ANDES THE HIGH RESOLUTION SPECTROGRAPH FOR THE ELT

ALESSANDRO MARCONI

PHYSICS & ASTRONOMY DEPARTMENT, UNIVERSITY OF FLORENCE, ITALY

ON BEHALF OF THE ANDES CONSORTIUM

FORMERLY KNOWN AS HIRES …

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ANDES, the high resolution spectrograph for the ELT: science case, baseline design and path to construction

A. Marconi[1,2], on behalf of the ANDES Consortium: M. Abreu[3], V. Adibekyan[4,5], V. Alberti[6], S. Albrecht[7], J. Alcaniz[8], M. Aliverti[9], C. Allende Prieto[10,11], J. D. Alvarado Gómez[12], P. J. Amado[13], M. Amate[10], M. I. Andersen[14,15], E. Artigau[16,17], C. Baker[18], V. Baldini[6], A. Balestra[19], S. A. Barnes[12,20], F. Baron[16,21,17], S. C. C. Barros[4,5], S. M. Bauer[12], M. Beaulieu[22], O. Bellido-Tirado[12], B. Benneke[16,17], T. Bensby[23], E. A. Bergin[24], K. Biazzo[25], A. Bik[26], J. L. Birkby[27], N. Blind[28], I. Boisse[29], E. Bolmont[28,30], M. Bonaglia[2], X. Bonfils[31], F. Borsa[9], A. Brandeker[26], W. Brandner[32], C. H. Broeg[33,34], M. Brogi[35,36,37], D. Brousseau[38], A. Brucalassi[2], J. Brynnel[12], L. A. Buchhave[39], D. F. Buscher[18], A. Cabral[3], G. Calderone[6], R. Calvo-Ortega[13], F. Cantalloube[29], B. L. Canto Martins[40], L. Carbonaro[2], G. Chauvin[22], B. Chazelas[28], A.-L. Cheffot[2], Y. S. Cheng[41], A. Chiavassa[22], L. Christensen[15,14], R. Cirami[6], N. J. Cook[16,17], R. J. Cooke[42], I. Coretti[6], S. Covino[9], N. Cowan[43], G. Cresci[2], S. Cristiani[6,44,45], V. Cunha Parro[46], G. Cupani[6,45], V. D'Odorico [6,47,45], I. de Castro Leão[40], A. De Cia[28], J. R. De Medeiros[40], F. Debras[48], M. Debus[63], O. Demangeon[4,5], M. Dessauges-Zavadsky[28], P. Di Marcantonio [6], F. Dionies[12], R. Doyon[16,17,21], J. Dunn[50], D. Ehrenreich[28,30], J. P. Faria[4,5], C. Feruglio[6], M. Fisher[18], A. Fontana[25], M. Fumagalli[51,6], T. Fusco[52,29], J. Fynbo[14,15], O. Gabella[53,54,55], W. Gaessler[32], E. Gallo[24], X. Gao[56], L. Genolet[28], M. Genoni[9], P. Giacobbe[36], E. Giro[19,57], R. S. Gonçalves[58,8], O. A. Gonzalez[56], J. I. González Hernández[10,11], F. Gracia Témich[10], M.G. Haehnelt[59], C. Haniff[18], A. Hatzes[60], R. Helled[61], H.J. Hoeijmakers[23], P. Huke[62,63], A. S. Järvinen[12], S. P. Järvinen[12], A. Kaminski[64], A. J. Korn[65], D. Kouach[66], G. Kowzan[67], L. Kreidberg[32], M. Landoni[9], A. Lanotte[28], A. Lavail[65], J. Li[24], J. Liske[68], C. Lovis[28], S. Lucatello[19], D. Lunney[56], M. J. MacIntosh[56], N. Madhusudhan[69], L. Magrini[2], R. Maiolino[18,59,70], L. Malo[16], A. W. S. Man[71], T. Marquart[65], E. L. Marques[46], C. J. A. P.

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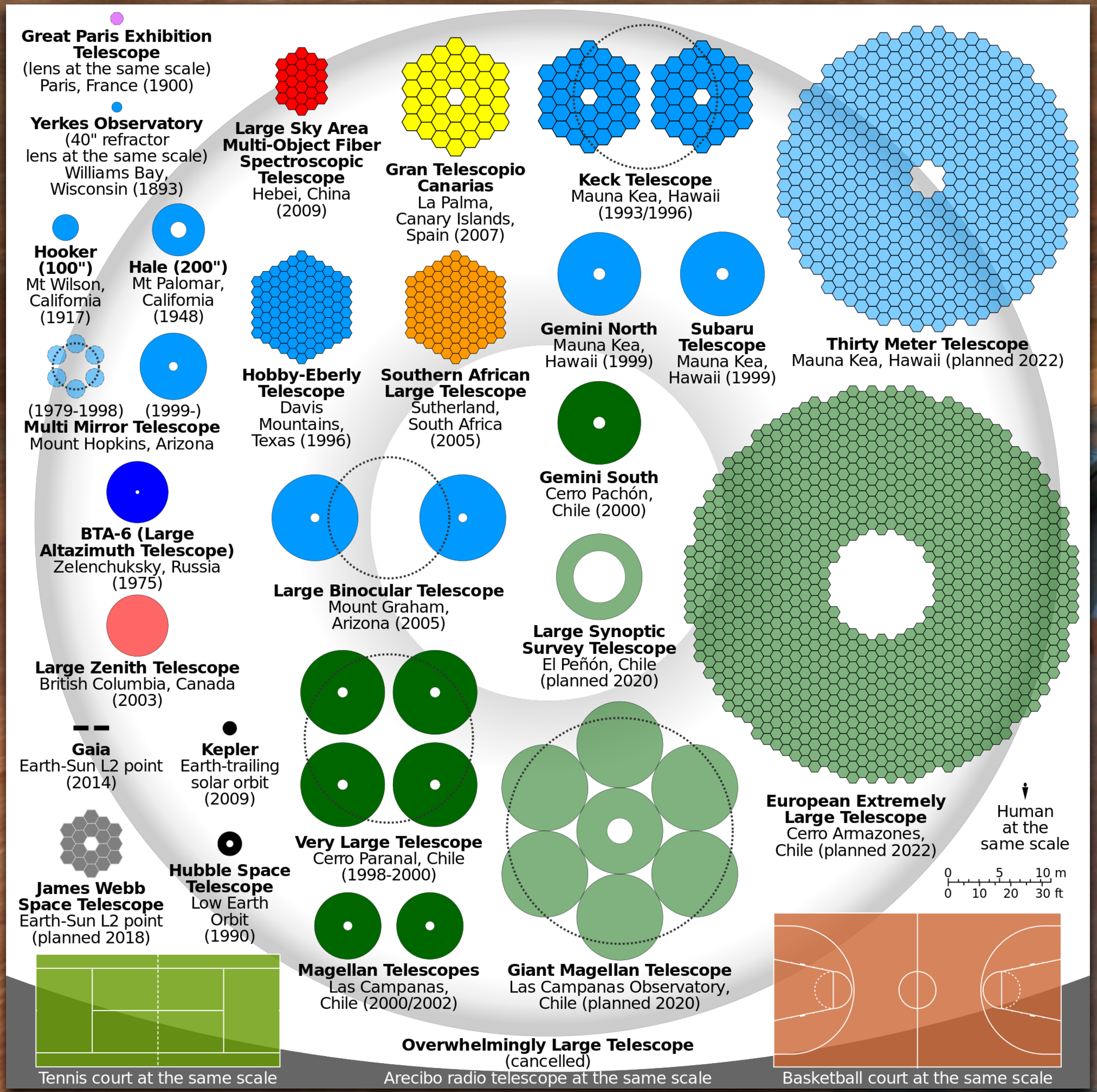
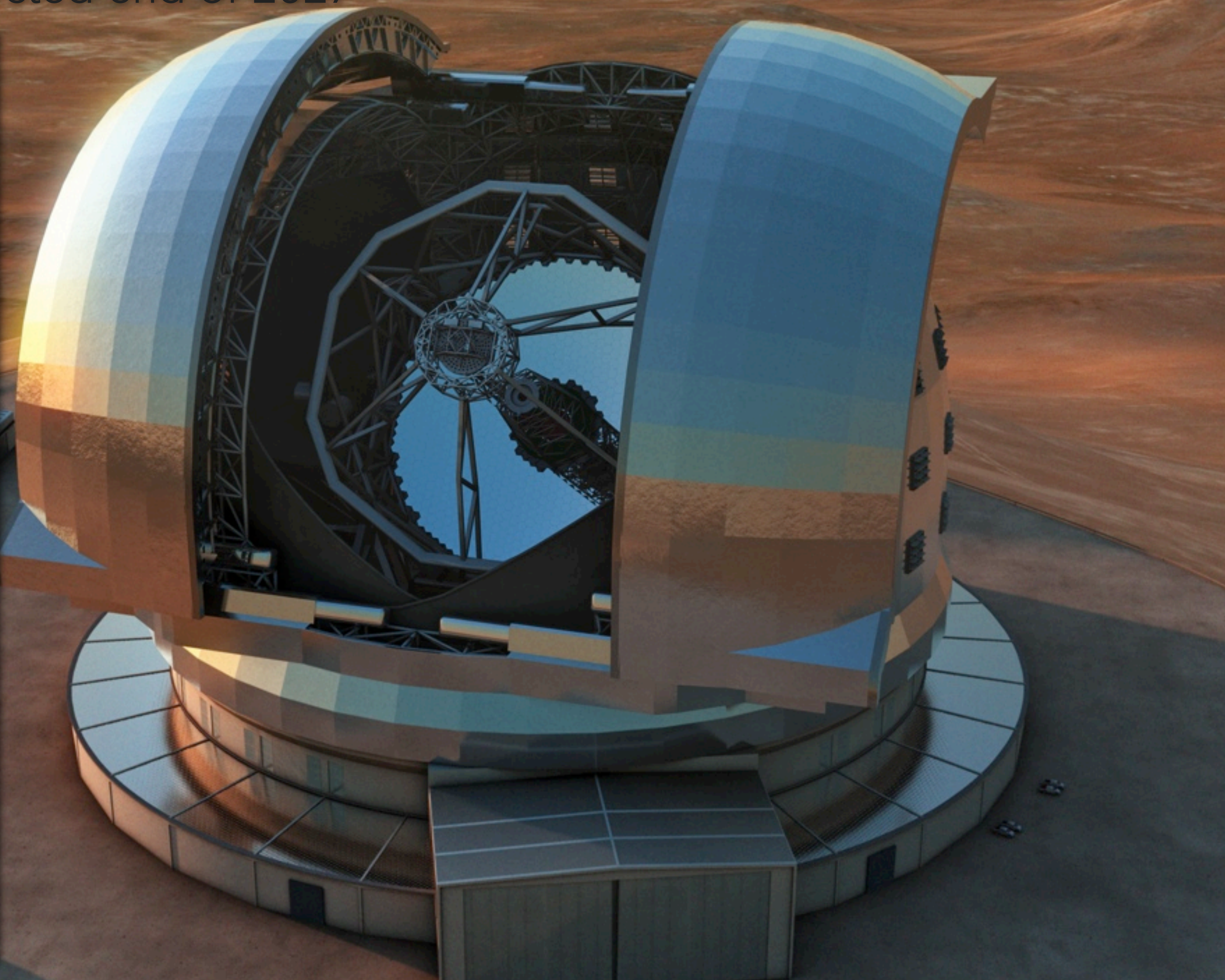
The European ELT

Largest optical/infrared telescope in the world

- 39-m segmented primary mirror
- fully AO assisted telescope
- On Cerro Armazones, integral part of the Paranal system
- Construction started 2015, first light expected end of 2027





Instrument	Main specifications			Schedule				
	Field of view/slit length/ pixel scale	Spectral resolution	Wavelength coverage (µm)	Phase A	Project start	PDR	FDR	First light
MICADO	Imager (with coronagraph) 50.5″ × 50.5″ at 4 mas/pix 19″ × 19″ at 1.5 mas/pix	*I, Z, Y, J, H, K* + narrowbands	0.8–2.45	2010	2015	2019		
	Single slit	*R* ~ 20 000						
MORFEO	AO Module SCAO – MCAO		0.8–2.45	2010	2015			
HARMONI + LTAO	IFU 4 spaxel scales from: 0.8″ × 0.6″ at 4 mas/pix to 6.1″ × 9.1″ at 30 × 60 mas/pix (with coronagraph)	*R* ~ 3 200 *R* ~ 7 100 *R* ~ 17 000	0.47–2.45	2010	2015	2018		
METIS	Imager (with coronagraph) 10.5″ × 10.5″ at 5 mas/pix in *L*, *M* 13.5″ × 13.5″ at 7 mas/pix in *N*	*L*, *M*, *N* + narrowbands	3–13	2010	2015	2019		
	Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*						
	IFU 0.6″ × 0.9″ at 8 mas/pix (with coronagraph)	*L*, *M* bands *R* ~ 100 000						
ANDES	Single object	*R* ~ 100 000	0.4–1.8 simultaneously	2018				
	IFU (SCAO)							
	Multi object (TBC)	*R* ~ 10 000						
MOSAIC	MOS ~ 7-arcminute FoV ~ 200 objects (TBC)	*R* ~ 5 000–20 000	0.45–1.8 (TBC)	2018				
	~ 8 IFUs (TBC)	*R* ~ 5 000–20 000	0.8–1.8 (TBC)					
PCS	Extreme AO camera and spectrograph	TBC	TBC					

PI: R. Davies
MPE, Germany

Instrument	Main specifications			Schedule				
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	Single slit	*R* ~ 20 000						
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	Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*						
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PI: R. Davies
MPE, Germany

PI: P Ciliegi
INAF, Italy

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MICADO	Single slit	*R* ~ 20 000	0.8–2.45	2010	2015	2019		
MORFEO	AO Module SCAO – MCAO		0.8–2.45	2010	2015			
HARMONI + LTAO	IFU 4 spaxel scales from: 0.8″ × 0.6″ at 4 mas/pix to 6.1″ × 9.1″ at 30 × 60 mas/pix (with coronagraph)	*R* ~ 3 200 *R* ~ 7 100 *R* ~ 17 000	0.47–2.45	2010	2015	2018		
METIS	Imager (with coronagraph) 10.5″ × 10.5″ at 5 mas/pix in *L*, *M* 13.5″ × 13.5″ at 7 mas/pix in *N*	*L*, *M*, *N* + narrowbands	3–13	2010	2015	2019		
METIS	Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*	3–13	2010	2015	2019		
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PCS	Extreme AO camera and spectrograph	TBC	TBC					

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MPE, Germany

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Univ. Oxford, UK

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HARMONI + LTAO	IFU 4 spaxel scales from: 0.8″ × 0.6″ at 4 mas/pix to 6.1″ × 9.1″ at 30 × 60 mas/pix (with coronagraph)	*R* ~ 3 200 *R* ~ 7 100 *R* ~ 17 000	0.47–2.45	2010	2015	2018		
METIS	Imager (with coronagraph) 10.5″ × 10.5″ at 5 mas/pix in *L*, *M* 13.5″ × 13.5″ at 7 mas/pix in *N*	*L*, *M*, *N* + narrowbands	3–13	2010	2015	2019		
	Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*						
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PI: R. Davies
MPE, Germany

PI: P Ciliegi
INAF, Italy

PI: N. Thatte
Univ. Oxford, UK

PI: B. Brandl
NOVA, Leiden
The Netherlands

Instrument	Main specifications			Schedule				
	Field of view/slit length/ pixel scale	Spectral resolution	Wavelength coverage (μm)	Phase A	Project start	PDR	FDR	First light
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	Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*						
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PCS	Extreme AO camera and spectrograph	TBC	TBC					

	Instrument	Main specifications			Schedule				
	First Light	Field of view/slit length/ pixel scale	Spectral resolution	Wavelength coverage (μm)	Phase A	Project start	PDR	FDR	First light
PI: R. Davies MPE, Germany	MICADO	Imager (with coronagraph) 50.5″ × 50.5″ at 4 mas/pix 19″ × 19″ at 1.5 mas/pix	*I, Z, Y, J, H, K* + narrowbands	0.8–2.45	2010	2015	2019		
		Single slit	*R* ~ 20 000						
PI: P Ciliegi INAF, Italy	MORFEO	AO Module SCAO – MCAO		0.8–2.45	2010	2015			
PI: N. Thatte Univ. Oxford, UK	HARMONI + LTAO	IFU 4 spaxel scales from: 0.8″ × 0.6″ at 4 mas/pix to 6.1″ × 9.1″ at 30 × 60 mas/pix (with coronagraph)	*R* ~ 3 200 *R* ~ 7 100 *R* ~ 17 000	0.47–2.45	2010	2015	2018		
PI: B. Brandl NOVA, Leiden The Netherlands	METIS	Imager (with coronagraph) 10.5″ × 10.5″ at 5 mas/pix in *L, M* 13.5″ × 13.5″ at 7 mas/pix in *N*	*L, M, N* + narrowbands	3–13	2010	2015	2019		
		Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*						
		IFU 0.6″ × 0.9″ at 8 mas/pix (with coronagraph)	*L, M* bands *R* ~ 100 000						
	ANDES	Single object	*R* ~ 100 000	0.4–1.8 simultaneously	2018				
		IFU (SCAO)							
		Multi object (TBC)	*R* ~ 10 000						
	MOSAIC	MOS ~ 7-arcminute FoV ~ 200 objects (TBC)	*R* ~ 5 000–20 000	0.45–1.8 (TBC)	2018				
		~ 8 IFUs (TBC)	*R* ~ 5 000–20 000	0.8–1.8 (TBC)					
	PCS	Extreme AO camera and spectrograph	TBC	TBC					

	Instrument	Main specifications			Schedule				
	First Light	Field of view/slit length/ pixel scale	Spectral resolution	Wavelength coverage (µm)	Phase A	Project start	PDR	FDR	First light
PI: R. Davies MPE, Germany	MICADO	Imager (with coronagraph) 50.5″ × 50.5″ at 4 mas/pix 19″ × 19″ at 1.5 mas/pix	*I, Z, Y, J, H, K* + narrowbands	0.8–2.45	2010	2015	2019		
		Single slit	*R* ~ 20 000						
PI: P Ciliegi INAF, Italy	MORFEO	AO Module SCAO – MCAO		0.8–2.45	2010	2015			
PI: N. Thatte Univ. Oxford, UK	HARMONI + LTAO	IFU 4 spaxel scales from: 0.8″ × 0.6″ at 4 mas/pix to 6.1″ × 9.1″ at 30 × 60 mas/pix (with coronagraph)	*R* ~ 3 200 *R* ~ 7 100 *R* ~ 17 000	0.47–2.45	2010	2015	2018		
PI: B. Brandl NOVA, Leiden The Netherlands	METIS	Imager (with coronagraph) 10.5″ × 10.5″ at 5 mas/pix in *L*, *M* 13.5″ × 13.5″ at 7 mas/pix in *N*	*L*, *M*, *N* + narrowbands	3–13	2010	2015	2019		
		Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*						
		IFU 0.6″ × 0.9″ at 8 mas/pix (with coronagraph)	*L*, *M* bands *R* ~ 100 000						
PI: A. Marconi INAF, Italy	ANDES	Single object	*R* ~ 100 000	0.4–1.8 simultaneously	2018				
		IFU (SCAO)							
		Multi object (TBC)	*R* ~ 10 000						
	MOSAIC	MOS ~ 7-arcminute FoV ~ 200 objects (TBC)	*R* ~ 5 000–20 000	0.45–1.8 (TBC)	2018				
		~ 8 IFUs (TBC)	*R* ~ 5 000–20 000	0.8–1.8 (TBC)					
	PCS	Extreme AO camera and spectrograph	TBC	TBC					

	Instrument	Main specifications			Schedule				
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	MICADO	Single slit	*R* ~ 20 000						
PI: P Ciliegi INAF, Italy	MORFEO	AO Module SCAO – MCAO		0.8–2.45	2010	2015			
PI: N. Thatte Univ. Oxford, UK	HARMONI + LTAO	IFU 4 spaxel scales from: 0.8″ × 0.6″ at 4 mas/pix to 6.1″ × 9.1″ at 30 × 60 mas/pix (with coronagraph)	*R* ~ 3200 *R* ~ 7100 *R* ~ 17 000	0.47–2.45	2010	2015	2018		
PI: B. Brandl NOVA, Leiden The Netherlands	METIS	Imager (with coronagraph) 10.5″ × 10.5″ at 5 mas/pix in *L, M* 13.5″ × 13.5″ at 7 mas/pix in *N*	*L, M, N* + narrowbands	3–13	2010	2015	2019		
	METIS	Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*						
	METIS	IFU 0.6″ × 0.9″ at 8 mas/pix (with coronagraph)	*L, M* bands *R* ~ 100 000						
PI: A. Marconi INAF, Italy	ANDES	Single object	*R* ~ 100 000	0.4–1.8 simultaneously	2018				
	ANDES	IFU (SCAO)							
	ANDES	Multi object (TBC)	*R* ~ 10 000						
PI: R. Pello LAM, France	MOSAIC	MOS ~ 7-arcminute FoV ~ 200 objects (TBC)	*R* ~ 5000–20 000	0.45–1.8 (TBC)	2018				
	MOSAIC	~ 8 IFUs (TBC)	*R* ~ 5000–20 000	0.8–1.8 (TBC)					
	PCS	Extreme AO camera and spectrograph	TBC	TBC					

	Instrument	Main specifications			Schedule				
	First Light	Field of view/slit length/ pixel scale	Spectral resolution	Wavelength coverage (μm)	Phase A	Project start	PDR	FDR	First light
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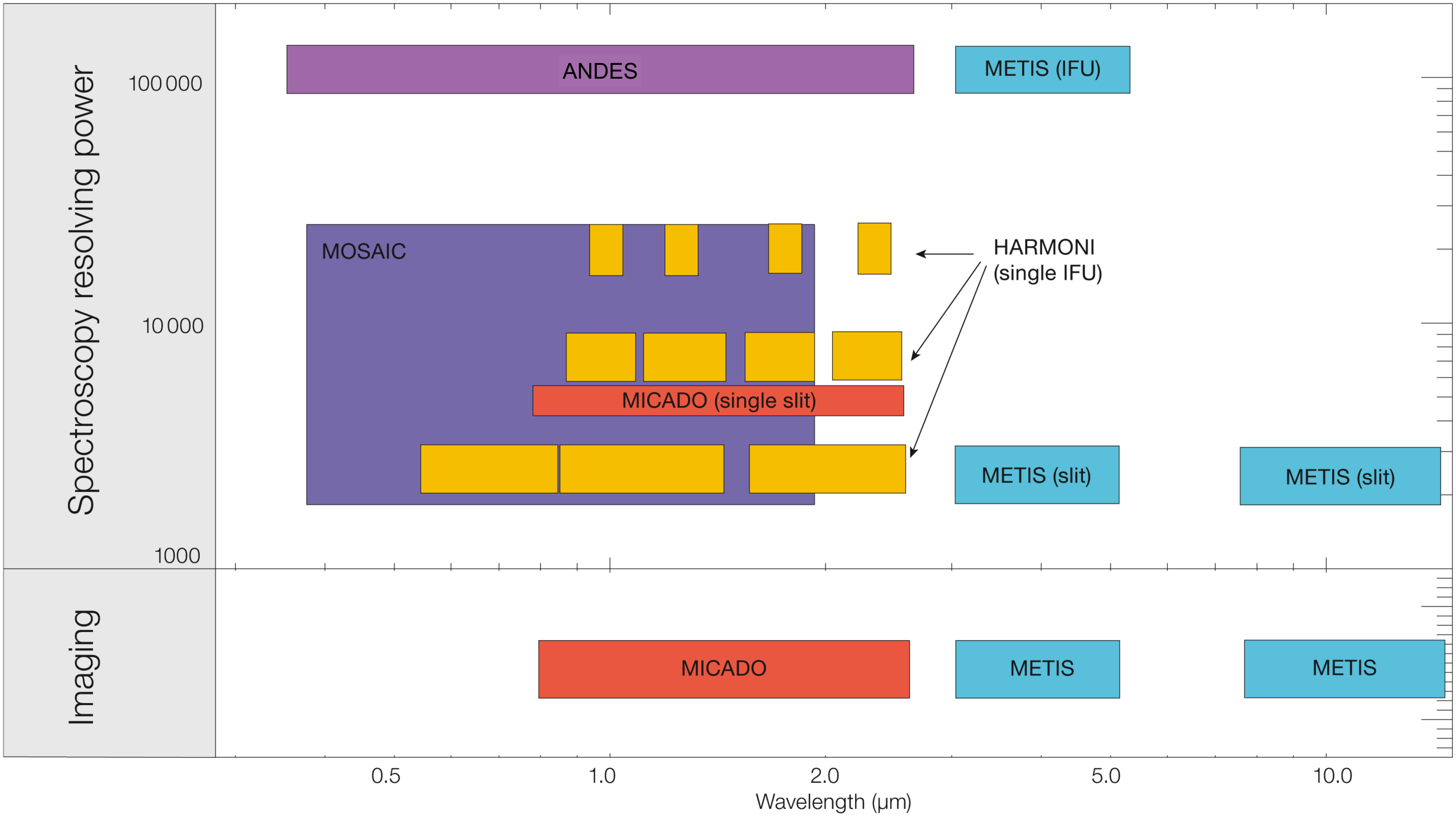
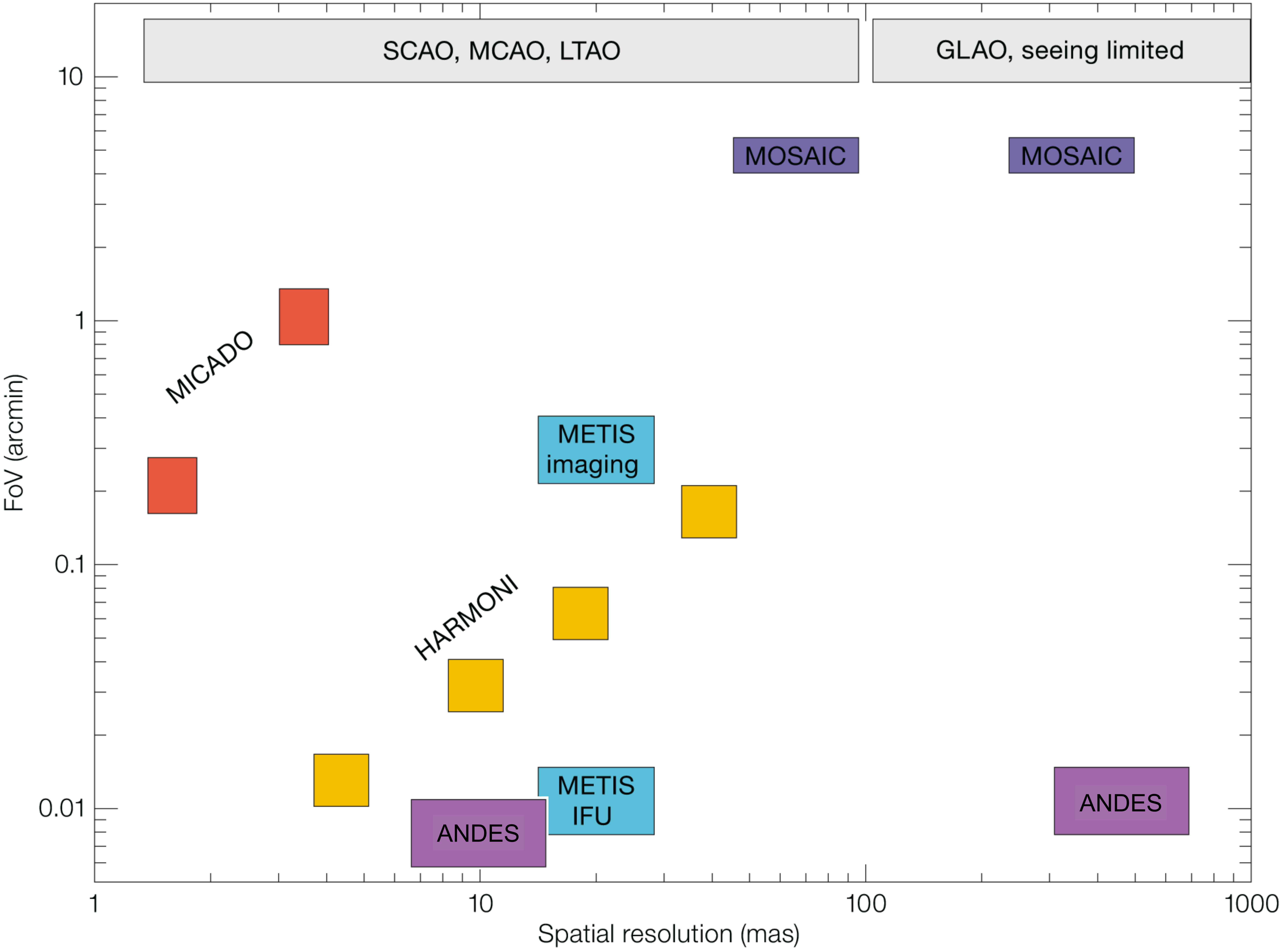
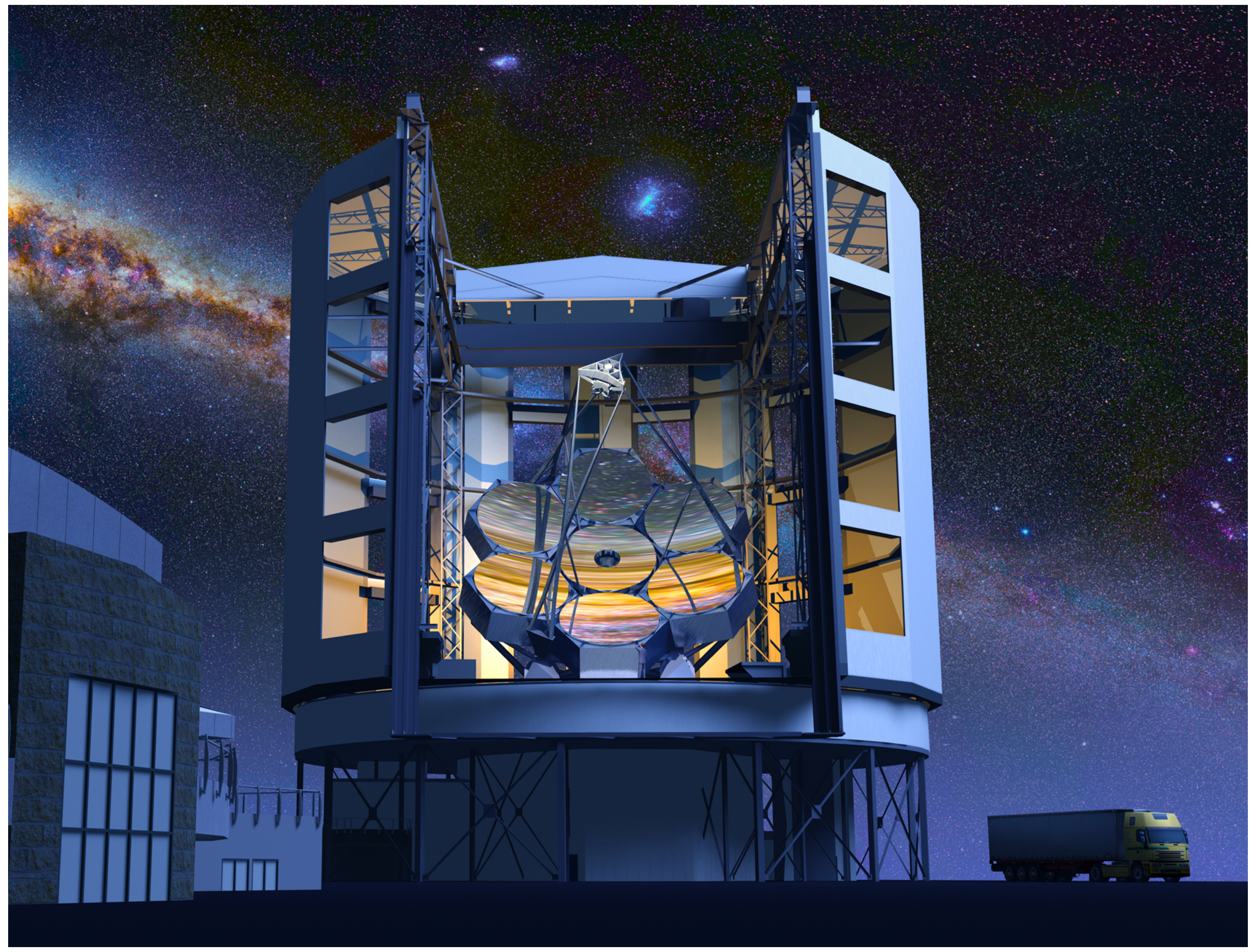


ANDES
METIS (IFU)
MOSAIC
HARMONI
(single IFU)
MICADO (single slit)
METIS (slit)
METIS (slit)
MICADO
METIS
METIS
Spectroscopy resolving power
Imaging
100 000
10 000
1000
0.5
1.0
2.0
5.0
10.0
Wavelength (μm)


SCAO, MCAO, LTAO
GLAO, seeing limited
MOSAIC
MOSAIC
MICADO
METIS
imaging
HARMONI
METIS
IFU
ANDES
ANDES
FoV (arcmin)
10
1
0.1
0.01
Spatial resolution (mas)
1
10
100
1000

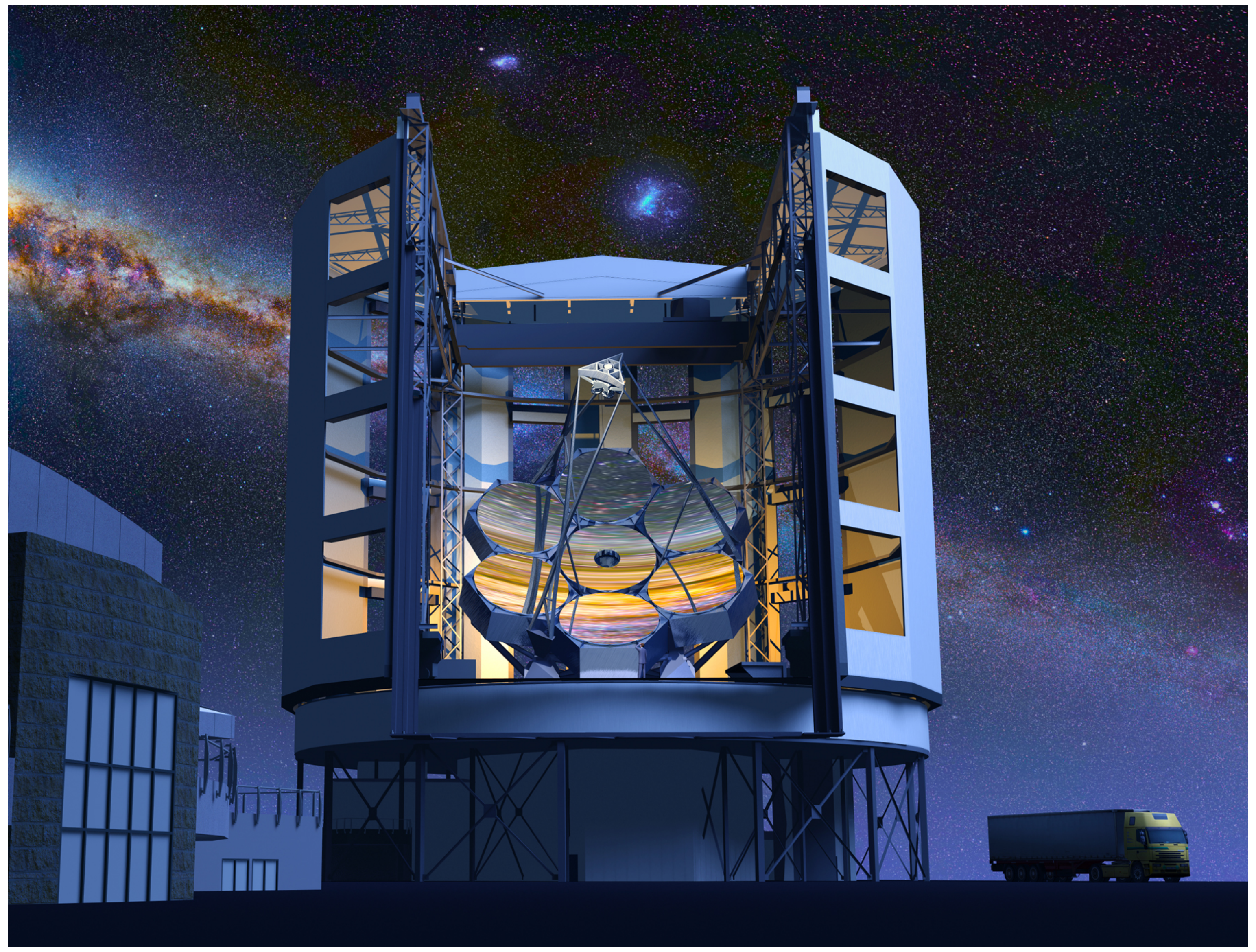
COMPETITORS OF ELT

Type of Instrument	GMT	TMT	ELT
Near-IR, AO-assisted Imager + IFU	GMTIFS	IRIS	HARMONI
Wide-Field, Optical Multi-Object Spectrometer	GMACS	WFOS	MOSAIC-HMM
Near-IR Multislit Spectrometer	NIRMOS	IRMS	MOSAIC-HMM
Deployable, Multi-IFU Imaging Spectrometer		IRMOS	MOSAIC-HDM
Mid-IR, AO-assisted Echelle Spectrometer		MIRES	METIS
High-Contrast Exoplanet Imager	TIGER	PFI	ELT-PCS
Near-IR, AO-assisted Echelle Spectrometer	GMTNIRS	NIRES	ANDES
High-Resolution Optical Spectrometer	G-CLEF	HROS	ANDES
"Wide"-Field AO-assisted Imager		IRIS	MICADO



COMPETITORS OF ELT

Type of Instrument	GMT	TMT	ELT
Near-IR, AO-assisted Imager + IFU	GMTIFS	IRIS	HARMONI
Wide-Field, Optical Multi-Object Spectrometer	GMACS	WFOS	MOSAIC-HMM
Near-IR Multislit Spectrometer	NIRMOS	IRMS	MOSAIC-HMM
Deployable, Multi-IFU Imaging Spectrometer		IRMOS	MOSAIC-HDM
Mid-IR, AO-assisted Echelle Spectrometer		MIRES	METIS
High-Contrast Exoplanet Imager	TIGER	PFI	ELT-PCS
Near-IR, AO-assisted Echelle Spectrometer	GMTNIRS	NIRES	ANDES
High-Resolution Optical Spectrometer	G-CLEF	HROS	ANDES
"Wide"-Field AO-assisted Imager		IRIS	MICADO



BROAD CONTEXT

ANDES

- European Extremely Large Telescope (ELT) will be the largest ground-based telescope at visible and infrared wavelengths
  - Flagship science cases: the detection of life signatures in Earth-like exoplanets and the direct detection of the cosmic expansion re-acceleration (both require high resolution spectroscopy)
- High resolution spectroscopy (HRS)
  - Interdisciplinary (from Exoplanets to Cosmology and Fundamental Physics)
  - Successful ESO tradition (UVES, FLAMES, CRIRES, X-shooter, HARPS; ESPRESSO)
  - More than 30% of ESO publications can be attributed to its high-resolution spectrographs.
- HRS At 8m-class telescope entered into photon starved regime
- **Merging of CODEX and SIMPLE concepts into HIRES (ANDES) with R~100.000 in 0.37-2.4 μm**
- **HIRES (ANDES) Phase A study started March 2016, completed March 2018**

