



Great “Space Weather Events” in March 1653 and September 1672 Were Not Supported With Simultaneous/Clustering Auroral Observations During the Maunder Minimum

Kentaro Hattori^{1*}, Hisashi Hayakawa^{2,3,4} and Yusuke Ebihara⁵

¹Graduate School of Science, Kyoto University, Kyoto, Japan, ²Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan, ³Institute for Advanced Research, Nagoya University, Nagoya, Japan, ⁴Space Physics and Operations Division, RAL Space, Science and Technology Facilities Council, Rutherford Appleton Laboratory, Harwell Oxford, Didcot, United Kingdom, ⁵Research Institute for Sustainable Humanosphere, Kyoto University, Uji, Japan

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*Correspondence:

Kentaro Hattori
hattori@kueps.kyoto-u.ac.jp

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The solar activity has been significantly weakened during the Maunder Minimum (MM: 1645–1715), whereas it has been somewhat controversial to reconstruct the actual solar-activity magnitude and the space weather activity in this interval. Here, the East Asian records provide unique references for the low-latitude aurorae in the MM, particularly with the (quasi-)simultaneous candidate auroral accounts in March 1653 and September 1672. These cases have formed unique cases for the intense space weather events and solar-terrestrial interactions in the MM. In particular, the former has been regarded as “virtually incontrovertible evidence” for an intense geomagnetic storm in the Maunder Minimum, despite significant suppression of the solar activity therein. Thus, this record has attracted scientific interpretations on the physical mechanism. However, our philological analyses have traced these source records further back to their original sources and have detected chronological problems in the Japanese source documents. For the 1653 March event, we have identified that the Japanese record retrospectively referred to a hearsay report between 31 December 1652 and 28 January 1653, instead of one on 2 March 1653. Our modification has been verified in two additional contemporary records. In addition, we have further analysed the candidate auroral report of 21 September 1672, which has been subjected to the doubts on the chronological errors. Herein, we have consulted contemporary records and reinforced the revised date of 7 September 1635. Our philological study has cast serious caveats on the reliability of the (quasi-)simultaneous East Asian records for candidate aurorae during the Maunder Minimum, emphasised the importance of philological studies on the auroral records, and highlighted that further discussions are required on the solar–terrestrial environment in the grand solar minima.

Keywords: maunder minimum, solar activity, aurorae, east asian historical records, philological analyses

INTRODUCTION

In the four centuries of telescopic observations since 1610, the Maunder Minimum (MM) (1645–1715) is an exceptional interval that has been uniquely characterised by extreme scarcity of sunspot occurrences, their extreme hemispheric asymmetry, and apparent loss of solar coronal streamers (Eddy, 1976; Riley et al., 2015; Usoskin et al., 2015; Hayakawa et al., 2021a). These characteristics contrasted the MM with regular solar cycles and even with the Dalton Minimum (Muñoz-Jaramillo and Vaquero, 2019; Hayakawa et al., 2020a; Hayakawa et al., 2020b; Hayakawa et al., 2021b; Arlt and Vaquero, 2020; Silverman and Hayakawa, 2021). Thus, the MM has been used as a standard reference to understand similar grand minima detected in cosmogenic isotopes in tree rings and ice cores (Usoskin et al., 2014; Brehm et al., 2021; Usoskin et al., 2021).

However, the exact level of solar activity during the MM has remained somewhat controversial, and it has required a series of analyses of historical records (Usoskin et al., 2015; Vaquero and Trigo, 2015; Zolotova and Ponyavin, 2015;

Svalgaard and Schatten, 2016; Carrasco et al., 2021). Similarly, it is scientifically important to analyse the space weather environment during the MM. Particularly, it is known that the occurrence frequencies of interplanetary coronal mass ejections (ICMEs) and resultant geomagnetic storms have occurred somewhat independent of the solar activity magnitude, such as the sunspot number (Kilpua et al., 2015; Lefèvre et al., 2016; Hayakawa et al., 2020c; Owens et al., 2021). Some statistical analyses have also extended the implications of the geomagnetic activity in deep solar minima to understand the space weather activity during the MM, such as those for the corona-hole activities and the ICME occurrence frequencies (Tsurutani et al., 2011; Owens and Lockwood, 2012).

Candidate auroral records have also been exploited to visualise the footprints of space weather events during the MM since Eddy (1976). As no geomagnetic measurements were known in the MM, these candidate auroral records have formed unique references for intense geomagnetic storms, the solar-terrestrial interactions, and the magnetospheric and ionospheric responses to the solar-wind transients in the

