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ANALYSIS OF THE KOREAN CELESTIAL PLANISPHERE: CH'ON-SANG-YUL-CHA-BUN-YA-JI-DO

CHANGBOM PARK
Seoul National University, Korea

ABSTRACT

We have analyzed the content of the Korean stone star chart, Ch'on-Sang-Yul-Cha-Bun-Ya-Ji-Do(hereafter Ch'on-Sang-Do). In the star map we have found 1468 stars, 4 more than the Chinese star catalog Bo-Chun-Ga. The four extra stars form a constellation, Jong Dae Boo 宗大夫.

The map projection law used in the star chart is found to be the polar equtorial and equidistance projection. The linear distance of an object on Ch'on-Sang-Do from the center is linearly proportional to the north polar angular distance. We have found from a statistical analysis that most stars with declination lower than 50 are at positions representing the epoch of around the first century. On the other hand, stars near the north pole with declination higher than 50 are at the epoch of about 1300, which is close to the time the chart was engraved. This implies that the original Ko-Gu-Rye Dynasty's star chart has been revised by astronomers of Cho-Sun Dynasty. We have also shown that stars on Ch'on-Sang-Do are engraved in such a way that their area is linearly proportional to the visual magnitude.

I. INTRODUCTION

Chun-Sang-Yul-Cha-Bun-Ya-Ji-Do (천상열차분야지도, 天象列次分野之圖; hereafter Chun-Sang-Do) is an atlas of the heavenly objects visible in Korea. It is engraved on a stone and contains various inscriptions besides the star map. Rufus(1913) called it a chart of the regular divisions of the celestial bodies, and Needham(1959) described it showing the positions of heavenly bodies in their natural order and their allocated celestial fields.

According to the inscription about the history of the planisphere, there was an old stone star map of Kogurye 高句麗 dynasty (BC37 - 668). However it was lost in a river during a war and its rubbings were out of stock as time passed. When the first king of Cho-Sun 朝鮮 dynasty (1392 - 1910) began to reign, a man presented a rubbing of the star map to him. King Tae-Jo 太祖 considered it invaluable and in the third year (1395) of his reign the ordered astronomers to reproduce the Kogurye's astronomical chart. Since the positions of stars on the old map did not match with the sky at that time, astronomers led by Kwon-Keun 權近(陽村) corrected positions of meridian stars 中星 at dark and dawn, and engraved the star map on a stone.

The stone, whose dimension is w122.5h211d12cm^3, is still kept in the Duck-Soo palace in Seoul. About 300 years later King Sook-Jong (肅宗) ordered one to re-engrave the stone star map. And a group of astronomers made a new model(1687) with identical content on a white marble of size w108.5 h206.5d30 cm^3. This version of stone planisphere is kept in Seoul in an excellent condition.

Chun-Sang-Do contains all astronomical knowledges of Korean people until the western astronomy was introduced in the 17th century. Many prints were made by the government during Cho-Sun dynasty, and there are countless hand copies still being found. Japanese astronomy is also founded on this star map as revealed by the Japanese's first star maps such as Ch'on-Sang-Yul-Cha-Ji-Do 天象列次之圖(1670) and Ch'on-Moon-Bun-Ya-Ji-Do 天文分野之圖(1677) (Park 1996).

Since this stone star map has been first studied by Hwang, Yun-Suk(18C) and Rufus(1913), there have been several controversies (see Park 1995a for a complete review). The first is the epoch of the star map. Some claimed that constellations were at those positions of the epoch of around the first century B.C (Rufus 1913: Park 1995). Others said that the epoch was the late period of Kogurye Dynasty, namely around 5 or 6th century (Jern 1975: Ree 1982: Park 1987). On the other hand, Lee (1986) estimated the epoch to be about AD200. The second controversy is whether or not the map was revised at the time it was engraved as described in the inscription. Most previous works either disregarded or suspected the inscription (Lee 1993 for example). Rufus(1913) has made a list of signs of revisions: that is, introduction of the zodiac (known to the east Asia in 8C), use of 須女 instead of 織女 or 女 in the 28 lunar mansion table, and use of a circle of perpetual apparition center at 38 which is approximatedly the latitude of Seoul. Park (1995a) has studied positions of the Polaris, the Big Dipper, Kak(角), Hang(亢) on the star chart, and also concluded that a revision was made. Other studies and comments on the star chart can be found in Jeng-Bo-Mun-Hun-Bi-Go 增補文獻備考 (1908), Rufus (1936), Rufus and Chao (1944), Needham and Ling (1959), and Needham et al. (1986).

