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Zero-vibration Sorption Cryocooler for Einstein Telescope

11-11-2025

IV ET Annual Meeting

STAC
Scientific and Technical Advisory Committee

David Shoemaker (Chair) - MIT
Viviane Fafone - Rome
Raffaele Flaminio - LAPP
Maddalena Mantovani - EGO
Sheila Rowan - Glasgow
Kazuhiro Yamamoto – Toyama
Gianluca Gemme – Virgo
Patriece Verdier – CNRS
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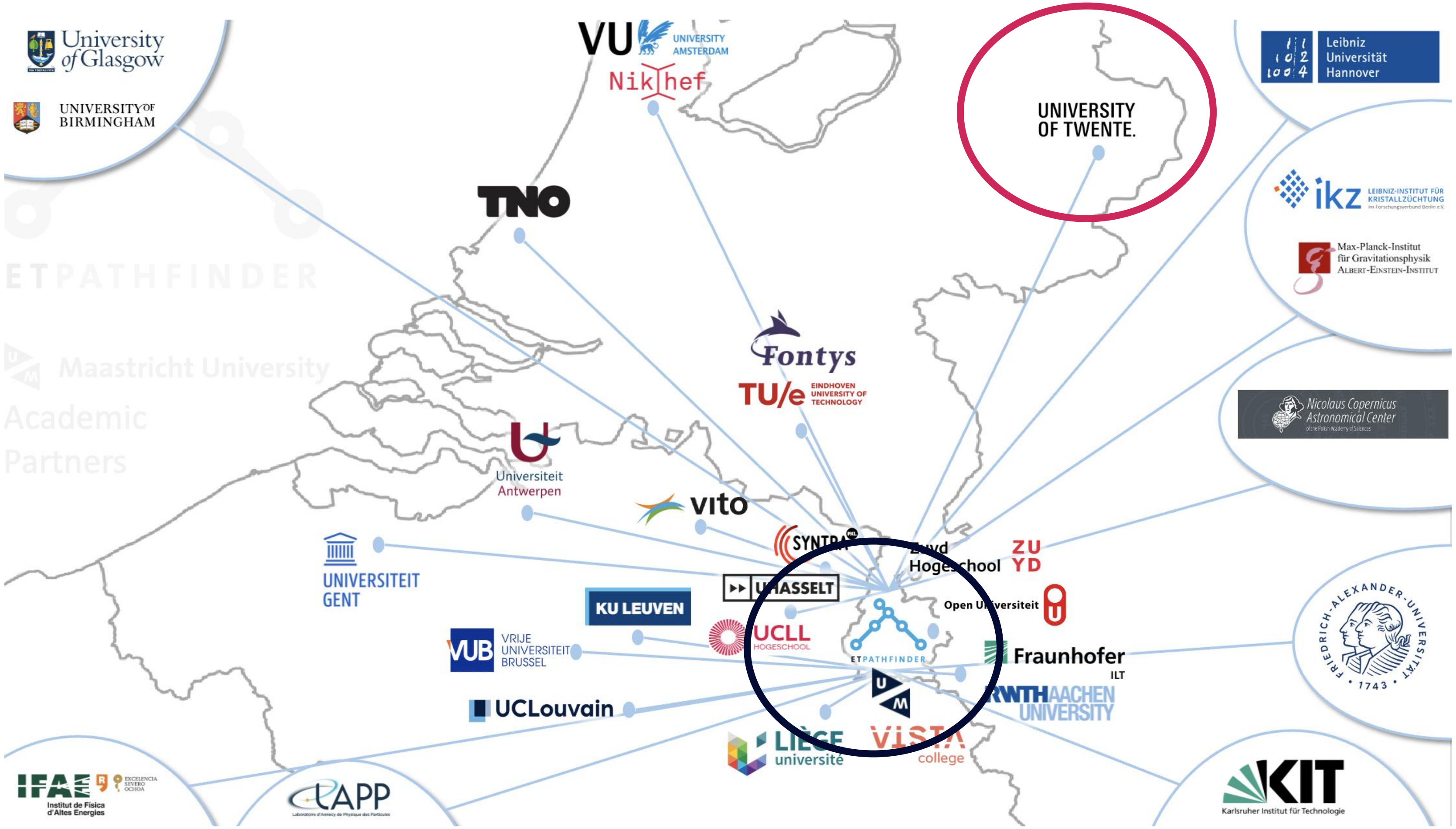
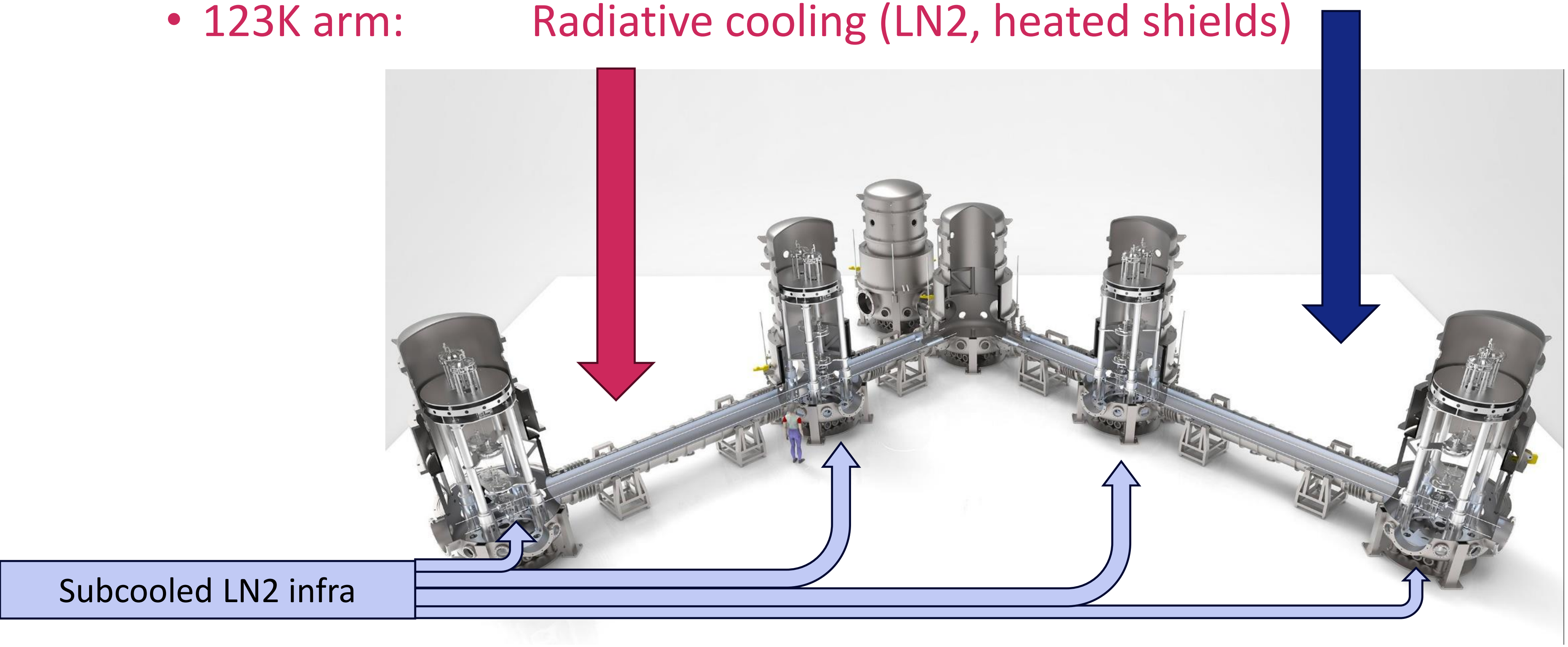
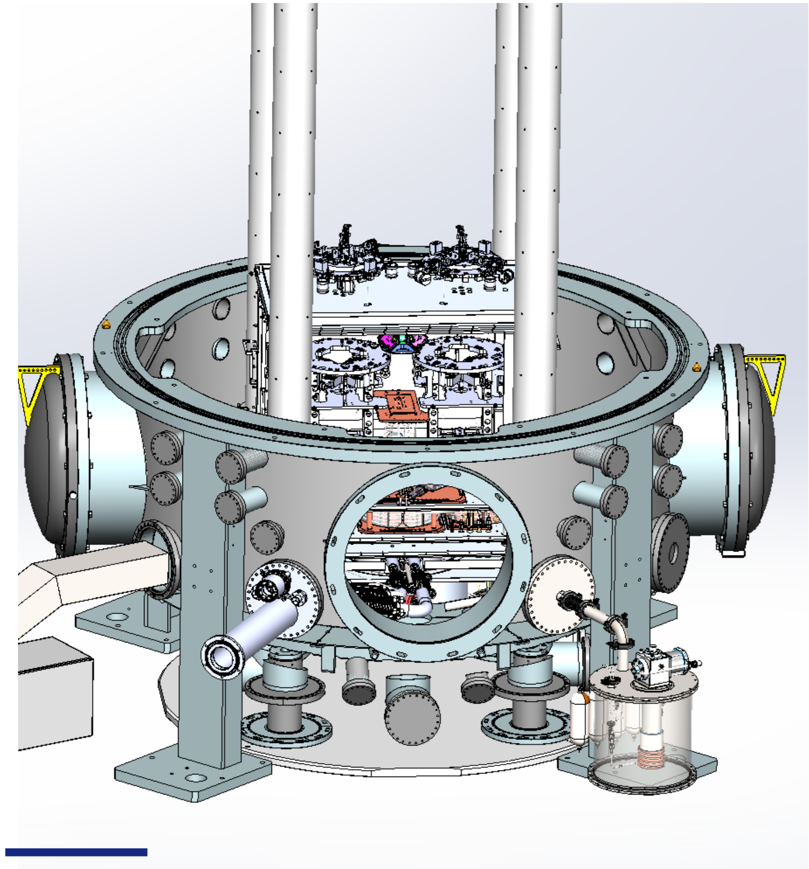


Aim and focus ETPF cryogenics

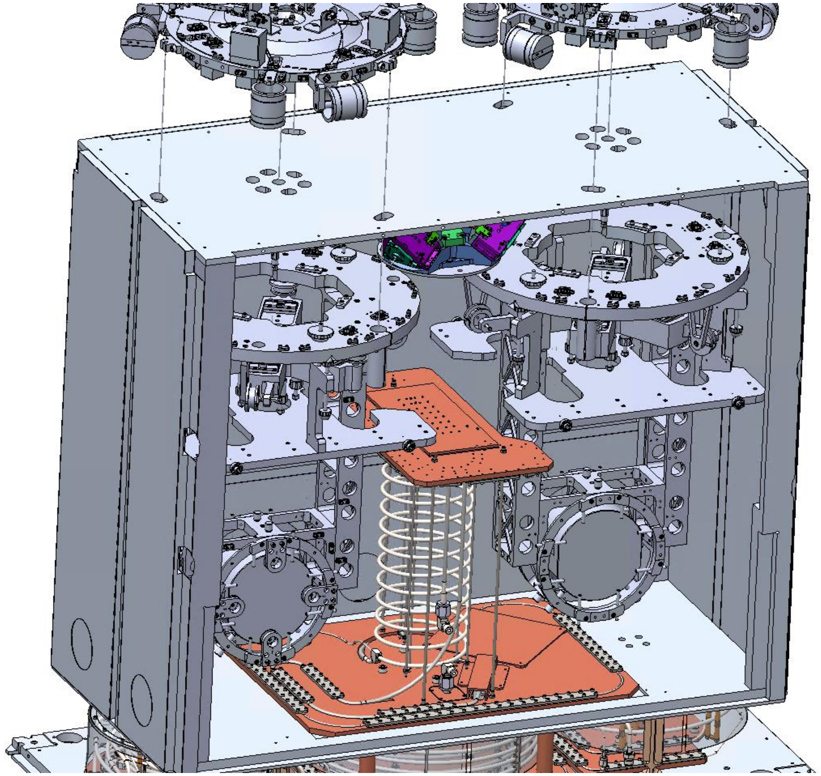
- Realize vibration-free cooling for Einstein Telescope Pathfinder
  - 10K arm: Joule-Thomson Cooler with Sorption compressor
  - 123K arm: Radiative cooling (LN2, heated shields)



