Transits of Venus – Halley's Recommendation and This Year's Phenomenon

ハレーの推奨した金星の日面経過と今年の現象

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Abstract: Edmond Halley (1716) recommended that the transit of Venus across the Sun's disk in 1761 be observed in order to measure the distance of an AU (astronomical unit), and assuming the solar parallax to be 12.5 arcsec (its correct value is now known to be 8.794 arcsec) he estimated the difference in the duration of the transit on 1761 June 6 between the East Indies and Hudson Bay would be 17 minutes. He correctly calculated the effect of the diurnal motion of the observation stations due to the earth's rotation but he missed the effect of the parallax due to the differences in the north-south direction of the observation stations, and therefore the transit in 1761 was not in fact a favorable event to determine the distance of an AU as Halley considered. On the other hand the transit of Venus occurring this year on 2012 June 6 is favorable to determine the distance of an AU. Although the distance of an AU is known precisely as 149,597,870.700 km, it has still educational value to know how past astronomers tried to obtain the distance of an AU from observations of transits of Venus.

Keywords: Transits of Venus, determination of an astronomical unit

1 INTRODUCTION

Transits of Venus across the Sun's disk are rare events. A transit of Venus will occur on 2012 June 6. The last transit of Venus occurred 8 years ago on 2004 June 8, but the next one will not occur for more than 100 years until the year 2117. In fact the transits occur in cycles of 121.5, 8, 105.5, and 8 years from the 15th century to the 30 century. Fig. 1 shows the paths of Venus across the Sun's disk for the transits occurring between 1761 and 2255. We consider the reason of the rarity of the Venus' transits here.

In order for a transit of Venus to occur, the Sun, Venus and the Earth have to be lined up in this order. Since Venus' orbit tilts by about 3°.4 with respect to the Earth's orbit, transits of Venus occur only at the inferior conjunctions of Venus which happen to be near the days when the Earth passes the ascending or descending node of Venus' orbit. Because the Sun's apparent diameter is about 32′, the heliocentric longitude of Venus at the inferior conjunction should be within about 3°.5 in total around the longitude of the ascending or descending node in order for a transit to occur. The dates of the Earth passing the ascending and descending nodes are around Dec. 9 and June 7, respectively, and therefore the transits occur only when an inferior conjunction of Venus happens to be within about 3.5 days in total around these dates.

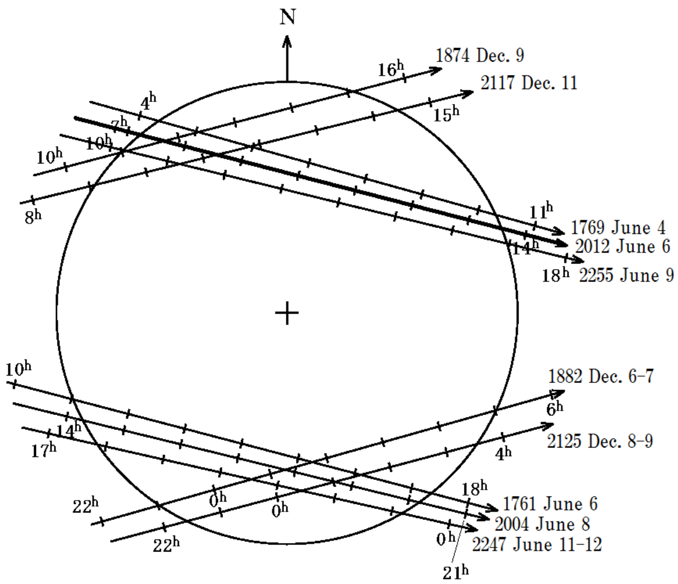

Fig. 1. Transits of Venus from 1761 to 2255
Dates and times are in Japan Standard Time.

