ICE & STONE 2020

WEEK 26: JUNE 21-27

Presented by The Earthrise Institute

Authored by Alan Hale

THIS WEEK IN HISTORY

21 JUNE 22 23 24 25 26 27

JUNE 22, 1978: U.S. Naval Observatory astronomer James Christy discovers Charon, Pluto's first-known moon. Charon, the discovery of which would be confirmed with a series of transit and occultation events between it and Pluto that began in 1995, provided a major step in our understanding of Pluto's size and physical nature. Pluto, its system of moons, and the New Horizons flyby through this system are the topic of a future "Special Topics" presentation.

JUNE 22, 2019: The ATLAS survey program based in Hawaii discovers a tiny asteroid, designated 2019 MO, that entered Earth's atmosphere over the Caribbean Sea and disintegrated a little less than twelve hours later. This is the fourth, and thus far most recent, event of this nature that has been detected; these are discussed in a future "Special Topics" presentation.

21 22 23 24 JUNE 25 26 27

JUNE 25, 2020: Comet 2P/Encke, the comet with the shortest-known orbital period, will pass through perihelion at a heliocentric distance of 0.337 AU. Around the beginning of July it becomes accessible from the southern hemisphere and may briefly be bright enough to detect with binoculars. It is this week's "Comet of the Week."

COVER IMAGE CREDIT:

Front and back cover: As part of the global effort to hunt out risky celestial objects such as asteroids and comets, ESA is developing an automated telescope, nicknamed 'Flyeye', for nightly sky surveys. This telescope – to be installed on Mount Mufara in Sicily – is the first in a future network that would completely scan the sky and automatically identify possible new near-Earth objects, or NEOs, for follow up and later checking by human researchers.

The telescope splits the image into 16 smaller subimages to expand the field of view, similar to the technique exploited by a fly's compound eye. Such fly-eyed survey telescopes provide a very large field of view: 6.7° x 6.7° or about 45 square degrees. 6.7° is about 13 times the diameter of the Moon as seen from the Earth (roughly 0.5 degrees). In the telescope, a single mirror of 1 m equivalent aperture collects the light from the entire 6.7° x 6.7° field of view and feeds a pyramid-shaped beam splitter with 16 facets. The complete field of view is then imaged by 16 separate cameras.

Artis's impression courtesy of ESA/A. Baker

21 22 23 24 25 JUNE **26** 27

JUNE 26, 1927: Comet 7P/Pons-Winnecke passes 0.039 AU from Earth, the second-closest confirmed cometary approach to Earth during the 20th Century. For a few days it was bright enough to detect with the unaided eye. Close comet approaches to Earth are the subject of a previous "Special Topics" presentation.

JUNE 26, 2012: A team of astronomers led by Mark Showalter discovers Pluto's fifth known moon, Styx, in images taken with the Hubble Space Telescope. Pluto and its system of moons are discussed in a future "Special Topics" presentation.

JUNE 26, 2014: American astronomer Marc Buie discovers the Kuiper Belt asteroid now formally known as (486958) Arrokoth with the Hubble Space Telescope. Arrokoth was encountered by the New Horizons spacecraft at the beginning of 2019. The Kuiper Belt, and the New Horizons mission, are discussed in future "Special Topics" presentations.

21 22 23 24 25 26 JUNE **27**

JUNE 27, 1949: German-American astronomer Walter Baade discovers the asteroid now known as (1566) Icarus from Palomar Observatory in California. With a perihelion distance of 0.19 AU, Icarus had the smallest perihelion distance of any known asteroid for over three decades. It makes close approaches to Earth on occasion, and in 1968 it became the first asteroid to be detected via radar.

JUNE 27, 1997: The main-belt asteroid (253) Mathilde is encountered by NASA's Near-Earth Asteroid Rendezvous (NEAR) spacecraft – later renamed NEAR Shoemaker – while en route to its final destination of the near-Earth asteroid (433) Eros. The NEAR Shoemaker mission is discussed in a future "Special Topics" presentation.

JUNE 27, 2018: JAXA's Hayabusa2 spacecraft arrives at its destination, the near-Earth asteroid (162173) Ryugu. Hayabusa2 left Ryugu late last year and is expected to return to Earth, with collected samples, this coming December. The Hayabusa2 mission is discussed in detail in a future "Special Topics" presentation.

