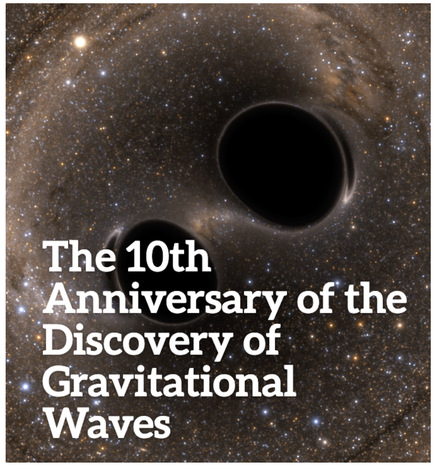
The Einstein Telescope Project

M. Martínez

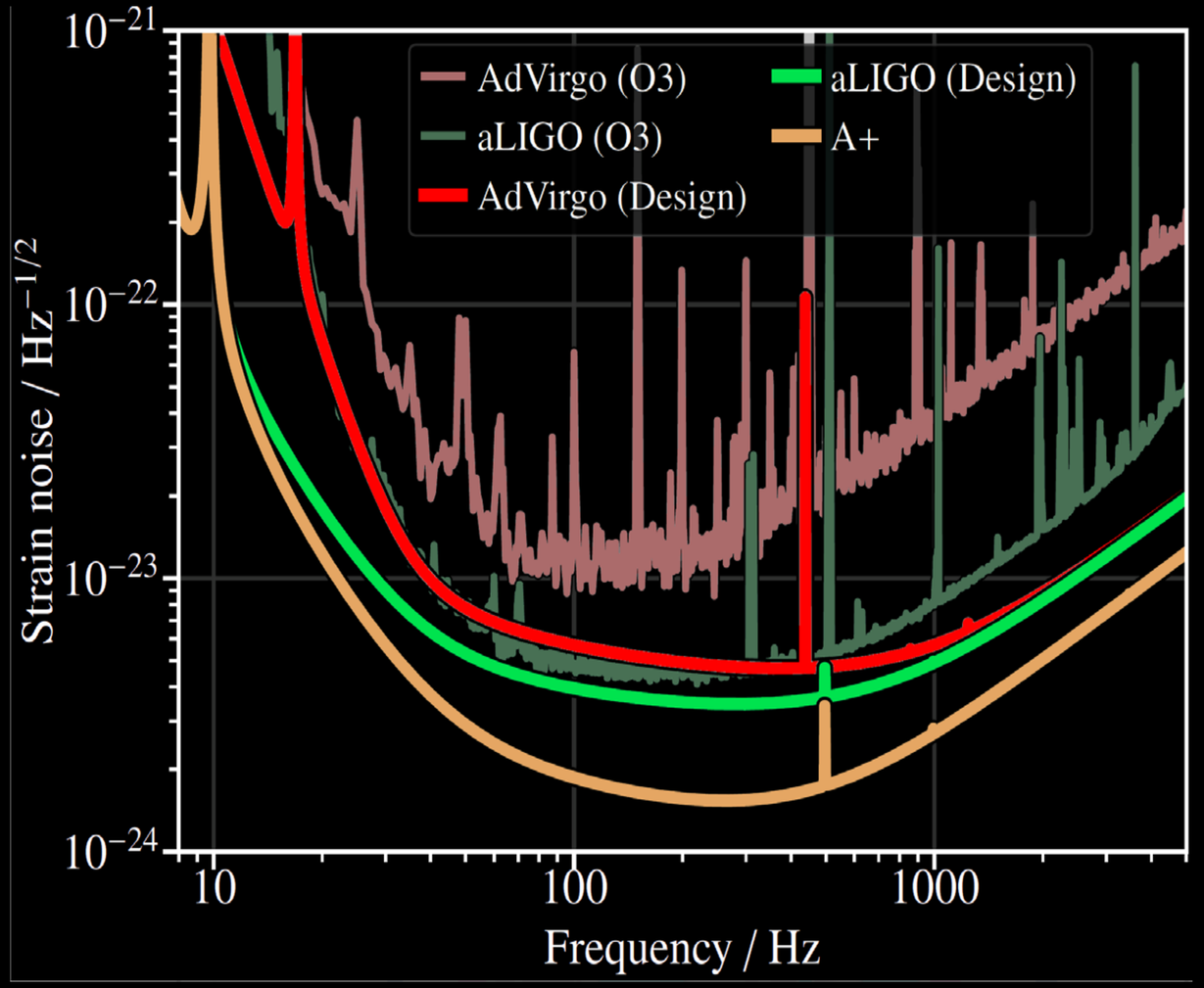


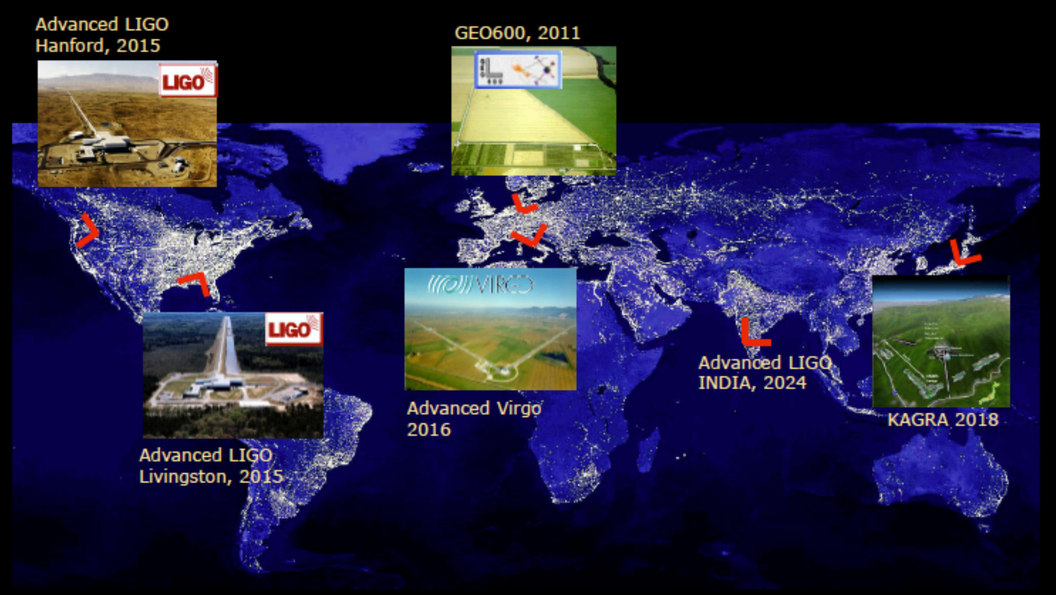
RENATA 2025, Zaragoza

Outline

- Prospects from LVK & future upgrades
- The Einstein Telescope
  - Physics Potential
  - ET Design & Discussions on Geometries
  - R&D for required technologies
  - TimeLines, Locations and Cost
  - Organisation and Political Support
  - Preparatory Phase & work with CERN
  - ET-Spain
- Final notes

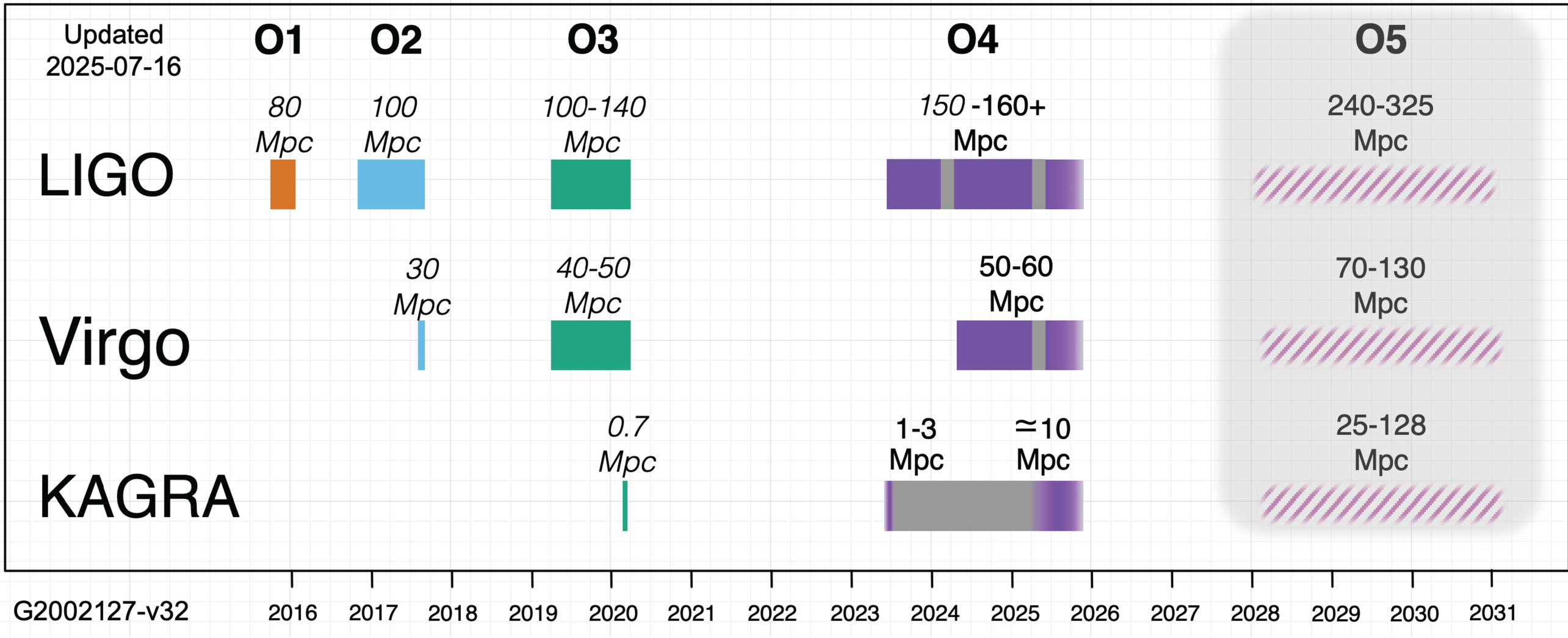
LVK sensitivity





In the next 6 -10 years the current interferometers will reach their design sensitivity…

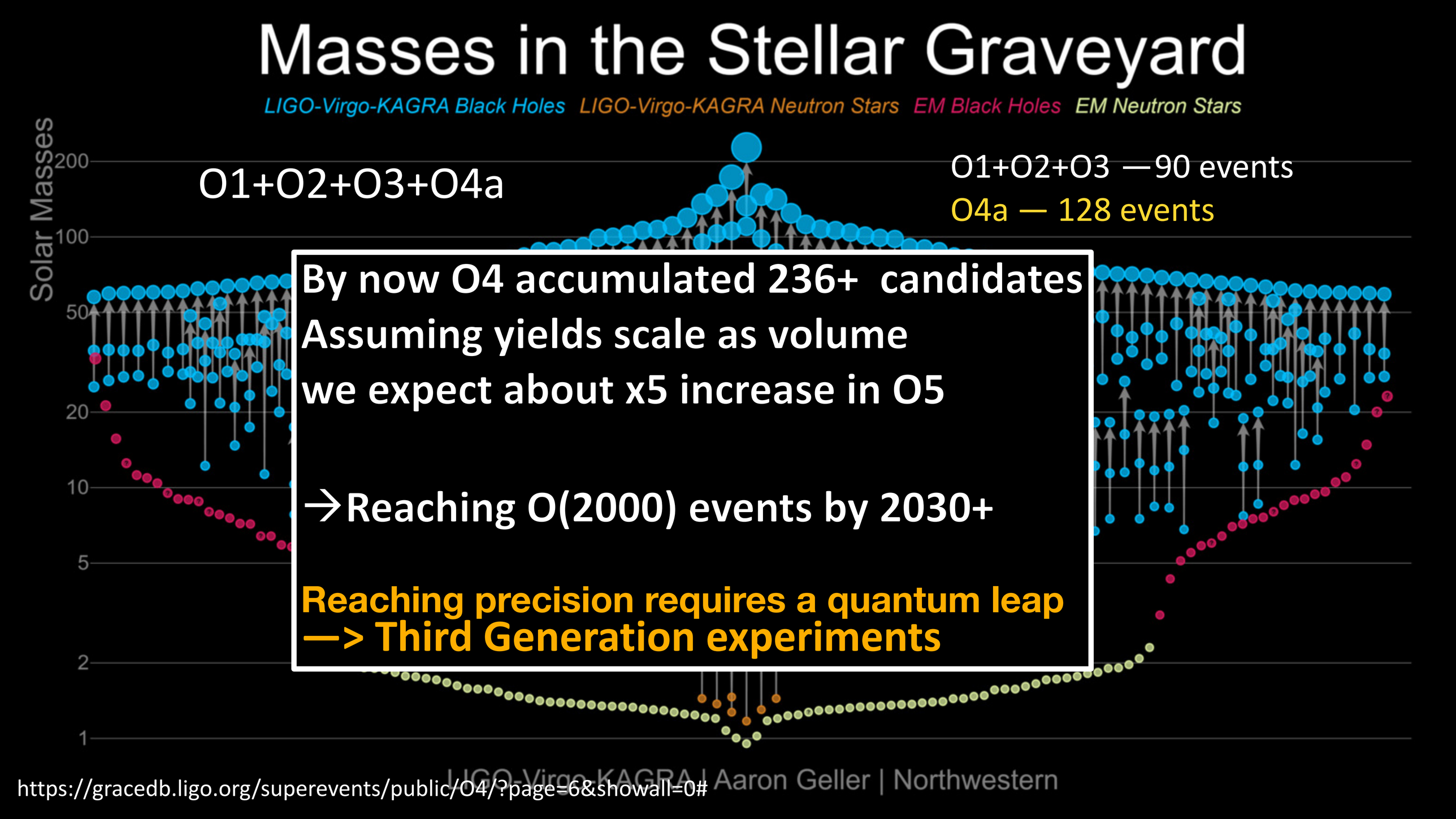
LVK Master Schedule



At present LVK program extends all the way to 2030+

—> Schedule now under revision due to uncertainties on LIGO NSF budget —> extended O4 ?

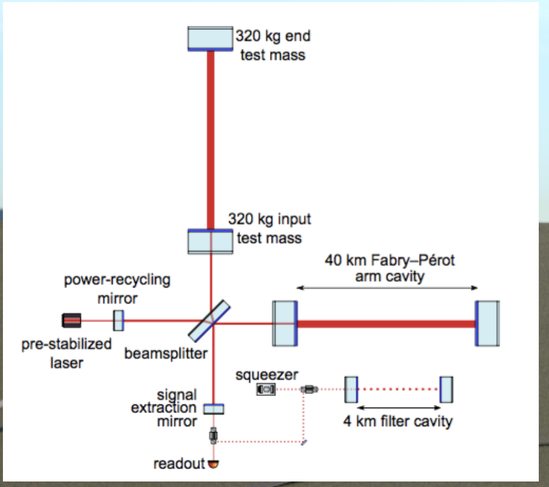
—> Would translate into a later O5 realisation — [my view]



https://gracedb.ligo.org/superevents/public/O4/?page=6&showall=0#

COSMIC EXPLORER

$1.6B (first estimation)



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

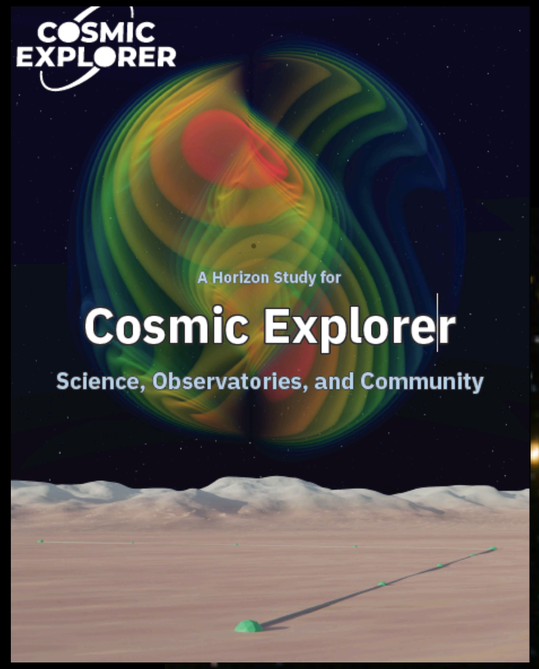
- A 40 km detector optimized for deep, broadband sensitivity
- A 20 km detector tuned to neutron-star post-merger signals

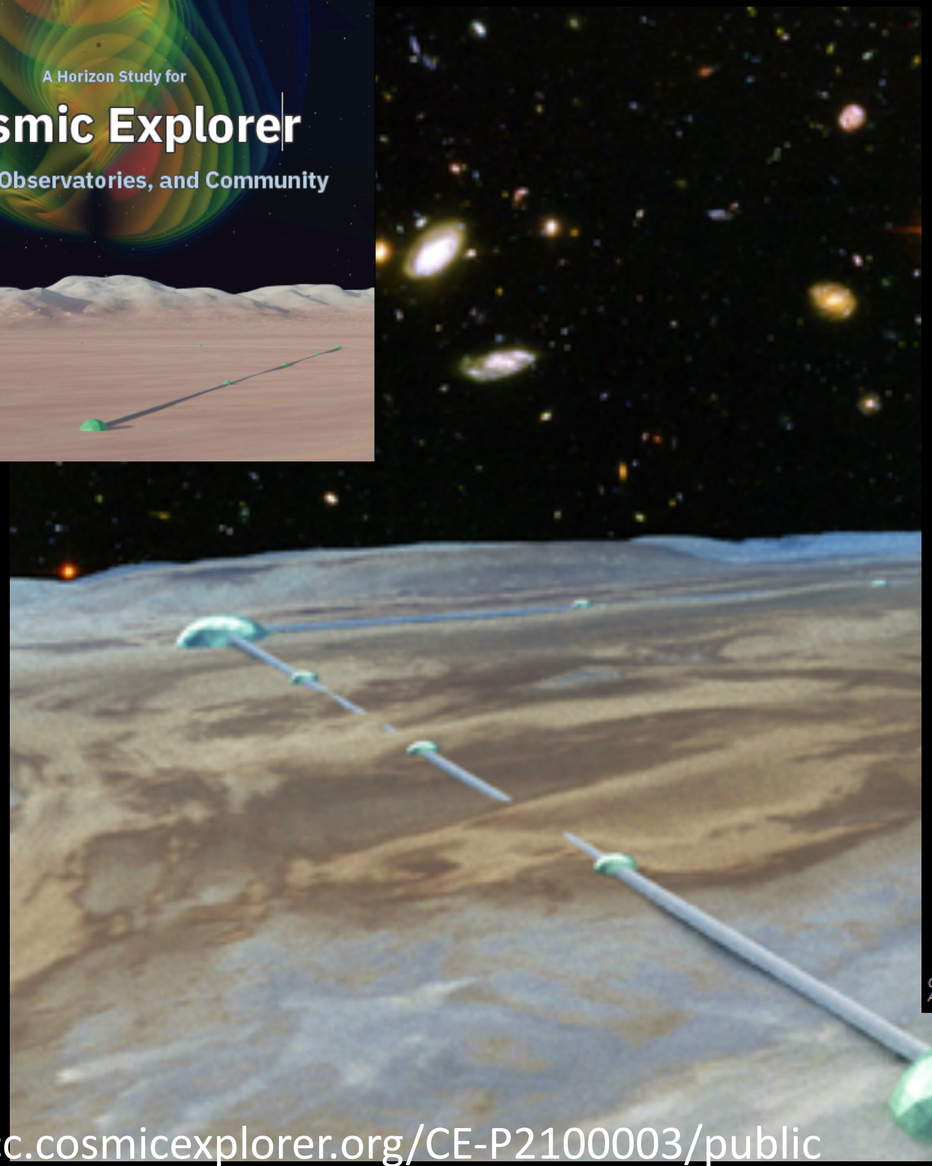
Two facilities improve localization and polarization information

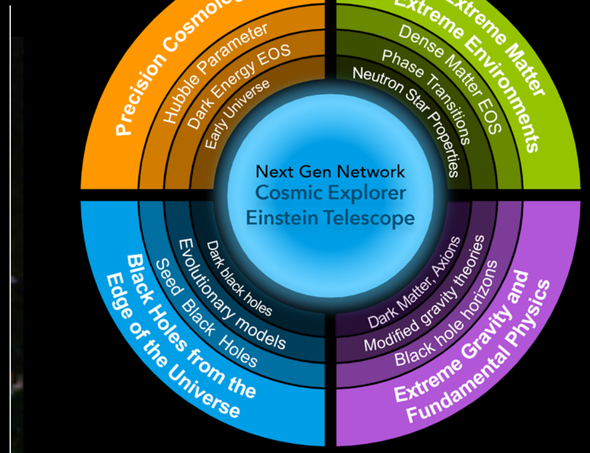
Cosmic Explorer will extend LIGO A+ technology **(room-temp silica, 1 µm laser)**, with Voyager technology **(123 K silicon, 2 µm laser)** as a secondary option

Cosmic Explorer (USA)

https://cosmicexplorer.org/







Recent recommendations

1- Focus on a 40km long L + ET

2. 40km L + 20km L in case ET is not realised

$9M from NSF for preliminary studies

As in LIGO, support from NSF very unclear

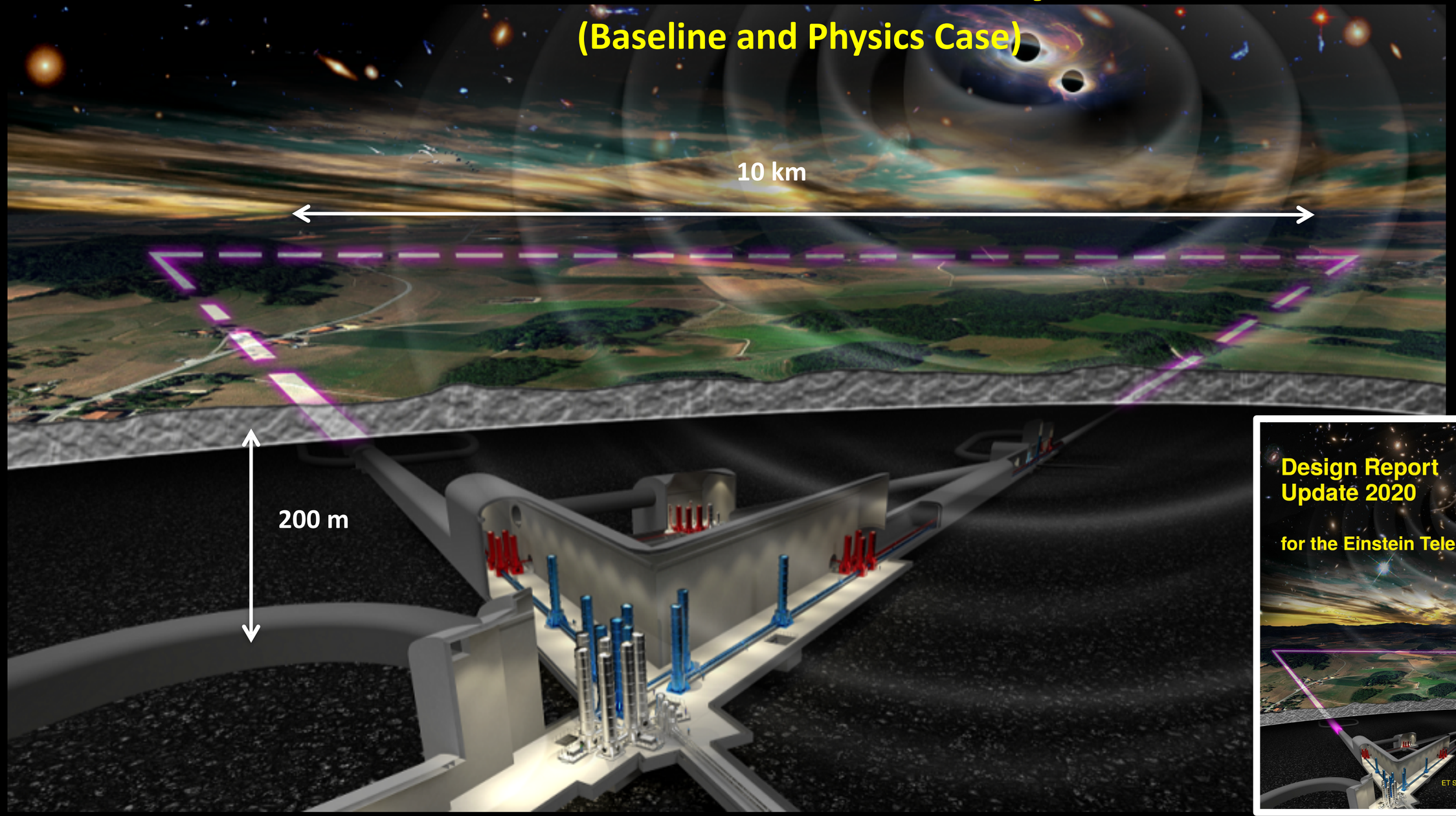
http://dcc.cosmicexplorer.org/CE-P2100003/public

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

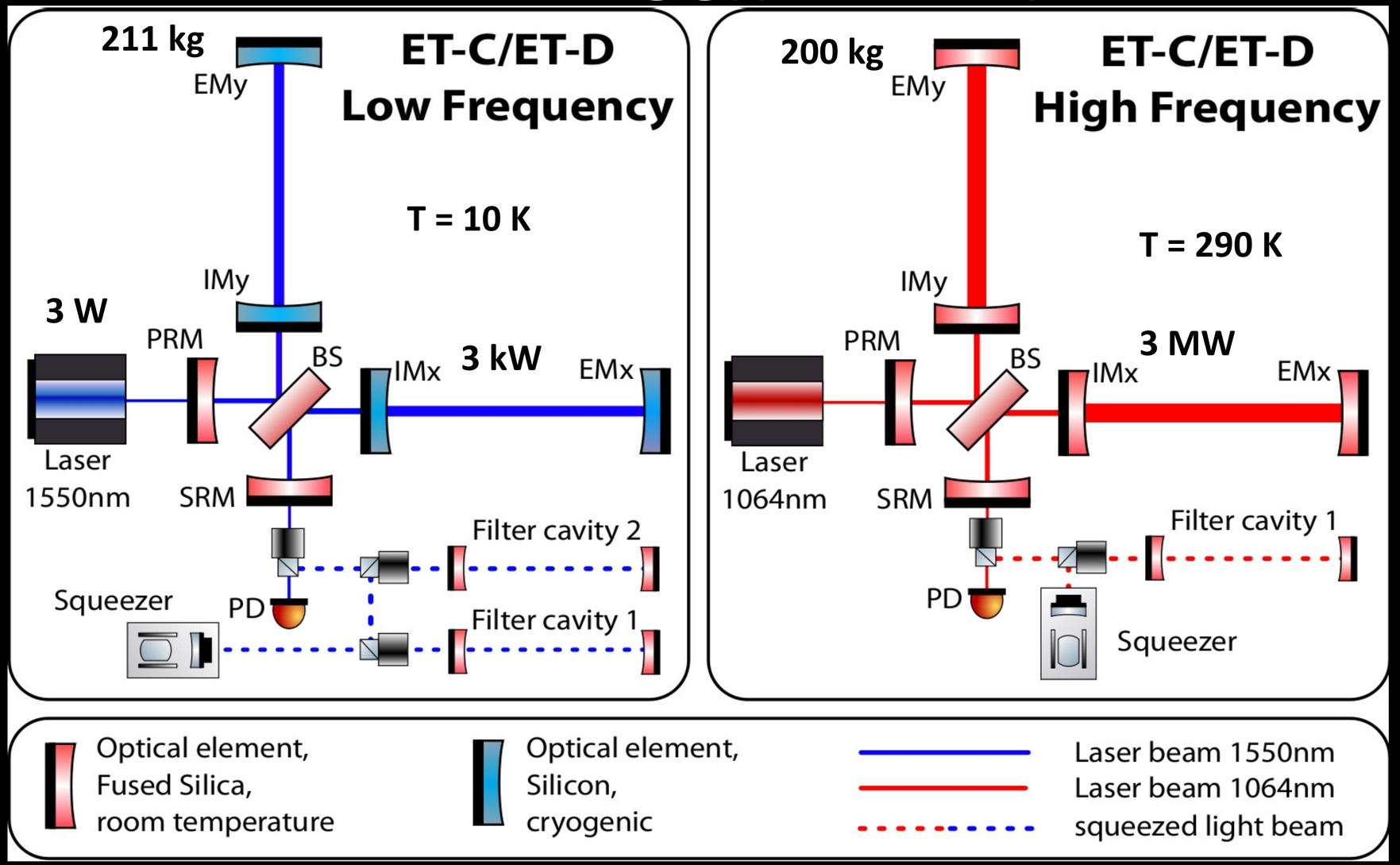
The Einstein Telescope

(Baseline and Physics Case)

