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THE FIRST CHINESE VERSION OF THE NEWTONIAN TABLES OF THE SUN AND MOON

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Abstract: This paper begins with an examination of the context of the production of the first Chinese version of the Newtonian tables of the Sun and Moon, and argues that the compilation of these tables by Jesuit astronomers in China was a response to the challenge of native Chinese astronomers to their authority in the official Bureau of Astronomy. Then the relationship between these tables and those eventually incorporated in the *Later Volumes of the Thorough Investigation of Calendrical Astronomy Imperially Composed* is discussed from a comparative perspective. It is found that these two sets of tables were based on the same set of underlying principles, although the earlier ones are more compact in format than the later ones. Finally, possible European sources of the tables are explored, and the paper concludes with the argument that the tables were a result of reconstruction by the Jesuit fathers in China on the basis of Newton's theory of the motion of the Moon, Grammaticus' luni-solar tables, and new data from other leading astronomers in Europe (such as Cassini).

There were two milestones in the history of Chinese predictive astronomy in the seventeenth and eighteenth centuries when China was under the influence of Western science through the Jesuits. The first one is the compilation of the *Chongzhen Lishu* 崇祯历书 (*Chongzhen Reign Treatises on Calendrical Astronomy*) between AD 1629 and 1634, which provided Chinese astronomers with a system of computational astronomy based on Tychonic schemes of planetary motions and many new achievements in astronomy since Copernicus. This book became the linchpin of official astronomy of the newly-established Qing Dynasty in 1644 under the new title *Xiyang Xinfa Lishu* 西洋新法历书 (henceforth XXL), or *Treatises on Calendrical Astronomy According to New Methods from the West*. The key person in the erection of this milestone was the famous German Jesuit astronomer, Johann Adam Schall von Bell (1591–1666).

The system laid out in the book was kept in use by the Qing Bureau of Astronomy without substantial change until 1730, when the second milestone was set up by another German Jesuit, Ignaz Kögler (1680–1746; Dai Jinxian, 戴进贤 is his Chinese name), who arrived in China in 1716 and was Director of the Qing Bureau of Astronomy from 1726 to his death. In the late 1730s, he masterminded and chiefly compiled a new book entitled *Yuzhi Lixiang Kaocheng Houbian* 御制历象考成后编 (henceforth LKH), or *Later Volumes of the Thorough Investigation of Calendrical Astron-omy Imperially Composed*. Completed in 1740 and published two years later, this book (Figure 1) is responsible for the earliest introduction of Newton's theory of the motion of the Moon into China for practical purposes (Dehergne, 1973: 137; Han, 1993; Lu, 1997; Pfister, 1932-34: 650; Shi, 1995: 34; Shi, 1996b). This was adopted as the orthodox version of imperial astronomy during the Qing Dynasty, and persisted for more than one and a half centuries, until the fall of the Dynasty (Shi Yunli, 2003). This book raised the accuracy of Chinese predictive astronomy to a totally unprecedented level.

The new book comprised ten *juan* (卷) or volumes (Hashimoto, 1971; Shi, 1996b), which can be divided into two major parts. The first part, *juan* 1 to 3, is the 'theoretical' portion devoted to the so-called *shuli* (数理), or mathematical principles, wherein the motions of the Sun and the Moon, including eclipses, are demonstrated to reveal the underlying principles for practical calculations.

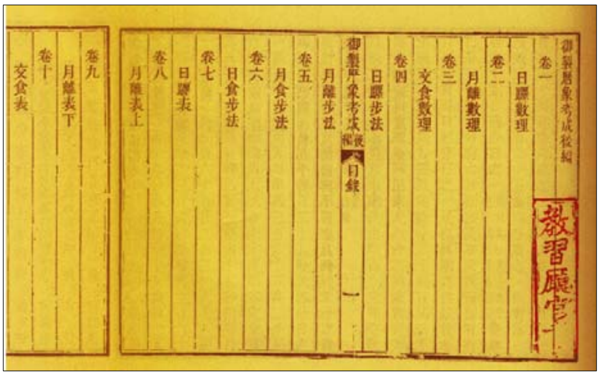

Figure 1: The table of contents of LKH (after Yunlu et al., 1742).

