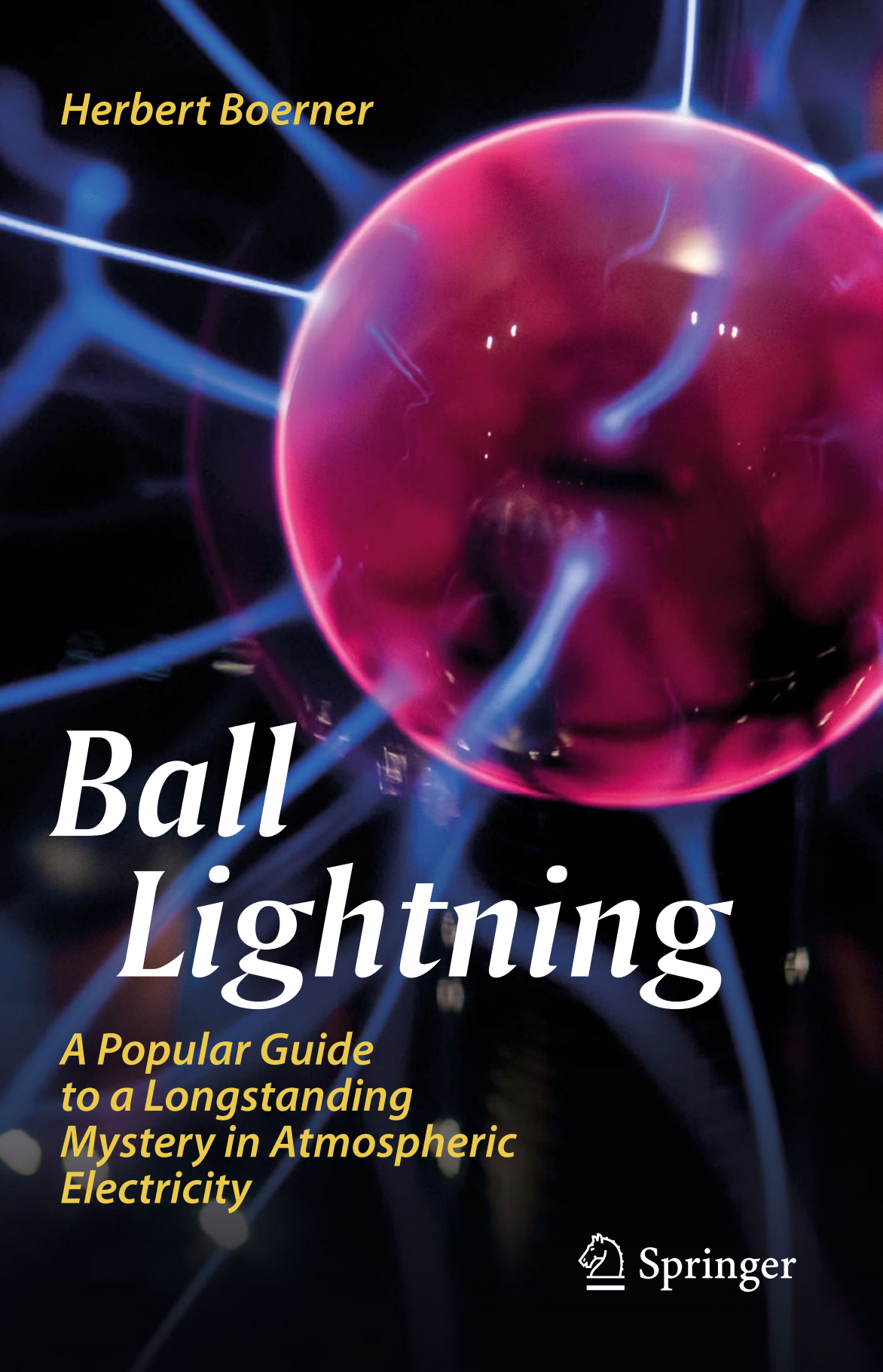
Herbert Boerner
Ball Lightning
A Popular Guide to a Longstanding Mystery in Atmospheric Electricity
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Cover illustration: Because ball lightening is so rare, photographs are few and far between and there are none that display the spectacular nature of this phenomenon well. To symbolize the idea of ball lightning, the cover photo shows a plasma globe, a device in which a barrier discharge is created in a noble gas atmosphere. The visual appearance may come close to that of an actual ball lightning.

