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

Title of Project: Formation of solar "anemone", the solar-jet source regions in coronal holes.

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

Number of days requested: 6

[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.

Three-dimensional (3D) magnetic null points are singular points of the solar atmosphere where the magnetic field intensity is null (Longcope 2005). In the solar corona, such nulls define preferential sites for the building-up of electric currents sheets and for the development of magnetic reconnection (Longcope 2005). 3D null points are thus magnetic topological structures tightly linked with diverse class solar active events over a broad range of scales, such as e.g. flares (Longcope 2005), coronal jets (Raouafi et al. 2016) and coronal bright points(CBP; e;g. Galsgaard et al. 2017, 2019). 3D null-point topological structure are thus key elements in numerical models of chromospheric jets (Nóbrega-Siverio et al. 2023) as well as coronal jets (Pariat et al. 2009; Touresse et al. 2024). Such type of jets are a key focus of the ANR-funded project JET2SB (Project n°ANR-25-CE31-7416) in which the co-investigators of this proposal (from FSLAC, LPP and LPC2E) are involved.

In particular, 3D null point are associated with observed features of the solar atmosphere having an "anemone" morphology (e.g. Shibata et al. 1992; Moreno-Insertis et al. 2008; Liu et al. 2011; Zhang et al. 2012). Such "anemone" shape is linked with the specific magnetic structure induced by a 3D null point: the "fan" separatrice field lines that pass through the null-point and that commonly adopt a dome-like shape; the two singular "spine" separatrices on each side of the "fan" separatrix surface. The fan-spine topology is characteristic of 3D null points and explains the specific observed flaring features of such region, such as the circular morphology of ribbons (e.g. Masson et al. 2009; Masson et al. 2017).

While 3D null points have been identified at key topological structures in a vast numbers of studies, surprisingly there is a lack of understanding of how they actually form. From a theoretical point of view, a 3D null point can only be formed in a low beta-environment from the *ab-nihilo* generation of a pair of 3D null points. This commonly occurs in reconnection currents sheets. These null points are however quite unstable and usually quickly annihilate. The formation of a single 3D null point from this process would imply the submergence under the photosphere of one of the null-point pair. This is likely uncommon. The second and most-plausible formation mechanism of "anemone" region results from magnetic flux emergence. Driven by the emergence of magnetic structures, singular 3D null points are believed to rise from the sub-photospheric layers. However, this mechanism has been only seldomly modeled, e.g. Török et al. (2009), Moreno-Insertis & Galsgaard (2013).

Despite the central role of 3D null points in the generation process of chromospheric and coronal jets, observations or the formation of the solar "anemone", the jet source region is actually almost absent in the literature. Only recently Duan et al. (2024), have analysed an example of the formation of such 3D null point topological structure. This absence results from the combined dificulty that they are relatively small regions, and thus requires high-resolution observation thanks to ground based instruments, while the observer needs to have the luck to target an relatively "empty" region where one hopes that an "anemone" will form. This field

of investigation remains thus largely unexplored.

Overall, the outstanding questions are that we would like to address through this observation proposal, and which are of interest to the JET2SB project, are:

- How are "anemone" regions formed?
- Is their formation associated with any type of solar activity?
- When do the distinct topological features of 3D null point structure become visible?

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 objectives of the observations are to obtain the dynamics of the formation of anemone region in conjunction with its magnetic field structure. We want to determine the chromospheric response to the evolution of the photospheric magnetic field during the emergence, formation and evolution of the 3D nulls. These objectives are the focus of the WP1 workpackage of the JET2SB project.

The measurement of the photospheric vector magnetic field, using simultaneously both the Fe I doublet arount 6302 Å and Fe I doublet around 5249 Å with a full polarization sequence, is essential for latter being able to reconstruct the 3D coronal magnetic field and determine the topology of such region. The transverse component may however be at the detection limits in some of the target anemone. The time scale of the evolution of the magnetic field is of the order of several tens of minutes, so a high cadence is not fully necessary for the magnetic field measurements. Measurements restricted to the line-of-sight component of the magnetic field ($\pm$V Stoke parameter), at higher cadence, are sufficient for an analysis of the variations of the magnetic flux.

This selection of both 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 Å 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 et al. 2013). On the other hand, the Fe I 6301-6302 Å 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)). Combining the spectropolarimetric information of both pairs @ 630 and 525 nm provides a robust reconstruction of the magnetic field vector in the photosphere.

