Boris R. German

A NEW LOOK AT THE CARRINGTON EVENT:

Comet Biela and Andromedids

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PREFACE

Despite the historic solar white-light flare observed on September 1, 1859, by R. Carrington, the influence of coronal mass ejections and solar energetic particles on Earth is not supported by the levels of nitrates and cosmogenic nuclides in fallout dating to 1859.

However, the intersection of Earth with the secondary comets and Andromedids meteors that arose after the breakup of Comet 3D/Biela in the 1840s explains the geomagnetic disturbances and auroras associated with the Carrington Event in August/September 1859.

The impact of cometary materials on Earth is rarely investigated because of limited observations. This study partially fills the gap.

For specialists in the physics of comets and meteors, solar flares, and planetary magnetospheres, as well as the general readership.

Freiburg, February 2026

Boris R. German

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INTRODUCTION

It is known that the historical Carrington Event occurred from August 26 to September 7, 1859, during which the strongest geomagnetic disturbance, low-latitude auroras, and ignitions along long telegraph lines in Eurasia, America and Australia were observed (Stewart 1861, p. 424). Extreme geomagnetic storms were recorded twice: on August 28 and September 2, 1859.

To date, researchers believe that the Carrington Event was caused by solar flares and two interplanetary coronal mass ejections (ICMEs) that impacted Earth. The flare on September 1, 1859, observed visually by R. Carrington and marked by a magnetic crochet trace (a characteristic 'hook' on the magnetogram), was identified as a solar white-light flare, i.e., with radiation in the continuum spectrum.

However, at the same time in 1859, astronomers expected observations of the Andromedids meteor shower and two secondary comets, which appeared together after the breakup of the 3D/Biela Comet in the 1840s. As is now believed, they were not observed due to poor weather. Nevertheless, published evidence indicated that the 1859 Carrington Event, with a high probability, was linked to the Andromedids and/or secondary comets of Comet Biela.

The 3D/Biela Comet, which has an orbital period of about 6.7 years around the Sun, belonged to the Jupiter family of comets and was independently discovered by astronomers J. Montaigne and C. Monsieur on March 8, 1772. Then Comet Biela was observed by J. Pons on November 10, 1805, and rediscovered again on February 27, 1826, by W. Biela. A meteor shower was also discovered along the orbit of the 3D/Biela Comet. Astronomer E. Herrick concluded that the 1838 radiant these meteors should be located near the Cassiopeia constellation or, more likely, the vicinity of the Perseus' sword cluster (Newton 1886, p. 423).

A close approach near Jupiter caused a gradual decrease in the longitude of the ascending node of the 3D/Biela orbit. As a result, the radiant of the meteor stream shifted to the γ-star (Alamak) in the Andromeda constellation, where it remains to this day as the source of the Andromedids meteor stream.

On December 19, 1845, the nucleus of Comet 3D/Biela was observed to be splitting, and on December 31, 1845, this process was complete. In mid-January 1846, astronomer M. Mori reported that the nucleus had disintegrated into two parts, so-called 'A' and 'B'. Each of them was a separate comet with a nucleus, coma, and tail (Fig. 1). Still, the 3D/Biela Comet was probably divided into a larger number of fragments[1], as the connecting arch was clearly traced be-

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1 In this book, I use the term 'fragments' to refer to both the large secondary comets 'A' and 'B' and the Andromedids

tween the two main parts. The 'A' secondary comet in 1846 appeared *diffuse and had as many as five multiple nuclei*.

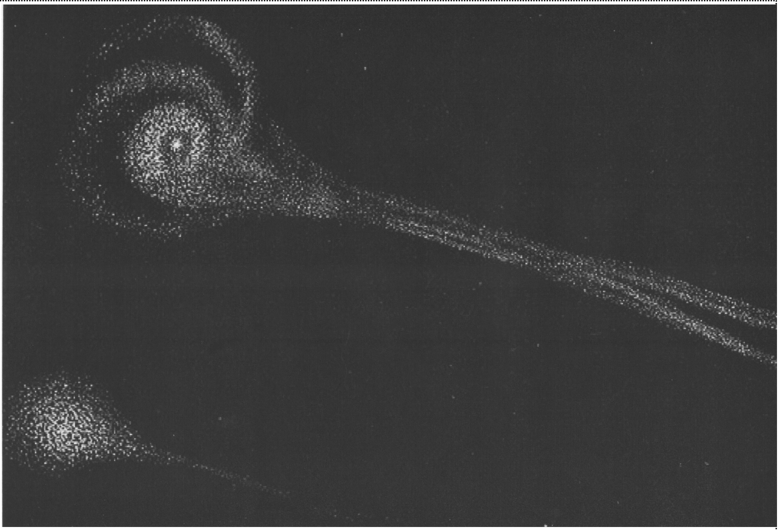

Fig. 1: Two secondary comets, 'A' and 'B', immediately after the disintegration of the parent Comet 3D/Biela in February 1846.

Source: adapted from Weiß, E. (1888): Beitrage zur Kenntniss der Sternschnuppen. In: Bilderatlas der Sternenwelt I: 11. (in Deutsch). A translation: Contributions to the knowledge of shooting stars. In: Picture Atlas of the Starry World I: 11.

Moreover, Hawkins et al. (1959, p. 183) assumed two different Andromedids streams: from 1741–1847 and from 1850–1899. When and where did they move? The appearance after the disintegration of the 3D/Biela Comet, its sec-

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meteor shower, since they appeared together after the disintegration of 3D/Biela in the 1840s.

ondary 'A/B' comets on August 26 and September 15, 1852, practically coincided with similar dates of geomagnetic storms from August 26 to September 7, 1859. Therefore, these secondary comets could have acted in August–September 1859, resulting in the intense geomagnetic storms and low-latitude auroras during the Carrington Event (German 2025g, #0008).

Since the Mazapil iron meteorite fell and was immediately discovered in Mexico on the day of the maximum of the Andromedids shower in 1885 (Hidden 1887, p. 221), the Comet Biela could have contained magnetic metallic fragments. Therefore, the movement of magnetised particles of meteors along the force lines of the geomagnetic field could cause effects indistinguishable from those created by particles of the solar wind. These include penetration into the magnetosphere/atmosphere from the north and south magnetic poles, as well as the initiation of auroras and induced telluric currents (GIC).

The absence of Andromedids activity in 1878 was estimated as the spread of the trail of comet 3D/Biela by no more than 40% of the length of its orbit. Later there was a gap of 7 years between the Andromedids of 1892 and 1899, and about 5 years between the Andromedids of 1899 and 1904 (Denning 1905, p. 853). This indicated a more significant differentiation over time of the remnants of the broken 3D/ Biela Comet along its orbit.

Nowadays, the Andromedids are observed from September to December. The main source of meteors is numerous filaments formed due to significant changes in the comet's orbit. If, on November 27, in both 1872 and 1885, there were several thousand meteors per hour (Fig. 2), then now, in the region of November 14, the Andromedids are only a weak stream with a maximum activity of fewer than 3 meteors per hour.

Fig. 2: The falling meteors on 18 November 1872 in Paris.

Source: adapted from Flammarion, C. (1894): Popular Astronomy: A general description of the Heavens, p. 534, Fig. 231.

A correct interpretation of the Carrington Event is important in light of the debate about the threats to terrestrial civilisation. However, the current hypothesis that the 1859 Carrington Event had an entirely solar origin faces significant difficulties. This will be discussed further.

1. Fragments of Comet Biela versus ICME

1.1 The Carrington Event

Astronomer J. Hubbard from Washington Observatory determined the orbital elements of both secondary Comet Biela's nuclei for perihelion passage in 1859 and calculated ephemerides for every fourth day, covering the period from March 23 to July 2, 1859 (Hubbard 1859, p. 229). Mr. Hind, Superintendent of the Marine Almanac, extended these ephemerides to provide daily position data from April 20 to July 24. Comparisons by H. Newton of data from the great meteor showers of 1798, 1838, and 1872, when the Earth was near the orbit of Comet Biela or crossing it, showed that the Andromedids were distributed, preceding the comet to a distance of 300 million miles and following it to a distance of 200 million miles (Denning 1905, p. 853). *The plasma dust component also follows comets outside their orbital plane.* Therefore, although it was assumed that Comet Biela should be expected towards the end of July 1859, it is not surprising that the secondary comets 'A/B' together with the Andromedids meteors, as well as comet plasma dust, could have appeared at the end of August.

The sudden disturbances of abnormally strong amplitude during magnetic storms were observed twice: on the evening of August 28 and on the morning of September 2, 1859. The violations were an oscillating pattern, as reflected in the change in polarity of telegraph currents. The perturbations throughout the planet continued until September 7, when the magnetic field calmed down (Stewart 1861, p. 424).

The publication of the scientific journal 'Weekly Herald' for September 1859, according to Diaz (1861, p. 335), stated that in the USA, all telegraph lines extended to the north, so that during the presence of a 'meteor', communication had to be interrupted. This mention of 'meteor' is not the only one. There were more examples, and in addition, related to γ-Andromeda.

Eyewitnesses reported that in many places, the lights had a magnificent appearance, while in others where this 'meteor' was also seen, the phenomenon of lights was rare. In other words, lights and the 'meteor' are not the same thing since many observers reported a 'meteor', but auroras were not observed everywhere.

Descriptions of this 'meteor' given by observers far from each other were collected by Professor E. Loomis and published in five main articles between August 28 and September 5, 1859, in the American Journal of Science and Arts (Boteler 2006, p. 159).

E. Loomis himself received a letter from the Secretary of the Smithsonian Institution, D. Henry, stating that there is a large collection of materials regarding this interesting 'meteor'.

According to this collection, Professor Hansteen from Christiania (Oslo) reported that on 29 August, in the east, a beam shot into γ-Andromeda (Shea and Smart 2006, p. 338). In 1885, Newton (1886, p. 419) noted that the Andromedids radiant was also located to the east of most observers. Interestingly, the artist Hevelius produced an image depicting a luminous beam shooting from the nucleus into the tail of Comet Halley on January 9, 1683 (Chambers 1909, p. 104, Fig. 41). This effect suggests the presence of electrical activity within comets (Peratt 1992; Thornhill and Talbott 2006).

