JKAS
Journal of the Korean Astronomical Society
http://jkas.kas.org
eISSN: 2288-890X · pISSN: 1225-4614

JKAS (2023), **56**, 1, 75–89
doi: 10.5303/JKAS.2023.56.1.75

Astronomical Phenomenon Records from Sukjong's *Chunbang-Ilgi*

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Received January 4, 2023; Accepted April 4, 2023; Published May 11, 2023

Abstract

We investigate the astronomical phenomenon records of Sukjong's *Chunbang-Ilgi* made by *Sigangwon* (Royal Educational Office of the Crown Prince) at which King Sukjong was the crown prince (i.e., 1667 January 24–1674 September 22). From the daily records of 2,799 days, we extract the astronomical records of 1,443 days and classify them into 14 categories. Then, we group the records of each category into five phenomena (Atmosphere, Eclipse, Daylight Appearance, Apparition, and Appulse) and compare them with the results of modern astronomical computations wherever possible. Except for Atmosphere group comprising records of meteorological events, such as solar halo, lunar halo, and unusual clouds, the significant findings in every other group are as follows: In Eclipse group, the solar eclipse that occurred on 1673 August 12 was unobservable in Korea, which is in contrast to the record of *Joseonwangjo-Sillok* (Annals of the Joseon Dynasty), which states that the sun was in eclipse around sunset time, as observed at *Nam* mountain. From the lunar eclipse records, we verify that the Joseon court did not change the date of the events observed after midnight. In Daylight Appearance group, we confirm that this phenomenon was observed during the daytime and not during twilight. We further suggest that if observation conditions are met, a celestial body brighter than −2.3 mag could be seen during the daytime with the naked-eye. In Apparition group, we find the possibilities that the Orionid meteor shower had influence on the meteor records and the seasonality on the aurora records. We also find that the Korean records in which the coma of comet C/1668 E1 was located below the horizon were overlooked in previous studies. Finally, we find that the records of Appulse group generally agree with the results of modern calculations. The records of *Beom* (trespass in literal) and *Sik* (eating in literal) events show average angular separations of 1.2° and 1.0°, respectively. In conclusion, we believe this work helps study the astronomical records of other logs of *Sigangwon*, such as Sunjong's *Chunbang-Ilgi*.

Keywords: history and philosophy of astronomy — methods: data analysis — astronomical data bases: miscellaneous — ephemerides

1. Introduction

Korea has a long history of astronomical observations and records, such as the *Samguksagi* (History of the Three Kingdoms, BC 57–AD 935), *Goryeosa* (History of the Goryeo Dynasty, 918–1392), and *Goryeosajeolyo* (Abridged History of the Goryeo Dynasty). Considering the Joseon dynasty (1392–1910), the *Joseonwangjo-Sillok* (Annals of the Joseon Dynasty, hereafter Sillok) is a representative source containing approximately 20,000 astronomical records (Yang 2004). The *Seungjeongwon-Ilgi* (Daily Records of Royal Secretariat, hereafter Ilgi) is another source of astronomical records for the dynasty. While Ilgi is known to have been written from the beginning of the Joseon dynasty, only records from 1623 to 1910 remain. In terms of time periods, although the records of Ilgi are approximately twice less than those of Sillok, it is approximately five times more than the latter in terms of volume. According to Park (2010), Ilgi comprises approximately 19,000 astronomical records for 159 years, from 1623 to 1782. At present, Sillok and Ilgi are designated as part of UNESCO's Memory of the World Programme and are widely referred to for information on the Korean historical astronomical records (e.g., Baade 1943; Stephenson & Willis 2008; Lee et al. 2009a; Shara et al. 2017).

Although less known than Sillok and Ilgi, the daily records made by *Sigangwon* (Royal Educational Office of the Crown Prince) of the Joseon dynasty also contain various astronomical events as well as educational materials. The *Sigangwon* records for each crown prince are commonly called *Donggung-Ilgi* (for more details, see Appendix A). In previous works, *Donggung-Ilgi* has been studied mainly in terms of the royal education of the Joseon dynasty (Kim 2007, 2008; Noh 2008;

Kim 2012a). Meanwhile, Kyung (2014) recently studied the records of portents, which comprised astronomical events such as the daylight observation of Venus, to dispute the theory of the Little Ice Age in the seventeenth century; however, he was concerned with meteorological records, such as solar halo, frost, and thunderbolt, and excluded astronomical records, such as solar eclipse, comet, and planetary movement.

As the first of a series of studies on the extant crown prince's *Donggung-Ilgi* in terms of astronomy, we investigate the astronomical phenomenon records from Sukjong's *Chunbang-Ilgi*, i.e., *Donggung-Ilgi* at which King Sukjong was the crown prince (1667 January 24–1674 September 22). The remainder of this paper is organized as follows: Section 2 outlines Sukjong's *Chunbang-Ilgi*, explains the methods of modern computations for astronomical phenomena, describes the astronomical records, and classifies them into 14 categories. In Section 3, we group these categories into five phenomena, analyze the records of each group, and compare them with the results of modern calculations wherever possible. Section 4 summarizes the findings of this study and presents the conclusions. For reference, we briefly introduce the *Donggung-Ilgi* and the terminology used in this study in Appendix.

2. Sukjong's *Chunbang-Ilgi*

2.1. Outline

Sukjong's *Donggung-Ilgi* was translated into four volumes by each different author(s) (Sung & Park 2008; Na 2008; Ju 2008; Shin 2008): one volume of Sukjong's *Ganghakcheong-Ilgi* (hereafter Ganghakcheong-Ilgi) and three volumes of Sukjong's *Chunbang-Ilgi* (hereafter Chunbang-Ilgi). In this study, we have referred to the Korean-translated versions. According to Sung & Park (2008), *Ganghakcheong* was installed in 1665, when King Sukjong was five years old, and *Sigangwon* in 1667, as he was nominated as the crown prince. Therefore, Ganghakcheong-Ilgi may have been made in 1666, but the records of the year are not extant. However, there are no astronomical records on Ganghakcheong-Ilgi (see Appendix A).

The records of Chunbang-Ilgi began on 1667 first month 1 (refer to Section 2.2), although King Sukjong was officially nominated as the crown prince on the 22nd day of the lunar month, and ended on 1674 eighth month 23 as he succeeded to the throne. The first astronomical record appears on 1667 first month 25, which states:

> *"At 3 watches, a meteor came from under the Gujin constellation and entered over the Hwagae constellation. Its shape looked like the fist, the tail length was 3–4 Cheok, and the color was red."*

This record is not contained in Sillok but is identical to that in Ilgi. Conversely, the record on 1667 second month 17, which says that "At the *Sa* double-hour (9–11 h in AST), the *Taebaekseong* (Venus) appeared on the toward the *Mi* (Southwest) direction" (see Figure 1), is not contained in Ilgi. Moreover, Ilgi has no records themselves for a couple of days before and after that day. On the other hand, Sillok simply says that the *Taebaek(seong)* appeared in daylight. For the historical astronomical terms and units used in this study, refer to Appendix B.

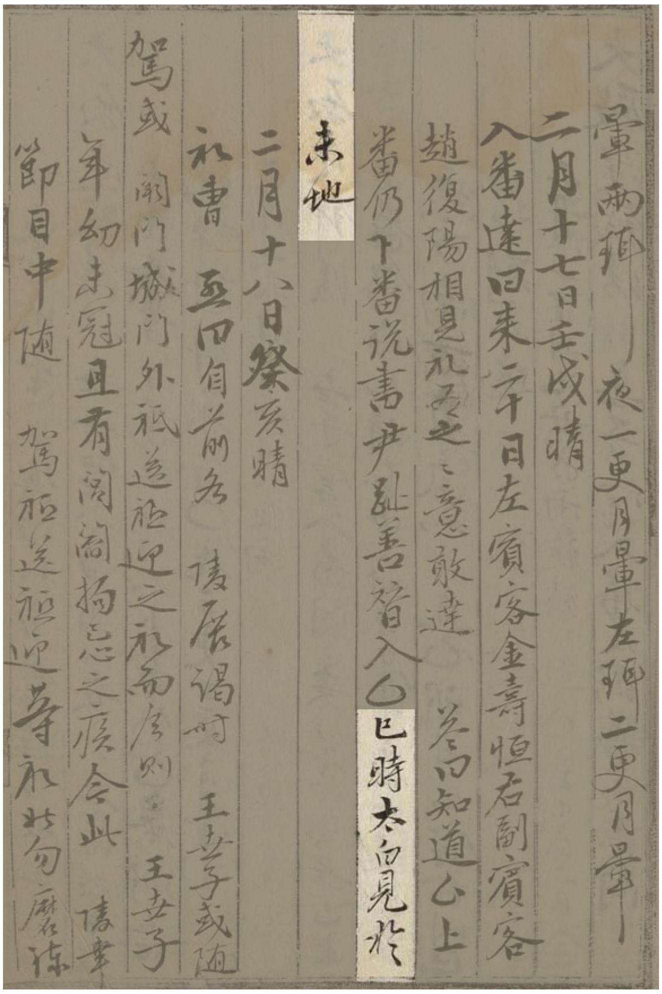

Figure 1. A section of a page from Chunbang-Ilgi on 1667 second month 17. The highlighted text reads, "At the *Sa* double-hour (9–11 h in AST), the *Taebaekseong* (Venus) appeared on the toward the *Mi* (Southwest) direction" (source: Kyuganggak Institute for Korean Studies).

