Overview ET project & Experimental Challenges

Andreas Freise

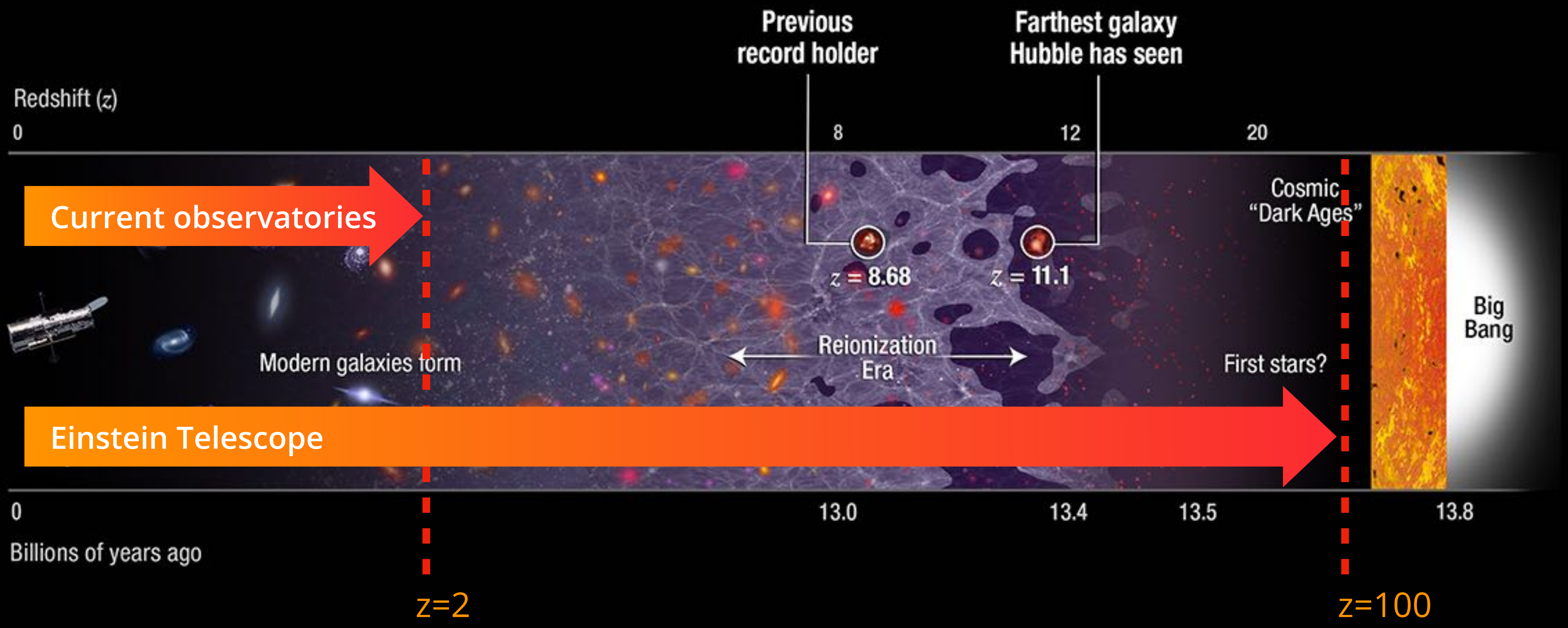
EP-Spain Meeting, 08.10.2021


LIGO Hanford 4km
GEO600 600m
Virgo 3km
LIGO India
(approved)
KAGRA 3km
LIGO Livingston 4km
Cosmic Explorer
(planned)
EINSTEIN TELESCOPE
Einstein Telescope
(planned)

New observatories or upgrading existing facilities?

- Ground-based GW observatories are currently being upgraded. Project pans exist up to the O5 observing run, planned for **2025-2027**.
- Discussions have started to plan further upgrades of existing detectors in the **post-O5 period**.
- However, eventually the benefits of such upgrades will be **limited by the facilities** (length of the arms, space in the building, environmental noise of the site, paging material)
- New observatories hope to use much **greater arm lengths**, which is not possible in the current locations.
- New locations allow potentially joint observation by a network of 3G and 2G detectors.

The case for future GW observatories



Early star formation, primordial black holes, seeds of supermassive black holes, standard-sirens to measure Hubble constant to much earlier ages …

[Credits: NASA, ESA, P. Oesch and B. Robertson (University of California, Santa Cruz), and A. Feild (STScI)]


Einstein Telescope
10 km
Large laboratories and
three 10 km long tunnels,
more than 200m underground
A future European
gravitational waves
observatory

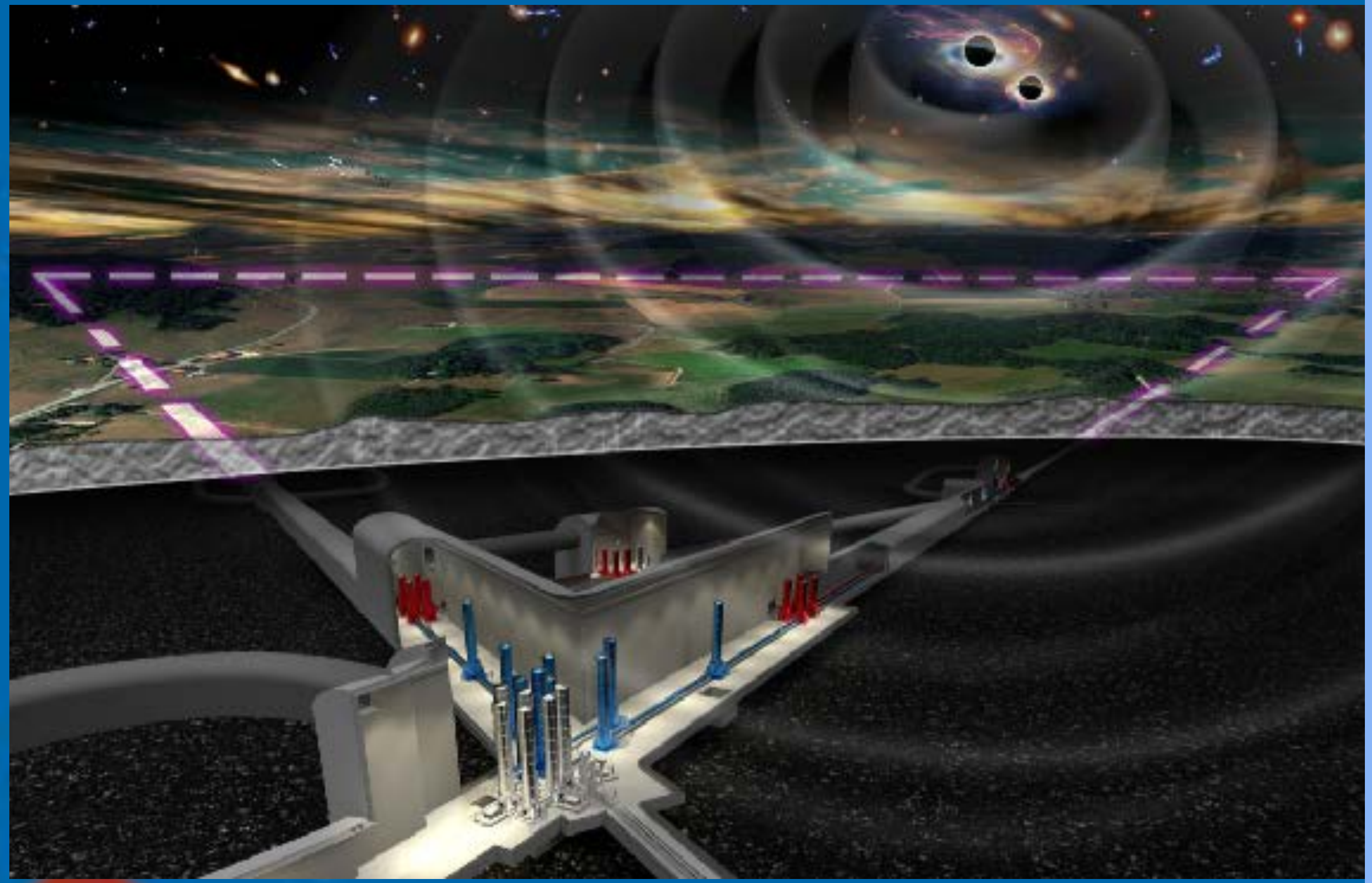
ET on the ESFRI roadmap

European Strategy Forum on Research Infrastructures

EINSTEIN TELESCOPE

ESFRI ROADMAP 2021

https://www.et-gw.eu/



Project submitted by:

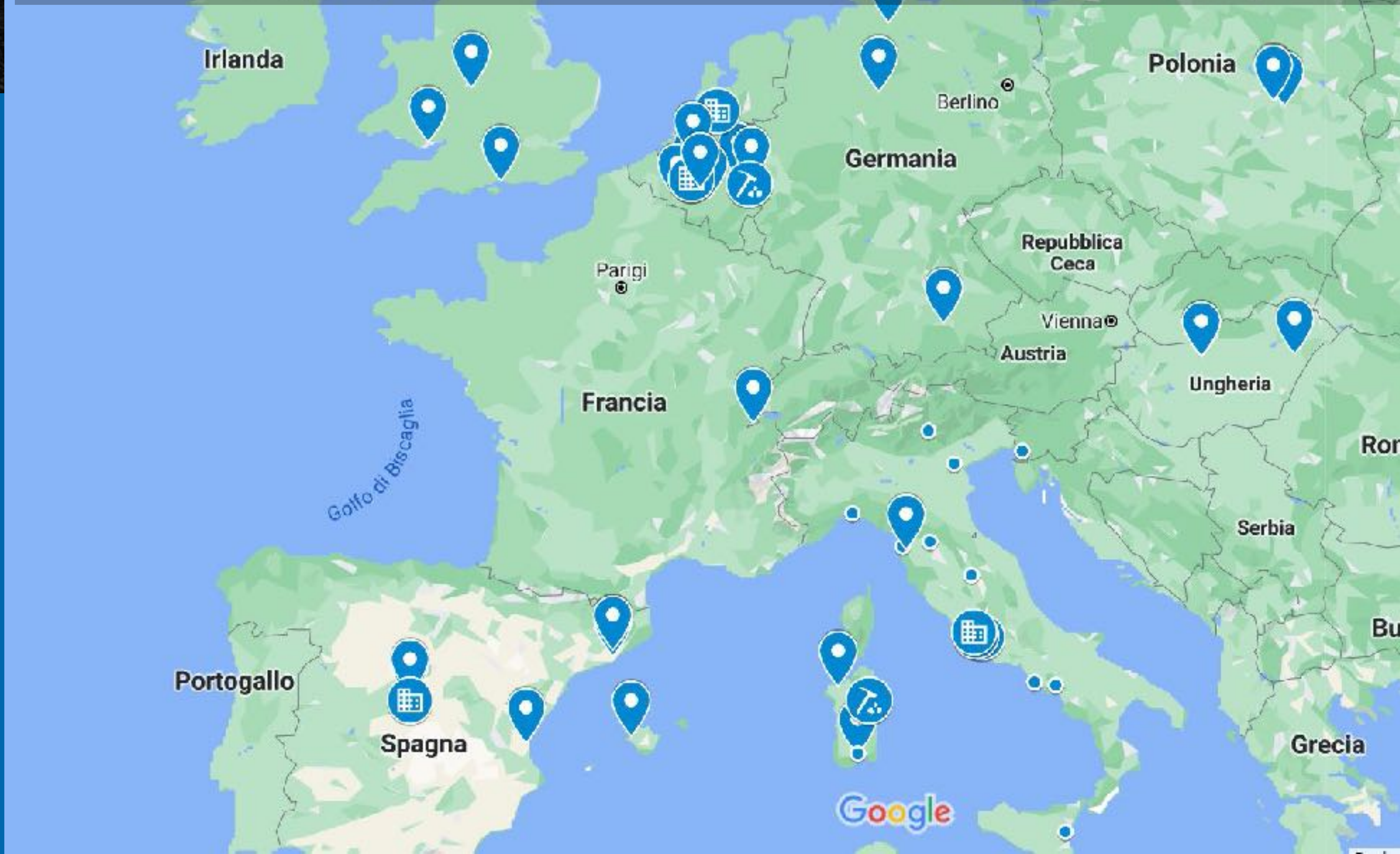
- **Italy** (Lead Country)
- Netherlands
- Belgium
- Spain
- Poland

30/06/2021:

ET is on the ESFRI roadmap!

