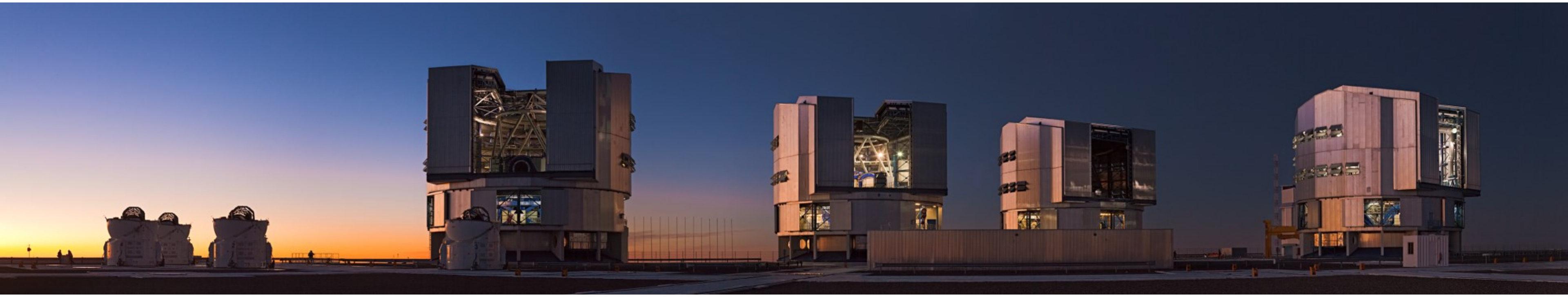
Cryogenics at the Extremely Large Telescope (ELT)

Gerd Jakob
ESO

About me

- Head of Instruments and Cryogenic Systems Group at European Southern Observatory (ESO)
- Cryogenic systems engineer for VLT and ELT
- Defining ESO vacuum and cryogenic standards
- Work package manager ELT instrumentation infrastructure



ESO's current flagship: the Very Large Telescope (VLT) at Cerro Paranal in Chile

ESO

- European Organization for Ground-based Astronomical Research in the Southern Hemisphere
- Intergovernmental Organization since 1962
- 15 European Countries and Brazil
- 750 Staff members
- Headquarters in Garching, Germany
- Office in Santiago, Chile
- Observatories in Northern Chile/Atacama

