Note

Harriot and Galileo: On sunspot observations

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§1 Introduction

Thomas Harriot (1560-1621) is known as the first astronomer to make astronomical observations with telescopes. He observed the Moon at the end of August in 1609, four months before Galileo Galilei (1564-1642).[1] He also observed sunspots before Galileo in December 1610, and he started continual observations in December 1611 about one year later. He carried on observations until January 1613, of which he left notes.

Galileo Galilei began observing sunspots in February 1612. One month earlier, he received a copy of Christoph Scheiner's *Tres Epistolae de Maculis Solaribus* through Marc Welser, an Augsburg banker.[2] In that book, Scheiner considered sunspots to be the shadows of stars revolving around the Sun. Galileo was invited by Welser to comment on Scheiner's book, and he started observing sunspots in February 1612. His records of sunspots started at that time and finished in August. He published his study as *Istoria e dimostrazioni intorno alle macchie solari e loro accidenti* in March 1613. This book consists of three letters to Marc Welser. He wrote the first letter on June 4, 1612, the second on August 14, and the third on December 1.

In this note, I will compare the descriptions and drawings of sunspots by Harriot and Galileo, and consider the characteristics of their observations.

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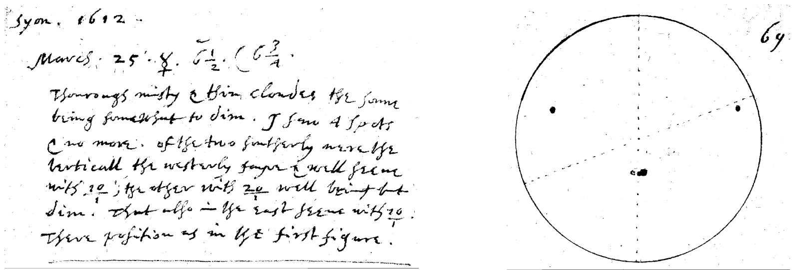
[1] For Harriot's life and scientific activity, see Shirley 1974 and 1983.

[2] The text is reprinted in OGG, Vol. 5, pp. 25–33, and its English translation is in Galileo and Scheiner 2010, pp. 58–73. For his life and scientific activities, see Daxecker 2004. At this time, Johannes and David Fabricius also observed sunspots. See Galileo and Scheiner 2010, pp. 24–34.

§2 Thomas Harriot

Harriot's notes are conserved in the Petworth House Archive: Harriot papers, vol. VIII: Spots on the Sun [HMC 241 VIII].[3]

He wrote the first record on December 8, 1610. As he used the Julian calendar, the day corresponds to December 18 on the Gregorian calendar. The difference between the two calendars is about ten days. In this note, I will write the day as December 8 Ju (December 18 Gr). The next record was on January 19, 1611 Ju (January 29 Gr) a month later. Then he stopped the observations for about a year, and he restarted them on December 1, 1611 Ju (December 11 Gr). He continued them until the end of January 1613 for about 13 months. His notes include about 200 days' observations in 76 folios. Each folio contains 2–4 days' records, of which each consists of a description and a figure.



Syon. 1612. / March. 25. ☿ [Wednesdy]. hor. $\frac{1}{2}$.(6$\frac{3}{4}$. /
Thorough misty & thin cloudes the sonne / being somewhat to dim. I saw 4 spots / & no more. of the two southerly nere the / verticall the westerly fayer & well seene / with $\frac{10}{1}$; the other with $\frac{20}{1}$ well being but / dim. That also in the east seene with $\frac{10}{1}$. / There position as in the first figure.

Fig. 1: Harriot's Record of March 25 Ju (April 4 Gr)

During this whole period, Harriot changed neither his method of observing sunspots nor his way of description of them. He viewed the Sun directly through a telescope using

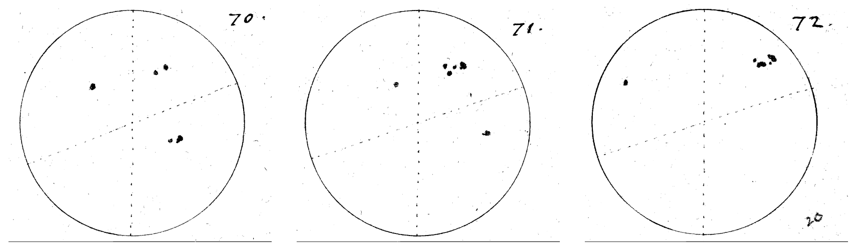
[3] I express my sincere gratitude to Lord Egremont for permission to reproduce the images from his collection. We can see their images at the website of ECHO. Jacqueline Stedall, Matthias Schemmel, Robert Goulding: Digital edition of Thomas Harriot's manuscripts, 2012–. Max Planck Institute for the History of Science. January 31, 2019. http://echo.mpiwg-berlin.mpg.de/MPIWG:FAYG83FB.

a filter. His telescopes had magnitudes of ten, twenty, and thirty times. He used them properly depending on the state of observations.

