FSLAC International Research Lab.

A new era for the THEMIS Solar Telescope

LPP Laboratoire de Physique des Plasmas

Jan 15th 2026, Freiburg, Germany

Étienne Pariat[1, 2], Bernard Gelly[1] & THEMIS team

[1] French-Spanish Laboratory for Astrophysics in Canarias (FSLAC) / IAC & CNRS IRL2009, Tenerife, ES

[2] LPP, Sorbonne Université, Ecole polytechnique, Institut Polytechnique de Paris, UPS, Observatoire de Paris-PSL, CNRS, Paris, FR

Methods and techniques for high-resolution spectro-polarimetry with current and future high-resolution telescopes: lessons learned and ways forward

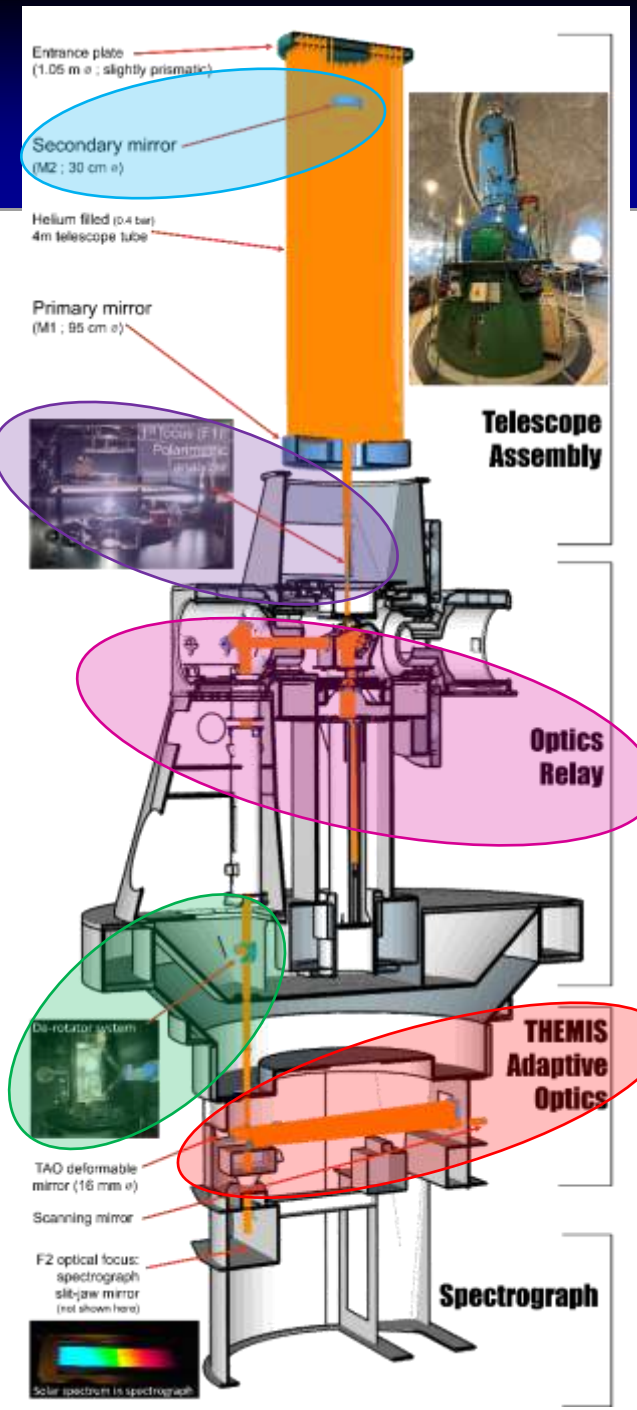
THEMIS Factsheet

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

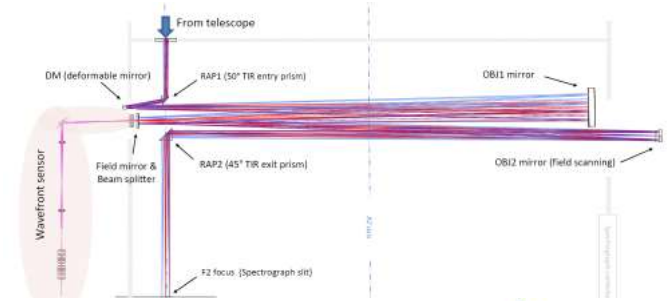
THEMIS @ OT in June 2025

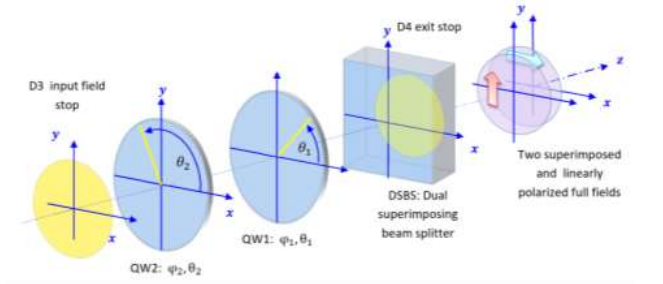
- **Main french solar telescope**
  - Designed by J. Rayrole, P. Mein & M. Semel
  - Located at Teide Observatory, Tenerife, Spain
  - 1st light in March 1996, & commissioned in 1999
- 1m-class solar telescope, with one the world "slowest" optical design:
  - Aperture: 92 cm ; Effective focal length: 57m
  - Effective focal ratio: f/62
  - 60"x60" to 120"'x120" square field-of-view
- **MulTi Ray spectrograph (MTR2): ideal for high-spectral resolution spectropolarimetry:**
  - Working spectral range: 4000 - 11000 Å
  - **Polarization calibration free**
  - **Ultra-high spectral resolving power**:
    - R ~ 200 000 - 300 000
  - **Simultaneous observations of user-defined set of up to 6 spectral ranges**:
    - ~6-7 Å spec. range width with ~25 mÅ res.

