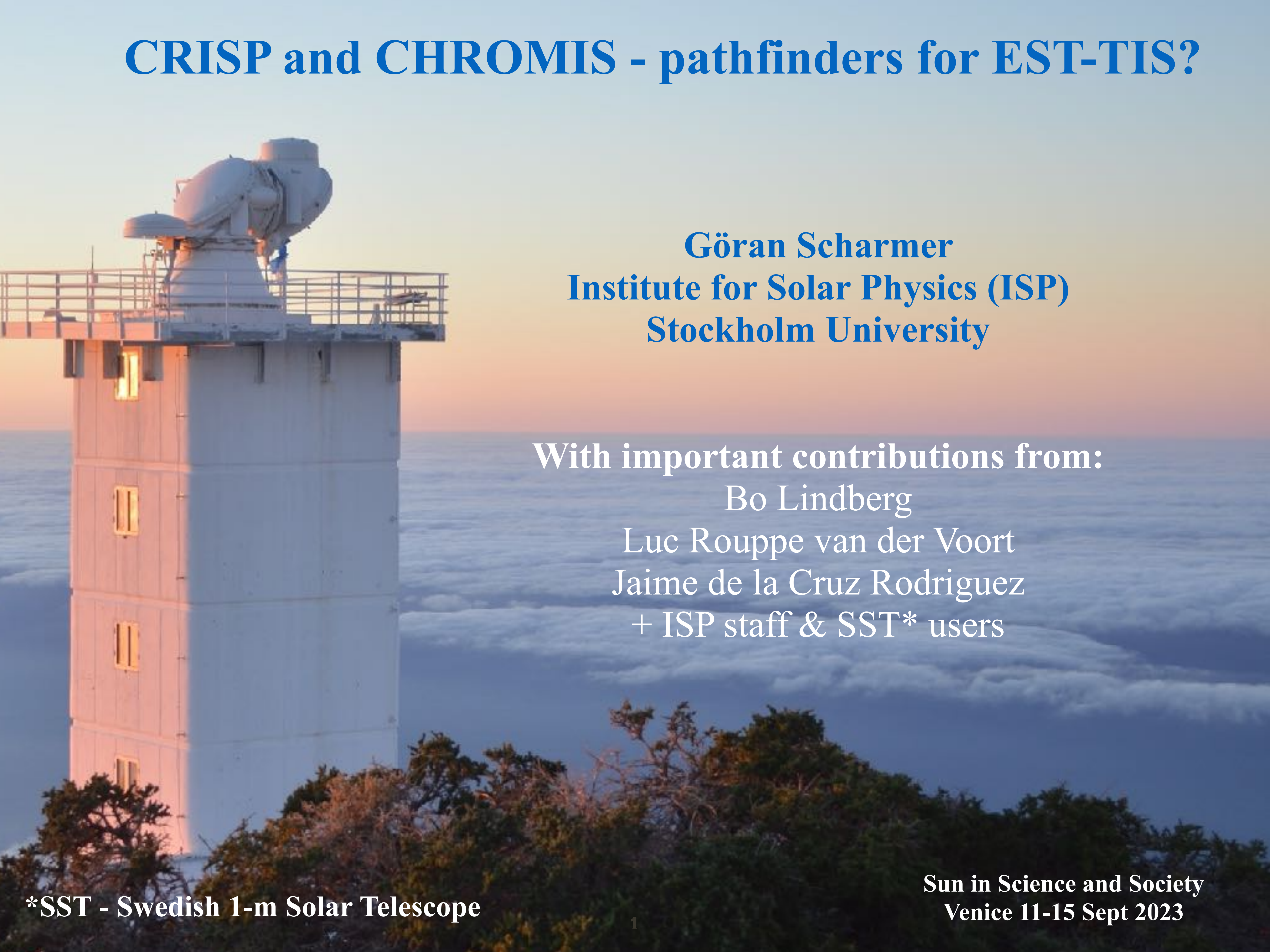

CRISP and CHROMIS - pathfinders for EST-TIS?

Göran Scharmer
Institute for Solar Physics (ISP)
Stockholm University

With important contributions from:
Bo Lindberg
Luc Rouppe van der Voort
Jaime de la Cruz Rodriguez
+ ISP staff & SST* users

***SST - Swedish 1-m Solar Telescope**

Sun in Science and Society
Venice 11-15 Sept 2023

What is EST-TIS?

- TIS = Tunable Imaging Spectropolarimeter
- TIS uses a **dual tunable Fabry-Pérot filter of moderate spectral resolution**
- **When coupled with pre-filters and a polarimeter, you can use TIS to scan through selected spectral lines to** deliver fundamental (though limited) **spectral and polarimetric diagnostics over a relatively large field-of-view**
- For EST, 3 TISes, operating in parallell, are foreseen to cover the blue, visible and near-infrared parts of the solar spectrum

How are CRISP and CHROMIS relevant for EST?

1. CRISP and CHROMIS are examples of **compact, cost-efficient and photon-efficient*** TIS-like designs
2. I will demonstrate that CRISP and CHROMIS **deliver data of higher science impact than that of other existing ground-based solar telescopes**
3. High impact science therefore expected with TISes on EST.
4. NOTE! EST site is located only ~65 m from the SST* site. CRISP/CHROMIS data therefore **also demonstrate the potential of the EST site!**