In the record on March 25 Ju (April 4 Gr), he first described the state of the air, clouds, and the Sun, and then the number, places, and states of sunspots (See Fig. 1).[4] He also mentioned the accidentals of sunspots: color, darkness, and shape. He sometimes described the magnitudes of the telescopes he used.

His drawing is very clear and accurate. He draws two straight lines on the Sun disk, of which one is vertical, and the other is the equator of the Sun. The equator line is so useful that we can know the time of observation and compare the drawings at different times. He mainly observes at 5 or 6 o'clock in the morning.

Harriot sometimes observed continuously for two or three days. Here we see the records on March 27, 28, and 30 Ju (April 6, 7, and 9 Gr) (See Fig. 2).[5]



March. 27. ♀. ho. $5a\frac{3}{4}$.(6*a*. Thourough misty ayer & thin cloudes I saw 5 spots & no more. The two in the north west were not seen before & well seen with $\frac{20}{1}$. The position of all are as in the 2 figure.

March 27 Ju (April 6 Gr)

March. 28. ♄. hor. $5a\frac{1}{2}$.(6. Thourough misty ayer I saw 6 spots & no more. Those in the north west quarter are now 4. Three of the ex= tremest well seen with $\frac{10}{1}$ & westerly fayre & great. The rest were but dim & seen but with $\frac{20}{1}$. There position as in the 3 figure.

March 28 Ju (April 7 Gr)

March. 30. ☽. $6\frac{1}{2}$.($6\frac{3}{4}$. Thourough thick ayer & thin cloudes I saw 5 spots & no more. That in the east is newly seen & sundly with $\frac{10}{1}$ but with $\frac{20}{1}$ fayre. of the 4 in the west two are seen great with $\frac{10}{1}$. & the easterly small are seen with $\frac{10}{1}$ though dimly. There position as in the 4 figure, with the shapes of the great ones.

March 30 Ju (April 9 Gr)

Fig. 2: Harriot's Records on March 27, 28, and 30 Ju (April 6, 7, and 9 Gr)

[4] HMC, fol. 20r.

[5] HMC, fol. 20r.

On these days, Harriot observed the Sun almost at the same time. We can see that the northwestern spots are moving to the right side and that their shapes are changing. He drew them but mentioned neither their motions nor their changes in shape. He might have identified each sunspot, but he did not relate its appearances on different days. His way of description did not change until the end of his observations.

As it will be shown, Harriot's attitude is very different from Galileo's and Scheiner's . For them, the motions and changes of sunspots are significant, because they are interested in the substance of sunspots. Galileo considered them to be something like 'clouds' situated very near the solar surface, while Scheiner considered sunspots to be shadows of stars revolving around the Sun.[6]

§3 Galileo Galilei

Galileo started continual observations in February 1612 and finished in August 1612. We can see his records in these three documents.

1: Manoscritti Galileiani, Parte III, Tomo X, car. 68t–70r.[7]
   Two folios contain the records from February 12 to May 3.
   They contain 22 figures.
2: The letter to Maffeo Barberini on June 2.[8]
   It contains nine figures from May 3 to 11.
3: The second letter of *Istoria e dimostrazioni intorno alle macchie solari*.[9]
   It contains 39 figures from June 2 to July 8 and from August 9 to 11.

The first document contains the records when Galileo observed sunspots directly. The second and third documents contain those obtained by the new method of observing sunspots. It is by projecting the Sun image on the sheet. Galileo learned the image projection method through the letter from his disciple Benedetto Castelli at the end of April. The method is as follows. First, draw a circle by a compass on a piece of paper,

[6] As regards Scheiner's view of sunspots, see Galileo and Scheiner 2010, pp. 47–57.

[7] Reprinted in OGG, 5, pp. 253–254. See Ito 2017.

[8] Reprinted in OGG, 11, pp. 304–311.

