GALILEO DID NOT STEAL THE DISCOVERY OF VENUS' PHASES A COUNTER-ARGUMENT TO WESTFALL

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1 Introduction

In 1985, Richard S. Westfall re-proposed the thesis that Galileo 'stole' the discovery of Venus' phases from his pupil, Benedetto Castelli.[1] I shall call Westfall's view the 'dishonesty thesis'.[2] According to the dishonesty thesis, Galileo was prompted to observe Venus by a letter from Castelli that he presumably received about 11 December 1610. In his letter, Castelli pointed out that if Copernican astronomy was true then Venus should display phases.[3]

In this paper, I shall argue that the dishonesty thesis is false. My counter-argument is based on my mathematical reconstruction of the real cycle of phases that Venus displayed during the period spanning summer to winter 1610.

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[1] I have quoted Westfall's article from Dear [1997, 113-132]. The Italian historian, Raffaello Caverni, was the first to propose the dishonesty thesis at the turn of the nineteenth century. Caverni's version of the thesis has been rejected by Westfall, *ibid.*, 130. In 1919, Antonio Favaro [1919], the editor of the National Edition of Galileo's works, refuted Caverni's thesis. Favaro's refutation was based on a gross error by Caverni, who attributed to the hand of Vincenzo Viviani a copy of a letter that instead had been written by Castelli himself. Cf. the details in *ibid.*, 290-291.

[2] Westfall [1997, 131]. 'Dishonesty' is used by Westfall.

[3] Westfall [1997, 126ff]. There is no proof that Galileo actually received Castelli's letter on 11 December 1610. This hypothesis simply suits Westfall's dishonesty theory. Castelli's letter is published in the National Edition of Galileo's works, cf. Galilei [1890-1909]. I have used this abbreviation: OGG, followed by the Roman numeral of the volume and page numbers in Arabic numerals. See Castelli's letter in OGG, X, 480ff.

Moreover, on the sole basis of his commitment to Copernicanism, Westfall argues, Galileo would have sent his cipher announcing the discovery of Venus' phases to Kepler, in Prague, the same day he would have received Castelli's letter.[4] This is totally implausible. When, about three weeks later, on 30 December 1610, Galileo answered Castelli's letter, he made very precise assertions on the pattern of evolution of Venus' phases during the previous three months.[5] As we shall see, these assertions could not have been made by predicting backwards the evolution of the cycle of the phases on the sole basis of Copernican astronomy.

In section 2, I will show the agreement of Galileo's reports with the mathematical reconstruction of the pattern of Venus' magnitude and phase during the period of his observations. In section 3, I will briefly discuss a few technicalities concerning the mathematical model.

2 Galileo's observations of Venus

On 30 December 1610, Galileo wrote to Castelli and Clavius reporting on the discovery of Venus' phases. According to the answer to Castelli, he had begun to make observations about three months earlier, i.e. at the beginning of October.[6] Thus, we can assume that Galileo began his observations of Venus' phases about 1 October 1610. Here is Galileo's slightly different account to Clavius.

> […] when Venus began to be visible in the evening sky, I started observing it and saw that its figure was circular, though extremely small. Afterwards, I saw that [Venus] grew in magnitude significantly, though always maintaining its circular shape. Approaching maximum elongation [*digressione*], [Venus] began to lose its circular shape on the other side from the Sun and within a few days had acquired a semicircular shape. This shape it maintained for a number of days. More precisely, it maintained [this shape] until it began to move towards the sun, slowly abandoning the tangent. It now begins to assume a notable corniculate shape. Thus, it will continue to decrease during the period in which it remains visible in the evening sky.[7]

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[4] Westfall [1997, 126 and 129]. The cipher was vague and simply said that Venus showed phases similar to those of the Moon. As we shall see, from 1 October to 11 December 1610 Galileo had attributed to Venus a change of phase from circular to semicircular.

[5] Cf. Galileo's answer to Castelli in OGG, X, 502-505. Galileo reiterated his general account of the discovery of Venus' phases in another letter sent to Clavius the same day, cf. OGG, X, 499-502.

[6] OGG, X, 503.

[7] OGG, X, 500. Translation into English is mine. Apart from the first lines of the passage concerning the beginning of Galileo's observations, the substance of the report is the same as that to Castelli.

