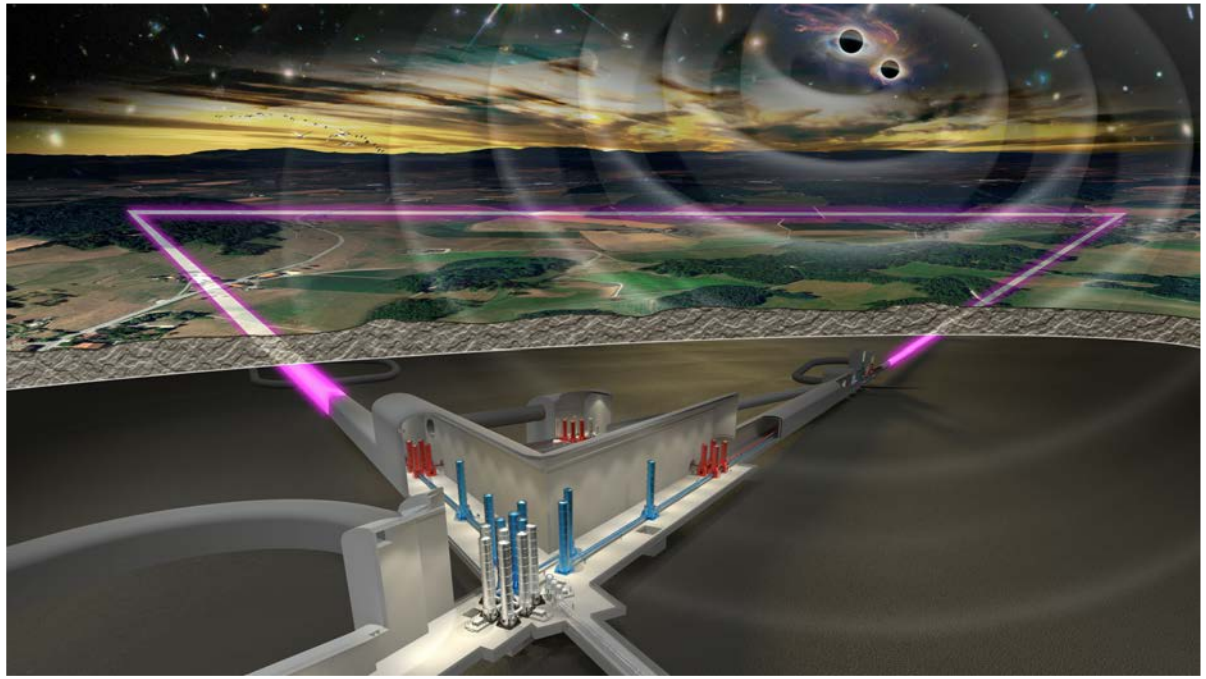


Vibration free cooling: Essential for Einstein Telescope (ET)

Prof Stefan Hild, University of Maastricht & Nikhef

www.einsteintelescope.nl / www.etpathfinder.eu

We have come a long way ….

688 Sitzung der physikalisch-mathematischen Klasse vom 22. Juni 1916

Näherungsweise Integration der Feldgleichungen der Gravitation.

Von A. Einstein.

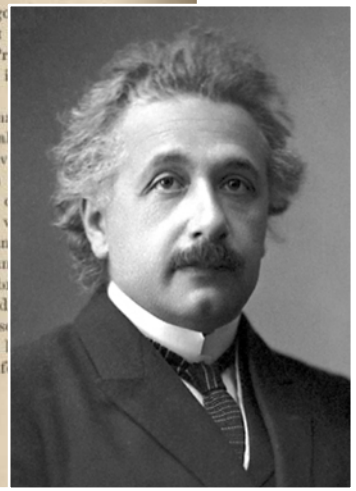
Bei der Behandlung der meisten speziellen (nicht prinzipiellen) Probleme auf dem Gebiete der Gravitationstheorie kann man sich damit begnügen, die $g_{\mu\nu}$ in erster Näherung zu berechnen. Dabei bedient man sich mit Vorteil der imaginären Zeitvariable $x_4 = it$ aus denselben Gründen wie in der speziellen Relativitätstheorie. Unter »erster Näherung« ist dabei verstanden, daß die durch die Gleichung

$$g_{\mu\nu} = -\delta_{\mu\nu} + \gamma_{\mu\nu} \qquad (1)$$

definierten Größen $\gamma_{\mu\nu}$, welche linearen orthoge
gegenüber Tensorcharakter besitzen, gegen 1
handelt werden können, deren Quadrate und Pr
Potenzen vernachlässigt werden dürfen. Dabei
je nachdem $\mu = \nu$ oder $\mu \neq \nu$.

Wir werden zeigen, daß diese $\gamma_{\mu\nu}$ in an
werden können wie die retardierten Potentia
Daraus folgt dann zunächst, daß sich die Grav
geschwindigkeit ausbreiten. Wir werden im
gemeine Lösung die Gravitationswellen und
untersuchen. Es hat sich gezeigt, daß die
Wahl des Bezugssystems gemäß der Bedingun
die Berechnung der Felder in erster Näherun
Ich wurde hierauf aufmerksam durch eine b
Astronomen de Sitter, der fand, daß man d
des Bezugssystems zu einem einfacheren Aus
feldes eines ruhenden Massenpunktes gelangen
gegeben hatte[1]. Ich stütze mich daher im f
mein invarianten Feldgleichungen.

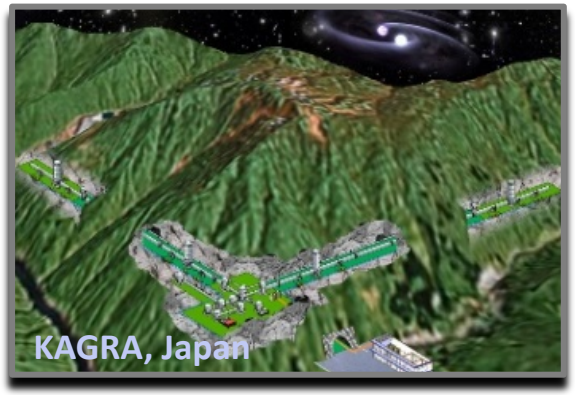
[1] Sitzungsber. XLVII, 1915, S. 833.



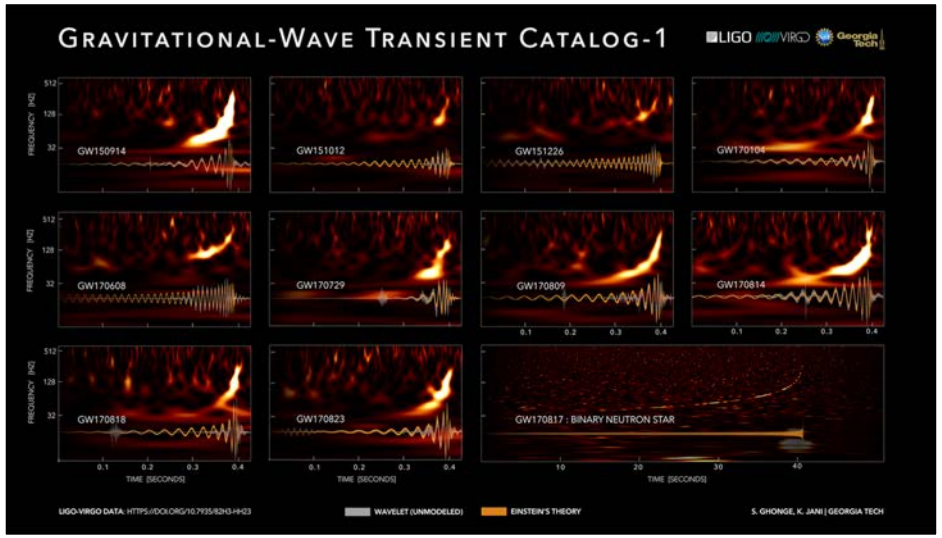

LIGO, Livingston, LA

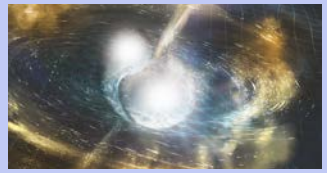

Virgo, Cascina, Italy


LIGO, Hanford, WA


KAGRA, Japan

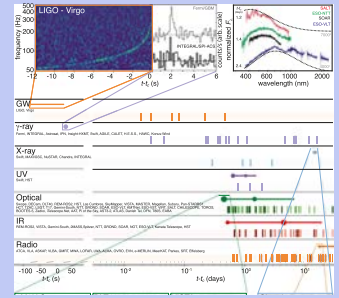
Fireworks of observations



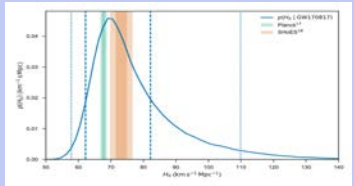


Confirmed BNS as origin for some GRBs

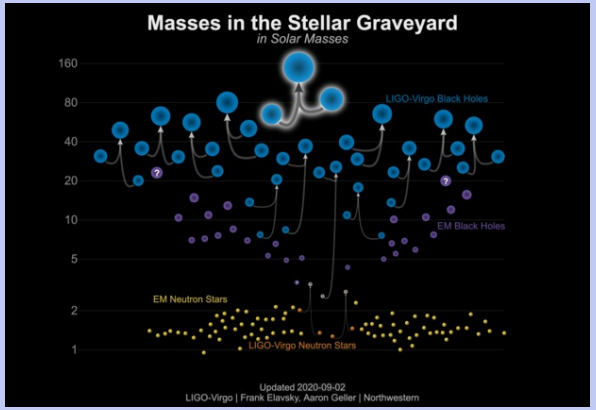
Ruled out some proposed EOS of neutron stars



