Einstein Telescope Project

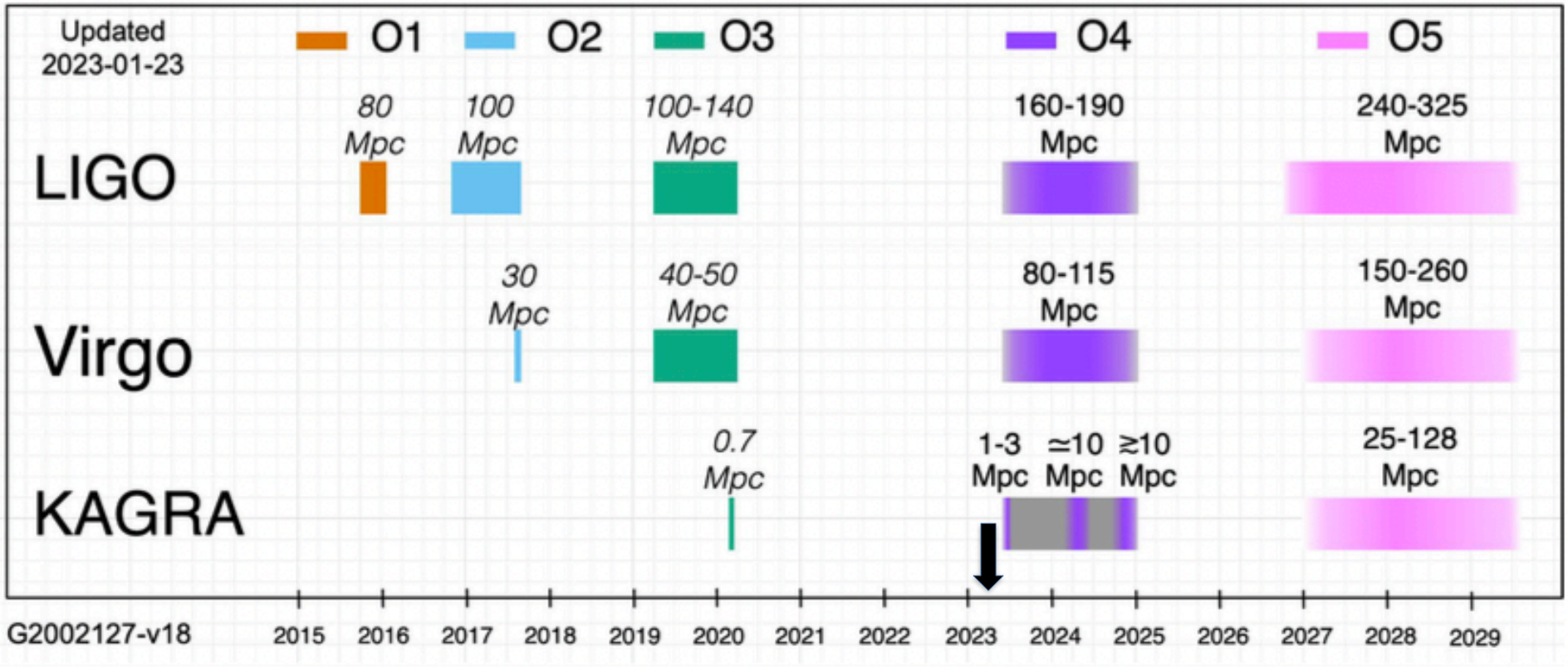
Mario Martínez

ICREA IFAE BIST

(..and some personnel notes..)

IMFP & CPAN joint meeting
Santander, October 2023

LIGO/Virgo/KAGRA status



O4 Observation period just started (May 24th 2023) with a foreseen duration of 18 months

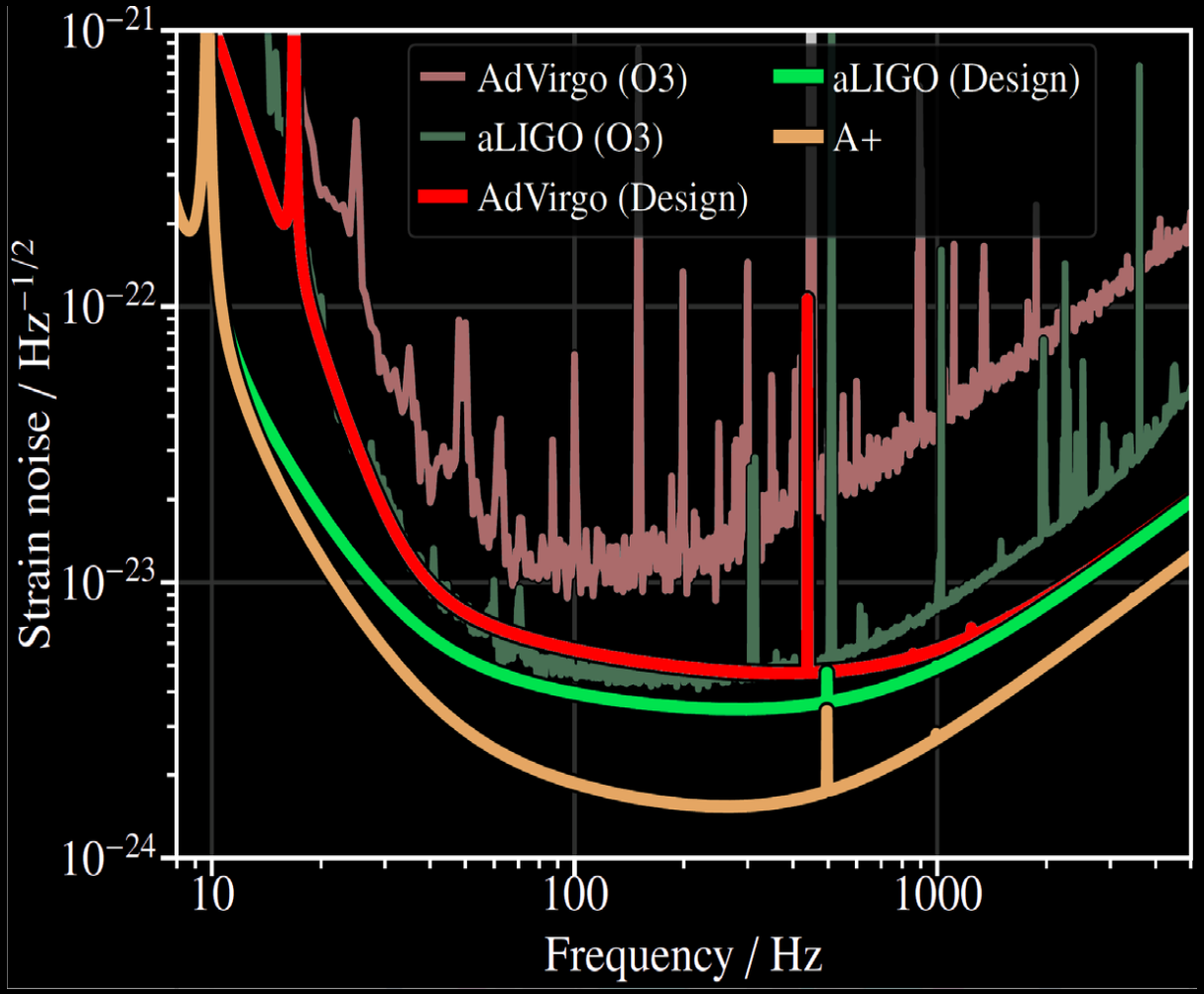
LIGO online with sensitivity about 147 Mpcs

KAGRA with limited sensitivity participated for about 1 month

Virgo delayed until sensitivity comparable to O3 —> plan for joining Feb/March 2024

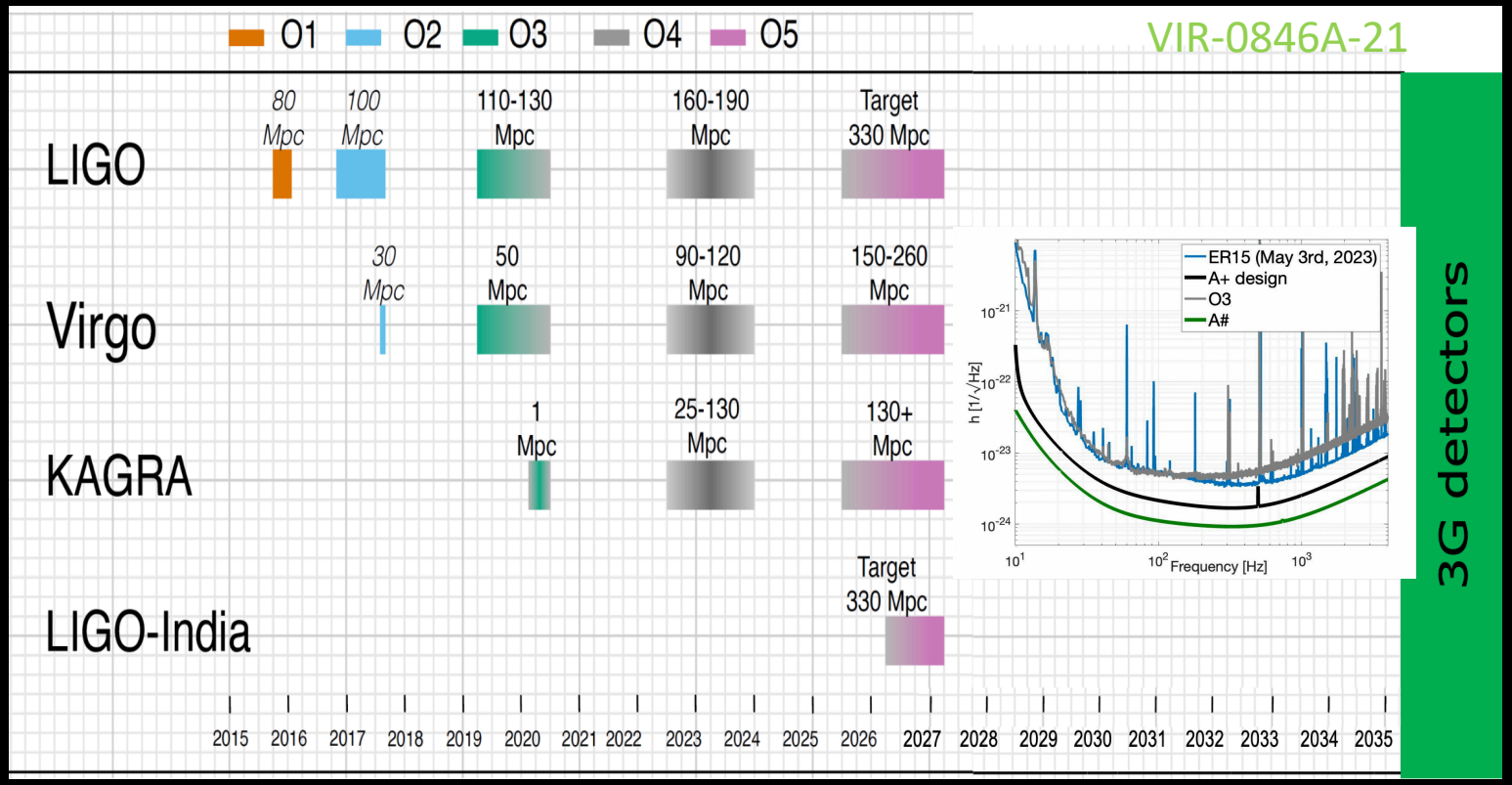
See talk by S. Husa in the plenaries

LVK sensitivity



In the next 5-6 years the current Interferometers will reach their design sensitivity…

What does the future hold?



e.g. ET ESFRI applications mentions operation period of 2035-2085

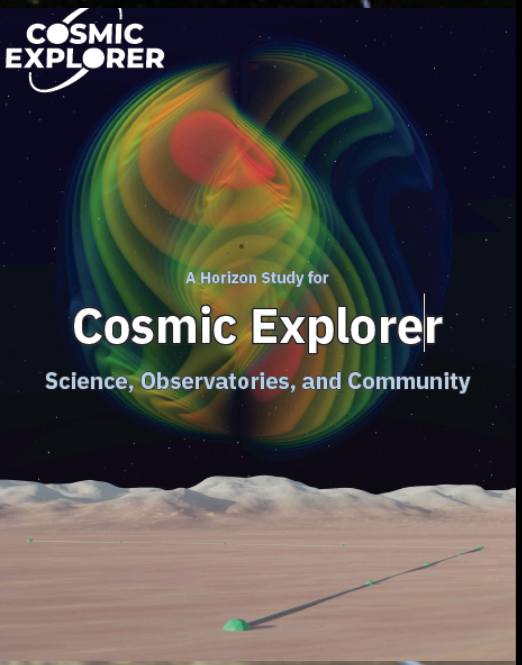
A+, AdVirgo+, KAGRA, LIGO India = Well underway

Post O5 (after mid 2028) planning just started

New facilities **ET, CE, NEMO …**

Footnote on O4:
It is not yet possible to give a definitive start date for O4, as there are some continued supply chain delays and the impact of COVID continues. We can say at this time that the O4 observing run will not begin before August 2022. We expect to be able to give a better estimate for the start of O4 by 15 September 2021 and will issue an update then.

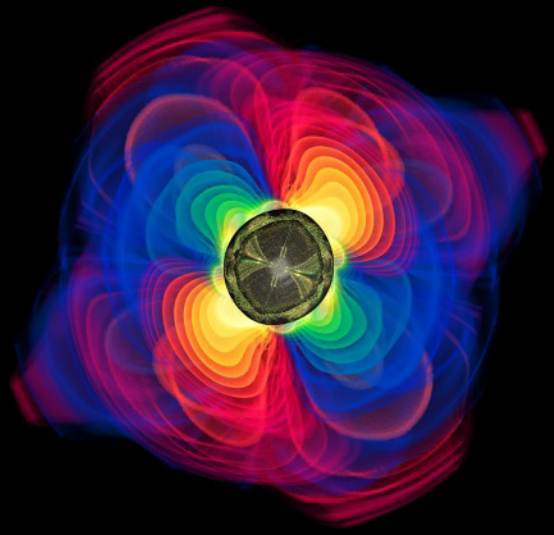
Cosmic Explorer (USA)



National Science Foundation
WHERE DISCOVERIES BEGIN

RESEARCH INFRASTRUCTURE GUIDE

NSF guidance for full life-cycle oversight of Major Facilities and Mid-Scale Projects

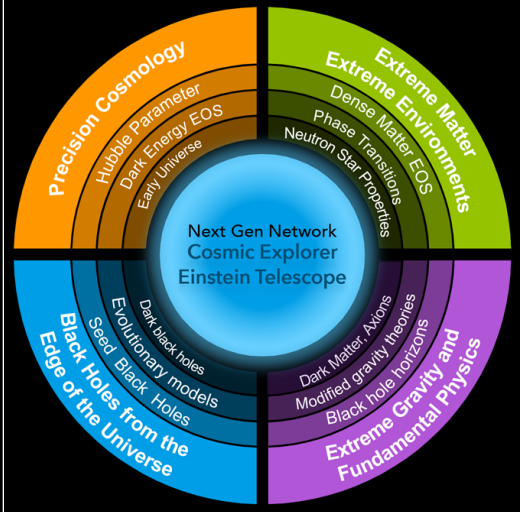


NSF Large Facilities Office
Office of Budget, Finance and Award Management

NSF 21-107
December 2021

Credit: Scientific contact by Ed Seidel (eseidel@aci.mpg.de); simulations by Max Planck Institute for Gravitational Physics (Albert-Einstein-AEI); visualization by Werner Benger, Zuse Institute, Berlin (ZIB) and AEI. The computations were performed on NCSA's Ir.

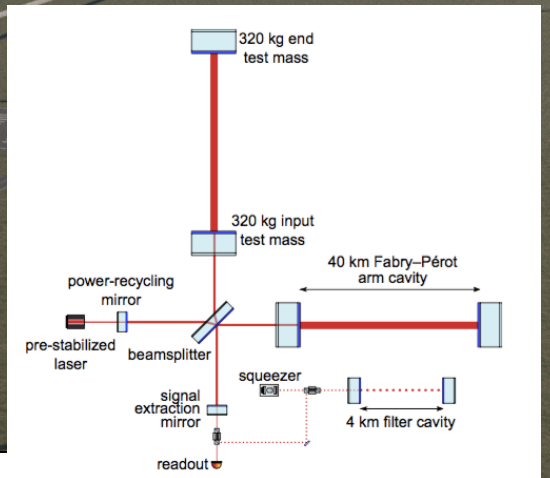
tps://cosmicexplorer.org/



http://dcc.cosmicexplorer.org/CE-P2100003/public

COSMIC EXPLORER

$1.6B (first estimation- US accounting)



Two widely separated, L-shaped surface facilities in the US:

- A 40 km detector optimized for deep, broadband sensitivity
- A 20 km detector tuned to neutron-star post-merger signals

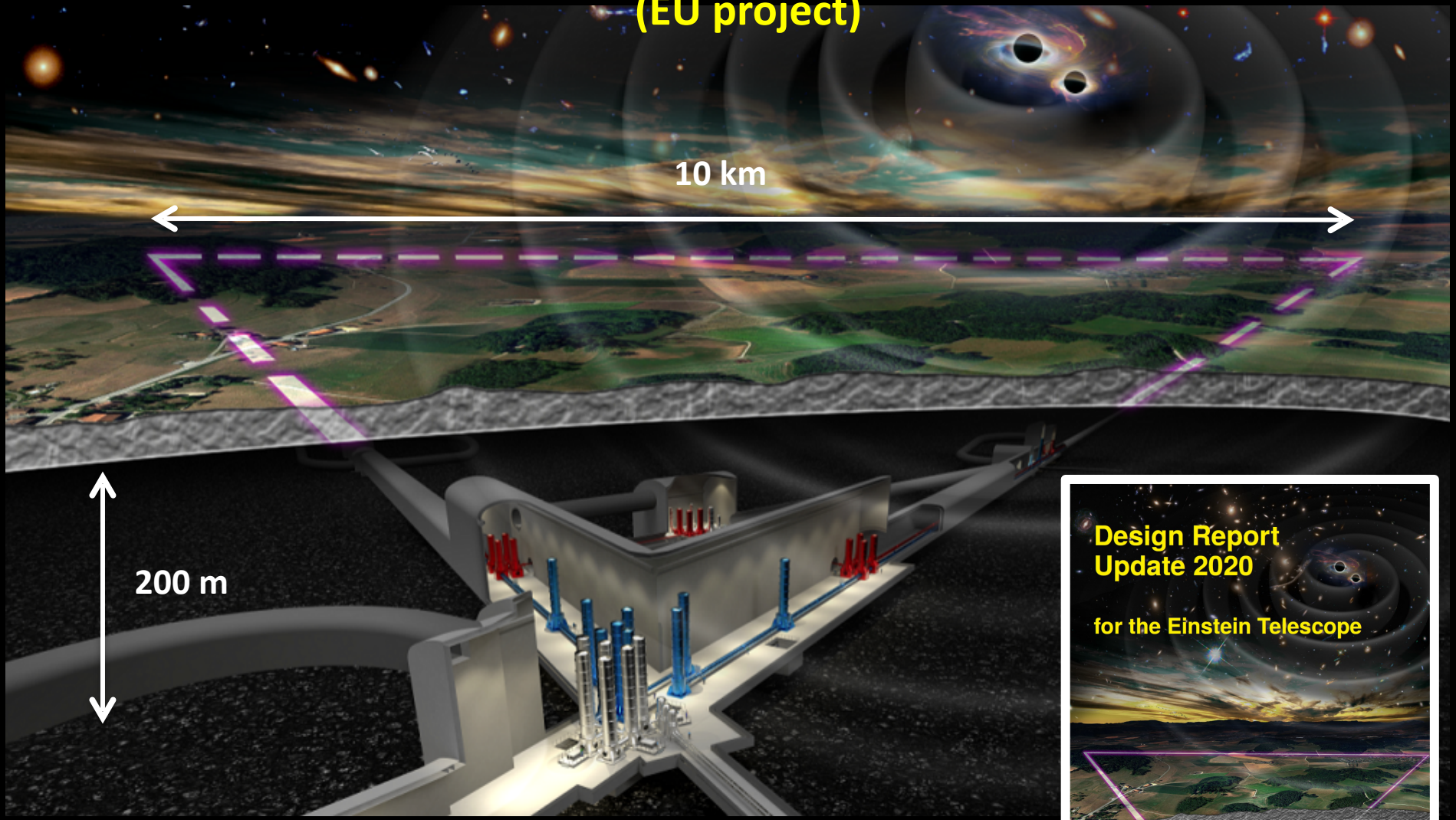
Two facilities improve localization and polarization information