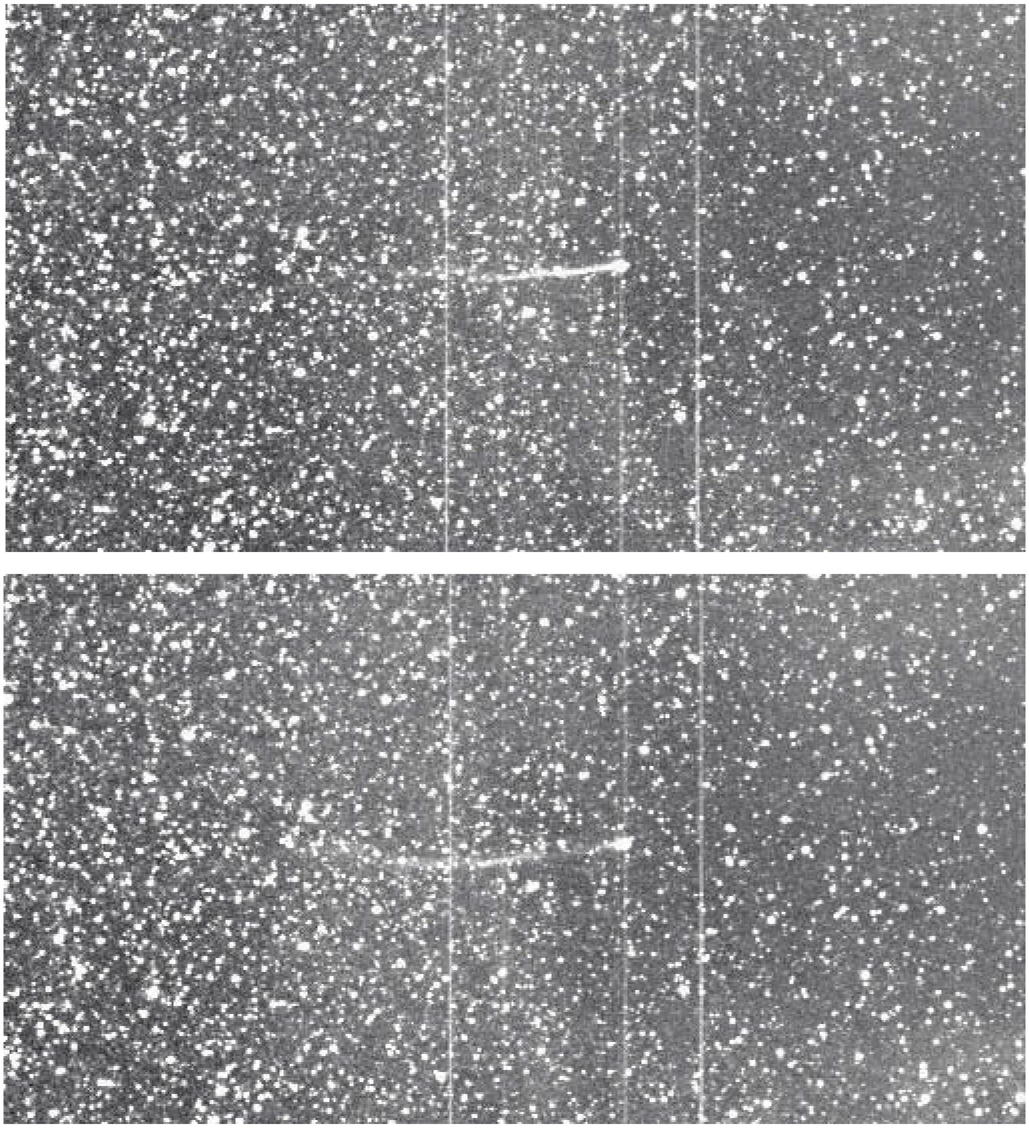
COMET OF THE WEEK: 2P/ENCKE

Perihelion: 2020 June 25.85, q = 0.337 AU

Comet 2P/Encke on two of its 20th Century returns. Above: January 17, 1961, from the mountains north of Los Angeles, California. Copyright Alan McClure. Left: January 5, 1994, as imaged by the 0.9-meter Spacewatch telescope in Arizona. Courtesy Jim Scotti.

In the early 19th Century the idea that comets might return to the inner solar system on a regular basis was still a bit of a novelty. This had been successfully demonstrated by the British astronomer Edmond Halley when the comet that now bears his name returned in 1758-59 – the story of which is recounted in a previous "Special Topics" presentation – but even though the astronomers and mathematicians of the time were able to calculate the orbits of comets, no other examples of a returning comet were known.

This changed in 1819 when the German mathematician Johann Encke set about calculating the orbit of a comet that had been discovered in November 1818 by the French astronomer Jean Louis Pons (who was one of the most prolific comet discoverers in history). Encke found that the positional measurements of Pons' comet were best fit by a short-period elliptical orbit, and then noticed a similarity to comets that had been observed during the recent past. The first of these was discovered on January 17, 1786 by the French astronomer Pierre Mechain, although this particular comet was only observed on two nights and no reliable orbit could be calculated for it. A second comet was discovered in November 1795 by Caroline Herschel



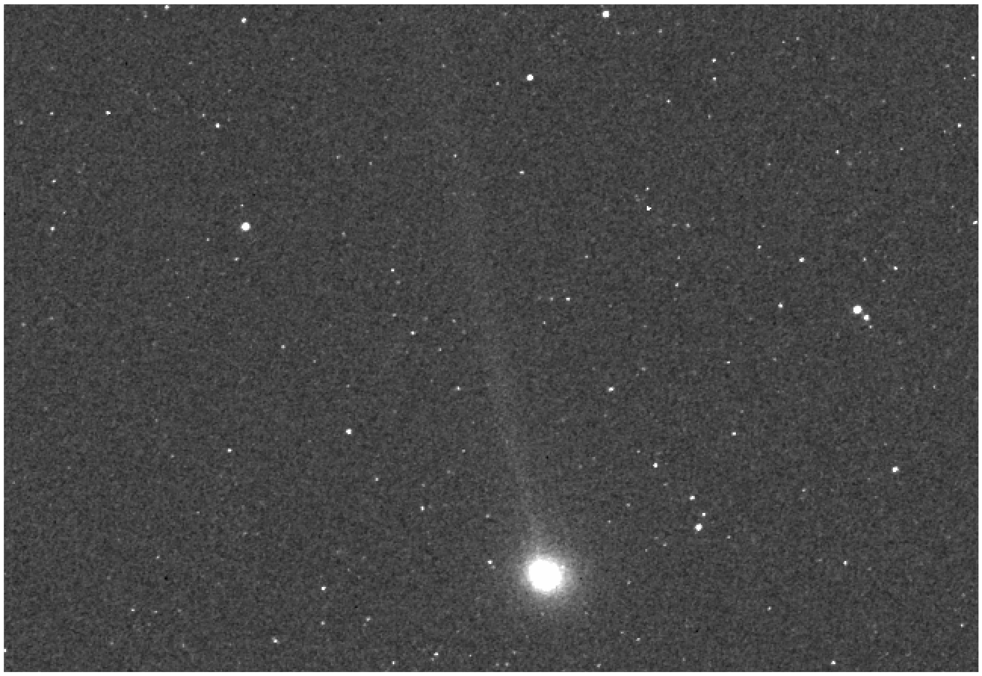
"Before" (top) and "after" (bottom) images of Comet 2P/Encke taken with the Heliospheric Imager aboard NASA's STEREO-A spacecraft on April 20, 2007, showing the comet's tail being ripped away by a passing coronal mass ejection. Images courtesy NASA.

