Solar imaging in Ca II

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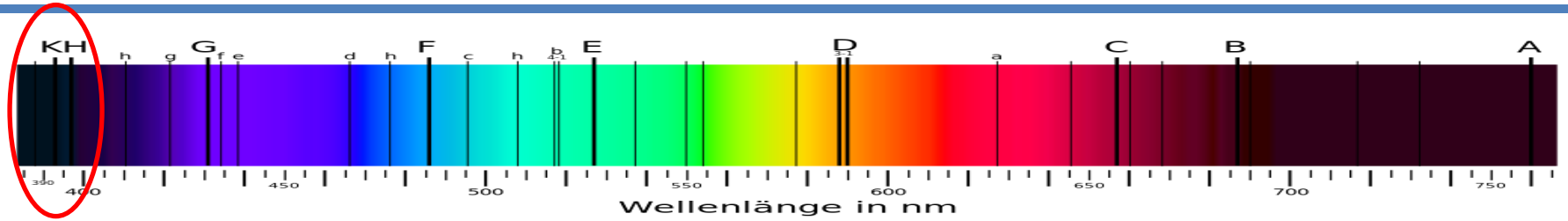
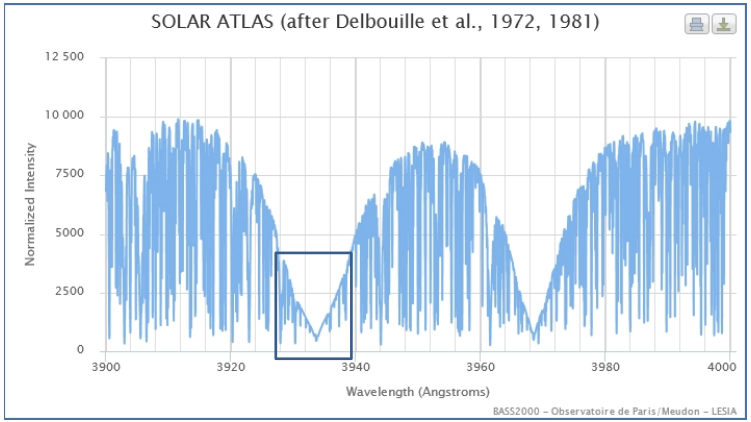
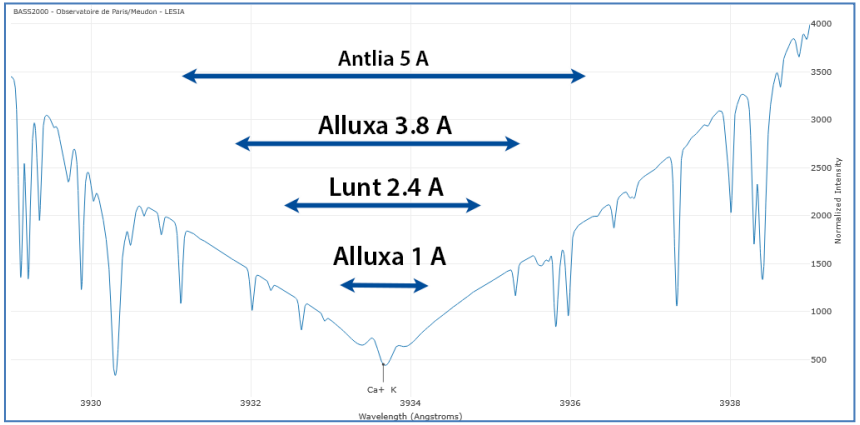
The chromosphere in Ca K et H

- Ca K and H: photosphere or chromosphere ?
- True and “false” Ca K filters.
- Current commercial offering.
- Good (and bad) optics for Ca K observation?
- How to deal with the solar energy flux ?
- Double-stacking, narrow band filters, tuning filter wavelength...

Ca K and Ca H lines

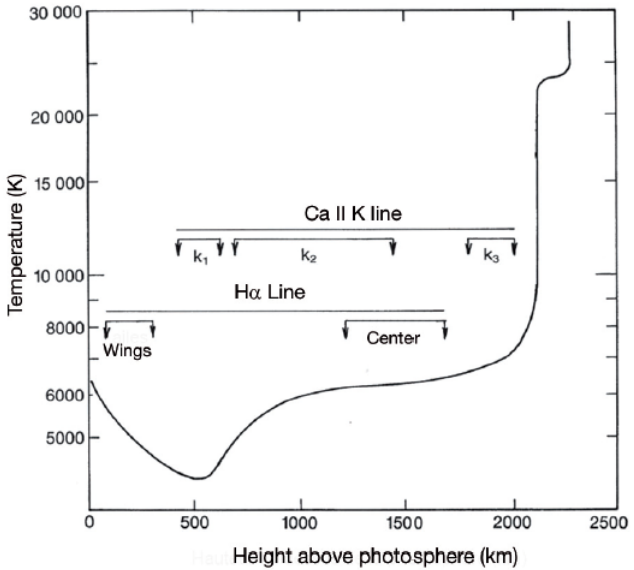






Equivalent width = 1.9 nm for Ca K and 1.4 nm for Ca H (vs 0.4 nm for Ha).
Very dark lines: center of line is 5% of continuum (vs 16% in Ha).

Wavelength/bandpass and layer sampled



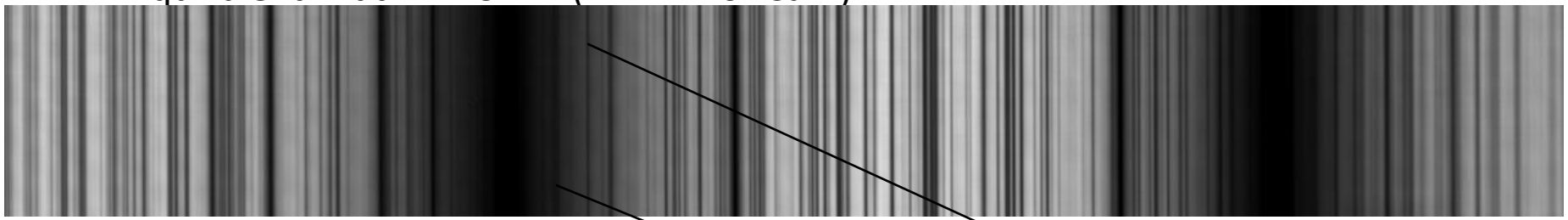
- Photosphere: layer from 0 to 500 km (= up to temperature inversion).
- Chromosphere: layer from 500 km to 2100 km (= up to corona base).

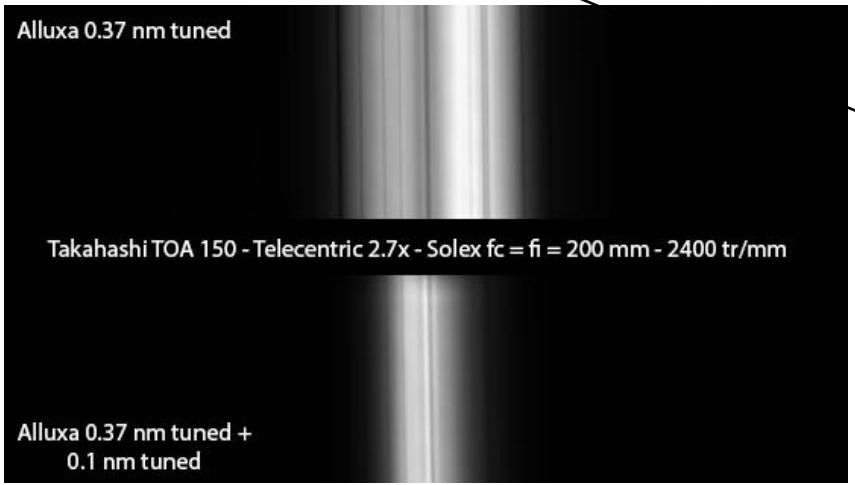
- Ca K line features:
  - K3 = core of the line: chromosphere, altitude range higher than center of Ha
  - K2: still in the chromosphere (800-1500 km).
  - K1: upper layer of the photosphere/bottom of chromosphere.

- Ideally, we would like to isolated K3 (= center of Ca K):
  - However, a filter of about 0.2 A FHWM is required to isolate K3.
  - Possible only with a spectroheliograph (SHG).
  - Usual Ca K filter are 2.4 A (Lunt) to 5 A (Antlia) => upper photosphere, some bits of chromosphere.
  - Alluxa 1 A Ca K filter is a major step forward, still 5 x larger than Ca K3. Need to be double-stacked for observation of the upper chromosphere.

Zoom on the Ca K line

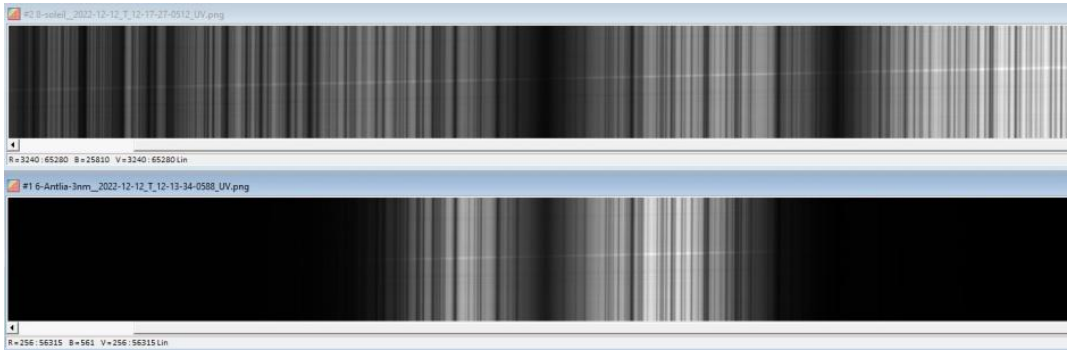
- Equivalent width = 1.9 nm (1.4 nm for Ca H)



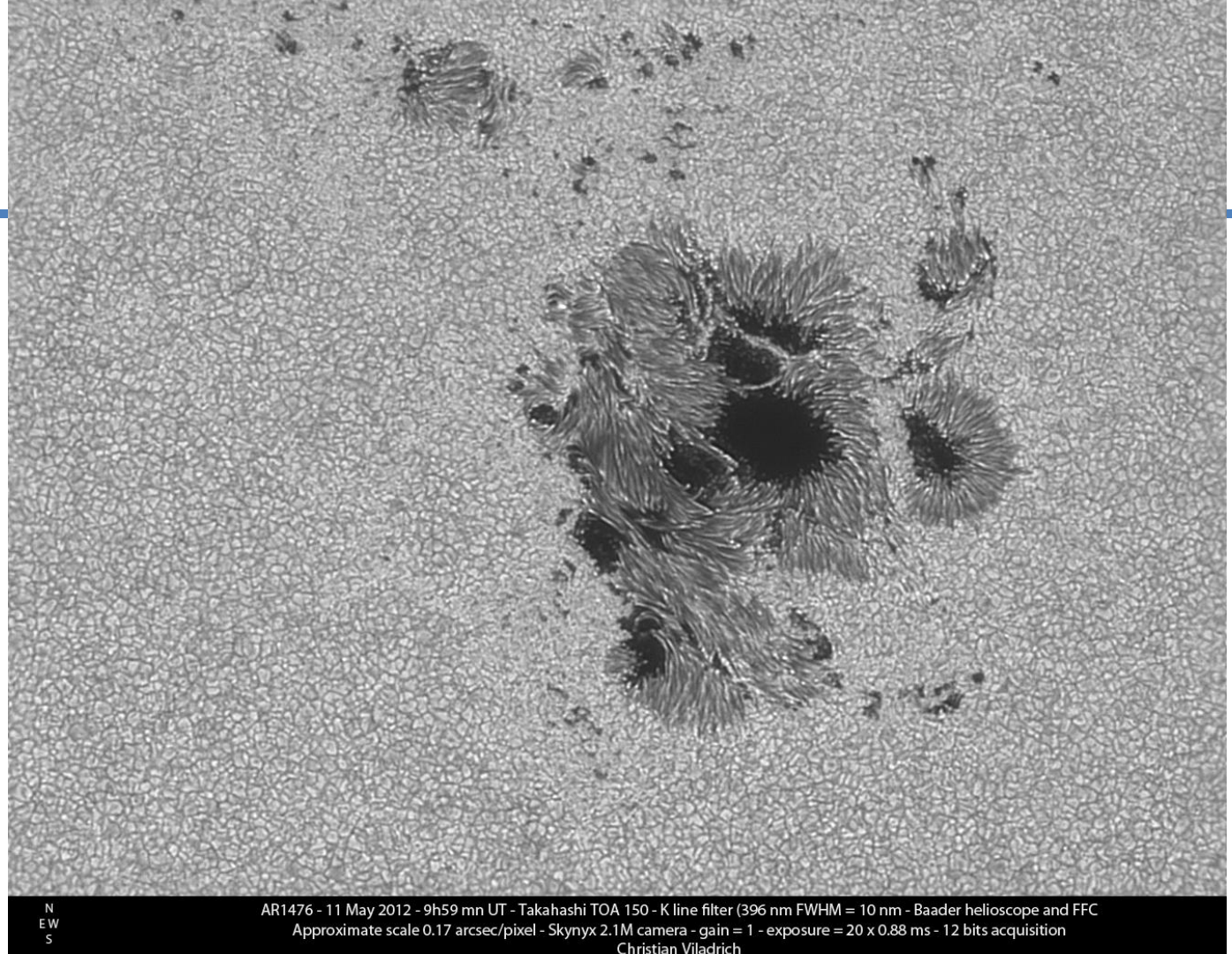


True and “false” Ca K filters

- Any filter larger than 5A is definitely NOT a Ca K filter, and will only show the photosphere and not the chromosphere.
- A “true” Ca K filter will show the “reverse” granulation and not the “normal granulation”
- “False Ca K filters”: Baader K-line (8 nm) and Calcium GenII (old and new), Antlia 393-3 nm.
- This is a bit misleading to call these filters Ca K filters.