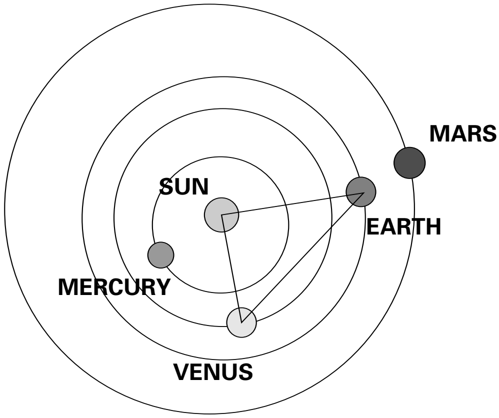

Fig. 1 The configurations of the planets on 1 October 1610.

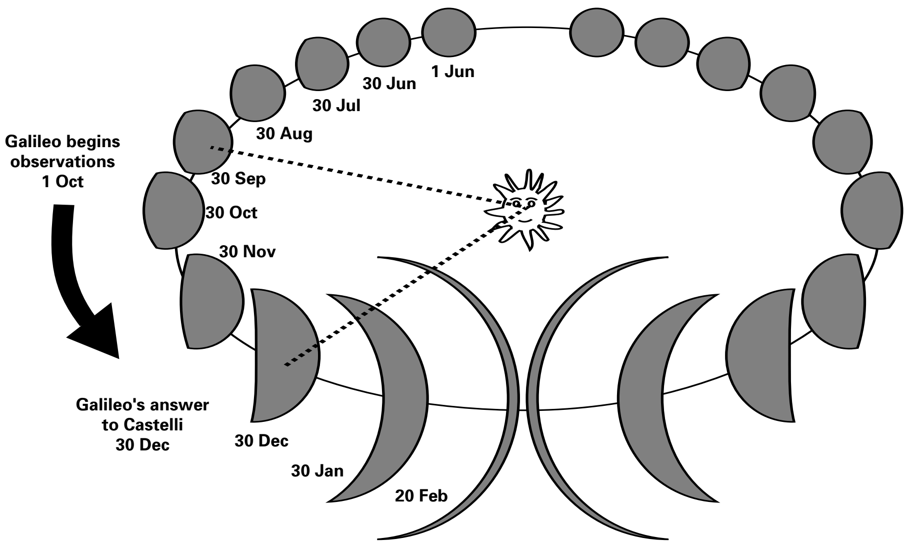

Fig. 2 Galileo's period of observation of Venus. Grey areas represent the illuminated parts of Venus. Both size and phase are represented in accordance with my mathematical model. Sizes are to be compared with each other since the images do not reproduce the dimensions that Galileo would have seen through his telescope, but simply the relative dimensions relative to each other. Note that I have assumed that Venus orbits the Sun along the ecliptic. See more details in section 3.

Galileo told Clavius that he had started observing Venus 'when Venus began to be visible in the evening sky' [*nel principio della sua apparizione vespertina*]. It is possible that Galileo's first observations might have begun in a rather causal way in the late spring or early summer of 1610. This would be consistent with the details of his report to Clavius, since at the beginning of summer 1610 Venus had just emerged from the superior conjunction with the Sun and was therefore extremely small and virtually circular. Perhaps, in his reply to Castelli, Galileo might have decided to leave aside these first casual observations and focus on the substance of the question.

Be that as it may, when Galileo undertook more systematic observations at the beginning of October, the configuration of the planets and Sun relative to each other was that given in Fig. 1. Fig. 2 presents an overview outlining the variation of both phase and magnitude for the entire cycle of Venus from the superior conjunction of May 1610 to the superior conjunction of December 1611. The period of Galileo's observations, from 1 October to 30 December 1610, is clearly marked by the dotted lines.

