The seeing is everything – past, present, and future solar observations from La Palma

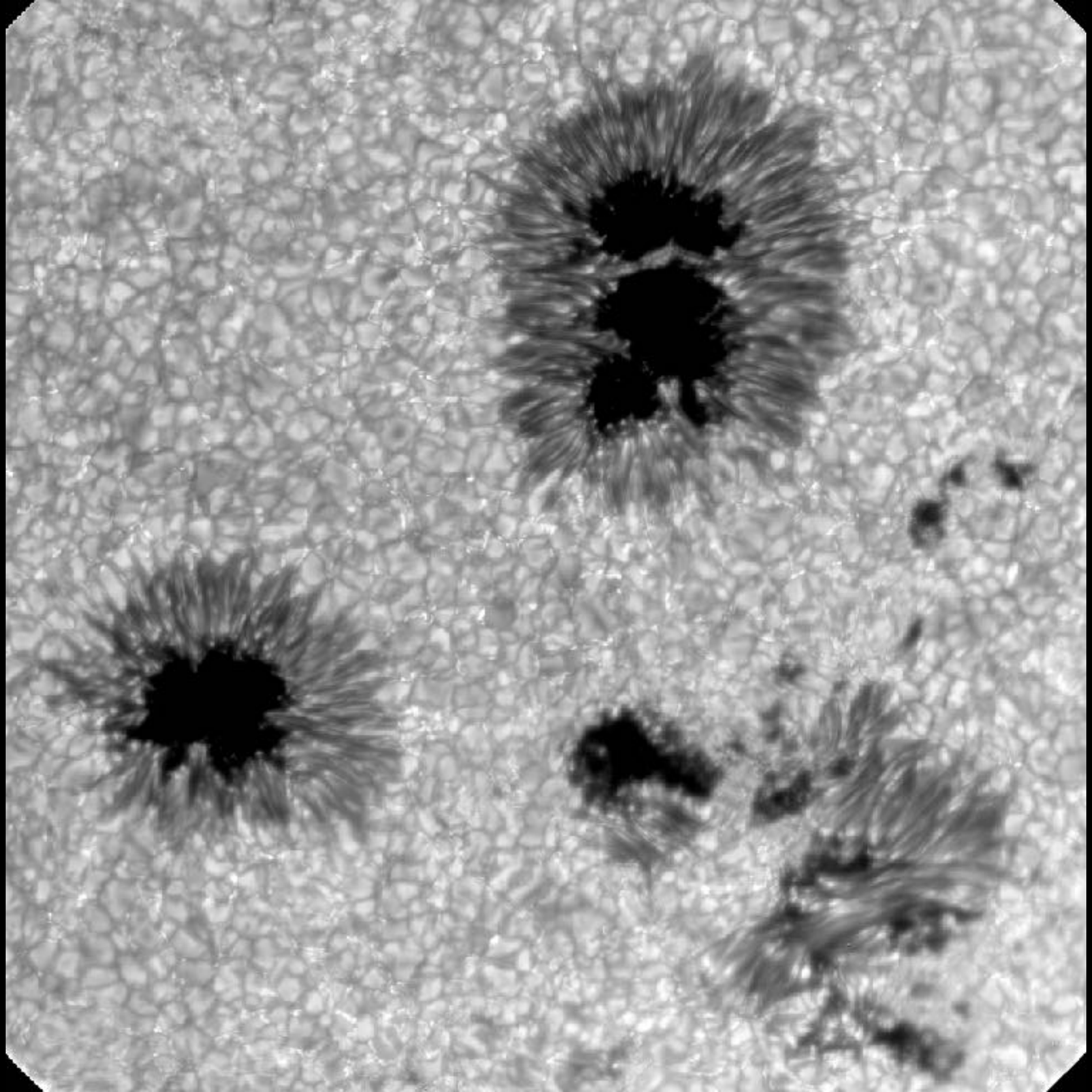
Uppsala 2022-12-01

Stockholm University

Dan Kiselman
Institute for Solar Physics
Department of Astronomy

SST image #1
22 May 2002

No image
restoration!



SST image #1
22 May 2002

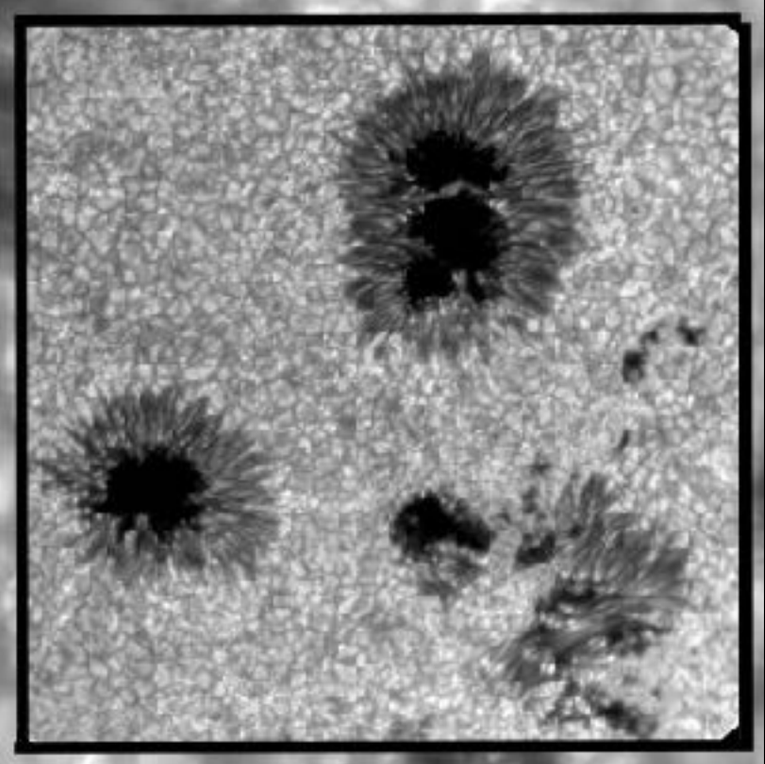
No image restoration!

