Synergie nationale scientifique et technologique autour du Spectrographe ANDES

French Collaboration for ANDES

ANDES

ANDES

ANDES IN A NUTSHELL

THE FOUR SCIENCE PRIORITIES AND TOP LEVEL REQUIREMENTS

FRENCH SCIENTIFIC CONTRIBUTIONS

FRENCH TECHNICAL CONTRIBUTION

CONCLUSIONS

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IN A NUTSHELL

ANDES is a modular, stable high-resolution spectrograph for the ELT
It combines common-user capabilities and cutting-edge science cases

LARGE INTERNATIONAL CONSORTIUM INTERNATIONAL 13 COUNTRIES AND 35 INSTITUTES (3 NON-ESO MEMBERS)

- **Brazil:** Federal Univ. of Rio Grande do Norte
- **Canada:** Univ. De Montreal, Herzberg Astrophysics Victoria
- **Denmark:** Univ. Copenhagen, Univ. Aarhus, Danish Tech. Univ.
- **France:** LAM Marseille, LAGRANGE Nice, IPAG Grenoble, IAP Paris, LMD Paris, IRAP/OMP Toulouse, LUPM Montpellier
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- **Sweden:** Uppsala Univ., Lunds Univ., Stockholm Univ.
- **Switzerland:** Univ. de Genève, Univ. Bern
- **United Kingdom:** Univ. of Cambridge, UK Astronomy Technology Centre, Heriot-Watt Univ.
- **USA:** Univ. of Michigan

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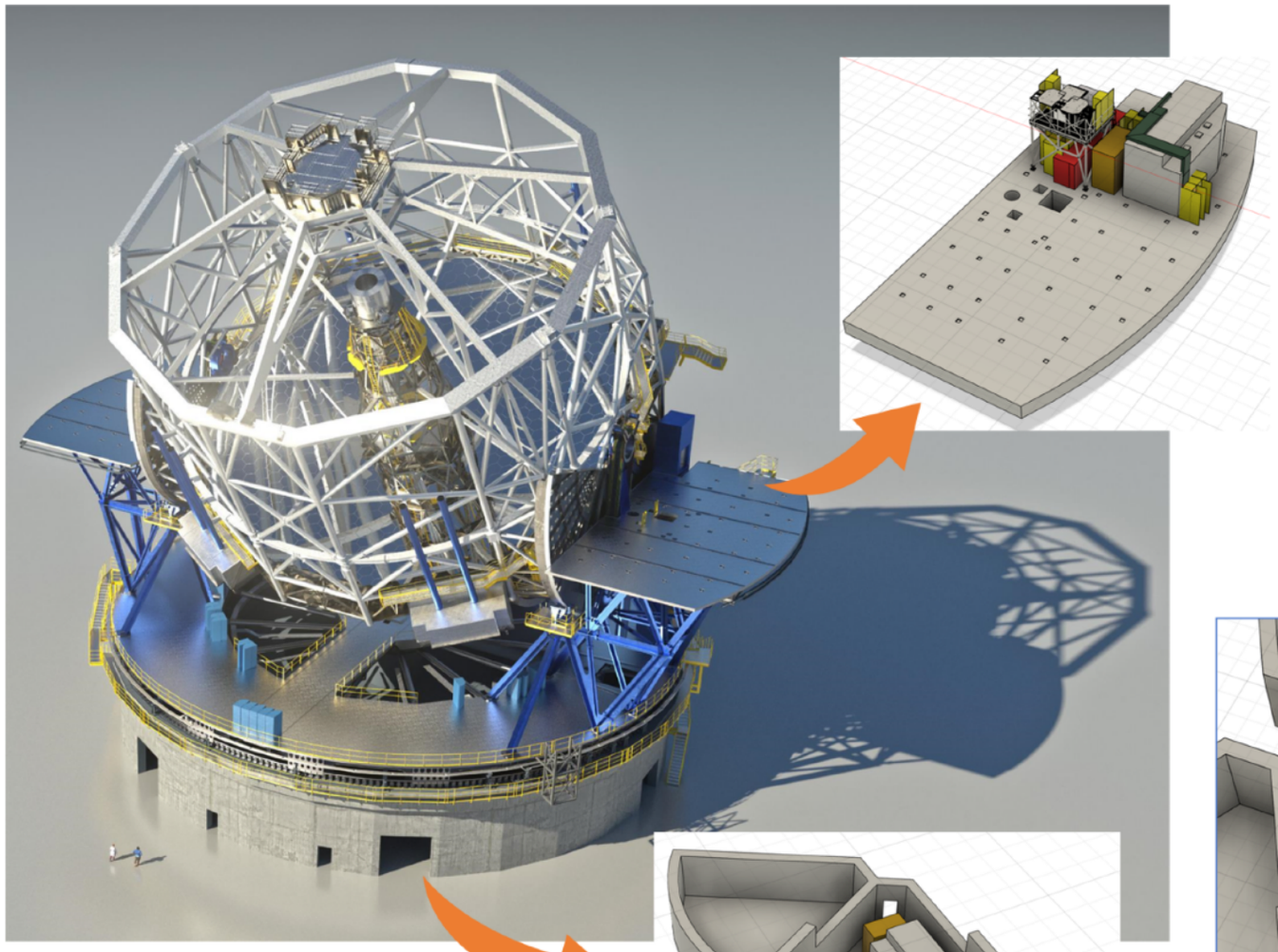
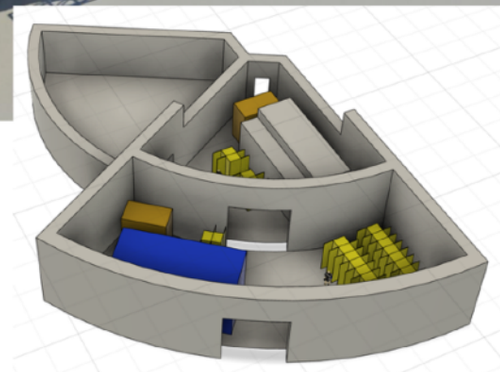
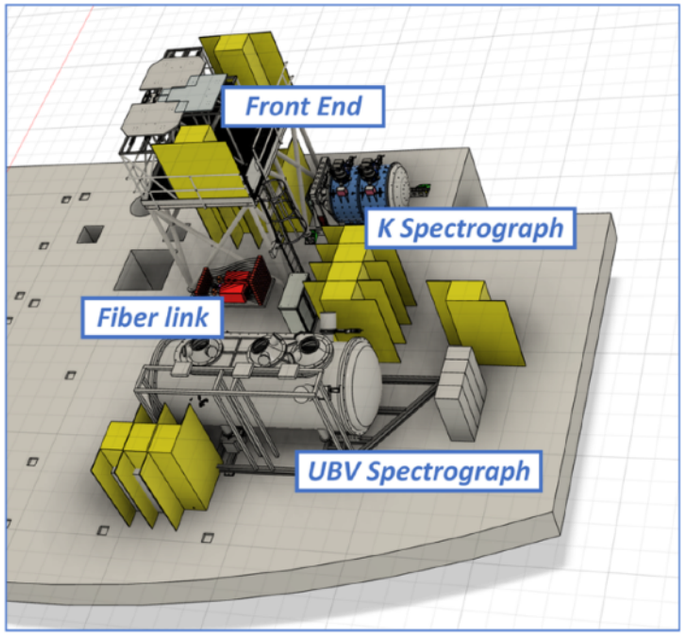
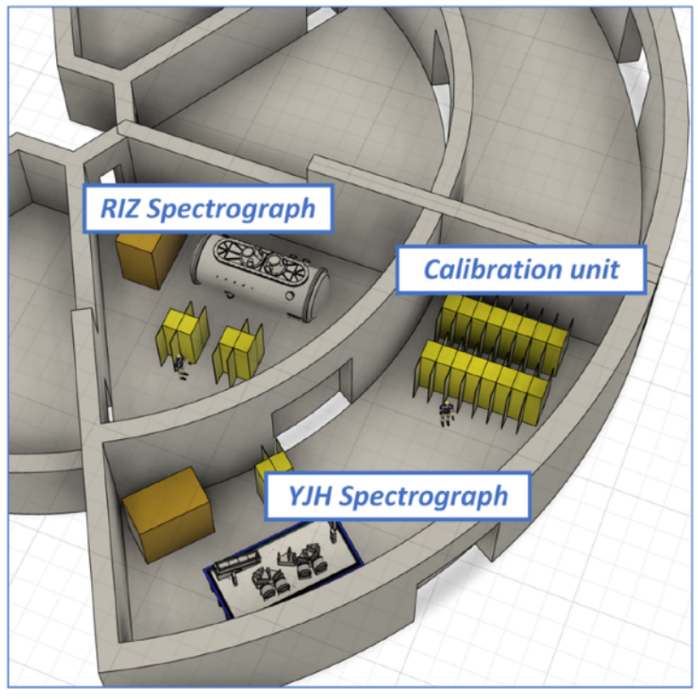
INSTRUMENT ARCHITECTURE

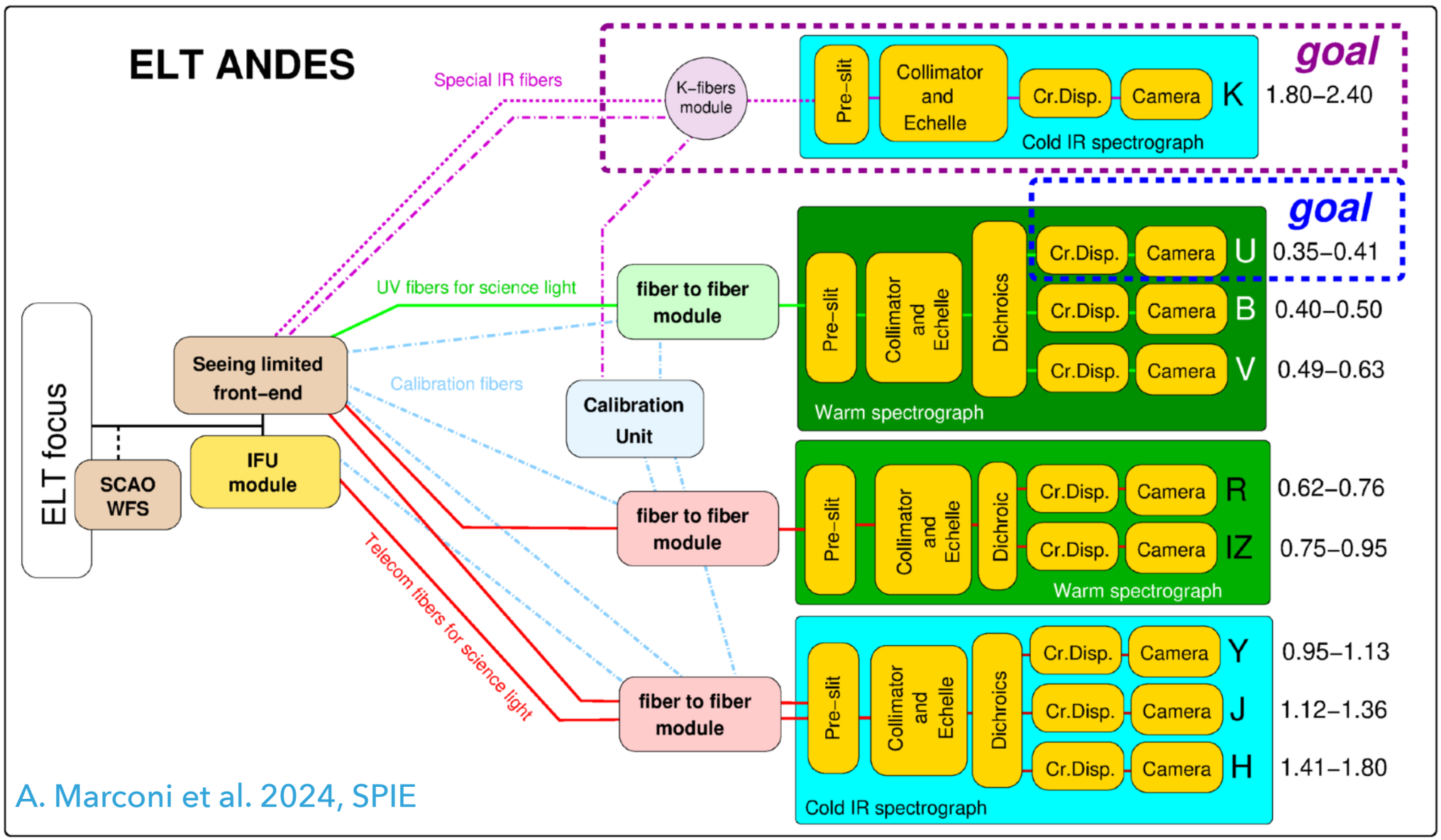








INSTRUMENT ARCHITECTURE



A. Marconi et al. 2024, SPIE

- Modular fiber-fed cross dispersed Echelle spectrograph
- Simultaneous range 0.4-1.8 μm (ultrastable BLUE+RED+NIR) Goal 0.37-2.4 μm; Resolution ~100,000
- Several interchangeable, observing modes: Seeing limited & SCAO+IFU

CALENDAR

ESO signature to the agreement 10 June 2024: ANDES will be installed on ESO's Extremely Large Telescope (ELT)

Phase B | Phase C | Phase D

2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031

ESO Council Approval Dec 2021

Kick Off meeting June 2022

System Architecture Review (SAR) Passed in October 2023

System (PDR)

Funding Review (FR)

Final Design Review (FDR)

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Composition of Science team will be reviewed at Funding Review

> 125 Shared GTO nights

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FRENCH SCIENTIFIC CONTRIBUTIONS

FRENCH TECHNICAL CONTRIBUTION

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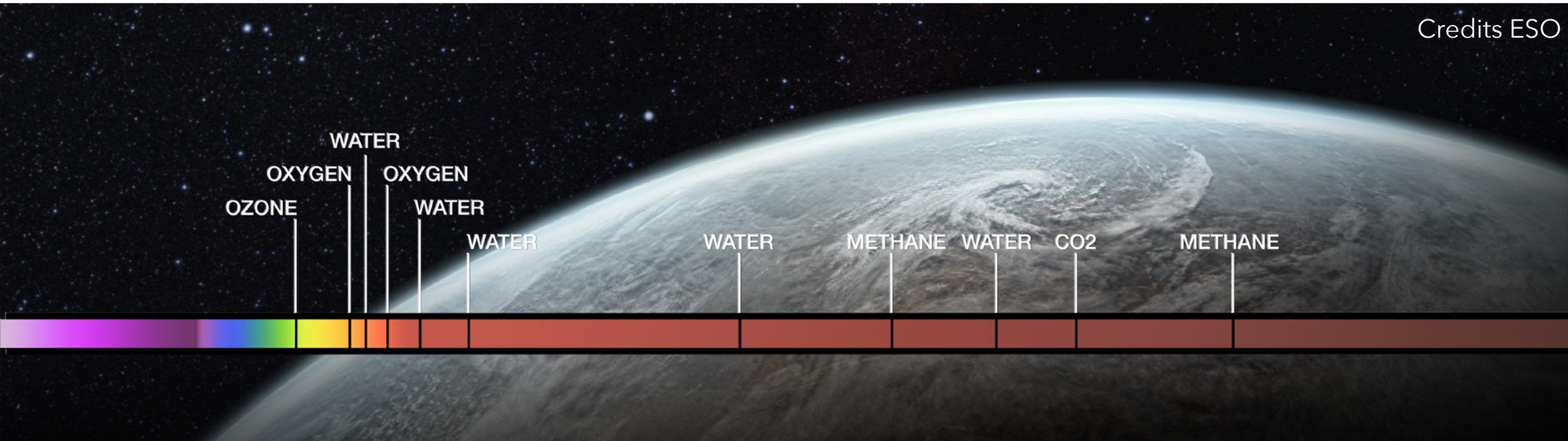
Exploring small rocky planets in the habitable zone of their stars via transmission spectroscopy (priority 1/4) is the leading science case of ANDES, while rocky exoplanet reflected light detection (priority 3/4).
Technical Requirements Specification for ANDES, ESO Document ESO-391757, 2022

More largely for ELT's instruments: the focus is on detecting and quantifying exoplanet atmospheres. ANDES will enable astronomers to analyze their chemical composition, weather, and stratification, requiring ELT's large collecting area to overcome the "photon-starved" regime and ultimately detect signs of life.



