-Earth asteroids, including (3200) Phaethon which appears to be the parent object of the Geminid meteor shower and which may have been an active comet in the past. (Phaethon is discussed in more detail in future "Special Topics" presentations.) The Wide-field Infrared Survey Explorer (WISE) spacecraft launched in late 2009 discovered 17 comets and several dozen near-Earth asteroids before its superfluid helium coolant ran out in early 2011; among its discoveries was the first-known – and so far only known – "Earth Trojan" asteroid, 2010 TK7. (Trojan asteroids are the subject of a future "Special Topics" presentation.) Two of WISE's detectors remained operational, and in 2013, under the mission name Near-Earth Object Wide-Field Survey Explorer (NEOWISE), WISE was reactivated to search for Earth-approaching asteroids, and to date has found approximately 200 such objects as well as 15 comets, including Comet NEOWISE C/2020 F3 which is currently a bright object in our nighttime sky and which is next week's "Comet of the Week."

At this time the most active and productive survey programs are the Catalina and Mount Lemmon surveys, Pan-STARRS, ATLAS, ZTF, and NEOWISE. If things go as planned, they will soon be joined by a larger effort: the Large Synoptic Survey Telescope (LSST) – recently renamed the Vera Rubin Observatory– a large 8.4-meter telescope that will be based in northern Chile. Construction of the Rubin Observatory telescope began in 2015 and it is expected to see "first light" this year, with full operations commencing in early 2022. The plan is for the Rubin Observatory to produce a ten-year-long survey wherein it will image the entire nighttime sky (visible from Chile) down to 24th magnitude every few nights, and the data will immediately become accessible to the public.

In the face of all the current and expected survey programs, it would seem that there is not a lot of room left for possible discoveries by amateur astronomers. Indeed, it has appeared for some time that the era of visual comet discoveries is all but over, although in November 2018 Don Machholz visually discovered his twelfth comet – the first visual comet discovery from anywhere in the world in eight years. Whether or not he, or anyone else, will ever find another comet in such a manner – especially once the Rubin Observatory survey becomes operational – remains to be seen.

It should be noted that two Japanese amateur astronomers, Shigehisa Fujikawa and Masayuki Iwamoto, independently discovered Machholz's comet at the same time with CCDs, and in fact Iwamoto discovered another comet just barely over a month later and then another one early this year. Indeed, several amateur astronomers have had successful discovery efforts with their own CCD and/or digital camera systems, one of these being the Southern Observatory for Near-Earth Asteroids Research (SONEAR) program run by several amateur astronomers in Brazil which has helped fill in the gap left by the termination of the Siding Spring Survey and which has discovered over 30 near-Earth asteroids and nine comets. Terry Lovejoy in Queensland has discovered six comets with his system; three of these became naked-eye objects, and two of these are future "Comets of the Week." Then there is Gennady Borisov in the Crimea, who has specialized in searching for objects at small elongations from the sun; in addition to some near-Earth asteroids he has discovered nine comets, including the recent interstellar Comet 2I/Borisov I/2019 Q4 – another future "Comet of the Week." Perhaps, then, there is still room for contributions from amateur astronomers and other aficionados of the nighttime sky.

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