PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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Astronomy in ancient and medieval China

By J. Needham, F.R.S., F.B.A.
Gonville and Caius College, University of Cambridge

[Plates 15–18]

Chinese astronomy differed from that of the Western world in two important respects: (*a*) it was polar and equatorial rather than planetary and ecliptic, (*b*) it was an activity of the bureaucratic state rather than of priests or independent scholars. Both features had advantages and disadvantages; the first led to the mechanization of celestial models long before the West, but deferred recognition of equinoctial precession till later. The second ensured remarkable sets of celestial observations antedating most of those recorded elsewhere, but discouraged causal speculation, especially in the absence of Euclidean deductive geometry. In cosmology, China developed three doctrines: (*a*) the Kai Thien universe, a domical geocentrism not unlike early Babylonian ideas, (*b*) the Hun Thien universe, essentially the recognition of the primary celestial spherical coordinates, and (*c*) the Hsüan Yeh system, which accepted the Hun Thien as methodologically necessary but viewed the heavenly bodies as lights of unknown nature floating in infinite empty space. Instrumentation developed early, armillary rings being in use by the end of the −2nd century and the complete armillary sphere by the end of the +1st.

Chinese astronomy differed from that of the Western world in two important respects: first it was polar and equatorial rather than planetary and ecliptic, and secondly it was an activity of bureaucratic States rather than that of priests or independent scholars. Both qualities had advantages and disadvantages. The first, the polar–equatorial situation, led to the mechanization of celestial models far earlier than in the West, but it deferred the recognition of equinoctial precession till later. Similarly, the bureaucratic situation ensured the recording of remarkable sets of celestial observations, but on the other hand it probably discouraged causal speculation, especially since the Chinese did not have Euclidean deductive geometry.

I think most people are well aware that from our present point of view nothing much was happening in China until about −1500 when the Shang period started, and after that during the Chou period there remain various records. But we have the fullest details from the Chhin and Han onwards, from about the −3rd century through the many centuries during which the dynastic histories were written, recording an enormous amount of astronomical information. Many people think that it is necessary to rely upon manuscript sources, as for example our friends the Arabists have to do in great part, but fortunately this is not the case in China because broadly speaking one can say that everything there is either printed or lost. Besides this, there probably are archives containing important astronomical data, which have not yet been opened, in China itself and also in countries like Korea, and I think that some considerable discoveries may be expected in the future on the basis of such archives.

Now as regards the polar and equatorial character, it is clear that Chinese astronomy was of this kind from the beginning. The calendrical problem was of course the simultaneous observation of the stars and the Sun, and presumably there are only two possible methods for ascertaining this relation, methods which people have called contiguity and opposability. The method of contiguity was, we know, that of the ancient Egyptians and the Greeks; it involved the observations of heliacal risings and settings, i.e. risings and settings just before sunrise and just after sunset. We all remember the famous heliacal rising of Sirius in ancient Egypt. This kind of observation did not require knowledge of the pole, meridian or celestial equator, nor any system of horary measurement. It naturally led to the recognition of the zodiacal or ecliptic constellations, and of stars appearing and disappearing simultaneously with them nearer or farther away from the ecliptic, the paranatellons as they used to be called. But the opposability method was that which was adopted by the ancient Chinese; they never paid much attention, so far as any of the records show, to heliacal risings and settings, but rather to the pole star (*pei chi*) and the circumpolar stars which never rise and never set. Their astronomical system was associated with the concept of the meridian, which would arise naturally out of the use of the gnomon, and they systematically determined the culminations and lower transits of the circumpolar stars.

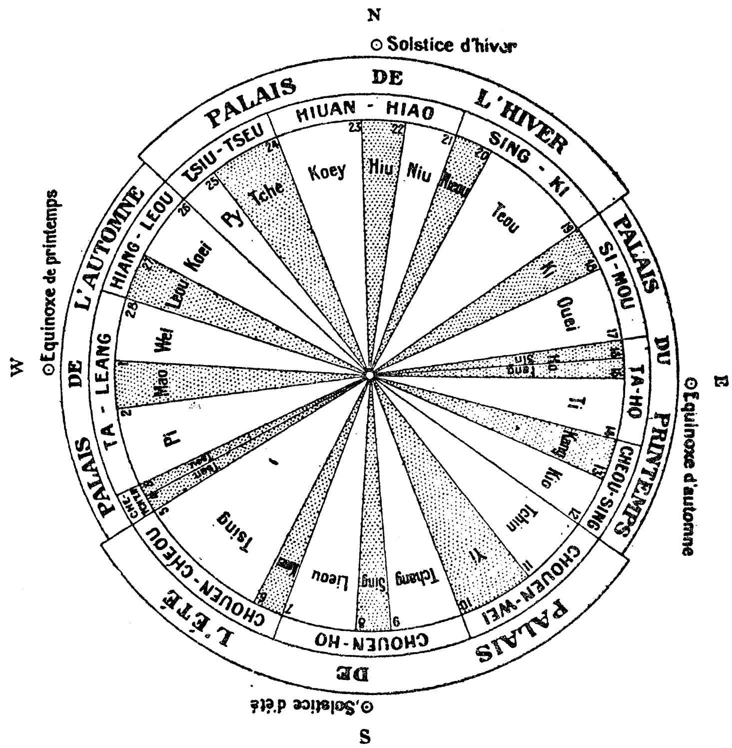


FIGURE 1. Diagram of a projection of the lunar mansions (*hsiu*) on the equator, done for the –24th century (de Saussure). The wide variation in their extensions may be noted.

I think one could really say that the celestial pole was the fundamental basis of Chinese astronomy. It was connected also with the microcosmic–macrocosmic type of thinking, because the pole corresponded to the emperor on earth, around whom the vast system of the bureaucratic agrarian state revolved naturally and spontaneously. I mentioned the gnomon (*piao*) just now, and clearly the meridian concept would arise very easily from this upright stick, because if you looked south you could measure the noon shadow, and if you looked north during the night you could measure the times at which the various circumpolars made their upper and lower transits. We have this in so many words in Chinese texts. Moreover, just as the influence of the Son of Heaven on earth radiated in all directions, so the hour-circles radiated from the pole. During the –1st millennium the Chinese built up a complete system of equatorial divisions defined by the points at which the hour-circles transected the equator (the *chhih tao*); and these divisions contained the 28 'lunar mansions' (*hsiu*), like segments of an orange filling up the celestial sphere, bounded by hour-circles and named from the constellations providing the 'determinative stars' or boundary markers (*chü hsing*). The classical diagram of de Saussure is given in figure 1.

Scholars have sometimes found it almost impossible to believe that a fully equatorial system of astronomy could have grown up without passing through an ecliptic phase, but those of us who study Chinese astronomy are quite sure that this happened. The classical type of Chinese sundial remained equatorial throughout the centuries (figure 2*a*, *b*, plate 15).

Having once established the boundaries of the *hsiu* by means of the characteristic asterisms scattered around the equator, and their determinative stars, the Chinese were in a position to know their exact locations even when invisible below the horizon simply by observing the meridian passages of the circumpolar stars which they could always see. Since they knew where the equator asterisms were at all times, they were able to solve the problem of the sidereal-solar positions, because the sidereal position of the full moon was in opposition to the invisible position of the Sun. In the same way we find growing up quite early in the late Chou, the Warring States period, and from the beginning of the Chhin and Han, from the −3rd century onwards, a rather full and complete recognition of the great celestial circles. This is known as the Hun Thien cosmological system, but it was not really a cosmology as often so called, it was rather the recognition of these circles. Naturally it accompanied the development of observational and demonstrational armillary spheres.

As regards the origin of the system of the *hsiu* or lunar mansions, this is a very difficult question because we get other systems of the same kind in other civilizations; particularly the *nakshatra* in India and the *manāzil* in the Arabic world. The *manāzil* do not compete of course, but indianists and sinologists have long been disputing about which is the older of the two, the Indian or the Chinese. I cannot today go into the argument on both sides, but one can say that only nine of the twenty-eight *hsiu* determinatives are identical with the corresponding *yogatārās* or 'junction stars' of the Indians, while a further eleven share the same constellation but not the same determinative star. Only eight of the determinative stars and *yogatārās*, however, are in quite different constellations, and of these two are Vega and Altair. On the Chinese side it is possible to say that the *nakshatra* do not show so clearly the coupling arrangements whereby *hsiu* of greater or lesser equatorial breadth stand opposite each other. Indian astronomy moreover, which was far more influenced by Greek astronomy than the Chinese was, does not show that keying of the *hsiu* and the circumpolar stars which is so important in China, in fact the essence of the Chinese system. Besides, the distribution of the *nakshatra* asterisms is much more scattered than that of those of the *hsiu*, following even less closely the position of the equator in the −3rd millennium.

On the other hand, as regards the documentary evidence, the Indians have very little to yield. There seems to be not much doubt that in the hymns of the *Rig Veda*, which correspond with the Shang oracle-bones and come down from about the −14th century, two *nakshatra* make their appearance. From that time onwards gradually the system is built up. It becomes complete in the *Atharva Veda*, for instance, and in the black *Yajur Veda* (all three recensions). This may mean that the system was fairly organized in India by about −800. But in China again there is much the same situation because that ancient calendar called the *Yüeh Ling* may come down from as far back as −850 and it mentions 23 out of the 28 *hsiu*. We cannot pursue the long argument this morning but nevertheless the problem is a very interesting one and it is not yet solved. I myself have always wanted to believe that the original circle of lunar mansions round the equator was Babylonian, so that in that way I could be happy to agree with Dr Aaboe in what he is saying at this conference on the importance of Babylonian origins in astronomy. The only difficulty is that it may be rather hard to find anything in Babylonian astronomy which could really have given rise to the *hsiu* and *nakshatra* systems.

May I now come to the question of celestial coordinates. In China we have a remarkable text called the *Hsing Ching* or 'Star Manual', the date of which is very unsure, though undoubtedly ancient. Some of its data appeared also in much later works such as the +8th-century *Khai-Yuan Chan Ching*. The *Hsing Ching* is certainly Han, but it may be a little earlier, and it records the positional measurements of many stars made by three astronomers of the −4th century, Shih Shen, Kan Tê and Wu Hsien. Some of them are *hsiu* or lunar mansion stars, and some of them are other stars all over the heavens grouped in asterisms. The epoch of the observations is not at all certain, and calculations have shown varying dates. None of the observations could be earlier than about −350, but some are a good deal later, so the catalogue as a whole may or may not be pre-Hipparchan (−134). Some of the measurements seem to have been made about

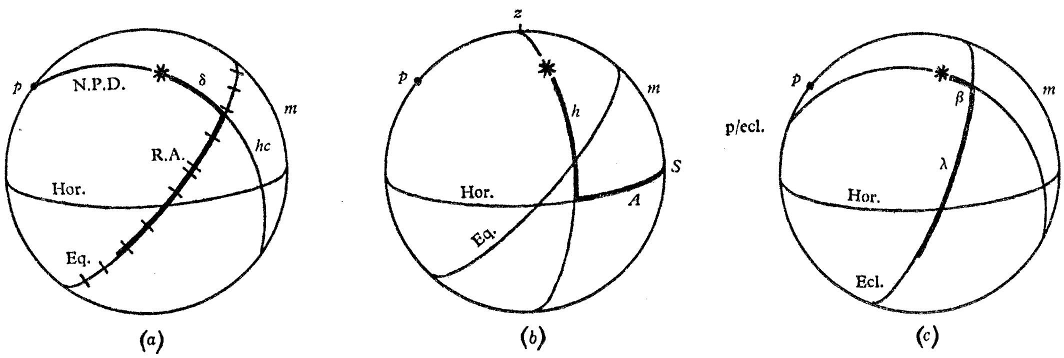


FIGURE 3. The three systems of celestial coordinates: (*a*) the equatorial Chinese, and modern, system; (*b*) the Arabic altazimuth system; (*c*) the Greek ecliptic system.

+130, nearer Ptolemy's time. The text gives the name of the asterism, the number of stars it contains, its position with respect to neighbouring asterisms, and measurements in degrees (on the $365\frac{1}{4}°$ basis of course) for the principal stars in the group; i.e. the hour-angle of the principal star measured along the equator from the first point of the *hsiu* in which it lies, and the north polar distance of the star. The text says, for example, that such and such a star is 2° forward from the beginning of the *hsiu* Hsin, and also that its distance from the north pole is 103°. Obviously the first corresponds to our modern right ascension, and the second gives the complement of our modern declination.

This is really quite interesting because I think it is well known (figure 3) that the Greek coordinates were essentially ecliptic, positions being measured along the ecliptic and towards the pole of the ecliptic. It is equally well known that the Arabic system made use of the horizon, taking the azimuth and altitude. This has the great disadvantage that it applies only to particular individual points on the Earth's surface. In China we never get the horizon system at all, or only perhaps extremely late under Arabic influence. On the other hand, the Greek system does make its appearance in the Thang period, when some of the Indian astronomers were working in China, for example a text may say that a star is so many degrees north or south of the ecliptic; but this is a late thing found only in the +8th, +9th and +10th centuries. All civilizations have used one or other of these three different types of star coordinates, and our modern ones are clearly Chinese. In this matter I would like to doubt, if I might, the impression given by Dr R. R. Newton, if that was what he intended to give, that all ancient systems were primarily horizon ones. I think it would be very hard to say that of Chinese astronomy in ancient times, for the polar-equatorial coordinates come in very early in Chinese culture.

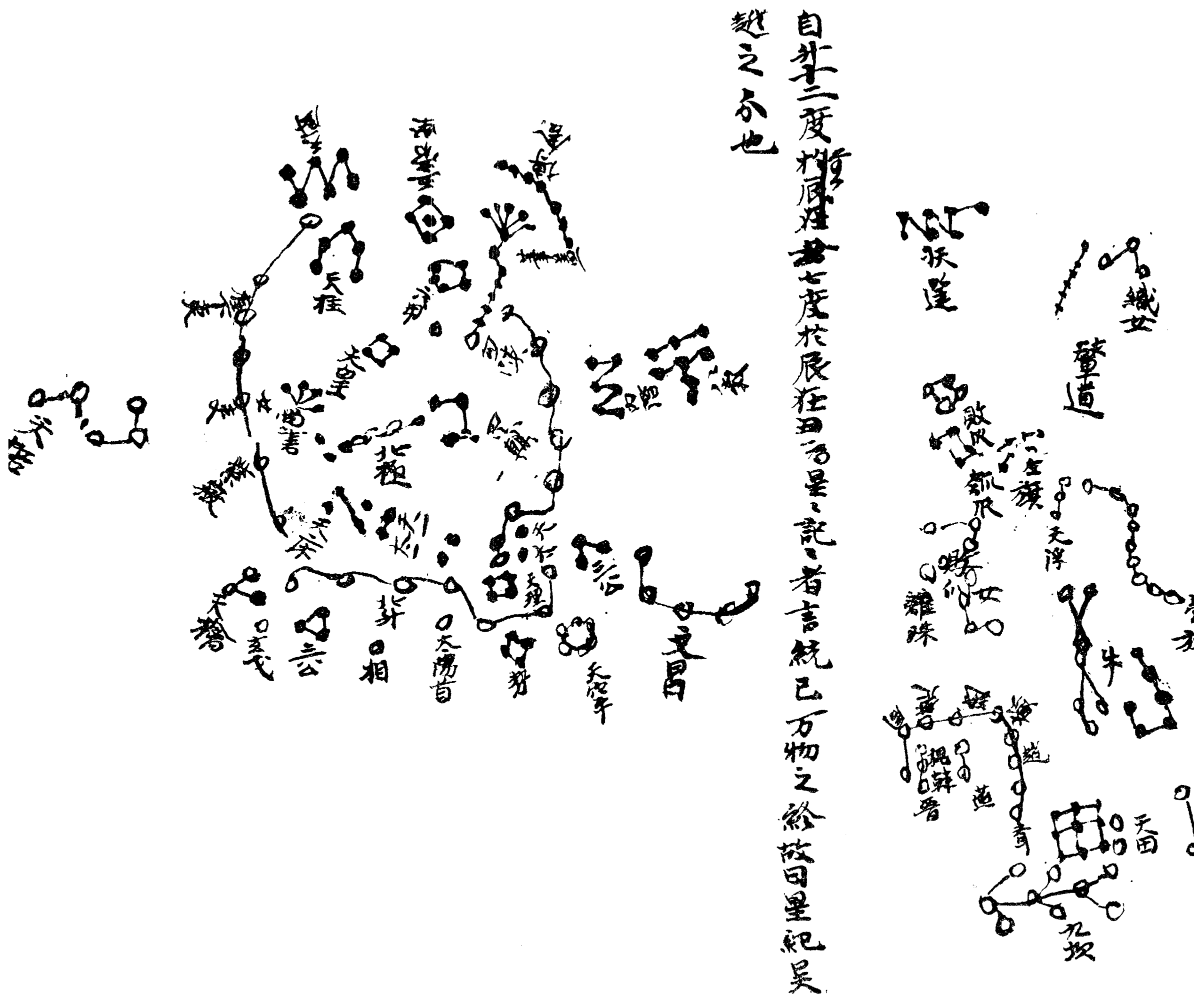


FIGURE 5. The Tunhuang MS. star map of +940 (Brit. Mus. Stein no. 3326). To the left, a polar projection showing the Purple Palace and the Great Bear below it. To the right, on 'Mercator's' projection, an hour-angle segment from 12° in Tou *hsiu* to 7° in Nü *hsiu*, including constellations in Sagittarius and Capricornus. The stars are drawn in three colours, white, black and yellow, to correspond with the three ancient schools of positional astronomers (those of Shih Shen, Kan Tê and Wu Hsien).