Cosmic Explorer will extend LIGO A+ technology **(room-temp silica, 1 µm laser)**, with A# experience (larger mirrors and powerful lasers) and with Voyager technology **(123 K silicon, 2 µm laser)** as a secondary (unlikely) option

The Einstein Telescope

(EU project)

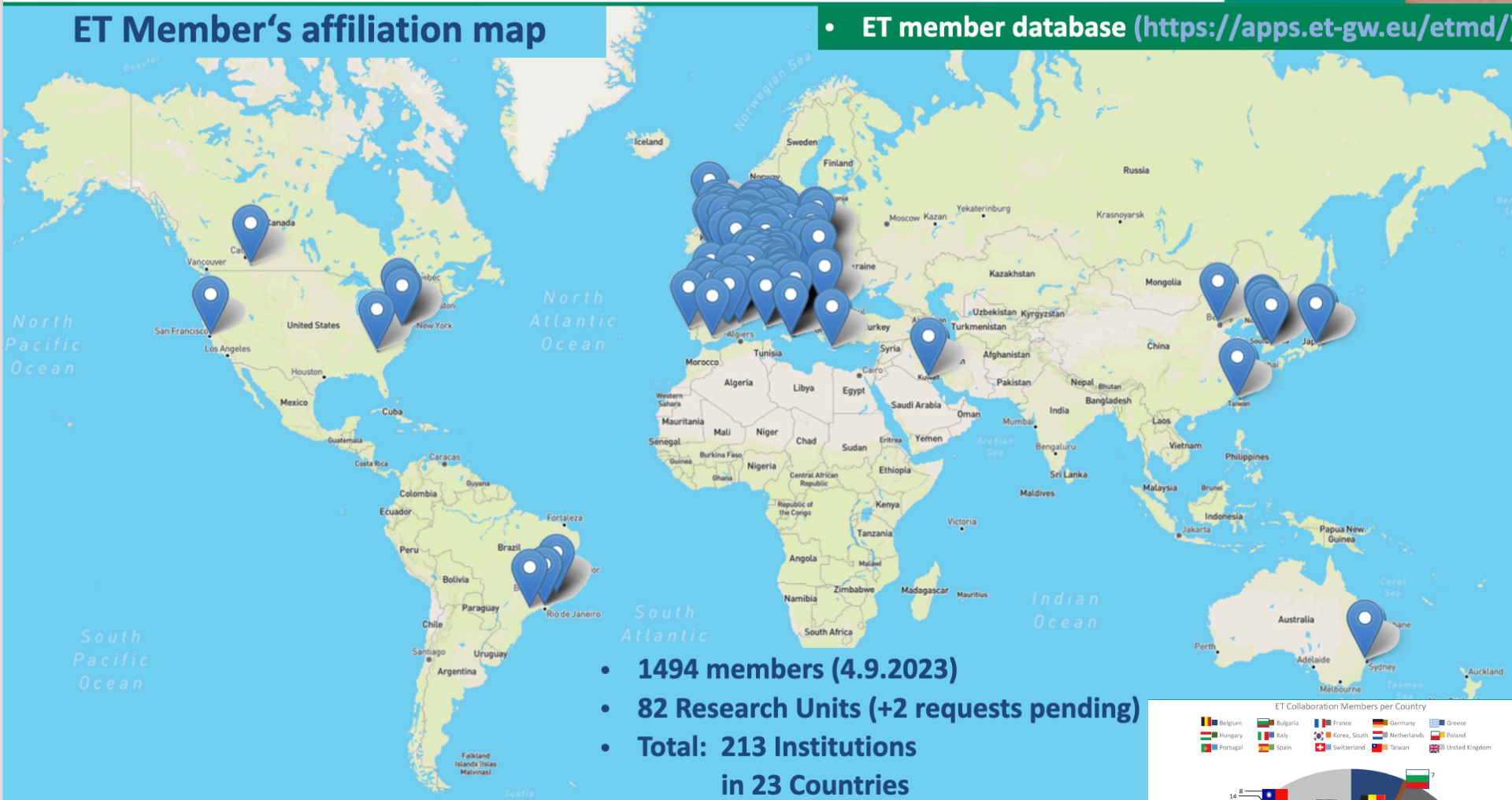
http://www.et-gw.eu/



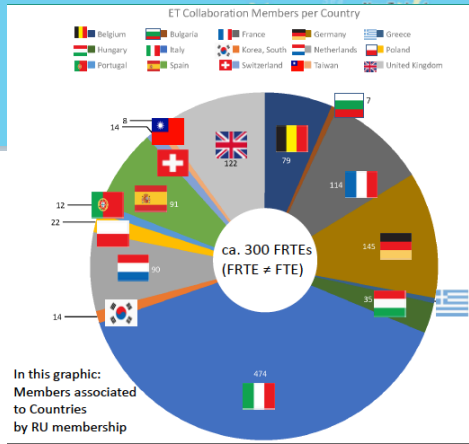
The Einstein Telescope Collaboration

ET Member's affiliation map

- ET member database (https://apps.et-gw.eu/etmd/



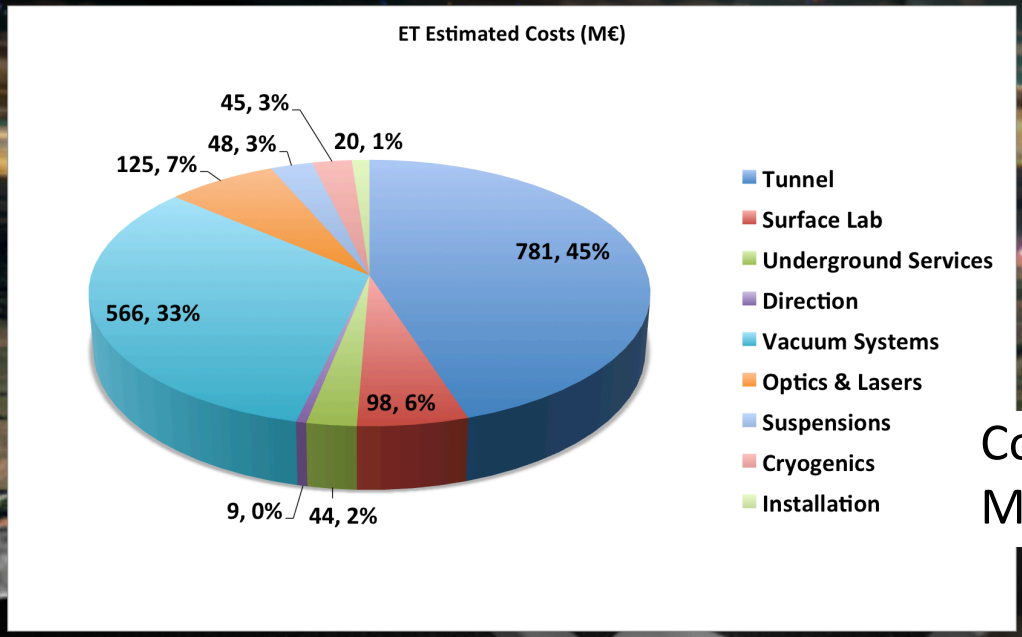
- 1494 members (4.9.2023)
- 82 Research Units (+2 requests pending)
- Total: 213 Institutions in 23 Countries



A Large Collaboration
(comparable to a LHC experiment)
Requires a proper Governance /Financial Model

- Collaboration Board in place
- Bylaws already in place

Estimated cost



Preparatory phase (170M€)

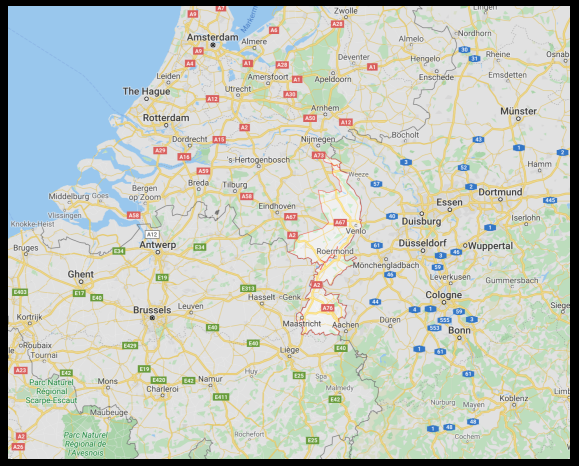
1. Site qualification (funded)
2. Site preparation (50 – 60 M€)
   Covered by host country
3. R&D on technology (95 M€) (funded)

Construction : 1900 M€ (in 10 years)
M&O : 37M€ /year

Host country is expected to contribute with > 50% of the total cost

Locations ?

O(100 M€) investment

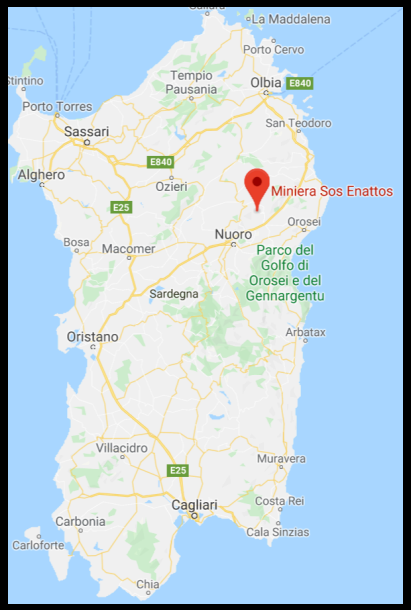


@ Limburg area (border NL-B-D)

→ Promoted by Nikhef

Intensive studies
@ Limburg,
@ Sardinia
@ Saxony
For characterize seismic, environmental noise, etc ...

O(100 M€) investment



@ Sardinia

→ Promoted by INFN

@ Germany is very present in ET
They foresee a large investment in the following years

→ Exploring Saxony as a third site possibility

→ Ongoing geological characterization of the site

Rising Construction Funds

In the Netherlands a formal request of 900M€ for ET@ Maastricht has been approved by the Science Minister to the NL Government

Italy approved a 50M€ project for enabling technologies and additional 350M€ for supporting ET@ Italy has been secured plus recent explicit support by italian Presidency for ET@Italy

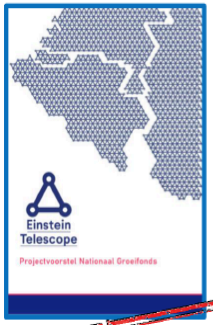
Ongoing discussion on the level of financial involvement by other EU countries in ET for the following years (common funds, etc..)

—> Hoping for collecting about 3M€ /year cash for 3 years…

Einstein Telescope in Euregio Meuse-Rhine (EMR)

Connected institutions in:
Belgium,
Germany &
the Netherlands

Nationaal Groeifonds (the Netherlands)



Emphasis on potential socio-economic Impact

Submitted by OCW Ministry (EZK Ministry support)

Supported by ~70 Dutch Industrial Institutions

APPROVED

In October 202[illegible] large funding proposal within context of the '*Nationaal Groeifonds*'. Decision in April 2022.

Includes 42 M€ for geology, R&D & organization as well as possible Dutch share towards ET realization

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ETIC – Einstein Telescope Infrastructure Consortium

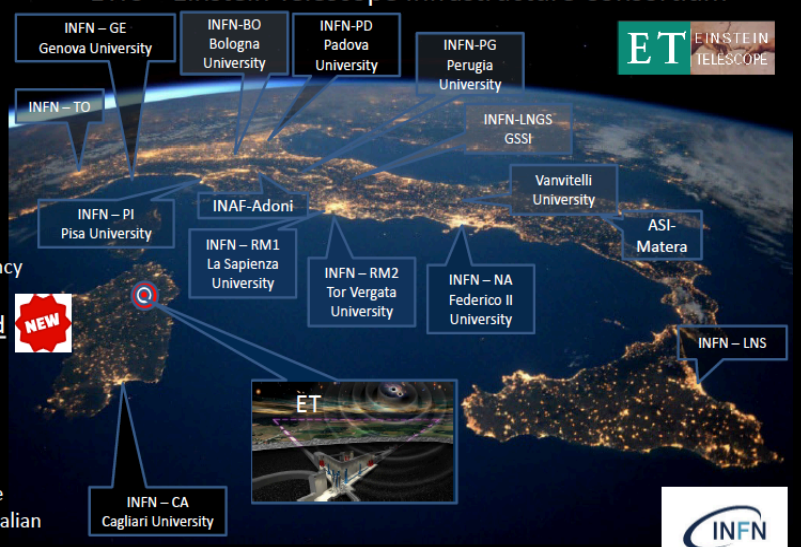
Next Generation EU Investment focused on ET enabling technology and Sardinian site candidature support

Leaded by INFN,
Partners:
11 Universities
INAF and Italian Space Agency

Budget 50M€ approved

Start of the project:
1st December 2022

Discussion ongoing with the Italian Government on an Italian share toward ET realization

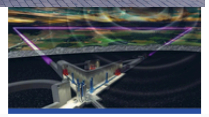


https://www.deutscheszentrumastrophysik.de/de

News from Germany

German Center of Astrophysics in Saxony became a reality → now approved

→ Big Data for Astroparticle physics
→ Technology (Si-sensors, Optics)
→ **Underground low noise Lab related to ET**



issenschaftspolitik

nschaftsinitiative plädiert für hes Zentrum für Astrophysik in usitz

Astronomie von Weltrang

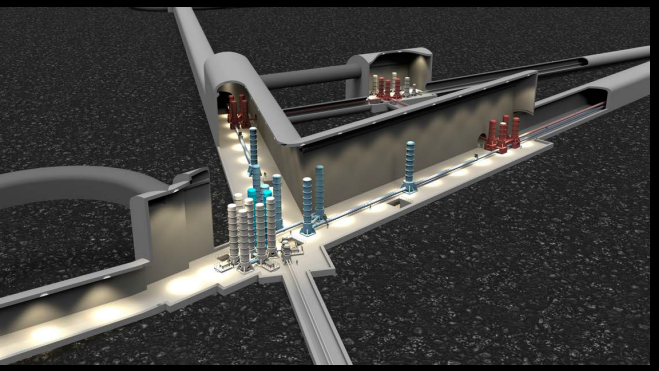
Pressemitteilung anhören

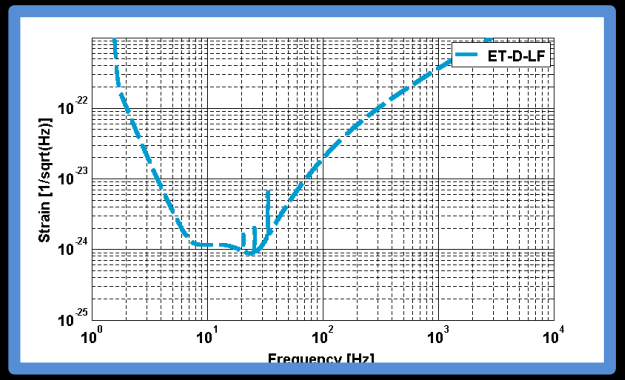
DESY.