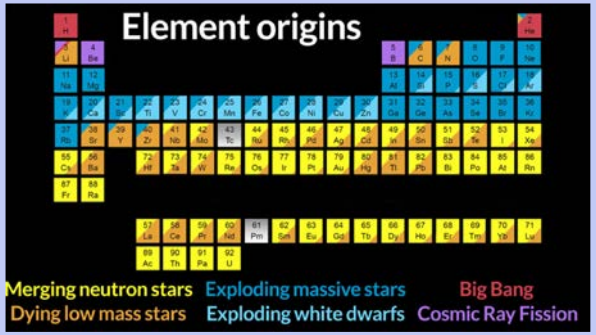
Start of GW multi-messenger astronomy



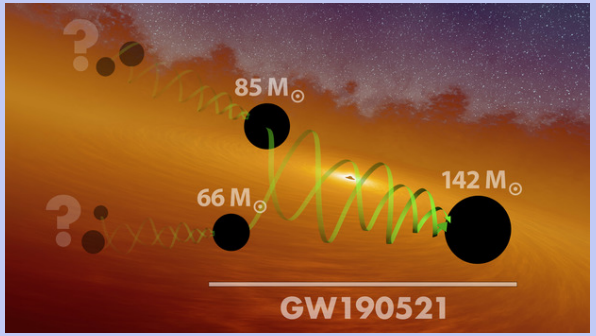
Cosmology independent of distance ladder



