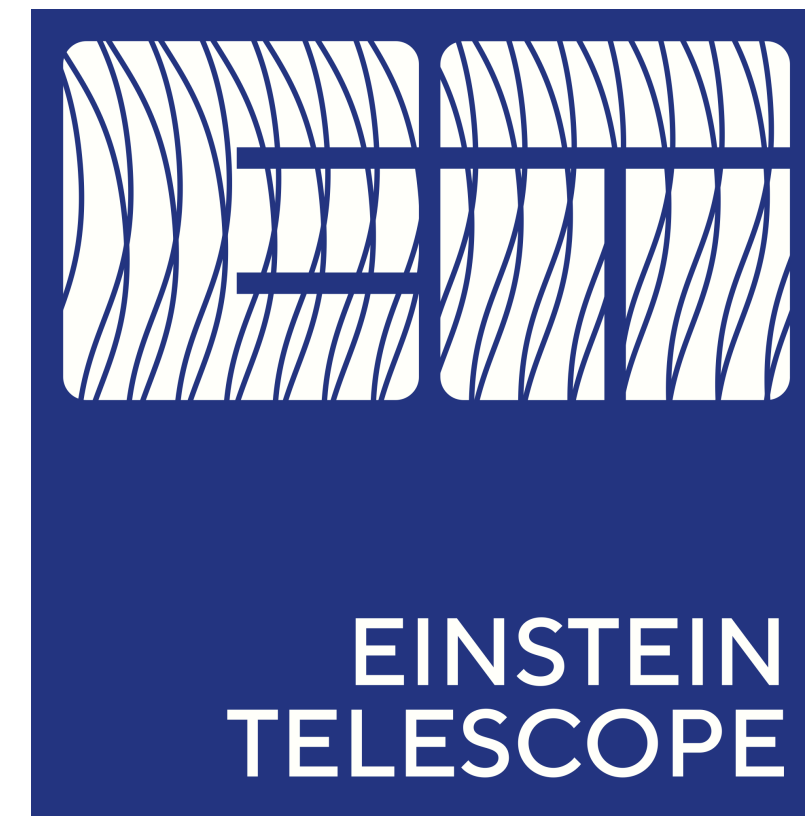


The Einstein Telescope Project



M. Martínez



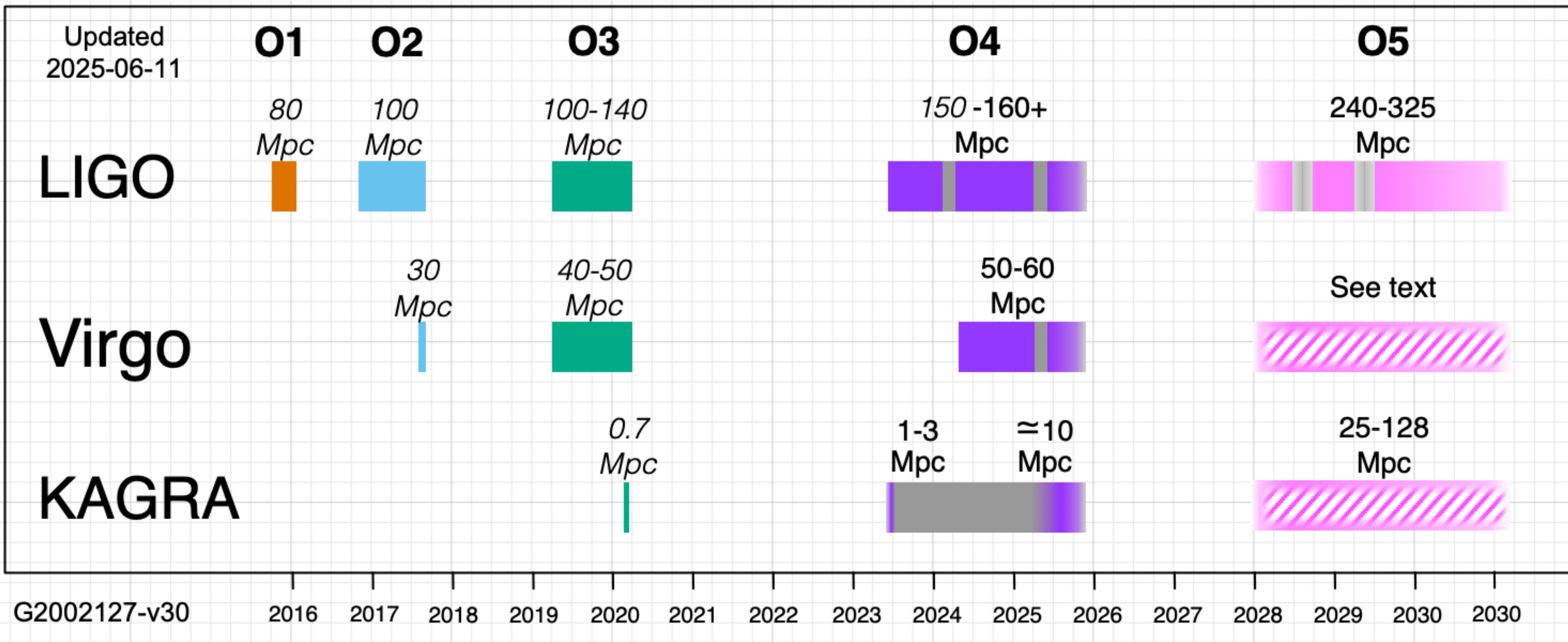
Iberian GW Meeting, Madrid, June 2024

Outline

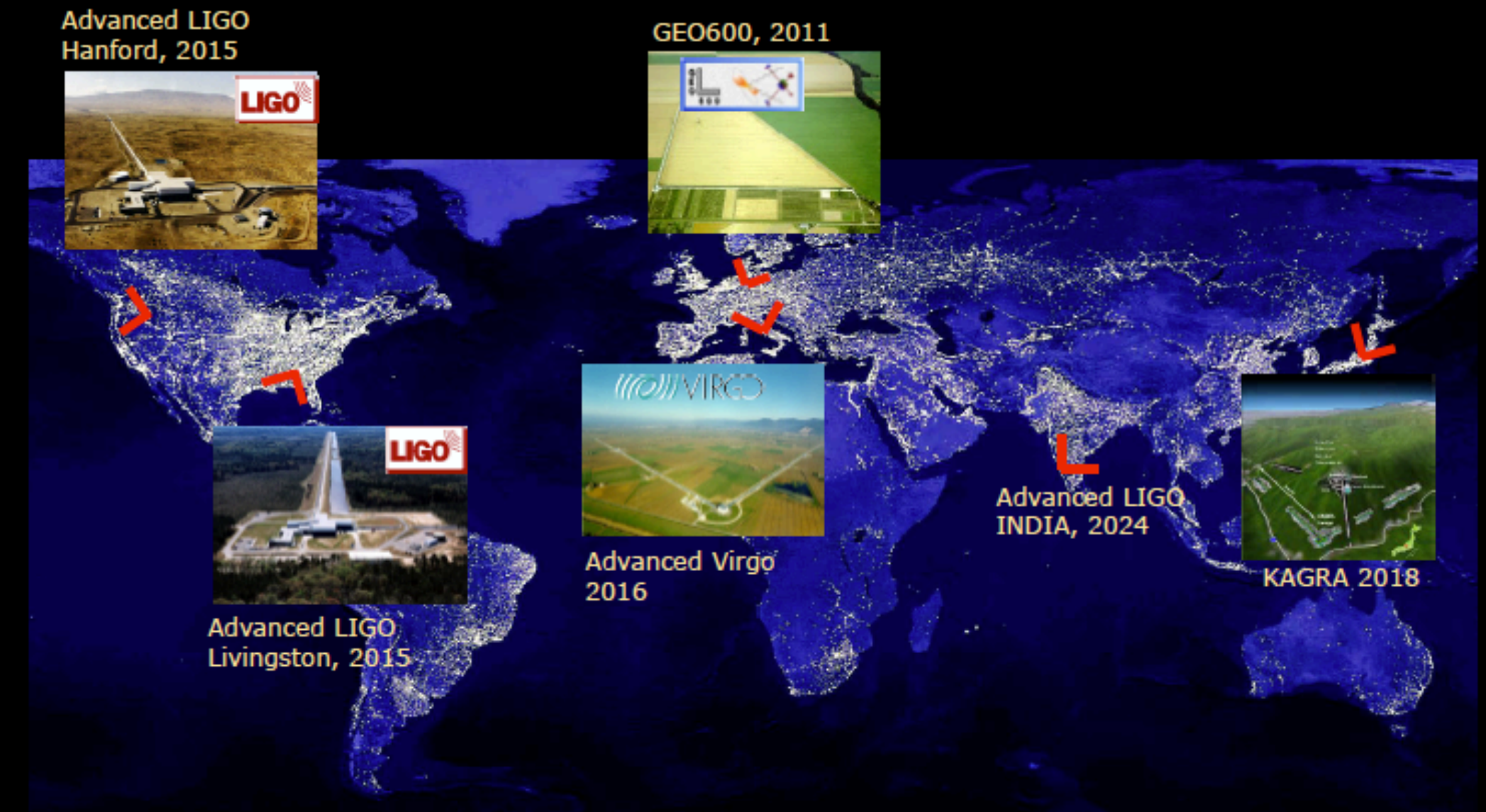
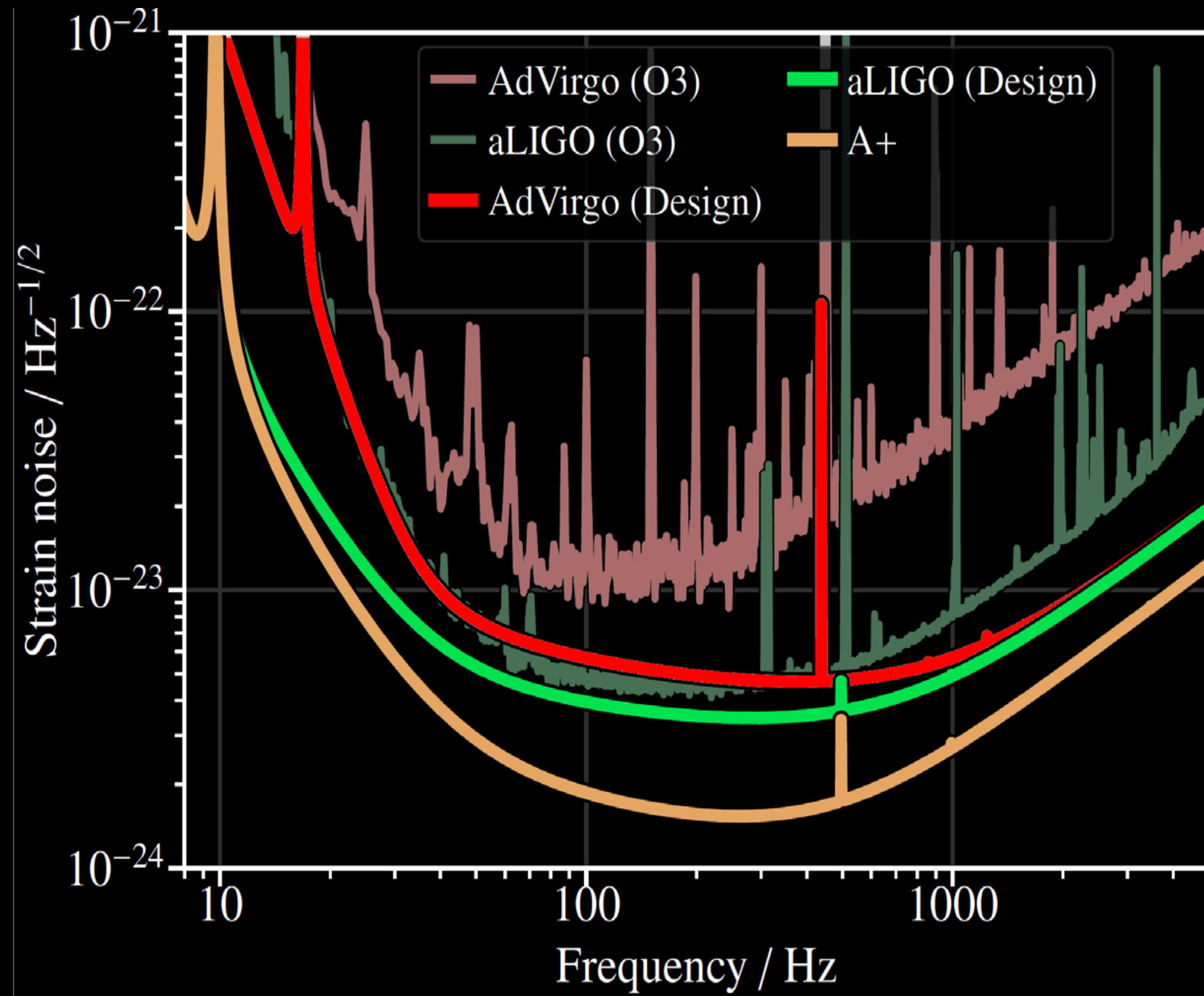
- Prospects from LVK
- The Einstein Telescope
- ET Design & Discussions on Geometries
- TimeLines, Locations and Cost
- Organisation and Political Support
- Preparatory Phase & work with CERN
- ET-Spain
- Final notes



LVK Master Schedule

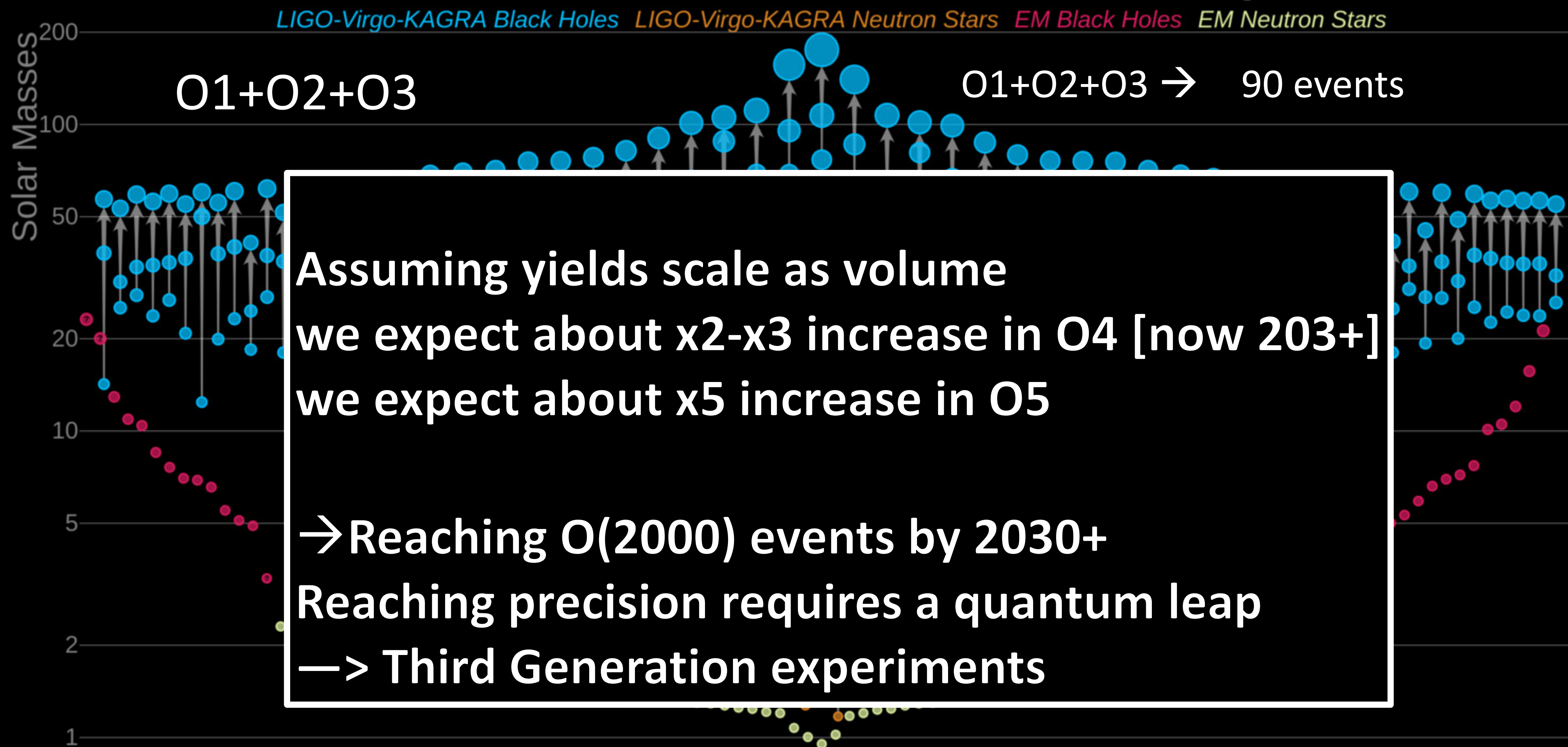


LVK sensitivity

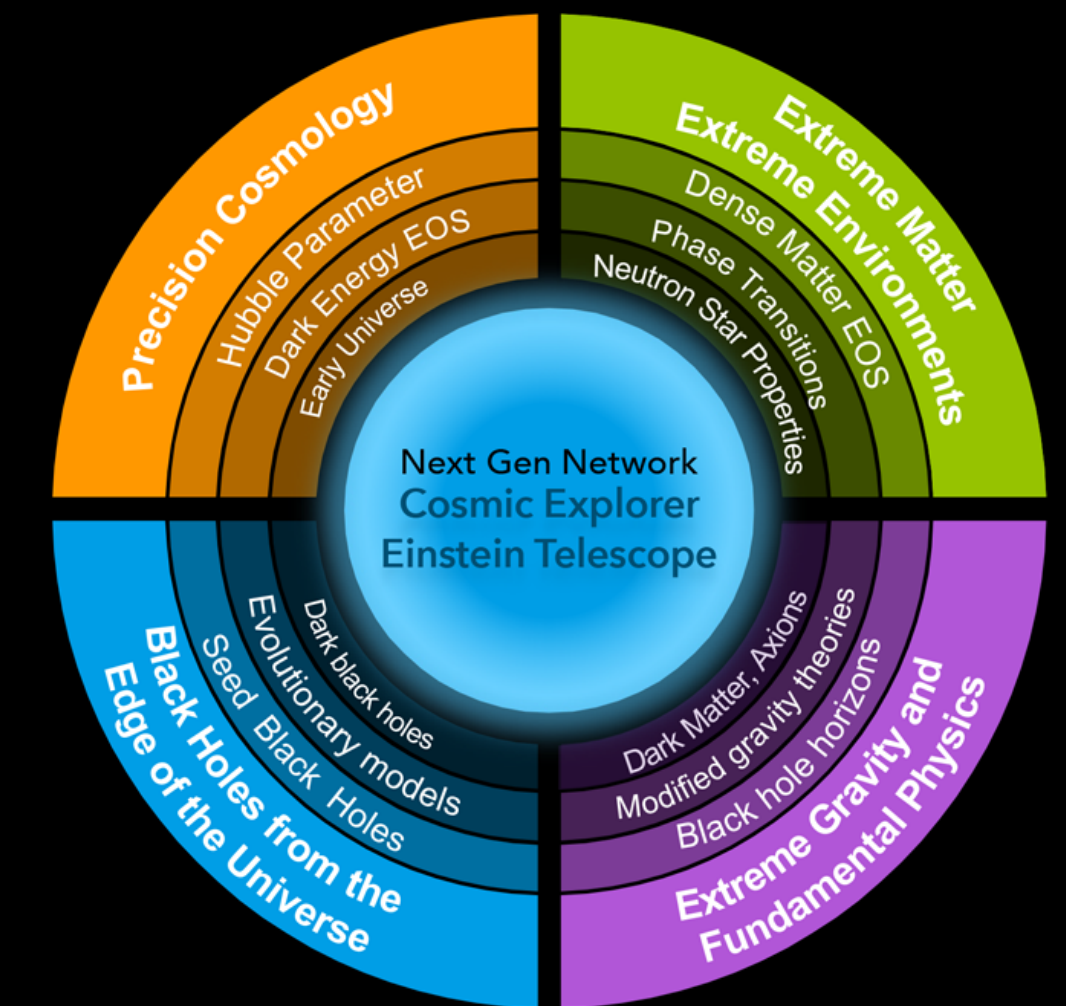
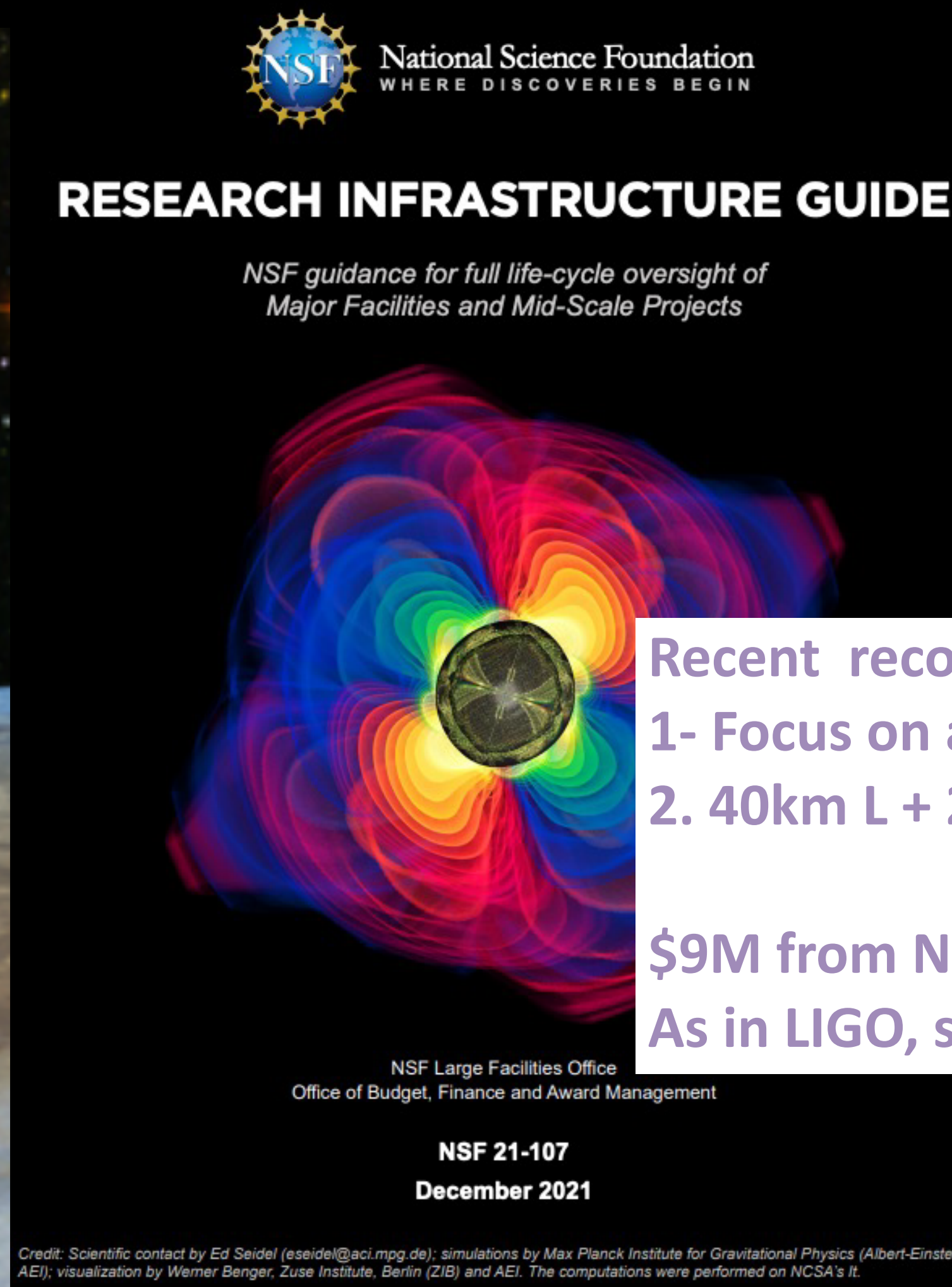
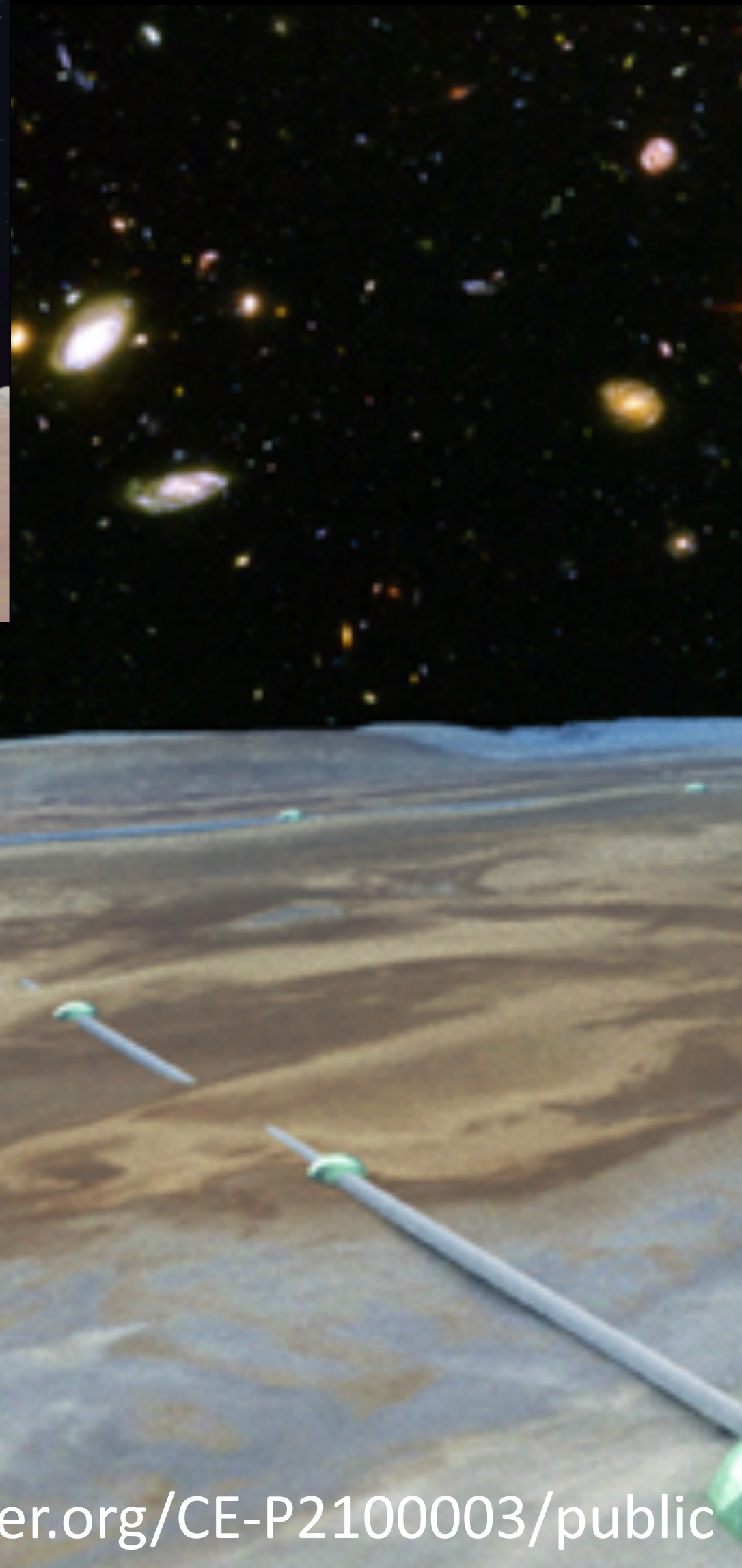
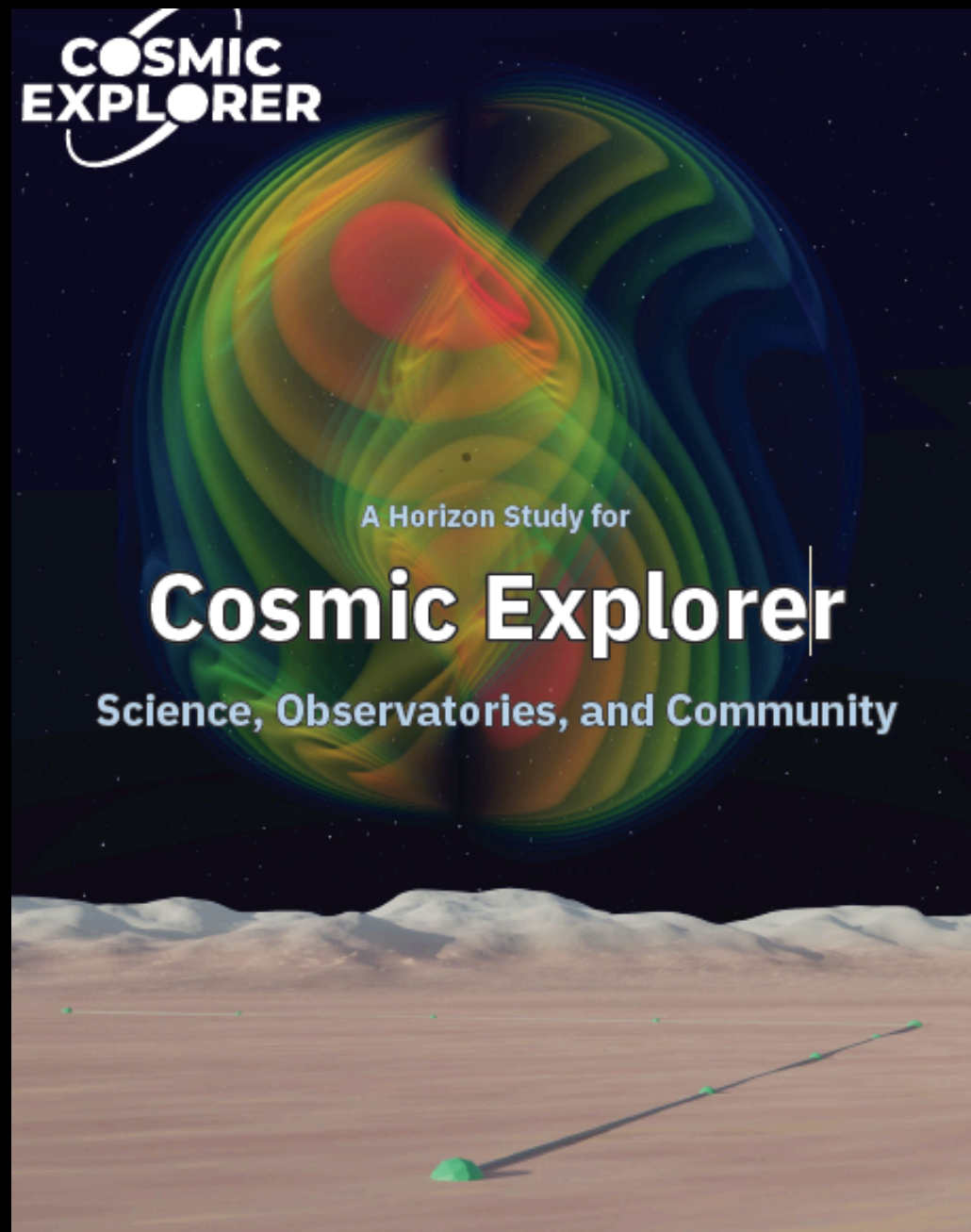


In the next 6 years the current Interferometers will reach their design sensitivity...

