THEMIS solar telescope
A new era begins

Laboratoire de Physique des Plasmas

Café spatial de l'équipe plasmas spatiaux du LPP ; Oct 6th 2025

FSLAC International Research Lab.

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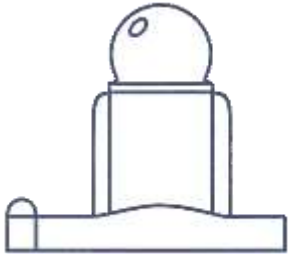


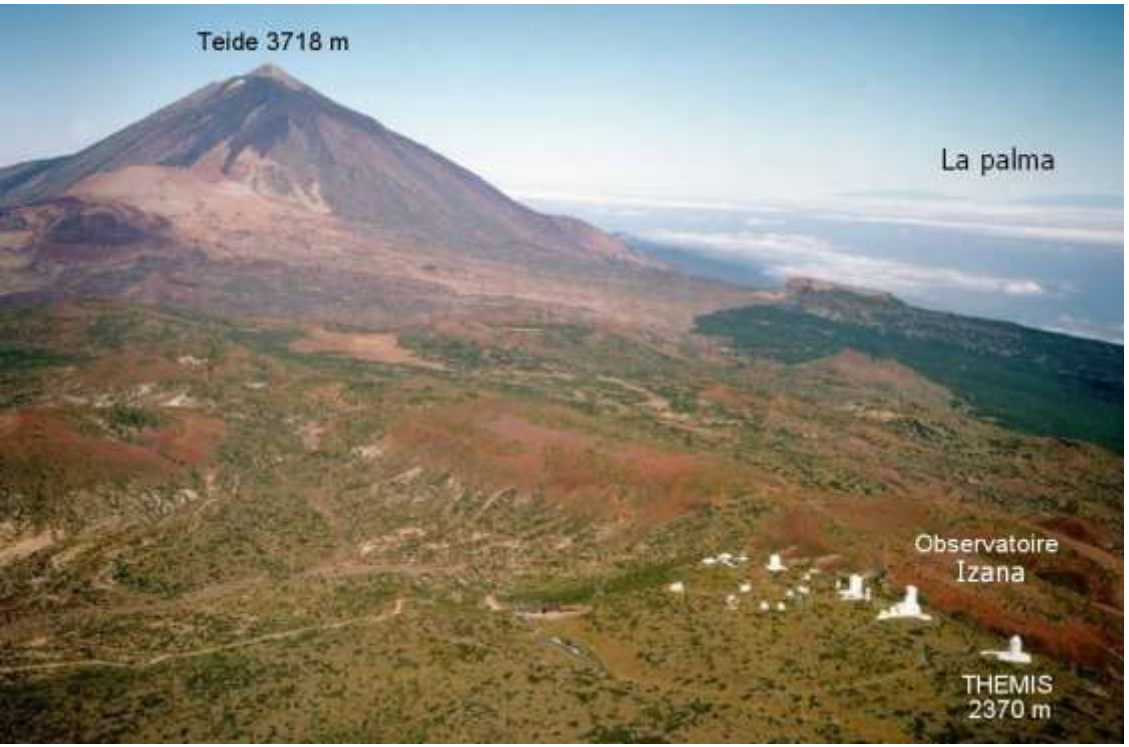
In memoria of Didier Laforgue

- Didier Laforgue passed away on June 20th 20205, after 23 years working at THEMIS as a system-instrument research engineer, and as a very appreciated observation operator.

Outline

- Introduction: THEMIS time line & characteristics
- THEMIS overhaul
- THEMIS data products
- THEMIS adaptive optics
- Spectropolarimetry with THEMIS 2.0
- Selected recent & future highlights

THEMIS timeline



1970's : European JOSO search & test observatory sites for optimum sky quality: selection of Tenerife and La Palma

1975 : First presentation of the THEMIS project by **J. Rayrole** at the Institut National d'Astronomie et de Géophysique.

1980's : Telescope design & instruments development at Paris Observatory, lead by **J. Rayrole, P. Mein & M. Semel**.

1992 : French INSU/CNRS, Spanish CSIS & IAC, & Italian INAF/CNR sign international cooperation agreements

1993 : Start of the construction of the THEMIS building

First light of the THEMIS telescope on March 16th 1996

1996-1999: THEMIS Commissioning

1999-2014: 1st phase of scientific exploitation

2009 : Withdrawal of the Italian partner.

2015-2018: Closure to observation for optical design overhaul.

2018- now : 2nd phase of THEMIS scientific exploitation.

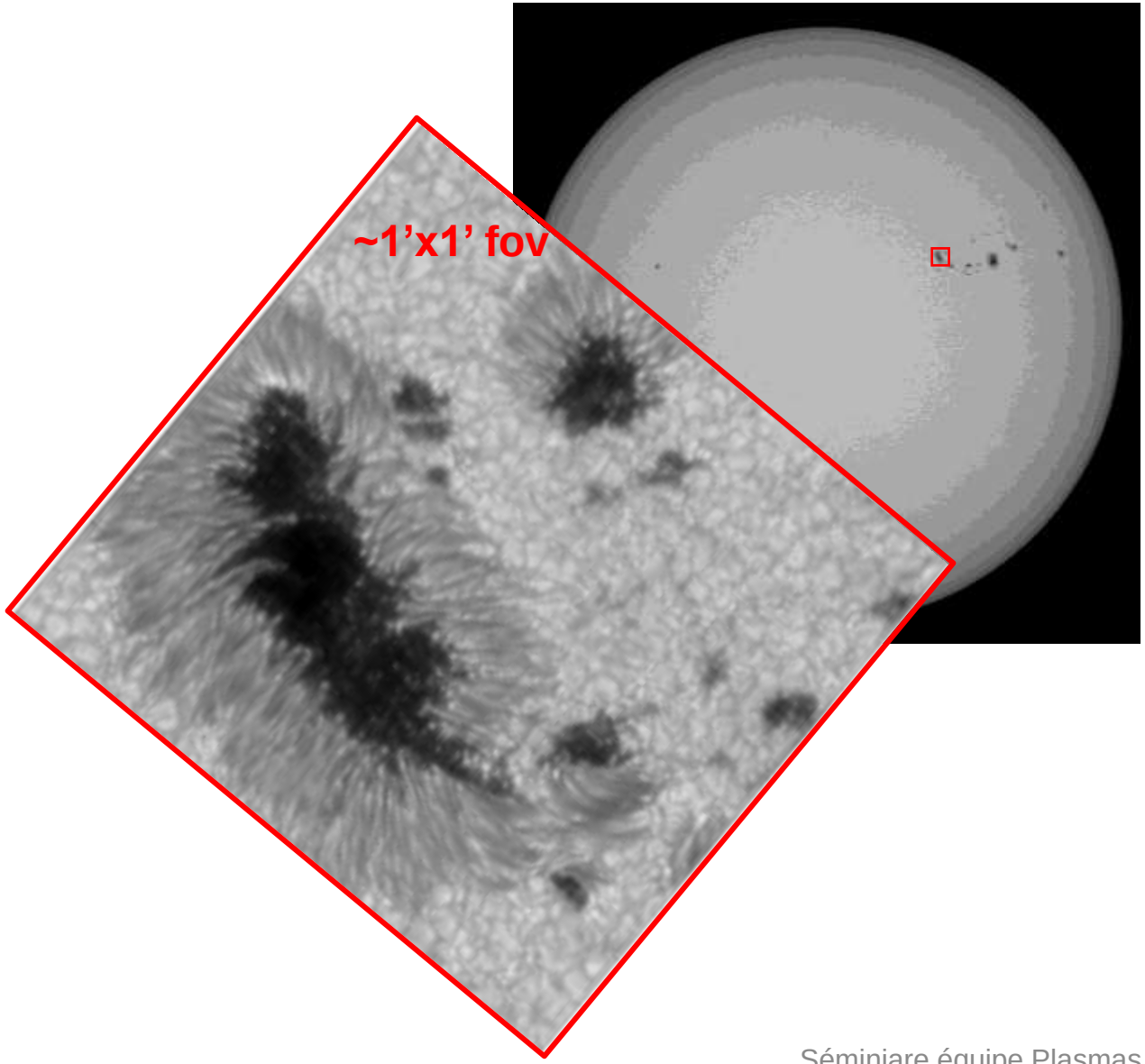
Dec. 2020 : 1st light of THEMIS Adaptive Optics in closed-loop.

June 2021 : Creation of FSLAC, joint international laboratory of INSU & IAC, overlooking THEMIS activities.

Key THEMIS optical design

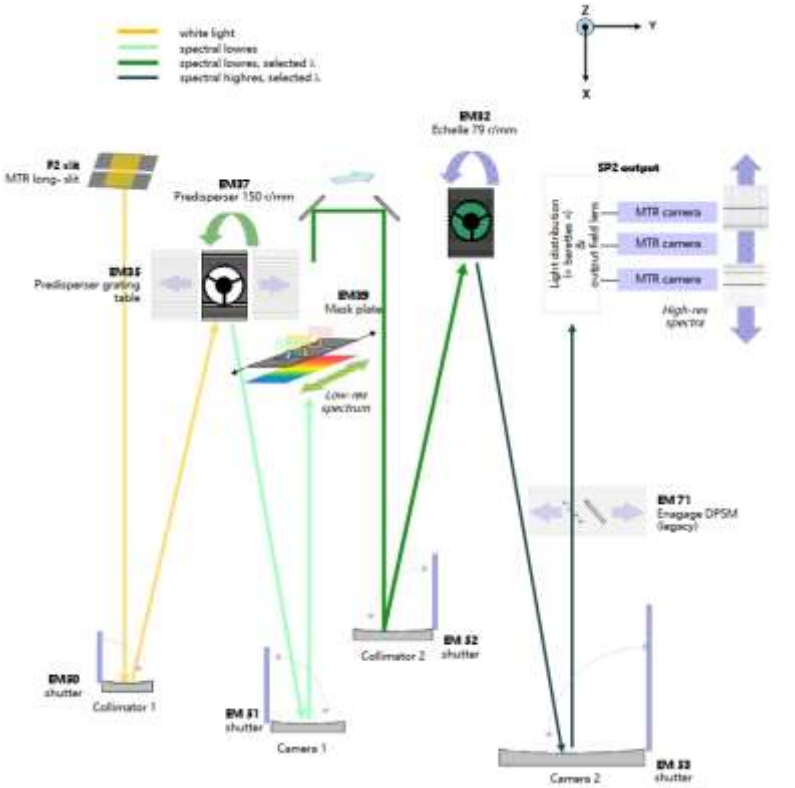
- 92cm Ritchey-Chrétien on alt-azimuthal mount.
  - ~6th largest solar telescope in the world
- **Very high effective focal length (57m) and focal ratio (f/62)**
  - High magnification capacity
  - **One of the world « slowest » optical telescope**
    - High loss of light, compensated by large solar flux
    - Less optical aberations
- **Polarization analyser at first optical focus**
  - Polarization fixed further along optical path
  - **→ unique polarization calibration free telescope : ideal for spectropolarimetry**
  - Pre adaptive-optic design : not ideal for imagery

THEMIS observation capabilities



- Small field-of-view: 1'x1' to 2'x2'
  - ~human eye resolution
  - Tennis ball at ~250m
  - ~1/215-900th of the solar surface
- 0.15" theoretical (diffusion) spatial resolution (@ ~600 nm)
  - Tennis ball at ~100 km
- Teide Observatory seeing:
  - Can reach down 0.3" at night
  - Typical solar condition are closer to 1"

THEMIS Spectrograph



- **As of today the main THEMIS instrument is the MTR2 spectrograph**
  - Tunable slit or 0.5” slit-jaw
  - Visible & near IR spectral domain: 4000-11000 nm
- **Ultra-high spectral resolving power**
  - R ~ 200 000 to 300 000
- **User-defined simultaneous multi-spectral lines observations**
  - No-instrument determined spectral ranges
  - Spectral ranges defined by user
    - fixed set-up for a given campaign
  - Up to 6 spectral range (3-4 in general)
  - ~ 6-7 Å spectral range/camera
  - Spectral resolution down to ~20-30mÅ (@6000 Å)

THEMIS Factsheet

Very well-maintained but,
be at that it may,
a 20th century instrument !

THEMIS @ OT in June 2025

- **Main French solar telescope** designed by J. Rayrole, P. Mein & M. Semel
  - Located at Teide Observatory, Tenerife, Spain
  - 1st light in March 1996, & commissioned in 1999
- 1m-class solar telescope, with **one the world "slowest" optical design:**
  - Aperture: 92 cm
  - Effective focal length: 57m
  - Effective focal ratio: f/62
  - 2'x2' square field-of-view
- **Ideal for high resolution spectropolarimetry:**
  - Spectrum range: 4000 - 11000 Å
  - Polarization calibration free
  - Ultra-high spectral resolving power: R ~ 200 000 to 300 000
  - Simultaneous observations of user-defined set of up to 6 spectral lines: 6-7 Å spectral range with ~30 mÅ resolution

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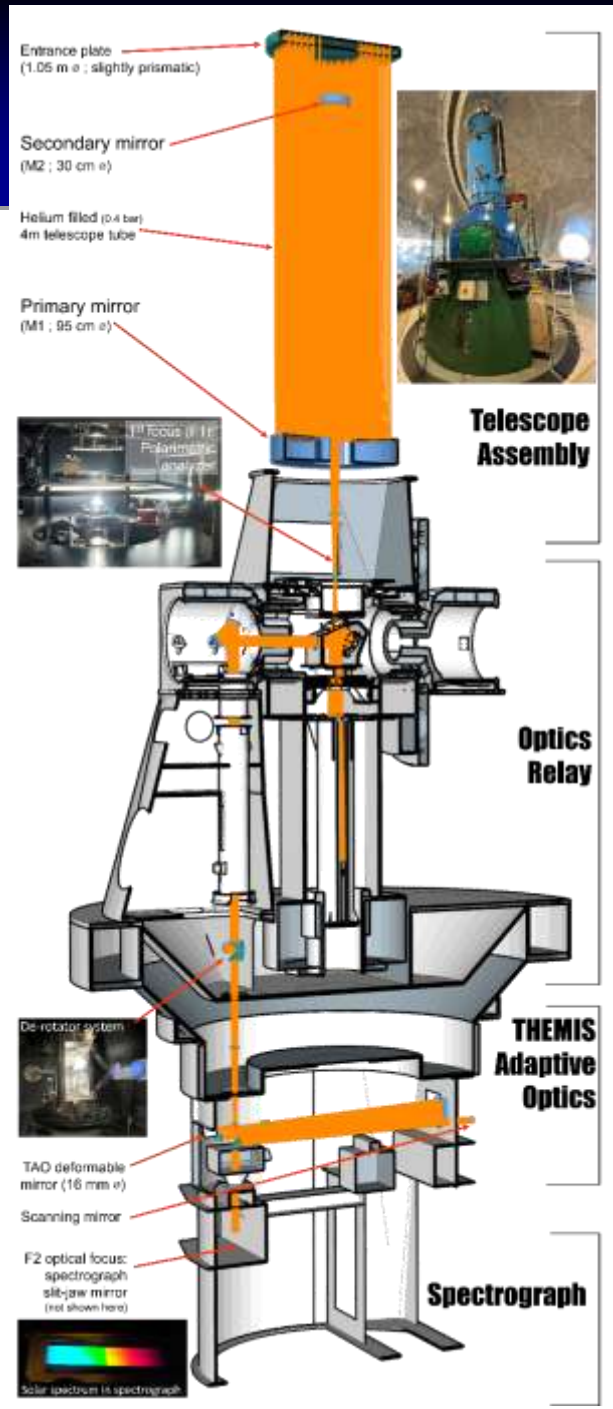
“Total makeover”: 2016 → 2020



- **THEMIS has been widely renewed and redesigned**
  - Thanks to EU collaborative funding: ~1M€ from 2 SOLARNET programs
  - **Successful renovation thanks to several French teams**

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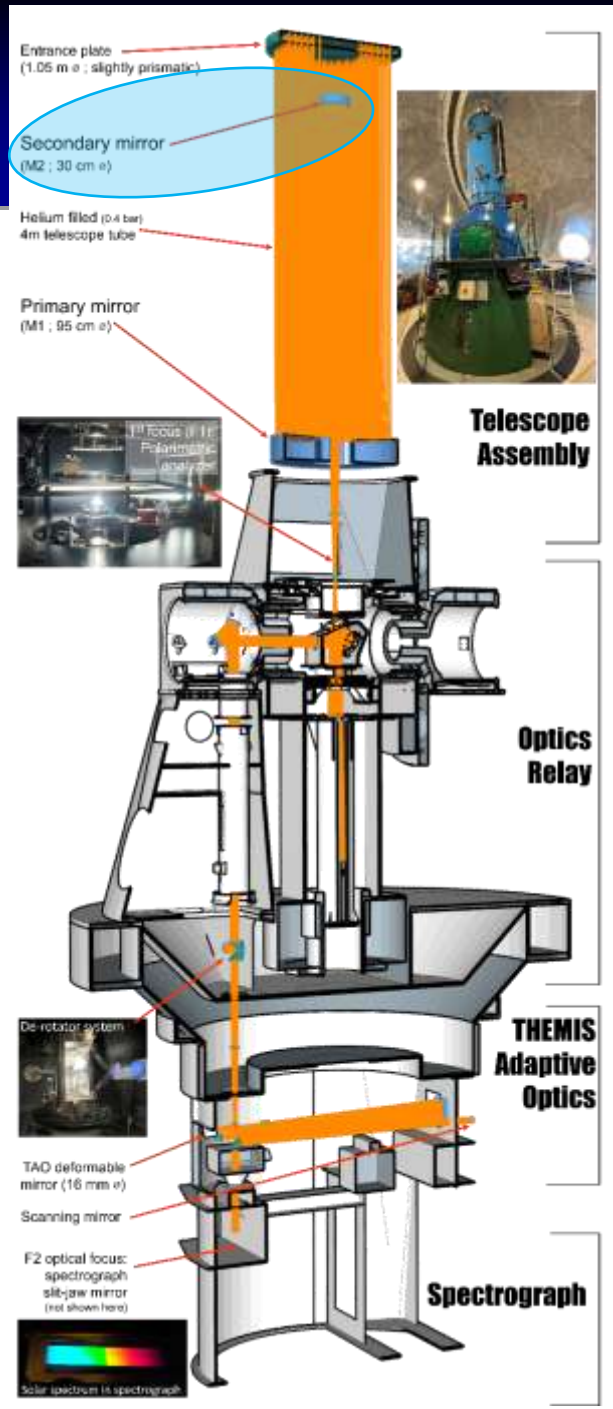

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- **M2 mirror re-aluminising** (William Hershel Telescope & THEMIS teams)

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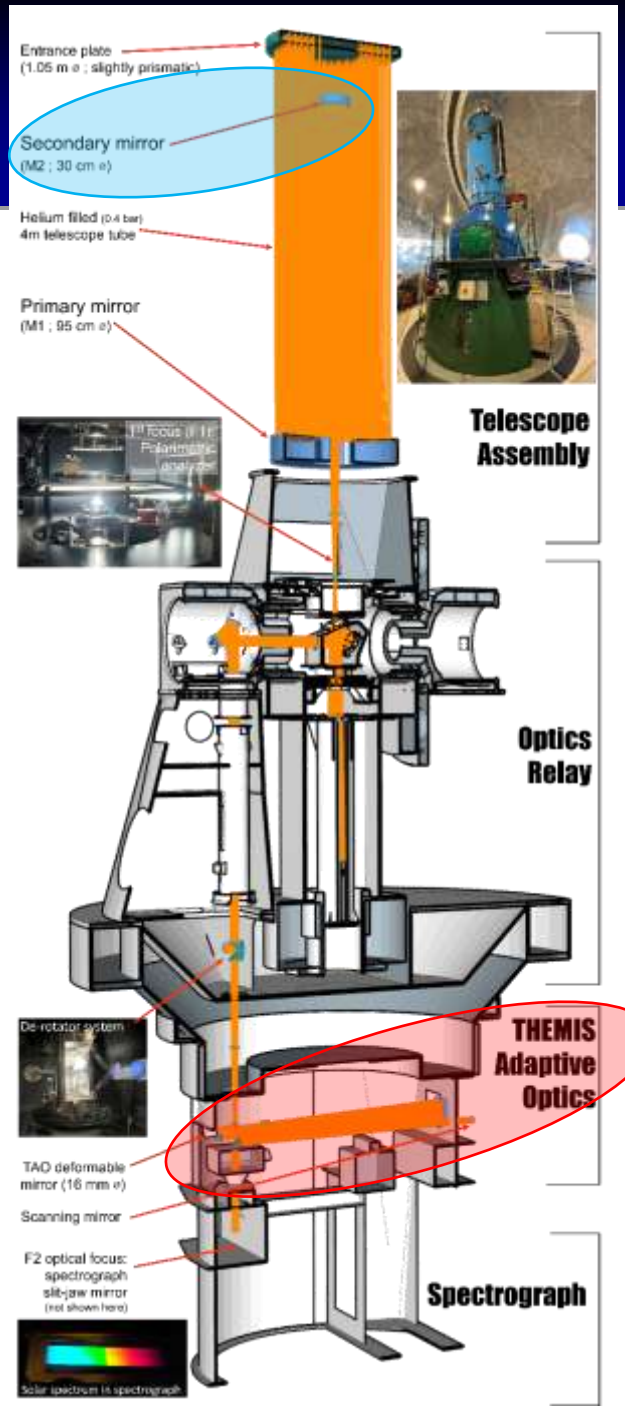

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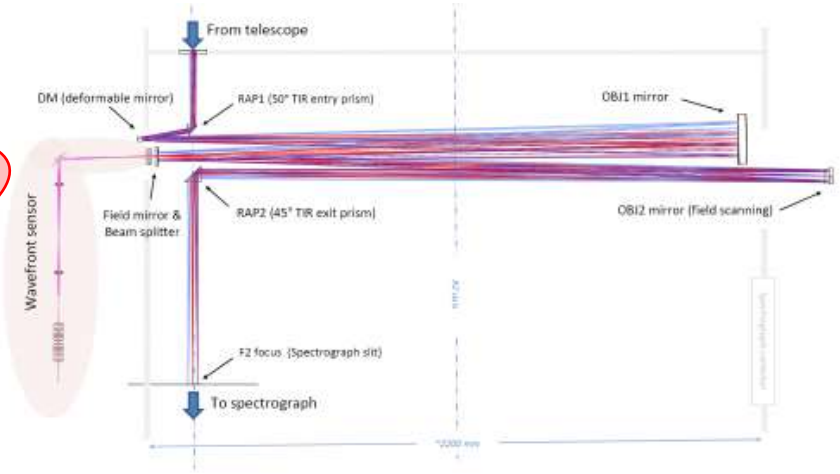