As the overview of Fig.2 shows, Venus undergoes enormous variation in apparent size and phase, but it does not follow a uniform pattern of change, either in shape or apparent size. For example, from 1 June to 30 September apparent size does not vary in an appreciable way. It is highly unlikely that the gibbous shape of the planet would have been recognizable by Galileo before the date we established for the beginning (according to the wording of the answer to Castelli) or the resumption (according to the wording of the letter to Clavius) of Galileo's period of observation. In fact, as we have seen, Galileo reported to Clavius that he had observed Venus growing 'in magnitude significantly, though always maintaining its circular shape'. These observations must have been made after the beginning of October since he basically repeated the same piece of information to Castelli, to whom he said that he had started observing Venus about three months earlier (i.e. at the beginning of October).[8]

When did Venus approach maximum elongation? Galileo's assertion is not very precise in this regard. But we can establish that maximum elongation was reached between 10 December and 20 December (cf. section 3). We can therefore assume that the period referred to by Galileo as 'approach to maximum elongation' lasted about three to four weeks before the point of maximum elongation, i.e. before a day between 10 and 20 December 1610 (cf. Fig. 3 for the phases on these days). Fig. 4 shows the configurations of the planets: (a) on 15 November, at the beginning of the period during which Venus, according to Galileo, approached maximum elongation, and (b) on 20 December, when Venus finally surpassed maximum elongation and started becoming crescent.

[8] OGG, X, 503.

Fig. 3 The passage of Venus' phase from slightly gibbous to slightly crescent. The first figure is Venus on 10 December 1610. The second figure is Venus on 20 December (sizes are relative to each other).

The crucial piece of information Galileo gives us is that Venus began to lose its circular shape during the period in which the planet approached maximum elongation and subsequently acquired a semicircular phase 'within a few days' [*in pochi giorni*]. Moreover, Galileo tells us that Venus maintained the semicircular phase for a number of days. These two peculiar features indicate that Galileo could not have predicted such non-uniform pattern of behaviour by working out these phenomena 'backwards' from the suggestion contained in Castelli's letter, even if the letter had arrived precisely on 11 December –as Westfall believes it did. For a Copernican it might have been easy to predict that Venus should display phases, but it was one thing to predict this type of behaviour qualitatively and quite another to predict the precise pattern of change in dimension and phase described by Galileo. This ability was not within the grasp of either Castelli or Galileo. These calculations would have required of Galileo a sophisticated mathematical theory of the appearance of the phases that he did not have. And the idea that such a complex pattern of change could have been guessed by Galileo overnight after receiving Castelli's letter seems even more implausible. There remains only one possibility, namely, that Galileo really did observe such complex pattern of behaviour.

It is also clear from his report that Galileo was unable to observe an appreciable change from circular to semicircular shape until the final part of his three-month period of observation. Although my mathematical reconstruction shows that Venus was clearly gibbous at the beginning of October, Galileo did not immediately 'see' this gibbousness, presumably not until the beginning of November, or even later on. In Galileo's words,

> I saw that [Venus] grew in magnitude significantly, though always maintaining its circular shape.[9]

This must have been due to the limitations of his telescope. What Galileo did see was:

[9] OGG, X, 500.

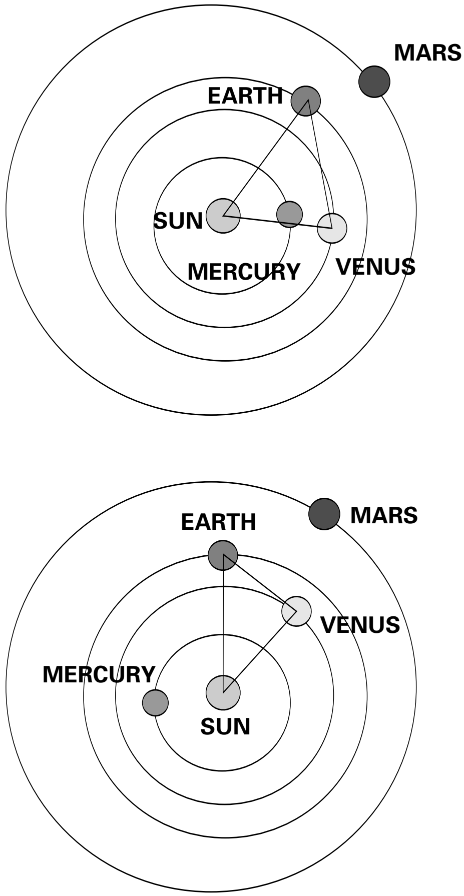

Fig. 4 The configuration of the planets on 15 November (above) and 20 December 1610 (below) at the beginning and end of the period Galileo referred to as 'approach' to maximum elongation.

(a) Venus remaining circular for sometime before undergoing the rapid change in phase that it displays when approaching maximum elongation, and
(b) the peculiar fact that Venus maintains the semicircular shape for a number of days.

These were the patterns his telescope allowed him to observe.