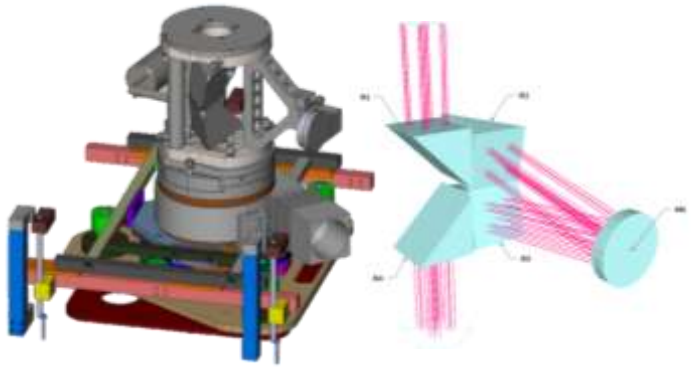
“Total makeover” : 2016 → 2020



- **THEMIS has been widely renewed and redesigned**
  - Thanks to EU funding: ~1M€ from 2 IAC-led SOLARNET programs
- **M2 mirror re-aluminising** (WHT & THEMIS)
- **Themis Adaptive Optics:** “classical” single-DM adaptive optics based on innovative wavefront sensing and mirror commanding concepts (AIRI@CRAL & THEMIS)
- **Superimposed dual-beam polarimetric analysis** without field limitation (Semel M., Lopez A., Le Men C. & THEMIS)
- **“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.

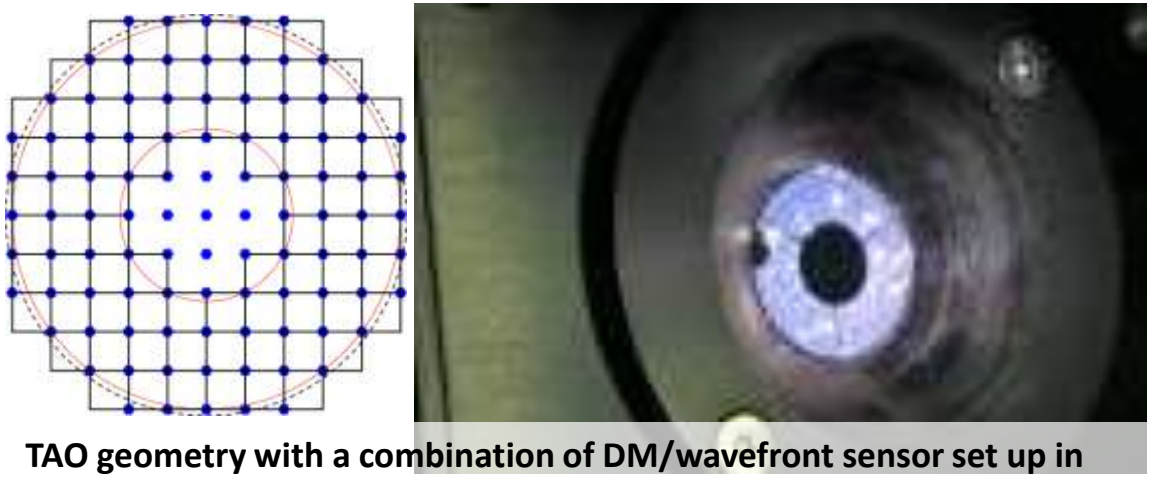






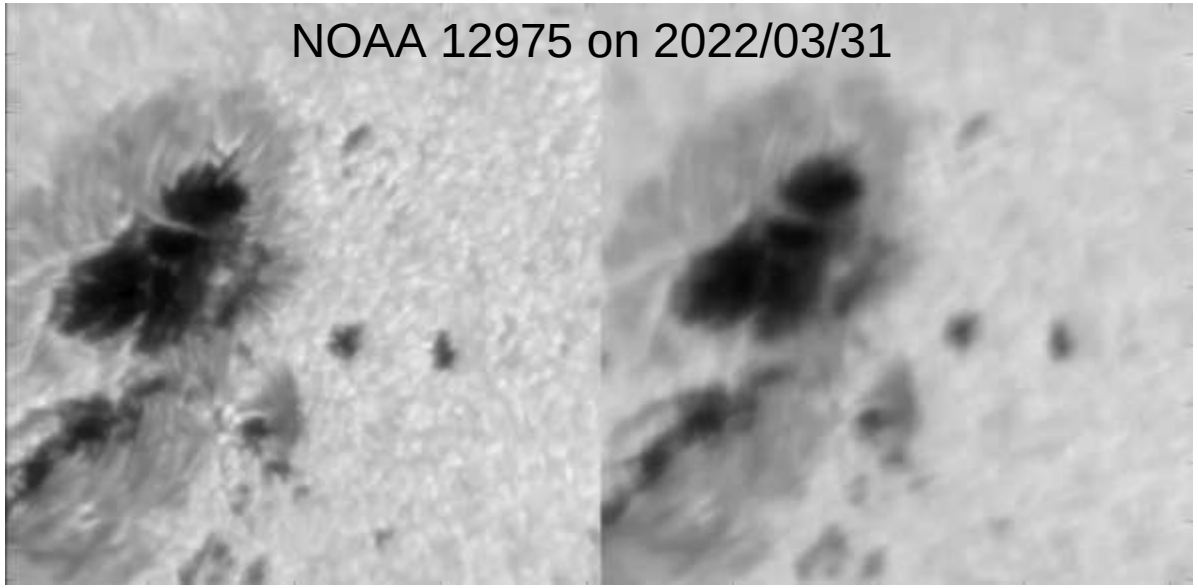
THEMIS Adaptive Optics (TAO)

- Specifications
  - **76 sub-aperture Shack-Hartmann WFS**
    - 380×380 pixel WFS images, Mikrotron EoSens 4CXP detector
  - **THEMIS-optical-path-compatible 16mm DM**
  - **97 actuators** on ALPAO deformable mirror
  - 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.

