IMAGING THE SUN

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Telescope Operation Disclaimer: *NEVER attempt to view the Sun through any optical instrument that has not been properly fitted with SAFE solar observing appliances. NEVER stare at the Sun with your unaided eyes, unless looking through a known and tested solar filter intended for such use*.

Sunlight & the eye (ICNIRP Guidelines[1])

The light from the Sun contains radiation energy across the whole electromagnetic spectrum. It generally radiates as a Black Body with energy peaking around 500 nm. Due to the absorption/ reflection by the Earth's atmosphere the energy levels vary across the whole spectrum.

The human eye is sensitive to solar radiation from 380 nm to about 780 nm. The maximum daylight sensitivity (photopic vision) occurs at 555 nm (in the green part of the sun's spectrum). As we age, our sensitivity to shorter wavelengths decreases, and in the adult population less than 1% of radiation below 340 nm and 2% of radiation between 340 and 360 nm reaches the retina.

Energy in the UV-A[2], can cause damage to the eye (as well as the skin). Likewise IR-A radiation can cause thermal injury to the eye. Normal visible light, if bright enough, can cause partial loss of sensitivity and temporary blindness.

Damage to the eye is more likely to occur due to exposure to UV-A, and bright visual light, rather than IR. There is a human "self-defence" reaction which generally makes involuntary eye movement when the eye is exposed to extremely bright light (eye movement, squinting, closing the eye) which reduces the effect of the energy, and gives some protection (Figure 1).

Solar filters

The safest way to observe the sun is the projection method. A refractor or (Newton) reflector is adequate for solar projection. Do not use compound (catadioptric) telescopes (*e.g.* Schmidt-Cassegrain, Maksutov)[3].

The Sun can only be observed visually when specially designed filters are used. The majority of these filters use a thin layer of chromium alloy or aluminium deposited in their surfaces[4]. A solar filter should transmit less than 0.003 % of visible light and no more than 0.5% of near-infrared radiation (Figure 2).

Special solar glasses (Eclipse glasses) can be used when a large sunspot appear on the solar disk. Welder's glass (#14) is also suitable for "naked-eye" observation of sunspots.

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[1] http://www.icnirp.org/
[2] The light between 100 nm and 400 nm is commonly called Ultraviolet (UV), [UV-C, 100-289 nm; UV-B, 280-315 nm; UV-A, 315-380 nm), red light beyond 780nm is called Infrared (IR). [IR-A, 780-1400 nm; IR-B, 1400-3000 nm; IR-C, 3000 nm – 1 mm]
[3] Heat damage to internal components have to be considered.
[4] *e.g.* Baader ASTROSOLAR TM filter, https://astrosolar.com/en/information/about-astrosolar-solar-film/astrosolar-technical-info/

Unsafe filters include exposed and developed colour film, exposed and developed black & white film, film negatives, smoked glass, sunglasses (single or multiple pairs), photographic density filters and polarizing filters, CDs and aluminized food wrappers. Solar eyepiece filters are also unsafe[5].

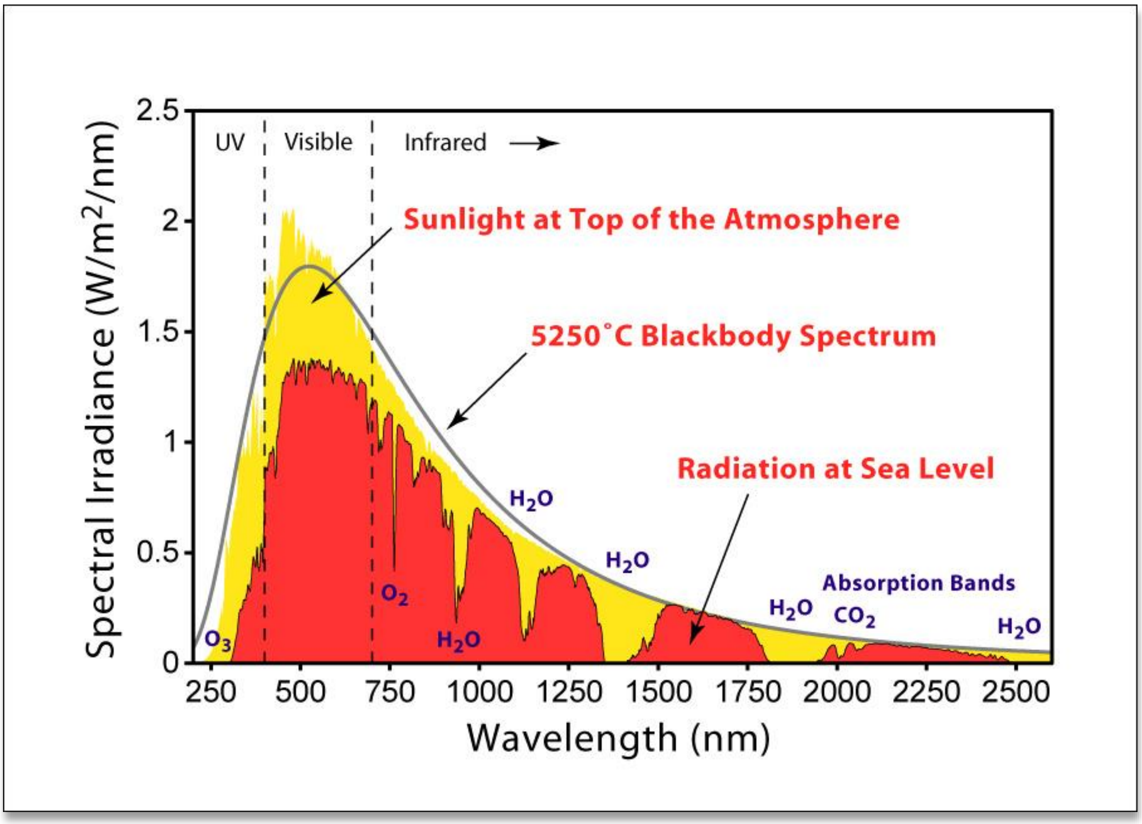

Figure 1- Sunlight before and after its passage through the Earth's atmosphere (http://en.wikipedia.org/wiki/File:Solar_Spectrum.png)

Solar telescopes

White Light

Most Telescopes can be adapted for white light solar observing and imaging. Unlike a night-time scope, an instrument for solar observing is not expected to gather a lot of light. When observing the Sun, most of the effort is spent in reducing the amount of light using objective filters (Figure 2) or Solar Herschel Wedges (Figure 3). Solar telescopes are usually 150 mm or less in aperture. A 125 mm aperture telescope has a theoretical resolution of 1 arc second. Smaller telescopes (50 to 100 mm aperture) are suitable for full disk observation and imaging while telescopes of 125 to 250 mm aperture can be used for high-resolution work. The sun as viewed thought objective filters can have a distinct coloration (blue, yellow or white depending on the filter). Solar Herschel Wedges are without any doubt the best way to observe/image the Sun in white light (*Continuum*). These devices absorb about 95% of the incoming sunlight. The remaining 5 % have to be reduced using neutral density filters. Solar Wedges should always be used with a refractor telescope. Other filters can be used to improve the low contrast of white light solar features (*e.g.* Baader Solar *Continuum*, UV/IR, different Wratten filters).

[5] These eyepiece filters usually crack due to excess heat when the telescope is pointed at the Sun.

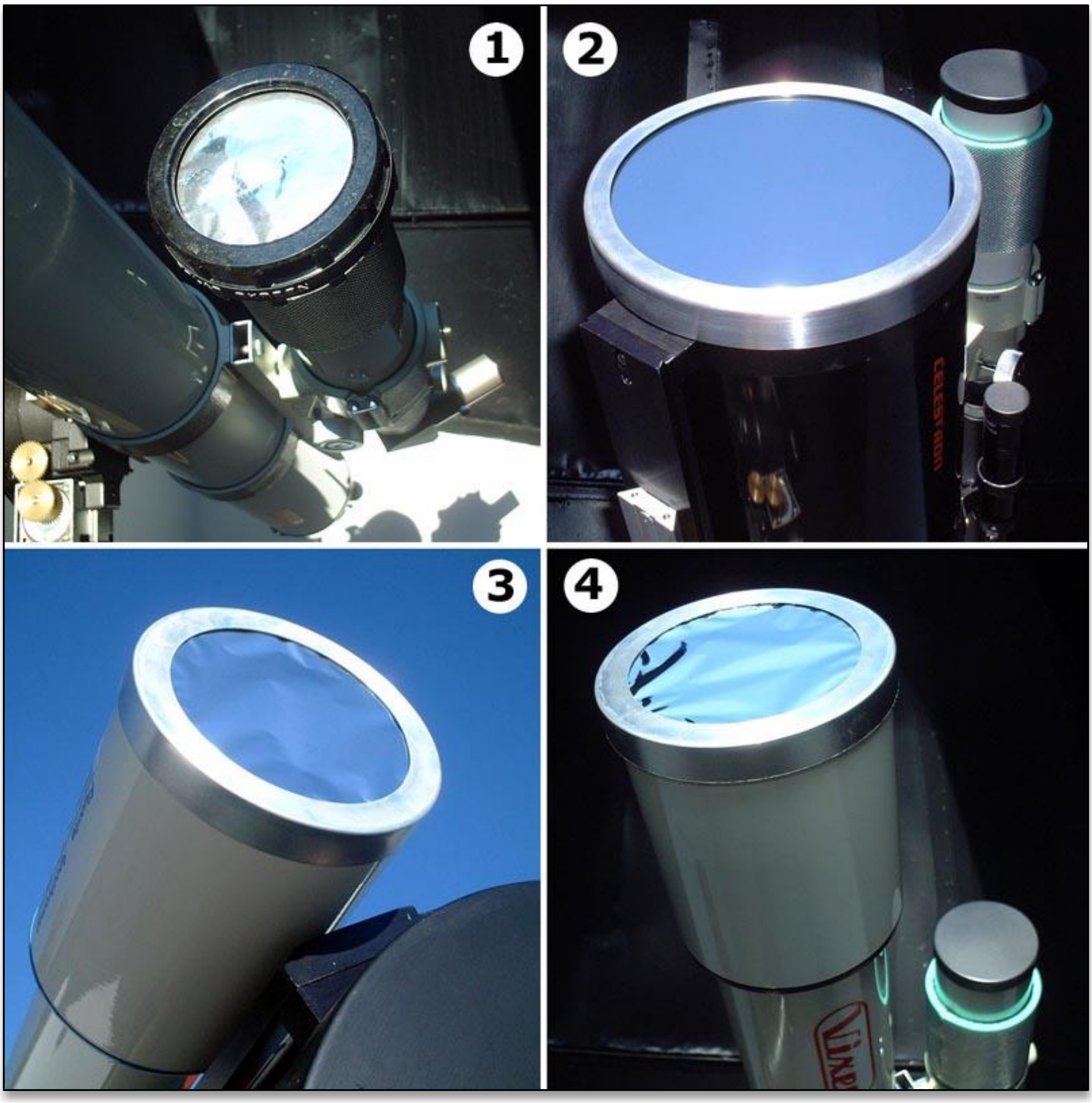

Figure 2 – Solar objective filters: 1- Mylar (Solar screen); 2- Thousand Oaks (glass); 3 & 4- Baader Astrosolar

H-alpha and Ca-K

Narrow band H-alpha (656.3 nm) solar filters are mainly of two types: (i) front loading and (ii) end loading. The front loading filter uses a large diameter etalon (an optical filter that operates by the multiple-beam interference of light, reflected and transmitted by a pair of parallel flat reflecting plates, based on the Fabry-Perot Interferometer) over the entrance of the telescope. The end loading etalon is smaller and it's placed inside the light path of the telescope. Each of these configurations has advantages and disadvantages. The narrower a filter's bandpass or bandwidth (the extent or band of wavelengths transmitted by a filter) the greater is the contrast of the resulting image. In order to observe prominences in H-alpha a filter with a 10-angstroms (1 nm) bandpass is needed. A narrower bandpass filter will show a certain number of features but a sub-angstrom filter is needed to observe all the details on the chromosphere. Filters for Ca-K (396.9 nm and 393.3 nm) observing can also be used with excellent results. Compared to the H-alpha line, the H and K lines are broader and thicker in appearance: a filter having a bandwidth of 2-10 Angstroms is sufficient for Ca-H or Ca-K observations (Figure 4, Figure 5).

Figure 3- Solar Herschel Wedges (APM 1 1/4", 2" LUNT, 2" Baader ceramic)

Solar Imaging

The recent advent of CCD cameras that can be operated in a video mode, taking 10 or more images per second for periods of up to a few minutes, can be used with excellent results for high-resolution imaging of the Sun[6]. Webcams[7] and astronomical digital video cameras are equipped with a color or a black & white CCD or CMOS.

These cameras operated with different interfaces (USB 1.0, UBS 2.0, USB 3.0, FireWire and GigE) capture several hundred to thousands of individual images (frames) in rapid succession storing them in popular video formats[8]. This video file includes frames seriously degraded by seeing and others that are less affected.