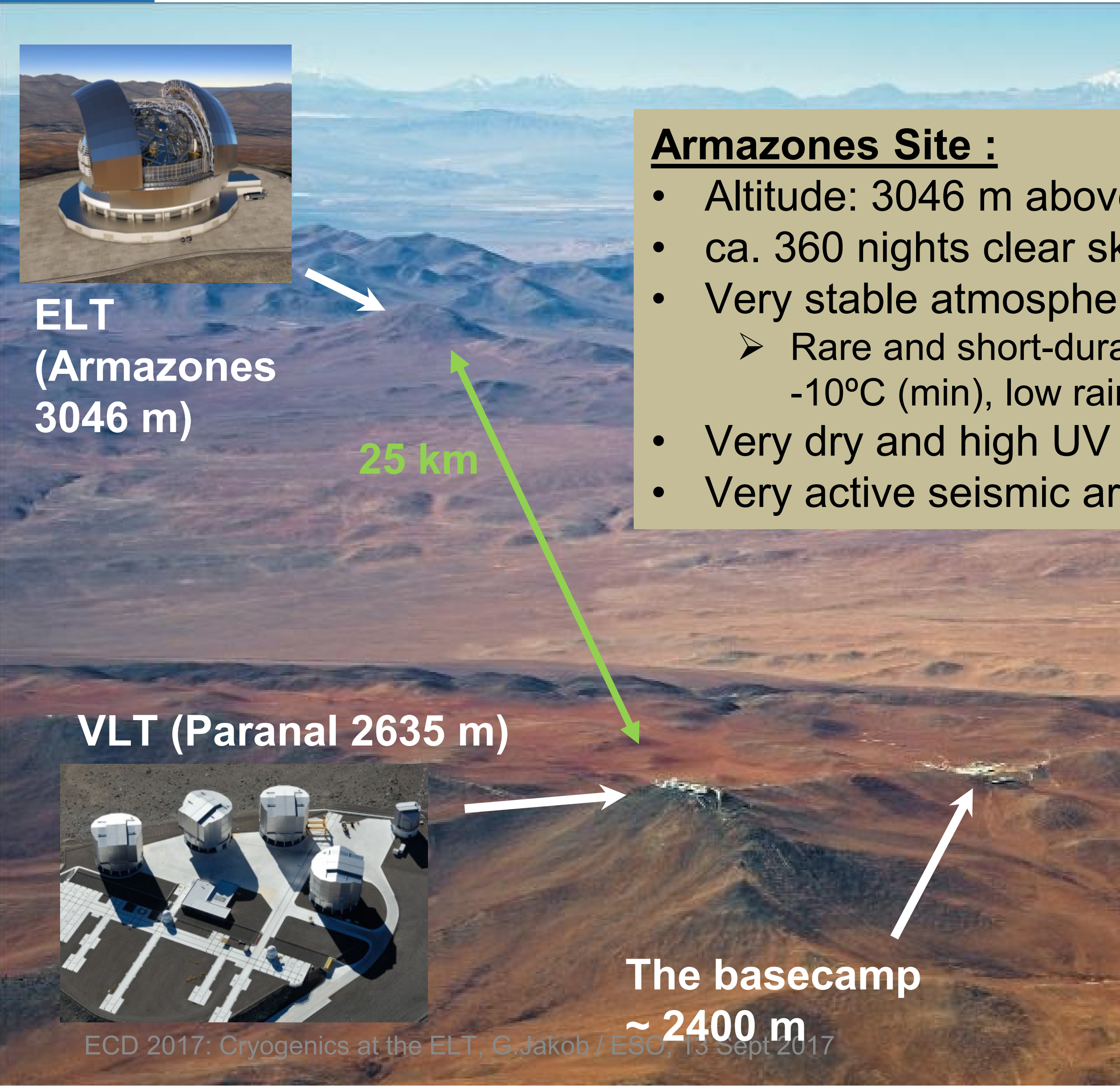



ESO in Chile

ESO telescopes

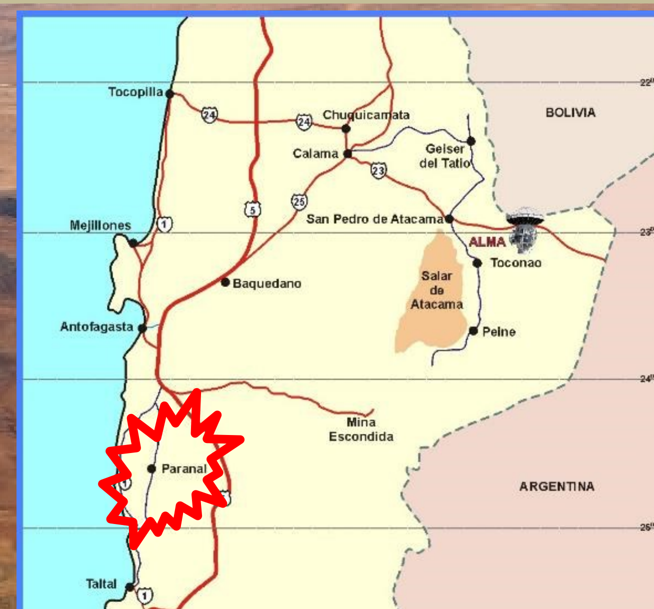
Name	Short	Size	Type	Location	Year
ESO 3.6 m Telescope	ESO 3.6 m	3.57 m	optical and infrared	La Silla	1977
MPG/ESO 2.2 m Telescope	MPG	2.20 m	optical and infrared	La Silla	1984
New Technology Telescope	NTT	3.58 m	optical and infrared	La Silla	1989
Very Large Telescope	VLT	4 × 8.2 m 4 × 1.8 m	optical to mid-infrared, array	Paranal	1998
Atacama Pathfinder Experiment	APEX	12 m	millimetre-/submillimetre-wavelength	Chajnantor	2005
Visible and Infrared Survey Telescope for Astronomy	VISTA	4.1 m	near-infrared, survey	Paranal	2009
VLT Survey Telescope	VST	2.6 m	optical, survey	Paranal	2011
Atacama Large Millimeter/submillimeter Array	ALMA	50 × 12 m 12 × 7 m 4 x 12 m	millimetre-/submillimetre-wavelength	Chajnantor	2011
Extremely Large Telescope	ELT	39.3 m	optical to mid-infrared	Cerro Armazones	2024

Armazones and Paranal



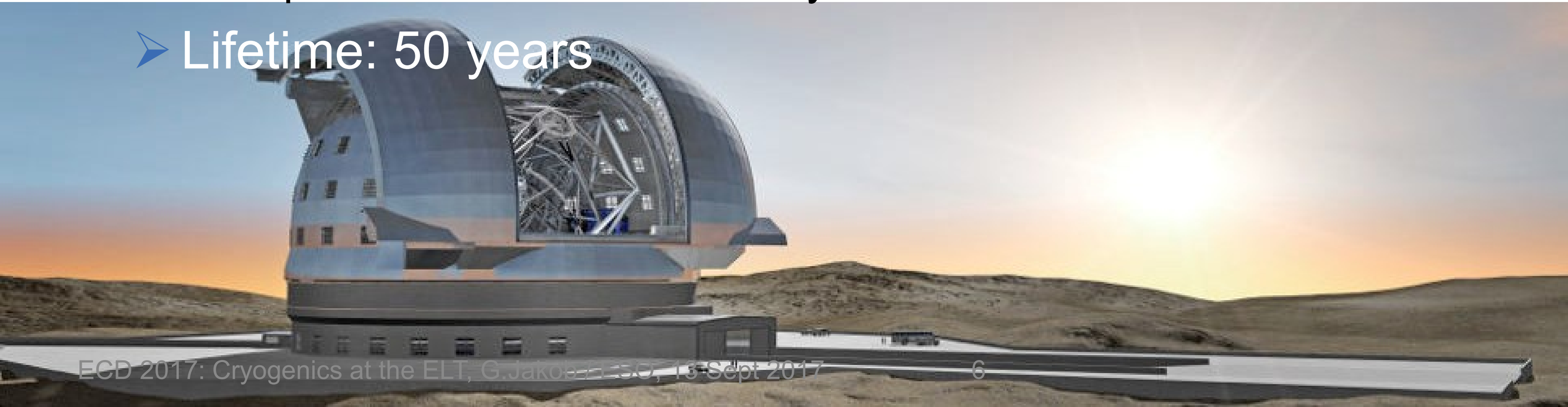
Armazones Site :

- Altitude: 3046 m above sea level
- ca. 360 nights clear sky, no light pollution
- Very stable atmospheric and weather conditions
  - Rare and short-duration storms, typ. 1/year, -10ºC (min), low rain or snow fall, possibly high winds
- Very dry and high UV radiation
- Very active seismic area !

