

### THE 1280 REFORM OF CHINESE ASTRONOMY

*Granting the Seasons: The Chinese Astronomical Reform of 1280, with a Study of its Many Dimensions and an Annotated Translation of its Records.* Nathan Sivin, with the research collaboration of Kiyoshi Yabuuti and Shigeru Nakayama (Sources and Studies in the History of Mathematics and Physical Sciences; Springer Science + Business Media, New York, 2009). Pp. 664. €50. ISBN 978-0-387-78955-2.

The “Season-granting system [*shou shi li*]” was promulgated during the reign of Khubilai, *de facto* founder of the Yuan Dynasty (1276–1368), a mere four years after the final conquest and establishment of Mongol rule over all of China. Simply stated, this most innovative and sophisticated of astronomical systems, like its many predecessors in China’s long history, was mainly designed to generate annual almanacs. But unlike any of its antecedents this reform takes its name from a singularly important passage in an ancient astronomical treatise, the pre-classical *Yao dian* or “Canon of Yao”, in which the legendary Emperor Yao is portrayed as commanding the “reverent bestowal of the seasons on the people [*jing shou min shi*]”, based on official observations of the culminations of seasonal asterisms. In this way, the revered canonical text firmly established the linkage between bureaucratic time-management and imperial charisma. As Nathan Sivin shows in his pioneering study, this linkage goes a long way toward explaining why Khubilai’s co-opted Chinese experts spared no effort in persuading him to invest unprecedented resources in the reform as a symbolic means of legitimizing the Mongol regime in the eyes of his historically attuned Chinese subjects. Today the very same expression, *shou shi*, figures in the name of China’s National Time Service Center — the ancient bureaucratic precedent still has resonance.

I offer this by way of preface because it reflects the kind of nuanced exposition by Nathan Sivin of this highly influential scientific and technological project: “I aim to portray the technical methods of astronomy as part of a continuum that enfolds every dimension of human activity, from algorithms to political maneuvering” (p. 8). Sivin set himself the task of elucidating the genesis and execution of the ambitious and costly reform enterprise in its cultural, political, bureaucratic, personal, and technical dimensions, and in this he succeeds admirably.

The first half of the volume is devoted to contextualizing the “Season-granting system”. Chapters 1 and 3, “Astronomical reform and occupation politics” and “The project”, address the overarching question alluded to above; how and why such a remarkable astronomical reform came about when it did, in the context of conquest by the Mongols, who were culturally utterly alien, and by Chinese standards, illiterate. Chapter 2, “Orientation”, with its extended discussion of Chinese mathematical tools, metrology, celestial motions, precision and accuracy, comparisons with Europe and Islam, etc., will become the standard reference on these matters of general interest. Chapter 4, “The observatory and its instruments”, describes in detail the physical layout of the observatory at the capital as well as the innovative instruments designed

by the project's most renowned participant, Guo Shoujing (1231–1316). Chapter 5, “The astronomers”, provides biographical sketches of the remarkable group of Chinese experts hand-picked by Khubilai for the project, their personal relationships, and their areas of responsibility.

The second half of the book offers a fully annotated translation of the surviving documentation, including the Canon with details of its computational methods painstakingly elucidated, precise technical descriptions of the instruments, the official biography of Guo Shoujing, and extensive glossaries of technical vocabulary. Of particular importance among the original documents is the project's lengthy “Evaluation” of many of the Season-granting system's predecessors, which preserves invaluable historical information on observational and computational methods spanning more than a millennium that would otherwise have been lost.

The book is handsomely produced, superbly edited, accessible, and affordable. The author has provided a list of emendations on-line at <http://ccat.sas.upenn.edu/~nsivin/Emendation.pdf>. I noted only three minor errors not included in that list: on page 71, where it says “Noon was the moment when the sun cast the longest shadow of the day”; page 114, where “Shih, Shen, and a third” should be “Shih, Kan, and a third”; and page 137, where Chinese *se-mu jen* (“colored-eyed people”) is left untranslated.

It remains only to comment on the intrinsic merit of *Granting the seasons* and whether the end product justifies the enormous expenditure in time and effort devoted to this work. The answer must be an emphatic: Yes! On one occasion only, Sivin lets fly at the parochial aims of “immaculate European astronomy” for which “ignorance of non-European astronomy is not ... mere ignorance, but a sign of good taste” (p. 555). As he goes on to stress, studies that transcend cultural boundaries and render accessible non-European developments must be among our most urgent priorities if we hope ever to be able to assess the role of Indian and Chinese knowledge “in the gestation of early modern science” (p. 557). Without a doubt, as far as China is concerned, *Granting the seasons* is the most important such contribution in half a century.