Specialized software[9] align, sort and stack hundreds to thousands of images, automatically producing a low noise composite image[10]. These images can be processed using aggressive image processing tools to bring out hidden detail[11] (Figure 6).

Amateur astronomers today regularly capture images of the Sun that rival those taken by professional astronomers. These images often constitute valuable scientific contributions.

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[6] Some high-end video cameras have high-speed data transfer of up to 120/s (USB 3.0, GigE and FireWire interfaces).
[7] The first webcams were mainly used as video conferencing devices.
[8] 8-bit avi files, 12-bit ser files.
[9] Registax - http://www.astronomie.be/registax/, Autostakkert - http://ww.autostakkert.com/, Avistack - http://www.avistack.de/
[10] Images are aligned using hundredths to thousands of reference points. The best resolution images are then staked producing a high signal to noise ratio final composite image.
[11] Usually wavelet-based image restoration algorithms.

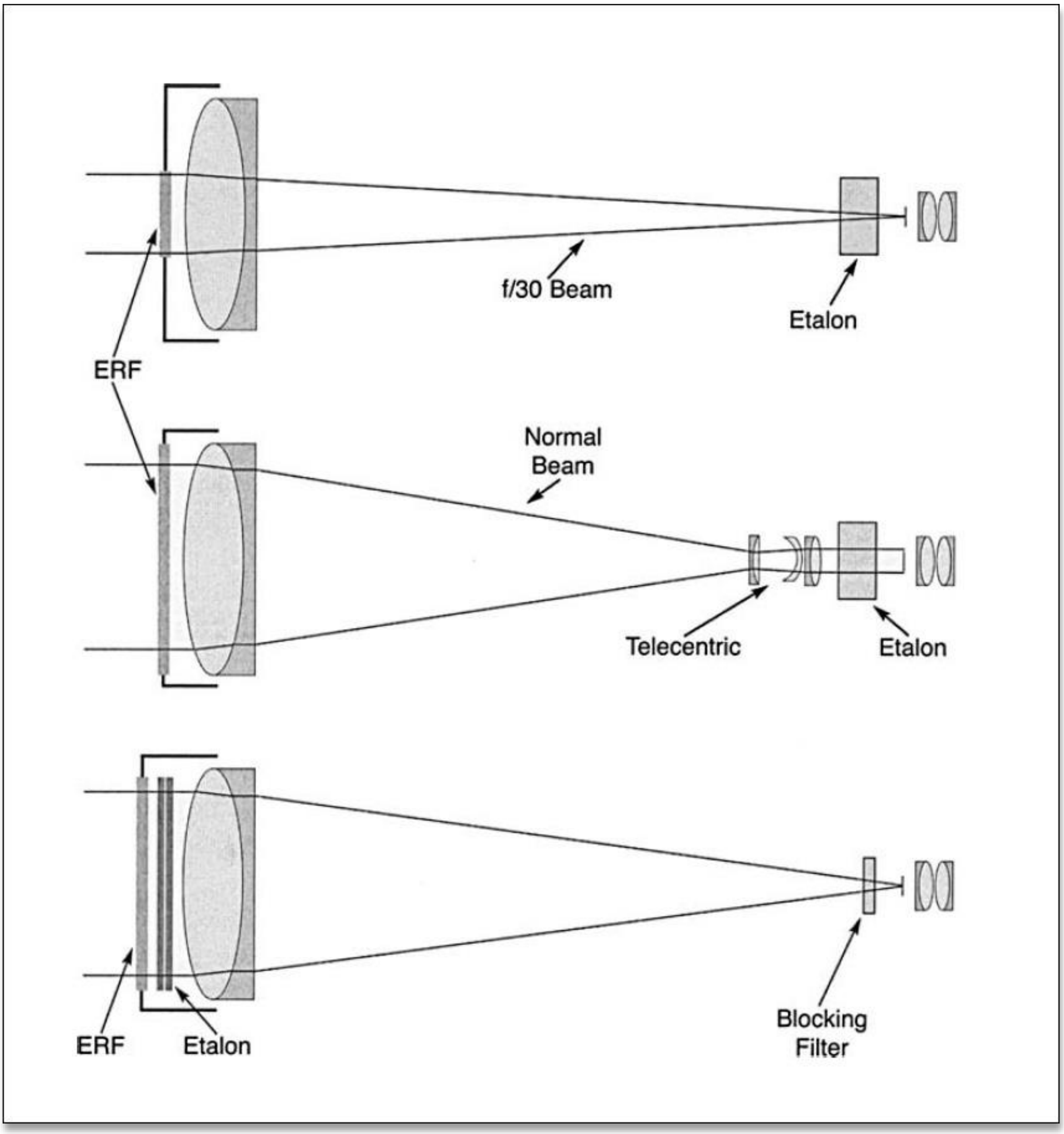

Figure 4- End-loading and front-loading narrow band solar filter telescope configurations. Adapted from Jenkins, J.L. (2009). *The Sun and How to Observe it (Astronomer's Observing Guides).* Springer

Below you will find several image processing tutorials that cover almost all aspects of solar astrophotography: (i) Full Disk imaging; (ii) High-Resolution White Light (*Continuum*) imaging; (iii) High-Resolution H-alpha imaging; (iv) Artificial flat-field.

More information can be found at the following web links:

http://re.apaaweb.com/
http://re.apaaweb.com/image_processing.html
http://re.apaaweb.com/sun_h_alpha.html

Figure 5- Solar telescopes (Pedro Ré, 2015).

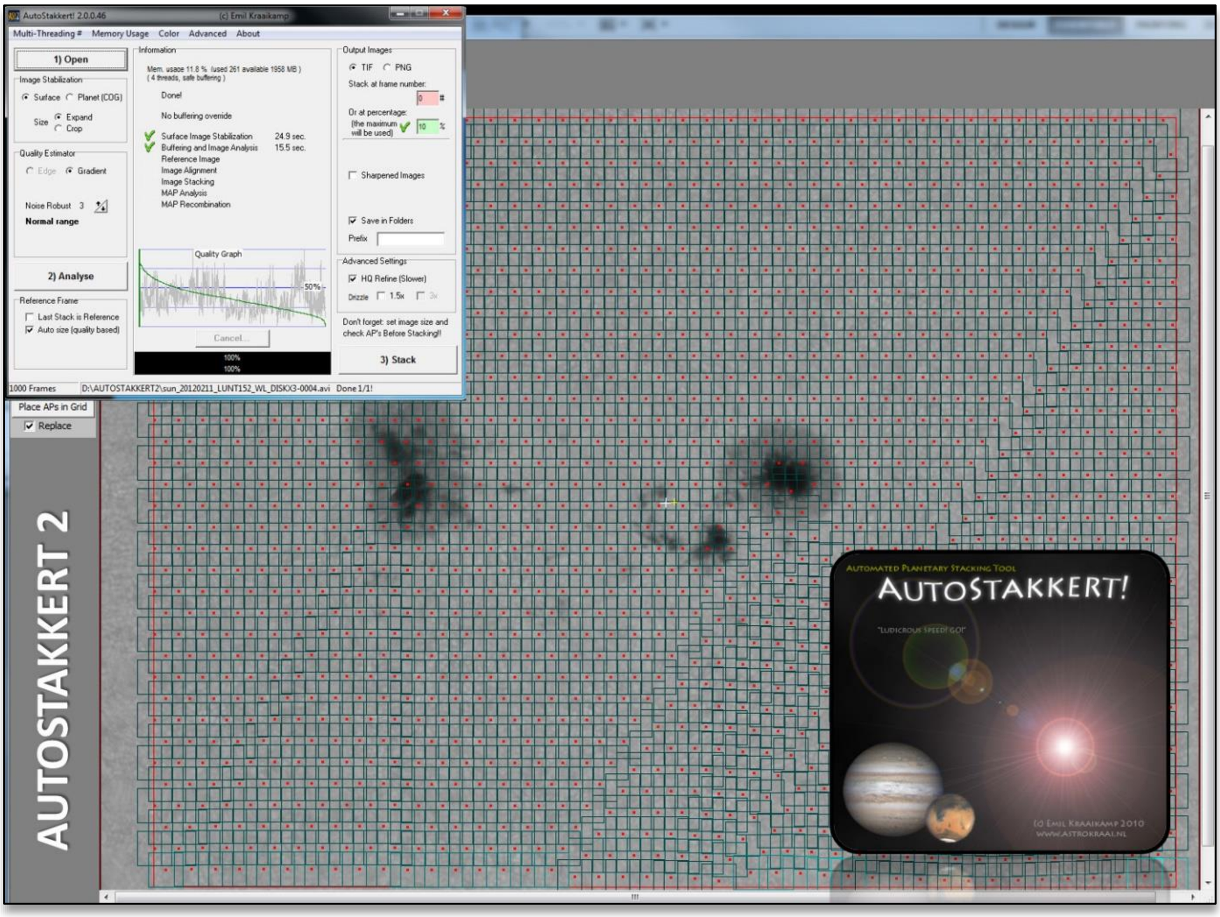

Figure 6- AUTOSTAKKERT 2 (freeware program for grading, aligning, and stacking solar, lunar and planetary images). http://ww.autostakkert.com/

FULL DISK IMAGING (White Light, Ca-K & H-alpha)

1. Acquire Full Disk images
2. Save AVI files (8 bits) or SER files (12 bits)
3. Open AVISTACK http://www.avistack.de/[12]
4. Select AVI or SER files
5. Turn off Update display (Avistack)
6. Choose Batch Processing (several video files can be batch processed)
7. Open REGISTAX http://www.astronomie.be/registax/
8. Open FIT file (aligned and stacked in Avistack or Autostakkert)
9. Process the combined image using wavelet-based image restoration algorithms
10. Reset the Wavelet filter (500 to 1000 center value)
11. Use layer 1, 2 and 3 of Wavelet filter (try several options)
12. Process image (DO ALL button)
13. Save image (16-bit TIFF file)
14. Open Microsoft ICE http://research.microsoft.com/en-us/um/redmond/groups/ivm/ice/ (MOSAIC)
15. Compose the Mosaic (drop individual images into Microsoft ICE)
16. Crop and save 16-bit TIF file (Microsoft ICE)
17. Process TIFF file in PHOTOSHOP
18. Use Curves to adjust contrast and brightness if necessary
19. Use Shadow/Highlights (Photoshop)
20. Use Smart Sharpen if necessary (Photoshop)
21. Use False Colour Mapping (Photoshop)
22. Save the final 16-bit TIF file (no compression)
23. Convert to 8-bit and save JPG file (no compression)

HIGH-RESOLUTION WHITE LIGHT (*CONTINUUM*) IMAGING

1. Acquire High-Resolution WL images (50 to 100 gamma DMK cameras)
2. Save AVI files (8 bits) or SER files (12 bits)
3. Open AVISTACK http://www.avistack.de/ or AUTOSTAKKERT http://ww.autostakkert.com/
4. Select AVI or SER files
5. Turn off Update display (Avistack)
6. Choose Batch processing
7. Open REGISTAX http://www.astronomie.be/registax/
8. Open FIT file (aligned and stacked in Avisatck or Autostakkert)
9. Process the stacked image using Wavelet-based image restoration algorithms
10. Reset the Wavelet filter (500 to 1000 center value) Wavelet Tab (Figure 7)
11. Use layer 1, 2 and 3 of Wavelet filter - Gaussian (try several options) Wavelet-based image restoration (Figure 8)
12. Process image (DO ALL button) (Figure 9)
13. Save image (16-bit TIFF file) Save TIFF 16-bit
14. Process TIFF file in PHOTOSHOP
15. Use Smart Sharpen (Figure 10)
16. Use Curves to adjust contrast and brightness (Figure 11)
17. Use False Colour Mapping (Figure 12)
18. Save the final 16-bit TIF file (no compression)

[12] Autostakkert can also be used to align, sort and stack individual frames http://ww.autostakkert.com/