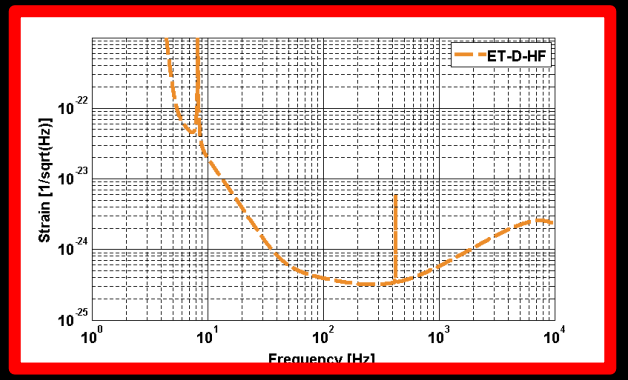
Dies ist eine Pressemitteilung von:

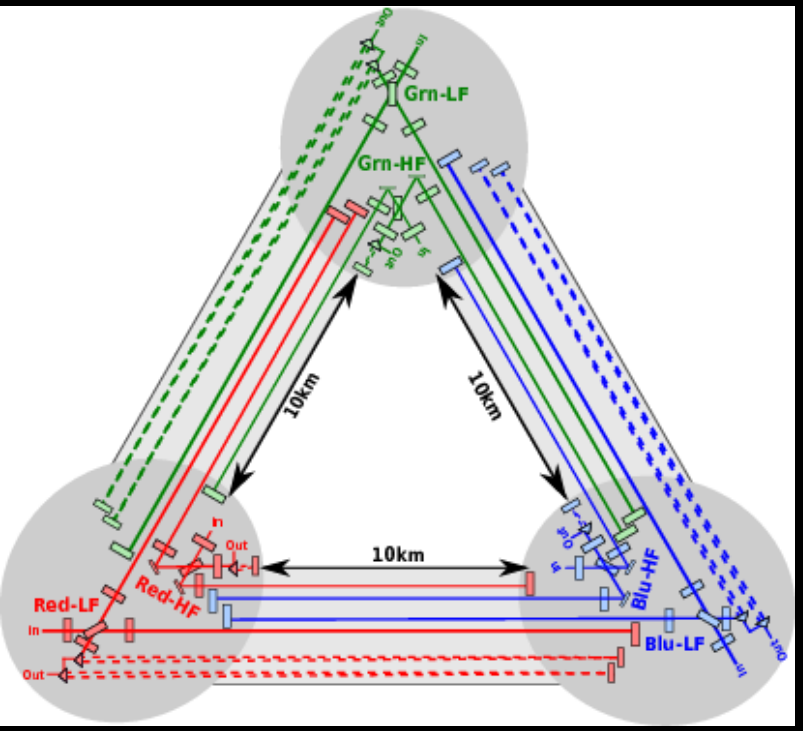
Thirdly, the settlement of the European gravitational wave observatory **"Einstein Telescope"**, which is already being planned, is to be examined in the granite stock of Upper Lusatia. **"The granite stock offers ideal conditions, the construction of the telescope under the earth's surface would tie in with the mining tradition of the region and would be an international lighthouse project,"** explains **Christian Stegmann, DESY director for astroparticle physics and supporter of the DZA.**

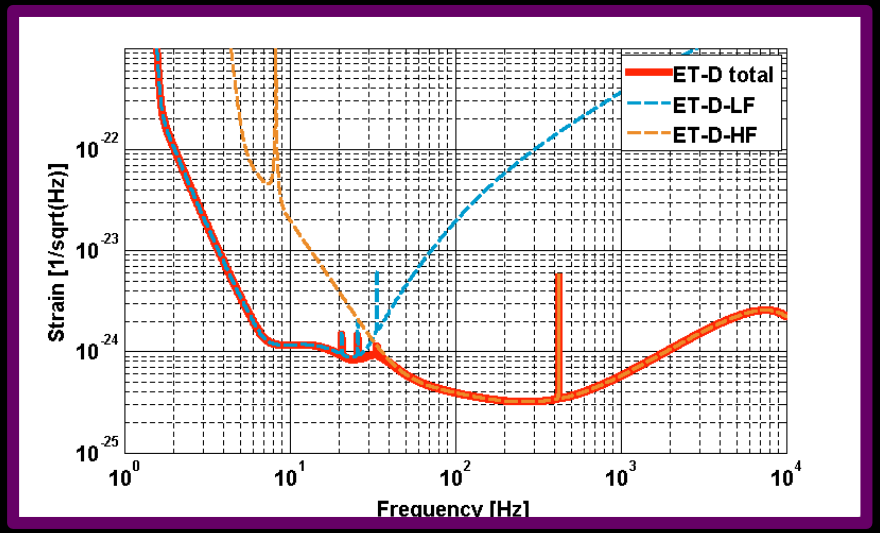
Einstein Telescope (6 in 1) Xylophone





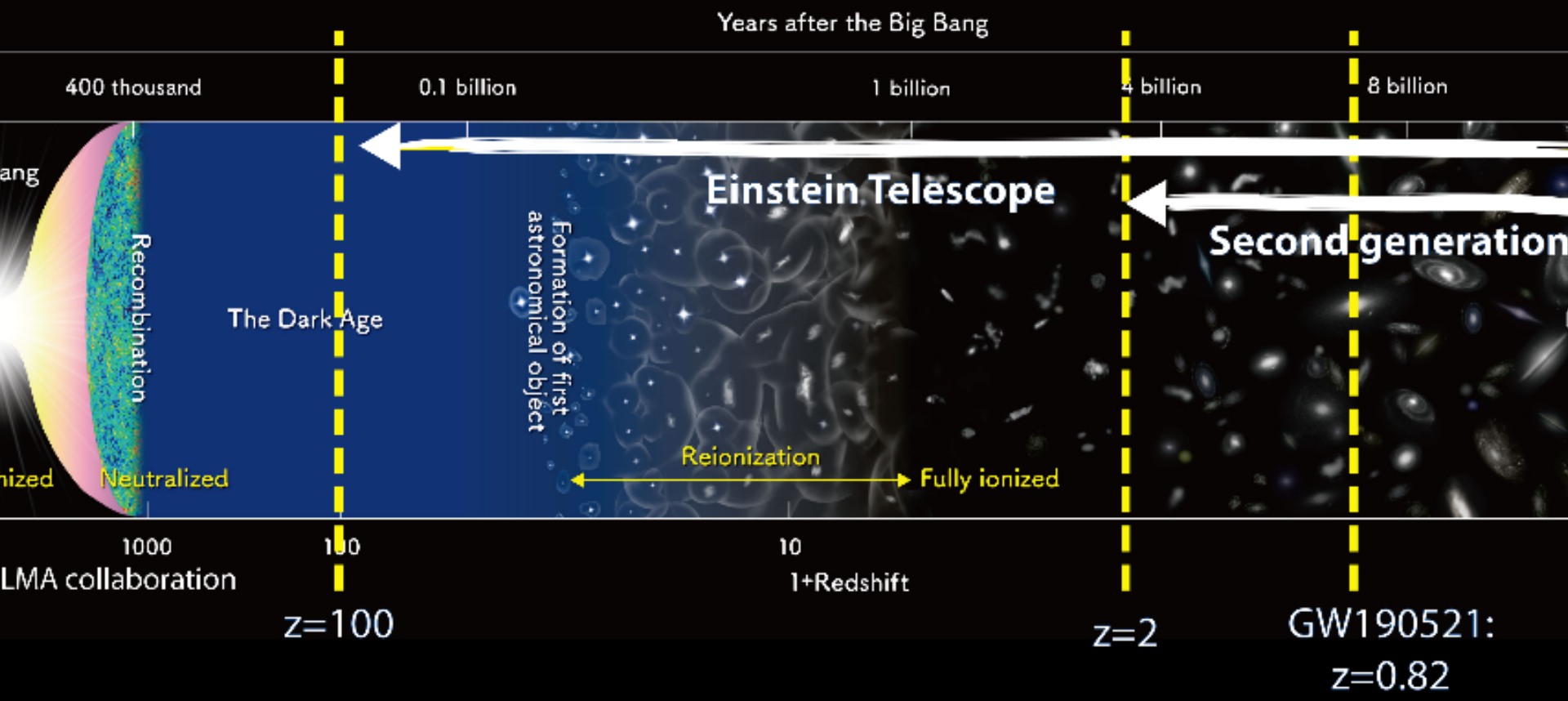






Each interferometer decoupled into 2 devices independent for the best sensitivity to low and high frequency

Detection horizon for black-hole binaries



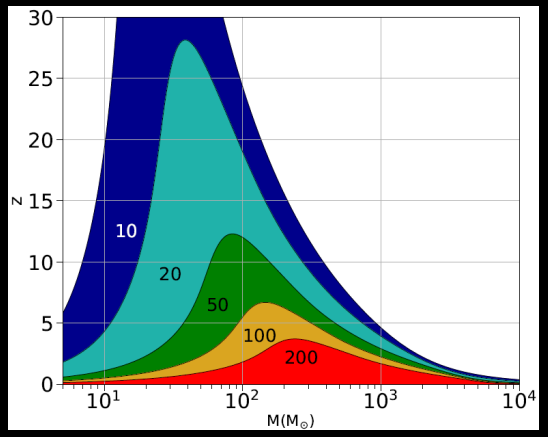
Huge rate of detections (about 1 per minute)

Extended redshift coverage up to the Dark Age

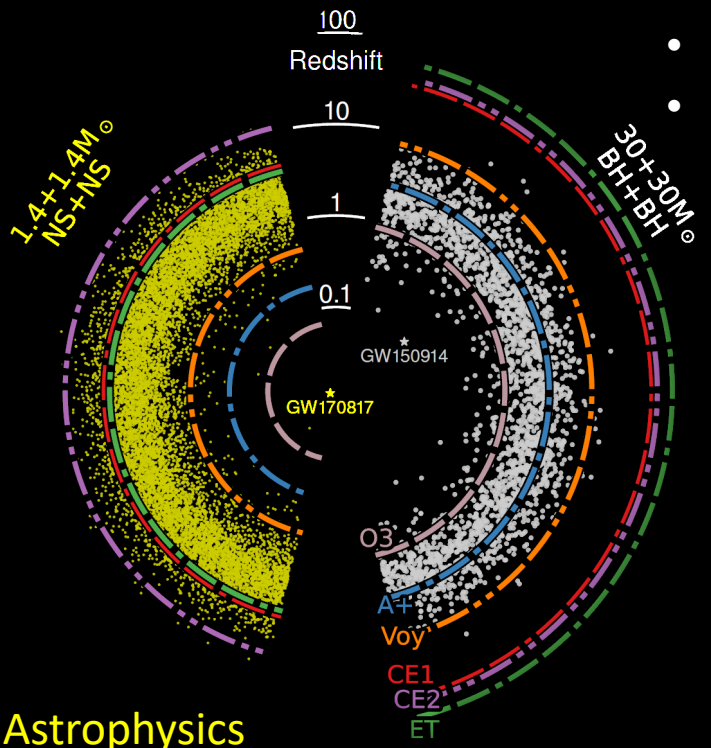
- Test for primordial BH origin
- Cosmology & Cosmography

Many events with very large Signal-to-Noise ratios

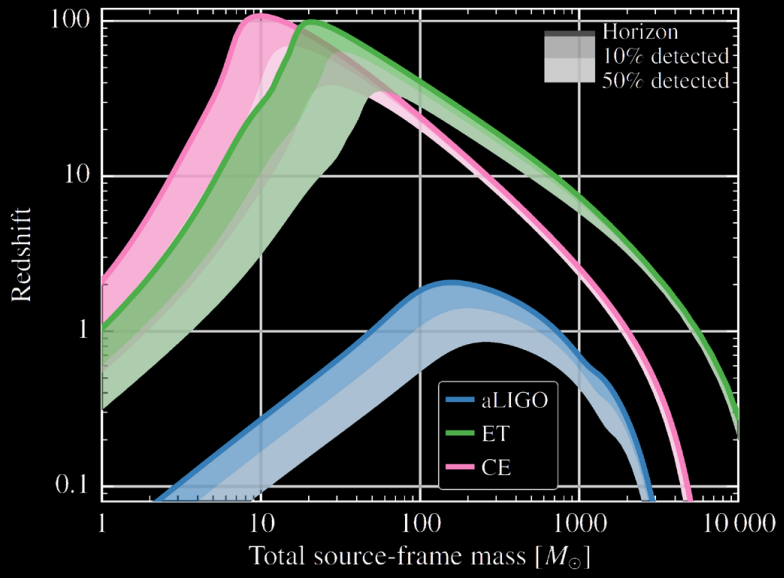
- Precision tests of GR predictions and detailed BH studies



Listening the whole Universe

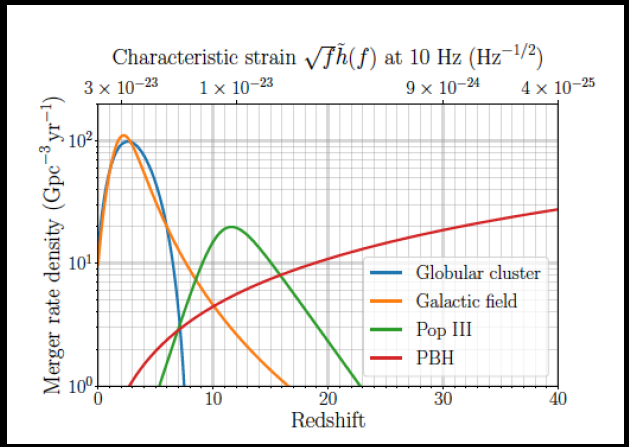


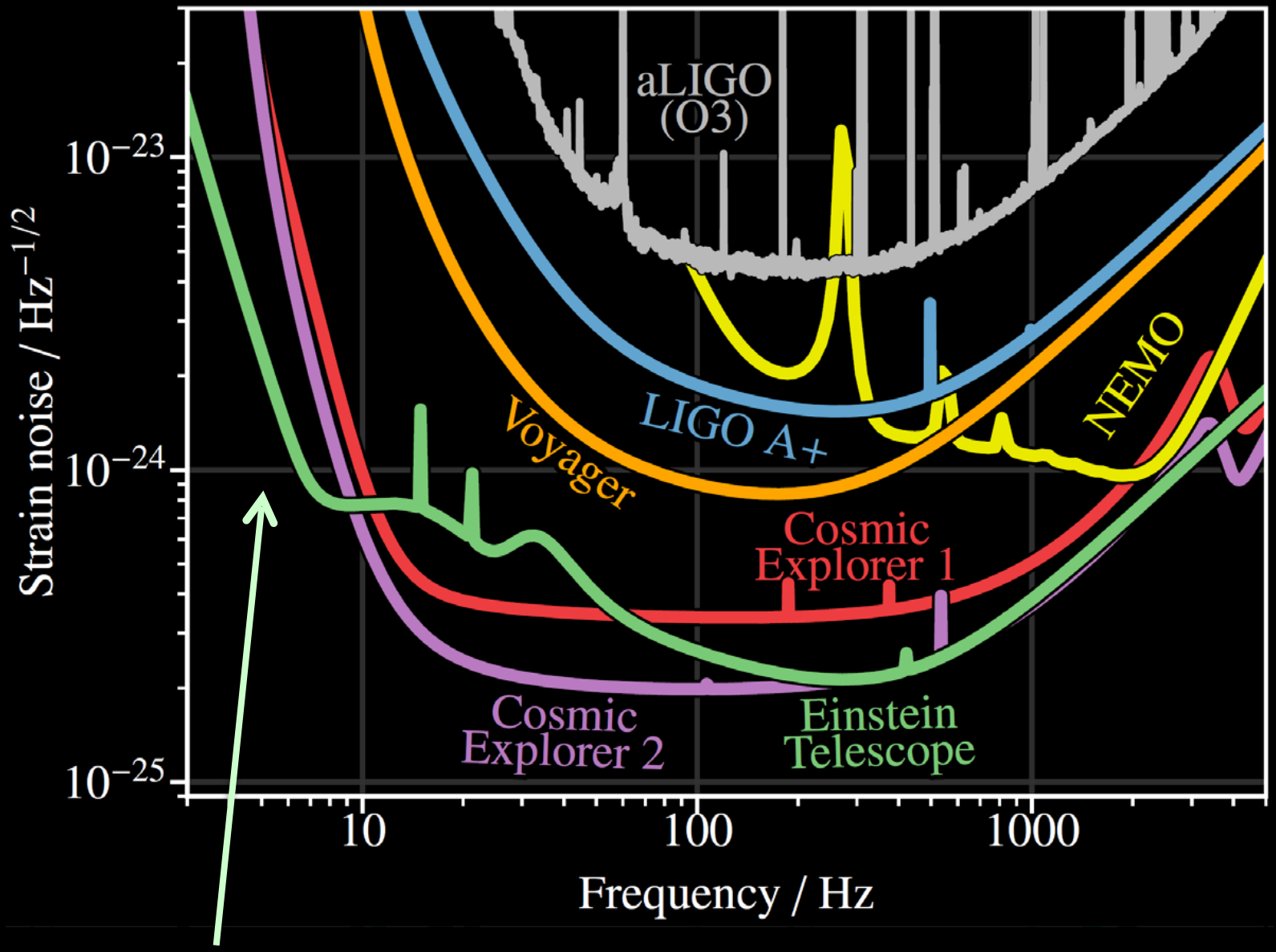
- 10^6 BH-BH / year up to z ~20 (230 Gpcs) and 10^3 M_{sol}
- 10^5 NS-NS / year up to z~2
- O(10^2 – 10^3) GW events with EM counterparts



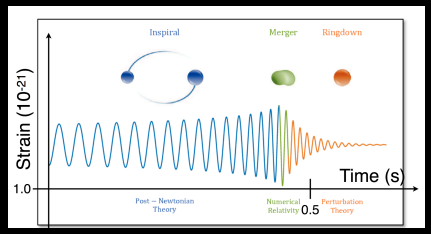
Astrophysics

- BH demography and evolution
- Primordials? Stellar?
- Are BHs part of the dark matter?
- Supernovae, Pulsars, Stochastic signals
- Properties of neutron stars
- Multi Messenger: Optical, Neutrinos, Gamma Rays





About one order of magnitude improvement w.r.t current detectors and an extended sensitivity to low frequencies → requires R&D



1 day 6 hr. 1 hr. 10 min. 1 min. 10 s 1 s 100 ms

aLIGO
ET
Voyager
CE

~3 h
~30 min

$M_1 = 1.4M_\odot$
$M_2 = 1.4M_\odot$
$z = 0.01$

Cumulative SNR

10^3
10^2
10^1

10^5 10^4 10^3 10^2 10^1 10^0 10^{-1}

Time till coalescence [s]

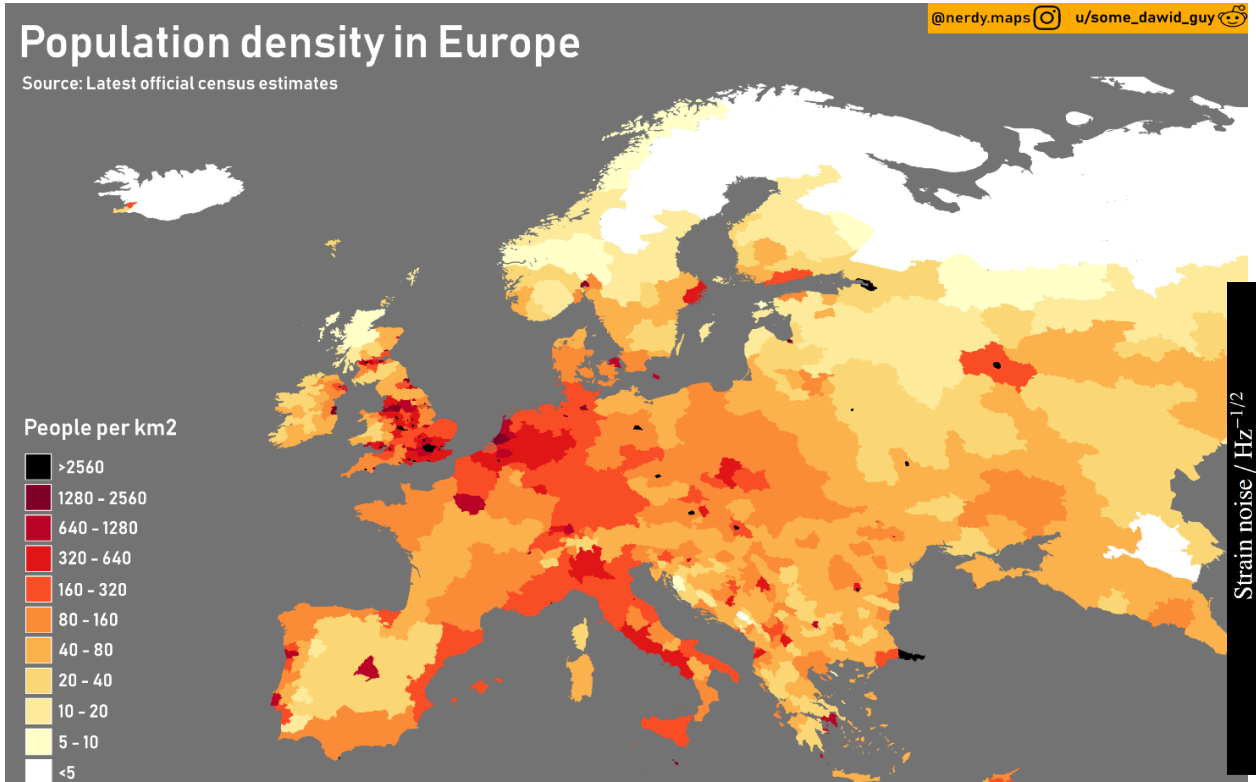
Credit: Evan Hall

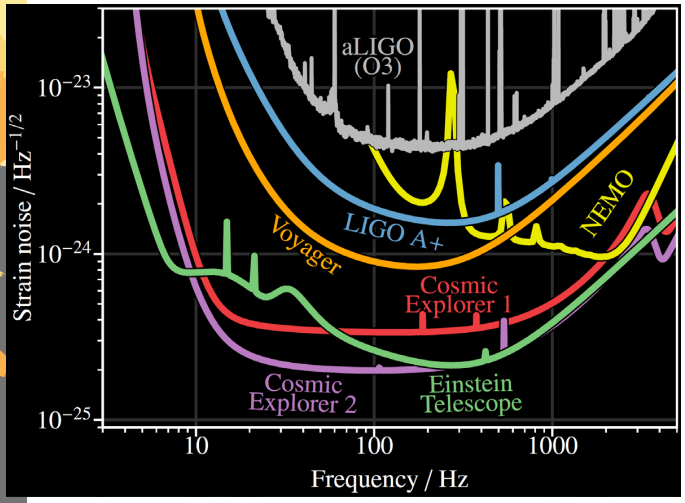
The sensitivity at low frequencies allows for an early detection

→ Very relevant for precise GR tests and facilitates the EM follow-ups.