Cryostat design ETPF



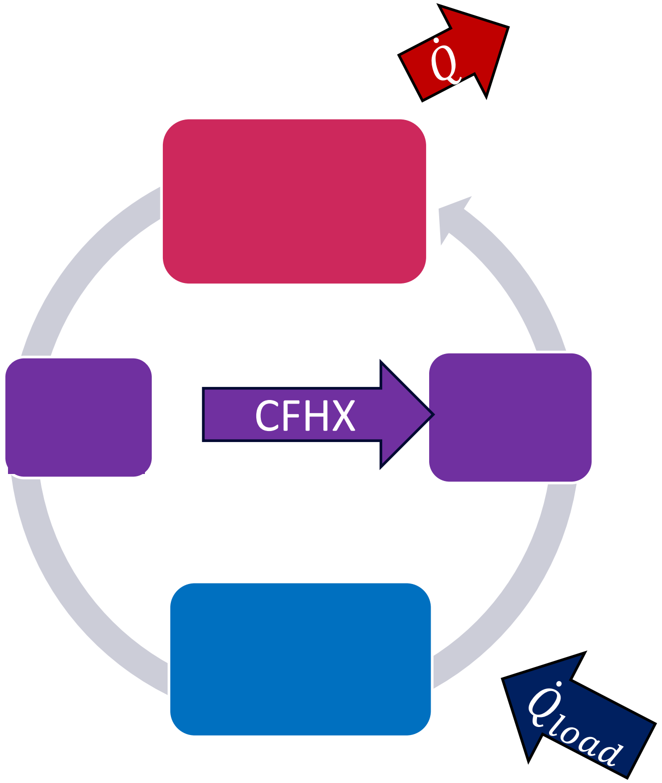
50 cm

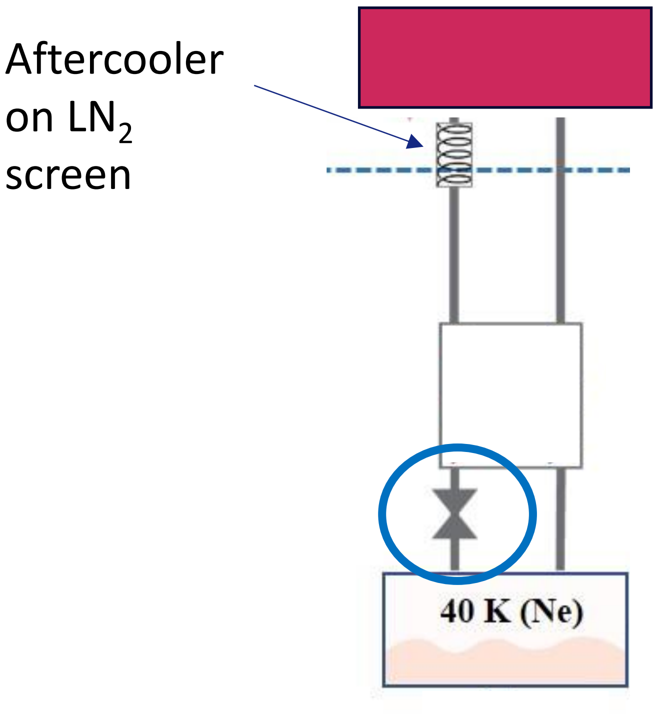


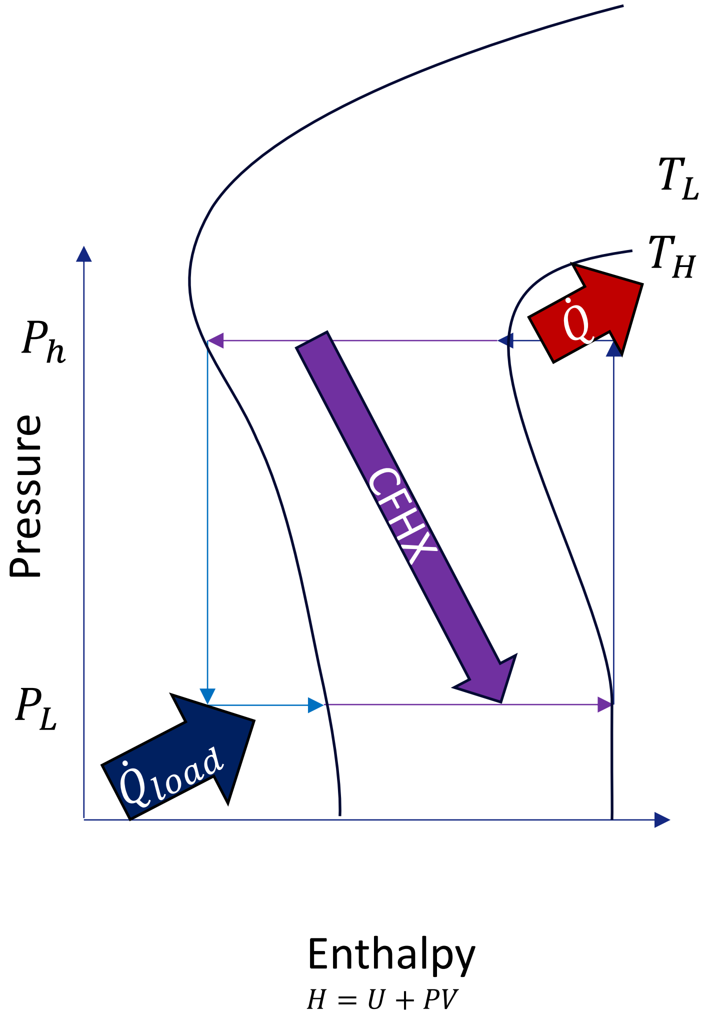
15 cm

On Sorption coolers

Joule Thomson cooling

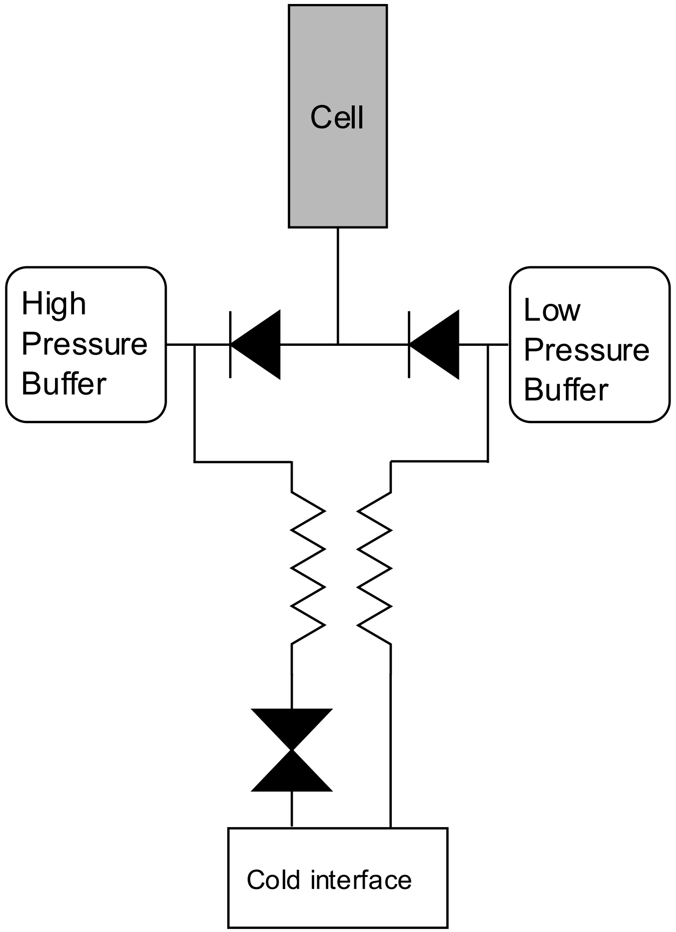






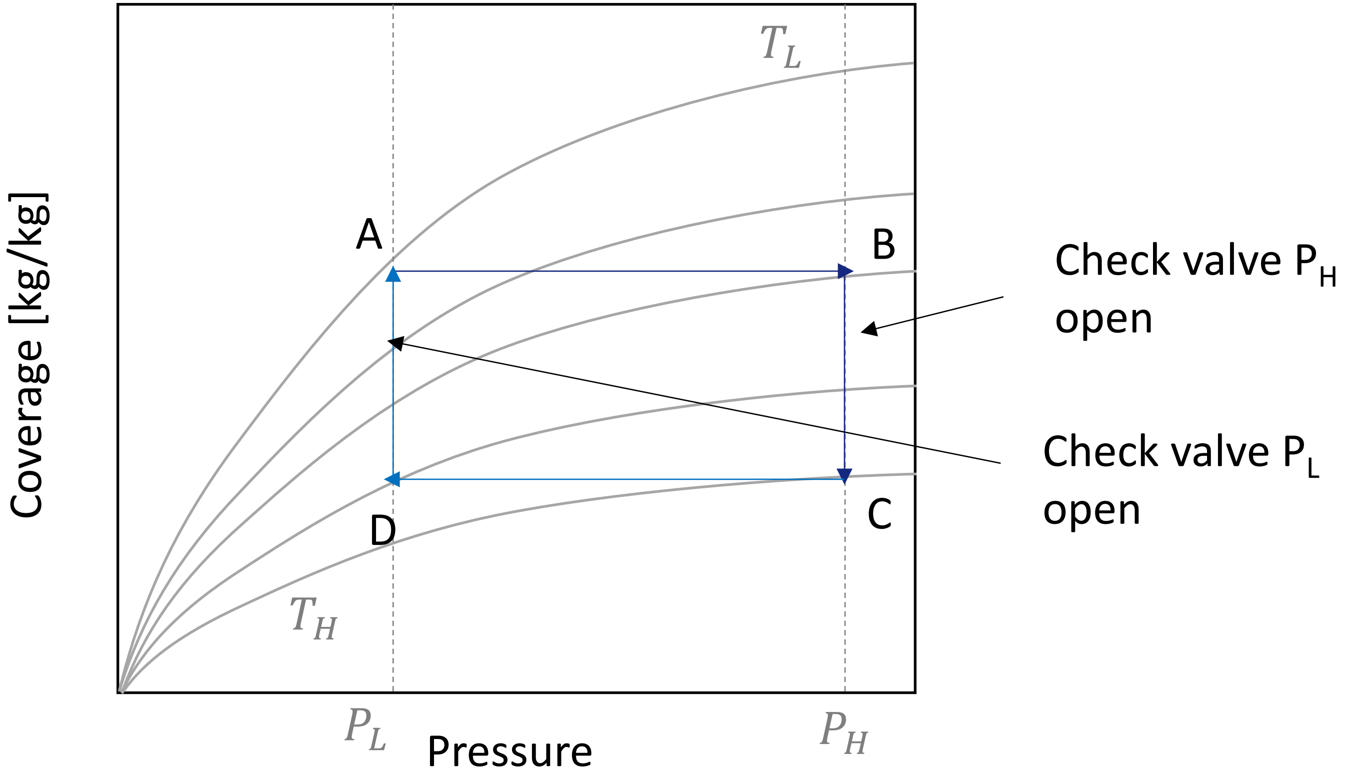
Sorption cooler

- Compression: Sorption cell
- Check valves: turn cell into a pump
- Buffers regulate constant pressure level
- Counter flow Heat Exchangers (CFHX) exchange enthalpy
- Joule Thomson restriction delivers cooling