In England, an auroral dome was also observed near γ-Andromeda (Shea and Smart 2006, p. 339).

It is now generally accepted that the disturbances during the Carrington Event were spreading from the north. It is therefore symptomatic that in northern countries, namely Norway and England, reports the direction of both the auroral beam and the dome towards γ-Andromeda.

On August 28, eyewitnesses in Cleveland, as reported by '*Washington Daily National Intelligencer*', noted a bright white light that formed a curve through Cepheus and Perseus. Between these constellations, closer to Perseus, as is known, is also γ-Andromeda.

Professor Twining at West Point, pointed out that on August 28, the streamers moved high through the Cassiopeia. As already mentioned, the astronomer E. Herrick concluded that the radiant of the meteors of Comet Biela in 1838 should have been located near the Cassiopeia constellation (Newton 1886, p. 423), which is the neighbour of γ-Andromeda in the sky.

On September 3, the '*New York Times*' reported that multicoloured bands of aurora crossed each other in the form of massive pillars between the constellations Aries, Taurus, and Medusa Head (in the Perseus constellation). Above the triangle formed by these constellations lies the γ-Andromeda star. From Athens, it was also reported that the aurora was limited to the east by the α-Perseus star.

Astronomer W. Denning, who had studied meteors for many years, claimed that the 1885 Andromedids shower was broad, extending up to 7°, and that he observed several meteors from a point south of γ-Andromeda.

It was stated (Diaz 1861, p. 331) that the luminous arch was beneath a dark segment in the Eridanus constellation and initially remained above the main aurora, stretching beyond the zenith (that is, the length of the auroral radiance was ≥ 90°). The arch subsequently 'disappeared' to the north in Eridanus. This does not exclude the '*Eridanus — γ-Andromeda*' direction.

The renowned poet Walt Whitman wrote in his poem 'The Year of Meteors' (1859–1860, p. 241) that it was the year of comets and meteors: a comet came from the north, shone in the sky, and a trail of meteors streaked overhead…

Although Comet C/1860 M1 and a meteor shower were also observed in New York in July 1860, Whitman's poem dates back to 1859–1860. Therefore, he could describe the 1859 Carrington Event.

Indeed, in New Haven, Prof. Shepard's attention was drawn to rapid pulsations and flashes overhead, which he thought indicated a low altitude of the phenomenon on September 2, 1859.

On August 28, a rapidly moving shooting star, i.e., meteor, was spotted. Additionally, an observer in Jefferson County noted a meteor on September 1 at 11 p.m. and on September 2 at 1 a.m., yet seven meteors.

The crew of the ship from California, in the Southern Hemisphere between squalls, in clear places in the sky, on September 2, observed lights flashing with *meteoric* brilliance (Shea and Smart 2006, p. 344).

The '*Melbourne Argus*' on September 1 reported that on August 28, over the town of Mount Gambier in South Australia, a bright meteor approaching the horizon exploded like a rocket, and a vivid aurora appeared immediately (German 2025a). This meteor's explosion and the subsequent aurora were also visible in Adelaide, 390 km from Mount Gambier town (Green et al. 2006, p. 147). Consequently, the auroras of the 1859 Carrington Event, including those at low latitudes, may have been caused by meteor explosions.

Finally, according to Secchi (1859a), sailors during the aurora over Civitavecchia Bay, 80 kilometres northwest of Rome, associated the fiery pillar they saw directly with a comet.

It is believed that, at the end of August and the beginning of September 1859, weather conditions for observations were poor. For example, all four magnetic stations in Russia — located in St. Petersburg, Ekaterinburg, Barnaul, and Nerchinsk — experienced overcast and cloudy conditions. Additionally, the Andromedids meteor shower in 1859 was expected to be weak.

Despite this, astronomer A. Secchi (1859a) reported that in Rome, beautiful rockets and auroral pillars of intense white and pale yellow light could be seen in the north, even through the clouds.

In Cleveland, Ohio, it was noticed that fire arrows flew from the north, like a terrible bombing (Cardenas et al. 2016, p. 257).

Regarding the rockets frequently mentioned by eyewitnesses, it is known that the meteor's substance extends from the head to the tail, reaching several kilometres in length and *resembling the tails of rockets* (Astapovich 1958, p. 338; German 2025b, #0027).

1.2 THE GEOMAGNETIC DISTURBANCES

1.2.1 CONTRADICTIONS IN THE STANDARD PARADIGM

The start of the 1859 Carrington Event was associated with the magnetic disturbances in Guatemala on August 26. At the same time, strong earthquakes occurred in neighbouring El Salvador (Canudas 1860, p. 1). Although the issue remains controversial, the causal link between an intense geomagnetic storm of solar origin and a simultaneous large earthquake is not recognised within the current scientific paradigm (Love and Thomas 2013, p. 1165). However, there are no issues with the connection between such earthquakes and meteor streams. It is known that the brightest meteors with a (–15) stellar magnitude and a luminous intensity of $I>10^{11}$ candela (cd) are recorded by seismographs (Astapovich 1958, p. 296, Fig. 142). For example, on January 20, 1977, a recorded meteor shower consisting of massive, dense rocks caused severe seismic activity on both the Moon and Earth. Furthermore, while in 1977 there were only stone fragments, in the case of the 3D/Biela Comet components, shock waves could have been generated by the passage of large iron-stone fragments near the magnetosphere or meteors in the atmosphere, thereby initiating telluric currents and earthquakes in El Salvador in August 1859.

It is assumed that following the magnetic disturbances of August 26, 1859, the first of two intense magnetic storms of the Carrington Event commenced on August 28 at 23 UT, as the aurora in Havana appeared around this time.

Today, one of the main arguments for the solar nature of the 1859 Carrington Event is a solar white-light flare in the region of sunspots, observed by astronomer R. Carrington at the Greenwich Observatory on September 1, 1859, at about 11:18 UT. According to R. Carrington, the white-light flare completely disappeared at 11:23 UT. Independent of Carrington, astronomer R. Hodgson registered on the horizontal H-component of the magnetogram at Kew Observatory at 11:22 UT, a sharp, small crochet, attributed also to the solar flare. However, it should be emphasised that the claim that registrations match at Greenwich and Kew, 20 km apart, is unreliable because there is no evidence of time synchronisation between these observatories (Beggan et al. 2024, p. 5, § 2.2). In turn, on September 1, geomagnetic disturbances at the Paris Observatory, according to the '*Comptes Rendus*' (T. XLIX, p. 473), were recorded at 11:30 UT.

A crochet-flare of ultraviolet or X-rays, explosive type on the Sun, quickly, through ~ 8 minutes, affects the Earth only on the illuminated side of the Earth as the Mogel–Dollinger effect (SID). However, during the 1859 Carrington Event, no one was monitoring X-rays or UV rays (Curto et al. 2016, p. 1). At the Rome Observatory, for example, the time about 11:22 UT was considered non-working, meaning no records were made.

Moreover, in Rome, the greatest deviation of the magnetic needle was recorded on September 1 at 7:20 a.m. Göttingen time (Secchi 1859a), that is, before the crochet was registered in England on the same day (Göttingen was about 40 minutes ahead of Greenwich).

Although this is considered a misprint and should have been September 2 (Bartels 1937, p. 235), the data, e.g., from places like St. Petersburg also indicate that the range of variation of the characteristics of the unipolar magnetometer, which measured declination, on September 1 (263'39") was almost 2.5 times higher than on September 2 (107'44"). At other Russian magnetic stations, the situation looked analogous.

Bipolar oscillations of the declination *D*-component were extreme in Rome, Nerchinsk and St. Petersburg. Within the framework of the solar origin of the Carrington Event, *such bipolar variations remain unexplained.*

On the other hand, bipolar variations can be explained:

(a) by dividing one cometary plasma dust tail or by several tails if they separated (that was highly probable; Appendix B), appearing 'competing' as two fire pillars on opposite sides of the magnetic meridian, as observed in Rome (Secchi 1859a).

(b) due to a fixed high-density plasma region within the comet’s environment (Espley et al. 2015, p. 8811), it could have oscillated symmetrically as the comet passed through

Earth's magnetosphere, generating shock waves. In 1986, e.g., symmetrical oscillations in the magnetic field of Comet 1P/Halley, associated with shock waves, were recorded.

Therefore, the claim that the trace on the London magnetograms on September 1, 1859, at 11:22 UT was directly related to a solar flare, and not, say, to a magnetosphere disturbance by a shock wave from fragments of the 3D/Biela Comet, remains a hypothesis, but not a fact. However, since solar white-light flares are not always, but often accompanied by plasma of ICMEs, the strong geomagnetic storm after the registration of the crochet on September 1, 1859, on the next day, September 2, 1859, that is, after ~17.6 hours, was associated by researchers with solar ICME. There is *no evidence for this*; in this case, they *postulated ICME*.

On September 2, 1859, measurements of the magnetic characteristics in Rome began a few hours after *the sudden onset* of the magnetic storm was recorded at Kew. A deviation of H~3000 nT occurred in Rome (Secchi 1859b, p. 458) when the Kew magnetogram was off-scale, and the amplitude of the data at the Colaba Observatory in Bombay, present-day Mumbai, India (magnetic latitude 10.5°N), was rapidly decreasing. However, in Rome, the variations of the declinometer, the vertical magnetometer, and the bifilar, measuring characteristics *D*, *Z*, and *H*, respectively, were not simultaneous, since their maximum changes occurred at different times (Secchi 1859b, p. 458).

The instruments at the Rome Observatory could measure up to ~300 nT. In addition, the data in Rome are quite difficult to interpret due to the lack of a base scale; therefore, the recalculation was performed using an approximation by the temporary scale. The above-mentioned estimate of H~3000 nT is not recorded in the tabulated series original data. Consequently, as noted by Blake et al. (2021, p. 8), the magnetic field deviation could be ±1000 nT.