Antlia 393 nm – FWHM = 3 nm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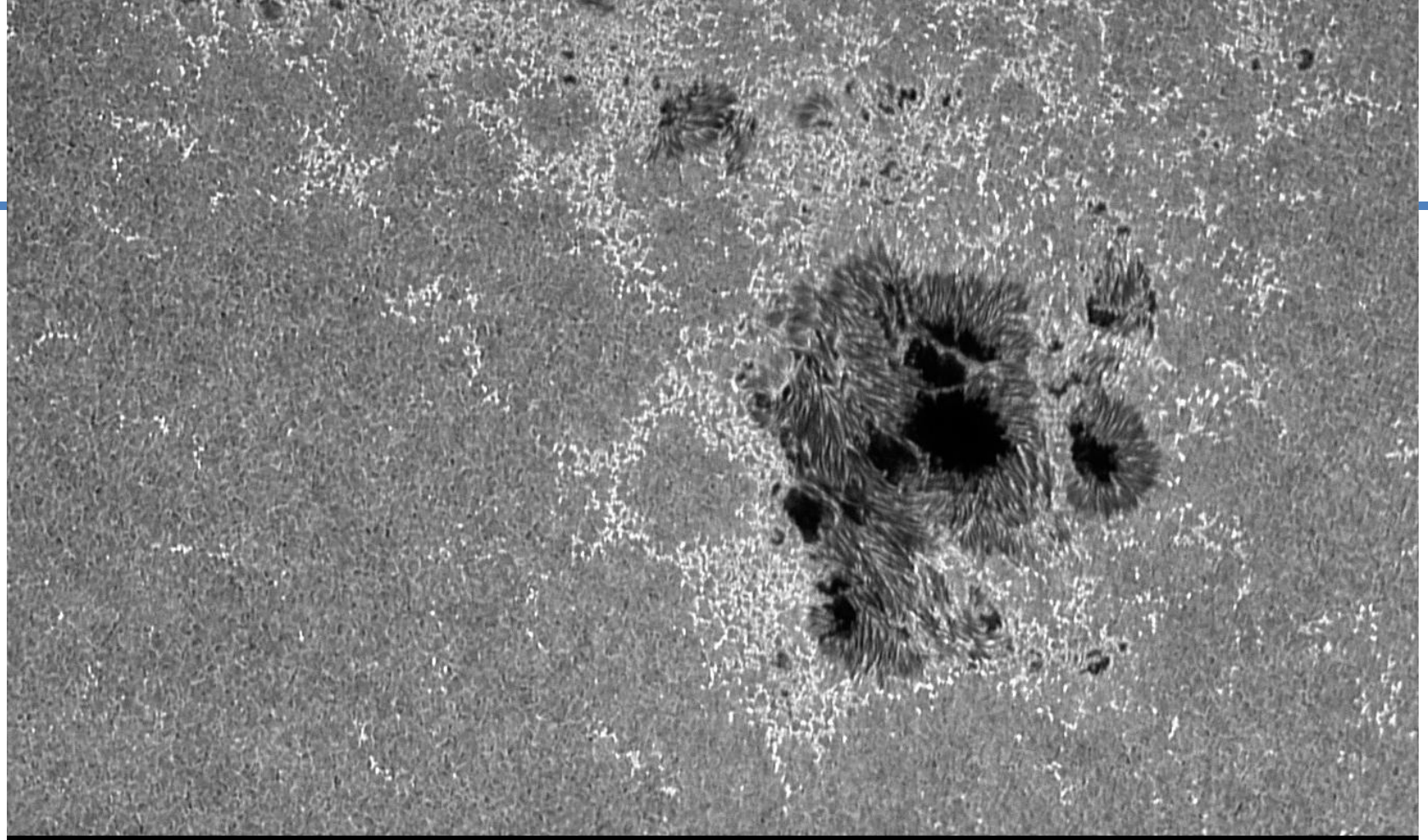
AR1476 - 11 May 2012 - 9h59 mn UT - Takahashi TOA 150 - K line filter (396 nm FWHM = 10 nm - Baader helioscope and FFC
Approximate scale 0.17 arcsec/pixel - Skynyx 2.1M camera - gain = 1 - exposure = 20 x 0.88 ms - 12 bits acquisition
Christian Viladrich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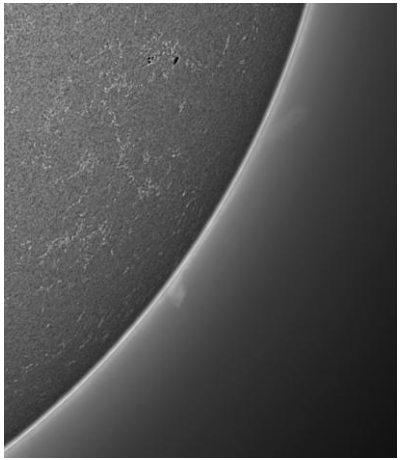
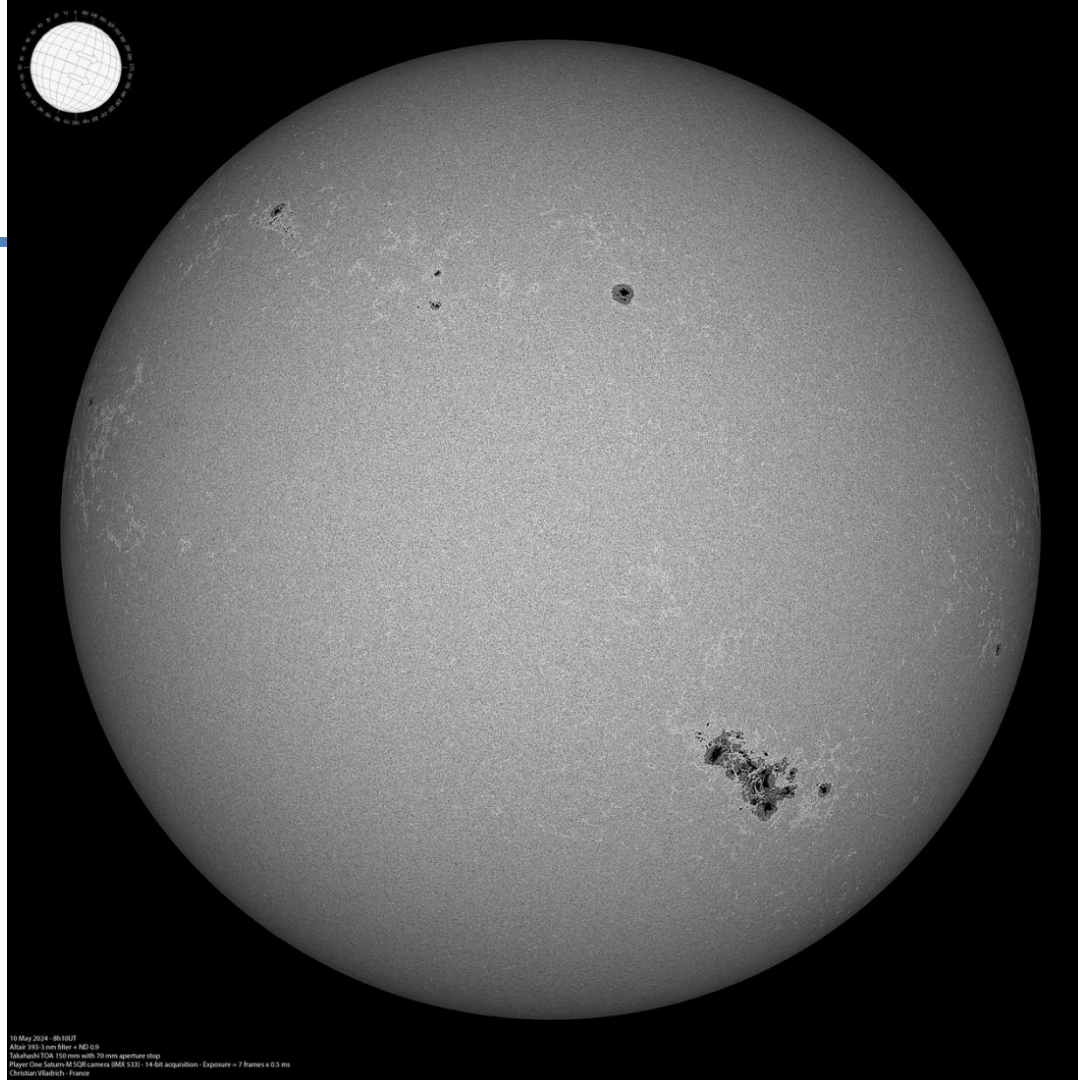
AR1476 - 11 May 2012 - 11h27mn20s UT - Takahashi TOA 150 - Ca K 393.3 nm FWHM = 0.24 nm - Baader Hershell - Taka X1.5 ED and APM X1.8 ED
Approximate scale = 0.23 arcsec / pixel - Skynyx 2.1M camera - gain = 4.8 - Exposure = 60 x 10.7 ms - 12 bits acquisition
Christian Viladrich

- Comparison of bandpass,

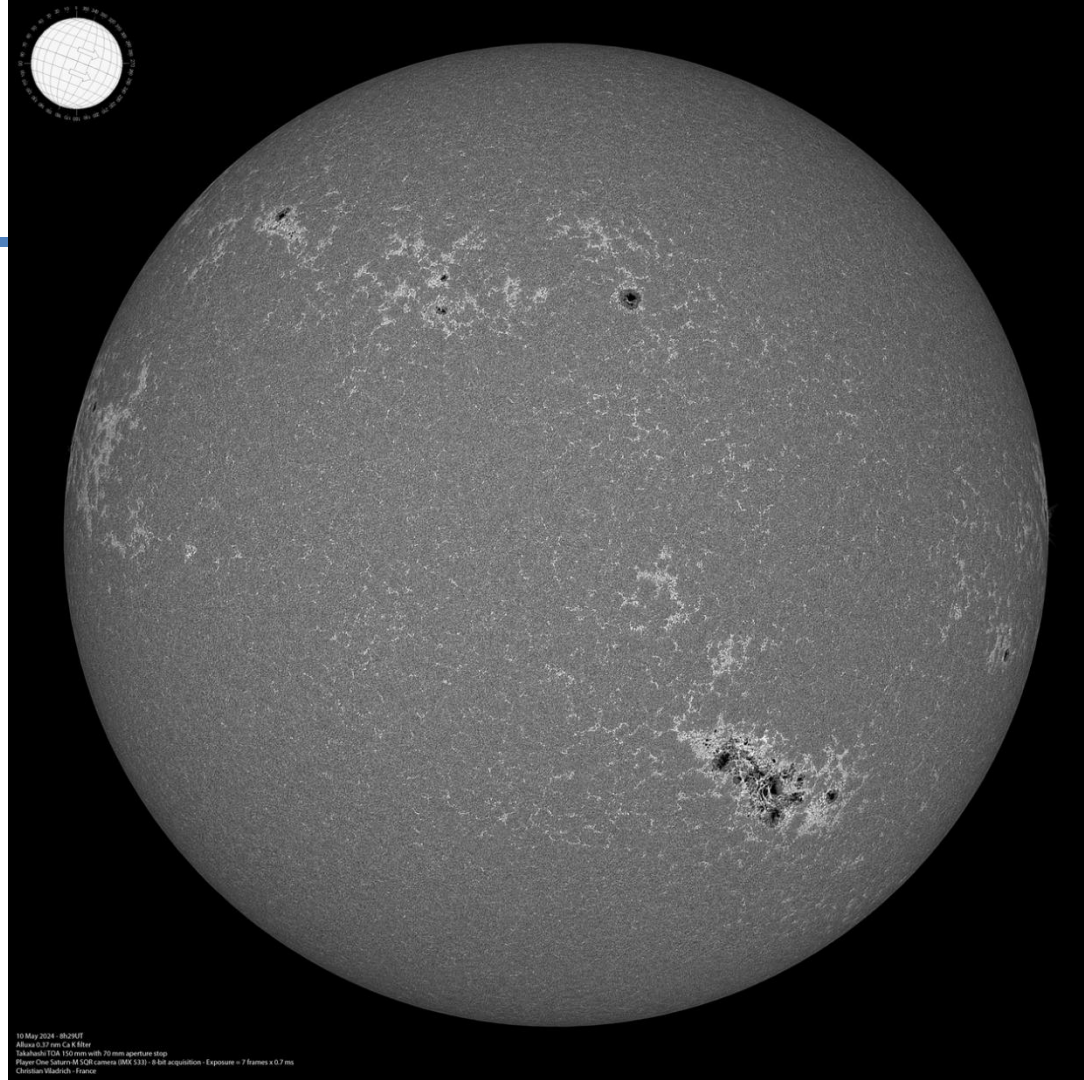
  full-disk images …

- Altair 393-3 nm.
- Photosphere.
- Normal granulation.
- Facular plages visible up to the center of the solar disk.
- Prominences faintly visible only with massive over-exposure:

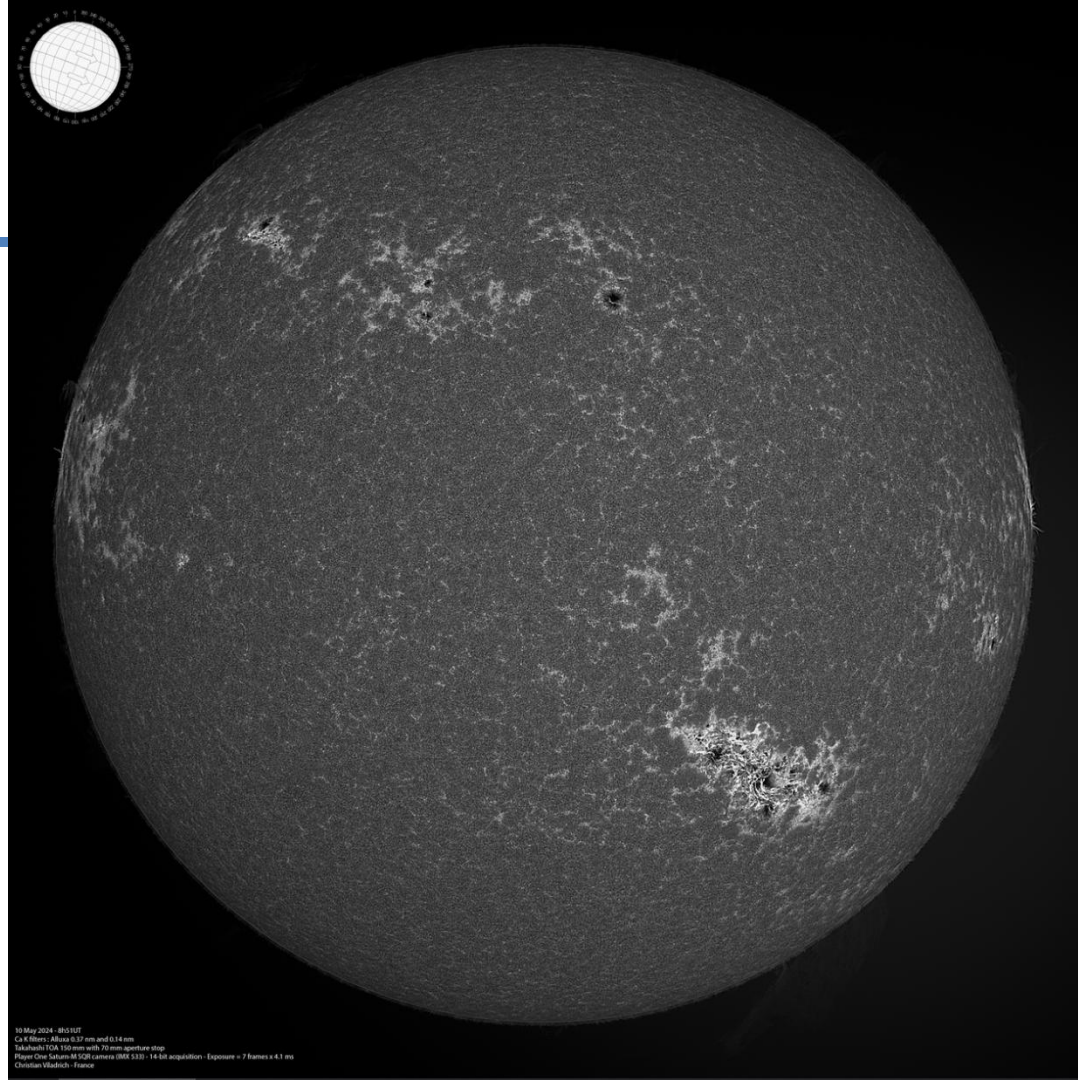




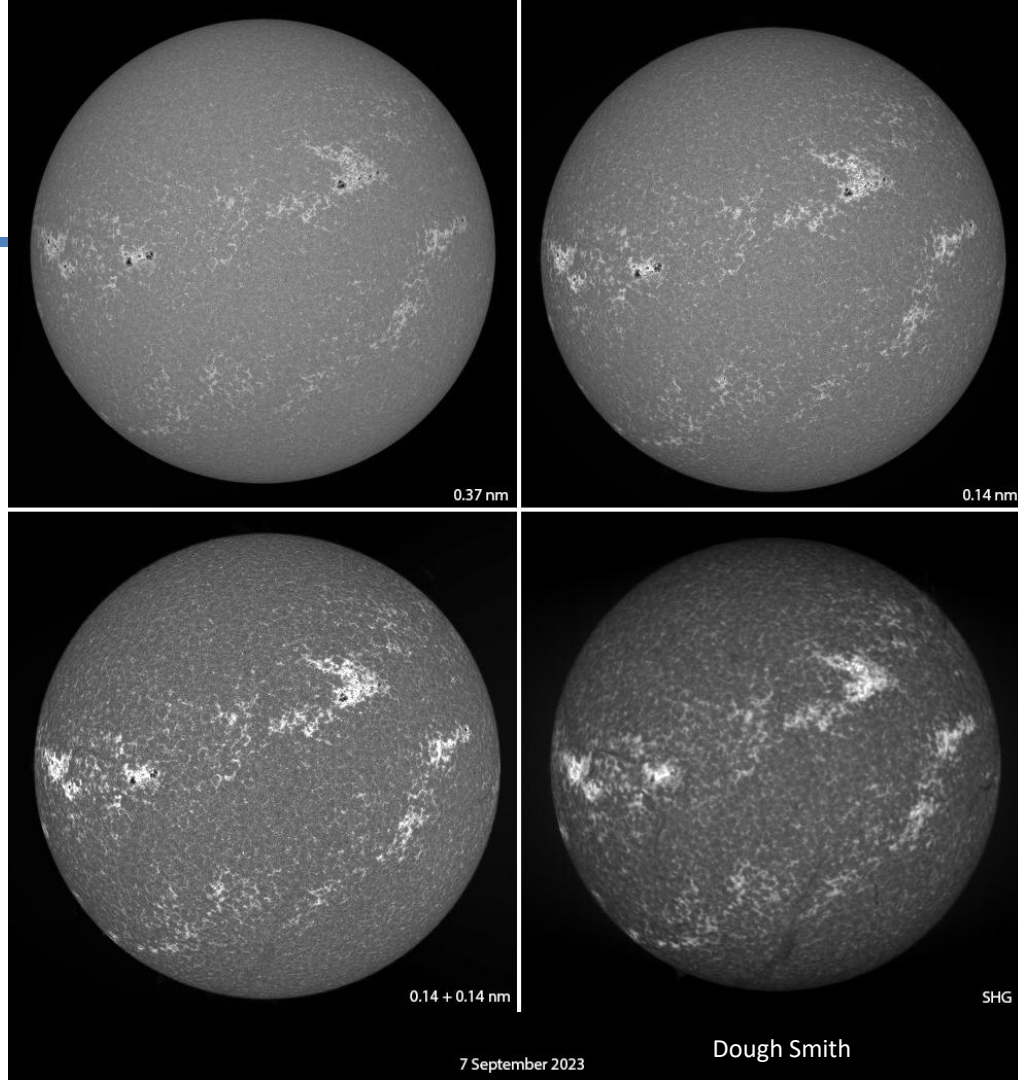
- Alluxa 0.37 nm Ca K.
- Upper photosphere/bottom of chromosphere.
- Reverse granulation.
- Facular plages.
- Flares.



- Double-stack Alluxa Ca K (0.1 nm + 0.1 nm).
- Upper chromosphere.
- Prominences visible (darker in Ca K compared to Ha).
- Filaments faintly visible.
- Fibrils visible at higher resolution.



- Filaments detection require very a narrow bandpass.
- Better with double-stack (0.1 nm + 0.1 nm).
- And much better with a SHG !



Bandpass and fibrils visibility

Difference between Ca K and H ?

- Ca K (393.37 nm) and Ca H (396.85 nm) images are strictly identical.
- However, Ca H images of the solar limb can be “polluted” by the nearby H epsilon line.
- Ca II observation is only done by imaging:
  - Most people are blind to Ca II (except young ones or older ones after cataract surgery).
  - Near-UV is not good for the retina.

Commercial offering

- We need a lot of light to keep exposure short (< 5 ms) and freeze turbulence !
- Old and **new** technology: low and high peak transmission …
- 5 Å bandpass:
  - **Antlia: dielectric filter with good peak transmission ?**
  - DayStar Quark: mica-spaced etalon, too dark for high resolution imaging.
- **Alluxa 3.8 Å:** dielectric, hard coating, 80% peak transmission, triple-cavity, excellent off-band blockage, expensive.
- 2 Å bandpass:
  - Lunt 2.4 Å.
  - DayStar PE 2 Å: too dark for high resolution imaging, very expensive.
- **Alluxa 1 Å:** dielectric, hard coating, 75% peak transmission, to be used with a blocking filter (ex:393-10 nm), can be double-stacked.
- SolarSpectrum 0.6 Å: mica-spaced etalon, too dark for high resolution imaging.

- The filter is just part of the story,

  the optics of the telescope is another …

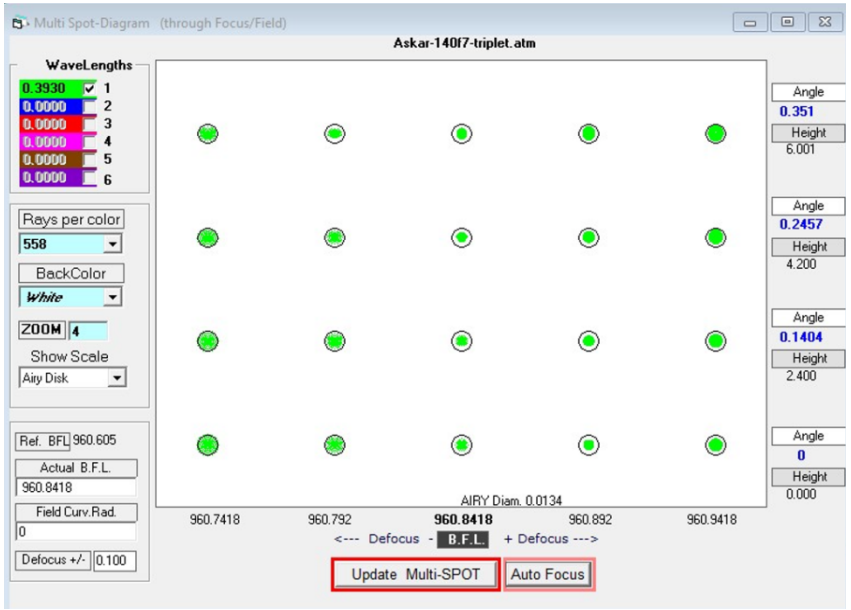
Ca K/H is a challenge for optics

- Most refractors are optimized for green light (some for red) and have poor performance in the blue, and even worse in the near-UV. This is not about chromatic aberration (different focus positions for blue and red), but about spherical aberration.
- Smaller diameters and larger f-ratios are better in near-UV.
- Most practical solution is to stop down the aperture (to about 60-40%).
- The other option is to increase the distance between the two lenses of the objective:
  - SkyWatcher EvoStar 150/1200 needs a 3.2 mm respacing,
  - SkyWatcher EvoStar ED102/900 needs a 1.6 mm respacing (source: SkyWatcher USA).
- Ideal telescopes for Ca II: all-mirror telescopes (Newton, Cassegrain and its variant).

Askar 140 mm f/7 triplet

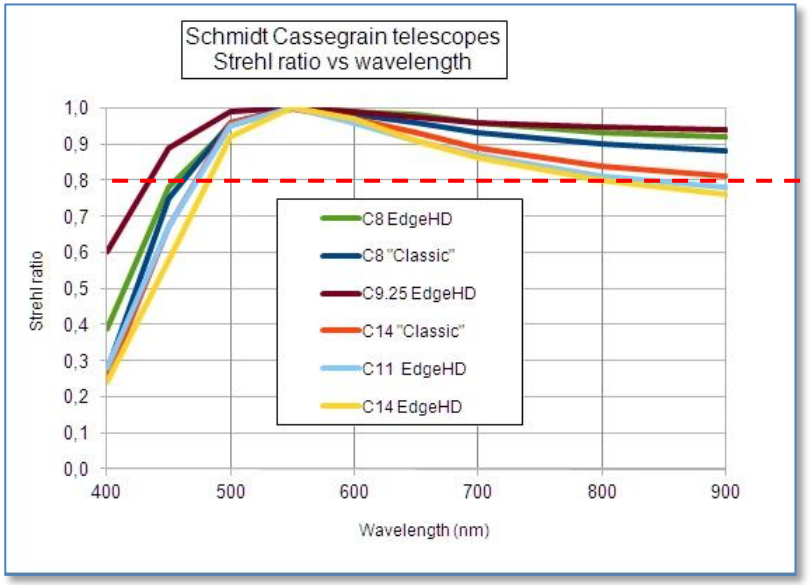
Full-aperture = very bad images in Ca II.

70 mm aperture stop = diffraction limited.

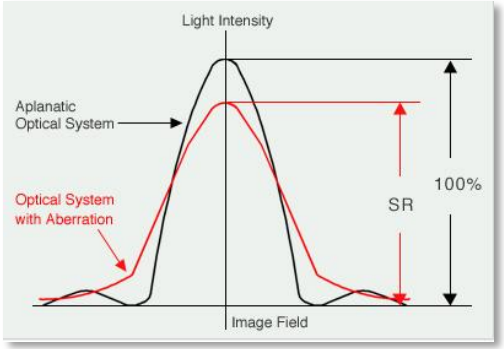


Schmidt-Cassegrain don’t like Ca K

- Strong spherical aberration in the near-UV:



Strehl ratio should be > 0.8 to have diffraction-limited images



Atmosphere is also more challenging in Ca K/H

- Turbulence increased by 1.9 × in Ca K/H compared to Hα (proportional to $\lambda^{1.2}$).
- Exposure time to freeze turbulence is 1.9 × shorter in Ca K/H compared to Hα.

Still, there is a good news

- We don’t need a large aperture for Ca K/H.
- Because diffraction is smaller in Ca K/H compared to Hα:
  - a 60 mm telescope in Ca K has the same resolution as a 100 mm in Ha,
  - a 100 mm telescope in Ca K has the same resolution as a 166 mm in Ha,
  - a 150 mm telescope in Ca K has the same resolution as a 250 mm telescope in Ha.
  - provided optics and seeing are good …

	Résolution (seconde d'arc)	1,4"	1,0"	0,8"	0,55"	0,41"	0,33"	0,28"
Ca K	Diamètre (mm)	60	80	100	150	200	250	300
Hα	Diamètre (mm)	100	133	166	249	332	415	498

- This is not yet the end of the story,

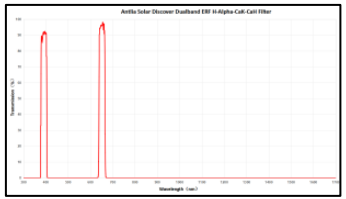
how to deal with the solar heat?

Options to deal with solar heat

- Astrosolar ND 3.8 (1/6300 transmission):
  - too dark for Ca K imaging,
  - However, OK for a 10 nm FWHM filter (continuum and others).
- Solar wedge:
  - transmission 5% (ND 1.3),
  - much better, OK for “wide” Ca K filter with high peak transmission, but a bit dark for a 1 A filter (and too dark for double-stack).

Optimal configurations (including double-stack 1 A Ca K):

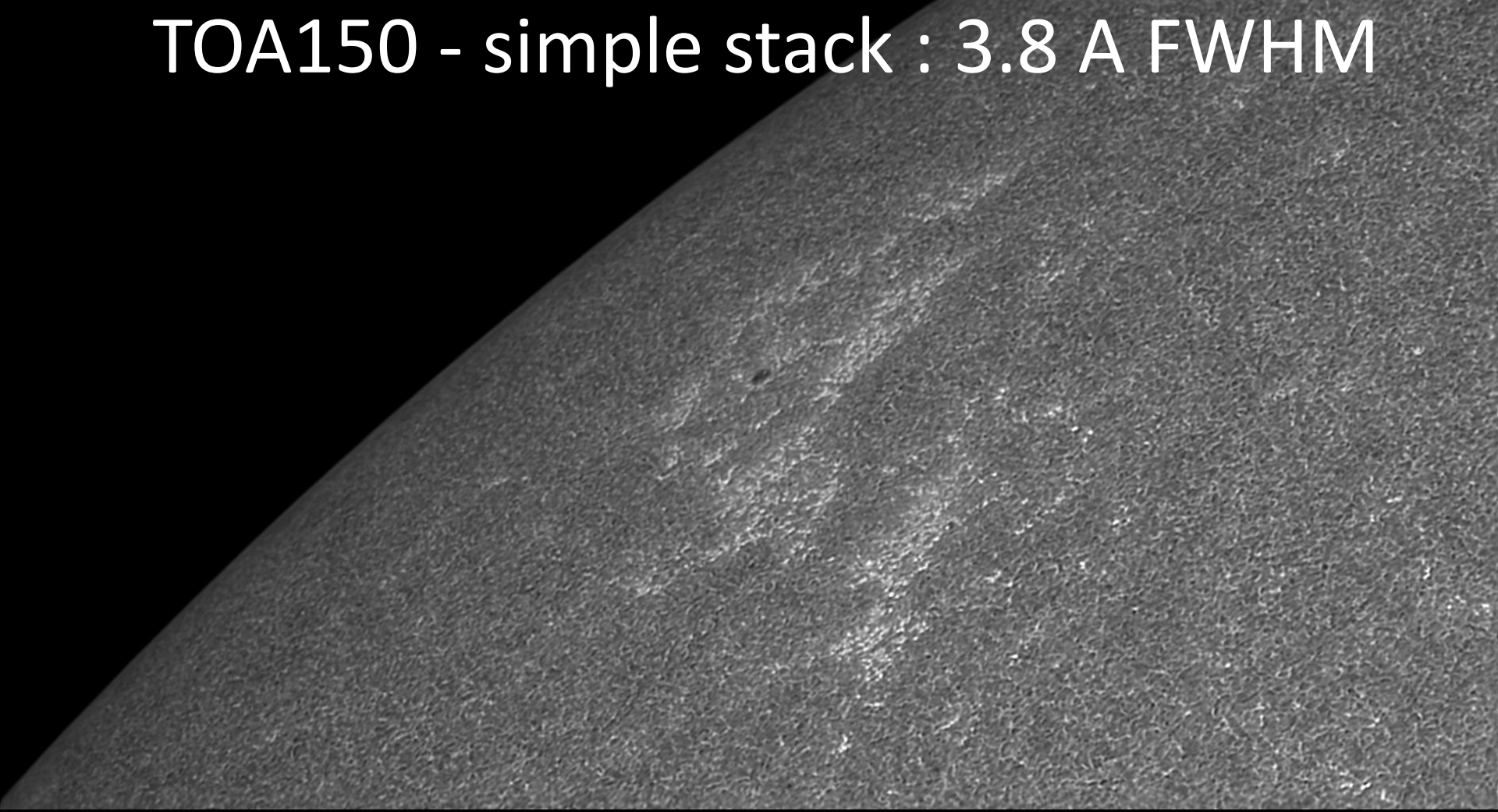
- Dual-band ERF (Ha + Ca K) in front of telescope aperture:
  - Altair: up to about 240 mm.
  - Antlia: up to 200 mm.



- And/or a 50 mm blue filter in internal position = sub-aperture ERF (with possible use of a 393-10 nm filter as an additional protection in front of the Ca K filter).

