ESO Cryogenics

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8th EIROforum School on Instumentation, 14 May 2024 @ ESO HQ

ESO Telescopes in Chile

40-m class

Extremely Large Telescope
ELT at Cerro Armazones (3046m)
2028

8-m class

Very Large Telescope
VLT at Cerro Paranal (2635m)
1998

4-m class

VISTA / VST
at Cerro Paranal
2009 / 2011

NTT / 3.6m Telescope
at La Silla (2400m)
1989 / 1977

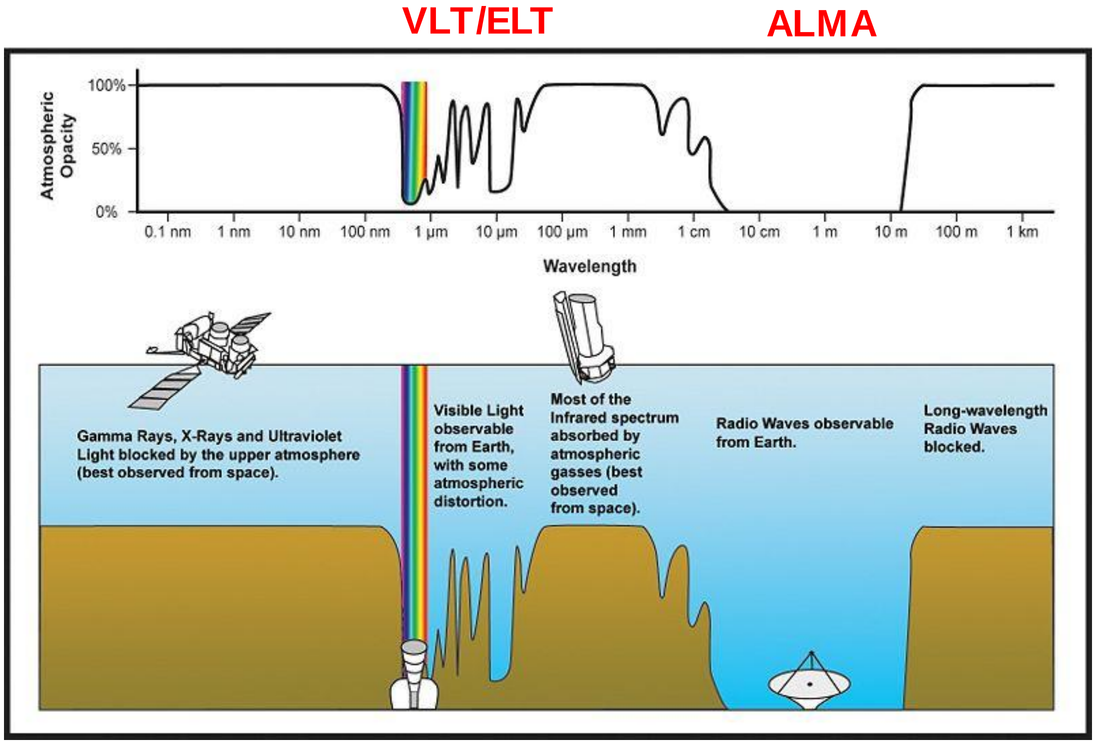
APEX and ALMA
at Chajnantor (5000m)
2005 / 2011

12-m class
radio telescopes

All of them require cryogenics!

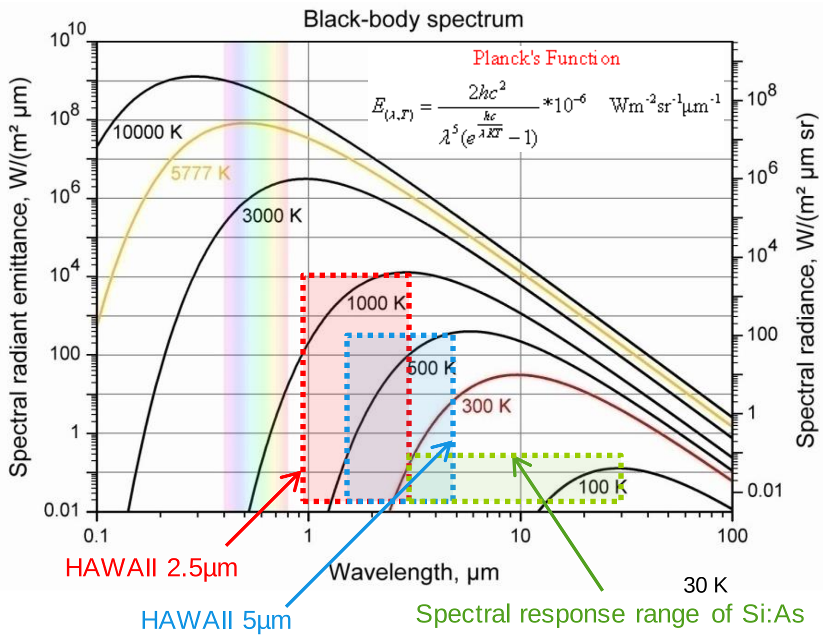
Wavelength range for astronomical research

- Wavelength range defined by individual science case
- Not all light passing earth atmosphere
  - Transparent for visible light, near-infrared, mid-infrared, radio waves
    -> allows observations from ground-based telescopes
  - Opaque for far-infrared, UV, X-rays, gamma rays, long radio
    -> observations from space telescopes



Background limited infrared detection (1)