The intensity of the *postulated* solar white-light flare in 1859, according to the amplitude ~110 nT of the magnetic crochet at Kew, was estimated as the class soft SXR-rays=X45(±5), the solar energetic particles (SEPs) fluence as F>30 MeV (Cliver and Dietrich 2013, A31-p1), and the mass of ICME as ~ 10^{13} kg (Hudson 2021, p. 449).

Since the strongest geomagnetic storms are generated by rapid coronal ejections, the distribution of their velocities is important. At the same time, according to Riley (2012, Section 3.1), indicated that translating what Carrington qualitatively described in 1859 into an X-ray stable peak stream rate is probably an *unsolvable task*. Hence, there are significant problems with ICME initial velocity estimates for the Carrington Event.

It is well known that flares and coronal mass ejections can affect Earth, depending on many factors on both the Sun and Earth, one of the main results of which is a radiation storm caused by SEPs. However, it is still believed that all conditions coincided during the 1859 Carrington Event by chance (Hudson, 2021, p. 450).

It was claimed that SEPs have a strong tendency to associate with solar white-light flares (Cliver and Dietrich 2013, A31-p2). This relationship suggests X-ray emission from electrons or γ-ray emission from protons (SPEs). The SPE intensity is determined by the levels of nitrate radicals, as well as the cosmogenic nuclides ^{14}C, ^{36}Cl, and ^{10}Be, formed in the Earth's atmosphere and deposited in ice cores, tree rings, and corals.

Naturally, the Carrington geomagnetic storm was to produce known atmospheric effects during solar flares (SFEs). Therefore, strange that the Carrington Event of this magnitude *did not* leave a noticeable imprint of nitrates in the polar ice, as well as a trace of cosmogenic nuclides: beryllium ^{10}Be (Usoskin and Kovaltsov 2012, p. 4; Wolff et al. 2012, L0850-p.1), chlorine ^{36}Cl (Miyake et al. 2023, p. 31), or of carbon ^{14}C (Usoskin and Kovaltsov 2012, p. 4; Uusitalo et al. 2024, p. 8).

It was stated that the absence of a statistically significant increase in the observed concentration of cosmogenic nuclides for 1859 indicates multiple proton ejections. Therefore, attempts have been made to compare the Carrington Event with the *complex* geomagnetic storm of 1989, which lasted ~ 24 hours.

Nevertheless, according to Tsurutani et al. (2023, p. 3, Section 3), the Dst profile for the geomagnetic storm on 2 September 1859 showed that the Carrington Event was caused by simple plasma injection; there was no indication of a complex storm.

The geomagnetic storm on August 28/29 was only a little weaker (–Dst=673 nT) than the historical geomagnetic storm on September 2 (–Dst=964 nT) (Love et al. 2025, p. 1). In addition, the auroras were being reported more often on August 28–31 than on September 1–3.

However, a single ICME is considered unlikely to trigger successive magnetic storms within a few days. Therefore, it has been suggested that the storm on September 2 may have been one of many storms associated with several ICMEs emanating from a common active sunspot cluster.

Therefore, as assumed by many researchers in the framework of the solar paradigm, since the first ICME clears this path (i.e., the so-called 'snowplough effect'), the next ICME, leaving the Sun a few days later, may advance almost without slowing down and lead to a strong geomagnetic storm.

However, a surface of the Sun before the Carrington Event was observed by renowned astronomers – Secchi, Schwab and others. Neither source of geomagnetic storms on the Sun was detected before the white-light flare on September 1, 1859 (Beggan 2024, p. 10, § 3.2).

According to the article 'Magnetic Effects of the Aurora' in '*Comptes Rendus*' (1860, T. XLIX, p. 473), the first magnetic disturbances attributed to the historical Carrington Event were simultaneously recorded at the Observatories in France (in Paris) and in Guatemala on August 26, 1859, when the geomagnetic declination changed between 9:30 a.m. and noon. However, during this period, the potential proton eruption on the Sun, inferred from sunspot observations, could have occurred on August 27 (Smart 2006, p. 215).

On August 25, 1859, there was only a tiny group of sunspots at the center of the Sun (Arlt 2011, p. 805), as well as a small group of sunspots on the eastern side of the Sun's disk. In my opinion, the presence not geoeffective sunspots was not sufficient to cause an ICME on August 27, resulting in the first magnetic storm on August 28–29.

Instruments at Kew recorded magnetic disturbances only when two bright spots were visible over a larger dark spot during Carrington's observation of the Sun on 1 September 1859. These sunspots disappeared behind the solar disk's edge within five minutes (Adams, 1883, p. 39). However, the Carrington Event lasted ~13 days.

This calls into question a *second postulate* for the Carrington Event: a connection between the solar activity and the 'clearing' of interplanetary space by the supposed ICME of August 28–29, 1859, 'snow plough' effect, which is attributed to the prelude leading to the rapid 'delivery' of the next ICME, initiating the geomagnetic storm of September 2, 1859.

In addition, as noted by Hayakawa et al. (2022, page 5, section 4), the September 2 storm was less effective in Dist Z but stronger than the August 28 storm in Dist H and Dist Y, making it difficult to understand their cause.

The recurrence of such a strong geomagnetic storm as September 2, 1859, should occur once every 60–200 years (Curto et al. 2016, p. 1; Green et al. 2006, p. 148). Even without mentioning that the geomagnetic storm on August 28, 1859, was almost as strong as the storm of September 2, already on February 4, 1872, i.e., in the next solar cycle, another storm comparable to the September 2, 1859, event was recorded.

The solar origin hypothesis for the Carrington Event cannot account for such a short interval between these unusually strong storms. However, fragments of Comet Biela may also have been responsible for the geomagnetic storm of 1872.

1.2.2 IS EVERYTHING ALL RIGHT WITH COLABA DATA?

Geomagnetic storms are of two types: (1) sudden commencement (SC) type, driven by strong magnetic fields of the ICMEs and high solar wind speeds, and (2) gradual (SG) type, caused by the corotating interaction region (CIR), associated with solar coronal holes. The Carington Event storm was SC-type (Lakhina et al. 2012, p. 273, Fig. 3) with the peak initial phase amplitude SSC ~120 nT, as recorded at Colaba.

At same time, the maximum average-hourly density profile was almost 14 times higher than similar values observed since then as noted by Cliver and Dietrich (2013, A13-p.3).

The horizontal H-component of the magnetic field recorded at Colaba showed an unusually rapid recovery on September 2. This effect surprised the researchers, as it did not reflect the intensity of the ring current.

Therefore, they assume unusual loss processes (Hayakawa et al. 2022, p. 33), or reject the most extreme values (Siscoe et al. 2006, 'Conclusion' section).

For some explanations of the rapid recovery phase of the Colaba magnetic storm, the key factor is the solar wind density, which is usually dominant in the ICME sheath. However, the anomalous *increase* in solar wind density ('plasma stopper') suggested by Li et al. (2006, p. 273) implies extremely high pressure following the shock. According to another study by Keika et al. (2015, p. 10), conversely, a sharp *decrease* in solar wind density occurs at the boundary between the ICME sheath and the subsequent magnetic cloud.

Contradictions are evident.

Furthermore, based on the solar paradigm for the Carrington Event, contrary to what would be expected from historical magnetograms, as noted by Hayakawa et al. (2022, Section 5), a magnitude discrepancy between the spot and hourly values (–1263 nT versus –1691 nT) was identified.

For a long time, from 2003, the most probable hypothesis was considered to be the ICME magnetic cloud with a southern component Bs~(−90 nT) of the magnetic field inside, which provided a peak H=(−1760 nT) during a geomagnetic storm on September 2 (Tsurutani et al., 2023, p. 1). Due to the Bs~(−90 nT), a maximum interplanetary electric field (IEF) of ~160 mV/m could have resulted. From this, taking into account low-latitude auroras and, accordingly, the plasmapause level, a magnetospheric convection electric field of ~20 mV/m was obtained. In this scenario, the extremely fast recovery of the magnetic storm is postulated to be a consequence of nonlinear losses in the ring current.

Still, another calculation showed that if the depression had resulted from the symmetric ring current, then the IEF would need to be ≥ 200–451 mV/m, which is considered implausible, as noted by Love and Mursula (2024a, p. 1). In addition, they observe that within a single time interval, the perturbation reached an absolute change rate of ≥2436 nT/h. It is not consistent with the symmetrical ring current.

According to Akasofu and Chapman (1960, p. 93, Fig. 3) as well as Ohtani (2022, p. 2), the idea that the observed geomagnetic H-depression at Colaba was caused by *the ring* *current and/or the auroral electrojet (AEJ), and therefore the ICME magnetic cloud, is ruled out*.

It was claimed (Siscoe et al. 2006, p. 173) that the Colaba magnetogram shows two main H-depressions on September 2: the first on the dayside until 11 a.m., presumably caused by the geoeffective *ICME sheath*, and then, 6 hours later, the main phase from 5 p.m., which the authors explain by the arrival of the ICME body. According to this interpretation, H~850 nT, but no H~1160, could have been obtained with a lower Bs-value of the ICME-sheath. However, if ionospheric currents caused such values, this would not be surprising (although the authors are doubtful that ionospheric currents could cause strong disturbances, given the low Bs-value). Therefore, magnetospheric currents were preferred. But in this case, values would be unprecedented.

On the other hand, according to the arguments made by Tsurutani et al. (2023, p. 3, Section 3), for the Carrington magnetic storm, magnetic fields of the ICME's sheath are excluded, since the value Bs~(−90 nT) is too large to arise inside the sheath in front of the ICME.

In addition, the storm at Colaba was of the classsic sudden commencement type: in the evening of September 2, the second H-depression had an amplitude three times lower than that of the morning H-depression and was therefore less important.

Then, Blake et al. (2021, p. 1) attempted to hypothesise compression and expansion of the entire Earth's magnetopause on September 2, 1859, using NASA's Space Weather Modelling Framework (SWMF), synthetic solar wind conditions, and a combination of fields of magnetospheric, ionospheric, and their coupling field-aligned currents (FACs). Still, as noted by Blake et al. (2021, p. 16), in the case of St. Petersburg and Barnaul, the SWMF does not explain the large positive B_H-deviation.

