OBSERVING TIME PROPOSAL FORM FOR

THEMIS - 2026

PROPOSAL

- **French time application**, email this form to: `themis.team@themis.iac.es`
Deadline: Friday February 13th, 2026

- **International time application**, email this form to: `themis.team@themis.iac.es`
Deadline: same as above

Also: ⇒ For technical details or instrumentation updates, please consult our website at:
`http://themis.iac.es` or inquire at: `themis.team@themis.iac.es`
⇒ Read the observation regulations on the last page of this form

1 General Information

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Affiliation(s): [1]FSLAC; [2]LPP ; [3]LPC2E

Title of Project: Exploring spectropolarimetric signatures of chromospheric jet drivers

Specify the observation modes: **MTR2** [X] **Polar** [X] **BBI** [X] **Special** [ ]

Number of days requested: 8

[X] **This proposal is linked to a PhD thesis preparation**
[ ] **This proposal is lead by a PhD student**

2 Proposed programme

A - Scientific rationale

Concise scientific background of the project, pertinent references; previous work plus justification for present proposal.

The solar magnetic field drives most of the solar atmospheric dynamics across all scales, from large sunspots to a vast network of small magnetic features. Generated within the solar interior, these fields rise into the lower solar atmosphere, namely the photosphere and chromosphere, aided by the convective motions, where they interact with the existing magnetic canopy. In particular, convective overshoot in the photosphere supplies energy that, channelled by such magnetic fields, drives several energetic phenomena in the upper layers. The magnetic field is fundamental to coupling these solar atmospheric layers, acting as a structuring agent that organises and facilitates energy dissipation through mechanisms such as shock-wave formation and magnetic reconnection (Wedemeyer-Böhm et al. 2009).

Chromospheric jets are evidence of impulsive energy release in the chromosphere. When observed on the solar disc, these jets are characterised by strong blueshifted or redshifted signatures in chromospheric spectral lines (such as the Hα line), indicating rapid upflows and downflows. Typically associated with on-disc spicules, they are commonly found near magnetic networks and plage regions with sizes on a megameter scale. Spicules are thin, dynamic, thread-like features that appear ubiquitously on the surface of the Sun (Bose et al. 2025). Given their ubiquity, the mass flux and energy they transport through the solar atmosphere, spicules' dynamics may play an important role in transporting energy into the corona, potentially contributing to coronal heating (Athay & Holzer 1982; Withbroe 1983; De Pontieu et al. 2011; Bastian et al. 2025). Moreover, the study of chromospheric jet origin, dynamics, and association with coronal and heliopheric processes is an active research topic, e.g. the ANR funded JET2SB project that is tightly linked with the present proposal.

Despite the complexities of the non-ideal chromospheric MHD regime, characterised by partial ionisation and a plasma beta near unity, state-of-the-art radiative MHD simulations have elucidated the potential mechanisms and magnetic structures driving chromospheric jets. These simulations identify two fundamental mechanisms involved in the generation of jets : MHD shocks propagating along magnetic field lines, which act as precursors to spicules (Srivastava et al. 2025), and magnetic reconnection between opposing flux systems, which triggers fast outflows that form jets (Moreno-Insertis et al. 2025). Physical processes associated with such mechanisms and magnetic structures imprint diverse spectral signatures in photospheric and chromospheric lines when they are synthesised from the simulations (e.g. Kawabata et al. 2024; Moreno-Insertis et al. 2025).

While numerical simulations consistently model the dynamics of the lower solar atmosphere, they remain approximations of its actual behaviour. It is therefore essential to validate these models against observations. Accurately characterising the solar atmospheric conditions during chromosphere jet evolution requires simultaneous, multi-line spectropolarimetric observations of both the photosphere and chromosphere (Díaz-Castillo et al. 2024; Hölken et al. 2026). This proposal is focused on the exploration of the spectral and polarimetric signatures of chro-

mospheric jets to characterise their underlying thermodynamic and/or magnetic drivers and atmospheric evolution. Specifically, we seek to evaluate the THEMIS capabilities of simultaneous, multi-line spectropolarimetric observations to reconstruct the stratification of temperature, line-of-sight velocity, and the magnetic field vector of the photosphere and chromosphere. This approach will enable a comprehensive diagnosis of the lower solar atmospheric state throughout the lifetimes of these jets.

B - Immediate objectives

Immediate objective of the proposal: state what is actually going to be observed, what shall be extracted from the observations, so that the feasibility becomes clear.