The patterns of behaviour described in (a) and (b) are non-linear. In other words, there is no proportionality between the pattern of change in shape and the elapsed time. Yet according to Westfall, during the two and a half weeks separating the (supposed) arrival of Castelli's letter from Galileo's answer,

> Venus was going through a critical portion of its orbit, in which at maximum elongation it gradually changed from a slightly gibbous phase to a thick crescent. At no point during December was its shape compatible with the Ptolemaic system.[10]

Such purported gradual pattern of change was nowhere to be visible through Galileo's telescope in the sky of either October, or November, or December 1610. The patterns of change Galileo described are not gradual. Not until much later was Venus to display a marked crescent form (cf. Fig. 2 and 5). This Galileo duly predicted in his letters to Clavius and Castelli.

> Now [i.e. on 30 December], it [i.e. Venus] *begins* to assume a notable corniculate shape. Thus, it will continue to decrease during the period in which it is visible in the evening sky and, in due course, we shall see it in the morning sky, with its thin corns on the other side from the sun...[11]

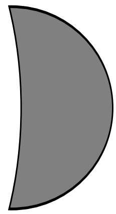

Fig. 5 Venus' shape on 30 December 1610.

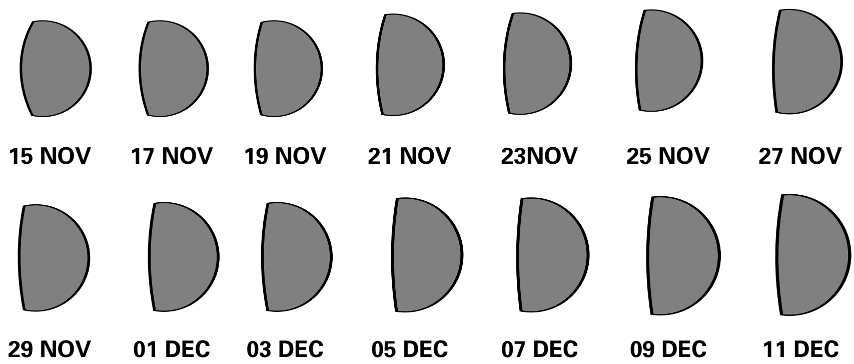

Fig. 6 The variation of Venus's phase and dimension during the approach to maximum elongation (sizes are relative to each other).

Galileo says that it begins to assume a notable corniculate shape (size is relative to the sizes of Fig. 3).

[10] Westfall [1997, 130].

[11] OGG, V, 500. Emphasis mine.

The real pattern of change that Galileo was confronted with during Venus' approach to maximum elongation is shown in Fig. 6. Venus' phase changes from markedly gibbous to nearly semicircular and remains such for a number of days, as Galileo reported to Clavius and Castelli (cf. also Fig. 3, where Venus on 20 December is slightly crescent but would have been seen as semicircular by Galileo). According to a piece of information Galileo furnished later on, Venus remained semicircular for about one month.[12] This might have frustrated Galileo's eager wait for the passage to crescent in late December. For this, as we shall see, was the second crucial event for Ptolemaic astronomy.

In all probability, the limitations of Galileo's telescope are responsible for his overestimation of the duration of the type of phase he could recognize. In other words, these limitations may have caused an 'exaggeration' of the non-linear effects that Galileo so clearly describes. The resolving power of his telescope was not sufficient to allow him to observe the slow change from moderately gibbous to semicircular (cf. the final images of Fig. 6 and the second image in Fig. 3) and he reckoned that the duration of the semicircular phase extended over a period of about one month, presumably from the second half of November to the second half of December. But this 'exaggeration' can only have been the result of real astronomical observations. Theoretical prediction on the sole basis of Copernican faith would almost surely have led Galileo to assume erroneously a more 'natural' pattern of behaviour, i.e. a linear one.

Galileo decided to wait until the end of December before answering Castelli's letter simply because until the end of December he was unable to discern clearly the corniculate shape with his telescope. At the beginning of his period of observation (1 October), Galileo observed Venus and attributed to it a circular shape. He subsequently observed it assuming a recognizable semicircular shape and remaining such for a number of days. He now wanted to be certain that Venus would eventually assume the corniculate shape. For this had profound implications for the Ptolemaic system.

