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研究ノート

The Earliest Evidence of the Introduction of Kepler's Laws into China as Observed in the *Lifa wenda*

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Abstract

Recently, we have discovered a manuscript, titled the *Lifa wenda* (曆法問答, Dialogue on Astronomy) by Jean-François Foucquet (Fu Shengze 傅聖澤, 1665-1741), at the British Library in London. On several pages of the manuscript, Copernicanism is referred to in connection with the explanation of planetary motions. More importantly, we find the earliest evidence of the introduction of Kepler's laws into China. Here we have elucidated made clear of the character of the discussions of elliptic orbits described in the manuscript. Since it was prepared in Chinese in Beijing in the 1710's, this is definitely the earliest evidence of a description of Kepler's laws in China. This completely predates the Chinese introduction, which had previously been thought to have occurred in 1742. The present paper also discusses the fact that Cartesian physics was also introduced in the manuscript.

Keywords : Kepler's Laws Copernicanism *Lifa wenda* J.-F. Foucquet China Introduction Manuscript Earliest Evidence Cartesian

抄　録

中国清代の康熙帝期の1710年代にイエズス会のフランス宣教師 J.-F. フーケが北京で完成した稿本『曆法問答』には，コペルニクスの太陽中心説が紹介され，またケプラーの法則が論じられている。前者については，これまで知られている中国に公式的に紹介された年代よりも半世紀は溯るものであり，後者については，四半世紀ばかり時代的に早くなるという結果になる。この稿本の一部分にあたるものがヴァチカン図書館に所蔵され，また完本に近いものが大英図書館に所蔵されていることが，筆者らの調査によって明らかになり，内容の分析の結果，こうした事実を突きとめることができた。この研究ノートでは，さらにデカルト，ないしデカルト主義者の力学をめぐる議論が惑星の運動を論じた個所においてなされていることについても紹介するものである。

キーワード：稿本『曆法問答』 コペルニクス説 ケプラーの法則 デカルト主義 イエズス会 宣教師フーケ 中国 大英図書館 ヴァチカン図書館

Recently, we have found the manuscript, titled the *Lifa wenda* (曆法問答, Dialogue on Astronomy) by Jean-François Foucquet (Fu Shengze 傅聖澤, 1665-1741), at the British Library[1]. Together with the other, partial, but, otherwise identical, version, which had been located at the Vatican Apostolic Library[2], the manuscript, especially Book V, Part 1, from the British Library, gives us the detail of how Kepler's first and second Laws introduced into China as early as in the 1710's. This means that we can go back the history of the introduction more than two decades earlier than the so far believed date.

On the other hand, when the *Chongzhen lishu* 崇禎曆書 had been compiled for several years from 1629, although Kepler's optical astronomy was extensively introduced, we cannot find the slightest evidence of the description of his Laws in it. Thus, the *Lifa wenda* can be regarded the earliest evidence, in which Kepler's Laws were openly discussed.

In connection with Kepler's Laws, Copernicanism was also discussed particularly concerning the instrumental model of the solar system, that is the Orrery, manufactured by O.C. Roemer, which had been brought to China by the French Jesuit missionaries and presented to Kangxi Emperor as from the French King, Louis XIV[3]. On several pages of the manuscript, Copernicanism is referred to in connection with the explanation of planetary motions as well. The latter of the evidences shows that Copernicanism had been introduced into China almost half a century before M. Benoist did in his *Treatise on the Earth* (*Kunyu quantushuo* 坤輿全圖説) in 1767[4]. Both of them can drastically change our understanding of the history of astronomy in China. First we should like to discuss the problem of the earlier introduction of Kepler's Laws.

1. Kepler's Laws

First of all, let us see how Kepler's Laws were accepted and developed in Europe

1) Oriental and India Office Collections, OR Add. 16634.
2) Borgia Cinese 319(1) and 319(2). Cf. Hashimoto & Jami 1997. In the paper, we have shown the table of the contents (cf. Table 1).
3) Nissen, Andreas, *Ole Roemer*, Copenhagen, 1944; p.32.
4) Yabuuti, Kiyosi, *Chugoku no Tenmon Rekiho*, Tokyo: Heibonsha, 1969, p.171.

