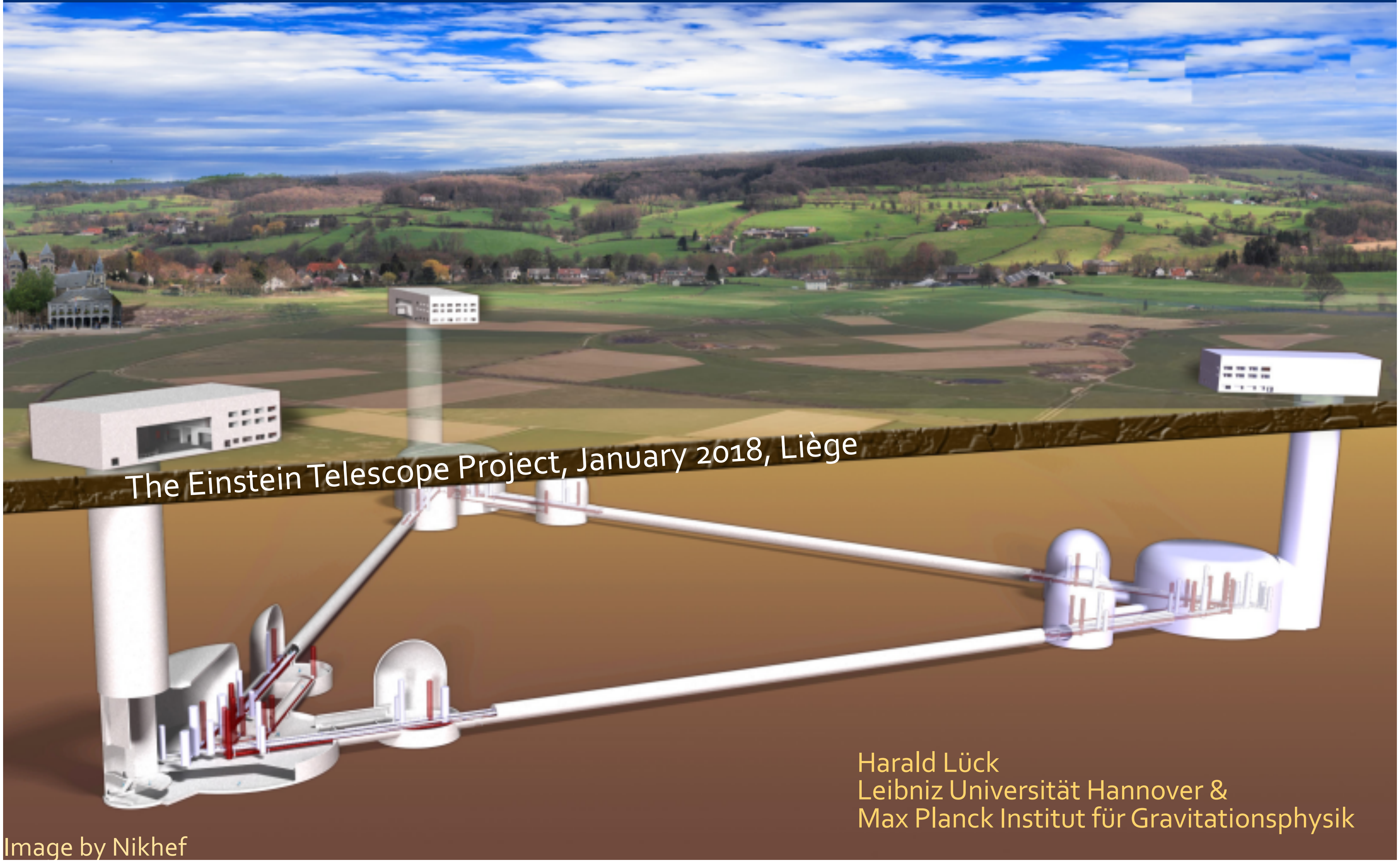
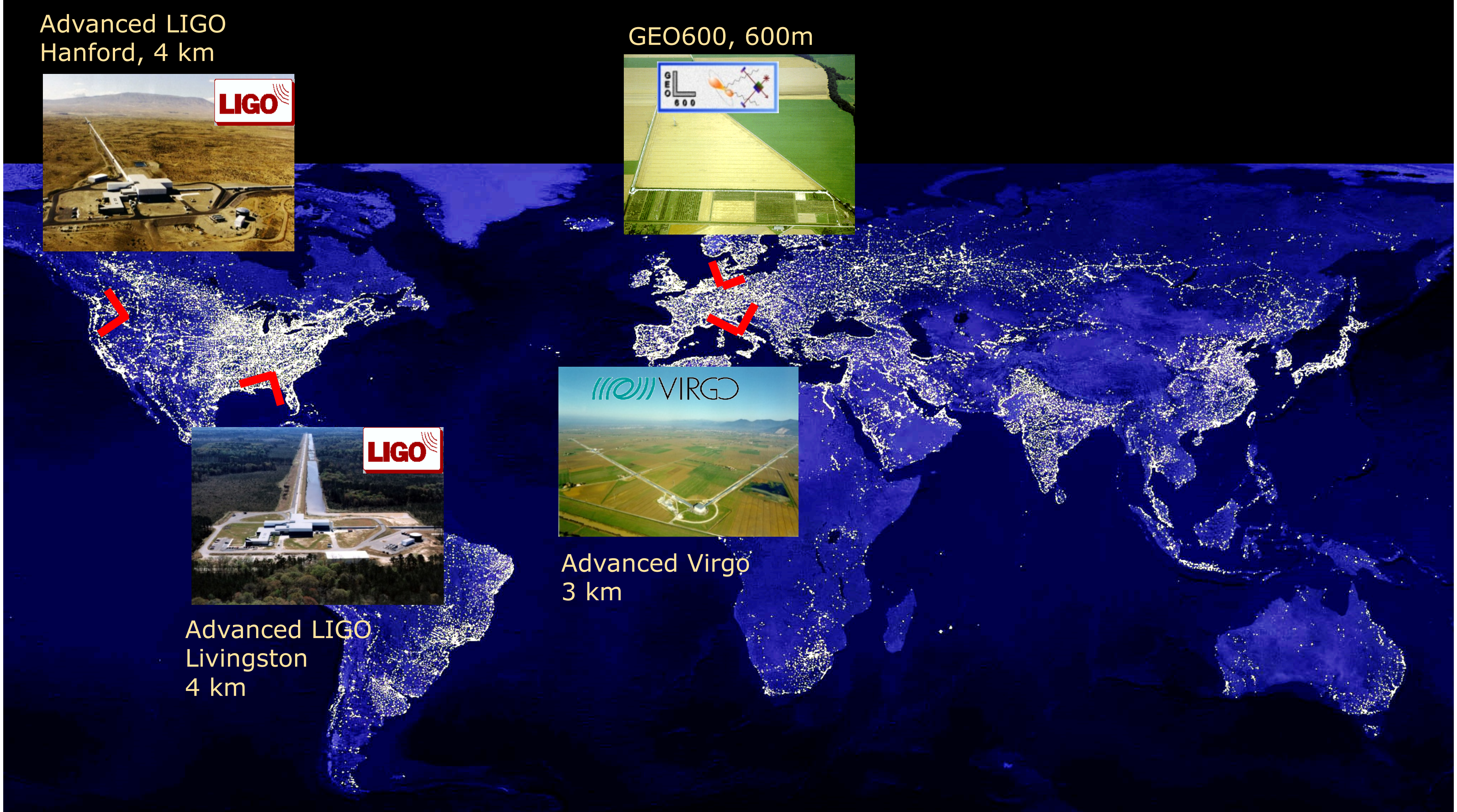
FROM THE ADVANCED DETECTORS TO THE EINSTEIN TELESCOPE



Harald Lück
Leibniz Universität Hannover &
Max Planck Institut für Gravitationsphysik

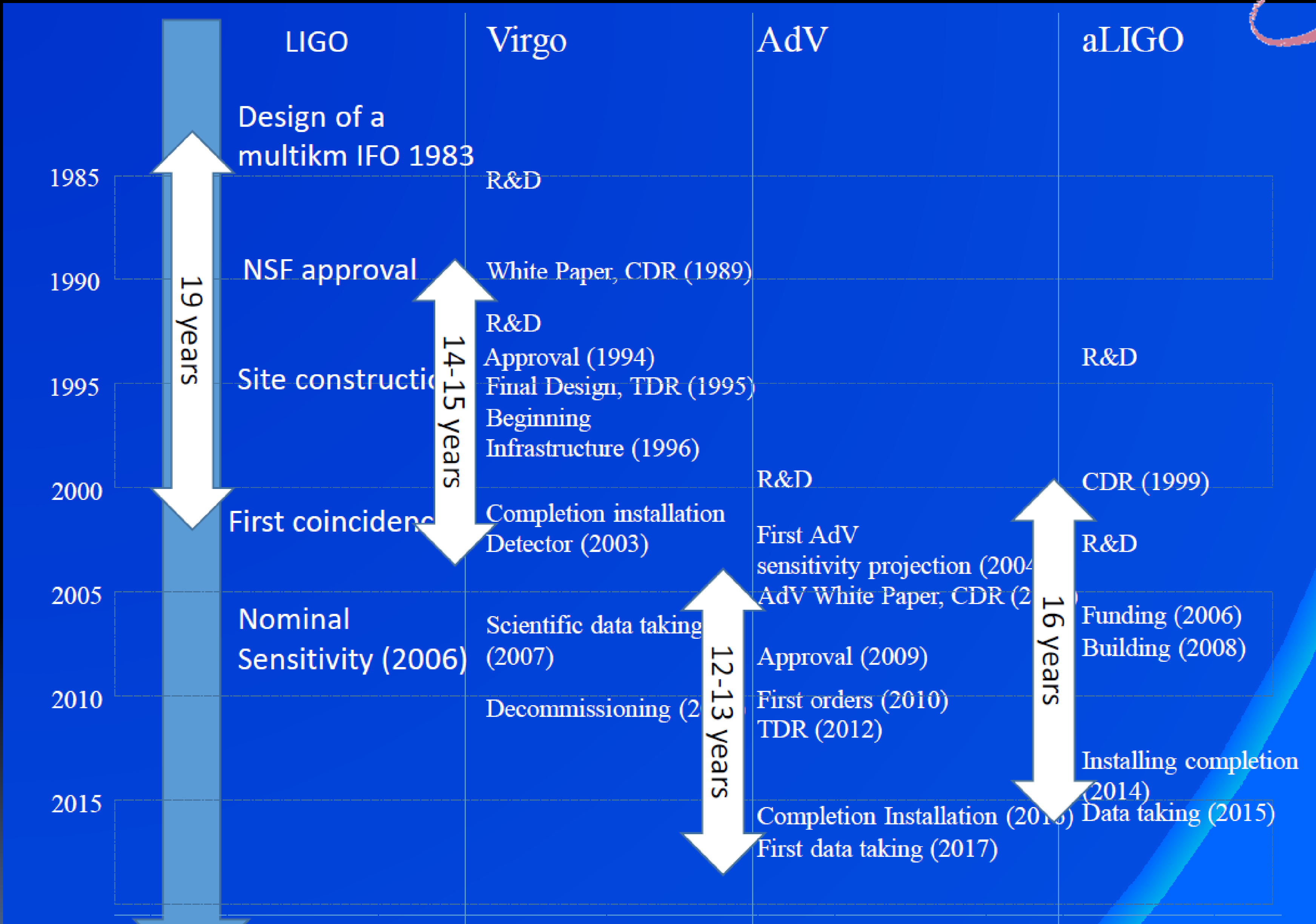
Image by Nikhef

The current GW Network



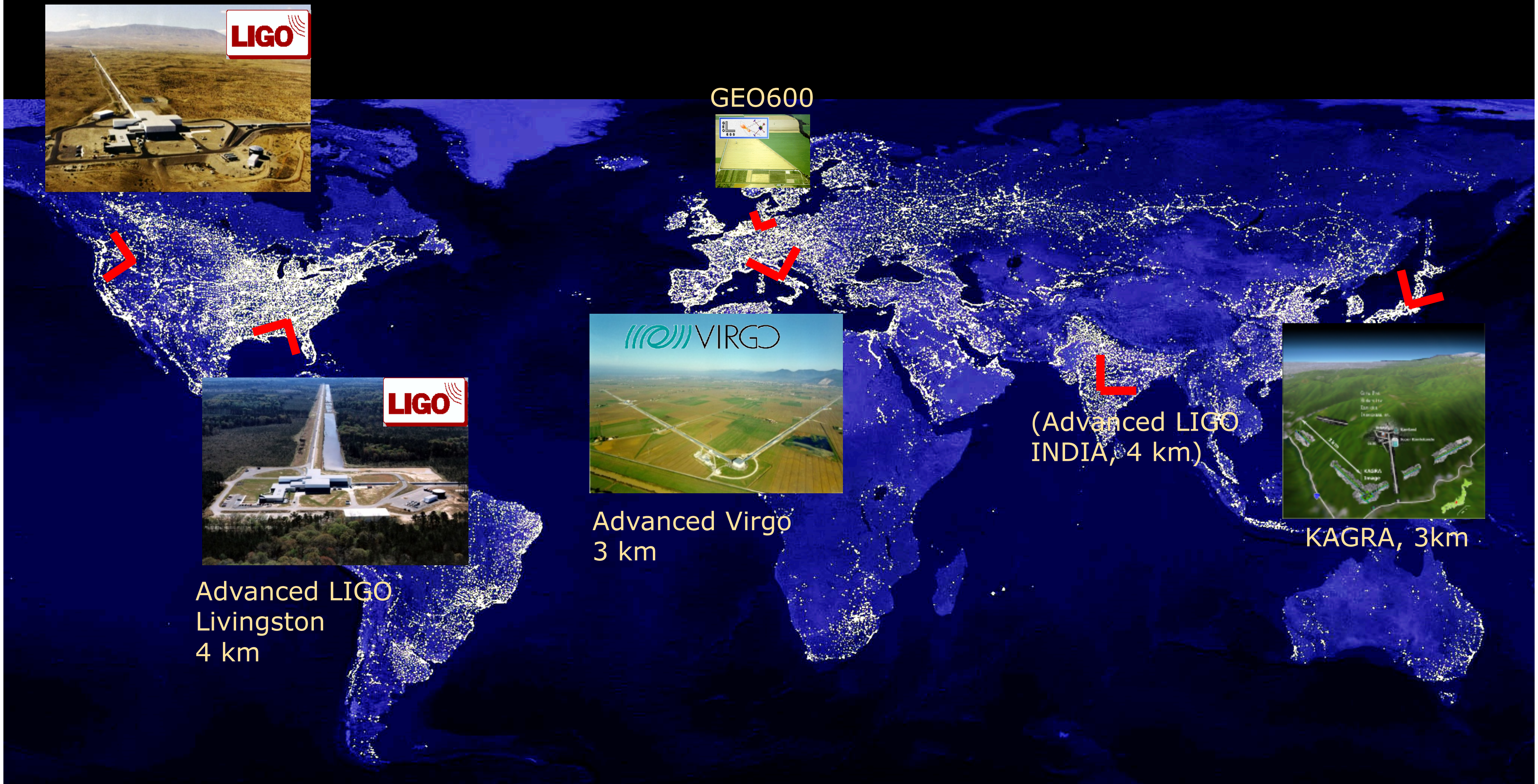
Duration of building GW Detectors

Slide : Michele Punturo

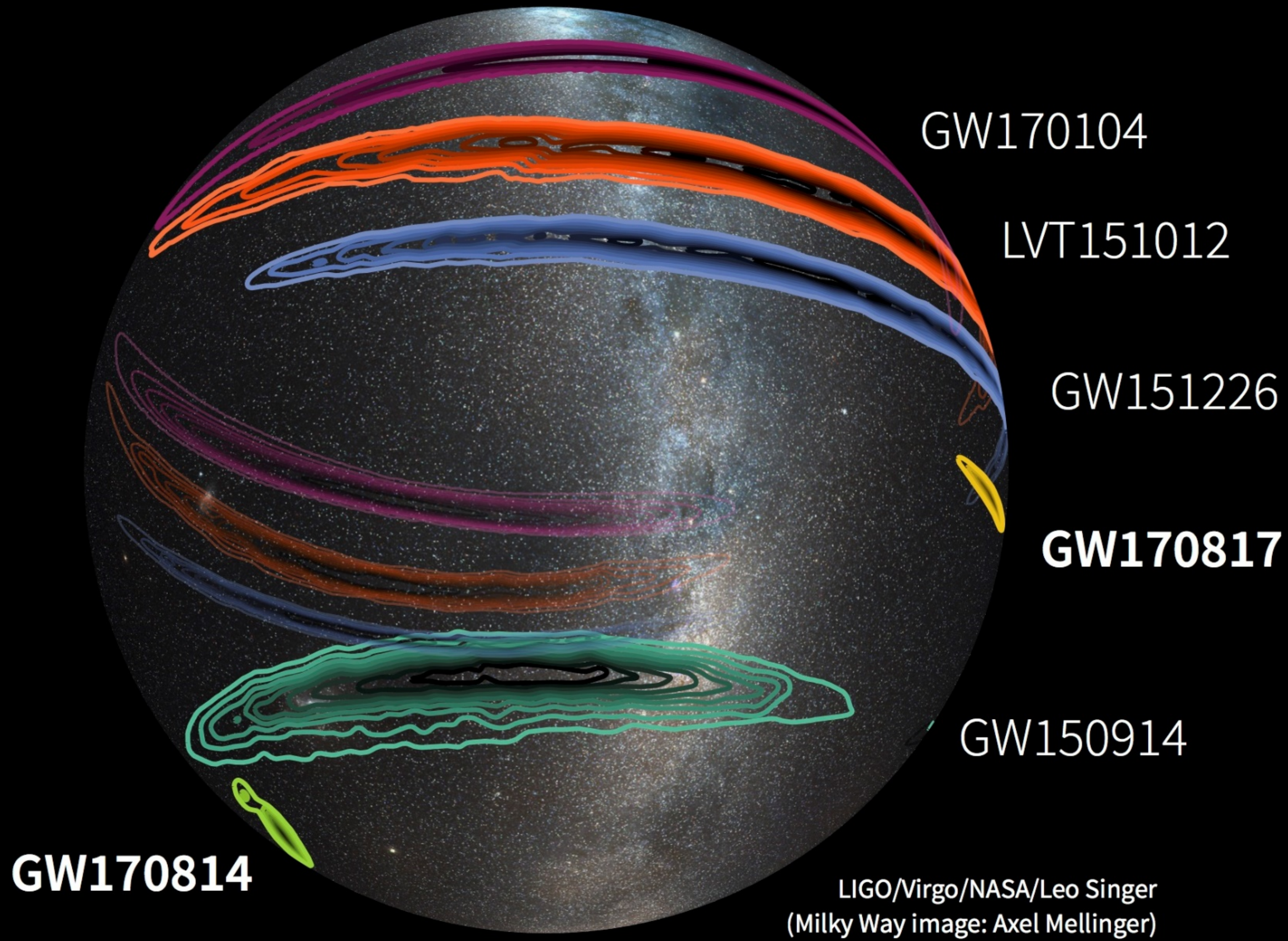


The full advanced GW Network (>2024)