19. Convert to 8-bit and save JPG file (no compression)

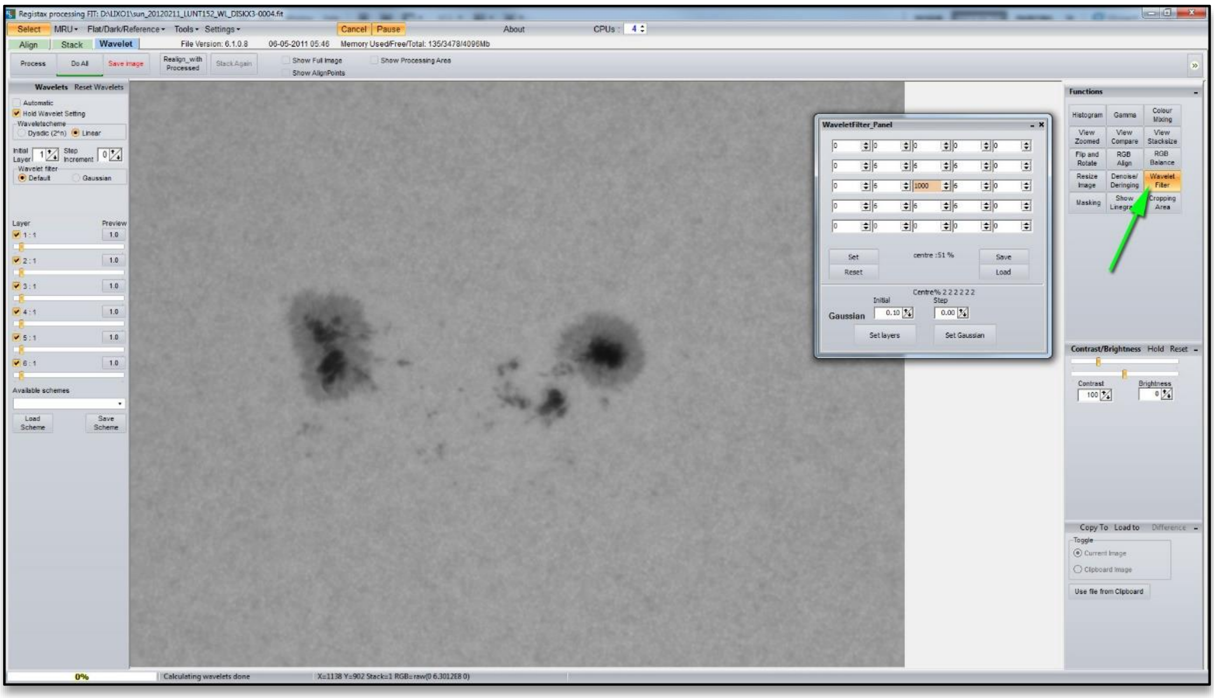

Figure 7- REGISTAX: Reset the Wavelet filter (500 to 1000 centre value)

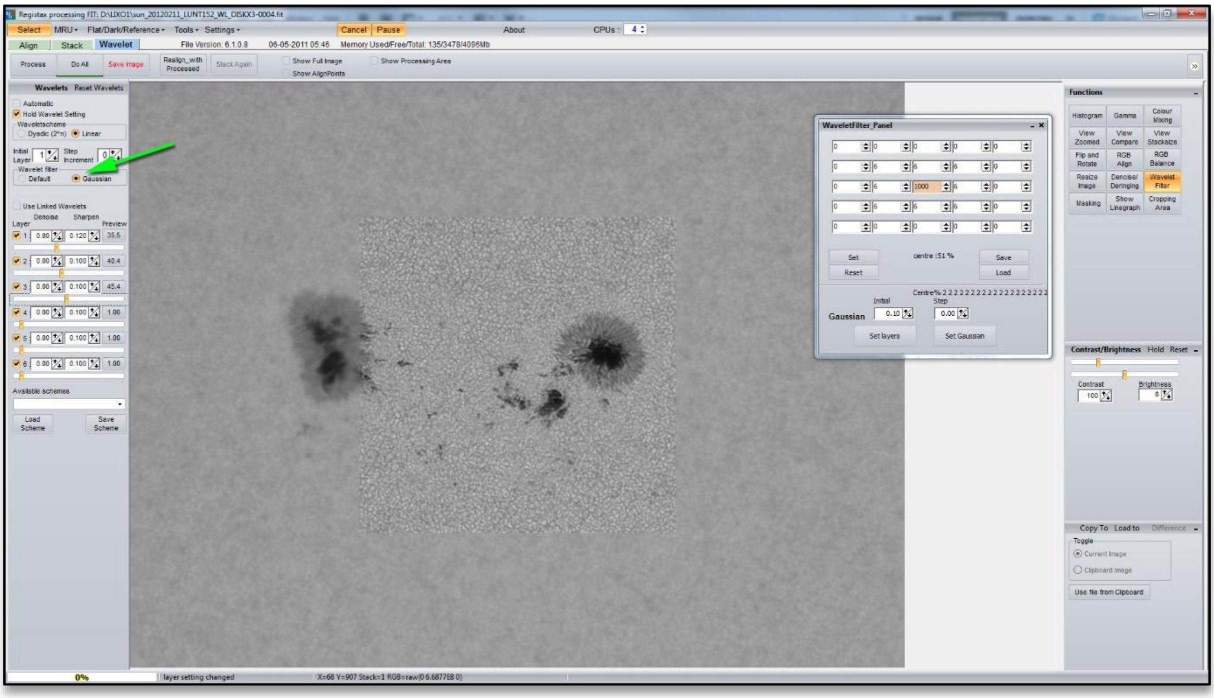

Figure 8- REGISTAX: Use layer 1, 2 and 3 of Wavelet filter - Gaussian (try several options)