- Considering Planck's function and Wien's displacement law: $\lambda * T = b = 2897.7\ \mu m\ K$
  - A 300K black-body emits the maximum intensity at 10µm
  - A 100K black-body at 30µm
  - A 30K black-body at 100µm etc.
- Integrating over detector spectral response and known emissivity gives photon flux on detector
  - Flux from background to be << astronomical source
- Important for eliminating the thermal background: the longer the wavelength, the colder the detector surroundings (optical system)
  - For observations at 3µm: T << 1000K (typically 100K)
  - At 5µm: T << 600K (typically 80K)
  - At 10µm: T << 300K (METIS @ 50K)
  - At 30µm: T << 100K (MATISSE, VISIR @ 25K)



Background limited infrared detection (2)

- Optics, detectors and low noise electronics of scientific instruments cooled to cryogenic temperatures
  - Elimination of thermal background, increased sensitivity (signal to noise), minimized dark current, better cosmetics, lower persistence, gain in quantum efficiency
  - As a rule of thumb, the detector cut-off wavelength defines its max. temperature

$$T_{max} = \frac{200\,K}{\lambda_{cutoff}}$$

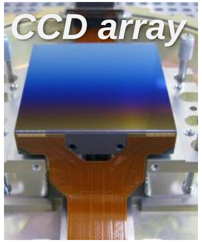
T_{max} = maximum detector temperature
λ_{cutoff} = detector cut-off wavelength

Detector type	λ_{cutoff} (µm)	T_{max} (K)	
CCD	1	200	*Visible light (VIS)*
HgCdTe (HAWAII 2.5µm)	2.5	80	*Near-infrared (NIR)*
HgCdTe (HAWAII 5µm)	5	40	*Mid-infrared (MIR) or thermal infrared*
HgCdTe (GeoSnap in ELT METIS)	13	15	
Si:As (AQUARIUS in VLT VISIR, MATISSE)	26	7	
Ge:Be	50	4	*Far-infrared (FIR) (not relevant for ESO)*
Ge:Ga	100	2	
Stressed Ge:Ga	200	1	

Examples for typical detector operating temperatures

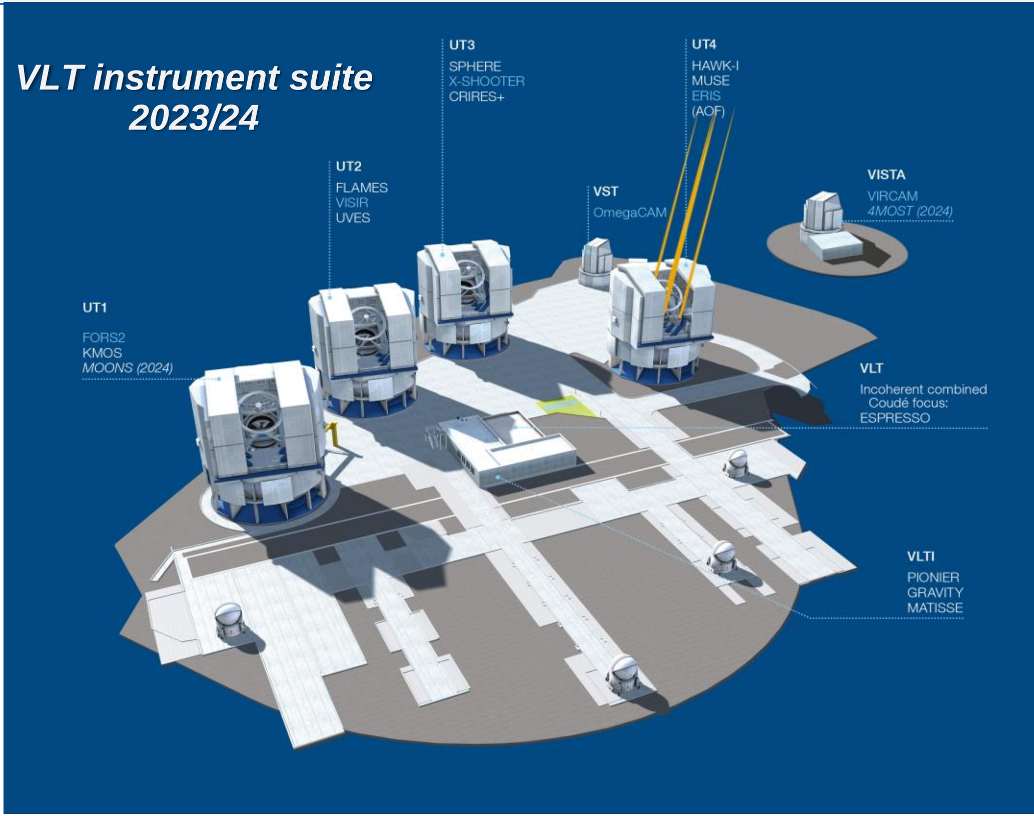
ESO cryogenics – overview

- Telescopes operating at ambient temperature
- Optics and detectors of science instruments cryogenically cooled
- Large cold masses requiring powerful cooling systems
  - Typical cold mass of a single VLT / ELT instrument: 500kg / 5000kg
- Cryogenic cooling based on Liquid Nitrogen (LIN) and cryo-coolers; running 24/7
- Instrument cryostats with integrated optical systems require vacuum systems for thermal insulation
- Instruments having own local cooling systems
- Observatories providing cryogenic infrastructure
- Aiming for automation, standardization and COTS products