2.2. Modern Computations

To compare the astronomical phenomenon records with the results of modern computations, we first converted lunisolar calendar dates of the records into Gregorian calendar dates referring to the works of Han (2002) and Ahn et al. (2009) and provided the dates in the latter calendar. When it was necessary to use the dates in the lunisolar calendar, we expressed the lunar month using an ordinal number to avoid confusion with the dates in the Gregorian calendar. For example, 1667 first month 1 (i.e., 1667 January 24 in the Gregorian calendar).

One of the characteristics of the astronomical records of Chunbang-Ilgi is that the observation hours, except for two records, have been included. We assumed the location of the observer to be Hanyang (present Seoul), having latitude and longitude of 37° 33′ 59″ N and 126° 58′ 58″ E (Park & Ahn 2020). For modern calculations, we used the astronomical al-

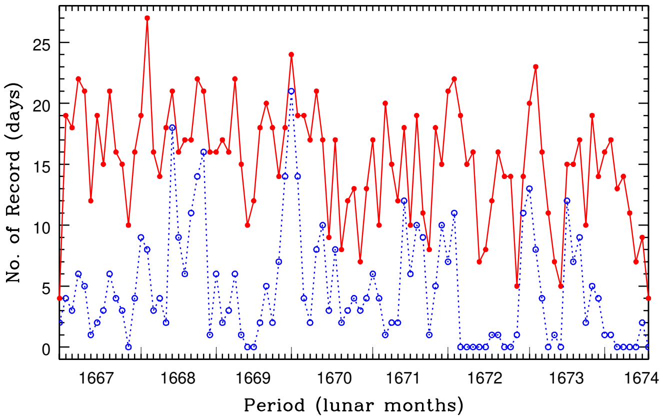

Figure 2. Monthly distribution of the astronomical records from Chunbang-Ilgi and Sillok according to the period. The horizontal axis is the lunar month from 1667 first month to 1674 eighth month and the vertical axis is the monthly number of days of records from Chunbang-Ilgi (red-filled circles) and Sillok (blue open circles).

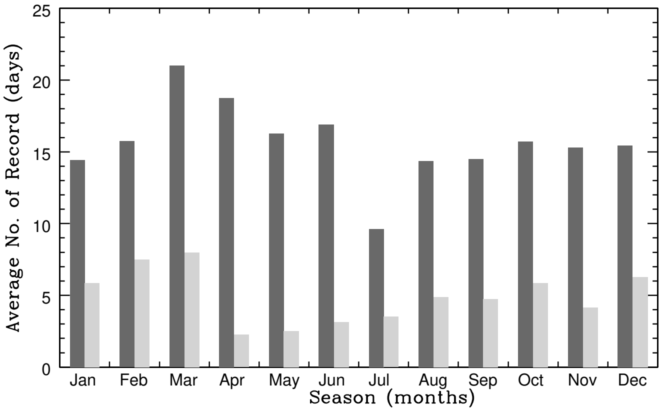

Figure 3. Histogram showing the average number of days of astronomical records according to the season. The horizontal axis represents the months from January to December, and the vertical axis is the average number of days of the records from Chunbang-Ilgi (dark grey color on the left) and Sillok (light grey color on the right).

gorithms of Meeus (1998), the DE405 ephemeris of Standish et al. (1997), and ΔT, which is the difference between the terrestrial (TT) and universal (UT) times, of Nautical Almanac Office (2010). Until 1787, the Joseon court used the *Datong* calendar in relation to the hour system (Lee et al. 2011); hence, the twilight time length was adopted as 36 min. Moreover, because the observation hours of the record have durations of 2 h and $\sim$2.218 h in units of a double-hour and watch, respectively, as introduced in Appendix B, we considered the observation hour as the midpoint of the duration unless mentioned otherwise. All the times obtained from modern calculations in this study are given in Korean standard time (KST), mean solar time (MST) with the standard meridian of 135° E (i.e., UT + 9 h). However, KST can be converted into the local AST of the records by correcting the longitude difference of -32 min (i.e., $\sim$127° E−135° E) and the equation of time (EOT), or vice verse (refer to Lee et al. 2011). Lastly, we referred to the work of Ahn et al. (1996) to identify the star names in the records with those in modern astronomy.

2.3. Distribution of Records

Of the 2,799 days, from 1667 January 24 to 1674 September 22, astronomical records including atmospheric phenomena, such as solar halo, lunar halo, and unusual cloud, are 1,443 days, which is 3.2 times more than that of Sillok during the same period. In contrast, Sillok comprises astronomical records for 32 days, half of which are records of the event that Venus was seen in daylight, that are not listed in Chunbang-Ilgi. Therefore, the Joseon court seems to have considered this event as an ominous portent in governing the dynasty.

Figure 2 shows the monthly distribution of astronomical records from Chunbang-Ilgi and Sillok according to the period. The horizontal axis represents the lunar month from 1667 first month to 1674 eighth month, and the vertical axis indicates the number of days of records per lunar month from Chunbang-Ilgi (red-filled circles) and Sillok (blue open circles). As shown in the figure, the number of Chunbang-Ilgi's records is larger than that of Sillok's records covering the entire period. However, both documents show similar tendencies in the variation in number according to the period. Meanwhile, compared to other periods, the number of Chunbang-Ilgi's record is very small in the two extremes, which may have been due to King Sukjong being nominated as the crown prince on 1667 first month 22 and being ascended to the throne on 1674 eighth month 23.

Figure 3 shows the histogram indicating the average number of days of astronomical records according to the season. The horizontal axis represents the months from January to December, and the vertical axis indicates average number of days of records from Chunbang-Ilgi (dark grey color) and Sillok (dim grey color). For reference, the number of January, October, November, and December is seven, and that of the other months is eight when converting lunisolar calendar dates of the records into Gregorian calendar dates. As seen from the histogram, the average number of days shows the maximum in March for records of Chunbang-Ilgi and Sillok and the minimum in July and April for those of the former and the latter documents, respectively. The reason that the records of Chunbang-Ilgi show a minimum in July is presumably because it is a rainy season in Korea.

2.4. Classification of Records

The astronomical record of a day usually comprises observations of one or more astronomical phenomena and rarely contains the contents of non-astronomical phenomena, such as the record on 1667 September 25, which discusses the problem in determining the birthday of the crown prince (i.e., King Sukjong). The problem was caused by the Joseon court reintroducing the *Datong* calendar of the Ming dynasty for three years since 1667, as did the Qing dynasty (Lee et al. 2010). Meanwhile, the same contents are recorded in Sillok one day early, September 24. Hence, the records of the *Donggung-Ilgi* could be used to crosscheck those of the Sillok or Ilgi. Another case is the record on 1667 December 8, which says

Table 1. Summary of the number of astronomical records belonging to each category from Chunbang-Ilgi.

Group	Category	Number
Atmosphere	Sun	790
	Moon	365
	Cloud	149
Eclipse	Solar Eclipse	6
	Lunar Eclipse	11
Daylight Appearance	Venus	258
	Jupiter	16
Apparition	Meteor	303
	Comet	24
	Aurora	112
Appulse	Entering	49
	Approaching	3
	Trespassing	29
	Eating	2
Total		2,117

that eight books of the *Baekryeok* (white almanac, in literal), estimated as the almanac without the book cover (Kim 2012b), were granted to eight officials of *Sigangwon*. The other case is the record of 1672 September 12 saying that there was a sound similar to that of the sky crying, which represents what astronomical phenomenon is unclear.

Therefore, except for these three records, we classified the events of astronomical records into 14 categories: Sun, Moon, Cloud, Solar Eclipse, Lunar Eclipse, Venus, Jupiter, Meteor, Comet, Aurora, Entering, Approaching, Trespassing, and Eating. We grouped these categories into five phenomena: Atmosphere, Eclipse, Daylight Appearance, Apparition, and Appulse. Table 1 summarizes the number of astronomical records belonging to each category. If there is more than one observation in the records of a day for the same category, it is counted as one unless mentioned otherwise. In the following sections, we analyze the astronomical records of Chunbang-Ilgi according to the group.

3. Analysis

3.1. Atmosphere Group

Similar to previous studies (e.g., Ahn et al. 2014, 2020), we excluded records on meteorological phenomena, such as frog, frost, and thunder, but included those associated with the sun, moon, and cloud. Records of atmospheric optics events around the sun and moon, such as solar and lunar halos, were classified into Sun and Moon categories, respectively, whereas those on unusual clouds were classified as Cloud category. These categories are grouped into Atmosphere phenomenon. The number of records of Sun, Moon, and Cloud categories are 790, 365, and 149, respectively, accounting for ~62% of the total. Although the records of Sun and Moon categories rank as the largest and second largest, respectively, they are fundamentally meteorological events, which are beyond the scope of this study. However, we briefly addressed the records of this group.

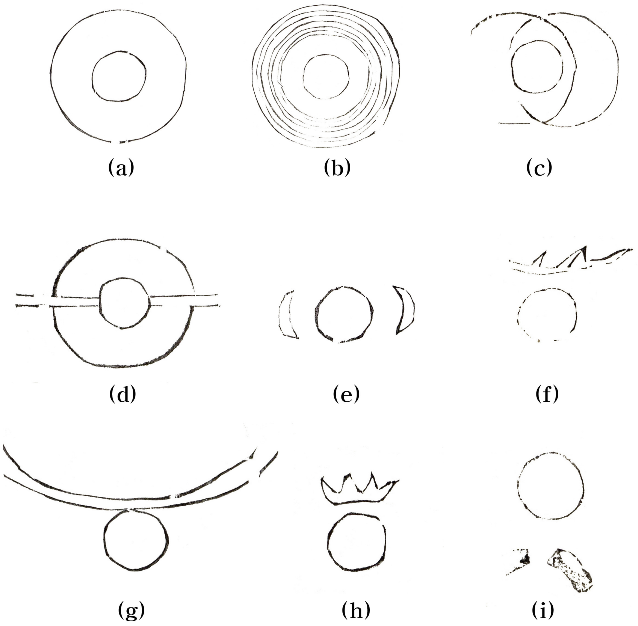

Figure 4. Sketches showing unusual atmospheric optics events occurred around the sun, as presented in *Cheonmundaeseong* (source: National Library of Korea). For details on each panel, refer to the text.