The exceptional capabilities of the THEMIS telescope and its MulTi-Ray spectrograph (MTR2), in terms of polarimetric calibration-free, stability and multi-spectral simultaneous observations, motivate this proposal considering the following objectives:

1. To establish a robust observation setup to record high-quality, simultaneous spectropolarimetric measurements of photospheric and chromospheric lines. This includes two photospheric Fe I doublets: @ 6301 and 6302 Å and @ 5247 and 5250 Å lines, and the chromospheric Ca II @ 8498 and 8542 Å lines and Hα line @ 6563 Å, specifically selected to capture the magnetic and thermodynamic properties of chromospheric jets.

2. To develop a standard data processing pipeline for spectropolarimetric diagnostics of the selected spectral lines, featuring benchmarked spectral analysis and multi-line, height-dependent inversion techniques.

3. To validate the capabilities of the chosen configuration and methods in reconstructing the stratification of the lower solar atmosphere, including temperature, line-of-sight velocity, and the full magnetic field vector to characterise the magnetic structure, energy transport and plasma dynamics during the life cycle of chromospheric jets.

This selection of iron doublets allows us to constrain the magnetic and thermodynamic properties of the photosphere, considering their distinct formation heights and sensitivities to physical parameters. On one hand, the Fe I 5247-5250 line pair formed in the middle photosphere is highly sensitive to the magnetic field strength. Belonging to the same multiplet, these lines share similar excitation potentials and line strengths, differing primarily in their Landé factors ($g_{\rm eff}$ = 2.0 and 3.0, respectively). This fact makes these lines respond similarly to the thermodynamic effects but diverge significantly in their response to magnetic fields, making them ideal for decoupling magnetic from non-magnetic effects (Stenflo 1973; Stenflo et al. 2013). On the other hand, the Fe I 6301-6302 line pair forms at different atmospheric heights and possesses different atomic parameters and Landé factors ($g_{\rm eff}$ = 1.7 and 2.5, respectively). This fact makes the pair particularly effective for constraining vertical gradients of temperature, line-of-sight velocity, and the magnetic field vector throughout the photosphere (Khomenko & Collados 2007). The spectropolarimetric information of both pairs @ 630 and 525 nm provides a robust reconstruction of the magnetic field in the photosphere.

The infrared Ca II triplet is widely used to probe the magnetic and thermodynamic properties of the chromosphere. While chromospheric lines are more difficult to model than photospheric ones, this triplet offers a good compromise between modelling feasibility and polarimetric sensitivity (de la Cruz Rodríguez et al. 2012). Specifically, the Ca II line @ 8542 Å has been used extensively to study the chromospheric magnetic structure, owing to its largest Landé factor ($g_{\rm eff} = 1.1$). Based on a detailed analysis of the Ca II line @ 8542 Å, Quintero Noda et al. (2016) demonstrated its high sensitivity to atmospheric parameters going from the photosphere to the middle chromosphere. While it has been shown that inferring chromospheric magnetic properties by inverting the Ca II line @ 8542 Å line alone may lack sufficient precision (Felipe et al. 2021), Quintero Noda et al. (2017) showed that the simultaneous inclusion of the Ca II line @ 8498 Å line significantly enhances sensitivity to physical parameters, providing a more robust reconstruction. Moreover, including the spectroscopy of the Hα line provides information on the chromospheric dynamics, fundamental to the identification of the upward and downward plasma flows in chromospheric jets.

These objectives align with the goals of WP1 within the JET2SB project, regarding the inference of the magnetic field vector in regions of chromospheric jet formation that may extend into the solar corona. Therefore, we aim to observe regions of open magnetic field configurations, such as equatorial coronal holes. This data will be complemented by EUV observation from SDO/AIA, Solar Orbiter/EUI and/o IRIS, if available, to characterise the potential coronal response to chromospheric jet dynamics.

C - Strategy for observing

Brief description of the observation method

As the first objective of the proposal is to identify the best observation configuration to capture the magnetic and thermodynamic properties of chromospheric jets, we initially propose two observational setups based on specific mechanisms and the good experiences of previous observational campaigns. These can be subsequently tuned to improve the performance.

For both observational setups, the primary targets are network regions located at the disc centre to avoid projection effects in the measurements. These correspond to relatively bright patches on intergranular regions observed in the G-band context images. Regions in low-latitude coronal holes and/or equatorial coronal holes observed near the disc centre will be prioritised. The first hour of observation is focused on identifying the region-of-interest or ROI based on G-band context images and fast scans in spectroscopic mode when the seeing is not still optimal. Once the ROI has been selected, the objective is to follow this region during the observation time, while conditions permit.

