Meteors And Showers A Millennium Ago

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ABSTRACT
Meteors can be classified into either sporadic meteors or showery meteors. We compile the meteor records in the astronomical archives in the Chronicle of the Koryo dynasty (918-1392), and investigate the spatial distribution of meteor streams along the orbit of the Earth from the 10th century to the 14th century. We see that meteors from meteor streams signalize themselves over noisy sporadic meteors, and that the seasonal activity of sporadic meteors was apparently regular. We discover the presence of a few meteor streams by analysing about 700 meteors in the Koryo period. We also compile the records of meteor showers and storms in the chronicles of Korea, Japan, China, Arab, and Europe, and compare their appearance dates with those of showers obtained above, as well as with the modern observations. We confirm that the three sets of data are in agreement with each other. The representative meteor showers are the Perseids, the Leonids, and the η-Aquarids/Orionids pair formed by Halley’s comet. The other weak or relic meteor streams are also observable but uncertain. Hence, we witness the regularity of meteor activity, which is seen to persist for a millennium.

1 INTRODUCTION
Comets scatter their evaporated particles around their orbit, and these materials eventually fill the cometary orbit due to the dispersion of momenta. The belts of such remnants are called meteor streams. When the Earth passes through meteor streams, meteor showers are seen on the sky. In particular, just before and after a comet passes through its perihelion, its meteor stream is greatly enriched and the meteor shower looks almost like a firework. This is often described as a meteor storm. After a long time, cometary materials are dispersed into the interplanetary space. If the dispersed meteoroids enter the Earth’s atmosphere,
we may see sporadic meteors. Presently the rate of major meteor showers is approximately one meteor shower per month. Meteors are observed and recorded by astronomers around the world both optically and in radio. Regular pattern of annual meteor activity is well illustrated in Figure 6 and Table 2 of Yrjölä and Jenniskens (1998).

Due to the advancement of observational techniques, weak meteor showers have become an attractive topic in this field. Hughes (1990) discovered that the apparently random sporadic meteors are not so random, and that about 20% of meteors during a non-shower day belong to weak showers. He also suggested that the flux of sporadic meteors can vary by about 30-40% over $10^4$ – $10^5$ years due to the statistical variations in the numbers of massive short period comets. Although modern astronomy provides precise and sensitive techniques for massive observation of meteors and showers, they cannot provide the data that can show the long-term variations of meteor activity over more than a few hundred years. Hence, it is worth discovering whether we can investigate the long-term variation of meteors and showers by analysing the astronomical records of ancient people.

Another important factor that determines the meteor flux, either sporadic or showery, is the distance between the Earth’s orbit and the nodal points of the cometary orbits. The orbits of comets are affected by gravitational perturbations due to major objects in the Solar system. The non-gravitational forces are also strong sources of orbital changes, but it is very hard to calculate the effects even in the modern astronomy. Hence, the ancient astronomical records in chronicles can be useful to understand the long-term effects of these forces on orbital displacement.

In this study we will investigate the meteor records written in the Koryo dynasty (918-1392) which is one of the dynasties in the Korean history. In Section 2 we explain which archives are authentic and reliable and how we compile the data. The analysis method is explained in Section 3, and the results are followed in the next Section. In the final Section we discuss our results.

2 KOREAN RECORDS

Korean astronomical records written in history books have several merits. Firstly, the duration of a Korean dynasty was typically around 500 years, and so the astronomers in the Koryo dynasty could observe the astronomical phenomena continuously. Moreover ancient Korean dynasties established their own Royal Observatories, and hired a number of pro-
The majority of astronomical records in the Korean history are preserved in a few major history books published by the historians of the successive dynasties. Some history books were also published privately. A number of the astronomical records of the Old Choson dynasty are remained in a book titled by The Ancient Chronicle of the Old Choson dynasty. However, this book was discovered in modern times, and unfortunately historians and bibliographers suspect that it may be a forged one. The astronomical records in the era of the Three Kingdoms (57 B.C. - 668 A.D.) and the Unified Shilla dynasty (668-935) are written in The Chronicle of the Three Kingdoms (Sam-Guk-Sa*) (Kim et al. 1145). Almost no astronomical records of the Parhae dynasty (698-926) are left due to the lack of its own history books. The astronomical records during the Koryo dynasty (918-1392) are preserved in The Chronicle of the Koryo dynasty (Koryosa) (Kim et al. 1451) and The Simplified Chronicle of the Koryo dynasty (Koryosa-Joryo) (Kim et al. 1452). The information during the Choson dynasty (1392-1910) are written in The Chronicle of the Choson dynasty (Choson-Wang-Jo-Shillok). These are surely vast sources of astronomical data for modern astronomy. The

