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Astronomical fire: Richard Carrington and the solar flare of 1859

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An explosion on the Sun in 1859, serendipitously witnessed by amateur astronomer Richard Carrington, plunged telegraphic communications into chaos and bathed two thirds of the Earth's skies in aurorae. Explaining what happened to the Sun and how it could affect Earth, 93 million miles away, helped change the direction of astronomy. From being concerned principally with charting the stars to aid navigation, astronomers became increasingly concerned with what the celestial objects were, how they behaved and how they might affect life on Earth.

The flare

At 33, Richard Christopher Carrington was already an accomplished young astronomer. He possessed a first-class education from Trinity College, Cambridge; had compiled a much-needed star catalogue that drew praise from all; and worked tirelessly as an unpaid ambassador for the Royal Astronomical Society (RAS). Then, on the morning of Thursday 1 September 1859, he found himself 'flurried by surprise' as he became 'an unprepared witness' to a celestial cataclysm [2].

He was working in his grandly appointed private observatory at Redhill, Surrey (Figure 1). At the sight of that morning's clear sky he had hurried into the dome, cranked up the shutter and prepared the beautiful 2-m-long brass telescope for action. He had followed the same routine since 1853, having resolved to make a long-term study of the Sun and the unexplained sunspots that speckled its surface [3].

Manoeuvring a distempered board into position, he aligned the telescope so that it threw the Sun's image onto the straw-coloured screen. Poking the front-end of the telescope through a made-to-measure hole, he slotted a larger board into position around the telescope, throwing a shadow across the board, allowing him to see the Sun's 11-in.-wide image clearly. Two gold wires, beaten into slivers and strung inside the telescope's eyepiece cast a diagonal crosswire on the image. Using the lines as position guides, Carrington set about sketching the entire face of the Sun, employing his draughtsman's skill to produce a lasting document of the exquisite surface details.

That day was special because he could see an enormous sunspot complex. No one knew what these blotches were. Some thought them openings in the bright clouds of the Sun or mountaintops occasionally revealed by a shifting atmosphere. The complex that Carrington gazed upon was huge beyond imagination. From tip-to-tip it was almost 10 times the diameter of the Earth. Yet on the Sun, it barely stretched a tenth of the way across the fiery disc. By eighteen minutes past eleven, he had finished the drawings and was now listening to the tick of the chronometer, recording the precise moments at which the various sunspots slipped beneath the crosswire. He would later use the timings to perform some elaborate mathematics to calculate the exact positions of the sunspots.

Without warning, two beads of searing white light, bright as forked lightning but rounded rather than jagged and persistent instead of fleeting, appeared over the monstrous sunspot group. Surprised, Carrington assumed that a ray of sunlight had found its way through the shadow-screen attached to the telescope. He reached out and jiggled the instrument, expecting the errant ray to zip wildly across the image. Instead, it stayed doggedly fixed in its position on the sunspot group. It was not some stray reflection; it was coming from the Sun itself. As he stared, dumbfounded, the two spots of light intensified and became kidney-shaped.

His scientific training switched on instantly and he noted down the time. Then, realising the rarity of the situation – certainly no one had ever publicly described the Sun behaving like this before – he hastened to find a witness.

Carrington's report of the event [2] does not make it clear whether he found anyone or not but upon his return, not 60 seconds later, his excitement turned to mortification as he saw the strange lights straddling the sunspot were already greatly enfeebled. Nevertheless, they were still visible and he watched them drift across the giant spot, contract into mere points and abruptly vanish.

He noted the time again, 11 h 23 m Greenwich Mean Time, sketching the position of the lights' appearance and disappearance (Figure 2). Staggered by what he had seen, he rooted himself to the telescope for over an hour but his vigil was to no avail; the Sun had returned to normal. He could see no indication that the strange phenomenon had ever taken place. The Sun's surface surrounding the spot and the details of the spot itself remained exactly as they had before the phantoms appeared.