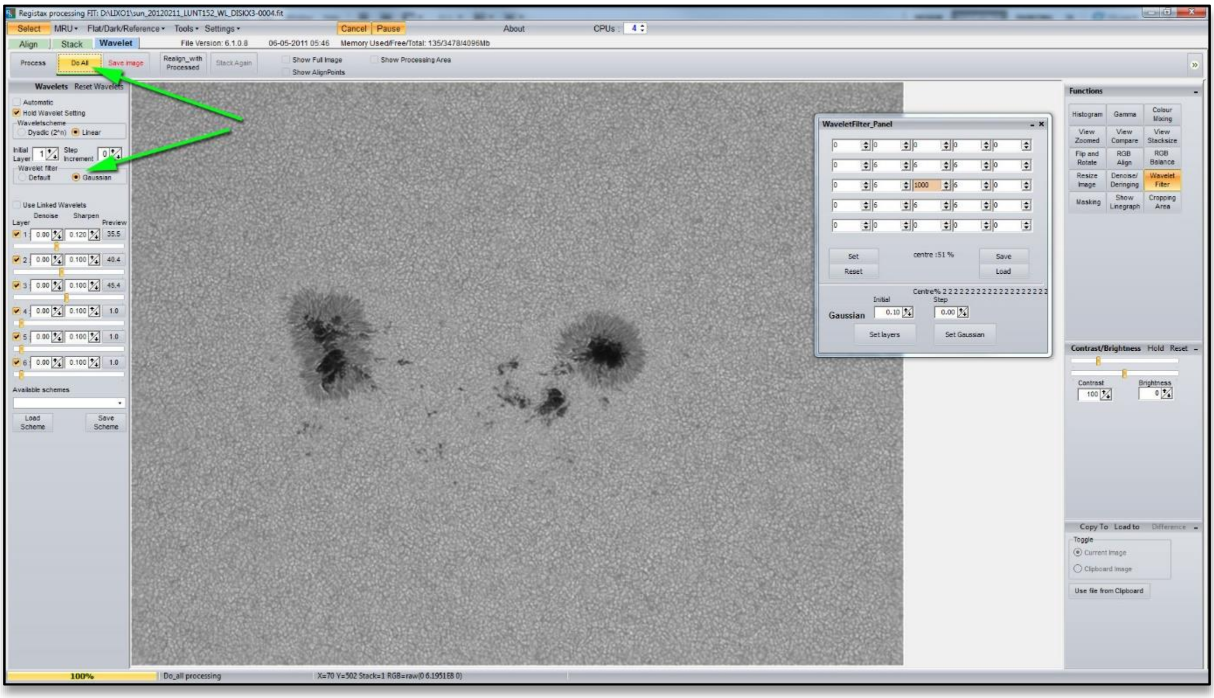

Figure 9- REGISTAX: DO ALL button

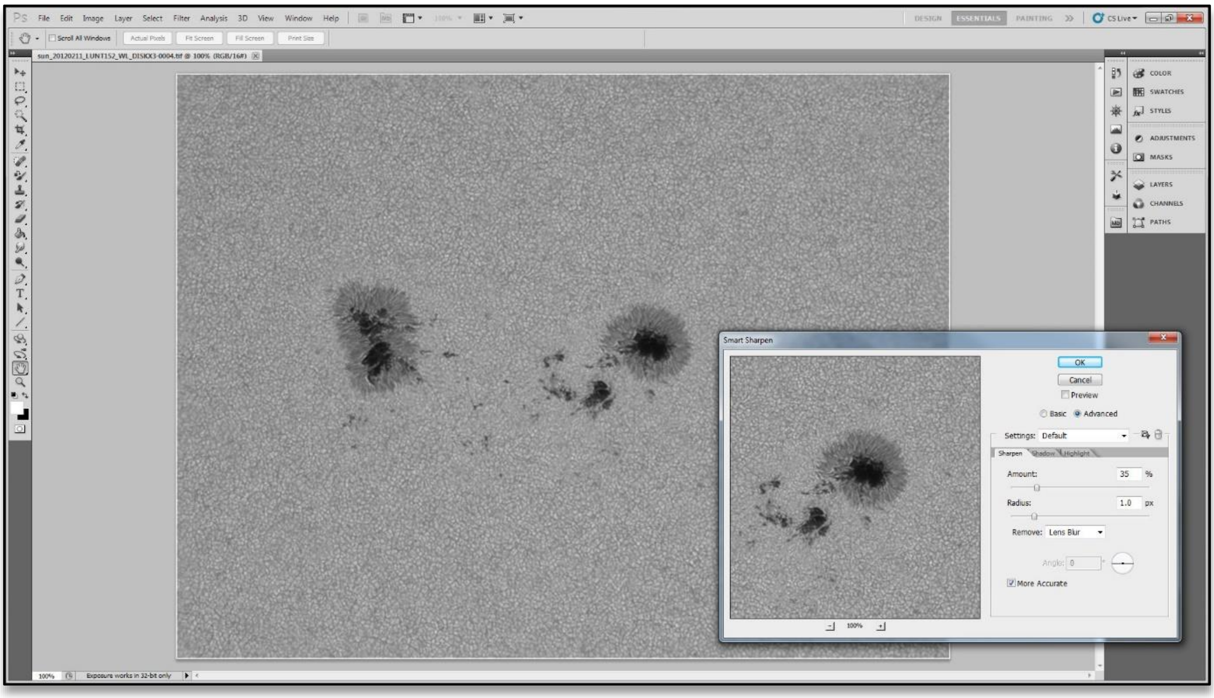

Figure 10 – PHOTOSHOP: Smart Sharp

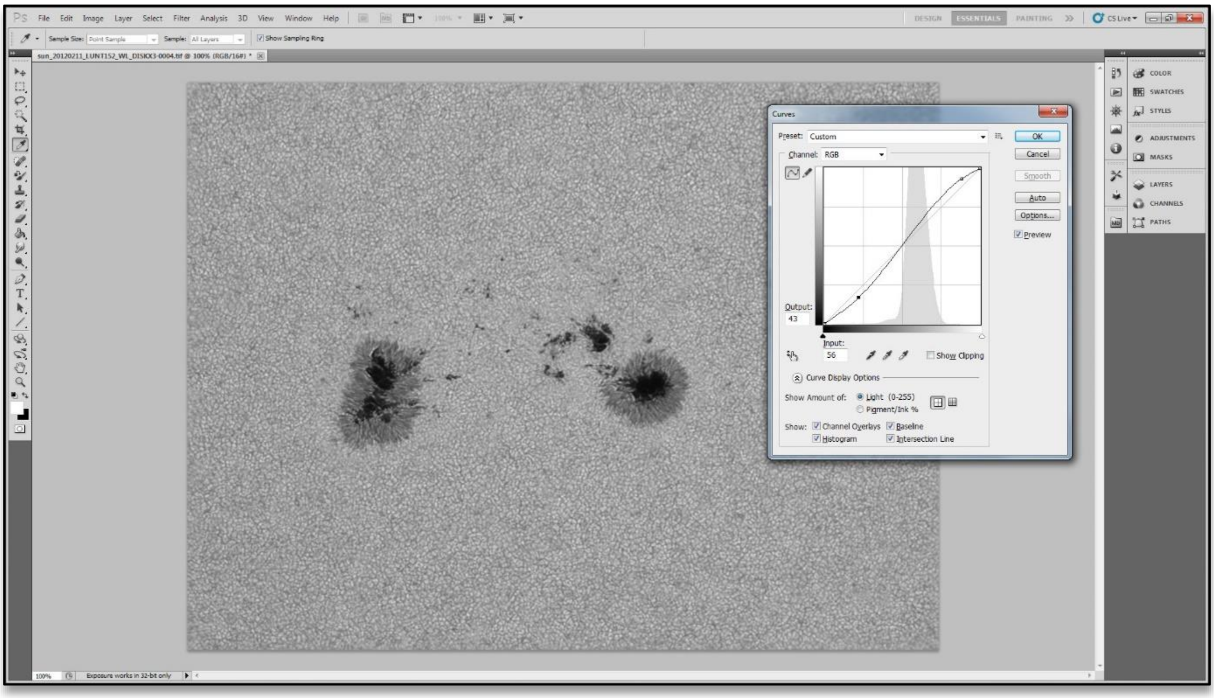

Figure 11- PHOTOSHOP: Use Curves to adjust contrast and brightness

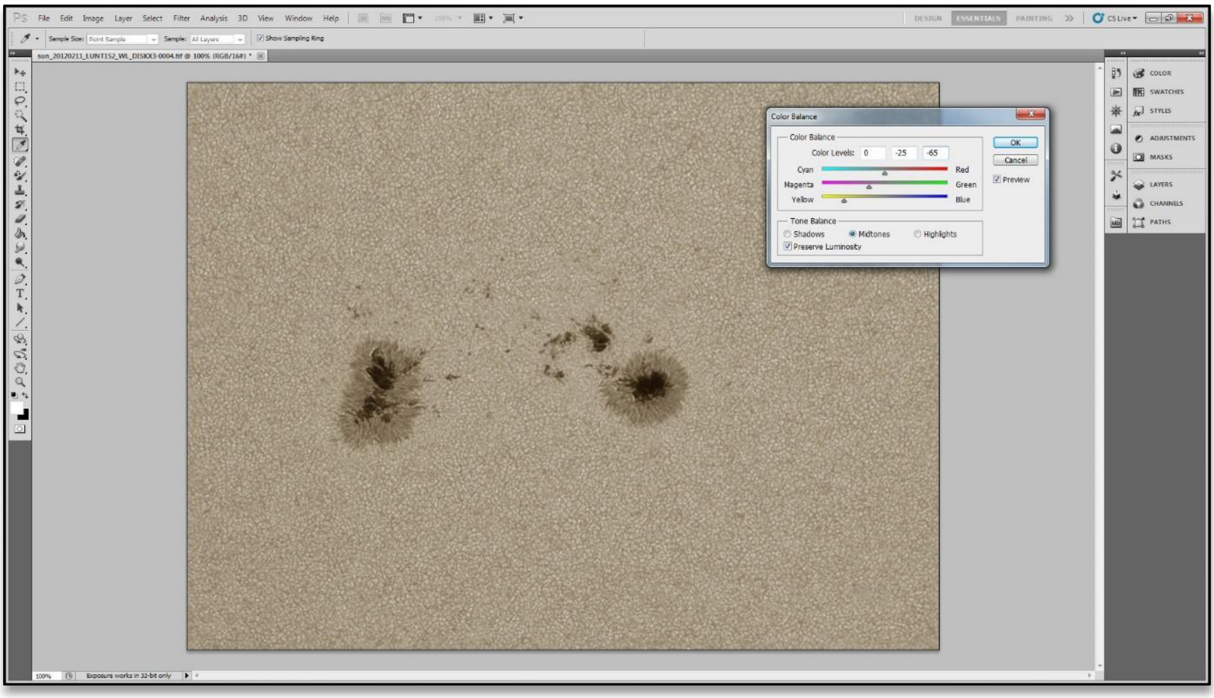

Figure 12- PHOTOSHOP: False Colour Mapping

HIGH RESOLUTION H-ALPHA IMAGING

1. Acquire high resolution H-alpha images (50 to 100 gamma DISK FEATURES, 200 to 250 gamma PROMS - DMK cameras)
2. Save AVI files or SER files (12 bits)
3. Open AVISTACK http://www.avistack.de/ or AUTOSTAKKERT http://ww.autostakkert.com/
4. Open REGISTAX http://www.astronomie.be/registax/
5. Open FIT file (aligned and stacked in Avistack or Autostakkert)
6. Process the combined image using Wavelet-based image restoration
7. Reset the Wavelet filter (500 to 1000 center value)
8. Use layer 1, 2 and 3 of Wavelet filter - Gaussian (try several options) (Figure 13)
9. Save image (16-bit TIFF file)
10. Process TIFF file in PHOTOSHOP
11. Use Curves to adjust contrast and brightness if necessary Curves (Figure 14)
12. Use Shadow/Highlights option (Figure 15)
13. Use Smart Sharpen or Unsharp Mask
14. False Color Mapping (Figure 16, Figure 17, Figure 18)
15. Save the final 16-bit TIF file (no compression)
16. Convert to 8-bit and save JPG file (no compression)

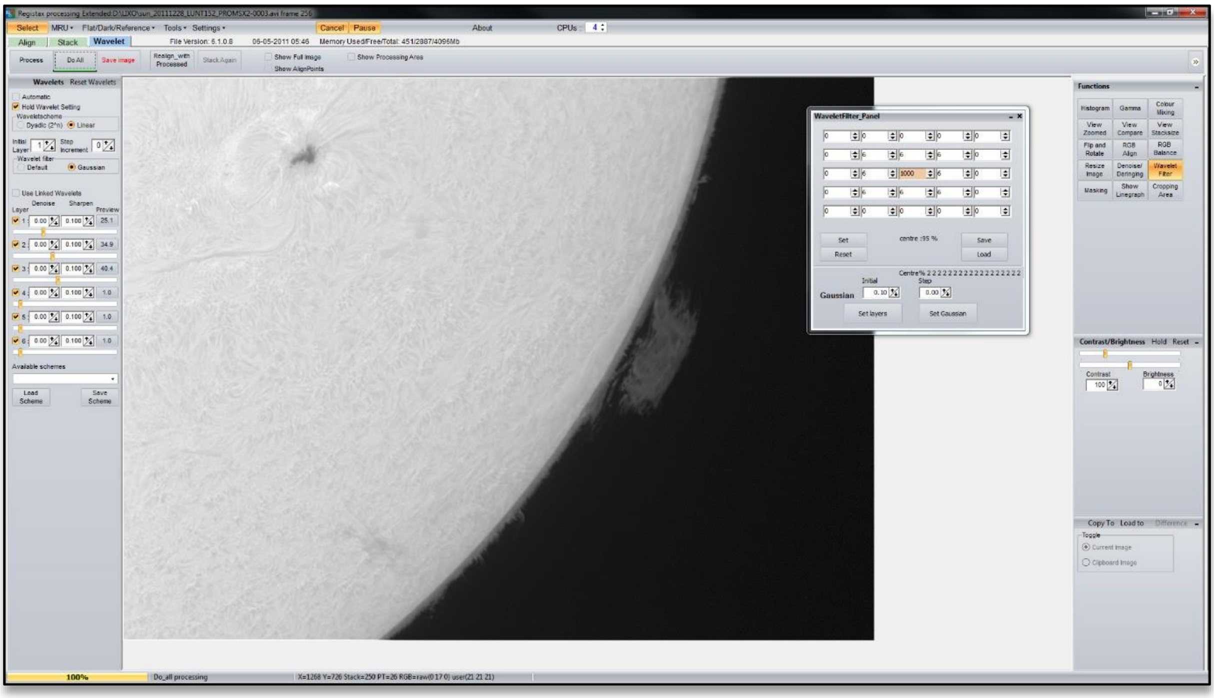

Figure 13- REGISTAX: Wavelet-based image restoration

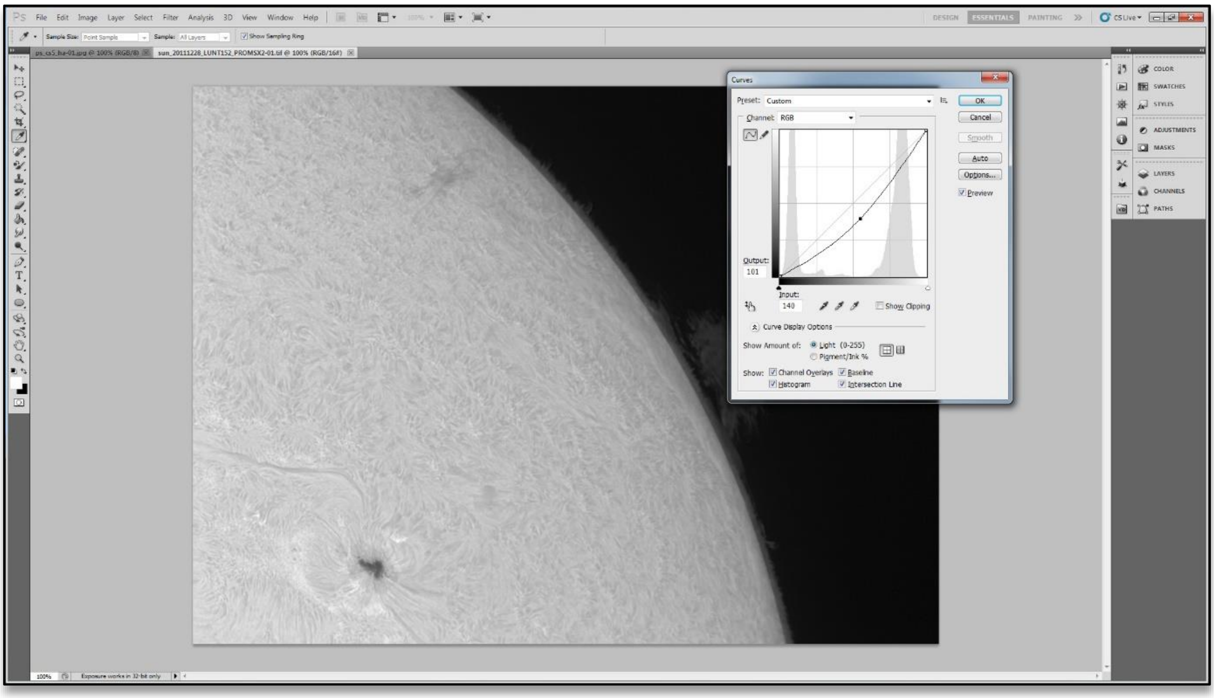

Figure 14- PHOTOSHOP: Process the TIF image in Photoshop (HR H-alpha image)

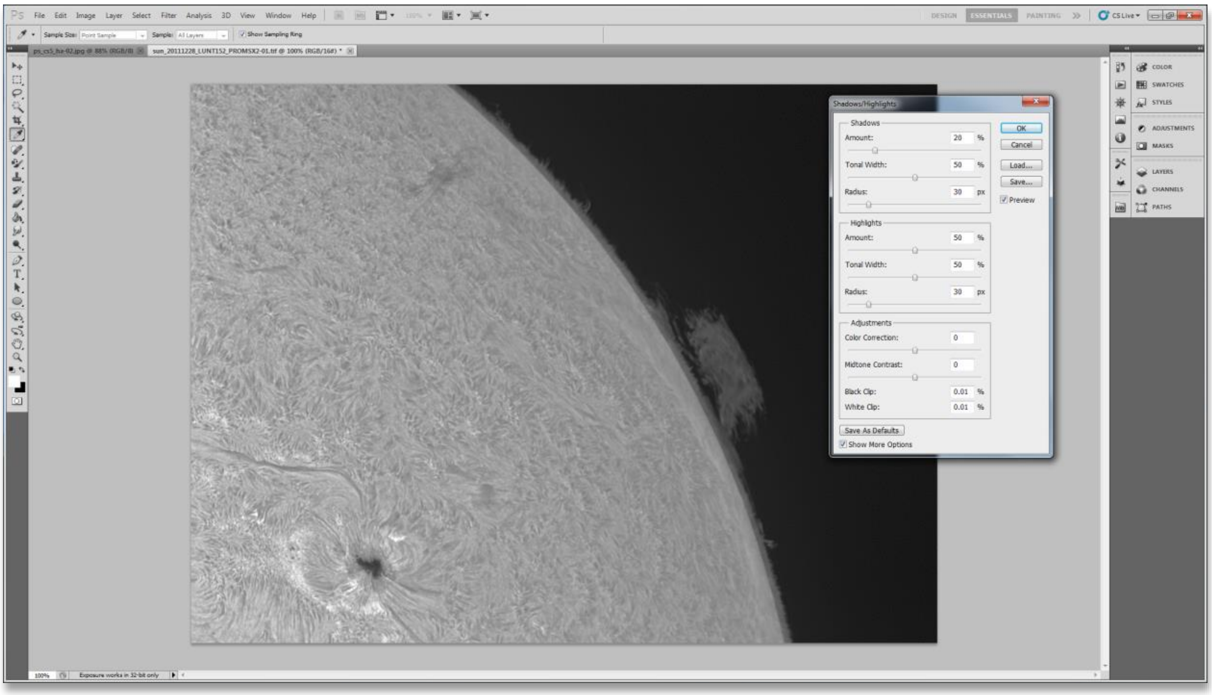

Figure 15- PHOTOSHOP: Shadow & Highlights (HR H-alpha image)

