




Thousands of reports of ball lightning objects have been recorded over several centuries. It is not uncommon that they appear inside structures, sometimes penetrating walls and windows or descending chimneys.

Ball Lightning

A Meteorological Enigma

by Walter Lyons 

Late afternoon on Monday, July 27, 2015, Vladimir Sokolov peered out his high-rise window at 9 Angelov Lane in Moscow's Mitino district. Dark clouds lowered as the gust front from an approaching thunderstorm brought strong west winds. Suddenly, his eye was attracted to a yellow glowing sphere above a forested area about 1,000 feet to his west. Initially moving toward him with the wind, the sphere began erratic lateral and vertical movements that seemed at odds with the wind currents. After watching in growing puzzlement for several minutes, he grabbed his camcorder and captured 125 seconds of video showing more of this bizarre movement until the sphere rose and moved again with the wind up and over his building. He posted the video to YouTube (<https://www.youtube.com/watch?v=eyRLOBimsHM>), not knowing two of his neighbors had also captured the event with their smart phones. But what was it? A lighted drone? Some kind of balloon or other floating object? Some scientists believe that Sokolov and his neighbors had captured that most elusive and much-doubted phenomenon known as ball lightning. The Moscow videos have since undergone intense scientific scrutiny, adding what some say is concrete evidence to centuries of reports of a phenomenon that others consider the meteorological equivalent to the legendary Yeti of the Himalayas.

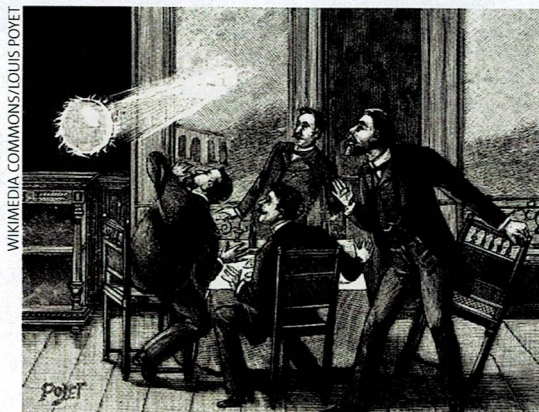
Ball Lightning: Is it Real?

There have been more than 10,000 reports of ball lightning found in sources ranging from tabloid newspaper articles to scientific journals. This plethora of sightings suggests that ball lightning is indeed a real phenomenon, albeit a puzzling one. In fact, surveys find that between 2% and 10% of

the population in thunderstorm prone areas have seen ball lightning.

The American Meteorological Society Glossary of Meteorology defines ball lightning as a rare and randomly occurring ball-shaped light observed floating or moving through the air close to the ground or inside buildings. While characteristics vary widely, ball lightning commonly occurs near lightning strikes, ranges in size from a baseball to a soccer ball, is often colored white or orange, and lasts for only a few seconds before disappearing, sometimes with a loud noise. One of the earliest documented cases occurred in England in 1638, when "a great ball of fire" was observed coming through a Devonshire church window during Sunday services. In 1837, renowned French scientist François Arago published the first compilation of ball lightning reports, beginning the arduous task of scientifically vetting these phenomena, which he called "one of the most inexplicable problems of physics." The ball lightning reports kept accumulating. In 1841 Milan, as a thunderstorm raged, an artist in the court of the Empress of Austria heard shouting outside and saw people running away from a reddish-yellow ball of "fire" floating along at second-story height before rising to explode with a dull crash. In the late 1800s, young Russian Tsar (to be) Nicolas II watched in horrified astonishment as, during a thunderstorm, a fiery ball penetrated a church window and whizzed past the head of his grandfather, Tsar Alexander II. In 1944, a glowing sphere passed through a closed window at the Division for Electricity and Lightning Research at the University of Uppsala, Sweden, leaving a circular hole about two inches across. During a 1962 thunderstorm in Berri, Australia, lightning struck a backyard, creating a hissing, bluish-green ball that floated to a house and burned through a window screen before disappearing inside. In 1969, a professor of electrical engineering published his experience on a New York to Washington D.C. flight, in which an opaque blue-white, glowing, soccer ball-sized sphere floated the length of the cabin aisle, one of dozens of similar reported aircraft ball lightning incidents.

