Note

Galileo's early observations of sunspots

Kazuyuki ITO*

§1 Introduction

In January 1612, Galileo Galilei (1564–1642) received a letter from Marc Welser (1558–1614) in Germany with an anonymous book titled *Tres epistolae de maculis in sole* (*Three letters on sunspots*, 1612). In his letter, Welser requested that Galileo comment on the book. Its author Christoph Scheiner (1573–1650) [1] describes his observations of sunspots and he concludes that they are the shadows of heavenly bodies revolving around the sun, such as Mercury and Venus. In February, Galileo began observing sunspots by directly seeing them with his telescope, and he recorded notes and figures. At the beginning of May, his disciple Benedetto Castelli (1578–1643) informed him of a new observation method, the projection method, which involves projecting the solar images onto a sheet of paper. Thus one does not have to see the sun directly, and can draw sunspots more precisely.[2] Galileo's first record of solar observation using the projection method is dated May 3, 1612. From then on, he continuously performed observations of sunspots until the middle of August.

The introduction of the projection method divided Galileo's observations of sunspots into two periods. The first period is before its introduction at the beginning of May, and the second one is after that. Galileo wrote three letters on sunspots to Welser, which were published in his book *Istoria e dimostrazioni intorno alle macchie solari e loro accidenti* (*History and demonstrations concerning sunspots and their accidents*, 1613). As the first letter was dated May 4, 1612, its contents were based on the observations during the first period. There he denied Scheiner's conclusion regarding sunspots, insisting that sunspots are on or near the surface of the sun, and that they are like little clouds in the

* Graduate School of Letters, Kyoto University

[1] See Daxecker 2004; Galileo and Scheiner 2010, Chapter 4. Cf. Biagioli 2007, Capter 3.

[2] Galileo described the projection method in the second letter of his *Istoria e dimostrazioni*. See Galileo and Scheiner 2010, pp. 126–127; OGG, V, pp. 136–137.

terrestrial world. The second and third letters were written during the second period; their contents were derived from the more accurate and continuous observations using the projection method. By the newly acquired evidences, Galileo strengthened his argument that sunspots are very near or on the surface of the sun. He did not change his concept that the sunspots were like little clouds.

In this paper, I will examine Galileo's observation notes on sunspots from the first period, and investigate when and how Galileo regarded them to be like little clouds.

§2 Notes on sunspots from the first period

Galileo's surviving notes from the first period began on February 12 and finished on May 3, and consists of two pages.[3] Galileo performed observations on 26 days:

February: 3 days: 12, 17, 23

March: 9 days: 1, 2, 7, 16, 17, 18, 20, 21, 31

April: 12 days: 3, 5, 6, 7, 10, 16, 18, 20, 21, 23

May: 2 days: 1, 3

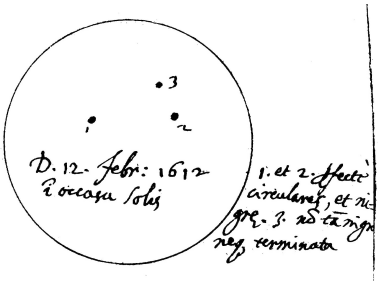

Fig. 1 February 12

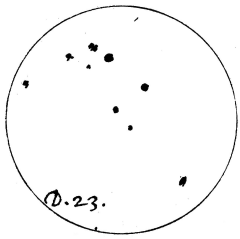

Fig. 2 February 23

The record of the first observation on February 12 has a circle for the sun, and there three spots are drawn as points and marked 1, 2, and 3.[4] Within the circle, "On the 12th

[3] They are reproduced in OGG, V, pp. 253–254.

[4] This record is transcripted in Bredekamp 2009, p. 233, n. 38 and translated into English in Galileo and Scheiner 2010, p. 79.

day of February 1612, at sunset"[5] is written. Beside it, we find a note that "1 and 2 perfectly circular, and black, and 3 not so black, not terminated."[6] On February 17, only one spot is drawn, and on February 23, nine spots are drawn with no explanation. On 1, 2, and 4 March, there is no spot.[7].

