religions

MDPI

Article

The Astronomical Innovations of Monk Yixing 一行 (673–727) †

Jeffrey Kotyk

Department of Asian Studies, The University of British Columbia, Vancouver, BC V6T 1Z4, Canada; jeffrey.kotyk@ubc.ca

† A draft of this paper was presented at the conference "Buddhism & Technology: Historical Background and Contemporary Challenges" at the University of British Columbia in Vancouver, BC, Canada on 20 September 2019.

Abstract: The Chinese monk Yixing 一行 (673–727) is unique in being an early architect of the Mantrayāna tradition (Esoteric Buddhism) in East Asia in addition to featuring as a significant individual within the history of astronomy and calendrical science in China. His legacy in the Buddhist world is well known, but the enduring appreciation of his scientific work in later centuries is less understood. The present paper will document the achievements of Yixing's work in astronomy while also discussing the perception and appreciation of his work in subsequent centuries.

Keywords: Yixing; Buddhism; astronomy; calendars; monks

1. Introduction

Yixing 一行 (673–727) is a well-known figure within the history of East Asian Buddhism. His lineage affiliations include Chan in China, and Zen and Mikkyō in Japan. He is also known for his work in astronomy and calendrical science. Research in Buddhist Studies concerning Yixing has generally focused on his Buddhist career, but non-Buddhist sources from the medieval period also provide ample details regarding his work in astronomy. These sources reveal that Yixing not only made an enormous contribution to Chinese science, but also that his work was positively evaluated and appreciated by Confucian writers throughout many subsequent generations. We will explore some of these sources to highlight the significance of Yixing in the history of Chinese science.

Kim observes that "during the Ming, many Confucian scholars were drawn towards the study of calendrical astronomy, long before the Jesuits' introduction of Western astronomy aroused interest in the subject."[1] Yixing's work was indeed part of the corpus of astronomical literature appreciated by Confucian scholars. As I will show below, Yixing was widely read for a whole millennium until Chinese astronomy was transformed following the introduction of European astrology during the seventeenth century. Yixing's status as a monk and his simultaneous excellence in the field of astronomy definitely calls into question some of Needham's remarks, such as his proposal that Buddhism in China was "inimical to carrying out scientific research" and that the epistemology of Buddhism—often focused on the impermanent and tenuous quality of perceived phenomena—made "Buddhism irreconcilable with Taoism and Confucianism and tragically played a part in strangling the development of Chinese science."[2] It has already been shown that, in fact, Buddhism in China neither hindered nor particularly encouraged astronomy, but rather the Chinese sangha was simply more of a passive recipient and consumer of Chinese science, in light of the careers of certain monks during the Tang period.[3] Buddhists also had a long heritage of astrology and calendrical science in India and China, which requires reference to astronomy and calculation (Kotyk 2018a, 2018c). Our main concern here, then, is to discuss how Yixing impacted the development of Chinese astronomy and how he was remembered in later sources, both Buddhist and non-Buddhist, rather than to revisit old ideas about Buddhism and science. Instead, I want to demonstrate that Yixing compartmentalized his

check for updates

Citation: Kotyk, Jeffrey. 2022. The Astronomical Innovations of Monk Yixing 一行 (673–727). *Religions* 13: 543. https://doi.org/10.3390/rel13060543

Academic Editors: Jinhua Chen and Kai Sheng

Received: 6 May 2022
Accepted: 8 June 2022
Published: 13 June 2022

work in astronomy from Buddhism, and later writers similarly treated his writings in the same manner.

This study will also argue that we can utilize materials from Buddhist sources, as well as those of the court and other non-Buddhist authors, to grasp Yixing's career in astronomy from a multifaceted angle. We might evaluate how his work was recognized and appreciated within the native Chinese history of astronomy. This approach of comparing and contrasting texts from court (i.e., "Confucian") and Buddhist authors has been gainfully employed in the past, and here I employ this same methodology in relation to Yixing's career in astronomy.[4] Building on the work of past scholars, I will also show how Yixing utilized technological innovation to create a more precise system of tracking planetary movements as a brief example of how his work impacted the development of Chinese astronomy. This study will further show how Yixing represents a rare example of a Buddhist monk engaging in the development of scientific astronomy during the medieval period. I will draw attention to some significant details of his work while also showing its relevance—or lack thereof—to his other career as a Buddhist monk and author.

2. Historical Background

Past studies have documented and analyzed the biographical accounts of Yixing and his ancestry. In an earlier study, I argued that we ought to understand the "historical Yixing" as a separate figure from a later reimagined pseudo-Yixing. The latter is a legendary figure to whom various texts and practices were attributed, starting from around the early ninth century. Some modern scholars and virtually all premodern authors have conflated these two figures. This has led to problematic chronologies of Yixing's life and his activities.[5] Again, I will emphasize in this study that we ought to distinguish between Yixing and pseudo-Yixing.

Our reconstruction of Yixing's work in astronomy depends upon several premodern sources. First is the *Jiu Tang shu* 舊唐書 (*Old Book of Tang*), which is a history of the Tang dynasty produced by Liu Xu 劉昫 (887–946) in 945. We can also utilize the *Xin Tang shu* 新唐書 (*New Book of Tang*). This revised history of the Tang dynasty was compiled in 1060 by Ouyang Xiu 歐陽修 (1007–1072) and Song Qi 宋祁 (998–1061), who apparently intentionally omitted Yixing's biography, perhaps due to anti-Buddhist biases and animosity toward the *saṃgha*, yet they still added documents related to Yixing's calendar, which they treated with respect. This indirectly points to an appreciation of his achievements in astronomy, despite the fact that he was a Buddhist monk. The *Tongdian* 通典 (*Comprehensive Account*), compiled in 801 by Du You 杜佑 (735–812), provides details about Yixing's astronomical projects. The *Tongzhi* 通志 (*Comprehensive Chronicle*), compiled in 1161 by Zheng Qiao 鄭樵 (1104–1162), lists a number of works—genuine and spurious—attributed to Yixing that were extant during the twelfth century. One of the more underappreciated sources on the history of astronomy and calendrical science in China is the voluminous *Gujin lüli kao* 古今律曆考 (*Study of Ancient and Present Tunes and Calendrical Sciences*), comprised of seventy-two fascicles, by Xing Yunlu 邢雲路 (1549–?). This text documents at length such sciences as they were understood during the late Ming dynasty prior to the introduction of European science. This work frequently mentions Yixing and his work, a point that highlights the utility and importance of his writings, even outside the Buddhist fold, some nine centuries after his death. The fact alone is highly significant, given that Yixing is arguably the sole Buddhist monk in China to have been afforded such enduring respect both in Buddhist and Confucian circles.