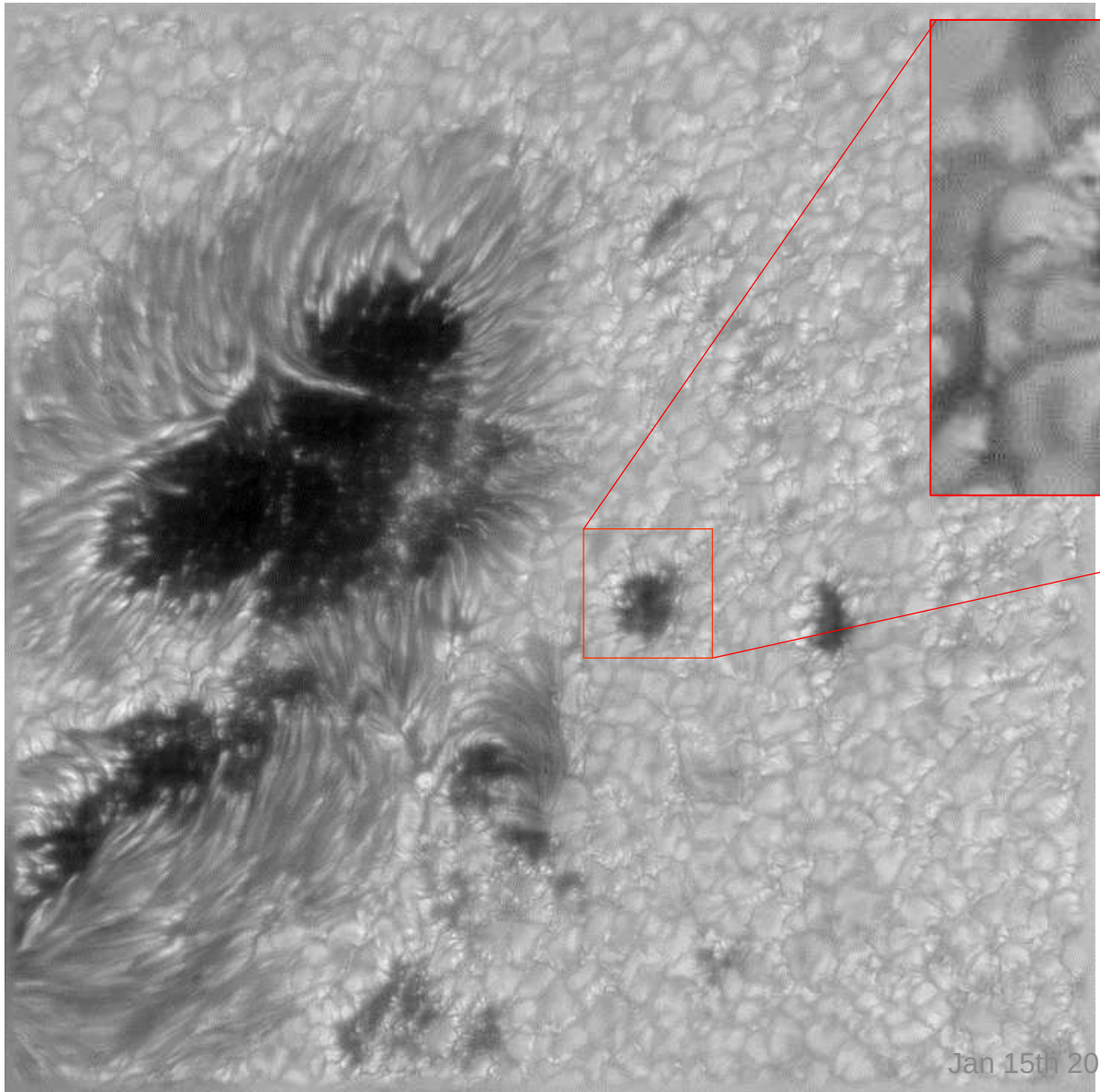


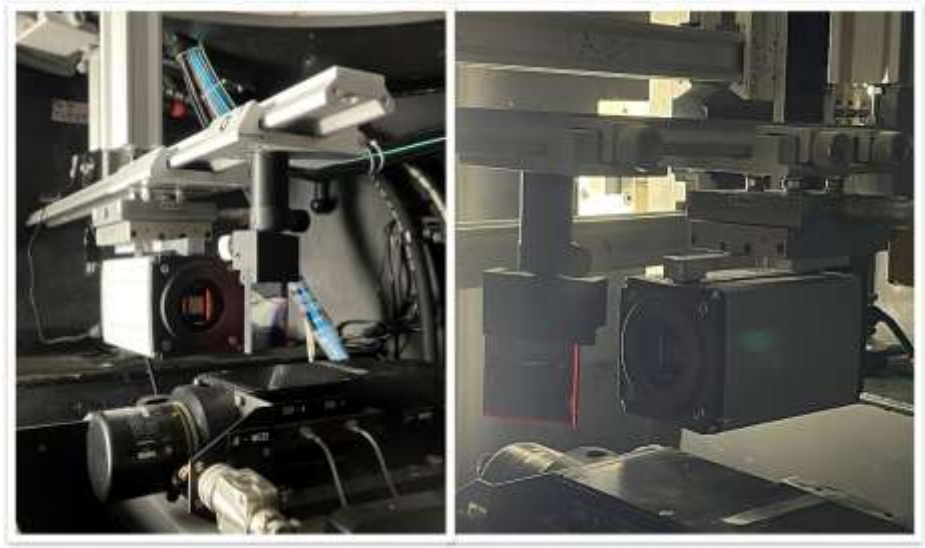
TAO geometry with a combination of DM/wavefront sensor set up in 'Fried configuration' with a spacing number of 10