The second part, *juan* 4 to 10, is the 'practical' portion devoted to the so-called *bufa* (步法), or computational methods. Two sets of computational methods are given for predictive calculations of the Sun, the Moon, and solar and lunar eclipses. Firstly a set of algorithms derived from the aforesaid underlying principles was explained in the first part, and then the procedures based on pre-calculated tables were furnished in the same part of the book. The core of these pre-calculated tables is a set of solar and lunar tables based on the rules suggested by Newton in his *Theory of the Moon's Motion* (TMM) published in 1702 in both English and Latin.[1] They opened a new era in the history of calendrical work in China.

It is noteworthy, however, that this set of tables was not the first Newtonian tables published in Chinese. According to Gu Cong, the Minister of Rites of the time, a set of new tables had been compiled ten years before 1742, which had been used in practical calculations at the official Bureau of Astronomy of the Qing Dynasty (Yunlu et al., 1742, front matter, memorials: 4b-5a). In a letter dating back to 1732, Andreas Pereira (1689-1743, Xu Maode 徐懋德 is his Chinese name), the then Vice-Director of the Bureau of Astronomy during the Qing Dynasty, verified that the Jesuit astronomers at the Qing Bureau of Astronomy did present a set of new tables to the throne shortly after 19 November 1731 (Rodriges, 1925: 95).

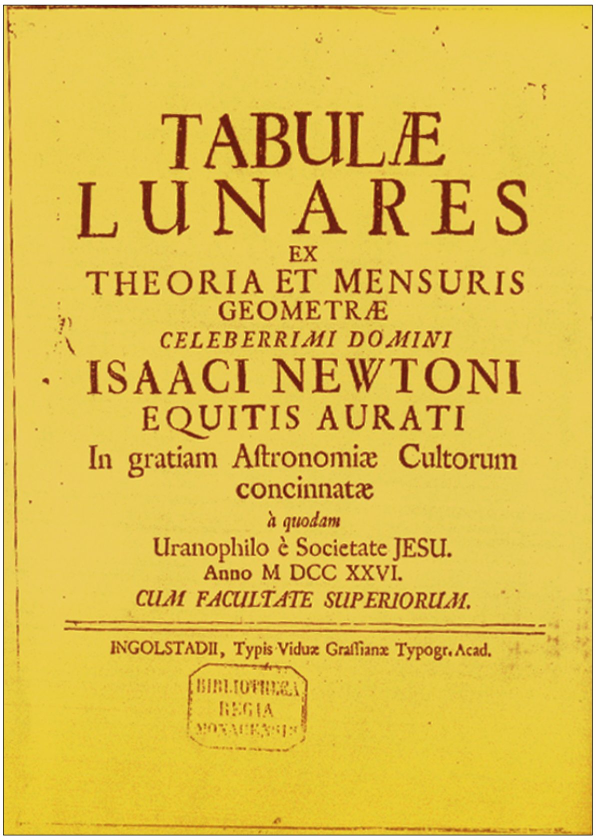
TABULÆ
LUNARES
EX
THEORIA ET MENSURIS
GEOMETRÆ
CELEBERRIMI DOMINI
ISAACI NEWTONI
EQUITIS AURATI
In gratiam Aſtronomiæ Cultorum
concinnatæ
à quodam
Uranophilo è Societate JESU.
Anno M DCC XXVI.
CUM FACULTATE SUPERIORUM.
INGOLSTADII, Typis Viduæ Graſſianæ Typogr. Acad.

Figure 2: First page of Grammaticus' tables (permission from Bayerische Staatsbibliothek).

So where are these earlier tables, and are they similar to the tables eventually published in the LKH? Recently, we examined a set of Chinese tables of the Sun and Moon preserved in the library of Paris Observatory, which turned out to be the set of tables compiled by Kögler and Pereira in late 1731. This paper will present some results of our preliminary analysis of this set of tables. We will try to answer three questions about these tables: (1) What was the context of their production? (2) What was their relation to the tables in the LKH? (3) What was their possible source?

Emperor Kangxi was very much in favor of Jesuit astronomers and quite versed in Western mathematics and astronomy after several years studying with several Jesuit astronomers, and in 1713 he established a Mathematical Academy within his court (Han, 1999a). One important work issued by the Academy was the re-edition and revision of XXL. The resulting edition, *Yuzhi Lixiang Kaocheng* 御制历象考成 (LK), or *Thorough Investigation of Calendrical Astronomy Imperially Composed* (Hashimoto, 1970; Shi, 1994a), had been completed by 1722. Two years later, it was published as the first of the three books devoted to astronomy, harmonics and mathematics, respectively, which comprises the magnificent series that is prefaced by Emperor Yongzheng and bears the boastful title *Yuzhi Lüli Yuanyuan* 御制吕历渊源 (*Origin of the Harmonics and Calendrical Astronomy Imperially Composed*).

