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SPECIAL REPORT

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FIRE IN THE SKY:

Everything You Could Possibly Need to Know About Asteroids, Comets and Meteors

by Bill Warren

Note: This report contains some material that has appeared in the Observer *in the past, but it's much more than a simple re-hash of previous articles. I've updated that material and added to it in many, many ways that give this report a depth that those articles never reached. I wanted it to be a compilation of everything I know and could find out about these fascinating subjects. I hope you enjoy reading it, and that you learn something from it. I know I did.*

Oh, one more thing: When referring to specific comets, I've used their popular names (e.g., Halley's Comet), rather than identifying them by their technical names.
-Bill

You're trash.

(Did he really say that?)

Well…Yes, I did. I've always wanted to say it. But don't worry, I'm trash too. All of us are. We're products of a process that began when the Sun became a star 4-1/2 billion years ago. Along with everything else in the solar system, we're debris left over when the Sun filled itself to overflowing and blinked into existence. The solar system is a vast junkyard of leftover parts.

The largest spare parts -- the planets -- are stable in their solar orbits. They are like big brothers and sisters in the solar family. Other, smaller parts such as comets and the dust they release as they approach the Sun are less stable, and they are at the mercy of anything larger that gets in their way.

Asteroids. Like everything else in the solar system, *asteroids* (a.k.a. *minor planets*) are space junk. Most of them are found in the *asteroid belt*, orbiting the Sun between Mars and Jupiter. Billions of asteroids inhabit the asteroid belt; they range in size from 600 miles in diameter (Ceres) to boulders, rocks and pebbles.

Some asteroids, however, have other orbital paths. As of June, 2016, 14,464 Near Earth Asteroids have been found to have orbits that bring them close to Earth's orbital path. *These* are the ones that represent the greatest danger to our planet. Most of them are less than ½ mile in diameter.

Presently, the most serious threat appears to be the binary Asteroid (410777) 2009 FD. Its primary component is 130 to 200 yards in diameter, and the other is 65 to 130 yards wide. That asteroid orbits the Sun every 436 days, and its orbit brings it very close to the Earth every two years. There is a 1 in 1,800 chance that it will hit the Earth on Sept. 24, 2182.

Asteroids generally are composed of the same elements and compounds as meteorites. Most of the meteorites found on Earth are pieces of asteroids.

Most asteroids are dark, reflecting less than 4% of the sunlight they receive. Only the largest and brightest of them can be seen in our backyard telescopes. Being closer to us than the stars, they move across the sky like the planets, changing their positions from one evening to the next.

The way to find a given asteroid is to draw or photograph its suspected location one night, and then do the same thing the next night. The asteroid will have moved, but not the stars around it.

Asteroids and comets are the only astronomical objects that can be named for living persons. (Remember that the next time a company offers to let you name a star after yourself, someone you love, a pet, etc. They'll do it for a fee of about $75 -- but it won't be an official name. Only the Central Bureau for Astronomical Telegrams, a nonprofit international organization, approves names for asteroids, comets and other celestial bodies, and CBAT doesn't sell names.)

In 2016, FRAC's Dr. Richard Schmude had an asteroid named for him by CBAT in recognition of his many contributions to international astronomy: Asteroid 30042 Schmude. (The number refers to the order in which asteroids are discovered. The first to be discovered, Ceres, is technically referred to as 1 Ceres.)

Meteoroids and Meteors. The smallest debris in the solar system is space rocks ranging in size from a yard in diameter to dust particles. Prior to entering Earth's atmosphere and becoming meteors, they are known as *meteoroids*.

Meteoroids are created in two ways: by collisions involving asteroids and other asteroids, the Moon or Mars; and by the Sun's effect on comets – "dirty snowballs" that have been pushed, pulled or knocked out of their resting place in the Kuiper Belt or the Oort Cloud.