In brief, Yixing was born in 673. Although traditional sources give 683 as his year of birth, Chen (2000) in his study of Yixing's life and genealogy convincingly demonstrates that 673 was more likely. The historical record relates that Yixing initially studied Chan Buddhism under the monk Puji 普寂 (651–739). Yixing was simultaneously a scholar of the monastic codes (Vinaya, *jielü* 戒律). He became well-known to eminent persons in the capital, but evaded invitations to present himself there, until finally in 717 he accepted an official summons from the court.[6]

Yixing's career in the capital (alternating between Chang'an and Luoyang), which lasted until his sudden death in 727, was fruitful and primarily comprised two directions. First, Yixing assisted the Indian monk Śubhakarasiṃha (Shanwuwei 善無畏; 637–735) in translating the *Vairocanābhisaṃbodhi* (*Dari jing* 大日經; *T* 848), which was completed in 724. Yixing appears to have functioned more as an editor in this project, rather than as a translator (although he is credited as translator), in light of the absence of evidence that would indicate he capably understood Sanskrit enough to translate it. There are actually few examples of monks from East Asia who capably read Sanskrit in the premodern period, apart from figures such as Xuanzang, who had spent years abroad in India.[7] The Chinese translation of the *Vairocanābhisaṃbodhi* was full of ambiguities, since it was from a newly introduced genre of Buddhist literature which dealt with the practices of *mantras*, *mudrās*, and *maṇḍalas*. Yixing therefore produced a commentary on the text (Dari jing shu 大日經疏; T 1796) based on the oral explanations Śubhakarasiṃha. This commentary in one section addresses the timing of rituals, and briefly explains the conventions of Indian astrology known to Śubhakarasiṃha, which I have argued are likely to reflect the conventions of astrology observed at the major Indian monastery of Nālanda. We can also observe in this section some astronomical theory related to lunar phases, which no doubt was penned by Yixing himself. Based on the overview of Indian astrology in the commentary, it appears that Śubhakarasiṃha certainly had some knowledge on the topic, but he does not appear to have directly affected the development of astrology or astronomy in China. In other words, Śubhakarasiṃha knew some Indian astrology, but Yixing was the astronomer, and his astronomy, as we will see, was chiefly Chinese in character and *not* Indian. Śubhakarasiṃha does not appear to have offered instruction on Indian astronomy (i.e., calculations and measurements).[8]

Yixing was indeed a pioneering figure of Buddhist Mantrayāna in East Asia. He later was enshrined in Japan as a lineage holder in Mikkyō (in both Shingon and Tendai). In contrast to Buddhist histories; however, Confucian historians in China remembered him primarily as an astronomer and reformer of the state calendar. Yixing's early official work in astronomy is recorded in the *Jiu Tang shu*, which reports the following:

> In year 9 of Kaiyuan [721] under Xuanzong, the Grand Scribe repeatedly reported to the throne that (predictions of) solar eclipses were ineffective. The *śramaṇa* Yixing was summoned to reform and produce a new calendar. Yixing's report stated, "Now if we seek to create a calendar and establish an epoch, we must first understand how to convert between the ecliptic (and the celestial equator). I request that the Prefect Grand Scribe take angular and chronological measurements of sidereal parameters." 玄宗開元九年, 太史頻奏日蝕不效, 詔沙門一行改造新曆. 一行奏雲:「今欲創曆立元, 須知黃道進退. 請太史令測候星度.」[9]

It is uncertain where and when Yixing acquired his expertise in astronomy and mathematics, but the court evidently agreed that he was capable, after the Prime Minister Zhang Yue 張說 667–730) elected him as a candidate for this task.[10] This nomination is reported in the *Jiu Tang shu*, which also states, "During the Kaiyuan era [713–741], the monk Yixing was proficient with the calendrical theories of various authors. He said that the *Linde li* (an earlier calendar) had been in use for a long time, and that its solar and sidereal parameters were gradually becoming different." 開元中, 僧一行精諸家曆法, 言《麟德曆》行用既久, 晷緯漸差.[11] This was during a time when Indian—or Sino-Indian—figures were operating at the Chinese court and practicing Indian astronomy. Bagchi (1898–1956) in 1953 already drew close attention to two of these families: the Gautamas and Kāśyapas.[12] One of the most prominent astronomers of Indian heritage at the time was Gautama Siddhārtha or Siddha (Qutan Xida 瞿曇悉達), who in 718 translated the **Navagraha-karaṇa* (*Jiuzhi li* 九執曆) from Sanskrit into Chinese at the request of the throne. This manual of mathematical astronomy provides formulas for accurately calculating a number of celestial phenomena. Whether Yixing ever directly studied under these astronomers is unknown, although he was clearly exposed to their works and was likely to have been inspired by them to some extent. Another Indian astronomer, who appears to have been a contemporary of Yixing, was the monk Kumāra (Jumoluo 俱摩羅). Yixing appears to have cited his theory for predicting solar eclipses.[13] We ought to note that Yixing was not the only monk in China to also have been an astronomer during the Tang period, but Kumāra was not nearly so influential.

Numerous sources, including Yixing's biography in the *Jiu Tang shu*, state that Yixing learnt mathematics from an unnamed individual on Mount Tiantai 天臺山 at the monastery Guoqing-si 國清寺, but this is certainly a fantastical tale, since it also relates that the stream of water outside the temple miraculously changed course after Yixing had fully learnt everything he needed from the unnamed teacher. This story, moreover, does not provide any names or dates.[14] I think it is plausible, if not likely, that Yixing was simply an autodidactic polymath, whose background afforded him the necessary resources, particularly books on mathematics, to become a self-taught astronomer, even in the face of law codes that prohibited the private study of astronomy by commoners, as well as the Buddhist literature that discourages or forbids the practice of mundane sciences, such as astrology and calendrical science.[15]

In any case, the histories of the Tang dynasty relate that Yixing was charged with the task of producing a new state calendar. He was already capable of this task by the year 721. He titled his calendar *Dayan li* 大衍曆. This calendar was officially adopted between 729–761. Yixing died unexpectedly in 727 before he could see his calendar put into operation, but the court appointed officials to consolidate his draft. The *Tongzhi* (*j*. 68) records that the original *Dayan li* was comprised of fifty-two fascicles.[16] The *Xin Tang shu*, however, only preserves an outline of the *Dayan li* (*j*. 27–28) and its important arguments. This is our main source of information on the calendar. Xing Yunlu (*j*. 15–16) gives an extensive discussion of the *Dayan li* with many details, many of which seem to derive from the *Xin Tang shu*. Upon surveying the above materials, it is clear that several specific matters were of importance to Yixing. These included, but were not limited to, the need for accurate understandings of exact solar positions relative to seasonal markers (the equinoxes and solstices), the precession of the equinoxes, and the ecliptic relative to the celestial equator. Yixing also sought to establish an exact definition for the New Moon. We will separately discuss each of these components within his research, but first we should briefly note his innovative use of number theory derived from the *Yijing*.