Sorption cycle

Joule-Thomson cooler with sorption-based compressor



Compression phase: **A → B**
Heater ON

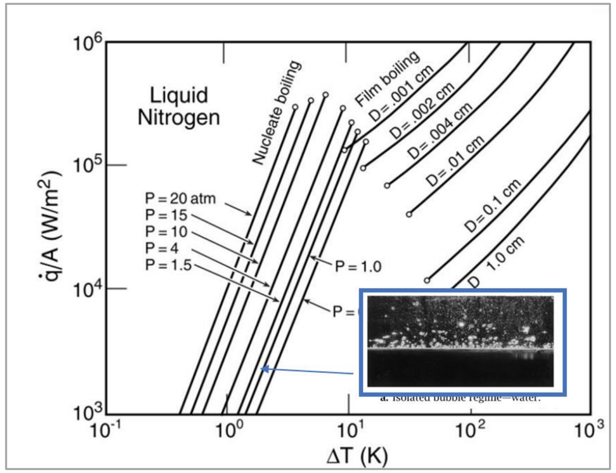
Outflow phase: **B → C**
Heater ON

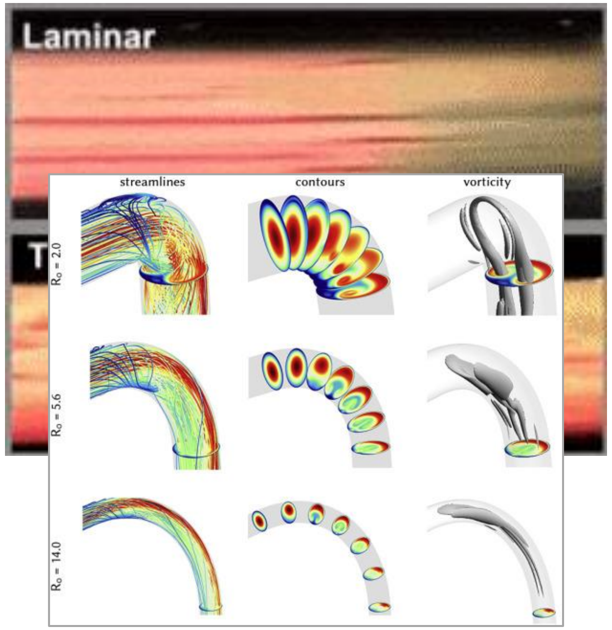
Decompression phase: **C → D**
Heater OFF

Inflow phase: **D → A**
Heater OFF

Vibration mitigation in design

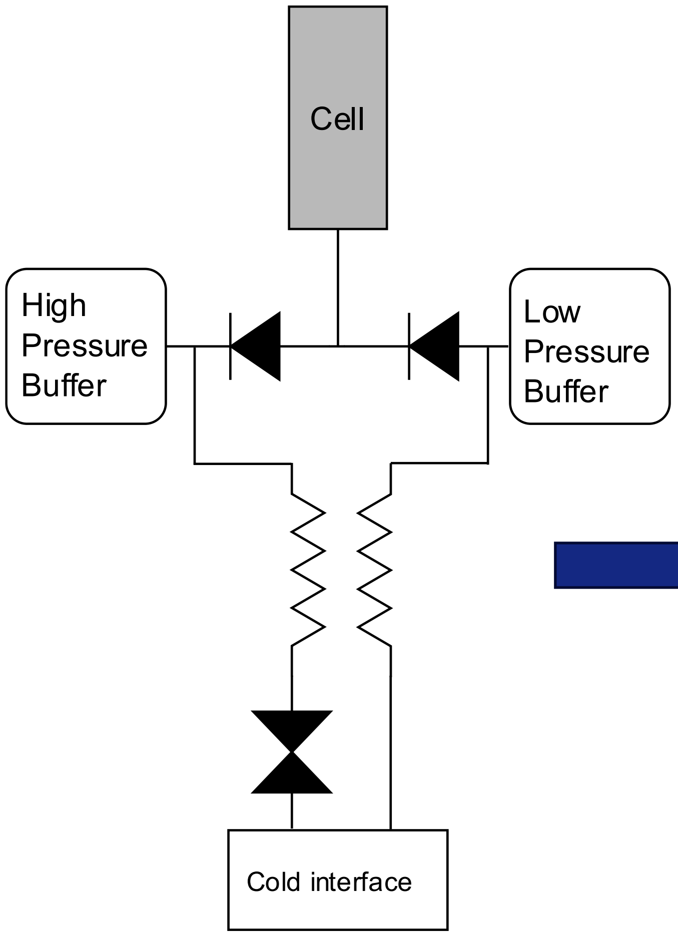
- Boiling in transport lines
  - → Subcooled LN2
- Boiling in evaporators
  - → Large area / wick material
- Unsteady / Turbulent flow
  - → Parallelization of Cells and CFHX — Re < 2000
  - → Optimize thermo-cycle for low flow. — $\Delta H(p_l, p_h) = \dot{Q}/\dot{m}$
- Secondary flow instabilities
  - → Low curvature of tubing — Dean=Re$\sqrt{d/D}$ <60
- Compression vibration
  - → Sorption compressor

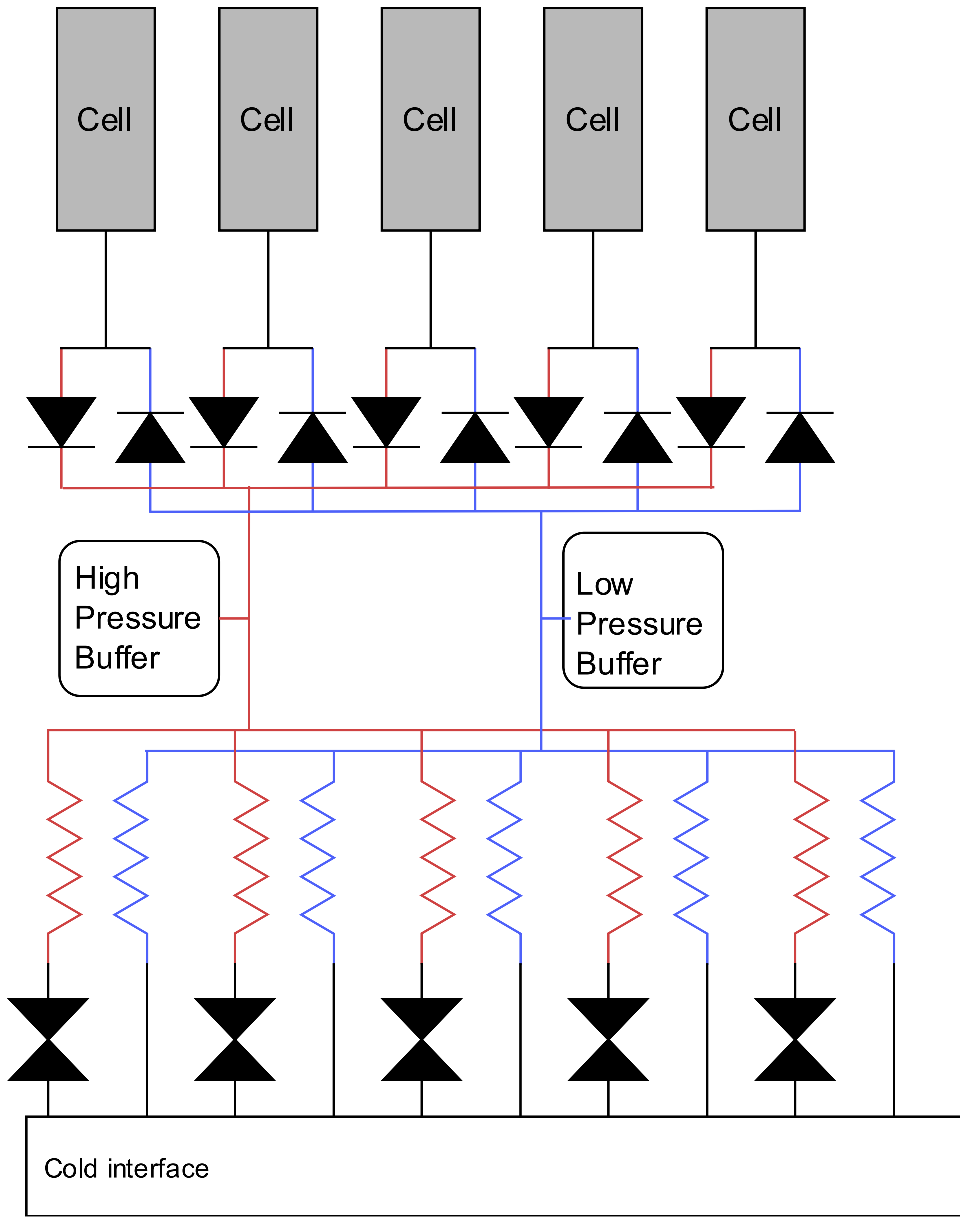




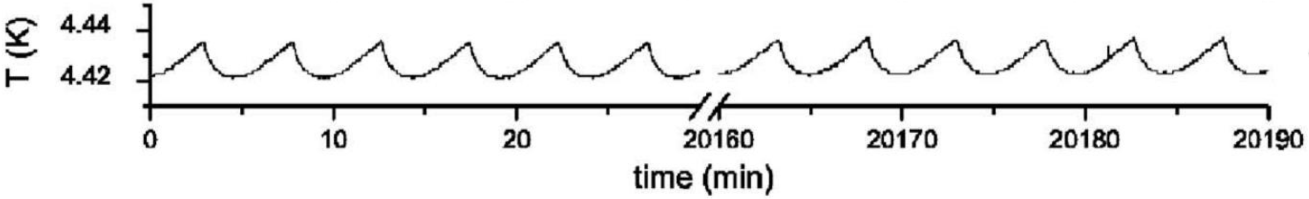
Modular design

- Cells
- Transport and CFHX
- JT-expanders
- Basically, everything can be made parallel to remain laminar.





