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Strange Lights in the Sky

When I was young I fancied becoming a doctor. The allure of medicine, of diagnosing diseases, of understanding the complexity of the human body – it all seemed endlessly fascinating. It offered a universe of ideas and challenges you could lose yourself in that could help person after person through challenges with illness and health. And then, in the midst of that momentum, when I was 14, in my little southwestern Ohio town, I went to a so-called star party.

Someone had set up a Criterion Dynascope 6-inch reflector, one of those telescopes with a long white tube and with the eyepiece fixed high at the upper end, and I peered in to take my first telescopic look at Saturn. That moment changed my life. Seeing the radiant light from Saturn's bright orange globe, encircled by golden orange rings, incised by a black gap, made me gasp. The pinpoint of a little saturnian moon hovered nearby. Everything just stopped. I was transfixed by the vision of another world – live, in real time – right before my eyes.

It was early 1976, and the crisp winter air was not yet ready to surrender to spring. Infected with this new awareness of the universe around me, I needed to find out everything I could – to take many more looks through telescopes, or in my case, my dad's pair of binoculars. Just as I was scrambling my first set of primitive equipment together, a friend called and gave me some promising news. "If you're getting into astronomy, you're in luck," he blurted out. "There's a bright comet that's gonna be amazing soon, but you'll have to get up early in the morning to see it!"

Along came another magic moment. Wandering out into the backyard, stepping across into the adjoining cornfield, and gazing up at the stars of Aquarius, I was thunderstruck at the sight. The icy cold air, dead silence of the early morning, and strange adventure of being out alone in a field before dawn added to the eerie, almost mystical sight that hovered over the planet. There, starkly visible in plain sight, like a shimmering sword hanging over Earth, was the bright glow of a comet with a fuzzy, starlike head and a long tail skirting upward and to the left. This was my first look at Comet West, the first look of many.

To someone who lived his whole life to that point on a "2-D planet," like most of us beset by issues of daily life, this was a dose of sudden magic. Who knew that you could simply walk out and so easily see such a range of incredible sights in the universe, far away from Earth? And not only was Comet West a spectacular sight, bright enough to be stunning in its odd and unexpected appearance, but it showed me in just a day or two that objects in the heavens changed rapidly. The comet altered appearance when viewed through a telescope and changed position in the sky from night to night. I was catching on that there's a whole lot more to this universe than I might have believed just a few days earlier.

Each day the comet rose in the early morning sky in the east, the tail peeking above the horizon first and then finally the head clearing the trees and moving up to complete the stunning portrait. Each morning it was fully visible in a dark sky before the creeping glow of dawn finally moved in and broke up the show. Here was a daily adventure, one that revealed the universe around us as a dynamic and unpredictable place. It demonstrated loudly that we inhabit just one little tiny spot in the cosmos, indeed even a small corner of our solar system. That late winter and early spring, Comet West became one of the Great Comets of the 20th century, peaking at magnitude –3, making it brighter than the planet Jupiter.

Strangely, you don't have to go very far back into history to reach the point when great thinkers believed comets were local phenomena, emissions of gas or smoke hovering in Earth's atmosphere. But then astronomers realized that if they were close, comets would be seen against slightly different star backgrounds from different places on Earth, and that didn't happen. The realization came on that comets are distant objects – at least much more distant than the Moon – moving through the solar system in very strange ways compared to the regular orbits of the planets.

So what exactly are comets, anyway? The answer requires looking at the way planetary scientists believe the solar system formed, some 4.6 billion years ago. The solar system consists of our Sun, a medium-sized star, and its attendant planets and other assorted debris, the whole collection being one of perhaps 400 billion stars and attendant small bodies in the Milky Way Galaxy. (And the universe contains some 125 billion galaxies astronomers know of – it's a rather large place.)

