

Advanced capabilities of the Dutch Open Telescope

F.C.M. Bettonvil, R.H. Hammerschlag, P. Sütterlin, G. Sliepen, A.P.L. Jägers, F. Snik.

The Dutch Open Telescope (DOT) is a telescope mainly used for high-resolution solar observations at the Observatorio Roque de los Muchachos (ORM) at a height of 2350m above sea level on the North-West Canary island La Palma, where the seeing can be excellent for high-resolution observations of the sun.

The DOT is of a special construction with open telescope on an also open tower to minimize the local thermal disturbance of the air above and in the telescope, where the primary beam is coming to the primary mirror. This is the basis of the advanced capabilities for large-field high-resolution images, sharp over the whole field during hours for movies showing the dynamic processes on the sun.

The DOT is also well suitable for the make of mosaics of images because of its equatorial mount. No image rotation is present without image de-rotator, hence uncomplicated optics in favour of good image quality and fast change from sub-field to next sub-field. In addition, the equatorial mount has the special design of declination axis above the hour axis. Consequently, the telescope is high above the tower platform during observations also in favour for good seeing.

Images and movies of fields at the solar rim are also excellent visible because of the low telescope stray light. This is reached by special optical design and fabrication of optical parts.

The following figures give an impression of the telescope setup and the reached imaging capabilities.

Figure 1. The principle of the open telescope and tower.

Figure 2. The realized telescope and tower.

Figures 3a to 3d. Large mosaic field of active solar region observed in several spectral bands made simultaneous.

Figures 4a to 4j. Mosaic strip over the whole sun from North-Pole region over the Equator to the South-Pole region. The strip in G-band (spectral filter 430 to 431nm) shows the small bright magnetic structures in the dark lines between the granules over the whole sun.

Figure 5. Image of the solar rim in CallH line at short wavelength of 396.8nm, sharp despite difficult concerning seeing.

Figure 6. How the mosaics are made automatically of chosen field on the whole solar image of the guider telescope.

Figure 7. Three images of mosaic movie over 5.5 hours with solar flare 4.7 hours after the start of the observations.

Figure 8: Combination of DOT mosaic observations with observations from space with satellite instrument.

Papers referred to in the figure captions:

- [1] R. Hammerschlag, F. Bettonvil, A. Jägers, G. Sliepen, "Cornelis Zwaan, Open principle and the future of high-resolution solar telescopes" in *Ground-based and Airborne telescopes*, Proc. SPIE 7012-21 (2008)
- [2] P. Nisenson, A. A. van Ballegooijen, A. G. de Wijn, P. Sütterlin, "Motions of isolated G-band bright points in the solar photosphere" in *The Astrophysical Journal*, Volume 587 Pages 458-463 (2003)
- [3] A.G. de Wijn, R.J Rutten, E.M.W.P. Haverkamp, P. Sütterlin, "DOT tomography of the solar atmosphere IV. Magnetic patches in internetwork areas" in *Astronomy & Astrophysics* Volume 441 Pages 1183-1190 (2005) DOI: 10.1051/0004-6361:20053373
- [4] Felix C.M. Bettonvil, Robert H. Hammerschlag, Peter Sütterlin, Robert J. Rutten, Aswin P.L. Jägers, Guus Sliepen, "Tunable H-alpha Lyot filter with advanced servo system and image processing: instrument design and new scientific results with the Dutch Open Telescope" in *Ground-based and Airborne Instrumentation for Astronomy*, Proc. SPIE 6269-12 (2006)
- [5] K. Tziotziou, G. Tsiropoula, P. Sütterlin, "DOT tomography of the solar atmosphere V. Analysis of a surge from AR10486" in *Astronomy & Astrophysics* Volume 444 Pages 265-274 (2005) DOI: 10.1051/0004-6361:20053604 [6]
- [6] R.H. Hammerschlag, F.C.M. Bettonvil "Manual for viewing DOT Movies and Papers" available in <https://drive.google.com/file/d/1ZPDagxeqHr90nKCGoYmIlh18LknR7RkU/view?usp=sharing>
- [7] Robert H. Hammerschlag, Guus Sliepen, Felix C. M. Bettonvil, Aswin P. L. Jägers, Peter Sütterlin, Yong Lin, Sara F. Martin, Olga Panasenco, Eugene P. Romashets, "Large-field high-resolution mosaic movies" in *Optical Engineering* Volume 52 (8), 081603 (August 2013)
- [8] Frans Snik, Felix C.M. Bettonvil, Aswin P.L. Jägers, Robert H. Hammerschlag, Robert J. Rutten, Christoph U. Keller, "The Ba II 4554 / H β imaging polarimeter for the Dutch Open Telescope" in *ASP Conference Series*, Volume 358, Pages 205-208 (2006)

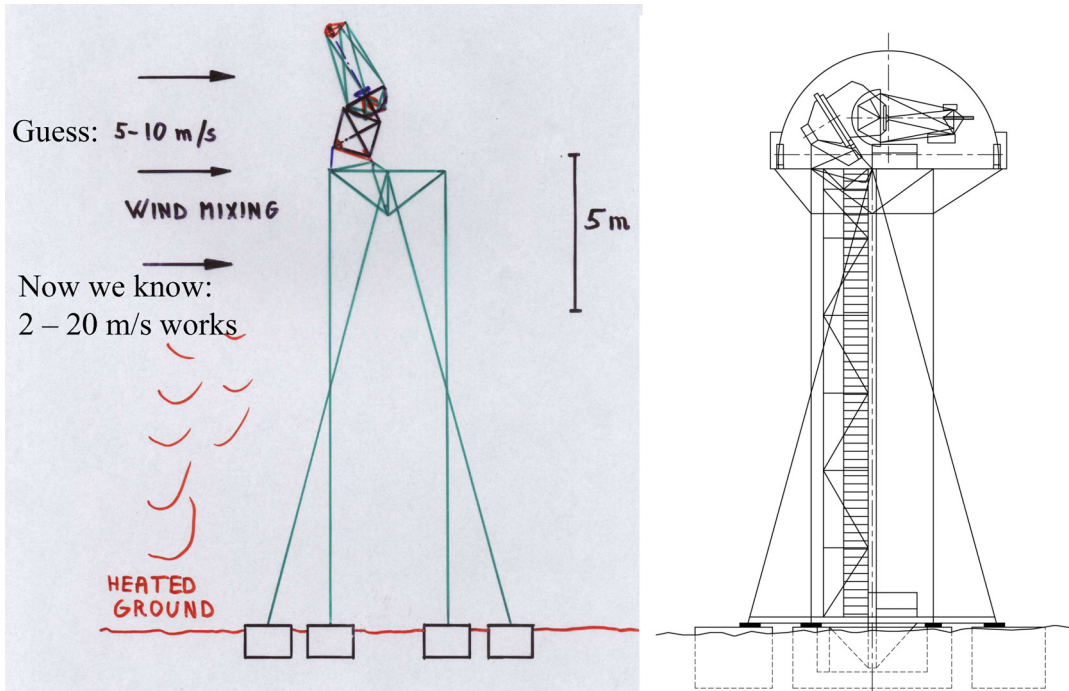


Figure 1. The open tower principle which followed from the site test measurements of Kees Zwaan. Left: Conceptual scheme. Right: Design scheme with open-foldable dome and telescope in parked position. Measurements with masts up to 30m height showed the mixing effect of wind. Large improvement of the seeing was in the height path from 10 to 15m. So a height of 15m was chosen for the open tower. See further ref. 1.



Figure 2. The DOT on its open steel framework tower with a height of 15m. The left picture shows the enclosure open while the DOT is observing. The right picture shows the enclosure closed as protection against bad weather.

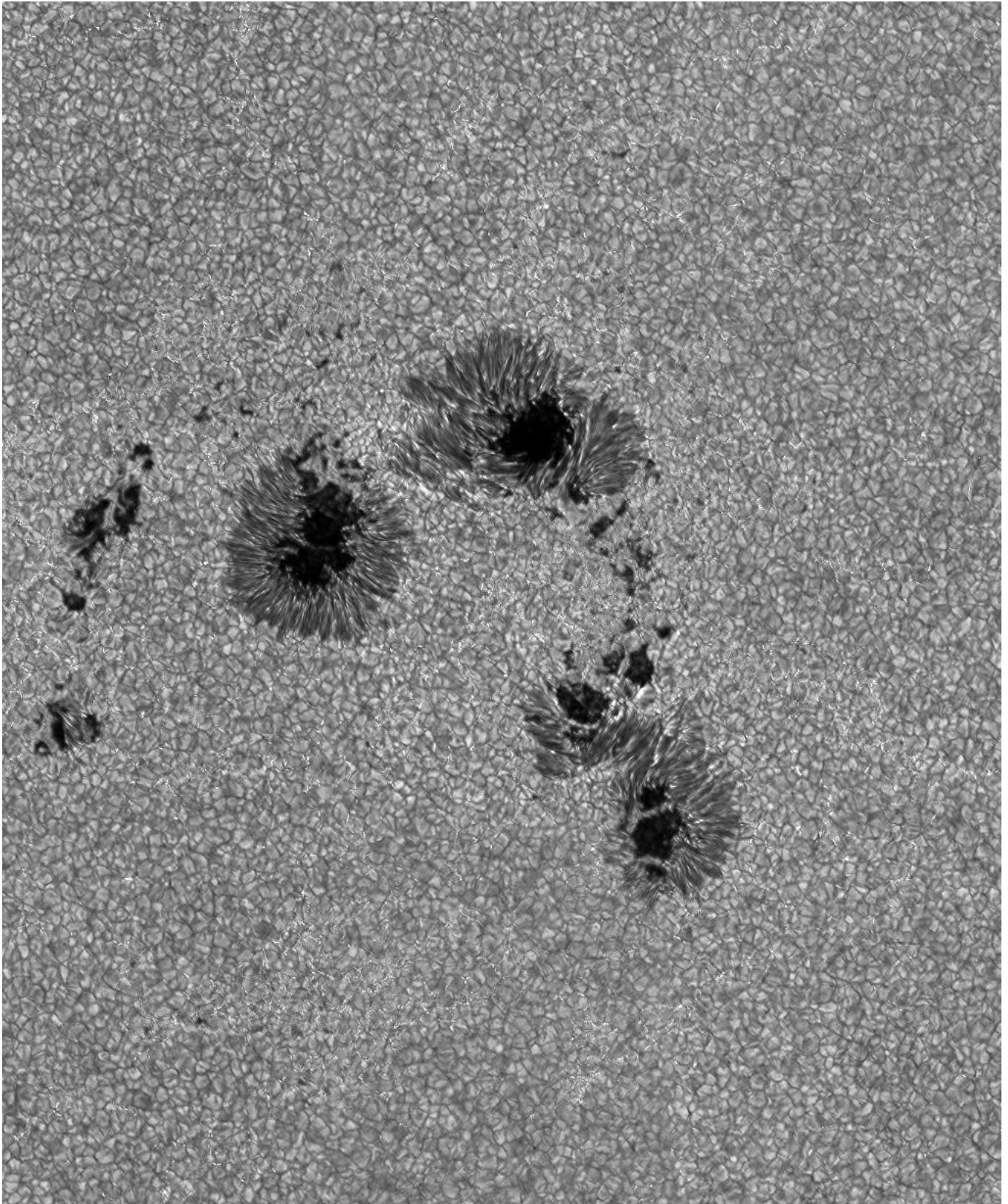


Figure 3. Mosaics of active region in several spectral bands made simultaneous. Field of view is 133 x 182 arcsec.