Found new class of heavy stellar mass BBH

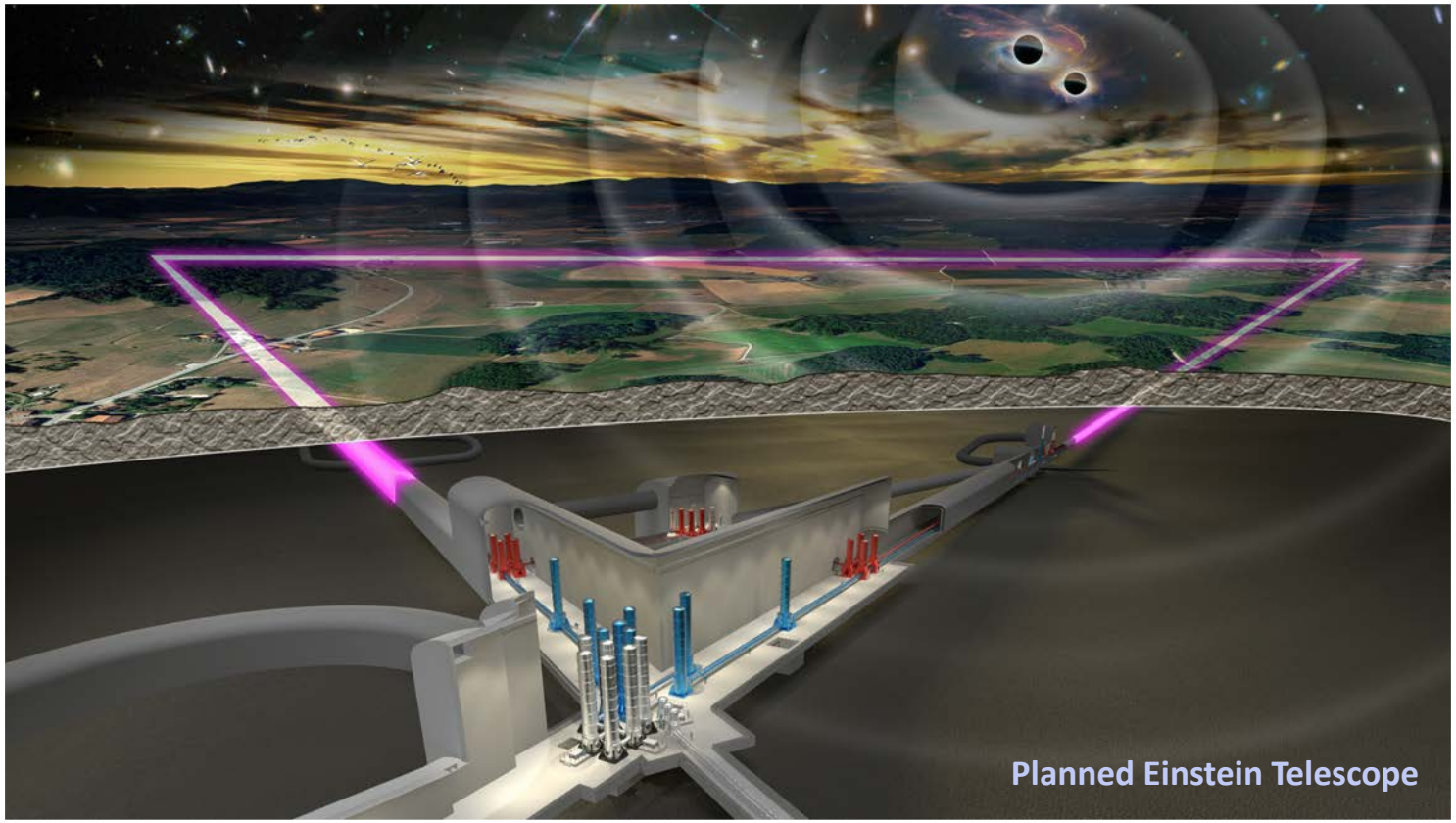


Confirmed Kilonova and R-process



Proved existence of intermediate-mass black holes

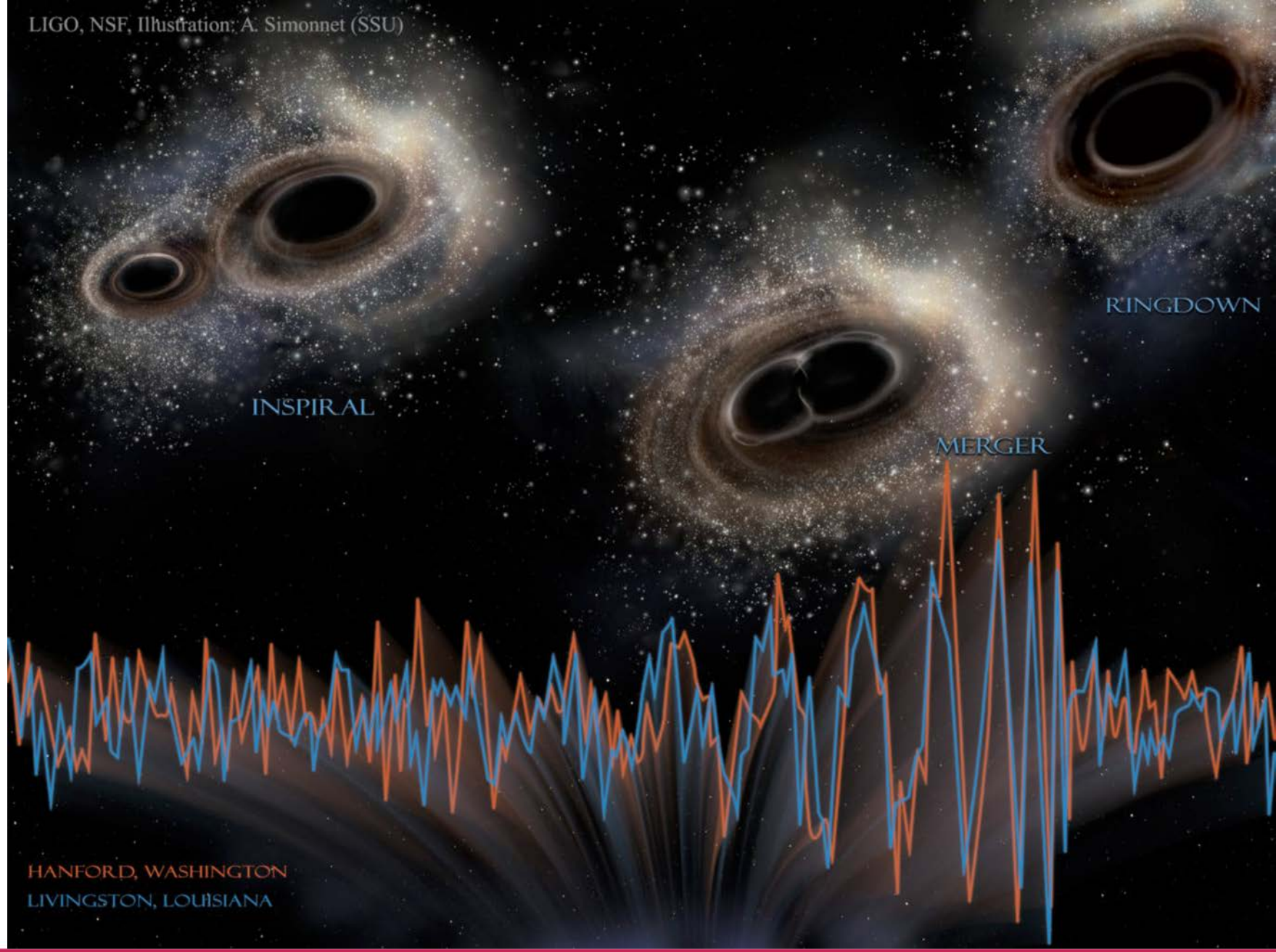
From current detectors to ET



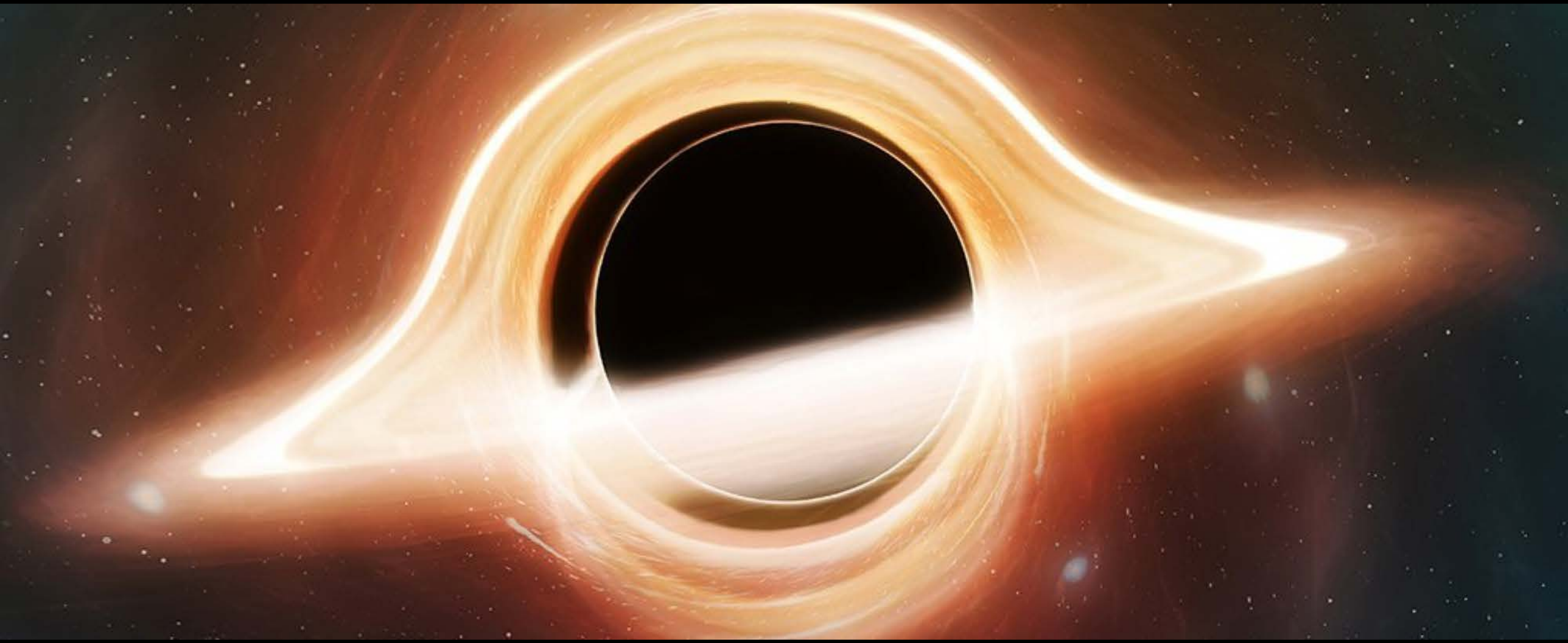
- Current detectors observe about one signal per week.
- ET will observe about 100.000 to 1.000.000 binary black holes mergers per year! And many other new sources => discovery space!

A new window to the Universe

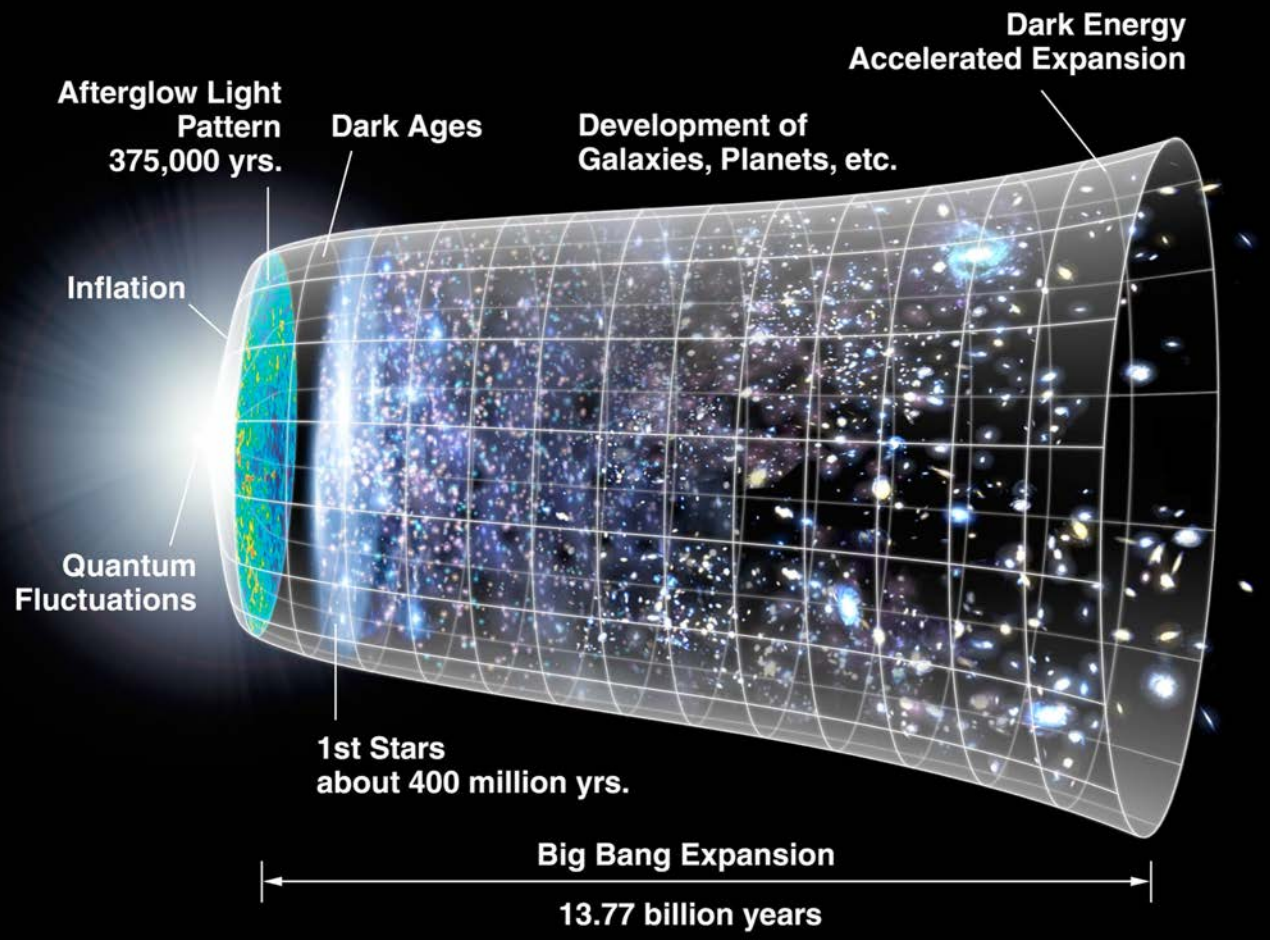
- Seeing dark objects otherwise not accessible with “normal” astronomy.
- Shedding light on the components of the Universe (dark matter, dark energy).
- Better understanding of Gravity, the least understood force.



What happens at the event horizon of a black hole? Do black holes have an inner structure?

