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Posted Date: 12 September 2025

doi: 10.20944/preprints202506.0545.v3

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Modern View of the Sun: Materials for an Experimental History at the Dawn of Telescopic Era

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Abstract

Galileo and the telescope revolutionized the concept of the Sun. The discovery of its rotation was possible due to the continuous observation of the sunspots. The *faculae* and the *maculae* with *umbra* and *penumbra* became accessible daily to new instruments, leaving the perfectly lucid disk to the realm of symbolism. Was this new view possible before the telescope? Technically, pinhole cameras can show the largest sunspots, as well as the naked eye under very particular conditions. However such observations were too scattered to produce any change in the established understanding of the Sun. Synoptic observations of the largest sunspots of the XXV solar cycle made with the naked eye, pinhole camera, and a telescope in camera obscura are presented and compared with the historical ones. Sunspots could have been discovered in Florence as early as 1475 with the pinhole meridian line of S. Maria del Fiore: the Spörer minimum (1460–1550) of the solar activity prevented it. Indications of white light flares and prominence observations appear in a drawing dated back to 1635, well before the first H-alpha inspections in the 19th century.

Keywords: ancient Egypt; sun; sunspots; Galileo Galilei; Athanasius Kircher; pinhole meridian lines; camera obscura; eye optical resolution; Spörer minimum

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1. Introduction: The Sun: From an Ideal Disk to the First Telescopic Sight

The Sun appears as a bright disk, and its dazzling luminosity normally prevents observations of its surface. Since antiquity, the Sun has been worshipped as a god. The Egyptians (Section 2) represented it either as a disk or as a sphere, with some elements suggesting direct observations of the corona and prominences during total eclipses. In Christianity (Section 3), St. Francis of Assisi in 1225 composed his *Cantico di Frate Sole*, in which the Sun represents God's qualities. Galileo Galilei (Section 4), with his telescope, first recognized, in 1611, that sunspots belonged to a rotating photosphere, proving the spherical nature of the Sun. The solar symbol was frequently used in the Catholic Church (Section 5), also appearing in the coat of arms of the Jesuit Pope Francis. The occasional observations of giant sunspots in the Middle Ages (Section 6), with the naked eye or through pinholes in a camera obscura, could have raised the question of the solar rotation before the telescope. The answer is suggested by the evolution of the largest sunspots of the XXV solar cycle observed by the naked eye (Section 7) and using a camera obscura (Section 8), and it helps better understand the quality of the pre-telescopic observations. The sunspots are visible (Section 9) with the pinhole meridian line of St. Maria degli Angeli in Rome, and the largest pinhole meridian line, realized by Paolo Toscanelli (1475) in the Dome of Florence, could have shown the largest sunspots, but the Sun was in the Spörer Minimum (1460–1550). Limb darkening (Section 10) is another clue for the solar sphericity, but the pinhole itself introduces limb darkening of the image. The invention of the telescope occurred just after the first map of the Moon, drawn with the unaided eye (Section 11) when the Sun restored its sunspot activity (Section 12).

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2. The Representation of the Sun in Ancient Egypt

The Sun has always been present to mankind, but only in the last four centuries has the question about its physical nature become meaningful.

The solar mythology in Egypt is very complex, and its discussion would largely exceed the scope of this work. The representations of the solar disk or sphere are well known. In Figure 1, the god falcon Ra-Haratki, is represented with the solar disk on top.

Figure 1. The representation of Ra-Haratki, Pyramidion of the scribe Ramose (Reign of Ramses II, Torino, Museo Egizio, item no. C. 1603). The cobra (uraeus) is present in the lower part of the solar disk (photo of the author).

There is a physical correspondence between the traditional representation of the Sun in Egypt and the phenomena visible during a total eclipse of the Sun. The uraei, in particular, are the red prominences departing from the solar disk. The rays are straight as in modern geometrical optics, first described by the Arab polymath Alhacen in 1028–1038 (Mark Smith 2010) while he was working in Egypt. In Figure 2, another colored example is from the Egyptian Museum of Turin.

Figure 2. The winged solar disk with two red uraei in a wooden stele. Turin, Museo Egizio, item no. C. 1568 (gift from Cairo Museum; photo of the author).

The winged Sun includes the wings (of the falcon Horus) and one or two cobras (*uraei*): their positions always start from the solar limb, resembling the prominences visible (without modern H-

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alpha filters) only during total eclipses. The wings are fully stretched, resembling the streamers occurring during the minimum phases of the solar cycles (Figure 3).

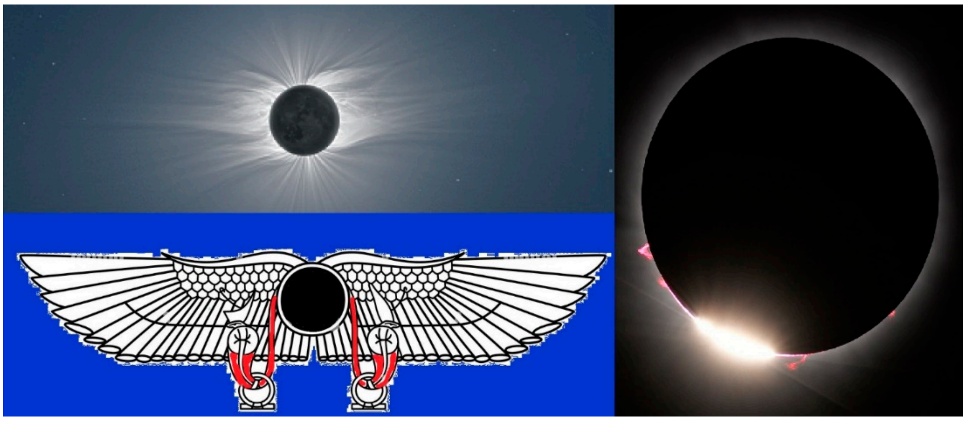

Figure 3. The total eclipse on 22 July 2009, pictured at Enewetak Atoll, Marshall Islands;Error! Reference source not found. the total eclipse of 8 April 2024 in the USA at the moment of prominences' visibility, and a sketch of the winged Sun. Both photos are taken in white light; the drawing is by the author.

The eclipse of 2009 was so long (5 m 42 s) that in the middle, no prominences appeared, because the Moon was angularly wider than the Sun. The eclipse of 2024 was captured at the moment of the diamond ring, occurring just before or just after totality, when the photosphere appears. Four prominences are well visible and in red color (belonging to the chromosphere). These are the natural correspondences to the *uraei*.

Despite the faint luminosity of the solar corona, the memory of this feature, along with the red prominences visible at the beginning and at the end of the totality, can be unforgettable for an observer. The red prominences at the start of the totality and toward the end attracted my attention during the total solar eclipse of 1999 in Riedering, Bayern, Germany. Since then, I started to reconsider the Egyptian solar symbology as coming directly from real observations of ancient total eclipses.

A great prominence on 14 July 2025 (Figure 4) offered the possibility to see its extension beyond the solar disk to explain the iconic appearances of the *uraei*.

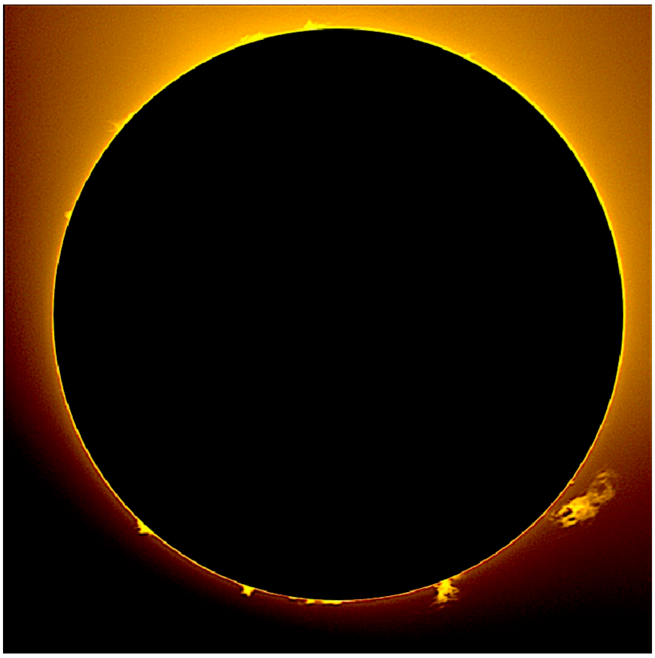

Figure 4. The Sun on 14 July 2025 h 17, with a great prominence in the western (lower) limb.[2] This prominence was long enough to explain the extension of the *uraei* (Figure 2).

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The hypothesis of identifying the wings with the solar corona during eclipses is not a novelty: other scholars did it in the past (Belmonte and Lull 2023).[3] Several total eclipses occurred on the Egypt over the millennia of its history, but the eclipses are completely under reported in the ancient Egypt, probably because they were considered as bad omens (Belmonte and Lull 2023). The hypothesis that an eclipse influenced Amenothep IV to change his name and the capital city in Egypt in his 4th year of reign: this eclipse was total in the place where the new capital Akhetaten was created (Belmonte and Lull 2023). The identification of the *uraei* with the solar prominences visible during the totality is new. The Uraeus[4] is the symbol of the goddess Wadget, a cobra who was considered as the patroness and protectress of Egypt. The colors and the representations of the figures of the solar disk (Figures 1–3) in general, reflect symbolic models, possibly originated by a real observation made at first and then transmitted as an iconic tradition.

Real observations did not improve these symbolic representations, even though the exception of the solar halo in the tomb of Meryre in Amarna, is an interesting reported case.[5] Finally, there are no sunspots imaged in the Egyptian representation of the Sun.[6]

3. The Sun of Christianity

Christ is called the "Sun rising from on hig" (Luke 1: 68–79), and to see the great brightness of the Sun eagle eyes are needed.[7] This legend and the text of Revelation (4: 6–8) form the basis of representing St. John the Evangelist with an Eagle, because he was the author of the most theological gospel. His sight was able to penetrate the secrets of God, as the eagle can gaze fixedly to the Sun. Examples of Christ-Sun are in Figure 5.