ET Consortium

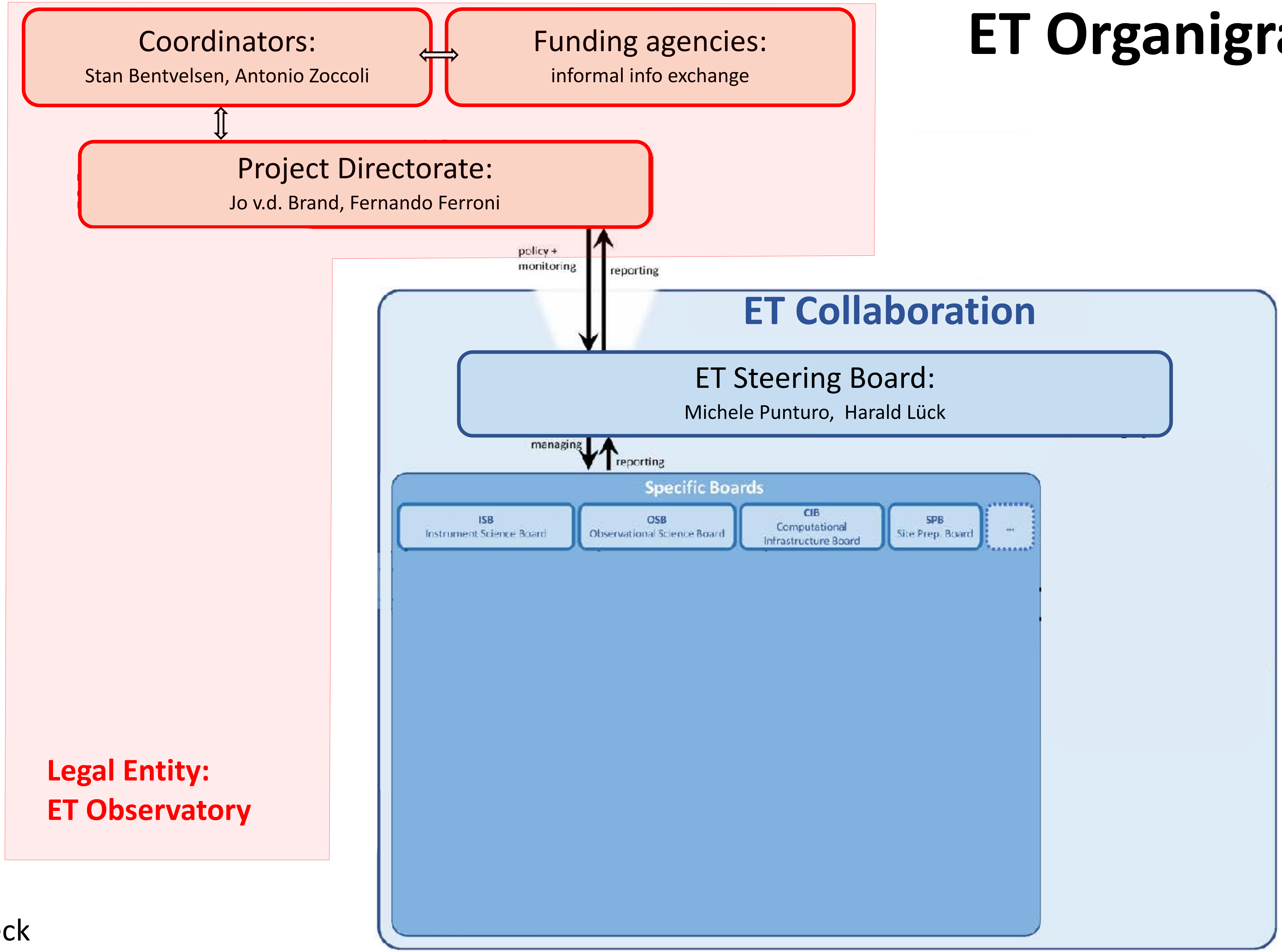
- ET CA signed by 41 institutions
- INFN and Nikhef are the coordinators of the consortium
- Funding expected in the next months by the governments in the frontline
- EU funding for the Preparatory Phase in 2022



Possible ET site(s)

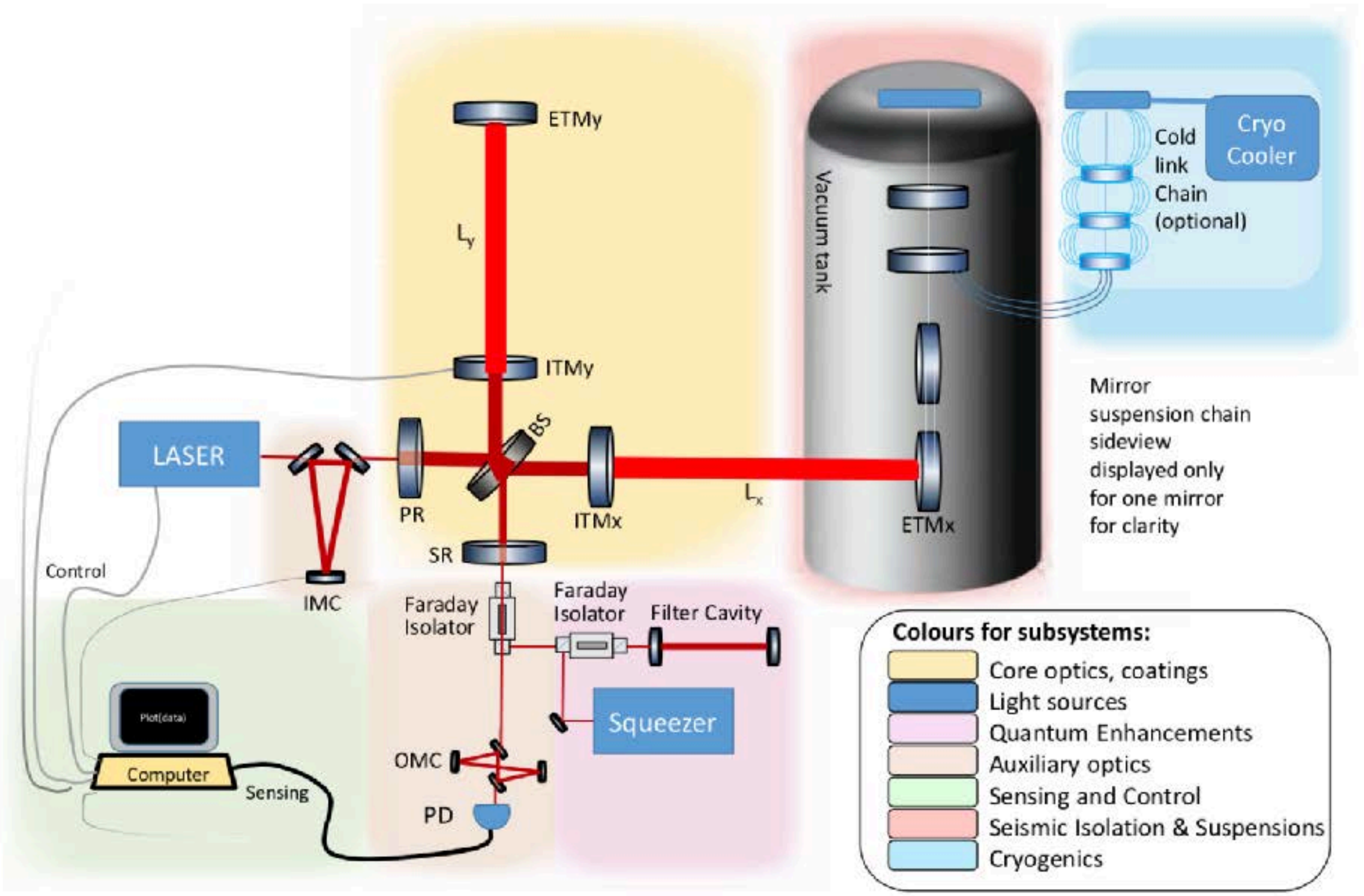
- Currently there are two sites, in Europe, candidate to host ET:
  - The Sardinia site, close to the Sos Enattos mine
  - The EU Regio Rhine-Meusse site, close to the NL-B-D border
- A third option in Saxony (Germany) is under discussion, but still too preliminary to be a candidate.
- Site decision foreseen for 2024/2025