Later, Carrington set to work on the maths. The lights had lasted but five minutes, yet he discovered they had traversed 35,000 miles (nearly four- and-a-half times the diameter of the Earth). To do that, the disturbance must have moved at around 420,000 miles/h. Such a staggering

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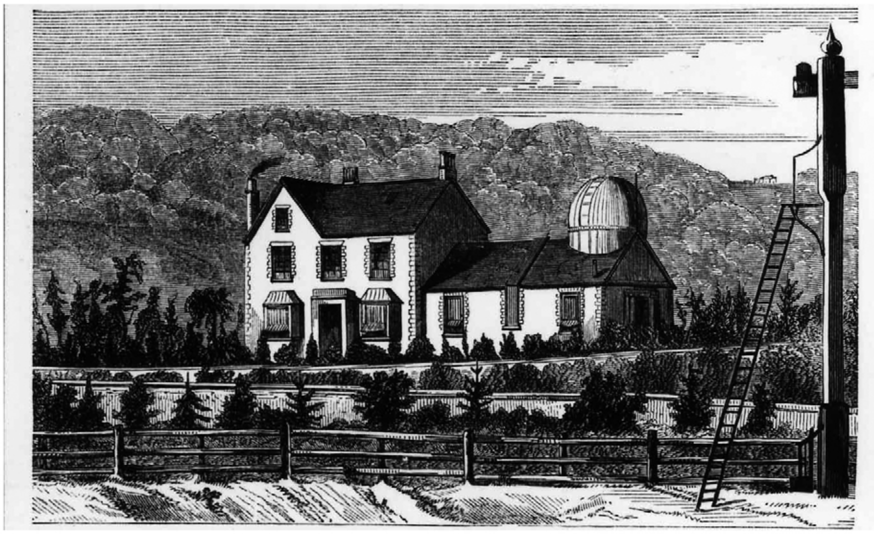

Figure 1. Richard Carrington's manor house with adjoining observatory at Redhill, Surrey. It was from here that he witnessed the solar flare. Reproduced, with permission, from the Royal Astronomical Society.

speed must have strained even Carrington's belief; the Victorians were still getting used to steam trains chuffing their way to 50 miles/h. Judging by the extent of the flare on his sketch, the original fireballs had each been about the size of the Earth.

Carrington would have known that such a momentous observation demanded a wholly independent scientific corroboration if his peers were truly to believe him. The perfect place would be the Kew Observatory, where his friend and RAS colleague, Warren de la Rue, was engaged in an experimental project to photograph the Sun every clear day (Figure 3). Carrington would need to visit Kew as soon as possible.

The aurora

That night, about 18 hours after Carrington's observation, the Earth's atmosphere erupted with aurorae, engulfing two thirds of the entire planet's sky [4] (Box 1). Amongst

