Orbital elements of comet C/1490 Y1 and the Quadrantid shower

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ABSTRACT
The Quadrantid shower, one of the most intense showers, has been observed at the beginning of January each year. However, the origin of the meteors is still unknown. It was Hasegawa who first suggested comet C/1490 Y1 to be the likely origin of the shower based on the historical records of East Asia. We analyse the records of Jo-Seon-Wang-Jo-Sil-Lok (the Annals of the Joseon Dynasty in ancient Korea) and calculate the preliminary orbital elements of comet C/1490 Y1 using a modified Gauss method. We find that comet C/1490 Y1 was a periodic one and its orbital path was very similar to that of the Quadrantid meteor stream. The determined orbital elements are perihelion passage time $T_p = 2.265652.2983$ d (1491 January 7.8 in UT), perihelion distance $q = 0.769$ au, eccentricity $e = 0.747$, semimajor axis $a = 2.03$ au, argument of perihelion $\omega = 164^{\circ}/03$, longitude of ascending node $\Omega = 283^{\circ}/00$ and inclination $i = 70^{\circ}/22$ for the epoch of J2000.0. We therefore conclude that our result verifies the suggestion that comet C/1490 Y1 is the origin of the Quadrantid meteor shower, but was a periodic comet. We discuss a possible link between this comet and the asteroid 2003 EH1 as well.

Key words: methods: data analysis – methods: numerical – comets: individual: C/1490 Y1 – meteors, meteoroids – minor planets, asteroids.

1 INTRODUCTION
Meteor showers can be spectacular astronomical events, displaying bright streaks of light in the sky as the Earth passes through a meteor stream. One of the most regular displays comes from the Quadrantid shower which can be viewed each January with a zenithal hourly rate of about 100. The peak in activity is quite short, usually less than a day (Shelton 1965), and the declination of the radiant is around $50^{\circ}$, making it essentially a Northern hemisphere shower.

The name of the shower originates from the Quadrans Muralis constellation, which is now a defunct constellation but existed when the stream was recognized in 1835 by Quetelet (Fisher 1930). Up to the present, however, the parent body of the meteors has not been clearly identified (Kaňuchová & Neslušan 2007).

There have been numerous suggestions regarding a possible parent for the stream, starting with Bouška (1953) who suggested comets C/1939 B1 and 8P/1790 A2 as possibilities. A list of early suggestions can be found in Williams et al. (2004a). More recently, comet 99P Macholz has been discussed by many authors (McIntosh 1990; Babadzhanov & Obrubov 1992; Jones & Jones 1993; Kaňuchová & Neslušan 2007). The increase in the number of near-Earth asteroids discovered has also led to some being identified as having similar orbits to the Quadrants, for example 1973 NA (Williams & Collander-Brown 1998) and 2003 EH1 (Jenniskens 2004). Babadzhanov, Williams & Kokhirova (2008) showed that the Quadrants and 2003 EH1 are definitely related. Another strong candidate, first suggested by Hasegawa (1979), is comet C/1490 Y1. Williams et al. (2004b) discussed the possibility that this comet and asteroid 2003 EH1 are dynamically related. Hasegawa’s suggestion is based on the historical records from China, Korea and Japan of the appearance of the comet. As in most other studies on ancient comets, he assumed the orbit of the comet to be parabolic (i.e. eccentricity of unity). Except for the eccentricity, his orbital path showed a good agreement with that of the Quadrants (Williams & Wu 1993). More detailed reviews of comet C/1490 Y1 and of the Quadrants can be found in Kronk (1999) and Jenniskens (2008).

For Korean records of comet C/1490 Y1, Hasegawa (1979) referred to Ho’s (1962) catalogue which was compiled from Jeung-Bo-Man-Heon-Bi-Go (explanatory notes of literary document). This is a secondary historical document compiled from the various first historical ones but abbreviated in descriptions, and therefore contains some errors. None the less, the book was one of the most frequently cited references on the study of ancient Korean astronomy (e.g. Rufus 1936; Needham et al. 1986) because it deals with various astronomical subjects covering the whole period of historic Korea.