Figure 3a. G-band 430.5nm, filter width 1.0nm. Multitude of CH spectral lines shows the solar photosphere, the "surface" where the visible light with continuous spectrum escapes. Outside the active region, the G-band shows granulation, the pattern of greyish blobs surrounded by dark inter-granular lanes. This granulation is the solar surface manifestation of the convection by which the sun transports energy through its outer part. The G band also shows, with special emphasis, magnetic elements appearing as tiny bright structures, known as "Bright Points". They cluster in the inter-granular lanes, being swept into these by the convective motions. They consist of slender, near-vertical magnetic "flux tubes" with magnetic field strength of about 1200-1500 Gauss. It takes a sharp telescope as the DOT to properly image these flux tubes. They brighten especially in the G band because the CH molecules dissociate within the flux tubes, making these more transparent viewing pipes into the hotter solar sub-surface gas. The image can be enlarged on the screen for better visibility of the tiny bright structures. See also ref. 2.

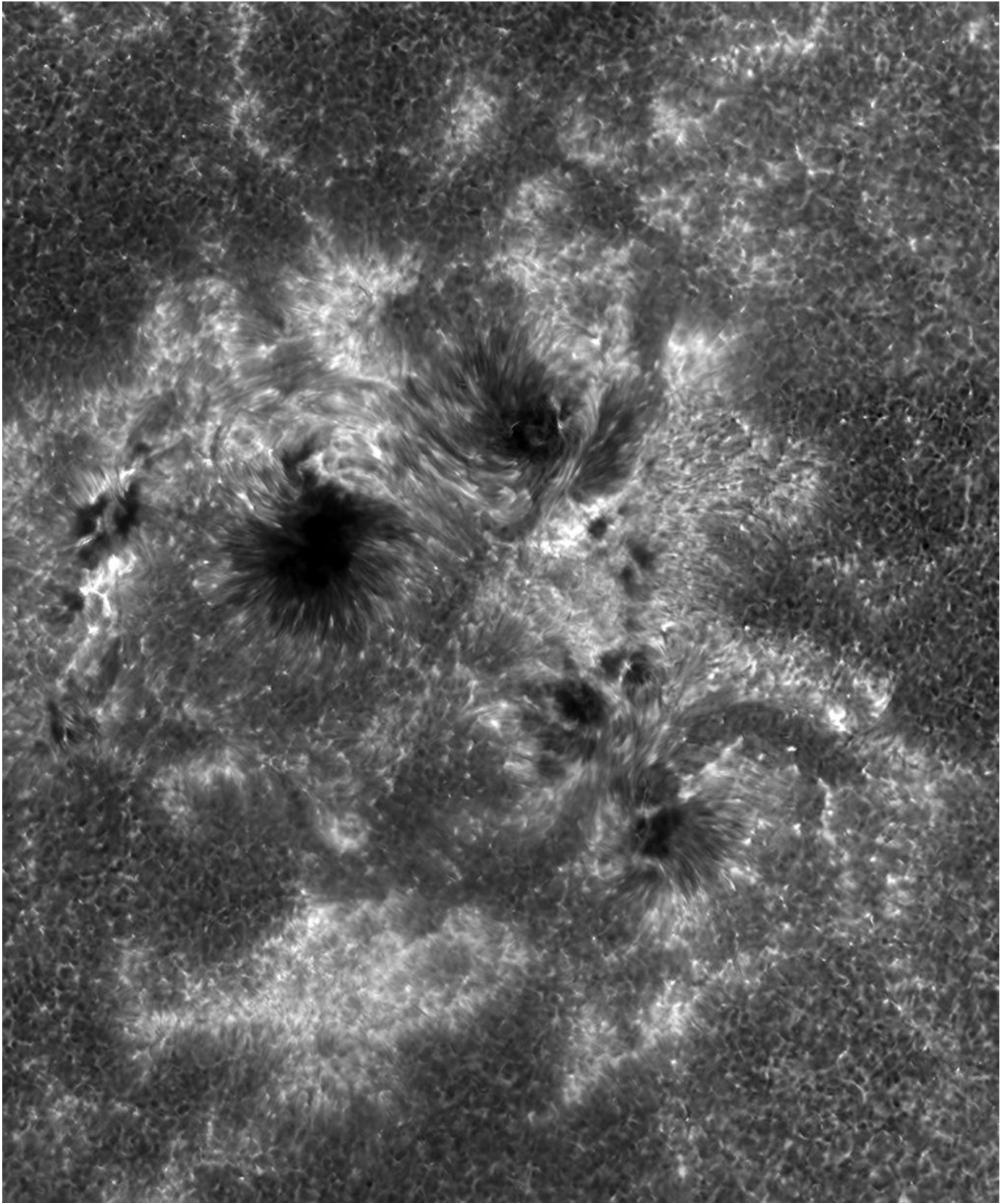


Figure 3b. Ca II H line 396.85nm, filter width 0.135nm. Same solar area as G-band in figure 3a at exactly same moment. The Ca II H line is formed a few hundred kilometers above the solar "surface" as seen in white light and G-band. This is the low chromosphere at height of about 400km, precise height depends on the degree of activity. This line is due to once-ionized calcium and is one of the two strongest in the visible-light part of the solar spectrum. The other is its companion, the Ca II K line at 393.37nm. They are wide adjacent absorption lines in the violet part of the spectrum. At this height, the magnetic regions, where large numbers of magnetic elements cluster together, known as "plages", are very bright. The dark areas contain "reversed granulation" with a partial contrast reversal of the granulation seen in the corresponding G-band image in figure 3a. Some isolated small bright features in the dark areas are due to shocks in the solar atmosphere, made by low-frequency sound waves that travel upward and steepen into shocks where the gas density decreases at larger height. See also ref. 3.

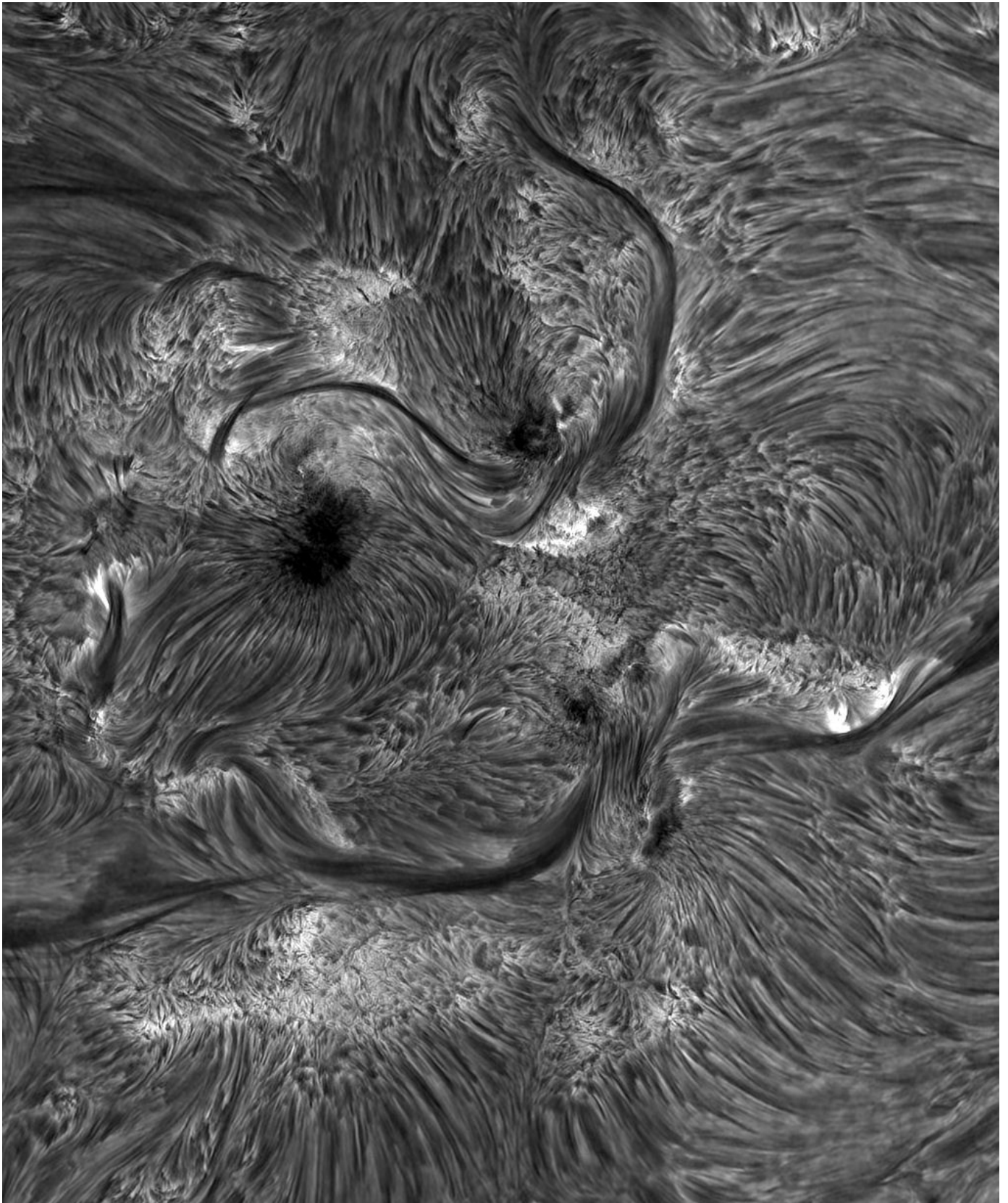


Figure 3c. H-alpha line 656.28nm, filter width 0.025nm. Same solar area as G-band and Ca II H in figures 3a and 3b at exactly same moment. Hydrogen H is about 80% of the solar gas and the H-alpha line is formed in the high chromosphere about 2000km above the solar "surface", again precise height depends on the degree of activity. The sunspot center parts, the umbrae remain dark in Halpha. Many so-called fibrils emanate away from the sunspots. They outline magnetic connections between different areas, like iron filings around a bar magnet show the magnetic field structure. The many fibrils show how complex solar magnetism is arranged within the solar atmosphere. The whitish areas surrounding the sunspots are plage, where large numbers of magnetic elements cluster together. The long slender dark structures are active region filaments. They end in bipolar regions where both positive and negative magnetic fields emerge through the solar surface. More including instrument see ref. 4. Movie based on the images of figures 3a to 3c see ref. 6.

