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The two worlds of the Geneva sphere: heaven and earth in a 17th century Japanese model of the cosmos

Christopher Cullen

Abstract

The early modern encounter between the sciences and technologies of Europe and East Asia that began with the 16th century arrival of Jesuit missionaries in ‘the Indies’ has been studied by many scholars. In Europe during this period, an interest in new developments in science and technology began to be seen as appropriate and even fashionable for people who had no pretensions to expertise. Most studies of the contacts initiated by the Jesuits have so far concentrated on the reception and appropriation of ‘western learning’ at the levels of East Asian elite power and specialist knowledge, particularly in China. The nature of our sources—or at least the sources that scholars have chosen to study—has not made it easy to find out what happened outside those limited circles. A device—which I shall call the ‘Geneva sphere’ from its current location—has recently come to light which appears to have been made in early Edo Japan, and which opens a so far unexpected window onto a way in which an East Asian public ‘consumed’ astronomical knowledge and imported technology with evident enthusiasm and relish, despite the disdain with which expert astronomers regarded their activity. I shall discuss this device, its nature and its origins, by way of exemplifying the broad issues set out in this abstract.

Key words: Clockwork, Celestial sphere, Astronomical instruments,
Japan-history of astronomy, Japan-history of horology

1. Introduction: the Geneva sphere as a cultural hybrid

The ‘Geneva sphere’ is a clockwork-driven model of the celestial sphere, produced in 17th century Japan.

A pair of parallel articles written by the present author and Hiraoka Ryuji discuss in some detail the historical, cultural and technical context within which the Geneva sphere originated¹. The conclusions of that article relevant to the present discussion are as follows:

(a) The Geneva sphere appears to be the sole surviving representative of a type of device well

known and widely appreciated in Japan in the first century of the Edo period. Descriptions of these devices say that they were models of the celestial sphere mounted on an axis, and provided with a clockwork mechanism that caused them to perform one rotation in a day and a night, thus representing the apparent movement of the heavens as seen by an observer on the earth. Major divisions of the heavens were marked on the exterior and interior of these spheres. This particular sphere is made of relatively pure copper, and is pierced by large holes giving a view of its interior, where small models of the sun and moon mounted on rings can be adjusted to represent their positions on any given day. The axis of this sphere is inclined to the horizontal at an angle that represents the latitude of Edo, modern Tokyo.

- (b) Within the sphere, a box square in its horizontal section bore on its upper surface a map of Eurasia and Africa, with the shapes and names of land-masses representing the current knowledge of those regions by European geographers. The surface bearing the map is level with the horizontal diametral plane of the sphere.
- (c) These models were not made for the use of persons with expert knowledge of astronomy, several of who ridiculed them as fit only to amuse the ignorant, but were objects of cultural consumption by non-experts, who were none the less fascinated by such representations of the cosmos, to the point that those who could not afford to own one are said to have flocked to see one exhibited.
- (d) The Geneva sphere is a hybrid device, created at the intersection of Japanese culture with the broader East Asian astronomical tradition of Chinese origin, and the horological and geographical knowledge imported from Europe by the Jesuit missionaries who gained access to Japan through Portuguese trading networks.

The weight-powered clockwork technology that drives the sphere is of European origin. The first clock introduced to Japan was a present given in April 1551 by the Jesuit missionary Francis Xavier to Ōuchi Yoshitaka 大内義隆 (1507-1551), lord of Suō 周防 province, in modern Yamaguchi prefecture. By the beginning of the Edo period, Jesuits were not only manufacturing clocks in Japan, but were also training Japanese students to a high level of skill. This legacy survived the expulsion of the Jesuits, and was the foundation of a vigorous native horological industry. This aspect of the sphere is discussed in detail in the other publication referred to. This paper concentrates mainly on two further aspects of this object. The first, and more complex, is the system of astronomical data inscribed on the sphere, and the other is the

¹ Cullen, Christopher and Hiraoka Ryuji 平岡隆二 (2019, forthcoming). “The Geneva sphere: An astronomical model from 17th C. Japan.” *Technology and Culture*; 平岡隆二、クリストファー・カレン (forthcoming, 2019) 「ジュネーブ天儀：17世紀日本の天文模型」『洋学：洋学史学会研究年報』. While this article was drafted by the present author, some parts of it make use of insights by my collaborator in these articles.



Figure 1. The Geneva Sphere: general view

geographical information shown on the horizon plate that forms the upper face of a box-like object inside the sphere. Both of these will be described and discussed from the point of view of their traditions of origin, and their role in the structuring of a culturally hybrid device. Finally, I shall review the evidence relating to a third feature of the sphere—the specifically Japanese features of the inscribed characters it bears.

2. The heavens on the Geneva sphere

2.1 Exterior

The ecliptic region

A belt of 365 rectangular slots, each about 2 mm wide and 6 mm high, runs slantwise around the middle of the sphere. This belt evidently represents the ecliptic—the circle round the celestial sphere marking the annual path of the sun round the heavens from west to east against the background of the stars, as seen by a terrestrial observer (thought of as located inside the celestial sphere) looking south in the northern hemisphere. This annual movement is in the opposite sense to the apparent daily rotation of the celestial sphere from east to west as seen by such an observer. The apparent annual motion of the sun relative to the stars is the result of the earth's annual orbit round the sun, while the apparent daily rotation of the entire celestial sphere, bearing the heavenly bodies with it, is the result of the earth's daily rotation about its axis.

Since the annual cycle of the sun round the heavens (which in East Asian astronomy was reckoned as running from one winter solstice to the next) takes place in close to 365 1/4 days, it is clear that each slot on this belt represents one day in terms of time, and one day's-worth of the sun's motion in spatial terms. In the Chinese astronomical tradition which provided the foundation for all East Asian astronomy, this day's-worth of solar motion is called a *du* 度 'measure' (*do* in Japanese). One complete circuit, which in modern terms would be divided into 360 degrees, thus contains 365 1/4 *do*, and a *do* is therefore a little less than one degree².

The plane in which the ecliptic belt lies passes through the centre of the sphere, and is inclined at an angle to the equatorial plane of the sphere (that is, the plane through the centre that is perpendicular to the axis of rotation). Measurements on the surface of the sphere show that the angle of inclination of the ecliptic is very close to the value of 24 *do* (about 23.6°) given for this angle (the obliquity of the ecliptic) in ancient Chinese sources. It is the apparent motion of the sun round this inclined circle in the course of a year that means that the sun is high in the sky at noon in summer, and low at noon in winter. In reality, the inclination of the sun's apparent path to the celestial equator is the result of the earth's axis being inclined at an angle to the perpendicular to the plane of its orbit round the sun.

The 24 solar seasons

In East Asia, the solar cycle from one winter solstice to the next was divided into 24 equal periods of time, known as *qi* 氣 (*ki* in Japanese). If we take the solar cycle as precisely 365 1/4 days, then each *ki* would occupy 15 7/32 days. As a result most *ki* are allocated 15 whole days in the calendar, while five are allocated 16 days, making a total of 365 whole days. More sophisticated listings may give the precise time of day at which each *ki* begins.

Each *ki* has a name consisting of two characters, and these names are marked on the outside of the sphere at intervals below the belt of slots along the ecliptic, with the characters of the name vertically aligned beneath one of the bars separating two slots, as for instance here, showing the case of winter solstice, *tōji* 冬至 (Figure 2):

The number of slots between two bars with the names of successive *ki* thus represents the number of days in one of the *ki*. The sequence of the *ki* runs from left to right as seen from outside the sphere; this represents the sun's annual circuit of the heavens in an eastwards direction, which from the inside of the sphere (the point of view of a terrestrial observer) would be seen as motion from right to left by an observer in the northern hemisphere looking due south. The names of the *ki* and their durations as indicated on the sphere are shown in

² Strictly speaking, since the sun's speed round the celestial sphere varies slightly throughout the year, 1 *du* is the mean daily motion of the sun. In China, this variation was first detected by Zhang Zixin 張子信 in the 6th century CE: see Christopher Cullen (2017a) *The Foundations of Celestial Reckoning: Three Ancient Chinese Astronomical Systems*. London, Routledge, 14, note 25. It was largely ignored in simplified non-specialist writing.