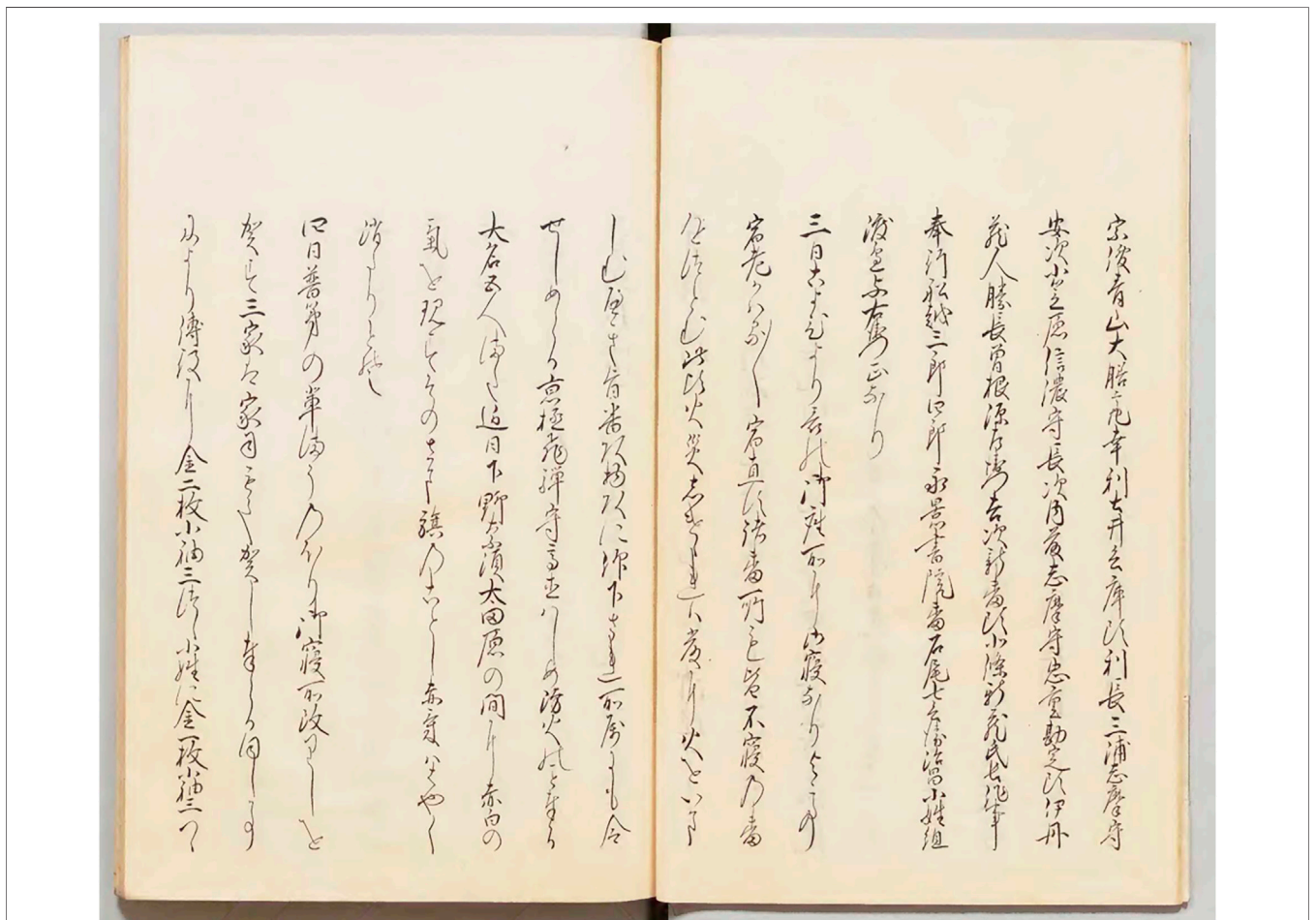


FIGURE 1 | Candidate auroral record in the original manuscript of *Genyu-in dono Gojikki* (J01), reproduced from the manuscript in the National Archives of Japan (MS Special 075-0001–0193, v. 5, f. 10a).

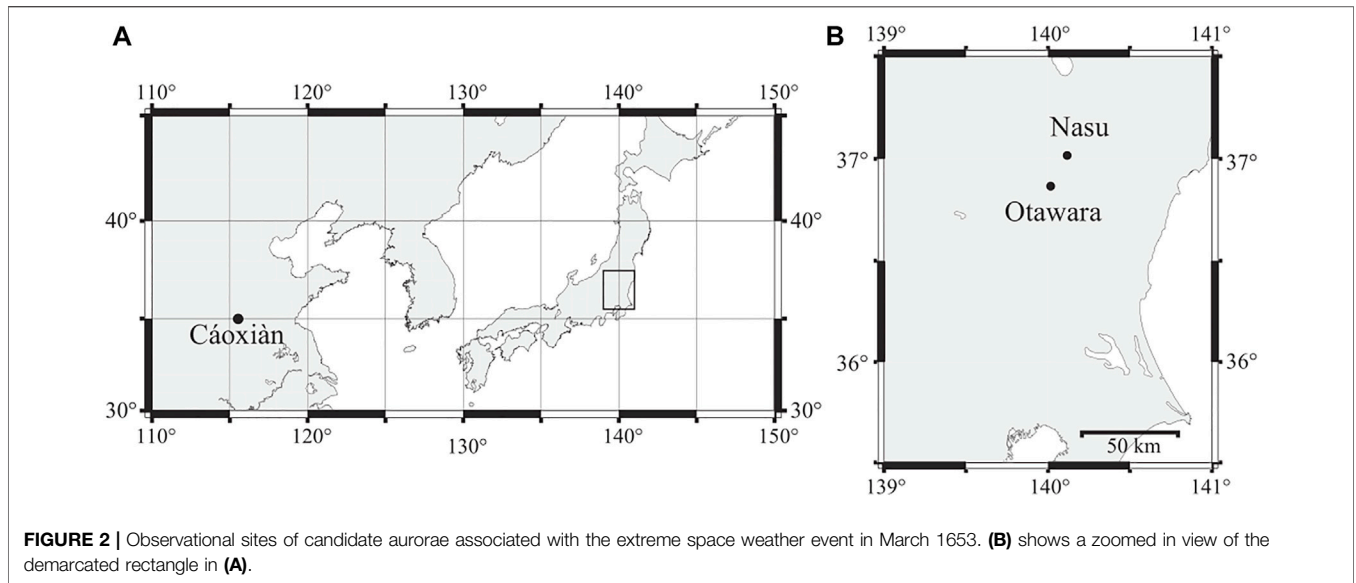


FIGURE 2 | Observational sites of candidate aurorae associated with the extreme space weather event in March 1653. **(B)** shows a zoomed in view of the demarcated rectangle in **(A)**.