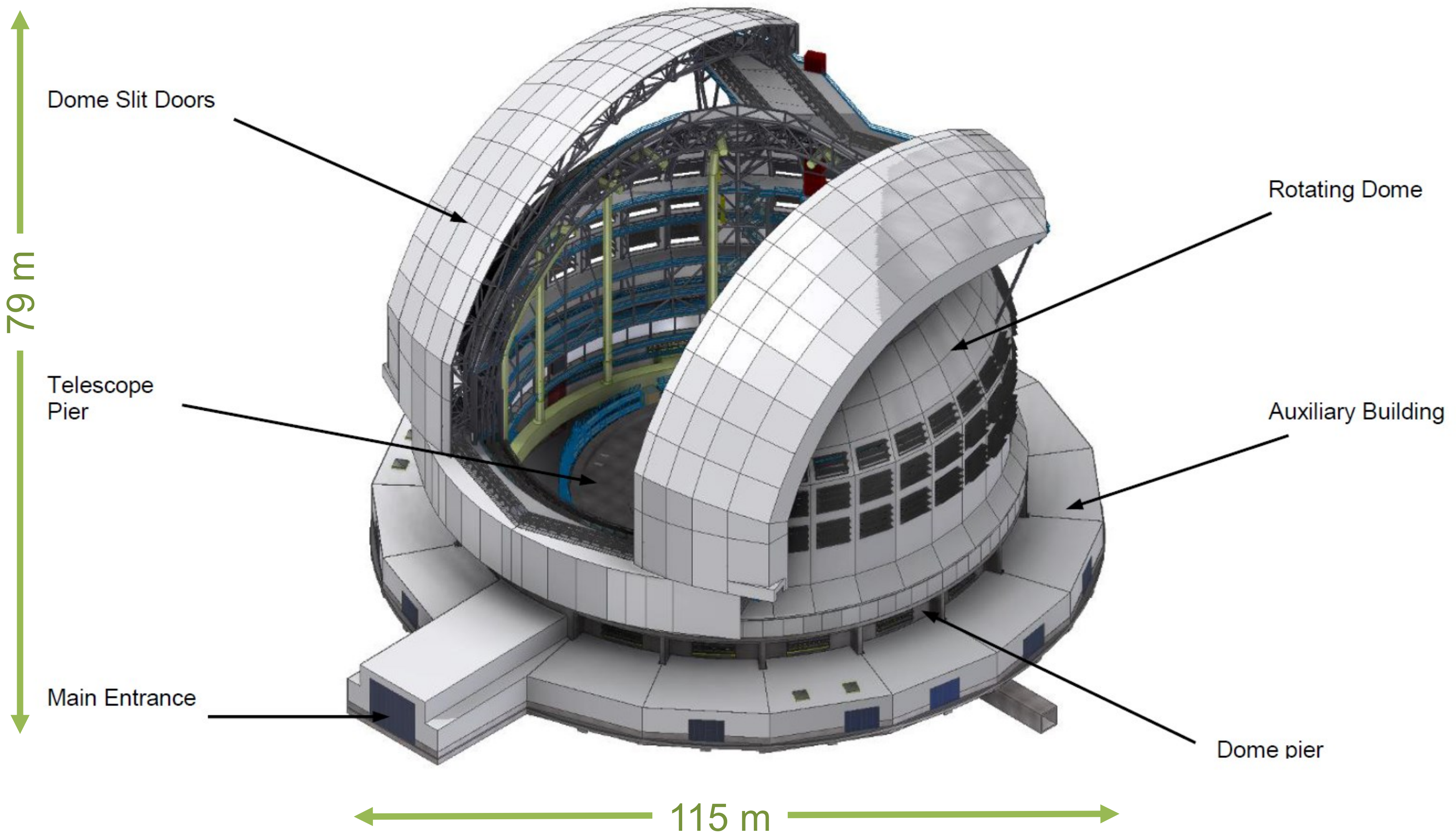


ELT
The world's biggest eye on the sky

- Largest optical/infrared telescope in the world
  - 39m segmented primary mirror, ~80m high building
  - Science: exo-earths, deep universe, fundamental constants
- Project
  - Construction 2014-2024, at Cerro Armazones in Chile
  - ESO cost:
    - Capital cost: ~1143 MEUR incl. instruments and contingency
    - Operation cost: ~50 MEUR / year
  - Lifetime: 50 years