Advanced LIGO
Hanford, 4 km

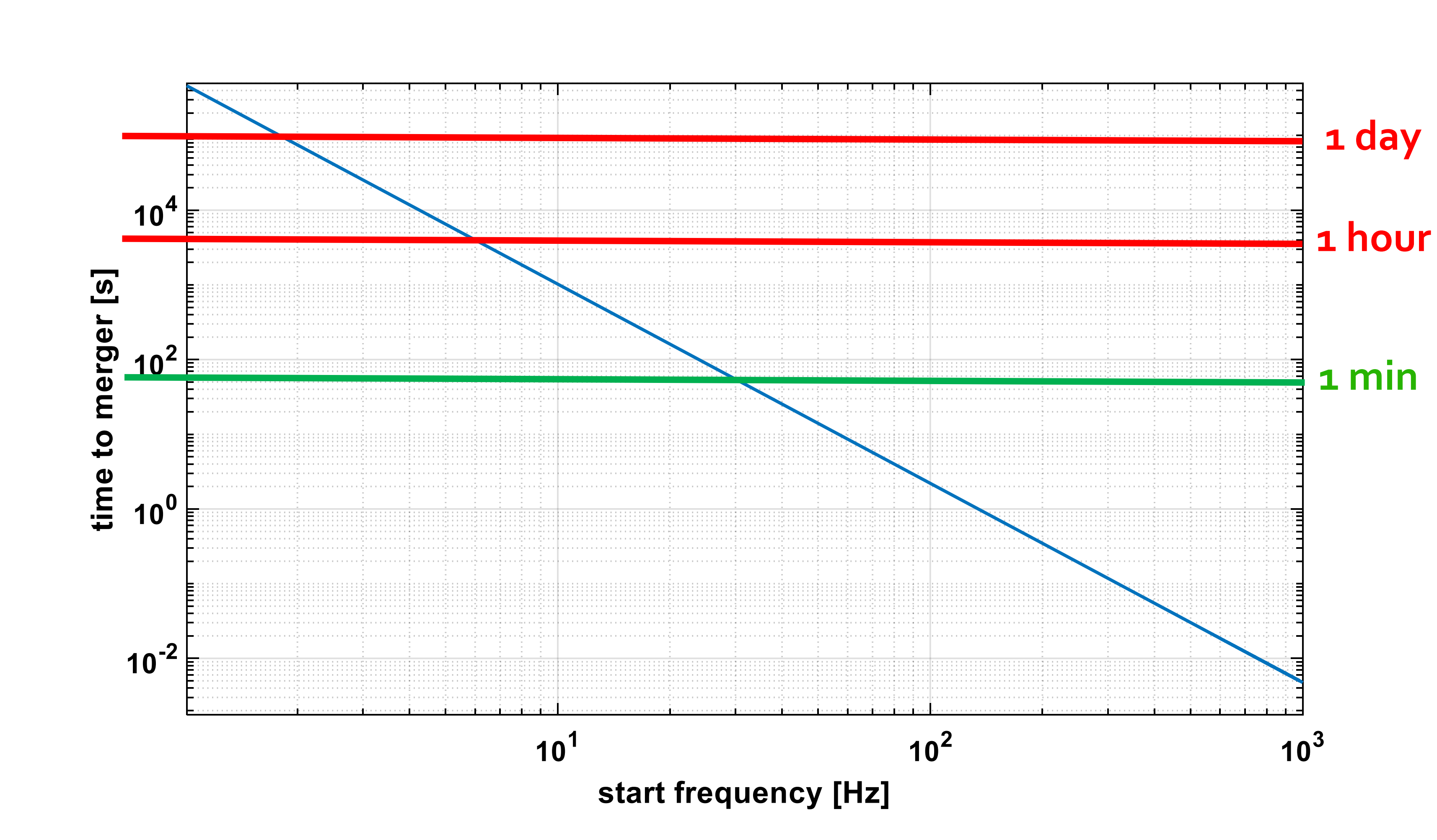


Triangulation of sources

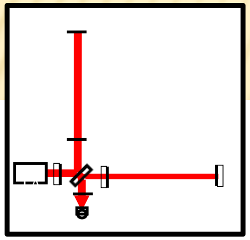


Global GWD positions

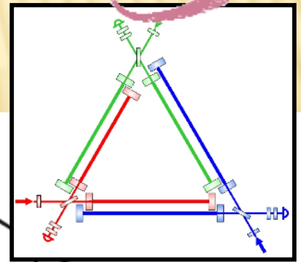
NS-NS „In Band“ duration

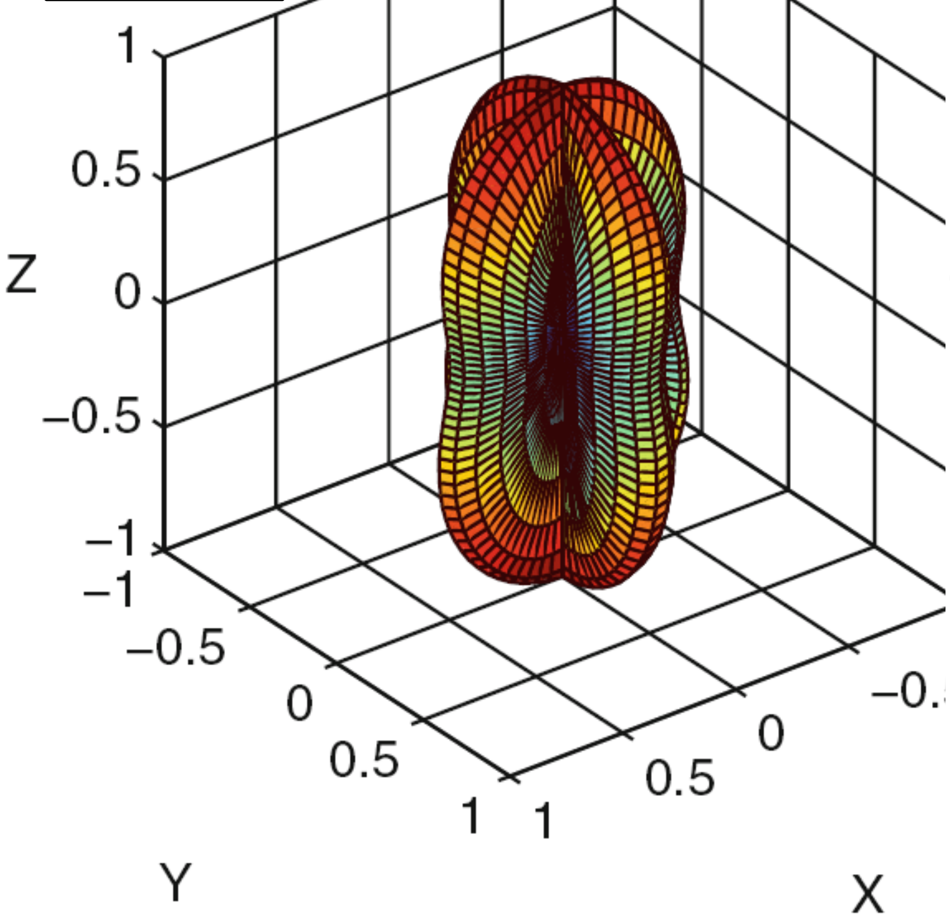


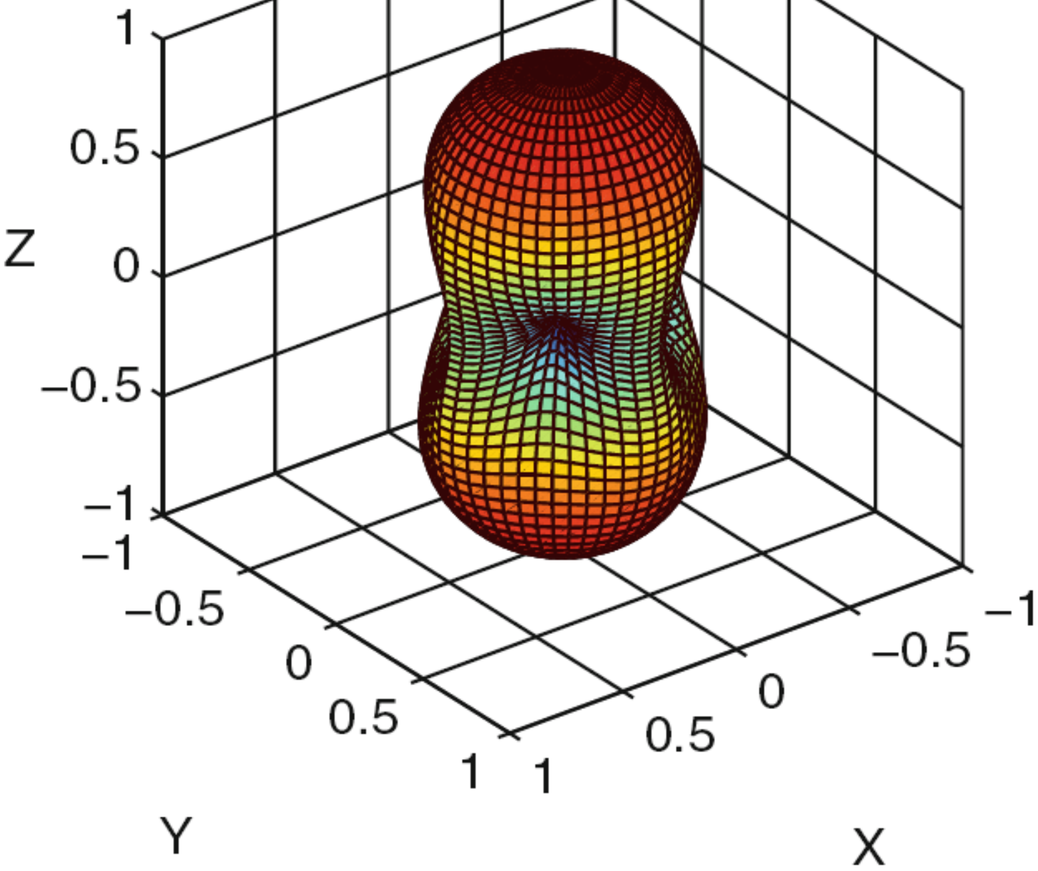
ANTENNA PATTERN



simple Michleson vs. triple Michelson



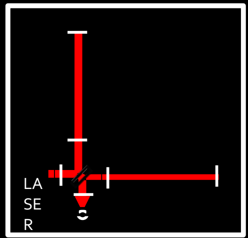


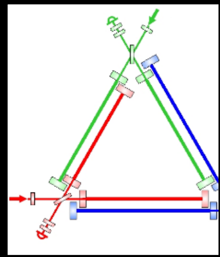


Freise et al. DOI 10.1007/s10714-010-1018-0

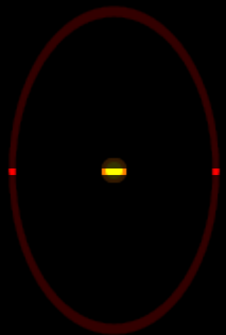
Polarisation

L-Shaped

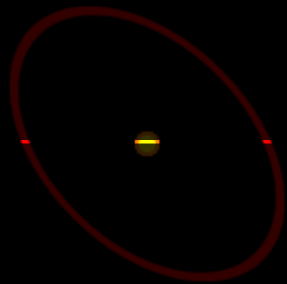




ET-Shape



+ polarization



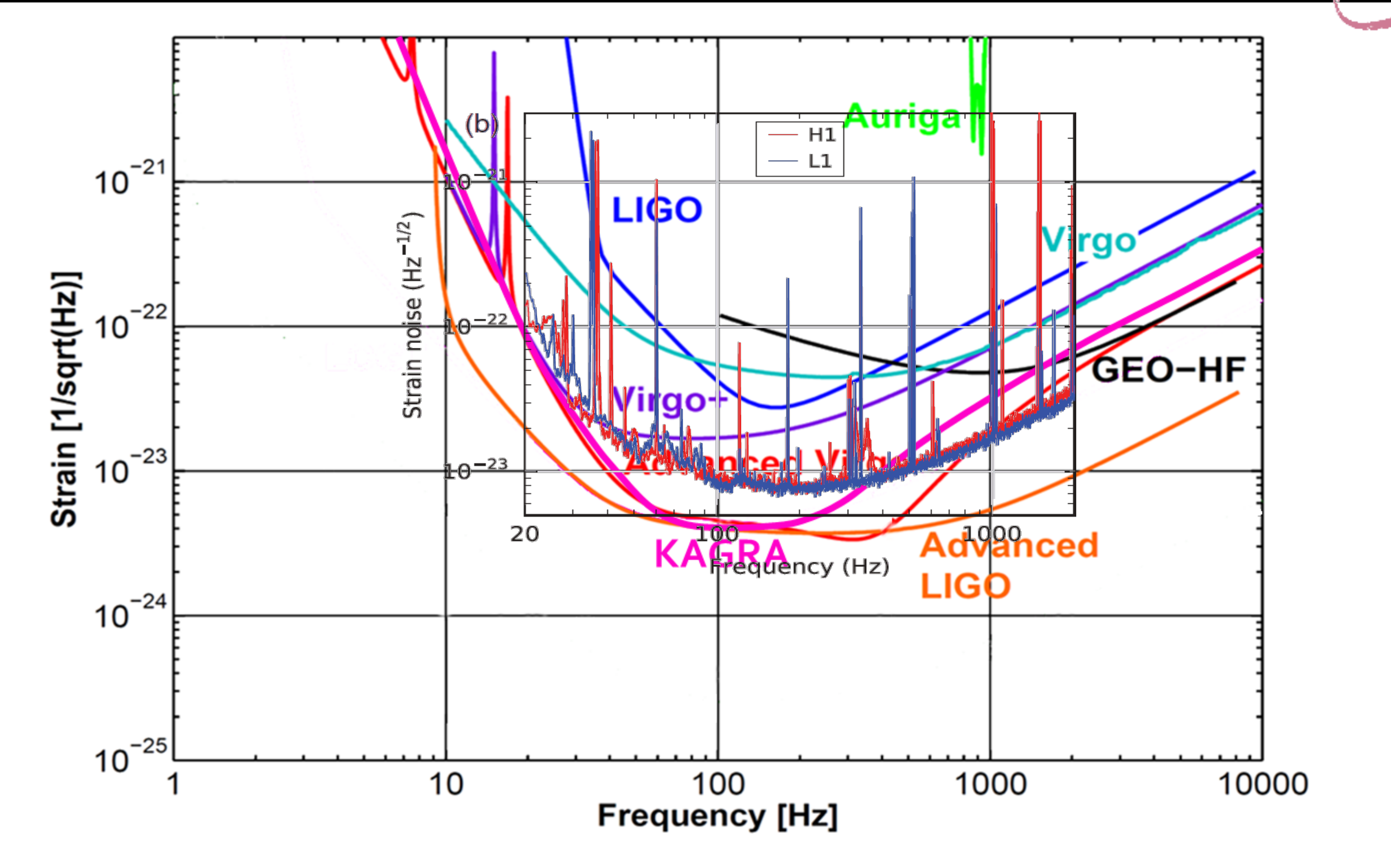
× polarization

left polarization