Cryogenic instruments at VLT

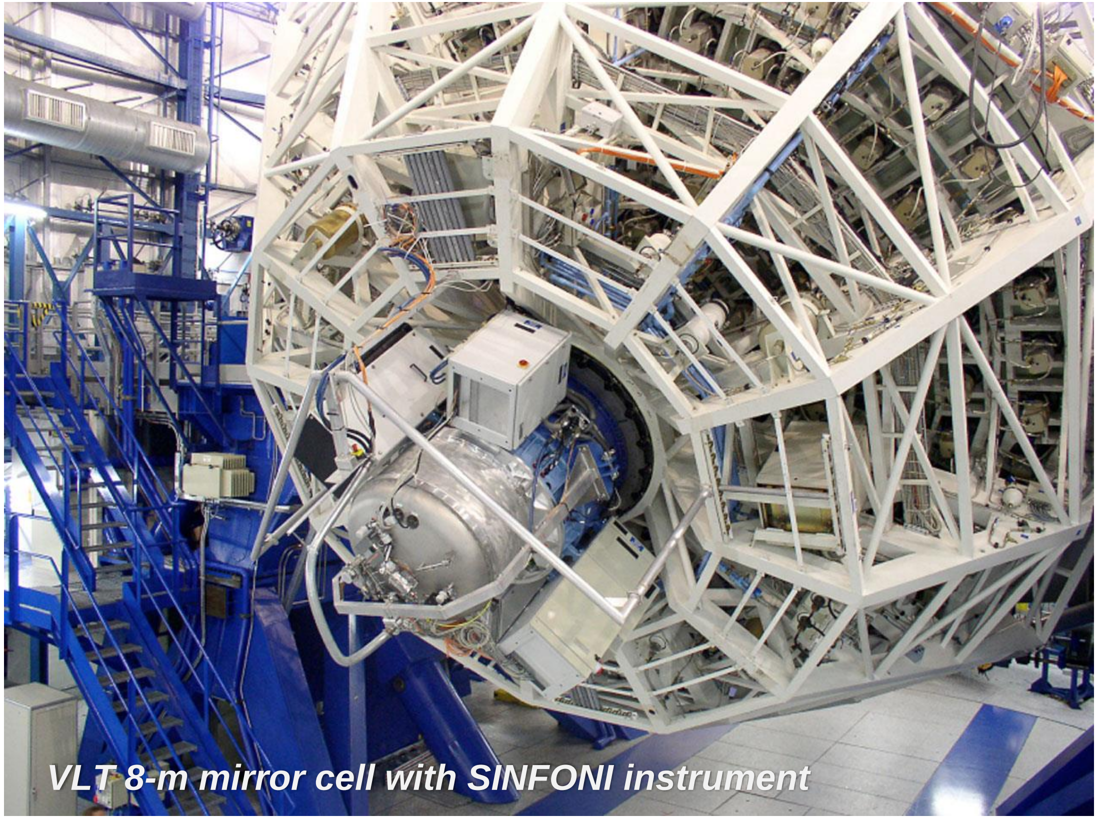
- ~ 20 cryogenic instruments in 24/7 operation
- Designed for a life cycle of 10-15 y
- ~ 1 - 2 new instruments every year; now 3rd generation of instruments
- Typical cold mass ~500 kg / 2500 L vessel / 3 t weight
  - New: MOONS: 3300 kg / 16000 L / 9 t
- Ongoing developments, procurements, construction
- LIN supply of instruments via portable dewars = labor-intensive
  - Plans for automated LIN distribution system



Cryogenic instruments at VLT as of today

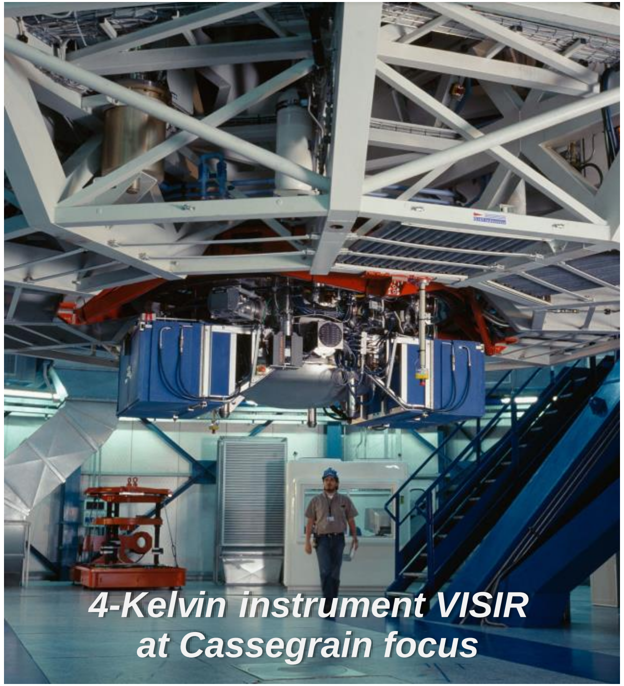
- Examples of LIN cooled instruments at VLT
  - Supply via portable LIN dewars + transfer lines