Now as for the constellations and the naming of them, it is rather an interesting thing that there is no overlap at all with the nomenclature in other civilizations. There may be a good deal of connexion between Greek and Indian names but practically nothing in China corresponds. From ancient times it was customary to represent constellations in a ball-and-link style, as we see on an inscribed brick from the Han period (±1st century, figure 4, plate 15). Figure 5 shows an early star map from the Chinese culture-area datable at about +940. This manuscript must be one of the oldest star-charts extant from any civilization. It gives a picture of the north polar region, the 'Purple Forbidden Palace', as it was called, in which you can see down at the bottom the shape of the Great Bear similar to the way everybody else saw it, but nothing else is the same. A European constellation can appear in several different asterisms on the Chinese planisphere; for example, Hydra comprises the three *hsiu* Chang, Hsiang and Liu, together with eight other star groups having no similarity of symbolism. And this is the case all along the line. There is nothing corresponding to Delphinus and Cancer and so on, the only overlaps are the Great Bear, or Northern Dipper (Pei Tou as we call it in Chinese), and of course naturally Orion (Shen) and the Pleiades (Mao), but apart from those there is simply no correspondence. What is rather interesting is that the agrarian bureaucratic nature of Chinese civilization led to a multitude of star and constellation names in which the hierarchy of earthly officials had their heavenly counterparts.

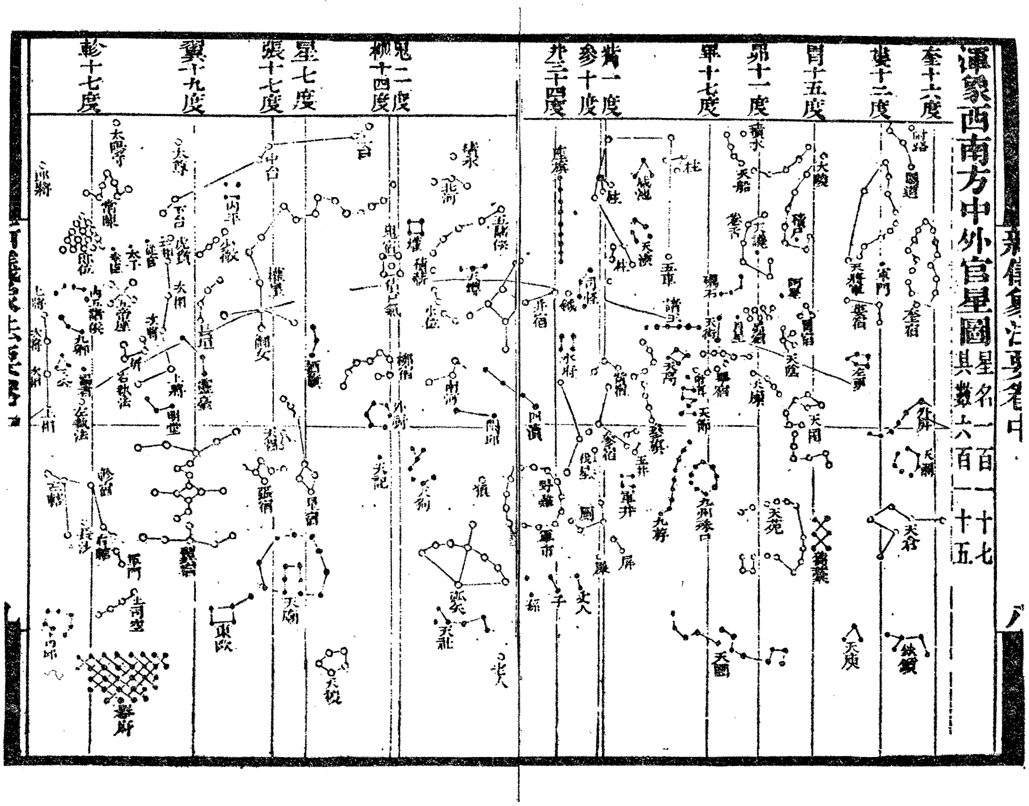
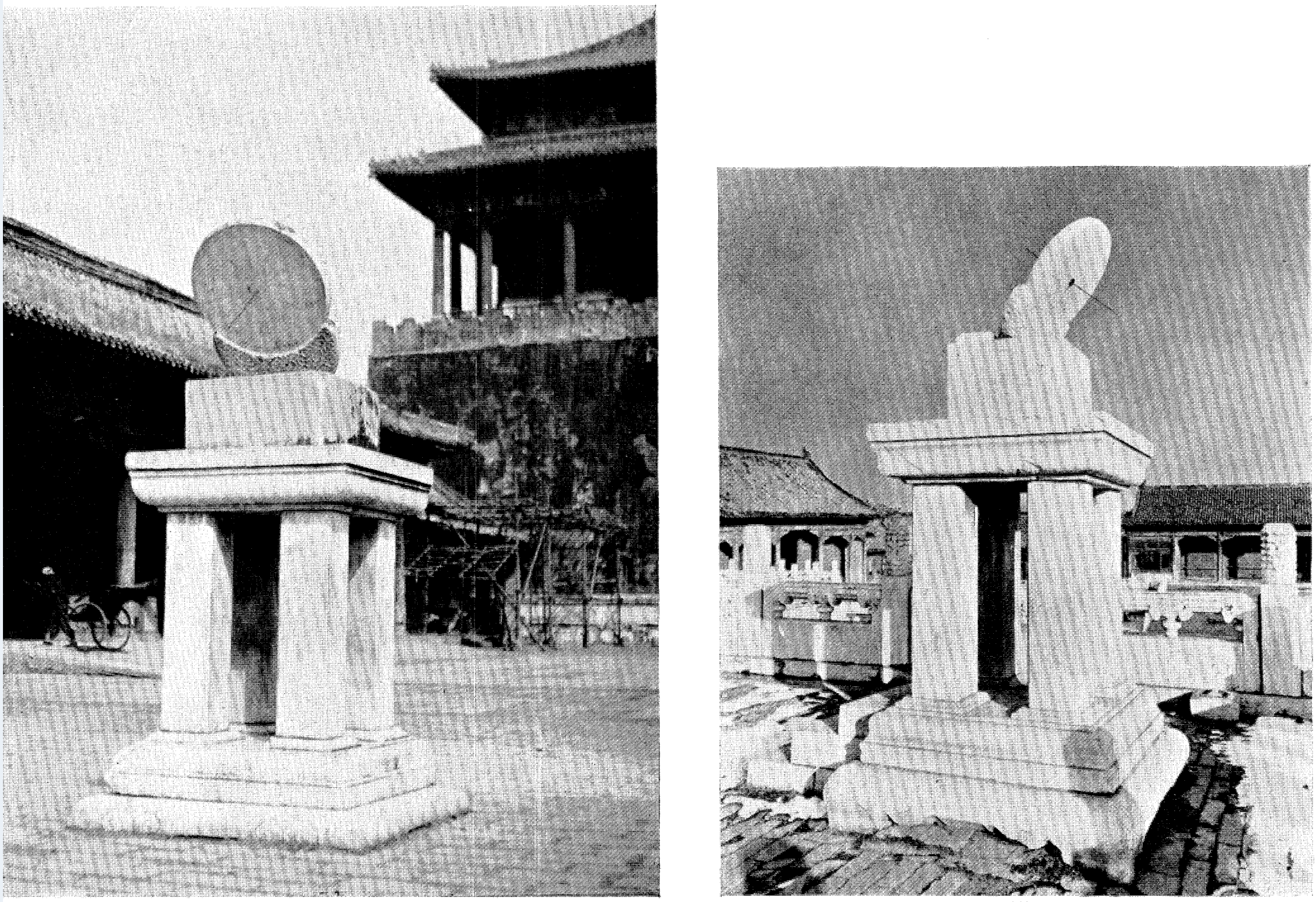


FIGURE 6. Star chart from Su Sung's *Hsin I Hsiang Fa Yao* (+1094), showing 14 of the 28 *hsiu* (lunar mansions), with many of the Chinese constellations contained in them. The equator is marked by the central horizontal line; the ecliptic arches upwards above it. The legend on the right-hand side reads: 'Map of the asterisms north and south of the equator in the southwest part of the heavens, as shown on our celestial globe; 615 stars in 117 constellations.' The *hsiu*, reading from right to left, are: Khuei, Lou, Wei, Mao, Pi, Tshui, Shen (Orion), Ching, Kuei, Liu, Hsing, Chang, I and Chen. The very unequal equatorial extensions are well seen.

Next, figure 6 shows what one can only describe as a star map on a Mercator projection, with the upright bands representing the *hsiu*, the lunar mansions of different widths or stretches, and then the equator running along the middle, the ecliptic also shown over half the heavens, and all the stars placed in their approximately right positions. This was the map of the stars which was made for the celestial globe set up by Su Sung in the Astronomical Clock Tower at Khaifêng, in +1088, some 500 years before Gerard Mercator. I shall want to say a word more about this instrument in a moment. A similar star chart in Japan has been described by Dr Imoto Susumu (figure 7, plate 16, gives the same hemisphere as figure 6). But it has the additional interest of being drawn on squared paper with the aim of greater accuracy. Though the



(*a*) (*b*)

FIGURE 2. Typical Chinese equatorial sundials in the Imperial Palace at Peking. (*a*) Outside the Wu Mên Gate (photo. A. R. Moore, *ca.* 1925). (*b*) On the platform of the Thai Ho Tien Hall (photo. Sirén, *ca.* 1910).

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FIGURE 4. The Moon passing through a constellation; from a Szechuanese moulded brick of Han date (from Wên Yü). The moon disk shows a toad under a tree (a legendary consequence of the lunar crater markings, etc.), and is borne along by a feathered and winged genius. The constellation is drawn in the usual ball-and-link convention.

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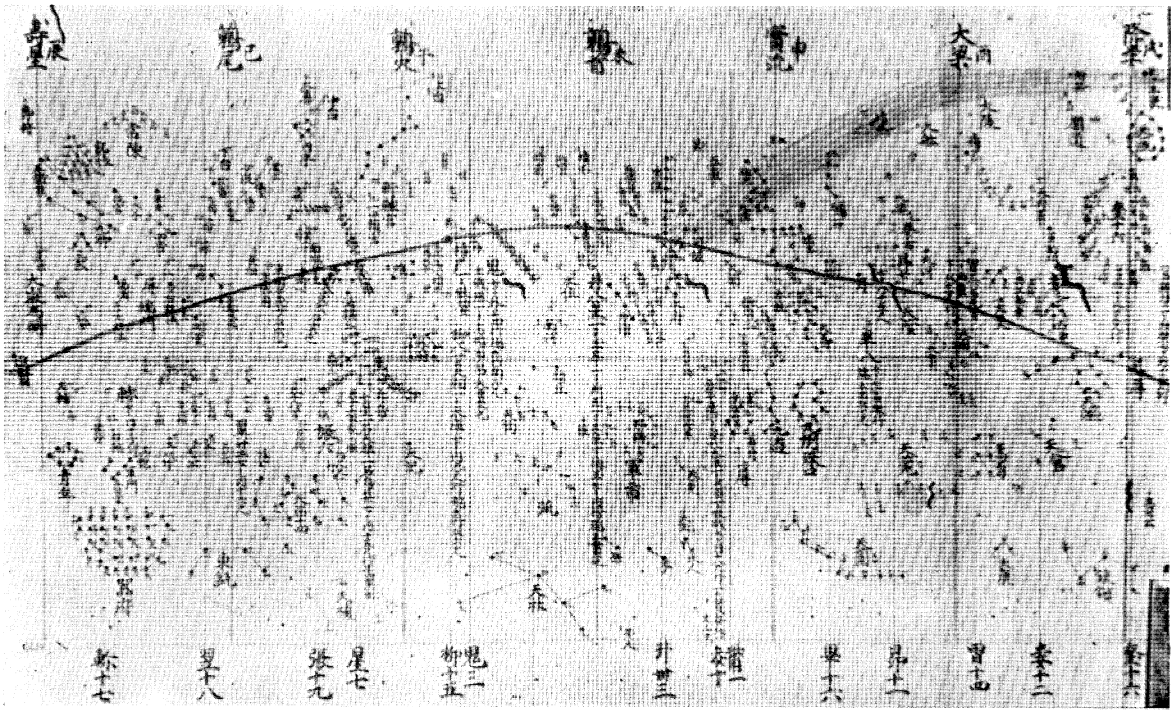

Figure 7. The same hemisphere as in figure 6, with the equator again horizontal and central, and the *hsiu* divisions and constellations shown, as before, on a 'Mercator's' projection; from a MS. star map *Kōshi-gettshin-zu* formerly preserved in Japan (Imoto Susumu). Many similarities with the preceding figure will be apparent, but the drawing has been done on squared paper for greater accuracy. Perhaps the original was more likely Sung than Thang.