TOP LEVEL REQUIREMENTS

- Spectral resolution: R = 100 000
- Wavelength range: 0.5–1.8 μm (requirement), 0.38–2.4 μm (goal)
- Wavelength calibration precision 1 m/s (goal: 20 cm/s), stable at the time scales of several hours

Coverage of all the major molecules
H_2O, O_2, CO_2, CH_4, NH_3, C_2H_2, HCN

Most of the stellar flux for M dwarfs, which are prime targets

K-band goal is highly beneficial for gas giant planets science cases (2 to 2.4 μm)

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(2 to 2.4 μm)

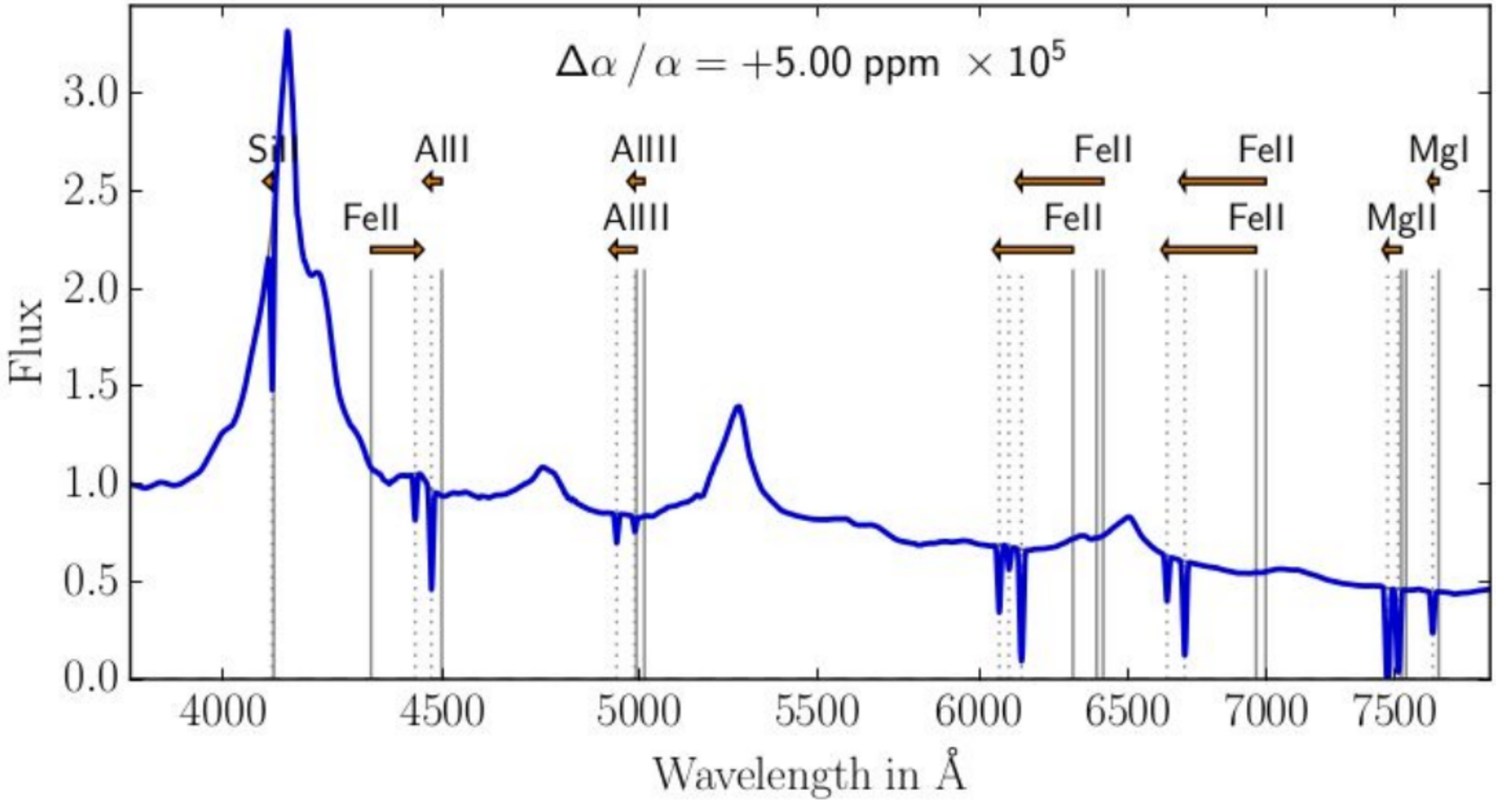
AO+Coronagraph and diffraction-limited Integral Field Unit mode in Y, J and H bands with 61 spaxels and 4 spaxels scales in the 10-100 mas range. Field of view from ≈10×10 to 100 ×100 mas

High PSF stability on daily timescales

Access to the reflected light signal

The standard model reproduces most observations but relies on poorly understood physics like inflation, dark matter, and dark energy. It's essential to test its foundations with stringent astrophysical constraints, whether they confirm or challenge the current paradigm.

ANDES absorption spectroscopy of distant quasars can probe key questions: variation of fundamental constants (priority 2/4), direct measurement of the cosmic accelerations (Sandage test, priority 4/4); (iii) Primordial nucleosynthesis and (iv) evolution of the CMB temperature



TOP LEVEL REQUIREMENTS

- Spectral resolution: R = 100 000
- Wavelength range: 0.37–0.84 μm (requirement), 0.33–0.9 μm (goal)

Cosmic variation of CBM temperatures
Characterisation of primitive stars
Redshift drift
Mass determination of Earth-like objects

- Wavelength calibration precision 0.7 m/s (goal: 0.5 cm/s)

Precision: 0.7 m/s (goals 0.5m/s) --> Fundamental constants
Accuracy: 1 m/s ---> Fundamental constants
Stability : 2 cm/s over the lifetime of the instrument --> Sandage Test

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FRENCH INVOLVEMENT

Karine Perraut : repr. INSU and Steering committee

Executive Board
1 representative per country
Bruno Leonardo Canto Martins, Lise Christensen, Isabelle Boisse, Klaus Strassmeier, Andrzej Niedzielski, Nuno C. Santos, Jonay Gonzalez Hernandez, Nikolai Piskunov, Christophe Lovis, Martin Haehnelt, Elena Gallo

I. Boisse LAM/OHP and A. Chiavassa (Lagrange)

Project Management Team
Omar Gabella, Lise Christensen, Manuel Amate, Izan de Castro Leão, Frédérique Baron, Piotr Masłowski, Elena Gallo + subsystems PMs

O. Gabella (LUPM)
(deputy P. Berio, Lagrange)

Science Team

I. Boisse (LAM), X. Bonfils (IPAG), A. Chiavassa (Lagrange), F. Debras (IRAP), M. Turbet (LMD), P. Noterdaeme (IAP)

Instrument Scientist Team
Silva Järvinen, Christophe Lovis, Oscar Gonzalez, Wolfgang Brandner, Elena Mason

M. N'Diaye (Lagrange)

SCAO
Italy
Enrico Pinna/ Chiara Selmi

→ 3 leading Modules

- Module Coronagraph: M. N'Diaye, A. Chiavassa, P. Bério (co-head) Lagrange
- Module IFU Calibration: J. Seidel and M. N'Diaye (Lagrange)
- Module IFU Performance: under discussion (Sweden/Lagrange)

Software
Portugal
Manuel Monteiro

DRS: I. Boisse (LAM)

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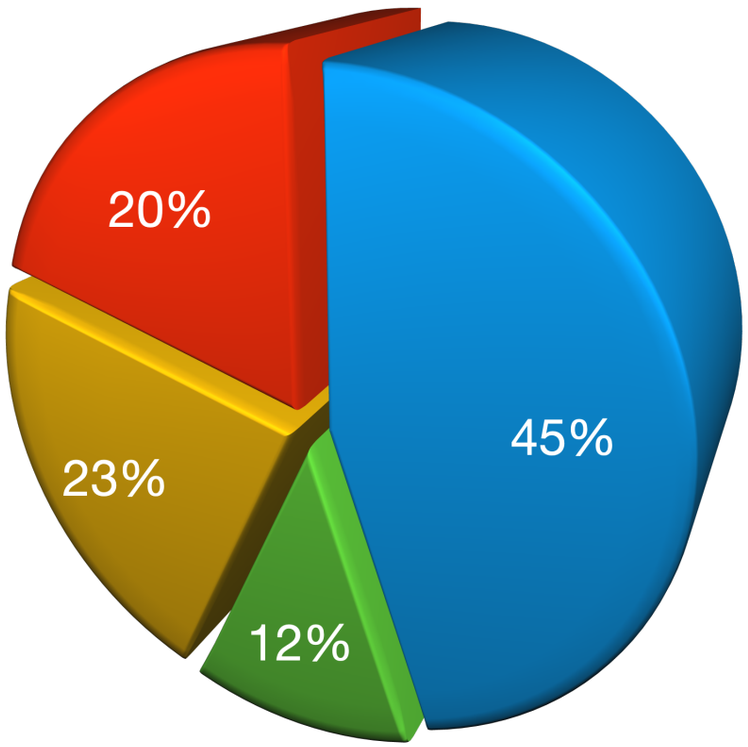


Resp. R. Maiolino (UK)

100 members in 4 Working Groups.
4 science referred papers in 2024-2025

WG1 45 me.

Exoplanets: characterization of Exoplanet atmosphere - detection of signature of life

Protoplanetery discs: dynamics - chemistry - physical conditions in the inner regions

I. Boisse (LAM), X. Bonfils (IPAG), A. Chiavassa (Lagrange), F. Debras (IRAP), M. Turbet (LMD)

WG2 23 me.

Stellar populations: metal enrichment and dynamics of extragalactics star cluster - resolved stellar populations

Stellar astrophysics: abundance of solar-type and cooler dwarfs in galactic disc bulge - halo and nearby dwarfs: tracing metal enrichment of Pop III stars in nearby universe

A. Chiavassa (Lagrange)

WG3 20 me.

Intergalactic medium: signature of reionization and early enrichment of ISM - IGM observed in high-z quasar spectra **Super massive black hole:** low-mass end

Galaxy evolution: massive early type galaxies epochs of formation and assembly

P. Noterdaeme (IAP)

WG4 12 me.

Fundamental physics: variation of fundamental constants - α, mp/me, Sandage test

P. Noterdaeme (IAP) –> co-Chair

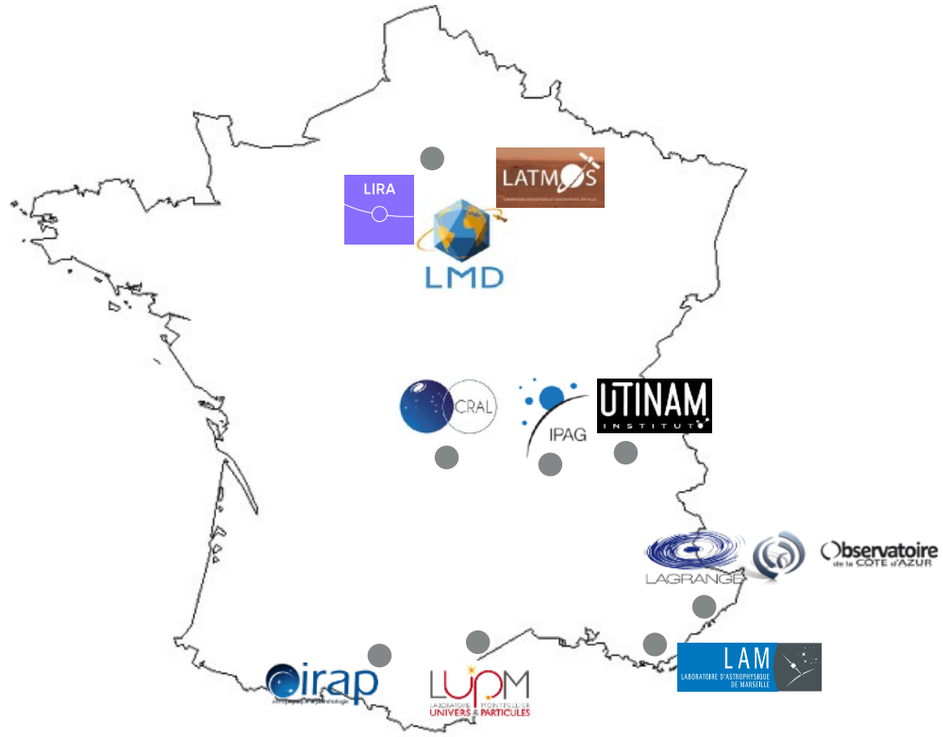
FRENCH CONTRIBUTION – EXOPLANETS AND PROTOPLANETARY DISKS

Ground-breaking Exoplanet Science with the ANDES spectrograph at the ELT

Enric Palle[1,2*], Katia Biazzo[3], Emeline Bolmont[4,5], Paul Molliere[6], Katja Poppenhaeger[7,8], Jayne Birkby[9], Matteo Brogi[10,11], Gael Chauvin[12], Andrea Chiavassa[12], Jens Hoeijmakers[13], Emmanuel Lellouch[14], Christophe Lovis[15], Roberto Maiolino[16], Lisa Nortmann[17], Hannu Parviainen[1,2], Lorenzo Pino[18], Martin Turbet[19,20], Jesse Wender[21], Simon Albrecht[22], Simone Antoniucci[3], Susana C. Barros[23,24], Andre Beaudoin[25], Bjorn Benneke[25], Isabelle Boisse[26], Aldo S. Bonomo[27], Francesco Borsa[28], Alexis Brandeker[29], Wolfgang Brandner[6], Lars A. Buchhave[30], Anne-Laure Cheffot[18], Robin Deborde[16], Florian Debras[31], Rene Doyon[25], Paolo Di Marcantonio[32], Paolo Giacobbe[11], Jonay I. González Hernández[1,2], Ravit Helled[33], Laura Kreidberg[6], Pedro Machado[34,35], Jesus Maldonado[36], Alessandro Marconi[37], B.L. Canto Martins[38], Adriano Miceli[39,17], Christoph Mordasini[40], Mamadou N'Diaye[12], Andrezj Niedzielski[41], Brunella Nisini[3], Livia Origlia[42], Celine Peroux[43], Alex G.M. Pietrow[7], Enrico Pinna[18], Emily Rauscher[44], Sabine Reffert[45], Philippe Rousselot[46], Nicoletta Sanna[18], Adrien Simonnin[12], Alejandro Suárez Mascareño[1,2], Alessio Zanutta[47], Mathias Zechmeister[17]

[1*]Instituto de Astrofísica de Canarias (IAC), 38200 La Laguna, Tenerife, Spain.
[2]Deptartamento de Astrofísica, Universidad de La Laguna (ULL), 38206 La Laguna, Tenerife, Spain.
[3]INAF - Astronomical Observatory of Rome, I-00043 Monte Porzio Catone, Rome, Italy.
[4]Observatoire de Genève, Université de Genève, Chemin Pegasi 51, 1290, Sauverny, Switzerland.
[5]Centre sur la Vie dans l'Univers, Université de Genève, Geneva, Switzerland.

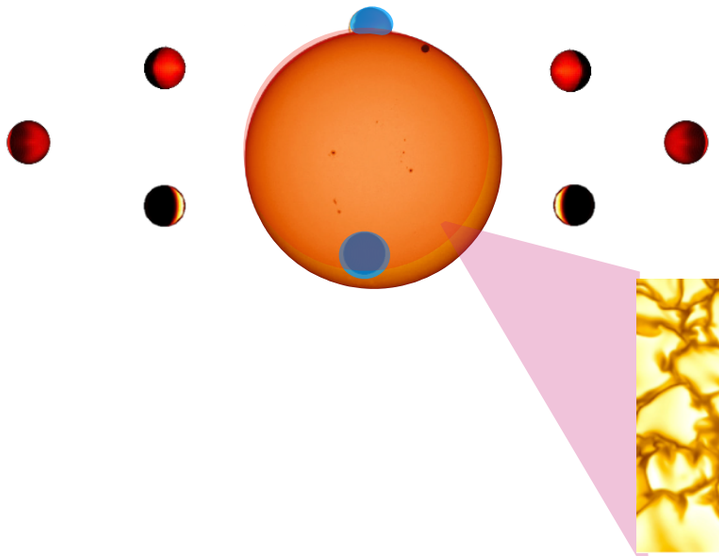
Palle et al. 2025



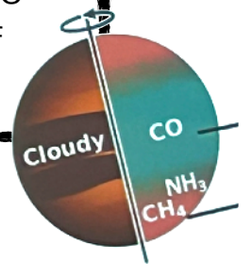
Significant contribution in terms of modeling and instrumental design for ANDES scientific cases (reflected light).