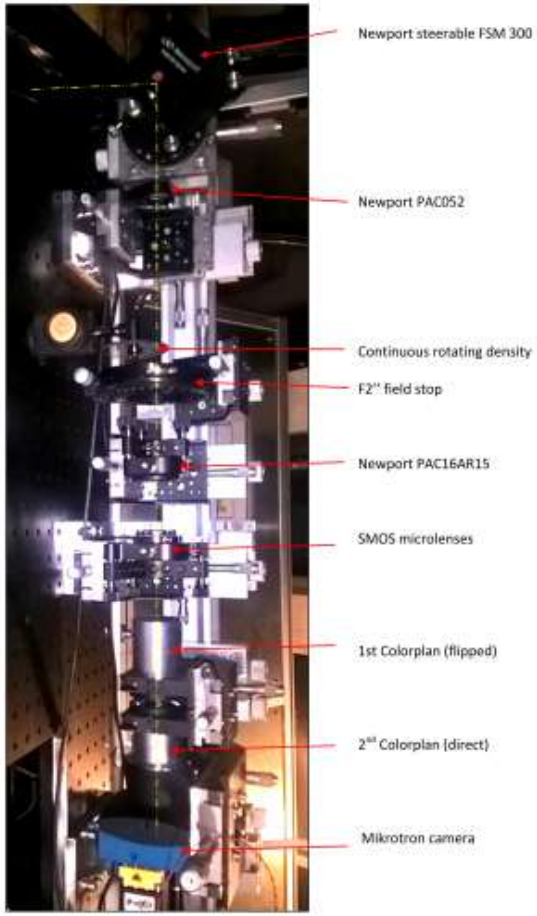

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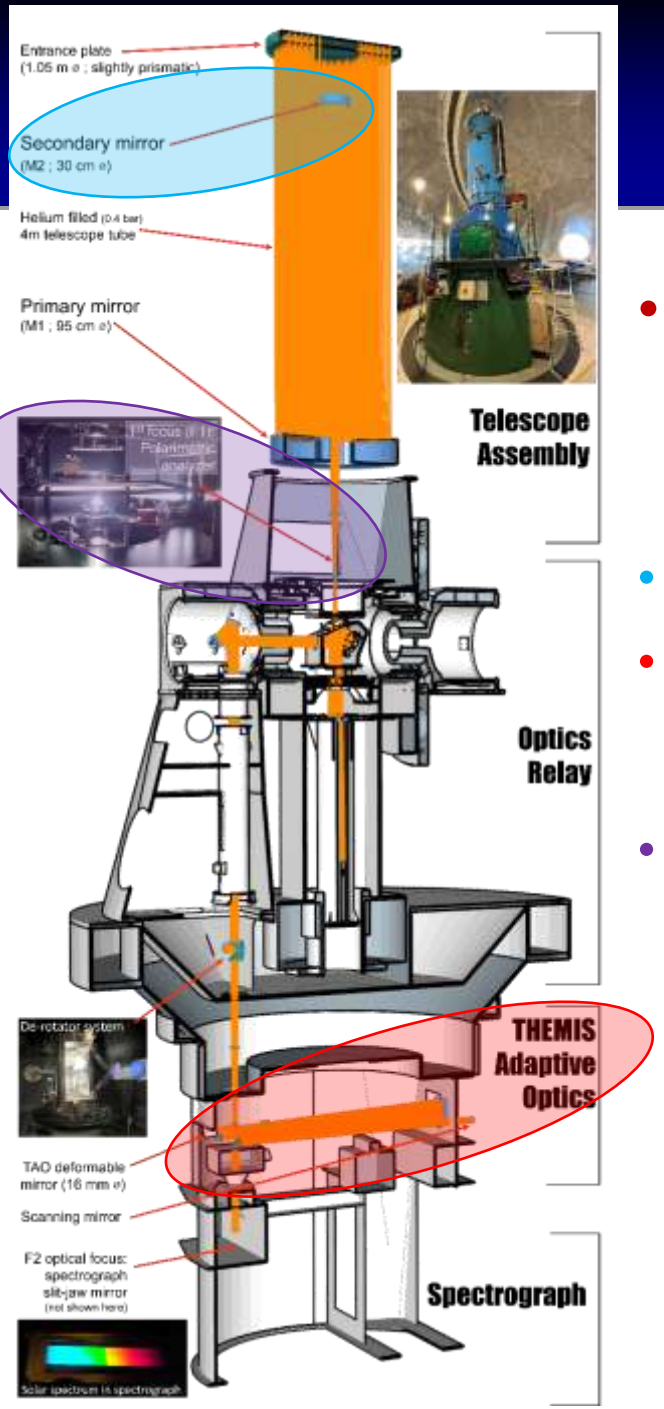

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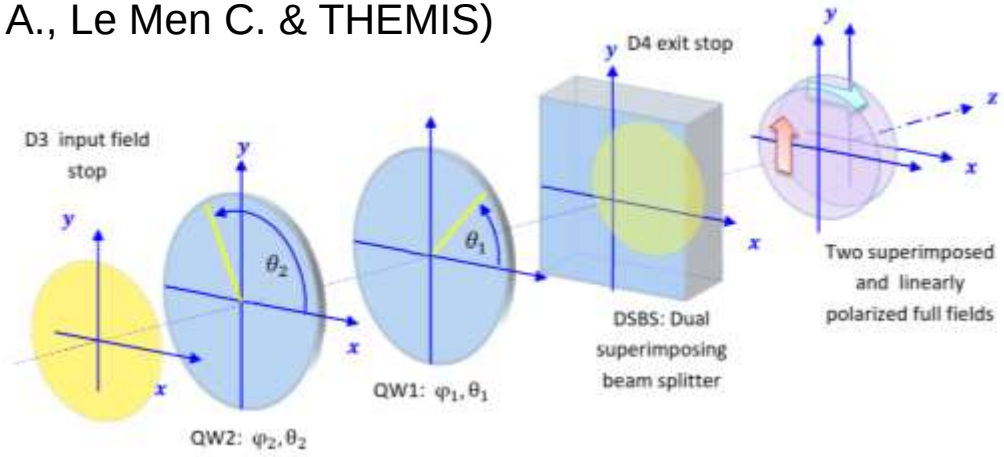

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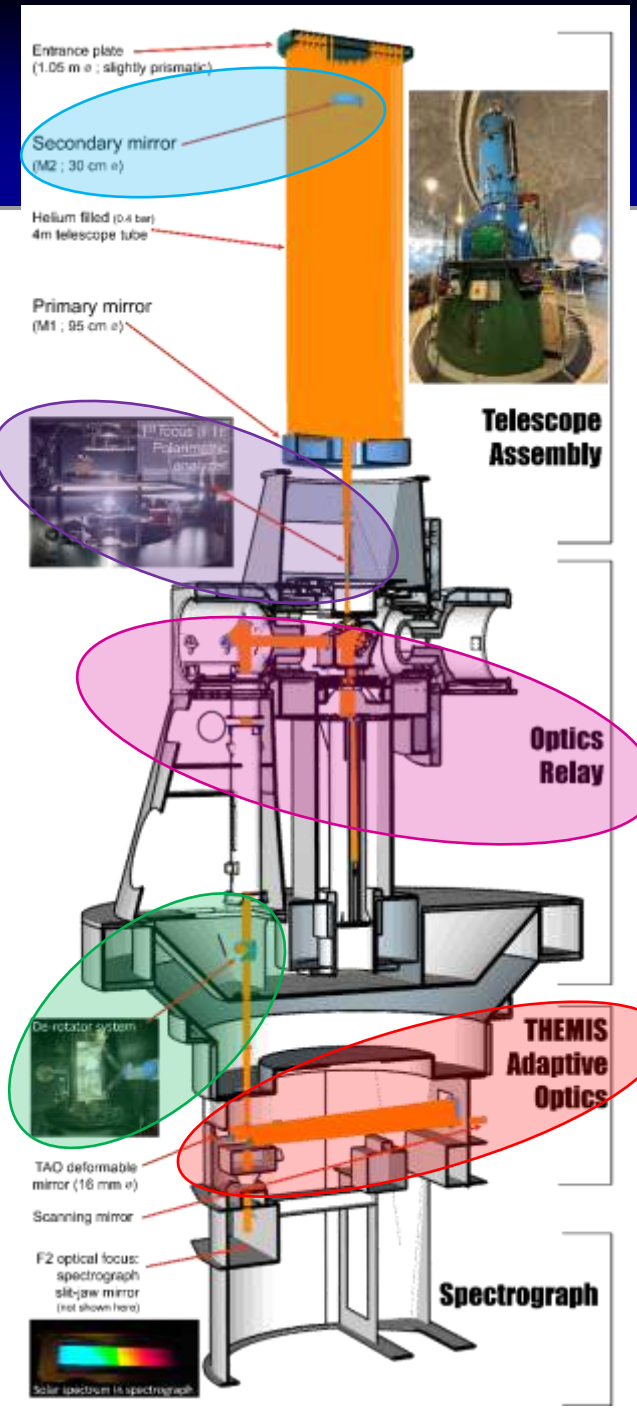

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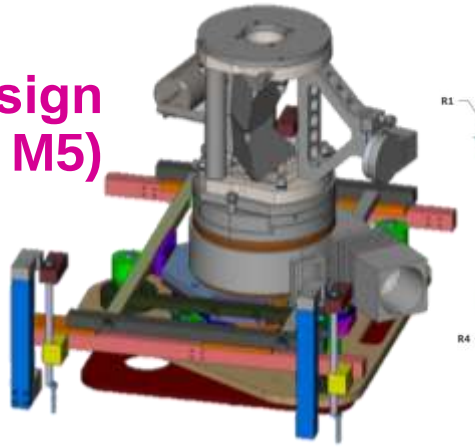
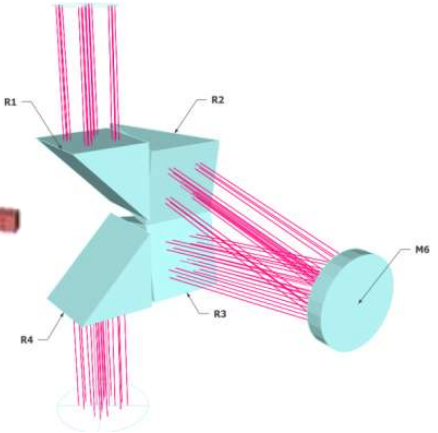
- **“Polarization- friendly” complete redesign of the whole transfer optics (M3, M4 & M5)** (Le Men, C. & THEMIS)
- **New de-rotator system** (THEMIS)
- + New context, broadband and spectral cameras.





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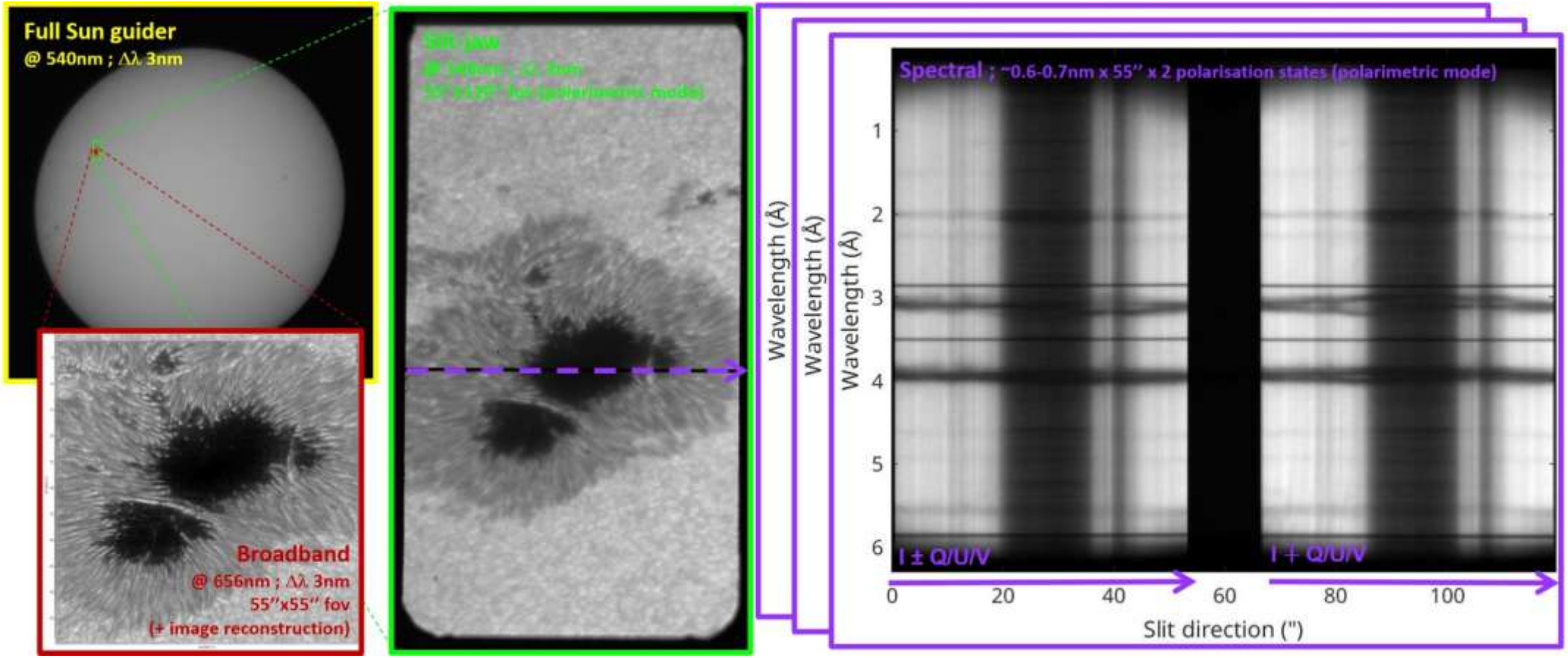
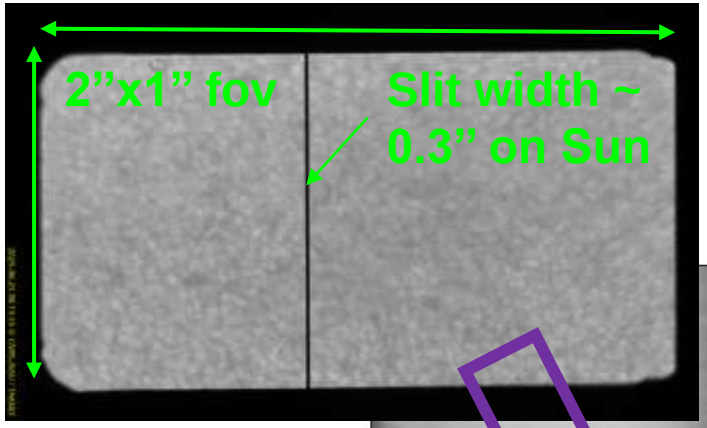
THEMIS primary data products

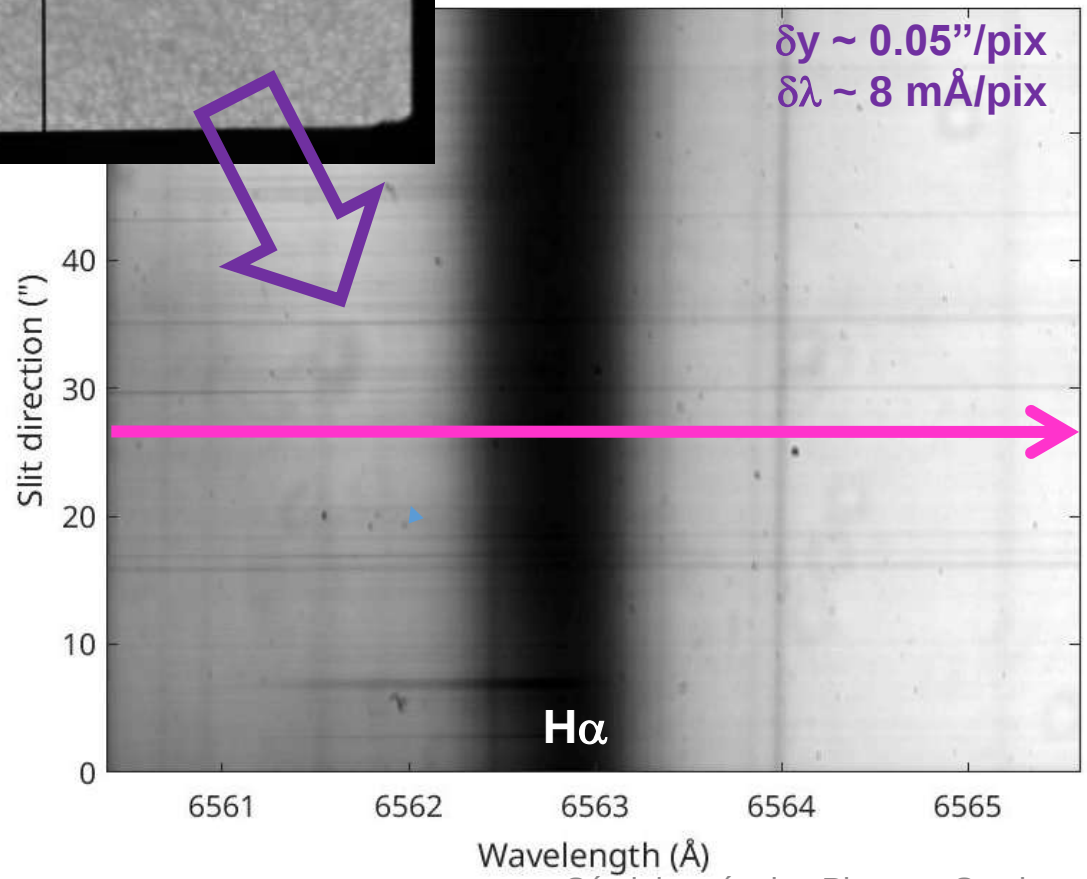
- **Full sun guider** & **spectrograph Slit-jaw** context images
- **BroadBand images (BBI)**
- Main science products: **MTR2 spectrograph spectral images**

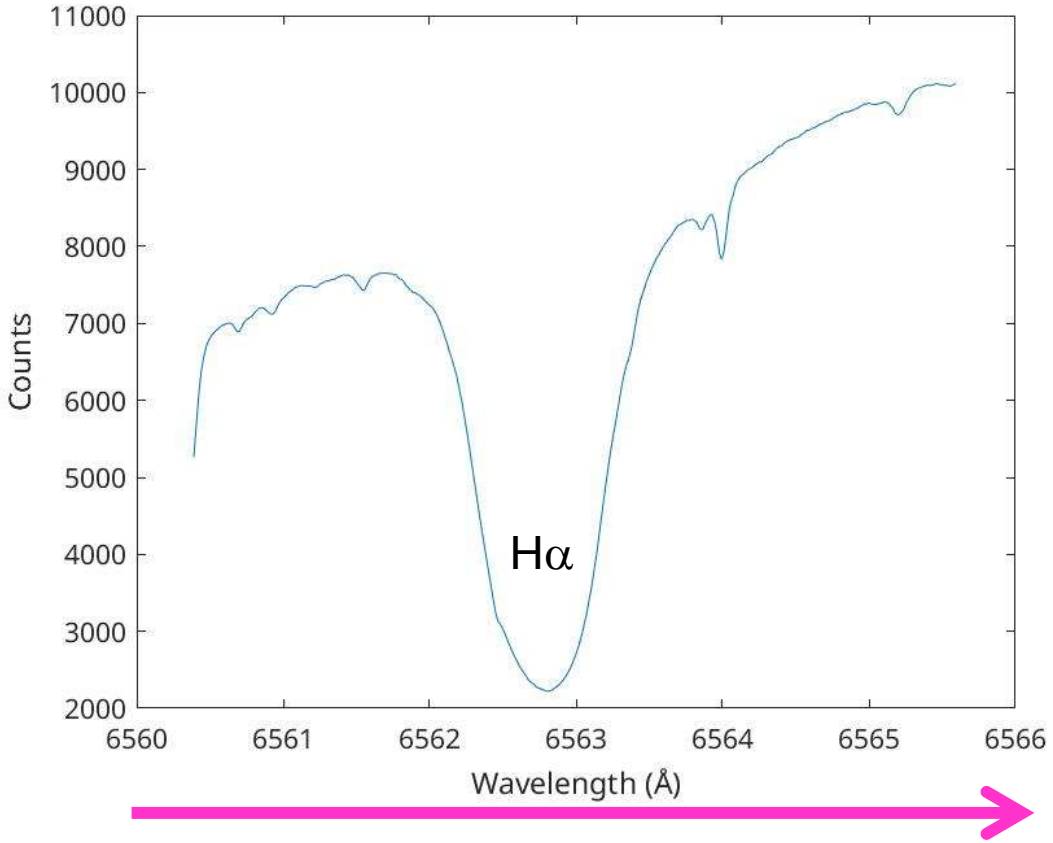


THEMIS spectral images



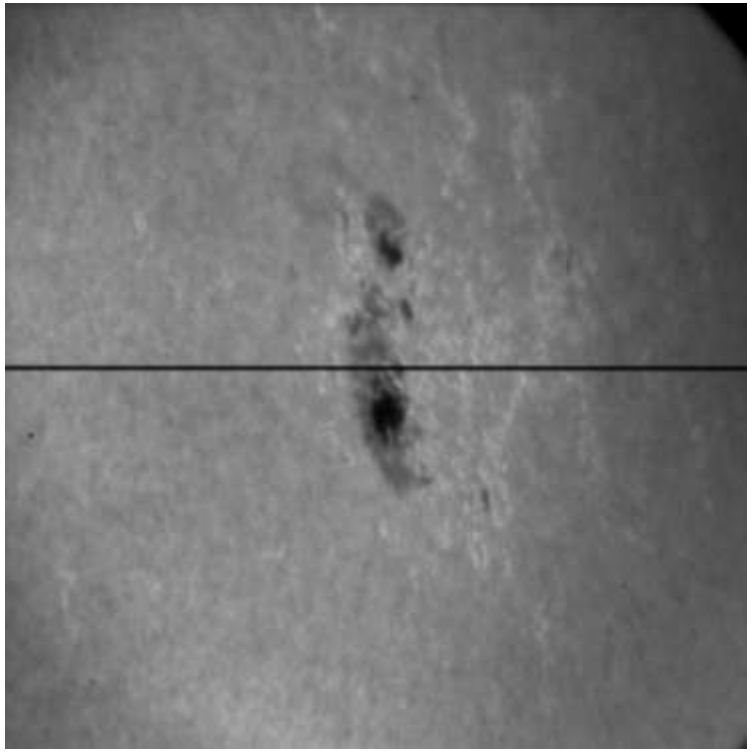
- **Spectrograms : (y,λ) images/camera**
  - y along slit length

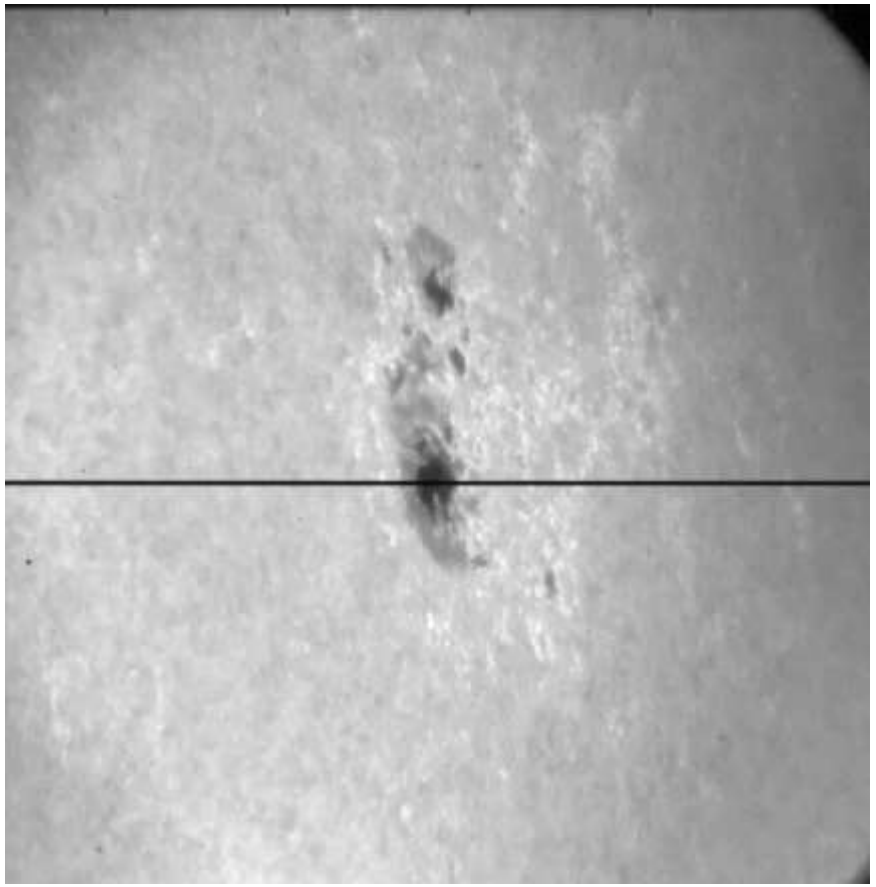




THEMIS spectral images

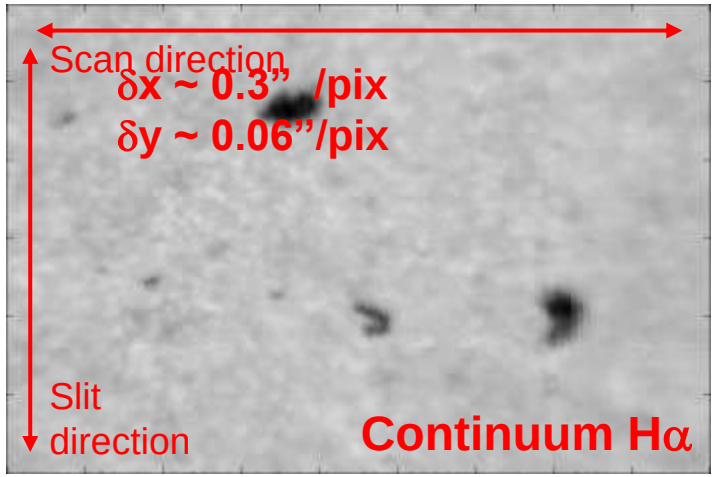
- **Spectrograms : (y,λ) images/camera** (y along slit length)
- Scan observation mode: scanning mirror used to produce fine orthogonal motion of the slit on the fov: scanning step size of δx with a <0.1” precision. Successive acquisitions at different positions
- **➔ spectral 3D datacubes (t ≡ x, y, λ)/camera**