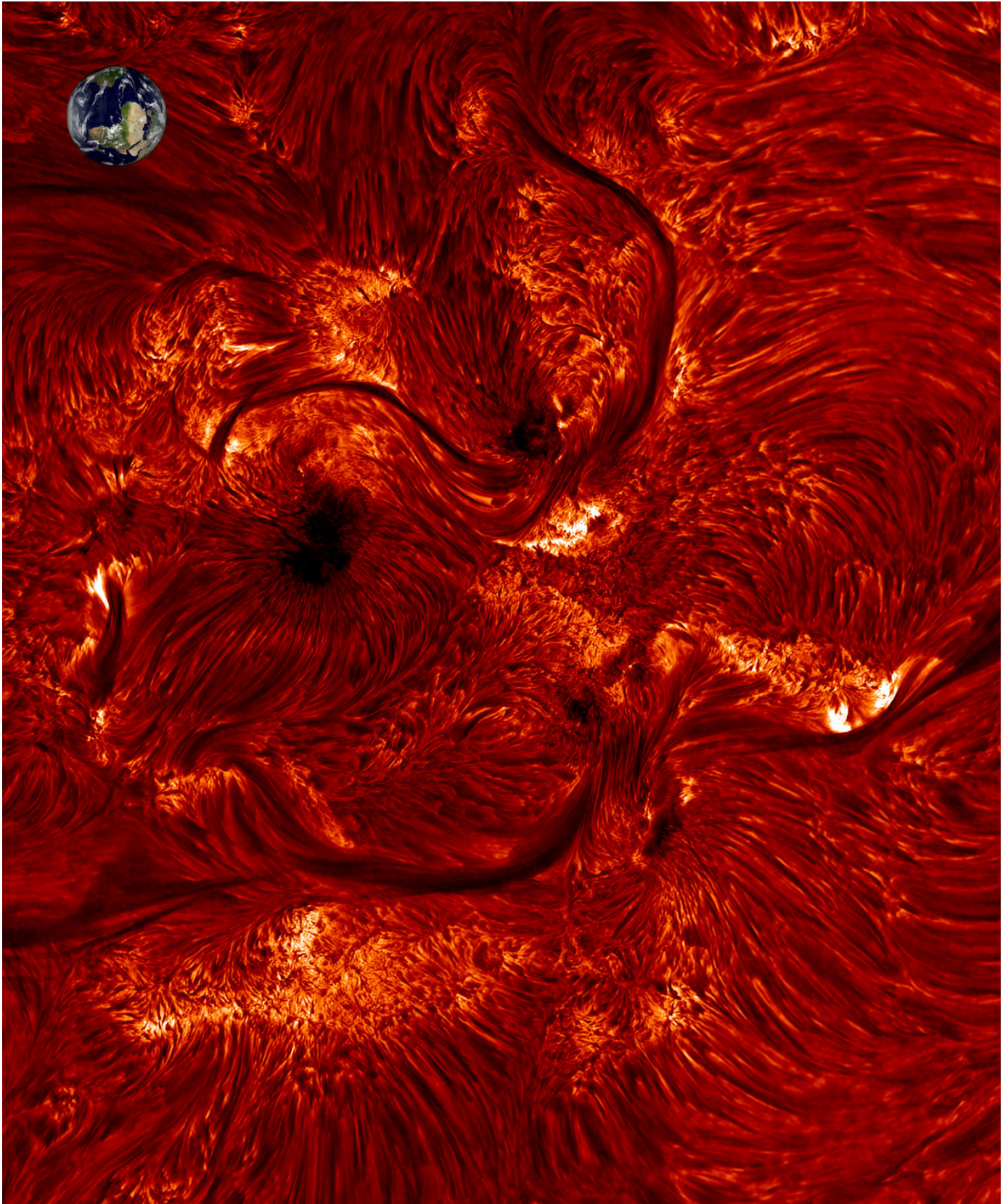


Figure 3d. H-alpha line 656.28nm, filter width 0.025nm of figure 3c with added colouring for more noticeable visibility of the structures. The inserted Earth photograph indicates the scale. The whole sun has a diameter of 109 times the earth.

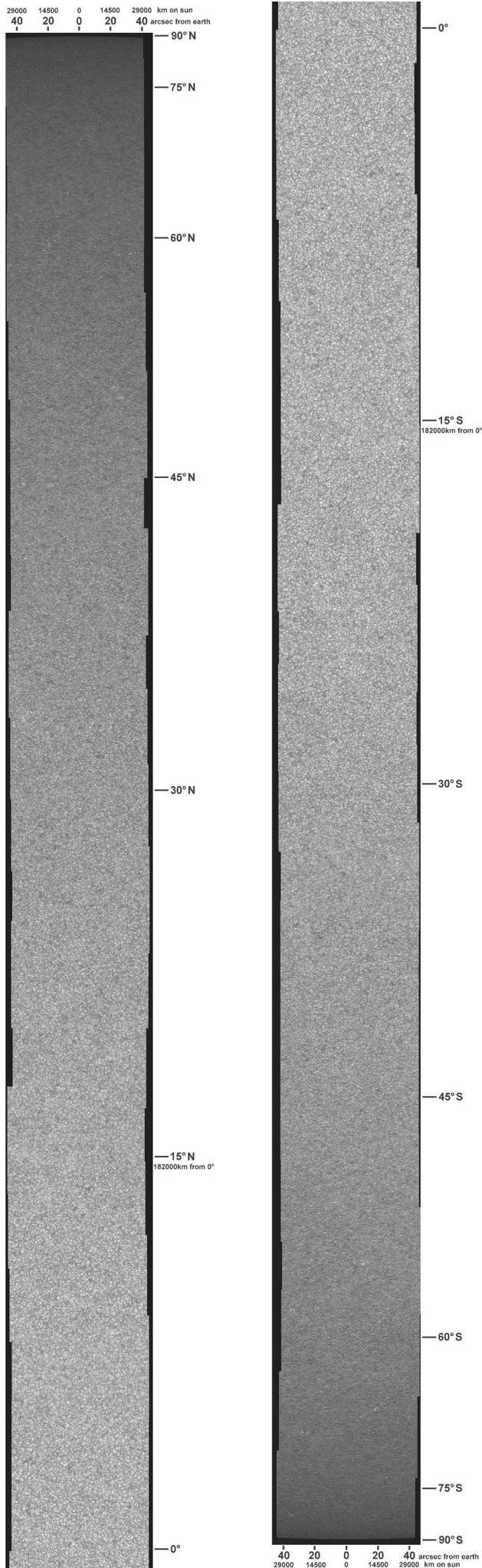


Figure 4. Mosaic strip over the whole sun from the North Pole region over the equator to the South Pole region. The strip is shown in two parts.
 Left: From North Pole region till equator near 0°.
 Right: From equator till South Pole region.
 The Bright Points are seen, when the image is strongly enlarged.

Details of the strip in images with more resolution are in the following 9 figures 4a till 4j with after each other:

- North Pole region 90°N to 60°N (Figure 4a)
- 45°N region (Figure 4b)
- 30°N region (Figure 4c)
- 15°N region (Figure 4d)
- Equator region around 0°N (Figure 4e)
- 15°S region (Figure 4f)
- 30°S region (Figure 4g)
- 45°S region (Figure 4h)
- South Pole region 60°S to 90°S (Figure 4i)

The Polar Regions at high latitude near 90° are at the dark rim of the solar image, Figure 4a the North Pole Region and Figure 4i the South Pole Region.

The parts directly near the rim are shown in Figure 4j with adapted brightness to show better the details possible because of telescope cameras with higher brightness depth than visible on screens.

Small bright structures, the Bright Points, are present over the whole sun.

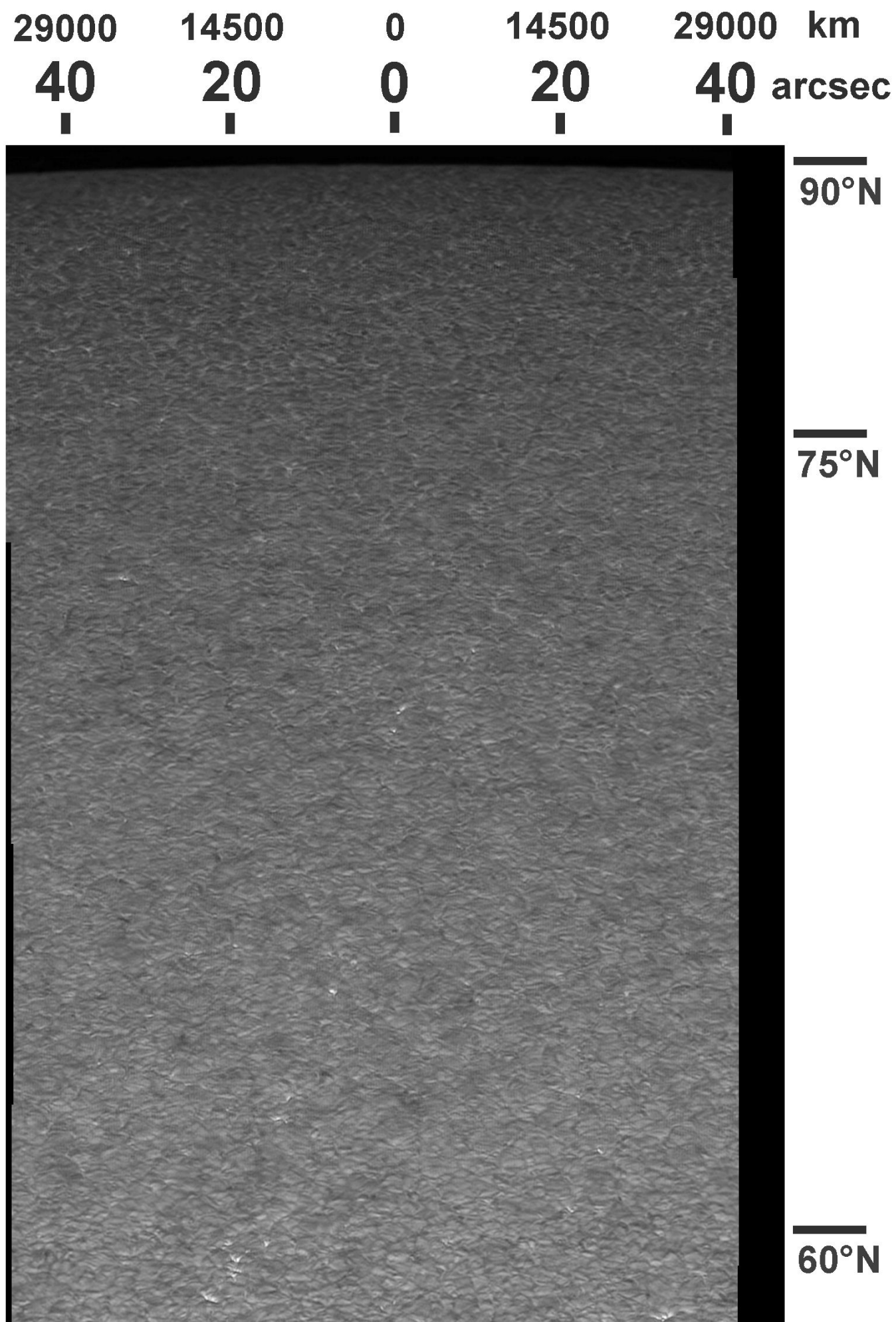


Figure 4a. North Pole region 90°N to 60°N of the strip over the whole sun from the North to South Pole regions.