in England – the sister of astronomer, and discoverer of Uranus, William Herschel, and an accomplished astronomer in her own right – which was followed for the next three weeks. A third comet was discovered in October 1805 by none other than Pons himself, and was followed for one month. Encke determined that all four of these comets were in fact the same object, and calculated an orbital period of only 3.3 years. He then predicted that the comet would next pass perihelion during the latter part of May 1822, and on June 2 of that year it was successfully recovered by German astronomer Carl Rumker (who was observing from Paramatta Observatory in New South Wales) quite close to Encke's predicted location. The comet was subsequently named in Encke's honor.

Encke's Comet still has the distinction of being the comet with the shortest known orbital period, although a handful of "active asteroids" (discussed in a future "Special Topics" presentation) have shorter periods. It has been observed on every return since that of 1822, with the exception of the return in 1944 when the viewing geometry was very unfavorable and moreover the world's astronomers were preoccupied with World War II. This year's return is the 64th at which it has been observed, and I have personally observed it on 12 returns going back to that of 1971. Perhaps not too surprisingly, it has faded some over the two centuries that we have been following it; while it was a naked-eye object of 4th or 5th magnitude during some of its early returns, over the past few decades it has not become brighter than about 7th magnitude.

Being as frequent and well-observed a visitor as it is, Comet Encke has played a significant role in our overall understanding of comets. Encke himself noticed that, even after allowing for gravitational perturbations by all the known planets, his comet was returning to perihelion a few hours earlier at each return, and to account for this he proposed a "resisting medium" in the solar system that was slowing it down and pushing it into a smaller orbit. A handful of additional comets also exhibited this same phenomenon, however in the 1930s a couple

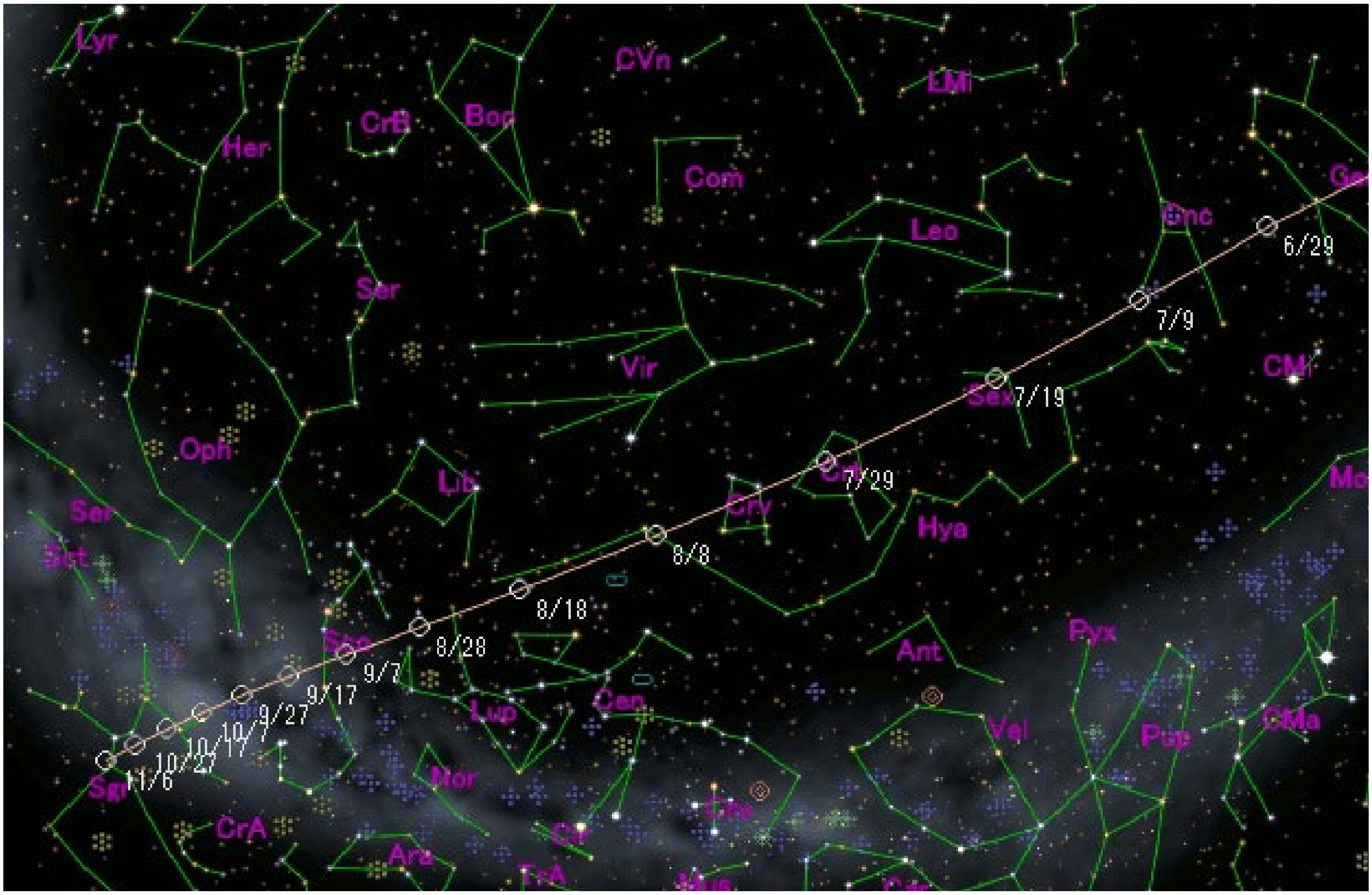
Comet 2P/Encke during its 2013 return, a favorable return for the northern hemisphere. Morning of November 7, 2013. Courtesy Franz Rumpf of Mondsee, Austria.