***though scanning and sampling λ is needed**

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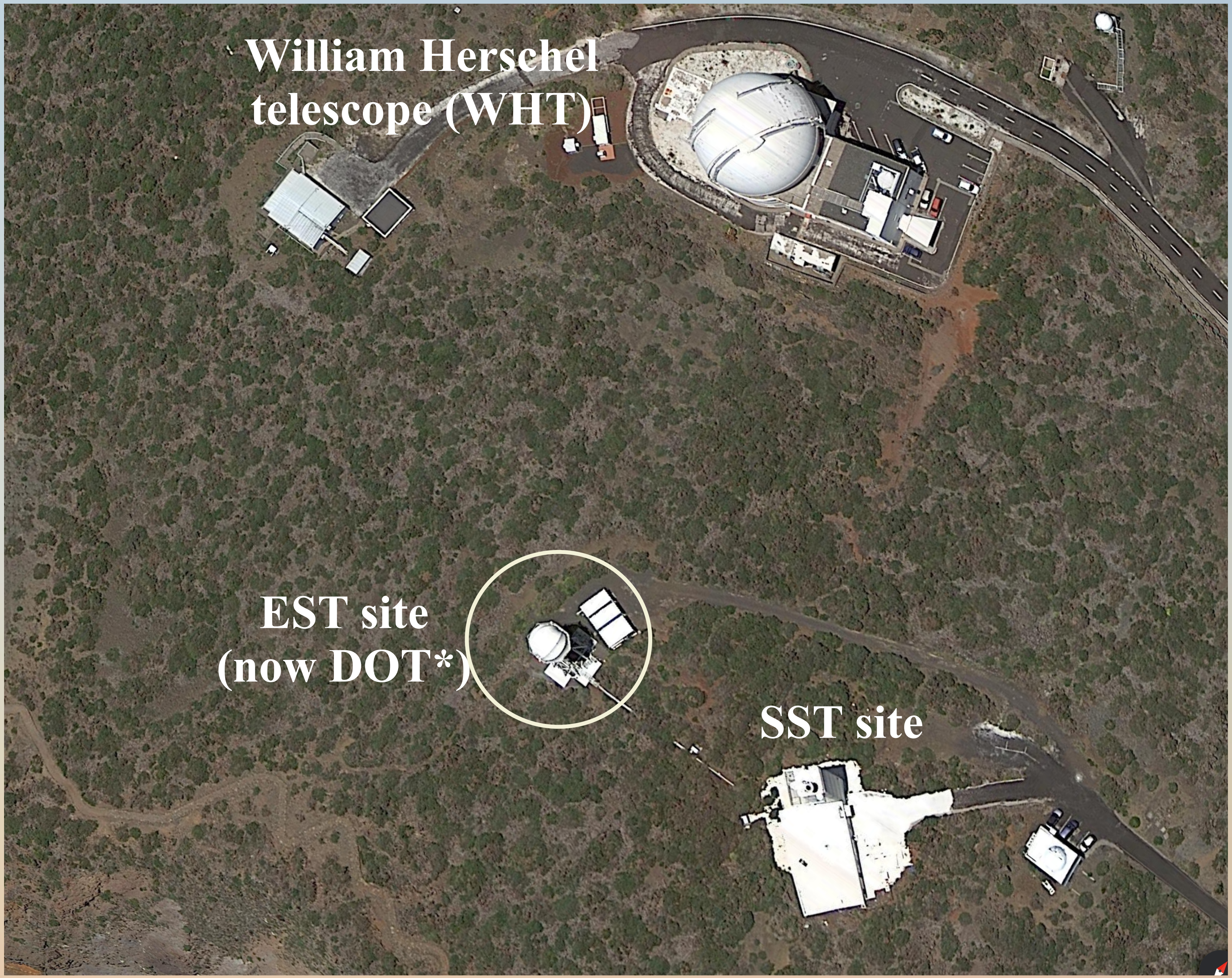
Distance SST - EST site: ~65 m!



Observatorio del Roque de los Muchachos, La Palma
(from Google Earth)

*DOT - Dutch Open Telescope

Essential properties of CRISP and CHROMIS

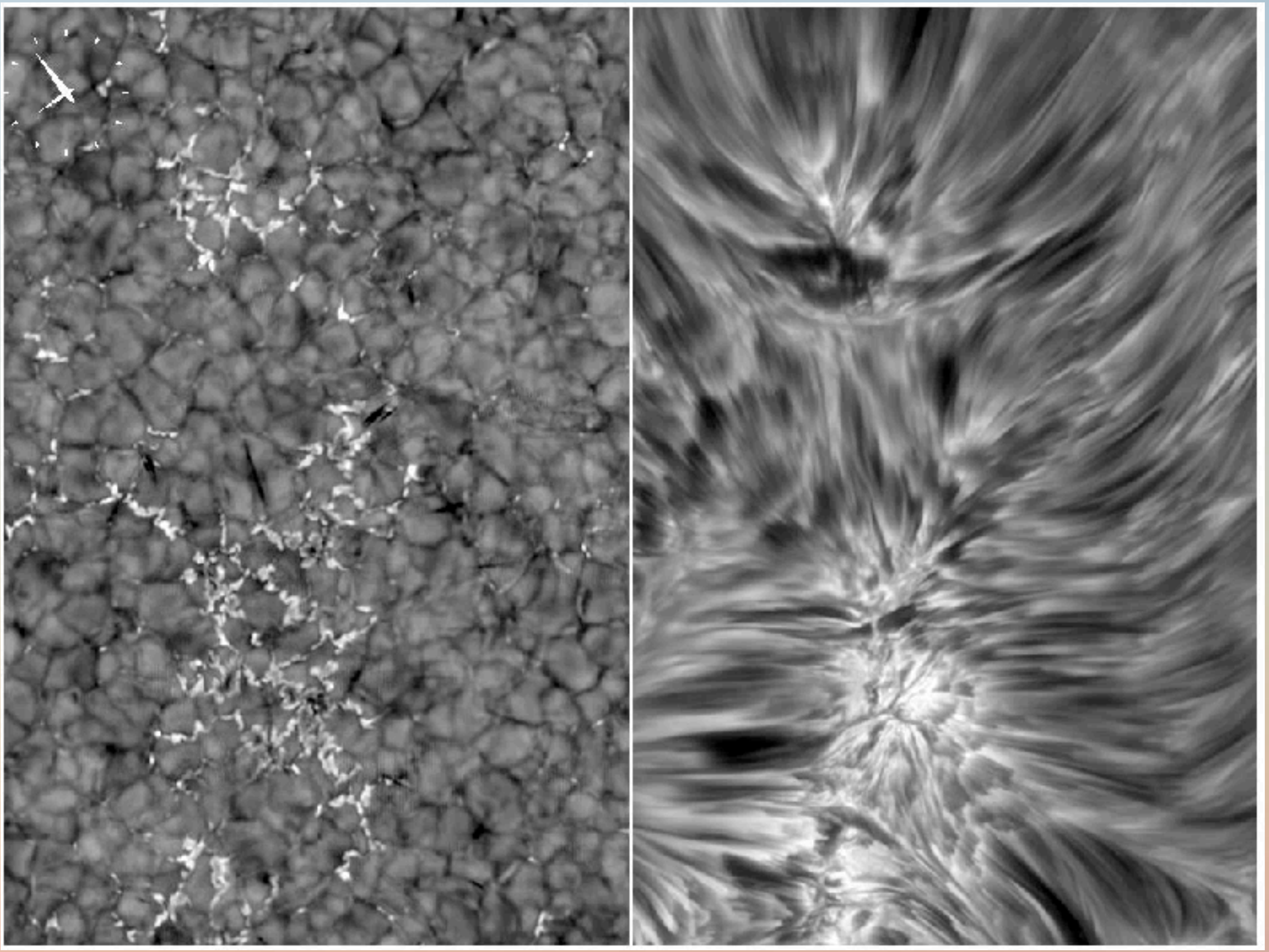
- Dual Fabry-Pérot based (spectro)polarimeters of moderate spectral resolution:
  - CRISP: λ=500-860 nm at a resolution of ~100,000
  - CHROMIS: λ=390-500 nm at a resolution of ~50,000)
- **Compact, “smart” design (1.5-1.6 m overall length)**
- **Lenses for high transmission. No (folding) mirrors.**
- Scharmer’s “reflectivity trick” (A&A 2006)
- CRISP and CHROMIS operate independently and in parallell (and augment each other)

But what about image quality?