3. *Yijing* Number Theory

The title of Yixing's calendar reveals its rich relationship with the *Yijing* 易經 (*Classic of Changes*, also called *I Ching* in English). The term *dayan* 大衍 (the "Great Expansion") is derived from a section of the *Yijing* (*xici shang* 繫辭上), in which Heaven is assigned the number 25, and Earth the number 30, together totaling 55, although the 'Great Expansion' is only 50 (there are various ancient theories concerning the subtraction of 5). The number of "application" (*yong* 用) is 49. The number theory derived from the *Yijing* (which is not astrological in character) is expressly stated in the *Li benyi* 曆本議 (*Arguments on the Calendar*), which is a summary of some of the primary arguments of the *Dayan li*. This was compiled after Yixing died prematurely (Yixing died in 727).[17]

In later centuries, during the Ming period, Yixing was still known for his integration of *Yijing* numerology into his calendar. Xin Yunlu (*j*. 16) notes this and reproduces numerous details concerning this development.[18] Kaji suggested that incorporation of this numerology into a calendar simply added perceived value, instead of furnishing any practical advantage.[19] In other words, it appeared innovative, while at the same time quite appreciable to literati, who were steeped in classical lore and metaphysics. An important point to note here is that Yixing utilized a native Chinese framework for crafting his calendar without any express reference to Indian or Buddhist cosmological and metaphysical concepts, although he still consulted some Indian materials, apparently in translation. Gautama Zhuan 瞿曇譔 (712–776), son of Gautama Siddhārtha, the translator of the *Navagraha-karaṇa*, argued in the year 733 that Yixing—who already died in 727—had plagiarized material from the *Navagraha-karaṇa*, although the formal investigation at court determined this claim was false.[20] This conclusion might have been premature, since, in fact, the use of a tangent table was an innovation that suddenly appears in the history of Chinese astronomy, as pointed out by Cullen, and its adoption by Yixing does point to a foreign source. Cullen therefore suggests that Yixing had likely learned the rules for relating gnomon shadows and solar zenith distances from one of his Indian counterparts in the capital. In other words, although his "use of the tangent was original, he ultimately depended on Indian sources for his introduction to trigonometry."[21] Nevertheless, while Yixing certainly understood some amount of Indian astronomy (presumably translated into Chinese), his calendar is primarily rooted in Chinese models and concepts (definition of the ecliptic, sidereal lunar stations based on the ancient Chinese system, etc.).

We might expect that a Buddhist monk such as Yixing would have been inclined to incorporate more Indian concepts into his work, but, in reality, his calendar was chiefly rooted in Chinese calendrical science and metaphysics. There actually was no precedent for adoption of foreign astronomical models until at least some members of the court took an interest in Indian astronomy, which no doubt facilitated the translation of the *Navagraha-karaṇa*, but empirical tests did not yield any positive outcome for the foreign model.

The compartmentalization of science and religion in Yixing's life highlights the clear division of his life into two separate simultaneous careers: one in astronomy and the other in Buddhist practice. Yixing was evidently committed to receiving and building upon a legacy of Chinese astronomy from antiquity, rather than expressly introducing significant Indian models into the Chinese system. He might have even had an impetus to do so, since Mantrayāna calls for the utilization of some amount of astrology, which was based on Indian astronomy, as we see in the *Susiddhikara-sūtra* (Ch. *Suxidijieluo jing* 蘇悉地羯羅經). This was translated by his close colleague Śubhakarasiṃha in 726.[22] Yixing, however, never attempted such a radical reform.

4. Gnomonic Measurements and Precession of the Equinoxes

The *Tongdian* (*j*. 26) relates that in the year 724, Nan Gongyue 南宫說 (d.u.) and others travelled to remote locations within the empire to take gnomonic measurements and report back to the throne. One group went to Annan 安南 (in modern Vietnam), and reported that the star Canopus (*laoren xing* 老人星) was especially high in the sky with numerous other uncharted and unnamed stars visible below it. Ohashi explains that these observations were taken between about 18° N to 51° N, whereas Cullen suggests 29° N to 52° N near the meridian 114° E (Ohashi's proposed range of latitudes is necessary to account for a position in northern Vietnam). This would mean that the Chinese observers did not venture into the southern hemisphere, which would have presented some unfamiliar stars to Chinese astronomers. Ohashi also states that Yixing himself also travelled to take measurements, but the relevant records do not actually suggest that he went on any of these expeditions.[23] After some time, the surveyors returned to the capital. Yixing was tasked with collating and analyzing the data from these various points of observation. He calculated that the distance between the southern and northern celestial poles to be over 80,000 *li* 里 (approximately 44,800 km).[24] To put this into contemporary perspective, Xuanzang wrote that the borders of India are more than 90,000 *li* in diameter.[25] Yixing clearly attempted to work with gnomonic measurements in a scientific manner involving experimentation. As Cullen also notes, the survey of 724 "was a field test, evidently successful, of I-hsing's (Yixing's) method for predicting seasonal shadow lengths at any location."[26] Setting aside how we might critically evaluate the conclusions today, Yixing's project was a success at the time.

The data acquired from these missions included measurements of shadows cast from different locations at the solstices and equinoxes. This set of data was used by Yixing to produce a tangent table. Judging from what is reported in the available sources, it would appear that Yixing's theoretical framework was hampered by the absence of reference to a spherical earth. Yixing would not have been ignorant of this alternate cosmological theory, since the aforementioned *Navagraha-karaṇa*, translated in 718, addresses the concept of terrestrial latitude. This concept was first rendered into Chinese as *suifang yan fa* 隨方眼法 ("method according to the location of the observer"). This appears to be a direct translation of the Sanskrit *sva-deśa-akṣa*, as pointed out by Yabuuchi.[27] One might initially speculate that, as a Buddhist monk, Yixing would have been inclined to preserve the typical Buddhist cosmology of Mt. Meru and the four continents positioned atop a disc-world, but he did not do this.[28] It must be observed that Chinese astronomers also did not adopt a spherical-earth model. Cullen importantly notes that "Chinese astronomers, many of them brilliant men by any standards, continued to think in flat-earth terms until the seventeenth century."[29] Yixing's astronomical framework in the *Dayan li*, drawing from this background, was primarily based on native Chinese models without any reference to Buddhist cosmology, yet curiously when we look to the commentary on the *Vairocanābhisaṃbodhi*, the cosmological worldview is clearly that of Mt. Meru and the four continents, i.e., the traditional Indian Buddhist cosmological worldview. For example, "The body of the Sun is one, but the divisions of time are each different for the four continents." 日体是一而四洲時分各異. Elsewhere we read, "These four continents also each have two flanking continents." 此四洲又各有二隨州.[30] This is, however, as much the voice of Śubhakarasiṃha as it is that of Yixing.

The aforementioned gnomonic measurements would have indicated to Yixing that determining the exact time of the solstices and equinoxes required reference to the point of observation, rather than using any single standardized number or sidereal position of the Sun. The sidereal position of the Sun at the equinoxes and solstices was also an issue that had to be addressed, since fixed stars move at a modern rate of one degree every 71.6 years.[31] This is called the precession of the equinoxes or, more commonly in modern times, axial precession. In practice what this means is that an observer would eventually notice that the Sun rises at the winter solstice (and other seasonal markers) into the preceding degree relative to what was observed in previous eras. This was already recognized well before Yixing's time. Xing Yunlu (*j*. 2) explains Yixing's contribution in history to the understanding of precession as follows:

> During the late Han, Liu Hong [c. 129–210] first realized that the winter solstice was late. During the Jin, Yu Xi [281–356] treated the sky as the sky and the seasonal year as the seasonal year (i.e., separately treating sidereal and seasonal parameters), producing a theory for calculating the differences in order to track the changes (between sidereal positions and seasonal markers), assuming that the Sun retreats one degree every fifty years, but this was erroneous. During the Song, He Chengtian [370–447] doubled that number, assuming a (solar) retreat of one degree every century, but again this was erroneous. During the Sui, Liu Zhuo [544–610] took the numbers from both schools, and assumed a (solar) retreat of one degree every seventy-five years. During the Tang, the monk Yixing calculated his *Dayan* calendrical system, and assumed a difference of one degree (between seasonal markers and sidereal positions) every eighty-three years. Each (theory) was close to one another. Guo Shoujing [1231–1316] calculated that the winter solstice was at the tenth degree of lunar station Qi. This was precise, but Shoujing thought that a difference of one degree every 66 years is also not a definitive theory. 漢末劉洪, 始覺冬至後天, 至晉虞喜, 乃以天為天, 歲為歲, 立差法以追其變, 約以五十年日退一度, 然失之過. 宋何承天, 倍增其數, 約以百年退一度, 又失之不及. 隋劉焯, 取二家中數以七十五年退一度. 唐僧一行推大衍曆, 以八十三年差一度. 各亦相近. 至郭守敬, 推冬至在箕十度, 斯為密近, 然守敬謂六十六年差一度亦非定法.[32]

There was clearly a persistent awareness over the centuries that revisions were necessary and desirable to determine the rate of the precession of the equinoxes. Each figure came to their own conclusions based on the data sets available to them, a fact that highlights that innovation was appreciated (rather than dogmatic adherence to the models of antiquity). Yixing contributed to this ongoing dialogue in history, thereby securing for himself a notable position in the history of Chinese astronomy.