The other required measurements correspond to the chromospheric dynamics. For those, we are primarily interested in analysing the H_α (@ 6563 Å) and Ca II (@ 8542 Å) lines. The analysis of chromospheric lines will provide us information on the dynamics around 3D null/anemone regions. Emission in chromospheric line center will inform us on possible heating because of

activity. Absorption can inform on moving features. Complementary analysis of the wings of the chromospheric lines shall provide complementary dynamics of possible plasma motions (by making e.g. Doppler maps). Overall, the chromospheric map will be essential to understand the activity of the anemone regions in link with their photospheric magnetic field dynamics. Of particular interest is the formation of "quiescent jet", i.e. long-lived jet-like emission that forms along the spine of the null. The presence of such feature shall be typical of the activation of reconnection at the 3D null point.

Additionally, the Ca II line is magnetically sensitive and its analyse with polarimetry can eventually provide us with chromospheric magnetic fields. Ca II chromospheric magnetic field measurements are however yet not fully mature (Felipe et al. 2021), and these magnetic field estimations are only a secondary objective of the present proposal.

These data shall be combined with EUV observations from SDO/AIA, Solar Orbiter/EUI and/o IRIS, if available, to obtain the coronal response of the 3D null dynamics.

C - Strategy for observing

Brief description of the observation method

During our 2025 campaign, we have been able to test different observation strategies and refine them. Ideally, we shall sample and analyze the formation of an anemone region within coronal holes, where such anemone regions are typical. Because we intend to perform magnetic field measurement, it is important that targets are as close as possible to solar disc-center to minimize projection effects and impact on the magnetic measurements. We will thus primarily target low-latitude extension or polar coronal holes and/or equatorial coronal holes. Such low-latitude extensions/equatorial coronal holes are common around solar maximum, hence this proposal is timely.

Our proposed observations strategy consist in the following : in the first hour of the day, when the seeing is still heavily impacted by the important width crossing of Earth atmosphere by the solar light at low solar elevation, we will perform fast scans (90" scanning range at 0.6" steps, without polarisation) of neighboring regions of the target coronal hole. Thanks to preliminary analysis of quicklooks of the data, this will enable us to determine a target/region of interest (roi): either a region with no strong field/chromospheric anemone features, or a region with a budding formation of an anemone. We shall also use space data to focus on possible forming anemone region and help us in the target choice.

Once the roi has been selected, the objective is to follow this region for the rest of the day, while seeing conditions permits. The observing strategy shall be to alternate scan of the roi, with a 90" extension orthogonal to the slit, at different cadence:

- 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 15min (with 0.6" step), or 30 min (with a 0.3" step). The scans shall permit to obtain vector magnetograms and the best magnetic reconstruction.
- scan of roi, with a 0.3" step, with only los polarimetry (+V,-V), if preliminary analysis shows only a weak signal with Q & U stokes parameter. These scans shall last about 10 minutes.

- high cadence scans of roi, with a 0.3" step, e.g. every 1-2 minutes, without polarimetry (+V), to capture the chromospheric dynamics. A scan shall last about 3 min and the objective is to repeat such scan 10 times sequentially, i.e. for about 30 minutes.

A typical sequence of observation shall thus be:

- slow scan full polarization; duration 15-30 min,
- 10 fast scans, no polarization; duration 30 min,
- scan with los polarization; duration 10 min,
- 10 fast scans, no polarization; duration 30 min,
- scan with los polarization; duration 10 min,
- 10 fast scans, no polarization; duration 30 min,
- slow scan full polarization; duration 15-30 min.

In case of absence of equatorial coronal hole, one could target polar coronal holes, although the high inclination regarding to the line-of-sight implies less meaningful magnetic field measurements. Other possible secondary targets are 3D nulls that form in the vicinity of active regions. Because of the more complex magnetic environment, understanding their dynamics is however less obvious that 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 with the primary goal to validate the daily target. These preliminary analysis will also enable to validate the observational setups selected and the quality of the observations, including the evaluation of the SNR of the polarimetric measurements. 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, i.e. either Stokes maps (for polarimetric measurements) or reconstructed spectroscopic images.

Regarding the magnetic inversion, we shall benefit from the Co-I expertise of Saida Diaz Castillo. 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 our ability to find a good target, i.e. an anemone region with some dynamics, we expect some relatively quick publication given the very limited number of exiting publication on this topic of describing anemone region appearance and early evolution.