In this work we will address these issues again. We will use positions of stars directly measured from the planisphere to find the epoch. This is because the description about the 28 lunar mansions

in the inscriptions seems not match with the content of the star map.

On the other hand, stars on Ch'on-Sang-Do are engraved with different sizes. Since brightness of stars has traditionally been expressed as size of stars in Korea (Park 1995b), it is clear that the difference in size of stars indicates their magnitudes. We will find the relation between the modern magnitude system and the ancient stellar size system. The last issue we will make is the map projection method. Large portion of the celestial sphere is mapped onto the planar stone surface of Ch'on-Sang-Do. It will be interesting to know how the map projection was made.

II. DATA

The content of the planisphere, Ch'on-Sang-Do, is as follow (see Figure 1):

a. the celestial astral chart
b. a table of the 12 zodiacal divisions
c. a circular chart of the constellations culminating at dark and dawn for the 24 solar periods.
d. a short treatise on the Sun
e. a short treatise on the moon
f. the heavens - cosmogony
g. a table of the 28 lunar mansions
h. a history of the chart

We have measured positions of stars in Ch'on-Sang-Do from several versions of the map. We have first used a modern rubbing of the Sook-Jong's stone model of Ch'on-Sang-Do to measure positions of all stars, the Mily Way, the polar circle, the equator, the ecliptic, and the outer circle. Positions of stars are recorded with respect to the center of the map which is determined by averaging the centers of the polar circle, the equator, and the outer boundary circle.

The results are compared with close-up photographs of the Tae-Jo and Sook-Jong's models and with three old rubbings kept in Kyu-Jang-Gak 奎章閣, the Royal library of Cho-Sun Dynasty. In these comparisons stars and constellation lines are inspected. We have found 1468 stars in the chart. This number is slightly different from previous studies. Rufus(1913) has counted 1463 stars while Jern (1975) and Park (1995) have found 1464 stars. These numbers are close to that of the traditional stars of Chinese ancient astronomy. The Chinese star catalog Bo-Chun-Ga步天歌, which is said to be written in around the 7th century (Yu 1987), contains 1464 stars. The way that stars in each constellation are connected, is basically the same in Ch'on-Sang-Do and Bo-Chun-Ga. However, Bo-Chun-Ga shows a drawing of only a group of constellations together with a list of stars in each small part of the sky, while Ch'on-Sang-Do is nearly an all-sky map of stars, the Milky way and so on. The extra 4 stars in Ch'on-Sang-Do form a constellation, Jong-Dae-Boo 宗大夫 near the galactic center. We have also inspected the oldest Chinese stone planisphere So-Ju(Suchow) 蘇州 chart (engraved in 1247), and the So-Song 蘇頌 chart, which are made