(To be demonstrated next…)

Disk counterparts of Type II spicules

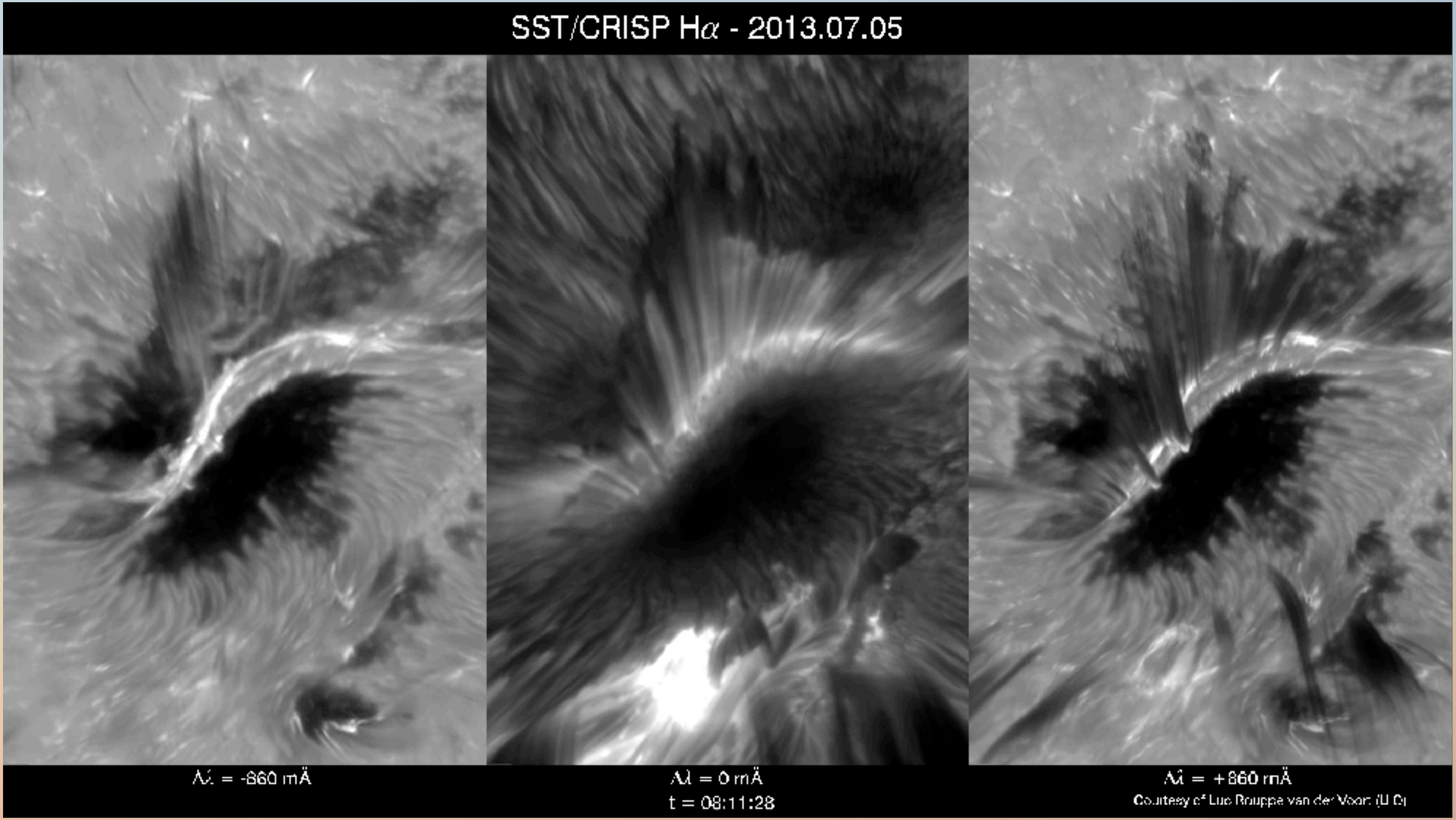
(discovered in far blue wing of Hα with CRISP - Rouppe van der Voort et al., 2009)
- one of the first data sets recorded with CRISP (15 June, 2008)!



(6.8 sec cadence)

Hα -1.3Å (-60 km/s)   Hα line core

Chromospheric dynamics above light bridge, using CRISP in Hα (Robustini et al. 2016 A&A 590, 57)



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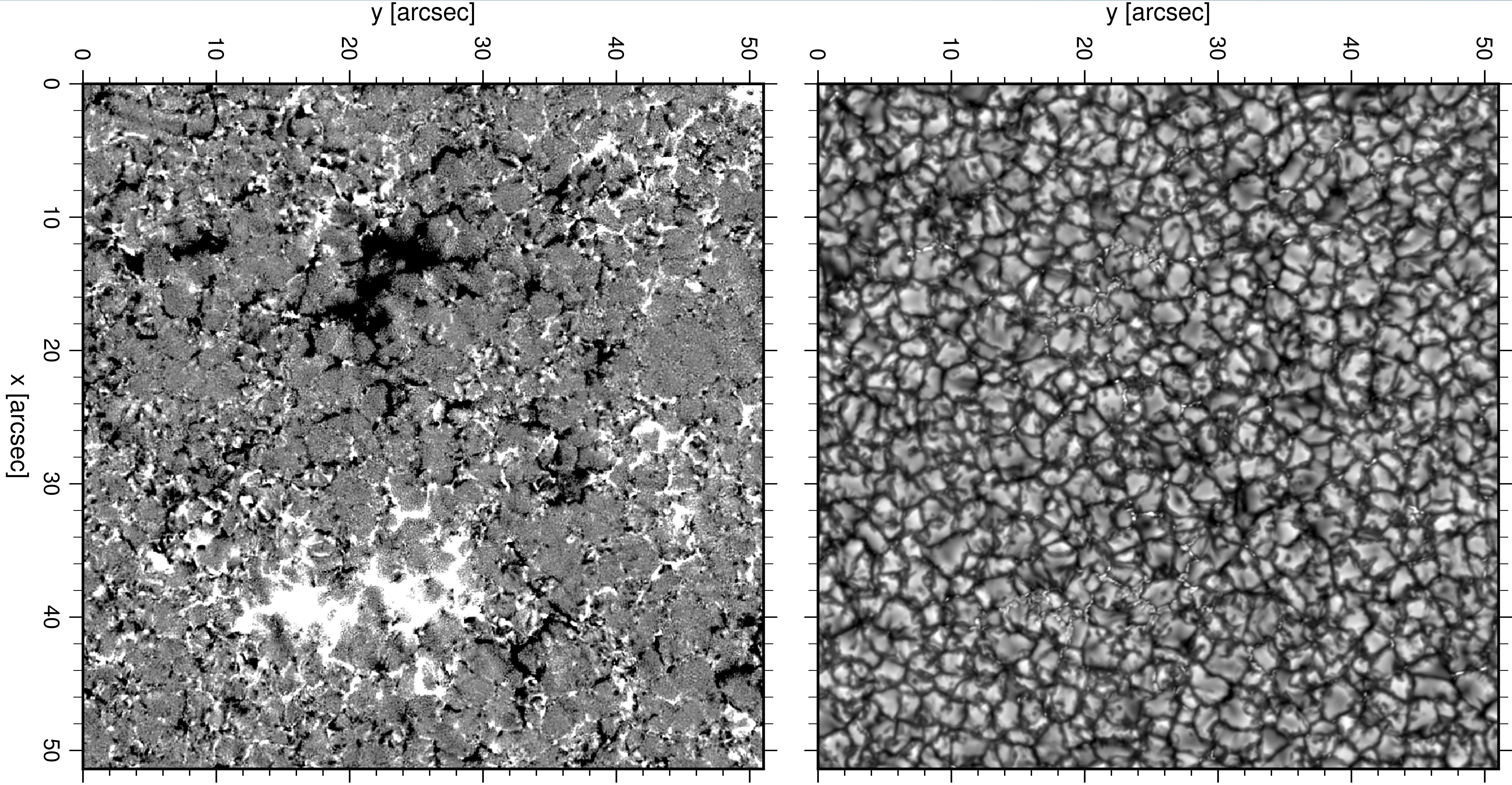
Outstanding CRISP data in Fe I line at 617.3 nm

Quiet Sun line-of-sight magnetic field from 8 sec CRISP data (7 line positions + cont.)