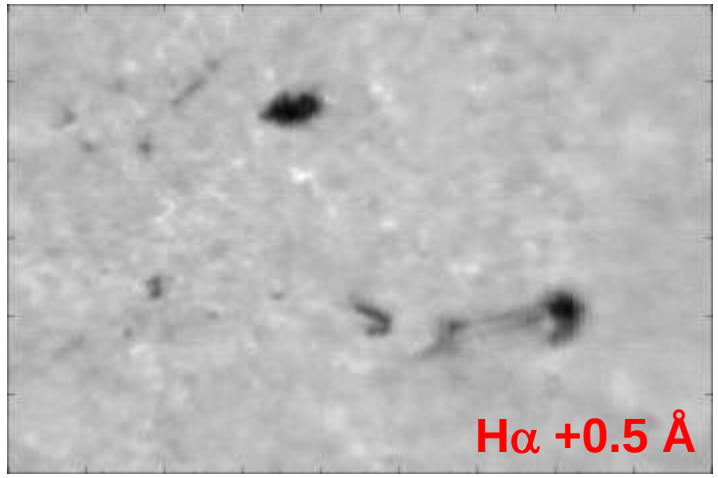


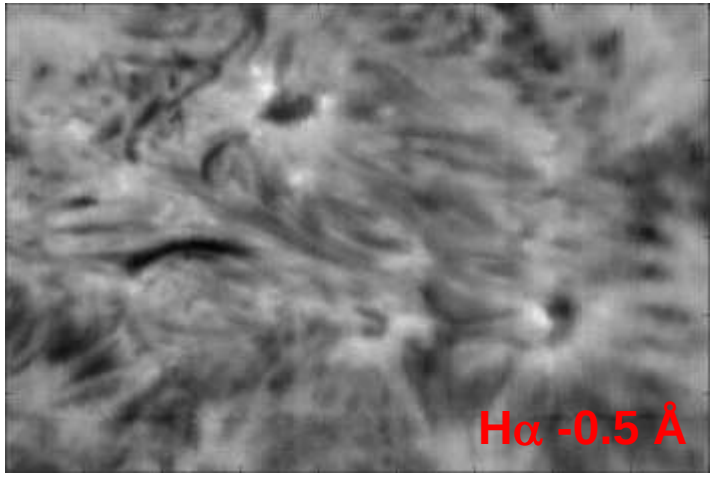


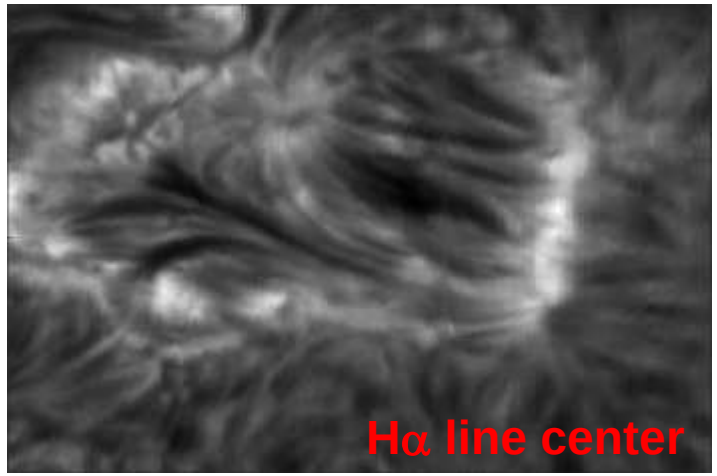
THEMIS L2 data products : reconstructed images

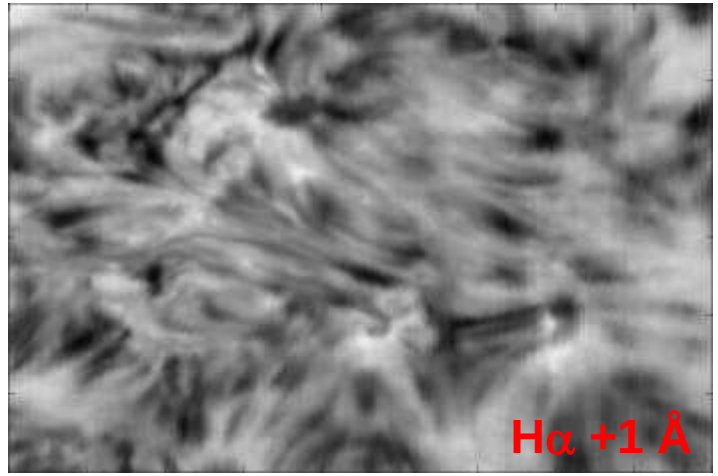
- From spectral 3D datacubes (t ≡ x, y, λ) per camera
- ➔ Reconstructed images (x(t),y) within the spectral domain range. Multiple maps at different wavelength at δλ spectral step.







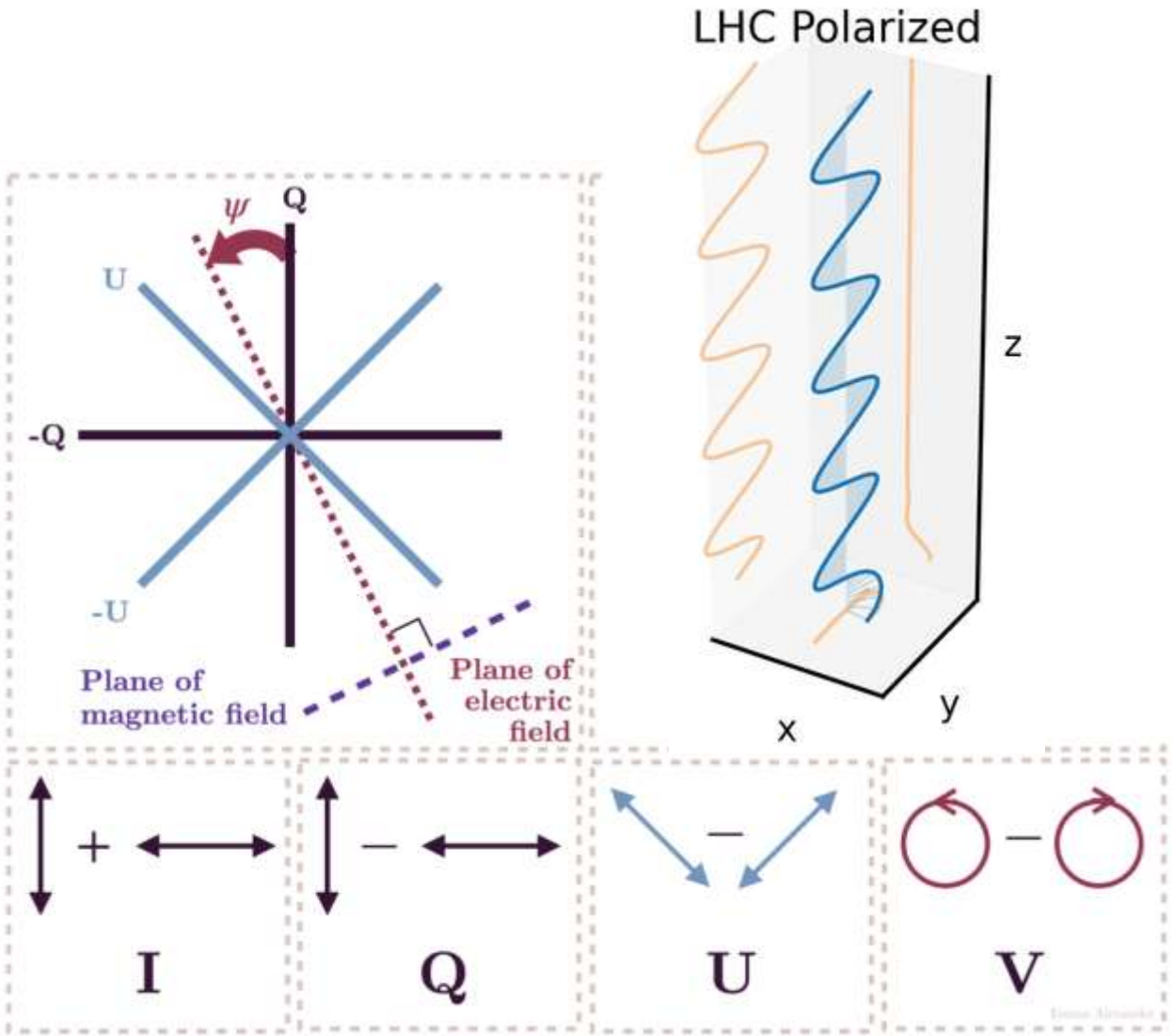




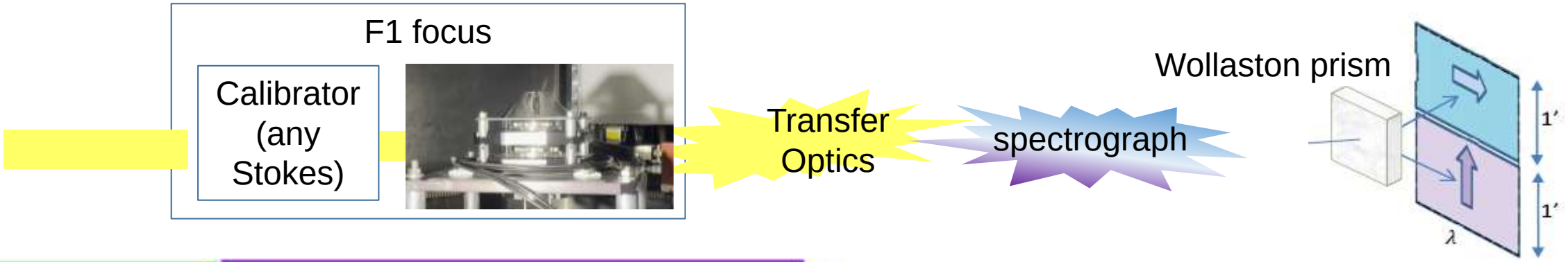
Light polarization

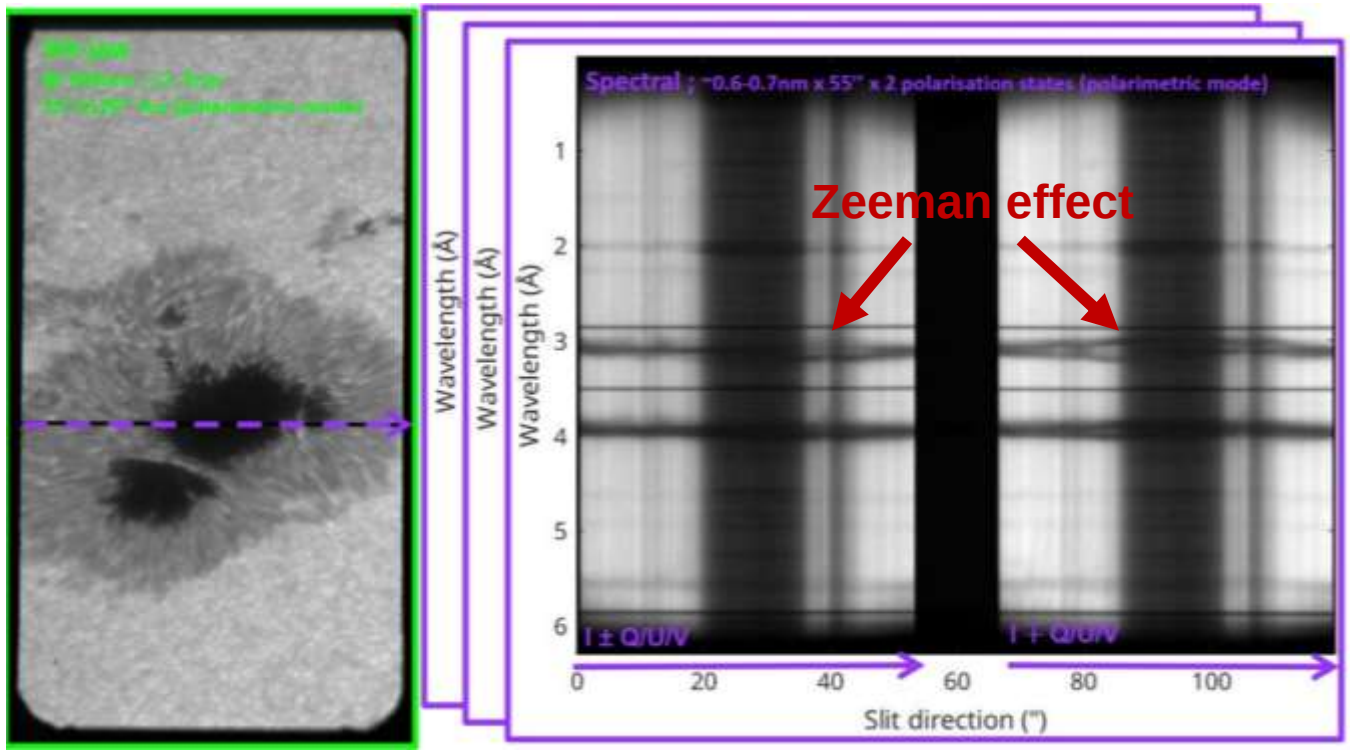
- Solar photospheric black body emission is unpolarized
  - Random orientation variation of (**E**,**B**) vectors of the electromagnetic wave
- Zeeman effect: presence of a static magnetic field induced a polarized splitting of the spectral line of magnetic field sensitive elements (e.g. Fe) into several components
  - Analyse of polarization permits to infer magnetic field of emission region
- **Light polarization can be described on a projection base: Stokes parameter**
  - I: light intensity
  - V: circular polarization
  - U,Q: linear polarization

$$S_0 = I = E_x^2 + E_y^2$$
$$S_1 = Q = E_x^2 - E_y^2$$
$$S_2 = U = 2E_xE_y\cos\delta$$
$$S_3 = V = 2E_xE_y\sin\delta$$



THEMIS Spectropolarimetric analysis





- **F1 polarimeter provides sequences of polarization states, I ± S (S in [Q,U,V]).**
  - Dual beam: simultaneous acquisition of I+S & I-S on camera (2 fov)
  - Beam echange: I+S, I-S sequentially measured
- Typical full spectropolarimetric sequence: I+V, I-V, I+U, I-U, I+Q, I-Q
- **➔ spectropolarimetric 3D datacubes: (t ≡ x & S, y, λ) per camera**

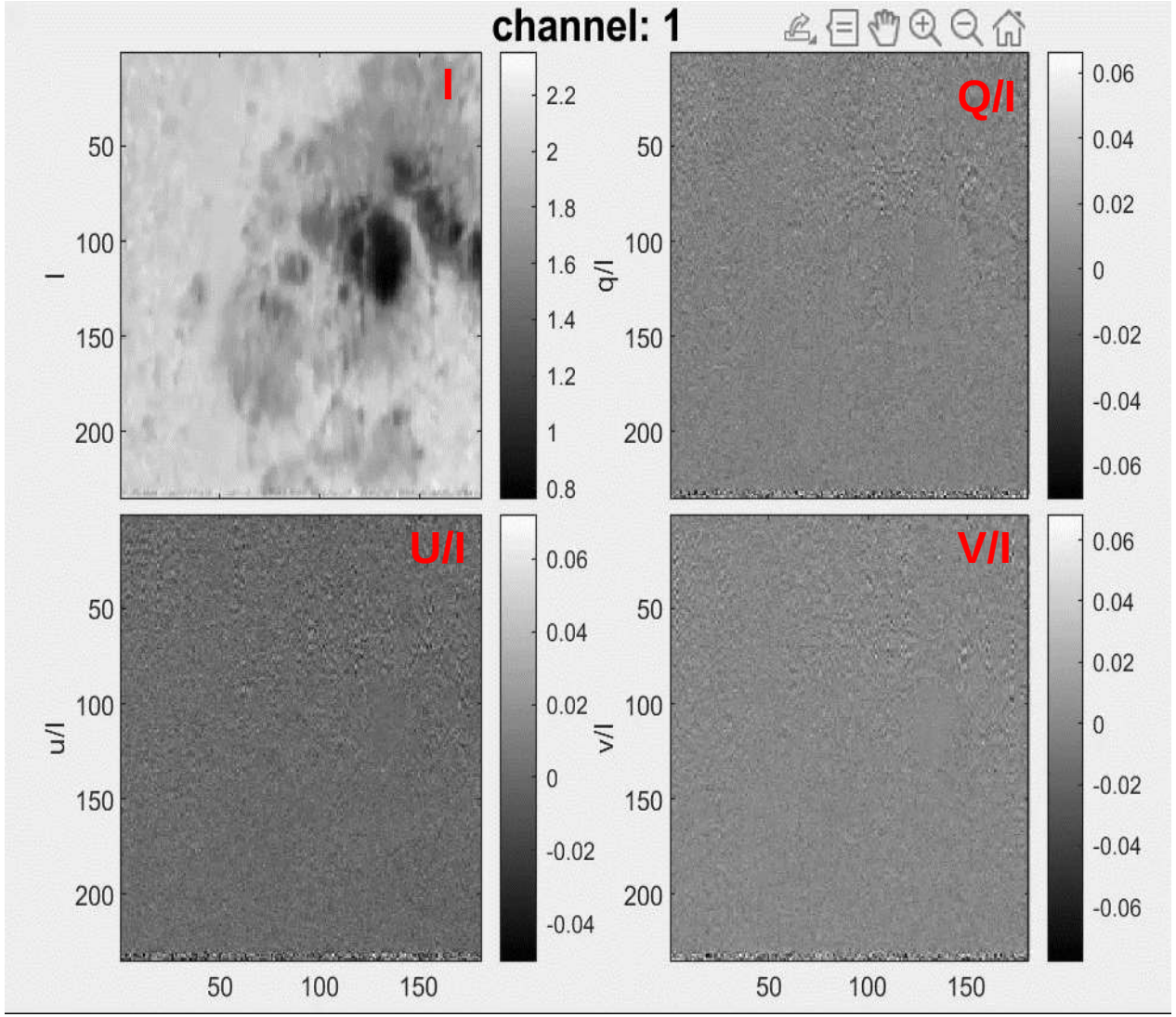
THEMIS L3 data products : Stokes maps

- **From spectropolarimetric 3D datacubes: (t ≡ x & S y, λ,) per camera**
- **➔ Extraction of the four Stokes parameter data cubes (x(t), y, λ):**
  - **4D data cubes (x, y, λ, S)**

- Stokes map are the used as inputs for magnetic invertion code ➔ calibrated magnetic field maps.

- Magnetic inversion code are presently being tested & implemented at THEMIS

  → Toward L4 data products



NOAA 14100 ; 29/05/2025 10:30-10:50 UT

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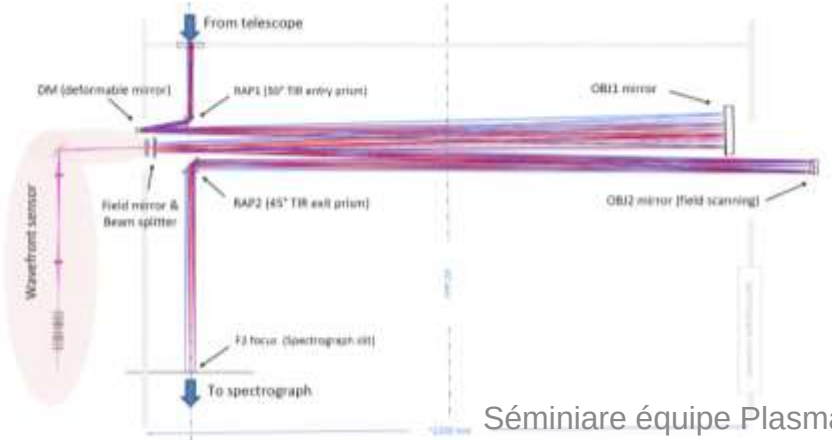
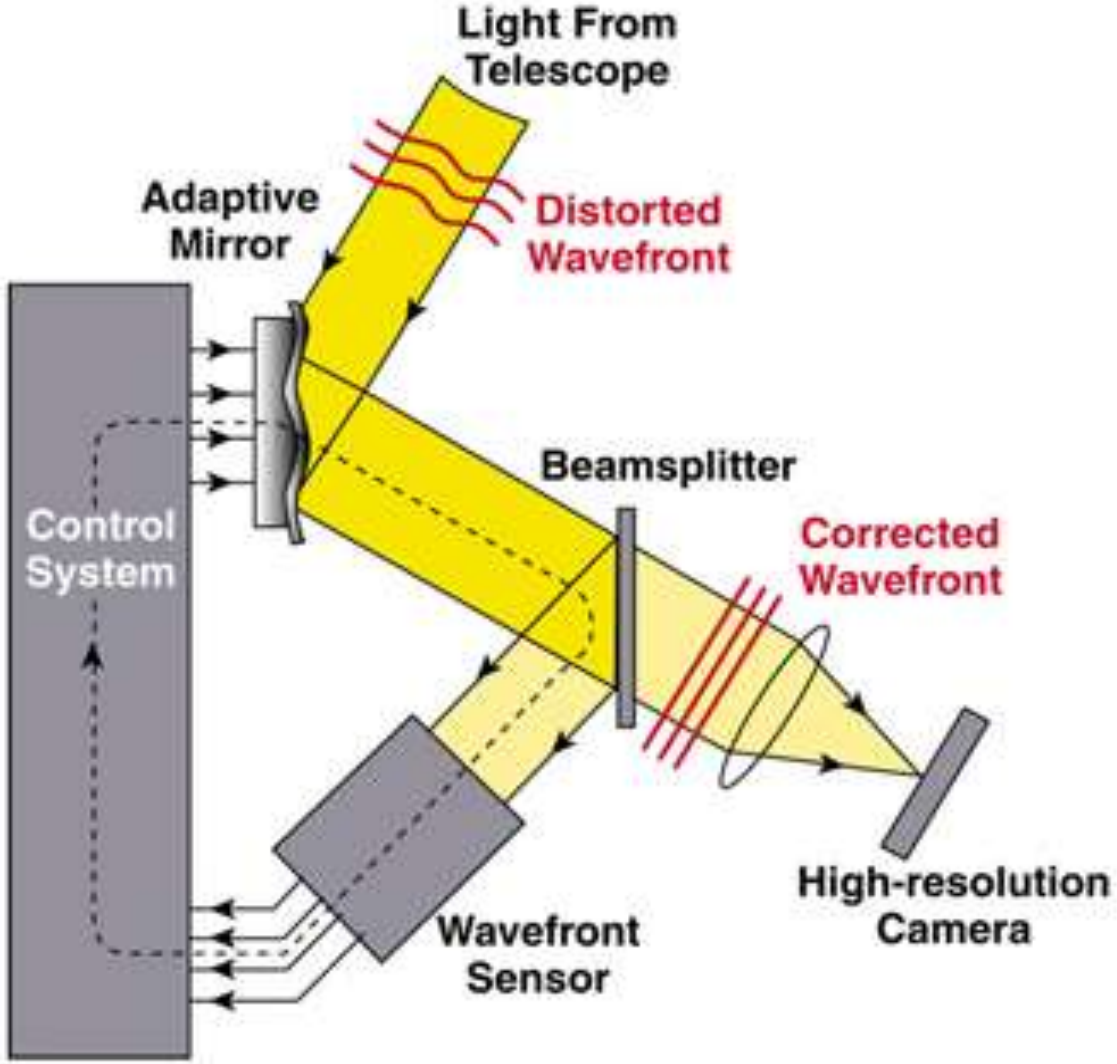
THEMIS Adaptive optics : principle

- Adaptive optics (AO) technology : correct distortions in light wavefronts due to turbulence or imperfections
  - Measures the incoming distorted wavefront thanks to wavefront sensor (WFS).
  - Very dynamically reshapes a deformable mirror in real-time with many small actuators
    - thanks to a real-time control computer equipped with an extremely fast processor
    - corrections shall happens faster than the timescal of the atmospheric turbulence
- THEMIS had a pre-AO era design
  - Adapting an AO has been particularly challenging





Crédit: *Lawrence Livermore National Laboratory and NSF Center for Adaptive Optics*

TAO linearized model of wavefront sensor data and DM commands in the THEMIS system

WFS data — Actual wavefront — Actuator commands — … some noise

$$\boldsymbol{d}_t = \boldsymbol{S}.(\boldsymbol{w}_t + \boldsymbol{M}.\boldsymbol{a}_t) + \boldsymbol{z}_t$$

Sensor linear response — Mirror influence matrix

- Wavefront is represented in the basis of influence functions of the DM

➔ **Requires to solve an inverse problem (*argmin*…) at each step (all terms may change with time), in real-time (~1kHz)**

Thiebaut, E., Tallon, M. et al, SPIE proceedings 2022

$$\boldsymbol{a}_{t+\delta t} = argmin\{\ \|\boldsymbol{y}_t + \boldsymbol{G}\,.\boldsymbol{a}\|^2_{Cov(\boldsymbol{z_t})^{-1}} + \mu_t \|\boldsymbol{a}\|^2_{\boldsymbol{W}} + \rho_t \|\boldsymbol{a} - \boldsymbol{a}_t\|^2\ \}$$