Figure 2. Winter solstice marked (the thread is a temporary marker added during measurement)

Table 1. The 24 solar seasons

	Name of the 24 'solar seasons' <i>ki</i> 氣 (Japanese/Chinese)			Days on sphere
1	冬至	Tōji/Dong zhi	Winter Solstice	15
2	小寒	Shōkan/Xiao han	Lesser Cold	15
3	大寒 ³	Daikan/Da han	Great Cold	15
4	立春	Risshun/Li chun	Establishment Of Spring	16
5	雨水	Usui/Yu shui	Rain Waters	15
6	驚蟄 ⁴	Kyōchitsu/Jing zhe	Awakened Insects	15
7	春分 ⁵	Shunbun/Chun fen	Spring Equinox	15
8	清明	Seimei/Qing ming	Clear And Bright	15
9	谷雨 ⁶	Kokuu/Gu yu	Grain Rains	16
10	立夏	Rikka/Li xia	Establishment Of Summer	15
11	小滿	Shōman/Xiao man	Lesser Filling	15
12	芒種	Bōshu/Mang zhong	Grain In Ear	15
13	夏至	Geshi/Xia zhi	Summer Solstice	16
14	小暑	Shōsho/Xiao shu	Lesser Heat	15
15	大暑 ⁷	Taisho/Da shu	Great Heat	15
16	立秋	Risshū/Li qiu	Establishment Of Autumn	15
17	処 ⁸ 暑	Shosho/Chu shu	Enduring Heat	15
18	白露	Hakuro/Bai lu	White Dew	16
19	秋分 ⁹	Shūbun/Qiu fen	Autumn Equinox	15
20	寒露	Kanro/Han lu	Cold Dew	15
21	霜降 ¹⁰	Sōkō/Shuang jiang	Frost Fall	15
22	立冬	Rittō/Li dong	Establishment Of Winter	15
23	小雪	Shōsetsu/Xiao xue	Lesser Snow	16
24	大雪	Taisetsu/Da xue	Great Snow	15
			TOTAL DAYS	365



Figure 3. 'Earth in effect' (left) before 'Great Heat (right)

Table 1:

In addition to the names of the solar seasons, there are six other terms marked near the ecliptic belt of slots. In four cases, the characters *doyō* 土用 'Earth in effect' appear three days before a seasonal *ki* marker (i.e. to the left of the marker seen from the outside), as in the case of 'Great Heat' shown in Figure 3.

The bars aligned with *doyō* and Great Heat are three spaces apart. Thus if *doyō* is designated day 1, Great Heat is on day 4. Similar markings appear three days before 'Frost Fall', 'Great Cold' and 'Grain Rains'. These markings are part of the system of allocating periods of the year to each of the 'Five phases' *gogyō* 五行, water, fire, wood, metal and earth¹¹. Each phase is allocated one fifth of the solar cycle, so if the length of this cycle is approximated as 365 days, each phase controls 73 days. The 73 days controlled by the phase wood, signifying rapid growth, begin with Establishment of Spring, followed by fire beginning with Establishment of Summer, then metal with Establishment of Autumn and water with Establishment of Winter.

³ The characters 土用 are marked three days before Great Cold, thus 18 days before Establishment of Spring.

⁴ Upper element of 驚 is in cursive form. See 4.

⁵ Followed by the characters 時正: see below on the possible significance of this.

⁶ The characters 土用 are marked three days before, thus 18 days before Establishment of Summer.

⁷ The characters 土用 are marked three days before, thus 18 days before Establishment of Autumn.

⁸ Replaces 處; this is an abbreviation, on which see 4.

⁹ Followed by the characters 時正

¹⁰ The characters 土用 are marked three days before, thus 18 days before Establishment of Winter.

¹¹ These terms refer to five phases of cosmic activity rather than to the physical substances whose names they borrow. See A. C. Graham (1989) *Disputers of the Tao: philosophical argument in ancient China*. La Salle, Ill., Open Court, 340-56 and Donald John Harper (1999). "Warring States Natural Philosophy and Occult Thought" in *The Cambridge history of ancient China: From the origins of civilization to 221 B.C.*, Cambridge, UK; New York, Cambridge University Press: 813-884, 809-10.

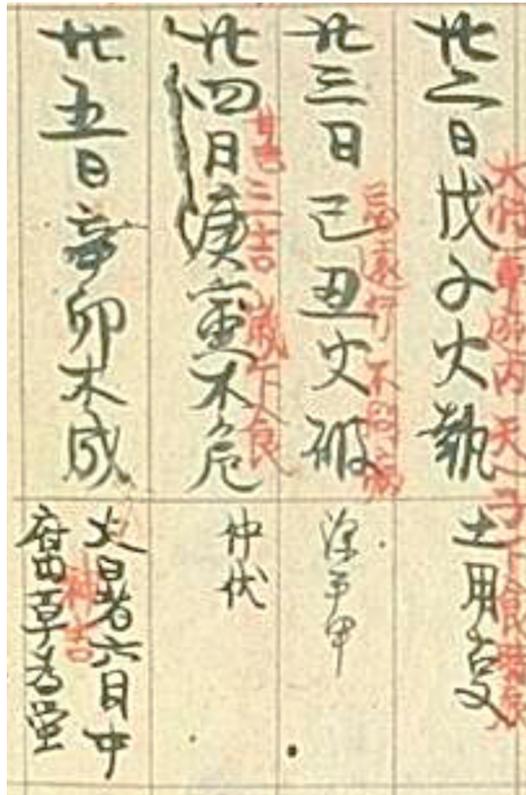


Figure 4. 'Earth in effect' (day 22) and Great Heat (day 25) in 6th lunar month of 1601.

The 73 days allocated to earth are divided into four portions shared amongst the four seasons—three portions of 18 days preceding the establishments of spring, autumn and winter, and one of 19 days preceding Establishment of Summer (since on this sphere Grain Rains has 16 days rather than 15). The 'Earth in effect' markings indicate when these periods begin, three days before the beginning of each *ki* preceding the beginning of an 'Establishment' *ki*, making $3 + 15 = 18$ days to the 'Establishment' *ki*. This system was already a part of Chinese calendrical practice shortly after the beginning of the Common Era, and was common to all countries that shared the Chinese tradition of systematic astronomical calculation¹².

We may see a Japanese example in a calendar of the *Guchūreki* 具注曆 'annotated calendar' type prepared for the imperial court by the *Onmyōryō* 陰陽寮 Bureau of Divination. The manuscript of the calendar for 1601, the beginning of the century from which the Geneva sphere appears to originate, of which a portion is shown in Figure 4 was written by the Confucian scholar Funahashi Hidekata 舟橋秀賢 (1575–1614)¹³.

The characters *doiyō* 土用 can be seen in the lower register of the first column on the right, corresponding to the 22nd day of the 6th lunar month of 1601. In the lower register of the leftmost column, corresponding to the 25th day, we find *Taisho* 大暑 'Great Heat'. It is clear,

¹² See Cullen (2017a), 265.

¹³ The MS comes from the Seike Bunko 清家文庫 Collection. For the images, see <http://edb.kulib.kyoto-u.ac.jp/exhibit/s089/image/1/s089s0001.html>, and following pages.



Figure 5. Characters after spring and autumn equinox labels

therefore, that the appearance of the markings of *doyō* on the sphere was simply a reflection of normal calendrical practice.

Two further markings on the sphere are associated with the equinoxes, as shown in Figure 5: To the right of the characters *shunbun* 春分 ‘Spring Equinox’ and *shūbun* 秋分 ‘Autumn Equinox’ we find in each case the characters *jishō* 時正. The characters are placed so that they align with vertical bars in the ecliptic band two spaces away from the bars aligning with the nearby equinox marking. Thus, if the equinox is day number 1, the day marked *jishō* is number 3.

Unlike the markings of *doyō* discussed above, the practice of adding these annotations after the equinoxes does not have its origins in China, where it is quite unknown. Nor is it found in Korea, whose calendrical practice closely followed that of China in recent centuries¹⁴. It is however well attested in Japan. Examples from the calendar for 1601 described above are shown in Figure 6 and Figure 7.