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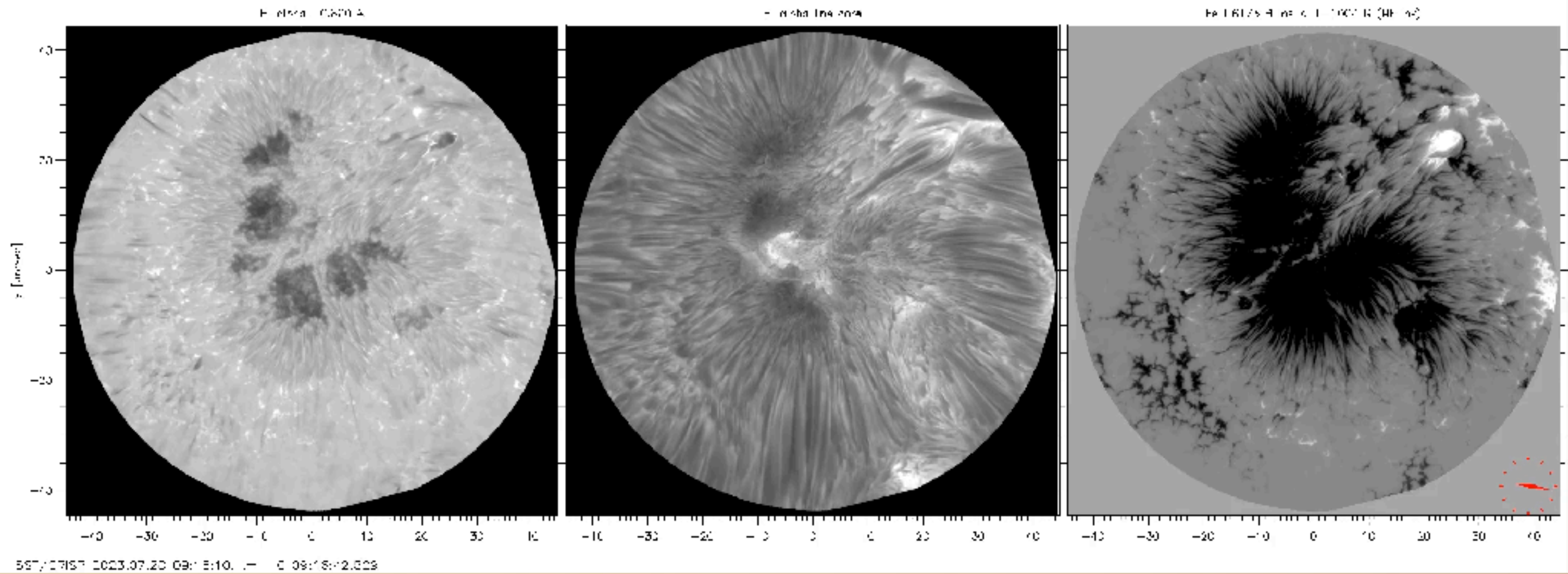
Chromospheric dynamics in Hα and photospheric magnetic field observed CRISP

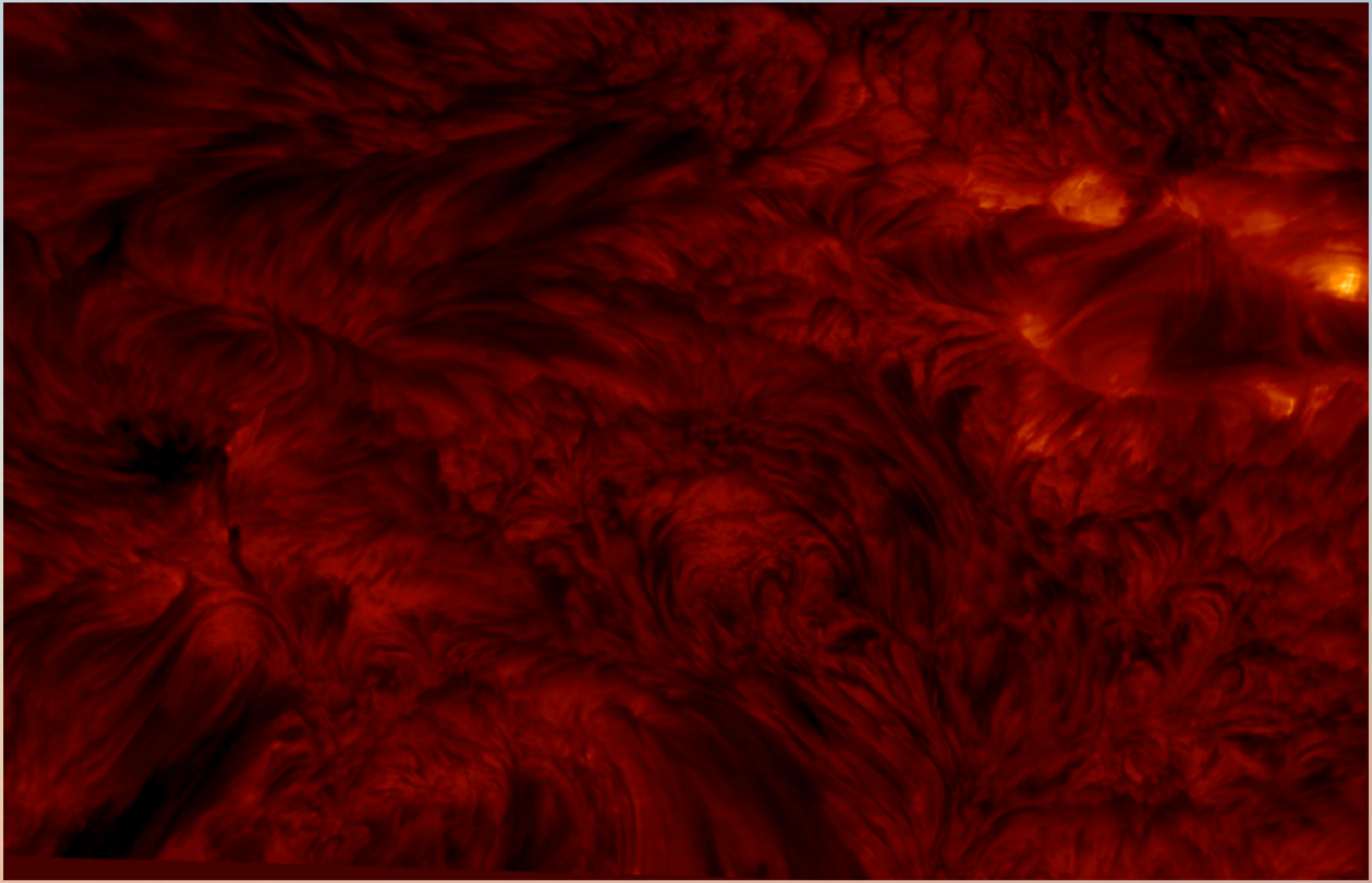
(using its recently extended circular field-of-view to 1.5 arc min dia)



(Ref.: L. Rouppe van der Voort et al. in prep.)

