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# ON THE CURRENT NATIONAL LANDSCAPE FOR THE SCIENTIFIC AND TECHNOLOGICAL CONTRIBUTIONS TO ANDES SPECTROGRAPH AT THE ELT

A. Chiavassa[1], I. Boisse[2], X. Bonfils[3], J. Morin[4], P. Noterdaeme[5], P. Petit[6], M. Turbet[7,8], C. Baillet[1], P. Berio[1], L. Bonhomme[6], Y. Caujolle[1], G. Chauvin[9,1,3], S. Cuevas[10], F. Debras[6], T. Fusco[11,2], O. Gabella[4], D. Kouach[6], M. Larrieu[6], C. Le Men[6], P. Martinez[1], M. N'Diaye[1], Y. Micheau[6], B. Neichel[2], F. Olchewsky[6], S. Ottogalli[1], K. Perraut[3], S. Rivoire[4], S. Rousseau[1], J.-F. Sauvage[11,2], J. V. Seidel[1], A. Spang[1], A. Simonnin[1] and H. Valentin[6]

**Abstract.** ANDES is a modular, stable, high-resolution spectrograph for the Extremely Large Telescope (ELT), being developed by an international consortium to pursue cutting-edge science cases in exoplanet characterization, stellar astrophysics, and cosmology. The French community contributes significantly to this project, with involvement in key areas such as high-contrast imaging and the design of a coronagraph module that enhances the instrument's capacity for reflected-light exoplanet studies. French co-authorship on core science white papers and co-leadership of scientific working groups further highlight this collaborative engagement with ANDES Consortium. These contributions are expected to yield high-impact scientific results once ANDES becomes operational.

Keywords: high-resolution spectrographs, high-contrast imaging, exoplanets, stars and planets formation, physics and evolution of stars, physics and evolution of galaxies, cosmology, fundamental physics

## 1 Introduction

ANDES (ArmazoNes high Dispersion Echelle Spectrograph) is a spectrograph for ELT that will provide spectral resolution of ≈100 000 with simultaneous wavelength coverage of 0.40-1.80 $\mu$m with the goal of extending it to 0.35-2.40 $\mu$m. ANDES is made up of three fibre-fed spectrographs ([U]BV, RIZ, YJH) with the addition of a U arm to the BV spectrograph, and a separate K band spectrograph (Fig. 1; Marconi et al. 2024).
Two different observing modes are present on ANDES (Fig. 1, left): (i) a seeing-limited front-end mode, with a spatial resolution limited by the atmosphere; it does not rely on the adaptive optics available on the ELT but directly captures the light from the telescope and directs it into the calibration unit before leading to the different science fibers. It can simultaneously observe spectra with a resolution of R = 100 000, covering wavelengths from 0.4 to 1.8 $\mu$m. (ii) A diffraction-limited mode named SCAO(Single Conjugate Adaptive Optics)-IFU(Integral Field Units) operating in the near-infrared, covering the Y to H bands (0.95-1.80 $\mu$m) with a spatial resolution up to the diffraction limit of the ELT (4 mas in the visible and 8 mas in H-band).

[1] Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Lagrange, CS 34229, Nice, France
[2] Aix Marseille Univ., CNRS, LAM, Laboratorire d'Astrophysique de Marseille, Marseille, 13388 cedex 13, France
[3] Univ. Grenoble Alpes, CNRS, IPAG, F-38000 Grenoble, France
[4] Laboratoire Univers et Particules de Montpellier, Université de Montpellier, CNRS, 34095 Montpellier, France
[5] Institut d'Astrophysique de Paris, CNRS-SU, UMR 7095, 98bis bd Arago, 75014 Paris, France
[6] Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse, CNRS, CNES, 14 avenue Edouard Belin, Toulouse, 31400, France
[7] Laboratoire de Météorologie Dynamique, IPSL, CNRS, Sorbonne Université, 4 place Jussieu, F-75252 Paris Cedex 05, France
[8] Laboratoire d'astrophysique de Bordeaux, Univ. Bordeaux, CNRS, B18N, allée Geoffroy Saint-Hilaire, 33615 Pessac, France
[9] Max-Planck-Institut für Astronomie, Königstuhl 17, Heidelberg, 69117, Germany
[10] Instituto de Astronomía, Universidad Nacional Autónoma de México, Apartado Postal 70-264, 04510 CDMX, México
[11] ONERA, B.P.72, F-92322 Chatillon, France