Since the sidereal revolution periods of Venus and the Earth around the Sun are 224.7008 days and 365.2564 days, respectively, the synodic period (the period from one inferior conjunction to the next) of Venus is 583.9213 days. In Fig. 2 the orbit of the Earth is divided into 5 equal parts by the points A, C, E, B, and D where A is in the direction of the descending node of Venus' orbit. The angle by which the Earth revolves around the Sun during the synodic period of Venus is 583.9213d × 360°/365.2564d = 575°.52 = 360°+180°+ 35°.52. On 2004 July 8 the inferior conjunction of Venus occurred when the Earth was near the point A, and therefore the transit of Venus was seen on that day. The successive inferior conjunctions occurred near the points of B, C, D, and E in this order, and the next inferior conjunction (which is the event on 2012 July 6) occurs after the inferior conjunction of 2004 by 583.9213d×5 = 2919.6d. Since this interval is only 2.4d shorter than the length of 8 years (365.25d×8 = 2922.0d), the inferior conjunction of 2012 occurs near the point A but just before the Earth's reaching the point A. The dates of these inferior conjunctions are 2004 June 8 and 2012 June 6 and therefore these dates fulfill the condition of seeing the transits (within 3.5 days in total around the date of the Earth's passing Venus' descending node). Hence the transit of Venus occurs both on 2004 June 8 and on 2012 June 6. In 2020 the inferior conjunction of Venus will occur again near the point A, but its date is 2.4d further earlier than in 2012, and so the date will no longer fulfill the condition of seeing the transits. The Earth's positions at the dates when Venus' inferior conjunctions of every 8 year occur move backwards. The next transit of Venus will occur when the inferior conjunctions occurring near the point B move backwards and reach the point near the direction of the ascending node of Venus' orbit and its date will be 2117 Dec 11, which is 105.5 years later from this year.

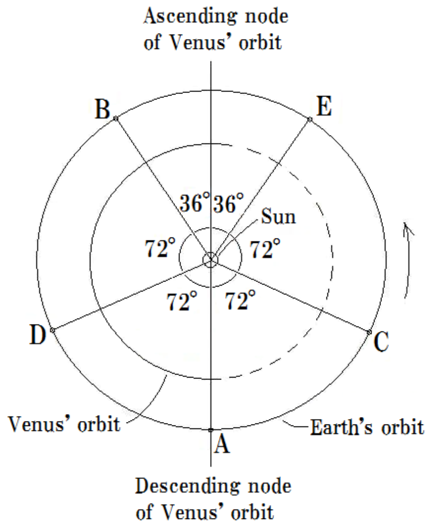

Fig. 2. Orbits of the Earth and Venus

As seen from the direction of the north pole of the Earth's orbit. The solid line of Venus' orbit is above the Earth's orbit while the broken line is below the Earth's orbit.

Note that the revolution period of the Earth with respect to the ascending or descending node of Venus' orbit is 365.2513 days, which is slightly different from the sidereal revolution period (365.2564 days) of the Earth around the Sun due to the movement of Venus' orbit.

2 HALLEY'S RECOMMENDATION

Edmond Halley was an English astronomer who was born in 1656 and died in 1742. He recommended in his paper written in 1716 that the transit of Venus across the Sun's disk in 1761 be observed in order to measure the distance of an AU (astronomical unit). His paper was written in Latin, but its English translation was published by J. Ferguson (1761). Another English translation was published by Hutton et al. (1809) and is given on an NASA Eclipse Web Site or other Websites. Roode (2005) summarizes Halley's idea.

In Halley's time relative distances between planets and the Sun were known from Kepler's third law, but their actual distances in kilometers were not known. The next transit of Venus was on 1761 June 6 and although Halley knew that he would be dead before the date of the transit, he recommended that it should be observed in order to know the distance to the Sun. Assuming the solar parallax to be 12″.5 (its correct value is now known to be 8″.794) Halley found that for the transit of Venus in 1761 the greatest difference to be expected was between locations in the East Indies, where Venus' stay was shortened by eleven minutes, and Hudson's Bay, where it was lengthened by six minutes, and therefore the difference in the duration between the East Indies and Hudson's Bay would be 17 minutes. The difference was produced due to the fact that the two locations moved in the opposite directions by the diurnal motion originated from the Earth's rotation, as shown in Figs. 3, 4, and 5. In fact as seen from Hudson's Bay Venus would enter the sun's disk a little before the setting of Venus and the Sun, and would go off a little after the rising of Venus and the Sun (i.e. in Hudson's Bay most of the transit would occur below the horizon).

