



ANDES

science, operations and calibrations

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discovery space

the unique combination of the 39m ELT aperture and ANDES $R=100,000$ spectral resolution simultaneously over the full optical and NIR range will push the frontier of quantitative, high resolution spectroscopy to unprecedented limits, especially in terms of

- **sensitivity**
depth → down to 20+ mag
contrast → down to $< 10^{-8}$
- **diagnostics** → simultaneous [U]BVRIZYJH spectral coverage with an overall spectral fidelity (precision/stability) of 1 m/s or better

science white papers

Ground-breaking exoplanet science with the ANDES spectrograph at the ELT

<https://ui.adsabs.harvard.edu/abs/2025ExA....59...29P/abstract>

talk by **F. Borsa - WG1**

The discovery space of ELT-ANDES. Stars and stellar populations

<https://ui.adsabs.harvard.edu/abs/2024ExA....57...17R/abstract>

talk by **A. Mucciarelli - WG2**

Galaxy formation and symbiotic evolution with the inter-galactic medium in the age of ELT-ANDES

<https://ui.adsabs.harvard.edu/abs/2024ExA....58...21D/abstract>

talk by **S. Salvadori - WG3**

Cosmology and fundamental physics with the ELT-ANDES spectrograph

<https://ui.adsabs.harvard.edu/abs/2024ExA....57....5M/abstract>

talk by **M. Viel - WG4**

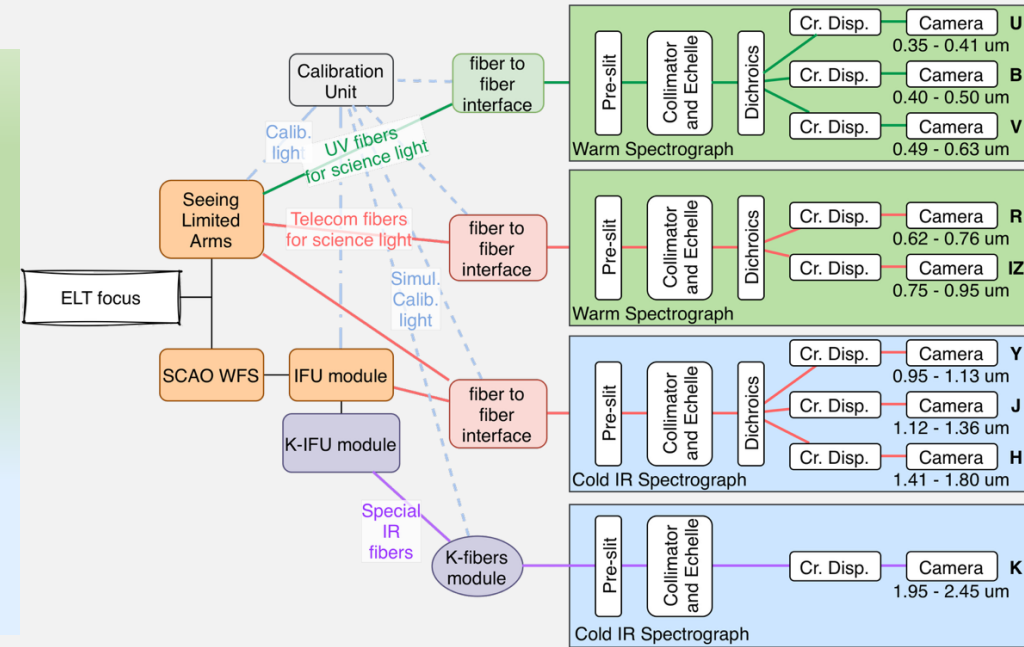
ANDES instrumental concept



modular design

spectrographs

- high spectral resolution, fiber-fed instrument with simultaneous full optical and NIR spectral coverage with **three independent spectrographs** covering the BV, RIZ and YJH bands
- extension to the [U] with an extra arm in the BV spectrograph and to the [K] with a fourth spectrograph
- [U]BV and [K] spectrographs on the Nasmyth platform, RIZ and YJH spectrographs in the Coude' room since they can be fed by very long fibers without significantly losing efficiency