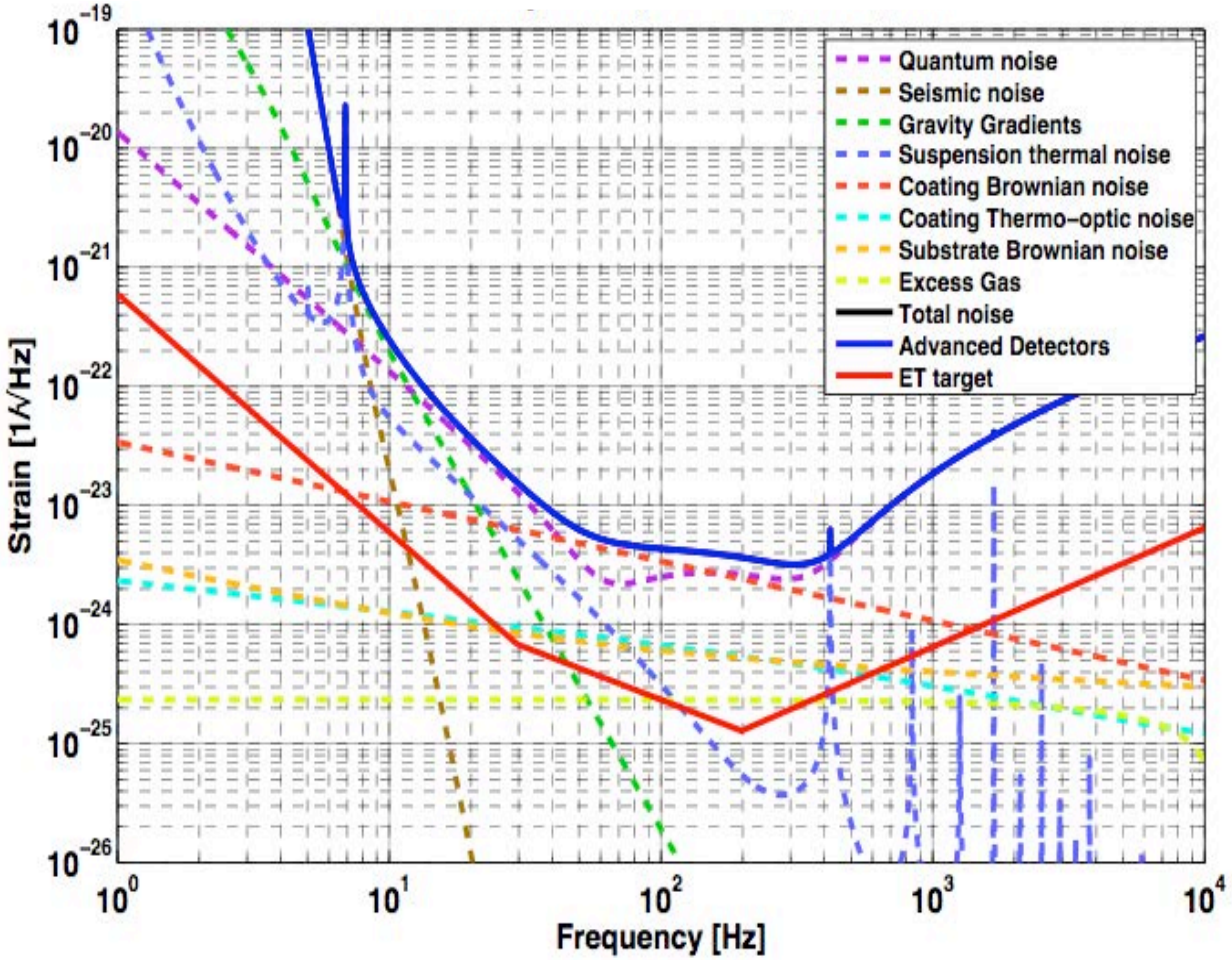
ET Organigram



Slide animation: H.Lueck

Instrument science challenges

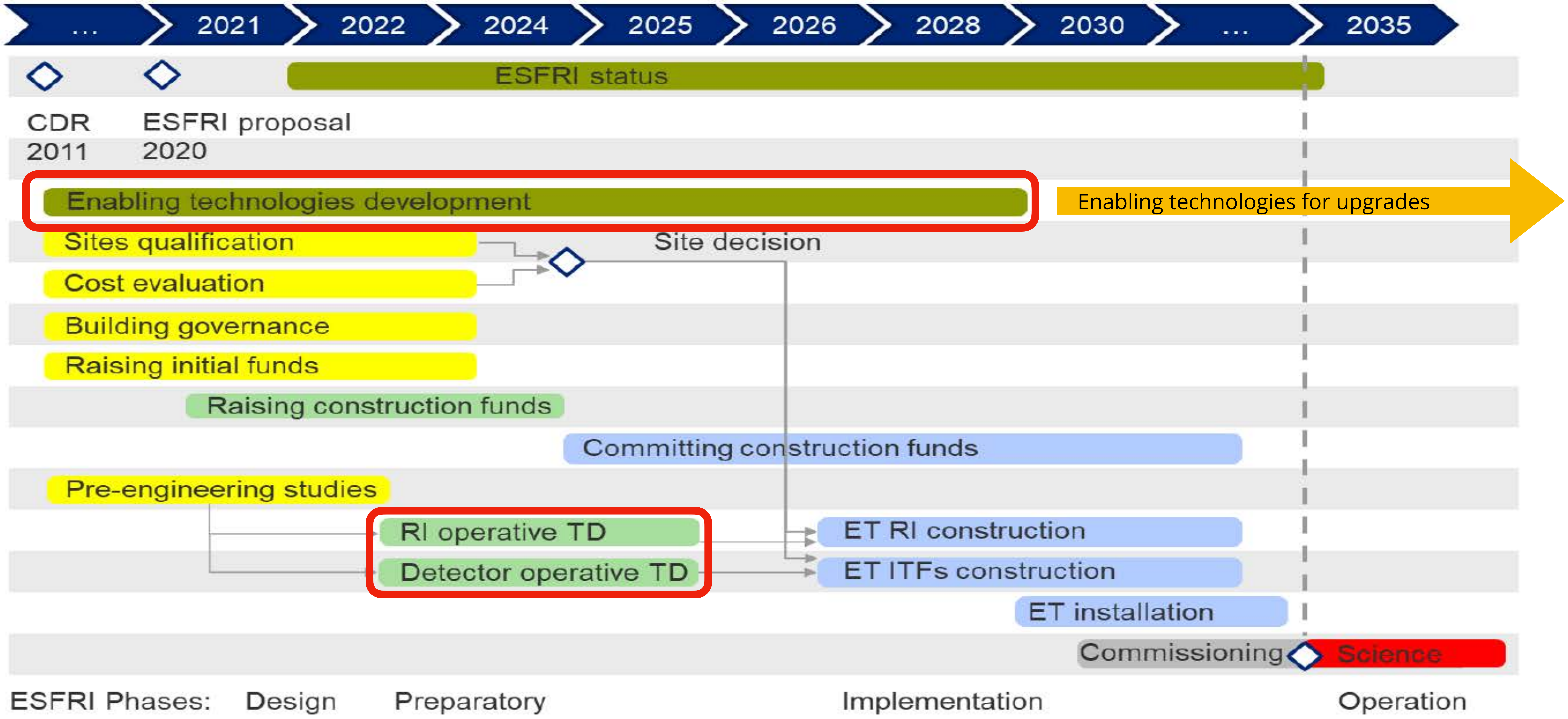


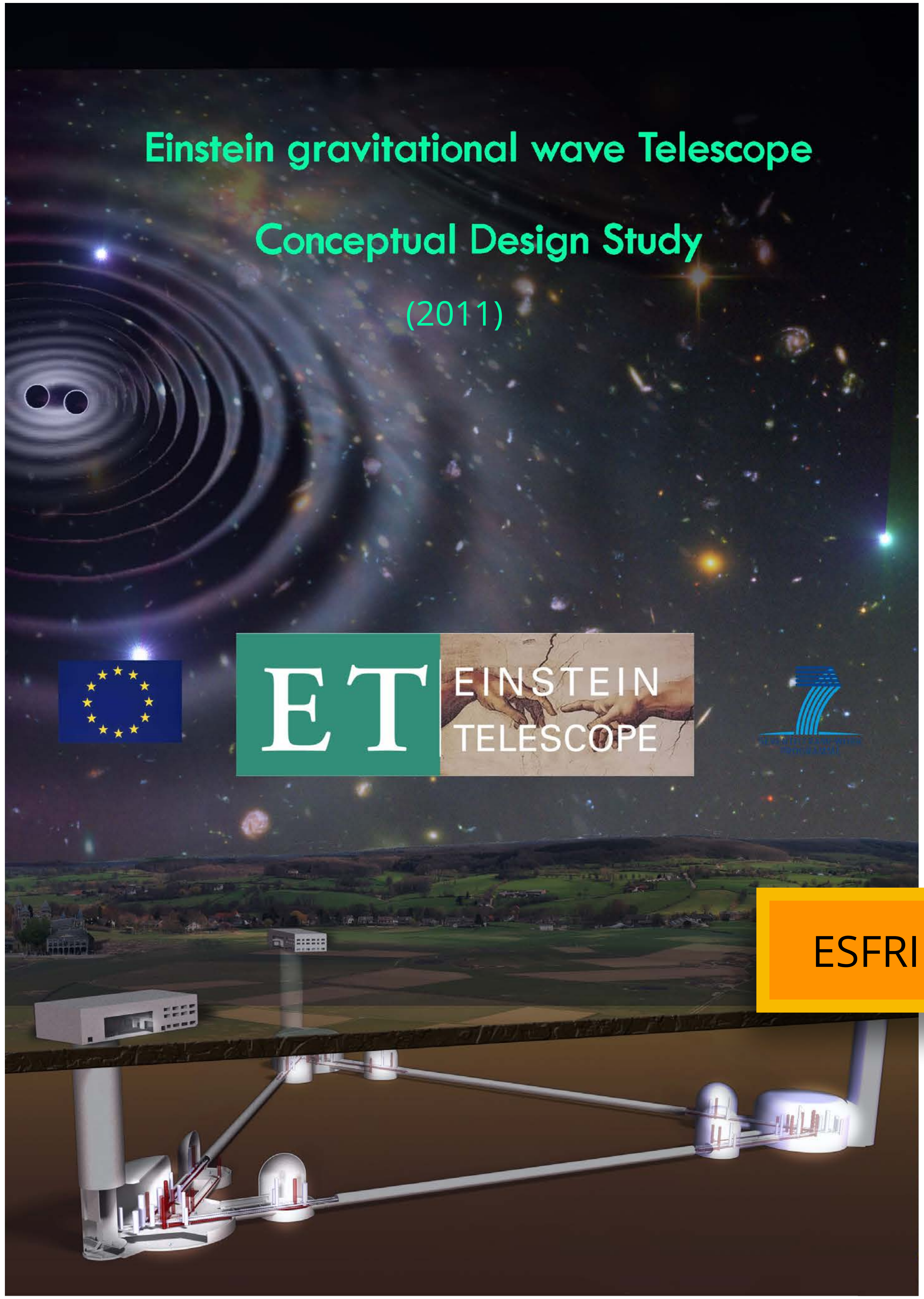


Project timeline

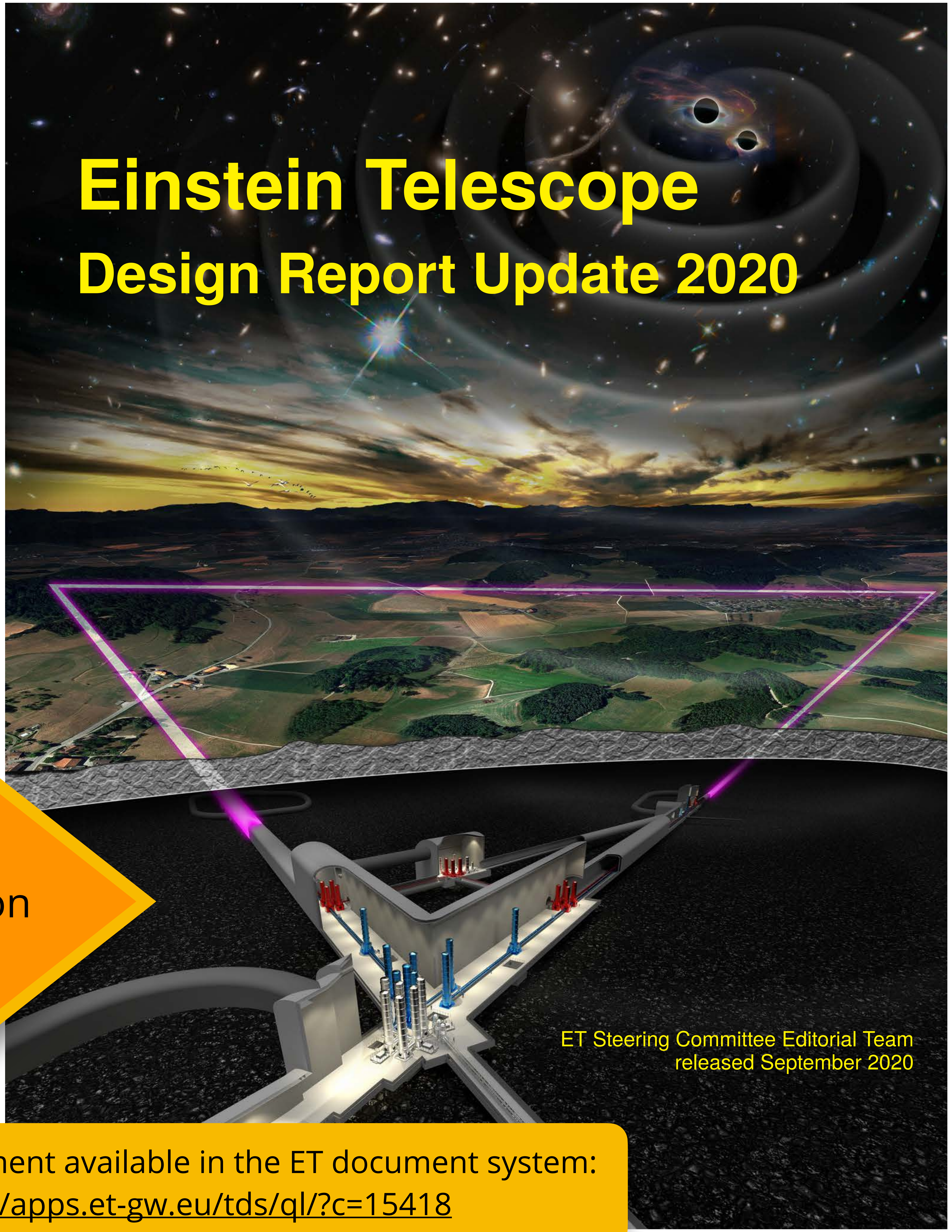
Approved by ESFRI for the 2021 Roadmap

* Tentative schedule





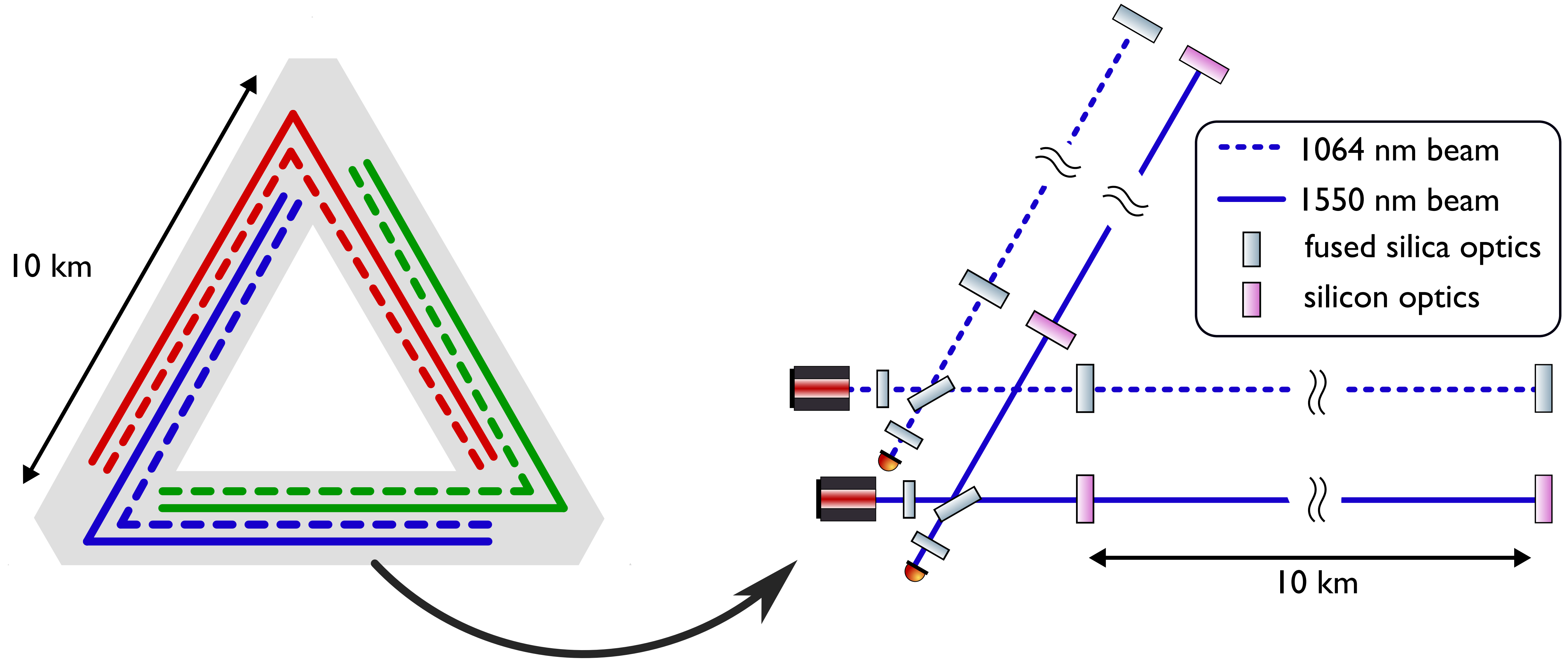
ESFRI Application

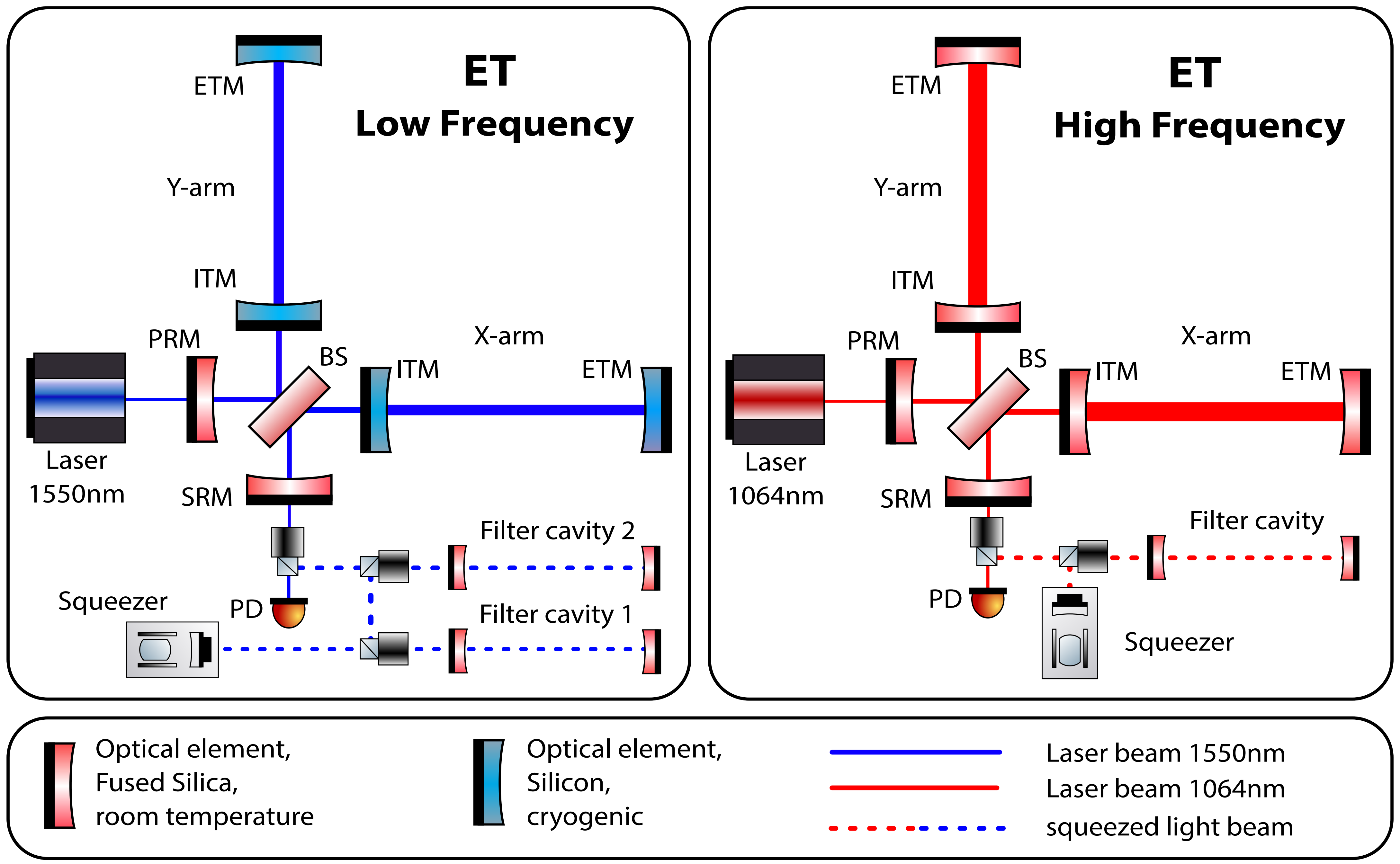


Document available in the ET document system:
https://apps.et-gw.eu/tds/ql/?c=15418