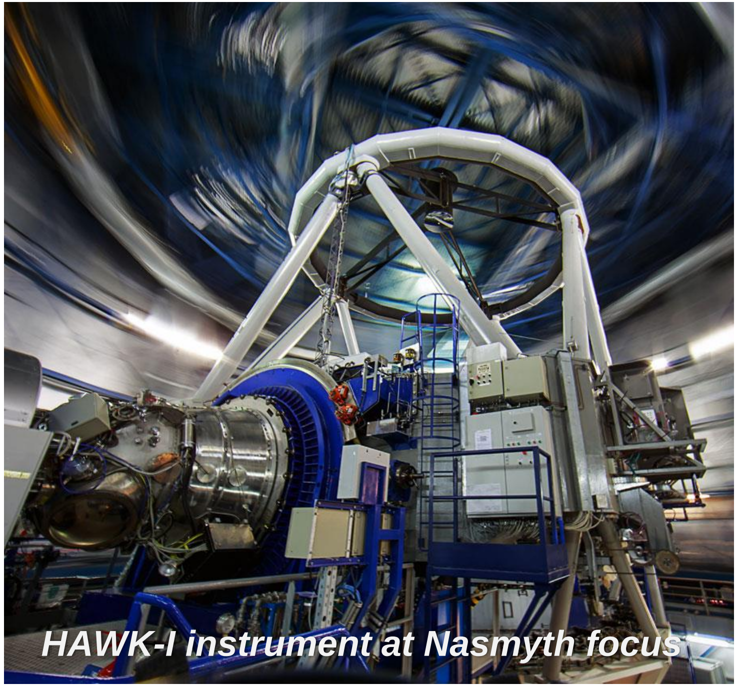

X-Shooter instrument LIN refilling


VLT 8-m mirror cell with SINFONI instrument

Cryogenic instruments at ESO as of today

- Examples of cryo-cooler instruments at VLT


4-Kelvin instrument VISIR
at Cassegrain focus


HAWK-I instrument at Nasmyth focus

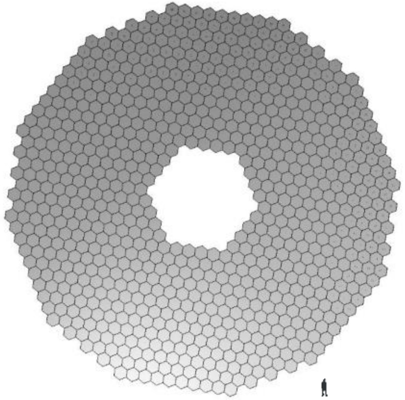
MOONS instrument cryostat
2.5 m x 2.5 m x 4 m

ELT – The world's biggest eye on the sky

- Largest optical / infrared telescope in the world
- 39-m segmented primary mirror, ~80m high building
- Construction 2014 – 2028 at Cerro Armazones (3046m) in Chile, ~25km away from Paranal

- ESO cost:
  - Capital cost: ~1500 M€ incl. instruments and contingency
  - Operation cost: ~50 M€ / year
- Lifetime: 50 years
- Several generations of "extremely large" cryo instruments

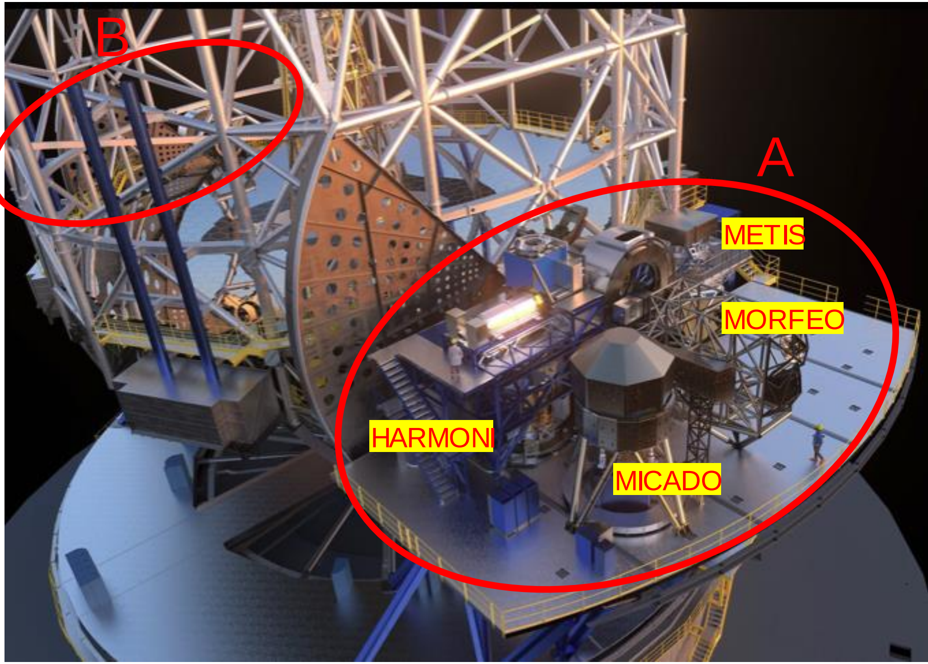
ELT – M1



39-m diameter
6x133=798 segments (1.4-m)
+1x133 spare segments
Total: 931 segments

ELT cryogenic instruments – future challenges

- Two tennis-court size Nasmyth platforms A and B for instruments
  - First light instruments (2028-2030):
    - MICADO, MORPHEO, METIS, HARMONI
  - 2030+ instruments:
    - ANDES, MOSAIC, 2nd AO, PCS
- Instruments scaling with telescope size: ~10 x VLT size
- Vessel volume / weight / cold mass: 25000+ L / 25+ t / 5000 kg
- Large cryo-vacuum systems



ELT Nasmyth A platform populated with first light instruments (artist impression)

Lessons learned from VLT towards ELT (1)

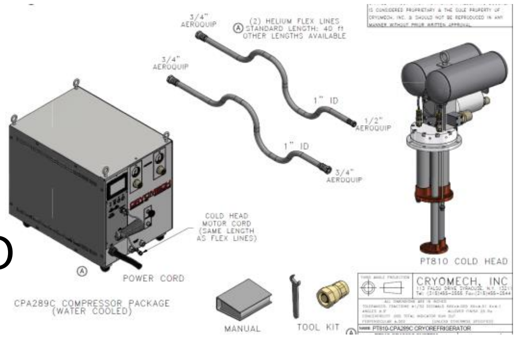
- Adopt proven concept of LIN cooling and local cryo-coolers
  - Early concept studies of Liquid Helium cooling etc. dropped
- Fully automated LIN distribution system from main outdoor 42,000L LIN storage tank to each consumer (science instruments), no portable LIN dewars
- Maintain LIN truck delivery service, no on-site LIN liquefier plant
  - Outsourcing instead of additional maintenance expense
- No cryogenic transfer lines through telescope rotating cable wraps to avoid possible long-term damage from dynamical bending stress (-> static piping only)
- COTS and state-of-the-art industry standards
  - Avoid one-off customized cooling systems (e.g. special developments from Universities)