E - Conditions necessary to reach the scientific objectives
Specifiy the critical need of: clear days, good seeing, level of solar activity...

Given that we are now in the early decreasing phase of the solar cycle, the level of solar activity remains high and equatorial coronal holes, and or low latitude extension of polar coronal hole shall be present.

Anemone regions being relatively small sized (tens of "), our 2025 observation campaign has demonstrated that excellent seeing conditions are needed, with good conditions being a minimum for proper scientific exploitation. In case of poor seeing, we shall likely change of target and science program in order to focus on larger scale activity, e.g. active region flares.

F - Minimum observation time necessary to reach the scientific objectives
Assuming good weather

The minimum observing time is about 3 days in order to capture several regions and possibly follow them over a few days, which corresponds to their typical lifetime.

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.

In 2025, our team has benefited fom about 16 days of observation, during the campaign n°233 (PI E. Pariat ; June 16th to June 25th) & n°234 (PI Jade Touresse ; May 19th 2025 to May 26th 2025). These first campaigns on the observations of anemone jet source region, have permitted us to test and improve our observing strategy, and understand which cadence and data quality we can expect to obtain with the MTR2 spectrograph.

Equatorial CH and/or low-latitude extension of polar coronal holes were present during all days of our campaign which permitted us to focus on the main science programs. Unfortunately, weather conditions included could cover, with some calima and seeing quality has never been excellent. Five mornings (May 23rd-24th ; June 21st & 24th-25th) presented sufficiently good seeing conditions for the observation of jet source regions. We estimate that we have (discontinous) 5h-6h of observations worth analysing further.

We developed some routes and performed quicklook analysis of all the Hα observations: image reconstructions from scans in selected wavelength (Continuum, Hα line center, H$\alpha \pm 0.5$Å, H$\alpha \pm 1$Å). These quicklooks allowed us to better determine which series of sequences were of the highest data quality (seeing, effective AO correction, target of interest) and shall be the focus of our analysis. We initiated preliminary analysis (e.g. Dopplergrams proxy) of some of the dataset. Figure 1 presents an example of such analysis of a jet source region.

We shall now carry a more complete analysis of the sequence identified with of a better quality. For those we have started to develop the code to analyse the Ca II lines, as well as the Fe I line. Regarding the analysis of polarization in the Fe I line, we are (too slowly) learning to use the reduction routines developed by B. Gelly/THEMIS team to obtain the Stokes maps. We

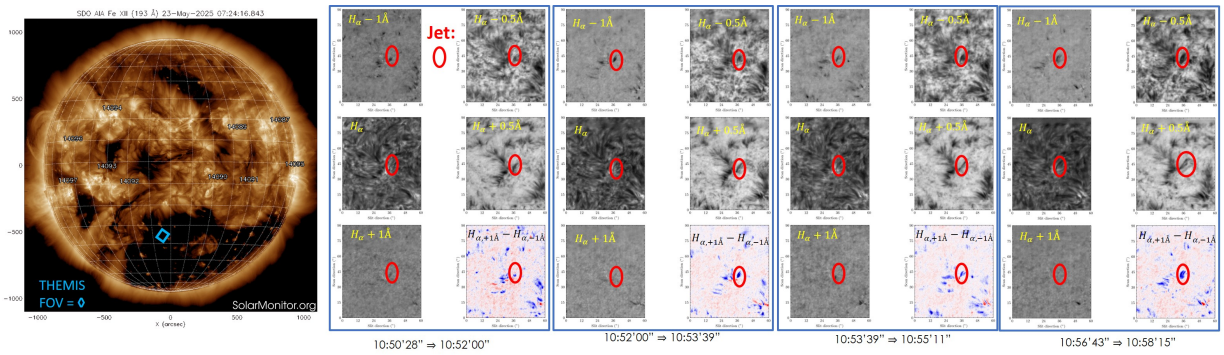


Figure 1: Preliminary analysis of Hα line observations on May 23rd. The sequence of scans (right panels) by the MTR2 spectrograph reveals a jet within an anemone region, observed in a CH (cf SDO/AIA 194 Å image, left panel)

shall then use the UNOFIT code to obtain the magnetic field maps. Other magnetic inversion code could also be used depending on opportunities.