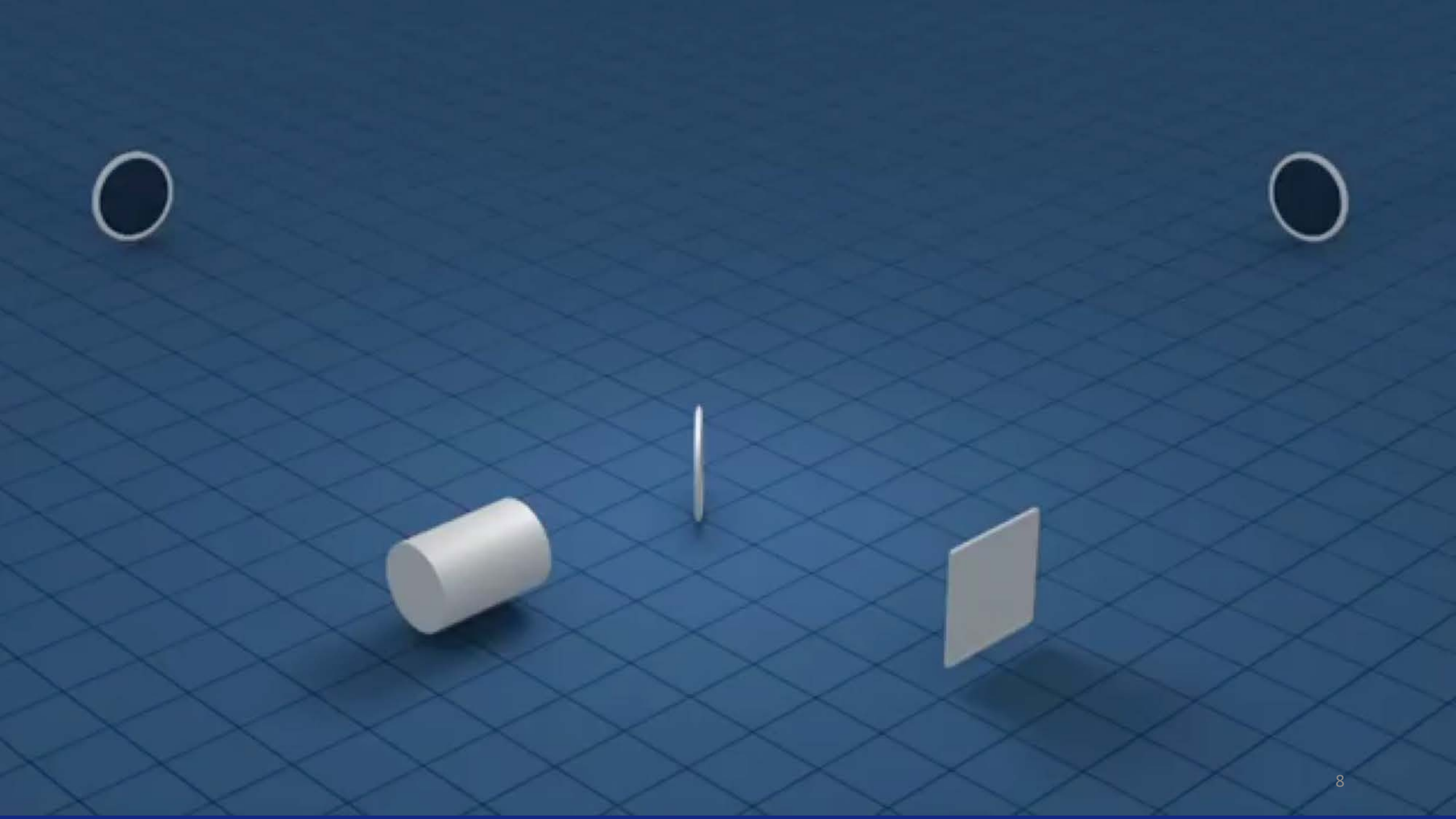


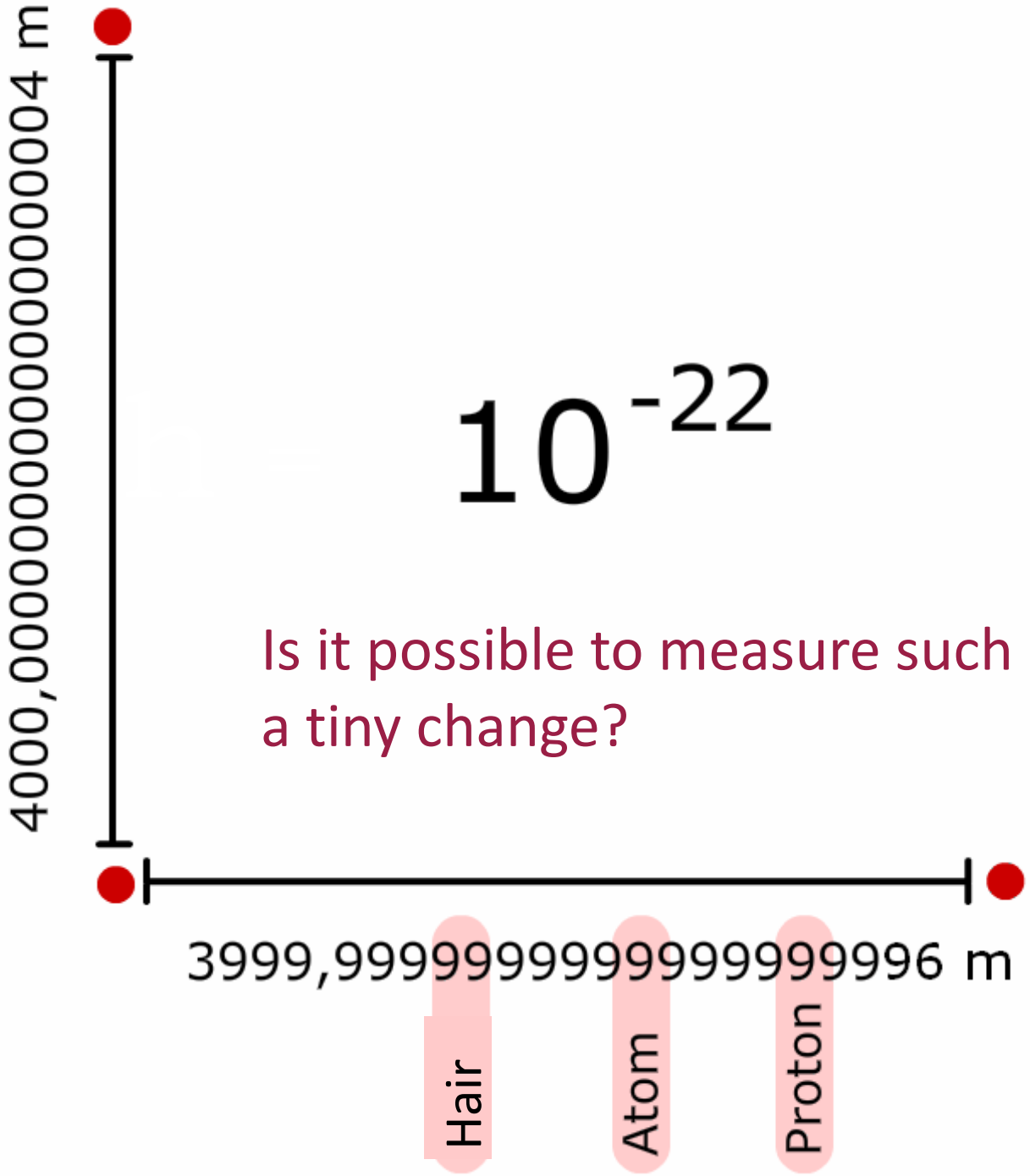
Seeing back towards the Big Bang



How is the Universe expanding

Quantum Gravity?

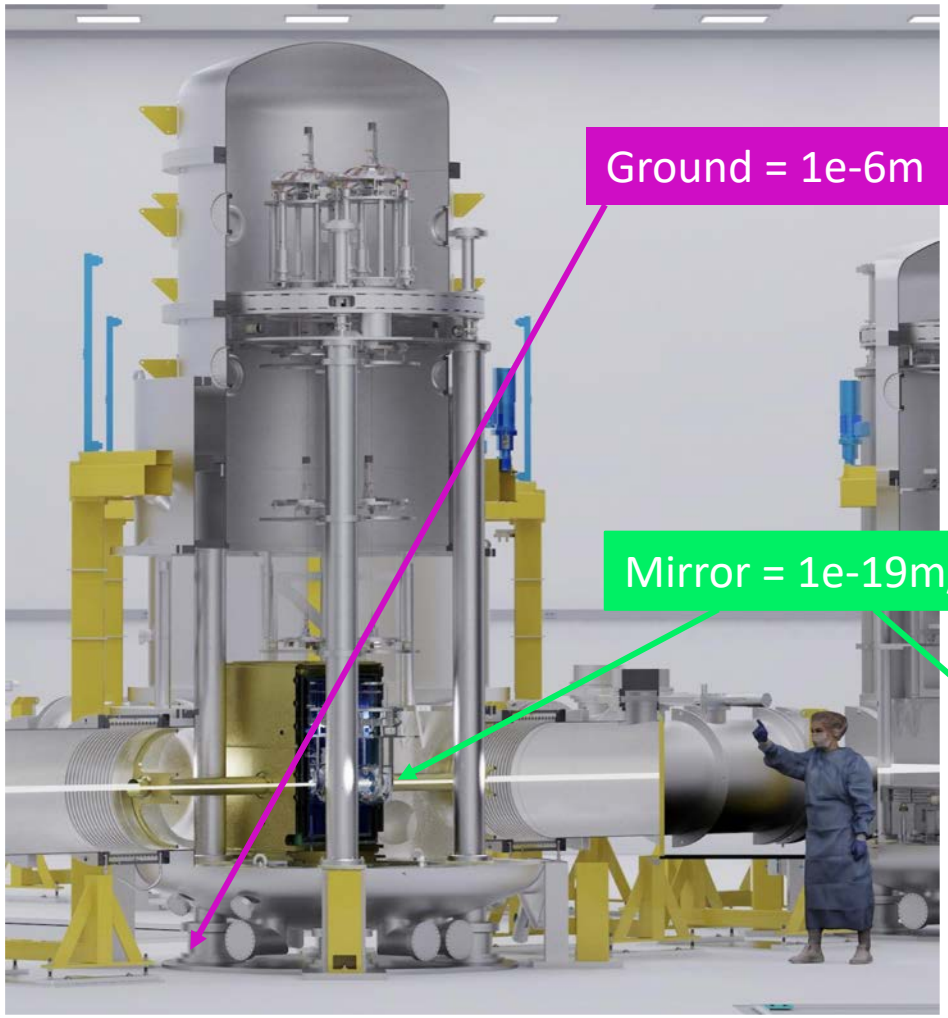


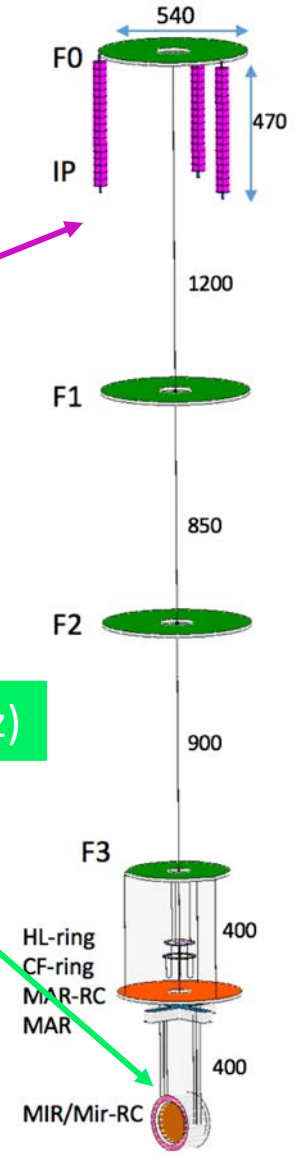

4000,000000000000000004 m
10^{-22}
Is it possible to measure such a tiny change?
3999,999999999999999996 m
Hair
Atom
Proton

Cryogenic challenge: Einstein Telescope

- How to cool a mirror to 10K, while keeping it quiet at a level of **1e-19m/sqrt(Hz)?**


Image Credit: LIGO Laboratory, MIT/Caltech

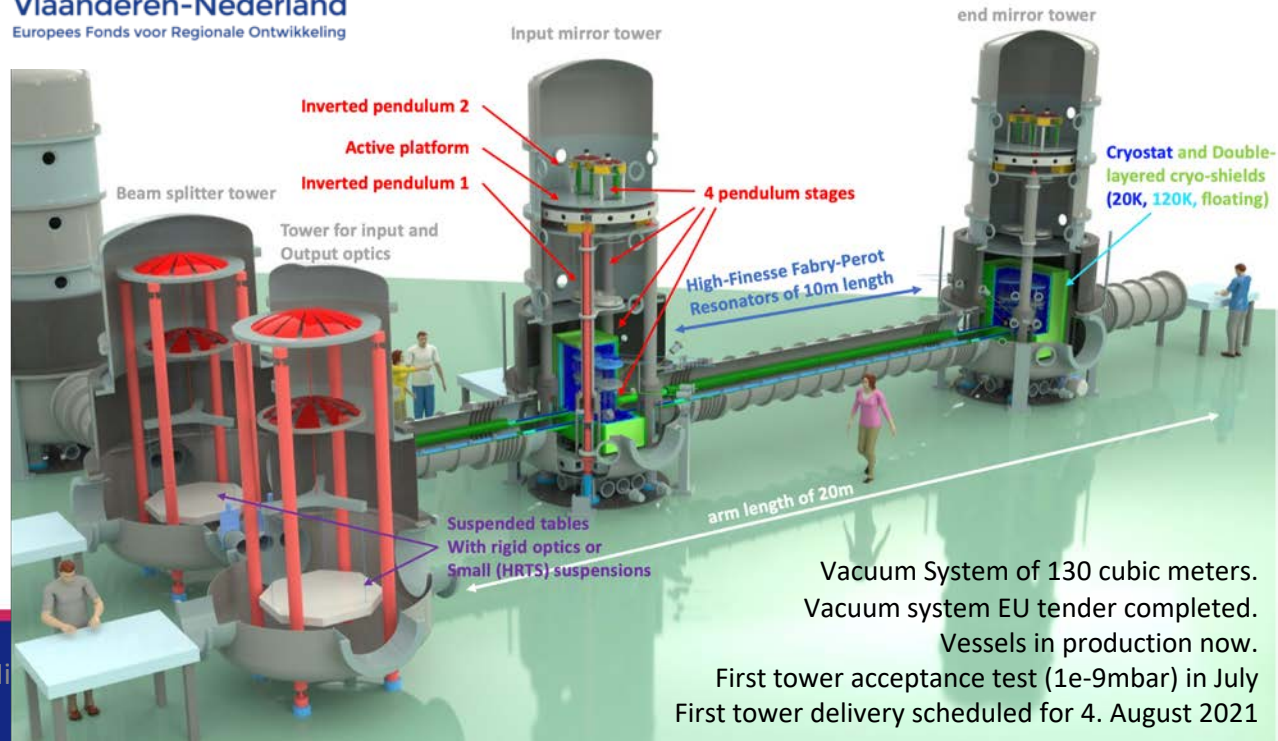




ETpathfinder Overview

- New facility for testing ET technology in a low-noise, full-interferometer setup.
- Key aspects: Silicon mirrors (3 to 100+kg), cryogenics cryogenic liquids and sorption coolers, water/ice management), “new” wavelengths (1550 and 2090nm), coatings
- Start with 2 FPMI, one initially at 120K and one 15K (2022+).
- 20 partners from NL/B/G/FR/SP/UK
- Initial capital funding of 14.5 MEuro.
- Detailed Design Report available at apps.et-gw.eu/tds/?content=3&r=17177
- Open for everyone interested to join.
- www.etpathfinder.eu