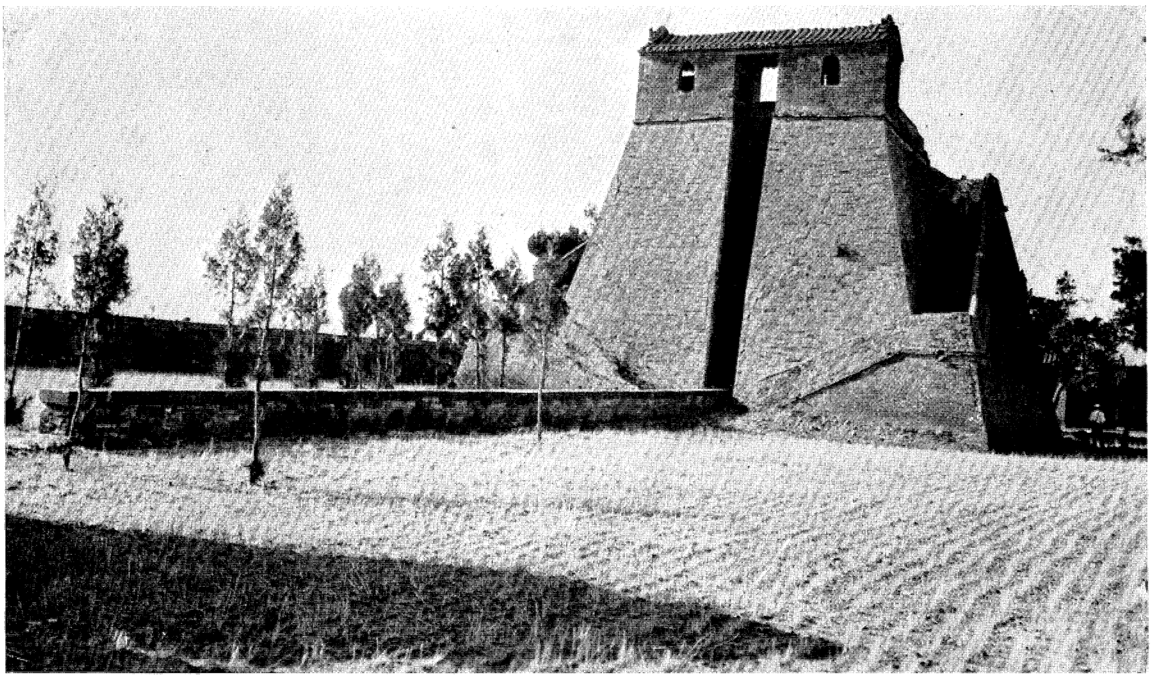

Figure 9. The Tower of Chou Kung for the measurement of the Sun's solstitial shadow lengths at Kao-chhêng (formerly Yang-chhêng), some 80 km southeast of Loyang, and for many centuries the site of China's central astronomical observatory. The present structure is a Ming renovation of the instrument built by Kuo Shou-Ching about +1276. The 12 m gnomon stood up in the slot, and its shadow was measured along the stone scale projecting on the left, with special arrangements to secure a sharp edge reading. One of the rooms on the platform housed a clepsydra (perhaps a hydro-mechanical clock), and the other probably an observational armillary sphere.

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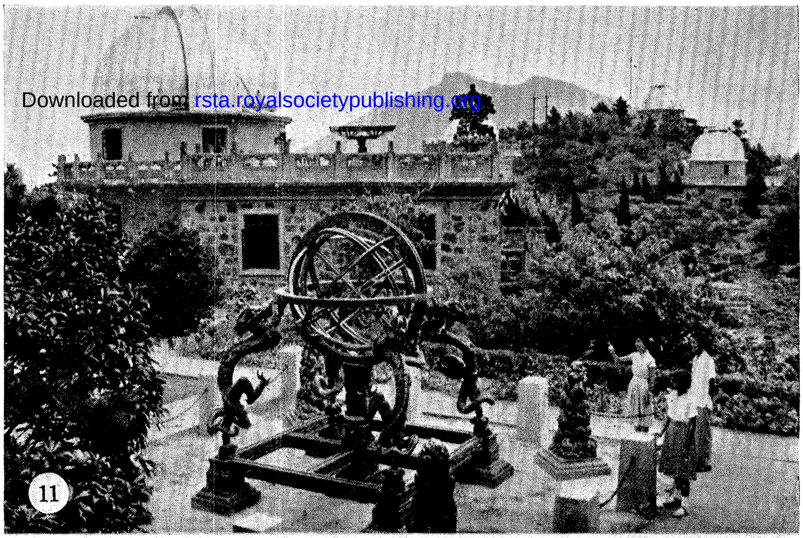

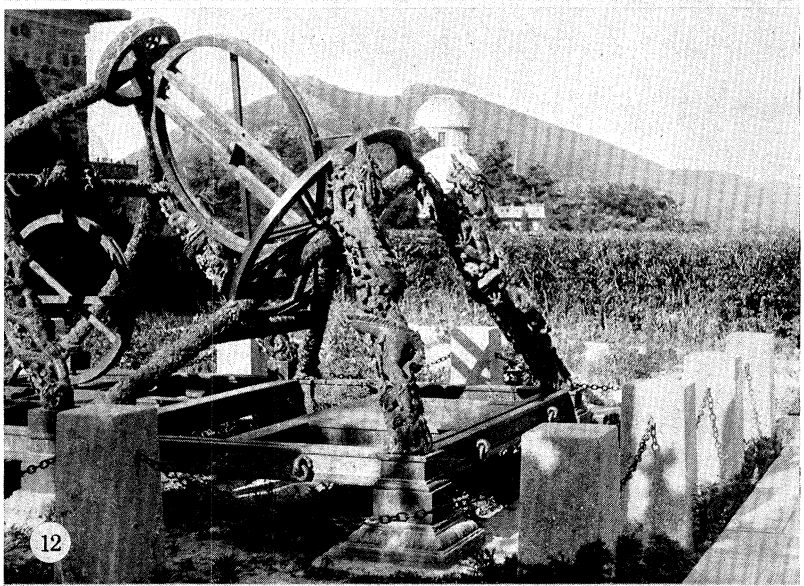

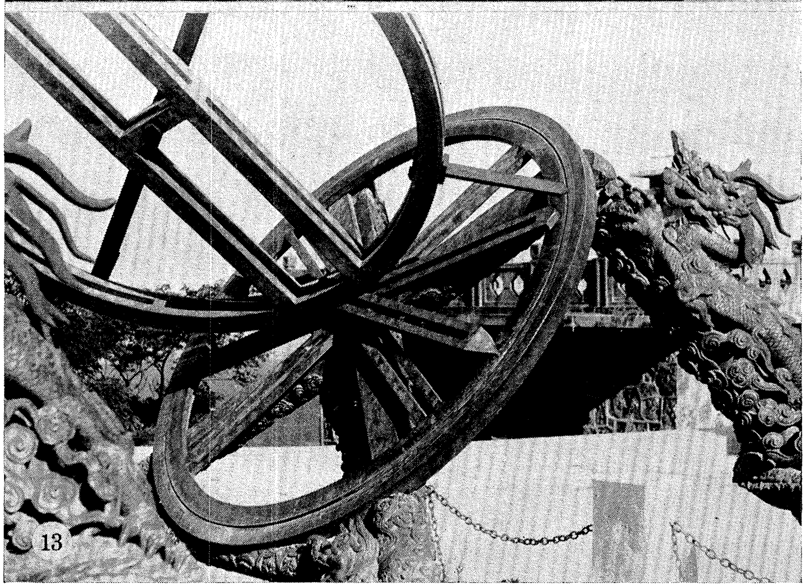

FIGURE 11. The equatorial armillary sphere of Kuo Shou-Ching (*ca.* +1276), now preserved in the grounds of the Purple Mountain Observatory, Nanking.

FIGURE 12. Kuo Shou-Ching's 'equatorial torquetum' (*chien i*, simplified instrument), precursor of all telescope equatorial mountings, in the grounds of the Purple Mountain Observatory, Nanking. Like the armillary sphere in figure 11, this instrument may be one of the identical replicas cast by Huang-Fu Chung-Ho in +1437 (orig. photo., 1958).

FIGURE 13. Detail view of part of the instrument shown in figure 12 (orig. photo., 1958). The bronze mobile declination split-ring or meridian double circle carrying the sighting-tube is well seen. Below, the fixed diurnal circle, and the mobile equatorial circle, with movable radial pointers probably used to demarcate the boundaries of *hsiu*.

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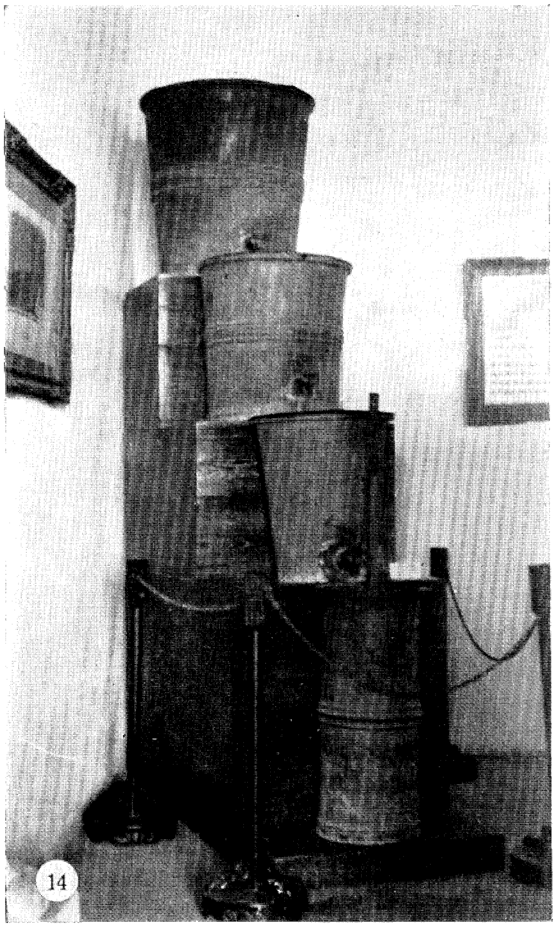

FIGURE 14. The famous polyvascular inflow clepsydra at Canton made in the Yuan dynasty (+1316) by Tu Tzu-Shêng (orig. photo., 1958).

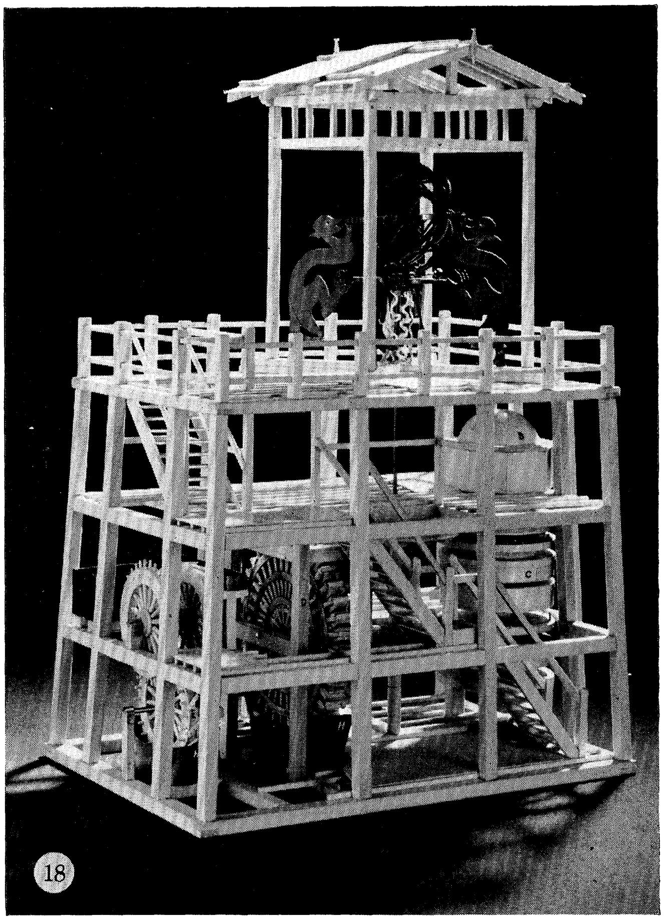

FIGURE 18. Model of the Khaifêng clock tower in the Science Museum at South Kensington (J. H. Combridge). Here it is seen from the back and right.

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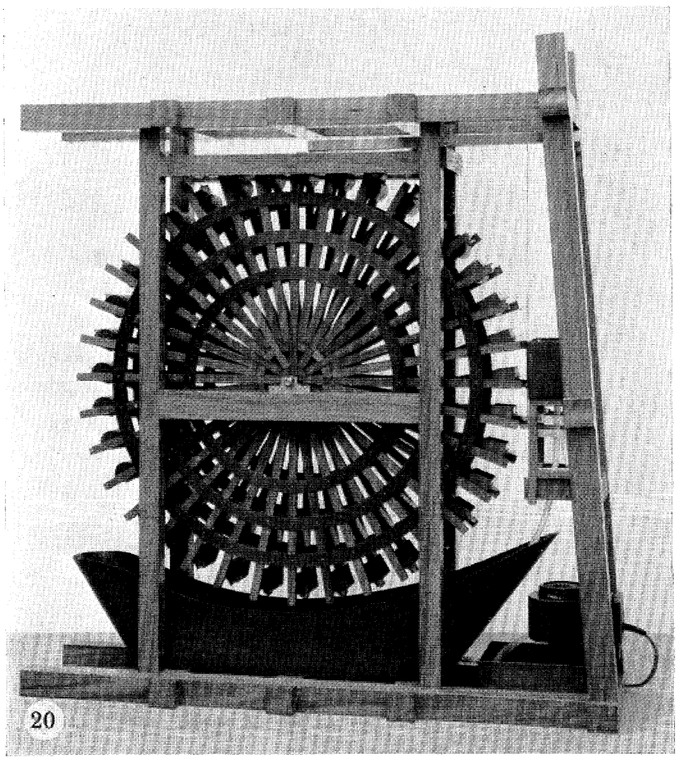

FIGURE 20. Working model of the hydro-mechanical escapement of the Khaifêng clock tower in the Science Museum at South Kensington (J. H. Combridge).

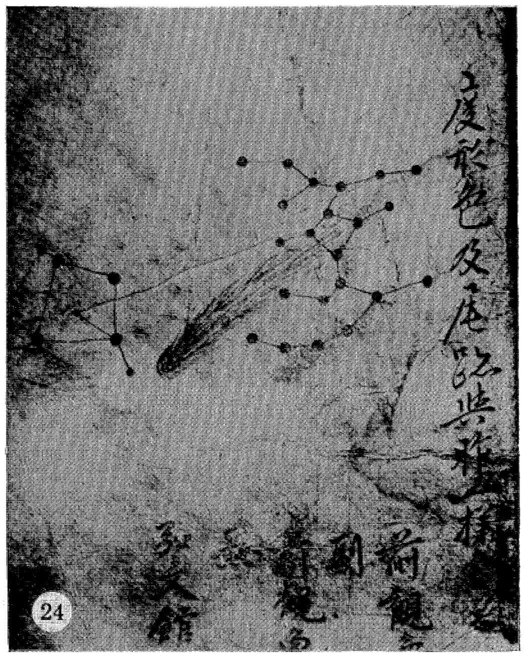

FIGURE 24. A comet of +1664, from the Korean astronomical archives (Rufus).

manuscript is of a later date, Imoto Susumu traces its origin back to the time of I-Hsing in the +8th century, since the R.A. values mostly, though not entirely, agree with those given by him. Su Sung may have drawn from the same source. Finally, we show the famous planisphere of Suchow (+1193) in figure 8.