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Foreword

The physical origin, the stability, and the energetic maintenance of ball lightning have challenged lightning science for more than a century. The phenomenon is relatively rare, but eyewitness reports are common enough to inspire inquiry and motivate a scientific explanation. The author of this book, Herbert Boerner, a physicist who has worked on this subject for many years, makes a new effort to solve this riddle. His new book on this enigmatic subject with its bizarre behavior is rich in background. Detailed eyewitness accounts and photographic evidence on ball lightning are gathered and reviewed. The lightning physics relevant to this topic is extensively addressed, including appropriate emphasis on positive cloud-to-ground lightning, especially the exceptionally energetic variety that is called "mesoscale lightning" (and which is capable of ringing the Earth's Schumann resonances to intensities 20 dB greater than all the ordinary lightning combined). Laboratory experiments pertaining to ball lightning are explored, as well as reviews of all major texts on this subject. The greatest strength of this new work lies in its emphasis on the comparison between theory and observation, with a judicious use of Occam's razor. This pursuit is no small task given the author's estimate for 200 different existing theories on ball lightning. In the end, the author is turning to James Clerk Maxwell for an answer. The theoretical constructions that may be the basis for this phenomenon are relatively new, and so the book is timely in providing valuable new stimulus to both newcomers and professional scientists interested in solving this puzzle.

MIT
Cambridge, MA, USA
April 15, 2019

Earle Williams

Preface

It is interesting to look at the first few lines of the books on ball lightning. They usually start by referring to the first scientific study of ball lightning, which was published by the French scientist Arago in 1838 (Arago, 1838), showing that the subject has been around for a long time. Most of these books conclude with a hopeful sentence, stating that within a reasonable number of years, usually about 10, the author expects the problems concerning the physical nature of ball lightning to have been fully resolved. As it turns out, so far, these predictions have been much too optimistic. Ball lightning was and still is the most enigmatic form of atmospheric electricity. Arago's study is now 180 years old, but so far, there is neither an accepted theory nor a credible experimental study of these objects. Many scientists don't even believe it exists at all, due to its exotic properties.

So why should I write a new book on this apparently intractable subject? The answer is that I think it is no longer so intractable. In the 20 years that have gone by since the last book on ball lightning was published (Stenhoff, 1999), there has been a lot of progress in the understanding of lightning. Lightning location systems covering almost all regions of the globe are now in operation, giving us real-time information on the location and type of lightning occurring over land and also over the oceans. With the help of these location systems, a number of well-documented cases of ball lightning (or BL for short) have now been collected, giving us some hints on the circumstances under which these enigmatic objects appear and disappear and also allowing us to perform some thought experiments that could put theories about BL to the test.

Who is the intended audience of this book? There are two groups of readers, but people interested in BL with a basic knowledge of physics constitute

the main readership. I have tried to keep the explanations as simple as possible (but not simpler), so everybody with a high school background in physics and mathematics should be able to follow the story rather easily. On the other hand, I have tried to be rigorous in applying well-proven scientific methods to eliminate unrealistic hypotheses, with which the field of BL research is unfortunately rife, so the readers with a scientific background but with a little knowledge of the field of BL research may also profit from reading this book. The information on BL is scattered over a number of books, some of which are difficult to get hold of, and also over a huge number of publications. Given the competitive atmosphere in science, most scientists will have been unable to get an overview of the topic of BL, and the book aims to provide a focused treatment with them in mind.

I begin the book by presenting several BL observations which I have collected from family members, friends, and acquaintances and which show that this interesting phenomenon is not so rare as many people believe. I then take a look at the photographic evidence and discuss some of the videos available.

One important aspect is the relation between what could be called mainstream science and BL. We will see the way natural science normally proceeds when analyzing new phenomena, and this will make it very clear why BL is such a hard subject for science. Then, we shall do a bit of philosophy, looking at an important tool called (rather fancifully) "Occam's razor."

The next chapter gives a short review of the earlier work on BL, but I will not attempt to duplicate the content of existing books. Almost all aspects of BL research were perfectly well covered in Mark Stenhoff's book *Ball Lightning: An Unsolved Problem in Atmospheric Physics* (Stenhoff, 1999). Yet his book was published in 1999, and new information on both BL and lightning in general has become available since then.

Lightning research has progressed a lot over the last 20 years, and since lightning is clearly the only way to produce BL, a whole chapter is devoted to the physics of electrical discharges, while another gives an overview of lightning physics.