Beginning in 1923 with German scientist Walther Brand's comprehensive book on *Der Kugelblitz*, every decade or so new a new book has evaluated these *foudre globulaire* or *boules de feu* (French) or *sharovaya molniya* (Russian). The 2003 encyclopedic *Lightning* (by Vladimir Rakov and Martin Uman) marveled that while research articles on "ordinary" lightning numbered some 6,000, there appeared to be some 2,400 additional scientific papers just on ball lightning. In his 1999 book *Ball Lightning: An Unsolved Problem in Atmospheric*



Classic 19th century engraving depicting ball lightning passing through a metal screen to enter a Paris meeting room during a thunderstorm.

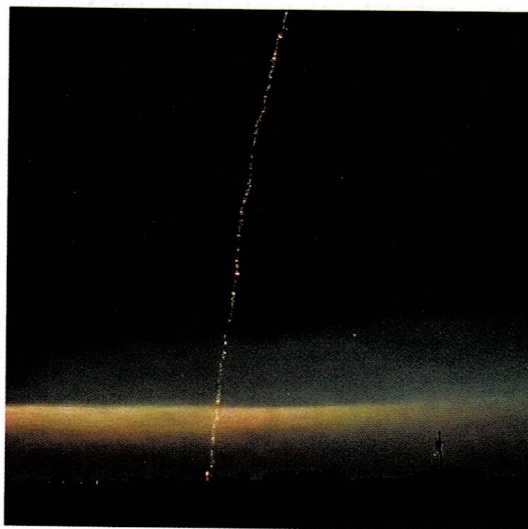
Physics, Mark Stenhoff presented a vast array of observations and numerous (conflicting) theories but expressed confidence that within 20 years this great mystery would be solved. Fast forward to 2019, when German researcher Herbert Boerner published his book *Ball Lightning: A Popular Guide to a Longstanding Mystery in Atmospheric Electricity*. The title's key word was still "mystery." However, some progress to illuminate the causes of this phenomenon is being made and you, the reader, might even be able to help in resolving this meteorological riddle, wrapped in a mystery, inside an enigma, to paraphrase Winston Churchill.

Skeptical Science

Many scientists confine ball lightning reports to the realm of yetis, little green men, poltergeists, and spontaneous human combustion, all "interesting" stories to be sure, but the seeming lack of detailed evidence does not motivate deeper investigation. In the past, the military periodically wondered if ball lightning could lead to a new type of weapon. Those attempting to harness nuclear fusion as an energy source using powerful magnetic fields to confine hot plasmas occasionally speculated if nature had conjured a way to use lightning to do it on the cheap. To this end, some physicists continued dabbled in ball lightning theories, but to get too deeply involved was not considered a good career move. The three pillars of science—observation, theoretical modeling, and laboratory simulation—must converge on a comprehensive understanding of a phenomenon that withstands repeated testing over time. But science is having a really hard time doing that with ball lightning. A planned observation of a rare and random event is a futile endeavor. Theories need to be constrained by actual observational data. And without knowing ball lightning's detailed characteristics, who knows if any lab simulations are the real thing? While scientists are skeptical folk, they are skeptical folk, they are, however, even more curious. Thus some still persist in speculating about its nature while sifting for clues buried in numerous ball lightning reports and hoping for a breakthrough.

What Isn't Ball Lightning?

Many luminous objects are simply called ball lightning, for lack of a better idea of what they might be. Bead lightning, rare and itself a considerable puzzle to science, forms after a cloud-to-ground (CG) lightning channel cools, breaking into numerous small irregular segments. This is not ball lightning. When thunderclouds boil overhead, enormously high electric fields become



TONY LAUBACH/WEATHERVIDEODTV

Bead lightning is rare and not well understood. It occurs when a cooling lightning channel breaks down into irregular segments lasting no more than a half second. It is not ball lightning.

enhanced at the tip of elevated and pointy conductors, and creepy St. Elmo's fire, a plasma with myriad small electrical streamers, glows a ghostly deep blue (from excited nitrogen molecules). A lot of interesting physics is going on, but the glows remain anchored in place until the high electric field subsides, and they are not ball lightning.