In the former case, asteroid fragments occasionally wander into Earth's atmosphere at speeds of thousands of miles per hour. When that happens, we see them as *sporadic* (random) *meteors* – temporary flashes of light zipping across the night sky. We see them because friction with the atmosphere literally burns them up and ionizes the air around them; they are "sporadic" because they are solitary travelers in space and we never know when or where they will appear. On any clear evening at a dark site, you're likely to see 6-10 sporadic meteors. An estimated ten tons of them burn up in Earth's atmosphere every day. We don't see most of them because (a) 70% of Earth's surface is water and much of the rest of it is uninhabited, and (b) half of the meteors fall during the daytime when the sky is too bright to see them.

Other meteoroids travel in groups numbering in untold billions, and their appearance is highly predictable, at least in terms of the times of year when we see them. They are *meteor showers* -- debris trails left by passing comets.

The Comet Connection. Comet appearances have been recorded for thousands of years. They have traditionally been regarded as omens of disaster or hardships because, in 43 b.c., a bright comet appeared and was said to be the soul of Julius Caesar, who had recently been assassinated. After that, rulers wanted to know as much as possible about comets, so comet-hunting became a very lucrative profession. The name *comet* comes from the Latin word <u>coma</u>, which means "hair" and refers to the comet's tail.

Comets come from the two most distant debris fields in the solar system: the Kuiper Belt and the Oort Cloud.

The *Kuiper Belt* is a thick, Saturn-like ring of billions or trillions of icy bodies composed of frozen gases and dust that orbit the Sun at a distance of 2-4 billion miles away. *Short-term comets* – those that return every few years – come from the Kuiper Belt.

Less than a thousand times farther out, near the limit of the Sun's ability to hold its family together, the *Oort Cloud* is a giant sphere blanketing the entire solar system. Its billions or trillions of icy bodies extend almost halfway to the nearest star. *Long-term comets* – those whose return visits are measured in hundreds or thousands of years – come from the Oort Cloud.

Objects in the Kuiper Belt and the Oort Cloud are thought to have appeared during the earliest stages of the solar system's formation, and they have not changed since then. Studying them gives astronomers a look at what the early solar system was like.

Most of the time, objects in the Kuiper Belt and the Oort Cloud remain where they are, far from the Sun's heat that would destroy them. Occasionally, though, collisions with other comets-in-waiting, or energy radiated by a nearby star, will nudge one of those dirty snowballs toward the Sun. Thus begins a long kamikaze-like death dive that will take the comet thousands of years to reach its target.

Comets are small. Most of them are no more than 25 miles in diameter. Four large comets would fit inside the Los Angeles metropolitan area, but the impact of even a small comet would wipe that area off the map.

For most of their sunward journey, comets cannot be seen from Earth. They are usually detected when reflected sunlight makes them visible at a point between 800-500 million miles away, i.e., somewhere between the orbits of Saturn and Jupiter. They can be identified by their relatively swift, asteroid-like movement across the sky from one evening to the next.

Discovering Comets. Since comets are named after their discoverers, discovering a new comet brings lasting worldwide fame – ask Dr. Alan Hale or Thomas Bopp (of Comet Hale-Bopp fame), or groups like PanSTARRS (Panoramic Survey Telescope and Rapid Response System) and LINEAR (Lincoln Near Earth Asteroid Research) that discover comets while searching for Near Earth Objects that could impact our planet. On an individual basis, David Levy has discovered 22 comets, Charles Messier discovered 13 and Don Machholz has discovered eleven. Comet Shoemaker-Levy 9 was the ninth comet to be discovered by the comet-hunting team of Levy and Gene & Carolyn Shoemaker.