Comet 2P/Encke during its 2013 return, a favorable return for the northern hemisphere. From the MESSENGER spacecraft in orbit around Mercury on November 17, 2013. At that time the comet was just 0.025 AU from Mercury. Image courtesy NASA/JHUAPL.

of comets were found to be exhibiting the opposite effect – the opposite of what a "resisting medium" would do. It was in significant part an attempt to account for this that Fred Whipple wrote and published his landmark 1950 paper – which was in fact subtitled "The Acceleration of Comet Encke" – wherein he proposed the "icy conglomerate" (or "dirty snowball") model for a cometary nucleus that has since been verified. (This history is discussed in more detail in a previous "Special Topics" presentation.) This acceleration that Comet Encke exhibits is now described under the term "non-gravitational forces" and is the result of material being ejected off the nucleus and acting in the manner of a rocket engine.

More recently, on December 12, 1970 Comet Encke was examined with the Orbiting Geophysical Observatory 5 (OGO-5) satellite, which detected a Lyman-alpha hydrogen cloud a few hundred thousand km across surrounding the coma. This was only the third comet, and the first comet of short period, to be found to be accompanied by such a cloud, and this provided strong evidence – now verified – that such clouds accompany almost all comets that visit the inner solar system. Three returns later, in November 1980 MIT student Paul Kamoun utilized the giant 300-meter Arecibo radio telescope in Puerto Rico to transmit and receive radar signals to and from Comet Encke – the first successful radar detection of a comet. The return signals indicated that the comet's nucleus is approximately seven km in diameter (although the "true" size is now known to be closer to five km). The mere fact that a solid nucleus was detected provided a strong form of supporting evidence for Fred Whipple's "icy conglomerate" model. Five returns after that, on July 4, 1997, while outbound from perihelion passage Comet Encke passed 0.190 AU from Earth, the closest it has come to our planet since its original discovery, and the closest approach it will make until June 2172 (approach distance 0.174 AU).



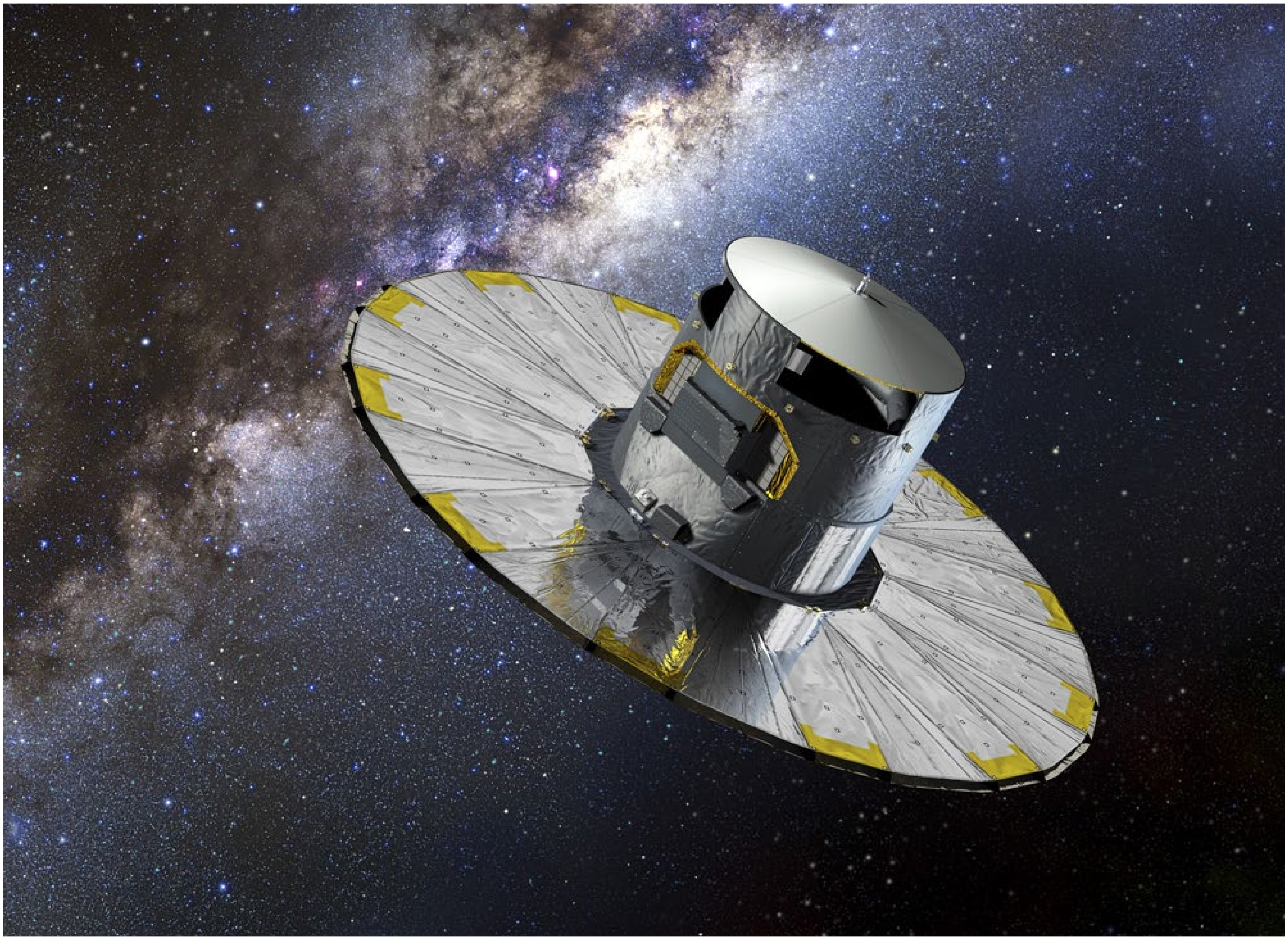
Track of Comet 2P/Encke through the constellations during July through October 2020. Courtesy Seiichi Yoshida.