- Objectives:
  - **✓ Closed AO loop on the Sun**
    - started from scratch mid-2016 → Dec. 2020
  - **✓ RTC software running in CPU @1250 Hz**
  - **Ongoing (→ winter 2025-2026): unsupervised AO system**
    - optimal correction whatever the conditions
    - provide inferred seeing conditions



THEMIS at diffraction limit: NOAA 12975

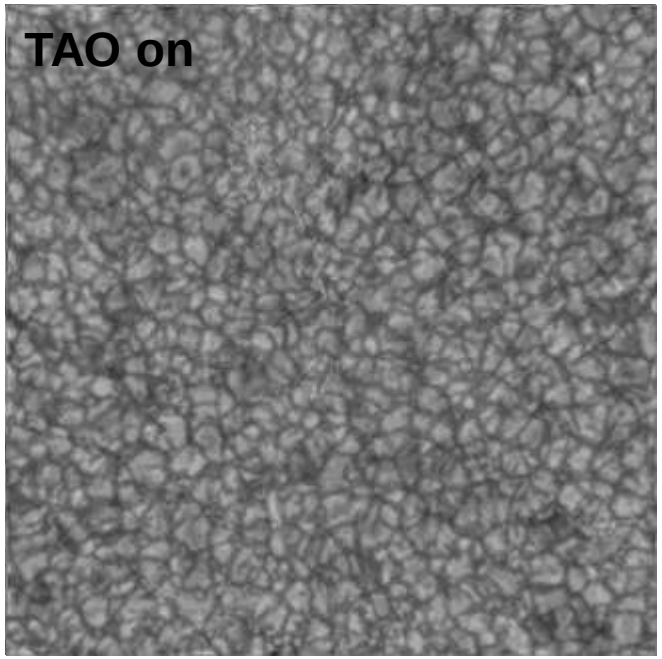


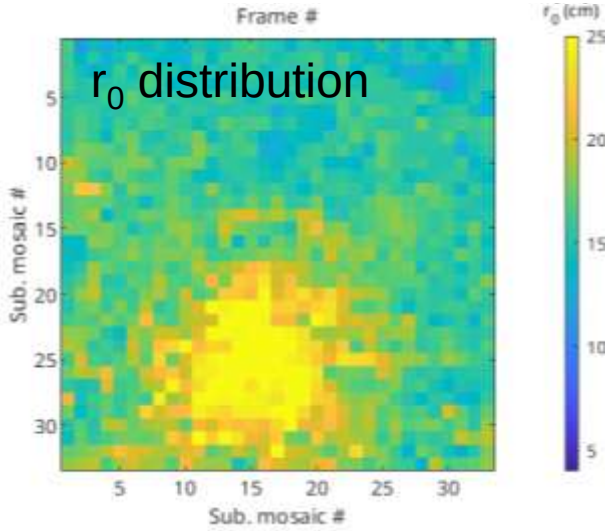


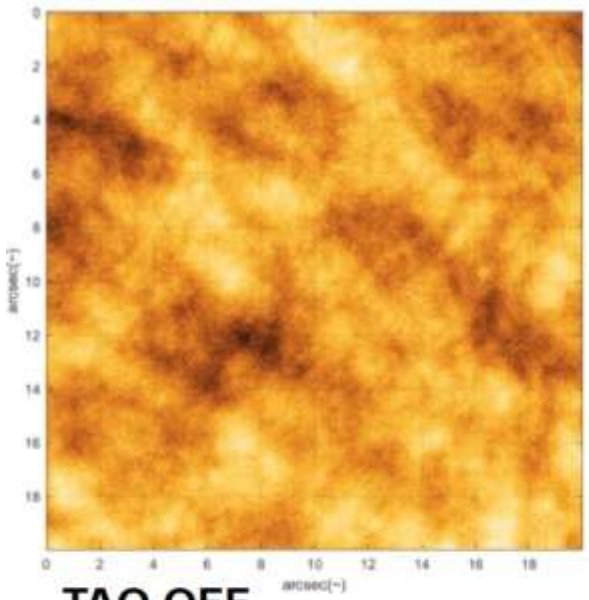
THEMIS Broadband Imaging (BBI)

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

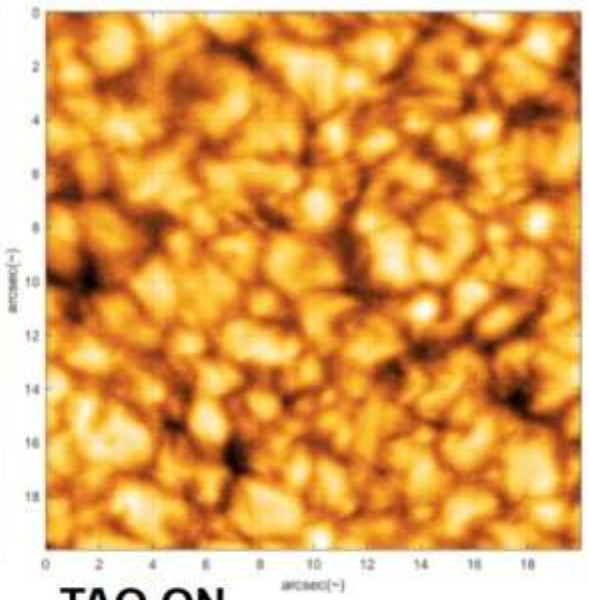
THEMIS Adaptive Optics (TAO): results on granulation



