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Comparison of telescopic and naked-eye sunspots for the very small spots on February 15, 1900 and January 30, 1911

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Abstract
In a recent discussion of the Maunder Minimum, two sunspot observations by Chinese court astronomers on February 15, 1900 and January 30, 1911 (±1 day) – presumably made with the unaided eye – were considered false detections because the spot areas of the largest spot on those days (±1 day) as recorded by the Royal Greenwich Observatory, would be too small for naked-eye detection, namely 11 and 13 millionths of a solar disk (msd), respectively (Usoskin et al. 2015). We revisit this issue here. First, we review theoretical and empirical considerations of the lower limit for the sunspot area detectable by the naked eye: under optimal conditions, very good observers can detect spots as small as ∼100 msd (and we present one example, where an observer reported a spot, when the largest spot on that day was only 65 msd, but being part of a longish group facilitating the detection). Then, we review all known sunspot observations on and around February 15, 1900 and January 30, 1911, including full-disk drawings. For February 15, 1900, Kalocsa observatory, Hungary, shows a feature close to the western limb with an area of 134 msd, but it is not clear whether it was a spot or faculae or pores (as spot, it could have been detectable even by naked-eye). The two spot groups detected in Kodaikanal, India, on January 31, 1911 and February 1 with 18.5 to 33.0 msd area would be too small for detection by the naked eye. However, the Chinese records for February 15, 1900 and January 30, 1911 do not even mention whether the observations were performed with a telescope or by the unaided eye. We conclude that there is no convincing evidence that these two – or even all – Chinese sunspot records are unreliable.

KEYWORDS
solar activity, sunspots

1 | INTRODUCTION: NAKED-EYE SUNSPOTS

Solar activity of past centuries can be reconstructed with radioisotopes, aurorae, and sunspots (review in Usoskin 2017). The latter were observed more or less regularly since the invention of the telescope in 1608. They were also observed in the pre-telescopic era with the unaided naked eye since at least two millennia – most by professional court astronomers in East-Asia (China, Korea, Japan, Vietnam), but a few also in Europe and Arabia (see, e.g., Wittmann & Xu 1987, Yau & Stephenson 1988, or Xu et al. 2000). Chinese court astronomers have continued to record sunspots seen with the unaided eye even after the import of the telescope to China in the 1620's, namely until 1918, the seventh year after the end of the Qing dynasty, see Yau & Stephenson (1988).

Considering the spot area distribution from the telescopic record (e.g. Hathaway 2015) and the ability of the human eye to detect sunspots (Schaefer 1991, 1993a, 1993b, similar in Vaquero & Vazquez 2009), one would expect many more naked-eye detections, in particular by the Chinese court astronomers. The mismatch between expectation and the historical record may be due to either

1. The Chinese court astronomers did not always observe (for sunspots), or
2. They did not always report detected sunspots (e.g. for political reasons, sunspots being interpreted as negative omen), or
3. Because most records are lost.

As far as some other phenomena are concerned, for example, comet Halley or total solar eclipses, the Chinese records are all but complete, see, for example, Xu et al. (2000) and Strom (2015). It is therefore most likely that the Chinese astronomers did not always search for sunspots. About one quarter of the Chinese naked-eye sunspot (NES) records are dated to within 1 day of new moon, when solar eclipses were possible.

Recently, by re-visiting the Maunder Minimum, Usoskin et al. (2015) compared the 10 NESs seen in China from 1874 to 1918 (Yau & Stephenson 1988) with data from the Royal Greenwich Observatory (RGO) telescopic sunspot group photographic catalog (solarscience.msfc.nasa.gov/greenwch.html), that is, for the time window, when the RGO observations were already running (since 1874) and while NESs were still recorded in China (until 1918). For the dates of the 10 NESs in this interval, they obtained the sunspot area of the largest spot from the RGO catalog for that very same day (±1 day to allow for a small date uncertainty in the Chinese record). Based on these spot areas and the limits provided by Schaefer (1993b), Usoskin et al. (2015) concluded that some five spots were definitely large enough for naked-eye detection, one was at the limit, two were clearly below the limit, and two (February 15, 1900 and January 30, 1911, ±1 day) would have been far below the limit. It would have strong consequences, if a significant part of the East-Asian NES would really be unreliable, for example, in Neuhäuser & Neuhäuser (2015) it was shown that ^{14}C maxima (i.e., solar activity minima) were often observed in around the same years as East-Asian NESs (and aurorae), for the time AD 725-824, so that the Schwabe cycle could be reconstructed for most of this time interval. Hence, it is important to clarify this issue:

1. Are there definite false detections of NESs for February 15, 1900 and January 30, 1911 (±1 day) by Chinese court astronomers?
2. If yes, is the whole record of NES reports from China unreliable?

Several aspects will be important in judging the reliability of sunspot reports made presumably by the naked eye – and of the two reports of 1900 and 1911 in particular:

1. The area limit of a naked-eye spot detection depends on many variables and has a wide range for different observers and conditions,
2. The Chinese records do not even mention whether the observations were indeed performed by naked eye or with a telescope, and
3. There may be drawings of the solar disk available for the relevant dates, not only from RGO.

Given its relevance for the depth and strength of the Maunder Minimum, we will here revisit this issue.

We first compare modern NES detections with telescopic images to empirically determine the minimum spot area detectable by the unaided eye, which we compare with theoretical estimates (Section 2). Then, we compare the Chinese naked-eye records (in particular for 1900 and 1911, the two smallest in Usoskin et al. (2015), see above) with the telescopic sunspot observations on those days, partly using drawings of the whole solar disk (Section 3). We finish with a short discussion and summary (Section 4).

In this article, we always refer to the *observed* sunspot area and not to the area corrected for foreshortening, unless otherwise stated, because it is the *observed* sunspot area that is reported by naked-eye observers that we aim to test. Even though the penumbra is lower in contrast than the umbra, it can contribute to the detectability of a spot. For telescopic observations, we refer to whole-spot areas and whole-spot group areas only and give the area in millionths of a solar disk (msd).

2 | MODERN NAKED-EYE SUNSPOT OBSERVATIONS

Schaefer (1993b) derived the minimum angular area $\Omega_{\rm lim}$ for naked-eye detection for typical spot brightness (distribution) near the center of the solar disk with 50% detection probability to be

$$\Omega_{\rm lim} = (35''/S)^2\, e \tag{1}$$

with the observer's Snellen ratio (or Snellen fraction[1]) S and e as correction factor for the threshold based on observer experience. Slataper (1950) determined that the human acuity and Snellen ratio is optimal for ages from 18 to 62 years (and drops more strongly afterwards). For typical values of $S = 1$ and $e = 1$ (Schaefer 1993b), we would get 1,225 square arc sec as minimum area (or 423 msd, for a mean solar angular diameter of 32 arc min), we would have $35''$ as typical spot size; Schaefer (1993b) showed that experienced NES observers can detect such small spots with some ~10% probability (bottom part of his Figure 1). However, if the Chinese imperial court selected those observers with the very best vision from the whole empire (and their star lists do include faint stars with sixth and seventh magnitude, see e.g., the Dunhuang map from the seventh century, Sun & Kistemaker 1997, Bonnet-Bidaud et al. 2009), then we may expect that even smaller spots could be detected (e.g., the highest Snellen fraction score recorded in a study of some US professional athletes was $S = 2$, see Kirschen & Laby 2006, then we would get a limit of 185 msd).

Mossman (1989) conducted a NES survey from February 1, 1981 to February 28, 1982 (when he was 56 years old) close to a solar activity maximum, observing from Liverpool, UK, on every day with some clear time with both naked eye and a telescope (to train the eye). Some 50 sunspots were detected by naked eye through haze or around sunset. Mossman (1989) concluded that he could detect spots down to a diameter of $0.4'$, close to the limit mentioned above, while Eddy et al. (1989) found from comparing Mossman's detections with high-resolution solar photographs and drawings that the limit is actually $0.3'$ for the umbral diameter of the spot. That limit corresponds to 88 msd. Mossman (1989) further concluded that smaller spots could be detected by naked eye if they were parts of larger groups or chains.

Keller (1980, 1986) could detect sunspots by the naked-eye down to a minimal penumbral diameter of 31 arc sec with observations in Schwabe cycle 21 (1976–1986) – for good eye sight. Then, based on observations of 20 amateur astronomers, Keller & Friedli (1992) could detect sunspots by the naked-eye down to a minimal penumbral diameter of 41 arc sec (and down to an umbral diameter of 15 arc sec) – for average eye sight. The lower envelope of umbral spot diameters (plotted versus angular separation of the spot from the solar disk center) detectable to the naked eye in Keller & Friedli (1992), their Figure 2, is fully consistent with the theoretical limit of the smallest mean umbral diameter for average human acuity by Schaefer (1991).

We have compiled NES records from amateur astronomers in Germany observed from 1996 to 2013. They report the number of spot (groups) per day seen by the unaided eye, mostly zero or one spot (group), but sometimes several spot (groups) – while they usually report the number of *spots*, we could possibly consider them as *spot groups*. Their data also include days, when at least one observer observed, but when none of one or several observers detected a spot, that is, all zero(s). For most months, the number of their observing days includes more than half of the days that month. Summaries of the data from German amateur astronomers from 1996 to 2013 were published in the German amateur astronomer journal *Sonne*.[2] The average Snellen ratio S of 41 observers of this amateur astronomer network (A-Netz) was measured to be S = 1.7 (Keller & Bulling 1994), corresponding to a spot limit of 146 msd according to Equation (1) – five observers even had S = 2.0.

