Diagnostics, Detectors, Sensors, Optics and Instruments at the European Southern Observatory

Big Science Business Forum 2022

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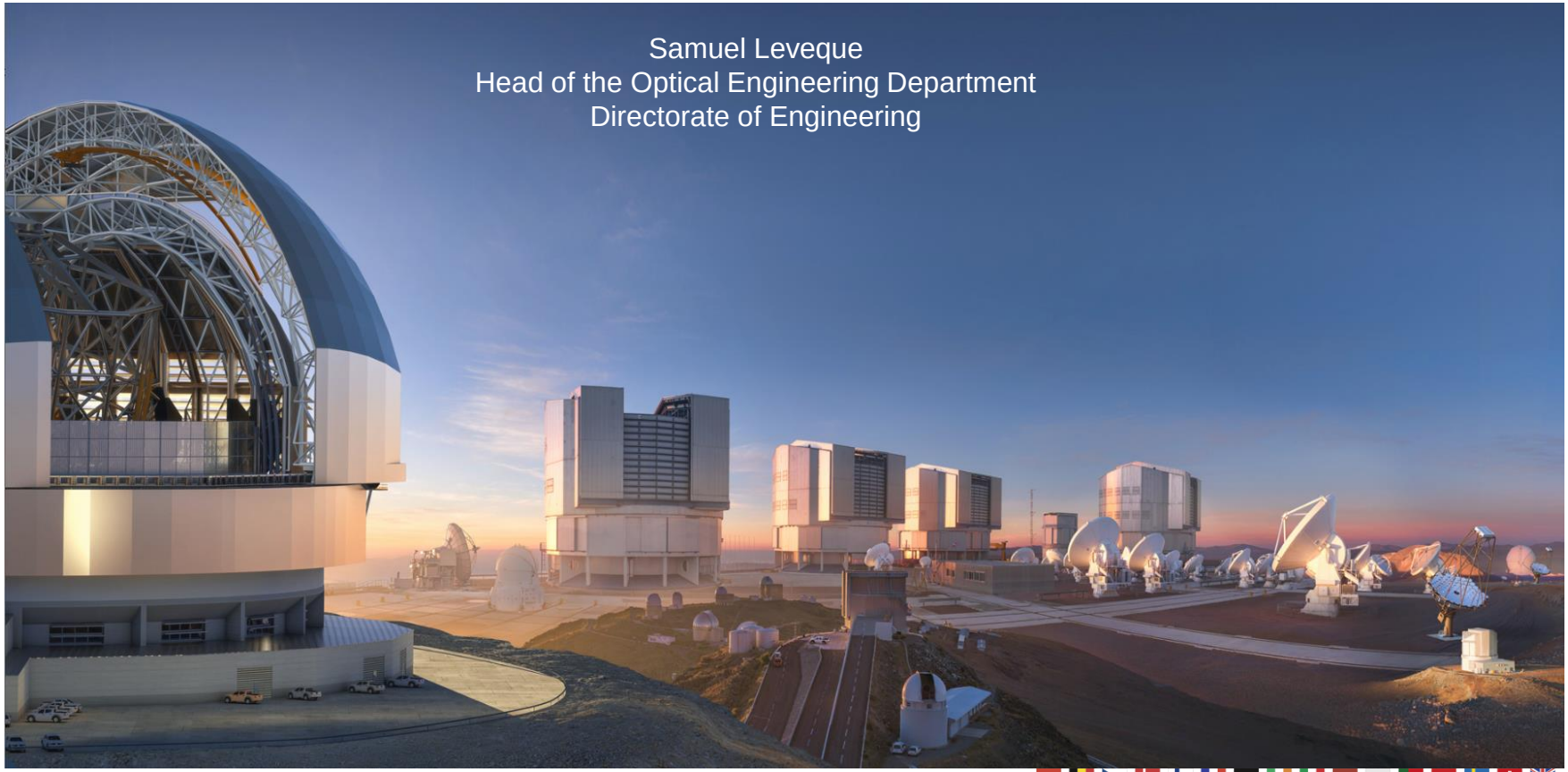

ESO's vision and mission

- Vision:
  - Deliver the Extremely Large Telescope (ELT), while keeping the Very Large Telescope (VLT), VLT Interferometer, and the Atacama Large Millimeter/submillimeter Array (ALMA) at the forefront of worldwide astronomy
- Mission:
  - Enabling major scientific discoveries by constructing and operating powerful ground-based observational facilities that are beyond the capabilities of individual member states
  - Fostering international cooperation in astronomy