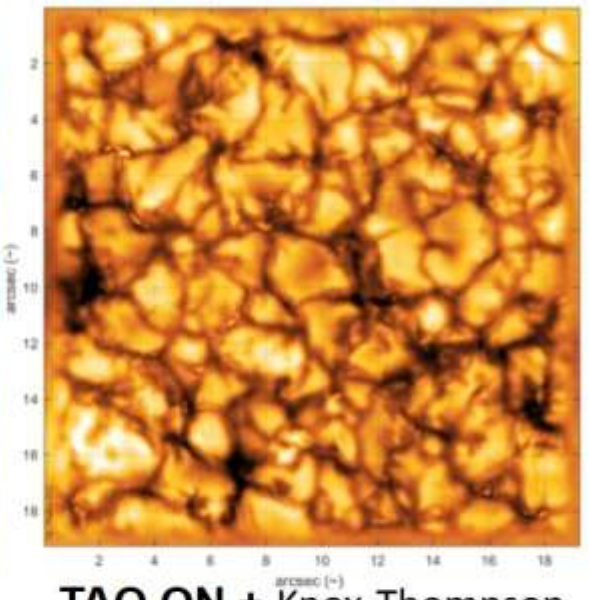




TAO OFF
- seeing "daytime bad" : r_0≈ 3-4 cm
- granulation contrast: 1.6 %



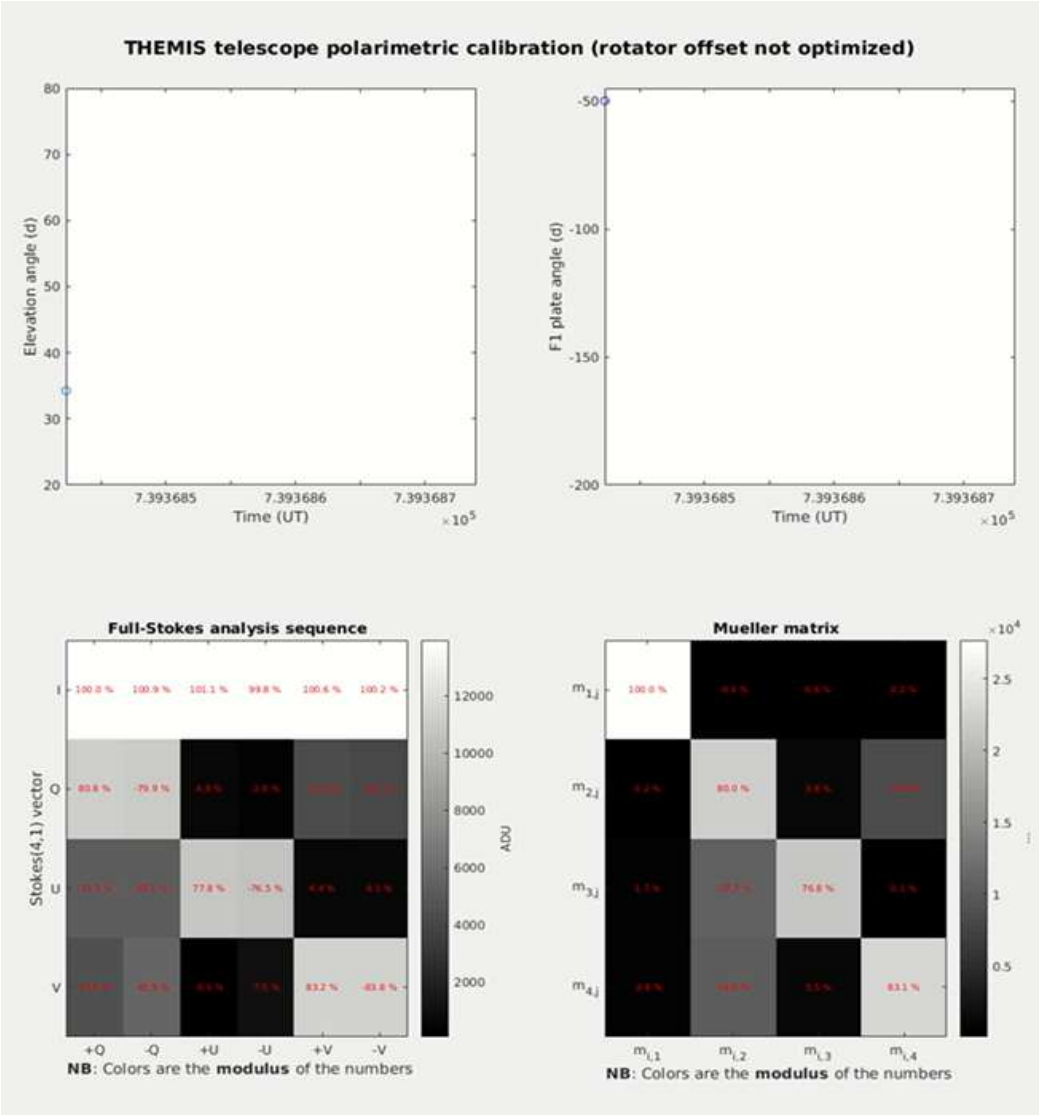
TAO ON
- seeing "daytime bad" : r_0≈ 3-4 cm
- granulation contrast: 4.2 %



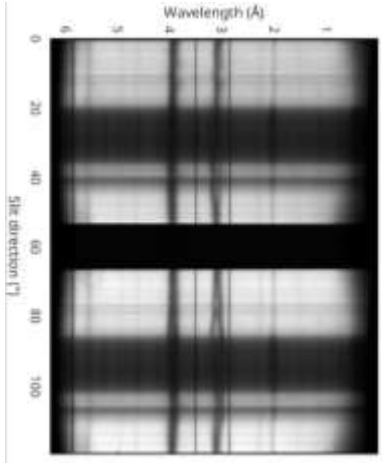
TAO ON + Knox-Thompson reconstruction (100 frames)
- granulation contrast: 9.6 %