after Kepler's introduction of elliptic orbits, replacing the combination of circular motions. According to C. Wilson, Ismael Boulliau was objecting to the magnetic mechanism hypothesized by Kepler to account for the eccentricity of the planetary orbits[5]. And, he composed the *Astronomia philolaïca* in 1645. Boulliau had imagined another way of deriving elliptical orbits from uniform circular motions, proposing for the first time, "from the general circumstances of planetary motion", that these orbits are elliptic. According to Boulliau, the circles lie in a cone and the mean motion takes place about the axis parallel to the base[6]. He failed to recognize that this implies an equivalent uniform angular motion about the non-solar focus; the hypothesis is thus equivalent to the empty-focus equant that Kepler's "Uranian friend" Albert Curz had proposed for the Moon (, to which Kepler refers in the *Rudolphine Tables*, 1627).

In the *Astronomia geometrica* of 1656, Seth Ward assumes that the "simple elliptical hypothesis" with the superior focus as equant point is true. Both Kepler and Boulliau had failed to recognise its truth. Another proponent of the simple elliptical hypothesis was Emile-François Pagan, who in 1657 published *La thëorie des planëtes*[7].

Now let us see how Foucquet describes and introduces the discovery and development of the theory of elliptic orbits in the *Lifa wenda* (Dialogue on Astronomy), which must have been prepared probably between 1712 and 1716[8]. In Book V Part 1, he begins the explanation of the development of European astronomy with the recent sixty-years development of the astronomical instruments and observational achievements in Europe[9], particularly after the establishment of the Paris Observatory, and alludes to the installation of the telescope mounted with micrometer (*liang wei ge* 量微格[10]) there.

5) Wilson, Curtis, "Predictive astronomy in the century after Kepler," Taton & Wilson 1989, 161-206; p.172.

6) Wilson 1989, p.173.

7) The full title is *La thëorie des planëtes du Comte de Pagan. oü tous les orbes celestes sont geometriquement ordonnez, convert le sentiment des astronomes.* Cf. Wilson 1989, p.178.

8) ARSI, Jap. Sin. II 154.

9) *Lifa wenda* V-1-1. In the introduction of the Treatise on Lunar Motion, Foucquet first discusses this topic in detail in Chapter III-1.

10) Book III Part 1, ff. 72a-b.

First of all Foucquet discusses the necessity of introducing the elliptical orbits in place of the combination of circular motions. Before the discussion of the problem of Martian motion, he particularly emphasizes the shift of the perihelion of the orbit of Mercury in order to demonstrate the inadequacy of circular motions. Then he describes how the recent observational results show the discrepancy from the theoretical calculations.

Foucquet tried to show how recent telescopic observations had become precise by reporting Huygens's determination of Saturn's ring making use of his long telescopes from 3rd March 1655, through 16th 1656, to 12th 1659[11]. In the manuscript, *Lifa wenda*, he explains the result with the heliocentric model of the solar system as Huygens did. Foucquet also tries to emphasize the importance of Cassini's telescopic observations of the surface of Jupiter, including a dark spot appeared between 1690 and 1691[12].

Kepler had derived the elliptic orbit of Mars making use of Tycho's observations of opposition. We can observe four observational data reduced from Tycho's observations in the *Lifa wenda*[13]. We can find these data cited from the *Almagestum novum* in 1651 by the Bolognian Jesuit astronomer, G.B. Riccioli, of which had been made use by Boulliau. Based on these data, together with other observational results by various astronomers in Europe, Foucquet tries to emphasize the inevitability of the introduction of the non-circular motions of the planets.

Then he discusses the mechanistic "necessity" of the introduction of elliptic orbits, alluding to the Cartesian physics, which we can observe immediately after the discussion of the non-circular motion of Mars[14]. We shall see this problem below soon.

Although Foucquet failed to give any illustrations to explain the geometrical orbit of planets in the manuscript, we can reconstruct what he means to describe, that is, the elliptic orbits in terms of Kepler's method. Following the explanation of Kepler's Laws, he discusses Boulliau's so-called revised method, Pagan's (Bagan 巴岡) simple method,

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11) V-1, ff. 3a-5b. The micrometer is described here.

12) V-1, 8b. Cf. The dark spot on Jupiter produced by the impact of Shoemaker- Levy 9 comet in 1995. As to Cassini's observation, see Tabe et al 1997.

13) V-1, ff. 36a-45b.