Sorption Cryocooling development at University of Twente

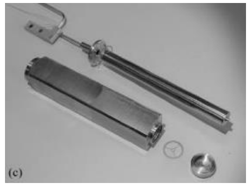


Long-life vibration-free 4.5 K sorption cooler for space applications, J.F. Burger (2007)

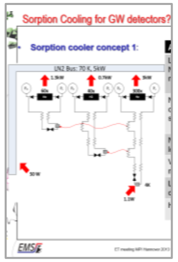
Academic

1995
TRL 1
University of Twente sorption cryocooler R&D start

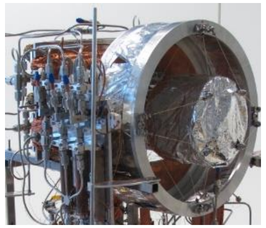
2001
TRL 2/3
Proof-of-concept Sorption cryocooler



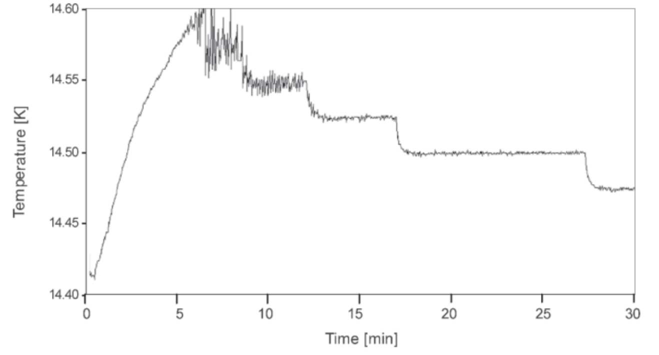
2007
TRL 4
ESA Darwin mission
10 mW @ 4.5 K demonstrator



2013
Marcel ter Brake presents at 5th ET symposium



2013
TRL 4
ESA Darwin mission
25 mW @ 14.5 K



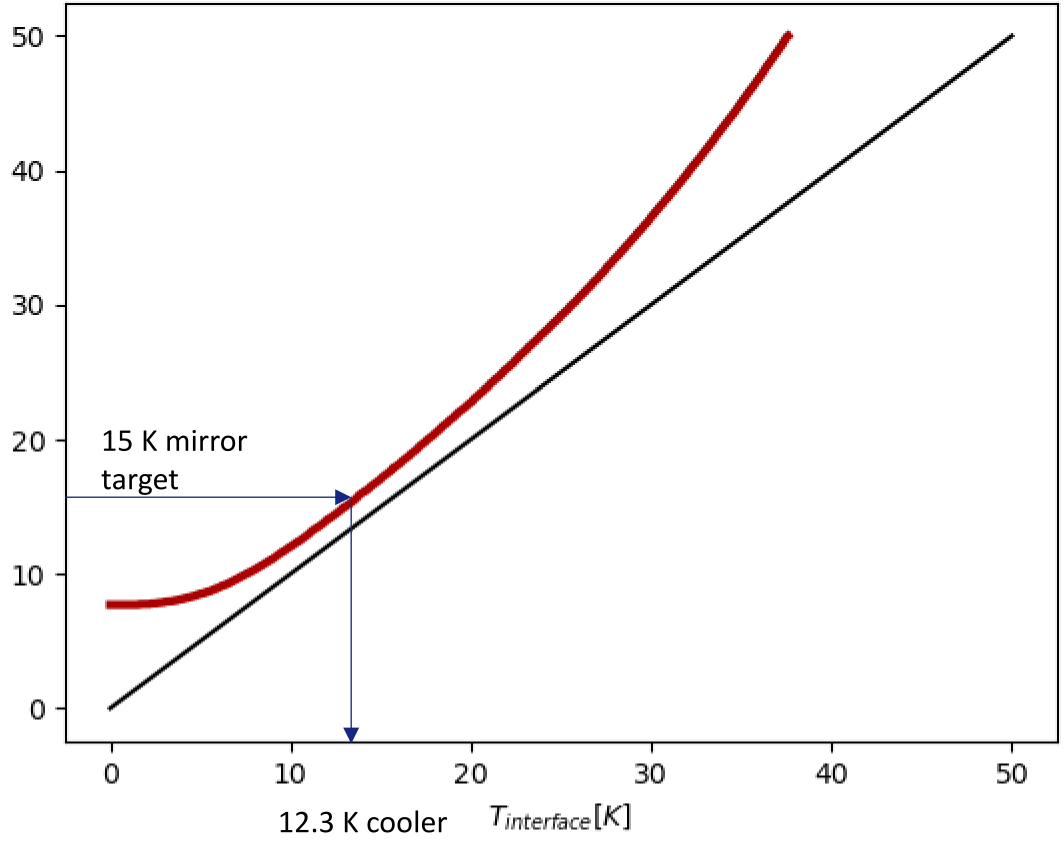
2014
TRL 4
METIS on E-ELT
0.4 W @ 8 K

2017
TRL 5
ESA Darwin mission
shaker testing

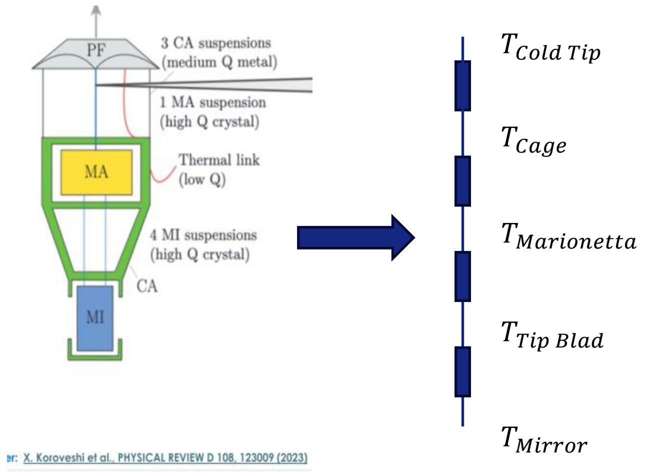
14.5 K Hydrogen Sorption Cooler: Design and Breadboard Tests, M. ter Brake (2011)

Sorption cryocooling for Einstein Telescope pathfinder

Expected performance

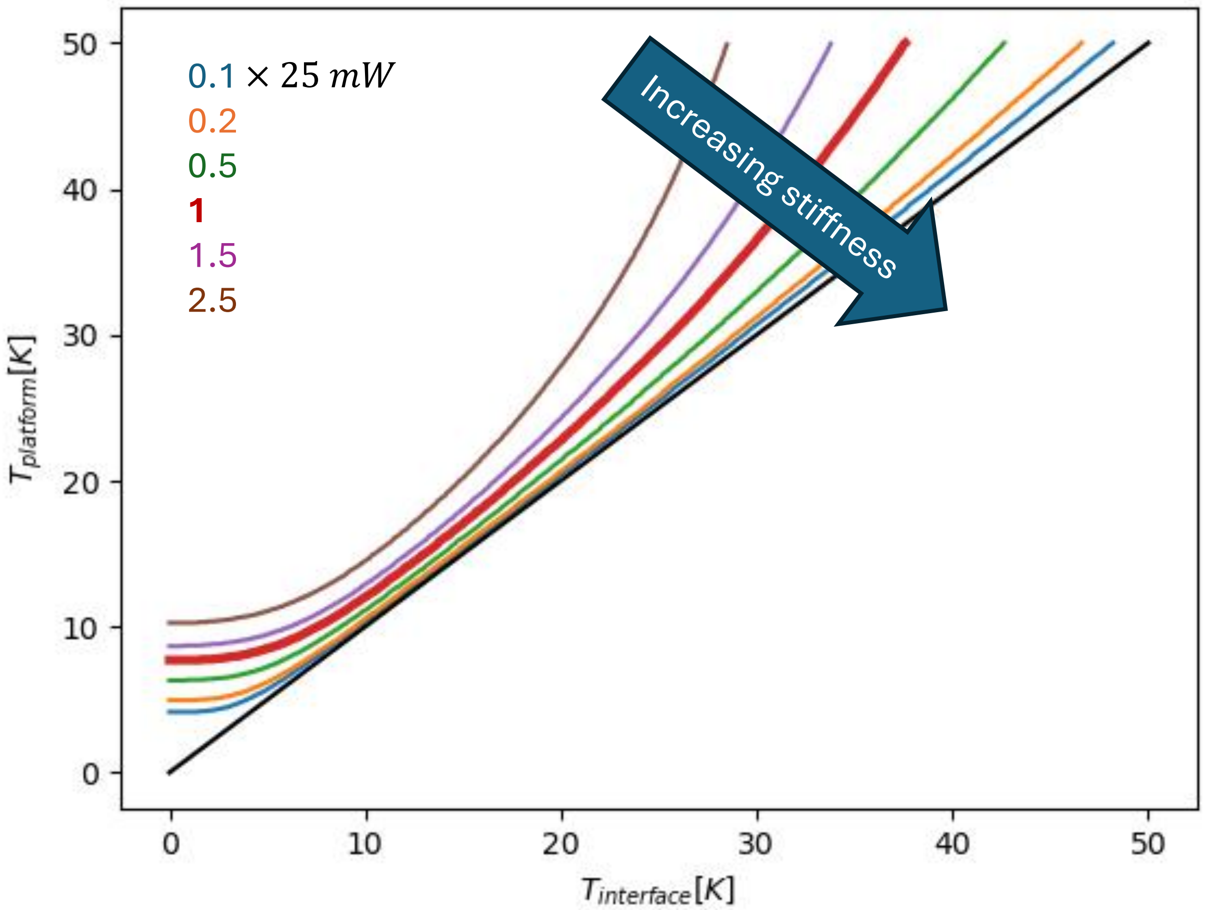


- Assumptions
  - Structures Bi <<1 → Lumped
  - Load of 25 mW on mirror
  - Radiation heat load negligible
- Model
  - Steady-state non-linear heat equation
  - Thermal resistance network



Al strands	7^2		#1 Marionetta - Si BladesTip	
#3 Interface – Platform/Cage			Length	0.1 m
Diameter	150 um		Thickness	1 mm
Length	1.0 m		Width	80 mm
#2 Platform/Cage-Marionetta			#0 Si BladeTip - Mirror	
Diameter	150 um		Diameter	1 mm
Length	0.3 m		Length	0.5 m

Expected performance



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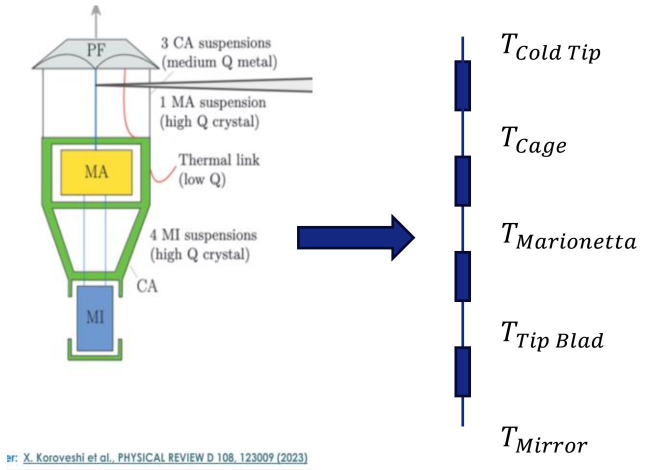

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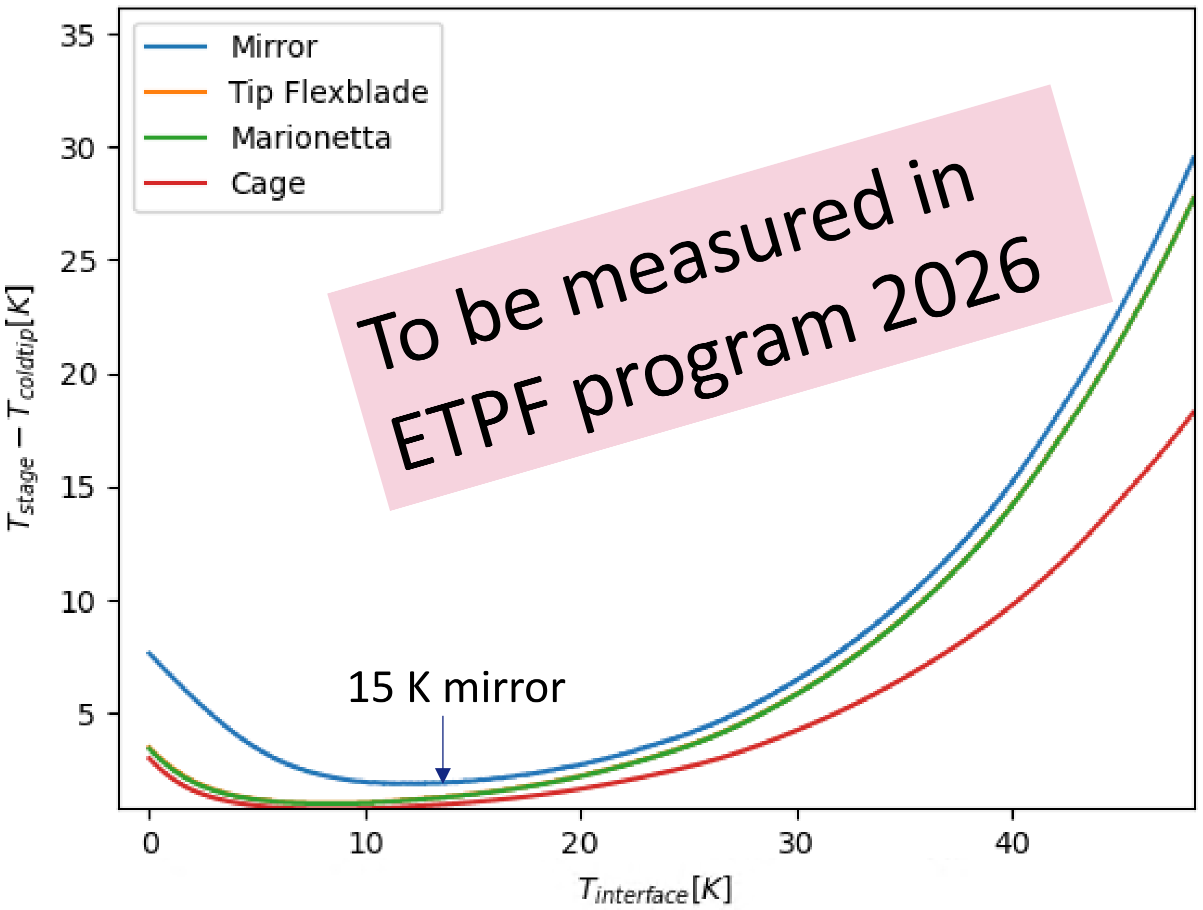
Length	0.3 m