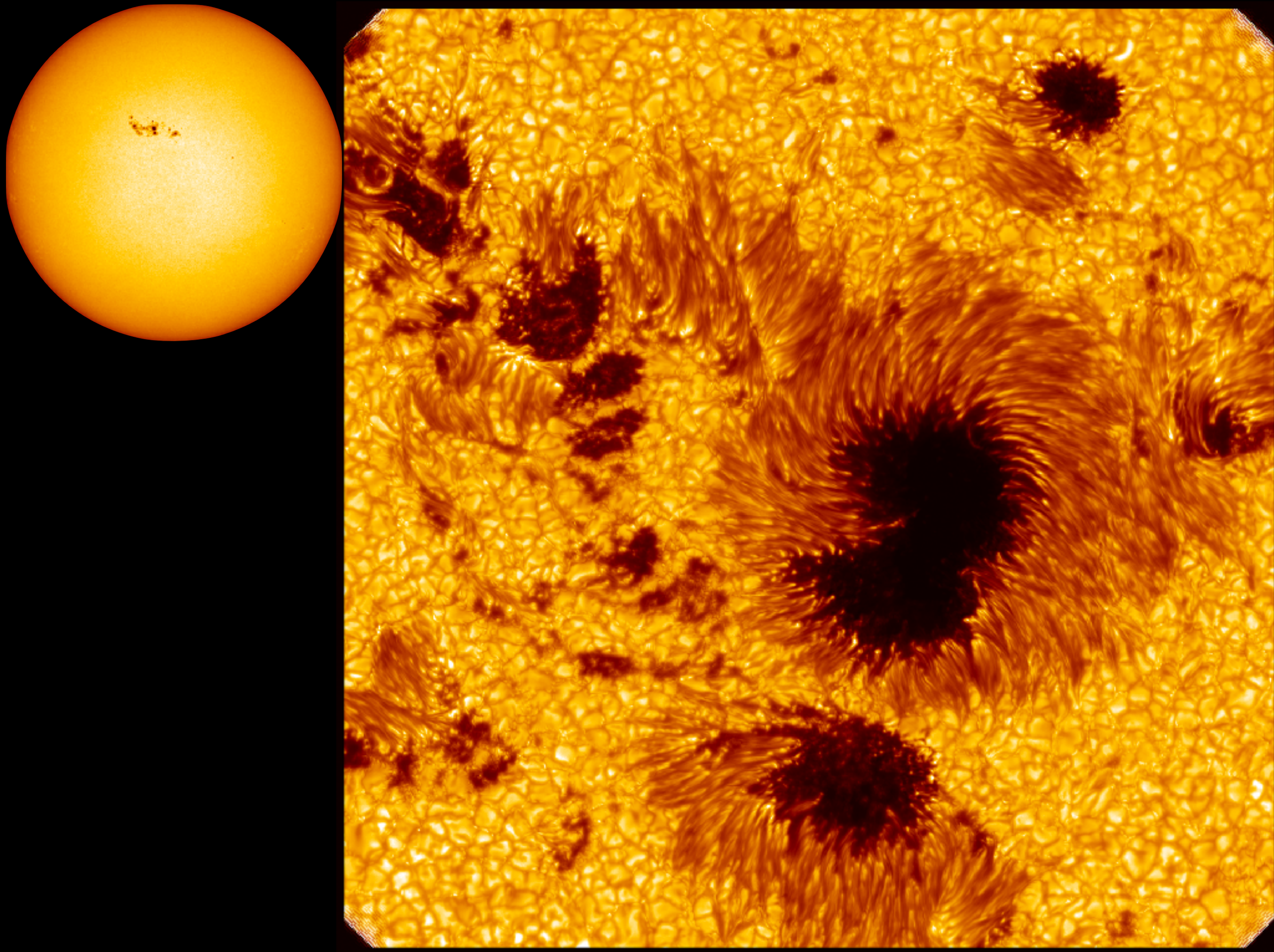
Granulation

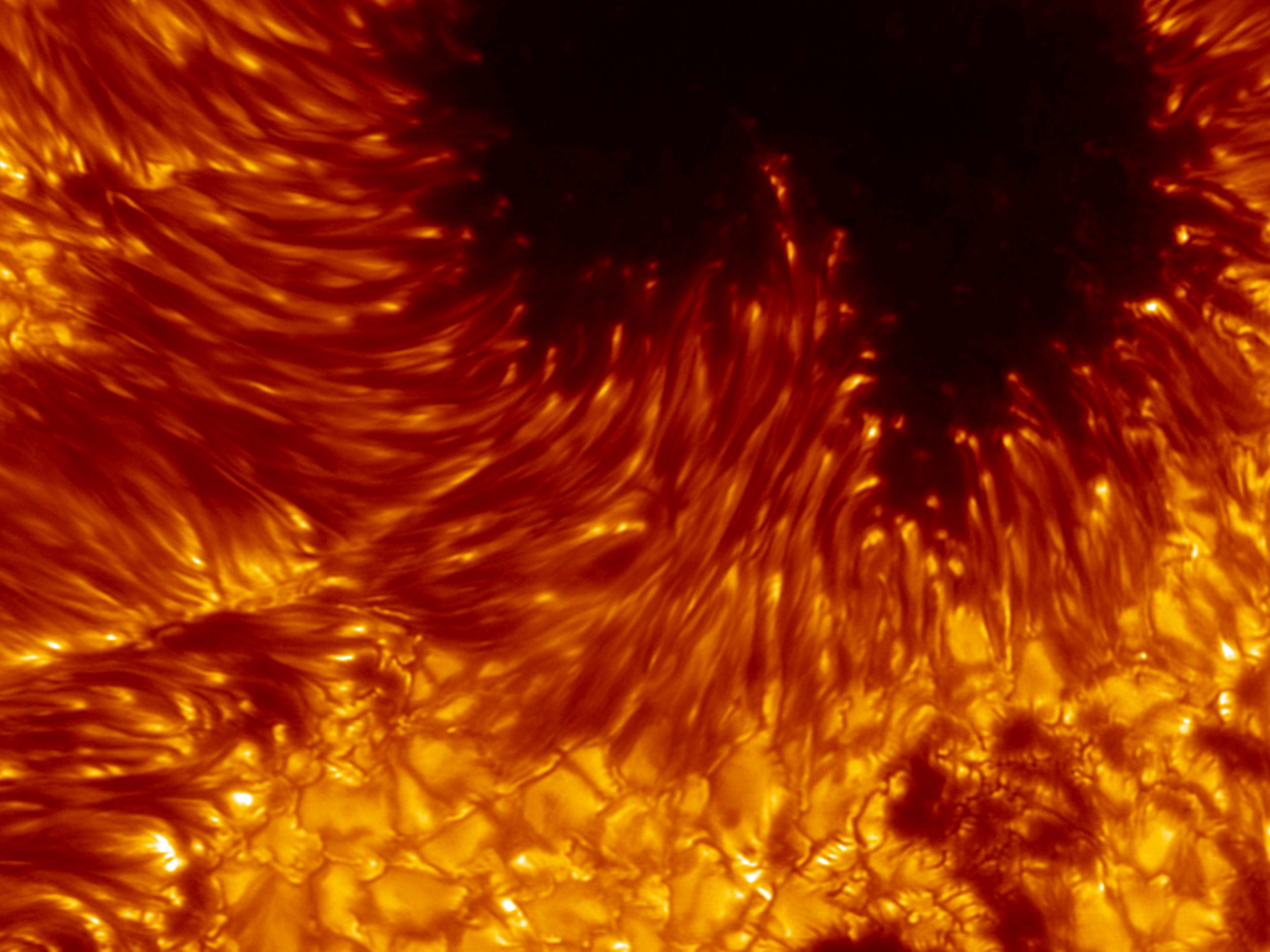
Magnetic bright points

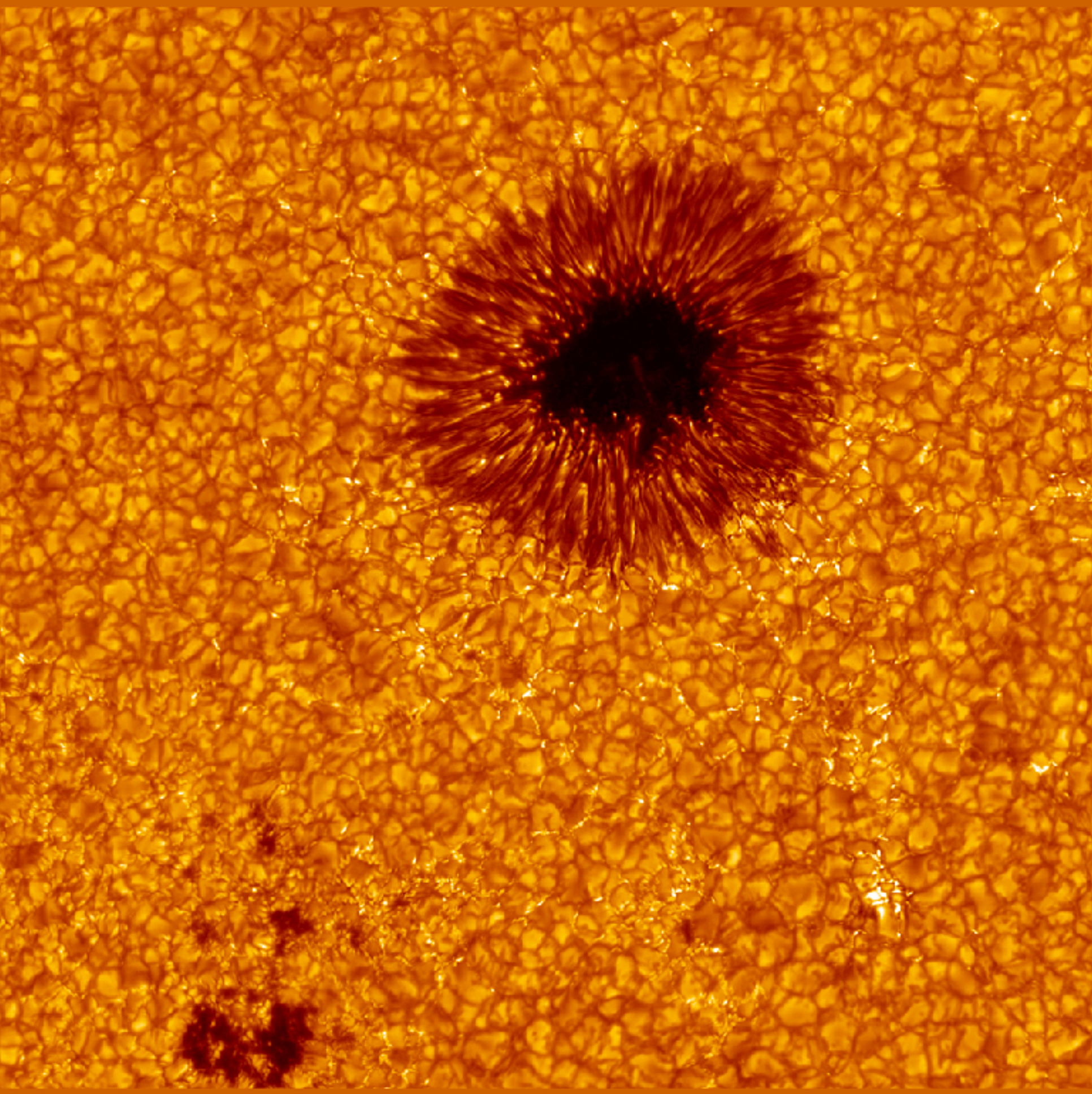
sunspot umbra

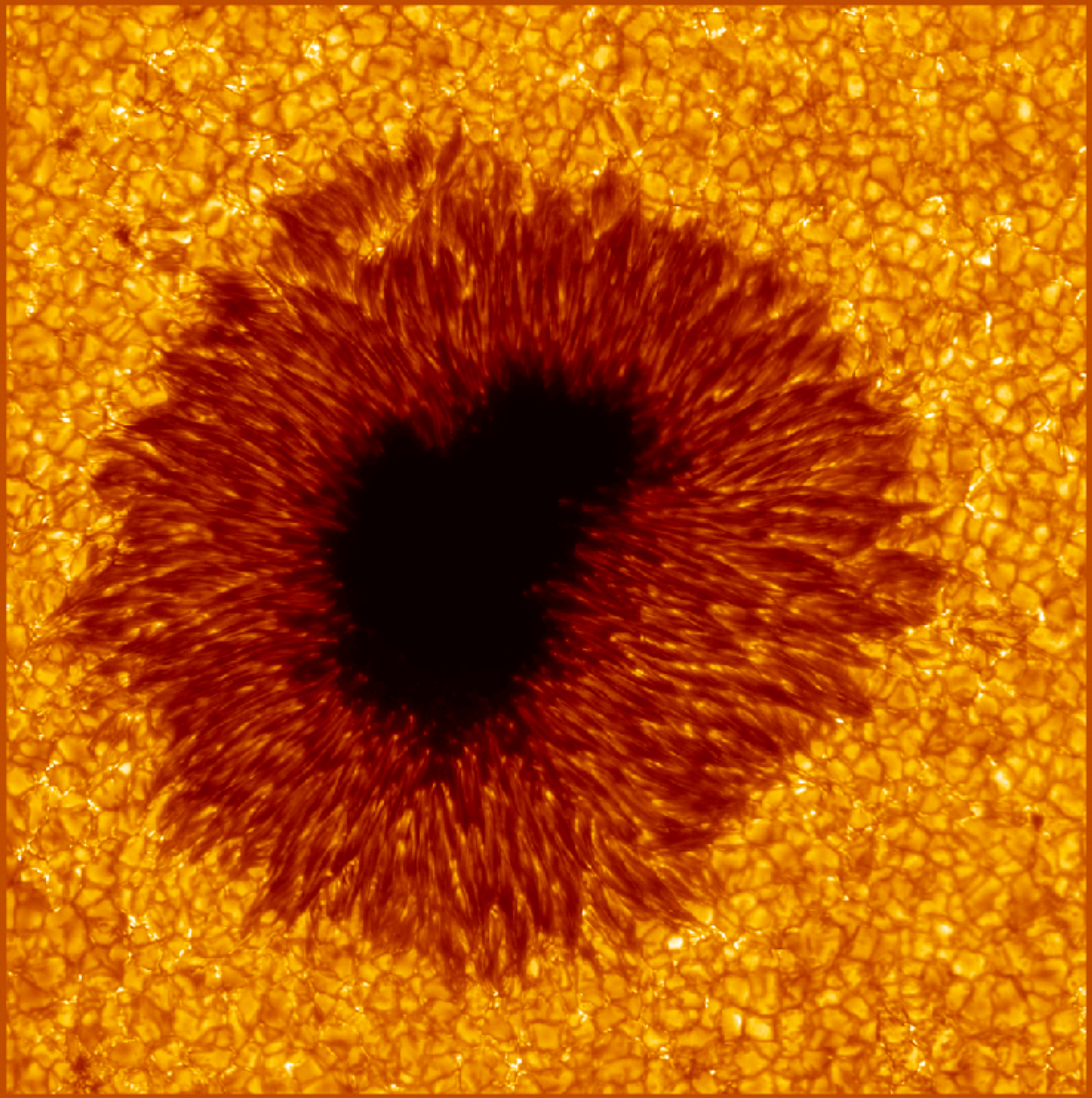
sunspot penumbra

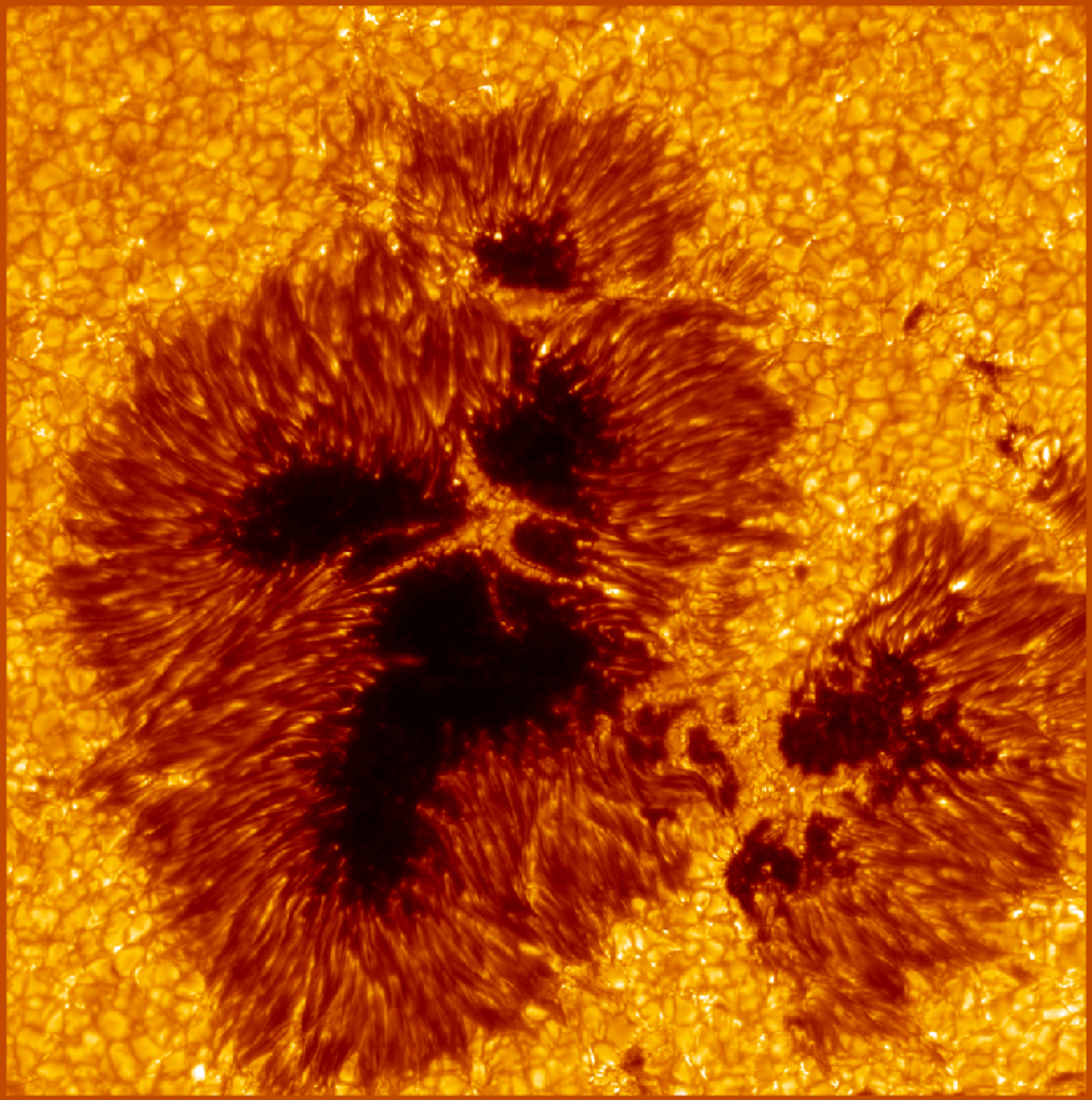


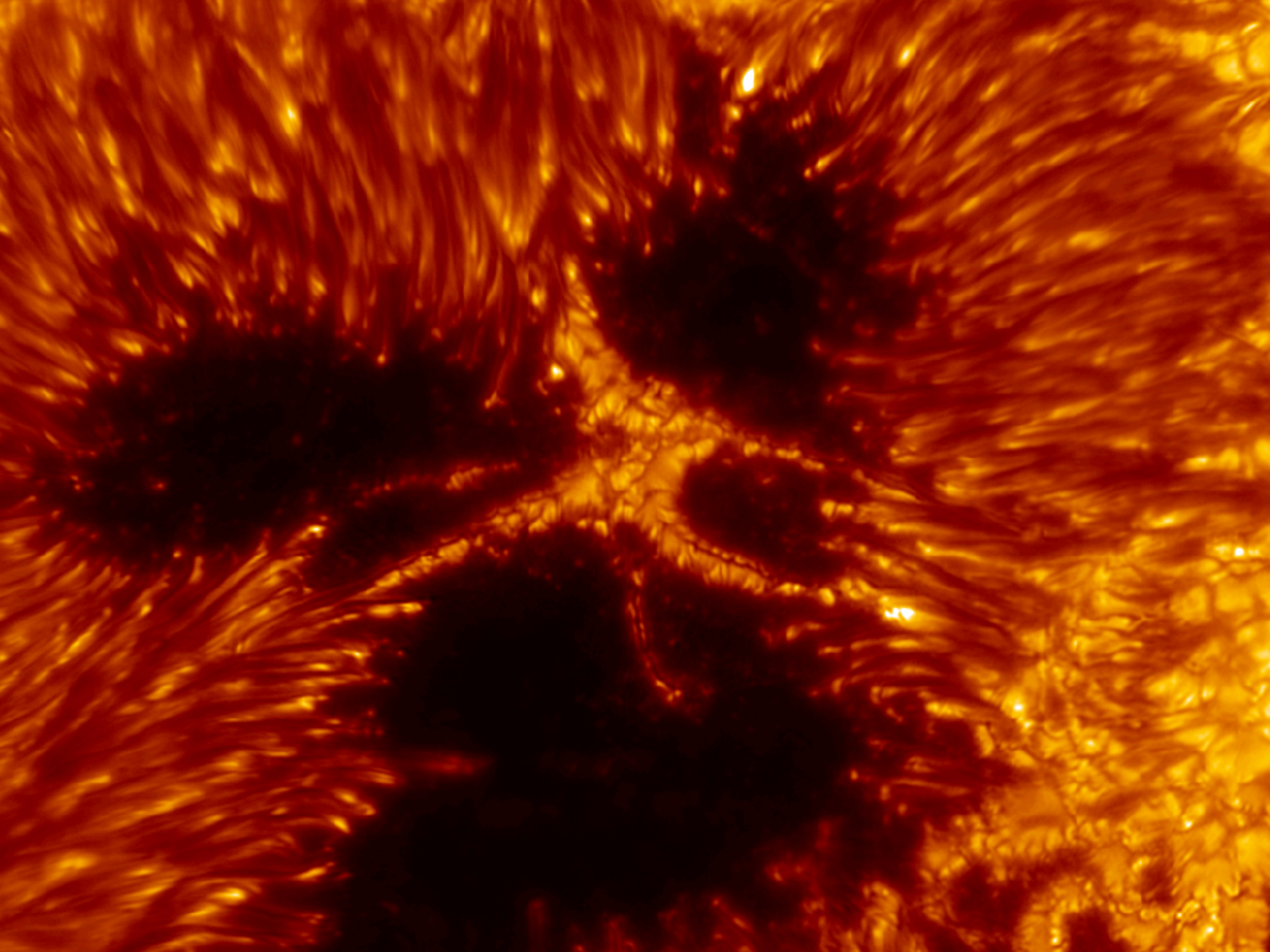






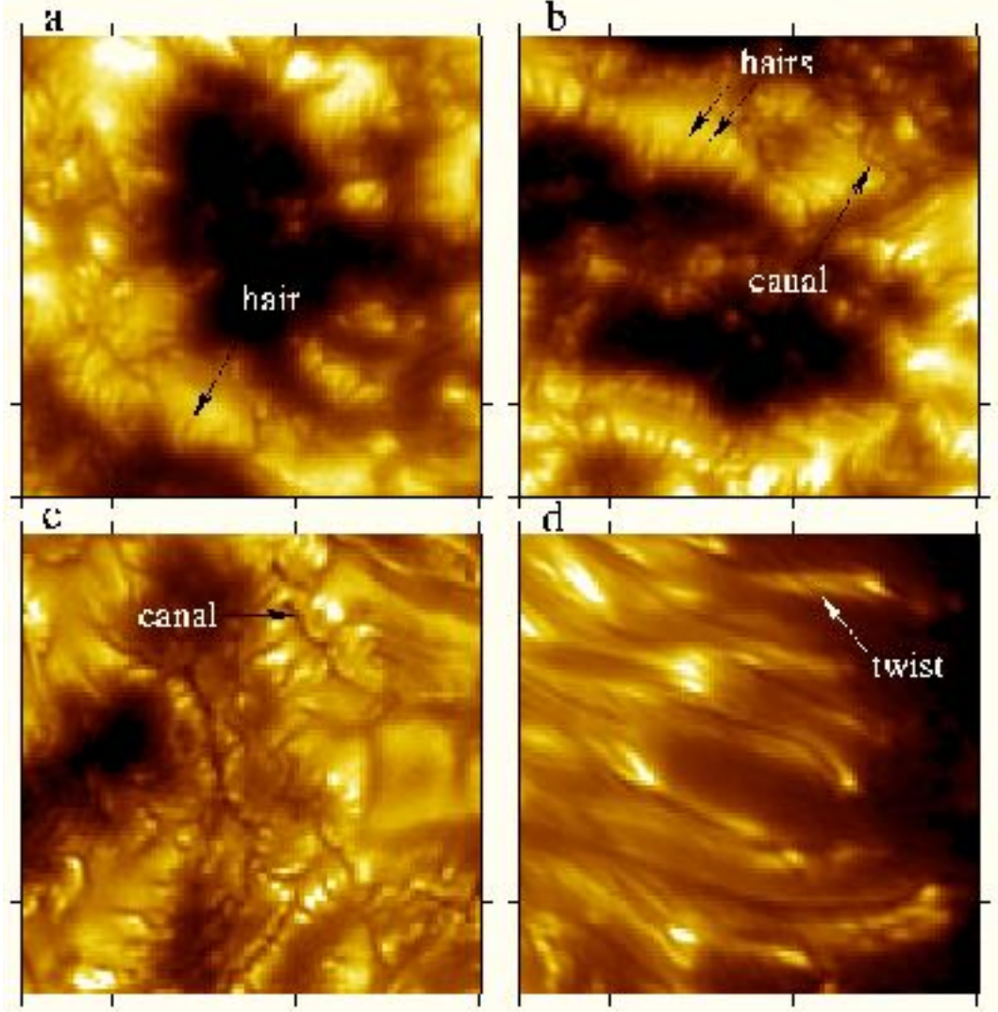




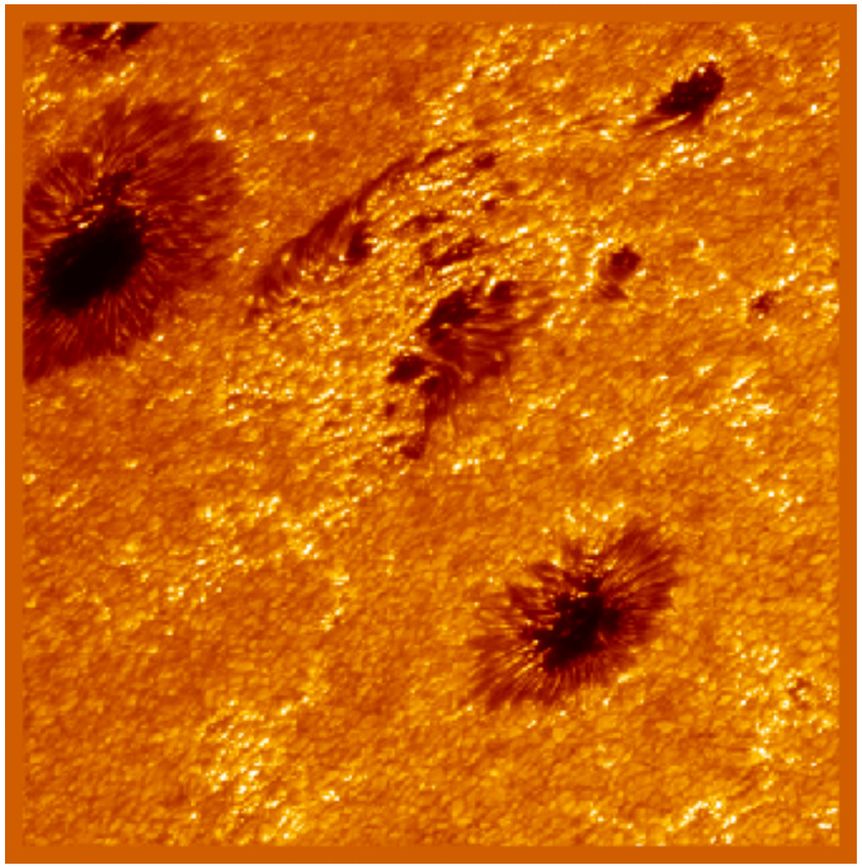


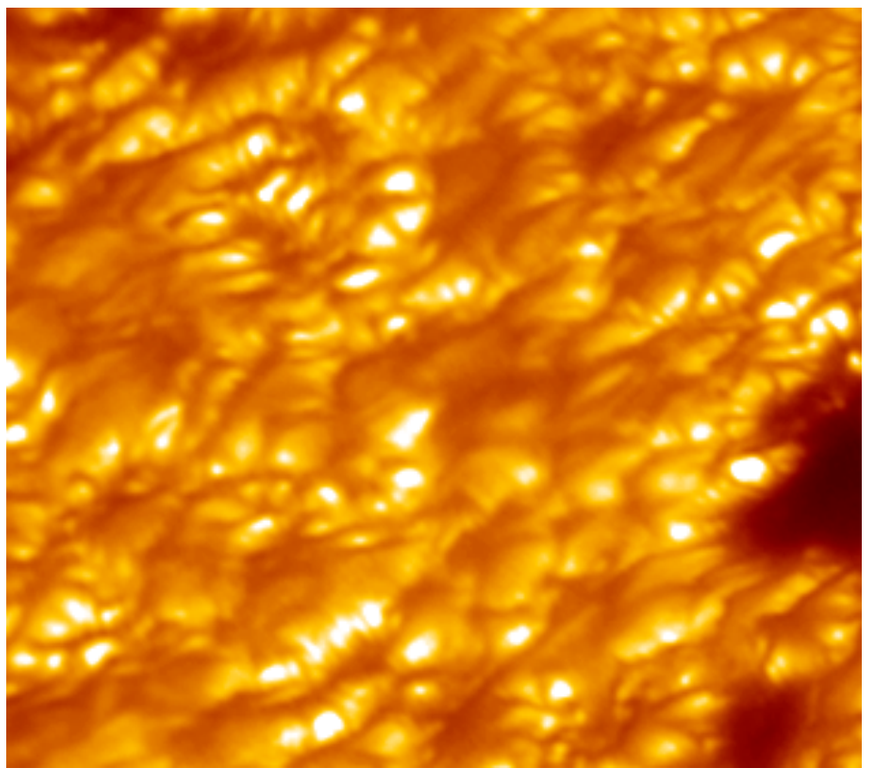
SST increased spatial resolution 2X to 0.1”: Discoveries just by looking!

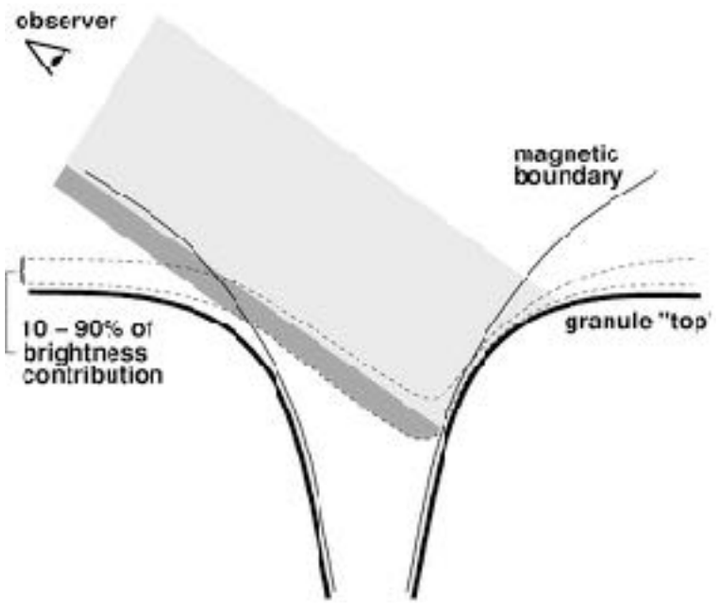
2002 Dark cores in penumbral filaments and other new structures



2004 Faculae explained







Keller et al. 2004

Don’t we get enough photons from the Sun already?

Don’t we get enough photons from the Sun already?

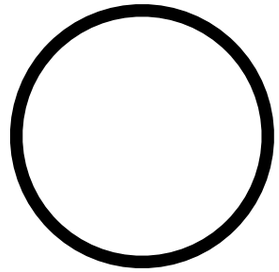
Scientists demand!
Co-temporal multi-diagnostic spectropolarimetric observations with high spatial, temporal, and spectral resolution!
With high S/N!

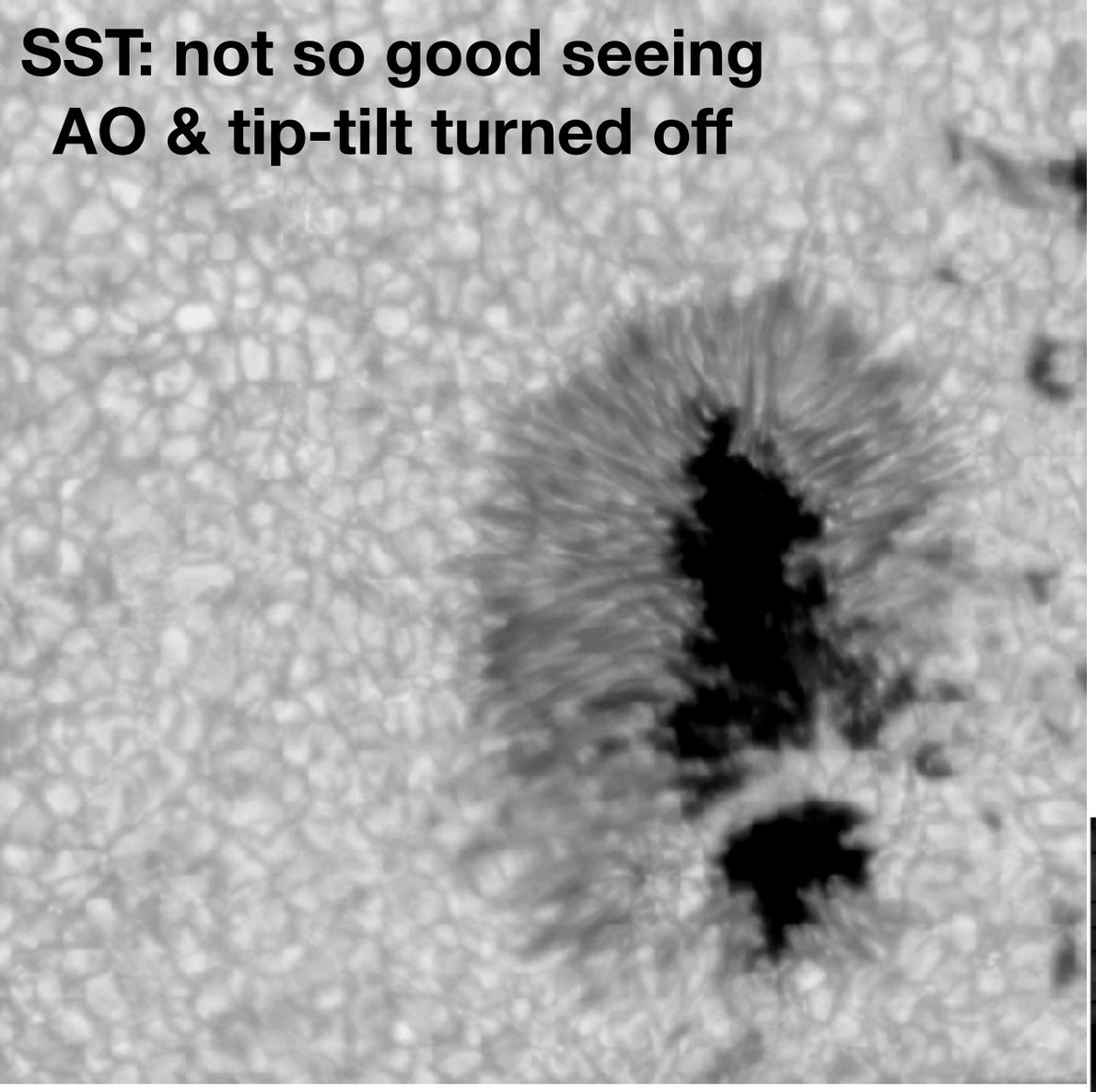
The Sun is a resolved object.

SST: Rouppe van der Voort

Why large solar telescopes?

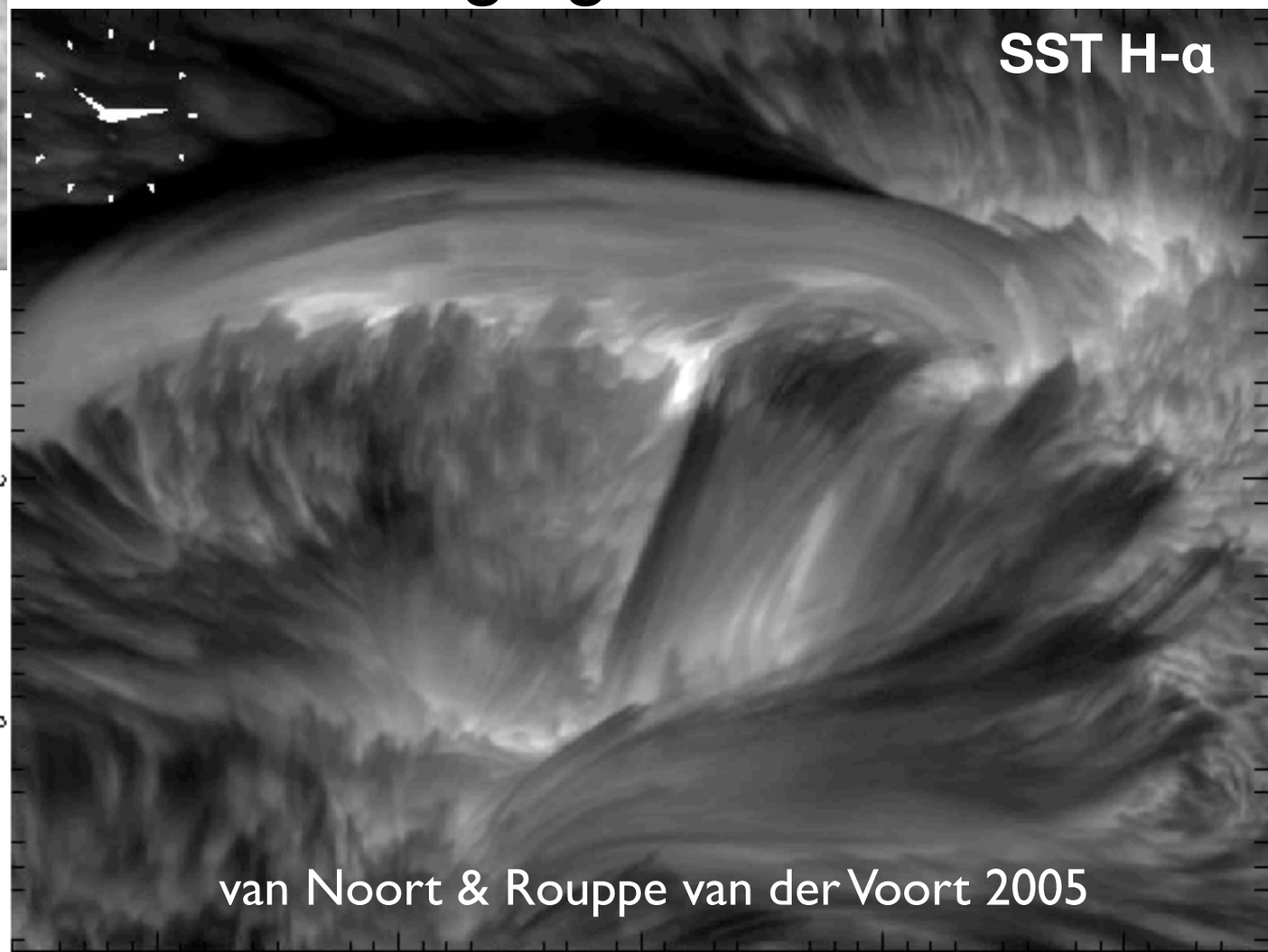
You can’t have everything.
Life at the diffraction limit is hard.
You are always photon starved.

- Light-gathering area ~ D^2 
- Diffraction-limited resolution element area. ~ D^{-2} □
- Exposure time to freeze solar scene ~ D^{-1}

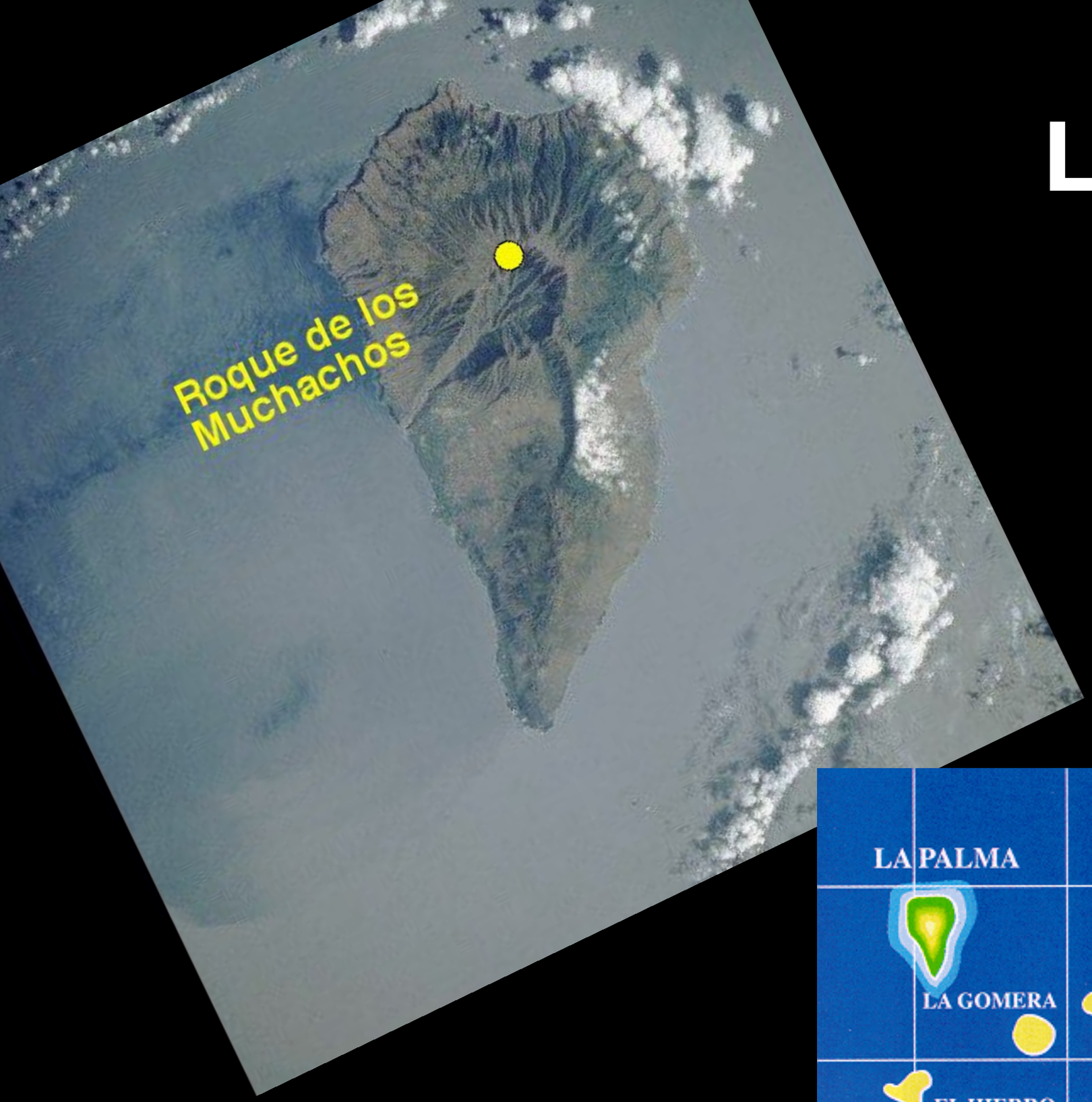


Seeing changes fast.