$\boldsymbol{G} = \boldsymbol{S}\,.\boldsymbol{M}$ is the **interaction matrix**

$\boldsymbol{y}_t = \boldsymbol{d_t} - \boldsymbol{G}.\boldsymbol{a}_t$ are ≈ open loop data

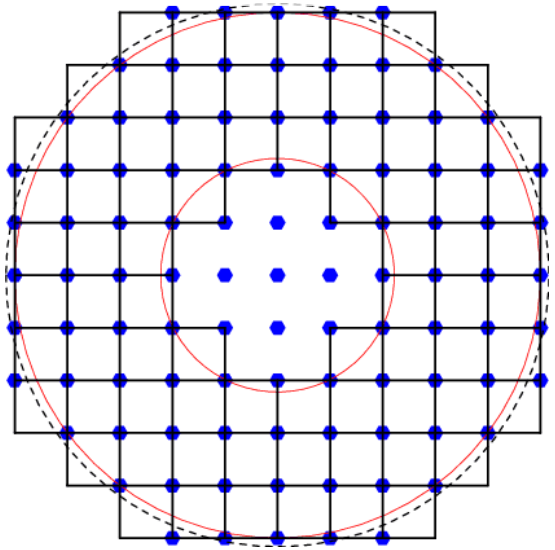
$\boldsymbol{\mu_t} > 0$ and $\boldsymbol{W} \approx Cov(w_t)$ are loop parameters to enforce spatial regularization

$\boldsymbol{\rho_t} > 0$ is a loop parameter to impose temporal continuity

THEMIS Adaptive Optics (TAO): specifications & objectives

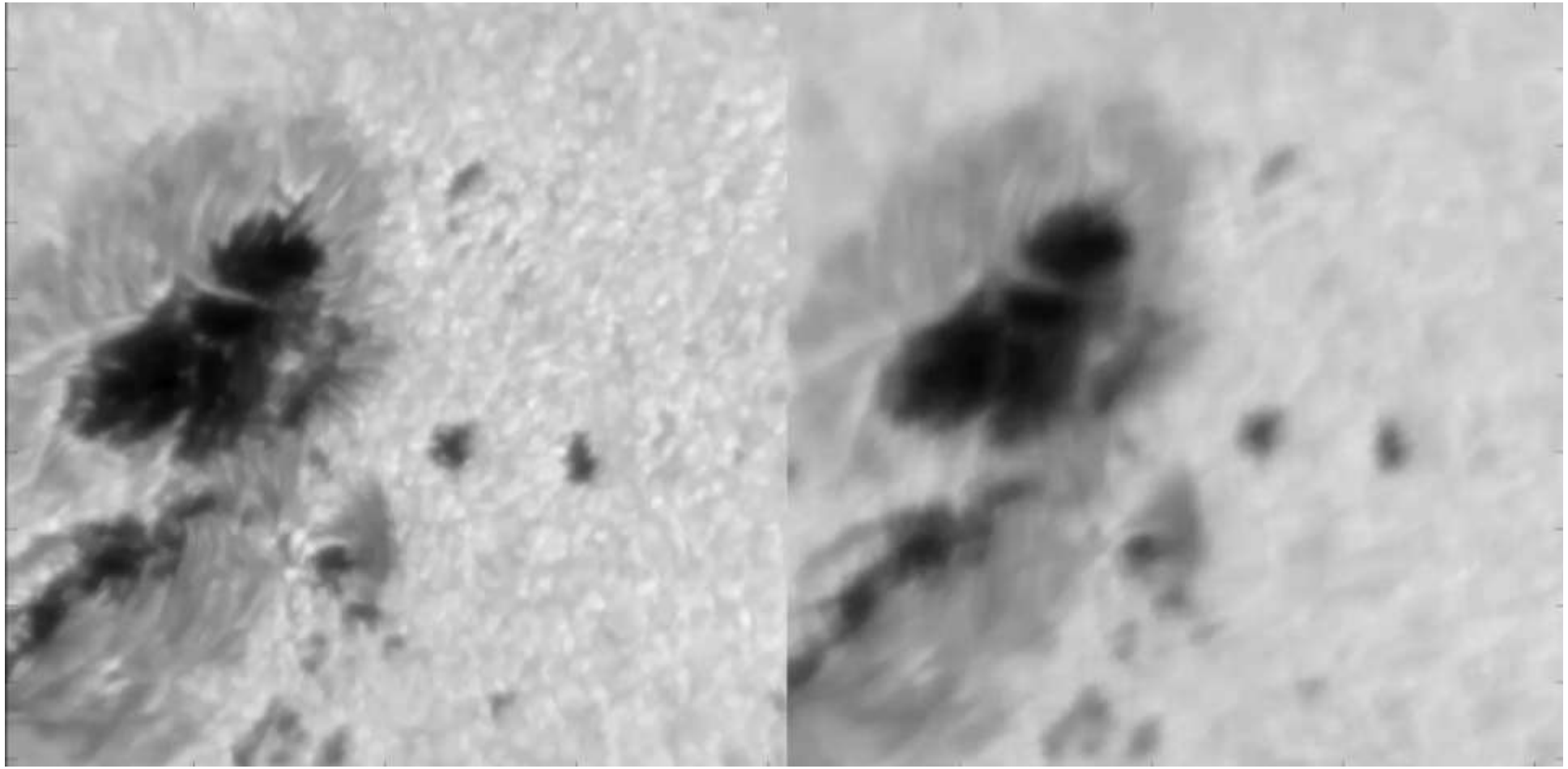
- Specifications
  - **76 sub-aperture Shack-Hartmann wavefront sensor** (10×10);
    - 380×380 pixel WFS images, Mikrotron EoSens 4CXP detector;
  - **THEMIS-optical-path-compatible 16 mm deformable mirror**
  - **97 actuator** on deformable mirror (11×11), from ALPAO
  - Real time correction (RTC)
    - Computer: CPU i7-4790K (Q2'14) at 4.2 GHz, 4 cores, up to 50 Gflops/core with AVX2 + FMA instructions.
- Objectives
  - ✓ **Closed AO loop on the Sun**
    - started from scratch mid-2016 → operative in December 2020
  - ✓ **RTC software running in CPU @1250 Hz** (no GPU)
    - flexible RTC software to implement and experiment new algorithms
  - **Next objective: unsupervised AO system** (optimal correction whatever the conditions)

TAO geometry with a combination of DM/wavefront sensor set up in 'Fried configuration' with a spacing number of 10

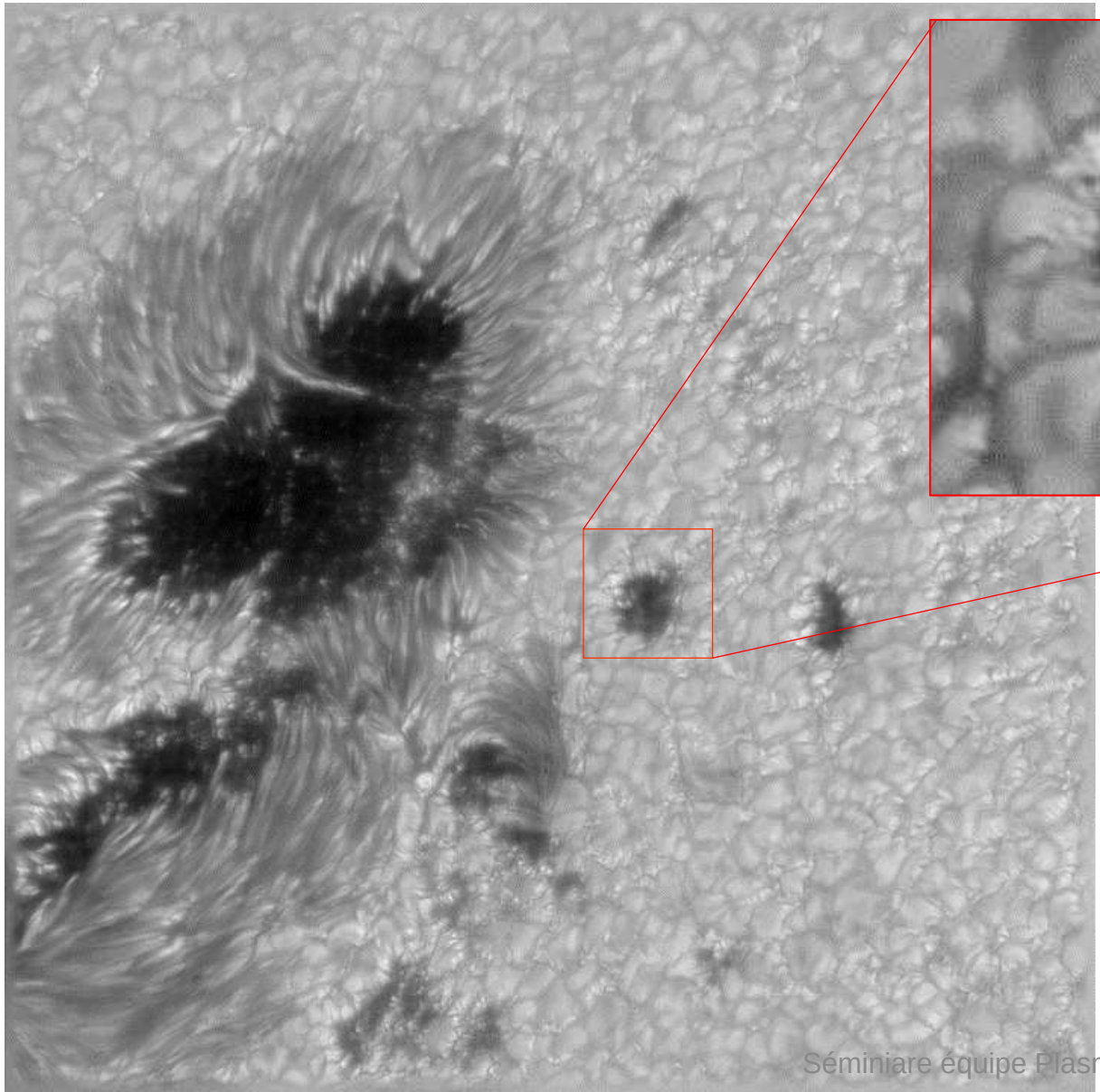


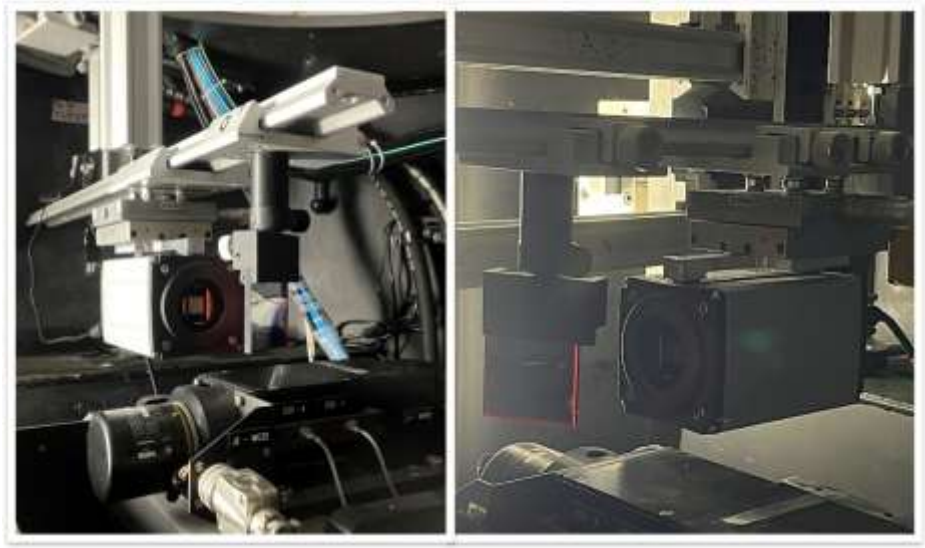
TAO going live on NOAA 12975

- Successive recordings in equivalent seeing conditions
- 55” square field, 20 image/s (0.3 ms), 2k x 2k (0.03” /px) on Broadband Imaging Camera



THEMIS at diffraction limit: NOAA 12975

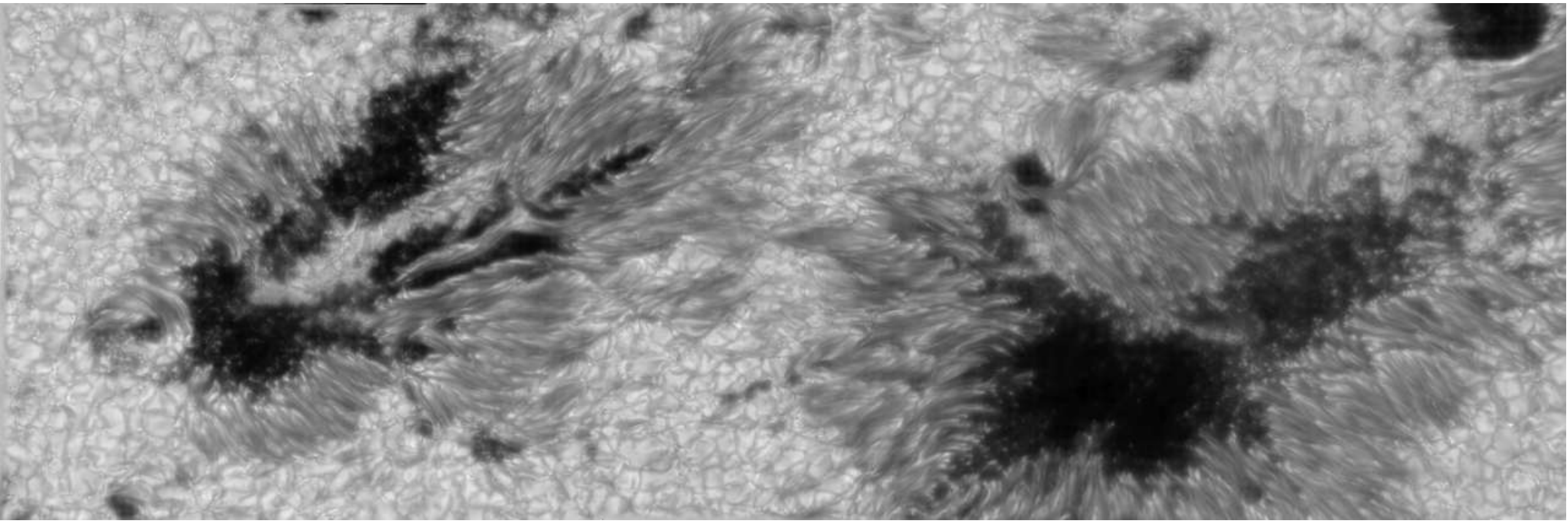




THEMIS Broadband Imaging (BBI)

- NOAA 12975 on 2022/03/31
- Observed @ 630nm ; 1nm broadband red filter
- 55”x55” FOV
- 100 BBI acquisition @ 40 images/s
- Knox-Thompson image post processing
- **➔ 0.17’’ resolution (0.035”/pixel) near THEMIS theoretical diffraction limit of 0.15”**

THEMIS at diffraction limit: NOAA 13354

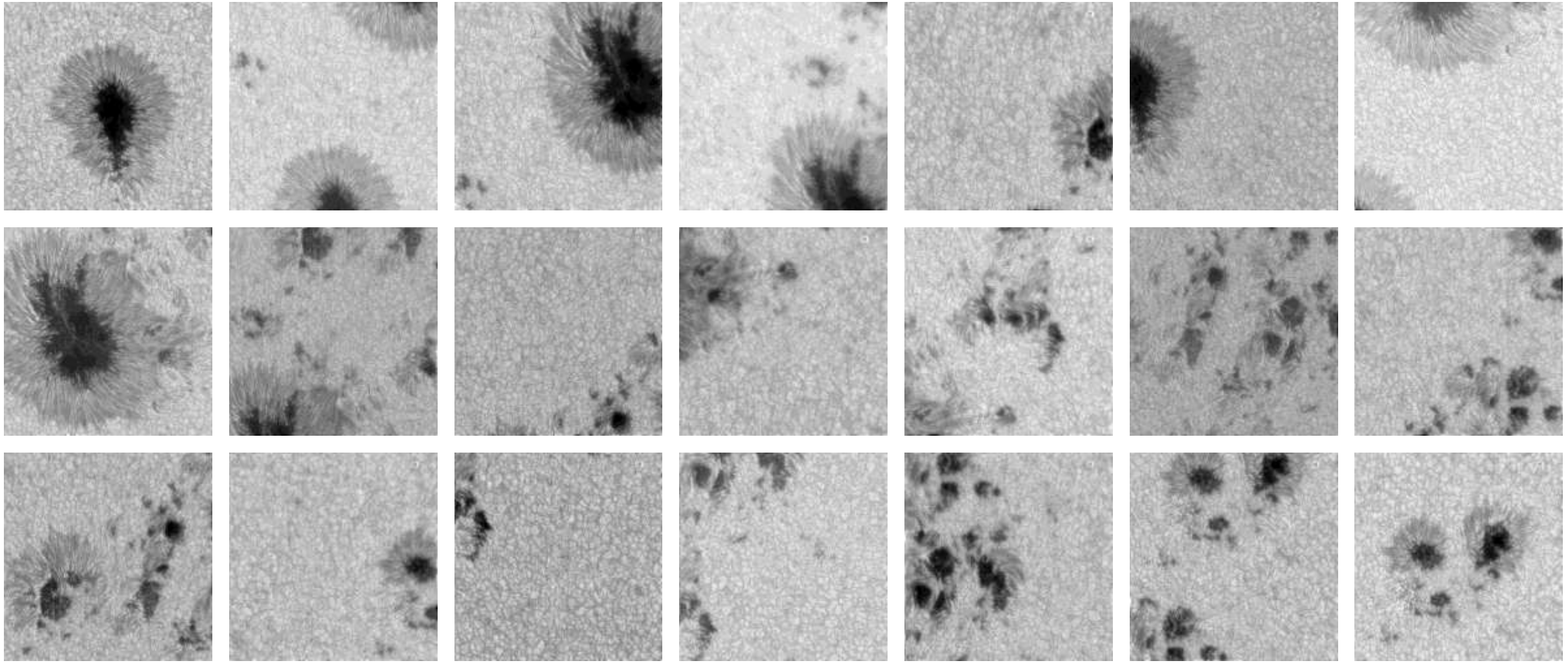


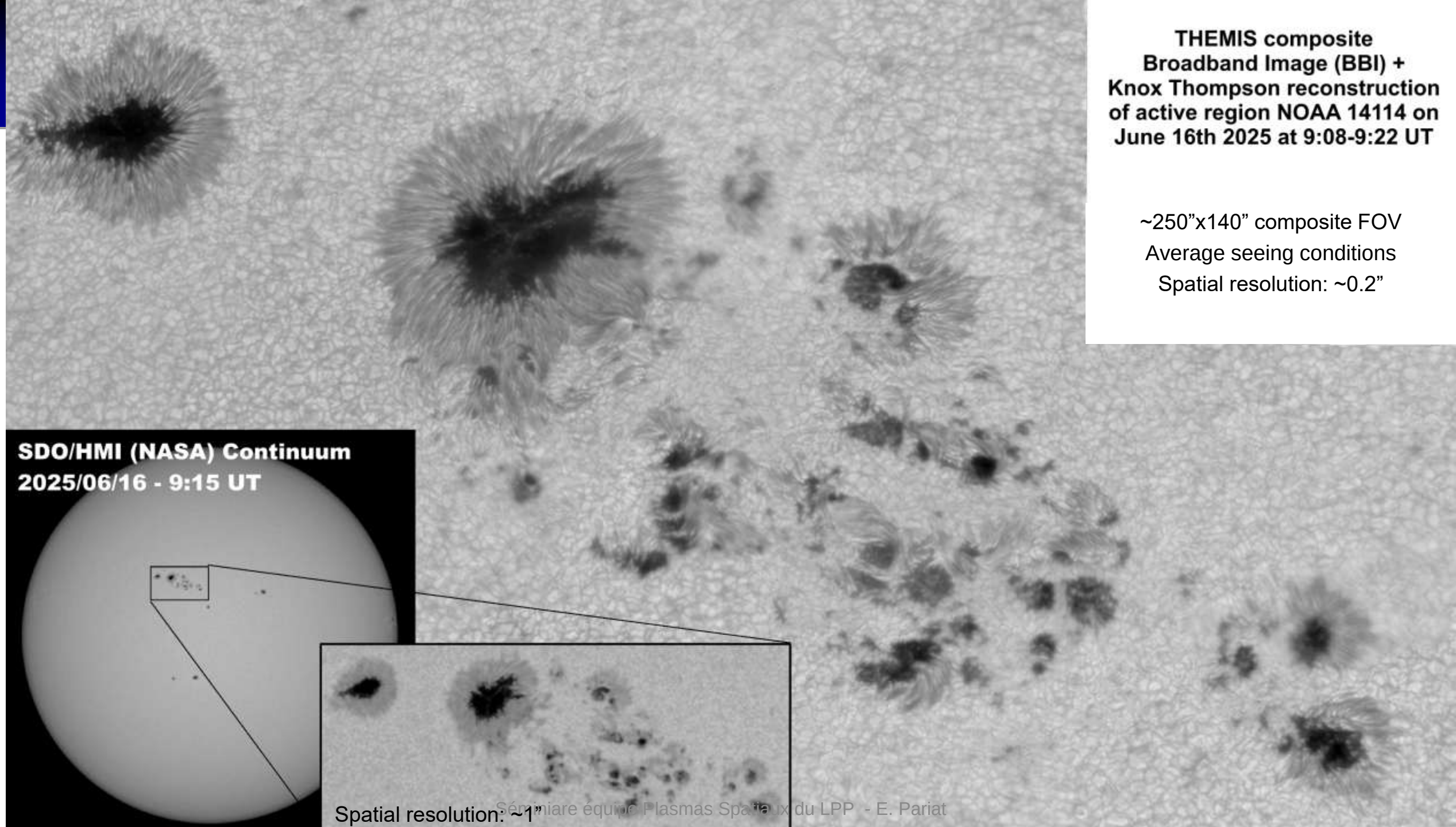
- NOAA 13354 on 2023/06/28 ; good seeing
- 150”x50” composite FOV
- **0.17’’ resolution (0.035”/pixel) near diffraction limit**
- Observed @ 630nm with 1nm broadband red filter

- **Several 55”x55” FOV acquisition by BBI camera in burst mode (40 images/s) + image restoration from residual seeing ➔ Routine operation with pipeline !**
- Images stitched together with Hugin software

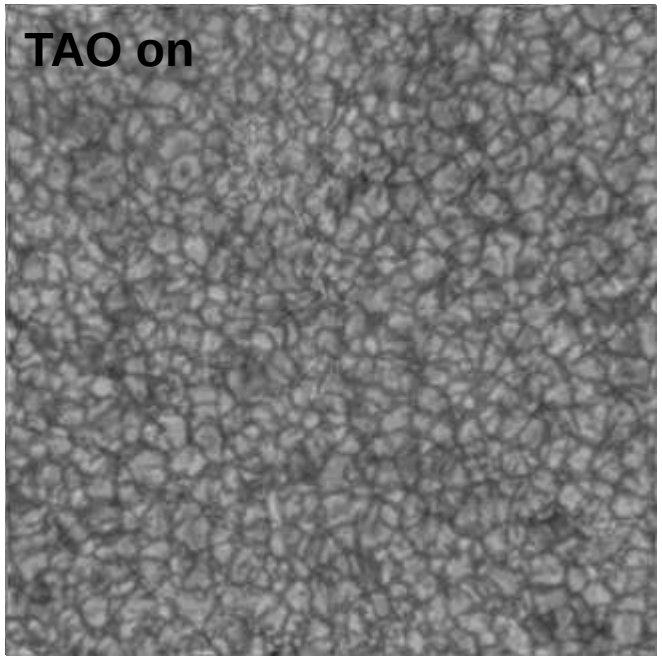
THEMIS large FOV reconstruction: NOAA 14114

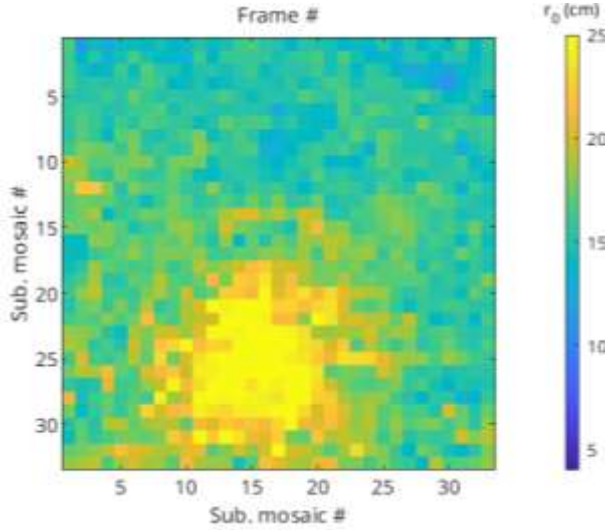
- Acquisition of sequential 21 BBI bursts (55x55” FOV) of NOAA 14114