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**MR2454047 (2009i:01002) 01A25****Sivin, Nathan (1-PA-HS)****★Granting the seasons: the Chinese astronomical reform of 1280, with a study of its many dimensions and a translation of its records.**

With the research collaboration of the late Kiyosi Yabuuti and Shigeru Nakayama.

Sources and Studies in the History of Mathematics and Physical Sciences.

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The present book is a study and translation of the astronomical treatise as found in the official *History of the Yuan Dynasty* (1279–1368). It partly reproduces, translated into English, the documentation of the so-called Season-granting system (*Shoushi li*), a set of methods for generating annual almanacs submitted to the throne in 1280. According to Sivin, it was the “most innovative, and certainly the most sophisticated and influential, of China’s many astronomical treatises”. (p. 5)

Based on 40 years of research, Sivin provides us in the first half of the book with a detailed investigation of a variety of contexts relevant to the the cultural, political, bureaucratic, personal and technical aspects of the astronomical reform during the early years of the Mongol reign. He thus prepares the ground for further research, allowing a methodological approach which Sivin has defended over the last several years under the term of ‘Cultural Manifolds’ [see, for example, *East Asian Sci. Technol. Med.* **23** (2005), 10–25]. The central idea is to link together the many dimensions of the historical situation with the content and technicalities of the analyzed text: the political importance of eclipse prediction can account for the relatively little importance given to planetary motions in Chinese astronomical history, the repeated importance of astronomical reform can be understood as a legitimizing strategy of a new dynasty, and in the case of the new Mongol reign in particular, developing a recognizable Chinese system allowed the maintenance of a cultural lineage.

The translations in the second half and the appendices of the book are complemented by a rich commentary and tables, which allows the reader, for example, to understand the technical terms of the many constants used in the calculations, or the origins of the data from observations with newly built instruments by the Court’s ‘Grand Astrologer’ Guo Shoujing (1231–1316).

The text has been very well revised and carefully edited; minor emendations have been pointed out by the author himself (see <http://ccat.sas.upenn.edu/~nsivin/Emendation.pdf>). Although it does not investigate the question of how mathematical writings and theories of the Yuan dynasty, in particular algebraic and interpolation techniques by Zhu Shijie, were related to contemporary astronomical techniques, it is an excellent and fairly complete source and reference book in a Western language for the specialist and non-specialist in the history of astronomy in China.

Reviewed by [Andrea Bréard](#)

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## MAA Reviews

# Granting the Seasons: The Chinese Astronomical Reform of 1280, With a Study of its Many Dimensions and an Annotated Translation of its Records

Nathan Sivin



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[Reviewed by Joseph W. Dauben, on 12/31/2009]

This impressive work is a detailed, technical study of the most innovative and significant astronomical system for generating annual almanacs in Chinese history. It was also a key element in the Chinese imperial and bureaucratic system, and as Sivin shows, instrumental in the Mongol strategy to rule the recently conquered country. This is also the first time that a major Chinese astronomical treatise has been translated into English, and for historians of astronomy, it will prove an indispensable addition to comparative studies of Greek, Islamic, Indian and European astronomical traditions. Reflecting the culmination of more than a thousand years of mathematical astronomy in China, Sivin's study illuminates "what the norms of practice were with respect to such matters as computation, the recording of time and celestial locations, the use of instruments, the keeping of records and the social and political organization of astronomical work." In short, this is a comprehensive study that encompasses much more than the astronomical system itself. Above all, Sivin situates the Seasons Granting System in its much broader social context, explaining its inner workings and wider significance.

In addition to explaining what Chinese astronomers accomplished, Sivin also wants to know how and why they approached astronomy as they did. Moreover, given that the Seasons Granting System was designed to inaugurate the newly established rule of the Mongols over China under the Great Khan, Sivin also explain how "occupation politics," as he puts it, were closely allied with astronomical reform. In so doing, he also explores the reciprocal influences of Islamic and Chinese astronomers on each other, and how their exchanges are reflected in the new calendar.

Sivin characterizes his study as the analysis of a cultural manifold: "I aim to portray the technical methods of astronomy as part of a continuum that enfolds every dimension of human activity, from algorithms to political maneuvering." But given the complexity of the manifold he has chosen to explore, Sivin narrows his focus to five of its most representative dimensions: the cultural, political, bureaucratic, personal, and technical facets of the Seasons Granting System. Chapter by chapter, the story unfolds as follows.