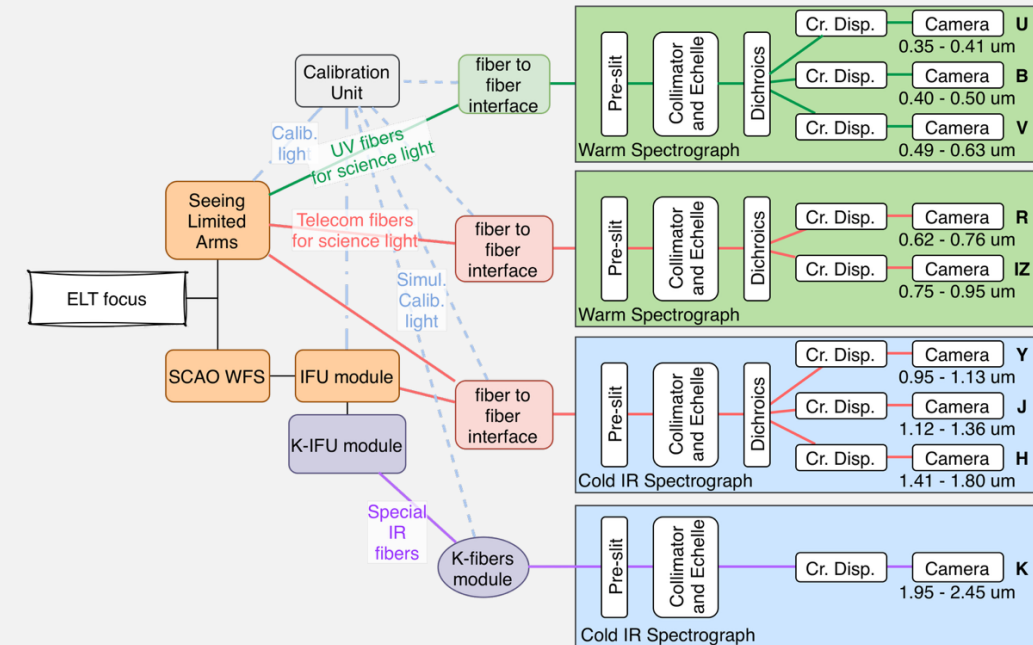
service moduli

- **Front-End (FE):** interface to the telescope, it also includes dichroics, ADCs and secondary guiding systems to split the light and optimally feeding each spectrograph
- **SCAO** module: to be used in combination with a small IFU and optionally with a coronagraph for nearly diffraction limit high resolution, high contrast spectroscopy
- **Calibration Unit (CU):** one per spectrograph, it includes a set of lamps and Fabry-Perot cavities for spectroscopic flats and wavelength calibrations and a few other tools for internal cross-calibrations
- **Fiber-Link (FL):** fiber-to-fiber interface to couple FE fibers (collecting light either from the telescope or from the CU) to the fibers feeding the spectrographs

ANDES instrumental concept

modular design - advantages

- more options for location and interface at the telescope
- mitigate risks associated with technical or managerial issues of individual modules during the construction, and afterwards during commissioning
- more options when in operation
 - most of the time ANDES is expected to work with the different spectrographs simultaneously
 - occasionally (*e.g.* for some science cases and/or observing modes, for technical problems/maintenance) it could also work with selected spectrographs



ANDES observing modes



concept

- different observing modes will be obtained using different and independent groups of fibers (bundles) feeding each spectrograph and selectable in the FE
- inside the spectrographs there will be a pseudo-slit for each observing mode

two baseline observing modes at $R \sim 100,000$

- seeing-limited spectroscopy in the [U]BVRIZYJH bands with two identical apertures on sky optimized for spectral fidelity
- integral-field spectroscopy assisted by adaptive optics (SCAO) in the YJH bands with a small IFU