Armed with this knowledge, the reader will then be ready for the discussion of some well-documented cases of BL observations which will allow us to draw rather strong conclusions concerning the nature of these objects.

Since Arago's work, there have always been scientists who are skeptical about the very existence of BL. However, a closer look at their arguments will show that their alternative explanations do not take sufficient note of the observational evidence and are often at odds with "Occam's razor."

The next chapter contains a critical review of the most popular theories of BL. As with the alternative explanations by skeptics, a check against the observations will allow us to eliminate almost all theoretical models.

I firmly believe that we have little chance of finding out what BL really is unless we can produce it in a laboratory in a repeatable way. Therefore, some experiments to generate BL, both accidental and intended, are presented. We will also see that we can define some parameters that may well be relevant for the creation of BL objects.

The last chapter wraps it all up. Finally, the appendix contains 26 original reports of ball lightning and bead lightning observations, that are relevant to the discussion in the book.

In my work on ball lightning, I have received help from many people, and without their support, this book would not have been possible. Donald Bäcker, Katja Näther, and Sven Näther shared their treasure trove of information on the Neuruppin event with me. Dr. Stephan Thern from BLIDS (Siemens) supplied me with information on lightning strikes, both for the Neuruppin case and also for my bead lightning observation. Regarding more recent investigations, Dr. Diendorfer from ALDIS kindly gave me the lightning strike data. I must also thank Dr. Diendorfer, Dr. Keul, Dr. Ute Ebert, and Dr. Earle Williams for the interesting and stimulating discussions. Over the last few years, I have exchanged literally hundreds of emails with Wilfried Heil and Peter Kocksholt who are collaborating with me on BL investigations; they have supplied me with information I could not possibly have obtained myself. I also have to thank the people that allowed me to use their photos in this book, see the figure captions for details. And last but not least, I would like to acknowledge the help of many of my friends and acquaintances who have shared their observations of ball lightning with me.

Mainz, Germany Herbert Boerner

Contents

1

Introduction

My interest in ball lightning dates back 40 years. When I was a physics student, I traveled around Australia as a backpacker, staying in youth hostels. The place I liked most was called "Lost World Youth Hostel", close to Lamington National park in southern Queensland. It was there that I bought a book called "Green Mountains" by Bernard O'Reilly (1962), describing the search for the survivors of a plane crash in 1937, near the location of the youth hostel, and the pioneer's life in the rain forest on the border ranges between Queensland and New South Wales.[1] Bernard was obviously a brilliant observer of nature, and he gave accounts of many interesting events, including the total solar eclipse of September 1922. In these mountains, in November of the same year, he witnessed what he called an "electric thunderstorm", which produced a considerable number of BL objects: luminous balls, glowing in a deep red, like the embers of a log fire. When I read this account, I immediately got hooked on these mysterious objects, which I had previously regarded as extremely rare oddities. However, this report quite convincingly showed that, under the right conditions, ball lightning events can be produced in quite large numbers. This suggests that it may be possible to generate such objects in the laboratory, giving a real chance to study their properties in detail. Back at university, I talked to my professor, who told me immediately that it would be much more worthwhile to concentrate on my PhD thesis than such exotic stuff. Well, I followed his advice (or request, I should say) but I never forgot about Bernard O'Reilly's account.

Many years later, when I managed to get some free time (our children had grown up by then), I started to investigate other ball lightning reports and

[1] The O'Reilly family still runs a holiday resort in Lamington National Park.

H. Boerner, *Ball Lightning*, https://doi.org/10.1007/978-3-030-20783-0_1

I obtained literature on the subject. Around the year 2000 I stumbled across a particularly interesting case which had happened at Neuruppin in eastern Germany in 1994, where no fewer than 11 ball lightning objects were seen in a brief winter thunderstorm. This case turned out to be extremely well documented, first by the staff of the local meteorological station, and then by a couple who interviewed the witnesses about 1 year later. When I was able to obtain data about the thunderstorm from a lightning detection network, a completely new twist to the story emerged and—as you will see later—it helped to clarify several questions concerning these enigmatic objects. A few years ago, I retired, and since then I have been able to devote more time to my hobby. The book is organized around accounts of observations which are currently our only sources of knowledge on ball lightning.