To discover a comet, you need four things: a *telescope* that is large enough to detect the light from very faint stars; a *star atlas* or *star charts* that show the locations of those faint stars; *patience*; and most of all, *luck*. With millions of amateur astronomers around the world searching for comets every night, you have to be looking in the right place at the right time, or someone else will discover your comet. If you find a fuzzy "star" that doesn't appear on your star chart, you might be looking at a comet. (Don't expect to see a tail, though: by the time a comet grows a tail, someone else will already have discovered the new comet.) That's what happened to Thomas Bopp one evening while he was looking at the globular cluster M75 in Sagittarius through a borrowed telescope: he saw a faint, fuzzy star that wasn't supposed to be there. If you have a similar experience, an e-mail to the Central Bureau for Astronomical Telegrams will tell you if you won the comet lottery.

(The "Telegrams" is because, when CBAT opened for business in 1920, telegrams – not e-mail, which at that time was still 70 years in the future -- were used to transmit urgent information that required faster transmission than regular mail. In 1992, the organization changed its name to CBET, the "E" referring to Electronic, but most people still refer to it as CBAT.)

Pinning the Tail On the Comet. Meanwhile, the comet isn't sitting around idly waiting to be discovered. It's zooming toward the Sun and running a gauntlet between the planets, any of which could destroy it or at least alter its path.

When the comet reaches a point about as far away as Jupiter, something amazing happens: it grows a tail. (At least, many of them do.) Or maybe even two or more tails: the Great Comet of 1844 had six tails!

Tails are the result of the comet's drawing near enough to the Sun for solar radiation to melt small portions of the icy surface, creating a halo around the comet. (Technically, it isn't "melting," but *sublimating*, which converts the ice into ionized gases and dust, not a liquid.) When that happens, the solar wind pushes the gas and dust tail(s) away from the comet. It's like the Sun is warning the comet, *Don't come any closer*! But the comet doesn't listen, it keeps on speeding toward the Sun, oblivious to its fate.

That's why, no matter where a comet is in space, its tail(s) always point away from the Sun.

(Incidentally, gas tails are blue, and dust tails are brown.)

The Comet's Fate…Assuming that it doesn't crash into Jupiter (or another planet) the way that Comet Shoemaker-Levy 9 did in 1994, one of three ultimate fates awaits the comet: (1) It will dive headlong into the Sun and dissolve like an ice cube tossed into a furnace; or else it will swing around the Sun and either (2) be tossed out of the solar system forever (as Comet Catalina was in Feb., 2016), or (3) it will remain in the solar system, establishing a solar orbit that will bring it back again. Comets in the latter category are known as *periodic comets* because – *surprise!* -- they return periodically. Halley's Comet visits us like clockwork every 76 years; it visited us in 1910 and 1986, and its next homecoming reunion will be in 2062.

Other periodic comets have longer and shorter periods of return. While Comet Hale-Bopp is a *long-period comet* that won't be back until the year 4385, Comet Encke is a *short-period comet*; its orbit is closer than the planet Jupiter, so Comet Encke returns every 3.3 years. (Encke presently is inactive; that is, it no longer leaves a noticeable debris trail behind it when it returns.)

…And What the Comet Leaves Behind. As our comet draws closer to the Sun, sublimation increases dramatically, with newly released gases and dust trailing behind it like Sheriff Buford T. Justice (Jackie Gleason) leaving the restroom in "Smokey and the Bandit." The gases eventually fade away like morning dew, but the dust tail remains, establishing a planet-like orbit around the Sun. When Comet Hyakutake passed by in 1996, its dust tail stretched 80^o across the sky.

Meteor Showers. In a few cases, Earth's orbital path annually crosses a swarm of cometary dust, producing *meteor showers* that are named, not for the comet that produced them, but for where they appear to be coming from.

Since all of the dust in a meteor shower is traveling together in a stream that can be hundreds of millions of miles long and take anywhere from a few days to two weeks for Earth to pass through it, all of the meteors in the shower will appear to be coming from the same part of the sky. That point, called the *radiant*, is identified by the constellation in which it is located. For example, meteors in the Perseids meteor shower may be seen anywhere in the sky, entering Earth's atmosphere at any angle – but regardless of where we see them, they appear to be moving away from the same place in the constellation Perseus.