Interreg
Vlaanderen-Nederland
Europees Fonds voor Regionale Ontwikkeling



Vacuum System of 130 cubic meters.
Vacuum system EU tender completed.
Vessels in production now.
First tower acceptance test (1e-9mbar) in July
First tower delivery scheduled for 4. August 2021

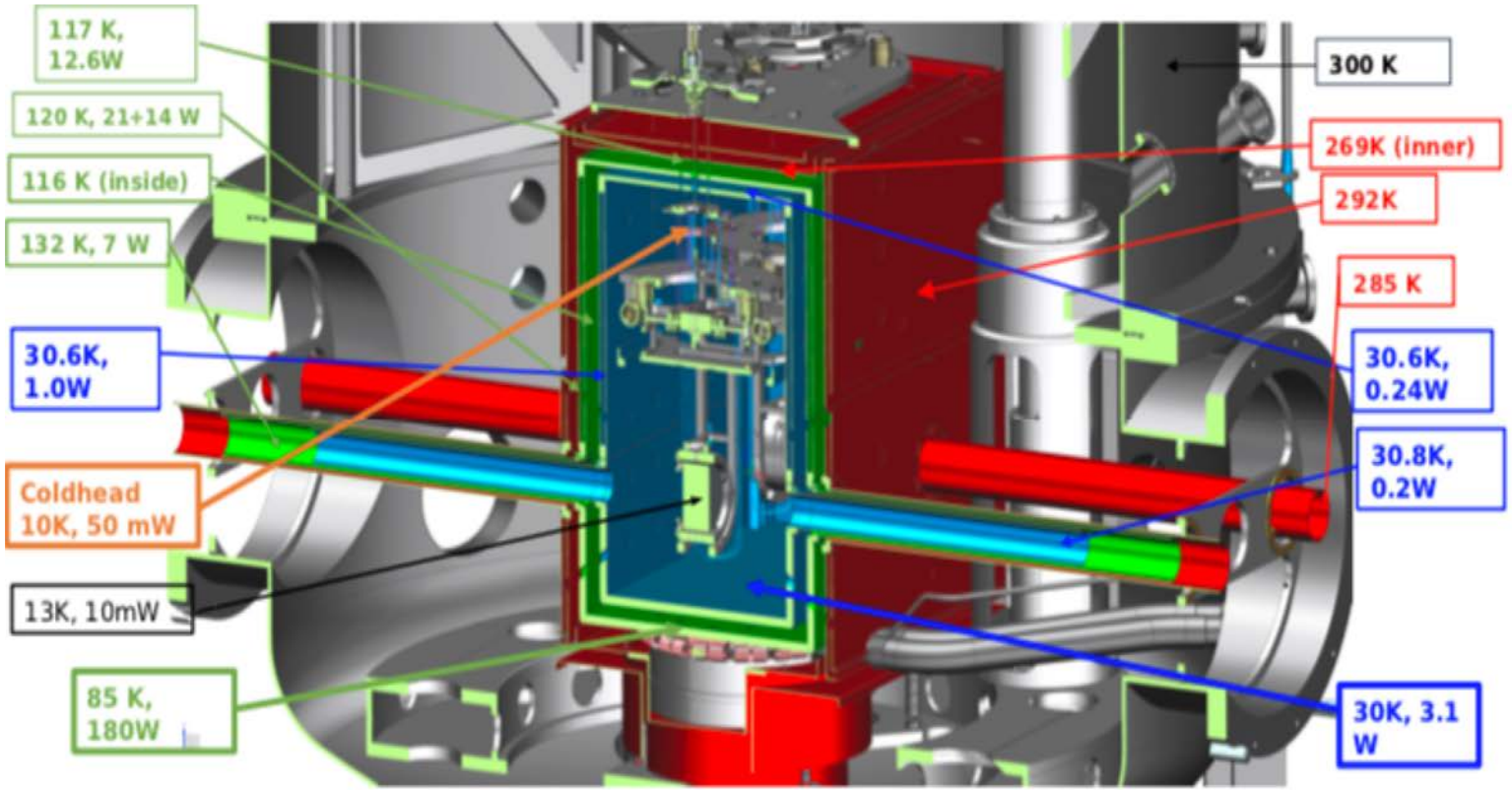
New Technologies

ET requires technological advances on all fronts:

- **New mirror material => Silicon**
- **New temperature => 10-20K**
- **New laser wavelength => 1.5-2.1 microns**
- **Advanced quantum-noise-reduction schemes**

Example: Cooling loads in ETpathfinder

- Mirrors need to be cooled to cryogenic temperatures (~15K, 123K), without introducing noise, i.e. cooling only possible via thin suspension wires.
- General approaches:
  - Dry system: pulse-tubes. Challenge = reduce and isolate vibrational noise.
  - **Sorption coolers (base line in ETpathfider) = more quiet, less cooling power.**
  - Cryogenic Liquids: LN2, He, HeII. Challenge = avoid bubbling; transfer liquids from surface 300m above the caverns …



ETpathfinder cooling budget

Twente Test Setup

- All cryogenic systems will be prototyped/calibrated in Twente first (EMS group ter Brake)

- We switched from phase separators to sub-cooled liquid Nitrogen:
  - 1 bar liquid Nitrogen cooled to ~67 K: no boiling in feed lines
  - Power << 0.1W/m^2 : avoid nucleate boiling.

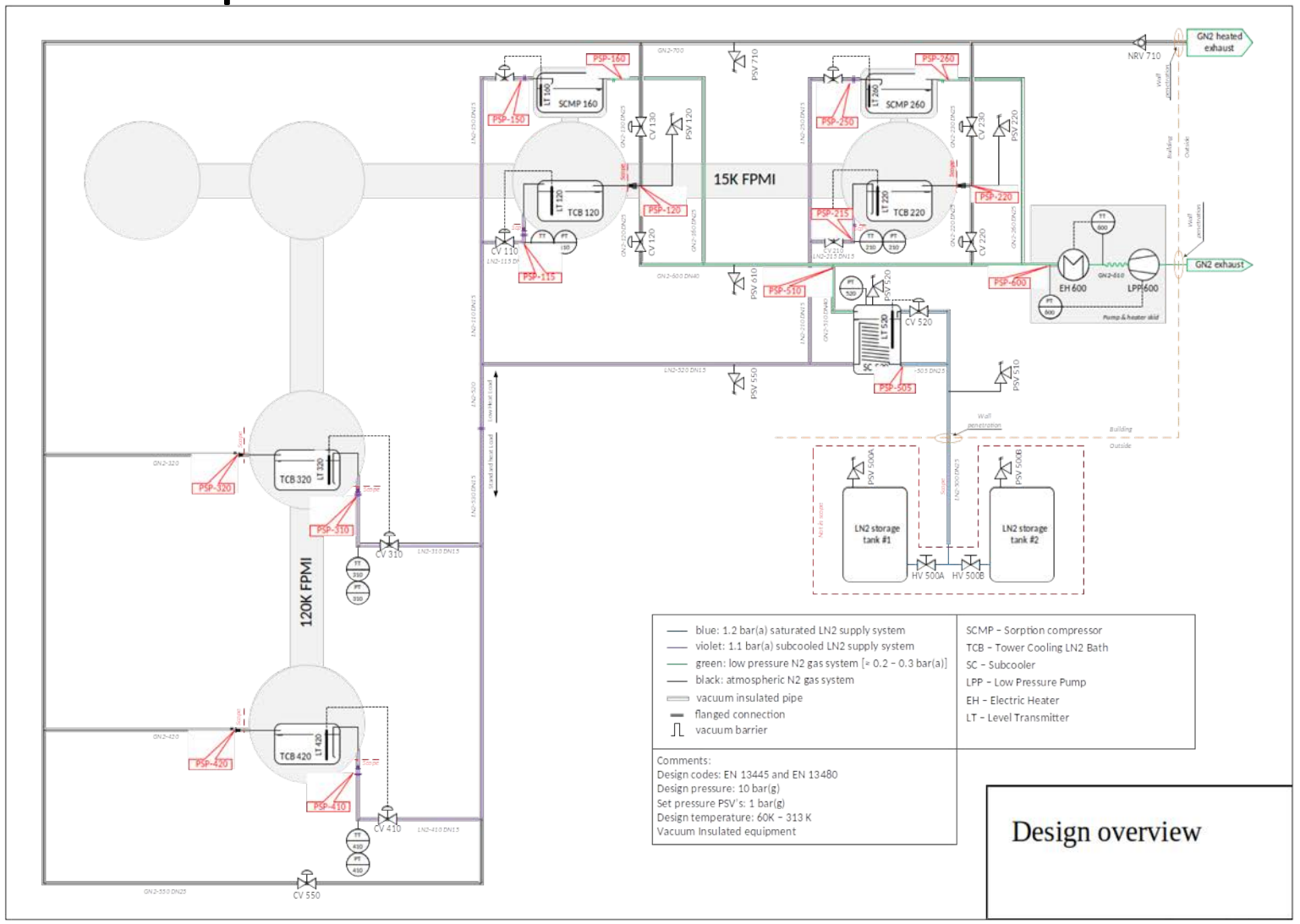
- Sorption cooler design is in progress; an additional temperature platform at 15K and an additional shield is needed.