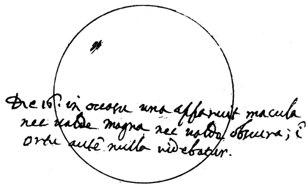
[9] Reprinted in OGG, 5, pp. 145–182. See also its English translation in Galileo and Scheiner (2010).

and set it ahead of the eyepiece of the telescope. Then project the Sun image on the sheet, and adjust the placement of the sheet so that the circumference of the Sun image overlaps the drawn circle. With that method, Galileo could get more accurate observations than when he had seen the Sun directly. Here his records are divided into two periods by the introduction of the new method. The first is that of directly seeing the Sun, and the second is that of projecting its image.

3.1 Directly Seeing Method

Galileo saw the Sun directly from February until the beginning of May. He left records for 26 days, of which three are in February, nine in March, twelve in April, and two in May. First Galileo intermittently observed, and then he began continuous observations a few days in March (16, 17, 18, 20, and 21 Gr) and in April (3, 5, 6, and 7; 28, 29, 30, May 1, and 2 Gr).

Die 16. in occasu una apparuit macula / nec ualde magna nec ualde obscura ; in / ortu autem nulla vidbatur.
[On the 16th day, at sunset only one spot appeared neither very black nor very obscure; however at sunrise, no spot has been seen.]



Die 17. in exortu / inferior erat nigrior / et magis terminata
[On the 17th day, at sunrise the inferior was darker and more terminated.]
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.
[On the 18th day, at sunrise the same one was seen to be more uplifted and more diluted, by chance because more vapor occupied the horizontal part, the superior one was so much more conspicuous, darker, and delineated.]

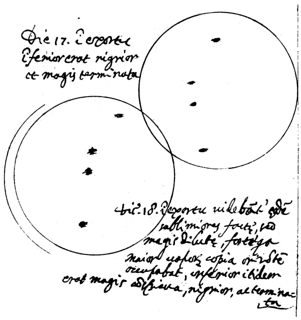


Fig. 3: Galileo's Records on March 16, 17 and 18 Gr

Galileo tracked the same sunspots for these days, and he investigated their states and motions. In the records of March 16, 17, and 18 Gr, Galileo mentioned the change of the state of a sunspot (See Fig. 3).[10] He inferred the existence of something like ‘vapor’ as a cause of the diluting of sunspots. Here he did not consider sunspots as stars revolving around the Sun, but as something situated near the Sun’s surface. He might regard the Sun’s surface as resembling the Earth’s that is surrounded by vapor. In *Sidereus nuncius*, Galileo insisted that the vapor surrounds the Moon and Jupiter.[11]

Further, Galileo considered sunspots as something like ‘clouds’ of our world. From April 5 to 7 Gr (and until 10 Gr), he was tracking the same sunspot marked ‘A’ (See Fig. 4).[12]

Die. 6. maculae A quae pridie tenuissae fuerant, concreuerant, et inferior pars erat ualde nigra et rotunda, superior uero in nubecula extensa apparebat, et ualde magna.
[On the 6th day, spot A that had been very thin on the day before, has grown, and the inferior part was very black and round, while the superior part appeared extended like a little cloud, and very large.]
D. 7. in occ. 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.
[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 the slightly altered form. The other spots were still near their precedent positions, and they also moved forward to the circumference, but were less conspicuous than late the previous day.]

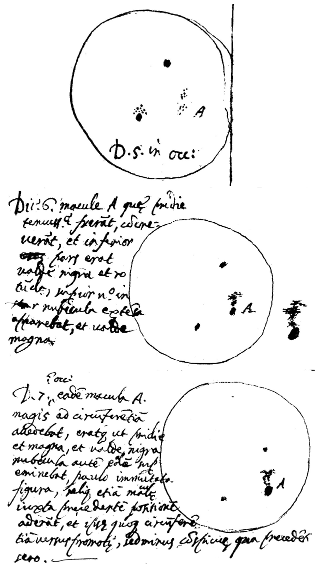


Fig. 4: Galileo’s Records on April 5, 6 and 7 Gr

His sketch of spot ‘A’ shows that its form is not regular, but irregular. Comparing sketches of different days, we can recognize the change in the form of spot ‘A’ and its motion from left to right. He wrote that the superior part appeared extended like ‘a little cloud’.

[10] OGG, V, p. 253.

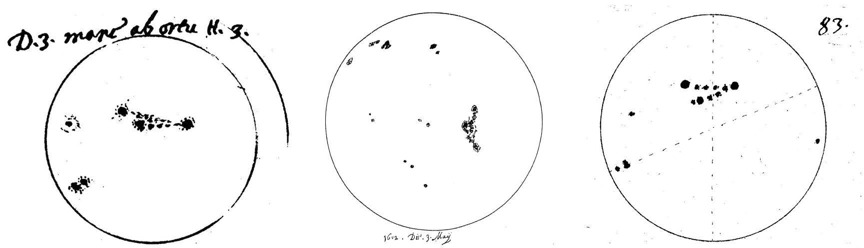
[11] OGG, III, pp. 70–71, 95–96. See also Galileo 2015, pp. 52–53, 87–88.