2

Ball Lightning: Observers' Tales

Some Reports to Whet Your Appetite

There are more people who have seen ball lightning then one would think. It's not so rare at all. During the last two years, I have been talking about my favorite hobby to most of my friends and acquaintances, and I was surprised to find out just how many have seen such objects. The count now stands at 12, and I hope to be able to add more soon. So let's have a look at some examples. These accounts will explain what ball lightning looks like much better than I could. We start with a case associated with the most enigmatic circumstances, because it took place in a modern all-metal plane.

"It was certainly before 1992, but I cannot remember the exact year. I was working as a flight attendant for BA, flying on a BAC One-Eleven. We had reached our cruising altitude and we three (me and my two colleagues) were standing in a circle in the small kitchen in the front of the airplane, me with my back towards the cockpit, when suddenly a bright golden sphere of about 40–50 cm diameter appeared amongst the three of us. I think it appeared just there, but it might also have come from the cockpit. It shot down the aisle towards the rear of the plane. We three saw it for sure, but I cannot remember if any of the passengers saw it as well. There cannot have been a thunderstorm outside, because then we would have been sitting with the seat belts fastened. I was sure that this was ball lightning, because when I was a little girl, I had already seen ball lightning. I was outside, fetching something for my father on a thundery day, with sheet lightning, when about 50 m away to the right a golden ball of maybe 1.5 m diameter appeared, moving fast in my direction."

Two acquaintances told me the following story:

H. Boerner, *Ball Lightning*, https://doi.org/10.1007/978-3-030-20783-0_2

"It was in Patagonia in 2008. Our car was standing on a dirt road on the Valdez peninsula. There was a thunderstorm going on, with lightning in the clouds but no lightning to the ground. There was no rain falling near the car. Suddenly a yellow ball of about 20 cm diameter fell vertically from the sky, hit the ground about 2 m away from the car, passed underneath it and hit a bush 100 m away, which burst into flames". My acquaintances were absolutely sure the bush was on fire after the ball had vanished.

Recently, I asked a good friend of mine about ball lightning and I was quite surprised to hear that she also had a story to tell:

"We—me and a friend of mine—were standing at the window watching the clouds and the frequent lightning of an unusually strong thunderstorm. The house was on a hill above the town, on a road leading downhill towards the center. Suddenly a yellow ball appeared on the road, moving fast downhill, faster than a car. Its intensity was blinding, it had a diameter of at least half a meter and its outer surface was not sharp, it looked like frayed or sparkling. It followed the road like a bicycle. I remember it clearly because we quarreled about where precisely it had vanished on its race downhill. I was about 12 or 13 years old and it was in a town called Gunzenhausen in southern Germany."

Last but not least, my mother-in-law had also seen one of these objects:

"I was living in a small village north of Berlin. On the afternoon of a hot summer's day in 1934 or 1935 I was swimming in the lake close to the village, when a thunderstorm came up. I rushed home on my bicycle, but the storm was quicker and rain and thunder caught up with me. On the right side of the rough village road was a fenced meadow. Suddenly, after a loud thunderclap, a bright red or orange/yellow ball approached me, rolling along the top wire of the fence. This round lightning was much smaller than a football, and its surface was not smooth, but it had many spikes which emitted sparks. I hasted home to tell my parents what I had seen. My father said it must have been ball lightning."

All these reports are typical of ball lightning observations. Usually these "balls of fire" are seen in a thunderstorm, but there are exceptions. In the accounts above, the ball lightning objects appear in the open, but they are often seen inside houses. This leads to some of the most puzzling reports, like those I collected from the Neuruppin case (which I will explain in detail below):

"I was sitting in my favorite corner of the living room, with my daughter playing around near the armchair. Suddenly, there was a bright light between me and the child. At first, I thought that the child had been playing with the camera, which was lying on the armchair, but she looked at me with a frightened expression. From the hallway, my husband was also looking at the light

with a stunned expression. It lasted only 1–2 seconds. It was directly over the floor, oval-shaped, like a large egg, and about 1 m long. In the middle it was blue and around the outside it was very bright. It didn't move…. Nothing was damaged. Outside it started to rumble and then there was a very loud bang." The son saw a similar object in a neighboring room, but it was of a yellowish color.

"I was sitting in the corner of the room, reading a newspaper. Suddenly something swished past me, coming through the closed window. The net curtains were closed, but the main curtains were open. The object had the size of a small glass lampshade and looked like a yellowish light bulb. From the window it moved to the opposite side of the room along the cupboards to my left, then it made a U-turn and came back straight towards me, but luckily it didn't touch me. It passed me at a close distance and went back out through the window. […] Its movement was very swift. It hissed, and the room was more brightly lit than by sunshine. […] I did not hear any thunder. The curtain was undamaged, as was the TV set."