Lessons learned from VLT towards ELT (2)

- Avoid product diversity: define applicable standard components catalogue
  - External partners committed to apply standardized cryo-vacuum components and system design, cryo-vacuum control and operating principles
  - Exchange with partners and stakeholders right from the start of a new instr. project
- Characterize every source of vibration for compliance in advance
  - Including cryocoolers, compressors, vacuum pumps, etc.
  - Know you budgets: We have very demanding vibration requirements for ELT (and VLT-I)
- No Gifford-McMahon (GM) cryocoolers allowed -> pulse tube coolers (PTC) only !
  - Plus, selected vibration compatible small-scale coolers (e.g. Stirling cooler)
- Development of vibration isolation systems for cryocoolers
- Provide cryogenic infrastructure with clearly defined interfaces to cryogenic instruments (LIN supply and return, high-pressure Helium supply for PTCs)

Lessons learned from VLT towards ELT (3)

- COTS cryocooler standardized for ELT
  - 2-stage PTC 14W @ 20K (or 1W @ 4K) / 80W @ 80K, ~9 kW input power
  - In total 36 compressors in ELT; up to 4 cryocoolers/compressors per instrument
  - Long Helium flex lines required (~100 - 120m)
  - Only one coldhead per compressor (no multiplexing)
  - Very demanding vibration requirements
  - Advanced vibration isolation systems developed at ESO



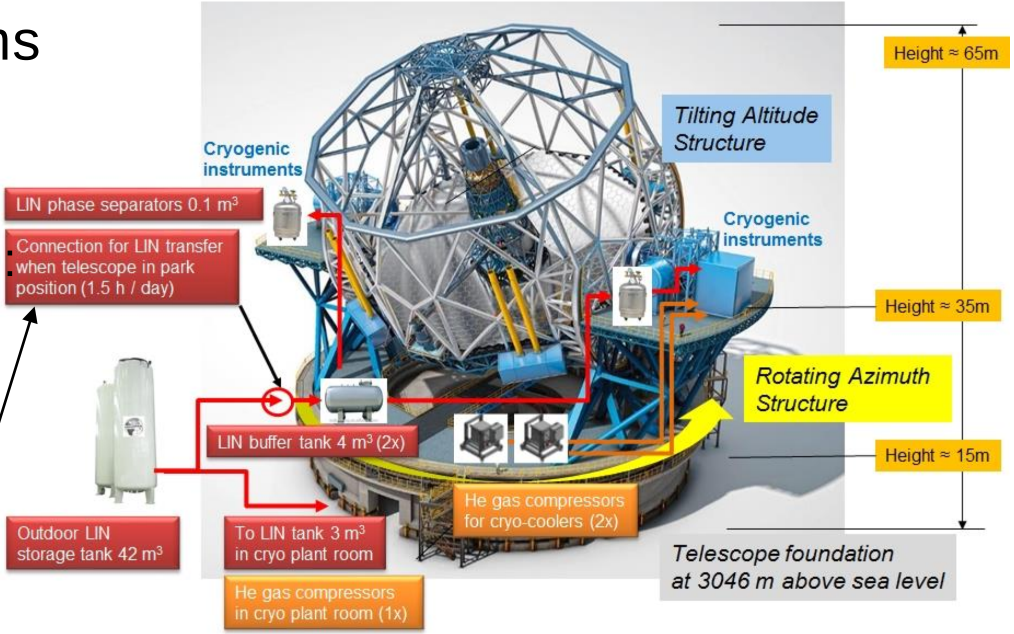
Anti-vibration (AV) mounts for compressors (left), coldheads (middle), Helium lines (right)

Unit	Frequency Range [Hz]		
	1 – 4.45	4.45 - 56	56 - 110
Nasmyth Instruments (RSS of force (x,y,z) [N] rms per one-third octave frequency bands)	1	0.4	2