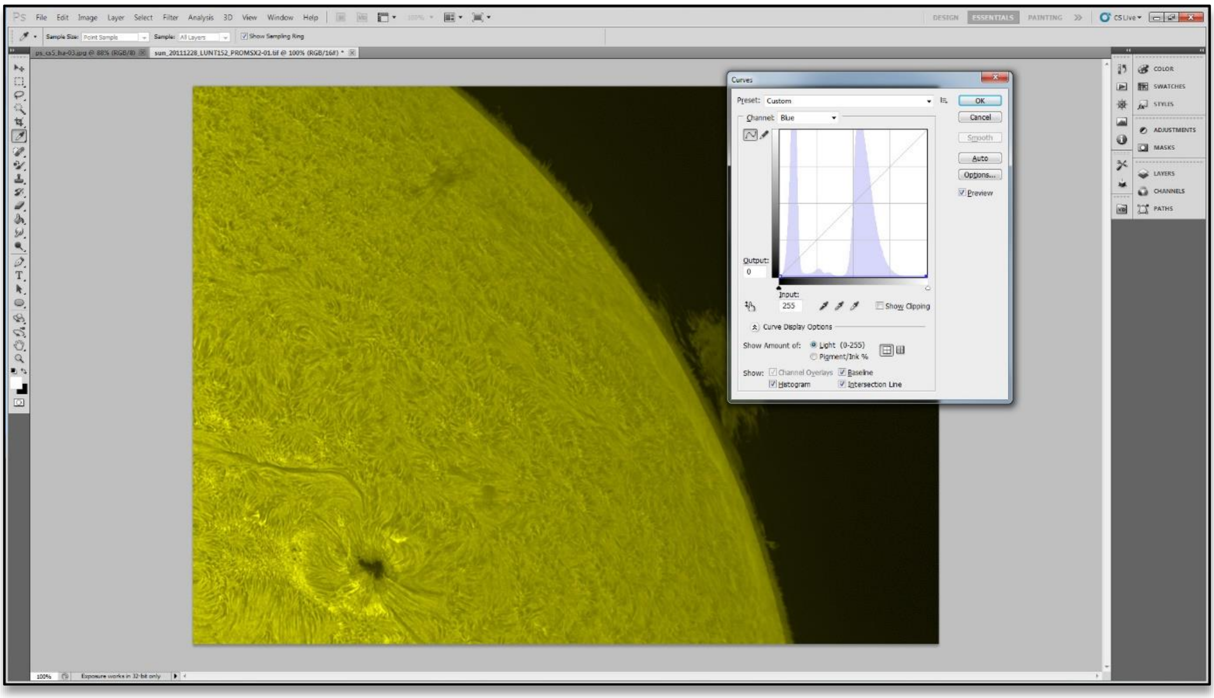

Figure 16- PHOTOSHOP: False Colour Mapping (Blue Channel)

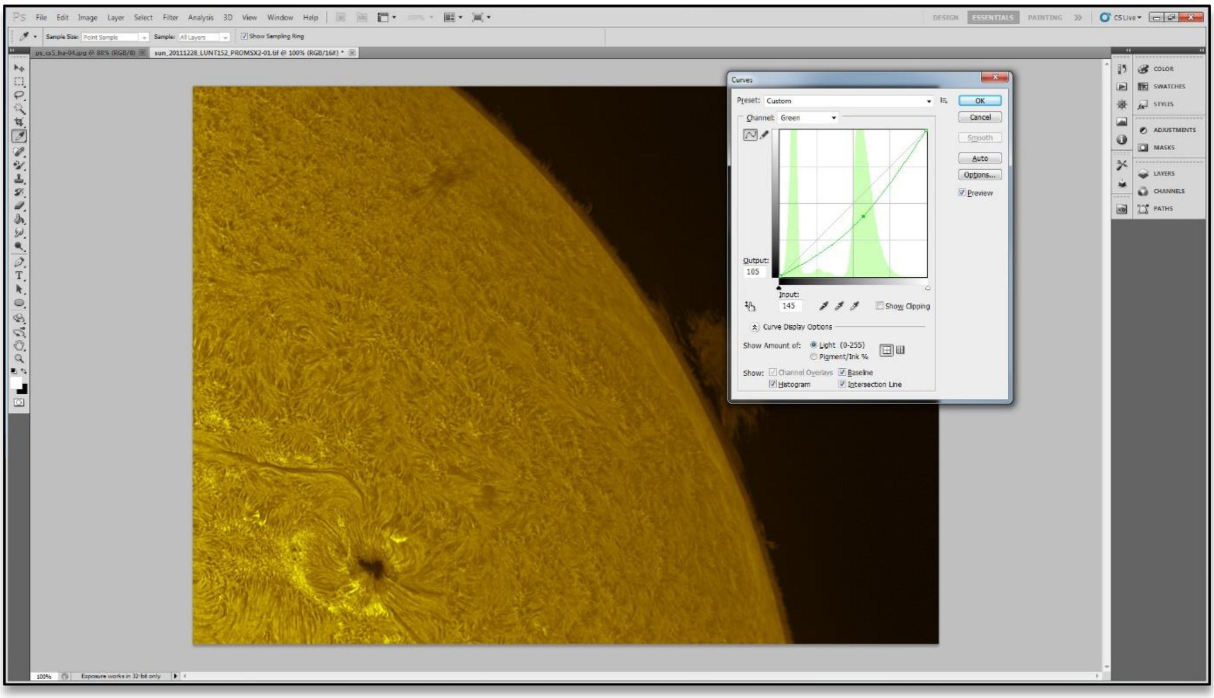

Figure 17- PHOTOSHOP: False Colour Mapping (Green Channel)

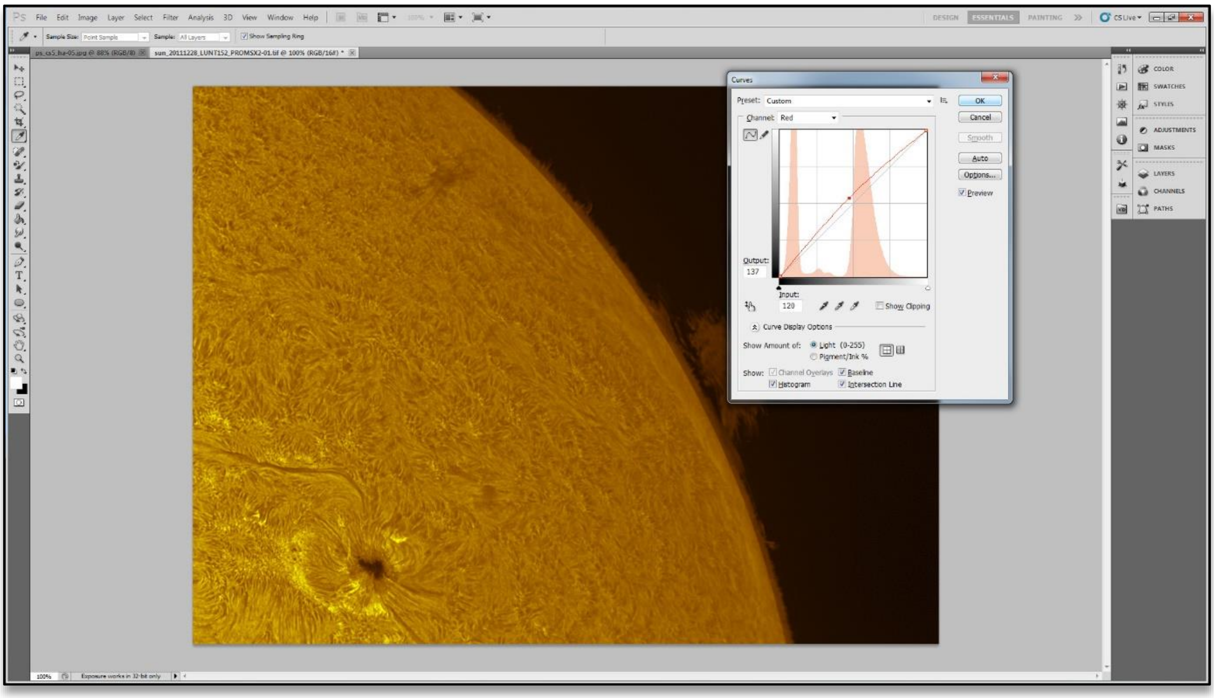

Figure 18- PHOTOSHOP: False Colour Mapping (Red Channel)

ARTIFICIAL FLAT-FIELD (Photoshop)

1. Open mosaic image (16-bit TIFF file) (Figure 19)
2. Create a new Layer (Figure 20)
3. Create a Mask (Figure 21)
4. Copy mosaic image to Mask
5. Apply a Median Filter (e.g. radius 25) (Figure 22)
6. Reduce Mask brightness (Curves) (Figure 23)
7. Apply Mask (Difference) (Figure 24)
8. Reduce Mask Opacity if needed (Figure 25)
9. Flatten Layers
10. Use Curves and/or Levels to adjust contrast and brightness (Figure 26)
11. Save flat-field corrected image (16-bit TIFF file)
12. Before/After (Figure 27)