Masses in the Stellar Graveyard



Cosmic Explorer (USA)



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

The Einstein Telescope

First CDR in 2010 - 2011

(Baseline and Physics Case)

10 km

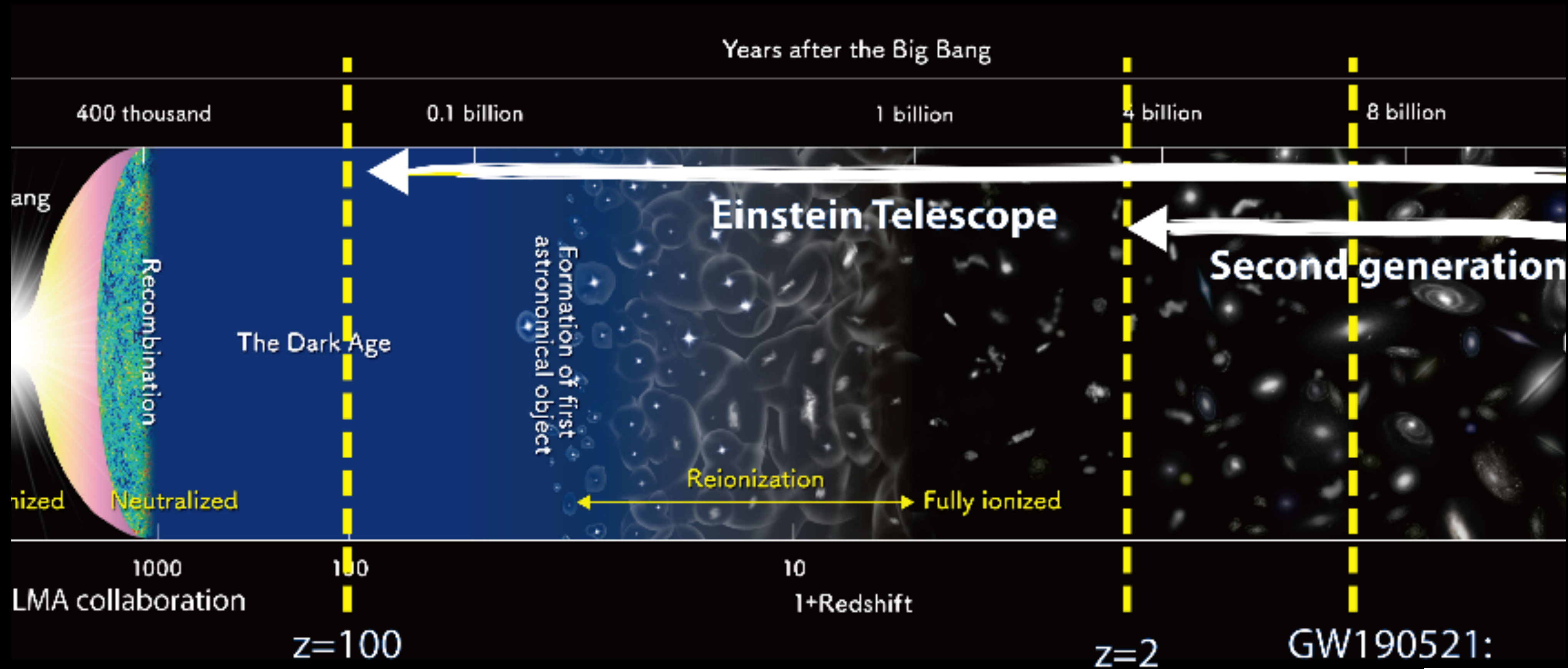
200 m

Design Report
Update 2020

for the Einstein Telescope

ET Steering Committee Editorial Team
released September 2020

Detection horizon for black-hole binaries



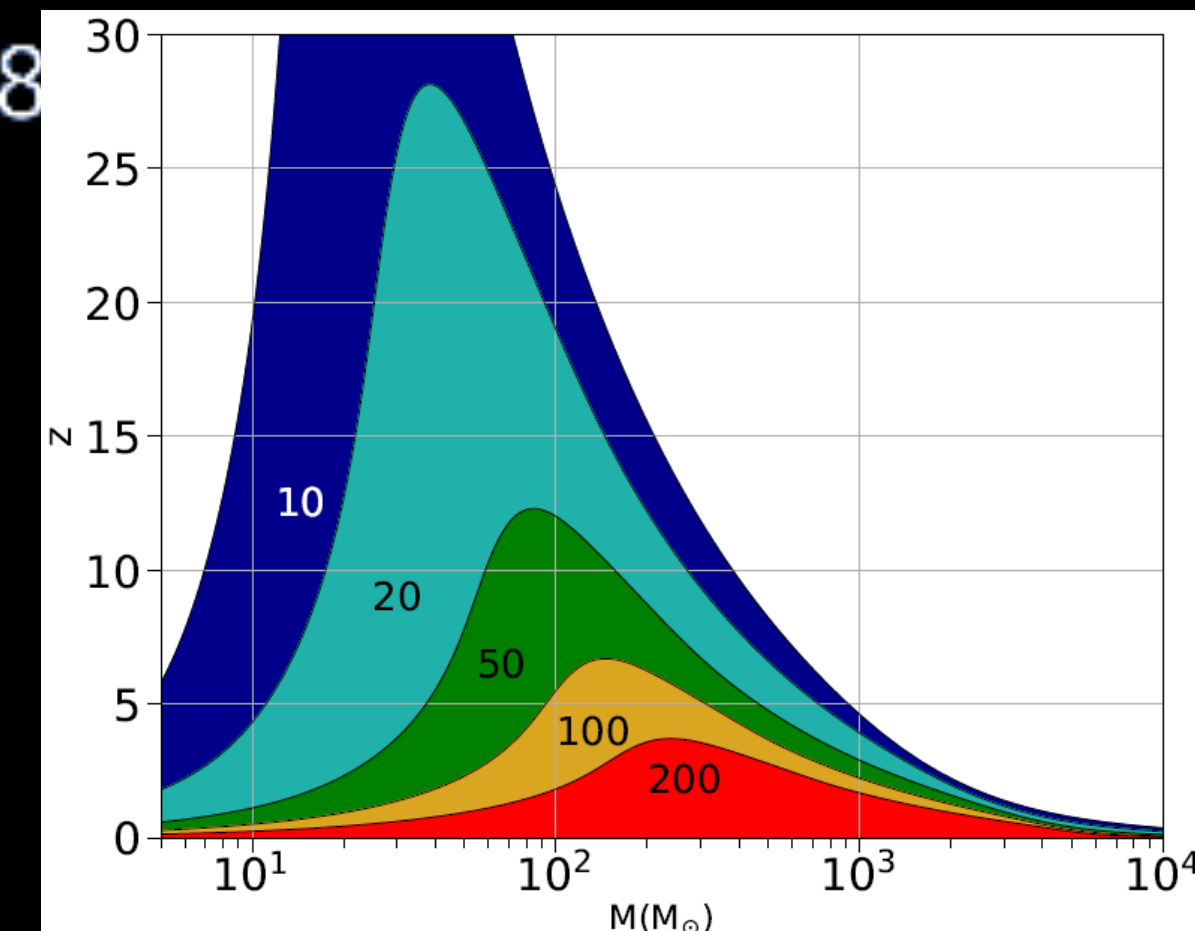
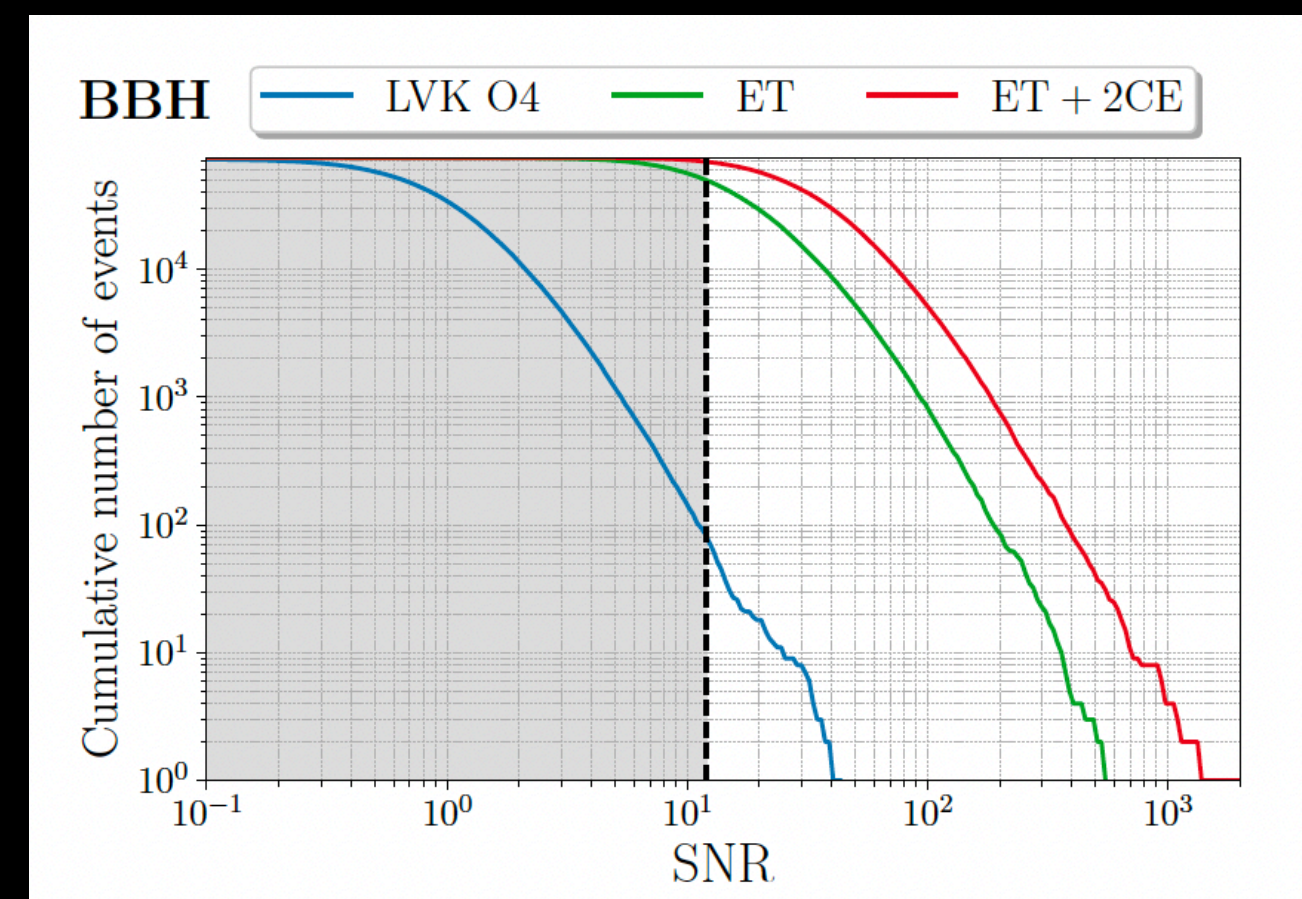
Huge rate of detections (about 1 per minute)

Extended redshift coverage up to the Dark Age

- Test for primordial BH origin
- Cosmology & Cosmography

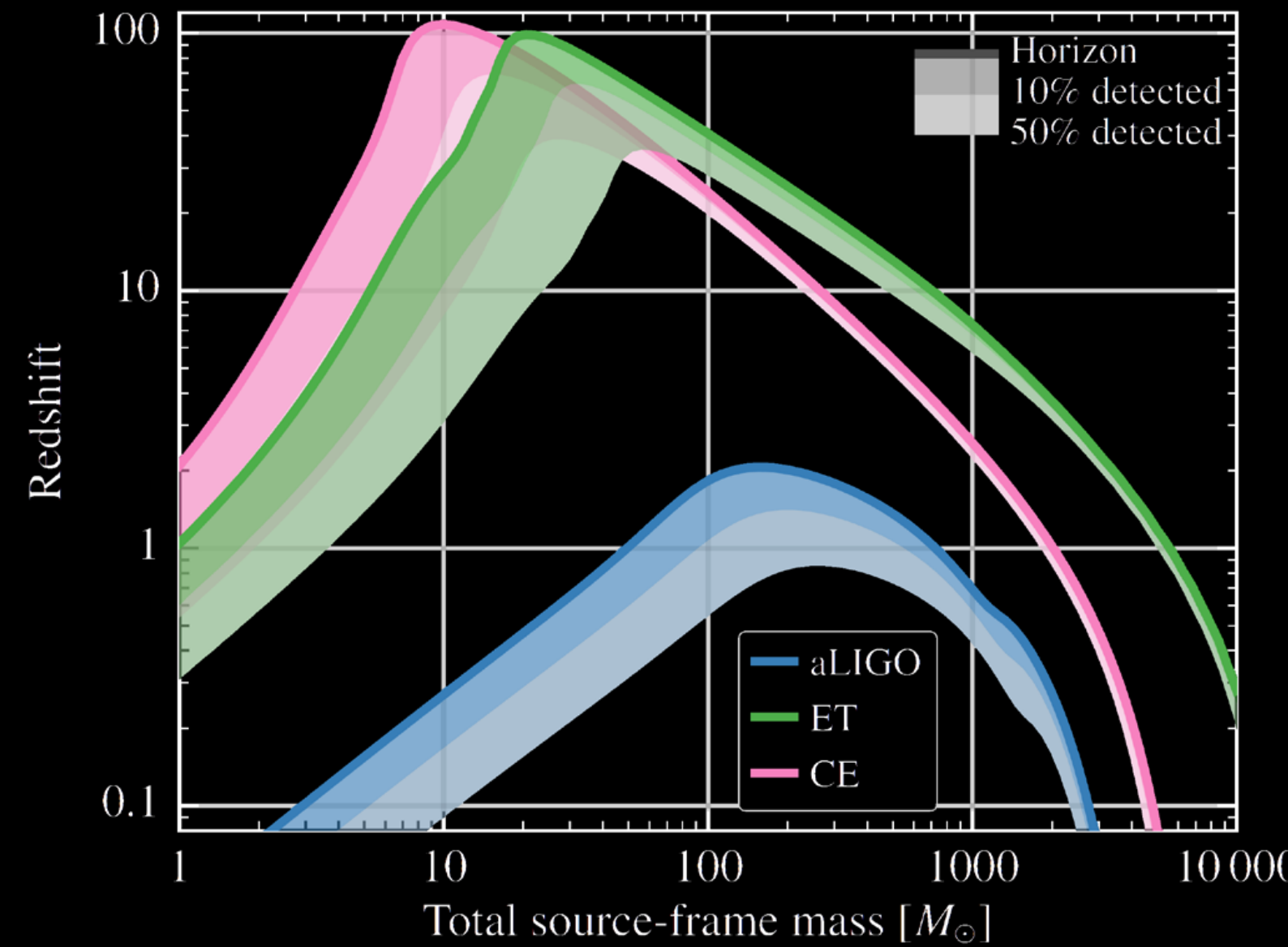
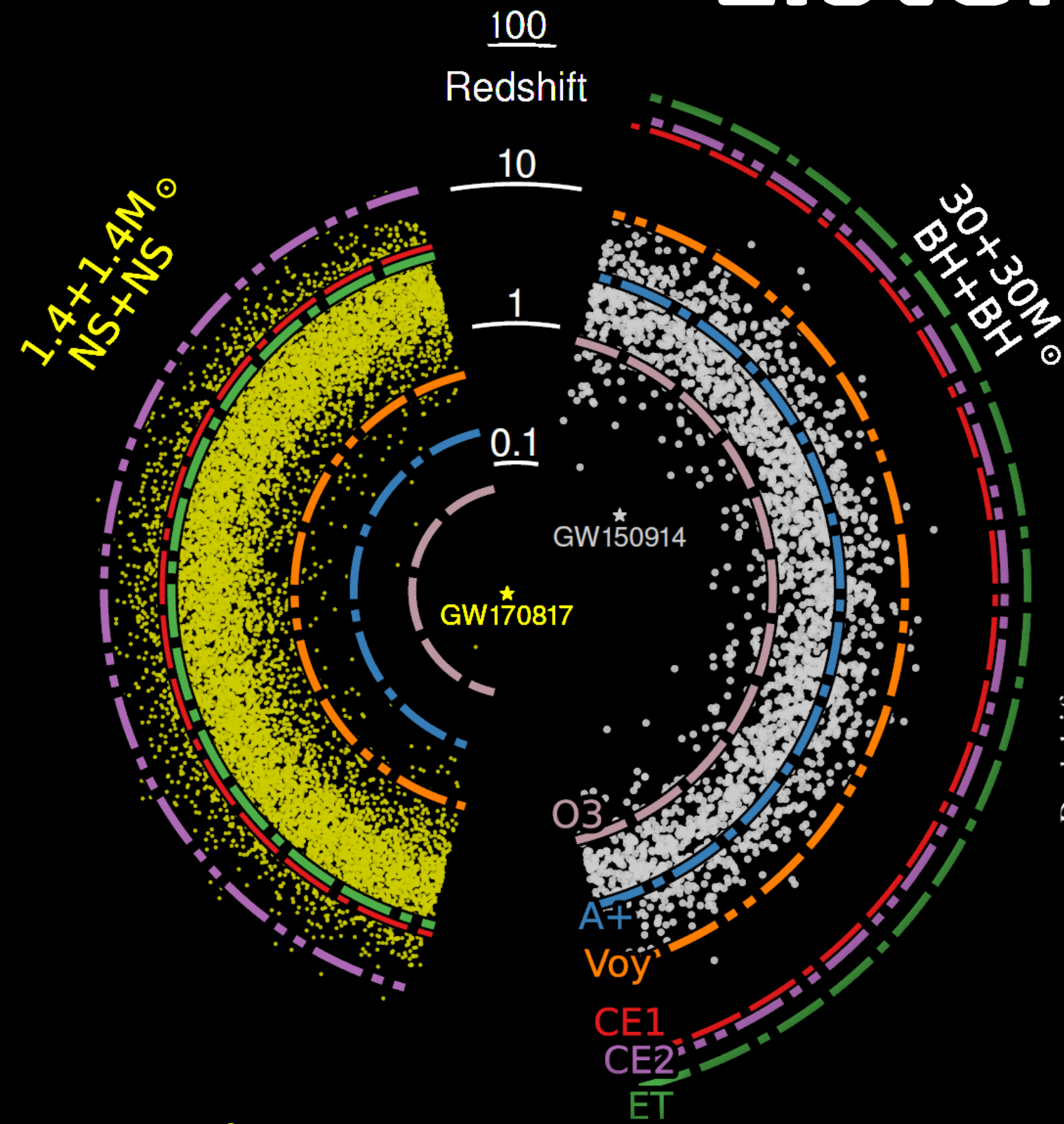
Many events with very large Signal-to-Noise ratios

- Precision tests of GR predictions and detailed BH studies



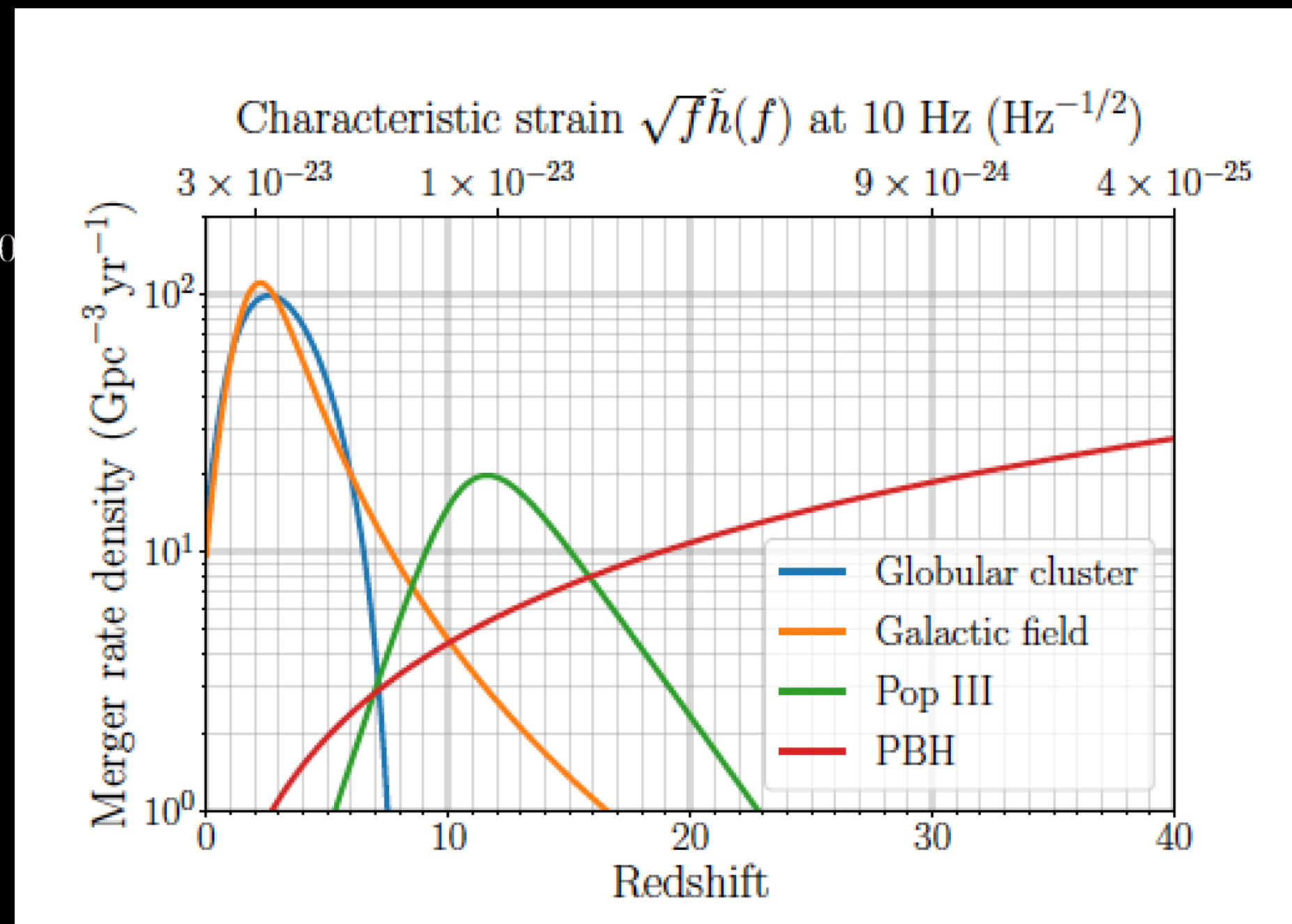
Listening the whole Universe

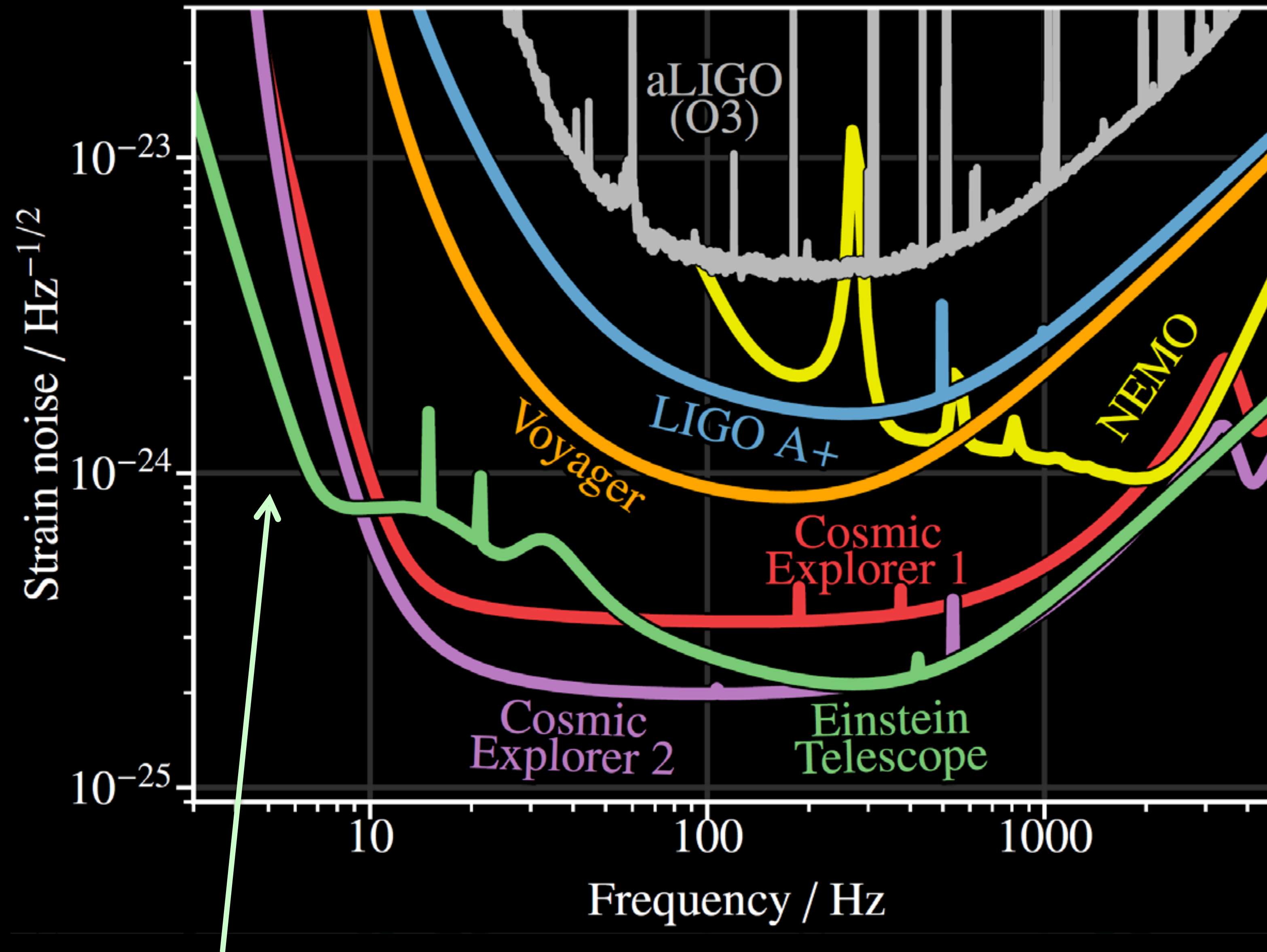
- 10^6 BH-BH / year up to $z \sim 20$ (230 Gpc) and $10^3 M_{\text{sun}}$
- 10^5 NS-NS / year up to $z \sim 2$
- $O(10^2 - 10^3)$ GW events with EM counterparts



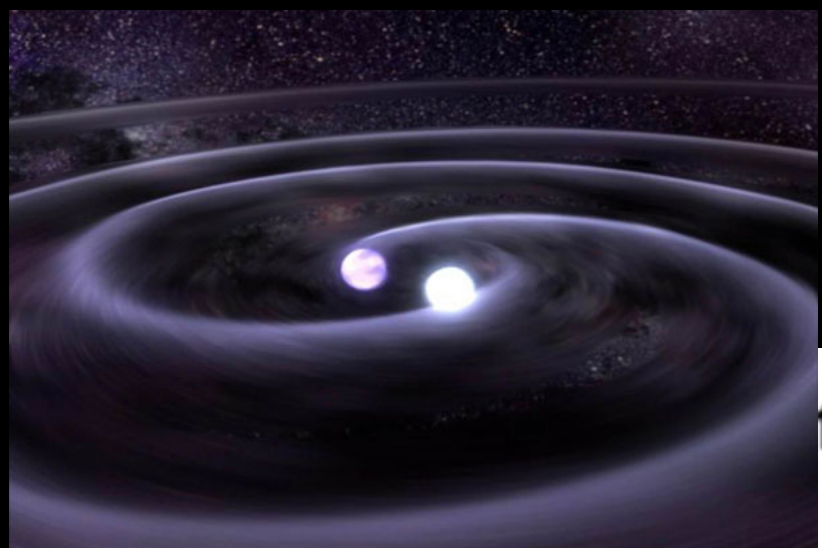
Astrophysics

- 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

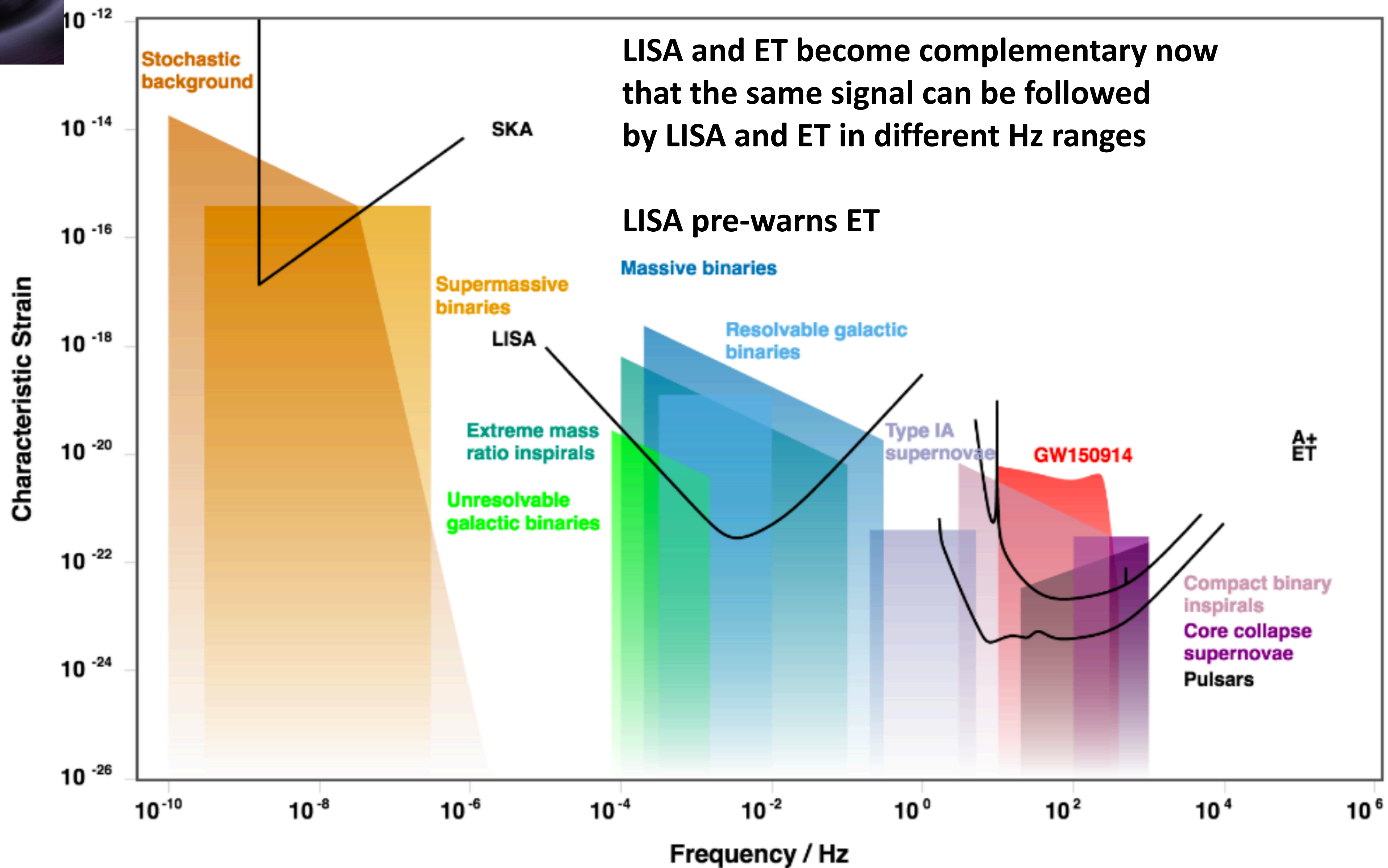




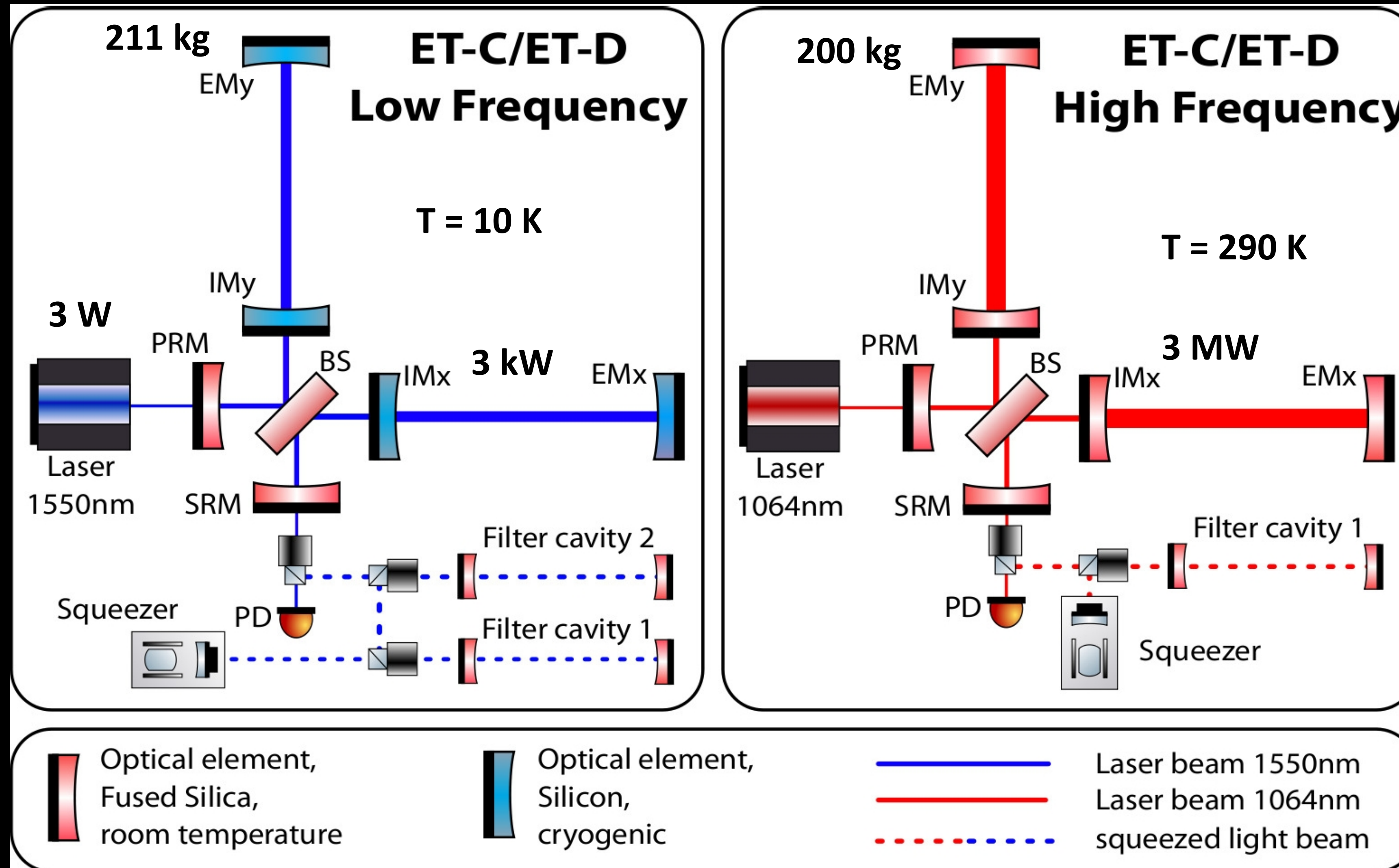
About one order of magnitude improvement w.r.t current detectors
and an extended sensitivity to low frequencies (...many orders of magnitude) $\rightarrow$ requires R&D