Thus, Veselovsky et al. (2009, p. 1) assumed that, separately, neither active regions on the Sun nor coronal holes were capable of explaining the observed phenomena. However, the Carrington storm was not of SG-type, associated with solar coronal holes.

A consensus has yet to be reached, and no more substantial proposals have been put forward.

Even, there was a suggestion by Love et al. (2024b, p. 1) that something was wrong in the Colaba Observatory data.

Nevertheless, during the 1885 Andromedids, the number of meteors decreased precipitously by the end of their registration (Newton 1886, p. 410). In a similar case, the magnetosphere can quickly return to its original state.

In addition, a wide cometary/meteor shower was capable of covering the entire Earth, including, in particular, at Colaba on September 2, 1859, first from the dayside and then from the evening side. An example is the observation of a collision between Comet C/2013 A1 Siding Spring and Mars (Sánchez–Cano et al. 2018, p. 8787).

The fragmented Andromedids also resolve the issue of selective magnetopause compression: negative B_H-deviations at Colaba, positive ones at St. Petersburg and Barnaul, and the absence of magnetometer B_H-deviation in Nerchinsk.

The large and anomalously rapid changes in Colaba could have been related to discharges of ionised cometary dust plasma. They were akin to lightning discharges during which a magnetic field change reaches a rate on the order of 10^{14} nT/h and a peak magnetic field of about 90 nT at a distance of 10 km. Several slightly smaller extremums on the magnetograms, recorded after the main extremum, can be explained by a smaller dusty density relative to the main part of the fragmented cometary stream.

Hence, with the Colaba data, it may be all right.

1.3 COMETS SUPPRESS PLANETARY MAGNETOSPHERES

Perturbances on magnetograms can occur not only due to the plasma ejected by the Sun but also for other reasons. According to the theory by Chapman and Ferraro (1931, p. 77), a geomagnetic storm can occur when cometary ionised particles from a meteor stream interact with Earth's magnetic field.

The Svalgaard–Mansurov effect demonstrated that when the external magnetic field is directed southward, magnetic reconnection allows cosmic plasma from any source to enter the Earth's magnetosphere. Therefore, the occurrence of magnetic storms is caused, among other things, by the state of the Earth's magnetic field and the orientation of the magnetic field of the meteor shower, since the properties of magnetohydrodynamic (MHD) waves depend on the direction of the wave vector relative to the magnetic field.

Furthermore, a comet generates a shock wave as charged particles swirl around magnetic field lines, forming a torus of velocities in space.

The behaviour of the magnetic field on September 1/2, 1859, was similar to that on August 28/29, 1859. Both times, three periods of oscillation on the magnetograms in London were noted (Stewart 1861, p. 425):

(1) from half a minute to ~ 4–5 minutes; (2) ~ 40–50 minutes; (3) ~ 6 hours.

- The initial sudden disturbances lasted for ~ 3 min and then changed more smoothly for another ~ 7 minutes. After this, their direction changed to the opposite.

  Such low-frequency oscillations are usually attributed to Pc5 continuous pulsations with a period from several to 10 minutes associated with geomagnetic storms (Jacobs et al. 1964, p. 180).

Notwithstanding, typical periods of dominant waves of the 1P/Halley Comet in 1986 were ~ 2–6 min, and the 3-minute period pulsations were caused by thermal ions due to their charge change and photoionisation.

This period corresponded well to rapid oscillations in telegraph wires during the Carrington Event.

- The 40–50 minute period during the Carrington Event is confirmed, e.g., by the description of the aurora on the night of August 28/29, 1859, when, according to Comptes Rendus (1860, p. 367), the inspector of the telegraph service of the Northern Railway at Noyelles-sur-Mer near St. Valery noticed a fairly bright white light in the sky, which then increased in intensity towards the horizon; this whitish light, which marked the beginning of the aurora, lasted for about three-quarters of an hour, i.e., about 45 minutes.

  This, 40–50 minute period, probably corresponded to auroral oscillations and bipolar variations due to a move of the cometary shower, what led to the compression-expansion of the magnetopause, as well as also correlated to the movement of *the whole aurora* from east to west, followed by retrocession in *the opposite direction*, as observed, e.g., at Havana on August 29.

- However, according to the article by Stewart (1861, p. 425), the main feature of the geomagnetic storms at Kew on August 28/29 and September 1/2, 1859, was a 6-hour period of two powerful waves *in the same direction*, which was most clearly observed in the curves of the horizontal and vertical components.

  In both cases these components decreased during the first 3 hours and increased during the next 3 hours, until they had again normal values after about 6 hours.

  Such a characteristic exactly corresponds to a characteristic of the passage of the Andromedids recorded on November 27, 1885, when an increase in the number of meteors was observed in the first 3 hours, and, after a peak, their number decreased over the next 3 hours. So that, according to Newton (1886, p. 425), within about 6 hours, the main part (9/10) of the stream had passed.

  In other words, if Andromedids caused the Carrington Event in 1859, then during the first 3 hours, their increase should have suppressed the geomagnetic field. After that, during the next 3 hours, when the flux of cometary fragments decreased, both geomagnetic components increased again, returning to normal values (German 2025c, #0031).

The division of the cometary tail, e.g., into two parts (Appendix B) can explain these two 6-hour waves.

It is well-known that, according to modelling by Jenniskens and Vaubillon (2007, p. 1044), the total mass of the Andromedids dust was lost in 1859 or 1866. Since observing conditions were good in 1866 (Kronk, 1999, p. 1), the total mass of the Andromedids' dust was, with a high probability, lost in 1859.

As already mentioned, the 'A' secondary comet in 1846 appeared *diffuse and had as many as five multiple nuclei*. Therefore, it can be assumed that at least two nuclei yet existed in 1859, and they could be responsible for the two powerful 6-hour waves of geomagnetic disturbances registered in Kew.

Thus, it is possible that the 'A' comet did not 'sleep' in 1859 and 'participated', independently or together with the 'B' secondary comet, in the geomagnetic storms during the Carrington Event. In such a case, the total mass of the Andromedids dust had been lost since the 'A' comet fragmented/exploded in 1859, e.g., over Civitavecchia Bay near Rome.

Interestingly, the quasi-6-h duration of the disturbance waves on magnetograms in 1859 allows us to compare it with the three long-lived-periodic 4-h jets associated with the nucleus of 1P/Halley Comet, observed during the 'TUNDE-M' experiment in

1986. It is clear that the duration of jets for the nuclei of different comets, such as the 3D/Biela and 1P/Halley, need not coincide. However, the existence of such a duration under various conditions is highly indicative.

As far as I know, all supporters of a solar origin for the Carrington event have not paid due attention to records of two disturbance waves with periods of about 6 hours, recorded twice on 28/29 and also twice on September 1/2 in Kew.

The 3.5-day pause between storms could have been due to the comet's rotation, which changed the direction of the dust-gas jets. However, the 3.5-day pause is not explained by the Earth's rotation after collision with ICME or its sheath. Cometary disturbances last for at least several days, unlike the immediate ICME and fast-stream transits (Sánchez–Cano et al. 2018, p. 8785).

The 6-hour schedule of the geomagnetic storms on August 28–29 and September 1–2, 1859, was typical of the passage of the Andromedids on November 27, 1885. In turn, the influence of the ICME's magnetic cloud and its sheath, as shown in the previous paragraph (1.2.1), was excluded because there is no evidence of enhanced levels of cosmogenic isotopes, nitrates, or an SPE's radiation storm in the 1859 deposits, nor was there a complex storm.

It should be added that after the disturbances of August 28–29 and September 1–2, geomagnetic activity was observed at least until September 7. From the perspective of the solar origin paradigm of the Carrington Event, this is inexplicable.

However, it is known that meteor streams can be heterogeneously distributed in space. The geomagnetic storms linked to the 1859 Carrington Event could have been triggered by a fragmented stream of the 3D/Biela comet, resulting from its passage near Jupiter.

The 1859 Carrington geomagnetic storms lasted ~ 13 days, from August 26 to September 7, 1859. According to Jenniskens and Vaubillon (2007, p. 1043), ~13 days are also required for Earth to pass through the Andromedids' main stream. Almost as much, from September 15 to 29, 1852, the secondary 'B' comet of the 3D/Biela was observed by Secchi (Flammarion, 1894, p. 499). The secondary 'A' comet was observed for approximately 28 days (Secchi 1872, p. 1581), and intriguingly, these observations began on August 26, 1852 — coinciding exactly with the day and month marking the start of geomagnetic storms during the Carrington Event in 1859. Consequently, the consistent interval of ~13 days, beginning on August 26, for both observations of the 3D/Biela fragments in 1852 and the magnetic storms in 1859, supports the idea that this comet was involved in the 1859 Carrington Event.

When the Comet C/2013 A1 Siding Spring collided with Mars in October 2014, NASA's spacecraft MAVEN detected chaos in the Martian magnetosphere at a distance of about 140×10^3 km as the comet's magnetic field overwhelmed it.

According to Espley et al. (2015, p. 8810, p. 8816), cometary ions are known to be 18 times more massive than solar wind ions, resulting in an energy density of cometary plasma two orders of magnitude higher than that of the normal solar wind. Disturbances were recorded near the induced magnetospheric boundary caused by the interaction of the plasma of the comet’s outer coma with Mars.

Even several hours after the comet 'departed' Mars, disturbances in the Martian magnetosphere continued to be measured. Similarly, disturbances during the Carrington Event after the historic storm of September 2, 1859, were observed up to and including September 7 (Stewart 1861, p. 424), when the magnetic field calmed down.

The Comet 73P/Schwassmann-Wachmann (hereafter – 73P) has been disintegrating since 1995, and its numerous fragments were connected by a meteor shower (Zhao et al. 2022, p. 37, Fig. 1), as were the fragments of Comet Biela by the Andromedids meteors in the 19th century.