My visionary note on CE vs ET

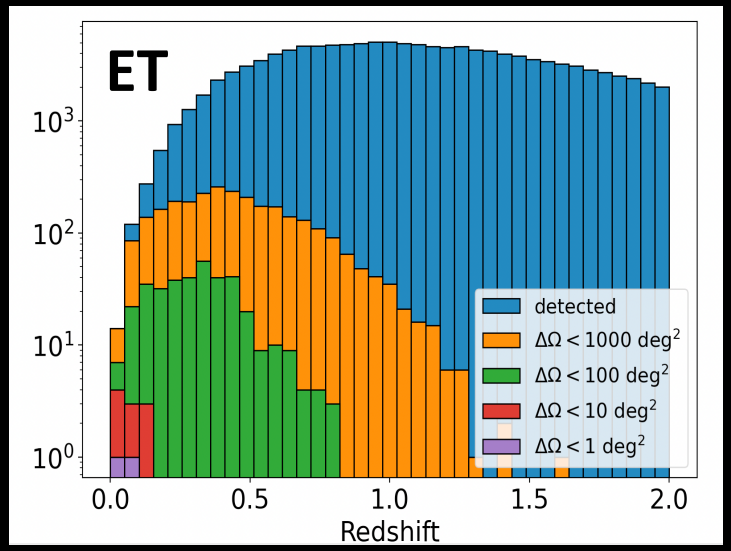
- CE with longer arms 40km + 20 km is better in the bulk of the sensitivity (10 - 200 Hz) and much cheaper by going on surface
- ET brings the new technology developments to reach low frequencies by going underground + cryogenics (following the path of KAGRA…)
- If ever EU decides to complement ET and build an affordable very long (O 25km) L-shaped one… you need to find a flat stable and empty place..

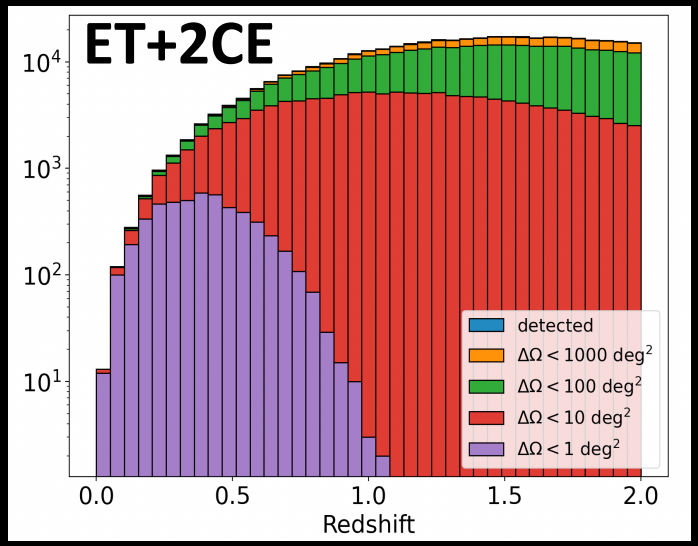




Sky localization

M. Branchesi (OSB)

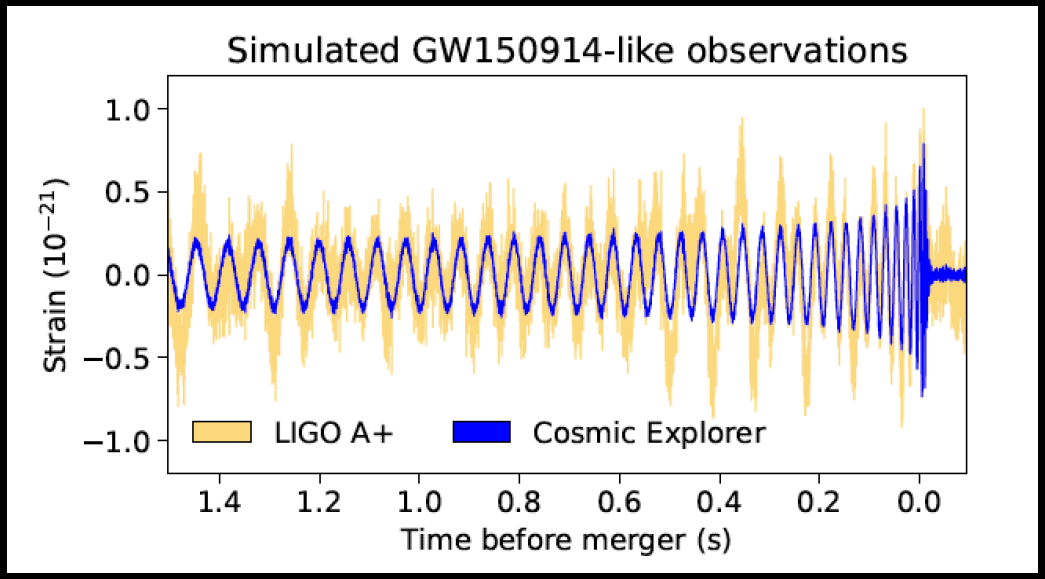




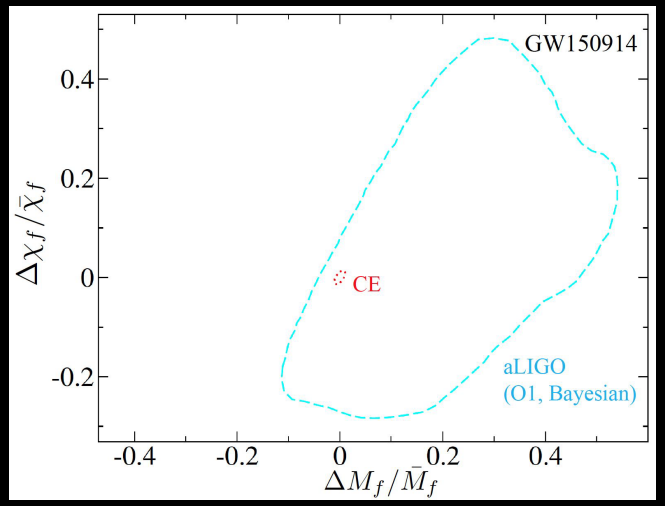
ET only configuration would allow for O(100) events / year with a sky-localizations (90% CL) < 100 deg²

ET + 2 CE configuration would allow for O(1000) events / year with a sky-localizations (90% CL) < 1 deg²

General Relativity Tests (cont.)

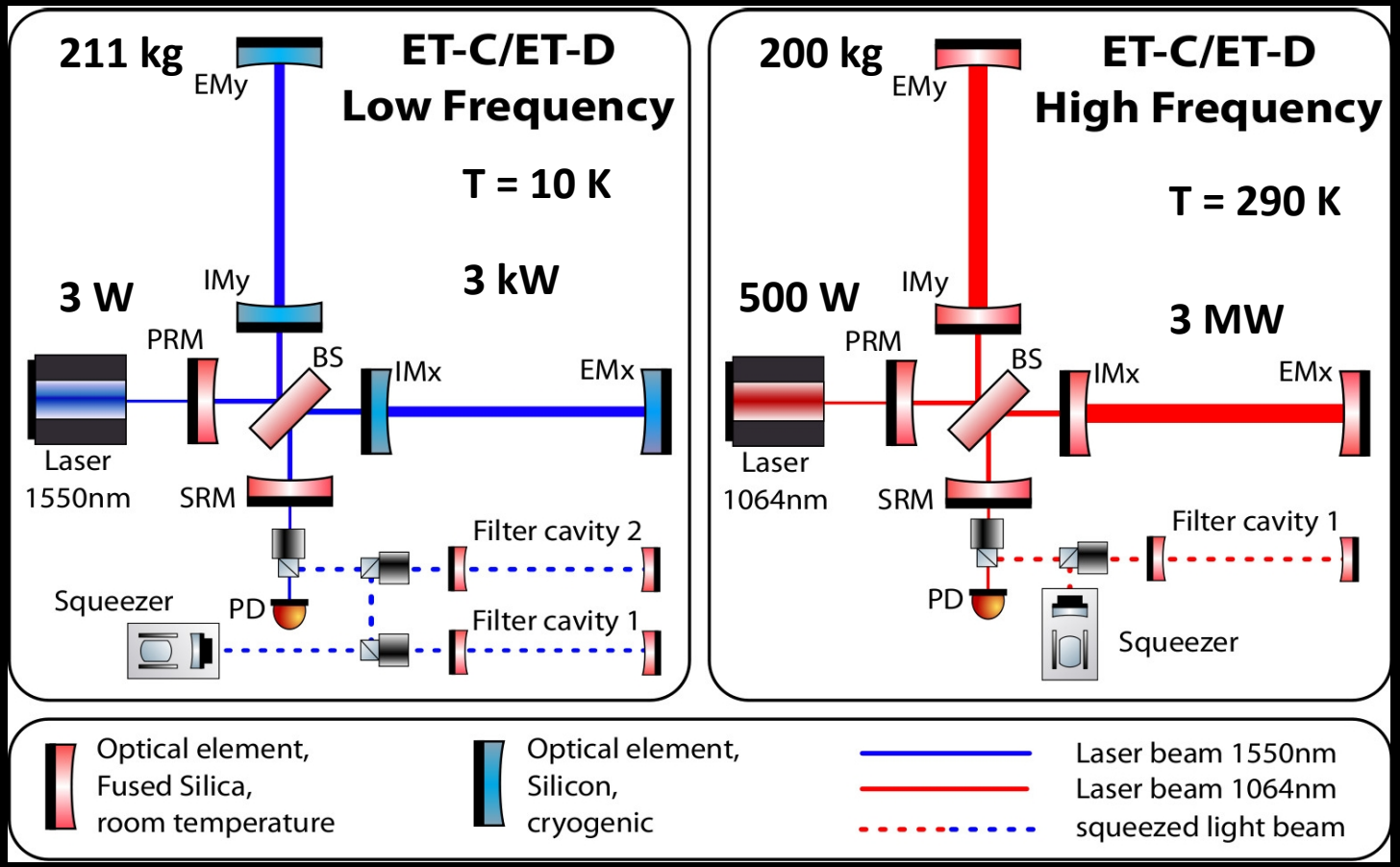


$$\frac{\Delta M_{\rm f}}{\bar{M}_{\rm f}} = 2\frac{M_{\rm f}^{\rm insp} - M_{\rm f}^{\rm postinsp}}{M_{\rm f}^{\rm insp} + M_{\rm f}^{\rm postinsp}},$$
$$\frac{\Delta \chi_{\rm f}}{\bar{\chi}_{\rm f}} = 2\frac{\chi_{\rm f}^{\rm insp} - \chi_{\rm f}^{\rm postinsp}}{\chi_{\rm f}^{\rm insp} + \chi_{\rm f}^{\rm postinsp}},$$



The huge boost in sensitivity and SNR allows for precise tests of GR improving by 2 orders of magnitude compared to 2G results.

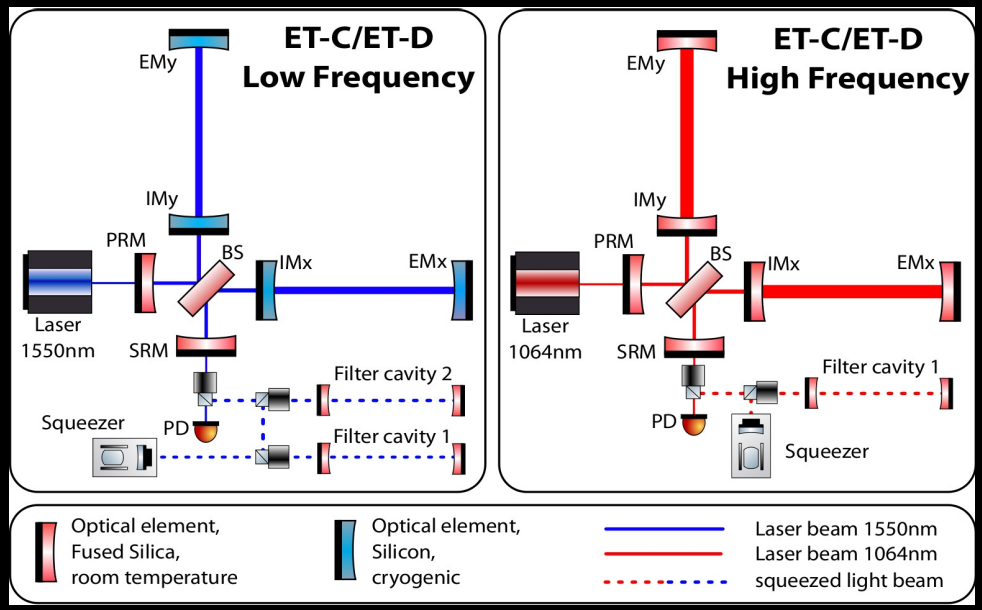
2nd Gen → ET



Underground
Cryogenic
Silicon mirrors
1550 nm (Si transparent)
New optical coatings
New suspensions / seismic controls

More powerful lasers
Larger fused silica mirrors
1064 nm (silica transparent)
New optical coatings
New thermal compensation systems

Enabling technologies and KTT



ET-HF

More powerful lasers
Larger fused silica mirrors
1064 nm (silica transparent)
New optical coatings
New thermal compensation systems
Frequency Dependent Squeezing

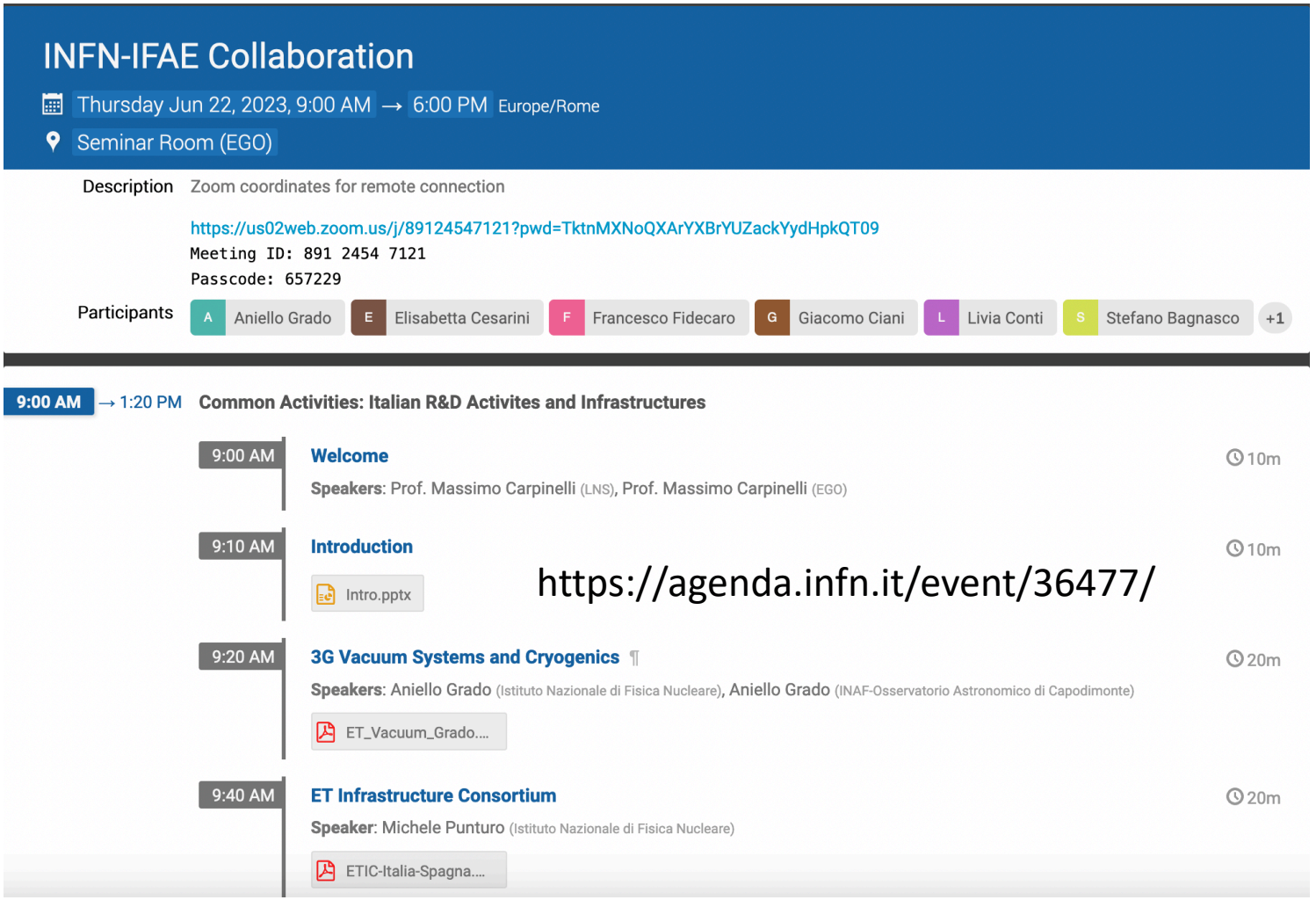
Challenging Engineering

New technology in cryo-cooling
New technology in lasers and optics
High precision mechanics and low noise controls
High quality opto-electronics and controls
Innovative adaptive optics
Innovative IR detection and Stray Light Control

ET-LF

Underground
Cryogenic
Silicon mirrors
Larger test masses
1550 nm (Si transparent)
New optical coatings
New suspensions / seismic controls
Frequency Dependent Squeezing

ET R&D (INFN-IFAE discussions)



INFN-IFAE Collaboration

Thursday Jun 22, 2023, 9:00 AM → 6:00 PM Europe/Rome

Seminar Room (EGO)

Description: Zoom coordinates for remote connection

https://us02web.zoom.us/j/89124547121?pwd=TktnMXNoQXArYXBrYUZackYydHpkQT09

Meeting ID: 891 2454 7121

Passcode: 657229

Participants: Aniello Grado, Elisabetta Cesarini, Francesco Fidecaro, Giacomo Ciani, Livia Conti, Stefano Bagnasco +1

9:00 AM → 1:20 PM **Common Activities: Italian R&D Activites and Infrastructures**

9:00 AM **Welcome** 10m

Speakers: Prof. Massimo Carpinelli (LNS), Prof. Massimo Carpinelli (EGO)

9:10 AM **Introduction** 10m

Intro.pptx

https://agenda.infn.it/event/36477/

9:20 AM **3G Vacuum Systems and Cryogenics** ¶ 20m

Speakers: Aniello Grado (Istituto Nazionale di Fisica Nucleare), Aniello Grado (INAF-Osservatorio Astronomico di Capodimonte)

ET_Vacuum_Grado....