Scientists believe the solar system formed as a giant disk as gravity pulled material inward, eventually assembling enough mass to enable the Sun to "turn on" its nuclear fusion and begin life as a star. The so-called solar nebula, the disk formed and spun in rotation by gravity as the solar system coalesced, contained lots of material that didn't make it into the Sun itself. Some of this material was eventually driven off by radiation pressure from the Sun's intense energy, but some continued to join together by gravity, sticking little bits into larger bits, and building planets.

But Sun and planets alone do not make a solar system. Several distinct zones make up our star's system. The innermost zone contains the terrestrial planets, including Earth. Next comes the asteroid belt, a region of rocky debris containing thousands of subplanet-sized bodies that together make up less mass than Earth's Moon. Next come the giant planets, including Jupiter and Saturn. And the outer zone contains the comets, icy bodies of frozen gases and dust.

Most comets are far, far away and exist in several groups. Some comets are locked up with other debris in the so-called Kuiper Belt, a disk of icy bodies that extends from about 4.5 billion km out to 7.5 billion km from the Sun – in the region of Pluto and other dwarf planets. (The Sun itself spans a mere 1.4 million km.) Other, more remote comets exist in a huge shell surrounding the solar system called the Oort Cloud. Planetary scientists believe some 2 trillion comets may exist in the Oort Cloud, nearly all of which never make their way in toward the Sun (and into our skies). The Oort Cloud extends a staggering distance into deep space, perhaps as many as 1.5 light years from the Sun; that's 40 percent of the way to the nearest star beyond our Sun. The comets themselves are typically just a few kilometers across. And some other zones and families of comets exist too.

In later chapters, we'll explore the great complexity of comets, their origins, and where they live in detail, and you'll see how incredibly rare a thing it is for a comet to move into the inner solar system and become terrifically bright. We'll discover that asteroids and comets, not long ago believed to be two separate things, are now blurring the lines of their relationships. We'll absorb the findings from spacecraft missions and ground-based telescopes that have studied both bright and faint comets and expanded our knowledge of these mysterious visitors. We'll revisit how comets have affected human culture, how people have celebrated or dreaded them throughout history. And we'll examine the best ways to observe and photograph comets from your own backyard, or whatever dark-sky sites you prefer.

The appearance of a bright comet in Earth's skies is one of the most exciting astronomical events of all. In fact, no other type of astronomy-related happening comes close in getting new people interested in the night sky. Whenever a really bright comet appears, chatter rises, club memberships increase, attendance at star parties zooms, circulations of astronomy magazines climb, and new blood enters the hobby of astronomy.

It's happened that way time after time since astronomy became an organized hobby, most recently with the Great Comets Ikeya-Seki (1965), West (1975/6), Halley (1985/6), Hyakutake (1996), and Hale-Bopp (1996/7). Now more than 15 years have passed since the last terrifically bright, well-placed comet has graced the skies of Northern Hemisphere viewers. But the time may have come.

My friend David Levy, one of history's most successful comet hunters, has a favorite saying. "Comets are like cats," he claims. "They have tails, and they do precisely what they want." This underscores one of the great challenges with comets – their lack of predictability. The latest go-around occurred in September 2012, when astronomers discovered a potentially bright comet that could dazzle observers the world over in the fall of 2013.

On September 21, 2012, astronomers Vitali Nevski from Vitebsk, Belarus, and Artyom Novichonok of Kondopoga, Russia, captured images of a new fuzzy object in the sky. Their instrument of choice was the 16-inch Santel reflector at Kislovodsk Observatory in Russia, along with a program of automated asteroid detection called CoLiTec. The telescope is one of 18 dedicated by the Russian Academy of Science to detection and tracking of faint objects in the sky, the network collectively termed the International Scientific Optical Network (ISON).

When the Russian astronomers alerted others that they suspected a comet, astronomers at the Mount Lemmon Survey in Tucson, part of the Catalina Sky Survey, and astronomers at the Pan-STARRS telescope in Hawaii checked earlier images and also found the object. The next night, more observations were made by Italian astronomers at the Remanzacco Observatory, using another network, this one called iTelescope. The Minor Planet Center in Cambridge, Massachusetts, clearinghouse for such astronomical discoveries, announced the new comet on September 24, 2012, three days after its discovery at a terrifically faint magnitude of 18.8.