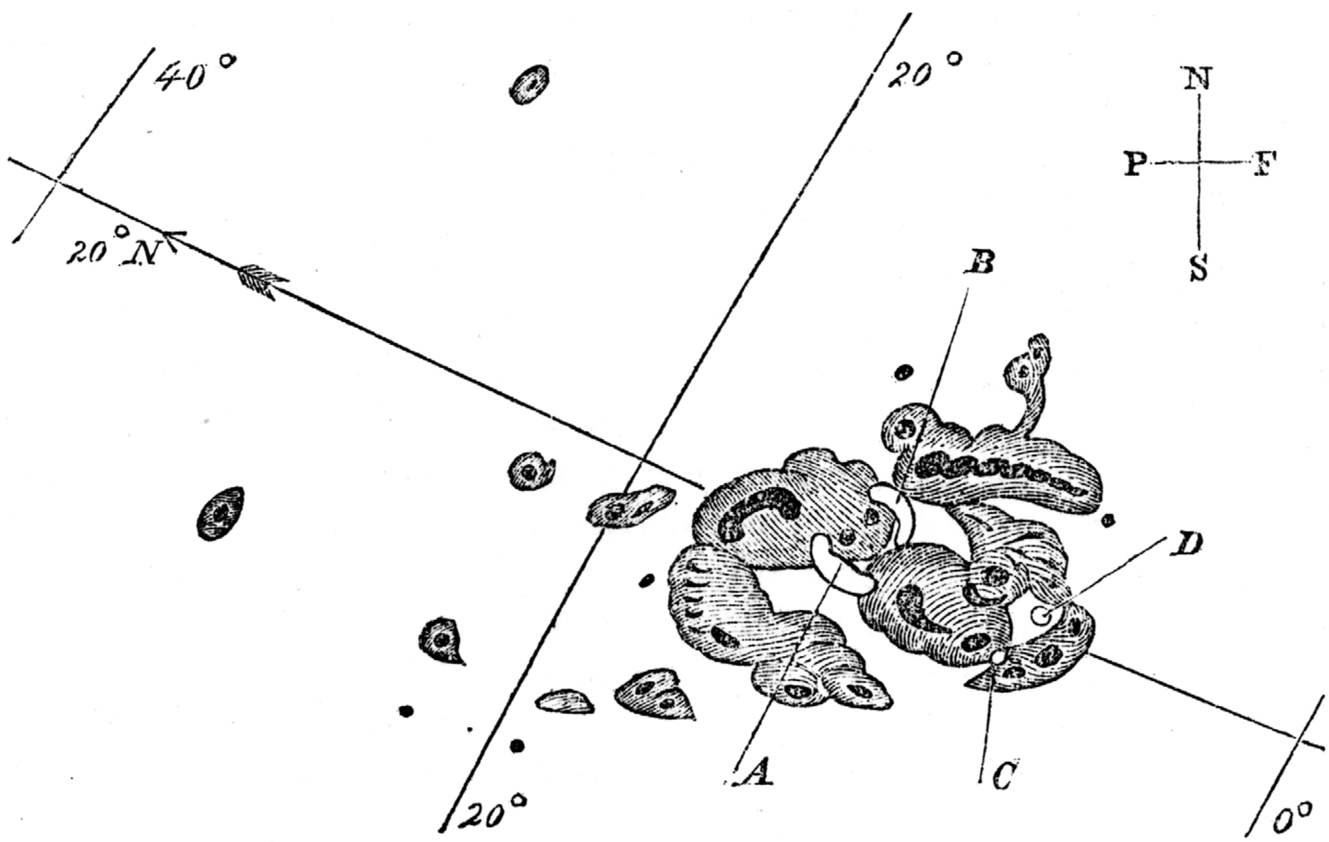

Figure 2. Richard Carrington's sketch of the solar flare taking place above the sunspot group on 1st September 1859. 'A' and 'B' represent the positions in which the two kidney-shaped spots of light appeared. 'C' and 'D' show the place where the shrunken lights disappeared. Reproduced, with permission, from the Royal Astronomical Society.

Figure 3. Warren de la Rue, to the left with his back turned, and the Kew photoheliograph. This picture was taken when the team from Kew observatory transported the instrument to Rivabellosa, Spain, in order to photograph the total eclipse of 1860. Reproduced, with permission, from the Royal Astronomical Society.

the first to witness the spectacle were those on the clipper ship *Southern Cross*, These two will then be consistent in style with 84 days out of Boston on its way to San Francisco [1,15]. It was at 1:30 in the morning, fighting a tremendous gale off the coast of Chile, when Captain Benjamin Perkins Howe and the ship's company sailed into a living hell. Hailstones from above and waves from all around whipped the deck. When the wind-lashed ocean spray fell away to leeward, the men noticed they were sailing in an ocean of blood. Lifting their eyes skyward, they saw the reason. It was obvious, even through the clouds: the heavens were wreathed in an all-encompassing red glow. 'The whole heavens were of a deep red, which color was reflected from the ocean' [11].

The sailors recognised the lights as the southern aurora that usually graced the skies near the Antarctic Circle, just as their northern counterparts clung to the Arctic. To see them from this far north was highly unusual and should have been a treat but maintaining their faltering control over the ship robbed the crew of the opportunity to appreciate the spectacle.

As the maelstrom intensified, they noticed other strange lights clinging to the ship itself, creating haloes around the silhouettes of the mastheads and yardarms. These new

Box 1. Aurorae

Aurorae manifest themselves in various forms, nowadays denoted by specific terms. Proceeding in order of increasing magnificence and sky coverage, the first hints of a display can often be a mild *glow*, hugging the horizon. Bright *patches* (sometimes called *surfaces* by scientists) can also appear; sitting like luminous clouds. Next is an *arc*, stretching like a fluorescent basket handle. *Rays* are sure signs of strengthening auroral activity, often born from arcs and reaching upwards like ragged picket fence posts. The crowning glory is when the entire sky is wreathed in celestial fire. Then, a structure called a *corona* appears in which rays from all around the sky converge to a point. It is a rare sight outside the polar latitudes and is the hallmark of exceptional activity. Aurorae come in different colours. Generally, red hues come from interactions with oxygen atoms taking place at higher altitudes than those producing green tones. Purple and violet emissions, sometimes described as blue, derive from the atmosphere's nitrogen atoms.

wraiths were also familiar and just as inexplicable. Sailors knew them as St Elmo's fire. The usually blue-white light often accompanied ships during extreme thunderstorms, but on this night their pallid glow had been stained the same roseate hue as the heavens above.