14) V-1, ff. 43a-45b.

and Riccioli's (Li-zhuo-li 利酌理) spiral orbit, successively.

Let us see his description of the so-called Kepler's method (Ke-bo-er *zhi fa* 刻白爾之法), in place of the areas rule, in the manuscript itself. He writes as follows:

> '(After having studied the record of observations of Mars by Tycho Brahe,) Kepler for the first time abandoned circular motions, and adopted the ellipse (*Dan-xing-xian* 蛋形線) for the orbit of Mars.'[15]

Here he did not use the term *Tuo-yuan* 橢圓[16], which became the standard representation after the compilation of the *Shuli jingyun* 數理精蘊 in 1723. In order to explain the new method (*Xinfa* 新法), he describes the geometry of ellipse, emphasizing the importance of understanding the character of it.

Foucquet constructs the ellipse, on which a planet moves, and also its auxiliary circle, and discusses the properties of the auxiliary circle. Firstly, he draws the auxiliary line, which is perpendicular to the major axis, then he shows that the ratio HF:GF is proportional to the ratio of the minor axis of the ellipse to the diameter of the auxiliary circle. Here HF is named the *liexian* 列線 and GH the *chengxuan* 正弦. And he goes on to show that the ellipse has two focuses (*juguangjuhuodian* 聚光聚火點, or abridged as *judian* 聚點), on the lower of which the sun is located (Fig. 1).

After that Foucquet explains the areas rule of Kepler[17]. He discusses how the planet moves on the ellipse about the sun. And, for the explanation, he makes use of Riccioli's representation, which we can read in the *Almagestum novum*(1651). Riccioli tries to discuss the areas rule introduced by J. Kepler[18]. Obviously Foucquet must have been describing the method, as a whole, relying on the contents of explanation as well as the illustrations from Riccioli's book (Fig. 2).

He also alludes to the cause of the elliptical motion of planets like magnetic force,

15) V-1, f.47b.

16) In the preface to the treatise on planetary motions, we observe as the term, *tuo-yuan*, has been used for the shape of orbits, oval or ellipse, other than circle (V-1, f. i). The term, *tuoyuan-xing*, with the hand radical for the character, *tuo*, has first appeared in the *Celiang quanyi* 測量全義, *quan* 6, in the *Chongzhen lishu*, where the conic sections are discussed. See the *Xinfa suanshu* 新法算書 edition, *quan* 92, p.9a, l.2; Taibei reprint version, 1972.

17) V-1, ff.50a.

18) V-1, ff.51b-52b.

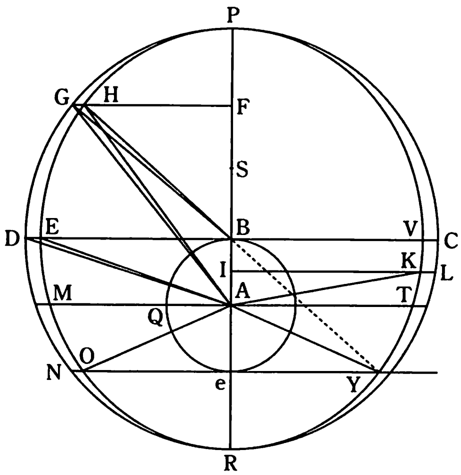

Fig. 1 From Riccioli's *Almagestum Novum* (1651), p.531.

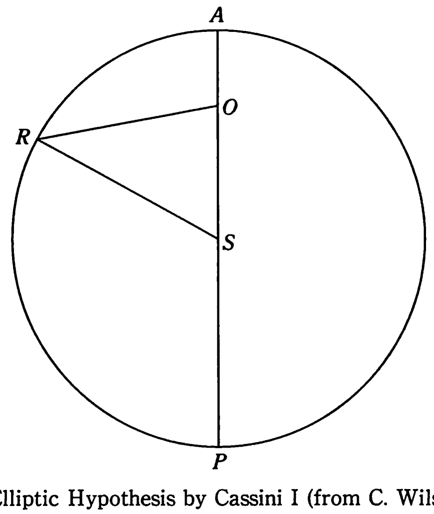

Fig. 2 The Elliptic Hypothesis by Cassini I (from C. Wilson, 1989, p.182)

which Kepler used. But, he declines Kepler's analogy, and follows Descartes' physics of the cause of motion. By doing so, he starts to introduce Boulliau's method as well as Pagan's so-called simple method, which used the second focus as the equant.