If we look at the annotations in the left-hand columns of each example (day 21 in the second month example, and day 29 in the eighth month), the meaning of the term becomes clear. On either side of the central text of the annotation in the fourth register, we see (from right to left):

日出卯時正

‘The sun rises at the exact [midpoint] of the double-hour *u* [05:00–07:00]’

日入酉時正

‘The sun sets at the exact [midpoint] of the double-hour *tori* [17:00–19:00]’

¹⁴ [14] I am grateful for the expert confirmation provided by Professor Shi Yunli as regards China, and Professor Jun Yong Hoon as regards Korea (private communications, October 2017)

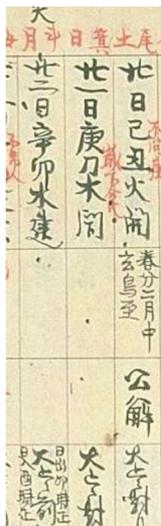


Figure 6. Days 20–22 of the second lunar month, 1601

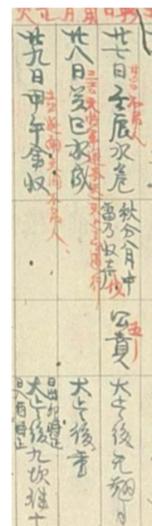


Figure 7. Days 27–29 of the eighth lunar month, 1601

Each ‘double-hour’ *ji/shi* lasted two hours, and its central instant was designated as *shō* ‘exact’. So in effect *jishō* 時正 means something like ‘exactly on the hour’, and refers to the times of sunrise and sunset expected at the equinox, when the sun rises at 06:00 and sets at 18:00, so that day and night are of equal lengths.

Why and when in Japanese history this strange disconnect developed between equinoctial sunrise and sunset and the equinoxes marked in the calendar is currently unclear. But it is undeniable that this was the case for centuries, and continued right up into the nineteenth century, when traditional *Guchūreki* calendars were officially abandoned by the newly restored imperial government in favour of the Gregorian calendar. An example from as long ago as the thirteenth century is known, and the general question of these markings in Japan has been discussed by a number of scholars¹⁵. What may be even earlier examples are found in a number of manuscripts of a Japanese hemerological treatise based on a Chinese work imported into China at some time before the ninth century¹⁶. In these manuscripts, which are based on an idealised scheme linking the 24 *ki* with fixed days of the lunar months, not only do

¹⁵ See Yasuraoka Kōsaku 安良岡康作 (1967–68) *Tsurezuregusa zenchūshaku* 徒然草全注釈 (A complete annotated translation of the ‘Notes from Leisure Hours’ [of Yoshida Kenkō 吉田兼好, 1284–1350]). Tōkyō, Kadokawa Shoten 角川書店, 144–149, Watanabe Toshio 渡辺敏夫 (1993) *Nihon no koyomi* 日本の暦 (Japanese calendars). Tōkyō, Yūzankaku 雄山閣, pp. 60, 63, 100–103; Hashimoto Manpei 橋本万平 (1966) *Nihon no jikoku seido* 日本の時刻制度 (Japanese time systems). Tōkyō, Hanawa Shobō 塙書房, p. 224. Such markings were not confined to calendars: see 4 for an example of a bell cast in Edo in 1684 in which the dating inscription refers to the *jishō* of autumn.

¹⁶ See the discussion in Yamashita Katsuaki 山下克明 (2015) *Heian jidai on’yō dōshi kenkyū* 平安時代陰陽道史研 (Studies of the history of Yinyang practices in the Heian period). Kyōto, Shibunkaku Shuppan 思文閣出版, 287–288, and chapter 3, 338–360. For examples of these manuscripts, whose date is not easy to establish, see <http://kanji.zinbun.kyoto-u.ac.jp/db-machine/toho/html/C0070001.html?big?1>, and <http://library.nao.ac.jp/kichou/archive/0264/kmview.html>.

we find examples of the dates of equality of day and night being placed two days after the dates given for the equinoxes, but we also see the extremes of day and night length marked as occurring three days *before* the dates given for the solstices—a feature not reproduced in later sources.

So far the reason why such practices become customary is unclear. But whatever their origins, the presence of this uniquely Japanese feature is a clear indication that the Geneva sphere is of Japanese origin. No other East Asian country would have inscribed the sphere in this way.

Polar regions, and the hexagrams

The north polar region of the sphere is occupied by a circular zone extending outwards approximately 30° from the pole, of which the outer edge is occupied by a band marked with the names of the 64 hexagrams. These hexagrams, *ke* 卦, are the basis of an ancient Chinese divinatory system set out in the text known as the *Ekikyō* 易經 (*Book of Change*), which had reached its current form by the beginning of the Common Era. These hexagrams became the basis of an elaborate cosmological system, through which all possible entities and processes were in theory correlated with a hexagram¹⁷. Each hexagram consists of a block of six lines (not shown on the sphere), with each line either broken or unbroken, forming figures such as the following:



The number 64 follows from the facts that the hexagrams cover all possible combinations of six broken or unbroken lines, and $2^6 = 64$. The hexagrams themselves do not appear on the sphere.

The order in which the hexagram names are laid out round the sphere is a version of what is commonly known in China as the Fu Xi 伏羲 order; Fu Xi was a sage of mythical antiquity to whom the basic concepts of the *Book of Change* are ascribed. Hemisphere A has the following hexagram names, which run in the order of the numbering anticlockwise from the right hand edge of the hemisphere, looking down on it from the north pole: see Figure 8 and Table 2. Hexagram number 8 in this list, *kun* 坤, corresponds to the culmination of the cosmic power of Yin 陰, which represents (among other things) dark and cold. It is not therefore surprising to find that it is aligned with the position of winter solstice on the ecliptic. The sequence of hexagram names continues in the same sense onto the north polar region of hemisphere B, where we find the sequence shown in Table 3:

Hexagram number 40 in this list, *qian* 乾, corresponds to the culmination of the cosmic power of Yang 陽, which represents light and heat. It is aligned with the position of summer solstice on

¹⁷ See for instance Graham (1989), 358–370.



Figure 8. Hemisphere A: north polar region

Table 2. Sequence of hexagrams on hemisphere A

1	否	9	復	17	明夷	25	臨
2	萃	10	頤	18	賁	26	損
3	晉	11	屯	19	既濟 ¹⁸ [濟]	27	節
4	豫	12	益	20	家人	28	中孚
5	觀	13	震	21	豐	29	夬[歸] ¹⁹ 妹
6	比	14	噬嗑	22	離	30	睽
7	剝	15	隨	23	革	31	兌
8	坤	16	无妄	24	同人	32	履

Table 3. Sequence of hexagrams on hemisphere B

33	泰	41	姤	49	訟	57	遯
34	大畜	42	大過	50	困	58	咸
35	需	43	鼎	51	未濟[濟]	59	旅
36	小畜	44	恆	52	解[解] ²⁰	60	小過
37	大壯	45	巽	53	渙	61	漸
38	大有	46	井	54	坎	62	蹇
39	夬	47	蠱 ²¹	55	蒙	63	艮
40	乾	48	升	56	師	64	謙

¹⁸ 濟 is an abbreviated form for 濟, the character more normally found in the name of this hexagram, and also in hexagram 51. In the form of 濟 on the sphere, the upper right element represented as 文 in standard typography is shown more like 六. See section 4.

¹⁹ 夬 is a loan form, also pronounced *ki*, used for the character 歸 more normally found in the name of this hexagram. See section 4.

²⁰ The variant character 解 has been used in place of the standard 解. See section 4

²¹ The lower two repetitions of 虫 appear in abbreviated form: see section 4.

the ecliptic.

As can be seen in Figure 8, each hexagram name is placed next to a rectangular area which is either gilded, or retains the brown colour of the main body of the sphere.

Within the band of rectangles corresponding to the hexagram names, there are seven further zones down to and including the circular zone around the pole. Each zone has half the number of rectangles of the zone that encloses it. This corresponds to a cosmology beginning from the undifferentiated *tai ji* 太極 ‘Supreme Ultimate’, represented by the central disk, which then divides into two in the next zone outwards to represent the basic principles of Yin 陰 (dark, feminine) and Yang 陽 (light, masculine), and so on outwards with increasing levels of differentiation to the 64-fold division of the eighth zone, outside which lie the hexagram names.

Apart from the north polar region of the sphere, some of the hexagrams are also marked elsewhere on the sphere: see section 0.