A SUBSET OF ANDES SCIENCE CASES

ANDES

- **Exoplanets** (characterisation of Exoplanets Atmospheres: detection of signatures of life)
- **Protoplanetary Disks** (dynamics, chemistry and physical conditions of the inner regions)
- **Stellar Astrophysics** (abundances of solar type and cooler dwarfs in galactic disk bulge, halo and nearby dwarfs: tracing chemical enrichment of Pop III stars in nearby universe)
- **Stellar Populations** (metal enrichment and dynamics of extragalactic star clusters and resolved stellar populations)
- **Intergalactic Medium** (Signatures of reionization and early enrichment of ISM & IGM observed in high-z quasar spectra)
- **Galaxy Evolution** (massive early type galaxies during epochs of formation and assembly)
- **Supermassive Black Holes** (the low mass end)
- **Fundamental Physics** (variation of fundamental constants - α, m_p/m_e Sandage Test)

Community White Paper: Maiolino et al. 2013, ArXiV:1310.3163

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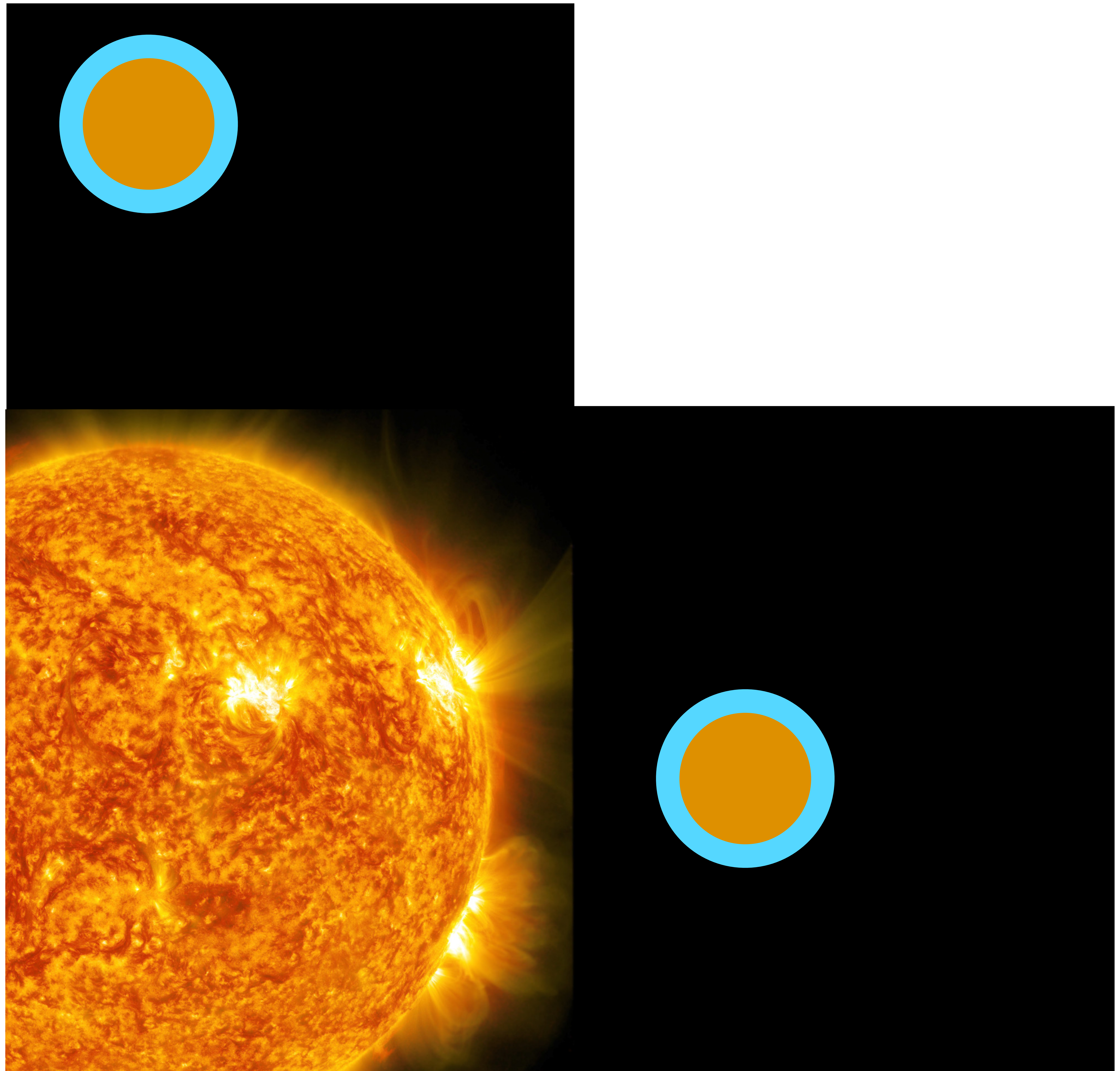
Community White Paper: Maiolino et al. 2013, ArXiV:1310.3163

To be updated in 2023 …

1.0
0.8
0.6
0.4
0.2
0.0
Relative flux
0.5
1.0
1.5
2.0
2.5
Wavelength (μm)
O_3
O_2
H_2O
H_2O
O_2
H_2O
CH_4
CO_2
H_2O
CO_2
CH_4
molecular oxygen
water
carbon dioxide
methane
Exo-Earths Atmospheres
Detecting signatures of life

EXOPLANET ATMOSPHERES

Use high-resolution spectroscopy to disentangle the planetary and stellar spectra by comparing the combined spectrum to a star-only reference spectrum aided by the radial velocity offset (e.g. Snellen+15)



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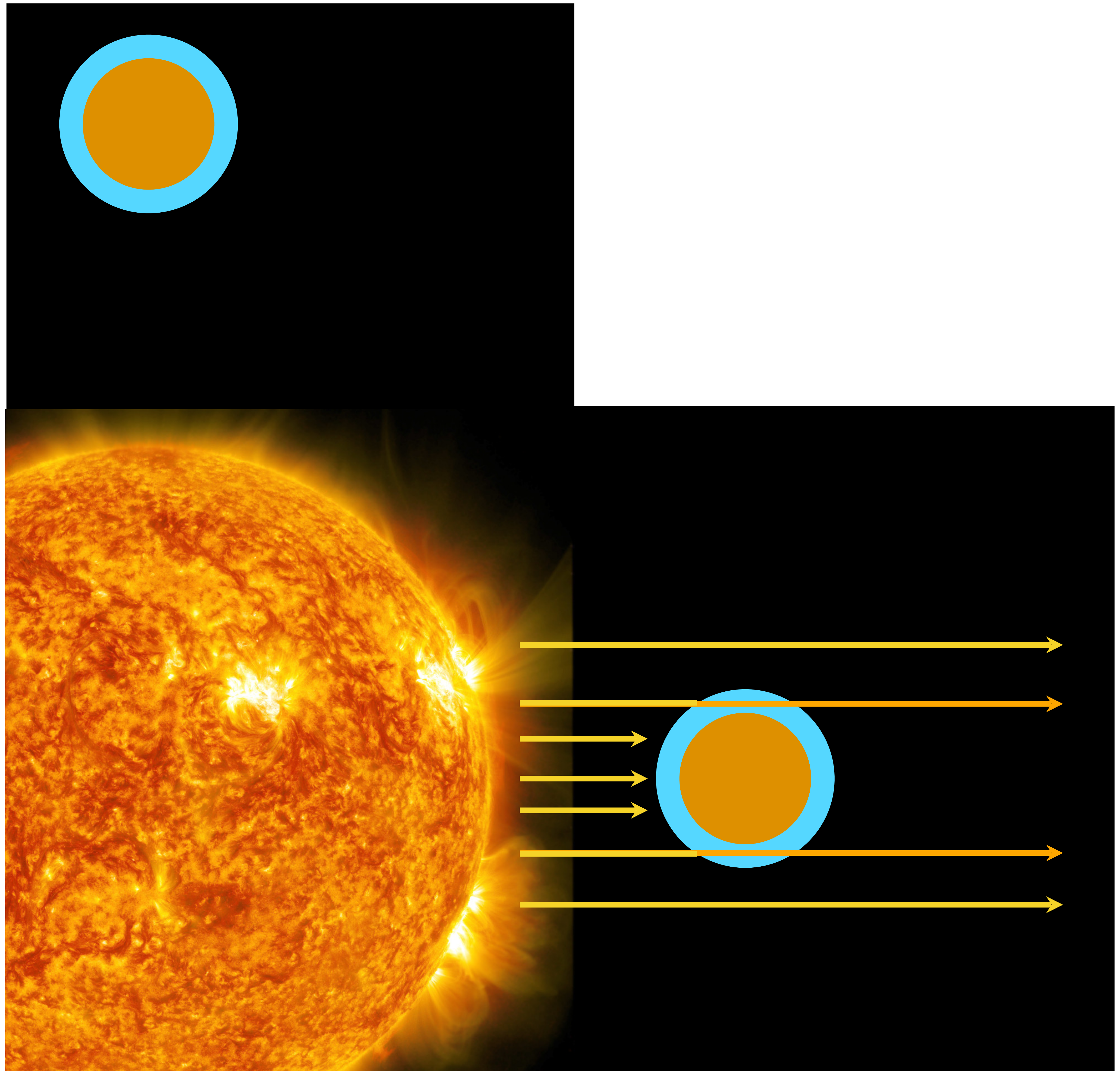

In transmitted light

Example: Trappist 1 planets ANDES cat detect:

- H_20 (1.3-1.7 μm) in 2 transits
- H_20 (0.9-1.1 μm) in 4 transits
- CO_2 in 4 transits
- O_2 in 25 transits

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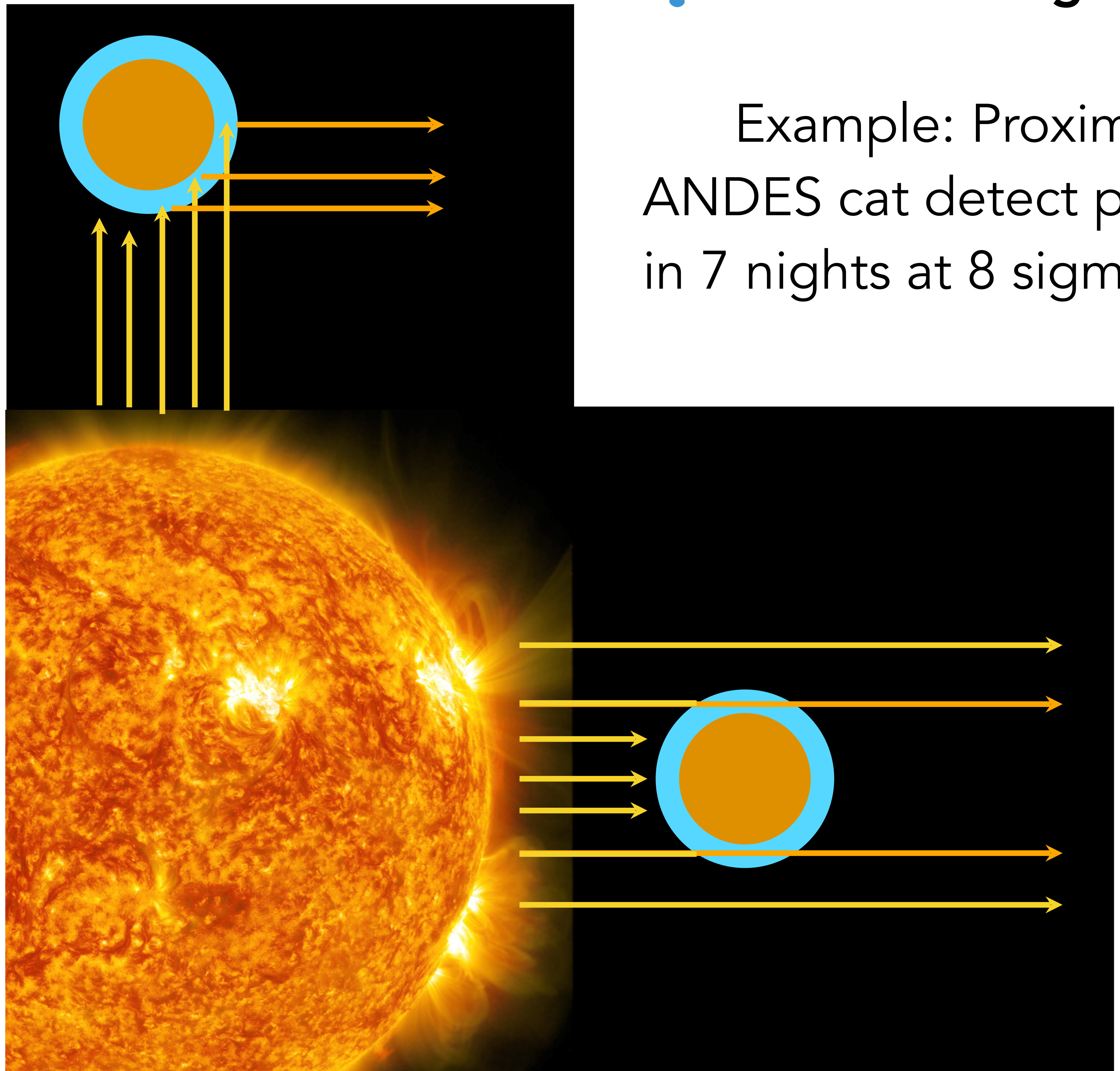
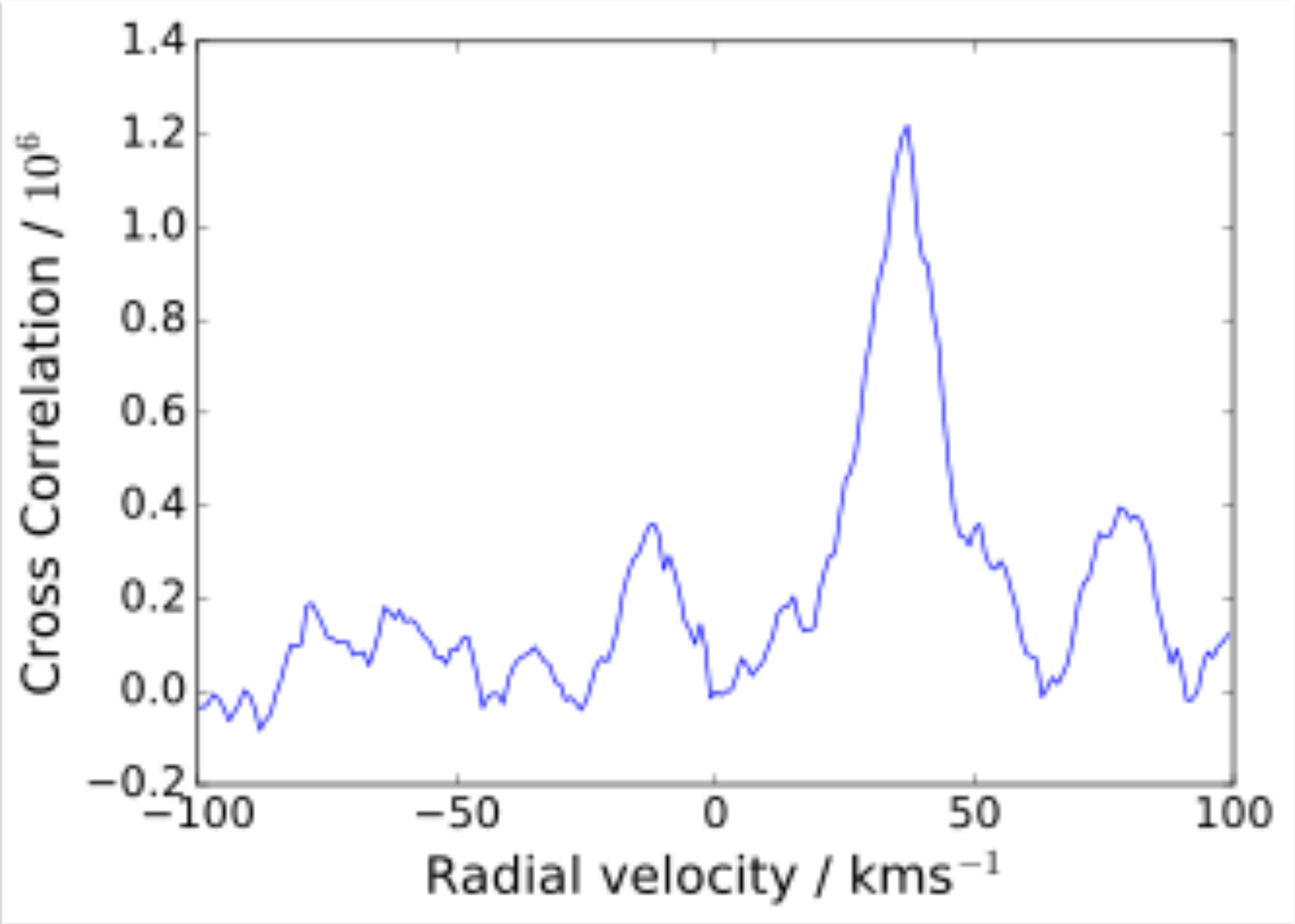


In reflected light

Example: Proxima b ANDES cat detect planet in 7 nights at 8 sigma level



CCF with the detection of Proxima b in O_2 in 70h (Hawker & Parry 19)

In transmitted light

Example: Trappist 1 planets ANDES cat detect:

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EXOPLANET ATMOSPHERES

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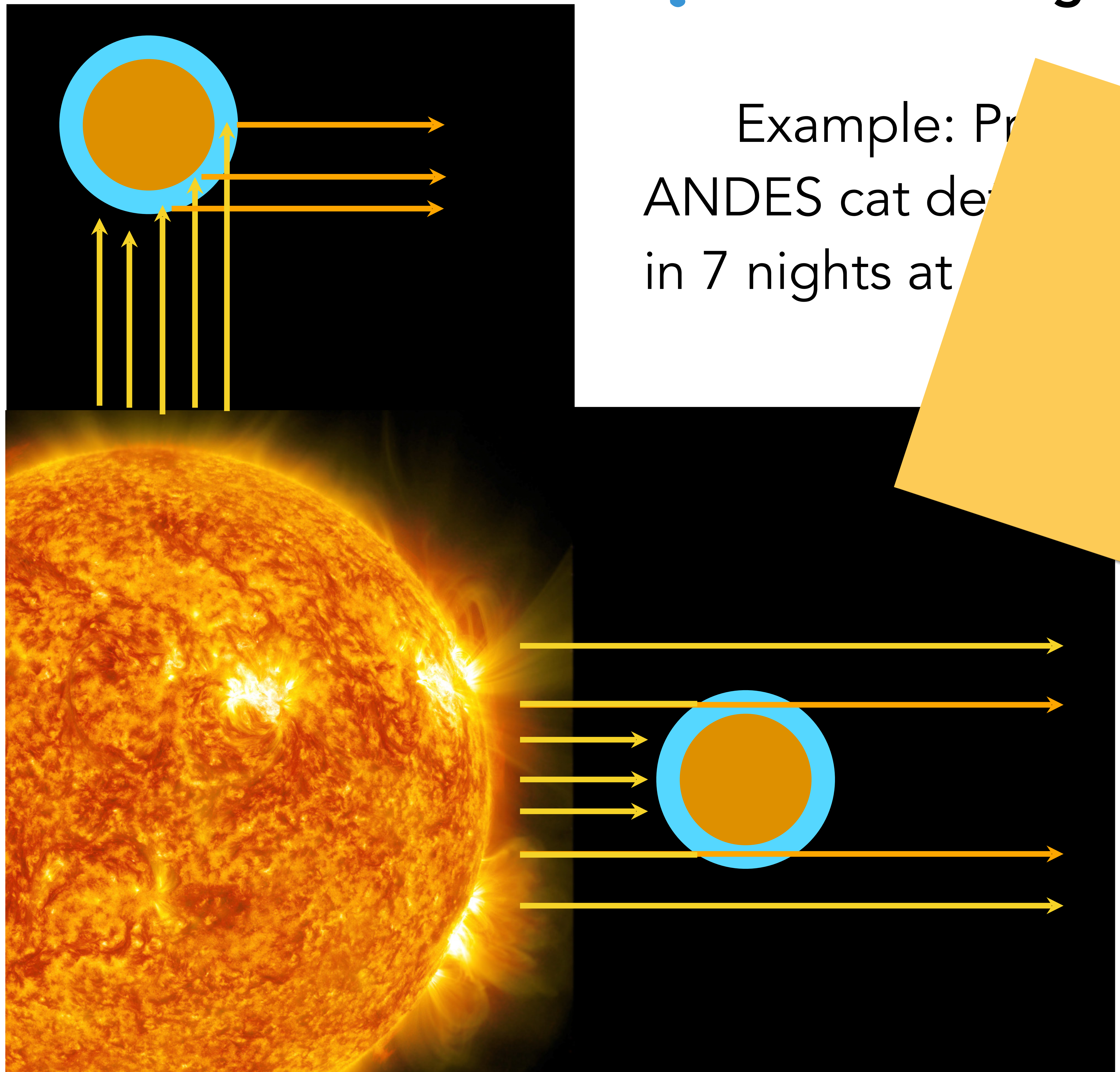
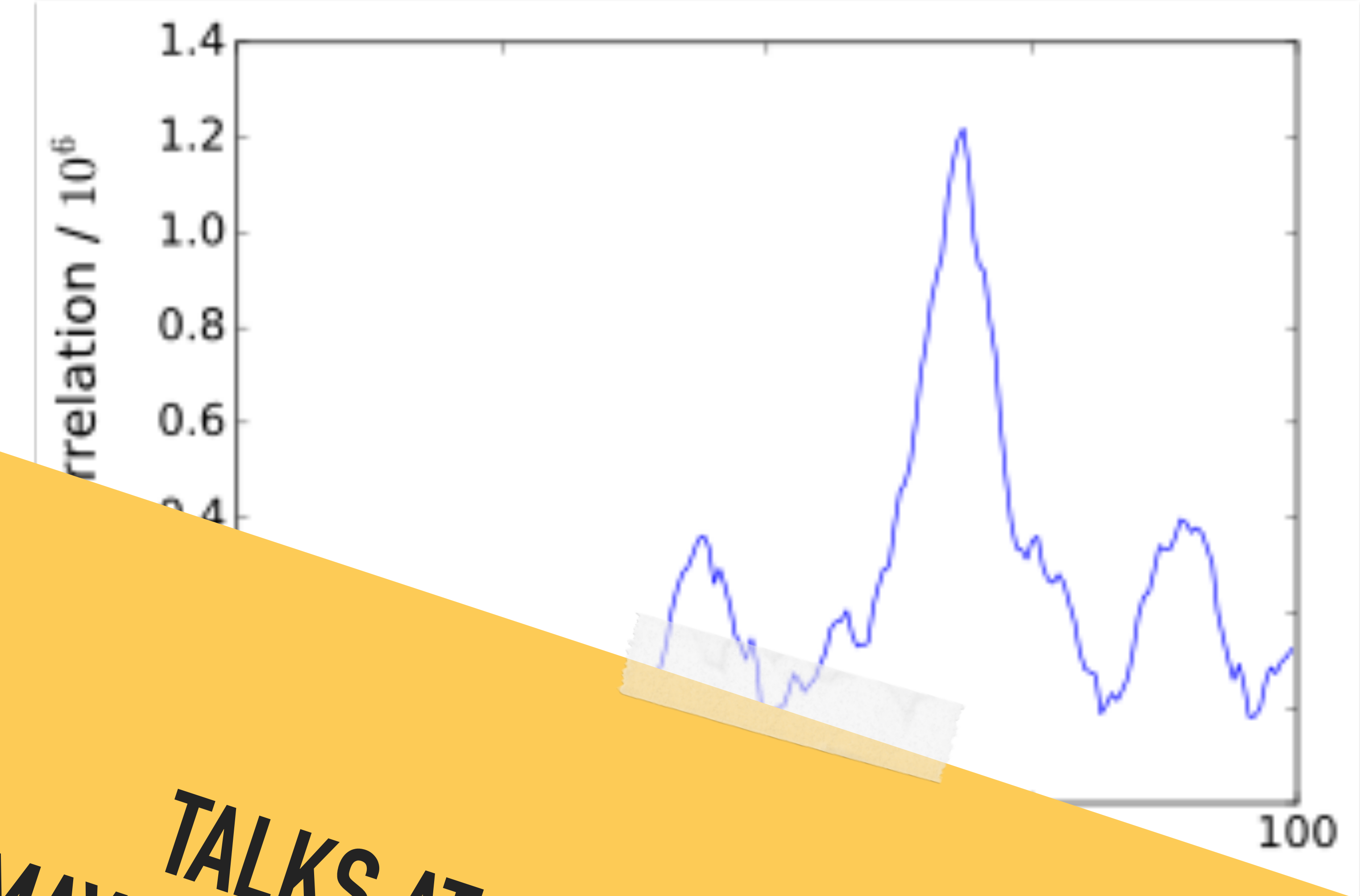


In reflected light

Example: Pr
ANDES cat de
in 7 nights at



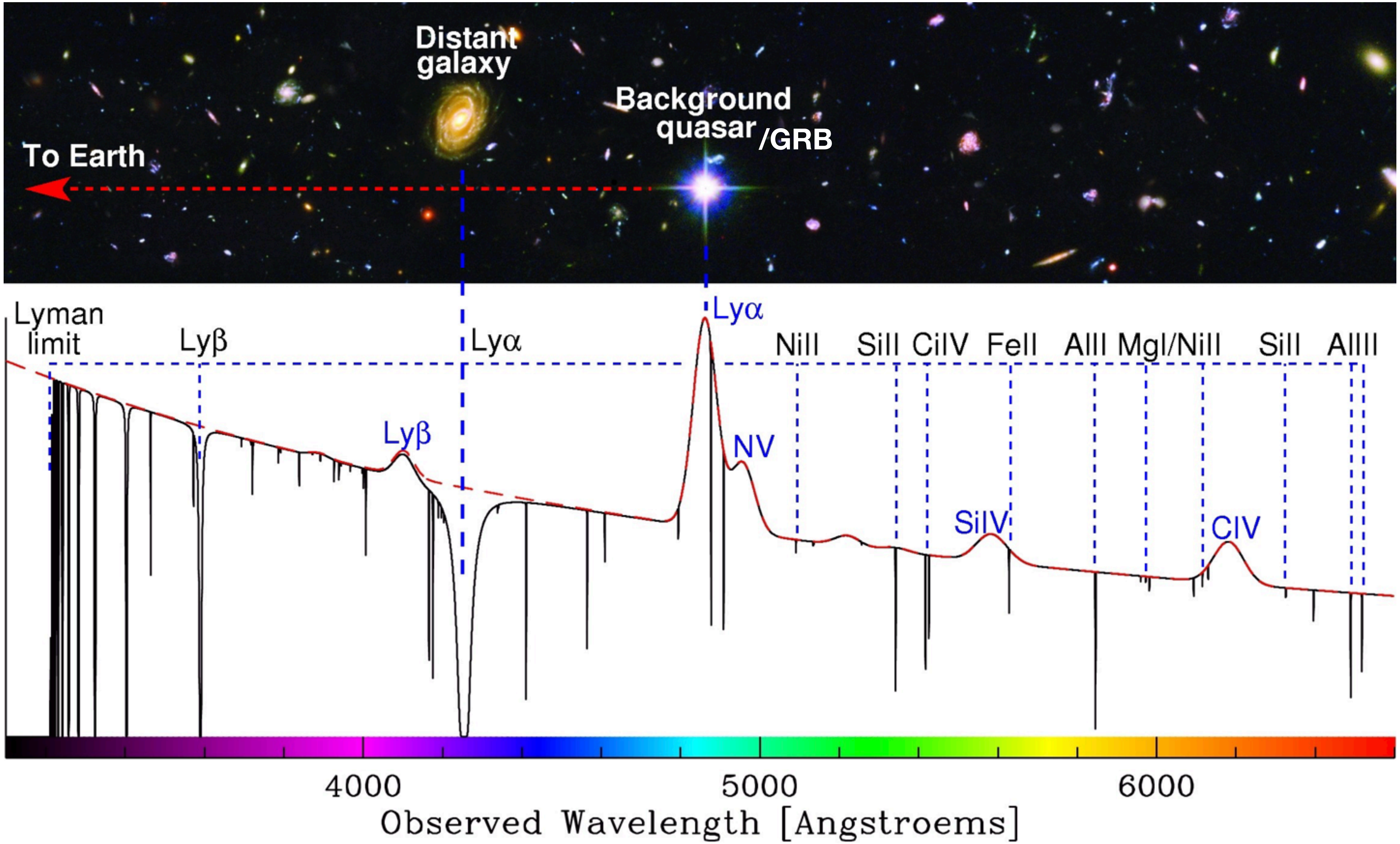
CCF with the detection of Proxima b in O_2 in 70h (Hawker & Parry 19)

TALKS AT THIS CONFERENCE BY
MAYOR, PEPE, SOZZETTI, SNELLEN ET AL.

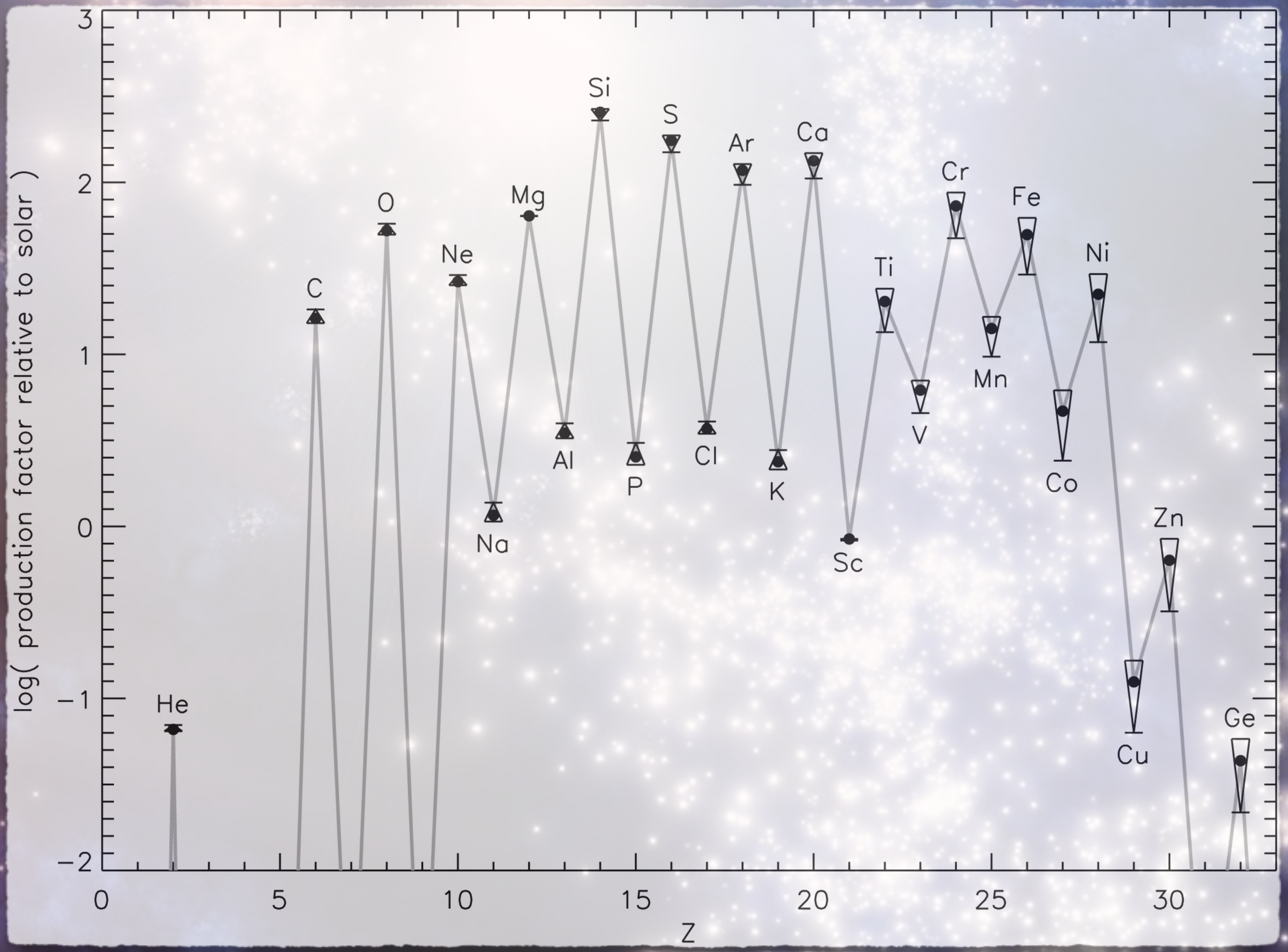
Exa

- $H_2$0 (1.3-1.7 μm)
- $H_2$0 (0.9-1.1 μm) in 4 trans
- CO_2 in 4 transits
- O_2 in 25 transits

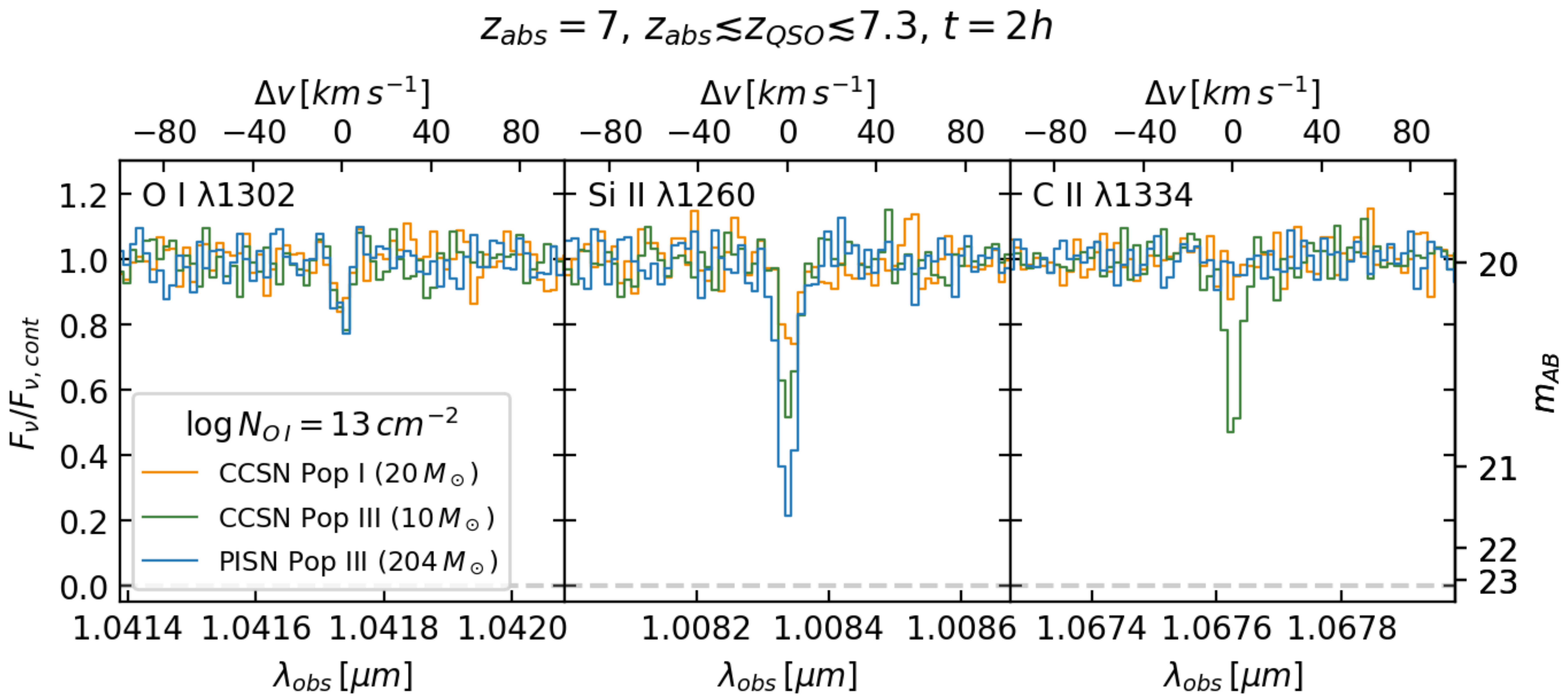
The Inter-Galactic Medium:
tracing the chemical enrichment of the universe (e.g. Pop III SNe)
High spectral resolution (R>50-100x10^3) and broad spec. cov. (opt+NIR)



Chemical enrichment imprint of primordial supernovae: the signature of Pop III stars

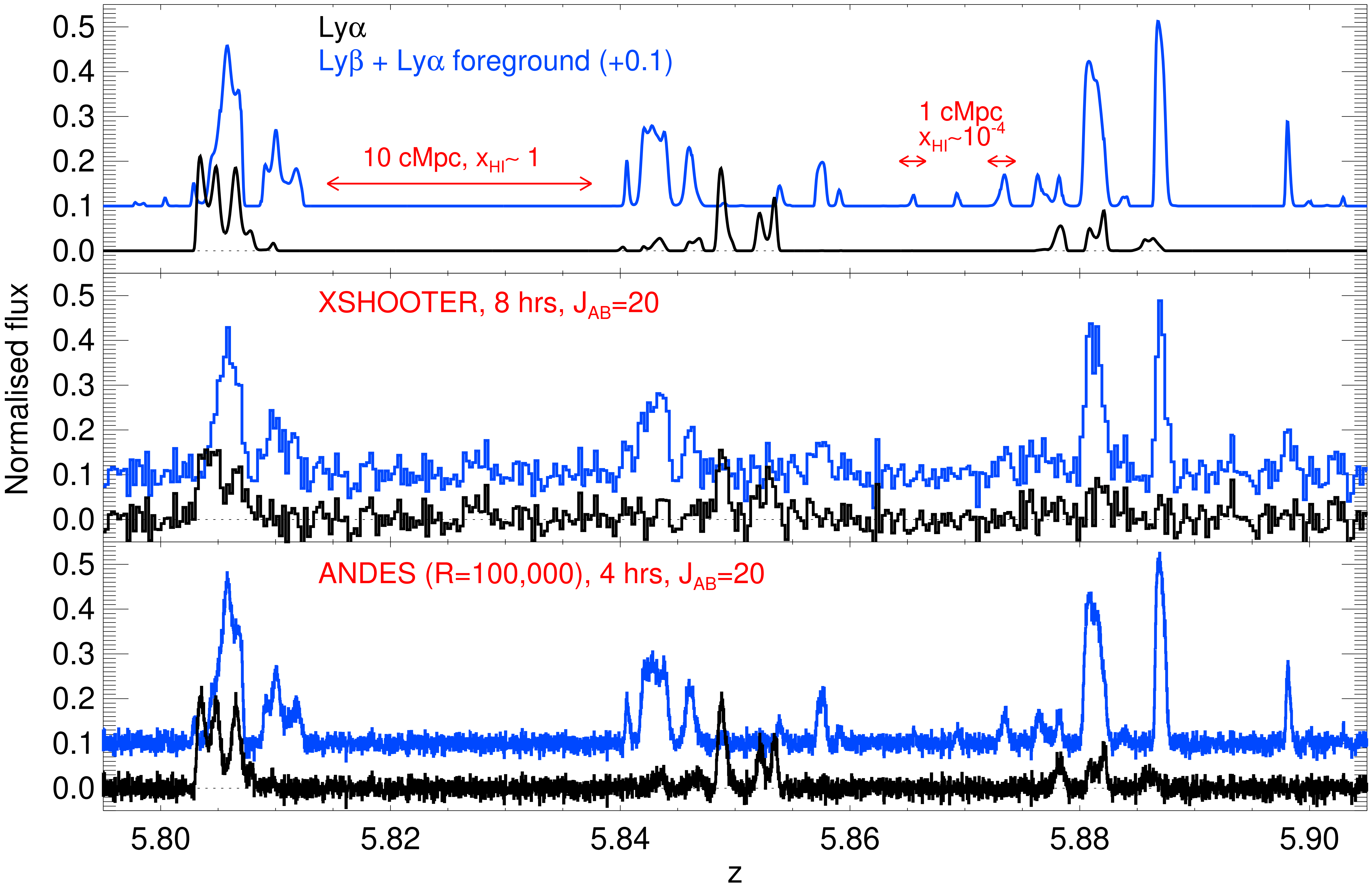


CHEMICAL ENRICHMENT IMPRINT OF PRIMORDIAL SUPERNOVAE:



PROBING THE EARLY CHEMICAL ENRICHMENT

Lyα and *Lyβ* coeval forest of Z=6.1 quasar during the age of reionization (completed by z~5.7)



PROBING THE EARLY CHEMICAL ENRICHMENT

ANDES

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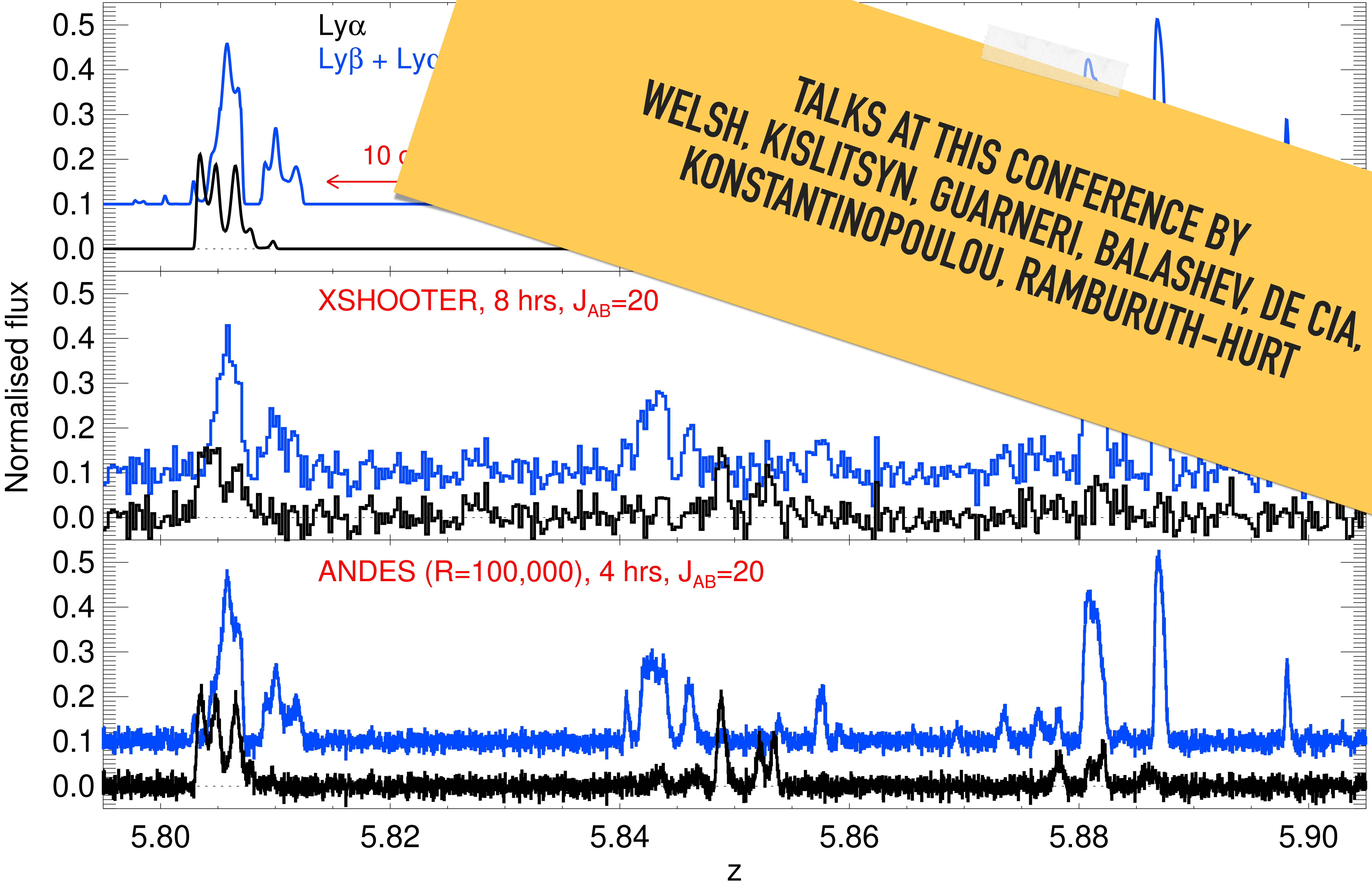
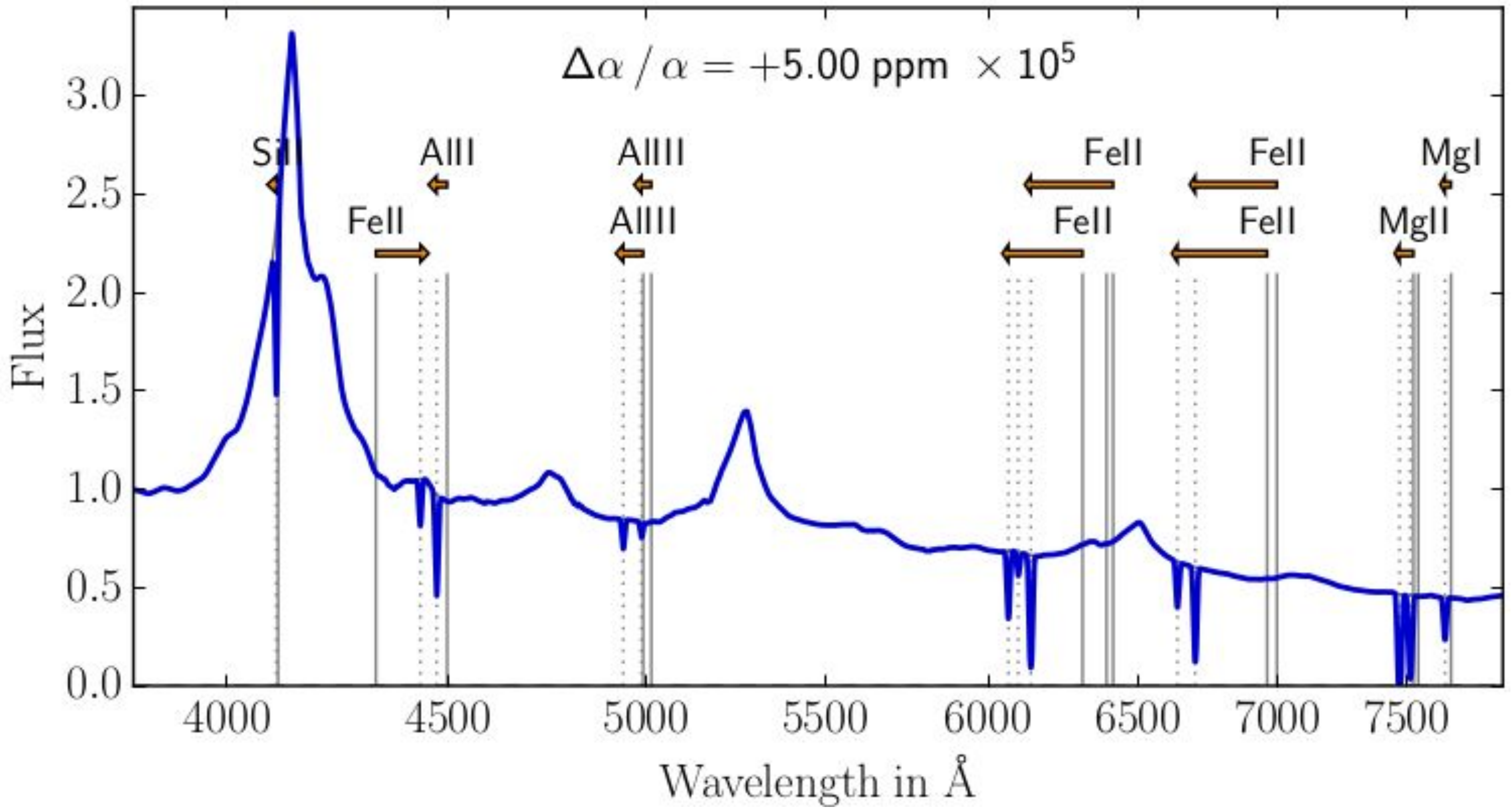


TALKS AT THIS CONFERENCE BY
WELSH, KISLITSYN, GUARNERI, BALASHEV, DE CIA,
KONSTANTINOPOULOU, RAMBURUTH-HURT

FUNDAMENTAL PHYSICS: VARIATION OF THE FUNDAMENTAL CONSTANTS

- Variation of α causes shift of quasar absorption lines
  - $\Delta\lambda$ between lines changes in characteristic way
  - relative velocities change as $\Delta v_i \sim Q_i \Delta\alpha/\alpha$
  - need accuracy of <1 m/s improve on systematic errors wrt UVES & ESPRESSO



courtesy of C. Martins

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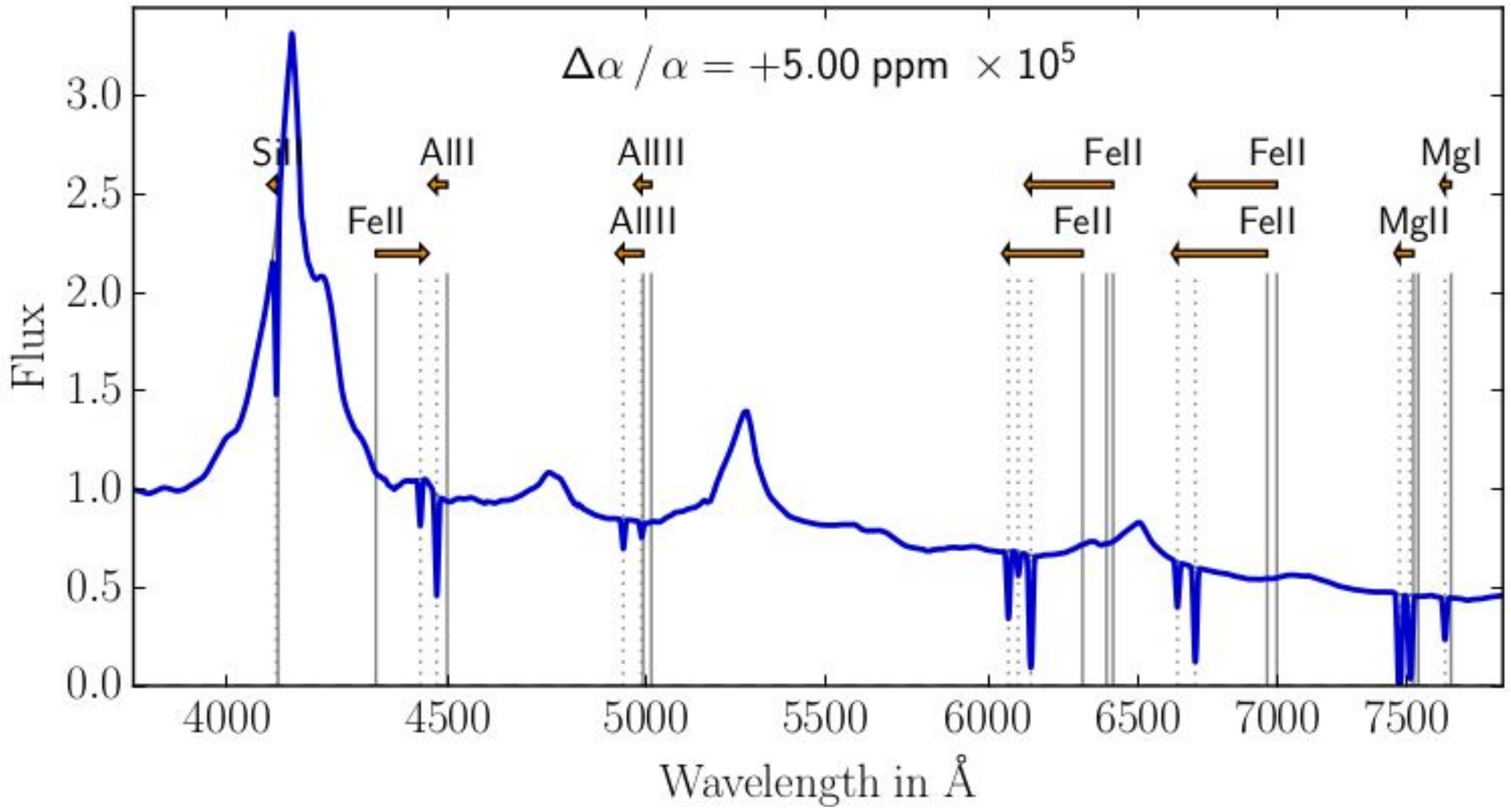

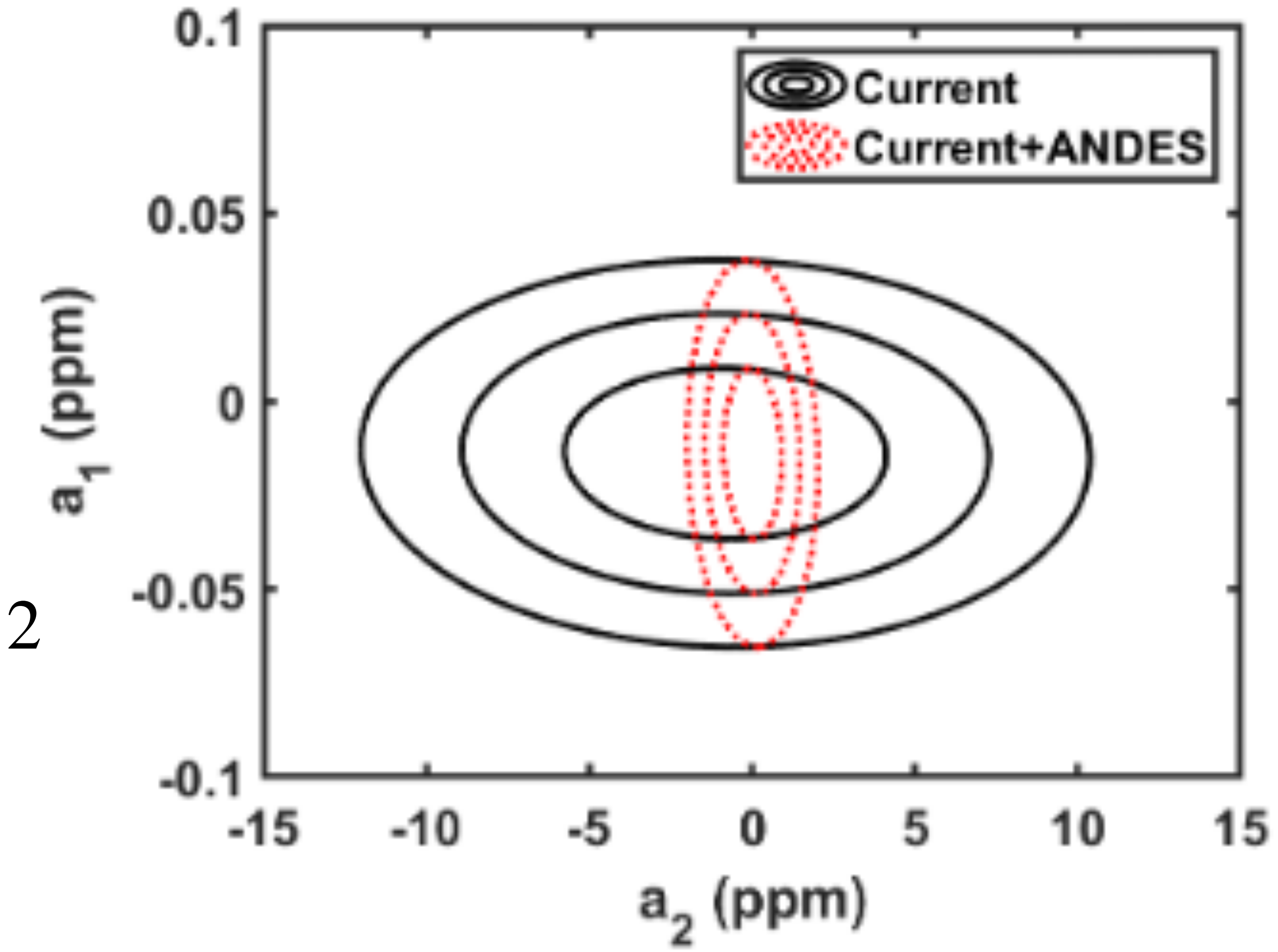

$$\frac{\Delta\alpha}{\alpha} = \mathbf{a_1} * \left(\frac{z}{z+1}\right) + \frac{1}{2} * \mathbf{a_2} * \left(\frac{z}{z+1}\right)^2$$

courtesy of C. Martins

FUNDAMENTAL PHYSICS: VARIATION OF THE FUNDAMENTAL CONSTANTS

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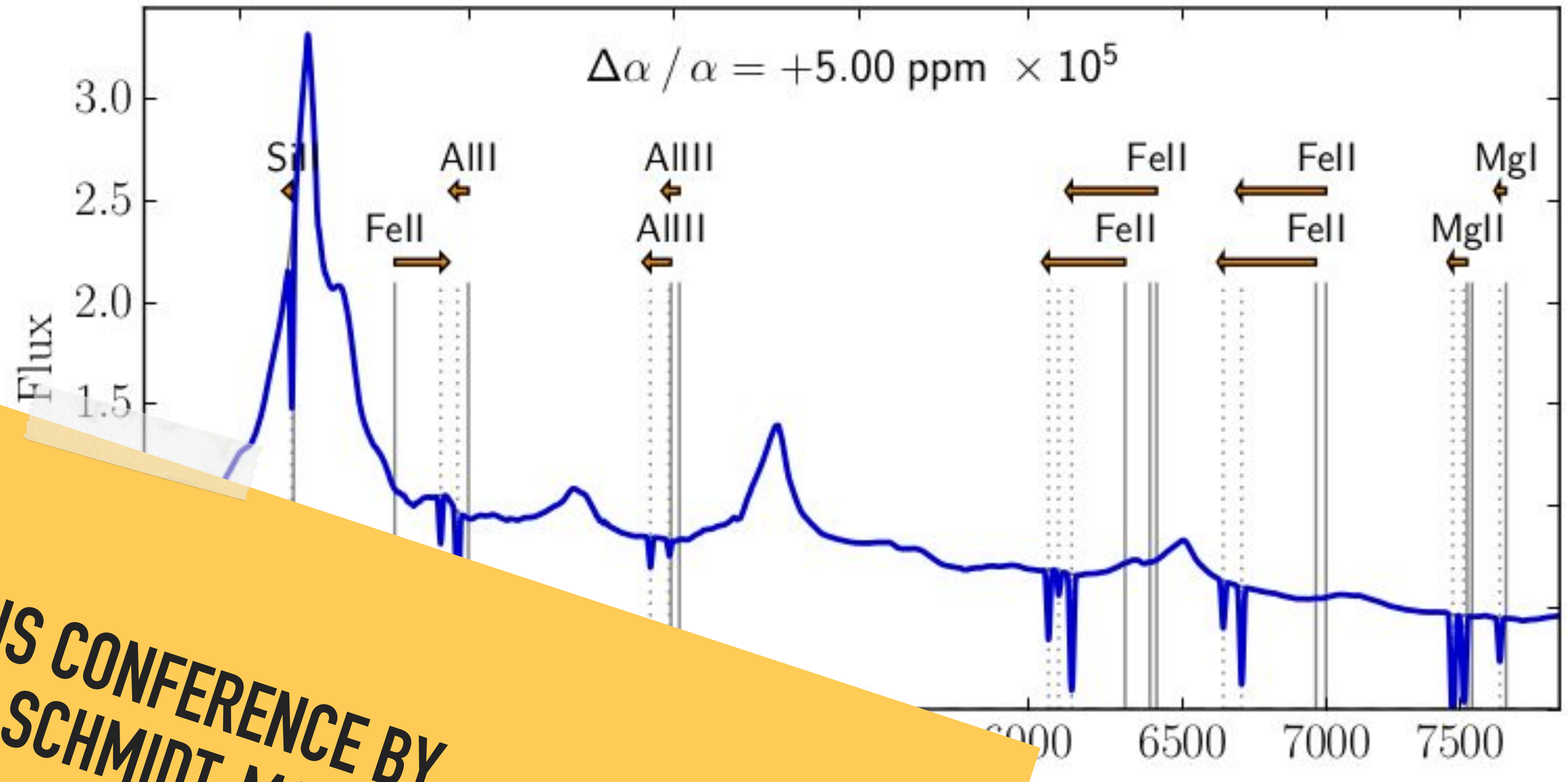
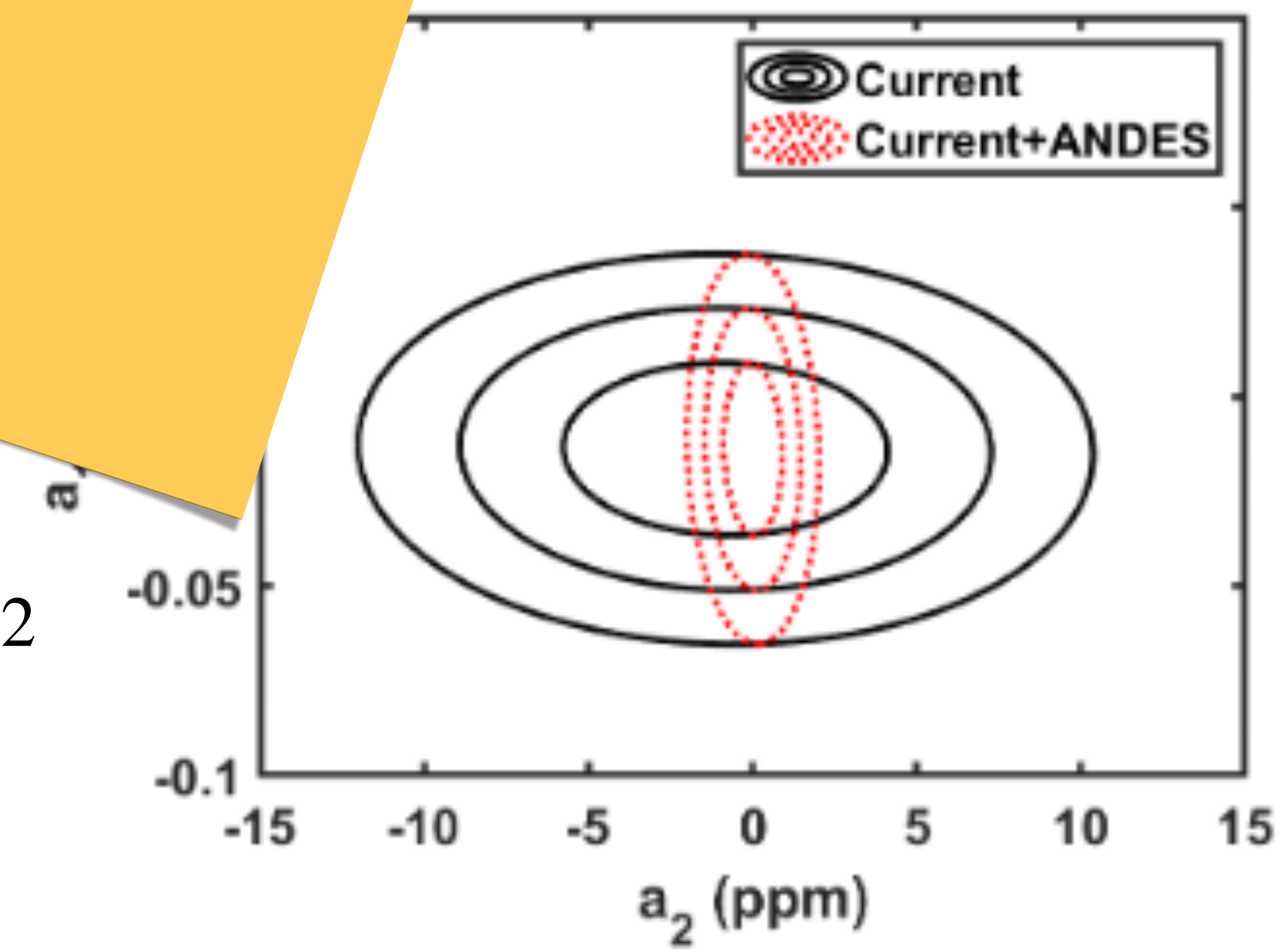


TALKS AT THIS CONFERENCE BY MURPHY, MILAKOVIC, SCHMIDT, MARTINS ET AL.



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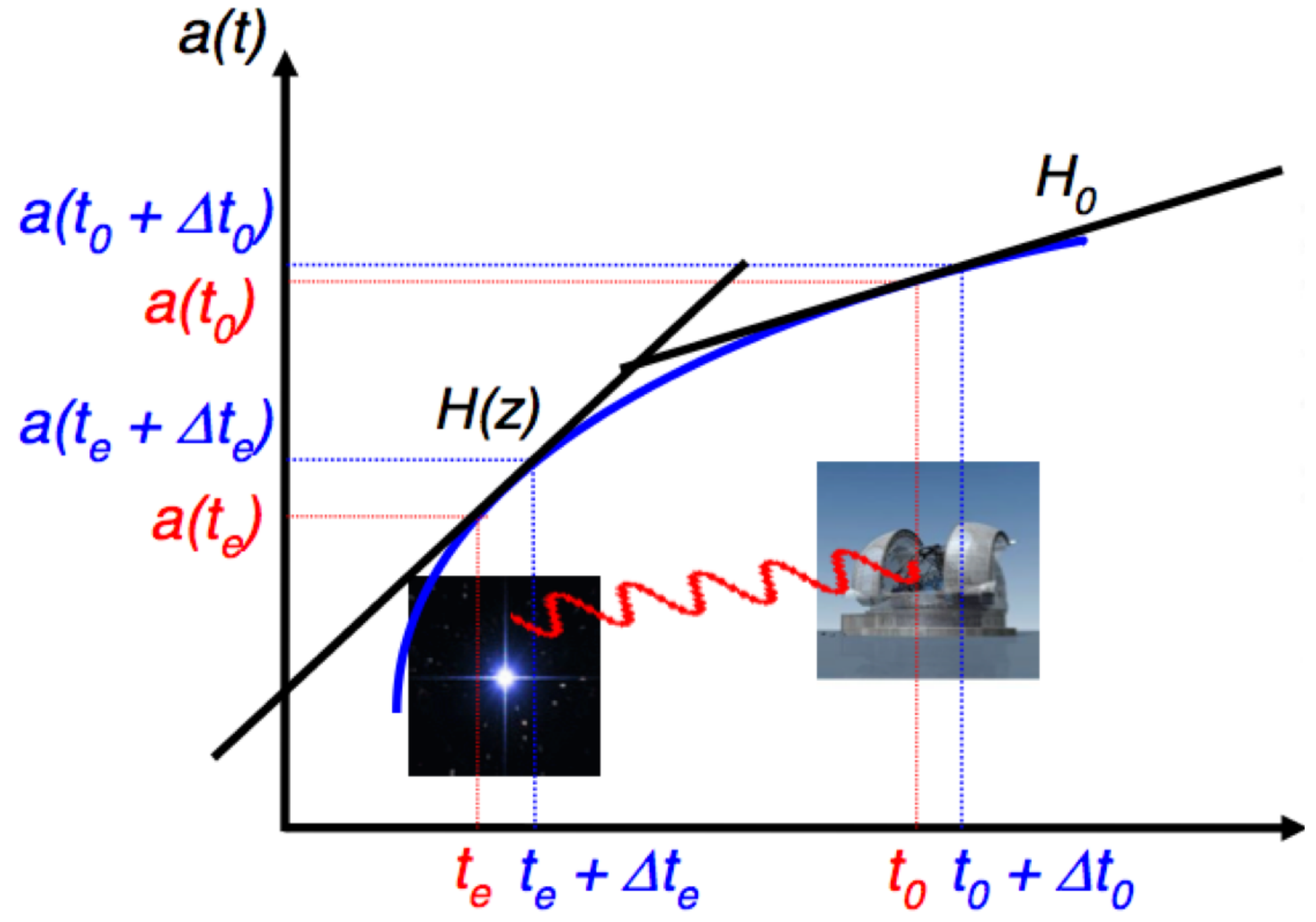
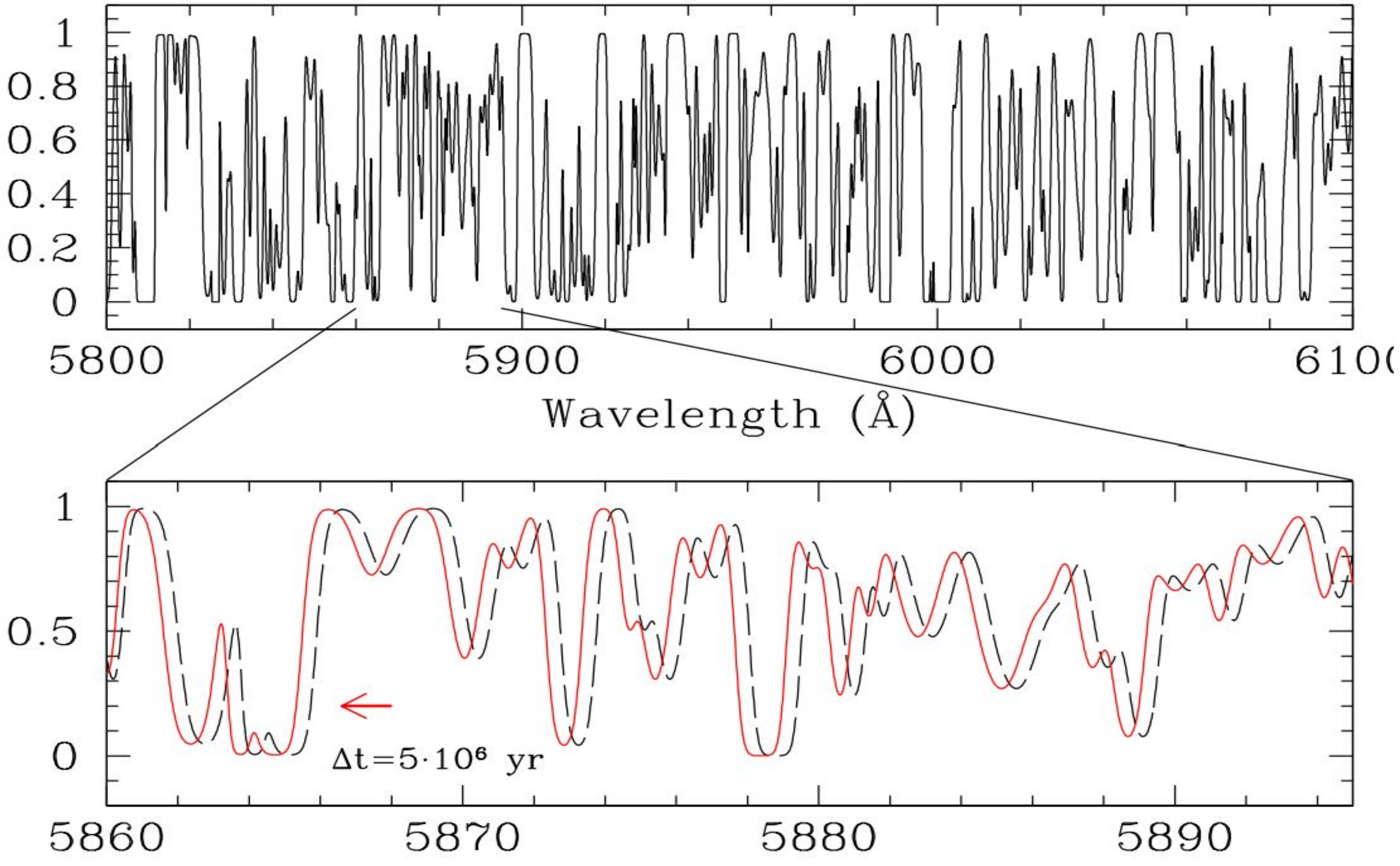
courtesy of C. Martins

REDSHIFT DRIFTS "SANDAGE TEST"

- Expansion of the Universe causes the redshift of distant objects to drift slowly with time
- Direct non-geometric, model-independent measurement of expansion history of the universe
- alternative to all other geometrical methods, exploring potential new physics
- expect signal of ~ cm/s/yr

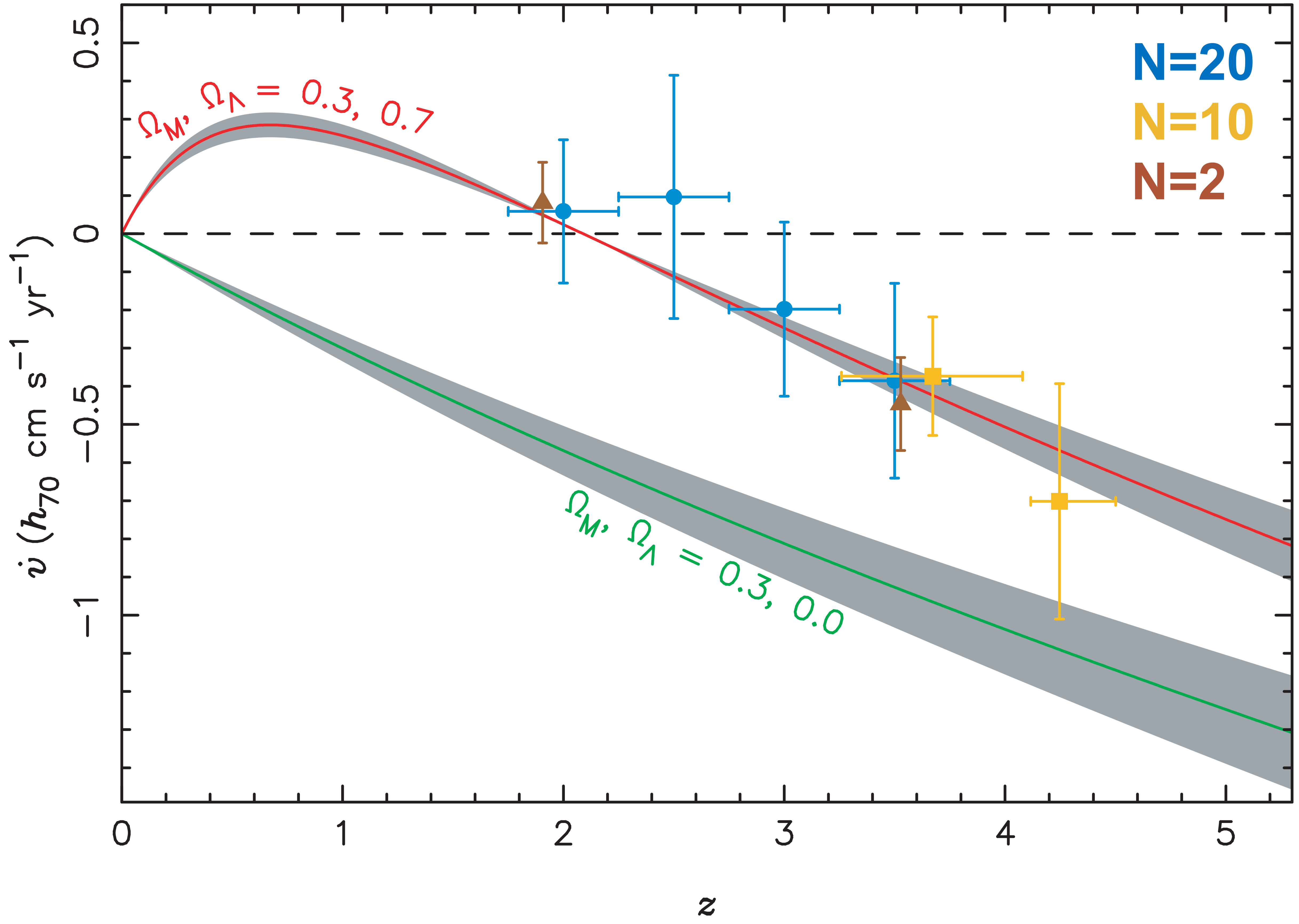




Cristiani et al. (2007)

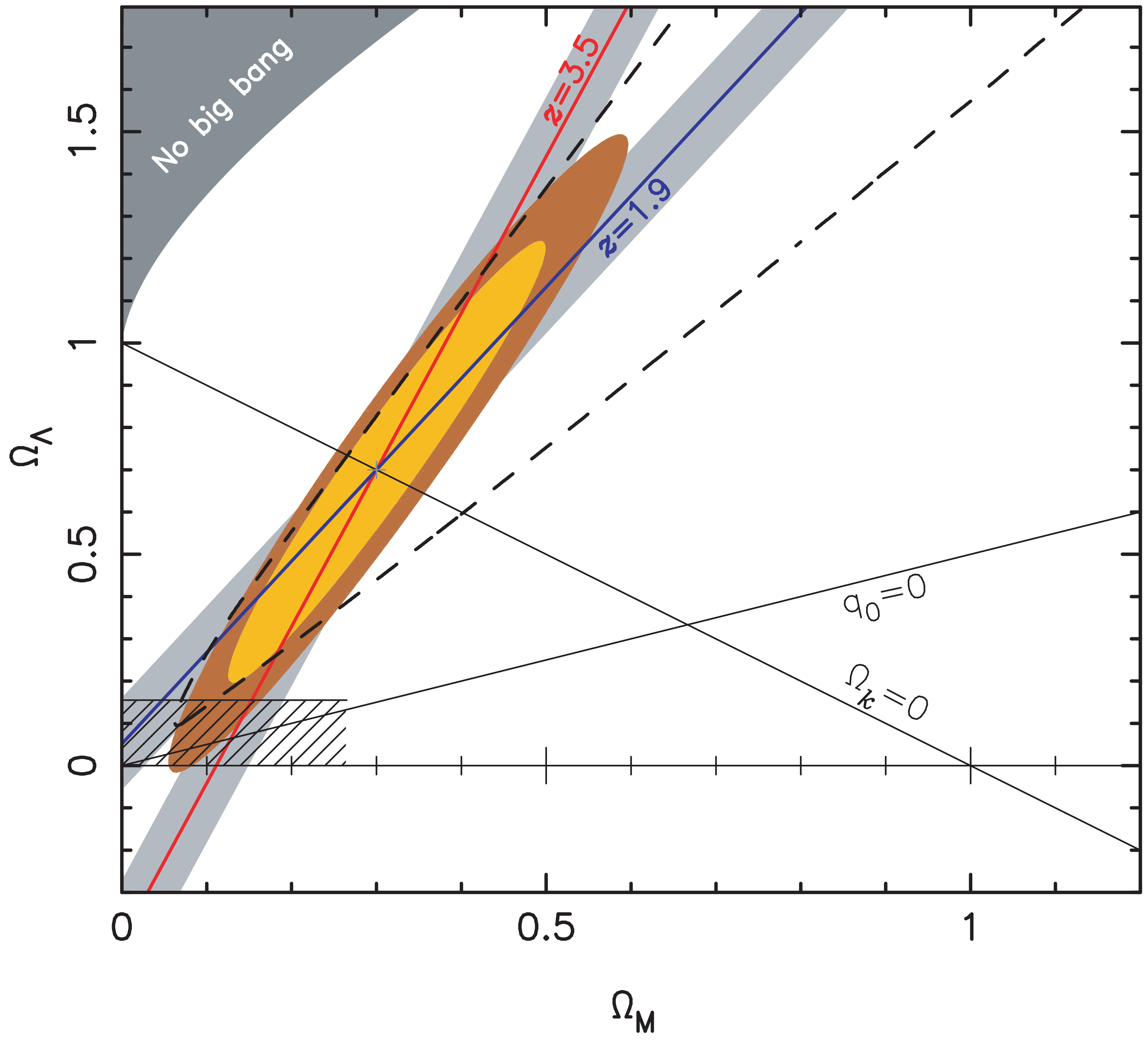
REDSHIFT DRIFTS “SANDAGE TEST”