Complementarity



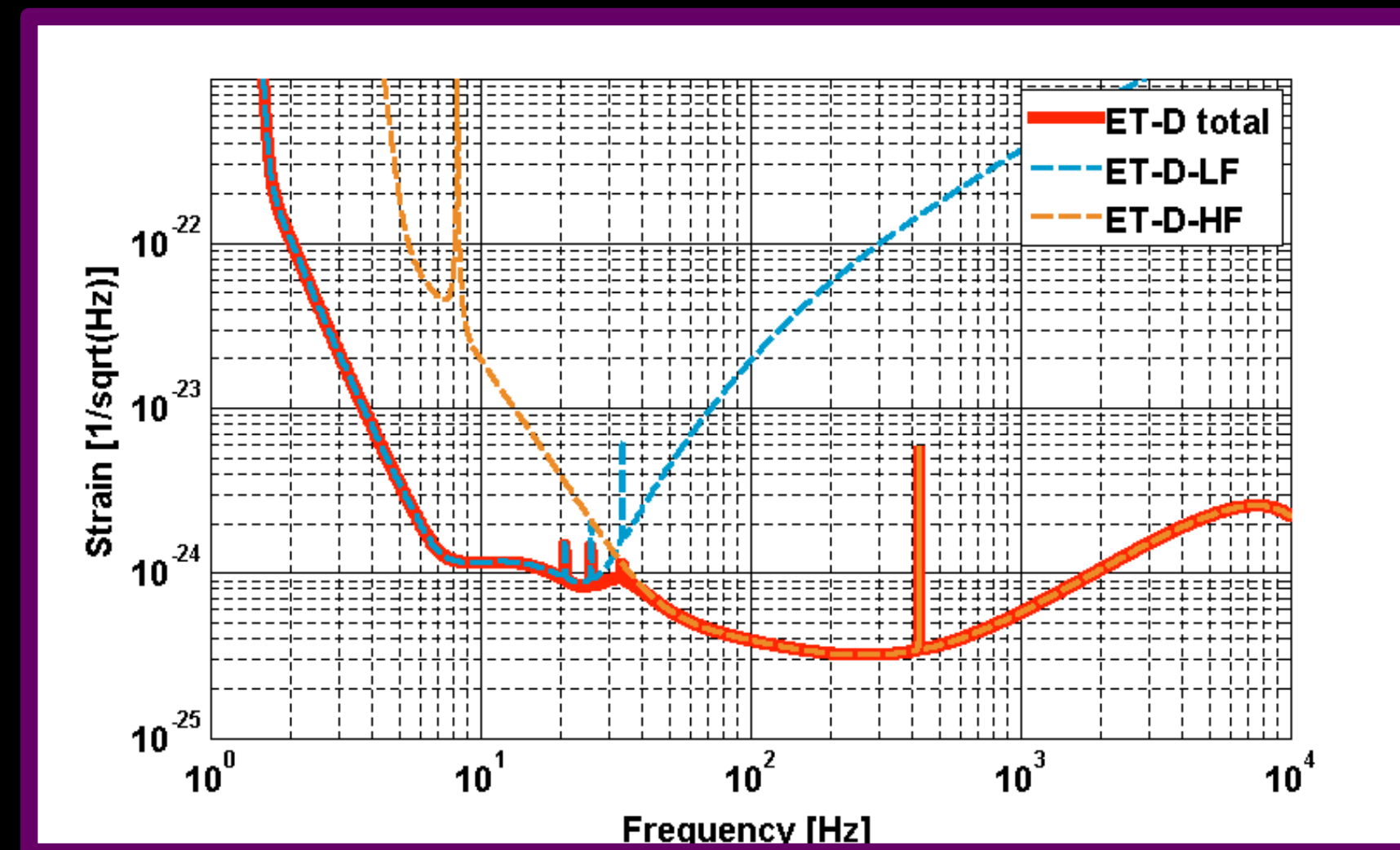
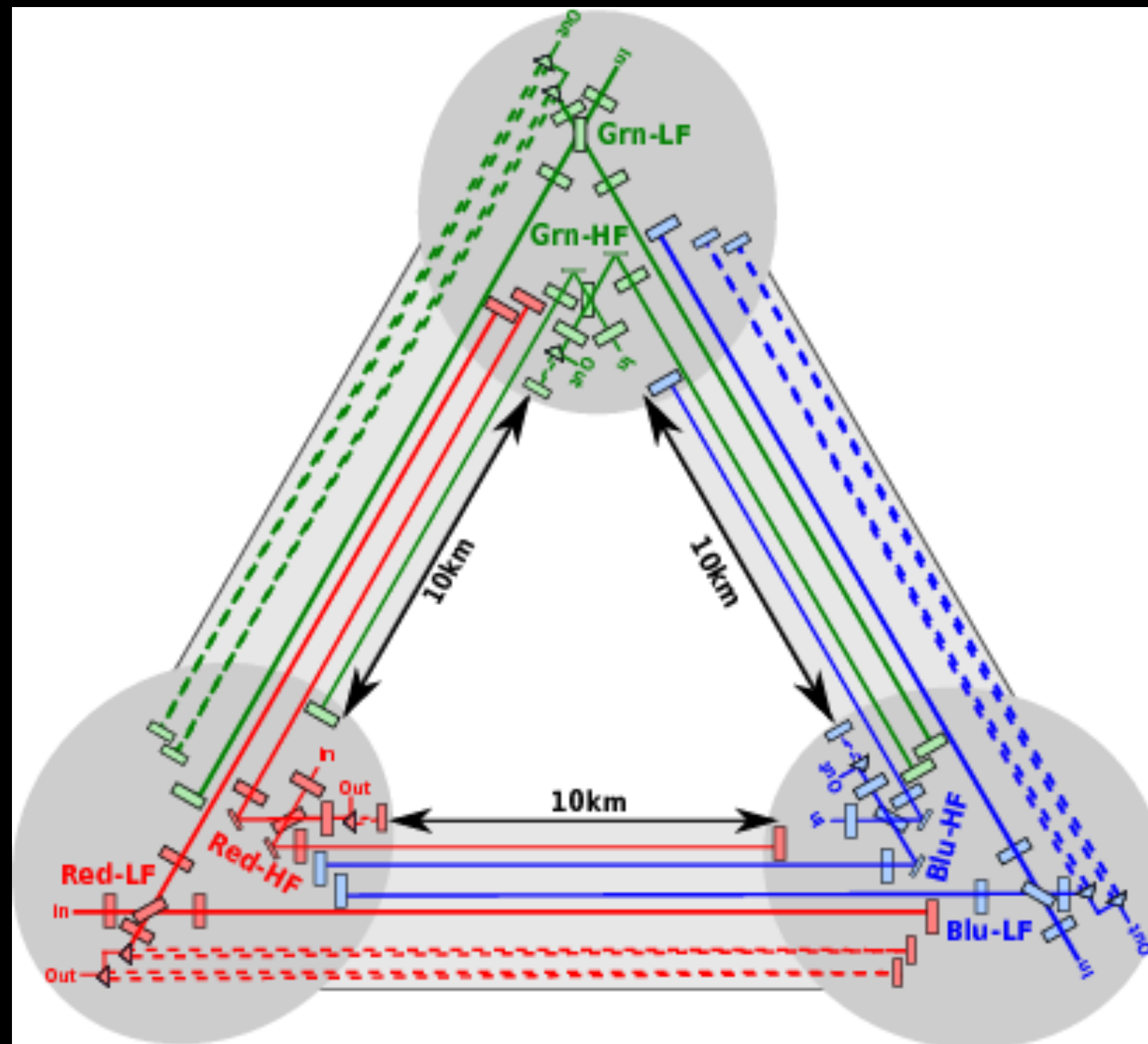
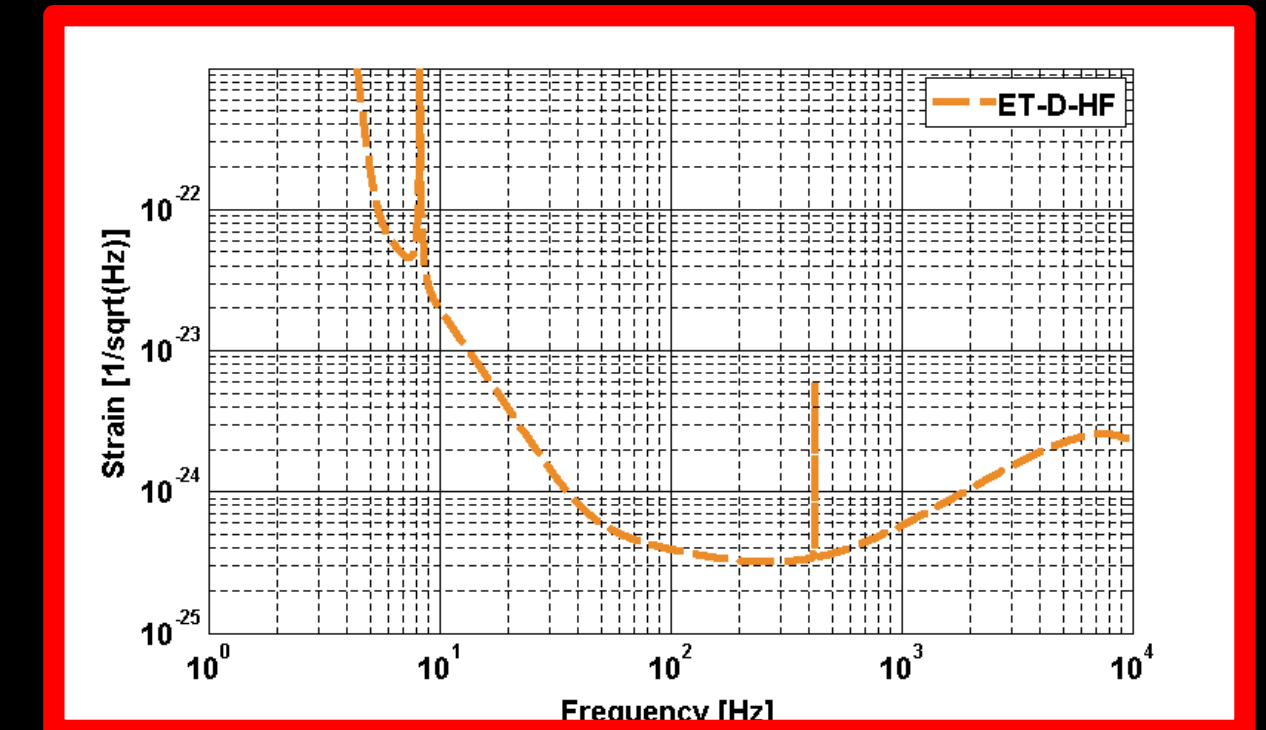
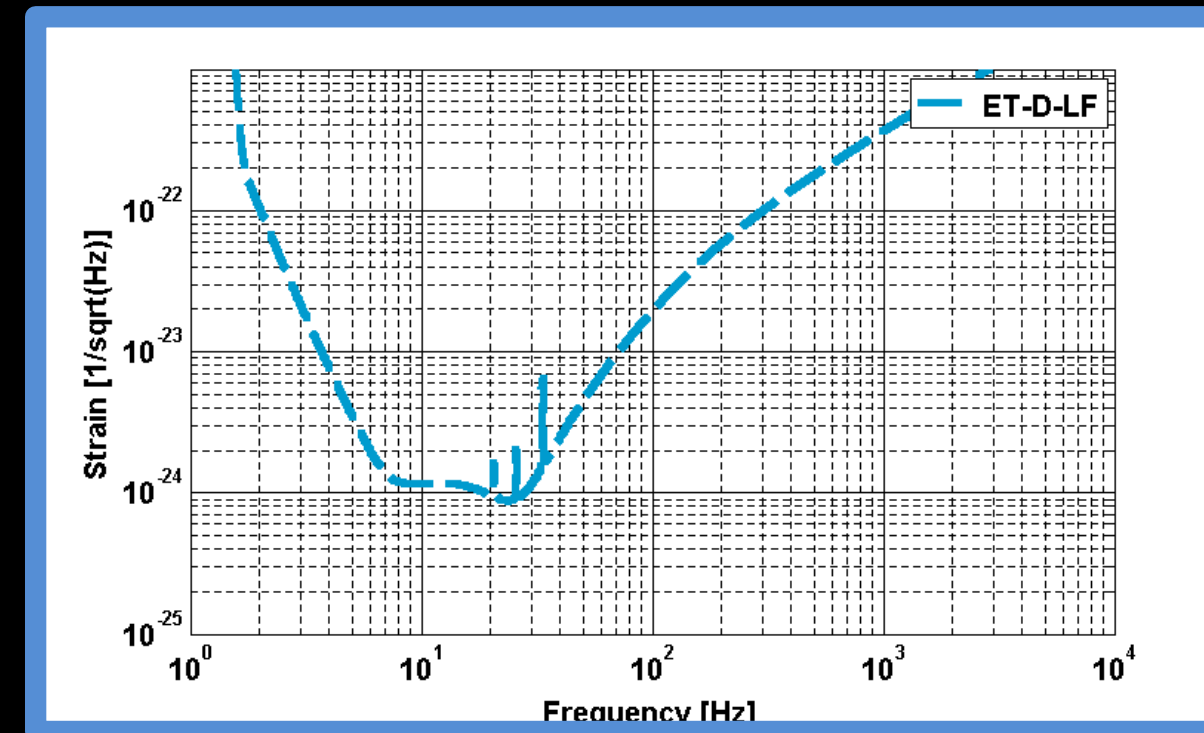
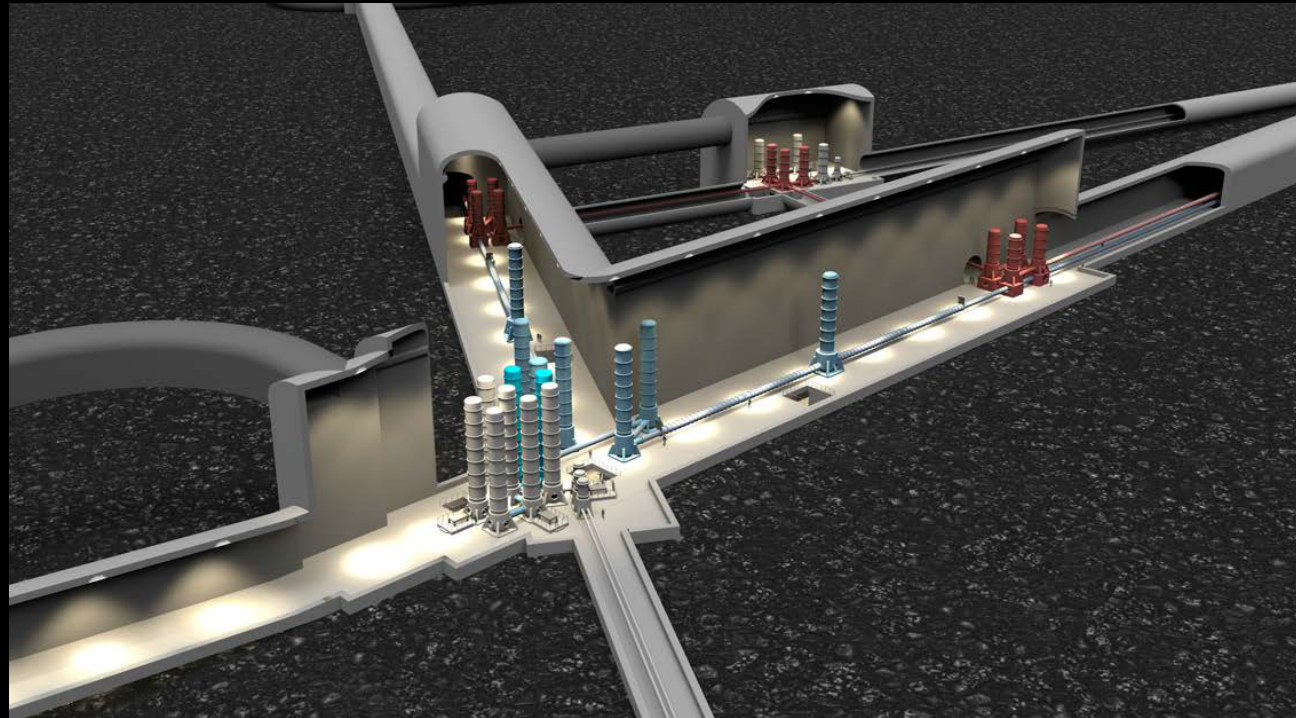
2nd Gen → ET



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

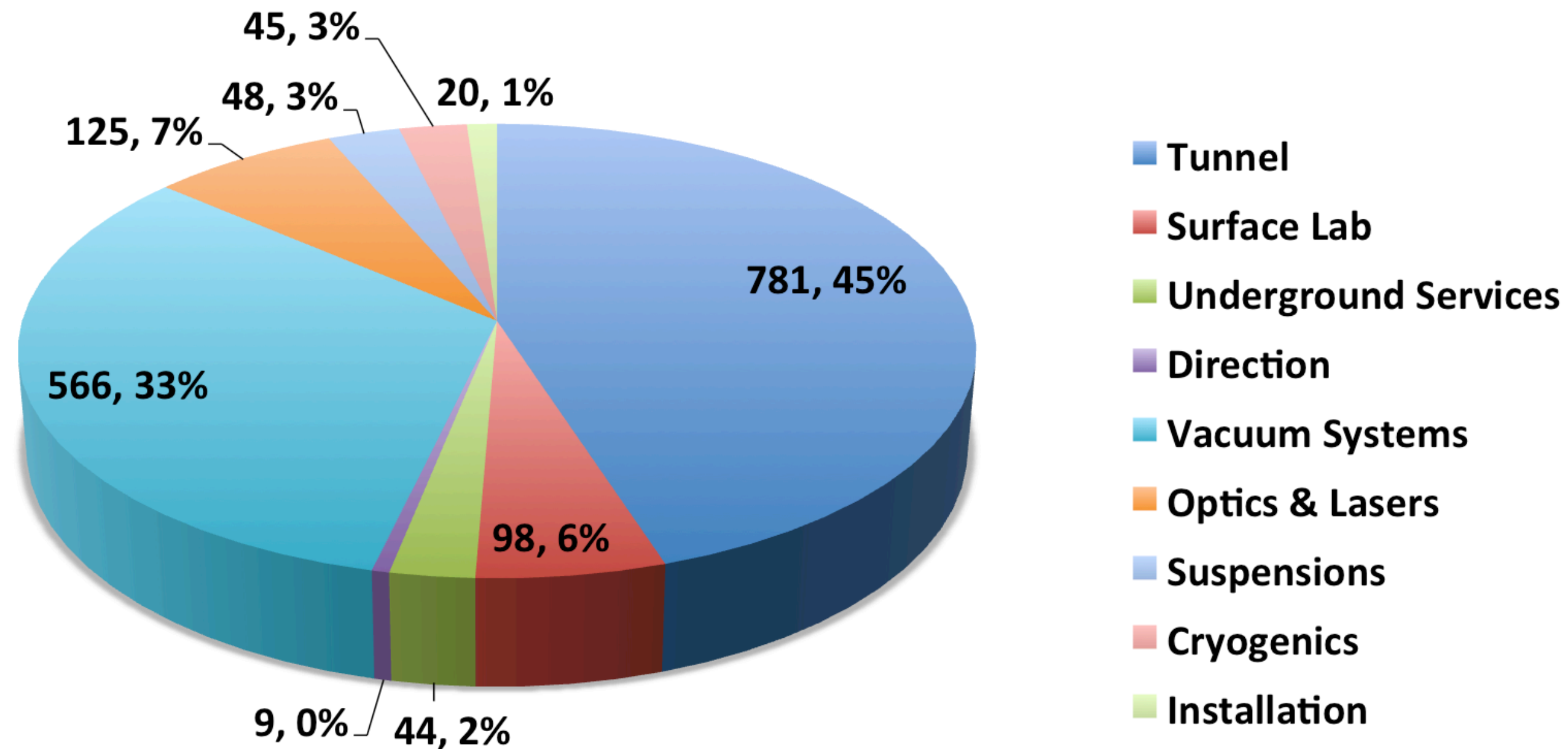
Einstein Telescope (6 in 1) Xylophone



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

Estimated cost (EU accounting)

ET Estimated Costs (M€)



Preparatory phase (170M€)

1. Site qualification (funded)

2. Site preparation (50 – 60 M€)

Covered by host country

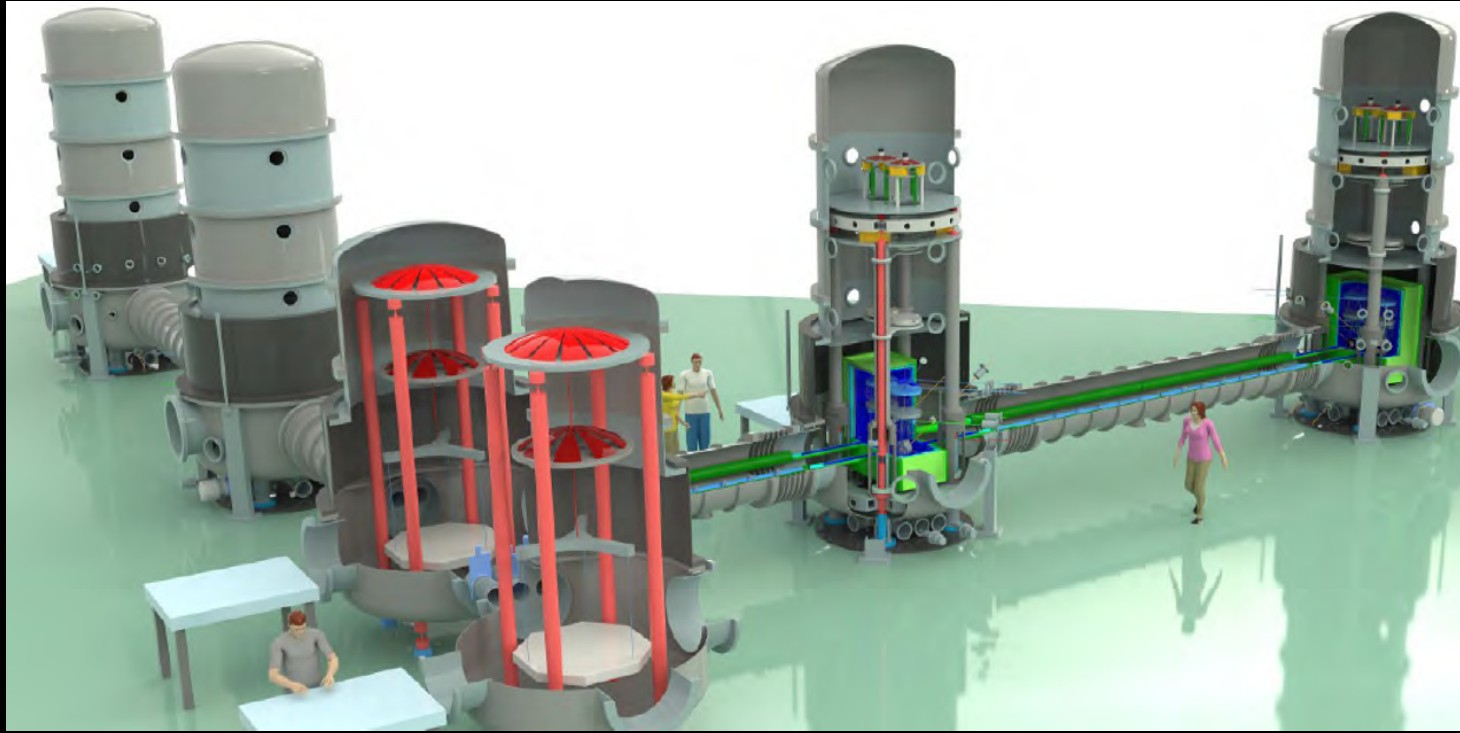
3. R&D on technology (95 M€) (funded)

Construction : 1900 M€ (in 10 years)

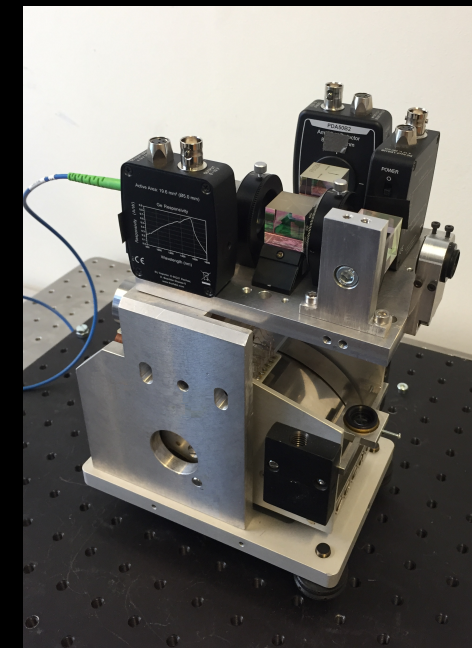
M&O : 37M€ /year

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

Ongoing R&D for ET (examples)

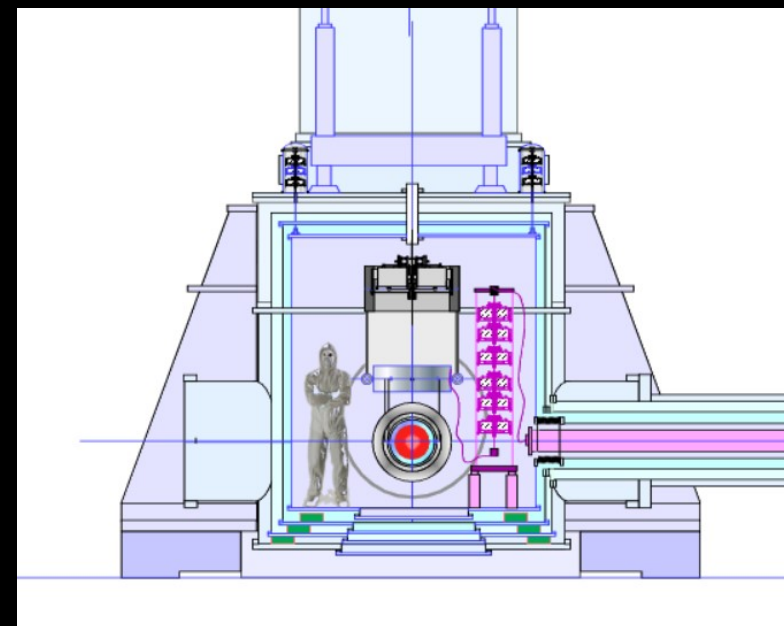


@ Maastricht small-scale prototype in order to study the operations in cryogenics with silicon optics at 1550 nm and with mirrors up to 100 kg (relevant for ET-LF)



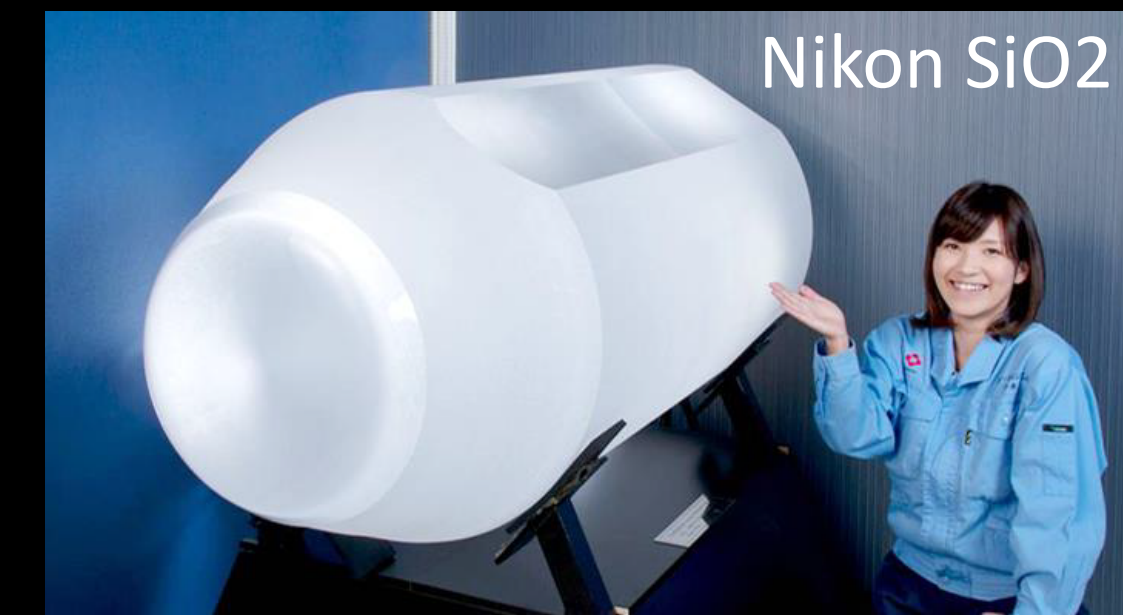
R&D in active mitigation of seismic / Newtonian noise