As with all comets, following its discovery and verification by other astronomers, the new fuzzy object received a designation, C/2012 S1, and its popular name would not be the name of one of the discoverers but, following international agreements, the search network abbreviation. So C/2012 S1 (ISON), or informally, Comet ISON (Figure 1.1), was born. (Many such search facilities have uncovered multiple comets, however, so care needs to be used in throwing around the term Comet ISON or those of other networks or surveys.)

ISON is exciting to astronomers because of its great potential as a so-called sungrazer – a comet that will swoop in very close to the Sun and therefore brighten dramatically. At perihelion, its closest approach to the Sun, the comet will pass a mere 1.8 million km from our star's glowing "surface." When this happens, on November 28/29, 2013, the comet could be dramatically bright, a significant fraction as bright as the Full Moon. But that will take place in a daytime sky, when the comet is only 1.3° northeast of the Sun.

Fortunately, the comet should be dazzling in a nighttime sky as well – to be more precise, in the early morning sky in mid-November. The comet could then shine as bright as the planet Venus and may well become the brightest comet ever seen by anyone now alive.

Another reason ISON's potential is exhilarating is that its orbit resembles that of another famous comet, C/1680 V1 (Kirch), which came to be called the Great Comet of 1680. Because the orbits are so similar, some astronomers have speculated they

Figure 1.1. The tiny fuzzball at the center of this image, shot on January 16, 2013, is 16th-magnitude Comet ISON (C/2012 S1), which observers hope will brighten dramatically by late in 2013. The imager used a 20-inch Ritchey-Chrétien scope, a CCD camera, and stacked exposures. Credit: Dean Salman/NOAO/AURA/NSF.

may have originated from the same parent body. If this is so, ISON may present a historic show as well. The Great Comet of 1680 was one of the brightest comets of the 17th century and was plainly visible during the day. And its distance from Earth at closest approach was nearly the same as ISON's will be. ISON will reach perigee, its closest passage of Earth, on December 26, 2013, some 63 million km from Earth.

At the turn of the New Year 2013, ISON glowed faintly at 16th magnitude as it floated among the stars of Gemini, near the bright twins Castor and Pollux. In addition to professionals at research observatories, amateur astronomers began to image the comet with a great sense of anticipation. Because of the orbital geometry of its path through the inner solar system, ISON will commence a big, semicircular, clockwise loop through the sky beginning in spring 2013, traversing Leo, Virgo, Scorpius, Hercules, and Ursa Minor by January 2014.

But the comet's great brightness will be a long time coming. By midsummer 2013 ISON will brighten to be an intriguing telescopic fuzzball; it likely won't be until early fall that ISON hits the range of being an impressive comet as viewed with binoculars. In October, the excitement will build as ISON's magnitude rises above 10, and sometime close to Halloween, the comet will become a naked-eye object.

Comet fever should grip the astronomy world – and maybe pop culture too – when ISON slinks across southern Leo and into Virgo during the first week of November.

By then, the comet will rise to 6th magnitude, and a few days later it will gain another magnitude and be visible with the eye alone from a suburban site. The comet then should increase by a magnitude every few days and will dazzle viewers who rise to see it in the early morning hours, perhaps 4 A.M. on into dawn. (That's the time slot occupied by Comet West during those memorable first few weeks of 1976.)

If predictions pan out, by about November 25 the comet will have become impressively bright, shining at negative magnitudes, and situated in eastern Virgo, approaching the border with Scorpius. November 28 is the comet's perihelion, its closest point to the Sun. ISON may then be as bright as Venus, or as much as 100 times brighter yet. If so, it will outshine everything in the sky save for the Sun and the Moon.

But remember that we're talking about the comet's total magnitude, its brightness if all of the light were compressed into a pointlike source. Because the comet is spread out over a large area, little areas of it will not appear as bright as Venus. But we're still talking about a comet that could cast shadows – a remarkable event that's unprecedented in our lifetimes.