Movable double-hour markers

The south polar region is much less elaborately marked. Figure 9 shows the south polar region of hemisphere A: The fifty small holes visible here are matched by fifty further holes (allowing for overlaps) on hemisphere B, making a total of one hundred holes. In an East Asian astronomical context, the most likely interpretation of these holes is that they correspond to the 100 equal *koku* 刻 (‘marks’, or ‘divisions’) into which a complete cycle of day and night was divided. The complete circuit of 100 holes is marked by the presence of six circular studs mounted on pins fitting into some of the holes, at approximately equal intervals round the circuit of 100 holes. These pins bear six of the twelve cyclical characters used as names for the twelve *ji* 時 ‘double-hours’ mentioned above. The table below shows the correspondence between the names and the double-hours in western time measures, on the basis that each double-hour *ji* represents exactly two modern western hours. This was always the case in China, but as mentioned above would only have been the case at the equinoxes in Japan:

It will be seen that the six studs present on the sphere as we have it today are not systematically chosen, nor are they appropriately positioned. Numbers 1, 2 and 3 on hemisphere A are not spaced at about at intervals of about 1/12 of 100, i.e. 8 or 9 holes as one would expect, but about double that interval so that they are evenly spread out over the whole circuit. Numbers 7, 9 and 10 are—even more anomalously—evenly spaced on hemisphere B, despite the unequal time intervals involved. I believe this situation can be explained as follows:

1. Originally there were twelve studs, showing a complete set of double-hours. These studs are movable, and would have been placed in holes appropriate to the season of the year. Thus, at summer solstice the stud for number 7, *uma* 午 (the double-hour centering on noon), might have been placed so that it was aligned with the marker for summer solstice, where at that date the sun would be located, and the other eleven would have followed in



Figure 9. South polar region of hemisphere A

Table 4. Double-hour names on sphere

Number in sequence	name		Double hour in western notation	Present on sphere?
1	子	ne	23:00-01:00	present
2	丑	ushi	01:00-03:00	present
3	寅	tora	03:00-05:00	present
4	卯	u	05:00-07:00	
5	辰	tatsu	07:00-09:00	
6	巳	mi	09:00-11:00	
7	午	uma	11:00-13:00	present
8	未	hitsuji	13:00-15:00	
9	申	saru	15:00-17:00	present
10	酉	tori	17:00-19:00	present
11	戌	inu	19:00-21:00	
12	亥	i	21:00-23:00	

sequence. The sphere would thus have functioned as a kind of clock, although there is no obvious index mark against which the hours might be read off.

2. At some stage in the history of this sphere, six of the studs were lost, and a person who did not understand the functioning of the sphere simply fixed the remaining studs in holes more or less evenly spaced round the sequence, thus producing the situation we see today.

The equatorial and tropical circles

The outer surface of the sphere is marked by six yellow parallel circular bands, about 0.6 cm wide, each one of which runs round the sphere in a plane at right angles to the sphere's axis of rotation. On a terrestrial globe, these would correspond to parallels of latitude, but in astronomical terms they are circles of constant declination (angular distance from the celestial



Figure 10. Tropical circle near summer solstice



Figure 11. Equator, autumn equinox (left) and spring equinox (right); the equinoxes align with the two studs in each case.

equator). The northernmost and southernmost two bands touch the regions of the ecliptic belt that go furthest north and furthest south at the positions of the sun around the summer and winter solstices; see for example the case of the summer solstice in Figure 10. In this image the band appears to come down from the upper right and left corners, before running with the ecliptic belt for a few cm.

These two outer bands appear to represent, in modern terms, the tropics of Cancer (in the north) and the tropic of Capricorn (in the south). If the other four bands were symmetrically placed with respect to the outer bands, then the celestial equator (mid-way between the tropics) would not be marked by a band. It seems, however, that the fourth band (counting from the north towards the south) is positioned about where the equator should be, since it crosses the ecliptic belt close to the positions of the spring and autumn equinoxes. The other three bands have no obvious astronomical significance, and it is unclear what purpose they are intended to serve. Apart from this lack of symmetry, the bands are not very precisely positioned on the sphere. It is clear from the figure above that the band showing the tropic of Cancer joins the ecliptic about 11 days before the summer solstice, and begins to separate from it only about 5 days later²². Also, while the fourth band (which roughly represents the equator) crosses the ecliptic belt close to the autumn equinox, it crosses the belt about 11 days before the spring equinox: see Figure 11.

The northernmost and southernmost circles, which as already noted appear to mark the tropics, are marked with a number of hexagram names. They appear in east-west sequence as follows; the measurements in cm are taken from the western end of the circle.

Northernmost circle:

Hemisphere A: 8 (7.5 cm).

²² In reality, the ecliptic and the tropic circles are lines on the celestial sphere rather than bands.



Figure 12: Three lodges preceding summer solstice on interior surface of hemisphere B

Hemisphere B: 41 (19.0 cm), 57 (31.0 cm), 1 (40.0 cm), 5 (47.0 cm.), 7 (54.0 cm)

Southernmost circle:

Hemisphere A: 9 (17.5 cm), 25 (8.5 cm), 33 (39.0 cm), 37 (50.0 cm)

Hemisphere B: 39 (0 cm), 40 (10.5 cm)

It is difficult to see any pattern in this distribution. In only one case (hexagram 40, 乾) does a hexagram on these circles align with the same hexagram in the polar region.

2.2 Interior

The ecliptic

The belt of slots representing the ecliptic, which on the outside of the sphere is marked with the names of the 24 solar seasons, bears two sets of annotations in the inner surface of the sphere. The principal annotations consist of the names of the twenty-eight *shuku* 宿 'lodges' into which the circuit of the heavens has been divided from as far back as the first millennium BCE. As in the case of the solar seasons, each lodge has a certain number of slots allocated to it, one slot representing in time terms a day spent in that particular lodge by the sun, or in angular terms one *do* 度 of the sun's motion from west to east—from right to left seen from the inside of the sphere with one's head towards the north pole.

In Figure 12 part of the interior of hemisphere B is shown. The translated names of three lodges are shown, numbered as in Table 5 below. As on the exterior surface, there are no index marks apart from the names of the lodges, but it is not difficult to estimate which bar between two slots should be taken as marking the start of a lodge. The position of the summer solstice marked on the exterior surface is identified by a piece of red thread knotted round the corresponding bar. The label 'Quail Head' refers to one of the twelve 'Jupiter Stations' discussed below. To find how many *do* there are in a lodge, we simply count the number of slots between the relevant bars. Thus Beak has 3 *do* and Triaster has 9 *do*. In Table 5, the number of *do* counted on the sphere are compared with those given in one of the most ancient

Table 5. The 28 lodges.

	Lodge	Hemisphere:	Triple Concordance width, <i>do</i>	Width on sphere, <i>du</i>	Difference	Notes
1	角 'Horn'	B	12	12	0	Autumn equinox at 7 <i>do</i> of Horn; Triple Concordance has 10 th <i>du</i>
2	亢 'Gullet'	B	9	10	1	
3	氏 'Base'	B	15	6	-9	
4	房 'Chamber'	B	5	6	1	
5	心 'Heart'	B	5	7	2	
6	尾 'Tail'	B	18	22	4	
7	箕 'Winnower'	A	11	11	0	
8	斗 'Dipper'	A	26	24	-2	
9	牛 'Ox'	A	8	7	-1	Winter solstice is at start of Ox; Triple Concordance agrees.
10	女 'Woman'	A	12	10	-2	
11	虛 'Barrens'	A	10	10	0	
12	危 'Rooftop'	A	17	15	-2	
13	室 'House'	A	16	17	1	
14	壁 'Wall'	A	9	9	0	
15	奎 'Straddler'	A	16	16	0	
16	婁 'Harvester'	A	12	20	8	Spring equinox at 7 <i>do</i> of Harvester; Triple Concordance has 4 <i>du</i>
17	胃 'Stomach'	A	14	15	1	
18	昴 'Mane'	A	11	11	0	
19	畢 'Net'	A	16	17	1	
20	嘴 'Beak'	B	2	3	1	
21	參 'Triaster'	B	9	9	0	
22	井 'Well'	B	33	33	0	Summer solstice is at 23 <i>do</i> of Well; Triple Concordance has 31 <i>do</i> .
23	鬼 'Ghost'	B	4	4	0	
24	柳 'Willow'	B	15	12	-3	
25	星 'Star'	B	7	7	0	
26	張 'Spread'	B	18	16	-2	
27	翼 'Wing'	B	18	19	1	
28	軫 'Axle tree'	B	17	17	0	
		TOTALS:	365	365		

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(and most widely known) listings of the lodges, that given in the Triple Concordance astronomical system *San tong li* 三統曆, compiled around 10 CE²³. In 19 out of 28 cases, the *do* count is either identical or within 1 *do* of the Triple Concordance values.