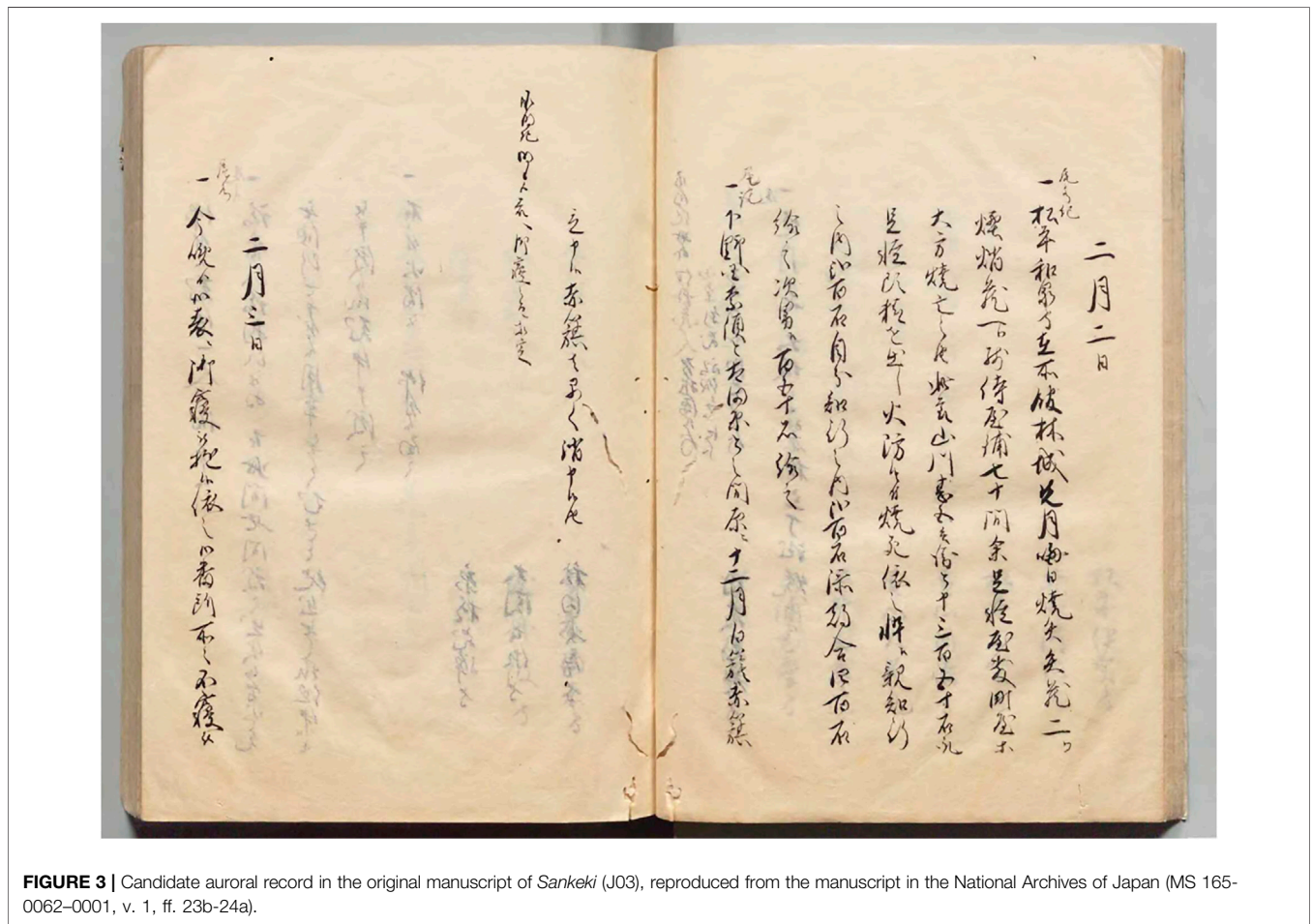


FIGURE 3 | Candidate auroral record in the original manuscript of *Sankeki* (J03), reproduced from the manuscript in the National Archives of Japan (MS 165-0062-0001, v. 1, ff. 23b-24a).

MM (Eddy, 1976; Silverman, 1993; Willis and Stephenson, 2000; Riley et al., 2015; Usoskin et al., 2015; Zolotova and Ponyavin, 2016; Isobe et al., 2019; Hayakawa et al., 2021a; Wang et al.,

2021a; Wang et al., 2021b). These records have visualised a notable decrease in space-weather-event frequency during the MM in several datasets, thereby confirming that auroral activity

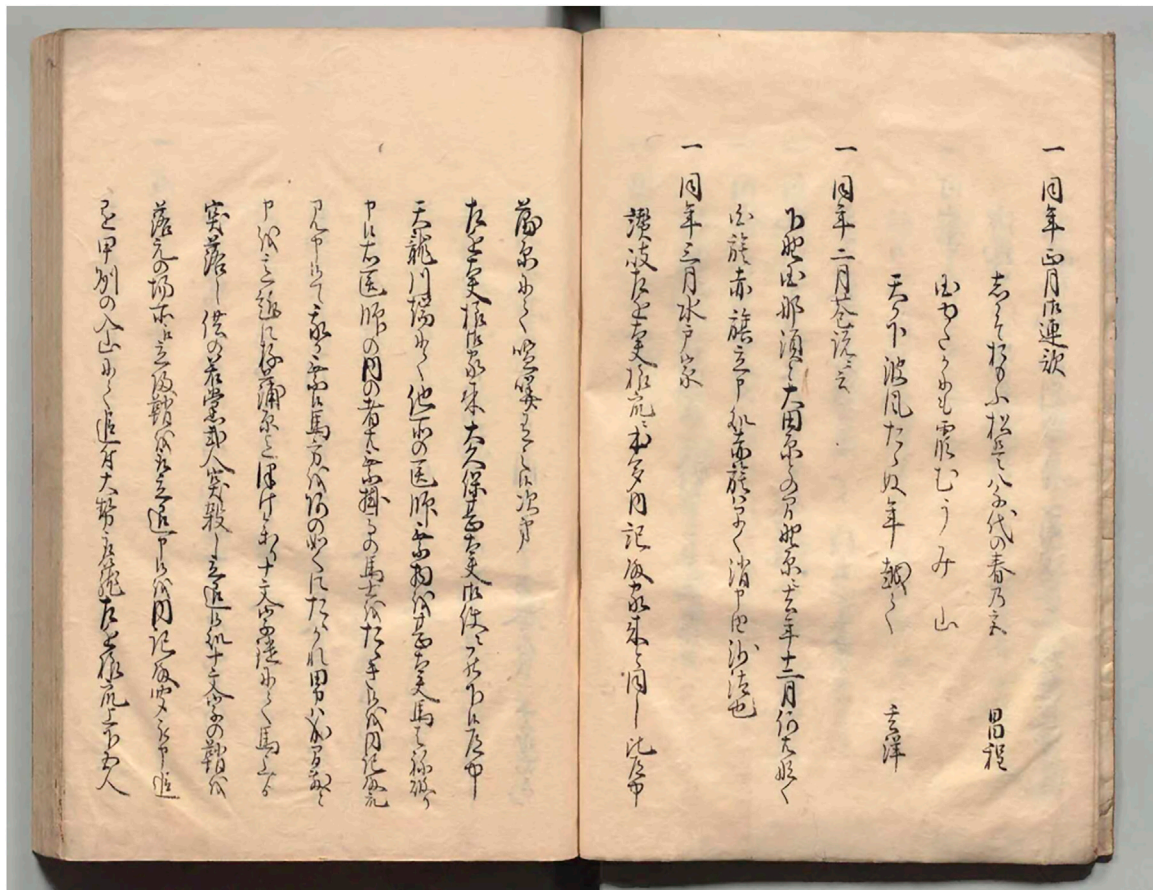


FIGURE 4 | Candidate auroral record in the original manuscript of *Sho Tomegaki* (ST:J04), reproduced from the manuscript in the National Archives of Japan (MS 158-0515-0007, v. 1, f. 3b).