Vibration requirements for ELT instruments

ELT cryogenic infrastructure (ECIS) - overview

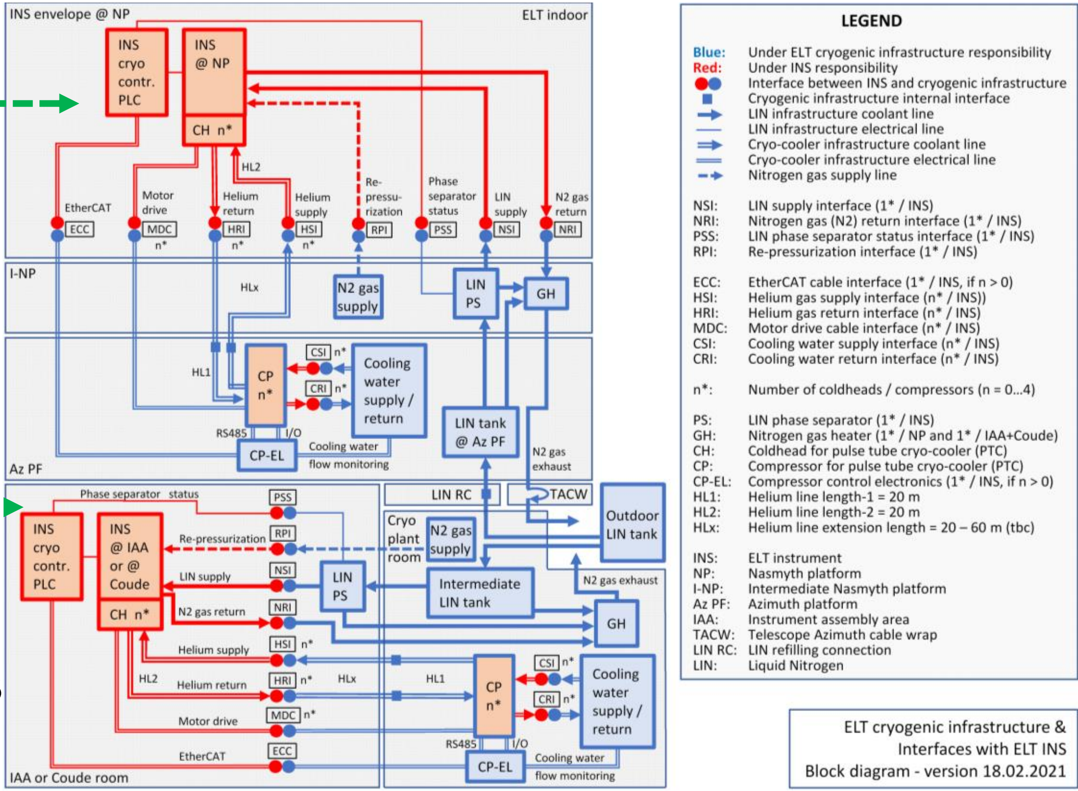
- ECIS contains of 2 sub-systems
  - LIN infrastructure
  - Cryo-cooler infrastructure
  - Instruments have interfaces with:
    - Both sub-systems (HARMONI, METIS)
    - LIN infrastructure only (MICADO)
    - Cryo-cooler infrastructure only (currently none)
    - None of both (MORFEO, *PDS*)
    - Tbc for HIRES and MOSAIC
  - Challenging development of fully automatic DN63 refilling connection with 6000 L LIN/h flow rate



The ELT cryogenic infrastructure functional concept. LIN infrastructure in red. Cryo-cooler infrastructure in orange.

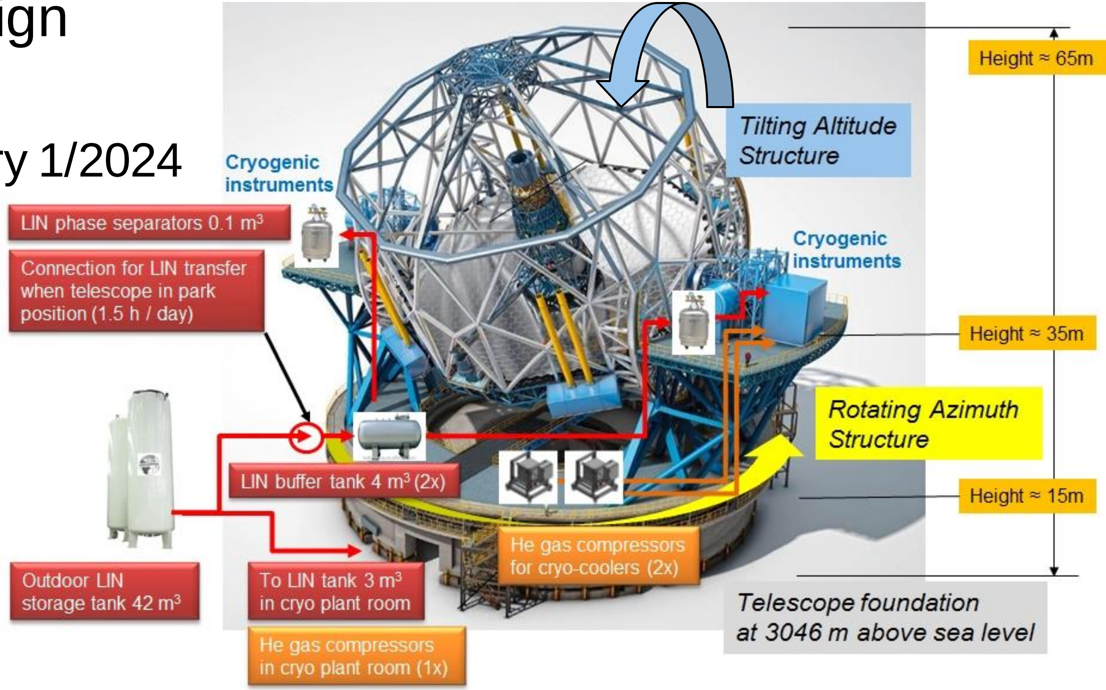
Block diagram
ELT cryogenic infrastructure – interfaces with ELT INS

- INS either @
  - NP
  - IAA
  - Coude room
- IF's with ECIS are the same for all INS locations
- Blue: ECIS part
- Red: INS part
- Bluered: CP →hybrid status



ELT cryogenic infrastructure - status

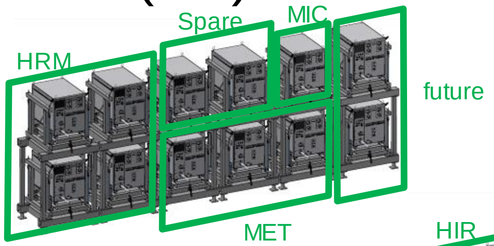
- ELT LIN infrastructure design specifications prepared
  - Contract signed with industry 1/2024
  - Expected completion 2027
- Small scale LIN infrastructure at ESO HQ
  - Contract signed 1/2024
  - Expected completion 2025
- Cryo-cooler infrastructure procurements and installations 2024-2027 by ESO



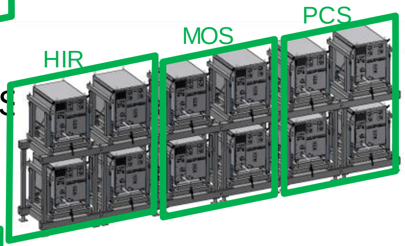
Principal concept of the ELT cryogenic infrastructure