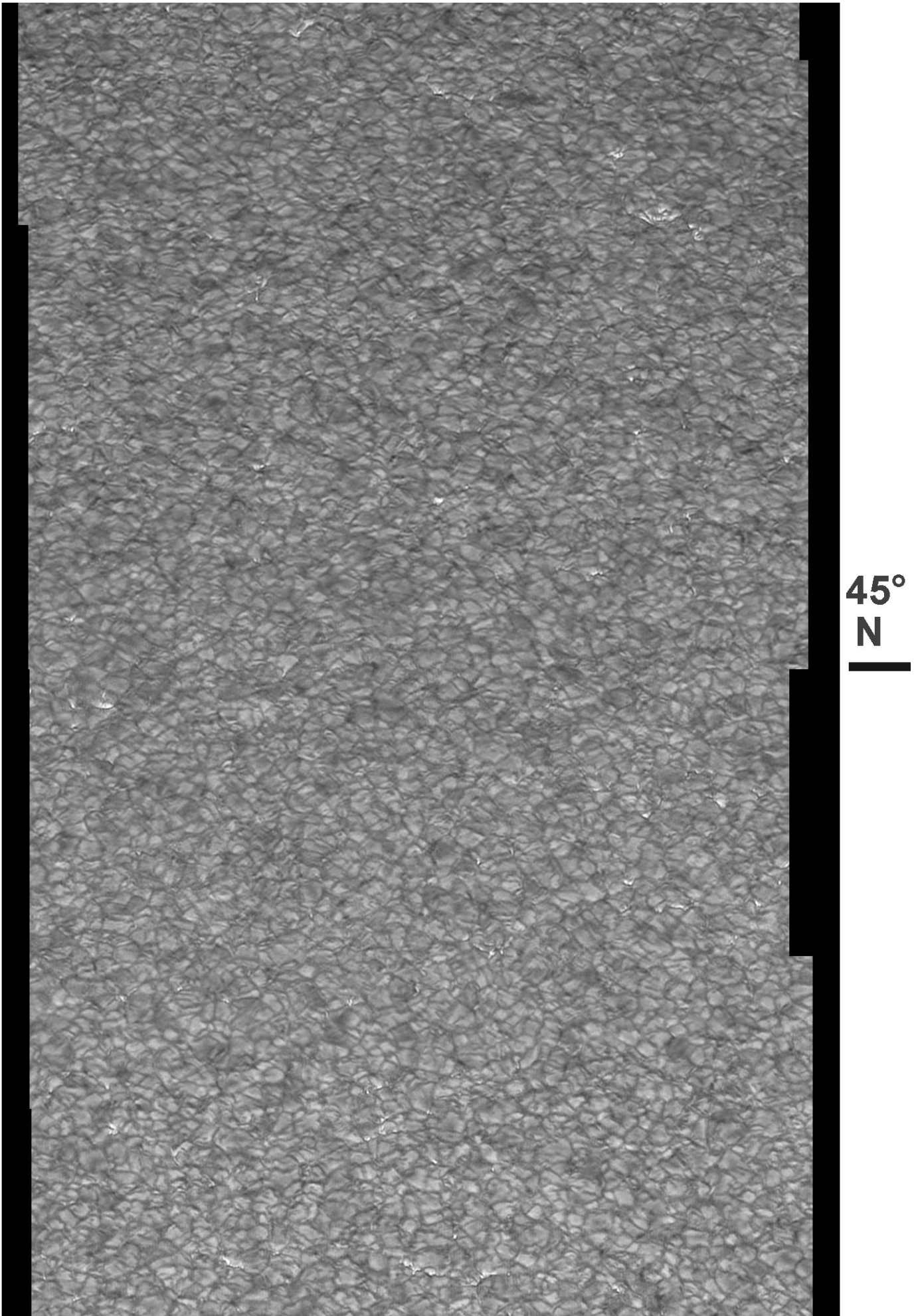


Figure 4b. Region around 45°N of the strip over the whole sun from the North to South Pole regions.

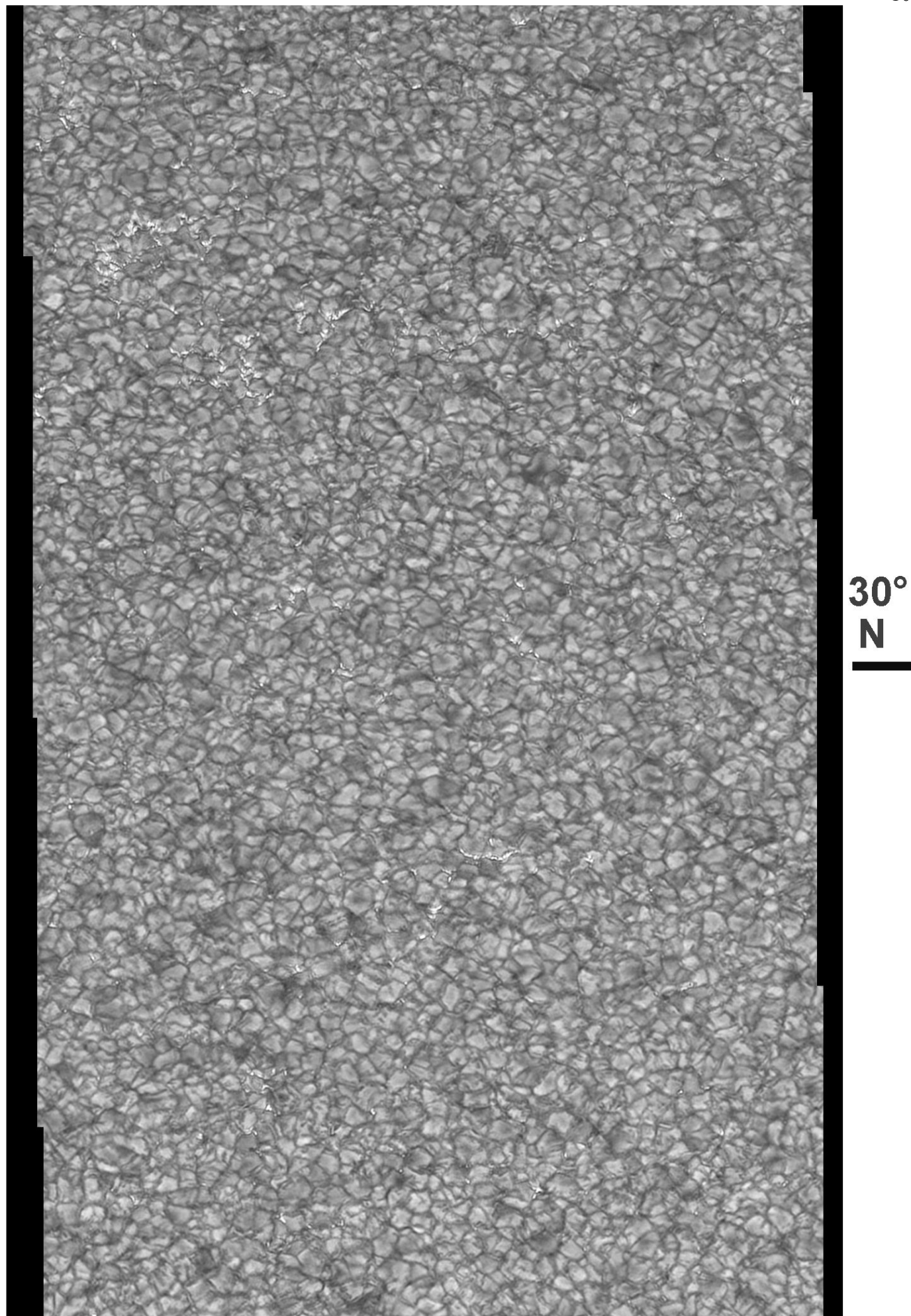


Figure 4c. Region around 30°N of the strip over the whole sun from the North to South Pole regions.

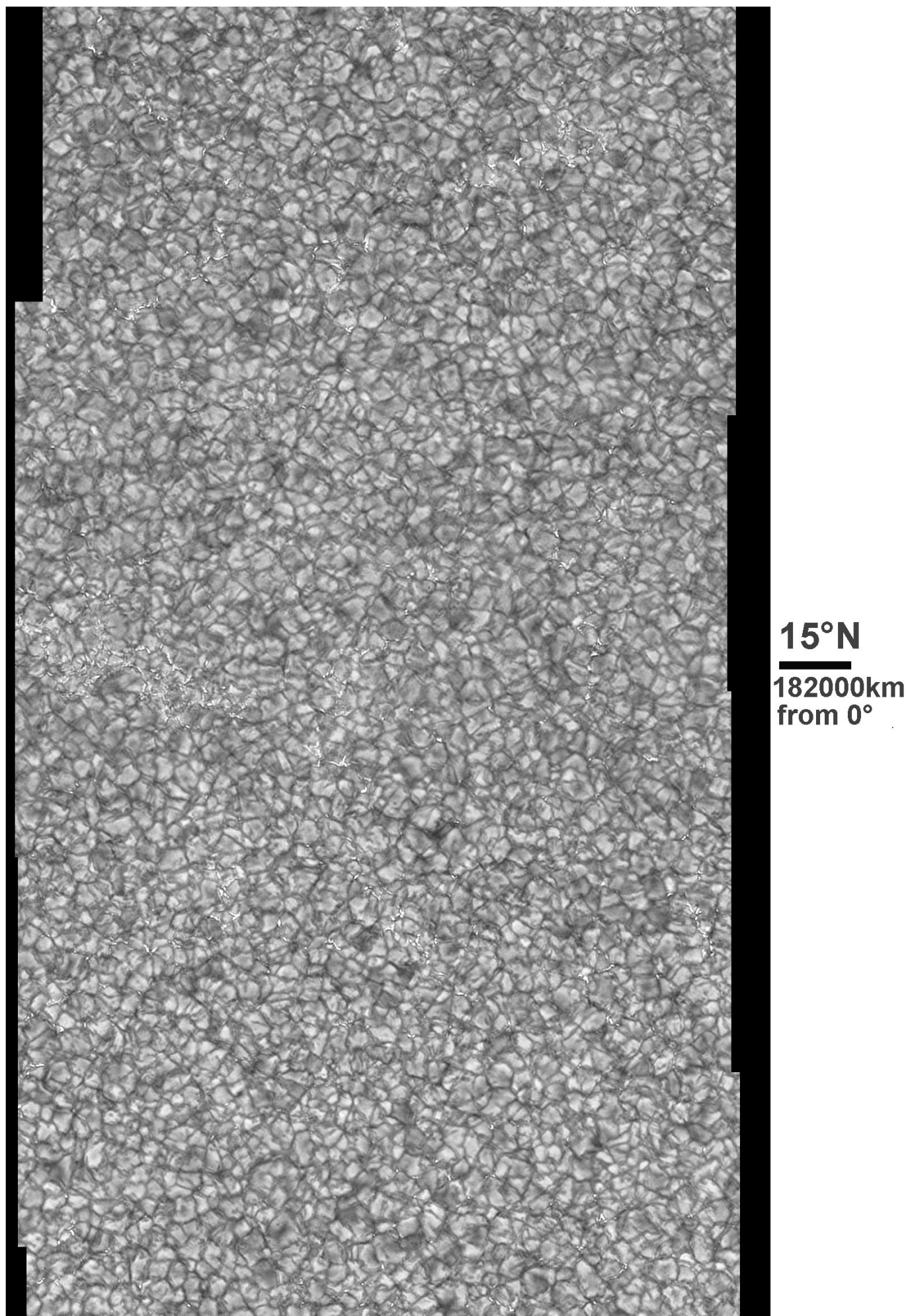


Figure 4d. Region around 15°N of the strip over the whole sun from the North to South Pole regions.