Einstein Telescope design

Parameter	ET-HF	ET-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10-20 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	45 cm/ 57 cm
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase (rad)	tuned (0.0)	detuned (0.6)
SR transmittance	10 %	20 %
Quantum noise suppression	freq. dep. squeez.	freq. dep. squeez.
Filter cavities	1×300 m	2×1.0 km
Squeezing level	10 dB (effective)	10 dB (effective)
Beam shape	TEM_{00}	TEM_{00}
Beam radius	12.0 cm	9 cm
Scatter loss per surface	37 ppm	37 ppm
Seismic isolation	SA, 8 m tall	mod SA, 17 m tall
Seismic (for $f > 1$ Hz)	$5 \cdot 10^{-10}$ m/f^2	$5 \cdot 10^{-10}$ m/f^2
Gravity gradient subtraction	none	factor of a few





New special focus: noise at low frequencies

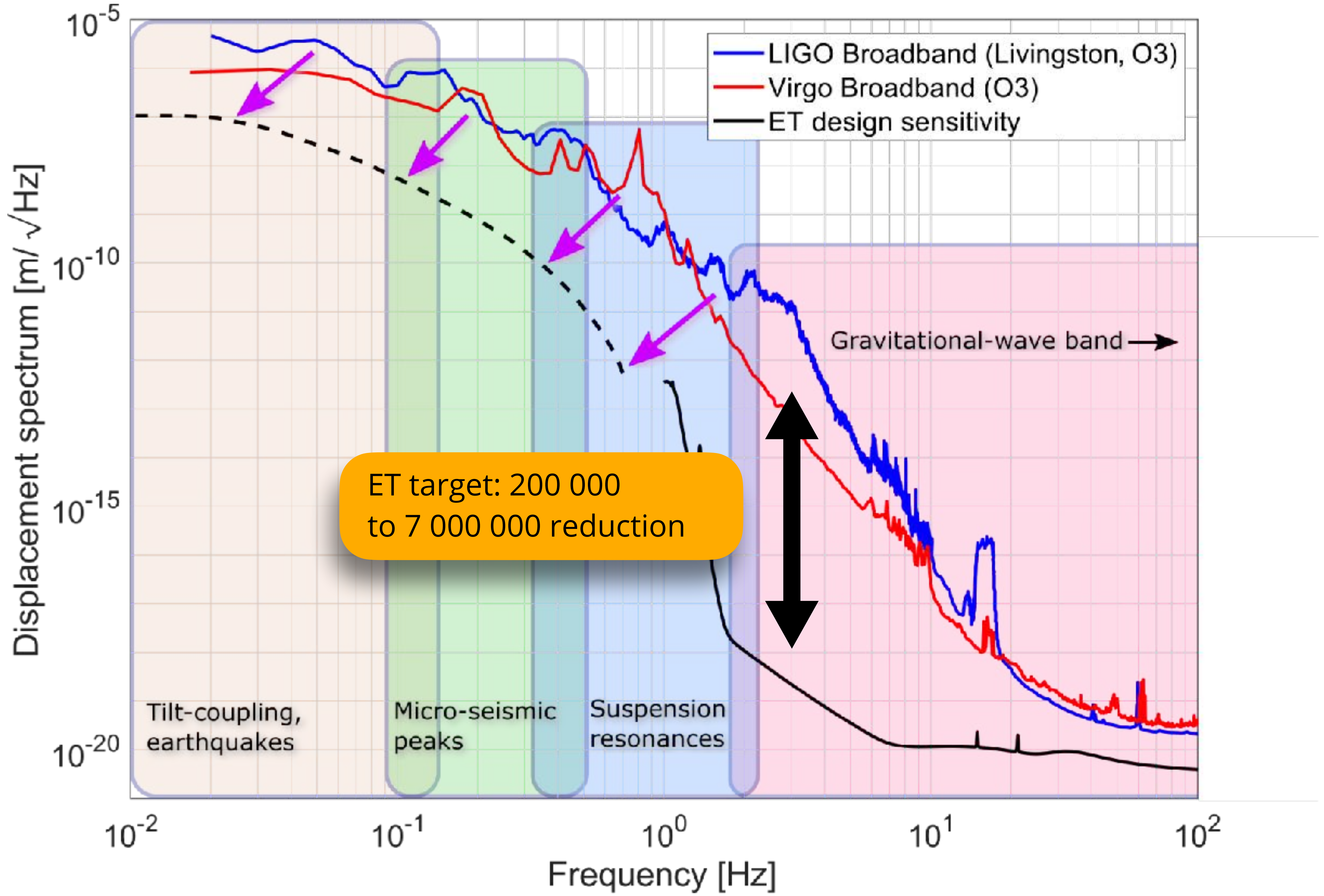
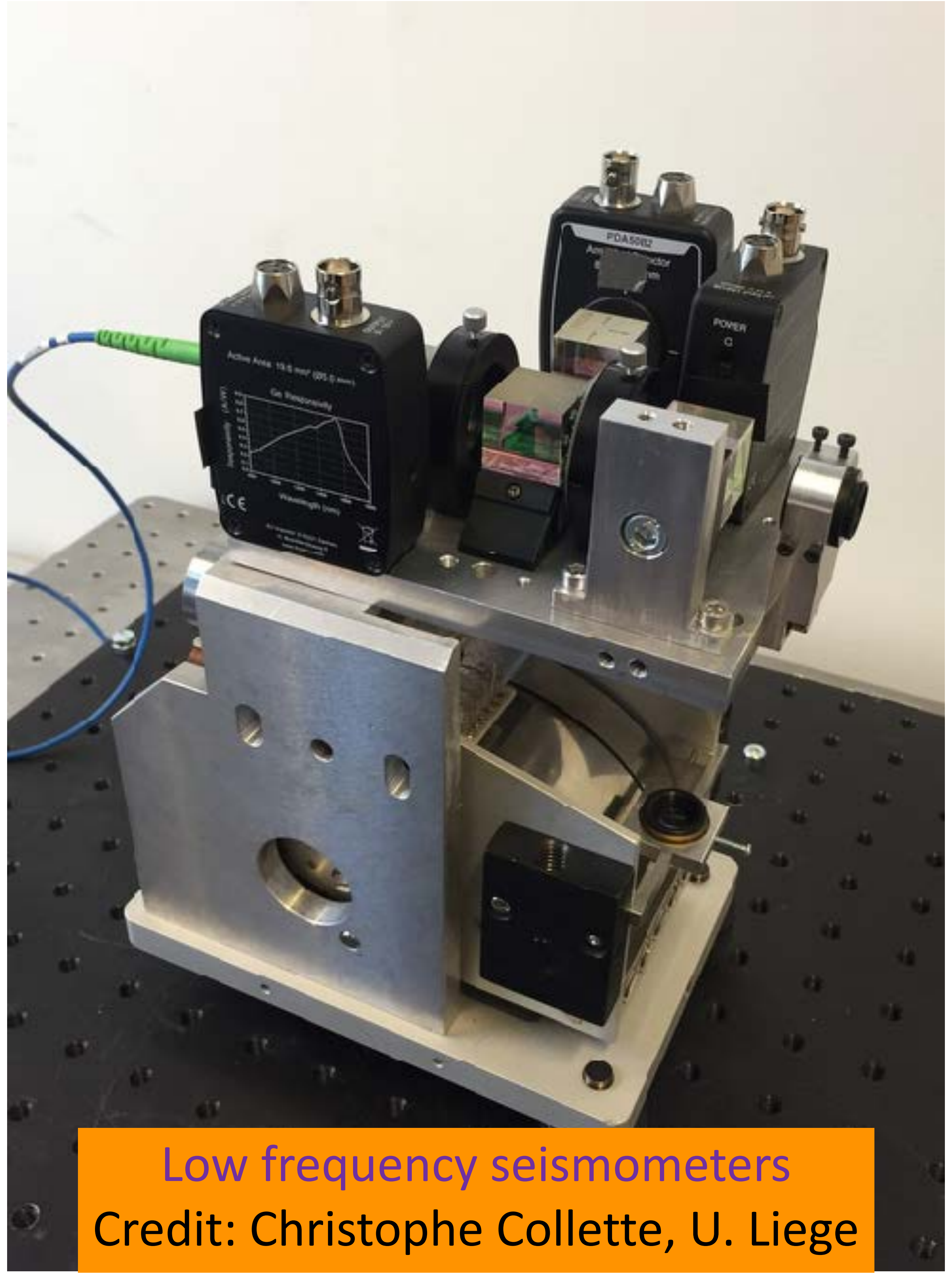