1. **Low-atmosphere magnetic reconnection as driver of chromospheric jets** requires characterising the magnetic field vector in the photosphere. In particular, we seek to study processes of magnetic flux cancellation and its response at the chromosphere. For this aim, we propose simultaneous observation of the Fe I doublets @ 630 and 525 nm in polarimetry mode and the Hα line in spectroscopy mode. The standard configuration of the MRT2 in the visible is optimal for this configuration. The observing strategy shall be

to alternate scans (rastering) of the ROI at different observation cadences. The number of scans will be defined depending on the extension of the ROI:

- scan of ROI, either with a 0.3" or a 0.6" step, with full polarimetry (+V,-V,+U,-U,+Q,-Q). These scans shall last up to 15 minutes (with 0.6" step), or 30 minutes (with a 0.3" step). We use these scans to produce vector magnetograms and reconstruct the photospheric magnetic field.
- scan of ROI, with a 0.3" step, with only line-of-sight polarimetry (+V,-V), if preliminary analysis shows only a weak signal with Q and U stokes parameter. These scans shall last about 10 minutes. We use these scans to produce longitudinal magnetograms of the photosphere.
- high-cadence scans of ROI with a 0.3" step every 1-2 minutes in spectroscopic mode (without polarimetry), to capture the overall chromospheric dynamics. Each scan shall last about 3 minutes runing from 5 to 10 sequential repetitions, lasting in total 15-30 minutes.

2. **Chromospheric magnetic reconnection or a shock front as drivers of chromospheric jets** requires thermodynamic and magnetic characterisation of the chromosphere. For this aim, we propose simultaneous observation of the Ca II lines @ 8542 and 8498 Å in polarimetry mode and the Hα line in spectroscopy mode. To increase the efficiency of the optical setup near the infrared, we request the use of an IR predispersor grating for this setup. The observing strategy shall be to alternate scans of the ROI at different observation cadences. The number of scans will be defined depending on the extension of the ROI:

   - scan of ROI, with a 0.3" step, with line-of-sight polarimetry (+V,-V), given the expected low Q and U Stokes signals in the chromosphere. These scans shall last about 15 minutes. We use these scans to produce longitudinal magnetograms of the chromosphere, depending on the signal level reached.
   - Sit-and-stare scans with the 0.3" slit with full polarimetry (+V,-V,+U,-U,+Q,-Q), lasting a maximum of 10 minutes. We use these scans to study the properties of dynamic events, such as MHD waves that can turn into shocks.
   - high-cadence scans of ROI with a 0.3" step every 1-2 minutes in spectroscopic mode (without polarimetry), to capture the overall chromospheric dynamics. Each scan shall last about 3 minutes runing from 5 to 10 sequential repetitions, lasting in total 15-30 minutes.

   Due to the specific sensitivity of the available cameras in the near-infrared, we anticipate limited performance in this spectral range. Consequently, this setup serves as a feasibility study for near-infrared observations using current THEMIS capabilities.

Other possible secondary targets are plage regions in the vicinity of active regions. Because of the more complex magnetic environment, understanding their dynamics is, however, less obvious than in equatorial coronal holes.

D - Strategy for data reduction and analysis

Brief explanation of the strategy for data reduction and analysis with description of available hardware, software, expected publication

Initial preliminary analyses will be performed on site to validate the observational setups selected and the quality of the observations, including the evaluation of the SNR of the polarimetric measurements and an interesting target to study. Post-calibration procedures, such as normalisation to the continuum intensity, wavelength calibration and alignment, among others, will be performed to have a science-ready dataset.

Given the second objective of this proposal, we will use diverse methods to infer the thermodynamic and magnetic properties of the photosphere and chromosphere. These mainly include Milne-Eddington inversion techniques, such as PyMilne (de la Cruz Rodríguez 2019) and VFISV (Borrero et al. 2011), and the height-dependent inversion technique SIR (Ruiz Cobo & del Toro Iniesta 1992) to infer the average values and the stratification of temperature, line-of-sight velocity, and the magnetic field vector in the photosphere. Given the departure from Local Thermodynamic Equilibrium (LTE) of the chromosphere, specific inversion techniques (DeSIRe - Ruiz Cobo et al. 2022) should be used to study the Ca II lines. Alternative methods to infer the longitudinal magnetic field, such as the Weak-Field-Aproximation (WFA), are applicable in the quiet chromosphere, where the magnetic field strength is relatively small ($\leq$ 1000 G). In addition, Dopplergrams can be computed for the chromospheric lines at different layers of the line formation region to study plasma flows.

Depending on the quality of the observations, we expect some relatively fast publication given the novelty of studying the photospheric and chromospheric coupling through multi-line spectropolarimetry.