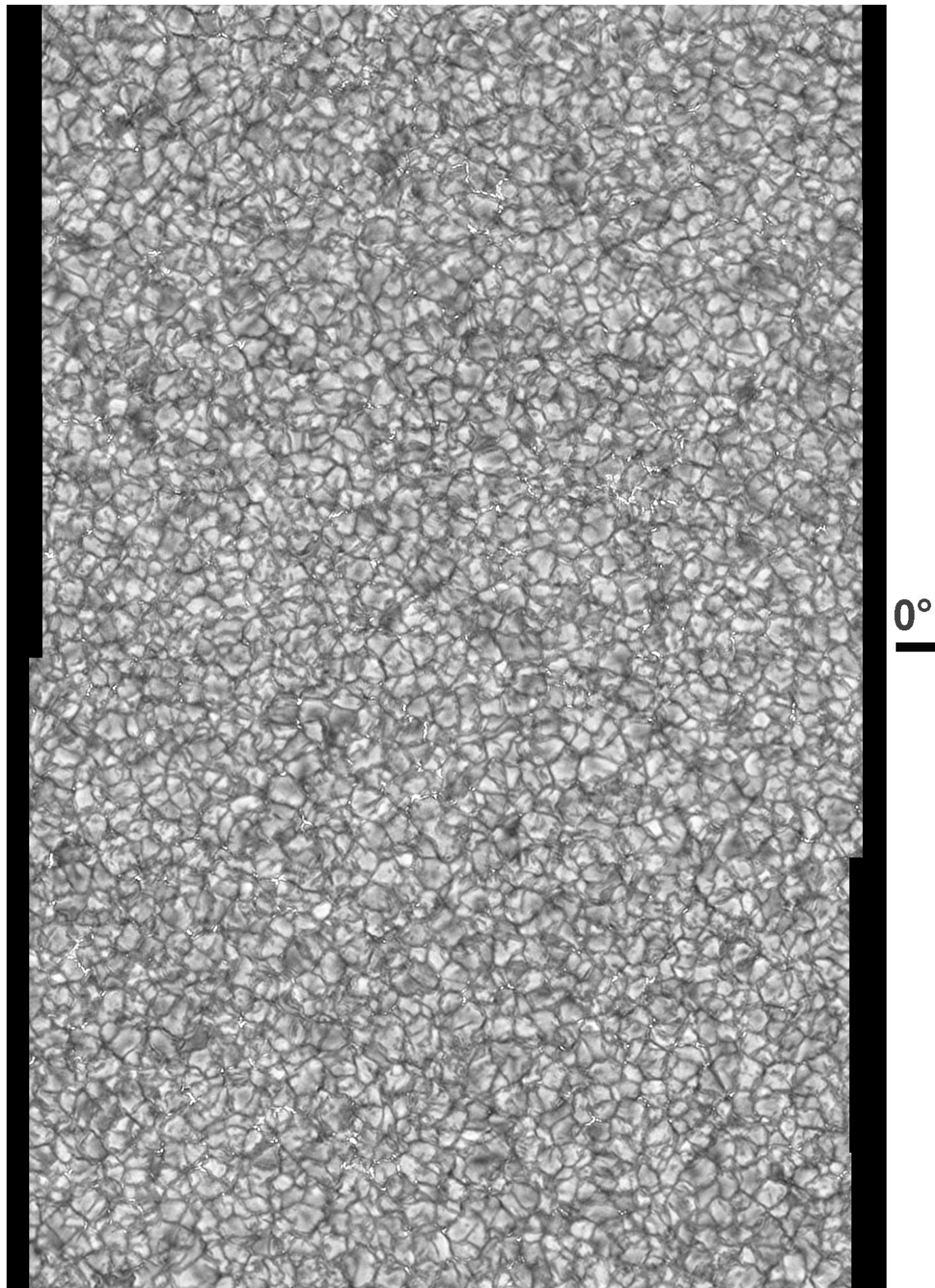


Figure 4e. Equator region around 0° of the strip over the whole sun from the North to South Pole regions.

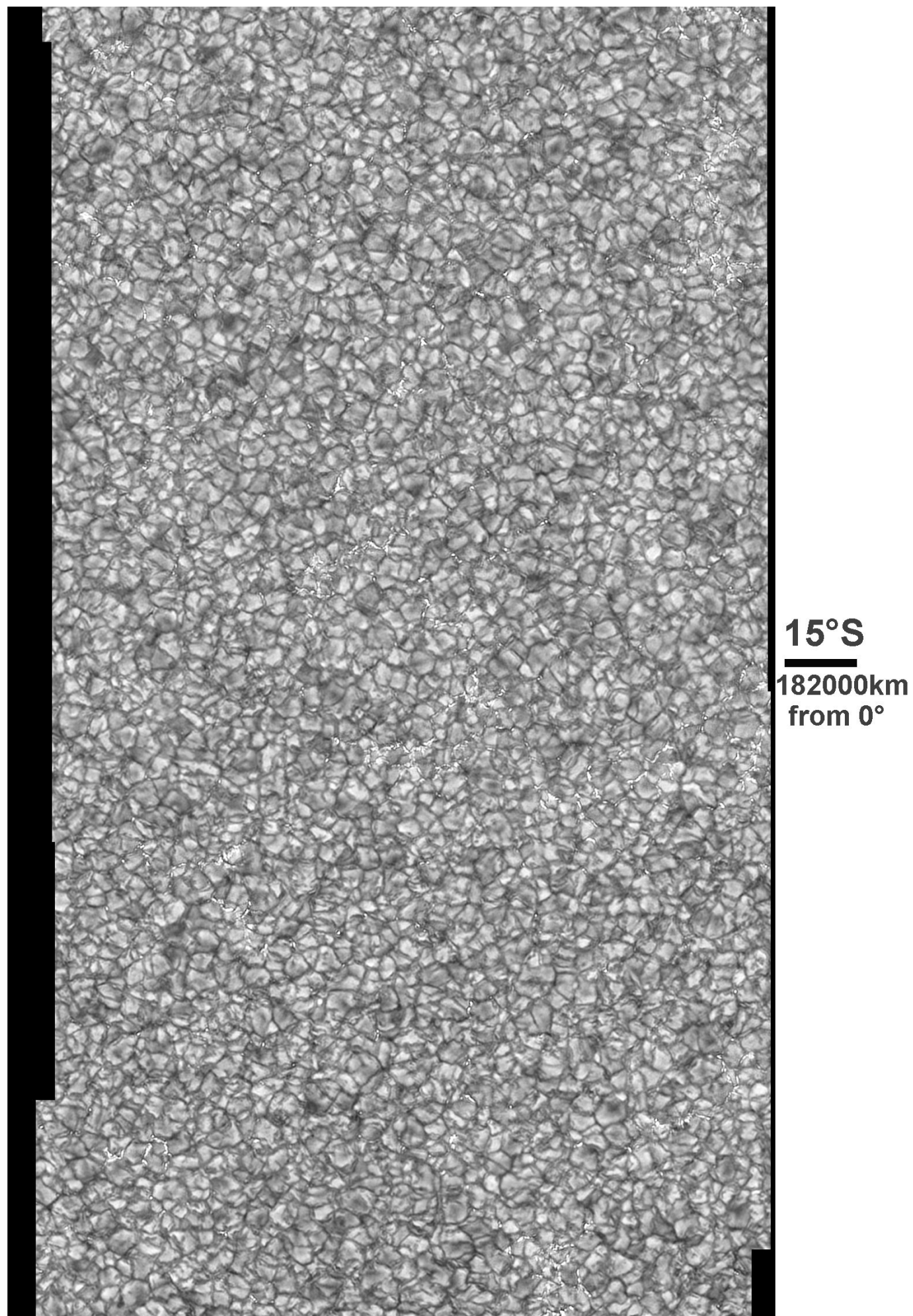


Figure 4f. Region around 15°S of the strip over the whole sun from the North to South Pole regions.