(In 2024, CRISP2 is expected to extend the observable field-of-view of SST to 2.5 arc min dia.)

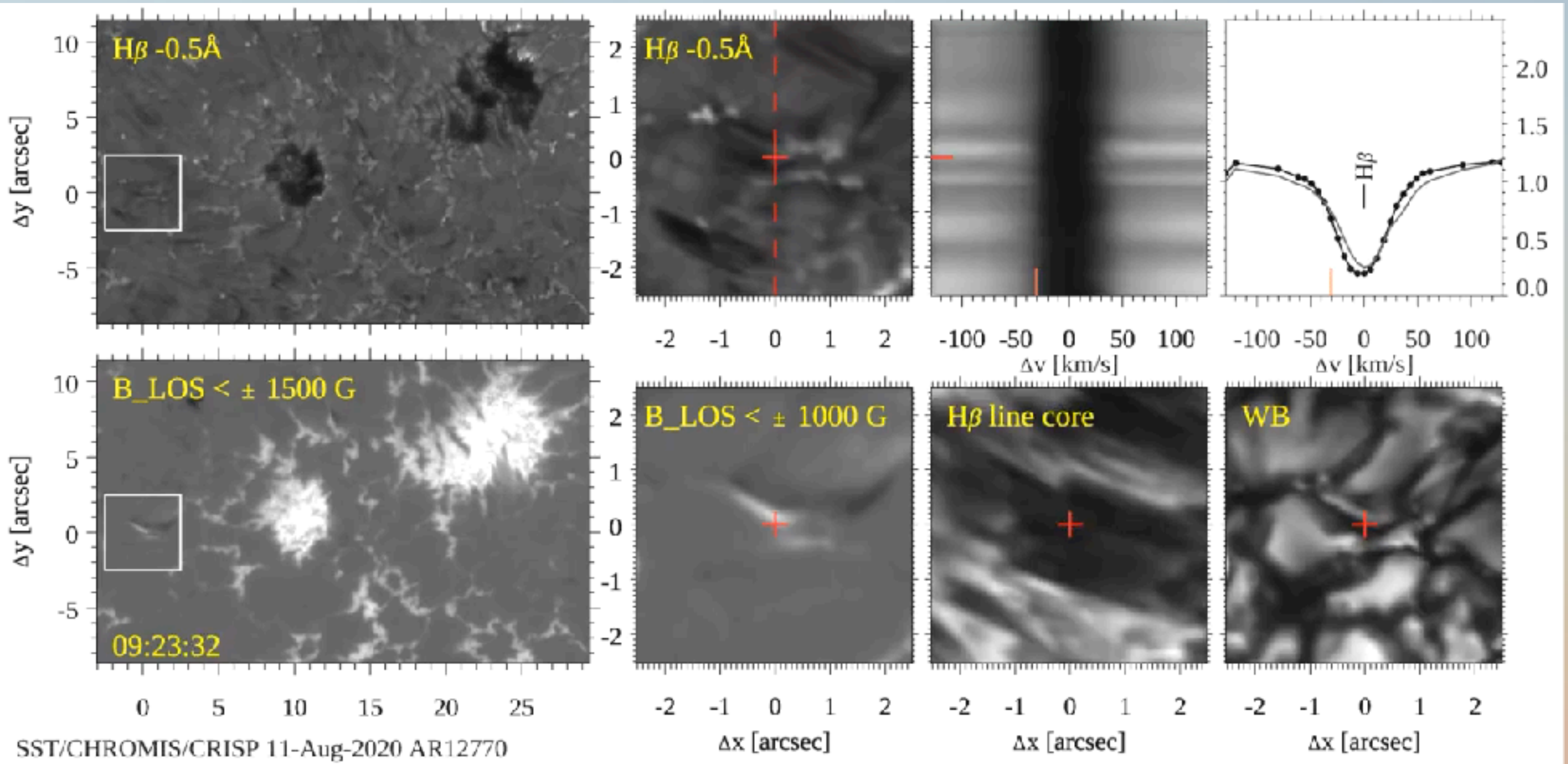
Spectacular flare captured in Hβ with CHROMIS



(Ref.: R. Joshi et al. in prep.)