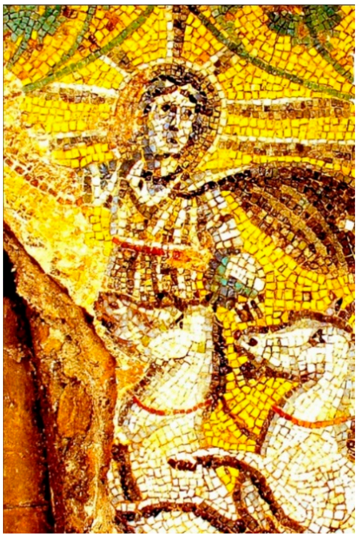

Figure 5. Christus Helios in the Mausoleo dei Giuli, Vatican necropolis (III century) on the left. The image of Christ in the triumphal arch in the Basilica of St. Paul outside the walls, Rome (IV century- rebuilt in XIX century) on the right side; photos by the author.

St. Francis of Assisi in 1225 composed the *Cantico di Frate Sole* expressing in poetry the representative role of God played by the Sun.

Laudato Si' mi Signore per frate Sole
Lo quale è iorno et al.lumini noi per lui
Et ellu è bellu et radiante cum grande splendore
Di te porta significatione[8]

Among Christian symbols, the Sun was used to represent Charity,[9] Wisdom[10] and Jesus (Figure 4). Representing God with the Sun is based on the Psalm 18, 6 *"In Sole posuit tabernaculum Suum"* (*In*

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the Sun He posed his tent). The representations of the solar symbols are flat, both before and after the evidences of a spherical Sun, not only in painting and mosaics, but also in sculptures.

St. Bernardin of Siena (1380–1444), a Franciscan friar, created the symbol of the radiant Sun with the acronym IHS *Iesus Hominum Salvator* inscripted inside (Figure 6).

This symbol was painted on a wooden table and used to give blessings, after his preachings (Figure 6 and 7).[11]

Figure 6. Table of the Christogram YHS. Church of St. Francis in Prato (1424). There are 12 main twisted rays, as the biblical number of the apostoles, or the tribes of Israel. In the frame it is reported the words (Philippians 2, 10)—*In nomine Iesu omne genu flectatur, coelestium, terrestrium, et infernorum*.

The possibility that the twisted rays recall prominences seen during total eclipses has been inspected (Zawilski 2021). During the life of st. Bernardin there were two total eclipses occurring near him: 1386 and 1431. He could have observed both of them.[12] The difference between thick twisted and thin linear rays may serve only to indicate the number 12, a symbol of fullness in the Bible, because so many prominences cannot be visible at once.

An evolution of the rays can be observed from the original table of

St. Bernardino (Figure 6) through the subsequent representations (Figure 7) up to the coat of arms of Pope Francis, where both the number of 12 and the differences between rays disappeared.

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Figure 7. The Sun with the acronym IHS, Iesus Hominum Salvator, created by St. Bernardin of Siena.[13] This symbol was adopted by St. Ignatius of Loyola, founder of the Jesuits, with the addition of the cross and the nails; it is in the coat of arms of Pope Francis.[14].

4. The Sun of Galileo and His Contemporaries: Planet or Star?

Galilei (1613) following the motion of the spots, interpreted them as located on the solar surface. Scheiner's orbiting planet or cloud interpretation dates from 1611 (the Apelles letters). In the Rosa Ursina (Scheiner 1630) he actually gave up that notion and even determined the Sun's rotational elements based on the spots, accepting that they belonged to the solar surface or close to it. In the *Borbonia Sidera* (Tarde 1620; see Figure 8), the spots were considered as *moving stars.*[15] Jean Tarde (1561–1636) was a French prelate, historian and astronomer,[16] who met personally Galileo in 1614.

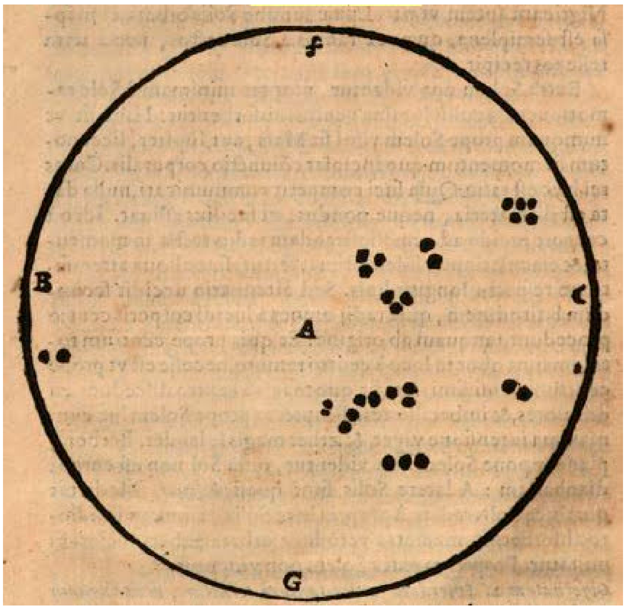

Figure 8. Diagram of sunspots from Borbonia Sidera (Jean Tarde 1620).[17].

Giordano Bruno[18] (1548–1600) considered the stars as very far suns (Bruno 1584), but his speculation did not rely on specific measures. A similar idea, supported by computations and observations was the one of Christiaan Huygens (1629–1695): the Dutch scientist Christian Huygens produced an image of the Sun through a pinhole in a darkened room. He varied the size of the pinhole until the image seemed equal in brightness to an image of Sirius, the brightest star. Since the pinhole

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admitted 1/27000 of the light of the Sun, Huygens concluded that Sirius was 27000 times farther away than the Sun (it is actually 543900 times farther away and substantially more luminous than the Sun, see Figure 9).[19]

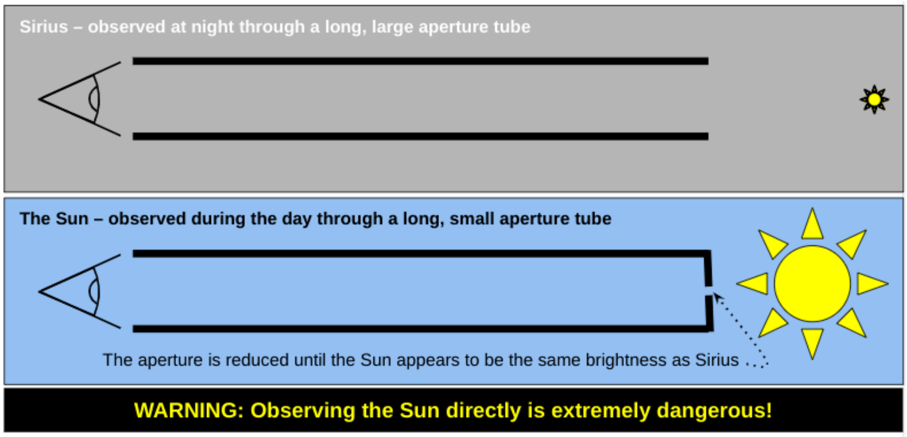

Figure 9. The Scheme[20] of the experiment of Huygens using a pinhole of focal 4 m.

From a physical point of view the Copernican hypothesis gave to the Sun[21] the central role of the Universe, but in Bruno's view the Sun became a star in the modern sense. Galileo, instead, when not dealing with "*fixae*" or fixed (stars), was still considering the possibility of the stellar motion. In this respect, the Earth orbiting around the Sun was a (moving) star (Galileo, Il Saggiatore, 1623).

The Greek word for moving star is "*planétes*". The difference with the other stars was only kinematic, while with Bruno it started to become a physical one: the stars were far suns. The difference between this view and the modern one required nearly three centuries to mature.It is to remark that at the end of XIX century, Camille Flammarion in his Astronomie Populaire still considered the possibility that the Sun could be inhabited (Flammarion 1875) as all other planets.

5. Naked Eye Sunspots Since the Middle Age

Solar activity and solar rotation were observed occasionally and reported in the medieval chronicles. The spots on the Sun were not yet recognized as sunspots on a rotating photosphere. It is noteworthy that Einhard, in the Vita Karoli Magni[22] mentioned a sunspot that appeared for seven days in 813 AD.[23] Another mention is in the Annales Regni Francorum (Royal Frankish Annals)[24] for 17 march 807 AD; it lasted eight days and it was interpreted as the planet Mercury passing in front of the Sun (Neuhäuser and Neuhäuser 2024). Two big spots on the Sun were drawn by John of Worcester on 8 December 1128, and Averroes reported of two spots seen at the time of Ibn Mu'adh by Ibn Mu'adh's nephew (Vaquero and Vasquez 2009).

Galileo himself was able to see a sunspot with the naked eye in 1612. He added a postscript on the "Disegni della macchia grande solare, veduta con la semplice vista dal Sig. Galilei, e similmente mostrata a molti, nelli giorni 19, 20, 21 d'Agosto 1612" stating that while he was undertaking his observations, a sunspot appeared which was so large it could be seen with the naked eye between 19 and 21 August 1612; this was then shown to many people, and included in his series of illustrations (Figure 10).