The ANDES project is carried forward by a large international consortium, composed of 35 Institutes from 13 countries from ESO Member States, Brazil, Canada, and the USA. ANDES started Phase B activities in September 2022: pre-phase B was successfully concluded in October 2023 with the System Architecture Review (SAR). The construction has finally formally started in June 2024, with the signature of the Construction Agreement with ESO*. The conclusion of Phase B and the beginning of subsequent phases are planned for the end of 2025, to bring ANDES to the telescope in late 2031/early 2032 (Fig. 1, right).

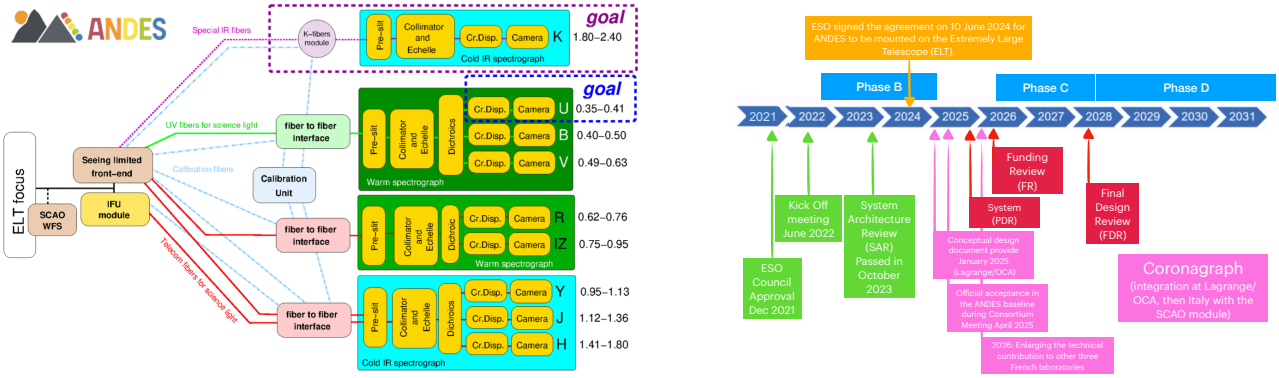


**Fig. 1.** *Left:* ANDES architectural design, outlining the instrument subsystems: Front End (seeing-limited and AO assisted with SCAO unit), Fibre Link, Calibration Unit, [U]BV, RIZ, YJH and K (cold spectrographs). Image from Marconi et al. (2024). *Right:* Schematic timeline of ANDES showing the different phases: green boxes mark completed steps, red boxes indicate upcoming milestones, and pink boxes refer to the Coronagraph module (see Section 4.1).

## 2 The science priorities and top-level requirements

The science goals and priorities of ANDES are organized into four main themes. **First: exoplanets and protoplanetary disks** where ANDES will probe planetary atmospheres from hot Jupiters to potentially habitable rocky worlds using transmission and reflected-light spectroscopy, aiming to detect biosignatures (e.g. $O_2$, $H_2O$, $CH_4$) and to study gas dynamics and chemistry in disks (Palle et al. 2025). **Second: stars and stellar populations**, where the instrument's precision abundance measurements will reveal the chemical evolution of the Milky Way and nearby galaxies, trace the first generations of stars, and shed light on nucleosynthesis processes (Roederer et al. 2024).
The top-level requirements (TLRs) associated with these cases are:

1. Spectral resolution: R = 100 000.
2. Simultaneous wavelength coverage: 0.50-1.80 $\mu$m (requirement), 0.38-2.40 $\mu$m (goal).
3. Wavelength calibration precision 1 m/s (goal: 20 cm/s), stable over time scales of several hours.
4. Adaptive Optics (AO) and Coronagraph and diffraction-limited Integral Field Unit mode in Y, J, and H bands with 61 spaxels and 4 spaxels scales in the 10-100 mas range. Field of view from ≈10×10 to 100×100 mas (see Section 4.1).
5. High PSF stability on daily timescales.