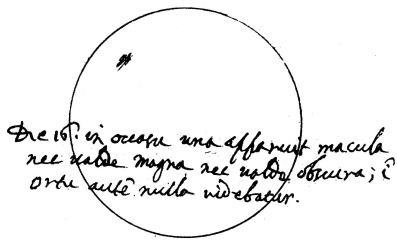

Fig. 3 March 16

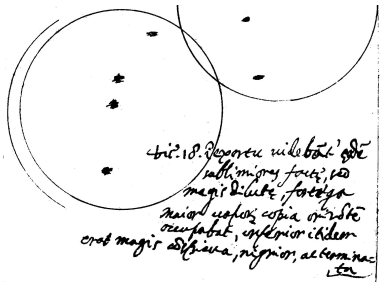

Fig. 4 March 18

From March 16 to 21 (16, 17, 18, 20, and 21), Galileo continuously observed sunspots, and he followed the same ones. On March 16, Galileo changed his way of drawing spots. Until then, he had drawn them as points, but now he depicted them in irregular forms. On March 18, he noticed changes in the position, form, color, and denseness of the sunspots.

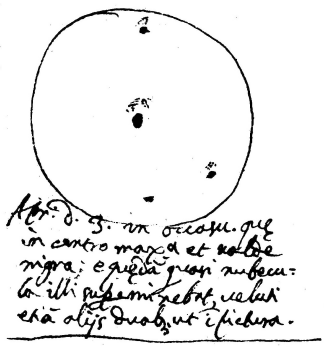

Fig. 5 April 3

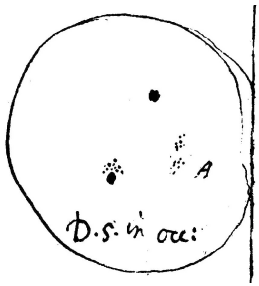

Fig. 6 April 5

[5] "D. 12. Febr: 1612 in occasu solis"

[6] "1. et 2. perfecte circulares, et nigrae. 3. non tantum nigra neque terminata "

[7] The records of March 2 and 4 are translated into English in Galileo and Scheiner 2010, p. 79.

From April 3 to 10, Galileo also continuously observed spots. On April 3, he depicted the spots as black points with a group of little points. This is the first note to state the resemblance of a sunspot to a small cloud.

> The center [spot] was biggest and very black, and something like a small cloud above it, just like the other two spots, as in the figure.[8]

In the figure, Galileo depicts "something like a small cloud"as a group of little points. On April 5, he marked a spot with "A"in the picture. The note for the next day describes the changes in the spot A's shape, which is enlarged beside the sun. This figure was reprinted in the first letter of *Istoria e dimostrazioni*.[9]

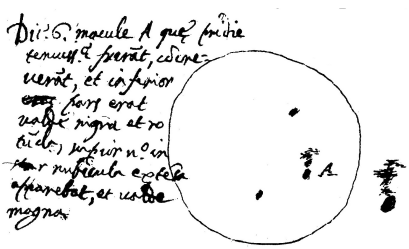

Fig. 7 April 6

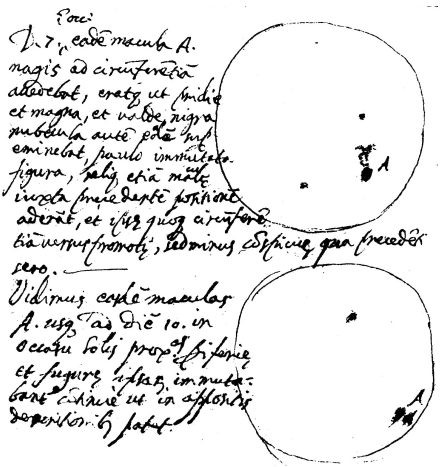

Fig. 8 April 7-10

The notes from April 6 to 10 are as follows.