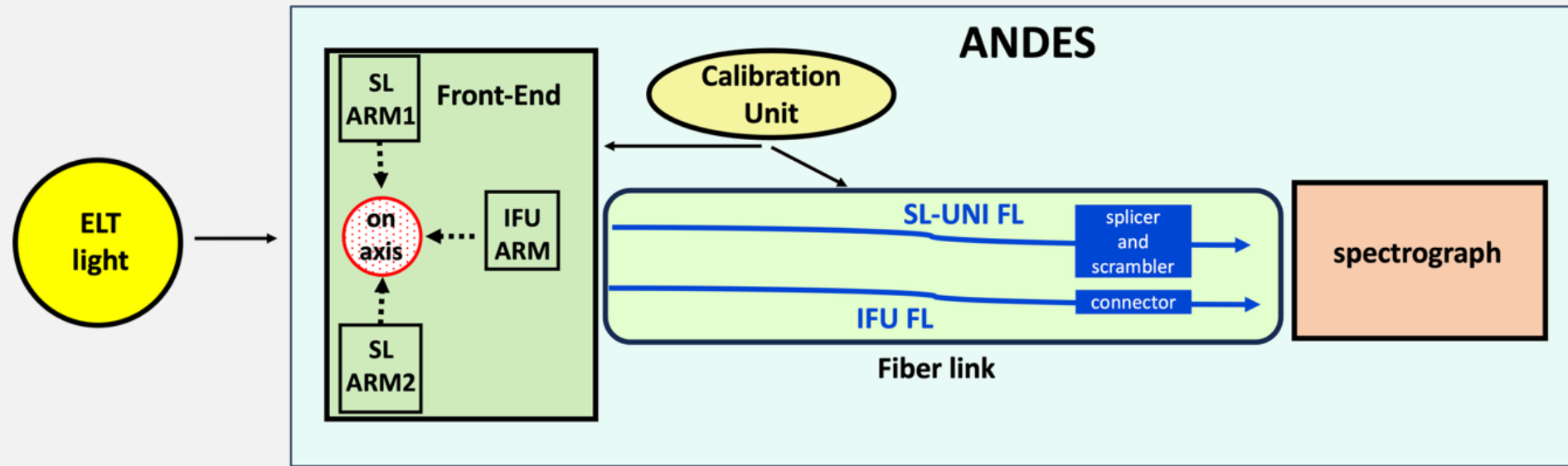
an additional SL observing mode optimized for very faint targets is under evaluation

K-band *work in progress ...*

spectrograph must be compact since it has to be located on the Nasmyth platform → AO assisted

- $R=100,000$, simultaneous observations with the YJH IFU-AO mode, only
- observing mode configuration under discussion/study: multi-mode fibers, possibly arranged in a mini-IFU or single-mode fibers to mitigate the modal-noise problem

ANDES overall functionality



ANDES will collect the light from a Nasmyth focus of the ELT via fibers in the front-end (FE).

When the SL mode is selected, one of the two SL FE (*i.e.* FE1 or FE2) collecting the light from the target will be on-axis, the other will be off-axis to collect the light from a nearby sky or from the CU.

When the IFU-AO mode is selected, the IFU FE, collecting the IR light from the target (optionally attenuated by the insertion of a coronagraph) will be on-axis. The SCAO module, always fixed on-axis, will collect the optical light of the NGS (normally the target itself). The IFU will be mounted on a small de-rotator and it can be offset by $\leq 3''$.

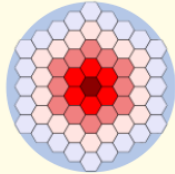
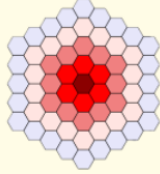
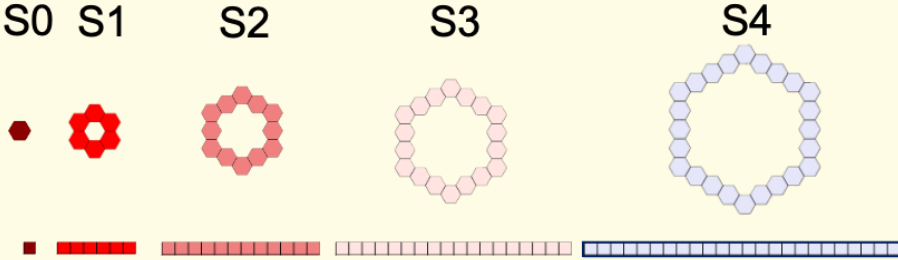
The light coming from the FE fibers will be coupled to the fibers that feed the spectrographs in the FL. In SL-UNI mode the FL will include a splicer and a scrambler, while in IFU-AO mode it will include fiber-to-fiber couplers.