TLRs 1, 2, and 3 will provide coverage of all the major molecules $H_2O$, $O_2$, $CO_2$, $CH_4$, $NH_3$, $C_2H_2$, HCN, and access to the highest stellar flux contribution of M dwarf systems, which are prime targets for exoplanetary and stellar science cases (Palle et al. 2025). The K-band range (2 to 2.4 $\mu$m) goal is highly beneficial for gas giant planets' science cases. TLRs 4 and 5 will provide access to the reflected light signal (Section 4.1).

*https://www.eso.org/public/announcements/ann24010/

**Third: galaxy formation and the intergalactic medium**, using absorption-line studies of distant quasars to reconstruct the thermal and chemical state of the ionized intergalactic medium and to probe baryon cycling in and out of galaxies (D'Odorico et al. 2024). **Four: cosmology**, where ANDES will enable fundamental tests such as measuring the redshift drift (Sandage test) to directly observe cosmic expansion, and constrain possible variations in fundamental constants over cosmic time (Martins et al. 2024).
The top-level requirements (TLRs) associated with these cases are:

1. Spectral resolution: R = 100 000.
2. Wavelength range: 0.37-0.84 $\mu$m (requirement), 0.33-0.90 $\mu$m (goal).
3. Wavelength calibration precision 0.7 m/s (goal: 0.5 cm/s).

TLRs 1 and 2 will provide insights into cosmic variation of cosmic microwave background temperatures and the characterisation of primitive stars. TLRs 3, with a precision of 0.7 m/s and an accuracy of 1 m/s, will help to compare the values of fundamental physical constants over 12 Gyr ago and 15 Gpc away with their current values on Earth. Achieving a long-term stability over the instrument's lifetime will enable direct measurements of the Universe's expansion history through the redshift drift of distant cosmological sources (the Sandage test).

Collectively, these science cases establish ANDES as a transformative facility for tackling fundamental questions in astrophysics and cosmology (Marconi et al. 2024).

## 3 French scientific contributions

ANDES's science goals are also of particular relevance to the French community, which has long-standing expertise in high-resolution spectroscopy and active involvement in ELT instrumentation, in particular for the high contrast imaging. Since 2022, a scientific team has been in place for ANDES Phase B (Fig. 1, right). Its composition reflects both the human and financial commitments of each partner. Out of a total of just under 100 participants, France is entitled to six representatives contributing across the four thematic teams described in Section 2, with affiliations spanning one or two work packages depending on expertise. The **first-priority** group includes 45 members, of whom 5 are from the French community; the **second-priority** group counts 23 members, including 1 from France; and the **third** and **fourth-priority** groups comprise 20 and 12 members respectively, the latter being co-chaired by a French representative. The scientific team works regularly to review the application of TLRs to different modules (e.g., calibration modes, K band, constraints, and objectives of high-resolution spatial-spectral modes, etc.).

Both in France and in the other partner countries, the number of members involved in the scientific teams does not correspond to the entire national community interested in the instrument. The ANDES Consortium, therefore, encourages each partner to set up national scientific teams. We have set up a scientific structuration at the national level that involves: (i) collecting scientific cases and the interests of the French community; (ii) coordination of the ANDES-science workshops in France; (iii) the creation of a national website hosted by the OCA (`https://projets.oca.eu/fr/andes-home`), which collects our contributions.