ELT cryocooler infrastructure: compressors

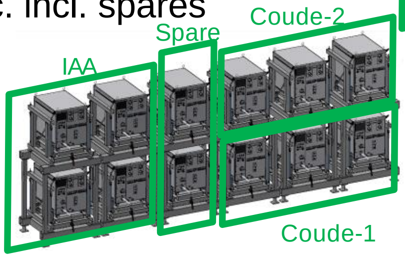
- Three arrays of each up to 12 compressors (CP) in different locations
  - @ Nasmyth-A instruments
    - 4 CP’s for HARMONI
    - 3 CP’s for METIS
    - 2 spare CP’s
    - 1 CP space reserved to MICADO
    - 2 spaces for future applications (MORFEO second client, next generation INS



  - @ Nasmyth-B instruments
    - 3* 4 spaces reserved for HIRES, MOSAIC, PCS etc. incl. spares



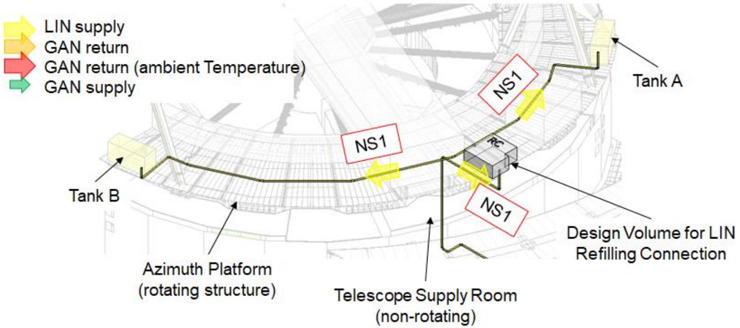
  - @ Cryo plant room for IAA and Coude
    - 4 CP’s for IAA instrument
    - 6 spaces reserved for Coude instruments
    - 2 spare CP’s

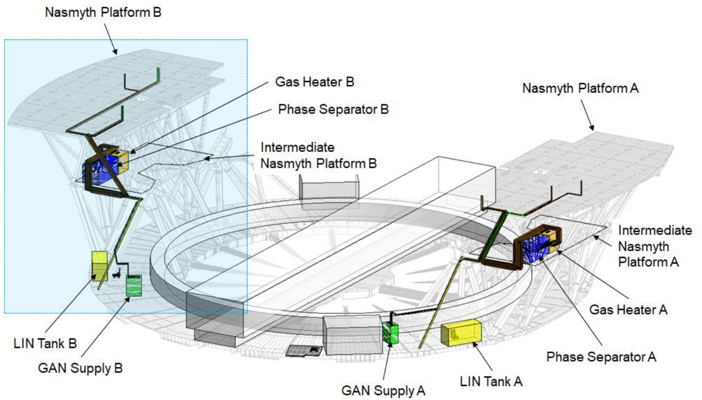


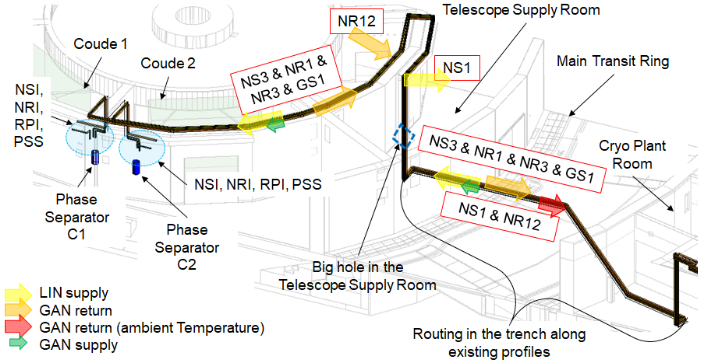
- Compressor arrays extendible if needed in the future
- Cryocooler infrastructure providing piping towards interface with instr.

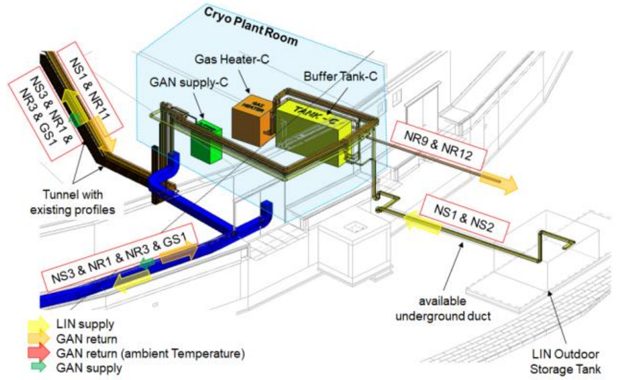
ELT LIN infrastructure

- Pipe routing for ELT (preliminary design)
  - LIN supply from outdoor storage tank to interfaces with science instruments
  - Warm gas return system
  - LIN = Liquid Nitrogen
  - GAN = Gaseous Nitrogen
  - LIN supply lines: DN20 - DN63