The solar scene at sub-arcsecond resolution is changing in seconds.



La Palma


Roque de los
Muchachos


LA PALMA
TENERIFE
Sta. Cruz
de Tenerife
GRAN
CANARIA
Las Palmas de
Gran Canaria
LANZAROTE
LA GOMERA
EL HIERRO
FUERTEVENTURA
AFRICA

La Palma

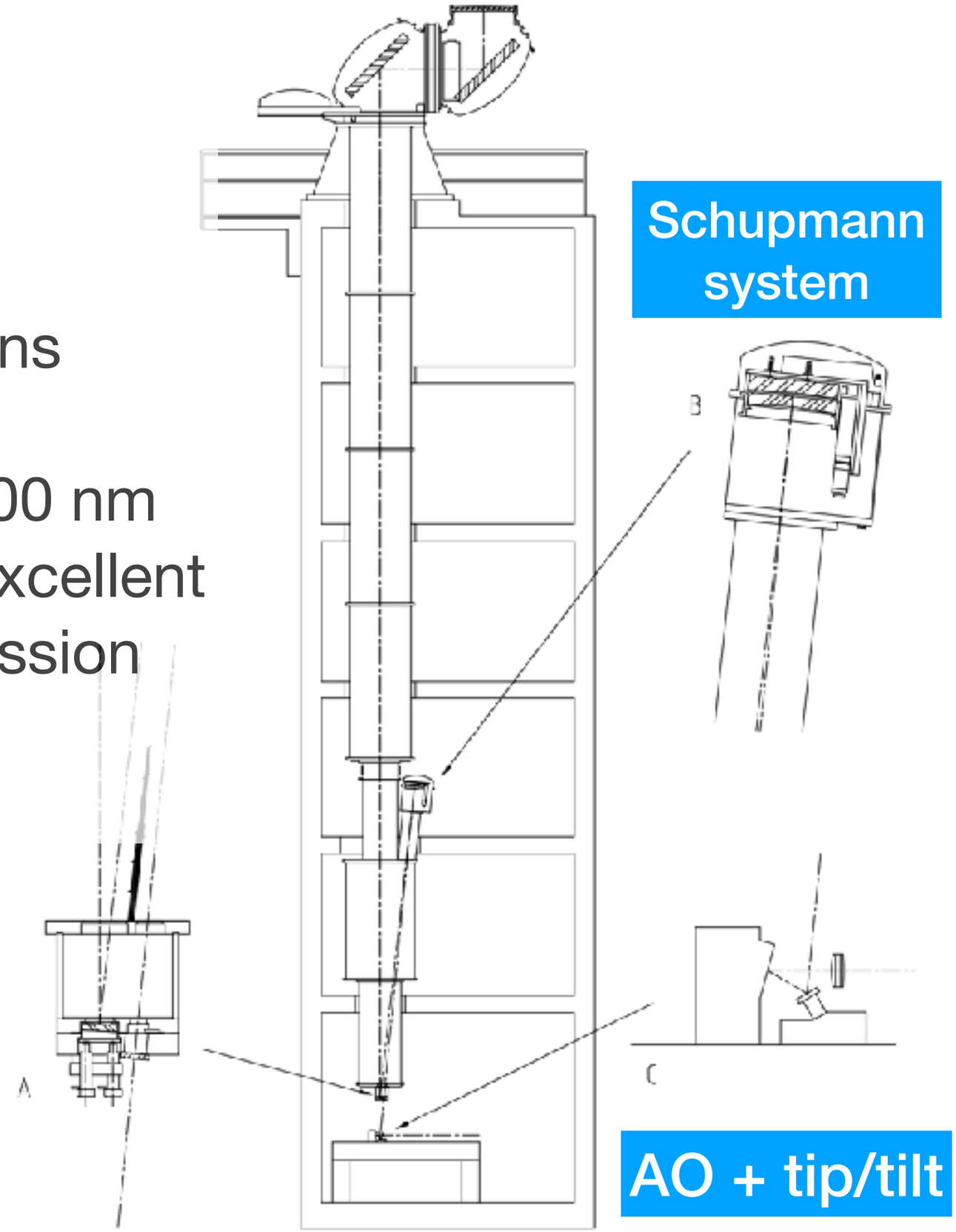

SST

Observatorio del Roque de los Muchachos, La Palma
2400 m altitude

SST

Swedish 1-m Solar Telescope SST

- Scharmer et al. 2003
- first light in 2002
- 0.97 m unobstructed aperture
- fused silica singlet objective lens
- vacuum tube *
- design range 350 nm < λ < 1100 nm
- optical components few, but excellent
- 6 reflections, 4 lenses: transmission 40-50% (verified)
- Diffraction-limited: 0.1” in blue




Göran S

Swedish 1-m Solar Telescope SST

- Scharmer et al. 2003
- first light in 2002
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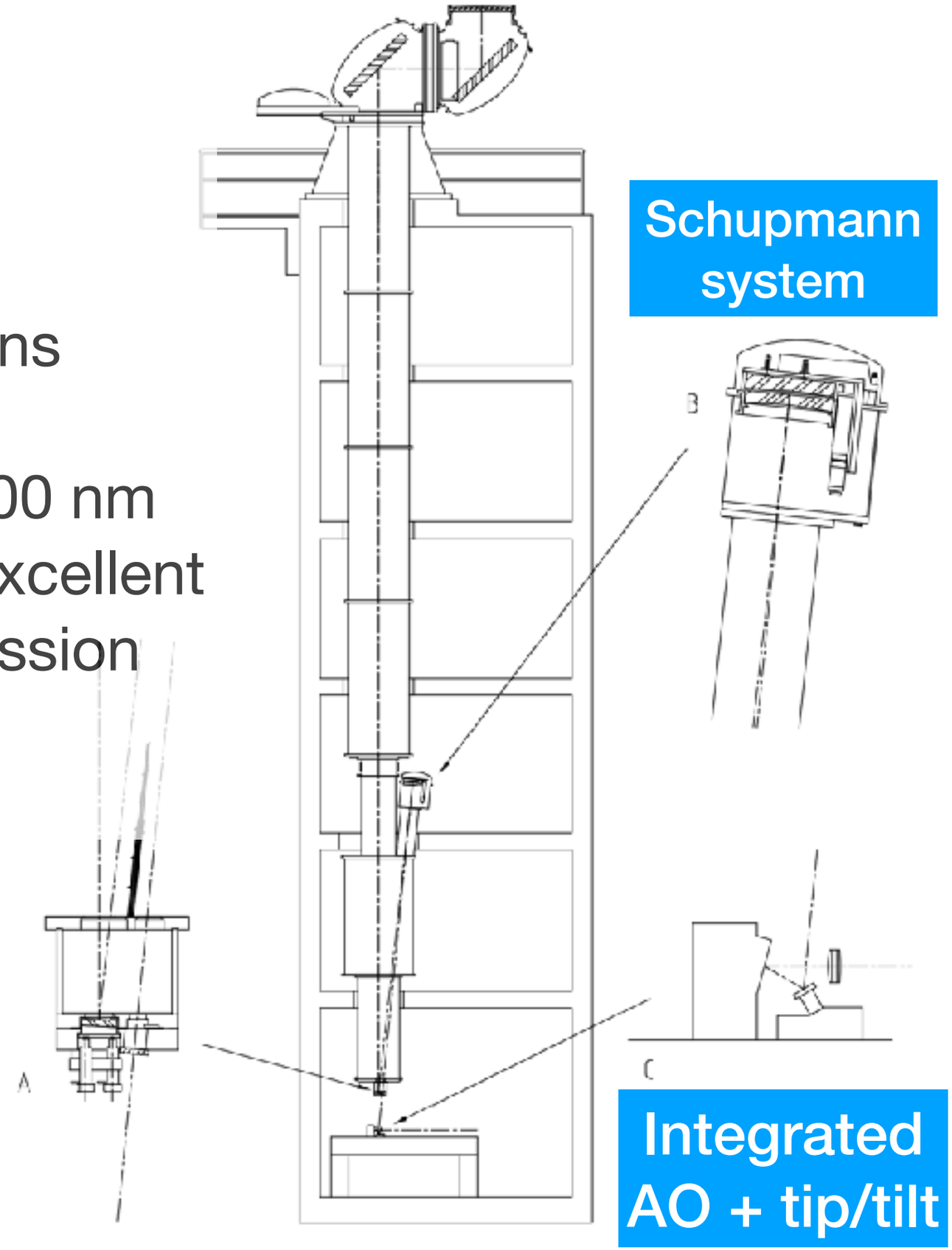
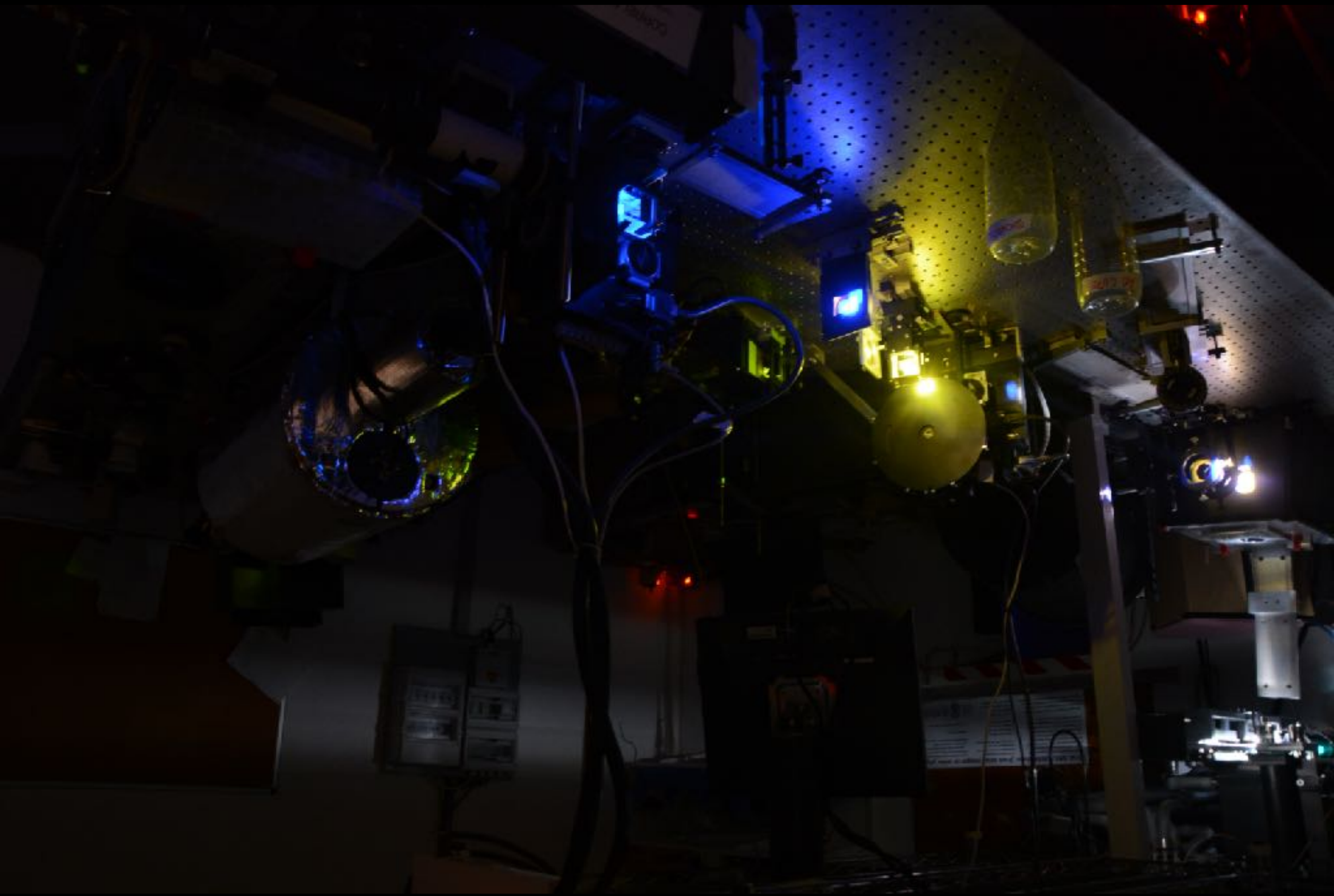




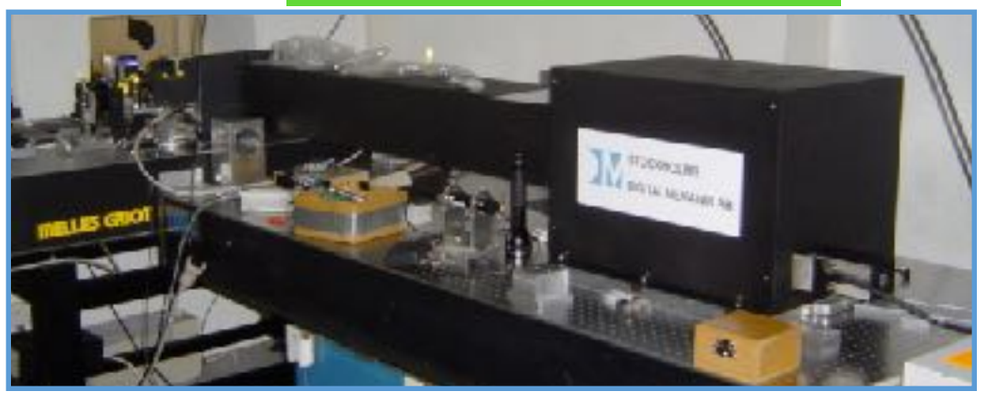
SST Instrumentation

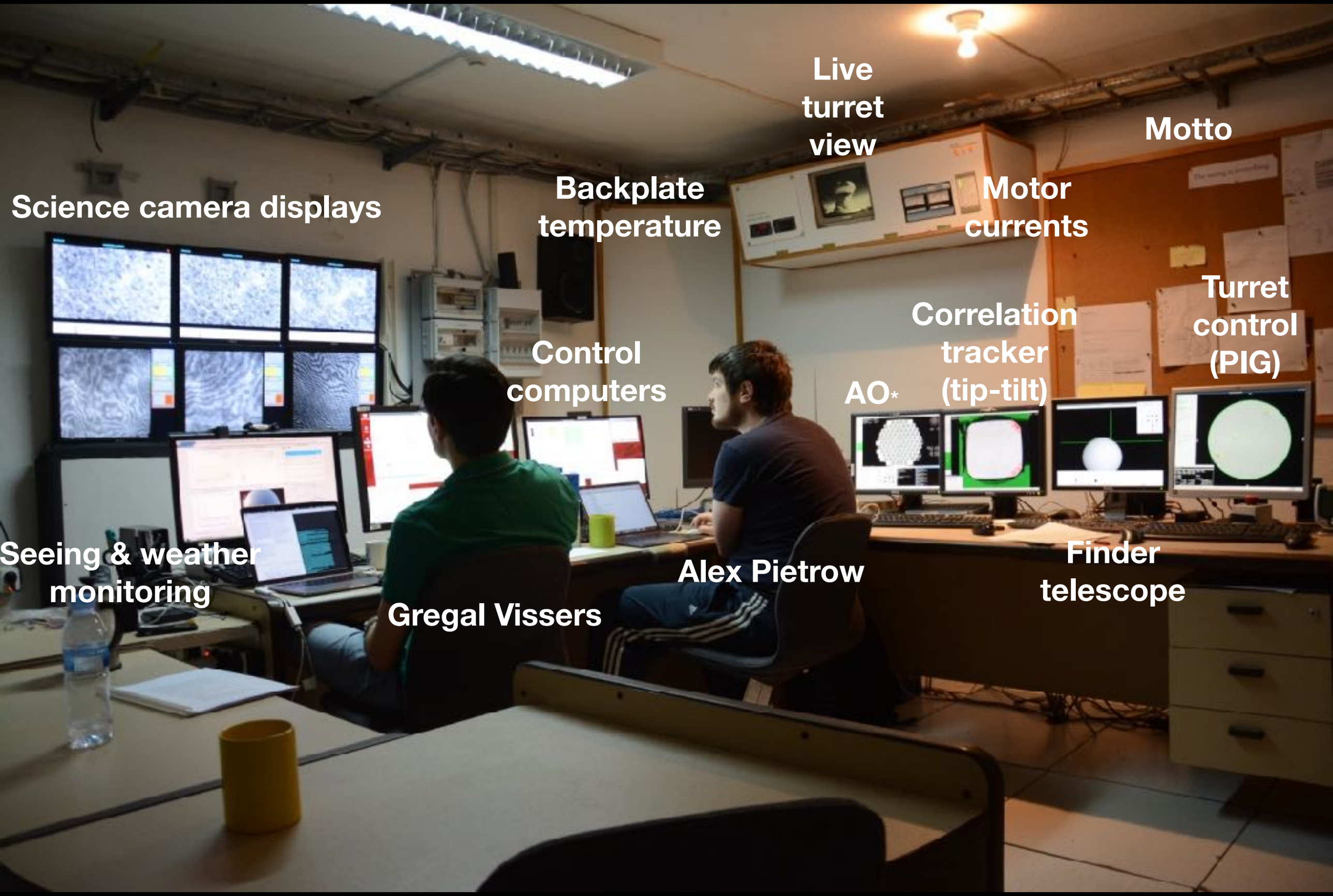
CHROMIS
imaging spectrometry
3900 Å – 5000 Å

CRISP
imaging spectropolarimetry
5200 Å – 8600 Å

HeSP
He 10830 3D spectropolarimetry
Not commissioned!

TRIPPEL
grating spectrograph
(currently with IFU)




Science camera displays
Backplate temperature
Live turret view
Motto
Motor currents
Turret control (PIG)
Correlation tracker (tip-tilt)
AO*
Control computers
Seeing & weather monitoring
Gregal Vissers
Alex Pietrow
Finder telescope

SST AO Interface

Closed loop: 100.0%
Subimages locked: 84.9
Framerate: 2.0 kHz

Shack-Hartmann Wavefront Sensor AO-85

Vrms: 1.36
Vpeak: 3.08

Pupil dx: 7.9679
Pupil dy: -1.4461
Angle: -0.0413

Tip: 0.3184
Tilt: 0.2051
Focus: 0.2219
32: 0.1358

Zero
Pause
Offset
Run
Calibrate
Reset O.V.
Reset flat
Randomize

r0: 15 cm

AO Calibration routines

Observer | Display | Technical | Dangerous

Exposure time
Dark field
Flat field
Wavefront calibration
Offset voltages
Control matrix

uxterm

```
Serial port opened, fd = 3...
[root@ao-intel]~>lockpoint 6
Stopping AO.
Process 4429 killed.
Serial port opened, fd = 3...
[root@ao-intel]~>lockpoint 5
Stopping AO.
Process 4489 killed.
Saved changed flatfield for lockpoint 6
Serial port opened, fd = 3...
[root@ao-intel]~>lockpoint 8
Stopping AO.
Process 4561 killed.
Serial port opened, fd = 3...
[root@ao-intel]~>lockpoint 0
Stopping AO.
Process 4520 killed.
Serial port opened, fd = 3...
[root@ao-intel]~>
```

Focus Control Program

Position : 51.0466

Status : Everything ok.

Step Size
Long
Med
Short
Tiny

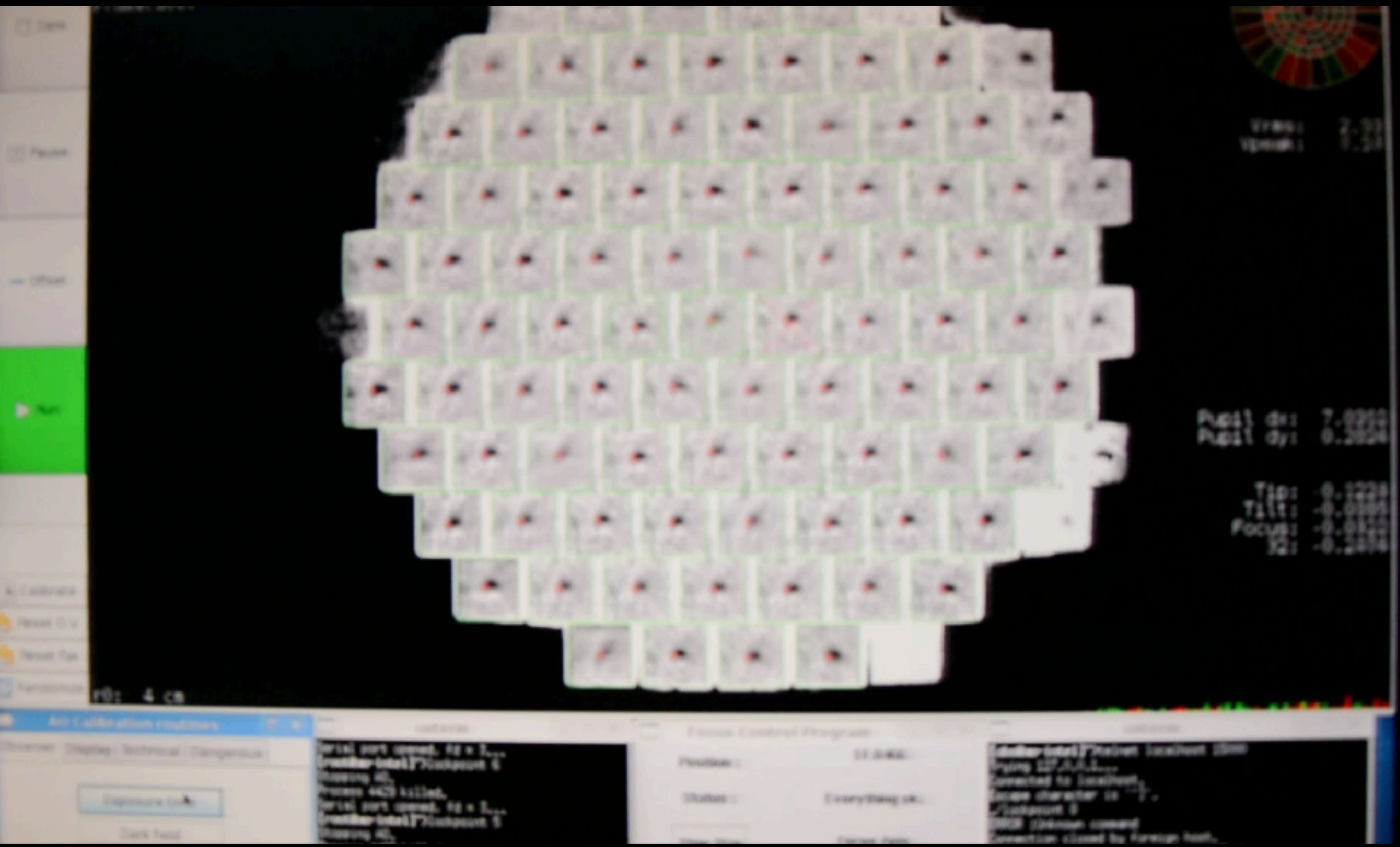
Focus Axis

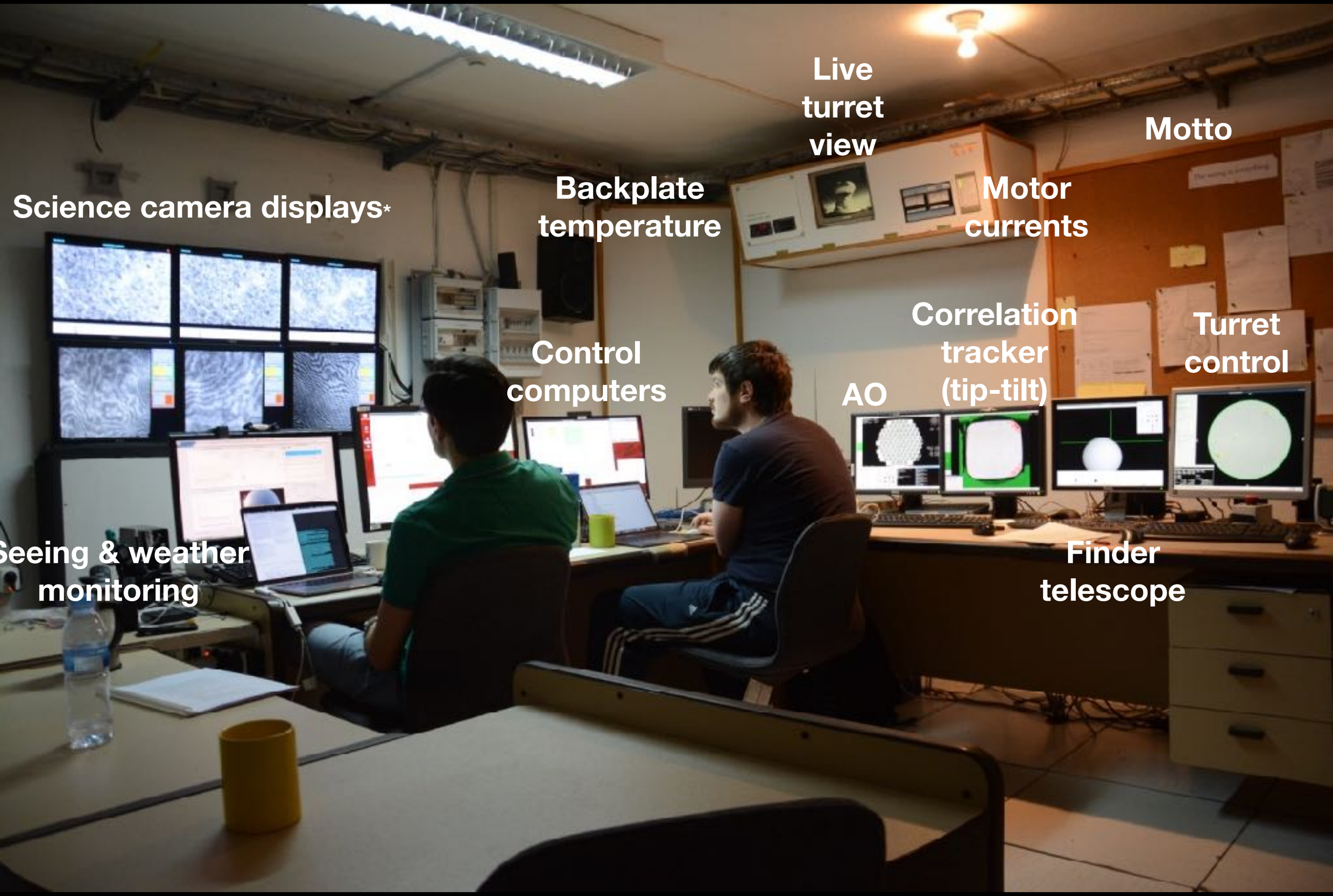
Focus Check

uxterm

```
[obs@ao-intel]~>telnet localhost 15000
Trying 127.0.0.1...
Connected to localhost.
Escape character is '^]'.
./lockpoint 3
ERROR :Unknown command
Connection closed by foreign host.
[obs@ao-intel]~>
```