Yixing's theory that the Sun retreats one degree every 83 years effectively constitutes a signature of his work that reappears elsewhere in the historical record, such as the table of 24 solar terms (*jieqi* 節氣) in the *Qiyao rangzai jue* 七曜攘災決 (*Secrets of the Seven-Planet Apotropaism*), a Buddhist manual of horoscopy and astral magic that was compiled between 806–865 from disparate sources.[33] This is an example of Yixing's work being directly utilized within early Chinese horoscopy. The 24 solar terms are each comprised of 15 days. They track the passage of the Sun through sidereal degrees of the 28 "lunar stations" or "lodges" (*xiu* 宿), and most importantly mark the seasons; hence the solstices and equinoxes are part of this system.[34] Simplified degrees are used because the table tracks 360 days in which the Sun progresses 1 degree every day. The ecliptic in China was generally treated as comprising 365.25 degrees (the nominal length of a tropical year), but the table does not address the remaining degrees, so the positions provided in the table are approximate.

With regard to the table of solar terms in the *Qiyao rangzai jue*, the text states, "There will be a difference of a degree or two if you rely upon this (table). It was calculated for after Kaiyuan 12 [724]. There occurs an error of one degree following eighty-three years." 若依此即差一兩度,從開元十二年向後計,滿八十三年即差一度.[35] This would indicate a connection to Yixing's model. We can cite additional evidence in support of this claim. The winter solstice (*dongzhi* 冬至) falls upon degree 9 of the station Dou 斗 in this table of solar terms. The account of the *Shoushi li* 授時曆, a state calendar which was implemented in 1281, is found in the *Yuanshi* 元史 (*j*. 52), the dynastic history of the Yuan dynasty. It is reported there that in 724 (year 12 of Kaiyuan) the winter solstice fell on degree 9.5 of Dou.[36] The solar table at hand does not use fractions, but this was presumably to facilitate ease of use for astrologers, who needed a convenient table for calculating planetary positions in horoscopes.

5. Accurate Definition of the Ecliptic

Yixing, like many other astronomers, sought to enhance and innovate, yet he simultaneously acknowledged the capabilities of the ancients (in this case, the ancients of China and *not* Buddhist India). As recorded in the *Xin Tang shu* (*j*. 31), Yixing and his colleague utilized improved technology, while also still offering a respectful nod to their predecessors, which perhaps was a polite necessity. Yixing, evidently, sought to carry and develop a tradition of astronomy that had been handed to him from many centuries prior, which was believed to stretch back to the sages of antiquity.

> In year 9 of Kaiyuan (721), Yixing received imperial orders, and went to work on reforming a new calendar. He wanted to understand the how to convert between the ecliptic (and the celestial equator), but the Grand Scribe did not possess an instrument for the ecliptic. Administrator for Troops of the Guard Command, Liang Lingzan, produced an armillary sphere out of wood. Yixing approved this. He then said unto the throne, "During Antiquity there existed the technique for an ecliptical armillary sphere, but such a device did not exist. Ancients pondered it, but they could never achieve it. Now, Lingzan's creation has the solar path and Moon intersect so that they always naturally line up. This is especially important for calculations, and I request that a casting be made with bronze and iron." The instrument was completed in year 11 [723]. 開元九年, 一行受詔, 改治新曆, 欲知黃道進退, 而太史無黃道儀. 率府兵曹參軍梁令瓚以木為游儀, 一行是之, 乃奏:「黃道游儀, 古有其術而無其器, 昔人潛思, 皆未能得. 今令瓚所為, 日道月交, 皆自然契合, 于推步尤要, 請更鑄以銅鐵.」十一年儀成.[37]

This apparatus was also upgraded with additional structures, cast in metal, which represented the celestial sphere in detail. The model turned by the power of flowing water. Representations of the Sun and the Moon were added to this setup, so that they became conjunct every 29 turns. The phases of the Moon were also displayed on the instrument. A wooden figurine was placed atop the plane of the device and would strike a drum and bell to keep track of the time. Eventually this device rusted out and no longer functioned, but the original apparatus for measuring the ecliptic enabled Yixing to take accurate measurements of the ecliptic as well as the Sun and planets.[38]

Yixing's calendar offered revised parameters of the 28 lunar stations, which are defined in two separate sets: one relative to the celestial equator and another relative to the ecliptic. These lists commence from Dou 斗 since it was the station on which the winter solstice fell at the time. The latter set was designed to accurately track planetary movements. His work reads, "The above (values) are all ecliptical degrees. The solar path is calculated, and the Moon and five planets orbit through this." 前皆黃道度, 其步日行, 月與五星, 出入循此. The commentary then gives the following explanation:

> In seeking the degrees of the lunar stations, there will always exist a remainder. Arrange the sequence to comprise the total degrees constituted with quarters (0.25), halves (0.50), and three-quarters [0.75]. When checking against the past and future, the contemporary degrees and parameters of the lunar stations will be acquired according to individual calculations for each degree that has shifted due to precession, so that you will be able to calculate the Sun, Moon, and five planets, as well as know their encroachments and holdings (in terms of omenology). 求此宿度, 皆有餘分, 前後輩之成少半太准為全度. 若上考古下驗將來, 當據差每移一度, 各依術算, 使得當時宿度及分, 然可步日月五星, 知其犯守也.[39]

The combined parameters of the ecliptical lunar stations equal 365.25 degrees, but the text notes that a "difference" (*cha* 差) is taken into account from the lunar station Xu 虛.[40] Yixing's important innovation here was creating a table and method for recalculating the ecliptical dimensions of lunar stations to account for changes in positions due to precessions, which in turn allowed for more precise calculations of planetary movements. Yixing indeed went so far as to redefine the dimensions of the lunar stations, although he still preserved the classical set of 28, which are spatially relative to native Chinese constellations. This kept his model in line with the orthodox Chinese uranography which stretched back to antiquity, but Yixing was still innovative.