First CDR in 2010 - 2011



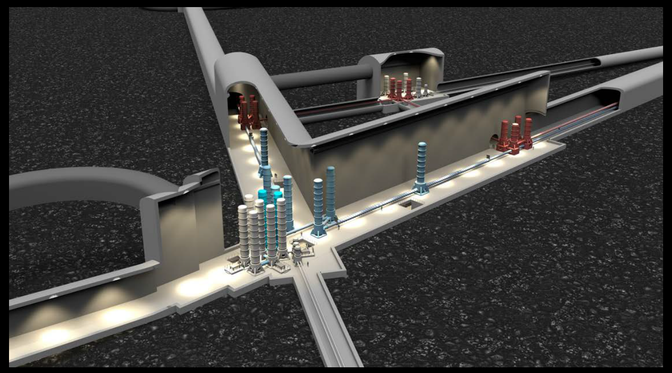
2nd Gen → ET

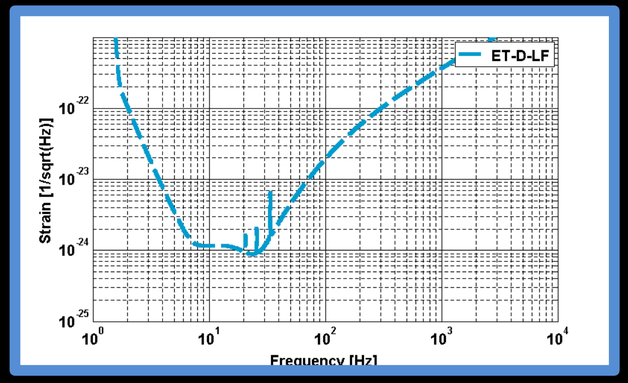


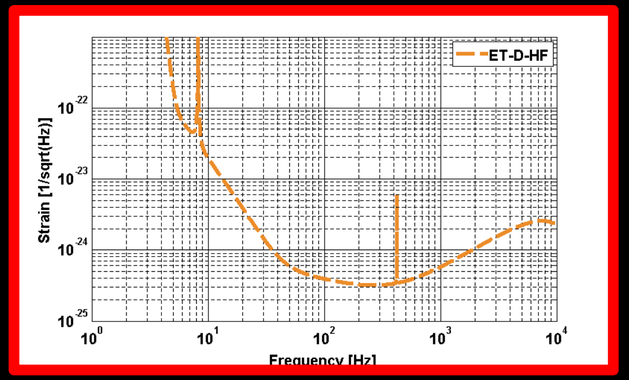
Underground
Cryogenic
Silicon mirrors
1550 nm (Si transparent)
New optical coatings
New suspensions / seismic controls

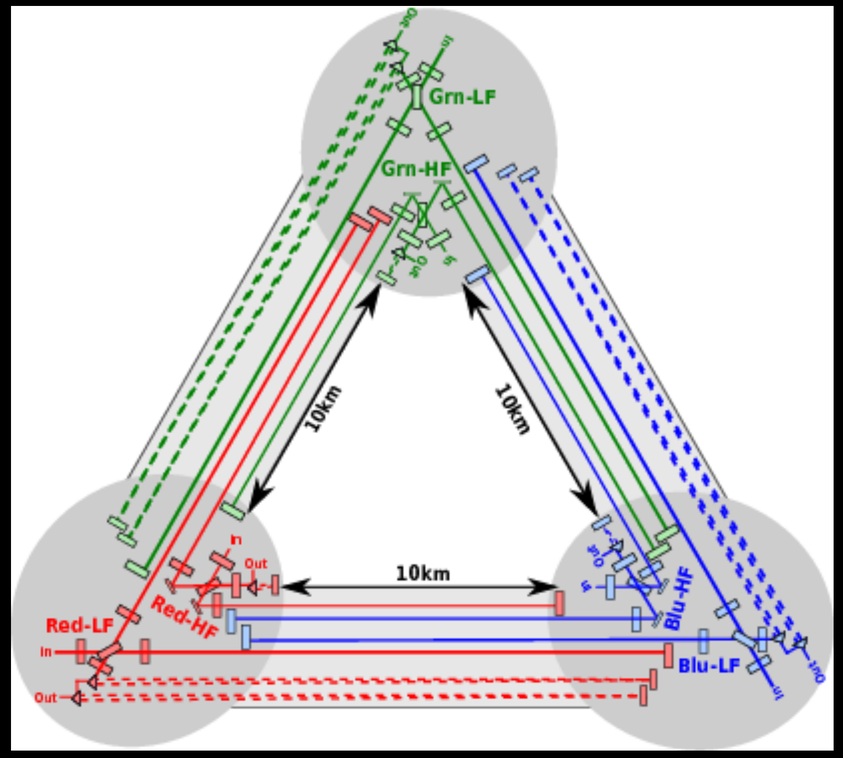
More powerful lasers
Larger fused silica mirrors
1064 nm (silica transparent)
New optical coatings
New thermal compensation systems

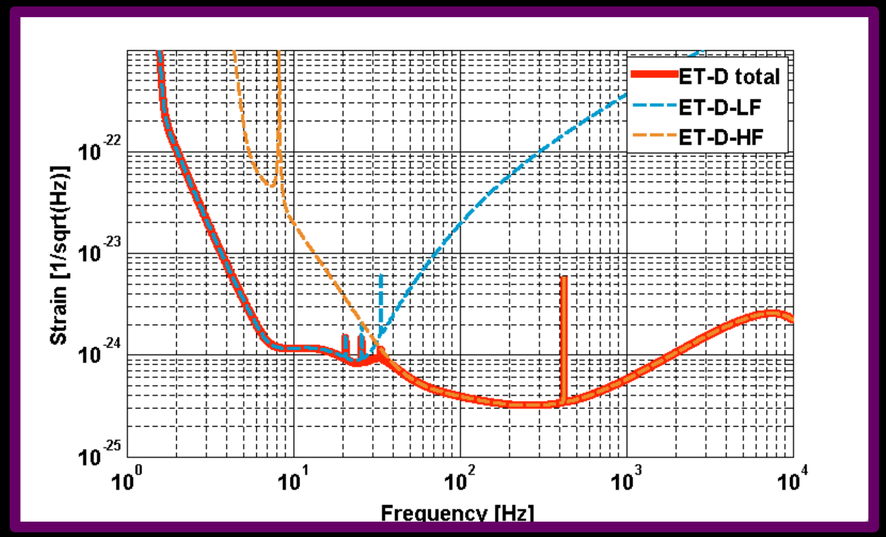
Einstein Telescope (6 in 1) Xylophone



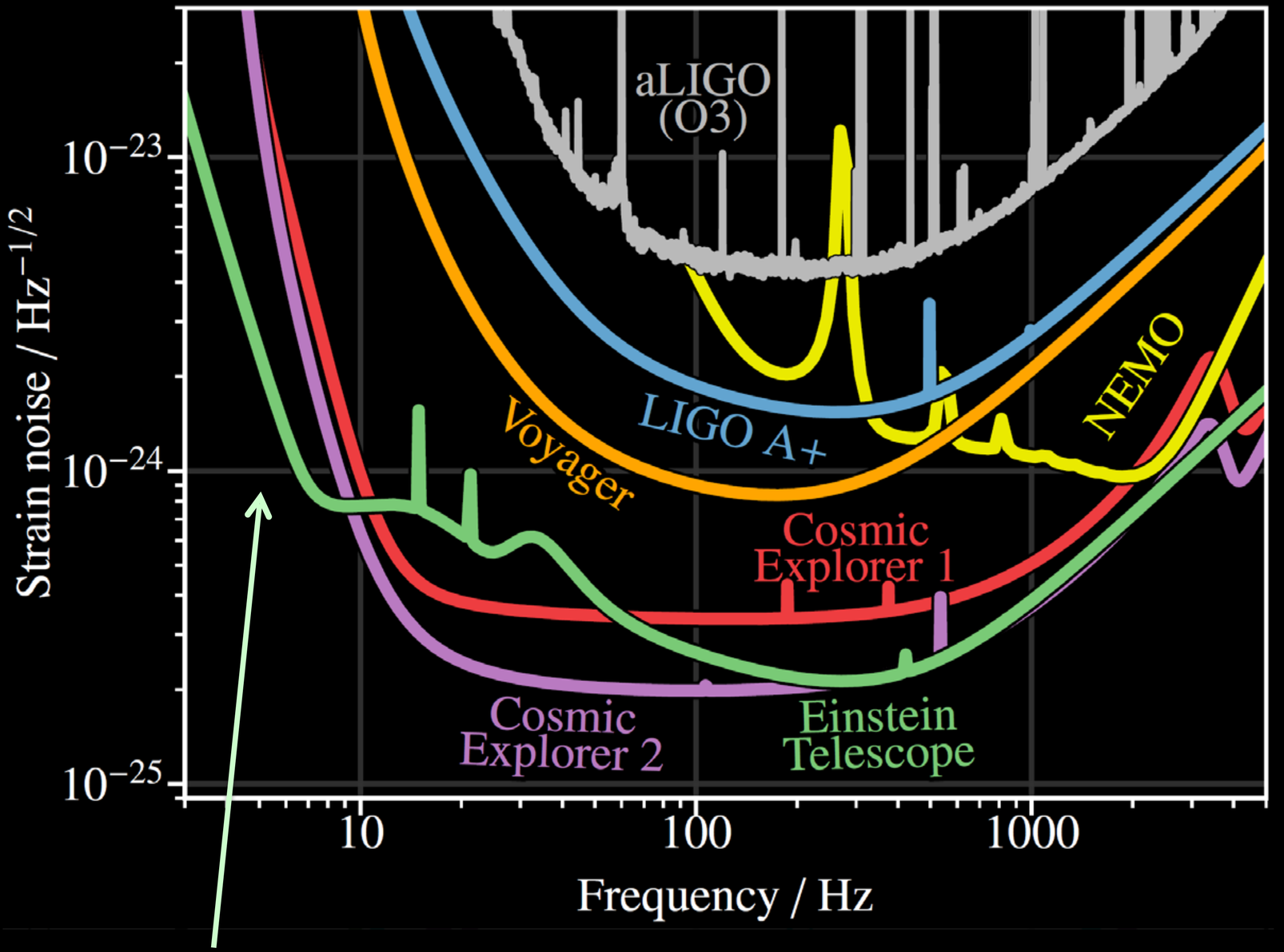






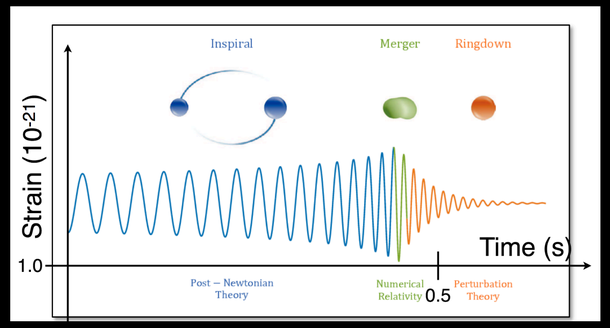


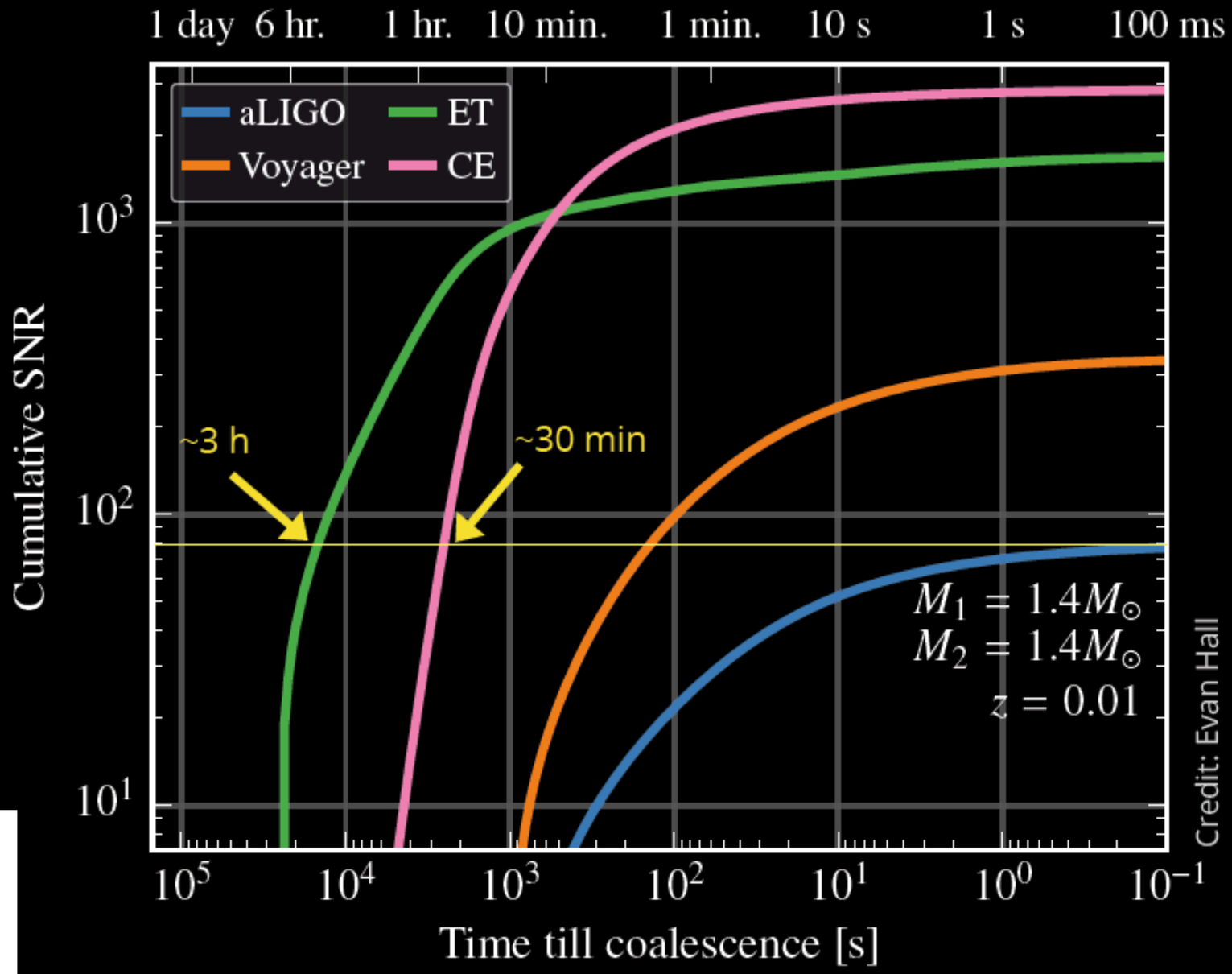
Each interferometer decoupled into 2 devices independent for the best sensitivity to low and high frequency



About one order of magnitude improvement w.r.t current detectors

and an extended sensitivity to low frequencies (….many orders of magnitude) →requires R&D

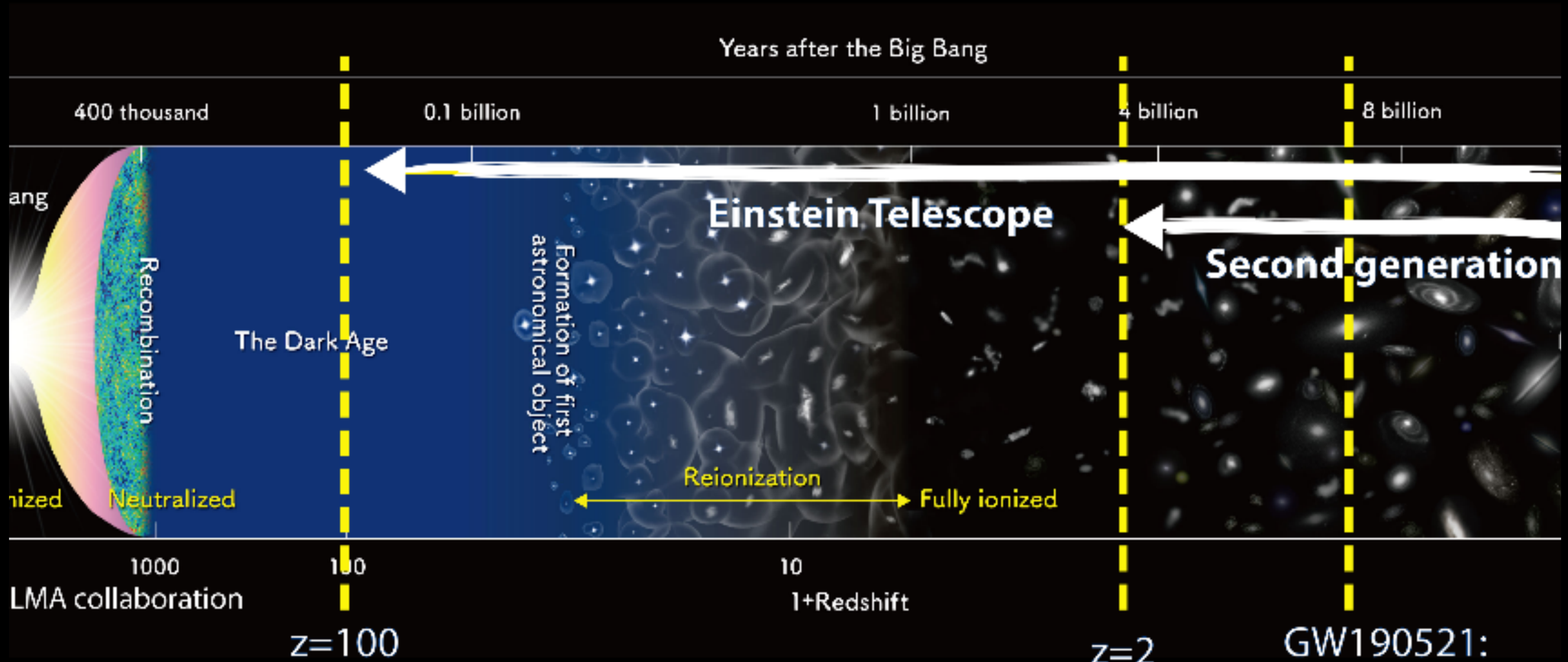




The sensitivity at low frequencies allows for an early detection

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

Detection horizon for black-hole binaries

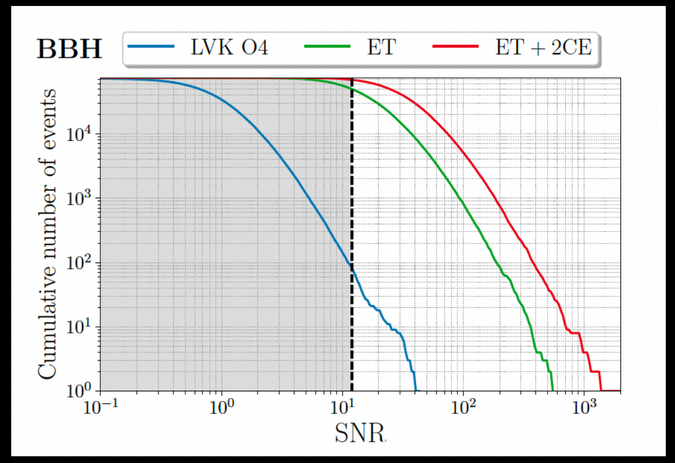


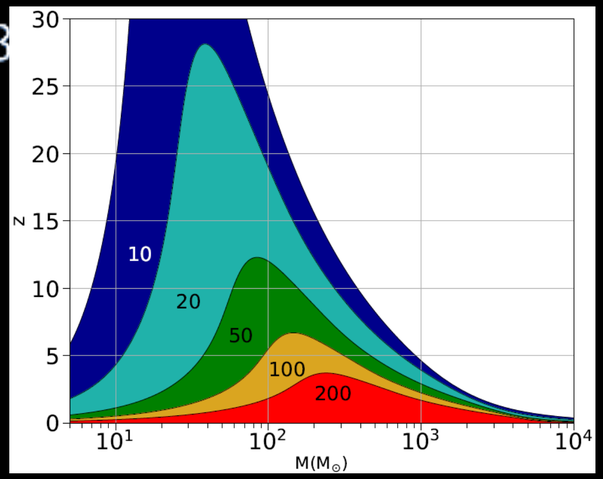
Huge rate of detections (about 1 per minute)
Extended redshift coverage up to the Dark Age

- Test for primordial BH origin
- Cosmology & Cosmography

Many events with very large Signal-to-Noise ratios

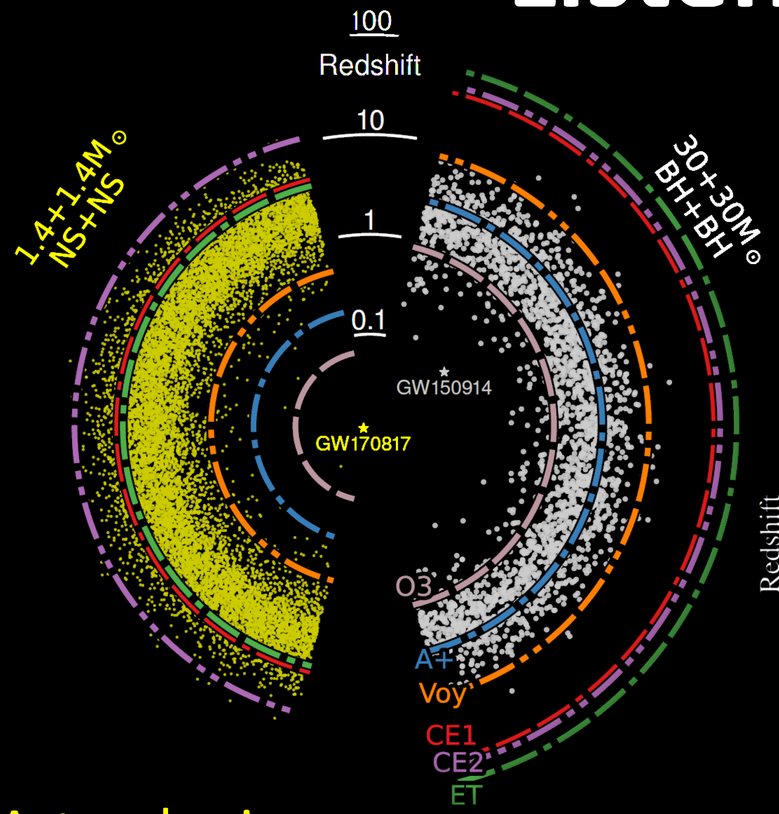
- Precision tests of GR predictions and detailed BH studies



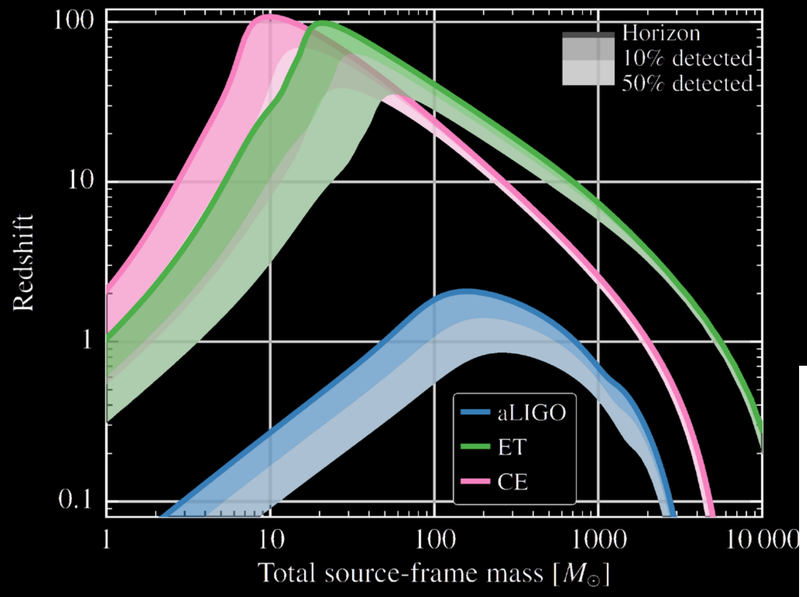


Listening the whole Universe

Iacovelli et al. 2022

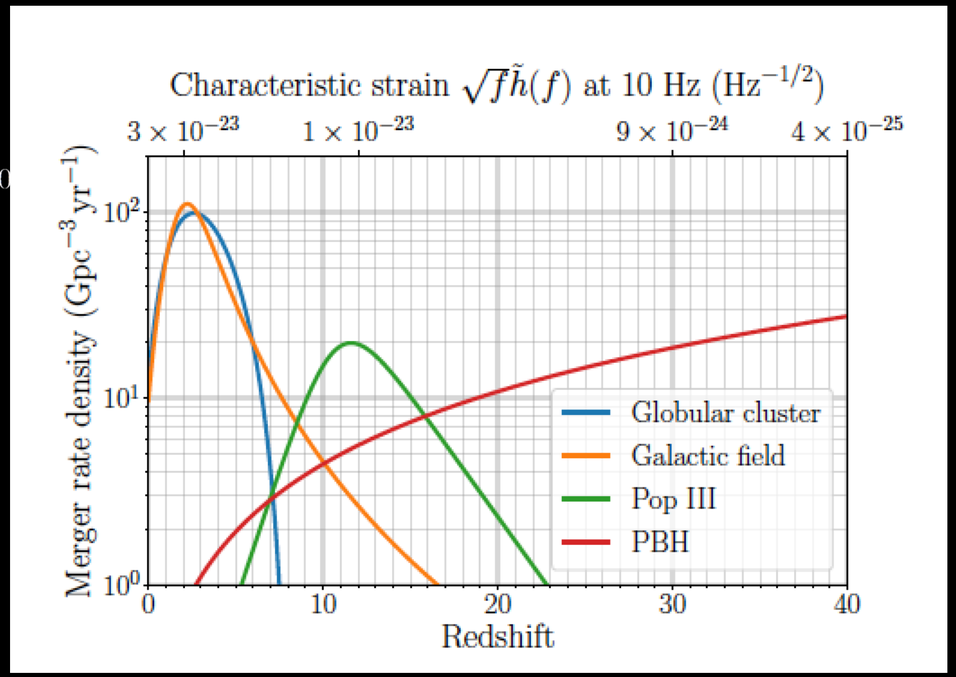


- 10^6 BH-BH / year up to z ~20 (230 Gpcs) and 10^3 M_{sun}
- 10^5 NS-NS / year up to z~2
- O(10^2 – 10^3) GW events with EM counterparts



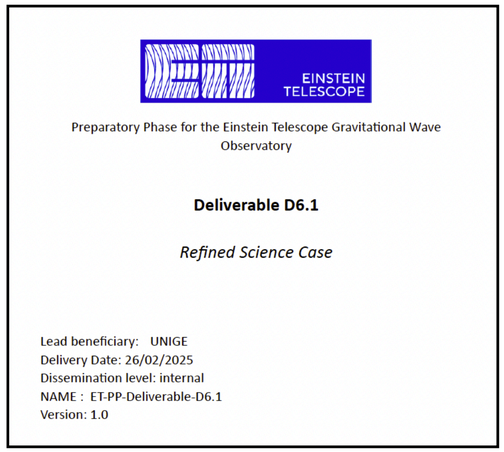
Astrophysics

- 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



ET Science

https://arxiv.org/abs/2503.12263v2


EINSTEIN TELESCOPE

Preparatory Phase for the Einstein Telescope Gravitational Wave Observatory

Deliverable D6.1

Refined Science Case

Lead beneficiary: UNIGE
Delivery Date: 26/02/2025
Dissemination level: internal
NAME : ET-PP-Deliverable-D6.1
Version: 1.0

Astrophysics

- **Black hole properties**

– origin (stellar vs. primordial)

– evolution, demography

- **Neutron star properties**

– demography, equation of state

- **Multi-messenger astronomy**

– joint GW/EM observations (GRB, kilonova,…)

– multiband GW detection (LISA)

- **Detection of new astrophysical sources**

– core collapse supernovae

– isolated neutron stars

– stochastic background of astrophysical origin

Fundamental Physics, Cosmology, HEP

- **Testing the nature of gravity**

– perturbative regime: inspiral phase of BBH, post-Newtonian expansion

– strong field regime: physics near BH horizon

exotic compact objects

- **QCD**

— interior structure of neutron stars probe ultra-high temperatures and densities

– exotic states of matter

- **Dark Matter / New Particles**

– primordial BHs

– axions, dark matter accreting on compact objects

- **Modified Cosmology**

– Dark Energy equation of state

– modified GW propagation @ cosmological scales

- **Stochastic backgrounds of cosmological origin and HEP**

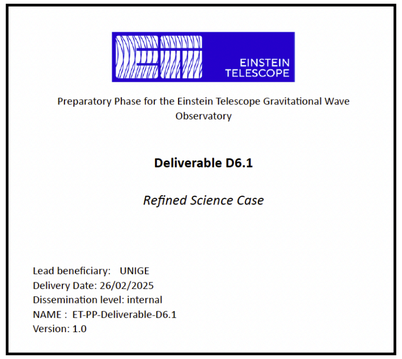
– inflation, first-order phase transitions

– cosmic strings, domain walls..