* The name of this book is widely known as Sam-Guk-Sa-Ki.
Korean records have been introduced to the international society mainly by foreign scholars (e.g. Imoto & Hasegawa 1958). However, they did not refer to the original historical books such as those in Table 1. They merely used digested versions of Korean history books, such as *Mun-Heon-Bi-Go* and *Yol-Sung-Shillok*, which have a number of ambiguous or wrong dates and misleading expressions for astronomical events.

In this paper we concentrate on the meteor records of the Koryo dynasty. The records have never been catalogued after thorough examination on errors in their dates, and so we first made the catalogue after correcting several erroneous dates. We use the data in the authentic history book or *Koryosa*. The records of meteor storms in the Korean history books are also surveyed. The detailed procedure of compilation was published in another Korean journal (Ahn et al. 2002).

A typical record of meteor reveals a few kinds of information such as date, time, starting and ending points, brightness, colour, and sound. The dates were represented by the calendar system used at that time, and they can be converted into Julian dates by utilizing the calendar conversion table established precisely before this work (Han 1996, Shim et al. 1999). In *Koryosa* there are 729 meteor records in total. One of them has no date, eight of them have ambiguity in calendar system, and fifteen of them were described as precursors of a meteor storm. These fifteen records are also excluded in our analysis, because they may bias the result. Hence, we have 705 meteors which can be analysed.

There appears no meteor records in the 10th century, to say nothing of other kinds of astronomical records. The extreme rarity of historical data during this century was caused by the invasion of the Kitanese army in 1011 A.D.. When the army occupied the capital city of Koryo, they fired the Korean documents and books of former ages. However, the Korean records from the 11th century to the 14th century show largely no discontinuity of records. On the other hand, the Chinese records show a bimodal distribution, in that there are few records in the reign of the Mongolian Empire (Hasegawa 1992).

### 3 METHOD

Events of sporadic meteors resemble random noise, while meteors belonging to meteor showers can be considered as a signal. The meteors caused by a meteor stream are likely to fall at nearly the same time of year, while sporadic meteors fall randomly. Hence, any concentration in appearance dates of meteors in *Koryosa* can be thought of as a sign of a meteor shower.
For meteor showers, astronomers usually rely on the solar ecliptic longitude \((\lambda_\odot)\) which is defined by the angle in degrees along the ecliptic from the Vernal equinox to the position of the Earth. Evidently the ecliptical coordinate system (equivalently the Julian and the Gregorian calendar systems) is not convenient to compare two events whose interval is as large as thousand years. That is because the origin of the ecliptical longitude or the Vernal equinox varies with time due to the precession of the Earth’s rotation axis.

In this paper we first locate meteor showers a millennium ago, and then compare their appearance dates with the modern observations to identify the meteor showers. In order to do so, we define the number of days after the perihelion passage time of the year, which is denoted by \(\Lambda\). In other words it is equivalent to relocate the origin of the ecliptic coordinate from the Vernal equinox to the perihelion. Since the orbit of the Earth is more stable than the Earth’s rotation, \(\Lambda\) is more adequate for our purpose. The perihelion passage time of the year is calculated by using the method in Meeus (1991).

4 RESULTS

4.1 Seasonal Variation of Sporadic Meteors

The results are shown in Figure 1, where peaks appear over a fluctuating background of sporadic meteors. These prominent peaks represents the major meteor showers in the Koryo period. According to Yrjölä & Jenniskens (1998), the level of sporadic activity can be expressed by a functional form:

\[
N(\lambda_\odot) = \langle N_{spo} \rangle - \Delta N_{spo} \cos(\lambda_\odot),
\]

where \(\langle N_{spo} \rangle\) is mean daily sporadic hourly count at the Summer solstice on June 21 and \(\Delta N_{spo}\) is the yearly amplitude due to the seasonal variation. Here \(\lambda_\odot\) is the solar ecliptical longitude. The Koryo data are too sparse to give us meaningful values for \(\langle N_{spo} \rangle\) and \(\Delta N_{spo}\). We need more detailed description and additional data such as weather conditions to compensate the sparseness of data, but there are few such detailed data in history books of the Koryo era. Hence, we will simply check the sinusoidal variation of seasonal activity of sporadic meteors in this study. Thus, we make a simple eye-fitting to the sporadic flux by Eq. (1). Here we exclude the prominent peaks over the fluctuating background. Data around \(\Lambda = 200\) are also excluded, because they can bias results. This is a season of Jangma, during

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which it rains continuously, being related with the East Asian Monsoon. However, the fitting is merely qualitative and can be thought of as an adjoint line in Figure 1.