Ball lightning search engine requests return literally millions of hits, including an array of images and videos. Many are clearly crude hoaxes, bright objects smeared by shaky camera moves, or people exercising their artistic talents. Most are simply other things people reflexively label ball lightning when noticing brilliant aircraft landing lights, flaming bolides, fireworks, deorbiting satellite debris, or tethered hot air balloon "glows," especially if one has a poor sense of distance or perspective. The culprits in many ball lightning reports could be escaped aluminum party balloons, giant soap bubbles (or blobs of floating foam from



WIKIMEDIA COMMONS/NITROMETHANE

The ghostly glow of St. Elmo's fire, seen here on a 500 kV power line corona ring, indicates extremely high electric fields are present, often presaging a lightning strike. It is not ball lightning either.

polluted waterways), distant car headlights distorted by ground temperature inversions, window reflections, military flares, and those old standbys, Venus and swamp gas (*ignis fatuus*: gases burped up by bogs and wetlands that ignite). One spectacular video from Belarus, showing a brilliant purple ball floating around railroad tracks while zapping nearby objects with electric bolts, attained over 4 million views for this “real ball lightning.” Unfortunately in this case, Minsk programmer Andrei Trukhonovets was practicing his CGI skills, which he proudly posted to the Web, not suspecting that it would be blatantly misrepresented by others. One interesting video of distant thunderstorm lightning suddenly shows a ball of light zooming past. Could it be ball lightning? A closer look reveals it was a firefly buzzing the lens. A California TV station breathlessly broadcast “a shocking and exclusive” ball lightning video, which was actually a rather impressive power transformer explosion after lightning struck distribution lines. It does pay to be skeptical. Yet, the more one digs, the more one unearths images, photos, and eyewitness reports that are real head-scratchers, not so easily explained away.

Then What Is Ball Lightning?

Ball lightning reports can be maddeningly anecdotal. But as someone once quipped, the plural of anecdote can be data. Over recent decades, numerous researchers have scoured thousands of eyewitness accounts, first sifting the wheat from the chaff. Then utilizing only those from credible observers (indeed, one study was limited to sightings by scientists), it appears that while each vetted ball lightning report is like a snowflake (no two are exactly alike), some repeatable patterns emerge. These patterns have also stayed quite consistent over many decades. While it is entirely possible there are several distinct varieties of ball lightning formed by different physical mechanisms, there are behaviors that encompass a large majority of ball lightning reports. The following list, aggregated from many studies, summarizes attributes common to a “typical” ball lightning eyewitness account:

- A thunderstorm in progress; ~90% after a CG lightning strike (up to several miles away)
- High peak current positive polarity CGs appear more conducive to ball lightning formation
- Occurs outside, often close to the ground, but can also be inside buildings and cabins of aircraft in flight
- Can pass through glass, metal screens, curtains; some leave small holes or burn marks

- Lifetimes: typically ~5 seconds but can range from <1 second to several minutes
- Shape: ~90% spherical, others are ellipsoids, disks, or irregular blobs
- Size: typically 6–12 inches, but ranges from pea size to many yards across
- Color: ~50% yellow or white, ~33% red or orange, ~10% blue or violet, and the remainder a mix
- Brightness: that of a 50-W to 100-W light bulb; occasionally brilliant objects reported
- Surface: from smooth to sparkling or rippling; can be opaque or translucent
- Motion: from stationary to “walking speed,” often against wind; some move at high speed
- Usually travel horizontally or descend from above; do not behave as if a hot air bubble
- Sometimes emit crackling or buzzing sounds; usually no heat is felt
- Shape, size, and color tend to stay fairly consistent until near termination
- Usually end by blinking out or exiting through a wall; sometimes explode with terrific noise
- Sometimes after an explosive ball lightning demise, there is strong smell of “ozone” or “sulfur”
- With some notable exceptions, ball lightning usually does not cause damage or injury.

Other ball lightning events seem to fit a slightly different mold. During a severe thunderstorm over Melbourne, Australia, in February 2002, a large (initially ~40 yards) orange-red sphere materialized high in the sky near a lightning channel. Initially stationary, it descended at great speed toward the ground, then “bounced” off the terrain several times while fractioning into several smaller spheres. After some 35–45 seconds and traveling eight miles, the last was seen rolling down an embankment with a swishing noise into a back yard. The orange sphere, then about a yard wide, exploded on contact with a BBQ grill. The initial stages of the event were seen by eyewitnesses and captured in a three-second time exposure by well-known nature and storm photographer Ern Mainka. Seven other credible individuals saw the event, allowing its journey to be reconstructed. Glowing orbs descending from electrified clouds are occasionally reported, but for once there was hard evidence.