ET refined science case

A > 870 pages document summarising the ET Science Case

A great success of the ET Collaboration

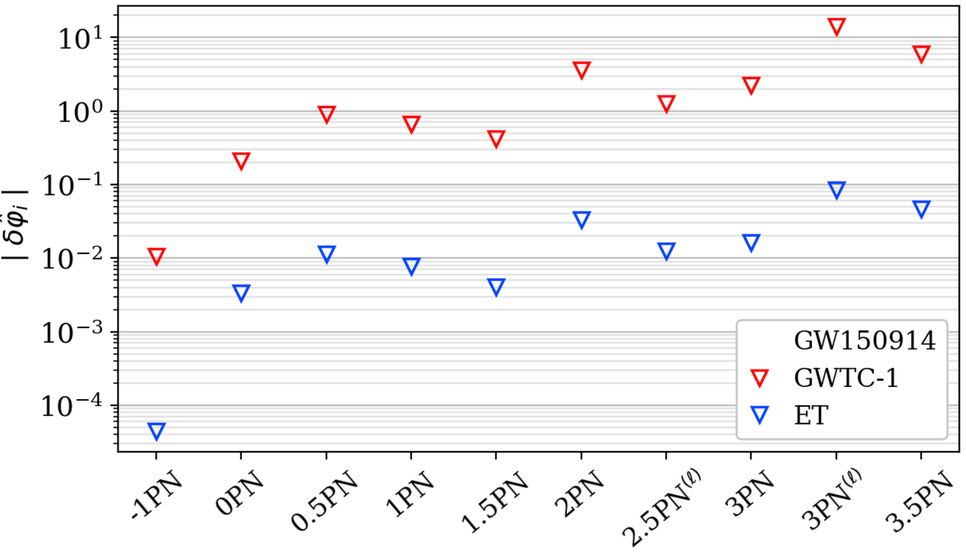


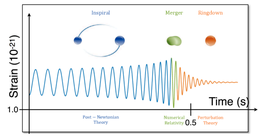
https://arxiv.org/pdf/2503.12263

Tests of GR

PN coefficients

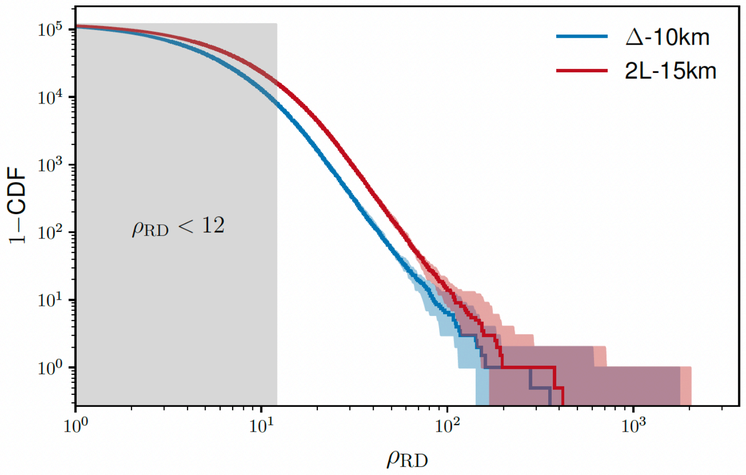
$$\Psi(f) = 2\pi f t_c - \varphi_c - \frac{\pi}{4} + \frac{3}{128\eta}\left(\frac{v}{c}\right)^{-5} \sum_{n=0}^{7} \left[\varphi_n + \varphi_n^{(l)} \log\left(\frac{v}{c}\right)\right] \left(\frac{v}{c}\right)^{n}$$

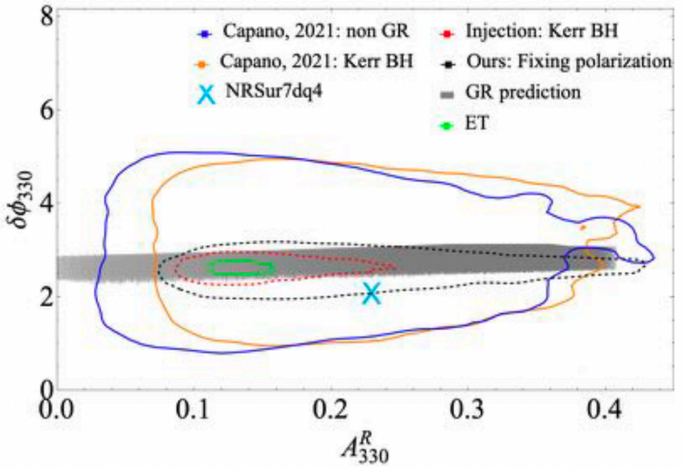


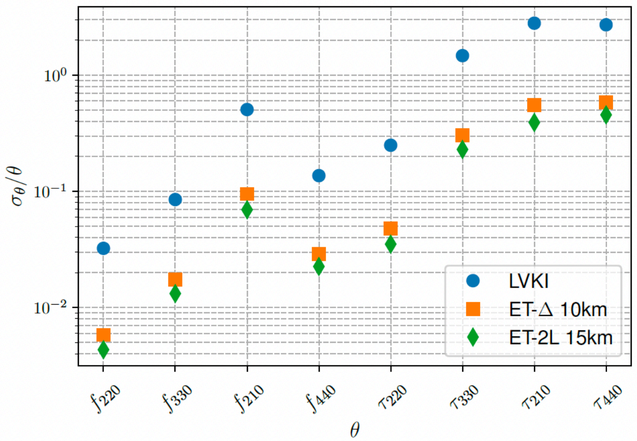


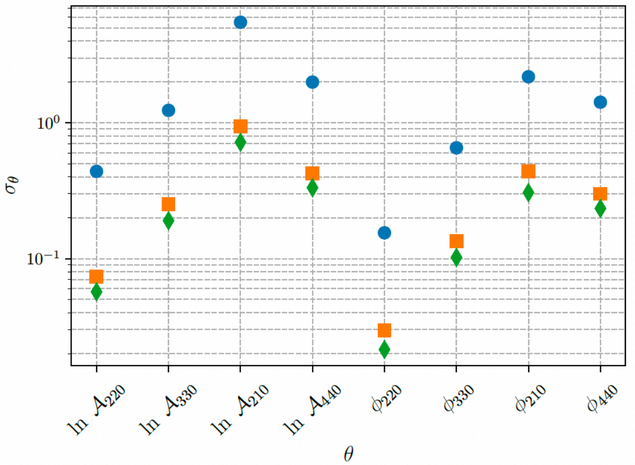
$$h_{+,\times}(t) = \sum_{lmn} \mathcal{A}_{lmn} \cos\left(2\pi f_{lmn} t + \phi_{lmn}^{+,\times}\right) e^{-t/\tau_{lmn}} \, \mathcal{Y}_{+,\times}^{lm}(\iota)$$

Ringdown and BH spectroscopy

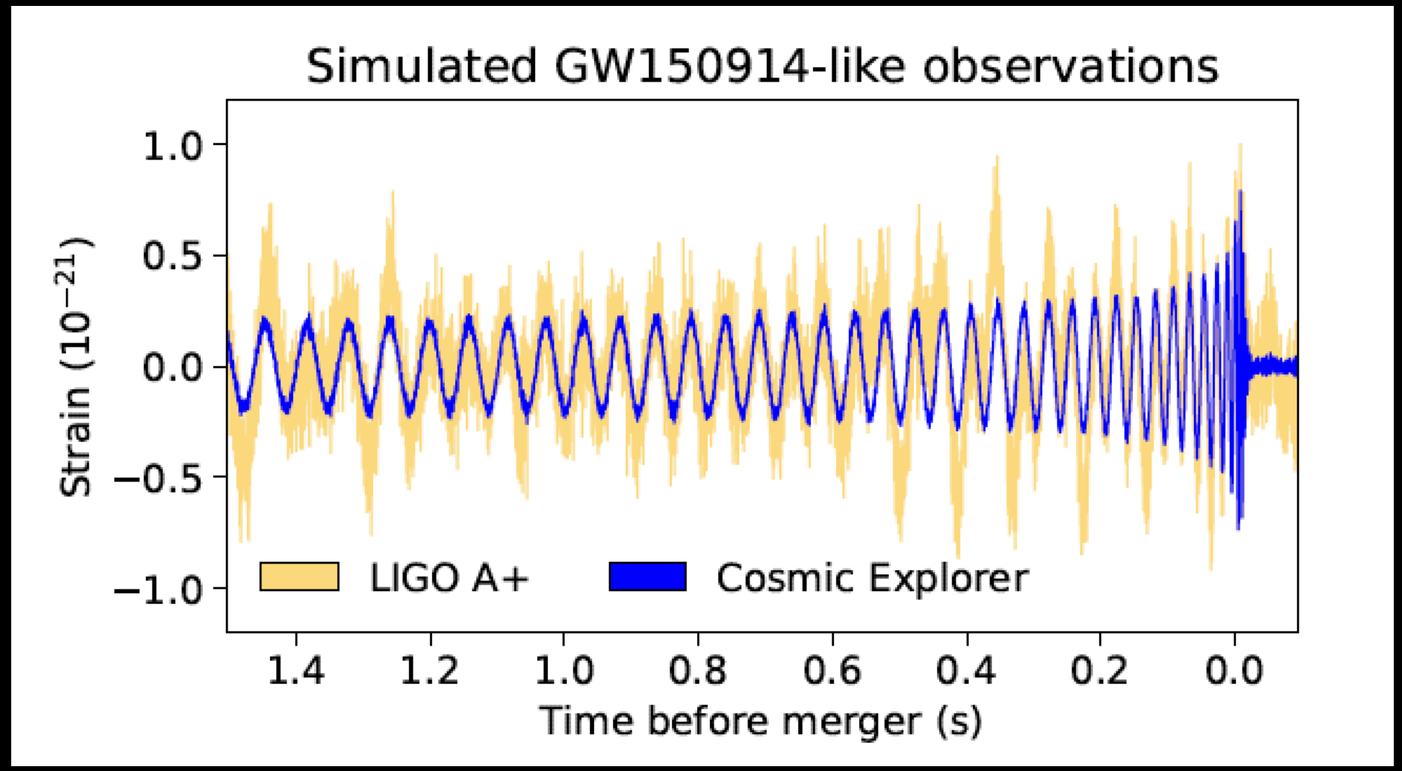








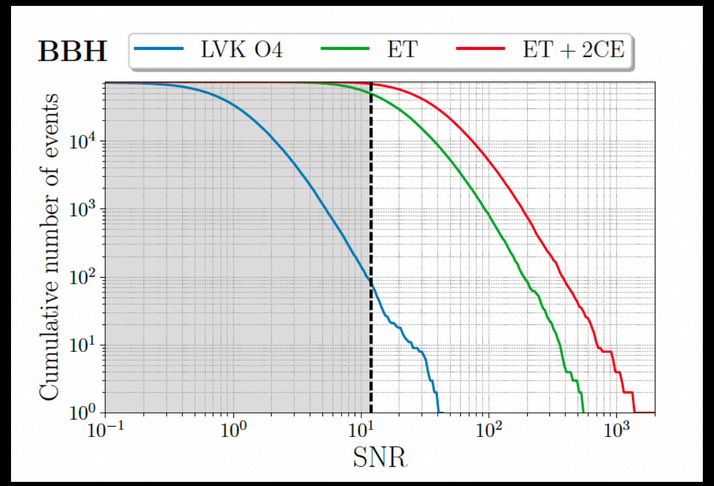
General Relativity Tests

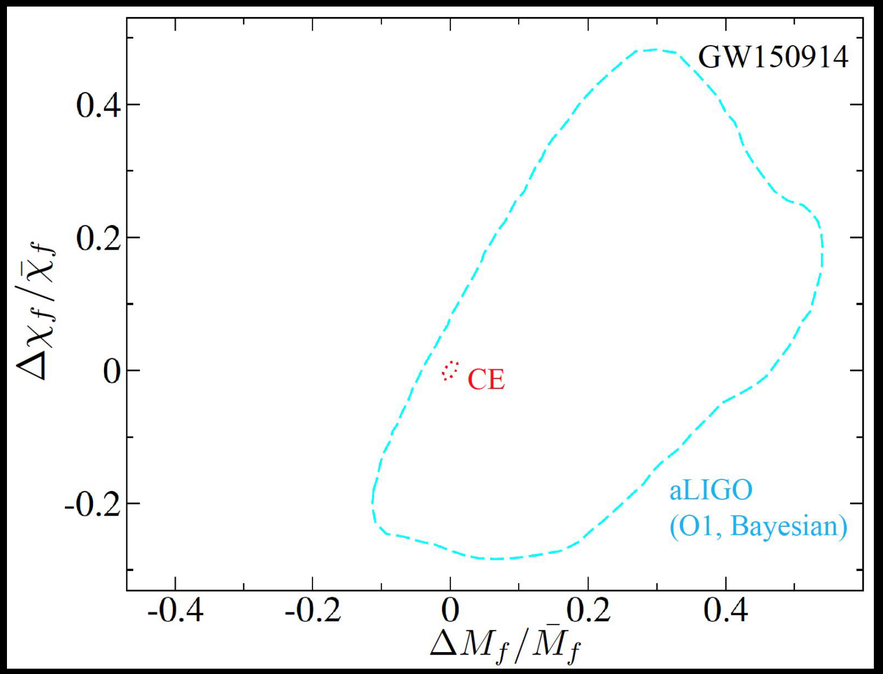


$$\frac{\Delta M_{\rm f}}{\bar{M}_{\rm f}} = 2\frac{M_{\rm f}^{\rm insp} - M_{\rm f}^{\rm postinsp}}{M_{\rm f}^{\rm insp} + M_{\rm f}^{\rm postinsp}},$$

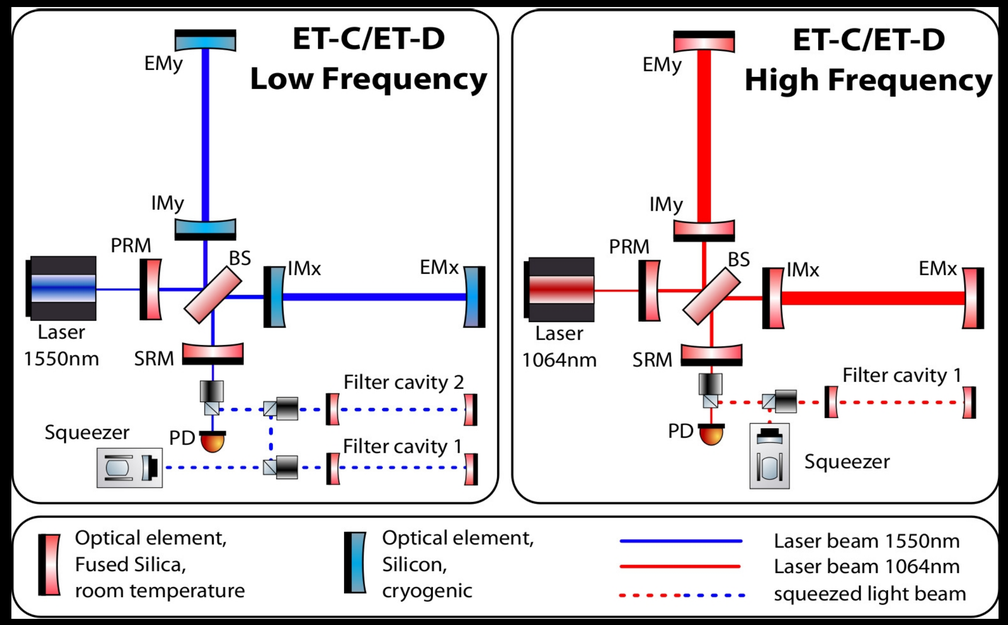
$$\frac{\Delta \chi_{\rm f}}{\bar{\chi}_{\rm f}} = 2\frac{\chi_{\rm f}^{\rm insp} - \chi_{\rm f}^{\rm postinsp}}{\chi_{\rm f}^{\rm insp} + \chi_{\rm f}^{\rm postinsp}},$$

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





Enabling technologies and KTT



ET-LF

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

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

Major R&D Facilities in ET (incomplete)

From the XIII ET symposium, an incomplete selection of thepresented large facilities

VATIGrav and Compact Laser Interferometry

Main goals:
- test DFMI-based compact displacement sensors on suspensions to reduce control noise
- test inertial sensors with highly sensitive interferometric displacement sensors
- study new suspension control and seismic isolation schemes

DFMI metrology

Optical head (COBRI)

Readout algorithm

Readout system and electronics

System-level testing

OmniSense at Nikhef

- Interferometric sensing (HoQI), compact and proven
- Fused-silica suspension
- Closed-loop control
- Careful shielding for thermal fluctuations, acoustics, and E-M
- Mechanical simplicity, no cables or magnets.

Etpathfinder in Maastricht

Interreg Vlaanderen-Nederland

2 FPMI interferometers:
1) 1550nm @ 18K
2) 2090nm @ 123K

Main target:
provide a testbed for ET technol
concepts and qualify them in lo
environment.

The AEI 10 m Prototype Facility

Main goal: Sub-SQL interferometry
Studies of vibration isolation / control

Fused-silica welding

∅ = 3 m

∅ = 1.5 m

= 3 m

= 10 m

See Monday talk by David Wu

On solid ground

DZA The German Centre for Astrophysics (DZA)

a centre for research, technology, and application

DZA concept : the challenges of astrophysics today

E-TEST : Einstein Telescope EMR Site and Technology

Radiative cooling

Vibration isolation

E-TEST objectives

- Large mirror (100 Kg)
- Cryogenic temperature (10-20 K)
- Isolated at low frequency (0.1-10 Hz)
- Compact suspension (4.5 meters)

Test facility for experimental investigations of the He-II based ET-LF payload cooling concept

Suspension and cooling concept studied for ET-LF

He-I: Cool-down process

He-II: Stationary-state operation

See Monday talk by Xhesika Koroveshi

CoMET - Coating Materials for Einstein Telescope

Goals:
- Capability to deposit virtually all the (amorphous) materials of interest for the GW community with the needed level of control.
- Ability to explore different process ranges (energies, growth kinetics etc.)
- Study of the physical processes occurring durign deposition

Coating deposition (samples)
- Ion beam
- Magnetron

Characterization facilities

LMA - Laboratoire des Materiaux Avances

New large optics coater facility

2.2 x 2.2 x 2 m³

Also investing into substrate growth and polishing

Aim: produce ET cryo-compatible substrates in sapphire

Existing LMA building

Extension

1 optic Ø1.5 m/600 kg
2 optics Ø0.8 m/300 kg

CAOS: Centro per Applicazioni sulle Onde gravitazionali e la Sismologia

New facility at the University of Perugia

Development of specific technology for the third- generation GW detectors, and

GEMINI at LNGS

Goals
- Test the limits of active seismic isolation in an underground environment
- Inter-platform motion control
- Underground environmental monitoring
- Test new approaches to controls optimization
- Test new inertial sensors

Vibration target

GEMINI

SAR-GRAV Laboratory

SAR-GRAV hosts ET activities as well as Geophysics and Fundamental Physics activities

PNRR project "Monitoring Earth Evolution and Tectonics" (MEET)
Principal Investigator: Giulio Selvaggi, INGV

Cavern that should host the Archimedes experiment

It is planned to test at least partially a preliminary version of the double-suspended inverted pendulum in a quiet underground environment.

See Monday talk by Enrico Calloni

Amaldi Research Center at Roma La Sapienza

Facility dedicated to cryogenics development for ET.

Build prototype payload

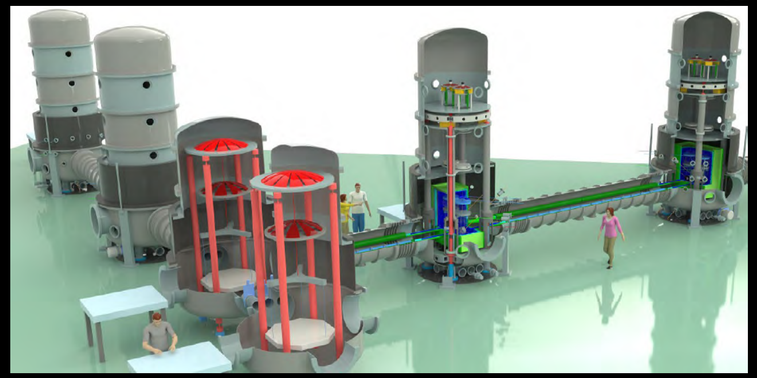
See Monday talk by Ettore Majorana

Glasgow
Amsterdam
Maastricht
Louvain
Hamburg
Hannover
Görlitz
Karlsruhe
Lyon
Padova
LNGS
Rom
Sos Enatos

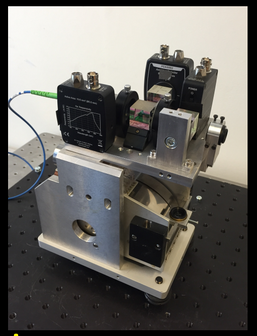
Landsat / Copernicus
U.S. Navy, NGA, GEBCO

Google Earth

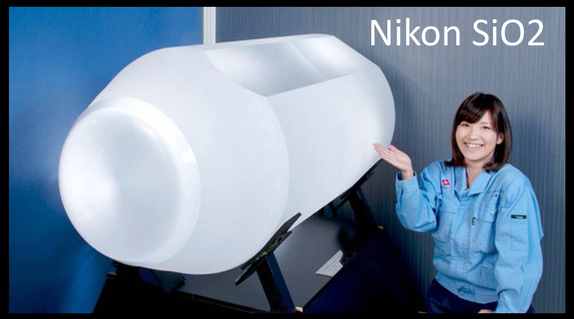
Ongoing R&D for ET (examples)

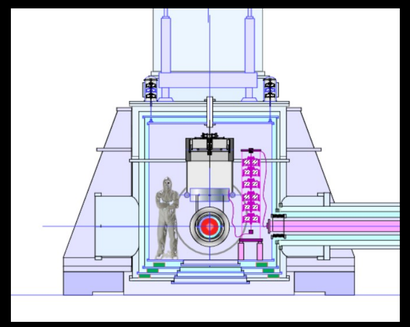


@ Maastricht small-scale prototype
in order to study the operations in
cryogenics with silicon optics at 1550 nm
and with mirrors up to 100 kg (relevant for ET-LF)



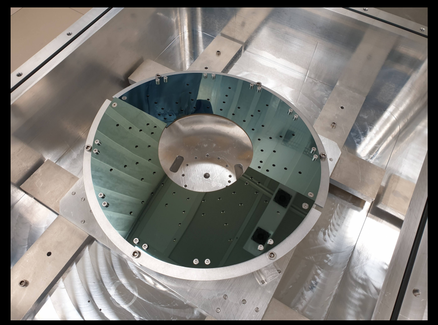
R&D for the production of mirrors up to
200kg based on silica or silicon of
high purity and homogeneity.





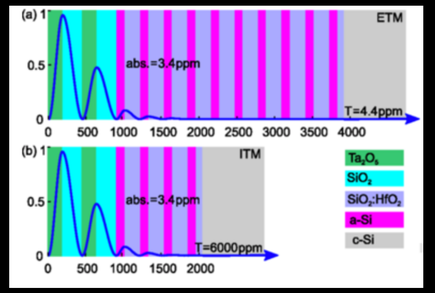
R&D in active mitigation
of seismic / Newtonian noise

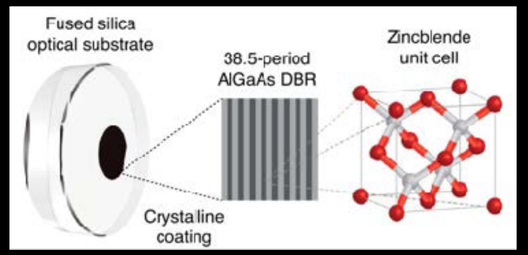
R&D on IR photo sensors &
active Stray Light monitoring



@ Rome and other R&D places
in cryogenic suspension

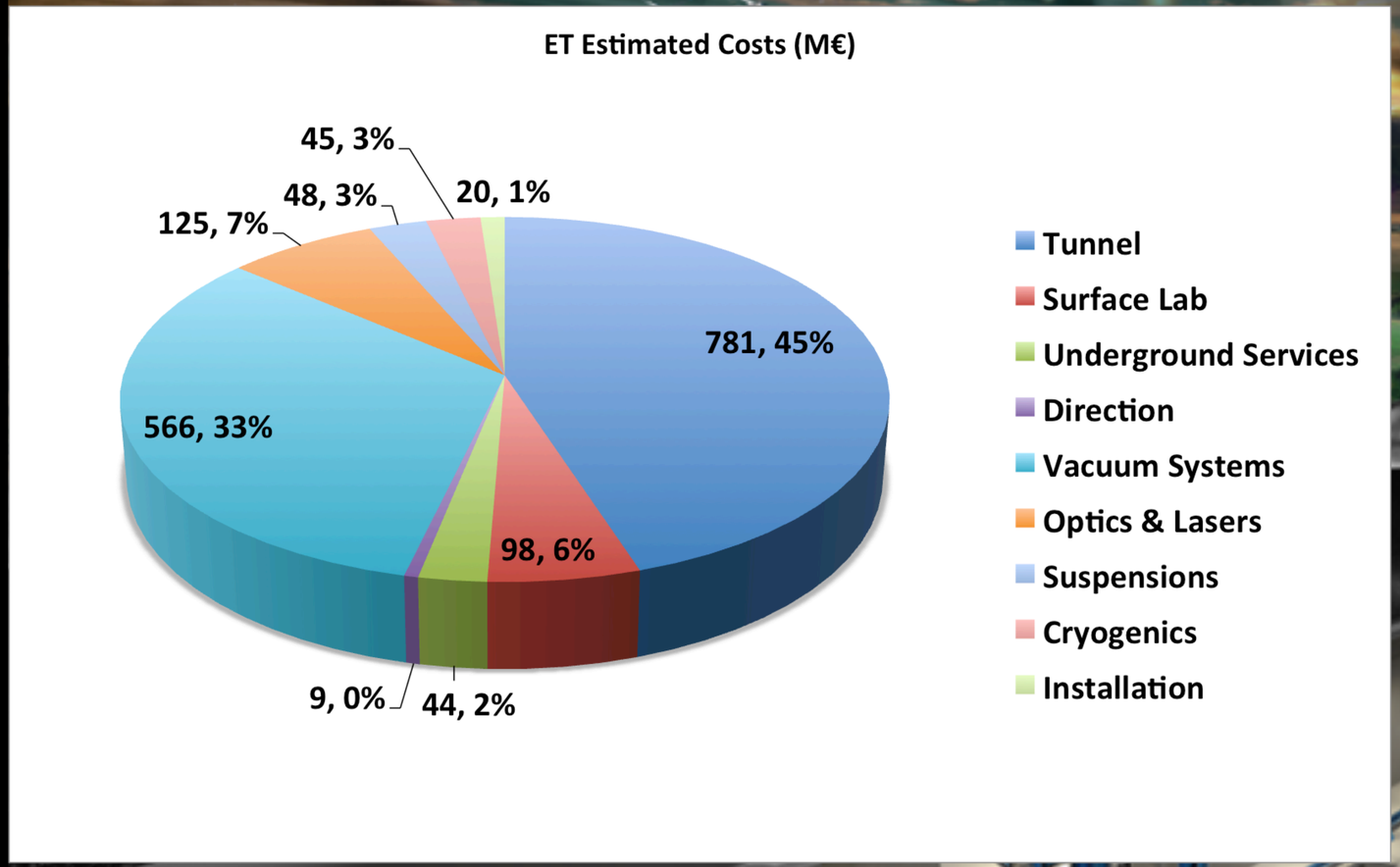
R&D in optical coatings reflective
with low absorption and reduced
thermal noise.