ANDES SL-UNI observing mode



observing mode	front-end	fiber link	spectrograph slit
SL-UNI [U]BV+RIZ+YJH spectrographs two identical apertures simultaneously illuminated by target and sky (SL-UNI-TS), or target and calibration (SL-UNI-TC) for wavelength reference; beam-switching of the two apertures is possible	input light from the telescope on two, individual large fibers	2 bundles of small fibers uniformly illuminated after scrambler & splicer, to maximize spectral fidelity	2 segments of uniformly illuminated fibers along each spectrograph slit

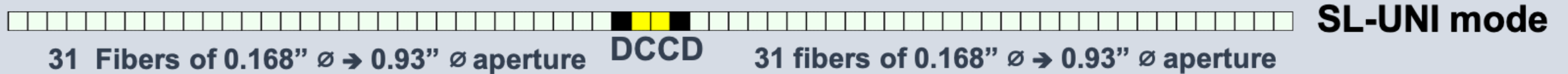
ANDES IFU-AO observing mode

observing mode	front-end	fiber link	spectrograph slit
IFU-AO YJH spectrograph IFU of maximum 61 spaxels; 4 spaxel scales of 7, 16, 35, and 100 mas are foreseen	input light from the telescope on a microlenses fiber bundle 	fiber bundle after fiber to fiber couplers 	4 segments (S1,S2,S3,S4), one per each hexagonal ring around the central spaxel, and the central spaxel (S0) S0 S1 S2 S3 S4 

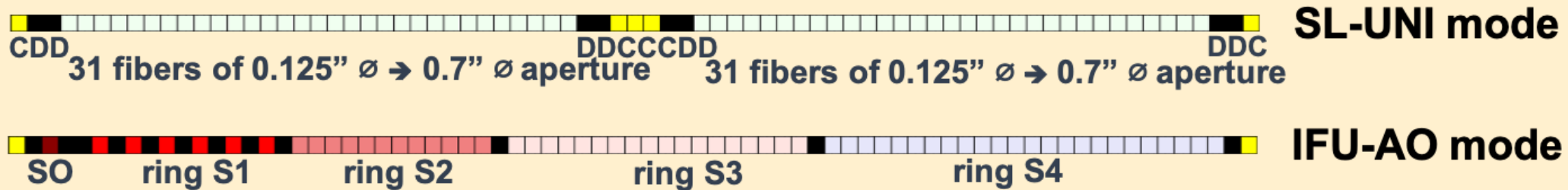
ANDES slit configurations



[U]BV, RIZ spectrographs → 9k x 9k detectors, 0.168" x 11.1" slit

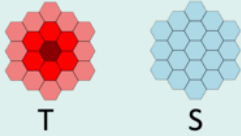
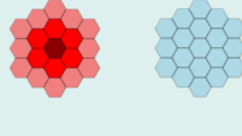


YJH spectrograph → 4k x 4k detector, 0.125" x 9.4" slit



- along each pseudo-slit the fibers of the two aperture bundles in SL mode or of the IFU bundle in the IFU-AO mode will be accommodated together with a few additional *free (dark) fibers* to separate the two SL apertures or the IFU rings on the detector
- during an observation, a few *free* fibers could be optionally illuminated by a calibration (FP) light at the level of the FL to provide a simultaneous wavelength reference

ANDES SL-PSF observing mode

observing mode	front-end	fiber link	spectrograph slit
SL-PSF [U]BV+RIZ+YJH spectrographs two identical apertures simultaneously illuminated by Target and Sky ; beam-switching of the two apertures is possible	input light from the telescope on two bundles of small fibers 	2 bundles of small fibers after fiber to fiber couplers 	2 segments of fibers along each spectrograph slit 

observations of very faint targets in SL-UNI mode → dramatically limited by detector noise, hence an additional mode that will

- preserve the telescope PSF thus offering some flexibility in terms of spectrum extraction, depending on the seeing
- use larger fibers thus working at lower spectral resolution

is highly desirable to improve the overall sensitivity

in particular:

two bundles of 19 fibers each, corresponding to two identical apertures on sky of 1.16'' at R=63k (optical) and of 1.00'' at R=54k (NIR)

bad seeing → it is important to maximize the aperture on sky, hence spectrum extraction can occur over the full aperture

good seeing → reducing the extraction aperture by using only the brightest fibers, thus slightly reducing the signal from the target but significantly reducing the number of pixels that are read-out, with a net increase of the SNR

ANDES calibration strategy

- should enable state-of-the-art, high precision and accurate spectroscopy.;
- should be sufficiently flexible to provide a baseline concept since the early stages of the project but, at the same time, to enable upgrades/new features (if/when relevant and/or affordable) anytime during the project phases.

baseline calibrations of the ANDES spectral data for both the SL and IFU observing modes