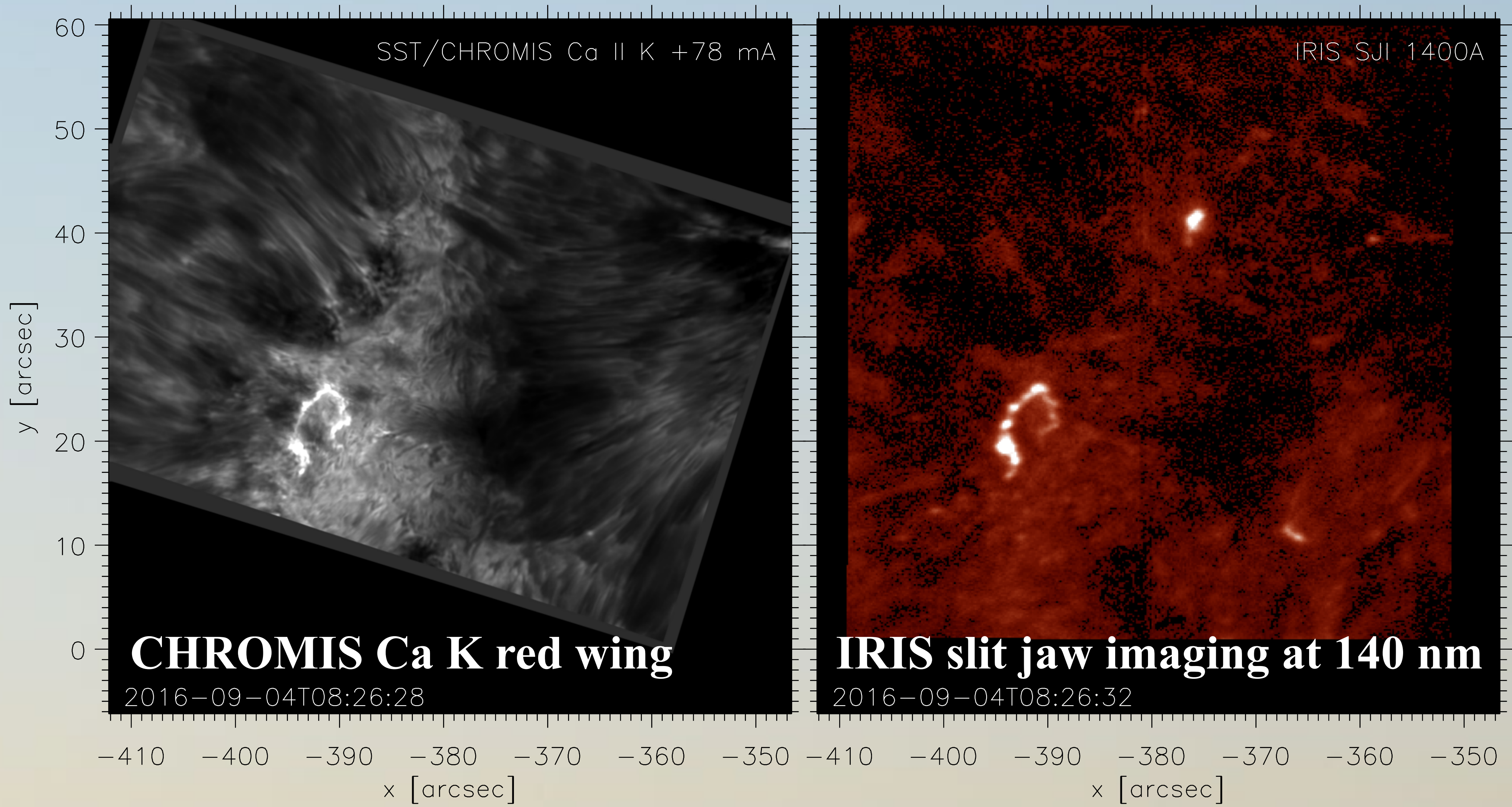
Complex diagnostics with CRISP+CHROMIS

(of so-called Ellerman bombs)

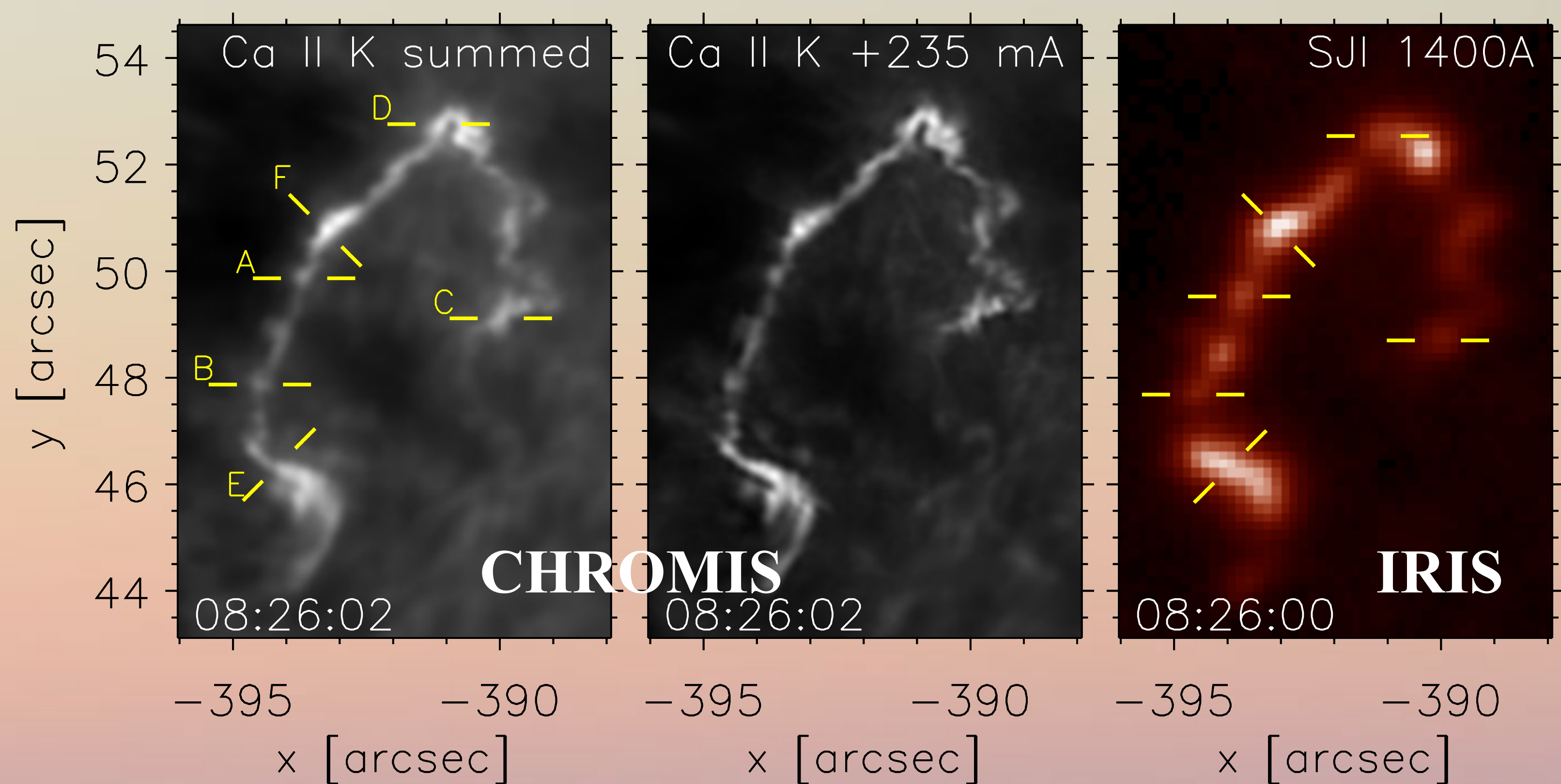


(Ref.: L. Rouppe van der Voort et al. in prep.)

CHROMIS+IRIS combination boosts science!



(from: P. Testa et al. 2023, ApJ in press)



- IRIS provides invaluable UV diagnostics from space…
- … while CHROMIS on SST adds invaluable high-resolution diagnostics*

*EST will be of fundamental importance also by boosting future European space-borne solar physics

Five high-profile CRISP-based papers

- "Alfvén waves in the lower solar atmosphere" (Jess et al. 2009, ***Nature***)
- "Magnetic tornadoes as energy channels into the solar corona" (Wedemeyer-Böhm et al. 2012, ***Nature***)
- "Detection of convective down flows in a sunspot penumbra" (Scharmer et al. 2011, ***Science***)
- "On the prevalence of small-scale twist in the solar chromosphere and transition region" (de Pontieu et al. 2014, ***Science***)
- "On the generation of solar spicules and Alfvénic waves" (Martinez-Sykora et al. 2017, ***Science*)**