- To speed up cool-down and as an alternative for sorption coolers, we also will install a cold helium loop:
  - Cryocooler cools He gas to ~6K
  - Supercritical gas/fluid mixture is pumped at constant pressure towards shields/cold finger
  - Can be switched off: gas can be pumped out from the lines

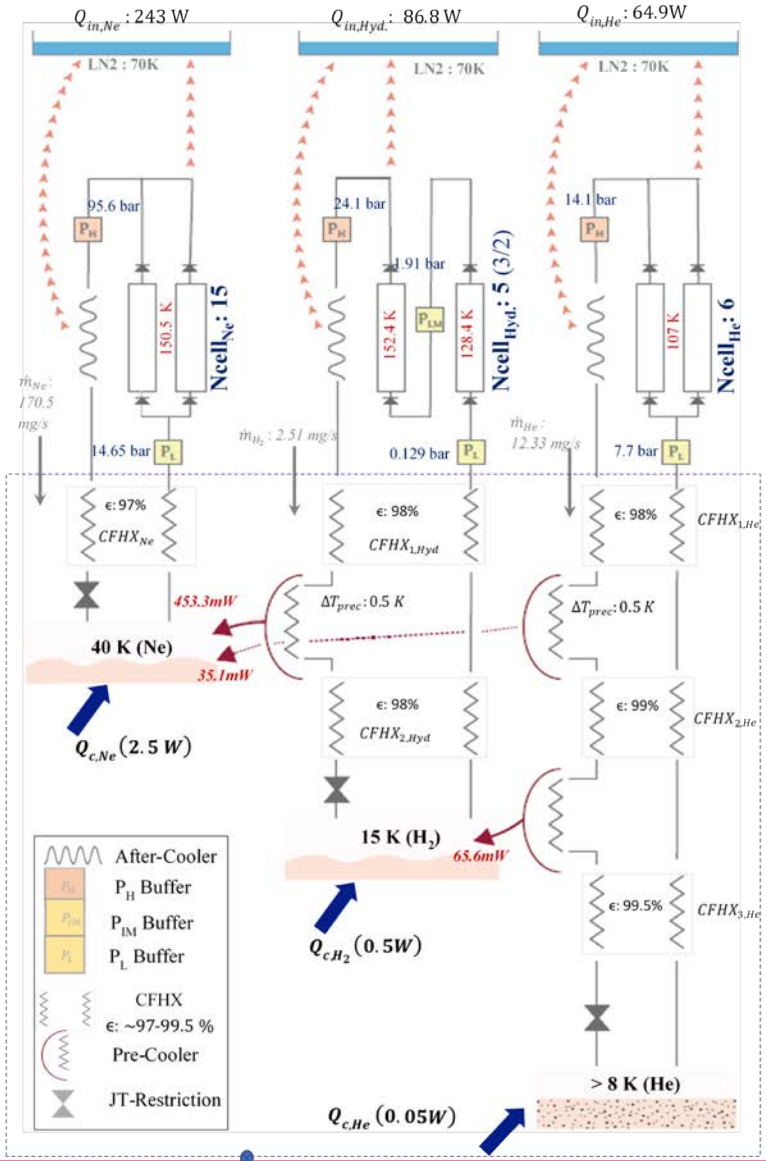
LN2 infrastructure of ETpathfinder

Sub-cooled liquid Nitrogen:

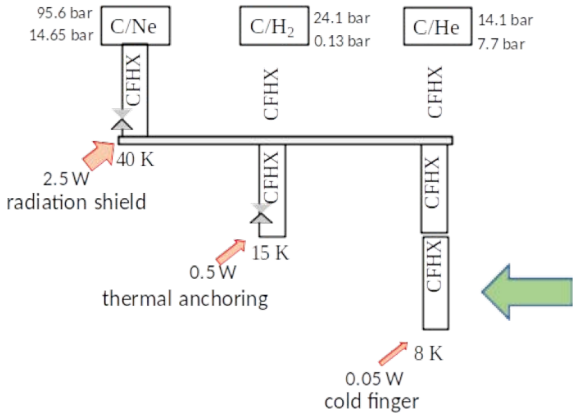
- 1 subcooler to cool down the 1-bar LN2 liquid (blue lines from storage vessel outside building) from 77K to 67K (purple lines: subcooled LN2)
- Transport to 4 towers and 2 sorption coolers.
- Green lines: gaseous nitrogen at 0.2 bar (from subcooler and sorption cooler units)
- Black lines: LN2 gas exhaust at 1 bar (wide lines to limit turbulence)
- System will be installed in Dec 2022

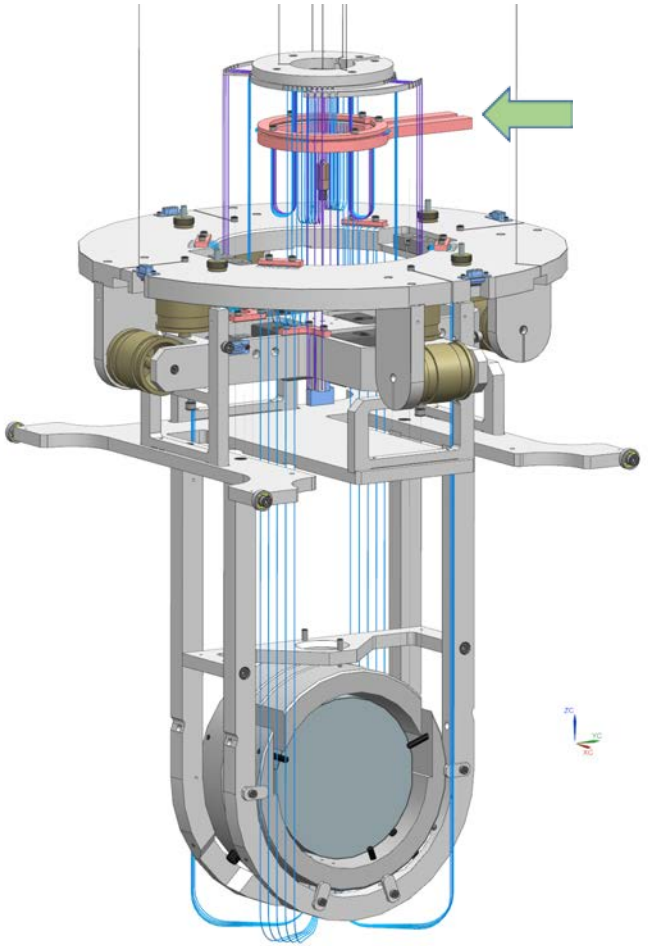


Sorption cooler design for ETpathfinder



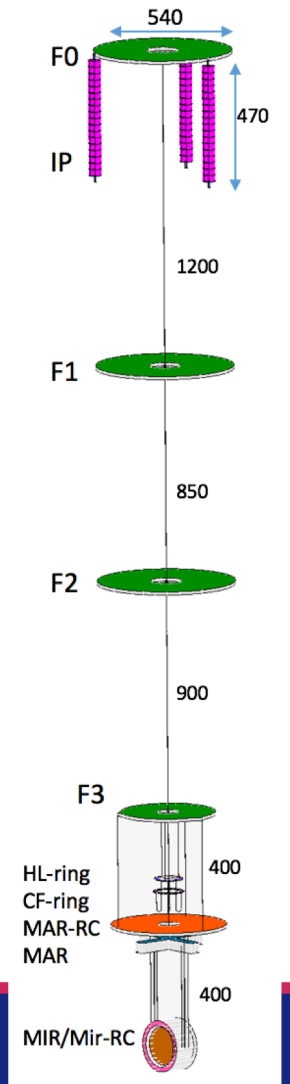
T heat sink at 70 K, entrance CFHX at 77 K			
Ne	H_2	He	Total
15 cells	5 cells	6 cells	26 cells
243 W	87 W	65 W	39 liter
			395 W



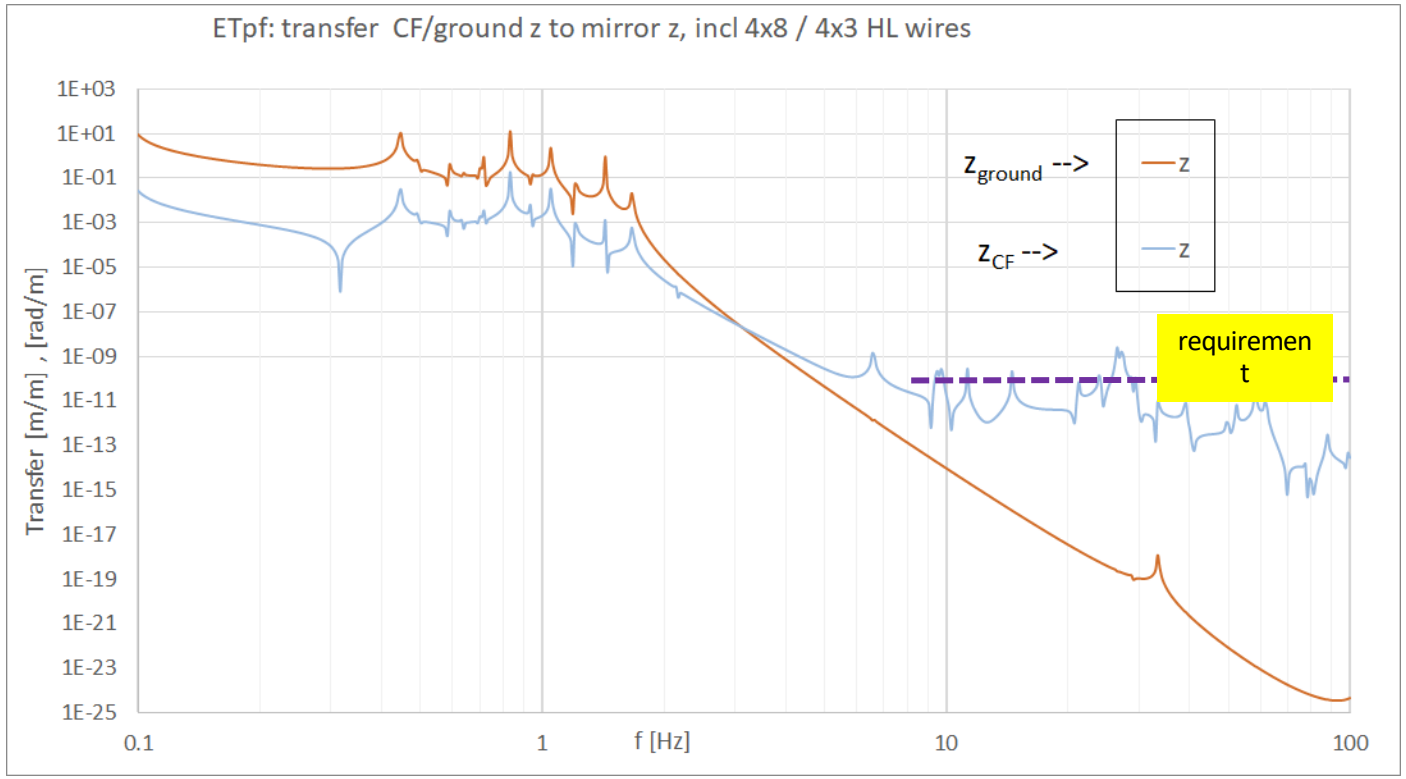


Coupling introduced by Jelly fish wires?