AlGaAs crystalline coatings

Estimated cost (EU accounting)



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

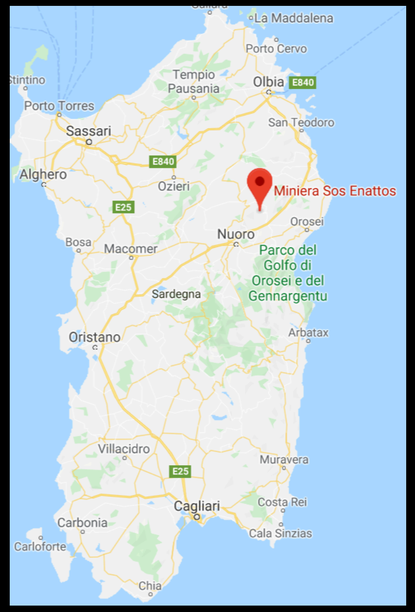
Host country is expected to contribute with > 50% of the total cost

Locations ?

@ Limburg area (border NL-B-D)

→ Promoted by Nikhef

Intensive studies
@ Limburg,
@ Sardinia
@ Saxony [now integrated in ET-PP]
For characterize seismic,
environmental noise, etc ...



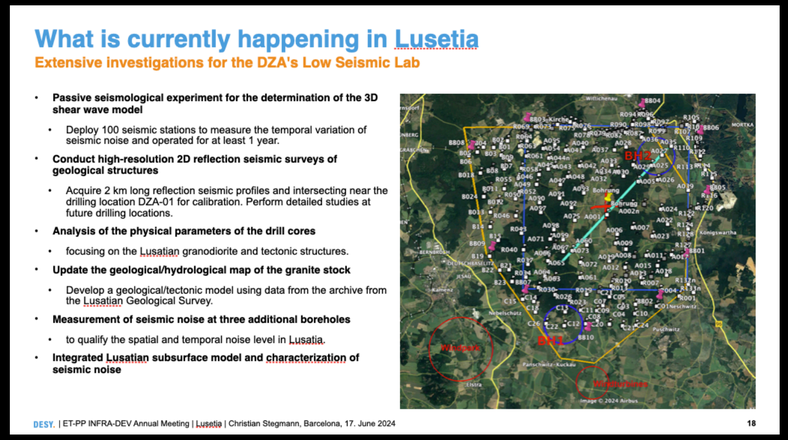
@ Sardinia

→ Promoted by INFN

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

→Exploring Saxony as a possibility
→ Ongoing geological characterization of the site

→3rd June 2025 : Germany formally asked to be considered a site candidate for ET



@ Lusatia

→ Promoted by DESY

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 950M€ for supporting ET@ Italy **has been secured**

Germany received O(20M€) for R&D and to carry our a comprehensive study and push for a candidature

COMUNICATO STAMPA

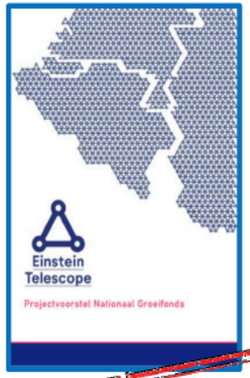
Ricerca, Governo rafforza candidatura Einstein Telescope
Il Ministro Bernini: "Scelta strategica per Paese ambizioso"

ROMA, 13 dicembre 2023 – Il Governo italiano è pronto a sostenere l'impegno finanziario per ospitare nel nostro Paese Einstein Telescope (ET), la grande infrastruttura di ricerca per lo studio delle onde gravitazionali che l'Italia si è candidata a realizzare in Sardegna, nell'area di Sos Enattos, a Lula.
Il Governo ha indirizzato ad Antonio Zoccoli, Presidente dell'Istituto Nazionale di Fisica Nucleare (INFN), ente coordinatore della candidatura italiana per ET, una lettera con la quale conferma l'impegno, istituzionale e economico, perché la proposta sia quella vincente in sede europea.
"La volontà di realizzare Einstein Telescope in Italia è stata fortemente sostenuta dal Governo. Si tratta di una scelta strategica per un Paese che vogliamo sempre più ambizioso. L'Italia è leader in Europa per la fisica, con la presenza di molte eccellenze scientifiche. Siamo convinti che ET contribuirà a rafforzare in modo decisivo la realizzazione di un ecosistema della ricerca e dell'innovazione sempre più attrattivo", ha detto il Ministro dell'Università e della Ricerca, Anna Maria Bernini.
Per ottenere l'assegnazione europea, il Governo ha deciso di programmare un piano di 'diplomazia scientifica' che coinvolgerà le nostre eccellenze universitarie e di ricerca, tra cui il Premio Nobel Giorgio Parisi. Sarà affidato loro un ruolo di coordinamento e divulgazione, perché sia resa nota nell'Unione la qualità della proposta italiana e quanto questa sappia rappresentare al meglio gli interessi comunitari.
Nella lettera del Sottosegretario di Stato alla Presidenza del Consiglio dei Ministri, Alfredo Mantovano, inviata al Presidente INFN Zoccoli, si certifica tra l'altro, l'importante impegno finanziario che il Governo è pronto ad assumere in caso di assegnazione dell'infrastruttura. Si tratta di circa 950 milioni di euro complessivi per i nove anni previsti per la costruzione (dal 2026 al 2035). In particolare, le spese serviranno alla realizzazione e all'acquisto di beni, materiali e tecnologie. La dotazione è stata prevista tenendo conto anche dell'elevato impatto occupazionale e di indotto atteso e del ritorno in termini di coesione territoriale.
Einstein Telescope sarà un osservatorio internazionale di terza generazione all'avanguardia assoluta nella ricerca fisica e astronomica. L'Italia ha ufficializzato la sua candidatura nello scorso mese di giugno. Il sito scelto per l'infrastruttura, e cioè nell'area della miniera dismessa a Sos Enattos a Lula (in provincia di Nuoro), è considerata ottimale per le eccellenti condizioni geologiche e ambientali che può garantire.

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 2023 the Netherlands Minister 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

27

ETIC – Einstein Telescope Infrastructure Consortium

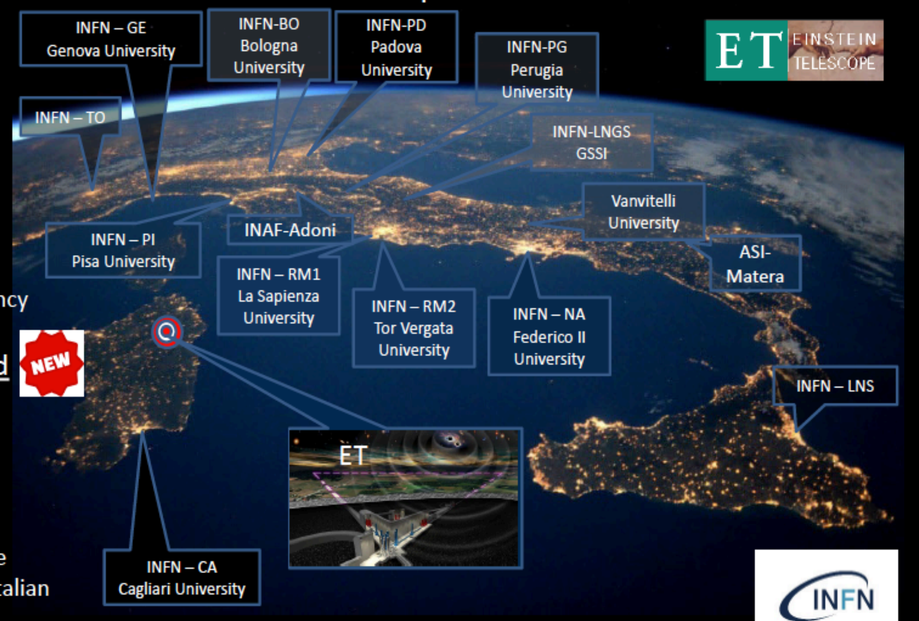
Next Generation EU Investment focused on ET enabling technology and Sardinian site candidature support

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

<u>Budget 50M€ approved</u>

Start of the project:
1st December 2022

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



ET experiment and ET Organization

ETO (ET Organisation)

- Board of governmental representatives
- Board of Scientific representatives
- Coordinators
- ET Directorate
- Project office
- Engineering department
- Administrative office
- ET-PP

ET Collaboration

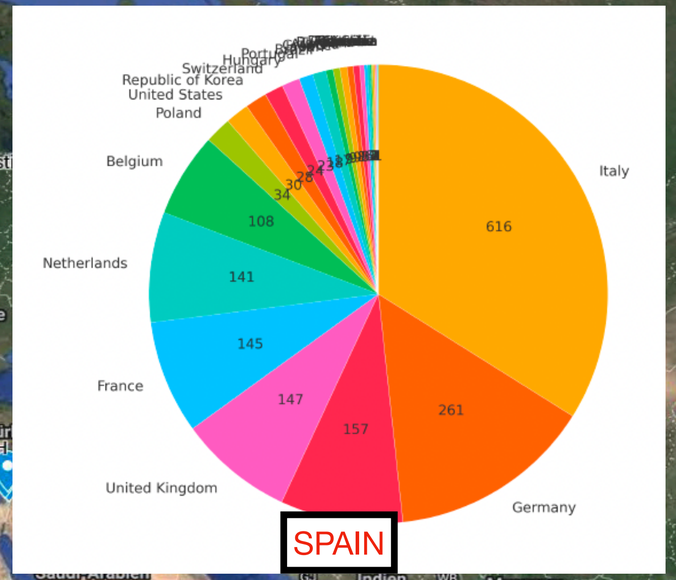
- Collaboration board
- Executive board
- Specific boards
  - ISB
  - OSB
  - EIB
  - SCB
  - SSB
  - ...

ET-PP is naturally framed inside ETO chart

ET research infrastructure, services, and vacuum system under ETO supervision

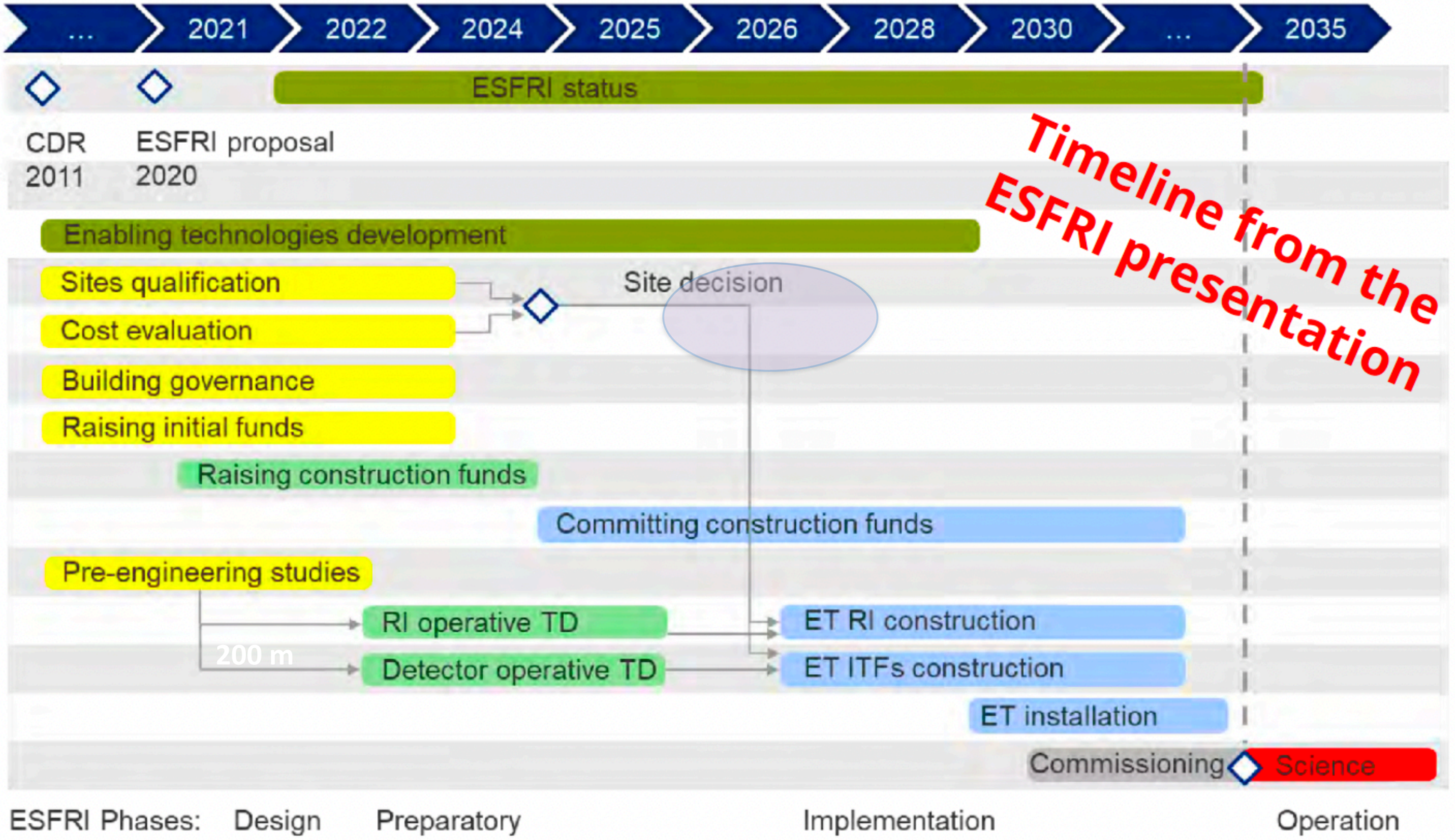
ET Scientific Collaboration dedicated to experiment design & scientific exploitation

ET Collaboration Member's Affiliation Map



- 1819 members (29.5.2025)
- 93 Research Units
- 263 Institutions
- in 31 Countries

https://apps.et-gw.eu/etmd/

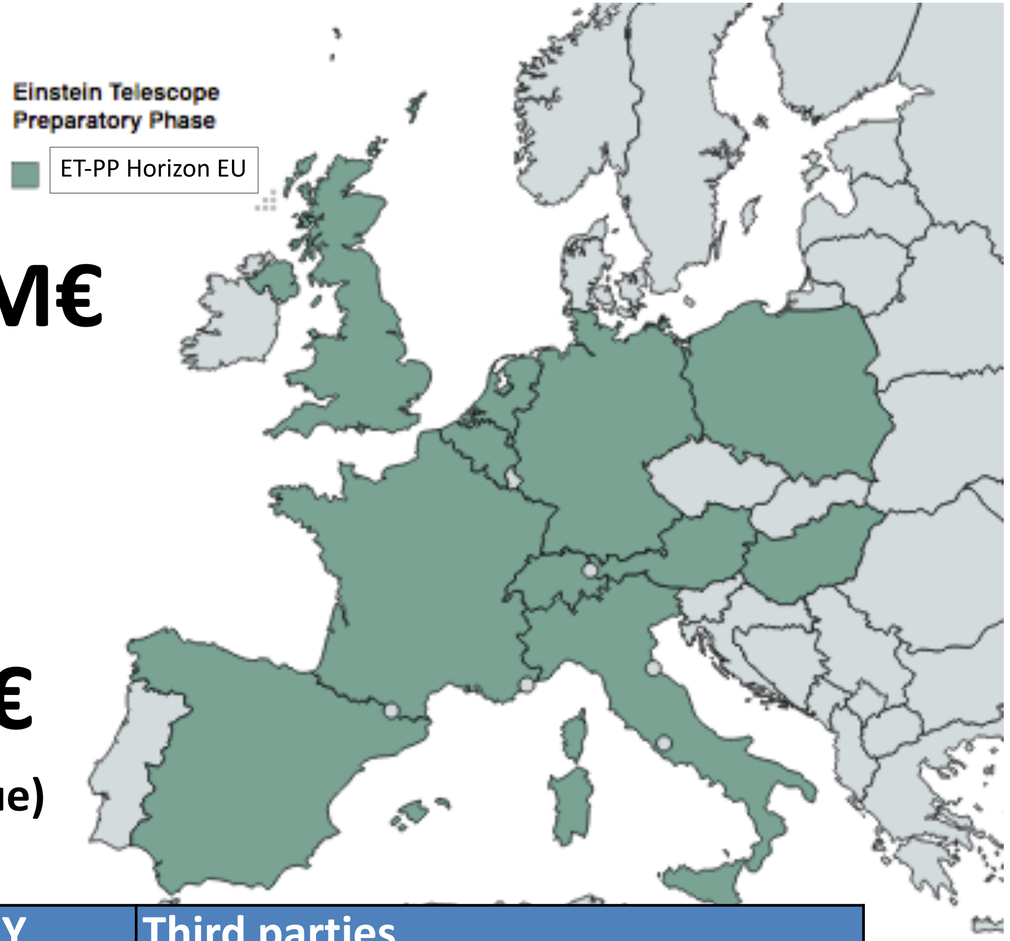


ET project is now in the preparatory phase

—> We know already ESFRI roadmap schedule was too optimistic based on simplified assumptions

—> We are in the process to define a new schedule and roadmap —> all became complicated…

INFRA-DEV ET-PP (Preparatory Phase)

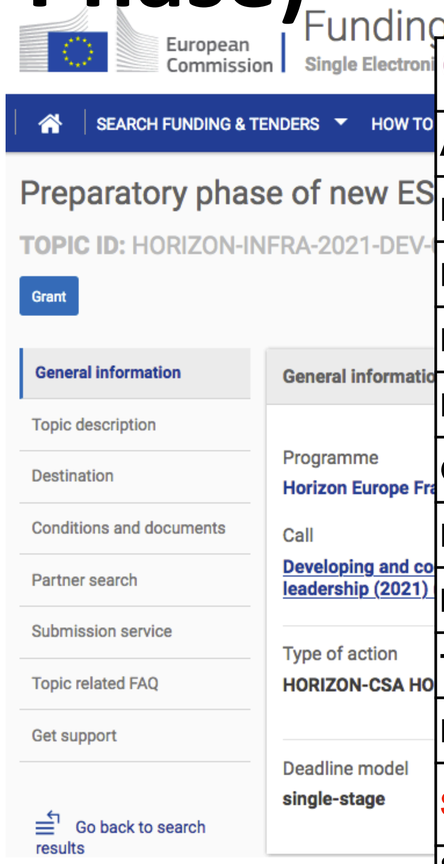


3.45M€

12M€

(total value)

COUNTRY	Third parties
BELGIUM	KU Leuven
GERMANY	RWTH (Aachen), AEI (MPI), LUH (Hannover)
THE NETHERLANDS	VU (AMSTERDAM), UM (MAASTRICHT)
SPAIN	ICCUB (Barcelona), UV (Valencia), UIB (Mallorca) CDTI (Madrid)
POLAND	NCBJ, CAMK, Cyfronet, IMPAN



COUNTRY	Partners
AUSTRIA	U. LEOBEN
BELGIUM	U. ANTWERPEN
BELGIUM	U. LOUVAIN
EGO	EGO
FRANCE	CNRS
GERMANY	DESY
HUNGARY	WIGNER RCP
ITALY	INFN
THE NETHERLANDS	NIKHEF
POLAND	U. WARSAW
SPAIN	IFAE BSC-CNS (affiliated)
SWITZERLAND (associated partner)	U. GENEVA
UK (associated partner)	UKRI CARDIFF GLASGOW

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

→ https://etpp.ifae.es

Work on sites

Status Update of Sardinia activities

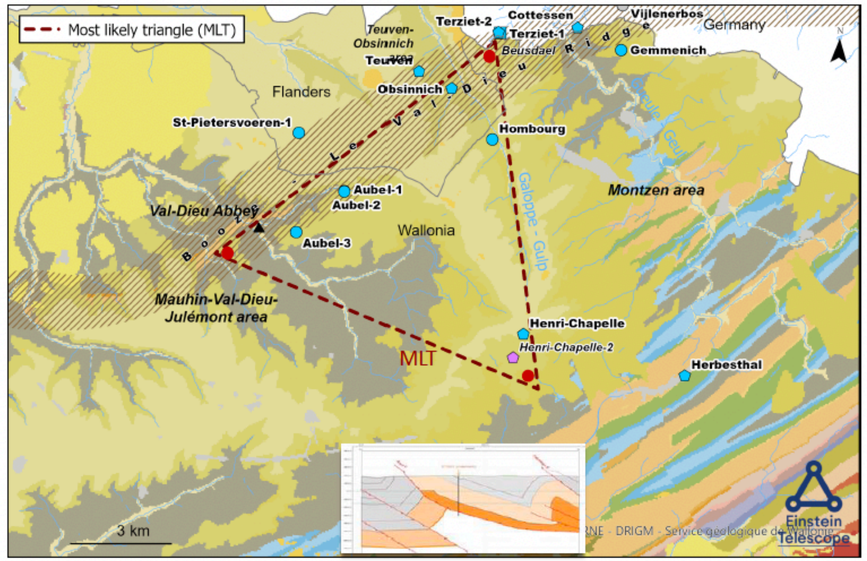
Davide Rozza on behalf of the Sardinian site characterization team

- Two Geometrical Options: Δ vs 2L
- Legal Framework and authorization
- Socio-economic impact
- Geological studies
- Site monitoring
- Noise impact Evaluation
- Engineering studies

From the geological and physical point of view, Sardinia is an optimal candidate to host the Einstein Telescope, either in Δ or in L (→ 2 sites) configuration!

Most Likely Triangle – based on current knowledge

Presentations: Bjorn Vink, Marc Boxberg, Wim Walk



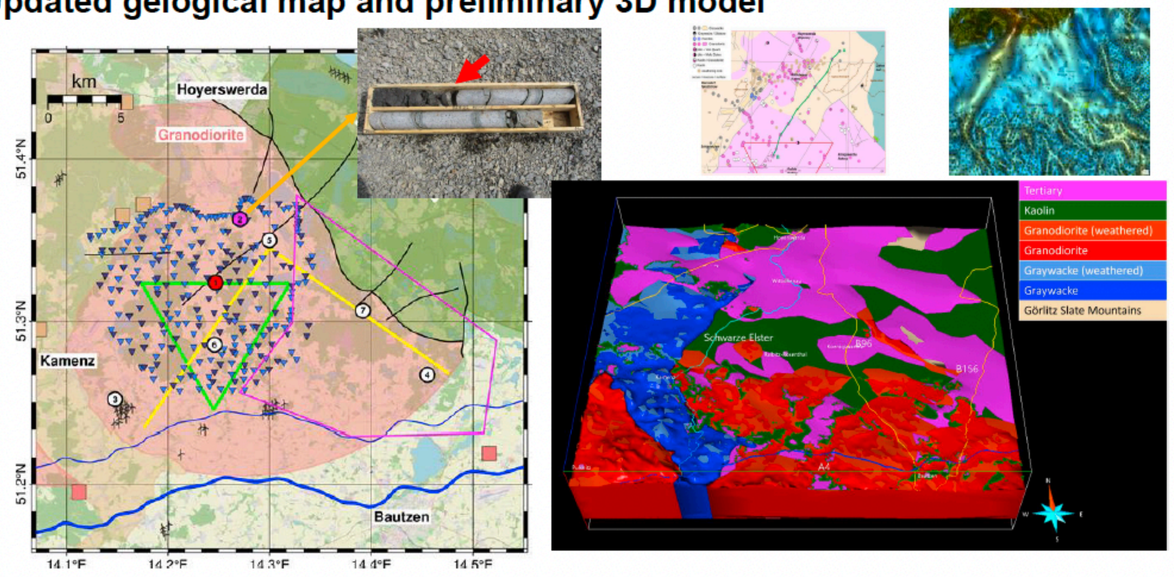
MLT location and depth convergence based on:

- Structural geology model (16 boreholes)
- Improved definition of Bose Val-Dieu block
- Geomechanical core evaluation
- Available seismic and ERT data
- Noise evaluation upcoming

2nd borehole campaign:

- Confirm vertices/depth (~ 5 new boreholes ●)
- Use recently completed seismic campaign data
- Refine hydro-geological model
- Investigate L (pending approval)

Updated gelogical map and preliminary 3D model



Based on re-evaluation of hundreds of borelogs

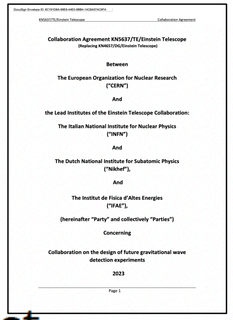
Sedimentary cover striped (model by Körschner, Freiberg)

Parallel work in each of the three sites
The work will not be completed for all the sites before Q4 2026
(Sardinia might have the results already in 2025)

Recently created panel to determine the parameters for site decision

—> Difficult to say when the decision on geometry and site(s) will take place
—> Very difficult political process with high level negotiations taking place

Working with CERN



Collaboration Agreement KN5637/TE/Einstein Telescope
(Replacing KN4457/TH/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 Física d'Altes Energies
("IFAE"),

(hereinafter "Party" and collectively "Parties")

Concerning

Collaboration on the design of future gravitational wave detection experiments

2023

Page 1

The Einstein Telescope is a 'recognised experiment' at CERN. We can access support provided it is cost neutral to CERN.

- **Vacuum pipe**: governed by an MOU between CERN, INFN, Nikhef and IFAE, CERN has started a dedicated activity to deliver the technical design report for the vacuum pipe in 2025. Currently a prototyp station is being built at CERN, supported by a large and efficient team.

- **Civil engineering**: an extension to the MOU has been agreed: CERN will provide consultancy and technical support towards the creation of the TDR for the civil engineering and technical infrastructure for 2026.

- **Document management**: project management requires specific tools, we are investigating the use of the CERN tool EDMS. CERN is providing support for a pilot study which has now started.

- **Engineering support**: technical designs at CERN are usually done by a large interdisciplinary team, including for example the safety group. We have organised several discussions with the relevant teams and are now formulating a plan for dedicated support for the design of the technical infrastructure.