One of the most frequent observers, Steffen Fritsche (visus 1.2), explained his observing technique to us as follows (our translation to English from his German):

> *I observe with both eyes and using a welding glass (type Athermal 14 A 1, 5 cm times 10.8 cm), which I have available at my school, in my bag, in the car, and at home. I also use cloud gaps. The sun must be visible without clouds for at least 20 to 30 s. The smaller the spot, the longer the observation would be needed. I can notice small spots only by indirect viewing.*

We have then compared these data with the modern telescopic USAF/NOAA database of sunspots groups and

[1] The visual acuity or Snellen ratio or Snellen fraction is the ratio between the distance at which a test observation is made divided by the distance at which the smallest optotype (e.g., letter or number) identified subtends an angle of five arc min

[2] www.vds-sonne.de/Archiv/archiv.php, also available in more detail from the authors and from Steffen Fritsche (steffen.fritsche@web.de)

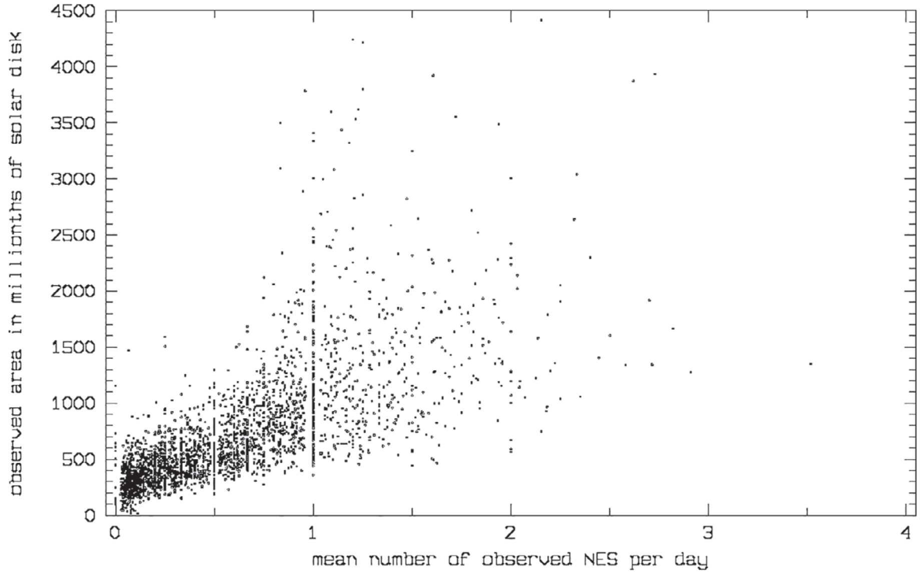

FIGURE 1 This figure shows the area (in msd) of the largest spot group from the telescopic USAF/NOAA database versus the mean number of naked-eye sunspots (NES) on the same day as observed by German amateur astronomers (see footnote 2). Many of them are smaller than a few 100 msd

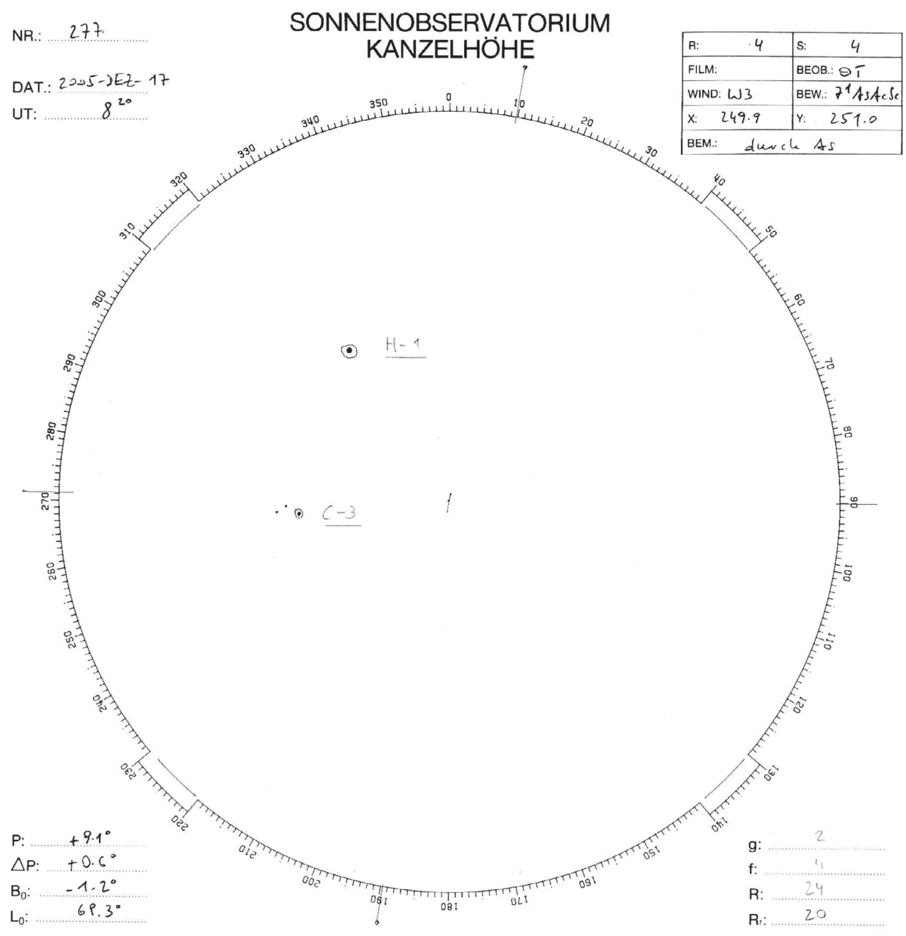

FIGURE 2 Full-disk image of the Sun for December 17, 2005 from Kanzelhöhe Observatory (cesar.kso.ac.at), Austria, when Brandl, a German amateur astronomer, reported one naked-eye sunspot (while nine other observers did not find any spot, Bröckels [from Figure 3] did not observe); on this day, the largest sunspot group in the USAF/NOAA database had 185 msd

their locations and areas available at solarscience.msfc.nasa.gov/greenwch.shtml (D. Hathaway, NASA MSFC). We first calculate the mean number of NES groups per day as reported by the abovementioned amateur astronomers (they report spots, but we assume that they mean groups). For days, when this mean number of NES groups is, for example, 1 (or even $x > 1$), we selected the largest (or the x largest) spot group(s) from the telescopic database. In Figure 1, we compare the telescopically observed spot area of the largest group on such days with the mean number

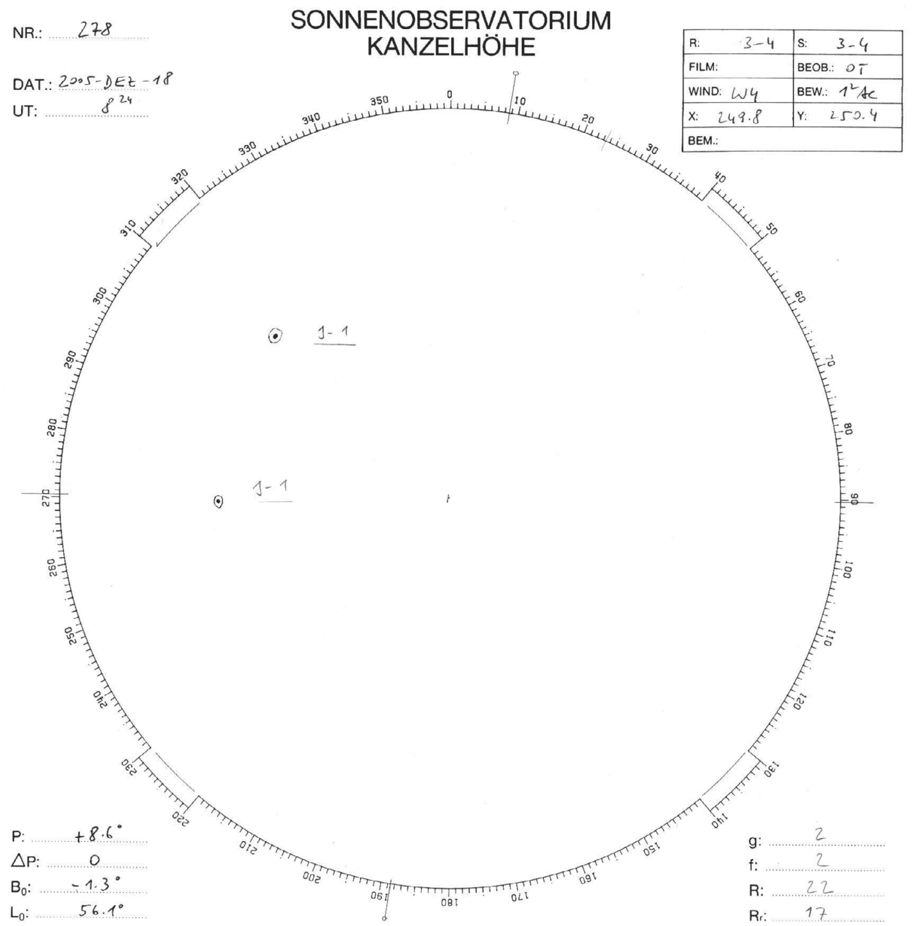

FIGURE 3 Full-disk image of the Sun for December 18, 2005 from Kanzelhöhe Observatory (cesar.kso.ac.at), Austria, when Bröckels, a German amateur astronomer, reported two naked-eye sunspots (while eight other observers including Brandl did not find any spot); on this day, the largest sunspot group in the USAF/NOAA database had 155 msd

of NES (groups) reported – the smallest spots (or groups) reported here by naked-eye observers have areas of less than 100 msd.

To verify the reliability of these naked-eye spot detections, we show the full-disk images of the Sun from Kanzelhöhe Observatory (cesar.kso.ac.at), Austria – namely for some particular days, when naked-eye observers reported the detection of particularly small spots, see Figures 2 and 3. We compare these images with the US Air Force (USAF)/US National Oceanic and Atmospheric Administration (NOAA) database[3], which added data from the Solar Optical Observing Network since 1976, when RGO stopped observing.

On December 17, 2005, the USAF/NOAA database lists three spot groups with areas 36–185 msd, and for December 18, 2005 then 117–155 msd. While Brandl could detect the largest spot of December 17, 2005 with 185 msd, he could not detect any of the spots on December 18, 2005 with 117–155 msd; his limit may be between 155 and 185 msd. Bröckel's limit is even smaller, as one of his spot groups had 155 msd only (sunspot area data from solarscience.msfc.nasa.gov/greenwch.shtml).