In this paper, we examine the records on comet C/1490 Y1 from Jo-Seon-Wang-Jo-Sil-Lok [the Annals of the Joseon Dynasty in Korea (1392–1910); hereafter Sillok] and calculate the orbital elements using a modified Gauss method. In Section 2, we list some
relevant records on comet C/1490 Y1 from Sillok and briefly introduce ancient astronomy in Korea. In Section 3, we explain the process of determining preliminary orbital elements from the records of Sillok. We present our results in Section 4 and summarize in Section 5.

2 RECORDS OF COMET C/1490 Y1 FROM SILLOK

Different from Jeung-Bo-Mun-Heon-Bi-Go, Sillok is one of the first-hand historical documents and contains more detailed descriptions of astronomical phenomena. In some cases, Sillok's records contain additional information such as observation time, angular distance from the north pole, length of a tail (in the case of a comet) and so forth. Hence, Sillok is one of the most important sources on the studies of past astronomical phenomena (e.g. Stephenson & Yau 1980; Hasegawa & Nakano 2003; Yang, Park & Park 2003). Recognized for its importance, Sillok was registered as a Memory of the World by UNESCO in 1997.

Chinese astronomers first discovered comet C/1490 Y1 at the south of Thien-Chin constellation at the end of 1490 and reported last on January 30 the next year (Kronk 1999). According to Sillok, this comet had been observed for 39 days nearly every day from 1491 January 2 to February 9 in Korea. In Table 1, we summarize some relevant records presented in Sillok. The first and the second columns are observation dates (in the Julian calendar) and the contents of Sillok's records, respectively. The table shows how systematic and detailed the records of Sillok are. For example, the record of 1419 January 23 tells us that comet C/1490 Y1 trespassed against $\eta$ Cet on 1491 January 22 while the Chinese record simply says that 'comet trespassed against Thien-Tshang' (see Ho 1962). In addition, the annals also describe some interesting facts such as who performed the observations at that time (i.e. Eung-Gi Kim and Ji-Seo Jo), why it was identified as a comet (i.e. due to the tail and its direction), what kind of astronomical instrument was used in the observations (i.e. a small simplified astronomical instrument; see Needham et al. 1986) and how to operate the instrument (not present in this study). Lastly, a star which appeared after 1491 February 5 is the object designated as X/1491 B1 in Kronk's (1999) catalogue. We express the names of the oriental constellations and the units of the angular distance in terms of the Chinese transliteration because these are better known to the international community.

In Fig. 1, we present a part of Cheon-Sang-Yeoel-Cha-Ban-Ya-Ji-Do (an ancient Korean star chart engraved on a stone in 1395, refer to Rufus 1912; Needham & Lu 1966; Park 1998) in order to provide a visual impression of oriental constellations and to help the understanding of ancient Korean uranography explained in the next section. In the figure, yellow dotted lines are lunar mansions and $\beta$ Aqr, $\alpha$ Aqr, $\alpha$ Peg, $\gamma$ Aqr and $\xi$ And are reference stars in each mansion. White solid lines are oriental constellations mentioned in this study: (1) Thien-Chin, (2) Jen-Hsing, (3) Chhu & Chiu, (4) Yun-Yu, (5) Lei-Pi-Chhen, (6) Thien-Hun and (7) Thien-Tshang.

Before 1895, the history of calendrical methods in Korea is basically the same as in China, hence the history of hour systems as well. Until 1653, the Joseon royal court used the 100-Divisions system which divides a day into 100 divisions. The court also