E - Conditions necessary to reach the scientific objectives

Specifiy the critical need of: clear days, good seeing, level of solar activity...

Solar activity remains high during the current early declining phase of the cycle, likely producing equatorial and low-latitude coronal holes. Since the regions of chromospheric jet formation are small (tens of arcseconds), they require excellent seeing for proper analysis. In case of poor seeing conditions, we will shift our focus to larger-scale activity, such as active regions, to ensure the best scientific return.

F - Minimum observation time necessary to reach the scientific objectives

Assuming good weather

The minimum observing time is about 4 days (up to 2 days per observational setup) to ensure the observations of at least two ROIs.

G - Report on the use of THEMIS over the last 3 years

If you have been using THEMIS during the last 3 years, describe(briefly) the quality/value of the data obtained and the scientific output generated.

THEMIS has not been used for these particular science objectives and observational setups over the last 3 years. However, our team has benefited from about 16 days of observation in 2025, during the campaign n°233 (PI E. Pariat ; June 16th to June 25th) and n°234 (PI Jade Touresse

; May 19th 2025 to May 26th 2025). These first campaigns were focused on the observations of the "anemone" jet source region. This experience motivates the proposed observing strategy.

Preliminary results of these two campaigns have been presented by Jade Touresse and Etienne Pariat during oral talks at different conferences, workshops and seminars:

- EST France Workshop 2025, June 2025, Paris, FR by J. Touresse;
- Journées de la SF2A, July 2026, Toulouse, FR, by E. Pariat;
- Seminar of the space plasma team of LPP, Oct. 2025, Paris, FR, by E. Pariat;
- Seminar of the solar group of IAC, Nov. 2025, La Laguna, ES, by E. Pariat;
- SO/PHI Science meeting, Dec. 2025, La Laguna, ES, by J. Touresse
- JET2SB kickoff meeting, Jan. 2026, Paris, FR, by E. Pariat
- Seminar of the space plasma team of LPP, Jan. 2026, Paris, FR, by J. Touresse
- Methods for high-resolution solar physics conference, Jan. 2026, Freiburg, DE, by E. Pariat.

3 Scheduling and support

A - Coordinated observation:
Please indicate if you are planning coordinated observations with other facilities.

No coordinated observations are scheduled at the moment. Some coordinated observation may be put in place at a latter time, but they shall no induce constraints on the actual planning.

B - Impossible Dates:
No constraining date at the moment.

C - Skills and support

[ ] I am expert in telescope and instrument handling and need no assistance.
[ ] A little help will be fine.
[X] I am not familiar with the telescope and/or the instrument and need assistance.

4 Technical proposal / Instrumental configuration

For the 2026 campaign, THEMIS proposes nominally:

1. **MTR2 in spectroscopy mode**
   In this mode we propose up to 4 (old) EMCCD Andor iXon camera (512x512) and up to 2 (new) Andor Zyla (2kx2k) cameras. Both 6 cameras can be setup and used at the same time (with their respective specs), in accordance with the SP2 output physical limitations.
2. **MTR2 in spectropolarimetry mode**
   THEMIS polarimetric analysis scheme is based on a full-Stokes analyzer located at the F1 prime focus. For any solar polarization state to measure, the output of the analyzer is made of dual superimposed complementary linear polarizations. Thanks to THEMIS polarization friendly new optical scheme, this output travels through the telescope and arrives unperturbed on the spectrograph cameras. Just in front of the camera, a Wollaston splitter separates the beam into complementary Stokes components to form the spectral focal plane.
   THEMIS owns three Wollastons, hence 3 cameras/3 wavebands at most can be simultaneously observed with polarimetric signal, among the 6 spectral cameras that THEMIS proposes. It is however possible to combine polarimetric and non-polarimetric cameras.
3. **Broadband imaging camera, running concurrently with the spectrograph** Nominal setup is for G-band, but this can be changed optionally (current setup is for 650 nm (red))
4. **THEMIS Adaptive optics (TAO)** is available and tested over sunspots and granulation with good results over significantly long periods of time (seeing dependent).
   - A slowed-down (100Hz) version of the same system can be used to stabilize Mercury.
   - While it is not possible to use TAO directly over the solar limb (or for neighboring prominences), during the 2025 campaign, tests have been carried to observe prominences while TAO was focused on granulation over an offset on-disc region. Even though the TAO isoplanatic region was located far from the targeted prominence, TAO nonetheless provided noticeable improvements.
5. **Available analysis softwares**
   - Knox Thompson image reconstruction for BBI
   - Reconstructed spectral map quick-looks for on site analysis, to be adapted to specific wavelength.
   - Stokes map quick-looks
   - Thanks to V. Bommier, a basic magnetic field inversion software package (running locally in IDL) is also available.