Over the centuries, the phenomenon of precession leads to slight changes in the positions of the stars in the celestial frame of references used by astronomers, and since the initial points of the lodges are defined with reference to certain bright stars, there will be corresponding small changes in the widths of the lodges. Most strikingly, the lodge Beak shrank away and eventually changed places with the lodge Triaster that it had previously preceded. In one listing given in the 13th century the width of Beak had already diminished from 3 *do* to 0.05 *do*, while Triaster had grown to 11 *do* from 9 *do*²⁴. It appears, however, that the sphere before us is based on the ancient values for lodge widths. In two cases however, there are what can only be called gross errors in the number of *do* allocated to lodges: lodge 3, Base, is given only 6 *do* instead of 15 *do*, and lodge 16, Harvester, is given 20 *do* instead of 12 *do*. These two errors of -9 *do* and $+8$ *do* are nearly equal and opposite. It may be that an error was made with one lodge, and only discovered after the names of so many other lodges had been inscribed on the sphere that the maker was unwilling to start work again, and simply changed the width of the other lodge to allow for the previous error.

The configuration of the lodges preceding the position corresponding to summer solstice on the interior surface of hemisphere B suggests that the position of the sun at the summer solstice falls 23 *do* after the start of the lodge Well; the Triple Concordance system places the summer solstice sun at 31 *do* of Well. The 8 *do* discrepancy is no doubt the effect of making Harvester (six lodges earlier) 8 *do* too wide, as noted above. The other seasonal solar markers are closer to their positions as given by the Triple Concordance: the correspondence for winter solstice (a key reference point in the Chinese astronomical tradition) and the start of the lodge Ox is precise. We may note that precession leads to a much more noticeable change in the relations between the solar position among the lodges and the seasons than it does in widths of lodges. Around 1600, the winter solstice sun was about 29 *do* to the west of the beginning of Ox; it had not been in the actual position given since the 5th century BCE. Clearly the sphere was made to reflect values found in books rather than those observed at the time of its manufacture²⁵.

²³ See Cullen (2017a), 118–119. The same values are given in Iguchi Jōhan 井口常範 (1689) *Tenmon zukai* 天文圖解 (*Illustrated explanations of astronomy*). Ōsaka, Kashiwaraya Yozaemon 柏原屋與左衛門; Itamiya Mohei 伊丹屋茂兵衛, 2, 18a–19b, where they are ascribed to Luoxia Hong 落下闳, active c. 104 BCE.

²⁴ See Nathan Sivin (2009) *Granting the Seasons: The Chinese astronomical reform of 1280, with a study of its many dimensions and a translation of its records*. New York, Springer, 91–92.

Table 6. The twelve stations

Sequence	Jupiter station name		Start in Triple Concordance	Start on sphere
1	星紀	Starry Marker	Dipper 12	Dipper 14
2	玄枵	Black Hollow	Woman 8	Woman 8
3	娵訾	Loggerhead Turtle	Rooftop 16	[Rooftop 20 =] House 5
4	降婁	Descending Harvester	Straddler 5	Straddler 9
5	大梁	Great Plank-Bridge	Stomach 7	Stomach 3
6	實沈	Shi Chen (a deity)	Net 12	Net 6
7	鶉首	Quail Head	Well 16	Well 9
8	鶉火	Quail Fire	Willow 9	[Willow - 1 =] Ghost 4
9	鶉尾	Quail Tail	Spread 18	Spread 16
10	壽星	Longevity Star	Axletree 12	Axletree 2
11	大火	Great Fire	Base 5	[Base - 1 =] Gullet 10
12	析木	Split Wood	Tail 10	Tail 15

The twelve stations

A further feature of Chinese astronomical practice appears in the markings on the inside surface of the sphere, in the form of the names of the twelve *ji* 次 ‘stations’ (often called ‘Jupiter Stations’) of which one, ‘Quail Head’ is shown on Figure 12. These stations are listed in Table 6, together with the location of the first *do* of each station as given in the Triple Concordance system, and represented on the sphere by the position of the name of the station.

In a few cases the situation on the sphere corresponds closely to the Triple Concordance, such as stations 1, 2, and 9. In most other cases there are considerable errors. This appears to be the result of the fact that the names of the stations are written some way further south of the ecliptic than the names of the lodges, and in many cases this means that the correct position of the station name would fall into one of the large cut-out sections of the sphere. Rather than omit the name, the craftsman has simply shifted it to a more convenient (if incorrect) position.

The Nine Roads

In Figure 12, a complex pattern of gilded bands can be seen crossing the ecliptic and crossing over one another; the bands are interrupted when they cross the name of a lodge or a station. Apart from these breaks, there are also gaps in the bands containing the names of the colours black *hei* 黑, red *chi* 赤, white *bai* 白 and blue *qing* 青. An example is shown in Figure 13.

²⁵ The winter solstice position of the sun had already moved 4 *du* away the start of Ox by the time the Triple Concordance listing was recorded around 10 CE. There are signs in some texts of this period that the shift in position had been noticed, and by the beginning of the second century CE astronomical officials were pointing out the discrepancy: see Cullen (2017a), 381-382.



Figure 13. The character *hei* 黒 'black' (shown on its side) on one of the bands representing the moon's 'Nine Roads'

There are two bands with the name of each colour, making eight in all. These, together with the ecliptic, which is the Yellow Road *kōdō* 黃道, make up the so-called 'Nine Roads' *kyūdō* 九道 anciently associated with the moon²⁶. The concept of the Nine Roads was an early attempt to make sense of the fact that the path of the moon against the background of the stars does not coincide precisely with the ecliptic, the path of the sun, nor is it fixed in position. At any moment, it follows a path that is inclined at approximately 5° to the ecliptic—but in successive orbits the points at which that path crosses the ecliptic (the nodes) shift slightly, making a complete circuit round the ecliptic in a little under 19 years. The Nine Roads are a very schematic attempt at representing this shifting of the lunar path. The maximum distance of the bands from the ecliptic is about 3.5 cm; this is about twice as large as the 1.6 cm that would represent 5°, given that the circumference of the sphere is about 115 cm. Clearly the bands do not represent actual paths that the moon might follow.

So far no reference has been made to a representation of the actual form of any constellation on the sphere: there is however just one such example of such a representation, which was revealed when ultraviolet light was used in an internal examination of hemisphere B. What was revealed is shown in Figure 14:

The seven gilded spots seen here clearly represent the seven bright stars of Ursa Major, *hokuto* 北斗 commonly known in English as the 'Northern Dipper'. Given that, as noted above, the line through its poles that divides hemisphere B in two corresponds to about 9 h of right ascension, the position of the Dipper as shown on the sphere is roughly correct in right ascension for a date of 1600, although the asterism is shown too close to the pole for the depiction to be realistic.

²⁶ See *Han shu* 漢書 (*History of Western Han dynasty*). (probably completed in present form c.110 CE, punctuated edition of 1962). Ban Gu 班固 (32–92 CE), Beijing, Zhonghua Shuju, 26, 1295, and Christopher Cullen (2017) *Heavenly Numbers: Astronomy and Authority in Early Imperial China*. Oxford, Oxford University Press, chapter 6.



Figure 14. The stars of the Northern Dipper inside hemisphere B, near the north pole.



Figure 15. Two of the retaining lugs for the main internal ring, and corresponding rivets seen from outside.

Sun and moon rings

A system of three rings is mounted inside the sphere, just above the ecliptic; two of these rings carry small spheres, which apparently represent the sun and moon. The sun sphere is yellow all over, while the moon sphere has half of its surface blackened.

The main ring of the system is fixed a little to the north of the ecliptic (i.e above it with the sphere in its normal mounted position), and is retained by grooves formed by a series of small protrusions or lugs, which are riveted into the metal of the sphere: see for example Figure 15. When the sphere is assembled, the main ring is held in place, but can easily be slid within the grooves to that it can be rotated to any desired position.

Below the main ring a lighter ring is fixed, and the sun sphere is fixed below this ring, so that the sun is roughly level with the ecliptic belt of slots, as shown in Figure 16:

By sliding the main ring round inside the sphere, the sun ring fixed to the main ring and the sun model attached to it will also rotate, so that the sun can be moved to the position corresponding to the season. Thus, for instance, ten days after winter solstice the sun should be moved so that it is ten slots to the east of the winter solstice position marked on the outside of the sphere, which will mean that on the inside of the sphere it will be 10 *do* from the start of the lodge Ox. i.



Figure 16. The sun model on a ring fixed below the main ring.