But Is There Enough Evidence?

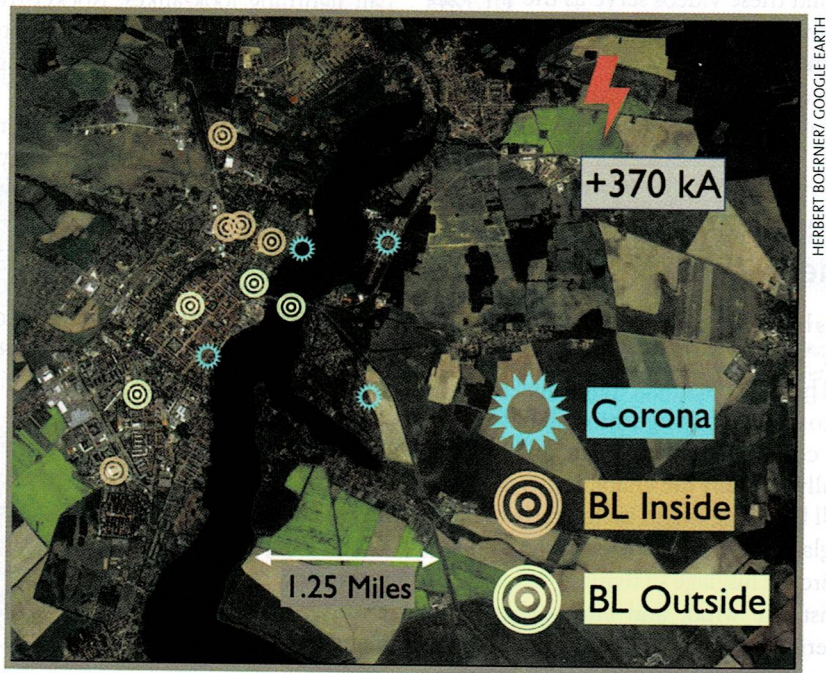
Skeptics often ask, with the plethora of cameras available today, where are all the ball lightning pictures? It’s a fair question, but given that an event often lasts only a few, highly unnerving

seconds, how many of us would be able to get that shot? It is not clear that most motion-activated security cameras would be triggered by a small, floating and (usually) relatively dim illuminated object. And has all the footage from always-on CCTV cameras been searched for ball lightning? Probably not. We do note that inspection of 12,000 images from the automated U.S. Prairie Meteorite Network operated in the 1970s found two cases resembling the Melbourne ball lightning event.

Corroborating evidence need not be photographic, as the strange goings on around Neuruppin, Germany, on January 15, 1994, attest. This small city of 30,000, in flat countryside about 40 miles northwest of Berlin, has its own meteorological office. In the warm sector of a low-pressure system, the day had been mild, cloudy with occasional rain. Darkness had fallen, and at 1708 LT the staff of the weather office saw a brilliant flash, followed about 10 seconds later by a thunderous boom. A local citizen called asking what had happened. Unsure of the cause, the chief meteorologist had the local newspaper request residents to send in their observations. To his amazement, they received 32 citizen reports—11 of which mentioned ball lightning (a term not used in the press story), several by multiple witnesses. They appeared both outside and inside of homes. There were generally spherical, ranged in size from egg to medicine ball, came in a variety of colors (white, yellow, red, blue), and typically lasted several seconds. One ball lightning object came

through a closed window, roamed the living room, and exited the same way. A cloth curtain was singed brown in two spots. Three reports of St. Elmo's fire indicate very high local electric fields. Post analysis turned up a significant clue. The initial bright flash came from the first lightning strike of the storm (located by the BLIDS lightning detection system), a powerful positive polarity CG with an enormous peak current of 370 kA (more than 10 times a "normal" +CG). Even more noteworthy, the +CG hit 4.3 miles from the meteorological station, and the 11 ball lightning objects all occurred several miles from the lightning strike point. Any theories of ball lightning must explain these separations from the strike point.