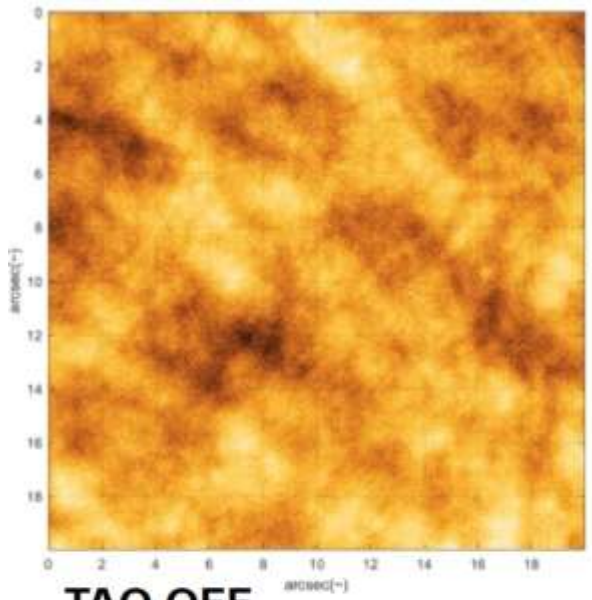



THEMIS composite
Broadband Image (BBI) +
Knox Thompson reconstruction
of active region NOAA 14114 on
June 16th 2025 at 9:08-9:22 UT
~250”x140” composite FOV
Average seeing conditions
Spatial resolution: ~0.2”
SDO/HMI (NASA) Continuum
2025/06/16 - 9:15 UT
Spatial resolution: ~1”

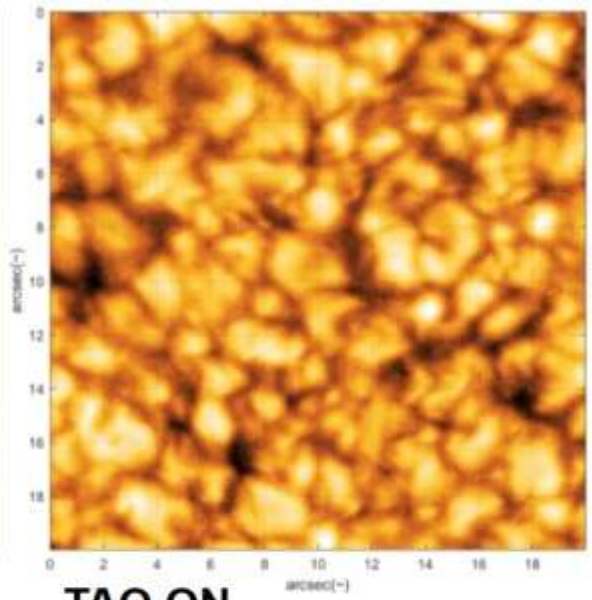
THEMIS Adaptive Optics (TAO): results on granulation



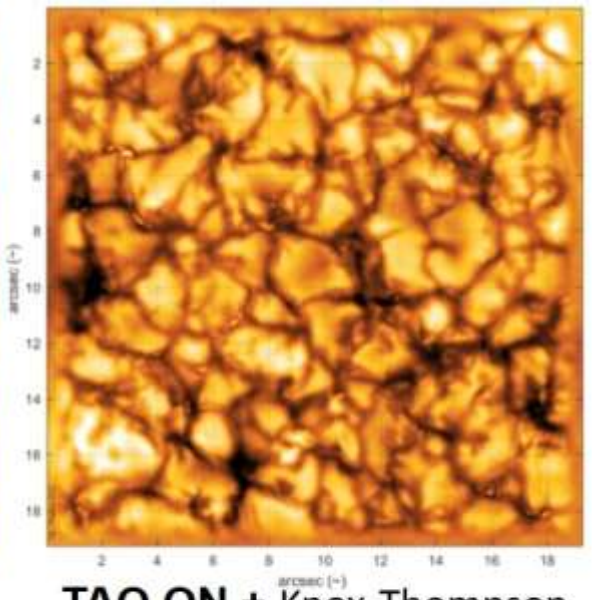




TAO OFF
- seeing "daytime bad" : r_0≈ 3-4 cm
- granulation contrast: 1.6 %



TAO ON
- seeing "daytime bad" : r_0≈ 3-4 cm
- granulation contrast: 4.2 %



TAO ON + Knox-Thompson reconstruction (100 frames)
- granulation contrast: 9.6 %

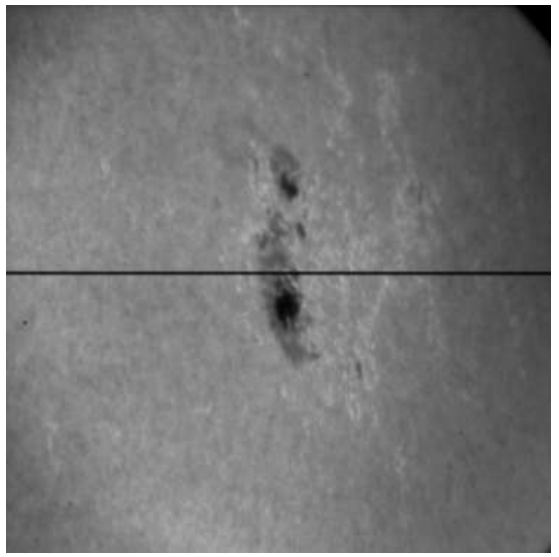
- TAO permits significant gain:
  - in effective seeing: e.g. Fried's coherence length from ~7cm (medium seeing) to ~25cm at TAO focus & ~17cm on rest of FOV
  - in granulation contrast

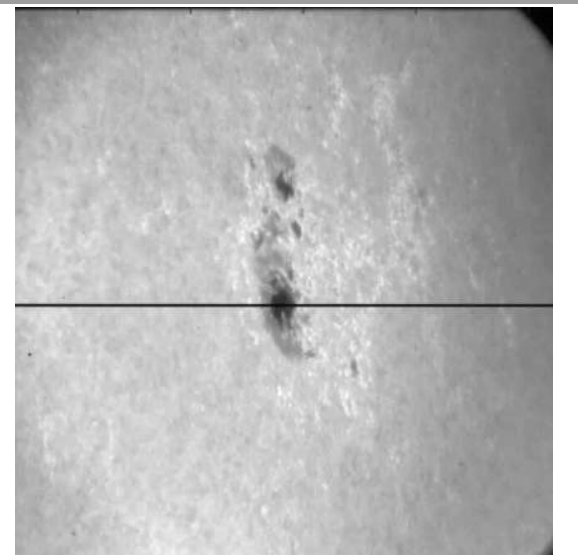
TAO for spectroscopy

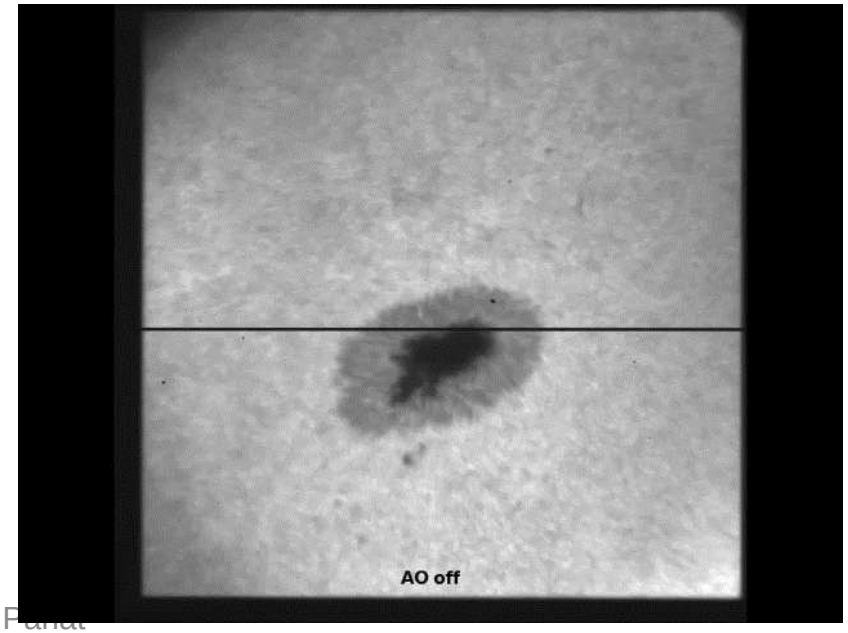
- Main strength and raison-d'être of THEMIS is spectropolarimetry!

- Requires scans of the region of interest by the spectrograph slit:
  - Scan duration of a 90" domain with 0.3" steps & 0.1 s spectral camera acquisition time
    - 3 min without polarimetry
    - 25 min with polarimetry

- **Spectroscopic measurement requires that TAO must hold and stabilize wavefront over FOV during extended periods of time.**

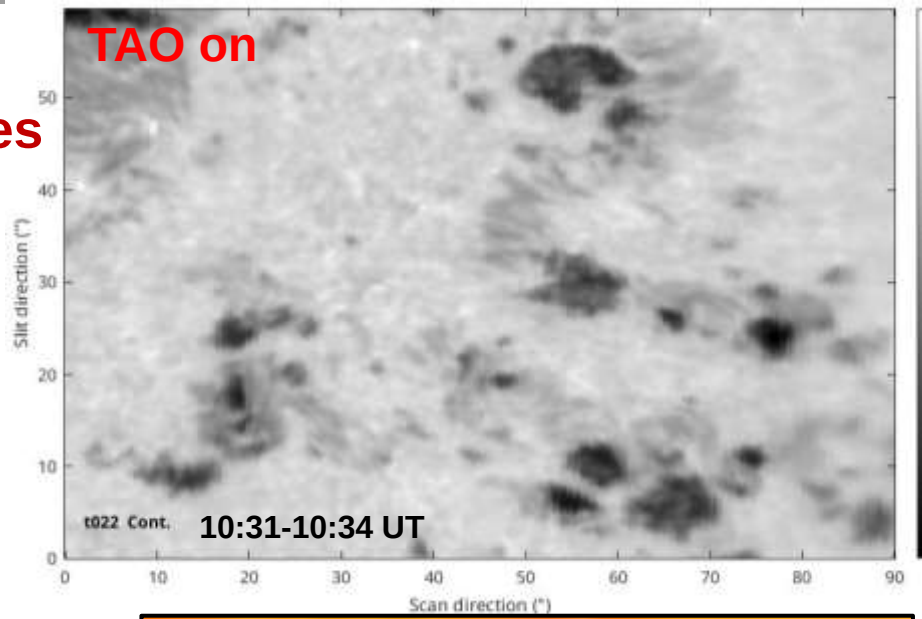


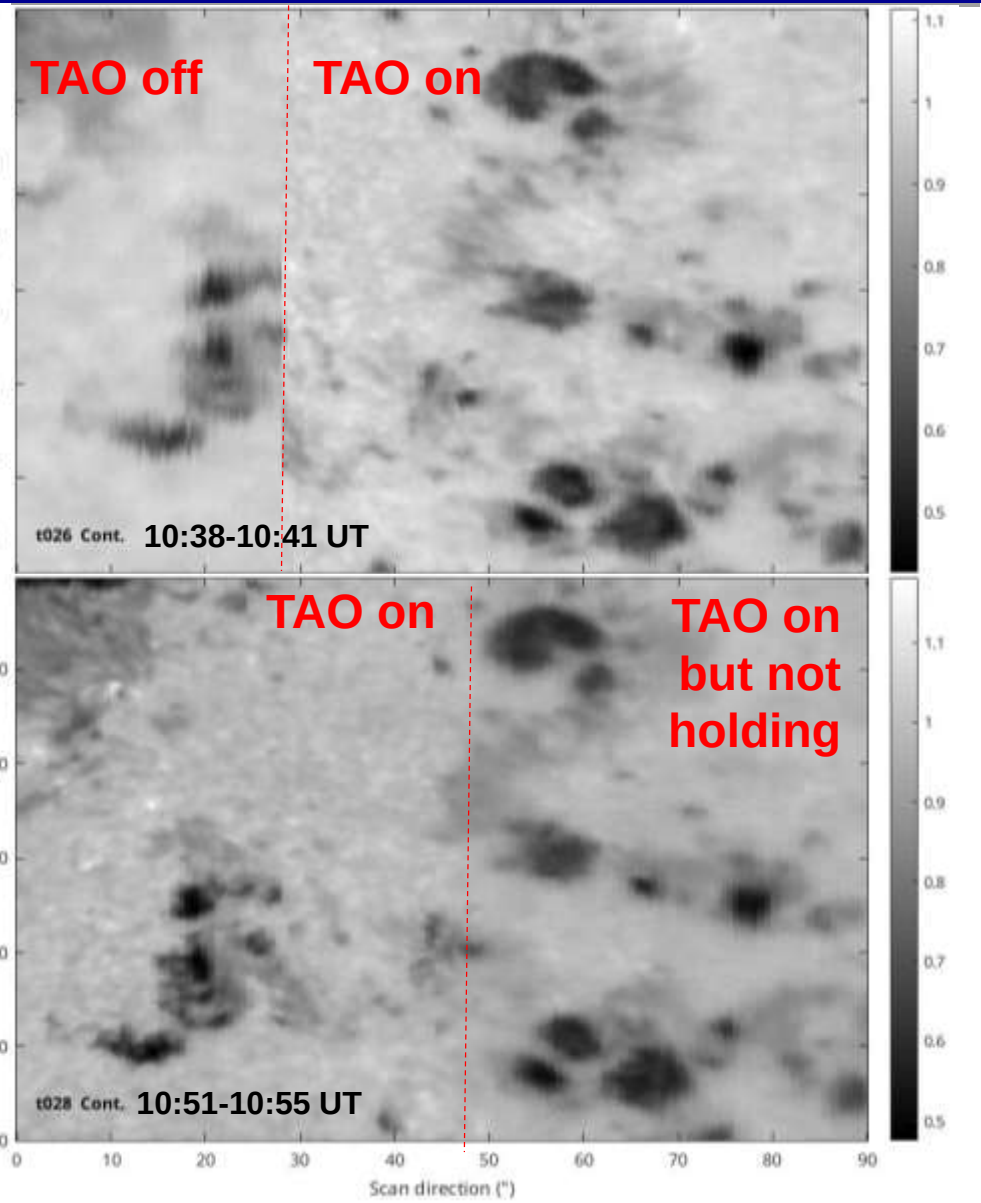




TAO for spectroscopy

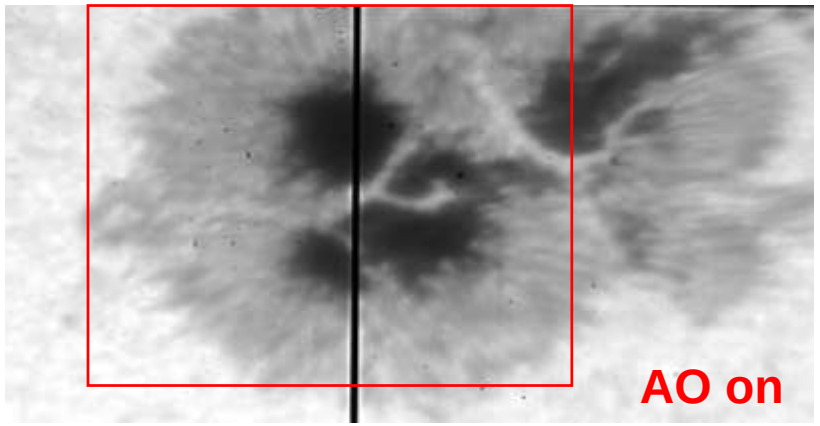
- **Spectroscopic measurement requires that TAO must hold and stabilize wavefront over FOV during extended periods of time.**
- Challenging
- Isoplanatic patch away from spectrograph slit in long scan
- Stable seeing over extended period of time remains needed

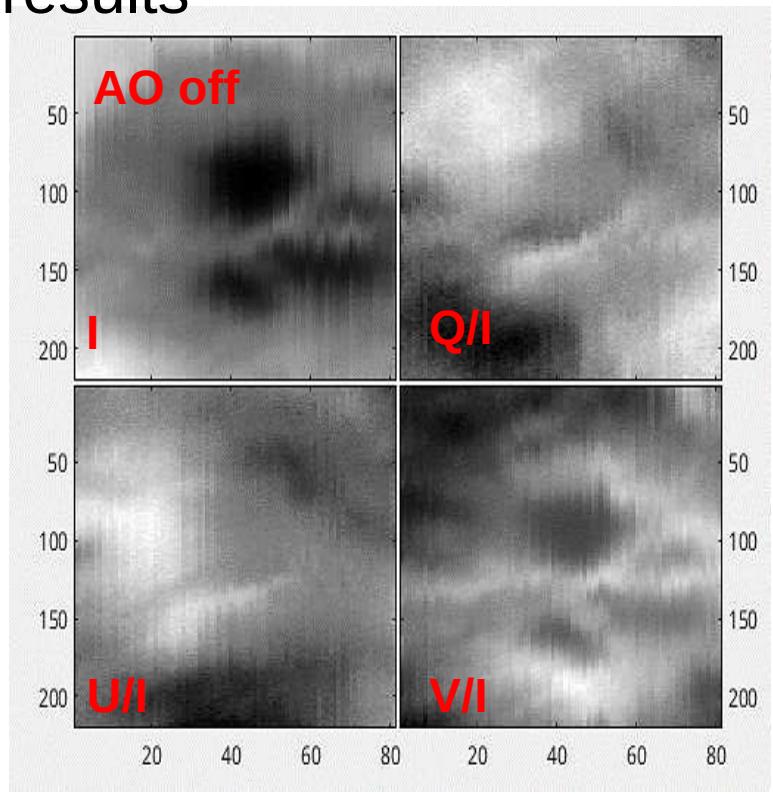


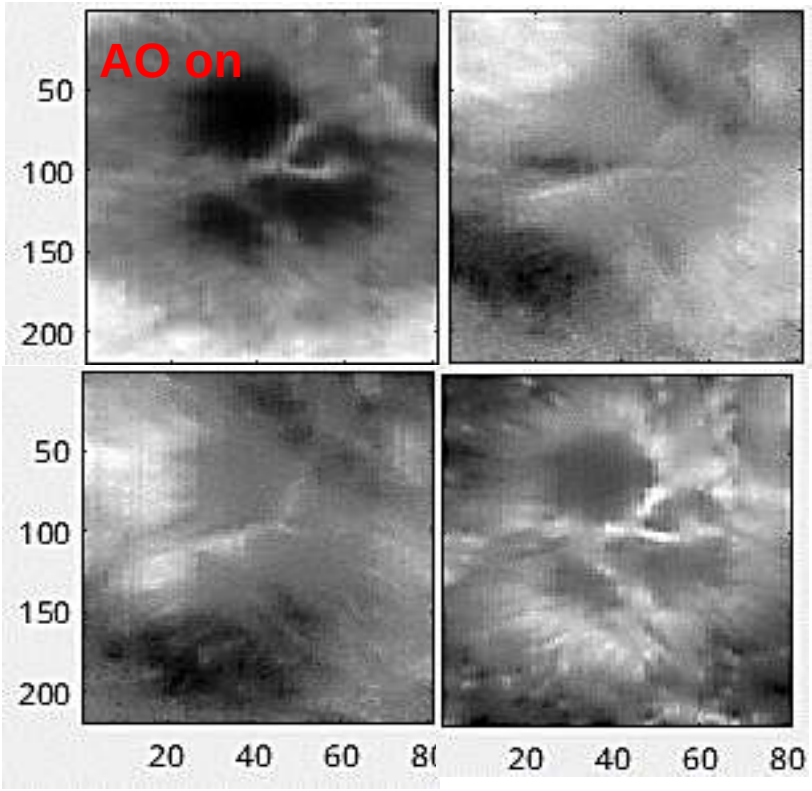


TAO for spectro-polarimetry

- TAO can also give good results on long spectropolarimetric scans
- **THEMIS goals : B maps with spatial resolution better than 0.5” arcsec**
  - 3 times better than before
  - equivalent to HINODE results





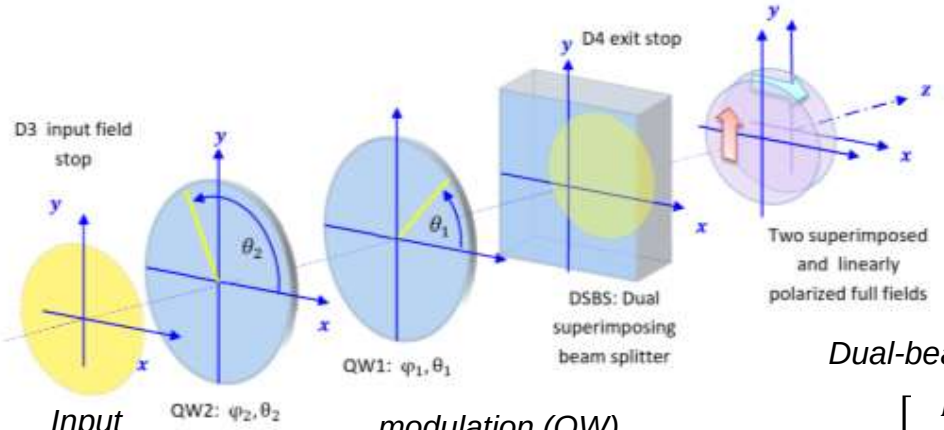


Outline

- Introduction: THEMIS time line & characteristics
- THEMIS overhaul
- THEMIS data products
- THEMIS adaptive optics
- Spectropolarimetry with THEMIS 2.0
- Selected recent & future highlights

THEMIS new polarimetric analysis scheme - 1

Full-Stokes analyzer (An4) located at the F1 prime focus, delivering dual-beam polarimetry with beam exchange.



Input *modulation (QW)*

$$S = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} \quad S_Q = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} \quad S_V = \begin{bmatrix} I \\ V \\ Q \\ U \end{bmatrix} \quad S_U = \begin{bmatrix} I \\ U \\ V \\ Q \end{bmatrix}$$

Double Savart plates:
- generate the dual beam feature
- then superimpose both beams: behave as one, differing only by their linear polarization state.