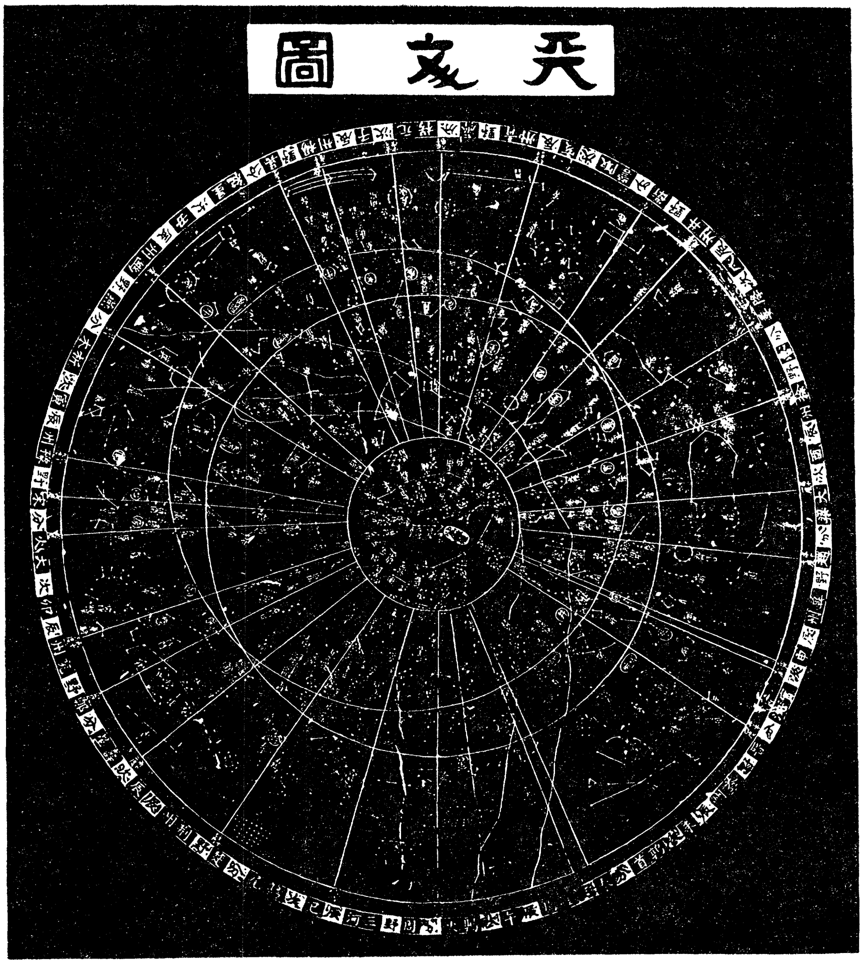

FIGURE 8. The Suchow planisphere of +1193 (Rufus & Tien). Note the excentric ecliptic and the curving course of the Milky Way (*thien ho*, the river of heaven). The map with its explanatory text was prepared by the geographer and imperial tutor Huang Shang, and committed to stone by Wang Chih-Yuan in +1247.

Coming back to the question of instrumentation, the earliest measuring device was undoubtedly the gnomon. We have many references to that in ancient books, such as the *Tso Chuan* and the *Chou Pei Suan Ching*. It must have been used from the Shang period, *ca.* −1500 onwards. The *Chou Pei Suan Ching* (Arithmetical Classic of the Gnomon and the Circular Paths of Heaven) and the *Chou Li* (Institutes of the Chou Dynasty) are both probably early Han texts but based on the usages of the centuries preceding. In many ways, the gnomon was a much used instrument in Chinese culture. Professor Willy Hartner has recently written an interesting new contribution on this, relating especially to the meridian line of observation posts set up about +725 under the Buddhist monk I-Hsing, the greatest astronomer and mathematician of his age. Now this was a chain of stations reaching from Indo-China right up to Siberia, and the

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seasonal observations of noon sun shadows with the gnomon were done at a dozen places along that line. Measuring just over 2500 km in length, this meridian survey must be one of the greatest efforts of organized scientific research in any medieval civilization.

The gnomon reached its climax in Chinese culture with the giant instrument set up by Kuo Shou-Ching about +1276 (figure 9, plate 16). This shows the long scale for the measurement of the Sun's shadow thrown by the 12 m gnomon, and the star observation platform is to be seen

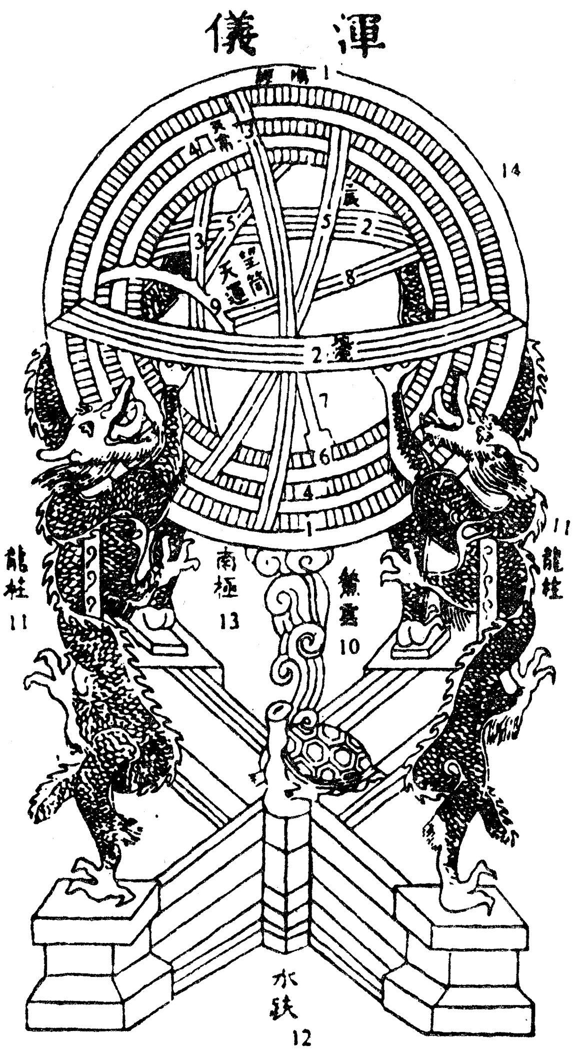

FIGURE 10. Su Sung's armillary sphere (*hun i*) of +1090, described in the *Hsin I Hsiang Fa Yao*, redrawn from the text and labelled by Maspero. For explanation of details see SCC, III, Fig. 159, p. 351.

at the top of the tower. One of the chambers there housed a clepsydra, perhaps a hydro-mechanical clock; the other probably an armillary sphere. This wonderful piece of giant astronomical equipment still exists at a place called Yang-chhêng not far from Lo-yang (in Honan) near the geographical centre of China, and it has been repaired in very recent times, in fact even during the Cultural Revolution. During the war it was used for target practice by the Japanese, and the top of one of the side chambers was knocked off, but no other damage was done, and it has now been completely repaired and restored. It must be regarded as a notable monument even though no doubt it was rebuilt under the Ming. The +13th-century data obtained with this gnomon still exist also, and are highly creditable for that time, especially as a sophisticated device, the 'shadow definer', was used to focus the image of the cross-bar and avoid the difficulty of the penumbra.

The development of armillary rings and spheres is an even more intriguing question. It is fairly certain that the most primitive form of armillary was a simple single ring with some kind of fiducial line or sights which could be set up in the meridian or equatorial plane. Measurement one way gave the north polar distance or declination, measurement the other way gave the position in the *hsiu*, i.e. the right ascension. No doubt that was all that Shih Shen and Kan Tê had at their disposal, and there is some evidence that it came down to about −100 because it may be that Lo-Hsia Hung and Hsien-Yü Wang-Jen had nothing else. But then things happened rather fast. Kêng Shou-Chhang introduced the first permanently fixed equatorial ring in −52, and an ecliptic ring was added by Fu An and Chia Khuei in +84; while with Chang Hêng's apparatus in +125 the sphere was complete with horizon and meridian rings. It is rather remarkable that this rapid evolution should have come about historically parallel with Greek times, and just before the life of Ptolemy himself.

Spheres of all kinds continued to be made without much change for many centuries. The one in figure 10 is the very famous instrument constructed by Su Sung in +1088 or so for the astronomical clock tower at Khaifêng which I mentioned before. In the Thang period, about +630, Li Shun-Fêng made the radical innovation of building not two nests of concentric rings but three, so it got rather over-complicated, but the design that Su Sung used is one which has many similarities with the equatorial spheres of Tycho Brahe in +16th-century Europe. Figure 11, plate 17, shows another sphere, that of Kuo Shou-Ching (+1276) which is to be found at the Purple Mountain Observatory near Nanking today. This was the same astronomer who made the giant gnomon device. But his major achievement was his equatorial torquetum or 'simplified instrument' (*chien i*), which did away with the unnecessary parts of the armillary sphere and achieved what was essentially an equatorial mounting of the sighting tube. One can still see it (figures 12 and 13, plate 17) on the top of the Purple Mountain at Nanking, and I am glad to report that it is in perfect order and very carefully preserved.

This brings me to the question of powered celestial models which I mentioned earlier, and that certainly was an extremely interesting development unexampled in any other culture. Twice already I have referred to the astronomical clock-tower of the late +11th century described in the *Hsin I Hsiang Fa Yao* (New Design for a mechanized Armillary Sphere and Celestial Globe), a book presented to the throne in +1092. These cosmic models, in fact demonstrational armillary spheres and celestial globes, were rotated by water power using a constant-level tank and a driving wheel with buckets. One might call it a mill wheel but it was retained and guided all the time by an escapement, so we use the term hydro-mechanical clockwork, and speak of the hydro-mechanical linkwork escapement. The background of the constant-level tank lay in clepsydra technology, for in the +6th century the older polyvascular trains of compensating tanks (figure 14, plate 18) had been superseded by arrangements of overflow tanks to produce a perfectly steady flow (figure 15).

The escapement was indeed a great invention; it was certainly in use by the time of I-Hsing and Liang Ling-Tsan at the beginning of the +8th century, and the only problem is whether it may go back much further. It is still uncertain whether Chang Hêng in the +2nd century had already got this or not. Thus using the constant-level tank, and the driving wheel retained

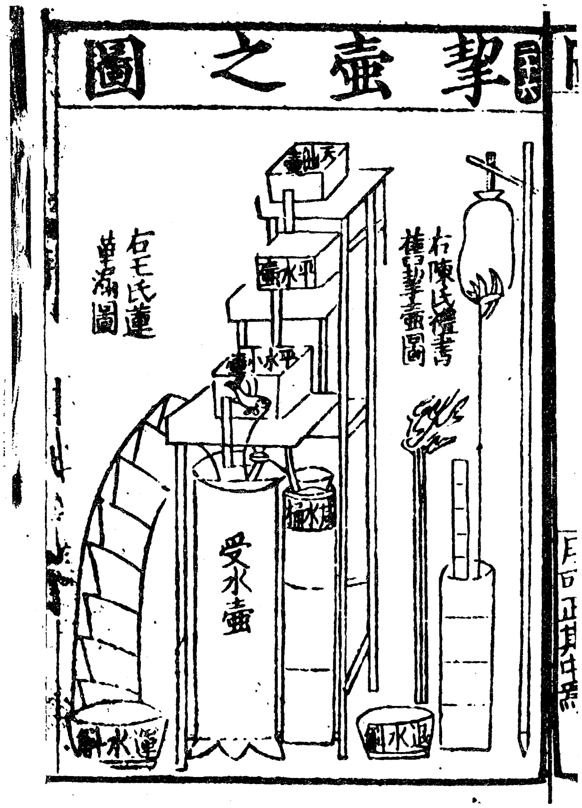

FIGURE 15. Overflow tank clepsydra for constant-level operation seen in a Sung edition of Yang Chia's *Liu Ching Thu* of +1155.

by the linkwork escapement, one had a real time measuring machine, and of course it may also be considered the first of all clock drives.

Figure 16 shows the appearance of the clock tower, with the tanks and the driving wheel laid open on the right; and you can see the celestial globe on the first floor, and on the roof the armillary sphere. I called it demonstrational just now, but that is not quite fair because it was certainly an observational one too, and we have speculated that one of the reasons for introducing the clock drive was so as to be able to turn round the 20-odd tonnes of bronze in time to make an observation just before dawn. But the globe rotating in the intermediate storey would have been for demonstration in times of clouds and storm when the heavens could not be observed directly. Figures 17 and 18, plate 18, show reconstructions of what the clock-tower looked like, and the mechanism follows in figure 19. Here one can see how the drive on the right-hand side at the bottom rotated the column bearing much jack work, and a celestial globe on a bevel drive at the top, and how after some time the long shaft was replaced by a chain drive, in fact mark 2 and mark 3 chain drives, getting progressively shorter and so better designed. Finally the escapement mechanism is seen in figures 20, plate 18, and 21; this is the device that is certainly of the +8th century and possibly of the +2nd.

Now these powered models illustrate, I think, the advantage which the Chinese found in having a polar-equatorial system. After all, the celestial latitude and longitude grid is a purely conceptional network thrown over the heavens, and along its lines nothing ever actually moves; but things of course do move on the circles parallel with the equator. Finally, figure 22 shows a

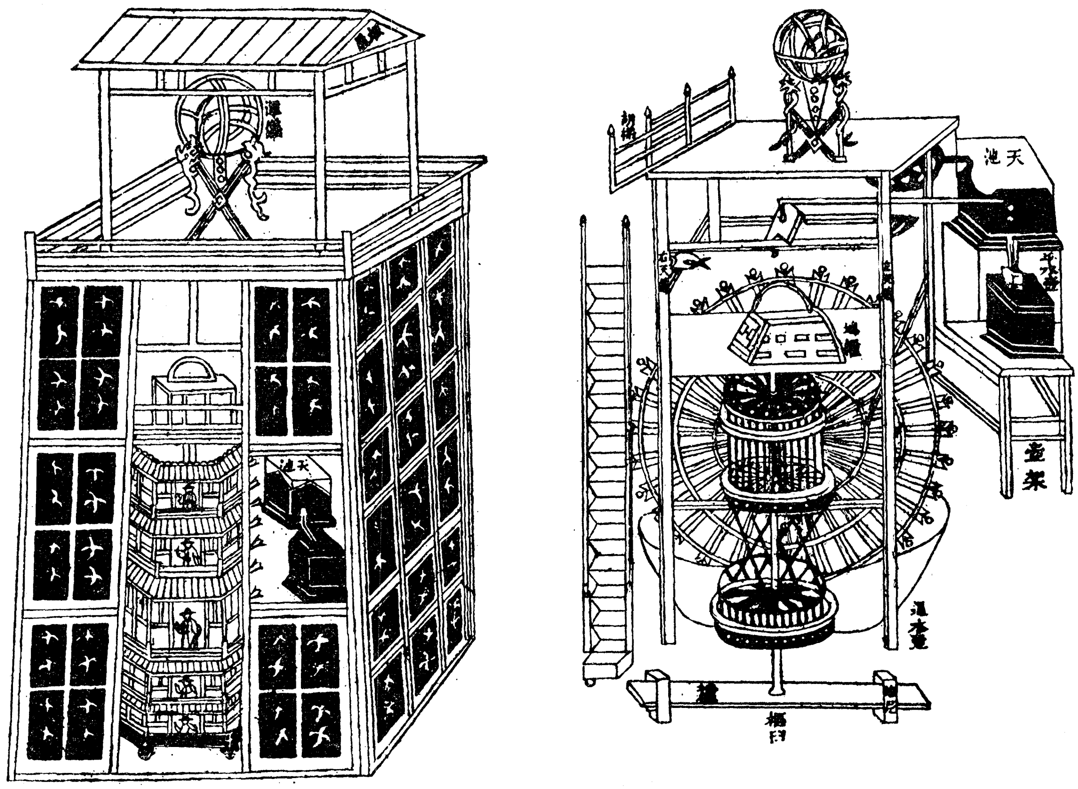

FIGURE 16. General views of the astronomical clock tower built at Khaifêng by Su Sung and his collaborators in +1090. On the top platform, some 11 m above the ground, there was a mechanized armillary sphere for observations; in a chamber on the first floor a mechanized celestial globe was installed, and below, in front of the hydro-mechanical clockwork, numerous jacks appeared at the openings of a pagoda facade, constituting a time-annunciator. The tower and its machinery are fully described in Su Sung's *Hsin I Hsiang Fa Yao*. (Left) External appearance, with a panel removed to show the constant-level tank. (Right) Internal structure. In front, the jack wheels and vertical shaft, behind this the driving wheel. On the right the constant-level tank delivering the water to the driving-wheel scoops or buckets. Above the driving wheel one can see a few traces of the escapement mechanism (cf. figures 20, 21). On the left, the staircase, on the top platform, the armillary sphere.

reconstruction by Dr Liu Hsien-Chou of I-Hsing's orrery arrangement for Sun and Moon models as deduced from the textual descriptions of his early +8th-century astronomical clock.