- **TAO permits significant quantitative image quality gain:**
  - **in effective seeing**: Fried's coherence length from r_0~7cm (ave. seeing)
    - ~25cm at TAO focus
    - ~17cm on rest of FOV, away from isoplanatic patch
  - **in granulation contrast**: from ~1-2% (bad seeing)
    - to ~10% (with image reconstruction)

THEMIS polarization analysis



- **New "polarization friendly" AO-compatible optical path:**
  - Polarization units + double Savart plates @ F1
    ➔ **dual-beam with beam exchange.**
  - Wollaston prisms in front of spectral cameras:
    ➔ complementary Stokes on camera FOV



- THEMIS Mueller matrix:

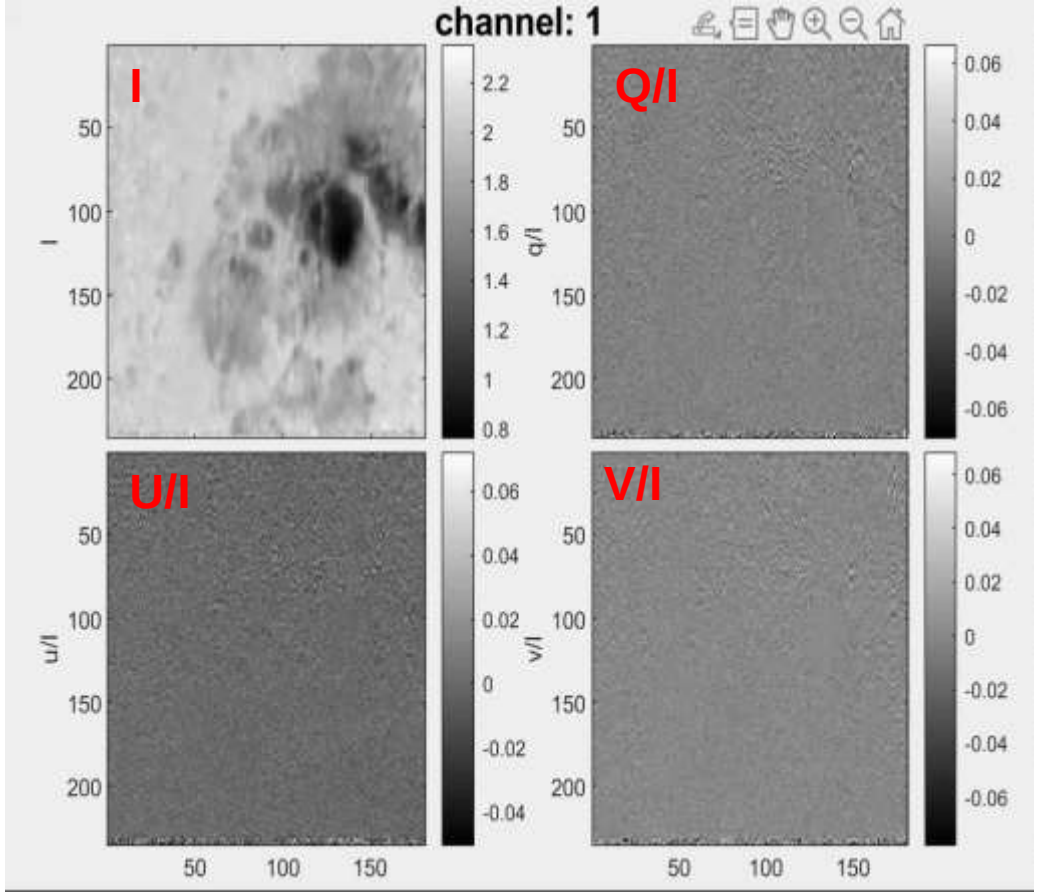
$$M_{THEMIS} = \begin{pmatrix} 1.000 & -0.009 & -0.003 & 0.001 \\ -0.008 & 0.885 & 0.016 & -0.033 \\ 0.014 & -0.436 & 0.872 & 0.033 \\ -0.019 & 0.415 & 0.008 & 0.873 \end{pmatrix}$$

  - 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 maps

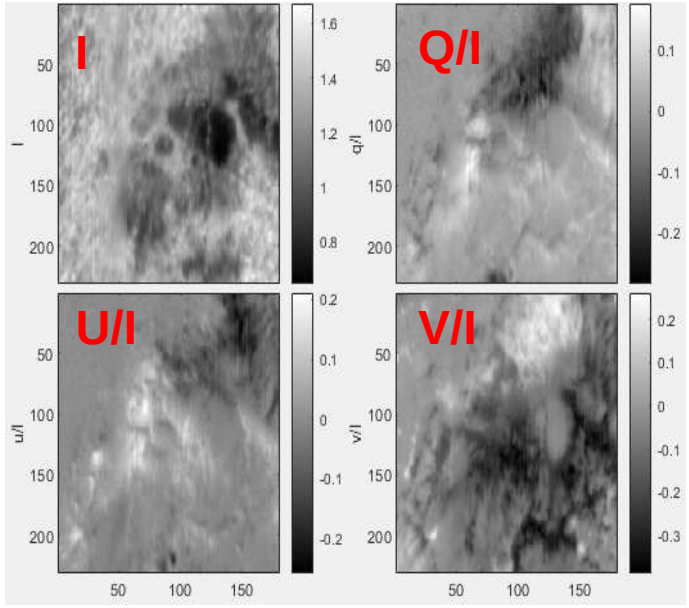
Stokes map datacube
- 256 λ channels after 2x rebinning
- 25mÅ /pixel spectral resolution