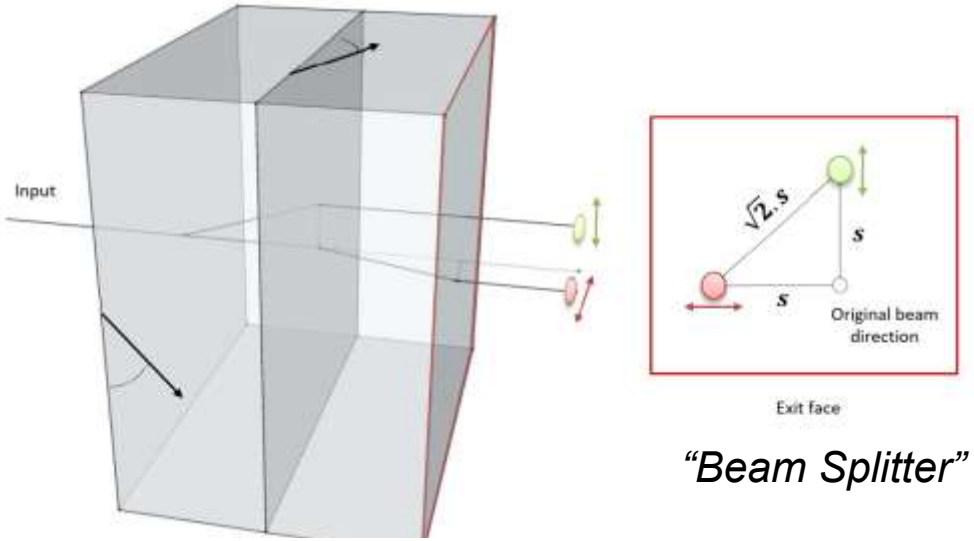
Dual-beam (single Savart plate)

$$S_{+Q} = \begin{bmatrix} I \\ +Q \\ 0 \\ 0 \end{bmatrix} \quad S_{-Q} = \begin{bmatrix} I \\ -Q \\ 0 \\ 0 \end{bmatrix}$$

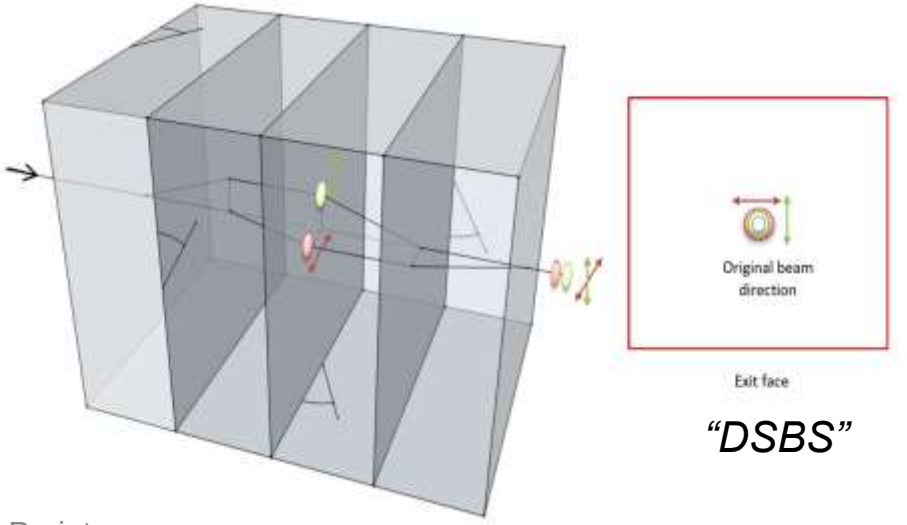
$$S_{+V} = \begin{bmatrix} I \\ +V \\ 0 \\ 0 \end{bmatrix} \quad S_{-V} = \begin{bmatrix} I \\ -V \\ 0 \\ 0 \end{bmatrix}$$

$$S_{+U} = \begin{bmatrix} I \\ +U \\ 0 \\ 0 \end{bmatrix} \quad S_{-U} = \begin{bmatrix} I \\ -U \\ 0 \\ 0 \end{bmatrix}$$

Beam exchange



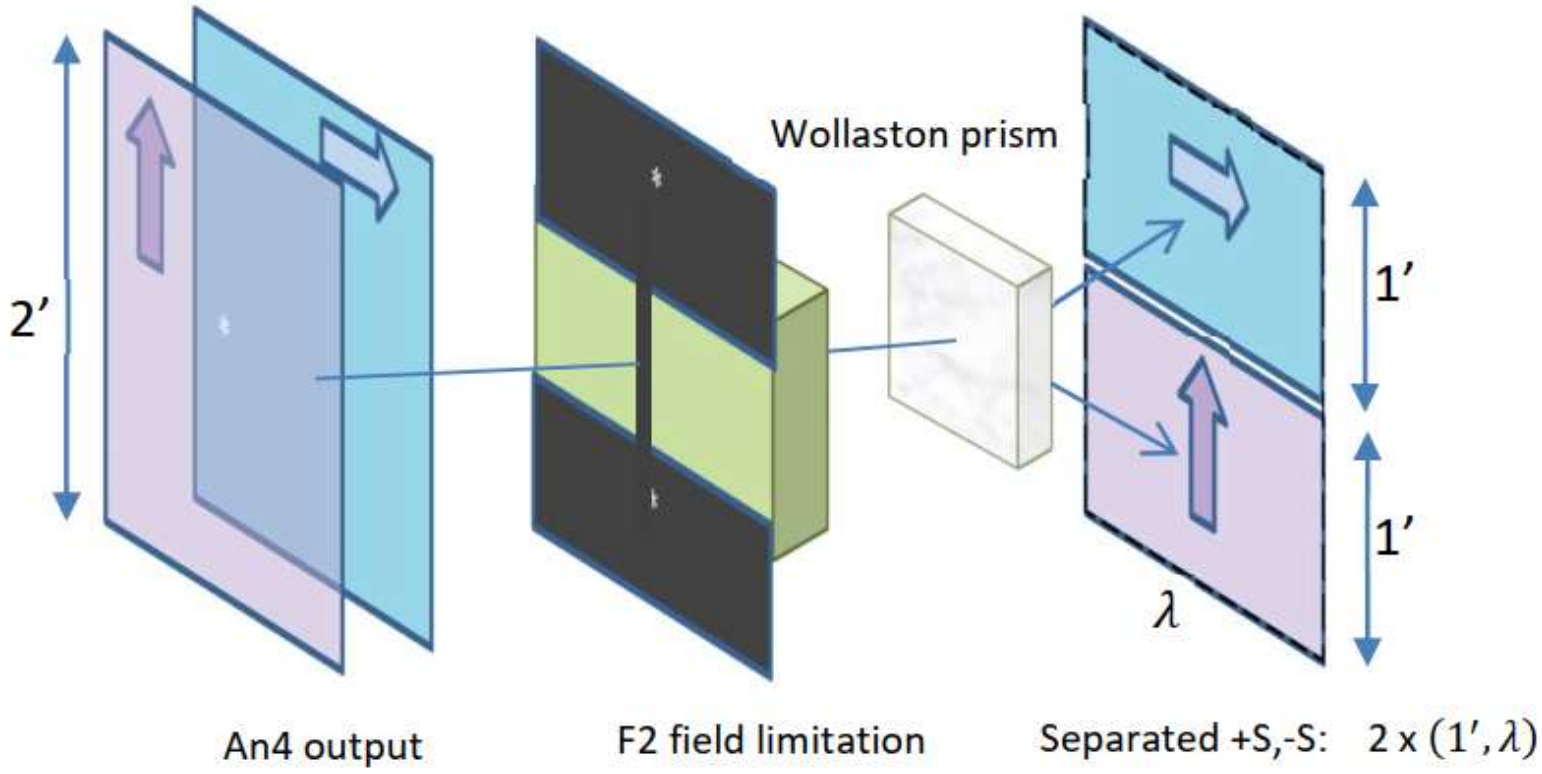
"Beam Splitter"

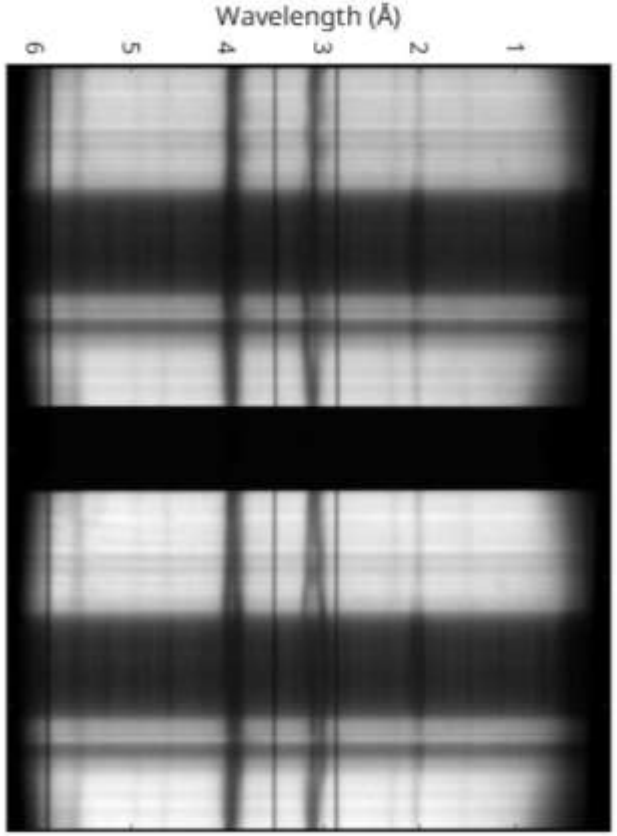


"DSBS"

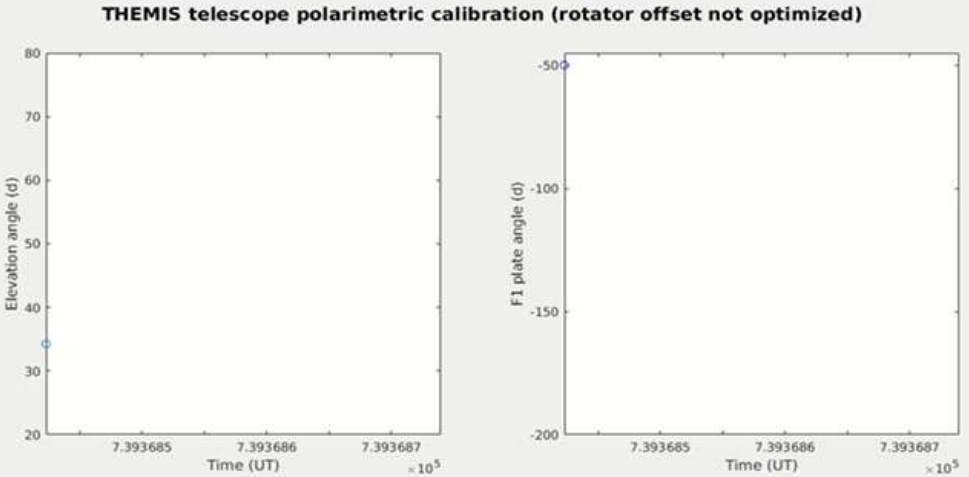
THEMIS new polarimetric analysis scheme - 2

- Thanks to THEMIS “**polarization friendly**” new optical path (**geometry of the elevation axis, field rotator, coatings)**, polarizer output can travel through the telescope and reach the spectrograph cameras “minimally perturbed”
- **Just in front of each of the spectral cameras, a Wollaston prism splitter separates the superimposed beam into complementary Stokes components** to form the spectral focal plane.





THEMIS Mueller matrix@~600nm



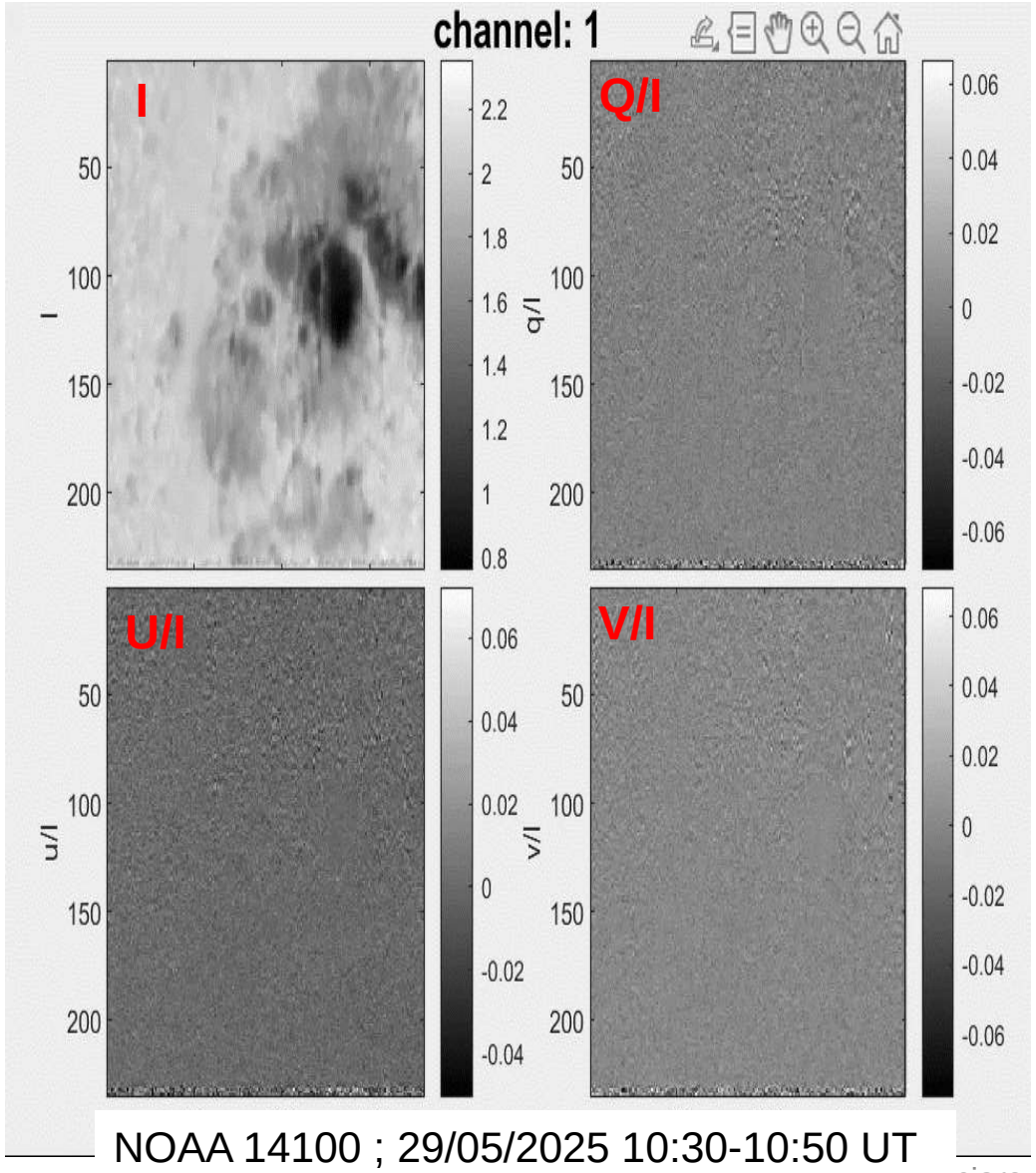
- THEMIS Mueller matrix:

$$M_{THEMIS} = \begin{pmatrix} 1.000 & -0.009 & -0.003 & 0.001 \\ -0.008 & 0.885 & 0.016 & -0.033 \\ 0.014 & -0.436 & 0.872 & 0.033 \\ -0.019 & 0.415 & 0.008 & 0.873 \end{pmatrix}$$

  - Averaged over one full day
  - Includes changing elevation axis and field derotation
  - Quite constant along one day

- **THEMIS remains a strongly polarization-calibration-free telescope, ideal for excellent spectropolarimetric measurements.**

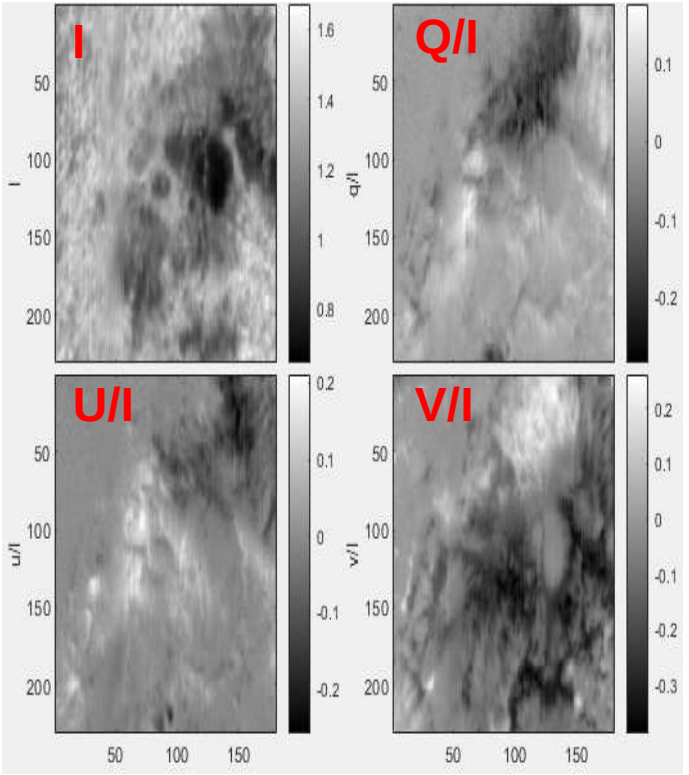
Stokes parameters



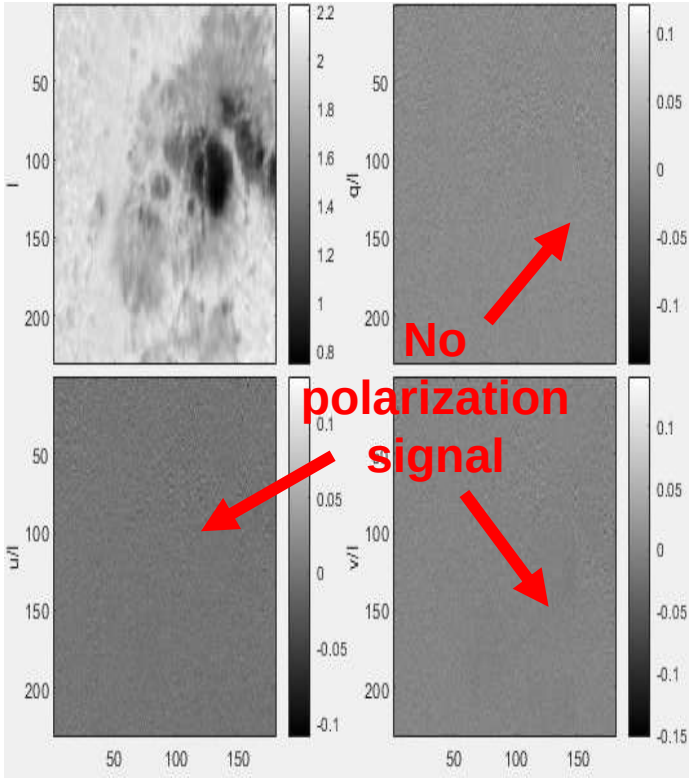
NOAA 14100 ; 29/05/2025 10:30-10:50 UT

- **Complete polarization signal is now routinely outputted**
  - 4D data array of 4 Stokes parameter (x, y, λ, S).
  - User-friendly software in development.
- THEMIS is on the verge of producing vector B maps

In Fe I Line



In continuum



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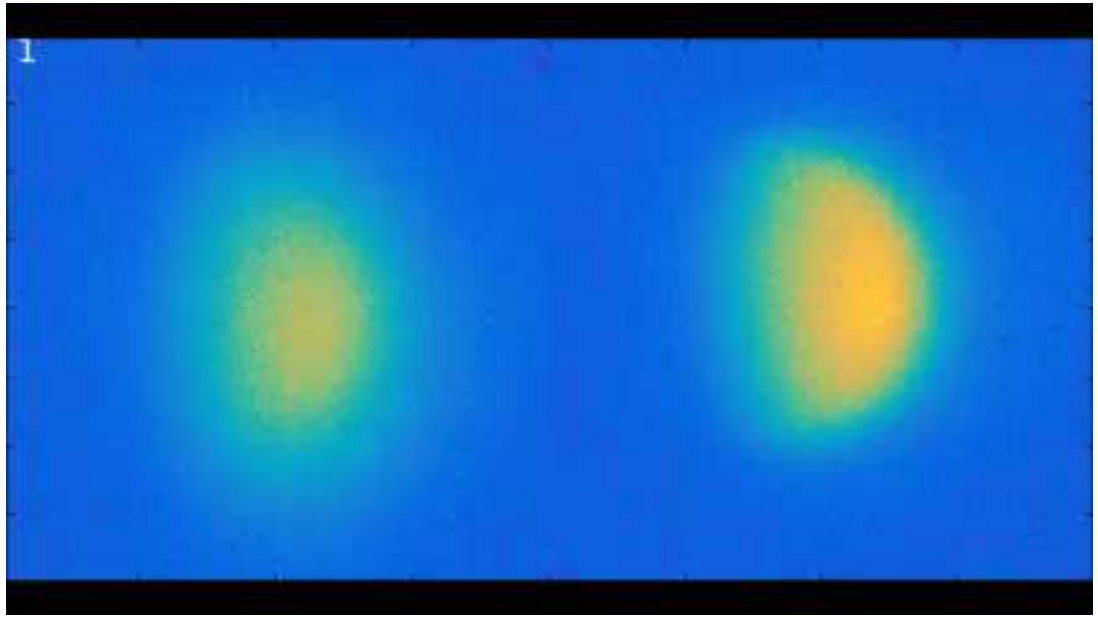
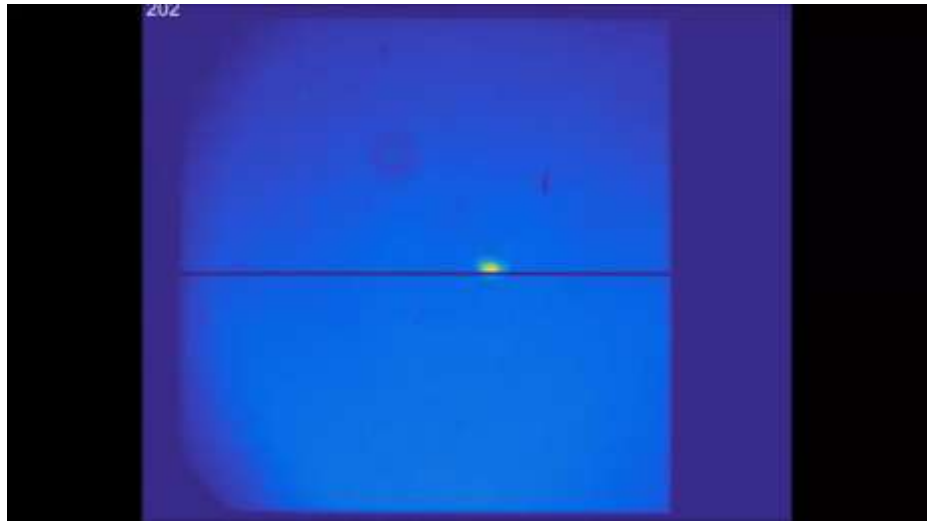
Mercury Observations

- **THEMIS is one of the best-suited telescope for ground based observation of Mercury.**
  - Work in daytime → extended period of observation of Mercury
  - Handle the low contrast of hermian emission relatively to the diffuse sky emission.
  - THEMIS FOV & resolution suited for Mercury
    - Mercury disk: ~6" wide.