Good video of a ball lightning event is desperately needed. There was considerable excitement in 2012, when lightning researchers in China's Qinghai Plateau deployed both conventional color and high-speed (3,000 fps) cameras, both equipped with diffraction gratings to capture light spectra. They caught a CG strike, immediately followed by a ball lightning object lasting 1.6 seconds while drifting at around 18 mph. Burn marks were found on the ground. The spectra showed the ball lightning to be rich in iron, calcium, and silicon ions, the latter of interest due to a prominent theory that ball lightning consists of flaming nanoparticles of silicon vaporized when lightning strikes soil. Was this the smoking gun? Maybe, but others have noted the object occurred adjacent to a 35-kV power line, perhaps covered with the local soil



Schematic of citizen reports of outside and inside ball lightning objects, and corona discharges, on January 15, 1994, in Neuruppin, Germany, associated with a +CG lightning strike with an enormous 370 kA peak current, which notably struck several miles away. Adapted from *Ball Lightning*, by Herbert Boerner (p. 161). Background from Google Earth.



Frame excerpted from the Vladimir Sokolov video of a reputed ball lightning object (arrow) over the Mitino District of Moscow, Russia on July 27, 2015. The yellow sphere was about 30 inches in diameter, had a lifetime of 4-5 minutes, and often moved erratically against the wind. Credit: Nitikin et al. (2018), *Journal of Atmospheric and Solar-Terrestrial Physics*; doi:org_10.1016_j.jastp.2018.07.001

dust. This may have simply been a common power line arc to ground (flashover).

Back to Moscow, 2015. Along with Vladimir Sokolov, Egor Chichin's smartphone captured 141 seconds of the object (<https://www.youtube.com/watch?v=frTCqnz8-Bg>), while neighbor Dmitry Novosyolov recorded 76 seconds, allowing Russian investigators to triangulate the 3D path of the object, estimated to be about 30 inches in diameter, for approximately two minutes of its estimated four- to five-minute lifetime. The motion of the object was clearly at odds with the strong steady winds, so it could not have been a balloon. Could these videos serve as the smoking gun? Some think it possibly is. Others, however, have sown doubts about the low-resolution video and wondered if the "ball lightning" might not actually have been an illuminated drone.

Mad Scientists' Theories and Experiments

Scientists hardy enough to tackle ball lightning aren't really "angry," but they are probably a bit frustrated. The more than 200 published theories purporting to explain ball lightning all have problems. Some contradict one another, and none to date can fully explain all characteristics of the "typical" ball lightning event, including how it can penetrate glass and metal screens, materialize within an aircraft fuselage (a flying Faraday cage), move against the wind, and emit light for an extended period of time with no apparent input energy. Some skeptics theorize that ball lightning is nothing more than image persistence upon seeing the bright parent lightning flash, or the result of transcranial magnetic stimulation (TMS) in

which intense magnetic fields induce a brief luminous hallucination in the brain. Interesting, but many ball lightning observers never see the parent lightning, nor have lightning magnetic fields of the intensity required for TMS been measured. Some theories go pretty far out on the theoretical limb: cosmic rays focused by storm electric fields, antimatter meteors, or stray miniature black holes. One highly dubious Internet theory holds that ball lightning events are actually visits by the extragalactic Blue Sphere Alliance, 9th Density beings who have come to assist humans to transition to the 4th Density (Mighty neighborly of them; but we would suggest the reader rather critically evaluate some items found on the Internet).

The more we try to understand ball lightning, the more questions arise, it seems. What is ball lightning composed of? Is it roiling plasma? Or vaporized silicon, or swarms of electrons or photons? Perhaps metastable states of oxygen, trapped microwaves, entangled electromagnetic fields, or something totally unknown? And what holds the ball together? Ball lightning emits light, but what else? In one case, a blue, baseball-sized object hovering inches from a glass door reportedly produced a yellow-green glow in the glass several times the sphere's size. Clearly, it was not a reflection. Testing showed that this type of glass fluoresces when subjected to intense ultraviolet light, X-rays, or maybe even gamma rays.

Intrepid engineers have used sparks from enormous banks of submarine batteries, high-voltage discharges under water, and materials zapped with microwaves and blasted away with lasers to make ball lightning look-alikes. Rocket-triggered lightning strikes directed into various substances yielded a variety of short lived "blobs" floating through the air. So are these ball lightning objects? Of course, on the Internet one learns that grapes irradiated in a microwave oven can generate a scary-looking ball of plasma. This proves something, but what? (And we do not suggest trying this at home...it would be a waste of grapes, and maybe your microwave.)