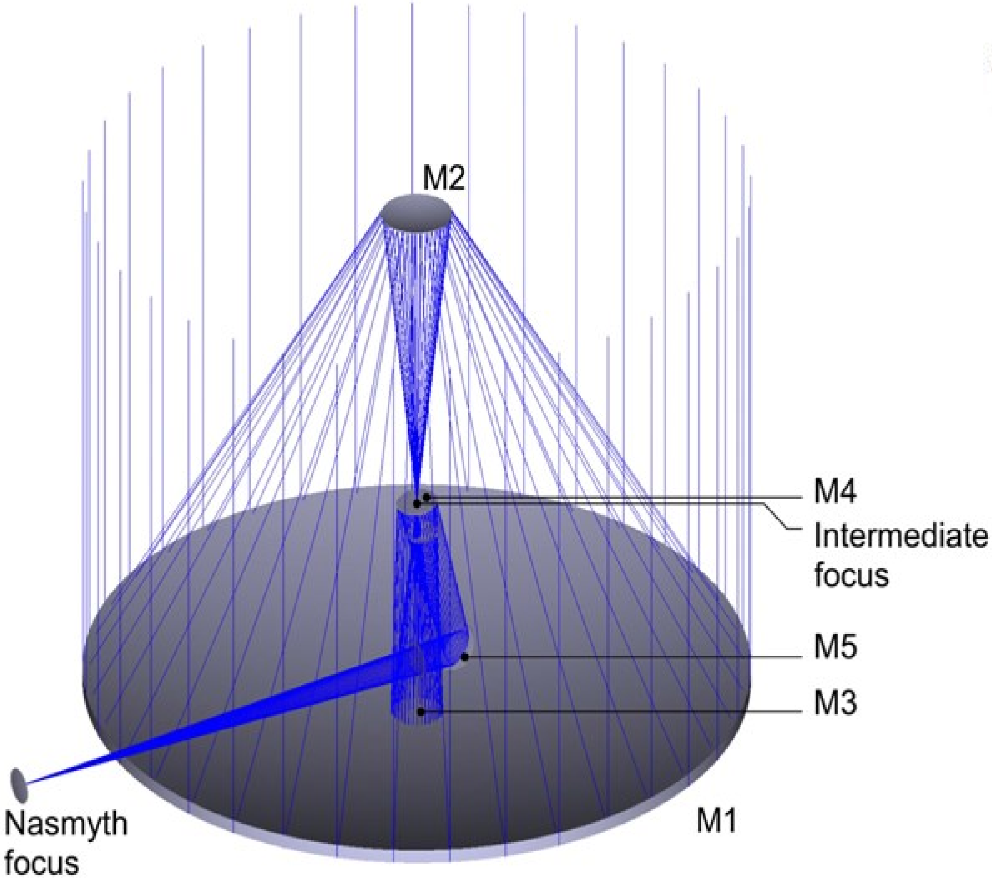
ELT Dome and Main Structure

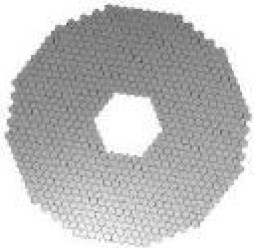


ELT Opto-mechanics

Optical design

- 3-mirror anastigmat on-axis + 2 flats
- diffraction limited over full 10′ FoV
- very low LGS wavefront aberrations

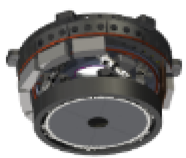




M1 Unit
39-m Concave – Aspheric f/0.9
Segmented (798 Segments)
Active + Segment shape Control

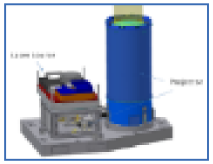
M2 Unit
4-m Convex Aspheric f/1.1
Passive + Position Control

M3 Unit
4-m – Concave – Aspheric f/2.6
Active + Position Control



M4 Unit
2.4-m Flat 1.95 mm Thin shell
5300 actuators 1 kHz AO correction
Adaptive + Position Control

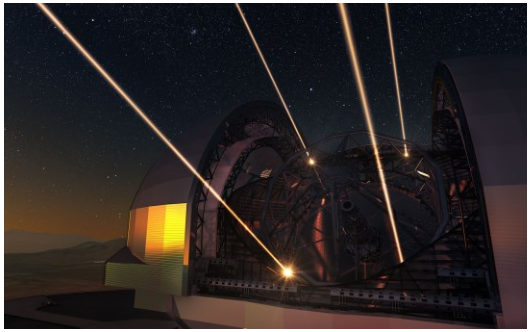
M5 Unit
2.7x2.1-m Flat
Passive + Fast Tip/Tilt



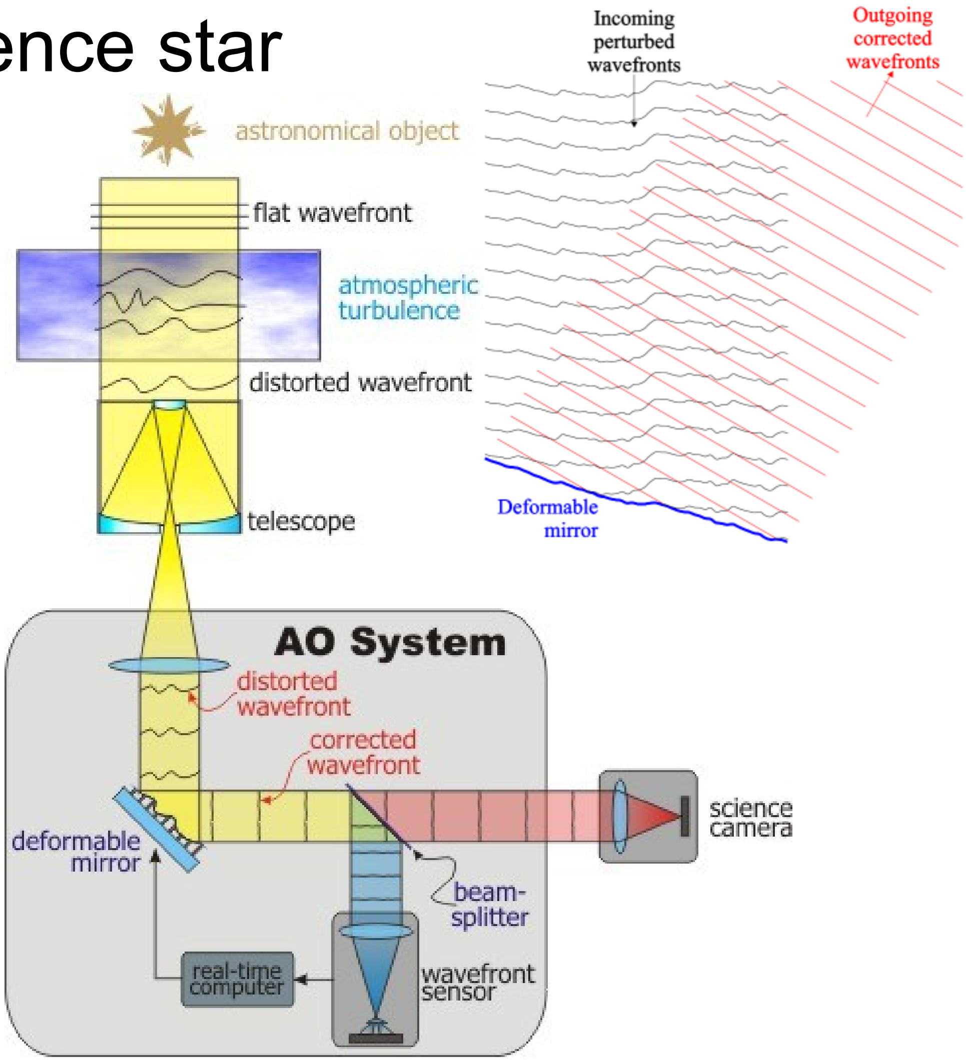
LGSU
(Laser Guide Star Units)
Laser Sources + Laser Beacons
shaping and emitting

ELT Adaptive Optics Principle

- AO requires bright reference star
  - Natural guide star
  - Artificial laser guide star
  - VLT: 4x 22 W lasers