- What about Ca K double-stack with the Takahashi TOA150 refractor…

TOA150 - simple stack : 3.8 A FWHM



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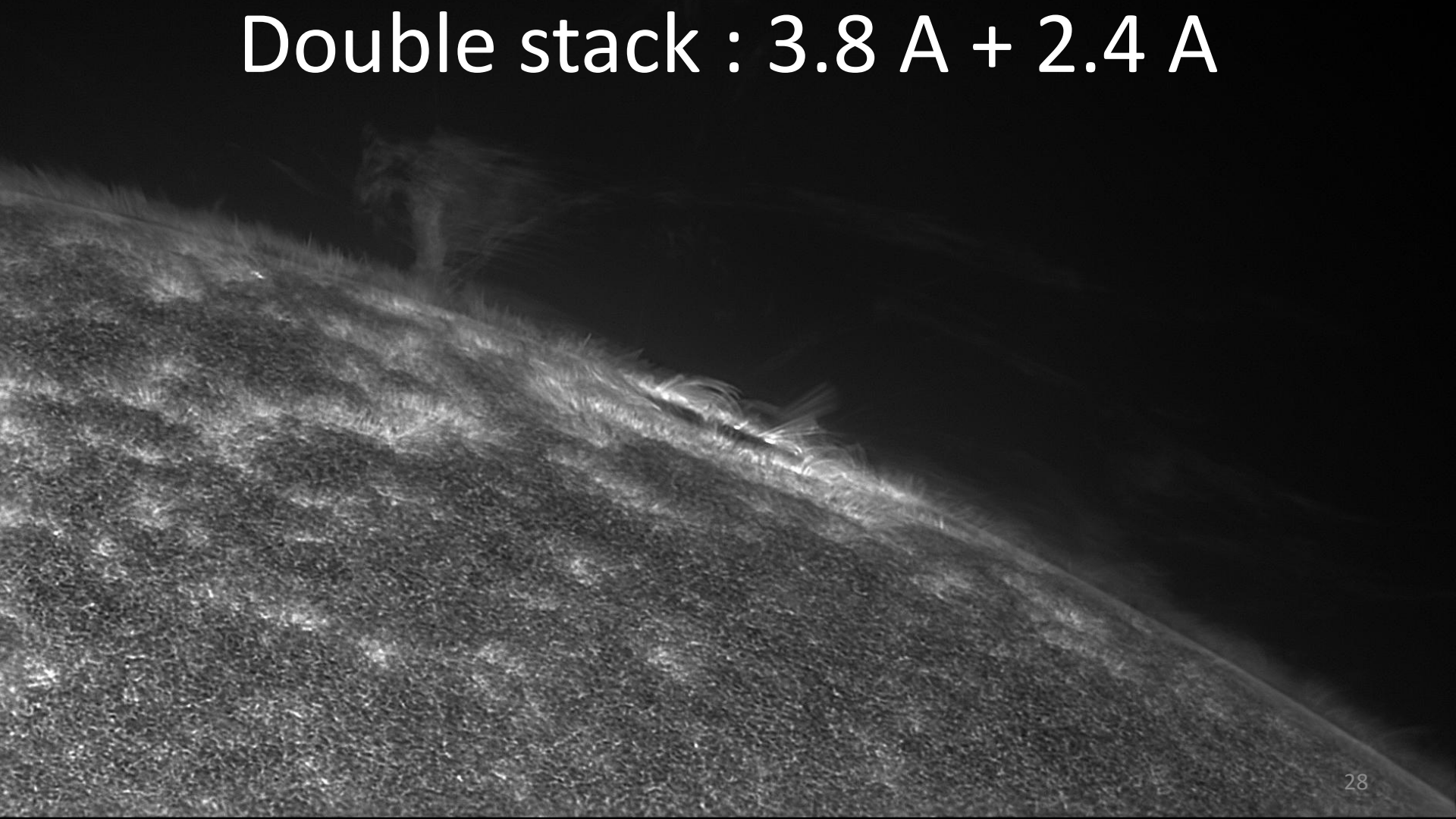
31 May 2020 - 8h40min UT - Takahashi TOA 150 - 50 mm sub-aperture blue ERF - EO 394-10 nm filter - Ca K Alluxa filter 393.44-0.37 nm
Scale : 0.18 arcsec/pixel - ASI290 camera - Exposure : 60 frames x 01.2 ms - Solar Scintillation Monitor (Min/Avg/Max) : 0.65 / 1.01 / 1.41 arsec

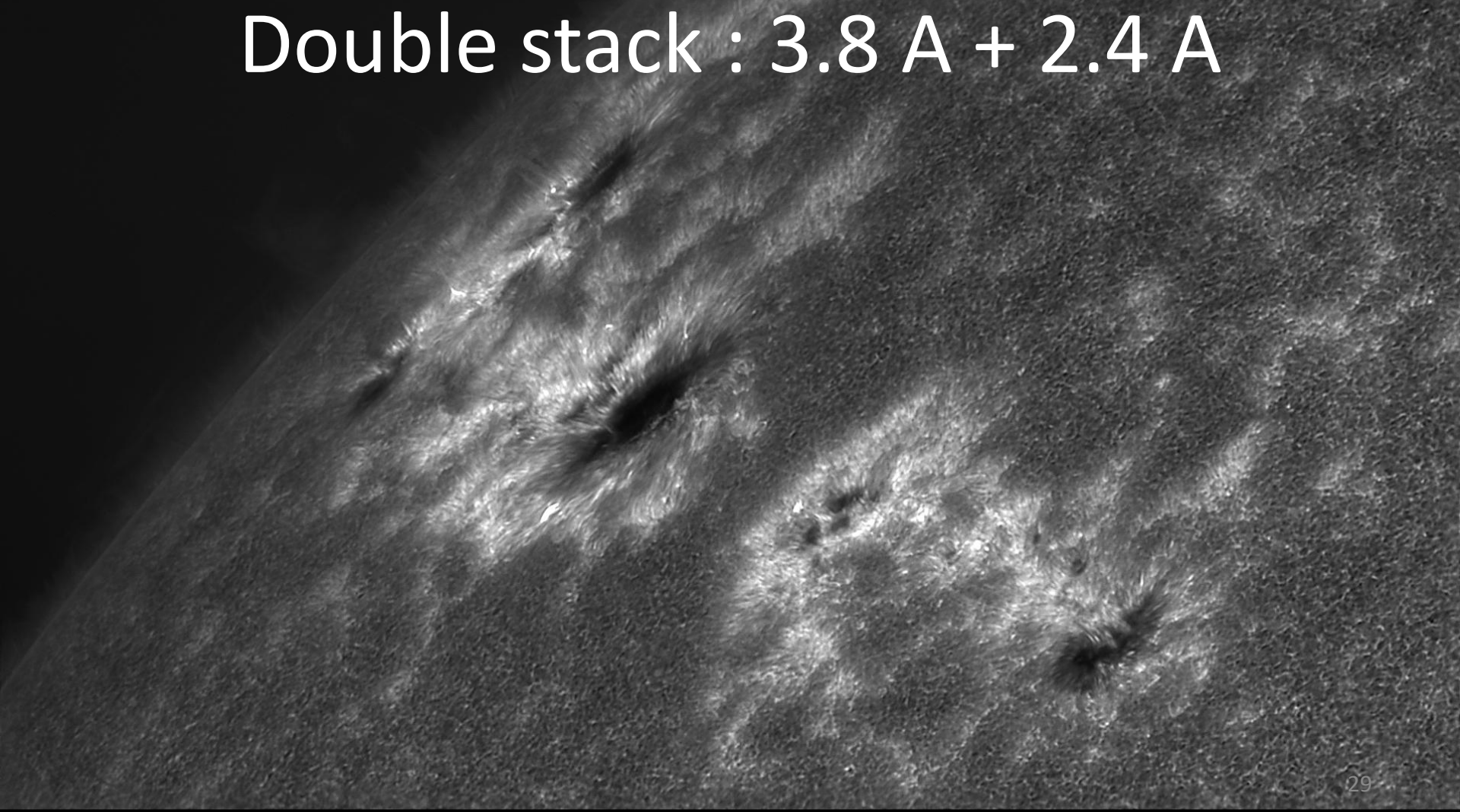
Double stack : 3.8 A + 2.4 A

58min UT - Takahashi TOA 150 - 50 mm sub-aperture blue ERF - EO 394-10 nm filter - Barr filter 393.25-0.24 nm - Alluxa filter 393.44-0.37 nm
csec/pixel - ASI290 camera - Exposure : 120 frames x 6 ms - Gain = 100 - Solar Scintillation Monitor (Min/Avg/Max) : 0.37 / 0.81 / 1.85 arsec

Double stack : 3.8 A + 2.4 A



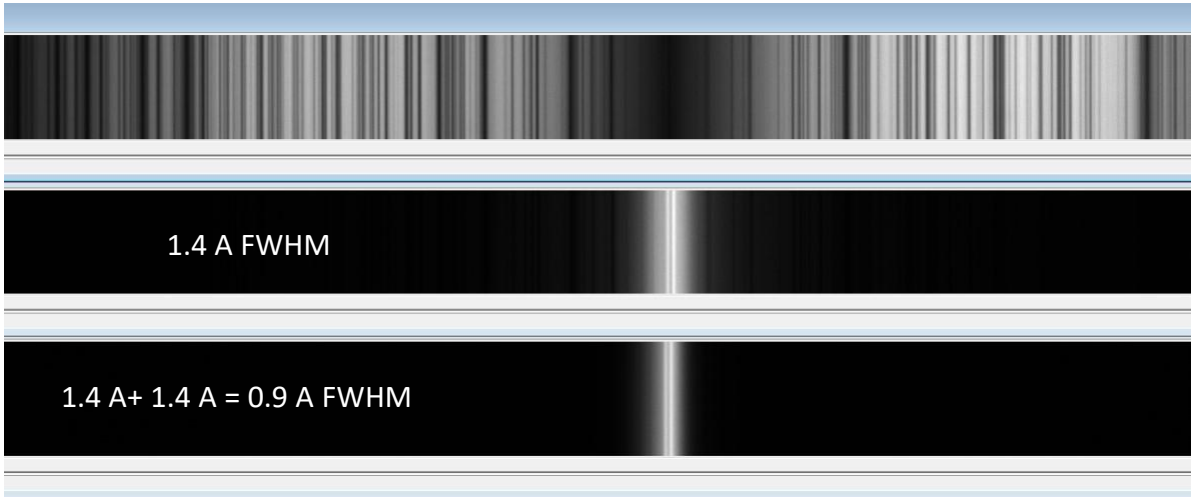
Double stack : 3.8 A + 2.4 A

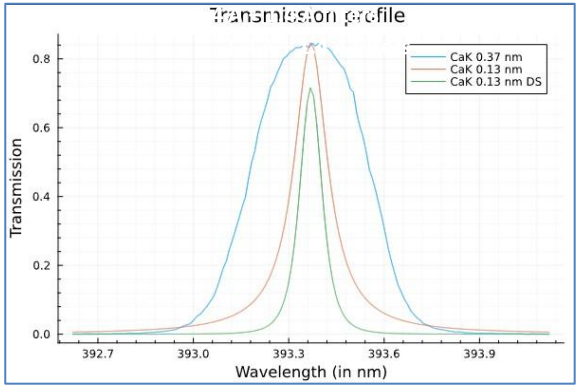


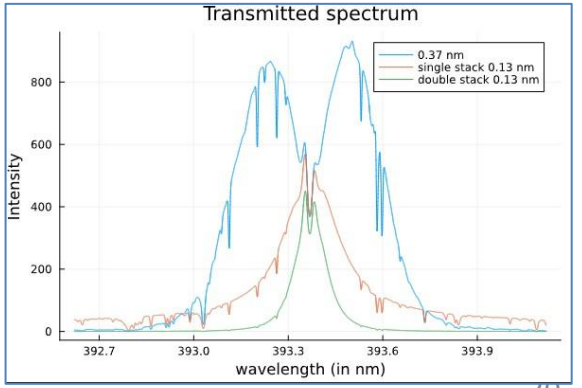
AR3075 - 24 March 2022 - 10h30 UT - Takahashi TOA 150 - Baader Planetarium FFC - Double stack Ca K combination: Barr Associates 0.24 nm + Alluxa 0.40 nm

Alluxa 0.1 nm from simple to double-stack

- Benefit of double-stacking is not to reduce the FWHM, but to cut down the parasitic light transmitted by the wings of transmission (coming from the photosphere).
- The transmission profile of the double-stack is steeper.



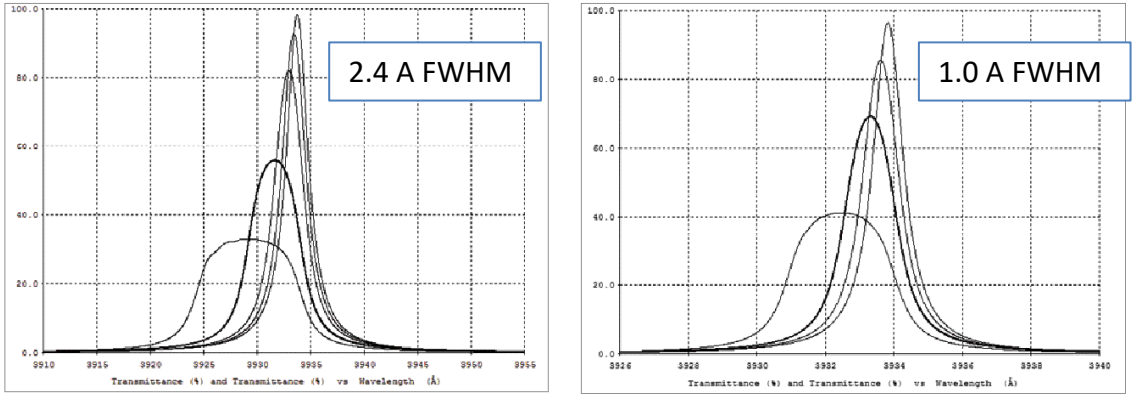




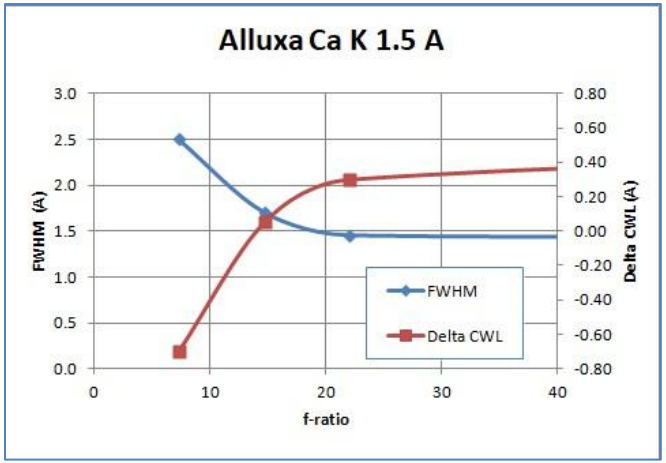
- Getting the most from narrowband Ca K filters …

Effective FHWM = f (f-ratio)

- Effective FWHM increases when f-ratio decreases.
- Best f-ratio for 0.1 to 0.2 nm Ca K filters ≥ f/15

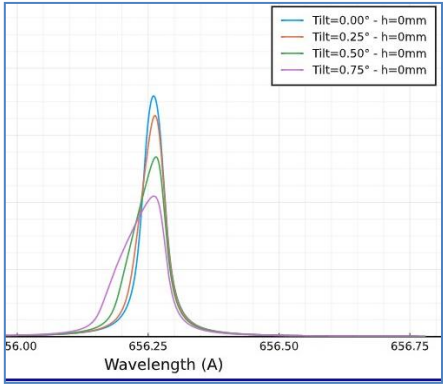


7.33 *Left: simulation of the transmission curve of a 0.24 nm Ca K filter for f-ratios of 30, 20, 15, 10 and 7. As the f-ratio decreases, the effective bandpass increases (0.34 nm at f/15, 0.5 nm at f/10, and 1.0 nm at f/7), the central wavelength shifts toward the blue, and the peak transmission decreases. Right: simulation of the transmission curve of a 0.10 nm Ca K filter for f-ratios of 30, 20, 15 and 10. Source: Mark Wagner, SolarSpectrum.*



Tuning Ca K 1 A filter(s) by tilt

- Tilting the filter:
  - shifts the bandpass to the blue (and possibility pushes reflections away the field of view).
  - however, the FWHM is increased and peak transmission decreases.