Let me return lastly to the theme of bureaucratism that I opened with, because it is really a very interesting feature, a characteristic of Chinese civilization which made it quite different from all others in those ancient times. One might say that the majority of the observers who thought and calculated and wrote about astronomical problems through 2000 years were in State service. They were organized in a special department of government, the Astronomical Bureau or Directorate, which went by various different names. The most ancient title of the Director was Thai Shih Ling, and although we have always been very conscious of his astrological function we feel that the true astronomical and calendrical element in the work of his department was amply sufficient to warrant the translation 'Astronomer-Royal'. He did of course have to keep his star-clerks on the watch, every moment of every night, for any unusual developments in the heavens. Celestial phenomena like novae, supernovae, eclipses, comets, meteor streams, sun-spots and all such things were regularly reported to the Imperial Court, because although individual genethliacal astrology came only very late to China, perhaps in

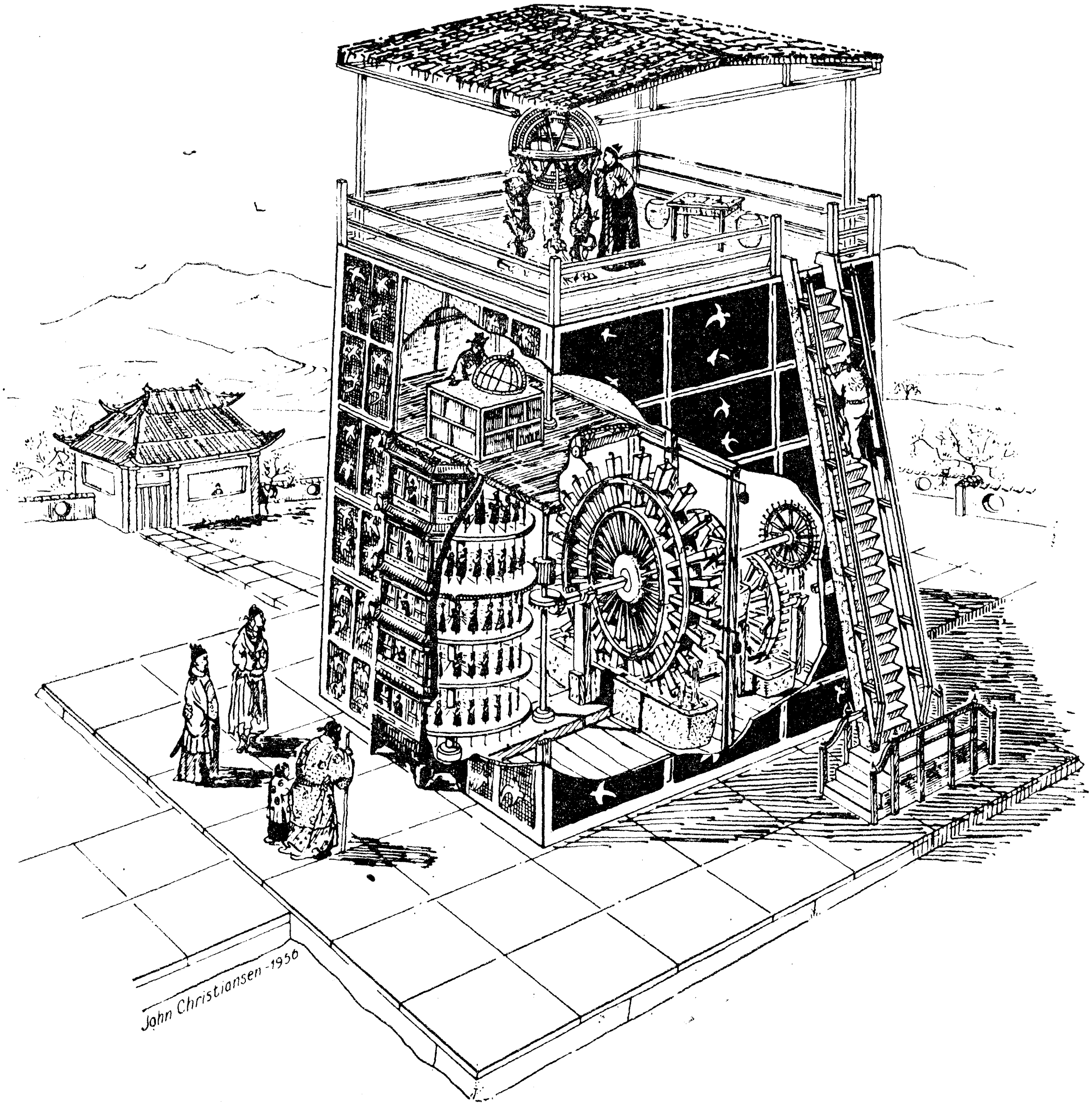

FIGURE 17. Pictorial reconstruction of the Khaifêng clock tower (J. Christiansen). Besides the components already mentioned, the norias which wound up the water back into the tanks are here glimpsed behind the driving wheel.

the Ming, the general belief that 'comets do foretell the death of princes' was a very old Chinese idea. The origin of the Bureau of Astronomy was thus perhaps twofold: the importance of keeping the calendar in order was a very important task, but the watch on the heavens for celestial events was also a strong motive. It is interesting that inauspicious happenings were generally regarded as *chhien kao* or reprimands from heaven, and the emperor or some high official, very often the emperor himself, took the guilt upon him, prayed, fasted and promised to amend. Omens were regarded really as signs of bad government, and there would be trouble if things were not put in order; such was the astrological function of the Bureau over the ages.

One remarkable fact not generally known is that in some periods it was customary to have two observatories at the capital both furnished with armillary spheres, clepsydras and all manner of necessary apparatus. For example, Phêng Chhêng tells us about this in the Northern

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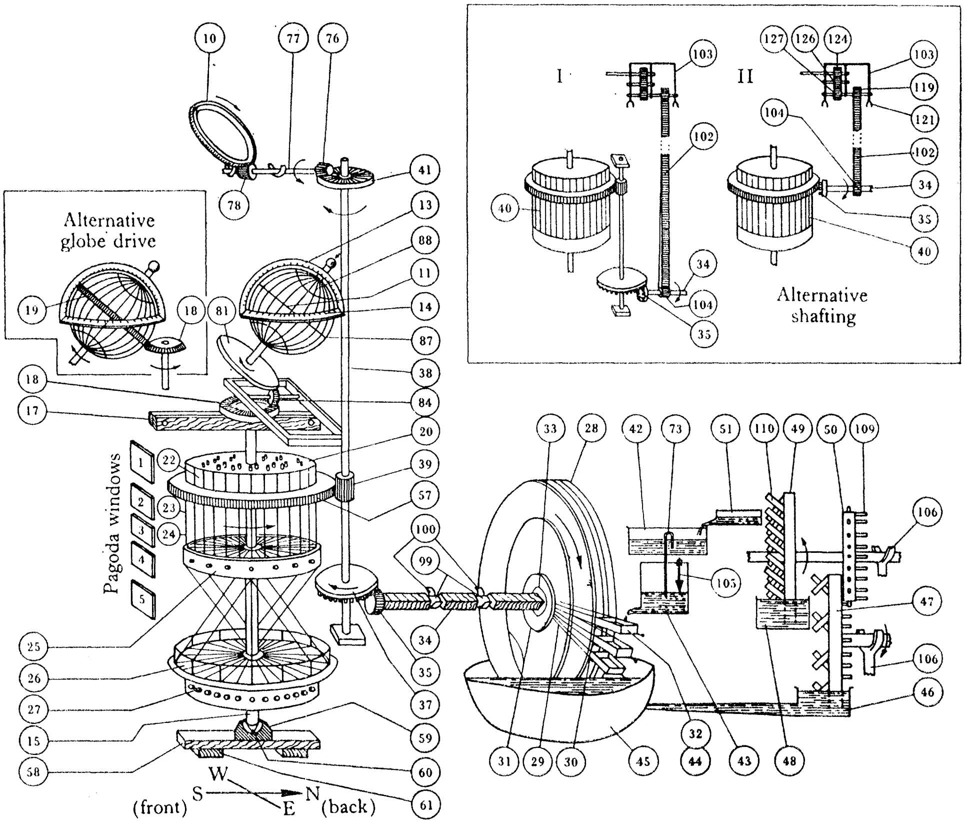


FIGURE 19. Diagram of the power and transmission machinery of the Khaifêng clock tower (J. Needham, L. Wang and D. de S. Price). Norias and tanks on the right, driving-wheel central, then the main vertical shaft (afterwards replaced by successively shorter chain-drives) operating jack-wheels, globe and armillary. For explanation of details see SCC, IV, pt. 2, fig. 652*a*, p. 452.

Sung. The Astronomical Department called the Thien Wên Yuan was located within the walls of the Imperial Palace itself, while the other one, the Directorate of Astronomy and Calendar, the Ssu Thien Chien, presided over by the Thai Shih Ling himself, was outside the walls. The data from the two observatories, especially concerning unusual phenomena, were supposed to be compared each morning and then presented jointly so as to avoid false or mistaken reports.

I have mentioned the grave political significance of celestial events. It is therefore rather interesting to find exhortations to security-mindedness addressed century after century to the astronomical officials. For example, the *Chiu Thang Shu* (Old history of the Thang Dynasty) tells us that in +840: 'in the twelfth month of the 5th year of the Khai-Chhêng reign-period an imperial edict was issued ordering that the observers in the Imperial Observatory should keep their business absolutely secret. "If we hear", it said, "of any intercourse between the astronomical officials or their subordinates, and officials of any other government departments, or miscellaneous common people, it will be regarded as a violation of security regulations which should be strictly adhered to. From now onwards, therefore, the astronomical officials are on no account to mix with civil servants and common people in general. Let the Censorate see to it".' All one can say about that is that there is nothing new about Los Alamos or Harwell, but whether or not the greatest scientific achievements happen under such conditions is another question. And I suppose that even a Galileo and a Priestley had their difficulties with the powers that were.

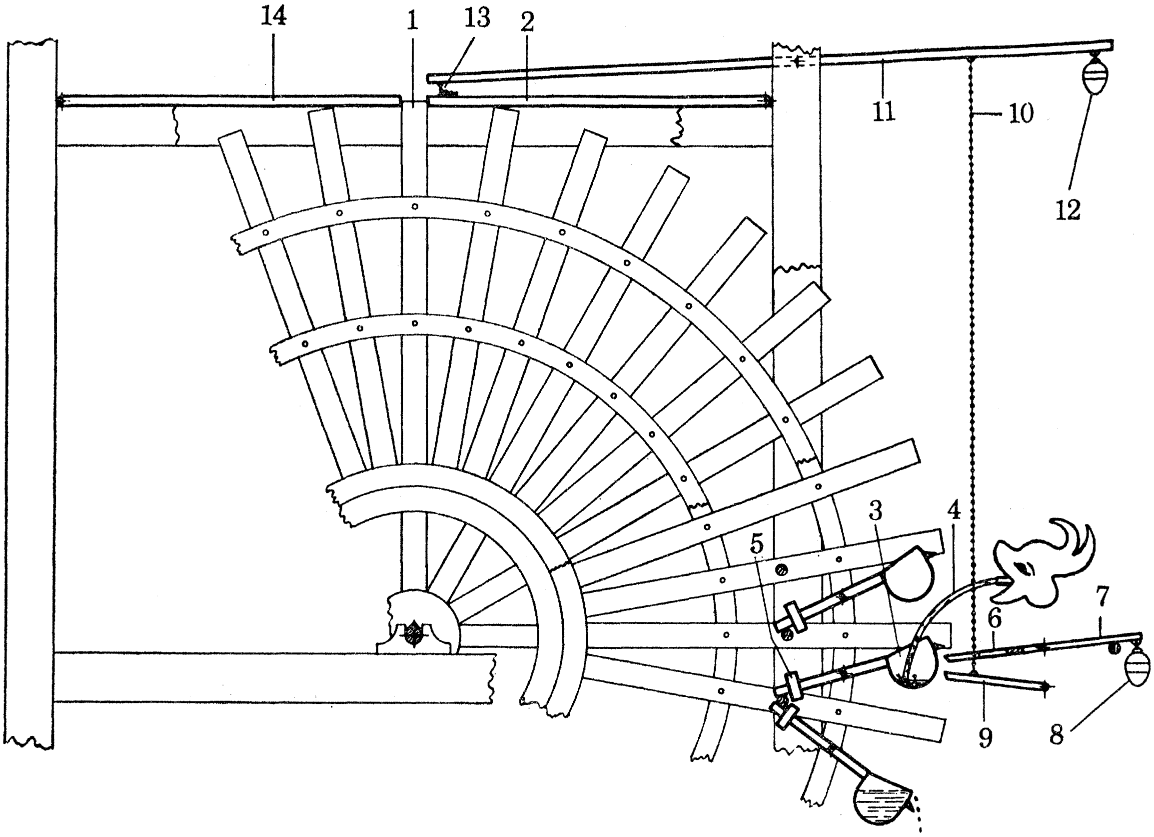


FIGURE 21. Diagram to illustrate the functioning of the hydro-mechanical linkwork escapement (J. H. Combridge). Each scoop bucket on the perimeter of the driving wheel is individually balanced; when it is full it descends, depressing a counter-weighted trip-lever, and operates a chain-and-link connexion which opens a gate at the top of the wheel and allows the next scoop bucket to come into place. One 'tick' took place about every 24 s. For further explanation of details see SCC, IV, pt. 2, fig. 658, p. 460.

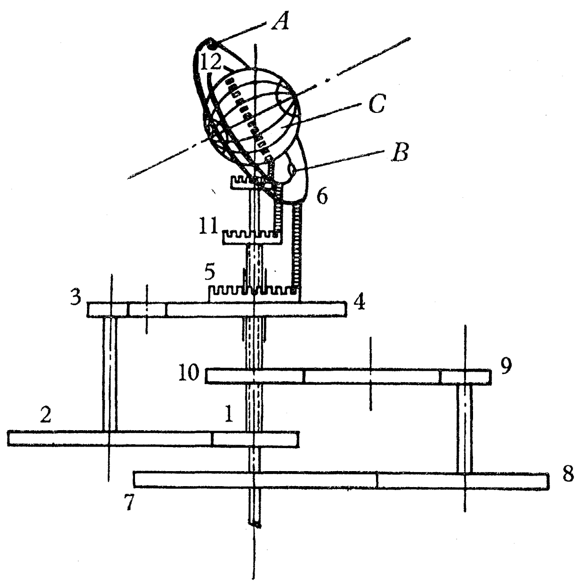


FIGURE 22. Reconstruction of the orrery movement of Chinese hydro-mechanical astronomical clocks (Liu Hsien-Chou). Only the Sun and Moon model movements are shown as well as that for the celestial globe, in a design which would have needed both concentric shafting and gear wheels with odd numbers of teeth. Remaining textual descriptions authorize it, however, for the instruments of I-Hsing (+725), Chang Ssu-Hsün (+979) and Wang Fu (+1124).

Something of what the observatories did has come down to us in extant texts. Records of eclipses start with the Shang oracle-bone material from −1361 onwards, and records of novae from −1300 (figure 23).