Figure 17. Moon model and associated toothed wheel and ring

e. at the 3rd *do* of the lodge Woman.

The mounting of the moon model is more complex. The model is fixed onto a small toothed wheel, which turns about an axle fixed into the moon ring. The teeth of this wheel engage with teeth on the main ring. The moon wheel can be slid round inside the main wheel; its inner edge has wide serrations that appear to be designed to make it easier to grasp it when changing its position. As the moon wheel moves past the teeth of the outer wheel it will turn on the axis of the cog wheel. Since as mentioned half the moon is painted black, an observer from inside the moon will see a simulation of the phases of the moon as it does so. (This is of course only a simulation, since in reality the phases are not caused by the rotation of a parti-coloured moon). The small wheel shown in Figure 17 has 8 teeth, and there are 244 teeth on the inner edge of the main ring. Thus if the moon makes a complete circuit round the inside of the sphere, it will make:

$$244/8 = 30.5 \text{ revolutions on its axis}$$

and will thus complete that number of phase cycles. In reality, however the moon has to make more than a complete circuit of the celestial sphere to show even one phase cycle from new moon to new moon, since it has to complete one circuit and then catch up with the sun, which will have advanced about $29 \frac{1}{2}^\circ$ eastwards from its original position. The moon wheel is evidently only intended to give a general idea of the phases of the moon rather than

representing them quantitatively.

The mechanism of the sphere makes no provision for the positions of the sun and moon models to be adjusted automatically with the passage of time. The only way to make sure they are in the right position on a given day would be:

1. Look up the month and the day in any traditional almanac based on the lunar calendar.
2. Look back in the calendar to find out how many days ago was the start of the most recent of the 24 solar seasons. Count the days since then, and adjust the sun wheel until the sun is the same number of day slots past the name of that season marked on the outside of the sphere.
3. Adjust the moon wheel so that the moon is in the position relative to the sun corresponding to the day of the lunar month. Thus, if it is the first day of the month (new moon), the moon should be positioned just in line with the sun. If it is the 15th day of the month (full moon) it should be directly opposite the sun. The lodges in which the sun and moon are found can be read off from the markings inside the sphere.

2.3 Axis

The sphere is mounted on an axis whose angle of elevation above the horizontal is designed to fit in with the view of the heavens seen by an observer at some particular latitude, a latitude equal to that angle of elevation. Thus an observer at the earth's north geographical pole (latitude 90° north) will see the present pole star (alpha Ursae Minoris) close to his or her zenith, and the heavens will appear to rotate about a vertical axis. On earth's equator (latitude 0°), the heavens will appear to rotate about a horizontal axis. Assuming that horizontal and vertical may be taken as defined by the main horizontal and vertical members of the supporting frame, we may estimate the latitude for which this sphere was manufactured.

A clear photograph of the sphere was taken from the side, and the lines shown in Figure 18 were constructed on a large print-out of the photograph. Measurements with a protractor showed that the main vertical and horizontal members are indeed perpendicular to within less than half a degree. It follows that the angle L, which is the latitude of the place for which the sphere was made, is given by:

$$\tan(L) = y/x$$

On a printed photograph, y was found as 10.75 cm, and x as 15.00 cm (it is of course the proportion of these dimensions that matters, not their absolute magnitude). Thus:

$$L = \arctan(10.75/15.00) = 35.6^\circ$$

If we assume that our measurements of x and y were accurate to ± 0.05 cm, then L will lie within the range 35.4° and 35.8°. We may compare this with the latitudes of capitals of East Asian countries as follows:

Beijing (Northern capital of the Ming dynasty): 39.9° N

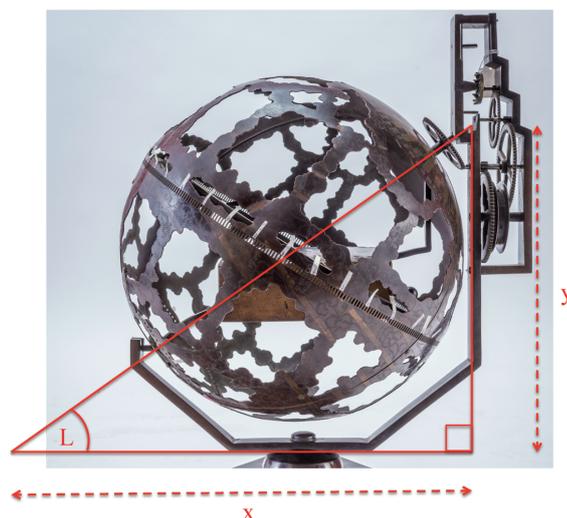


Figure 18. Finding the angle of elevation of the sphere's axis

Seoul (capital of Choson Korea): 37.6° N

Edo (now Tokyo): 35.7° N

Kyōto: 35.0° N

Nanjing: (Southern capital of the Ming dynasty): 32.1° N

Edo, the effective capital of Japan under the Tokugawa shogunate from 1603, is clearly the best fit for the place of manufacture of this device. If however we are prepared to accept that neither the makers nor the users of this device demanded very high precision, it would have also performed satisfactorily enough in representing what would have been seen by someone who observed the heavens from the imperial capital at Kyōto, which seems to have remained the standard position for astronomical references²⁷.

3. Representations of the earth

Shape, position and dimensions.

Inside the sphere an object in the form of a rectangular box is mounted, so that it remains fixed in place while the sphere rotates around it. The box is held with its upper surface horizontal and in the same plane as the centre of the sphere. The box is square in horizontal section, with sides measuring approximately 17.3 cm, and a depth of 5.8 cm. The centre of the upper surface of the box is displaced about 1.5 cm horizontally from the position of the centre of the sphere, 'northwards' towards the side of the sphere closer to the clockwork mechanism.

²⁷ The *Tenmon Zukai* gives a value for the altitude of the pole for 本朝 '[seat of] the present court' of $35 \frac{3}{4}$ do, or 35.2° ; this is however a reference to the capital of the Japanese emperor at Kyoto, latitude 35.01° N. Iguchi Jōhan 井口常範 (1689), 2, 17a;

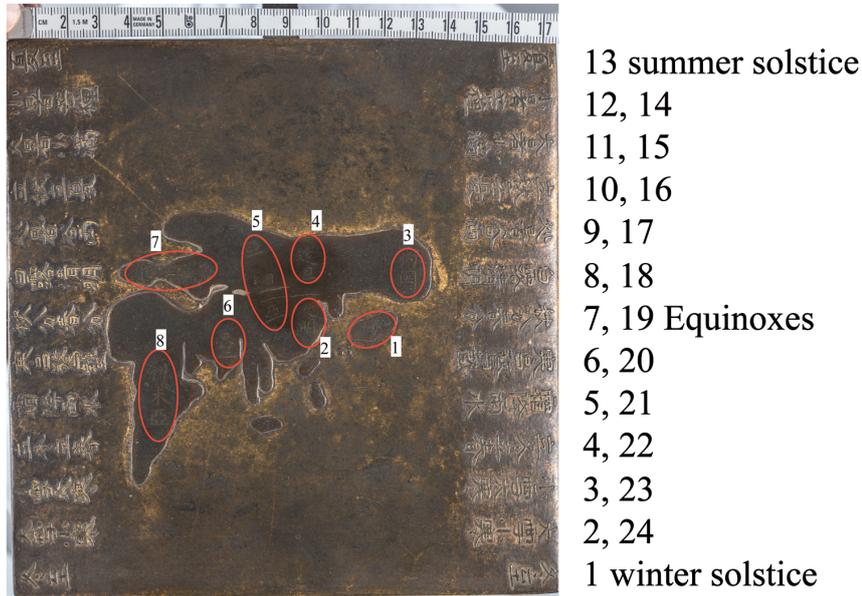


Figure 19. Map on upper surface of 'earth model'

Map

The upper surface of the sphere has a map cast onto it, showing Asia, Europe and Africa: see Figure 19.

The map is marked with the names of countries and regions as follows:

1. 日本 *Riben* (Jap. *Nihon*): Japan
2. 大明 *Da Ming* (Great Ming): China
3. 狗国 *Gouguo* ('Dog country'): Eastern Siberia
4. 達旦 (abbrev. from 韃靼) *Dada* 'Tartary'
5. 亞細亞 *Yaxiya*: Asia
6. 天竺 *Tianzhu*: India
7. 歐羅巴 *Ouluoba*: Europe
8. 利未亞 *Liweiya*: Libya (= Africa)

Most of these names are not native East Asian terms, but have been taken over, together with the shapes of the continents depicted, from the versions of western cartography created in East Asia by the Jesuits from the mid 16th century. A world map in the Chinese encyclopedia *Sancai tuhui* 三才圖會 ('The complete illustrated cosmos', published 1607) was largely based on such western cartography, and shows most of the names on the earth model map: see Figure 20.