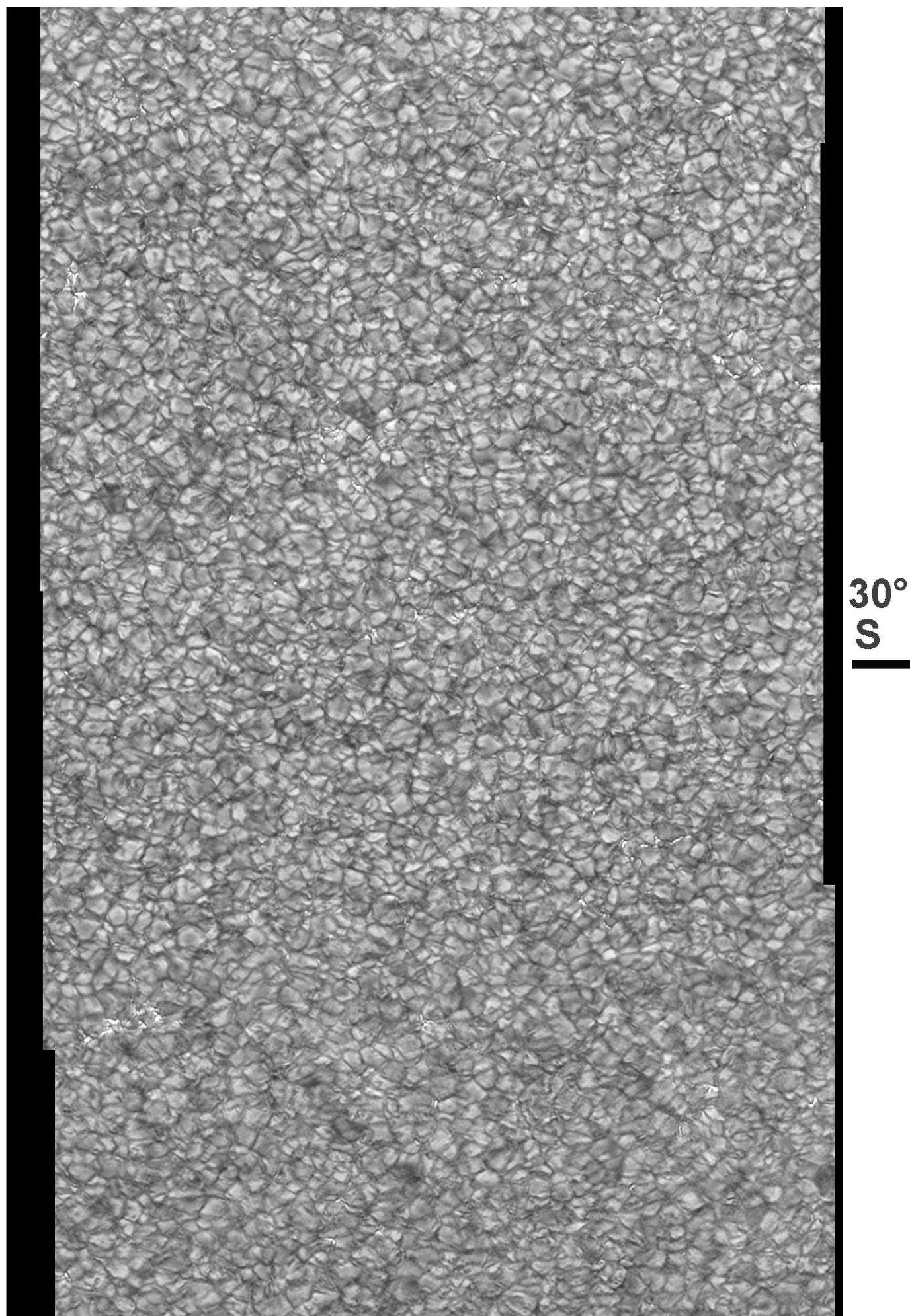


Figure 4g. Region around 30°S of the strip over the whole sun from the North to South Pole regions.

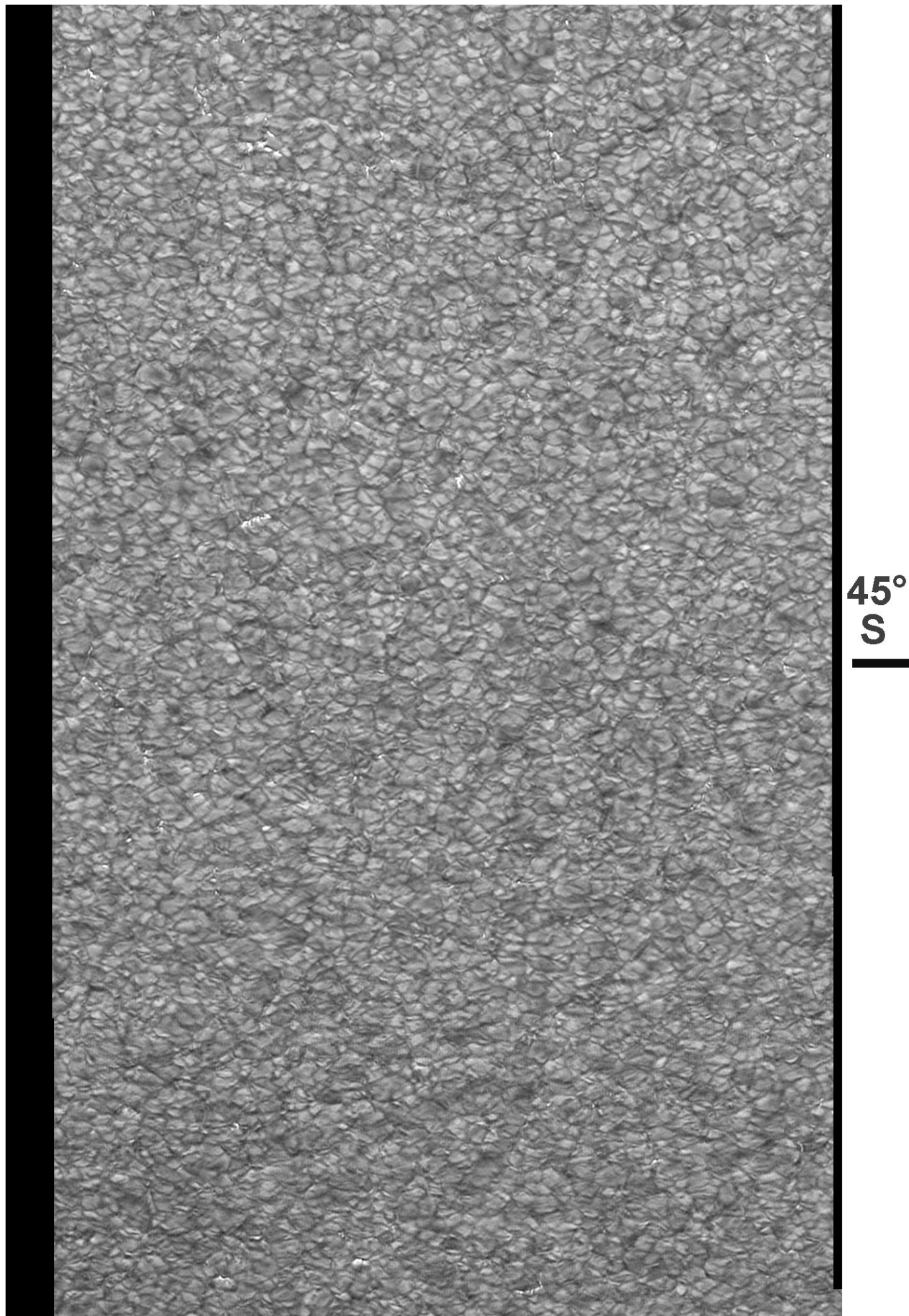


Figure 4h. Region around 45°S of the strip over the whole sun from the North to South Pole regions.

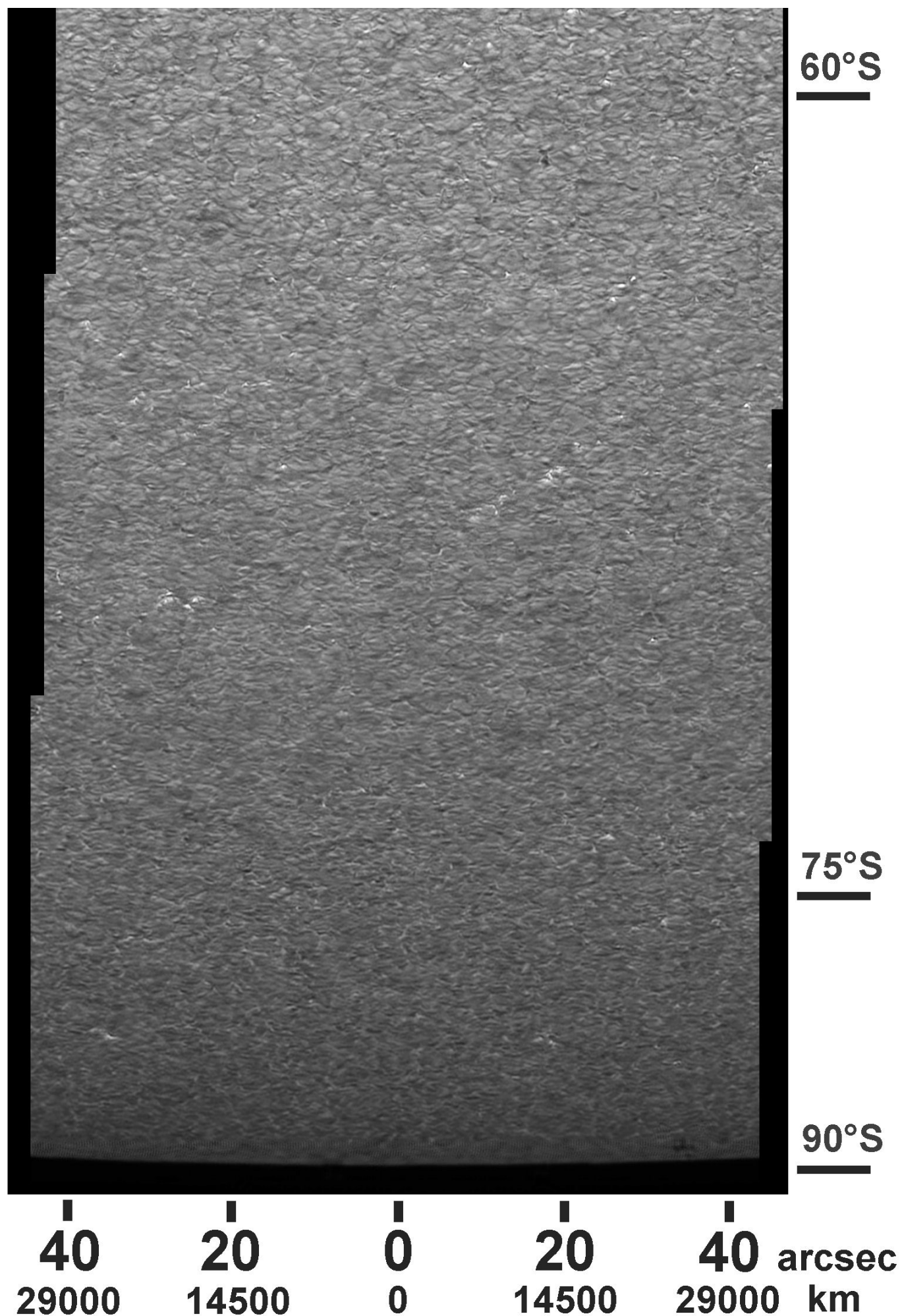


Figure 4i. South Pole region 60°S to 90°S of the strip over the whole sun from the North to South Pole regions.