It's like looking at railroad tracks: if you look straight down at them, they are several feet apart. But if you look farther away, they appear to merge into one track in the distance. Whether we're talking about meteor showers or railroad tracks, it's a matter of perspective, an optical illusion.

As noted earlier, meteors come in all shapes and sizes. The greatest threats to Earth are: comets; large chunks of debris resulting from asteroid collisions; and rogue asteroids that are not part of the asteroid belt. *Those* are the "planet killers" that the media like to remind us are lurking out there with malicious intentions.

As for the meteors in meteor showers – well, *No*. Those streams aren't called "dust tails" for nothing. The comets that produce them are only a few miles in diameter. Most of those meteoroids are no larger than grains of sand. They light up momentarily as they enter Earth's atmosphere, and they're gone even as you see their brief glow. The ones that are large enough to survive their passage through Earth's atmosphere are known as *micrometeorites*. They fall to Earth at a rate of about one per second, and they comprise 95% of all the meteorites on Earth.

Most of the meteors we see are about as bright as a moderately bright star; that's why meteors are commonly referred to as "shooting stars" or "falling stars."

Observing Meteor Showers. Watching a meteor shower is simplicity itself. All you need is your eyes, since binoculars or a telescope will restrict your viewing area to a tiny piece of sky. You won't see many meteors that way.

The only other aids you'll need are: a reclining lounge chair or a blanket to lie on so you won't have to crane your neck upward for long periods; clothing that will keep you warm at night or in the pre-dawn hours; and insect repellent or other seasonal comfort aids.

Where you look doesn't matter, because meteors can be seen anywhere in the sky. You won't see more meteors near the radiant than anywhere else. The radiant merely shows you what direction they came from. Just direct your attention to the part of the sky that is farthest from any light sources such as the Moon or city lights, and lie back to watch the show.

Sometimes you may see what looks like a meteor coming straight at you, growing brighter as you watch it, until it rivals Venus in brightness. It isn't a meteor, though, it's an Iridium flare – sunlight temporarily reflecting off an Iridium telecommunications satellite. Iridium satellites produce the brightest flares of all Earth-based satellites.

If a meteor or fireball is actually coming toward you – well, you'd better hope that your name isn't on that particular bullet. You won't outrun it, and you can't hide from it. (Hasn't happened yet, though, has it?)

On that depressing possibility, let's turn our attention to…

Meteor Colors. Color, like beauty, is in the eye of the beholder. The colors of reported meteors range across the spectrum from red to blue. Being brighter than other meteors, *fireballs* are most likely to display vivid colors. The most commonly reported colors – yellow, green, blue-green and blue – are due to elements within a meteor or the atmosphere that emit a distinctive color when vaporized. Iron glows yellow, nickel appears green, magnesium is blue-green, and blue is thought to be associated with fast-moving meteors at higher altitudes.

If you see a red meteor, it's a relatively slow-moving meteor that reached Earth's lower atmosphere, ionizing the nitrogen and oxygen in the air around it.

The Sound of (Meteor) Music. Extremely bright fireballs that explode as *bolides* at altitudes of less than about 30 miles have been known to generate sonic booms. I've never heard one – but I never hear much of anything. They occur, though. Since sound waves travel much more slowly than light waves, the sonic boom will occur anywhere from 90 seconds to four minutes after the fireworks-like explosion.

The other sound generated occasionally by meteors is hissing or sizzling. (I heard it once: as the meteor sped by, I heard a sound like bacon frying. To anyone with normal hearing, it might have sounded like an airborne vacuum cleaner.) That sound is thought to be associated with VLF (very low frequency) radio waves interacting with the nearby environment.

Tuning In to Meteor Showers. What if it's cloudy? Well, you can *listen* to the meteors on your car radio regardless of whether the sky is cloudy or clear.