ESO's Telescopes in Chile

VLT(i) instruments

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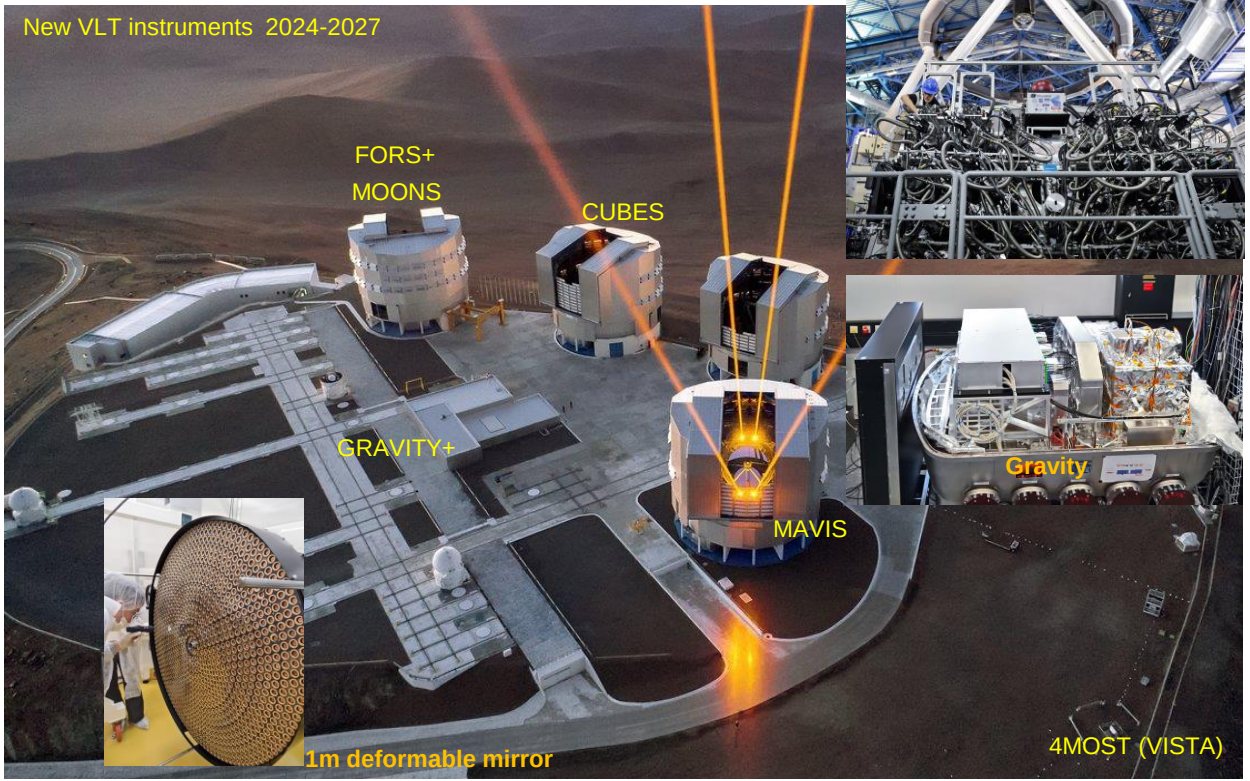
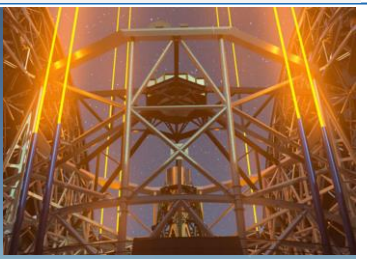
- Suite of 17 instruments spectrographs or imagers covering the VIS & IR (λ<20μm)
- Interferometric mode
- 6 new instruments designed & built by consortium of institutes, with contributions from industry
- benefit from the Telescope's Active/Adaptive optics, including Laser guide stars



The ELT

Status of the ESO's ELT construction, R.Tamai et.al., https://doi.org/10.1117/12.2631613