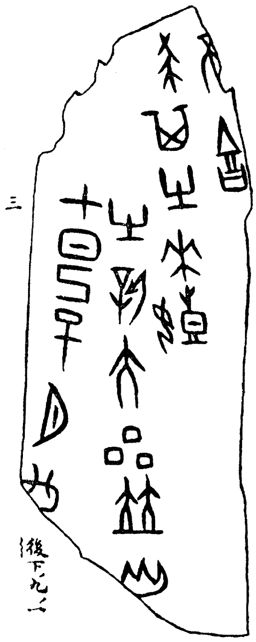


Figure 23. The oldest record of a nova; inscription on an oracle-bone dating from about −1300.

The oracle-bones are of course difficult to interpret, but nevertheless they provide evidence of great importance. As for supernovae, there was the famous one of +1054, the Crab supernova. There has recently been an interesting paper by our collaborator Professor Ho Ping-Yü and others on the difficulties of locating and identifying that exactly. Then there is the abundance of documentation on comets. Figure 24, plate 18, shows a manuscript drawing of a comet passing between two *hsiu* constellations on the night of 28 October +1664; it comes from the Korean archives. For comets in general we have Chinese records from −613 onwards. Recently a very interesting paper appeared by a friend of ours, Dr Chiang Thao, from Dunsink Observatory, on the recurrences of Halley's comet calculated from Chinese records. Finally sun-spots were being sedulously recorded from −28 onwards, a fact which I think would have been a great surprise to Galileo and Christopher Scheiner if they had ever been aware of it. Here there is cause for warm agreement with Dr R. R. Newton, who spoke so interestingly on the usefulness for modern astronomy of studies in ancient records. Almost every month some new paper comes out dealing with something based on Chinese data. There was one the other day about a nova of +363 which may be a radio source and could be identified from these records.

My last remarks must concern cosmologies. The Kai Thien cosmology, with a domical arrangement of the Earth and the heavens, was rather Babylonian, obviously very primitive (figure 25), and did not play much part after the Chhin and Han in China. At this time there was perfected the Hun Thien cosmology, which (as I said) was really the recognition of the great celestial circles. Finally there was the Hsüan Yeh cosmology, which is of greater interest because it maintained that the stars were lights of uncertain origin, floating in infinite empty space, and that the planets and moving stars were carried round in this dark space by some kind

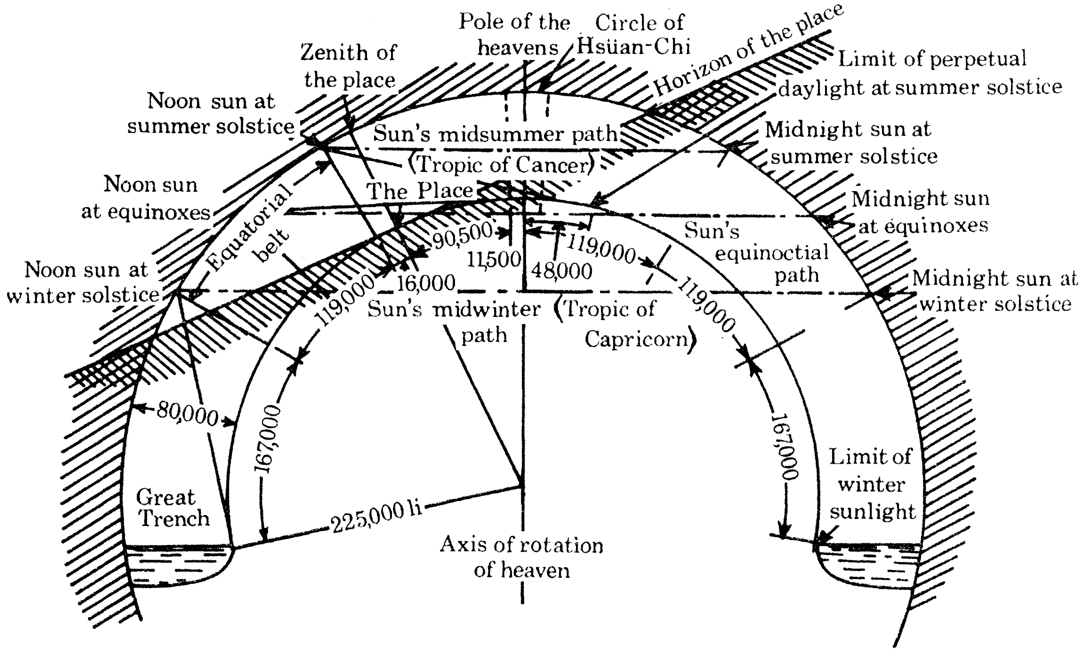
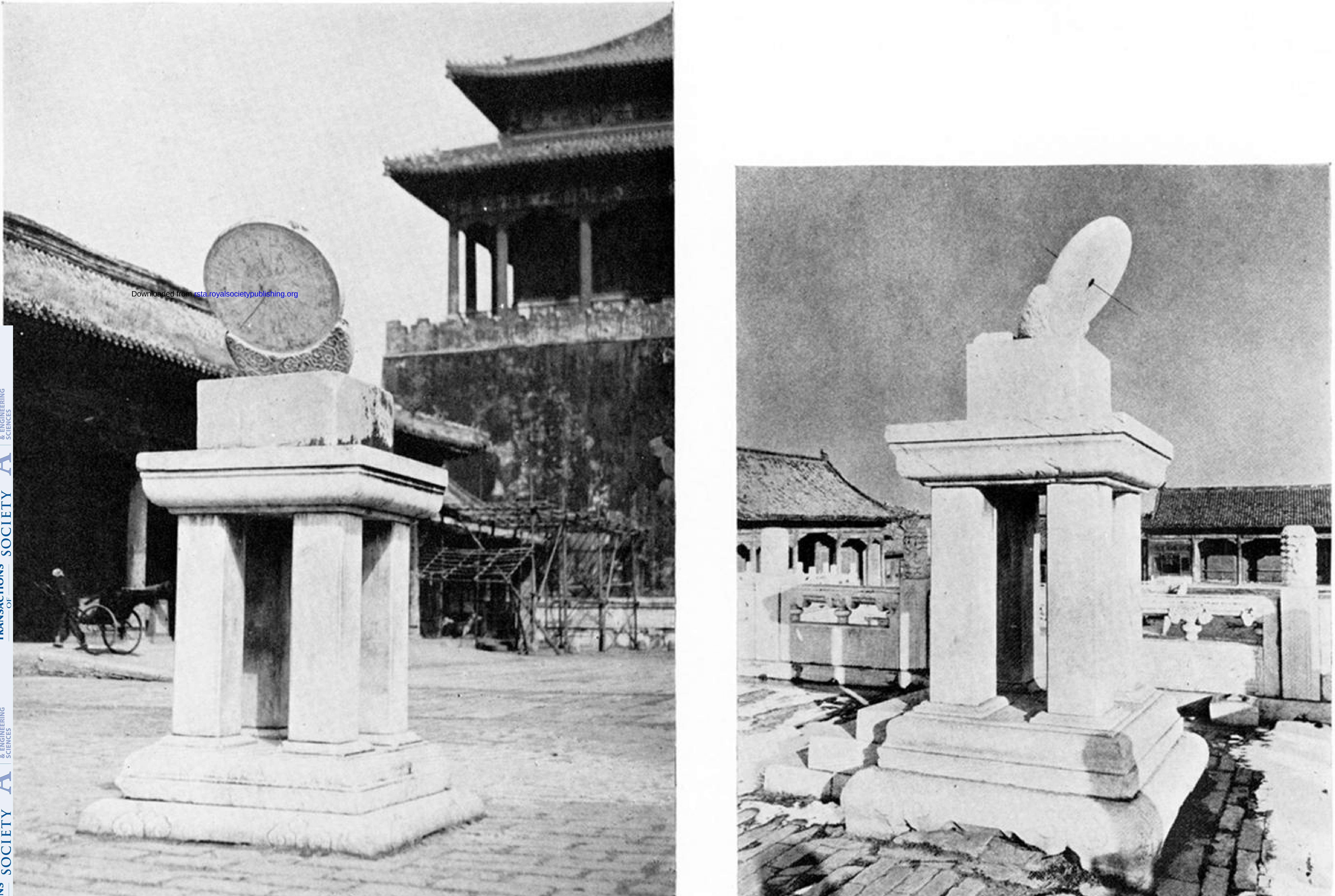


FIGURE 25. The Kai Thien cosmology (Chatley).

of wind. Since Euclidean deductive geometry was not available, no Ptolemaic geometrical model was devised, and all through the ages calendrical calculations were done by algebraic methods, thought about the actual mechanics and geometry of the solar system being laid aside. Recently our collaborator Professor Nathan Sivin has studied how this preference came about, in his interesting monograph 'Cosmos and Computation in Chinese astronomy'. Perhaps that preference was again a Babylonian characteristic. In any case the Hsüan Yeh theory was rather modern and long before its time. One could say that if the Chinese had no Euclidean geometry they had no crystalline celestial spheres either, so they did not have to break out of them at the time of the Renaissance; and it may even be that a knowledge of the Chinese conceptions helped Giordano Bruno, William Gilbert and Francis Godwin to take this great step themselves.

To sum it all up, Chinese astronomy cannot be neglected by anyone who seeks for an oecumenical account of the development of human knowledge of the starry firmament and our own place within it. It is all the more important on account of its extreme originality, influenced indeed a little by Babylonia and India, but unlike the latter culture highly independent of those Greek and Hellenistic discoveries which had so wide-ranging an influence everywhere west of Turkestan.

NOTE: The romanization system adopted in this paper is that of Wade-Giles, with the substitution of an *h* for the aspirate apostrophe. Full documentation, with Chinese characters, will be found in *Science and Civilization in China* (7 vols., Cambridge, 1954–), herein abbreviated as SCC.



(a) (b)

FIGURE 2. Typical Chinese equatorial sundials in the Imperial Palace at Peking. (*a*) Outside the Wu Mên Gate (photo. A. R. Moore, *ca.* 1925). (*b*) On the platform of the Thai Ho Tien Hall (photo. Sirén, *ca.* 1910).

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FIGURE 4. The Moon passing through a constellation; from a Szechuanese moulded brick of Han date (from Wên Yü). The moon disk shows a toad under a tree (a legendary consequence of the lunar crater markings, etc.), and is borne along by a feathered and winged genius. The constellation is drawn in the usual ball-and-link convention.

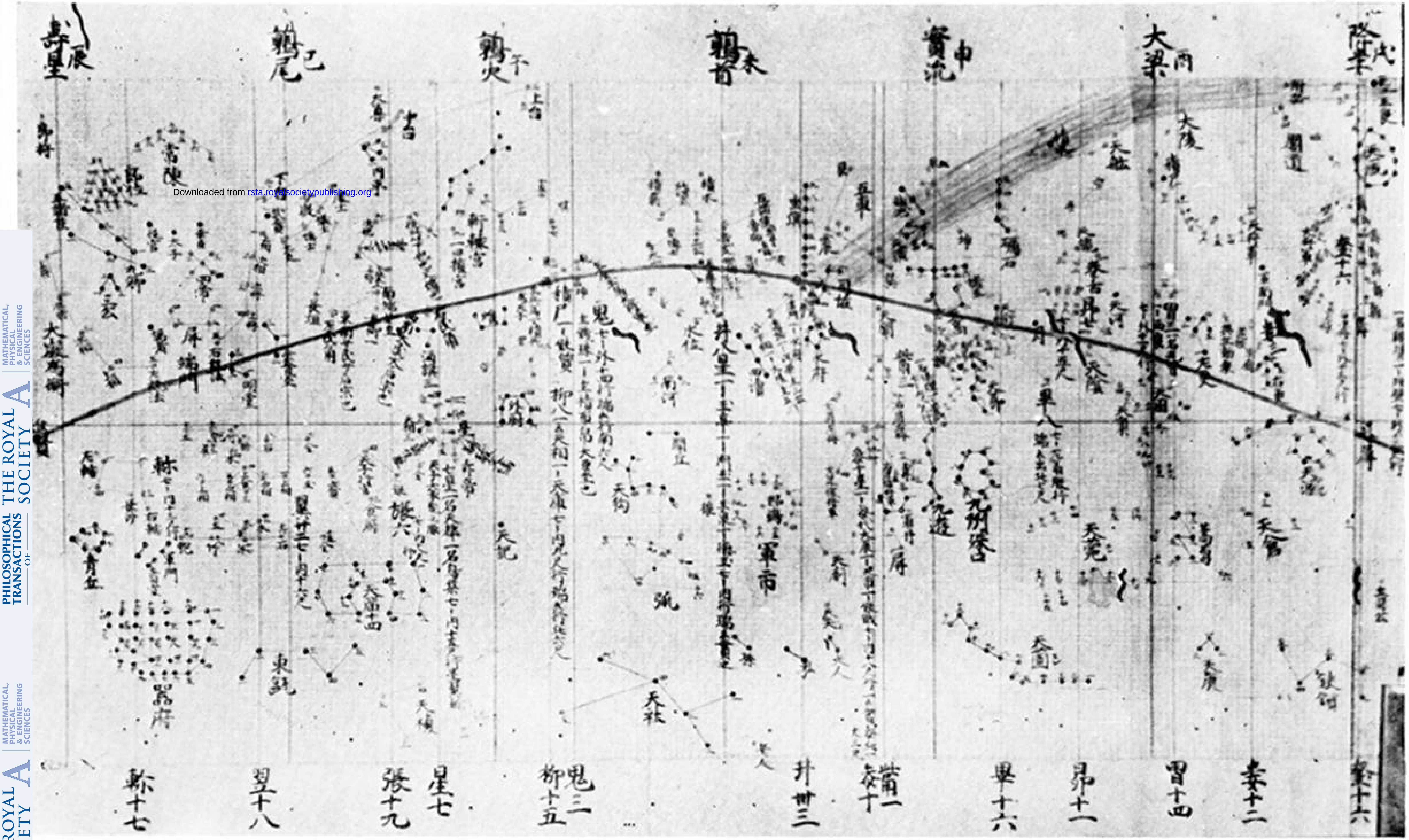

FIGURE 7. The same hemisphere as in figure 6, with the equator again horizontal and central, and the *hsiu* divisions and constellations shown, as before, on a 'Mercator's' projection; from a MS. star map *Kōshi-gettshin-zu* formerly preserved in Japan (Imoto Susumu). Many similarities with the preceding figure will be apparent, but the drawing has been done on squared paper for greater accuracy. Perhaps the original was more likely Sung than Thang.