As meteors pass through Earth's atmosphere, they leave behind a trail of ionized gas molecules. If you tune your radion to a commercial FM station you can't normally pick up that's about 600 miles away – say, 91.7 FM (WMKL in Miami) or 91.5 FM (WBJC in Baltimore) – you'll hear static. But whenever a meteor zips through the atmosphere, the radio waves will bounce off the meteor's ion trail and the station will come in loud and clear until the signal fades back to static in a second or two.

Peak Experiences. Dust particles aren't equally distributed throughout a meteoroid stream. They are most densely concentrated toward the center of the stream. In observing terms, it's known as the meteor shower's *peak*, i.e., the time when you're likely to see the most meteors that the shower has to offer. That peak is highly predictable: it occurs during the pre-dawn hours. Why? Because the Earth rotates on its axis as it moves through space. After midnight we're on Earth's "front edge" (i.e., we're facing in the direction that earth is rotating), so we're facing the oncoming meteors. As Earth rotates, the radiant rises in the east along with the stars, planets and everything else. When the radiant is at its highest point, the Sun will be rising.

It's the same effect you get when driving in the rain: more rain hits the front windshield than the rear windshield because that's the direction you're traveling. Because you're moving, you're not just driving *through* the rain, you're driving *into* it.

You may see occasional meteors from a meteor shower before midnight, too, the same way you can see rain on the rear window of your car. But most of it will be concentrated in the pre-dawn hours.

At peak, the best annual meteor showers may display as many as 60-100 meteors per hour. For 2-7 days before and after peak, however, you're likely to see a few early arrivals or latecomers every night. You'll know if they're part of the meteor shower if they appear to have come from the direction of the radiant. Sporadic meteors come from any direction.

"I've seen it raining fire in the sky."
-**John Denver**
Rocky Mountain High (1972)

Meteor Storms. Occasionally, Earth passes through a debris trail that is so densely concentrated that the term meteor shower doesn't accurately describe what is happening. On those rare occasions, *meteor storms* have produced many thousands of meteors per hour. They usually are associated with the Leonids meteor shower, which occurs annually in November. It is the dust tail left by Comet Tempel-Tuttle, and its radiant is always in the constellation Leo.

Normally, the Leonids is not an especially productive shower. However, every 33 or 34 years Earth passes through an especially dense stream of Leonids dust.

*On the evening of Nov. 12-13, 1833, observers in Boston saw an estimated 240,000 Leonids meteors rain down in a 9-hour period.

*Near dawn on Nov. 17, 1966, observers in the American southwest watched in amazement as a 40-meteors-per-hour Leonids rate leaped to an incredible 150,000 meteors an hour in just a few minutes. And during a 5-minute span at peak, those observers estimated the fall at 40 meteors per *second*! Maybe that's what Bob Dylan meant when he sang, "A hard rain's gonna fall."

*The 1999 Leonids storm produced 3,000 meteors per hour at peak.

Fireballs and Bolides. Not all meteors are dust particles. Some are larger. You'll know the large ones by how long they light up the sky. The larger the meteor, the longer it will burn and the farther it will cross the sky as a fiery flash. If you see a meteor move all the way from one horizon to the other, it probably entered Earth's atmosphere about the size of an English pea. And if it lights up the sky like the planet Venus or a child running with a sparkler in the dark, it might have been as large as a marble, or maybe even a basketball or larger than that. Such bright meteors are known as *fireballs*. In their wake, they often leave behind vapor trails that can linger in the sky for 15 minutes or longer. Some fireballs have been bright enough to be seen in the daytime.

According to the American Meteorological Association, fireballs that explode like fireworks at the end of their treks across the sky are known as *bolides*. (I thought bolides and fireballs were the same thing.)

Impact Craters. Fireballs are rare because large meteors are rare. But fireballs are the most likely candidates to survive their nose-dive through the atmosphere and create *impact craters*. When that happens, regardless of their size or the size of the craters they produce, they become *meteorites* when they reach the ground.