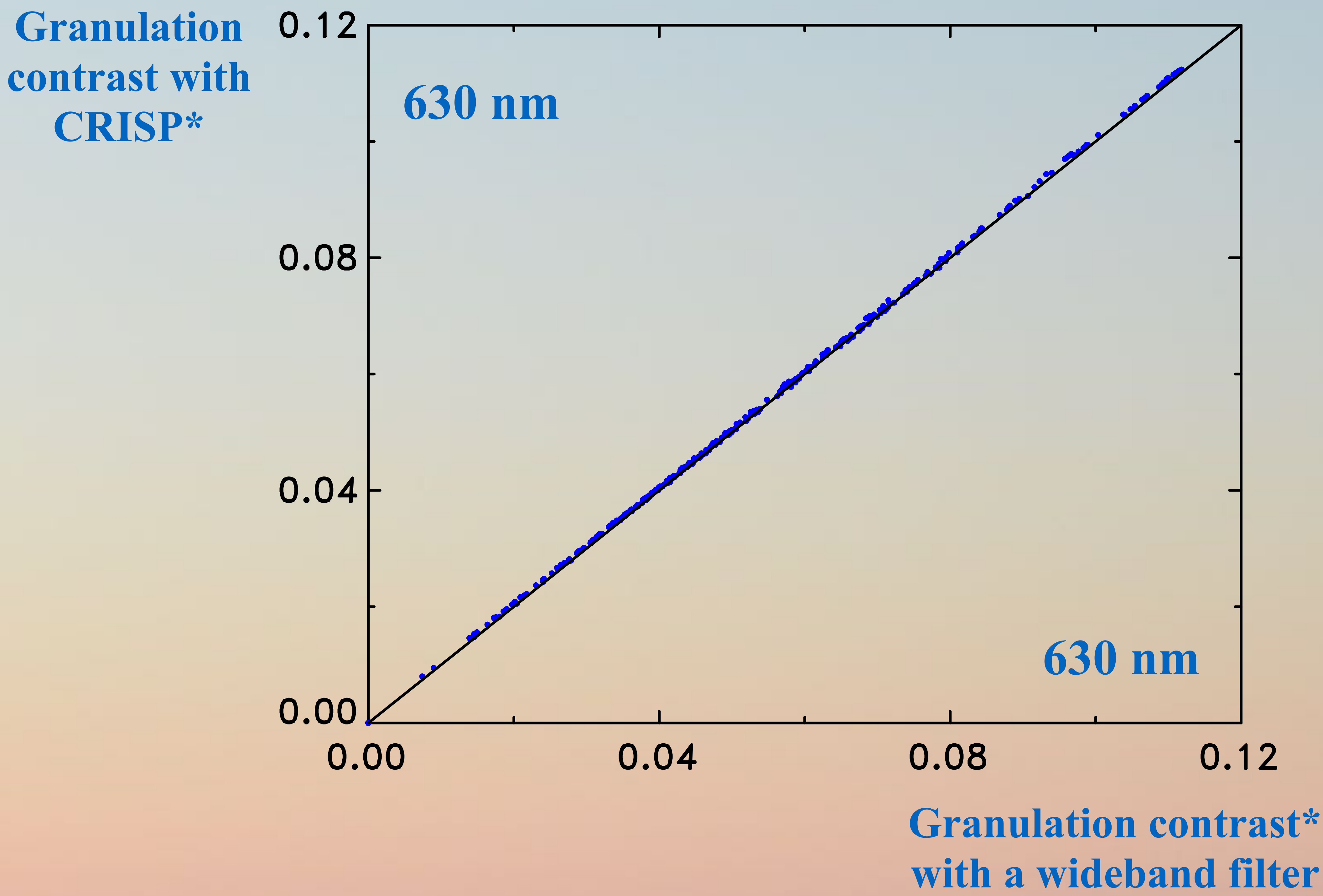
CRISP "design" paper (2008) citations:

Cited in 348 papers
These 348 papers are cited 9733 times

CRISP delivers outstanding image quality

(in the sense of not degrading the excellent SST image quality)

From G. B. Scharmer et al. A&A 625, A55 (2019)



*NOTE! Granulation contrast is an excellent measure of the Strehl, used to characterise optical quality!

CRISP delivers outstanding image quality

(also when compared to that of any other telescope)

Observed granulation contrasts with SST/CRISP

Wavelength (nm)	525.0		557.6		630.1		853.5	
	NB	WB	NB	WB	NB	WB	NB	WB
No corr.	10.9	10.5	10.7	10.6	9.2	9.2	6.3	5.6
MTF corr.	11.8	11.5	11.8	11.6	10.2	10.2	7.2	6.2
MFBD corr.	13.9	13.7	13.4	13.1	11.7	11.5	8.2	7.2
r_0 (m)	0.164		0.239		0.238		0.270	

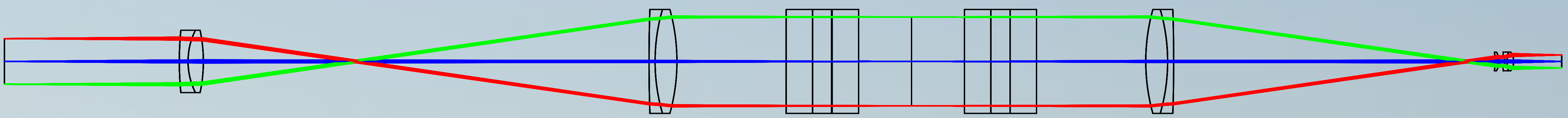
Compare Sunrise: 8-8.5%

Compare Hinode: 7%

(The above are 2 sec averages)

(from G. B. Scharmer et al. A&A 625, A55 (2019)

Is a CRISP-like design possible for EST-TIS?



Simplified design study clearly indicated feasibility of a compact EST-TIS:

Inputs

- Early version of EST re-imaging system (POP) used - now obsolete
- Wavelength range: 500-680 nm
- Field-of-view diameter: 1 arc min (circular)
- F-ratio at etalons: 140 (130 might be possible)

Outputs

- Etalon clear apertures: > 171 mm
- **Overall length: ~3.8 m possible (lens based, no need for folding mirrors)**
- **Strehl: > 95% at all wavelengths and over the entire field-of-view**
- POP focus curve compensation: by moving camera lens (last lens)
- Image scale match to camera pixel size: by replacing camera lens

NOTE! An exhaustive and more realistic design study of EST-TIS will be presented by Francisco Javier Bailén at 9:30 on Thursday

Conclusions

1. CRISP and CHROMIS constitute compact, cost-efficient and photon-efficient (though needing sampling in λ) instruments that deliver high-quality data and enable high-impact science
2. **CRISP and CHROMIS are based on successful design concepts that can now be considered proven**
3. Preliminary studies clearly indicate that **the concepts of CRISP and CHROMIS can be used to develop TISes for EST** (to be discussed by Francisco Javier Bailén on Thursday)
4. Such TISes on EST are likely to be of major importance for exploiting the science potential of EST
5. **Data recorded with SST only 65 m from the EST site indicates the potential of the EST telescope, and its future science**

Thanks for listening!