First, records such as "there was a halo around the sun" are easily recognizable. On the other hand, it is difficult to understand what the event of other records, such as "there was (the shape of) a *Shin* (shoes, in literal) below the halo," represents, although it is estimated as an unusual atmospheric optics event. Meanwhile, various illustrations associated with the phenomena of Sun and Moon categories are depicted in the book *Cheonmundaeseong* (Great Achievements in Astronomy), compiled around 1653 by Ding Huang, a Chinese scholar (Lee et al. 2008). In Figure 4, we present several pictures related to the records of Sun category from *Cheonmundaeseong*. We believe that these pictures will be useful as references for relevant research fields. Each panel in the figure displays the events that occurred around the sun: (a) halo, (b) multiple halos, (c) two overlapping halos, (d) the *Baekhong* (white rainbow, in literal) penetrating the sun, (e) ears, (f) *Gi* (Vapor) with the shape of a back, (g) vapor in the shape of putting on the head, (h) vapor in the shape of a crown in the upper, and (i) vapor in the shape of shoes in the lower.

Second, as pointed out in previous studies (e.g., Hayakawa et al. 2016, 2017), records such as the white rainbow penetrating the sun and the appearance of "a vapor" or "a cloud-like vapor" might be the observations of the aurora event. Particularly, the suggestion that the white rainbow event is an auroral candidate was also supported by Carrasco et al. (2017). Moreover, Chunbang-Ilgi holds records of colored cloud-like vapor observed at night. However, for consistency purposes, only the records on "vapor like a fire light" were classified into Aurora category, as mentioned in Section 3.4.3.

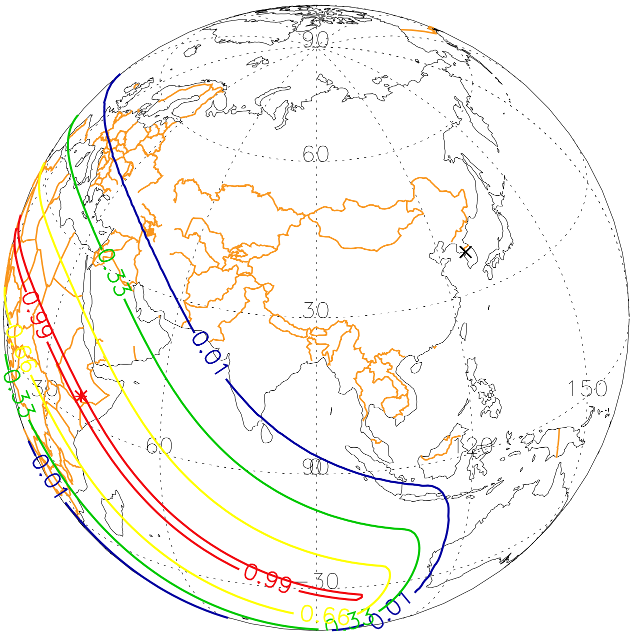

Figure 5. A diagram of the solar eclipse that occurred on 1673 August 12. The red asterisk and black cross symbols indicate the points of greatest eclipse and the location of Seoul, respectively.

3.2. Eclipse Group

This group comprises two categories: Solar and Lunar Eclipses. Although phenomena such as the moon eclipsing a star/planet have also been recorded, these records are classified into Eating category, which is analyzed in Section 3.5.2.

3.2.1. Solar Eclipse

As shown in Table 1, the records of Solar Eclipse category are six. Meanwhile, only two eclipses that occurred on 1669 April 30, and 1671 September 3 were visible in Seoul during the period Chunbang-Ilgi was made (Ahn et al. 2011).

First, the record for 1667 June 22 contains an account saying, "Yesterday, the solar eclipse occurred below the horizon," with small letters. However, no solar eclipse event occurred that day on earth. Meanwhile, the record for 1673 February 17 states that, although there was a solar eclipse at the *In* double-hour (3–5 h in AST), the *Gusikrye* (a ritual performed during the eclipse proceeded) was not performed because the eclipse occurred below the horizon. Furthermore, the record for 1673 August 12 states that the solar eclipse should have happened at the *Yu-Jeong* single-hour and 2 marks (~17 h 30 min in AST), but it did not occur after all. Subsequently, the record for the next day quotes the report saying that the sun was eclipsed around sunset time yesterday, which was observed from the *Nam* (South) mountain. However, according to this study, this eclipse was unobservable in Korea, as shown in Figure 5.

Table 2 summarizes the eclipses times for the two solar eclipses observed in Seoul, calculated based on the studies by Lee (2008) and Choi et al. (2019). Column 1 of the table is the Gregorian calendar date (Date), columns 2–6 are the times of sunrise (SR), beginning of the eclipse (P1), greatest eclipse ($\mathrm{GE}_{\odot}$), end of the eclipse (P4), and sunset (SS), respectively, and columns 7–9 show the difference between TT and UT (i.e., ΔT), equation of time (EOT) at 12 h in KST, and the magnitude (mag) of the eclipse at the instant of greatest eclipse, respectively. The last column shows the observation hours from the records in KST. For a solar eclipse that occurred on 1669 April 30, the modern calculations for the eclipse times agree with the times of Chunbang-Ilgi; that is, there was a solar eclipse at the *Mi* and *Shin* double-hours (~13 h 29 min–17 h 29 min in KST). For reference, Sillok says that there was a solar eclipse at the *Shin* double-hour (~15 h 29 min–17 h 29 min in KST) in the volume of King Hyeonjong and that there was a solar eclipse in the revised volume of the king.

Conversely, modern calculations differed from the record for the solar eclipse that occurred on 1671 September 3, as shown in Table 2. Although the record says that a solar eclipse occurred at the *Shin* double-hour (~15 h 31 min–17 h 31 min in KST), the eclipse progressed approximately during the *Yu* double-hour (~17 h 31 min–19 h 31 min in KST). Therefore, it is estimated that there is a typo in Chunbang-Ilgi. However, this assumption is difficult to verify because there is no record of this eclipse in Sillok, presumably because the eclipse magnitude was too small (0.15 mag) even at the instance of greatest eclipse.

3.2.2. Lunar Eclipse

According to our study, there were eleven observable lunar eclipses in Seoul, including the seven penumbral eclipses, among 19 eclipses during the period when Chunbang-Ilgi was made. As specified in Table 3, the number of records of lunar eclipses in Chunbang-Ilgi is eleven, including four predicted eclipses.

Four records, for 1667 July 6, 1668 November 18, 1671 September 18, and 1672 March 13, say that lunar eclipses occurred at 1 watch, night, 4 and 5 watches, and 2 and 3 watches, respectively. Meanwhile, the record for 1667 November 29 says that *Seoyeon* (lecture for the crown prince) would be taking a break because of the lunar eclipse, whereas the record for the next day (i.e., 1667 November 30) says that lunar eclipse occurred at 2 and 3 watches. Similarly, the record for 1672 September 6 says that *Seoyeon* would be taking a break due to the lunar eclipse that would occur below the horizon. Conversely, the record for 1670 April 4 mentions the times on the lunar eclipse that would occur on the next day; *Chohyu*, *Siksim*, and *Bokwon* are *Yu-Cho* single-hour and 3 marks, *Sul-Cho* single-hour and 2 marks, and *Hae-Cho* single-hour and 1 mark, respectively. Subsequently, the record for the next day, 1670 April 5, says that the lunar eclipse occurred at 1 and 2 watches; hence, *Gusikrye* was performed. In contrast, the record for 1674 July 17 states that although the lunar eclipse occurred at night, *Gusikrye* was not performed owing to the rainy and cloudy weather. The record for 1674 January 20 states that the lunar eclipse would occur two days later. However, no lunar eclipse is recorded on this day. According to our study, a lunar eclipse occurred on that day but was unobservable in Seoul. Therefore, there are seven records of actual observations of

Table 2. Summary of the eclipse times for the solar eclipses that occurred on 1669 April 30 and 1671 September 3. All times are given in KST.

Date	SR (h:min)	P1 (h:min)	$\mathrm{GE}_{\odot}$ (h:min)	P4 (h:min)	SS (h:min)	ΔT (s)	EOT (min)	mag	Note (h:min)–(h:min)
1669 Apr. 30	05:38	14:29	15:48	17:00	19:21	+27	+3.2	0.66	13:29–17:29
1671 Sep. 03	06:03	17:41	18:15	18:47	18:59	+25	+0.9	0.15	15:31–17:31

SR, P1, $\mathrm{GE}_{\odot}$, P4, and SS are the times of sunrise, beginning of the eclipse, greatest eclipse, end of the eclipse, and sunset, respectively. ΔT, EOT, and mag are the difference between TT and UT, equation of time at 12 h in KST, and the eclipse magnitude at the instant of greatest eclipse, respectively.

Table 3. Summary of eclipse times for seven lunar eclipses observable in Seoul. All times are given in KST.