ANDES

Transmission & emission spectroscopy

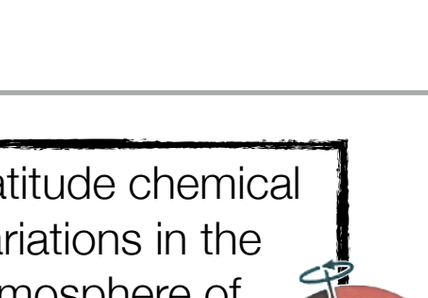


Latitude chemical variations in the atmosphere of brown dwarfs



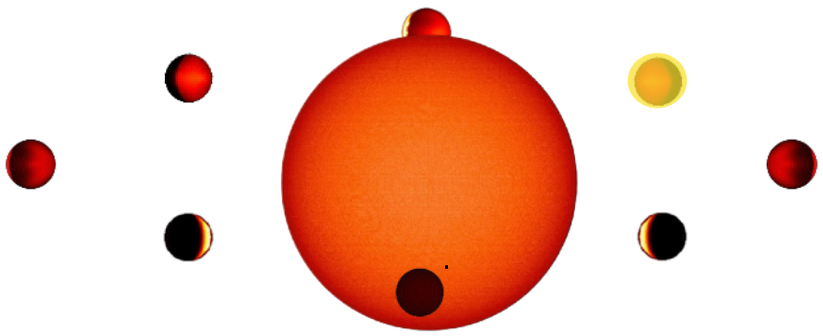
Atmospheric physics of temperate gaseous and sub-Neptunes exoplanets

Atmospheric characterization, circumplanetary disks, exomoons of young gas giant planets

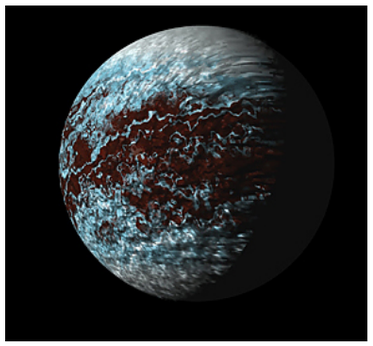


Stellar contamination: activity, molecular absorption, variability

Reflected light spectroscopy



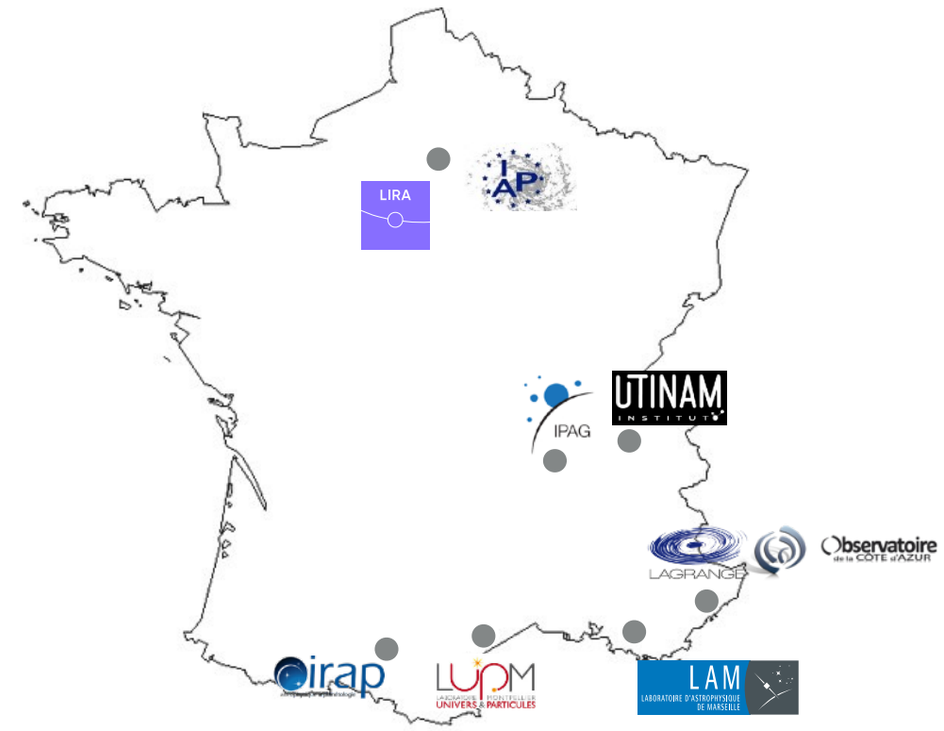
Presence of atmosphere, cloud properties and surface composition, albedo of rocky planets and Super Earth



FRENCH CONTRIBUTION – STARS AND STELLAR POPULATION

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

Ian U. Roederer[IUR1,IUR2*], Julián D. Alvarado-Gómez[JAG], Carlos Allende Prieto[CAP1,CAP2], Vardan Adibekyan[VA], David Aguado[DA1,DA2], Pedro J. Amado[PJA], Eliana M. Amazo-Gómez[EMAG], Martina Baratella[MBA1,MBA2], Sydney A. Barnes[SAB], Thomas Bensby[TB], Lionel Bigot[LB], Andrea Chiavassa[AC], Armando Domiciano de Souza[AD], Camilla Juul Hansen[CJH], Silva P. Järvinen[SPJ], Andreas J. Korn[AJK], Sara Lucatello[SL], Laura Magrini[LM], Roberto Maiolino[RM], Paolo Di Marcantonio[PM], Alessandro Marconi[AMa], José R. De Medeiros[JRM], Alessio Mucciarelli[AM1,AM2], Nicolas Nardetto[NNa], Livia Origlia[LO], Celine Peroux[CP], Katja Poppenhäger[KP1, KP2], Cristina Rodríguez-López[CRL], Donatella Romano[DR], Stefania Salvadori[SN], Patrick Tisserand[PT], Kim Venn[KV1], Gregg Wade[GAW], Alessio Zanutta[AZ]



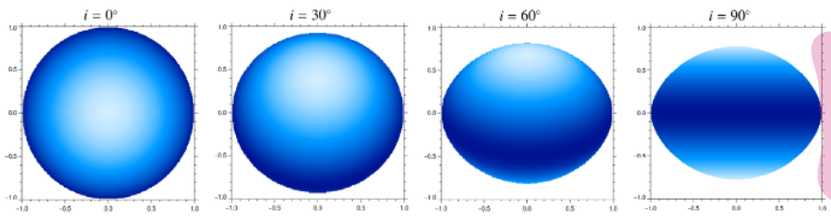
6 scientific cases (out of a total of 17) come from the French community

+ several other expressions of interest

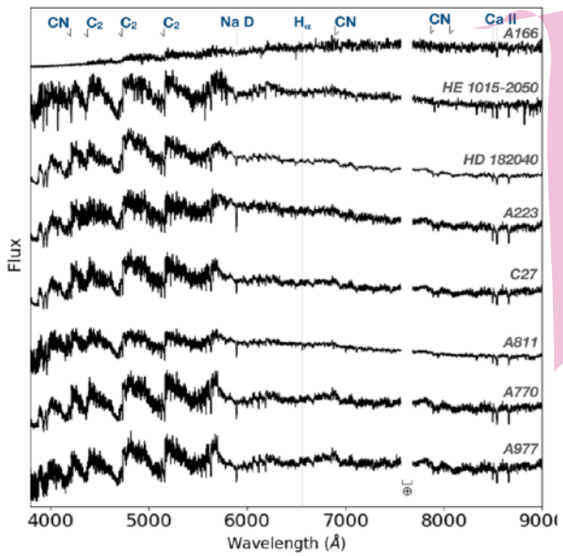
Roederer et al. 2024

ANDES

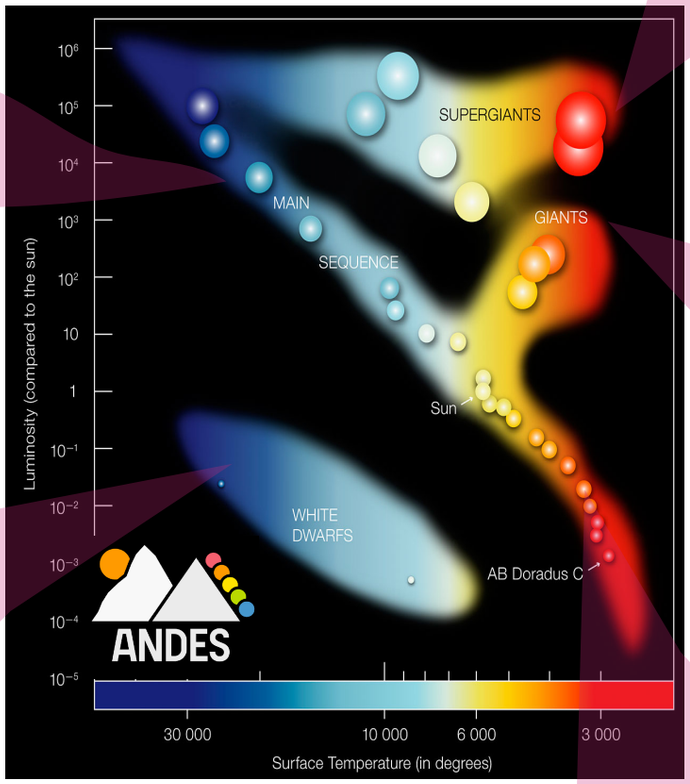
Fast rotating stars:
Subtle effects of rotation in spectral lines and gravity darkening



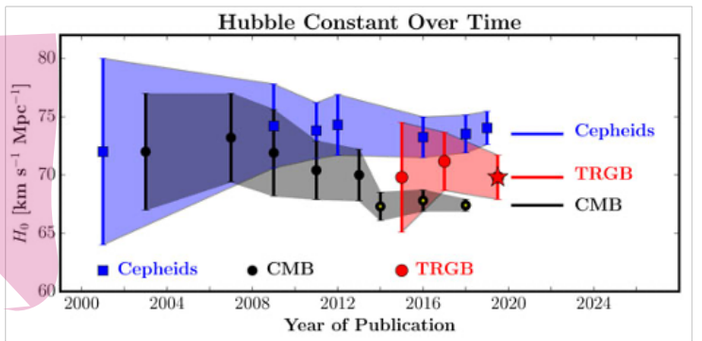
Products of White Dwarf mergers in Milky Way thin disk, bulge, halo, and other galaxies

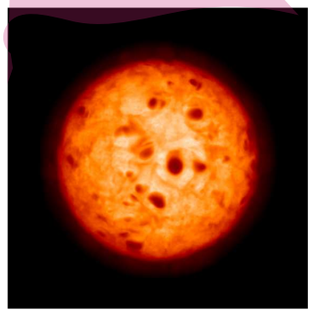


Chemical composition of massive evolved stars in nearby Galaxies

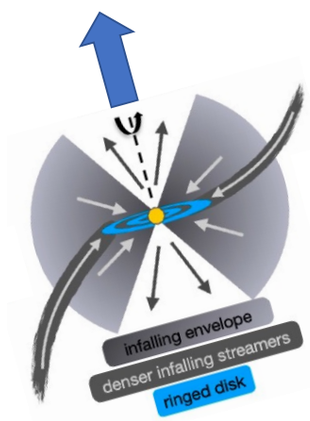


Calibrating properties of Cepheid variables for the cosmic distance ladder





Cool dwarf stars:
Atmospheric parameters, chemical composition, velocity fields, circumstellar material



Magnetism of newborn protostars

FRENCH CONTRIBUTION – GALAXY AND INTERGALACTIC MEDIUM

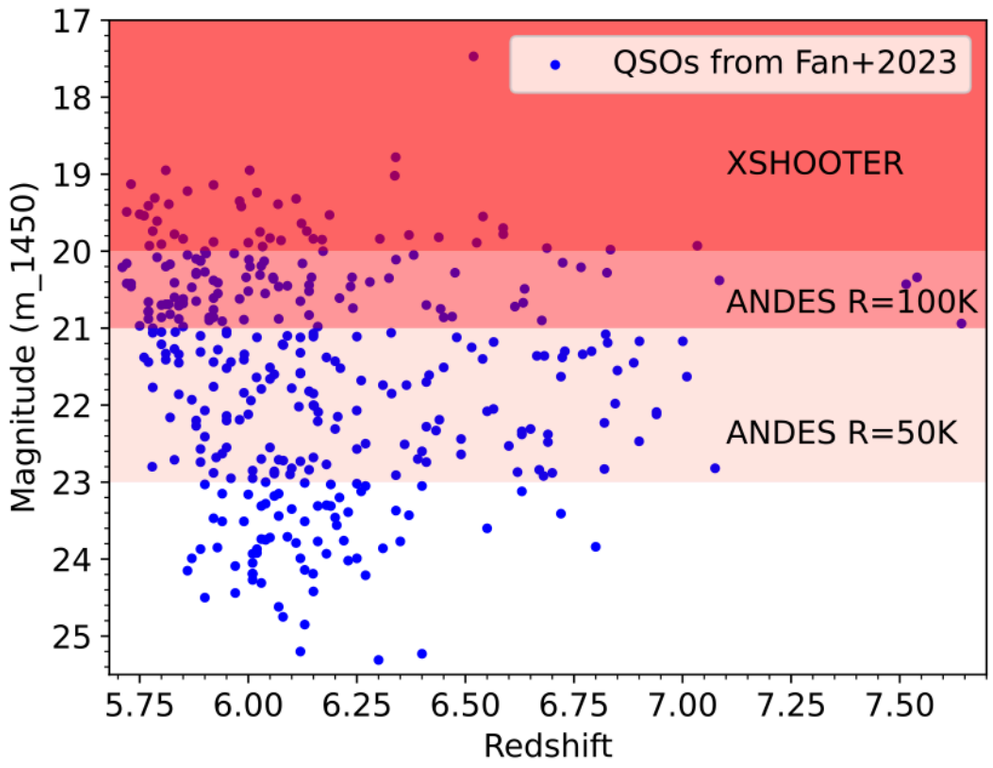
Galaxy Formation and Symbiotic Evolution with
the Inter-Galactic Medium in the Age of
ELT-ANDES

Valentina D'Odorico[1,2,3*], James S. Bolton[4], Lise Christensen[5],
Annalisa De Cia[6,7], Erik Zackrisson[8,9], Aron Kordt[8],
Luca Izzo[10,5], Jiangtao Li[11], Roberto Maiolino[12],
Alessandro Marconi[13,14], Philipp Richter[15,16], Andrea Saccardi[17],
Stefania Salvadori[13,14], Irene Vanni[13,14], Chiara Feruglio[1,3],
Michele Fumagalli[18], Johan P. U. Fynbo[5], Pasquier Noterdaeme[19],
Polychronis Papaderos[20], Céline Péroux[6], Aprajita Verma[21],
Paolo Di Marcantonio[1], Livia Origlia[22], Alessio Zanutta[23]

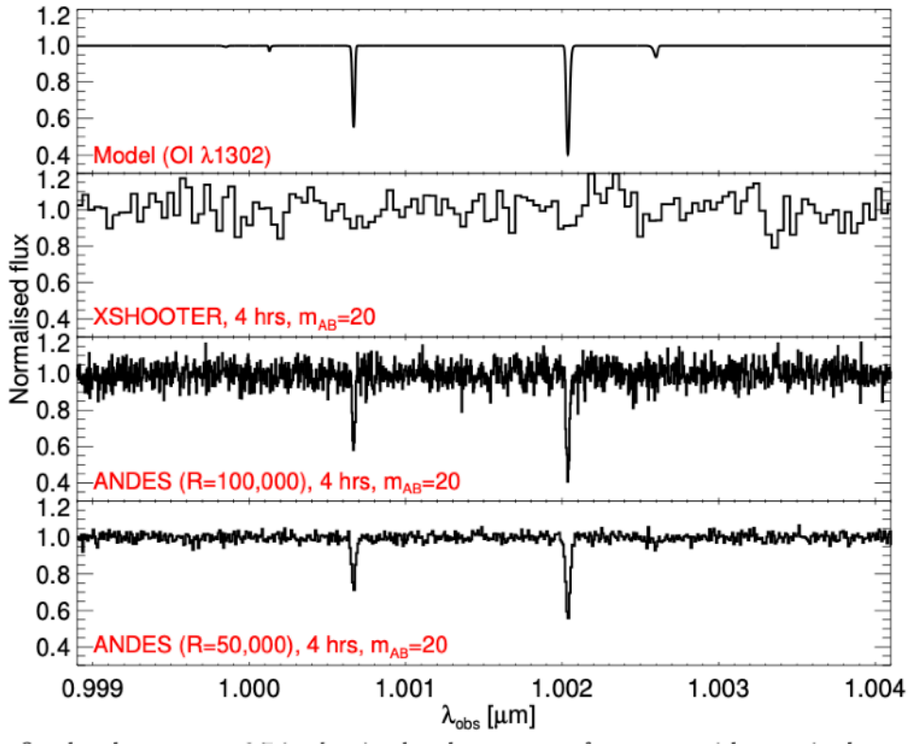
Valentina D'Odorico et al. 2024

FRENCH CONTRIBUTION – GALAXY AND INTERGALACTIC MEDIUM

Probing the gas in, around and outside galaxies from the local Universe up to the reionisation epoch



Probing the gas in, around and outside galaxies from the local Universe up to the reionisation epoch