Most meteorites are relatively small, and they do not produce craters that we can recognize as such. That doesn't mean they pose no danger to us – bullets are small and dangerous, too – but unless you're directly in a small meteorite's path, you're safe.

Like the meteors that produce them, impact craters come in all sizes. Sudbury Basin Crater in Canada is 160 miles in diameter. Chicxulub Crater off the coast of the Yucatan Peninsula in Mexico is 110 miles in diameter. (The 6-mile-wide meteor that created it also killed off the dinosaurs and practically everything else 65 million years ago.) Barringer Crater in Arizona, the most famous meteor crater on Earth, is ¾ mile in diameter and 500 feet deep; the meteor that created it was the size of a bus. (Re Barringer: it's famous for two reasons: the impact occurred just 50,000 years ago, making it the most recent large impact crater; and because the impact occurred in a dry desert area, it has not been altered by more recent geologic processes.)

Meteor craters usually are round – or, as is the case with Wetumpka Crater near present-day Montgomery, AL (4-1/2 miles in diameter) and The Cove at Woodbury, GA (3-1/2 miles in diameter), horseshoe-shaped due at least in part to the acute angle of the meteor's approach. In fact, most of the verified meteor craters on Earth were first identified in satellite photos, or by astronauts or airplane pilots. From the air, Wetumpka Crater and The Cove are immediately recognizable as possible impact sites.

Our planet probably contains millions of as-yet undiscovered impact craters, most of them smaller than the ones I've mentioned. No one knows for sure how many there are, because if they aren't found shortly after impact they begin to fill in via the effects of erosion, weathering, the emergence of new plant life, and other geologic processes.

Beyond that, it's not easy to identify impact craters because hollowed-out depressions exist everywhere on Earth. To determine the origin of a suspected impact crater, geologists look for meteorites in that area – or, lacking that, they search for evidence of "disturbed geology." Such disturbances include the presence of: (a) quartz that was deformed, or "shocked" by the immensely powerful shock waves generated by the impact; (b) iridium (a rare metallic element) or (c) cone-shaped rocks called "shatter cones." All of them are created only by nuclear detonations or meteor impacts. Without finding at least one of the above at or near the suspected impact site, all you have is a hole in the ground.

(Actually, I've been misleading you here: none of them has been found at The Cove. But those of us who have been there and seen it up close and personal from various angles are 100% convinced that it's an impact crater.

Wetumpka, on the other hand, is a verified impact crater: Dr. David King's research team found shocked quartz at a depth of 600 feet in 1998.)

Classifying Meteorites. Classifying meteorites is a complex subject. For our purposes, however, we'll use the traditional three broad categories of meteorites: stony; iron; and stony-iron.

Stony meteorites comprise 69% of all of the meteorites that have been found on Earth. They are subdivided into two groups: *chondrites*, or silicatebased rocks (i.e., the minerals found in sand); and *achondrites*, which are simply rocks or stones that do not contain silicates.

Of the remaining meteorites, 28% of them are *iron* (or an iron-nickel alloy), and the remaining 3% consists of *stony-iron meteorites* composed partly of iron and partly of materials other than nickel.

Finding Meteorites: Meteorite Falls and Meteorite Finds. Unfortunately for meteorite hunters, meteorites don't arrive bearing signs reading "I'm a meteorite!" Since Earth's outer layer, or crust, is basically composed of rocks and stones and 69% of the meteorites on Earth are stony, the odds of correctly identifying a rock in your backyard as a meteorite are considerably lower than your chances of winning the MegaMillions lottery.

Since we're talking about finding meteorites, however, the first and most important step is to know where to look for them. Earth is, after all, a very large planet that offers abundant hiding places for meteorites. Meteorite hunters narrow down their searches to two places or techniques: meteorite falls (specific places) and meteorite finds (search techniques).