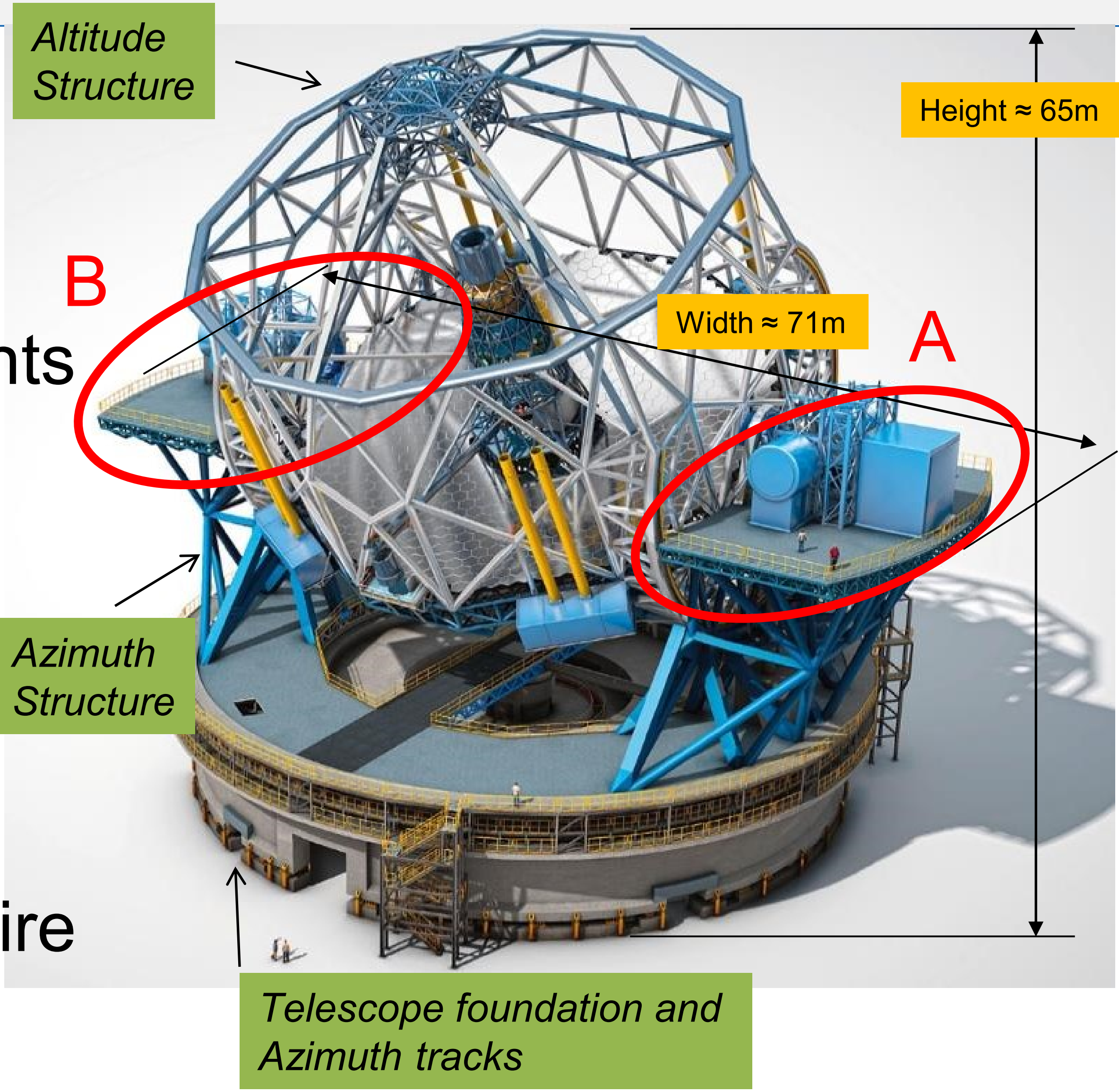


  - ELT: 6x 22 W lasers



ELT Science Instruments (cameras)

- Two tennis-court sized Nasmyth platforms for science instruments
  - Nas A
  - Nas B
- 3-4 instruments per platform
- Camera optics and sensors require cryogenic cooling

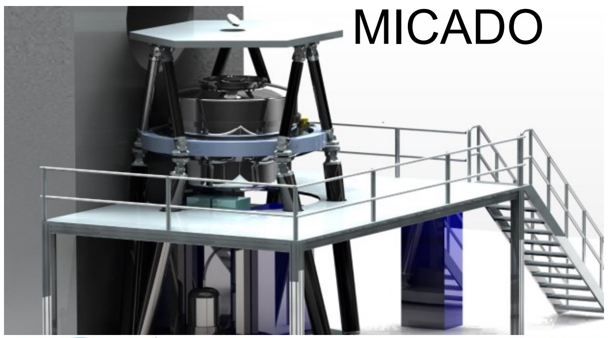


ELT Instruments

A MICADO, HARMONI, METIS, MAORY (design & construction)

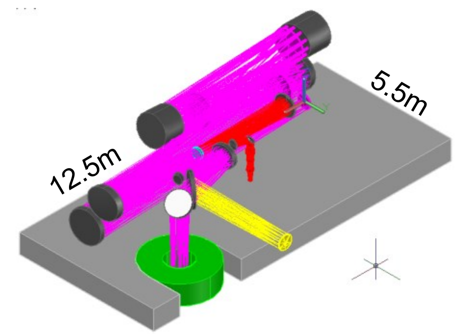
B MOS & HIRES (Phase A studies), PCS (R&D studies