The ball lightning in the first report appeared inside the house basically "out of thin air". It didn't move and was gone quickly without leaving a trace. In the collection of sightings from Neuruppin, there is another case like this, and reports from other sources confirm this observation. In the second report, the object entered through a closed window and a curtain, made a round trip of the room, and went out through the window again. Such a behavior is fairly often reported. When someone who has not seen ball lightning hears such reports for the first time, the reaction is often "this simply cannot be true, such a thing cannot exist". The reaction of most physicists is similar, and even more vehement, but they also have some arguments to support their point of view, as we will see later. On the other hand, witnesses are often perfectly trustworthy (as is the case for those quoted above), so we can exclude the idea that they were simply inventing a story to puzzle the scientific community. But what did they see then? Was it really something physical or was it a hallucination? Or something preternatural, as some people claim?

Did They Really See Ball Lightning or Was It Something Else?

Several other natural phenomena have characteristics that may appear similar to the objects in the accounts given above. In the nineteenth century or earlier, meteorites were often confused with ball lightning. When meteorites

enter the atmosphere, this sometimes produces brilliant fireballs that travel for hundreds of kilometers before exploding. We now understand the origin of these bolides, but this was not known before the beginning of the nineteenth century, and initially it was not widely accepted. In fact, Thomas Jefferson is supposed to have said: "I would rather believe a Yankee professor would be lying than stones would fall from the sky".

Bolides vanished from the ball lightning reports at the beginning of the twentieth century when their origin was clear, but then another and more serious source of confusion appeared: electrical power lines. When lightning strikes power lines, electrical arcs may appear at various points along the line, for example, across insulators or at over-voltage arresters. These arcs can be very bright and may sometimes look more or less spherical, especially if viewed from a distance. There is one photo of such an arc producing a luminous mass of air which was blown away by the wind and could be seen for a few seconds (Stenhoff, 1999).[1] Some storm chasers call these arcs "flashballs". When they are not insulated, the bare wires of power lines may also touch and produce arcing between the different phases. These arcs can travel along the lines for some distance. Quite spectacular videos of such events can be found on the net, often erroneously labeled as "ball lightning observations".

Normal lightning can also adopt strange shapes which may mimic a more or less spherical source of light, but this is quite rare, and it only applies to objects that appear high in the sky.

Since WWII, aliens would appear to be visiting us in their spacecraft in amazing numbers. Of course, the alleged observation of UFOs has been linked to ball lightning and vice versa. Yet there is a fundamental difference between UFO and ball lightning observations: whereas the ball lightning objects have a quite consistent description, the UFOs seem to appear in a bewildering variety of forms.

When we compare the reports above with these possible sources of misidentification, it is clear that none of the cases can be attributed to them. Neither bolides nor high-voltage arcing can be held responsible for the observations. But is there something else that we might have missed? People interested in ball lightning have compiled a list of additional phenomena that could be the culprit (Stenhoff, 1999), but basically none of them could possibly be linked to our reports except one: corona discharge or St. Elmo's fire. In order to explain what this is, I can supply an observation of my own. Unfortunately, so far, I have never seen ball lightning, but I was once lucky

[1] A more recent example of multiple "flashballs" can be found here: http://foudre.chasseurs-orages.com/viewtopic.php?t=6313&highlight=

enough to observe St. Elmo's fire. In early October 1980, I visited Santorini island in the Aegean Sea. For almost a week the weather was perfect, but in the morning when I was about to fly back to Athens, a cold front approached the island from the north. I was waiting for the bus to the airport at a small road in the countryside when I saw a dark and ominous shelf cloud approaching at great speed. Lightning fell from it onto the countryside below. I hoped that the bus would arrive before the thunderstorm, but the clouds came faster. Just before the shelf cloud was overhead, I heard a strange humming noise. Looking up, I saw yellow bundles of flame on the insulators of a power line. They were dirty yellow in color, writhing around and humming and hissing. I knew what it was and that it signaled the existence of a very high electric field produced by the thunderstorm clouds, threatening me with a close lightning strike. I looked for shelter, but the house nearby was locked, and its entrance porch provided only very little protection. Seconds later, torrential rain came down, and the flames slowly went out. I was soaked through by the rain and I missed the bus, but since the flight was several hours late due to the bad weather, I did not miss the plane.