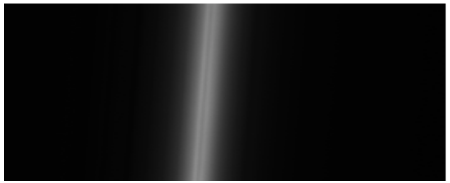
- Tuning a single-stack: look for darkest image.
- Tuning a double-stack: tune each filter in turn, then possibly fine tuned #2 mounted on #1.
- How to deal with reflections in double-stack configuration:
  - Try increasing distance between both filters.
  - Telecentric lens seems to behave better than Barlow lens.

Tuning the 1 A Ca K filter by heating

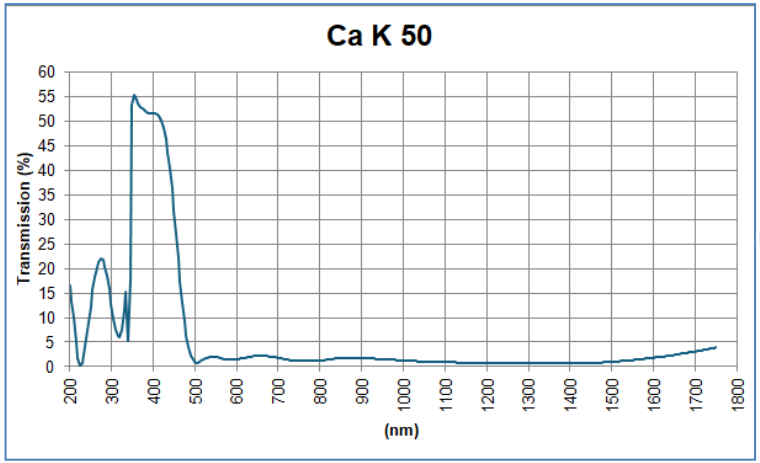
- Alluxa 1 A Ca K temperature coefficient = 0.04 A/10°C.

CWL drift =	0.04	A/°C
Température	Delta CWL (A)	
4	-0.6	
10	-0.4	
15	-0.2	
20	0.0	
25	0.2	
30	0.4	

- Low-tech home-made regulator:
  - Less than 50 €.
  - Heating band wrapped around T2 tube.
  - Digital thermo-regulator including temperature sensor and temperature display.
  - Accurate enough for double-stack 0.1 nm Ca K filter (+/-0.5 C = +/-0.2 A).
  - Use of a modified SHG700 to set the temperature right on Ca K center.
  - NB: both Ca K filters have about the same nominal temperature.



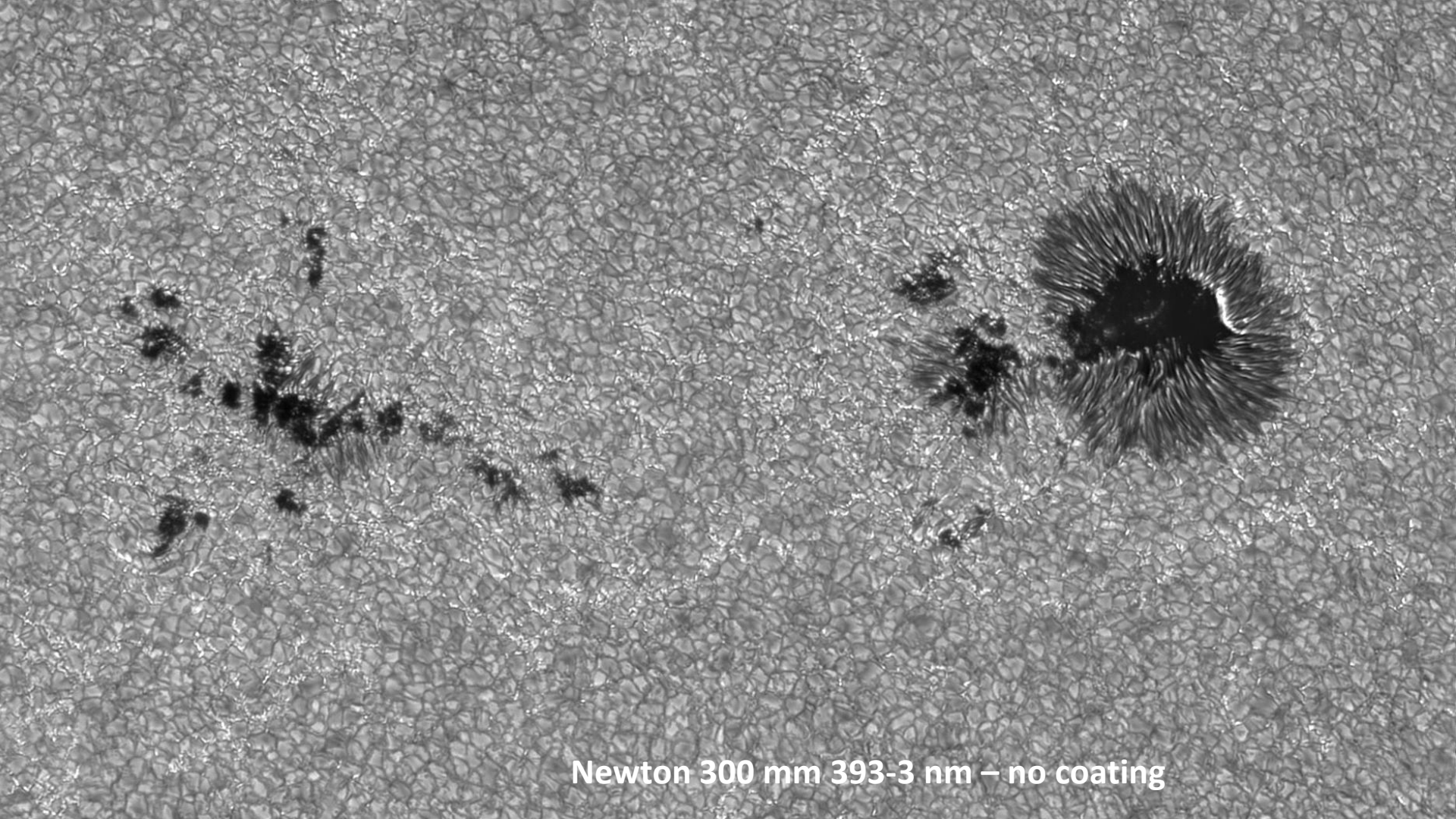
Looking for higher resolution: Soleye CAK50 coating

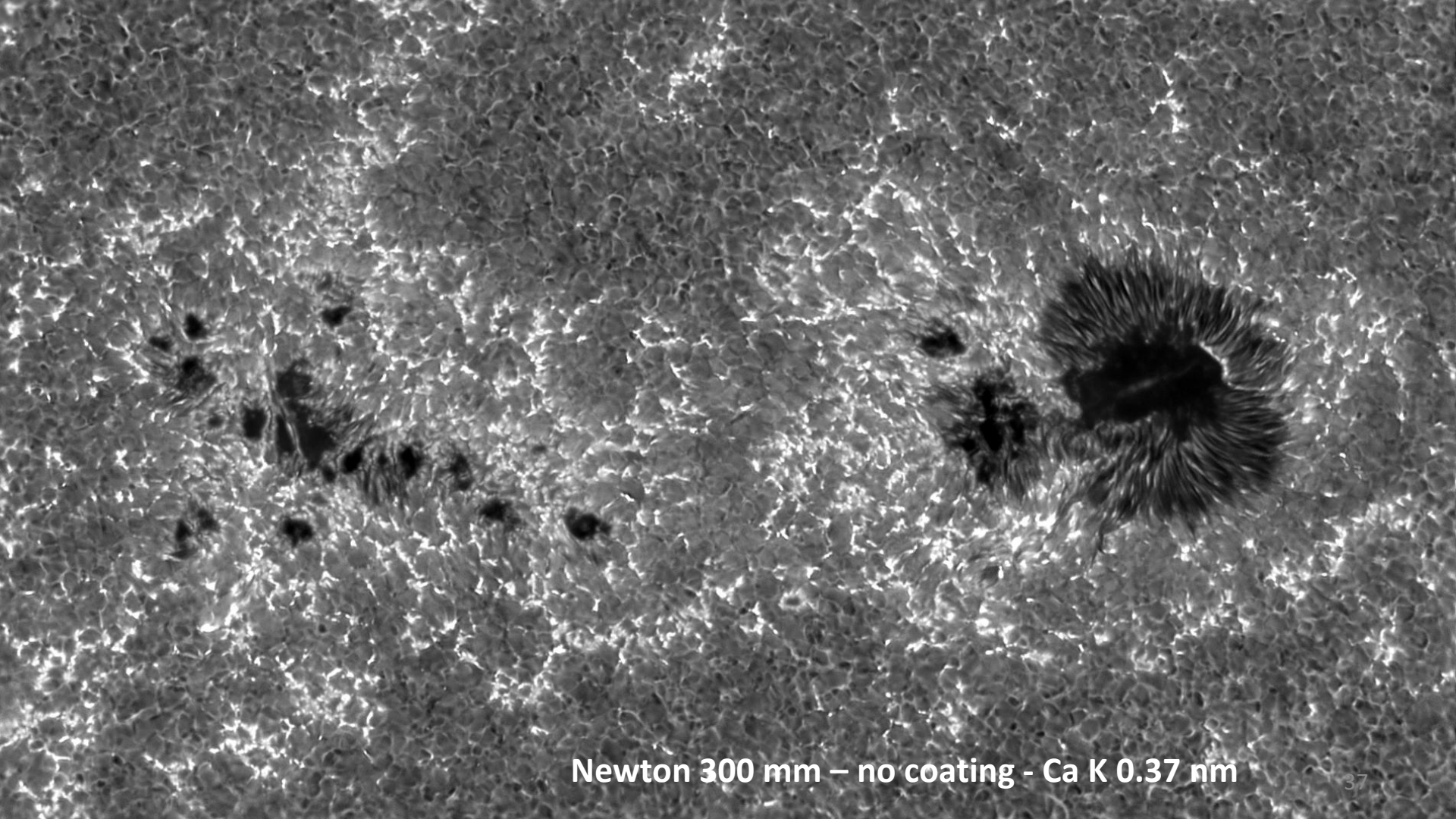


- Only 8.8 watt at the focus of the 300 mm Newtonian.
- TZ3-s telecentric protected by an Altair 393-3 nm filter.

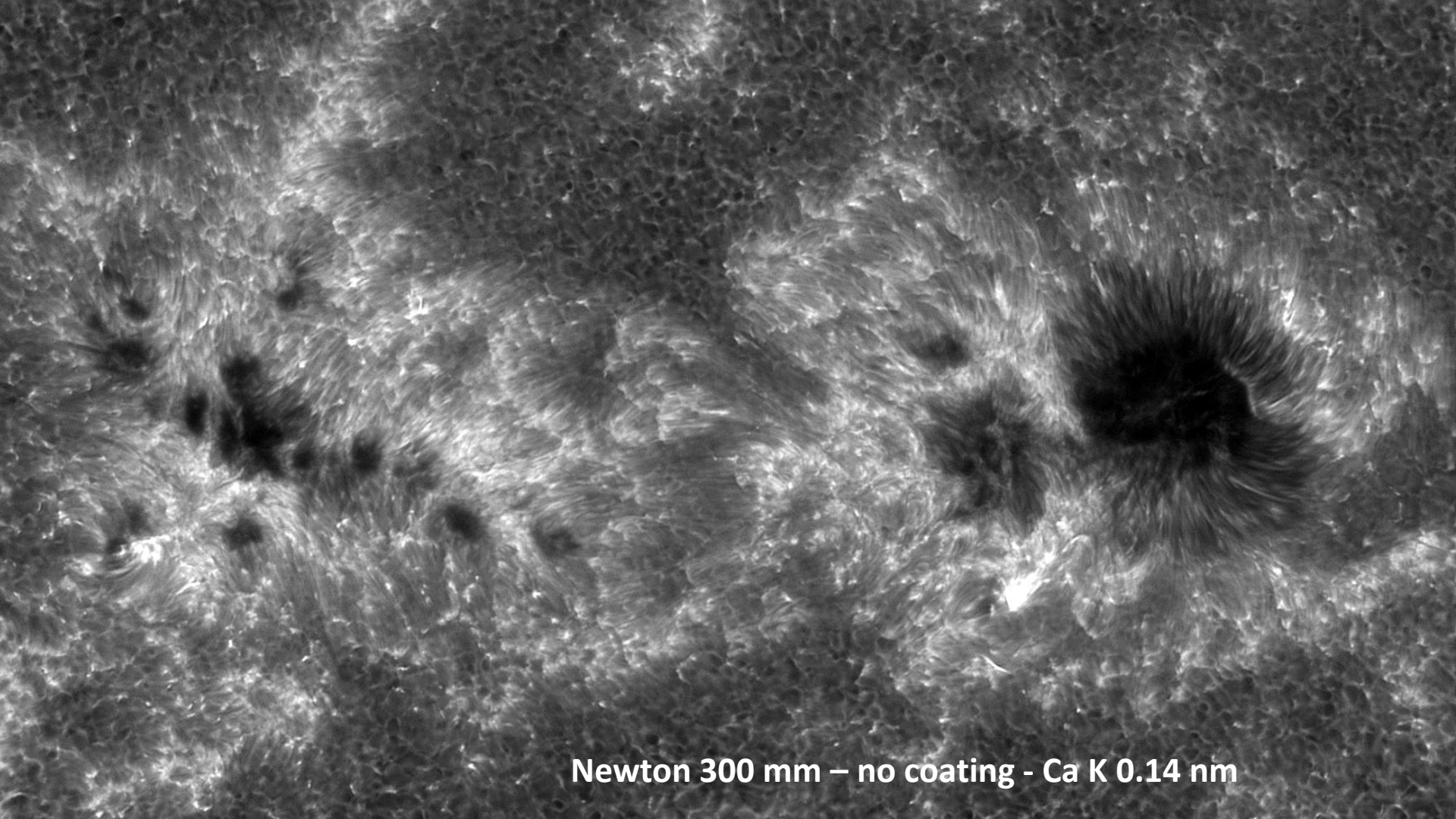
```
coating CaK50 - space
total energy      =  111.7 W.m^-2 100.0 %
band 280_400nm    =   35.6 W.m^-2  31.8 %
band 400_700nm    =   58.4 W.m^-2  52.3 %
band 700_1100nm   =    5.3 W.m^-2   4.8 %
band 1100_4000nm  =   13.4 W.m^-2  12.0 %
ERF filter transmission coefficient= 8.3 %
```