RECENTLY SIGNED — MAY 2025

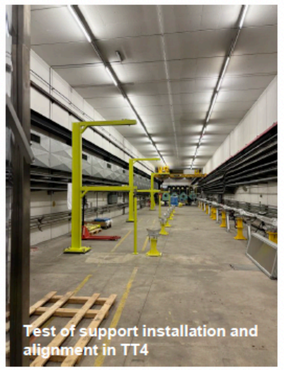
ET Vacuum Pipe TDR

As coordinated by CERN —> a history of great success

WP 6.2: Deliverables and milestones (2)

Pilot sector: from conceptual design to installation

Fabrication and installation



Test of support installation and alignment in TT4

Installation of the extremity support in TT4

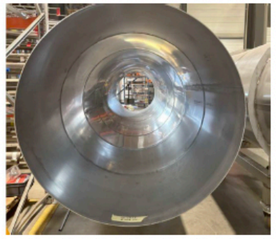
Compensation bellows in the CERN's vacuum firing furnace

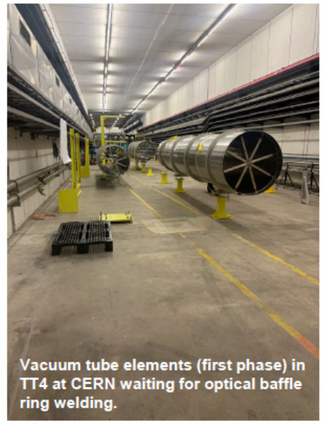
WP 6.2: Deliverables and milestones (3)

Pilot sector: from conceptual design to installation.

Fabrication and installation

Vacuum tube elements (first phase) at the supplier production plant





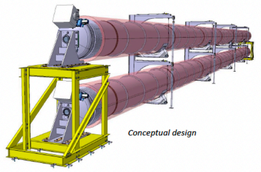
Vacuum tube elements (first phase) in TT4 at CERN waiting for optical baffle ring welding.

- The **detailed installation and measurement plan** was prepared in January and is updated monthly based on input from the fabrication teams.
- Currently, the measurements are organized into three main steps:

1. **Dust generation** during tube junction assembly.
2. Performance evaluation of **pumps and instrumentation.**
3. Performance evaluation of a **36-metre-long pipe** (scheduled to begin in August).

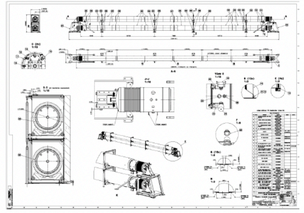
WP 6.2: Deliverables and milestones (1)

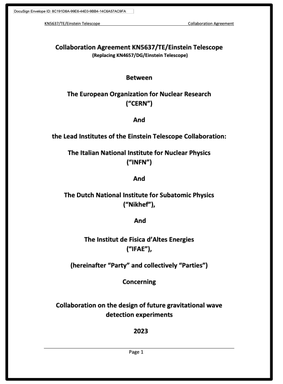
Pilot sector: from conceptual design to installation



Conceptual design

Technical design





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Concerning

Collaboration on the design of future gravitational wave detection experiments

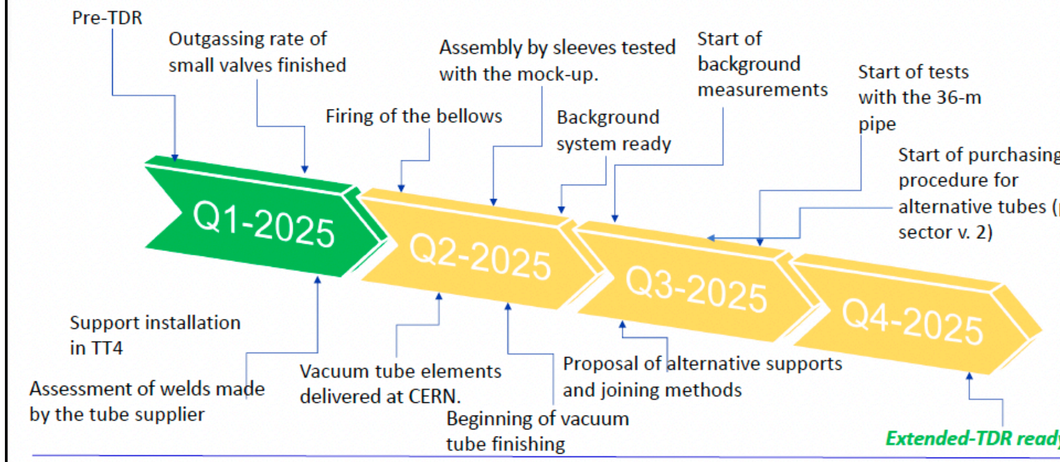
2023

Updated master plan that includes the new addendum of our collaboration with NIKHEF, INFN and IFAE:

	2025				2026				2027			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Manufacturing and installation of pilot sector												
Measurement with pilot sector (phase 1)												
Extended-TDR												
Purchasing of material for phase 2												
Measurement with pilot sector (phase 2)												
Purchasing of material for phase 3												
Measurement with pilot sector (phase 3)												
Technical documents for ET-beampipe market survey												
Final TDR												

WP 6.2: Deliverables and milestones (6)

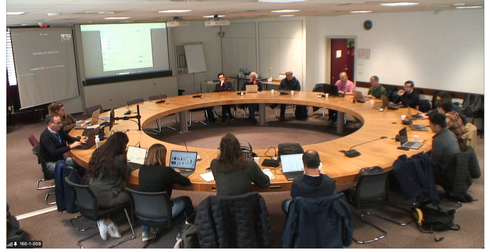
Expected technical results and achievement in 2025:



(Slides taken from P. Chiggiato (CERN) during EC review on May 2025)

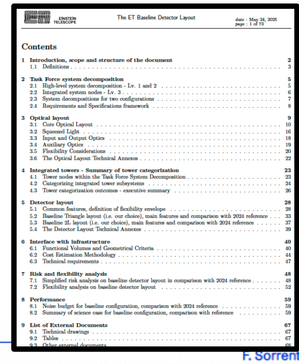
ET Optical Layout

Task force coordinated by ETO

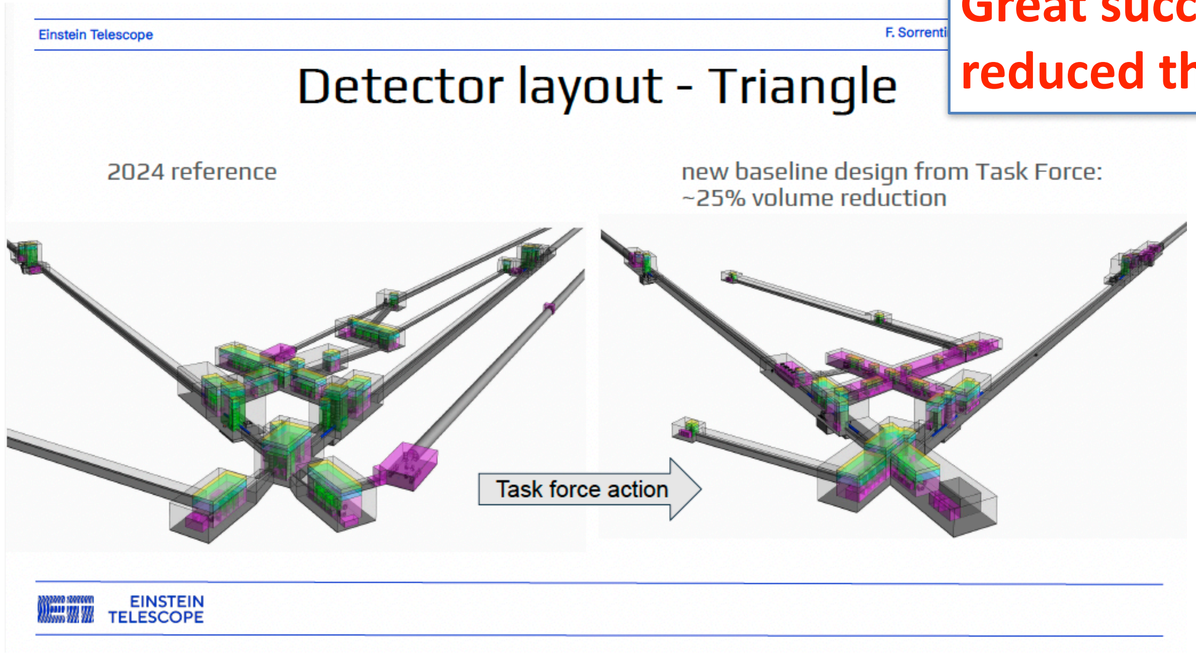


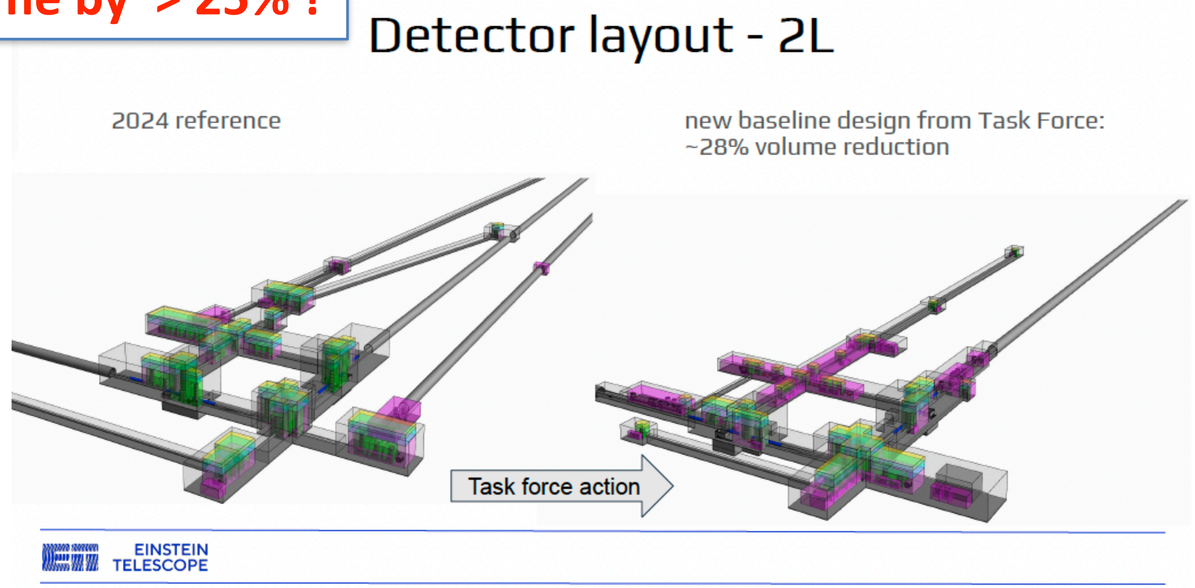
- The definition of the ET layout was taking too long and started pointed to very expensive civil engineering costs
- Fundamental input for Local teams in the different sites
- A task-force was put in place — delivered layout in May

- Main driver for civil infrastructure cost is from tunnels (arm + FC + IMC)
  - ~ 3200 m^3 in 2L (~80% of total volume)
  - ~ 2500 m^3 in Triangle (~70% of total volume)
- Main actions within Task Force
  - Move all filter cavities in main tunnels
  - Reduce length of input mode cleaners
  - Reduce number of nodes (towers) and connections (pipes) in vertex cavern



Great success with huge impact reduced the volume by > 25% !





ETO Engineering & CERN

Civil Engineering activity for ET in Phase 1 – MOU CERN

Deliverable	Description of civil engineering documents to be produced by ETO and reviewed and supported by CERN	Date
D1	Work Plan explaining the roadmap to produce the TDR	Q4 2023
D2	Review and assessment document of existing information relevant for civil engineering	Q1 2024
D3	Requirements and specific objectives for the civil engineering tender documents for consultant(s) to develop civil engineering layouts/specifications and to produce cost/schedule report and risk analysis	Q2 2024
D4	Configuration of design tools (Geoprofiler, GIS data, BIM model etc.)	Q3 2024
D5	Structure of the TDR	Q4 2024
D6	TDR	Q4 2026

MOU established with CERN 2024-2026

- *support ETO on the preliminary TDR for the civil engineering infrastructure.*
- *review the activity plans and the documents from the local teams (TETI and EMR)*

ETO Civil Engineering meeting with Local Teams
(EMR and TETI)
Meeting date: 29-30 April 2024
Meeting location: CERN

ADDENDUM NO. 1
KR5754/SCE
TO
FRAMEWORK COLLABORATION AGREEMENT
KN 5637/TE

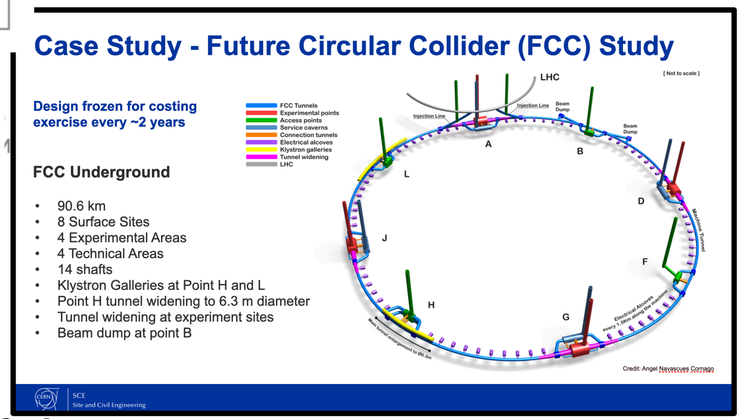
BETWEEN: THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH ("CERN"), an Intergovernmental Organization having its seat at Geneva, Switzerland,

AND: THE NATIONAL INSTITUTE FOR NUCLEAR PHYSICS ("INFN"), established in Rome, Italy,

AND: THE DUTCH NATIONAL INSTITUTE FOR SUBATOMIC PHYSICS ("Nikhef"), established in Amsterdam, The Netherlands,

AND: THE INSTITUT DE FISICA D'ALTES ENERGIES ("IFAE"), established in Barcelona, Spain,

Hereinafter each individually referred to as a "Party" and collectively as the "Parties",

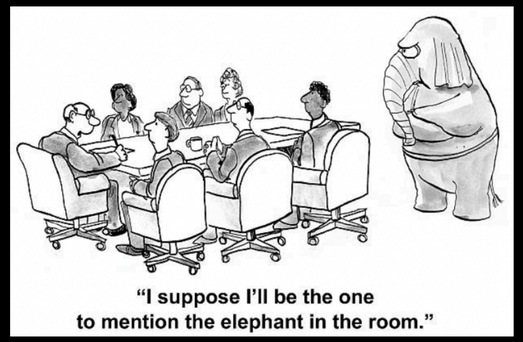


ET will count with the supervision of the same CERN team behind the recent FCC studies —> will guarantee the quality

Layout discussion

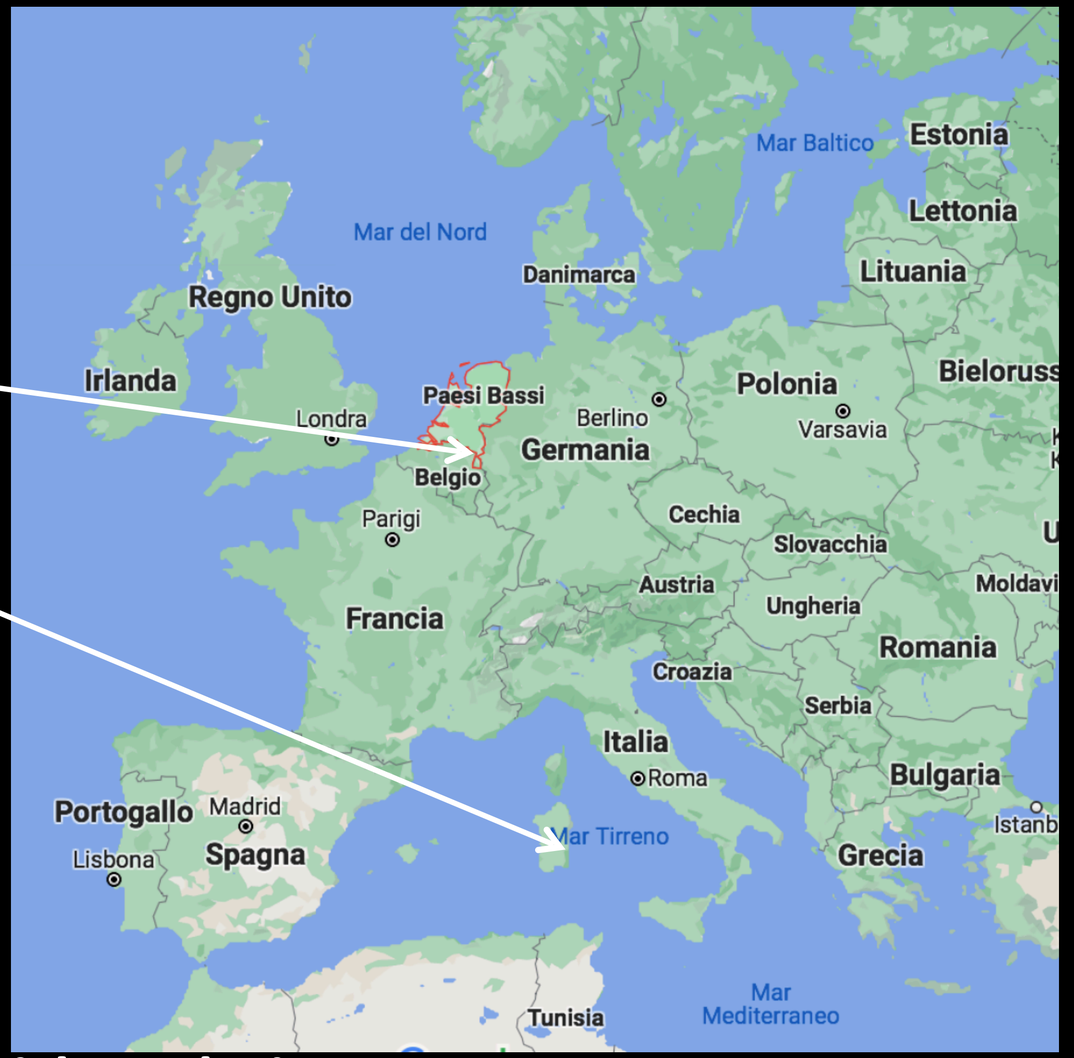
Branchesi, Maggiore et al. 2023

Triangle 10 km



2L of 15 km

2L misaligned of 45˚



Full sensitivity: HF+LF

Only HF

Always underground

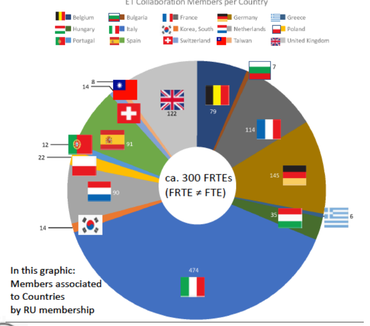
Scientific community made a study of physics potential comparing ET-baseline (triangle) vs 2L configurations

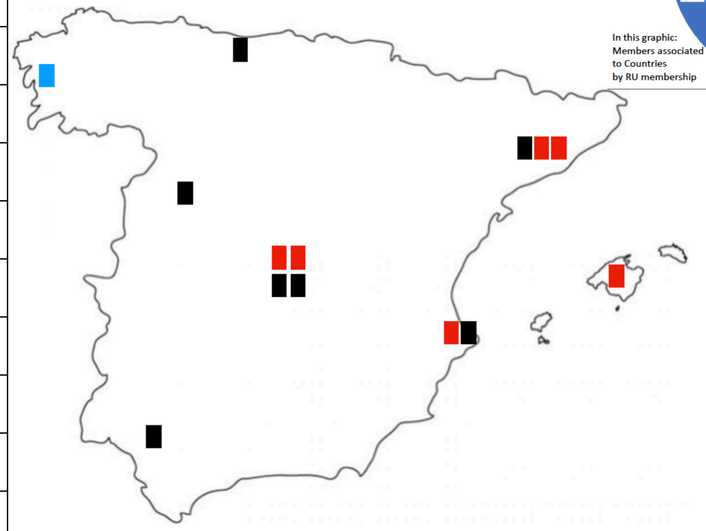
—> ETO received the mandate to present full cost of risk analysis

—> Will compare underground 10 km ET triangle vs underground 2L 15km

Map of Spanish involvement in LVK/ET

Group	LVK	ET	Hardware	Computing	Note
CIEMAT	Virgo	Y	Y	YY	Hardware/Analysis
ICE	LISA	Y	YY-LISA	N	Not allocated FTEs for HD
IFAE	LIGO-Virgo	Y	YY	YY	TH/Ops/Analysis/Hardware
IFIC		Y			TH
UIB	LIGO	Y		Y	TH/Analysis
USC	LIGO	N			TH/Analysis
USAL		Y			TH
IFT	Virgo	Y			TH/Analysis
UCM		Y			TH
UCAN		Y			TH
ICCUB	Virgo	Y		Y	TH/Analysis
UV	Virgo	Y			TH/Analysis
IEM		Y			TH/Analysis
IAA		Y			TH/Analysis





- There are many groups interested in ET, some of them from HEP, some of them detector builders
- A reduced number with hardware capacities
- Most of them Theory and/or GW data analysis oriented
- As today work to do to consolidate a large experimental community in Spain.
- Very significant Computing Capacities

It is the time for groups interested to build their hardware capacities participating in ET R&D programs

We are actively exploring synergies with other research centers (engineering departments - UPC, UPM) in Spain

A number of ICTS directly involved — BSC — RES , ALBA, CLPU

UIB Contributions to ET

- **Members:** ~17 active researchers (staff, postdocs, PhDs, engineers) in the ET member database.
- **Main Contributions**:
  - Waveforms (Div. 8 & 1): Development and improvement of waveform models (BBH, BNS, BHNS, IMBHs, eccentric/hyperbolic binaries, matter effects, memory, tidal effects, systematics).
  - Neutron Star Searches (Div. 7): Pipelines for continuous and long-duration transient signals; software development and optimization.
  - Cosmology & Populations (Div. 2 & 3): Cosmology with ET, primordial black holes, astrophysical population studies.
  - Synergies & Broader Impact: Links with LISA and other GW observatories, numerical relativity, Bayesian parameter estimation, gravitational lensing, noise mitigation, education & outreach.
- **Leadership & Service:**
  - Participation in ET governing and scientific bodies:
  - ET Data Access Policy Committee
  - ET Collaboration Board
  - ET Editorial Committee

UCM Contributions to ET

22 members - 4 FRTE

Departamento de Física Teórica y
Departamento de Estructura de la Materia,
Física Térmica y Electrónica de la UCM

IPARCOS

Contributions:

OSB Div 01 – Fundamental physics
OSB Div 08 – Waveforms
OSB Div 06 – Nuclear physics

Participation in

- ET blue book: The Science of the Einstein Telescope
- Black hole spectroscopy: from theory to experiment, E. Berti et al

Lines of research

Ringdown phase, quasinormal modes of compact objects in alternative theories of gravity: black holes, neutron stars, wormholes, boson stars, etc.

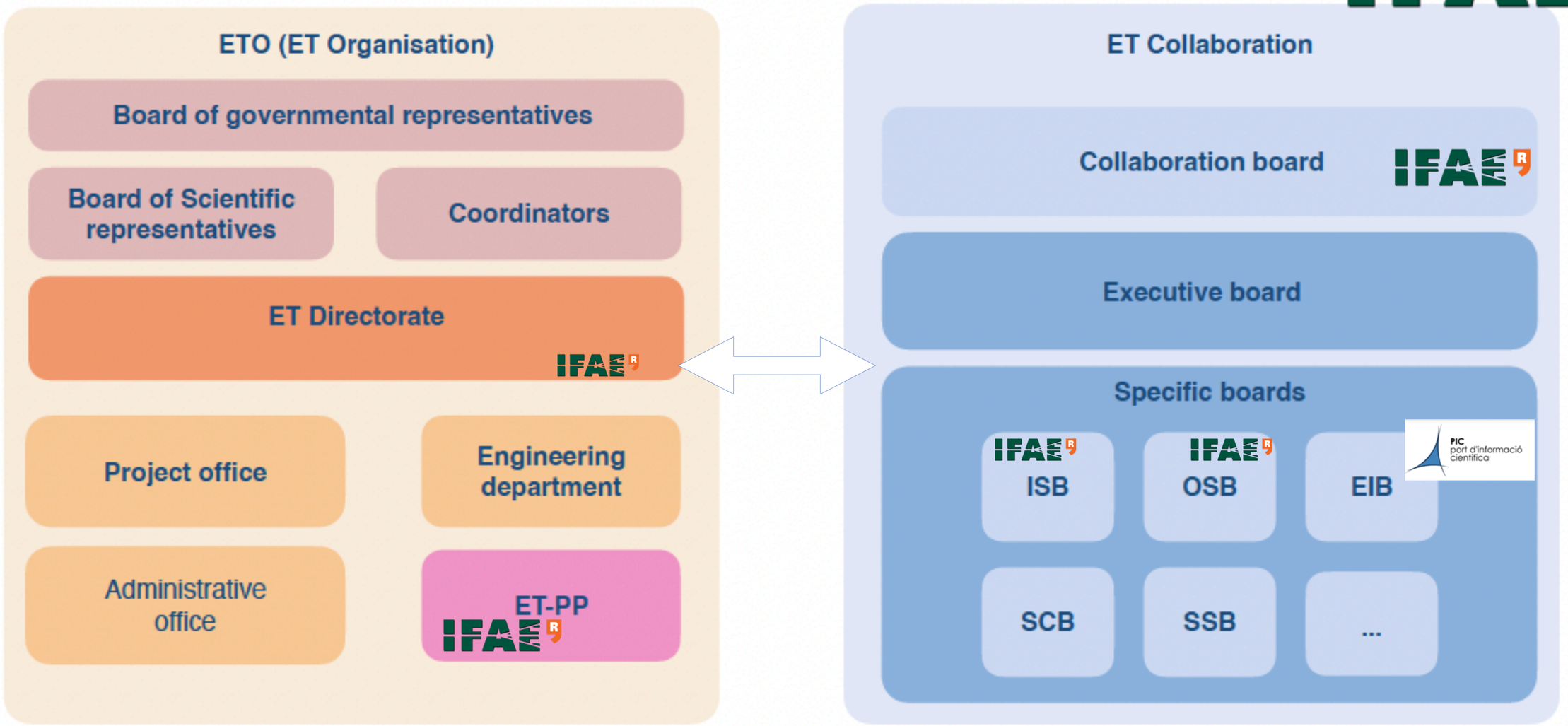
Equation of state: QCD studies for neutron stars and strong interactions from neuron star mergers

Cosmology, inflation, dark matter models and detection.