FRENCH CONTRIBUTION – COSMOLOGY AND FUNDAMENTAL PHYSICS

Cosmology and fundamental physics with the
ELT-ANDES spectrograph

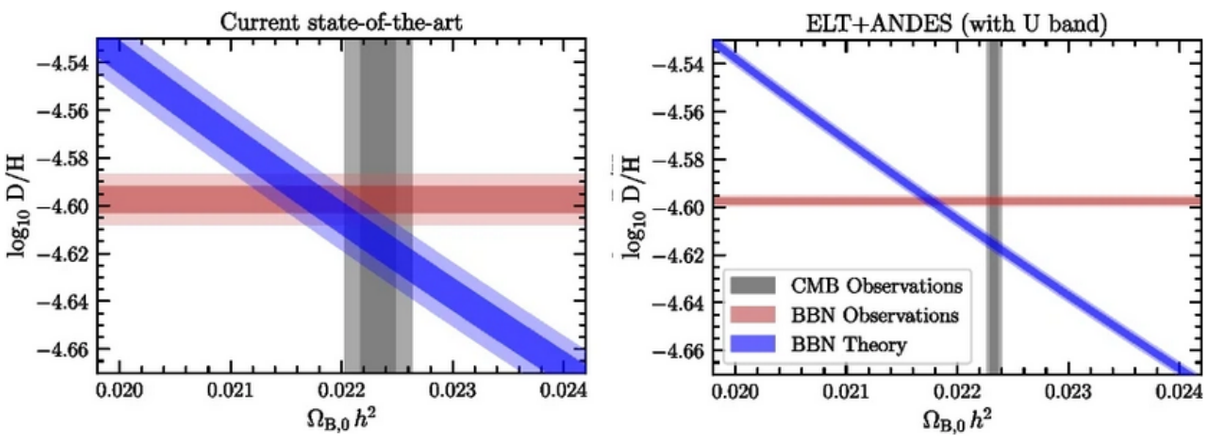
C.J.A.P. Martins[1,2*], R. Cooke[3], J. Liske[4], M.T. Murphy[5],
P. Noterdaeme[6,7], T.M. Schmidt[8], J.S. Alcaniz[9], C.S. Alves[1,10],
S. Balashev[11], S. Cristiani[12,13,14], P. Di Marcantonio[12],
R. Génova Santos[15,16], R.S. Gonçalves[17,9],
J. I. González Hernández[15,16], R. Maiolino[18], A. Marconi[19],
C.M.J. Marques[1,2,20], M.A.F. Melo e Sousa[1,20], N.J. Nunes[21],
L. Origlia[22], C. Péroux[23,24], S. Vinzl[25], A. Zanutta[26]

Martins et al. 2024

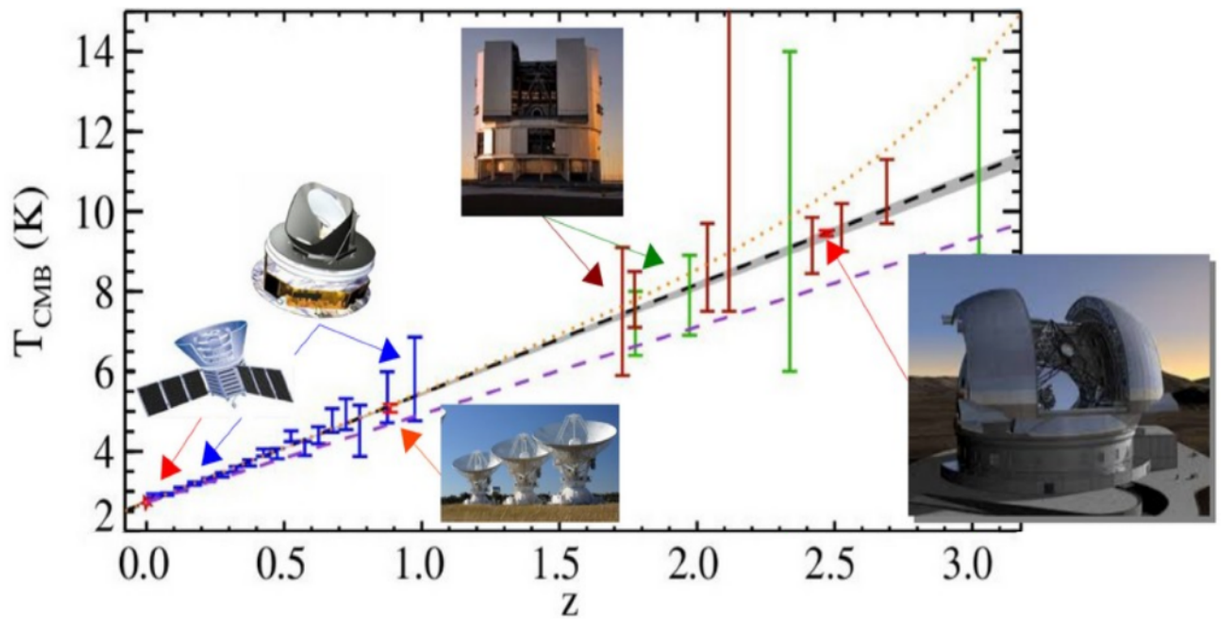
FRENCH CONTRIBUTION – COSMOLOGY AND FUNDAMENTAL PHYSICS

Constrain the proton-to-electron mass ratio with cosmic time, hunting for new physics

BBN nucleosynthesis: primordial composition of the Universe



T_{CMB}: Constrain deviation from the linear relation with z (adiabatic expansion of the Universe): new physics? variation of fundamental constants



ANDES

ANDES IN A NUTSHELL

THE FOUR SCIENCE PRIORITIES AND TOP LEVEL REQUIREMENTS

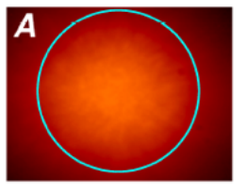
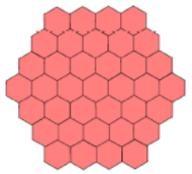
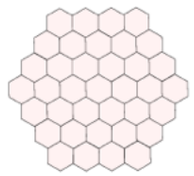
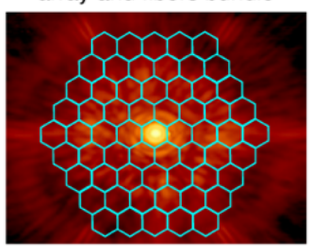
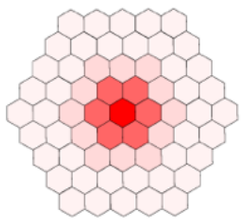
FRENCH SCIENTIFIC CONTRIBUTIONS

FRENCH TECHNICAL CONTRIBUTION

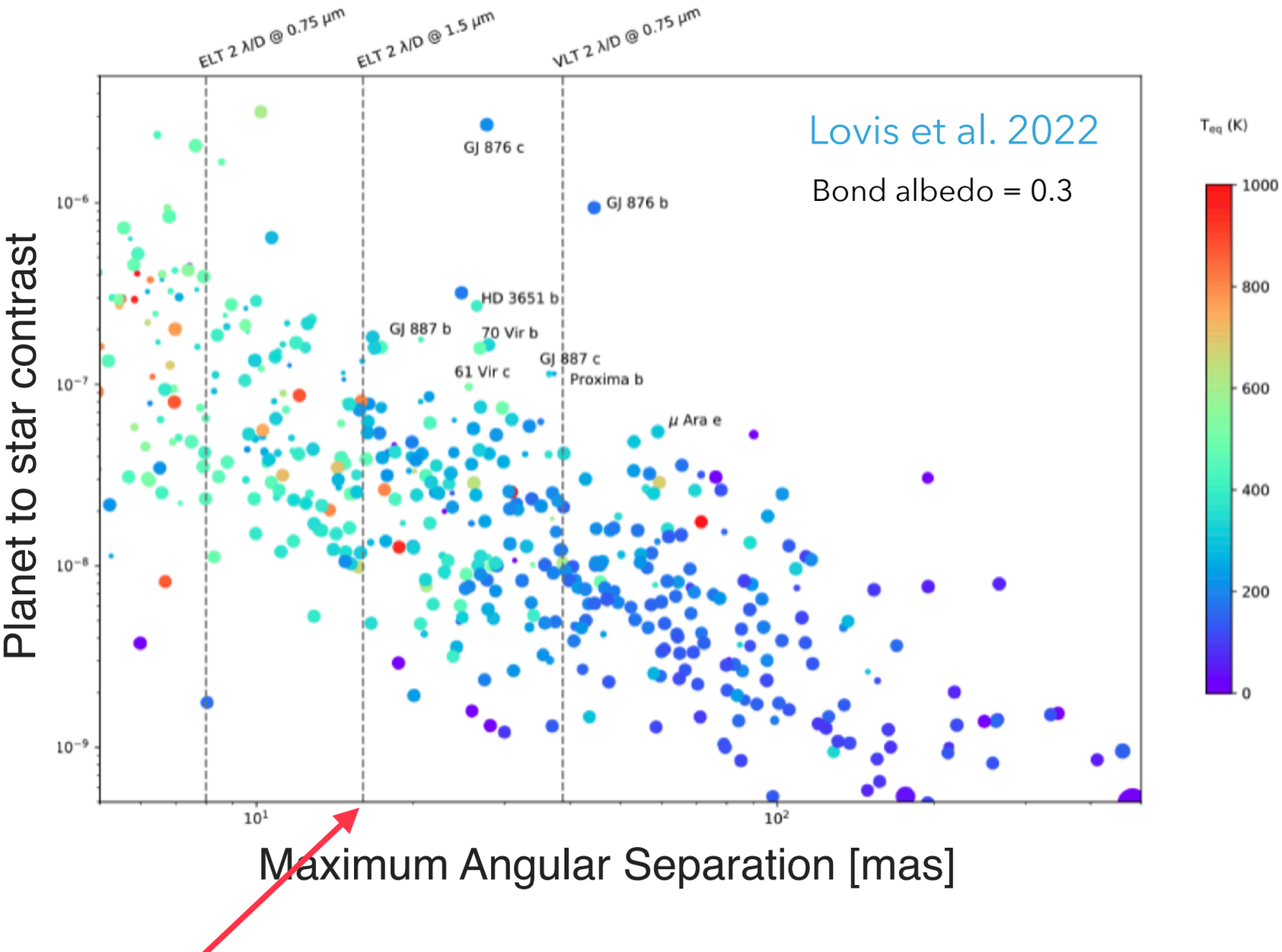
CONCLUSIONS

OBSERVATION MODES

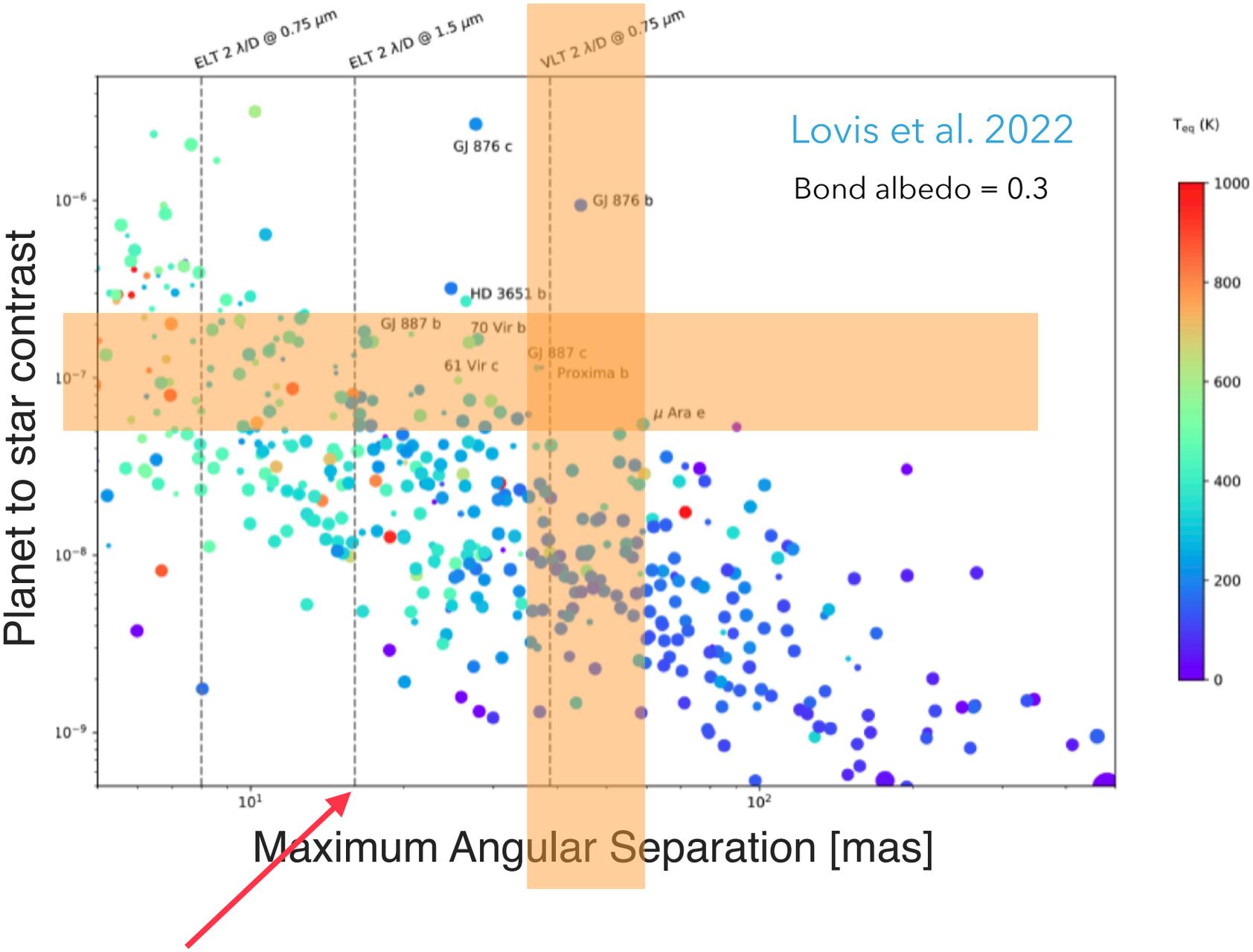
Transmission science cases

	Front–end	Fiber–to–fiber interface	Light distribution along spectrometer slit
Seeing limited observing mode	PSF on single large fiber  	Light distribution on fibers bundle after scrambler and slicer  	
IFU–SCAO observing mode	PSF on microlenses array and fibers bundle 	Light distribution on fibers bundle after fiber to fiber couplers 	

Reflected light science cases


ELT 2 λ/D @ 0.75 μm
ELT 2 λ/D @ 1.5 μm
VLT 2 λ/D @ 0.75 μm
Lovis et al. 2022
Bond albedo = 0.3
GJ 876 c
GJ 876 b
HD 3651 b
GJ 887 b
70 Vir b
GJ 887 c
61 Vir c
Proxima b
μ Ara e
T_{eq} (K)
1000
800
600
400
200
0
Planet to star contrast
Maximum Angular Separation [mas]
ANDES threshold
in H band