9:40 AM **ET Infrastructure Consortium** 20m

Speaker: Michele Punturo (Istituto Nazionale di Fisica Nucleare)

ETIC-Italia-Spagna....

Ongoing discussions with INFN to figure out possible synergies for R&D

—> Unique opportunity to enlarge the lines of competence in the Spanish Institutions

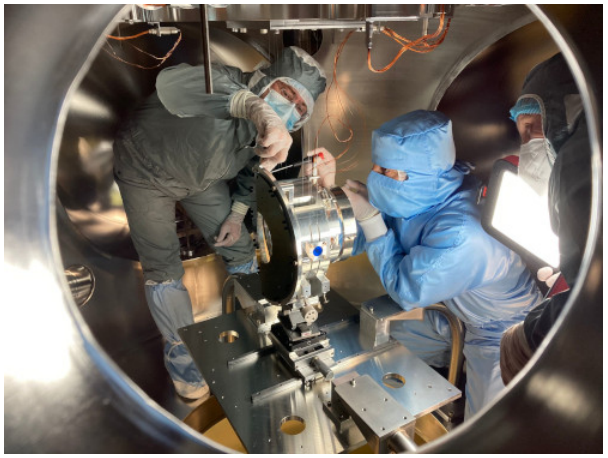
—> Some areas of collaboration adequate for other centres but beyond IFAE's current competences

Possible areas of R&D

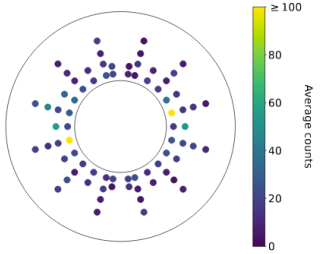
- IFAE is considering (*still exploring*)
  - **Stray light control**
    - **Active monitoring of stray light**
    - **ET pre-alignment system**
    - **Simulations**
    - **Baffle strategy at core of the ET arms**
    - **Characterisation of materials and optical coatings for baffles**
  - **Mirror suspensions + payloads**
    - ***Wireless readout technology***
    - ***Customised electronics+DAQ***
  - Active Noise Mitigation
    - *Customised electronics+DAQ*
    - *Computing resources for modelling*
  - Computing resources for data management

- Other contributions could include
  - ET optical layout
  - Wavefront Sensing and Control
    - Phase cameras
    - Hartmann Wavefront Sensors
    - Optical Simulations
    - Quadrant photodiodes
    - ……..
  - Actuators on Optics
    - Ring Heaters
    - Deformable Mirros
    - ……
  - Quantum Noise Reduction
    - QNR simulations
    - Integrated squeezed vacuum source
    - …….

Instrumented baffle @ Virgo



Installed in April 2021 @ EGO
(demonstrator @ IMC cavity end mirror)



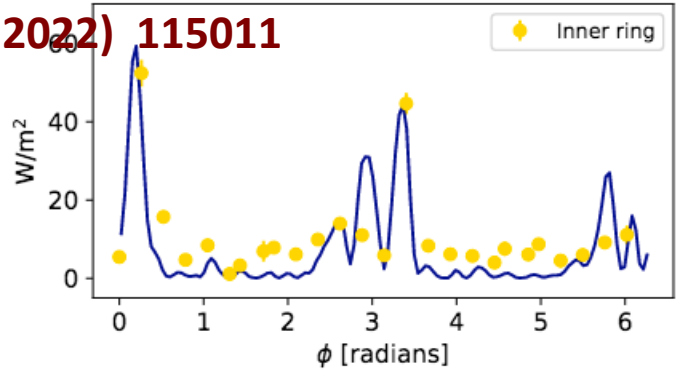
The installation of the first instrumented baffle in Virgo has demonstrated that the active monitoring of the stray light at the core optics of interferometers is feasible

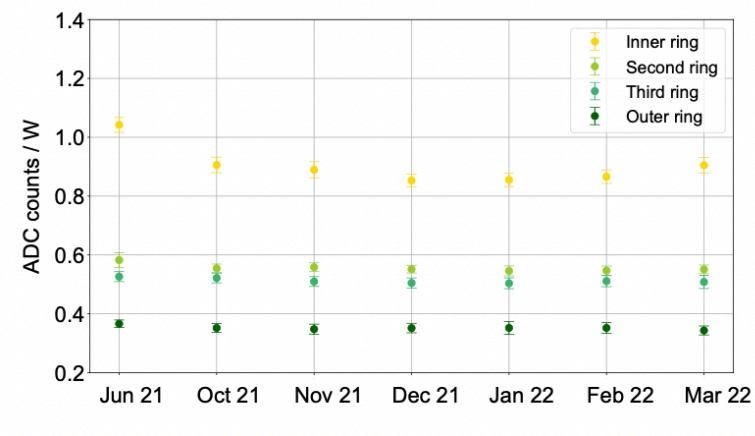
O. Ballester et al., CQG 39 (2022) 115011

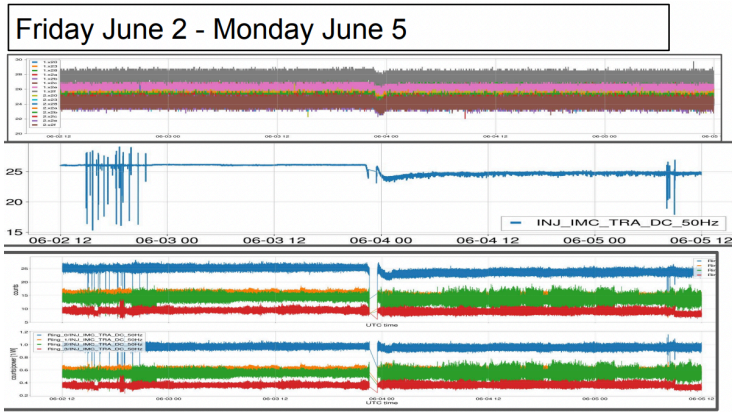
More than 2 years of stable operation with no degradation of cavity observed

M. Andres-Carcasona et al., Phys. Rev. D 107, 062001 (2023)

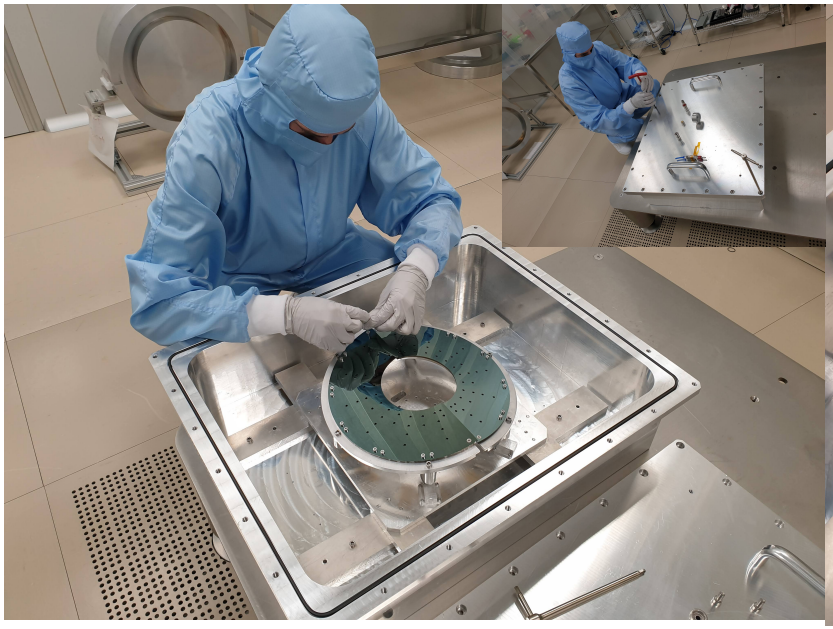
Comparison with FFT simulations

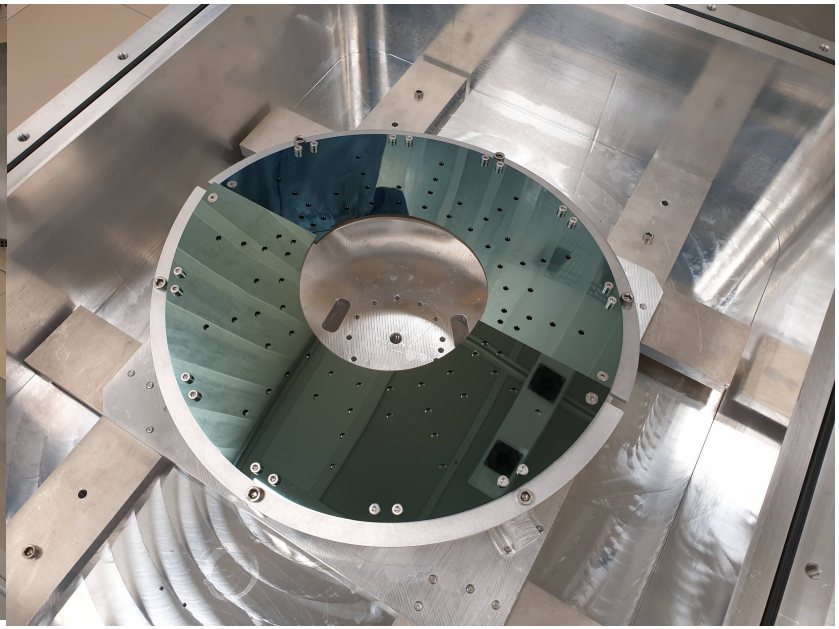


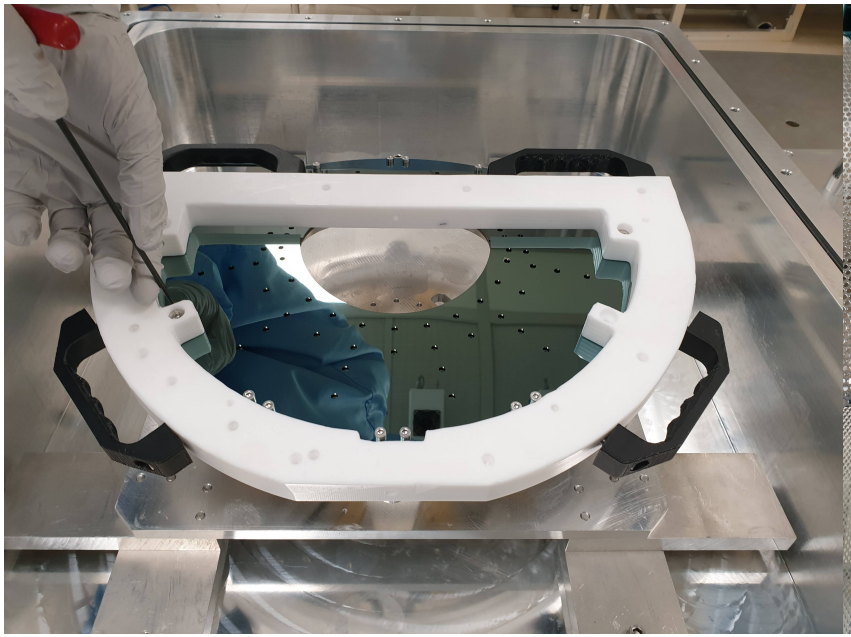


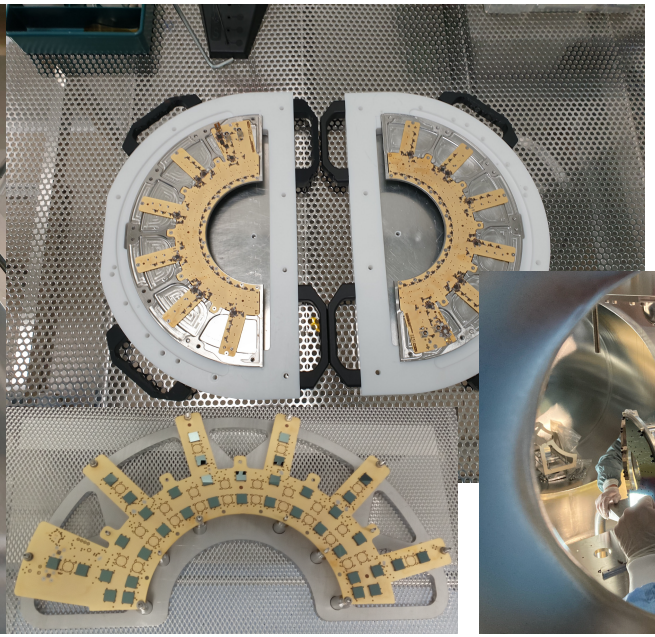


Installation @ IMC end mirror (April 2021)



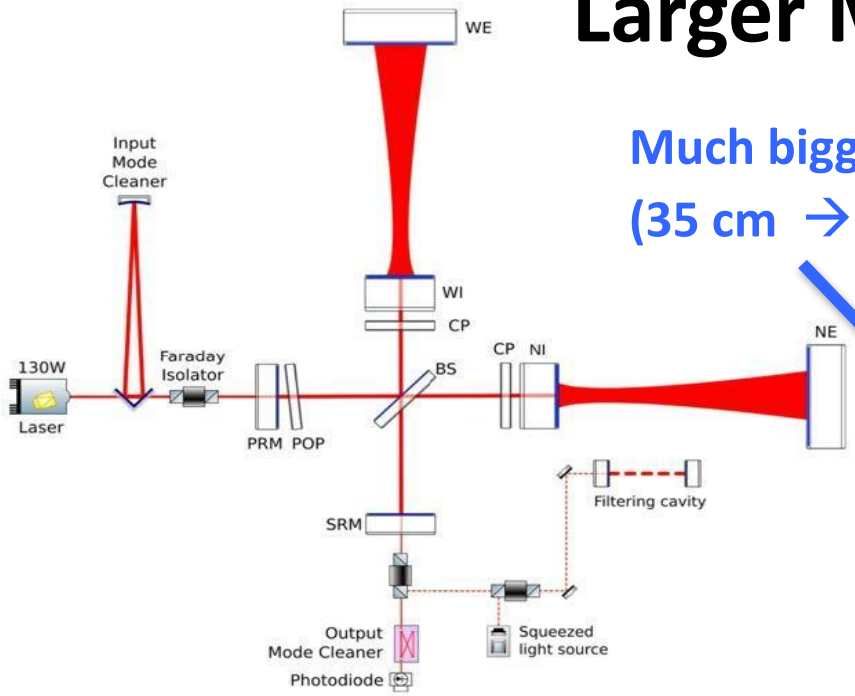




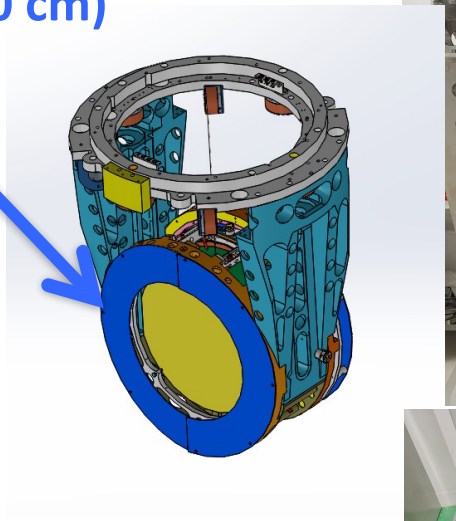


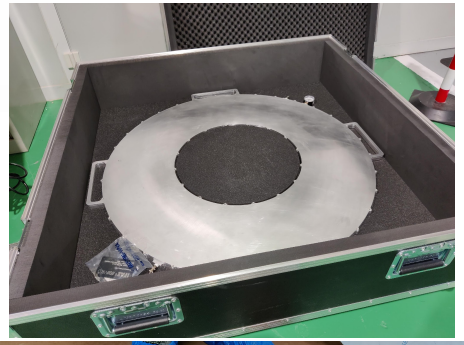
Larger Mirror Baffles

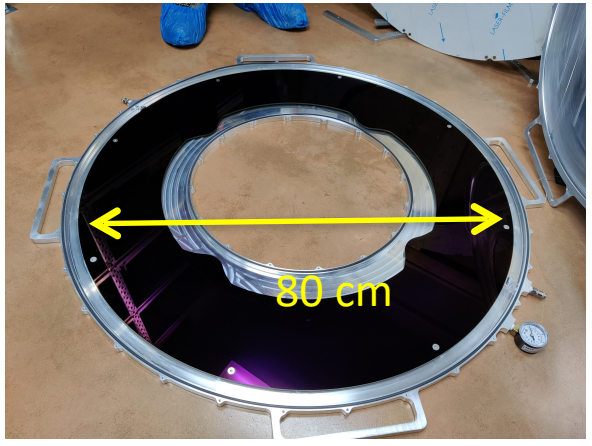
In collaboration with Rome and Pisa



Much bigger than IMC
(35 cm → 80 cm)



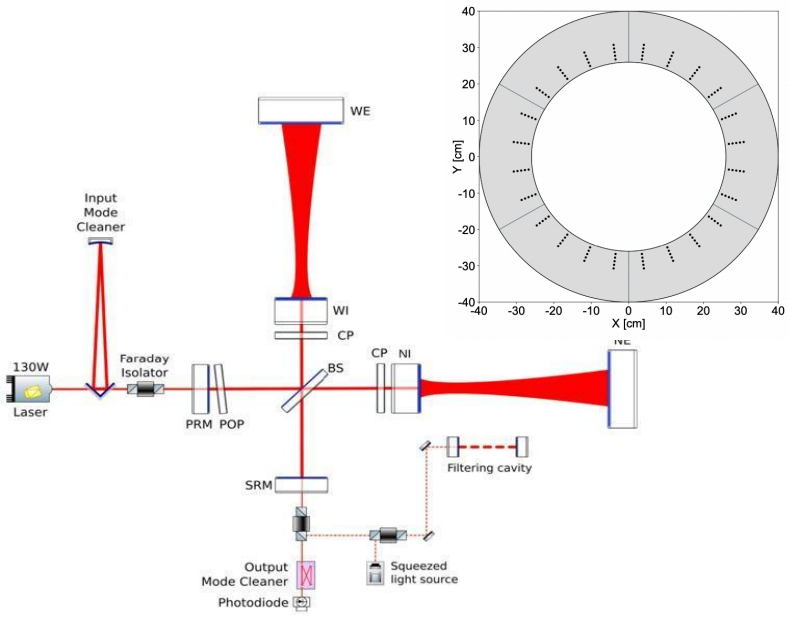




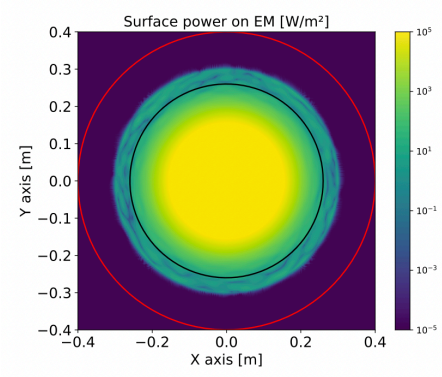
- New large mirrors (100kg) for O5 (or post O5)
- Completely new payload and baffling
- **New instrumented baffles being produced**
  - 120 sensors
  - New DAQ at 1kHz / serial + wireless readout
  - Further Improvements on polished material