Date	MR (h:min)	U1 (h:min)	U2 (h:min)	$\mathrm{GE}_{\leftmoon}$ (h:min)	U3 (h:min)	U4 (h:min)	MS (h:min)	ΔT (s)	EOT (min)	Umag	Note (h:min)–(h:min)
1667 Jun. 06	19:47	17:33	18:30	19:18	20:06	21:03	29:36	30	+2.1	1.62	20:25–22:03
1667 Nov. 30	17:01	21:33	22:39	23:31	24:23	25:28	31:52	30	+10.7	1.72	20:27–25:39
1668 Nov. 18	17:03	22:33	—:—	23:52	—:—	25:10	31:42	28	+14.2	0.49	(17:55–30:41)
1670 Apr. 05	18:50	18:59	—:—	20:31	—:—	22:03	30:26	26	−2.6	0.70	19:34–23:34
1671 Sep. 18	18:22	25:38	26:36	27:25	28:14	29:12	30:29	25	+6.1	1.70	25:29–29:40
1672 Mar. 13	18:23	22:16	—:—	23:20	—:—	24:25	30:52	24	−9.6	0.33	21:24–25:46
1674 Jul. 17	19:34	27:45	29:12	29:30	29:47	31:15	29:27	22	−5.4	1.05	(20:27–28:47)

MR and MS are the times of moonrise and moonset. U1, U2, $\mathrm{GE}_{\leftmoon}$, U3, and U4 are first external contact, first internal contact, greatest eclipse, last internal contact, and last extern contact times of the umbra, respectively. ΔT, EOT, and Umag are the difference between TT and UT, equation of time at 18 h in KST, and the magnitude of the eclipse of the umbra at the instant of greatest eclipse, respectively.

lunar eclipses. In particular, three records of 1668 November 18, 1674 January 20, and 1674 July 17 are not recorded in Sillok and Ilgi.

Based on the studies by Lee et al. (2016) and Lee (2017a), we calculated the eclipse times for seven lunar eclipses and summarized in Table 3. Column 1 shows the Gregorian calendar date (Date), columns 2 and 8 are the times of moonrise (MR) and moonset (MS), and columns 3–7 are first external contact (U1), first internal contact (U2), greatest eclipse ($\mathrm{GE}_{\leftmoon}$), last internal contact (U3), and last external contact (U4) times of the umbra, respectively. Columns 9–11 are ΔT, EOT at 18 h in KST, and the magnitude of the eclipse of umbra (Umag) at the instant of greatest eclipse, respectively. If the date is changed to the next day, we add 24 h to the time. For example, 29 h on 1667 June 6 indicates 5 h on 1667 June 7. The last column shows the observation hours from the records in KST. If the observation hour is recorded as simply "at night", the night period (i.e., *Yagak*) is given in parentheses. As shown in Table 3, the observation hours of the records generally agree with the results of modern computations. Meanwhile, the record for 1671 September 18 confirms that the Joseon court did not change the observation day after midnight, as pointed out in previous studies (e.g., Ahn & Park 2004). The record for 1670 April 5 also confirms that the times of *Chohyu*, *Siksim*, and *Bokwon* represent those of U1, $\mathrm{GE}_{\leftmoon}$, and U4, respectively, as pointed out by Lee (2017a) and Choi et al. (2019). Compared with the results from modern calculations, the predicted hours for the lunar eclipse on 1670 April 5 show differences of approximately 34, 20, and 6 min in the times of *Chohyu*, *Siksim*, and *Bokwon*, respectively.

3.3. Daylight Appearance Group

While the daylight appearance events of Venus and a comet have been recorded in the *Goryeosa* (Choi et al. 2018), Venus and Jupiter are the celestial bodies of this group recorded in Chunbang-Ilgi. Therefore, in this study, the categories of Daylight Appearance group are two: Venus and Jupiter. Although the daylight appearance event of a celestial body belongs to Apparition group, those two categories are separated from this group in terms of the Joseon court considered as an important ominous event, as mentioned earlier, and being observed during daylight time, unlike other astronomical phenomena.

3.3.1. Venus

A notable feature in the records of Chunbang-Ilgi is that different terms such as the *Taebaekseong* and *Geumseong* (currently used Korean term for Venus) were used for Venus based on daytime and nighttime occurrences, respectively. Compared to the records of Sillok, the records of Chunbang-Ilgi are more detailed. For example, while the record of Sillok on 1667 March 11 says that "Venus appeared in daylight," the record of Chunbang-Ilgi on the same date says that "At the *Sa* double-hour, Venus appeared on toward the *Mi* direction (see Figure 1). Of the 258 records on the daylight appearance of Venus, the number of events observed at *Jin*, *Sa*, *Mi*, and *Shin* double-hours (7–9, 9–11, 13–15, and 15–17 h in AST, respectively) are 1, 125, 131, and 1, respectively, indicating that the records of Venus category designate the events that occurred during the daytime and not twilight.

As Halley first discovered, Venus at an elongation of 40° is the brightest viewed from the Earth (Hogg 1947), which is also mentioned in the *Seoungwan-Ji* of the Joseon dynasty (Lee

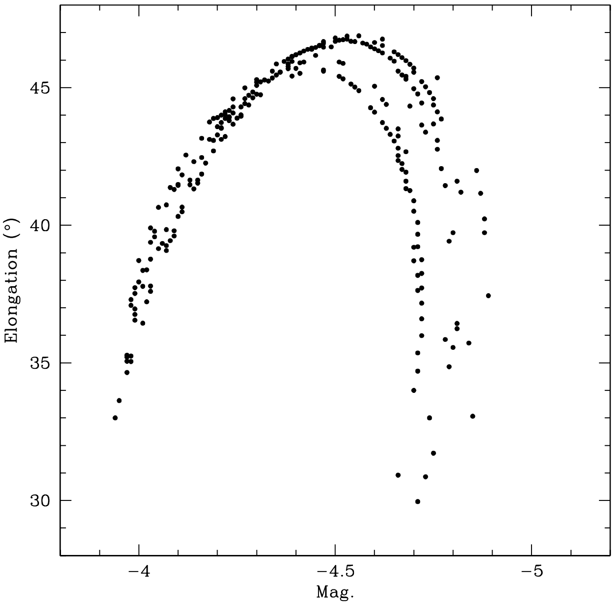

Figure 6. Relationship between the apparent magnitude and elongation of Venus from Chunbang-Ilgi's records on the daylight appearance event of Venus.

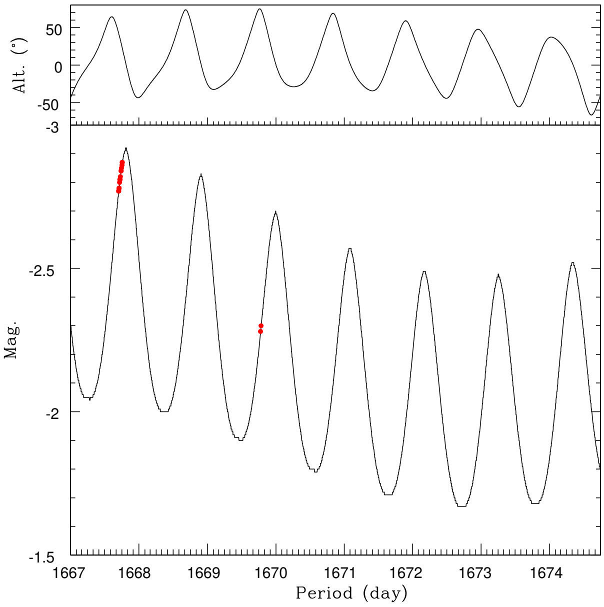

Figure 7. Altitude (upper panel) and apparent magnitude (lower panel) of Jupiter at the daily sunrise time from 1667 January 24 to 1674 September 22. The red circles in the lower panel represent the apparent magnitude of Jupiter on the dates of the records.

et al. 2003). Figure 6 shows the relationship between the apparent magnitude and elongation of Venus as determined from 258 records. Based on the work of Hilton (2005), we calculated the apparent magnitudes of Venus. For the observation hours of the *Jin*, *Sa*, *Mi*, and *Shin* double-hours, we assumed 8, 10, 14, 16 h in KST, respectively. As a result, the minima and maxima of the apparent magnitudes are −3.9 and −4.9 mag, and the elongation angles are 30.0° and 46.9°, respectively. Meanwhile, the mean magnitude and elongation are −4.4 ± 0.3 mag and 42.4° ± 3.8, respectively. These values are in good agreement with the results from the records of the *Goryeosa* (−4.5 ± 0.3 mag and 39.8° ± 7.8), with slightly large deviations (Lee 2017b).

3.3.2. Jupiter

The observation hours of the *Myo* and *Jin* double-hours (5–7 and 7–9 h in AST, respectively) are specified in the records of Jupiter category, as in Sillok. Since these hours overlap with the sunrise times, particularly for the *Myo* double-hour, it is unclear whether Jupiter was observed in daylight or twilight. However, it is worth nothing that the observation hours are given in units of double-hour, and not watch. Furthermore, if Jupiter was seen in twilight time, observations of other celestial bodies, such as Mars, would also have been recorded. Moreover, similar to the record for 1668 May 23 on the observation of an unusual cloud, the observation hours for Jupiter would have been recorded as "at *Maesang*" (morning twilight time) or "at *Chohon*" (evening twilight time). Therefore, it is estimated that the daylight appearance events of Jupiter are possible with the addition of other factors, discussed below. In practice, it is known that these events were witnessed with the naked-eye (e.g., Russell 1918; Sampson 2003).