Proxima Cen 10^{-7}

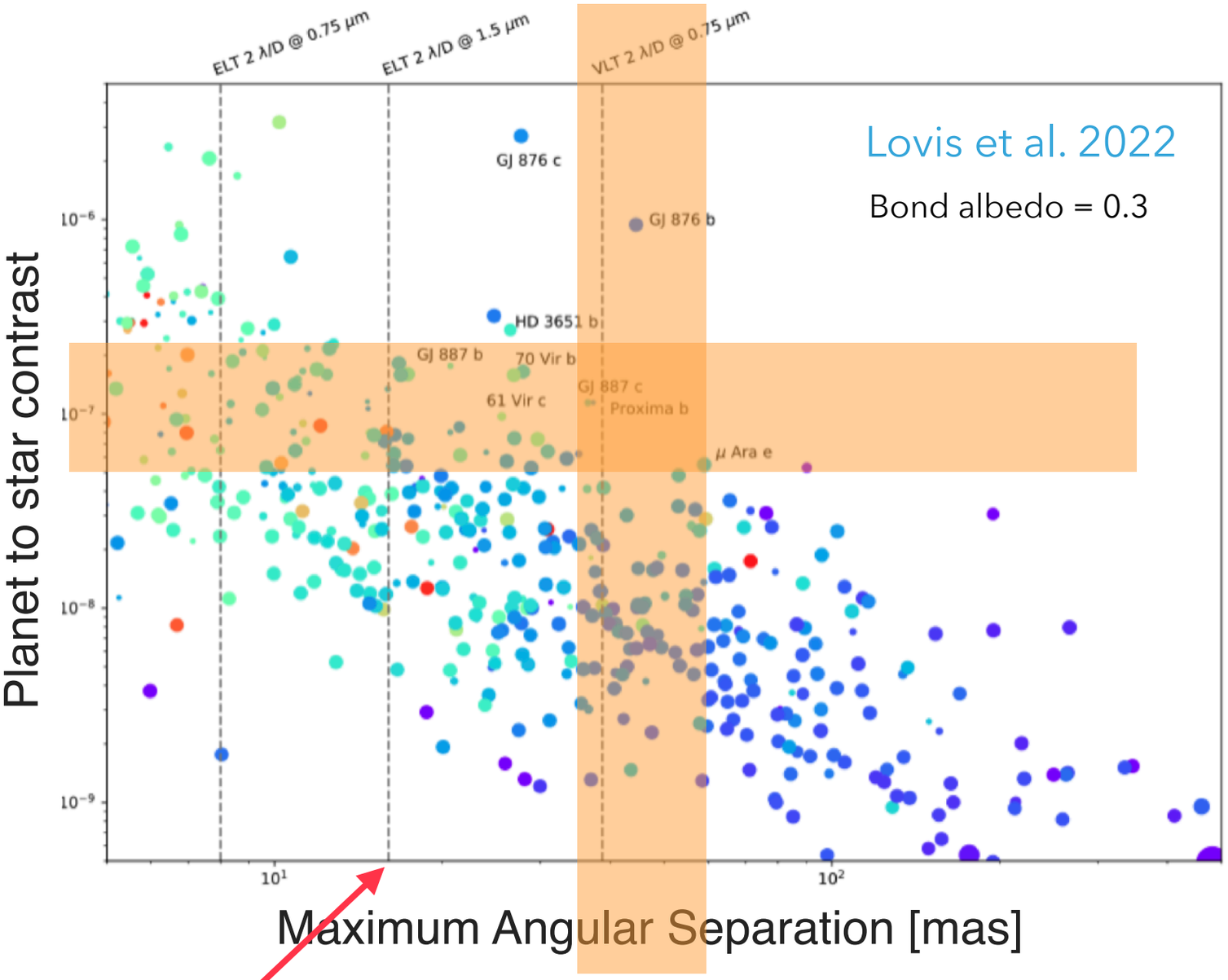


Lovis et al. 2022

Bond albedo = 0.3

ANDES threshold in H band

Proxima Cen 10^{-7}

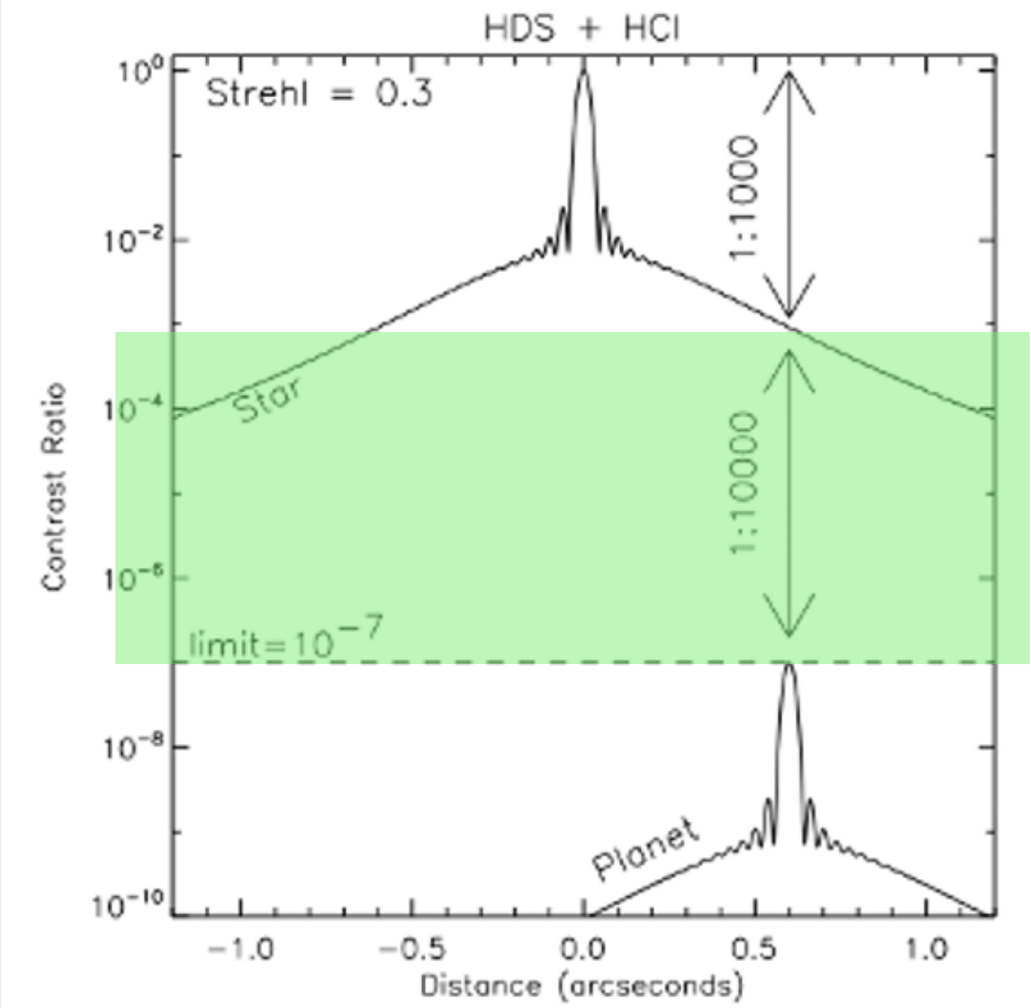


Lovis et al. 2022

Bond albedo = 0.3

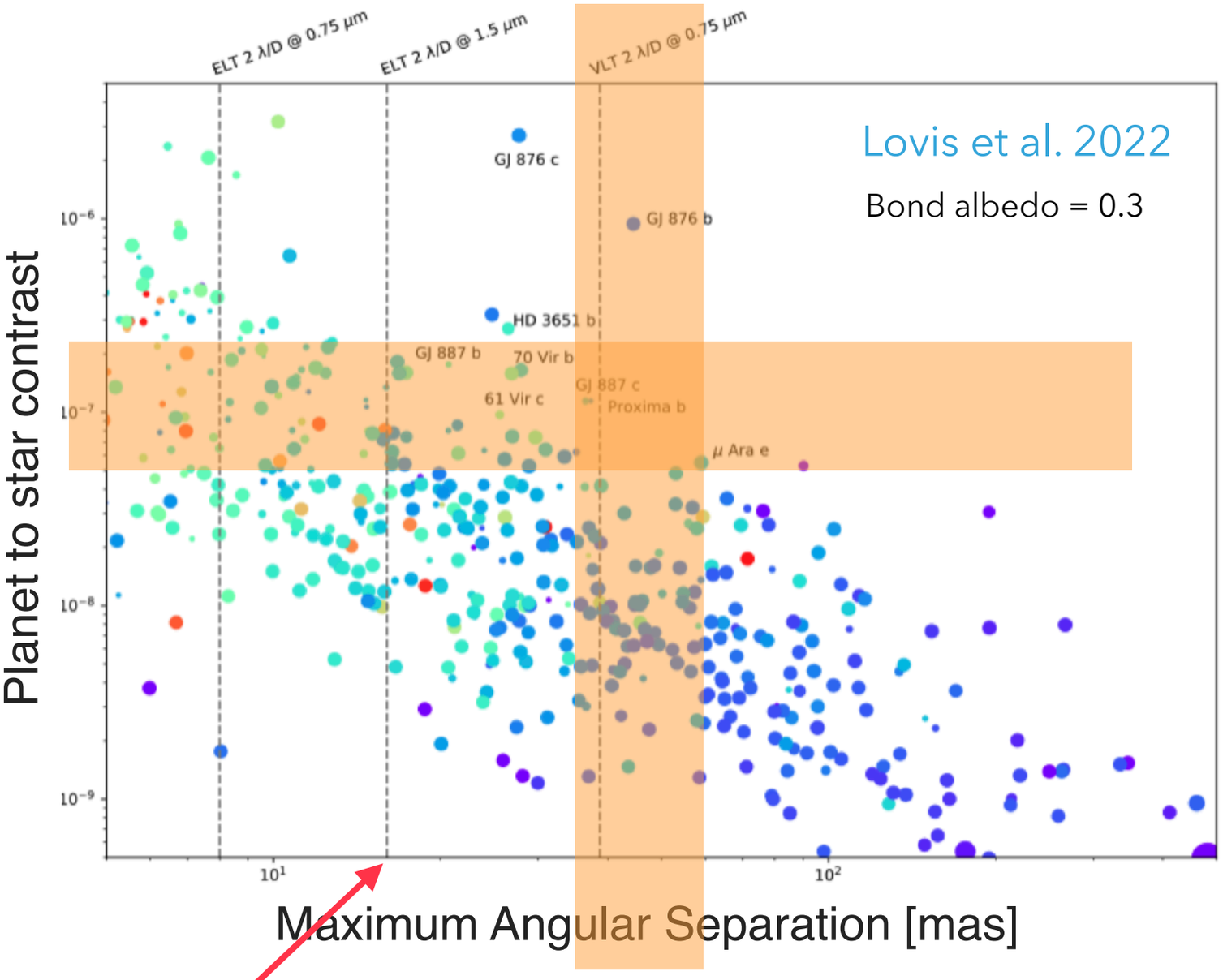
ANDES threshold in H band

Snellen et al. 2015 (theoretical values)



The detection and characterization of faint sources angularly close to very bright stars requires a diffraction-limited PSF of the ELT (SCAO module) in the near-infrared, high-contrast techniques (HCI), and high-dispersion (R~100,000) spectroscopy (HDS)

Proxima Cen 10^{-7}

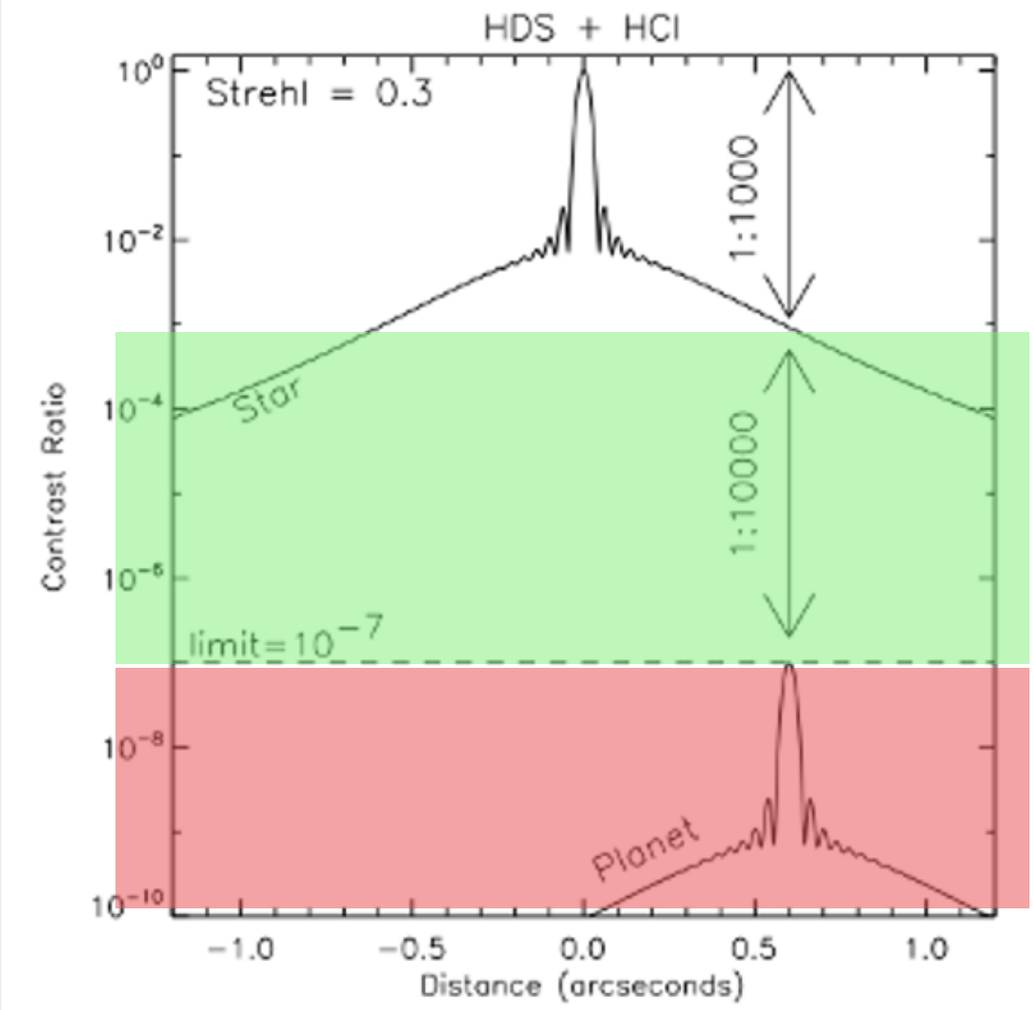


Lovis et al. 2022

Bond albedo = 0.3

ANDES threshold in H band

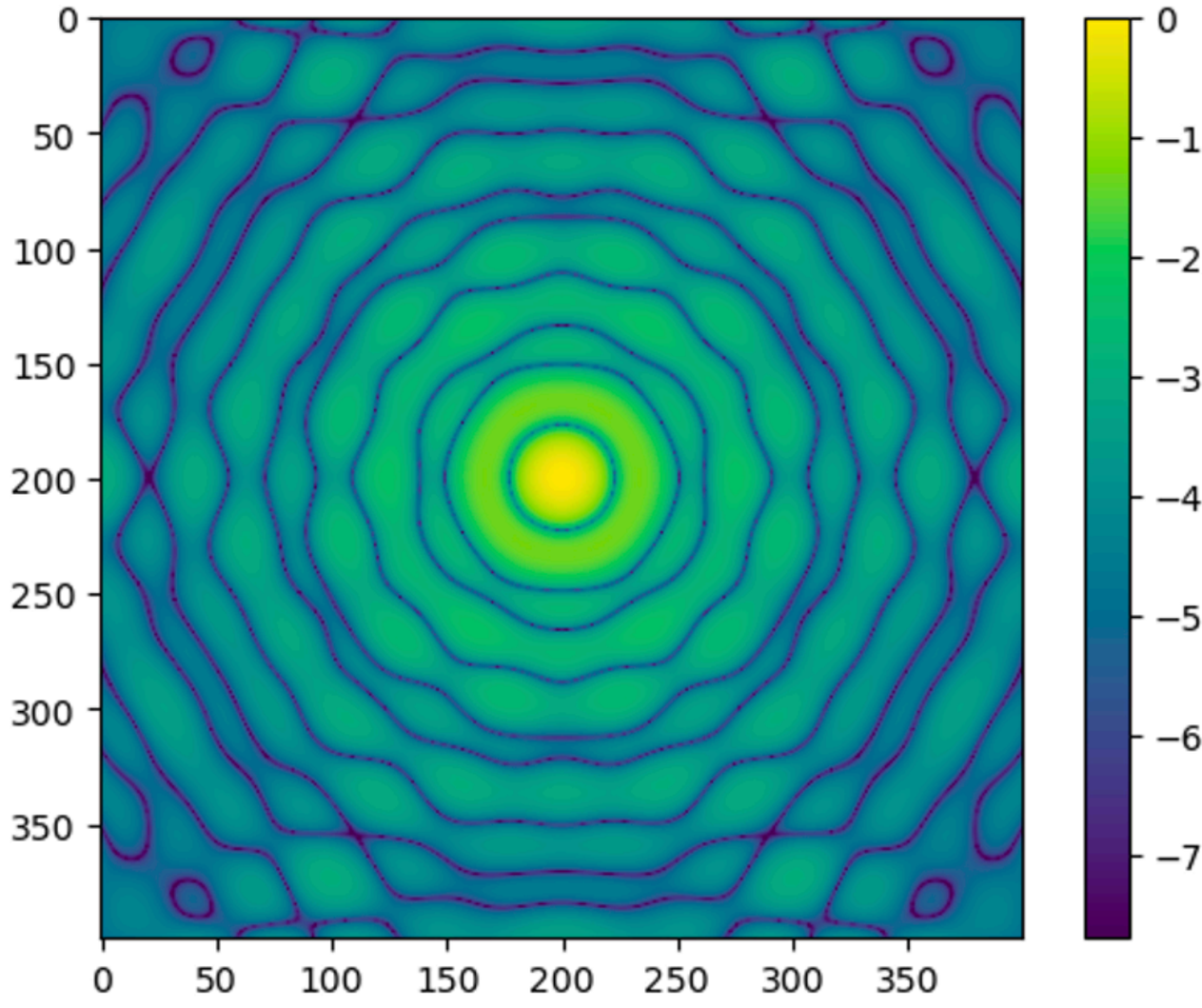
Snellen et al. 2015 (theoretical values)



The detection and characterization of faint sources angularly close to very bright stars requires a diffraction-limited PSF of the ELT (SCAO module) in the near-infrared, high-contrast techniques (HCI), and high-dispersion (R~100,000) spectroscopy (HDS)