We can conclude that naked-eye observers (with particularly good eyes and/or observing at good conditions) can indeed detect small sunspots with an area down to ~155 msd.

Then, as indicated by Mossman (1989) one can sometimes detect a (longish) group made of several small spots, even if all the individual spots are too small for individual detection. We can show an example for this effect in comparison to the German amateur NES observers, namely for June 26, 1997, when German amateur astronomer Rübsam reported *one spot*, which is the longish group seen on Figure 4; the largest group that day had only 65 msd according to the USAF/NOAA database, that is, probably too small for individual detection by naked-eye observation – detected only because it was part of a larger structure and/or very long.

In Figure 5, we show the daily telescopic sunspot number (from sidc.oma.be/silso/data files) versus the mean number of NES observed on those days: the more NES were reported, the larger was also the daily telescopic sunspot number. A similar behavior was noticed by Eddy et al. (1989) by comparison with modern naked-eye observations from England (Mossman 1989).

[3] https://solarscience.msfc.nasa.gov/greenwch.shtml

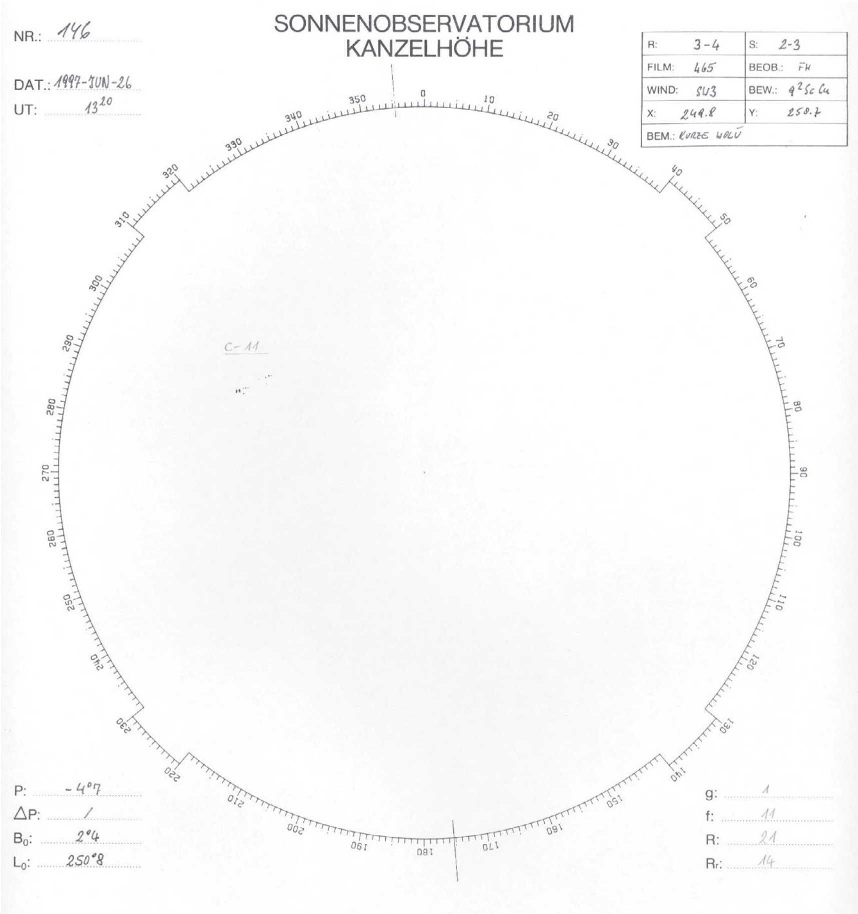

FIGURE 4 Full-disk image of the Sun for June 26, 1997 from Kanzelhöhe Observatory (cesar.kso.ac.at), Austria, when the German amateur astronomer Rübsam reported one naked-eye spot, even though the longish group seen had an area of only 65 msd (according to the USAF/NOAA database)

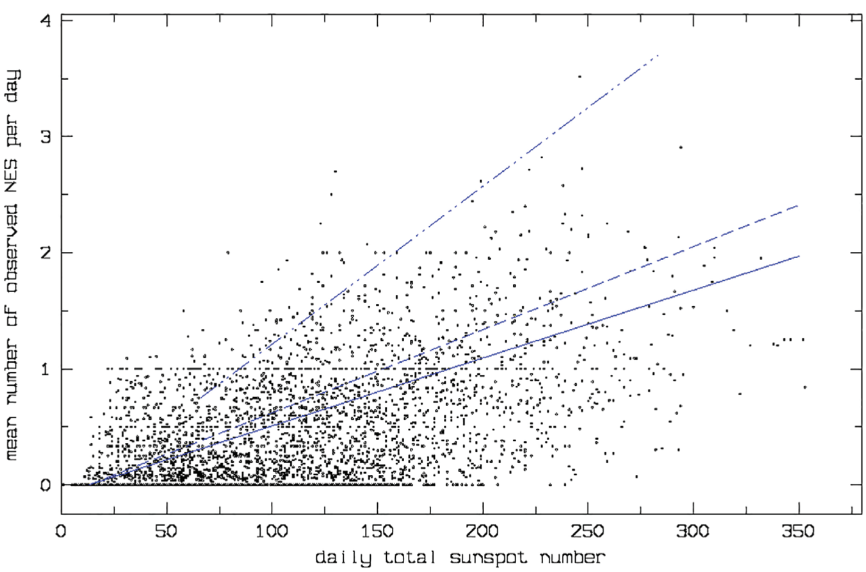

FIGURE 5 Mean number of naked-eye sunspots (NES) versus daily telescopic sunspot number (SIDC Silso) on those days (footnote 2). The lines show the relationship between the number of NES and relative sunspot numbers as found by A-Netz (Keller 1989 cited as priv. Comm. by Schaefer 1991) as lower line, observer Hans U. Keller (Schaefer 1991) as middle line, and observer S.J. O'Meara (Schaefer 1991), also known from night-time astronomy, as upper line; the lines (and data) are found in Figure 1 in Schaefer (1991). The observer Stephen J. O'Meara has a particularly good acuity, while the relationships from Keller and A-Netz agree well with our data. While there is a large scatter in the diagram, we notice that (a) when the relative sunspot number is low (≤100), then naked-eye detections are also low (≤2), and (b) when the relative sunspot number is large (≥250), none of the naked-eye observers missed all spots

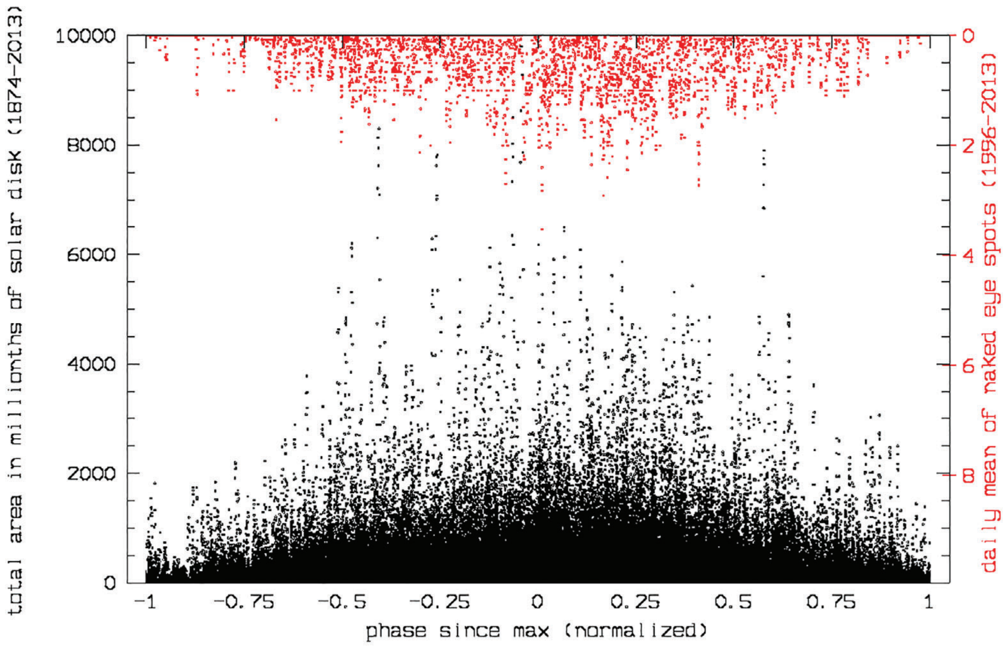

FIGURE 6 Telescopic sunspot total area (msd) of the largest group of a certain day (from the telescopic USAF/NOAA database, solarscience.msfc.nasa.gov/greenwch.shtml) in black (counted from bottom to top on the left axis) and the mean number of naked-eye spots observed by the A-Netz that day (red, counted from top to bottom on the right axis) versus the Schwabe cycle phase (normalized phase before and after maximum (maximum at 0), 13-month mean maxima and minima times from Hathaway (2015)

We also show the distribution of spot areas of naked-eye spots over the respective Schwabe cycle phase: Figure 6 may show that the majority of the largest naked-eye spots observed by the A-Netz occurs mainly around or shortly after the Schwabe cycle maximum, but that also a large number of large spots is seen before the maximum, and that small spots are detected in smaller numbers anytime, also during the activity minimum. This finding is relevant for Grand Minima: for example, in the Maunder Minimum, the detection of NESs alone does not mean that solar activity was not low.