At first glance, the compilation of LK seems to be nothing more than a revision and re-edition of the old XXL in order to get rid of the technical defects and obscurities existing in that book. But Han Qi (2002) has made it clear that the whole project was meant to be a very important step in accelerating the Chinese assimilation of Western astronomy in China, and breaking the Jesuit monopoly over astronomical affairs within the country. The project was commissioned exclusively to native scholars who worked independently of the Bureau of Astronomy which was then technically dominated by Jesuit astronomers. No names of any Jesuits appear in the long list of those who compiled the *Origin of Harmonics and Calendrical Astronomy Imperially Composed* (Jami, 2001: 701-702; Yunlu et al., 1724, front matter, names of officers: 1a-4a). However, most of the contents are based on knowledge introduced by the Jesuits from Europe (Englefriet, 1998: 437-438; Jami, 1989; 2001: 701-702), and Jesuit astronomers were frequently called upon for advice during its compilation (Han, 1999). Moreover, the major members of Kangxi's Academy, including Mei Yuecheng 梅珏成 and He Guozong 何国宗, were stubborn adversaries of the Jesuit astronomers (Han, 2002). After the publication of LK, they began to openly challenge the Jesuit authority in astronomy, and they suggested to the Emperor that the Directorship of the Bureau of Astronomy should now be assigned to a member of the Academy, such as Mei Yuecheng, rather than to Europeans (Rodriges, 1925: 88-89).

Facing this kind of challenge, the Jesuit astronomers in Beijing decided on a counter offensive. In 1727 they received the *Tabulae Lunares* (Grammaticus, 1726), written by the German Jesuit astronomer Nicasius Grammaticus (see Figure 2), which turned out to be the first Newtonian tables of the Sun and Moon ever published in Europe.[2] During the lunar eclipse on 19 August 1728, predictive calculations made with the tables of La Hire and Grammaticus were compared with the actual observation and the result was clear: "The observation was very different from the calculation of la Hire's tables, but extremely close to the calculation made with the papers sent here from Germany last year. They are solar and lunar tables according to Newton's system." (Gaubil, 1970: 213). The Jesuit astronomers in Beijing also decided to use the solar eclipse of 15 July 1730 as a test case, as it was the first solar eclipse of large magnitude visible from Beijing since the publication of LK. Before the eclipse, Kögler and Pereira submitted their prediction using the new method to Ming Tu, the Manchu Director of the Bureau of Astronomy, and reported to him the error of the prediction made with LK. After an observation of the solar eclipse that verified what they reported, Ming Tu presented a petition to Emperor Yongzheng, confessing tactically that "slight errors" of LK had been detected through the observation while the prediction made independently by Kögler and Pereira had proved to be correct. He thus proposed that a decree be issued to the two Jesuits so that they could organize some skillful personnel to conduct a thorough investigation and to make the necessary corrections (Rodriges, 1925: 91-93; Yunlu et al., 1742, front matter, memorials: 1a-2a). After this proposal had been granted by the Emperor, Kögler and Pereira compiled a new set of luni-solar tables. According to Pereira, the correctness of their new theory was proved again in the same way by the lunar and solar eclipses of 9 November and 29 December 1731, respectively, and the new tables were presented to the Emperor a few days after the observation of the second eclipse (Rodriges, 1925: 95). This indicates that the tables were finished in late 1731.

According to Gu Cong, the new tables were not compiled as a independent book, but as a supplementary part to the tables in LK. In addition, they came with "… neither any explanations on the underlying principles, nor any instructions for computational procedures [on the basis of the tables] …" (Yunlu et al., 1742, front matter, memorials: 4b-5a). These two features apply exactly to the tables preserved in the Paris Observatory which we have analyzed (Figure 3). The tables are printed under the title *Yuzhi Lixiang Kaocheng Biao* 御制历象考成表 (LKT), or *Tables of the Thorough Investigation of Calendrical Astronomy Imperially Composed*. Before each table, there are some words explaining the major terms listed in the table as well as how to find the value corresponding to a given variable. However, we could not find any word explaining how the values in the table were calculated and how these tables can be used in practical computations relating to the Sun and the Moon.