SST AO interface | Focus Control Program | xterm | xterm | 10:01:56




Science camera displays*
Backplate temperature
Live turret view
Motto
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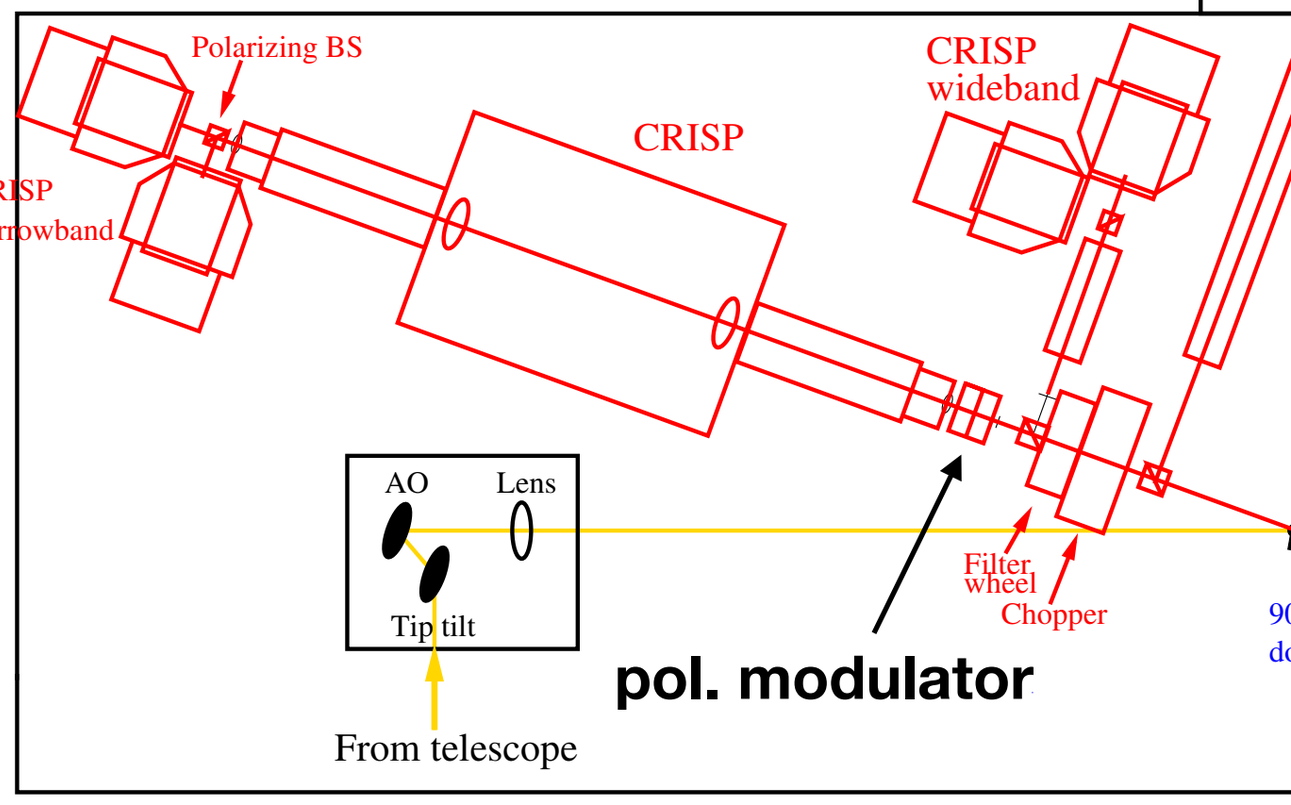
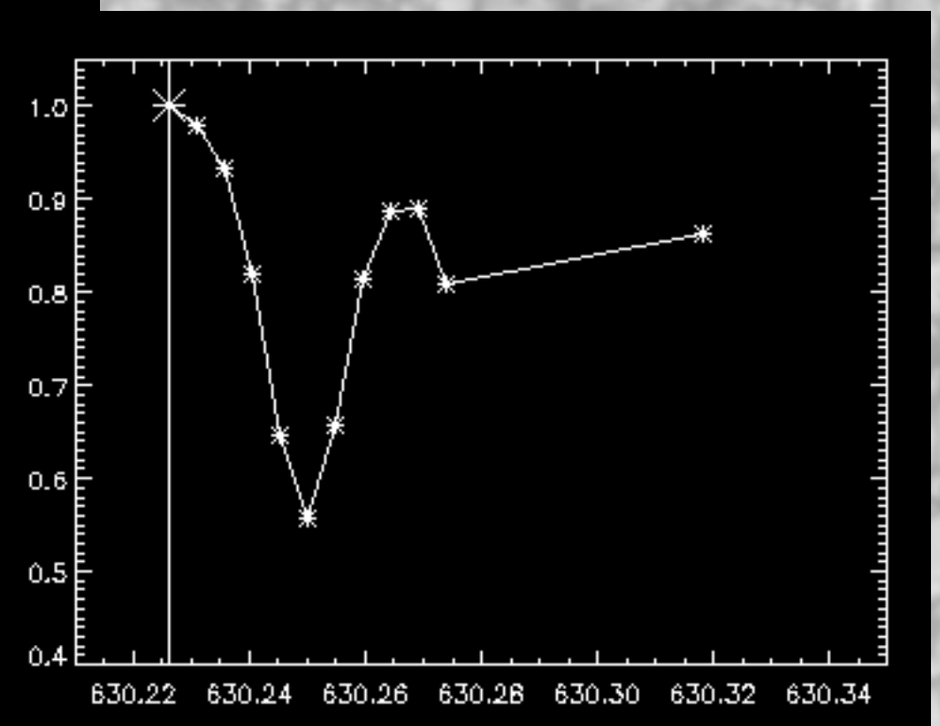
Control computers
AO
Correlation tracker (tip-tilt)
Turret control
Seeing & weather monitoring
Finder telescope

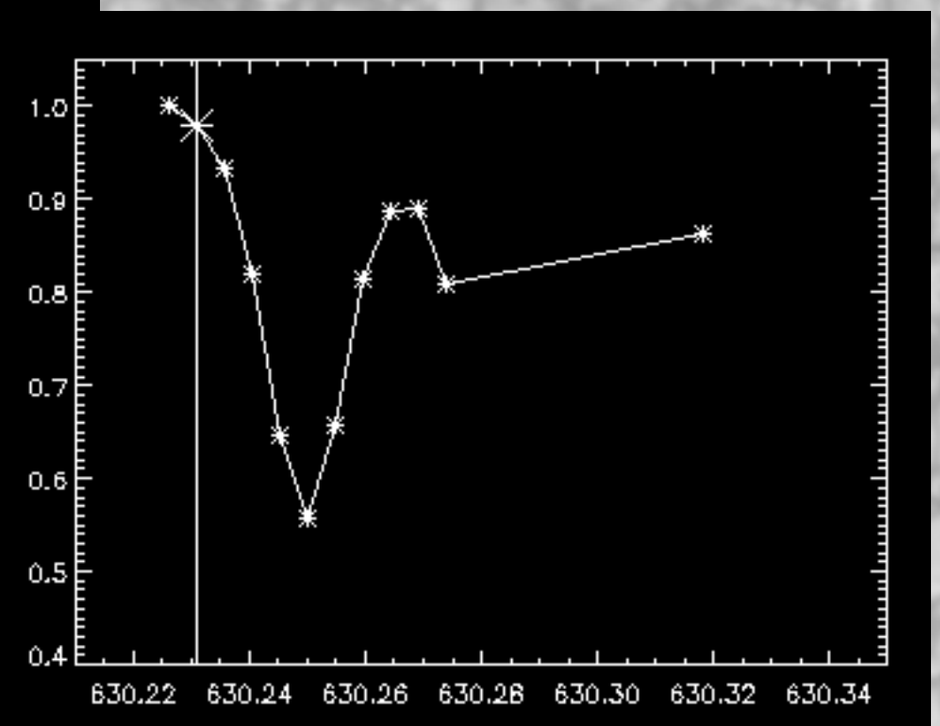
CRISP = CRisp Imaging SPectropolarimeter

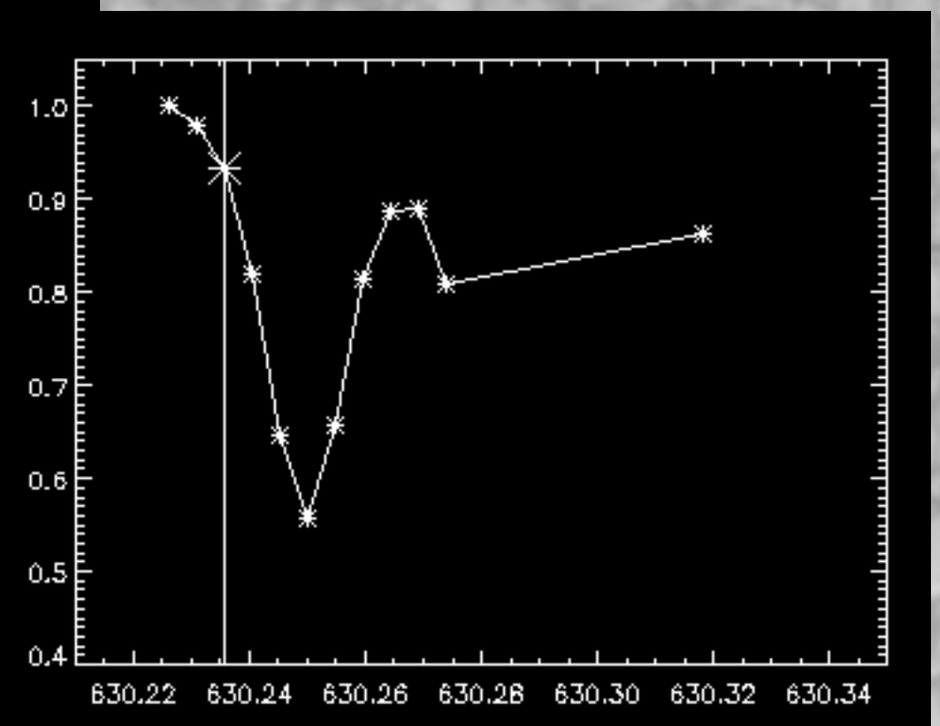
- 2008
- Double Fabry-Pérot interferometer (Scharmer 2005)
- Works as a narrow filter that tunes very fast.
- Full Stokes polarimetry
- 5200 Å - 8600 Å
- R ~80000
- Prefilters: Mg I b 5173, He D_3 5876, Fe I 6173, Fe I 6302, Hα 6563, Ca II 8542, and some older ones including Na D 5896
- New larger detectors in August 2022



SST/CRISP @6302Å




1.0
0.9
0.8
0.7
0.6
0.5
0.4
630.22
630.24
630.26
630.28
630.30
630.32
630.34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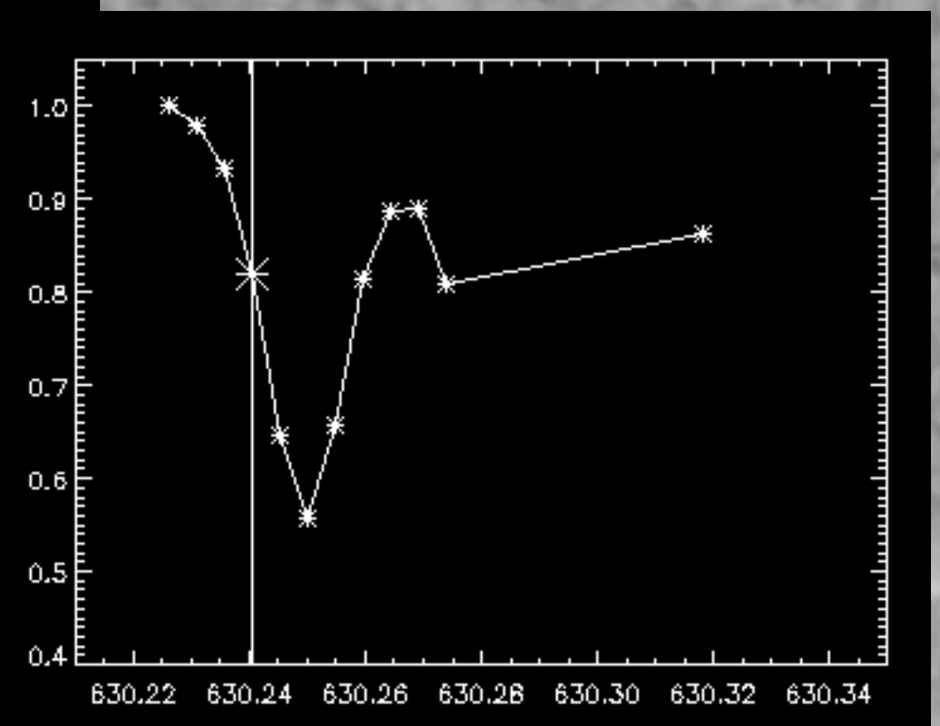
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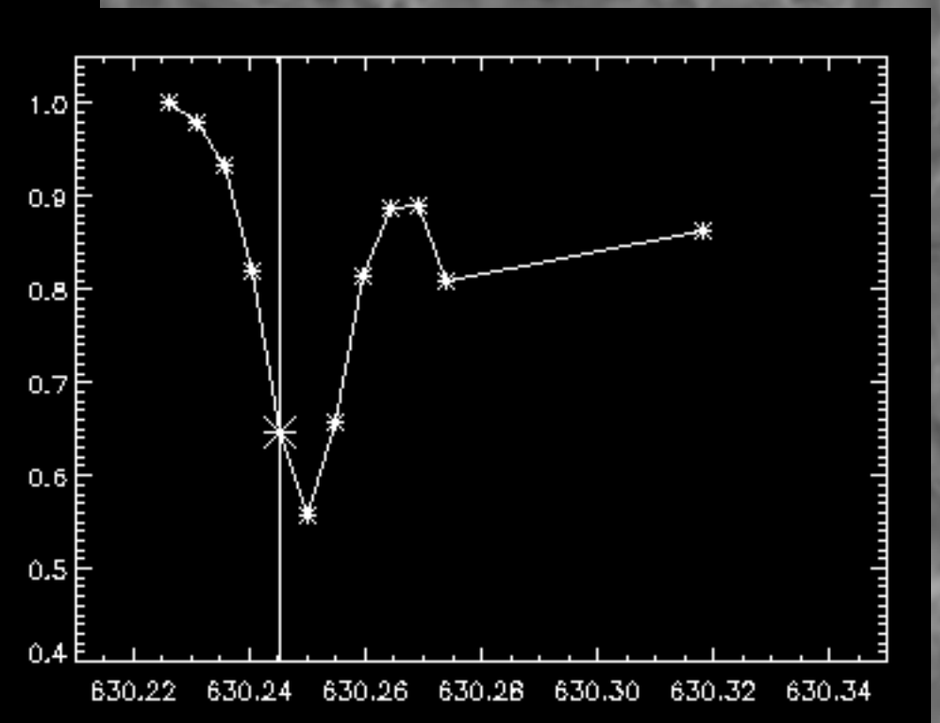
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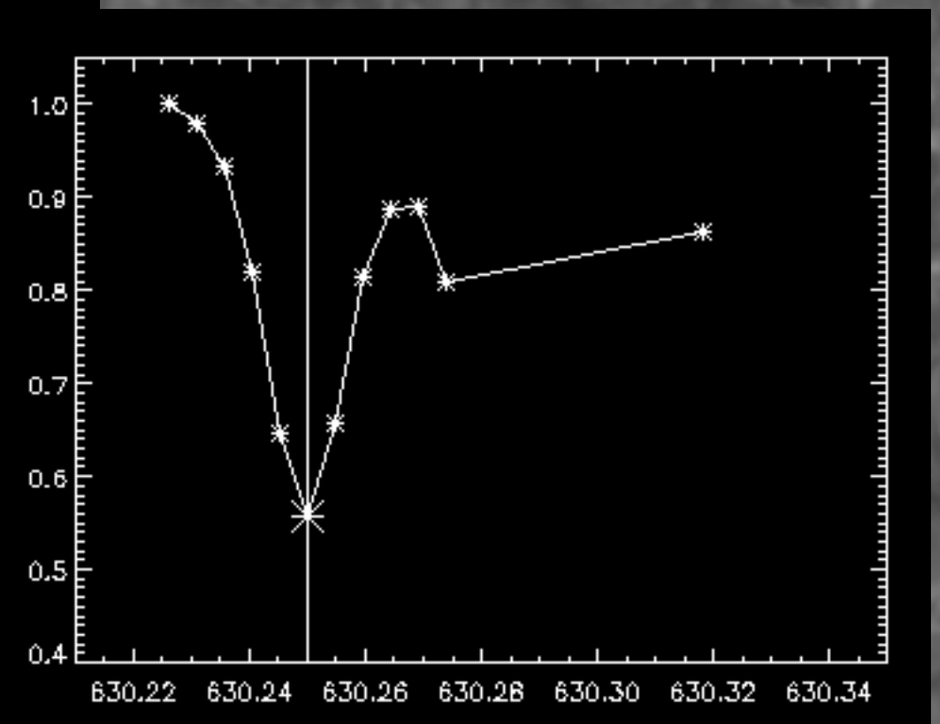
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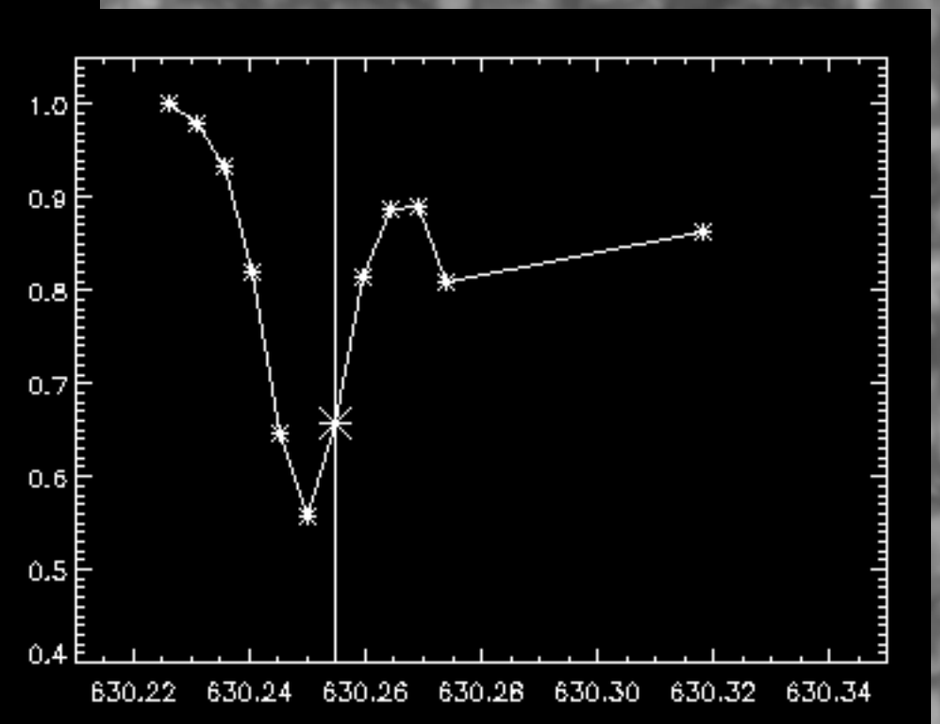
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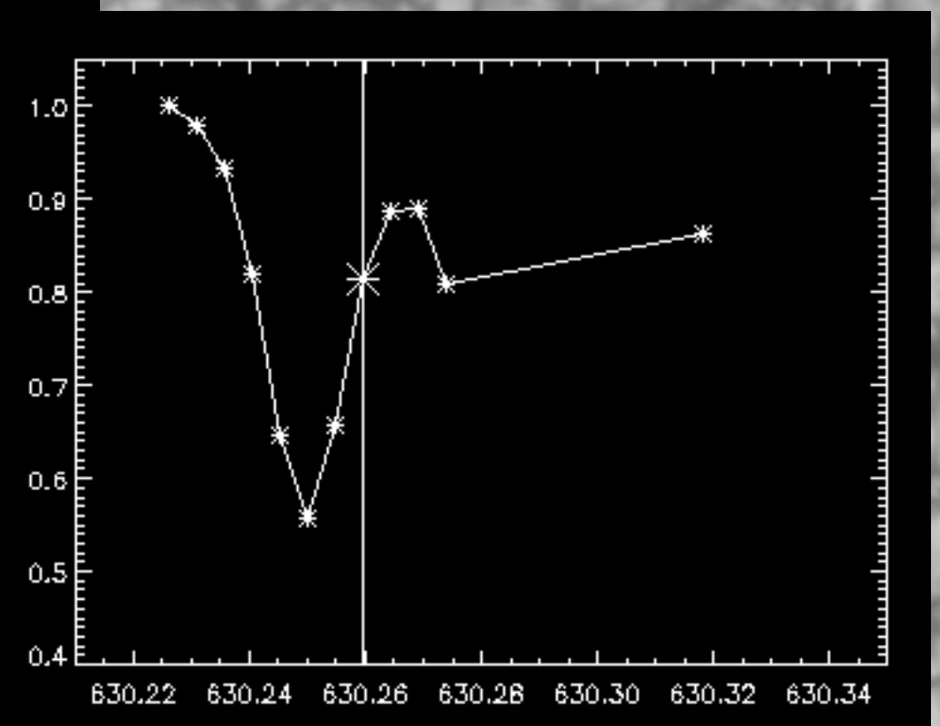
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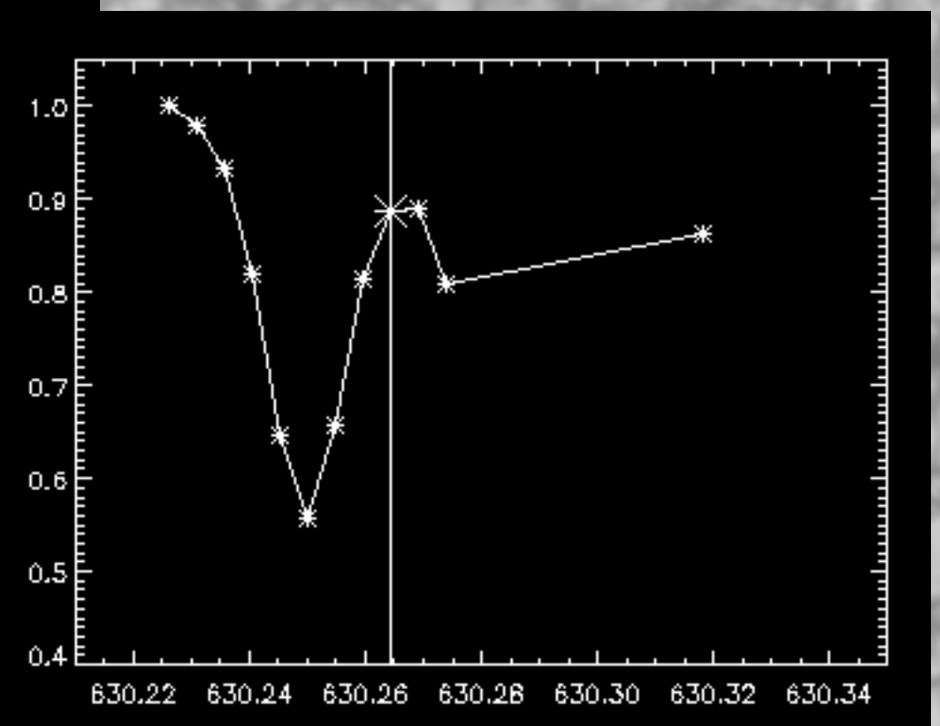
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0.9
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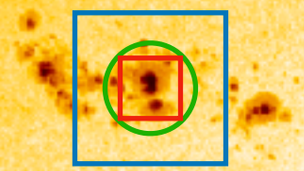