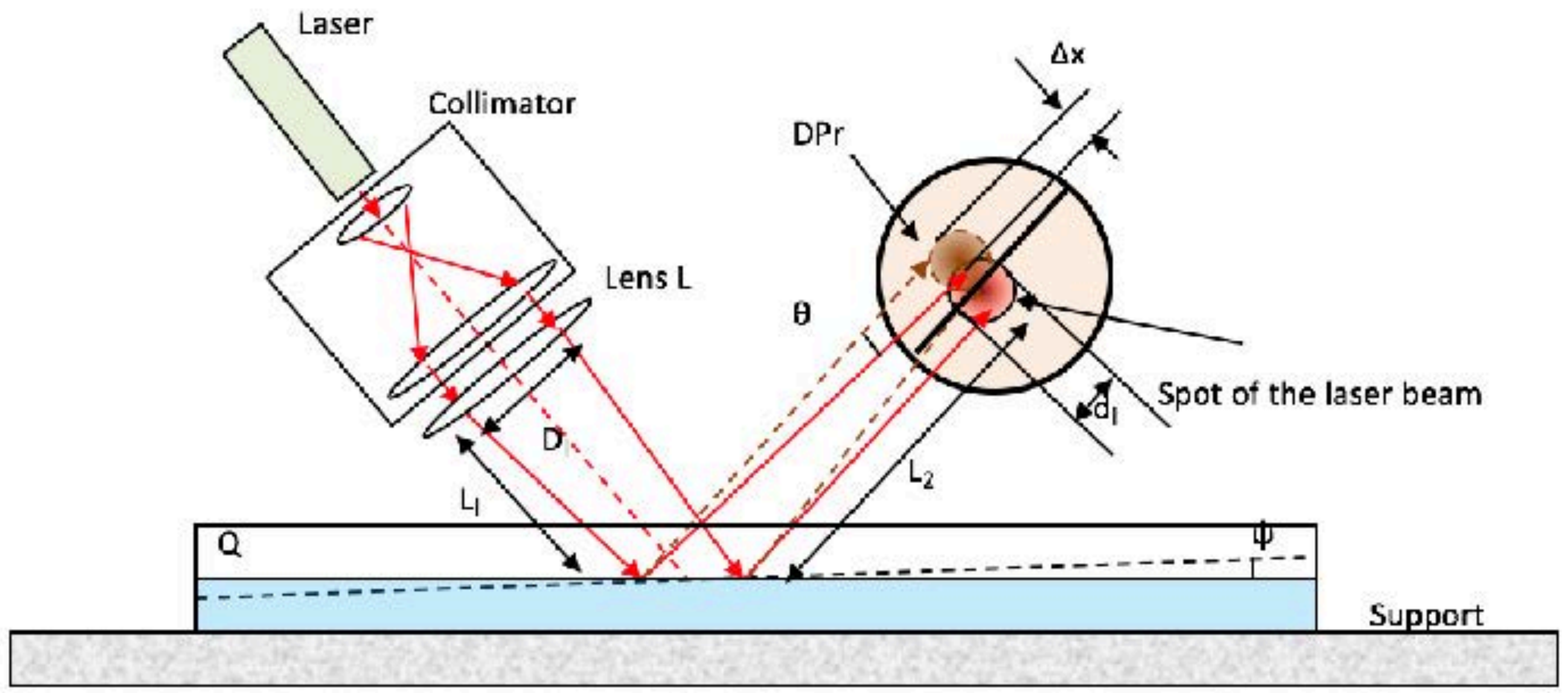
Image: Conor Mow-Lowry

R&D example: advanced seismic sensors

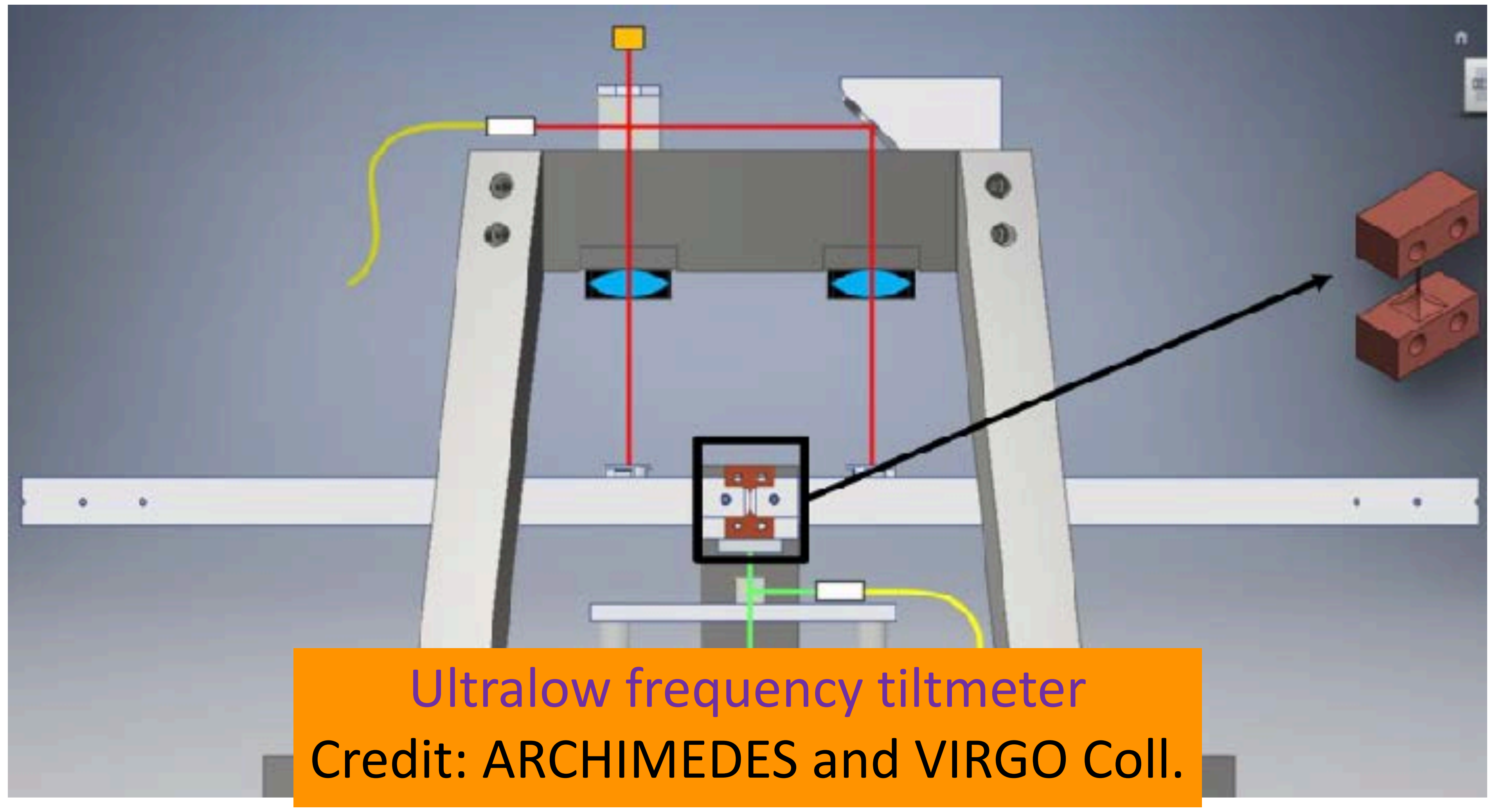
6-D interferometric readout inertial sensor
Credit: Conor Mow-Lowry, VU Amsterdam



Low frequency seismometers
Credit: Christophe Collette, U. Liege



Laser inclinometer, Credit: B. Di Girolamo, CERN

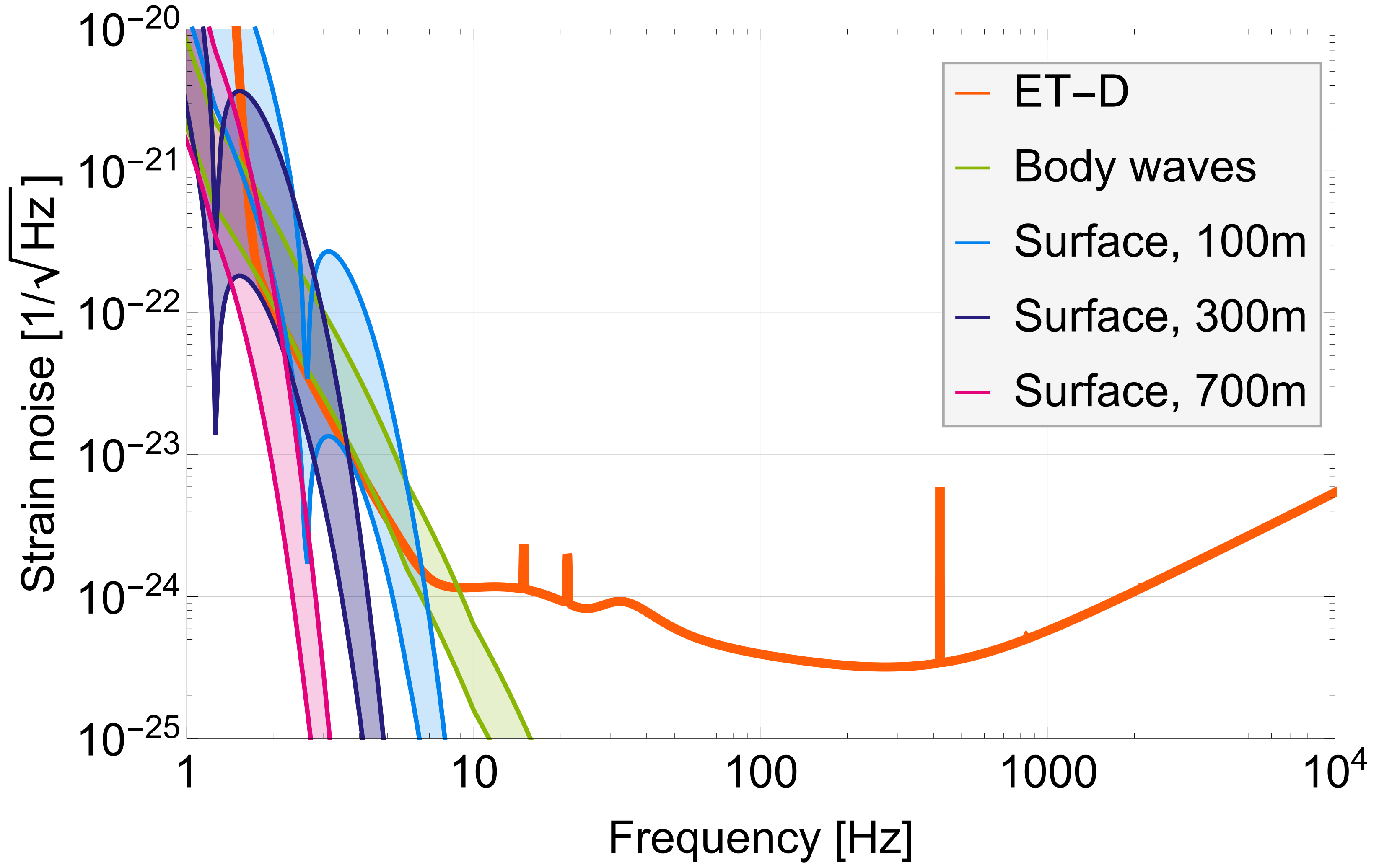


Ultralow frequency tiltmeter
Credit: ARCHIMEDES and VIRGO Coll.

Goal: inertial control at low frequencies for suspension shortening and RMS motion suppression

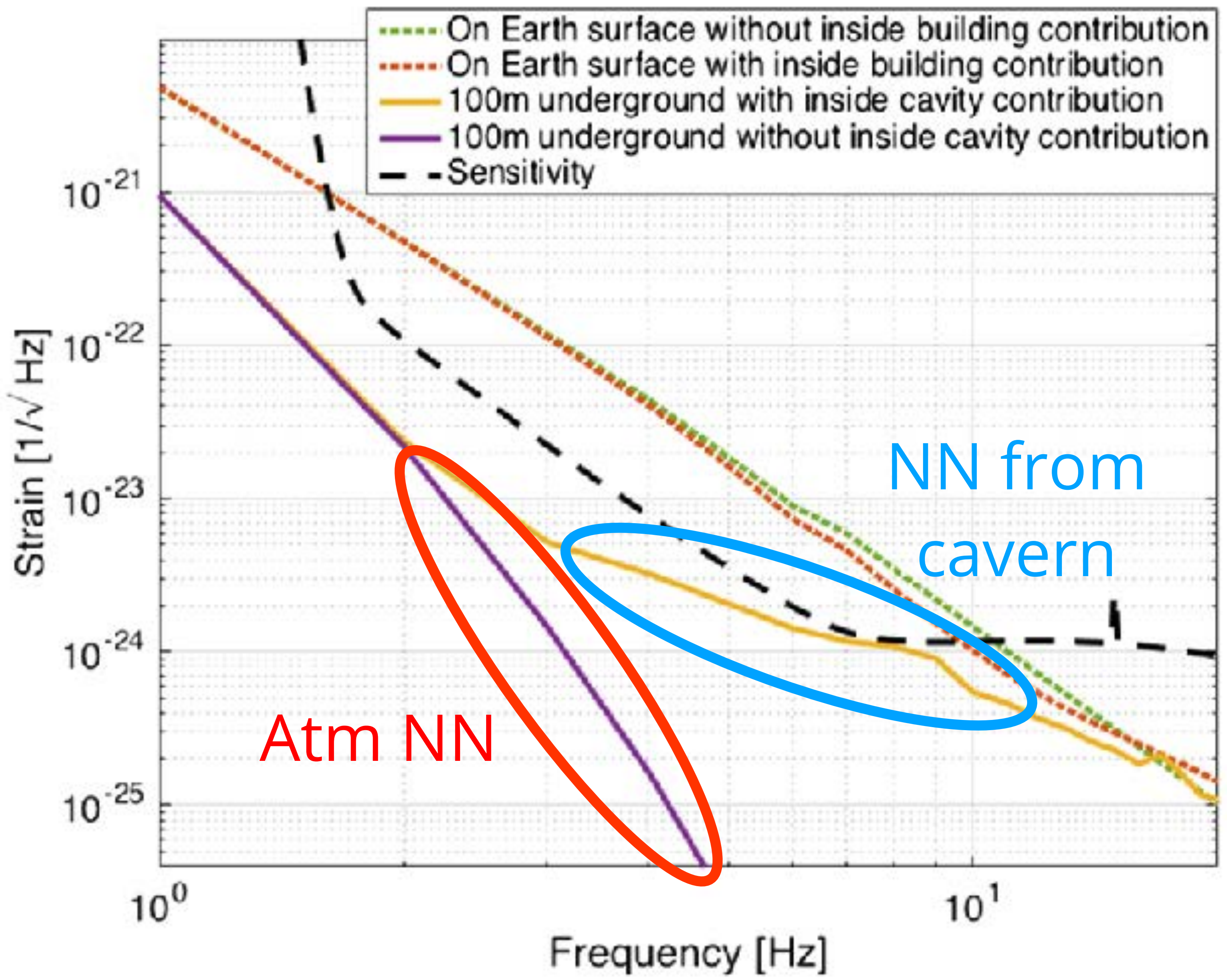
Underground and low noise

Seismic Newtonian noise (NN)



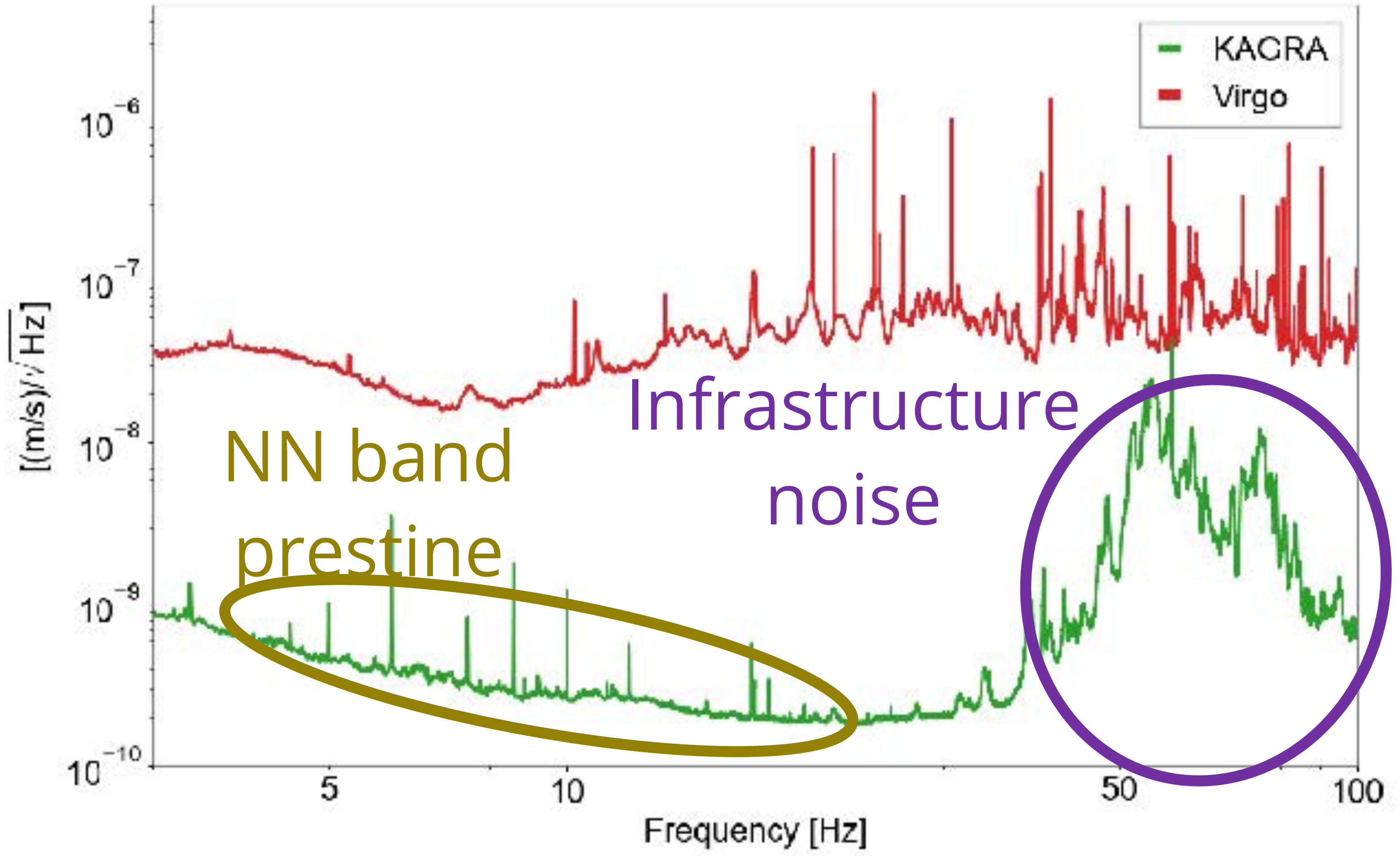
ET is planned >200m underground. Further mitigation of NN from seismic surface and underground fields might be achieved with noise cancellation using arrays of seismometers.