did not completely suspend either (Silverman, 1992; Riley et al., 2015; Usoskin et al., 2015; Vaquero and Trigo, 2015; Vázquez et al., 2016; Hayakawa et al., 2021a). Several candidate auroral records have been located in mid/low-latitude regions, and they have been associated with significant geomagnetic storms that most likely resulted from ICMEs (Matsushita, 1956; Willis and Stephenson, 2000; Vázquez et al., 2016; Zolotova and Ponyavin, 2016; Isobe et al., 2019). However, caveats must be noted here because philological case studies have revealed that several probable misinterpretations have apparently overestimated the auroral frequency, mimicking atmospheric optics and meteor showers with the candidate auroral records (Réthly and Berkes, 1963; Usoskin et al., 2017; Hayakawa et al., 2021a; Stangl and Foelsche, 2021). In this regard, these philological case studies are particularly important, which occasionally overturn the ground basis of our understanding on the space weather activity back in the MM, as conducted in the thorough philological discussions in Usoskin et al. (2017) against the conventional interpretations in Zolotova and Ponyavin (2016).

Among the candidate auroral records in East Asia, those of March 1653 and September 1672 are the most reliable records

of space-weather episodes with simultaneous and quasi-simultaneous auroral observations in East Asia (Willis and Stephenson, 2000; Nakazawa et al., 2004). The March 1653 event has been tentatively associated with a great filament eruption because historical sunspot records indicate few to no sunspots on the contemporary solar disk based on Hevelius' record (Isobe et al., 2019), whereas the existing datasets (e.g., Hoyt and Schatten, 1998) have been regularly subjected to the revisions (Vaquero et al., 2016; Hayakawa et al., 2021c). In contrast, the reliability of the September 1672 storm has recently attracted critical reanalyses (Isobe et al., 2019). If confirmed, these candidate aurorae will form unique references for the extreme space-weather events in the MM because they are among the few events that are supported by quasi-simultaneous observations, and the observational sites are located at low magnetic latitudes. This study makes a novel contribution to the literature by tracing the Japanese record back to its provenance, and we show that the existing understanding differs slightly and should be modified. References of historical records for Japanese auroral observations in this study are shown in **Supplementary Material**.

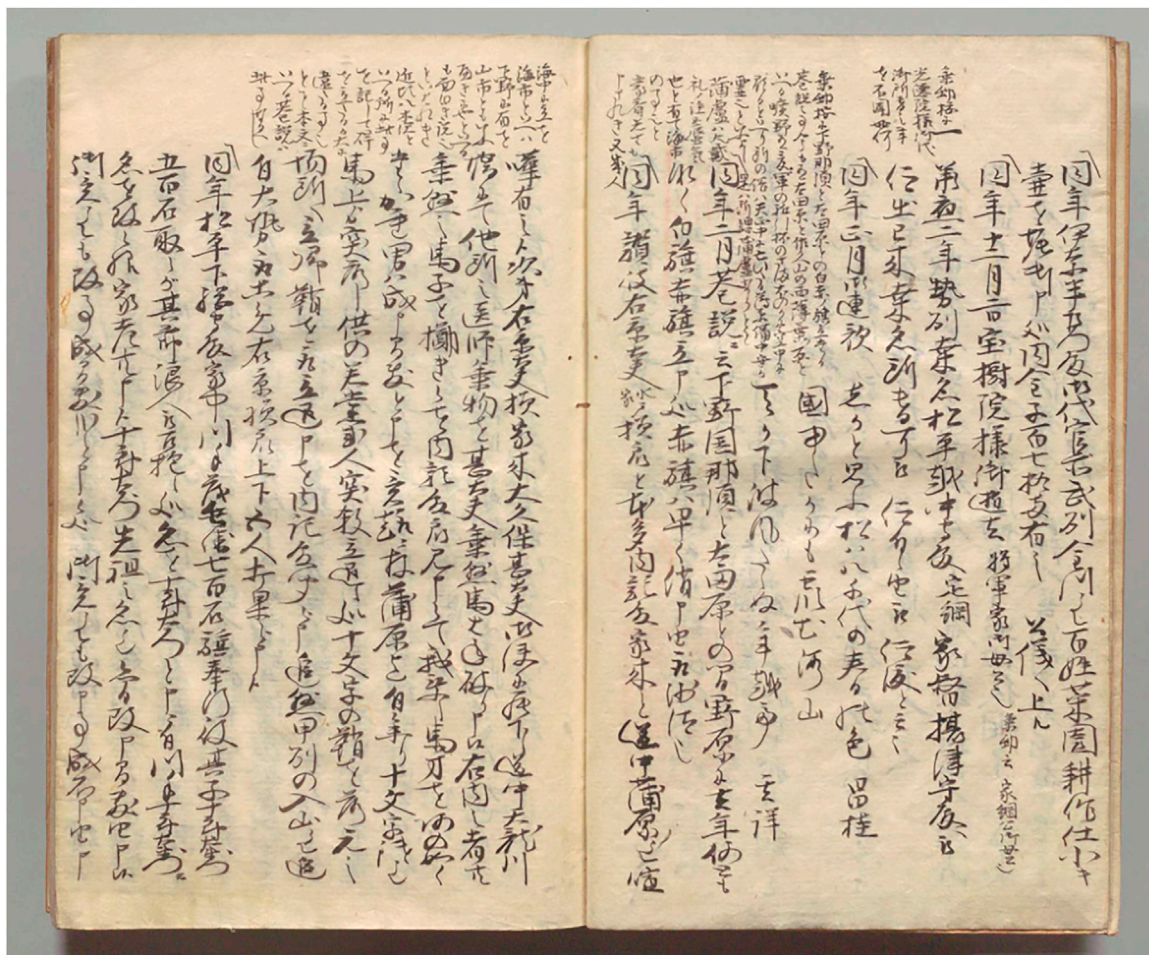


FIGURE 5 | Candidate auroral record in the original manuscript of *Ohshuku Zakki* (OZ:J05), reproduced from the manuscript in the National Diet Library of Japan (MS 238-1, v. 79, f. 2b).