The first chapter considers astronomical reform and its political significance. Here Sivin focuses on the history of

Khubilai Khan, grandson of Chinggis Khan, and his most important advisor, Liu Ping-chung, a Ch'an monk who became Khubilai's most important political advisor. Adept at mathematics, astrology and divination, Liu emphasized the value of astronomical reform as a traditional Chinese means of asserting legitimate imperial authority. Although Liu died before the plan could be carried out, Khubilai understood that ritually marking the unification of China was of the utmost significance. Moreover, the calendar then in use, the so-called Revised Great Enlightenment System (Ch'ung-hsiu Ta-ming li) of 1180, was nearly a century old when the charge came to establish an Astrological Commission (T'ai-shih yuan) in 1278, which included 77 officials, 44 student observers, and a coterie of employees about whom no historical records survive. As Sivin explains: "One reason the new Chinese-style system was so impressive is that this was by all accounts the most elaborate and expensive reform ever carried out. It involved a new observatory, outfitted with a set of large bronze armillaries and other instruments, some of them unprecedented in design. Kuo Shou-ching also built two 40-foot high brick gnomons with a kind of pinhole camera that determined with remarkable exactitude the length of the tropical year." The reformers not only carried out their own observations, but drew on centuries of Chinese astronomical records to test their ability to predict eclipses to the nearest quarter of an hour.

With this background in mind, the following chapter is devoted to a general introduction to the social organization of astronomy in China. This includes a discussion of the various meanings attached to the Chinese word "li," usually translated as "calendar," but Sivin explains why he prefers to render this as "mathematical astronomy," something broader than "calendrical science" and encompassing an entire astronomical system concerned with astrology as well as the ritual issuing of yearly almanacs, from which the system takes its name: "Granting the Seasons." This was all of direct concern to the emperor and the success of his reign.

As the Son of Heaven, the emperor was expected to maintain the harmony of the state and cosmos through various rituals, including promulgation of the annual almanac and his participation in the various important matters of state that accompanied this. Sivin explains at length the politics of astronomical reform in the context of the Mongol reign, the related history of observatories in China, and the mathematical tools used by Chinese astronomers. This section of the book will be of special interest to historians of mathematics. Here Sivin explains how rods representing numbers were manipulated on counting boards to carry out arithmetic computations. He explains the Chinese decimal place-valued number system and how fractions were used, along with trigonometry, metrology, chronology, date reckoning, and the division of the tropical year into 12 *ch'i*, each approximately 30.4 days long. He also provides details about time reckoning, the Chinese system of recording celestial position (which was equatorial), celestial motions, and eclipse records (both observed and calculated). Chapter 2 concludes with a comparison of Chinese astronomy and various more familiar systems devised by Islamic and European astronomers.

Chapter 3 goes into greater detail about the origins and process of the astronomical reform undertaken at the inception of the Yuan dynasty (1279-1368). Sandwiched between the Song and Ming, the Season-Granting System was intended to mark the transition to the Yuan dynasty, and in fact, the calendar was maintained virtually unchanged well into the Ming. The season-granting project began in 1276, with the appointment of two officials to plan it. The next two years were spent hiring personnel and reviewing previous astronomical systems to determine their strengths and weaknesses. In 1279 this all coalesced into an official Commission, accompanied by the construction of instruments and a building to accommodate its work, whereupon an empire-wide survey of latitudes began. The following year, the Season Granting System was submitted to the throne for approval. It was officially adopted the following year, in 1281, but the observatory meant to support the Commission's work was not actually completed until 1286, and the instruments and complete documentation of the new system were not finalized until 1290. The goal was a system that could generate accurate ephemerides indefinitely, and the fact that it was able to do so for nearly four centuries suggests how successful the reform actually was.

Chapter 4 is devoted to the astronomers who actually participated in the astronomical reform, including Liu Ping-chung (the season-granting reform was his "brainchild"), Wang Hsun (who was in charge of the project), Kuo Shou-ching (who tested the system and eventually succeeded Wang as Grand Astrologer, Kuo was also responsible for documenting the entire project), Chang I (skilled in divination and a supervisor of the astronomical reform), and Hsu Heng (who urged the importance of accurately determining the winter solstice and the exact length of the tropical year, both crucial to issuing dependable ephemerides over a long period of time). Others like Chang Wen-ch'ien, Yang Kung-I, and Ch'en Ting worked with a retinue of specialists that included computists, timekeepers, editors, printers, various clerks and students. Particularly interesting is Sivin's characterization of these as self-made men, not specialists but "civil-service generalists."