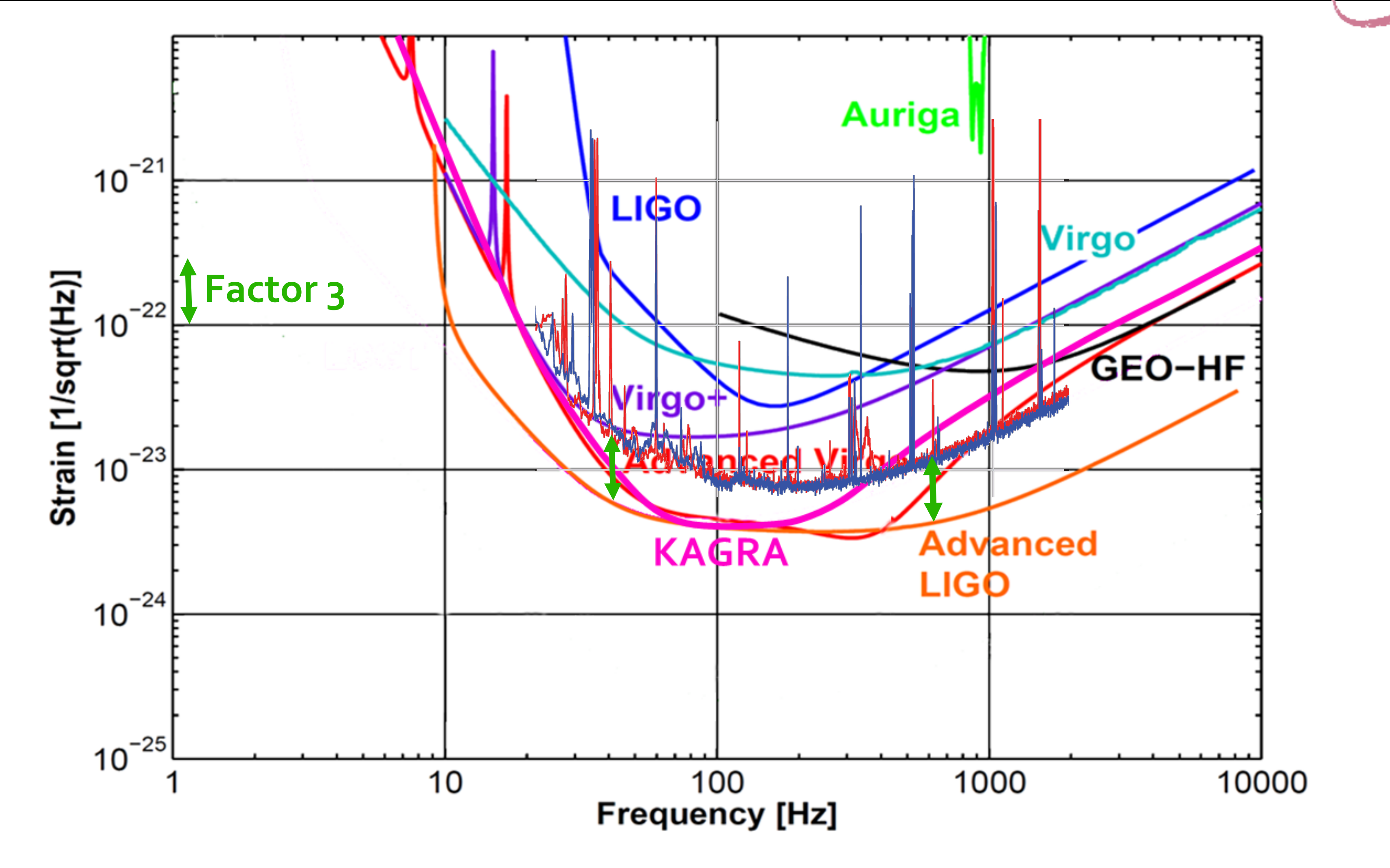
right polarization

Gifs from http://www.tapir.caltech.edu/~teviet/Waves/gwave_details.html

Sensitivity evolution



Still ca. 3x to aLIGO design

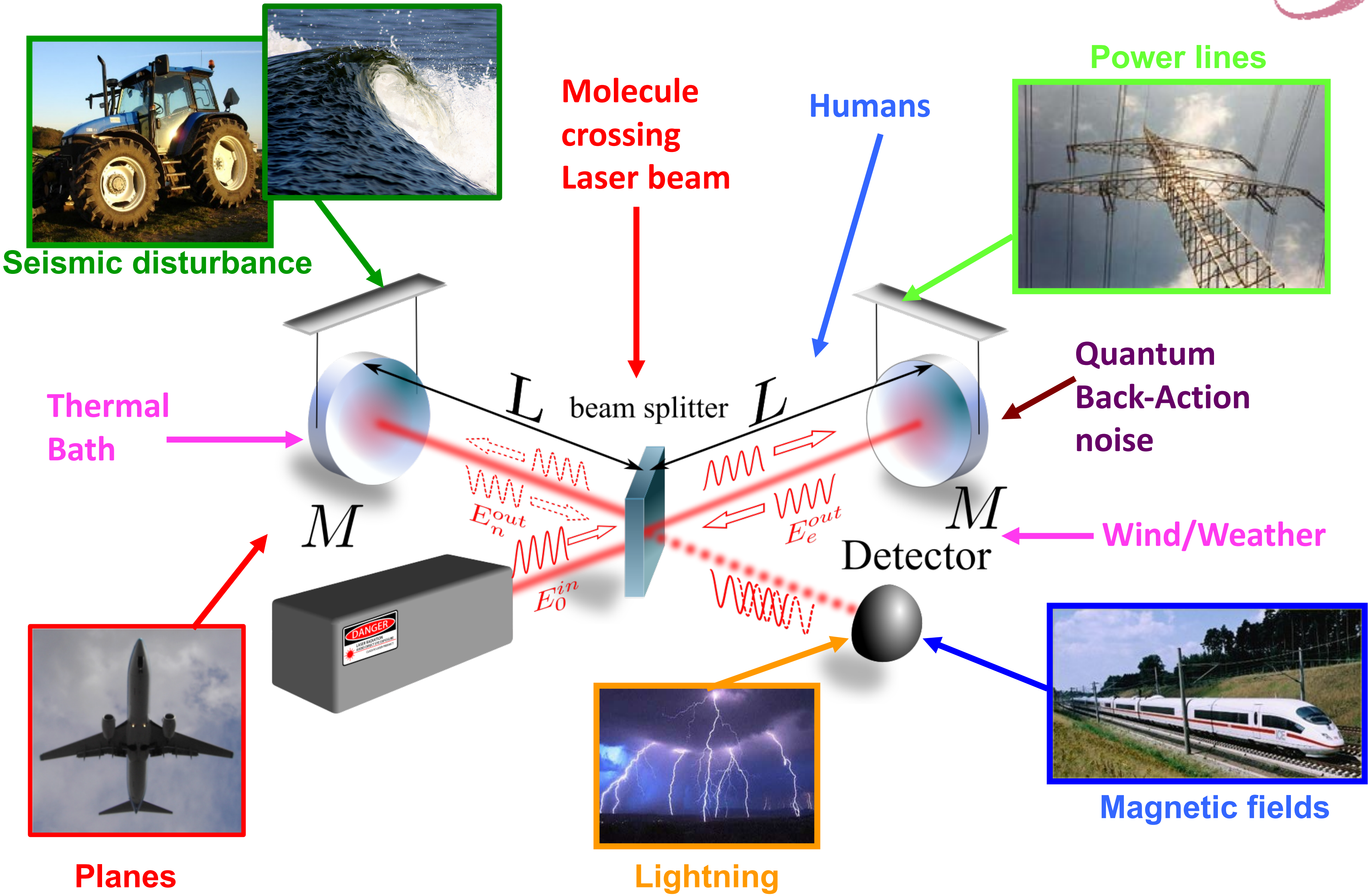


Factor 3 in sensitivity → factor 3^3 in event rate

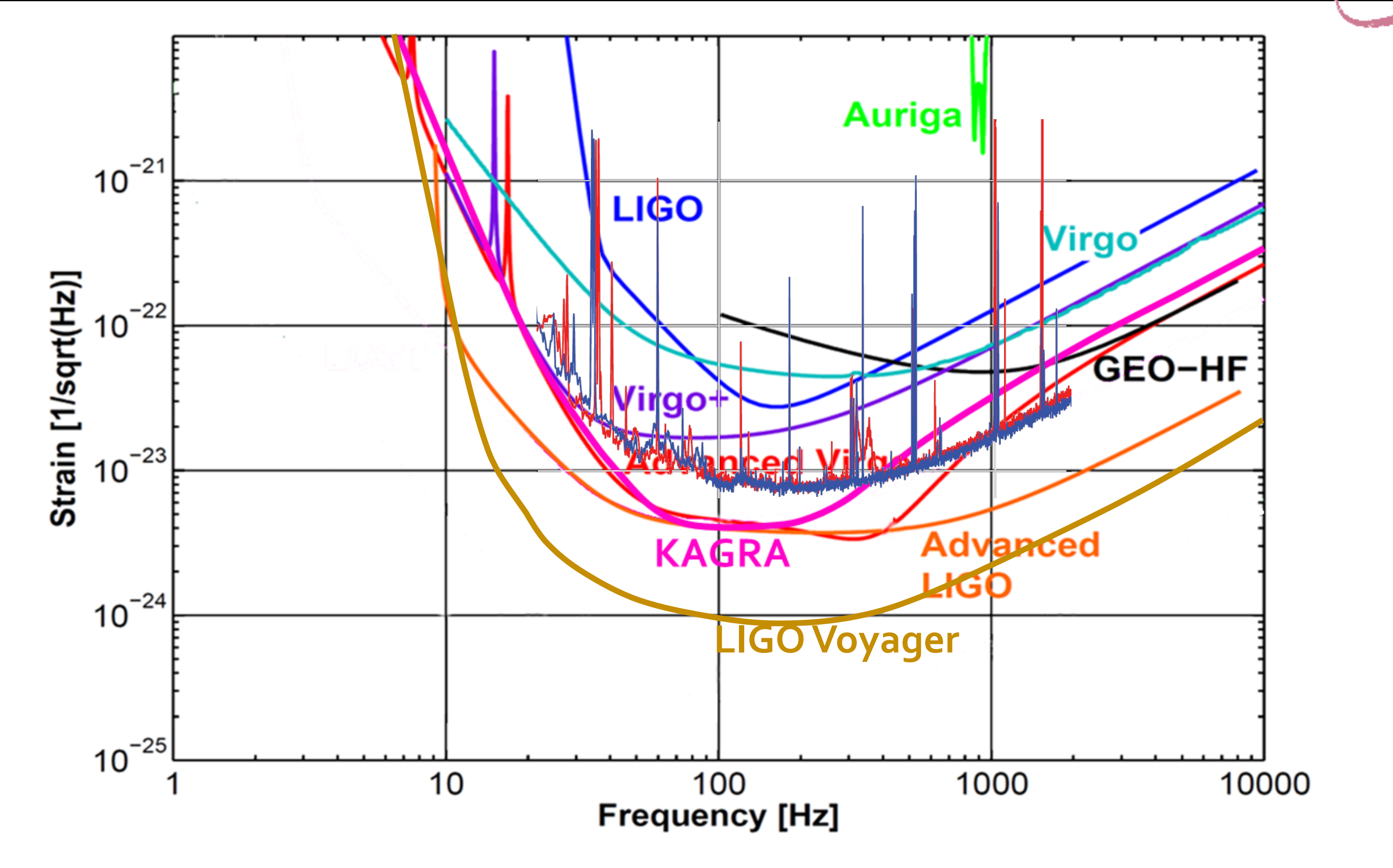
See also: D. V. Martynov *et al.*, Phys. Rev. D 93, 112004 – Published 2 June 2016

Myriad of Disturbances

Slide: S. Danilishin



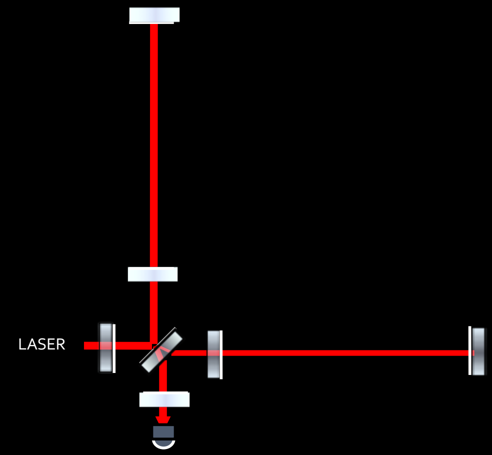
Limits of the infrastructure



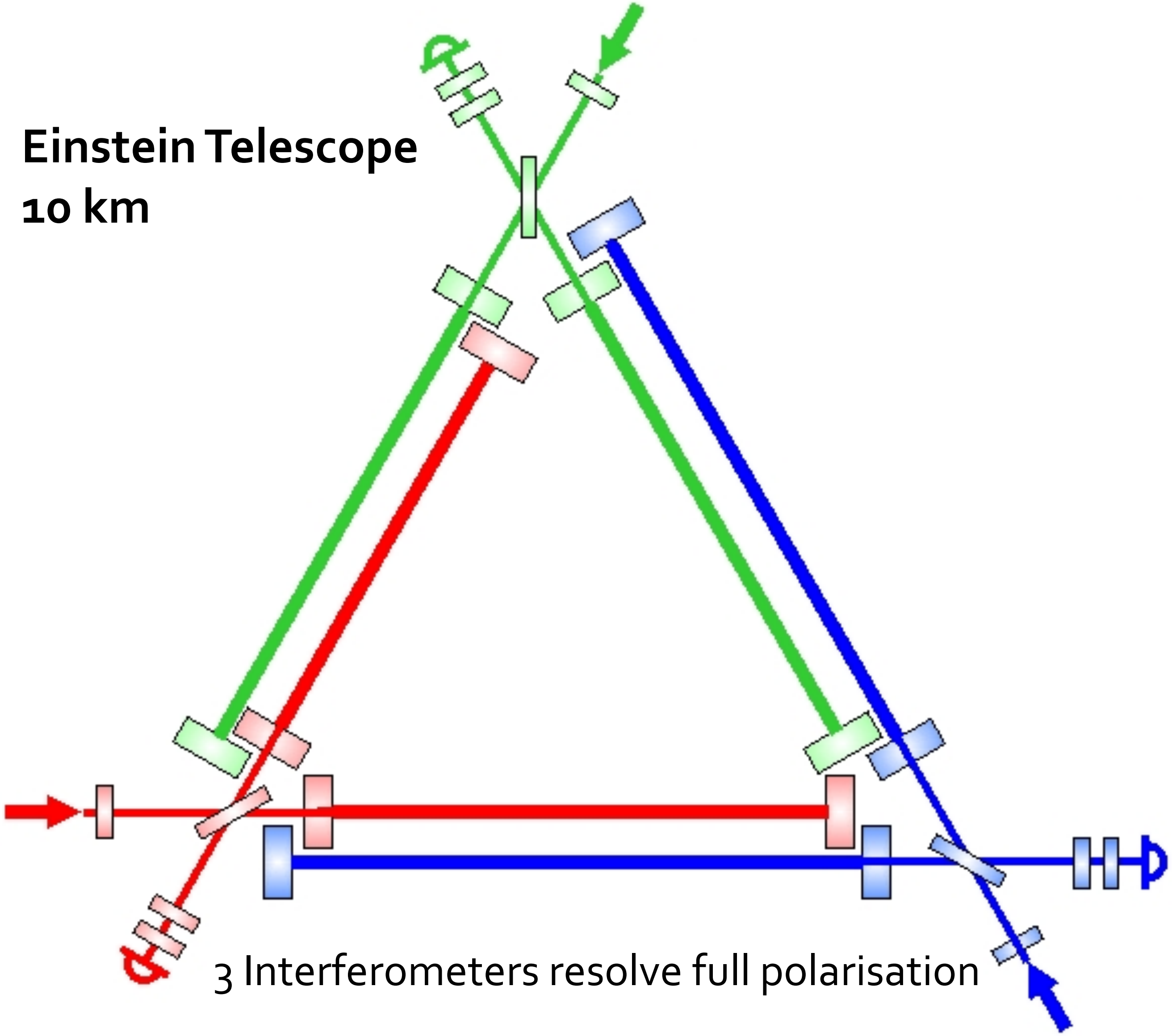
Voyager sensitivity transcribed from https://dcc.ligo.org/LIGO-G1601461/public

The Size

The Einstein Telescope will have 10 km arms
→ gain a factor >2.5 w.r.t. advanced LIGO