Please indicate below your expected technical setup. Remember that a spectrograph simulator and an acquisition simulator are available at `https://themis.iac.es/doku.php?id=technical:mtr2`
As a minimum, indicate the spectral wavelengths at which you will be using the MTR spectrograph and the need for spectropolarimetry.

We would like to use the TAO capacities and our scientific objetives requires high-quiality polarimetric measurements.

We would like to use MTR2 with the following lines with polarimetric measurements/cameras:

- First observational setup (Using the standard MRT2 configuration in the visible):
  - With polarimetry: Fe I doublet @ 6301 and 6302 Å, with Zyla Camera

  - With Polarimetry: Fe I doublet @ 5247 and 5250 Å, with iXon Camera (unless a 3rd Zyla Camera is available)
  - Without Polarimetry: H_α @ 6563 Å, with Zyla Camera
- Second observational setup (Using the IR predispersor grating):
  - With polarimetry: Ca II line @ 8542 Å, with Zyla Camera
  - With Polarimetry: Ca II line @ 8498 Å, with iXon Camera (unless a 3rd Zyla Camera is available)
  - Without Polarimetry: H_α @ 6563 Å, with Zyla Camera

The spectral simulators indicate that this setup is doable.

We shall also use the broadband imaging camera. We shall use the G-band to identify the ROIs.

References

Athay, R. G. & Holzer, T. E. 1982, ApJ, 255, 743
Bastian, T. S., Alissandrakis, C., Nindos, A., Shimojo, M., & White, S. M. 2025, ApJ, 980, 60
Borrero, J. M., Tomczyk, S., Kubo, M., et al. 2011, Solar Physics, 273, 267
Bose, S., Joshi, J., Testa, P., & De Pontieu, B. 2025, ApJ, 983, L7
de la Cruz Rodríguez, J. 2019, A&A, 631, A153
de la Cruz Rodríguez, J., Socas-Navarro, H., Carlsson, M., & Leenaarts, J. 2012, A&A, 543, A34
De Pontieu, B., McIntosh, S. W., Carlsson, M., et al. 2011, Science, 331, 55
Díaz-Castillo, S. M., Fischer, C. E., Rezaei, R., Steiner, O., & Berdyugina, S. 2024, A&A, 691, A37
Felipe, T., Socas Navarro, H., Sangeetha, C. R., & Milic, I. 2021, ApJ, 918, 47
Hölken, J., van Noort, M., Solanki, S. K., et al. 2026, A&A, 705, A220
Kawabata, Y., Quintero Noda, C., Katsukawa, Y., et al. 2024, ApJ, 960, 26
Khomenko, E. & Collados, M. 2007, ApJ, 659, 1726
Moreno-Insertis, F., Hansteen, V. H., & Nóbrega-Siverio, D. 2025, ApJ, 995, 137
Quintero Noda, C., Shimizu, T., de la Cruz Rodríguez, J., et al. 2016, MNRAS, 459, 3363
Quintero Noda, C., Shimizu, T., Katsukawa, Y., et al. 2017, MNRAS, 464, 4534
Ruiz Cobo, B. & del Toro Iniesta, J. C. 1992, ApJ, 398, 375
Ruiz Cobo, B., Quintero Noda, C., Gafeira, R., et al. 2022, A&A, 660, A37
Srivastava, S., Chatterjee, P., Dey, S., & Erdélyi, R. 2025, ApJ, 989, 39
Stenflo, J. O. 1973, Solar Physics, 32, 41
Stenflo, J. O., Demidov, M. L., Bianda, M., & Ramelli, R. 2013, A&A, 556, A113
Wedemeyer-Böhm, S., Lagg, A., & Nordlund, Å. 2009, Space Sci. Rev., 144, 317
Withbroe, G. L. 1983, ApJ, 267, 825

Observer Charter at THEMIS

All data obtained at THEMIS remain the property of CNRS[1]. No observing fee is requested from observers. Observers are requested to collaborate with THEMIS regarding the data formatting, and to provide information about observing conditions and all information needed concerning the data processing.
The observer agrees to :

- **acknowledge the use of the THEMIS telescope in any published paper using the corresponding data.**[2]

[1] Centre National de la Recherche Scientifique, 3 rue Michel-Ange, F75794 PARIS Cedex 16, FRANCE

[2] "The THEMIS telescope is operated on the island of Tenerife and yearly funded by the french Centre National de la Recherche Scientifique - Institut National des Sciences de l'Univers: CNRS-INSU"