ANDES



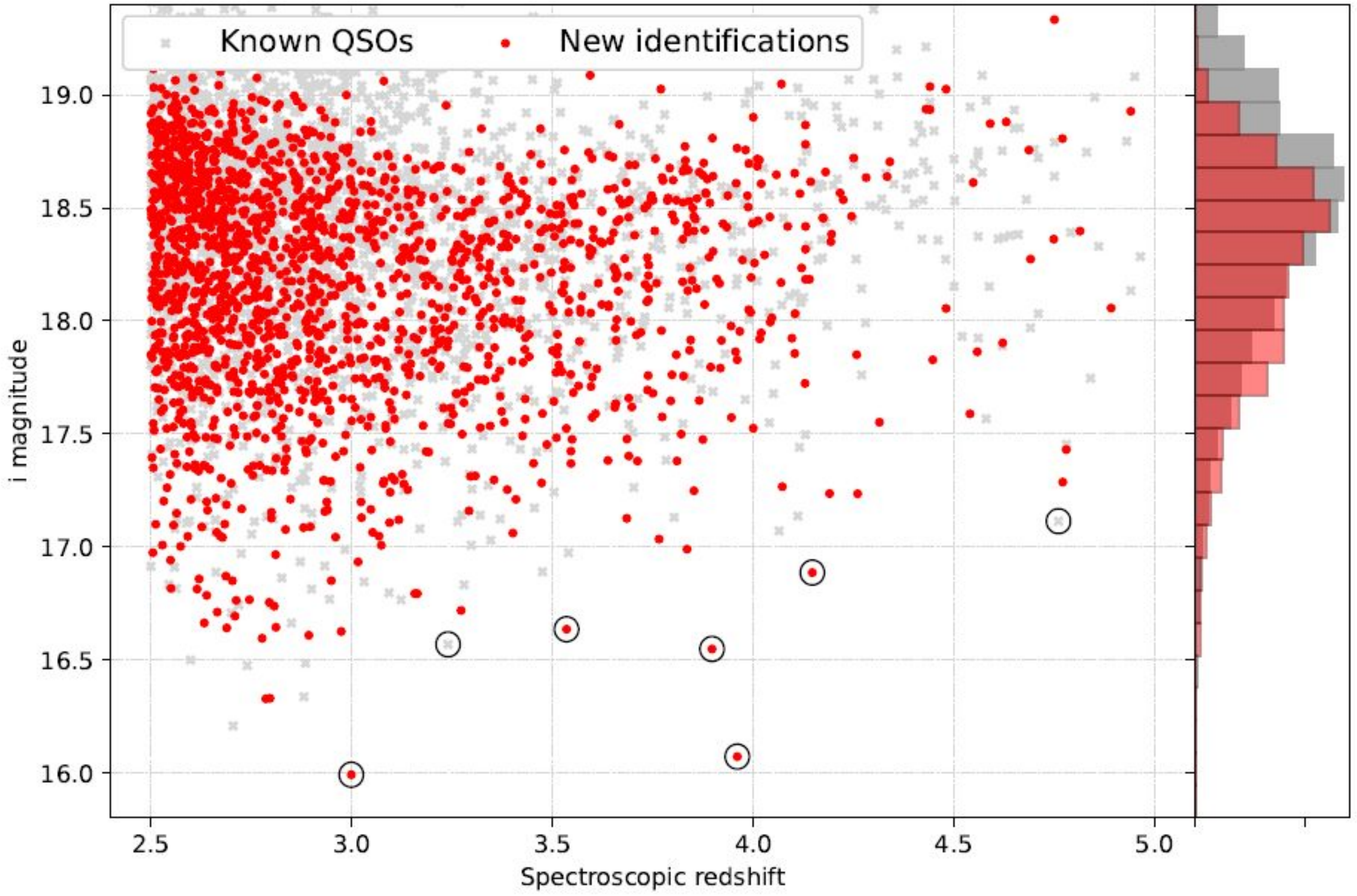
Δt~20 yr, T_{exp} ~ 4000hr

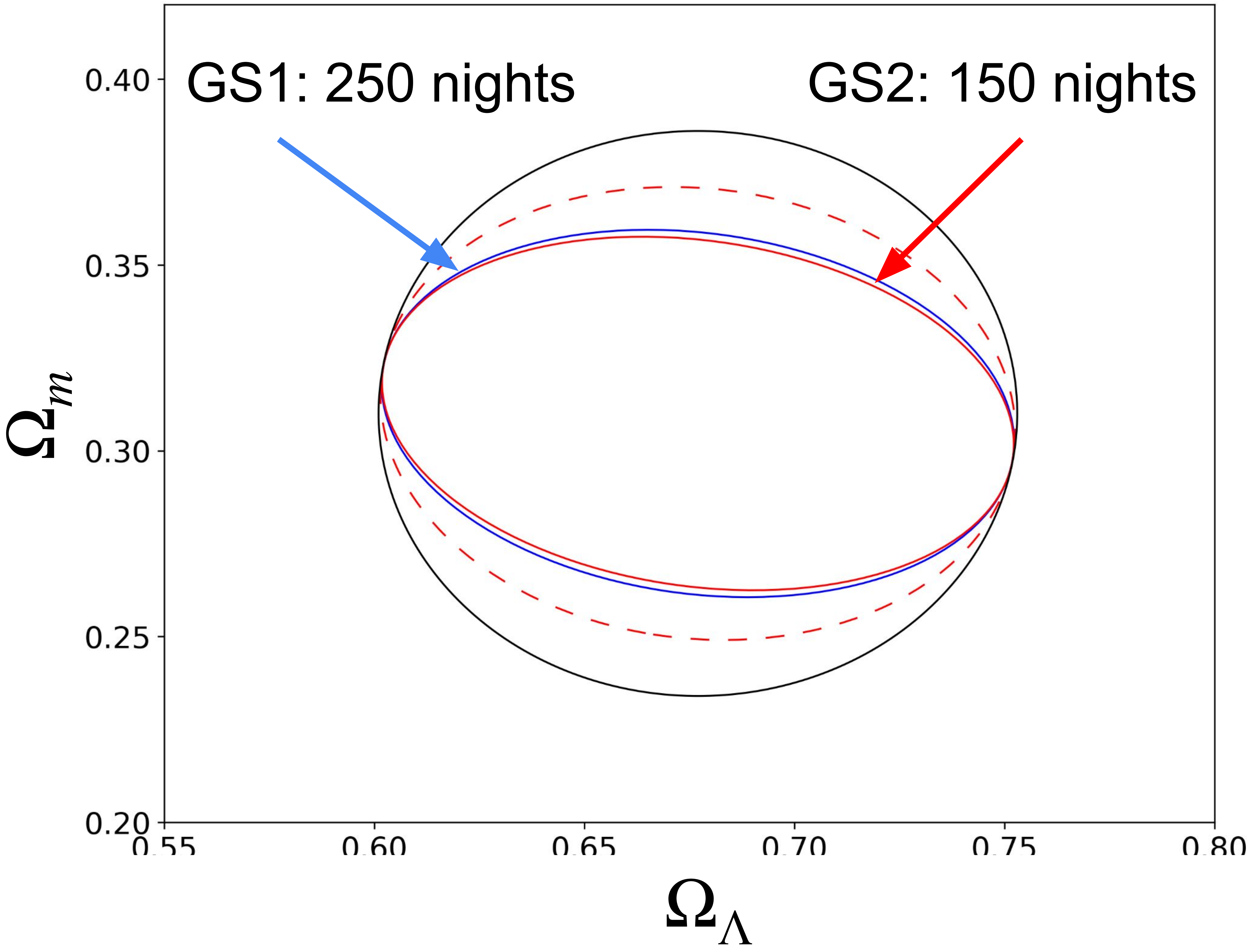
Liske et al. 2008



REDSHIFT DRIFTS "SANDAGE TEST"

- New Golden Sample of 'superbright' high-redshift quasars significantly reduces observation time for the same experiment time (Cristiani et al. 2023)





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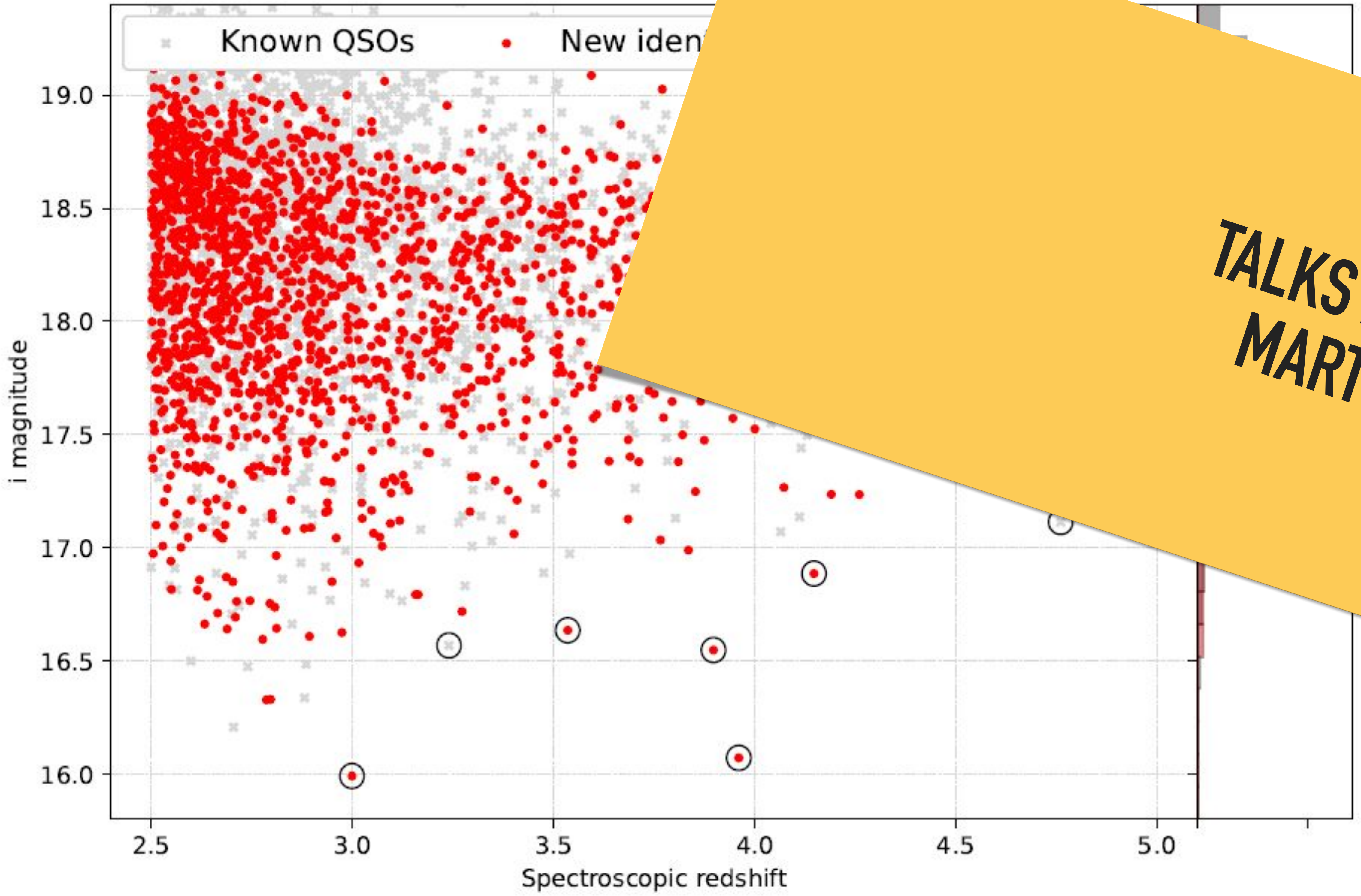
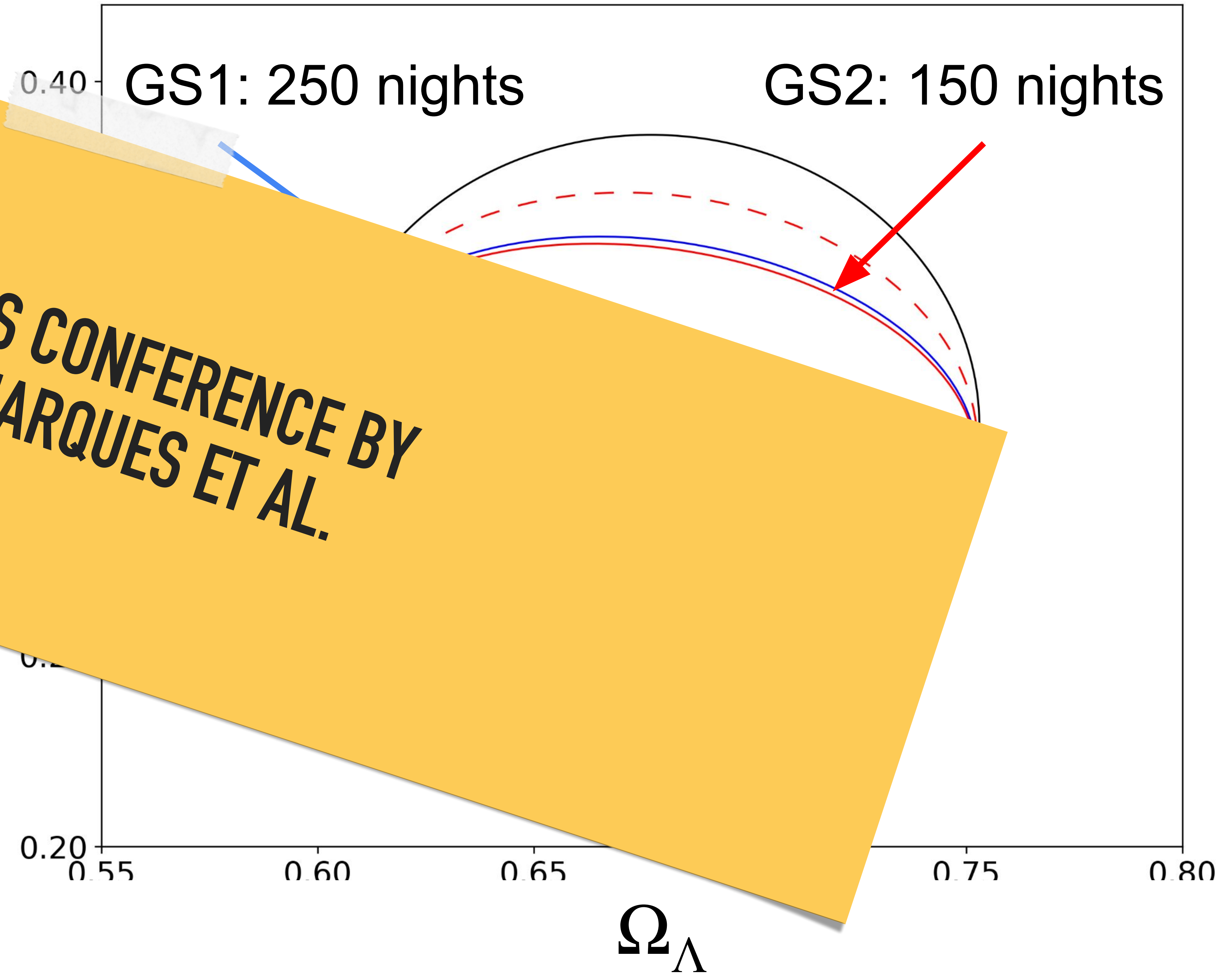
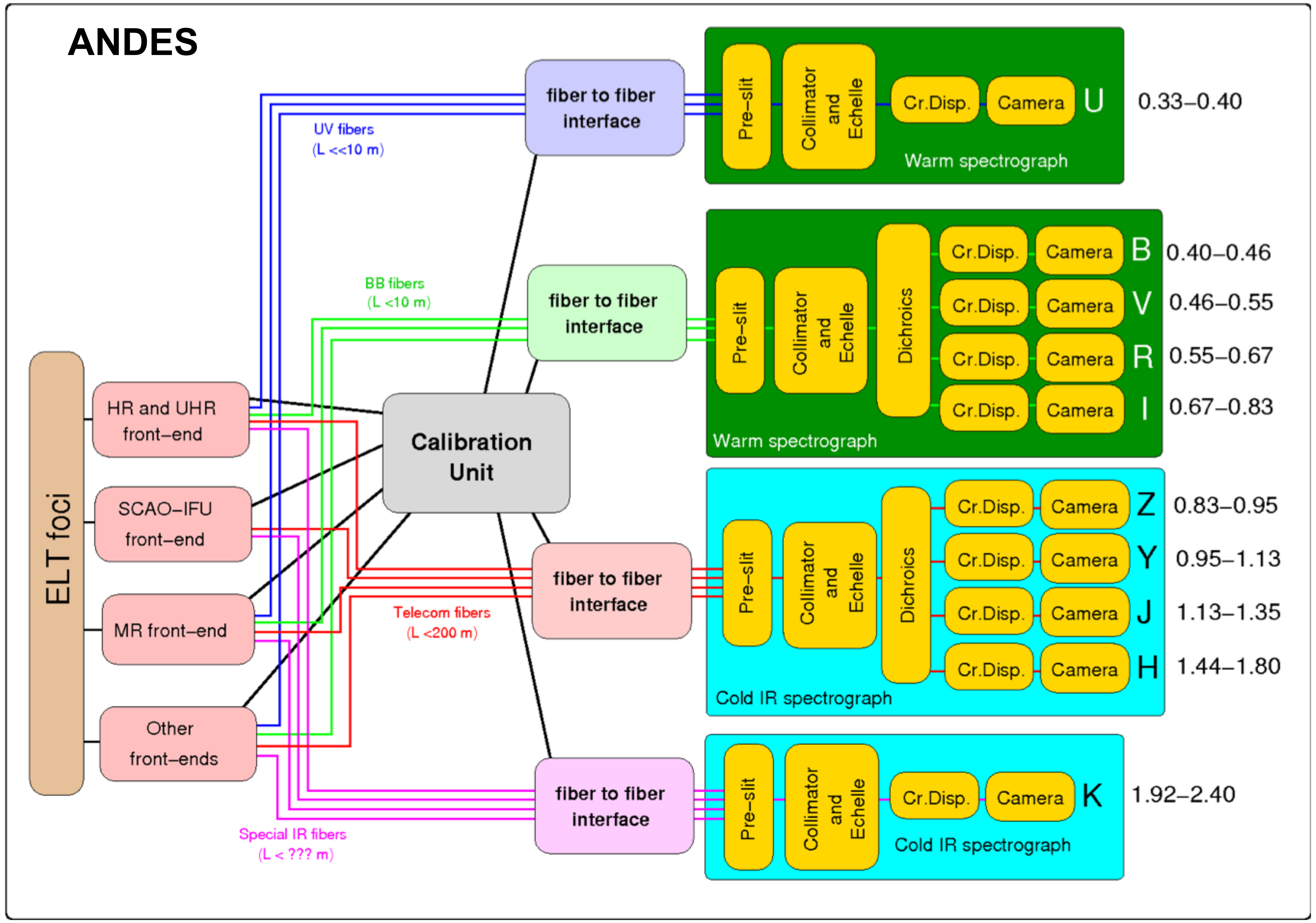




TALKS AT THIS CONFERENCE BY MARTINS, MARQUES ET AL.

SCIENCE PRIORITISATION

- Combination of science cases requires:
  R~100,000, 0.33< λ<2.4 μm and many different observing modes
- Achievable with a fibre-fed modular system



SCIENCE PRIORITISATION

ANDES

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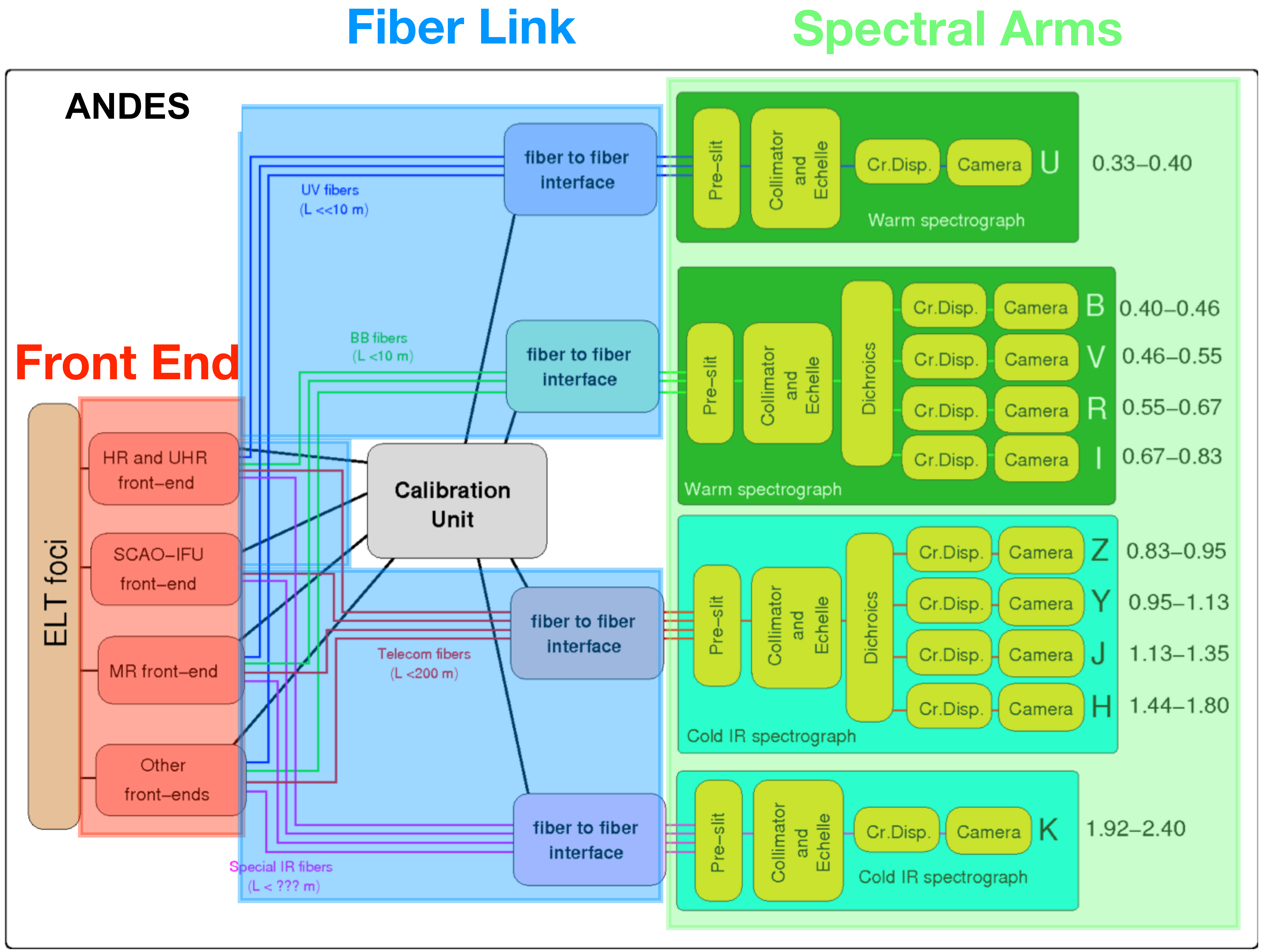

old architecture (Phase A)

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ANDES

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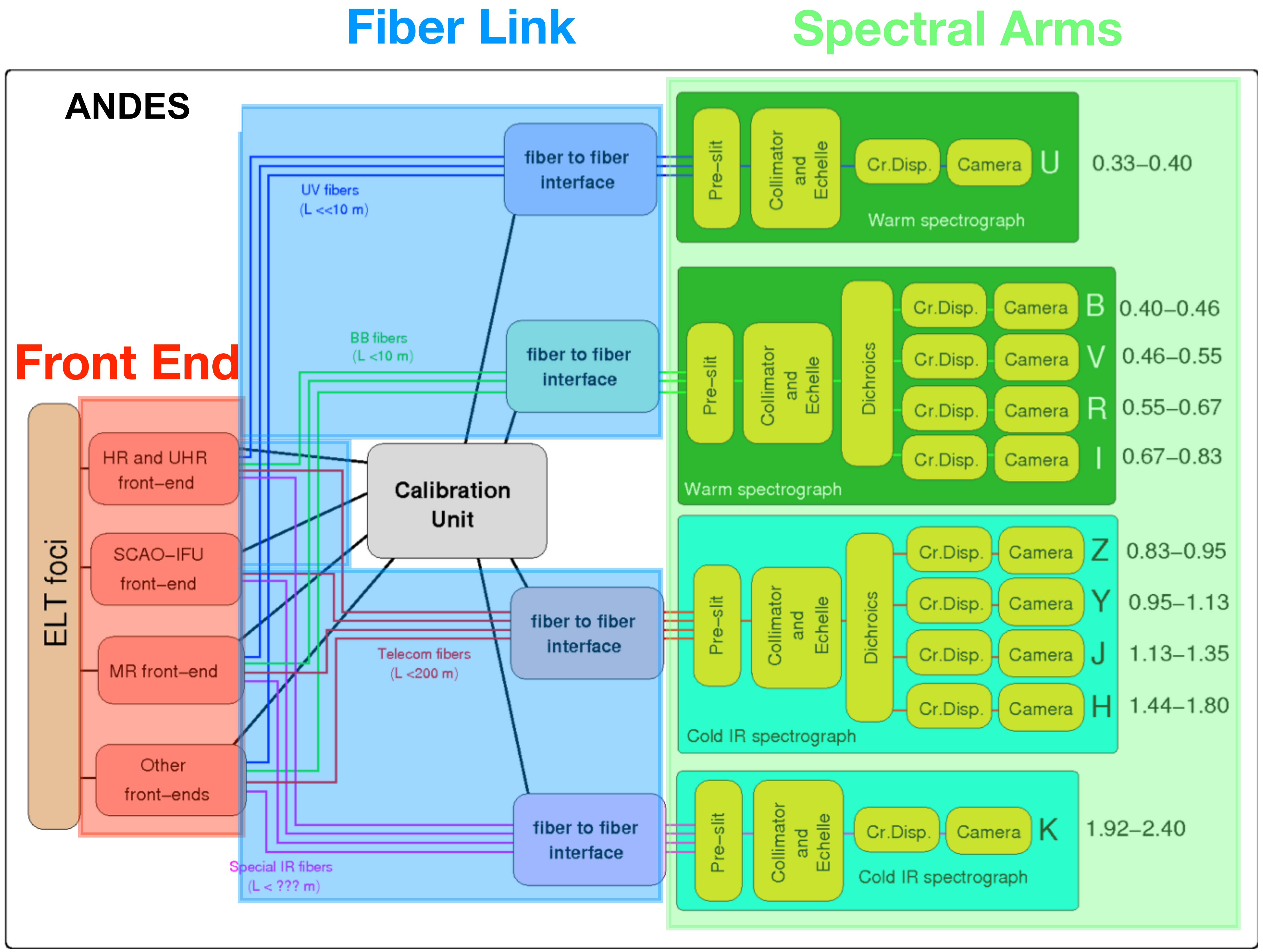

>50 MEUR modular instrument (hardware only): prioritisation of science requirements mandatory

old architecture (Phase A)

SCIENCE PRIORITIES

ANDES

* Priority 1: Exoplanet atmospheres via transmission spectroscopy (potential detection of bio-signatures)
  * TLR 1: R > 100,000, 0.5-1.8 μm, et alia; drive the ANDES baseline design
  * Enables: reionization of Universe; characterization of Cool stars
  * Doable: detection and investigation of near pristine gas; 3D reconstruction of the CGM; Extragalactic transients

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  - TLR 2: blue extension to 0.37 μm
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SCIENCE PRIORITIES

ANDES

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  - Enables: Planet formation in protoplanetary disks; characterization of stellar atmospheres; Search of low mass Black Holes
  - Doable: characterization of the physics of protoplanetary disks
- Priority 4: Redshift drift (Sandage test)
  - TLR 4: λ accuracy 2 cm/s, stability 2 cm/s
  - Enables: Mass determination of exoplanets (Earth-like objects)
  - Doable: Radial velocity search for exoplanets around M-dwarf stars

SCIENCE PRIORITISATION

ANDES

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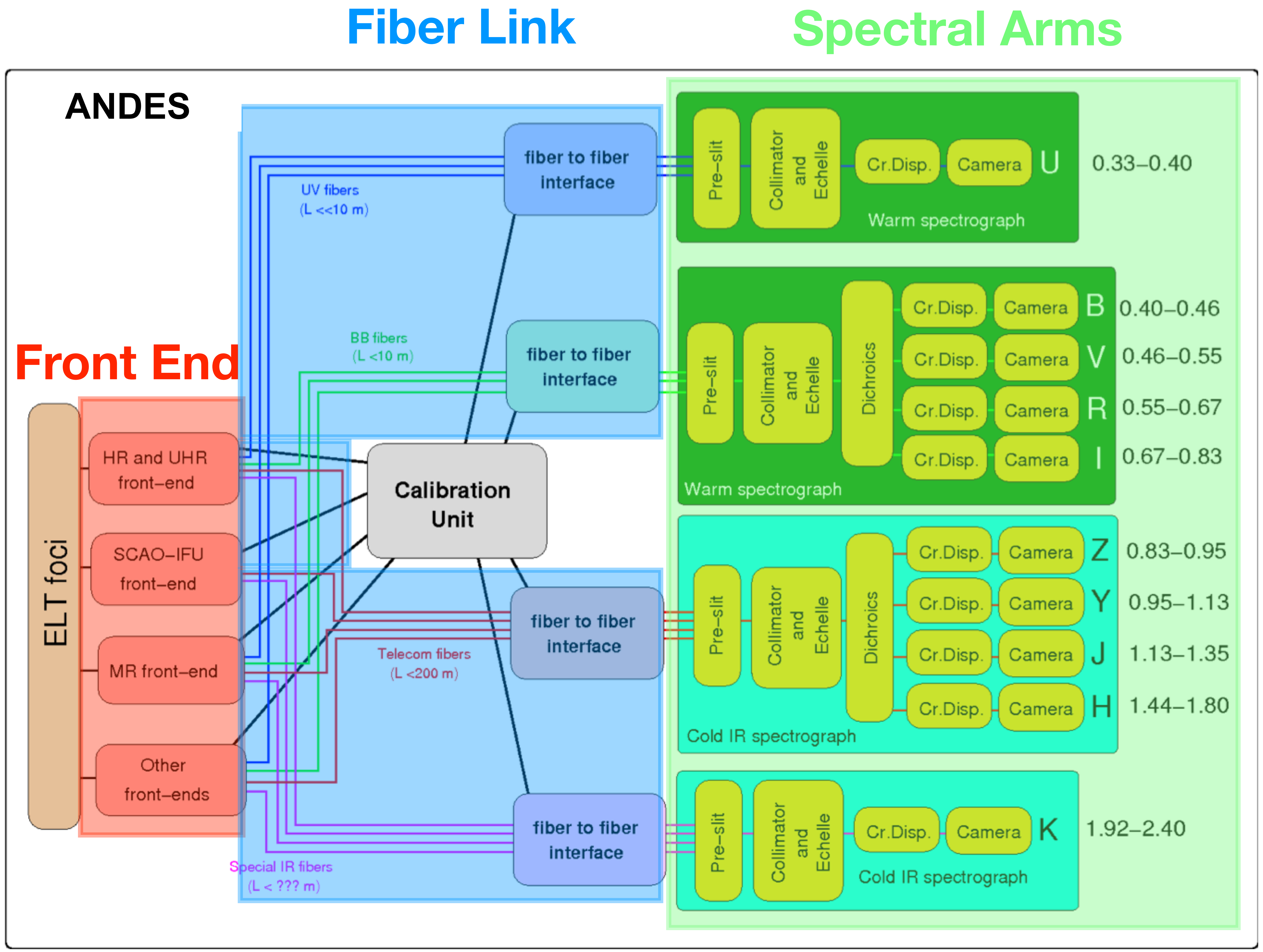
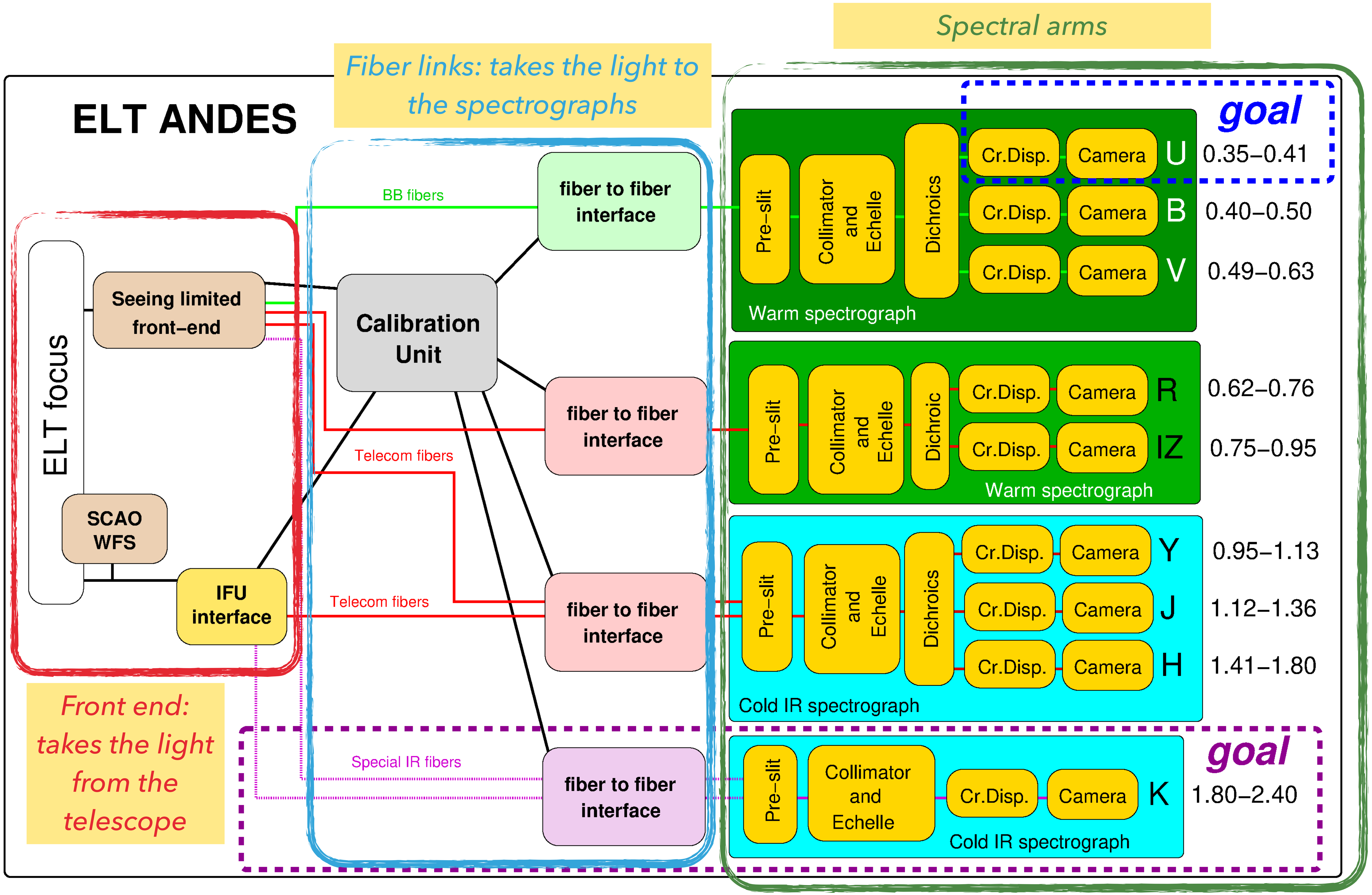


>50 MEUR modular instrument (hardware only): prioritisation of science requirements mandatory

old architecture (Phase A)