Chapter 5 describes the observatory and its instruments. Construction of the headquarters for the project and the observatory commenced in 1279, of which today virtually nothing survives. To support the reform project, Kuo

Shou-ching designed more than a dozen instruments for the observatory, along with others to be used by the astronomers conducting the empire-wide survey accompanying the project. Copies of three of these instruments survive in Nanjing, at the Purple Mountain observatory — an armillary sphere based on one designed by Shen Kua, the so-called “simplified instrument,” and a bronze gnomon. Sivin describes the most important instruments and evaluates their unique features. Remarkably, only two were ready before 1280, and Sivin concludes that there is no clear evidence that the new instruments played any role in the new system that was submitted to the emperor in 1280. Thus the Season-Granting System itself depended on observations made with old instruments and prototypes. In 1279 a plan was approved to build five large gnomons, 10 meters high, in 5 major cities; today only one of these survives, at an ancient observatory built in Gaocheng, Henan. Two instruments accompanied the gnomons: the shadow aligner and the observing table. The so-called “ingenious instrument, 玲瓏儀 *ling-lung yi*, is only known from vague descriptions, and was probably a thirteenth-century prototype of the surviving fifteenth-century armillary sphere. The “simplified instrument” was a modified version of more elaborate armillary spheres, and was supplemented by two additional instruments, a standing revolving instrument and a pole-observing instrument. The “upward-facing instrument” was a bowl-shaped scaphe sundial; the “direction-determining table” was a device for setting up mobile instruments, a mechanically driven celestial globe, and a variety of other instruments, some designed for travelling survey teams, including a “ball gnomon” — a suspended standard instrument (probably a plumb line) — and a mounted “standard instrument” (most likely a horizontal level).

After its victory over the Yuan dynasty in 1368, the Ming maintained its predecessors’ observatory in Ta-tu (Pei-ching/Beijing). It also erected a new observatory in 1385 at its new capital, Nan-ching (Nanjing). When the government moved back to Beijing between 1409-1421, it built a second observatory there. Unlike its Mongol predecessor, the Ming government did not devise a new astronomical system to establish a new celestial order, but simply relied on the old Yuan system to generate annual almanacs. Thus the Season-Granting System remained in official use for some 350 years — a record as Sivin says. This only changed in 1644, when the Manchu government handed authority for almanacs over to Jesuits astronomers. Based on documentary evidence, Sivin concludes that the instruments that survive from the Ming were basically copies of their Yuan predecessors, as originally designed by Kuo Shou-ching.

Among their technical innovations, Yuan astronomers substantially improved arc-sagitta methods that originated two centuries earlier, in ways analogous to spherical trigonometry. None of this was further developed in the Ming. Moreover, when the Han overthrew the Mongols, one of the first things the emperor T’ai-tsu did was to forbid the study of both astrology and mathematical astronomy outside of the court, with severe penalties for violators. The outcome: no one applied for positions in the astronomical bureau, which would have been tantamount to admitting having studied mathematics. As Sivin puts it: “Both Khubilai and Ming T’ai-tsu were among the most prominent of those rulers whose administrations became instruments of their wills. And in China, as this study makes abundantly clear, astronomy, astrology, and divination were affairs of state.”

An important question Sivin asks: Was there much influence from Islamic culture in the west on the Mongols of the east? Jamāl al-Dīn built Muslim instruments and as co-director of the Palace Library in 上都 Shangdu (Xanadu) during the period of reform, also had some authority over both the Chinese Directorate of Astronomy as well as the Muslim Directorate. Did Jamāl’s instruments influence those built in China or the cosmological ideas of the Yuan Chinese? Sivin concludes that influence was missing or negligible. Islamic astronomers were not part of the Yuan astronomical reform team, and there is no evidence of any Islamic astronomical manuals or handbooks translated into Chinese or Mongolian during the Mongol period. However, in the Ming dynasty such translations became common.

Sivin emphasizes that our knowledge of the Season-Granting System relies upon documents that survive, and the records of the entire process are a complex combination of technical reporting and political positioning. As he explains: “Historians take their sources where they find them. But the Season-granting system offers an exceptional opportunity to explore how technical bureaucracy formed the original record, and historiographic bureaucracy shaped the final one” (227). Chapter six is devoted to a study of the surviving records.