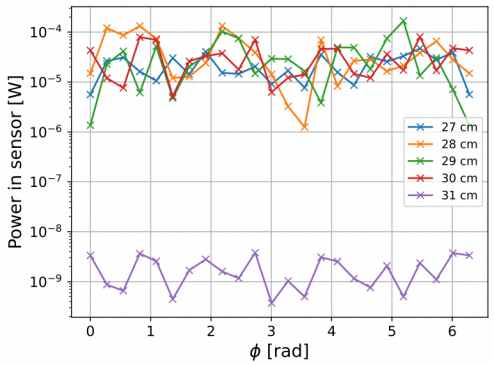
Interest in LIGO A# for testing a prototype

Simulations for Large Baffles

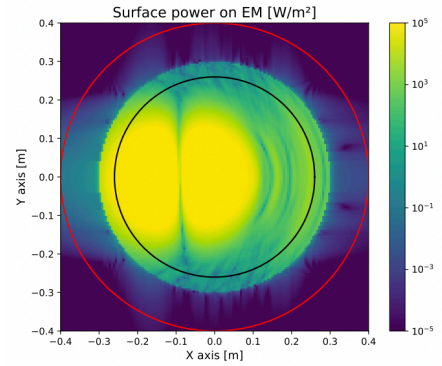


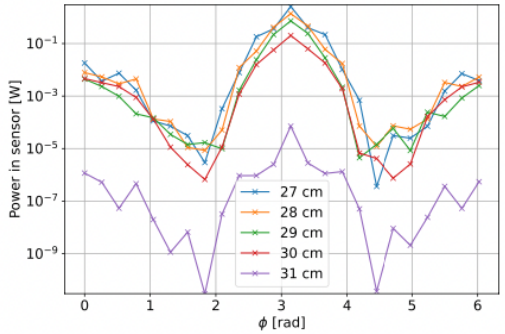
Nominal configuration



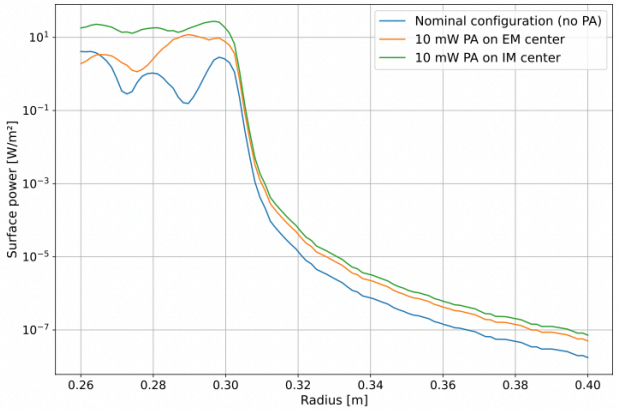


Mis-aligned configuration (0.8 micro rad)





Mirrors with point absorbers



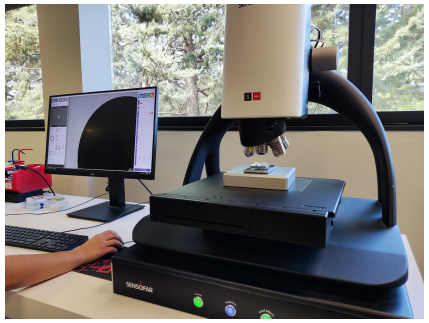
Using SIS simulations we showed the potential of instrumenting baffles

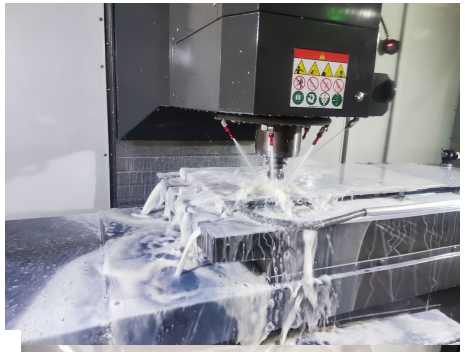
- Pre-alignment of the optical cavity
- Detection of point absorbers in the mirrors
- Large sensitivity to mirror optical characteristics (scattering, surface roughness)
- Correlation with glitches —> 1kHz readout + adapted DAQ gains / ring

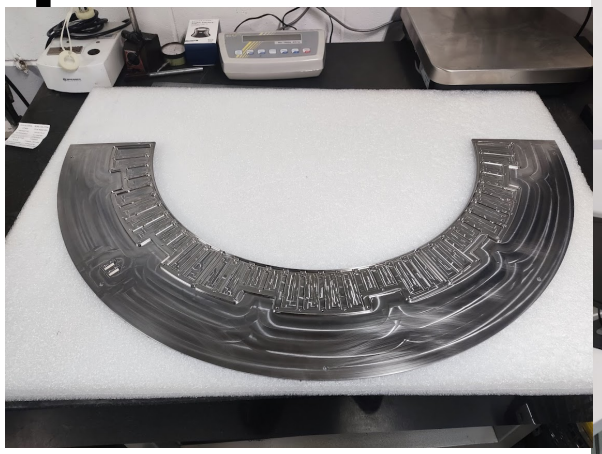
A. Macquet et al., Class. Quantum Grav. 40, 077001 (2023)

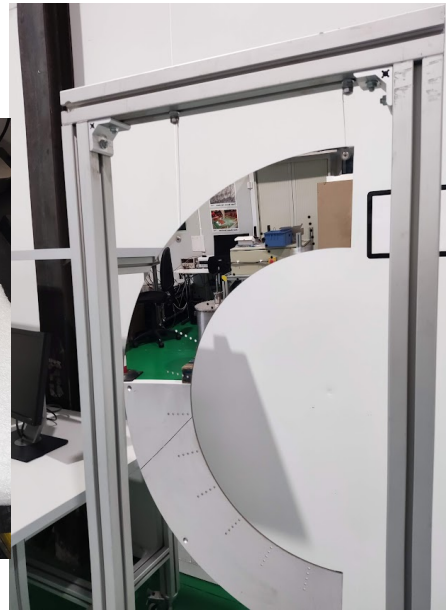
In close collaboration with H. Yamamoto (Caltech)

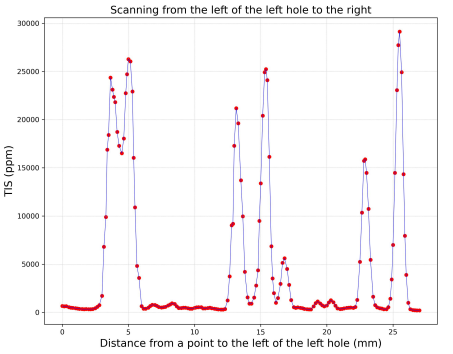
Baffle Pre-production

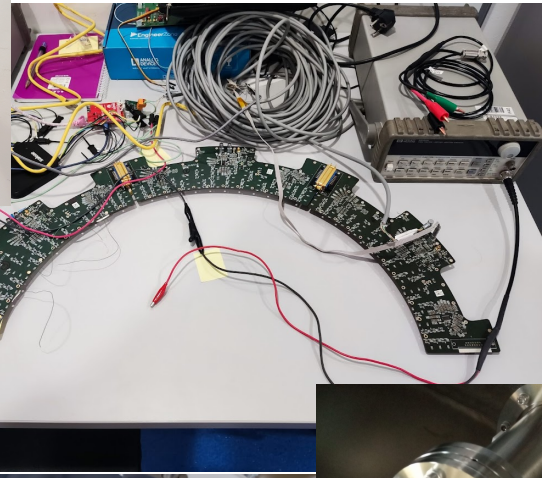


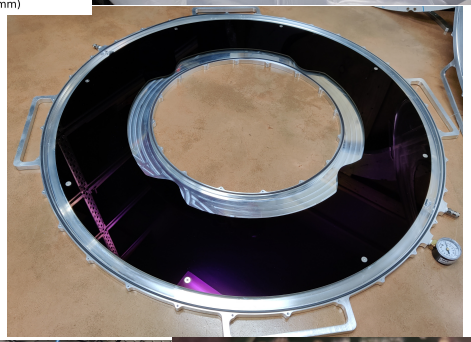


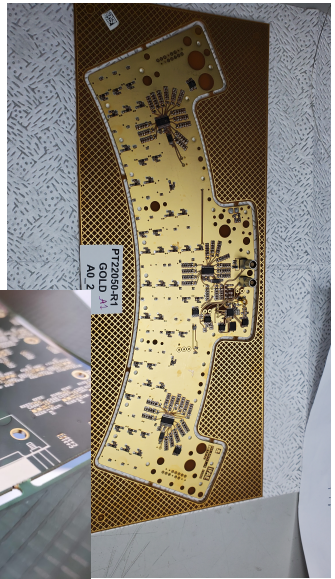


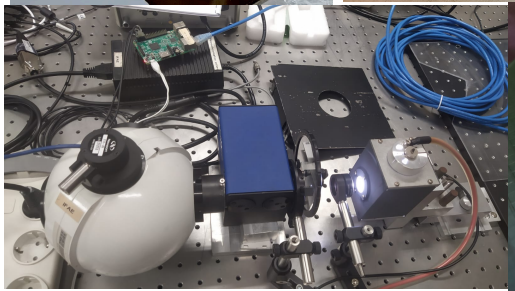


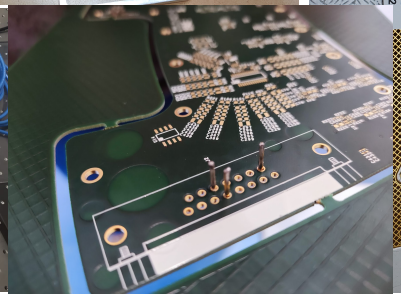


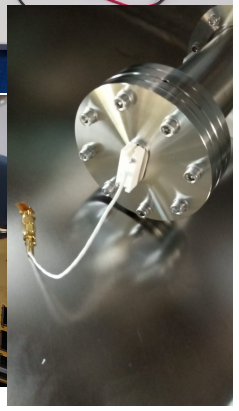




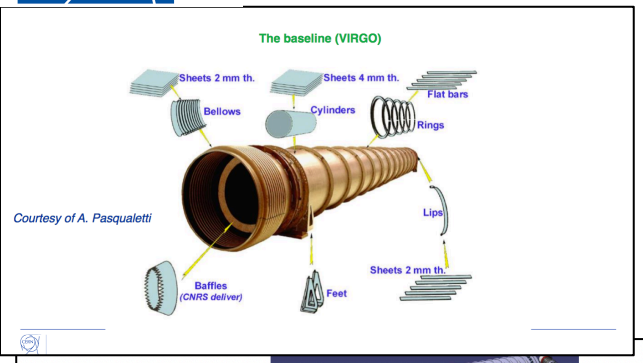




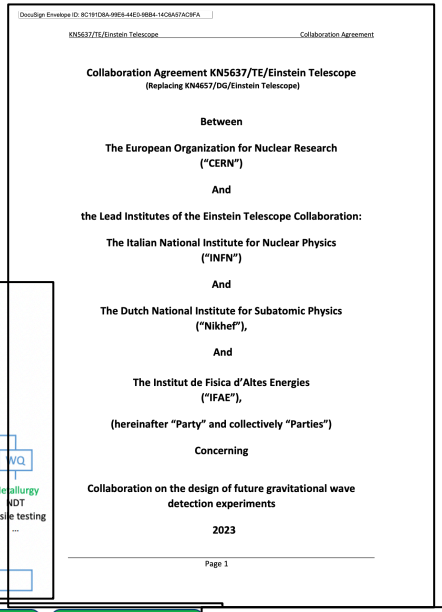




ET & CE vacuum pipe design



MoU signed with CERN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KN5637/TE/Einstein Telescope Collaboration Agreement

Collaboration Agreement KN5637/TE/Einstein Telescope
(Replacing KN4657/DG/Einstein Telescope)

Between

The European Organization for Nuclear Research
("CERN")

And

the Lead Institutes of the Einstein Telescope Collaboration:

The Italian National Institute for Nuclear Physics
("INFN")

And

The Dutch National Institute for Subatomic Physics
("Nikhef"),

And

The Institut de Fisica d'Altes Energies
("IFAE"),

(hereinafter "Party" and collectively "Parties")

Concerning

Collaboration on the design of future gravitational wave detection experiments

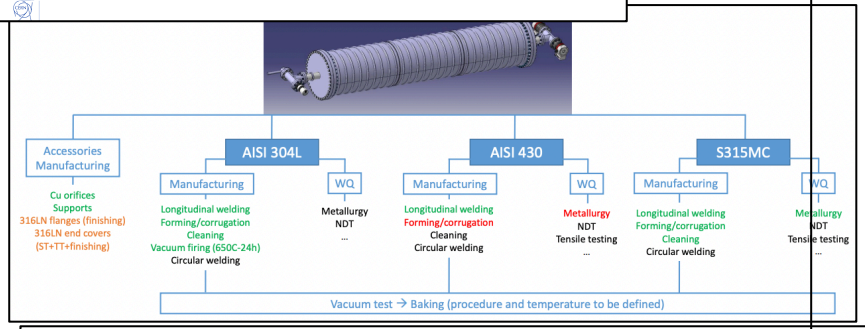
2023

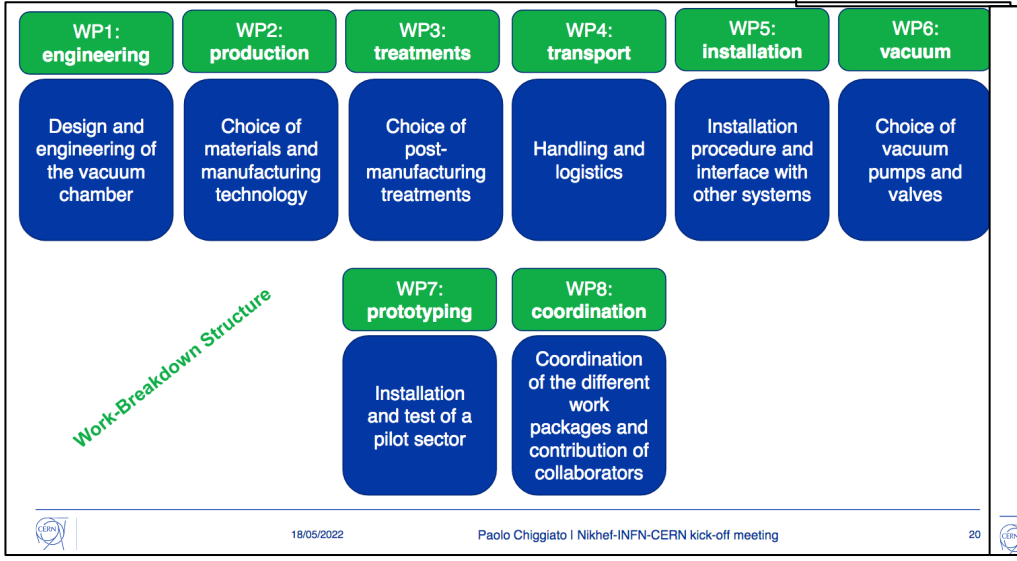
Page 1

On-going effort led by CERN on the design of ET vacuum pipe **(1/3 of the total ET cost)**

Deliver TDR in 3 years

- Physics requirements
- Vacuum / Cryo Technology
- Civil Infra-structure
- Cost Reduction/Optimization
- Prototyping

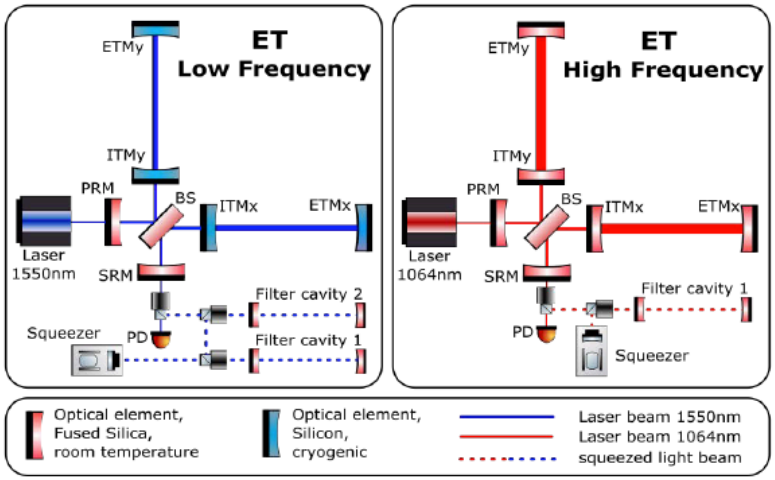


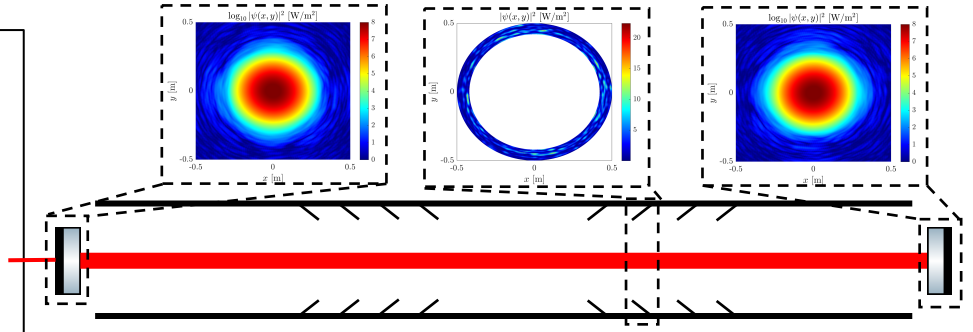


Global planning

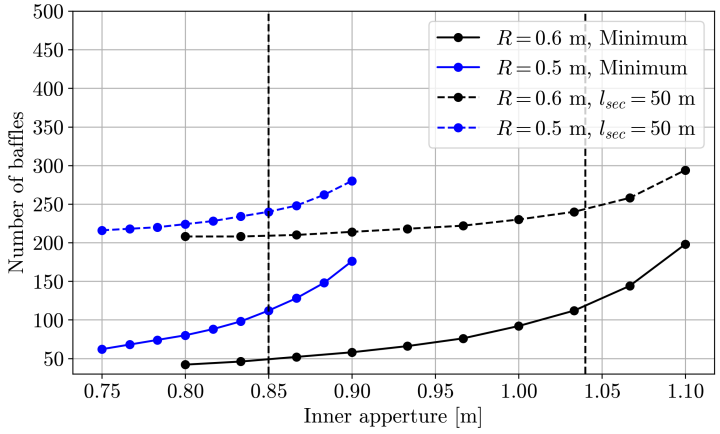
	First year				Second year				Third year			
	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4
Functional specifications												
Roles and agreement with Institutes												
Optimisation of baseline, including cost analysis												
Definition of alternative solutions												
Cost & performance of alternative solutions												
Optimisation of interfaces with services/infrastructures												
Decision about vacuum design for pilot sector at CERN.												
Prototyping of the selected solutions.												
Technical design report (ET vacuum system).												