In particular, the French community has made several significant contributions to the scientific cases presented in the white papers, especially for exoplanets and stars. Concerning the exoplanet (Fig. 2, left) science paper (Palle et al. 2025), 9 co-authors joined the effort and contributed to the: (i) study of the emission of tenuous planetary atmospheres in the Solar System; (ii) the atmospheric physics of temperate gaseous and sub-Neptunes exoplanets; (iii) the atmospheric characterization, circumplanetary disks, exomoons of young gas giant planets; (iv) the presence of atmosphere, cloud properties and surface composition, albedo of rocky planets and Super Earth; (v) the stellar contamination: activity, molecular absorption, variability. In addition to this, people are also interested in determining the latitude chemical variations in the atmosphere of brown dwarfs.
Concerning the stellar (Fig. 2, right) science paper (Roederer et al. 2024), 5 co-authors contributed to the paper with 6 out of 17 scientific cases regarding: (i) the chemical composition of massive evolved stars in nearby galaxies; (ii) the subtle effects of rotation in spectral lines and gravity darkenin in fast rotating stars; (iii) the calibration of the properties of Cepheid variables for the cosmic distance ladder; (iv) the products of White Dwarf mergers in Milky Way and other galaxies; (iv) extragalactic asteroseismology. In addition to this, other researchers are interested in developing science cases on the magnetism of newborn protostars and characterising the atmospheric parameters and chemical/dynamical properties of cool dwarf stars.
One French researcher also contributed to several scientific studies, including those in Martins et al. (2024),