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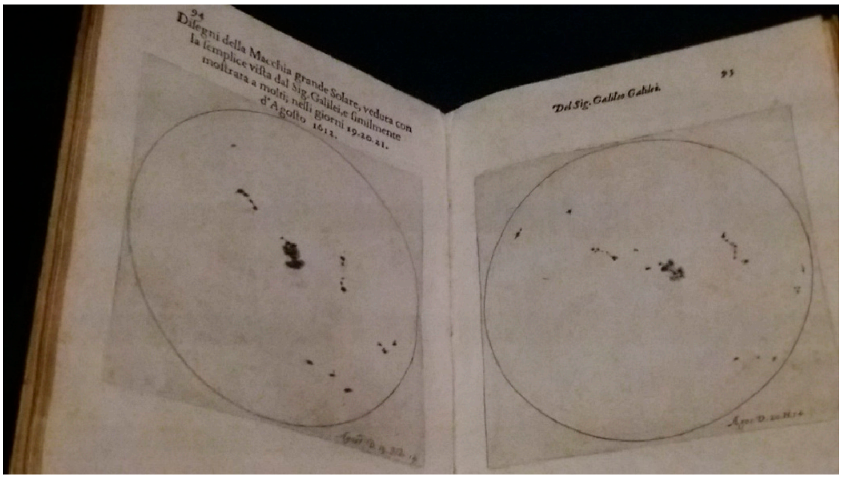

Figure 10. The naked eye sunspot of Galileo seen on 19 and 20 August 1612.[25] Author's photo.

I conduct similar experiments with naked eye sunspot observations during the appearance of the sunspot AR 4079, one of the largest of the last decades (details in Section 7).[26]

The observations with naked eyes of sunspots through fog or atmospheric haze (Schaefer 1993; Vaquero 2007a, 2007b), though historically plausible, are not a scientifically reliable or safe method. Observing through smoked glasses was less safe than with modern Mylar filter. The sunspots were observed by Galileo through his telescope at sunset or sunrise, but this method is also dangerous for the retina. There is no way to observe a sunspot on the Sun directly; only during a solar eclipse a very short glimpse (less than 0.1 s) may allow to see in the transient image left on the retina the lunar profile "biting" the Sun. In rare cases, as in Figure 11, the clouds allowed for some instants to see the eclipse directly but their disomogeneity would not permit to observe the sunspots.

Figure 11. The partial solar eclipse of 29 March 2025 at IRSOL, Locarno Switzerland. The eclipse reached 21% of magnitude 23 min before this photo. Author's photo.

The eclipse of Figure 11 was visible to the naked eye at 15.2% of eclipse through that cloud. The Moon profile was 294″ inside the solar disk. A large sunspot has a lower contrast than the Moon's profile on the Sun; the dimension of AR 4079 at its maximum reached about 150″ ×50″ included the *penumbra* (as in Figures 12 and 13).

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Figure 12. The Sun with sunspots and limb darkening, as in the projection of the Sun on 9 May 2025 h 14:04 UT. The 105 cm wide image is projected in camera obscura by a telescope Antares 20 × 60 at 5.4 m. Author's photo.

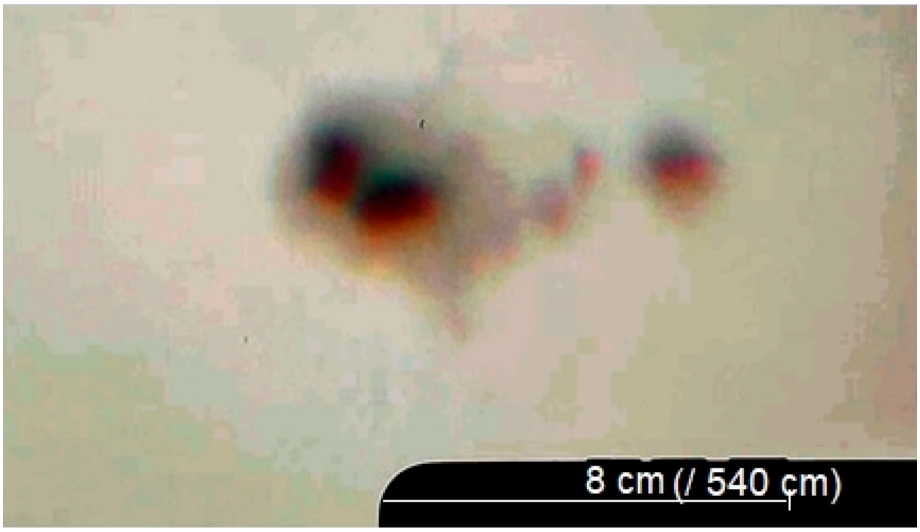

Figure 13. The sunspot AR 4079 projected at 540 cm on 6 May 2025 while its area was 1250 MH—Millionths of solar Hemisphere.[33] Author's photo.

The Sun is dazzling, and these experiments have been realized with great care, to avoid any damage on the retina. I want to stress that, without protecting filters, staring at the Sun with naked eyes, may permanently damage the retina, especially the *macula lutea*, the area responsible for colors detection.

6. Naked Eye Sunspots in 2025: Experiencing the Eye Resolution

When the Sun is high over the horizon and the sky is clear, a sunspot's umbra is 10^4 times as intense as the atmospheric halo of the Sun.[27]

The luminosity of the photosphere can be reduced to 10^{-4} using a Density 4 Mylar filter or, more efficiently, using projection (Section 5).

The angular dimension of the sunspot has to be around 0.5′, the angular resolution of the eye in daylight, to be visible even if the eye is not in direct sunlight. The diameter of the pupil in such conditions is 3 mm, and the Rayleigh criterion gives about 33″ of resolution, but a sunspot has to be bigger than that to emerge from the still bright photosphere. Moreover, to be distinguished, the sunspot has also to be distant from the limb, which is darker than the center of the Sun. This is why a big and steady sunspot on the Earthside photosphere for 14 days, is actually visible to the naked eye only for 8 days, possibly explaining the duration of the observation reported at the time of Charlemagne.[28]

We can say—experimentally with AR 4079 in May 2025—that the longitude of a great sunspot with respect to the central solar meridian has to be comprised within 60°E and 60°W to be enough separated from the darker limb. To be visible to the (alerted) naked eye the dimension of the *umbra* has to be larger than 1′ at the center of the disk. Its visibility, if the spot is stable, can last for 8 days. The sunspot at Charlemagne epoch had to be at least 3′ wide to be visible through fog, thin homogeneous clouds or at sunrise or sunset, when the Sun appears dimmer.

The present observations were conducted knowing that there was a large sunspot, while a genuine discovery should occur without prior knowledge.

For these observation I used: a Mylar filter D4, a grey filter 13%, a pinhole of 1.75 mm to compensate the eye visual defects and an additional orange filer, because the Sun was at 1.5 airmasses, and it was too bright to allow the sunspots to be seen without reducing the overall luminosity.

Consequently, the conditions of visibility of a sunspot to normal eyes without refractive defects are:

1. Dimension of the *umbra* larger than one arcminute;
2. Distance from the limb at least 3 arcminutes.

We have to remark that modern populations have significantly degraded eyesight, particularly in urban and East Asian contexts (Holden et al. 2016).

The use of the pinhole–along with the Sun filter-reduces the effects of eye’s refractive defects in the direct sight.[29]

7. The Camera Obscura for Pinholes and Telescopes

These iconographic and historical premises outline the long period before the invention of the telescope, when the observations of sunspots were incidental and not yet understood.

The architects in Florence achieved perspective representationsusing a *Camera Obscura* (King 2009) illuminated by a pinhole. The largest pinhole-meridian line designed to study the obliquity of the ecliptic and shift of the Julian calendar around the summer solstice was realized by Paolo Toscanelli (1475) in the Dome of Florence.[29] Ulugh Begh in Samarcand realized a great gnomon with solar projection in 1435, along with a stellar catalogue. Giacomo Della Porta (1590) described the principles of the *Camera Obscura* and Kepler 1571–1630 utilized them in his astronomical research (Kepler 1604; Sigismondi and Fraschetti 2001). The visibility of sunspots with a pinhole, at 2 m of distance is possible for sunspots as small as 13″ and 3′ from the limb. The pinhole can be 2 mm wide,[31] and the camera does not require a perfect darkening (Sigismondi 2002).

Christoph Scheiner (1573–1650) used a parallactic machine to follow the projected solar image in the *Camera Obscura* (Scheiner 1630) and he made the best drawings of his time (Secchi 1884).

Here we use the *Camera Obscura* to assess the observable details and the physical phenomena that can be tracked in the days following the initial observation, in order to understand how that technique has contributed to increase the knowledge of the Sun.

Scheiner was the first to notice in 1612 that the Sun’s disc is brighter at the centre than at the edges, an effect we now call limb darkening. In a letter to his friend Federico Cesi in 1613, Galileo denied that the effect exists, although he may have changed his mind later (Engvold and Zirker 2016).

The sunpots and the limb darkening are clearly visible in the whole image of the Sun in Figure 16.[32] The further details of *umbra* and *penumbra* and the *faculae* are well visible. The images here presented are obtained in a *camera obscura*, with the telescope introducing the light, to reproduce the observations described by Christoph Scheiner (1573–1650) in the *Rosa Ursina* (Scheiner 1630).

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The projecting telescope, used in these experiments, has a 60 mm-doublet,[34] and a prismatic mirror before the eyepiece, to deviate the light so that the Sun is projected on the wall, and not on the floor as Scheiner (1630) did. The observation on the wall, at 540 cm of distance, is very comfortable: there is enough time to detect the *faculae* and the tiniest sunspots. The estimate of R,[35] the daily sunspot number, is always within a 10% range from the official averages.[36] The intensity of the image, is about 3/1000 of the direct sunlight,[37] and it is bright enough to show also the sky background within 1° of the field of view of the telescope.[38]

The *faculae* are visible in white light only near the limbs (Figure 14), to about 1/10 of the solar diameter, although Scheiner and Kircher represented them even at the center (Figures 18 and 19).