ET stray light simulations



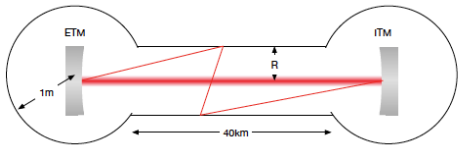


IFO	λ	mode	mirror ⌀	R_C	w_0	z_0	w	$g-$factor
ET-HF	1064 nm	TEM_{00}	62 cm	5070 m	1.42 cm	5000 m	12.0 cm	0.95
ET-LF	1550 nm	TEM_{00}	45 cm	5580 m	2.9 cm	5000 m	9.0 cm	0.63



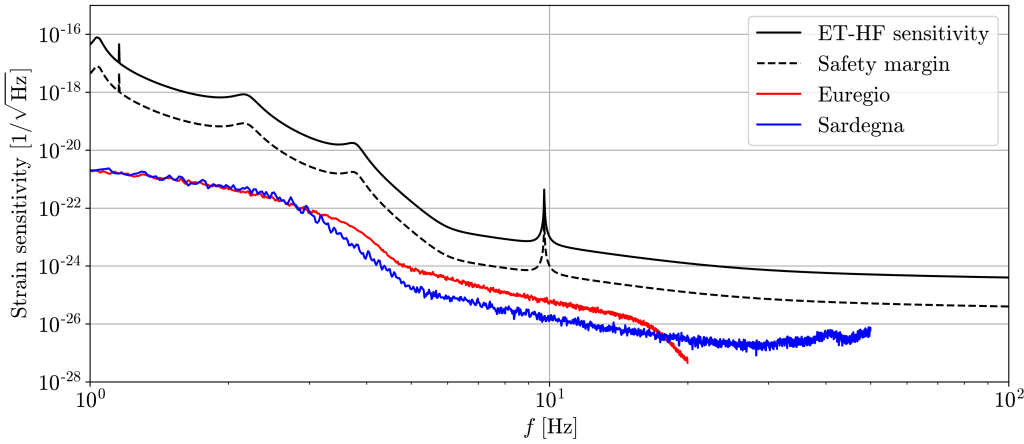
Running optical simulations to determine the best strategy for stray light mitigation in ET

—> Desire to extend it to CE



A joint effort with CERN on the very details of the vacuum pipe design and the baffling strategy including active monitoring inside the cavity

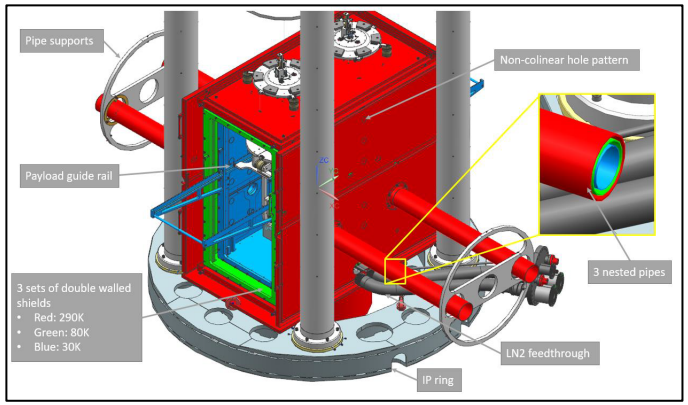
—> IFAE will build baffle prototypes



M. Andrés-Carcasona et al., accepted in PRD

ETpathfinder(s)

A collaboration established with Etpathfinder @ Maastricht

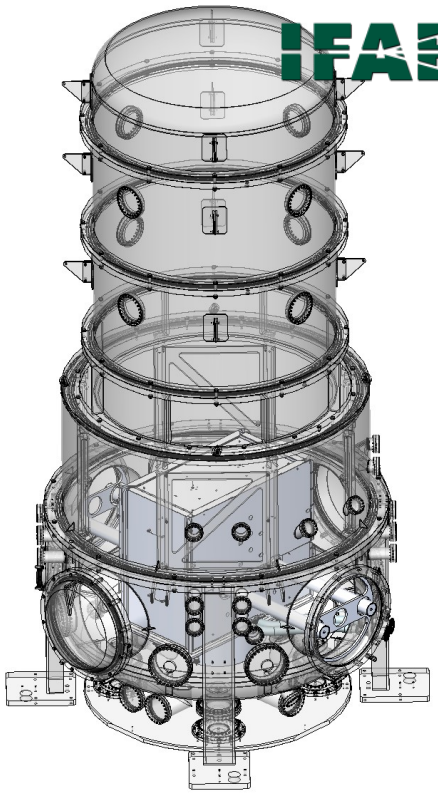


→ **IFAE redesigned the cryo-shielding [paid by Nikhef]**

→ **IFAE will contribute to its installation in 2024**

→ **Pre-alignment & monitoring of the mirror surface at 30K (instrumented baffle with sensors for λ = 1550 nm)**

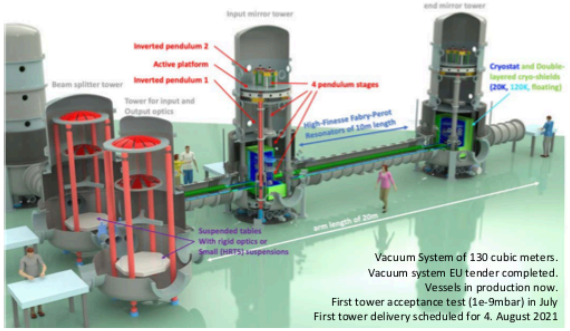
→ **R&D on materials for coated baffles to reduce scattered light**



A. Utina et al., Class. Quantum Grav. 39 215008 (2022)

ETpathfinder

- **New facility for testing 3G 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), new coatings …
- Start with 2 FPMI, one 120K and one 15K.
- **16 official partners from NL/B/G/FR** + a few more involved, but not yet official partners (like AEI, KIT, Bham, Cardiff, Barcelona etc).
- **Initial capital funding of 14.5 Meuro (no personpower).**
- Detailed **Design Report** available at apps.et-gw.eu/tds/?content=3&r=17177
- **Open for everyone interested to join.**
- **www.etpathfinder.eu**

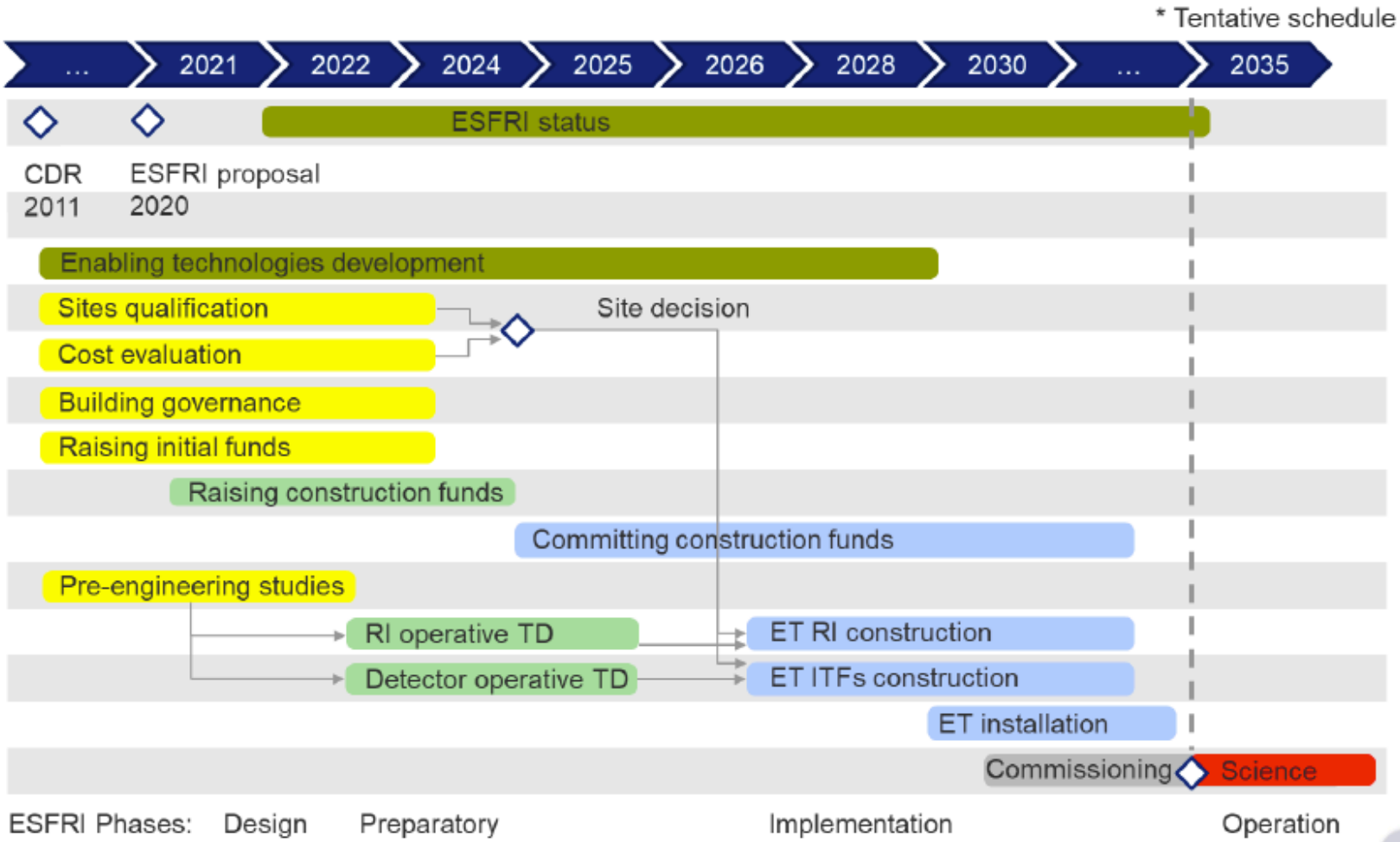


Nikhef SAC, 2021-05-26

Slide from last Nikhef SAC Meeting

Ongoing top-level discussions with INFN-based pathfinders to develop common technology for ET

ESFRI: project timeline



ET project is now entering the preparatory phase

Einstein Telescope as ESFRI

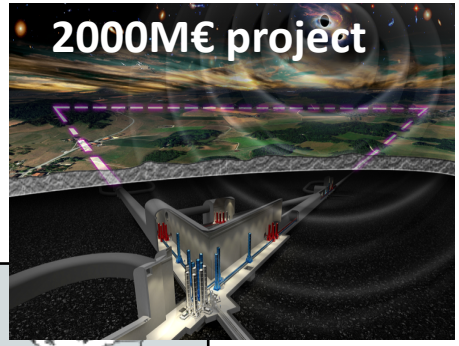
European Commission | Funding & tender opportunities
Single Electronic Data Interchange Area (SEDIA)

SEARCH FUNDING & TENDERS | HOW TO PARTICIPATE | PROJECTS & RESULTS | WORK AS AN EXPERT | SUPPORT

Preparatory phase of new ESFRI research infrastructure projects

TOPIC ID: HORIZON-INFRA-2021-DEV-02-01

Grant

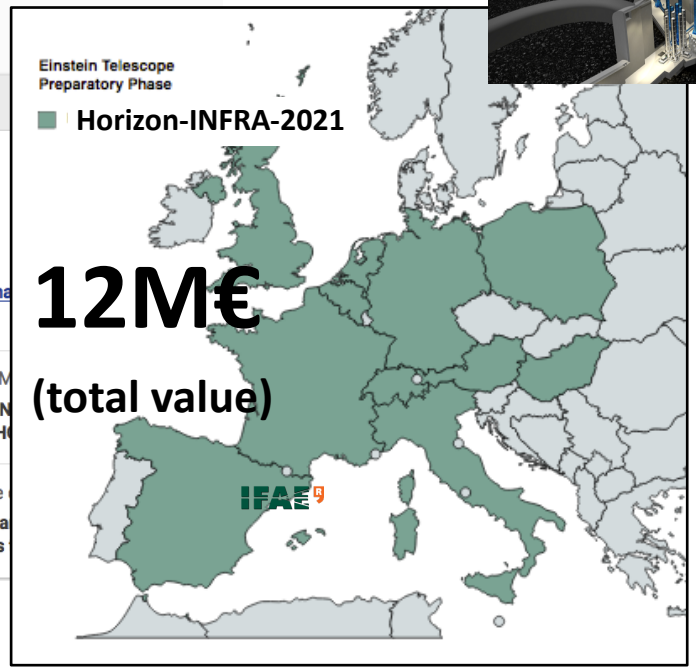


Goals for ET Preparatory Phase

- Governance
- Financial architecture/plan/framework
- ET legal entity
- Final ET design and cost evaluation
- Site or sites selection
- Construction funding
- User services
- Computing model
- Sustainability

3.45M€

(approved)

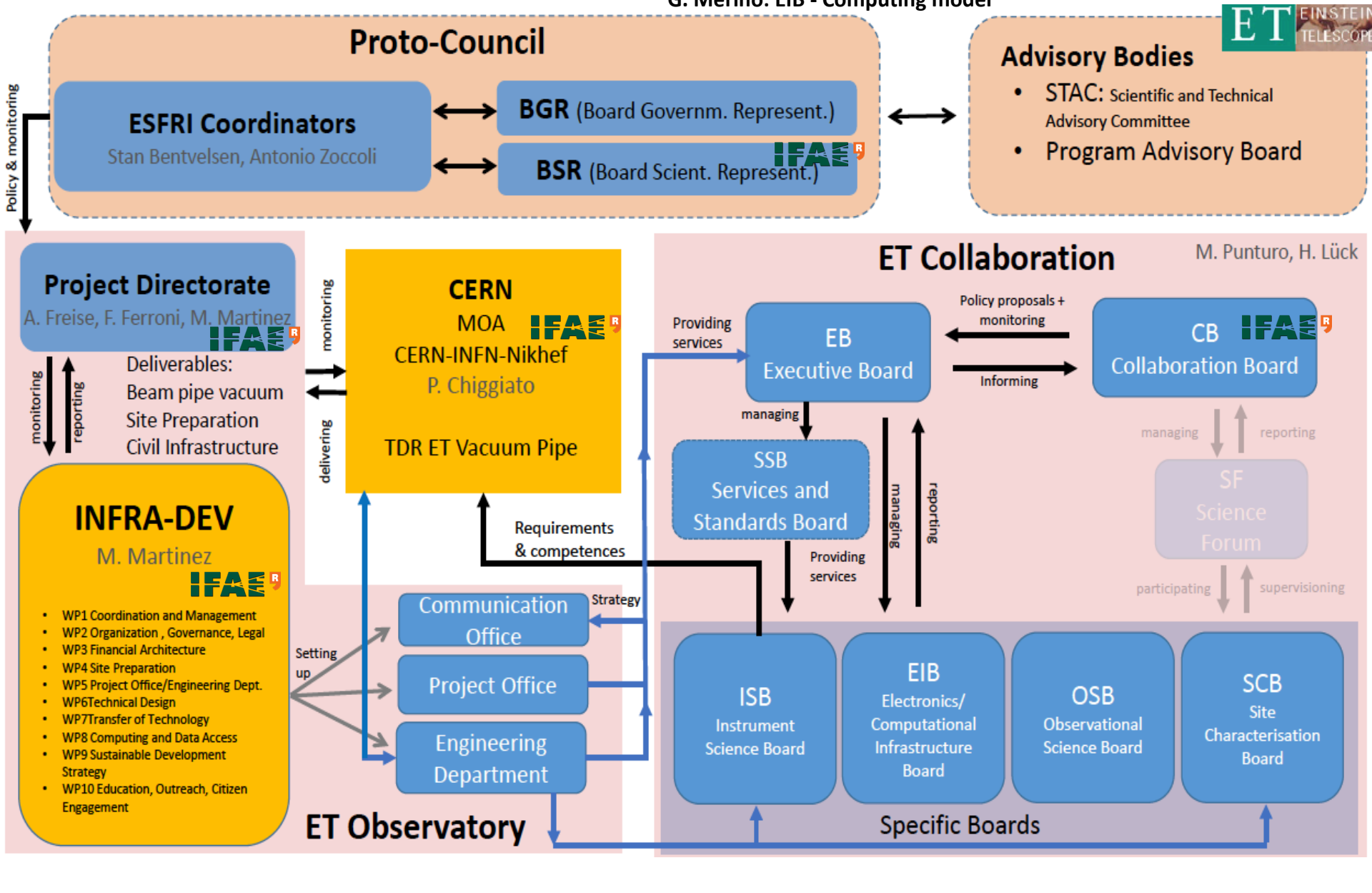


Einstein Telescope Preparatory Phase (ET-PP) in 2022 – 2026
HORIZON-INFRA-DEV EU Project coordinated by IFAE (M. Martínez)

→ **Project started 1st September 2022 (https://etpp.ifae.es)**

ET Governance

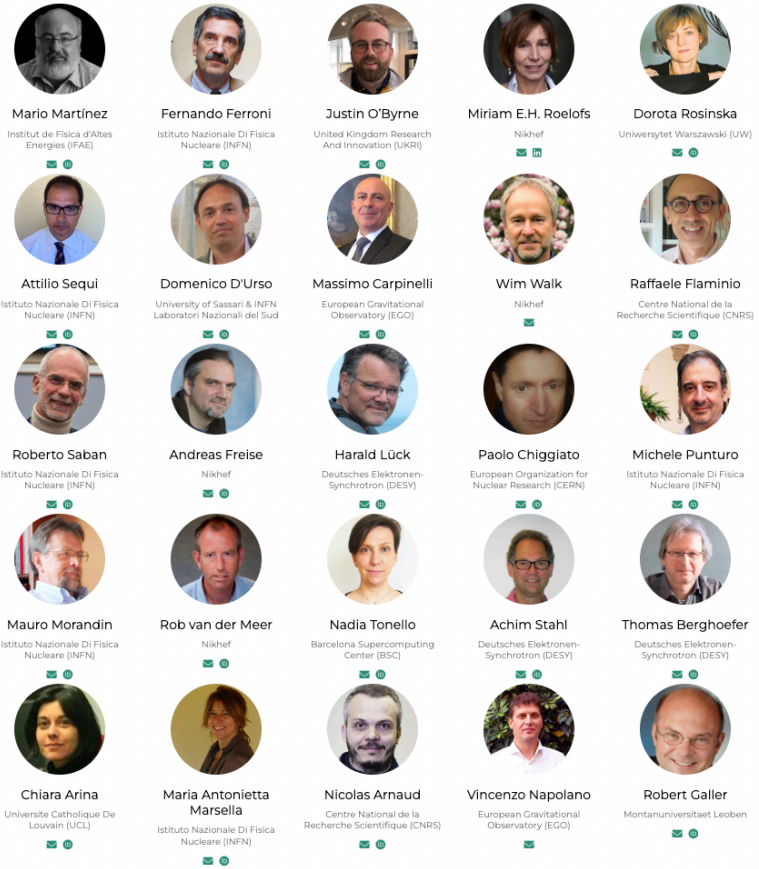
E. Coccia: Chair ET Collaboration Board
M. Martinez: ET Directorate, ISB - SLC co-coordinator
O. Pujolas, D. Blas: OSB - Cosmology
O. Piccinni: OSB - CW
G. Merino: EIB - Computing model



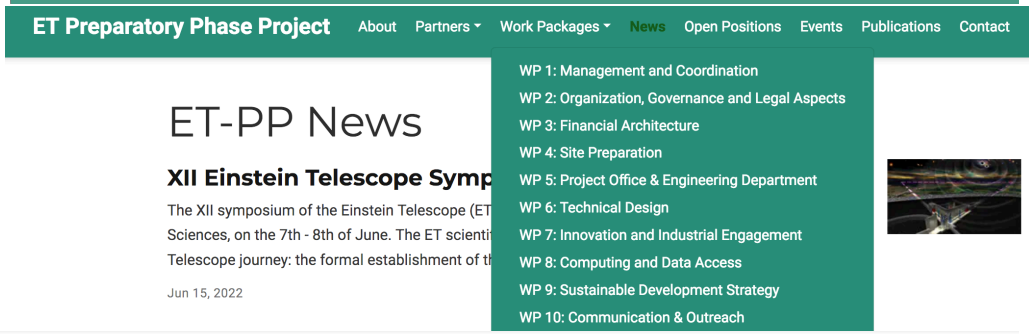
ET-PP web online

https://etpp.ifae.es

ET-PP Work Package Leaders



ET-PP bi-annual meetings taking place in BCN (next one Dec 11-12)



WP 5: Project Office and Engineering Department

Work package led by CNRS

Objectives

WP5 - Project Office and Engineering Department [led by CNRS]- has the mission to establish the ET RI Project Office and the corresponding Engineering Department. The role of this WP is to set-up a project management environment for the ET construction project.