Acoustic NN



Atmospheric NN cancellation would be extremely challenging due to lack of a good monitoring system. ET can avoid it by going underground!

Low-noise environment



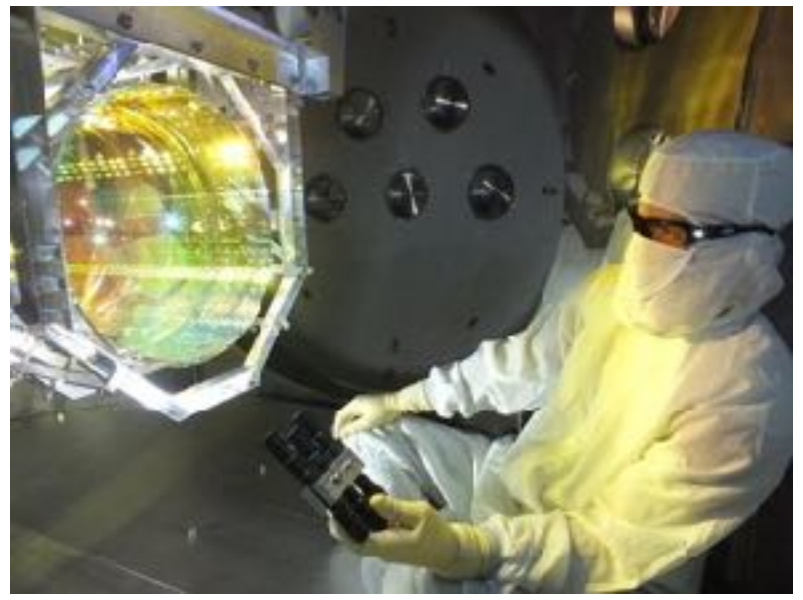
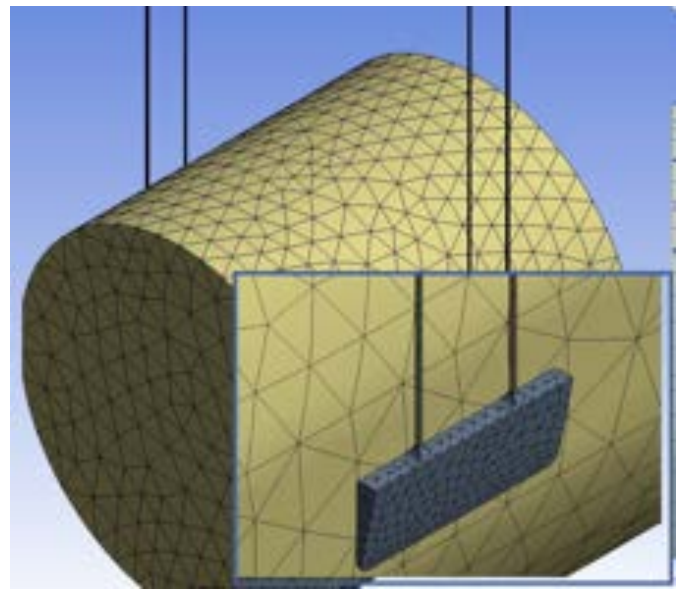
We must create a low-noise infrastructure. If KAGRA can do it (not creating excess noise in the NN band), so can the Einstein Telescope.

R&D challenge example: Optics

- Scaling challenge: *substrate* (ET-HF silica / ET-LF silicon) of 200 kg-scale with required purity and optical homogeneity/abs. is a challenge, and *coating challenge.*

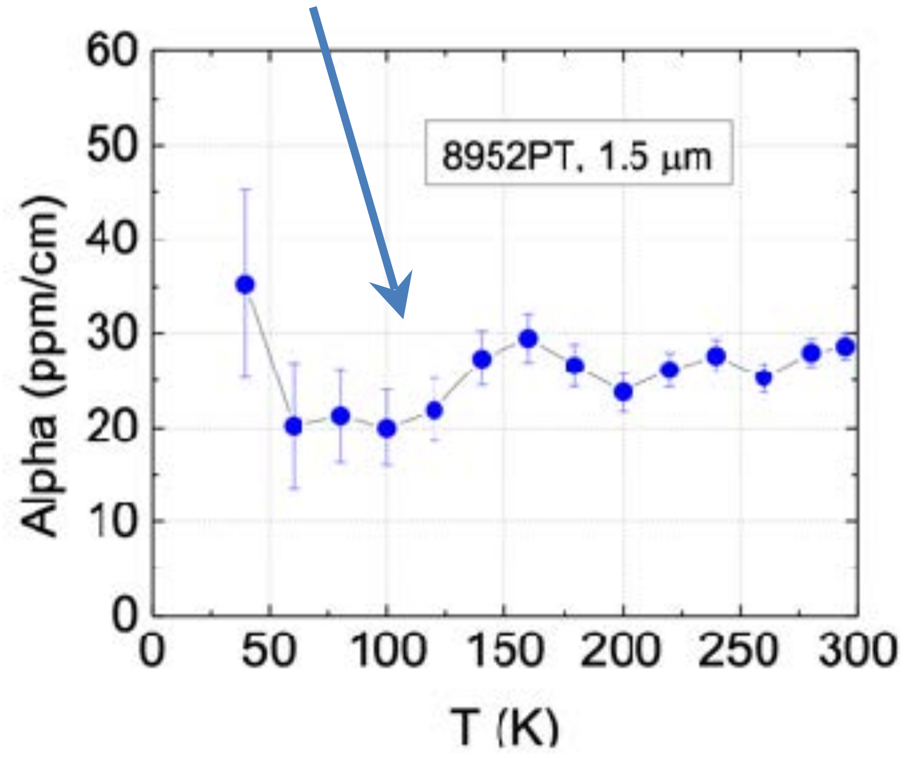
Absorption of “best 45 cm” MCZ Si: 1.5um

Stanford/Glasgow/Berkeley/Caltech 2019

Advanced LIGO – 40 kg / ET 200 kg

Nikon SiO_2



- Coatings: major challenge over recent years: coating solutions often either satisfy thermal noise requirement *or* optical performance requirement – not both.
- Progress towards first scalable design for ET-LF, however ET-HF target not met.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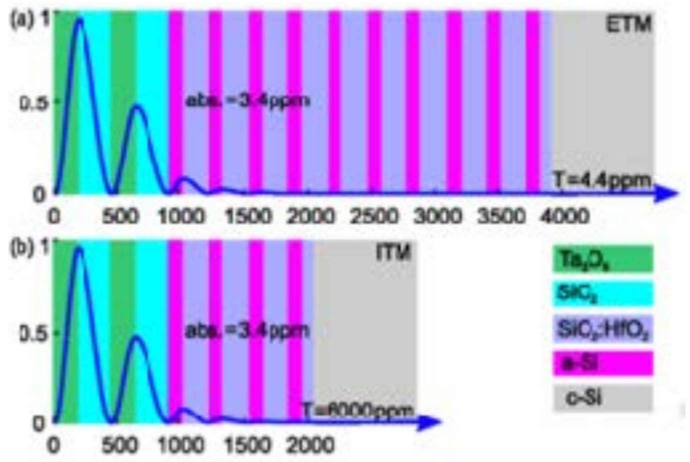
Featured in Physics Editors' Suggestion

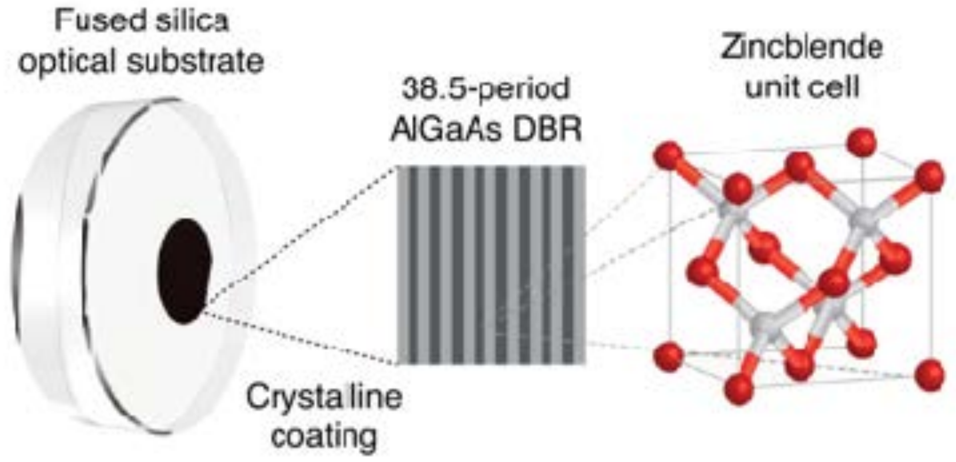
Mirror Coating Solution for the Cryogenic Einstein Telescope

Kieran Craig, Jessica Steinlechner, Peter G. Murray, Angus S. Bell, Ross Birney, Karen Haughian, Jim Hough, Iain MacLaren, Steve Penn, Stuart Reid, Raymond Robie, Sheila Rowan, and Iain W. Martin

Phys. Rev. Lett. 122, 231102 – Published 13 June 2019



ET-LF coatings: Craig *et al.*, Phys. Rev. Lett. **122**, 231102 (2019)



AlGaAs crystalline coatings might satisfy ET-HF but currently limited to ~200mm dia.

Cryogenics and laser wavelength

- Cryogenic mirrors and mirror suspensions can significantly reduce the thermal noise
- This requires change of material as fused silica does not show this effect. Alternatives crystalline materials such as silicon and sapphire
- Silicon cannot be operated at 1u, different wavelength is requires
- Wavelength change impacts many aspects of the interferometer and depends on many technology developments