Of the 16 records on the daylight appearances of Jupiter, 14 and 2 events were observed in 1667 and 1669, respectively. Interestingly, while the 1667 events were primarily observed in September and all at the *Myo* double-hour, all events of 1669 were observed in October and at the *Jin* double-hour. Additionally, all events were recorded almost on successive days. Figure 7 shows the altitude (upper panel) and apparent magnitude (lower panel) of Jupiter at the daily sunrise time from 1667 January 24 to 1674 September 22. The red circles in the lower panel represent the apparent magnitude of Jupiter on the record dates.

According to modern calculations, Jupiter was the brightest on 1667 October 24 with a magnitude of −2.9. However, it would have been impossible to observe Jupiter in daylight around that time, considering that Jupiter began to set below the horizon before sunrise. In addition, it might have been difficult to observe Jupiter in daylight in late November 1668, when it was the second brightest, due to seasonal reasons. It is known that the sky is bluer, it is easier to observe the celestial body in daylight with the naked-eye (Ellis 1995). In Korea, the sky is the bluest in September and October. After late November 1668, it would have been also impossible to observe Jupiter in daylight because Jupiter was set below the horizon before sunrise. The third brightest period was around late December 1669; however, it again would have been impossible to observe Jupiter in daylight due to seasonal reasons. Jupiter could have been observed in daylight around mid-October 1669 in the sense that it was the season when the sky was the bluest. In addition, it is estimated that elongation played an important role in observing Jupiter in daylight in mid-October of 1669, although the brightness during this period was dimmer than during the same period in 1668. Based on our calculations, the apparent magnitude and elongation of Jupiter were found to be −2.3 mag and 105°, respectively, in mid-October of 1669 and −2.7 mag and 71°, respectively, in mid-October of 1668.

To emphasize, it might have been possible to observe Jupiter in daylight with the naked-eye through the effect of several factors, such as brightness, season, and elongation. Most importantly, the observation of Jupiter during the day was possible owing to the presence of an export observer who understood planetary movements well (Peters 1984). Consequentially, a celestial body brighter than −2.3 mag can be observed in daytime under appropriate observational conditions, which differs from the suggestion of Weaver (1947), who insisted that only a celestial body brighter than −3.3 mag can be observed in daylight.

3.4. Apparition Group

This group comprises three categories: Meteor, Comet, and Aurora, which are records of the observations of each object. Although the observations of a guest star (in literal; i.e., supernova or nova), sunspot, and so forth can be classified as a category in Apparition group, there are no records of these events in Chunbang-Ilgi.

3.4.1. Meteor

As mentioned in Sillok, a meteor is observed every day. Approximately 5–6 meteors brighter than 6.5 mag can be observed per hour, although it varies based on the season, observer's latitude, and so forth (Cox 2000). However, because meteor observations are recorded for 304 days, one per nine days on average, it is inferred that only exceptionally bright or unusual meteors were reported. Meanwhile, it is notable that Chunbang-Ilgi's records on a meteor thoroughly follow the regulation of the observation report described in the *Seoungwan-Ji*, like the records on other astronomical phenomena. According to the *Seoungwan-Ji*, the observation of a meteor is regulated to report the observation hour, appearance and disappearance locations, color (e.g., red, white, blue, and yellow), trajectory length, and shape (e.g., fist, jar, and pot). Additionally, facts such as the ray of a meteor shone the ground, a sound was accompanied, and so forth are also included, if present.

For example, the record for 1668 September 8 says, "At 2 watches, a meteor appeared at the *Daereung* constellation (9, τ, ι, κ, β, and 16 Per) and moved toward the northern sky. Its shape resembled a brass rice bowl, its tail was as long as 5–6°, and its color was red. The meteor ray shone on the ground with a sound." Therefore, it is inferred that the astronomical records of Chunbang-Ilgi are copies of the original observational reports without editing. Conversely, the records of Sillok can be identified as edited briefly, considering Sillok for the same date says that "At night, a meteor appeared. The ray shone on the ground with a sound." Considering this meteor was bright enough to shine on the ground and was accompanied by a sound, it is estimated to be a fireball rather than an ordinary meteor.

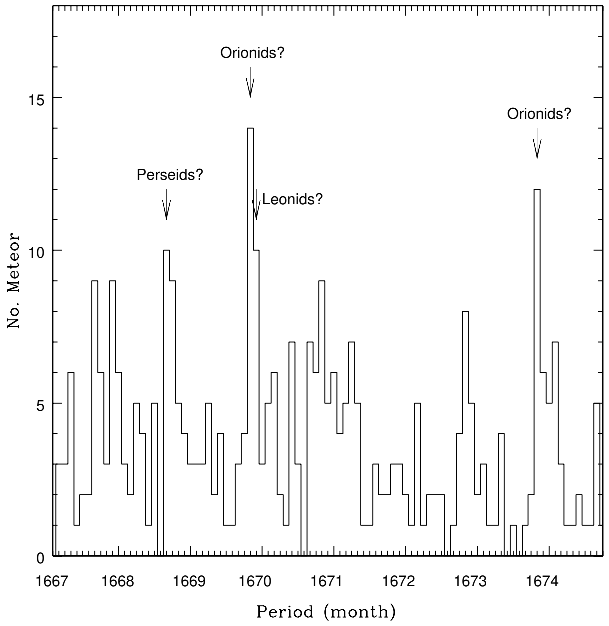

Figure 8. Monthly distribution of the number of meteors according to the period.

The number of meteors reported in the records of 304 days is 340, approximately 1.1 per day, of which 77 (∼23%) were estimated as fireballs. On the other hand, there are no records of a meteor shower event. This event is also not recorded in other sources when Chunbang-Ilgi was made (Ahn 2004; Yang et al. 2005; Jenniskens 2008). Although we cannot role out the possibility of seasonal effects, the distribution of the number of meteors implies the influence of the Orionid, Perseid, and Leonid meteor showers. Figure 8 shows the monthly distribution of 340 meteors according to the period, which shows the maximum in October 1669 (14 meteors) and the second maximum in the same month for the year 1673 (12 meteors). October is the peak time for the occurrence of the Orionids, which was originated from 1P/Halley (Lee & Ahn 1997). The peak times of the Perseids and Leonids are August and November, respectively, and the third maxima (10 meteors) appears in August 1668 and November 1669. However, the number of meteors in August and November in other years is relatively small.

Finally, a meteor shows the color as a result of the physical and chemical reactions of the meteoroid as it falls into the atmosphere (Wu & Zhang 2003). Of the 340 meteors, 241 and 92 were described as red and white, respectively. One meteor each was observed in blue, yellow, blue-red, and pale-white, while three had no color description.

3.4.2. Comet

Observations of C/1668 E1 comet, first discovered on 1668 March 3 at the Cape of Good Hope (Kronk 1999), for 24 days are recorded in Chunbang-Ilgi. The C/1668 E1 comet was first discovered in Korea on 1668 March 8, during twilight, but only the comet tail was described as "a stream of white vapor." Joseon astronomers could not identify it as a comet until the

15th day of March because they could not see its root (in literal; i.e., coma). Then onwards, the records referred to the stream as the *Chiwoogi*; that is, a comet with a curved tail according to the *Seoungwan-Ji*. Although the records of Chunbang-Ilgi do not explain why the stream was designated as the *Chiwoogi*, those of Sillok do specify the reason. According to the record of Sillok, the royal court dispatched two astronomers to Ganghwa Island on 1668 March 11 to confirm the coma. Two days later, a white vapor stream was observed after sunset from the top of Goryeo mountain (N.B.: not Mani mountain). However, a coma was not observed because it was still below sea level. The record for 1668 March 16 mentions that the observation reported from Gangwha Island states that the coma size was as large as a basket (in literal), and hence, it was a *Chiwoogi*. On the contrary, the records of Chunbang-Ilgi from the 18th to 30th March, during which the comet was unobservable due to weather, are not recorded in Sillok.

The C/1668 E1 comet is a member of the Kreutz sungrazing group, which is characterized as it closely approaches the sun with a very long and narrow tail (Marsden 1989). Since only a few of Kreutz comets are known for their orbital elements, it is valuable to precisely determine the orbital path of C/1668 E1 comet (Hasegawa & Nakano 2001). However, no Korean records contain observational data, such as the *Geogeukdo* and *Ipsudo* (angular distances from the North pole and the determinative star of 28 Chinese lunar mansions, respectively), which could have been utilized to obtain the orbital elements (for details, refer to Lee et al. 2009a). Instead, we verified the records of the tail length of comet C/1668 E1. The observation on 1667 March 11 states that "At 1 watch, a white vapor stream starting from the western sky reached to the *Gujusugu* constellation (39, 38, 42, 48, 56, and 55 Eri) passing through the second star of the *Cheonwon* constellation (i.e., π Eri). The length and width of the stream were 5 *Jang* and 1 *Cheok* (i.e., 50° and 1°), respectively, and the stream was shaped like a comet. At (1 watch and) 5 sub-watches, it was set below the horizon." While, the *Gujusugu* constellation comprises nine stars in the *Cheonsang-Yeolcha-Bunya-Jido*, which is a representative Korean star chart engraved on a stone in 1396 (Park 1998), only six stars were referred to the *Seonggyeong* compiled by Nam, Byeong-Gil in 1861 (Ahn et al. 1996), which is referred to in this study.