Our comparison shows that these tables are basically similar to the tables incorporated in the *juan* 8-10 of LKH, except for the following minor differences:

(1) The tables in LKT are printed in two *juan*, while the tables in the LKH are presented in three *juan*.
(2) LKH includes three tables that do not appear in the LKT, one relating to the calculation of the angles between the ecliptic and different meridians, and the other two relating to the calculation of the syzygy.
(3) The tables in the LKT are generally more compact than those in the LKH. For example, in the Table of the Equation of Center of the Sun the values of the equation of center are pre-calculated for every degree of the mean anomaly of the Sun, while the same values in the LKH table are pre-calculated for every arc minute of the mean anomaly of the Sun.
(4) Some tabulated values in the LKT tables have slight errors, but these have been corrected in the LKH tables.

From the last two points it is clear that Kögler and Pereira recalculated these tables during the compilation of the LKH.

Up to now, no unanimity has been reached over the exact source of the solar and lunar tables in LKT and LKH. While some scholars believed that Kögler and Pereira "… had referred to Whiston's [tables] in *Praelectiones Astronomicae* …" (Lu, 1997: 178) during their composition of the tables, others suggested that the tables were translated from Newtonian tables such as the Grammaticus tables. For example, Dehergne (1973: 137) notes that Kögler translated into Chinese the *Tables of Newton* and Grammaticus' *Lunisolaires Tables*. Obvious confusion and misunderstanding have been caused by this uncertainty, and this can be seen from a recent remark on the history of the LKH tables:

> … the earlier two tables of solar and lunar motions that Kögler appended to the *Lixiang kaocheng* were based on Nicaise Grammatici's tables. However, Kögler had officials of the Astronomical Bureau translate the new tables for solar and lunar motion based on Newton's theory without providing explanation of instruction for computating … The result of the revision, commissioned in 1737 and printed in 1742, was entitled *Lixiang kaocheng houbian* … The tables [in it] were based on Cassini and Flamsteed's method of calculation … (Haslberghe and Hashimoto, 2001: 724-725).

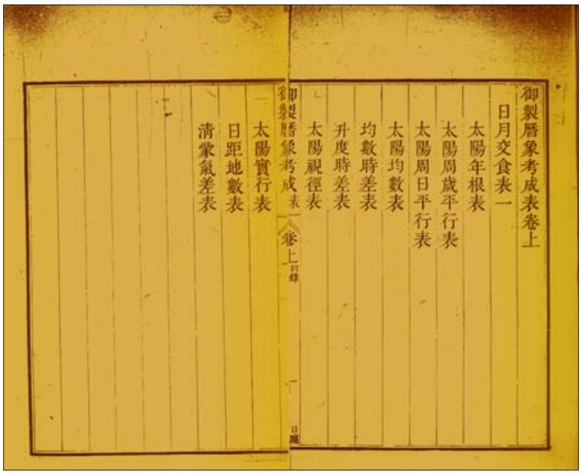

Figure 3: First page of LKT (courtesy of the Library of Paris Observatory).

There is an anonymous note in the front of the LKT preserved in the Paris Observatory, and this dates to 13 July 1734 and begins with the following words:

> Tables Lunisolaires du R.P. Grammatici — tranduittes en Chinois et Imprimées à la Chine par les soins R.P. Ignace Kögler et Andé Perira. (Kögler and Pereira, *ca.*1732: the cover page).

From this note (Figure 4) it seems very clear that the LKT is just a translated version of Grammaticus' tables.

Our analysis indicates that there is no reason to believe that these tables have any connection with the solar and lunar tables in Whiston's *Praelectiones Astronomicae*, because Whiston's tables are simply non-Newtonian. In fact, on the title page of his book, Whiston clearly acknowledges his tables as "… being those of Mr. Flamsteed, corrected, Dr. Halley, Monsieur Cassini, and Mr. Street …" (Whiston, 1705).

Nor can we say that Kögler and Pereira simply translated the Grammaticus tables, even though these were the only Newtonian tables available in print before 1730 (Kollerstrom, 2000: 205-223). This is not only because the Grammaticus tables are much more compact in format compared to the corresponding tables in the LKT and LKH, but also on account of the following facts:

(1) The tables of the mean solar and lunar motions in LKT and LKH are all adapted to the meridian of Beijing with the epoch beginning at midnight of 23 December 1722, whereas the Grammatici tables are set to the meridian of Ingolstadt with the epoch

beginning at noon of 31 December 1700, although the same values for the speed of the mean Sun, mean Moon, solar apogee, lunar apogee and node are applied in both the LKT and Grammatici tables.