<table>
<thead>
<tr>
<th>Date</th>
<th>Records</th>
</tr>
</thead>
<tbody>
<tr>
<td>1491 January 3</td>
<td>One-Watch yesterday, there was a faint light with 4–5 $\text{chi}^b$ tails around the 11th lunar mansion. King Seongjong ordered observation to Eung-Gi Kim and Ji-Seo Jo.</td>
</tr>
<tr>
<td>1491 January 6</td>
<td>One-Watch yesterday, the comet was unobservable due to heavy clouds.</td>
</tr>
<tr>
<td>1491 January 7</td>
<td>Yesterday, the position of the comet was 6° from the 12th lunar mansion and 65° from the north pole. Identified as a comet due to its tail and the direction.</td>
</tr>
<tr>
<td>1491 January 8</td>
<td>Venus appeared at the daytime.</td>
</tr>
<tr>
<td>1491 January 9</td>
<td>Yesterday, the position of the comet was 11° from the 12th lunar mansion and 76° from the north pole. Used simplified astronomical instrument for the observations of the comet.</td>
</tr>
<tr>
<td>1491 January 10</td>
<td>Yesterday, the position of the comet was 14° from the 12th lunar mansion and 79° from the north pole.</td>
</tr>
<tr>
<td>1491 January 11</td>
<td>Yesterday, the position of the comet was 2° from the 13th lunar mansion and 81° from the north pole.</td>
</tr>
<tr>
<td>1491 January 12</td>
<td>Yesterday, the position of the comet was 4:5 from the 13th lunar mansion and 84° from the north pole.</td>
</tr>
<tr>
<td>1491 January 14</td>
<td>Yesterday, the comet was located above Yun-Yu constellation.</td>
</tr>
<tr>
<td>1491 January 15</td>
<td>Yesterday, the comet moved below the first star of Yun-Yu constellation from the east.</td>
</tr>
<tr>
<td>1491 January 20</td>
<td>Yesterday, the comet moved between Lei-Pi-Chhen and Thien-Hun constellations.</td>
</tr>
<tr>
<td>1491 January 21</td>
<td>Yesterday, the comet moved above the first star of Thien-Tshang constellation from the west ($\iota$ Cet).</td>
</tr>
<tr>
<td>1491 January 23</td>
<td>Yesterday, the comet trespassed the second star of Thien-Tshang constellation from the west ($\eta$ Cet).</td>
</tr>
<tr>
<td>1491 January 25</td>
<td>First-Watch yesterday, the comet moved into the centre of Thien-Tshang constellation.</td>
</tr>
<tr>
<td>1491 January 26</td>
<td>First-Watch yesterday, the comet moved into 2 or 3 $\text{chi}$ south-west of the second star of Thien-Tshang constellation from the east ($\tau$ Cet).</td>
</tr>
<tr>
<td>1491 January 29</td>
<td>First-Watch yesterday, the comet moved into 2 or 3 $\text{chi}$ south-east of $\tau$ Cet.</td>
</tr>
<tr>
<td>1491 January 31</td>
<td>One-Watch yesterday, the comet trespassed the first star of Thien-Tshang constellation from the east (57 Cet).</td>
</tr>
<tr>
<td>1491 February 05</td>
<td>First-Watch yesterday, the comet moved into the east of 57 Cet.</td>
</tr>
<tr>
<td>1491 February 06</td>
<td>A star appeared from the east of $\eta$ Cet.</td>
</tr>
<tr>
<td>1491 February 12</td>
<td>One-Watch yesterday, the comet moved into the east of 57 Cet.</td>
</tr>
<tr>
<td>1491 February 14</td>
<td>A star disappeared.</td>
</tr>
</tbody>
</table>

$^a$Refer to the text.
$^b1\text{chi} = 1°.5 \pm 0.24$ (Kiang 1972).
$^c$Refer to Fig. 1.
Oriental constellations presented in Cun Peg as the reference stars of Cheon-Sang-Yeol-Cha-Bun-Aqr and ADL α400, ±×. Cet (cf. Kiang 1972). For the purpose of illustration, we also α2009 The Authors. Journal compilation Seo-Un-Gwan 2009 RAS, MNRAS =β(1) the Royal Bureau of Astronomy in the chi ADN. Seong-Kyung C ±×Seo-Un-Gwan-Ji Aqr (see Fig. 1). As can be found in C−Aqr, UT(1)360 C=βis the correction term of 1389–1393 C46x72 mansion and the north pole. However, the value of 365 25 was used to cover the great circle in the sky until the 1650s. Therefore, the observational values by an astronomical instrument simply can be converted into right ascension and declination as the following:
\[
\begin{align*}
\alpha &= \alpha_k + C \times \frac{\text{ADL}}{15} \\
\delta &= 90^\circ - C \times \text{ADN},
\end{align*}
\]
where \(\alpha_k\) is the right ascension of the reference star of the \(k\)th lunar mansion in units of hours and \(C\) is the correction term of \(\frac{360}{365.25}\). ADL and ADN represent angular distances from a lunar mansion and from the north pole, respectively, in units of degrees. In this study, we use β Aqr, α Aqr and α Peg as the reference stars of the 11th, 12th and 13th lunar mansions, respectively (Kiang 1972; Cullen 2006).

