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Comparison of Armillary Sphere in Ancient China and Western World †

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Abstract: Armillary spheres were developed in the East and the West for a long time. They independently developed various functions for astronomy. In this article, we discuss the differences in mechanical structures, appearance, and functions between the armillary spheres in ancient China and Europe. The earliest armillary sphere in ancient China was invented by Luo Xia Hong (落下閎) between 156 BC and 87 BC. Then, the armillary sphere in ancient China improved with the historical development of astronomy. The famous armillary sphere was built in an astronomical clock tower (水運儀象台) by Su Song (蘇頌) in the Song (宋) dynasty. This armillary sphere was an astronomical apparatus for the observation of celestial phenomena and the correction of time standards. However, the armillary sphere in Europe had different applications, even though the structures were similar. The armillary spheres in Europe simulated the sun's trajectory in one day to predict the sunrise and sunset positions. They adjusted the tilting angle of the celestial sphere with the altitude of observation to observe the path of the stars around the ecliptic. Through this review, the armillary spheres in ancient China and Europe are defined clearly.

Keywords: armillary sphere; ancient China; Europe

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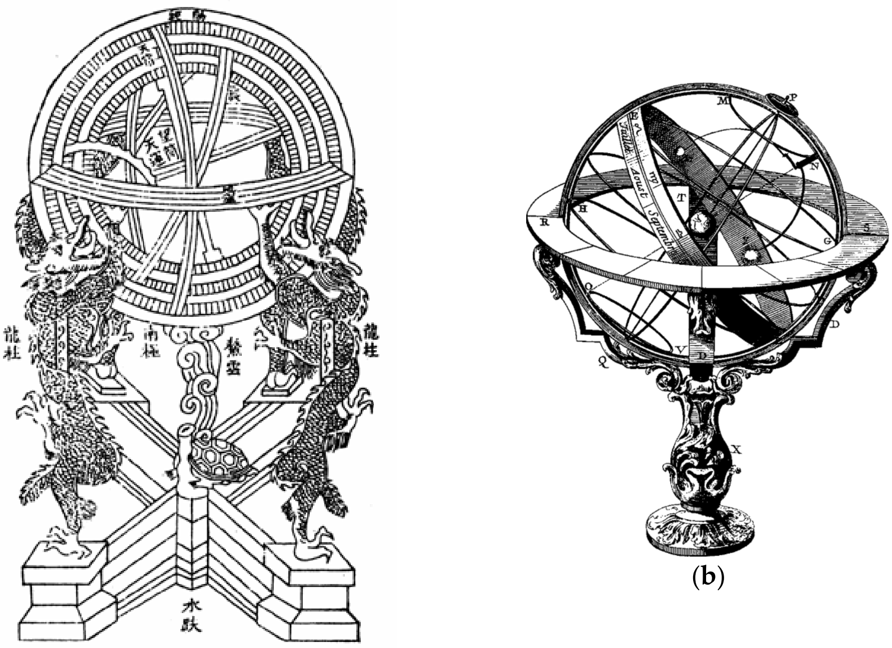
1. Introduction

Celestial bodies in the sky interested humankind to discover their secrets, whatever people located on the ground. People tried to explain the period phenomena and the cyclic motions of celestial bodies by constructing the appearance of the universe and the corresponding theories. Astrology and astronomy were successively developed with observation and records for a long time. Owing to the observation requirements, several astronomical mechanical devices were created, such as armillary spheres, quadrants, sundials, and astrolabes. Armillary spheres were invented by different ancient civilizations around the world. Even though the appearances of armillary spheres from various areas are different, their functions are almost the same. Such mechanical devices were applied to observe the positions of celestial bodies and even to correct time.

The armillary spheres are combined with several rings to form a sphere in ancient China or the ancient Western world, as shown in Figure 1. These rings with various scales were used to construct a coordinate system of the universe. The core of the formed sphere is the Earth. The design represents that the geocentric model was the essential theory in the period that the device was created. Though their appearances are similar, the sizes of the physical models have huge differences. The ancient Chinese model is heavy and huge, and it is a floor-standing type. The ancient Western model is smaller; it is a desktop or handheld type.