When the seeing was not of sufficiently good for the jet observations, we carried some complementary observations to test some observations modes. We then focused on observations of emerging flux region and of active regions, for which the seeing is less critical. For example on June 16th 2025, we used BBI to obtain a large fov observations of the whole active center NOAA 14114. We obtained 21 BBI burst, used the THEMIS speckle image reconstruction software and used a stiching software (Hugin). Figure 2 presents the resulting observation of this 250"x140" composite FOV of NOAA 14114 at 0.2" resolution. We also used the time to carry some tests on AO performance.

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.

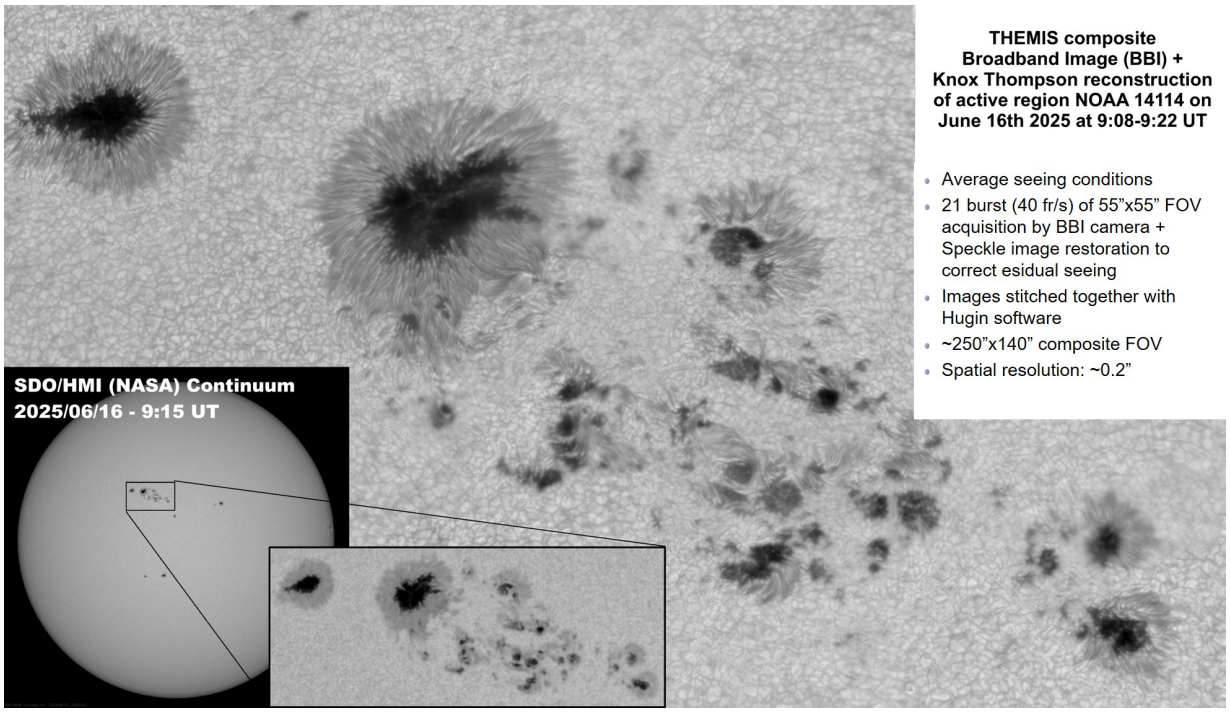


Figure 2: NOAA 14114 observation of AR14114 by THEMIS on June 16th and comparison with SDO white light observation.

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 not induce constraints on the actual planning.

B - Impossible Dates:

The PhD defense of Jade Touresse, at a date not known yet, shall take place in September 2026, will constitute a strong availability limitation. The defense date shall however hopefully be known in the coming weeks.

C - Skills and support

[ ] I am expert in telescope and instrument handling and need no assistance.
[X] A little help will be fine.
[ ] 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 project requires polarimetric measurements.

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

- Fe I doublet @ 6302 Å, with a Zyla Camera
- Fe I doublet @ 5249 Å with an iXon Camera (unless a Zyla Camera is available).
- Ca II @ 8542 Å, with an iXon Camera (unless a Zyla Camera is available).

and the following one without need of polarimetry:

- H_α @ 6563 Å, with a Zyla Camera

The spectral simulators indicate that this set up is do-able.

We shall also use the broadband imaging camera. We shall use the G-band although we would be extremely interested if an H_α option would be available at some point in the future.

References

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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"