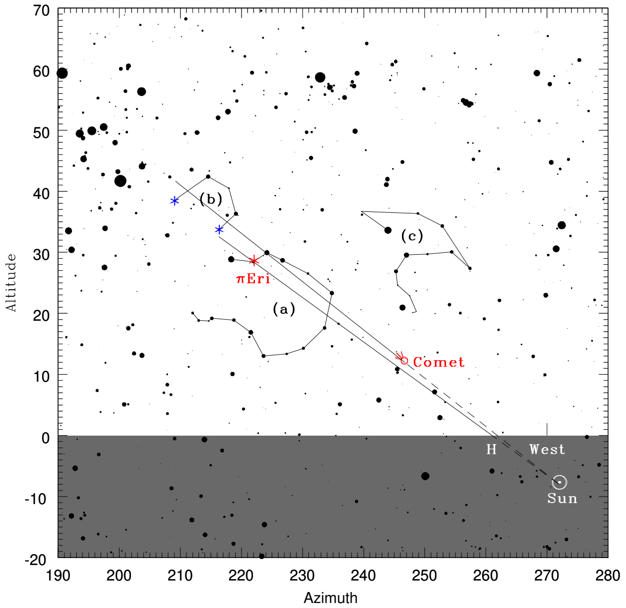

Figure 9. Azimuths and altitudes of the sun and C/1668 E1 comet combined with the constellations mentioned in the records. (a) *Cheonwon*, (b) *Gujusugu*, and (c) *Cheongyun*. Blue asterisks in the *Gujusugu* constellation are 39 and 56 Eri on the right and left sides, respectively. The red asterisk in the *Cheonwon* constellation is π Eri. The symbol H represents the point where the horizontal line meets the line connecting the positions of the sun and π Eri.

Figure 9 shows the horizontal coordinates of the sun and the C/1668 E1 comet (cf. Figure 21 in Hasegawa & Nakano 2001). The epoch is 1668 March 11.85 in KST (i.e., 1 watch on the date), and the position of the comet was calculated using the orbital elements of Marsden (1989). The figure shows constellations (a) *Cheonwon*, (b) *Gujusugu*, and (c) *Cheongyun*. The blue asterisks on each side in the *Gujusugu* constellation represent the first and fifth stars of the constellation (i.e., 39 and 56 Eri, respectively), whereas the red asterisk in the *Cheonwon* constellation represents the second star of the constellation (π Eri). The symbol H around the sun indicates the point where the horizontal line meets the line connecting the position of the sun and π Eri. The angular separation of 53.8° between the point H and 39 Eri is in good agreement with the value in the record of ~5 *Jang*. In contrast, the angular separation between C/1668 E1 comet and 56 Eri is 42.6°. Even if the tail length can vary within the duration of 1 watch, the important point is that the comet is placed above the horizon if the orbital elements of Marsden (1989) are employed. This is inconsistent with the fact that we found from the record of Chunbang-Ilgi; the coma was located below the horizon around 1 watch, and its tail disappeared at 1 watch and 5 sub-watches.

3.4.3. Aurora

Stephenson & Willis (2008) studied 96 records on "a vapor like *Hwagwang* (fire light, in literal)" from Sillok and Ilgi for four years, from 1625 and 1628. Considering that they are mainly observed at the vernal equinox, it was suggested that vapors like fire light in the Korean records indicated aurora events. It was also suggested that the auroras at those times were faint, considering that the events observed around the full moon were very few. We conducted an analysis similar to that of Stephenson & Willis (2008). A total of 112 aurora events, counted as one for more than two observations in a single night, are recorded in Chunbang-Ilgi. Figure 10 shows the distribution of the number of aurora records based on the season (upper panel) and lunar age (lower panel). In the upper panel, the number of auroras is weighted as eight months values for January, October, November, and December records. The reference time taken to calculate the daily lunar age was 21 h in KST, whereas 3-day intervals were chosen arbitrarily for the lunar age in the lower panel. As shown in Figure 10, March (i.e., around the

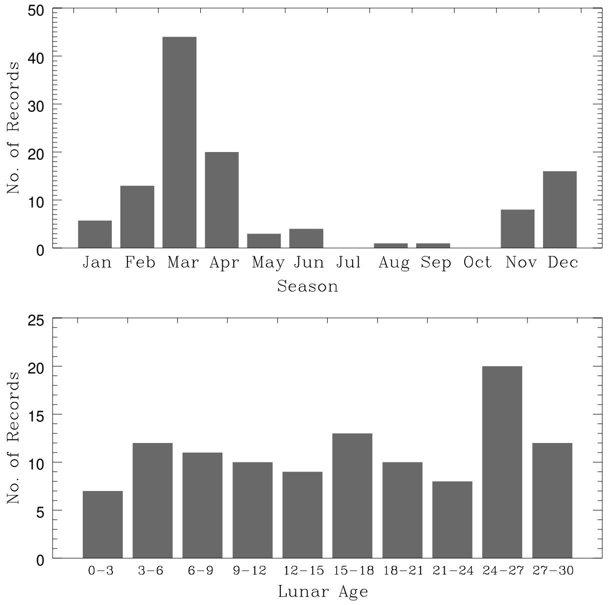

Figure 10. Distribution of the number of aurora records according to the season (upper panel) and lunar age (lower panel).

vernal equinox) shows the maximum number of aurora records according to the season, similar to the results of Stephenson & Willis (2008) and Harrison (2005). Conversely, the number of aurora records according to the lunar age does not show a minimum around the full moon; instead, the frequency shows no significant tendency in general, which is also found in the Chinese records of the Song dynasty (Hayakawa et al. 2015). Nonetheless, it is worth noting that the distribution shows the maximum in the lunar ages of 24–27 days (i.e., around the last quarter moon), which is also found in the European records of the 18th century (Vaquero & Trigo 2005). Consequently, it is necessary to analyze long-term records in the future.

3.5. Appulse Group

The categories belonging to this group are the records described using the terms *Ip*, *Sik*, *Beom*, and *Sanggeo*. According to the *Seoungwan-Ji*, the *Ip* (enter, in literal) and *Sik* (eat, in literal) events are when one celestial body is still seen and entirely unseen, respectively, in the case of being screened by the other celestial body (hereafter, Entering and Eating categories, respectively). The *Beom* (trespass, in literal) event is when the rays of two celestial bodies reach within 0.1° of each other (hereafter, Trespassing category). Meanwhile, *Sanggeo*, referring to when two celestial bodies approach each other (hereafter, Approaching category), is not an astronomical term but an expression meaning "(angular) separation between ∼ is." Of these four categories, Entering category has limitations for quantitative analysis because all records on this event mention specific territories in the sky whose boundaries are unclear. Therefore, the records of Entering category were analyzed separately from the other categories.

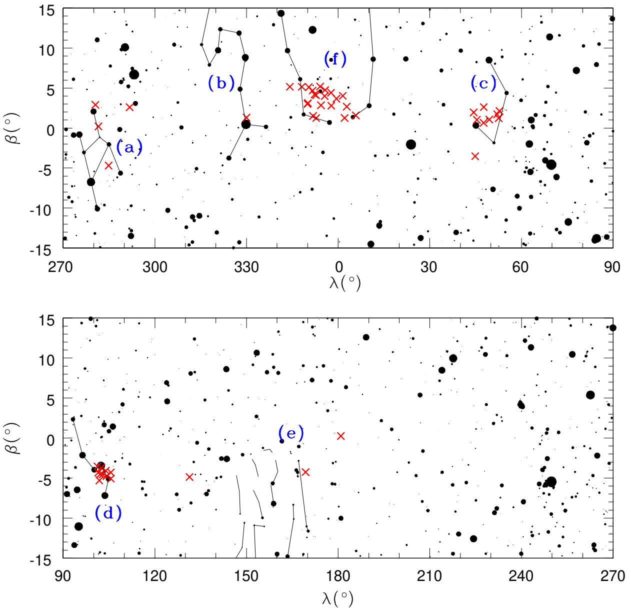

Figure 11. Calculated positions of the celestial bodies from the records of Entering category. The horizontal and vertical axes are the ecliptic longitude (λ) and latitude (β) of the epoch of J2000.0, respectively. The areas where the celestial bodies entered are (a) *Dongjeong*, (b) *Heonwon*, (c) *Jeo*, (d) *Namdu*, and (e) *Woorim* constellations, and (f) the *Taemi* enclosure.

3.5.1. Entering

The records of Entering category rank 49, the largest number among the 83 records of Appulse group. Figure 11 shows the positions of celestial bodies in the ecliptic coordinates for the J2000.0 epoch from the records of Entering category, except for the record for 1668 January 30 without the observation hour. The territories entered by a celestial body are (a) *Dongjeong* (8 stars including γ Gem), (b) *Heonwon* (16 stars including α Leo), (c) *Jeo* (4 stars including β Lib), (d) *Namdu* (6 stars including σ Sgr), and (e) *Woorim* (45 stars including δ Aqr) constellations, and (f) the *Taemi* enclosure (10 stars). For reference, the big (in literal) star in the *Heonwon* constellation (i.e., α Leo) was called *Heonwon-Daeseong*. The *Woorim* constellation comprises 15-star groups, with each group paired with three stars. The *Taemi* enclosure comprises two parts: *Dong* (East) *Taemi* (5 stars including ϵ Vir) and *Seo* (West) *Taemi* (5 stars including δ Leo) (left and right side groups in the *Taemi* enclosure in Figure 11, respectively). The area corresponding to the gate for entering the *Taemi* enclosure interior was called *Danmun* (Main Gate). The records of Entering category are in agreement with the results of modern calculations, as shown in Figure 11, except for a few of records.