This adherence to classical Chinese conventions on the part of Yixing stands in contrast to what we observe in the *Navagraha-karaṇa*, which uses a system of reformed *nakṣatras*. Older Indian texts which had been translated into Chinese in earlier centuries, such as the *Śārdūlakarṇāvadāna*, define 28 *nakṣatras* of varying dimensions using *muhūrtas* (a unit of time), but following the introduction of the zodiac signs into India during the early centuries of the Common Era, Indian astronomers redefined the parameters of the *nakṣatras* and produced a system of 27 *naksatras* consisting of uniform dimensions.[41] The *Navagraha-karaṇa* gives the following explanation:

> A formula involving the *nakṣatras* is included within these methods. The *nakṣatras* are uniformly 800 parts (minutes) each. In India they determine whether the day is auspicious or inauspicious based on the *nakṣatra* in which the Moon alights, and the activities associated with that *nakṣatra* are also undertaken. Furthermore, only 27 *nakṣatras* are employed, starting with Aśvinī, with Abhijit excluded, and ending with Revatī. The *nakṣatra* Abhijit always augurs auspicious times and is not included amongst the *nakṣatras*. 宿法於此術中, 凡是宿平等為八百分. 天竺每以月臨宿, 占其日一即休咎, 仍取其宿用事. 又唯用二十七宿, 命婁為始, 去牛, 終奎. 其牛宿恒吉祥之時, 不拘諸宿之例.[42]

In addition to this text, we can also observe this model of equalized *naksatras* and the related system of *navāṃśas* (ninths of a *nakṣatra*) explained in the commentary on the *Vairocanābhisaṃbodhi*, which we will recall was compiled by Yixing on the basis of the oral explanations provided by Śubhakarasiṃha.

> *Lunar station convergences*: The 27 *nakṣatras*. Heaven (i.e., the ecliptic) is divided into twelve chambers like the twelve Jupiter stations here (in China). Each station has 9 quarters (*pāda*). The ecliptic is altogether 108 quarters. Each *nakṣatra* gets four quarters, which constitutes the course of movement that the Moon travels in

one day. The Moon has gone once around the ecliptic after transiting for 27 days. 言宿直者, 謂二十七宿也. 分周天作十二房, 猶如此間十二次. 每次有九足, 周天凡一百八足, 每宿均得四足, 即是月行一日裎. 經二十七日, 即月行一周天也.[43]

It is certain that Yixing was aware of how Indian astronomers defined *nakṣatras*, in particular the model of 27 *nakṣatras* of uniformly equal dimensions, which was unprecedented in China until that point. Yixing's work would have been subject to enormous criticism had he attempted to entirely revise the system of Chinese lunar stations, which had been in use since antiquity, after his exposure to Indian models, but there is nothing to indicate he ever had such a motivation.

6. Redefining the New Moon

Lastly, another important issue to which Yixing directed his attention was the technical inaccuracy of how the New Moon (*shuo* 朔) was conventionally determined. His lunar calendrical theory is also the sole known example of one of his astronomical theories appearing in his Buddhist writings, although we should also recognize the fact that not all of his writings are extant.

The lunar months in the Chinese calendar are arranged so that generally the New Moon falls upon the first day of the month while the Full Moon falls upon on the fifteenth. The Full Moon appears when the Sun and Moon are in direct opposition to one another, while the New Moon is when the Sun and Moon are conjunct. The problem is that the New Moon and Full Moon do not necessarily fall exactly on the first and fifteenth days of the lunar month, respectively.

Yixing proposed a scientific definition the New Moon as "when the Sun and Moon are conjunct within a degree." 日月合度謂之朔.[44] This is relatively simple, but it shifts away from what was understood as an "averaged" or "mean" New Moon (*ping shuo* 平朔), which refers to the traditional way of determining the lunar cycle through general observation. Yixing gives the following explanation:

With respect to the averaged New Moon of the ancients, the Moon appearing in the morning is called the "Moon rising at sunrise," while appearing in the evening is called the "Moon rising at sunset." Now these are decreased or increased (i.e., modified) according to the progression of the Sun and the velocity of the Moon. (The fixed New Moon) will sometimes progress ahead of or fall short of that day [i.e., the averaged New Moon, which is traditionally defined as the first day of the lunar month]. This is considered a fixed New Moon. 古者平朔, 月朝見曰朒, 夕見曰朓. 今以日之所盈縮, 月之所遲疾損益之, 或進退其日, 以為定朔.[45]

In this revised system, the New Moon and Full Moon are "fixed" (*ding* 定), i.e., scientifically defined according to the real positions of the Sun and Moon. This concept of a fixed New and Full Moon is mentioned in Yixing's commentary on the *Vairocanābhisaṃbodhi*:

Also, the calendar calculates the Sun and the Moon. The averaged degrees of motion make for averaged New Moons. It will always align in a lesser (29) or greater (30) month [on the same day]. Sometimes [the date for the New Moon] will pass or be late with respect to the averaged movements of the Sun and Moon as their speeds will also differ. This is why a fixed New Moon will sometimes be ahead or behind a day. A fixed Full Moon will sometimes be on the fourteenth or on the sixteenth. Generally speaking, the time when the Moon is completely full is designated as the fifteenth day of the waxing period (Skt. *śukla-pakṣa*). The time when the Moon is exactly half like a bow string will be the eighth. It may be arranged based on this, and then one gets a fixed date. 又曆法通計日月, 平行度作平朔, 皆合一小一大. 緣日月於平行中, 又更有遲疾, 或時過於平行, 或時不及平行, 所以定朔或進退一日, 定望或在十四日或在十六日. 大抵月望正圓滿時, 名為白分十五日. 月正半如弦時, 亦為八日. 但以此准約之, 即得定日也.[46]

In light of the parallels with Yixing's calendar, this part of the commentary is clearly Yixing's voice, and not that of Śubhakarasiṃha. The reader is being cautioned that the true Full Moon may sometimes appear a day ahead or behind the fifteenth day of the lunar month. This matter was important for the purposes of timing rituals, since the true phase of the Moon ought to be considered, rather than simply assuming that the first or fifteenth of the calendar month always align with the New and Full Moons respectively. This was important to Yixing in particular, since the *Vairocanābhisaṃbodhi* calls for the *maṇḍala* to be produced on auspicious days, such as the day of the Full Moon. The fruits of the *maṇḍala* would be compromised if the proper phase of the Moon—among other factors such as the day of the week—were not strictly observed. Again, this is one rare instance in which Yixing's work in calendrical science was directly applicable to Buddhist activities. Otherwise, his work in astronomy was separate from Buddhism.

7. Conclusions

The survey above shows that a newly collected data set of gnomonic measurements, the production of an improved armillary sphere with a ring representing the ecliptic, and generally improved astronomical theory, all enabled Yixing to create a more precise calendrical system at the request of the court. Yixing did not frame himself as a revolutionary in science, but rather gave a respectful nod to his predecessors and positioned himself as a developer atop the achievements of past figures. Later generations afforded Yixing a significant place in the history of astronomy.

Yixing's incorporation of concepts from the *Yijing* into his theoretical framework is unique. Xing Yunlu in the 16th century interestingly does not mention Yixing throughout his outline of Buddhist, Daoist, Indian, and Islamicate models of cosmology and astronomy (*j*. 28).[47] This would seem to indicate that Xing Yunlu thought of Yixing as a credible astronomer whose work belonged to the history of official court astronomy in China. The extant primary sources that discuss Yixing's work in astronomy indeed do not display any Buddhist elements, such as the cosmology of Mount Meru and the related system of kinetics that explain planetary motions through winds. The models of kinematics we observe in Buddhist Abhidharma literature are also absent from Yixing's astronomical work. Yixing instead was more inspired by Chinese—not Buddhist—metaphysics. This is an important point, since it demonstrates that Yixing was willing to (and probably simply had to) set aside Buddhist cosmology in order to work within a different field. This was presumably out of necessity, since the state is unlikely to have permitted any radical changes to the foundations of astronomy and astrometric models. The absence of any significant adoption of Indian astronomy in Chinese translation—such as that of the Gautamas—by Yixing or anyone else only confirms this assumption.