SOURCE DOCUMENTS FOR THE MARCH 1653 STORM

Tokugawa Jikki (徳川実紀: hereafter *TJ*) and *Yānzhōufū Cáoxiànzhì* (兗州府曹縣志; v. 18, f. 10a: hereafter *YCZ*) have been cited as the simultaneous 1653 candidate auroral records in Japan and China in previous studies (Matsushita, 1956; Willis and Stephenson, 2000; Isobe et al., 2019). Here, we have consulted the original manuscripts (J01 and J02) of *TJ* from the National Archives of Japan (Figure 1) to confirm Isobe et al. (2019) translation (e.g., correcting Odawara to Otawara), and we compared this with their translation of the Chinese candidate auroral record. *TJ* is the official chronicle of Tokugawa Shoguns of the Edo period, of which *Genyu-in dono Gojikki* of the fourth shogun Tokugawa Ietsuna (1651–1680) includes the 1653 candidate auroral descriptions (J01 and J02). We present a modified version of Isobe et al. (2019) translation as follows:

On Joo 2nd year, 2nd month, 3rd day (1653 March 2), ... recently, red and white vapours appeared between Nasu and

Otawara in Shimotsuke. They were like flags. It is said that the red vapour vanished earlier. (*Genyu-in dono Gojikki*, v. 5, f. 10a).

On Shūnzhì 10th year, 2nd month, 3rd day (1653 March 2), during night, fiery lights illuminated the heaven in four directions. After a while, they became a blue wisp. (*YCZ*, v. 18, f. 10a).

Since Matsushita’s study (1956), the subject of this report was interpreted as one of the low-latitude aurorae observed in Japan on 2 March 1653, and this interpretation has been followed in the scientific community (Osaki, 1994; Willis and Stephenson, 2000; Nakazawa et al., 2004; Isobe et al., 2019). This record has been associated with the Chinese record of the same date to confirm the candidate auroral observations at Nasu (N37°01', E140°07'), Otawara (N36°52', E140°01'), and Cáoxiàn (N34°59', E115°32'), as shown in Figure 2. Following the archaeomagnetic field model GUFM1, we have computed the magnetic latitudes (MLATs) of the candidate auroral observations as 29.7° MLAT, 29.9° MLAT, and 28.4° MLAT, respectively.

In these studies, “recently” in *TJ* has been interpreted as 2 March 1653, namely the record entry date; however, this term

admittedly involves some chronological ambiguity. Following our investigation on the record provenance for this entry in *TJ*, we have revealed that the date actually referred to Joo period, 1st year, 12th month (31 December 1652–28 January 1653). According to Komiya (2000), *Sankeki* is one of the original materials of *TJ*, and the source of *Genyu-in dono Gojikki* in *TJ* in 1653/1654 (Joo period 2nd year) relied on *Sankeki*. Here, we have consulted the original manuscript from the National Archives of Japan, and we translated this record as follows:

In the 12th month, red flags and white flags were hoisted in a field between Nasu and Otawara in Shimotsuke. It is said that the red flag vanished earlier. (*Sankeki*, v. 1, ff. 23b-24a).

This record is similar to that described in *TJ*, except for some minor details. First, the reddish and whitish vapours are described as reddish and whitish flags here. Second, this record dated the phenomenon to be in the "12th month" instead of "recently" in *TJ* (Figure 3). This confirms that this record was most probably not an observation on 2 March 1653, but a recollection on this date of previous hearsays. This event is chronologically located in the 12th month of the previous year of the entry date, namely Joo 1st year 12th month, which ranges from 31 December 1652 to 28 January 1653. Therefore, this report requires the revision of the observational date of the

said candidate aurora from 2 March 1653 to within the period of 31 December 1652–28 January 1653.

This date range is further confirmed with the parallel records in *Sho Tomegaki* (hereafter *ST*) and *Ohshuku Zakki* (hereafter *OZ*), which read as follows:

In the same year (Joo 2nd) second month, it was rumoured that last year, the 12th month, white flags and red flags were somehow hoisted in a field between Nasu and Otawara in Shimotsuke. It is said that the red flag vanished earlier. (*ST*, v. 1, f. 3b).

In the same year (Joo 2nd) second month, it was rumoured: last year, the 12th month, white flags and red flags were somehow hoisted in a field between Nasu and Otawara in Shimotsuke. It is said that the red flag vanished earlier. (*OZ*, v. 79, f. 2b).

These records also dated the candidate aurora to be in the "12th month," as shown in Figures 4, 5. *OZ* (J05) had been written under Norimura Komai (1766–1846) since 1815. Figure 5 shows J05, which was adopted from MS 238-1 (v. 79, f. 2b) of the National Diet Library of Japan. The author of *ST* is unknown, and *OZ* (J05) is an essay by Norimura Komai. A part of *OZ*, including the auroral descriptions, have been transcribed by an online crowdsourcing platform 'Minna de