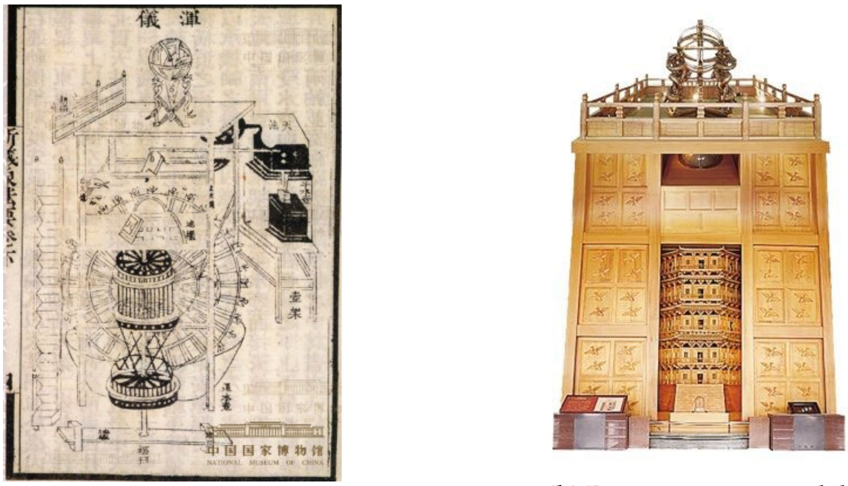
(a) (b)

Figure 1. Armillary spheres in (**a**) China and (**b**) Europe.

The origin of their invention in the ancient Western world is questionable. Eratosthenes (276–194 BC) and Anaximander of Miletus (611–547 BC) could be the inventors. In Ptolemy's *Almagest*, these instruments were much simpler, and the structure had three or four rings. They could be existing or simpler armillary spheres. There are no manuscripts to prove it. One known opinion is that the earliest complete armillary was invented by the meteōroskopion of the Alexandrine Greeks in about AD 140. This structure of the earliest Greek device included nine rings around the globe. The instrument had nine rings, including the horizon, meridian, Equator, tropics, polar circles, and ecliptic and a ring for supporting the skeleton of the sphere. The armillary sphere was an important astronomical device for observing and measuring the positions and motions of celestial bodies until the appearance of the telescope in the 17th century [1–3].

The armillary sphere was invented independently in ancient China. The earliest inventor is Luo Xia-Hong (落下閎) between 156 and 87 BC. However, people misunderstood that the first known armillary sphere in China was created by the astronomer Geng Shou-Chang (耿壽昌) around 52 BC. The early model had a simple design with several rings representing the celestial equator and meridian. Correctly understood, the astronomical model invented by Geng Shou-Chang (耿壽昌) was the celestial globe (Figure 2). The armillary sphere in ancient China improved with the historical development of astronomy. During the Eastern Han dynasty (漢朝), a famous astronomer Zhang Heng (張衡, 78–139 CE) improved the armillary sphere. He created a more complex design incorporating an equatorial ring, a meridian ring, and a horizon ring. However, the device did not have an element (tube) for observation. The astronomical device by Zhang Heng demonstrated celestial bodies. The most amazing armillary sphere was built in an astronomical clock tower (水運儀象台) by Su Song (蘇頌) in the Song dynasty (宋朝) (Figure 3). The clock tower included the armillary sphere, celestial bodies, a time chime device, and a mechanical clock. These devices were driven by a water wheel [4–6].

Figure 2. Celestial globe by Geng Shou-Chang (耿壽昌).



(**a**) Historical record

(**b**) Reconstruction model

Figure 3. Astronomical clock tower (水運儀象台).

At present, people confuse the armillary sphere and celestial globes. There is incorrect information on websites. Armillary spheres independently developed in ancient China and the ancient Western world. Their functions and the structure are similar. Hence, we present the historical development of the armillary sphere by analyzing its structure and functions and identifying the armillary sphere and the celestial globe.

2. Armillary Sphere and Celestial Globe

Armillary spheres and celestial globes are different astronomical devices. Armillary spheres are used to observe, and celestial globes are used to demonstrate the positions of known stars in the sky at one moment in one night. However, owing to the description of the ancient literature, people misidentify these two mechanical devices without drawings or due to the misunderstanding of how to operate the devices recorded in the ancient manuscripts.