> On the 6th day, the spot A, which had been very thin on the day before, had grown, and the inferior part was very black and round, while the superior part appeared extended like a little cloud, and very large.

[8] "in occasu. quae in centro maxima et ualde nigra; e quaedam quasi nubecula illi supereminebat, ueluti etiam alijs duabus, ut in pictura."

[9] Galileo and Scheiner 2010, p. 100; OGG, V, p. 107.

> On the 7th day, at sunset, the same spot A came nearer to the circumference, and was large as the day before, but a very black little cloud was above it, in a slightly altered form. The other spots were still near their precedent positions, and they also moved forwards toward the circumference but were less conspicuous than late the previous day.
>
> We saw the same spot A until the 10th day, at the sunset very near to the periphery, and its figure changed continuously, as shown in the contiguous drawings.[10]

During this period, the spot A has moved toward the circumference, and its shape has contracted horizontally.

From April 28 to May 3, Galileo followed a very large spot, whose "length occupied a sixth or at least a seventh of the solar diameter." It isn't depicted as a circle, but as a group of fine lines - "something like a cloud."

The figures of these spots are reprinted together in a figure in the first letter of *Istoria e dimostrazioni*.[11] As the circle of the suns are not described, their places are not shown; only their shapes are depicted. Galileo's interest was directed to the nature of sunspots, which he insisted were not the shadows of stars but were something similar to little clouds.

Thus, we can believe that at the beginning of April, Galileo had the idea that sunspots were similar to little clouds in the terrestrial world instead of being the shadows of celestial bodies.

§3 The expansion of the terrestrial world into the celestial world

It is known from Galileo's notes at the beginning of April that he conceived sunspots to be "something as a small cloud."How did he arrive at this idea? In *Sidereus nuncius* (*The*

[10] "Die. 6. macule A quae pridie tenuissae fuerant, concreuerant, et inferior pars erat ualde nigra et rotunda, superior uero in nubecula extensa apparebat, et ualde magna.

D. 7. in occi eadem macula A. magis ad circumferentiam accedebat, eratque ut pridie et magna, et ualde nigra nubecula autem eadem supereminebat, paulo immutata figura, reliquae etiam maculae iuxta precedentem positionem aderant, et ipsae quoque circumferentiam versuspromotae, sed minus conspicuae qua precedente sero.

Uidimus easdem maculas A. usque ad diem 10. in occasu solis proximae periferiae et figurae ipsarum immutabantur continue ut in appoistis descriptionibus patet."

[11] Galileo and Scheiner 2010, p. 100; OGG, V, p. 107.

sidereal messenger, 1610), inferring the irregularity of the moon surface from its appearance, Galileo utilized an analogy between the earth and the moon. When he considered the dark parts of small spots to be the shadows of craters, he relied on the similarity to a valley surrounded by mountains. Because the sun shines obliquely, mountains cast shadows on a valley. Galileo insisted that these shadows were same as the dark parts of small spots on the moon.[12] He believed in the existence of a vapor sphere around the moon like the earth, and applying this to Jupiter, he inferred that a vapor sphere surrounded Jupiter, too.[13] Thus, Galileo relied on knowledge of the terrestrial world to interpret new phenomena of the moon and Jupiter observed with telescopes.

Regarding the solar spots, he also tries to conceive them using an analogy to terrestrial phenomena. In the first letter, he confirms that we cannot "establish and affirm any conclusions as certain ", because the substance of the spots is "unknown and imaginable to us."[14] By way of analogy to materials familiar to us, the characteristics of spots mostly resemble those seen in clouds. He recognizes that the sunspots consist of the different substance from vapor, and he insists only that we do not know of anything else that is more similar to sunspots than clouds.[15]

In the third letter, Galileo concludes as follows.