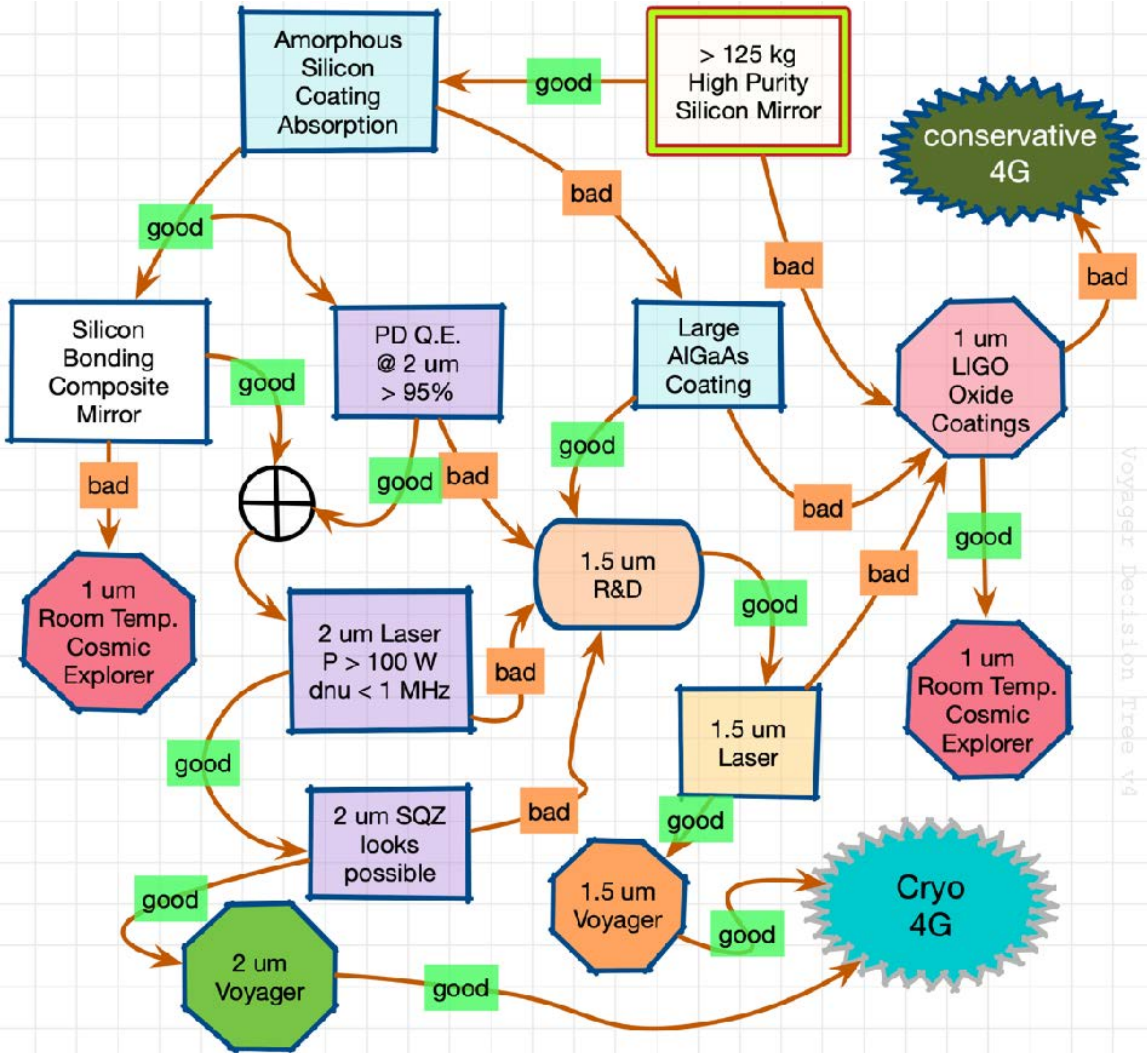
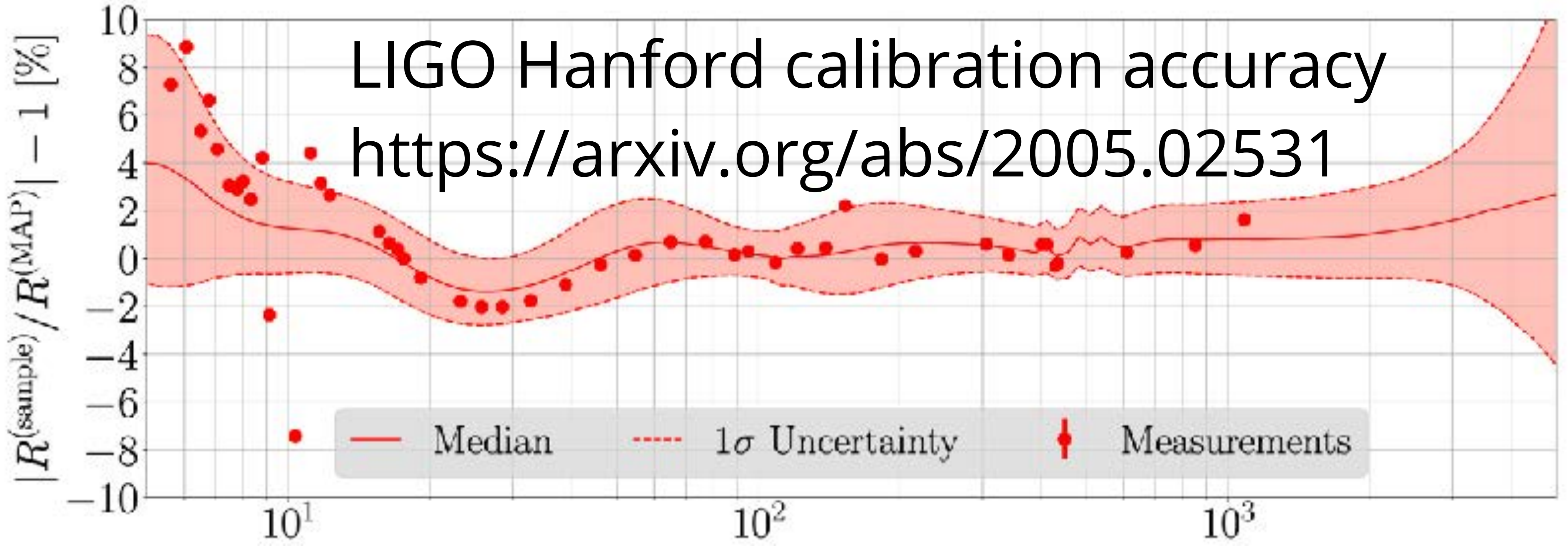


Image: Rana Adhikari GWADW 2018

Calibration must improve as much as SNR

- 3G detectors such as ET will require sub-one-percent calibration accuracy in order to fully benefit from their increased sensitivity
- Self-calibration, i.e. calibrating the detector using the detected signal and null-streams can help to achieve that.
- ET provides such a null-stream stand-alone, which is sky-position and polarisation independent (this is not the case for a distributed network).



LIGO Hanford calibration accuracy
https://arxiv.org/abs/2005.02531

B. Sky-independent null stream

The design of the proposed 3G detector ET envisages three V-shaped interferometers, one each at the three vertices of an equilateral triangle. The sum of the responses of the three interferometers, as we shall see below, is a null stream no matter where the source is in the sky. In fact, this is true more generally for any configuration that has a closed topology. Consequently, self-calibration with ET is significantly simpler.

Self-calibration of Networks of Gravitational Wave Detectors

Bernard F. Schutz
*School of Physics and Astronomy, Cardiff University, Cardiff, UK, CF24 3AA and Max Planck Institute for Gravitational Physics (Albert Einstein Institute), 14476 Potsdam/Golm, Germany**

B. S. Sathyaprakash

September 2020, https://arxiv.org/abs/2009.10212

ESFRI

Current focus: Enabling Technologies

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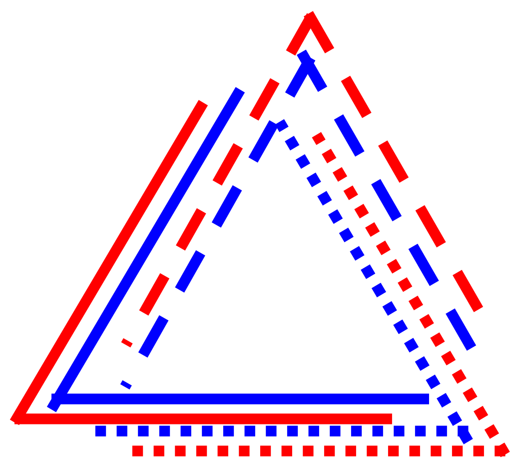
- The multi-interferometer approach asks for two parallel technology developments:



ET-LF:

- Underground
- Cryogenics
- Silicon (Sapphire) test masses
- Large test masses
- New coatings
- New laser wavelength
- Seismic suspensions
- Frequency dependent squeezing

- **ET-HF:**
  - High power laser
  - Large test masses
  - New coatings
  - Thermal compensation
  - Frequency dependent squeezing

Challenging engineering

New technology in cryo-cooling

New technology in optics

New laser technology

High precision mechanics and low noise controls

High quality opto-electronics and new controls

Evolved laser technology

Evolved technology in optics

Highly innovative adaptive optics

High quality opto-electronics and new controls

Advanced detectors and their development programmes are a crucial de-risking factor for ET-HF

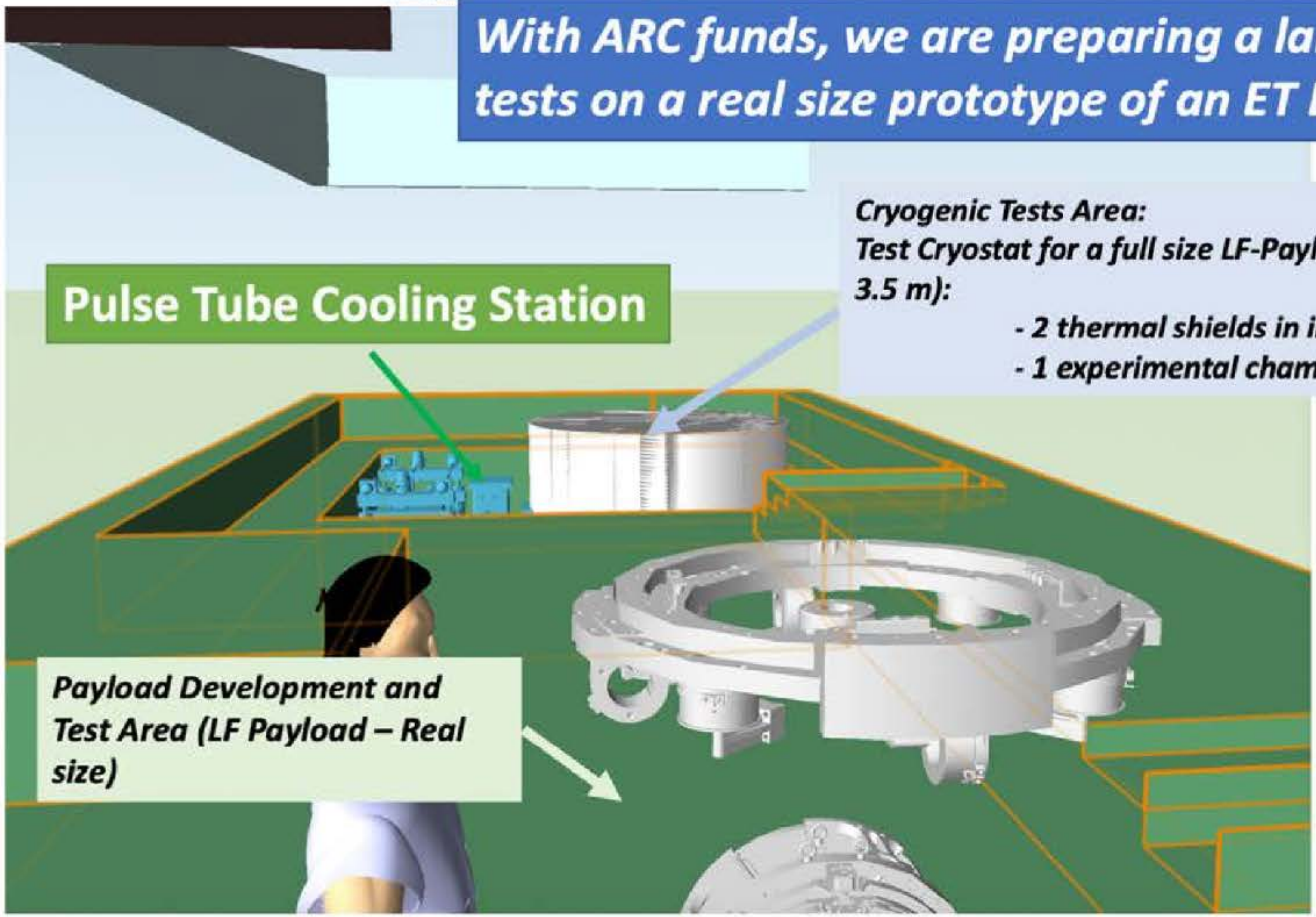
ETpathfinder

- 10m prototype facility, currently under construction in Maastricht
- 14.5M€ investment
- ~20 universities and research institutes from NL/BE/DE/F contribute

[Slide: Jan-Simon Henning]

3G Gravitational-Wave Lab

With ARC funds, we are preparing a lab for low temperature tests on a real size prototype of an ET LF-Payload



Cryogenic Tests Area:
Test Cryostat for a full size LF-Payload, cooled by two PT (~Ø 3 m x 3.5 m):

- ***2 thermal shields in insulation vacuum***
- ***1 experimental chamber with separated vacuum***

The Rome1 ET Group:

From Virgo:

Sibilla	Di Pace	(Post Doc Researcher)
Ettore	Majorana	(Full Professor)
Valentina	Mangano	(Post Doc Researcher)
Luca	Naticchioni	(INFN Researcher)
Maurizio	Perciballi	(INFN Technician)
Paola	Puppo	(INFN Researcher)
Piero	Rapagnani	(Associate Professor)
Fulvio	Ricci	(Full Professor)

From CUORE:

Angelo	Cruciani	(INFN Researcher)
Antonio	D'Addabbo	(Post Doc Researcher LNGS)
Stefano	Pirro	(INFN Researcher)