Electrical discharges like this are often seen in places where the electric field in the atmosphere is very high. These discharges are observed at sea, in particular, where a ship is the largest object above the waves for many miles around. Sailors, being eminently superstitious, regarded them as a sign from heaven indicating that the worst of the thunderstorm was over, but this would appear to be a misconception, because they clearly indicate that the electric field of the thunderstorm is still very high. Airplanes also sometimes display this phenomenon.[2]

This type of discharge is clearly related to the electric field created by the thunderstorm. The color is usually blue,[3] but in my case, the insulators may have been contaminated with salt from the sea nearby, giving the yellowish appearance due to the sodium vapor present in the discharge.

In several books or publications on ball lightning, it is claimed that this discharge can be confused with BL because it takes the form of a glowing ball. I would tend to disagree with this statement, since I have not been able to find a single description of such an observation in which corona discharge actually takes this form. Corona discharge is always described as consisting of a bundle of filaments, called streamers, emanating from sharp points of objects, usually

[2] Many images on the web alleged to show St. Elmo's fire on cockpit windows are actually discharges on the surface of the window and not a corona discharge.

[3] The blue color is due to excited nitrogen molecules in the air.

conductors. A discharge like this can only take the form of a sphere if it is starting from a round conductor like a door knob, or something similar.

At this point, readers will probably ask themselves whether there is any independent evidence of the existence of BL, like photos or videos, which can resolve the problem. And if so, why doesn't he show it? Indeed, there are photos and videos, but few are clearly authentic, and they do not show all the known features of BL.

Summary

- I am surprised how many of my friends and acquaintances have seen BL. The reports are from people I can trust, so there are no "fake reports".
- Confusion with other natural phenomena like St. Elmo's fire can be excluded in all these cases, since St. Elmo's fire clearly differs from what is reported as BL.
- Up to the nineteenth century, bolides streaking across the sky were confused with BL.
- In the twentieth century, arcing at high voltage lines became a new source of confusion.
- Since the end of WWII, UFO sightings abound and some of them may be due to BL objects.

3

The Search for Photographic Evidence

The search for photos or videos of ball lightning is an endless story of confusion and obfuscation, starting basically with the widespread availability of cameras and photographic plates in the early twentieth century and continuing up until today with powerful video recorders at everybody's fingertips. When photographers tried to catch photos of normal lightning, they discovered a technique which is still used even now: one must do it at night and keep the shutter open until lightning appears in the field of view of the camera. When the camera is fixed on a support like a tripod, everything is fine, but when one has no stable support, the camera will shake and move. In this case, street lights will create luminous traces on the film, but lightning is a very short phenomenon and will appear crisp. You can see this in the photo below (Fig. 3.1) which I took leaning against a pole: the lightning is quite sharp, but the street lights below leave jumbled traces because my hand holding the camera was shaking a lot.

The inexperienced photographers of around 1900 first interpreted these traces as tracks produced by moving ball lightning, and it was only after considerable debate that the correct interpretation was accepted. Unfortunately, books on ball lightning often waste a lot of effort on discussing this type of "evidence". The first photographs which are completely compatible with ball lightning are from an automated camera system called "Prairie meteorite network". This was a network of 16 cameras spread out over seven prairie states in the United States: every night they would automatically take photos of the sky in order to record traces of meteorites. The cameras had shutters closing periodically at 16 1/3 Hz, so tracks produced by meteors appeared as "dotted" lines, making it possible to measure the velocity of these objects. With more

H. Boerner, *Ball Lightning*, https://doi.org/10.1007/978-3-030-20783-0_3

Fig. 3.1 Photo of linear lightning with traces of street lights at the bottom. From the author

than one photo of such a track, triangulation was possible, and the end point of the track could be estimated. In almost 10 years of operation, only one meteorite was found by this method, so its efficiency was not really convincing. Nowadays, professionals[1] and also many amateurs[2] chase meteorites with much better electronic cameras, and they are also much more successful. For us the important thing is that the cameras took photos every night, regardless of the weather, so they also produced a considerable number of lightning photos. About 14,000 of these images were analyzed with about 120,000 lightning tracks (Tompkins and Rodney, 1980), looking for signs of ball lightning. The result was two candidates for ball lightning and 22 for bead lightning. Images of airplanes, cars, and firework rockets launched on Independence

[1] See https://fireballs.ndc.nasa.gov/

[2] http://www.meteorastronomie.ch