(2) The maximum value of the equation of solar center in the LKT and LKH is 1° 56′ 13″, while Grammaticus adopted Newton's value of 1° 56′ 20″. The reason for the difference is evidently that while Grammaticus used Newton's eccentricity of the solar orbit (0.016917), Kögler and Pereira adopted 0.016900, which turns out to be Cassini's value (Taton and Wilson, 1989: 193). When compared with the eccentricity of Earth's orbit at the beginning of 1722 (0.016825) and calculated with a modern algorithm (see Meeus, 1991: 151), Cassini's value is better than Newton's.

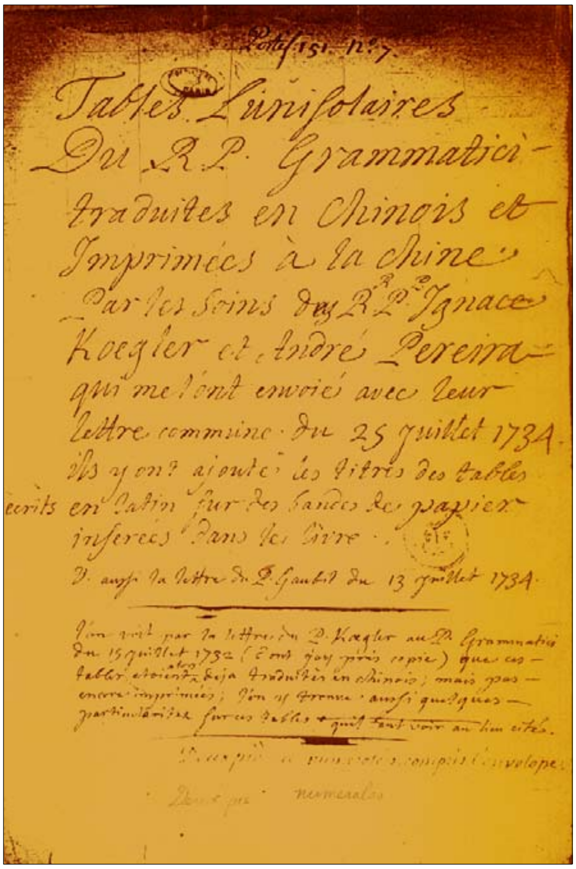

Figure 4: The anonymous note in front of LKT (courtesy of the Library of Paris Observatory).

(3) Since the *yi pinjun* 一平均 (literally, the first mean equations) of the lunar longitude, apogee and node (Newton's annual equations of the Moon, lunar apogee and node) are proportional to and thus have to be calculated from the solar equation of center, the table for these equations in LKT and LKH are also different from the corresponding tables provided by Grammaticus. Therefore, it is not reasonable to say that the annual equation amplitudes of the Moon and the node in LKT and LKH are derived from TMM as some scholars believe (e.g. see Kollerstrom, 2000: 222-223).

(4) The peak values of the *zuigao jun* 最高均 (literally, the equation of apogee of the Moon, which corresponds to Newton's second equation of lunar apogee) from LKT and LKH and the Grammaticus tables are also different. While LKT and LKH give 12° 18′ 15″, Grammaticus' value (1726: 3) only amounts to 12° 17′ 54″.[3] This difference is due to the use of different radii of the Horrox-wheels, or equivalently the maximum and minimum eccentricities of the orbit of the Moon, in the calculation of the equation. While Kögler and Pereira used the same radii as appeared in the TMM, Grammaticus' approach remains a riddle for us.

(5) The peak value of the *Zhengjiao jun* 正交均 (literally, the equation of lunar node, equivalent to Newton's second equation of lunar node) in LKT and LKH tables is 1° 29′ 42″, again differing from the corresponding value 1° 29′ 58″ in the Grammaticus tables. From the LKH it is clear that the model used by Kögler and Pereira in the calculation of this value is an equivalent of Newton's as used in TMM. However, we have no knowledge about Grammaticus' model because he says nothing about it. His peak value turns out to be very close to the value provided by J. Machin in his Scholium to Proposition 33 in Book 3 of the *Principia*, namely 1° 29′ 57″ (Newon, 1999: 864).