He correctly calculated the effect of the diurnal motion of the two locations due to the Earth's rotation but he missed the effect of the parallax due to the differences in the north-south direction of the observation stations, as is explained below.

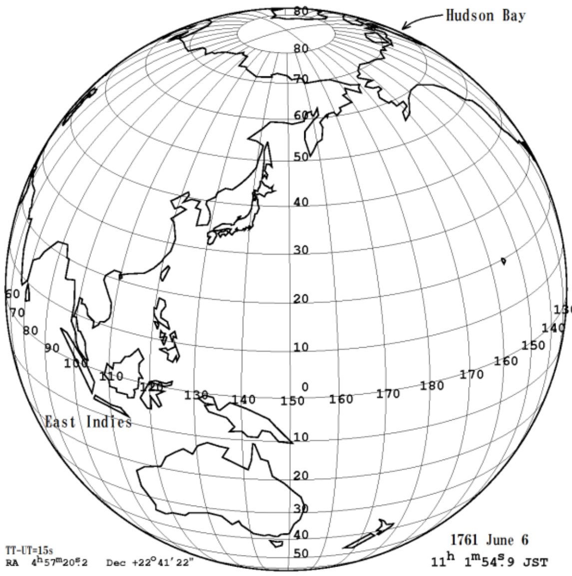

Fig. 3. Regions where the beginning of the transit in 1761 can be seen

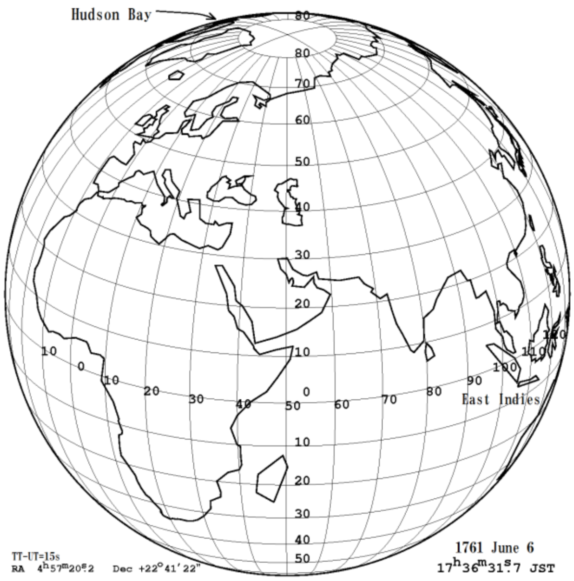

Fig. 4. Regions where the end of the transit in 1761 can be seen

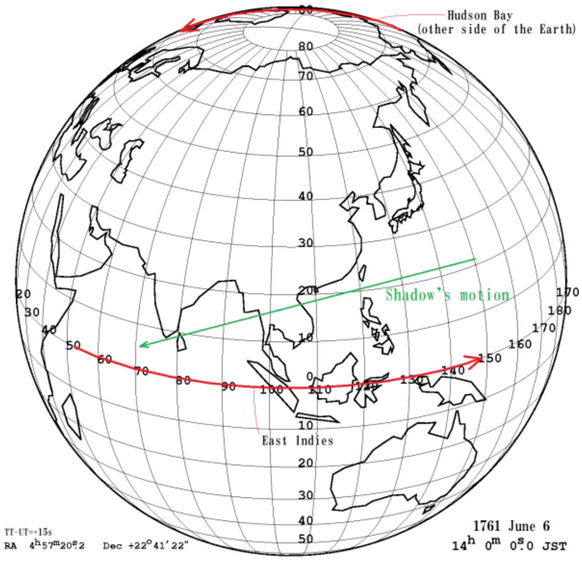

Fig. 5. Earth's rotation and the motion of Venus' shadow at the transit in 1761

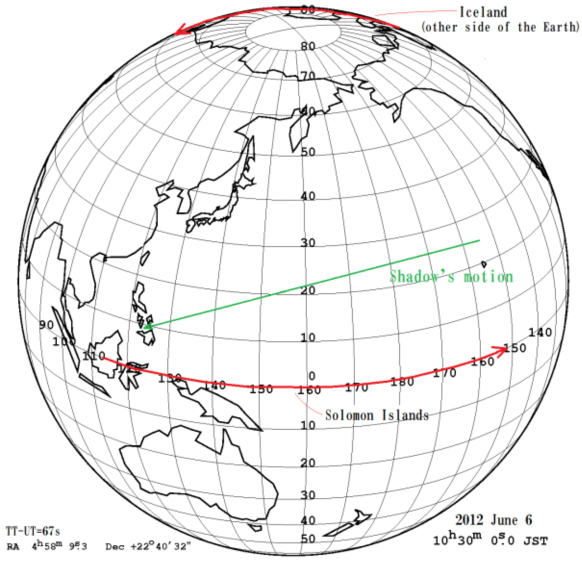

Fig. 6. Earth's rotation and the motion of Venus' shadow at the transit in 2012

At the event in 1761 Venus passes over the southern part of the Sun (see Fig. 1), and therefore at the northern stations on the Earth, like Hudson's Bay, the apparent path of Venus over the Sun's disk lies south in comparison with that at the geocenter, and it makes the duration shorter, which cancels the longer duration due to the rotation. As a result, as shown in Table 1, which gives the predictions for the East Indies and Hudson's Bay calculated with the current theory, the difference in the durations of the two locations is only 53 sec, which is not to be compared with 17 minutes predicted by Halley.

As shown above, the 1761 transit of Venus was not as favorable as Halley considered to determine the distance of an AU.

3 TRANSIT OF VENUS IN 2012