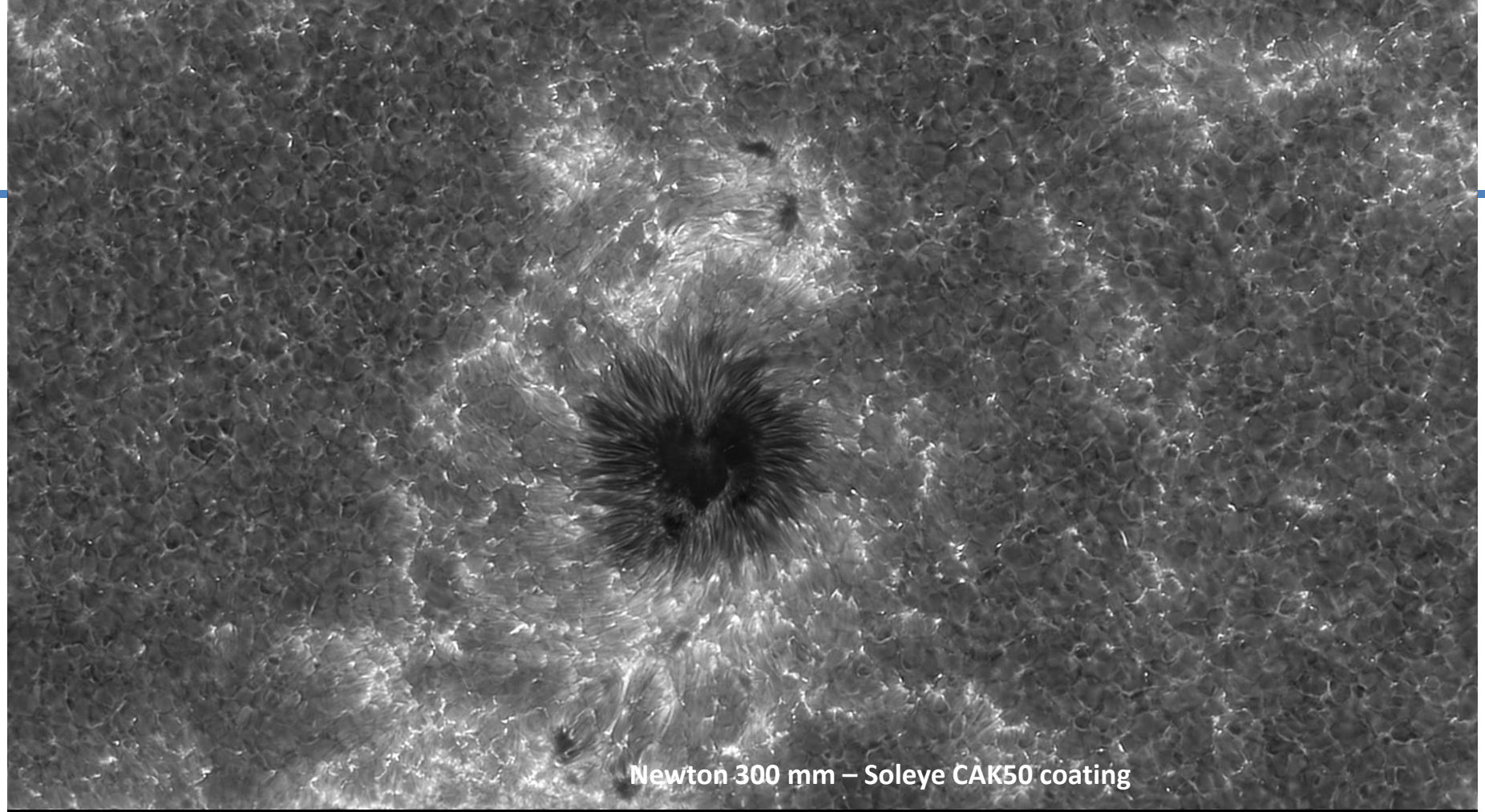
```
filtre bleu Astronomik - space
total energy      =  390.1 W.m^-2 100.0 %
band 280_400nm    =   14.8 W.m^-2   3.8 %
band 400_700nm    =  173.9 W.m^-2  44.6 %
band 700_1100nm   =    5.8 W.m^-2   1.5 %
band 1100_4000nm  =  197.3 W.m^-2  50.6 %
ERF filter transmission coefficient= 28.9 %
```


Newton 300 mm 393-3 nm – no coating



Newton 300 mm – no coating - Ca K 0.37 nm


Newton 300 mm – no coating - Ca K 0.14 nm



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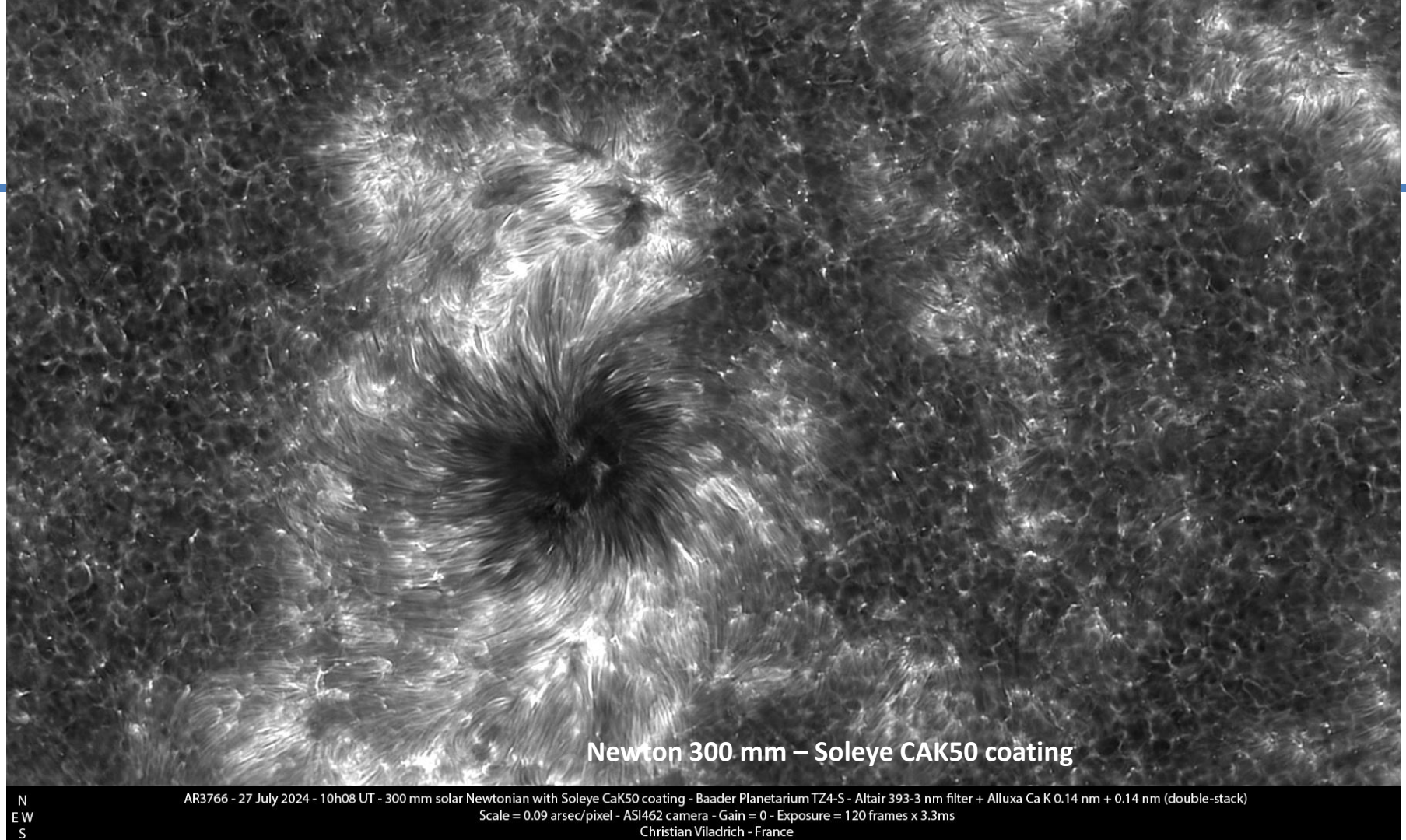
AR3766 - 27 July 2024 - 8h17 UT - 300 mm solar Newtonian with Soleye CaK50 coating - Baader Planetarium TZ4-S - Altair 393-3 nm + Alluxa Ca K 0.14 nm
Scale = 0.09 arsec/pixel - ASI464 camera - Gain = 0 - Exposure = 120 frames x 1.5 ms
Christian Viladrich - France



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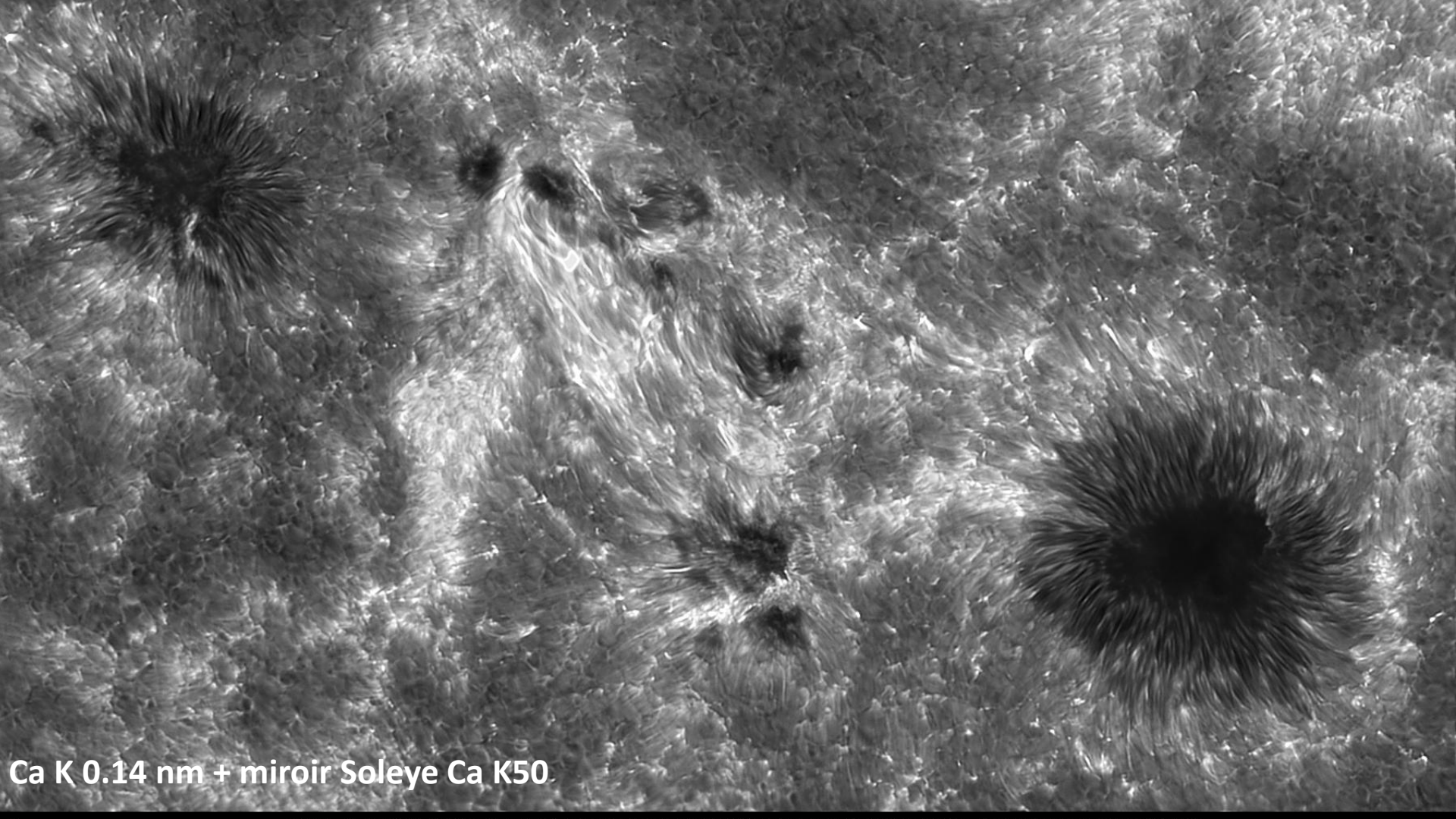
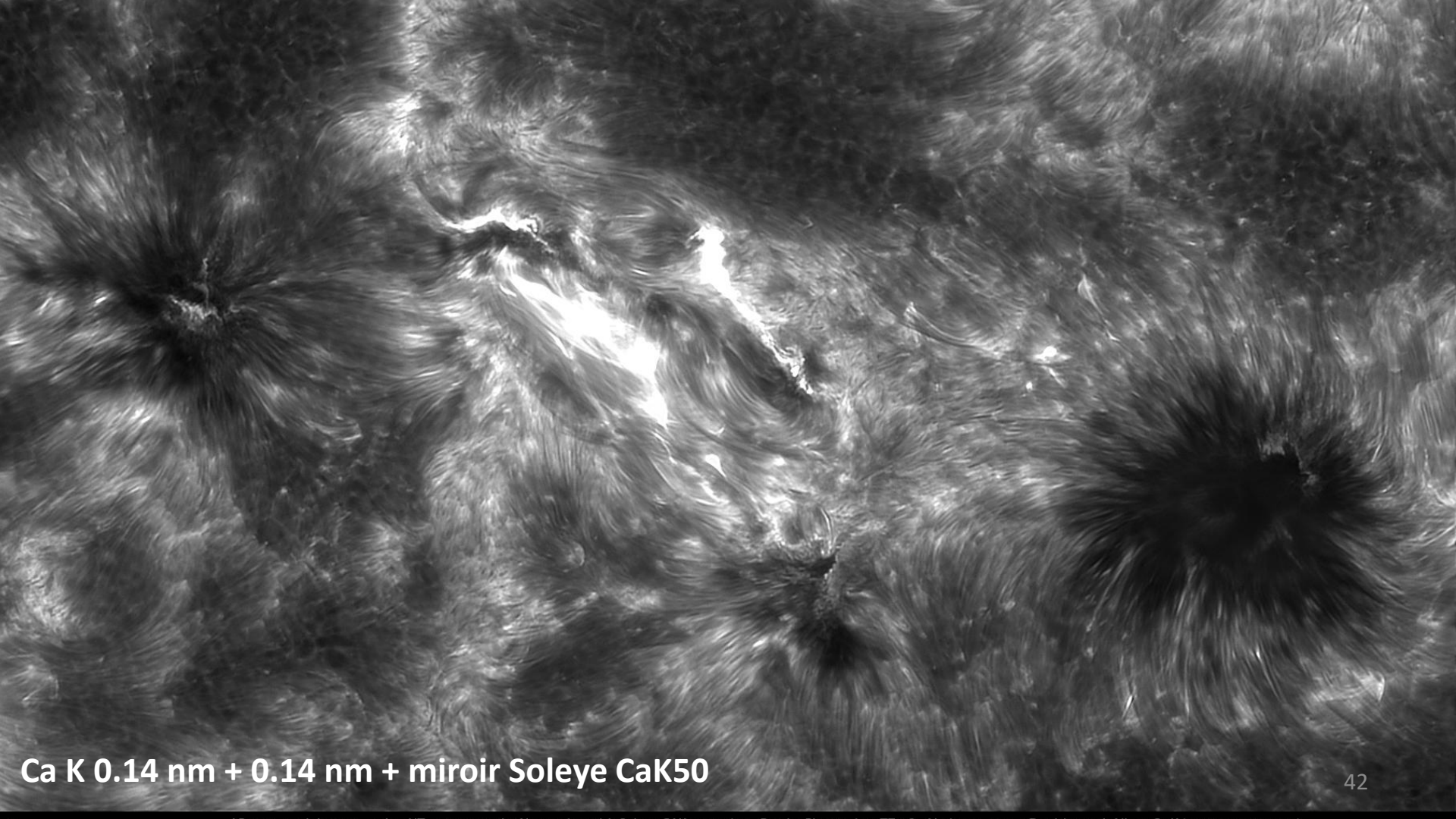
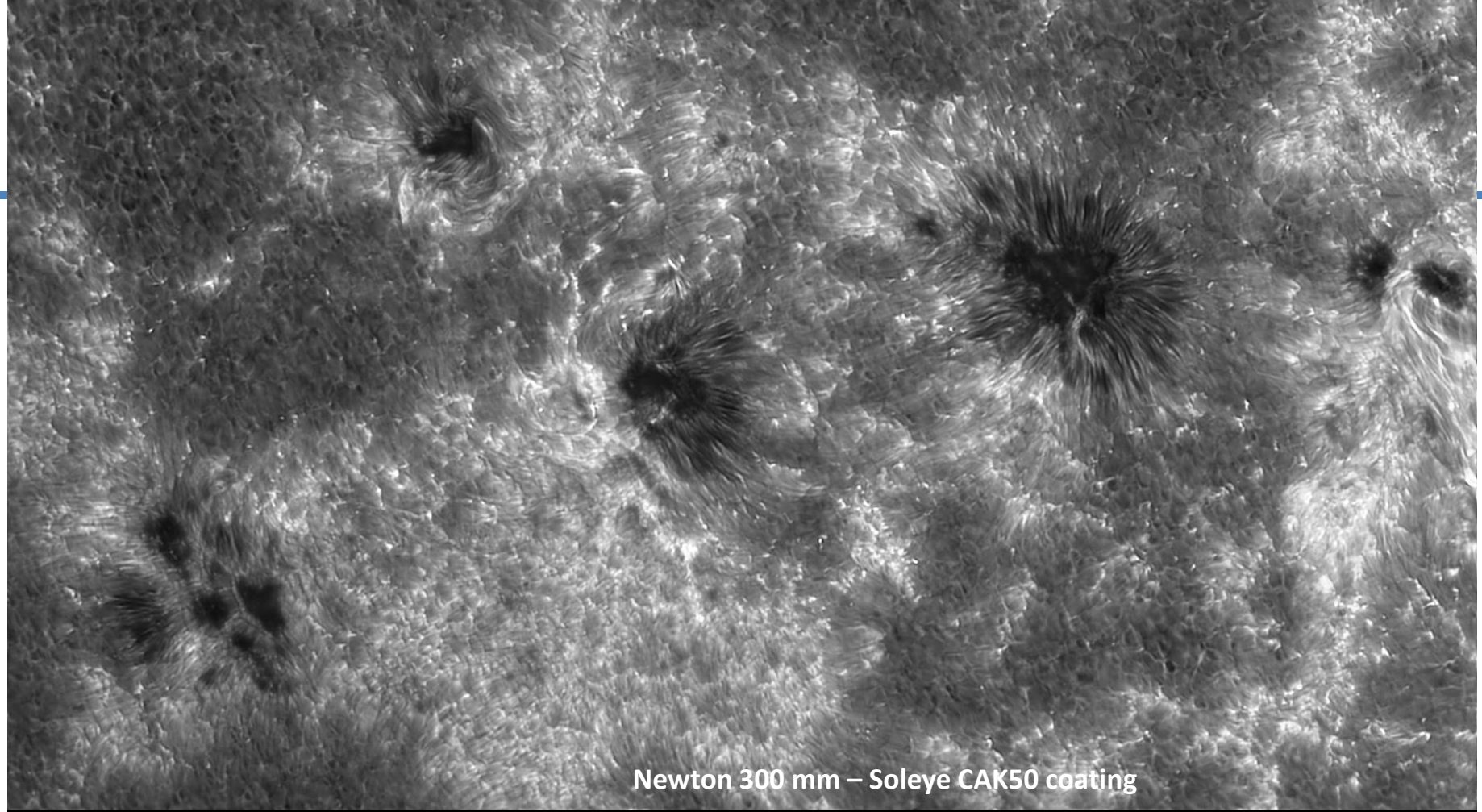
AR3766 - 27 July 2024 - 10h08 UT - 300 mm solar Newtonian with Soleye CaK50 coating - Baader Planetarium TZ4-S - Altair 393-3 nm filter + Alluxa Ca K 0.14 nm + 0.14 nm (double-stack)
Scale = 0.09 arsec/pixel - ASI462 camera - Gain = 0 - Exposure = 120 frames x 3.3ms
Christian Viladrich - France