FEM simulated performance



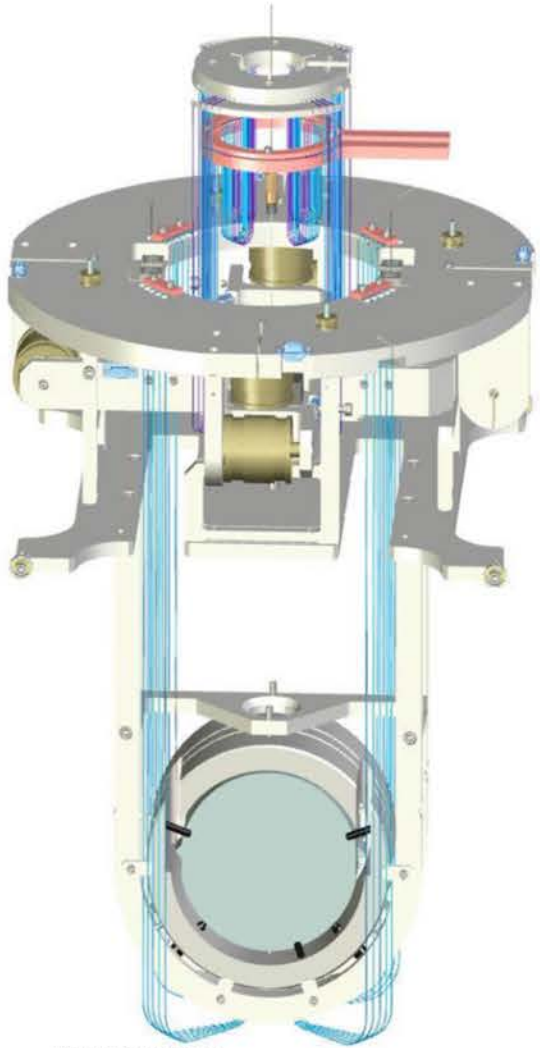
Horizontal response



Ground vibration transmission from cold finger is still dominant…no safety margin

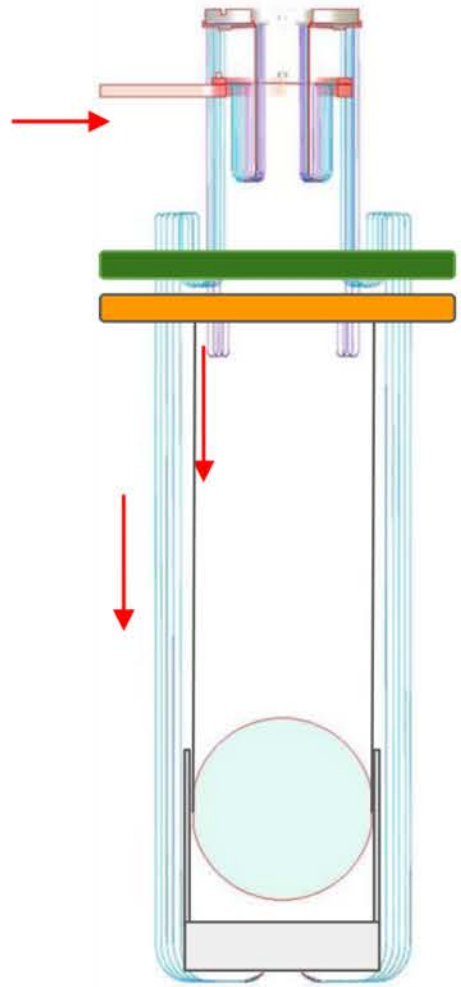
Vibration test setup

Payload prototype

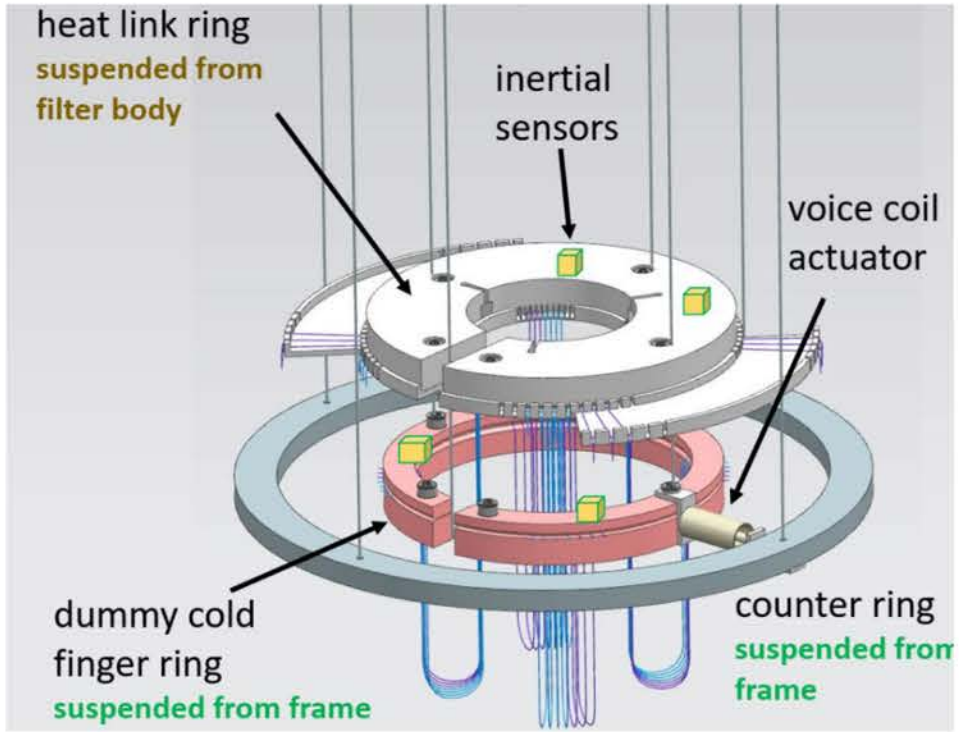


Cold Finger (CF) introduces ground vibrations

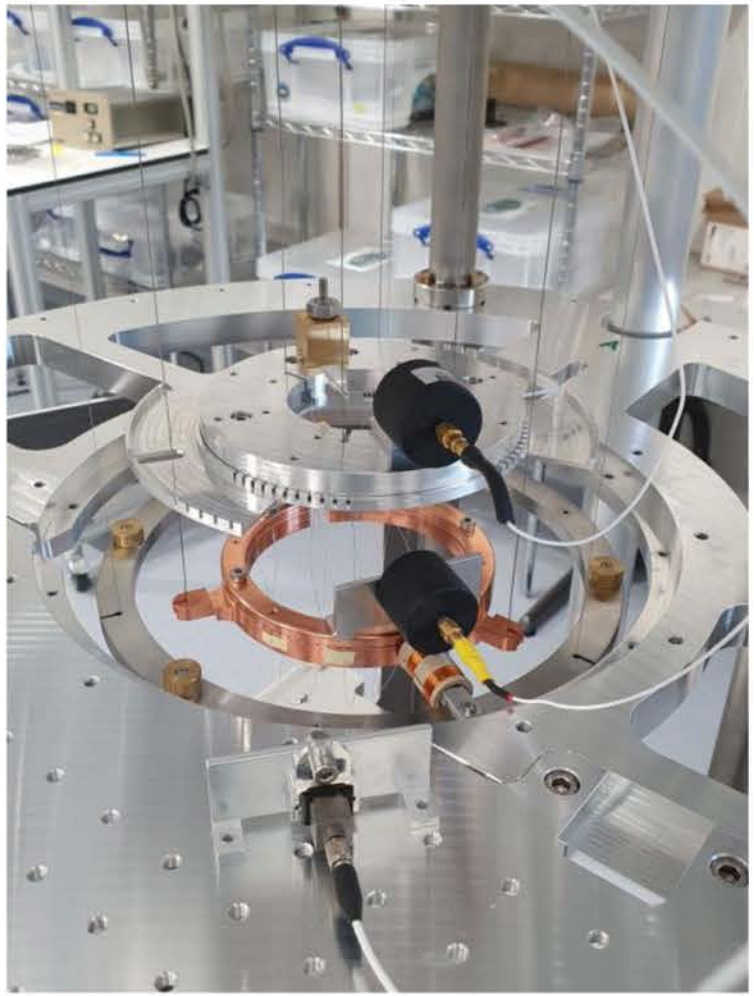
These propagate through the suspended payload chain and affect the mirror stability via the marionette