#1 Marionetta SiBladesTip	
Length	0.1 m
Thickness	1 mm
Width	80 mm
#0 SiBladeTip Mirror	
Diameter	1 mm
Length	0.5 m

Expected performance
(same data)



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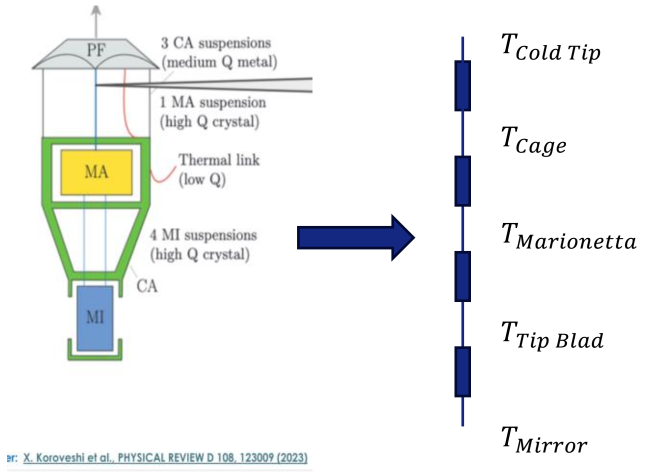

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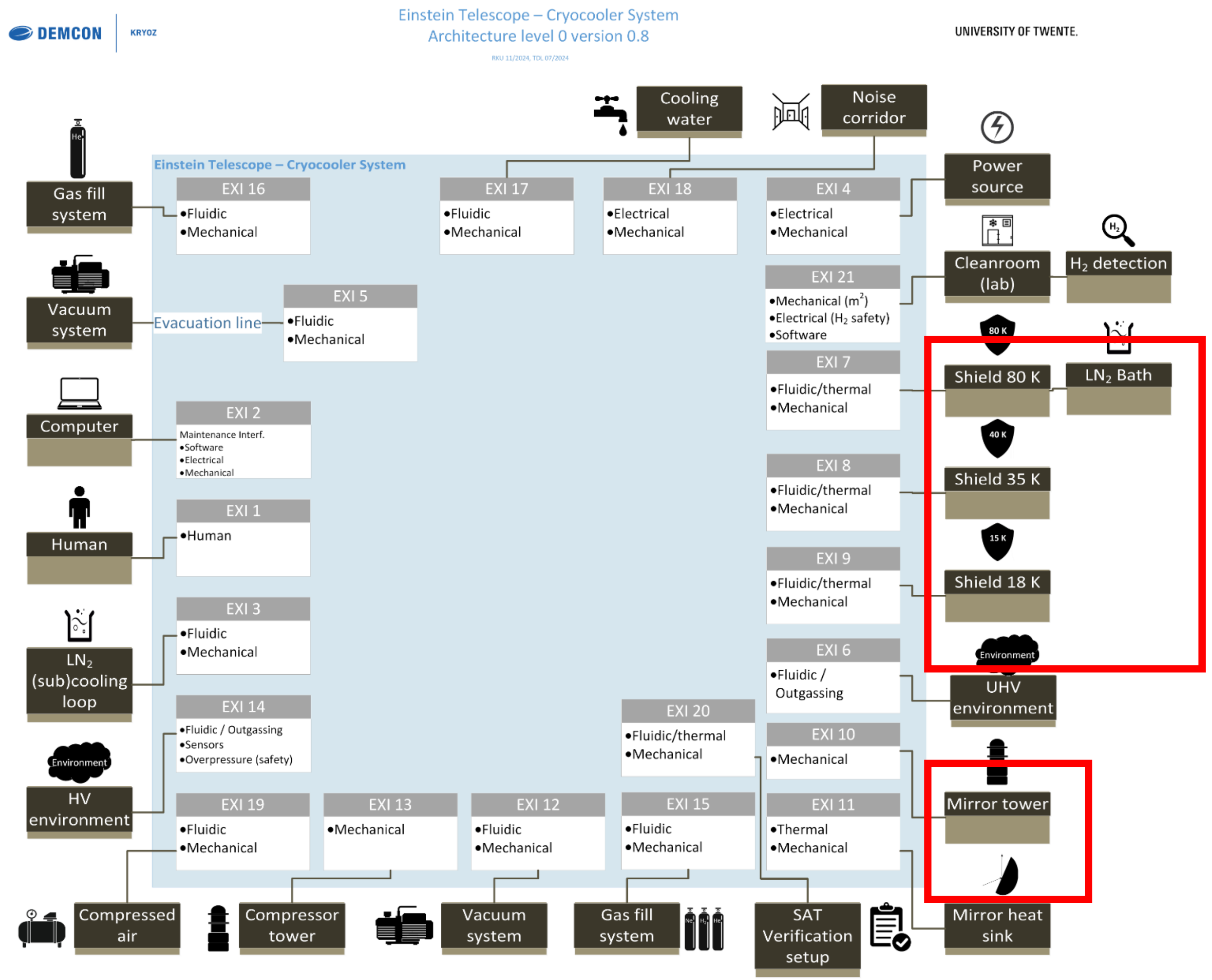
Development approach for ETpathfinder

Q1 2024
Requirements definition



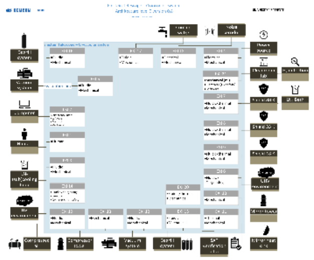
Activities
- Systems engineering:
  - Requirement definition
  - Identify external interfaces
  - System architecture

Fabricated external interfaces imposes design constraints

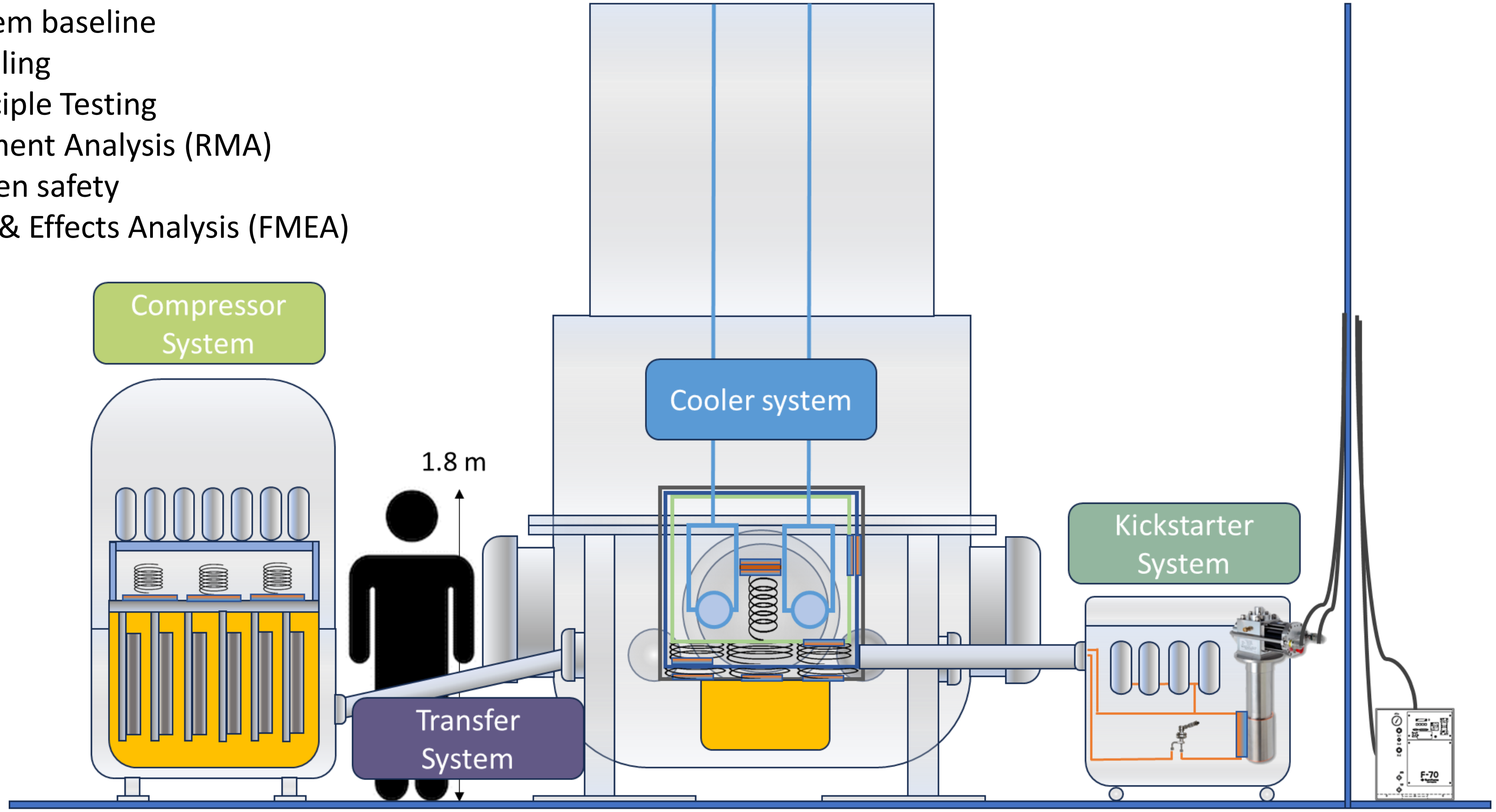
Development approach for ETpathfinder

Activities
- Establish system baseline
- System modelling
- Proof-of-principle Testing
- Risk Management Analysis (RMA)
    - Hydrogen safety
- Failure Mode & Effects Analysis (FMEA)