Contrary to Westfall's opinion that 'at no point during December was its [i.e. Venus'] shape compatible with the Ptolemaic system', there is nothing incompatible with Ptolemy's system at any single point of Venus' phase cycle. If Venus were always below the Sun, as was normally assumed in the Ptolemaic system, then it should display a pattern of crescent phases similar to that visible in late December 1610. What is really incompatible with Ptolemy's system is the fact that Venus is sometimes above the Sun and sometimes below the Sun. While Venus can be gibbous both above and below the Sun, it can only be crescent below the Sun.

Venus' maximum elongation occurred at the time when Galileo might

[12] At the end of February 1611, Galileo wrote a letter in which he was more precise than in his account to Clavius and said the Venus remained semicircular for about one month at the time of maximum elongation. The person to whom the letter was written is not known. Cf. OGG, XI, 53.

have received Castelli's letter (exactly on 11 December, according to Westfall, or later on). But this coincidence cannot have been the spark that ignited Galileo's programme of observation of Venus. It was simply too late. If he only then had realized the importance of Castelli's qualitative prediction and therefore had decided to begin new observations of Venus, he would have observed Venus already nearing the exact semicircular phase, thus completely missing the non-linear pattern of change during the 'approach to maximum elongation'. And, as we have seen, he could neither have guessed this peculiar pattern of change by calculating it 'backwards', nor have attributed a period of about one month to the duration of the semicircular phase.

To sum up, Galileo did not dishonestly appropriate the merit of the prediction of the existence of Venus' phases and did not steal the discovery from his pupil, Benedetto Castelli. Moreover, contrary to Westfall's interpretation of the whole episode, Galileo after having observed Venus nearly circular needed to wait until Venus began to display a corniculate shape. Only in this way could he have had confirmation that Venus was periodically above and below the Sun. This conclusion seriously weakens Westfall's general thesis that Galileo used the telescope 'more as an instrument of patronage than as an instrument of astronomy'.[13] Indeed, Galileo stressed the importance of Venus observations for Ptolemaic astronomy indirectly, but with unequivocal words, in his letter to the most venerable astronomer of his time, Christoph Clavius.

> Now, Sir, we can rest assured that Venus goes around the Sun [...], doubtless the centre of the revolutions of all planets.[14]

Of course, Galileo knew that this was no proof of Copernicus' system. Therefore, in his letter to Clavius, he did not mention the motion of the Earth and contented himself with asserting that the Sun must be the centre of the revolutions of all planets. Finding new evidence for the Copernican motions of the Earth would prove to be much more difficult, even for Galileo.

3 The mathematical model

A few words on the mathematical model I have used to calculate Venus' various positions, magnitudes and phases are in order. On 1 March 1611 Venus reached inferior conjunction with the Sun. This prediction was made by Giovanni Antonio Magini, the then famous astronomer and

[13] Westfall [1997, 128].

[14] OGG, X, 500. Translation is mine.

human computer.[15] Galileo himself verified that Venus indeed approached inferior conjunction (though it was very 'high', i.e. north of the ecliptic).[16] Conjunction can be used a starting point in order to calculate backwards the position of Venus relative to Earth with sufficient precision. Assuming standard astronomical values for Venus' period and mean distance from the Sun, one can work out a simple formula for the distance of Venus from Earth simply hypothesising that both Venus and Earth follow circular orbits and move with uniform angular speed (the errors introduced by this approximation are not significant for our purposes). Let us refer to Fig. 7.

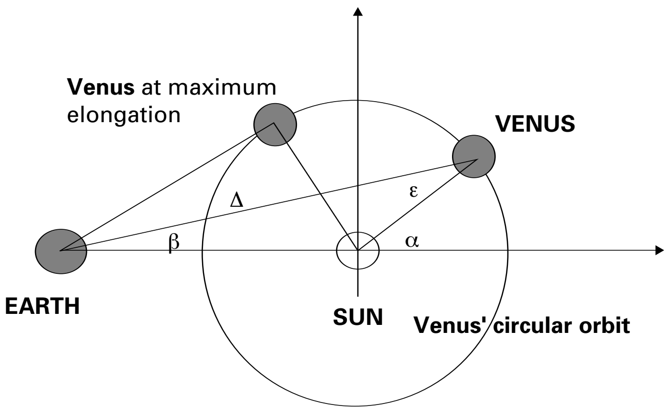

Fig. 7 A simple model of the distance of Venus from Earth.