After reviewing of the standard histories kept by each imperial dynasty, whose rationales were both didactic and political, Sivin turns to the transmission and publication of the astronomical treatises. The most interesting part of this chapter is devoted to studies of the Yuan reform. Both Korea and Japan adopted the Yuan system, and this served to increase the level of mathematical ability in both Korea and Japan. But what really inspired study of the Yuan astronomical reform in all three countries was the 考證 *k’ao-cheng/kao zheng* (Evidential Studies movement) beginning at the end of the Ming dynasty in the 17th century, the basic aim of which was to recover the ancient classics with the intent of showing that they anticipated Western knowledge as transmitted to China by the Jesuits.

The leading figures of this movement in China were 黄宗羲 Huang Tsunghsi/Huang Zongxi and Mei Wen-ting/Mei Wending, while in Japan, Seki Takakazu (Kōwa) and his disciple Takebe Katahiro also made careful studies of the Season-Granting System.

The earliest foreign evaluation of the Yuan system was made by the Jesuit Antoine Gaubil, who was intent on introducing Chinese mathematical astronomical computational methods to Europe. Much later, the "indefatigable" Scots missionary Alexander Wylie, who worked in China for 30 years for the London Missionary Society, also provided important accounts of Chinese mathematical and astronomical accomplishments. But not until Joseph Needham's *Science and Civilisation in China* did the "ignorance and prejudice" that underlay most Western evaluations of Chinese science begin to change. Sivin's evaluation of Needham's important volume 3 on Chinese mathematics and astronomy is instructive, especially for historians of mathematics: "Needham's curiosity about quantitative matters was less acute than about other topics, so that he relied more than elsewhere on old secondary sources. He failed to understand the centrality of the almanac in the astronomical tradition, dismissing the reiterated astronomical reforms as 'of minor scientific interest,' and discussing them only cursorily." Sivin also mentions other surveys of Chinese astronomy and the Season-Granting System by Japanese scholars (notably Yabuuchi Kiyoshi and Nakayama Shigeru), and in China by Ch'en Mei-tung/Chen Meidong.

Chapters 7 through 10 provide Sivin's translation of the Season-Granting System, the first two of which are devoted to an elaborate evaluation of the new system, comparing it to earlier systems and using hundreds of historical observations to test the accuracy of the Season-Granting System. Chapter 7, "Evaluation of the Season Granting System," opens with the introduction written by the compilers of the *Yuan History*. Here it is pointed out that irregularities "are inherent in the celestial motions," and hence it was not part of the Chinese approach to astronomy to expect one model of the heavens to serve in perpetuity to make accurate predictions. It was assumed that adjustments would always be necessary from time to time, i.e. "correcting them is unavoidable." When the Yuan dynasty began, for a brief period of time it made use of the preceding Chin dynasty's (revised) Great Enlightenment System of 1180. But in 1220, during a military campaign in the midst of which a predicted lunar eclipse did not materialize, Chinggis ordered that adjustments be made to correct the system. However, it was at the time of a grand conjunction in 1210, when the sun, moon and five planets were aligned like "strung pearls" that "vouchsafed ... the Grand Progenitor's assumption of the Mandate." (Indeed, this was taken to be "the most splendid sign of a new cosmic and political order." Here separate sections are devoted to:

1. "Determination of *Ch'i* from Observation." This describes a number of instruments and how they were used to determine 氣 *chi/qi* (i.e. divisions of the year). Subsections cover computation of the winter solstices (for 1277, 1278, and 1279) and summer solstices (for 1278 and 1279).
2. "Year Surplus and Annual Difference." Here the tropical year fraction is computed and accounts given for precession of the equinoxes, 歲差 *sui-ch'a/sui-cha*. This includes comparison of the Season-Granting System with five other Chinese astronomical systems, and a general evaluation of the exactitude of ancient as well as contemporary astronomical systems.
3. "Angular Extensions of the Lunar Lodges along the Celestial Perimeter." The Chinese used a system of 28 stars and the arcs between them to divide the celestial equator into lodges, 宿 *hsiu/su (xiu)*, which were not equal but varied considerably in the distances spanned by each lodge. Their widths also changed over the centuries, and the Evaluation contains a table of their varying equatorial extensions between the Han and Yuan eras. These changes were due in part to the effect of precession on the positions of the determinative stars, and to different choices of the determinative stars that marked the different lodges, as well as to difficulties in mistaking a determinative star for a brighter one nearby.
4. "Tread of the Sun." Here determination of the apparent position and motion of the sun is considered with respect to the lunar lodges.
5. "Expansion and Contraction of the Solar Motion." This refers to the differences between the angular motions of the sun in winter and summer.
6. "Slackening and Hastening of the Lunar Motion." This treats the lunar anomaly.
7. "Crossing Cycle of the White Way." Here the problem arises of the "crossing cycle," 交周 *chiao chou/jiao zhou*, or nodal month, i.e. the time it takes the moon, from the moment its orbit intersects the sun's path, the ecliptic, to return to its next intersection. Because the Chinese used equatorial coordinates, it was necessary to consider the projection of both the lunar orbit and the ecliptic on the equator. The lunar nodes are essential for eclipse prediction.