We can see in the figure that the sporadic fluctuations show rough agreement with the fitting curve. This general trend that the flux is small in spring and large in autumn, is caused by the fact that the Earth’s rotation axis is inclined and so altitudes of radiant points are higher in autumn than in spring. Our result supports the idea that the meteor data of the Koryo dynasty is faithfully representing the natural phenomena.

4.2 Prominent Meteor Showers

Now let us turn our attention to the major meteor showers which appear as peaks in Figure 1. The most prominent peak appears on about $\Lambda = 225$. When we convert this date into the ecliptical longitude, we can see that it corresponds to $139^\circ \leq \lambda_\odot \leq 142^\circ$. (In this paper, the solar longitudes of meteor showers are expressed for B1950.) According to the table given by Yrjölä & Jenniskens (1998), this corresponds to the Perseids ($\lambda_\odot = 139^\circ$), whose parent comet is 109P/Swift-Tuttle. Since the orbit of this comet has a nearly normal inclination, the gravitational perturbation of other objects in the solar system is rather small, and consequently its orbit is preserved for a long time.

The other prominent peaks appear in winter ($250 \leq \Lambda \leq 360$). One of the most strong peaks appears in the period $297^\circ \leq \Lambda \leq 316^\circ$ which corresponds to $213^\circ \leq \lambda_\odot \leq 232^\circ$. We can find two current major meteor streams in this period, which are the Taurids ($\lambda_\odot = 223^\circ$) and the Leonids. The parent comet of the Taurids is 2P/Encke, and its orbital inclination is merely $i = 12^\circ.4$. However, since its apheilon distance amount to 4.1 AU, the comet does not experience great gravitational perturbation of the Jupiter, so that its orbit is persistent over centuries (Sitarski 1988). The orbital period of comet Encke is only 3.3 years, which is easily short enough to be depleted in dust. Hence, the comet cannot supply lots of meteoroids to the meteor stream these days. However, historical studies indicate that activity of the Taurids during the 11th century may have been comparable to today’s Perseids (Astapovic & Ternteva 1968, Hasegawa 1992, Bone 1993). However, it should be noted that the active durations of the Taurids and the Leonids overlapped in the period of Koryo, so that it is not easy to discriminate between them.

The present ecliptical longitude of the Leonids is $\lambda_\odot \approx 235^\circ$, which implies its position on the ecliptic has shifted over the years. In fact, since the precession of the nodal points of
the parent comet, 55P/Tempel-Tuttle, is 1.6 day per century (Mason 1995), we can estimate the ecliptical longitude of the Leonids during 10-14th century to be about $220^\circ \leq \lambda_\odot \leq 225^\circ$, which is in good agreement with the peak seen above at $250 \leq \Lambda \leq 360$. Contrary to either 109P/Swift-Tuttle or 2P/Encke, the parent comet of the Leonids, 55P/Tempel-Tuttle, has an orbit that is close to the ecliptic, so that the stronger gravitational perturbation makes the orbit precess.

In spring there is another shower at $\Lambda = 126$ or $\lambda_\odot = 48^\circ$. The signal is very marginal, but its ecliptical longitude corresponds to the $\eta$–Aquarids, whose parent comet is Halley’s comet. It is well-known that this shower has a pair shower, the Orionids at $\lambda_\odot = 208^\circ$. We can find the weak feature of the Orionids at $\Lambda = 289$ or $\lambda_\odot = 205^\circ$. Since the bin size of the horizontal axis in the figure is as large as 4 days, we can say that this small peak is likely to be the Orionids. When we compare the annual meteor activity in the Figure 6 of Yrjölä & Jenniskens (1998), we can see that both meteor showers are relatively weak in strength. The signals are observed to be weak, but the pairness of their appearance and the strong activity seen in the data of the meteor storm for both showers indicate that the $\eta$–Aquarids/Orionids were active in the Koryo period.