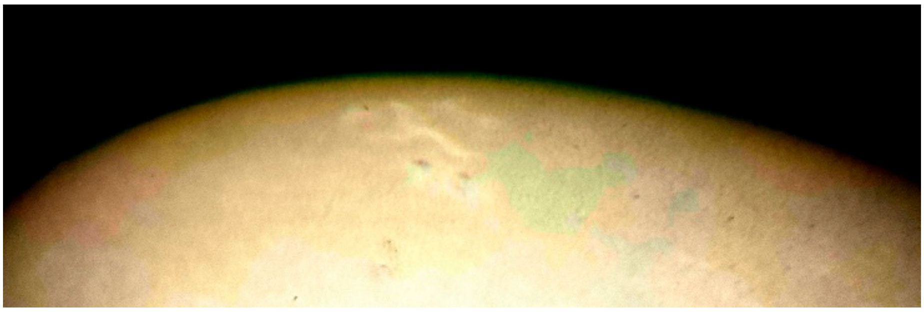

Figure 14. Camera obscura projections: the brightest *faculae* (AR4081 and AR 4086 on 12 May 2025) have a shallower contrast[39] than *umbrae* and *penumbrae*. Author's photo.

Once the rotation of the Sun was established, the presence of the *faculae* at the center could have been inferred, although the explanation of their invisibility at the solar center requires the knowledge of modern atomic physics,[40] as does their increasing temperature with the quote above the photosphere (Smith 1963).

Variations in the luminosity of the *faculae*, with occasional white light flare (Figure 15), or with flares at the limb, are possible,[41] even if their occurrences are documented only after the Carrington event (Carrington 1859) on a great sunspot, where the contrast is much larger.[42] Scheiner and Kircher (Figures 18 and 19), pictured many "light wells" (writing on some *putei lucis*), bright spots, they may have occasionally observed a flare in white light near the limb.

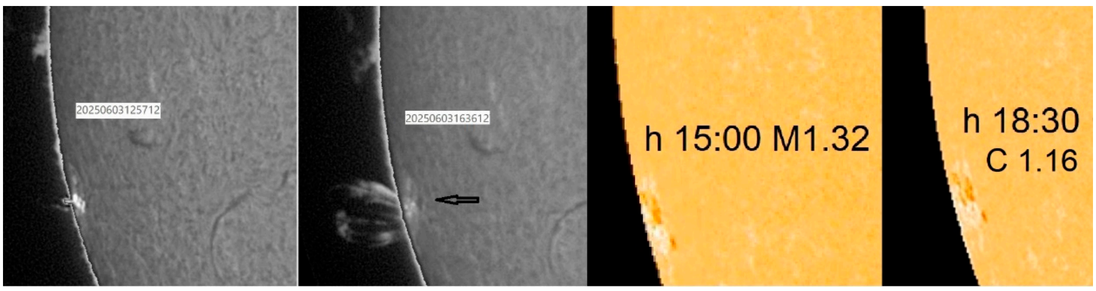

Figure 15. The M1.44 flare on 3 June 2025 at 13Z on AR 4105 in H-alpha (grey-left Teide Observatory) and white light (orange-right SDO Satellite). The flare faded expanding out of the solar limb. The flare intensity in X-ray class is indicated.[43].

8. The Sunspots in the Churches

V. S. vedendo in chiesa da qualche vetro rotto e lontano cader il lume del Sole nel pavimento, vi accorra con un foglio bianco e disteso, che vi scorgerà sopra le macchie [Galileo, Istoria e Dimostrazioni sopra le macchie solari, Lettera 2]. If your Excellency see the light of the Sun falling on the floor of a church, through some broken glass, go there with a white and plain paper, and you will see the spots.

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Already thousands years ago the Nature could have given the possibility to see the spots, even not sharply defined as through a telescope. Galileo in the same Letter mentioned above expressed this thesis. An accidental pinhole can be found in windows or through the leaves of a tree, as already described by the pseudo-Aristotle in the third book of the Problems (Aristotele 2002). The solar eclipses were seen also in this way during the partial phases, since the antiquity.

Nevertheless accidental pinholes through the leaves of the trees (Figure 16), or through the glasses of a church's window, did not permit to anticipate the discovery of sunpots. While projection is physically valid, contrast and sharpness limitations likely made these occurrences ineffective for meaningful observation.

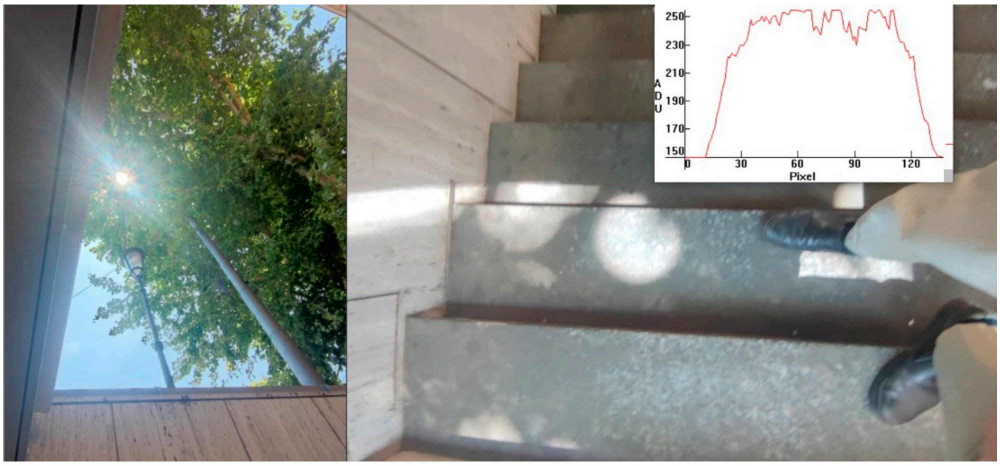

Figure 16. Pinhole image through a plane tree (Platanus Occidentalis). The limb darkening is mainly due to the opening of the accidental pinhole's aperture, evaluated to about 58 mm, convoluted with the solar limb darkening. From the limb to the maximum luminosity there are 24 pixels (370"), over a diameter of 123 pixels (300 mm, projected from about 30 m). Brightness profile obtained with IRIS software (Buil 2010).

In 1475 Paolo Toscanelli realized a pinhole in the dome of St. Maria del Fiore, at 90 m of height, to study the position of the giant solar image (1 m) formed on the Northern nave of that Cathedral, the largest church in the World until the completion of St. Peter's in Vatican (1612). The idea of Toscanelli anticipated, with a stable instrument, the consideration of Galileo of more than a century, but the sunspots were not observed.[44]

Another city which could have been hosted the discovery of the sunspots is Bologna. There Egnazio Danti (1536–1586) realized a great pinhole-meridian line in the Basilica of St. Petronio in 1577. Cassini reshaped in 1655 the same instrument and created his Heliometer, fixing the pinhole width at 1/1000 of its height (Heilbron 2001). It is likely that Danti used the same proportion, but he did not have time to employ this instrument, as he was summoned in Rome for the Calendar Reformation (Pope Gregory XIII 1582) and for the decoration of the Gallery of the Maps, now part of the Vatican Museums. The Pope created him bishop of Alatri. The last historical instrument that could have anticipated the discovery of the sunspots is the pinhole camera of the Torre dei Venti in Vatican made by Danti in 1580 (Sigismondi 2014). The ratio pinhole-height for the meridian of the Tower of Winds is 14:5180 or 1/370 (Table 1).

Table 1. The pinholes meridian lines operating in churches before the invention of the telescope were in Florence, Bologna (the one built by Danti is no more existent and it was replaced by Cassini's, that's why the visibility is hypothetical) and in Vatican. Their parameters are compared with the ones of St. Maria degli Angeli in 1999 and since 2002, after the restauration of the pinhole to its circular shape. In all cases the sunspots could have been visible.

Meridian Line/Date	Pinhole Diameter/Height	Visibility of the Sunspots
S. Maria del Fiore (1475)	50/90000 = 1/1800	Yes, only in June–July

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St. Petronio (Danti 1577)	Not known	Probably Yes
Torre dei Venti (1580)	14/5180 = 1/370	Yes (>30″ or 400 MH)
St. Petronio (Cassini 1655)	27/27000 = 1/1000	Yes
St. Maria degli Angeli (1999)	40/20353 = 1/500	Yes (>25″ or 300 MH)
St. Maria degli Angeli (2002)	10–23/20353 = 1–2.3/2000	Yes

The limit of visibility of the sunspots with a pinhole diameter equal to 1/1000 of its height is around 100 MH and it has been verified in Santa Maria degli Angeli[45] and in San Petronio[46] meridian lines.

The observations with pinhole instruments may have not been systematic, and the contrast of the sunspots observed with the pinholes is shallow, but it is sufficient for following them for some days, during the solar rotation. There existed at least three instruments in Italy on which the sunpots could have been seen, before their discovery with the telescope.

The lack of observations of the sunspots in the end of 15th and during the 16th century is a consequence of the duration of the minimum of Spörer, with the Sun without big sunspots (1460–1550).

Finally it is noteworthy that Kepler observed two big sunpots in 1607 (Kepler 1609) with a pinhole camera, normally used to measure the magnitudes of solar eclipses: he drawn sunspots on May 18/28 and confirmed then with naked eye (Hayakawa et al. 2024). He believed to have seen Mercury on the Sun, probably because the conditions of visibility did not last enough to anticipate the discovery of sunspots, even by only a few years before Galileo.

The case of Kepler, known as a very keen observer, not because his sight but for his intelligence, is significant: even after observing spots, he did not recognize them as anything beyond incidental phenomena. Even if the spots were there, the low resolution of the instrument and their rapid variability of their appearance did not help to recognize them.

9. The Sun and the Jesuits

The radiant Sun (Figures 6 and 7) is the symbol characterizing the Company of Jesus, founded by St. Ignatius of Loyola in 1540. The Sun has been also object of the scientific studies of the Company over the centuries. The contemplation of Nature is part of the spirituality of St. Ignatius,[47] as Nature was created by the Word of God. A strong development of observational and theoretical studies occurred at the headquarter of Jesuits, the Collegio Romano. The astronomical tradition started with Christopher Clavius (1535–1612) continued spreading all over the World. Matteo Ricci (1552–1610), Giovanni Paolo Lembo (1570–1618), Orazio Grassi (1583–1654), Christoph Scheiner (1573–1650), Christoph Grienberger (1561–1636), Giovanni Battista Riccioli (1598–1671), Athanasius Kircher (1602–1680), Francesco Maria Grimaldi (1618–1663), Rudjer J. Boscovich (1711–1787) Francesco De Vico (1805–1848), Angelo Secchi (1818–1878) are part of a largely incomplete list, of contributors of solar astronomy.