Ca K 0.14 nm + miroir Soleye Ca K50



Ca K 0.14 nm + 0.14 nm + miroir Soleye CaK50



N
E W
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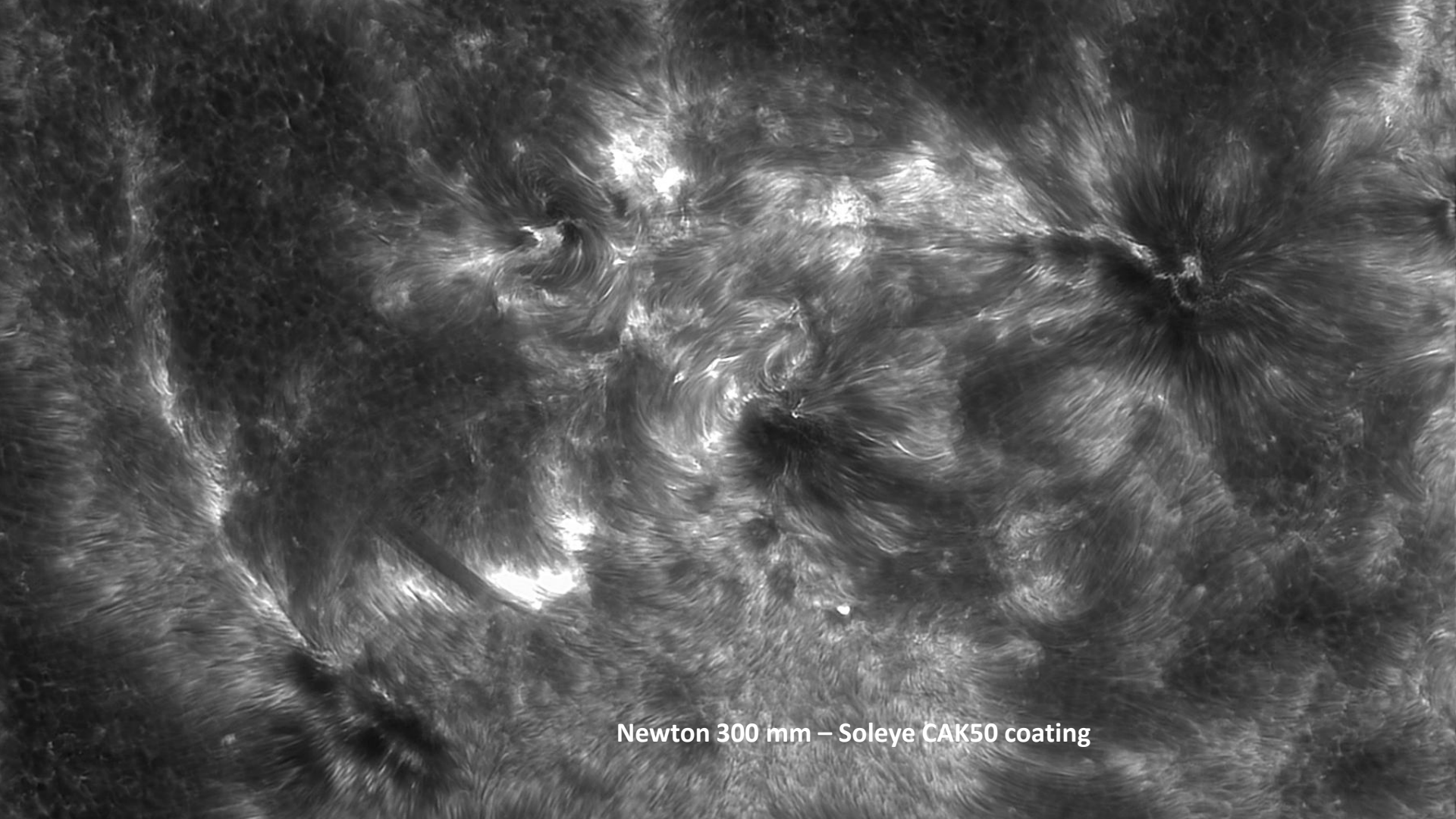
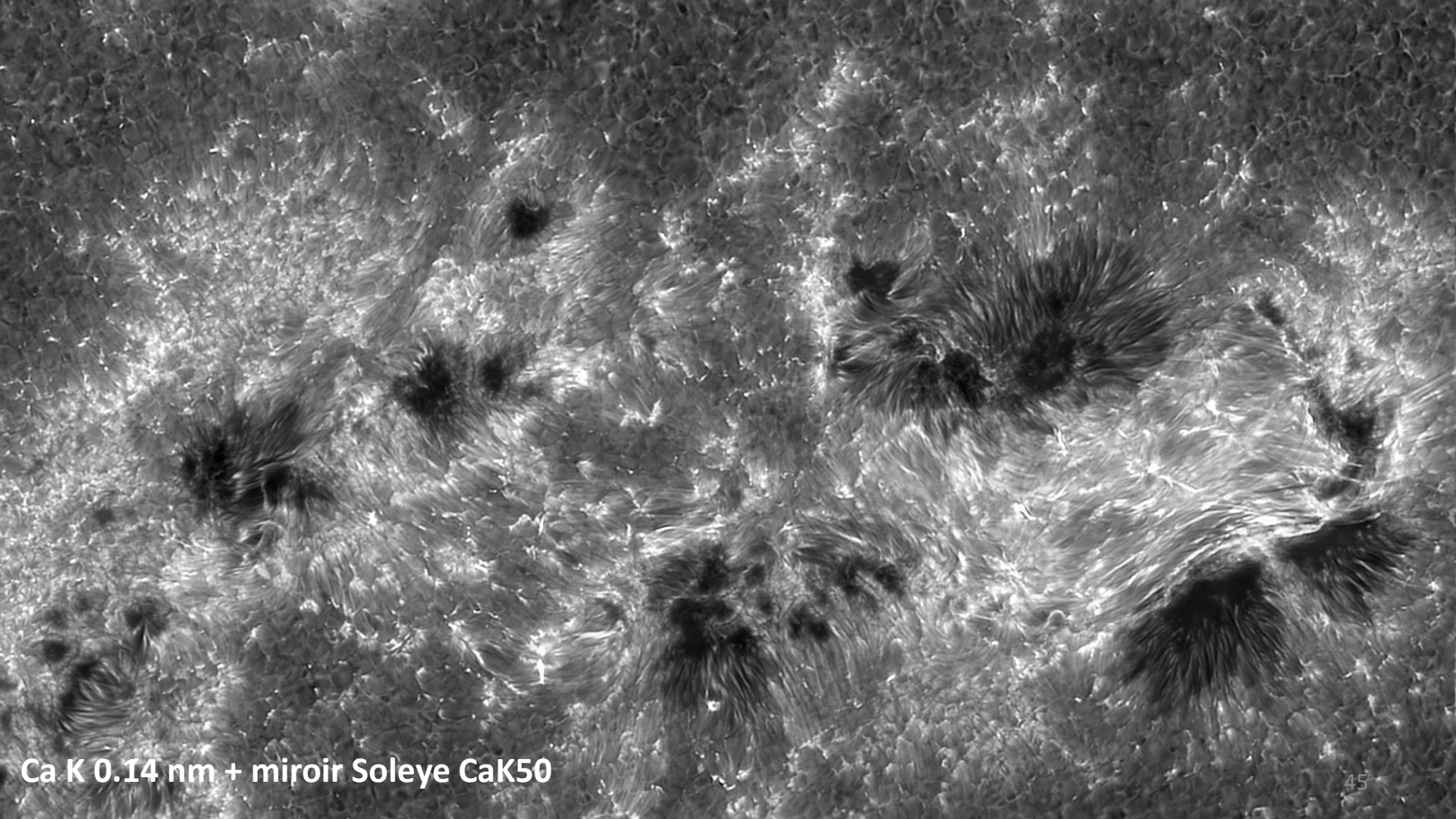
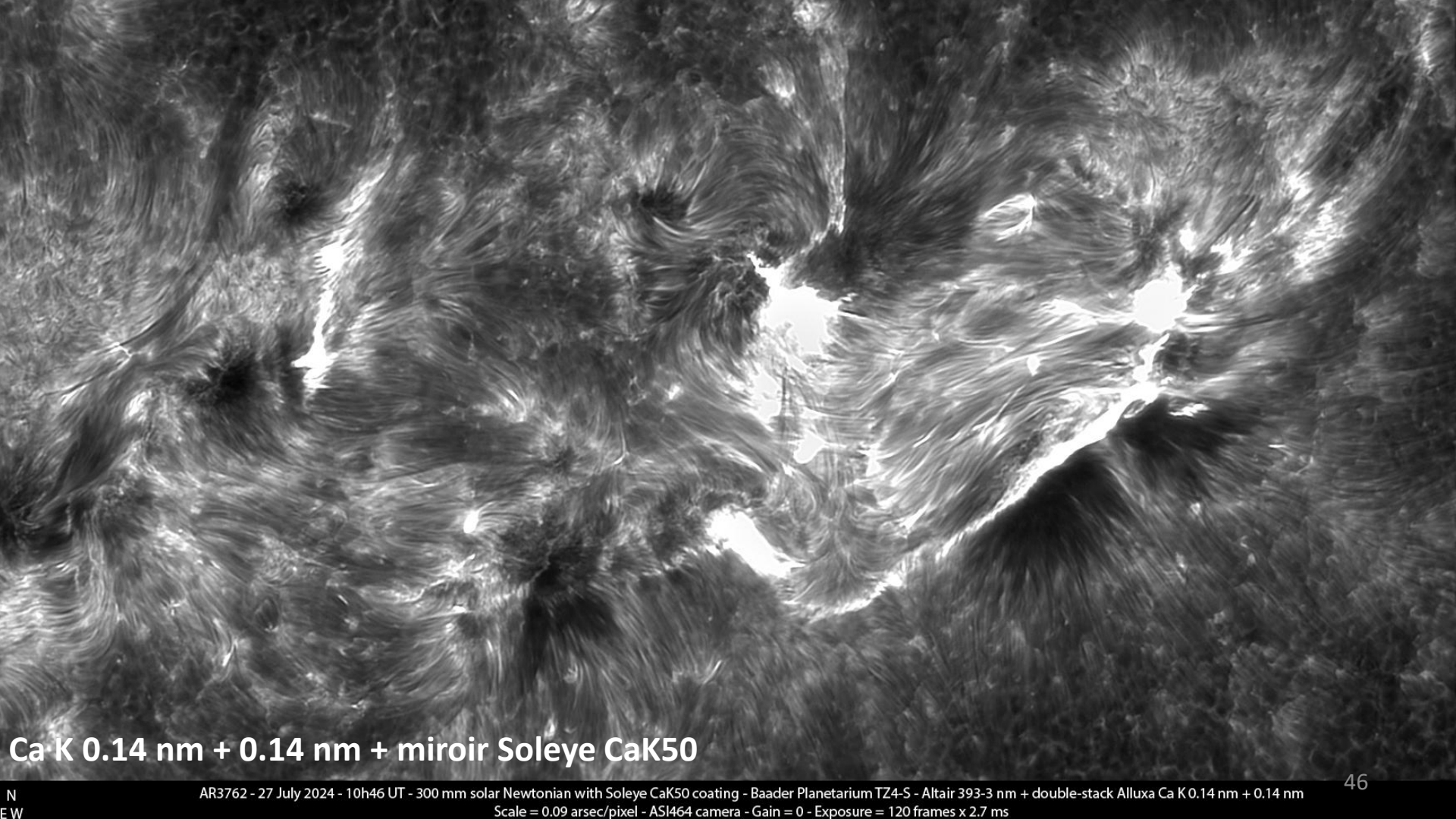
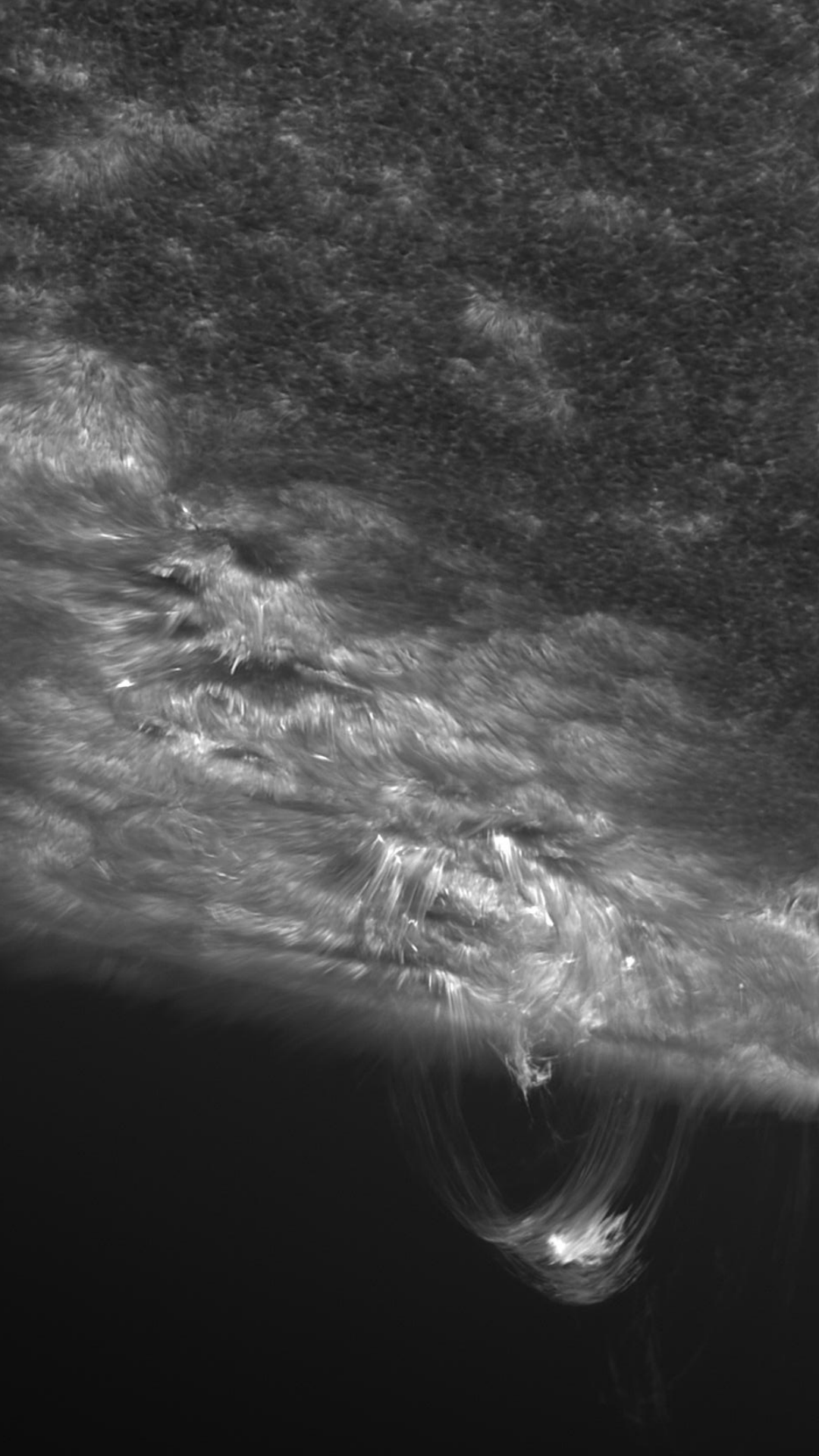
AR37657 - 27 July 2024 - 8h42 UT - 300 mm solar Newtonian with Soleye CaK50 coating - Baader Planetarium TZ4-S - Altair 393-3 nm + Alluxa Ca K 0.14 nm
Scale = 0.09 arsec/pixel - ASI464 camera - Gain = 0 - Exposure = 180 frames x 1.3 ms
Christian Viladrich - France