During a temporary lull, they witnessed an even more astonishing display. 'Mysterious lights were seen shooting up in spiral streaks nearly to the zenith now flashing out with meteoric brilliancy, and now looming up against the horizon, as with the blaze of some terrible conflagration', wrote one eyewitness [11].

The storm finally abated at dawn when the attendant sunlight drove the aurora from the sky. Upon their arrival at San Francisco on 22 October, Captain Howe and the ship's officers swore that they had never seen anything as magnificent as the 2 September auroral displays. They discovered that theirs was not an isolated experience (Figure 4). In Cahawba, Alabama, for example, Dr Matthew Troy reported that 'The aurora was first observed about 1 a.m. An arch spanned the heavens from E. to W. a few degrees south of the zenith. To the north the sky had a distinct greenish tinge. The most magnificent displays of colored light were nearly overhead. The light was so great that fine newsprint could be read by it; and it continued with varying brilliancy till obscured by daylight' [8]. Most accounts attested that the aurorae were chased from the sky by the daybreak, although some had the spectacle brought to a premature end by the appearance of rain clouds [7–10,12,13,16].

The cause of these glorious displays remained a mystery. Back in 1741 Olof P. Hiorter, a Swedish graduate student under the tutelage of Professor Anders Celsius (after whom the centigrade temperature scale is also known) had noticed a pronounced disturbance in compass needles whenever an aurora was overhead. So the aurora was somehow magnetic but, beyond that, people knew very little. That all changed the day Carrington walked into the Kew Observatory in Old Deer Park, Richmond.

The magnetic storm

No one at Kew had seen the solar flare or photographed the Sun that day, unfortunately. However, the magnetic instruments had captured the disturbance. Each consisted of a compass needle hung on a silken thread in a darkened room. The needle pointed north, corralled by Earth's magnetic field. Any change in the field resulted in movement recorded as a ray of light shone onto the reflective needle, from where it bounced onto a slowly rotating drum. Around the drum was fixed a curve of photographic paper. Every day at 10 a.m., the Kew technicians changed this paper, which snailed round at just three-quarters of an inch per hour so that 24 hours later, it had produced a tracing 18-inches. long. Any disturbance of the Earth's magnetic field showed as a jagged line.

Carrington was shown the scroll for 1 and 2 September. Despite the restricted scale of the tracing, the Earth's magnetic field had obviously recoiled, as if struck by a magnetic fist, at exactly the same time as he had seen the flare. The abrupt part of the disturbance had lasted just three minutes but it had then taken seven to die back down to normal. Providing they were not being fooled by mere coincidence, it seemed that Carrington's flare had somehow reached out across some 90 million miles of void and struck the Earth. They were not just sharp jabs, either. Eighteen hours after the initial disturbance, the Kew needles again started moving, surpassing the strength of the deflection at 11:20. This time, instead of a single punch, the Earth began to suffer a sustained assault that surpassed anything seen at Kew since it began collecting data decades earlier. In fact, on the day Carrington stood in Kew, the needles were still uneasy. The magnetic storm, although diminished, had by no means subsided [14].

As darkness fell on the evening of 2 September, the aurorae were still raging, finally affording Europeans a view of the unprecedented light show. Dozens of reports filtered in from around the globe, lending weight to the suspicion that Earth had been subject to a celestial event of enormous proportions. And Richard Carrington may have witnessed its birth. But could anyone actually back up his story of the tumultuous outburst? No matter how eloquently, diagrammatically or mathematically he described what he had seen, there would undoubtedly be sceptics. That was the nature of science – no acceptance without proof – and the more extraordinary the claim, the more extraordinary the proof required.

Carrington did have one asset: his reputation. He was known for his meticulous attention to detail. Even the Astronomer Royal, George Airy, consulted him on the precision of observations taken from the hallowed domes of Greenwich.

The aftermath

The beguiling lights had disabled the telegraph system, wiping out communications across the world. Business depended on the telegraph for trading stocks and shares, governments relied on it for intelligence and news, and individuals used it to keep in touch with loved ones. For days after Carrington's flare, nature refused to allow these arteries of information to flow freely. Worse still, the aurora also presented a danger to life and limb. In Philadelphia, a telegrapher was stunned by a severe shock whilst testing his communications equipment. The stations using a chemical system marking sheets of paper were put in the gravest danger when the currents surged powerfully: the paper caught fire, engulfing the stations in

Figure 4. An engraving of the aurora used to illustrate an article by Elias Loomis in *Harper's New Monthly* magazine, 1869. Loomis collected together many of eyewitness observations from the aftermath of the Carrington flare. Reproduced with permission from Stuart Clark.

choking smoke. In Bergen, Norway, the aurora conjured such strong electrical currents that operators had to scramble to disconnect the apparatus, risking electrocution to save the equipment.