At its brightest moment, ISON could shine at magnitude –9.5. By then it will be a daytime object a mere 1.3° from the Sun. This will make seeing the comet at its brightest difficult; trained observers who block out the disk of the Sun will be able to see it, but it will not be an easy observation when the comet is so close to the solar disk.

Comet ISON lies right in the head of Scorpius at perihelion and thereafter swings north toward Hercules. The first week of December should see it as a 1st-magnitude object with a sweeping tail, and Northern Hemisphere viewers will be well placed to see the comet as it slowly fades toward month's end. By January 8, 2014, the comet will be a mere 2° from Polaris, the North Star, and will have dimmed to about 6th magnitude, reaching the naked eye limit once again.

Of course predicting comet magnitudes makes for a dangerous game. The comet's orbit is well known, but assumptions about the comet's composition, how solid it is, its reflectivity, and how volatile its gases and dust are make the brightness of ISON uncertain. Recent astronomical history knows one great story of a comet that everyone believed would certainly be dramatically bright, and in the end it fizzled. That is the story of Comet C/1973 E1, Kohoutek.

Shortly after its discovery, Comet Kohoutek was touted as the "comet of the century." Among the prognosticators who believed Kohoutek would put on a spectacular show was Carl Sagan, not yet world famous as the creator of *Cosmos*, the book and television miniseries, but famous enough as a compelling scientist (and astronomy professor at Cornell) to appear on the *Tonight Show* alongside Johnny Carson.

Sagan predicted a sensational view of the comet as Kohoutek brightened late in 1973 and early in 1974. The comet, after all, promised a great deal to astronomers as they studied its orbit. It had been discovered on March 7, 1973, by Czech astronomer Luboš Kohoutek (1935–), who along with other astronomers found that the comet was a long-period object with a hyperbolic orbit that would carry it extremely close to the Sun. The date of perihelion was fixed as December 28, which would provide the world with an end-of-year, holiday spectacle.

Astronomers excitedly found the comet would pass close to Earth and quite close to the Sun, a mere 21 million km. The blowing of the horn about how fantastic Kohoutek would be ramped up expectations and created quite a flurry of attention in the popular media and culture, aside from Sagan's regular pronouncements.

The comet's effects ranged from the ridiculous to the sublime. David Berg, founder of the Children of God, predicted a doomsday event for January 1974. In December 1973, jazz musician Sun Ra put on a Comet Kohoutek show. The comic strip *Peanuts* featured the comet over a week-long span as Snoopy and Woodstock hid under a blanket from the mysterious light from the sky. The comet influenced musical works at the time or later by Pink Floyd, R.E.M., Journey, Kraftwerk, and Weather Report.

And the reasons for optimism were valid. The feeling was that, with such an orbit, Comet Kohoutek must be an Oort Cloud object, originating from far out in the solar system and therefore fresh, rich in volatile gas and dust that would stream off the comet as it warmed in the glow of sunlight like water vapor taking to the air on a foggy London morning. Astronomers believed the comet had never been to the inner solar system before and therefore was a good, solid object.

But as Kohoutek approached the inner solar system, it lagged significantly behind the predicted magnitudes. Comet Kohoutek seemingly fooled the experts on two counts: In hindsight, it may well have originated from the closer Kuiper Belt, not the distant Oort Cloud, and therefore could have had a relatively rocky composition with minimal volatile ices, gas, and dust. Moreover, rather than reflecting sunlight efficiently and developing significant tails spread across the sky, the comet partially disintegrated as it approached perihelion, prior to its closest approach to Earth. Thus, although it became a naked-eye comet, to many, Kohoutek was an outright dud.