The idea that the sunspots were bodies extraneous to the nature of the Sun was functional to preserve the perfection of the celestial body used to represent the perfection of God. The first Jesuits who observed the sunspots were alsoinclined to coherence with this paradigm.

No spot could be imagined in a divine symbol, and this has been a major concern in the early debate between scientists and theologians. The Jesuits, before accepting the Copernican system adopted the Tychonic system to preserve the agreement between the Scriptures and the physics of the Cosmos (Figure 17, the famous *Sol ne movearis (Sun, stand thou still)* of Joshua 10, 12), through father Scheiner, were oriented toward a spotless Sun, with opaque bodies orbiting it.

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Figure 17. "Move not, O Sun" Mosaic V century AD, St. Maria Maggiore, Rome. Author's photo.

The representations of the Sun in Figure 8 and in Figure 18 (whose original is probably the image in Figure 19, published by (Kircher 1665) are separated by 15 years at least: solar activity appear very intense , as one may infer from the large number of spots in Figure 8, and the volcanic activity with many clouds in Figure 11. It is relevant that this image of the Sun, among scholars, as the Cardinal De Zelada, remained iconic up to the end of 18th century, for at least 163 year, despite the improvement in optical technology during that period.

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Figure 18. The solar surface observed in Rome in 1635 by Christoph Scheiner and Athanasius Kircher, in the Hall of Meridian, Vatican Museums, Vatican. This is depicted on a wooden door created for Cardinal Francesco Saverio De Zelada in 1798.[48] Author's photo.

The interpretation given to sunspots was that they were clouds of smoke ejected by volcanoes on the solar surface. On the solar limb there are flames that recall the *spiculae*, firstly described by father Angelo Secchi (1818–1878) only two centuries after Scheiner and Kircher. Secchi observed the Sun with a very good refractor of Merz, fully exploiting the achromatic doublet, patented in 1758 by John Dollond;[49] the quality of the solar image seen by him was superior to the one seen by Scheiner and Kircher. About the plumes of smoke out of the limb, drawn by Kircher, they might include the memory of some observations of prominences made during total eclipses or some exceptional observation at sunset/sunrise. Secchi (1884)[50] reported such an observation of Pietro Tacchini at sunset on the 8 August 1865 in the Mediterranean sea onboard a steam ship. The white spots are the *faculae*, that the artist reported all over the Sun, but in reality are visible only at the *royal zones* of the limb (±50° from the solar equator).

The original figure, copied on the wooden window, is the following Figure 19.

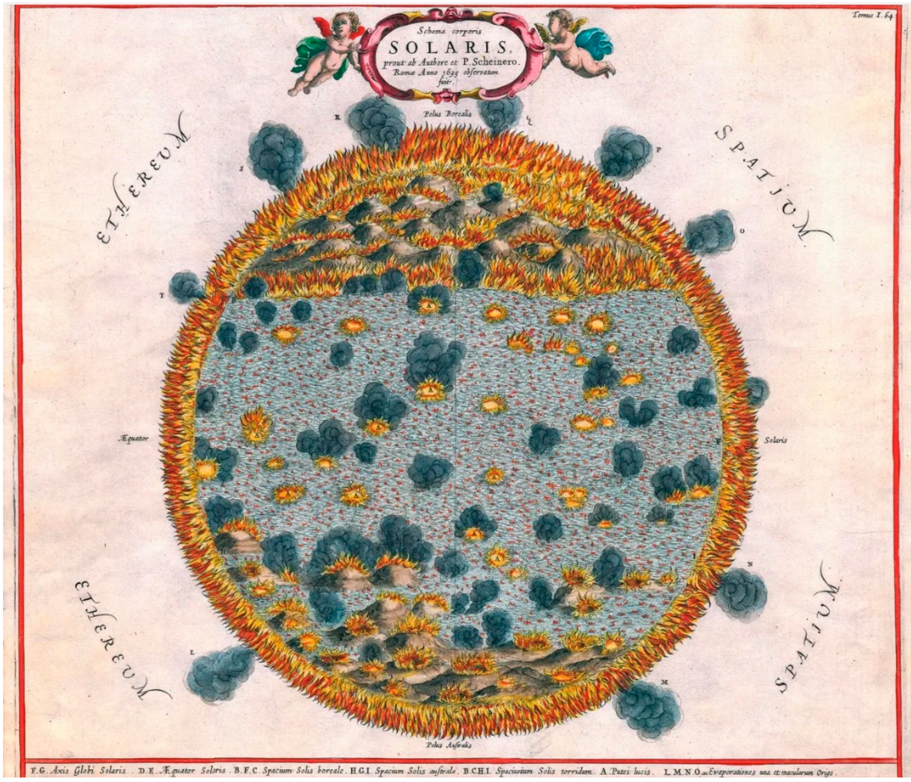

Figure 19. Athanasius Kircher, *Schema corporis solaris*, with the *zona torrida* (called royal way of the sunspots by Christopher Scheiner), the spaces *borealis* and *australis*, the wells of light, the volcanoes with dark condensations. This schema was based on observations with Father Scheiner in 1635. [51] It served as the model for the painting on wood created in 1798 (Figure 18).

10. Limb Darkening and Rotation: The Proofs of the Spherical Sun.

By analogy with the Moon (Section 11) the Sun was considered a sphere, but an observational proof could come from the rotation of the sunspots, or from the limb darkening. There is an instrumental limb darkening of the image, due to the geometrical optics of rays coming from a disk uniformly luminous through the pinhole-objective.

The solar disk presents a limb darkening, evident in the first regions near the limb, but this effect appear entangled with the instrumental limb darkening produced by a pinhole (Figure 20). Moreover when the pinhole is small the effects of geometrical optics are entangled with wave optics due to the diffraction occurring in a narrow opening.

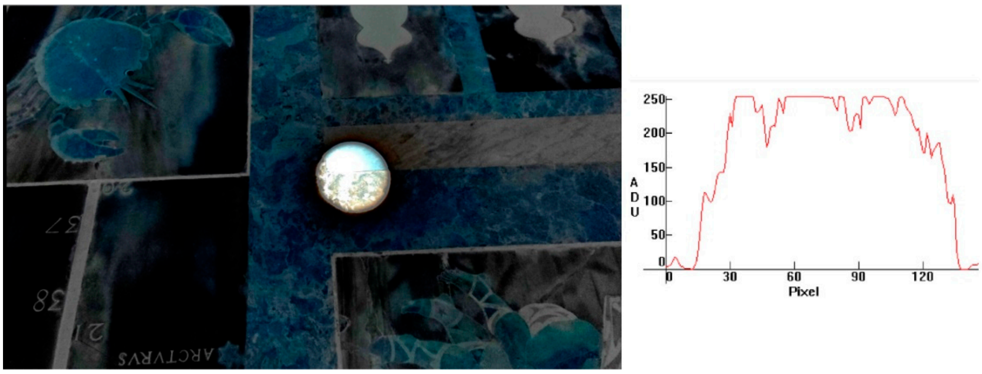

Figure 20. The Sun at the Clementine Gnomon in St. Maria degli Angeli on 30 May 2025. The Limb Darkening is sharper than Figure 15, because the pinhole is 25 mm wide, 22 pixel (333") from limb to saturation over a diameter of 125 pixel (220 mm). Brightness profile obtained with IRIS 5.59 software (Buil 2010).

Is it possible to distinguish the solar limb darkening from the pinhole limb darkening? The latter is dependent on the pinhole dimension, and it enlarges the geometrical image $D_\odot = f \cdot \tan(\theta_\odot)$ of the Sun by the width *d* of the pinhole itself.

Therefore the observed image is $D = f \cdot \tan(\theta_\odot) + d$ where f is the focal length of the pinhole (distance pinhole-image) d is the diameter of the pinhole, and $\theta_\odot$ is the angular diameter of the Sun. The smaller is d relative to D, the more precise the measurements, with d/D < 30 considered a satisfactory condition..[52]

The Limb Darkening contrast in white light is shallow (~16%) (Rogerson 1959) and atmospheric seeing (turbulence) also reduces limb sharpness in historical projection systems.

The Limb Darkening of the Sun has to be observed with a telescope (Figure 21) able to show the required detail to disentangle it from the pinhole's shadowing of geometrical optics, or from the diffraction spread of the solar limb through the tiny pinhole. The main characteristic of solar limb darkening is its steeper increase toward the inflection point, compared with the shallower limb darkening of a pinhole, which depends on the pinhole's diameter.

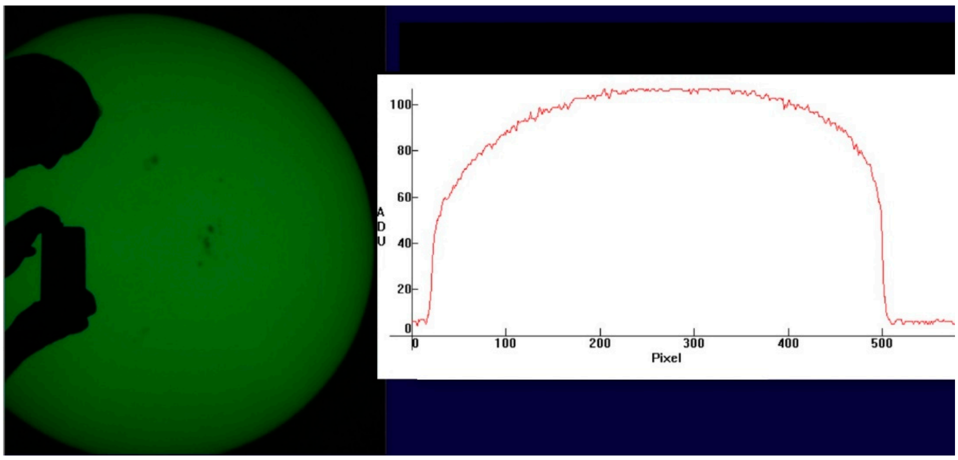

Figure 21. the Limb Darkening Function (E-W) of the Sun on 31 May 2025 in Camera Obscura, through a 20 × 60 mm refracting telescope. The image has 104 cm of diameter and it is projected at 540 cm of distance from the telescope. AR 4099 and 4100 are well visible. West is 45° to the right. Brightness profile obtained with IRIS 5.59 software (Buil 2010).