On May 30 and June 6, 2006, it was noted that O+ ions escaping from the cometary tail 'delivered' by solar wind magnetic tubes (by the pinch effect?) to Earth, where large pressure enhancements on the magnetosphere were observed.

Zhao et al. (2022, p. 42, Fig. 5) discovered that there were evident correlations between the flux of comet's ions O+ and Dst, AEJ, and auroras.

As already indicated, according to recent estimates, the external magnetic field required to produce the geomagnetic storm on September 2, 1859, could have been ~ *90 nT*. On July 3, 2015, an unprecedented increase in the magnetic field *to ~ 300 nT* was measured by the '*Rosetta*' spacecraft at Comet 67P/Churyumov–Gerasimenko (hereafter – 67P), indicating that the accumulation of magnetic energy was a factor of about six greater than that usually accumulated inside the coma of the 67P (Goetz et al. 2019, p. 2). The magnetic field of the 3D/Biela Comet, taking into account the possible iron-nickel nucleus, probably could have been even greater.

The registered magnetic fields of the comets are sufficient to explain the H-changes on September 2, 1859, at the geomagnetic latitude of Rome and at Colaba, whereas the solar-origin hypothesis of the Carrington event cannot account for them.

It is well known that the variations of magnetic waves as they approached the nucleus of the 1P/Halley Comet in 1986 gradually increased in magnitude, *differing from solar* ones and indicating instability that excited long MHD waves. They were caused by elastic, compressible plasma due to the pinch effect and the 'freezing' into a magnetic field. The magnetic waves are dispersionless, which contributes to the emergence of a plasma MHD waveguide (Nakariakov 2020, p. 1). From here, filamentary plasma can reach large distances, where MHD waves can be observed.

Since electrical energy accumulates inside, the comet can explode, like an overstressed capacitor, in the event of discharges. The observation of a comet over the Civitavecchia Bay, and the lights on both sides of magnetic north in Rome (Secchi 1859a), correlates with the fact that the maximum deviation of the horizontal component, H~3000 nT, during the Carrington Event on the magnetogram was recorded precisely at the Rome Observatory. However, when the disturbance peak in Kew/Rome occurred on September 2, 1859, in Bombay, it was noon. Therefore, it could not have been affected by geomagnetic activity caused by ICME/sheath in the midnight sector in Europe (Boteler 2006, p. 170).

Why did magnetograms record two disturbance waves at Kew on September 2, 1859, while the Colaba Observatory recorded only one? Colaba was situated in the south, away from the main Andromedids stream, which extended from the north-northeast across European countries such as Norway, England, Italy, and France, as well as the United States towards Cuba and Mexico. The stream was likely highly fragmented, or perhaps only one powerful cometary/meteor plasma-dust discharge occurred in the Colaba area, while two occurred over Kew on September 2, 1859.

In this way, based on the evidence presented, it can be argued that the expected encounter with fragments of the 3D/Biela Comet could more likely to have caused such a long series of geomagnetic disturbances from August 26 to September 7, 1859, than ICME' magnetic clouds and their sheaths, as currently assumed by the traditional paradigm relying on a set of postulates and random coincidences.

1.4 Did Carrington observe an unusual solar event?

It has been found that almost half of strong geomagnetic storms with a minimum of index Dst≤(–300 nT) occurred in association with sunspot groups ≤1000 millionths of the solar hemisphere (µsh) (Cliver et al. 2022, p. 141). For example, the storm manifestations on February 4, 1872, are attributed to the activity of an eruption from the region of solar spots near the center of the disk on the morning of February 3, 1872 (Secchi, 1872, p. 1581). However, this region covered only ~ 461 µsh. For comparison: according to the assumptions, the 1859 Carrington geomagnetic storm originated in association with solar spots of an area ~ 2300 µsh.

During the 18th solar cycle, the storm originated in association with a spot group of an area ~ 5000 µsh (e.g., Newton 1955, p. 666). According to various estimates of the 1859

Carrington storm, Dst values ranging from (–918 nT) to (–1760 nT) are comparable to the horizontal component observed at Colaba in 1872, scaled to (–1600 nT) (e.g., Nevanlinna 2008, p. 171). The estimate of the total radiated energy of the solar flare during the 1859 Carrington Event, ~ 4×10^{25} J, based on the sketch and description, does not exceed the energy of later flares (Hudson 2021, p. 449).

Therefore, *neither the area of the spots nor their activity is the decisive argument*: such spots will always be found on the solar disk.

Overall, there is a small but significant anti-correlation between the region of the sunspot group from which ICME originated and auroral or geomagnetic responses (Lockwood et al. 2025, p. 3596). In addition, evidence was presented for suppression of CMEs when they are overlaid by strong magnetic fields (Cliver et al. 2022, p. 136).

In principle, solar white-light flares are explained by the magnetic reconnection theory. They are usually observed in visible images of the Sun during larger X-ray flares (Woods et al. 2006, p. A10S14-p.1). Nevertheless, the energy of solar white-light flares is small compared to both the spatial and spectral total solar irradiance (TSI). Therefore, it was previously difficult to isolate them in TSI records.

However, solar flares in the optical continuum, as modern technology has shown, are not at all uncommon. In 1989, for example, a small telescope recorded fifteen solar white-light flares in the optical continuum over the course of a year (Babin and Koval 2005, p. 107). As published by Matthews et al. (2003, p. 1108), the X-ray Telescope on the Yohkoh satellite (Japan) observed twenty-eight solar white-light flares in 2003. Still, geomagnetic disturbances similar to those recorded during the Carrington Event were not observed. In my opinion, this is due to the absence of a strong impact on the Earth by ICME. No such ICME impacts probably also occurred in 1859, either. The detection of a crochet trace on magnetograms only indicates wave components in the electromagnetic range.

The idea of an impact on Earth's magnetosphere is not supported because, as already noted, there are no cosmogenic isotopes, nitrates, or evidence of a radiation storm from energetic solar particles in the 1859 deposits.

Moreover, according to B. Stewart (1861, p. 427), R. Carrington, in a communication to the Royal Astronomical Society, describes light as entirely independent of the great spot or groups of spots, whether it was their nuclei/umbras.

Thus, the most famous experts in the field of solar physics, Akasofu and Kamide (2005, A09226-p1, Section 6), argue that *there is no certainty* that what Carrington observed was an unusual solar event.

2. Aurorae during the Carrington Event

2.1 Issues of the current paradigm

In addition to geomagnetic disturbances, another important aspect of the Carrington Event is the unusual auroras. There are conflicting opinions and unresolved issues regarding the auroras from their solar genesis perspective.

These include: colours and anomalous brightness of auroras, their isolation at the low-latitude, the energy of the particle precipitation, the maximum diameter of the auroral rays bundle, the type of auroras, etc.

(a) Colours of auroras.

The general consensus is that during the Carrington Event, reds and whites were the dominant colours of auroras.

Many investigators assumed that the red colour might have resulted from an auroral sheet-like structure. However, it is well known that sheet-like auroras at low latitudes, with a predominance of red, are considered problematic.

No less remarkable were the white auroras at all latitudes. Nevertheless, it is now established that white auroras are numerous during increases in ^{14}C in the Earth's atmosphere, with subsequent precipitation and accumulation caused by SEPs (Abbot and Juhl 2016, p. 2181). Therefore, the paradox in the context of the Carrington Event is that high levels of this isotope were not detected in the 1859 deposits (Miyake et al. 2023, p. 31; Usoskin and Kovaltsov 2012, p. 4; Uusitalo et al. 2024, p. 8). This fact also negates the postulation that the fluence of solar energetic particles was F>30 MeV.

Then why, during the Carrington Event, were there many white auroras if no high level of ^{14}C was detected in 1859?

Since SEPs were not confirmed not only by ^{14}C levels but also by other cosmogenic isotopes, could the 3D/Biela's secondary comets/meteors have been responsible for the colours, including white, of the auroras during the Carrington Event?

Dust tails of comets, which scatter sunlight, are of different colours but are usually *white or yellow*.

Many years ago, Chambers (1909, p. 8) argued that shades such as '*yellowish*' or *'ruddy*' are not unusual in both the nuclei and tails of comets, but a *white* or silver-grey hue dominates most comets. Examples from the past, marked by Chambers, include the comets of 1769, 1811, and 1843, Comet Donati of 1858, Comet Koggia of 1874, Comet Fabry of 1886, and others.

More recently, the Hale-Bopp Comet showed *a white dust tail*, but also had a yellow (sodium) tail. In turn, against the backdrop of the cool blue stars, the Comet Siding Spring, which emitted in the infrared, appeared red, including its dust tail. At the same time, the gas tails of comets, containing ions of water, carbon monoxide/dioxide, and cyanide, have a bluish colour due to fluorescence.

Meteor showers arise from comets' fragmentation. Since meteors originate mainly from comet tails, their colour corresponds to the colours of these tails.

According to Astapovich (1958, p. 455), Andromedids appear reddish at a brightness magnitude of (+3) and white at (–3). Furthermore, the glow from thermally excited atoms causes the various initial colours of meteors to turn white within seconds.

Tupman (1885, p. 80) described the 1885 Andromedid meteors as *white and red.*

In turn, Capron (1885, p. 82) noted that larger meteors appeared white with long yellow or reddish-yellow trails and were 3–4 times larger and brighter than Jupiter; the intermediate ones were also white, while the smaller ones appeared bluish, and some displayed yellow or yellow-red hues.

In the '*Washington Daily National Intelligencer*' of August 31, 1859, unusual auroras were reported, described as pure milky white. At the same time, Chambers (1909, p. 4) noted that an ordinary cometary tail often appears as a stream of milky-white light. For example, the inner and brightest zone of Comet Pons in 1884 was notable for its milky appearance (Chambers 1909, p. 97). Consequently, the white colour could have been 'introduced from the outside in a ready-made form' into the Earth’s atmosphere.

Thus, the cometary-meteor hypothesis solves the problem of the colours of the auroras associated with the Carrington Event (German 2025d, #0032), since red and white are the dominant colours of the dust tails of comets, as well as Andromedid meteors.