3 | THE CHINESE OBSERVATIONS IN 1900 AND 1911 – COMPARED TO FULL DISK IMAGES

As mentioned, Usoskin et al. (2015) found two dates (±1 day), where there was both a presumable NES detection from China and a telescopic sunspot detection from RGO – however, for days, when the largest (telescopically known) spot would be far too small for a naked-eye detection. The details are as follows (we cite both the old Wade-Giles style romanization as in the cited papers and the new pinyin style equivalents in brackets):

(a) February 15, 1900:

- RGO: a spot group with an area of 11 msd for February 14 (no spots for February 15 to March 2),
- Yau & Stephenson (1988) for February 15, 1900:
  Kuang-hsu (Guangxu) reign-period, 26th year, 1st month, 16th day:
  Within the Sun there was a black spot, source: Hsiang-ch'eng Hsien-chih (Xiangcheng xianzhi) 37
- Chinese text for February 15, 1900:
  Ri zhong you hei zi,
  our literal translation:
  Sun center has black one(s)
  (the suffix rendering *hei* into a diminutive noun).

(b) January 30, 1911:

- RGO: a spot group with area of 13 msd for January 30
- Yau & Stephenson (1988) for January 30, 1911:
  Hsuan-tung (Xuandong) reign-period, 3rd year, 1st month, 1st day:
  Within the Sun there was produced a black spot,
  source: Ch'ing-feng Hsien-chih (Qingfeng xianzhi) 2.
- Chinese text for January 30, 1911:
  Ri zhong sheng hei zi,
  our literal translation:
  Sun center produced black one(s).

We show the Chinese text in Figure 7.

We have cited above the translations by Yau & Stephenson (1988); the other compilations by Wittmann & Xu (1987) and Xu et al. (2000) do not include data for Chinese sunspots after 1700. In Kawamura et al. (2016) on sunspots and aurorae in the Qing dynasty (until 1912), the

Chinese Text and Titles as Cited in Chen Zungui (1984)

15 Feb 1900
清光緒二十六年正月十六日，日中有黑子 (Source: 項城縣志)

30 Jan 1911
清宣統三年元旦，日中生黑子 (Source: 清豐縣志)

FIGURE 7 The Chinese text reporting the spots in 1900 and 1911 (English translation at the beginning of Section 3)

authors did not find any sunspot record, but see Neuhäuser et al. (2018) for a critical review on their work.

The area of the spots with 11 and 13 msd, respectively, is a factor of 8 to 9 below the rough limit for an observer with very good view (185 msd, see above), and even smaller than the 65 msd spot reported by a naked-eye observer as shown in Figure 4.

We should keep in mind that the professional Chinese court astronomers did not always observe without any instrumental help, even before the invention of the telescope. It is known that they observed the Sun (and detected sunspots) around sunrise or sunset as well as through fog, haze, or ash clouds. They may also have used a Camera Obscura for solar observations. In one particular case, the observer mentioned a bowl of water: *"On the 22nd [June 1618], at 1–3 pm, I used a bowl of water at home to observe the sun and saw a black vapor on one side of the Sun,"* from Song-jiang Fu-zhi (Songjiang Fuzhi) 47 – Abbot & Juhl (2016) incorrectly translated as "… *and saw a black vapor next to the sun"* [ri pang], but it is clear philologically and from several (partly simultaneous) observations that the Chinese *"ri pang"* here means *"on one side of the Sun"* (see Neuhäuser et al. 2018 for discussion); both Wittmann & Xu (1987) and Yau & Stephenson (1988) translated the latter part as *"within the sun there was a back vapour"*; and even in Abbot & Juhl (2016), this observation from June 22, 1618 is listed as sunspot, so that it cannot be *"next to the sun"* in the sense of *"outside"* of the sun.

We will now discuss the observations of February 14/15, 1900 and January 30, 1911 in detail.

3.1 | Sunspot observations on and around February 14/15, 1900

For February 8 and 15, 1900, a drawing of the whole Sun is available from Kalocsa Observatory, Hungary, which we show here in Figure 8; see Baranyi et al. (2016) for details on this observatory and its solar data.

The observer drew and wrote the following (in German, partly stenography):

- The solar disk is almost fully drawn as a circle.

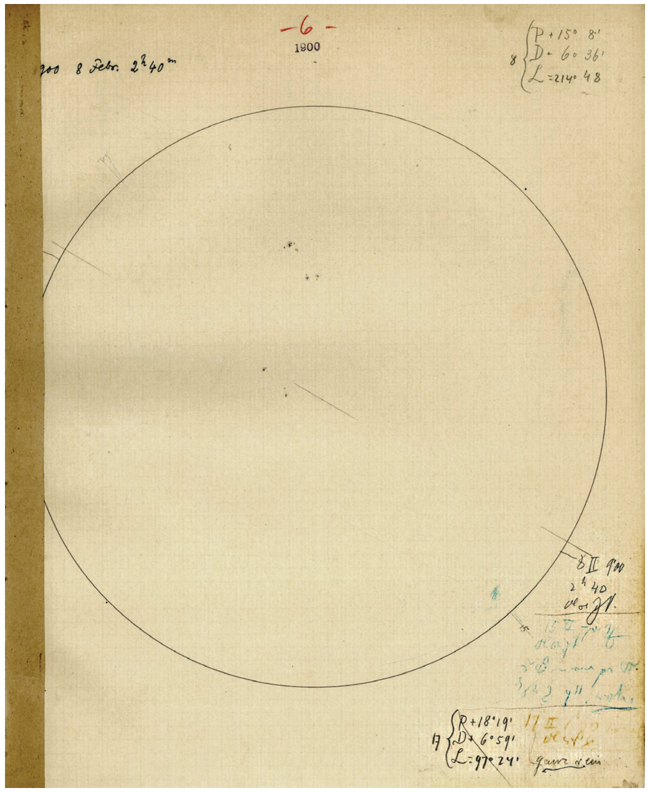

FIGURE 8 Drawing from telescopic observation at Kalocsa for 1900 February 8, 15, and 17, see text for caption. We have taken the image from fenyi.solarobs.csfk.mta.hu/en/databases/HHSD. We improved the contrast for parts of the text in the lower right (but see also Figure 9)

- The typed number above the disk is *1900*, the year of observation (all other text is hand-written).
- In the upper left corner, the text says *8 Febr. 2 h 40 min*, that is, the date and time (afternoon) of one of the two observations drawn on the disk.
- In the upper right corner, the observer gave the solar position angle and the heliographic coordinates of the solar disk center. … (lines omitted) …
- In the lower right corner, the first three lines give again the date of the first observation: *8 II 900* for February 8, 1900, *2 h 40* for 2:40 h pm.
- The next four lines (between two horizontal lines) in dark blue, written by the same hand as the previous three lines above them, give information on a second observation also drawn onto the solar disk, namely for *15 II - v.* for February *15*, *1900* (*– v.* could be an abbreviation for *vormittags*, German for ante meridiem), followed by the astronomical sign for Jupiter, indicating that the day was a Thursday (indeed, February 15, 1900 was a Thursday).

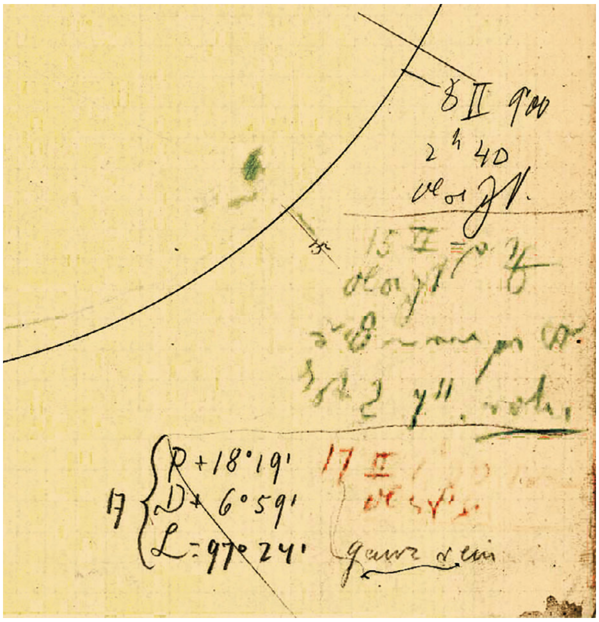

FIGURE 9 Enlargement of the lower right corner of the telescopic observation at Kalocsa for 1900 February 8, 15, and 17, see text for details. The original image was provided to us by Tünde Baranyi from the Heliophysical Observatory, Konkoly, Hungary, and it was contrast-improved by us

- The very last line says in black *ganz rein*, which is German and means *fully clear* (immaculate), that is, the Sun was clear of spots on February 17.
- Then, there are of course sunspots drawn for February 8 and 15: three pairs or groups of spots can be seen near the center of the disk and above it; these are the spots for February 8, 1900, the main date, as nothing different is indicated; then, there is also a spot pair seen in the lower right corner very close to the limb – and also close to the tick mark marked with *15*, so that these are the spots seen on February 15, 1900. (No spots can be found for February 17, and the Sun was said to be *clear*.)

The Kalocsa observations for February 19, 23, and 24, 1900 then say *kein Fleck* for *no spot*; then, on February 25 also no spots, but on the next clear day, March 4, one sunspot group near the disk center[4].

We have measured the area of the largest feature of February 15 and obtained about 1,000 square arc sec (or 134 msd). For a spot, this would be close to the limit for average conditions according to Schaefer (1993b), see our Equation (1), that is, detectable by a good observer, even though close to the limb.

We list several spot observations on and around February 15, 1900 from different observatories in Table 1.

The RGO database lists only a small spot area (11 msd) for 1 day earlier, February 14 – and then no spots from February 15 to March 2, 1900.

We would like to note that for February 14, 1900, the RGO database lists an unusual group number (62001), so that this observation may have come from some source other than RGO observations. Also, the group number 4912 listed by Kalocsa for February 15, 1900 (134 msd as measured by us from Figure 8) is not at all listed by RGO. In the RGO ledger, however, the group for February 14, 1900 is given as number 4912.

Furthermore, as seen in Table 1, the sunspot areas of Kalocsa and RGO do not agree well with each other (for other dates), but the RGO areas are smaller than the Kalocsa areas by a factor of 2–8. This could be caused by different gray scale limits during the measurements. And this could then also mean that the spots listed with 11 and 13 msd in RGO for February 14, 1900 and January 30, 1911, respectively, were in fact also larger, but had relatively small contrast between spot and surrounding photosphere.