R&D on IR photo sensors

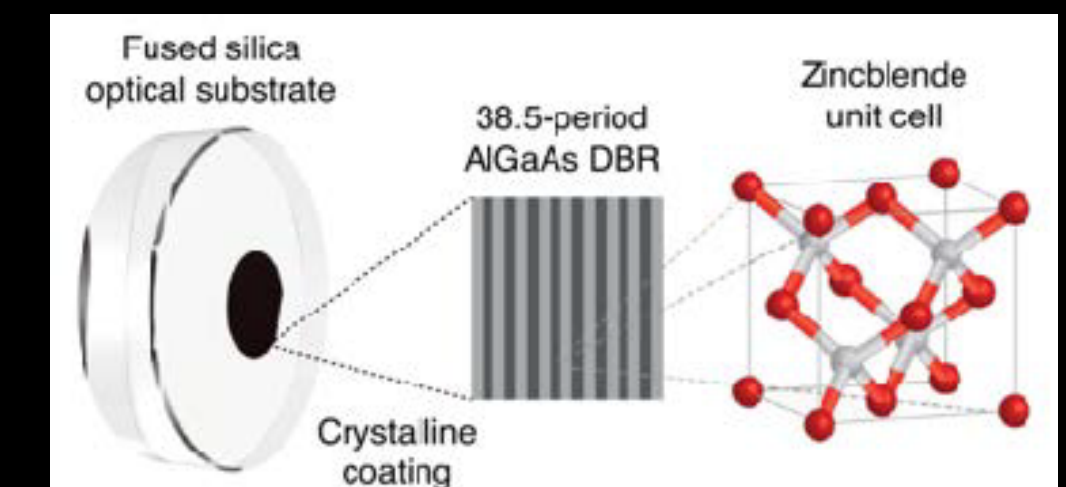
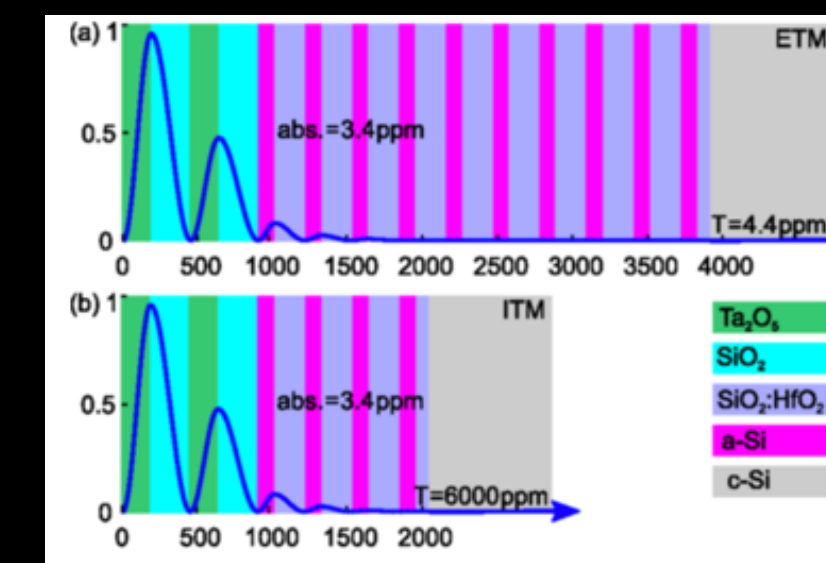


@ Rome and other R&D places in cryogenic suspension

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



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



AlGaAs crystalline coatings

Major R&D Facilities in ET (incomplete)

ET

EINSTEIN
TELESCOPE

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

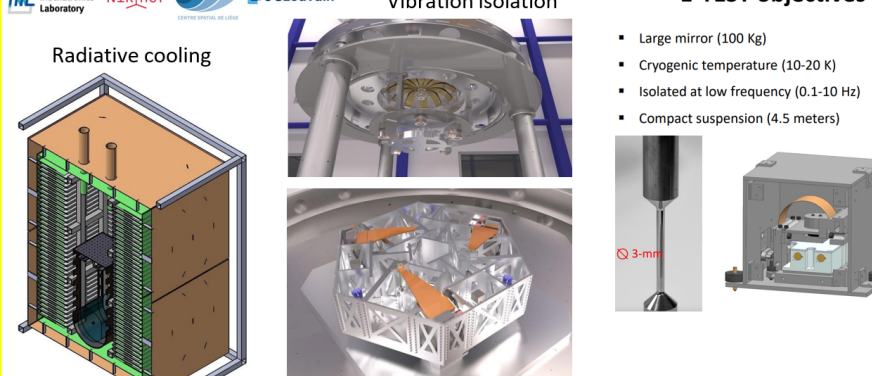
E-TEST : Einstein Telescope EMR Site and Technology

Vibration isolation

Radiative cooling

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)

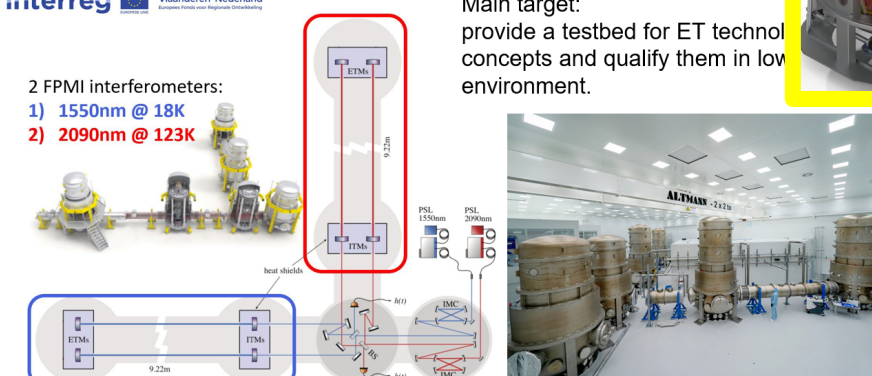


Etopathfinder in Maastricht

2 FPMI interferometers:

- 1) 1550nm @ 18K
- 2) 2090nm @ 123K

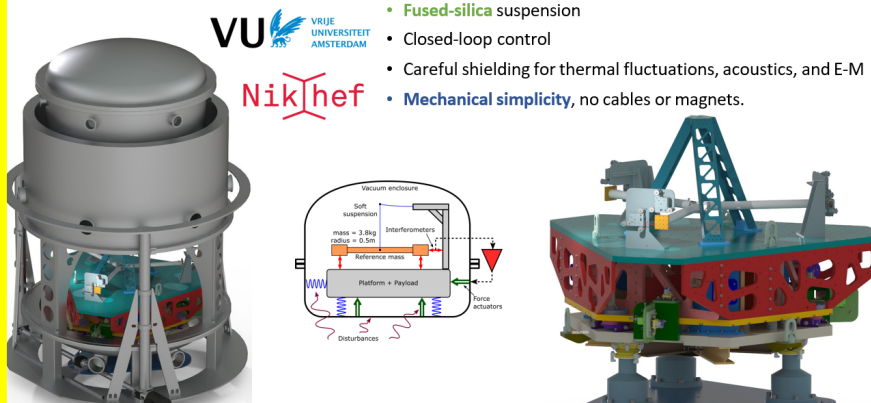
Main target: provide a testbed for ET technology concepts and qualify them in low environment.



Omnisense at Nikhef

VU Amsterdam

- 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.



VAIIGrav and Compact Laser Interferometry

GRAVITATIONAL WAVE DETECTION

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

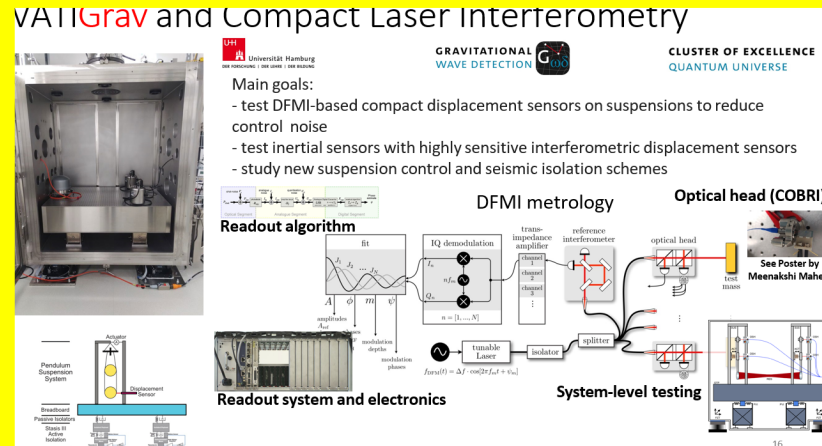
Readout algorithm

DFMI metrology

Optical head (COBR)

Readout system and electronics

System-level testing



The AEI 10 m Prototype Facility

Main goal: Sub- μ L interferometry

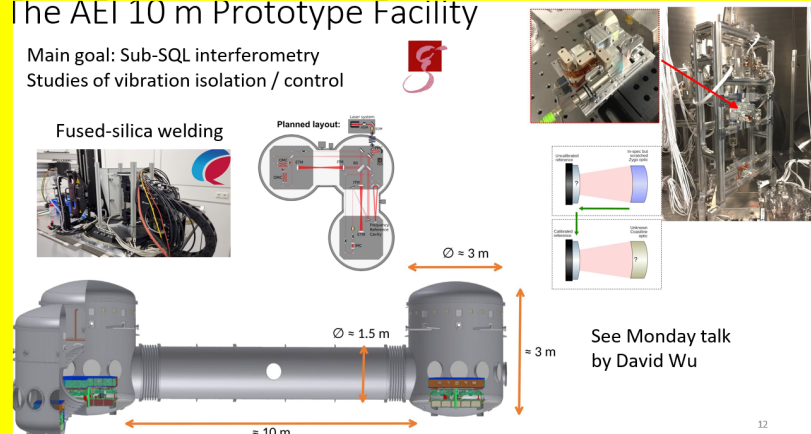
Studies of vibration isolation / control

Fused-silica welding

Planned layout:

- $\phi = 3$ m
- $\phi = 1.5$ m
- $\phi = 3$ m
- $\phi = 10$ m

See Monday talk by David Wu

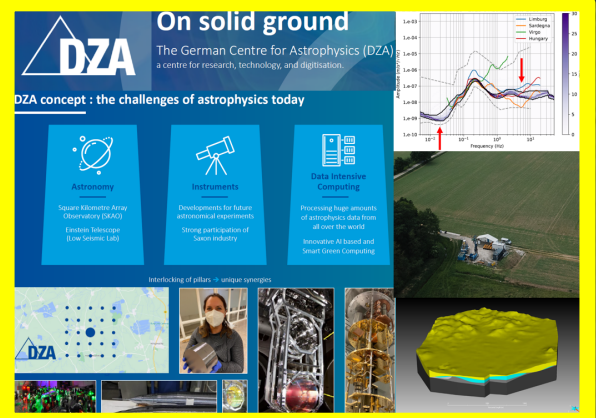


On solid ground

DZA

The German Centre for Astrophysics (DZA)

DZA concept : the challenges of astrophysics today



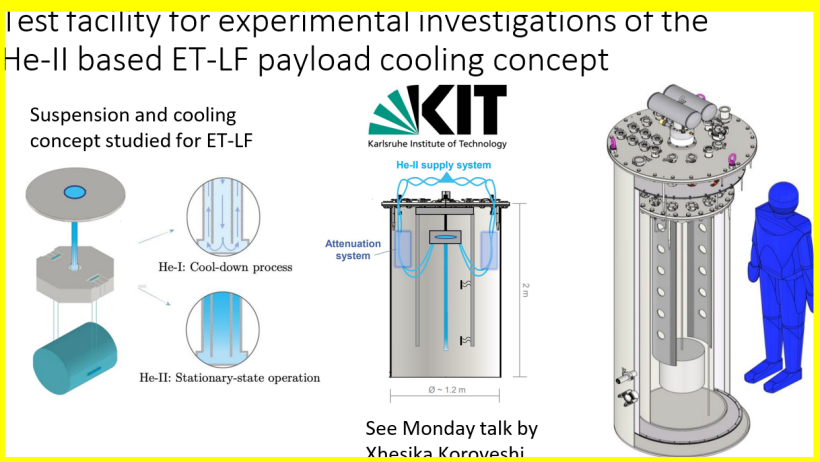
Test facility for experimental investigations of the He-II based ET-LF payload cooling concept

Suspension and cooling concept studied for ET-LF

He-II supply system

He-II: Stationary-state operation

See Monday talk by Xhesika Koroveschi



CoMEI - Coating Materials for Einstein Telescope

Goals:

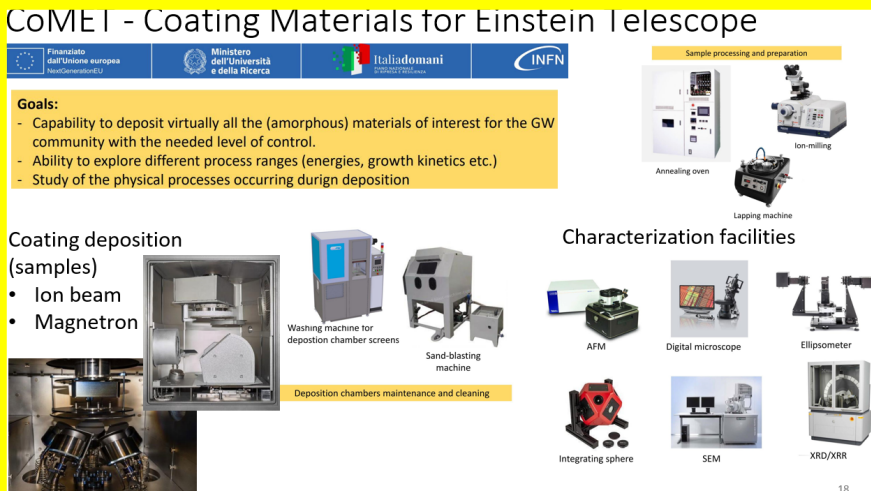
- Capability to deposit virtually all the (amorphous) materials of interest for the GW community with the needed level of control.
- Ability to explore different process ranges (energies, growth kinetics etc.)
- Study of the physical processes occurring during deposition

Coating deposition (samples)

- Ion beam
- Magnetron

Characterization facilities

- AFM
- Digital microscope
- Ellipsometer
- SEM
- XPS/VR



LMA - Laboratoire des Matériaux Avancés

Also investing into substrate growth and polishing

New large optics coater facility

Aim: produce ET cryo-compatible substrates in sapphire

Existing LMA building

Extension

2.2 x 2.2 x 2 m³

1 optic: ϕ 1.5 m/600 kg

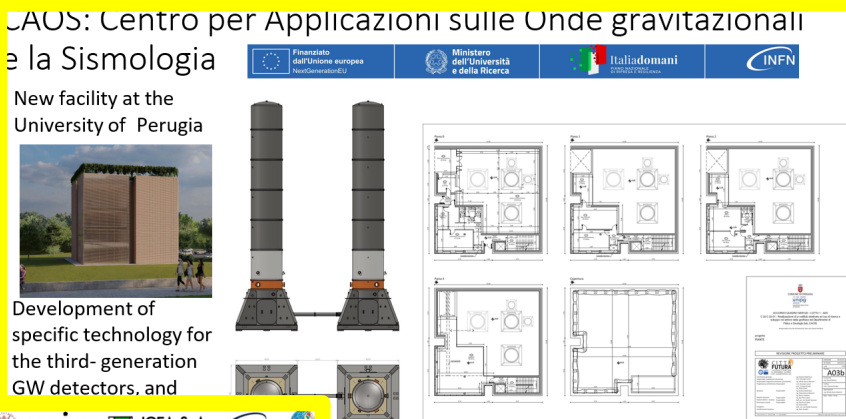
2 optics: ϕ 0.8 m/300 kg



CAUS: 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



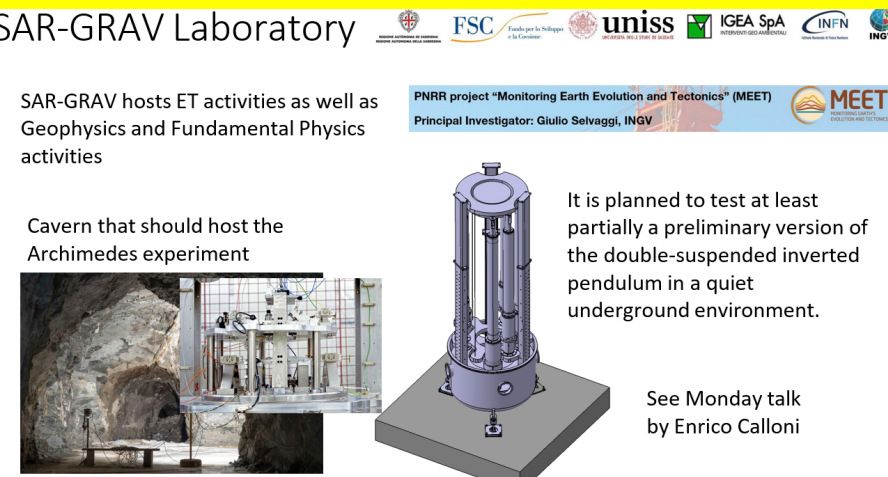
SAR-GRAV Laboratory

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

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

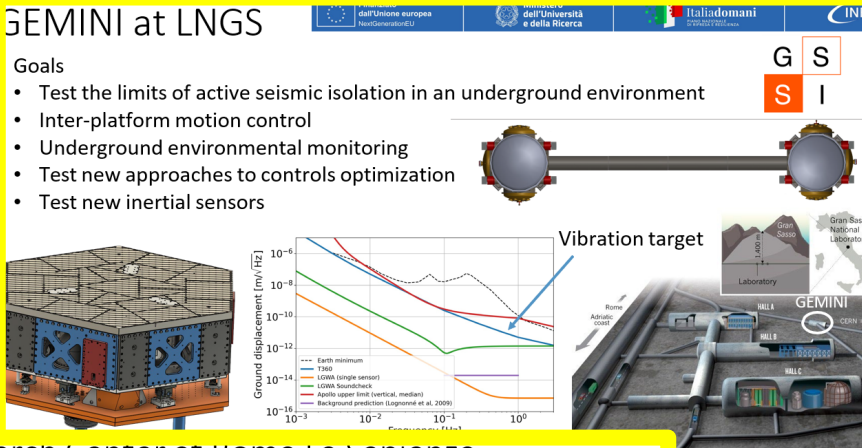


GEMINI at LNGS

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

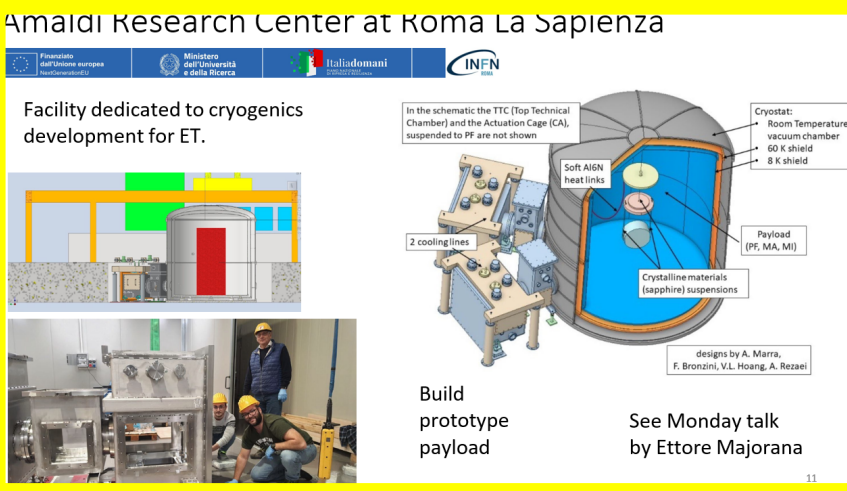


Amaldi Research Center at Roma La Sapienza

Facility dedicated to cryogenics development for ET.

Build prototype payload

See Monday talk by Ettore Majorana



Locations ?

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

@ Limburg area (border NL-B-D)

→ Promoted by Nikhef

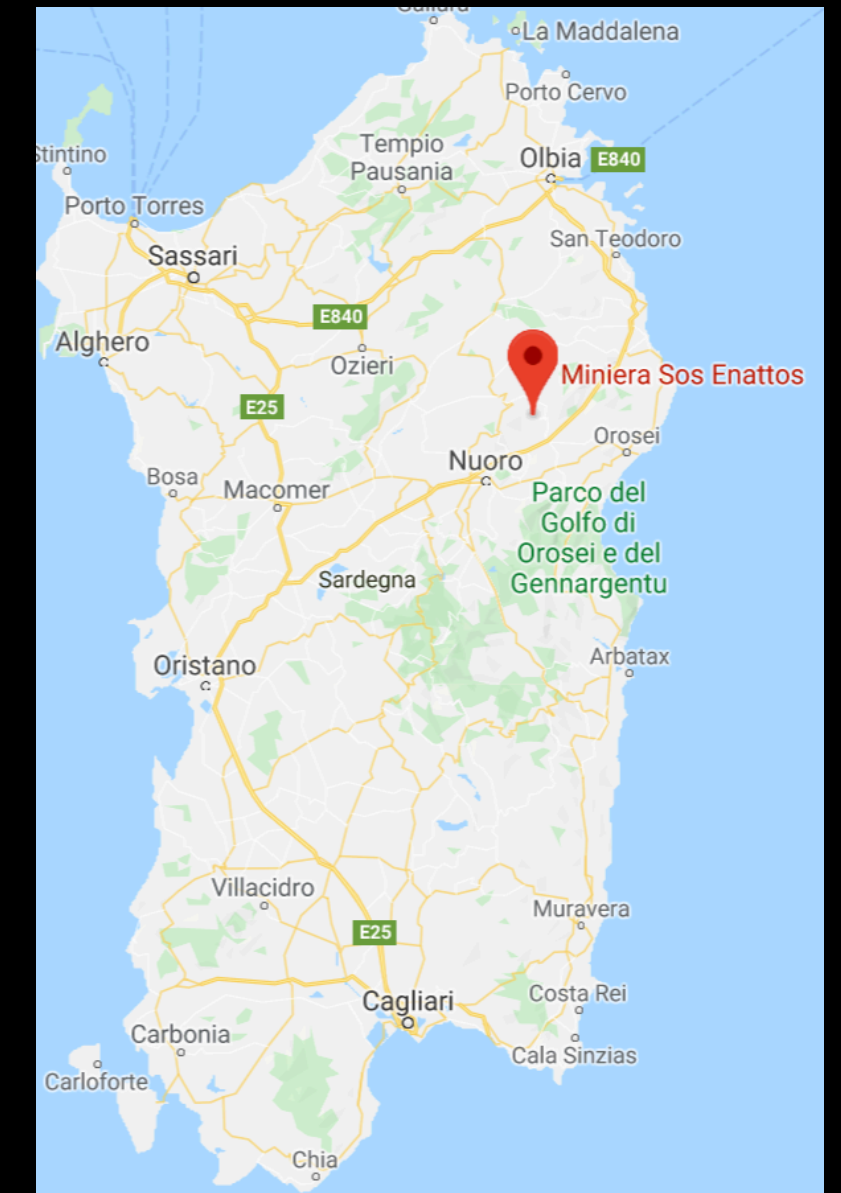


@ Germany is very present in ET and ETpathfinders
They foresee a large investment in the following years

→ 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



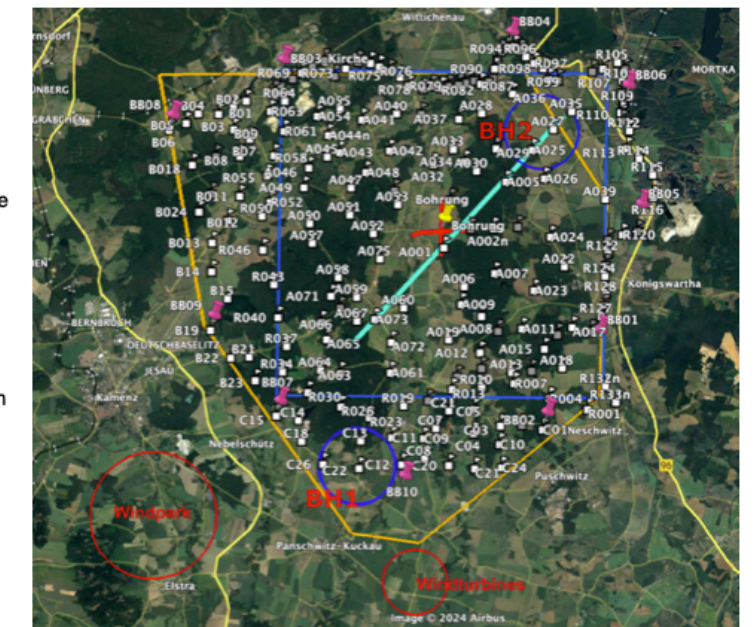
@ Sardinia

→ Promoted by INFN

What is currently happening in Lusatia

Extensive investigations for the DZA's Low Seismic Lab

- Passive seismological experiment for the determination of the 3D shear wave model
- Deploy 100 seismic stations to measure the temporal variation of seismic noise and operated for at least 1 year.
- Conduct high-resolution 2D reflection seismic surveys of geological structures
- Acquire 2 km long reflection seismic profiles and intersecting near the drilling location DZA-01 for calibration. Perform detailed studies at future drilling locations.
- Analysis of the physical parameters of the drill cores
- focusing on the Lusatian granodiorite and tectonic structures.
- Update the geological/hydrological map of the granite stock
- Develop a geological/tectonic model using data from the archive from the Lusatian Geological Survey.
- Measurement of seismic noise at three additional boreholes
- to qualify the spatial and temporal noise level in Lusatia.
- Integrated Lusatian subsurface model and characterization of seismic noise



@ 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 out a comprehensive study and push for a candidature

Time to discuss the level of financial involvement by other EU countries in ET for the following decade —> Spain ?

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 comuni.

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.

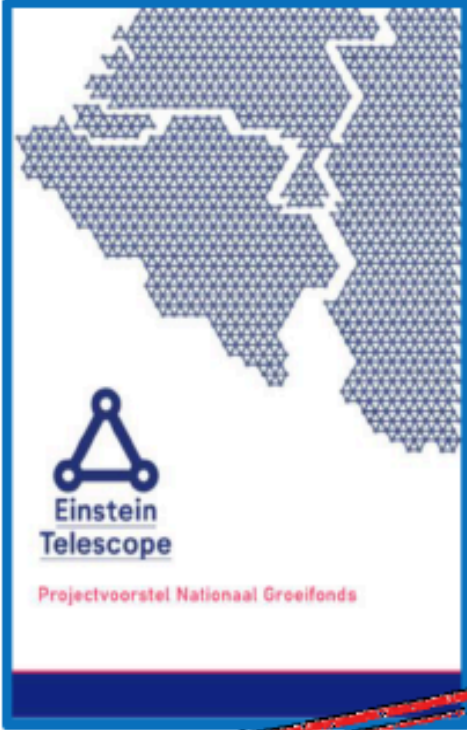


Einstein Telescope in Euregio Meuse-Rhine (EMR)



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 Institutions

APPROVED

In October 2022 the Netherlands submitted large funding proposal within context of the 'National Groeifonds'. Decision in April 2022.

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

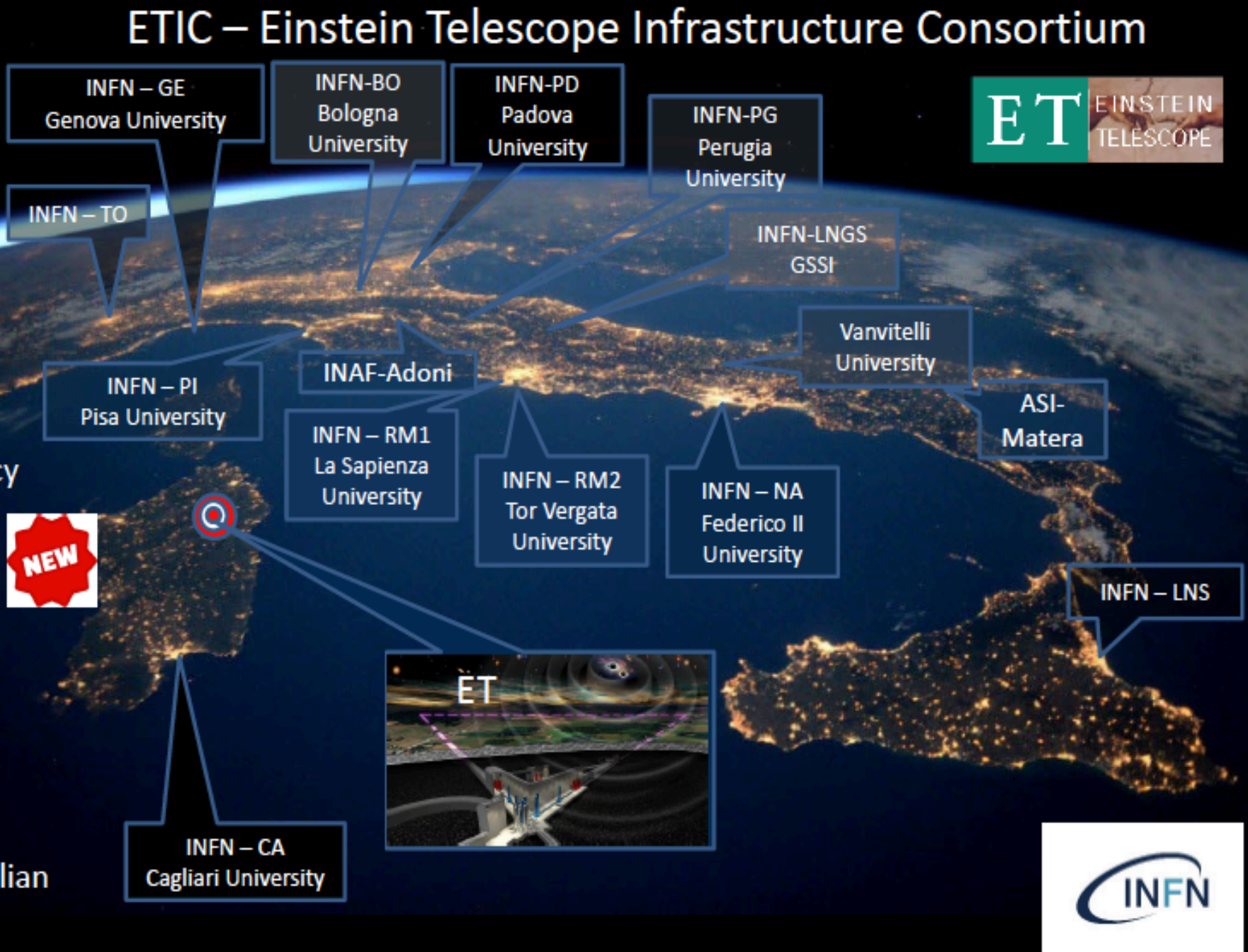
Next Generation EU Investment focused on ET enabling technology and Sardinian site candidature support

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

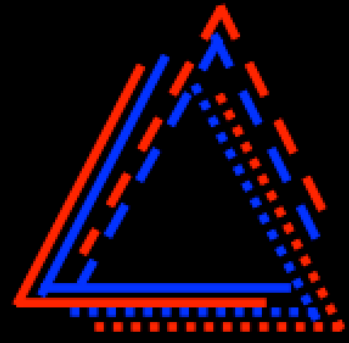
Budget 50M€ approved

Start of the project: 1st December 2022

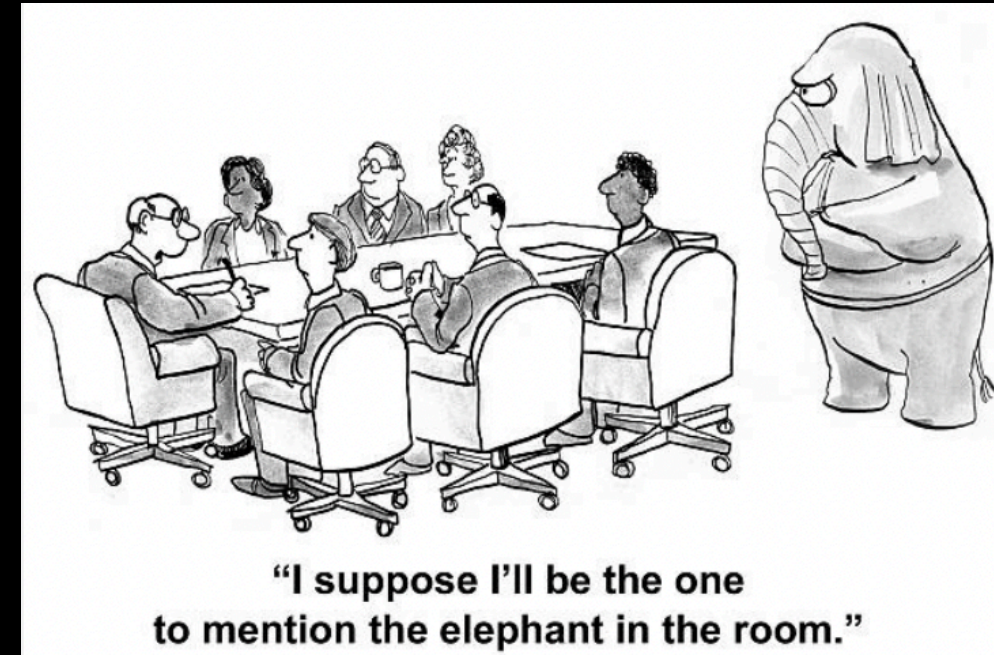
Discussion ongoing with the Italian Government on an Italian share toward ET realization