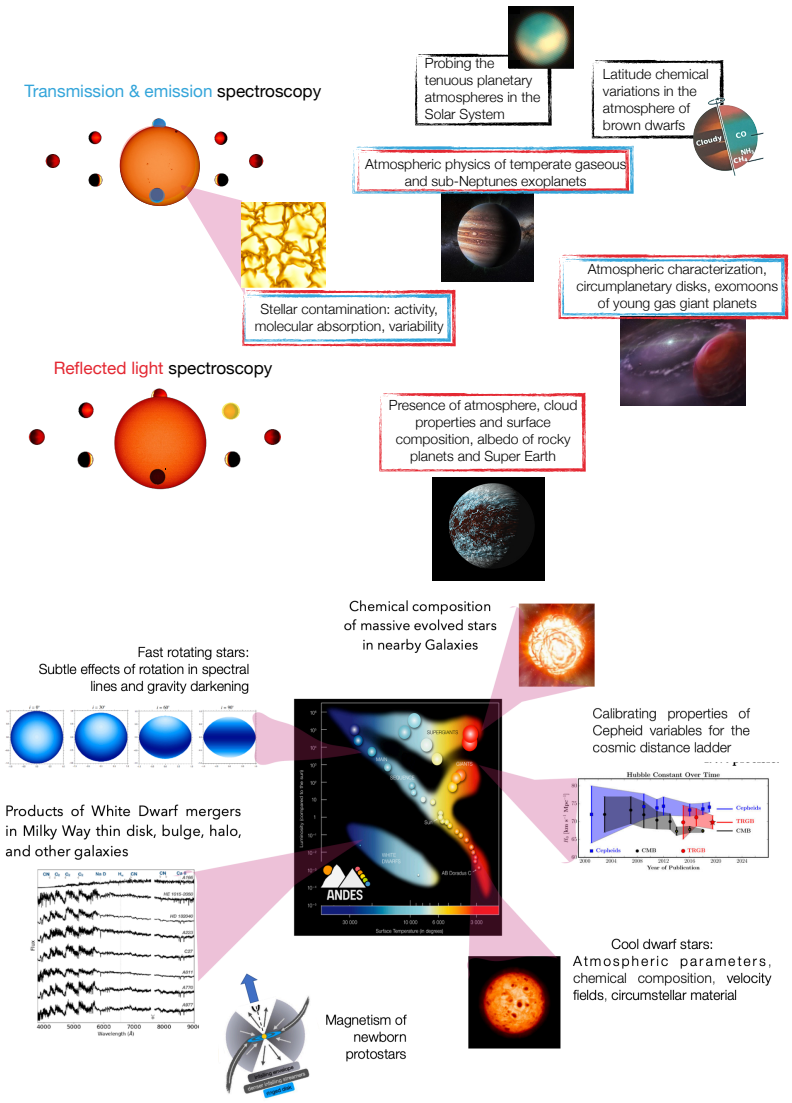


**Fig. 2.** Principal contribution of the French community to the science cases in *exoplanets and protoplanetary* paper (Palle et al. 2025, left) and stars and stellar populations paper (Roederer et al. 2024, right). Some additional science cases have beed added to the one reported in the papers.

which addressed constraints on the proton-to-electron mass ratio over cosmic time, the adiabatic expansion of the Universe, and its primordial composition, as well as in D'Odorico et al. (2024), which focused on probing the gas in, around, and beyond galaxies from the local Universe up to the epoch of reionisation.

## 4 French technological contributions

### *4.1 Coronagraph module*

The detection and characterization of faint sources (e.g., the reflected light of rocky planets close to their stellar hosts, one of the main science cases of ANDES) located angularly close to very bright stars requires the combination of high-dispersion spectroscopy (HDS) with high-contrast imaging (HCI). HDS, by exploiting spectral and time-differential filtering techniques, provides a powerful tool to probe the properties of extrasolar planets, while HCI aims to spatially separate the planetary signal from the stellar halo. However, HDS is fundamentally limited by the overwhelming photon noise from the host star, whereas HCI suffers from residual quasi-static speckles. Snellen et al. (2015) proposed that the joint use of a high-dispersion integral field spectrograph with

HCI could, in principle, achieve contrast levels of $\approx 10^{-4} \times 10^{-3}$, i.e., approaching the $\approx 10^{-7}$ contrast required to detect rocky planets such as Proxima b (Turbet et al. 2016). Nonetheless, this capability has yet to be conclusively demonstrated.

During Phase A, only the SCAO system was considered for ANDES, without the inclusion of a High-Contrast mode such as the one implemented for other ELT instruments. Following the PhD research work of A. Simonnin at Lagrange (2022-2025), the ANDES consortium proposed in early 2024 the design and implementation of a coronagraph † module for ANDES. This initiative led to the creation of a dedicated team at Lagrange, which produced an opto-mechanical design and performance simulations for a Lyot-type coronagraph (Fig. 3), demonstrating the feasibility of achieving a contrast of $3{\times}10^{-3}$ at an angular separation of 20 mas.
In addition to this, A. Simonnin's doctoral work resulted in the development of the first end-to-end post-AO simulator (Fig. 3, rightmost panel; APU, Simonnin et al., in preparation), designed for integration into the ANDES pipeline and intended for extensive use by the Consortium. This mode combines high-contrast imaging with high-resolution spectroscopy, thereby enabling the technology readiness levels required to address the ANDES top-level science case for reflected light from rocky exoplanets and further opens significant avenues for the study of temperate gas giants and young Jupiter-like planets.

The Coronagraph Module was officially incorporated into the ANDES baseline during the April 2025 consortium meeting, and the team will participate in the system Preliminary Design Review (PDR) scheduled for spring 2026 (Fig. 1, pink boxes in right panel).

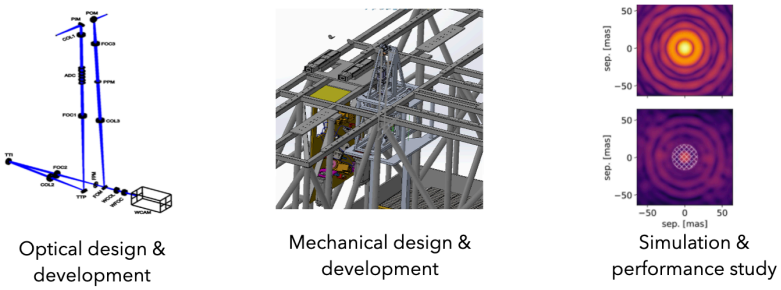


**Fig. 3.** Opto-mechanical design (left and center) and simulation of performances performed by the Lagrange team for the development of the Lyot-type coronagraph of ANDES.