A *meteorite fall* is an area where a meteor (or pieces thereof) has been seen falling to Earth. Two examples: When a 10,000-ton bolide exploded above Chelyabinsk, Russia in 2013, meteorite hunters immediately began searching for fragments in and around that city. There was no shortage of eyewitnesses to the event, and small fragments were found. And earlier, in 1803, thousands of meteorites were collected when villagers in L'Aigle, France, saw them fall from the sky.

(Trivia fact: Meteors are hot when they are burning up in Earth's atmosphere, but not when they land as meteorites. Small meteors, at least, do not retain that heat. By the time they land, they have slowed down to 200 to 400 mph and are no longer melting due to friction. If you saw one land, you could pick it up immediately without burning your hand. The Alabama woman who was hit by a 9-pound iron meteorite in 1954 was severely bruised – but not burned – when the meteorite crashed through her roof, bounced off a fireplace and a radio and struck her thigh.)

A *meteorite find* typically involves searching areas where meteorites are likely to be found, or where they tend to stand out from their surroundings. One such area is Antarctica, where any meteorite, whether stony, iron or stony-iron, is immediately recognizable because everything else around it is snow or ice. Glaciers are equally likely to be productive sources, for the same reason. But because glaciers essentially are slow-moving rivers of unstable ice, they are a very dangerous place to search for meteorites.

Deserts are another beneficial search area because they remain basically unchanged for long periods of time. For example, if you come across a rock (or rocks) in the vast sand dunes of the Sahara Desert, you're likely to be looking at a meteorite. Still…deserts are large places, and unless you're very lucky you need to know where to look.

When, in 2009, an incoming meteoroid as large as an automobile was tracked by astronomers before it entered earth's atmosphere, its eventual landing site in Sudan's Nubian Desert was plotted to within 11 square miles. A search team found 280 meteorites, the largest about as big as an orange.

A third search area is known meteor craters. Arizona's Barringer Crater is literally the best of two worlds: it is located in the desert, and it is instantly identifiable as a meteor crater. (Unfortunately, collecting meteorites there is prohibited, but you get my point.)

Ancient meteor craters in other places tend to be somewhat more iffy because they change and fill in over millions of years, burying meteorites and other evidence of an impact that originally was on or below the surface. That might have been the case at The Cove, where no meteorites, iridium, shocked quartz or shatter cones have ever been found.

Freshly plowed fields offer excellent possibilities for unearthing buried meteorites. That's how a farmer discovered the 65-ton Hoba West meteorite in Southwest Africa (now Namibia) in 1920. It is the single largest meteorite ever found. Native Americans used that same technique to find iron and stony meteorites that they shaped into arrowheads.

Most meteorites are stony and therefore resemble terrestrial rocks to novice meteorite hunters To experienced hunters, however, stony meteorites appear radically different from other rocks in the vicinity. That's not much to go on, but if they were easy to recognize, everyone would find them. The best hint regarding stony meteorites is to visit a science museum and study the specimens they have on display, so you'll know what to look for.

The easiest meteorites to find are iron-based. They respond to magnets, and thus are detectable by anyone using a metal detector. Iron and stony-iron meteorites occasionally are found by individuals using metal detectors for other purposes such as searching for coins, jewelry, Civil War relics, etc.

Beyond their response to magnets, other tell-tale signs of iron meteorites can be fantastic, often jagged and sharp-edged shapes that developed as the meteor's exterior melted; or else they may display a pitted, golf ball-like appearance due to portions of their exteriors being scooped out by melting during their heat- and pressure-filled passage through Earth's atmosphere. And if they are iron, they may show evidence of rusting. (But terrestrial iron rusts, too.) Even with those clues, though, specimens must be examined by a geologist to verify their extraterrestrial origin.

The smallest meteorites – called *micrometeorites* – are also the most numerous. They range in size from dust particles to 2mm. Many of them are iron-based, and therefore they react to a magnet passing over them. Larry Higgins has pointed out that you might find micrometeorites by running a magnet along the rain gutters of your house – but you're also likely to find yourself in a hospital bed if you aren't careful while climbing around on your roof!