4.3 Weak Showers

Another conspicuous peak is seen at $\Lambda = 270$, corresponding to $\lambda_\odot = 186^\circ$. In the Table 2 of Yrjölä & Jenniskens (1998), we can find that the Sextantids has the coincident ecliptical longitude $\lambda_\odot = 186^\circ \pm 2^\circ$. However, its ZHR† is estimated to be merely 9 meteors per hour, which is very weak. However, we can not exclude the possibility that the Sextantids was stronger in the medieval era than now.

There appears a prominent peak at $\Lambda = 335$. Current major meteor showers observed in December are rather variable in strength. Representative ones are the Boötids and the Geminids. Their present ZHR is as large as 110 and 140, respectively. Although we see in Figure 1 a prominent peak at $\Lambda = 335$ or $\lambda_\odot = 251^\circ$. This peak does not correspond to either the Boötids or the Geminids. According to Table 2 of Yrjölä & Jenniskens (1998), this peak may correspond to the $\chi$–Orionids.

The peaks at $\Lambda = 34$ and $\Lambda = 95$ may correspond to the recent showers, the Feb-Draconids and the N-Virginids, respectively. When considering another catalogue of meteor

† Zenithal Hourly Rate
showers (Bone 1993), these weak peaks are believed to be aged and depleted showers or relics of dead comets. However, the existence and the activity level of these weak showers in the Koryo period are still uncertain.

4.4 Temporal Variations

In order to check the possibility of the temporal variation and confirm the validity of our results, we divide the data into two sets, around 1150 A.D.. The histogram is even more fluctuating because of the small amount of data. However, the seasonal variation of the meteor flux and the conspicuous peaks such as the Perseids and the possible Leonids around $\Lambda = 300$ can be seen in Figure 2. The dotted lines represent the annual variation of sporadic meteors observed recently. This indicates that the meteor activity had persisted during the Koryo dynasty, and that the showers we discovered are realistic and meaningful. This is also supported by other researches for the independent data set compiled out of the history books of the Sung and the Ming dynasties (Hasegawa 1992), and for the Koryo data (Hasegawa 1998). We will discuss this in Section 5.

4.5 Meteor Storms

Roughly speaking, the meteor storms written in chronicles form a subset of meteor showers, but they are splendid enough to be frequently recorded in ancient chronicles. We define the data sets as follows: (A) meteor showers found by analysing the data of sporadic meteors in *Koryosa*, (B) meteor showers and storms recorded in historical books listed below, (C) meteor showers observed recently.

It is much interesting if three data sets have some correlations. Motivated by this fact, we check the consistency among these three sets of data. We collect the records of meteor showers and storms from chronicles of Korean, Japanese, Chinese, Arabian, and European countries (Dall’olmo 1978, Kanda 1935, Rada & Stephenson 1992, Hasegawa 1996, Mason 1995, Imoto & Hasegawa 1958, Beijing Observatory 1988). We collect the Korean records of meteor showers with a thorough survey of the Korean archives, and the catalogue will be published elsewhere. After appearance dates of all the data being converted into the same time coordinate or $\Lambda$, we check the conformity in appearance dates between the showers and the storms. We show in Figure 3 their appearance dates in year. The broad stripes that are yellow, blue, and red in colour represent the active duration of each current meteor
shower denoted on the left of the box. The narrow lines represent the durations of maximal activity for each current meteor shower. The symbols represent the meteor storms reported by civilizations, and each meaning can be consulted in the figure caption.

First of all, it is remarkable in the figure that the current maxima of the \( \eta \)–Aquarids and the Orionids, remnants of Halley’s comet, show an exact conformity to those of the historical meteor storms. The Perseids also shows similar agreement, and the appearance date seem to have been a few days later than now. That is to say, its \( \Lambda \) was a few days larger than now.

The Leonids displays its firework in a relatively short duration, and their displaying date has been delayed year by year at a rate of 1.6 days per century (Mason 1995). According to the compilation of Mason (1995), the earliest record of the Leonid storm is traced back to 902 A.D. in Egypt. However, the Orionids overlapped with the Leonids around the 9th century. Hence, even if there are any record of the Leonids in any chronicle, it is uncertain whether it belongs to the Leonids or the Orionids.