Advanced LIGO
4 km

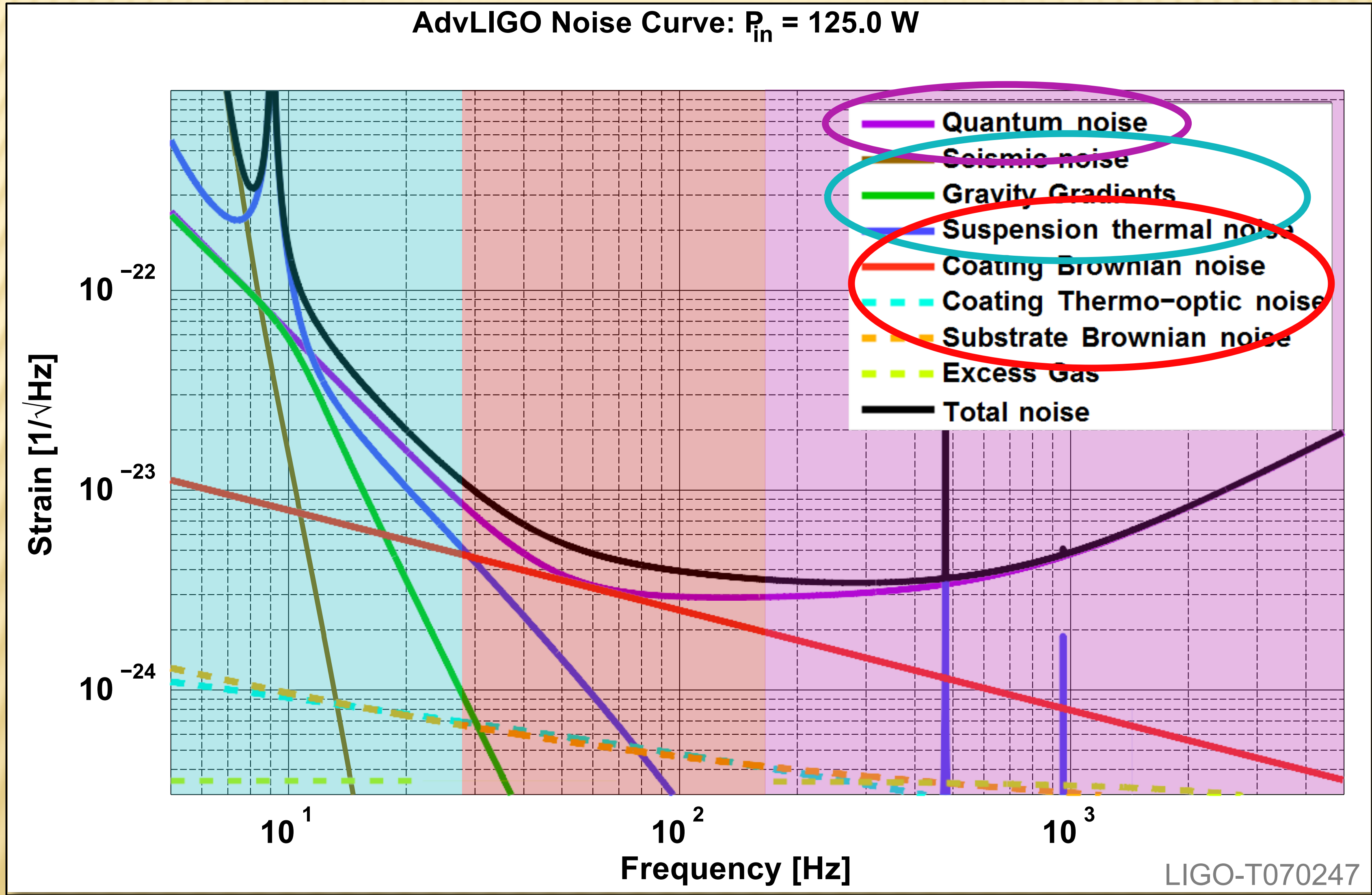


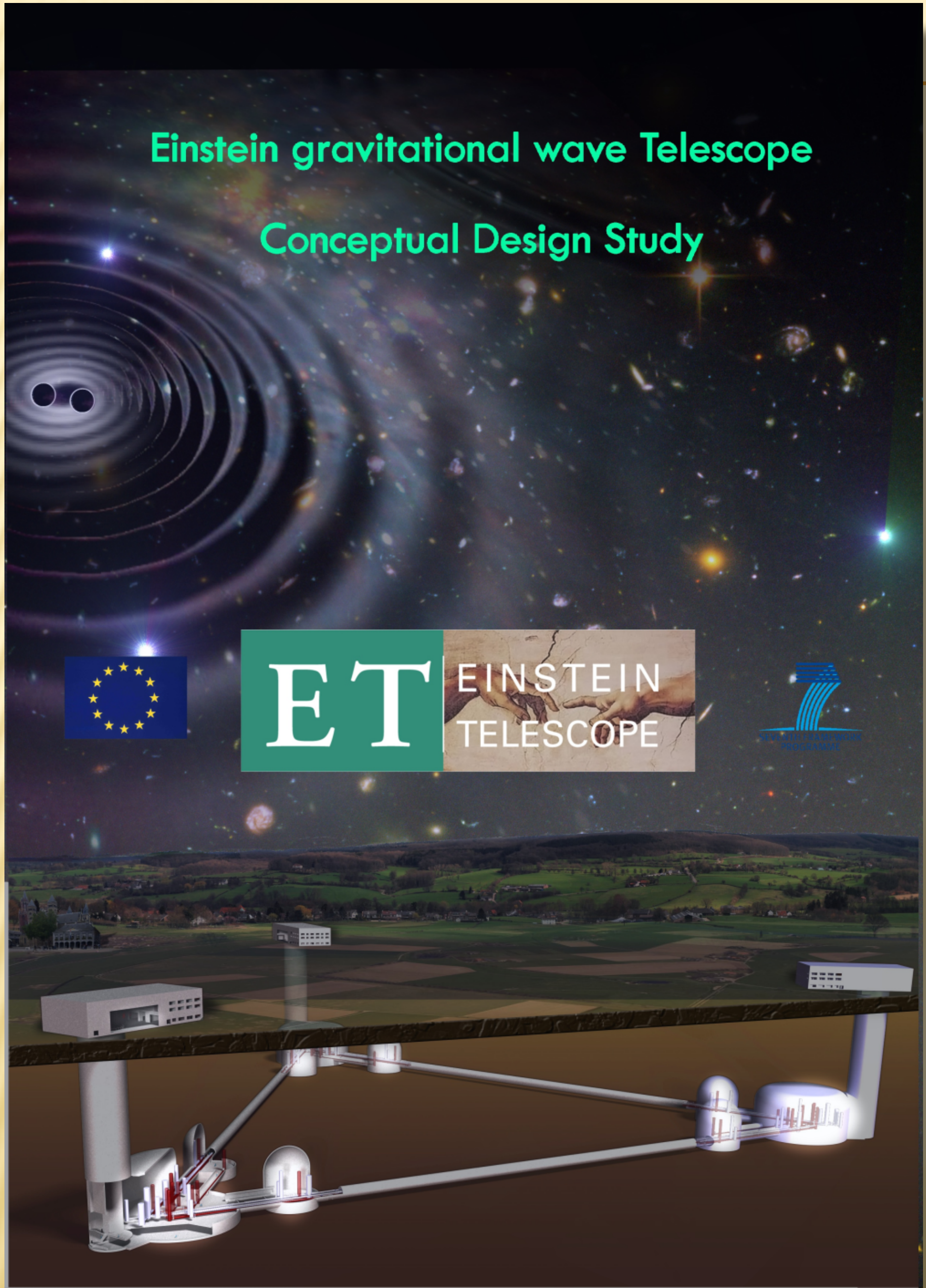
Einstein Telescope
10 km

3 Interferometers resolve full polarisation

NOISE SOURCES LIMITING ADVANCED DETECTORS

(EXAMPLE ALIGO)





Einstein Telescope Conceptual Design Study

supported by the European Commission under the FP7-design studies framework

- May 2008 - May 2011

Review and update

- Pan European effort
- Science Team = ca. 250 members

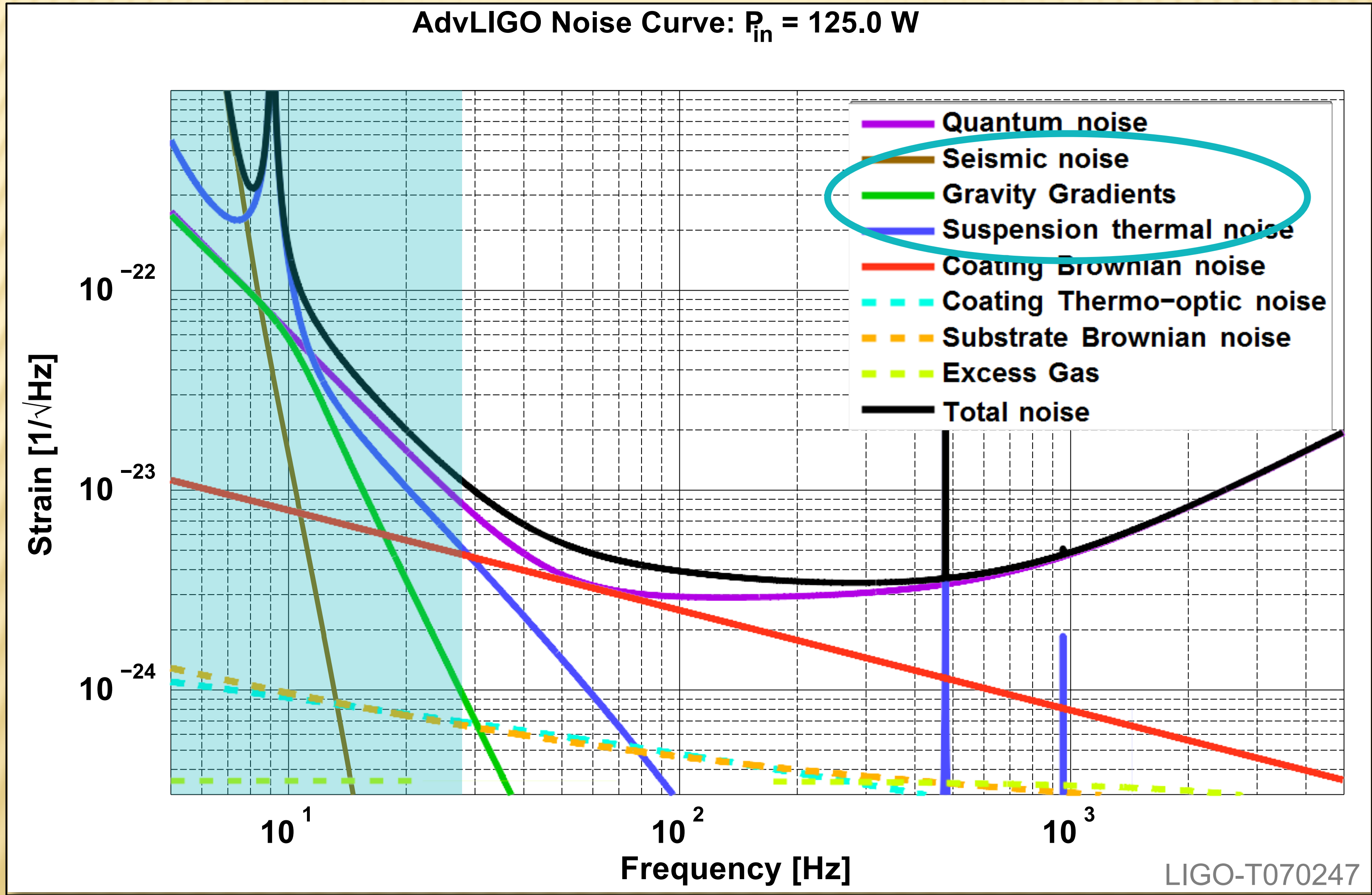
http://www.et-gw.eu/etdsdocument

EINSTEIN TELESCOPE

Updating the Design Study

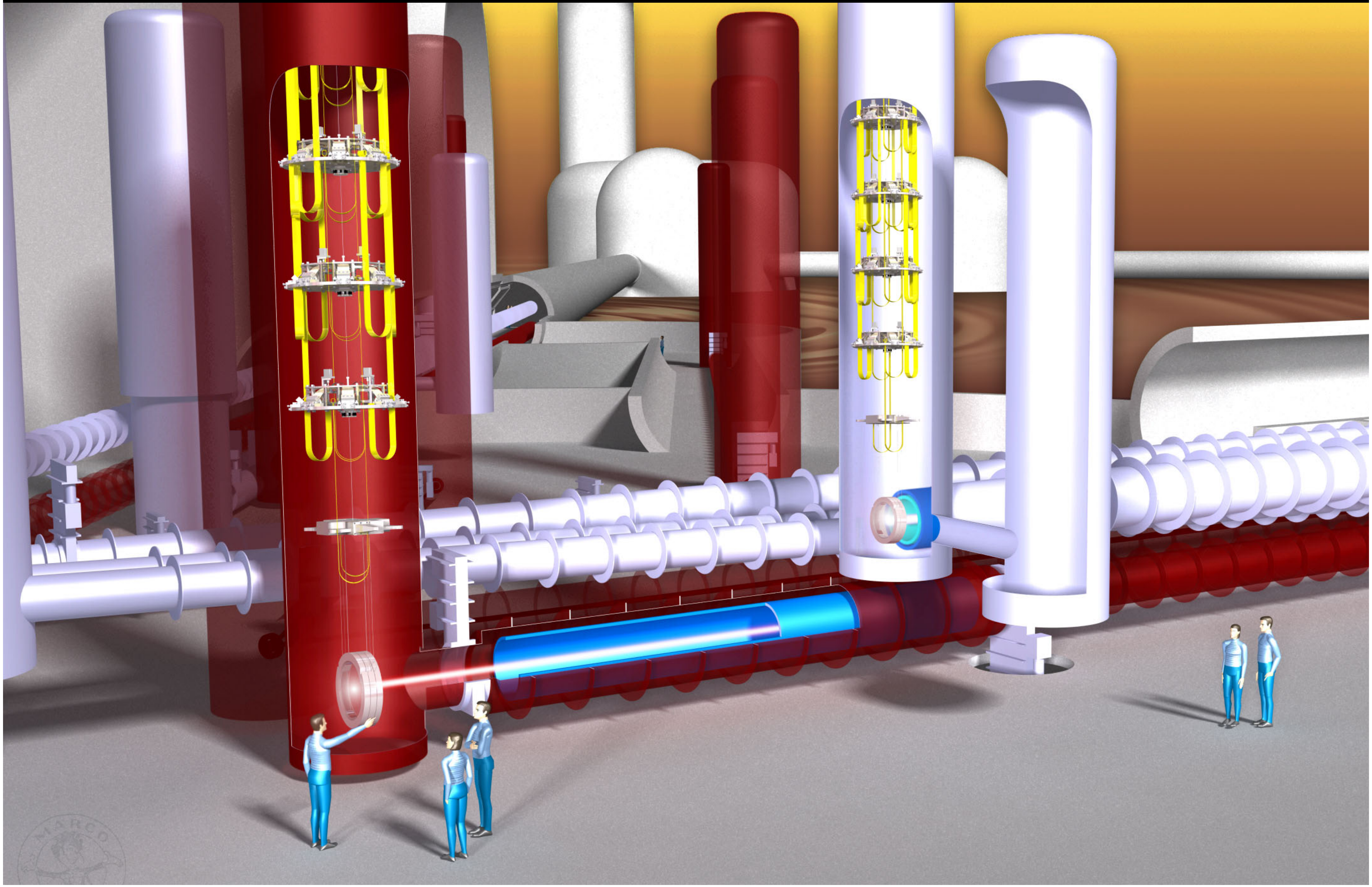
- Review the results from the conceptual design study in the light of new R&D results
- Substrate options sapphire / silicon
- Position meter vs speed meter
- Cryogenic 20K vs 120 K
- Xylophone vs single detector
- Revisit science case for low frequencies
- …