Another point to emphasize here is that, in reality, Yixing's Buddhist career was largely separate from his career as an astronomer. In other words, Buddhism neither inspired nor informed his study of astronomy. The Buddhist community also does not appear to have utilized his calendar or advanced scientific work in any notable capacity beyond what we noted above. There might not have been any pressing need to do so, but this just highlights that his two professions were, in practice, quite separate from one another.

Yixing was the only court astronomer in Chinese history who served as a monk and officially worked on the state calendar (the aforementioned monk Kumāra was another figure from the Tang period, but he was not commissioned to work on the state calendar), but Yixing's status as a monk alone cannot qualify his calendar as possessing any "Buddhist" features or quality. We can, however, observe that it was Yixing's eminence as a Buddhist writer and practitioner that brought about an invitation to the capital. This relocation clearly brought together the "causes and conditions" which enabled his career as an astronomer to flourish. If he had not come to the capital in the capacity as an eminent monk, he might not have ever been involved in astronomy at the state level. In that sense, Buddhism only enabled Yixing's career in science, but he was in large part separated from the Buddhist community when it came to astronomy. The Buddhist community might have celebrated his status as an astronomer, but they had little actual connection to it. In contrast to

Needham's aforementioned remarks, it would seem reasonable to affirm that Buddhism neither hindered nor directly encouraged Yixing's work in science.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: I must thank my colleagues at the time in 2019 for offering suggestions and criticisms. I also thank Jinhua Chen for inviting me to present the paper at the conference and later facilitating the publication of my study. I finally wish to thank the reviewers of this study, all of whom offered valuable critiques and comments, which I incorporated into the final version.

Conflicts of Interest: The author declares no conflict of interest.

Abbreviations

SKQS Siku quanshu 四庫全書. *Yingyin Wenyuan ge Siku quanshu* 景印文淵閣四庫; 全書. 1500 vols. Taipei: Taiwan Shangwu Yinshuguan, 1983; *T Taishō shinshū daizōkyō* 大正新脩大藏經. 100 vols. Takakusu Junjirō 高楠順次郎 and Watanabe Kaigyoku 渡邊海旭 et al., eds. Tōkyō: Taishō Issaikyō Kankōkai, 1924–1934. Digitized in CBETA (v. 5.2) and SAT Daizōkyō Text Database (https://21dzk.l.u-tokyo.ac.jp/SAT/satdb2015.php; accessed on 16 May 2022); *X Xuxiu Siku quanshu* 續修四庫全書. Shanghai Guji Chubanshe 上海古籍出版社, 1995.

Notes

1 The relationship between Chinese literati culture and science is an ongoing and important discussion. See Kim (2014, p. 146) for extended discussion.

2 Ronan and Needham (1978, pp. 264–65) discussed the roles of Daoism and Buddhism in the development of science in China. Many of their statements require careful consideration, especially in light of recent studies that demonstrate in particular that Buddhists did not ideologically or practically restrict scientific discussions. See also Needham's study on Chinese astronomy (Needham 1959).

3 See especially remarks in Kotyk (2020, pp. 278–281, 287).

4 I first utilized this approach of comparing state and Buddhist texts in a critical evaluation and reconstruction of Yixing's biographical data. See Kotyk (2018d, pp. 1–37). Later, I applied this methodology to the monk Xuanzang 玄奘 (602–664). See Kotyk (2019, pp. 513–44).

5 For biographical studies on Yixing, see Osabe (1963); Wu (2009); Kotyk (2018d).

6 The biographical survey of Yixing by Jinhua Chen remains the foundational study for our understanding of Yixing's life. See especially Chen (2000, pp. 25–31).

7 For a recent article on the historical study of Sanskrit in China and Japan, see Kotyk (2022b).

8 For a translation and analysis of this section in the commentary, see Kotyk (2018b).

9 *Jiu Tang shu* 35.1293. Translation adapted from Kotyk (2020, p. 278). "Sidereal" refers to positions in the sky based on fixed stars. As Cullen (2000, p. 366) points out, *jintui* 進退is a technical term that refers to a "numerical conversion between the coordinates of a series of equal steps along the equator and a simultaneous series of equal steps along the ecliptic—but reckoned using different set of widths of lodges." This difference necessitated taking accurate measurements from the ecliptic.

10 Zhang Yue and Yixing had an earlier relationship before the latter moved to the capital. See Chen (2000, p. 27). The political significance of Yixing's appointment as an astronomer is also interesting, but this is a topic for another time.

11 *Jiu Tang shu* 32.1152. See chronology of Yixing's career given in Wu (2009, p. 104). Translation adapted from Kotyk (2020, p. 278).

12 Bagchi (2011, pp. 193–94) discusses Indian or "Sino-Indian" families who operated as astronomers in the Chinese court during the Tang period. He was one of the early, if not the first, scholar, to recognize their significance in the history of science in China.

13 *Jiu Tang shu* 34.1265. Kotyk (2020, p. 280). Bagchi (2011, pp. 193–94).

14 Kotyk (2018d, pp. 13–15). *Jiu Tang shu* 191.5113

15 For a discussion of the restrictions on the study of astrology and astronomy in Chinese Buddhism, see Kotyk (2017a). See also Whitfield (1998).

16 *SKQS* 374: 412a8-9.

17 *Xin Tang shu* 27a.588–591.

18 *SKQS* 787: 171–172.

19 Kaji (1956c). See also extended discussion in Kaji (1956a, 1956b).

20 *Xin Tang shu* 27a.587. Sen (1995, p. 203).

21 See remarks in Cullen (1982, pp. 24, 30–32). Cullen's study is highly important for our understanding of mathematical astronomy in the Tang.

22 This scripture states that certain rituals should be carried out during lunar and solar eclipses, which we ought to note would require significant skill in astronomy. There is furthermore a need to consider the Moon's position in the *nakṣatras*, which technically requires an understanding of an Indian astrometric model. See discussion of this in Kotyk (2022a).

23 The two scholars give different numbers, but I am unclear on how they arrived at them. See Ohashi (2011, p. 172); Cullen (1982, p. 1).

24 *SKQS* 603: 321b4-16. The length of a single *li* varied over time. 1 *li* constitutes 1800 *chi* 尺, each of which during the Tang period was 31.1 cm. During the Tang, therefore, 1 *li* equaled roughly 0.56 km (0.35 miles). See parameters for traditional Chinese measurements in Togawa et al. (2011, p. 1742).

25 *T* 2087, 51: 875b27-28.

26 Cullen (1982, p. 15). The objectively scientific quality of Yixing's work has also been emphasized. See the study by the Astronomical History Research Group Shanxi Observatory (1976).

27 *SKQS* 807: 942b10. See translation and comments in Yabuuchi (1989, p. 40).

28 Buddhists in China during the Tang period were exposed to spherical-earth models, but continued to envision the world and write about it in flat-earth terms. See Kotyk (2021) for an extended discussion of this matter.