Given that the Kalocsa observers mostly drew spots in black and faculae in blue or red, it is also possible that the feature in the SW on February 15, 1900 are faculae or changing pores instead of a spot. Indeed, the RGO ledger (*Greenwich Photo-heliographic results* ledger, see Willis et al. 2013) lists a facula for February 14, 1900 at a latitude of 12.7° and also a facula for February 16, 1900 at a latitude of 12.1°, consistent with the feature seen in Figure 8. (However, it also happened that Kalocsa observers have drawn spots with color, e.g., on September 16, 1884.)

For group number 4909, the Greenwich Photo-heliographic results (RGO ledger, see Willis et al. 2013) reports: "February 6–13: A few regular spots, diminishing rapidly in size. The group is not seen on February 10, but is very large on the next day," it may possibly have been this group with rapidly changing size that was seen by the Chinese.

In the RGO ledger (see Willis et al. 2013) for February 15, 1900, neither spots nor faculae are listed, but the Sun was observed that day at Kodaikanal Observatory, India, at 07:21 h UT (that observation is not yet available on www.iiap.res.in/centers/kodai). For February 14, 1900, two new small spots (not observed before) are listed (observed also in India) as part of group number 4912 at a position as in our Table 1 (this is the group number as in the Kalocsa catalog, while the current RGO catalog gives 62,001, see Table 1). The spot group numbered 4912 (or 62,001) was seen in India only on February 14, 1900, but neither during the 6 days before nor on the next 3 days, when the Sun was also observed in India (measured on February 14 and the days before and after by C.F. Lait and E.W. Maunder).

4 fenyi.solarobs.csfk.mta.hu/ftp/pub/HHSD/Haynald/1900/19000219_Kalocsa.jpg and 19000225_Kalocsa.jpg

Table 1 Sunspots on and around February 15, 1900: in the second column, RGO for Royal Greenwich Observatory (online catalog and ledger, e.g., RGO/Kod. means that the data from the RGO online catalog come from the observations as Kodaikanal as seen in the ledger), Kal. for Kalocsa, HS98 for Hoyt & Schatten (1998); third column gives number of the spot group according RGO; fourth column is central meridian distance (CMD); fifth column is the latitude (south negative); last column is the apparent sunspot group area in millionths of a solar disk (msd)

Date	Observatory	Group no.	CMD [°]	Latitude [°]	Area [msd]
February 7, 1900	RGO	no observations			
February 8, 1900	HS98	4 groups			
February 8, 1900	Kal.	4907	18.4° E	9.3°	11.5
February 8, 1900	Kal.	4907	16.8° E	10.3°	1.3
February 8, 1900	Kal.	4907	17.2° E	11.0°	6.4
February 8, 1900	Kal.	4907	19.0° E	9.5°	1.3
February 8, 1900	Kal. ave.	4907	17.9 ± 1.0° E	10.0 ± 0.8°	Sum = 20.5
February 8, 1900	RGO	4907	18.2° E	10.7°	164
February 8, 1900	Kal.	4908	26.3° E	11.7°	26.8
February 8, 1900	Kal.	4908	26.7° E	10.6°	6.4
February 8, 1900	Kal.	4908	26.4° E	12.2°	6.4
February 8, 1900	Kal.	4908	27.1° E	11.9°	1.3
February 8, 1900	Kal.	4908	26.0° E	12.5°	1.3
February 8, 1900	Kal.	4908	24.4° E	11.9°	6.4
February 8, 1900	Kal. ave.	4908	26.2 ± 0.9° E	11.8 ± 0.7°	Sum = 48.6
February 8, 1900	RGO/Kod.	4908	27.1° E	12.5°	126
February 8, 1900	Kal.	4909	4.3° E	− 10.5°	6.4
February 8, 1900	Kal.	4909	5.5° E	− 9.7°	1.3
February 8, 1900	Kal. ave.	4909	4.9 ± 0.8° E	− 10.1 ± 0.6°	Sum = 7.7
February 8, 1900	RGO/Kod.	4909	5.4° E	− 10.1°	20
February 8, 1900	Kal.	4910	11.2° E	− 9.9°	11.5
February 8, 1900	RGO/Kod.	4910	11.7° E	− 10.0°	27
February 9–14, 1900	Kal.	No observations			
February 9–12, 1900	RGO/Kod.	Various spots			
February 13, 1900	RGO/Kod.	4909	60.5° W	− 10.1°	13
February 13, 1900	Wolfer	6	37.5° W	13.3–15.0°	8 (*small*)[e]
February 14, 1900	RGO/Kod.	62001[a]	53.9° W	6.2°	11
February 15, 1900[c]	Kal.	4912[b]	63.2° W	13.1°	134[d] (Figure 8)
February 15, 1900	Wolfer	6	68.9° W	5.8–8.9°	8 (*small*)[e]
February 15, 1900	RGO/Kod.	Neither spots nor faculae			
February 16, 1900	Kal.	No observations			
February 16, 1900	RGO/Kod.	No spots, but 3 faculae			
February 17, 19, 23, 24, 1900	Kal.	No spots			
February 17–21, 1900	RGO/Kod.	Neither spots nor faculae			
February 15 to March 2, 1900	RGO	No spots			

[a] Unusual spot group number; area is given as zero in RGO database (a pore?); in the RGO ledger, one group is listed as number 4912 with two small spots – seen only on February 14.
[b] This group number does not appear in the RGO list (at least not under that number), but in Kalocsa.
[c] HS98 and Wolfer (1901) list several telescopic observers for February 15, 1900, see text (Section 3.1).
[d] Our measurements (spot(s) or faculae or pores).
[e] Our measurements of spot locations and areas from Wolfer's drawings, see Figure 12 (Wolfer 1900, 1901).

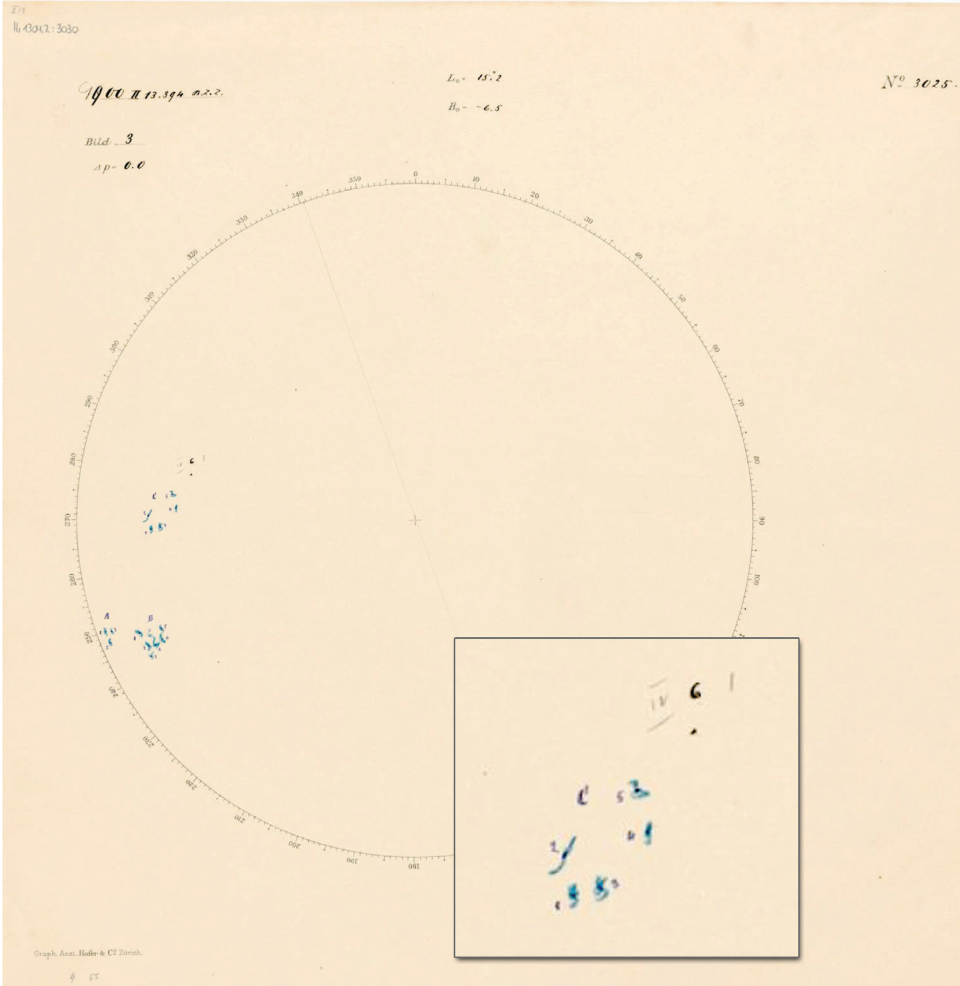

FIGURE 10 Wolfer's full disk drawing for 1900 February 13, when he detected the small spot number 6 in the upper left quadrant (position angle ∼ 280°), close to the western limb, see our enlargement in the bottom right. The other features labeled with letters are faculae. This figure is available on dx.doi.org/10.7891/e-manuscripta-60791 from ETH Zürich, Switzerland

Hence, this spot group seems to have formed anew on or around February 14 and it did not remain long.