There is some evidence that Comet Encke was once part of a much larger object that has largely broken up over the past few tens of millennia. The Taurid meteor shower – actually two separate showers, one that peaks around October 10 and the other which peaks around November 12, and both of which are spread out over several weeks and have low rates of 5 to 10 meteors per hour – and a stronger daytime Beta Taurid meteor shower that peaks near the end of June, appear to be associated with Comet Encke, as do several near-Earth asteroids and possibly the object that produced the Tunguska impact event in June 1908 (discussed in next week's "Special Topics" presentation). The densest part of this "Taurid stream" was predicted to pass close to Earth in mid-2019, but despite careful searches no unusual objects or phenomena appear to have been detected.

Comet Encke was photographed when near aphelion in 1972 (following its perihelion passage early the previous year) and thus is now followed all the way around its orbit. Following its most recent perihelion passage in March 2017 it went through aphelion (heliocentric distance 4.09 AU) in early November 2018 and was imaged just a few days later as a 20th-magnitude object by a German amateur astronomer, Werner Hasubick. On the present return it has approached perihelion from behind the sun and has been in sunlight for the past several months; perhaps somewhat surprisingly, it did not become bright enough to detect while in the field of view of the LASCO C3 coronagraph aboard SOHO. Shortly after the beginning of July it should become visible in the evening sky in the constellation Cancer and over the next few weeks it tracks to the east-southeast through the constellations of Hydra, Sextans, Crater, and Corvus. It may be as bright as 7th magnitude when it first appears but should fade rapidly and grow very diffuse while doing so, and will likely become undetectable visually within about a month or so. Because the comet remains at a fairly small elongation south of the sun throughout this time it will be visible only from the southern hemisphere; those of us in the northern hemisphere miss out completely.

The northern hemisphere should get its chance during the next return, in 2023 (perihelion October 22). The comet should come within visual range by late August or early September, when it will be conveniently placed in the morning sky in the constellation Auriga, and over the next six weeks it tracks towards the east-southeast through Gemini, Cancer, and Leo. By the time it disappears into morning twilight shortly before mid-October it may be close to 7th magnitude.

SPECIAL TOPIC: ORBITS AND FUTURE RETURNS



Artist's conception of ESA's Gaia spacecraft. Courtesy ESA.

"Ice and Stone 2020" participants have undoubtedly noticed that I have often discussed how this-or-that comet or asteroid will be returning to the inner solar system or passing by Earth at some point in the future, and perhaps have wondered how such things are determined. In principle, the processes by which such events are calculated are relatively straightforward, although as is usually true in many other scientific disciplines – and, indeed, life as a whole – the reality can be considerably more complex. With modern computer technology this can nevertheless be performed with relative ease, and the results are considerably more accurate than they were in earlier times – although a small bit of uncertainty is always present.

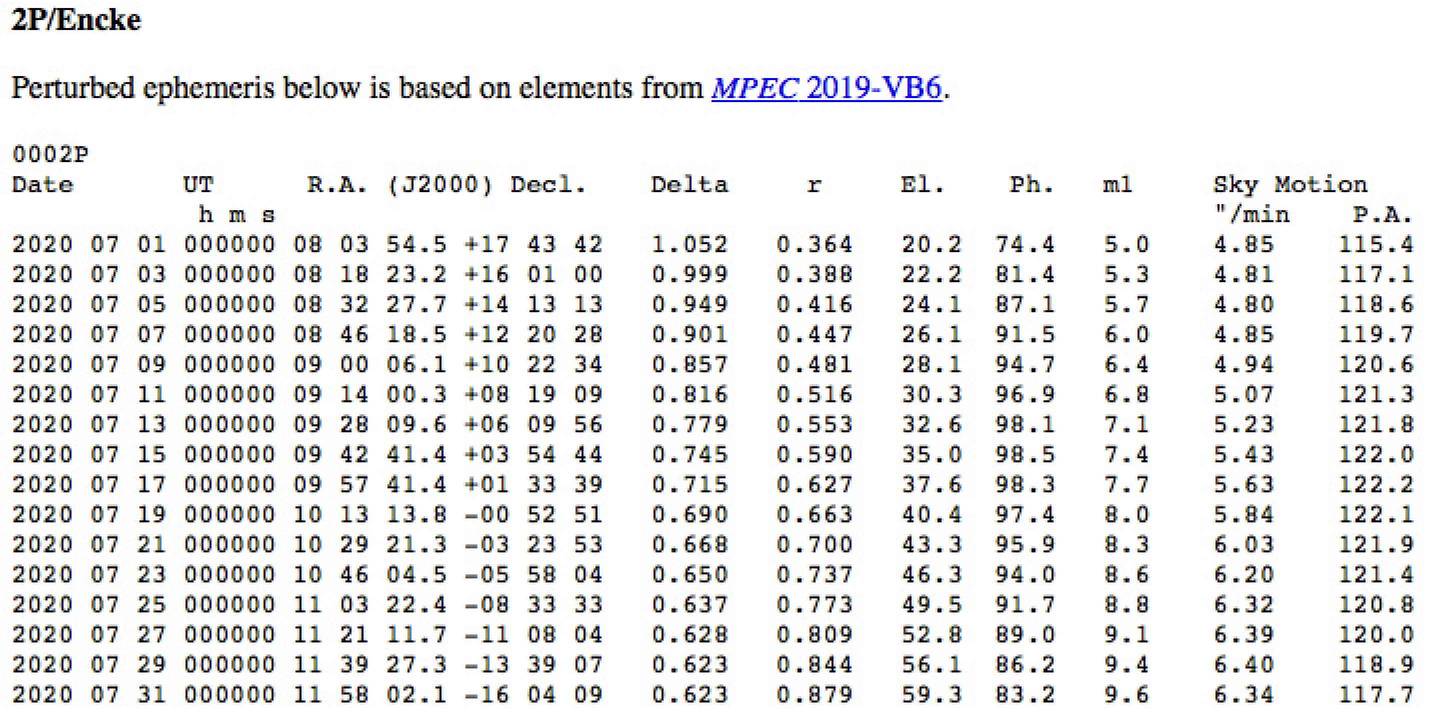
Once a new object is discovered, the first priority is the measurement of its position – i.e., its celestial coordinates of right ascension and declination – with respect to background stars, a practice called "astrometry." In theory, this can be performed with the unaided eye, and indeed this was the case prior to the invention of the telescope; the 16th-Century Danish astronomer Tycho Brahe could do so with an accuracy of an arcminute, and indeed it was from his astrometric measurements of the planets, Mars in particular, that his protégé Johannes Kepler derived his Three Laws of Planetary Motion. Before the development of astro-photography astrometry was often performed by the usage of a device called a "filar micrometer" that was inserted within the eyepiece of a telescope, but once astro-photography came into its own during the latter part of the 19th Century astrometric measurements could be performed from photographs. With modern electronic devices like charge-coupled devices, i.e., CCDs, and specially-designed software it is now possible to perform astrometric measurements to a high degree of precision and accuracy, to well within an arcsecond.