At the transit of Venus in 2012 Venus passes over the northern part of the Sun (see Fig. 1). Therefore as opposed to the event in 1761 the event in 2012 is favorable to determine the distance of an AU. In fact the effects of the Earth's rotation and the parallax strengthen the difference in the durations for e.g. the Solomon islands and Iceland (see Fig. 6). In fact as shown in Table 2 the difference in the durations becomes almost 21 minutes. Even within Japan, the difference in the durations can be about 2 minutes as shown in Table 3.

As is discussed above, the transit in 2012 is favorable for determining the distance of an AU. Since the distance of an AU is known precisely as 149,597,870.700 km (Luzum et al. 2011) from radar observations to planets, transits of Venus has no scientific value now, but they still have educational value about how past researchers tried to determine the distance of an AU from transits of Venus, and the transit of Venus in 2012 is good for such educations.

Table 1. Predictions for the transit in 1761 by the current theories

1761 Jun 6 (UT)	Geocenter	East Indies 100°E, 0°N	Hudson Bay 80°W, 59°N
1st	02:01:55	02:05:58	02:01:46
2nd	02:20:01	02:23:39	02:20:25
Sunset			02:24:29
Sunrise			08:11:29
3rd	08:18:26	08:16:58	08:14:37
4th	08:36:32	08:34:34	08:33:19
Dur.(2→3)	05:58:25	05:53:19	05:54:12

Table 2. Predictions for the transit in 2012

2012 Jun 5-6 (UT)	Geocenter	Solomon 160°E, 0°N	Iceland 20°W, 59°N
1st	22:09:41	22:14:09	22:03:28
2nd	22:27:29	22:31:51	22:21:03
Sunset			22:24:50
Sunrise			04:12:13
3rd	04:31:43	04:26:23	04:36:28
4th	04:49:31	04:44:05	04:54:03
Dur.(2→3)	06:04:14	05:54:32	06:15:25