- TAO successfully running for Mercury observations since 2021
  - Hardware and software identical to solar obs.
  - Requires slowing down AO from 1kHz to 150Hz

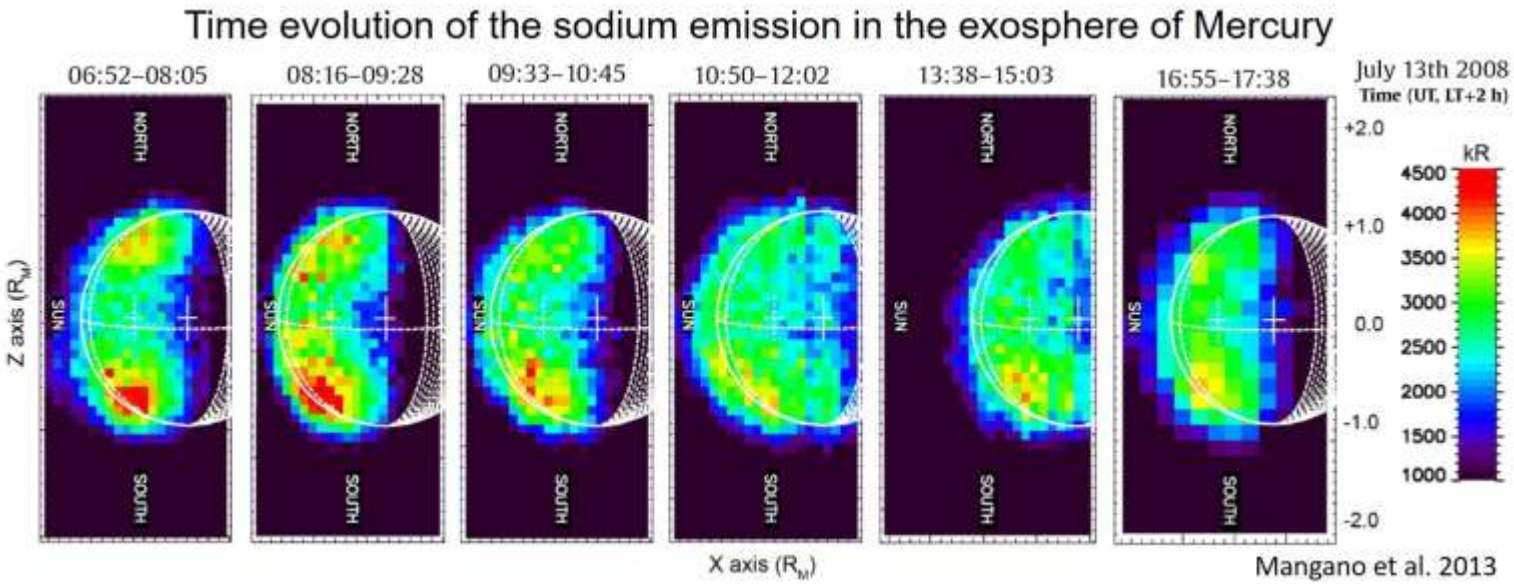
- Recurrent observations campaigns led by F. Leblanc (LATMOS) & V. Mangano (INAF, Rome, IT)





Mercury Observations

- Sub-arcsecond mapping of Mercury Na exospheric emission
  - Must separate reflected solar Na emission from hermian self-emission
  - → Benefit from doppler shift due to Mercury orbital motion.
- **Study hourly dynamics of Na emission distribution due to space weather impact**
  - Peaks of Na emission roughly co-spatial with magnetic footprints.
  - Space weather induced dynamics : varying SW particles penetrating Mercury exosphere and flowing to the surface induces Na emission



Sodium emission of Mercury
observed by THEMIS on May 5th, 2025

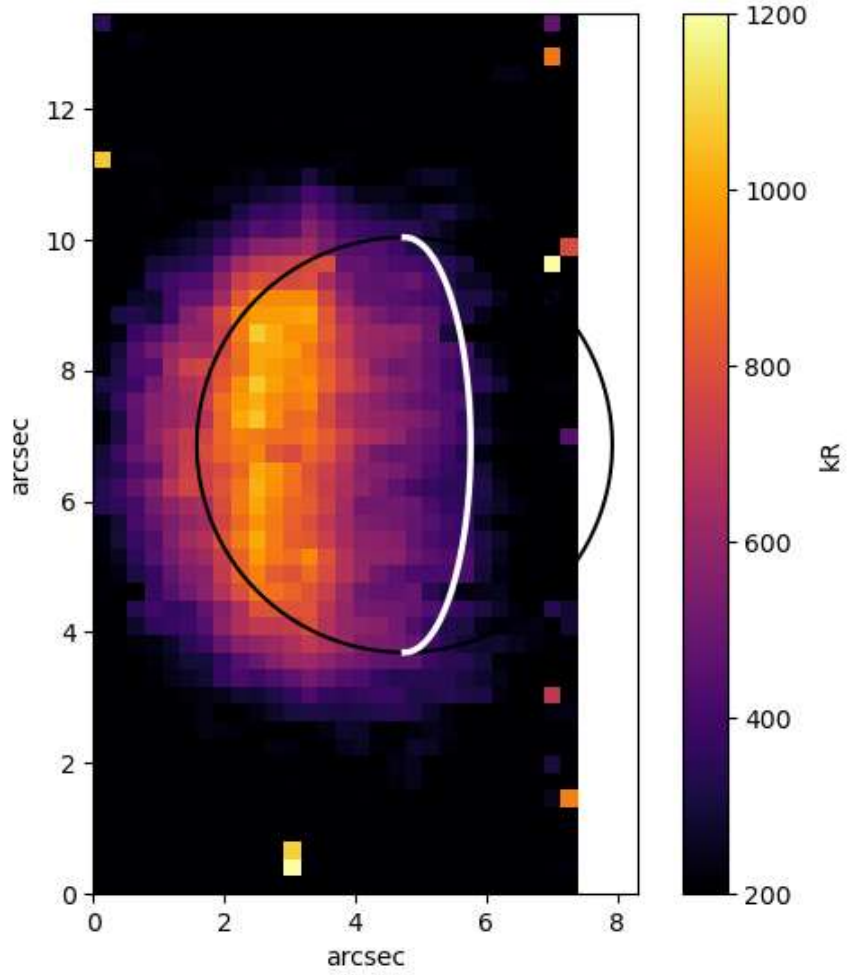
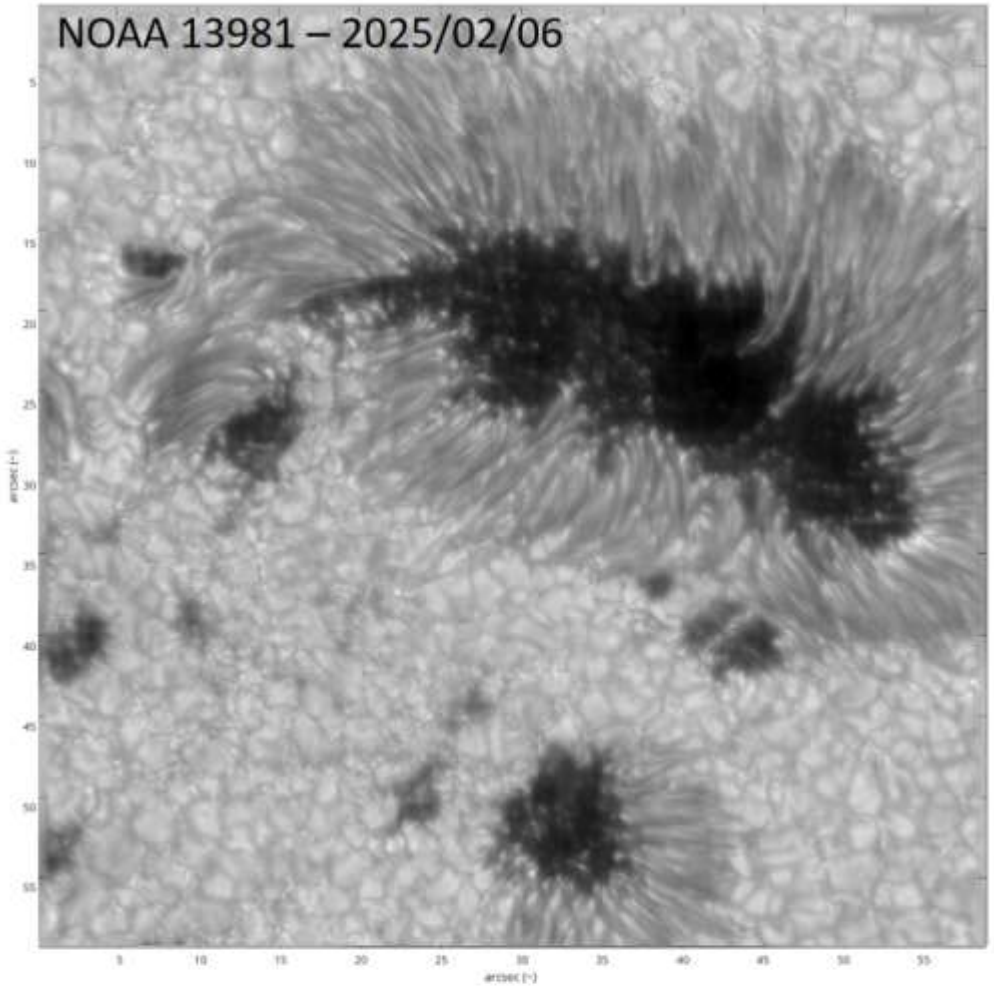


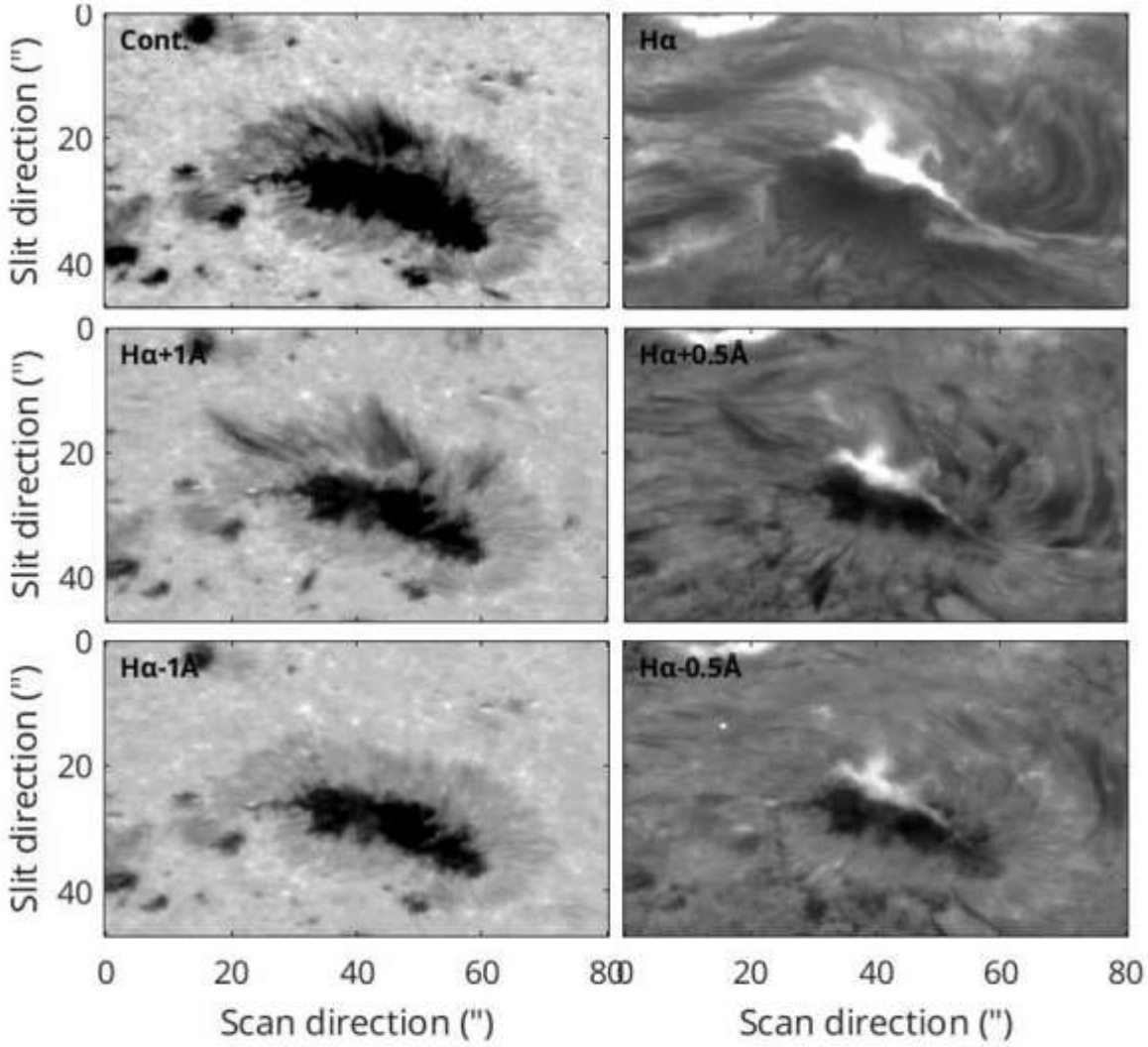
Image Courtesy: Mangano, Leblanc

Solar Flare observations : flare ribbons

Off-campaign observations of Jade Touresse & Etienne Pariat during an M-class flare



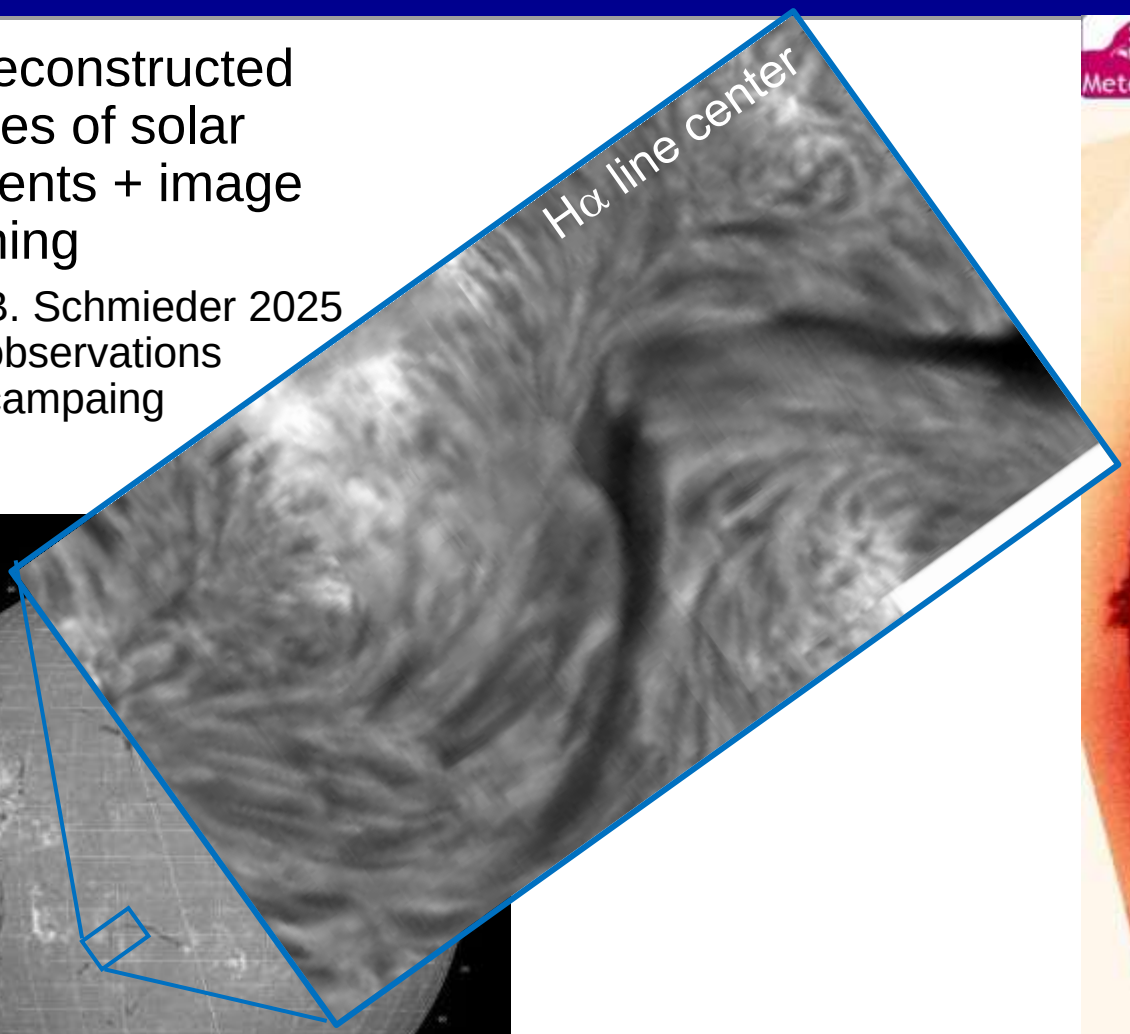
Broadband Image (red continuum)
+ image reconstruction

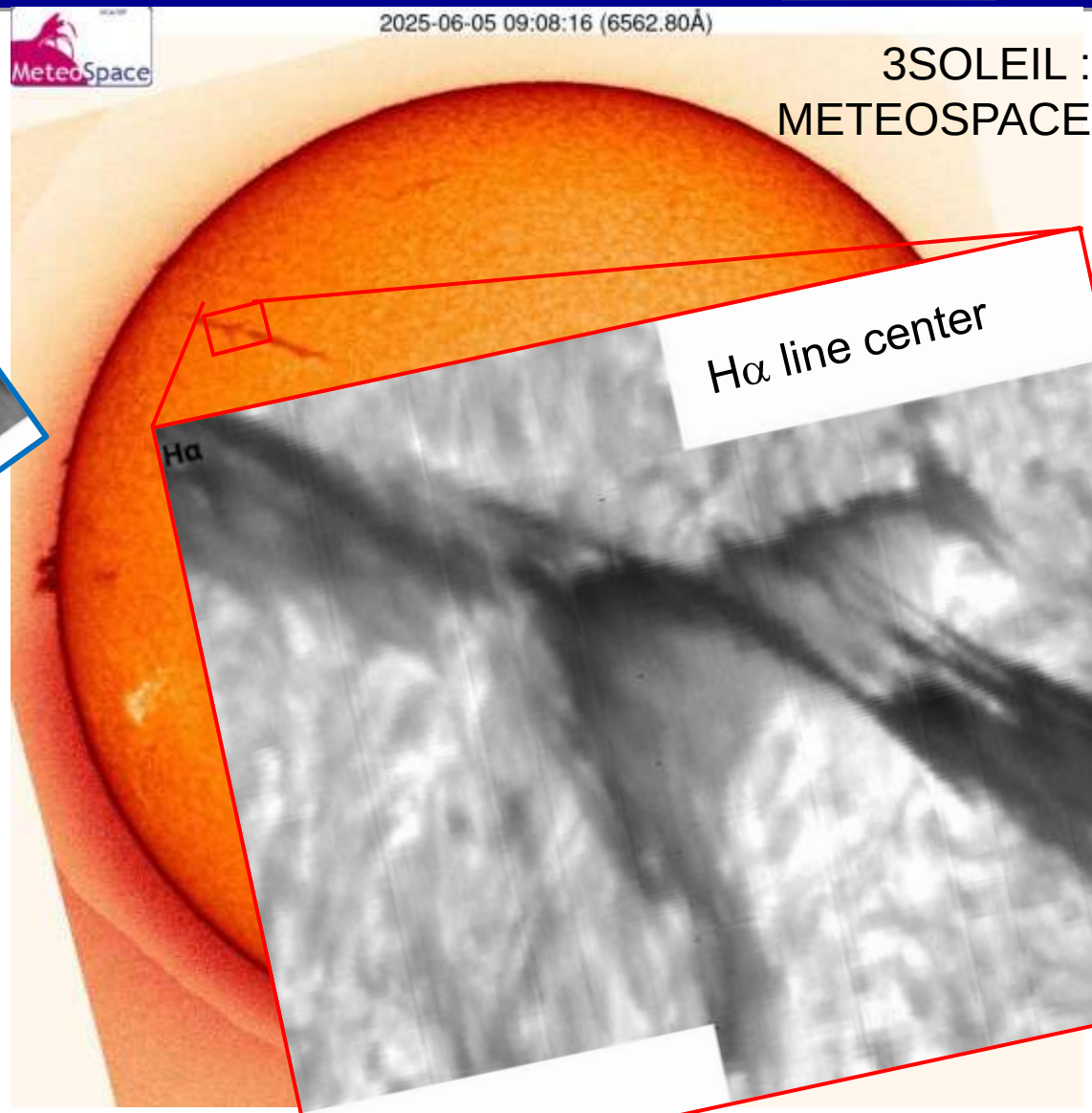


MTR2 spectrograph
reconstructed intensity maps

Solar filaments observations

- Hα reconstructed images of solar filaments + image stitching
  - B. Schmieder 2025 observations campaing

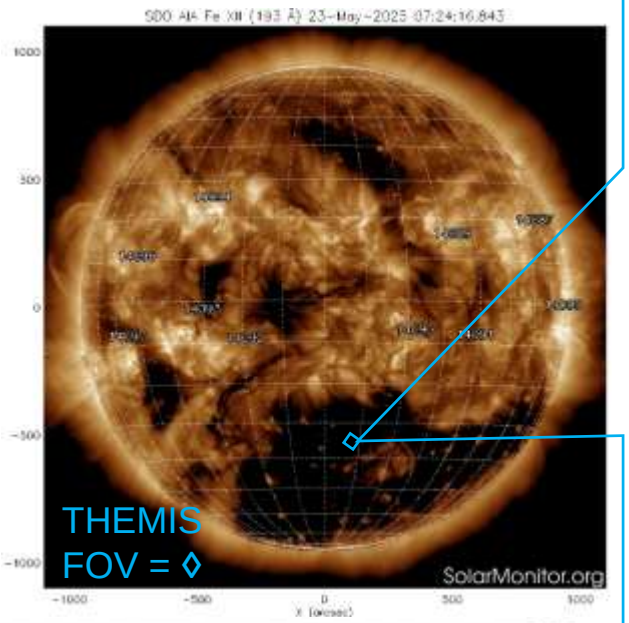


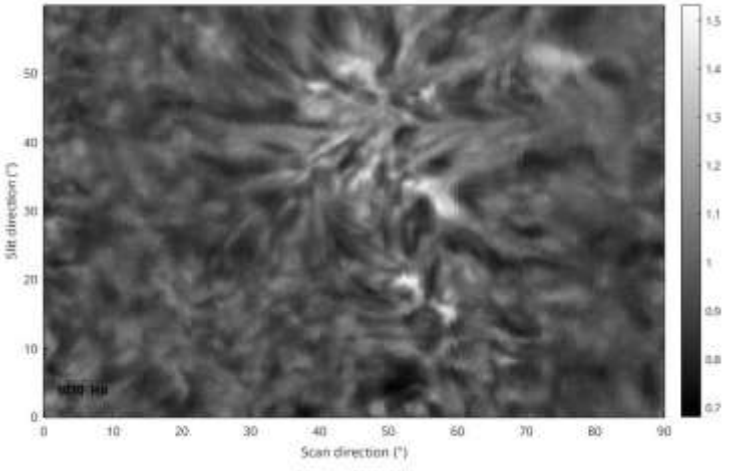


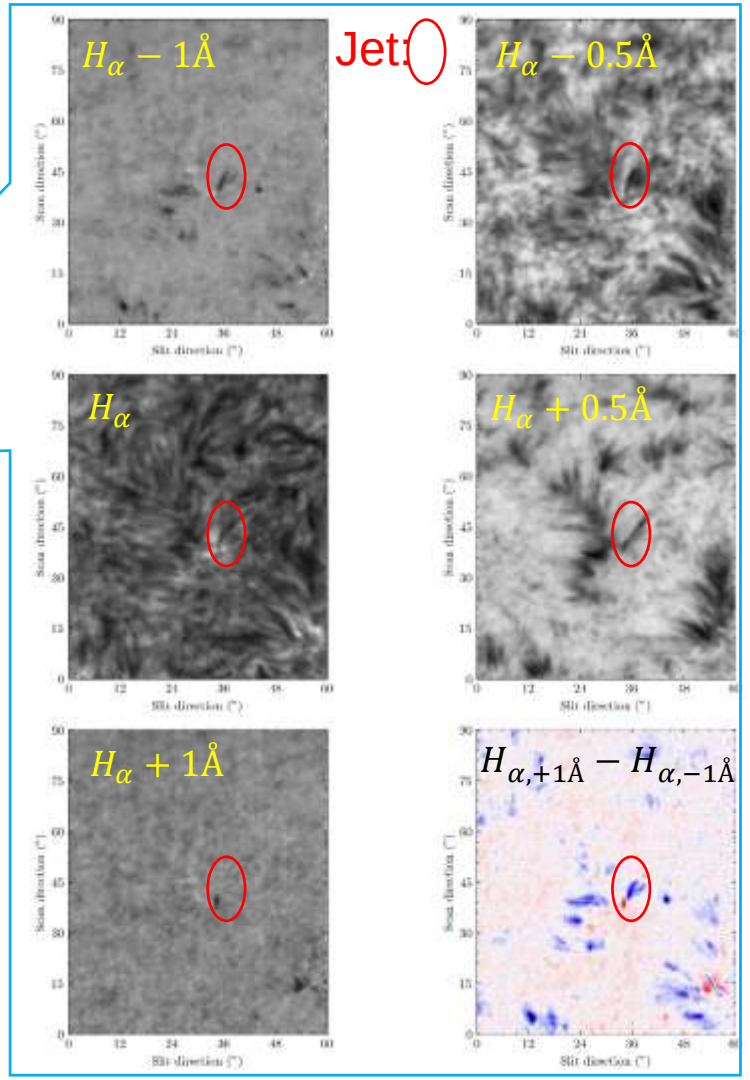
3SOLEIL :
METEOSPACE

Coronal holes and jet observations

- Two campaigns of observations, respectively led by Jade Touresse & Etienne Pariat on analysis of coronal holes regions
  - ~ 3 weeks in May-June 2025
  - Spectroscopic observations in Chromospheric lines: Hα, Ca II (8542 Å)
  - Spectropolarimetric observations of Fe I (6301 Å) → magnetic field maps
- Goals:
  - Understand formation of “anemone” structure, jets source region in CH
  - Estimate rotational speeds and mag topology of coronal jets
- Preliminary analysis: quicklooks of Hα emission : center, wings, doppler-like







10:53’39” ⇒ 10:55’11”

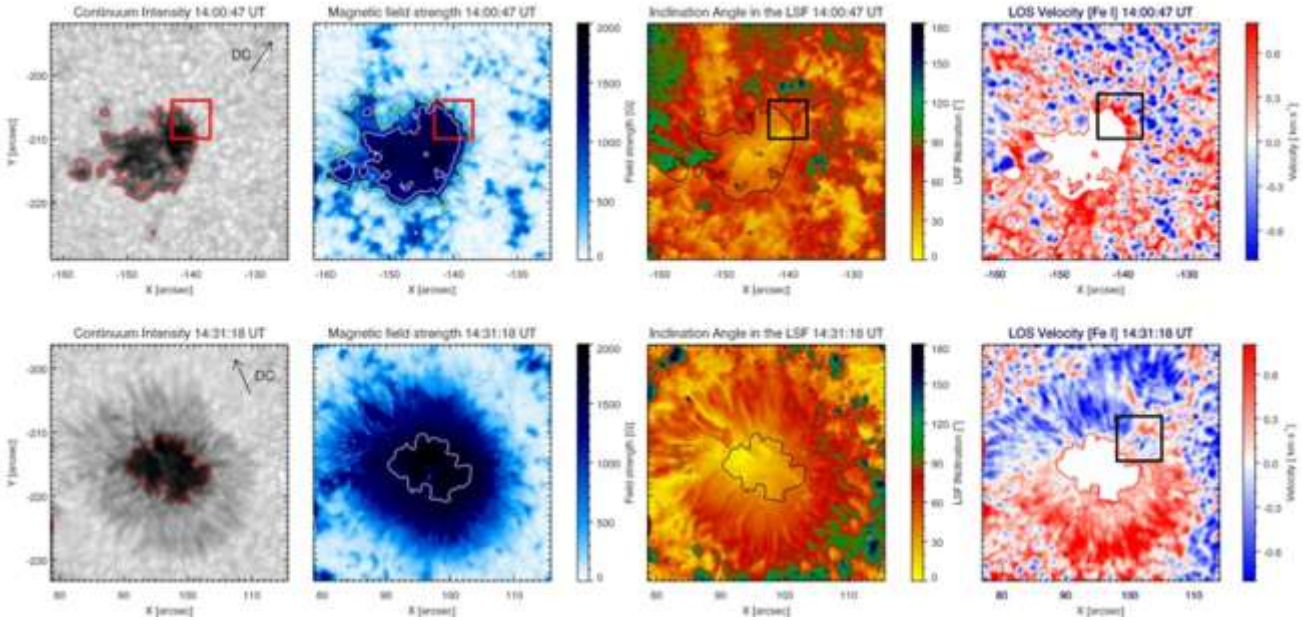
Upcoming : IBIS 2.0 to THEMIS

IBIS : Interferometric BIdimensional Spectrometer

- INAF solar spectro-imager (x, y, λ), dual Fabry-Perot / 200 000 spectral res. / short exposure times / polarimetric mode
- Running at the Dunn solar tower (DST) from 2003 to 2019: ~100 papers based on IBIS over 15 years