MICADO



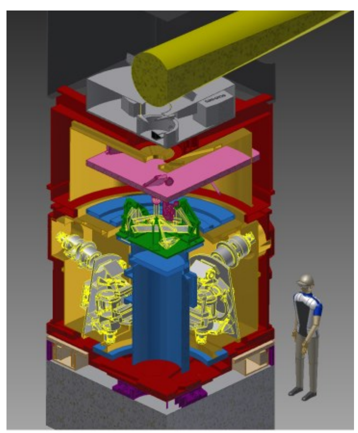
MAORY

INAF OA Bologna
IASF Bologna
OA Arcetri
OA Brera
OA Capodimonte
OA Padova
INSU/CNRS-IPAG



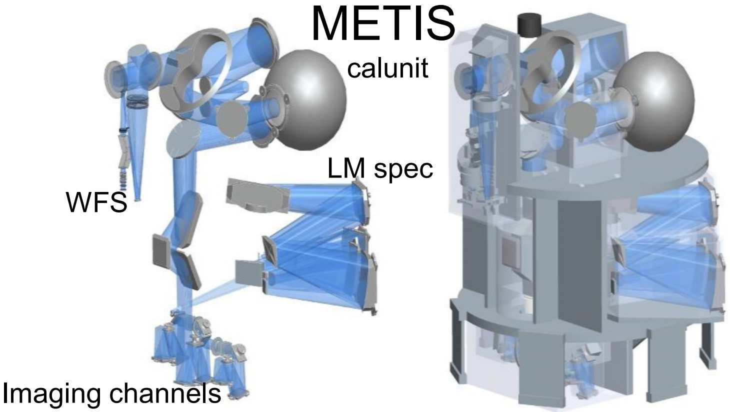
HARMONI

Uni. Oxford,
UK ATC,
CRAL,
CSIC,
IAC,
RAL,
IPAG,
ONERA,
LAM,
ESO



METIS

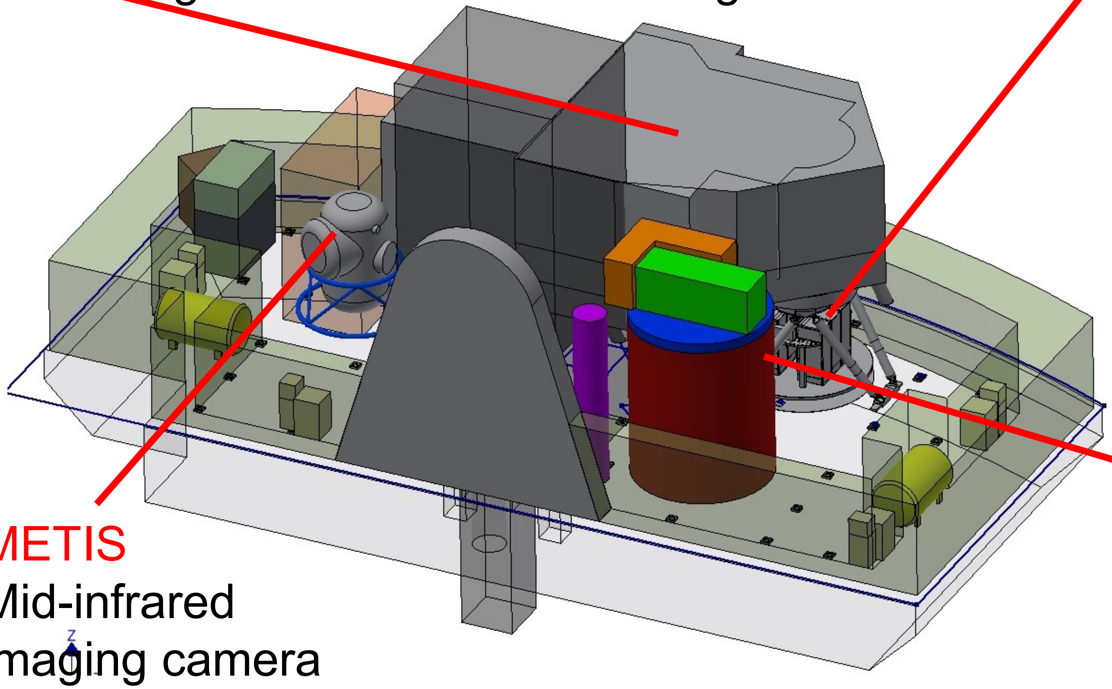
NOVA, MPIA, CEA-Saclay, UK ATC, K.U.Leuven, ETH Zurich



ELT Nas A Instruments

MAORY Multi-conjugate AO system using 6 laser guide stars and 3 natural guide stars