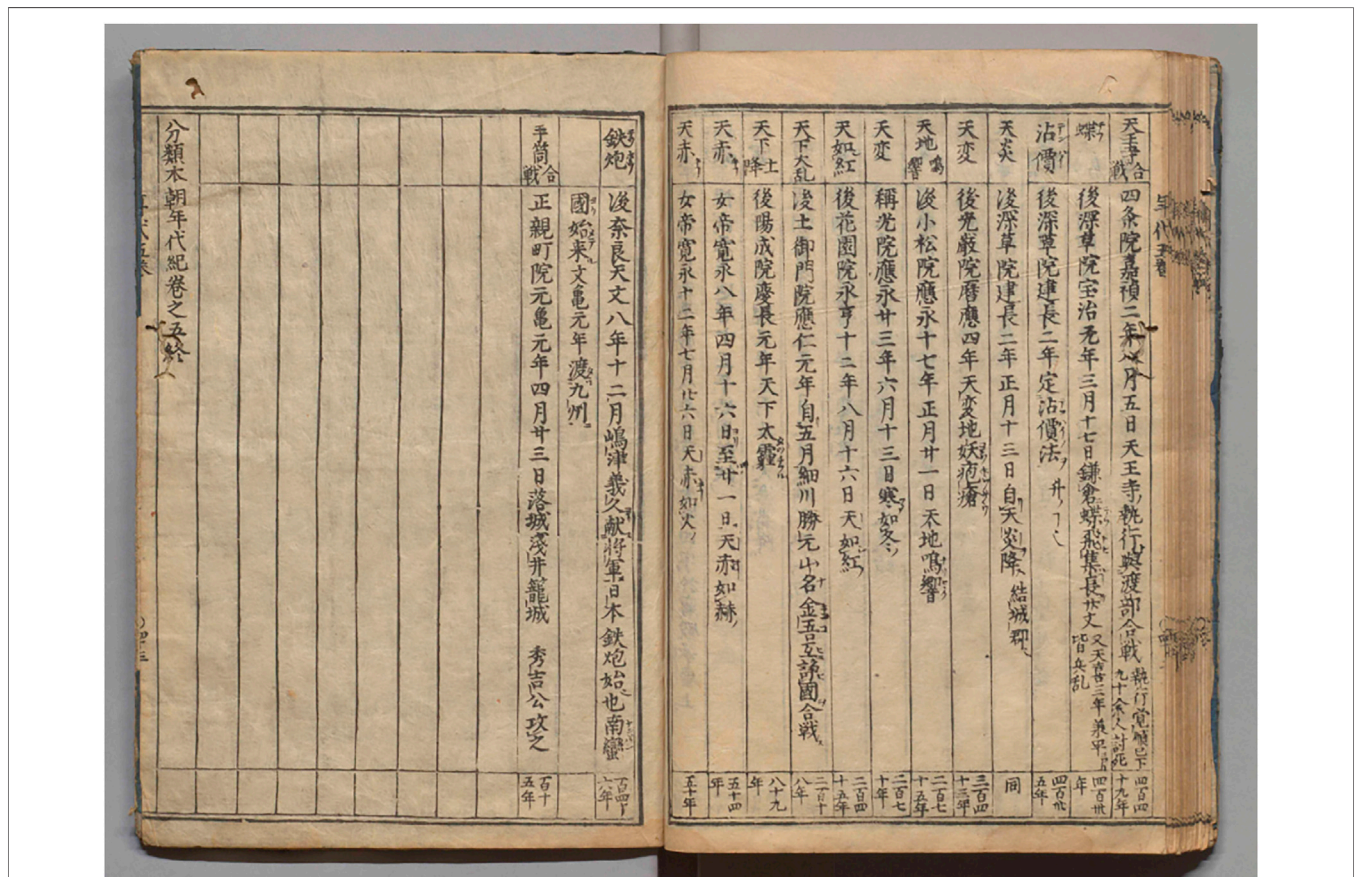


FIGURE 6 | Candidate auroral record in the original manuscript of *Honcho Nendaiki* (HN:J06), reproduced from the manuscript in Ochanomizu University (MS D11/633/5, v. 5, f. 42b).