It is interesting to observe Cassini's method explained as the fourth method in the *Lifa wenda* under discussion. He assumed the simple elliptic hypothesis; if S is the focus where the eye (or Sun or Earth) O is the centre of the ellipse, ARP a circle with radius equal to the semi-major axis of the ellipse, and if the true anomaly is $v_R = < ASR$ and the mean anomaly M_R, then $<AOR = 1/2\ (M_R + v_R)$ (see Fig.3), where $AB = v_A - v_B$, $DF = M_A - M_B$, $BC = v_B - v_C$, $DE = M_B - M_C$: only the differences in true and mean anomaly being observationally determinable[19]. The intersections G and H fix the line GH on which point O, the centre of the ellipse is found by dropping a perpendicular from B. As the text suggests[20], he invented *cassinoid*, with the aim of obtaining a possible orbit for the planets in which the superior focus would serve as the equant point, and introduced another kind of elliptic orbit[21].

As the fifth method he also explains Riccioli's spiral orbit of the sun (or planets). We just would like to show this from the figure from Riccioli's original book (cf. Fig.4). As a whole, we can repeatedly say that he is rather faithfully following the *Almagestum novum* by G. B. Riccioli

However we must point out that, the long discussion of Kepler's Laws notwithstanding, Foucquet eventually transcribed as the astronomical tables La Hire's *Tables* in 1702, instead. La Hire had produced the *Tables*, totally relying on his own observations

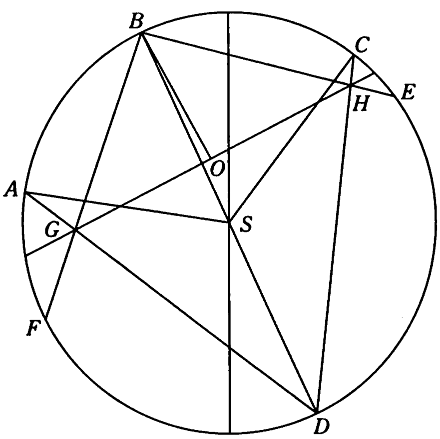

Fig. 3 Cassini's Procedure for Determining Eccentricity and Aphelion from Observation (C. Wilson 1989, p.183)

19) Cf. Wilson, 1989, pp. 182-183.
20) V-1, ff.78a-83b.
21) Cf. Wilson, 1989, p.183.

made for long time at the Paris Observatory after he succeeded Jean Picard. It was, indeed, practical astronomy, which Foucquet was trying to introduce in the manuscript, although he tried to explain even the physics of planetary motions.

In this connection it is also worthwhile to point out that he brought to China the achievements of determination of astronomical constants which were remarkably improved after the invention of the telescope mounted with micrometer. To mention a few examples: the obliquity of ecliptic, Cassini's determination of horizontal parallax of the Sun as well as the refraction up to the zenith. Chinese astronomers had only known Tycho's refraction, which had been introduced several decades ago.

2. Copernicanism

In the *Almagestum Novum* of 1651, G. Riccioli rejects the ellipse because he does not find the empirical evidence for it sufficiently convincing. But, in his later book, the *Astronomia reformata* of 1665, Riccioli is anti-Copernican as ever, claiming in fact to have proved the immobility of the earth. However, he has then adopted the ellipse as provisional basis for planetary theory[22]. Nevertheless, he discussed the theory of Copernicus (Ge-bai-ni 歌白尼) as the hypothesis of the universe, when introducing the semi-Tychonic world system[23].

It seems likely that the Jesuit missionaries in China, who took care of the Imperial Astronomical Observatory in Beijing, eventually followed Riccioli's choice for the adoption of Kepler's Laws. It was crucial for them to compile the *Lixiang kaocheng houbian* (暦象考成後編, Sequel to Astronomical Compendium) in 1742. This is until now believed to be the first, formal introduction of Kepler's theory of elliptic orbits, for which the German Jesuit missionary, Ignatius Koegler (Dai Jinxian 戴進賢), together with the Portuguese missionary, Andreas Pereira, took responsibility for the compilation as the Astronomer Imperial (*Qintianjianzheng* 欽天監正) of the Qing dynasty.