QFT in curved spacetimes, Quantum gravity

IFAE @ ET Organization

About 20 persons



M. Martinez is part of ETO Directorate and Coordinator of ET-PP EU project
E. Coccia is Chair of the ET Collaboration board
Co-convener of ET-SLC WG (until 2021 — fall 2025)

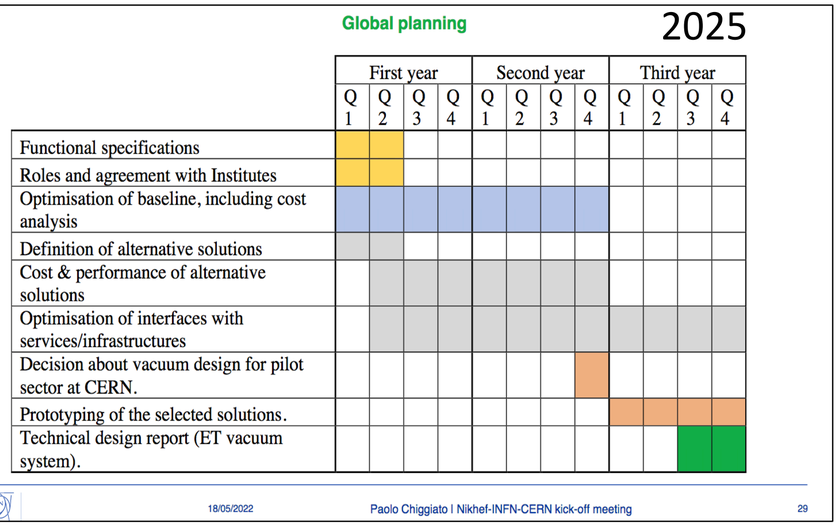
Contributions to ET Detector Simulations
Refined ET Physics Case
- Fundamental Physics @ High Temperatures
- Cosmology & Population studies
- Test of General Relativity

Computing

ET & CE vacuum pipe design

MoU signed with CERN

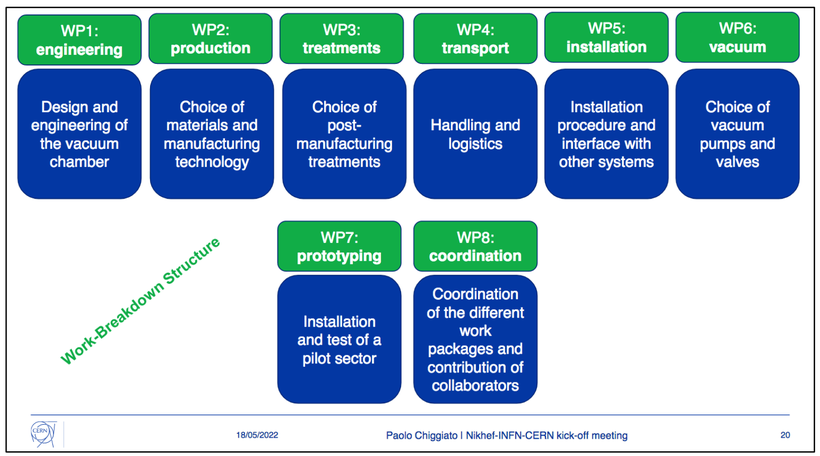
IFAE strategically placed in areas with huge industrial returns close contacts with Ministry and CDTI [being part of ET-PP]



Global planning 2025

	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).												

18/05/2022 Paolo Chiggiato I Nikhef-INFN-CERN kick-off meeting 29



WP1: engineering — Design and engineering of the vacuum chamber

WP2: production — Choice of materials and manufacturing technology

WP3: treatments — Choice of post-manufacturing treatments

WP4: transport — Handling and logistics

WP5: installation — Installation procedure and interface with other systems

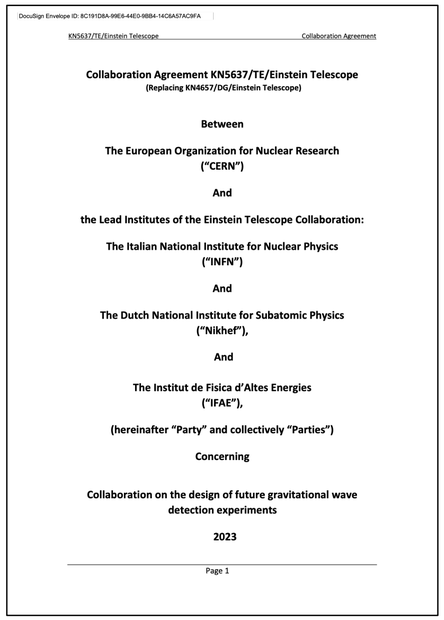
WP6: vacuum — Choice of vacuum pumps and valves

Work-Breakdown Structure

WP7: prototyping — Installation and test of a pilot sector

WP8: coordination — Coordination of the different work packages and contribution of collaborators

18/05/2022 Paolo Chiggiato I Nikhef-INFN-CERN kick-off meeting 20



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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"),

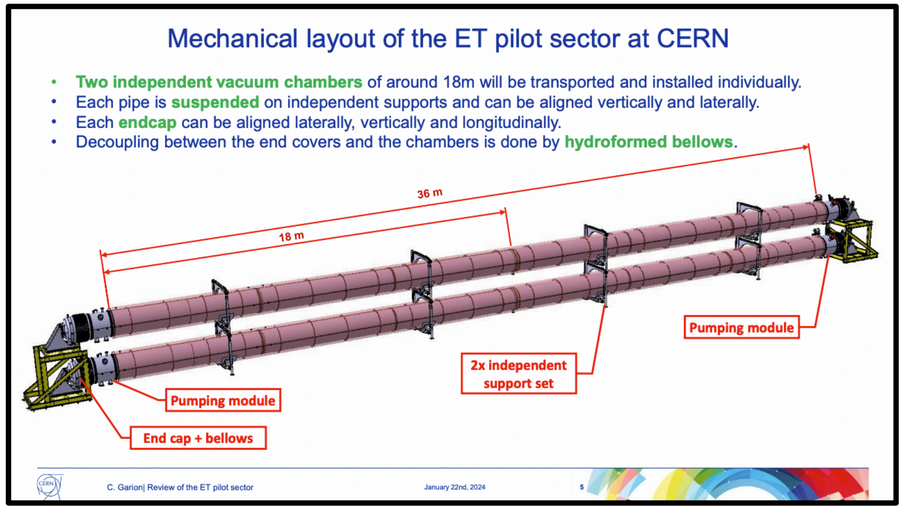
(hereinafter "Party" and collectively "Parties")

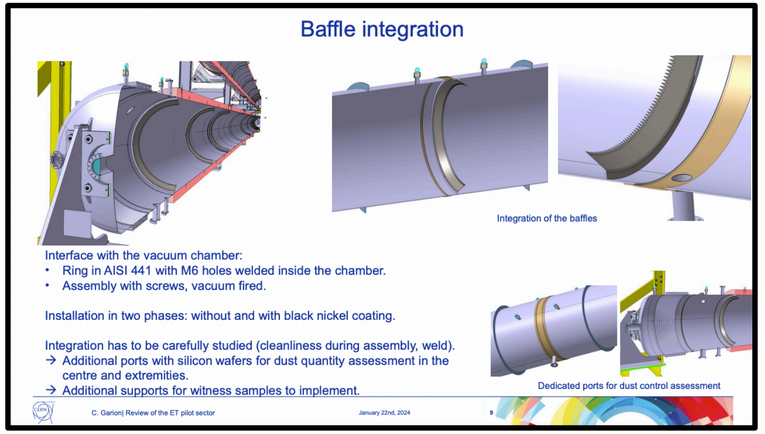
Concerning

Collaboration on the design of future gravitational wave detection experiments

2023

Page 1





Led by CERN :

design of ET vacuum pipe (1/3 ET core cost)

—> Prototypes 40 m long + UHV tests

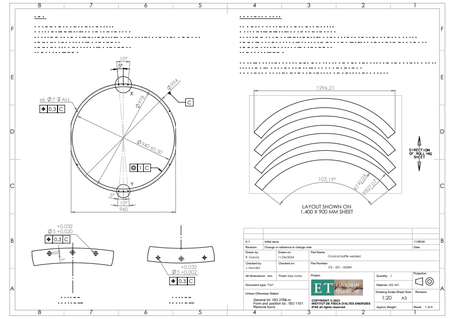
—> TDR by 2025 as main deliverable

—> [exploring extending action to 2027]

—> IFAE running stray light simulations

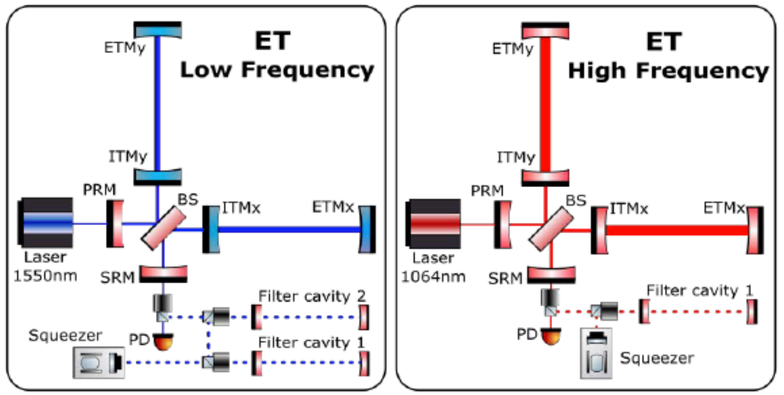
—> IFAE in-kind contribution - O(14) baffles (w/wo special optical coatings)

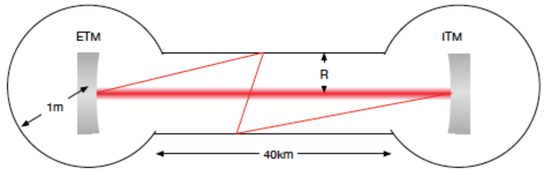
—> Synergy with LIGO and Cosmic Explorer

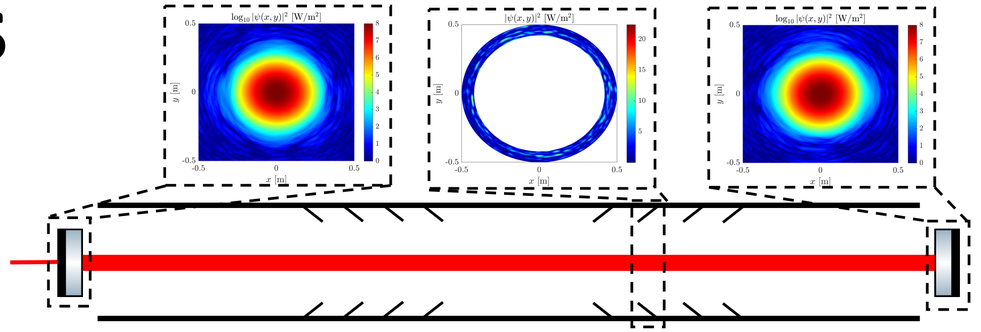


Launching baffle production now

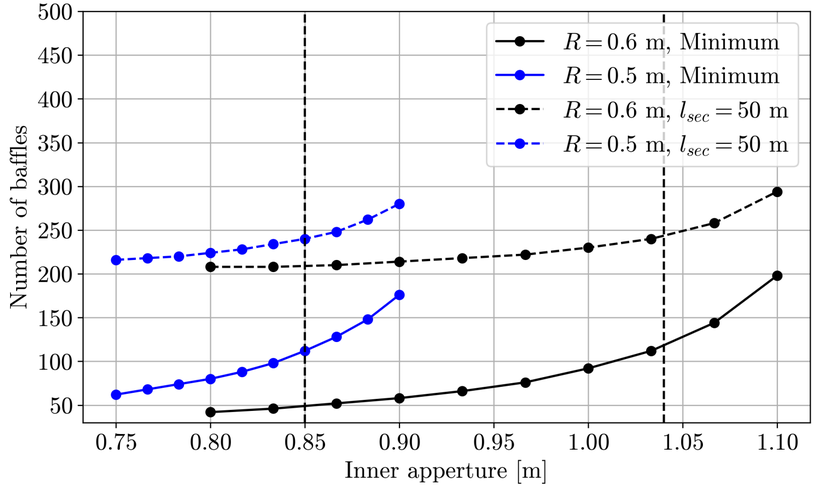
ET stray light simulations







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



Detailed simulations of the light propagation in the optical cavities

—> Crucial input to determine tune diameter [huge impact on cost]

—> Determines the mitigation strategy for reducing stray light noise

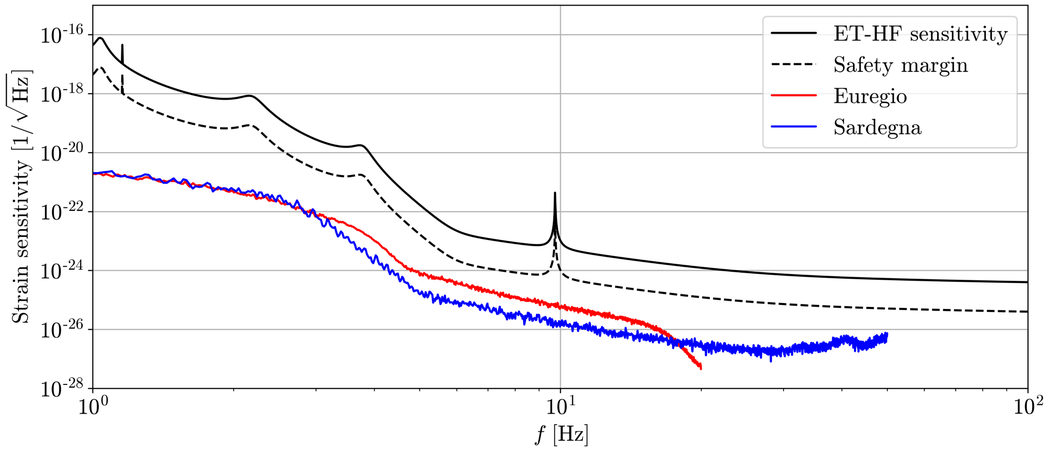
—> Determines the baffle requirements (dimensions and optical specs)

—> Determines the distribution of baffles in the 10km and 15km arms

—> Possible thanks to close relation with Caltech - LIGO since 2020

—> Running common ET/Cosmic Explorer meetings on Stray Light Control

IFAE recognised now as the reference inside ET for these aspects



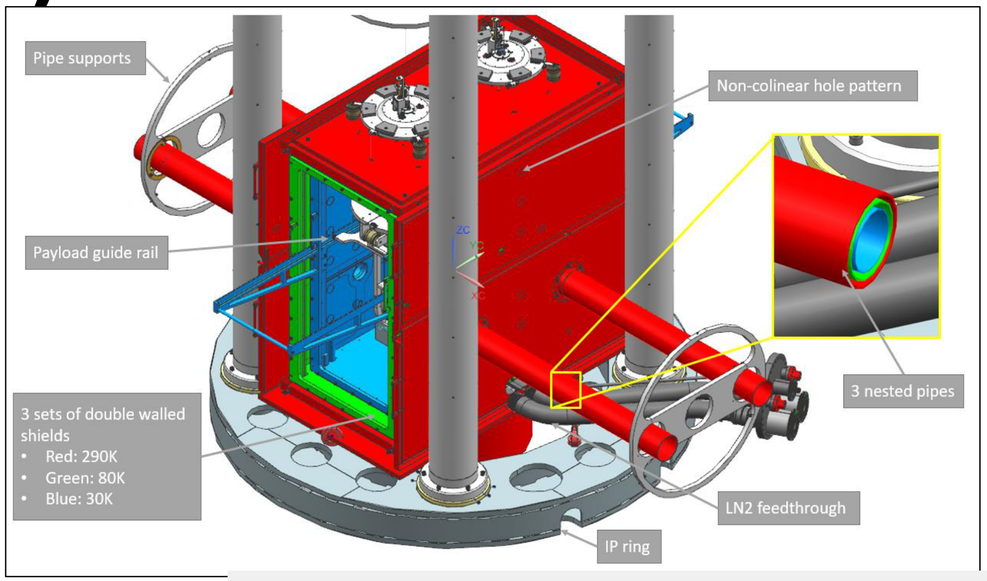
M. Andrés-Carcasona et al., Phys. Rev. D 108, 102001 (2023)

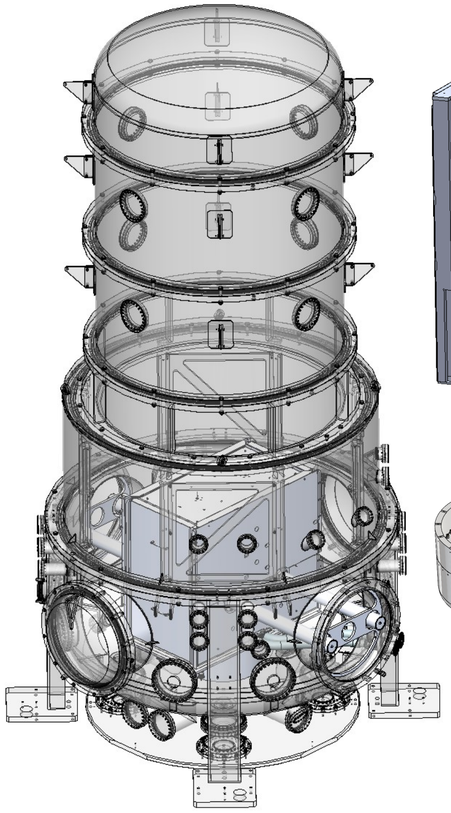
ETpathfinder(s)

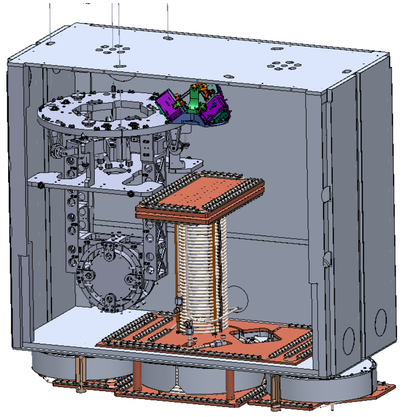
A collaboration established with Etpathfinder @ Maastricht

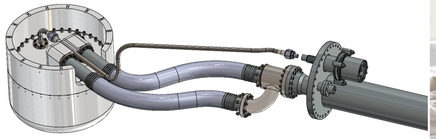
- IFAE redesigned the cryo-shielding & LN2 vessel [in-kind contribution]
- IFAE will contribute to the installations in 2025/2026

- Pre-alignment & monitoring of the mirror surface at 80 - 290 K
  (instrumented baffle with sensors for λ = 1550 nm)

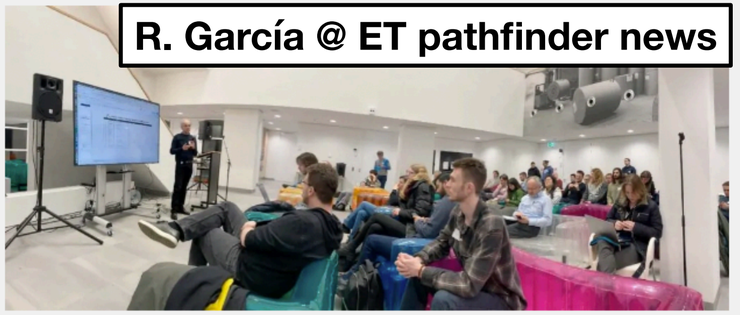








R. García @ ET pathfinder news



ETpathfinder workshop in February 2024. Photo: ETpathfinder / UM

Staying on the cutting edge

One of the contributors at the workshop was Rafael Garcia from the Spanish institute for high energy physics IFAE. He recalls how his group was asked to help finish the ETpathfinder thermal shields, which in four stages help thermally isolate the mirrors in the innermost part ETpathfinder. Garcia: "These shields protect the mirrors from heat radiation coming from the environment. The design has to take into account also the assembly and accessing to the mirrors, among other manufacturing aspects related with Ultra High Vacuum environments."

Asked why IFAE decided to get involved in the ETpathfinder, Garcia doesn't have to think long. "IFAE is part of the Einstein Telescope and is always happy to collaborate with top-level institutions. This is the case of ETpathfinder, probably the most advanced R&D platform for ET in Europe. Personally speaking, it's a privilege for me having the opportunity to work for such a research facility. It allows me to stay on the cutting edge!"

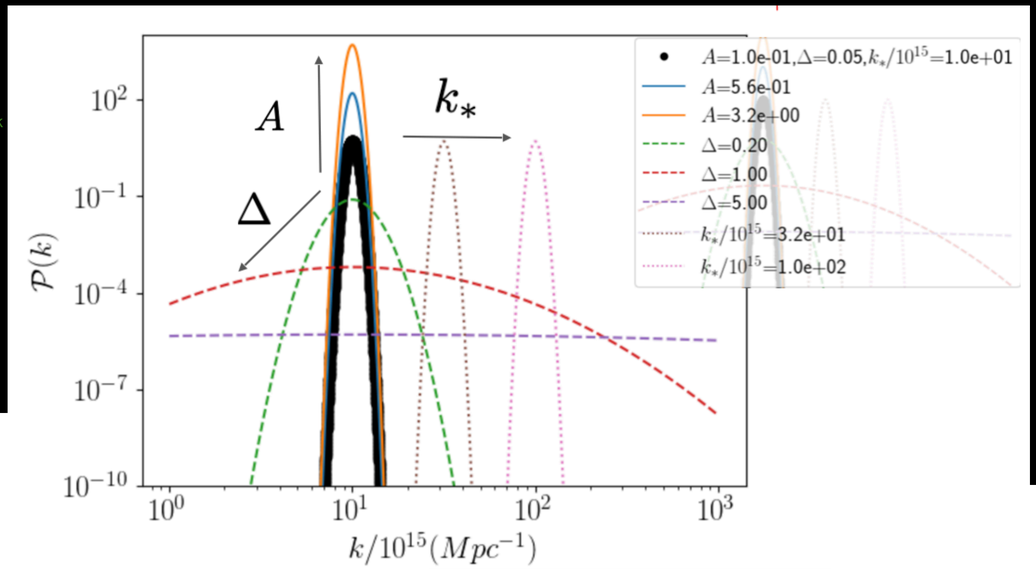
Stochastic signals in pBH formation

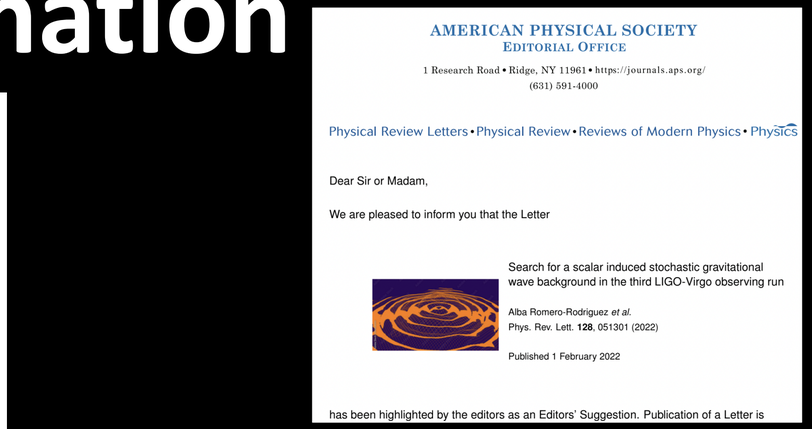
Scalar induced GW background

Integrated power of the peak — Location of the peak

$$\mathcal{P}_\zeta(k) = \frac{A}{\sqrt{2\pi\Delta}} \exp\left[-\frac{\ln^2(k/k_*)}{2\Delta^2}\right]$$

Width of the peak

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EDITORIAL OFFICE

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Physical Review Letters • Physical Review • Reviews of Modern Physics • Physics

Dear Sir or Madam,

We are pleased to inform you that the Letter

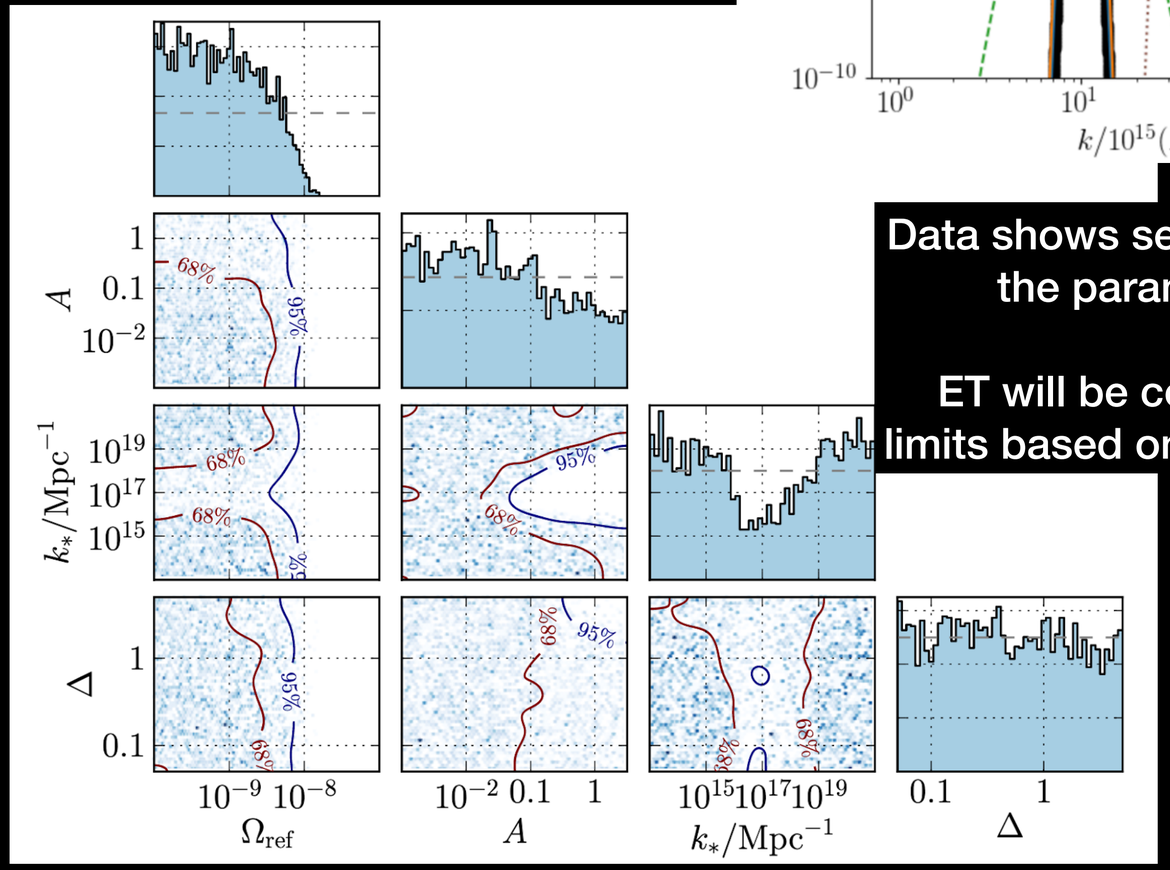
Search for a scalar induced stochastic gravitational wave background in the third LIGO-Virgo observing run

Alba Romero-Rodriguez *et al.*
Phys. Rev. Lett. **128**, 051301 (2022)

Published 1 February 2022

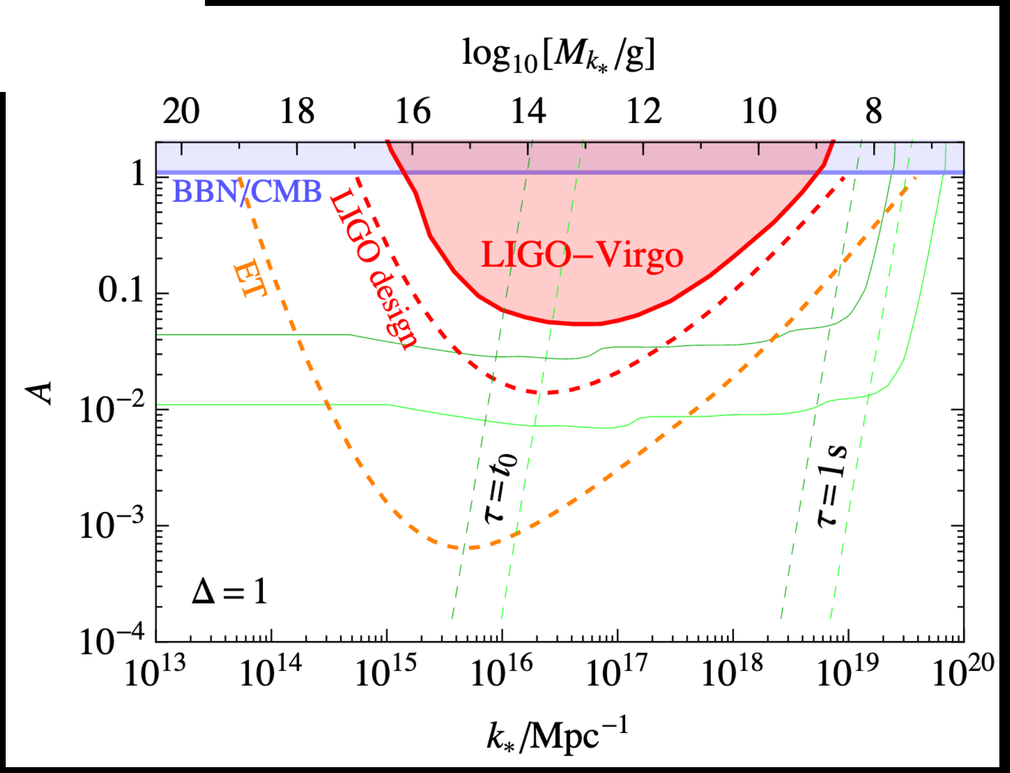
has been highlighted by the editors as an Editors' Suggestion. Publication of a Letter is

Phys. Rev. Lett., vol. 128, p. 051301 (2022)



Data shows sensitivity in part of the parameter space

ET will be competitive with limits based on PBH abundance



Participation of CSIC in Einstein Telescope

- Instituto de Ciencias del Espacio (ICE, CSIC y IEEC):
- Instituto de Astrofísica de Andalucía (IAA, CSIC):
- Instituto de Física Corpuscular (IFIC, CSIC y UV):
- Instituto de Estructura de la Materia (IEM, CSIC):
- Instituto de Física de Cantabria (IFCA, CSIC):
- Instituto de Física Teórica (IFT-CSIC/UAM):

ET-CSIC Research Unit

In close collaboration

MINISTERIO DE CIENCIA E INNOVACIÓN — CSIC

Madrid, a 5 de febrero de 2020

Subdirección General de Internacionalización de la Ciencia y la Innovación
Ministerio de Ciencia e Innovación

Asunto: CARTA DE APOYO INSTITUCIONAL A LA PROPUESTA Einstein Telescope-ESFRI

Estimado Subdirector General:

Por la presente, nos complace comunicarles que la Agencia Estatal Consejo Superior de Investigaciones Científicas (CSIC) expresa su firme apoyo a la candidatura "**Einstein Telescope**", con el fin de ser incluida en la Hoja de Ruta 2021 del Foro Estratégico Europeo de Infraestructuras Científicas (ESFRI).