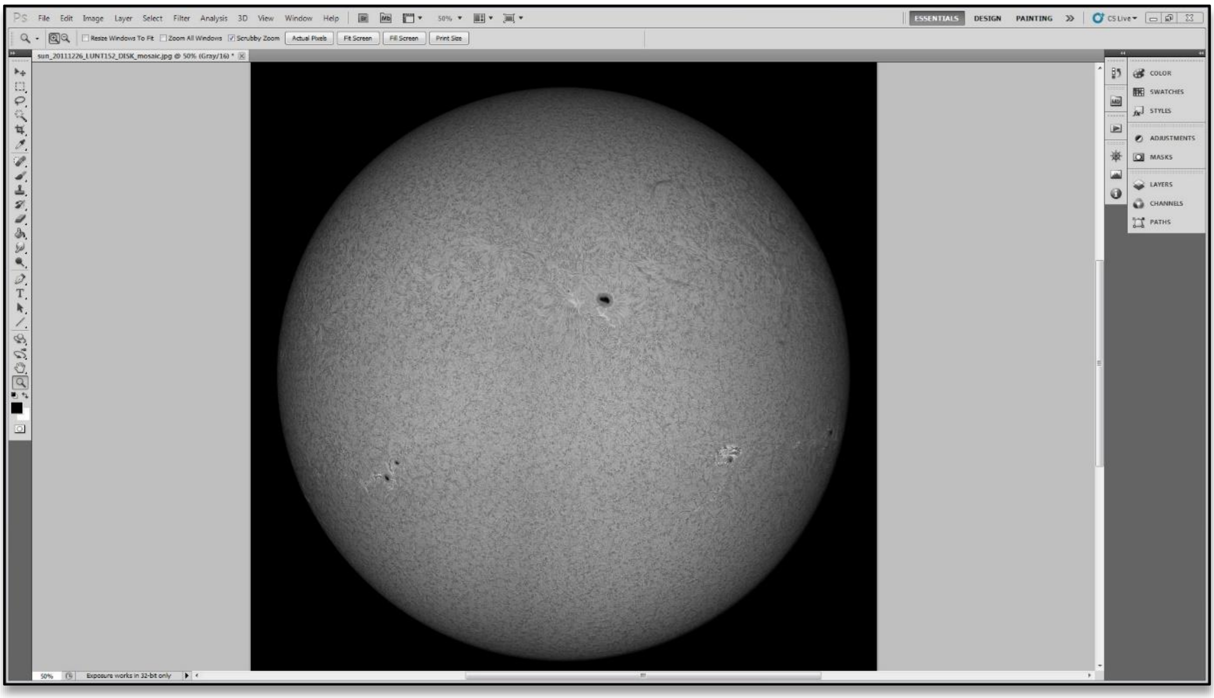

Figure 19- PHOTOSHOP: Open Mosaic image

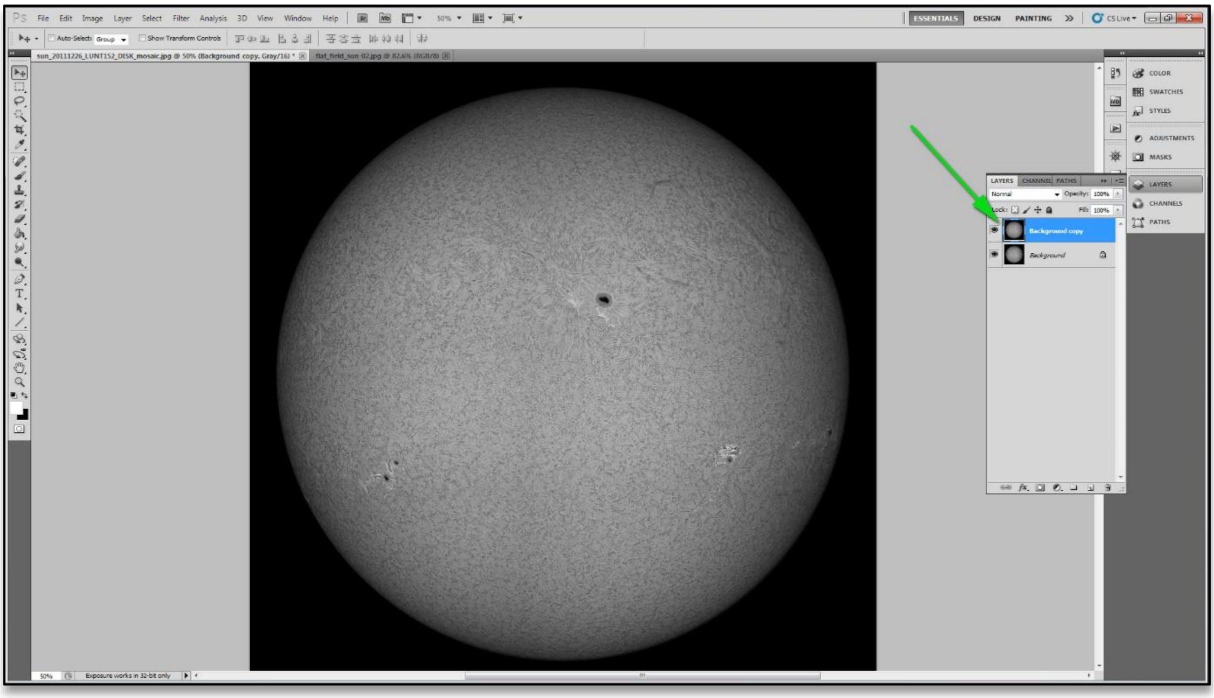

Figure 20- PHOTOSHOP: Duplicate Layer

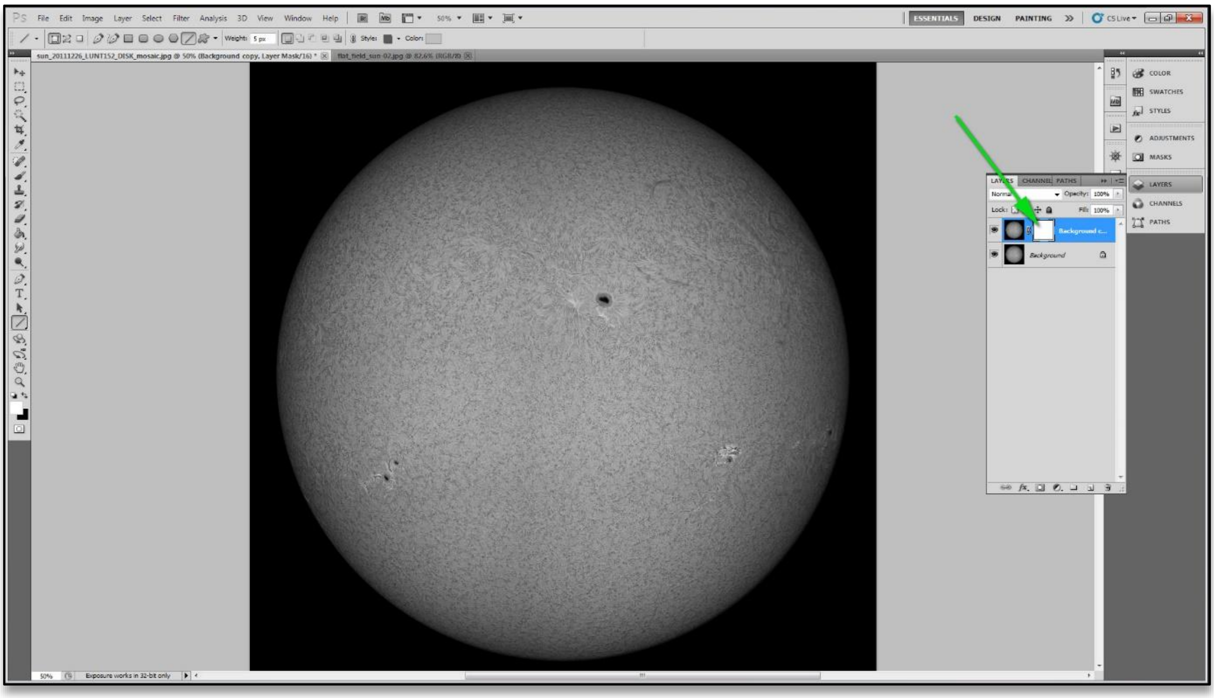

Figure 21- PHOTOSHOP: Create a Mask

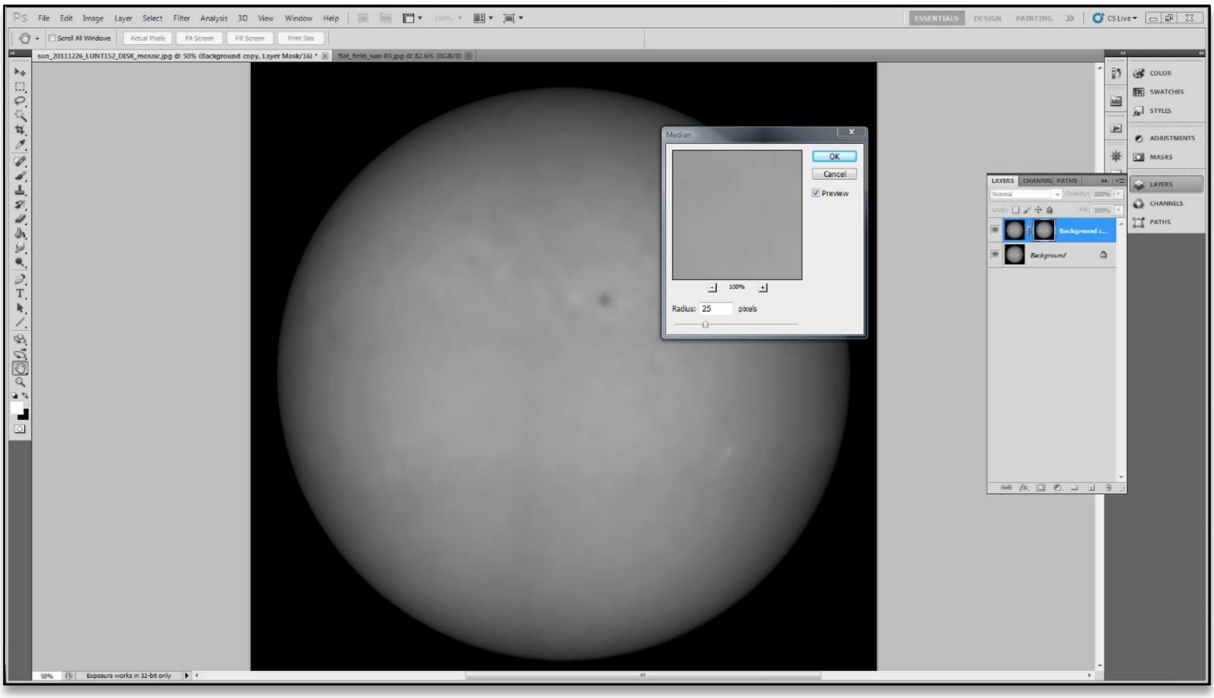

Figure 22- PHOTOSHOP: Apply Median Filter

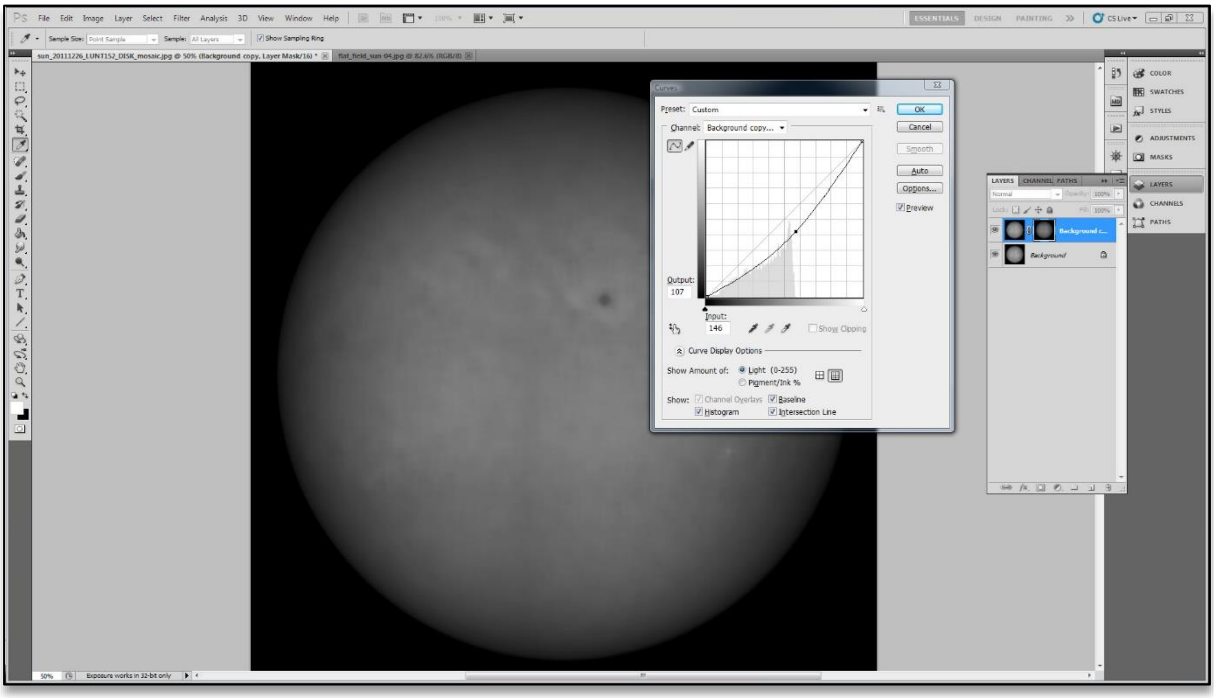

Figure 23- PHOTOSHOP: Reduce Mask brightness

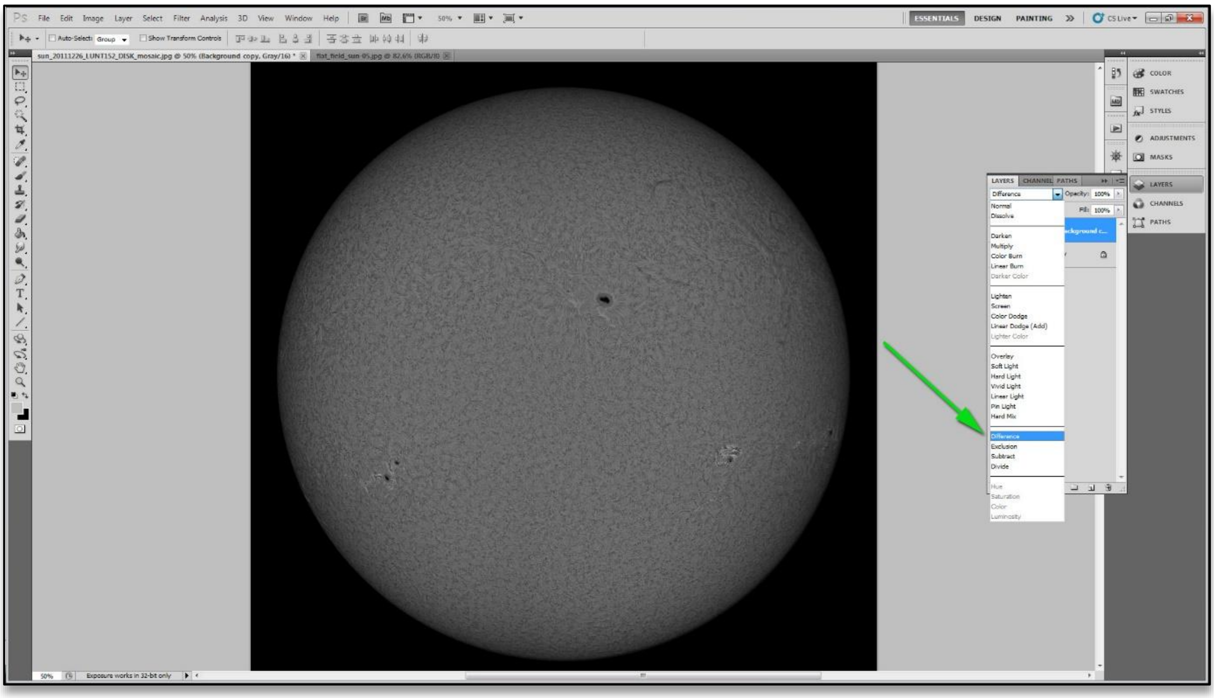