CRISP former FOV: 1´ square
CRISP FOV Sep 2022: 1.5’ circle
CRISP2 FOV: ~2.5’ square

Photosphere

Fe I 6302

Chromosphere

Ca II 8542

Photospheric polarization

Chromospheric polarization

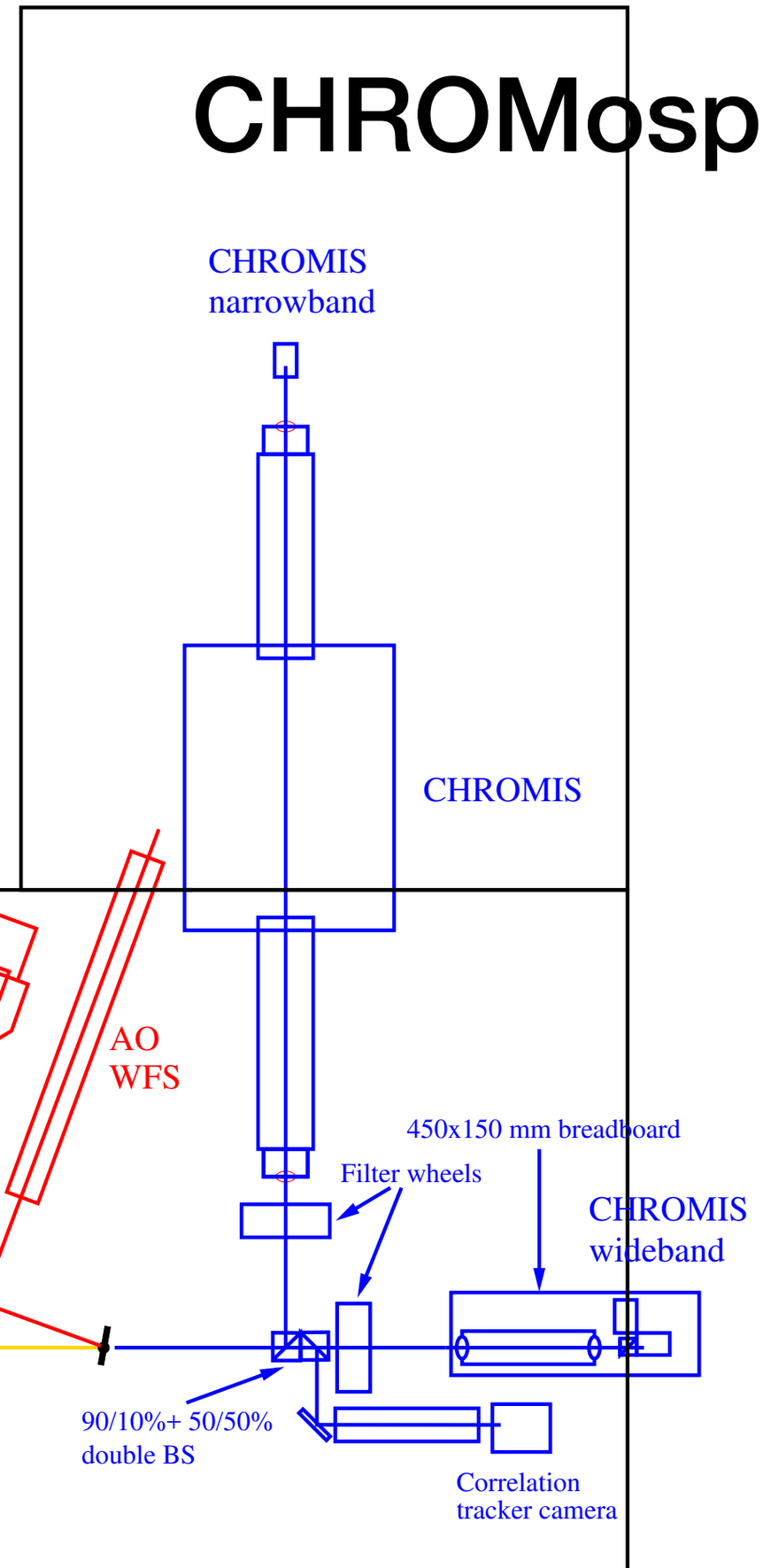
miles de km sobre el Sol

0 5 10 15 20 25 30

Red:
circular polarization
~ vertical B
Green:
linear polarization
~horizontal B

SST/CRISP
Jaime de la Cruz Rodríguez

CHROMIS =
CHROMospheric Imaging Spectrometer



- 2016
- Double Fabry-Pérot interferometer (similar to CRISP)
- No polarimetry
- 3800-5000 Å
- Prefilters: Ca II H & K cores+wings+continuum, H-β

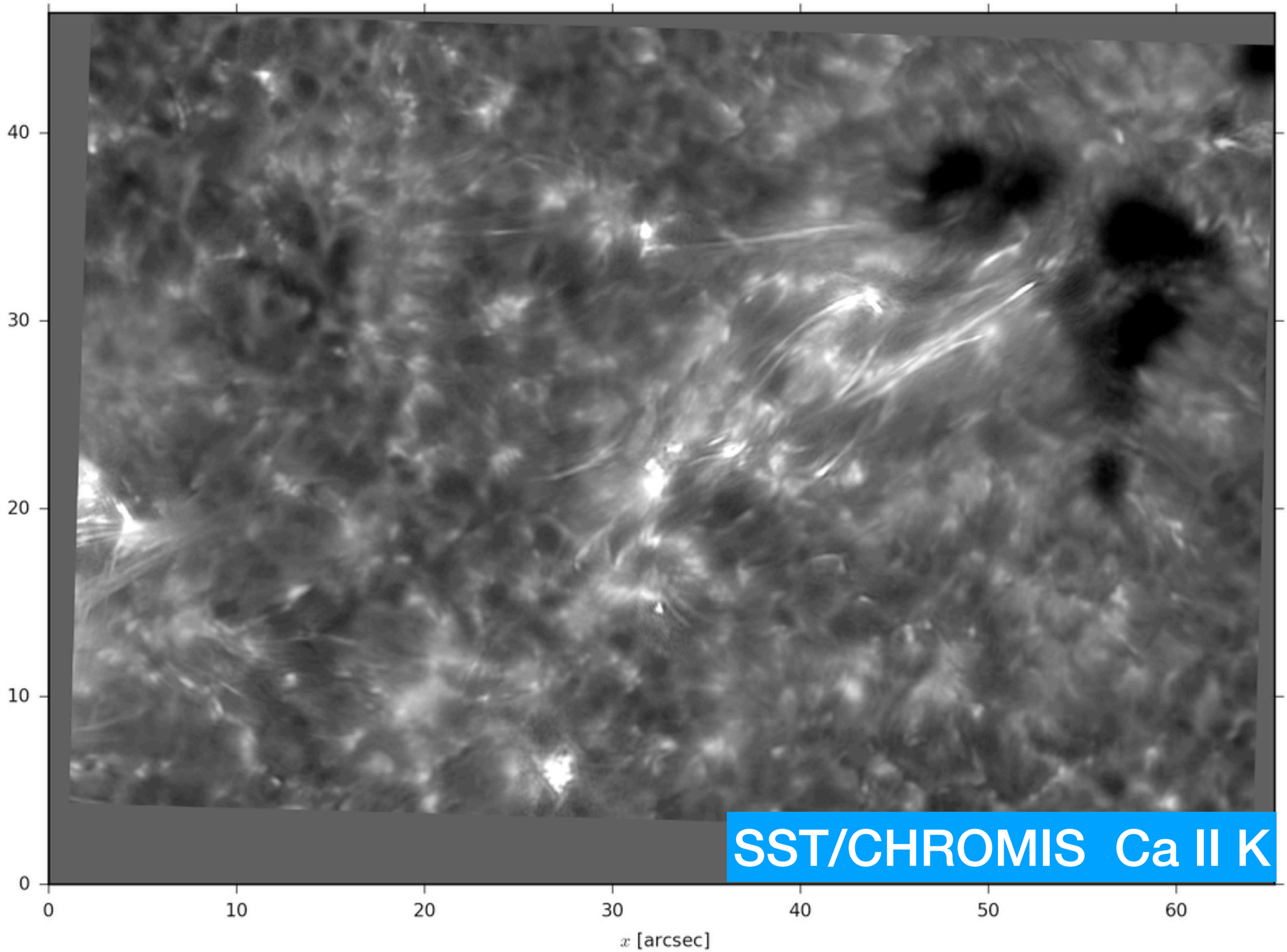
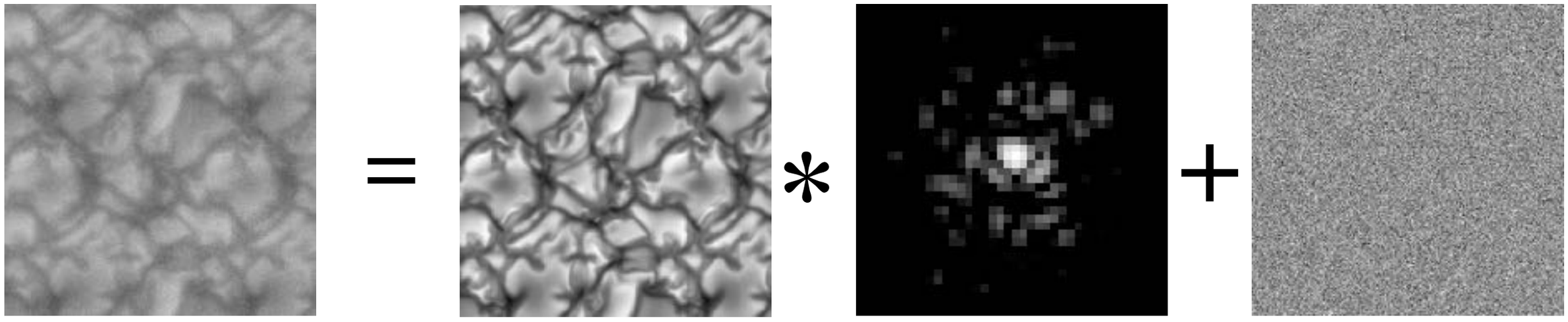

SST/CHROMIS Ca II K
y [arcsec]
x [arcsec]
0
10
20
30
40
50
60

Image restoration

image = object * PSF + noise



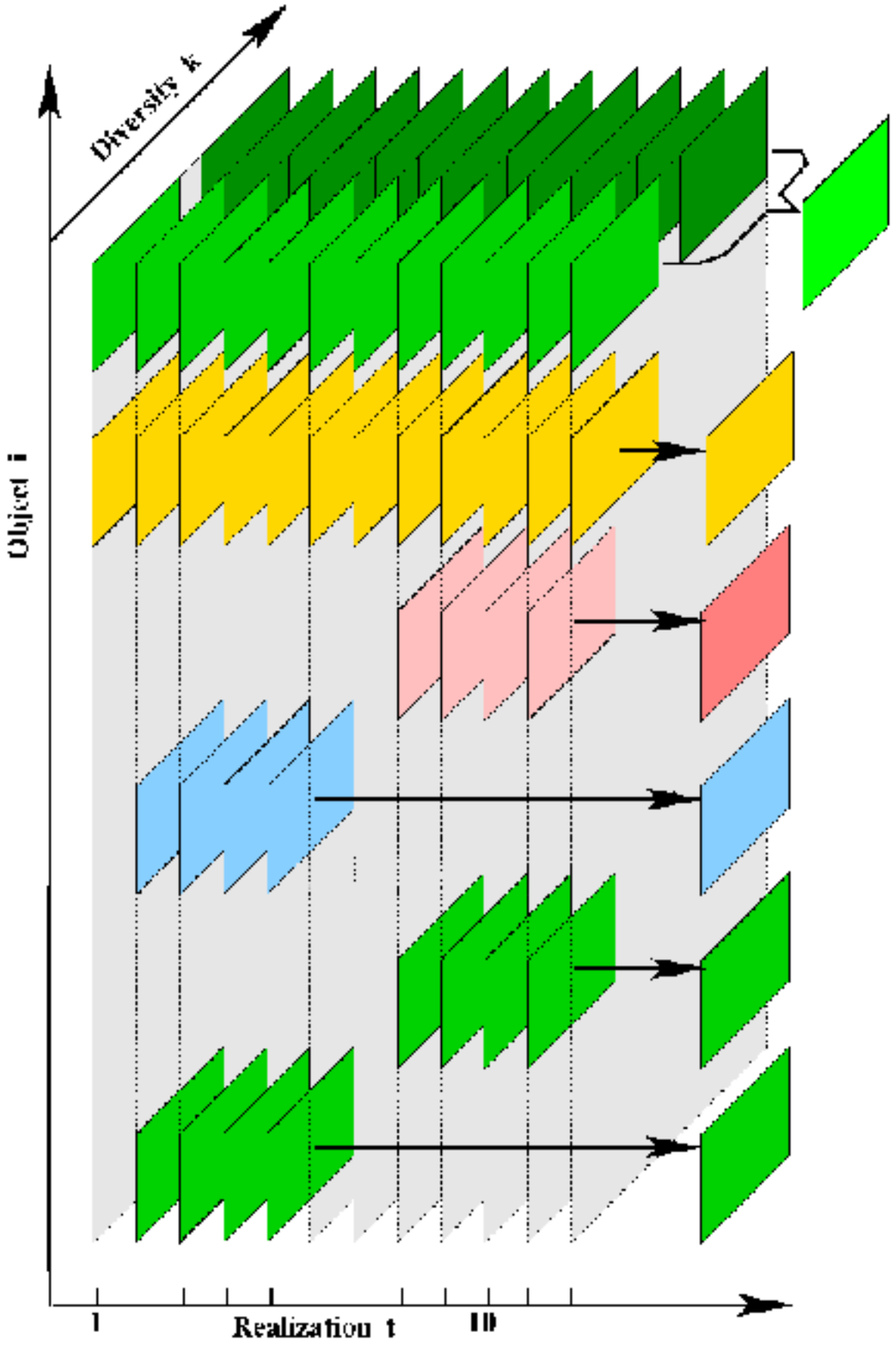
observed | unknown | unknown | unknown but modelled

Multi-Object Multi-Frame Blind Deconvolution MOMFBD

Estimate object and PSF simultaneously using
exposures with different PSFs of the same object
and
exposures of different objects with the same PSF.

Also Phase Diversity: focus and out of focus image pairs

MOMFBD



WB Anchor

Fixed Wing

NB (1)

NB (2)