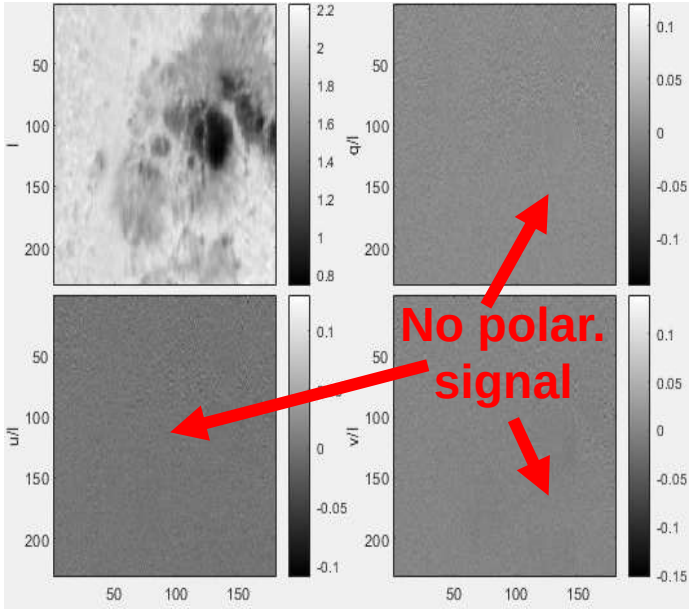
NOAA 14100 ; 29/05/2025 10:30-10:50 UT

- **Complete polarization signal now routinely measured**
  - 4D data array of 4 Stokes parameter (x, y, λ, S).
  - User-friendly software in development.
- **THEMIS goals : B maps with spatial resolution < 0.5”**
  - x10 area resolution improvement

Fe I Line center



Continuum

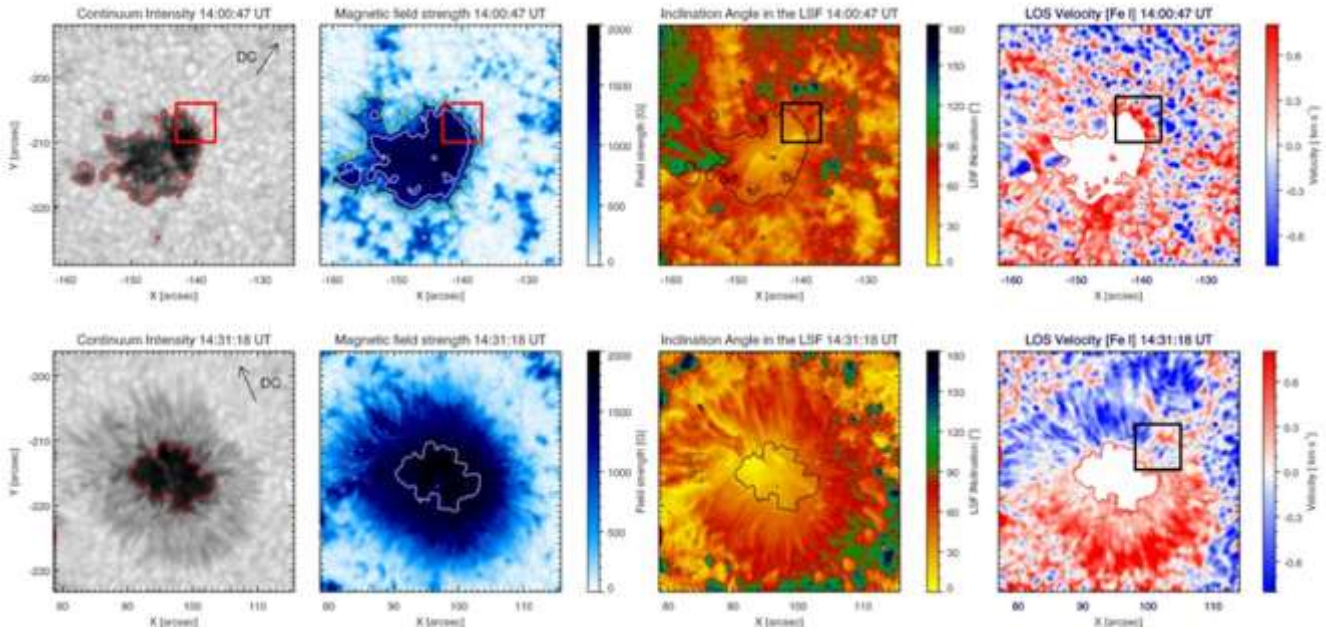


Upcoming : IBIS 2.0 @ THEMIS

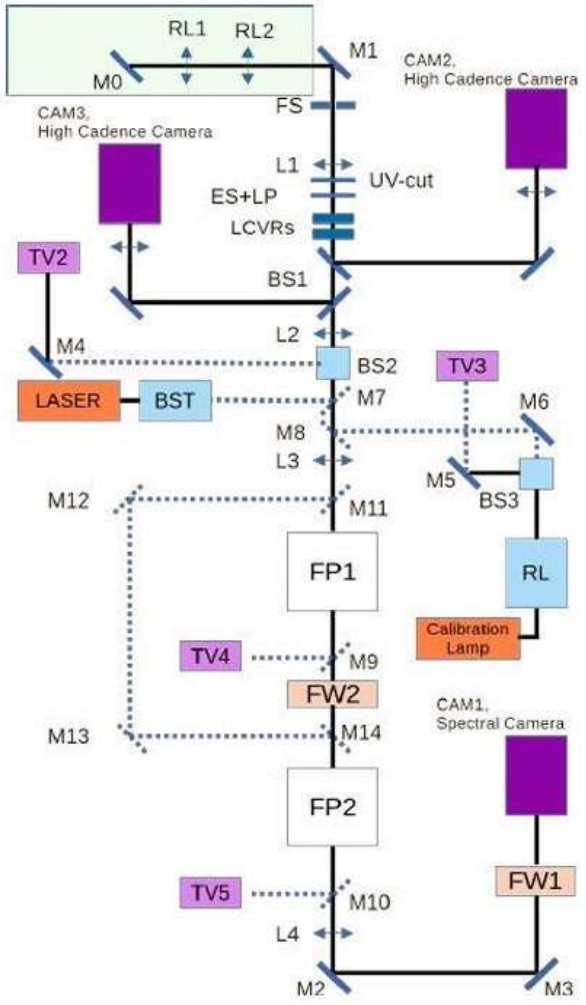
IBIS : Interferometric BIdimensional Spectrometer