Table 3. Duration differences inside Japan for the transit on 2012 June 6

JST	Sapporo	Naha
1st	07:10:03	07:11:49
2nd	07:27:37	07:29:30
3rd	13:30:25	13:30:21
4th	13:47:51	13:47:46
Dur.(2→3)	06:02:48	06:00:51

4 JAPANESE TERMS FOR "TRANSITS"

There are two Japanese terms "経過" and "通過" for the English word "transits". I will give some comments about it below in Japanese.

金星が太陽の前面を通過する現象には，金星の「日面経過」，「日面通過」，「太陽面通過」などの用語が使用されている．混乱を避けるために，公開天文台ネットワーク (PAONET) では，一般の方に分かりやすいという理由で，2004 年 4 月に「太陽面通過」を使用するように提案した．しかし，理科年表等では「日面経過」が使用されている．ここではこの「日面経過」という用語について少し触れておく．

国立天文台暦計算室によると，「日面経過」という言葉が本暦 (当時の東京天文台が編集し神宮司庁が頒布していた暦書) に記載されたのは 1924 年 (大正 13 年) ５月８日の水星日面経過からで，理科年表 (暦部) では理科年表が創刊された 1925 年 (大正 14 年) 版以後最初の水星日面経過が起こった 1927 年版 (昭和２年版だが，昭和に改元される前に発行されたため大正 16 年版になっている) に「水星ガ太陽ノ面ヲ横切ル現象即チ水星ノ日面経過ガアル」と説明し，以後，この現象は「日面経過」で統一されている．言葉を変えると別の現象を意味するという誤解を与える恐れがあるということで，国立天文台暦計算室では今後も「日面経過」を使用する意向だということである．「経過」という用語は一般には「時の経過」のように使われるのが普通だと思われているだが，実は天文学では「掩蔽」に対する用語として「経過」が存在する．つまり，「掩蔽」とは一般に小さな天体の前面をより大きな天体が通過して小さな天体が隠される現象なのに対して，大きな天体の前面を小さな天体が通過する現象を「経過」という．このことは大きな辞書にも説明されている．たとえば広辞苑で調べると「経過＝太陽面を内惑星・彗星などの天体が通り過ぎる現象。また、惑星面をその衛星が通過すること。」とある．いうまでもないことと思うが「通過」にはこのような特別な意味は載っていない．理科年表では 1950 年 (昭和 25 年) 版から 1970 年 (昭和 45 年) 版までの 21 年間，「木星の４大衛星の諸現象」というページがあったが，そこ

でも衛星が木星面を横切る現象を「経過」と言っていた．天文年鑑などでは現在でも木星の衛星現象で「経過」が使われている．また，前回の 1874 年 (明治７年) の金星日面経過を伝える当時の新聞記事でも「金星経過」なる語が使われていたことは，東京日日新聞・横浜毎日新聞・郵便報知新聞などの記事で確認できる (その一部は「星ナビ」2004 年６月号 p.79 の雨宮正実氏の投稿記事でも確認できる)．もっとも，当時は「金星過日」なる語も使われていた．

なお，文部省 (現在の文部科学省) と日本天文学会が著作権を所有する学術用語集の天文学編 (増訂版, 1994 年刊行，発行所は日本学術振興会，発売所は丸善(株)) には英語の transit の訳語に (「正中」以外に) 「太陽面通過」を当てているが，これは感心しない． transit の日本語は上で説明した「経過」である．つまり，太陽面だけでなく，木星面などの前面をその衛星などが通過するのも transit である．太陽の前面を通過することを英語で表すとすれば transit over the disk of the Sun のようになるだろう．学術用語集の編者はこれらの事実を知らずに「太陽面通過」という訳語を transit に当ててしまったようだ．

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