HCI of 10^{-3} at about 3 λ/D for the coronagraph when combined with the SCAO

REFLECTED LIGHT



E2E ANDES simulator

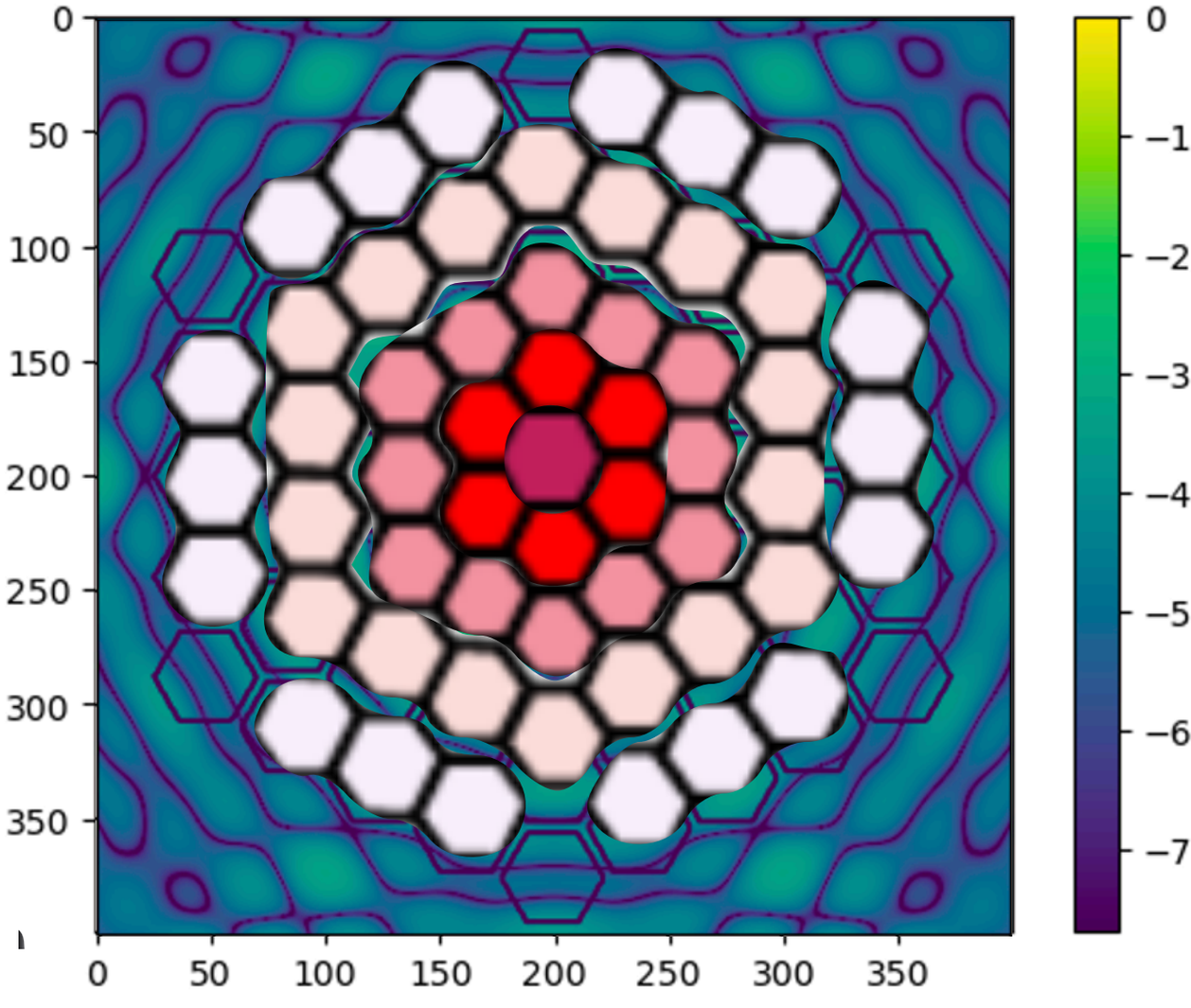
Simonnin et al. in prep.

REFLECTED LIGHT

FoV of 40 - 50 mas

4-5 rings on the slit and spaxel scales of 5/10/100 mas but other options (e.g., 7/15/35/100 mas)…

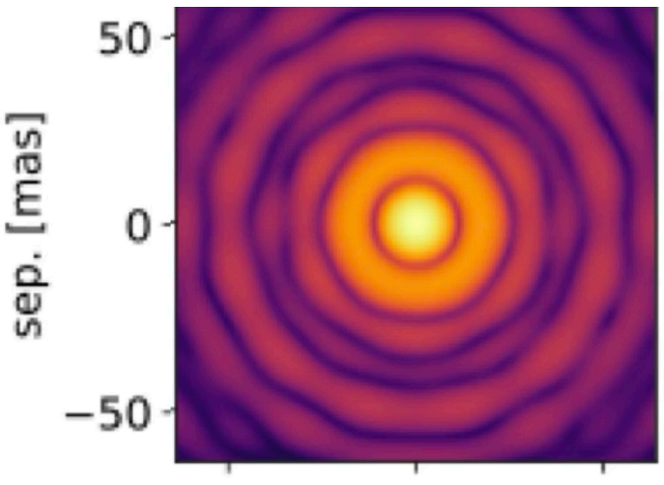
All under discussion



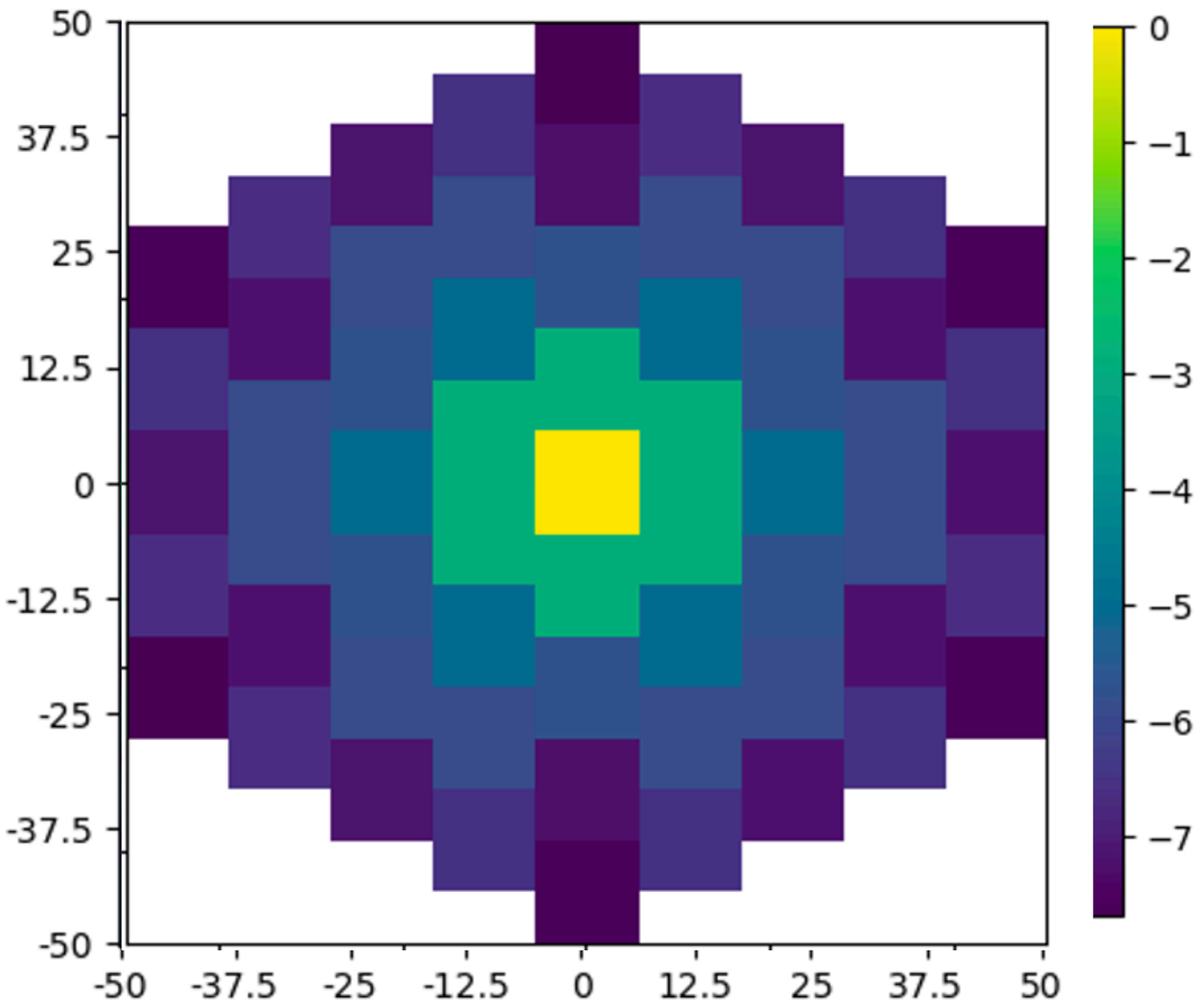
E2E ANDES simulator
Simonnin et al. in prep.

REFLECTED LIGHT

Without



Coronagraph



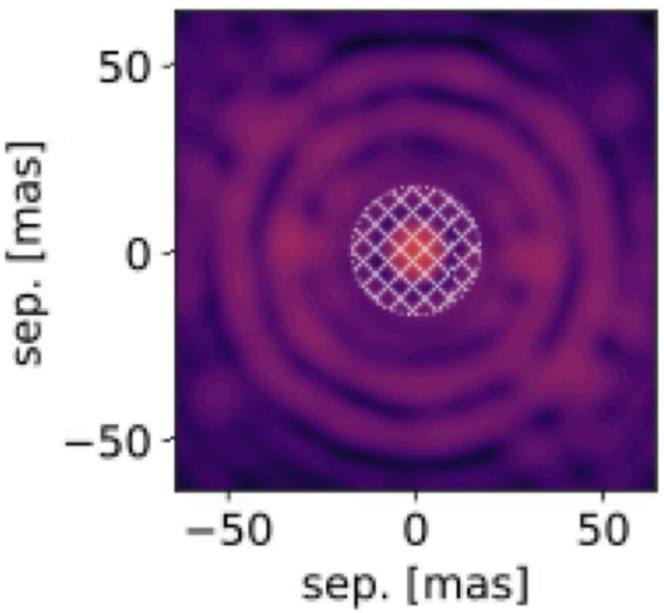
E2E ANDES simulator

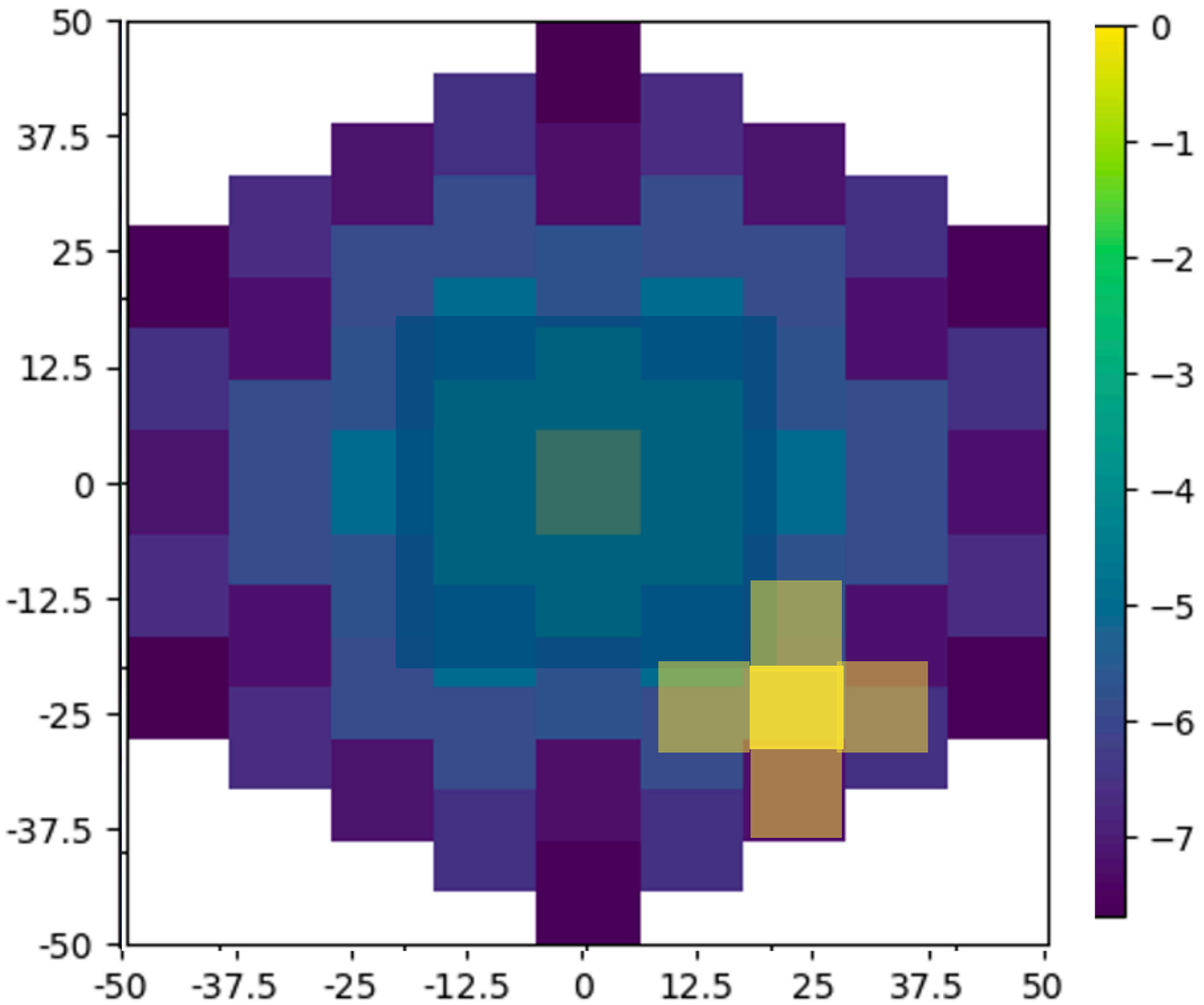
Simonnin et al. in prep.