In many ancient transcripts, the appearances of armillary spheres and celestial globes are described as spheres. Armillary spheres are built by several rings to form a spherical structure, and the surface of the structure is not filled up. Several rings are fixed and some rings are rotatable. The rings support each other. The endpoints of fixed or rotatable inner rings are connected to the outer one, as shown in Figure 4. Because the armillary sphere is used for observation, this device has an element to improve the accuracy and convenience of observation, using a straight tube or a tube with a cross at the front sight. Furthermore, with the development of astronomical observation, the structures of armillary spheres became complicated. Rings were added to the device for measuring or simulating the planets' motions.

(a)

(b)

Figure 4. Ancient armillary spheres in (**a**) China and (**b**) Europe.

As to celestial globes, the common styles are constructed as hollow balls (Figure 5). The known stars are engraved or bulging on the surface of the ball. The ball constructed on the frame is rotatable. Therefore, users can rotate celestial globes to demonstrate the sky based on the time and day. Celestial globes were built based on observation records for a long time, which seem to constitute big data or statistics. Certainly, they were used to predict the celestial phenomena occurring in the next few days.

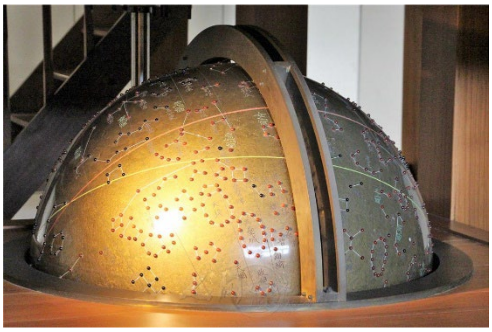


Figure 5. Ancient Chinese celestial globe.

The armillary sphere in ancient China is too complicated to conventionally operate. The structural designs of armillary spheres have more than nine rings. An astronomer (郭守敬) improved the device by separating its multiple functions and what was called the abridged armillary (簡儀), as shown in Figure 6. In the ancient Western world, a mechanical device assembled by several concentric rings was similar to the armillary sphere. The device aimed to simulate the periodic motions of the sun, the moon, and the planets. According to the literature survey, a device including 47 concentric rings survived [7].

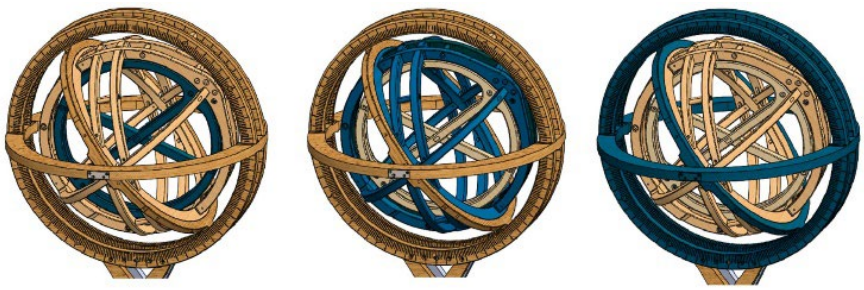
Figure 6. Abridged armillary (簡儀).

3. Armillary Sphere in Ancient China

The armillary sphere, an ancient astronomical instrument representing the celestial sphere with rings and hoops, has a rich history in China, reflecting significant advancements in astronomy and instrumentation.

The theory of Sphere Heavens (渾天說) describes the evolution of the structure of the universe, which has become complete through continuous additions and expansions of concepts by scholars of various dynasties. When the theory of Sphere Heavens developed in the Eastern Han Dynasty, the famous astronomer Zhang Heng advocated that the sky and the Earth were spheres like an egg, with the sky being the eggshell and the earth being the yolk, the sky thus enclosing the Earth. Based on this, Zhang Heng improved the armillary sphere to create a complicated design incorporating an equatorial ring, a meridian ring, and a horizon ring. The more developed the astronomical theory became, the more complex the armillary sphere device became. In the Tang dynasty (唐朝, 618−907 AD), the astronomer Li Chunfeng (李淳風) created an astronomical observation device with three spherical layers in 633 AD called the "nest", which corrected astronomical observations from many aspects. He also designed a tube on the device for observing. The installation of the tube was finished, but the astronomer Yi Xing (一行, 683−727 AD) played a pivotal role in enhancing the instrument. He added more rings to represent the ecliptic and celestial poles, which increased its precision.