According to Hoyt & Schatten (1998, henceforth HS98), also a few telescopic sunspot observers noticed one spot group on February 15, 1900, namely Wolfer, Broger, Catania, Lewitzky, and Tacchini. HS98 may refer to Wolfer (1901); for Catania, HS98 cite *National Geophysical Data Center*, *1990. Solar Variability Affecting Earth. CDROM*, *NGDC-05/1*; Wolfer (1901) listed in his Table 2 for February 15, 1900 a daily relative sunspot number of 7 as observed with two small telescopes with 8 cm and 4 cm apertures (SSN = 11 with correction factor 0.6 for himself, hence 7), but zero spots for all remaining days that month. Wolfer (1901) then also gives the following sunspot number (relative number) for several observers, always for February 15, 1900: Wolfer (Zürich) 1.1, Broger (Zürich) 1.5, Winkler (Jena) 0.0, Quimby (Berwyn, USA) 0.0, Mascari (Catania) 1.1 (communicated to Wolfer by Ricco), v. Konkoly (Ogyalla) 0.0, Scharbe (Jurjew) 1.1 (communicated to Wolfer by Lewitzky), von Kaulbars (St. Petersburg) 0.0, Freyberg (St. Petersburg) 0.0, Tacchini and Pallazo (Rome) 1.1, and Subottine (St. Petersburg) 0.0 – slightly different from HS98. In the figure on double-page 115/116 in Wolfer (1903) one can also see that the Zürich sunspot number was 7 on February 15, 1900 (i.e., one spot group as above). Interestingly, there seems to be no clear relation between aperture and detectability of the spot in the data for February 15, 1900: the observers with apertures 6.5, 7.6, 9, 10, and 11 cm (and one with unknwon aperture) detected no spots, while three observers with 8 cm aperture and one with 33 cm (plus one with unknown aperture) did detect one spot (see Wolfer 1901).

In Wolfer's observational log (ETH Zürich), he has *"keine Beobachtung"*, that is, *"no observation"* for February 12, 1900, then for February 13 one spot (his number 6, $b = 13.5^\circ$ and $l = 176.8^\circ$, see our Table 1) plus three groups of three to seven faculae, then for February 14, he wrote *"keine Protuberanzen,"* that is, *"no prominences,"* and did not list anything else (hence, either almost no changes or no observations), then for February 15, one spot (again his number 6, see our Table 1) plus seven groups of two to 26 faculae, and then for February 16 only five individual entries for faculae, then for February 17, he wrote *"keine Flecken,"* that is, *"no spots,"* and listed two groups with

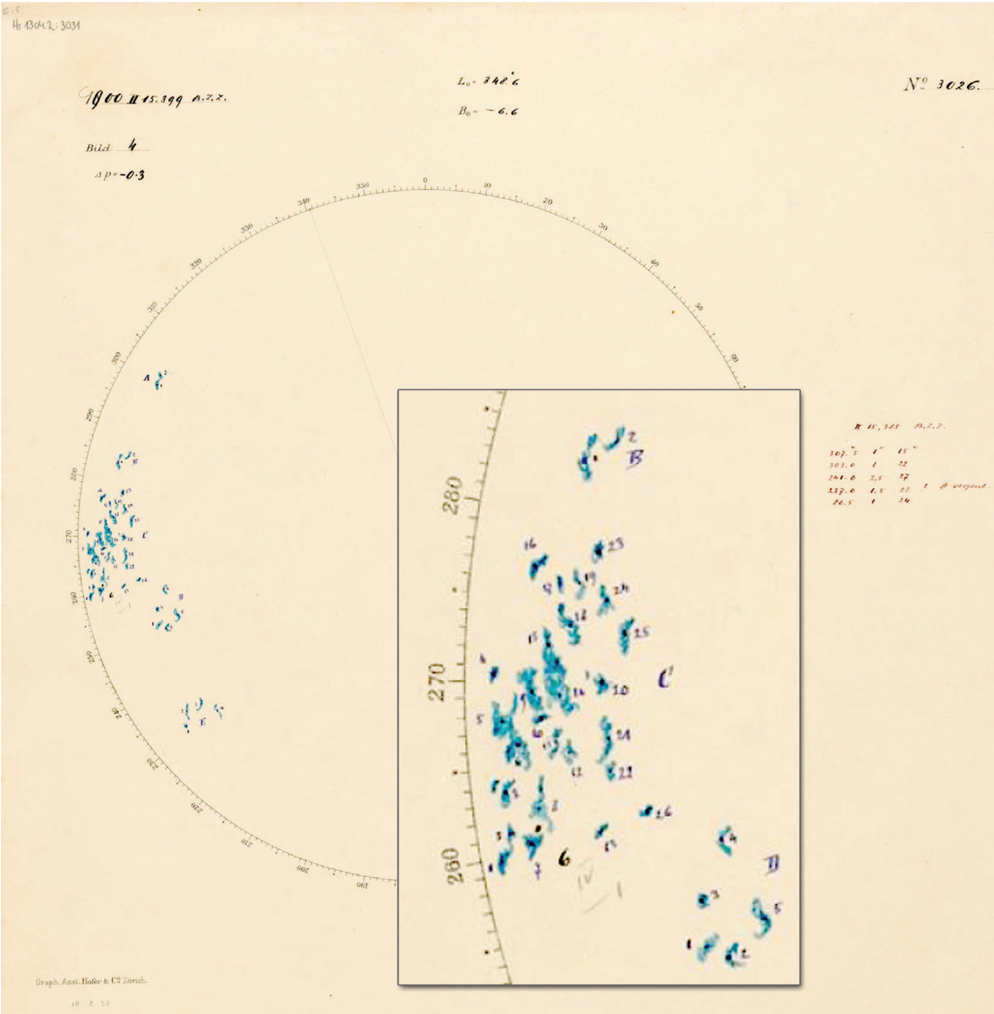

FIGURE 11 Wolfer's full disk drawing for 1900 February 15, when he detected again the small spot number 6 at position angle ~ 260°, now even closer to the western limb, see our enlargement in the bottom right. The other features labeled with letters are faculae. This figure is available on dx.doi.org/10.7891/e-manuscripta-60829 from ETH Zürich, Switzerland. The spot is better seen on Wolfer's drawing shown in Figure 12

FIGURE 12 Wolfer's full disk drawing for 1900 February 15 (9:30 h) with the spot numbered by him with 6 (contrast enhanced by us)

Table 2 Sunspots on and around January 30, 1911: in the second column, RGO for Royal Greenwich Observatory, Kal. for Kalocsa, Kod. for Kodaikanal; third column gives number of the spot group according RGO or Kodaikanal; fourth column is central meridian distance (CMD); fifth column is the longitude (south negative); last column is sunspot group area in millionth of a solar disk (msd), as measured by us for Kodaikanal images (Figures 14 and 15)

Date	Observatory	Group no.	CMD [°]	Latitude [°]	Area [msd]
January 15–29, 1911	RGO	No spots[a]			
January 30, 1911	RGO	6922	44.4° E	−20.0°	13[b,c]
January 27–30, 1911	Kod.	No spots			(Figure 13)
January 28–31, 1911	Kal.	No spots[d]			
January 27, 1911	Wolfer	“No spots”			
January 29, 1911	Wolfer	“No spots”			
January 30, 1911	Wolfer	Unambigious: “no spots,” but four groups listed[g]			
January 31, 1911	Wolfer	“No spots”			
January 16–February 10, 1911	Wolfer	No spots seen on his drawings (Wolfer 1911a, 1911b)			
January 31, 1911	RGO	No spots[b]			
January 31, 1911	Kod.	1954	ca. 37–38° E	ca. – 18.0°	Spot 1: 9.2
January 31, 1911	Kod.	1954	ca. 37–38° E	ca. – 18.0°	Spot 2: 4.3
January 31, 1911	Kod.	1954	ca. 37–38° E	ca. – 18.0°	Spot 3: 4.9
January 31, 1911	Kod.	1954	ca. 37–38° E	ca. – 18.0°	Sum: 18.5 (Figure 14)
February 1, 1911	RGO	6922	19.9° E	−19.5°	14[b]
February 1, 1911	Kod.	1954	ca. 27–29° E	ca. –19°	Spot 1: 6.1
February 1, 1911	Kod.	1954	ca. 27–29° E	ca. –19°	Spot 2: 7.3
February 1, 1911	Kod.	1954	ca. 27–29° E	ca. –19°	Spot 3: 9.8
February 1, 1911	Kod.	1954	ca. 27–29° E	ca. –19°	Sum: 23.2 (Figure 15)
February 1, 1911	Kod.	1955	ca. 40° E	ca. –25°	Spot 1: 1.8
February 1, 1911	Kod.	1955	ca. 40° E	ca. –25°	Spot 2: 4.1
February 1, 1911	Kod.	1955	ca. 40° E	ca. –25°	Spot 3: 4.9
February 1, 1911	Kod.	1955	ca. 40° E	ca. –25°	Sum: 33.0 (Figure 15)
February 1, 1911	Kal.	No observations			
February 2, 1911	Kod.	No spots			
February 2–8, 1911	RGO	No spots[e]			
February 2, 1911	Kal.	No spots[f]			
February 3, 1911	Kal.	No observations[f]			
February 4–7, 1911	Kal.	No spots[f]			

[a] According to the *Greenwich Photo-heliographic results* ledger (see Willis et al. 2013) the sun was observed all these days: January 15, 16, 18–20, 22, 23, 25, 28, 29 by Cape, January 17 by Kodaikanal, January 21 and 27 by Daehra Dun, and on January 24 and 26 by Greenwich, always faculae, but no spots.
[b] RGO ledger gives RGO as observatory for January 30 and 31 as well as February 1.
[c] Hoyt & Schatten (1998) list the following telescopic observers for January 30, 1911 (number of groups in brackets): RGO (1), Wolfer (0), Broger (0), Mount Holyoke College/MA/USA (0), Quimby/USA (0), Bemmelen (0), Woinoff (0), Stempell (0), Bodocs (0), Lissak (0), Guillaume (1), Stonyhurst Coll. Obs. (0).
[d] http://fenyi.solarobs.csfk.mta.hu/ftp/pub/HHSD/Haynald/1911/19110125_Kalocsa.jpg.
[e] The Sun was observed all these days (February 2–8) by Cape, always faculae, but no spots.
[f] http://fenyi.solarobs.csfk.mta.hu/ftp/pub/HHSD/Haynald/1911/19110202_Kalocsa.jpg.
[g] Wolfer wrote “no spots,” but also listed four groups of 1 to 2 entries and wrote “*gr. kl. Fleck – 20°*”.