REFLECTED LIGHT

Coronagraph

With

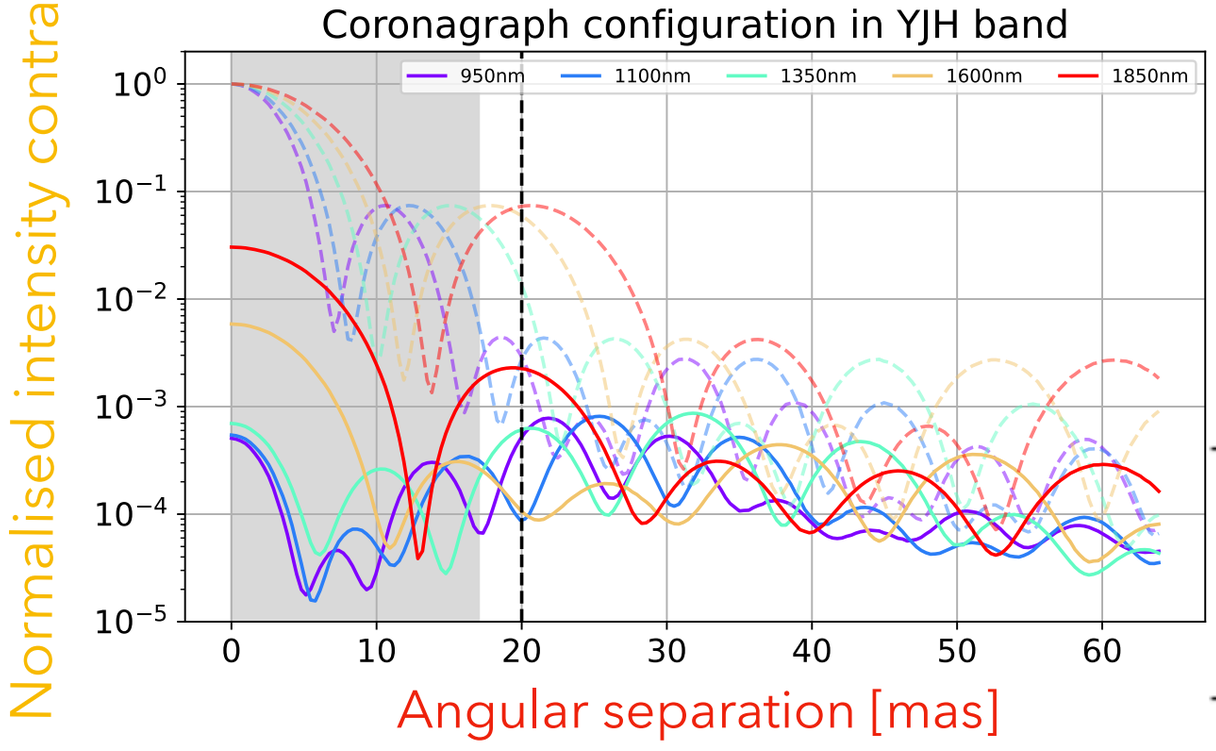


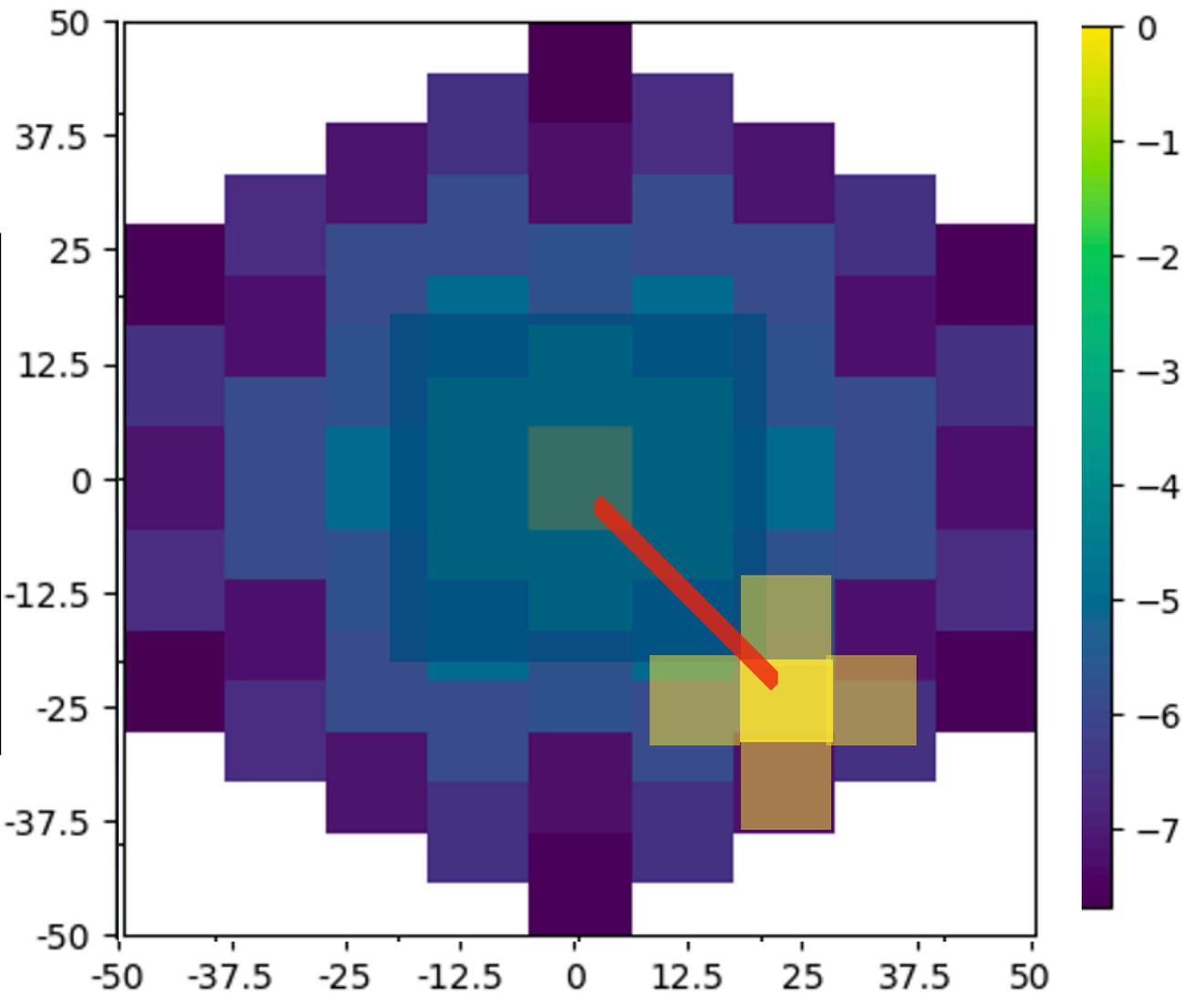


E2E ANDES simulator

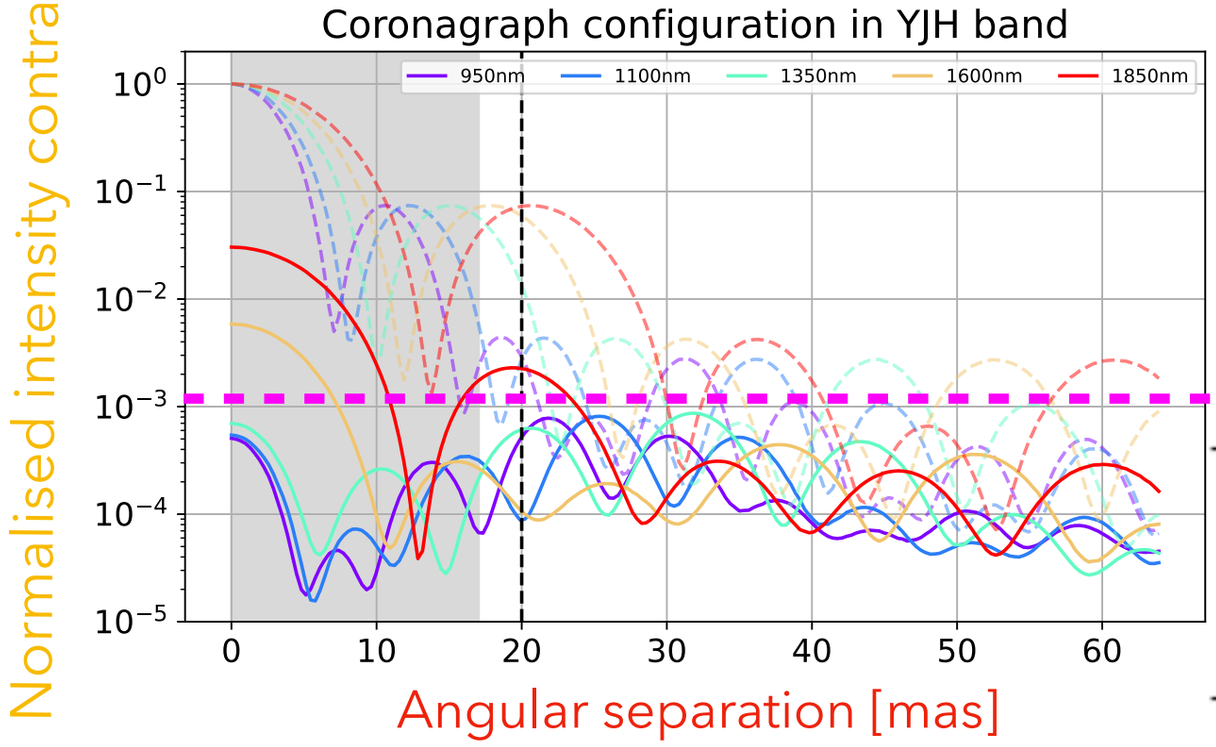
Simonnin et al. in prep.

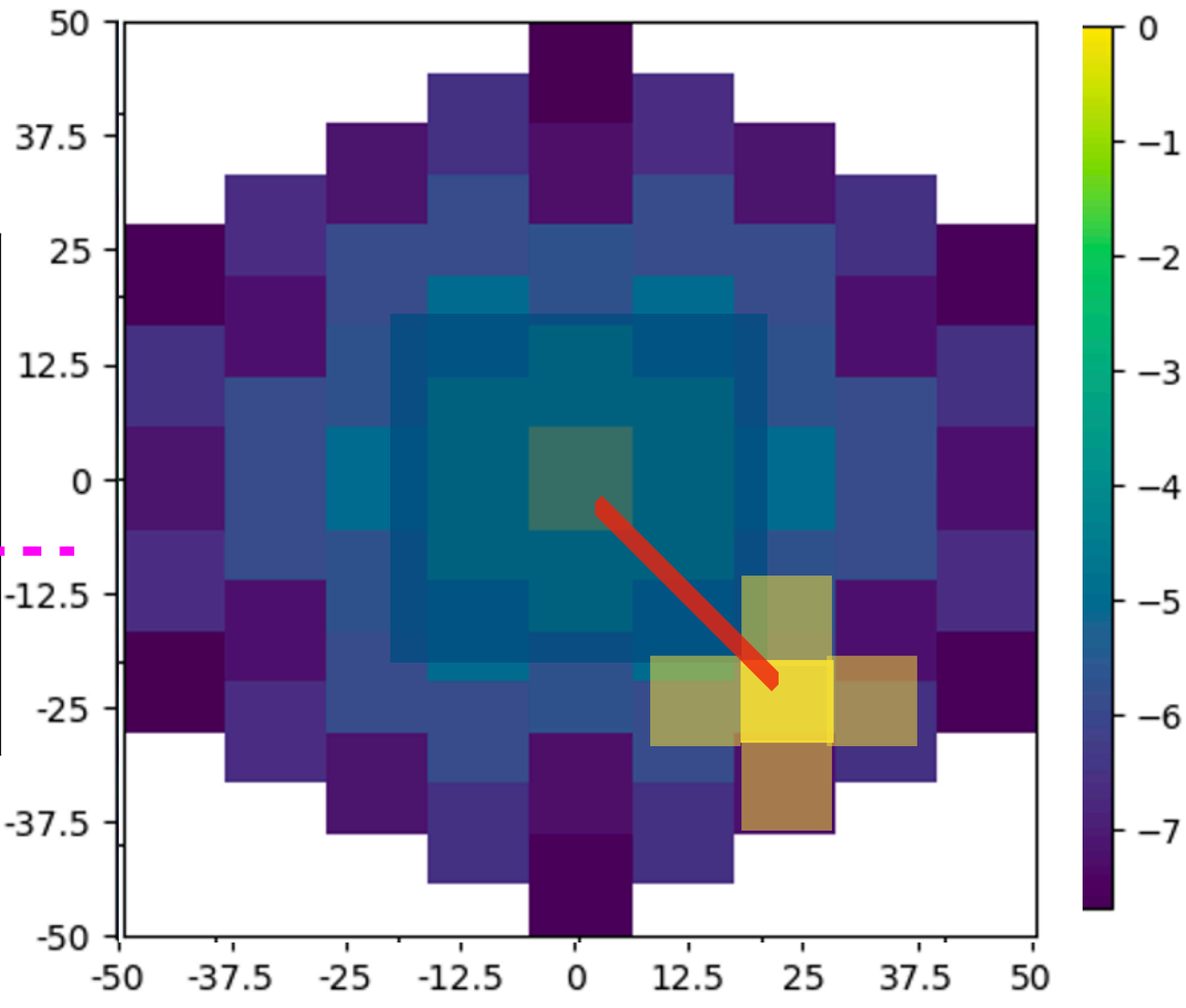
REFLECTED LIGHT





REFLECTED LIGHT



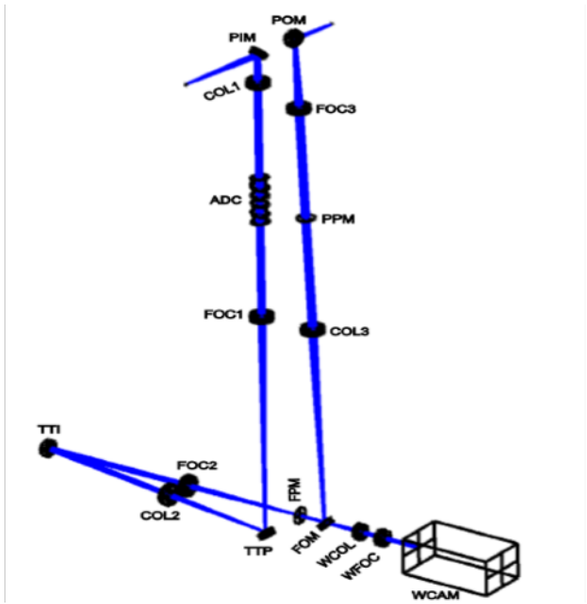


Goal: Contrast better than 3×10^{-3} at 20mas in the YJH bands

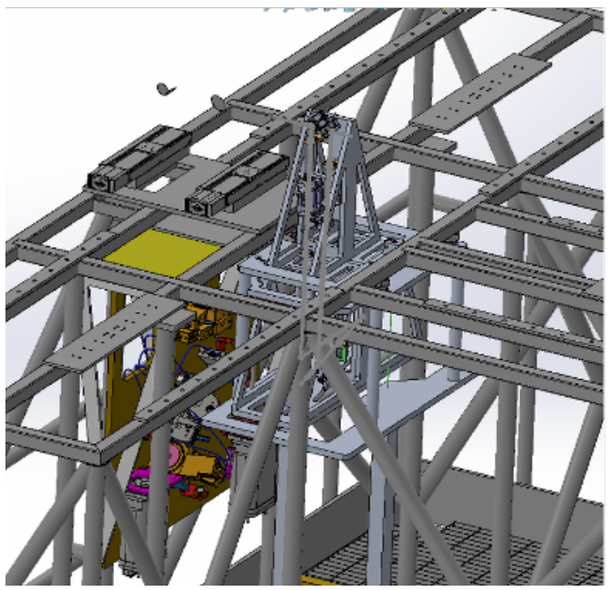
THE CORONAGRAPH MODULE

Lagrange is responsible for the design & development of Coronagraph module for ANDES since March 2024. Coronagraph (not originally in the baseline) is included between the SCAO and IFU.

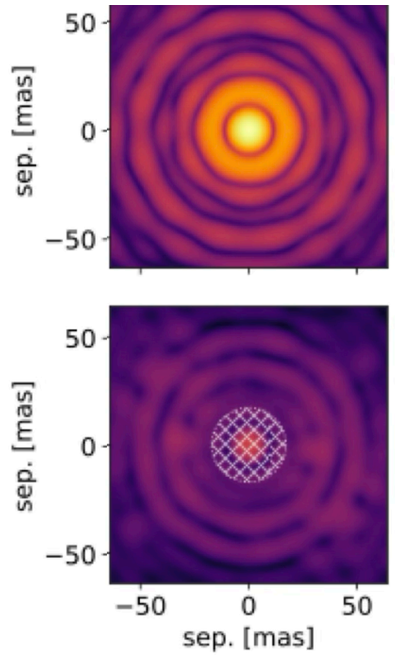
Actual goal: contrast of 3×10^{-3} in YJH bands at 20 mas



Optical design & development



Mechanical design & development



Simulation & performance study

Coronagraph Design Document, ANDES consortium (Jan 2025)

ANDES

ESO signature to the agreement 10 June 2024: ANDES will be installed on ESO's Extremely Large Telescope (ELT)

Phase B | Phase C | Phase D

2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031

- 2021: ESO Council Approval Dec 2021
- 2022: Kick Off meeting June 2022
- 2023: System Architecture Review (SAR) Passed in October 2023
- 2024: Conceptual design document provide January 2025
- 2025: Official acceptance in the ANDES baseline during Consortium Meeting April 2025
- 2026: Increasing of the technical contribution with LUPM & IRAP joining the effort
- 2026: Funding Review (FR)
- 2026: System (PDR)
- 2028: Final Design Review (FDR)

Coronagraph
(integration at Lagrange, then Italy with the SCAO module)