Besides five records that include observational values, Sillok also provides two valuable pieces of information on the comet: trespass events on 1491 January 23 and 31. According to Seo-Un-Gwan-Ji, Records of Seo-Un-Gwan (the Royal Bureau of Astronomy in the Joseon Dynasty), a trespass event is defined as a phenomenon in which the light rays of two celestial bodies have influence on each other within a cum, a 10th of a chi (i.e. 0.15). We therefore use the coordinates of invaded stars for the records of a trespass event. To identify the invaded stars, we refer to the work of Ahn, Park & Yu (1996). They studied oriental stars listed in Seong-Kyang, a star catalogue written by a Korean astronomer Byeong-Gil Nam in 1861, to identify with modern ones. According to their work, the first star of Thien-Tshang constellation from the east is 57 Cet, not \(\upsilon\) Cet (cf. Kiang 1972). For the purpose of illustration, we also depict reference stars in Fig. 1 together with the stars addressed in this study.

3.2 Data reduction
We use a total of seven data points in orbital calculations: records on 1491 January 7, 9, 10, 11, 12, 23 and 31. We compute the coordinates of the reference stars for the epoch of 1491.0 by correcting the effects of the precession and nutation and then calculate the right ascensions and declinations of comet C/1490 Y1 using equation (1). We use the algorithms of Meeus (1998) and proper motion values of Perryman et al. (1997). To estimate the observation time, we first subtract 1 day from the day of the record because all records mention the observations performed on the previous day. Next, we compute the time-span ranging from the sunset to the sunrise using Meeus’ algorithms (Meeus 1998) and VSOP87 solutions with the full periodic terms (refer to Bretagnon & Francou 1988). By subtracting 1.2 h from the time-span and dividing into five intervals, we estimate the time corresponding to One-Watch. For the records without information on the observation time, we assume One-Watch by analogy with the remaining records.

In Table 2, we summarize seven angular position data for comet C/1490 Y1. The first column is an identification number, the second the day of the record, the third the right ascension in hours and the fourth the declination in degrees. The last three columns are rectangular coordinates of the Sun in au.

3.3 Error estimate
Following the records of comet C/1490 Y1, there are also records of the observations for Mars from 1491 March 5 to May 2. We compared the reported positions with modern celestial mechanical calculations and found positional errors of 0.080 ± 0.042 h and 0.310 ± 0.040 in right ascension and declination, respectively. For the records of trespass events, the error is 0.15 in angular distance as mentioned above. We also found that each Watch had a range of ~2 h around January.

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Figure 1. Oriental constellations presented in Cheon-Sang-Yeol-Cha-Bun-Ya-Ji-Do, ancient Korean star chart engraved on a stone. Constellations connected by white solid lines are (1) Thien-Chin, (2) Jen-Hsing, (3) Chhu & Chiu, (4) Yun-Yu, (5) Lei-Pi-Chhen, (6) Thien-Hun and (7) Thien-Tshang. Lunar mansions are depicted by yellow dotted lines together with reference stars in each mansion. Reproduced by permission of Kyuganggak Institute for Korean Studies.
4 RESULTS

For 35 subsets made from the combination of three out of seven data, we calculate preliminary orbital elements using the modified Gauss method developed by Marsden (1985, 1991) which uses coordinate transformation and closed f and g series. Of 35 subsets, we obtain orbital elements similar to the Quadrantids stream from the subset composed of records on 1491 January 11, 23 and 31. This result indicates that the records of trespass events (i.e. 1491 January 23 and 31) contribute most to the orbital calculation. It is a natural consequence because the records of trespass events provide more accurate information on a comet’s positions than those of observations by an astronomical instrument. Trespass events are also very useful because they cover the longest time-span compared with the first four data in Table 2, which are very close in time and therefore essentially provide only one point on the orbit. Julian day of 2265660 in Table 2 corresponds to mid-day on 1491 January 15.