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The limb darkening is also observable without focusing optics (Figure 22, St. Maria degli Angeli pinhole meridian line) and it does not help to perceive unambiguously the spherical nature of the Sun.

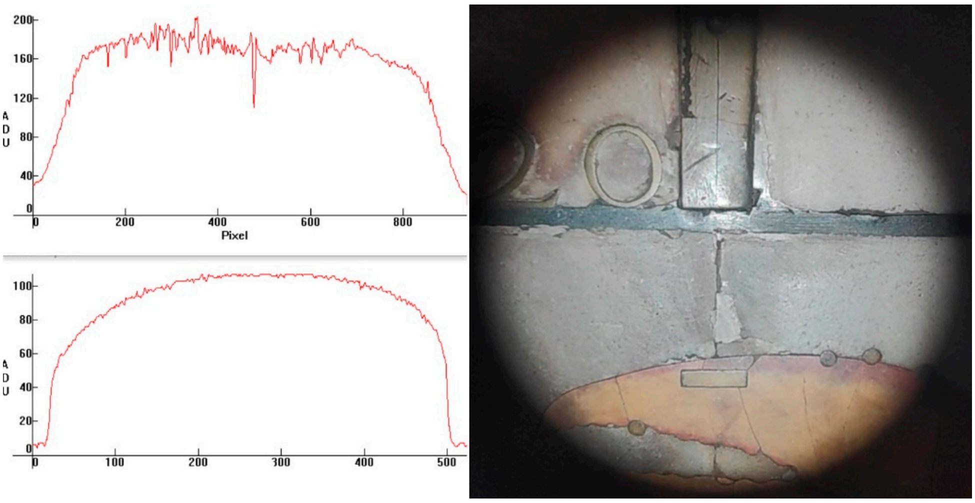

Figure 22. The pinhole limb darkening at the Clementine Gnomon (31 May 2025 13:07:55 UT). The curve below in comparison is the solar limb darkening at the 60 mm refracting telescope (already shown in Figure 21). The nearly linear rise of the upper curve—obtained with IRIS 5.59 software (Buil 2010)—is visible as a dimmer ring around the solar image.

11. The Moon Was Already Spherical and with Spots

After considering the similar nature between the Sun and the fixed stars, we have to address its sphericity. The three dimensional representations in Egypt (Figure 1) show already a sphere, but the definitive proof arrived in 1610 with the telescope. The analogy with the Moon, also regarding its spots (Figure 23), could have contributed to the idea of a spherical Sun with spots, which is not evident by itself.

Figure 23. The Moon on 5 and 8 May 2025 h 22 UTC. Photo by the author. Antares 20 × 600 telescope, Xiao-Mi11 smartphone.

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The motion of the terminator and its shape provides to evidence the spherical nature of the Moon. The contrast of the lunar markings is rather shallow, and their distance from the brighter limb introduces a visibility problem.[53]

The presence of permanent spots is a characteristic of our natural satellite, they are known since the most antique ages but strangely Moonspots did not have names until a few years before the invention of the telescope, when William Gilbert (1544–1603) physician to Queen Elizabeth I and the discoverer of terrestrial magnetism drafted the one reported in Figure 24.

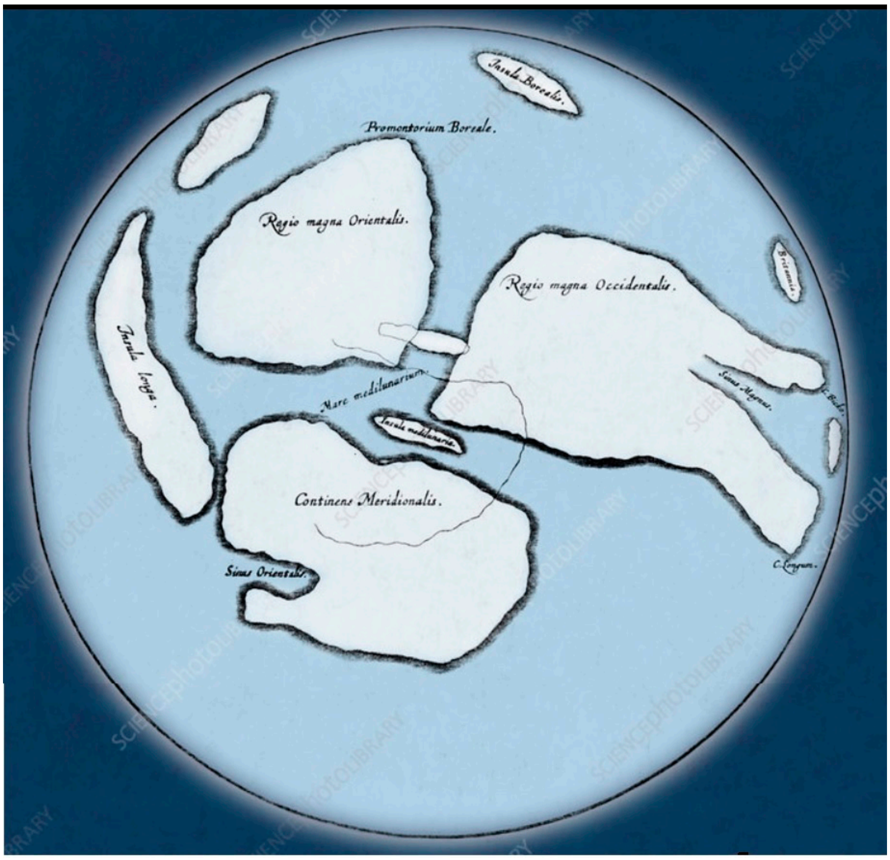

Figure 24. The Moon of William Gilbert (Gilbert 1601):[54] the Galilean *Maria* are here *Continents*.

The resolution at naked eye for the understanding of the permanent nature of thelunar markings, while only the changing terminator showed the spherical nature of the Moon. The geocentric orbit, producing the lunar phases, compensates the absence of visible rotation: the lunar rotation is synchronized with the orbit 1:1. But the solar rotation was discovered by Galileo following his observation of sunspots. The solar limb darkening helped to perceive the three-dimensionality of the Sun.

Galileo's telescope immediately provided a significant advance in understanding the nature of the Moon, due to the large number of visible details. The uncertainty of the ancient theories on the lunar spots (e.g., Dante in Divine Comedy, Paradise II (Dante 1321) or Gilbert with continents floating on a vaste ocean), vanished with the first telescopic observations, and planetography as well as celestial mechanics started in a modern way.

12. Conclusions: The Right Instrument at the Right Time

The Sun had always spots during the human history, but the possibility to see them did not coincide with the actual discovery, although great pinholemeridian lines were operating since 1475 in Florence, 1577 in Bologna and 1580 in the Vatican.

It is likely that the Spörer minimum of the solar activity (1460–1550) contributed to delay their discovery, with a long lasting "blank Sun" completely spotless or with small spots, without the largest groups visible to the unaided eye, as occurred in AD 807 and 813 when occasional large spots were observed up to 8 consecutive days.

Solar activity over millennia has been reconstructed (Usoskin 2023) using various proxies, since the observation of great sunspots is too scattered before the invention of the telescope. This paper may suggest by indirect evidnce that the recovery of the sunspots' solar cycle after the Spörer minimum was rather smooth and, if not completely spotless, without very large sunspots, which would have been detectable through many pinhole instruments.

Improvements of building techniques in pinhole cameras for observing the Sun allowed Kepler to observe sunpots in 1607, but he did not recognize their solar nature either because he did not continue these observations or because the spots evolved rapidly loosing *umbra* and gaining *penumbra*,which is not visible through a pinhole.[55]

After the invention of the telescope and the discovery of sunpots, Kepler observed them through pinholes cameras (Sigismondi and Fraschetti 2001), before having the possibility to use the telescope of Galileo.

The discovery of the sunspots occurred both with the telescope and following the end of the Spörer minimum. The theory of instruments as trigger[56] of a scientific revolution is supported in this work, but Nature's conspiracy of a long-term solar activity minimum contributed to set the date of the discovert to 1610 rather than a century earlier. The cultural environment was not ready to accept a Sun with spots. The Dominican Tommaso Caccini[57] in 1614 with the homily on "Viri Galilaei" accused Galileo to move the Earth around a spotted Sun. Caccini's disposition was based on a symbolic idea of the Sun as representative of God (Sections 1 and 2.),that would not have changed rapidly in any case. The cultural environment, one century before "Galileo's era", may not have been a decisive factor for the missed discovery of the sunspots. It was the lack of evidence: no sunspots since 1460 for the Spörer minimum, and the lower resolution of a giant pinhole camera, with respect to a telescope.These two concomitants factors prevented the discovery of the sunspots, not a fixed paradigm of thinking.