[12] OGG, V, pp. 253–254.

In the first letter of *Istoria e dimostrazioni intorno alle macchie solari*, Galileo reproduced the figures of spot ‘A’, and he showed the changes in them.[13] He concentrated on revealing the nature or substance of sunspots and therefore did not pay much attention to their positions.

3.2 Image Projection Method

Galileo introduced the new method on May 3 Gr. That day he left two drawings of sunspots, of which one is made by directly looking the sun and another by projecting its image on the sheet (See Fig. 5). [14]



Galileo 1: Directly Seeing Method   Galileo 2: Projection Image Method   Harriot (23 April Ju)

Fig. 5: Records of Galileo and Harriot on May 3 Gr

When we compare the images of Galileo 1 and 2, the accuracy of Galileo’s drawings is improved drastically by the introduction of the image projection method. The images of sunspots in Galileo 1 are too large compared to the size of the solar surface, and less accurate than Harriot’s. They seem to be exaggerated to show that sunspots are like clouds. As regards the directly seeing method, Harriot is superior to Galileo.

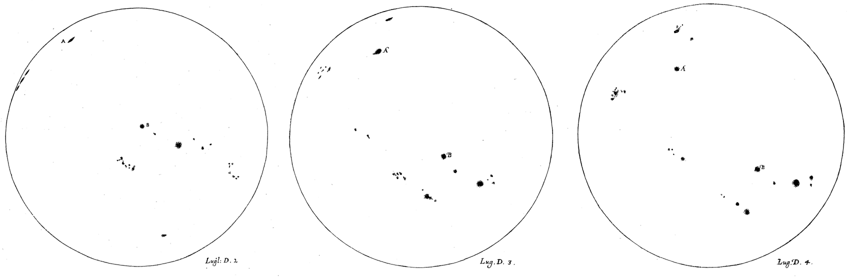
After introducing the image projection method, Galileo was more interested in the widths, positions, and intervals of sunspots. In the second letter of *Istoria e dimostrazioni intorno alle macchie solari*, he referred to the daily changes in their positions and intervals. Here we compare three drawings on July 2, 3, and 4 Gr (Fig. 6).[15]

We can follow the changes in the positions of the sunspots A and B and the interval

[13] OGG, V, p. 107. See also Galileo and Scheiner 2010, p. 100.

[14] OGG, V, p. 254; XI, p. 307; HMC, fol. 23r.

[15] OGG, V, pp. 173–175.



July 2 Gr July 3 Gr July 4 Gr

Fig. 6: Galileo's Records on July 2, 3, and 4 Gr

between them. As their motion and interval reach their maximums near the center of the Sun's surface and diminish near the circumference, he demonstrated that sunspots are very close to the solar surface using geometrical reasoning.

He also noticed a shared motion in all sunspots. They move along the equator of the Sun from west to east, and they cross the solar surface in about 15 days. From that, Galileo inferred the rotation of the Sun itself.

§4 Summary

Galileo's observations on sunspots started with the aim of refuting Scheiner's view that sunspots are the shadows of stars revolving around the Sun. Galileo insisted that those are not the shadows, but something like 'clouds', and they are in the vicinity of the solar surface. Here his observations through telescopes were closely linked to clarifying the nature of sunspots. Their results are regarded as experiential proof of his thoughts.

The changes in the shapes of sunspots indicate that they are not the shadow of celestial bodies, and their irregularities lead to Galileo's inference that they are like clouds on the Earth. Here he attempts to deny the distinction between the terrestrial world and the heavenly world and to understand the new knowledge of the latter by analogizing it with the former.

We cannot find such an attitude in Harriot's solar observations. He depicted what he saw very accurately, but he did not discuss the nature of sunspots. He never led cosmological arguments as Galileo did. Thus he was an excellent observer, but only an observer compared with Galileo.

Galileo's achievements consist not only in describing observation results through telescopes, but also in connecting them to a new cosmological argument and offering a new image of the universe. From the empirical evidence obtained by telescope observations, he demonstrated that sunspots are very close to the solar surface. This idea was incompatible with the traditional cosmology that celestial bodies including the Sun are perfect and immutable. Thus Galileo extended the earthly world to the celestial world. We can call Harriot as a 'pure observer', whereas Galileo was a 'cosmological observer'.

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