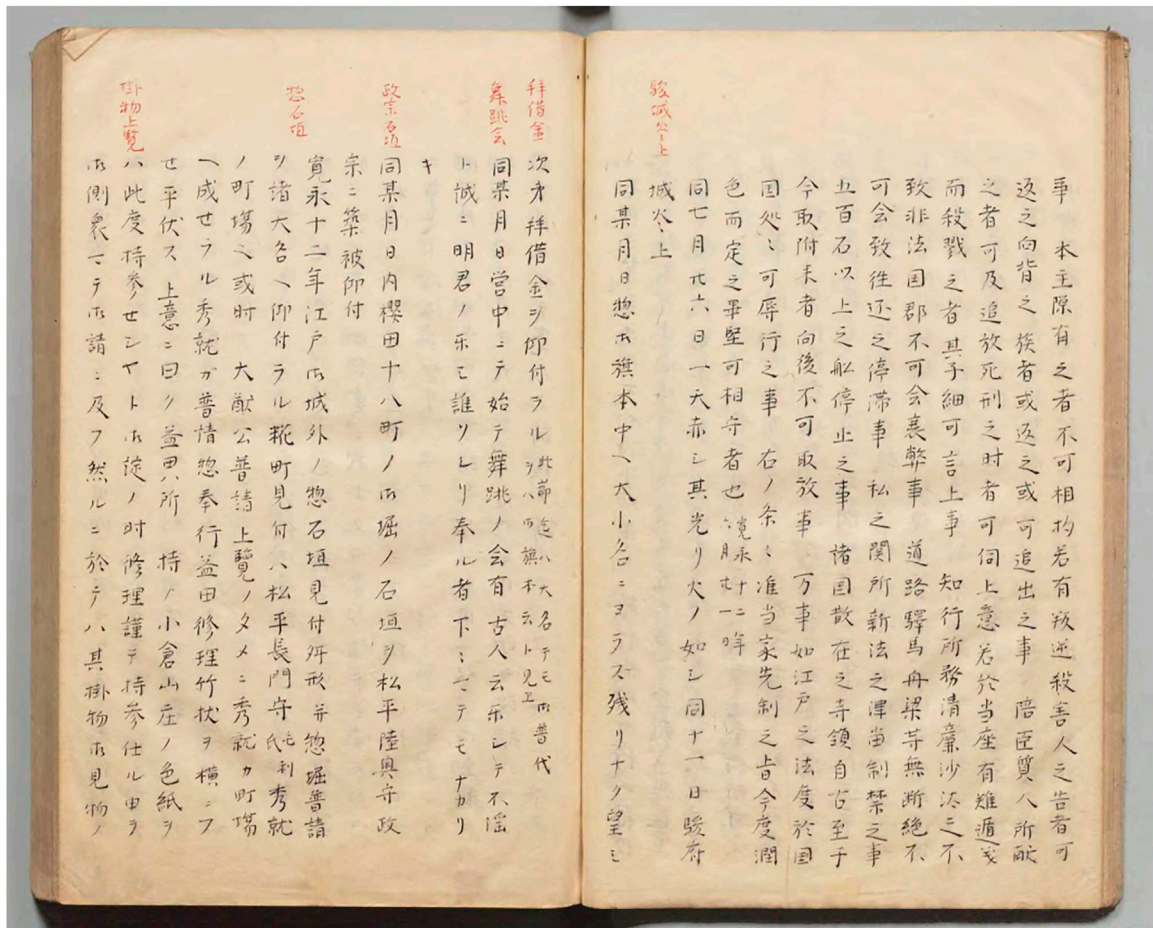


FIGURE 7 | Candidate auroral record in the original manuscript of *Kunshin Genkoroku* (J07), reproduced from the manuscript in the National Archives of Japan (MS 158-0515-0007, v. 7, f. 22b).

Honkoku’ (Hashimoto and Kano, 2018). Notably, these records explicitly clarify that the candidate aurora appeared ‘the previous year’, but its description was not explicitly clarified in *Sankeki* (Figure 3). Their chronological order indicates that OZ owed this record to ST, whereas it is not certain if the candidate auroral records in *Sankeki* relied on these manuscripts.

SOURCE DOCUMENTS FOR THE SEPTEMBER 1672 STORMS

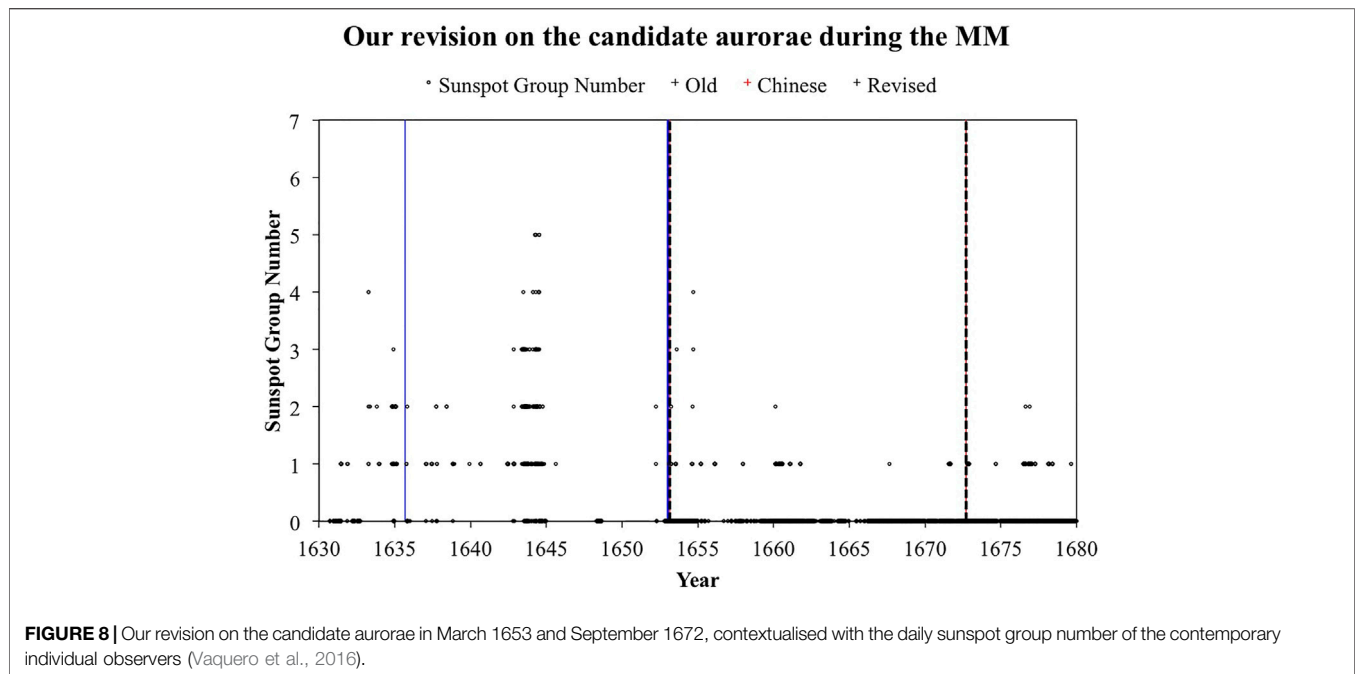
Honcho Nendaiki (本朝年代記, v. 5, f. 42b; hereafter *HN*) and *Píngwàngzhì* (平望志, v.13, f.6b; hereafter *PZ*) have been associated with the quasi-simultaneous 1672 candidate auroral records in Japan and China in previous studies (Osaki, 1994; Nakazawa et al., 2004); however, this has been subjected to criticism by Isobe et al. (2019). Here, we have consulted the original manuscript of *HN* from Ochanomizu University (Figure 6) and translated these records from the original source documents:

事 本主原有之者不可相拘若有叛逆殺善人之告者可
 逐之向背之族者或逐之或可逐出之事 陪臣質人所敵
 之者可及追放死刑之時者可伺上意若於当座有難遁
 而殺戮之者其手細可言上事 知行所務清濠沙汰之不
 致非法固郡不可會喪弊事 道路驛馬舟梁等無斷絕不
 可會致往還之滯滯事 私之閑所新法之律當制禁之事
 五百石以上之船停止之事 指國散在之寺鎮自古至于
 今取附未者向後不可取放事 万事如江戸之法度於國
 國處、可辱行之事 石ノ糸、准当家先制之昔今度潤
 色而定之罪堅可相守者也 寛永十二年
 同七月廿六日一火赤ニ其光リ火ノ如シ同十一日駿府
 城々上
 同某月日惣西標本中へ大小名ニヨラズ残りナク望ミ

On Kāngxī 11th year 8th month 1st day (21 September 1672), during night, crimson vapour filled the heaven like fiery sand. (*PZ*, v.13, f.6b).