8. "Day and Night Marks." This explains determination of the lengths of day and night at different times of the year for locations north and south of the capital.

In Chapter 8 Sivin continues his discussion of the "Evaluation of the Season-Granting System," divided here into the following sections (for which numbering continues from the preceding chapter):

9. "Eclipses." This section begins with a paragraph that summarizes its intent: "The test of an astronomical system's exactitude is its treatment of eclipses. In this art of pacing the celestial motions, exactitude is hard to come by." This section includes consideration of numerous eclipses from past records, including two ancient solar eclipses and 37 eclipses recorded in the Spring and Autumn Period (722-481 BCE). In fact, Sivin includes a table of eclipses, the "Evaluation" having omitted a partial eclipse of 655 BCE; Sivin also includes modern computations. The Evaluation also lists 35 solar eclipses from the Three States on (221-280 CE), where comparisons with the Great Enlightenment system are offered as a systematic proof of the superiority of its immediate successor, i.e. the Season-Granting System. Another subsection here is devoted to lunar eclipses of former eras, 45 in all, with scores for the accuracy of lunar eclipse predictions included for both the Season Granting-System and the Great Enlightenment System.

10. "Corrected Conjunctions." This refers to the determination of a celestial position by adding a correction to its mean value. This section considers how the concept evolved and its use in the Season Granting System.

11. "Disuse of Accumulated Years and Day Divisor." These were two features of early systems that the Yuan astronomers rejected. The first, "accumulated years," was the practice of counting all cycles from a single epoch in the very distant past. The second was the use of what Sivin dubs "elaborate fractional parts," for example, calculating the synodic month as 29 499/940 days. This section also contains a comparison of 44 astronomical systems. As Sivin emphasizes, their use (or disuse) was often a matter of technical quality or court politics: "If we wish to understand their content and originality, comprehending the political and personal as well as the astronomical dimension is indispensable."

The next two chapters are devoted to translation and commentary on the "Canon of the Season-Granting System." Here Sivin divides the Canon into two parts, corresponding to the two chapters of the original Canon. Chapter 9 includes the following four sections:

1. "Pacing the *Ch'i* and Lunations." This concerns the basic lunar-solar divisions of the civil calendar, computation of the date of the winter solstice for a given year, and other phenomena, including dates of mean quarter moons, the full moon, and following conjunction, the dates at which to insert 16-day rather than the standard 15-day *ch'i*, and dates at which to insert 29-day rather than 30-day months. The Canon directs explicit computations for determining the various dates under consideration.

2. "Pacing the Putting Forth and Gathering In." This chapter is devoted to the determination of when intercalary months needed to be inserted into the calendar, determination of the *ch'i* divisions of the tropical year, and various basic time conversions. The tropical year was divided into twelve *ch'i* (30.44 days long); these were further subdivided into two halves, nodal and medial halves of 14.22 days, and these were in turn further subdivided into three phases, or *hou*, of 5.07 days. Since each *ch'i* is nearly 30 ½ days long, intercalary months were needed to adjust for this accumulating surplus.

3. "Pacing the Tread of the Sun." 日躔 *jih-ch'an/ri chan* refers to the apparent rather than mean motion of the sun. Among computations explained here are those to determine solstices, lunar syzygies, the apparent equatorial position of the sun at winter solstice, equinoxes and summer solstice, midnight and noon positions, in particular midnight and noon preceding solstices and equinoxes.

4. "Pacing the Travel of the Moon." Like the previous section for the sun, this section is devoted to computing various aspects of the motion of the moon, including quarter moons, full moons, and next conjunctions, tabulation of the moon's equation of center, apparent daily motion, apparent lunar syzygie, equatorial positions of the apparent moon for solstices and equinoxes, as well as times of midnight, dawn and dusk, for the apparent moon at syzygie.