- **CSIC** has participated from the very beginning in the Einstein Telescope project, from the preliminary design studies to the entrance in the **European Strategy Forum on Research Infrastructures (ESFRI)**, to which it provided institutional support.
- **ET-CSIC RU Lead:** Dr. Carlos F. Sopuerta (ICE-CSIC)

Participation of CSIC in Einstein Telescope

✦ Current Statistics of the ET-CSIC Research Unit:

Number of members: 37 = 20 (ICE) + 6 (IFIC) + 2 (IFCA) + 5 (IAA) + 3 (IEM)

Number of FRTEs: 7.6

Permanent Staff: 18
Postdocs: 11
PhD Students: 5
Engineers: 2
Communication Staff: 1

Participation in different Divisions of the Observational Science Board **(several contributions to the ET Blue Book)**

✦ Scientific Contributions of the ET-CSIC Research Unit:

✳ **Instrumentation**: No official contribution yet. But there are ongoing studies on:

(I) Noise mitigation at low frequencies (thermal and magnetic) based on LISA and LISA Pathfinder experience.

(II) Laser and opto-electronic systems and quantum technologies.

(III) Participation in other astronomical missions/observatories to detect EM (X- and gamma-rays, UV-optical-nIR, mm-radio) and Neutrino Counterparts.

(IV) Software development.

Participation of CSIC in Einstein Telescope

✦ Scientific Contributions of the ET-CSIC Research Unit:

✳ **Data Analysis**: Based on experience in LISA Pathfinder and LISA and LVK.
Search and Parameter Estimation Methods based on Bayesian inference techniques (MCMC, NS, etc.).
Simulation-Based Inference Methods.
Stochastic methods for the detection and characterization of GW backgrounds.
Developments for Counterpart events (EM and neutrinos) = Multimessenger Astronomy with GWs.

✳ **GW Source Modelling**:
Development and construction of Phenomenological Waveform models for Binary Black Holes, covering the whole range of mass ratios (Numerical Relativity, post-Newtonian, Black Hole Perturbations).
Studies on the physics of Neutron Stars and their Equation of State and Transport properties for Binaries.
Simulations of Binary Neutron Stars
Studies on the physics of Black Holes and their Quasinormal Mode Spectrum.
Studies of Gravitational Wave microlensing using N-body and Numerical Simulations.

Participation of CSIC in Einstein Telescope

✦ Scientific Contributions of the ET-CSIC Research Unit:

✳ **Astrophysics**:
Observations of Neutron Stars (Pulsars, Magnetars, Pulsar Nebulae)
Neutron Star Population synthesis studies
Evolution of binary sources containing collapsed objects and of their gravitational wave emission.
Observations of intermediate-mass black hole candidates.
Studies of Gravitational Wave probes of Dark Matter environments

✳ **Cosmology**:
Studies of the production of Early-Universe GW backgrounds (inflation, preheating, axions, primordial black holes) and Cosmic Strings;

✳ **Fundamental Physics**:
Gravitational Wave Theory including modifications of General Relativity for the production and propagation of gravitational waves.
Analysis of differences between Black Holes and other Exotic Compact Objects by means of ET detections.
Studies of modified gravitational theories for GW tests.

ET Research Unit - IFT Madrid

Application to ESFRI: 7 Feb 2020
Approved entry in ET: 14 Sep 2022
Full RTE updated: 11 Jul 2023

Members

Juan Garcia-Bellido (head)
Savvas Nesseris (perm)
Sachiko Kuroyanagi (perm)
Ester Ruiz Morales (perm)
Matteo Fasiello (perm)
Ogan Ozsoy* (postdoc)
Alexandros Papageorgiou (pd)
Gonzalo Morras (PhD st.)
Cristobal Zenteno (PhD st.)

Contributions

Collaboration Board (JGB)

OSB Div1 – Fundamental Physics
OSB Div2 – Cosmology
OSB Div3 – Population Studies
OSB Div4 – Multimessenger

Research Unit

@USAL

Fundamental Physics: Astrophysics and Cosmology

Fundamental Physics, including Cosmology and Astrophysics. Devoted to

a) stochastic GW background, LCDM and Dark Energy models

b) fundamental physics from multi-messenger astrophysical events

c) GW constraints on the nuclear equation of state and collapse of ultradense stars

Some members involved in REDONGRA (Spanish GW network)

And MULTIDARK, RENATA, **CPAN**

(and other collaborations SKA, MAAT@GTC, LPQI, JPAS..)

Sinergies with ICTS local facility CSIC+USAL, Centro de Láseres pulsados ultraintensos, CLPU

La Red Española de Física de Ondas Gravitacionales (REDONGRA) es una Red Estratégica financiada por MICIU/AEI/10.13039/501100011033

ICCUB ET Research Unit

RU leader: Pablo Barneo (post-doc)

Members: 18 members, 6 academic staff + 6 post-doc + 3 Ph.D. students + 3 technical staff

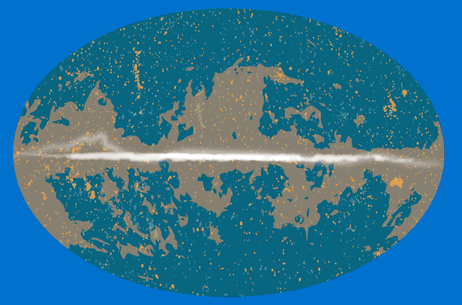
Activity: 3.2 FRTE, 78% OSB + 19% eIB + 3% Infra-Dev

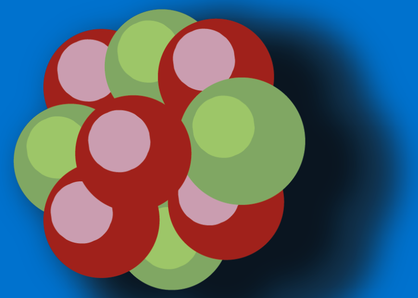
Contributions:

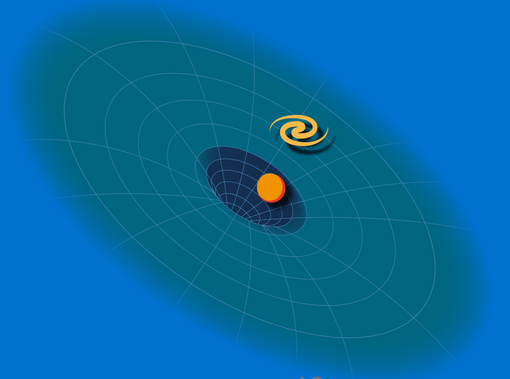
- (OSB) Contribution to the Blue Book: “The Science of the ET” (arxiv:2503.12263, tbp in JCAP): Tomas Andrade, Pilar Ruiz-Lapuente, Jacopo Fumigalli
  - EOB waveform models with NR
  - Optical counterparts of GWs
  - Theory of GWs of cosmological origin
- (eIB) Development of ET MDC and pipeline workflows: Javier Castañeda, Georgy Skorobogatov

Publications: 4 papers

- Black hole spectroscopy (***Phys. Rev. D 111, 024018, 2025***)
- Actively Learning Numerical Relativity (***Phys. Rev. D 110, 024080, 2024***)
- NR informed EOB waveforms for dynamical capture in BBH (***Phys. Rev. Lett. 132, 101401, 2024; Phys. Rev. D 109, 084025, 2024***)





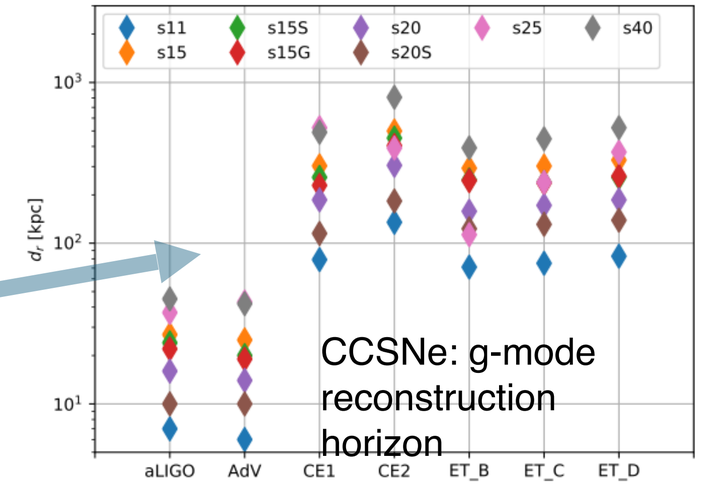


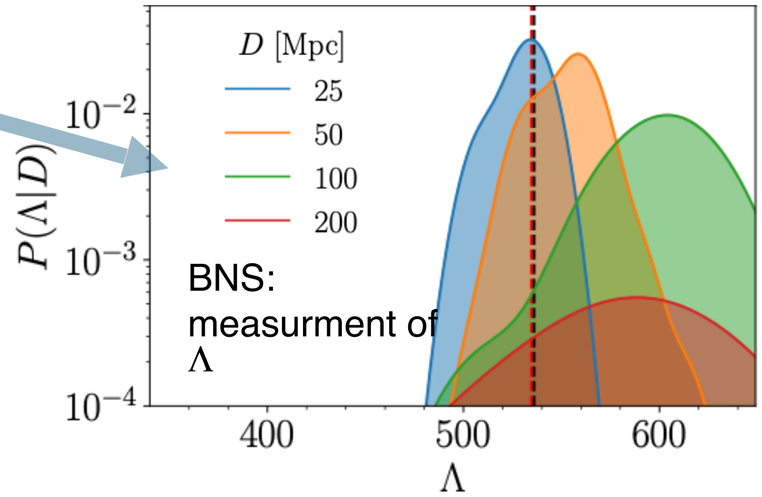
University of Valencia ET Research Unit

- RU leader: Pablo Cerdá-Durán
- 20 members (10 permanent + 6 post-doc + 4 PhD students)
- 4.55 FRTEs (95% in the OSB)
  - Simulations of BNS mergers and CCSNe (2.65 FRTEs)
  - Fundamental physics and cosmology (1.4 FRTEs)
- **Activities**
  - OSB**: Contribution to the Blue Book**: "The Science of the ET", JCAP, 2025 (arxiv:2503.12263) → Cerdá-Durán, Obergaulinger, Sanchis-Gual, Torres-Forne
  - **Participation in committees**:

Publication examples:

- CCSN detection perspectives with ET (Veutro et al 2025)
- Inference in CCSN with ET (**Bizouard et al 2021**, Powell et al 2024)
- Identifying thermal Effects in BNS mergers with ET (**Miravet-Tenés et al** 2023, **2025**, Villa-Ortega et al 2025)





Isabel Cordero-Carrión

- Communications and Education Committee (until 2024)
- Member Conduct and Ethics Committee

Miquel Miravet-Tenés

- Early Career Scientists Support Committee

Computing for ET at CIEMAT

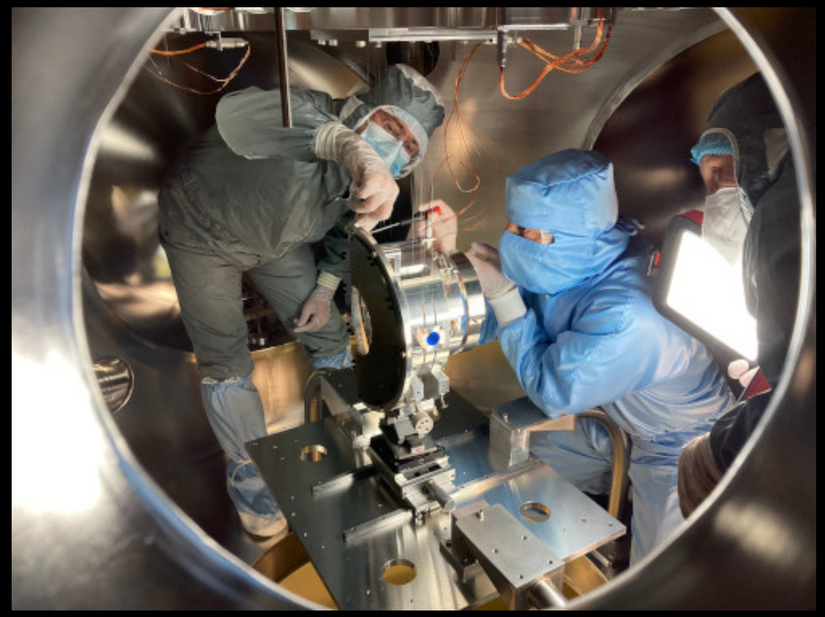
Developing the ET Computing Model and providing a running estimate of the computing resources needed.

- Overall architecture of the e-Infrastructure. Different time and criticality domains: online, low-latency and offline.
- Collaborate with OSB and define a process to evaluate computing needs from the evolving scientific program of the collaboration.

Coordinated work with WP8 from ET Preparatory Phase HE project.

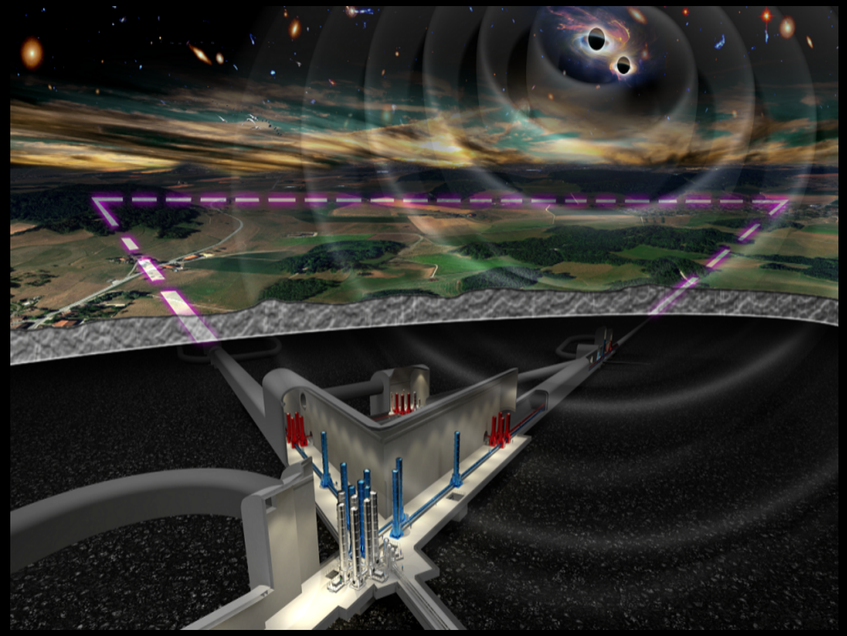
- D8.1: Computing and Data Requirements
- D8.2: Computing and Data Model
- D8.3: Data Access Implementation Guidelines

Led by G. Merino



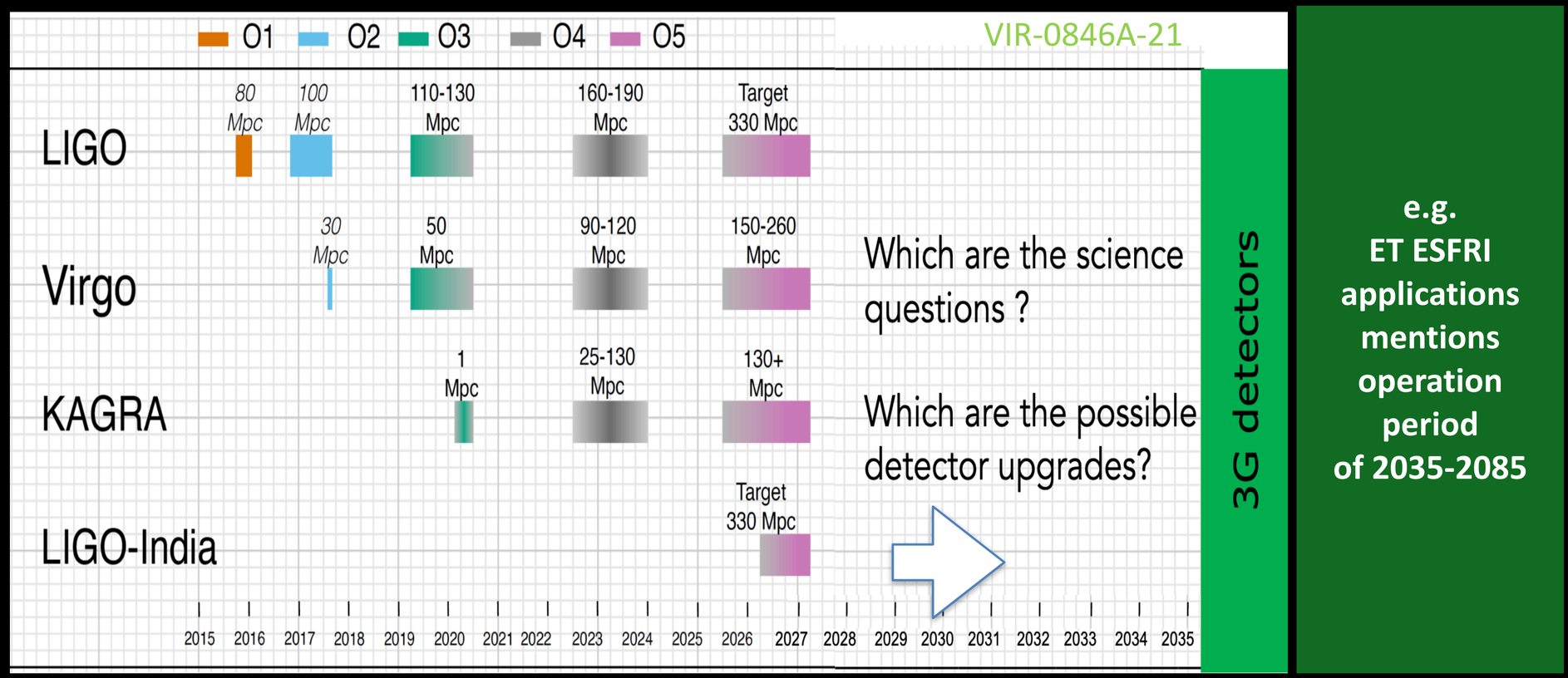
Final notes

- ET is the leading EU 3G project today and is regarded as a flagship
- Strong proposals for hosting the ET infrastructure in place including already secured money for construction **(but floor is always moving)**
- In the following years the ET project will progress towards a site selection(s) , final design and governance, costs and risk studies, aiming for starting construction before the end of the decade [?]



- ET-PP EU Preparatory Phase Project is a tool to build coherence in the process (never easy…) and to glue “competing teams”
- The re-discussion of ET geometry saga might slow down the progress as it is putting ET in a “non-projected quantum state of geometry and location(s)”
- ET-Spain needs to grow and get experimental community more involved in R&D and detector designs activities —

What does the immediate future hold?



3G detectors

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

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.

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

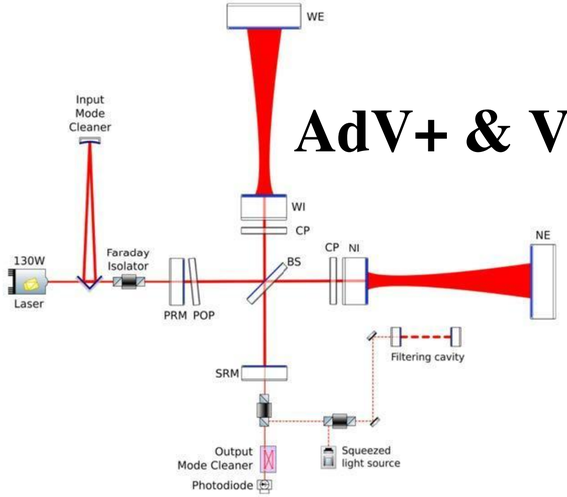
Post O5 (after mid 2028) planning just started

New facilities **ET, CE, NEMO …**

Old slide : now post-O5 is beyond 2030+
—> this tells you how schedules evolved with time —

Post-O5

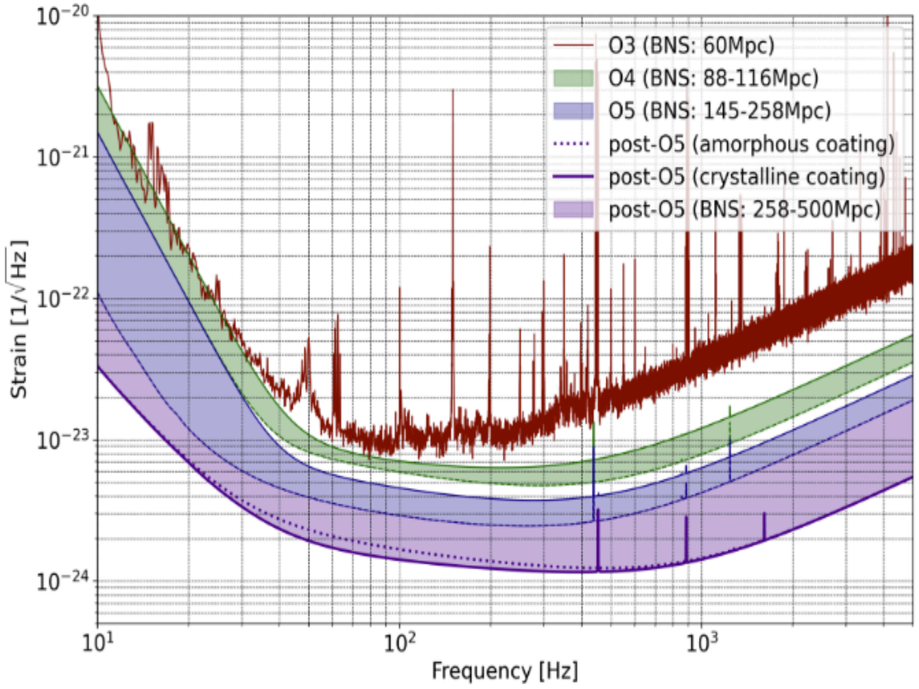
AdV+ & Virgo-NEXT



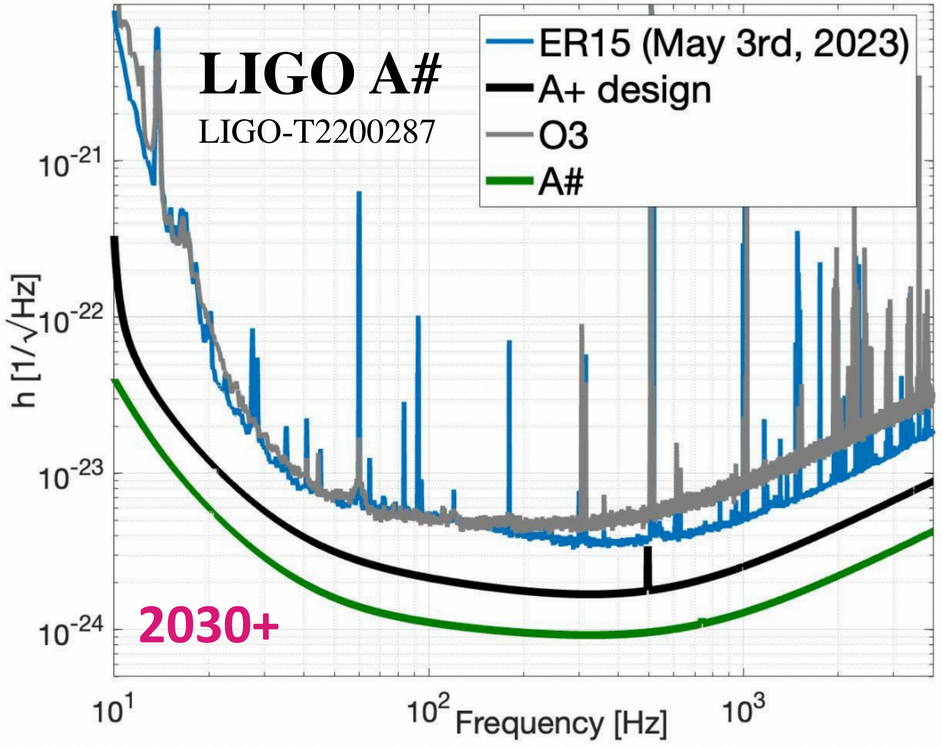
Major difficulties in Virgo during O4 commissioning is forcing Virgo to revisit O5 and post O5 plans

—> Installation of stable recycling cavities by O5

AdV sensitivity evolution from O3 to post-O5



This bring you to 2030+ entering into diminishing returns regime for 2G experiments



Higher laser power → 1.5 MW

Heavier test masses → 100 Kg

Improved coatings (reduce coating thermal noise)

Refine quantum squeezing

Improve suspensions

Improve seismic isolation

R&D on new mirror coatings is an active area of research BUT still requires multiples years of effort