Layout discussion



Triangle 10 km



2L of 15 km

2L misaligned of 45°

Full sensitivity: HF+LF

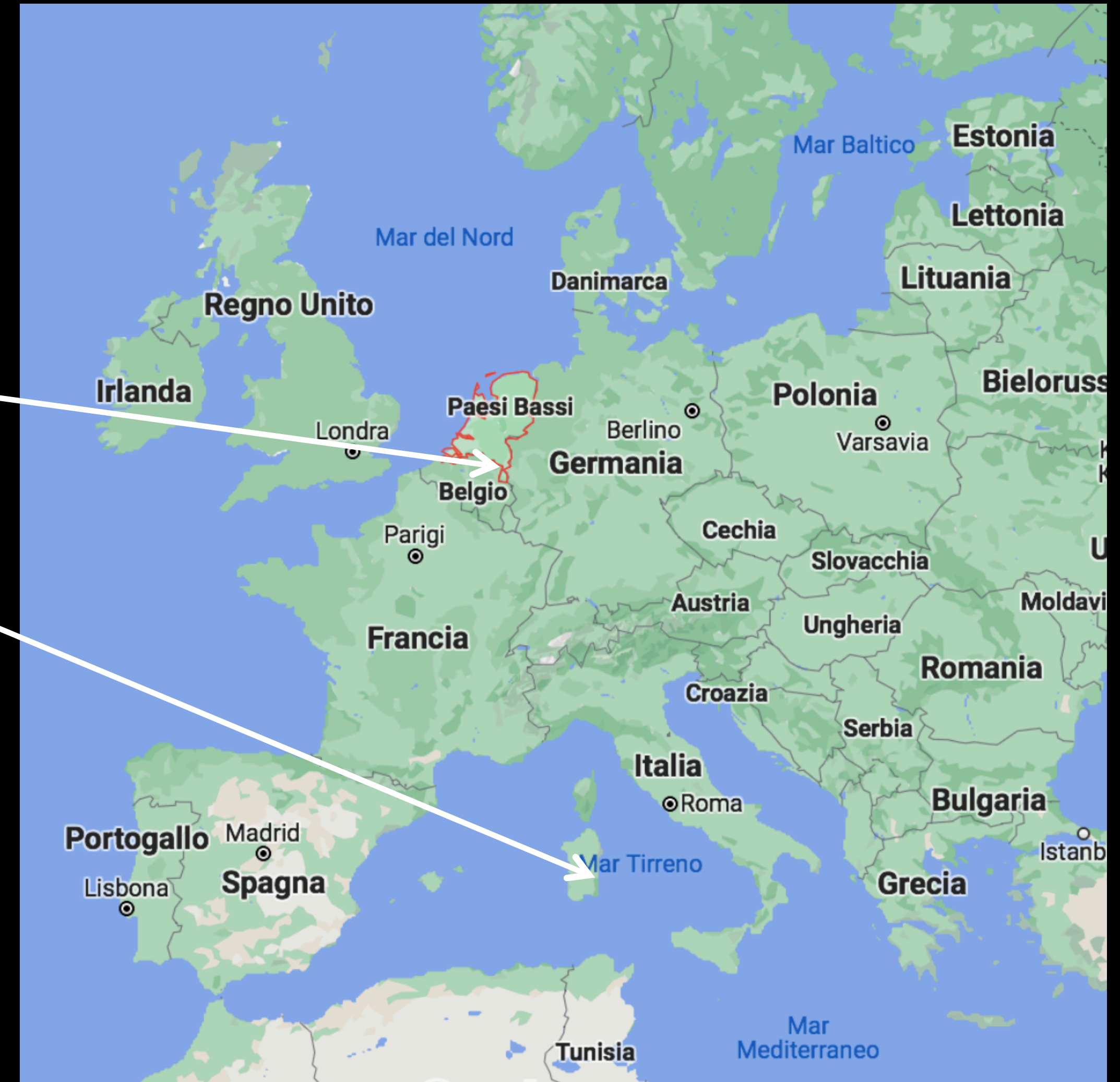
Only HF

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

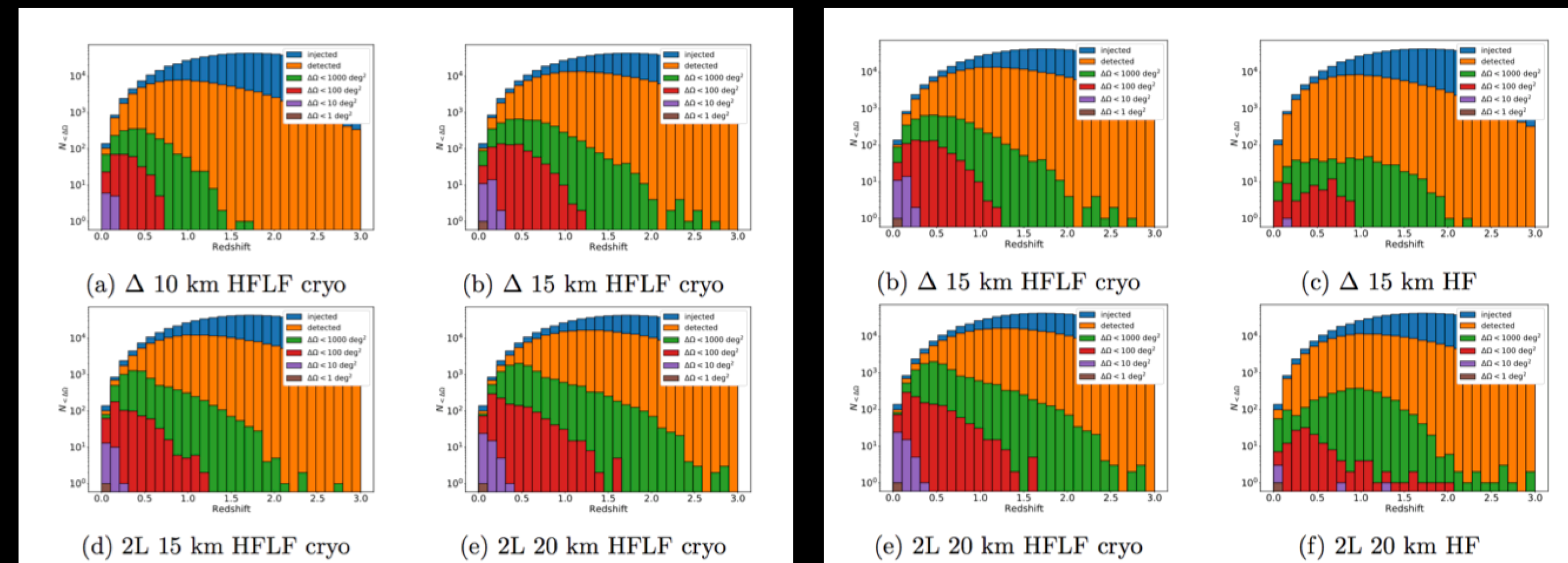
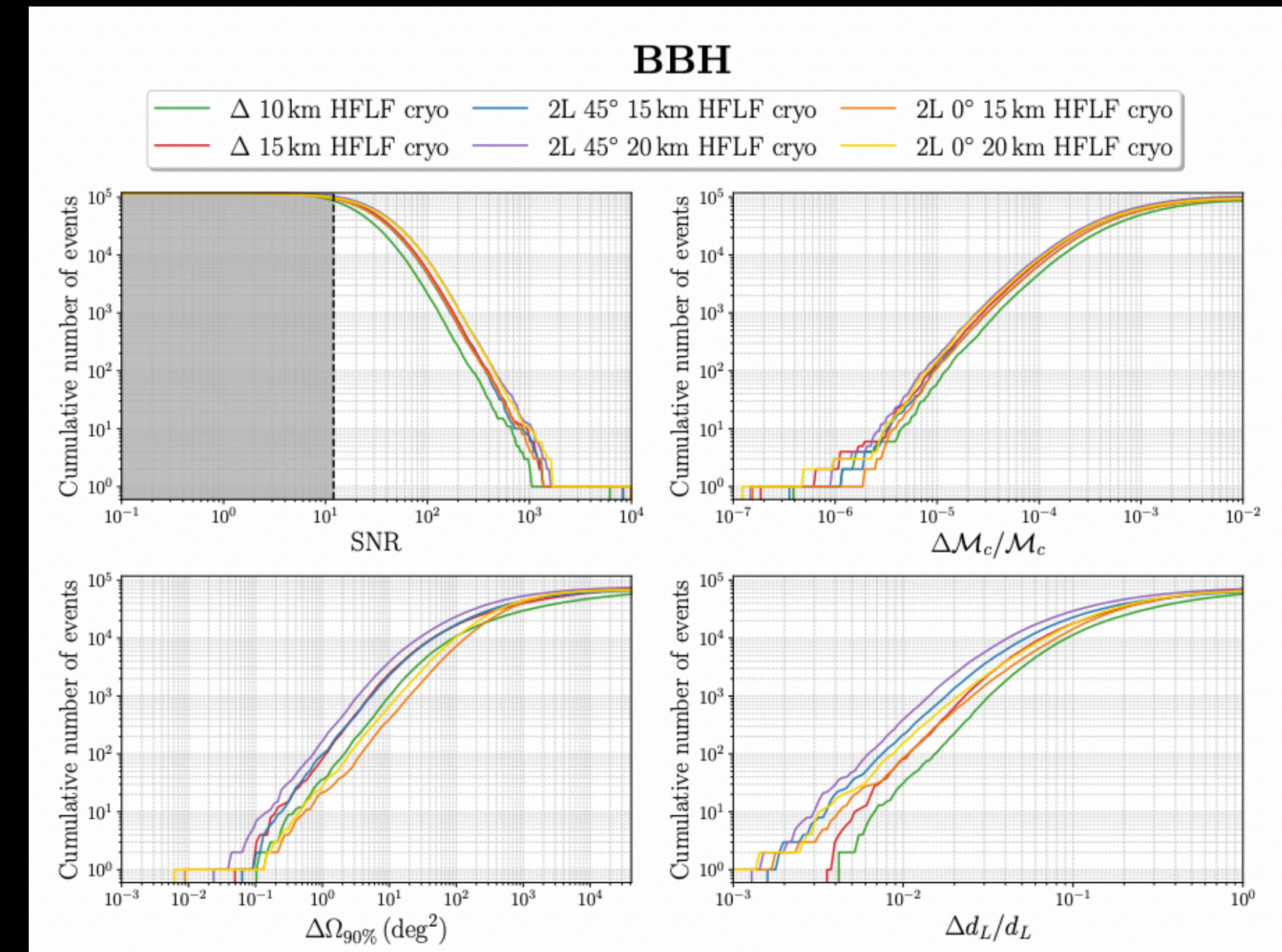


Comparative studies (only physics potential)

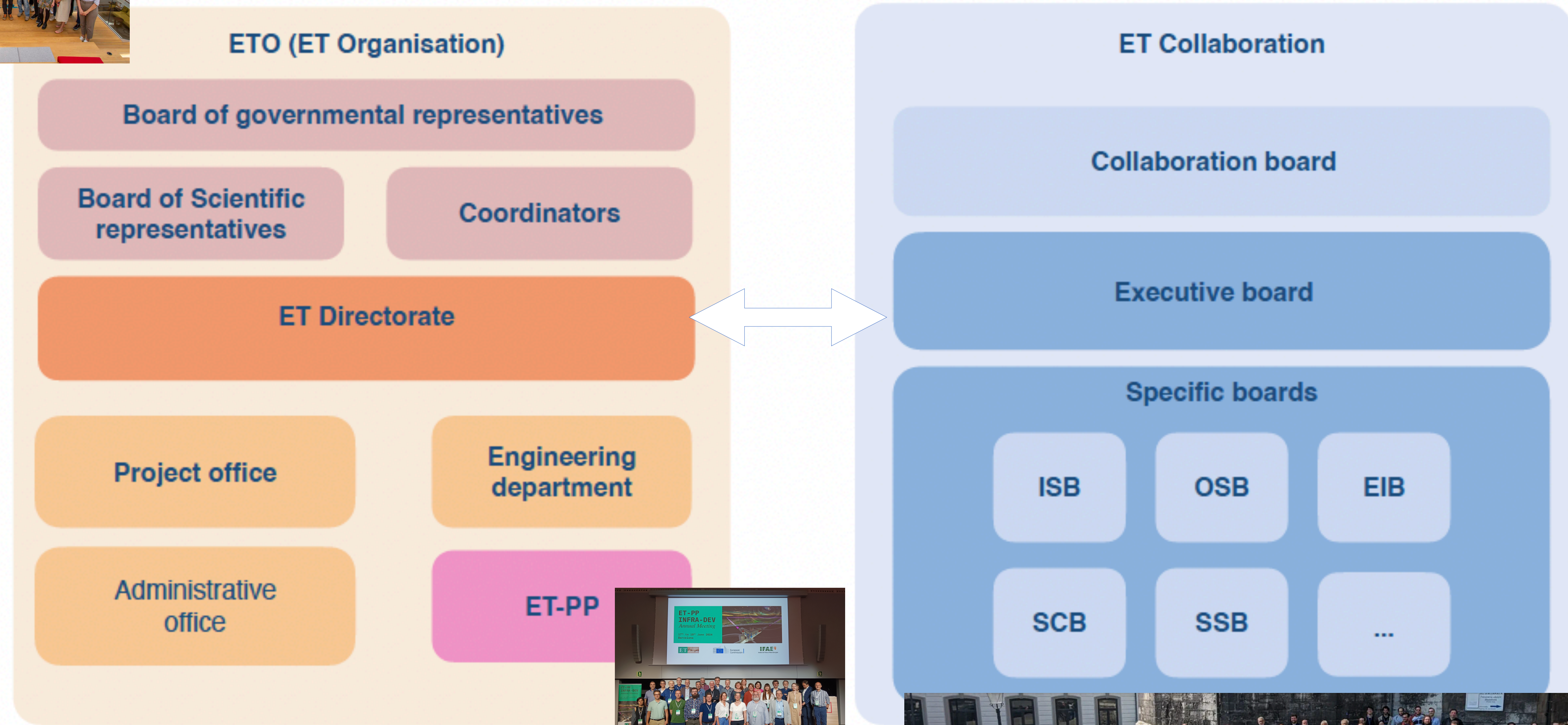
arXiv:2303.15923

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 $\Delta 10$ km
- Only LF makes BNS pre-merger alerts possible $\rightarrow$ impact on multi messenger
- Concerns about possible correlations in the Δ compromising stochastic searchers

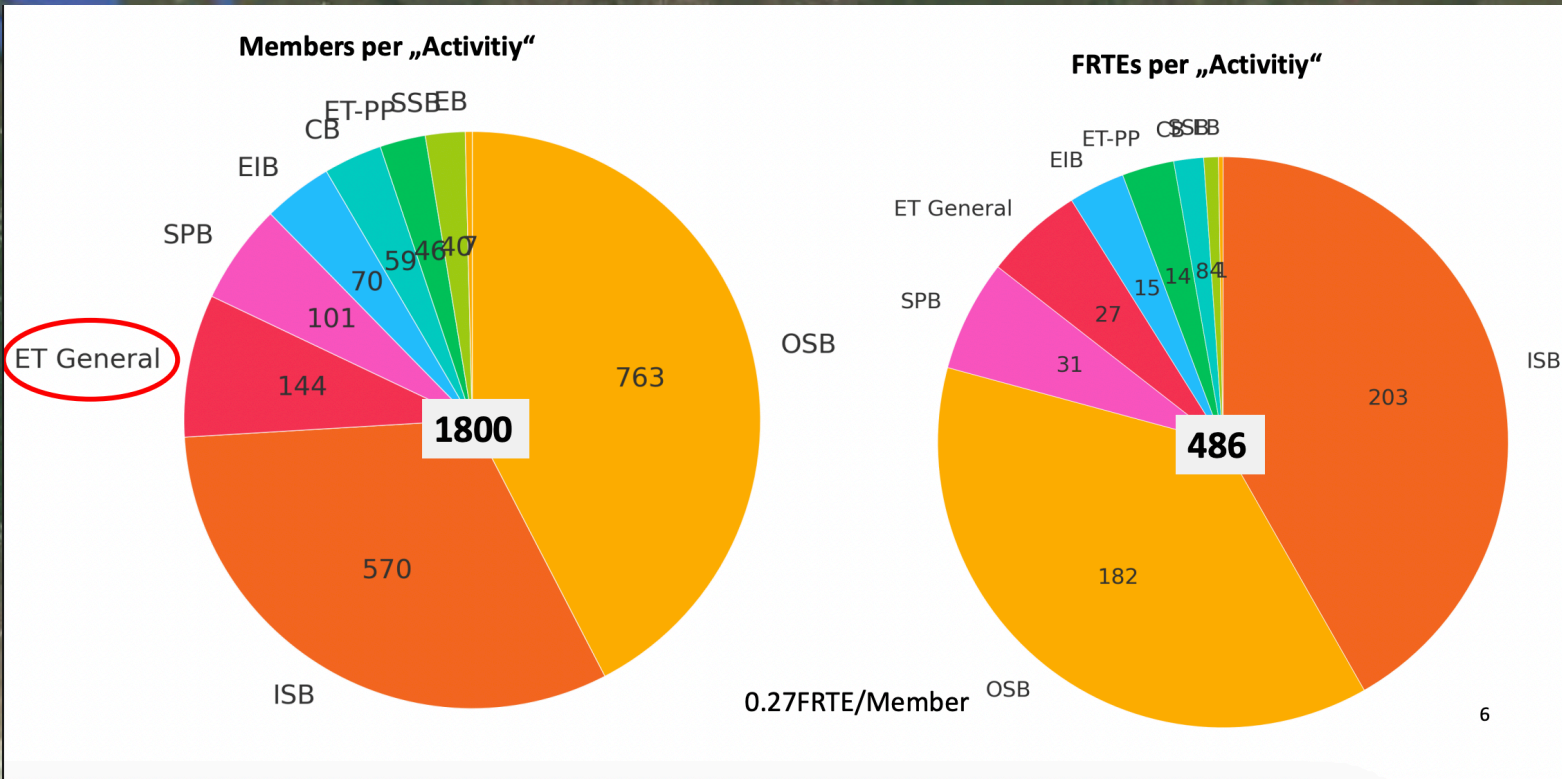
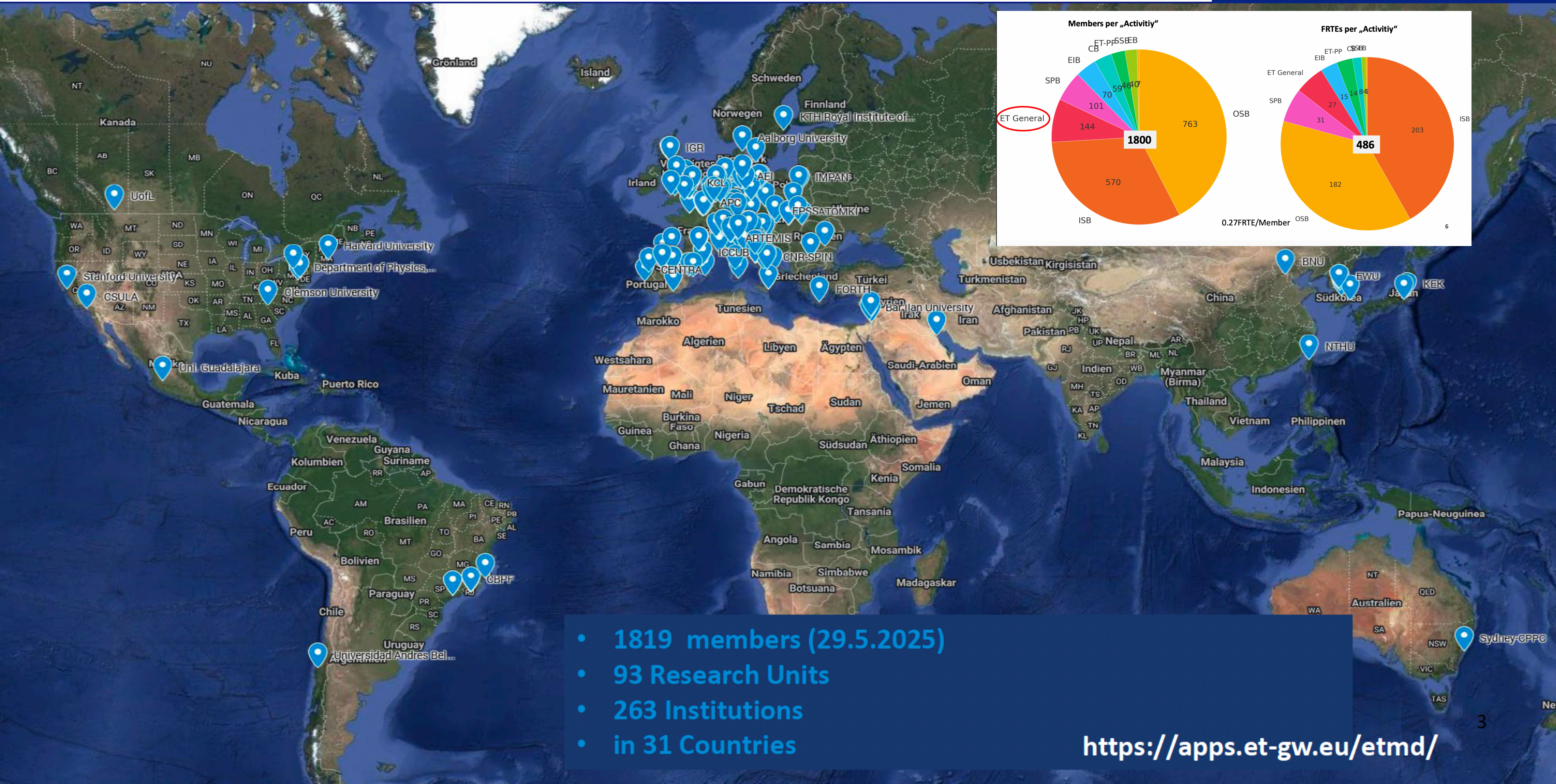
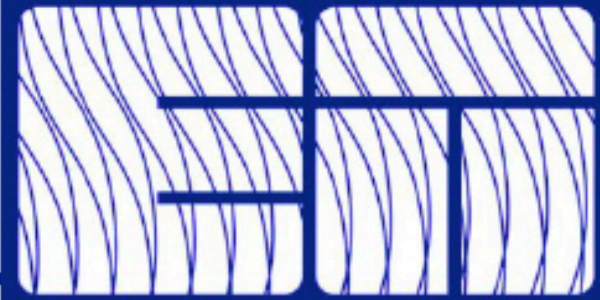


ET experiment and ET Organization



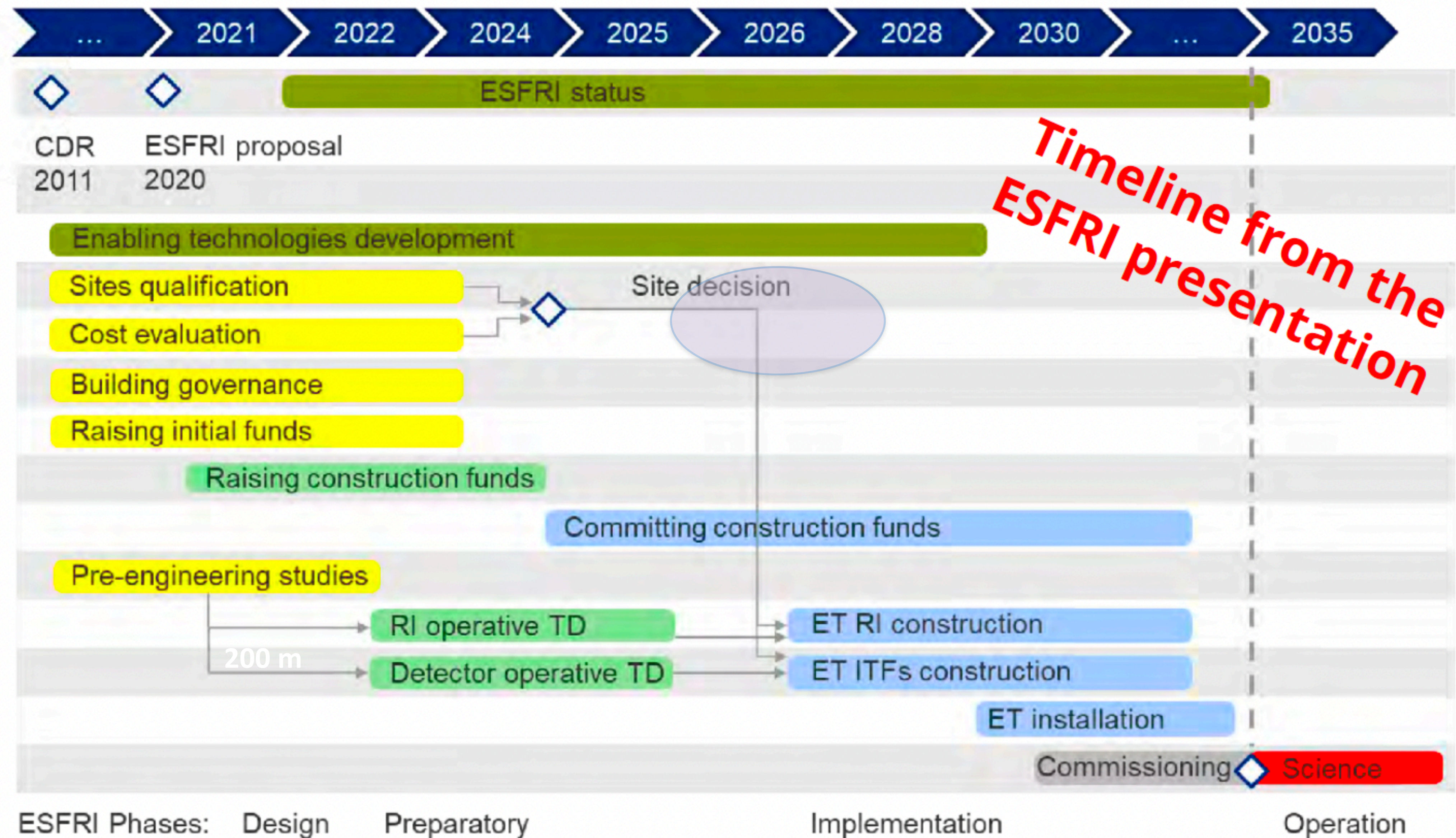
ET-PP is naturally framed inside ETO chart
ET research infrastructure, services, and vacuum system under ETO supervision
ET Scientific Collaboration dedicated to experiment design & scientific exploitation

ET Collaboration Member's Affiliation Map



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

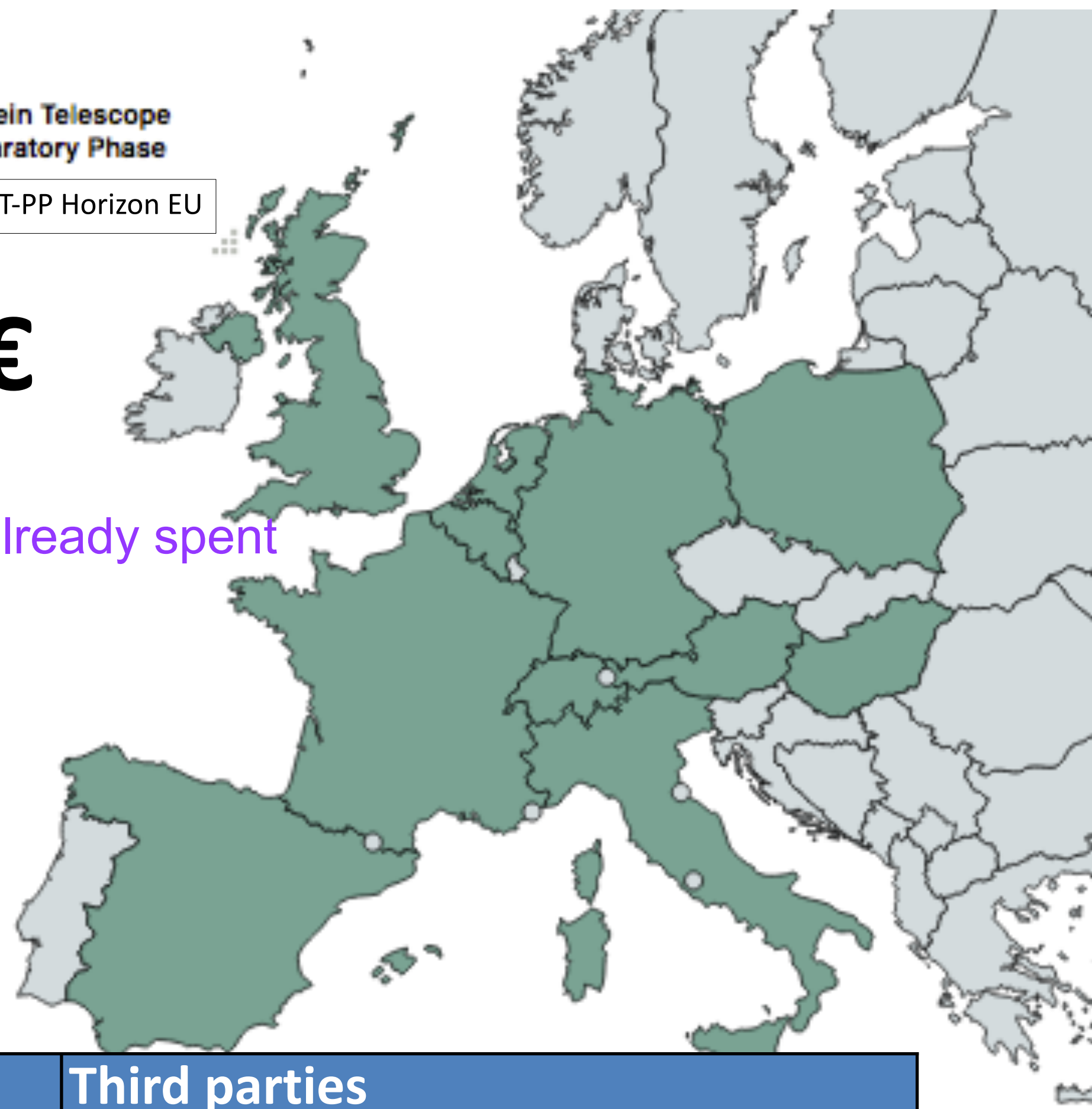
<https://apps.et-gw.eu/etmd/>



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€

> 50% funding already spent

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



European Commission

Funding & tender opportunities

SEARCH FUNDING & TENDERS

HOW TO

Preparatory phase of new ES

TOPIC ID: HORIZON-INFRA-2021-DEV-

Grant

General information

Topic description

Destination

Conditions and documents

Partner search

Submission service

Topic related FAQ

Get support

General information

Programme

Horizon Europe Fra

Call

Developing and co

leadership (2021)