This environment will be supported by consultative and executive bodies equipped with means to monitor, control, coordinate and report on the technical design, the engineering, the technical specifications, the risks, the budget and the schedule.

These activities are project-wide and make use of methodologies and tools which are the same across the whole of the ET construction project.

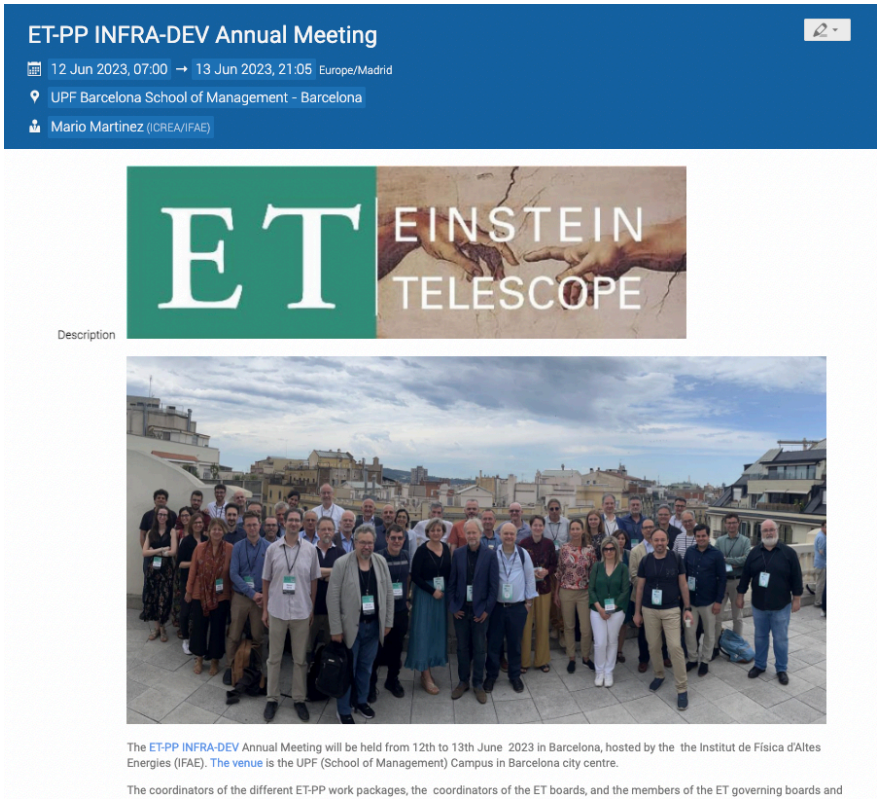
R. Flaminio (CNRS), **A. Freise (NIKHEF)**, and **R. Saban (INFN)** act as co-coordinators of WP5 in this proposal.

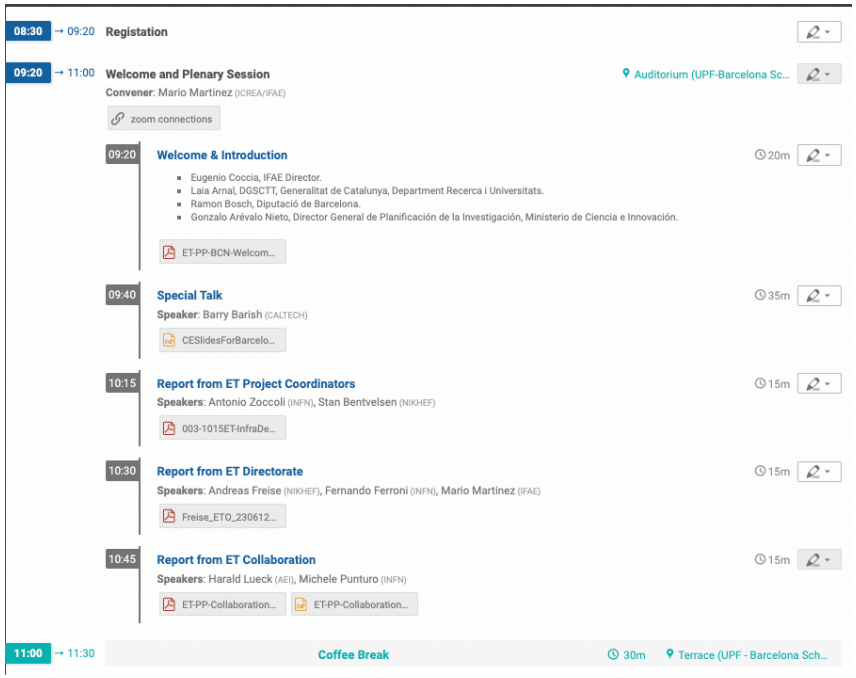
Deliverables

- D5.1 Structure and the mandate of the Project Office. (M25)
- D5.2 Functionalities required from the tools in support of the project management. (M25)

https://indico.ifae.es/event/1671/timetable/?view=standard

2nd ET-PP annual Meeting in June 2023

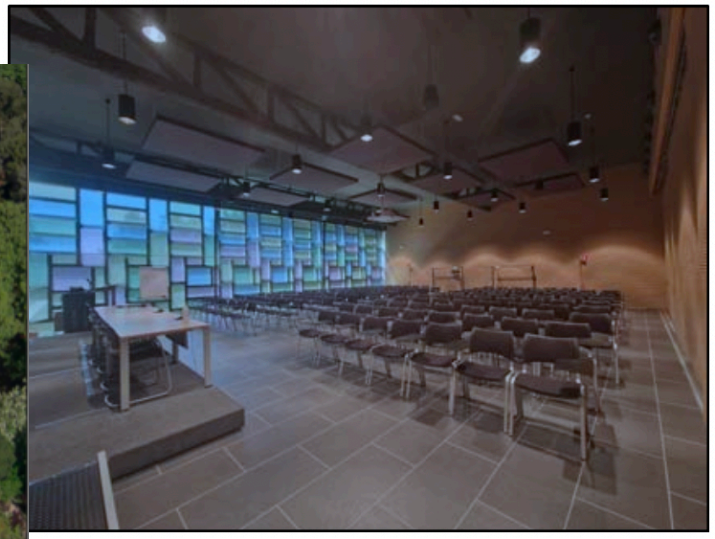


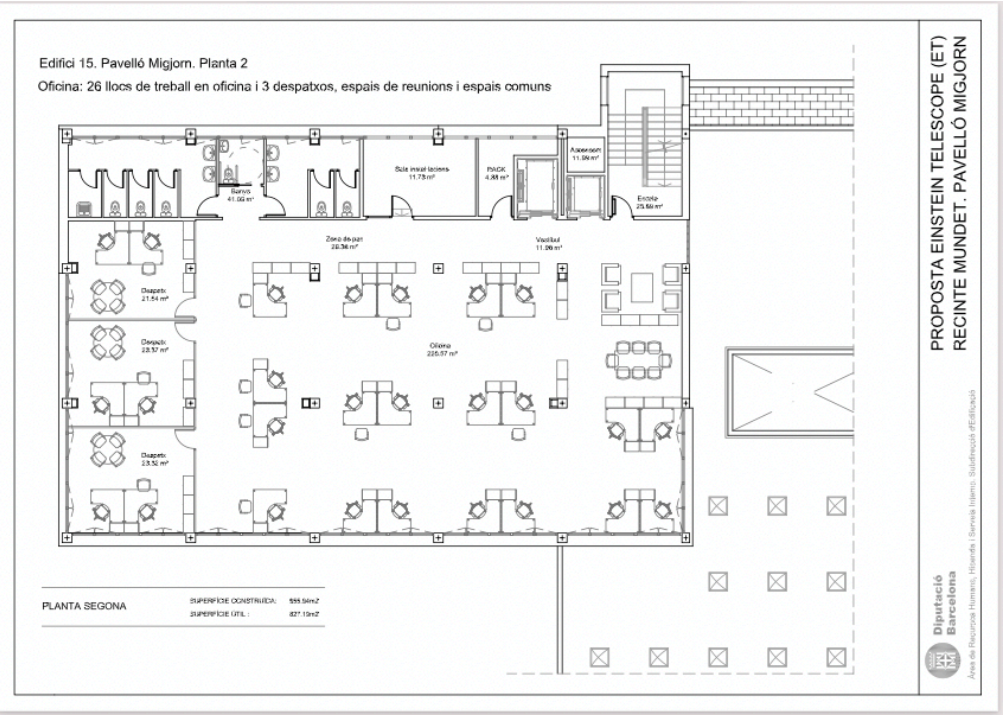


we are now entering a 1-y reporting process with EC including milestones, deliverables, budget execution and in-kind contributions

Enormous amount of information collected in the slides
This offers you a fair overview of the status of the project

ET@BCN Building





The Barcelona Provincial Council has offered IFAE the use of a floor of a building for ET (950 m2) downtown BCN Office space + access to meeting rooms [agreement being prepared now]

We plan to use it as ET@BCN building for ET + ETO management discussions

Can also be regarded as a hub for ET@Spain

Final Word

CPAN Meeting final message

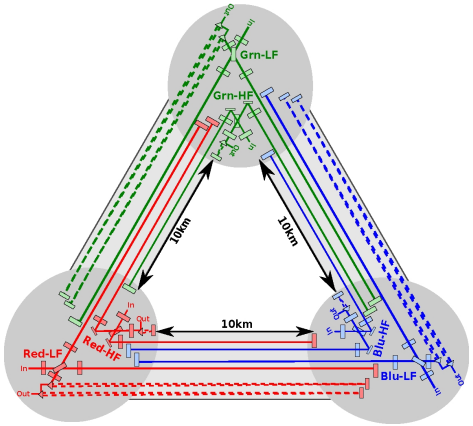
- Time for the large HEP centres in Spain interested in GWs to act coherently and to have a plan of action for participating together in the ET R&D Developments and in the responsibilities in the ET Organisation.

- Let's have a ET@Spain meeting before the end of the year or early 2024..maybe @ the ET@BCN hub.

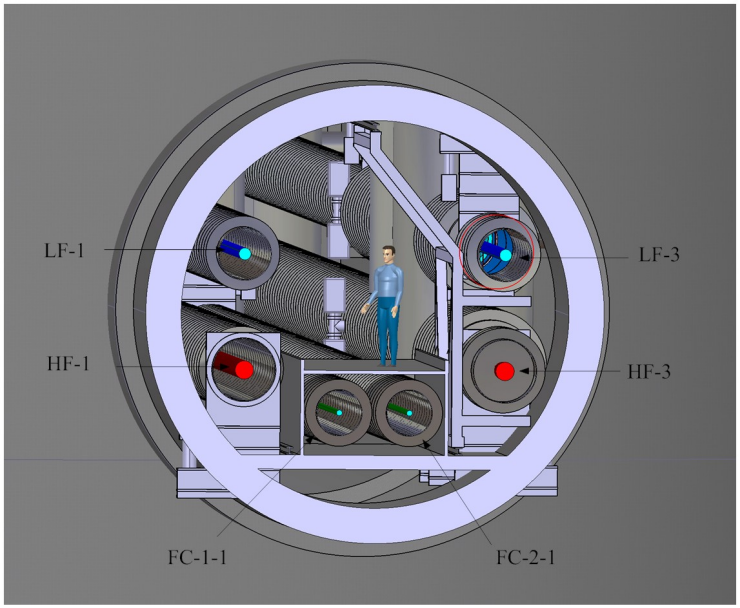
Industrial Opportunities (vacuum)

~10^5 m^3

560 M€



In its current design ET involves the production of more than 120km of ~1 m diameter tubes instrumented by hundreds of deflecting baffles



The experiment runs under ultra high vacuum (UHV) conditions

- 10^{-10} mb for H_2 , 10^{-11} mb for N_2
- 10^{-14} mb for Hydrocarbons

Optical requirements (reduced reflectivity and scattering of surfaces) condition the pipe design

- Precise mechanics
- Surface treatments for outgassing & cleanliness
- High-quality polishing
- Optical AR coatings @ 1 – 2 microns (close to mirrors)

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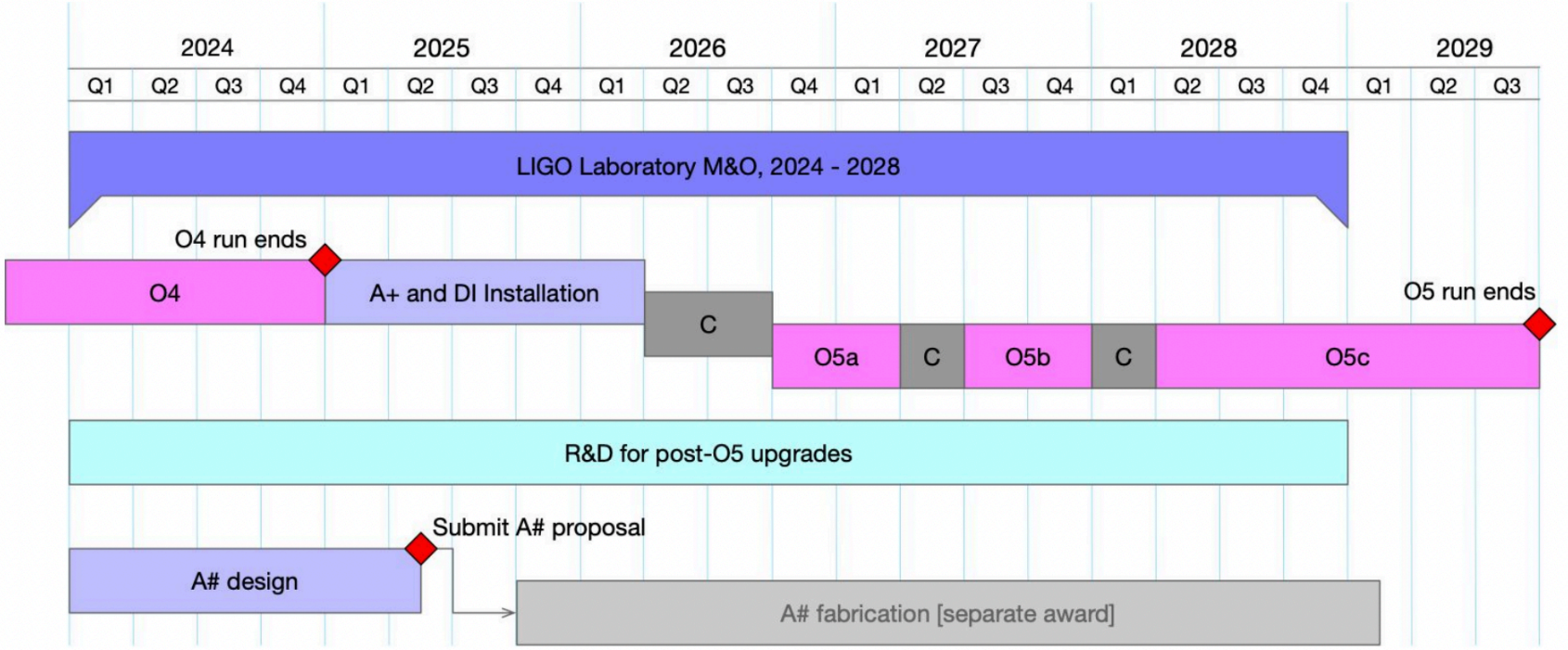

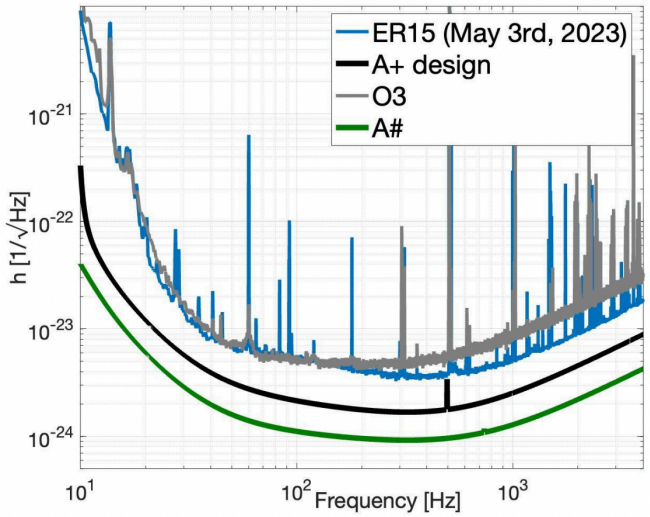

Mainly 4 new components:

- Larger Test Masses (40 → 100 kg) with improved suspensions
- Seismic isolation improvements
- Higher levels of laser power and squeezing
  - 1.5MW arm power (x2 A+ design, x4 current)
  - 10 dB squeezing (up to 6 dB current)
- Reduced coating thermal noise
  - x2 below A+ design; A+ design not yet achieved