ANDES

ANDES IN A NUTSHELL

THE FOUR SCIENCE PRIORITIES AND TOP LEVEL REQUIREMENTS

FRENCH SCIENTIFIC CONTRIBUTIONS

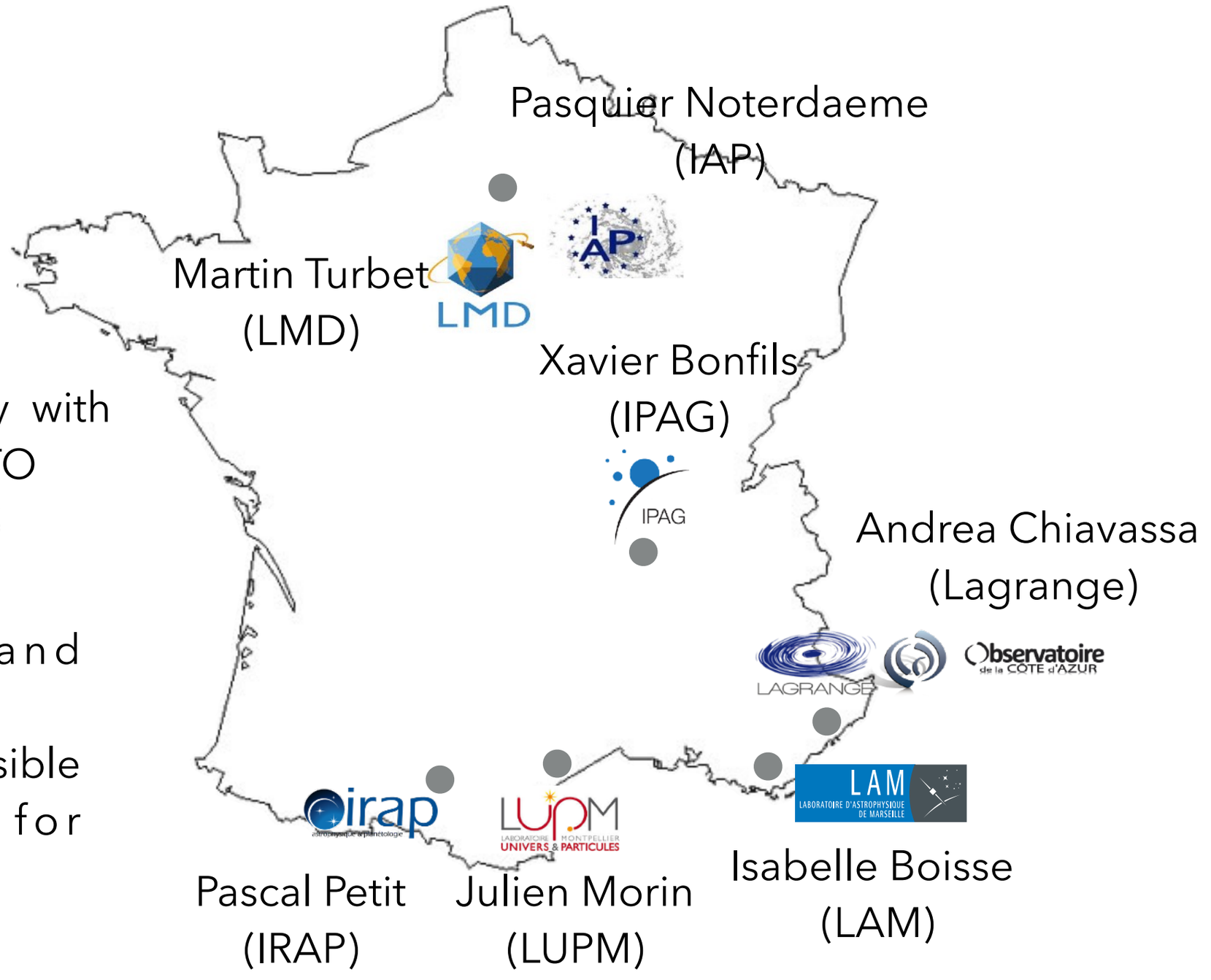
FRENCH TECHNICAL CONTRIBUTION

CONCLUSIONS

CONCLUSIONS

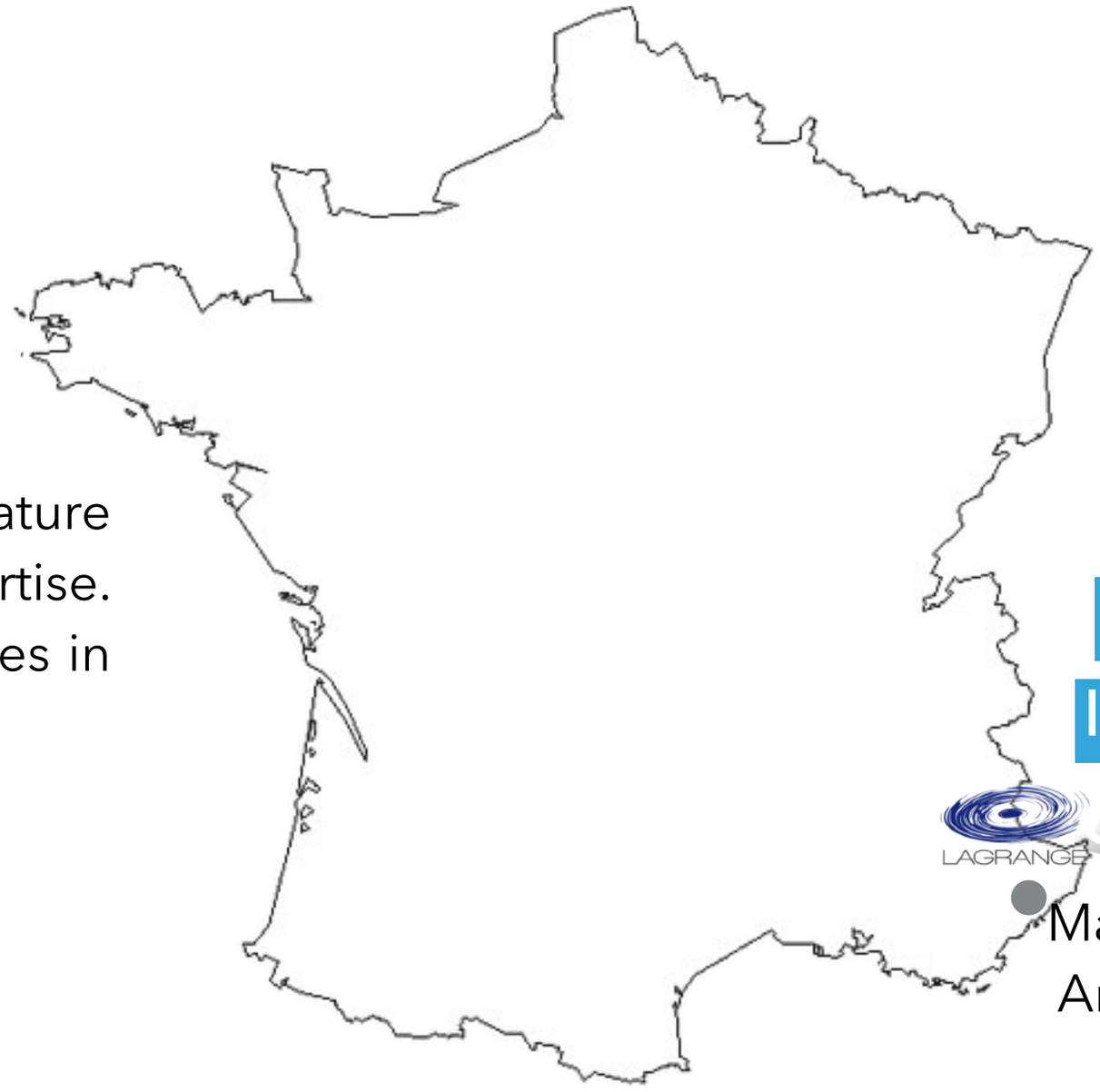
- Science cases are in synergy with METIS, JWST, ARIEL, and PLATO
- ANDES is a pathfinder for PCS

- National team active and motivated
- French scientific expertise visible and well represented for exoplanets and stars.



CONCLUSIONS

- Recognition of the unique nature of French High Contrast expertise.
- Lagrange is leading 3 modules in SCAO systems



CORONAGRAPH

IFU CALIBRATION

IFU PERFORMANCE

LAGRANGE

Observatoire de la CÔTE d'AZUR

Mamadou N'Diaye
Andrea Chiavassa
Philippe Berio
Julia Seidel

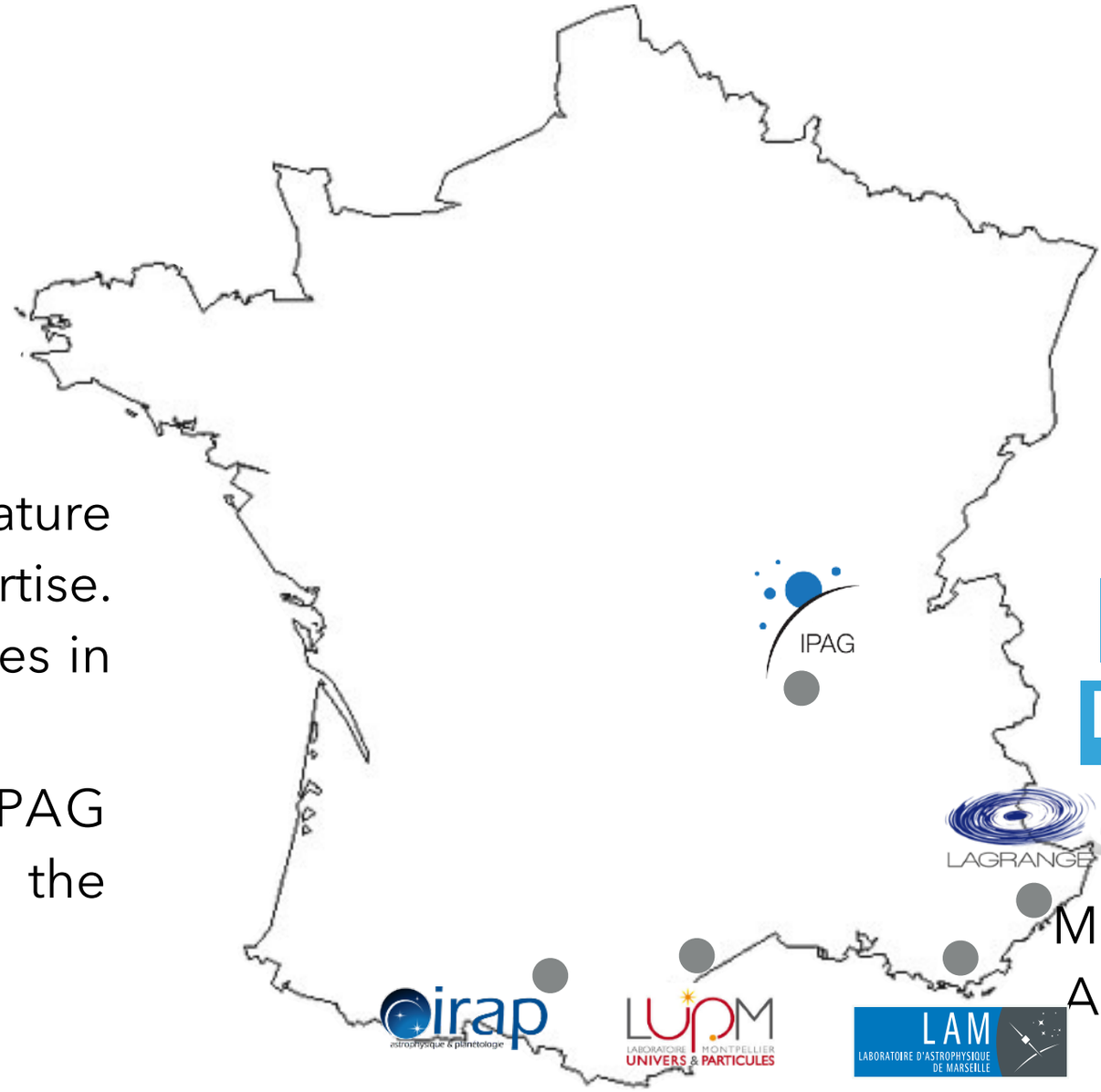
33.1 FTE
en 2023

→

44.1 FTE
en 2025

CONCLUSIONS

- Recognition of the unique nature of French High Contrast expertise.
- Lagrange is leading 3 modules in SCAO systems
- IRAP and LUPM (LAM&IPAG under discussion) will join the technical efforts in 2026



CORONAGRAPH

IFU CALIBRATION

IFU PERFORMANCE

Mamadou N'Diaye
Andrea Chiavassa
Philippe Berio
Julia Seidel

33.1 FTE
en 2023

→

44.1 FTE
en 2025

ANDES RELATED CONFERENCES IN 2026 AND 2027

ANDES science French community meeting in fall 2026 - Montpellier

HORS3S

High-Resolution Exoplanet and Stellar Characterization Today and in the ELT Era

Granada, Spain

6-10 July 2026

ANDES international consortium meeting in spring/summer 2027 - Nice

CONCLUSIONS

Register for the French community mailing for the planetary science list and propose your science case. All the instructions are here:

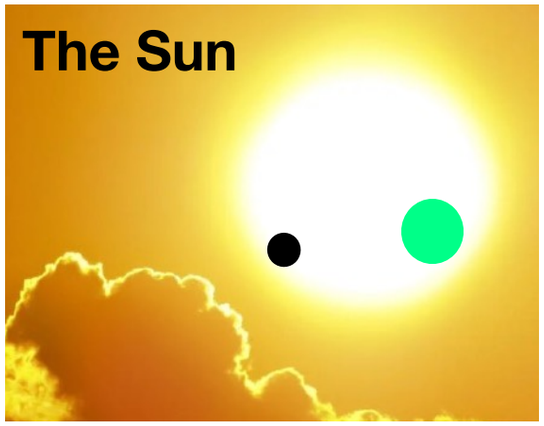
French community mailing for stellar physics list: physique_stellaire_andes@oca.eu

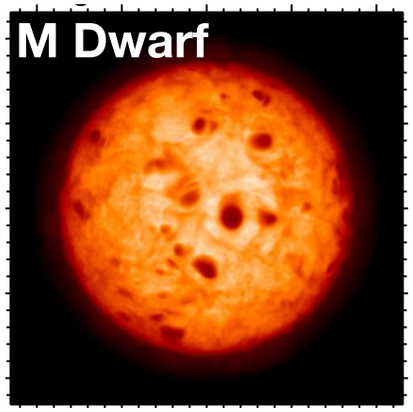
French consortium website https://projets.oca.eu/fr/andes

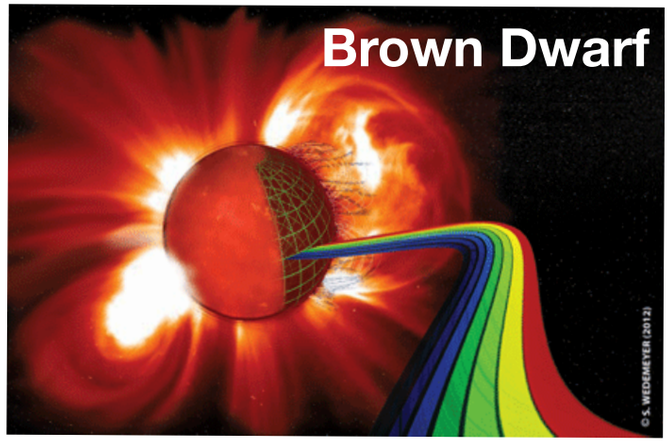
ESO website https://elt.eso.org/instrument/ANDES/

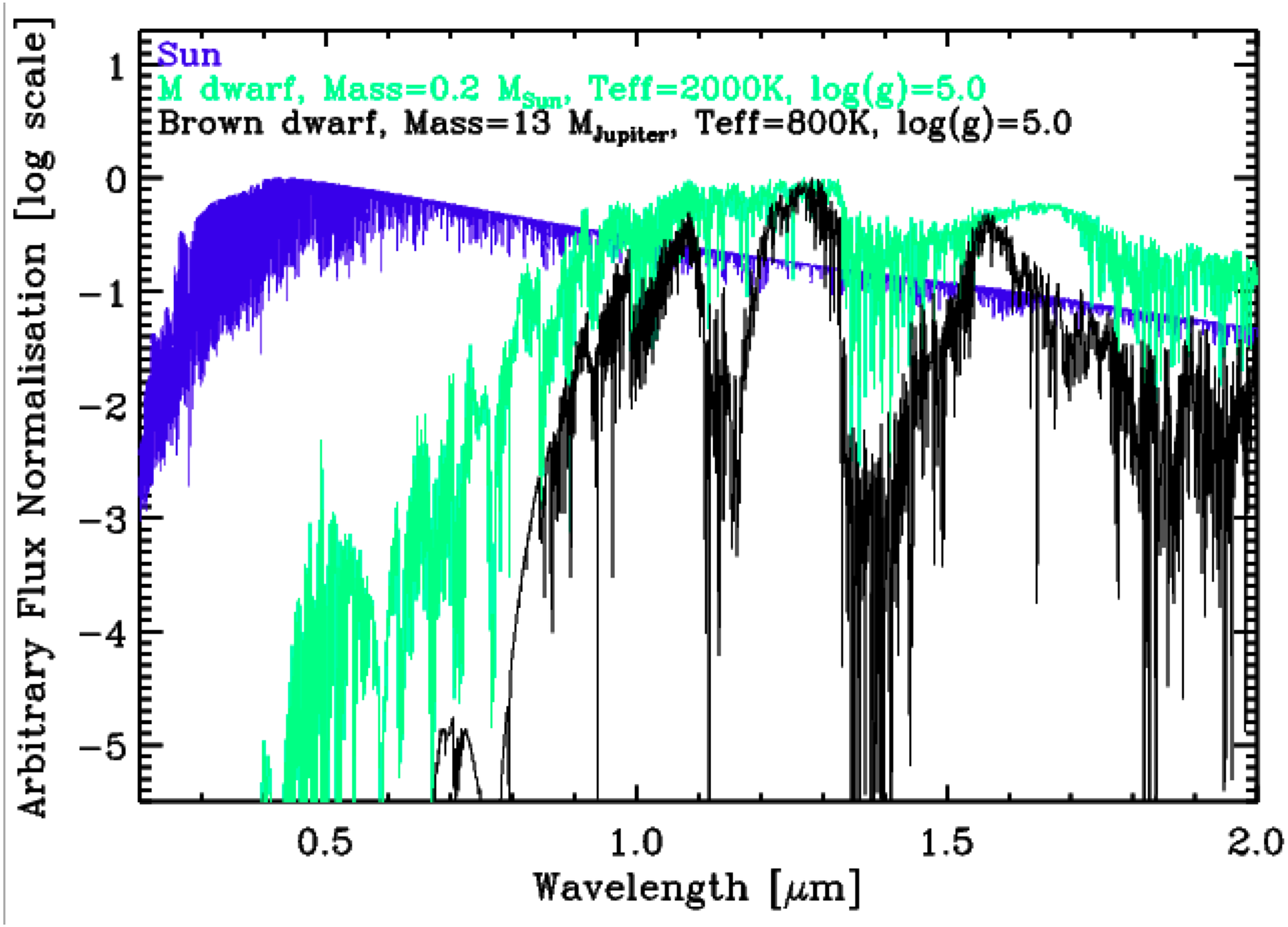
Consortium website http://andes.inaf.it

ETC calculator https://andes.inaf.it/instrument/exposure-time-calculator/


The Sun


M Dwarf


Brown Dwarf


Sun
M dwarf, Mass=0.2 M$_{Sun}$, Teff=2000K, log(g)=5.0
Brown dwarf, Mass=13 M$_{Jupiter}$, Teff=800K, log(g)=5.0
Arbitrary Flux Normalisation [log scale]
1
0
−1
−2
−3
−4
−5
0.5
1.0
1.5
2.0
Wavelength [μm]