NOISE SOURCES LIMITING ADVANCED DETECTORS



ET EINSTEIN TELESCOPE

Suspension towers

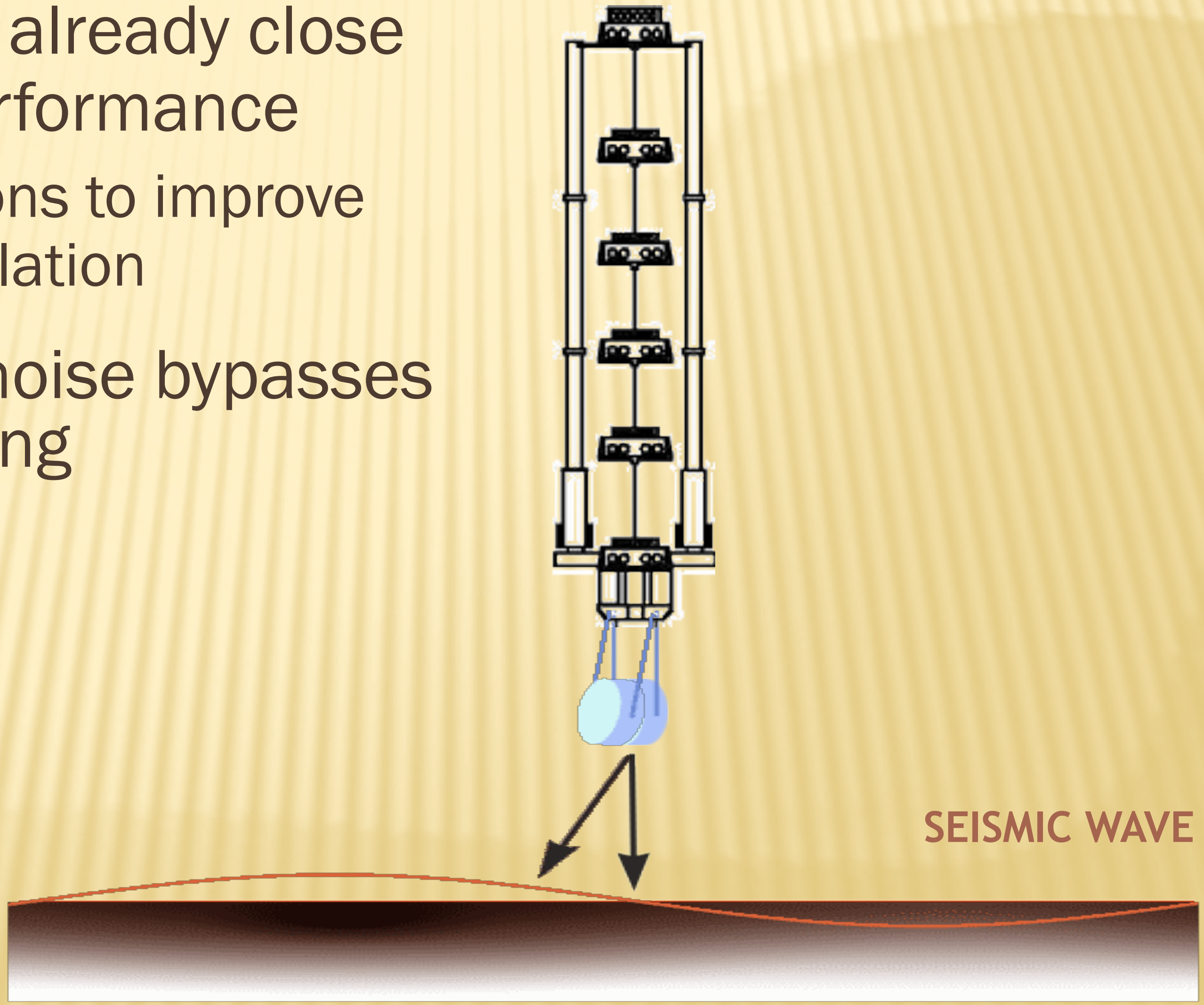


ET EINSTEIN TELESCOPE

LOW FREQUENCIES

Newtonian Noise

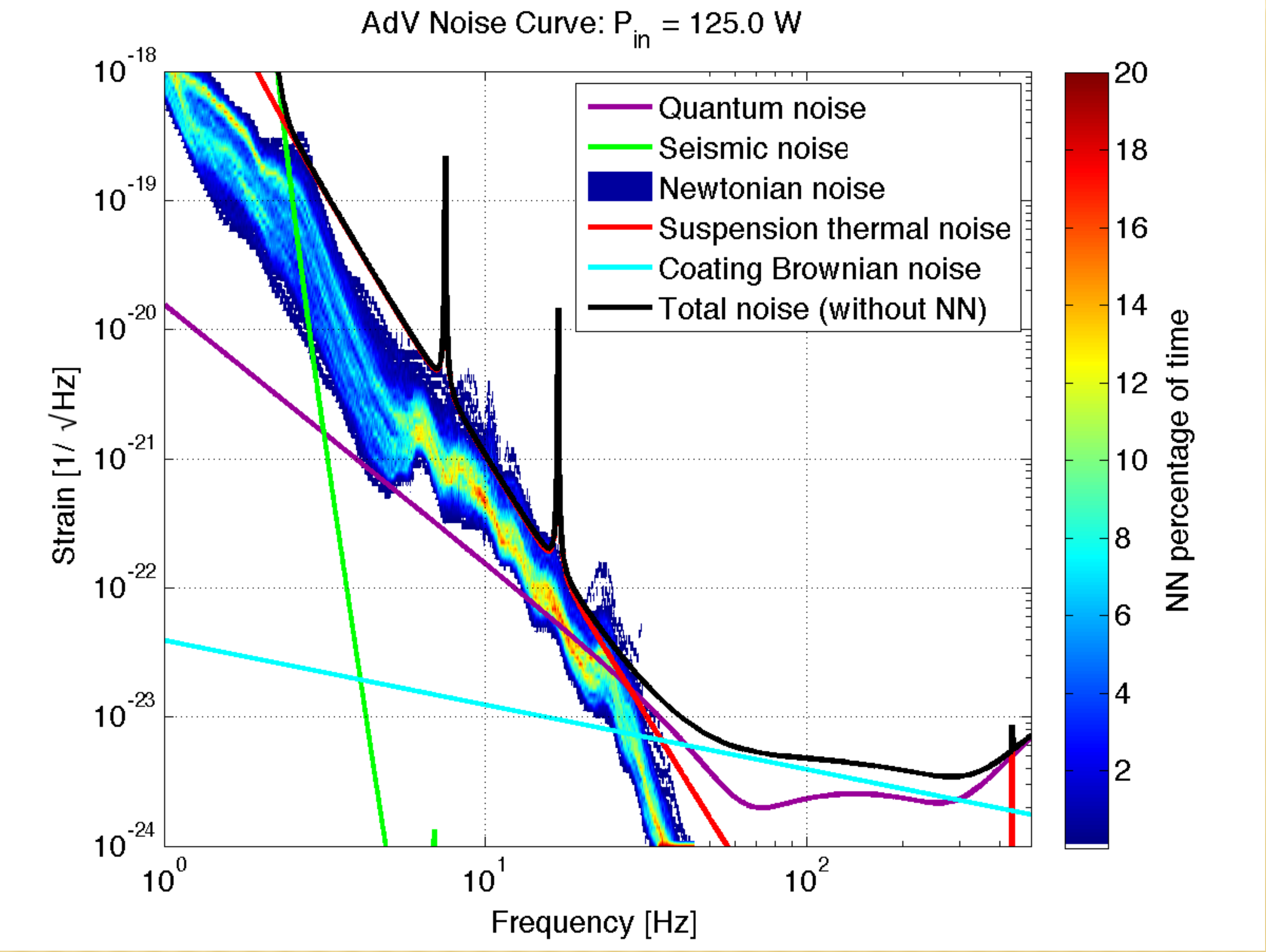
- Virgo and advanced Virgo seismic filtering is already close to the required performance
  - Longer suspensions to improve low frequency isolation
- Gravity gradient noise bypasses the seismic filtering



Credit M.Lorenzini

GRAVITY GRADIENT NOISE IN ADV

- The GGN noise can already limit the AdV sensitivity during days with high seismic activity:



M. Punturo (VIR-0073B-12)
M.Beker (GWADW 2012

LOW FREQUENCIES

Seismic Noise

ET seismic requirements

5×10^{-10} m/$f^2 \approx 2 \times 10^{-16}$ m^2/s^4 /Hz

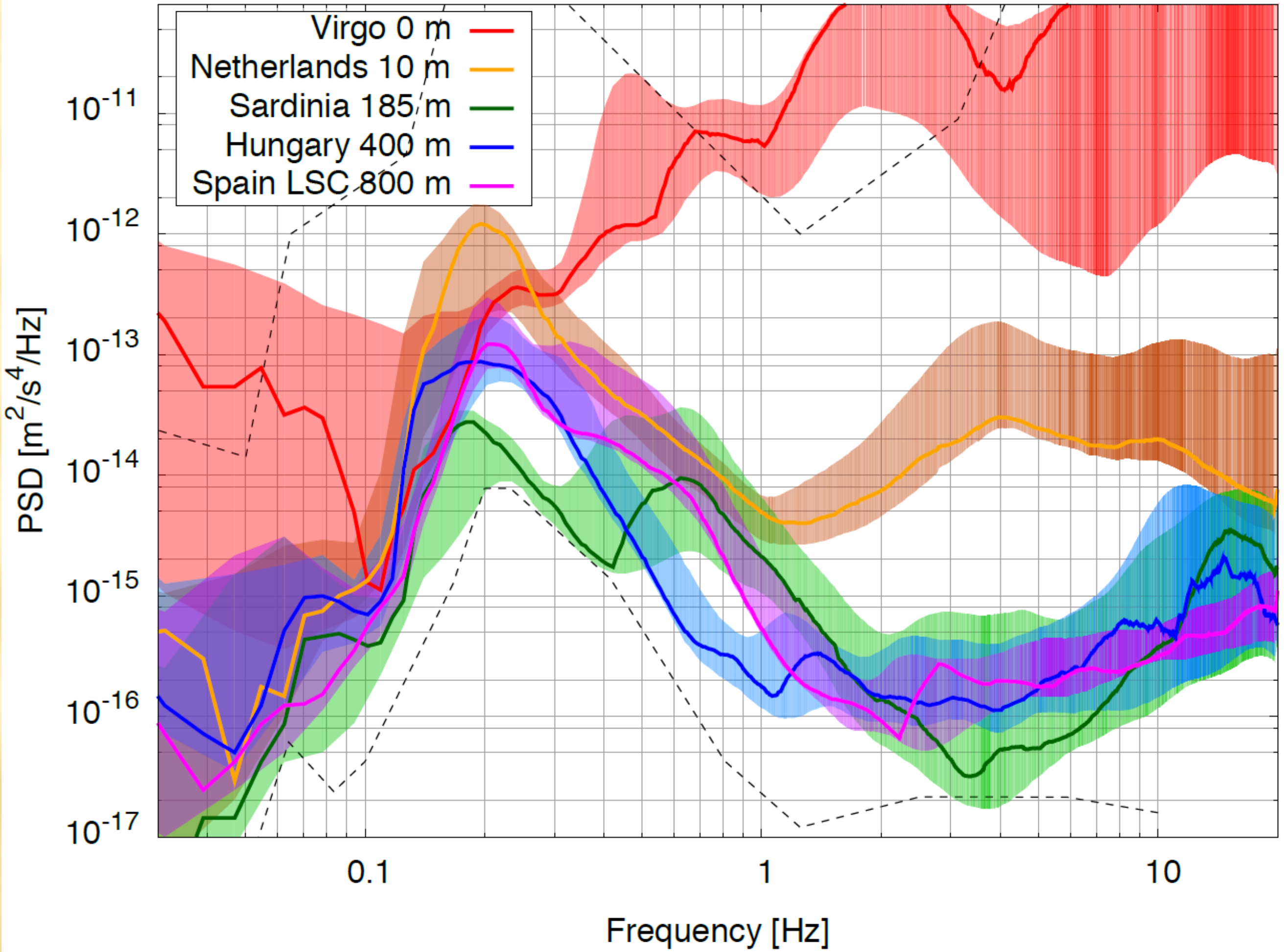
→Underground sites

- Several 100 m

- Location w.r.t. oceans
- Population density
- Geology

Several short term studies have been made.

Long term studies being performed.



Mark Beker, David Rabeling, Nikhef
Fulvio Ricci *et al.*, Roma1

GO UNDERGROUND

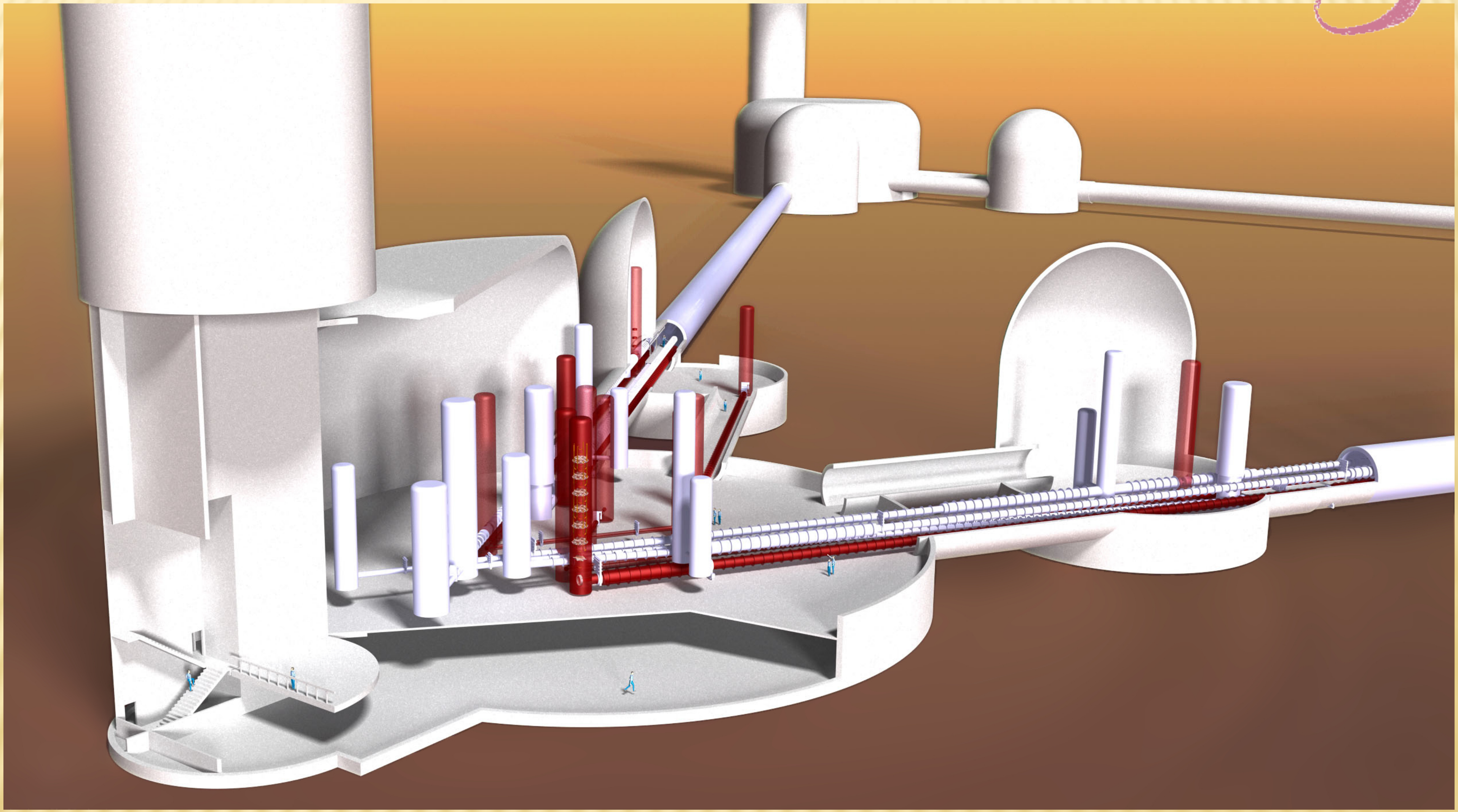


Image: Nikhef

ET Baseline: Build 200m underground

Site selection

Underground location

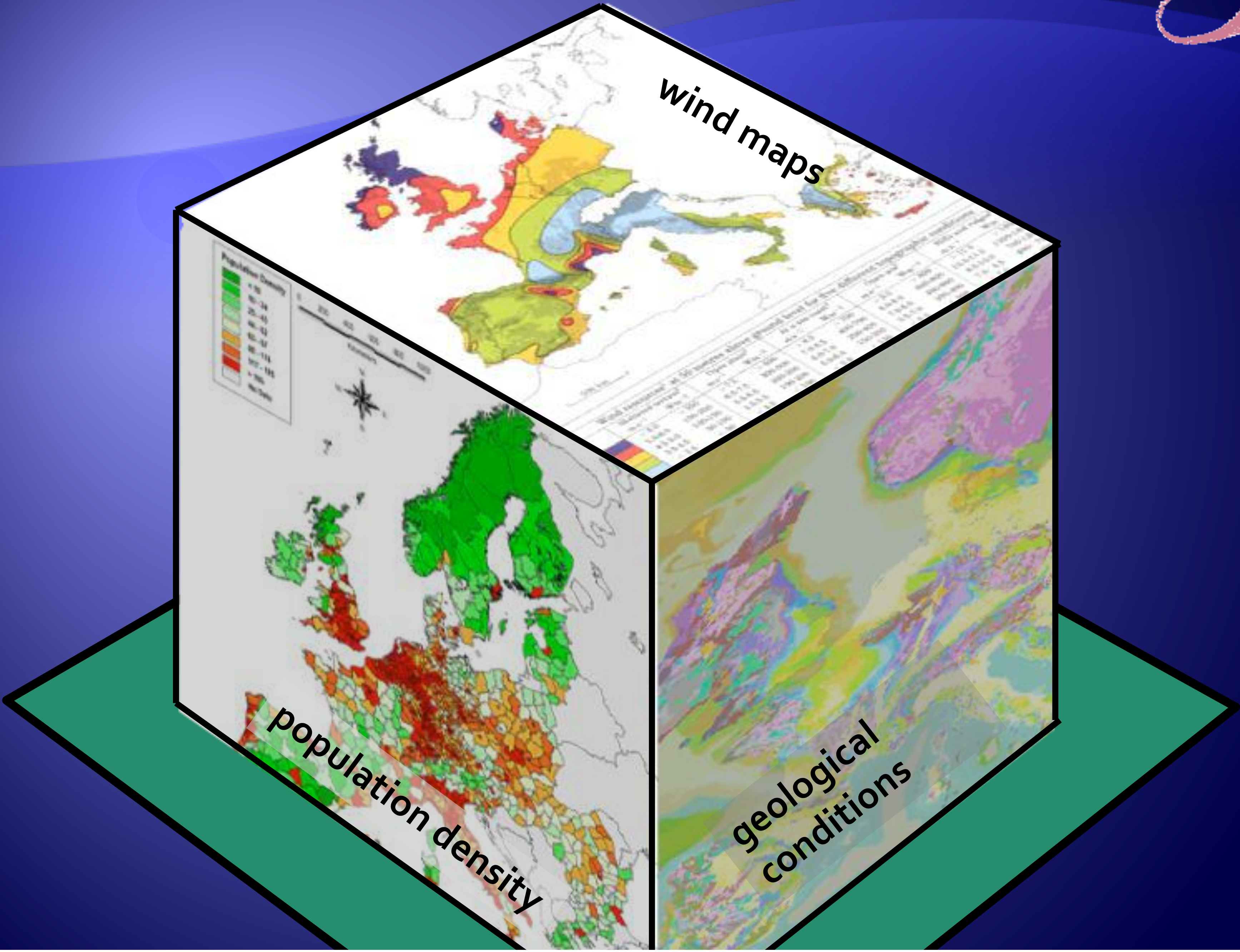
Large instrument (10km scale)

= difficult / impossible above ground in Europe

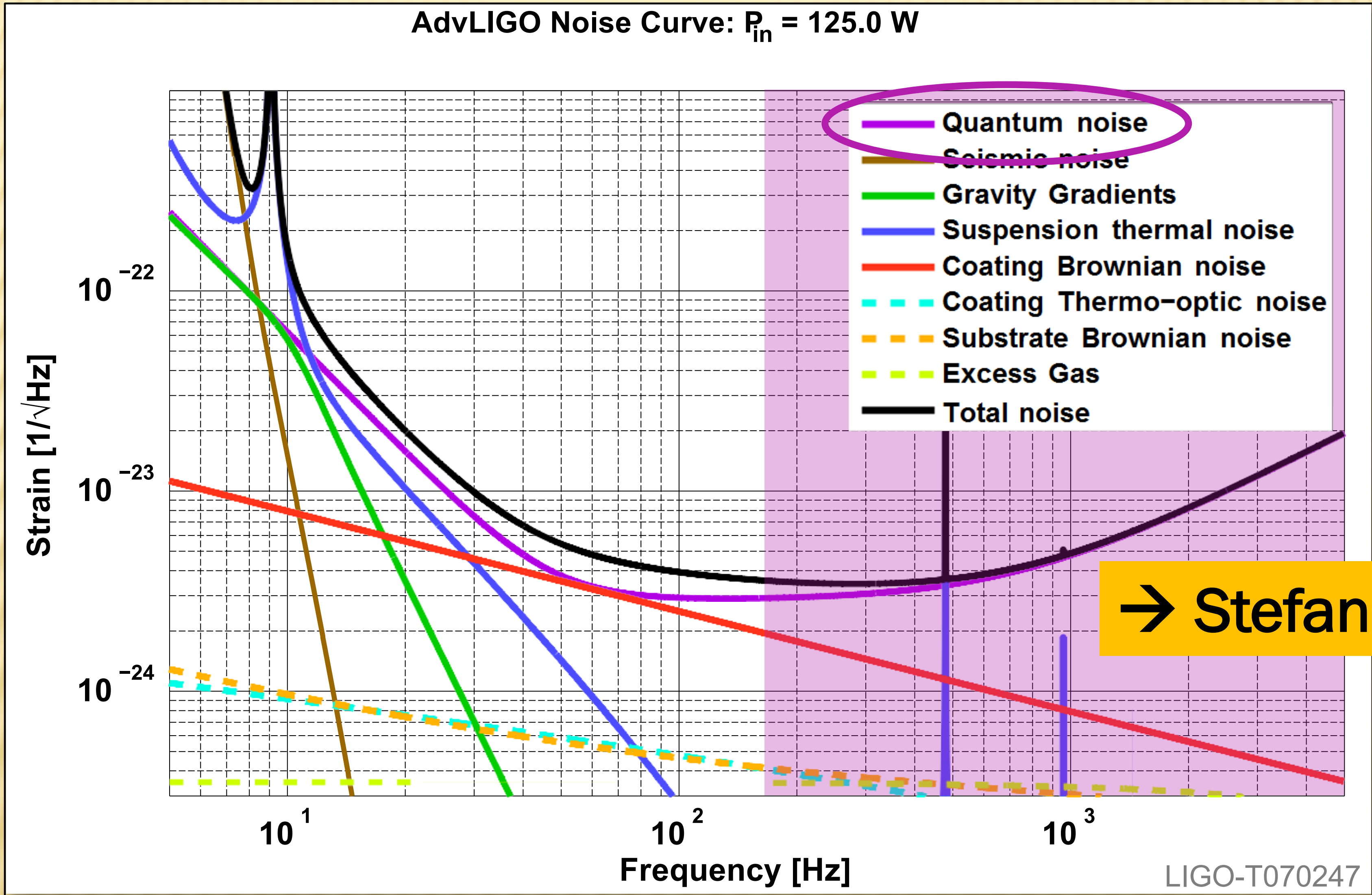
Selection aspects:

- Scientific
- Safety
- Costs
- Legal
- Environmental
- Fincancial
- Political
- ...