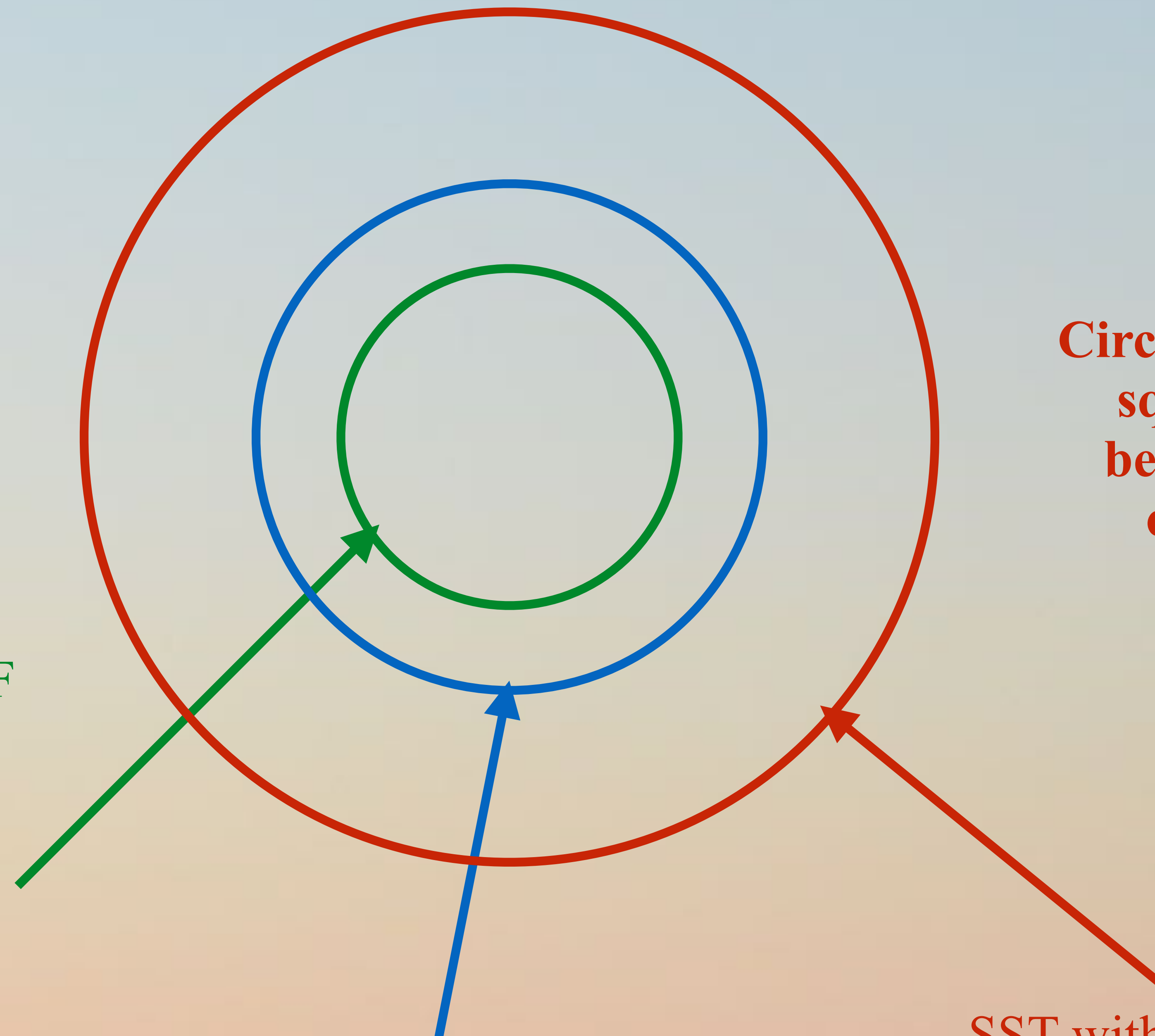
Extra slides
(not used)

Why is the CRISP design successful?

The design maximises throughput and minimises image quality degradation:

1. The design minimises the number of optical components. It uses lenses (not mirrors), to make the system compact, highly transmitting and stable (no folding mirrors), telecentric design, and my "reflectivity trick" to deal with cavity errors.
2. Detailed simulations using Zemax were used to establish alignment tolerances. These and measurements of lens properties after manufacture were used to tune the final design of CRISP, which was built as a monolithic instrument without (mis)alignment possibilities.

FOV summary
(VTF, CRISP & CRISP2)

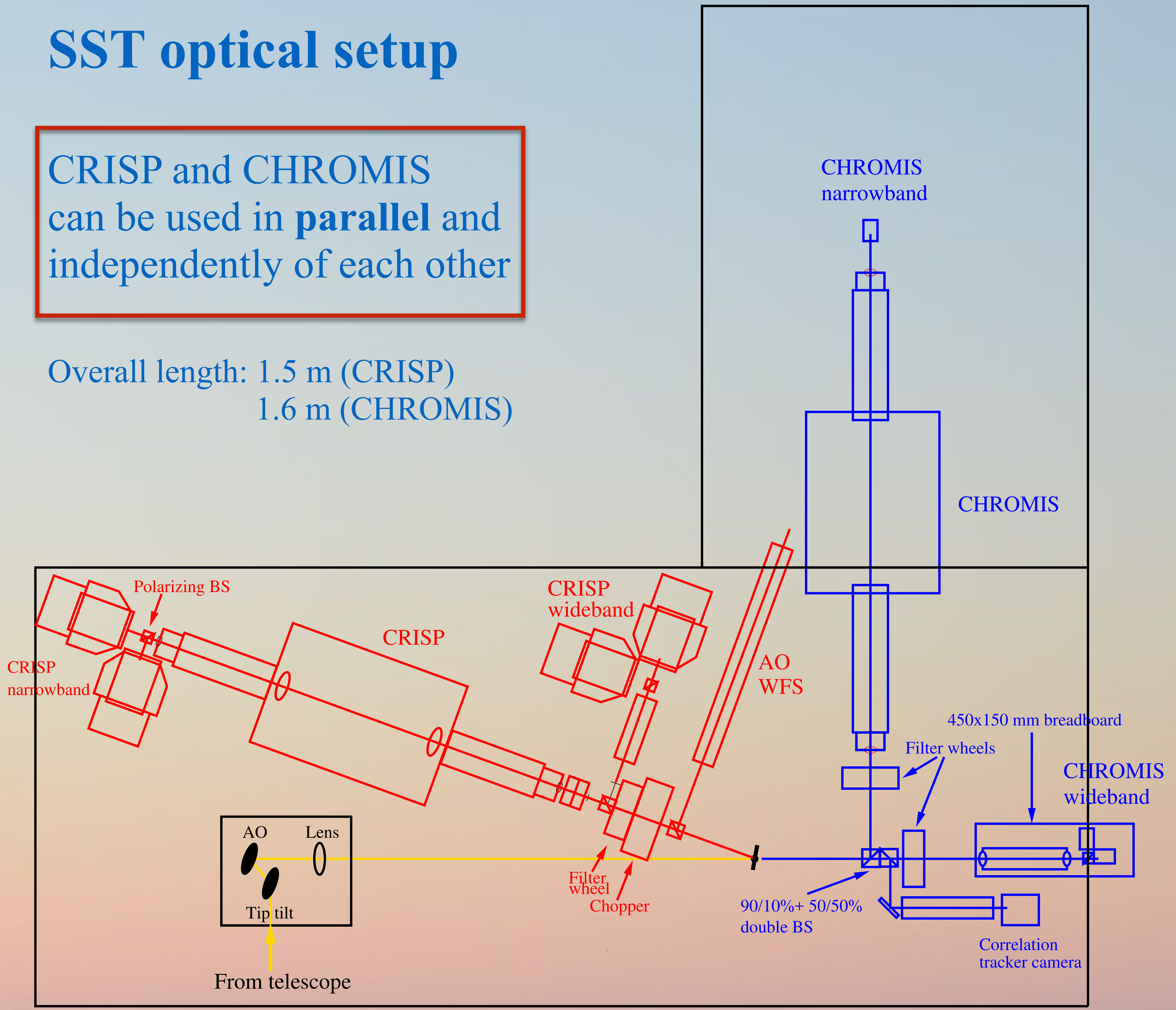


NOTE
Circular FOV better than square FOV - allows better alignment with other instruments

SST optical setup

CRISP and CHROMIS
can be used in **parallel** and
independently of each other

Overall length: 1.5 m (CRISP)
1.6 m (CHROMIS)



CHROMIS 390 nm wideband image