As of April, 2016, there have been only 1,140 verified meteorite falls involving eyewitnesses in recorded history, and just 38,660 other documented meteor finds. (That's why meteorites are so valuable and expensive.)

Collecting, Buying and Selling Meteorites. Collecting meteorites is a hobby in itself, but it's not for anyone with limited resources such as time and money. Finding them yourself is, as I've pointed out, both difficult and unlikely. Traveling to known meteor falls can be very expensive -- and by the time you get there, more experienced and knowledgeable meteor hunters probably have already found the largest and best meteorites.

Searching for meteorites is time-consuming, and there's never any guarantee that you'll be successful. As a result, many if not most meteorite collectors buy their meteorites from reputable meteorite hunters.

Why, then, would anyone want to become a meteorite hunter? For the challenge it presents, of course – and for the same reason that salvage experts search the ocean floor for shipwrecks that might contain vast treasures for those who are bold, skillful, persistent and lucky enough to find them.

All meteorites are valuable and expensive; exactly how valuable they are depends on their size and type of meteorite – and, even more important, their origin. The larger the meteorite of a given type, the more valuable it is. And meteorites of lunar or Martian origin are extremely rare: they sell for many thousands of dollars per gram.

In 2012, 35 small fragments of green stony achondrite meteorites designated as NWA 7325 were found in a marketplace in Erfoud, Morocco in northwest Africa. In all, the stones weighed 12.2 ounces, and they were tentatively identified as having come from the planet Mercury. If their identification holds up – and so far it hasn't been disproven – they are the rarest and most valuable meteorites ever found. Unless you're as wealthy as Bill Gates, don't even think of trying to buy one.

How do astronomers know where a meteorite comes from? By comparing its chemical composition with that of planets and asteroids whose composition are known. When they find a match – *presto!* – that's where the meteorite came from. The chemical composition of the NWA 7325 meteorites matched that of Mercury as determined by the *Messenger* spacecraft that orbited Mercury between 2011-2015.

There are no meteorites from Jupiter, Saturn, Uranus or Neptune because nothing ever reaches their surfaces. Their dense atmosphere destroys everything that enters it.

The same is true of Venus: only the largest meteors could penetrate its thick, soupy atmosphere and reach its surface. Even then, though, that atmosphere would incinerate venusian fragments expelled by the impact and prevent them from escaping into space.

Earth has occasionally been struck by meteor fragments from Mars because the Red Planet has relatively little atmosphere to burn up martian fragments sent out into space from impacts with asteroid fragments.

The Moon has no atmosphere, but lunar meteorites are rare because it is such a small target for asteroid fragments to hit. And despite Earth's larger size and greater gravititational influence, space is a very large place and our planet is a relatively small target for lunar fragments to hit.

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Annual Meteor Showers

When periodic comets return, sometimes their fresh debris trails produce new meteor showers that are named, not for the comet that spawned them, but for whatever constellation they appear to be coming from. For example, Halley's Comet has produced two annual meteor showers, the Eta Aquarids in May and the Orionids in October. (See below.)

In all, there are about two dozen annual meteor showers. (Not every incoming comet leaves a debris trail that Earth's orbit will pass through.) Most showers don't produce many meteors at peak, and even fewer before or after that. Here are nine of the best, listed by their estimated peak dates (which may vary by a day or two from one year to the next). Their peak rates and duration also vary annually.

Name	Peak	Meteors Per Hour	Duration (Days)
Bootids	Jan. 3	25-100	2
Lyrids	Apr. 22	5-15	4
Eta Aquarids	May 4	5-25	6
Delta Aquarids	July 29	5-20	14
Perseids	Aug. 12	50-100	5
Orionids	Oct. 21	10-20	4
Leonids	Nov. 18	5-100	varies
Geminids	Dec. 14	50-100	5
Ursids	Dec. 22	5-15	4

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