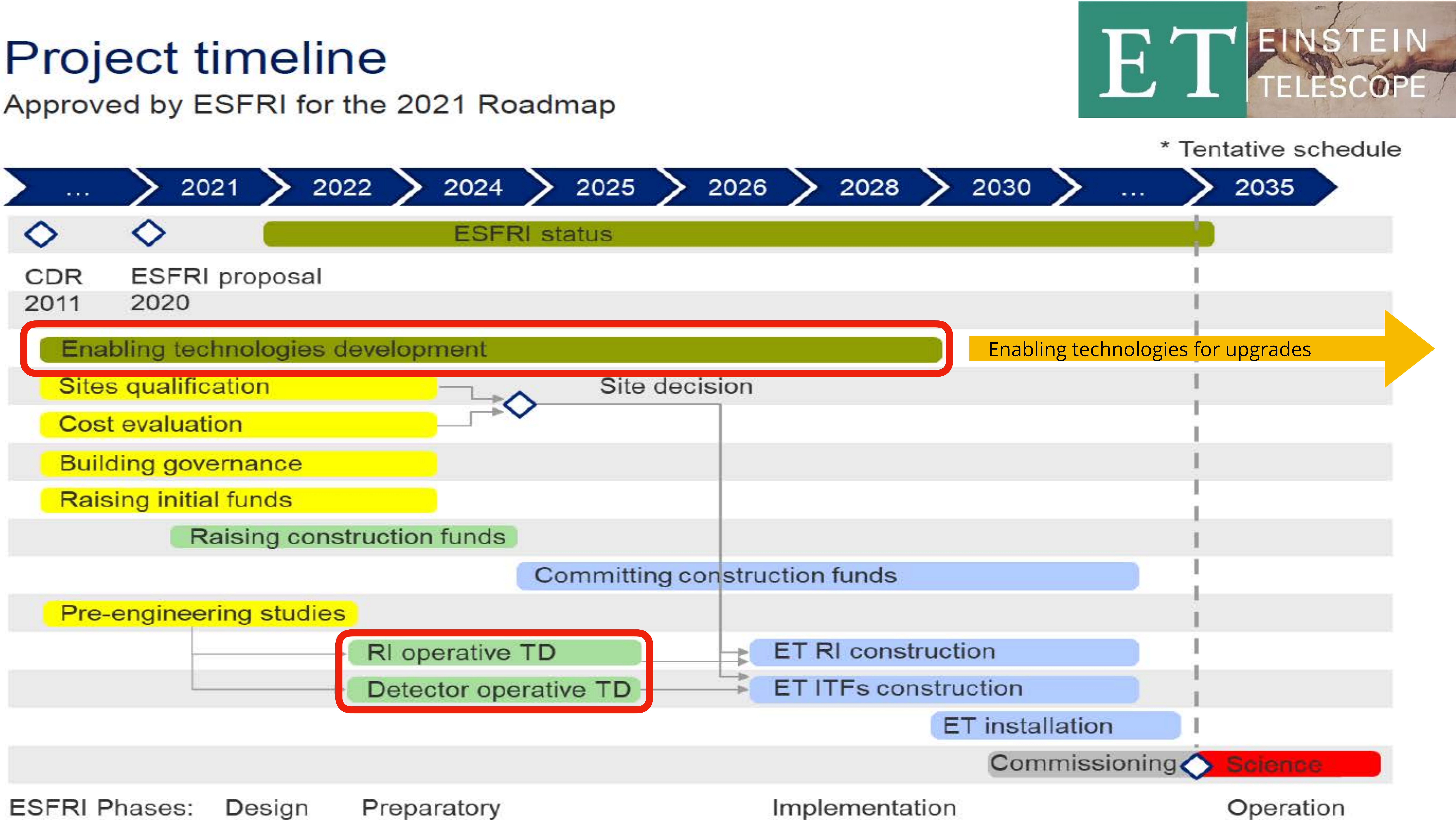
From EGO:

Paolo Ruggi (EGO Researcher)

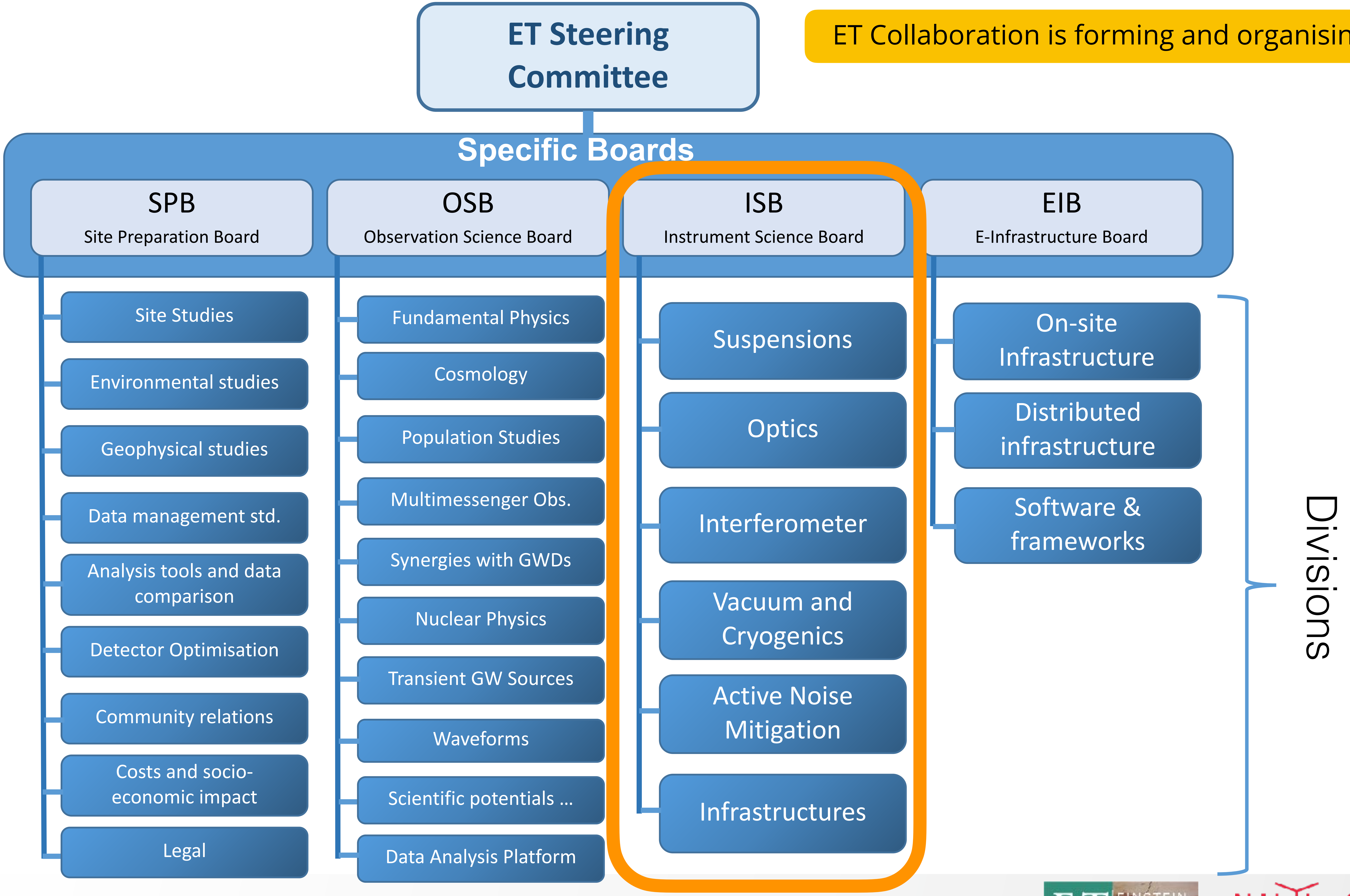
[Slide: Piero Rapagnani GWADW 2021]

Project timeline

Approved by ESFRI for the 2021 Roadmap



ET Collaboration is forming and organising



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ISB: Instrument Science Board

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How to join ET instrument science activities?

- The collaboration is currently forming, **a good time to join!**
- Over the next years, we will develop enabling technologies, this will include enhancing known systems from current detectors, adapting known technologies from other fields, and developing technological readiness of new technologies.
- In parallel we are establishing the community that will develop the **technology for upgrades for ET over a 50 years** timespan.
- Many systems are based on existing technologies, but the ET scope is much larger than the previous GW community. **Support by new groups is welcome in every subject.**
- **How to get started? Join the collaboration via a ISB working group, see instructions on https://wiki.et-gw.eu/ISB/WelcomePage**

Organization and contacts

Instrument Science Board	Andreas Freise	Gianluca Gemme
Suspension Division	Alessandro Bertolini	Francesco Fidecaro
WP I.1 Suspension chain	Roberto Passaquieti	Oliver Gerberding
WP I.2 Payload Design	Paola Puppo	Jan-Simon Henning
WP I.3 Test-Mass Suspension	Giles Hammond	Flavio Travasso
WP I.4 Seismic Isolation Platform	Christophe Collette	Alberto Gennai
WP I.5 Auxiliary Optics Suspensions	Franco Frasconi	Joris van Heijningen
Optics Division	Edwige Tournefier	Stuart Reid
WP II.1 Core Optics LF	Alex Amato	Iain Martin
WP II.2 Core Optics HF	Jessica Steinlechner	Benoit Sassolas
WP II.3 Lasers	Benno Wilke	Margherita Turconi
WP II.4 Input and Output Optics	Keiko Kokeyama	Michal Was
WP II.5 Squeezed Light	Henning Vahlbruch	Giacomo Ciani
WP II.6 Wavefront Sensing and Control	Alessio Rocchi	Martin van Beuzekom
WP II.7 Scattered Light	Thomas Bretz	Mario Martinez
Interferometer Division Presentation	Stefan Hild	Jérôme Degallaix
WP III.1 Observatory Design and Noise Budget	Stefan Danilishin	Teng Zhang
WP III.2 Optical Layout Sensing and Control Scheme LF	Julia Casanueva	Daniel Brown
WP III.3 Optical Layout Sensing and Control Scheme HF	Hartmut Grote	Annalisa Allocca
WP III.4 Data Acquisition and Real-Time Control	Bas Swinkels	Loïc Rolland
WP III.5 Calibration	Thierry Pradier	Laura Nuttall
WP III.6 Noise Characterization	Lucia Trozzo	Nicolas Arnaud

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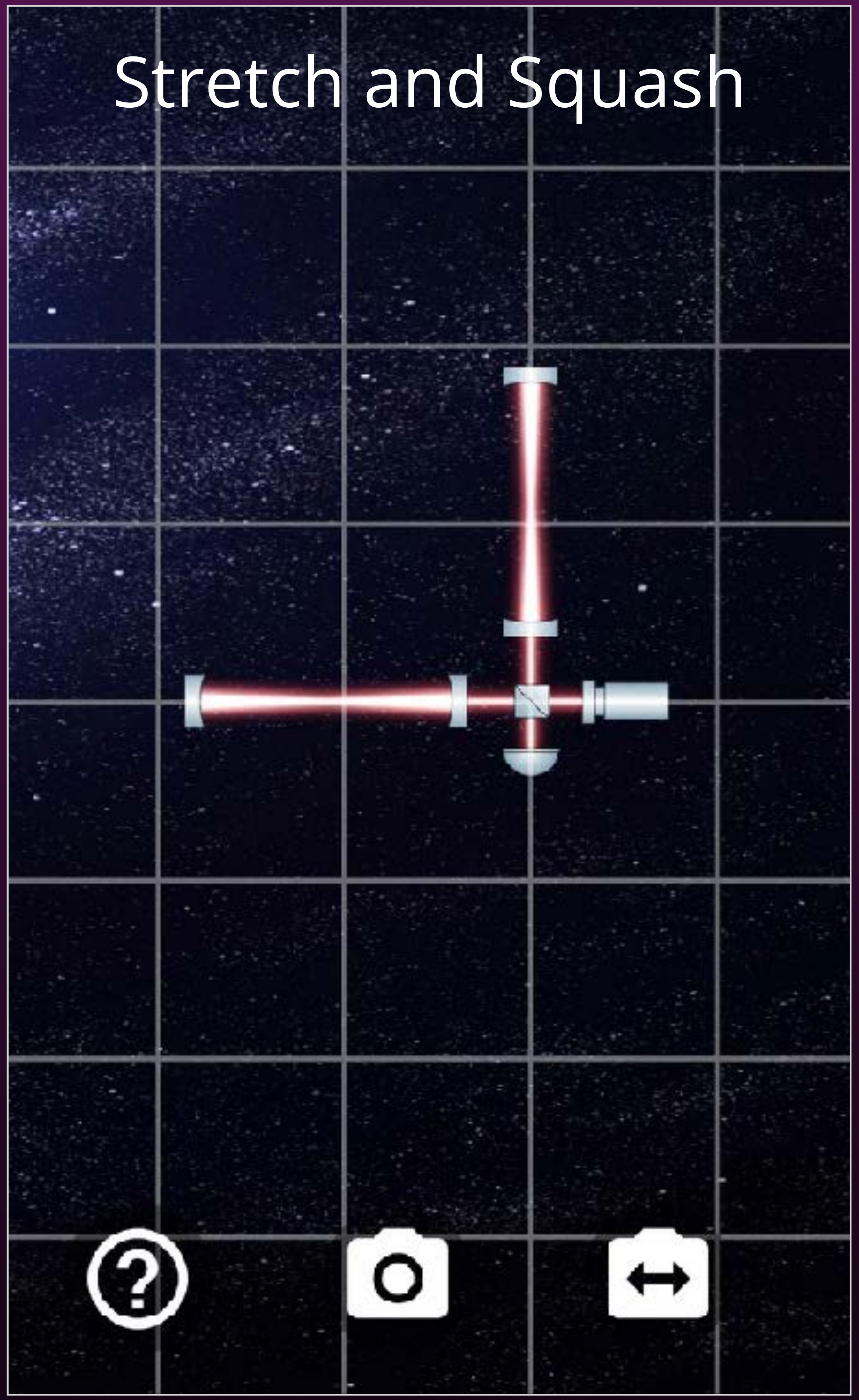

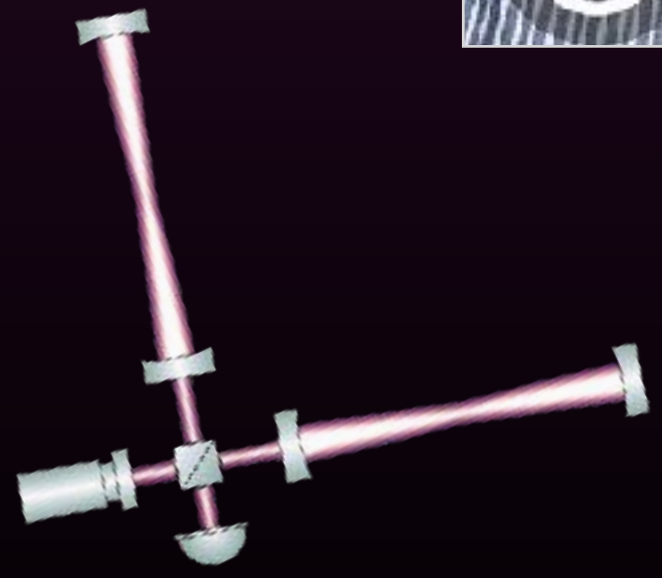

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