An astrometric measurement can only be as a good as the stars' positions from which it is measured. The development of accurate star catalogs is thus an important part of this overall process, and this has steadily improved over the years. Until fairly recently stellar positions measured by ESA's HIgh Precision PARallax COllecting Satellite (Hipparcos) mission – an acronym that references the 2nd Century B.C. Greek astronomer Hipparchus of Nicaea, who performed pioneering work in the measurements of stars – that was launched in 1989 provided the foundation for the best catalogs, but these are now being superseded by measurements from ESA's Gaia mission (launched in 2013) that ultimately will provide high-accuracy positional determinations for approximately one billion stars. Because of the "wobbling" phenomenon called "precession" – discovered, incidentally, by Hipparchus – and also the fact that the sun and all the other stars are in constant motion with respect to each other, star catalogs need to be referenced to a specific date in time. At present this is the beginning of the year 2000, although presumably within a couple of decades this will shift to 2050.

One other significant issue that arises in astrometric measurements is parallax. Measurements are, for obvious reasons, not made from the center of the earth, but rather from various locations on Earth's surface, and this can affect an object's measured position, especially in the case of an object near Earth. Observatories and institutions that have demonstrated the successful ability to perform astrometric measurements are assigned an official "Observatory Code" by the IAU's Minor Planet Center, which lists each site's "parallax factors" based upon its latitude, longitude, and altitude above sea level. Although I no longer perform astrometric measurements from my home site, when I was doing so during the early 2000s my Observatory Code was 921.

Once astrometric measurements are obtained, an orbit can be calculated from these. Then, after an orbit is determined, it is possible to compute an "ephemeris" (plural "ephemerides"), i.e., a list of appropriate celestial coordinates that the object will occupy at various points in time. In this procedure, the object's location in its orbit at the time in question is determined, and then the earth's location in its orbit is determined for the same time, and via a coordinate transformation the object's sun-centered location is transferred to an Earth-centered location. With the application of a site's parallax factors it is possible to calculate an ephemeris for a specific geographical location on Earth (or in space, for that matter).

An orbit is defined by various terms called "elements" that describe an orbit's size, shape, and orientation, and there is also a time element involved. One of the orbital elements is the "inclination," i.e., how steeply the orbit is inclined with respect to the plane of the



2P/Encke

Perturbed ephemeris below is based on elements from *MPEC* 2019-VB6.