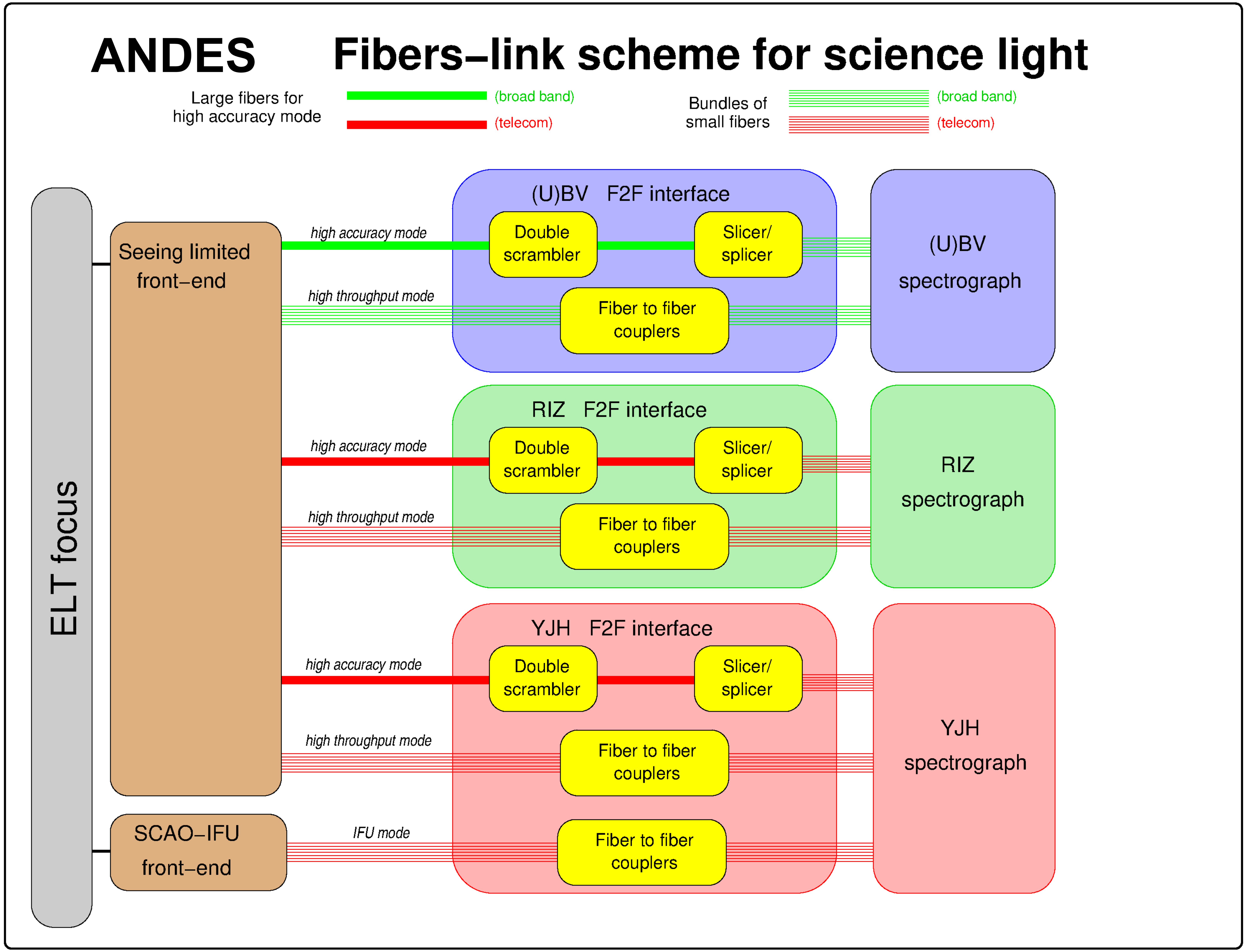
INSTRUMENT ARCHITECTURE



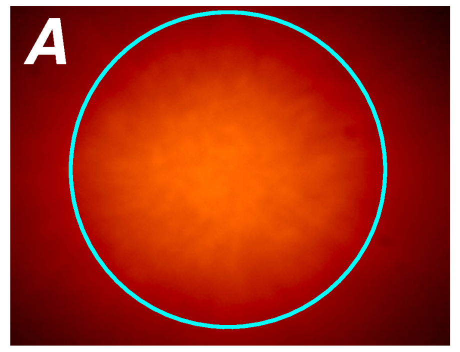
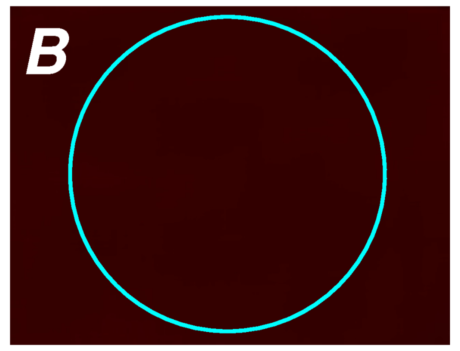
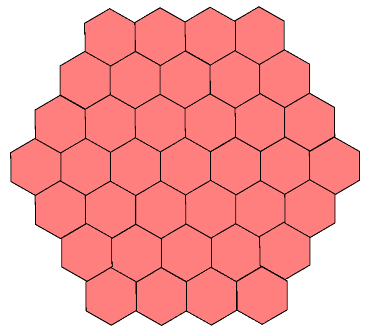
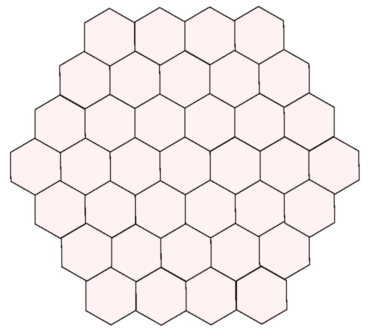
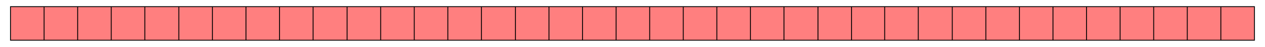
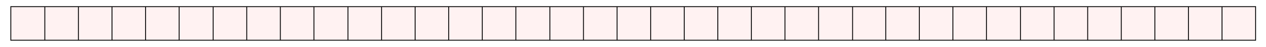
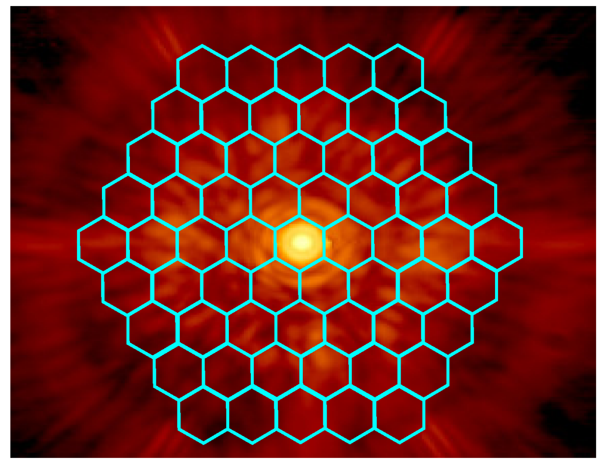
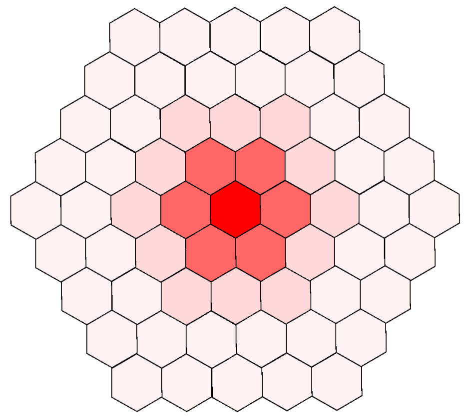
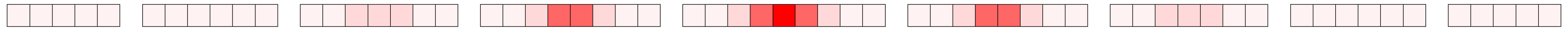
- Modular fiber-fed cross dispersed Echelle spectrograph
- Simultaneous range 0.4-1.8 μm (ultrastable BLUE+RED+NIR) Goal 0.37-2.4 μm; Resolution ~100,000
- Several interchangeable, observing modes: Seeing limited & SCAO+IFU

OBSERVING MODES: THE FIBRE FEEDING

- Different observing modes from different fibre bundles
- No moving parts in spectrographs: stability!



OBSERVING MODES: THE FIBRE FEEDING

	Front–end	Fiber–to–fiber interface	Light distribution along spectrometer slit
Seeing limited observing mode	PSF on single large fiber **A**  **B** 	Light distribution on fibers bundle after scrambler and slicer **A**  **B** 	Uniform light distribution  **A** Uniform light distribution  **B**
IFU–SCAO observing mode	PSF on microlenses array and fibers bundle 	Light distribution on fibers bundle after fiber to fiber couplers 	Sliced hexagonal field 

OBSERVING MODES: THE FIBRE FEEDING

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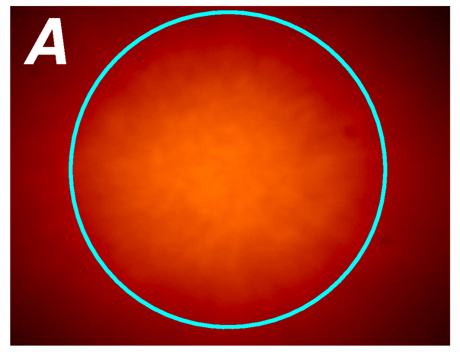
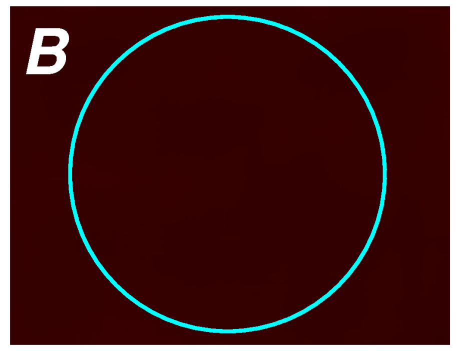
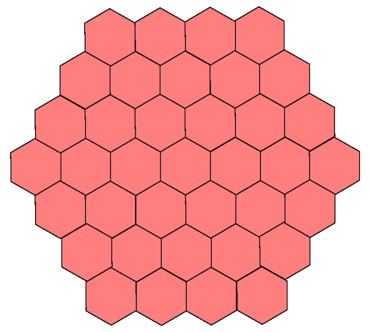
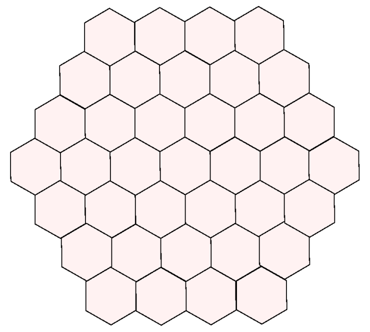
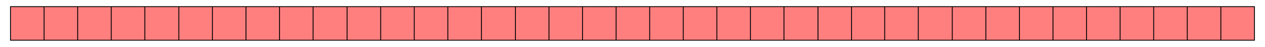
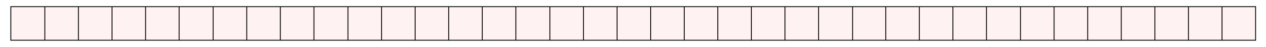
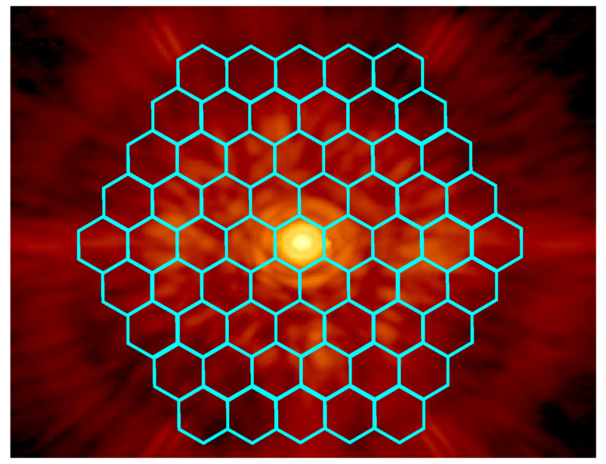
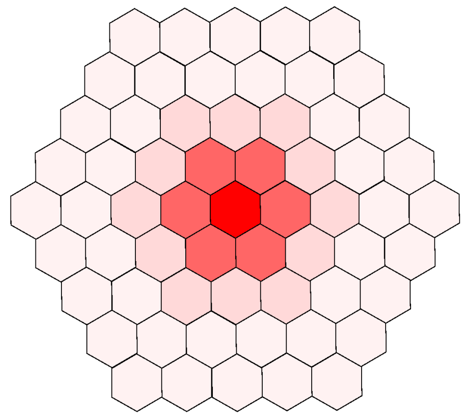
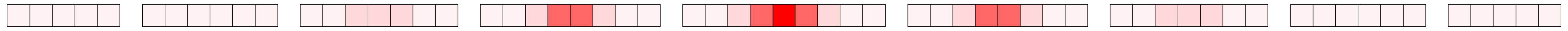
Seeing limited observing mode	PSF on single large fiber ***A***  ***B*** 	Light distribution on fibers bundle after scrambler and slicer ***A***  ***B*** 	Uniform light distribution  ***A*** Uniform light distribution  ***B***
IFU–SCAO observing mode	PSF on microlenses array and fibers bundle 	Light distribution on fibers bundle after fiber to fiber couplers 	Sliced hexagonal field 

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OBSERVING MODES: THE FIBRE FEEDING

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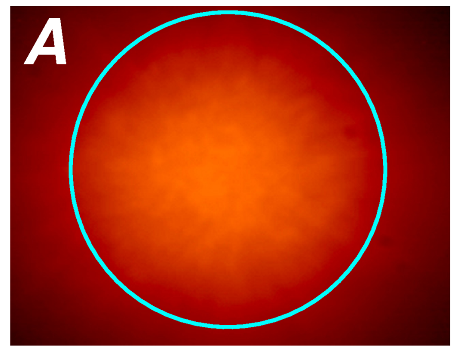
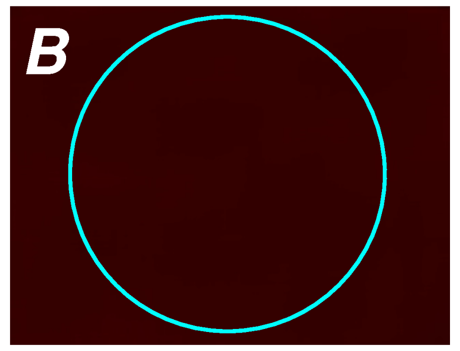
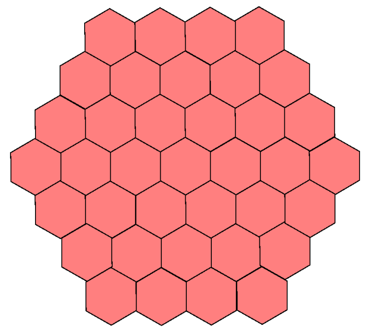
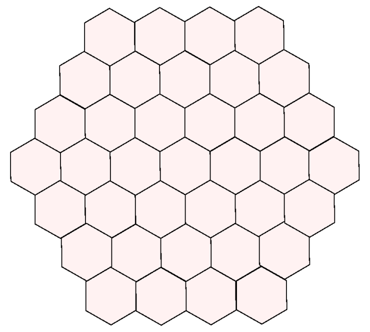
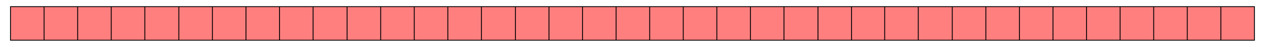
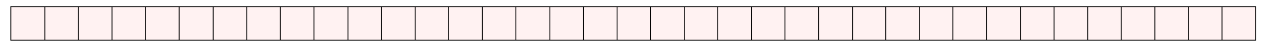
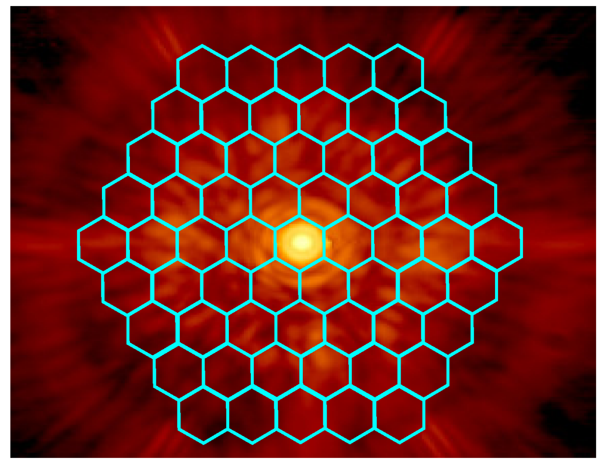
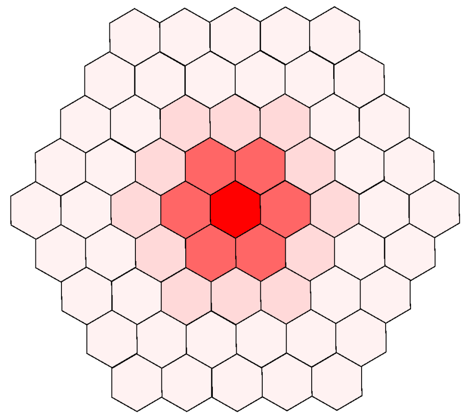
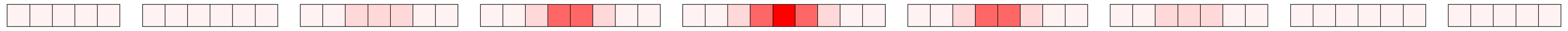
Seeing limited observing mode	PSF on single large fiber ***A***  ***B*** 	Light distribution on fibers bundle after scrambler and slicer  ***A***  ***B***	Uniform light distribution  ***A*** Uniform light distribution  ***B***
IFU–SCAO observing mode	PSF on microlenses array and fibers bundle 	Light distribution on fibers bundle after fiber to fiber couplers 	Sliced hexagonal field 

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OBSERVING MODES: THE FIBRE FEEDING

ANDES

IL = Imagination Limited

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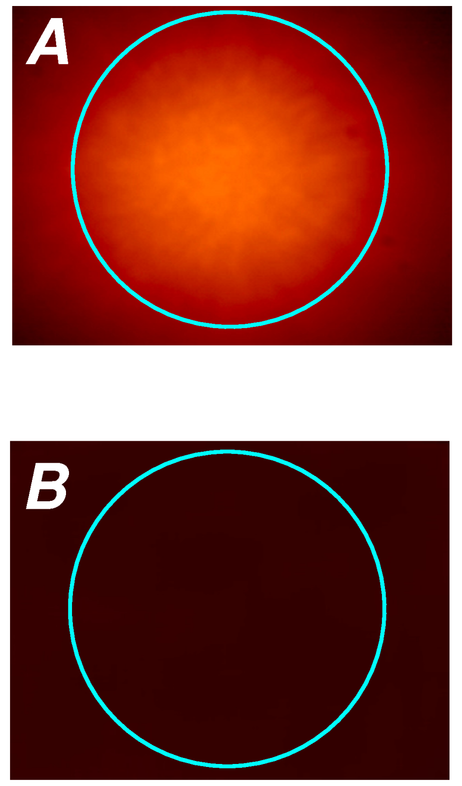
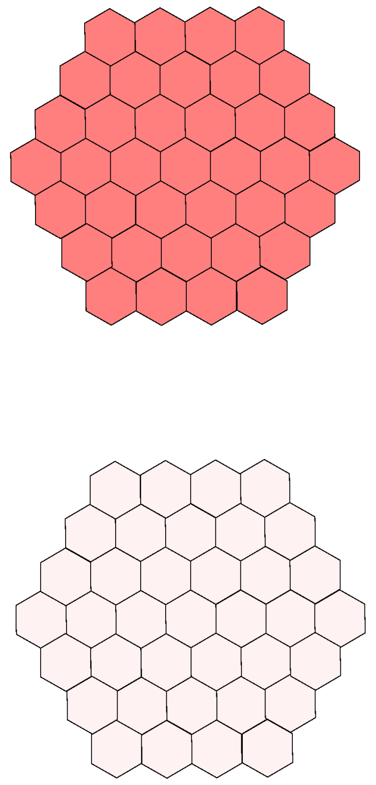
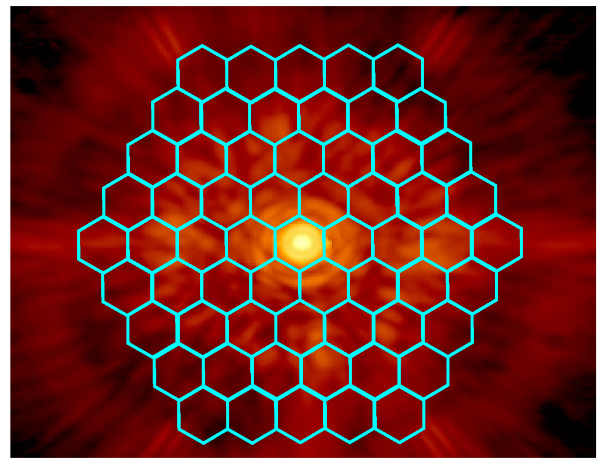
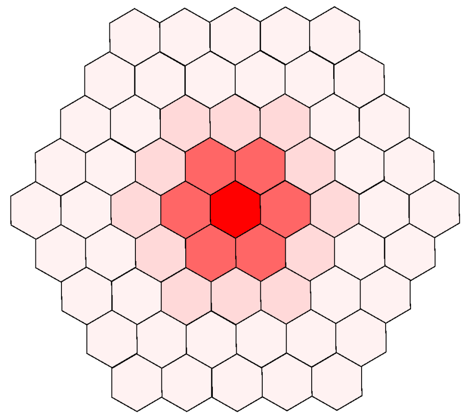
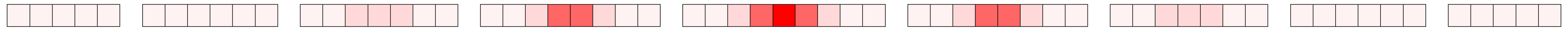
Seeing limited observing mode	PSF on single large fiber 	Light distribution on fibers bundle after scrambler and slicer  ***A*** ***B***	Uniform light distribution Uniform light distribution  ***A*** ***B***
IFU–SCAO observing mode	PSF on microlenses array and fibers bundle 	Light distribution on fibers bundle after fiber to fiber couplers 	Sliced hexagonal field 

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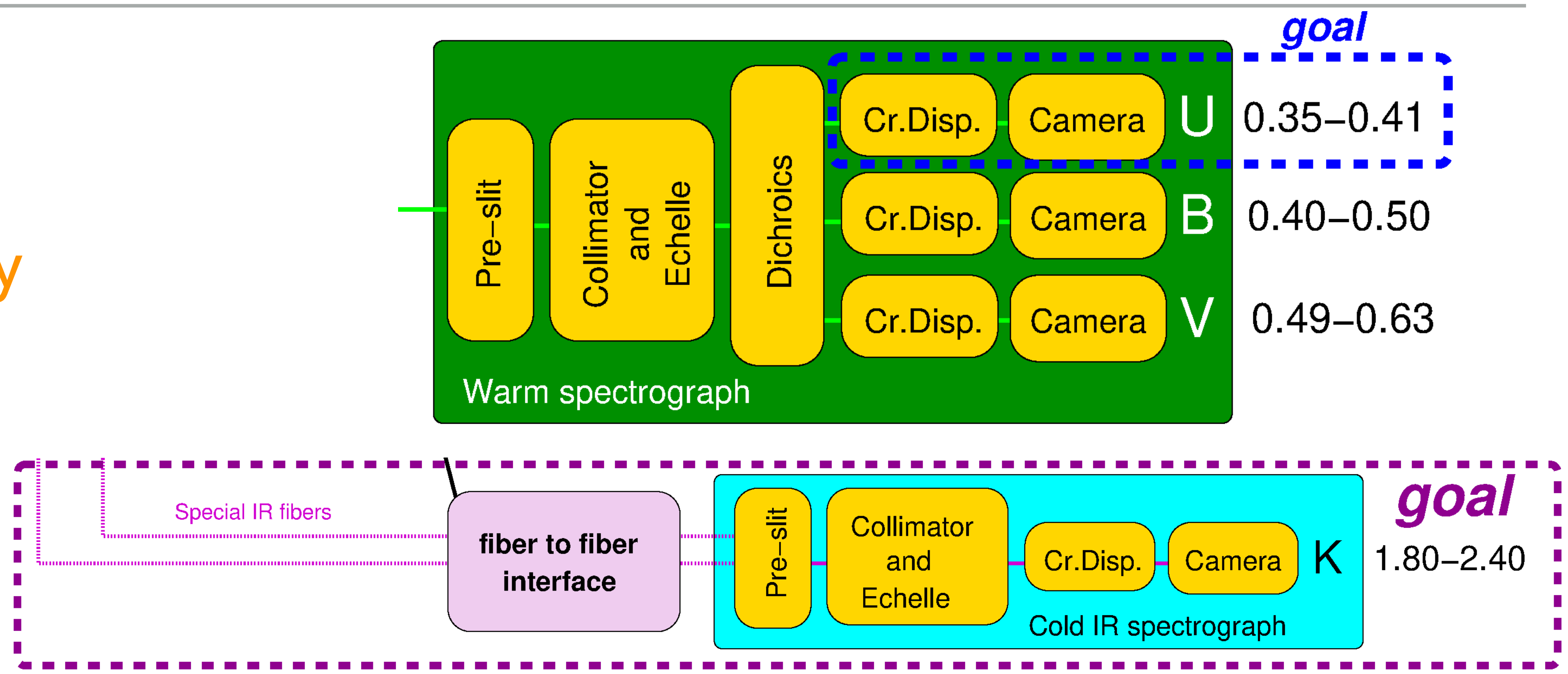
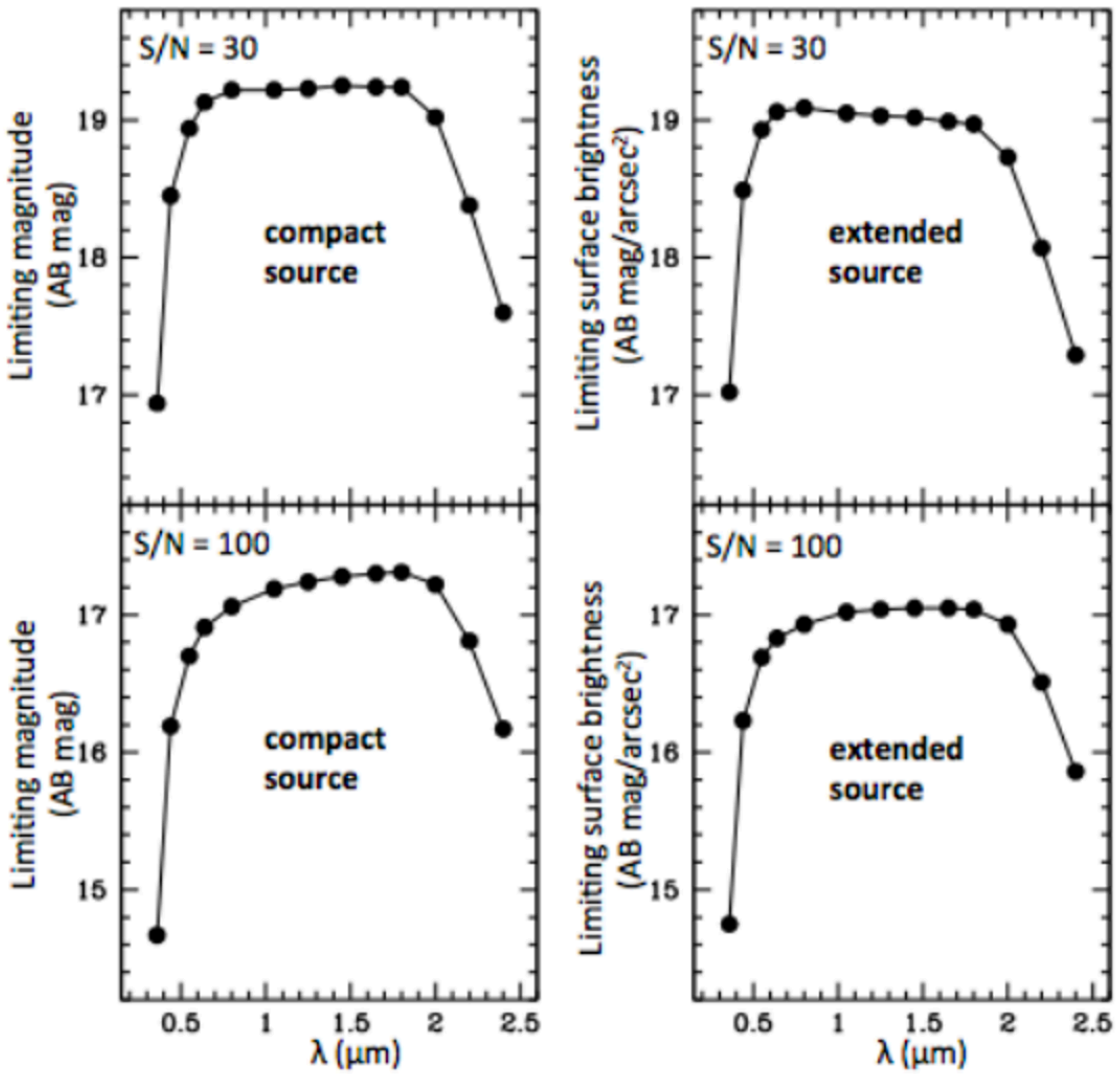
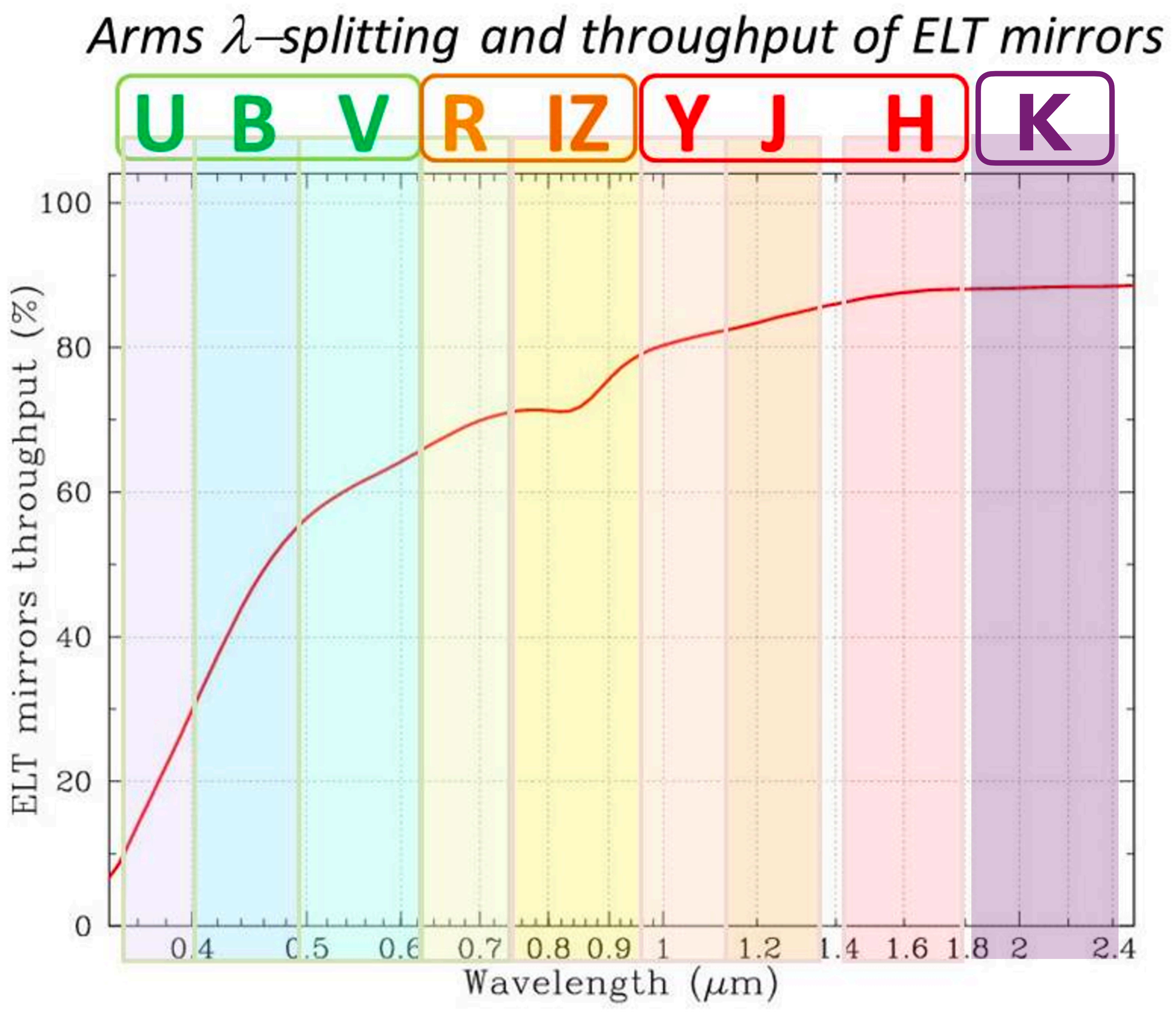
THE EXTENSION TO 0.35–0.41

- The current design allows an extension of the wavelength range as low as 0.35 µm and as high as 2.4 µm: U and K band under study
- However the total transmission of the ELT drops below 0.4 µm to the silver coating.
- An improved blue-sensitive silver coating is in R&D but it will not be available until a few years after first light.
- In the meantime we need to verify whether ELT+ANDES can still be more sensitive in the blue than VLT+ESPRESSO

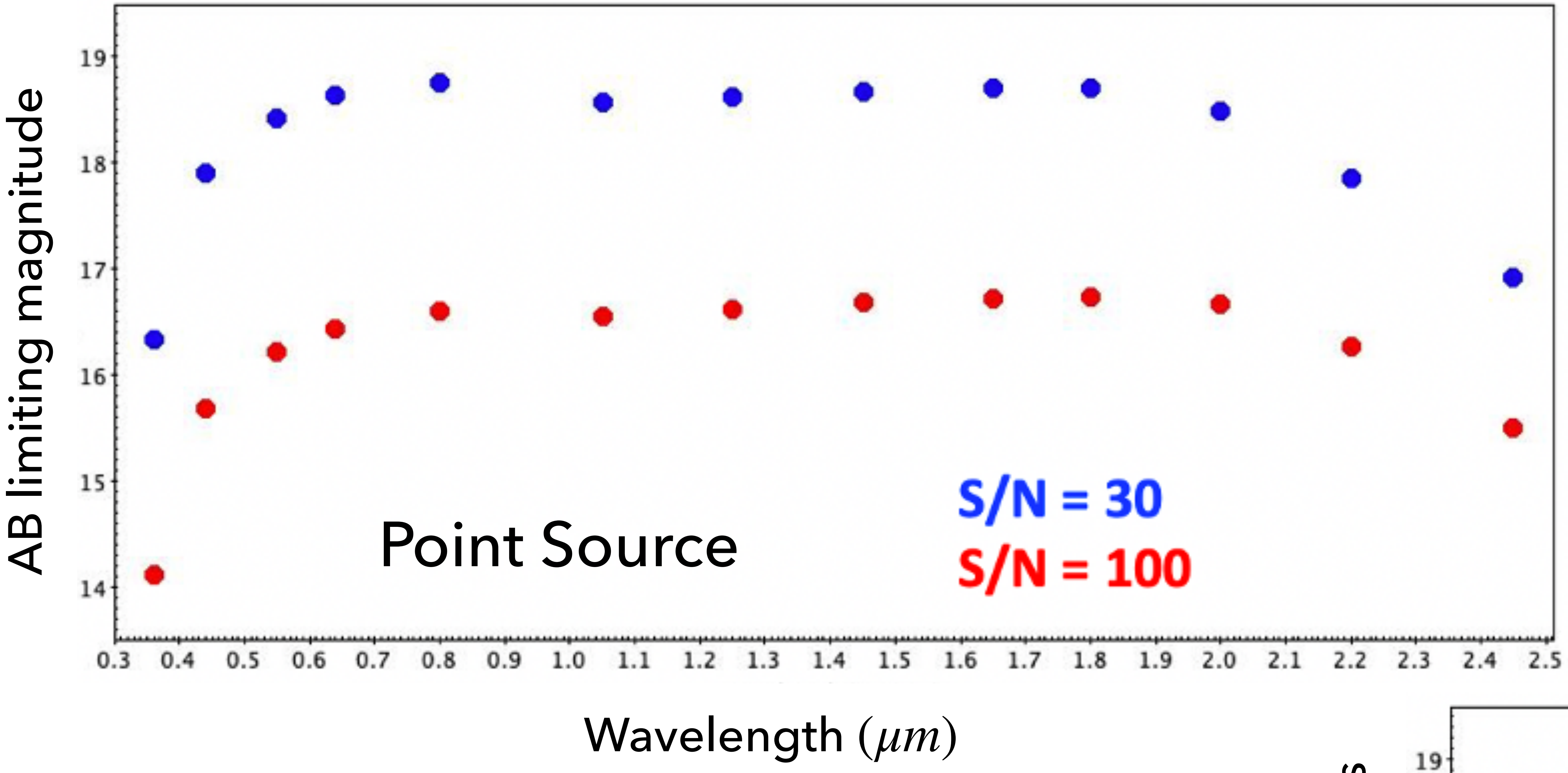






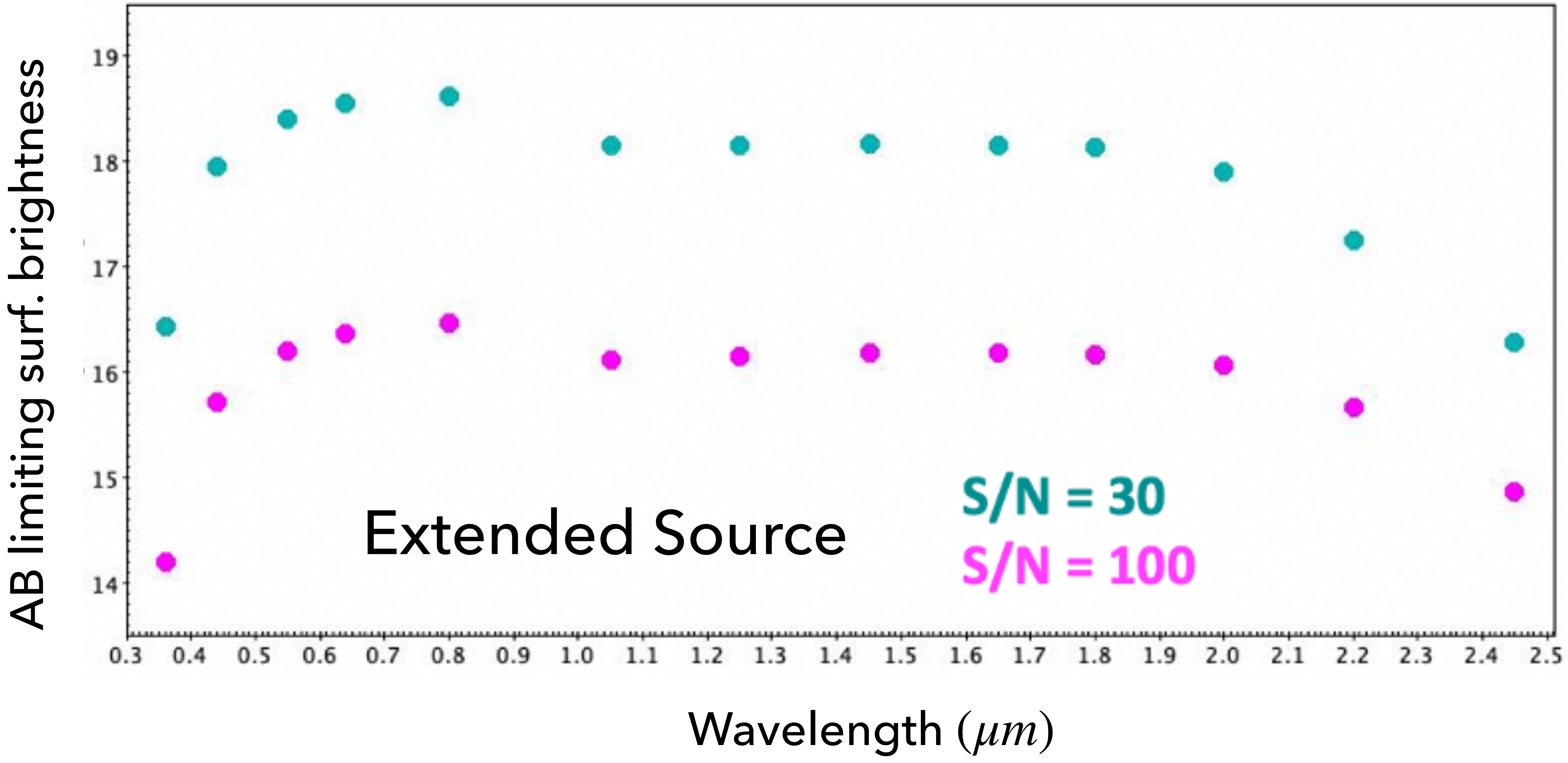
ANDES PERFORMANCES

ANDES



- The expected limited magnitude for seeing limited observations is m_{AB} = 20 in 1 hr with SNR=10 per resolution element.