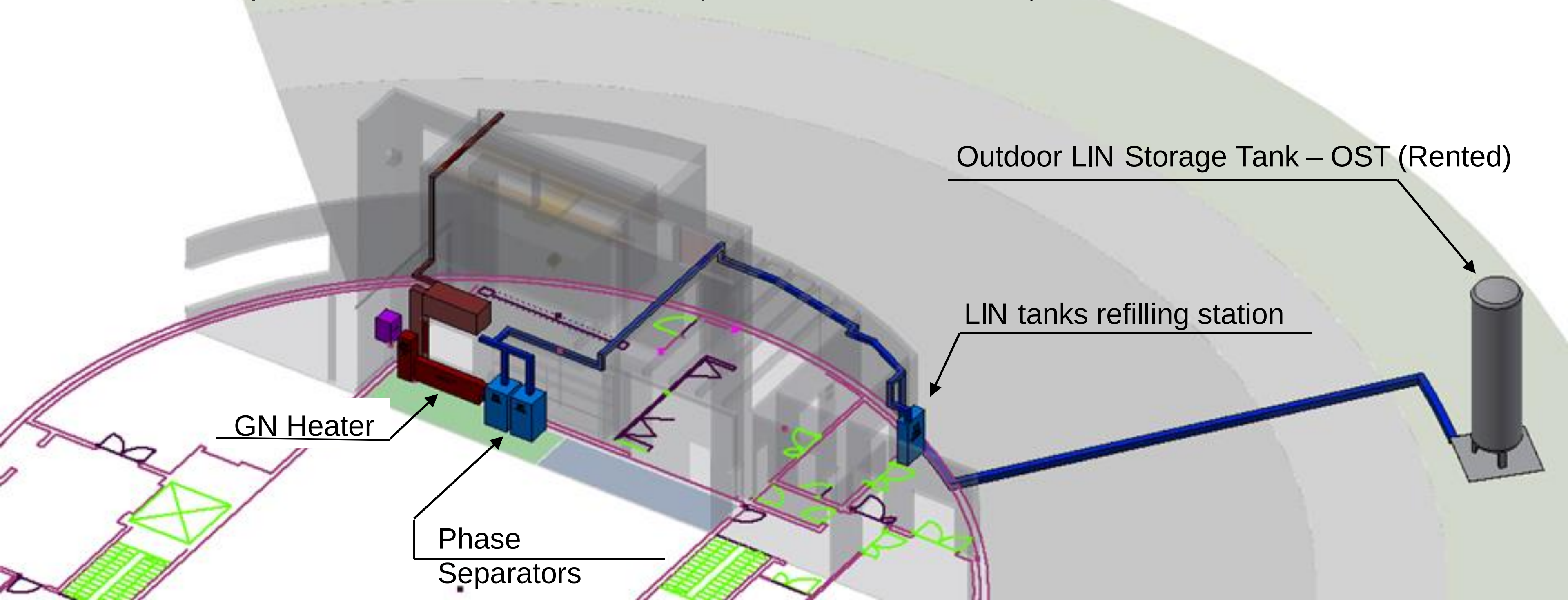






ESO HQ LIN infrastructure

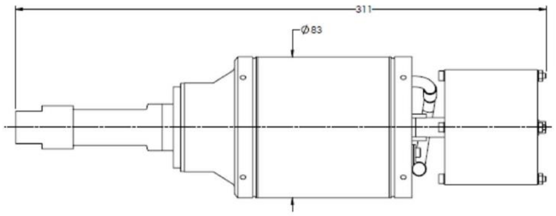
Concept of ESO HQ Technical building LIN upgrade (as pathfinder for the ELT LIN infrastcture and as required for MICADO instrument test phase in ESO's LIH 2026)



Next steps

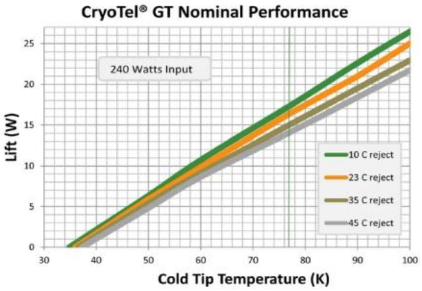
- Follow up ELT LIN infrastructure design
  - Preliminary design review 6/2024; final design review 1/2025; installation 2026-2027
- Final design of ELT cryocooler infrastructure
  - Procurements 2024-2026; installation 2026-2027
- Follow up ESO HQ LIN infrastructure design and manufacturing
  - Final design review 6/2024
  - Installation and commissioning 1st half of 2025
- Price inquiry for Paranal (VLT) LIN infrastructure: similar system as for ELT
  - Concept developed; technical specification prepared; expected contract duration 3.5y
- Further implementation of Stirling cooler CryoTel GT AVC
  - Replacing LIN detector cooling systems of existing and future La Silla & Paranal instr.
- Hiring another cryogenics engineer: see open position @ ESO Rectruitment Portal

Alternative cryo-cooler for ELT / VLT / La Silla



Sunpower CryoTel GT AVC

- COTS Stirling cooler with cooling capacity
  of ~ 2 W @ 40 K
  or ~18 W @ 80 K
- Now also low temp. (LT) version with ~2 W @ 30 K
- Can be operated in any orientation
- No compressor required, no flex lines
- Water cooling and just 250 W electrical input power for controller required
- No IF's with ELT cryo-cooler infrastructure, all IF's and control managed instrument internally
- Completely maintenance-free device, MTTF > 20y, in space since +15y
- Very compact design: L ~ 320 mm, dia. ~ 100 mm, weight < 5 kg
- Comes with inbuilt Active Vibration Cancellation (AVC) system (2^{nd} gen.)
- Excellent results in ESO's vibration test bench (f = 60 Hz)
- Selected as cryo-cooler for ELT PDS detector cryostat (techn. 1^{st} light instr.)
- Excellent candidate for cooling instrument detectors from 30 K to 150 K and replacing LIN cooling



ELT – Construction

Status 29th August 2023: Sunrise over Cerro Armazones shot from 25 km away on Cerro Paranal

Credit to Eduardo Garces and Nicolas Dubost / ESO

ESO Cryogenics

Gerd Jakob
European Southern Observatory (ESO)

End of presentation – many thanks for your attention

ESI2024, 14 May @ ESO HQ