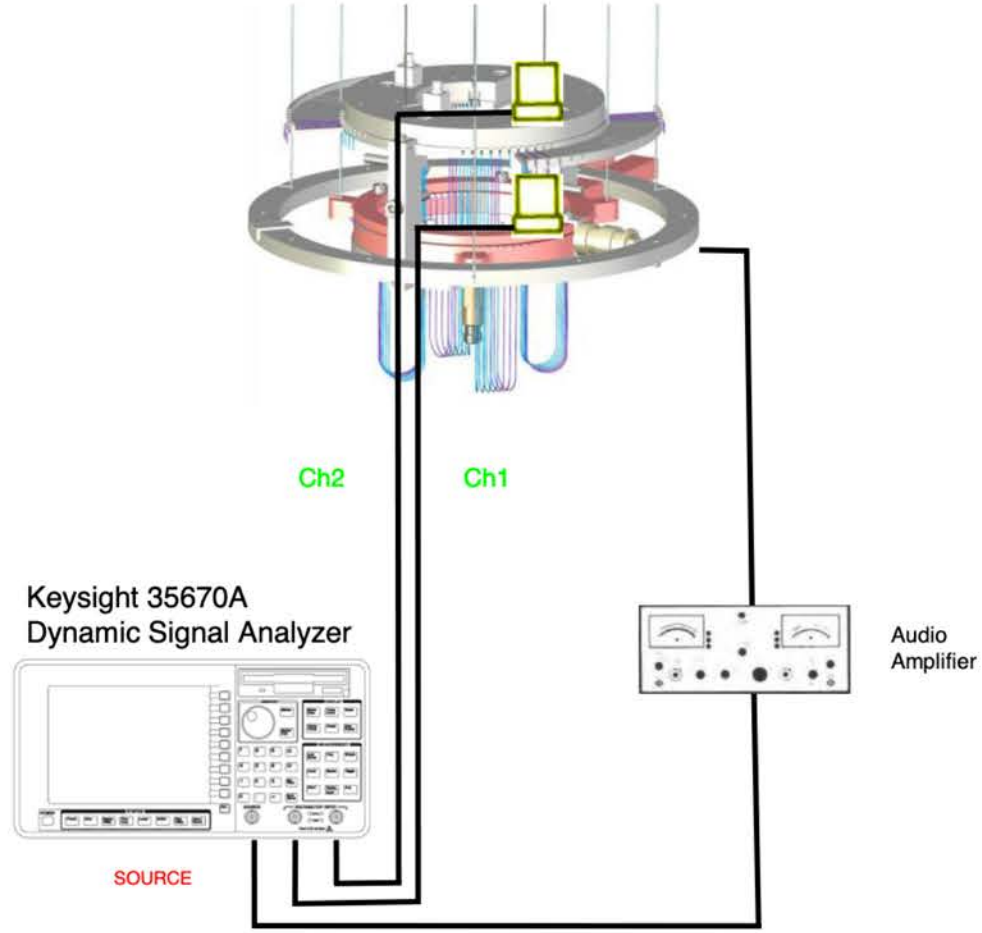


The setup purpose is to measure these vibrations via the jellyfish wires. A voice coil actuator feeds vibrations which are sensed by accelerometers placed on target masses.

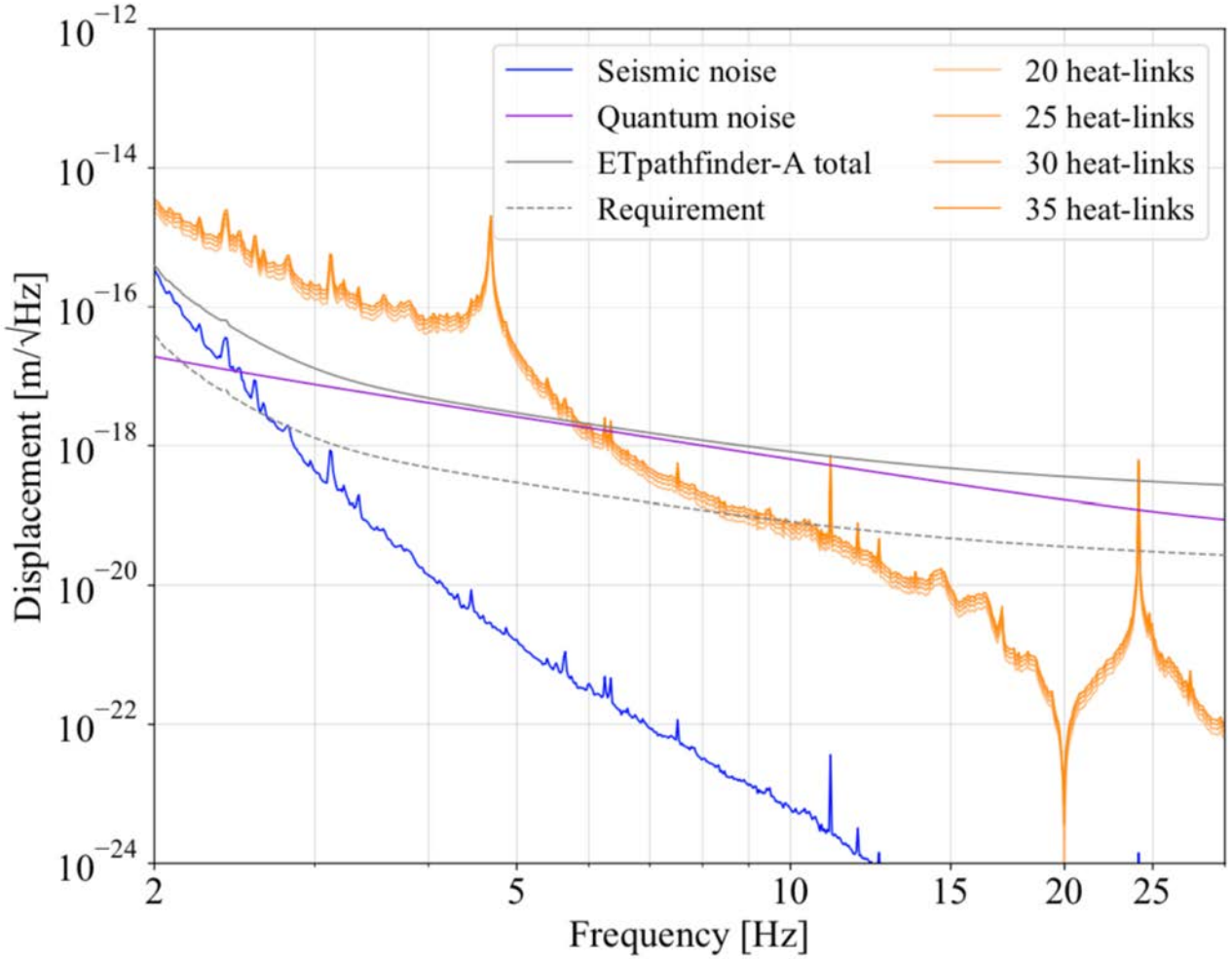


Test Setup and configuration





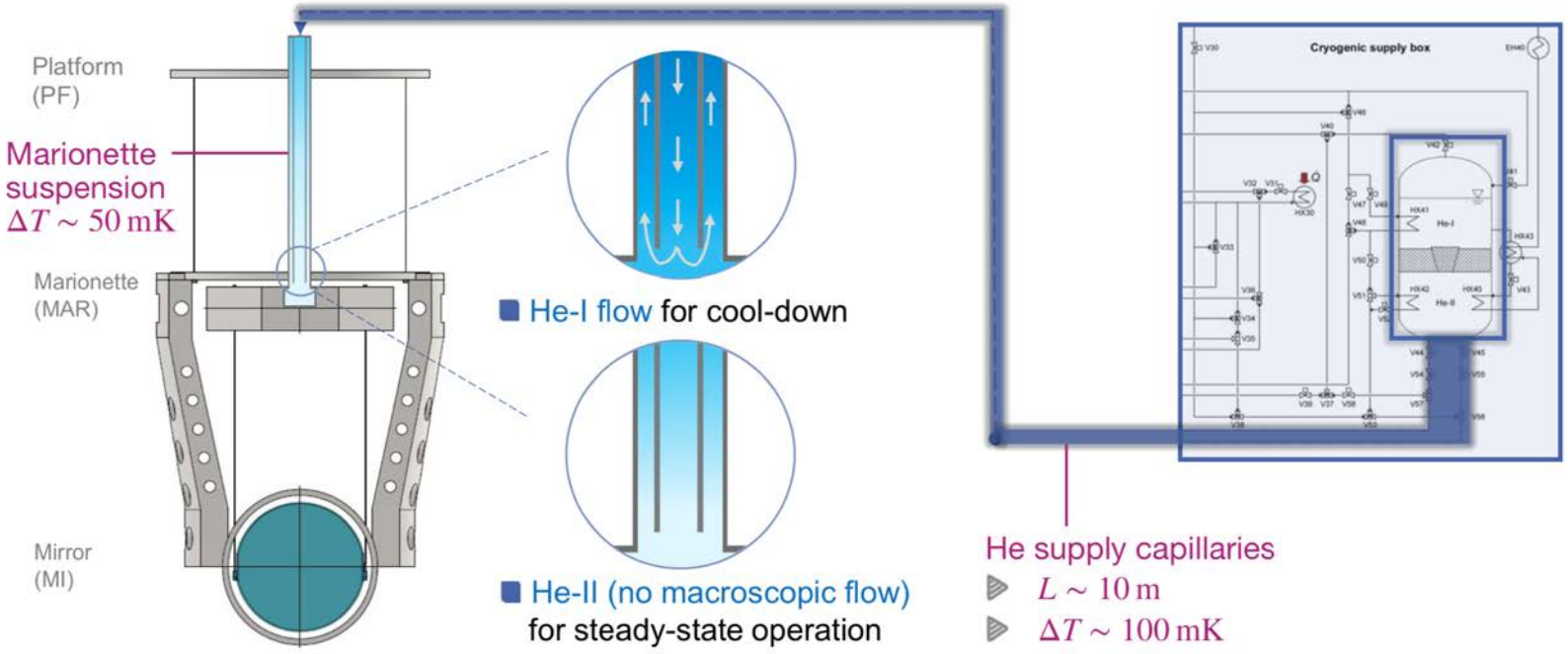
Projected noise for ETpathfinder



Other cooling strategy persued within ET: HeII

He-II detector cooling concept

Karlsruhe Institute of Technology



35 26.08.2022 S. Grohmann et al. – Cryogenics for ET – European Cryogenics Course 2022 Organisational Unit: Refrigeration and Cryogenics

Thank you for your attention.

Questions?