MICADO
Infrared imaging camera and spectrograph
0.8 – 2.4 µm

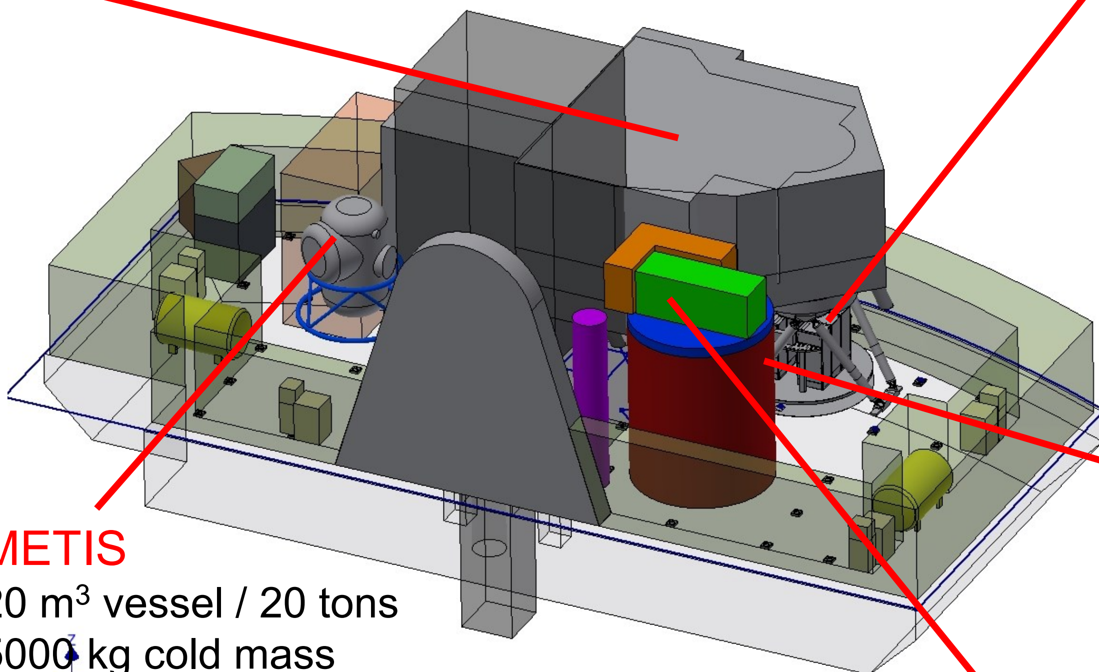


HARMONI
Optical and near-infrared spectrograph
0.4 µm – 2.4 µm

METIS
Mid-infrared imaging camera and spectrograph
3 µm – 20 µm

ELT Nas A Instruments

MAORY optics cooled to 0°C



MICADO

10 m^3 vessel / 20 tons
2000 kg cold mass
10 W @ 30K, IR detector
200 W @ 80 K, optics structure
200 W @ 120 K, thermal shield
Cryo-coolers, LN2 pre-cooling
LN2 continuous flow cooling

HARMONI

32 m^3 vessel / 25 tons
5000 kg cold mass
10 W @ 30 K, IR detectors
100 W @ 80 K, optics and CCDs
300W @ 100 K, thermal shield
Cryo-coolers and LN2 pre-cooling

METIS

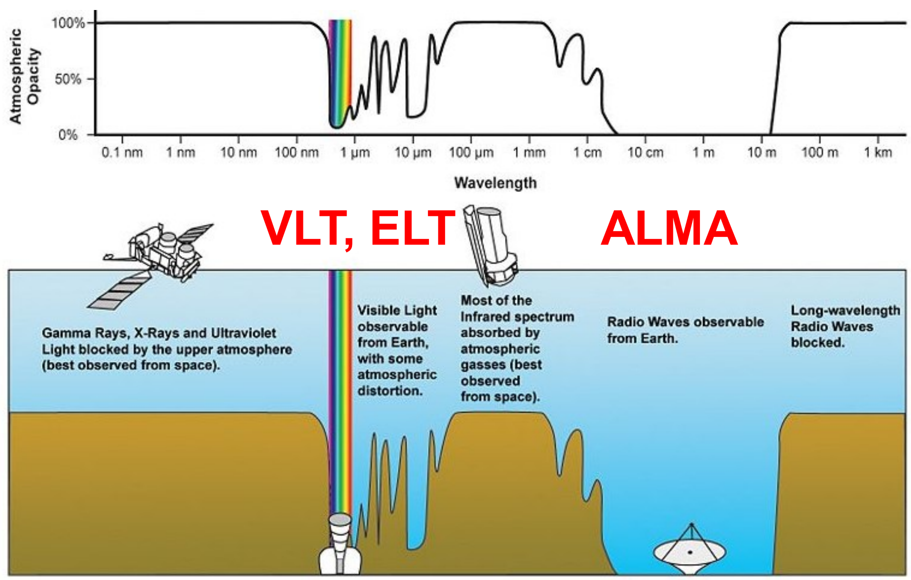
20 m^3 vessel / 20 tons
5000 kg cold mass
2 W @ 4 K, mid-IR detectors
20 W @ 20 K, mid-IR optics structure
10 W @ 30 K, IR detectors
70 W @ 60 K, optics structure
300 W @ 80 K, thermal shield, fore optics
Cryo-coolers and LN2 pre-cooling

HARMONI pre-optics

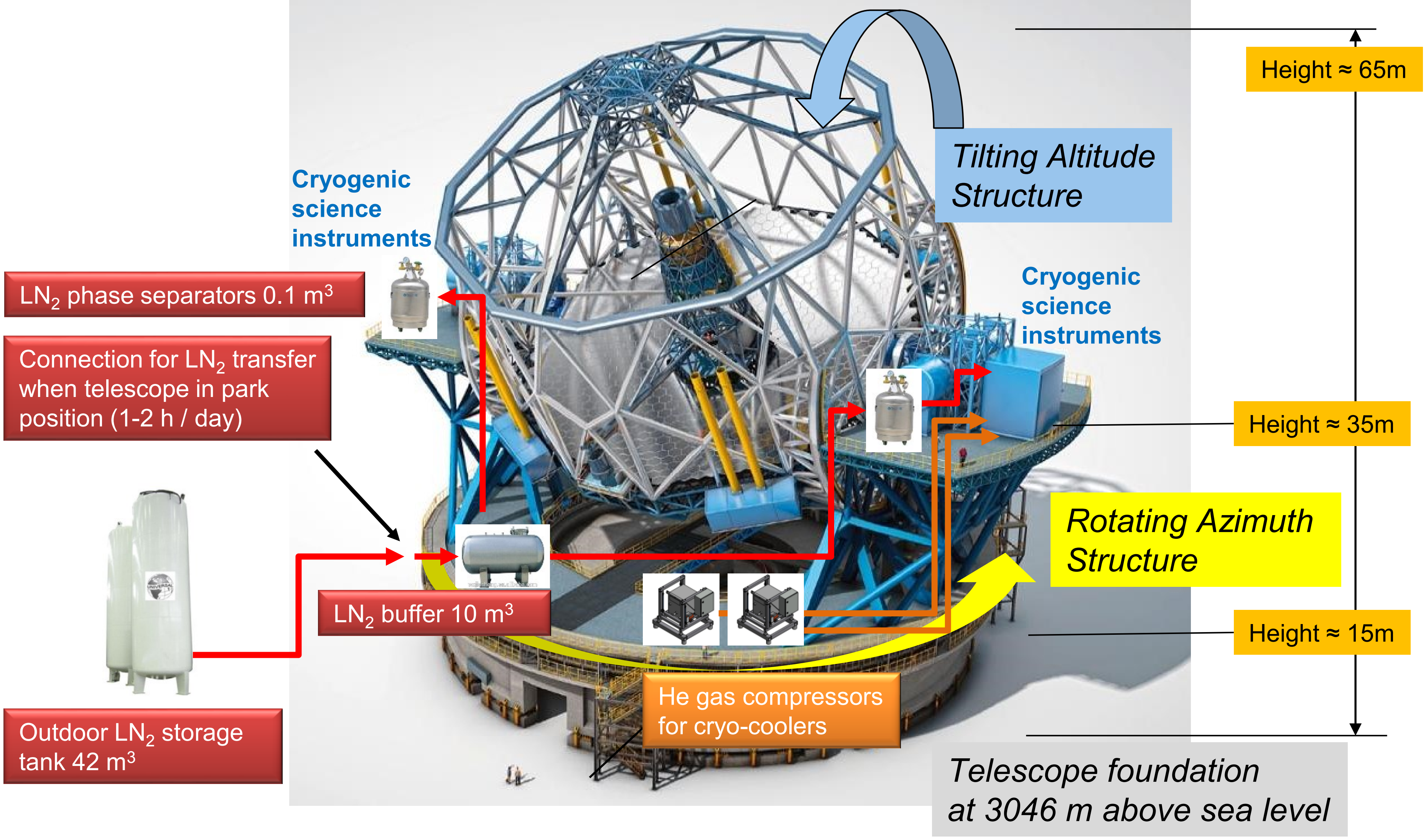
1200 W @ 245 K
LN2 continuous flow cooling