WB Extra 1

WB Extra 2

CHROMIS WB-PD

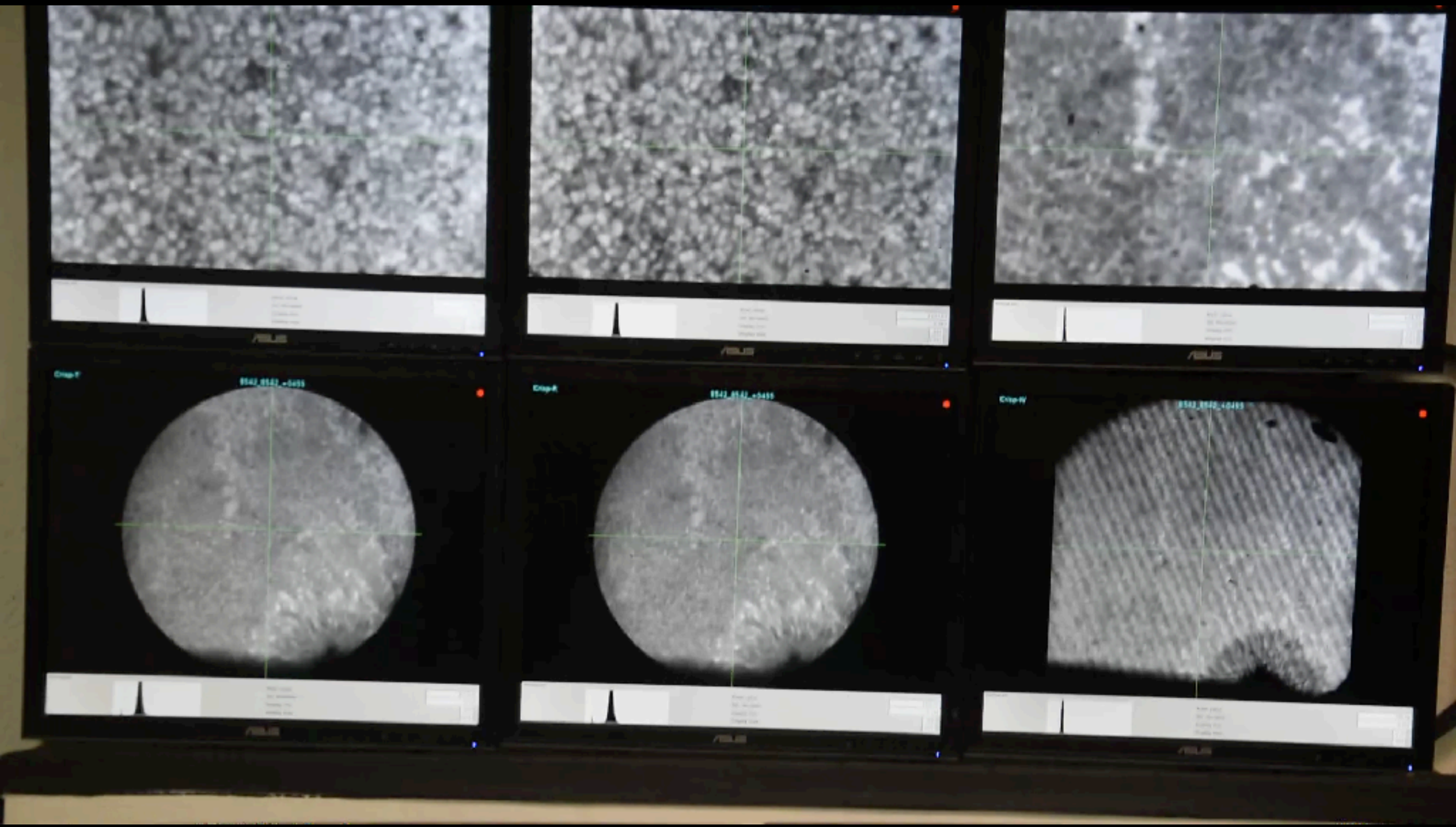
CHROMIS WB

CHROMIS NB

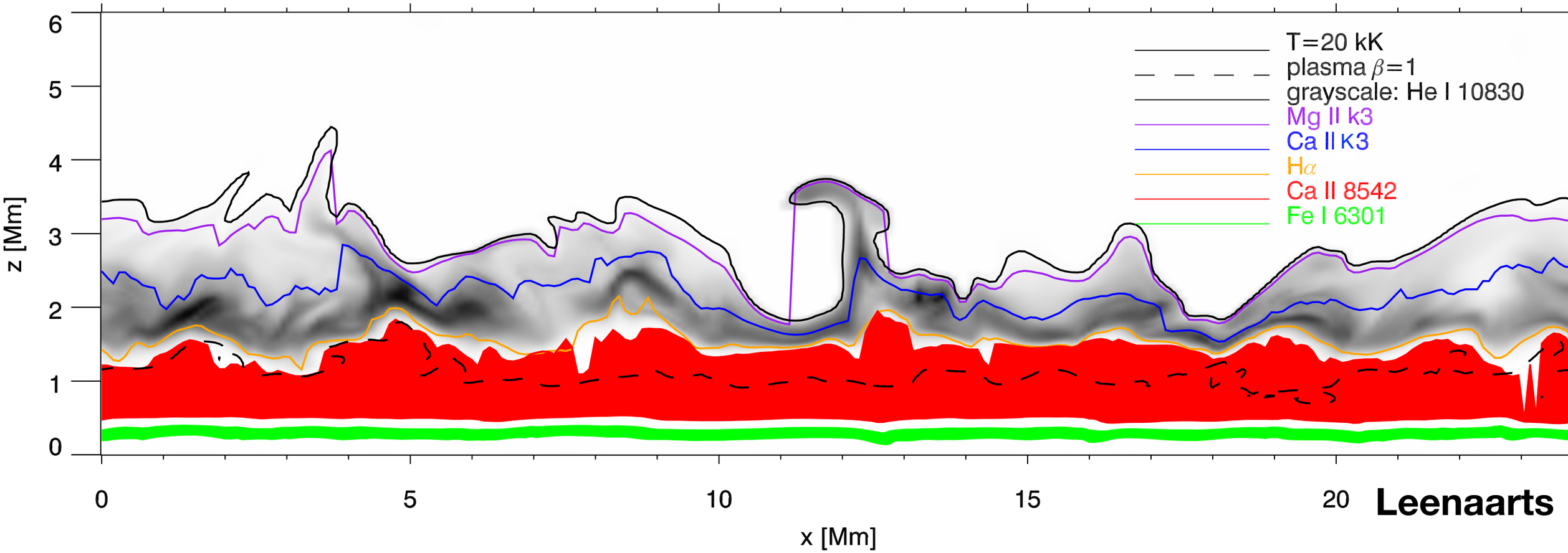
CRISP NB-T

CRISP NB-R

CRISP WB

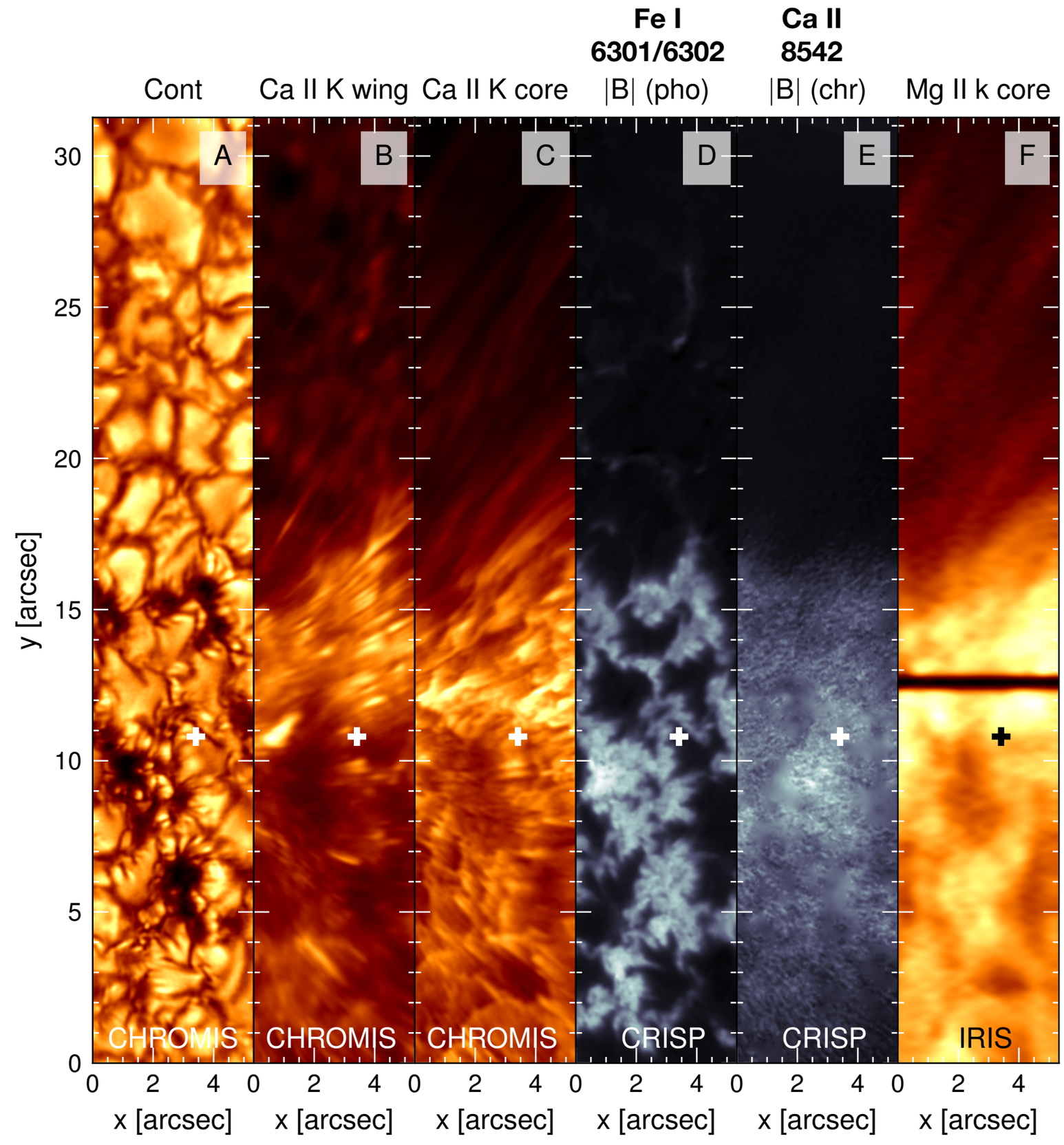


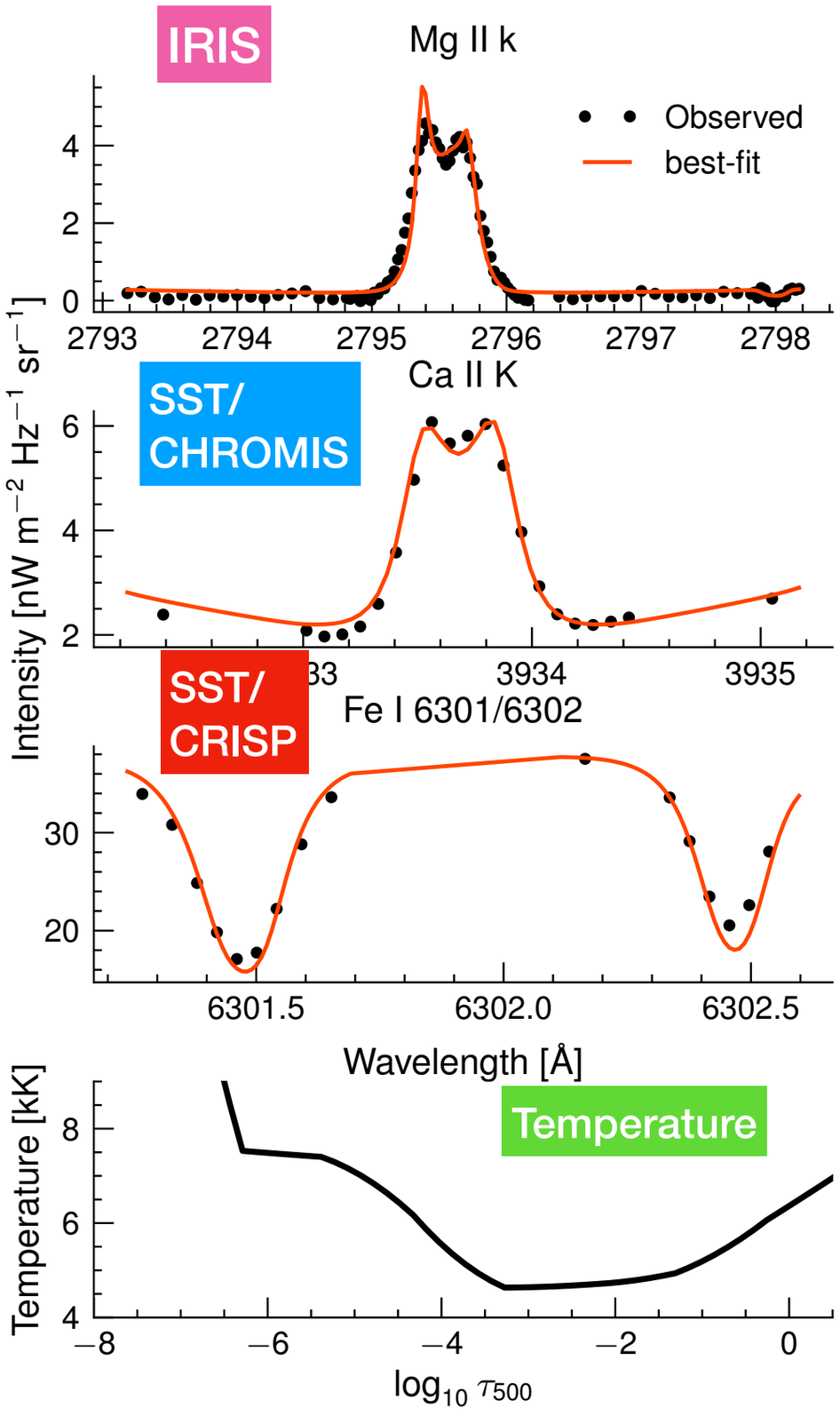
Height of formation for spectral lines in the solar photosphere and chromosphere Computed in a 3D BIFROST simulation



Typical observing programmes combine a number of these lines.

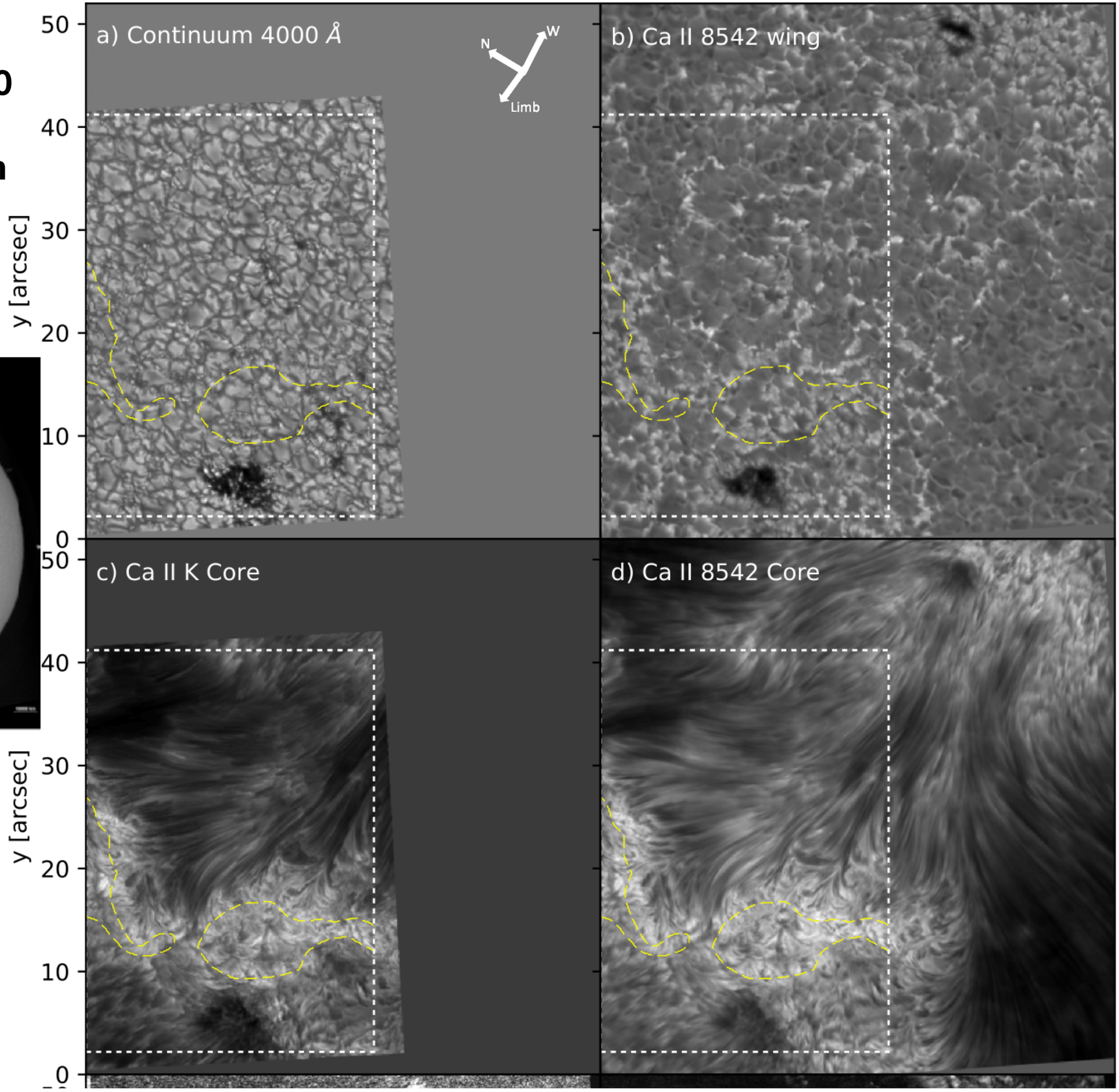
Multi-line diagnostics + inversion code ⟹ physical parameters



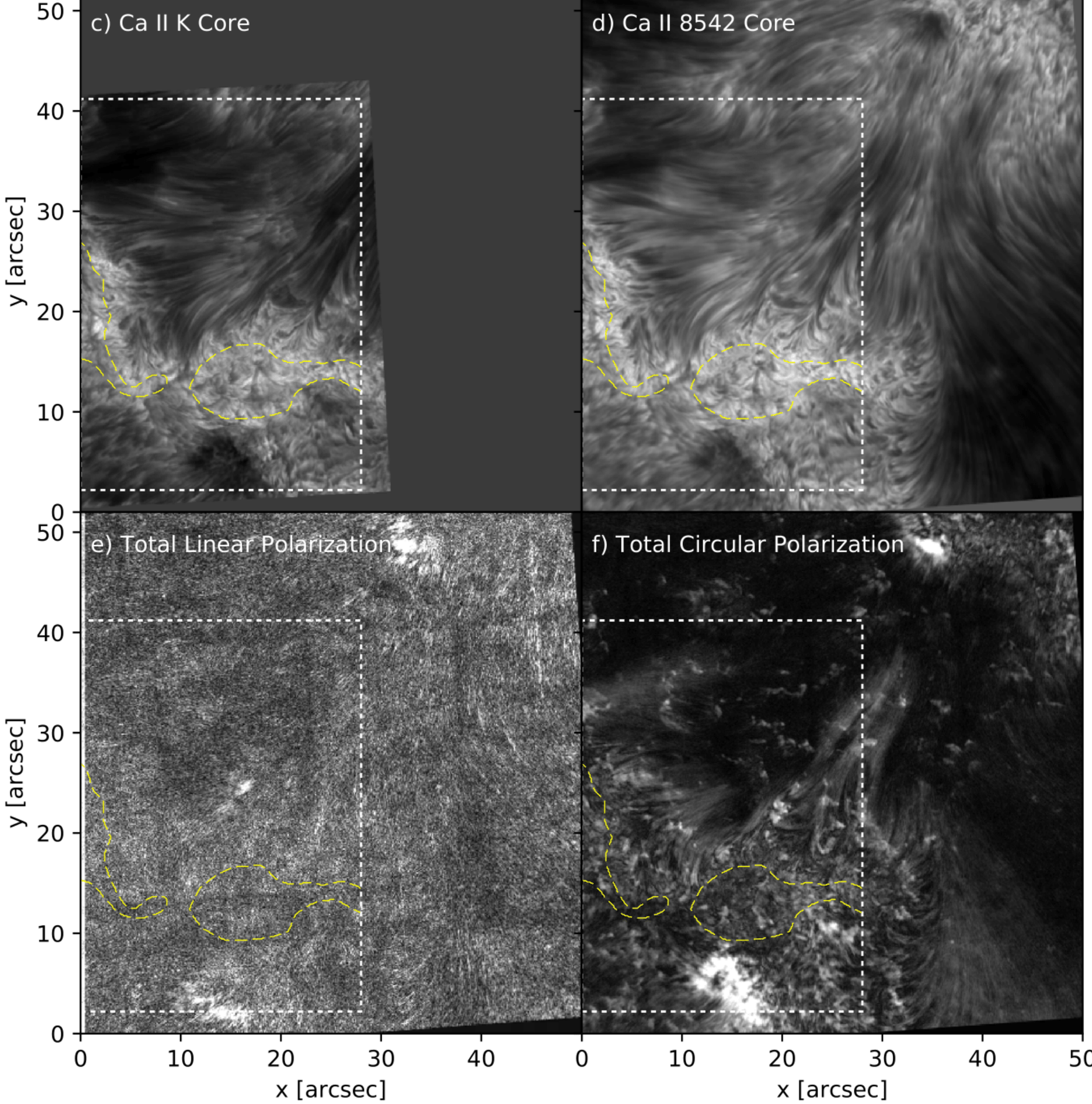


de la Cruz Rodríguez

Pietrow et al. 2020
Chromospheric magnetic fields in plage
μ=0.8



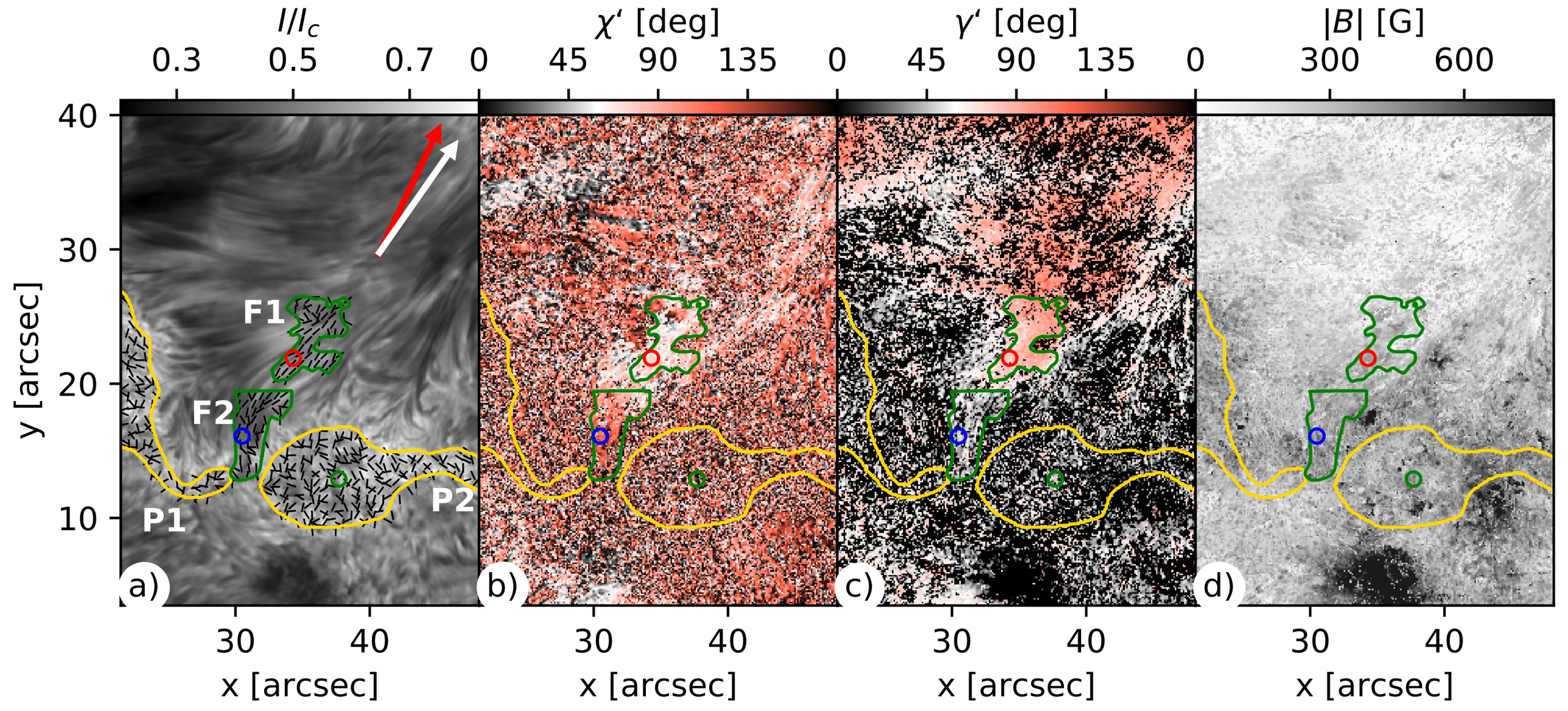
Pietrow et al. 2020
Chromospheric magnetic fields in plage
μ=0.8

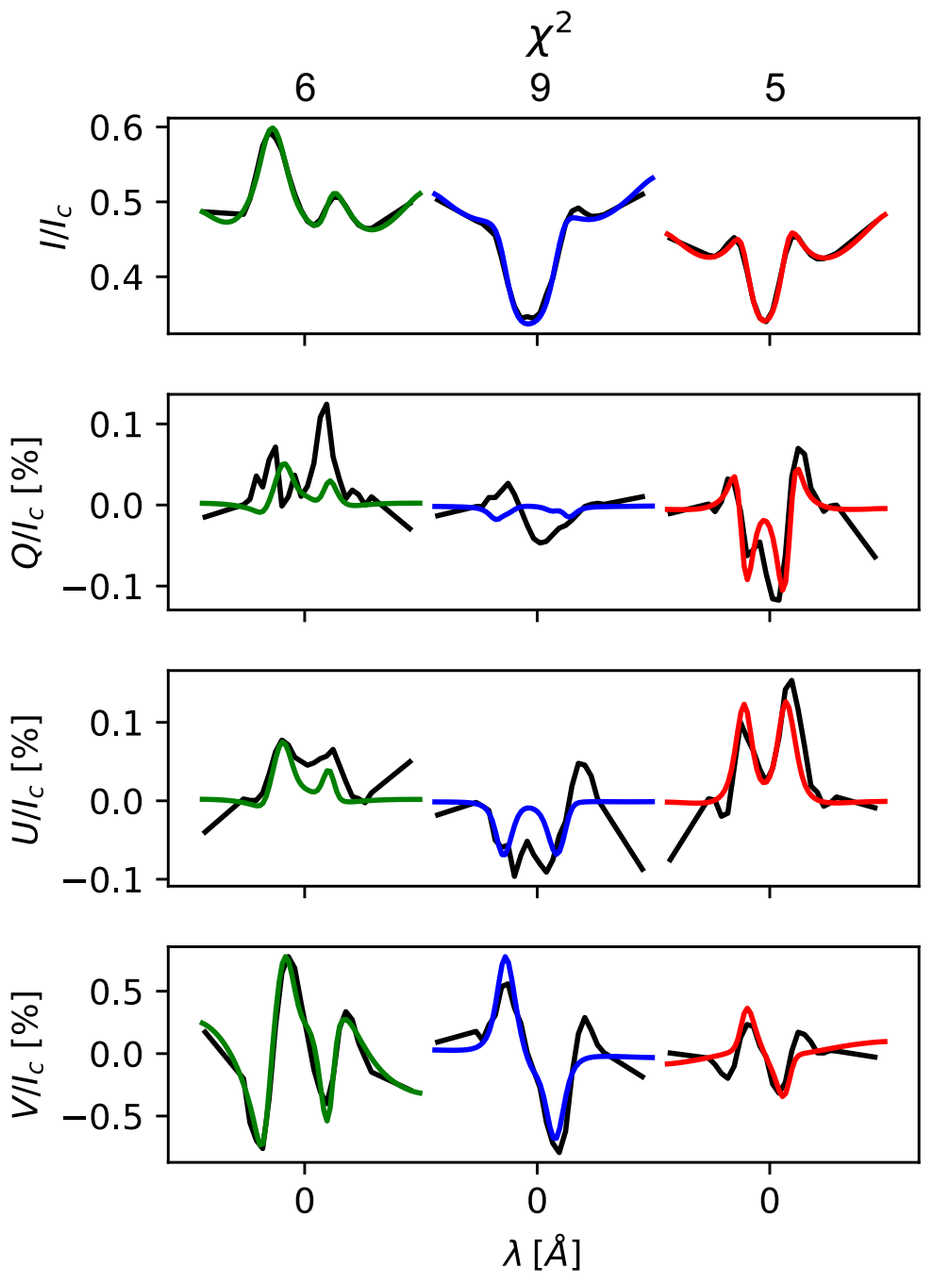


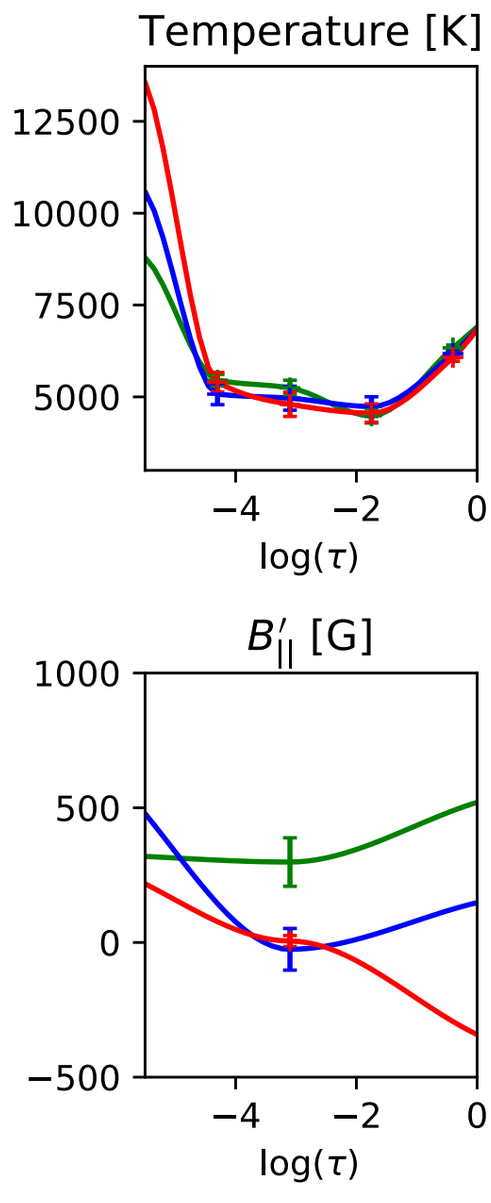
- darks & flats & polcal
- MOMFBD
- Fourier filtering fringe removal
- Neural network noise reduction
- Binning in space and time
- PCA fringe removal

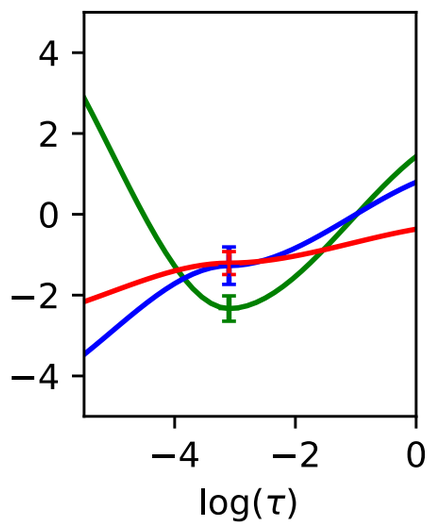
Many tricks with STiC inversion code (de la Cruz et al. 2016, 2019)

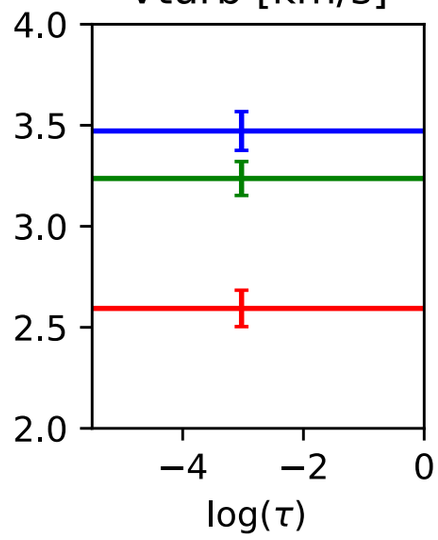
Signal inside green contours!
B = 400G
Worked for one data set only…



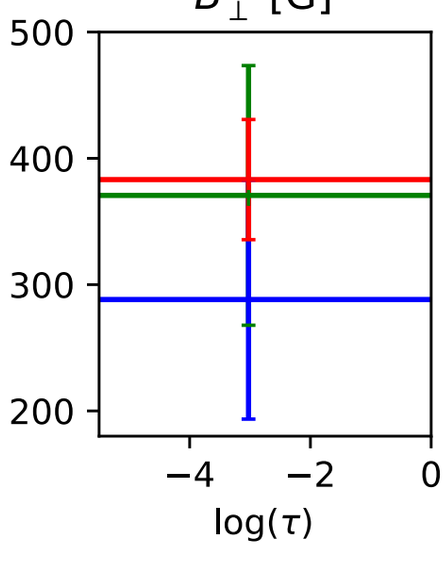

χ^2
6
9
5
I/I_c
0.6
0.5
0.4
Q/I_c [%]
0.1
0.0
−0.1
U/I_c [%]
0.1
0.0
−0.1
V/I_c [%]
0.5
0.0
−0.5
0
0
0
λ [Å]

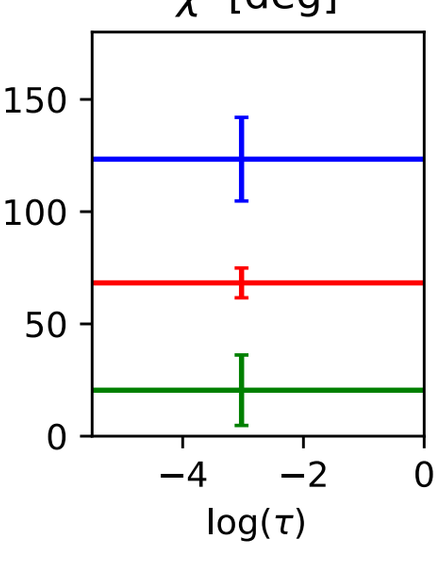

Temperature [K]
12500
10000
7500
5000
−4
−2
0
log(τ)


Vlos [km/s]
4
2
0
−2
−4
−4
−2
0
log(τ)


Vturb [km/s]
4.0
3.5
3.0
2.5
2.0
−4
−2
0
log(τ)

$B'_{||}$ [G]
1000
500
0
−500
−4
−2
0
log(τ)


$B'_{\perp}$ [G]
500
400
300
200
−4
−2
0
log(τ)


χ' [deg]
150
100
50
0
−4
−2
0
log(τ)

SST and you

- The Institute for Solar Physics is supported by the Swedish Research Council as an infrastructure of national interest.