The observation of some white light flares may have driven Scheiner and Kircher to represent the solar surface with many bright points (Figures 11 and 12) all over the "royal zone" at ±50° from the solar equator. Angelo Secchi (Secchi 1870) considered this drawing as fruit of the fervid imagination of Father Kircher, because they did not have access to H-alpha imaging (a technology available only since 1870s). The active regions in fact appear bright at this wavelength. Bright flares in the *faculae*–especially near the solar limb- may have anticipated the modern H-alpha views of the Sun already in the "Galileo's era" of white light solar astronomy. Kircher, an insightful collector of scientific informations, may have included in his drawings the prominences observed during total solar eclipses or -very rarely- at sea during sunsets or sunrises.[58] Secchi himself (Secchi 1884) reported such a sunset event.

Egyptian representations of the solar disk, as well as the Christian ones (Sections 2 and 3) may reflect the inheritance from the same phenomena of the solar prominences, preserved in the iconography.

Funding: This research received no external funding

Conflicts of Interest: The author declares no conflict of interest.

Notes

1. http://www.zam.fme.vutbr.cz/~druck/eclipse/Ecl2009e/Tse2009_200_mid/0-info.htm (accessed on 8 September 2025). Authors: M. Durkmüller and P. Aniol. This eclipse was observed during the deepest solar minimum (720 days of blank Sun) occurred in 2009–2010.
2. Photo made by the author at the 70/400 Solarmax Coronado H-alpha telescope of Asiago Astrophysical Observatory, Pennar Observing Station (ex- Schmidt dome); elaboration made by prof. Sabina Favore.

3. "According to (Brewer 1991), it is not difficult to see the similarity between this image and that offered by the wings of the celestial god Behedety, spreading about the solar disc, one of the most frequent and undoubtedly most symbolically charged representations of the solar deity. Although quite speculative and impossible to prove, this hypothesis is quite suggestive." Quoted from (Belmonte and Lull 2023) pp. 517–18.
4. https://symbolsarchive.com/uraeus-symbol-history-meaning/ (accessed on 8 September 2025).
5. (Belmonte and Lull 2023) page 195 Figure 4.2 from (Congdom 2000).
6. The observing conditions at the level of the horizon, which in Egypt are usually poor owing to air-borne dust, could facilitate the observation of sunspots, especially when they were large during solar maximum, the atmosphere acted as a filter for their observation. In fact, it seems that it was the morning mist conditions in some valleys of ancient China that facilitated the first observations of sunspots with the naked eye that appear to be found in the 9th–8th century BC (referenced in the Chou Í or book of Changes of Zhou, a divinatory and oracular text). However, no Egyptian documents are known where these observations can be verified. (Belmonte and Lull 2023) p. 194–95.
7. Available online: https://www.corpus.cam.ac.uk/articles/eagles-and-sun-medieval-bestiary-0 (accessed on 31 July 2025). *Aquila dicitur ab acumine oculorum*: the Eagle is known for the acuteness of sight, in the medieval tradition (Isidore of Sevilla, VII century AD).
8. Blessed be, Oh Lord for brother Sun/which is the day and You illuminate us by him/and it is nice and radiant with great splendor/of You it brings signification.
9. E.g., in St. Francis of Paula. https://www.christianiconography.info/francisDiPaola.html (accessed on 8 September 2025).
10. E.g., in the tumb of the Pope Benedict XIV in St. Peter's, a woman with a gilded Sun on the breast, https://www.stpetersbasilica.info/Monuments/BenedictXIV/BenedictXIV.htm (accessed on 8 September 2025).
11. Original image reported in this https://it.wikipedia.org/wiki/File:Neri_di_bicci_(attr.),_tavoletta_con_cristogramma_lasciata_da_san_bernardino_dopo_una_sua_predicazione_a_prato,_01.jpg (wikipedia, accessed on 27 July 2025).
12. (Zawilsky 2021). Bologna, 1 January 1386, In that year [1386], on the first day of January. […] and then there was an eclipse of the sun in such a way that one had to lit candles during meals in whole Bologna; http://www.solareclipses.pl/Sources/1386/1386_I_1_Bologna_1.pdf (accessed on 8 September 2025). The second eclipse, 12 february 1431, was after the invention of the solar logo with the acronym YHS/IHS: http://www.solareclipses.pl/Sources/1431/1431_II_12_Foligno.pdf (accessed on 8 September 2025).
13. https://www.catholic.org/saints/saint.php?saint_id=7 (accessed on 8 September 2025). Painter: Benvenuto di Giovanni (this image was made in Siena in 1475) The acronym's spelling become as today IHS, from YHS. https://www.sanfrancescopatronoditalia.it/notizie/religione/sapete-cosa-il-trigramma-di-ges%C3%B9-inventato-da-fra-bernardino-da-siena--44455 (accessed on 8 September 2025).
14. https://es.wikipedia.org/wiki/Francisco_(papa)#/media/Archivo:Coat_of_arms_of_Franciscus.svg/2 (accessed on 8 September 2025).
15. Planet in Greek means "moving star", that's why the moving planets around the Sun were called "stars". Also the Earth orbiting around the Sun become technically a star, and this was the debate of the times.
16. https://en.wikipedia.org/wiki/Jean_Tarde (accessed on 8 September 2025).
17. https://en.wikipedia.org/wiki/Jean_Tarde#/media/File:Diagram_of_Sunspots_from_Borbonia_Sidera.jpg (accessed on 8 September 2025).
18. https://domenicani.net/page.php?id_cat=3&id_sottocat1=95&id_sottocat2=100&id_sottocat3=0&titolo=Giordano%20Bruno (accessed on 8 September 2025).
19. Chris Impey and P. Grey, E. Brogt, A. Baleisis on https://www.teachastronomy.com/textbook/Properties-of-Stars/Measuring-Star-Distances/ (accessed on 12 May 2025). (Impey et al. 2023) relying on Hoskin (1977).
20. https://physicsteacher.blog/wp-content/uploads/2023/03/image-9.png (accessed on 12 May 2025).
21. To a point very close to it.

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22. (Eihnard n.d.) https://thelatinlibrary.com/ein.html#32 (accessed on 8 September 2025). Chapter 32 *et in sole macula quaedam atri coloris septem dierum spatio visa* (transl. *And in the sun, a certain spot of black color was seen over the course of seven days.*) written circa 817-836 AD.
23. This episode was already quoted by Galileo Galilei (1613) in his first work dedicated to the sunspots.
24. *Nam et stella Mercurii XVI. Kal. Aprilis visa est in sole quasi parva macula, nigra tamen ["tamen" missing in MSS group E], paululum superius medio [D3, E: media] centro eiusdem sideris [B5, C3, E3, E6, E7: syderis], quae a nobis octo dies conspicitur. Sed quando primum intravit vel exivit, nubibus impedientibus [B1, B4, C1, D3: imped.]* https://journals.sagepub.com/doi/10.1177/00218286241238731#fn5 (accessed on 8 September 2025). translation: *For on the 16th day before the Kalends of April, the star Mercury was seen in the sun as a small spot, black however, slightly above the middle of the center of that same star, which is visible to us for eight days. But when it first entered or exited, it was obscured by clouds.*
25. Galileo, Istoria e dimostrazioni sopra le macchie solari (1613), at the exhibit La Città del Sole, 16 November 2023–11 February 2024, Palazzo Barberini, Roma. https://barberinicorsini.org/evento/la-citta-del-sole-arte-barocca-e-pensiero-scientifico-nella-roma-di-urbano-viii/ (accessed on 8 September 2025). The three letters of Galileo, combined in the Istoria are here (Galilei 1613) with all sunspots drawings.
26. With 1250 MH—Millionths of solar Hemisphere at maximum extent it ranges just out the list of the 25 largest sunspots appeared since 1996 https://www.spaceweatherlive.com/en/solar-activity/top-25-sunspot-regions.html (accessed on 8 September 2025). A list encompassing the maximum solar activity in the XX century is this https://solarwww.mtk.nao.ac.jp/en/bigspots.html (accessed on 8 September 2025) (1892–2014). I have observed with naked eye also the sunspot AR 3780 in August 2024 https://www.spaceweatherlive.com/en/solar-activity/region/13780.html (accessed on 8 September 2025) and AR 3784 https://spaceweather.com/images2024/12aug24/hmi1898.gif (accessed on 8 September 2025) with 700 MH which realized a pair with AR3780 recalling the pair drawn by Jonh of Worcester on 8 December 1128, https://en.wikipedia.org/wiki/Sunspot_drawing (accessed on 8 September 2025). https://youtu.be/VHl1yX5aoMk (accessed on 13 August 2024) AR 3848 https://www.spaceweatherlive.com/en/solar-activity/region/13848.html accessed on 5 October 2024 https://youtube.com/shorts/AIDz9npxPy8 (accessed on 8 September 2025) reached 980 MH and it was visible to the naked eye, with a Mylar screen.
27. This has been verified observing the Sun with the spot AR4079 with a pinhole + filter (10^{-4} transmittance) with the right eye and the sky backround aournd the Sun without filters with the left eye: the darkened part of the filtered Sun was as luminous as the sky background.
28. AR 4079 https://www.spaceweatherlive.com/en/solar-activity/region/14079.html (accessed on 8 September 2025) was seen with naked eye until 9 may 2025, and the days of visibility are 9 over 15, from 28 April to 12 May. The same active region, after a whole solar rotation, at the beginning of June 2025 catalogued as AR4100, was less compact, with a smaller *umbra*, and it was no more visible to the naked eye. The same active region come again visible as AR 4100 on May 25 at the limb, and on May 27 it was already visible to a small pinhole camera (knowing that it was there) but never to the naked eye. https://www.spaceweatherlive.com/en/solar-activity/region/14100.html (accessed on 8 September 2025) had its largest area of 440 MH with umbral dimension < 1'. Another relevant sunspot is the bigger one of AR 4087, 270 MH on May 16. The diameter of the *umbra* was 13", while the *penumbra* get 36". It is just below the limit of visibility with naked eye. https://www.spaceweatherlive.com/en/solar-activity/region/14087.html (accessed on 8 September 2025). The distance from the limb on 16 May 2025 would have been enough to be visible to the naked eye, if larger. If the spot would have to be discovered, it should have been more evident. The *umbra* AR 4079 was 75" nearly 6 times larger than AR 4087, that permitted its observation with naked eye, in limiting conditions.
29. This idea was given to me by Leopold Halpern (1925–2006) in 2000.
30. Archivio dell'Opera del Duomo di Firenze. Quaderno Cassa, serie VIII-I-61, anno 1475, carta 2v MCCCCLXXV. Spese d'Opera: *E adì detto [16 agosto, n.d.a.] lire cinque soldi quindici dati a Bartolomeo di Fruosino orafo, sono per il primo modello di bronzo di libbre 23 once 4, fatto per Lui a istanza di maestro Paolo Medicho per mettere in sulla lanterna, per mettere da lato di drento di chiesa per vedere il sole a certi dì dell'anno. Lire 5 soldi 15.* Source: (Baldini 2005).