Site selection aspects



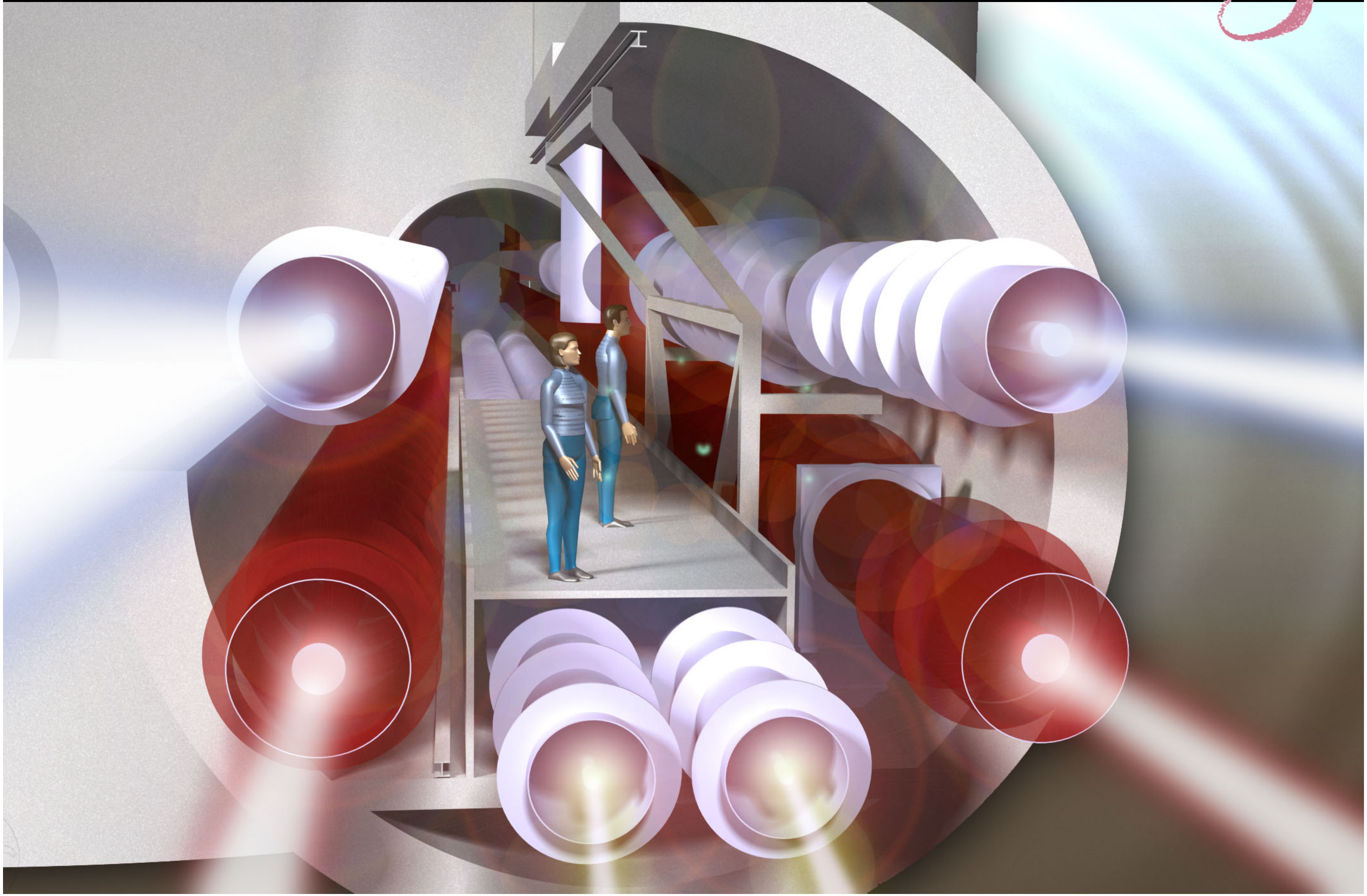
HIGH FREQUENCIES



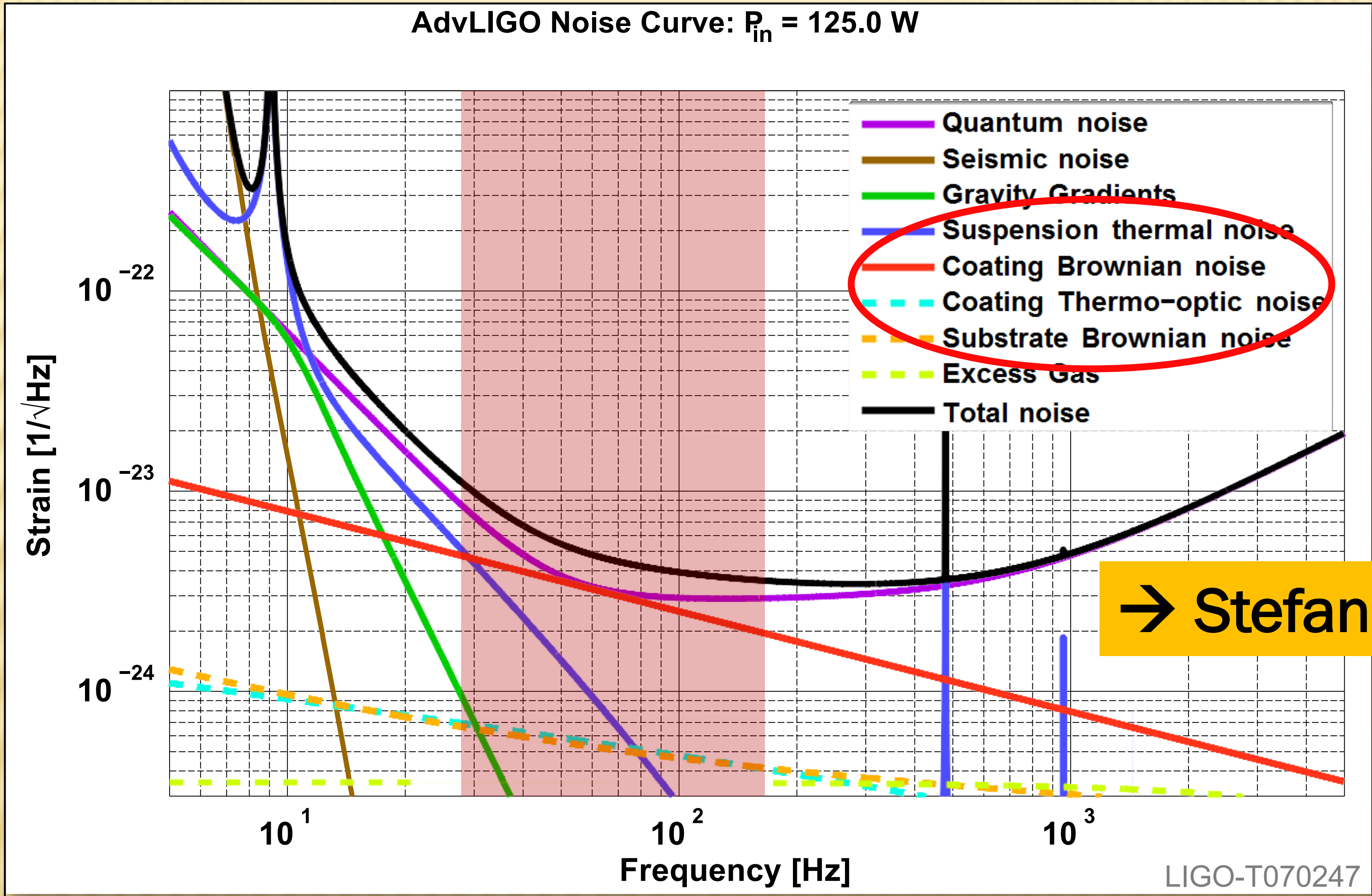
→ Stefan Hild

Shot noise limited → increase light power (ET: 3 MW)
→increase mirror mass (ET: ~200kg)

The infrastructure



MID FREQUENCIES



→ Stefan Hild

ET EINSTEIN TELESCOPE

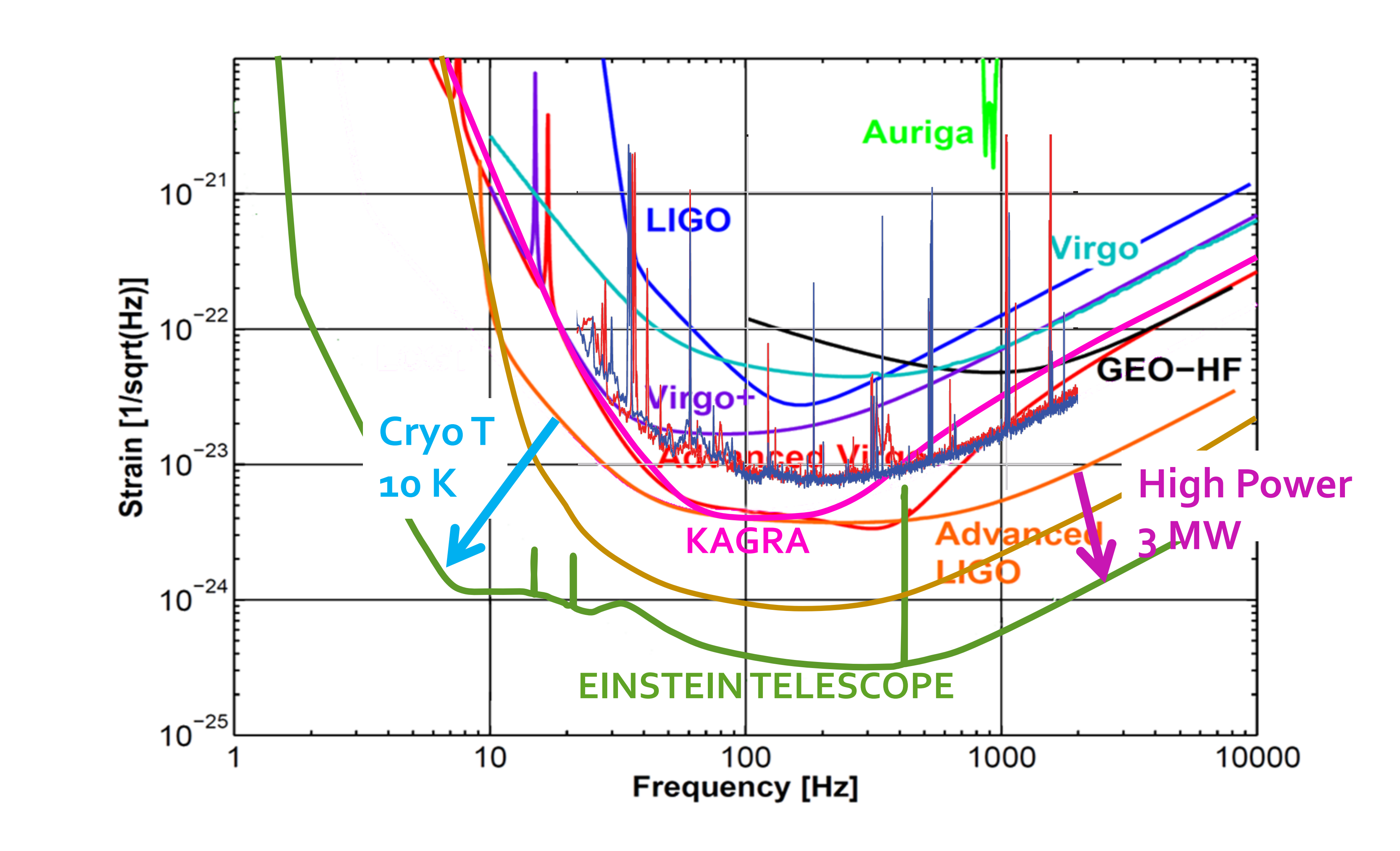
COATING THERMAL NOISE

$$s_x(f) = \sqrt{\frac{4\,KB\,T\,d\,\Phi}{f\,Y\,\omega^2\,\pi^2}}\ [\mathrm{m}/\sqrt{Hz}]$$

Displacement amplitude spectral density

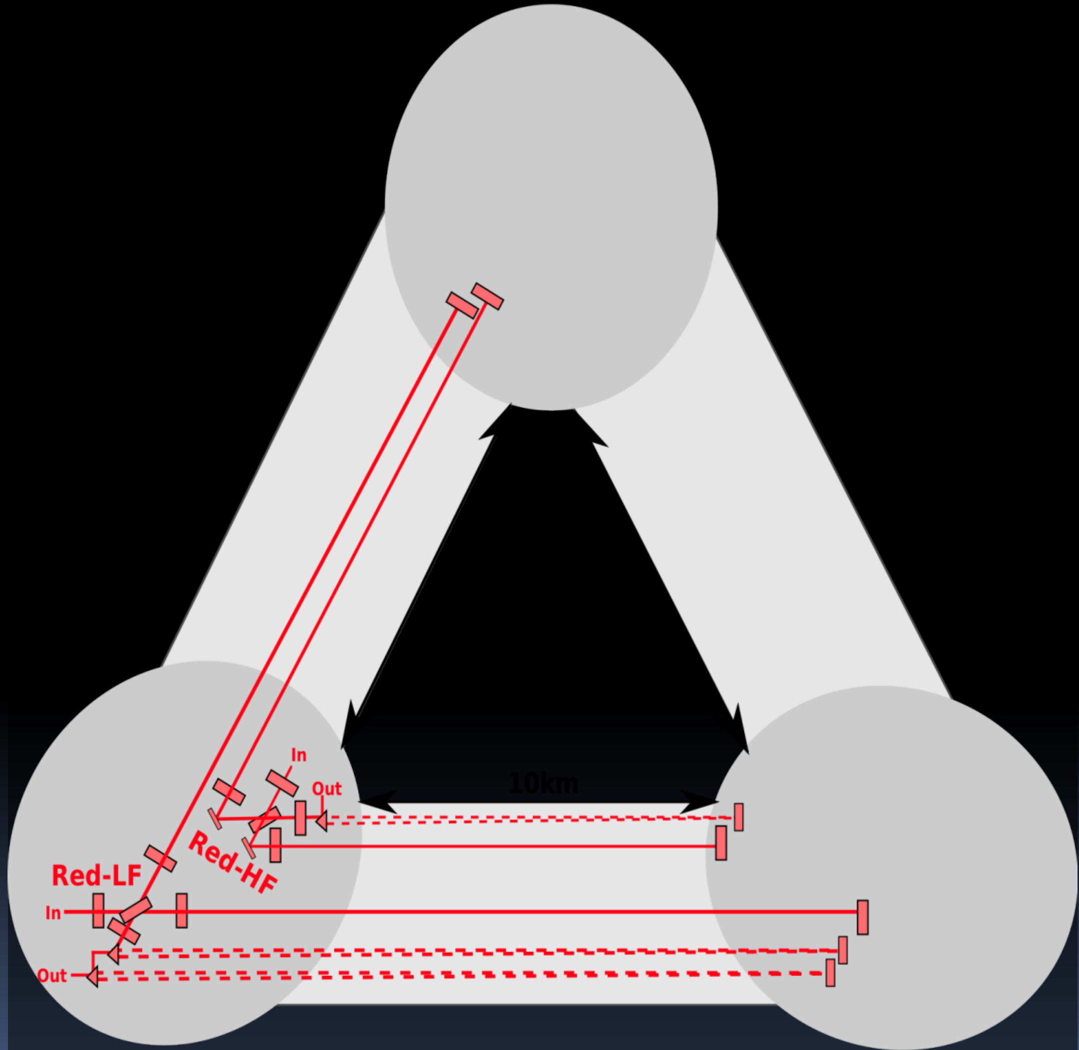
- ω → Large beams/ higher order modes (affects coating and substrate)
- Φ → High Q / low Phi
- d → optimise layer structure to minimise high loss materials and to minimise coating thickness
  → High index difference for minimising coating thickness
- T → Low temperature