5 DISCUSSION

We have investigated the sporadic meteors and showers in the Koryo dynasty (918-1392). We found that the seasonal activity of sporadic meteors shows rough agreement with the modern observation. We also found that there were a few prominent meteor showers and storms: the Perseids, the Leonids, and the possibly \( \eta \)–Aquarids/Orionids pair. There were also weak and aged meteor showers. The meteor showers known from the Koryo data are in good agreement with the meteor storms compiled from the world-wide chronicles, as well as with the modern observation.

Our results can be supported by analyses of independent data in another historical archives such as the Sung dynasty (960-1279) and the Ming dynasty (1368-1644). Hasegawa (1992) investigated the Chinese and the Japanese records of meteors. The number of the Chinese records during the period of the Koryo dynasty (918-1392) amounts to 1638, while that of the Koryo records is 729. The Chinese meteor records increase sharply in number around 1070 A.D. and 1430 A.D., just at the beginnings of the Sung and the Ming dynasties. This may be attributed to the changes in the principles or the methods of the meteor observation in the dynasties (Hasegawa 1992). Also there are few meteor records during the Yuan dynasty (1271-1368) of the Mongol empire. On the other hand, the temporal
distribution of the meteor records in the Koryo dynasty has a broad peak around the 12-13th centuries. Hence two sets of data are statistically independent and complementary with each other, because both the observers and the characteristic periods are different.

Hasegawa (1992) investigated the monthly variations of meteors recorded in China during 1-1000 A.D. and all centuries after 1001 A.D., which was shown in Figure 3 of his paper. He discovered two conspicuous maxima in July-August and November-December. He thought that these two maxima are in agreement with recent observations, and insisted that this supports the reliability of the Chinese records. He concluded that the July-August peak is the Perseids, and that the November-December peak is the Taurids.

Hasegawa (1998) also applied his work to the Koryo meteor records, and concluded that the meteor records of the Koryo dynasty show the same pattern in the variations of meteor flux as seen in the Chinese records. However, unfortunately, he only inspected the monthly variations in both papers, and so the time-resolution is not fine enough to see the individual meteor showers. The temporal resolution in our study is about five days. As a result, we can see that the Perseids existed a thousand years ago, and that the Hasegawa’s November-December shower is not likely to be the Taurids, but the Leonids, because of its appearance date and the coincidence with the records of the meteor storms. At any rate, Hasegawa’s study supports our conclusions.

The meteor records of the Choson dynasty (1392-1910) were written in the Chronicle of the Choson dynasty. The total number of records amounts to about 3500. We have been carrying out the similar researches on the Choson data, and the analysis for the part of records in the Choson dynasty have been finished. The results support our conclusion in this paper. The results will be published elsewhere.

We conclude that the major meteor showers and storms a millennium ago might be caused by the same short-period comets to the current ones, and their activities were similar to those of present showers. It is interesting that although everyday meteors seem to be sporadic and random, there is a regularity, which lasts for at least a millennium.

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Figure 1. Annual meteor activity extracted from the meteor data in the astronomical archives of the Koryo dynasty (918-1392). In the horizontal axis, $\Lambda$ is days from the perihelion passage time of that year to the apparition of meteors. The sinusoidal dotted line stands for the fitting curve of the recently observed annual variation of sporadic meteors. The peak denoted by P is the Perseids, LT means the Leonids and the Taurids mixture, and two H's mean the $\eta$-Aquarids and the Orionids, whose parents is Halley's comet.
Figure 2. Annual meteor activity extracted from the meteor data in the astronomical archives of the Koryo dynasty (918-1392). In the horizontal axis, $\Lambda$ is days from the perihelion passage time of that year to the apparition of meteors. Here we divided the data into two sets around 1150 A.D.. The sinusoidal dotted lines stand for the eye-fitting curve of the recent seasonal variation of sporadic meteors.
Figure 3. Historical meteor showers drawn from the world wide data sources of east Asian, Arabian, and European countries. The thick stars and the solid vertical bars represent the Korean data, the blue cross and the dotted vertical bars the Chinese data, the thin stars and dashed vertical bars the Arabian data, the triangular stars the Japanese data, and the green empty triangle the European data. The vertical bars represent the data whose dates are given only up to month. The wide stripes represent the active duration, and narrow stripes in them stand for the maximum activity. The names of major showers are written on the left side of the stripes. The vertical axis is the number of days after the perihelion passage for each shower.