Type of action

HORIZON-CSA HO

Deadline model

single-stage

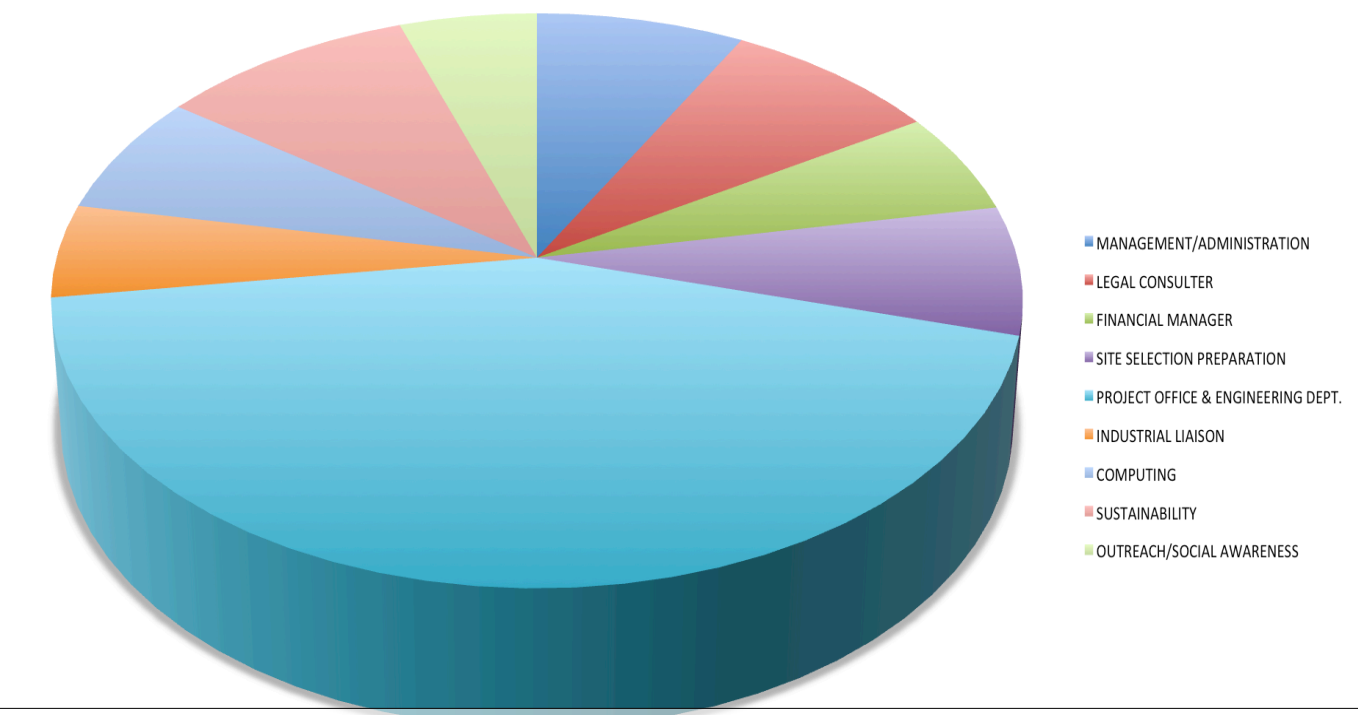
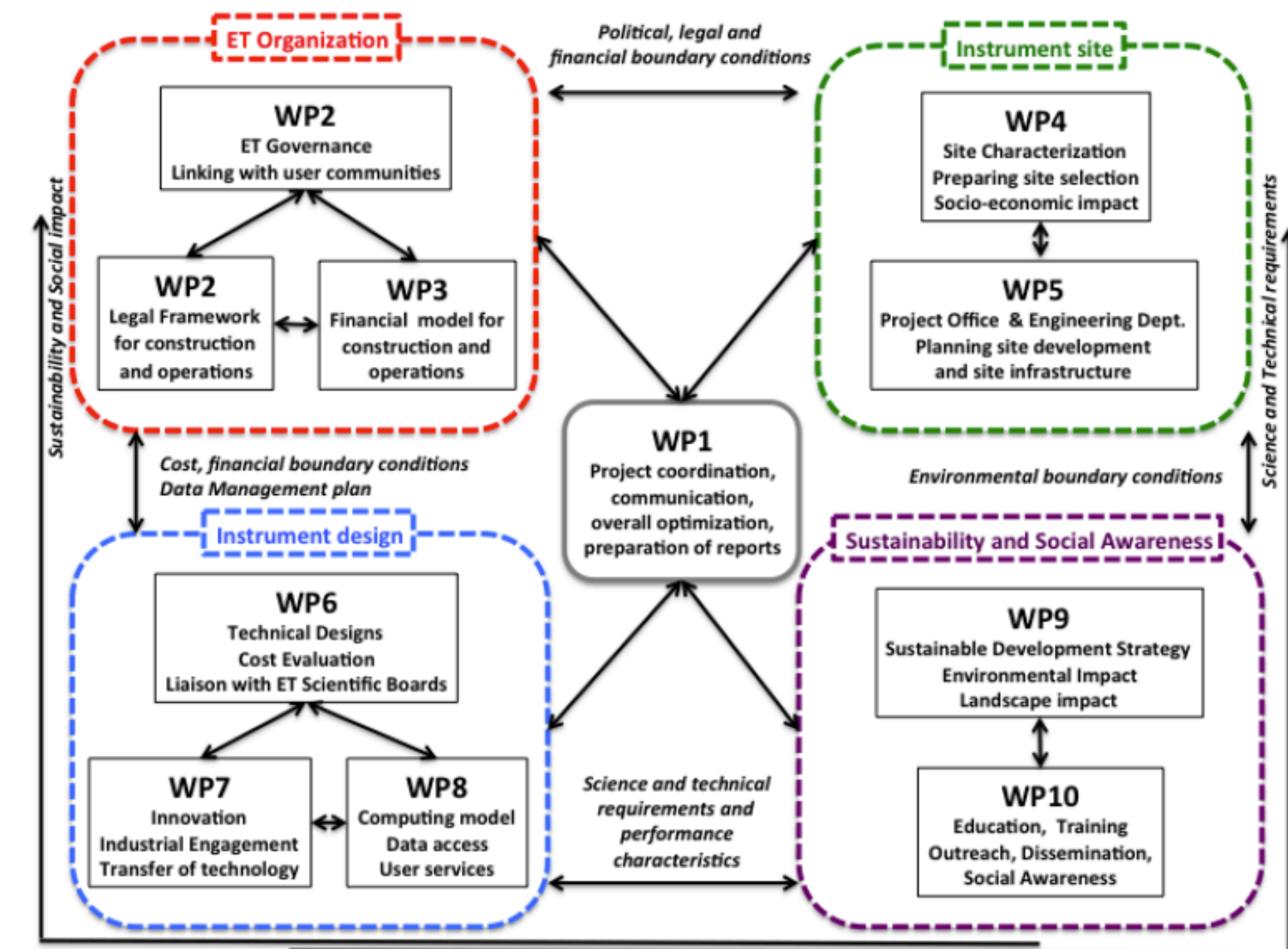
Go back to search results

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
→ <https://etpp.ifaes.es>

Work Packages (WPs)

- **WP1 Coordination and Management**
- **WP2 Organization, Governance and Legal Aspects**
- **WP3 Financial Architecture**
- **WP4 Site Preparation**
- **WP5 ETO - Project Office / Engineering Dept.**
- **WP6 Technical Design**
- **WP7 Transfer of Technology**
- **WP8 Computing and Data Access**
- **WP9 Sustainable Development Strategy**
- **WP10 Education, Outreach and Citizen Engagement**



A large fraction devoted to the creating of the Project Office/ Engineering Department (44%)

Funding for expert consulting on legal and financial aspects, socio-economic impacts, site selection related studies

Significant funding for sustainability studies

Funding for ET-PP management, KTT, Computing model, and Outreach/Communication

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 Funcional 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



Mario Martínez
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Fernando Ferroni
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Justin O'Byrne
United Kingdom Research And Innovation (UKRI)





Miriam E.H. Roelofs
Nikhef





Dorota Rosinska
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
Istituto Nazionale Di Fisica Nucleare (INFN)





Harald Lück
Albert Einstein Institut & Institut für Gravitationsphysik der Leibniz Universität Hannover





Paolo Chiggiato
European Organization for Nuclear Research (CERN)





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Nicolas Arnaud
Centre National de la Recherche Scientifique (CNRS)





Veronica Buccheri
Istituto Nazionale Di Fisica Nucleare (INFN)





Vincenzo Napolano
European Gravitational Observatory (EGO)





Robert Galler
Montanuniversitaet Leoben



Latest developments in ET-PP consortium

- Following developments in Germany and Lusatia there is an increasing interest of DESY to have deeper involvement in ET-PP
- Conversations with DESY progressing very well for an enhanced German involvement in ET-PP
 - New WP4 [site characterisation] co-coordinator already appointed and integrated in activities & acting as Lusatia liaison
 - New expert from DESY on sustainability will assist WP9 [sustainability] efforts
 - Planning for enhanced participation in WP3 [financial model](DESY already co-coordinating)



Andreas RietBrock (KIT)



Denise Voelker (DESY)

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

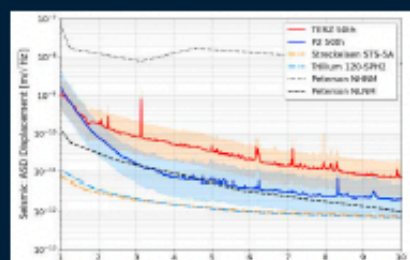
Geological studies

Site monitoring

Noise impact Evaluation

Engineering studies



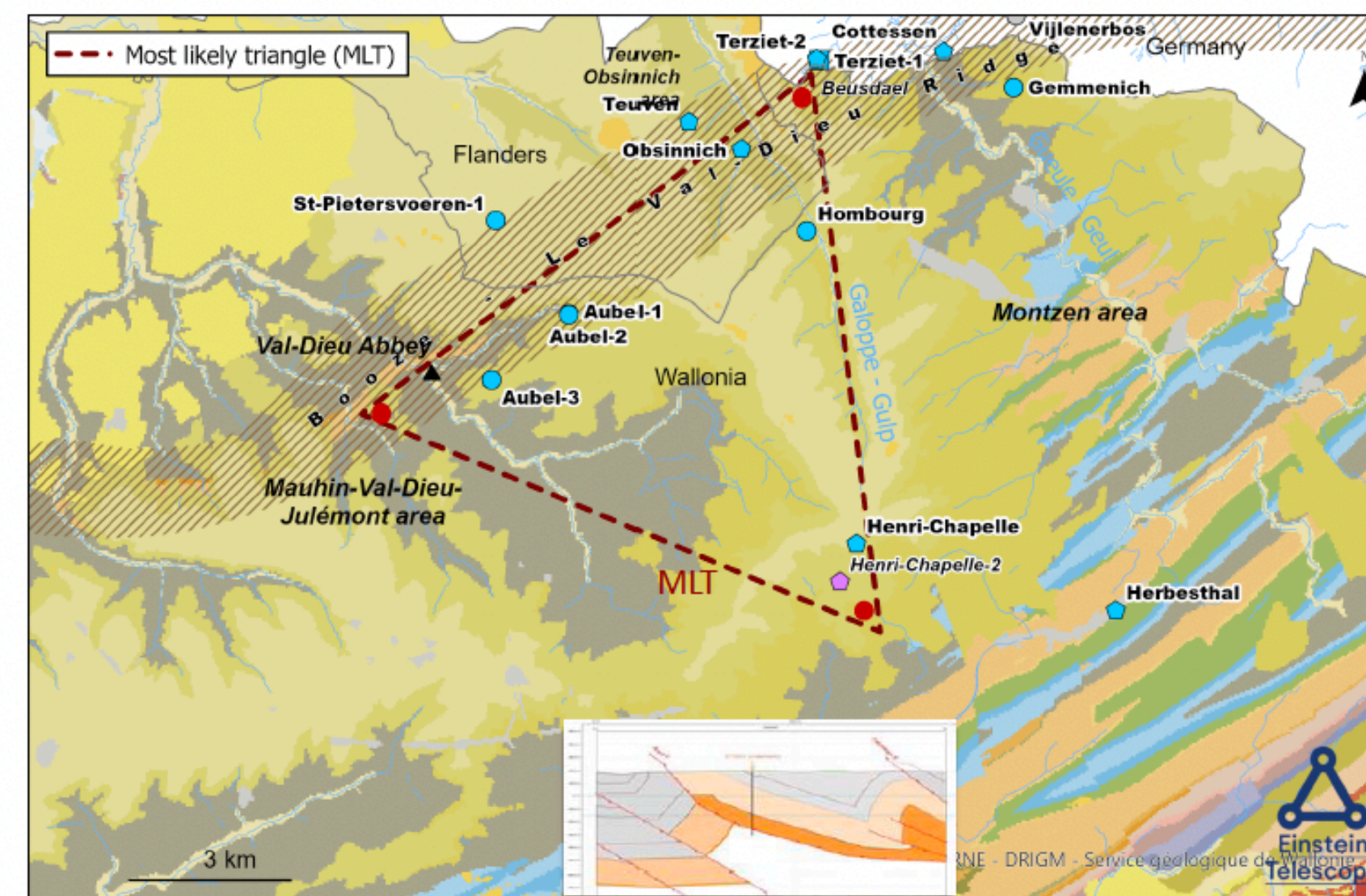





From the geological and physical point of view, Sardinia is an optimal candidate to host the Einstein Telescope, either in Δ or in L ($\rightarrow$ 2 sites) configuration!

Most Likely Triangle – based on current knowledge

Presentations: Bjorn Vink, Marc Boxberg, Wim Walk



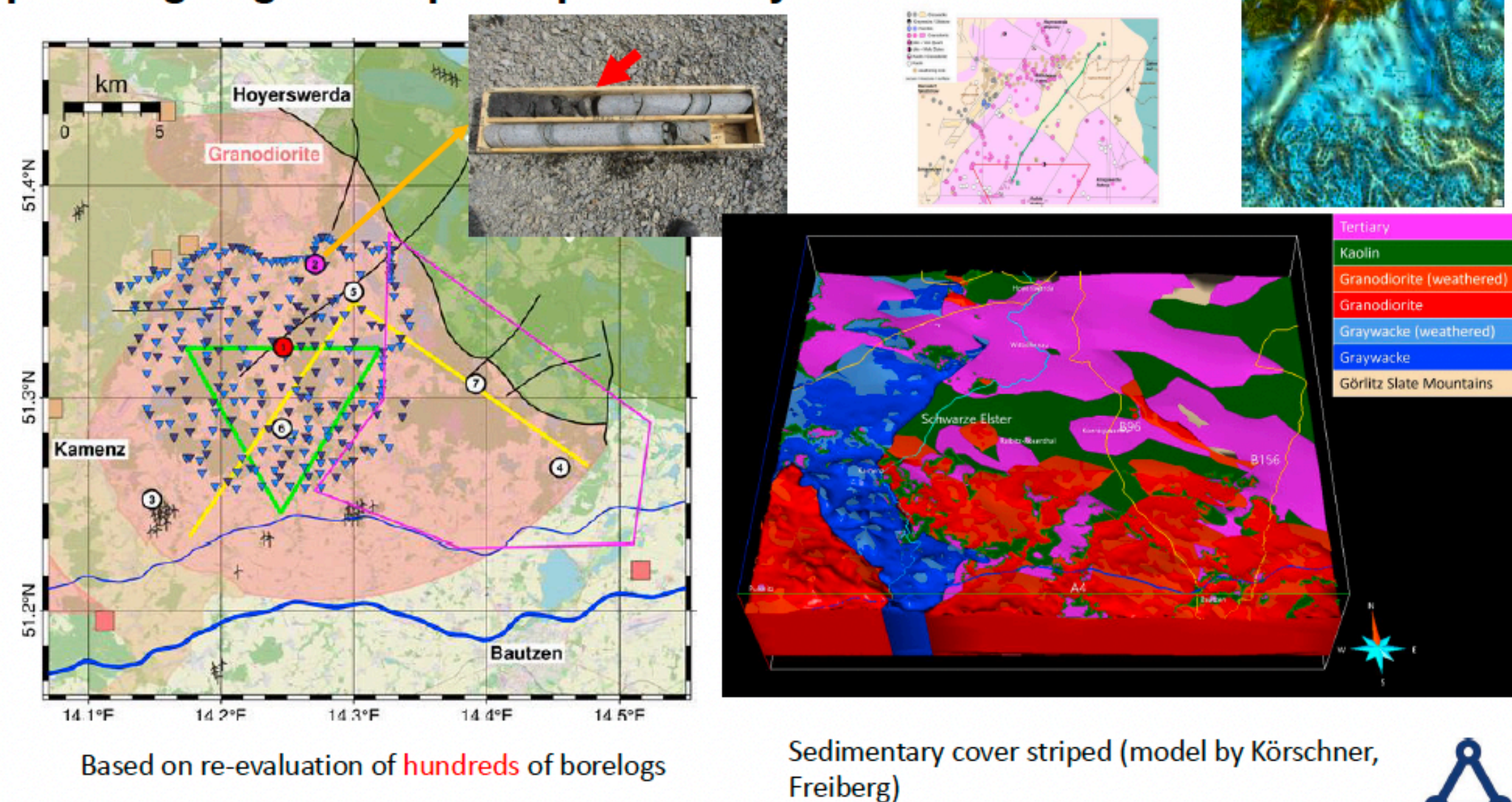
MLT location and depth convergence based on:

- 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 geological map and preliminary 3D model



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

$\rightarrow$ Difficult to say when the decision on geometry and site(s) will take place

$\rightarrow$ Very difficult political process with high level negotiations taking place

EMR-TETI civil engineering - Timelines

Example 1: Civil engineering (with CERN)

Timeline		2023				2024				2025				2026			
Activities	Dur (mon)	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	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

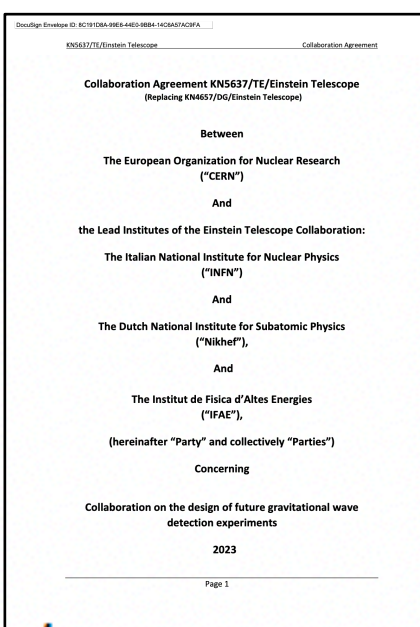
Sardinia site

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

Preliminary dates that will still change!



Working with CERN



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

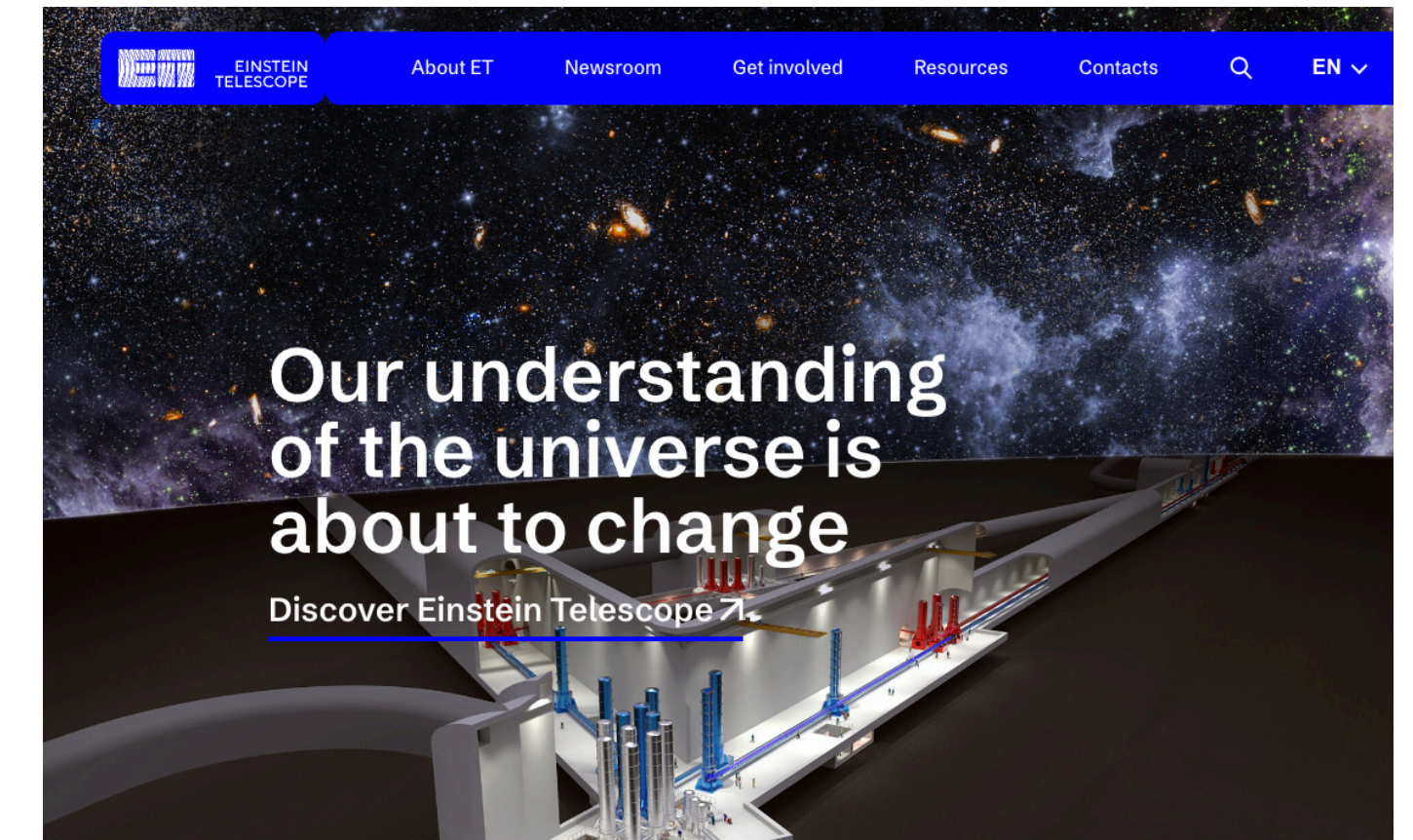
- **Vacuum pipe:** governed by an MOU between CERN, INFN, Nikhef and IFAE, CERN has started a dedicated activity to deliver the technical design report for the vacuum pipe in 2025. Currently a prototyp station is being built at CERN, supported by a large and efficient team.
- **Civil engineering:** an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

Summary of ET-PP achievements

Highlights

- ET-PP seed money funding ETO allows forming the partnership for the early in-kind contributions
- Functional ETO - Project office and Engineering Dept in place
- New established ET identify in place and a new Web site coming along very soon
- ET Communication office emerging making ET very visible in the public domain
- ET Refined Science Case Document released (Blue Book) by ET Collaboration
- Vacuum Pipe TDR v1 released under the ETO supervision
- New ET Optical Layout as driven by ETO
- Multiple solid documents on KTT, Innovation and Industrial returns in place
- Multiple solid documents on Computing Requirements in place
- Multiple solid documents on communication and outreach strategy in place
- Key Documents from the Candidate Sites and Sustainability Planning in place



<https://einsteintelelescope.eu>



ET Vacuum Pipe TDR

As coordinated by CERN —> a history of great success

Preparatory Phase for the Einstein Telescope Gravitational Wave Observatory

2nd review meeting (RP2) — 15.05.2024

WP 6.2: Deliverables and milestones (2)

Pilot sector: from conceptual design to installation

Test of support installation and alignment in TT4

Installation of the extremity support in TT4

Fabrication and installation

Compensation bellows in the CERN's vacuum firing furnace

ET EINSTein TELESCOPE

Project: 101079696 — ET-PP, 2nd review meeting

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Preparatory Phase for the Einstein Telescope Gravitational Wave Observatory

2nd review meeting (RP2) — 15.05.2024

WP 6.2: Deliverables and milestones (3)

Pilot sector: from conceptual design to installation.

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

Fabrication and installation

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

ET EINSTein TELESCOPE

Project: 101079696 — ET-PP, 2nd review meeting

11

- 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).

Preparatory Phase for the Einstein Telescope Gravitational Wave Observatory

2nd review meeting (RP2) — 15.05.2024

WP 6.2: Deliverables and milestones (1)

Pilot sector: from conceptual design to installation

Conceptual design

Technical design

ET EINSTein TELESCOPE

Project: 101079696 — ET-PP, 2nd review meeting

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Collaboration Agreement KNS637/TE 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

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												

Preparatory Phase for the Einstein Telescope Gravitational Wave Observatory

2nd review meeting (RP2) — 15.05.2024

Expected technical results and achievement in 2025:

WP 6.2: Deliverables and milestones (6)

Pre-TDR

Outgassing rate of small valves finished

Assembly by sleeves tested with the mock-up.

Firing of the bellows

Background system ready

Start of background measurements

Start of tests with the 36-m pipe

Start of purchasing procedure for alternative tubes (pilot sector v. 2)

Support installation in TT4

Assessment of welds made by the tube supplier

Vacuum tube elements delivered at CERN.

Proposal of alternative supports and joining methods

Beginning of vacuum tube finishing

Q1-2025

Q2-2025

Q3-2025

Q4-2025

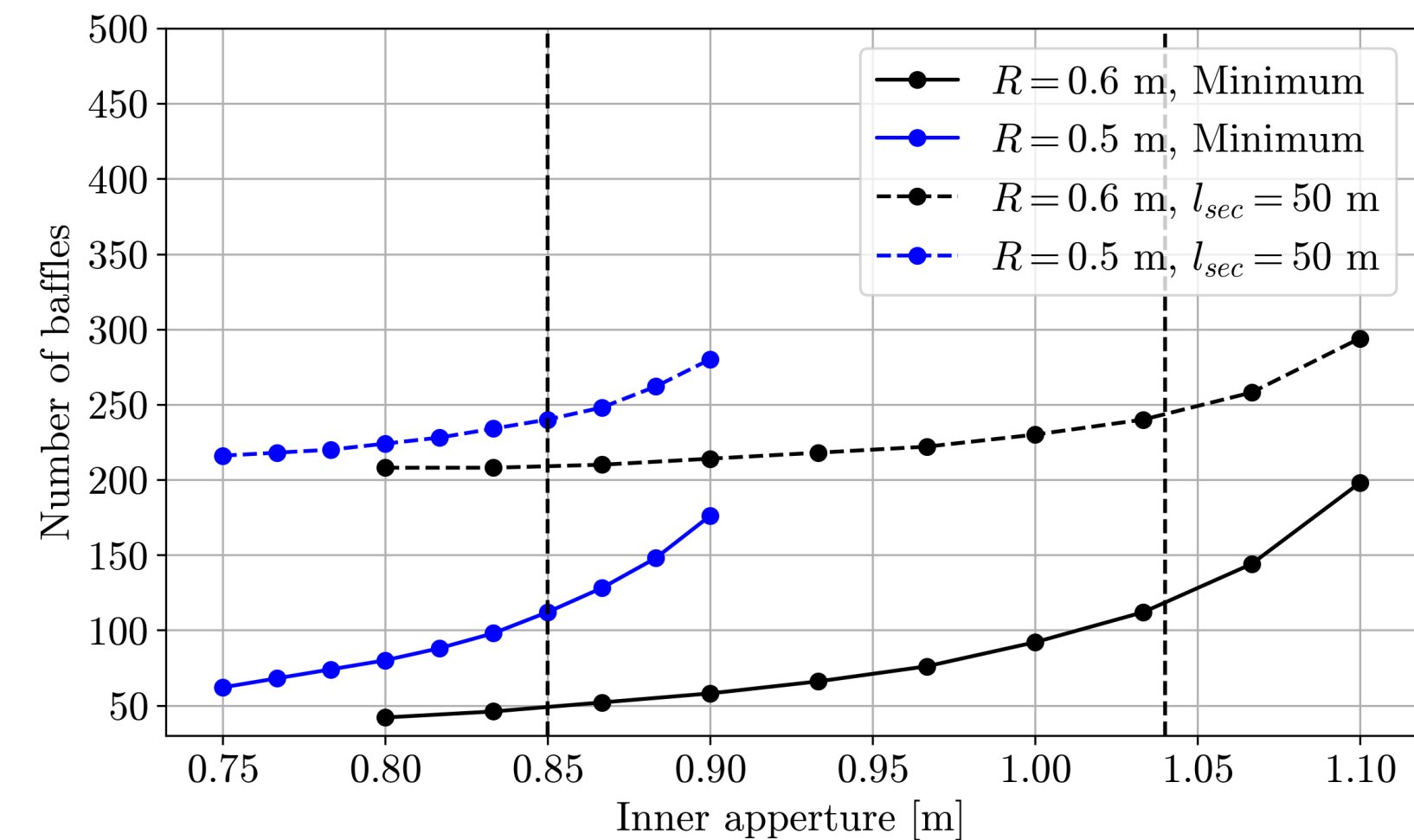
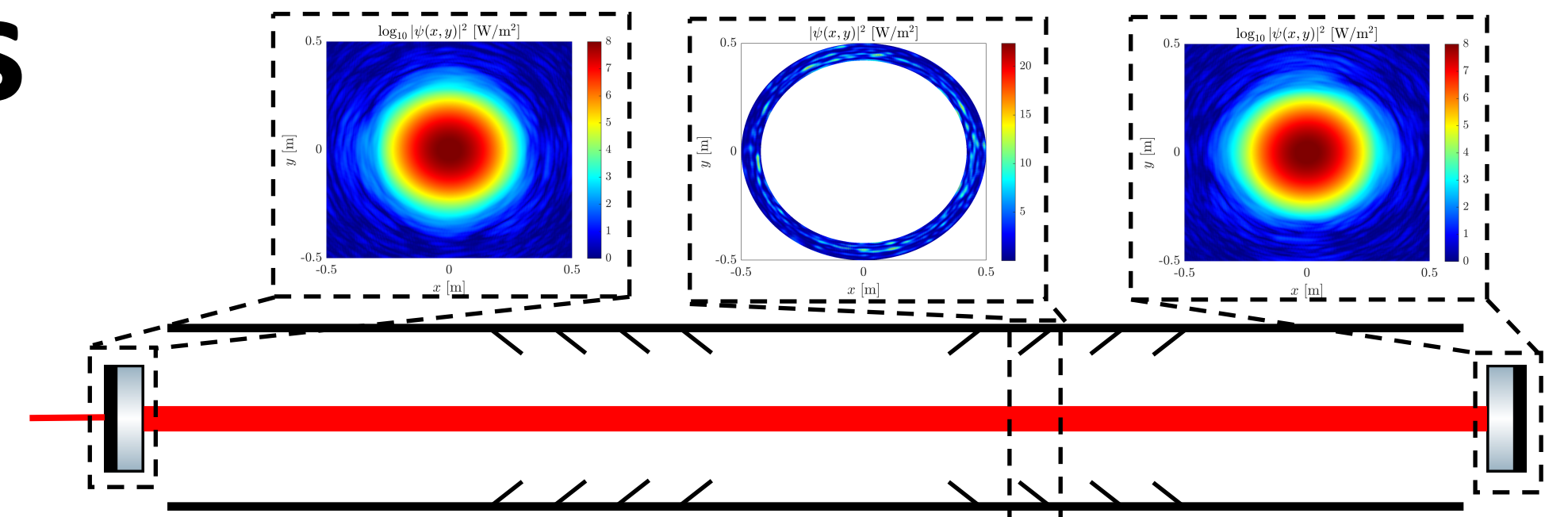
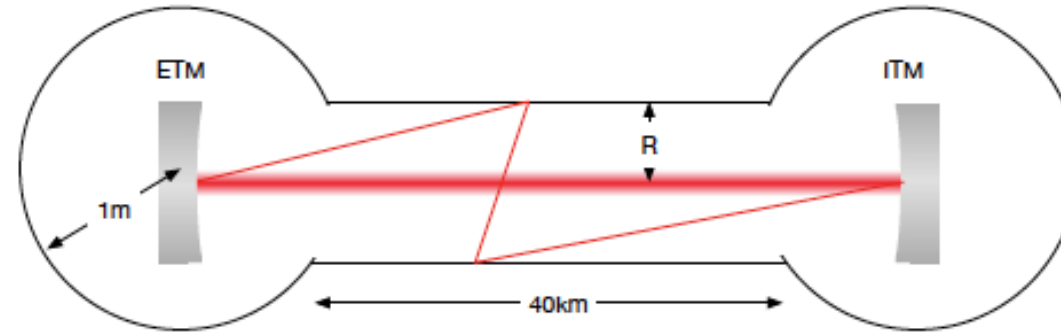
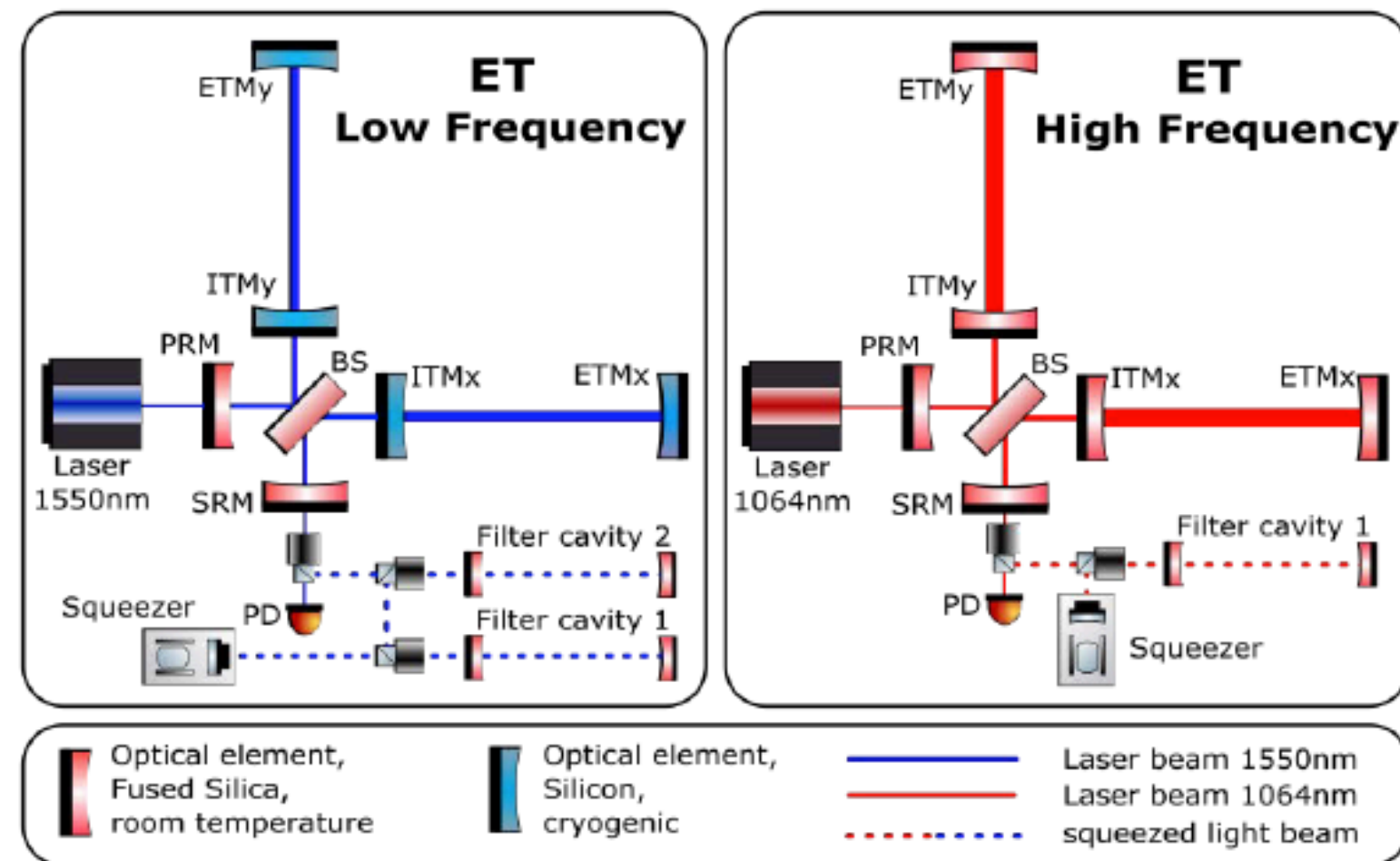
Extended-TDR ready