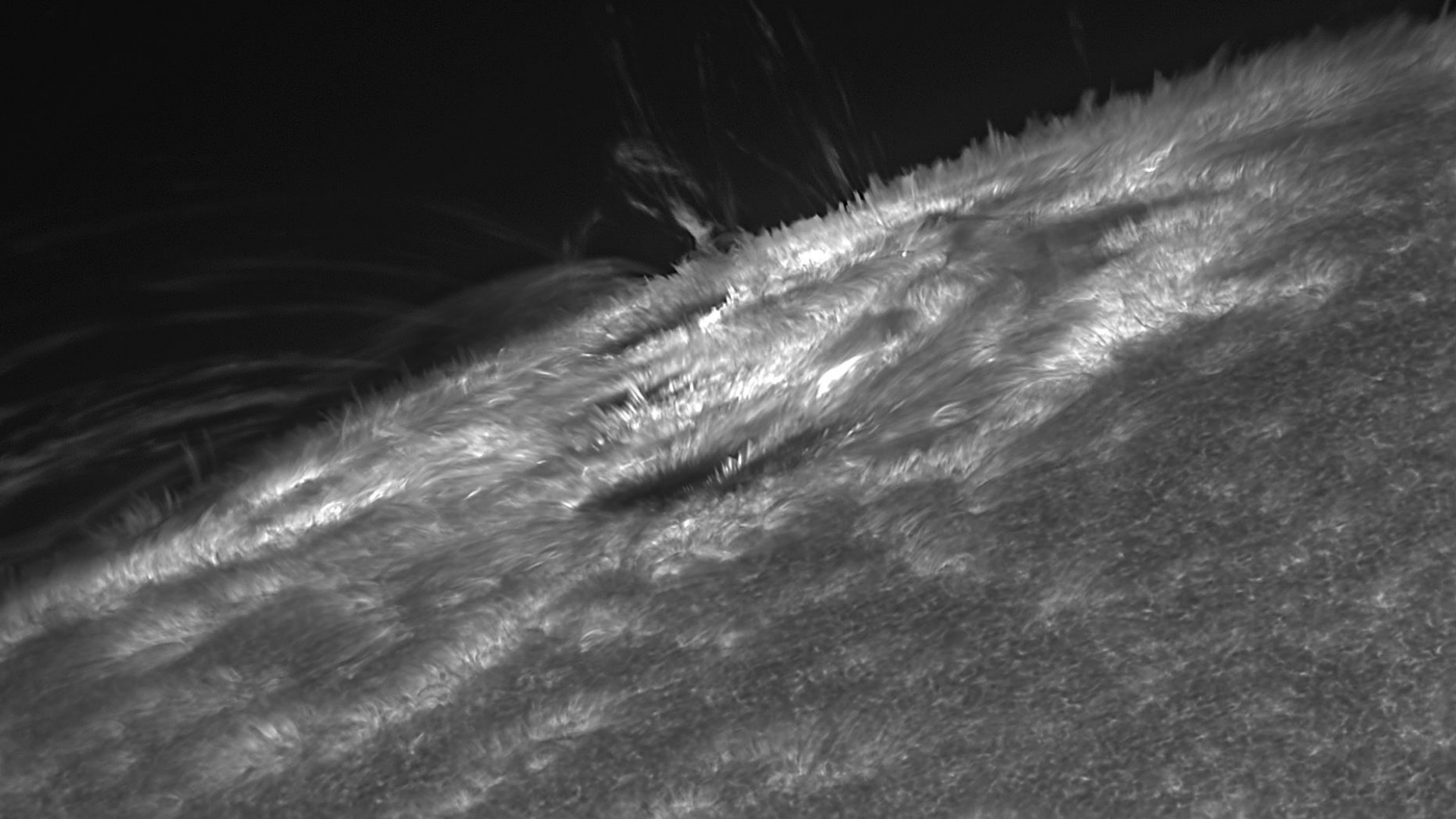

Newton 300 mm – Soleye CAK50 coating

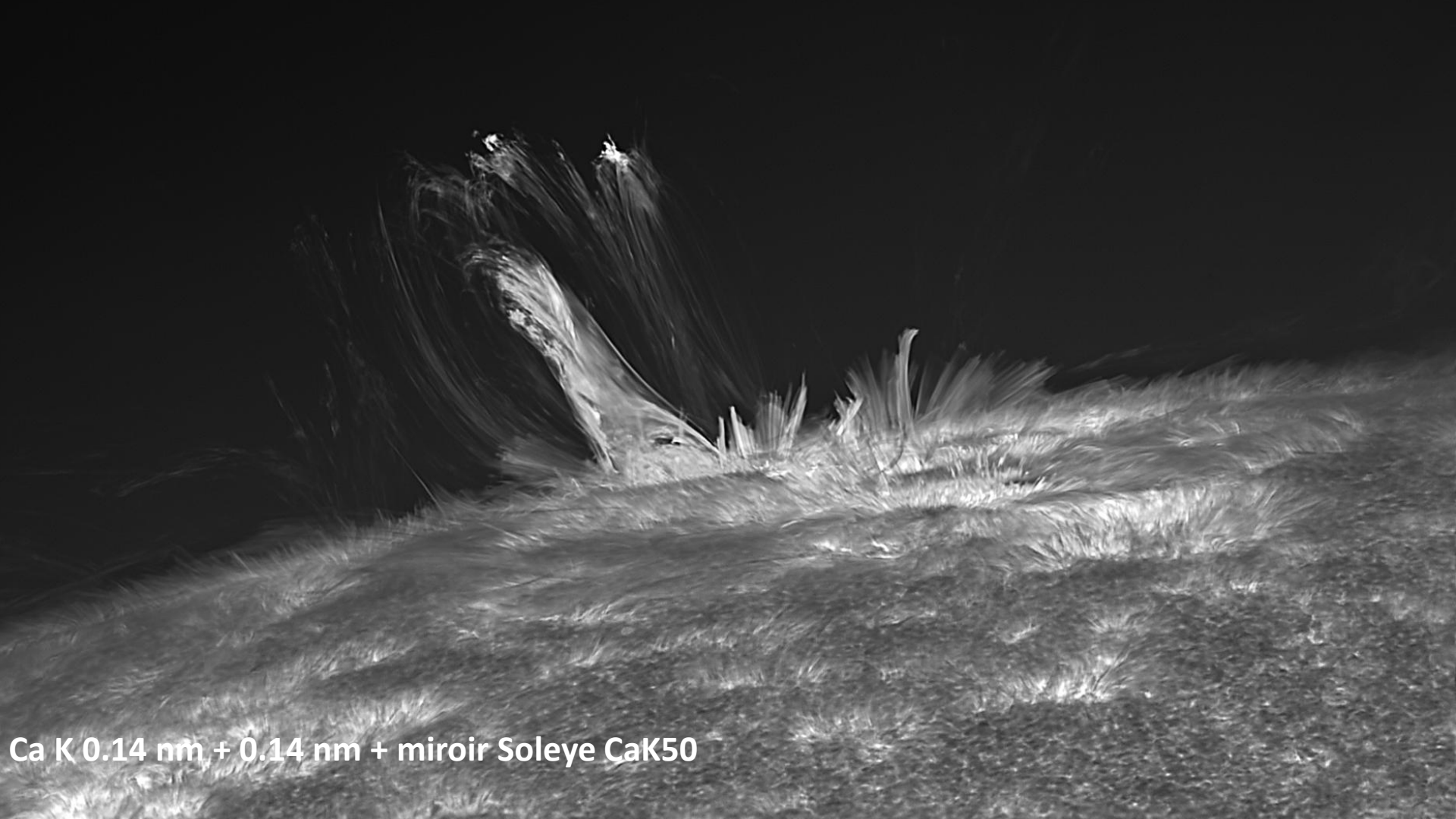


Ca K 0.14 nm + miroir Soleye CaK50

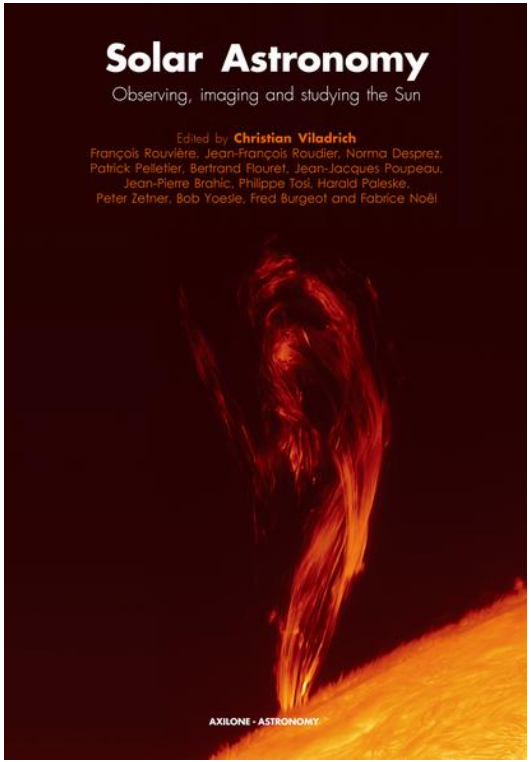

Ca K 0.14 nm + 0.14 nm + miroir Soleye CaK50
N
E W
AR3762 - 27 July 2024 - 10h46 UT - 300 mm solar Newtonian with Soleye CaK50 coating - Baader Planetarium TZ4-S - Altair 393-3 nm + double-stack Alluxa Ca K 0.14 nm + 0.14 nm
Scale = 0.09 arsec/pixel - ASI464 camera - Gain = 0 - Exposure = 120 frames x 2.7 ms

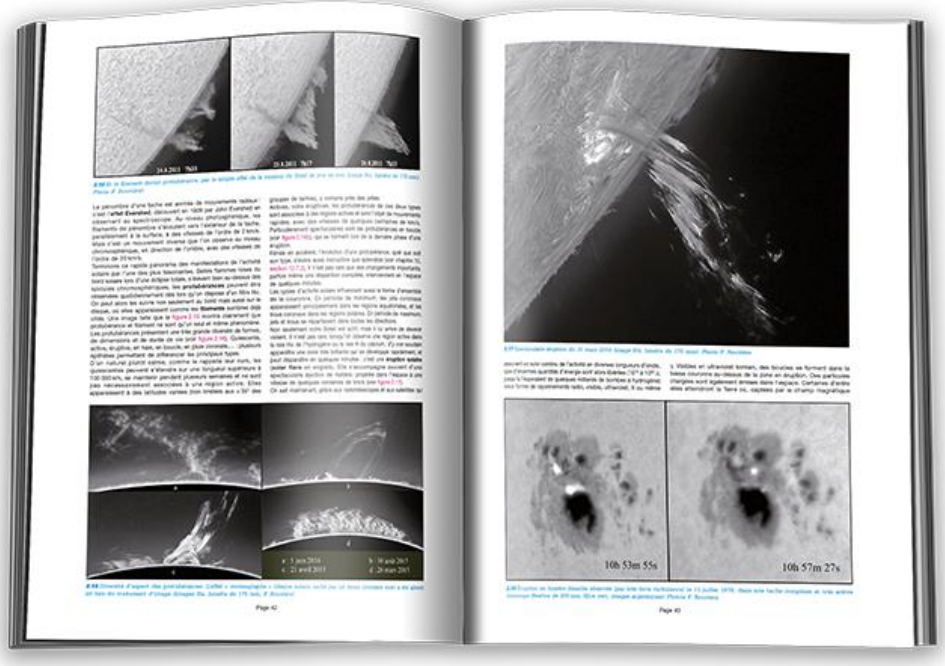





Ca K 0.14 nm + 0.14 nm + miroir Soleye CaK50

Thank you…Questions ?





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