29 This is an important observation by Cullen (1980, p. 42). As he points out, it was only with the advent of new astronomy via the Jesuits that astronomers in China adopted a spherical-earth model.

30 *T* 1796, 39: 619a2-3, 693b25-26.

31 Note that a Chinese *du* 度 is normally translated as degree (it is a measure of circumference, and it is not angular). It would convert to 1.014583 of a modern degree, since the Chinese did not use the originally Mesopotamian parameter of 360 units when dividing the celestial equator. Instead, the Chinese divided the celestial equator into 365.25 units. For ease of understanding, I simply translate the Chinese term as degree. See Guan (1989, pp. 77–80).

32 *SKQS* 787: 19b11-20a1

33 For a study of these texts, see Kotyk (2017b). See also Yano (1995).

34 The Chinese "lunar stations" (also translated as "mansions" following the Latin) are not identical to Indian *nakṣatras*, but the former ones were used as functional equivalents for the latter in East Asia. A *nakṣatra* is also a type of lunar station, but the varying systems of parameters in Indic sources all differ from Chinese models. Indian systems employ either 28 or 27 *nakṣatras*. Cullen (2017, p. 186) translates the Chinese term as "lodge" (not "lunar lodge"), which reflects the literal semantic sense of the word. Cullen also points out that "the system of the lodges antedates the foundation of the empire by at least a few centuries: the names of all 28 lodges appear in an approximate circle on the lid of a lacquer box found in a tomb dated to 433 BCE'. The earliest list of these with measurements dates to 139 BCE." Cullen does not accept the oft-used translation of "lunar mansion"—which in itself is a reflection of the Latin translation of the twenty-eight *manāzil* from Arabic. Cullen (2011, pp. 83–95) points out that in usage, it is not only the Moon that can lodge in these stations, but the other planets as well. However, I think that the concept in question is still connected to the Moon, given the lunar orbital period of 27.3 days. Whether the Moon was consciously associated with the stations or not also likely changed over the centuries. In the mid-Tang period (eighth century), Amoghavajra very clearly connected them to the Moon, following the example of the *nakṣatras*, a connection that already had a precedent in the Chinese translation of the *Śārdūlakarṇāvadāna*. See discussions in Kotyk (2022a).

35 *T* 1308, 21: 450c5-7.

36 *Yuanshi* 52.1131.

37 *Xin Tang shu* 31.806. Adapted from translation in Kotyk (2020, p. 279). See also relevant discussion in same article.

38 *Xin Tang shu* 31.806–807.

39 *Jiu Tang shu* 34.1241–1242.

40 The problem here is that the *Jiu Tang shu* reads 六虛之差十九太, but this is unclear in meaning. I believe *liu* 六 is a scribal error for *fen* 分. *Jiu Tang shu*, 34.1240–1241. Same in *Xin Tang shu* 28a.646. The parameters for lunar stations relative to the celestial equator include a comment that reads 虛分七百七十九太. This gives us 779.75. To understand this, we need to see the section concerning the solar path (*bu richan shu*步日躔術), which gives the following parameters (*Xin Tang shu* 28a.642): Degrees of ecliptic: 365 (周天度三百六十五). Portion of Xu: 779.75 (虛分七百七十九太). [Rate of] precession: 36.75 (歲差三十六太). To make sense of the latter two numbers, we have to divide them by the "universal formula" (*tongfa* 通法) of the calendar, which is 3040 (the number of units of time within a single day according to this calendrical system). See Zhang et al. (2008, p. 497). The ecliptic becomes 365.2564 Chinese degrees, and the annual rate of precession is 0.01208. Yixing calculated that the Sun retreats 1 degree every 83 years, hence an annual rate of 0.01208 × 83 = 1.00264 (Chinese degree). Yixing clearly sought to account for the difference between the sidereal (avg. 365.2563 days in modern terms) and tropical years (avg. 365.2421 days), a difference of approximately

twenty minutes according to the modern standard. Also, the lunar station Xu is comprised of 10.2564 Chinese degrees. Compare also Table 2 in Yano (1986, p. 30).

41 The day is comprised of thirty *muhūrtas*. The dimension of a *nakṣatra* was defined based on the amount of time required for the Moon to transit through it. Although Buddhists were aware of it, this model was never actively observed in China or Japan. See discussions in Kotyk (2022a). Zenba (1952, pp. 174–82).

42 *SKQS* 807: 937a8-9. See alternate translation in Yabuuchi (1989, pp. 21–22). This system here is related to the *navāṃśas* or ninths of a zodiac sign. The *navāṃśas*, it appears, are an autochthonous Indian concept, but some scholars have connected it to a concept also attested in Hellenistic/Latin horoscopy, although this link is only speculative and tentative in character. See Gansten (2018, p. 180, fn. 60).

43 *T* 1796, 39: 618a8-11. Translation adapted from Kotyk (2018b, p. 15).

44 日月合度謂之朔. *Xin Tang shu* 27a.594.

45 *Xin Tang shu* 27a.591. Translation adapted from Kotyk (2018b, pp. 13–14). The terms *nü* 朒 and *tiao* 朓 specifically refer to the apparently irregular visibility of the first and last crescent on the calculated mean day of the New Moon, which indicates that the "New Moon" as specified in the calendar is not the true New Moon. I must thank the anonymous peer-reviewer for pointing out this fact.

46 *T* 1796, 39: 617c28-618a5. Translation adapted from Kotyk (2018b, 12–13).

47 *SKQS* 787: 320–331.

References

Primary Sources

Dari jing shu 大日經疏. *T* 1796.
Dari jing 大日經 (Skt. *Vairocanābhisaṃbodhi*). *T* 848.
Gujin lü likao 古今律曆考. *SKQS* 787: 1–754.
Jiu Tang shu 舊唐書. Beijing: Zhonghua Shuju, 1975.
Jiuzhi li 九執曆 (Skt.**Navagraha-karaṇa*). *SKQS* 807: 933–943.
Qiyao rangzai jue 七曜攘災決*T* 1308.
Susiddhikara-sūtra (*Suxidijieluo jing* 蘇悉地羯羅經). *T* 893.
Tongdian 通典. *SKQS* 603–605.
Tongzhi 通志. *SKQS* 372–381.
Xin Tang shu 新唐書. Beijing: Zhonghua shuju, 1975.
Yuanshi 元史. Beijing: Zhonghua shuju, 1976.