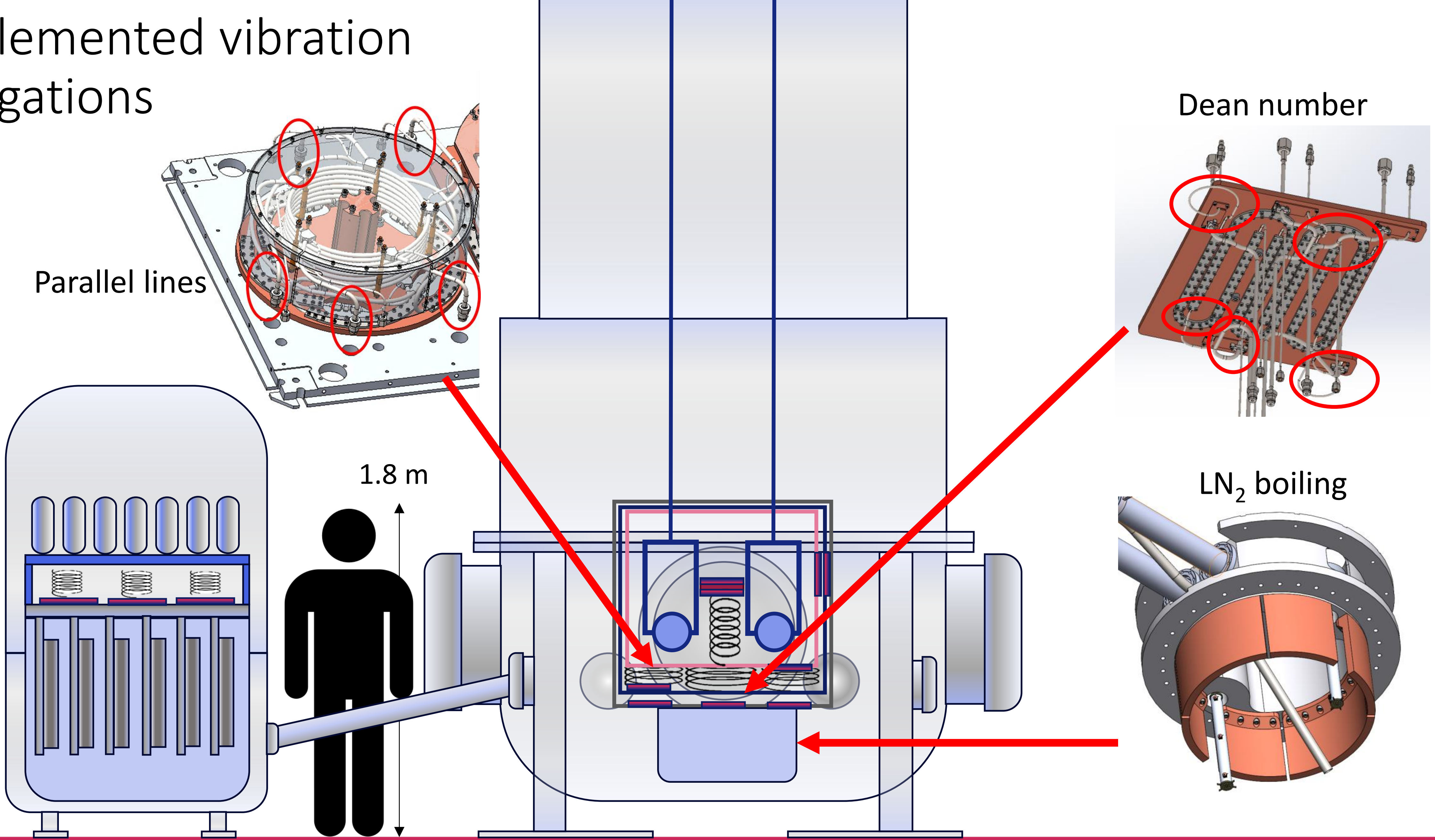
Q1 2024
Requirements definition



Q3 2024
Completion Concept Design

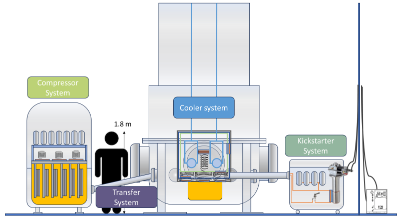


Implemented vibration mitigations

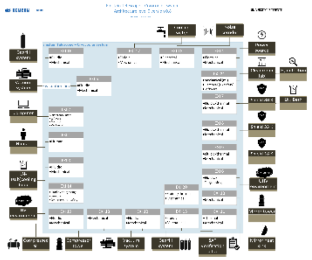


Development approach for ETpathfinder

Q1 2024
Requirements definition



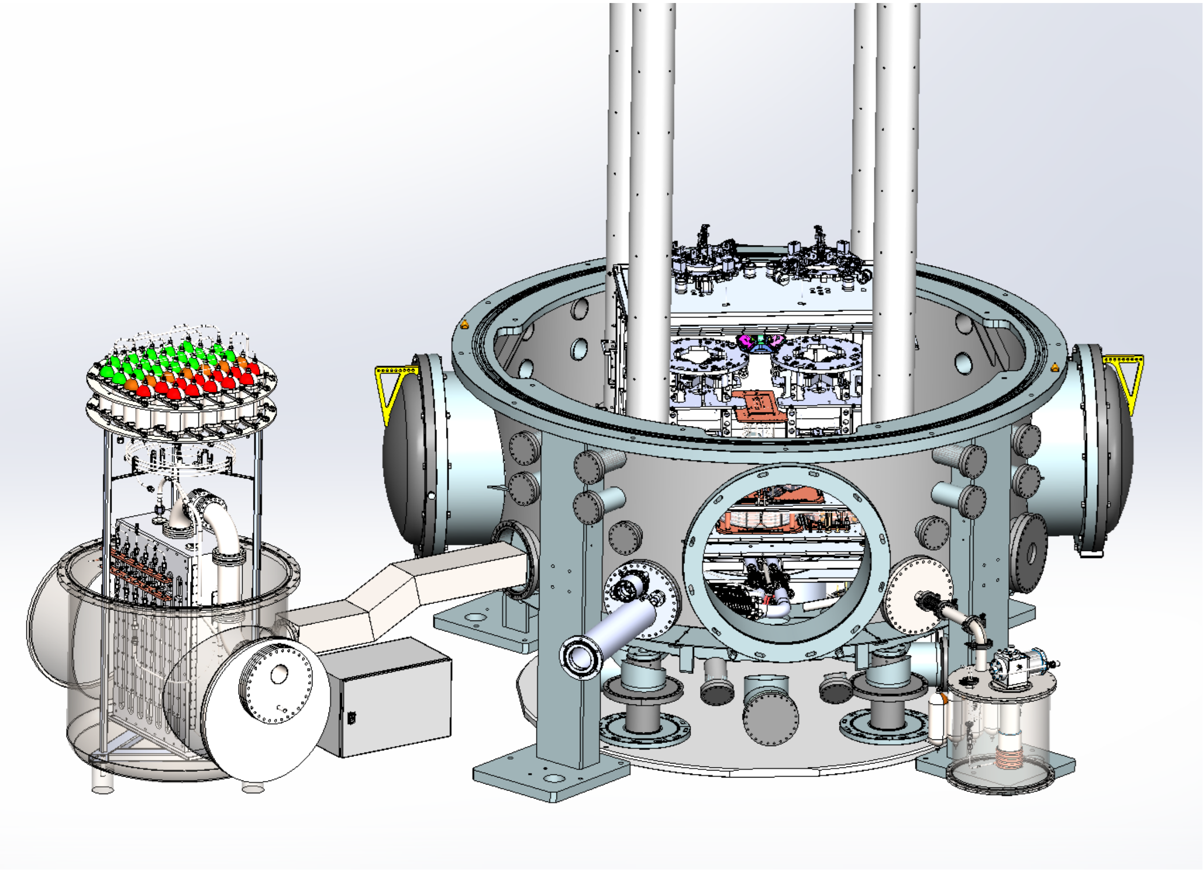
Q2 2025
Completion Detailed Design



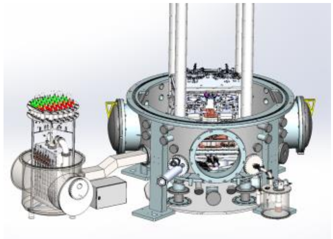
Q3 2024
Completion Concept Design

Activities

- CAD-drawings
- Component selection
  Cryo & UHV compatible



Development approach for ETpathfinder



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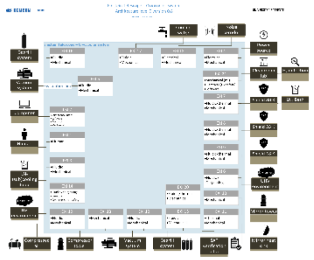
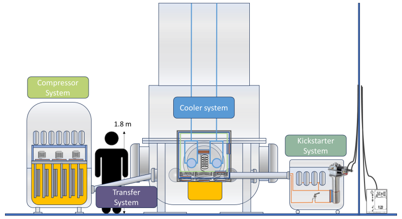