On Kan’ei 12th 7th month 26th day (7 September 1635), the heaven was red. (*HN*, v. 5, f. 42b).

These candidate auroral records locate the observational sites at Kyoto (N35°01’, E135°46’) and Píngwàng (N30°59’, E120°38’). Following the archaeomagnetic field model GUFM1, we have computed their magnetic latitudes (MLATs) as 29.7° MLAT and 28.4° MLAT, respectively. However, as commented by Isobe et al. (2019), the Japanese candidate auroral record was misdated as 17 September 1672 in previous studies (Osaki, 1994; Nakazawa et al., 2004), and the actual record is dated on 7 September 1635. Among the existing scientific literature, the Japanese report of the 1672 candidate aurora was first proposed in Osaki (1994), and this may be because the word Kan’ei (寛永) was misread as Kanbun (寛文), as explained in Isobe et al. (2019). This is probably because they are sharing the same Chinese character in their first characters. This mistake has been carried over to Nakazawa et al. (2004) as well.



Our archival investigation has attributed further credibility to this interpretation using independent contemporary records. **Figure 7** shows a folio of *Kunshin Genkoroku*, which reads: “On Kan’ei 12th 7th month 26th day (7 September 1635), the entire heaven was red. Its brightness was like a fire” (*Kunshin Genkoroku*, v. 7, f. 22b). Here, we find more details than those in *HN*, such as the spatial coverage of the whole sky and the brightness being compared with a fire. This record robustly confirms the date given in *HN* and leaves little doubt on the chronological misinterpretation in Osaki (1994) and Nakazawa et al. (2004).

SUMMARY AND DISCUSSIONS

In this study, we have philologically analysed two clusters of the East Asian candidate auroral records from March 1653 and September 1672, which have been associated with simultaneous and consecutive auroral observations (Willis and Stephenson, 2000; Nakazawa et al., 2004). The former has been particularly considered as “virtually incontrovertible evidence” of auroral activity during the MM (Willis and Stephenson, 2000), and has been tentatively associated with a possible filament eruption (Isobe et al., 2019). However, our philological analyses have revealed dating problems in the Japanese records of these candidate aurorae.

For the March 1653 event, the Japanese record was derived from *TJ* (**Figure 1**) and dated as 2 March (Joo 2nd year 2nd month 3rd day); it was assumed that the “recent” celestial phenomenon occurred on the date the record was created. However, we investigated *Sankeki*, which is the original source for *TJ* in this year, and we revised the event date to the period 31 December 1652–28 January 1653. This revision has been supported by two contemporary records: *ST* and *OZ* (**Figures 4, 5**).

Likewise, for the September 1672 event, the original date was previously subjected to criticism by Isobe et al. (2019). We have confirmed their criticism with further archival evidence (**Figure 6**). We have also reinforced the revised date of 7 September 1635 (instead of 21 September 1672) with further contemporary records (**Figure 7**). As a result, we consider these records do not indicate a genuine aurora in September 1672 but a probable candidate aurora in September 1635.

Therefore, our study challenges the evidence supporting simultaneous observations in Japan and China, thereby, challenging the “virtually incontrovertible evidence” of auroral activity during the MM (Willis and Stephenson, 2000; Isobe et al., 2019). Our conservative interpretation is consistent with the known datasets for the contemporary sunspot group number (Vaquero et al., 2016), as these datasets locate the closest active days (with sunspots) for the alleged (quasi-)simultaneous auroral candidates on 2 March 1653 and 17 September 1672 only more than almost a month apart: on 5 February 1653 and 18 October 1672 (**Figure 8**). This means that the Sun was at least not quite active, while we certainly need to be extra cautious on the data scarcity and the contamination of ghost spotless days (Vaquero et al., 2016; Hayakawa et al., 2021c; Hayakawa et al., 2021d). This is fully contrasted with the simultaneous candidate auroral records in June 1680, which has been coupled with a distinct sunspot group at its chronological proximity (Hayakawa et al., 2021a).

However, their independent descriptions do not seriously contradict auroral interpretations, especially for the datable Chinese records. The reddish and fiery colourations are consistent with the typical low-latitude aurora, which is related to the type A aurora (Chamberlain, 1961, pp.124–125), and stable auroral red arcs (Rees, 1961; Kozyra et al., 1997), where low-energy electrons excite atomic oxygen in the upper atmosphere. The 1653 event may be also associated with the “blue wisp,” which refers to

bluish emissions of molecular nitrogen ions, known as the sunlit aurorae (Hunten, 2003), although it is difficult to draw a definite conclusion since the observation time is unknown. These reports are confirmed as nighttime observations, owing to the observed colouration and significant spatial extents. There is a possibility that energetic neutral atoms originate from the storm-time ring current and result in bluish emission from molecular nitrogen ions (Tinsley et al., 1986). However, it is extremely difficult to associate these phenomena with atmospheric optics because nighttime atmospheric optics have a limited spatial extent and virtually imperceptible colourations when observed with the human eye (Minnaert, 1993, pp. 207–232).

Overall, these case studies have confirmed that the East Asian auroral evidence during the MM are no longer “virtually incontrovertible,” but still represent possible stray auroral activity in this period. This insight favours the significantly reduced space-weather activity during the MM (Silverman, 1992; Usoskin et al., 2015; Vaquero and Trigo, 2015; Hayakawa et al., 2021a), rather than persistent moderate space weather activity during that time (Schröder, 1992; Zolotova and Ponyavin, 2016). The abovementioned case studies have also emphasised the importance of philological case studies for candidate aurorae during the MM, which has been highlighted in previous studies (Usoskin et al., 2017; Hayakawa et al., 2021a). Further critical investigations on the candidate auroral records during the MM are required to robustly reconstruct the space weather variability at that time.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

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AUTHOR CONTRIBUTIONS

This research was performed with cooperation of the authors: KH surveyed historical records and made philological contributions. HH interpreted these records and arranged their information. YE made contributions on the interpretation and analysis of the auroras, supervising this study. All authors read and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fspas.2022.832618/full#supplementary-material>

- the Maunder Minimum: Comparative Study of the Total Eclipse Drawings in 1706 and 1715. *J. Space Weather Space Clim.* 11, 1. doi:10.1051/swsc/2020035
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