Secondary Studies

Astronomical History Research Group Shanxi Observatory (Zhongguo kexueyuan Shanxi Tianwendai tianwenshi zhengli yanjiu xiaozu 中国科学院陕西天文台天文史整理研究小组). 1976. Woguo lishishang diyici tianwen daci celiang ji qi yiyi—guanyu Zhang Sui (Seng Yixing) de ziwuxian celiang. 我国历史上第一次天文大地测量及其意义—关于张遂(僧一行)的子午线测量. *Tianwen Xuebao* 天文学 17: 209–16.
Bagchi, Prabodh Chandra. 2011. *India and China Interactions Through Buddhism and Diplomacy: A Collection of Essays by Prabodh Chandra Bagchi*. Edited by Bangwei Wang and Tansen Sen. Delhi: Anthem Press India.
Chen, Jinhua. 2000. The Birth of a Polymath: The Genealogical Background of the Tang Monk-Scientist Yixing (673–727). *Tang Studies* 18–19: 1–39. [CrossRef]
Cullen, Christopher. 1980. Joseph Needham on Chinese Astronomy. *Past & Present* 87: 39–53.
Cullen, Christopher. 1982. An Eighth Century Table of Tangents. *Chinese Science* 5: 1–33.
Cullen, Christopher. 2000. Seeing the Appearances: Ecliptic and Equator in the Eastern Han. *Ziran kexueshi yanjiu* 自然科学史研究 19: 352–82.
Cullen, Christopher. 2011. Translating 宿 *sukh/xiu and 舍 *lhah/she—'Lunar lodges', or just plain 'lodges'? *East Asian Science, Technology, and Medicine* 33: 83–95. [CrossRef]
Cullen, Christopher. 2017. *Heavenly Numbers: Astronomy and Authority in Early Imperial China*. Oxford: Oxford University Press.
Gansten, Martin. 2018. Origins of the Tājika System of Astrological Aspects and Dignities. *History of Science in South Asia* 6: 162–99. [CrossRef]
Guan, Zengjian 关增建. 1989. Chuantong $365\frac{1}{4}$ fenfu bu shi jiao du. 传统3651/4分度不是角度. *Ziran bianzheng fa tongxun* 自然辩证法通讯 63: 77–80.
Kaji, Tetsujō 加地哲定. 1956a. *Daien reki* kō (zoku zoku). 大術暦考 (続々). *Mikkyō bunka* 密教文化 35: 1–18.
Kaji, Tetsujō 加地哲定. 1956b. *Daien reki* kō (zoku). 大衍暦考 (続). *Mikkyō bunka* 密教文化 34: 1–12.
Kaji, Tetsujō 加地哲定. 1956c. *Daien reki* kō. 大衍暦考. *Mikkyō bunka* 密教文化 33: 1–11.
Kim, Yung Sik. 2014. *Questioning Science in East Asian Contexts: Essays on Science, Confucianism, and the Comparative History of Science*. Leiden: Brill.

Kotyk, Jeffrey. 2017a. Can Monks Practice Astrology? Astrology and the Vinaya in China. In *Rules of Engagement: Medieval Traditions of Buddhist Monastic Regulation*. Edited by Susan Andrews, Jinhua Chen and Cuilan Liu. Hamburg: Hamburg University Press, pp. 503–17.

Kotyk, Jeffrey. 2017b. Iranian Elements in Late-Tang Buddhist Astrology. *Asia Major* 30: 25–58.

Kotyk, Jeffrey. 2018a. Astrological Determinism in Indian Buddhism. *Journal of the International Association of Buddhist Studies* 41: 145–67.

Kotyk, Jeffrey. 2018b. Early Tantric Hemerology in Chinese Buddhism: Timing of Rituals According to Śubhakarasiṃha and Yixing. *Canadian Journal of Buddhist Studies* 13: 1–29.

Kotyk, Jeffrey. 2018c. The Sinicization of Indo-Iranian Astrology in Medieval China. *Sino-Platonic Papers* 282: 1–95.

Kotyk, Jeffrey. 2018d. Yixing and Pseudo-Yixing: A Misunderstood Astronomer-Monk. *Journal of Chinese Buddhist Studies* 31: 1–37.

Kotyk, Jeffrey. 2019. Chinese State and Buddhist Historical Sources on Xuanzang: Historicity and the *Daci'en si sanzang fashi zhuan* 大慈恩寺三藏法師傳. *T'oung Pao* 通報 105: 513–44. [CrossRef]

Kotyk, Jeffrey. 2020. The Chinese Buddhist Approach to Science: The Case of Astronomy and Calendars. *Journal of Dharma Studies: Philosophy, Theology, Ethics, and Culture* 3: 273–89. [CrossRef]

Kotyk, Jeffrey. 2021. Examining Amoghavajra's Flat-Earth Cosmology: Religious vs. Scientific Worldviews in Buddhist Astrology. *Studies in Chinese Religions* 8: 203–20. [CrossRef]

Kotyk, Jeffrey. 2022a. Astronomy and Calendrical Science in Early Mikkyō in Japan: Challenges and Adaptations. *Religions* 13: 458. [CrossRef]

Kotyk, Jeffrey. 2022b. The Study of Sanskrit in Medieval East Asia: China and Japan. *Hualin International Journal of Buddhist Studies* 4: 240–73. [CrossRef]

Needham, Joseph. 1959. *Science and Civilisation in China, Volume 3: Mathematics and the Sciences of the Heavens and the Earth*. Cambridge: Cambridge University Press.

Ohashi, Yukio. 2011. Astronomy and Mathematics of Yixing. In *Mapping the Oriental Sky: Proceedings of the Seventh International Conference on Oriental Astronomy*. Edited by Nakamura Tsukō, Wayne Orchiston, Mitsuru Sōma and Richard Strom. Tōkyō: National Astronomical Observatory of Japan, pp. 171–78.

Osabe, Kazuo 長部和雄. 1963. *Ichigyō Zenji no kenkyū* 一行禪師の研究. Kobe: Kōbe Shōka Daigaku Keizai Kenkyūsho.

Ronan, Colin Alistair, and Joseph Needham. 1978. *The Shorter Science and Civilisation in China: An Abridgement of Joseph Needham's Original Text*. Cambridge: Cambridge University Press, vol. 1.

Sen, Tansen. 1995. Gautama Zhuan: An Indian Astronomer at the Tang Court. *China Report* 31: 197–208. [CrossRef]

Togawa, Yoshio 戸川芳郎, Sato Susumu 佐藤進, and Hamaguchi Fujio 濱口富士雄. 2011. *Zenyaku kanji kai* 全訳漢辞海. Tokyo: Sanseidō.

Whitfield, Susan. 1998. Under the Censor's Eye: Printed Almanacs and Censorship in Ninth-Century China. *The British Library Journal* 24: 4–22.

Wu, Hui 吳慧. 2009. Seng Yixing shengping zaiyanjiu 僧一行生平再研究. *Yuanguang xuebao* 圓光學報 14: 77–110.

Yabuuchi, Kiyoshi 藪内清. 1989. *Zuitō rekihō shi no kenkyū Zōtei* 隋唐曆法史の研究 増訂. Kyoto: Rinsen Shoten.

Yano, Michio. 1986. The *Chi'yao jang-tsai-chueh* and its Ephemerides. *Centaurus* 29: 28–35. [CrossRef]

Yano, Michio. 1995. A Planetary Ephemeris in Japanese Buddhist Astrology: A Case of Transmission. In *East Asian Science: Tradition and Beyond*. Edited by Keizō Hashimoto and Catherine Jami. Kyoto: Kansai University Press, pp. 73–81.

Zenba, Makoto 善波周. 1952. Matōga gyō no tenmonrekisū ni tsuite 摩登伽經の天文曆數について'. In *Tōyōgaku ronsō: Konishi, Takahata, Maeda san kyōju shōju kinen* 東洋學論叢: 小西高畠前田三教授頌壽記念. Edited by Bukkyō Daigaku. Kyoto: Heirakuji Shoten, pp. 171–214.

Zhang, Peiyu 張培瑜, Shuren Bo 薄樹人, Meidong Chen 陳美東, and Tiezhu Hu 胡鐵珠. 2008. *Zhongguo gudai lifa* 中國古代曆法. Beijing: Zhongguo Kexue Jishu Chubanshe.