- spectro-imager (x, y, λ) : dual Fabry-Perot & interference filters
- 200 000 spectral resolution
- short exposure times / polarimetric mode

https://www.ibis20.inaf.it



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)**



Ermolli et al. 2024

Upcoming : IBIS 2.0 to THEMIS

- 2003-2019: running at the Dunn solar tower (DST) ~100 papers based on IBIS over 15 years
- Upgraded IBIS looking for suitable telescope since 2019
- TAO performance attractive for IBIS
- THEMIS has no equivalent instrumental mode

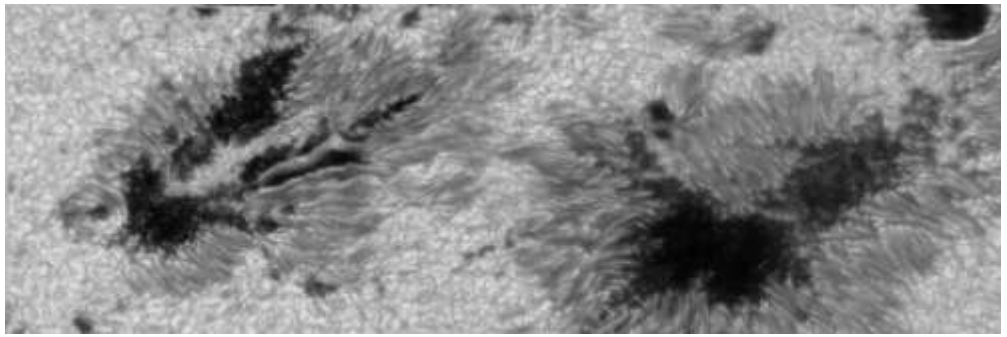
- ➔ Memorandum of Understanding signed between INAF and CNRS in winter 2024-2025
- **Nov. 25: preparatory installation of optical bench**
- **Spring 2026 : IBIS 2.0 installation & commissioning.**

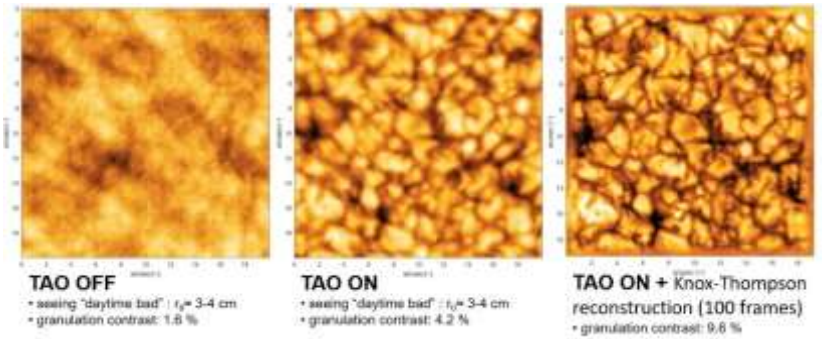
- **IBIS2.0 is an outstanding <u>synergic complement</u> of THEMIS long slit spectrograph**
- **Foster and renew French-Italian scientific collaboration** in high-resolution solar physics, beneficial at large for EU solar physics (e.g. EST)

Nov. 2025

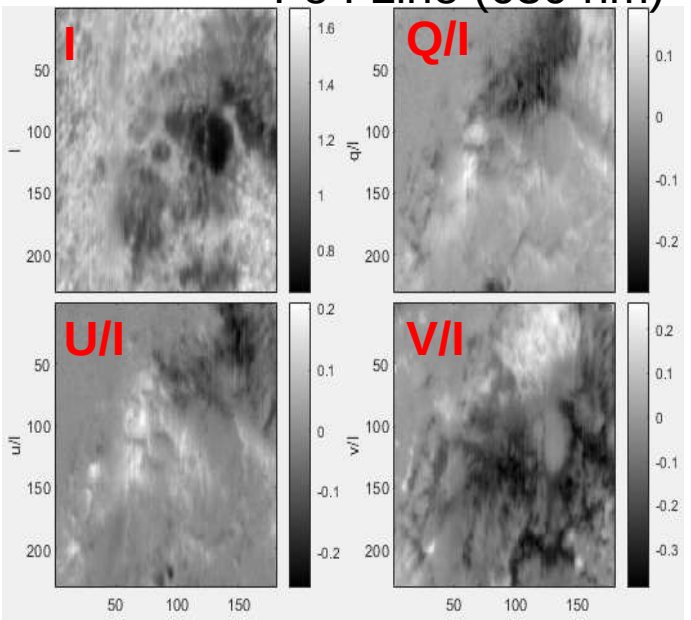
Takeaways

- **THEMIS is now a competitive 21st century telescope in the 1m-1.5m class with renewed spectropolarimetric capacities synergic with existing infrastructure**





Fe I Line (630 nm)



- **Installation of the IBIS 2.0 spectro-imager (spring 2026)**
- Funded science projects
  - hiring of early career researchers (1 PhD, 2 Postdocs) + 1 operator
  - shall strengthen French high res. solar phys. community
- New outreach tools
  - THEMIS website; Instagram account
- **Call for (reduced) 2026 campaign now open !**

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