In ancient China, the most well-known form of the armillary sphere was presented by Su Song (蘇頌) in the Song Dynasty (宋朝, 960–1279 CE). This form, on a water-moving instrument platform, had three systems consisting of Liuhe Yi (六合儀), Sanchen Yi (三辰儀), and Siyou Yi (四游儀), combined with a viewing tube (窺管) and a stand (鰲雲柱), as shown in Figure 7 [4]. This armillary sphere, including nine rings, was built on top of an astronomical clock tower (水運儀象台). The base was a cross-shaped water supply mechanism (水跌). This special design of the base was to correct the horizontal level of the device. The mechanical devices in the tower were driven by a water wheel. Hence, the armillary sphere had a celestial ring running on water to track celestial bodies, observe the movements of stars, and record their coordinates. It is a symbol of the maturity of the development of China's armillary sphere.



Siyou Yi (四游儀) Sanchen Yi (三辰儀) Liuhe Yi (六合儀)

Figure 7. Structural analysis of ancient Chinese armillary sphere.

The viewing tube involving the Siyou Yi design is convenient to observe through because it can be rotated in three axial directions. Then, the astronomer added front sight on the viewing tube to improve measurement accuracy. In the Ming dynasty (明朝, 1368–1644 AD), Guo Shoujing (郭守敬) changed the style of the viewing tube so that the observation room would not be affected.

Throughout its development, the armillary sphere in ancient China exemplified the ingenuity and dedication of Chinese astronomers to understand the cosmos. The instrument's evolution reflects broader scientific and technological advancements and highlights China's significant contributions to the history of astronomy.

4. Armillary Sphere in Ancient West World

As far as armillary spheres in the ancient Western world are considered, the center of the early model is the Earth, known as Ptolemaic. The later models using the Sun as the center are known as Copernican. No matter whether the models are suspended or rested on a stand, their structures are similar. Only differences exist between these two conceptual models like the position and the tilting angle of the ecliptic.

The armillary sphere has a rich history in the Western world, tracing back to ancient Greek and Roman times and evolving through the Middle Ages into the Renaissance. In ancient Greece and Rome, the concept of the armillary sphere is attributed to the ancient Greeks. The earliest known references date back to 3rd century BCE. Hipparchus (190–120 BC) is known to have used an armillary sphere for his astronomical observations and calculations. Claudius Ptolemy (100–170 AD) described the operation of an armillary sphere in his work *Almagest*, which became a cornerstone of astronomical knowledge for centuries. During the early Middle Ages, much knowledge of armillary spheres was preserved and enhanced by Islamic scholars. Islamic astronomers such as Al-Battani (858–929 AD) and Al-Sufi (903–986 AD) used and refined armillary spheres, incorporating them into their astronomical studies.

Armillary spheres were reintroduced to Europe through translations of Arabic texts during the 12th and 13th centuries. Gerard of Cremona (1114–1187 AD) translated many of these works, reintroducing classical and Islamic astronomical knowledge to European scholars. Then, several revivals and innovations of armillary spheres were presented in the Renaissance. Johannes de Sacrobosco (1195–1256 AD) and Regiomontanus (1436–1476 AD) studied and wrote about the armillary sphere. Nicolas Copernicus (1473–1543 AD) utilized the armillary sphere to develop his heliocentric theory, challenging the geocentric model of Ptolemy. By the 16th and 17th centuries, armillary spheres were commonly used in universities for teaching astronomy. They also became valuable tools for navigation, aiding explorers during the Age of Discovery.

An armillary sphere represents the celestial sphere with rings and hoops centered on the Earth (geocentric model) or Sun (heliocentric model), as shown in Figure 8. The primary rings and hoops around the center are as follows [8].