Chapter 10 brings the Canon to an end, with three chapters consecutively numbered from the preceding section as follows:

5. "Pacing the Centered Star." The "centered star," 中星 *chung-hsing/zhong xing*, is whatever star crosses the meridian at a given moment. This was a means for telling the time at night based upon knowing when a particular



star crossed the meridian. Here computations are explained for determining declination and polar distance of the ecliptic, the lengths of night and day, times of sunrise and sunset, the times and lengths of night watches and their subdivisions, the nightly arc of stellar motion, the positions of stars that culminate at dusk, dawn and each night watch, and the day and night marks for any latitude.

6. "Pacing Crossing Coincidences." 交會 *Chiao-hui/jiao hui*; "crossing coincidences" refers to conjunctions, *jiao* meaning intersection and *hui* a gathering or meeting. Here computations determine when the sun or moon transits lunar nodes, solar eclipses taking place at the lunar node, lunar eclipses at opposite nodes. Computations include times for lunar opposition, conjunction, the midnight preceding apparent conjunction and opposition, corrections for the effect of parallax on the time of the maximal phase of an eclipse, determination of the apparent sun at maximal phase of eclipse, parallax corrections, intervals from node to syzygy for lunar and solar eclipses (including their magnitude and duration), determination of lunar eclipses in night watches, the magnitudes of solar and lunar eclipses at sunrise or sunset, and the sun's ecliptic location at maximum phase of solar or lunar eclipses.

7. "Pacing the Five Stars." This section of the Season-Granting System was copied almost in its entirety from its predecessor, the Revised Great Enlightenment System of 1180. This is devoted to planetary theory, with the derivation of three constants used for all five planets, and then separate computations of constants and tabular models for their various phases of motion. The planets were named according to the five Chinese elements: Jupiter, 木星 *mu-hsing/mu xing*, the wood star; Mars, 火星 *huo xing*, the fire star; Saturn, 土星 *tu xing*, the earth star; Venus, 金星 *jing xing*, the metal star; and Mercury, 水星 *shui xing*, the water star. In this section solar conjunctions with each of the planets are computed, along with the changes in apparent velocity for the planets, the apparent positions of each planet at midnight, as well as last and first appearances for each of the planets. Velocities were also carefully measured to compute retrogradations and stationary points.

After 550 pages of introductory material, translated text and commentary, Sivin devotes his closing Chapter 11 to his "Conclusion." Overall, he sees no real history of continued progress in Chinese astronomy—not all successively later systems were better than their predecessors. Some changes that were praised as advances turned out to be retrograde astronomically, while other excellent systems were rejected, often with severe criticism, for political reasons, despite their technical merits. As Sivin points out: "Pitched battles were not only due to technical disagreements; the importance of the almanac to state ritual made computational systems a natural target for attacks by political factions. Evaluations after the fact by historians carry their own difficulties." With this in mind, Sivin then sets out to evaluate the overall significance of the Season-Granting System and its technical achievements.

He begins by pointing out how far the history of science has come since Joseph Needham launched his multi-volume study of Chinese science and technology. Largely assuming that the standard of excellence was how well ancient Chinese theories compared with modern practice, this meant determining to what extent something like the Season-Granting System gave correct answers, or how often and to what extent was it wrong? Instead, Sivin's approach attempts to understand the cultural manifold within which the Season-Granting System came into existence, and his goals are correspondingly much more illuminating and ambitious: "What I am trying to reconstruct is the complex of social, political, intellectual, and technical relations and meanings within which individual astronomers did their own work." He lists his three major goals explicitly:

1. What were the authors or planners trying to accomplish?
2. To what extent did they accomplish this goal?
3. To what extent is it worth accomplishing?

As to the first question, the Yuan Evaluation makes it clear that the major goal of the Season Granting System was to improve on the failed techniques of its predecessor, the Revised Great Enlightenment System. New instruments were built for this project, observations of polar altitudes and other data were made across the empire, with special attention paid to winter solstices, length of the tropical year, apparent solar and lunar motions, motion of the lunar nodes, and the variable lengths of day and night. Kuo Shou-ching also introduced new methods for computing apparent solar and lunar motions, converting between equatorial right ascension and ecliptic longitude for determining the obliquity of the ecliptic, and for converting the moon's position on its orbit to ecliptic longitude. However, in reply to his second question, Sivin suggests there is "good reason to believe that the reformers aimed for more innovation than they attained."