> I say that for the present it is enough for me to have demonstrated that the spots are neither stars, nor solid matter, nor located far from the Sun, but that they appear and disappear around it in a manner not dissimilar to that of clouds or other smoke-laden vapors around the Earth.[16]

Galileo does not consider the sunspots to consist of the same materials as clouds. In the second letter, however, he applies the law of inertial motion to sunspots.[17] This law is called that of circular inertia. A terrestrial body has a tendency of falling to the center of the earth and of resisting upward movement, while on a horizontal surface it does

[12] Galileo 2009, pp. 59–60; OGG, III-1, pp. 63–64.

[13] Galileo 2009, pp. 65–66, 93; OGG, III-1, pp.70–71, 95–96.

[14] Galileo and Scheiner 2010, p. 98; OGG, V, p. 105.

[15] Galileo and Scheiner 2010, p. 101; OGG, V, p. 108.

[16] Galileo and Scheiner 2010, pp. 294–295; OGG, V, p. 236.

[17] Galileo and Scheiner 2010, pp. 124–125; OGG, V, pp. 134–135.

not resist any motion and remains at rest or continues uniform motion. Although this law was intended only for terrestrial bodies like cloud, Galileo applied it to sunspots. Here he extended the laws of the terrestrial world to the celestial world. We can say that Galileo extended the physics of the terrestrial world into the celestial world. This led to the overthrow of the traditional worldview that divided the universe into two different worlds: the terrestrial world and celestial world. Galileo's conception of sunspots as clouds was an important step in this process.

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Appendix: Galileo's observation notes on sunspots

[in OGG, V, pp. 253–254.]

D. 12. febr: 1612 in occasu solis
1. et 2. perfecte circulares, et nigrae. 3. non tantum nigra neque terminata

D. 17. in occ. una tantum aderat macula occidentalis

D. 23.

D. 1. Martij nec in ortu nec in occi aderant maculae

D. 2. Martij in orienti solis nulla apparuit macula ; et consumpsit in exortu pulsationes 270

Die 4. Martij nulla apparuit macula, et consumpsit in suo exortu pulsationes 250

Die 16. in occasu una apparuit macula nec ualde magna nec valde obscura ; in ortu autem nulla videbatur.
exortu Die 17. in inferior erat nigrior et magis terminata

Die. 18. in exortu uidebantur eadem sublimiores factae, sed magis dilutae, forte quia maior uaporis copia orizontem occupabat, inferior itidem erat magis conspicua nigrior, ac terminata

Di. 20, in occasu

Die. 21. in exortu.

Die 31. in occasu

Apr. d. 3. in occasu. quae in centro maxima et ualde nigra; e quaedam quasi nubecula illi supereminebat, ueluti etiam alijs duabus, ut in pictura.

Die. 6. macule A quae pridie tenuissae fuerant, concreuerant, et inferior pars erat ualde nigra et rotunda, superior uero in nubecula extensa apparebat, et ualde magna.

D. 7. in occi eadem macula A. magis ad circumferentiam accedebat, eratque ut pridie et magna, et ualde nigra nubecula autem eadem supereminebat, paulo immutata figura, reliquae etiam maculae iuxta precedentem positionem aderant, et ipsae quoque circumferentiam versuspromotae, sed minus conspicuae qua precedente sero.
Uidimus easdem maculas A. usque ad diem 10. in occasu solis proximae periferiae et figurae ipsarum immutabantur continue ut in appoistis descriptionibus patet

Die 16. mane H. 1. ab ortu una tantum satis 2 cospicua uidebatur ut in figura cui adstabat alia uelut nubecula tenuissa et informis quae uix conspiciebatur.

Die. 19. H. 3. ab ortu

Die. 20. in occi

Die 26. in occasu

D. 28. H. 21. erant maculae omnes quas unaequique uideri maximae.

D. 29. in occasu eadem macula figuram immutauerat, et erat maxima

Die 30 in exortu cernebantut eaedem maculae ut in figura, quarum longitudo sextam aut saltem septimam partem diametri solaris occupabat

Maij D. 1. in cocasu

D. 3 mane ab ortu H. 3

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