Prefocal, Phasing & diagnostic Stations



Secondary mirror (M2)
4.2-metre diameter
Aspheric f/1.1Convex

Fourth mirror (M4)
2.4-metre diameter
Flat
Thin
Adaptive

Segmented (6 petals)
SiC reference body
5000 actuators/sensors
at kHz

Fifth mirror (M5)
2.7 × 2.1 metres
Flat
Fast Tip/Tilt

Focus

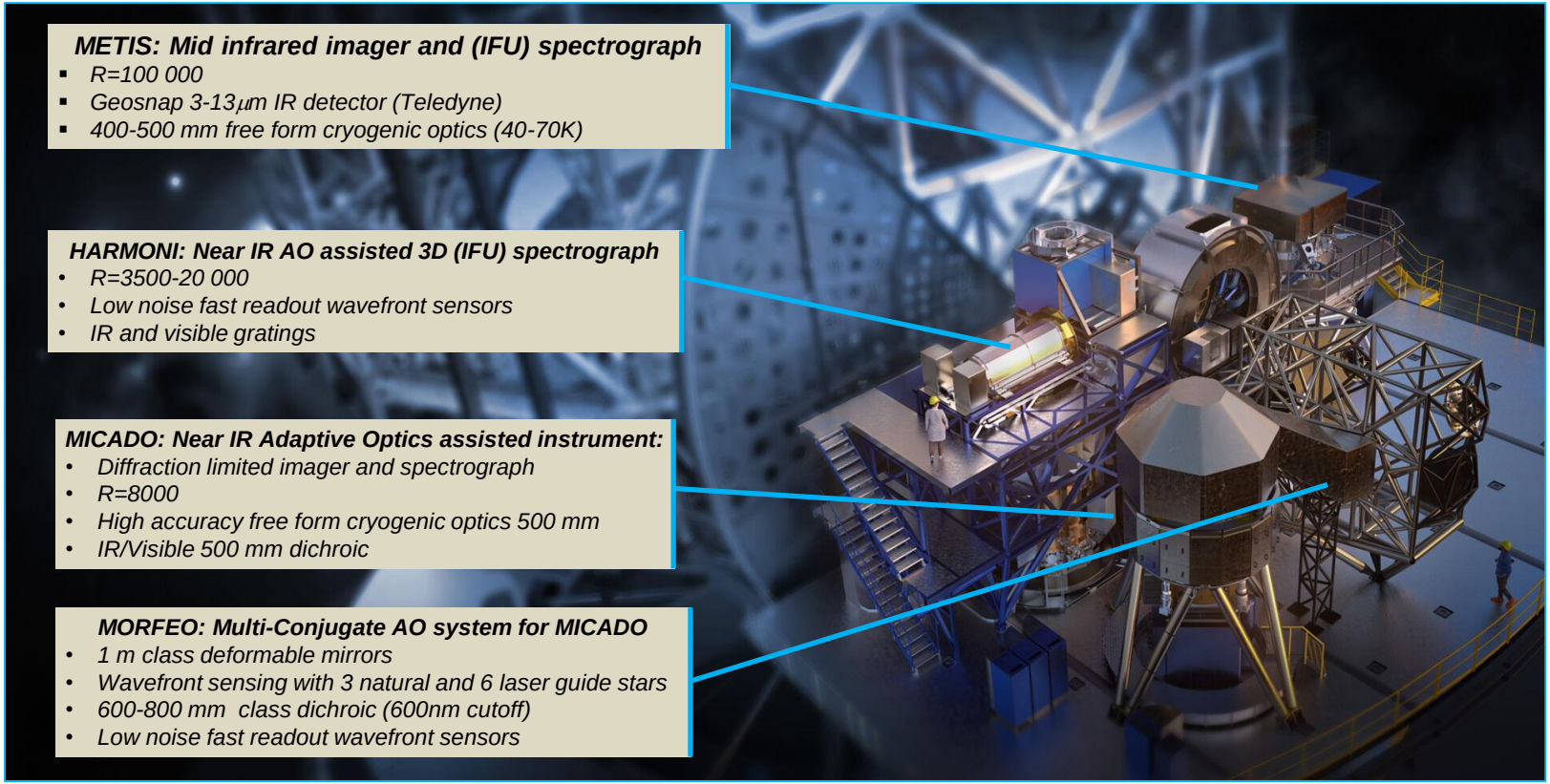
Tertiary mirror (M3)
3.8-metre diameter
Aspheric f/2.6 Concave

Science instrument Platform

Primary mirror (M1)
39-metre diameter
Concave
798 hexagonal segments
Active

4500 edge sensors and 2500 position actuators at nm resolution and 7000 warping harnesses; >10 000 components

ELT First set of Instruments & Technologies (in Final Design Phase)



METIS: Mid infrared imager and (IFU) spectrograph

- *R=100 000*
- *Geosnap 3-13μm IR detector (Teledyne)*
- *400-500 mm free form cryogenic optics (40-70K)*

HARMONI: Near IR AO assisted 3D (IFU) spectrograph

- *R=3500-20 000*
- *Low noise fast readout wavefront sensors*
- *IR and visible gratings*

MICADO: Near IR Adaptive Optics assisted instrument:

- *Diffraction limited imager and spectrograph*
- *R=8000*
- *High accuracy free form cryogenic optics 500 mm*
- *IR/Visible 500 mm dichroic*