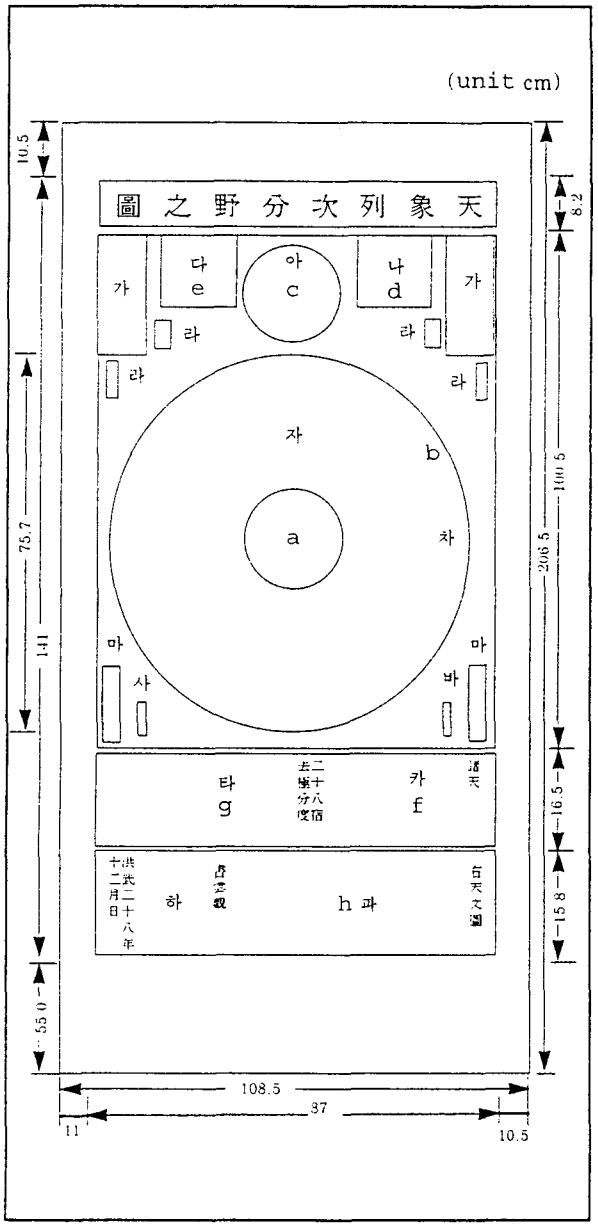

Fig. 1.— The content of the Korean planisphere, Ch'on-Sang-Yul-Cha-Bun-Ya-Ji-Do (the Sook-Jong's model. Taken from Park 1995). Description about each part is in the text. The Tae-Jo's model has the same structure and content except that the title at the top and the two rows of inscriptions at the bottom panel are separately engraved at the lower part of the stone.

before Ch'on-Sang-Do. We found that the constellation does not exist in these Chinese maps.

We have then identified stars in Ch'on-Sang-Do by comparing constellations with those of modern star catalogs and atlases(cf. Ahn, Park and Yu 1996). The Bright Star Catalogue (1982) and the Becvar's atlas of the sky (1948) are mainly used in this comparison. We have made a list of 375 stars that are most certainly identifiable.

Diameters of stars engraved on the Tao-Jo's stone model are measured off projected images of the photographic films. Even though some parts of the chart are severely worn out, we have been able to accurately measure sizes of 109 stars out of 375 identified stars by using gauge circles.

The Chinese star catalog, Bo-Chun-Ga, has figures of constellations in which stars have different sizes. On the other hand, the Chinese stone planisphere So-Ju chart, and the So-Song chart mark stars as dots and do not distinguish stars in size. In order to compare the size-magnitude relation in Ch'on-Sang-Do and Bo-Chun-Ga, we have also measured the same 109 stars from the figures of Bo-Chun-Ga. Diameters of stars are normalized in both measurements so that the size of the zeroth magnitude star, Arcturus (大角; Boo) is 1.

III. RESULTS OF ANALYSIS

a. Position of the Observer

To find the origin(the north pole) of the star chart we have defined three circles on the chart, namely the circum-polar circle (circle of perpetual apparition), the equator, and the outer boundary circle (circle of perpetual occultation). From the relative sizes of these circles one can estimate the latitude of the observer. We assume that the polar angular distance is proportional to the linear distance from the north pole of the map, which turns out to be true below. We measure the radii of the polar circle and the equator to be 94mm and 222.4 mm, respectively. This means the latitude of the observer is 38, which is very close to the latitude (37.6) of Seoul, the capital of Cho Sun dynasty, or Gae Sung(38), the capital of Korea 高麗 (918-1392) dynasty. On the other hand, the outer boundary circle gives the polar distance of 145, or the latitude of 35. This latitude roughly corresponds to that of the southern part of Korean peninsula. Therefore, the star chart of Ch'on-Sang-Do contains heavenly objects that can be seen in the whole Korean territory. This result basically agrees with Rufus(1913) and Park(1995).

b. Determination of the Epoch

When we compare stars on Ch'on-Sang-Do with those of modern atlases, we have noticed that many of constellations occupy larger areas on Ch'on-Sang-Do than they should do even though relative distances between constellations are on average correct. This implies a very important

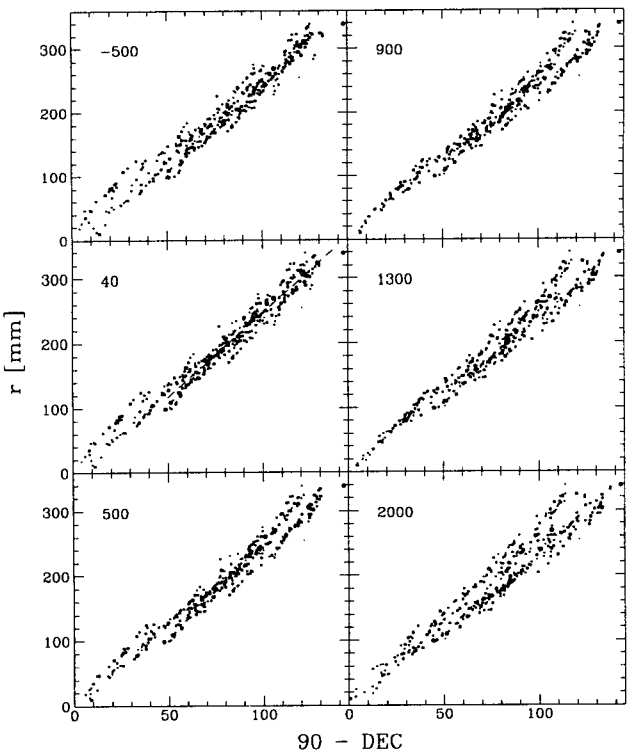

Fig. 2.— Relation between the linear distances of 375 stars from the center of Ch'on-Sang-Yul-Cha-Bun-Ya-Ji-Do and their north polar angular distances(90-DEC) at six trial epochs.