ET EINSTein TELESCOPE

Project: 101079696 — ET-PP, 2nd review meeting

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



IFO	λ	mode	mirror $\varnothing$	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

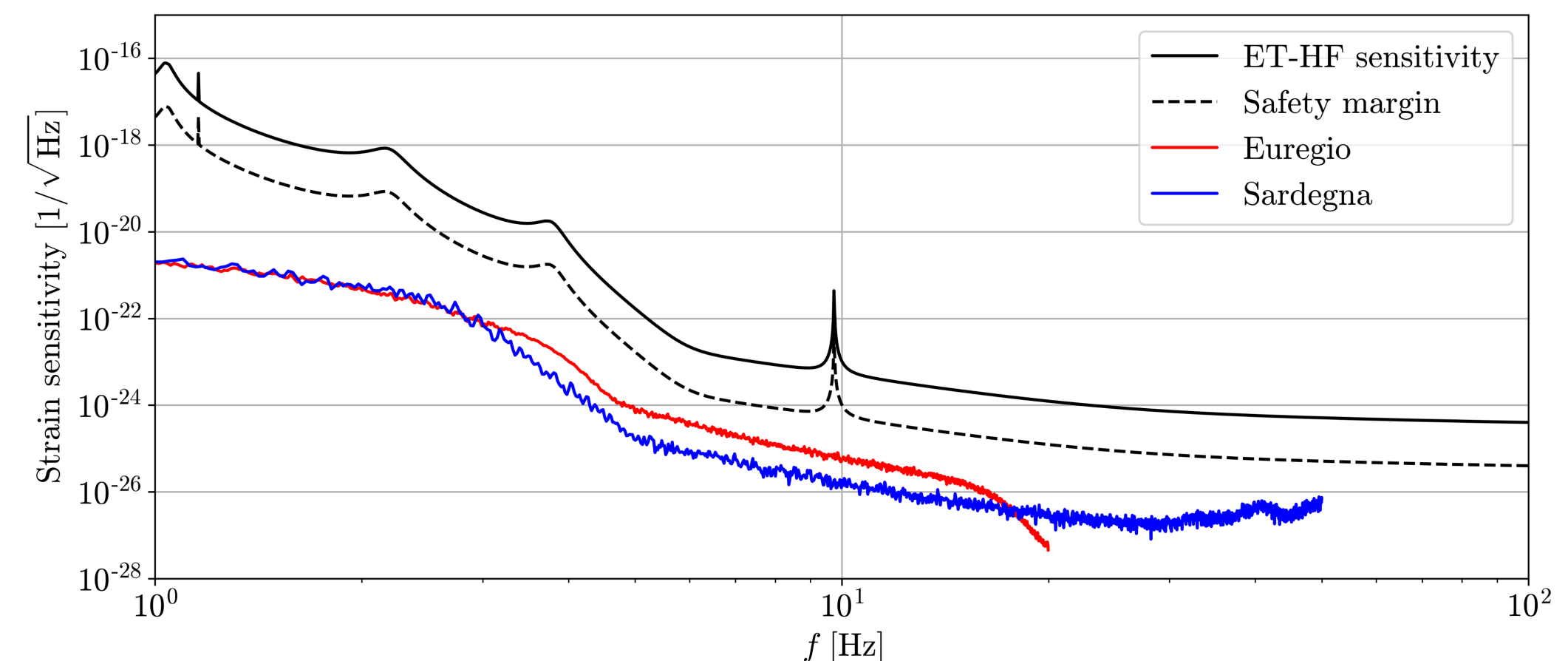
Detailed simulations of the light propagation in the optical cavities

- > 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 arm

- > Possible thanks to close relation with Caltech - LIGO since 2020
- > Running common ET/Cosmic Explorer meetings on Stray Light Control

See talk by Marc Andrés on latest results in non-ideal conditions and including the 15km L configuration

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



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

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

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”,



Future Accelerator Studies [FS]
SL: John Osborne
DL: Mar CERN
International Linear Collider, CLIC, Muon Collider, LHeC
External Reviews e.g. ESS, XFEL, DUNE etc.



Future Circular Collider (FCC) Underground Studies and Site Investigations



Physics Beyond Colliders (PBC)
Einstein Telescope
Physics Beyond Colliders



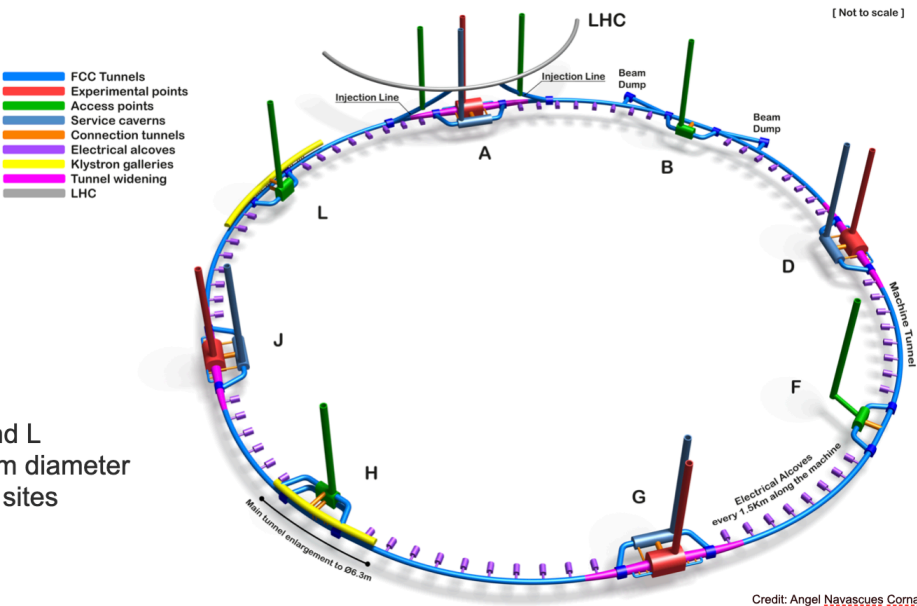
Tunnel Asset Management (TAM)
Tunnel R&D
Photogrammetry/
Fibre Optic Studies

Case Study - Future Circular Collider (FCC) Study

Design frozen for costing exercise every ~2 years

FCC Underground

- 90.6 km
- 8 Surface Sites
- 4 Experimental Areas
- 4 Technical Areas
- 14 shafts
- Klystron Galleries at Point H and L
- Point H tunnel widening to 6.3 m diameter
- Tunnel widening at experiment sites
- Beam dump at point B

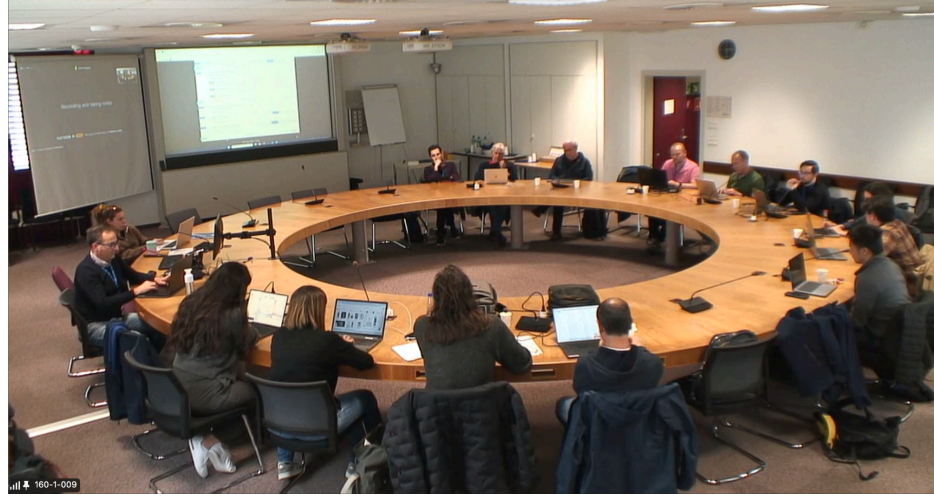


ET will count with the supervision of the same CERN team behind the recent FCC studies —> will guarantee the quality



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 m³ in 2L (~80% of total volume)
 - ~ 2500 m³ 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

The ET Baseline Detector Layout	
date: May 26, 2025 page: 1 of 73	
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1.1 Definitions	2
2 Task Force system decomposition	5
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2.2 Integrated system nodes - Lr. 3	6
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4.3 Tower categorization outcomes - executive summary	26
5 Detector layout	28
5.1 Common features, definition of flexibility envelope	28
5.2 Baseline Triangle layout (i.e. our choice), main features and comparison with 2024 reference	33
5.3 Baseline 2L layout (i.e. our choice), main features and comparison with 2024 reference	37
5.4 The Detector Layout Technical Annex	39
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F. Sorrentino - ETO Design Task Force update

Einstein Telescope

F. Sorrentino

Detector layout - Triangle

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

2024 reference

new baseline design from Task Force:
~25% volume reduction

Task force action

Detector layout - 2L

2024 reference

new baseline design from Task Force:
~28% volume reduction

Task force action

ET Science

[arXiv:1912.02622](https://arxiv.org/abs/1912.02622)

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

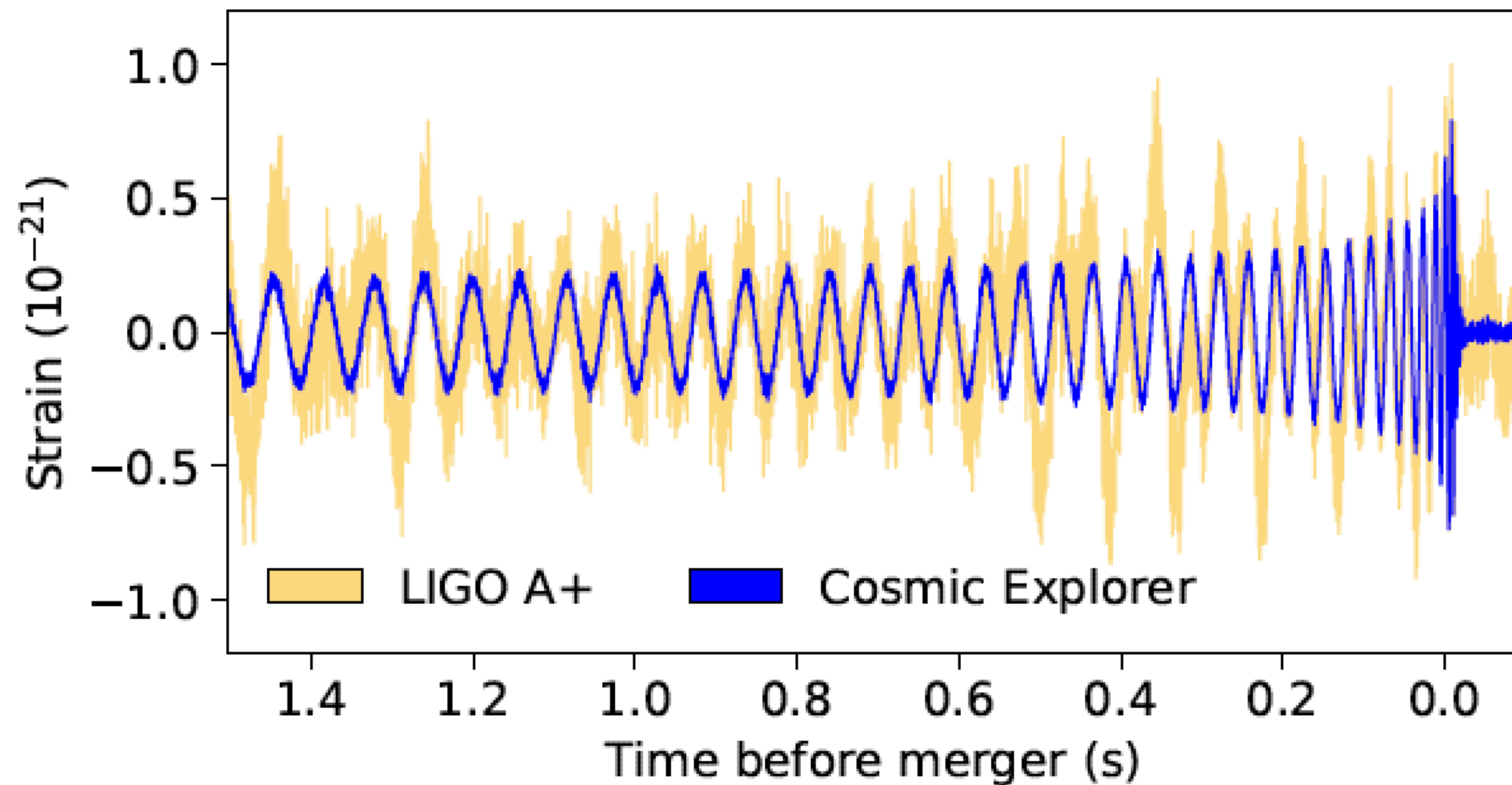
Fundamental Physics, Cosmology, HEP

- **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 recently concluded a new refined Science Case (Next slides)

General Relativity Tests

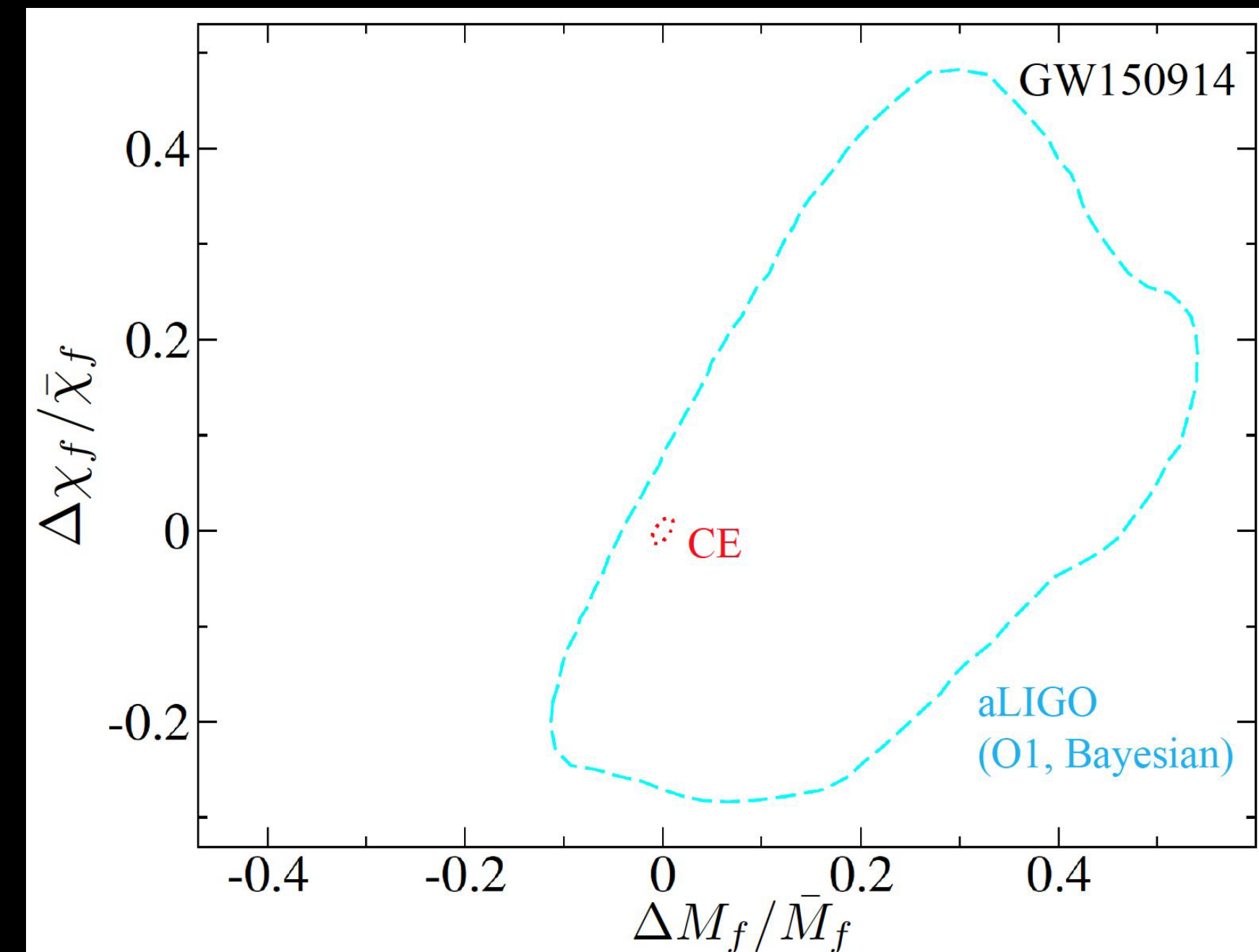
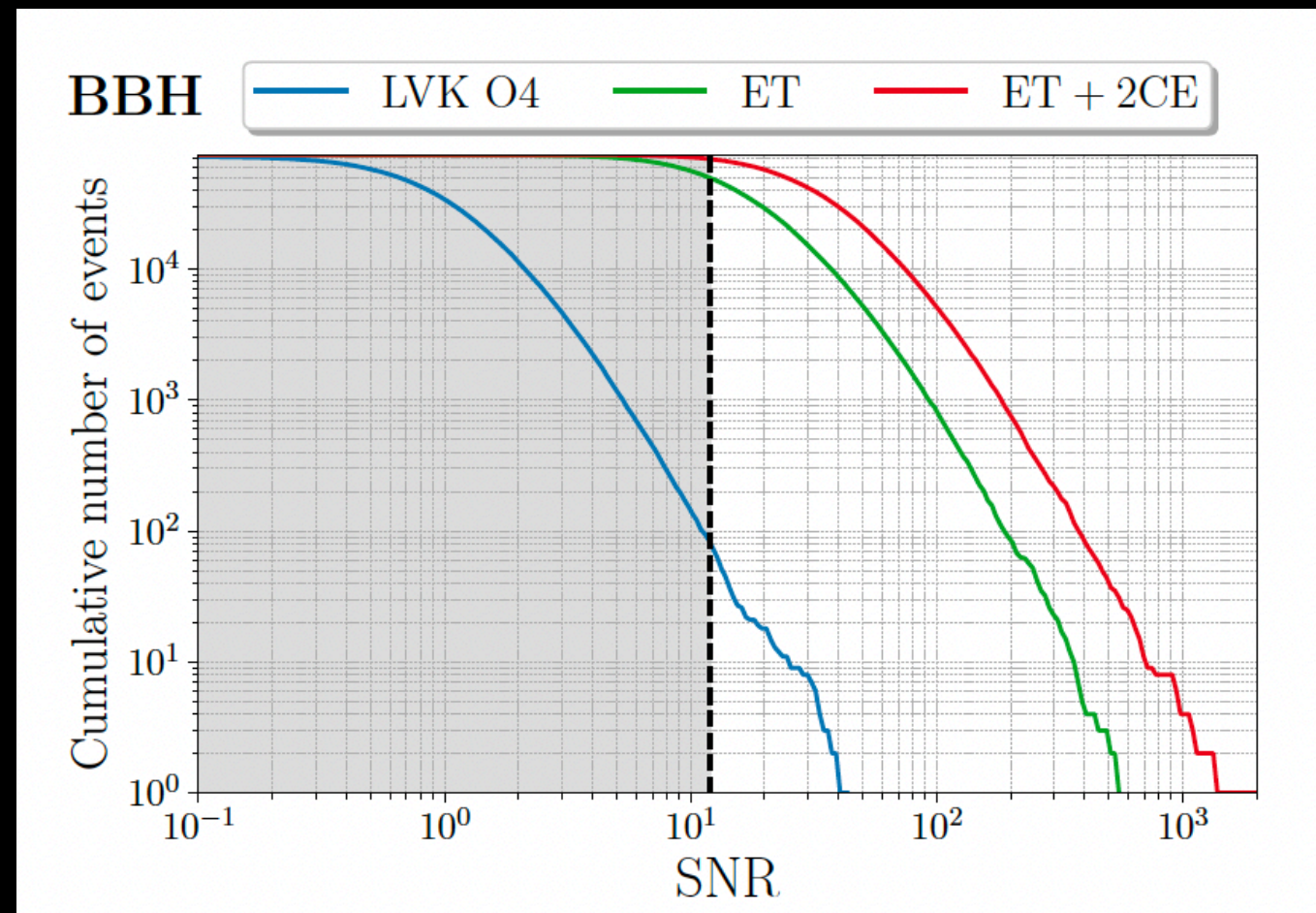
Simulated GW150914-like observations



$$\frac{\Delta M_f}{\bar{M}_f} = 2 \frac{M_f^{\text{insp}} - M_f^{\text{postinsp}}}{M_f^{\text{insp}} + M_f^{\text{postinsp}}},$$

$$\frac{\Delta \chi_f}{\bar{\chi}_f} = 2 \frac{\chi_f^{\text{insp}} - \chi_f^{\text{postinsp}}}{\chi_f^{\text{insp}} + \chi_f^{\text{postinsp}}},$$

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

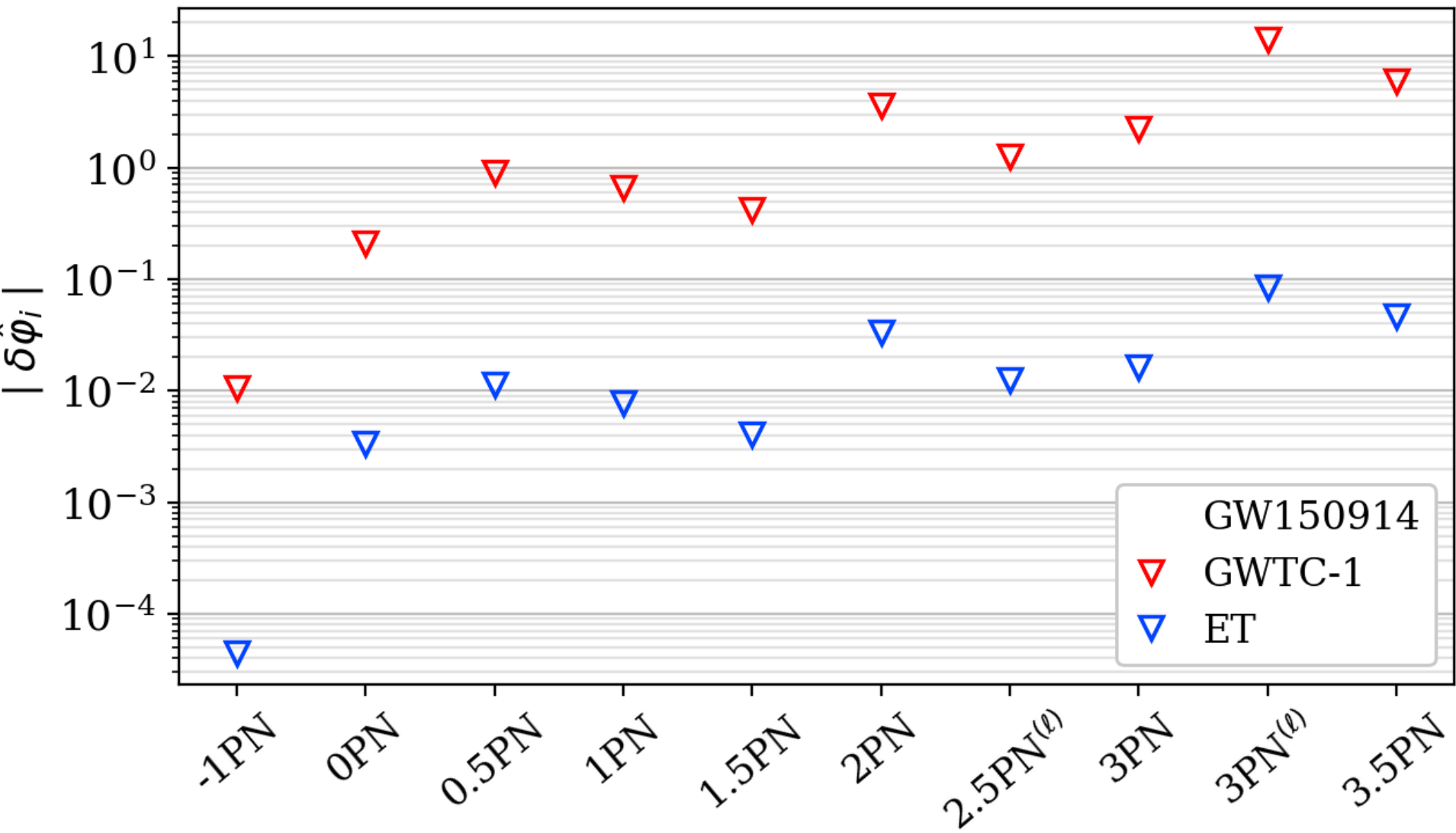


ET refined science case

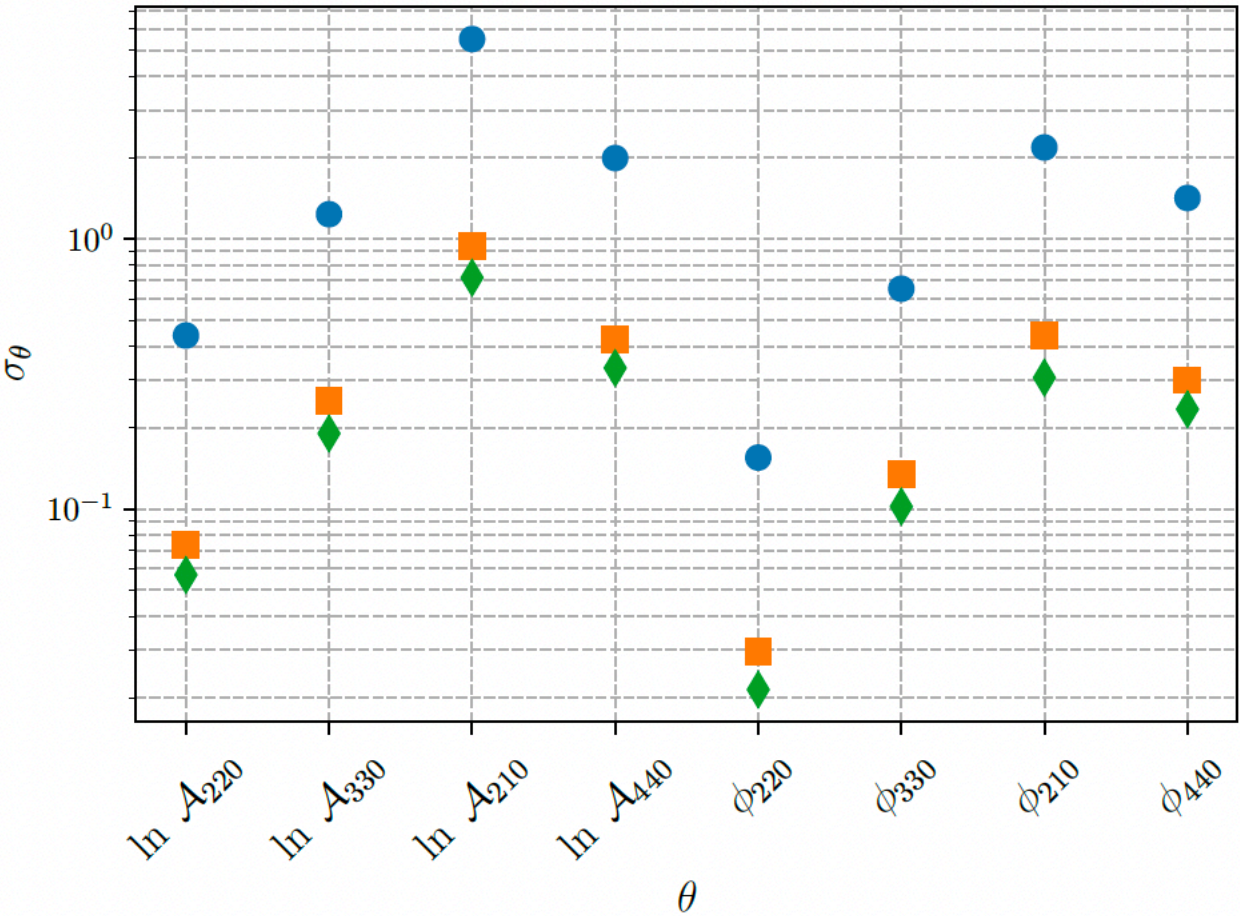
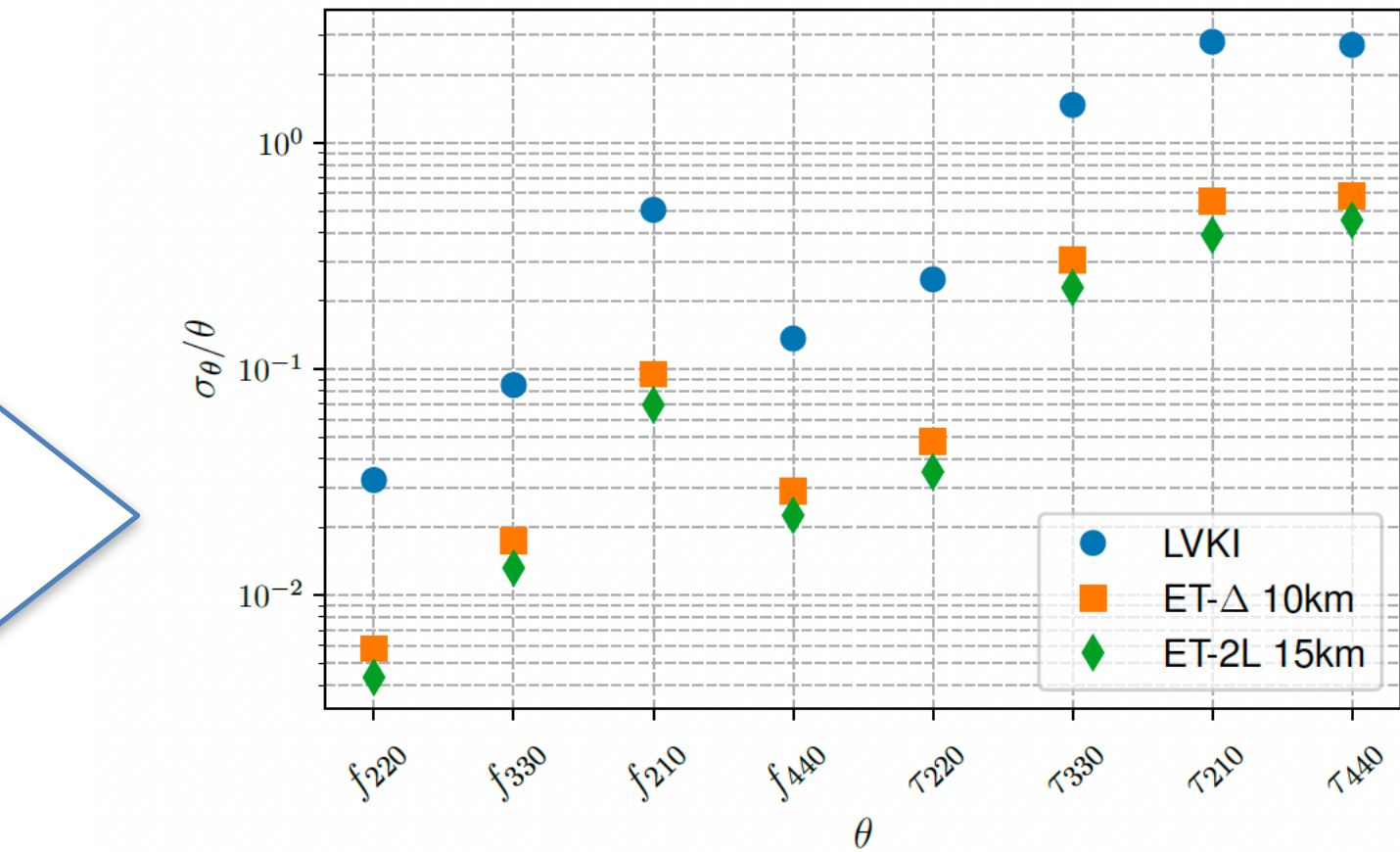
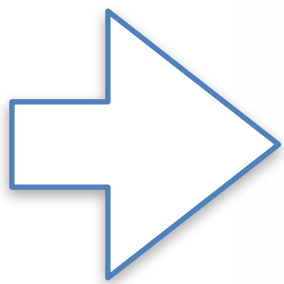
Tests of GR