R = 100000 Exposure time=1800 s

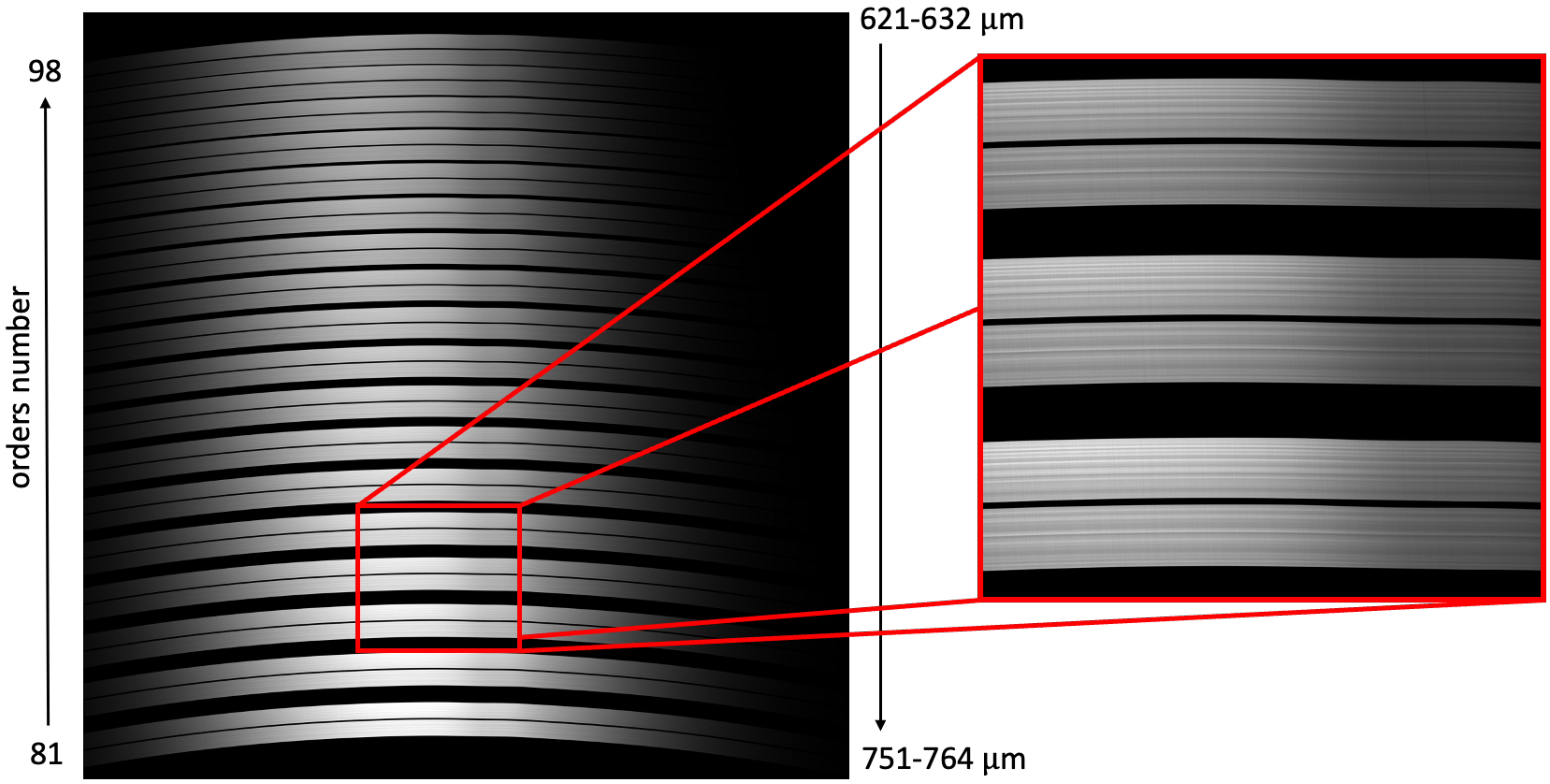


- Check the ETC, always updated with the latest instrument performances:

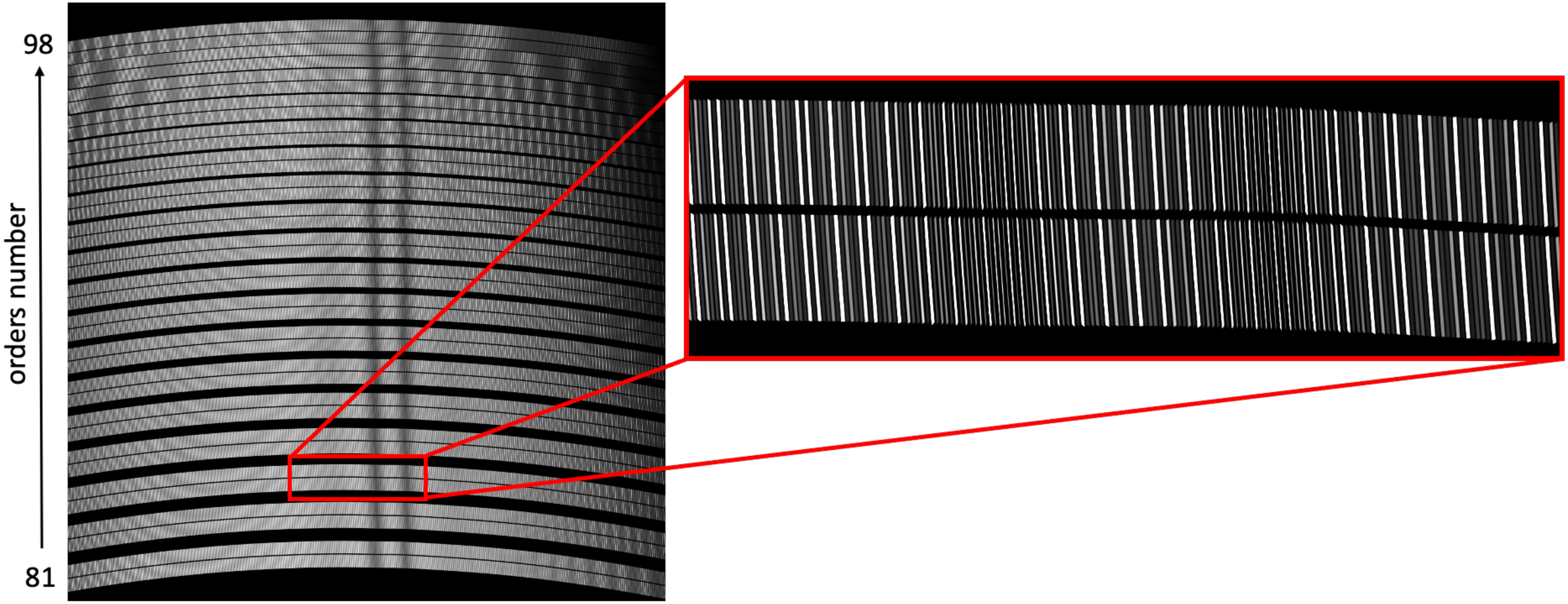
  hires.inaf.it/etc.html

COURTESY OF N. SANNA

END-TO-END SIMULATIONS: FLAT FIELD (RIZ)



END-TO-END SIMULATIONS: FABRY-PÈROT (RIZ)

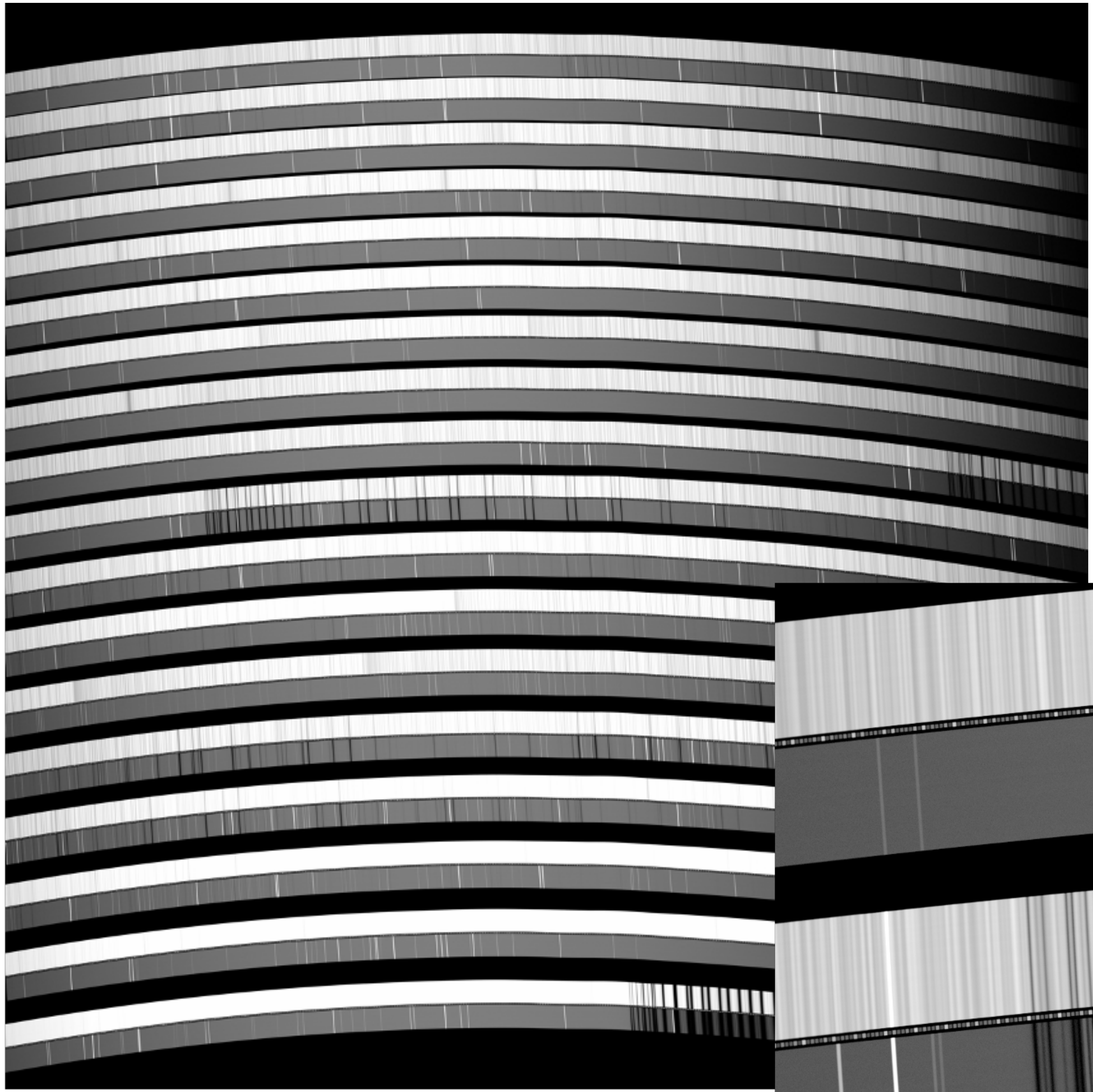


END-TO-END SIMULATIONS: SCIENCE SPECTRUM (RIZ)

- Object: Phoenix
  - Effective temperature: 3500 K
  - Surface gravity: 4.0
  - Magnitude: 16
- Sky:
  - Airmass: 1.5
  - PWV: 5 mm
  - Moon FLI: 0.5

COURTESY OF A. SCAUDO

END-TO-END SIMULATIONS: SCIENCE SPECTRUM (RIZ)



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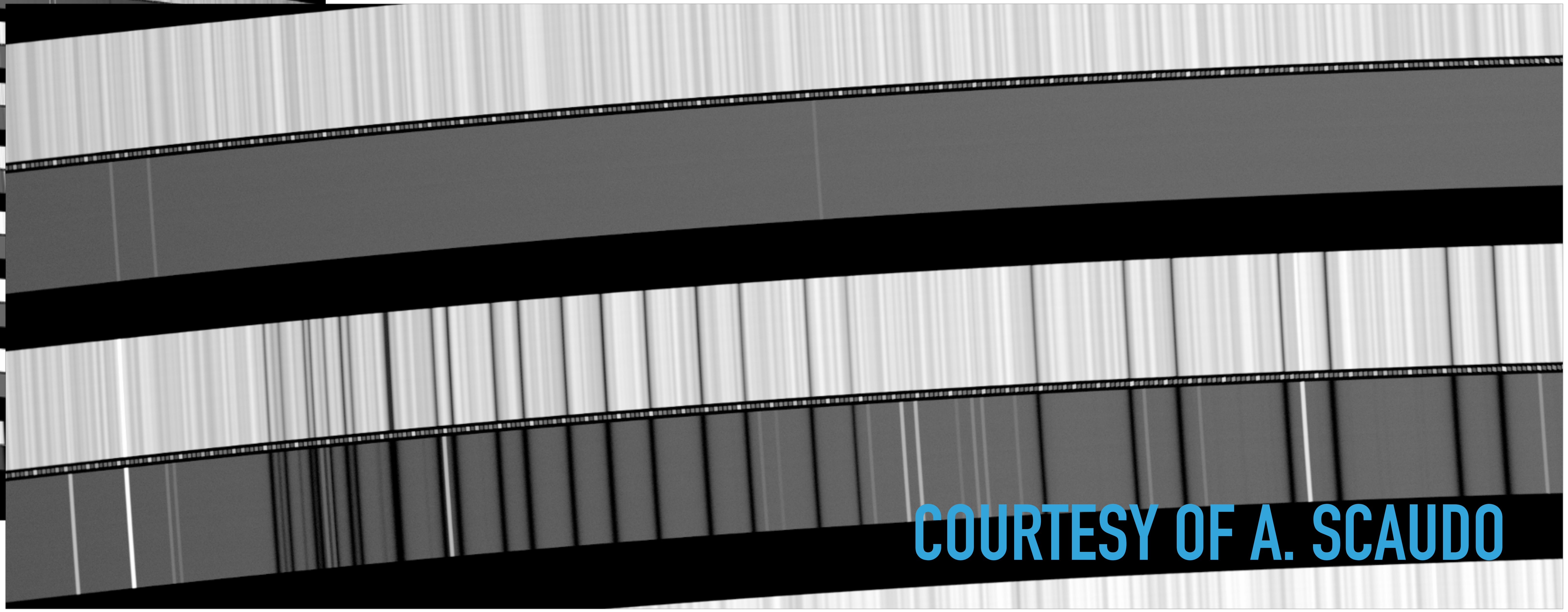

COURTESY OF A. SCAUDO

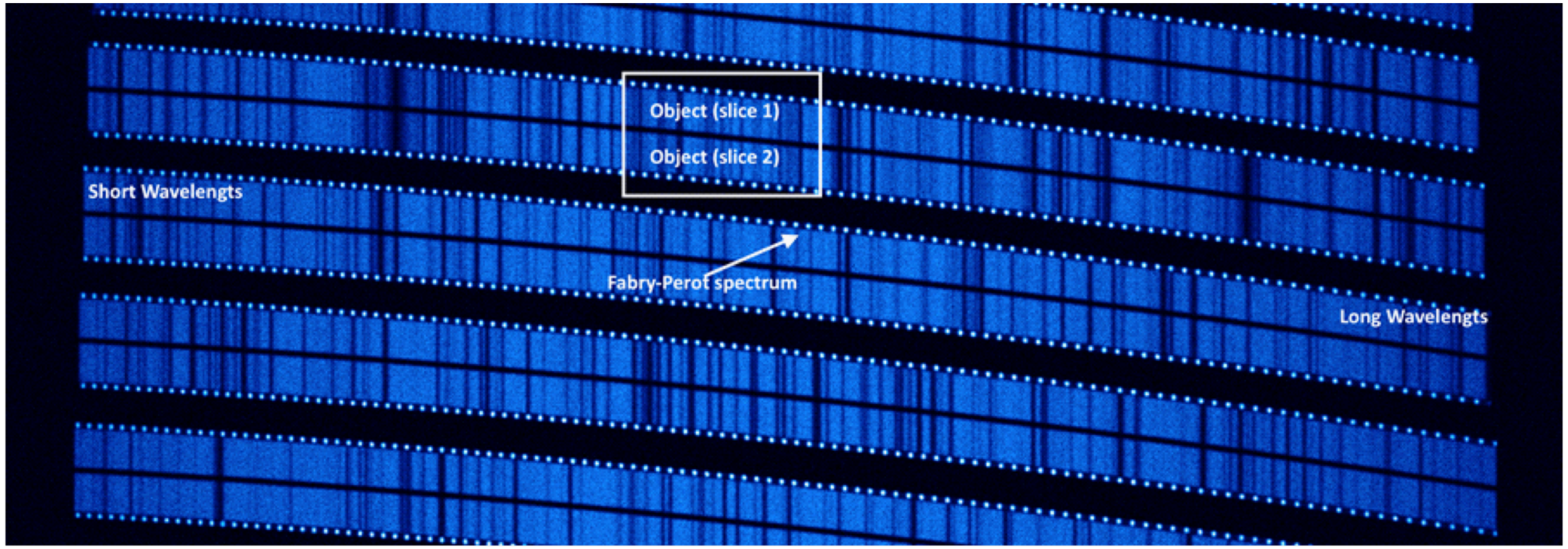

Figure 1: Simulated science spectrum

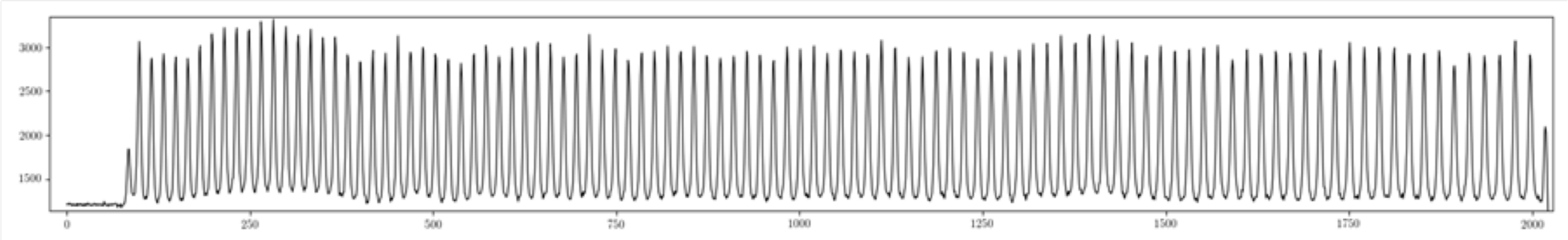

Figure 2: Extracted Fabry-Perot spectrum

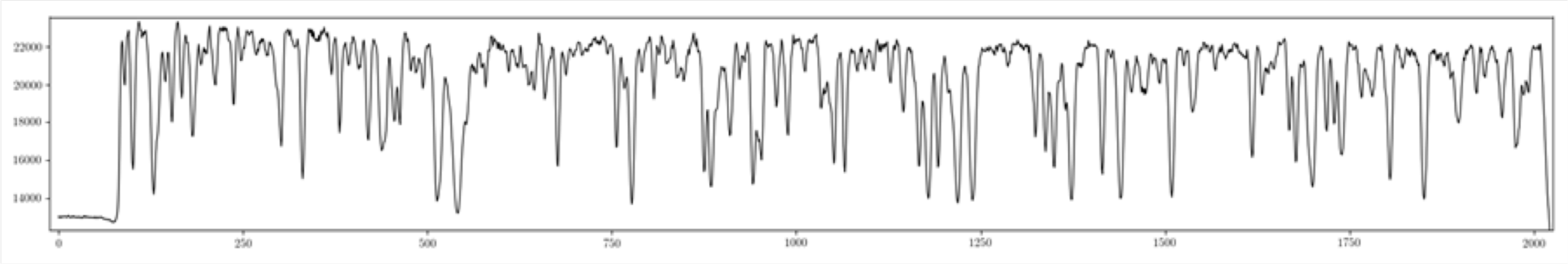

Figure 3: Extracted science spectrum

https://aws.amazon.com/blogs/publicsector/the-italian-national-institute-of-astrophysics-explores-the-universe-with-the-cloud/

https://www.youtube.com/watch?v=d0YrAoWI0sc

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by AWS Public Sector Blog Team | on 13 NOV 2018 | in Education, Government, Public Sector | Permalink | Share

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The National Institute for Astrophysics (Istituto Nazionale di Astrofisica or INAF) is an Italian institution that conducts scientific research in astronomy and astrophysics. INAF research ranges from the study of the planets and minor bodies of the solar system to the large-scale structure of the Universe.

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

Recently, INAF has been involved in two large projects where they turned to the Amazon Web Services (AWS) Cloud: the ESO Extremely Large Telescope (E-ELT) and Cherenkov Telescope Array (CTA).

Is there complex life outside of Earth?

The first project is the design of the ultra-high resolution spectrograph HiReS for the ESO Extremely Large Telescope (E-ELT). Thanks to the unprecedented quality of the data and the accurate structural stability, researchers will be able to detect bio signatures in the atmosphere of planets outside of our solar system for the first time. The aperture of the European Extremely Large Telescope will give them the ability to detect the presence of complex life outside of Earth and to complete a census of the composition of Earth-like planets that orbit their host star at a distance that allows it to sustain life. This system is complex and the simulations required to assess its potentiality produce TBs of data each.

The second project involves scientific simulations of the Cherenkov Telescope Array (CTA), a large facility that will observe galactic and extragalactic sources that irradiate photons in the band of gamma rays, allowing for the study of ultra-high energy physics. As in the previous scenario, each simulation of CTA collects TBs of data in each run.

Both projects require a large amount of computational power to handle TBs of data. Each simulation of HIRES requires a million GPU hours and produces more than 5 TB of raw data, while in the case of CTA, each simulation requires more than 300,000 CPU/hours to produce events and process data on the cloud for more than 60 TB each time.

INAF evaluated the possibility of procuring the necessary hardware to perform these computing tasks, but the Total Cost of Ownership (TCO), coupled with the on-demand nature of this research, led them to the cloud.

AWS Cloud for on-demand computing

For both E-ELT and CTA, the team used Amazon Elastic Compute Cloud (Amazon EC2) to perform the large-scale calculations seen in Figure 1 and 2. For both projects, INAF used Amazon Simple Storage Service (Amazon S3) for the storage of the processed data, and AWS Lambda and Amazon Simple Queue Service (Amazon SQS) for managing the flow and tasks between EC2 instances. The availability of long-term storage with Amazon Glacier allowed the team to store data cost-effectively.

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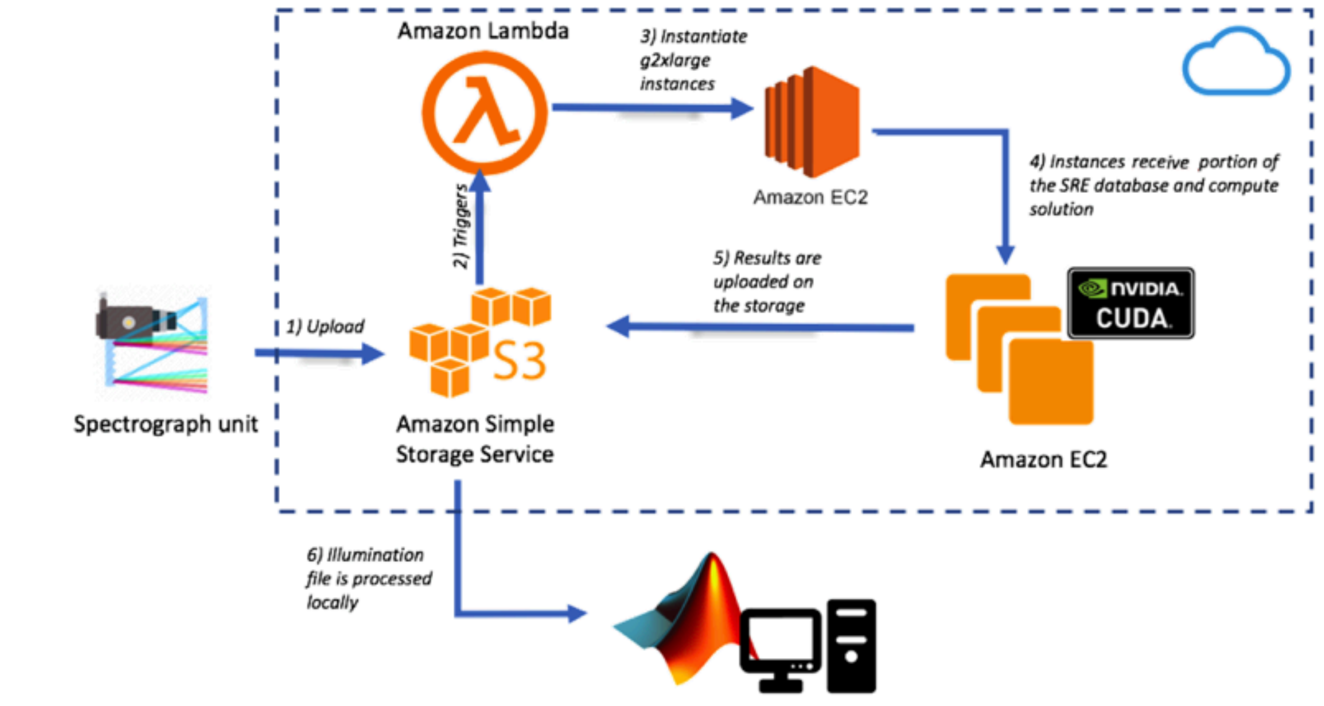


Figure 1 – AWS Architecture for ESO-HiReS simulation. Input coming from the spectrograph design are uploaded to Amazon S3. Then, AWS Lambda initiates EC2 g2x.large instances to perform a CUDA simulation and then the results are stored back on S3.

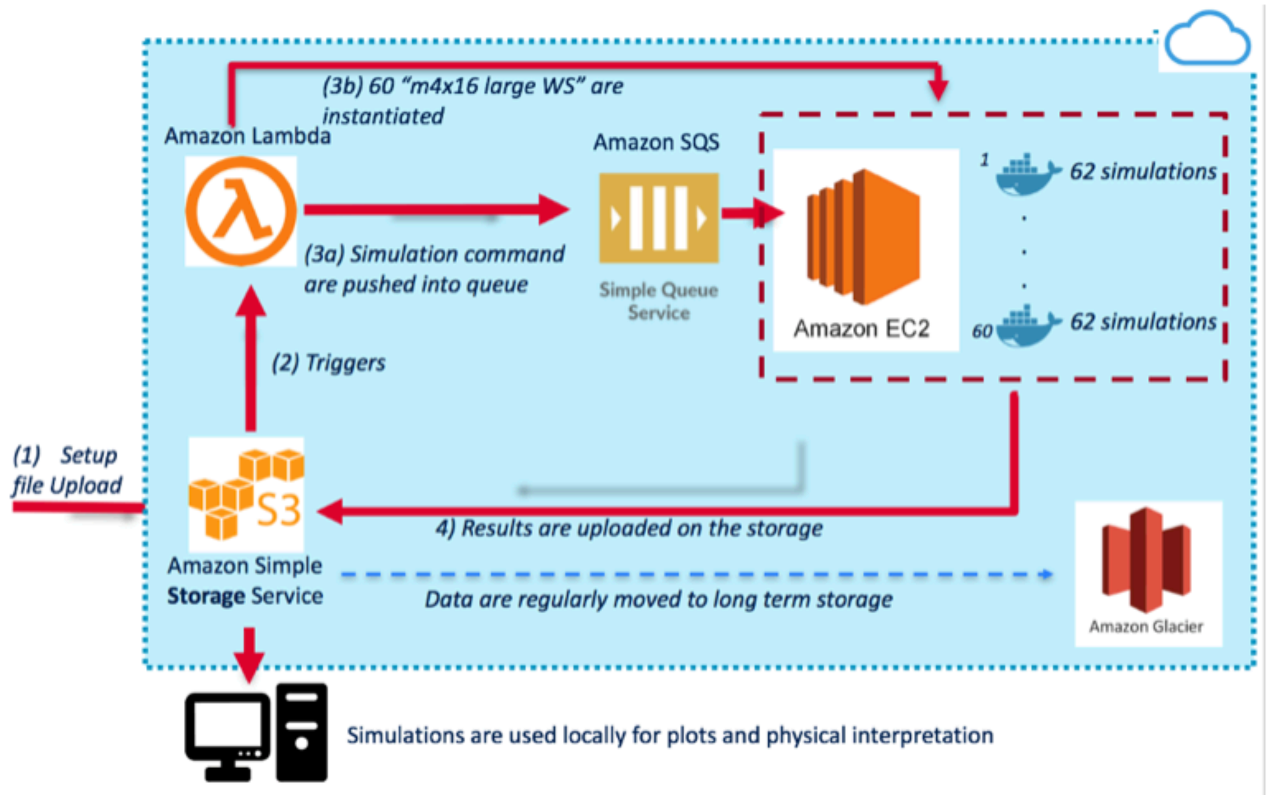
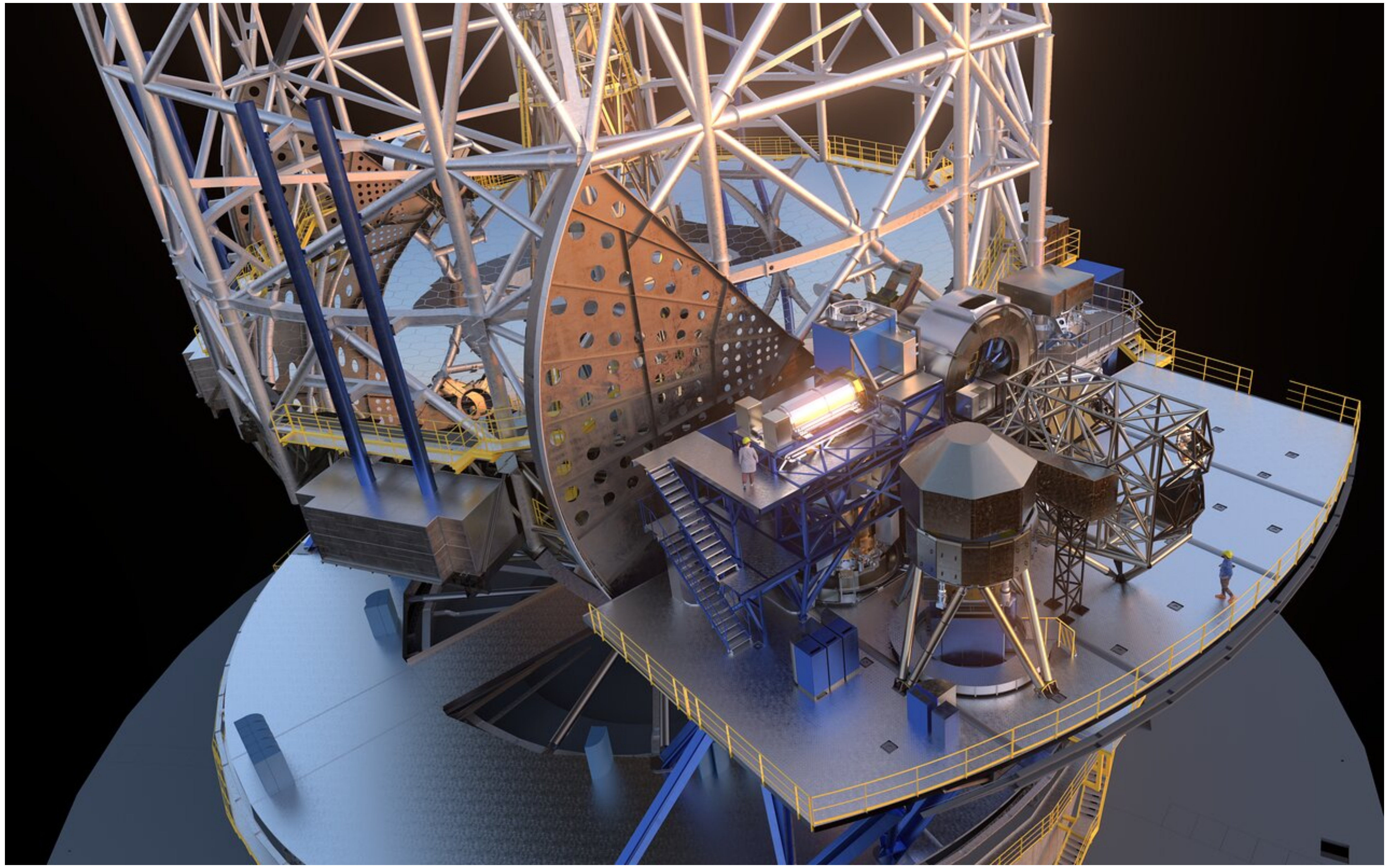


Figure 2 – AWS architecture for CTA simulations. As in the case of HIRES, the architecture provides triggers from S3 as soon as the input for simulations are uploaded. An Amazon SQS FIFO queue is used to dispatch simulations between EC2 instances. Then, the processed data is sent back to S3. They make use of Docker to containerize the software and Amazon Glacier for long-term storage.