- detector bias (only CCDs) and dark frames for dark subtraction and RON determination;
- detector flatfields for bad pixel masking, gain and linearity measurements;
- spectroscopic flatfields using the two SL apertures and the IFU in the FE for determining order location and geometry, and blaze function;
- spectra of wavelength calibration sources (**HCL and FP**)

additional features/tools to possibly improve the calibration performances currently under study

- inclusion of a **iodine absorption cell** in the ANDES FE, to provide a wavelength calibration through the same light path of the science target;
- inclusion of a **fiber masking system** in the ANDES FL slicers/splicers of each spectrograph that will illuminate selected fibers, only, with a calibration light, for an optimal tracing of the PSF along the slit.

possible future upgrades

- inclusion of a **IRS/FTS** for the characterization and monitoring of calibrators;
- **LFCs** for absolute wavelength calibration if/when technical/operational readiness for the systematic calibration of astronomical spectra can be proven.

***off-line* calibrations**

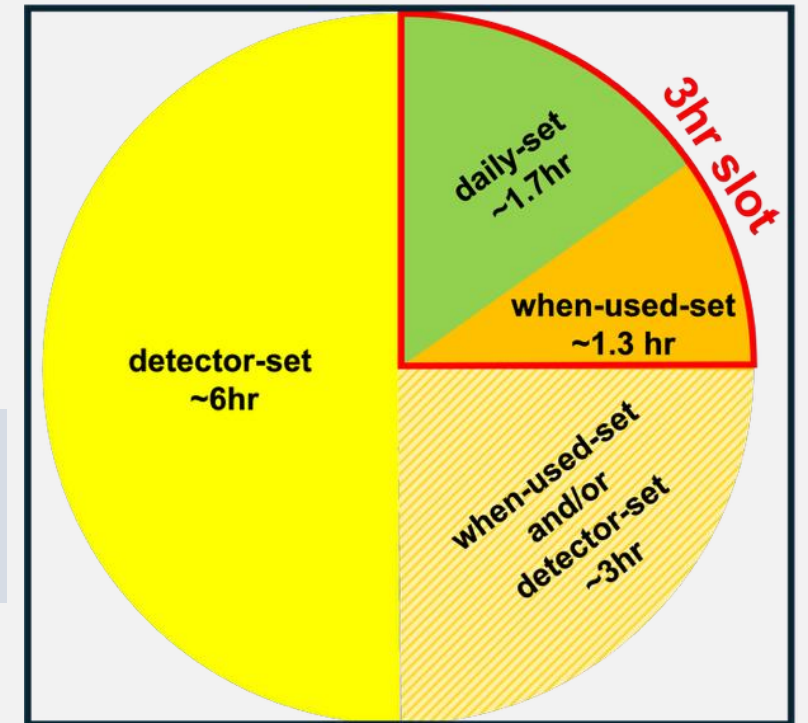
most of the ANDES calibrations of spectral data will occur *off-line*, *i.e.* when ANDES is not observing
they will not require the use of the telescope or the night sky → acquirable anytime within the 24hr when ANDES is not observing;

detector-set: detector bias (only with CCDs), dark and led flat-field frames

daily-set: calibration frames of selected observing modes and configurations, taken normally every day and used also for trending purposes

when-used-set: calibration frames of those observing modes and/or configurations non included in the daily-set, taken when used by ANDES during the night

within the 3hr slot reserved by ESO for daily calibrations → priority to the daily-set and the wavelength and LSF/PSF calibrations which can mostly benefit from a relatively quiet environment



***on-line* calibrations** - when ANDES is observing and required by the science program

- wavelength reference frames simultaneous to the target observation by illuminating with the FP (baseline) light
 - one of the two SL apertures in the FE (SL-UNI-TC observing mode)
 - a few dedicated fibers in the FL, in order to check for possible shifts between day and night wavelength references
- sky spectra, simultaneous with the target obs in the SL-UNI-TS observing mode, before/after a target obs in IFU-AO mode;
- spectra of telluric, RV and/or spectro-photometric standard star spectra;
- spectra of fast rotating stars with inserted a iodine cell for cross-checking daytime wavelength calibration.

for an optimal (e.g. 2 cm/s) barycentric correction

- [U]BV and RIZ spectrographs will have a standard exposure meter optical device (at least one per spectrograph to account for chromaticity)
- YJH spectrograph will likely adopt an exposure meter based on the individual Up The Ramp (UTR) frames from the detector read out