- Observational project? Contact us *now*!

- Data? You can browse the Stockholm SST Archive.

Stockholm SST Archive βeta

Search

https://dubshen.astro.su.se/sst_archive/

Sign in | Sign up

Search

Start Date: 2000 - 01 - 01

End Date: 2022 - 10 - 12

Instrument: All

Spectral Lines: None Selected

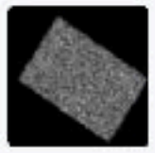
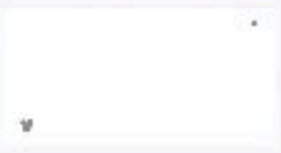
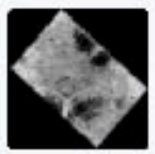
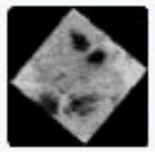
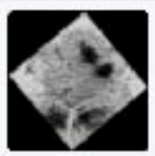
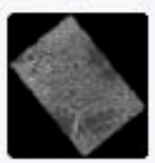
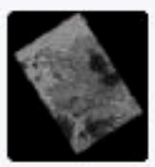
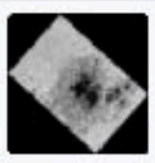
Polarimetry: Any

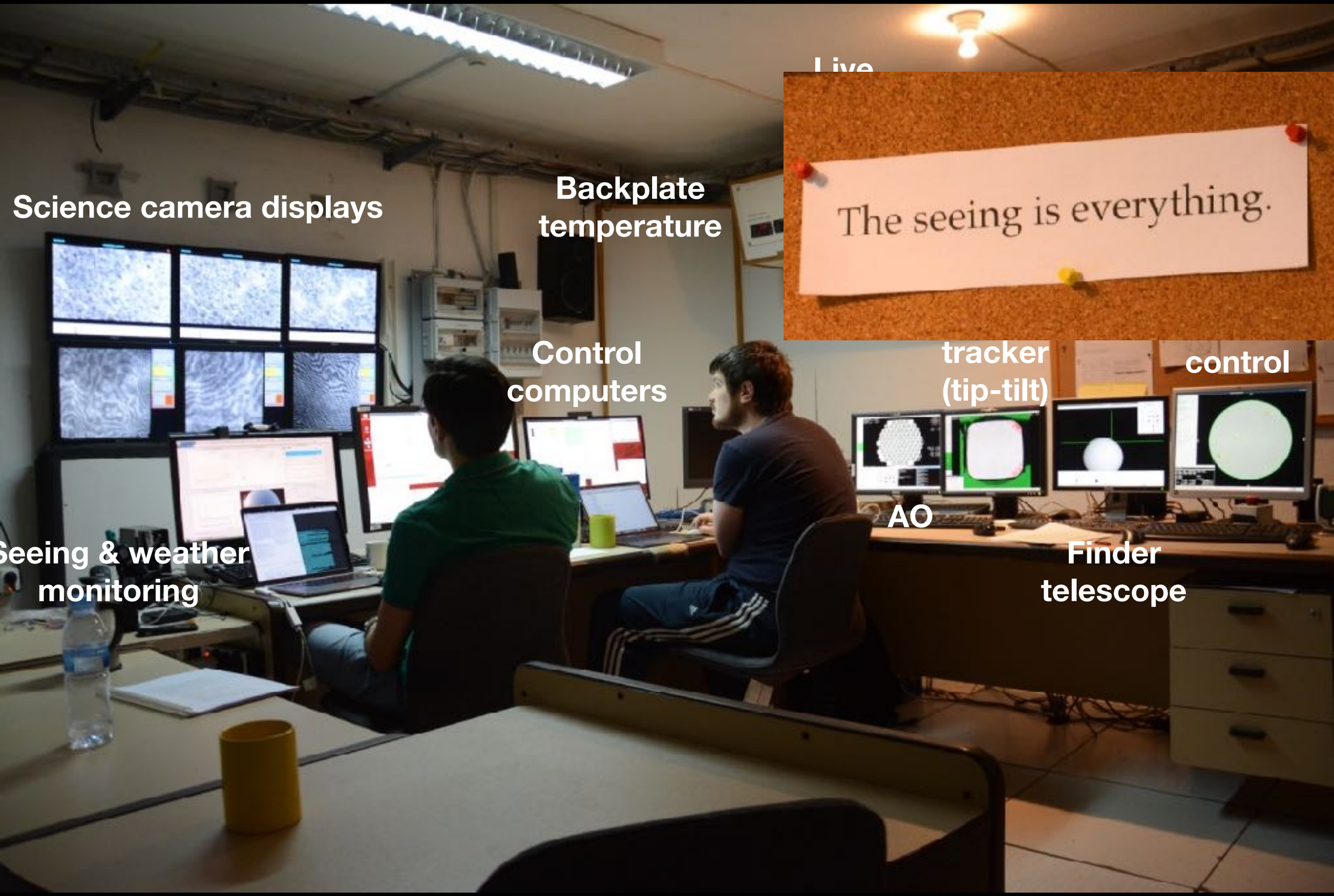
Advanced query :

Search

Showing results 1 to 25 of 190

← 1 2 3 4 5 6 7 8 →

Preview	Spectral Line(s)	Spectral Line Profile	Instrument	Time of Observation (UTC)	Data Size	Download
	3950, 7772, 6302, 8542		CHROMIS	2022-06-03 12:18:35	234.5 GB	4
	4846, 3950		CHROMIS	2022-05-19 10:26:30	55.4 GB	3
	8542		CRISP	2022-05-19 10:25:37	81.1 GB	
	6302, 8542		CRISP	2022-05-19 08:58:11	46.6 GB	2
	4846, 3950		CHROMIS	2022-05-19 08:57:46	121.0 GB	3
	3950		CHROMIS	2022-05-19 07:21:48	130.7 GB	
	8542		CRISP	2022-05-19 07:21:33	180.9 GB	
	4846, 6302, 3950, 8542		CHROMIS	2022-05-17 10:24:28	33.6 GB	5

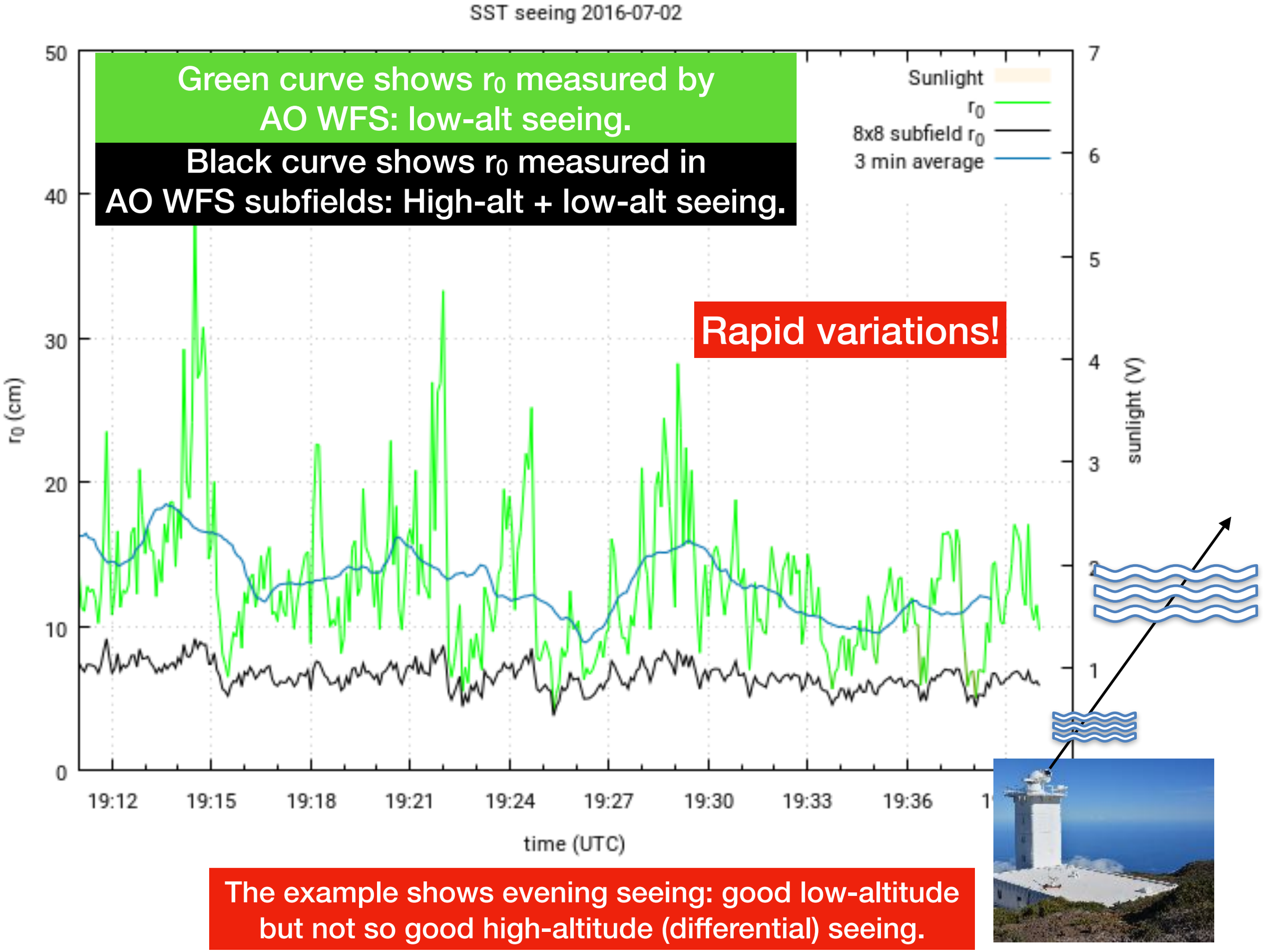

Science camera displays
Backplate temperature
Live
The seeing is everything.
Control computers
tracker (tip-tilt)
control
AO
Seeing & weather monitoring
Finder telescope

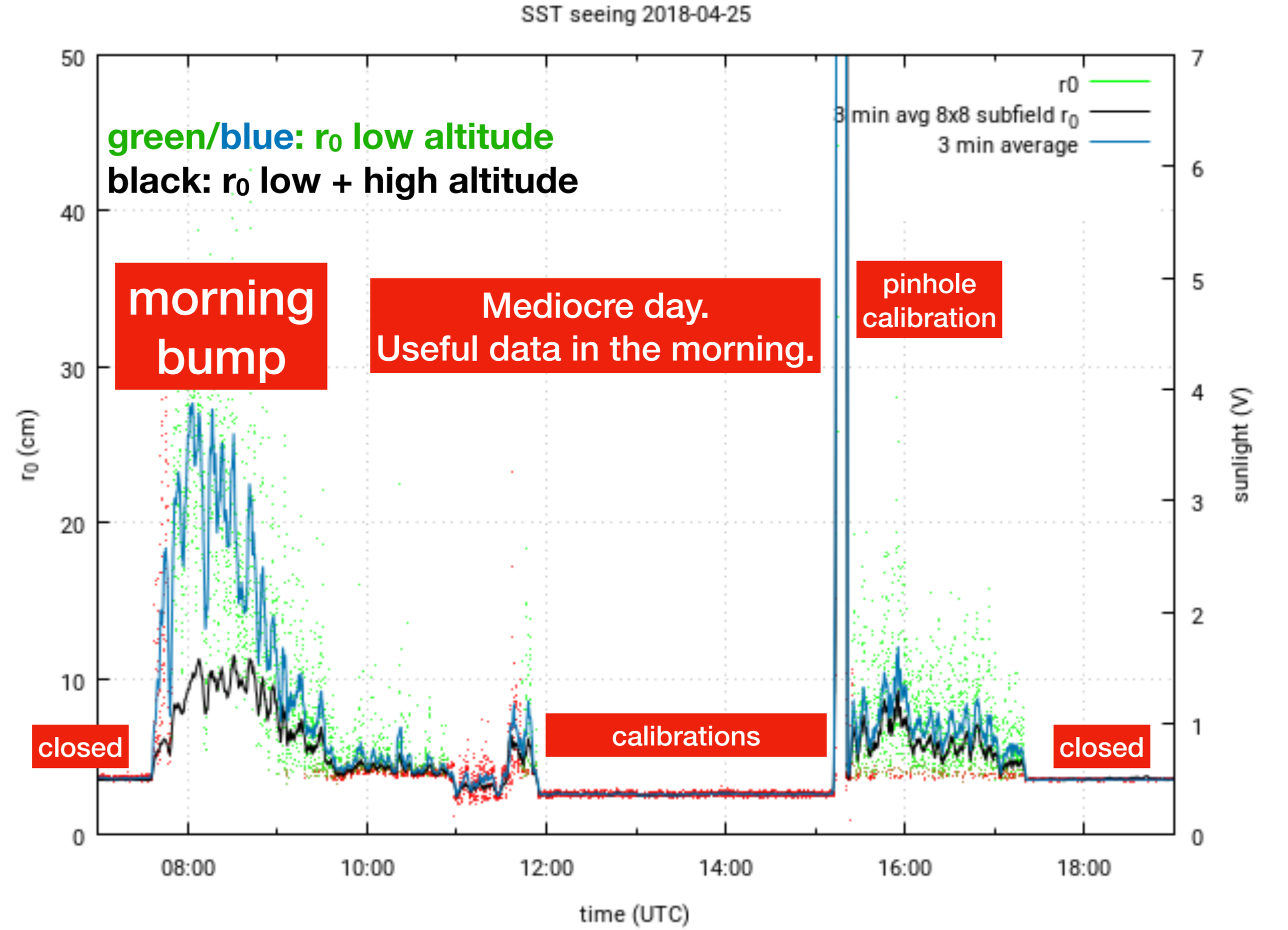
Seeing

- Fried parameter r_0 [cm]
- Typical scale of turbulence-caused wavefront deformations
- Higher values = good seeing
- Can be interpreted as diameter of telescope that can reach the diffraction limit.

SST: not so good seeing
AO & tip-tilt turned off

SST seeing curves produced by AO @550 nm.




SST seeing 2018-04-25
green/blue: r0 low altitude
black: r0 low + high altitude
morning bump
Mediocre day.
Useful data in the morning.
pinhole calibration
closed
calibrations
closed
r0
3 min avg 8x8 subfield r0
3 min average
r0 (cm)
sunlight (V)
time (UTC)
0
10
20
30
40
50
0
1
2
3
4
5
6
7
08:00
10:00
12:00
14:00
16:00
18:00

SST seeing 2017-07-10

A rather good day!

Sunlight
3 min avg. SHABAR
r0
3 min avg 8x8 subfield r_0
3 min average

r_0 (cm)

sunlight (V)

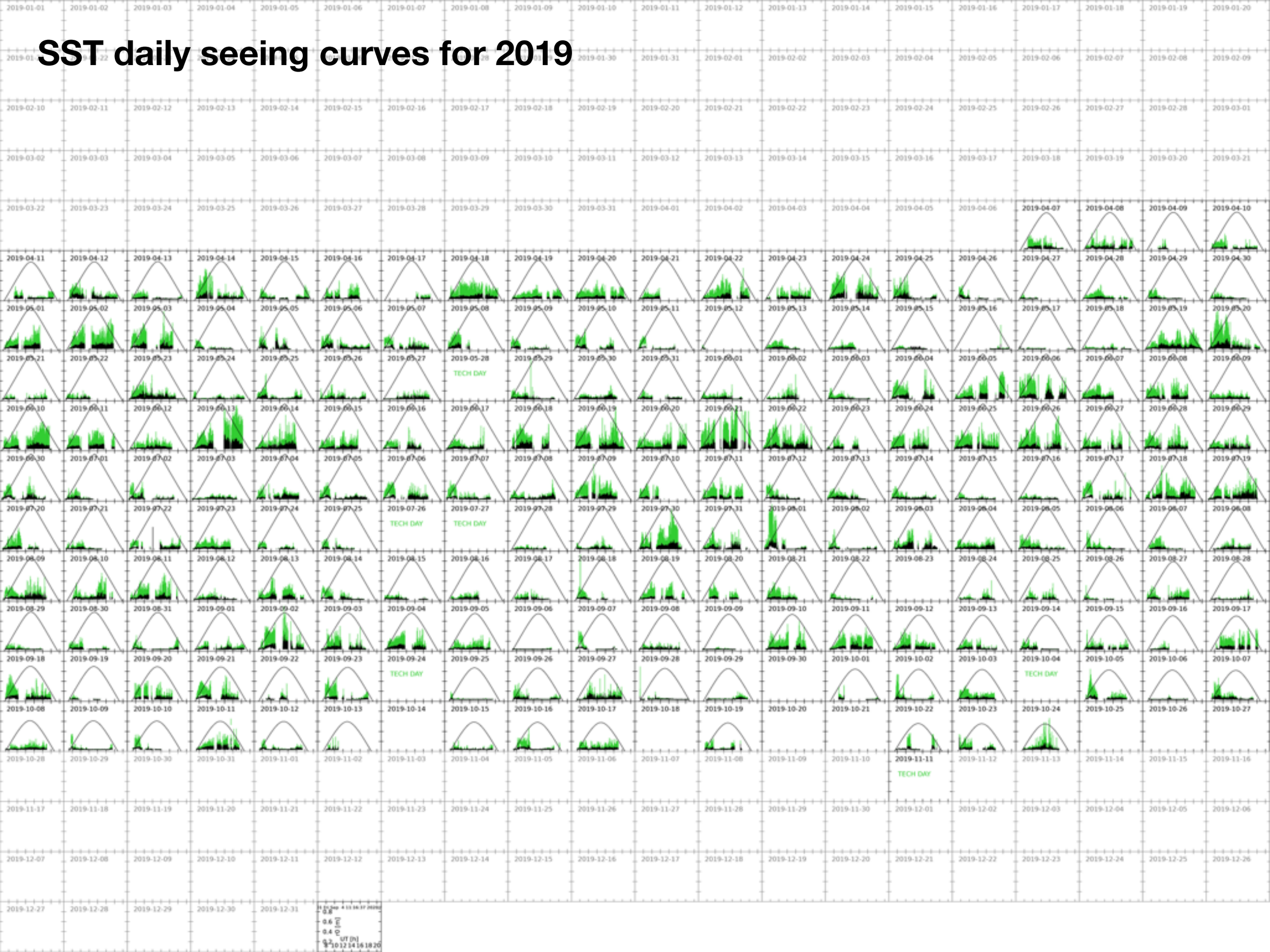
50
40
30
20
10
0

7
6
5
4
3
2
1
0

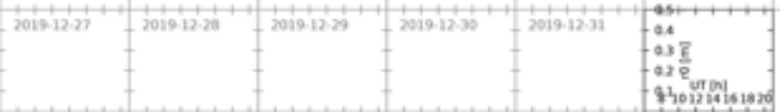
08:00
10:00
12:00
14:00
16:00
18:00

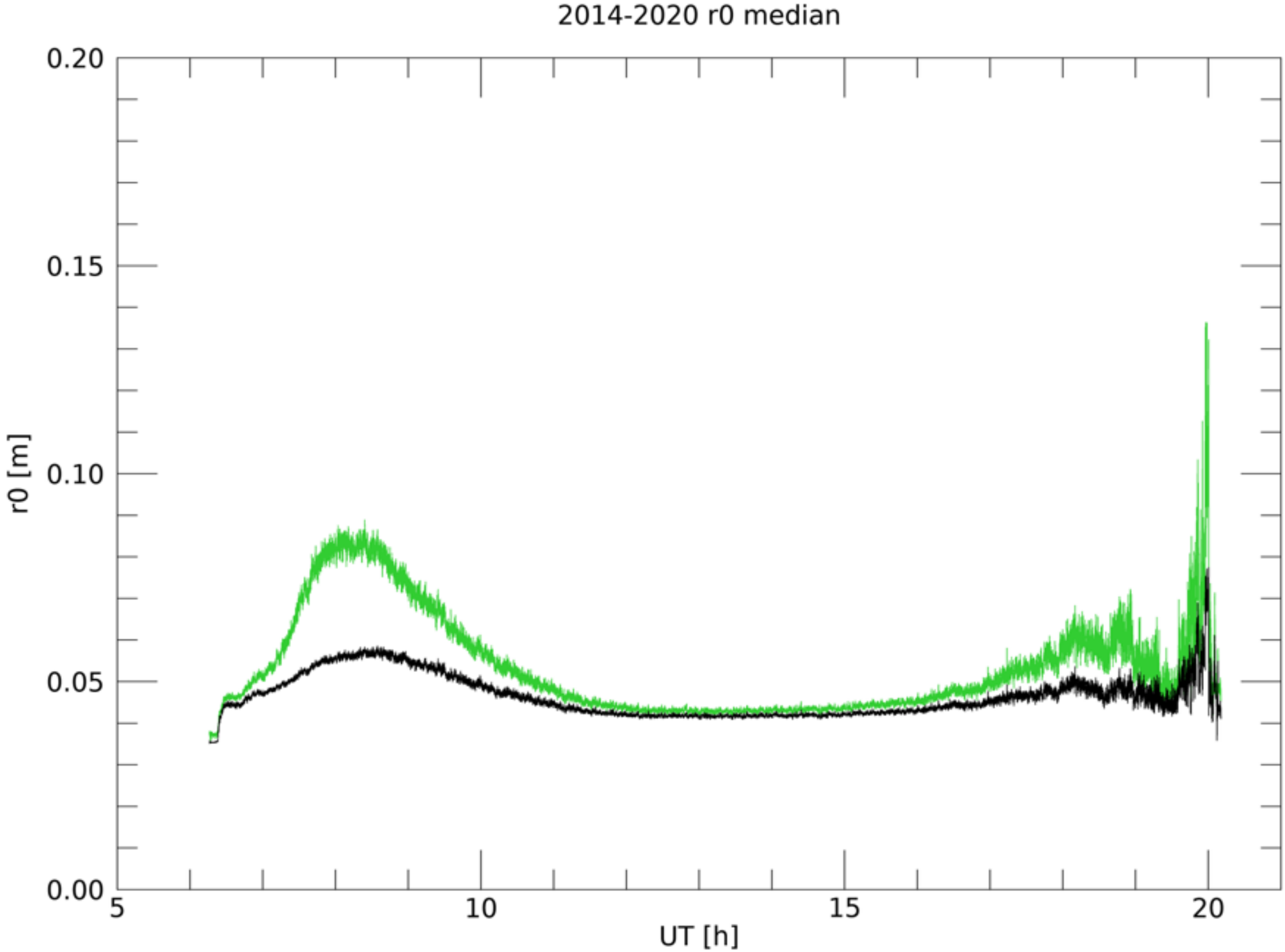
time (UTC)