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0002P
Date        UT      R.A. (J2000) Decl.    Delta      r      El.    Ph.    m1      Sky Motion
           h m s                                                                  "/min    P.A.
2020 07 01 000000 08 03 54.5 +17 43 42   1.052   0.364   20.2   74.4   5.0    4.85     115.4
2020 07 03 000000 08 18 23.2 +16 01 00   0.999   0.388   22.2   81.4   5.3    4.81     117.1
2020 07 05 000000 08 32 27.7 +14 13 13   0.949   0.416   24.1   87.1   5.7    4.80     118.6
2020 07 07 000000 08 46 18.5 +12 20 28   0.901   0.447   26.1   91.5   6.0    4.85     119.7
2020 07 09 000000 09 00 06.1 +10 22 34   0.857   0.481   28.1   94.7   6.4    4.94     120.6
2020 07 11 000000 09 14 00.3 +08 19 09   0.816   0.516   30.3   96.9   6.8    5.07     121.3
2020 07 13 000000 09 28 09.6 +06 09 56   0.779   0.553   32.6   98.1   7.1    5.23     121.8
2020 07 15 000000 09 42 41.4 +03 54 44   0.745   0.590   35.0   98.5   7.4    5.43     122.0
2020 07 17 000000 09 57 41.4 +01 33 39   0.715   0.627   37.6   98.3   7.7    5.63     122.2
2020 07 19 000000 10 13 13.8 -00 52 51   0.690   0.663   40.4   97.4   8.0    5.84     122.1
2020 07 21 000000 10 29 21.3 -03 23 53   0.668   0.700   43.3   95.9   8.3    6.03     121.9
2020 07 23 000000 10 46 04.5 -05 58 04   0.650   0.737   46.3   94.0   8.6    6.20     121.4
2020 07 25 000000 11 03 22.4 -08 33 33   0.637   0.773   49.5   91.7   8.8    6.32     120.8
2020 07 27 000000 11 21 11.7 -11 08 04   0.628   0.809   52.8   89.0   9.1    6.39     120.0
2020 07 29 000000 11 39 27.3 -13 39 07   0.623   0.844   56.1   86.2   9.4    6.40     118.9
2020 07 31 000000 11 58 02.1 -16 04 09   0.623   0.879   59.3   83.2   9.6    6.34     117.7
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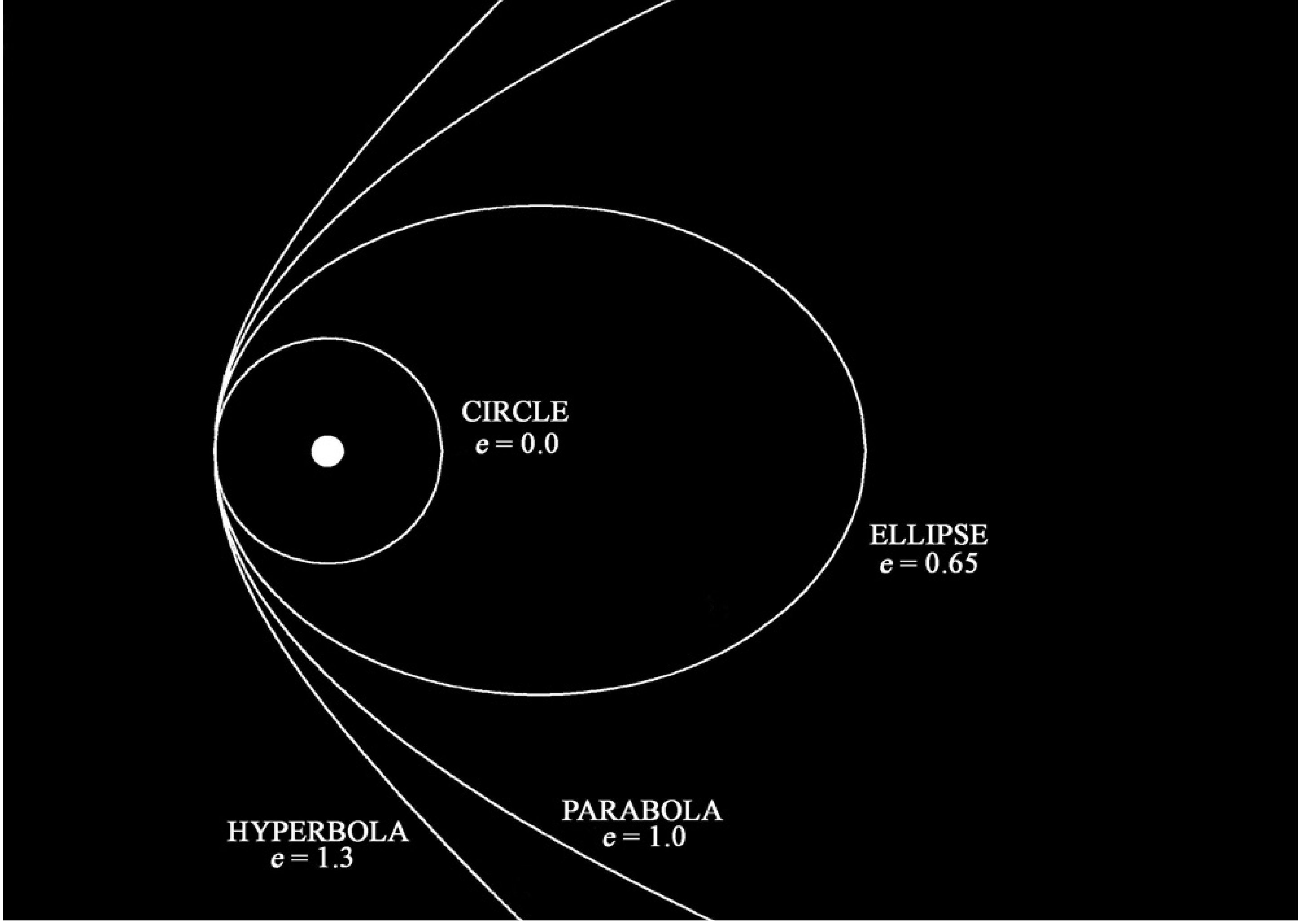
Ephemeris for Comet 2P/Encke (this week's "Comet of the Week") for July 2020, as generated by the Minor Planet Center's ephemeris generator. The columns (left to right) give: Date and time in Universal Time; Right Ascension and Declination (for reference date 2000); Geocentric distance ("Delta") and Heliocentric distance ("r") in AU; elongation (angular separation from the sun) in degrees; phase (sun-comet-Earth angle) in degrees; approximate predicted magnitude; sky motion in arcseconds per minute (identical to arcminutes per hour) in position angle (degrees; 0 is north, 90 degrees is east).



Different types of orbits. Ellipses and circles are closed curves; parabolas and hyperbolas are open curves.

earth's orbit (otherwise known as the "ecliptic"). An orbital inclination of 0 degrees is in the same plane as the ecliptic, whereas an inclination of 90 degrees is exactly perpendicular to the ecliptic. Inclinations greater than 90 degrees (up to 180 degrees) are "retrograde," i.e., an object in such an orbit travels around the sun in the direction opposite that of Earth.