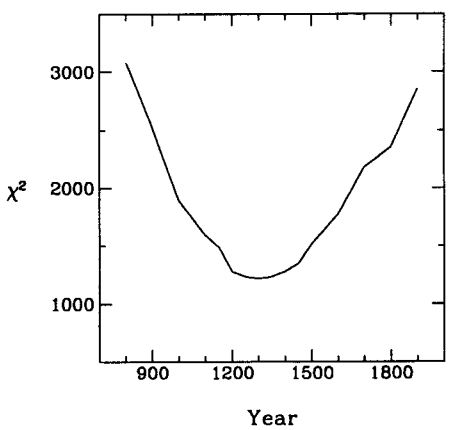

Fig. 3.— The x^2 of the relation shown in Figure 3 for 46 stars with DEC > 50. The minimum is at the year around AD1300, consistent with the claim that positions of some of the stars have been revised in AD1395.

point. One can not determine the epoch of Ch'on-Sang-Do based on positions of several stars or special points like the vernal or autumnal equinoxes. The problem is statistical in nature.

In our determination of the epoch we use all 375 identified stars. We first choose an epoch and calculate positions of stars of the modern Bright Star Catalog at that epoch taking into account the precession and the proper motion(Meeus 1991). We then find the relation between the linear distances of stars from the center of Ch'on-Sang-Do and their north polar angular distances(90-DEC). If we chose a right epoch, the relation would be tight with a small dispersion and show us the map projection law. Figure 2 shows the relations at six trial epochs. By varying the trial epoch from 501 BC to AD2000 by 5 years we have found that the relation becomes tightest at the epoch of about AD 40 for stars with DEC $<$ 50, that is, outside the north polar circle. We also find that the relation is linear (the best fitting line is shown in Figure 2). This means that the map projection law is the polar equatorial and equidistance projection where the distance of an object from the center of the map is linearly proportional to its angular separation from the north pole.

On the other hand, stars with declination higher than 50 show different behaviour. They show the best relation at around AD1300, which is close to the time Ch'on-Sang-Do was engraved. Figure 3 shows the variation of x^2 of the relation from the best fitting lines when the trial epoch is varied. Figure 3 strongly suggests that the stars near the north pole have been reobserved and their positions are corrected at the time the chart was made.

We find that shapes of constellations and the way stars are conneted in each constellation of Ch'on-Sang-Do are basically the same as those in Bo-Chun-Ga 步天歌, which is known to be written in the 7th century. Since most stars in Ch'on-Sang-Do locate at places approximately 2000 years ago, the star chart of Ch'on-Sang-Do is older than Bo-Chun-Ga' s figures.

In order to demonstrate that the epoch should not be determined from a few reference points we have compared the relative position of the Vernal equinox with those of the nearby 19 stars in right ascension at various trial epochs. The precession and the proper motion of stars change the relative position in right ascension. We find the best matching epoch of AD770. However, when we use the autumnal equinox and its nearby 87 stars, we find 150BC. Rufus(1913) have similarly obtained the first century BC by using the position of the autumnal equinox.

c. Stellar Magnitude System

Stars in Ch'on-Sang-Do have different sizes. Since brightness of stars has traditionally been explained by size, it would be interesting to know the size-magnitude relation. Figure 4 compares constellations of Ch'on-Sang-Do with those of Bo-Chun-Ga. Both maps distinguish stars by different sizes. We have compared the areas of 109 stars with their visual magnitudes. The upper panel of Figure 5 shows the size-magnitude relation of Ch'on-Sang-Do (Tae-Jo's model). It is clear that there exist a linear relationship between the area and the magnitude of stars even though the dispersion is not small. The size-magnitude relation shown in Figure 5 can be fit by a simple formula, area=1-0.2 mag-