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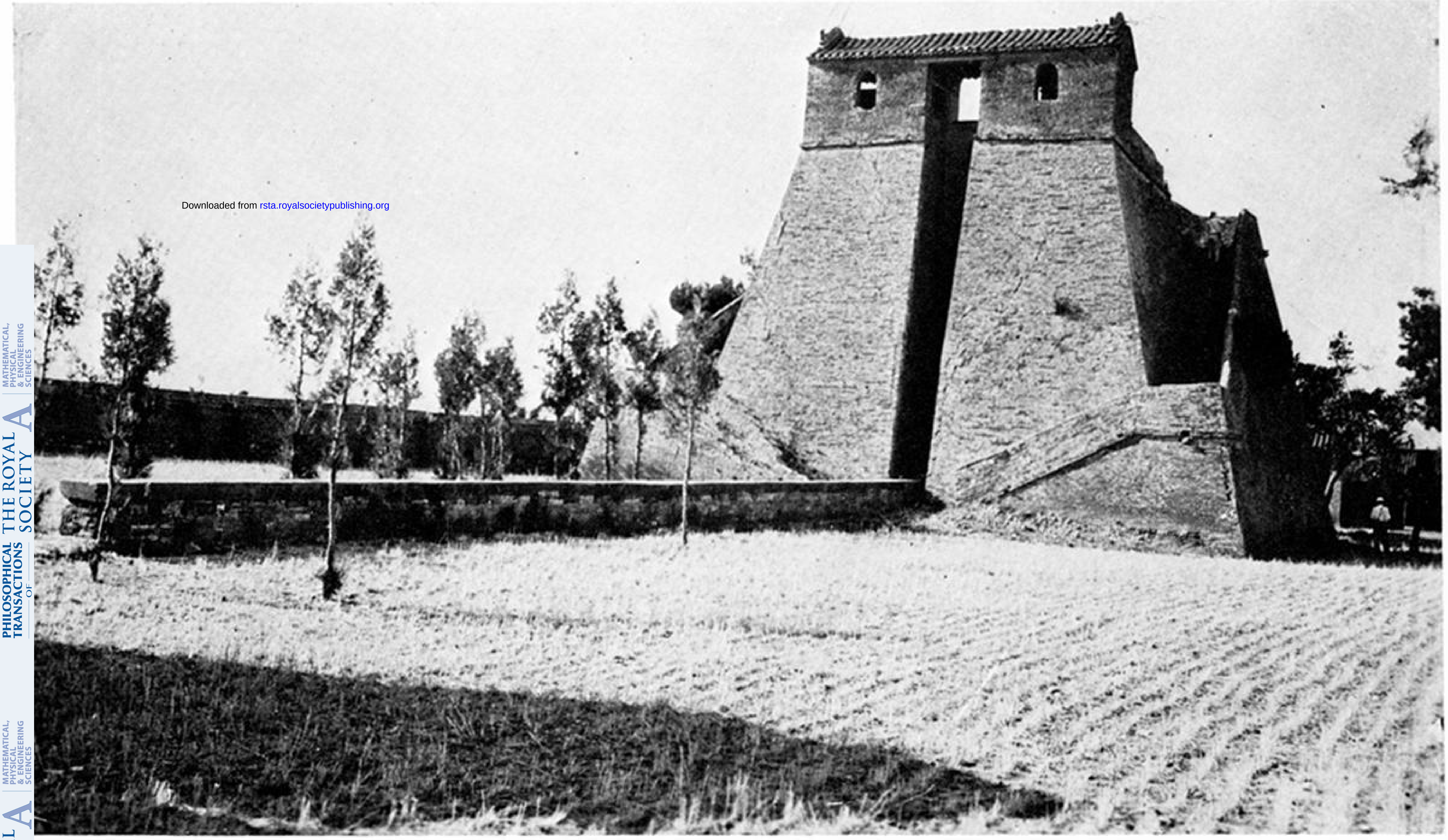

FIGURE 9. The Tower of Chou Kung for the measurement of the Sun's solstitial shadow lengths at Kao-chhêng (formerly Yang-chhêng), some 80 km southeast of Loyang, and for many centuries the site of China's central astronomical observatory. The present structure is a Ming renovation of the instrument built by Kuo Shou-Ching about +1276. The 12 m gnomon stood up in the slot, and its shadow was measured along the stone scale projecting on the left, with special arrangements to secure a sharp edge reading. One of the rooms on the platform housed a clepsydra (perhaps a hydro-mechanical clock), and the other probably an observational armillary sphere.

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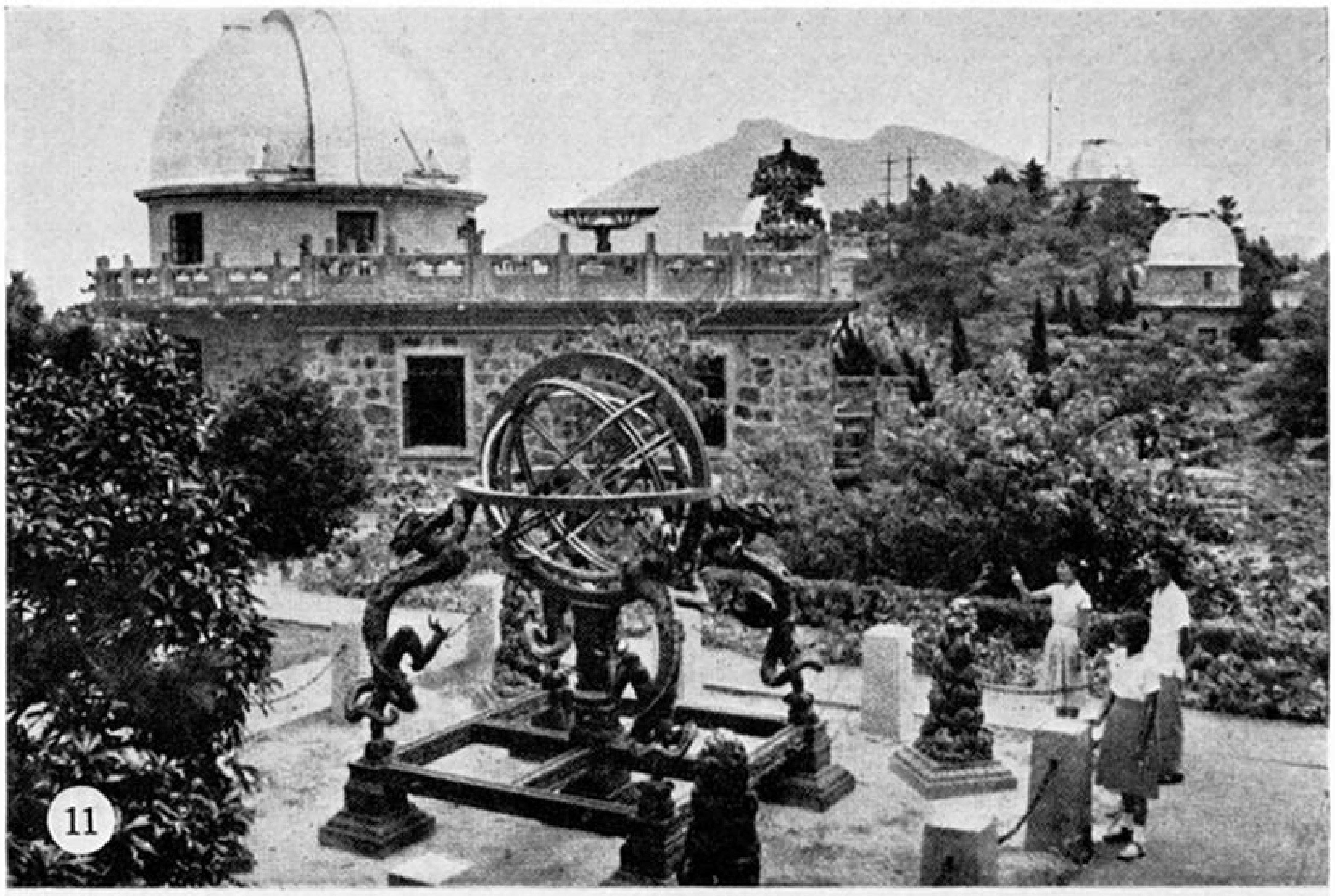

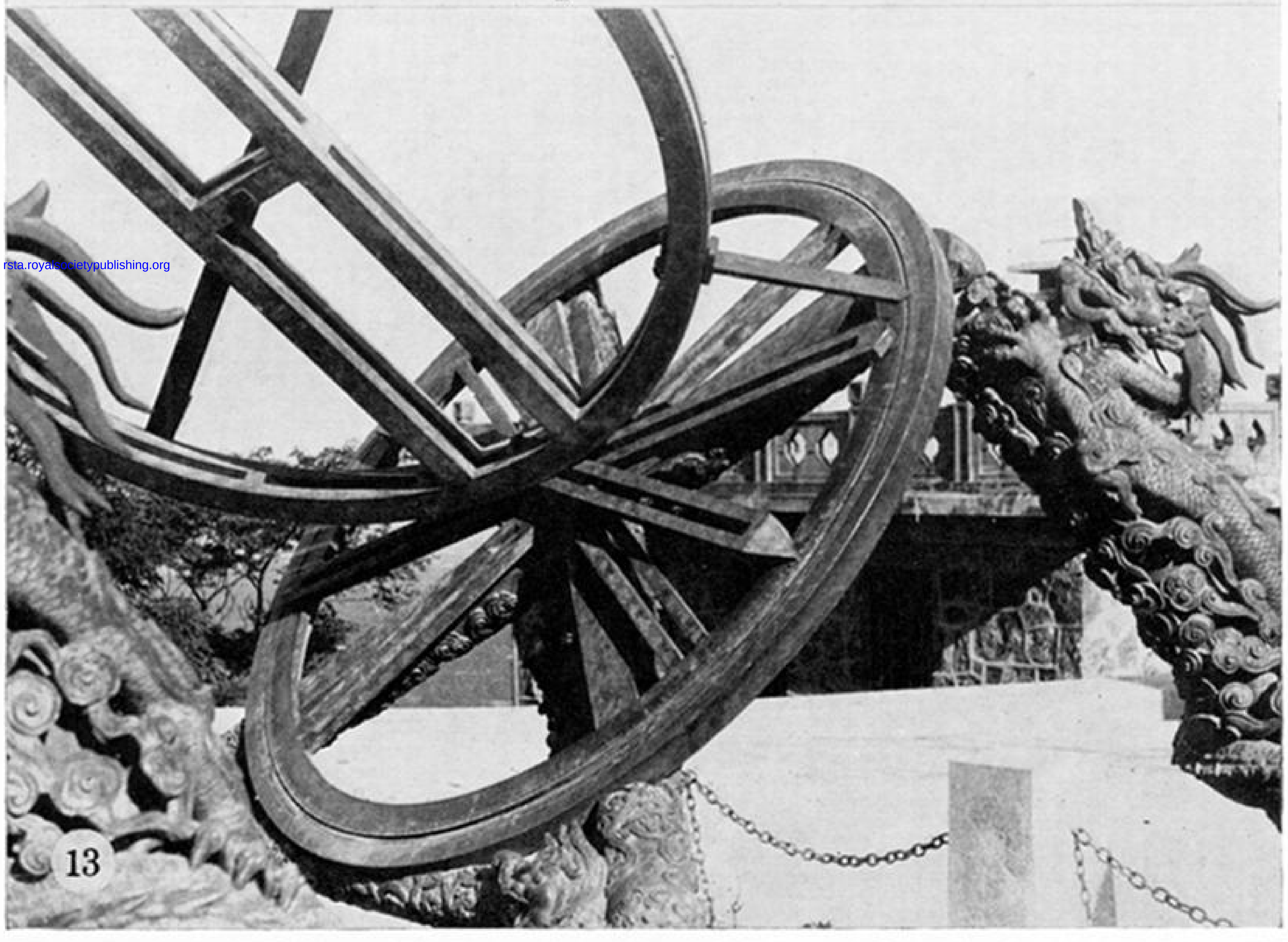

FIGURE 11. The equatorial armillary sphere of Kuo Shou-Ching (*ca.* +1276), now preserved in the grounds of the Purple Mountain Observatory, Nanking.

FIGURE 12. Kuo Shou-Ching's 'equatorial torquetum' (*chien i*, simplified instrument), precursor of all telescope equatorial mountings, in the grounds of the Purple Mountain Observatory, Nanking. Like the armillary sphere in figure 11, this instrument may be one of the identical replicas cast by Huang-Fu Chung-Ho in +1437 (orig. photo., 1958).

FIGURE 13. Detail view of part of the instrument shown in figure 12 (orig. photo., 1958). The bronze mobile declination split-ring or meridian double circle carrying the sighting-tube is well seen. Below, the fixed diurnal circle, and the mobile equatorial circle, with movable radial pointers probably used to demarcate the boundaries of *hsiu*.

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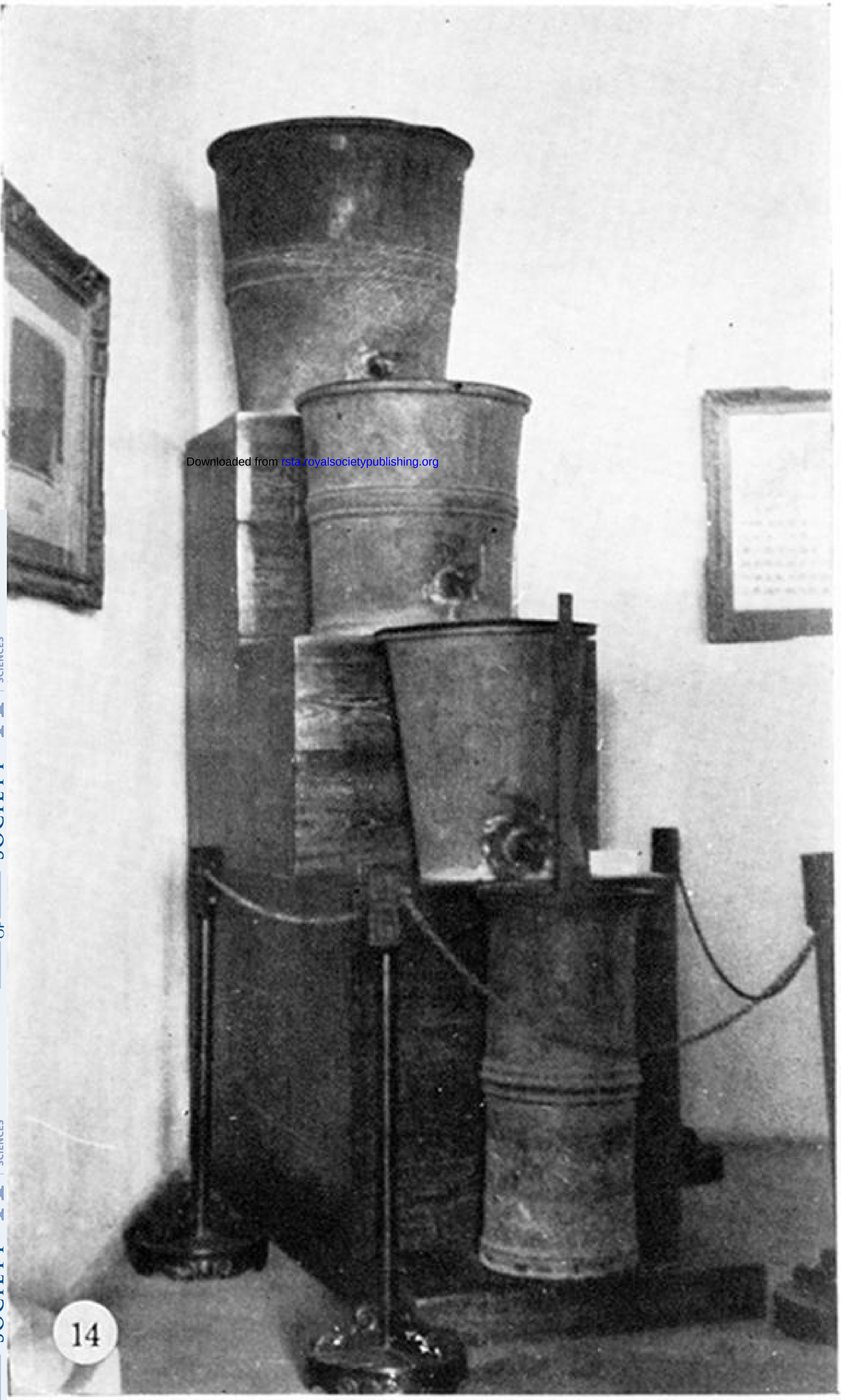

IGURE 14. The famous polyvascular inflow clepsydra at Canton made in the Yuan dynasty (+1316) by Tu Tzu-Shêng (orig. photo., 1958).