The lesson is simple: No one can accurately predict a comet's brightness beforehand, even knowing its orbit well, because of many small but potentially important unknown factors. ISON will be a great sight: no doubt. Only by early 2014 will we all know whether it was really the comet of our lifetimes, the century, several centuries, or just another pretty good comet. But the upside with this discovery is that it could "fizzle" compared to the predicted magnitudes and still be a remarkably, perhaps historically bright comet. That's pretty encouraging. I urge you to follow the comet's progress in *Astronomy* magazine and on the magazine's Web site, www.Astronomy.com.

Well, whether it be the excitement over observing a bright comet or the anticipation of what might be to come, one question soon comes to mind: Just what exactly is a comet, anyway? The Greeks originated the word *kometes*, which translates to "long-haired," referring to what early observers thought of as "hairy stars" because of their observed glowing tails. Although most people think of comets as a "streak" of light in the sky, a comet is really a tiny body floating along some kind of orbit in the solar system. Comets are clumps of frozen ices, gas, and dirty rock the diameter of a small town – they span an average of 5 kilometers or so across – and only when this frozen chunk approaches the inner solar system and heats up from the Sun's warmth does it begin to outgas and produce a tail, becoming a spectacle in the sky.

Later chapters will describe the nature and physics of comets in detail, but for now, suffice it to say that its physical body is called the nucleus. The observational parts – coma, a hazy cloud of light surrounding the nucleus, and tails – arise from the solar heating as the comet approaches the Sun. The nucleus is really the physical being of the comet, and planetary scientists believe cometary nuclei formed in the proto solar system some 4.6 billion years ago as icy outlying material that did not gravitationally clump together into larger objects.

As solar system bodies go, comets are tiny. You could stack 2,500 of them side by side across Earth's equator. Yet they are plentiful – the deep recesses of the outer solar system may hold as many as 2 trillion comets. The bulk of a comet is frozen ices and gases; it is chiefly composed of water, carbon monoxide, carbon dioxide, formaldehyde, and methanol. Along with the frozen ices and gases are variable amounts of dust.

The unpredictable nature of comets as they approach the Sun and warm up results from their variable composition, the amounts of various gases and dust, the "freshness" of the comet – some have taken previous trips to the inner solar system – and the dynamics of the orbit. When the frozen block of comet approaches the Sun and warms, its ices begin to sublimate, transforming directly from a solid to a gas, and this creates the diffuse coma, which is surrounded by a large halo of hydrogen. The coma also contains dust grains liberated from being locked in the ice.

As the comet continues to warm, more gases escape and dust grains leap forth, and as the volume increases, the solar wind and radiation pressure from the Sun push these particles into a gas or plasma tail (typically bluish) and often a separate dust tail (white to yellowish in color), pointing away from the Sun.

Comets are one major type of small body in the solar system. The other consists of rocky bodies without frozen gases that mostly live in separate places – the asteroids. Together, comets and asteroids make up the vast majority of the small bodies in the solar system. For hundreds of years, astronomers classified comets and asteroids as two completely different creatures – apples and oranges. As we'll see later, however, at least in some cases, this distinction is becoming blurred as new discoveries are made.

One important feature that distinguishes comets is their peculiar orbital track around the Sun. They typically have large orbital eccentricities – orbits that differ markedly from circles – and high orbital inclinations, often tipping them at a strange angle compared with the orbits of the planets. Eccentricities are sometimes elliptical, sometimes parabolic, and sometimes even hyperbolic in the cases of comets that have been influenced by the giant planets and slung like pinballs in a crazy game of orbits. The angle of cometary orbits relative to the plane of the solar system is essentially without limits. Clearly, chaos in the early solar system was instrumental in setting up the paths of these celestial wanderers. Many are well behaved; others drop down at crazy angles like dive bombers; some even have so-called retrograde orbits, moving around the Sun in the opposite direction of Earth and the other planets.

As with all sciences, astronomy was for hundreds of years chiefly a game of classification. To help understand the orbits of comets – and where they might be coming from – planetary scientists created a dividing line for comets based on their orbital periods.