(b) Was there an expansion of the auroral oval towards the equator?

It is known that during strong geomagnetic events, the system of polar currents expands equatorward. Therefore, many investigators assumed that during the Carrington Event, the expansion of the auroral oval corresponded to the timing of magnetic disturbances.

However, e.g., at 6 p.m., the 'Boston – New Bedford' line operated with intervals, although there was no aurora at that time (Boteler 2006, p. 162). Analogically, in Paris, the magnetic telegraph needles were in constant motion from 4:00 to 8:00 a.m. on September 2, yet no auroras were observed that day, as noted in the publication by '*Comptes Rendus*' (T. XLIX, p. 365). In turn, according to Diaz (1861, p. 331), a huge luminous auroral arc was visible over the hills, but the declination needle remained motionless.

In addition, Tyasto et al. (2009, p. 153) marked that magnetic B_H-deviation were recorded in Barnaul (53° 20′ N) on September 2, 1859, while they were absent in Nerchinsk

(51° 59′ N), which had of the magnetic latitude (~ 45° N) south of Barnaul (~ 47° N), whereto the auroral oval should have propagated consistent with the timing of magnetic disturbances. This is paradoxical within the framework of the solar origin of the Carrington Event. In the case of a fragmented cometary stream, everything is explainable, as it could have gaps.

Therefore, it is *doubtful that the expansion of the auroral oval is consistent with the timing of magnetic disturbances*.

Since the auroral oval corresponds to electric currents in the ionosphere, which have a latitudinal distribution, the strongest argument against associated auroras during the Carrington Event, with the equatorial spreading of the auroral oval, was the effects on long telegraph lines, observed in a meridional rather than a latitudinal direction.

The '*Comptes Rendus*' indicated that in Europe, the most significant effects were observed, for example, on lines from Zurich to Berne, from Stuttgart to Tübingen and Karlsruhe, and from Paris to Marseilles and further north (Smart et al. 2006, p. 340).

Canadian geophysicist Boteler (2006, p. 159) was surprised by the ignition of telegraph lines during the Carrington Event, not only in the latitudinal, but also in the meridional direction from Boston to Portland at the Elizabeth Cape in the United States. They occurred orthogonally to the auroral electrojet. Boteler attributed this phenomenon to the coastal effect between Boston and Portland.

However, the telegraph lines in Europe, noted above, were not connected across sea coasts, and consequently, no coastal effects between them were. This indicates that the ionosphere was dominated by a meridional current during the Carrington storm.

The model in 'latitude–longitude' coordinates showed that with the development of eddy currents in the magnetosphere, ionospheric currents prevail in the 'north–south' direction (Belakhovsky et al. 2020, p. 17). In comets, eddy currents form due to the pinch effect and produce cometary filaments in tails. In principle, fragments of Comet Biela could have passed tangentially through the Earth's magnetosphere. However, some of them penetrated the atmosphere.

It is believed that usually auroras occur within the auroral oval centred at 67° (±6°) latitude in both hemispheres. Indeed, the H~3000 nT deviation at the geomagnetic latitude of Rome, recorded in 1859, is observed only at higher magnetic latitudes (Chapman 1957, p. 7). Therefore, Blake et al. (2020, p. 2) assert that the MLAT at Rome 38.6° in 1859 is very low for an AEJ observation, even by the extreme-storm standard.

In any case, as Akasofu and Kamide (2005, A09226-p2) argued, it was *doubtful that the auroral oval descended to low latitudes*.

The exclusion of AEJ restricts the variants of potential causes of anomalous auroras, including those at low latitudes, as well as the explanation in the framework of the solar paradigm for H~3000 nT deviation at Rome Observatory on September 2.

According to modern estimates, the upper boundary of the auroras in 1859 was located at an altitude of ~ 400 km (Hayakawa et al. 2020, p. 5). At the same time, when meteors penetrate to low altitudes, about 50 km, they are observed from the Earth's surface only within a limited sector due to parallax. Meanwhile, scientists asserted in 1859 that auroras had been observed at altitudes of 100–1000 km. In my view, this suggests auroras' origin is either related to Comet Biela's secondary comets or Andromedids' explosions.

During the comet's 2014 impact with Mars, instruments recorded increased ionisation at altitudes of 105–150 km on both the night and day sides, caused by dust particles evaporated in the ionosphere and the comet's O+ fluxes. It is known that the cyclotronic radius of oxygen ions can reach up to 50.000 km. A persistent metallic layer in the Martian ionosphere was observed for 2.5 days, peaking many hours after the peak of the dust flux (Sánchez–Cano et al. 2018, pp. 8788, 8792).

Auroras occurring in connection with meteor showers have been known for a long time (Astapovich 1958, p. 430). As early as November 1799, A. Humboldt pointed out the effect of sky glow in connection with meteors. Admiral F. Wrangel also claimed that in the 19th century, he had repeatedly observed meteors initiating the auroral pillars (Wrangel 1827, p. 155; 1841, p. 1).

It was reported that, in November 1832, in Kursk Province, during the passage of meteors, it seemed as if dawn were beginning on all sides, and the lower part of the sky, around the horizon, was belted by a pale whitish cloud with separate bright crimson patches (Svyatsky 1922, p. 134). In England, a similar phenomenon was observed in 1933 and 1938 (Astapovich 1958, p. 430). It is therefore not surprising that during the Carrington event in Henry County, Indiana, the redness disappeared, but a cloud with a bright white fringe was left on the northern horizon.

(c) The low-latitude auroras.

The isolation of the September 2–3 auroras in La Union and San Salvador (El Salvador) from other low-latitude auroras (Hayakawa et al. 2022; Kimball 1960, p. 1) is not explained by the current paradigm of the solar origin of the Carrington Event.

However, fragmented swarms of meteors spread across and intersect the entire Earth with gaps due to their heterogeneity.

In rarefied streams, the distance between meteors reaches a million kilometres, but their commonality has been proven. This also applies to meteorites. For example, on January 30, 1868, identical compositions were established for meteorites that fell in Poland (near Pultusk), Madagascar (Nosy Be), and Italy (Lerici) (Astapovich 1958, p. 359).

The dense part of the 1885 Andromedids, as written by Newton (1886, p. 414), was approximately 100.000 miles in breadth, and the entire stream in thickness covered around 200.000 miles. The 1885 radiant was dispersed over a large area.

Therefore, the auroras caused by the Andromedids meteors of 1859 could have reached any point on our planet, including low-latitude regions, and might not have been directly dependent on the position of the plasmapause.

Under clear-sky conditions, individual auroras, as mentioned by scientists in 1859, could have been visible as far as the equator.

Such auroras were probably what were seen on September 2–3 at La Union and San Salvador (El Salvador)

(d) The energy of the particle precipitation.

Many researchers expected that during the Carrington Event, a very dense layer of ionised plasma (or ring current) and/or a high concentration of electrons in the plasmasphere could have formed.

Furthermore, it has been argued that if auroras, including whitish ones, were caused by the fallout of electrons with energies above ~1 keV, then the cause of the fallout is not understood (Hayakawa et al. 2020).

These issues remain unresolved.

However, the dense ion-electron population can be successfully attributed to the comets (Zhao et al. 2022, p. 41).

In contrast to the above-mentioned 'open question’, it should be noted that particles with energies *up to* 2 MeV have been recorded in comets (Sánchez–Cano et al. 2018, p. 8779).

(e) The anomalous brightness of auroras.

The brightness of the auroras of the Carrington Event, at which the Earth’s total illumination equals that observed during the full moon, corresponded according to Chamberlain (1961, p. 124) to the International Class IV Benchmark (IBC).

Since then, even modern scientific instruments have not registered such bright low-latitudes auroras. However, I will add that solar flares in white light are frequently observed, and coronal mass ejections frequently 'visit' our Earth.

Results from the '*Deep Impact*' mission to Comet Tempel in 2005 revealed *an increase in brightness* due to electric discharge and scattered sunlight on the ejected plasma dust after the impact.

If the meteors in 1859 had a metallic conductive composition, then, due to the perpendicular component, when crossing geomagnetic field lines, Foucault induction eddy currents could arise within them. This could lead to the skin effect, the successive detachment of outer sheaths, and, accordingly, to auroras (German 2025e, #0034).

The scenario could have been similar to the 1994 collision of fragments of the Shoemaker–Levy Comet with Jupiter (Churymov and Kruchinenko 1994, p. 10): high-speed entry into the magnetosphere/atmosphere → heating and explosions → transformation into plasma → auroras.

For the 1994 collision, the intensity of the shock wave radiation from one fragment of Comet Shoemaker–Levy was approximately ~ 10^{24} erg/sec (~ 10^{17} J/sec), according to Churymov and Kruchinenko (1994, p. 12).

In the Earth's atmosphere, the power of meteors was estimated at ~ $18x10^{17}$ erg/sec (Astapovich 1958, p. 425). Such a value explains the brightness of the auroras in 1859, which was equal to the surface illumination during a full moon.

The illumination of the surface during a full moon is ~ 0.2 lux, which corresponds to the luminosity of a fireball at a distance of 450 km in ~ 40×10^{9} cd (Astapovich 1958, p. 274). Fireballs of the same brightness as the moon and even brighter than the moon were observed.

For instance, regarding the apparent brightness of the large meteor in 1718, E. Halley reported that the full moon vanished and all the stars in the sky disappeared as if it were daytime.

The impressive size of meteors is associated with thermal ionisation of both the air and the substance of the meteor itself, and the subsequent recombination of ions, which leads to glow and auroras.

At a speed of ~ 40 km/sec, a meteoric body of 1 g is capable of ionising a 20-km cylinder with a diameter of 0.5 km in the atmosphere by short-wave radiation in 0.5 sec (Astapovich 1958, p. 435).

(f) The maximum diameter of the auroral rays bundle.

Finally, we have reached one of the *decisive* moments.

In 1859, the maximum diameter of the auroral rays bundle, noted by Shea and Smart (2006, p. 377), was ~20 miles (~*32.2* km), including probably a meteor track (Appendix A).