In connection with the problem of Copernicanism, or heliocentrism, we should not

22) Wilson 1970, p.111.

23) III-1, f.6b. As to the "semi-Tychonic" world system of Riccioli, see Schofield 1981, and Schofield, "Tychonic and semi-Tychonic World Systems," Taton & Wilson 1989, 32-44; esp. p. 40.

overlook Foucquet's discussion of the method of the determination of the longitude, making use of the satellites of Jupiter, which Galileo had originally suggested. In the discussion of the determination of differences in the terrestrial longitude, the discovery of finite velocity of light by O.C. Roemer, making use of the satellites of Jupiter, played an important role[24].

But, here, we must point out that Roemer's planetary model, based on the heliocentric idea, has been explained in detail as the appendix to the Treatise on Eclipses in the *Lifa wenda*[25]. The instrument was presented to Kangxi Emperor from Louis XIV, when the French Jesuit missionaries arrived in Beijing[26].

Now, we have to continue to discuss the problem of the determination of geographical positions. Cassini's instructions furnished a clear picture of the best seventeenth century research methods and at the same time explained how the terrestrial longitude could be determined by timing the eclipses of the satellites of Jupiter[27]. The most satisfactory time observations of Jupiter could be made of the immersions and emersions of the first satellite.

When Jean de Fontaney, a Jesuit professor of mathematics at the College of Louis le Grand, was preparing to leave for China as the head of the first French Jesuit mission, G. D. Cassini trained him. On his way to China he contributed data on the longitudes of the Orient[28]. Later the French missionaries worked for the imperial enterprise of the survey for the map of China in the late 1710's.

Foucquet, depending on the *Traitē de la Lumiere* of 1690 by C. Huygens, discussed this method of geodesy. We can see the explanation of the method, which faithfully reflects Huygens's discourse (cf. Fig.4)[29]. And Foucquet categorically asserts that

24) Debarbat, S., and Wilson, C., 1989, "The Galilean satillites of Jupiter from Galileo to Cassini, Roemer and Bradley", Taton and Wilson 1989, 144-157; p.156.

25) III-1, paragraph 14, which has been omitted from the British Library version, the part of which, otherwise, seems to be copied from the original version. The omission means that the censorship seemed to be executed.

26) Nissen 1944, p.32. Later Roemer manufactured the model based on the Tychonic world system in Paris.

27) Brown 1979, pp.221ff.

28) *Ibid*., p.220.

29) V-2, f.33a. Fig. from Thompson 1912, p.8.

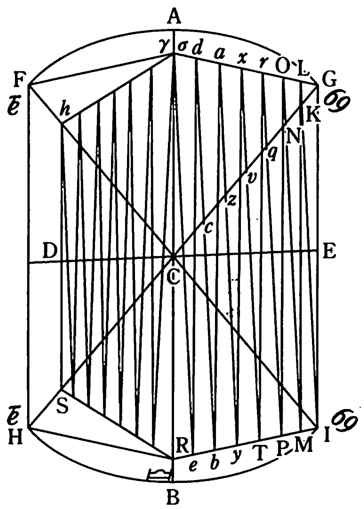

Fig. 4 Riccioli's Spiral Orbit (G. B. Riccioli, *Astronomia Reformata*, 1665, p.66)

“the satellites of Jupiter were best made of for cartography by making use of the method, which relied on the velocity (*liuxing* 流行) of light, which had been determined by Roemer”[30].

It is interesting enough to read in the beginning of the discussion that Foucquet meant to draw the illustration of the model to show the motion of the first satellite of Jupiter. He does not try to revise Roemer's model of the solar system. Instead, he faithfully explains the model itself. For this purpose, he says that the sun 'stands still' (*budong* 不動)[31] without any motions in the centre of the orbit of Jupiter as well as of that of the Earth.

3. The Cartesian Basis of Foucquet's Physics

Lastly we should like to see Foucquet's scientific knowledge of physics as it is reflected in the manuscript under discussion. This is crucial in order to understand how Foucquet recognized the cause of planetary motions. Here we can say that his discussion clearly based on Cartesian mechanism.

30) V-2, f.32b.
31) V-2, f.33a.

As for the mechanism of planetary motions, he first explains Kepler's magnetic mechanism as the cause of planetary motions. Then he moves on to introduce Boulliau's ellipse, because he followed Riccioli, who had not agreed with the analogy of magnetism used by Kepler.