Figure 24- PHOTOSHOP: Apply Mask

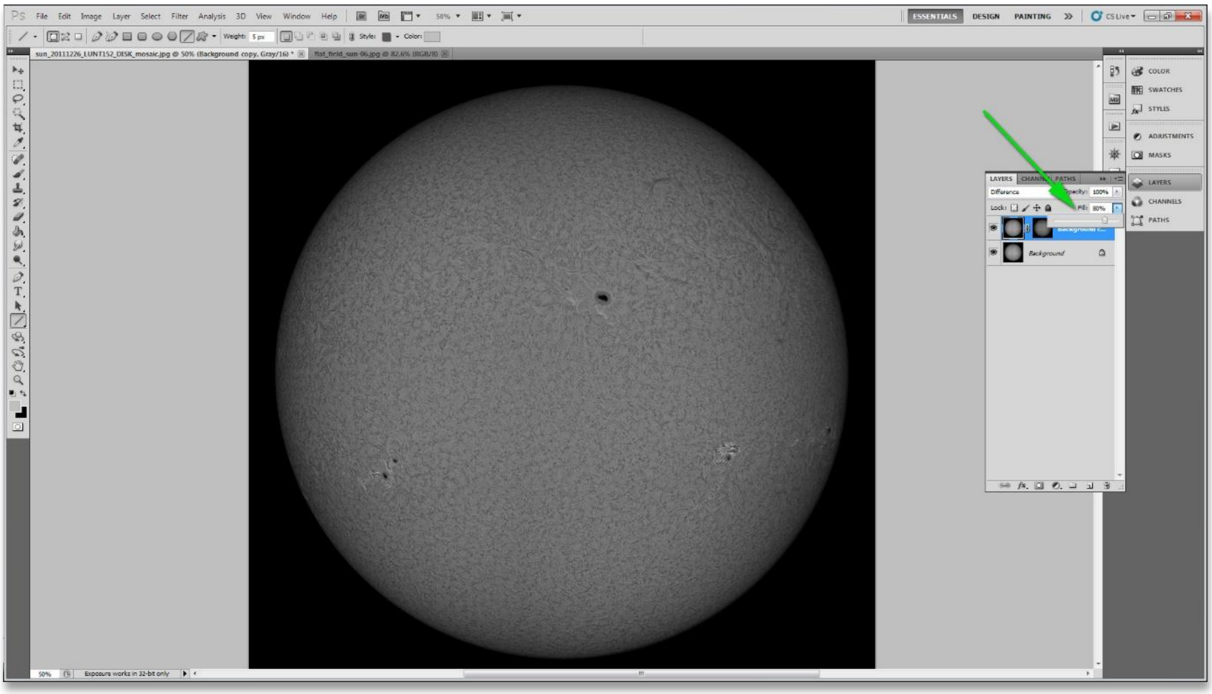

Figure 25- PHOTOSHOP: Reduce Mask Opacity

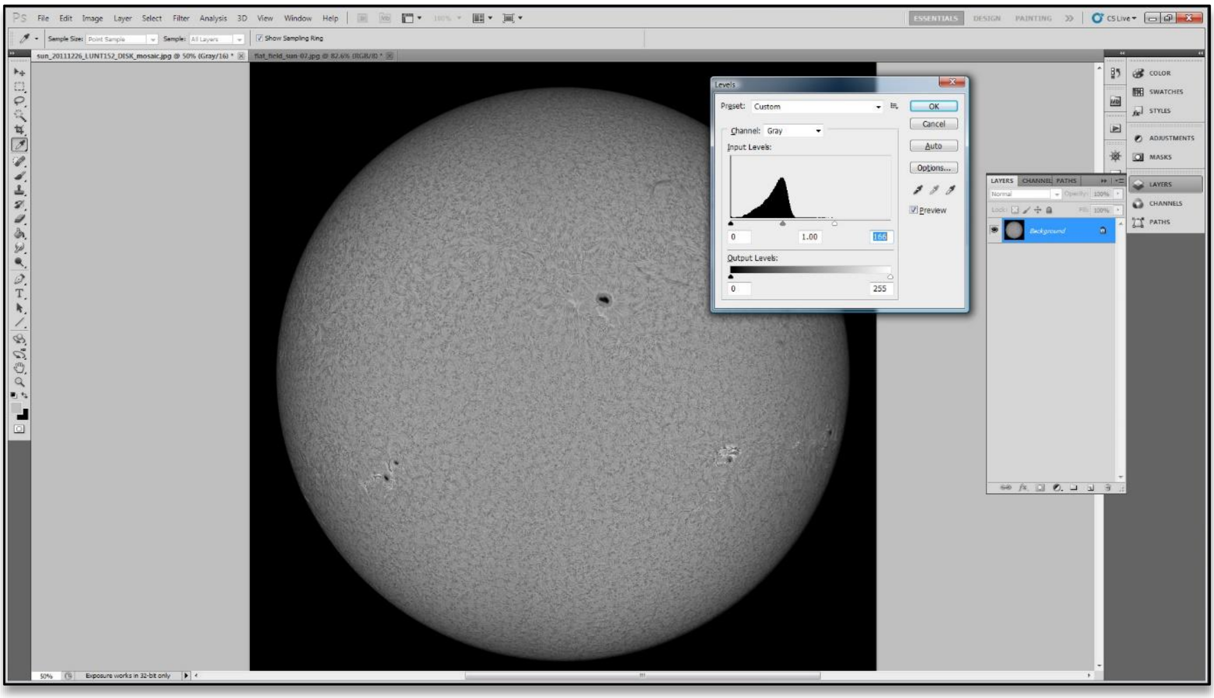

Figure 26- PHOTOSHOP: Curves and Levels

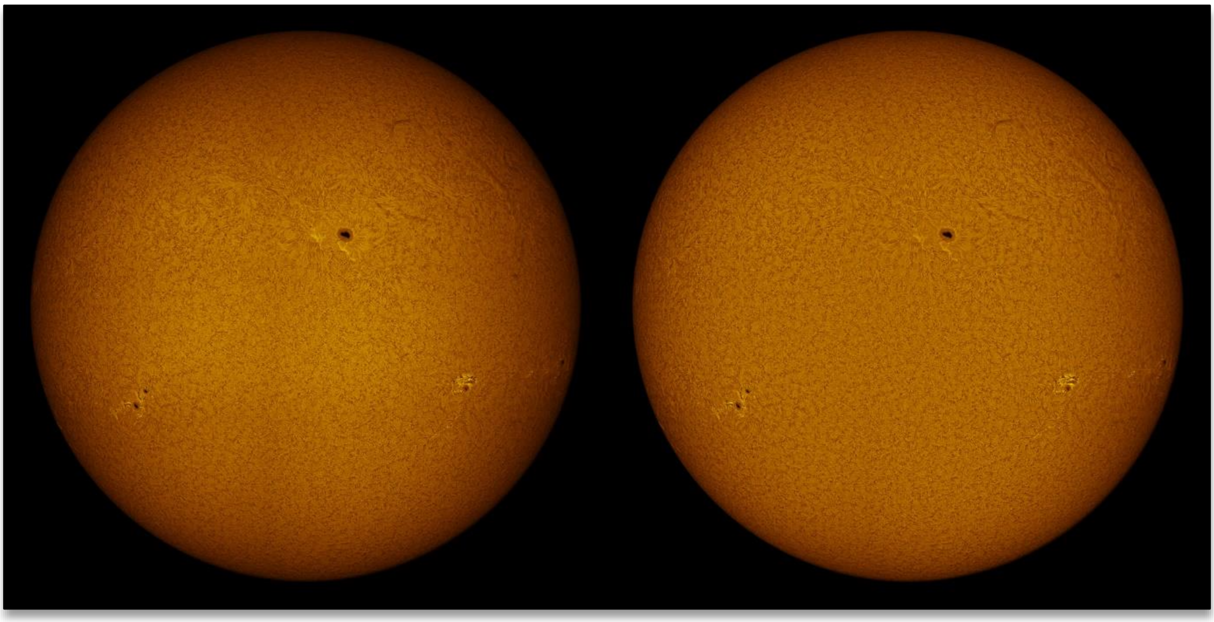

Figure 27- PHOTOSHOP: Before/After (Photoshop)

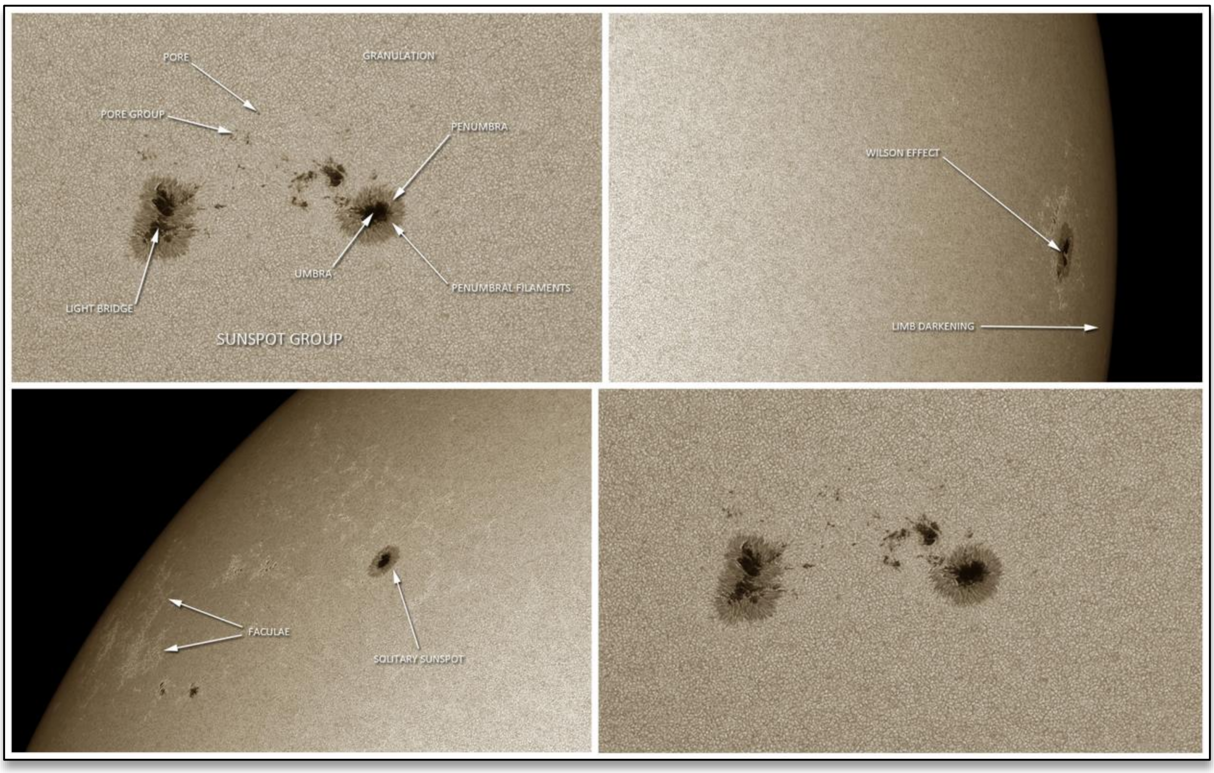

Figure 28- White Light (Photosphere) features (Pedro Ré)

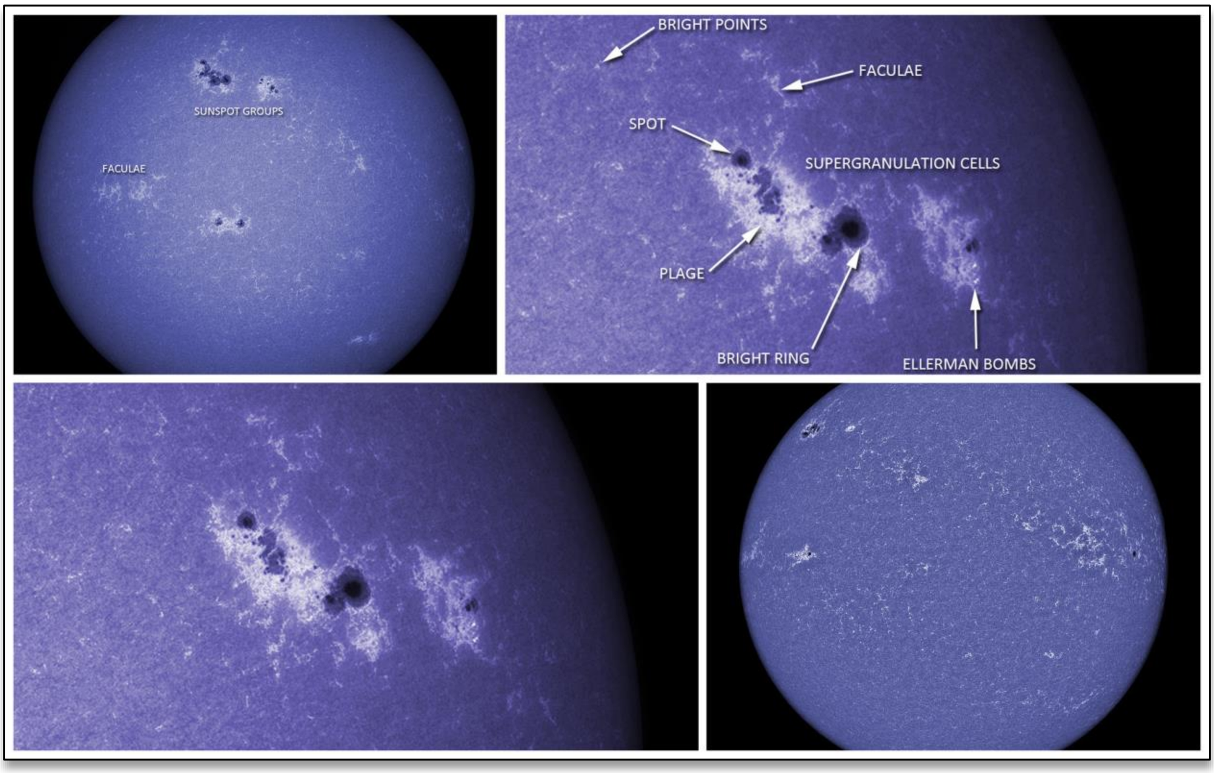

Figure 29- Ca-K (Chromosphere) features (Pedro Ré)