The space corresponding to each visible meteor in the densest part of the 1885 Andromedids shower was equal to a cube with an edge length of *~32.8 km* (Newton 1886, p. 425).

Empirically, depending on the brightness of a typical meteor, the length of its path was found to be *~33.0 km* (Astapovich 1958, §151, p. 239).

However, according to modern data, the standard diameter of the auroral rays bundle *associated with ICME is only ~1 km or less* (Baranoski et al. 2003, p. 47).

The conclusion is obvious.

2.2 DIFFUSE AURORAS AND ELECTRIC FIELDS OF COMETS

The type of auroras observed during the Carrington Event requires separate consideration. In addition to the two postulated ICMEs, proponents of the solar paradigm of the Carrington Event were also forced to postulate a new type of auroras: neither the diffuse nor discrete ones (e.g., Lui et al. 1973, p. 857), but the so-called 'low-latitude' auroras (Hayakawa et al. 2020, p. 125), i.e., ad hoc.

Although discrete auroras were also observed, very *diffuse*, structureless auroras on August 28/29 and September 2/3, 1859, were reported by many eyewitnesses, according to Green et al. (2006, p. 148).

According to the electrical theory of comets, *diffuse electrical discharges* occur in comets, leading to the emission of radiation at various frequencies, including X-rays, which are a primary characteristic of comets.

The '*ROSAT*' space telescope first detected the soft X-rays of Comet C/1996 B2 Hyakutake in March 1996 (Lisse 1996, p. 205). Since then, X-rays have been observed from many comets, including, most recently in December 2025, the interstellar Comet 3I/Atlas.

In addition, according to calculations by Maris (1927, p. 839), the emission of meteors in both the ultraviolet and soft X-ray ranges in the Earth’s atmosphere cannot be ruled out.

When the Earth passed through the tail of Comet Tebbutt in 1861, an unusual phosphorescent glow was observed on the evening of June 30, very similar to *a diffuse aurora* (Chambers 1909, p. 145).

In turn, the '*Rosetta*' probe identified the auroral origin of the emissions from the coma of Comet 67P/Churyumov–Gerasimenko. The aurora resembled the *diffuse aurora* on Mars. However, on Comet 67P, solar wind electrons were accelerated by the *ambipolar field inside the comet*, whereas on Mars, they are accelerated by the Sun. Therefore, as written by Stephenson et al. (2021, A119-p.16), auroras are stable on the comet, whereas on Mars, diffuse auroras are observed only due to strong solar events.

Thus, the mechanism of energy accumulation due to the internal ambipolar field allows comets to have magnetic fields of the order of 3000 nT and more.

Consequently, the Biela’s secondary comets/meteors could literally 'bring auroras with themselves' to Earth during the Carrington Event.

The detachment of comet tails has long been known (Chambers 1909, p. 65). Their ionisation explains the appearance of Andromedids on 14 November 1872, immediately after the solar white-light flare on 13 November 1872 (German 2025f, #0053). In 1798, 1838, and 1847, the longitude of the Sun was close to the node of the orbit of the 3D/Biela Comet in 1772 (Newton 1886, p. 424). This implies the possibility of their further synchronisation, including the time of the 1859 Carrington Event, as well as in 1872.

The magnitude of the geoelectric field on the Earth's surface (GIC) during the Carrington Event geomagnetic storm of September 1–2, 1859, is about *4 mV/m* (Pulkkinen et al. 2008, p. 8, Section 3). Recently, modeling of the electric field observed from 67P Comet for one day showed a magnitude of up to *4 mV/m* but calculations were also performed for a magnitude of *10 mV/m* on the comet's surface (Lewis et al. 2024, Section 3, Fig. 4). In this case, the change in electron temperature with cometocentric distance, as well as the magnetic field, was not taken into account. Such characteristics are close to the estimates of the possible electric fields (GIC) responsible for the Carrington Event.

Chambers (1909, pp. 25, 125) wrote that observers repeatedly claimed that comets flickered, like the Aurora Borealis. The tracks of some large comets vibrated. This was noted for the tails of the comets of 1618, 1769, and 1874.

Significant signs of pulsations were also present for Comet Morehouse of 1908. According to Chambers (1909, p. 125), the vibrations began in the head of the comet, and they seemed to travel in a few seconds along the entire comet's length.

On September 3, 1859, the report from Rochester noted that the white streamers of the aurora constantly flickered and danced.

Interestingly, in October 1835, astronomers compared the nucleus of Comet Halley to a stream of fire (Chambers 1909, p. 115); at times this flame scintillated, resembling the flickering of auroras. The observed scintillations and flashes can be attributed to plasma discharges, which exhibit nonlinear behaviour.

Already, K. Birkeland concluded that electric currents flow predominantly along filaments formed by magnetic fields induced by these currents (Fig. 1).

It is appropriate to cite supporting examples:

- Comet Pons in January 1884 had a nucleus consisting of two parts of different brightness, united by a pronounced twisted connection (Chambers 1909, p. 97).

- Comet Morehouse on November 19, 1908, had a tail consisting of separate strands that intertwined like strands of rope (Chambers 1909, p. 32).

- Comet Swift in 1899 showed signs of twisting, which suggested the idea of rotation or oscillation about a line drawn from the Sun to the comet (Chambers 1909, p. 26).

According to an article in the 'Providence Daily Post' (Rhode Island) published on September 3, 1859, similar filaments were also observed during the Carrington Event, when auroral light sometimes appeared as web-filaments that sometimes broke and fell to the ground (Green et al. 2006, p. 148).

Nitrogen and cosmogenic isotope deposits dating to 1859 do not support the solar origin hypothesis for the Carrington Event. What about these regarding the cometary hypothesis?

The answer is simple: the signal of cosmogenic isotopes and nitrates in the ices in 1859 is not high, since primarily into the Earth's atmosphere had entered the dust cometary fraction. The conductive dust was responsible for both the electrical currents within the comet and the anomalous brightness of the auroras, which resulted from the comet's discharges and from the scattering of sunlight on the dust. These auroras were probably observed by eyewitnesses of the Carrington event across various regions of the planet. Additional auroras were produced by meteor explosions (Section 2.1).

More arguments in favour of the cometary hypothesis in connection with the Carrington Event also include the following (specific examples are given in Appendix B):

(a) Observations within the auroras of dark bands, which are characteristic of the comet tails separation (Chambers 1909, p. 25),

(b) The visibility of stars through unusual dark clouds — an effect previously noted for Comet Biela by J. Herschel, when it passed in front of a cluster of stars, without causing an obscuring effect (Chambers 1909, p. 14).

I think these arguments also provide grounds for relating the Carrington Event auroras to secondary comets and the Andromedids meteors of Comet Biela.

CONCLUSION

- The current paradigm, based on the observation of a solar white-light flare by Carrington on September 1, 1859, as well as the hypothesis of impact on the Earth's magnetosphere by ICMEs' magnetic clouds, including their sheaths, does not explain the features of geomagnetic storms at the Observatories in Bombay and Rome, as well as two disturbance waves, with 6-h period, twice on August 28/29 and September 1/2 at Kew.

- It is unclear whether the observation by Carrington was truly an unusual solar event. Solar flares in the optical continuum, as modern technology has shown, are far from uncommon.

- Neither the impact of postulated ICMEs nor the anticipated high abundance of solar energetic particles (SEPs) during the Carrington Event is supported by traces of nitrates and/or cosmogenic isotopes ^{10}Be, ^{36}Cl, and ^{14}C found in terrestrial deposits of 1859. Thus, it can be stated that solar flares occurred, but there was no geoeffective ICME.

- Since there were no geoeffective sunspots or solar flares recorded before 1 September 1 1859, and the fast solar wind is not capable of initiating powerful geomagnetic storms with sudden commencement type, the claims of a 'cleansing' of the interplanetary space by 'snow plough' effect, associated with the solar activity and geomagnetic storm on August 28, 1859, as a prelude to the historical geomagnetic storm of September 2, 1859, are unfounded.

- All the phenomena associated with the Carrington event are in good agreement with the intersection of the Earth with secondary comets and Andromedids meteors of the disintegrated Comet Biela, expected by astronomers in 1859. The Andromedids lost most of their dust mass, with a high probability, in 1859.

- The eyewitness accounts published by the Smithsonian Institution contain numerous observations confirming meteor explosions across different parts of the planet, including a comet over Civitavecchia Bay near Rome.

- The X-ray and/or ultraviolet radiation currently attributed to the solar white-light flare of September 1, 1859, is also characteristic of comets.

- The mechanism of energy accumulation due to the internal ambipolar field allows comets to have magnetic fields of the order of 3000 nT and more. Cometary ions, such as O^+, are several times heavier than solar wind ions, leading to a cometary plasma energy density two orders of magnitude greater than the typical solar wind energy density. Therefore, O+ and other cometary heavy ions entering the Earth’s magnetosphere/ionosphere either as a result of their 'delivery' by solar wind magnetic tubes or within magnetic cometary tubes, could have caused the unusually high Dst geomagnetic indices and the abnormal auroras observed during the Carrington Event. Modern scientific evidence for such a possibility was obtained for the Comet 73P/Schwassmann-Wachmann in 2006.

- The main feature of the geomagnetic storms at Kew on August 28/29 and September 1/2, 1859, was a 6-h period, when the horizontal and vertical components in both cases twice decreased over the first 3 h, and increased over the next 3 h, until they again reached normal values after about 6 hours. This behaviour exactly corresponds to the passage of the Andromedids recorded on November 27, 1885, when an increase in the number of meteors was observed in the first 3 h, and, after a peak, their number decreased over the next 3 h, so that within 6 h the main part of the stream had passed. In other words, during the first 3 h, the increase in the Andromedids should have suppressed the geomagnetic field, and during the next 3 h, when the flux of cometary fragments decreased, both geomagnetic components increased again, returning to normal values.