> "Thanks to AWS, we were able to concentrate on science and simulations. We were able to scale as soon as the project required us to do so. It was critical to obtain the required power quickly," said Marco

ANDES AT ELT

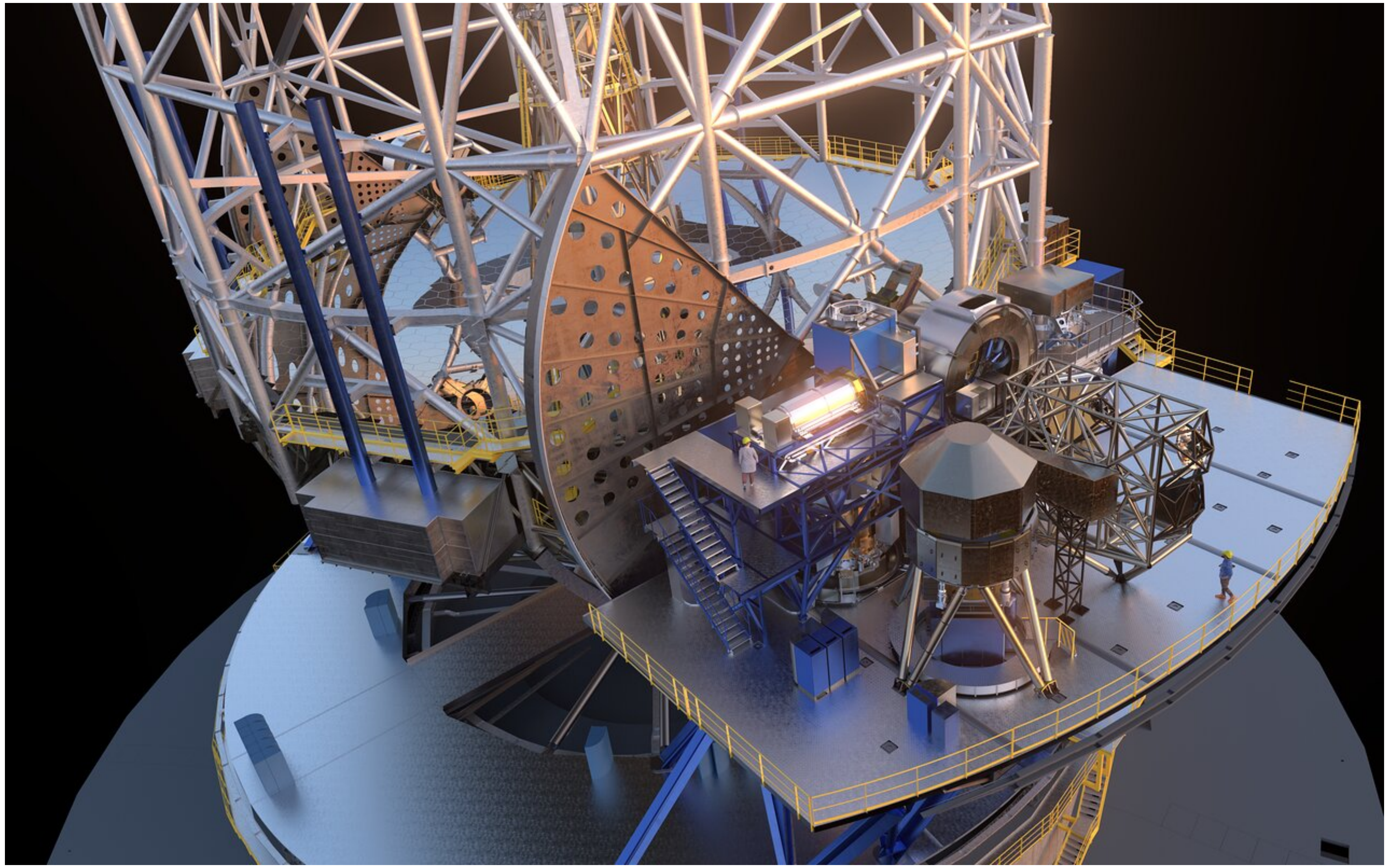
Telescope



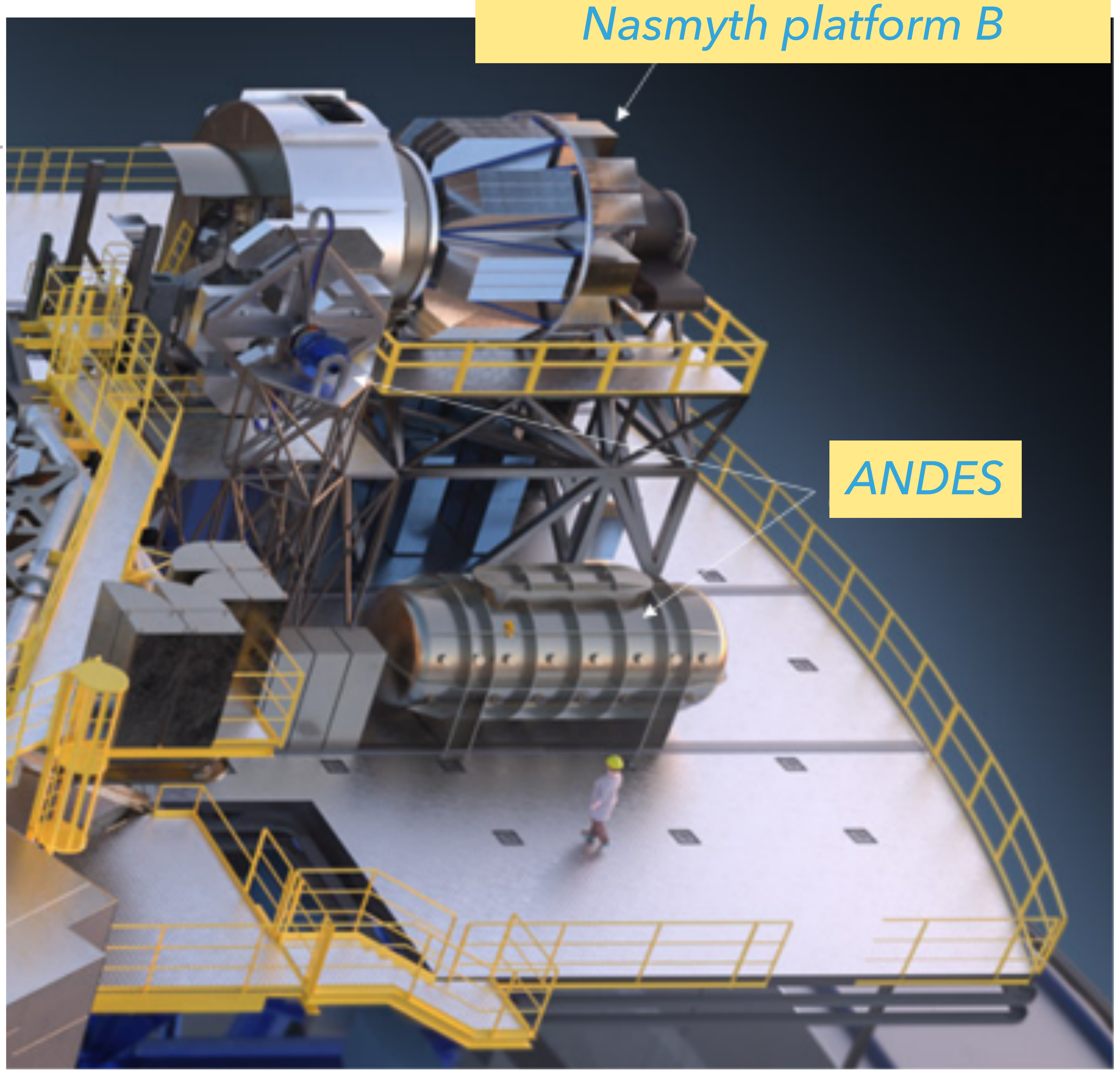
Nasmyth platform A

ANDES AT ELT

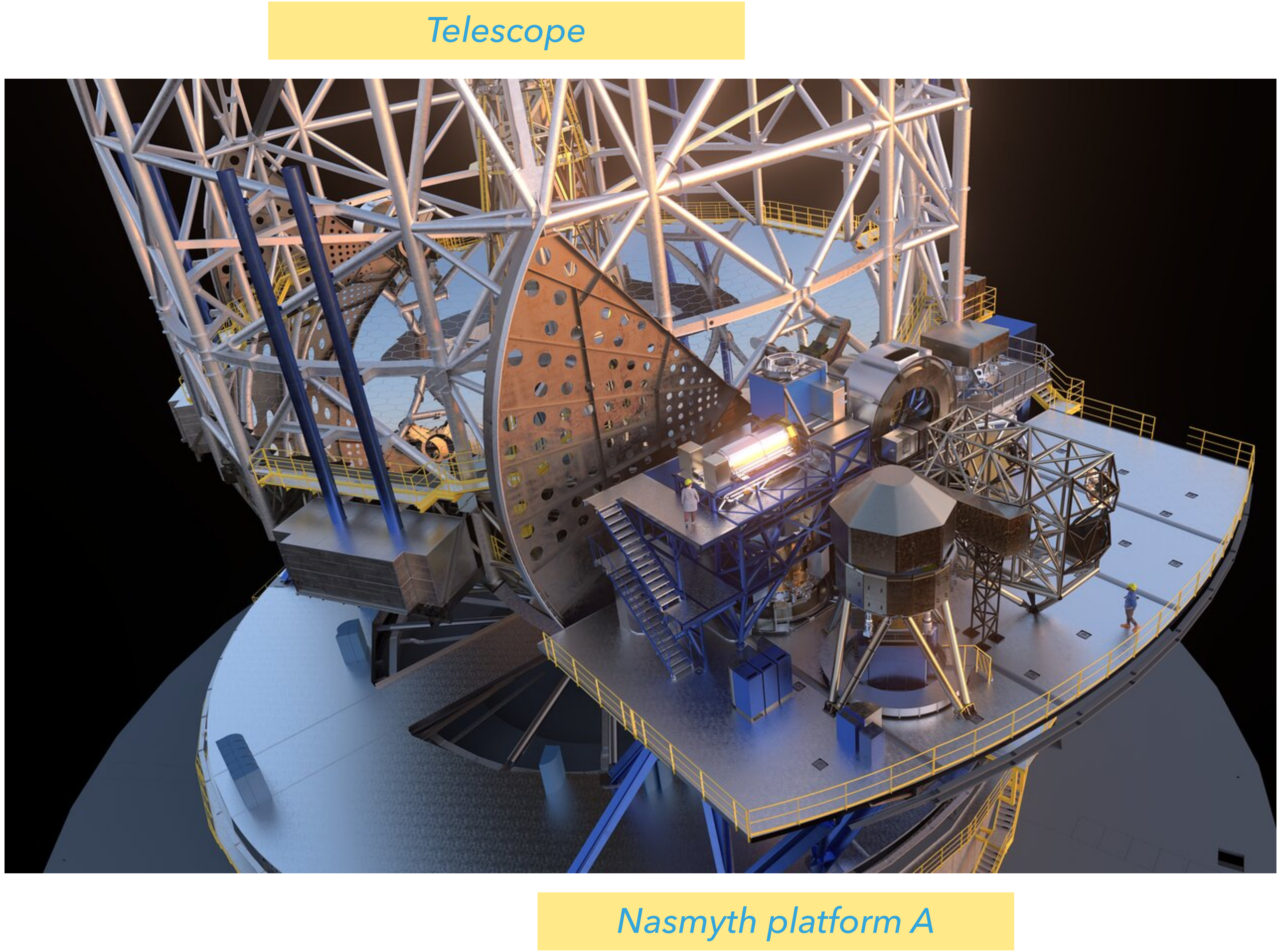
Telescope

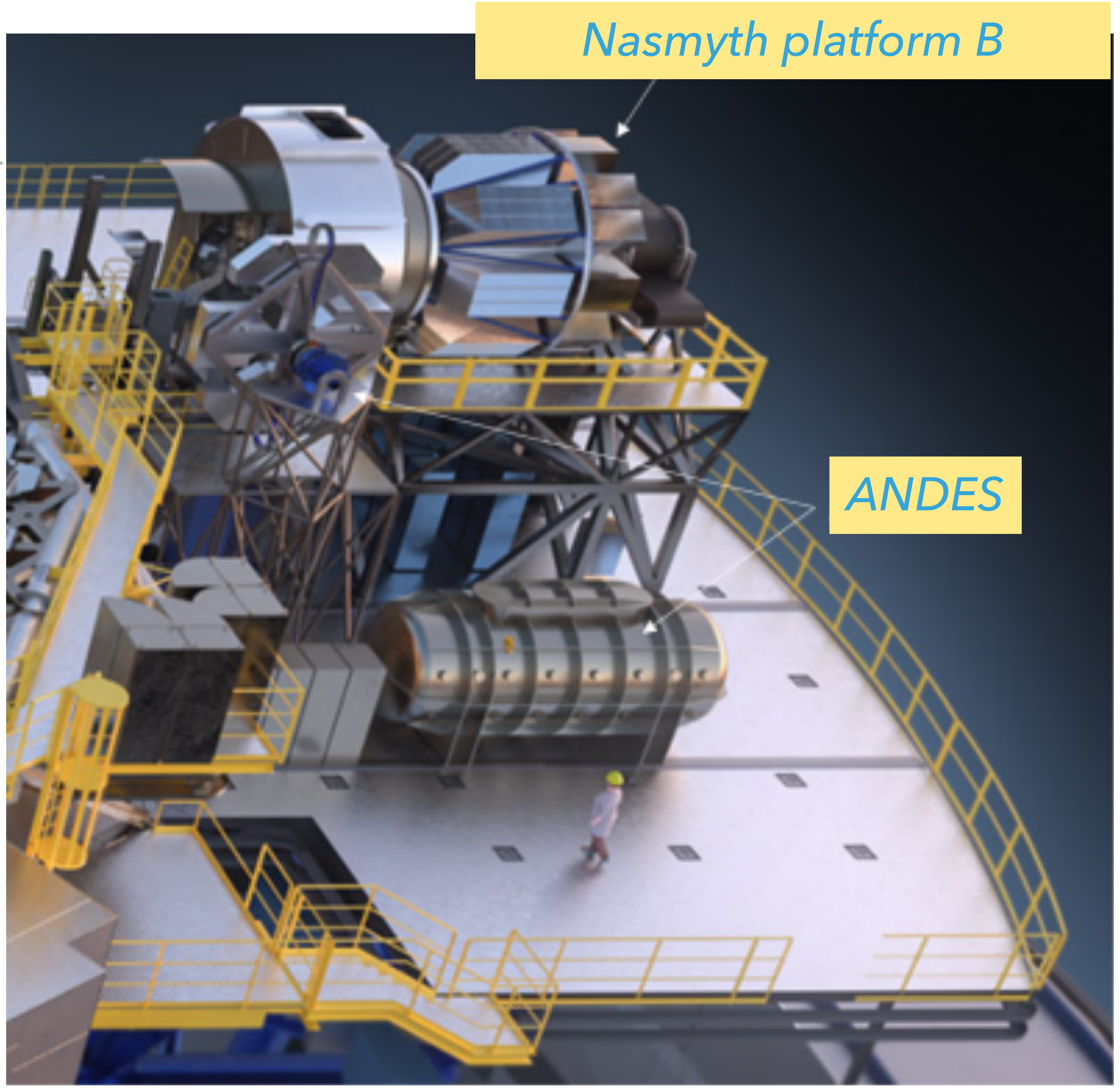


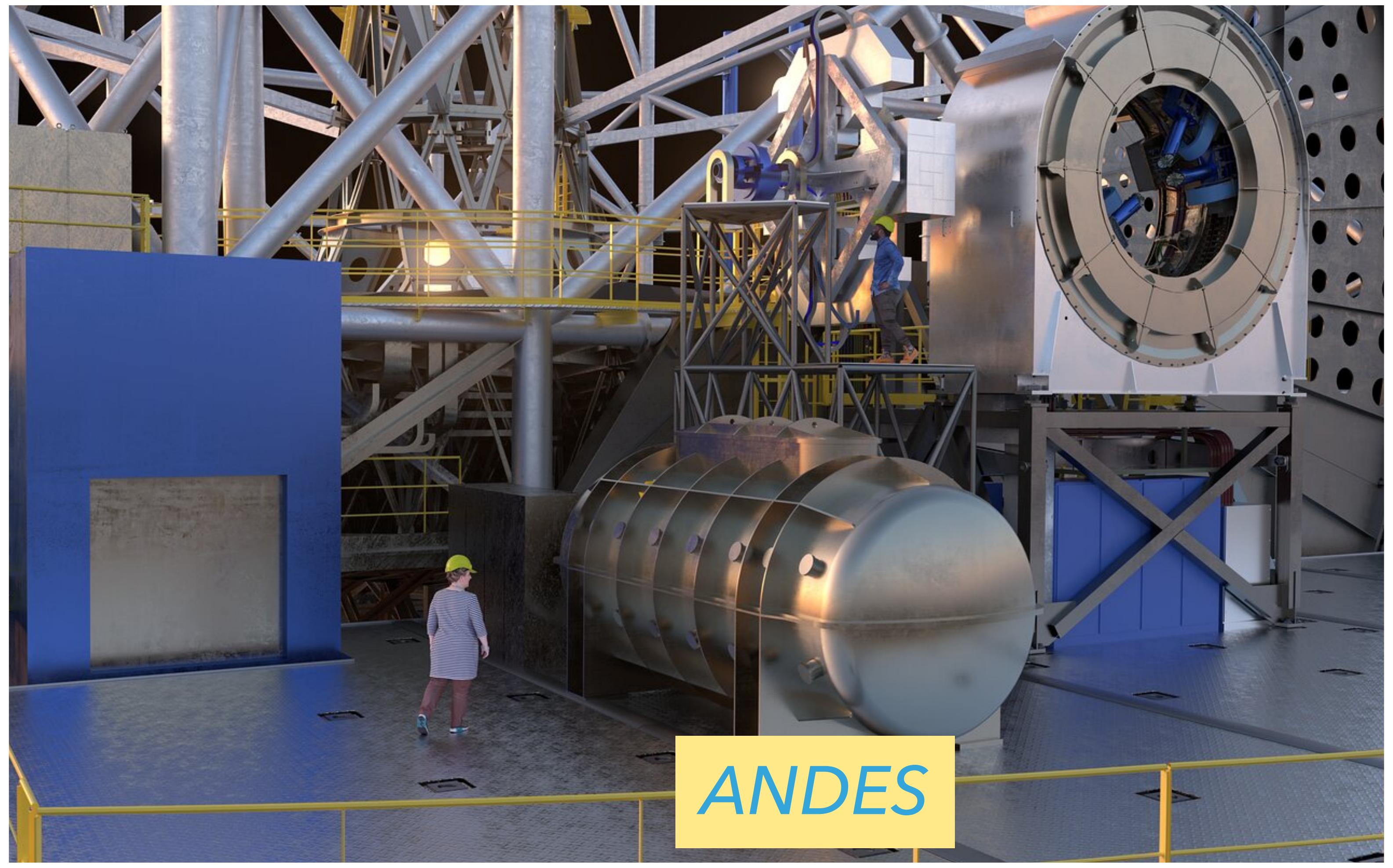
Nasmyth platform A



ANDES AT ELT


Telescope
Nasmyth platform A


Nasmyth platform B
ANDES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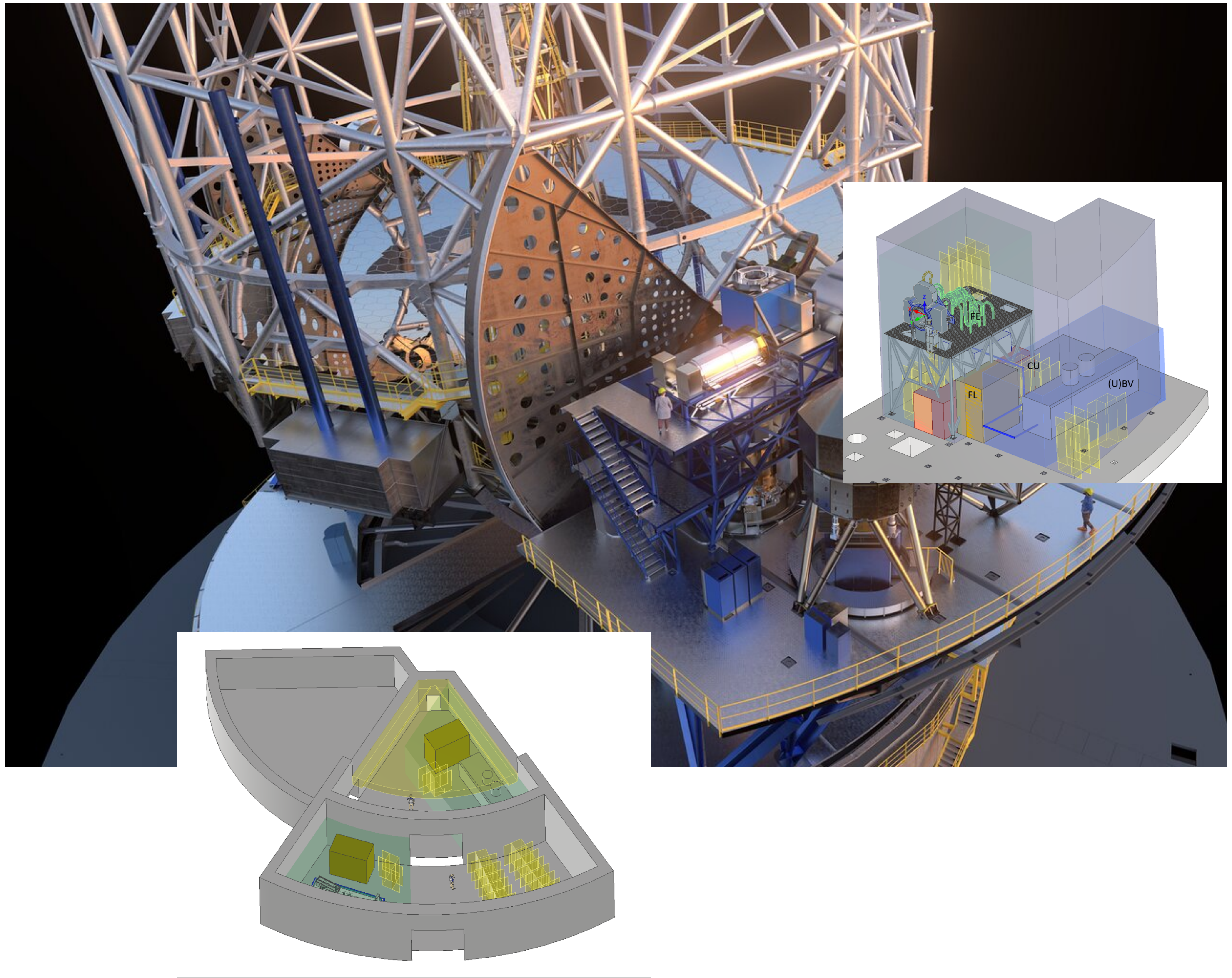
ANDES AT ELT



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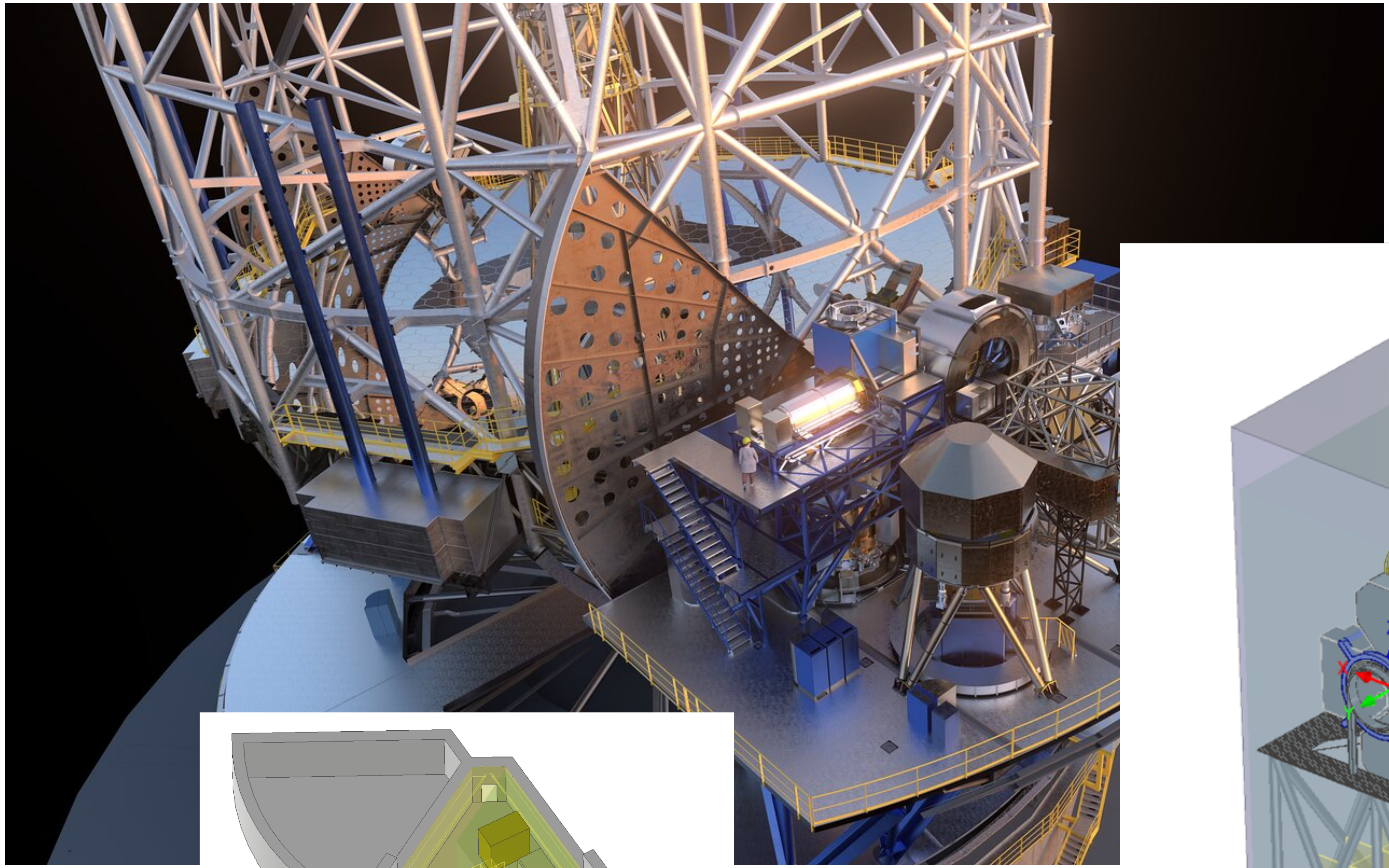

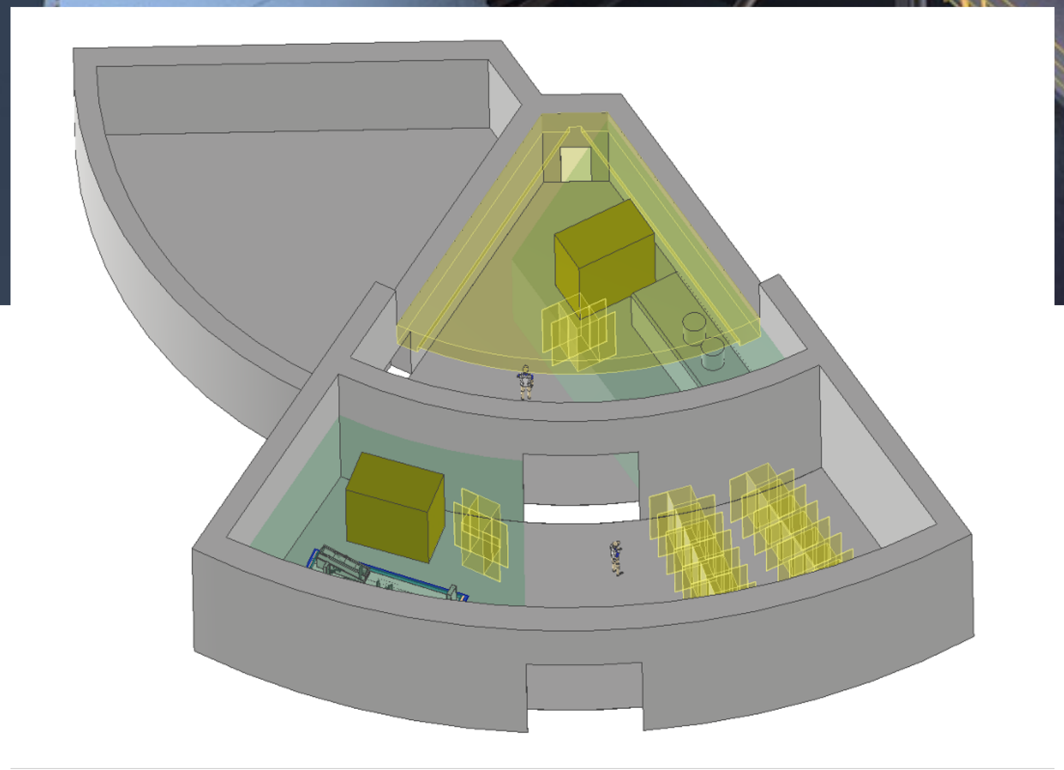

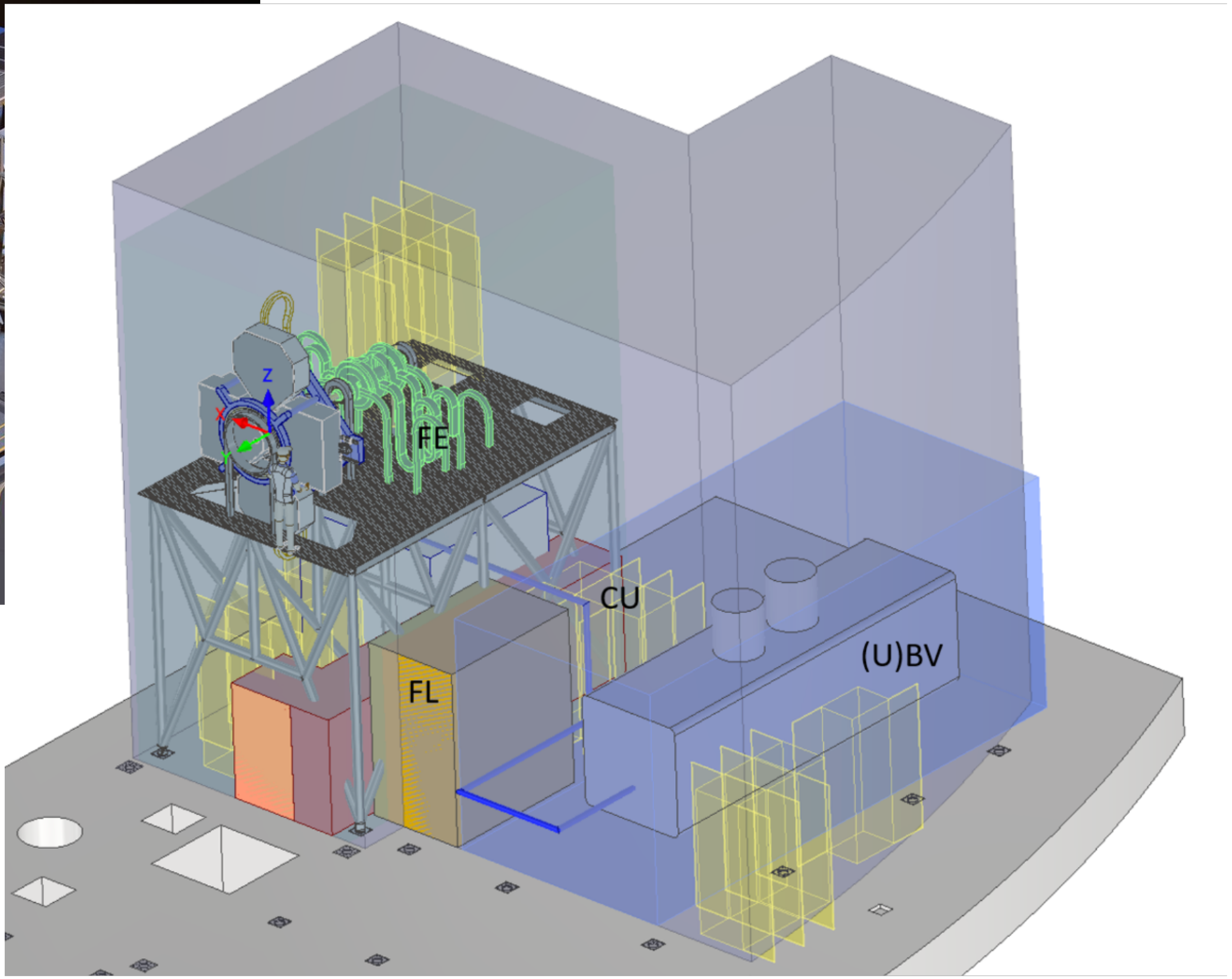

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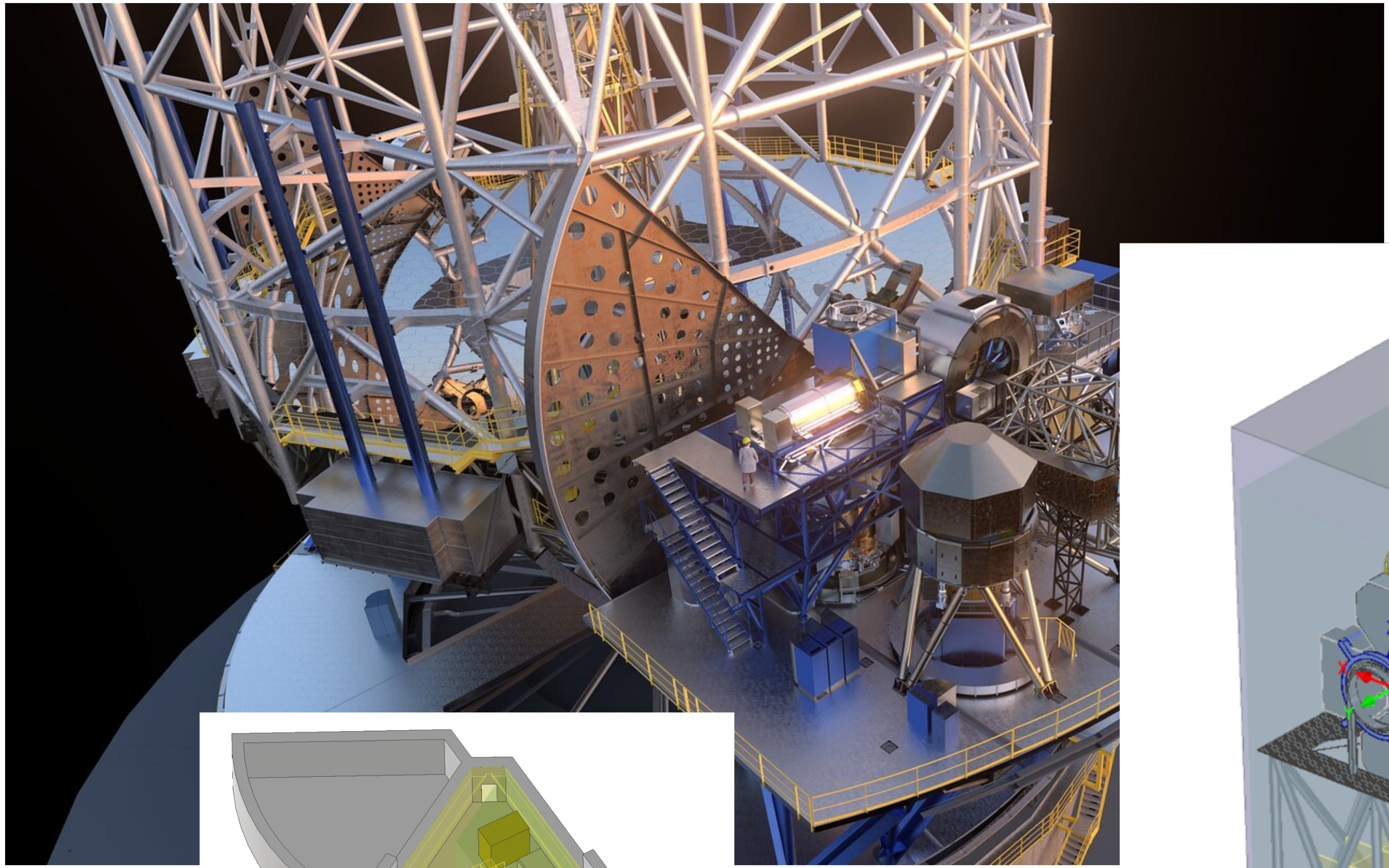

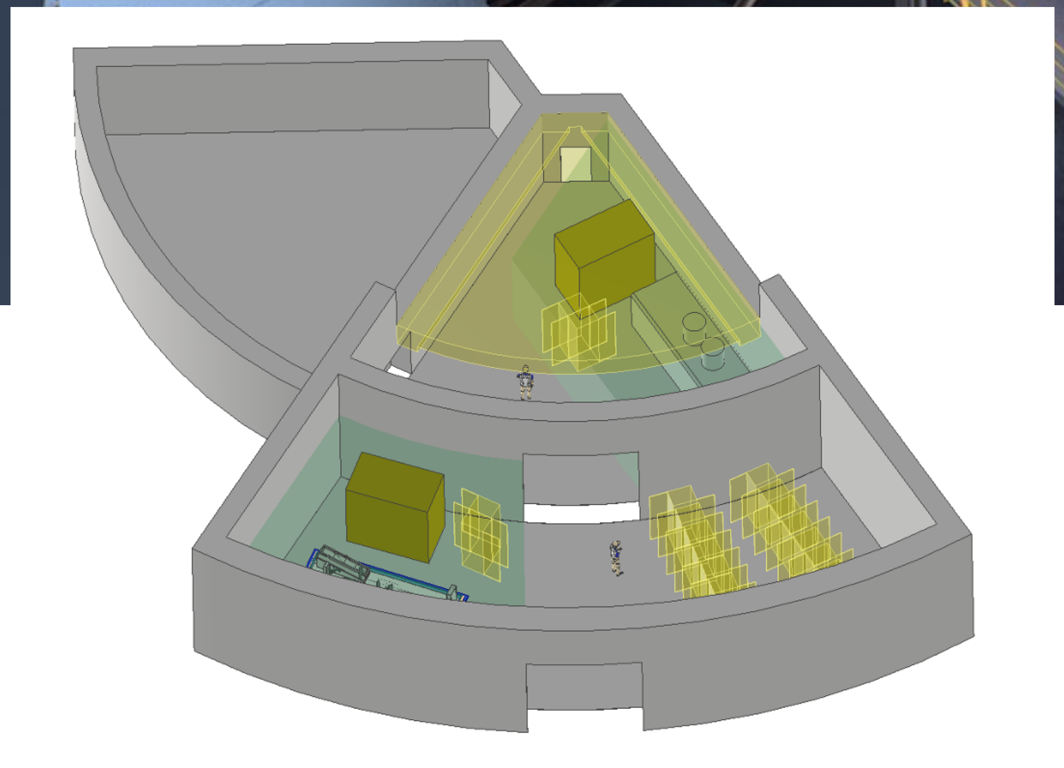

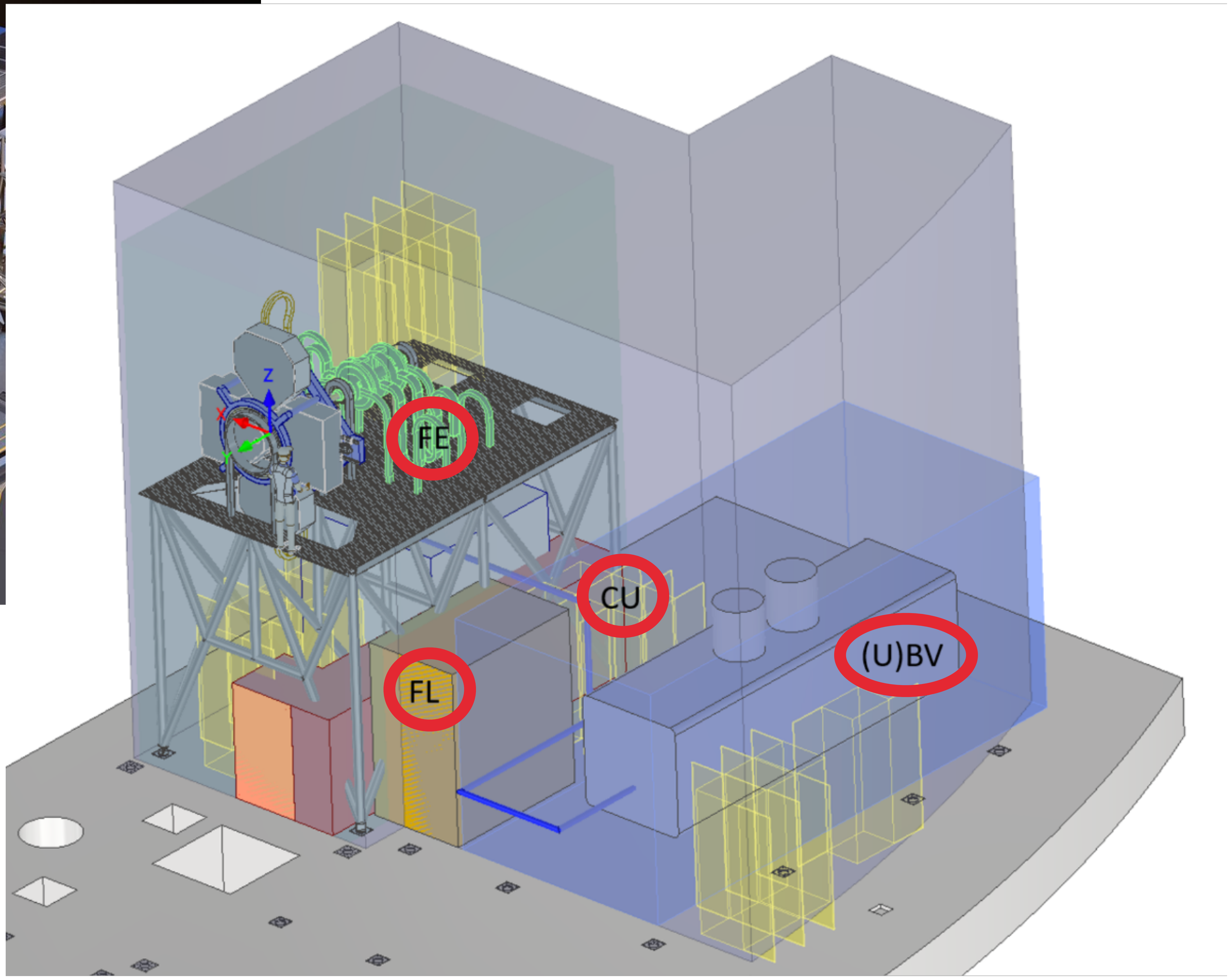

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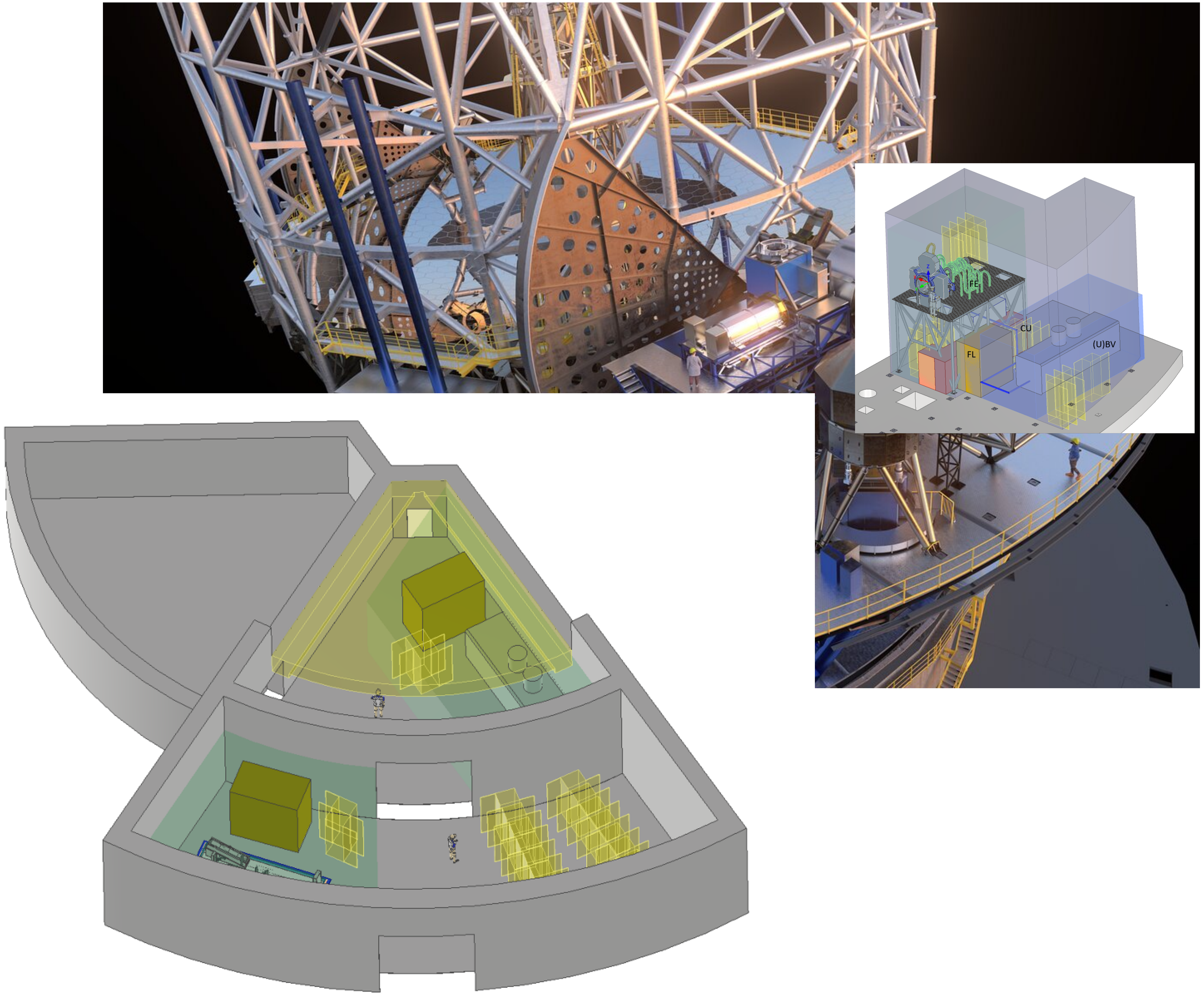