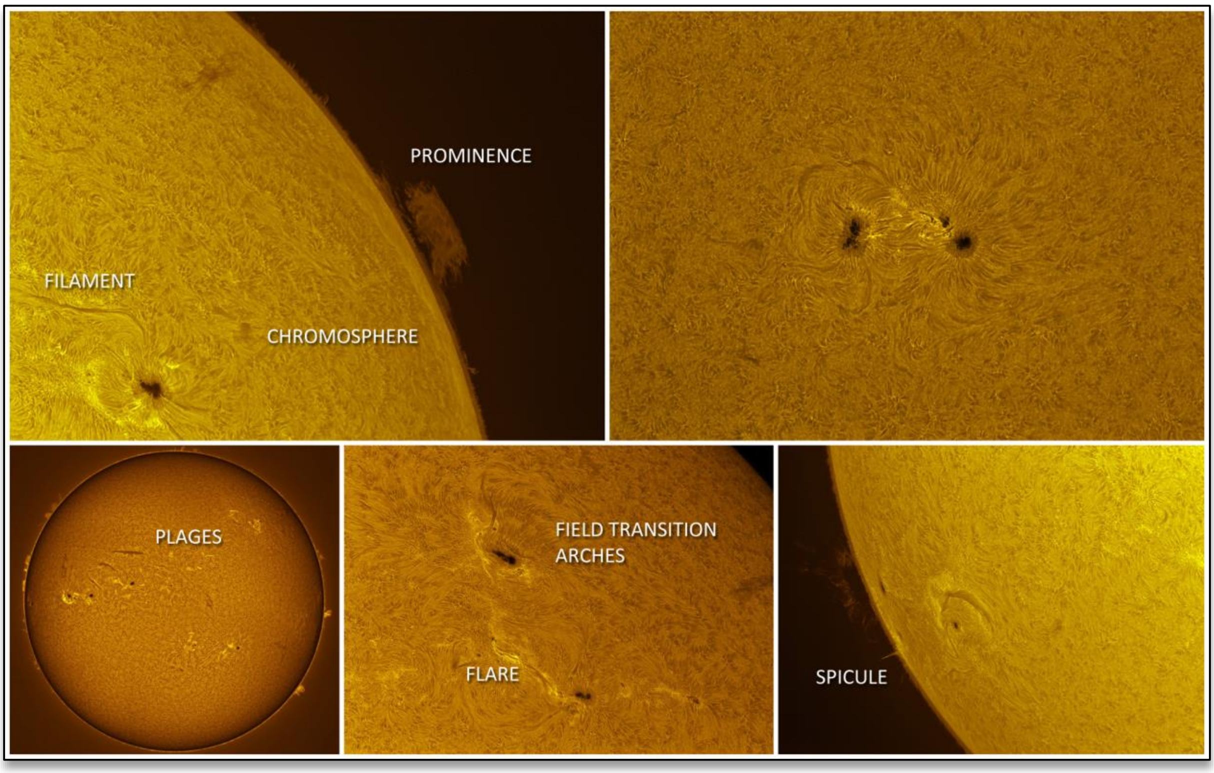

Figure 30- H-alpha (Chromosphere) features (Pedro Ré)

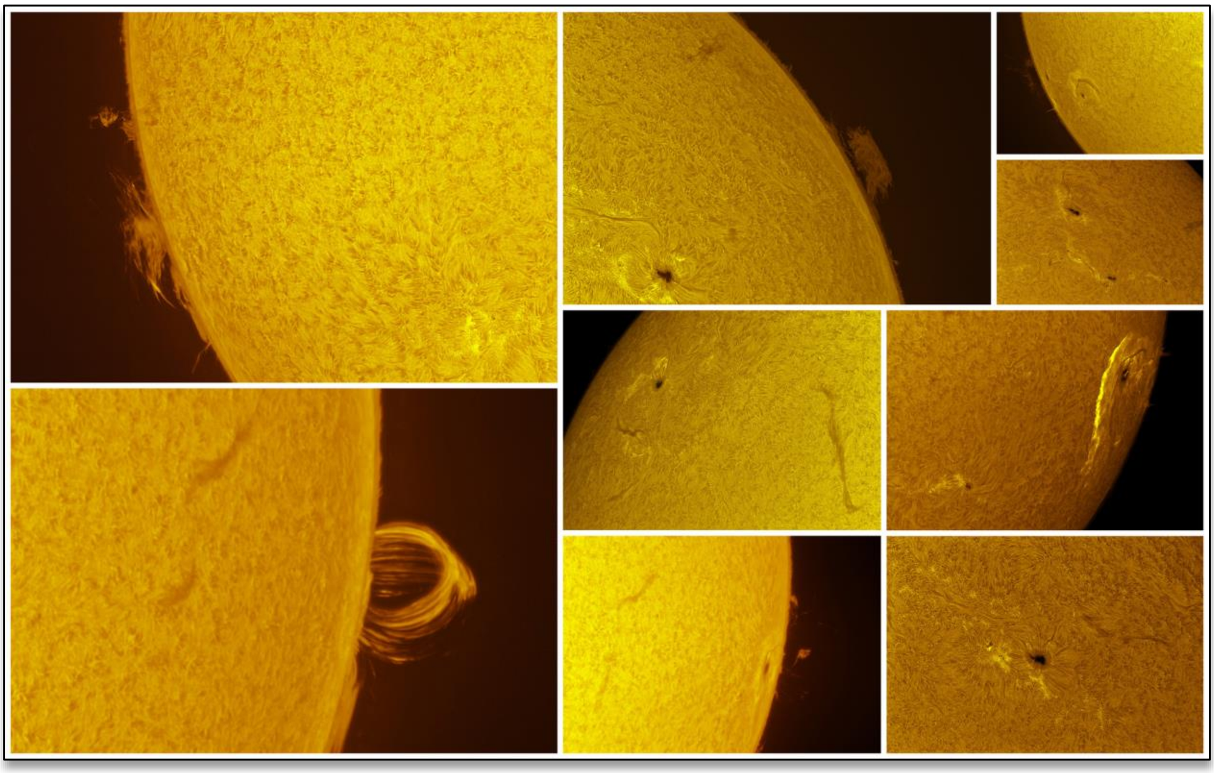

Figure 31- H-alpha Prominences and Chromospheric Features (LUNT152, Pedro Ré)

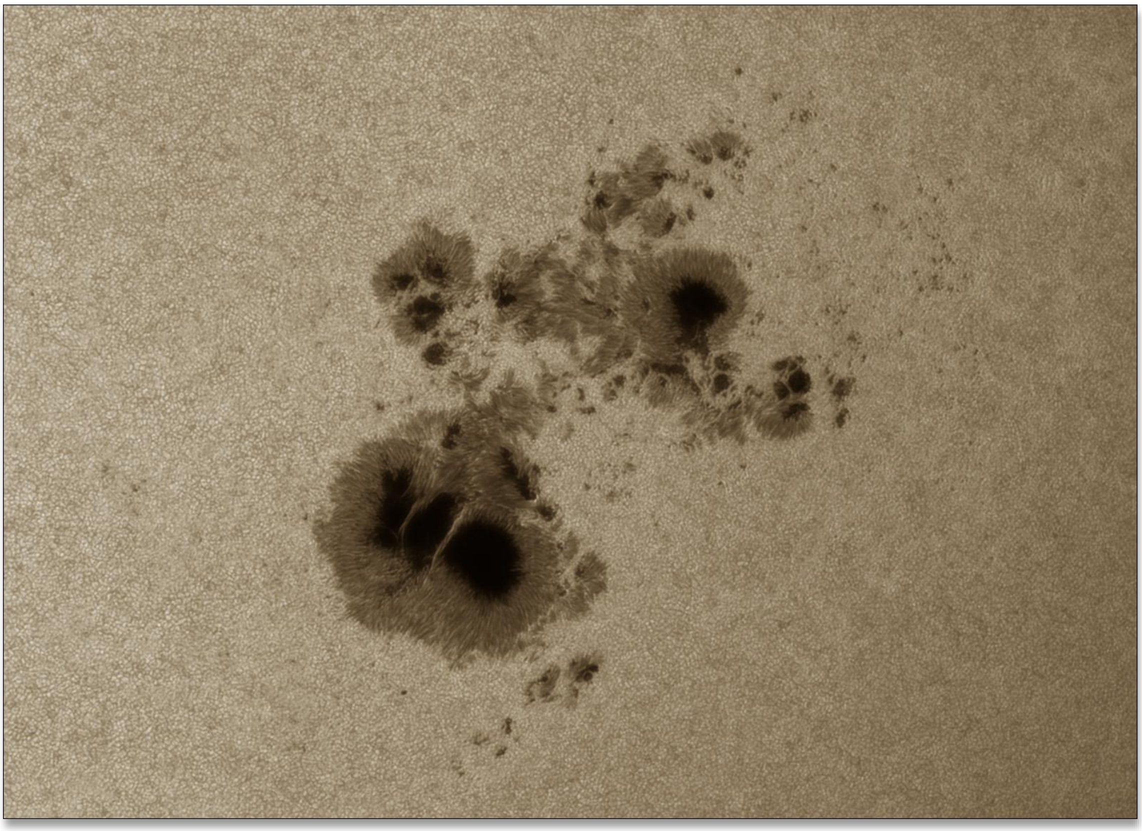

Figure 32- SUN (20141025) AR12192 WL. LUNT152 F/6, 2" Baader Ceramic Herschel Wedge, X4 Powermate, PGR GRASSHOPPER 3 (Pedro Ré)

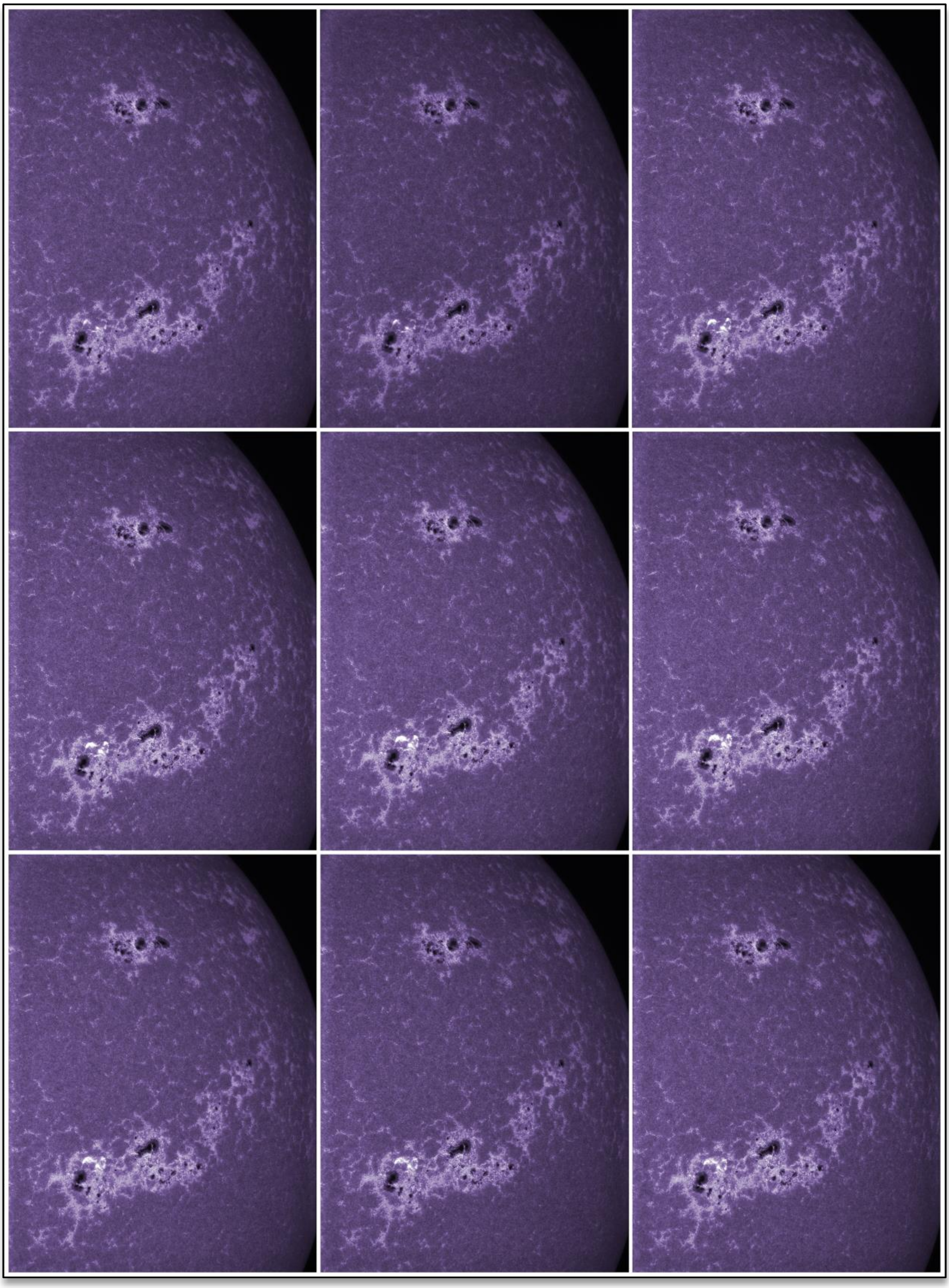

Figure 33- SUN (20140928) Ca-K FLARE (09:02/09:06 UTC). LUNT152 F/6, LUNT152 CaK Module, X1.6 Barlow, PGR GRASSHOPPER 3 (Pedro Ré)