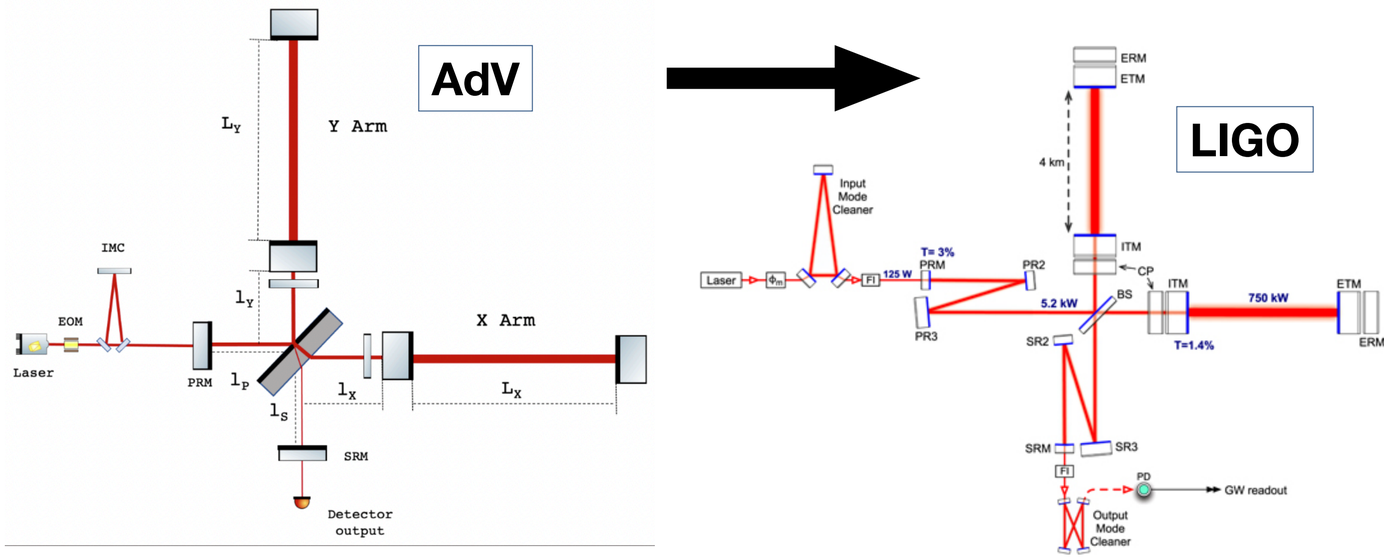
→ Fact 2 improvement on sensitivity

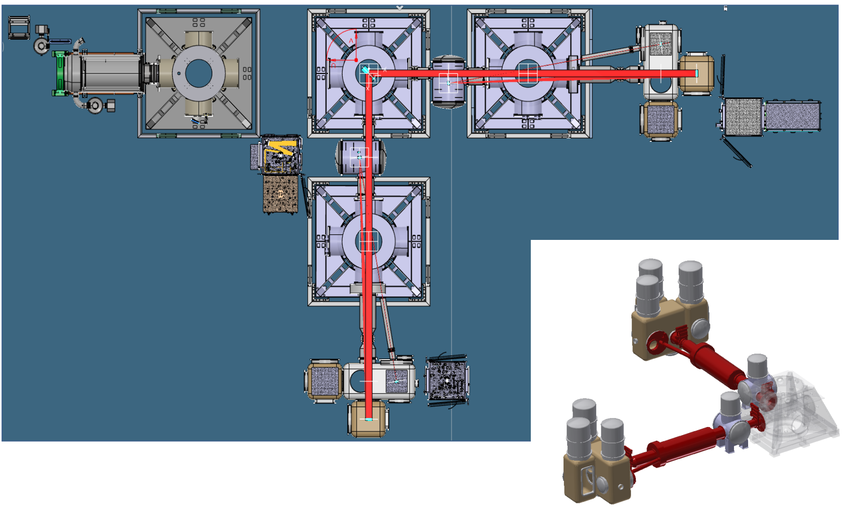
→ Factor 10 improvement in rates

→ O (3k€) events in one year

→ Reaching BNS up to 500 – 600 Mpcs

Virgo's recycling cavities



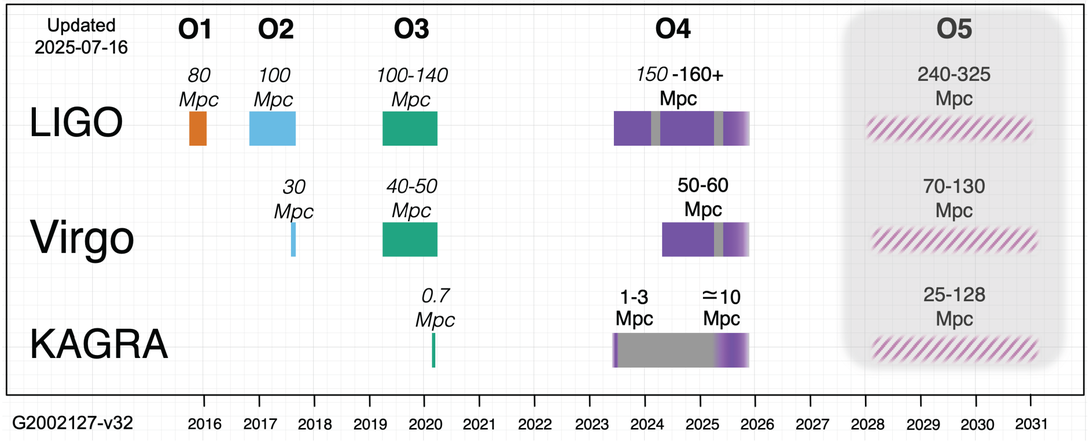


The introduction of new stable recycling cavities is a major intervention that requires:

* New mirrors, vacuum towers, pipes, new suspensions
* Big interventions in existing towers
* Big intervention in central building
* In addition Virgo needs to replace the main mirrors in FP arms
* Will allow Virgo to increase the laser power

* Will bring Virgo to the 100 - 160 Mpc sensitivity

Plan under deep discussion as would involve a very long shutdown (until 2030+) — late participation in O5



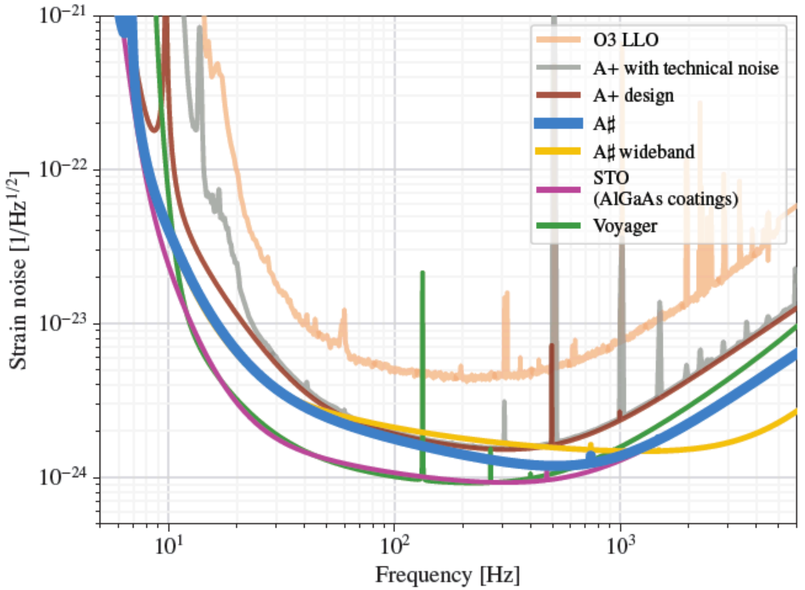
According to plans — O5 and post-O5 programs (if confirmed) will take the field to the 2035+

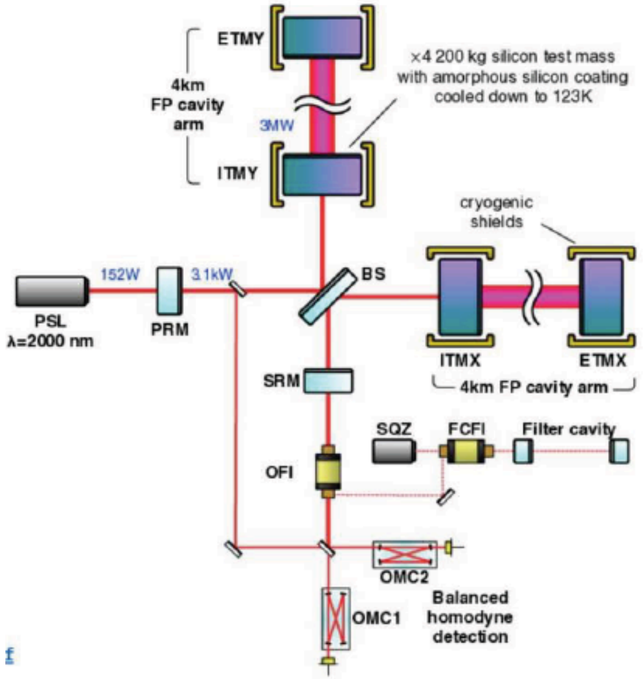
Voyager

Additional potential further upgrade of LIGO
Factor x3 improved in reach for BNS (1100 Mpcs)

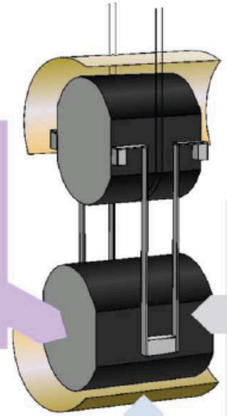
Going cryogenic temperatures (123K)
Larger masses with new substrate material
Different wavelength (2000 nm)

Planned for the next decade





VOYAGER CORE IDEAS



① Amorphous silicon coating
- Reduces thermal noise. Prospect of a **4-7x** reduction from aLIGO level
- Favors **2 µm** wavelength

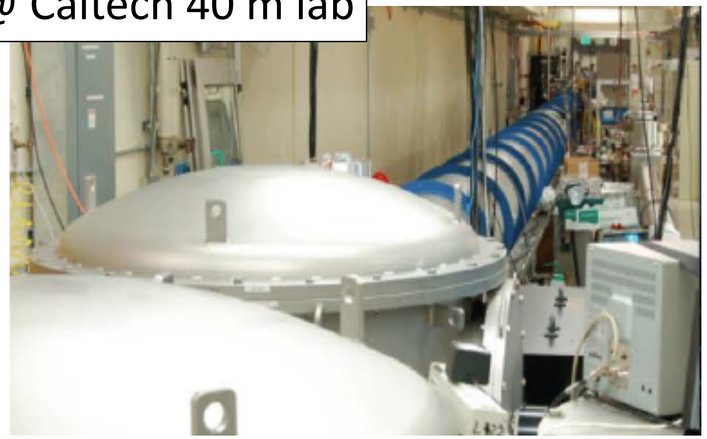
② Crystalline silicon substrate
- Improves quantum noise. **200 kg** mass, **3 MW** power
- High thermal conductivity, ultra-low expansion at **123 K**

③ Radiative cooling
- Still efficient at **123 K**
- Suspension design not constrained by cryogenics

LIGO-G2001631

At this point it is not obvious this will be implemented as part of the LIGO upgrade planning

Mariner prototype
@ Caltech 40 m lab

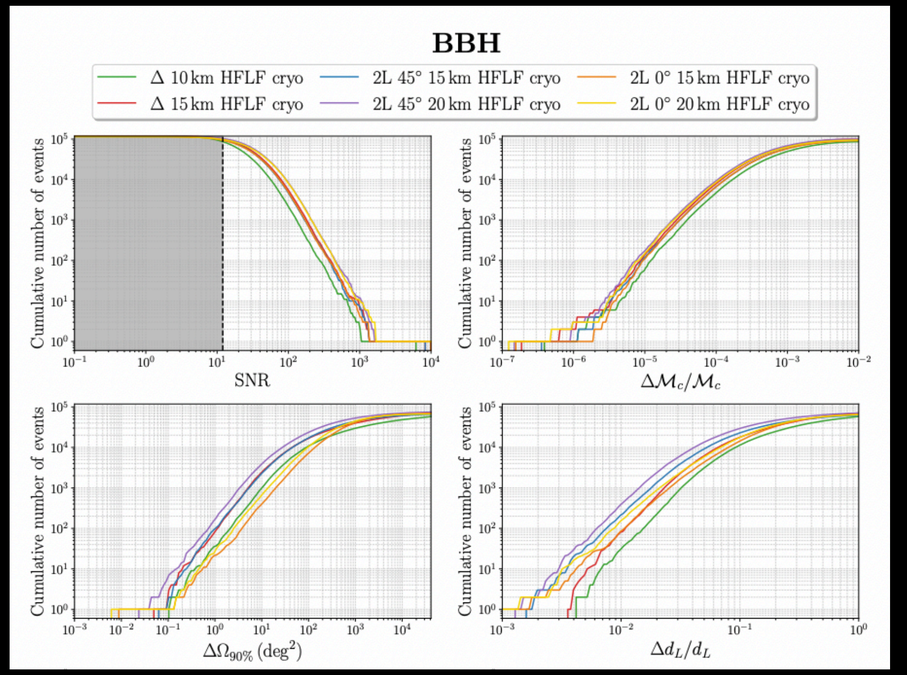


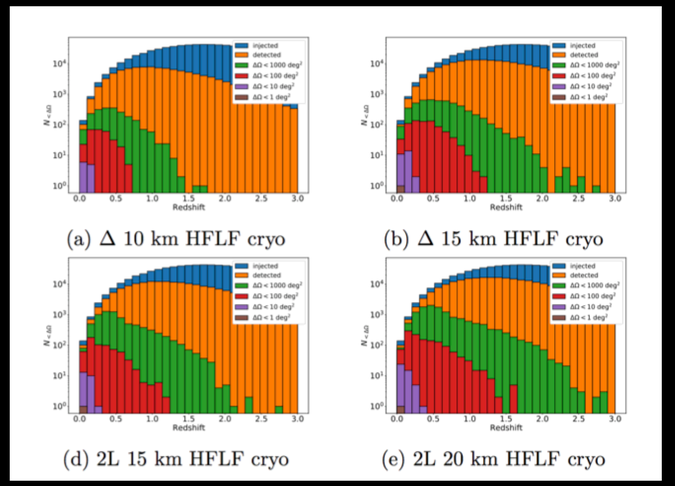
https://dcc.ligo.org/public/0142/T1700231

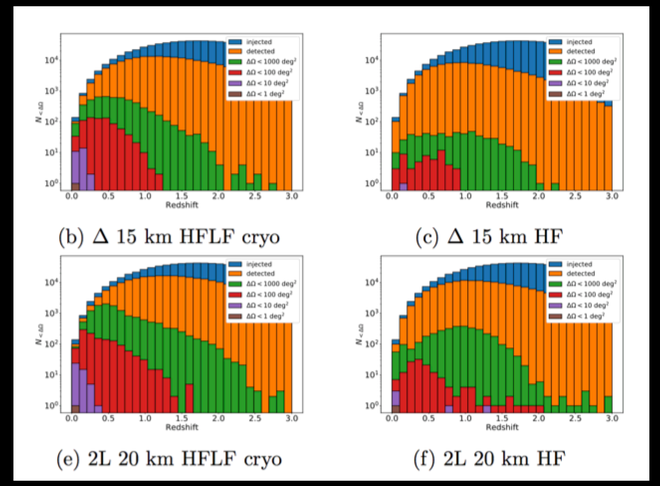
Comparative studies
(only physics potential)

arXiv:2303.15923 Branchesi, Maggiore et al. 2023

- The conclusions are the expected ones
  - Longer arms perform better
  - Only 1L is not an option (dependent on overall network)
    - Either one site Triangle or 2 sites L
- NO LF translates into reduction of well localised events (more severe for triangular configuration)
  - 2L HF 15 km comparable to HFLF Δ10km
- Only LF makes BNS pre-meger alerts possible —> impact on multi messenger
- Concerns about possible correlations in the Δ compromising stochastic searchers



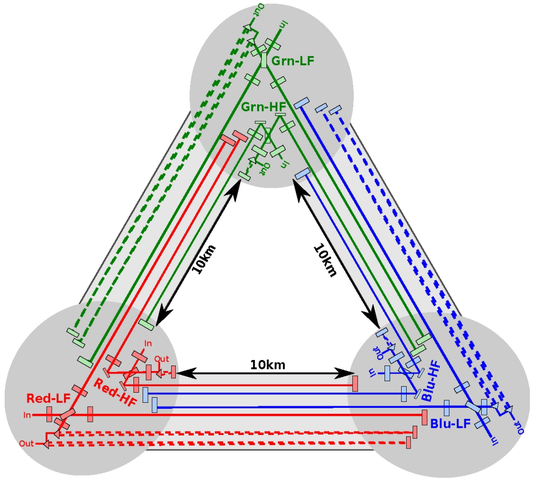


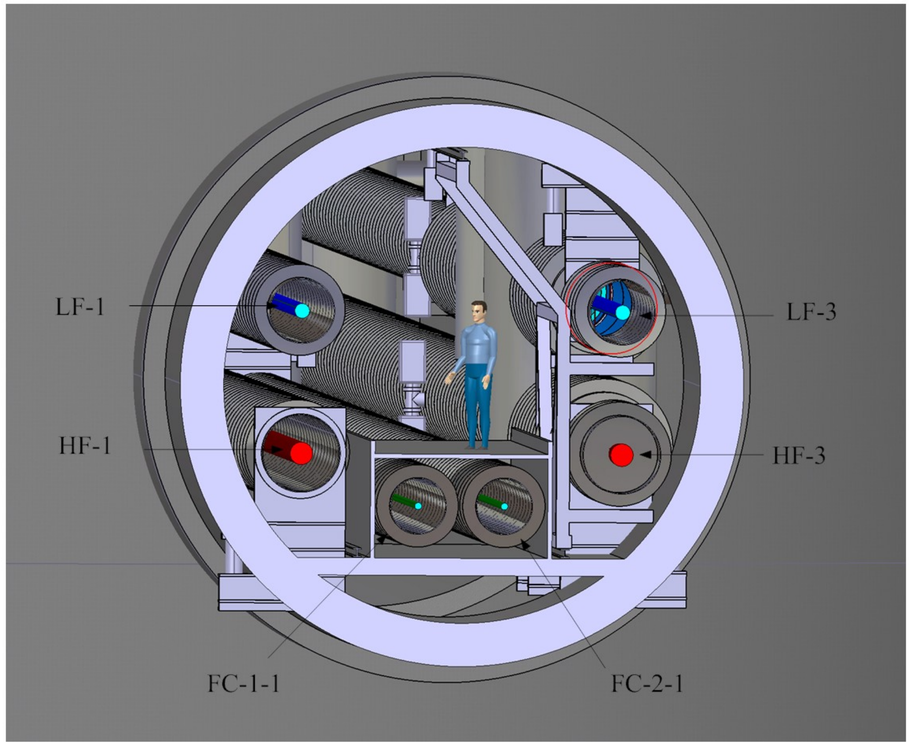


ET vacuum system

~10^5 m^3

560 M€





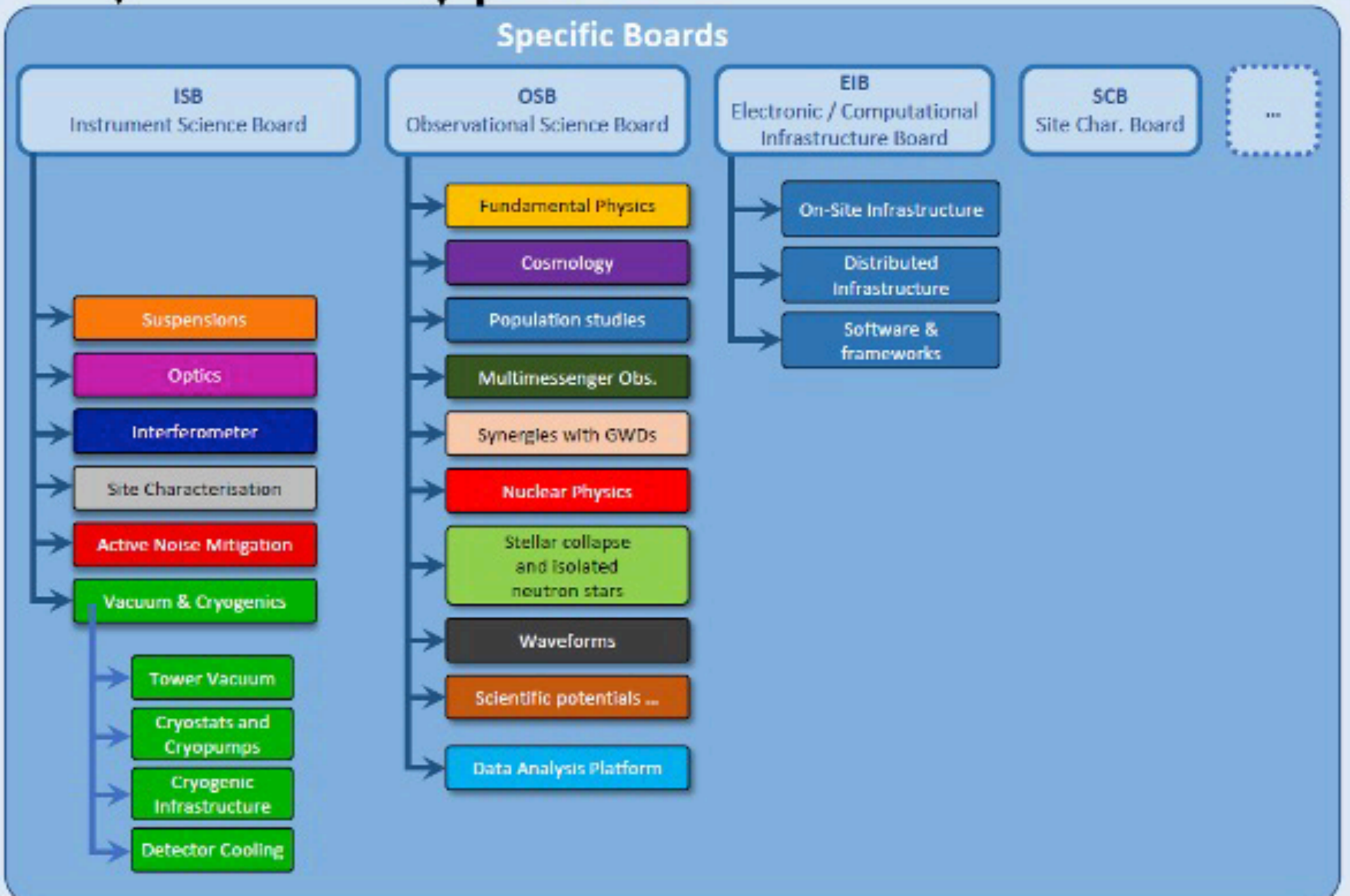
In its current design ET involves the production of more than 120km of ~1 m diameter tubes instrumented by hundreds of deflecting baffles

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)


Specific Boards
ISB
Instrument Science Board
OSB
Observational Science Board
EIB
Electronic / Computational Infrastructure Board
SCB
Site Char. Board
...
Suspensions
Optics
Interferometer
Site Characterisation
Active Noise Mitigation
Vacuum & Cryogenics
Tower Vacuum
Cryostats and Cryopumps
Cryogenic Infrastructure
Detector Cooling
Fundamental Physics
Cosmology
Population studies
Multimessenger Obs.
Synergies with GWDs
Nuclear Physics
Stellar collapse and isolated neutron stars
Waveforms
Scientific potentials ...
Data Analysis Platform
On-Site Infrastructure
Distributed Infrastructure
Software & frameworks
supervising
participating
SF
Science Foru

EMR-TETI civil engineering - Timelines

Example 1: Civil engineering (with CERN)

Timeline / Activities	Dur (mon)	2023 Q1	Q2	Q3	Q4	2024 Q1	Q2	Q3	Q4	2025 Q1	Q2	Q3	Q4	2026 Q1	Q2	Q3	Q4
EMR																	
Technical studies subsurface	?																
1st Assessment subsurface	?																
Draft Bidbook	?																
Location Scenarios	?											?					
Structure Design	?																
Cost Estimate	?																
Tender Plan Construction Phase	?																
Logistics Plan Construction Phase	?																
Spatial Plan Corner Points	?																
Risk Register	?																
Implementation plan & tender dossier	?																
TETI																	
Performing Surveys & Drillings	12																
Positioning of Underground Structures (Triangle and 2L)	12																
Underground Service Plants	12																
Surface Buildings	7																
Construction of Underground Structures	16																
Cost and Time Estimation	2																
Permissions and opinions for construction	16																

EMR site

- *Underground investigations (surveys, drilling and testing)* — *Q2 2025*
- *Positioning and construction design* — *Q3 2025*
- Implementation plan & tender dossier (Bidbook. ?) — Q3 2026

Sardinia site

- *Underground investigations (drilling and testing)* — *Q1 2025*
- *Positioning and construction design* — *Q2 2025*

Preliminary dates that will still change!

BASELINE layout

Sardinia Site investigations

Sardinia design

EMR Site investigations

EMR -design

EMR Implementation plan & tender dossier

Q4 2024 | Q1 2025 | Q2 2025 | Q3 2025 | Q4 2025 | Q1 2026 | Q2 2026 | Q3 2026 | Q4 2026

ET-PP web

https://etpp.ifae.es

Deliverables & Milestones

Deliverables

#	Deliverable	WP	Status
D1	D1.1: Dissemination and Exploitation (D&E) Plan	1	EC approved
D2	D1.2: Data Management Plan (DMP)	1	EC approved
D3	D2.1: Report providing options for legal entity	2	EC approved
D4	D2.2: Minutes of meetings with EC and involved ministries	2	EC approved
D10	D4.1: Scan of legal procedures, permitting and land acquisitions	4	EC approved
D11	D4.2: Updated socio-economic impact studies	4	in EC portal
D15	D5.1: Structure and mandate of the Project Office	5	EC approved
D16	D5.2: Functionalities required from the tools in support of the project management	5	EC approved
D17	D5.3: .Structure and mandate of the Engineering Department	5	EC approved
D18	D5.4: Funcional Engineering Department	5	in EC portal
D19	D5.5: Funcional Project Office	5	in EC portal
D20	D6.1: Refined Science Case	6	in EC portal
D21	D6.2: Vacuum pipe Design	6	in EC portal
D26	D7.1: Innovation plan	7	EC approved
D30	D8.1: Computing and Data Requirements	8	in EC portal
D36	D10.1: Initiate strategic media and communications plan	10	EC approved
D37	D10.2: Launch consortium website and social media accounts	10	in EC portal
D38	D10.3: Formulate strategic media and communications plan	10	in EC portal

WP 6: Technical Design

Work package led by INFN

Objectives

WP6 - Technical Design [led by INFN]- has the mandate to provide the ET-PP project management with a refined scientific case, the Technical Design Report (TDR) of the RI hosting the ET interferometers, and the TDR of the set of detectors (interferometers) and facilities (vacuum and cryogenic apparatuses and plants) composing ET.

Furthermore WP6 has the duty to elaborate a data management plan (DMP) and a Data Access Policy in synergy with WP8 (see below) and WP2. The activities in WP6 take place inside the ET Collaboration and will take full advantage of the existing technical and scientific boards inside the experiment.

The chairs of the ET Steering Committee: **H. Lück (LUH and AEI)** and **M. Punturo (INFN)** act, together with **P. Chiggiato (CERN)**, as co-coordinators of WP6. **P. Chiggiato** coordinates the R&D and technical design of the ET pipe-arm vacuum system.

Deliverables

- D6.1 Refined Science Case
- D6.2 Vacuum pipe Design
- D6.3 Preliminary RI TDR
- D6.4 Preliminary DET TDR
- D6.5 RI TDR
- D6.6 DMP and Data Access Policy

Harald Lück

Albert Einstein Institut & Institut für Gravitationsphysik der Leibniz Universität Hannover

Paolo Chiggiato

European Organization for Nuclear Research (CERN)

Michele Punturo

Istituto Nazionale Di Fisica Nucleare (INFN)

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.

C. Olivetto (SACLAY), **P. Werneke (NIKHEF)** and **A. Variola (INFN)** act as co-coordinators of WP5 in this proposal.

Deliverables

- D5.1 Structure and the mandate of the Project Office.
- D5.2 Functionalities required from the tools in support of the project management.
- D5.3 Structure and the mandate of the Engineering Department.
- D5.4 Functional Engineering Department.
- D5.5 Functional Project Office.

Christian Olivetto

Université Paris-Saclay

Patrick Werneke

Nikhef

Alessandro Variola

Istituto Nazionale Di Fisica Nucleare (INFN)

ET-PP Work Package Leaders

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United Kingdom Research And Innovation (UKRI)

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Nikhef

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Uniwersytet Warszawski (UW)

Domenico D'Urso

University of Sassari & INFN Laboratori Nazionali del Sud

Massimo Carpinelli

European Gravitational Observatory (EGO)

Wim Walk

Nikhef

Christian Olivetto

Université Paris-Saclay

Patrick Werneke

Nikhef

Alessandro Variola

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Nikhef

Nadia Tonello

Barcelona Supercomputing Center (BSC)

Achim Stahl

Deutsches Elektronen-Synchrotron (DESY)

Thomas Berghoefer

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