The shapes of land masses shown on the earth model are however closer to another Jesuit-based source, such as this very detailed map, entitled *Kunyu wanguo quantu* 坤輿萬國全圖 'Complete map of the myriad countries of the world', originally prepared by Matteo Ricci in China in 1584, and printed in 1602 by the Christian convert Li Zhicao 李之藻. Copies of this map are known to have reached Japan by 1605 at the latest, and were used for teaching in the Jesuit academy in Kyōto²⁸. See Figure 21:

Here Japan is shown as a significant land-mass, similar to its depiction on the earth model map, as opposed to the small circular island shown in the *Sancai tuhui* version.

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Figure 20. Part of world map from *Sancai tuhui* 1607 edn.

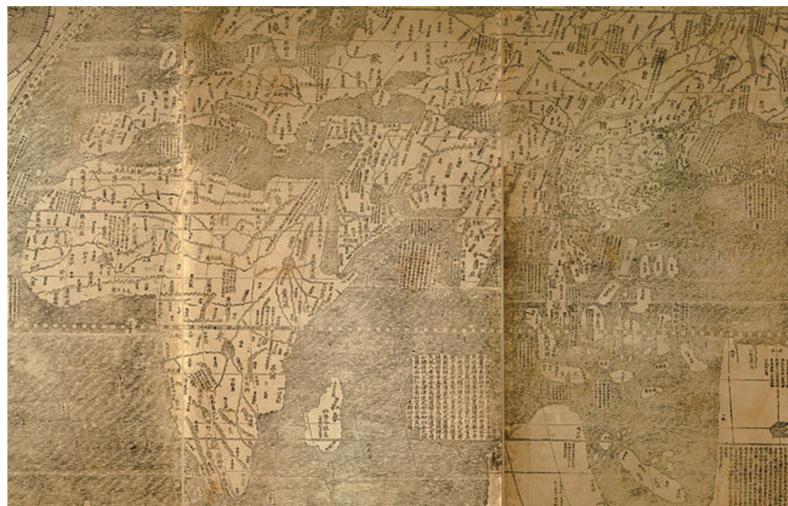


Figure 21. Asia, Europe and Africa on the *Kunyu wanguo quantu* (1602)

The 24 seasons

The east and west edges of the map on the earth model are identically marked with the names of the 24 solar seasons, as indicated by the numbers marked on the eastern edge of the map in Figure 19. Winter solstice *tōji* 冬至 is marked at the south-east and south-west corners of the map, and summer solstice *geshi* 夏至 at the north-east and north-west corners. The two equinoxes are marked together at the mid-point of the eastern and western borders, and the rest of the 24 seasons are marked in pairs in ascending and descending order, as shown by the

²⁸ Kazutaka Unno (1994). "Cartography in Japan" in *The History of Cartography, Vol. 2, book 2: Cartography in the Traditional East and Southeast Asian Societies*, Chicago, University of Chicago Press: 346-477, 404. See also Unno Kazutaka 海野一隆 (1921-2006) (2003) *Tōzai chizu bunka kōshōshi kenkyū* 東西地圖文化交渉史研究 (*Monographs on the history of cartographical exchange between the East and the West*). Ōsaka, Seibundō 清文堂, 33-92, particularly figs 4 and 11-14.

numbering in Figure 19, which follows the numbering of the seasons in Table 1.

It seems likely that these markings are intended to indicate the directions of rising and setting of the sun over the observer's horizon at different seasons; however, they do so in a schematic rather than a quantitatively exact manner. The positions of the equinoxes directly due east and west do indeed represent the fact that any terrestrial observer will see the sun rise due east and set due west at those seasons, and in general terms both sunrise and sunset shift northwards in the summer and southwards in the winter. For the rest of the year, the departure from reality becomes more and more marked as we near the solstices. According to the map, for instance, the sun rises and sets at the solstices 45° to the north (summer) and the south (winter) of the east–west line. To see that, an observer would have to be at a latitude of 55° N, level with the mouth of the Amur river, and well to the north of the present Chinese frontier. In contrast, observers at latitudes such as Beijing, Seoul and Tokyo would see solstitial sunrises and sunsets about 30° north and south of their east–west lines.

Date and origins of the earth model map

On the basis of this evidence set out above, we may conclude:

1. The map is based on sources that were first published in China by Jesuit missionaries, and which were circulating in Japan by the early 17th century.
2. The map must have been prepared some time before or a few decades after 1644, since it was in that year that the Ming 明 dynasty (1368–1644) fell, and was replaced by the Qing 清 dynasty (1644–1911). From that date onwards, the Chinese landmass would have been more appropriately labeled *Da Qing* 大清, not *Da Ming* 大明, though the latter usage could certainly have persisted in Japan for some time.

A flat earth?

An obvious question to ask about the earth model is whether the person who made it believed that the earth was flat. In the absence of any text accompanying the model, this question cannot be given a definitive answer. On the other hand, the balance of probability does seem to be against the view that the flat (partial) map of the earth was put in place to represent an earth believed to be flat. The clockwork that drives the sphere, and the map on the earth model, both indicate that the Geneva sphere was made by someone who had contact, direct or indirect, with Jesuit teaching. Francis Xavier expounded the sphericity of the earth in Japan as early as 1552, and this continued to be a basic part of the education given by Jesuits to their converts. An elementary book on Christianity published in 1605 also stated that the earth was a sphere, and made enough of an impact to attract the attention of an eminent Japanese scholar who opposed the idea²⁹. Further, it is difficult to see how someone who had seen and copied a Jesuit world map can have failed to notice that it was based on a spherical earth, or have

The two worlds of the Geneva sphere: heaven and earth in a 17th century Japanese model of the cosmos imagined that the map made sense in terms of a flat earth. Descriptions of similar devices in Korea specifically state that the flat map surface represents the observer's horizon plane, and it seems likely that the same is true of the Geneva sphere³⁰.

3. The question of abbreviations in inscriptions

A notable feature of the sphere, and of the map on the earth model that it contains, is the use of abbreviated forms of a small number of the Chinese characters 漢字 *kanji/han zi* used in the inscriptions it bears. These include:

On the earth model map: 国, for full-form 國 *koku/guo* 'country'

In the names of solar seasons marked round the ecliptic on the exterior of the sphere:

谷雨 for full-form 穀雨 *kokuu/gu yu* 'Grain Rains', the 9th of the 24 solar seasons.

処暑 for full-form 處暑 *shosho/chu shu* 'Enduring Heat, the 17th of the 24 solar seasons.

In the names of the 12 Jupiter-stations marked near the lodge names marked round the ecliptic on the interior of the sphere:

实沈 for full-form 實沈 *jitchin/shi chen*, the 6th of the 12 Jupiter stations (see 0).

In the hexagram names shown near the north pole (see 0):

Hexagram 29: 皈妹 for full-form 歸妹 *kimai/gui mei*

Hexagrams 19 and 51: 既濟 for full-form 既濟 *kisai/ji ji*, and 未濟 for full-form 未濟 *misai/wei ji*

In the last case, the abbreviated form used for 濟 is not quite the same as the modern typographical abbreviated form—see Figure 22.

Hexagram 52: the variant 解 has been used in place of the standard *kai/jie* 解.

Hexagram 57: The two lower elements 虫 in full-form *ko/gu* 蠱 have been abbreviated to the form shown in Figure 23:

There are other instances in which standard characters have been marked on the sphere in a more cursive 'handwritten' style than would normally have been found in a formal printed document, such as in the list of the 24 divisions of the solar cycle, where in the name of the 6th division *Jing zhe* 'Excited insects', normally written as 驚蟄, the first character is given in the form shown in Figure 24:

At first sight, the use of these forms on the sphere is rather unexpected—at least to a researcher like the first author (Cullen) who is mainly accustomed to reading standard editions of pre-modern Chinese texts such as the classics and histories, in which the use of full

²⁹ On the introduction of the idea of the spherical earth to Japan, see Shigeru Nakayama (1969) *A history of Japanese astronomy. Chinese background and Western impact*. Harvard University Press, Cambridge Massachusetts, 87-88.