2 and 5 faculae. We show his drawings for February 13 and 15 in Figures 10–12. We can conclude that Wolfer saw spot number 6 on both February 13 and 15. Wolfer called the spot *“klein,”* that is, *“small,”* and indeed, we measure 8 MSD only for both dates. Given the relatively large change in CMD by 31.5° in 2 days from February 13 to 15, what is labeled twice as *“spot number 6”* by Wolfer is probably not the very same spot, but maybe from the same group.

The observations and drawings mentioned above were made in two different ways: 25-cm drawings by projection using a 15-cm refractor (Figures 10 and 11) and eyepiece observations (aerial image at 64 magnification) through a smaller 82-mm refractor (Figure 12 showing only a sketch), much less precise than the 25-cm drawings (Wolfer 1900, 1901).

We conclude that there was a spot on the Sun on February 15, 1900 (Wolfer), which may have been too small for the naked eye, while the feature seen in Kalocsa (spot, faculae, or pores) could have been detectable by the naked eye, if it was a spot. A small spot may still have been detected in China, namely with a telescope, which was available. Chen (1984), the source Yau & Stephenson (1988) cite for these records, does not specify whether the sunspots observed by naked-eye or with the use of a telescope.

3.2 | Sunspot observations on and around January 30, 1911

For January 30, 1911, the RGO entry lists spot group no. 6922 with 13 msd only; RGO has no entries the days before, January 15–29. RGO spot no. 6922 for January 30, 1911 has a position angle from heliographic north of 112.2° (SE), Carrington longitude 226.8°, heliographic latitude −20.0° (south), and a central meridian distance of −44.4° (east).

We list spot observations on and around January 30, 1911 from different observatories in Table 2.

In the *Greenwich Photo-heliographic results* ledger (see Willis et al. 2013) for January 30, 1911, one small spot group (number 6922) and three faculae are listed to have been observed at Greenwich at 14:40 h UT (measured by A.H. Smith and C.F. Lait); group number 6922 was observed only on January 30 and February 1, not on any other days. Hence, this small group may have formed on or around January 30 (on the western side), and it did not stay long.

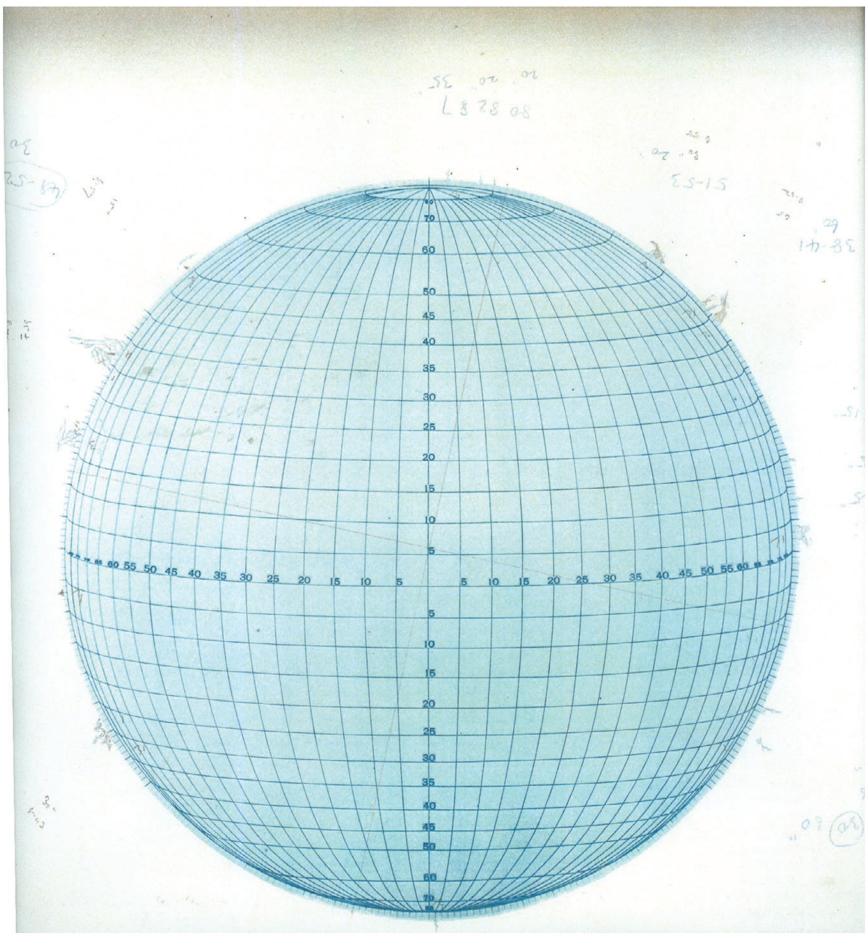

FIGURE 13 Full disk drawing from Kodaikanal Observatory, India, for 1911 January 30: no spots, but faculae and prominences

The former may be consistent with the wording recorded in China for January 30: *"Within the Sun there was produced black spot(s)"* (Yau & Stephenson 1988), or *"Sun center produced black one(s)"* (our literal translation), they may mean one (or several?) new spot(s) with *produced*.

The Chinese verb used here, *"sheng,"* may be transitive or intransitive; it can mean *to come into being*, *be born*, *to arise*, *to give rise to*, *to be produced*, or *to produce*. In the context of sunspots, *"sheng"* can mean *newly formed*, or, since this spot was seen for a total of 13 days (December 19–31), it was probably seen first near the eastern limb, the meaning would then be *(newly) appeared*.

The records for February 10, 1185 and May 23, 1186 use the phrase *"ri zhong sheng hei zi"*. The *"ri zhong"* could reasonably be rendered as a locative or the subject of the sentence. In the former case, *"sheng"* becomes intransitive or passive (i.e., *"In the (middle/center of the) sun*, *black spot/s was/were produced/born/formed/grew"*); note that the Classical Chinese, like the modern standard language, did not distinguish between singular and plural). The term *"ri zhong"* could mean the center of the solar disk or just somewhere on the solar disk. In the latter case, *"sheng"* would be active with the *"middle of the sun"* as the agent: *"The middle/center of the sun produced black spot(s)"*). However, the former translation (sunspot production in the middle/center of the Sun) is well possible here (February 10) because there is also a sunspot record for February 11 (Korea), but then another one from February 15–27 (13 days, explicitly reported to have been seen *"every day"*), so that the latter one (February 15–27) can be one spot seen from east to west, while the former one(s) on February 10 and 11 must be different spot(s) seen perhaps only for a few days (e.g., from the middle of the sun towards the western limb). It is similar for the spot(s) seen from May 23 to 27, 1186, they could have appeared or were seen first in the middle/center of the Sun. Then, the spot(s) 1201 January 9–29 (21 days) also must be more than one particular spot (or group), that is, the first one could have appeared first in the middle of the Sun.

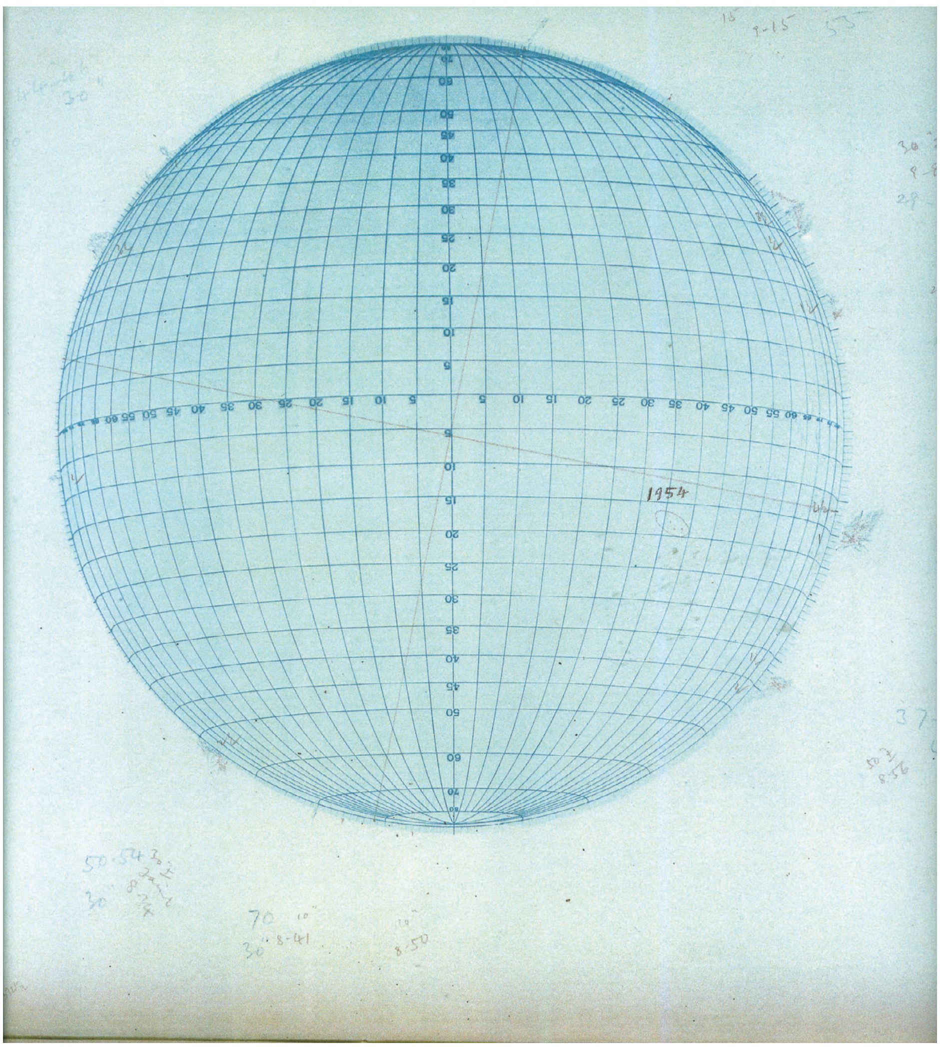

FIGURE 14 Full disk drawing from Kodaikanal Observatory, India, for 1911 January 31: one spot group (no. 1954) together with faculae and prominences; the spot group with three small spots has a total area of 18.5 msd as measured by us