New infrastructure + new technologies



INSTALLATION OF ET

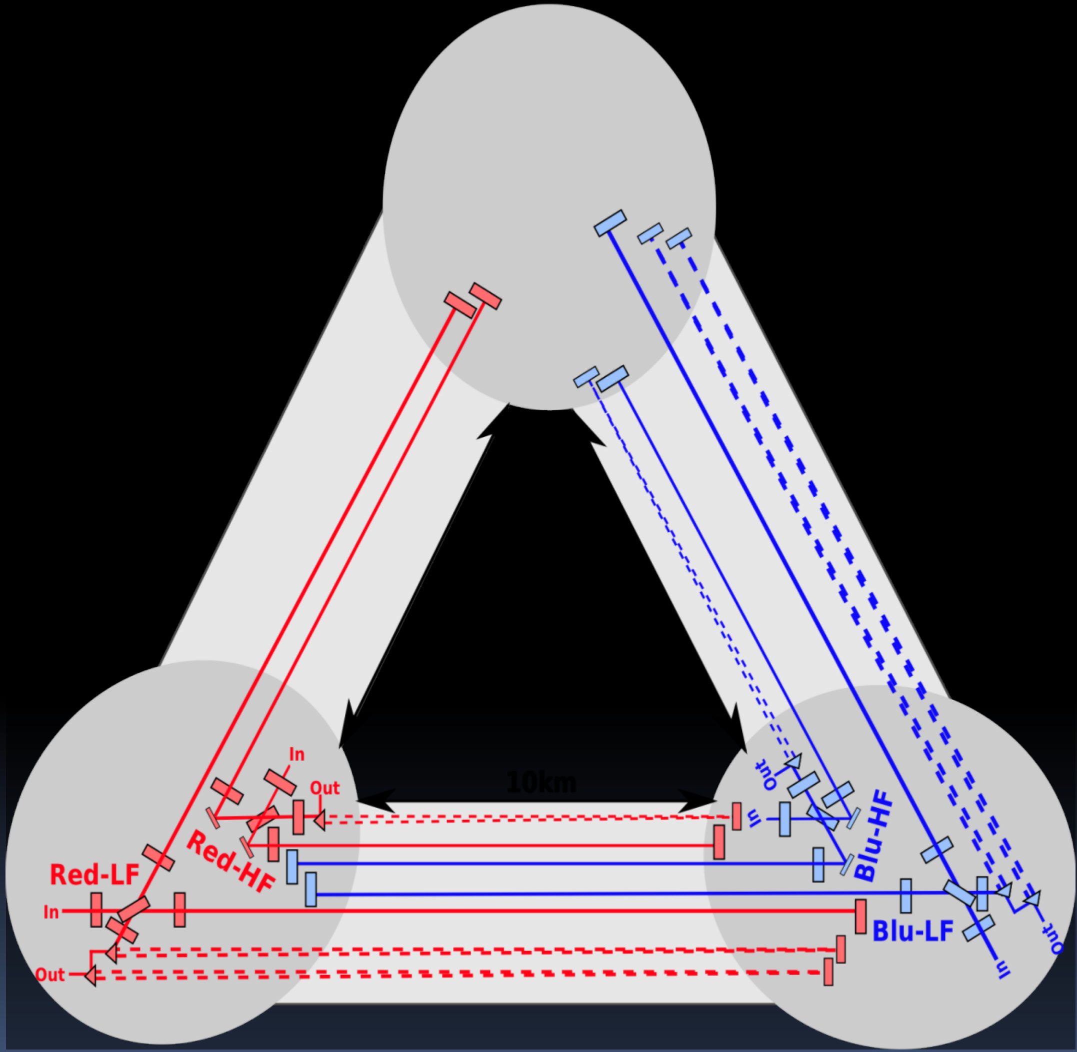
For efficiency reasons
build a triangle.
Start with a single
xylophone detector.



INSTALLATION OF ET

For efficiency reasons build a triangle.
Start with a single xylophone detector.

Add second Xylophone detector to fully resolve polarisation.

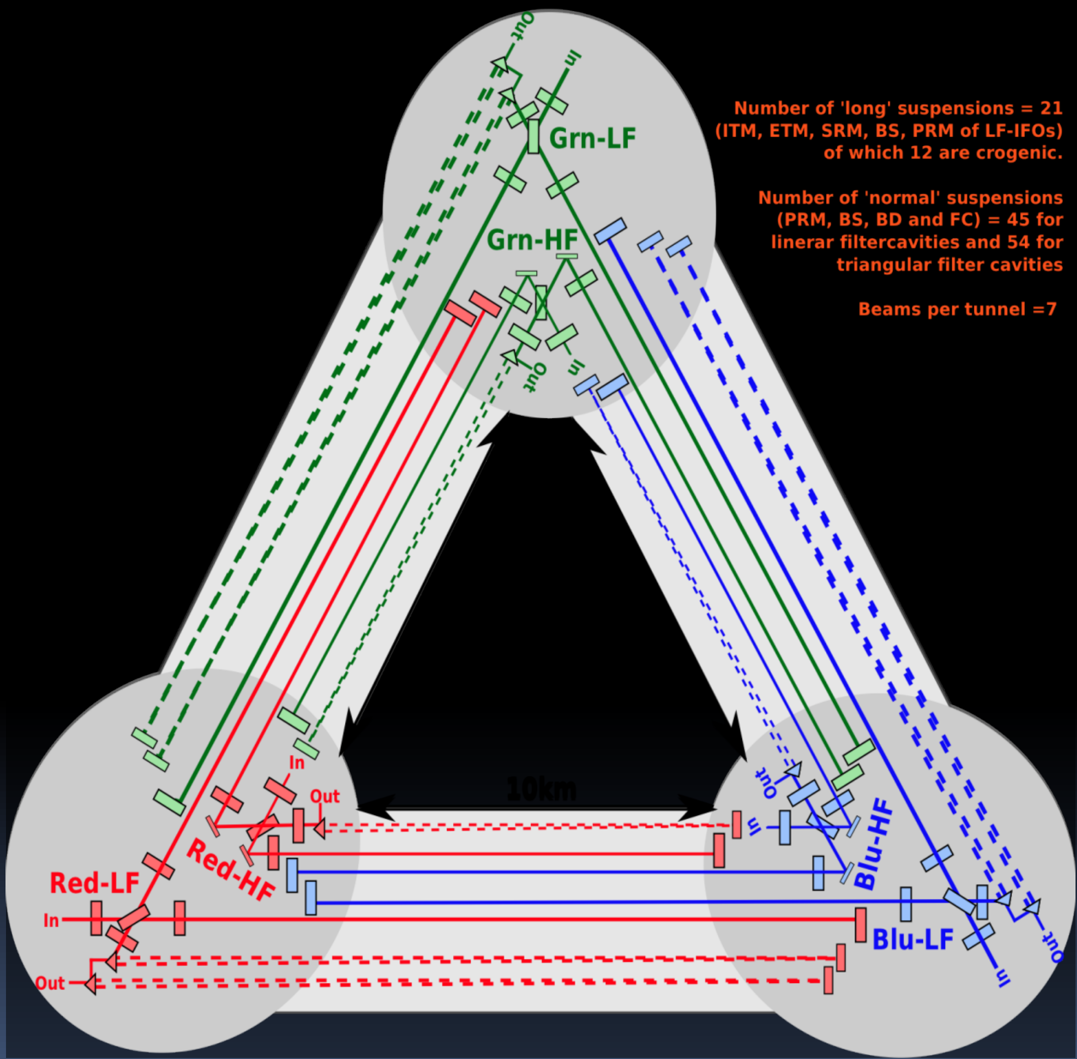


INSTALLATION OF ET

For efficiency reasons build a triangle.
Start with a single xylophone detector.

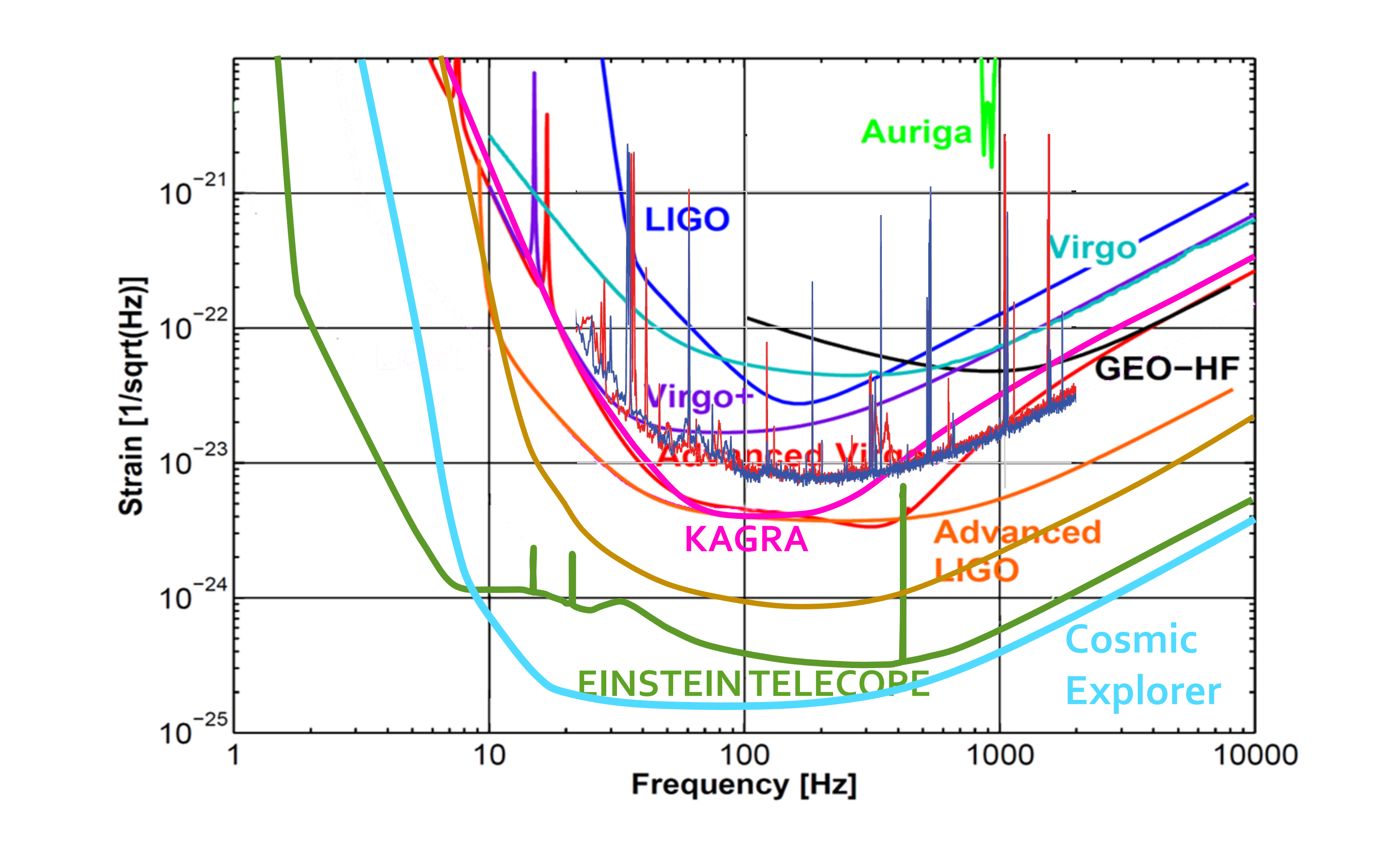
Add second Xylophone detector to fully resolve polarisation.

Add third Xylophone detector for redundancy and null-streams.



Ideas Beyond LIGO Voyager

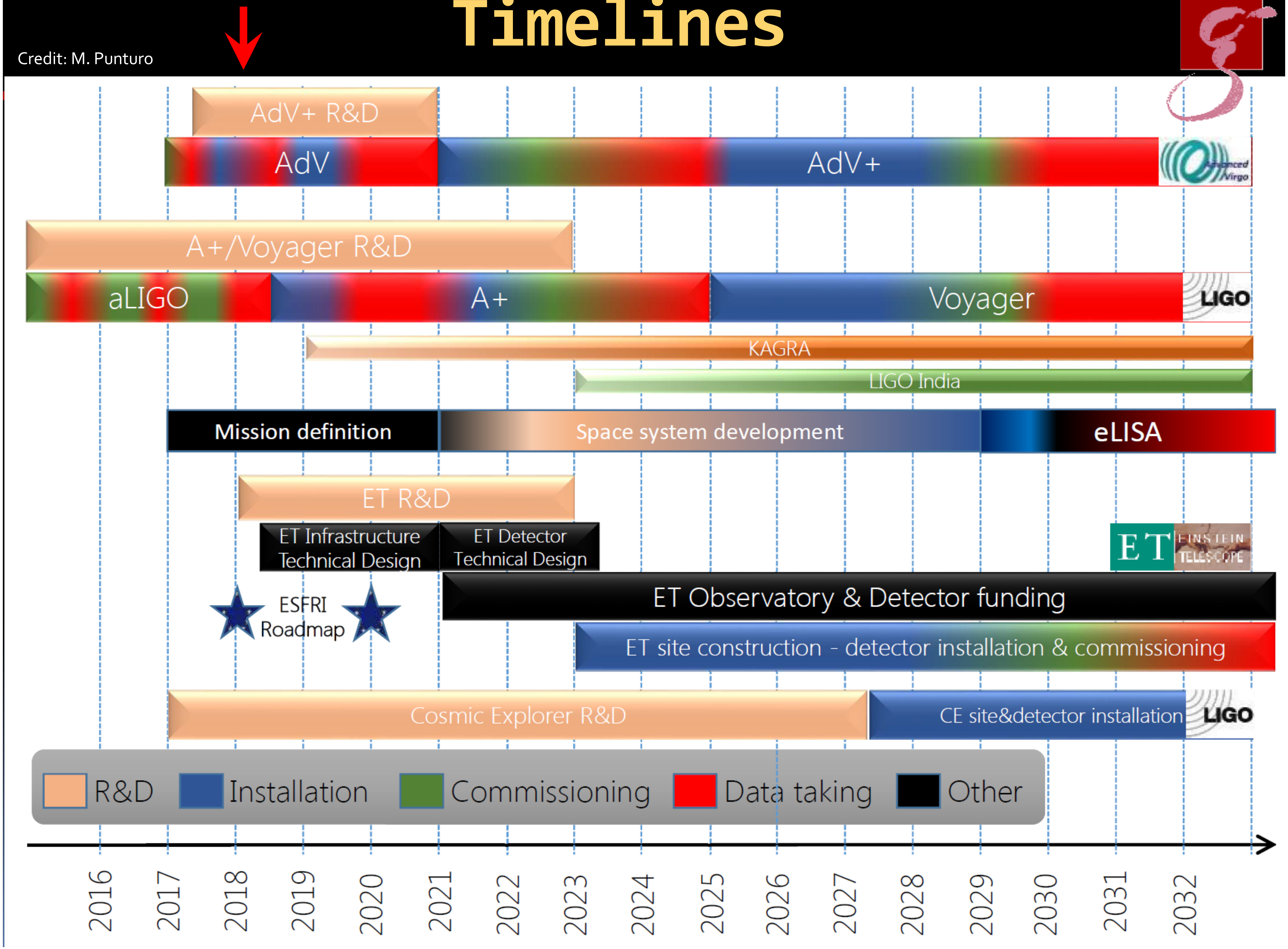
Comparison ET vs CE tricky : Δ vs L



Cosmic Explorer sensitivity transcribed from PRL 118, 151105 (2017)

Timelines

Credit: M. Punturo



WORLD-WIDE COORDINATION

GWIC
Gravitational Wave International Committee

The membership of GWIC represents all of the world's active gravitational wave projects*, as well as other relevant communities, covering gravitational wave frequencies from nanohertz to kilohertz. Each project has either one or two members on GWIC depending on size.

ACIGA Bram Slagmolen

Einstein Telescope Michele Punturo

European Pulsar Timing Array Michael Kramer

GEO 600 Karsten Danzmann, Sheila Rowan

IndIGO Bala Iyer, Somak Raychaudhury

KAGRA Yoshio Saito, Takaaki Kajita

LIGO Dave Reitze, Gabriela Gonzalez

LISA Neil Cornish, Bernard Schutz, Ira Thorpe, Stefano Vitale,

NANOGrav Maura McLaughlin

Parkes Pulsar Timing Array George Hobbs

Spherical Acoustic detectors Odylio Aguiar

Theory Community Clifford Will

Virgo Fulvio Ricci, Jo van den Brand

IUPAP AC2 (ISGRG) Beverly Berger

IAU D1 Marica Branchesi

Executive secretary : David Shoemaker
Co- secretary: Stan Whitcomb

*no CMB community membership

GWIC 3G SUBCOMMITTEE

https://gwic.ligo.org/3Gsubcomm/

GWIC creates Subcommittee to Coordinate Third-Generation Ground-based Interferometers

With the recent first detections of gravitational waves by LIGO and Virgo, it is both timely and appropriate to begin seriously planning for a network of future gravitational-wave observatories, capable of extending the reach of detections well beyond that currently achievable with second generation instruments.