Foucquet assumes that the Sun is located in the centre of the great circle of planetary orbits, and that it is the essence of the fire (*fuo-zhi-jing* 火之精) and can be the source of the motions (*dong-zhi-yuan* 動之原)[32]. The five planets all receive its movement, because they are in the aether, which transmits the motion from the Sun. It is called the moving power of the aether (*jingqi-zhi-nengli* 精気之能力).

And Foucquet gives to the discourse the reason why the power causes the non-circular motions of planets[33]. It is because, as he tells us, Descartes stated that the motions in the heaven were not perfectly circular[34]. First Foucquet tries to show that, if the centrifugal force works, it should cause the circular motions of planets. In order to explain the mechanism Foucquet cites Descartes' second law of nature from the *Principles of Philosophy*, and explains the planetary motion, although the figure is missing from the manuscript, depending on the Cartesian illustrations (Fig.5).

He describes that in the heavens the aether exists and expels the five planets, and says that if the expelling power of aether (*jingqi* 精気) comes from the Sun straight and uniform, then the revolution of the planets should be circular. But, as the manuscript says, it obliquely works, so that the orbits of the planets should be elliptic[35]. We must understand that his suggestion came from Leibniz's theory of planetary motion. Leibniz supposed that "the vortex carrying the planets rotated in spherical layers. And, in order to account for the elliptical orbit, he postulated two motions of the planets; a radial motion from layer to layer and a trans-radial motion in which the planet moved with the same speed as the fluid."[36]

32) V-1, f.45a.

33) V-1, ff.43a-45b.

34) René Descartes, *Principia Philosophiae*, III-34. 1644.

35) V-1, f.45b.

36) Aiton, Eric J., "The vortex theory in competition with Newtonian celestial dynamics", Taton & Wilson 1989, 3-21, especially, p. 10.

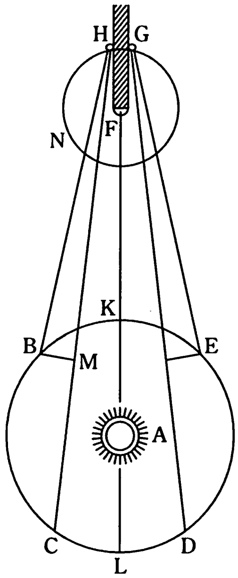

Fig. 5 From Huygens, *Treatise on Light*, 1690; English translation by S.P. Thompson, 1912, Dover ed., p.8.

In a few words, we can repeatedly say that Foucquet's concern with the cause of the planetary motions centred on Cartesian physics.

Then, as to the propagation of rays in straight line, he continues to discuss the problem in terms of the concept of the medium of subtle aether (*jingqi* 精氣), relying on the physical arguments by Descartes as well as Huygens[37]. It is interesting enough to find that he here mentions the idea of vortex (*xuanquan-zhi-bo* 旋圈之波) in the medium[38]. It is also interesting to read that he transcribes 'physics' into the Chinese term, *gewuqiongli-zhi-xue* 格物窮理之學[39].

Lastly, as to the propagation of the light, the manuscript discusses that the luminous body impulses the surrounding aether, and propagates the ray in all directions. We have found the whole discussion here has been comprised of the complete translation of the *Treatise on Light* by Christiaan Huygens in 1690, including the discussion of

37) V-2, f.43a.
38) V-2, ff. 44a-45a.
39) V-2, f. 32b.

Roemer's determination of the velocity of light and that of the longitude, using the first satellite of Jupiter[40].

We can find this extensive discussion in the chapter of Part 2, Book V, of the *Lifa wenda*, where Foucquet discusses the problem of determination of longitude by making use of it[41]. We can definitely say that Huygens was a crucial authority for Foucquet in the explanation of this optical problem as well.

The next step we must take is the more detailed analysis of the nature of the treatise on planetary motions, that is treated in Book V of the manuscript, and the problems of the solar and lunar motions together with the treatise on eclipses, which consists of the first three books of it. And, our future work should be carried out concerning the historical fact of whether or not Foucquet's introduction of Kepler's Laws had any significant effect on the compilation of the *Lixiang kaozheng houbian* in 1742.

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40) English translation by Thompson 1962.

41) V-2, ff. 33a-46a.