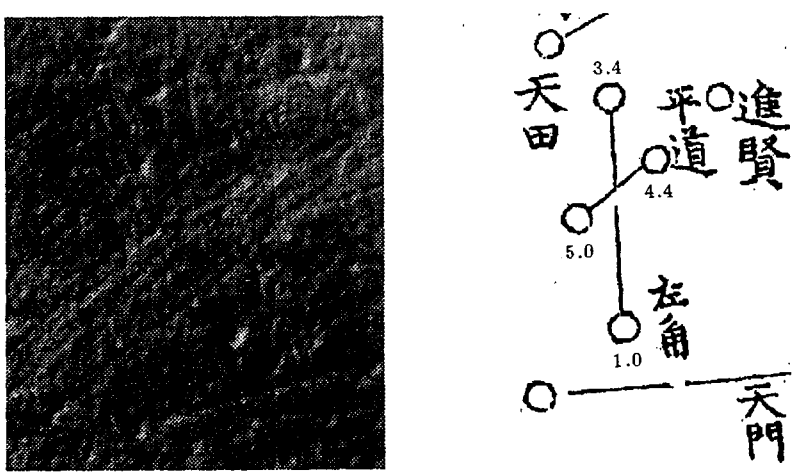

Fig. 4.— Sizes of stars in Ch'on-Sang-Yul-Cha-Bun-Ya-Ji-Do and Bo-Chun-Ga(right column) in the region near Spica (Virgo). The numbers in the right panels are magnitudes of stars.

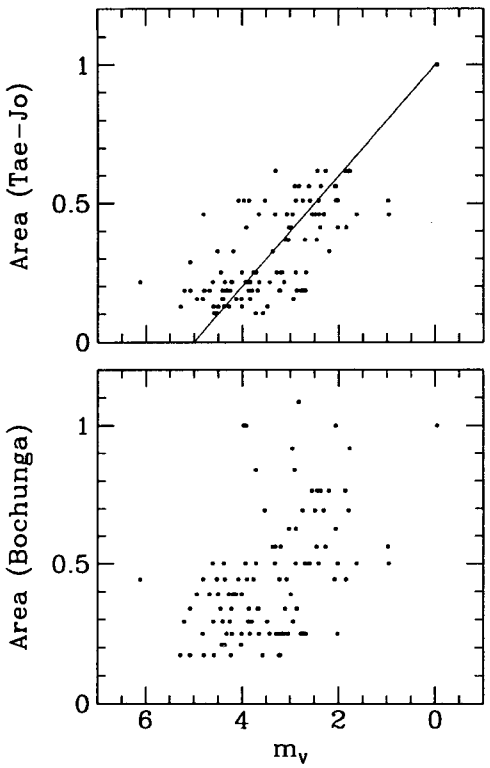

Fig. 5.— The size-magnitude relation of Ch'on-Sang-Yul-Cha-Bun-Ya-Ji-Do (Tae-Jo' s model: upper panel) and of Bo-Chun-Ga(lower panel). The area of the 0-th magnitude star, Arcturus 大角, is normalized to 1.

nitude (the straight line of the upper pannel). In the bottom panel is shown the relation of Bo-Chun-Ga which is much worse compared to that of Ch'on-Sang-Do. We have noticed that the Sook Jong's stone model of Ch'on-Sang-Do and the old rubbings do not show correlation between area and magnitude as good as the Tae-Jo's model does.

VI. CONCLUSIONS

By statistically analyzing the star chart Ch'on-Sang-Yul-Cha-Bun-Ya-Ji-Do, we have been able to make several conclusions.

First, we have found 1468 stars on Ch'on-Sang-Do, 4 more than the Chinese star catalog Bo-Chun-Ga. The four extra stars form a constellation, Jong Dae Boo 宗大夫, that does not exist in Bo-Chun-Ga.

Second, the map projection law used in the star chart is the polar equtorial and equidistance projection. The center of the map is located at the north pole, and is encircled by the equator. And the linear distance of an object on Ch'on-Sang-Do from the center is linearly proportional to the north polar angular distance.

Third, we have found from a statistical analysis that most stars with declination lower than 50 are at positions representing the epoch of around the first century. On the other hand, stars near the north pole with declination higher than 50 are at the epoch of about 1300, which is close to the time the chart was engraved. This implies that the original Ko-Gu-Rye Dynasty's star chart has been revised by astronomers of Cho-Sun Dynasty. It is to be emphasized that the epoch of the map should not be determined based on a few stars or special points on the map since the sizes of constellations are in general magnified and their relative locations are not accurate.

Fourth, we have found that stars on Ch'on-Sang-Do are engraved in such a way that their area is linearly proportional to the visual magnitude. Since the original map of Ko-Gu-Rye Dynasty is roughly 2000 years old, it would be interesting to compare the size of stars of Ch'on-Sang-Do with the magnitude of stars listed by Ptolemy(2C) or Hipparchus(2C BC).

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