### *4.2 Calibration Unit*

The Calibration Unit (CU), led by Göttingen's group, is essential for providing precise light sources to calibrate three spectrographs, including white-light flats, Fabry-Pérot sources, hollow-cathode lamps, and astrocombs for wavelength calibration. France has contributed significantly to the CU development from the early phases, participating in sub-tasks during Phase A (white-light lamps, mechanical studies, control software, and hollow-cathode lamps) and leading the development of a Light Distribution Point (LDP) test bench during pre-Phase B. In Phase B, France is responsible for the Light Guiding module regrouping the LDP and internal CU fibers, oversees white-light lamps, and provides expertise on hollow-cathode lamps.
Over the last two years, French involvement in the CU and Fiber modules has been limited due to personnel turnover and reduced recognition within the Working Package. The INSU monitoring committee (end 2024) recommended refocusing on high-contrast module contributions. Consequently, the Consortium was informed in spring 2025 that French commitments to the CU will conclude after the Preliminary Design Review (spring 2026) to concentrate national expertise on the coronagraph module (Fig. 1, right).

### *4.3 Other implications*

I. Boisse has been involved in discussions and document preparation for the data reduction software (DRS) and data analysis science (DAS) since the beginning of phase A, drawing on her experience in the visible and

† A coronagraph is an optical instrument designed to block or strongly suppress the light from a bright star so that much fainter nearby sources, such as exoplanets, circumstellar disks, or stellar companions, can be observed

near-infrared (SOPHIE, SOPHIE-red, SPIRou). The ONERA-LAM team is involved and responsible for a sub-WP to analyse and simulate the SCAO mount in collaboration with the responsible in Arcetri.

## 5 Perspectives

ANDES represents a cornerstone instrument for the Extremely Large Telescope (ELT), designed to address some of the most fundamental questions in modern astrophysics and cosmology. ANDES will enable transformative science across four key themes: exoplanets and protoplanetary disks, stars and stellar populations, galaxy formation and the intergalactic medium, and cosmology. Several science cases are in synergy with, e.g., METIS@ELT and space missions such as JWST, ARIEL, and PLATO.
The French scientific community (Fig. 4) plays a significant role in the ANDES consortium, contributing expertise in high-resolution spectroscopy, high-contrast imaging, and the development of advanced instrumental modules. French researchers are actively involved in shaping the scientific cases, particularly in the study of exoplanets, stars, and fundamental cosmology. The recent inclusion in the ANDES baseline of a coronagraph module, initiated by French teams, demonstrates the consortium's adaptive response to scientific needs, enhancing ANDES's capability to detect and, possibly, characterize reflected light from exoplanets. The upcoming Preliminary Design Review in 2026, which will include the work done for the coronagraph module, will be a key step toward.
ANDES is expected to become an important facility for the astronomical community, supporting discoveries that may have a lasting impact. Its development continues through international collaboration, with France contributing to the scientific and technological work that will shape the next phase of astronomical research.

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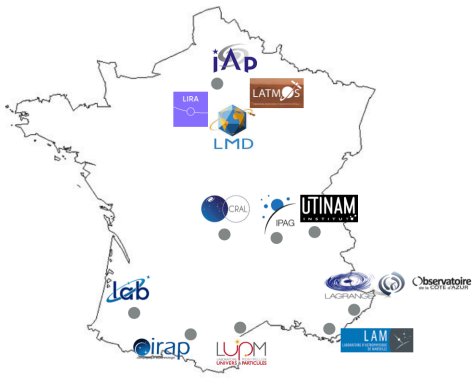


**Fig. 4.** Map of the French institutes where scientific or technological work for ANDES is carried out.

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