We performed a least-squares adjustment (e.g. Boulet 1991) to improve the orbital elements with all seven data points. However, we failed presumably due to somewhat large errors in observations by an astronomical instrument, particularly in right ascension (~1:2). In Table 3, we present our and Hasegawa’s preliminary orbital elements for comet C/1490 Y1. We also list the results of other studies on associated objects. In the table, the first column is object name and other columns are orbital elements:

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
ID & Julian day & $a_{1491.0}$ & $e_{1491.0}$ & X & Y & Z \\
\hline
1 & 2265650.88419 & 22.053676 & 25.93429 & 0.417677 & -0.8172441 & -0.3554515 \\
2 & 2265652.886257 & 22.382218 & 14.59959 & 0.4491863 & -0.8033028 & -0.3493867 \\
3 & 2265653.886987 & 22.579343 & 12.13552 & 0.4647339 & -0.7959541 & -0.3461899 \\
4 & 2265654.887722 & 22.789650 & 10.16427 & 0.4801369 & -0.7883565 & -0.3428849 \\
5 & 2265655.888462 & 22.953921 & 7.20739 & 0.4953900 & -0.7805127 & -0.3394730 \\
6 & 2265666.896796 & 0.716267 & -12.91460 & 0.6519516 & -0.6788436 & -0.2952586 \\
7 & 2265674.907282 & 1.596609 & -23.35432 & 0.7508476 & -0.5888331 & -0.2561119 \\
\hline
\end{tabular}
\caption{Orbital elements of comet C/1490 Y1 and associated objects in the epoch of J2000.0.}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
Objects & $T_p$ & $q$ & e & a & $\omega$ & $\Omega$ & i \\
\hline
Quadrantids (1995)$^a$ & – & 0.979 & 0.69 & 3.14 & 171.2 & 283.1 & 71.05+72.7 \\
Quadrantids (1491)$^b$ & – & 0.758 & 0.74 & 2.94 & 164.5 & 284.7 & 70.5 \\
C/1490 Y1 (1491)$^c$ & 1491 January 7.8 & 0.769 & 0.75 & 3.04 & 164.0 & 283.0 & 70.2 \\
C/1490 Y1 (1491)$^d$ & 1491 January 8.9 & 0.761 & 1.00 & 3.10 & 164.9 & 280.2 & 73.4 \\
2003 EH$_2$ (1491)$^e$ & 1490 April 13 & 0.570 & 0.82 & 3.17 & 164.2 & 286.2 & 66.0 \\
2003 EH$_3$ (1491)$^f$ & (1491 January 8.9) & 0.759 & 0.76 & 3.10 & 164.5 & 285.5 & 69.2 \\
2003 EH$_3$ (1491)$^g$ & – & 0.732 & 0.76 & 3.10 & 164.0 & 285.5 & 67.6 \\
2003 EH$_3$ (2003)$^a$ & 2002 February 24.5 & 1.192 & 0.62 & 3.13 & 171.4 & 282.9 & 70.8 \\
\hline
\end{tabular}
\caption{Angular position data for comet C/1490 Y1 in the epoch of 1491.0.}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|}
\hline
ID Julian day & $a_{1491.0}$ & $e_{1491.0}$ & X & Y & Z \\
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\caption{Angular position data for comet C/1490 Y1 in the epoch of 1491.0.}
\end{table}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure2.png}
\caption{The path of comet C/1490 Y1 together with oriental constellations (solid line) and lunar mansions (dotted line). The red solid and blue dotted lines are orbital paths from our and Hasegawa’s studies, respectively. The crosses represent seven data points from Sillok’s records and filled blue rectangles are reference stars in each lunar mansion.}
\end{figure}

In Fig. 2, we depict the paths of comet C/1490 Y1 using our and Hasegawa’s orbital elements. The crosses represent the comet’s positions from Sillok’s records. The red solid and blue dotted lines show the comet’s paths from our and Hasegawa’s orbits. Because the comet was observed around the perihelion, it is hard to distinguish between both paths despite the different eccentricities. Although
both paths closely pass through Jen-Hsing, they cannot satisfy the Chinese record, which described the constellation the comet trespassed (Ho 1962). In Fig 2, we also present oriental constellations, lunar mansions and reference stars for the purpose of comparison with Fig. 1.