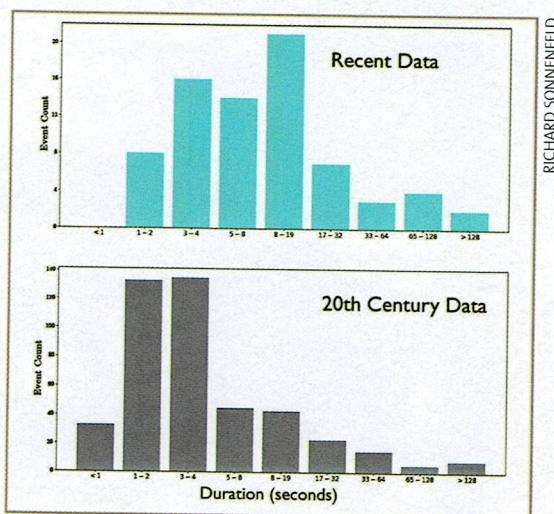
Recent research has revealed some really strange things are happening inside thunderstorms. Nuclear processes are generating intense bursts of gamma rays (the highest-energy electromagnetic radiation) that nature usually produces inside the likes of black holes and supernovae. These were first detected heading into space by satellites, and more recently, at ground level beneath some low cloud base winter thunderstorms in Japan. We speculate that rare ground level gamma-ray bursts emitted by the leaders of lightning channels, which occasionally travel horizontally many miles at low altitudes before dropping a powerful +CG, might just be a factor in understanding ball lightning formation. Until we have many more comprehensive investigations of ball lightning, however, this and other theories will remain problematic.

Be Part of the Research

Clearly, ball lightning remains enigmatic for scientists and the public alike. This science, after 180+ years, is still in its infancy. The good news is that, as a weather enthusiast, you can contribute to the knowledge base. Anyone who has observed a ball lightning event can record their observations at <http://tinyurl.com/BLReport>, a website developed by Professor Richard Sonnenfeld of the Langmuir Laboratory at New Mexico Tech in cooperation with researchers worldwide. Its goal is to match credible ball lightning reports with meteorological information, such as lightning detection networks, 3D lightning mapping arrays, NEXRAD radar, and the Geostationary Lightning Mappers on GOES 16/17. One recent report, augmented by an extensive interview, is summarized:

Around 5:00pm, 15 August 2021, as the sky darkened from an approaching storm, a North Carolina woman and her child looked outside their window to see a brilliant white beach ball-sized sphere hovering about 8 feet above her backyard – with several leaves swirling wildly just above it (!) After about 10 seconds, it disappeared with a loud explosion, also heard by neighbors. The leaves fell to the ground. There were no burn marks anywhere to be found, though their Internet service went dead.

Beyond scrutinizing individual reports, this growing database will further refine our descriptions of BL's characteristics. Hopefully you will be able to capture a video, but regardless, it is critical to promptly create a written record of




RICHARD SONNENFELD

Histogram of the reported durations (in seconds) of ball lightning object observations showing similarities in recent reports and from compilation made in the mid-20th century. Lifetimes last from 1 second to several minutes, with 2-20 seconds being most common.

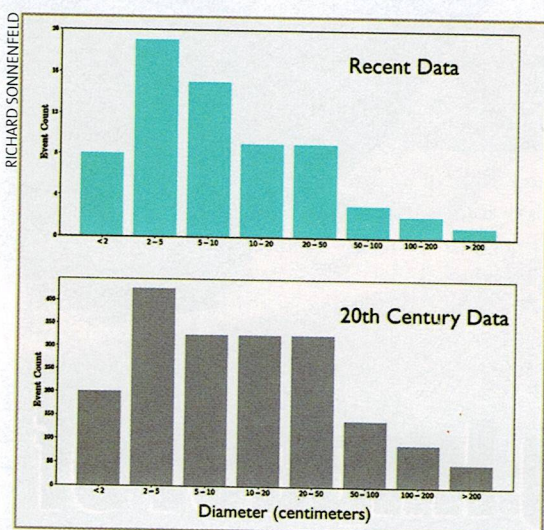
the object's appearance and behavior (relaying on memory later often leads us astray.) Please record the detailed weather conditions and especially the location and precise time of the BL event (to match up with lightning detection data). Who knows, now that you know what to look for, maybe you will someday obtain that "smoking gun" video or observation that helps untangle this meteorological enigma. w

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Histogram of the reported diameters (2.54 cm = 1 inch) of ball lightning objects from recent reports and a compilation of those made in the mid-20th century. They show essentially the same pattern.