3.5.2. Approaching, Trespassing, and Eating

Table 4 summarizes the results of modern calculations for the records of Approaching, Trespassing, and Eating categories. Column 1 shows the sequential number (No.), columns 2 and 3 are the observation date (Date) and the hour in units of watch (Watch), respectively, and column 4 is the celestial bodies

(Celest. Bodies) involved in events. The celestial bodies identified in this study are indicated in parentheses. For example, the record for 1667 November 5 (No. 6) says that the moon trespassed against the *Dongjeong*, a constellation comprising eight stars (μ, ν, γ, ξ, ϵ, 36, ζ, and λ Gem), at 4 watches, and the moon was the closest to ϵ Gem according to our analysis. Meanwhile, the record for 1667 August 28 (No. 4) says that the moon trespassed against the fifth star of the *Namdu* constellation. According to the *Seonggyeong*, the *Namdu* constellation comprises six stars, where the second and fifth stars are λ and τ Sgr, respectively. However, the moon was the closest to λ Sgr, which is the fifth star when counted reversely from the order listed in the *Seonggyeong*. Column 5 shows the calculated angular separation (A.S.) between the two celestial bodies. As the moon moves faster than the planets, the angular separation was calculated at intervals of 0.0007 d (~1 min) for the entire duration of the observation hour, given in units of watch, and the minimum angular separation is presented in the table. Category types A, T, and E representing Approaching, Trespassing, and Eating categories, respectively, are noted in the last column. For Approaching category, the angular separation given in the record is also presented in this column, using parentheses.

First, there are three records for Approaching category (Nos. 1–3), all of which are events between planets. According to this study, the observational values of the records are in great agreement with the results of modern computations (see Table 4), with an average angular separation of 0.8°. Second, the total number of records for Trespassing category is 29 (Nos. 4–32) with an average angular separation of 1.2° ± 0.8 which shows general agreement with the result of Ahn et al. (2010), 1.0° ± 0.6. Trespassing category can be divided into four cases based on the relationships between the moon–planet, moon–star, planet–planet, and planet–star. The number of records for moon–planet and planet–planet is one each (No. 24 and 14, respectively), with angular separations of 0.8° and 0.4°, respectively. Conversely, the number of records for the moon-star and planet–star is 21 and 6, with average angular separations of 1.4° and 1.0°, respectively. Lastly, the number of records of Eating category is two (Nos. 33–34), and both are events wherein the moon shielded a planet (Mars) and a star (τ Sco) with an average angular separation of 1.0°, which is slightly less than that of Trespassing category. Very recently, Lee (2023) studied angular separations for *Ip*, *Beom*, *Eom* (covering, in literal), and *Sik* events from the records of the Goryeo and Joseon dynasties and found $0.51^{\circ}{}^{+1.10}_{-0.32}$ and $0.18^{\circ}{}^{+0.43}_{-0.11}$ for *Beom* and *Sik* events (i.e., Trespassing and Eating categories in this study), respectively, from the records of the Joseon dynasty. One reason for the discrepancies in our results may be the observation duration. That is, while we calculated the angular separation at the observation hour given in the record, Lee (2023) determined the angular separation by finding its minimum value during the observable hours. However, in a strict sense, Eating category is not an occultation event, considering the angular radius of the moon, which is ~0.27° (Cox 2000).

Table 4. Summary of the results of modern calculations for the records of Approaching, Trespassing, and Eating categories.

No.	Date	Watch	Celest. Bodies	A.S.(°)	Note
01	1668 Mar. 29	1	Venus/Jupiter	1.2	A(1.00)
02	1670 Sep. 06	4	Venus/Jupiter	0.6	A(0.75)
03	1670 Dec. 06	1	Mars/Saturn	0.7	A(0.75)
04	1667 Aug. 28	2	Moon/λ Sgr	0.5	T
05	1667 Oct. 29	5	Mars/σ Leo	0.2	T
06	1667 Nov. 05	4	Moon/(ϵ Gem)	1.0	T
07	1667 Nov. 26	5	Mars/ζ Vir	0.4	T
08	1668 Feb. 29	4	Moon/(γ Vir)	1.5	T
09	1668 Aug. 06	1	Mars/(ι1 Lib)	1.1	T
10	1668 Aug. 25	1	Mars/δ Sco	0.3	T
11	1669 Feb. 21	4	Moon/α Lib)	0.3	T
12	1669 May 08	1	Moon/(ζ Leo)	0.4	T
13	1669 May 10	1	Moon/σ Leo	3.4	T
14	1669 Dec. 30	1	Venus/Saturn	0.4	T
15	1670 Jan. 29	1	Moon/(η Tau	1.5	T
16	1670 Feb. 08	5	Mars/β1 Sco	0.1	T
17	1670 Feb. 13	5	Moon/(α Sco)	1.4	T
18	1670 May 06	3	Moon/α Sco	1.2	T
19	1670 Aug. 08	5	Moon/(η Tau)	0.7	T
20	1670 Sep. 08	1	Mars/ϕ Sgr	0.1	T
21	1671 Feb. 03	5	Moon/α Sco	0.3	T
22	1671 Mar. 28	3	Moon/(ι1 Tau)	3.8	T
23	1671 May 15	2	Moon/(α Leo)	3.1	T
24	1671 Oct. 27	5	Moon/Jupiter	0.8	T
25	1672 Jan. 10	1	Moon/(ζ Tau)	0.7	T
26	1672 Jan. 16	2	Moon/(α Leo)	1.9	T
27	1672 Dec. 09	5	Moon/ρ Leo	0.8	T
28	1673 Feb. 23	2	Moon/(ζ Tau)	1.3	T
29	1673 Mar. 24	1	Moon/(β Tau)	0.7	T
30	1673 Sep. 16	1	Moon/τ Sco	1.2	T
31	1672 Nov. 02	5	Moon/(α Leo)	1.5	T
32	1673 Dec. 27	2	Moon/ρ Leo	3.0	T
33	1668 Feb. 04	3	Moon/Mars	0.9	E
34	1672 Jun. 06	3	Moon/τ Sco	1.0	E

It is natural to expect the brightness of the moon to affect the observations of events involving it at that time. Figure 12 shows the relationship between the lunar age and angular separation from the records of these events. The blue rectangles and red circles represent angular separations from the records of Trespassing and Eating categories, respectively. It can be seen that the angular separation decreased toward the first or last moon day and increased around the full moon day, indicating that moonlight influenced the observations.

Even under the influence of moonlight, angular separations greater than ~3.0° in the records of Trespassing category (i.e., Nos. 13, 22, 23, and 32) seem larger compared to the mean value of this event, which is 1.2°. This could be a typo in the records themselves or a misidentification of stars in the records with modern ones. The record for 1671 March 28 (No. 22) showed the largest angular separation of 3.8°, which indicates that the moon trespassed against the second star of the *Jeo* constellation (ι1 or γ Lib), comprising four stars (α2, ι1, γ, and β Lib), at 3 watches. According to this study, the moon

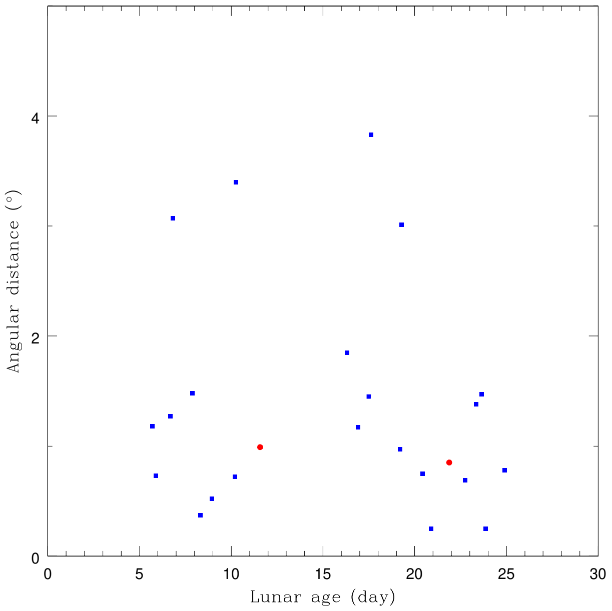

Figure 12. Relationship between the lunar age and angular separation from the records of events involving the moon. Blue rectangles and red circles represent the results from the records of Trespassing and Eating categories, respectively.

was closer to ι1 than to γ Lib. However, 33 Lib was one of the stars closest to the moon with an angular separation of 1.2°, which is classified as roAp (rapidly oscillating Ap star) with a visual magnitude of ~6.67 (Holdsworth et al. 2018). The record showing the second largest angular separation (No. 13) states that the moon trespassed against the fourth star of the *Seo Taemi* enclosure (β Vir, σ, ι, θ, and δ Leo) at 1 watch. The fourth star is σ Leo, which is also confirmed from the record on 1667 October 29 (No. 5), which states that Mars trespassed against the fourth star of the *Seo Taemi* enclosure at 5 watches. Therefore, the possibility of misidentification with the modern star is low. For reference, ω Vir with a visual magnitude of 5.36 was the closest to the moon on 1669 May 10, and the angular separation was 1.1° at 21.7 h in KST (i.e., 1 watch). The contents of the remaining two records (Nos. 23 and 32) are the same; that is, the moon trespassed against the *Jwagak* (left horn, in literal) star in the *Heonwon* constellation at 2 watches. According to the record for 1672 December 9 (No. 27), the moon trespassed against the same star, ρ Leo. Therefore, although the angular separation of 3.0° is significantly large in the record on 1673 December 27 (No. 32), the possibility of misidentification with a modern star is again low. Conversely, the angular separation between the moon and ρ Leo was 8.5° on 1671 May 15 (No. 23), and that between the moon and the *Woogak* (right horn, in literal) star, α Leo, was 3.1°, as shown in Table 4. Therefore, it must be a typo in the original text or in print.