The most remarkable point in our result is the eccentricity. Our orbital elements show that comet C/1490 Y1 is a periodic one. However, it has been never observed since 1491. Assuming a nodal distance of 5.2 au in Hasegawa’s orbital elements (hence, $e = 0.768$ and $a = 3.28$ au), Williams & Wu (1993) suggested a possibility that the comet escaped from the observable orbit or was broken by the perturbation of Jupiter. However, our result (i.e. nodal distance of 7.1 au) suggests no strong interaction with the Sun and/or planets. Therefore, the result supports the suggestion of Jenniskens (2004) in which the parent body of the Quadrantids would still remain. One possible hypothesis is that the comet was originally an asteroid but showed cometary activity around 1491, but now the activity is turned off and it remains as a dormant comet. Though we cannot explain what caused the activity, several minor planets that displayed cometary activity are currently reported (Groussin, Lamy & Jorda 2004; Hsieh, Jewitt & Ishiguro 2009). The orbital elements, of course, would change as they lose mass. This hypothesis is also in good agreement with the suggestion of Jenniskens (2004): the Quadrantid stream originated from comet C/1490 Y1 around 500 years ago and presumably asteroid 2003 EH1 is the comet’s remnant.

Meanwhile, Sillok also contains doubtful records relating to comet C/1490 Y1. If our (or Hasegawa’s) orbital path is correct, the angular distance from the north pole is $\sim 74^\circ$ (in Chinese degrees), not $65^\circ$ as recorded on 1491 January 7; the observational value might be a typo. If the record is true, on the other hand, it means that the comet underwent a violent change when approaching the perihelion. As an another example, there is no record of comet C/1490 Y1 on January 8 although the daytime appearance of Venus is recorded. In this case, it seems that the record was merely omitted rather than the comet was actually unseen because Sillok does not clearly state that the comet was unobservable as in the record of 1491 January 6. However, we cannot exclude the possibility that the comet was actually unobservable because it passed through the perihelion at that time, in other words, the possibility that the true perihelion passage time is about 7.3 d in UT (remember all records are written of events that had happened the day before).

5 SUMMARY

We investigate the astronomical records of Sillok and calculate the orbital elements of comet C/1490 Y1. Sillok contains valuable information on the comet such as observation time, right ascension, declination and so on. However, it has never been directly referred to in previous studies. Using the modified Gauss method, we compute preliminary orbital elements of the comet based on the observational records in Sillok. We find out that our orbital elements show an excellent agreement with those of the Quadrantid stream including the eccentricity. This fact strongly supports that comet C/1490 Y1 is the origin of the Quadrantid shower as first pointed out by Hasegawa (1979). Also, our result shows that the comet was a periodic one and had no experiences of closer encounter with the Sun or planets. None the less, it is known that the comet has never been observed before and after 1491. So, we suspect that the comet still remains as a dormant comet such as 2003 EH1, on a different orbital path from that of the parent body due to the cometary activity.

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REFERENCES

Hasegawa I., 1979, PASJ, 31, 257
Ho P. Y., 1962, Vista Astron., 5, 127
Kiang T., 1972, Mem. R. Astron. Soc., 76, 27
McIntosh B. A., 1990, Icarus, 86, 299
Marsden B. G., 1985, AJ, 90, 1541
Needham J., Lu G.-D., 1966, Physis, 8, 137
Williams I. P., Ryabova G. O., Baturin A. P., Chernitsov A. M., 2004b, Earth, Moon, Planets, 95, 11

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