With simple trigonometry one can work out Venus' distance from the Earth, Δ, as a function of angle α. On 1 March 1611, at inferior conjunction, we have $\alpha = 180^o$. The intermediate positions follow from the fact we can assume $\alpha = \omega_V - \omega_E$, where ω_V, ω_E are the angular speeds of Venus and Earth.

Angle ε is the parameter used to calculate Venus' phase. Let us call it 'perspective' angle. We can assume that the Sun's light illuminates one half of Venus because of the great distance of Venus from the Sun. At maximum elongation, for example, e=90°, and we see Venus semicircular. I have adopted a simplified model for the calculation of the curve separating light from darkness on Venus' surface. It proceeds as follows. With reference to Fig. 8, imagine we observe Venus in a particular position and the perspective angle is e. Then we have the following formula for the curve separating light from darkness (let P be a generic point on this curve):

$$Y_P = \sqrt{(R^2 - Z^2)} * \cos(\varepsilon),$$

[15] Cf. Magini [1610]. See p. 168.

[16] Cf. Galileo's letter of 25 February 1611. OGG, XI, 53.

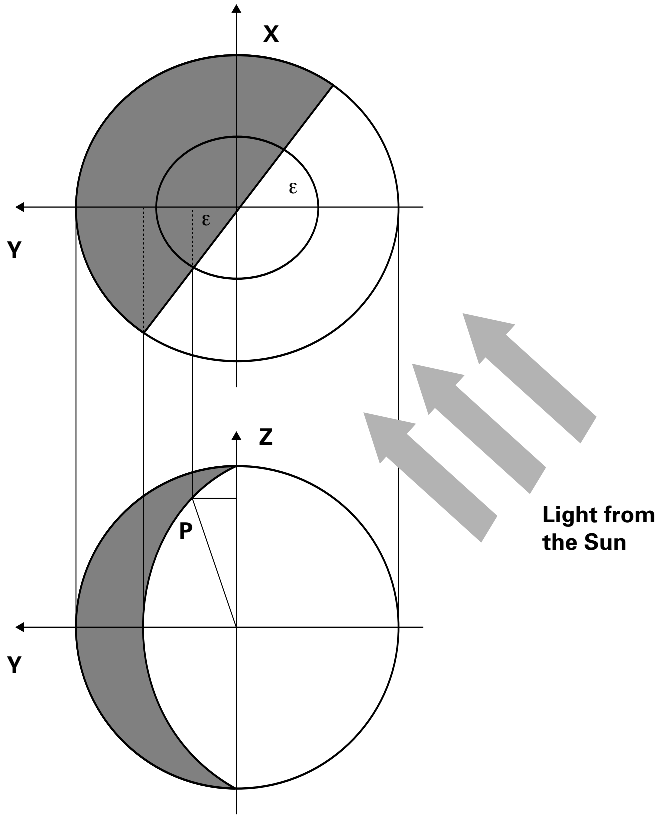

Fig. 8 The curve dividing light from darkness on Venus (the grey area represents darkness). In the first image Venus is seen from above while in the second image the point of view is on the equatorial plane.

which is an ellipse (R is Venus' radius and the image is projected onto the plane X=0).[17] Venus' apparent size is calculated by assuming that Venus' apparent diameter is inversely proportional to Δ.

Finally, the positions of the planets given in Fig. 1 and Fig. 4 have been calculated with *Home Planet*, a software package for sky simulations.[18] The rest of the computations has been carried out with another software package, *Mathcad 5.0+*. The prediction of the time of Venus' maximum elongation deduced by the sky simulator data (between 10 and 20 Decem-

[17] An elliptical curve was derived for the phases of the Moon by Scipione Chiaramonti, who did not believe in Venus' phases. Cf. Chiaramonti [1653]. Chiaramonti never accepted Galileo's observations of Venus' phases. Cf. Ciaramonti [1644, 183ff].

[18] The *Home Planet* package is in the public domain and available at the following internet address: http://www.fourmilab.to/homeplanet/homeplanet.html.

ber 1610) is in accord with the date obtained with my simplified model based on the assumption of circular and uniform orbital motions (it is to be noted that my model seems to run a bit late and predict a maximum elongation date a few days later than the sky simulator, but this is immaterial since we need not establish this date with absolute precision).

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