IBIS2.0 @THEMIS

- Upgraded IBIS waiting for suitable telescope since 2019
- TAO performance attractive for IBIS
- THEMIS has no equivalent instrumental mode. **Memorandum of understanding (MOU) signed !**
- **Winter 2025-2026 : IBIS 2.0 installation and commissioning.**

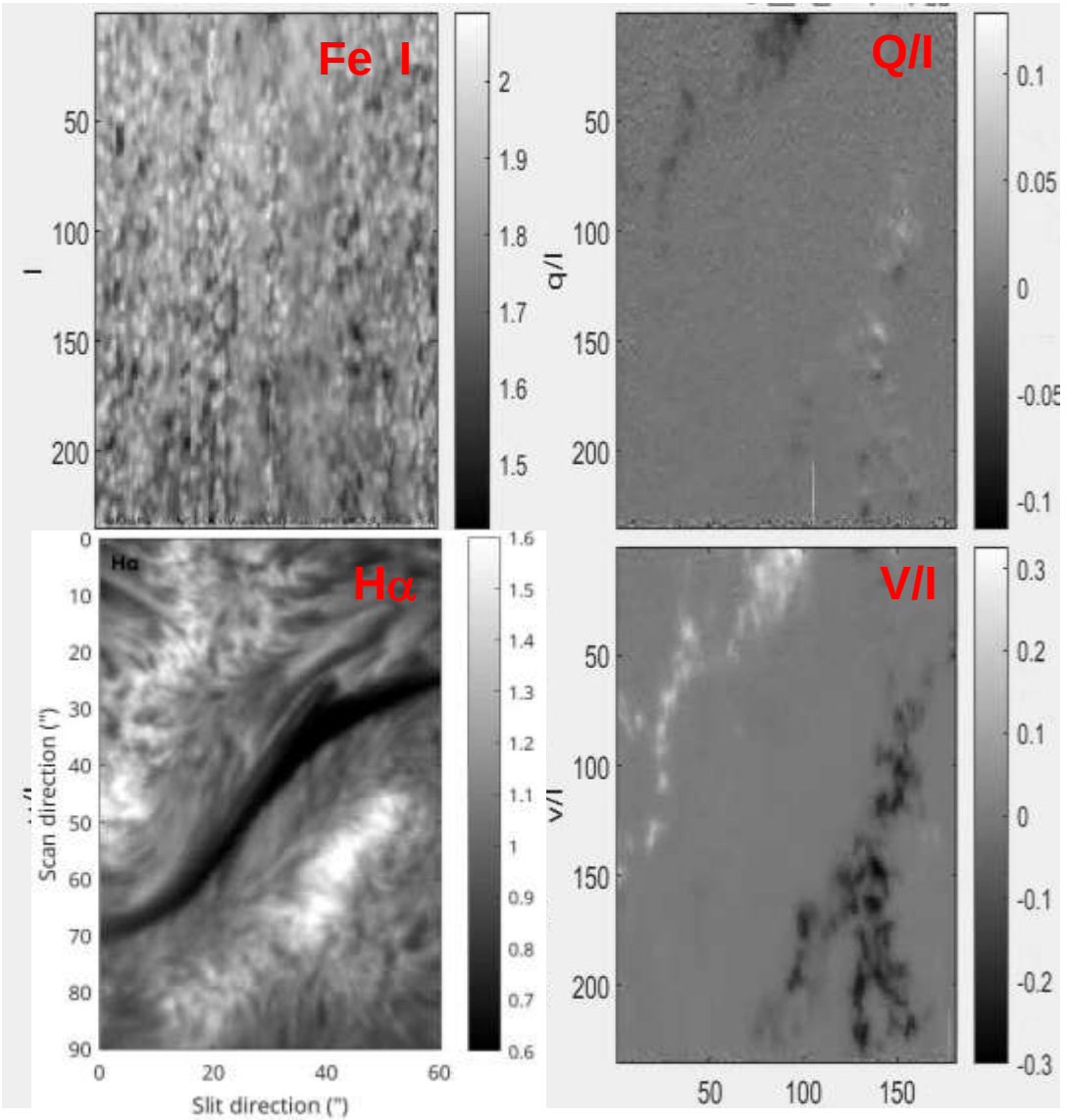


Intensity, magnetic field strength, field inclination angle, and LOS velocities on 2012 May 28 (14:00-14:30 UT): before (top) and after (bottom) penumbra formation. SIR inversion of the Stokes profiles of the Fe I 630.25 nm line acquired by IBIS. **(from Murabito et al. 2016)**

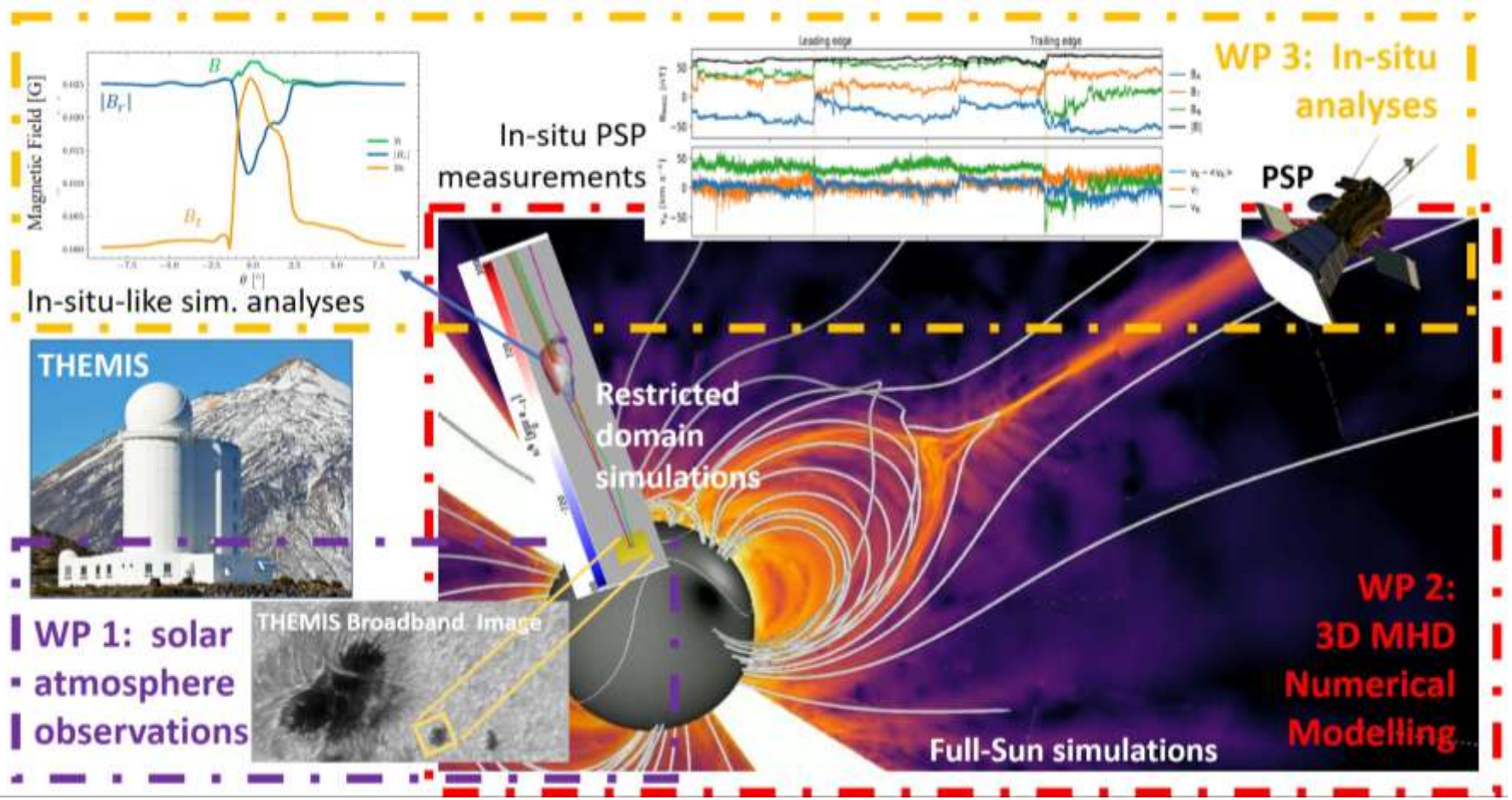
- **Outstanding synergic complement of THEMIS long slit spectrograph**
- **High scientific return for a limited technical investment**
- **Foster and renew French-Italian scientific collaboration** in high-res. solar phys.
- THEMIS offers IBIS2.0 a chance at planetary observations with AO.

In consideration: THEMIS for space weather

- Research for space weather is a strength of the French heliophysics community
- THEMIS shall eventually be out passed by 4m-class telescope (DKIST, EST)
- THEMIS is the main French-owned asset that can provide **B** field maps
  - Presently, high-dependence on NASA SDO/HMI for vector magnetic field measurements of EU community
- THEMIS is presently an INSU observation station (ANO-3)
  - Mutualization of several solar-related SNOs in consideration at ATST & INSU toward space weathers
- **Reflection toward part usage of THEMIS in service mode with the production of datasets of interest for SW: magnetic map of eruptive regions (active regions, filaments, …)**

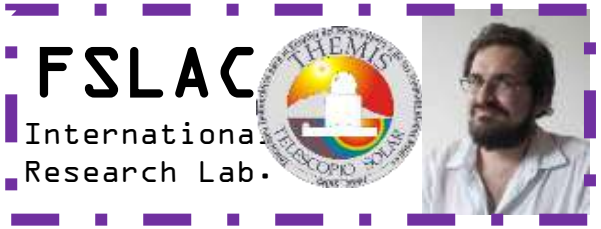


JET2SB Project



Clara Froment
Thierry Dudok de Wit
+ 1 post-doc

Sophie Masson
G. Aulanier; J. Touresse
+ 2 PhDs: Léa D'Herbommez
Jorge Romero Castañeda



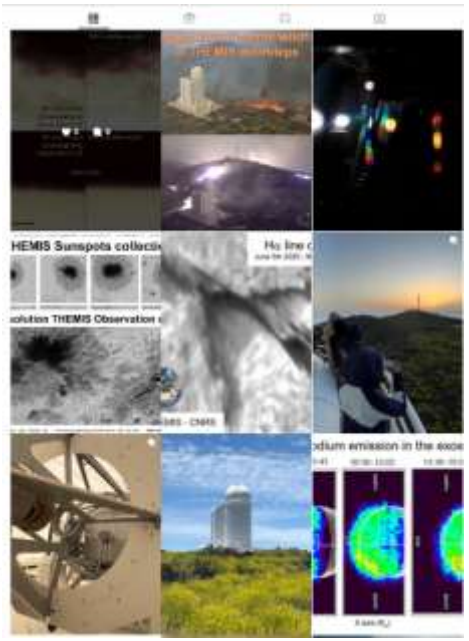
Etienne Pariat
Bernard Gelly
+ 1 Post-doc

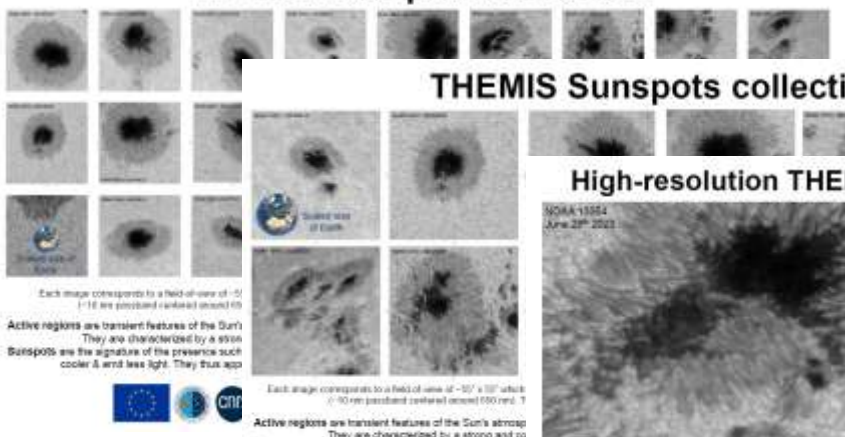
- ***Do/to which extend, solar jet-like events induce Switchbacks?***
- ***How do they contributes to the acceleration of the solar wind?***

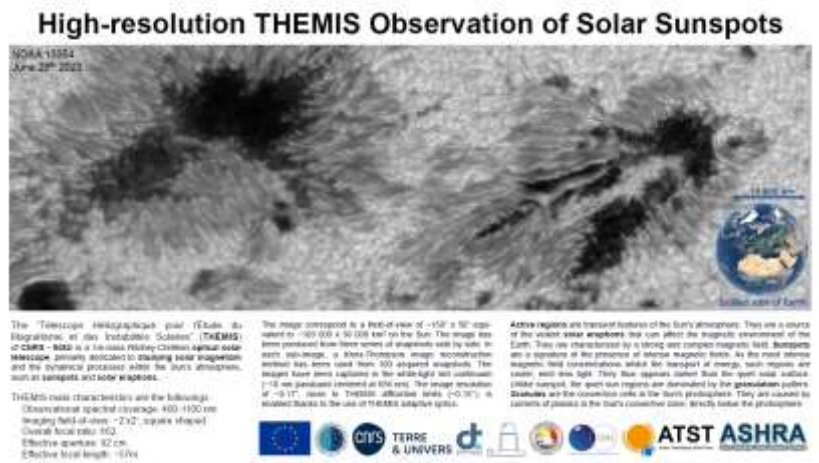
Outreach

- New THEMIS website:
  - Feedbacks welcomed
- New Instagram account
  - Follow us @themis_solar
- Downloadable posters on THEMIS highlights

https://www.themis.iac.es/

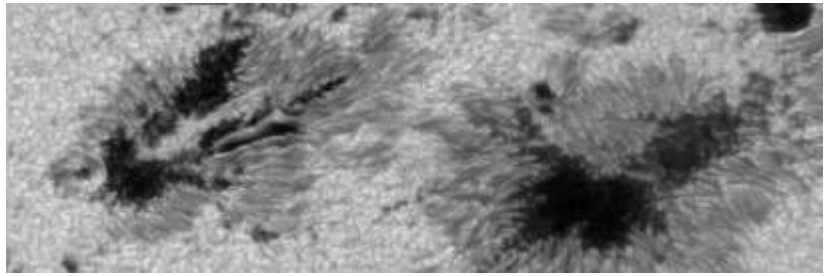


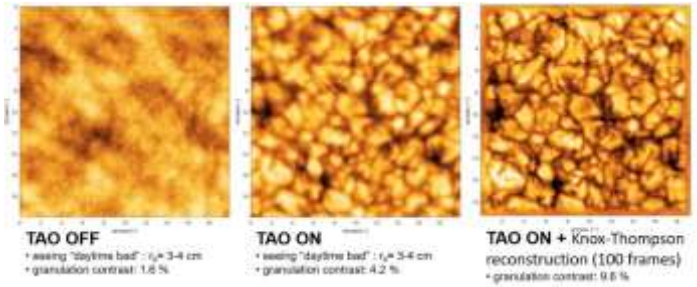


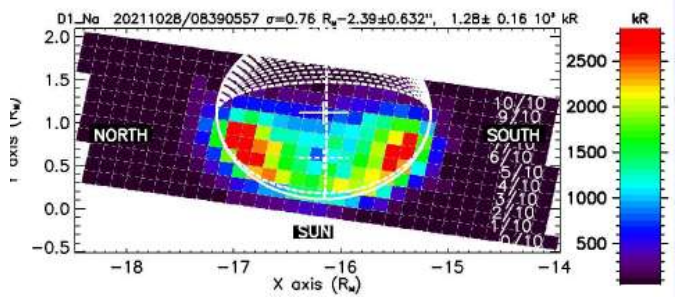


Takeaways …

- THEMIS is a competitive 21st century telescope with unprecedented capacities
  - THEMIS is a real challenger in the 1m-1.5m class of solar telescopes.







- Installation of the IBIS 2.0 spectro-imager (spring 2026) will trigger an even larger European wide interest.

- **Reminder: 50-75% of THEMIS obs. time dedicated to French-lab.-based PIs**
  - THEMIS is highly open to all scientists based in a French laboratory
  - Observation at THEMIS is not reserved to an elite of high-resolution spectro-polarimetry expert !
  - The THEMIS team is dedicated to assist anyone in performing observations with THEMIS
  - **Young-researchers at French laboratories are highly welcomed to discover/run/follow ground-based solar observations campaigns**

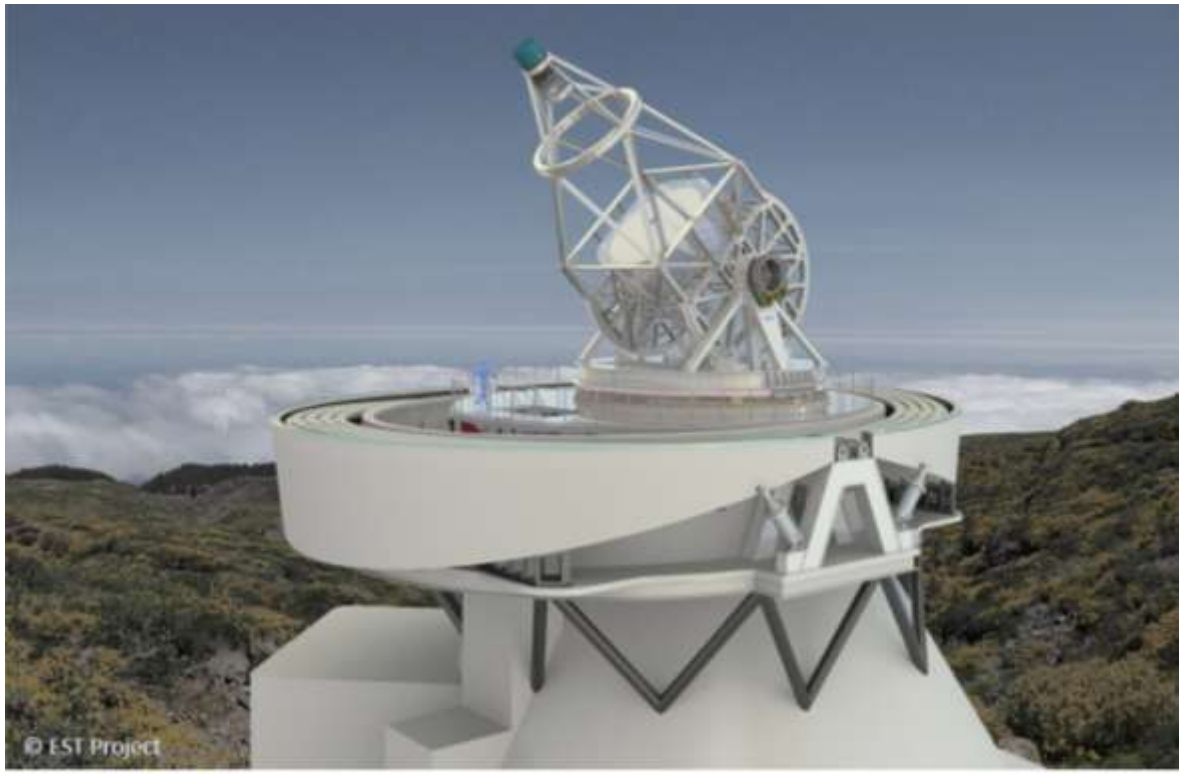
… critical threats exits …

… and nevertheless !

THEMIS **IS NOT** the future of ground-based solar physics because

the European Solar Telescope

IS THIS FUTURE !

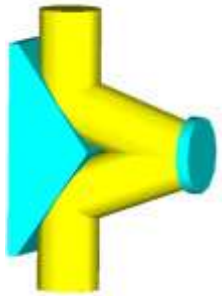


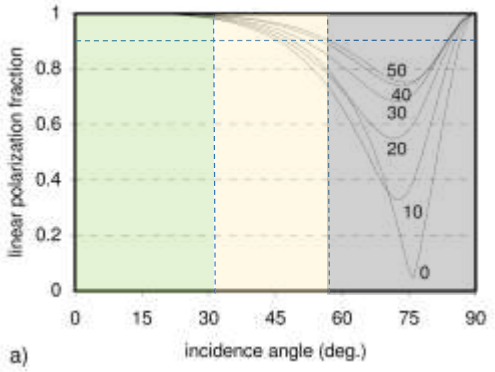
White paper on interest, contribution & participation of the French community to the EST project is being written:

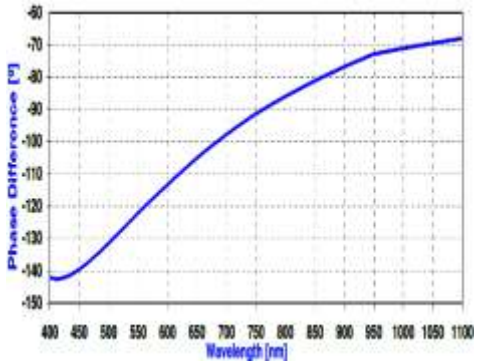
JOIN NOW !

Example of a "polarization friendly" field rotator

- **BAD (really bad …)**
- Made of 3 mirrors with incidence = **55º** / 20° / **55°**
- chromatic retardance is enormous (60°)

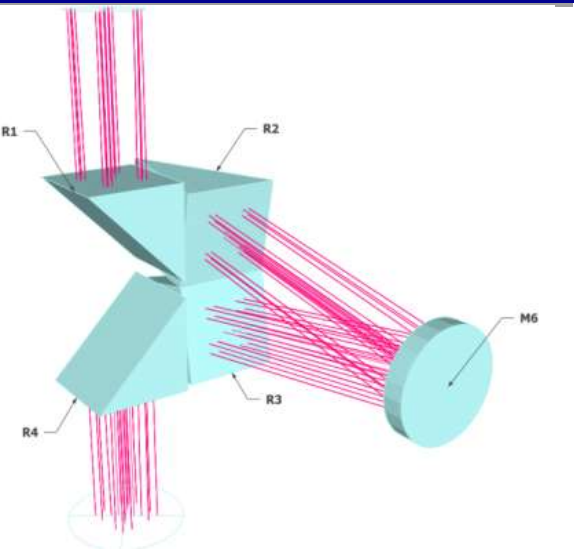


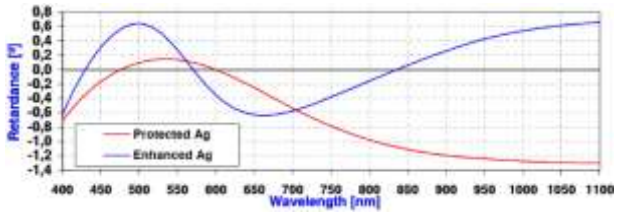




$$M_{Rot}(Ag) = \begin{bmatrix} 0.943 & 0.057 & 0 & 0 \\ 0.057 & 0.943 & 0 & 0 \\ 0 & 0 & 0.007 & -0.941 \\ 0 & 0 & 0.941 & 0.007 \end{bmatrix}$$

- **MUCH BETTER !!**
- Rotator, composed of 2 prisms and one mirror incidence=45º /45°/ 10° / 45° /45°
- **Retardance cancellation** of the crossed prisms@100° (zero retardance for 90° only)
- **Coating required** on prisms hypothenuse





$$M_{ROT} = \begin{bmatrix} 0.9991 & 0.0009 & 0 & 0 \\ 0.0009 & 0.9859 & -0.0205 & 0.1605 \\ 0 & 0.0179 & 0.9989 & 0.0189 \\ 0 & -0.1607 & -0.0157 & 0.9859 \end{bmatrix}$$