In response, GWIC is forming a standing **Subcommittee on Third Generation Ground-based Detectors**. This subcommittee is tasked with examining the path to a future network of observatories/facilities and making recommendations for coordinated development of a 3G network.

GWIC 3G subcommittees

1) Science drivers for 3G detectors
2) Coordination of the Ground-based GW community
3) Networking among ground based GW community
4) Agency interfacing and advocacy
5) Investigate governance schemes

Image credit: VISUAL FACILITATORS JOHANNA BAUMANN

1) ***Science Drivers for 3G detectors:*** *Chairs: Kalogera, Sathyaprakash*

commission a study of ground-based gravitational wave science from the global scientific community, investigating potential science vs architecture vs. network configuration vs. cost trade-offs, recognizing and taking into account existing studies for 3G projects (such as ET) as well as science overlap with the larger gravitational-wave spectrum.

2) ***Coordination of the Ground-based GW Community****: Lueck, McClelland*

develop and facilitate coordination mechanisms among the current and future planned and anticipated ground-based GW projects, ***including identification of common technologies*** and R&D activities as well as ***comparison of the specific technical approaches to 3G detectors***. Possible support for coordination of 2G observing and 3G construction schedules.

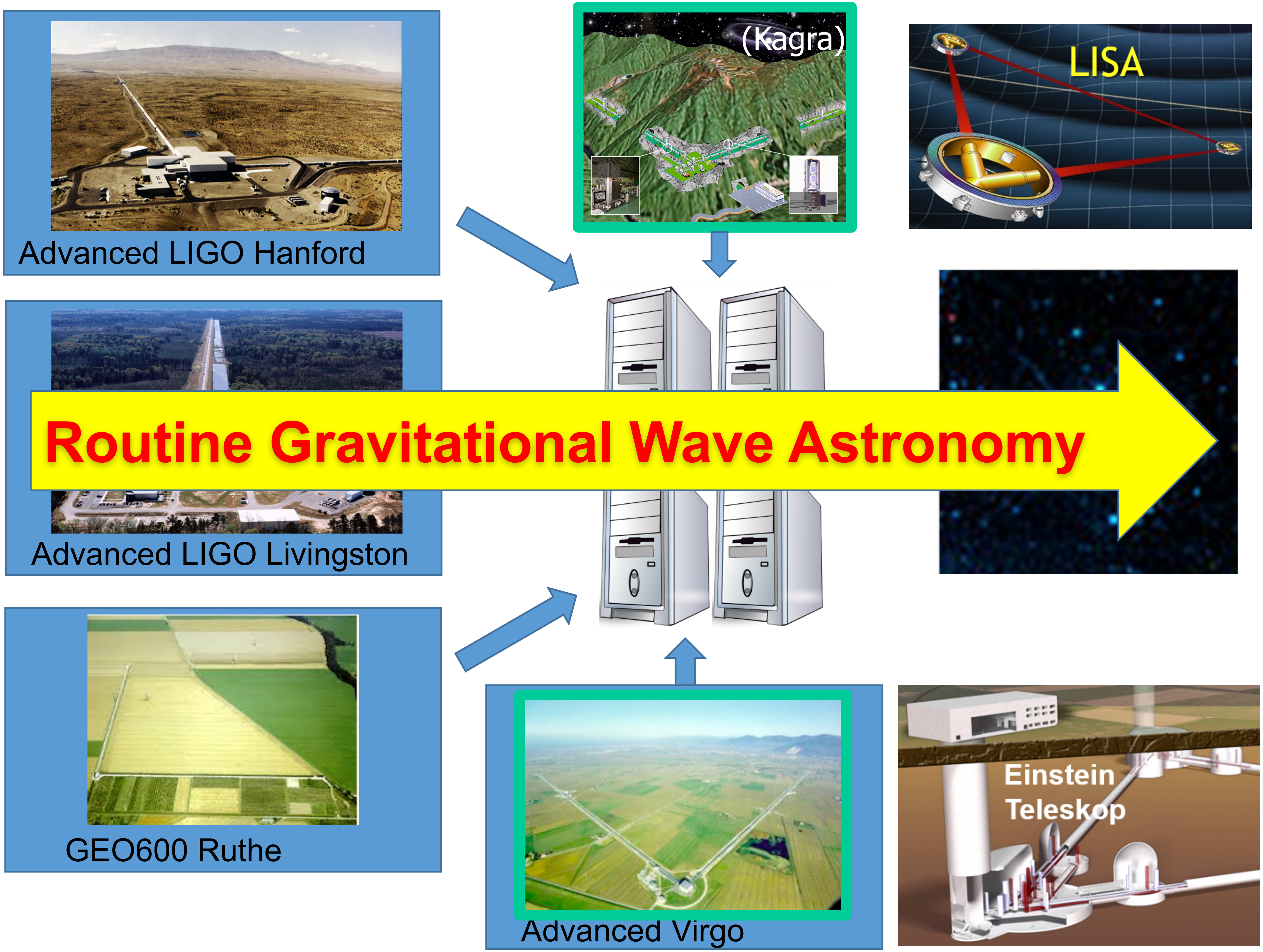
3) ***Networking among Ground-based GW Community****: Punturo, Reitze*

organize and facilitate links between planned global 3G projects and other relevant scientific communities, including organizing:

- town hall meetings to survey the community
- dedicated sessions in scientific conferences dedicated to GW physics and astronomy
- focused topical workshops within the relevant communities

Next Steps

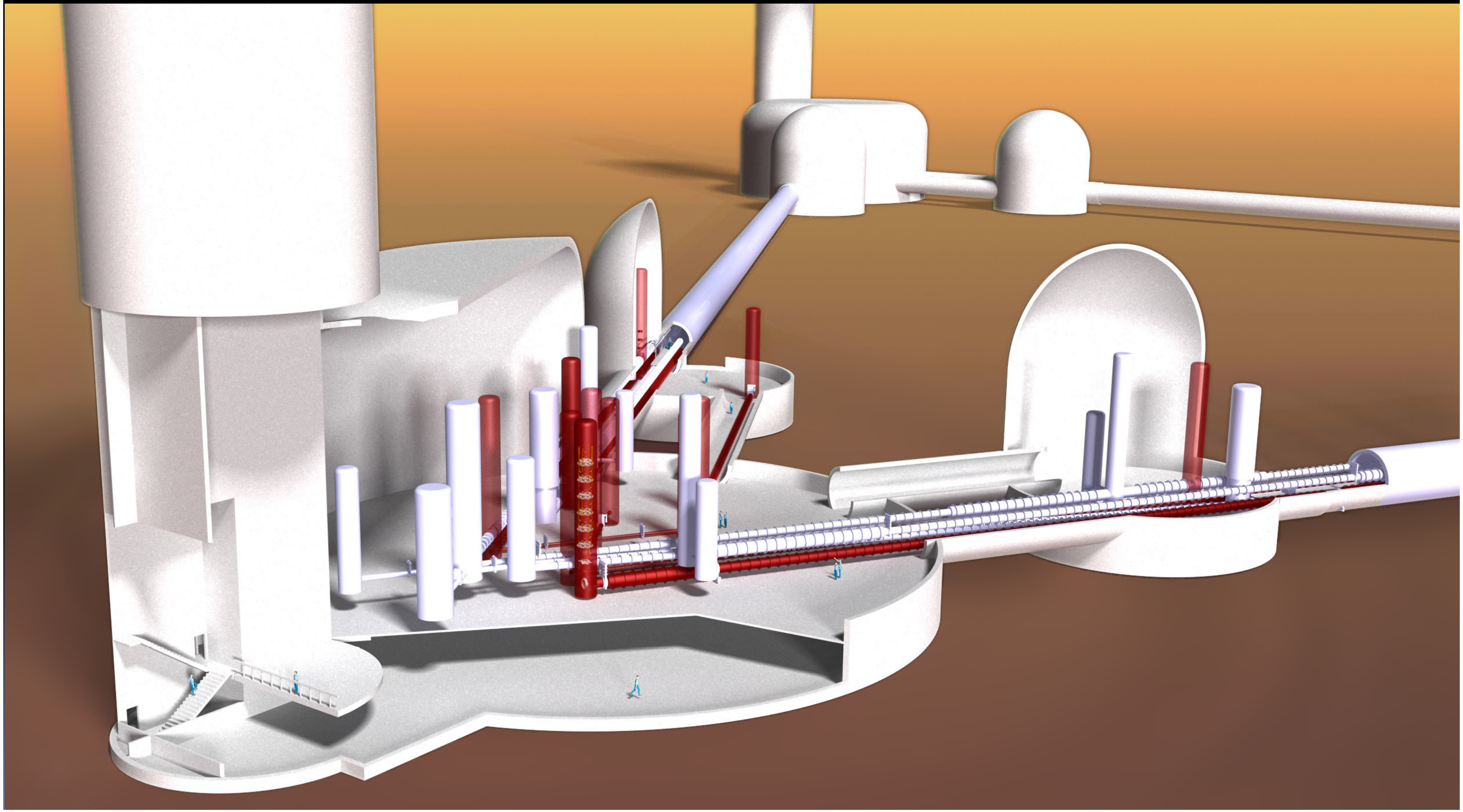
- Get Einstein Telescope onto the ESFRI roadmap
- Convert ET science team into ET collaboration
- Coordinate worldwide activities (GWIC)
- Coordinate actions of national funding agencies in world-wide GW activities (GWAC = GW agency correspondents)
- Further strengthen interaction with astronomy/astroparticle community
- Get more institutions/people involved in GW research & technical design



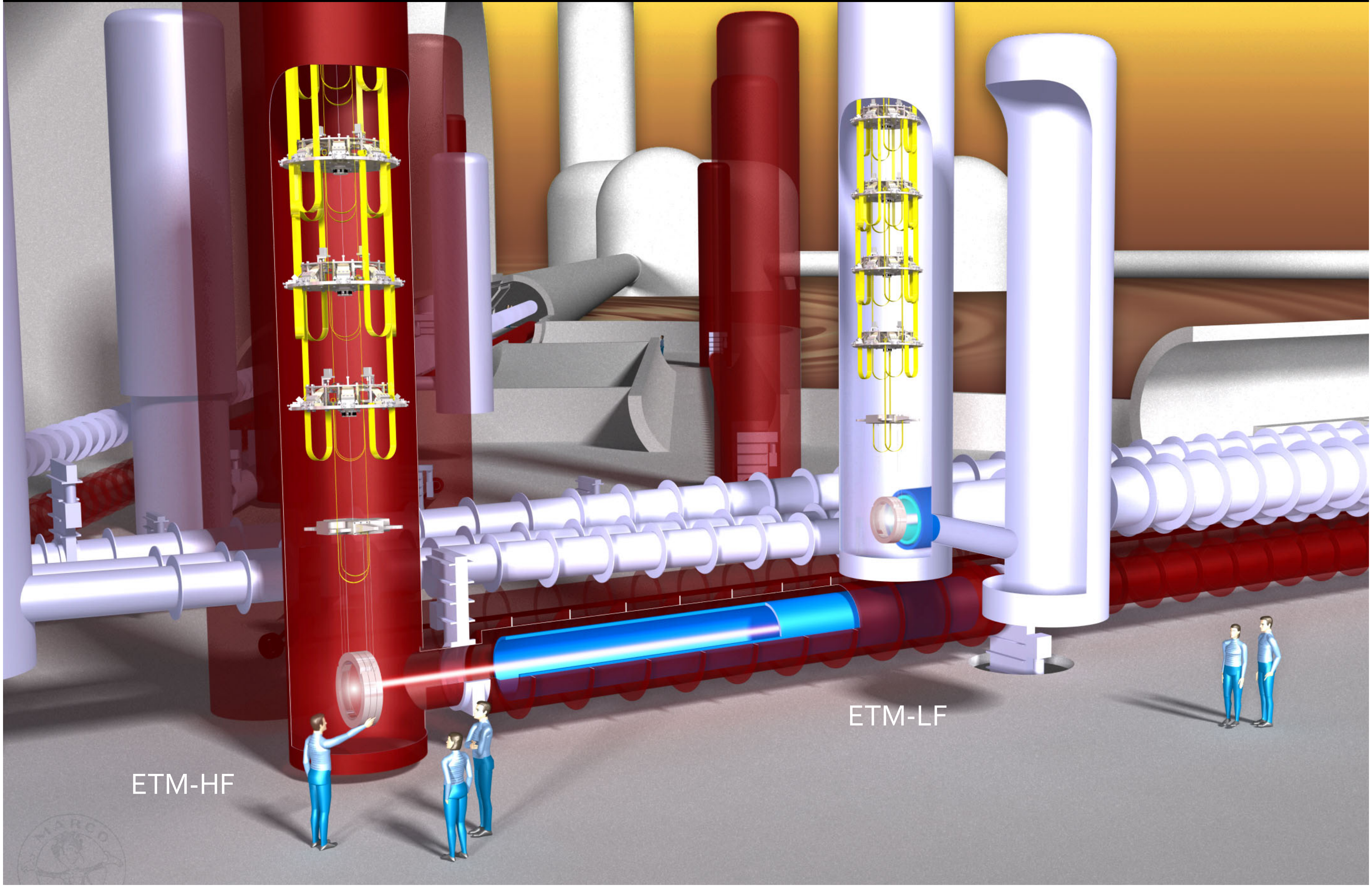
(Kagra)
LISA
Advanced LIGO Hanford
Routine Gravitational Wave Astronomy
Advanced LIGO Livingston
GEO600 Ruthe
Advanced Virgo
Einstein
Teleskop


www.et-gw.eu
www.aei.mpg.de
www.einstein-online.info
einsteinathome.org
www.geo600.org
elisascience.org
www.ligo.org
www.ego-gw.it
Einstein Telescope

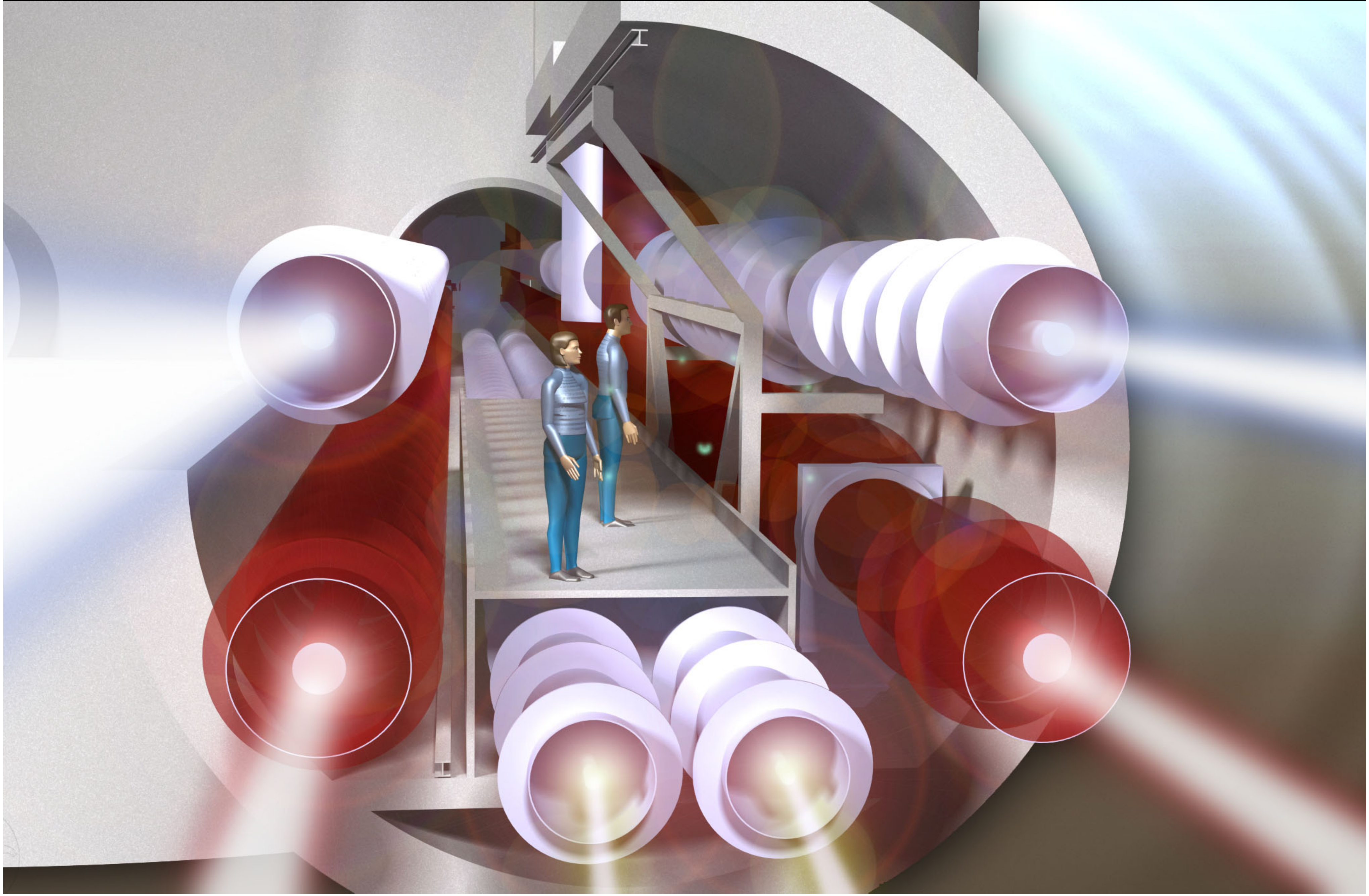
The infrastructure



The infrastructure



The infrastructure




Einstein Telescope