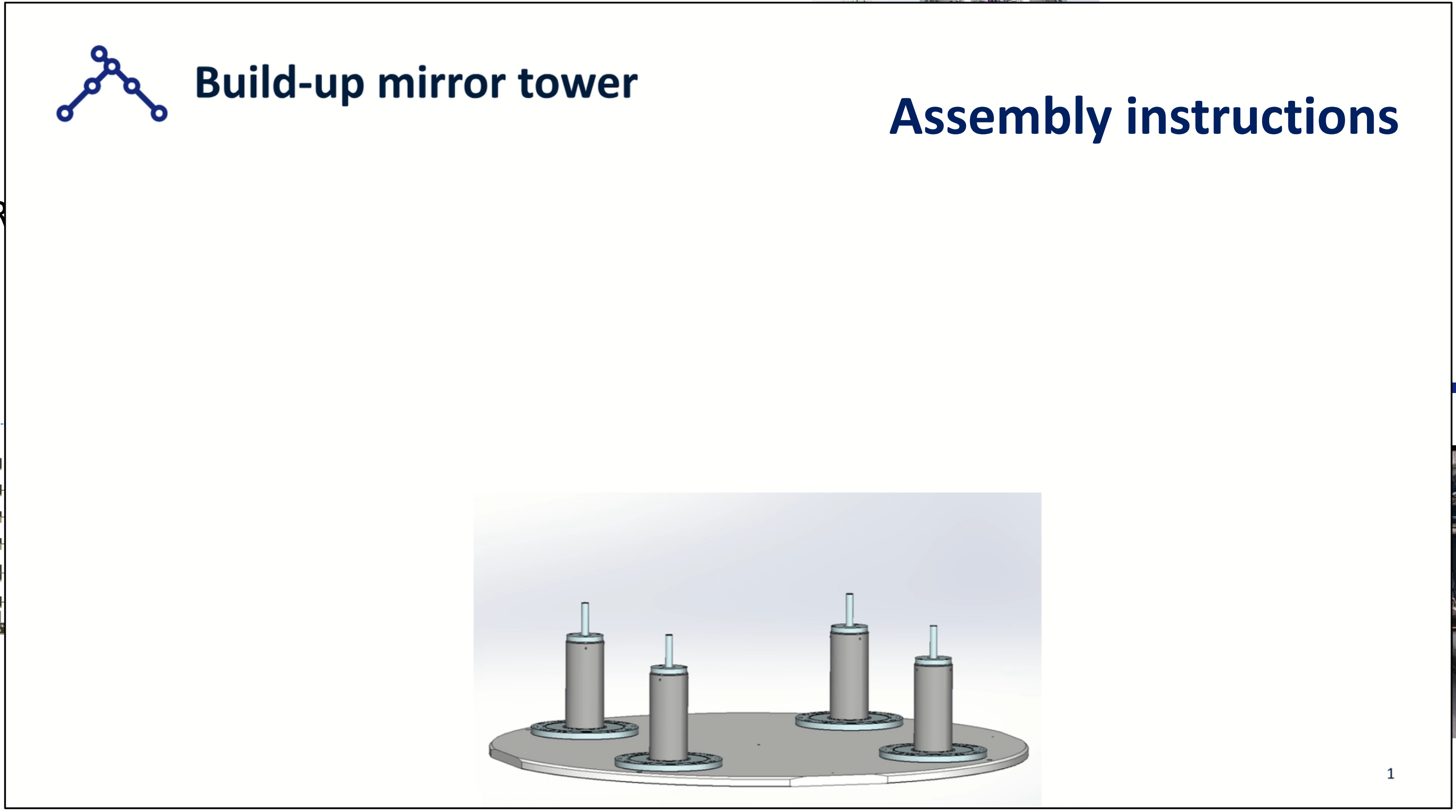


Q3 2024
Completion Concept Design

Q2 2025
Completion Detailed Design

Q4 2025
Complete integration at University of Twente

Development approach for ETpathfinder

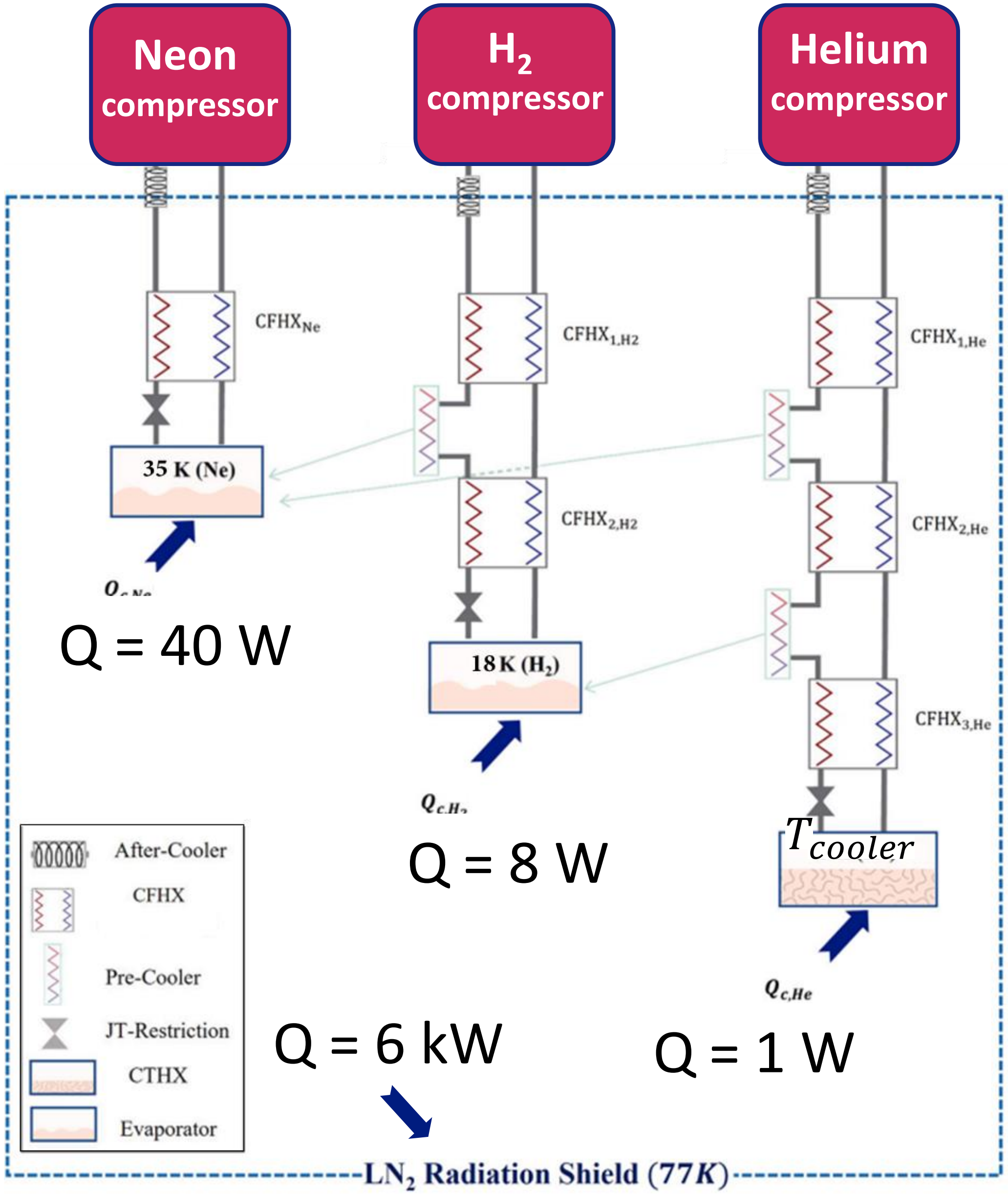


Q4 2026
Complete integration & verification at ETpathfinder

Sorption cryocooling for ET-LF

Concept desig ET-LF

- Scalable design, able to cool Einstein Telescope mirrors
- T_{cooler} =
  5.3 – 15K
  (single phase He)
  3.5 – 5.3 K
  (two-phase He)



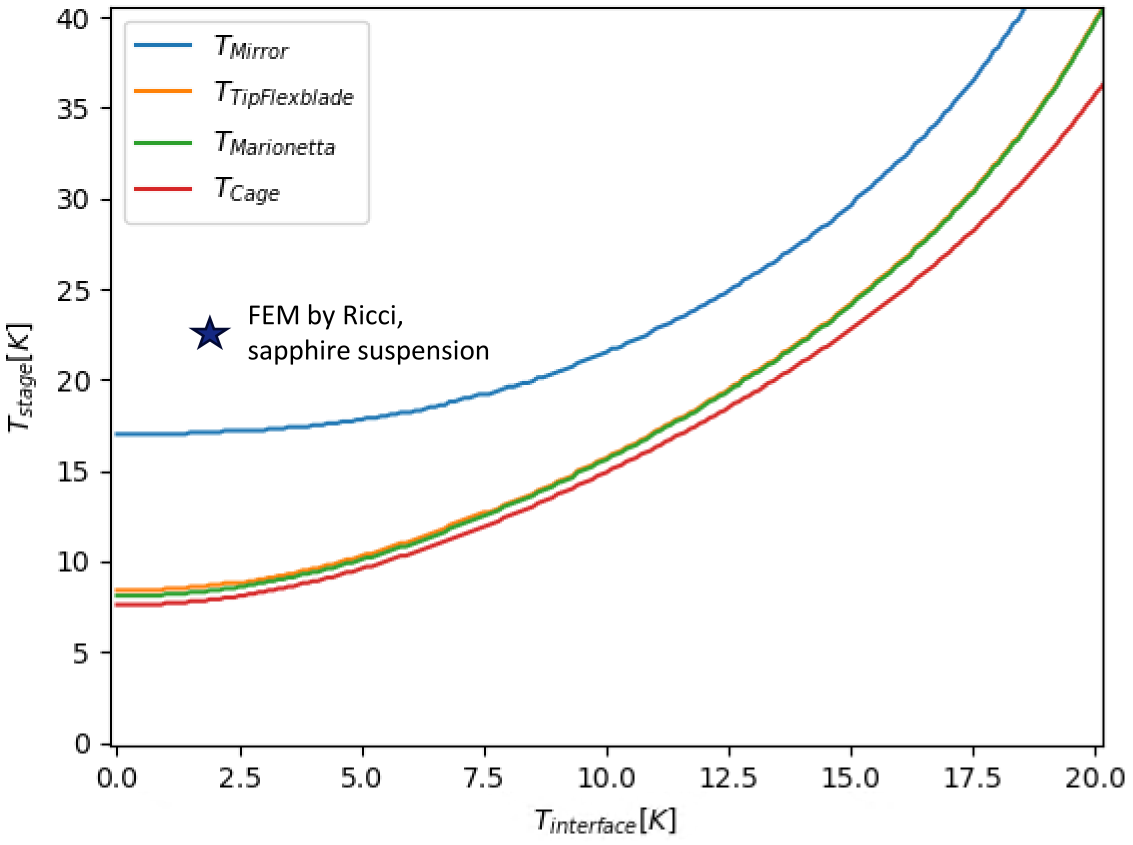
T_{cooler}
Trade-off between thermal noise and mechanical noise.

Again:
Colder does not imply better: non-linear k of Al

Mirror vibr. lvl → $T_{platform}$
Decoupling criteria → $\frac{L}{A}$

Supporting_Document_for_The_ET_Baseline_Detector_Layout, p. 83-88, Henk Jan Bulten (2025)
Vibration-free cooling of optical instruments, ET meeting MPI, Marcel ter Brake, Hannover (2013)

Expected performance



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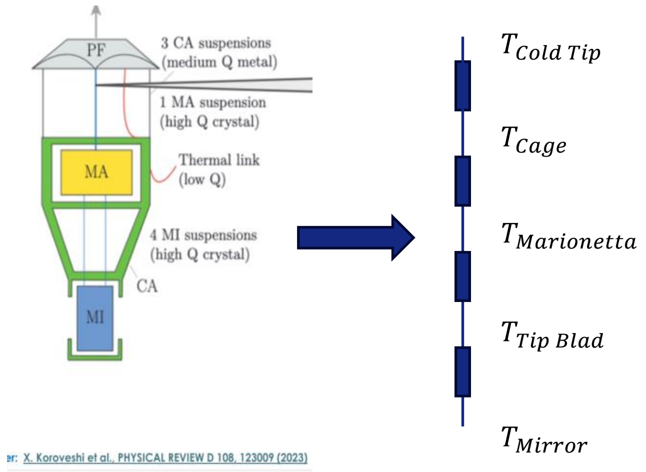
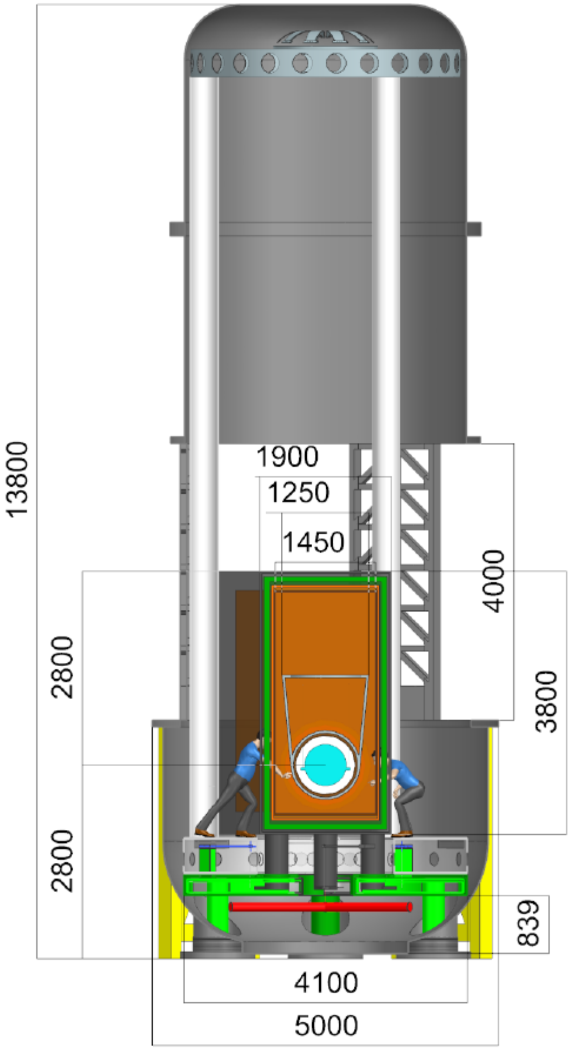