Long-period comets, those with periods of more than 200 years, are governed by highly elliptical orbits, and they reside at the outer limits of the solar system. These creatures spend their lives in a celestial deep freeze, a measurable fraction of the distance to the nearest star away, and move in only rarely and briefly to our part of the cosmos. In fact, an enormous shell of comets surrounds the solar system, and the distinguished Dutch astronomer Jan H. Oort (1900–1992) proposed in 1950 the existence of the source of these long-period comets, and the great sphere of cometary nuclei took on his name, the Oort Cloud.

An interesting class of long-period comets exists in the Kreutz Sungrazers. They are named for German astronomer Heinrich Kreutz (1854–1907), who demonstrated their relationships. This family of comets is characterized by orbits that carry the celestial visitors very close to the Sun, which sometimes makes them exceptionally bright. Sungrazers sometimes plow straight into the Sun or break apart as a result of the Sun's gravitational influence.

By contrast, short-period comets have orbits of 200 years or less and are further divided into two distinct groups. These objects are much closer residents of the solar system. They comprise the Halley-type comets, which have periods of 20 to 200 years, and the Jupiter-family comets, with periods of less than 20 years. The Halley class feature orbits that are randomized, just as the long-period comets do, but the orbits of the Jupiter-family comets are inclined more closely to the ecliptic plane, as are those of the planets.

Of the 2 trillion comets that may exist in the Oort Cloud, astronomers have observed and cataloged about 4,200. Some 1,500 of these are Kreutz Sungrazers and

484 are short-period comets. In recent years astronomers have even detected comets in extrasolar planetary systems, the first in observations of the Beta Pictoris system in 1987. Of the 10 so-called exocomets discovered to date, all were detected around young stars, and they may help tighten the picture of how solar systems form.

This is a pretty strong indicator of how fast astronomy is moving as a science. Several hundred years ago many of the planet's best thinkers believed that comets were atmospheric phenomena. Now we're observing comets that are dozens of light-years away.

Come to think of it, that's one of the things that struck me as a teenager, lying out in that field, gazing up at Comet West. Suddenly, after I learned a little about what comets are, it hit me. They hammer home the immensity of the cosmos. Yes, they are relatively nearby. But seeing them move from night to night – changing their place against the backdrop of the stars glistening behind them – is extremely powerful. I think it triggers something deep within the soul.

And that seems always to have been the case. The earliest records of cometary observations are from China and date from about the year 1000 B.C. Similar observations may have been made by inhabitants of the marshy land in southeastern Mesopotamia known as Chaldea. By about 550 B.C., Greek philosophers recorded comets as wandering planets. In his scheme of spherical shells making up the cosmos, Aristotle (384–322 B.C.) wrote in *Meteorology* (*ca.* 330 B.C.) that comets are residents of the lowest such sphere and called them "dry and warm" atmospheric exhalations.

Not only were comets viewed as local phenomena, but for centuries they were also taken as portents of doom, omens of some impending event, usually a disaster. Only with the writings of Thomas Aquinas (1225–1274) and Roger Bacon (*ca.* 1214–1294) did the notion that comets may not be lurking in Earth's atmosphere begin to step forward. But further intellectual work on the subject would really have to wait until the world emerged from the gloomy deep freeze of the Middle Ages.

Real progress on understanding comets stepped up when Paolo dal Pozzo Toscanelli (1397–1482), an Italian mathematician and astronomer, observed what would come to be known as Halley's Comet in 1456, along with a number of other comets during the previous and following decades. Observations made by Toscanelli and later by Danish nobleman and astronomer Tycho Brahe (1546–1601) began to define comets more precisely. Tycho's observations of Comet C/1577 V1 in particular demonstrated the comet's distance as being much farther away than the Moon.

In the late 17th century, German amateur astronomer Georg S. Dörffel (1643–1688) observed two bright comets in 1680 and 1681 and realized the two comets were one comet – C/1680 V1 – seen before and after perihelion, and that the comet had a parabolic orbit about the Sun. This provided ammunition for the great physicist Isaac Newton (1642–1726), who used his newfound theory of gravitation to