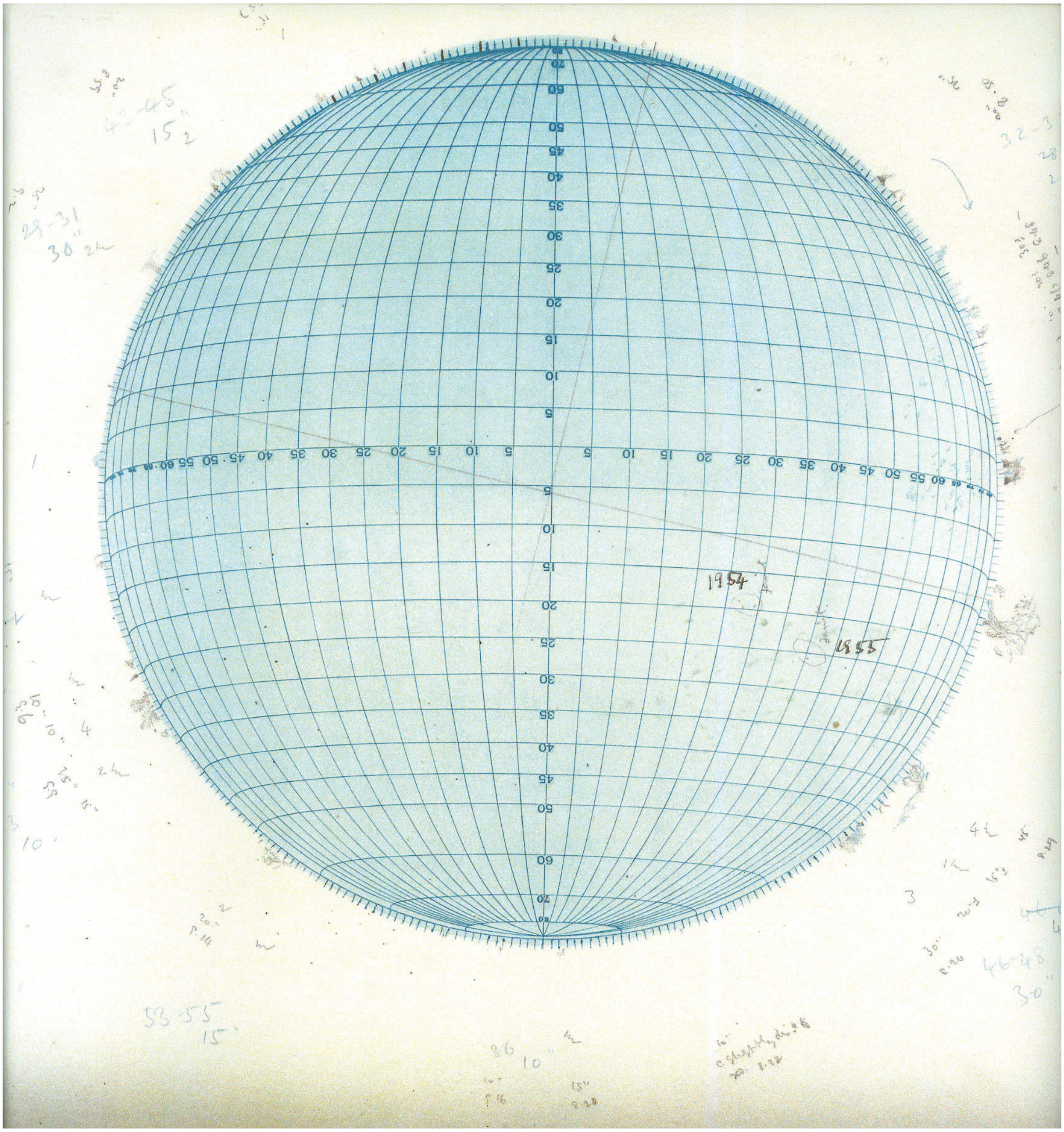

FIGURE 15 Full disk drawing from Kodaikanal Observatory, India, for 1911 February 1: two spot groups (no. 1954 and 1955) together with faculae and prominences. The spot group areas are 23.2 msd for group 1954 and 33.0 msd for group 1955, as measured by us

Kalocsa Observatory does have some observations around the end of January 1911: for January 17, 19, 20, 23, 24, 25, 28, 29, 30, 31, 1911 as well as for February 2, 4, 5, 6, and 7 *"Sonne ganz rein"* for *"Sun is clear"* of spots. On the other hand, RGO did detect spot group no. 6922 on January 30, 1911 and February 1 in the SE quadrant (but has no data the other days). The spot has an area of 13 msd, that is, again much too small for detection with the naked eye.

Then, the Sun was also monitored at Kodaikanal Observatory, India (www.iiap.res.in/centers/kodai, data obtained from D. Banerjee, priv. Comm.), around these days: Kodaikanal detected *no spots*, *but faculae and prominences* for January 27, 28, 29, and 30, 1911; then, they detected one spot group (no. 1954) on January 31 and two spot groups (no. 1954 and 1955) on February 1 – on both days together with faculae and prominences; then, on February 2, again *no spots*, *but faculae and prominences*. Their full disk images for January 30, January 31, and February 1 are shown in Figures 13–15. The spots drawn on these images may not be drawn to scale, but just at about the correct position.

For three small Kodaikanal spots on January 31, 1911 (Figure 14), we measured its total area to 18.5 msd (group no. 1954). For February 1, 1911, we obtained a total of 23.2 msd for group 1954 and 33.0 msd for group 1955 (Figure 15).

According to HS98, in addition to RGO, also the telescopic sunspot observer Guillaume from Lyon, France, noticed one spot group on January 30, 1911.

In Wolfer's own observational log (ETH Zürich), he has *"keine Flecken,"* that is, *"no spots"* in the first lines for January 27, 29, 30, and 31, 1911; for those days, there are always at least 10 entries with coordinates (for faculae or prominences); but also on January 30 together with four groups of 1 to 2 entries, he wrote in larger letters *"gr. kl. Fleck – 20°"* which could mean *"grey small spot – 20°."* A latitude of about $b = -20^\circ$ would be fully consistent with the observation at RGO of spot number 6922 at CMD 44° (east) and $b = -20^\circ$ (south) on January 30, and then at CMD 19.9° and $b = -15.5^\circ$ on February 1, see Table 2. Also, for Kodaikanal Observatory, a new spot appeared on January 31, which was not seen January 27–30. However, on Wolfer's own drawing for 1911 January 30, such a spot is not visible, neither for any other day January 16 to February 10, 1911 (Wolfer 1911a, 1911b). If it was just *gray*, the contrast (or temperature difference) between spot and surrounding photosphere may not have been sufficient for some observers to notice the small spot.

Unfortunately, we could not determine the spot area for Wolfer's *"grey small spot"* on January 30; see Wolfer (1911a, 1911b).

The fact that spots were detected on January 30 (RGO) as well as on January 31 and February 1 (Kodaikanal) is then consistent with the Chinese spot report for January 30 (perhaps observed in the evening at around sunset by the Chinese), but the spot of 13 msd (RGO 6922) would have been too small for detection by the unaided eye (three spots with 18.5 msd to 33.0 msd total area per group the next 2 days (Kodaikanal) is also too small).

Furthermore, the Chinese record cited above for 1911 again does not specify at all whether the observation was performed by the naked eye or by a telescope or by both.

4 | DISCUSSION AND SUMMARY

It is believed that the Jesuit Johannes Terrenz Schreck did not bring the telescope to China before 1621 (see Archimedes Project, on Johann Schreck [Terrenz], see archimedes2.mpiwg-berlin.mpg.de).

Hoyt & Schatten (1998, henceforth HS98) report telescopic observations for sunspots from China for 1686, namely that some Jesuit(s) searched for spots, but did not detect any on February 6, 7, 8, 11, 12, and 16–19, 1686 (HS98 quote as source Mem. Acad. Sci. Paris, 1686. Vol. 7), that is, during the deep phase of the Maunder Minimum (confirmed for all these days by La Hire in Paris, see HS98). The next Chinese telescopic sunspot observations reported in HS98 are by R.P. Jartoux, a Jesuit missionary to Bejing, China, in 1701 and 1705 (HS98 quote Wolf 1730, 1857 as well as Jartoux 1705), that is, in solar cycle −4, which is the last in the Maunder Minimum, when solar activity returned: one spot group 1701 November 1–13 (as Cassini) and also 1705 August 3 and 4 as well as September 17–20 (similar by Cassini). The last Chinese telescopic sunspot observations reported in HS98 (within the imperial epoch until 1912) are by Antoine Gaubil (1689–1759) from China, who detected one spot group each on 1725 May 1, 4, 6, 7, 8, and 10 and then two groups on 1725 May 26 and 28 (HS98 quote as sources Wolf 1866 and Souciet 1729–1732), that is, after the end of the Maunder Minimum.

It is well possible that the above cited Chinese records, so far assumed to describe naked-eye spots, were actually performed with a telescope – or that an observer thought to see the spot also by naked eyes only after he had seen the spot through a telescope.

We have confirmed that one can detect naked-eye spots down to about 150 msd. In exceptional cases, smaller spots can be noticed, for example, on June 26, 1997 one amateur astronomer reported one naked-eye spot, even though the longish group seen had an area of only 65 msd (according to the USAF/NOAA database). For 1900 February 14 ± 1 and 1911 January 30 ± 1, telescopically detected spots were even smaller, although while Chinese astronomers did report one spot each. Since the textual information in the Chinese observations of both 1900 February 14 ± 1 and 1911 January 30 ± 1 do not mention whether the observations were performed by naked-eye and/or by a telescope, they cannot be used to disqualify the Chinese sunspot records – neither these two specific ones nor the (pre-telescopic) naked-eye record as a whole.

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Hathaway (solarscience.msfc.nasa.gov/greenwch.shtml and sidc.oma.be/silso/datafiles). RN would also like to thank Dagmar L. Neuhäuser for discussion and help.

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