4. Summary and Conclusion

In this study, we investigated various astronomical phenomenon records from Sukjong's *Chunbang-Ilgi* (shortly Chunbagn-Ilgi), daily records made by *Sigangwon* from 1667 January 24 to 1674 September 22, in which King Sukjong was the crown prince. Of the 2,799 days of the records, 2,117 astronomical records were found, counting separately if the record for one day record contains observations of more than one different event. We first introduced Chunbang-Ilgi, explained the methods of modern calculations for astronomical events, and examined the distribution of records based on the time period and season. Furthermore, we classified astronomical records into 14 categories (Sun, Moon, Cloud, Solar Eclipse, Lunar Eclipse, Venus, Jupiter, Meteor, Comet, Aurora, Entering, Approaching, Trespassing, and Eating) and grouped them into five phenomena: Atmosphere, Eclipse, Daylight Appearance, Apparition, and Appulse. Next, we analyzed the records of each group and compared them with the results from modern computations wherever possible. A summary of our findings for each group is as follows.

Atmosphere: Sun, Moon, and Cloud. We classified the records of atmospheric optics events around the sun and moon, such as solar and lunar halos, into Sun and Moon categories. Furthermore, records of unusual clouds, including auroral candidates, were classified into Cloud category. The number of records for this group accounted for ~62% of the total. Although these categories have been considered astronomical phenomena in previous studies, they are fundamentally meteorological phenomena. In this study, we simply introduced the sketches presented in the historical literature entitled *Cheonmundaeseong*, corresponding to the events of Sun category for reference in relevant research fields.

Eclipse: Solar and Lunar Eclipses. Although there were six records in Solar Eclipse category, only two solar eclipses were observable in Korea. We found that the record of the solar eclipse that occurred on 1671 September 3 was in good agreement with modern calculations. However, the solar eclipse that occurred on 1673 August 12 was impossible to observe in Korea, which was inconsistent with the record of Sillok. Meanwhile, seven lunar eclipses were observable although there were eleven records in Lunar Eclipse category. All records of this category agreed with modern calculations based on the length of the twilight time of the *Datong* calendar, which was 36 min. In addition, we confirmed that the Joseon court did not change the date of the observations made after midnight.

Daylight Appearance: Venus and Jupiter. The records of this group on the observations of Venus and Jupiter were verified to be during the daytime but not during twilight. Furthermore, we found that the minimum magnitudes for Venus and Jupiter were −3.9 and −2.3, respectively, indicating a celestial body bright than approximately −2.3 mag would be visible during the day if the observational conditions are adequate.

Apparition: Meteor, Comet, and Aurora. Although the records of Meteor category do not clearly mention a meteor shower, we found the possibility of the influence of the Orionid meteor shower from the analysis of the distribution of the number of records according to the period. From the records of Comet category, we found that the Korean record, which states that the coma of the C/1668 E1 comet (a Kreutz sungrazer) was below the horizon, has been overlooked in previous studies. The records of Aurora category showed that they exhibited peaks in March and around the last moon days, depending on the season and lunar age, respectively.

Appulse: Entering, Approaching, Trespassing, and Eating. We found that the records of Entering category (i.e., *Ip* events) were in good agreement with the results of modern calculations, while those of Approaching category (i.e., described with the expression *Sanggeo*) were much better in agreement compared to Entering category. The records of Trespassing and Eating categories (i.e., the *Beom* and *Sik* events, respectively) showed average angular separations of 1.0° and 1.2°, respectively. Furthermore, the analysis of the relationships between the angular separation and lunar age showed that moonlight influenced the observations.

In conclusion, we believe that Chunbang-Ilgi is a valuable source of Korean historical astronomical records. Furthermore, we believe this work can help study the historical astronomical records of other *Donggung-Ilgi*, such as Sunjong's *Chunbang-Ilgi*, and the subjects of modern astronomy, such as the Kreutz sungrazing comet.

Acknowledgments

This work was supported by research grants from Daegu Catholic University in 2018.

Appendix A. *Donggung-Ilgi*

Whenever a prince was nominated as the crown prince, *Sigangwon* was installed and maintained daily records, similar to Ilgi. The daily records of *Sigangwon* were called *Donggung-Ilgi* because a crown prince dwelled in *Donggung* (Eastern Palace). *Donggung-Ilgi* was also called *Chunbang-Ilgi* and *Chungung-Ilgi* after the nicknames *Chunbang* and *Chungung* for *Sigangwon* and *Donggung*, respectively. Currently, *Donggung-Ilgi* is used as the common designation for the daily records of *Sigangwon* and other royal educational offices.

In this sense, Sukjong's *Donggung-Ilgi* comprises two parts: Sukjong's *Chunbang-Ilgi* and his *Ganghakcheong-Ilgi* made by *Sigangwon* and *Ganghakcheong* (Royal Education Office of the Prince), respectively. It is known that the *Donggung-Ilgi* of 27 kinds are preserved in the Kyuganggak Institute for Korean Studies (Ok 1999). Compared to Sillok and Ilgi, *Donggung-Ilgi* is a chronologically incomplete document in that it is the records for the crown prince or prince; however, the latter document is an original copy, while the former documents were recompiled two or three times (Kim et al. 2008).

Moreover, according to the *Seoungwan-Ji* (Treatise on the Royal Astronomical Bureau) compiled by Ju-Deuk Seong in 1818, astronomical observations made by *Seoungwan* (Royal Astronomical Bureau) were reported to *Seungjeongwon* (Royal Secretariat) and *Sigangwon* (Jeon 1974), but not to *Ganghakcheong*. This might be why astronomical records are not included in *Ganghakcheong-Ilgi*. Meanwhile, Similar to Ilgi, *Donggung-Ilgi* was handwritten in Chinese characters in cursive and semi-cursive styles. Recently, several *Donggung-Ilgi* scripts were translated into Korean, including the original text in print.

Appendix B. Terminology

Chinese astronomical systems have used sexagenary cycles comprising ten *Cheongan* (Heavenly Stems) combined with twelve *Jiji* (Earthly Branches). Sexagenary cycles assigned to a year and a day were called *Secha* (Cyclical Year) and *Iljin* (Cyclical Day), respectively. Similar to other historical documents, in the *Donggung-Ilgi*, a year was expressed with the cyclical year (e.g., the *Jeong-Mi* year for 1667), and a cyclical day was used together with the day number (e.g., *Byeong-Oh* day for the lunar first day). For the order and Chinese characters of 60 cycles, refer to Appendix B of the study by Lee et al. (2012).

Chinese hour systems also used twelve earthly branches based on the apparent solar time (AST). A day was divided into twelve *Si* (Double-Hour) with equal intervals, and the names of double-hours were used with twelve earthly branches, such as the *Ja* and *Oh* double-hours. Furthermore, a double-hour was subdivided into two equal intervals called *Cho* (First Half) and *Jeong* (Latter Half). Therefore, each day was composed of 24 single-hours (e.g., the *Ja-Cho* single-hour), and local noon (i.e., the moment when the sun transits on the observer's meridian) was represented by the *Oh-Jeong* single-hour. Additionally, the units of *Gak* (Mark) were utilized in the Chinese hour system, but the scales were different from the calendars; for example, a day was 100 and 96 marks in the *Datong* calendar of the Ming dynasty (1368–1644) and the *Shixian* calendar of the Qing dynasty (1636–1912), respectively. Therefore, the length of 1 mark in the *Datong* calendar corresponds to 14.4 min in the modern hour system. Alternatively, the mark units were used to subdivide the length of every single-hour into five ranges; 0, 1, 2, and 3 marks with 14.4 min and 4 marks with 2.4 min (Lee et al. 2009b). Hence, the *Oh-Jeong* single-hour and 3 marks in the *Datong* calendar correspond to the period from 12 h 28.8 min to 12 h 43.2 min in AST.

Apart from these units, the *Gyeong* (Watch) and *Jeom* (Sub-Watch) were utilized for the *Yagak* (Night Period), which is the period from the end of *Chohon* (Evening Twilight) to the beginning of *Maesang* (Morning Twilight). The twilight length also varied according to the calendar. It was 250 *Bun* (Minute) in the *Datong* calendar, which is 36 min in the modern hour system. Similarly, the night period was divided into five equal ranges; 1, 2, 3, 4, and 5 watches. In particular, 1 watch was interchangeably called the *Cho* watch. Each watch was also equally subdivided into five classes; 1, 2, 3, 4, and 5 sub-watches. As a result, the length of each watch varied according to the calendar and the season. On applying the length of the twilight time in the *Datong* calendar, the lengths of each watch were 1.608 and 2.648 h in the summer and winter solstices, respectively, approximately 2.218 h on average.

Jang, *Cheok*, and *Chon* were used as units of an angle:

0.1 *Jang* = 1 *Cheok* = 10 *Chon*. Although Kiang (1972) suggested the ratio of *Cheok*/degree to be 1.5 from the Chinese astronomical records, it is generally considered to be ~1; that is, 1 *Cheok* is approximately 1° (e.g., Hasegawa & Nakano 2001). Meanwhile, astronomical observations used cardinal direction systems of four, eight, and so on. Terms such as *Gam* (North), *Gan* (Northeast), *Jin* (East), *Son* (Southeast), *Ri* (South), *Gon* (Southwest), *Tae* (West), and *Geon* (Northwest) were used in the eight-cardinal direction system. For the terms used in other cardinal systems, refer to Ahn et al. (2020). Lastly, all the Chinese systems mentioned above were adopted by the Joseon dynasty.

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