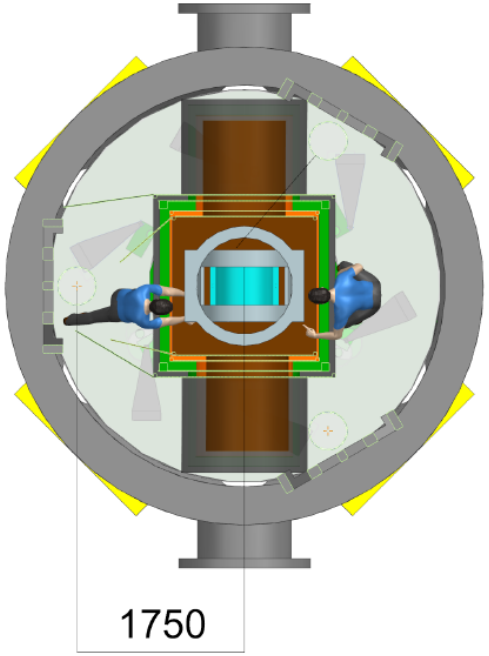
Al strands	7^3
#3 Interface – Platform/Cage	
D3	150 um
L3	1.0 m
#2 Platform/Cage-Marionetta	
d2=	150 um
L2	1.0 m

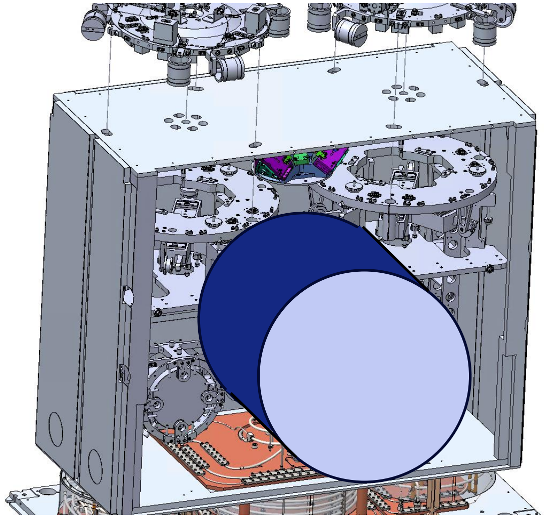
#1 Marionetta - SiBladesTip	
L1	0.1 m
Thickness	1 mm
Width	80 mm
#0 SiBladeTip - Mirror	
d0	3 mm
L0	1.2 m

Integration in Einstein Telescope: tower

- Counterflow Heat Exchangers can be placed anywhere between the shields.
- Warm feedthroughs at vacuum wall
- Gas Helium loop with dedicated heat exchangers for cooldown.







ETPF cryostat comparison with ET mirror

Supporting_Document_for_The_ET_Baseline_Detector_Layout, p. 83-88, Henk Jan Bulten (2025)

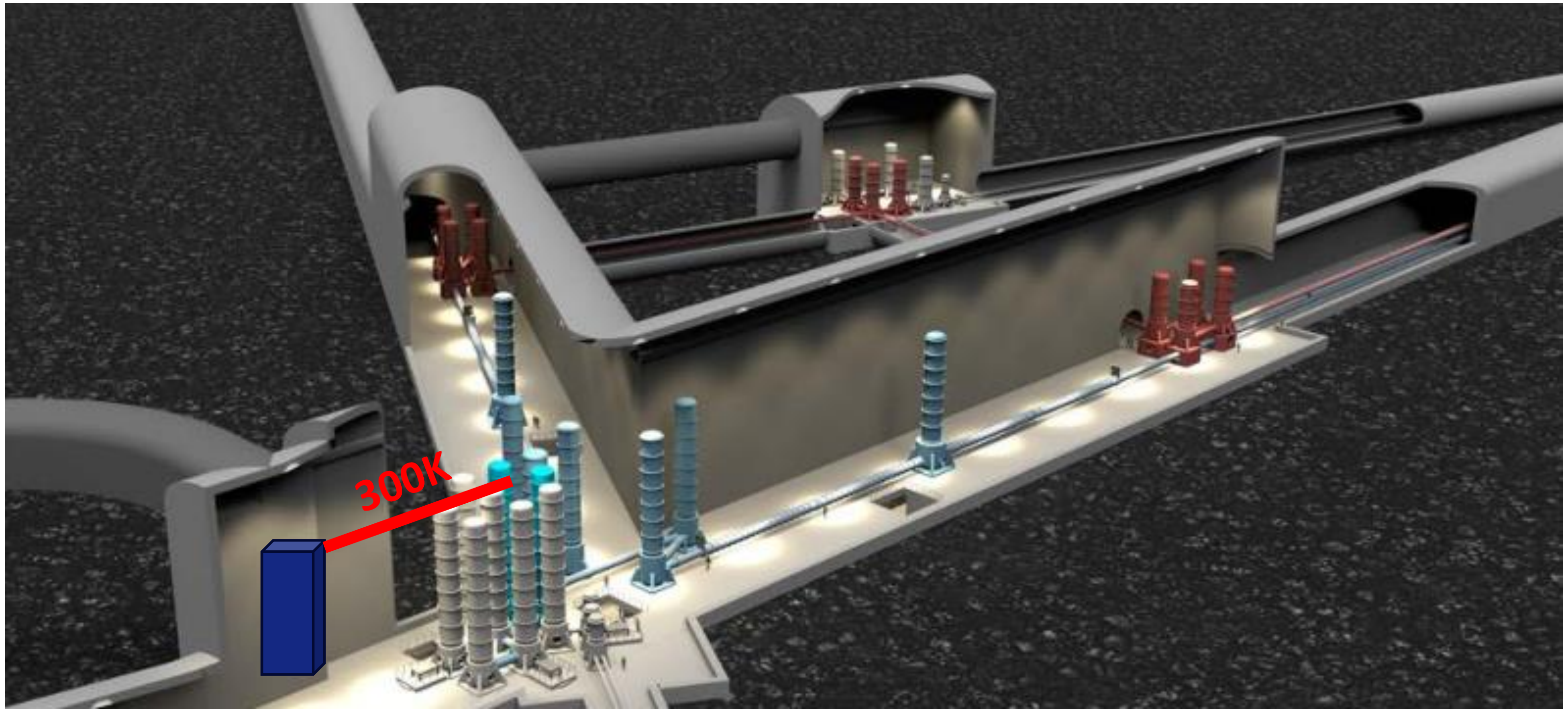
Integration in Einstein Telescope: facility

Compressor:

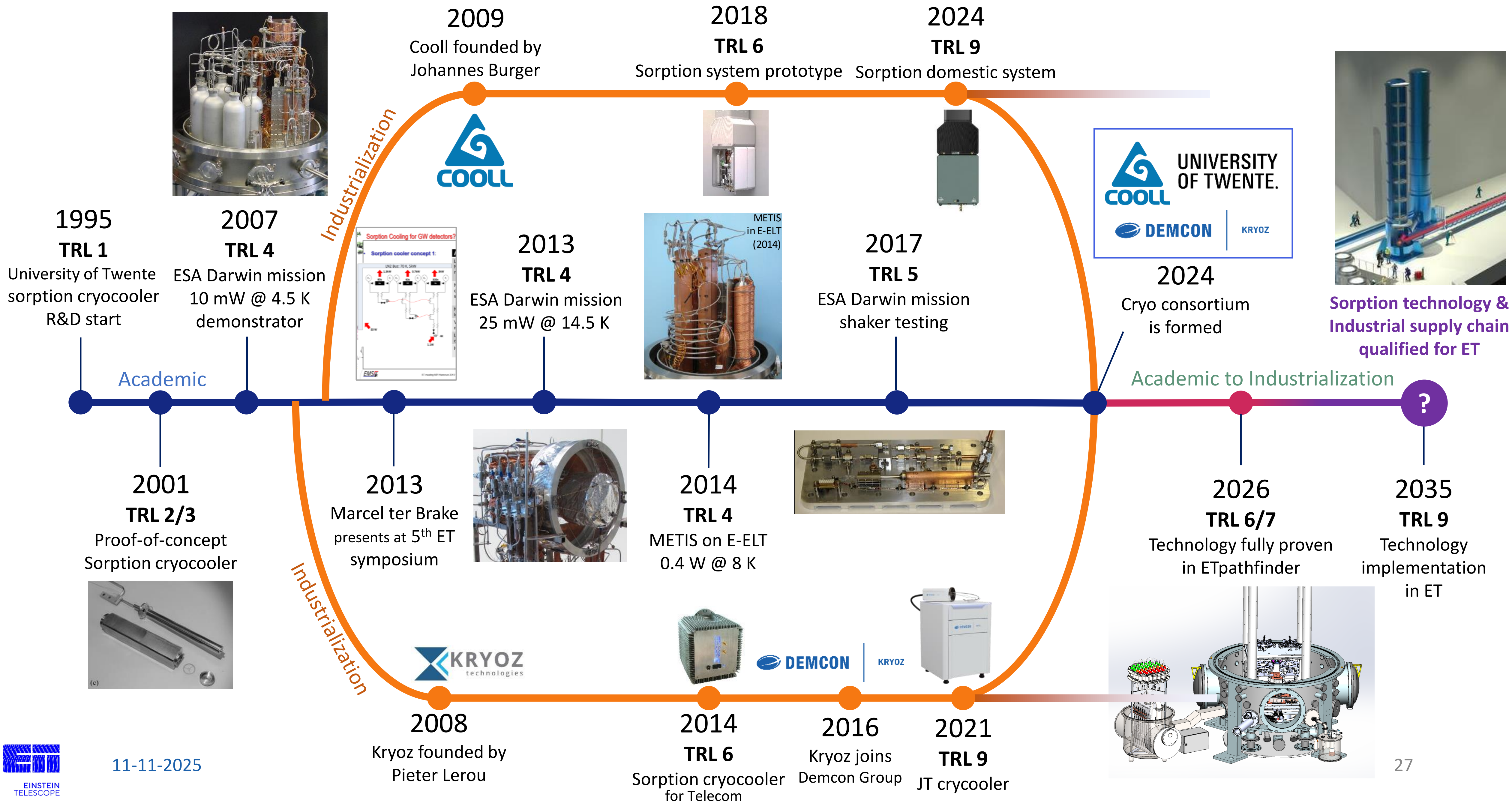
- ETPF: 1 m^3 for 50 mW at 8K
  →ET: 20 m^3 per 1W at 8K

Low quality vacuum (HV: 10^{-4} mbar)

Warm transfer lines allow for flexible placement of compressor



Roadmap sorption cryocooling for Einstein Telescope



Key take-aways

Sorption-based JT-cryocooling has unique properties for ET:

1. The system optics are cooled with a low, laminar gaseous Helium mass flow, minimizing potential vibrations
   - LN2 backend cooling source allows for a low Helium mass flow close to the optics
2. No actively moving components
   - Low vibration
   - Low maintenance/high reliability, essential for continuous operation for a large-scale underground observatory
3. The sorption compressor design is scalable to meet cooling requirements ET
4. Compressor and Cooler transfer gas lines operated at room temperature
   - Flexibility in tube length
5. No interfacing with suspension framework necessary
   - Required volume budget fits in radiation shields
6. System is designed to be Fluid-Induced Vibrations neutral
7. Cooldown within 7 days for ETpathfinder, 9 days for ET
8. High TRL (6/7 in 2026, aim: 9 in 2035)
   - Technology benchmarking in ETpathfinder facility in 2026/2027

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“It is our ambition to demonstrate the technical readiness and low-displacement noise performance of sorption-based Joule-Thomson cryo-cooling for Einstein Telescope”

EINSTEIN TELESCOPE

Thank you!

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UNIVERSITY OF TWENTE.

DEMCON | KRYOZ

COOLL

EINSTEIN TELESCOPE