As networks of communication became reestablished, the astronomical grapevine began to circulate with Carrington's claims and a second astronomer – Richard Hodgson, Esq. of Highgate – soon came forward with supporting evidence. Hodgon, himself a Fellow of the Royal Astronomical Society and the inventor of a special eyepiece that screened out the Sun's fearsome light, was a credible source, and the revelation that he too had observed 'a very remarkable phenomenon' during routine observations of the Sun on 1 September was of considerable interest. Carrington insisted that they exchange no further information until the next appropriate meeting of the Royal Astronomical Society when they would independently describe what they'd seen.

On 11 November 1859, the Fellows of the Royal Astronomical Society gathered in anticipation at Somerset House, London. They listened with rapt attention as first Carrington and then Hodgson offered their accounts. Carrington showed an enlarged copy of the precision drawing he had made on the day and lodged the artwork at the society's rooms, so that absent members could inspect it at their leisure. Taking his place in the audience, he listened as Hodgson told his story, anxious to learn whether their accounts would tally.

In broad agreement with Carrington, Hodgson told how he had been 'suddenly surprised at the appearance of a very brilliant star of light, much brighter than the sun's surface, most dazzling to the protected eye, illuminating with its light the upper edges of the adjacent spots, not unlike in effect the edging of the clouds at sunset . . .' [5,6]. His timings matched Carrington's. However, Hodgson confessed that his surprise – and the fleeting nature of the outburst – had prevented him from making an accurate drawing. Instead, he had executed a sketch. It too was left behind for private inspection after the meeting and it was noted in the editorial comments of the Society's journal that it was a well-executed drawing, exciting much interest at the meeting. For unknown reasons, though, the journal did not reproduce it alongside Carrington's and it now seems lost.

At the end of the discourses, no Fellow could be in serious doubt that something unprecedented had taken place on the Sun or, more likely, just above it, for Carrington had convincingly argued that since the Sun's surface had displayed no difference before and after the event, the flare must have taken place high above the sunspot group. As for the putative link between the flare and the aurorae, there was considerable debate. Both men had mentioned these two features; Carrington even showed photographs of the Kew charts, pointing out the magnetic jolt at the time of his flare and drawing attention to the subsequent and incredibly powerful magnetic storm that coincided with the aurorae. He thought it important, but he remained a paragon of scientific scepticism, cautioning his audience that whilst the simultaneous occurrence may deserve further consideration, 'One swallow does not make a summer' [3].

Carrington's caution

One reason for Carrington's overt caution was that no one could conceive of a mechanism by which the Sun's explosive force could be conveyed to Earth. If the link were real, it would require new physics and Carrington was not about to commit the classic amateur blunder of drawing a mammoth conclusion from a single, solitary example.

The Director of the Kew Observatory, Balfour Stewart, was in no doubt, however. When he presented an analysis of the Kew results to the Royal Society in 1861, he told them that in recording the signal in 1859, 'our luminary (the Sun) was taken in the act' [14]. History has proven him right.

With the luxury of a century and a half's hindsight, we can now see that Carrington's and Hodgson's discovery of the solar flares was a tipping point in astronomy. We now know that the suddenly release of pent-up magnetic energy in a solar flare has the ability to fling billions of tonnes of electrically charged gas off the Sun, into space. When this collides with Earth, it sets the Earth's magnetic field ringing like a bell, which in turn can induce electrical currents to flow along any long conducting piece of metal.

In 1859, none of this was known and the sudden demonstration of the Sun's ability to disrupt life on Earth catapulted astronomers into a headlong race to understand the nature of the Sun. In the same year, Robert Bunsen and Gustav Kirchhoff made their breakthrough in the analysis of light given off by a gas to betray its composition, giving astronomers the means with which to investigate the Sun's composition.

Gradually the emphasis of astronomy changed from charting the stars for navigation to understanding their physical nature, and traditional astronomy began its transformation into present-day astrophysics.

Acknowledgement

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