(6) The lunar equation of center is handled very differently in LKT and LKH and Grammaticus' *Tabulae Lunares*. LKT and LKH provide a complete table for this equation, whose computational rule is clearly given in LKH (Shi, 2003). However, no corresponding table can be found in the *Tabulae Lunares*. Instead, the readers are instructed to calculate the equation for any given mean anomaly from a couple of intermediate parameters dependent on the angular distance between the Sun and the apogee of the Moon. The intermediate parameters are provided in a table, but Grammaticus simply does not say a word about their source, so that it is very difficult for his readers to figure out the underlying model of his approach to the problem.

From these facts, it is evident that the solar and lunar tables in LKT and LKH are results of new calculations done by Kögler and Pereira. Or more exactly, they are new constructions, rather than simple translations. That must have been the reason why Hallerstein referred to the LKH tables as the "… lunisolar tables constructed from the numbers and measures of the illustrious Newton …" when he sent a copy to the Royal Society of London in 1750 (Hallerstein, 1750: 319-320). Gaubil (1970: 646) has also described the tables in this way. Undoubtedly, after realizing that the Newtonian tables were most suitable for use in China, Kögler and Pereira began to study the underlying theory of the tables. By the early 1730s they had developed a set of computational rules, and they were able to predict the solar eclipse of that year and then calculate the tables in LKT. Then, when asked to compile an explanation for these tables, they simply embodied these rules in *juan* 4 of LKH and developed a systematic demonstration for them, which became the 'theoretical' portion of LKH. Of course, the new tables in LKH were recalculated with the same set of rules. The only difference is that smaller steps of the variables were now applied. Rendering the rules in *juan* 4 of LKH into computer routines, we can generate exactly the solar and lunar tables (*Richan biao* 日躔表 and *Yueli biao* 月离表) in LKT and LKH, given the necessary parameters and conditions.

NOTES

1. The English version is an independent pamphlet, while the Latin version is actually part of David Gregory's astronomical textbook. Newton also included a version of this theory in the second and third editions of his *Principia* (Cohen, 1975).

2. The first claim to have composed 'Newtonian' lunar

tables was made by the French astronomer Joseph-Nicholas Delisle, an earnest promoter of Newtonian philosophy in Europe. He eagerly recommended Newtonian astronomy to continental astronomers including Grammaticus. Although Delisle's network of communications extended as far as to cover Jesuit astronomers in Beijing, his role in the introduction of Newtonian astronomy to China is still an open question (see Kollerstrom, 2000: 208-209, 211; Schaffer, 1990: 267-271, 268).

3. The value is 12° 15′ 4″ in TMM, and 12° 18′ in the second and third editions of *Principia*. Calculating with the procedure and parameters provided in TMM, we find that the value in TMM is a mistake. The correct value should be the one used in LKH. Leadbetter (1729: iii-iv) already noticed this mistake in his book, which was the first ever published to explain how to construct lunar tables on the basis of Newton's TMM.

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The Sun And Moon. Support This Game. The Sun And Moon By Daniel Linssen. Made for Ludum Dare #29. Works best in Chrome and Opera. May contain bugs. If you use another browser please consider downloading the Windows Version. Now on Steam! A + D / Left + Right: move left and right W / Up / Spacebar: jump L Shift / R Shift / Z: action Esc: exit to level select / exit to title screen R: restart level M: mute/unmute audio. website | twitter | email. More information. A Chinese spacecraft has become the first to land on the far side of the moon in a historic moment for human space exploration. The successful touch down was hailed as a major technical feat and is seen as a important step towards Chinaâ€™s wider ambitions in space. The robotic probe Changâ€™e 4 landed in the unexplored South Pole-Aitken basin, the biggest known impact structure in the solar system, at about 2.30am GMT on Thursday. Prior to confirmation of the landing and the release of the first close-up shots of the far lunar surface by the Chinese state broadcaster CCTV, many details of the mis Contemporary English Version Let the king live forever like the sun and the moon. Good News Translation May your people worship you as long as the sun shines, as long as the moon gives light, for ages to come. Holman Christian Standard Bible May he continue while the sun endures and as long as the moon, throughout all generations. International Standard Version May they fear you as long as the sun and moon shine â€" from generation to generation.Â Aramaic Bible in Plain English They shall revere you with the sun and before the moon to a generation of generations. GOD'S WORDÂ® Translation May they fear you as long as the sun and moon [shine]- throughout every generation.