31. Another confirmation comes from the sunspots on 30 May 2025, AR 4100 and AR 4099, both with *umbrae* of 20″ and visible at 2.5 m of distance through the shades producing accidental pinholes. The best pinhole produces the fainter circular image. The accidental pinholes created by the leaves of a plane tree (Platanus Occidentalis) did not work for seeing the spots (Figure 16). The experience leading to the 2002 article on American Journal of Physics (77) were made with different pinholes and with plane mirrors, without glass coating, to send the solar image at distances up to 20 m, with the vision of the sunspots. The experiences with pinholes presented here are intentionally less elaborated, to simulate the conditions for the discovery of sunspots by chance.
32. The limb darkening function ranges from 30 ADU (limb) to 190 ADU (inner part) and it is photographed from 1 m of distance.
33. The intensity of the *umbra* of AR4079 (6 May) is 10/200, the *penumbra* is 120/200; 200 is the intensity of the photosphere around the spot in ADU, Analogue-Digital Units. The photographic camera used here is the XiaoMi-11, it doesn't have an exceptional resolution but it reproduces well the eye's logarithmic response to intensity.
34. The optical quality of the telescope is superior with respect to 1630, so we can indee see the details more easily. The doublet was not yet invented (by J. Dollond in 1758). To futher enhance the view I added a green photographic filter (wide band) before the objective lens.
35. R is from Rudolph Wolf and it is R=10G+N, with G the number of sunspots' groups and N the number of sunspots.
36. This is an average over several observers, certified at SILSO, https://www.sidc.be/SILSO/datafiles (accessed on 8 September 2025).
37. The estimated value is given by squaring the ratio of the objective's diameter to the image's diameter $(6/105)^2 = 3.3\cdot\times 10^3$
38. I have seen clearly a bird fliyng on the line of sight, across the Sun, until it was a solar radius outside the photosphere, even if the solar limb appeared sharp. There is a remaining luminosity of the background below 29 ADU (there is a non linear correspondance with real intensity).
39. The luminosity of the *faculae* versus the unperturbed surrounding photosphere is 185/155 in ADU. This is a good indication of the contrast observable with the naked eye in the camera obscura.
40. It is due to the absorption of photons by hydrogen atoms partially ionized in the solar atmosphere, Donald H. Menzel, Our Sun published in Harvard in 1949, chapter 7, p. 205 in the Italian Edition *Il Nostro Sole* (Menzel 1981).
41. This study has been conducted on C-class and M-class flares, in particular M3 on 26 May and M9 on 25 May 2025 erupted from AR 4098 and M1.4 on 26 May from AR 4100, the same spot as AR4079 after half a solar rotation in the solar far side. In the aforementioned flares of May there was not an optical counterpart visible in the camera obscura projection. The visible counterpart was seen with the M1.44 flare of 3 June 2025 13:03Z, observed clearly at M1 phase in Camera Obscura (Figure 16). The transient remained visibile for 10 minutes, among the two spots of AR 4105, then fading to the normal facular level; the bright *facula* is visible also in the satellite SDO images of 13:00Z (M1.32), and faded at 16:30Z (C1.16).
42. In Figure 13 the sunspot's *umbra* is 10 ADU over 200 ADU of the solar photosphere around it.
43. This flare was visible in Camera Obscura as the brightest *facula* over one month of observations (May 2025) and its fading was also visible. https://youtube.com/shorts/zE76313vktU (accessed on 8 September 2025) (Hα, 2 minutes after the X-ray peak) and https://youtu.be/yji21KUFwi8 (accessed on 8 September 2025) (green filter wide band 23 minutes after the X-rays peak). Another example is the C2.2 flare at the solar limb on AR 4167 https://youtube.com/shorts/rts2mFntmX0?feature=share accessed on 6 August 2025 at 14:25Z.
44. The possibility to see the sunspots with a lensless pinhole, started my interest in the meridian line of St. Maria degli Angeli in September 1999. The sunspot AR 8692 [https://www.spaceweatherlive.com/it/attivita-solare/regione/8692.html (accessed on 8 September 2025)] was there and it was possible to detect it as an enhancement of *penumbra* in the image projected on a white paper. At that time the pinhole was of irregular shape, about 4 cm × 2 cm. The image of the Sun was 30 cm × 20 cm, so the pinhole dimension was about 3′ wide, while the sunspot was only 25″ wide at its maximum.

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To have a clear visibility of the sunspot its angular width should be comparable with the angular width of the pinhole at the position of the image.

45. https://youtu.be/71J4ZWpZflw (accessed on 8 September 2025) video recorded on the meridian line for the AR 4168, with 250 MH on 6 August 2025 https://www.spaceweatherlive.com/it/attivita-solare/regione/14168.html (accessed on 8 September 2025). This sunspot was visible also on 7 and 8 August 2025 https://youtu.be/4_f4e8daTXQ (accessed on 8 September 2025).

46. https://youtube.com/shorts/sb7nn_QSE-g (accessed on 8 September 2025) video recorded on 18 June 2025 with the AR 4114 (360 MH) and AR 4115 (110MH). https://www.spaceweatherlive.com/it/attivita-solare/regione/14114.html https://www.spaceweatherlive.com/it/attivita-solare/regione/14115.html (accessed on 8 September 2025).

47. (Gionti 2018) https://www.icra.it/mg15/FMPro%3F-db=3_talk_mg15_.fp5&ps::web_code=4958892514&-format=session_mg15.htm&-lay=talk_reg&main_1::Attivo=Yes&talk_accept=Yes&-SortField=order2&-SortOrder=ascend&-Max=50&-Find.html (accessed on 8 September 2025).

48. https://catalogo.museivaticani.va/index.php/Detail/objects/MV.44213.0.0 (accessed on 8 September 2025).

49. https://en.wikipedia.org/wiki/John_Dollond (accessed on 8 September 2025).

50. A. Secchi (manuscript dated 1870) Il Sole, Firenze (posthume edition 1884) reproduced in (Secchi 1884), pp. 127–28.

51. A. Secchi expressed a judgment on this drawing in the text (c. 1870) *Su di un antico disegno del sole dato dal P. Kircher*: it belongs to the book of https://artsandculture.google.com/asset/schema-of-the-sun-athanasius-kircher-1602-1680/cQFXz1p6okQTRw (published in Amsterdam, (1665) p. 64. According to his deep experience in solar spectroscopy Secchi notes that the Sun is "devised" by Kircher and not "observed"as it is written in the title of that gravure. This text is available at the Gregorian University websites: https://gate.unigre.it/mediawiki/index.php/Page:Su_di_un_antico_disegno_del_sole_dato_dal_P._Kircher.pdf/1 (accessed on 8 September 2025) and https://gate.unigre.it/mediawiki/index.php/Page:Su_di_un_antico_disegno_del_sole_dato_dal_P._Kircher.pdf/2 (accessed on 8 September 2025).

52. In the case represented in Figure 20 all parameters are known, and $D_\odot = 198.7$ mm, d = 25 mm, and the measured image is 225.6 mm wide. The difference between D and $D_\odot$ is 26.9 mm, just 1.9 mm more than the pinhole dimension. The solar effect is unnoticeable at this level of accuracy

53. E.g., Mare Crysium, visible in Figure 23 at mid left, near the Western lunar limb, has a relative intensity (ADU) of 130/180 with respect to the lunar Terrae, brighter, around it. The limb is generally brighter than all Terrae. The distance between the Mare Crysium to limb is around 2'. The Moon and the Sun have approximately the same angular diameter, and the longitude of the center of Mare Crysium is 59° W. This feature is the smaller visible with the naked eye, using the pinhole and the grey Moon filter at 13% of transmission, to avoid to be bleached by the luminosity of the Moon, better to do in twilight with the sky still blue: it is at the limit of the resolving power of the eye, as the greatest sunspots that should be within ±60° of longitude from the central meridian (Section 7). Mare Crysium was reported also in the map of William Gilbert (1601), and named *Britannia* (Figure 24).

54. https://www.sciencephoto.com/media/1193953/view/moon-map-by-william-gilbert-1603 (accessed on 8 September 2025). The redrawn map is in Whitaker Ewen, Mapping and naming the Moon: A history of lunar cartography and nomenclature (Cambridge 1999) and the research article is of (Pumfrey 2011).

55. The sunspot AR 4100, already mentioned in the previous notes, at the third rotation has lost the large *umbra*, which is visible to the naked eye or through a pinhole, and splitted into a complex region with prevalence of *penumbra*, which is much less visible without a telescope.

56. (Galison 1997), quoted in (Dyson 2012).

57. http://156.54.191.164/enciclopedia/tommaso-caccini_%28Dizionario-Biografico%29/ (accessed on 8 September 2025) (Ricci-Riccardi 1902).

58. https://www.space.com/stargazing/eclipses/amateur-astronomers-capture-groundbreaking-photos-of-suns-corona-during-partial-solar-eclipse (accessed on 8 August 2025).

Peer-reviewed version available at *Histories* **2025**, *5*, 48; doi:https://doi.org/10.3390/histories5040048

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