MORFEO: Multi-Conjugate AO system for MICADO

- *1 m class deformable mirrors*
- *Wavefront sensing with 3 natural and 6 laser guide stars*
- *600-800 mm class dichroic (600nm cutoff)*
- *Low noise fast readout wavefront sensors*

2nd generation ELT instruments and technologies (Phase A study level)

HIRES: HIgh REsolution Spectrograph:
Technologies to be developed

- *High-efficiency gratings for high resolution spectroscopy R > 100,000*
- *Robust & high-efficiency fibres for K-band (2.0 < λ < 2.4 μm)*
- *Coating with high performance from 0.35 to ~2 μm*
- *Ultra stable calibration source: Laser Frequency Comb*

MOSAIC: Multi Object AO assisted spectrograph
Technologies to be developed

- *Large format VPHs (~300mm) for medium resolution spectroscopy (5,000-20,000) in optical and near-IR*
- *Curved detectors (CCD) 4Kx4K*
- *Coating with high performance from 0.35 to~2microns*

Required technologies

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- CMOS and new IR detectors for AO or IR imaging applications
- Curved visible and IR detectors to compact/simplify instrument designs
- Free form optics
- High accuracy calibration sources: Laser Frequency Comb-ultra stable Fabry Perot
- High stability deformable mirrors with 10-20k actuators at high speed
- Laser sources and new LGS AO concept improving sky coverage
- Robust & high-efficiency fibres for K-band ($2.0 < \lambda < 2.4$)
- Secure transmission grating availability
- Promising technology: astrophotonics e.g. integrated spectrograph, tip-tilt sensing, heterodyne interferometry…

Large CMOS detectors

- Motivation: Guarantee long-term access to scientific-quality detectors in the visible wavelengths for astronomy.
- CCDs are state-of-the-art visible detectors used in all ESO visible instruments.
  - CCD production is decreasing in favor of CMOS. Only 1.5 suppliers worldwide are still producing large-format CCDs, and cost continuously increases.
  - Availability not guaranteed beyond ~1 decade, and TBC in next 5 years (ELT).
- Alternative: CMOS detectors
  - New readout schemes / operation modes, lower prod. Cost / pixel.
  - Some established design houses and larger variety of manufacturers.
  - Commercial CMOS specifications do not (yet) reach our requirements,
- Investment and development required. MEU development requiring partnership

Curved detectors and large IR detectors

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- Curved detectors rated as enabling technology
  - Larger detectors behind faster cameras are needed e.g. for future survey telescopes or future massively multiplexed spectrographs (ELT 2nd generation instruments).
  - Curved detectors open a new way to design compact, high-performance optical systems (better image quality and throughput with less optical surfaces)
  - Synergy with space application (e.g. large field of view earth observation missions): high cost savings impact through simplification of the optical design
  - Project started with ESA &Teledyne for a 4k x 4k CCD231-84: 500 mm spherical concave radius
- Large IR Detectors
  - foster availability of a European NIR/SWIR large format arrays for space and ground based astronomy applications (low photons flux)
- MEU development requiring partnership

Deformable mirrors for adaptive optics

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	VLT/ELT short/mid term			ELT long term	
	MAVIS	GRAVITY+	HARMONI	MOSAIC	PCS
Number of actuators	54x54	40x40	28x28	32x32	128x128
Actuator pitch	1.5 mm	2.5 mm	1.5 mm	1.5 mm	1.5 mm
Pupil diameter	80 mm	100 mm	40 mm	50 mm	190 mm
Control frequency	1 kHz	1 kHz	500 Hz	1 kHz	4 kHz
Stroke (TBC)	5 µm	10 µm	10 µm	5 µm	2 µm
Resolution	-	-	-	-	0.1 nm
Stability with time	N/A	N/A	Yes	Yes	N/A
Stability with temperature	Yes	Yes	Yes	Yes	Yes
Stability with gravity	Partly	Partly	Yes	Yes	Partly
Low power consumption	N/A	N/A	N/A	N/A	N/A
…					

Example of a technology development:
Φ=96mm 64x64 (3228) actuators deformable mirror produced (used by ELT-MICADO test bench & TMT-PFI)

- Next: scale 1 DM prototype for ELT PCS
- Funding to be identified at a level of 2-3 MEu