Beyond this, Sivin points out that because the astronomers involved in the Yuan astronomical reforms were

establishing the political legitimacy of a new dynasty, they were “dedicated functionaries of the Mongol regime in North China, and in all of their very diverse careers worked to spread its power to the south, to reunite China.” This meant that social and moral, as well as political goals, were always in mind.

In retrospect, the Season Granting System was largely successful in so far as it remained with only minor modifications the official astronomical system used in China until the Jesuits arrived and the official Astronomical Bureau was placed in their hands. This was done with the intent of using the more accurate methods of western astronomy for Chinese purposes, but that did not happen until 1644. Meanwhile, in Korea and Japan, the Season-Granting System remained in use considerably longer.

To conclude, Sivin turns to the difficult but necessary question of what should be the rightful place of Chinese or East Asian astronomy generally in the overall history of astronomy? Until recently, Asian astronomy has largely been ignored by historians of astronomy, who write as if the entire history of the subject were simply a western development, a succession of modifications of Hellenistic astronomy until the time of Newton. But as Sivin emphasizes, European thought in mathematics, astronomy, and natural philosophy were all influenced by such non-European novelties as Arabic numerals and algebra, Indian trigonometric functions, and Chinese paper and printing. In fact, Sivin sees early modern (western) science as “an endless series of territorial, ethnic, and racial mixings.”

Considered for its own intrinsic interest, if the value of the Season-Granting System is reflected in its accuracy (as Sivin points out, one of the goals of the Yuan system was to achieve “unprecedented accuracy”), then for the most basic data needed for the calendar — predictions of solstices and lunations, for example — the Season-Granting System is far more accurate than needed for purely practical purposes. As for eclipses, the accuracy of the Season Granting System’s predictions reflect the quality of a number of related matters — including quality of determining apparent solar and lunar motions, the obliquity of the lunar orbit with respect to the ecliptic, and the accuracy of timekeeping. By Sivin’s own calculations and those recounted in the Evaluation, “the Season-granting system indeed attained the clear superiority in accuracy that the Evaluation claimed.” The one area in which the system did not pretend to present any innovations was its wholesale adoption of the system for “Pacing the Five Stars” (7 above), to be found in the Revised Great Enlightenment System of 1180. The reason for this, most probably, was that planetary positions were not as important in the Chinese context as they were for western astrology. Nevertheless, precision and accuracy are not the only measures of success that matter. As Sivin wisely puts it: “Given our ignorance, it will be some time before the results of investigations can make possible a textured estimate of the Yuan astronomers’ accomplishment.”

As the most mature development in Chinese astronomy that prevailed for 350 years, the Season Granting System has an important place in the history of Chinese science. In particular, in the history of astronomy it serves to show the remarkable attainments of Chinese computational methods. Moreover, as Sivin points out, it was the result of “a bureaucratic project of larger dimensions than was conceivable elsewhere.” He goes on:

China’s rich records can throw light on the intermarriage of various technical traditions in the Islamic world that eventually made possible the emergence of modern astronomy in Europe. Chinese astronomy, in any open-minded history of astronomy, will reward attention commensurate with its importance. The Season-granting system has allowed us a close look at the high point of that tradition, which spanned without interruption nearly two thousand years.

Two appendixes in Sivin’s account are also noteworthy and deserve readers’ attention. The first, Appendix A, is devoted to the instruments designed by Kuo Shou-ching and described in detail in the “Treatise on Astrology” that was included as part of the Yuan History. Although Sivin shows that the actual instruments built for the Ta-tu observatory differed in significant ways from these specifications, unfortunately none of which survive, several are pictured. The second Appendix B is an edited “account of conduct,” namely of the life and works of the astronomer Kuo Shou-ching, based upon the account by his colleague, the astronomer and polymath Ch’i Lü-ch’ien, to be found in the official biography in the *Yuan History*.

Suffice it to say that historians of science will find this an eye-opening and informative book, well worth the attention it deserves to be read carefully. It is full of detail on every page, from which a good, basic understanding of the goals and achievements of Chinese astronomy may be derived. But the attentive reader will also find that in his approach to illuminating the cultural matrix within which he situates a broader understanding of the Season Granting System, Sivin has done much more than simply provide the detailed analysis of a significant example of astronomical theory and practice—he has shown how the accomplishments of Chinese science deserve to be studied

and considered on a comparatively equal footing with that of western science.

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## Reader Reviews

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