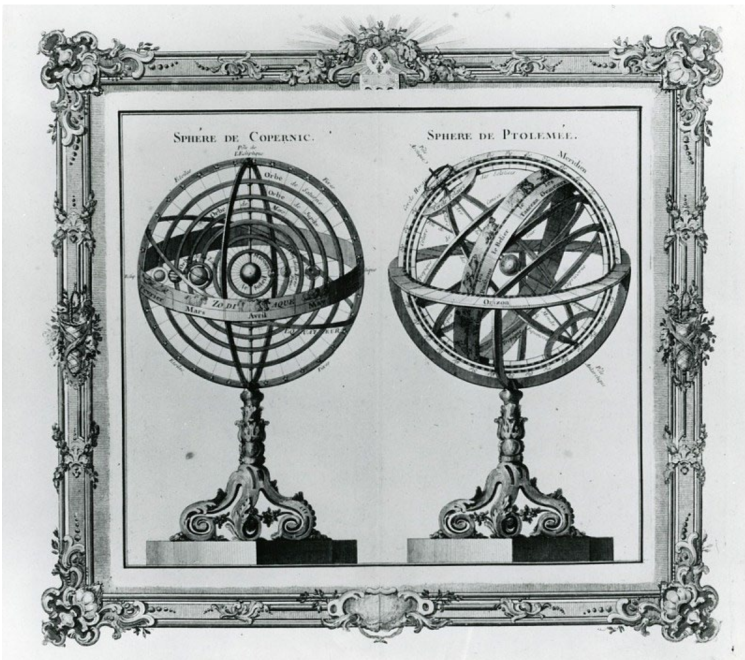


Figure 8. Armillary spheres for the geocentric model and the heliocentric model.

- The equatorial ring represents the celestial equator.
- The ecliptic ring is tilted relative to the equatorial ring; it shows the path of the Sun (the ecliptic).
- The meridian ring represents the local meridian, passing through the celestial poles and the zenith.
- The horizon ring represents the observer’s local horizon.
- The tropic rings represent the Tropic of Cancer and the Tropic of Capricorn.
- The Arctic and Antarctic Circles represent the Arctic and Antarctic Circles.

Except for the rings, there are additional components and adjustable features. Small circles, called almucantars, are parallel to the horizon in several armillary spheres. Rete is a mesh-like structure representing the starry sky, often used in conjunction with the ecliptic ring to show constellations and star positions. The rings rotate to align with the positions of celestial objects, helping to demonstrate celestial mechanics and navigation techniques. Between the sphere and the base, a slot is designed to adjust the tilting angle based on the altitude of observers, as shown in Figure 9.

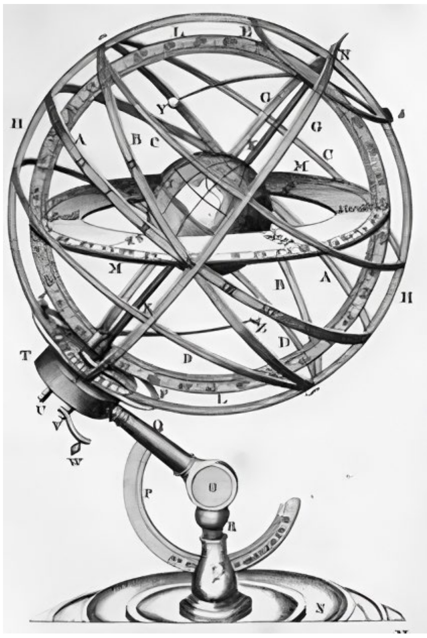


Figure 9. Adjustable design for altitude.

5. Conclusions

With the advent of the telescope and more advanced astronomical instruments, the practical use of armillary spheres declined. These devices played different roles. The armillary sphere was used for teaching, observational purposes, and as a tool for astronomers to understand the movements of celestial bodies. And they remain important historical artifacts displayed in museums as symbols of early scientific inquiry and discovery.

There is wrong information on the armillary sphere and the celestial globe. Hence, we introduce the origin of armillary spheres in ancient China and the ancient Western world. Then, the historical developments, the functions, and the structural analysis of armillary spheres in ancient China and the ancient Western world were presented. Although they are astronomical mechanical devices for observation and have similar appearances, they have different structures and applications.

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