Needs for transmission gratings

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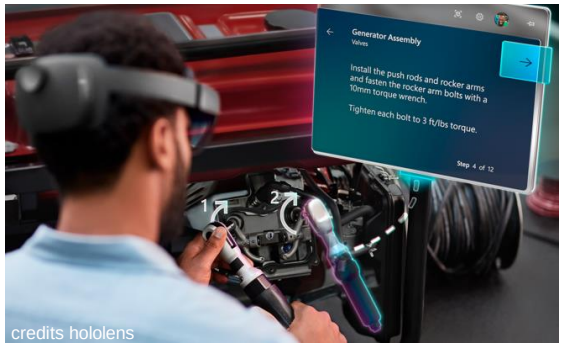
- Type of gratings needed for forthcoming projects
- Need to engage with industry to secure availability

Instrument	Ws	Wh	Type	Lines/mm	Angle of Incidence	Diff Order	Size	Size	Needed
CUBES	0.3	0.352	T	3107	36.07	1	170	220	1
	0.346	0.405	T	3600	35.82	1	170	220	1
BLUE MUSE	0.35	0.58	T or TG	1000	13.9	1	200	100	25
MAVIS	0.37	0.732	TG	750	12	1	40	40	1
	0.51	1.009	TG	550	12	1	40	40	1
	0.425	0.555	TG	1830	26.6	1	40	40	1
	0.63	0.887	TG	1000	22.24	1	40	40	1
VLT HRMOS (ESO concept)	0.36	0.374	T	4400	54	1	300	520	4
HARMONI	0.462	0.809	T	457	5.49	1	160	160	2
	0.81	1.369	T	284	12	1	164	156	4
	1.45	2.45	T	159	12	1	164	156	4
	0.83	1.05	T	664	21.4	1	164	160	4
	1.046	1.324	T	526	21.4	1	164	160	4
	1.435	1.815	T	384	21.4	1	164	160	4
	1.951	2.469	T	282	21.4	1	164	160	4
	0.827	0.903	T	1414	41.2	1	164	196	4
	1.538	1.678	T	760	41.2	1	164	196	4
	2.017	2.201	T	580	41.2	1	164	196	4
	2.199	2.4	T	532	41.2	1	164	196	4
FORSup	0.524	0.64	TG	484	17	1	105	112	1
	0.695	0.849	TG	480	18.23	1	105	112	1
	0.33	0.62	TG	660	6.08	1	105	104	1

Diagnostic, Integrated Operation

- New perspectives offered by e.g. Augmented Reality, in the way we Integrate, Maintain, Train, Remote support, Manage stock, and Design
- Assessments in telescope environments started at ESO



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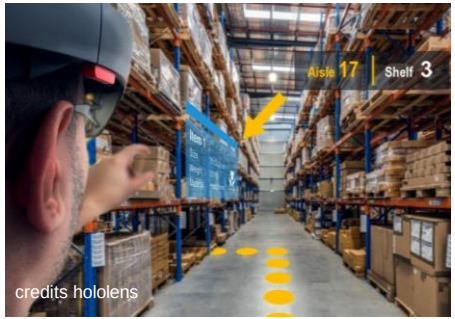

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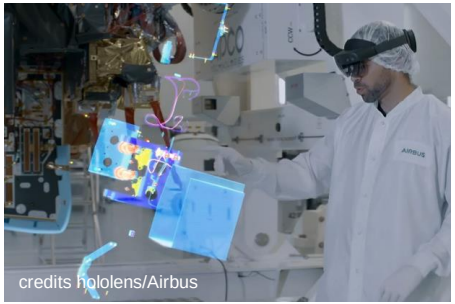
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ESO's Procurement

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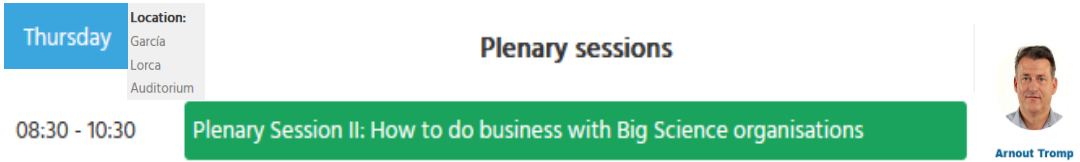
- Competitive tendering within ESO Member States
  - Lowest price-compliant tender or "Best Value for Money"
  - Approval by Finance Committee >500KEu (>250KEu for single source)
  - Details in Arnout Tromp's talk



- Projection for diagnostic,detectors,sensors,optics and instruments,
  - New instruments: multi-MEu projects
  - Maintenance and operation
- ELT operation costs:50Meu/Year

	2019	2020	2021	2023
Complete systems				
Detector systems incl. control				
Optical/mechanical systems				
Controls/electronical sys.				
Other scientific equip./comp.				
Workshop/Laboratory equip.				
Small tools/small equipments	15MEu	40MEu	30MEu	20MEu