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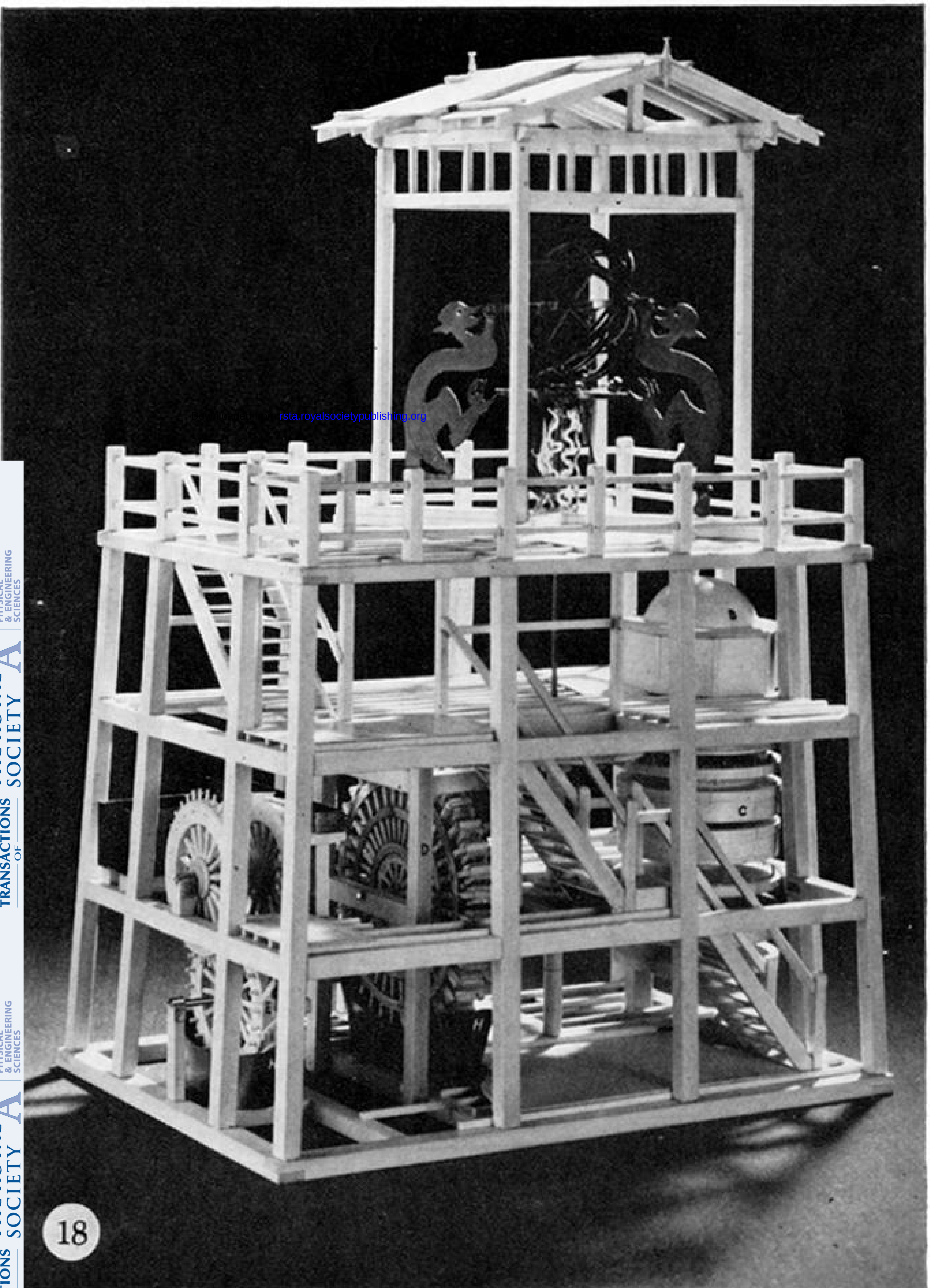

FIGURE 18. Model of the Khaifêng clock tower in the Science Museum at South Kensington (J. H. Combridge). Here it is seen from the back and right.

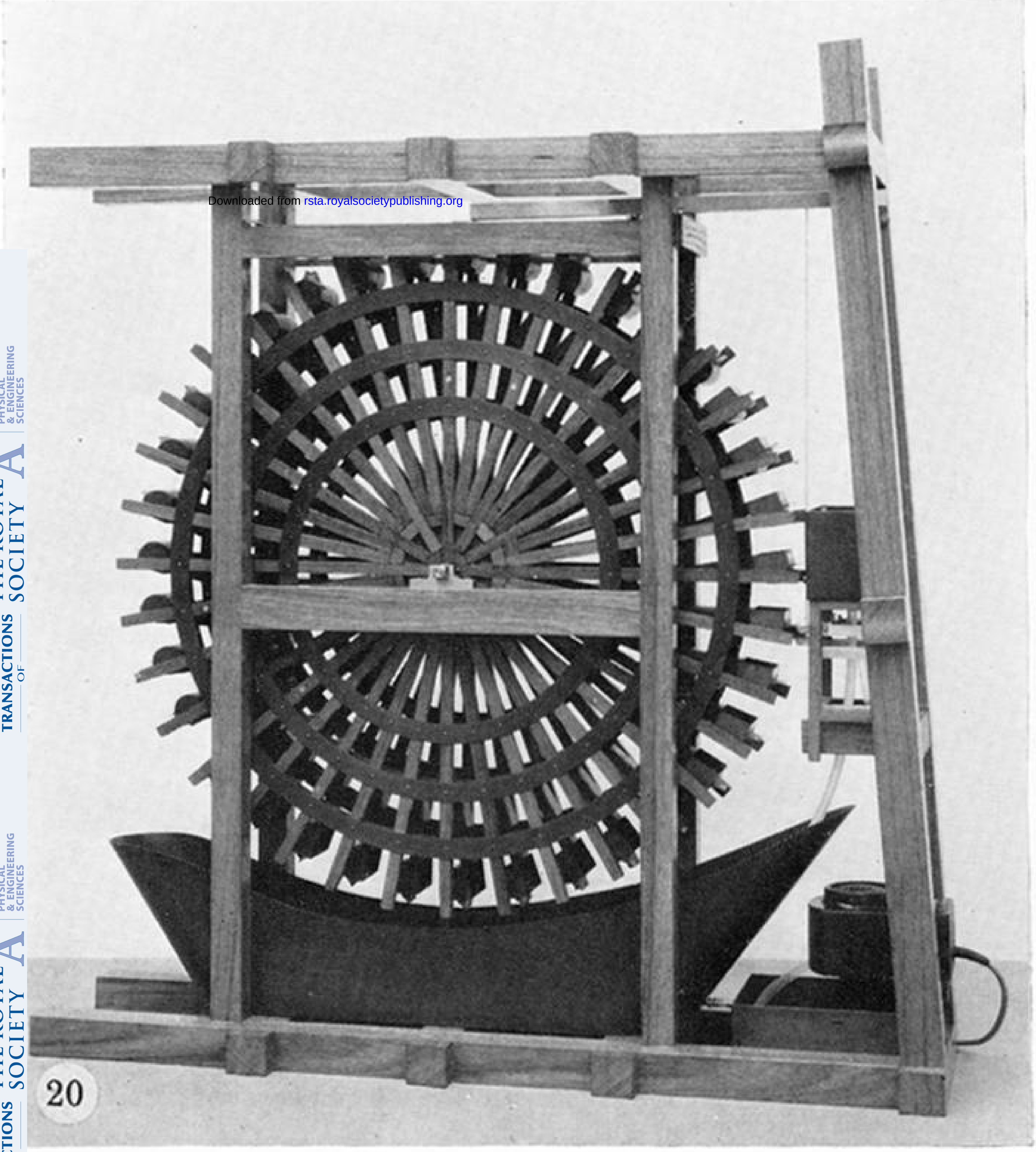

FIGURE 20. Working model of the hydro-mechanical escapement of the Khaifêng clock tower in the Science Museum at South Kensington (J. H. Combridge).

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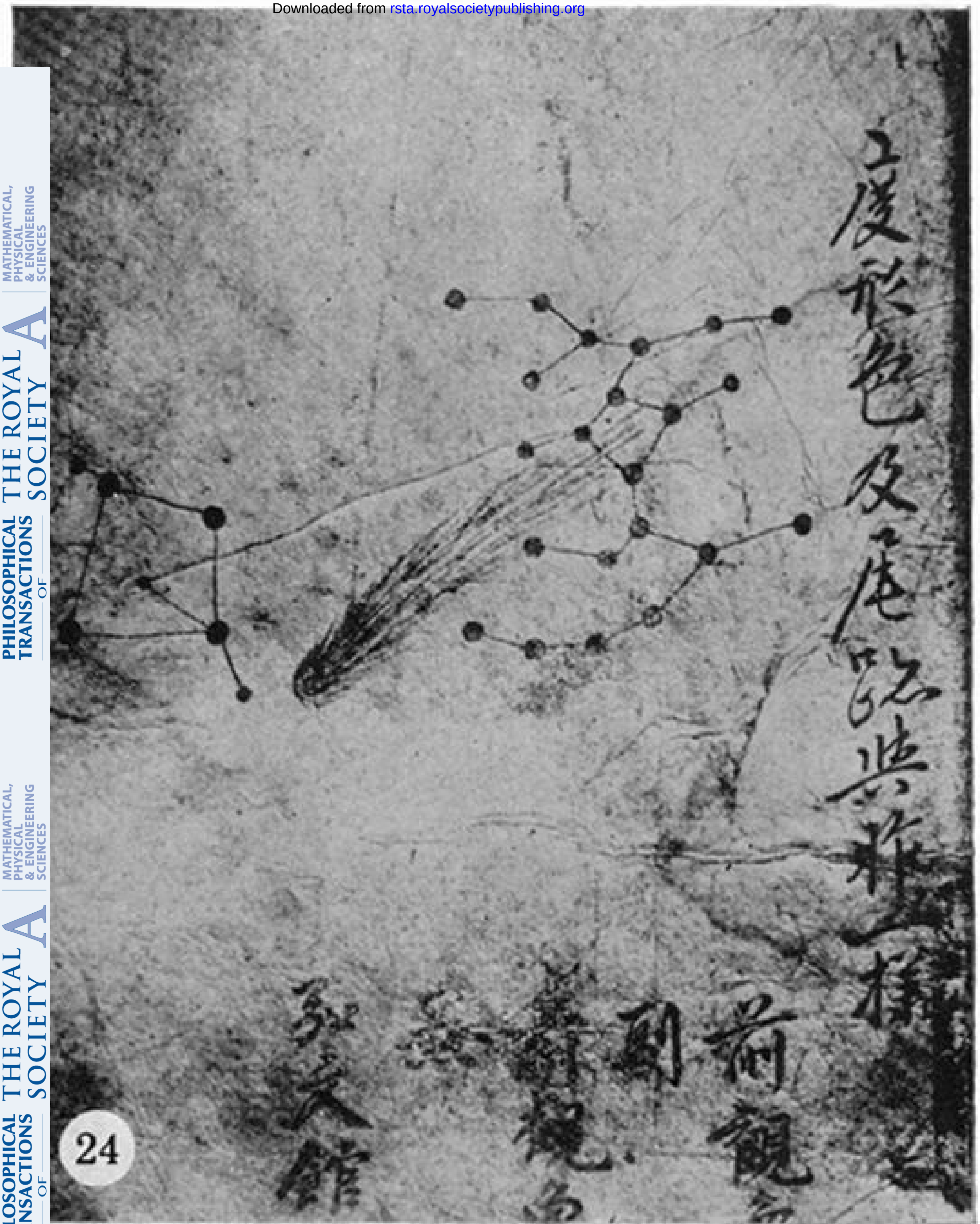

FIGURE 24. A comet of +1664, from the Korean astronomical archives (Rufus).

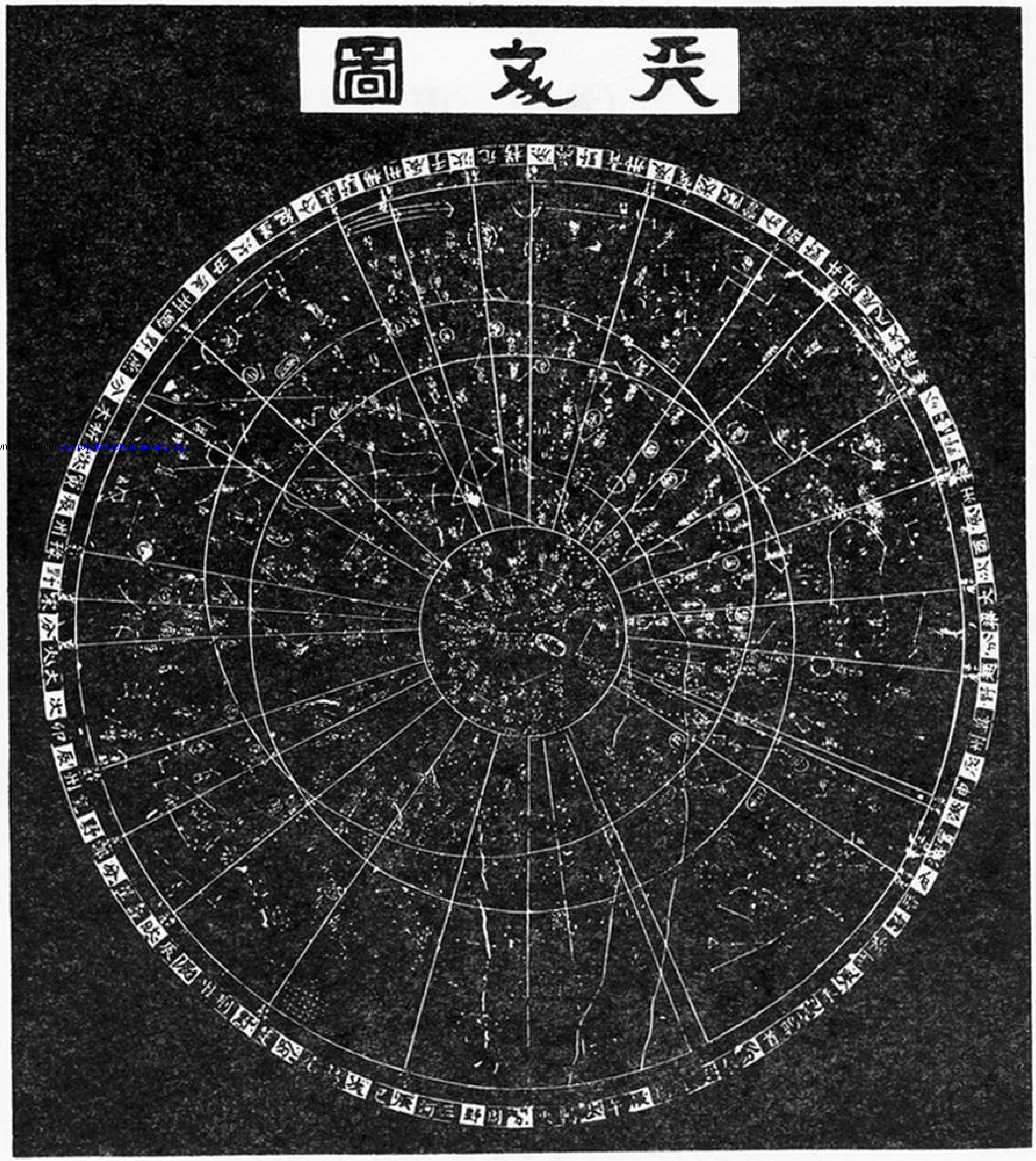

Figure 8. The Suchow planisphere of +1193 (Rufus & Tien). Note the excentric ecliptic and the curving course of the Milky Way (*thien ho*, the river of heaven). The map with its explanatory text was prepared by the geographer and imperial tutor Huang Shang, and committed to stone by Wang Chih-Yuan in +1247.

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