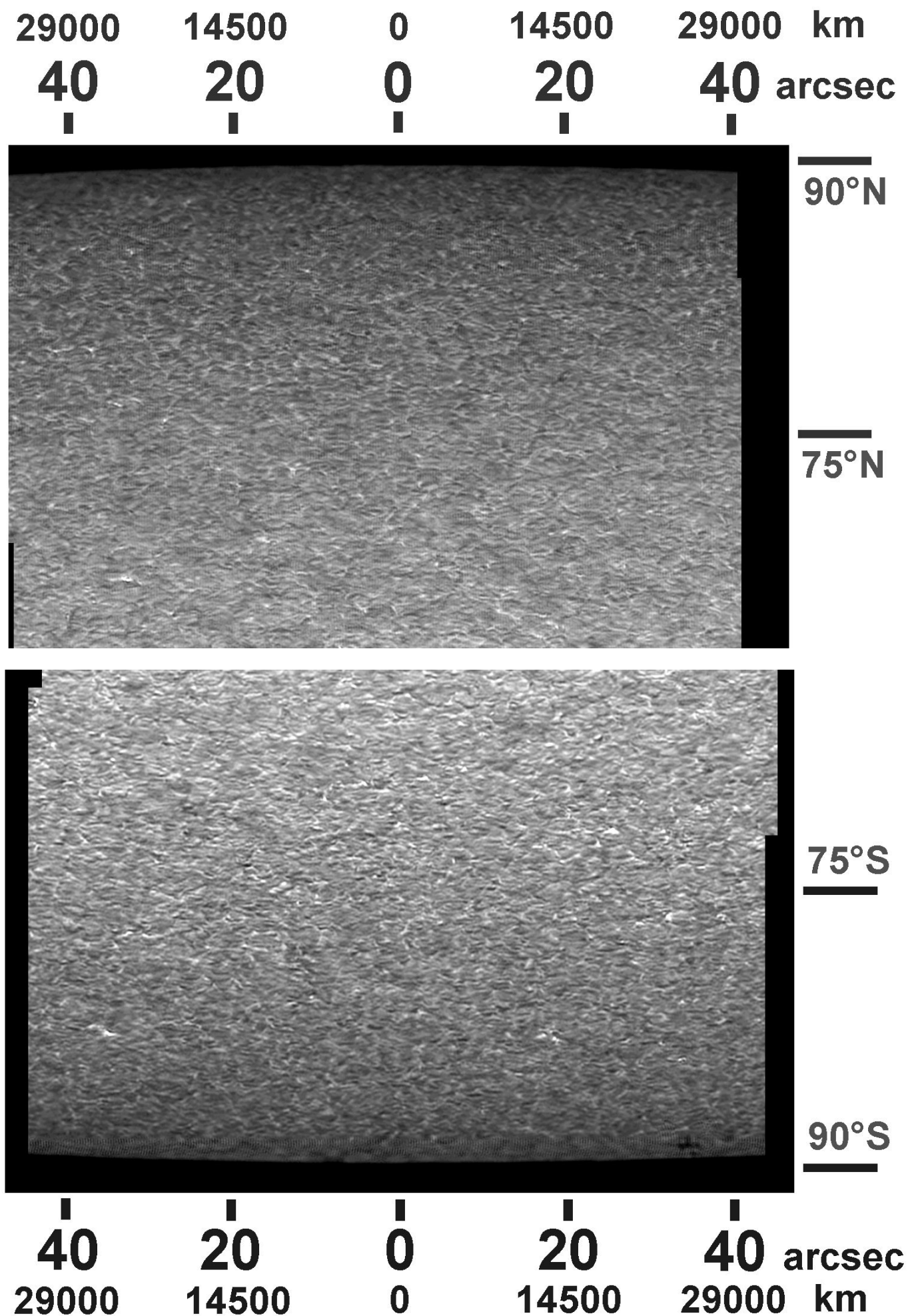


Figure 4j. Polar Regions at the rim of the solar image with adapted brightness for the darker rim to show the details, possible because the telescope cameras have more bits in brightness depth than visible on screens.

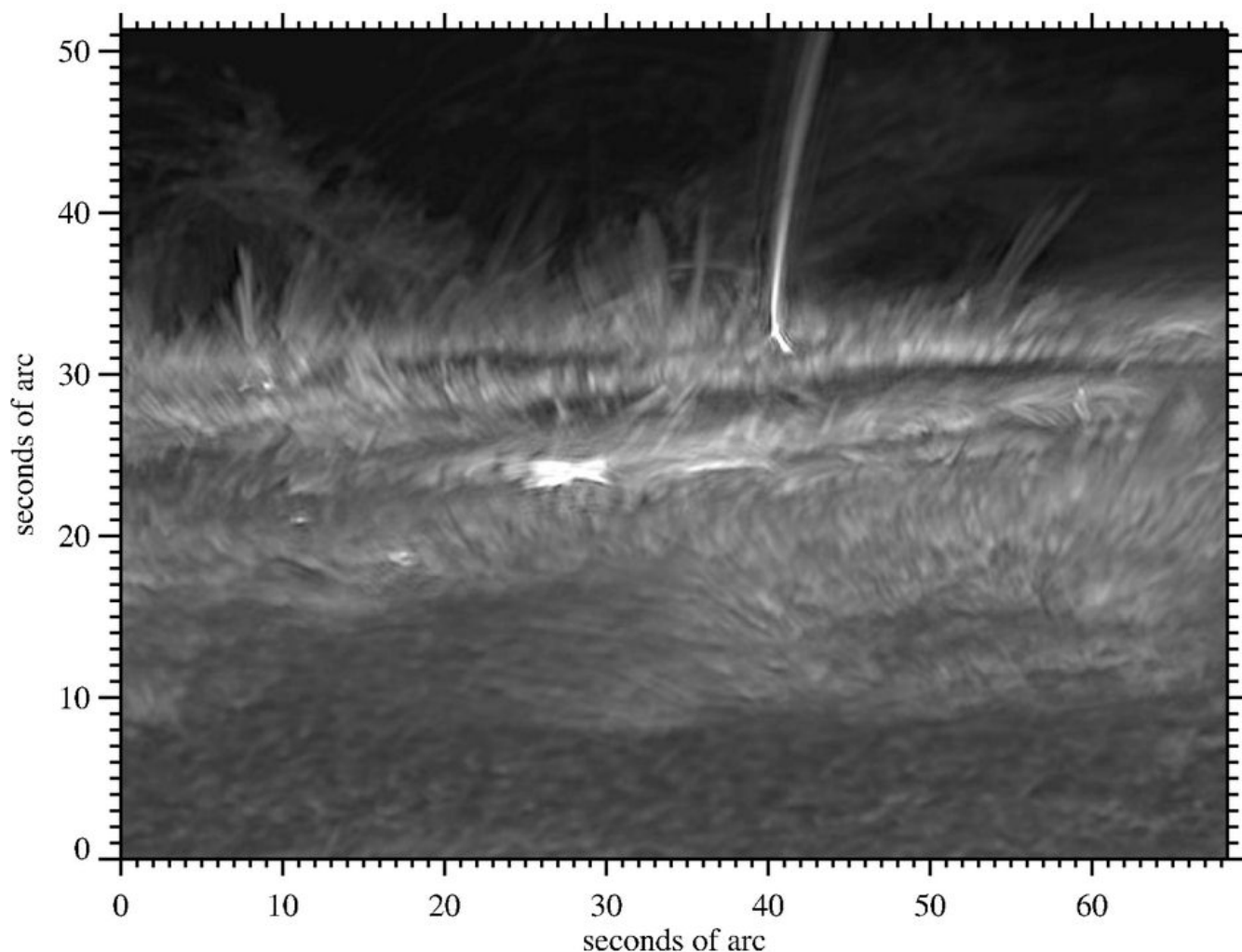


Figure 5. Image of the solar rim in Ca II H line at the short violet wavelength of 396.8nm, which is difficult concerning seeing. The outgoing gas streams at the rim, the fine fibrils in the chromosphere, and the bright solar surface are visible simultaneously because of the low stray light of the DOT. The sunspots appear as flat dark pancakes amidst the bushes of chromospheric fibrils. The large upward gas stream is called a surge, which was visible during a few hours. It may have resulted from magnetic reconnection. More in ref. 5 and how to see movies in ref.6.

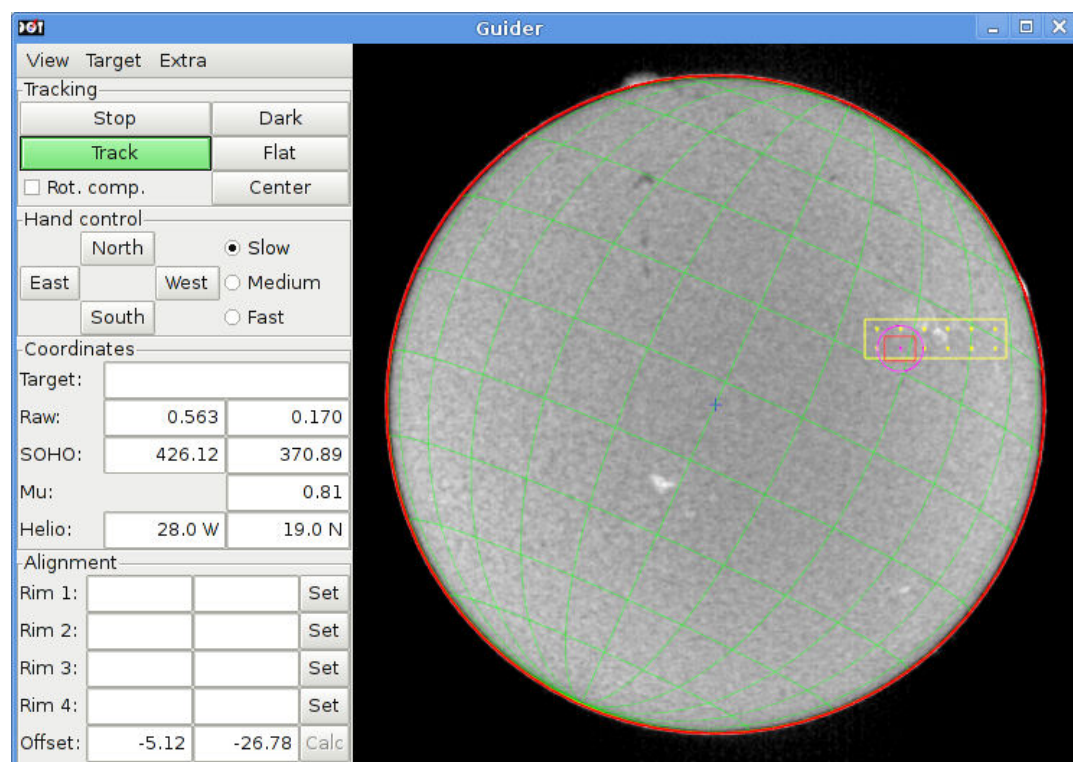


Figure 6. Guider-telescope image of the whole sun with a mosaic field of 6 by 2 fields taken during the second sub-field observation. The array of bright points indicates the subfield centres, which the guiding PC calculates after the observer has drawn with the mouse the desired field, the yellow rectangle. The red ring at the rim is absent before the start of observations with active guiding. The details at the rim, like prominences, are well visible and the solar image is shown on full screen with the full resolution of the guider for choose of field.