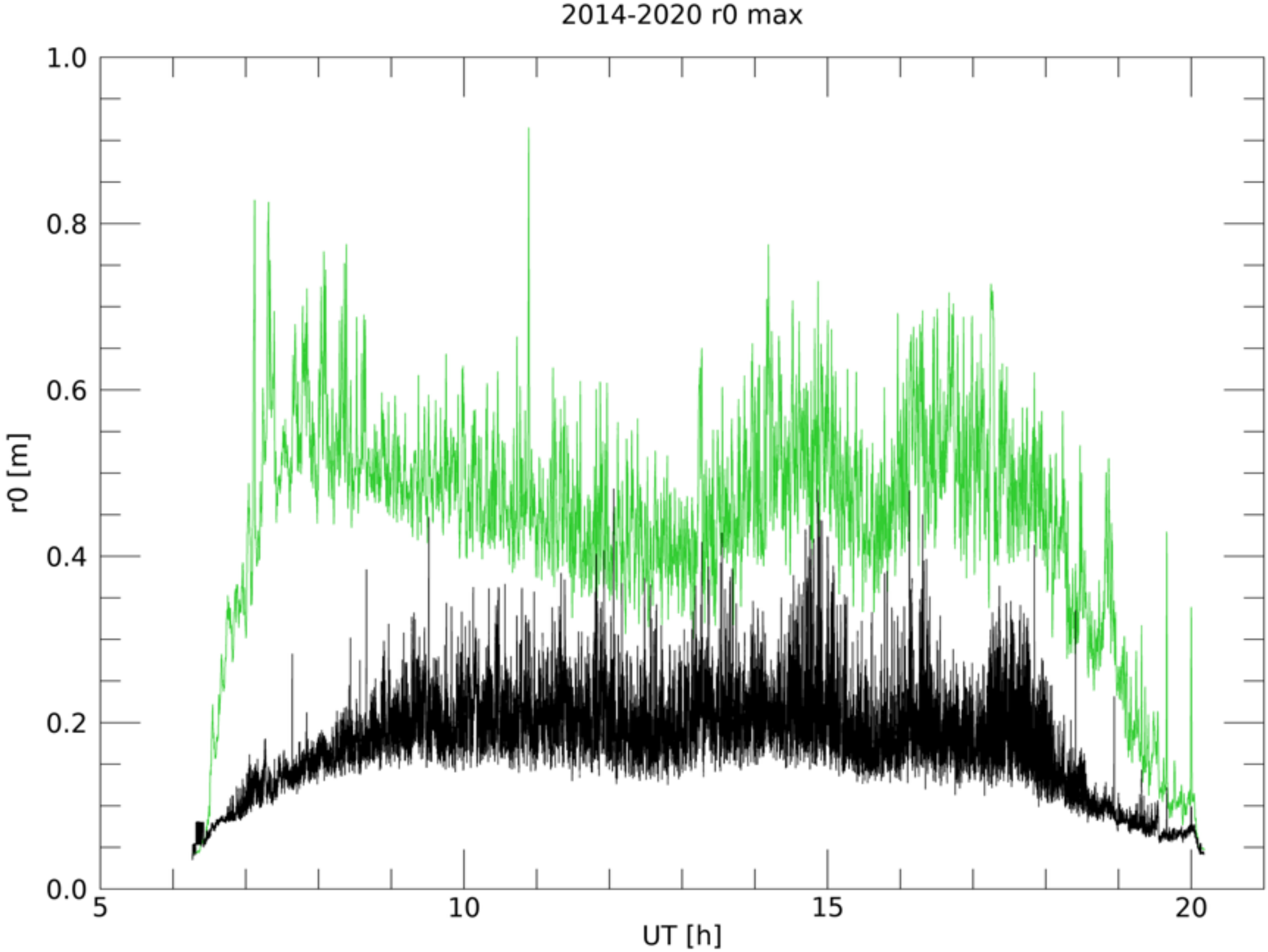
SST daily seeing curves for 2019



SST daily seeing curves for 2019




2014-2020 r0 median
0.20
0.15
0.10
0.05
0.00
r0 [m]
5
10
15
20
UT [h]


2014-2020 r0 max
r0 [m]
1.0
0.8
0.6
0.4
0.2
0.0
5
10
15
20
UT [h]

Datasets from SST & SVST publications 2002–2017

Nature, Science

elevation

El [deg]

0
20
40
60
80

6
8
10
12
14
16
18
20

UT [h]

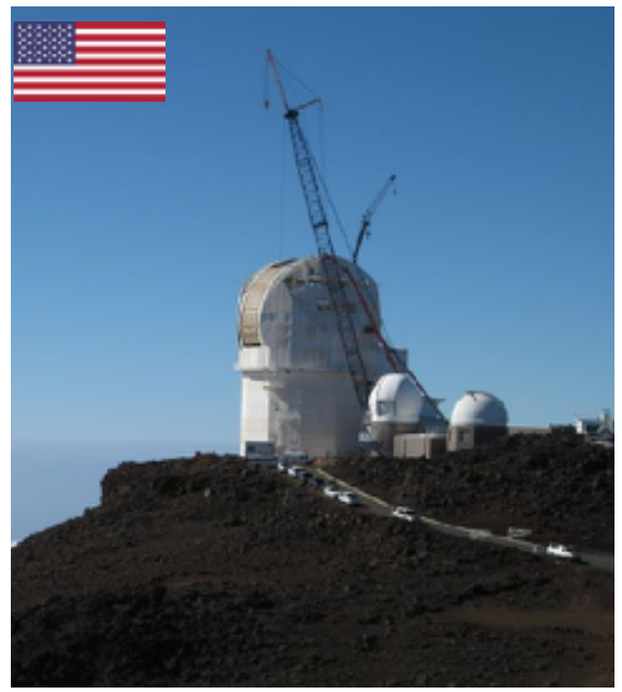
time

History

LEST (2.5 m; cancelled 1998; La Palma)

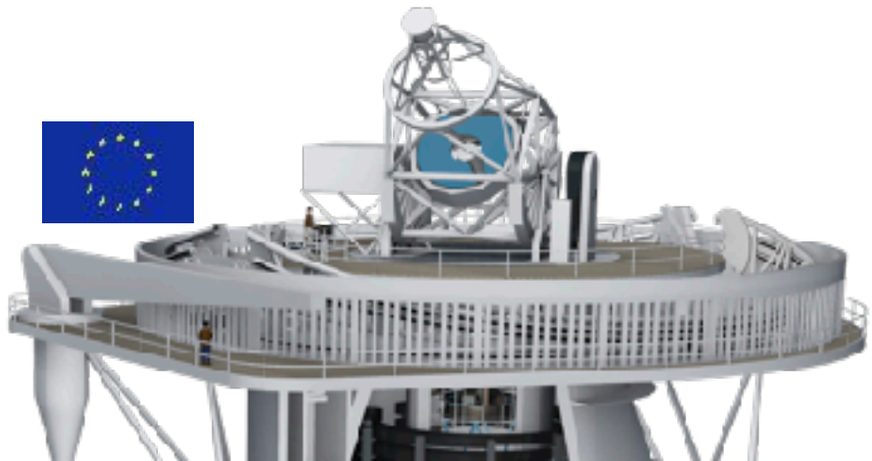
SST (0.97 m; 2002; La Palma)

GREGOR (1.5 m; 2014; Tenerife)



DKIST (4 m; 2019; Haleakalā, Maui, Hawaii)

EST – envisioned 2006, on ESFRI list since March 2017.



European Solar Telescope

Optical design: Gregorian

Heat rejector

- M1: 4.2m
- M2: 0.8 m, adaptive
- M3-M6: adaptive

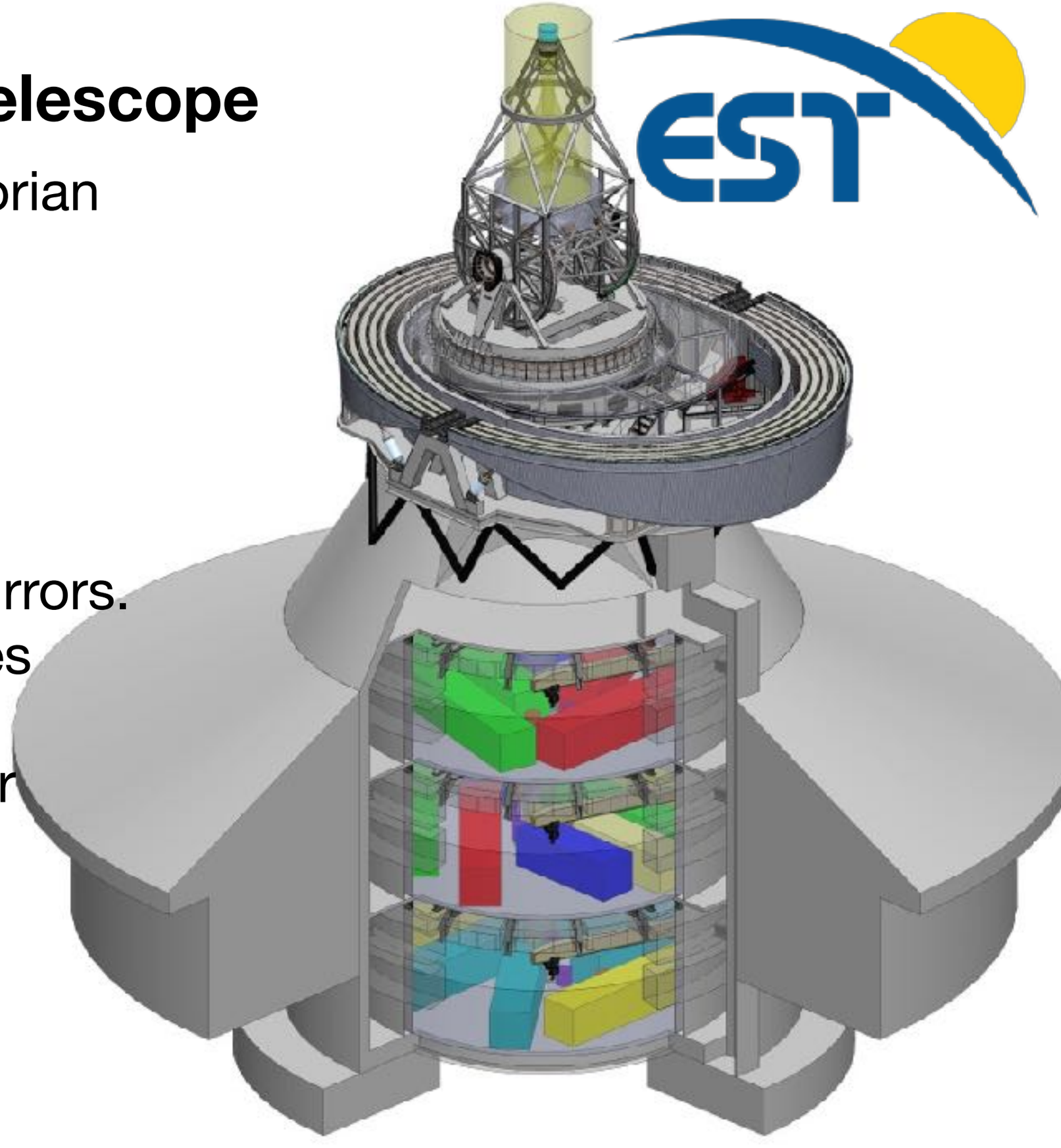
Minimise number of mirrors.

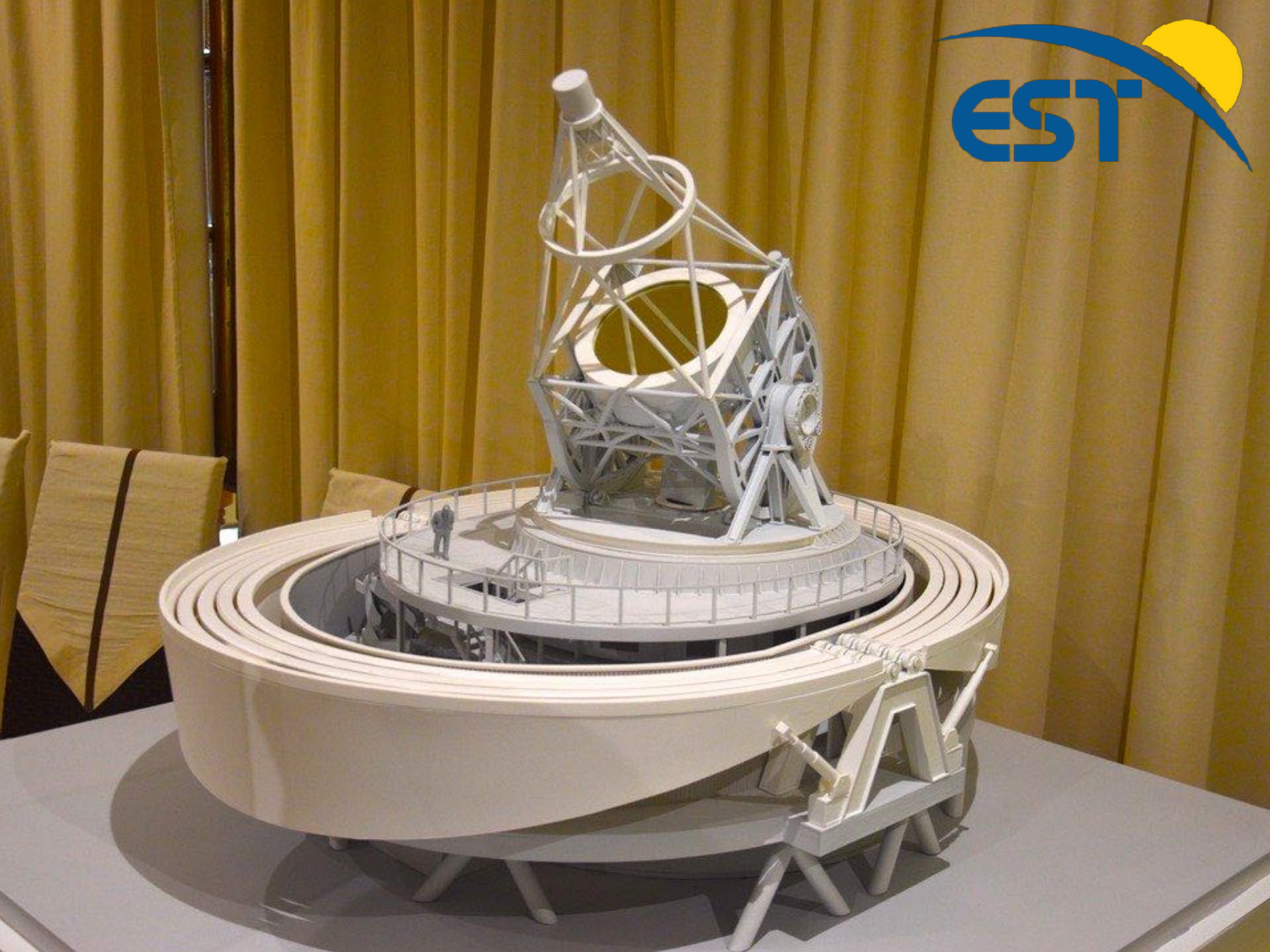
Relay optics: lenses

Instrumentation suite for cospatial and cotemporal diagnostics

680-1100 nm:
2 IFU’s, 1 Tunable filter

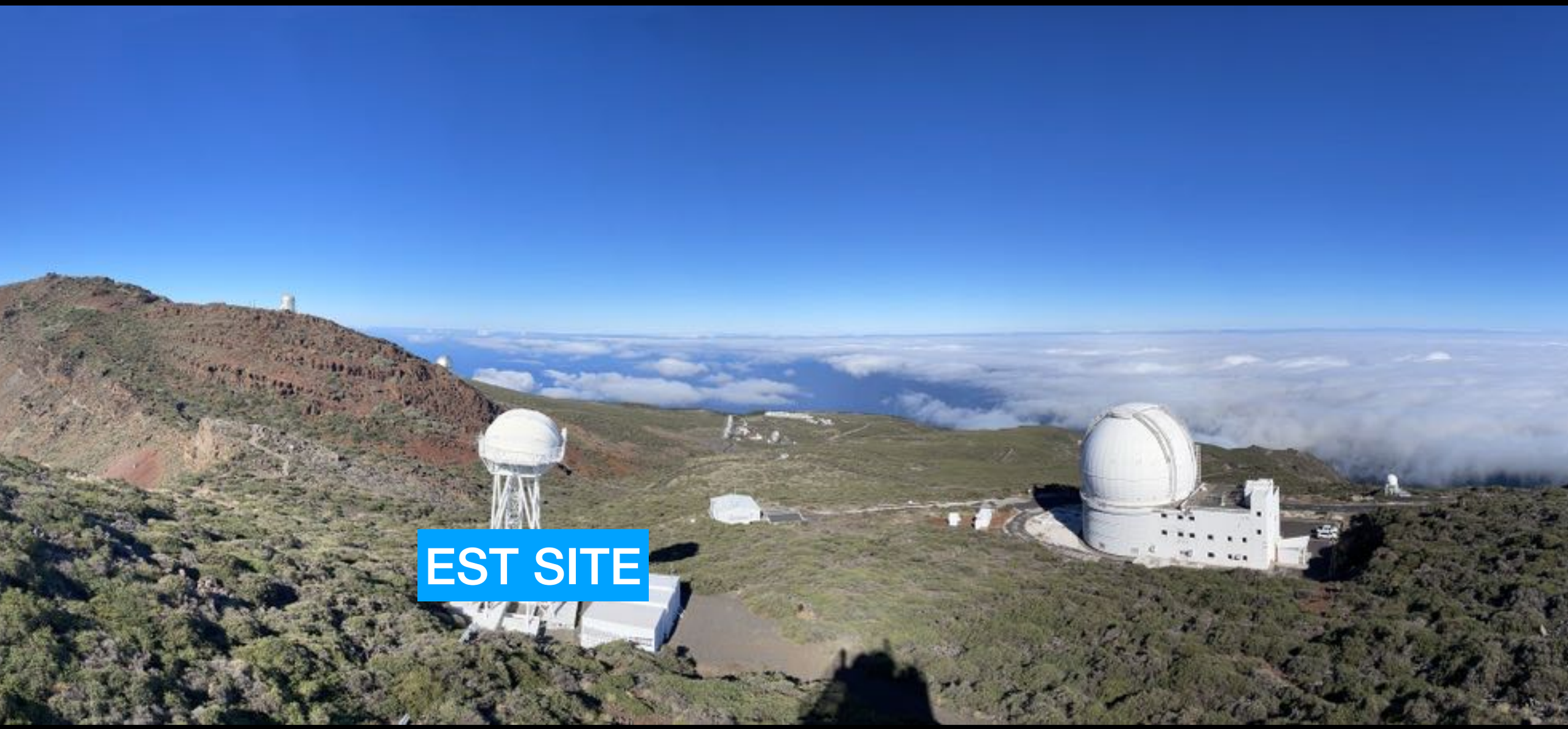
380-680 nm:
2 IFU’s, 2 Tunable filters

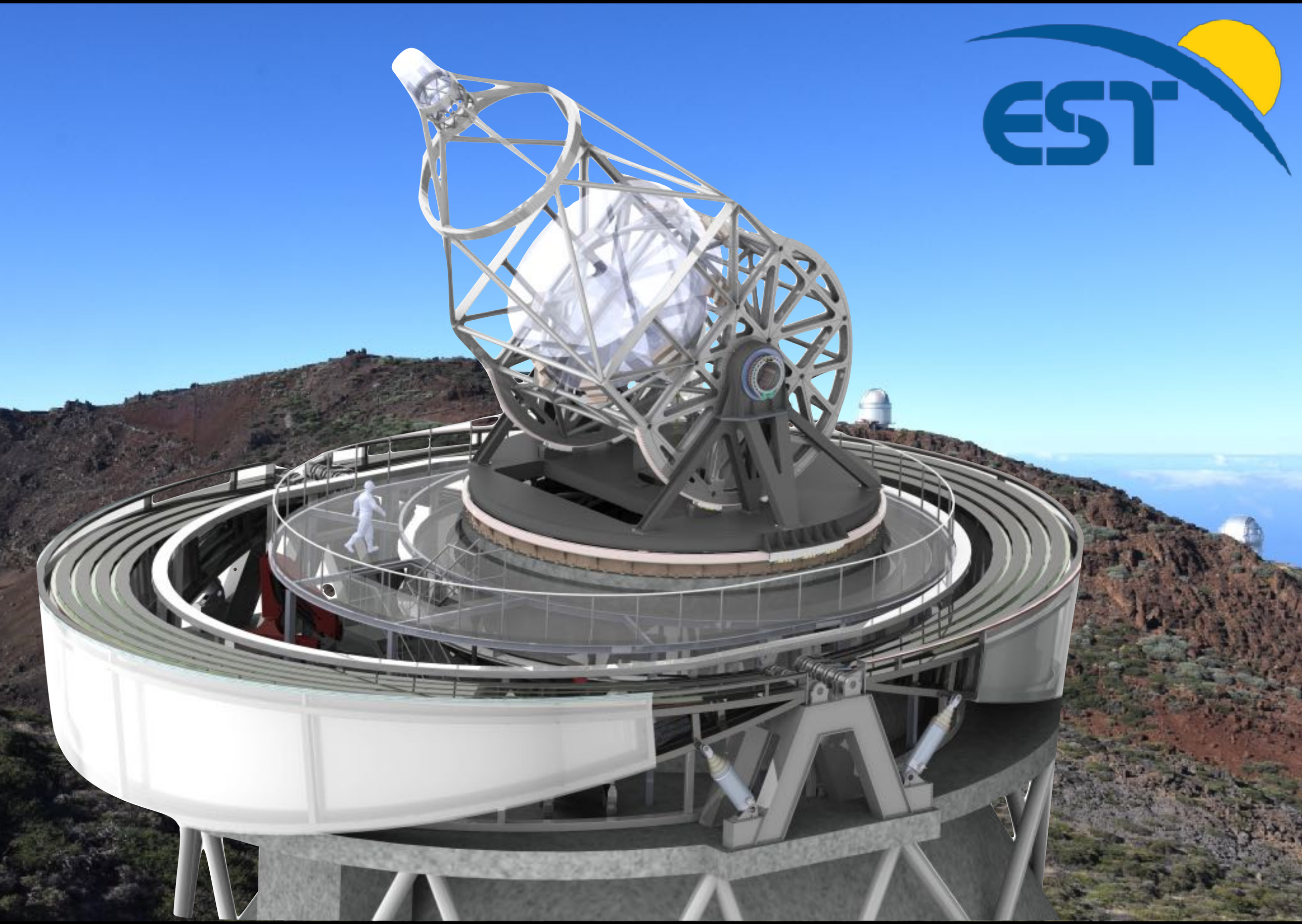



EST


EST
IDOM

Site decided!
Next to SST

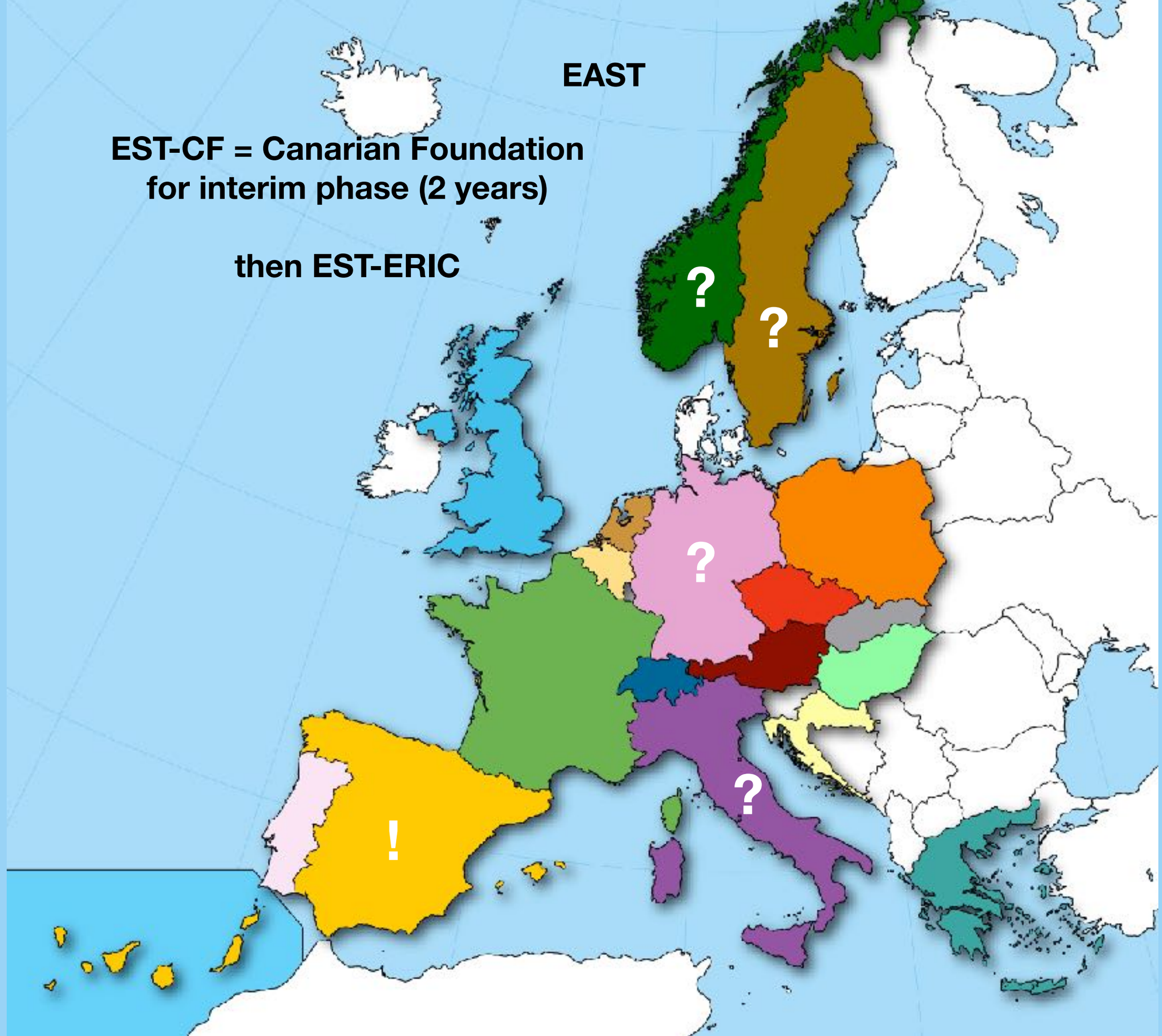

EST SITE


EST

EAST

EST-CF = Canarian Foundation
for interim phase (2 years)

then EST-ERIC



Thank you

- SST still going strong after 20 years.
- Focus moved upwards: photosphere → chromosphere
- New instrumentation being developed.
- EST
- The seeing is everything.