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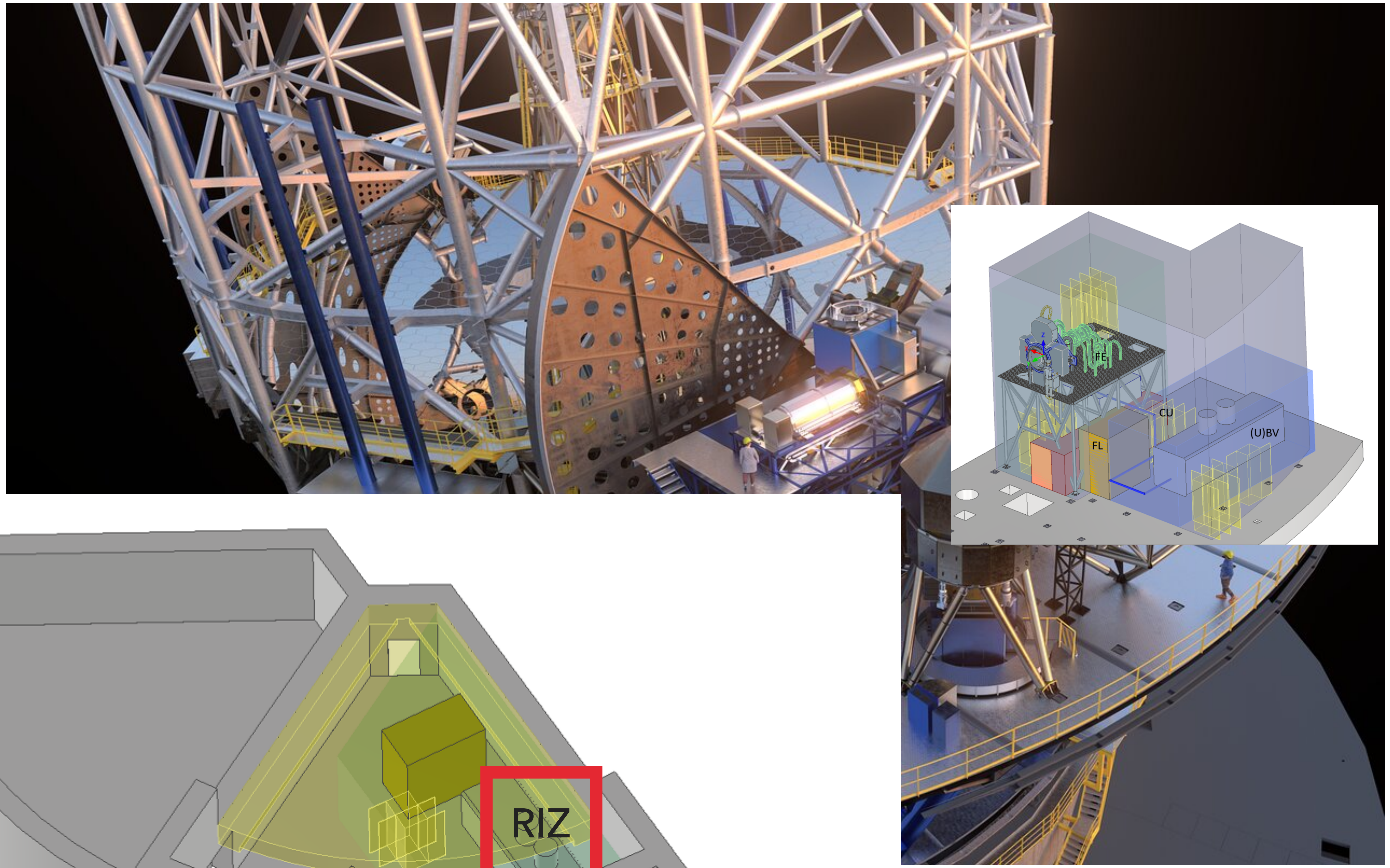

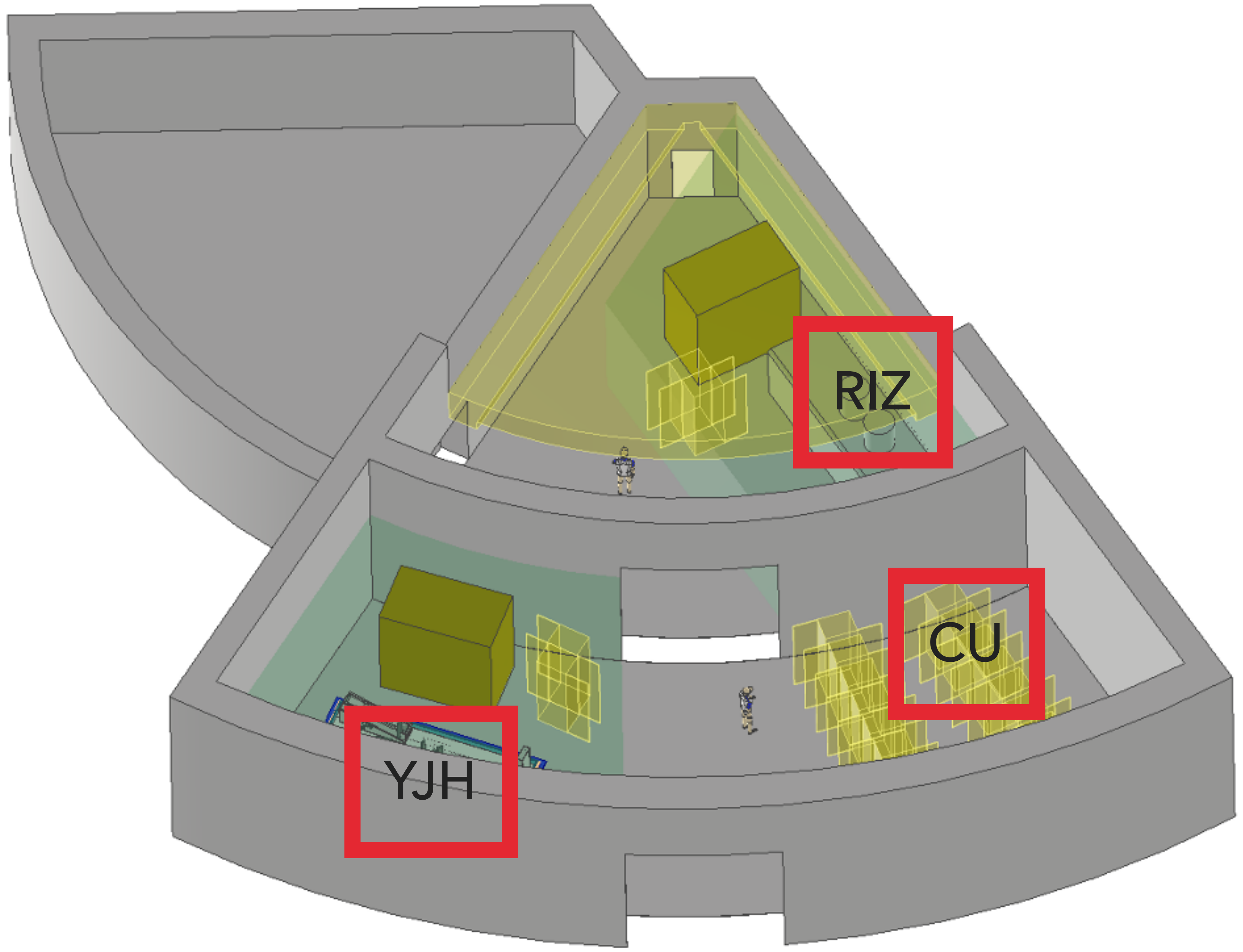


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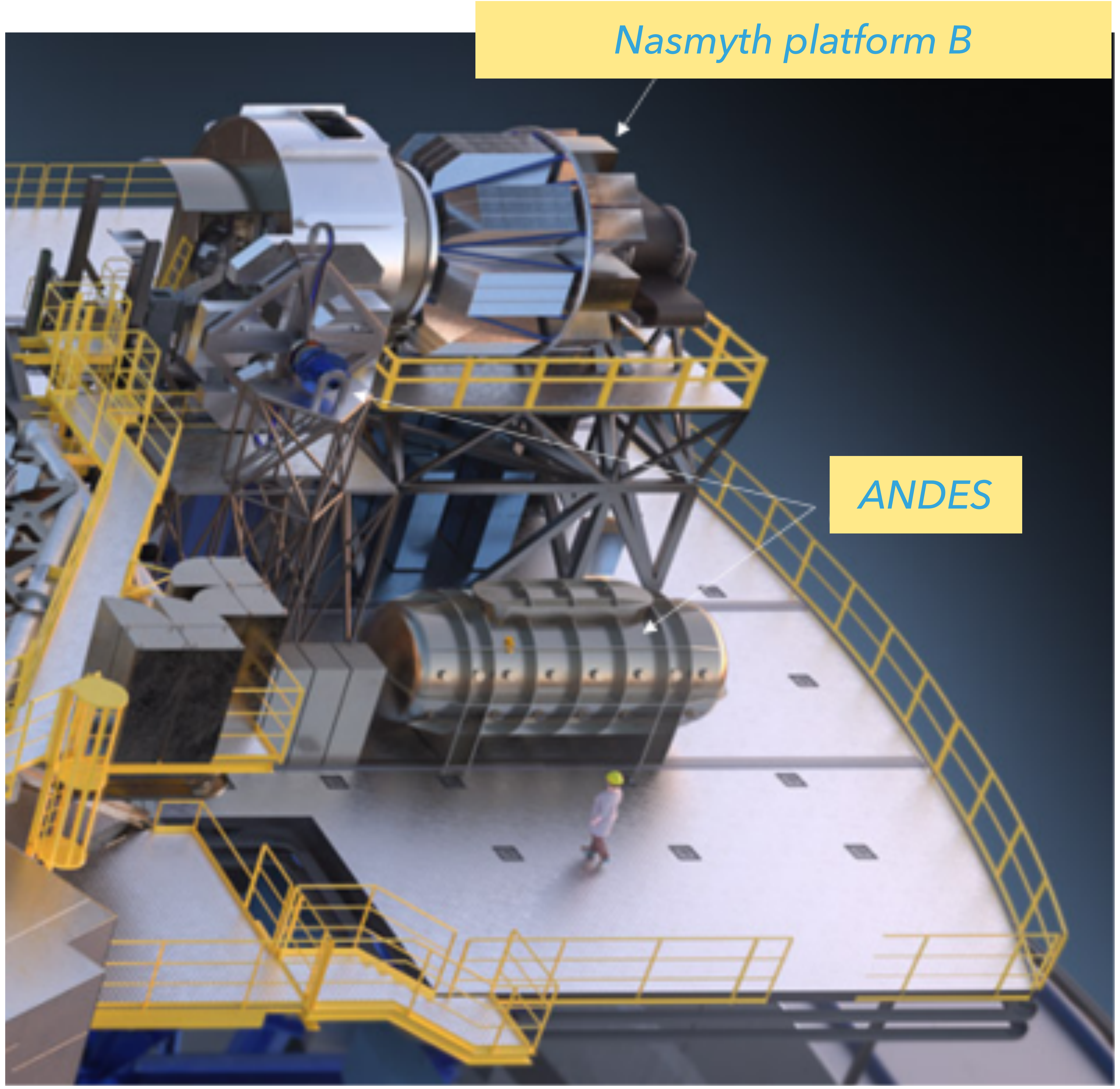
ANDES AT ELT: SUMMARY OF CAPABILITIES



- Modular fiber-fed cross dispersed echelle spectrograph
- Three ultra-stable spectral arms: (U)BV, RIZ , YJH (and K)
- Simultaneous spectral range 0.4-1.8 μm (0.37-2.4 μm goal)
- Spec. Resolution ~100,000
- Goal: 0.7 m/s precision and 1 m/s accuracy
- several, interchangeable, observing modes: Seeing limited & SCAO+IFU module
- Sensitivity: 1h, SNR = 10, AB=20
- Proposed baseline design capable of fulfilling the requirements of the 4 top science cases + of many additional science cases
- Seeing limited mode makes ANDES simple risk free instruments delivering cutting edge science

ANDES

CONSORTIUM

- **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,
  IRAP/OMP Toulouse, LUPM Montpellier
- **Germany:** AIP Potsdam, Univ. Göttingen, Landessternwarte Heidelberg, MPIA Heidelberg, Thüringer Landesternwarte Tautenburg, Univ. Hamburg
- **Italy:** INAF Istituto Nazionale di AstroFisica (Lead) (Arcetri, Bologna, Brera, Padova, Trieste)
- **Poland:** Nicolaus Copernicus Univ. in Toruń
- **Portugal:** Inst. Astrofísica e Ciências do Espaço, CAUP Porto, Lisbon
- **Spain:** Inst. Astrofísica de Canarias (IAC), Inst. Astrofísica de Andalucía (IAA - CSIC), Centro de Astrobiología (CSIC-INTA) Madrid
- **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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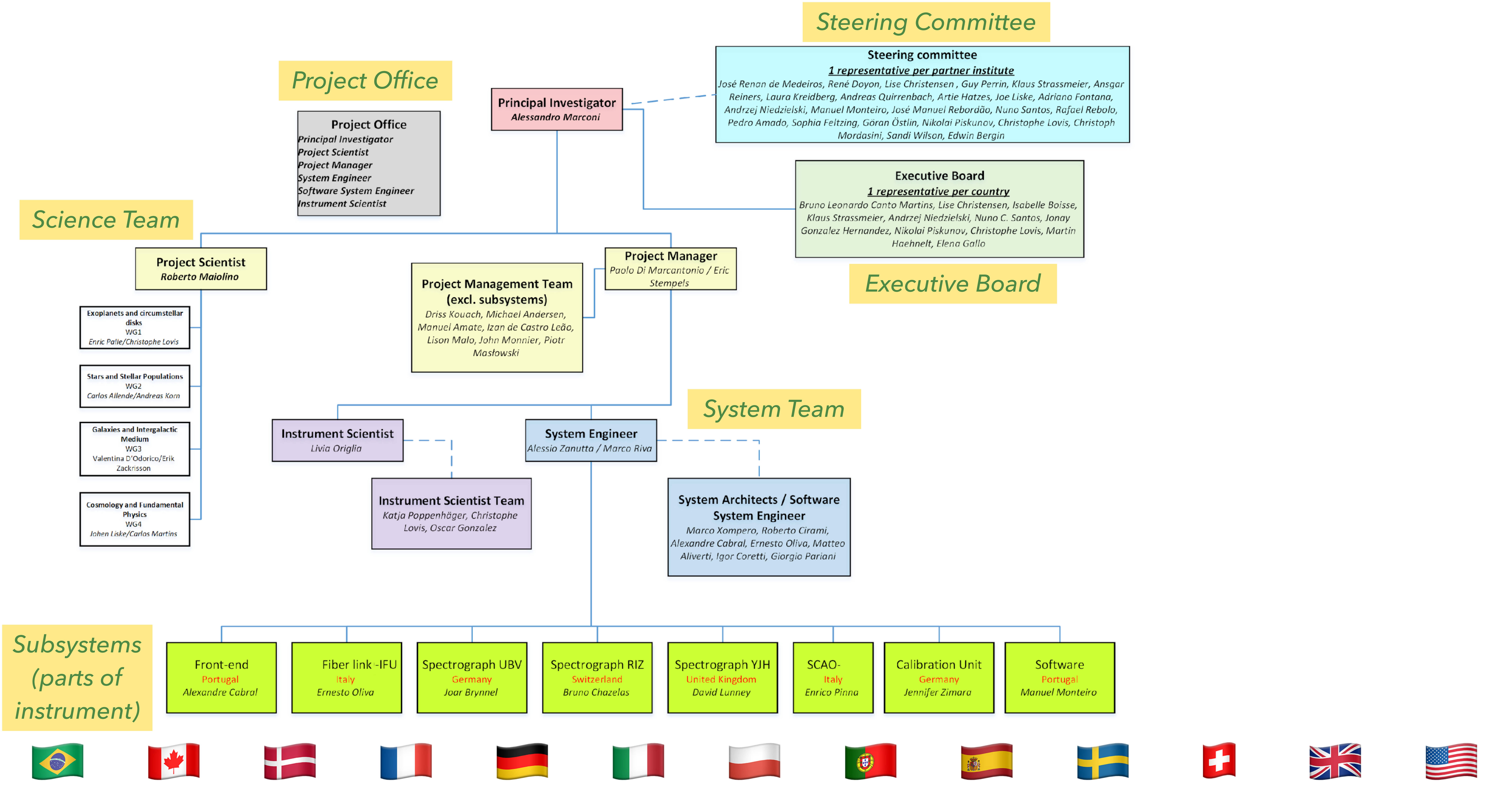

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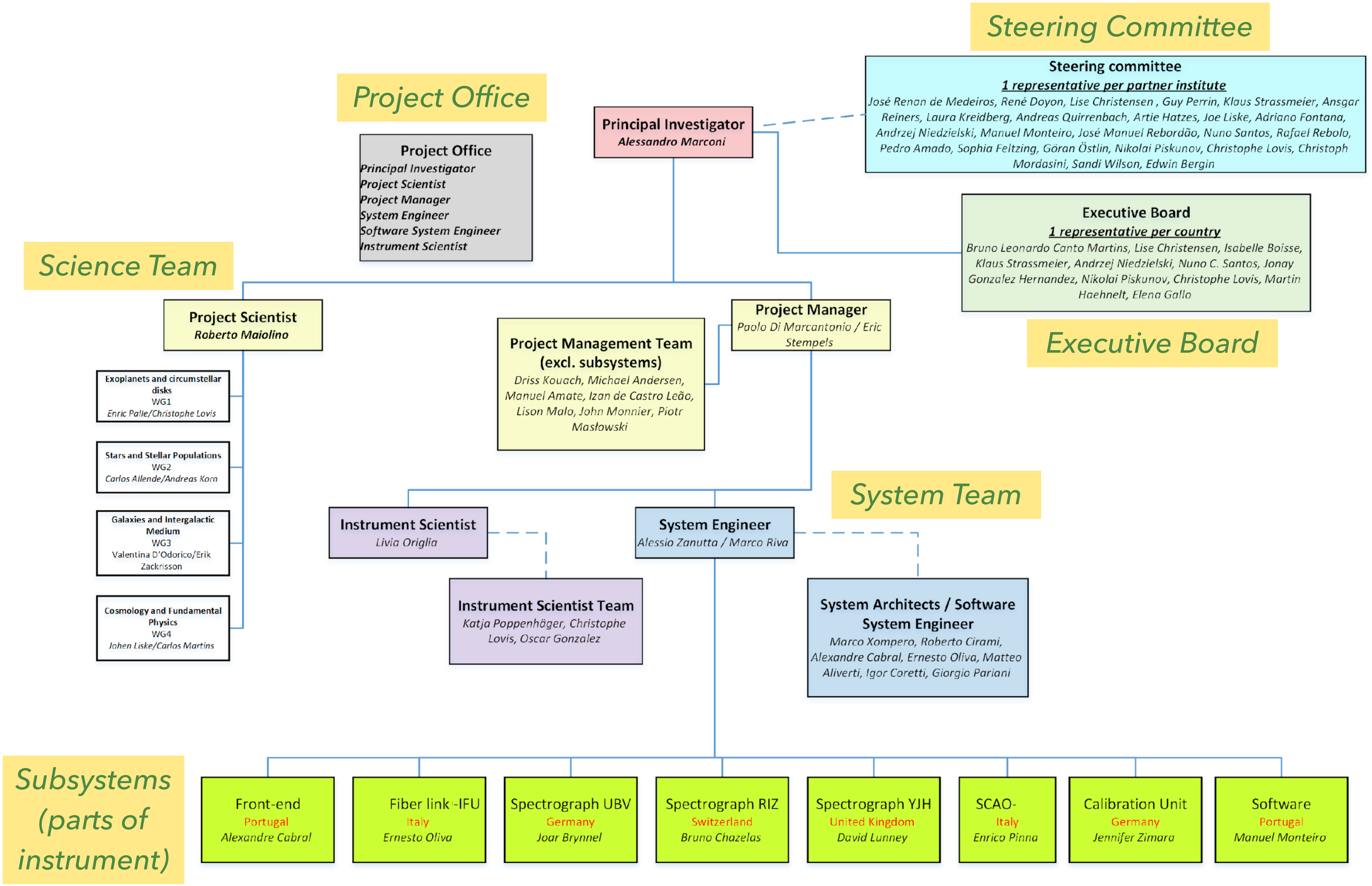


13 countries, more than 30 institutes

>200 people
The state-of-the-art scientific and technological expertise in high-resolution spectroscopy in Europe

COST, GTO & SCHEDULE

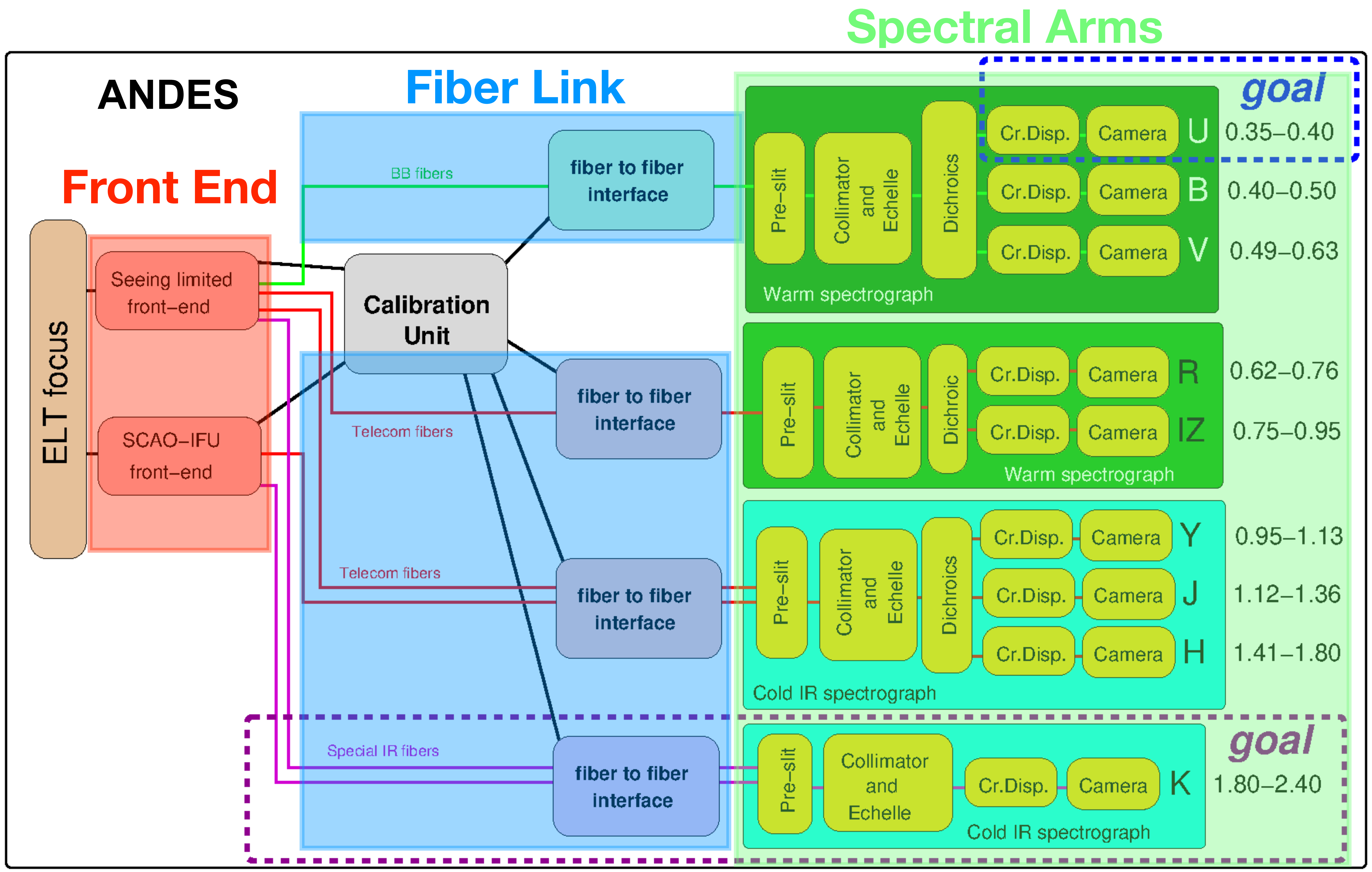
ANDES

Total estimated cost of baseline design is ~35 MEUR, + 650 FTEs

- **more than 125 GTO nights which will be used for Consortium science programs**

Schedule

- **Phase A: 2016-2018**
  Completed!
- *ANDES Construction approved by ESO Council on Dec 2021!*
- *Started Phase B activities in 2022*
- **Phase B (PDR): 2023-2024**
- **Phase C (FDR): 2025-2026**
- **Integration (PAE): 2027-2030**
- **Commissioning & PAC:2031**



SUMMARY OF ANDES PROJECT

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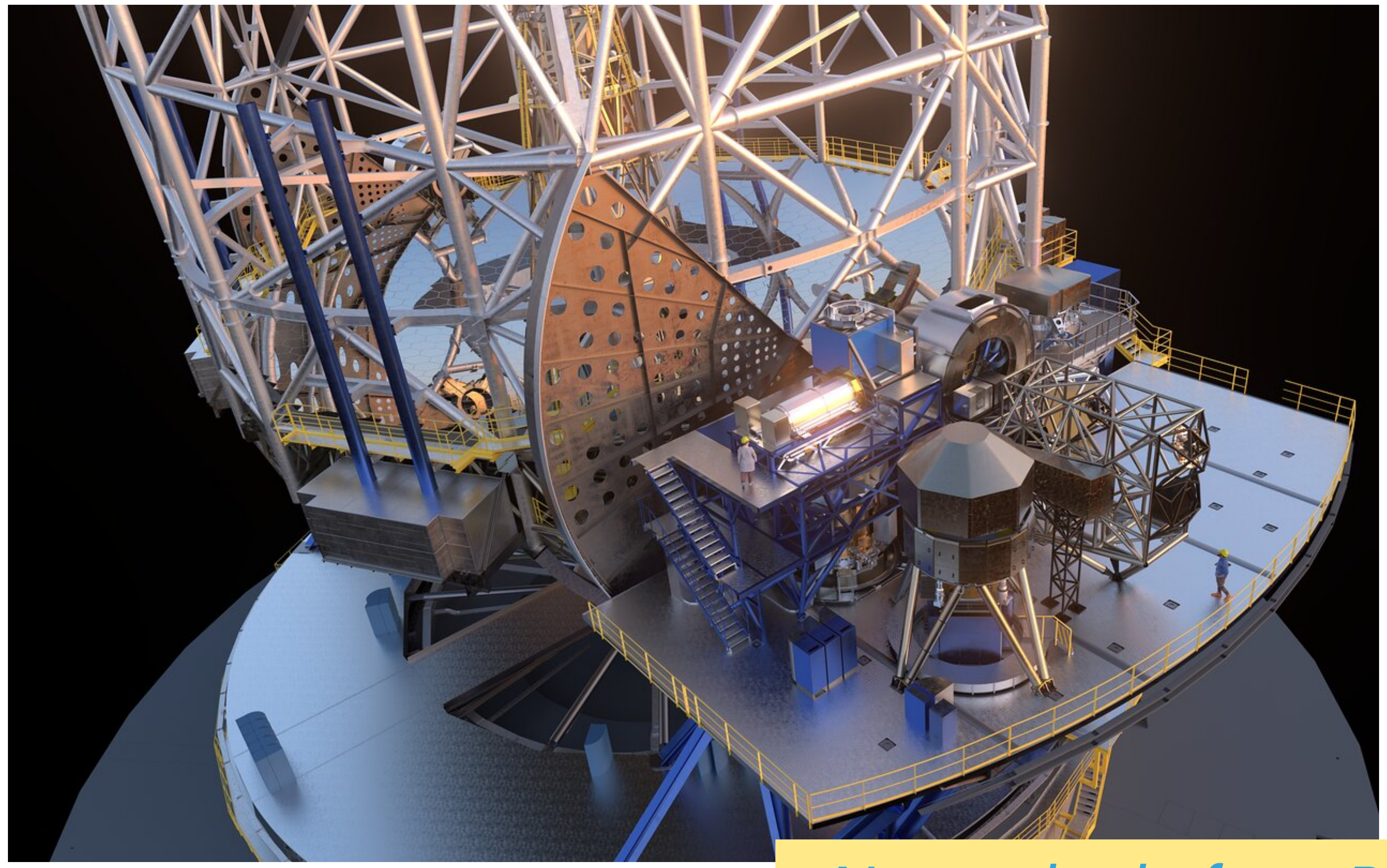
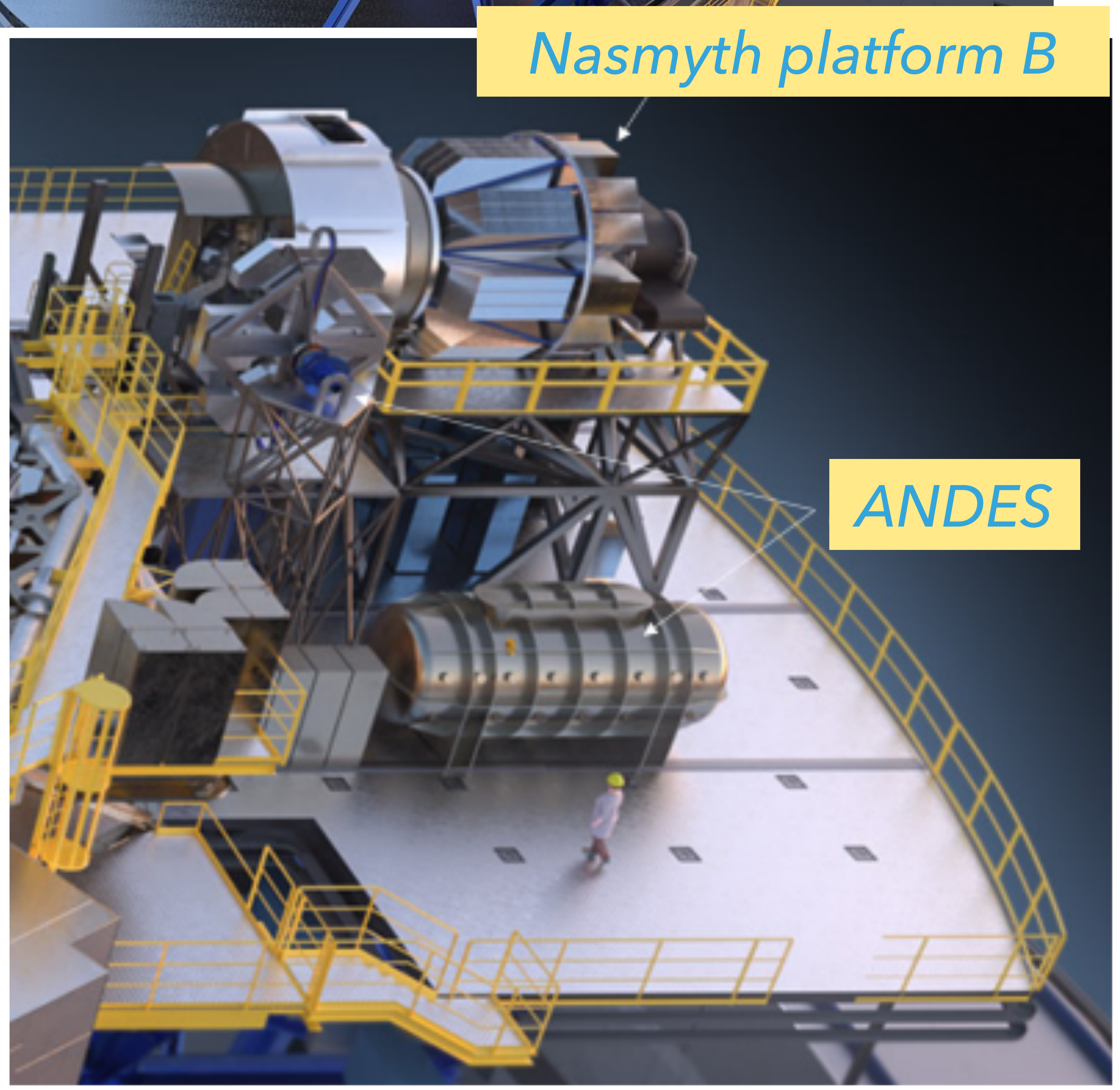
- International consortium: **32+ institutes, 13 countries, >200 people**
- Successful Phase A study 03/2016 - 03/2018
- **Aggressive schedule: Start Phase B ~2022, @ELT in ~2031**
- **Science priorities (plus many other great science cases …):**
  1. biomarkers from exoplanet atmospheres in transmission
  2. variation of fundamental constants of Physics
  3. biomarkers from exoplanet atmospheres in reflection
  4. direct detection of Cosmic acceleration through Sandage effect
- **Modular fiber-fed cross dispersed echelle spectrograph**
- **Simultaneous range 0.4-1.8 μm (ultrastable BLUE+RED+NIR)**
  Resolution ~100,000
- **Several interchangeable, observing modes:**
  Seeing limited & SCAO+IFU
- **Total estimated cost of baseline is 35 MEUR, + 550 FTEs**
  - technically "simple"
  - almost pupil independent
  - great science cases (fulfills top 4 priorities)
  - modular, staged deployment possible





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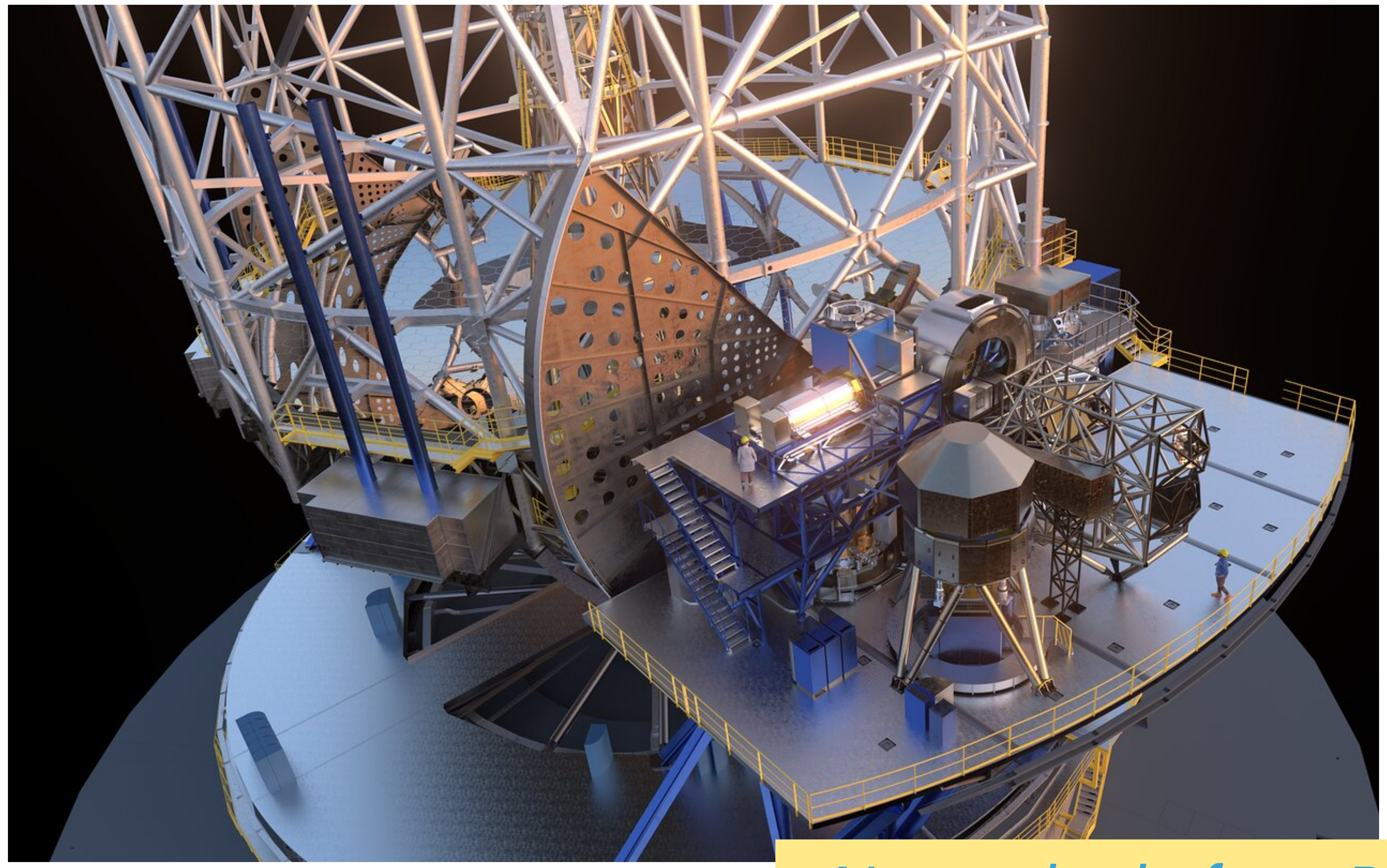

CONTACT ALESSANDRO.MARCONI@INAF.IT IF INTERESTED

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