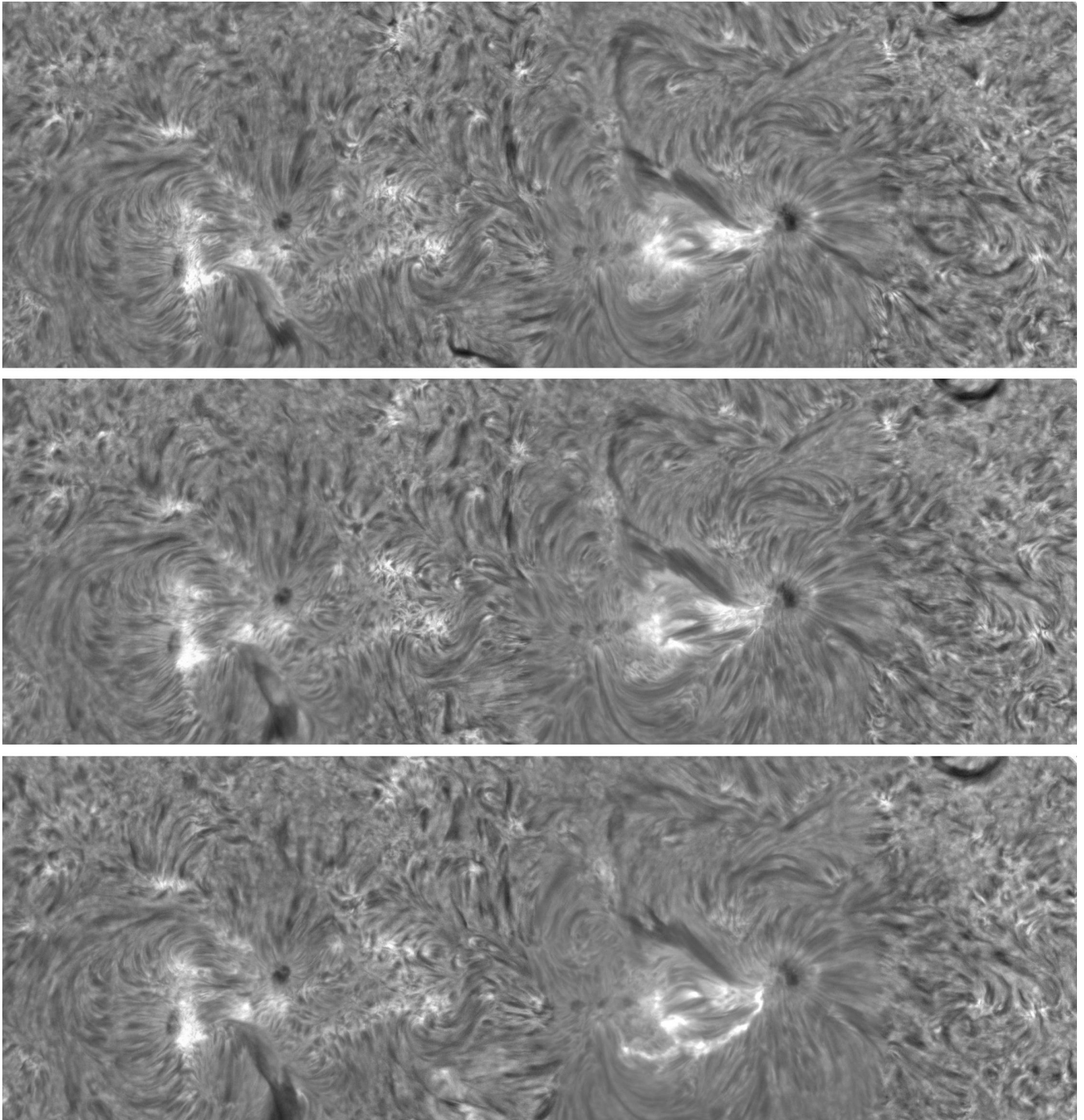


Figure 7. Three images from mosaic movie over 5.5 hours with area of 2x6 camera fields as indicated in Figure 6 of the telescope guider image showing the whole sun. The size of the area is 480x165 arc-sec. The shown images are in the H-alpha line centre at 656.3nm. A solar flare occurred 4.7 hours after the start of the observations. The upper two images are short time before the flare: 13.2 and 6.6 minutes. The bottom image is at the moment of the flare. A new active region is on the left side, an old one at the right side with magnetic boundary in between, see more explanation in Figure 8. New magnetic flux is welling up with high velocities in the new active region visible by the rapid change of the fibrils along the magnetic field, see explanation in Figure 3c. The interactions of the new and pre-existing magnetic fields can produce flares by de-stabilization of filaments, which are longer-lived bows of moving gas along the magnetic fields, see in Figures 3c and 8 with explanations. The new bright structure seen only in the bottom image is a solar flare, first indication in its early stage in the middle image. The flare is from the old spot in the old active region in the direction of the new active region to the left side. The contrast of the structure in the field around the flare is seemingly lower in the bottom mosaic than in the two previous ones. This is because the program to represent the mosaic on the screen has an automatic contrast adaption to be able to clearly show the full range of intensities in the image especially during a solar flare. More information including how the mosaic movies are made in ref. 7.

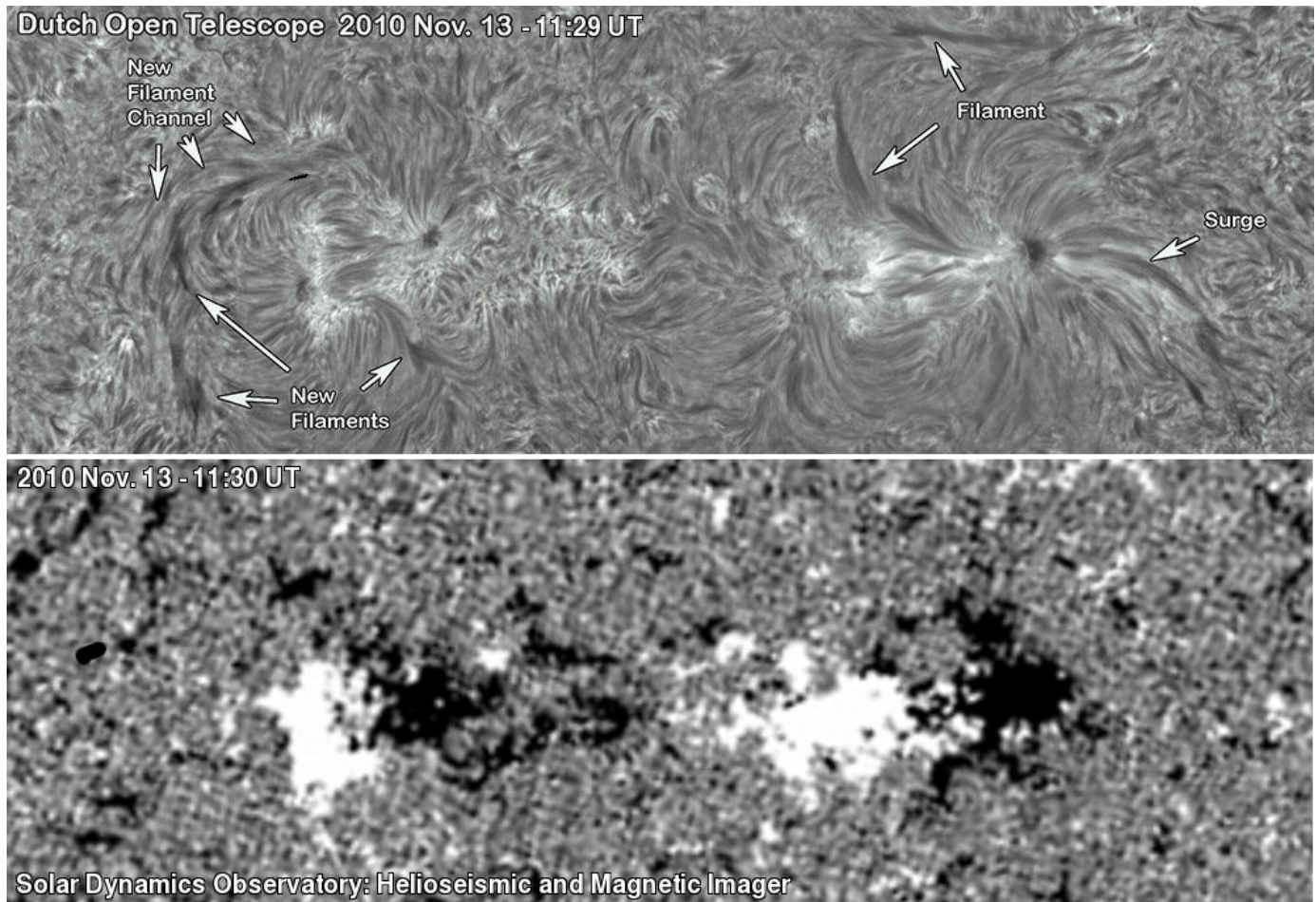


Figure 8. *Top:* Mosaic of 6x2 images in the H-alpha line center from the same mosaic movie over 5.5 hours as in the previous Figure 7. This mosaic was taken 0.2 hours shortly after the start of the mosaic sequences of images and 4.5 hours before the solar flare shown in Figure 7. Movies are an important asset for correct identifications of all of these dynamic solar features which change at different rates. The main subjects are two “active regions”, one left of center, and the other right of center. Each active region consists of bright areas called “plage”. Within these brightened areas are sunspots which are the compact, nearly-round, dark areas. Everywhere around the plage and sunspots are elongated, thread-like structures known as “fibrils” which are organized in patterns around the plage and sunspots because they follow the direction of the local magnetic field, see Figure 3c with 3.6 times larger scale on the sun with explanation. Figure 5 shows the fibrils imaged at the rim of the sun. The organized fibril patterns enable the identification of the boundaries of the active regions which are often also marked by dark “filaments”, see also Figure 3c. Mosaic movies were taken of these two regions to study the formation and evolution of filaments that develop in and around the active regions. The filaments are designated by arrows with the exception of the arrow furthest to the right side of the image which points to a short-lived feature called a “surge”. In a single image, a narrow “surge” of mass along the local magnetic field can appear similar to a filament, but a surge is a temporary ejection of mass lasting minutes till a few hours, see Figure 5 showing a surge seen at the rim of the sun. On the other hand, filaments are longer-lived dynamic structures that develop specifically at boundaries where the local magnetic field has a sharp reversal from positive to negative polarity.

Bottom: Magnetogram of same region at same time with SDO (Solar Dynamics Observatory) in space. The polarity changes are visible near the solar surface from where the magnetic structures originate. The same polarity is in and nearby around a spot. A sharp polarity boundary is between the two spots in the new active region on the left side of the mosaic. A less sharp boundary is between the new active region and the old one near the middle of the mosaic.

Noticeably the DOT mosaic has a higher resolution: pixel size 0.1 arc-sec at DOT, 0.5 arc-sec at SDO. A magnetograph on the DOT would give magnetic information near the solar surface in the same resolution as the magnetic structures in the high chromosphere by the H-alpha images. The construction of a magnetograph based on polarimetry in the Ba II line of 455.4nm is started on the DOT. Magnetic field observations in high resolution in the higher photosphere can be added when the construction is finished. See also ref. 8.