Another important orbital element is the "eccentricity" (usually written as "e") which in general terms describes the shape of the orbit. An orbit with an eccentricity of 0 is a circle, whereas eccentricity values between 0 and 1 are ellipses, with the higher the eccentricity indicating a more elongated orbit. An eccentricity of exactly 1 is a parabola, and an eccentricity greater than 1 is a hyperbola. Objects in parabolic and hyperbolic orbits are unbounded, i.e., they will never return to the inner solar system, whereas objects in elliptical and circular orbits are bounded and will return after a period of time. (Obviously, objects in circular orbits remain the same distance from the sun all the time.) The highest eccentricity ever observed in a natural object is the recent interstellar Comet 2I/Borisov I/2019 Q4 – a future "Comet of the Week" – which has an orbital eccentricity of 3.4.

The calculation of an orbit follows directly from Newton's Law of Universal Gravitation, although in the pre-computer era this was mathematically laborious. In principle, an orbit can be calculated from three positions, however in practice since each position has some error associated with it the more positions that are available, the better-determined the orbit. Orbits based on only a few positions and/or over a short arc can be "indeterminate," i.e., any number of widely disparate orbits can be fit through the available measurements. As more and more astrometric measurements become available and as the observation arc becomes longer, the "true" orbit begins to emerge, although this is always subject to refinement as more data is collected. It sometimes happens that, once a reasonably valid orbit is determined, "pre-discovery" images of the object in question may be identified weeks or months after the fact, thus allowing for a much more accurate orbit to be calculated. An example of this is Comet Hale-Bopp C/1995 O1 (a future "Comet of the Week"); once the first reasonably good orbits were calculated, a pre-discovery image on a photograph taken over two years earlier allowed the determination of a very solid orbit.

If the sun and the orbiting object were the only objects in the universe, the object would remain on that same orbit indefinitely. Of course, there are many other objects around, primarily the various planets, including – especially – Jupiter, and each of these objects exerts a gravitational pull that perturbs the object and affects its orbit accordingly. (Indeed, numerous comets have approached closely to Jupiter and have had their orbits dramatically affected, some of these even ejected from the solar system altogether on hyperbolic orbits.) While the solution of the "two-body" problem is relatively straightforward, it turns out that there is no analytical solution to the "three-body" or "general n-body" problem; the calculation of orbits that properly involves these perturbing effects can only be performed numerically. Again, back in the pre-computer days this was an extremely laborious process mathematically, but is now accomplished via computers with relative ease. Such orbits are called "osculating" orbits and are referenced to a specific date called the "osculation epoch;" in real terms, such an orbit is the one that the object in question is traveling in at that specific point in time.

Other effects can appear as well. Comets eject material from their nuclei in jet-like geysers that act as small rocket engines that push the nuclei in the opposite direction; this effect is described under the term "non-gravitational forces" and these were first detected in Comet 2P/Encke, this week's "Comet of the Week." Each comet is different, and sometimes the same comet will exhibit different non-gravitational forces at different times, and thus these can only be determined empirically. Small asteroids, in particular, can experience something called the "Yarkovsky-O'Keefe-Radzievskii-Paddack," or "YORP," effect, wherein sunlight striking different sides of the asteroid and its own resulting thermal emission can affect its rotation and thus introduce small changes in its orbit. Astrometric measurements of objects near the sun, and the orbits of the objects themselves, can also be affected by General Relativity.

Once all the various effects are allowed for inasmuch as the available data will permit, it is now possible to make predictions for where an object will be in the future. For main-belt asteroids, which generally travel in low-inclination nearly-circular orbits, this is a relatively straightforward process, and once an asteroid has been observed at a few successive oppositions its orbit can be considered "safe" and it can be assigned a permanent number. (The designation and numbering processes are described in a previous "Special Topics" presentation.)

The first predicted return of a periodic comet is somewhat more uncertain, in part because of unknown non-gravitational forces, and it is not unusual for a predicted time of perihelion passage to be off by up to a day or so. (In the pre-computer era, predicted perihelion times could be off by up to several weeks.) Once a comet has been observed on a second return it can then receive a permanent number.

The situation is similar with respect to near-Earth asteroids. These tend to be relatively small objects and are often only detectable when they are relatively close to Earth, and thus several returns may elapse before they are recovered; it is not unusual for first-time recoveries to be off by a few days or more. As with the other objects, once a near-Earth asteroid has been well observed enough such that its orbit can be considered "safe," it can be assigned a permanent number.

Pre-discovery image of Comet Hale-Bopp C/1995 O1, from a photographic survey plate taken April 27, 1993 – over two years before the comet's discovery – from Siding Spring Observatory in New South Wales. Reproduced with permission from the Australian Astronomical Observatory.

Even the orbits of objects – especially periodic comets and near-Earth asteroids – that are considered "safe" and that are numbered can only be considered "safe" for a few centuries or, at most, a few millennia. The uncertainties in even the best-determined orbits propagate and grow larger over time, and objects can drift into and out of "resonances" with planets such as Jupiter (i.e., an object in 3:2 resonance with Jupiter will orbit the sun three times for every two orbits that Jupiter makes). The orbits of the centaurs – discussed in a previous "Special Topics" presentation – are unstable over a timescale of millennia, and over timescales of tens to hundreds of millions of years the orbits of all the planets are unstable. For example, numerical simulations have shown a tiny but nevertheless real chance that Mercury could be ejected from the solar system, or could strike the sun, or Venus – or even Earth – sometime with the next few billion years. The upshot of all this is that the solar system we see now, including all the various "small bodies" that are the focus of "Ice and Stone 2020," is a transient thing, just like everything else in life.

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