Cryogenic Instruments

- Why do we cool the instruments?
  - To reduce the thermal radiation of the surroundings
  - To minimize the number of warm optical surfaces
  - To minimize the dark current of IR detectors (= thermal excitations of electrons)
  - To optimize detector flat fielding and persistence effects
  - -> all together increases instrument sensitivity
  - The longer the wavelength, the colder the instrument!
    - 20 µm: optics @ 20 K
      detector @ 4 K



ELT Cryogenic concept



ELT related cryo-vacuum challenges

- Largest VLT instrument 2.5 m^3 vs. 25+ m^3 at ELT
- VLT cold mass some 100 kg vs. some tons at ELT
- Requires new cryo-vacuum standards
- Reliable LN2 truck delivery service in Atacama desert
  - State of the art at VLT, but larger amounts required
- Advanced cryogenic infrastructure vs. portable LN2 dewars at VLT
- Avoid cryogen lines through telescope cable wraps
  - Requires automated locking LN2 transfer connection
  - Buffer tank refilling requires 60 L/min (3600 L/h)

ELT related cryo-vacuum challenges

- Cooldown of one instrument requires 5000+ L LN2
- LN2 buffer tanks with 10000 L per platform
- Very demanding vibration requirements
  - Budgeted by allowable on-sky wavefront error: 50 nm rms

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 isolation of cryo-coolers and compressors
  - Locate compressors away from sensitive Nasmyth platform -> at Azimuth platform

ELT related cryo-vacuum challenges

- Introduction of new low vibration cryo-coolers
  - COTS pulse tube cryo-coolers (PTC)
  - PTC MTBM ~ 5 years vs. ~ 2 years of GM coolers at VLT
  - Length of He lines limited to ~ 100 m, tests ongoing

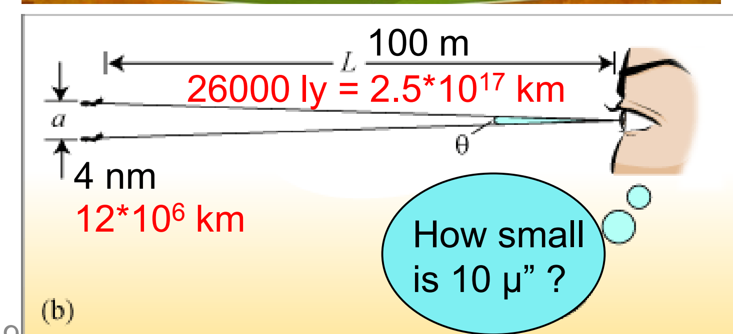
cryo-cooler model	working principle	2nd stage capacity (W)	1st stage capacity (W)	lowest temp. (K) @0W	cold head length (mm)	cold head mass (kg)	compr. model	compr. input power (kW)	compr. mass (kg)	operating frequ. (Hz)	service interval cold head (years)	service interval compr. (years)	orientation of cold head
PT410	2-stage PT	1W @4K	35W @45K	2.8	650	20	CP289C	8	134	1.4	5 - 6	2	cold end down
PT810	2-stage PT	14W @20K	35W @45K	8	650	20		8	134	1.4	5 - 6	2	cold end down
PT63	1-stage PT	10W @30K / 20W @40K		23	400	7.4	CP830	3.5	70	1.4	5 - 6	2	cold end down
GT-AVC	1-stage Stirling	2W @40K / 15W @80K		35	300	3.1	n/a	0.24	n/a	60	20	n/a	any

- METIS: 3x PT410
- HARMONI: 4x PT810
- MICADO: 1x PT63

} 8-12 compressors per platform

Something to remember

- Angular resolution of ELT: 5 milli-arcseconds
  - First telescope to characterise Earth-like exoplanets
- Angular resolution of GRAVITY using VLT as astronomical interferometer: 10 micro-arcseconds
  - Required to probe the physics close to the event horizon (Schwarzschild radius) of the black hole in the centre of our Galaxy –> probe Einstein's theory of general relativity
  - 10 μ" = length a human hair grows in 1 second as seen from 100 m !
  - We are in the middle of exciting observations with VLT/GRAVITY
  - Stay tuned !



Armazones – home of ELT today