These disturbances were likely associated with two jets/discharges of secondary comets 3D/Biela and/or the fragmented Andromedids shower. Comet 'A' could have had several nuclei and hence been capable of initiating several waves of disturbances in some days. The division of the cometary tail into two parts can also explain the two 6-hour waves recorded at the Kew Observatory.

However, the concept of ICMEs is refuted because there is no evidence of enhanced levels of cosmogenic isotopes, nitrates, or a radiation storm from energetic solar particles in the 1859 deposits, as well as the complex storm on 2 September.

- The observed diameter of the auroral rays contradicts the hypothetical ICMEs, but is consistent with cometary/meteoric characteristics.
- The current solar paradigm for the Carrington event cannot adequately explain the lack of magnetic B_H-deviation in Nerchinsk on September 2, 1859. The fragmented, with gaps, cometary stream does this successfully.
- The large and anomalously rapid changes in Colaba could have been related to discharges of ionised cometary dust plasma akin to lightning discharges.

- The predominant colours of the auroras — red and white, which are also predominant for comets and Andromedids — support the idea of collision between Earth and secondary comets and Andromedids meteors during the Carrington Event.

  Furthermore, dark streaks and clouds characteristic of dust comet tails were observed.

- The current standard paradigm postulates an unknown type of auroras — neither diffuse nor discrete — but, ad hoc, 'low-latitude'. However, during the Carrington Event, predominantly diffuse auroras were observed. Diffuse discharges inside comets and/or, given the diameter of the auroral beams, meteor explosions could be responsible for the initiation of diffuse auroras.

- For proponents of the classical solar paradigm, isolated auroras in El Salvador, as well as two H-depressions in Colaba on September 2, 1859, first on the dayside and then on the evening side, pose problems. However, wide meteor showers covering the entire Earth can reach any locations, including low-latitude regions, as well as the Colaba Observatory in India, first on the dayside and then on the evening side.

- The anomalous brightness of the auroras, which does not fit within the solar paradigm of the Carrington

Event, is explained by discharges of secondary comets of the 3D/Biela as well as Andromedids explosions and the reflection of sunlight on cometary dust.

- The signal of cosmogenic isotopes and nitrates in the ices in 1859 is not high, since primarily into the Earth's atmosphere had entered the dust cometary fraction.

- The recurrence of such a strong geomagnetic storm as September 2, 1859, should occur once every 60–200 years. Still, already in the next solar cycle, on February 4, 1872, another storm comparable to the September 2, 1859, event was recorded. Science offers no satisfactory explanation for this fact from the perspective of solar origin for the Carrington Event, but fragments of Comet Biela could also be responsible for the geomagnetic storm of 1872.

Although Comet Biela has most probably ceased to exist, the analogous class of comets, possessing enormous electrical charges, poses a dangerous threat to our civilisation.

If this new concept is correct, the current paradigm of the solar origin of the Carrington Event should be reconsidered.

The scientific community will likely benefit from further research.

Appendix A

AURORAS RAYS IN 1859 AND ANDROMEDIDS METEORS

Calculations showed that the speed of the Andromedids meteoroids of 1885 relative to the Earth was 57.300 km/h (Newton 1886, p. 414). From here, taking into account the hourly number of meteoroids ~5·1, the space corresponding to each visible meteor in the dense part of the group was a cube, the edge of which was equal to the cube root of (57.300×π)/5·1, i.e., *~32.8 km* (Newton 1886, p. 414).

According to Shea and Smart (2006, p. 377), the auroral beam diameter during the Carrington Event reached ~20 miles (including, probably, a meteor track), that is, *~32.2 km*.

For example, the fireball of March 24, 1933, over New Mexico, USA, had a track reaching ~4000 km^3, and several dozen small meteorites fell during this event (Astapovich 1958, p. 338; Nininger 1934, p. 291).

Since the diameter of the trace of a fireball is two orders of magnitude greater than its body (Solynuk 1980) and the body's radius of the fireball is ~ R=150 m, their combined diameter would be *D~30 km*.

Empirically, depending on the brightness of an ordinary meteor, the length of its path was established to be *~33 km* (Astapovich 1958, p. 239).

However, according to modern data (Baranoski et al. 2003, p. 47), the standard diameter of the auroral beam, *due to the impact of ICME, is only ~1 km or less.*

Appendix B

ADDITIONAL ARGUMENTS: DARK BANDS AND DUST CLOUDS

(a) It is known that often comet tails are divided in the middle by a dark band.

Such a noticeable dark band was characteristic, for example, of Comet Morehouse on November 18, 1908 (Chambers 1909, p. 25).

Eyewitnesses of the Carrington Event also repeatedly reported a dark band in the auroras:

- According to Shea and Smart (2006, p. 360), in Illinois, a *dark band* appeared under a white sky; after that, the dark belt remained on the horizon.

- Similar reports of a broad *dark band* extending over the hills, above which rose a huge luminous arch, came from the Southern Hemisphere as noted by Diaz (1861, p. 331).

Therefore, these messages may indicate that the comet's tail was *crossing the Earth*.

The division of the cometary tail into two parts can explain the two 6-hour waves at the Kew Observatory during the Carrington Event.

It was known that the Tasmanian newspaper 'Hobart Town Mercury' reported that a nebulous substance similar to stardust had been precipitated from the sky during the geomagnetic storm caused by the Carrington event.

However, such dust is poorly associated with coronal plasma ejections, but well associated with *dust produced by the fragmentation of comets*, as well as with the so-called *fog meteors* known in meteoritics (Astapovich 1958, p. 357).

For example, it was well known that the passage of the meteor stream from June 22 to 26, 1975, coincided with peaks in the conductivity of the E-layer ionosphere in Brazil.

Fragments of this meteor stream were well modeled as dust balls.

Over ten days, meteoroid material affected atmospheric ionisation at levels comparable to those of a solar flare.

(b) Multiple reports of dark clouds during the Carrington Event.

- In Burlington, a significant number of black clouds were observed moving south.

- At Cape Otway, Australia, as the '*Melbourne Argus*', September 1, 1859, noted, throughout multi-coloured light were dark heavy clouds (Green et al. 2006, p. 147).

Could these clouds be associated directly with the cometary dust, or with clouds of dust lifted from the ground by impacts of the 3D/Biela fragments?

In the latter case, it probably makes sense to search for craters in the marked locations, primarily at the bottom of Civitavecchia Bay, and also to examine the ice cores from 1859 in Greenland and Antarctica for the presence of the cosmic substance matching the composition of the Mazapil meteorite.

At the same time, there were the following interesting reports during the Carrington Event:

- According to Diaz (1861, p. 340), through the light of the aurora, all the stars could be seen.

- The sky in Hamilton was covered in a dark, cloudy substance, yet stars could be seen through it, *so it was no ordinary cloud* (Shea and Smart 2006, p. 348).

Since the astronomer J. Herschel once observed Comet 3D/Biela, which passed in front of a cluster of stars (Chambers 1909, p. 14) *without causing any of their obscuring effect*, it is reasonable to attribute the above reports of dark clouds to the dust fraction of fragments/meteors of Comet 3D/Biela.

CONFLICT OF INTEREST

The author declare no conflicts of interest relevant to this study.

GLOSSARY

Ambipolarity – the conjugate motion of positively and negatively charged particles, which ensures the conservation of internal electric fields.

Bifilar magnetometer – the device, which can be used for measuring (absolute) horizontal intensity and field variations; in this, the needle is suspended by two threads so that its movement is constrained.

CIR – originating from coronal holes, corotating high-speed streams, which overtake slower-speed solar wind.

CMEs – coronal mass ejections by the Sun.

Crochet – a sharp, small hook-shaped excursion on the magnetograms, attributed also to the solar flare.

Declination – deviation from true north, i.e., the angle between the geographic north pole and magnetic north, where a compass points.

'Deep Impact' – the NASA mission to Comet Tempel in 2005, to determine its interior composition and other characteristics; the comet turned out to be dustier and less icy than expected.

Dst-index – an index whose maximum negative value is an accepted measure of the intensity of a magnetic storm.

FACs – field-aligned currents flow along the Earth's magnetic field lines, coupling the dynamic energy/momentum between the magnetosphere and high-latitude ionosphere.

Fluorescence – re-emission of absorbed (sun)light.

GIC – geomagnetic induced currents.

ICMEs – interplanetary coronal mass ejections by the Sun, travelling through space, often accompanied by a shock wave and magnetic cloud, potentially leading to geomagnetic storms.

IEF– interplanetary electric field (IEF=−VxBs, where V is the speed of the solar wind, Bs is the interplanetary magnetic field).

'MAVEN' – Mars Atmosphere and Volatile Evolution spacecraft.

Pinch effect – a generation of self-limiting magnetic fields, forming dense filamentary structures in the comets due to electric currents flowing through the comet's dusty plasma.

Ring current – a flow of charged particles orbiting the Earth in the equatorial plane, centred at altitudes of ~10000-60000 km, and forming a toroidal electric current in the magnetosphere. A ring current associated with enhanced magnetospheric convection and/or magnetospheric sub-storms lowers Dst.

SEPs – solar energetic particles.

SFEs – solar flares.

Sheet-like auroras – auroral light in the form of vertical sheets, due to the movement of cosmic particles along the lines of the geomagnetic field.

SID (the Mögel–Döllinger effect) – a change in conductivity in the ionospheric dynamo-region, manifested only on the illuminated side of the Earth.

SIR – a stream slow–fast interaction regions, including CIR, where the total pressure reaches a maximum; the SIR-related shocks can efficiently accelerate charged particles and trigger geomagnetic activity.

'Snow plough' effect – a 'cleansing' of the interplanetary space by the first ICME, which is attributed to the prelude leading to the rapid 'delivery' of the next ICME.

SPEs – emission from solar protons, probably are a subset of SEPs.

'Suisei' (PLANET-A) – the spacecraft, part of the 'Halley Armada' mission, took measurements of the comet's environment directly on site for the first time.

'TUNDE-M' – the experiment used two analysers/telescopes aboard the Vega-1 spacecraft, which detected intense fluxes of energetic (> 40 keV) ions in the vicinity of Comet 1P/Halley in 1986.

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