³⁰ See section 5.



Figure 22. Abbreviated form of 濟



Figure 23. Abbreviated form of 壘



Figure 24. Cursive form of 驚

forms of characters is universal. In both China and Japan, it is nowadays normal to use officially authorised simplified versions of a large number of characters that are complicated to write in their original forms. The use of 国 for full-form 國 as noted above is an example that is common to the current lists of authorized simplified characters promulgated in both China and Japan; 谷 is also used for 穀. However the simplified character lists of both countries (which are not identical) were not officially promulgated until after World War 2, from the 1950s onwards. Why, therefore, do we find such characters on an object that must presumably have been made some time before it was bought on the antiques market in Paris, previous to the death of the original purchaser in 1936?

In the first place, inspection of a wider range of pre-modern Chinese texts will show that

the use of non-standard forms in printed books was quite common outside the context of high-status texts of the kinds mentioned above. (Liu Fu 劉復 1930) surveys a wide range of Chinese texts over the last thousand years, and records the abbreviations 國/国 (p. 14), 實/实 (p. 21) and 處/処 (p. 68) found on the Geneva sphere, and the variant 解/解 (p. 128), together with a number of abbreviations for 歸 (p. 134), though not the one found on the sphere. The use of 谷 for 穀 is also recorded in the quite formal context of a 10th century Chinese encyclopedia for imperial use³¹.

We may find some of the abbreviations on the sphere in a standard dictionary of Japanese abbreviated cursive forms, such as (Kodama Kōta 児玉幸多 1977), with 國/国 (number 719), 實/实 (number 1051) and 處/処 (number 4780); the cursive form of 驚 shown above is reproduced almost exactly in the second form given under number 6154. More may be found in pre-modern Japanese works on variant character forms, such as (Arai Hakuseki 新井白石 (1657-1725) 1995 ed.), which records 國/国 (p. 298), as well as the abbreviation of the element 齊 to 齐 (p. 307) as in 濟/濟, and the abbreviation of the element 蟲 in the character 蠱 shown in Figure 23 (p. 304). A work of similar date, (Nakane Genkei 中根元圭 (1662-1733) 1692; 1995 ed.), records 處/処 (p. 30 and p. 257), 國/国 (p. 39, and with a variant lacking the interior dot, p. 255). Both works also have examples of different variant forms for other characters shown in abbreviated form on the sphere.

All the examples cited so far come from printed or in some cases handwritten texts on paper. But might one not expect that someone taking the trouble to reproduce a text on an elaborate metal object such as the Geneva sphere—necessarily a time-consuming and costly process—would avoid the use of abbreviations that might suggest themselves in the case of a less troublesome and much more rapid medium? Interestingly, this appears not to be the case. A convenient repertory of inscriptions on metal from the early Edo period may be found in a survey of cast inscriptions on bells, (Manabe Takashi 眞鍋孝志 and Hanabusa Kenjiro 花房健次郎 1989). There we find a considerably number of variant characters used in such inscriptions, including ones found on the sphere: 國/国 (p. 3 upper, line 7 and p. 35 upper, line 5), 濟/濟 (p. 49 lower, line 1), and 歸/皈 (p. 88 upper, line 3)³². The third example comes from an inscription on a temple bell with a date equivalent to 1704, cast for the Tōfukuji 東福寺 temple in Tokyo, and still to be seen there today. We may note too that another bell inscription dated to the year 1684 (p. 53 lower, column 9) contains the expression *Aki jishō/qiu shi zheng* 秋時正 ‘the *shi zheng* of autumn’ as part of its date of manufacture: see above, 0 on the

³¹ Thus 谷雨 is found as a variant for 穀雨 in 10, 6b, on page 51 in *Tai ping yu lan* 太平御覽 (Imperial readings of the Tai Ping reign period). (983 CE, 1960 reprint of Song edition). Li Fang 李昉 et al., Beijing, Zhong Hua Press. Professor Hashimoto Takehiko has kindly pointed out that 谷 is also recognized as equivalent to 穀 in a number of other pre-modern usages. Examples may be seen in Morohashi Tetsuji 諸橋轍次 (1955) *Dai kanwa jiten* 大漢和辭典 (*Great Chinese-Japanese Dictionary*). Tokyo, Taishukan 大修館, 10, 628, entry 谷 36182, senses 5 & 6, also entry 谷雨 (same page)

significance of this usage as a sign of the Japanese provenance of the Geneva sphere.

Overall, it appears that we may not only say that the use of non-standard character forms *itaiji* 異体字³³ was not unusual in early Edo Japan, but that the use of such forms was a particularly common phenomenon in that period. Thus Yamashita Mari carried out a careful statistical analysis of a large quantity of textual material, in which she counted the number of times a selected set of thirty common characters appeared in their standard forms, or in ‘popular’ variants or simplifications thereof. She stated her conclusions as follows:

In material from the 17th century, it may be deduced that popular characters were more widely used than standard characters, and in the subsequent 18th century, materials using standard characters become more common. [...] Materials with high standard character usage rates are limited to philosophy, languages, and natural science, while in historical, literary, and social scientific materials there is greater utilization of popular characters even after 1700 when usage rates of standard characters increase. (Yamashita Mari 山下真理 2016: 46-47)

Paradoxically, it appears that the presence of variant character forms in the inscriptions on the sphere, far from being in any way anomalous, are a further piece of evidence that indicates a provenance in 17th century Japan.

4. Successors and imitators?³⁴

The references to the making of objects such as the Geneva sphere in Japan place all such activity in the first hundred years of the Edo period, the 17th century. There are references to such devices in 18th century sources, and it seems that one of them at least may have survived in a temple in Kyoto until the second half of the 19th century. But so far I know of no further trace of anyone in Japan actually making further clockwork-driven spheres similar to the device discussed here. It seems that the fashion for clockwork models of the cosmos was a

³² In fact, although not noted in the reference sources consulted for this work, the use of 𪛗 for 歸 is encountered quite commonly in 17th century writing, including, for instance, a manuscript dating from the second half of the 17th century of a work on the astronomy taught by the Jesuits, the *Kenkon bensetsu* 乾坤弁説. There the common expression *kichaku* 帰着 ‘conclusion’ is written as 𪛗着. See José Miguel Pinto Dos Santos (2011). “A Study in Cross-cultural Transmission of Natural Philosophy: The Kenkon Bensetsu.” Universidade Nove de Lisboa, PhD, 388, and Hiraoka Ryuji 平岡隆二 (2008). “The transmission of Western cosmology to 16th century Japan” in *History of Mathematical Sciences: Portugal and East Asia III. The Jesuits, the Padroado and East Asian science (1552-1773)*, Singapore, World Scientific: 81-98, 95.

³³ More precisely, we may distinguish 俗字 *zokuji/su zi* ‘popular’ or ‘vulgar’ character forms, 略字 *ryakuji/lue zi* ‘abbreviated characters’, and 宛字 *ateji/wan zi* ‘loan characters’, the last category representing characters that have been simply borrowed for their sound alone, without distinction of form or meaning.

³⁴ For fuller details, see Christopher Cullen and Hiraoka Ryuji 平岡隆二 (2019, forthcoming) “The Geneva sphere: An astronomical model from 17th C. Japan.”

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fashion that came and went in Japan,

As for the question of influence elsewhere in East Asia, there are definite indications in Korea: we know that Song Yiyeong 宋以穎 made a clockwork powered celestial model in 1669, and what is more, we are told that inside the sphere there was ‘a [piece of] paper depicting the mountains and seas as a horizon plane’, clearly recalling the map on the flat upper surface of the box in the Geneva sphere. We have further accounts of such devices from Korea: the private scholar Hong Daeyong 洪大容 (1731–1783), is said to have made a sphere in which “at the centre of the polar axis an iron plate was fixed, level with the horizon, on which was engraved a comprehensive map of mountains and rivers, to represent the surface of the earth.” There is good reason to think that the original stimulus for the construction of such devices reached Korea from Japan.

The unique feature of the social and historical context of the Geneva sphere is however unparalleled elsewhere in East Asia: a popular enthusiasm for astronomical models amongst non-experts, including non-experts who had the money to indulge their enthusiasm through fine craftsmanship to the kind used in the construction of this device. There are obvious parallels with the enthusiasm for astronomical displays in Europe, such as the ‘orreries’ of 18th century England. How far this enthusiasm may have expressed itself in other forms during early Edo is a topic that invites investigation.

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