PN coefficients

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



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

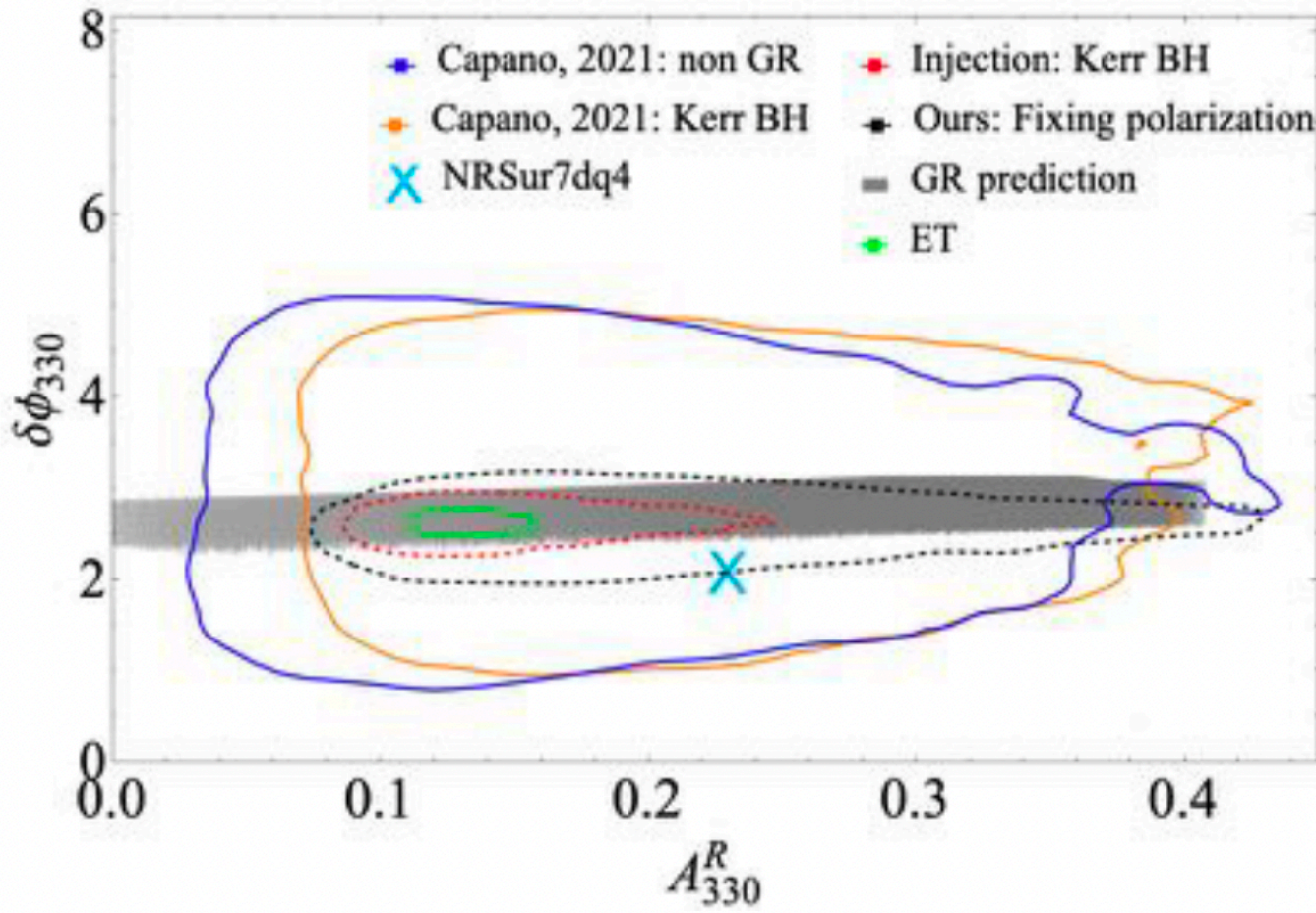
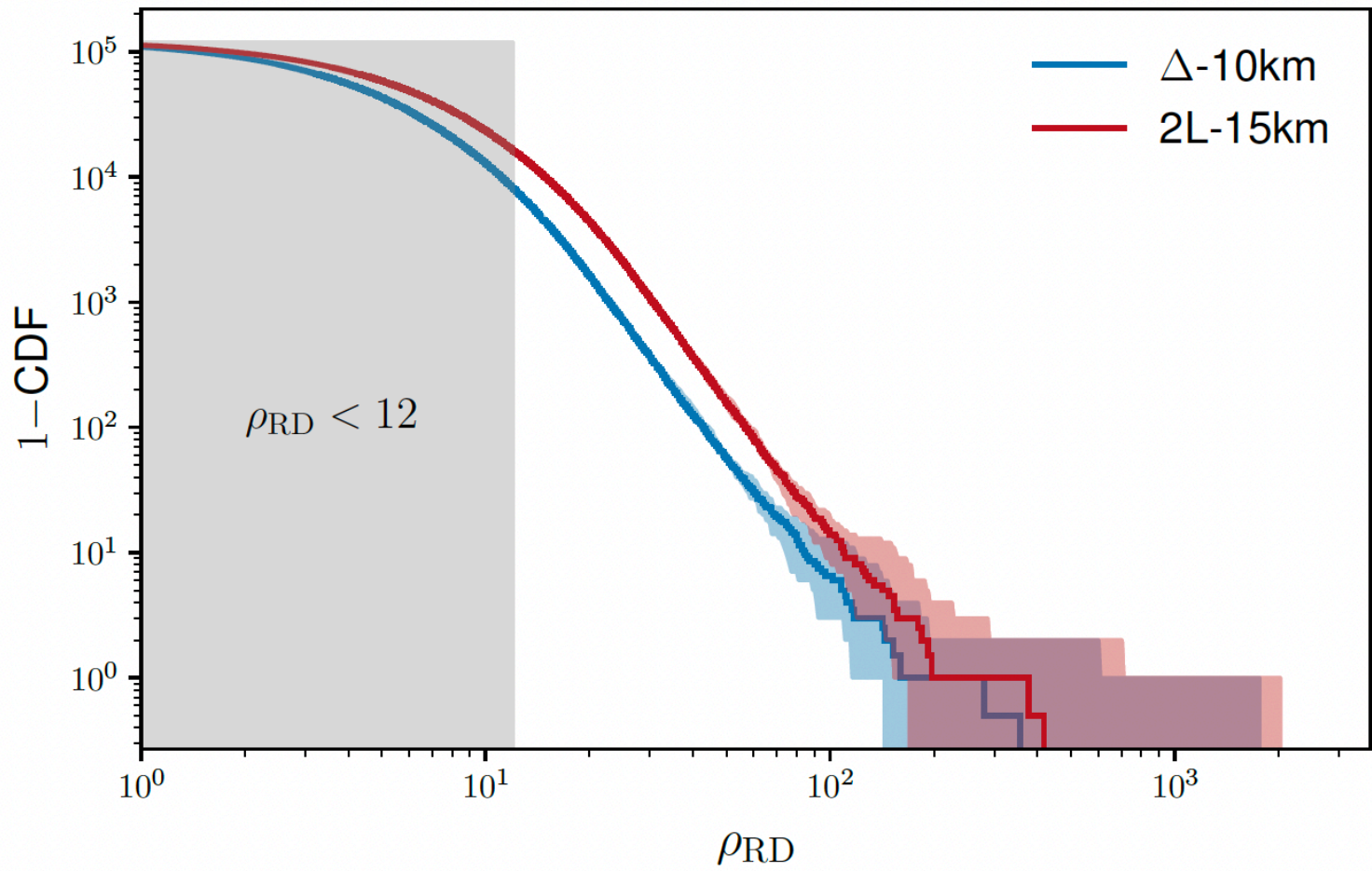


A > 870 pages document
summarising the ET Science Case

A great success of the ET Collaboration
and a central ET-PP deliverable

<https://arxiv.org/pdf/2503.12263>

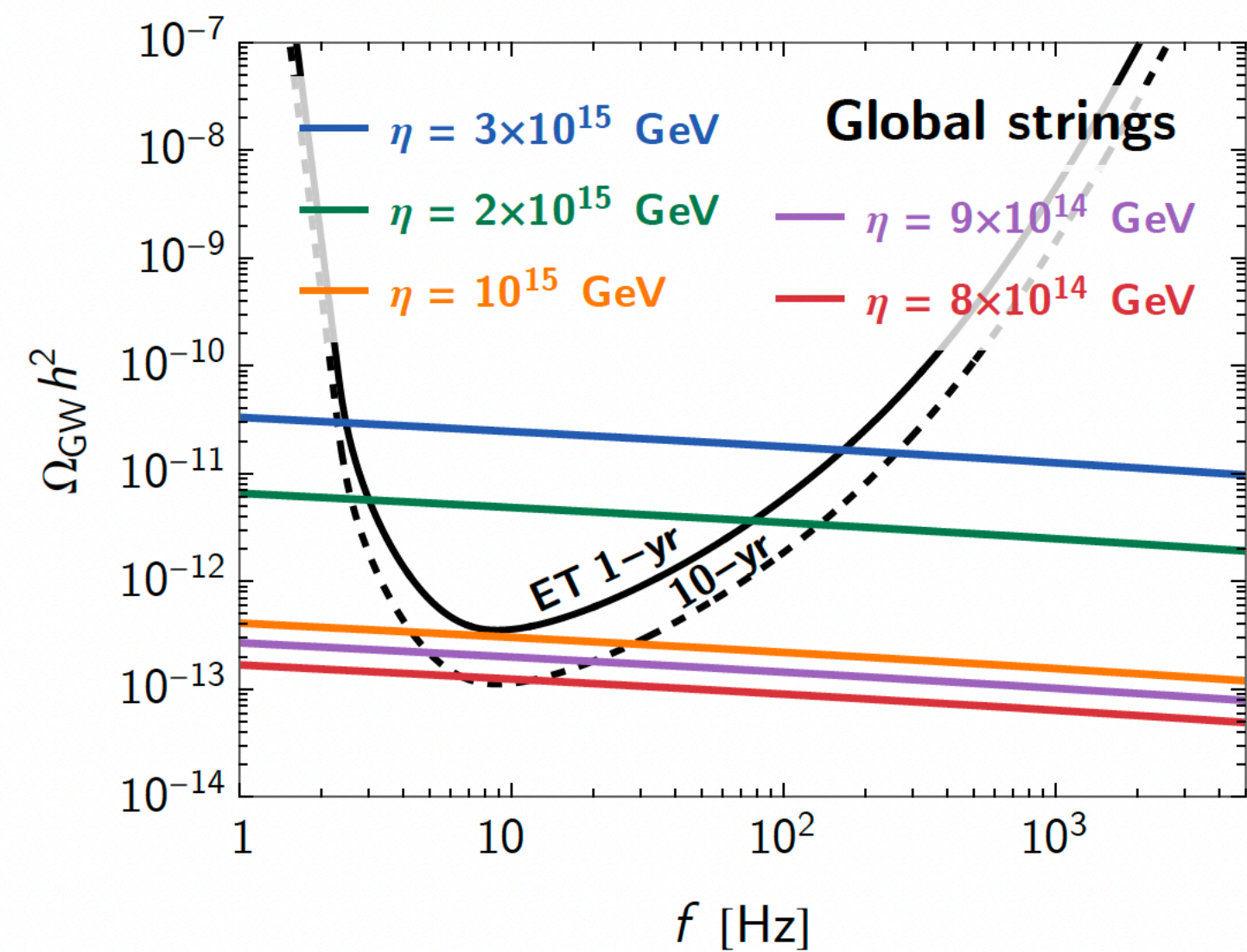
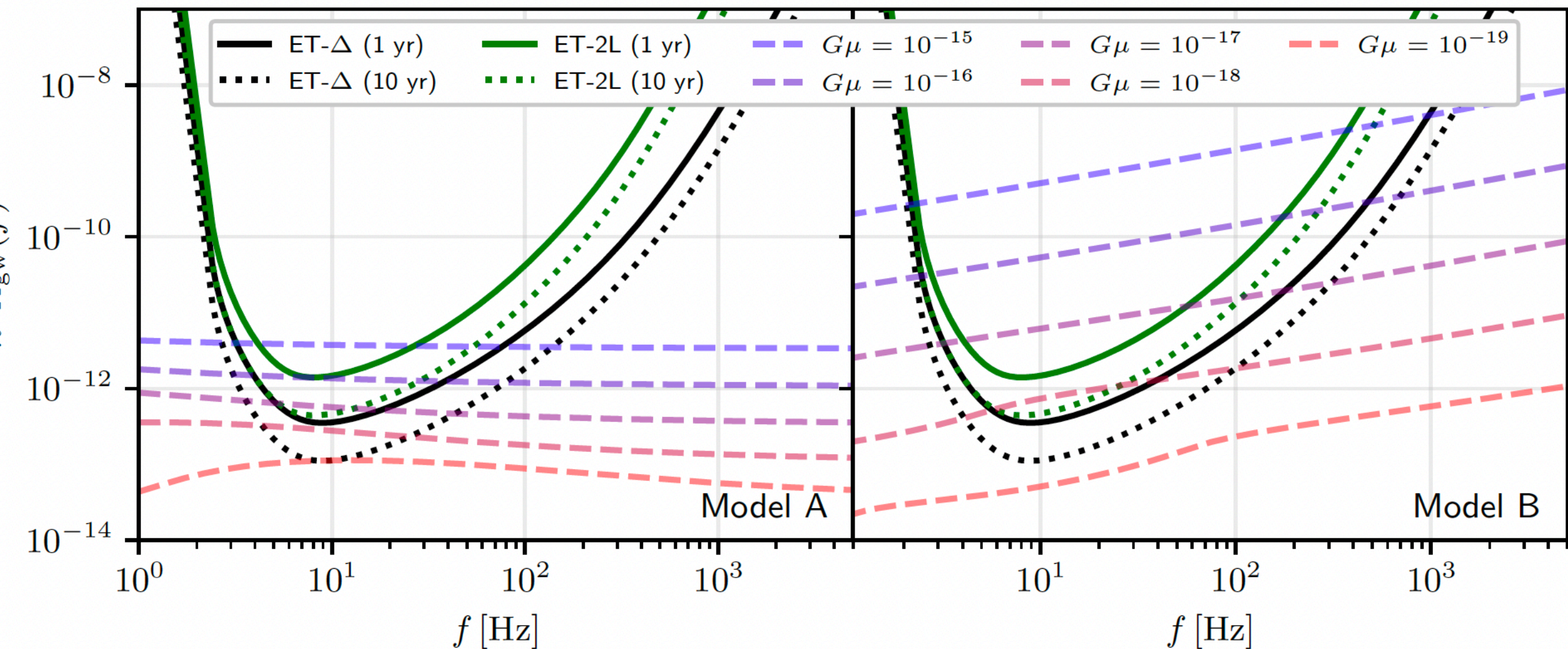
Ringdown and BH spectroscopy



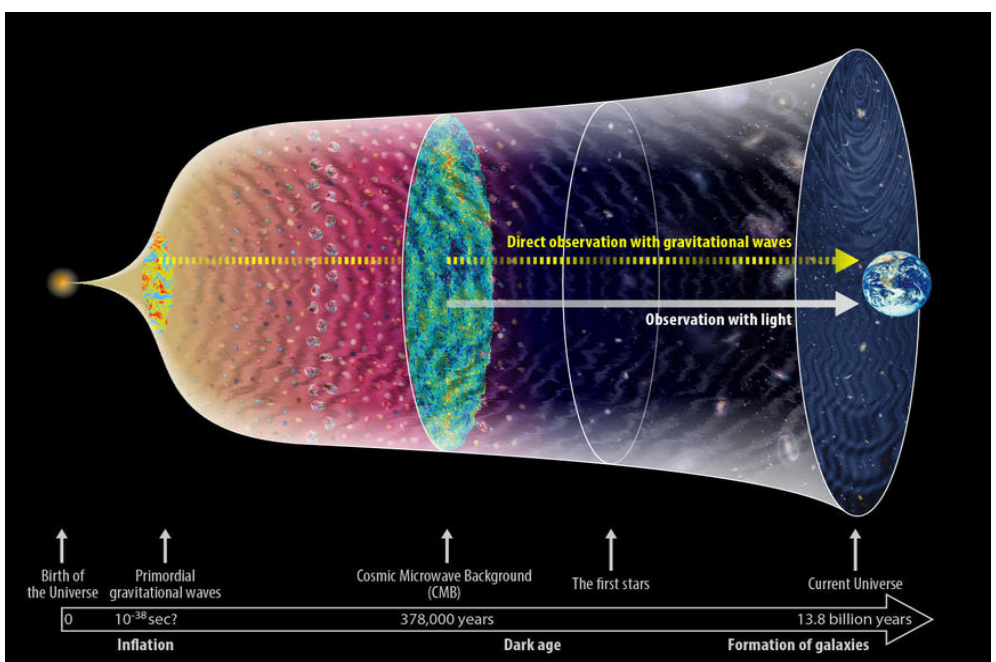
ET refined science case

Cosmology

Cosmic strings



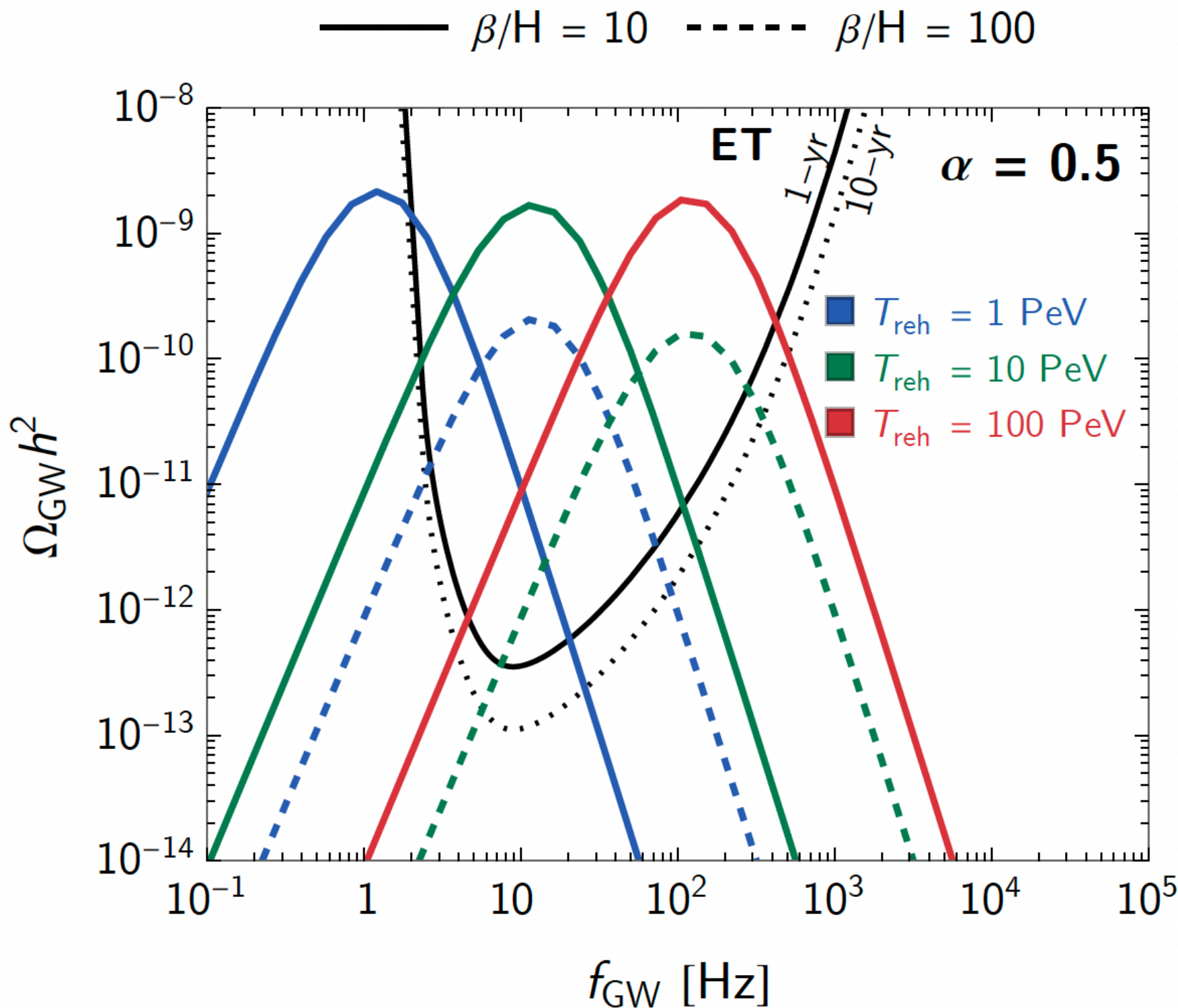
$$G\mu(t) \sim 10^{-6} \left(\frac{\eta}{10^{16} \text{ GeV}} \right)^2 \log \left(\frac{H^{-1}(t)}{w} \right)$$

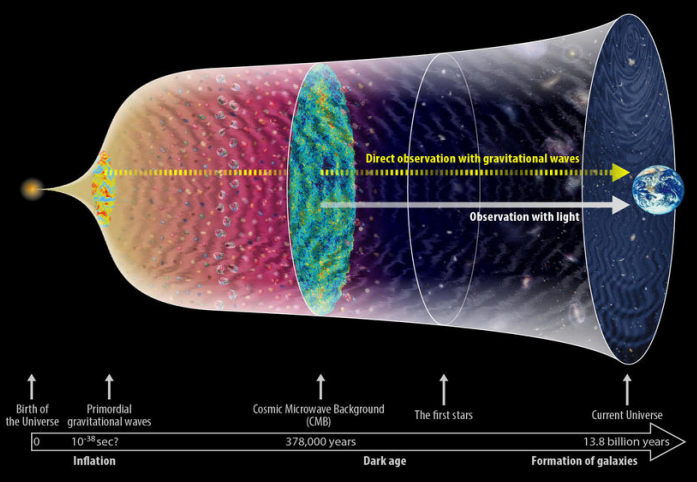


<https://arxiv.org/pdf/2503.12263>

Phase transitions

$$f_{\text{peak}} \approx \mathcal{O}(1) \times 10^{-5} \frac{1}{H_{\text{reh}} R_{\text{coll}}} \frac{T_{\text{reh}}}{100 \text{ GeV}} \text{ Hz}$$

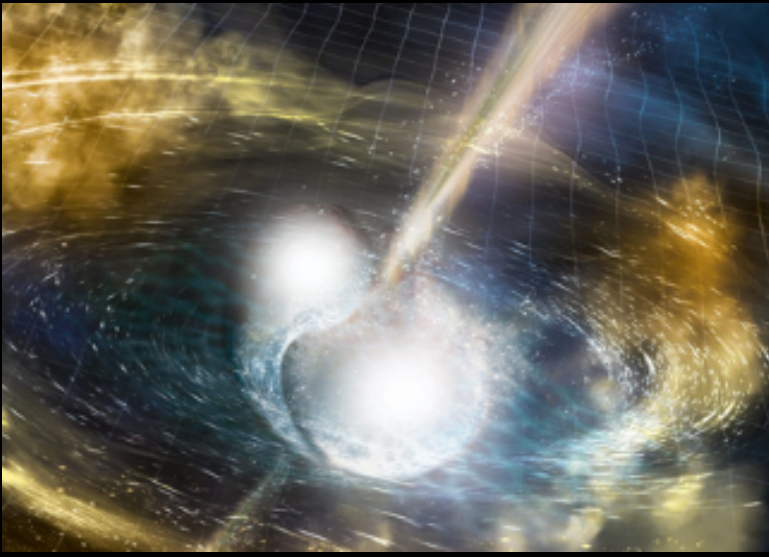




$$m_{\text{det}} = (1 + z)m$$

Cosmology

in models beyond GR

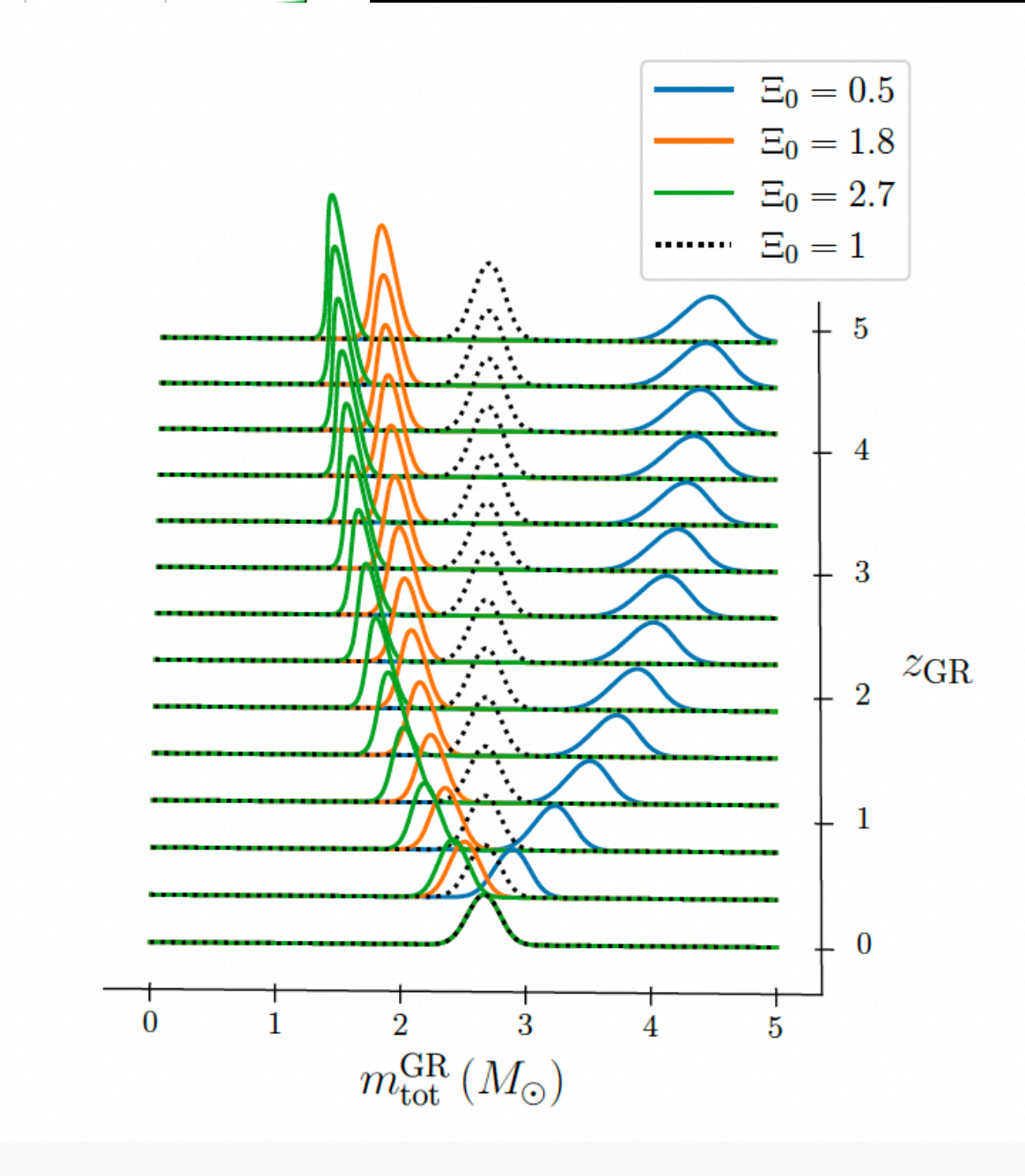
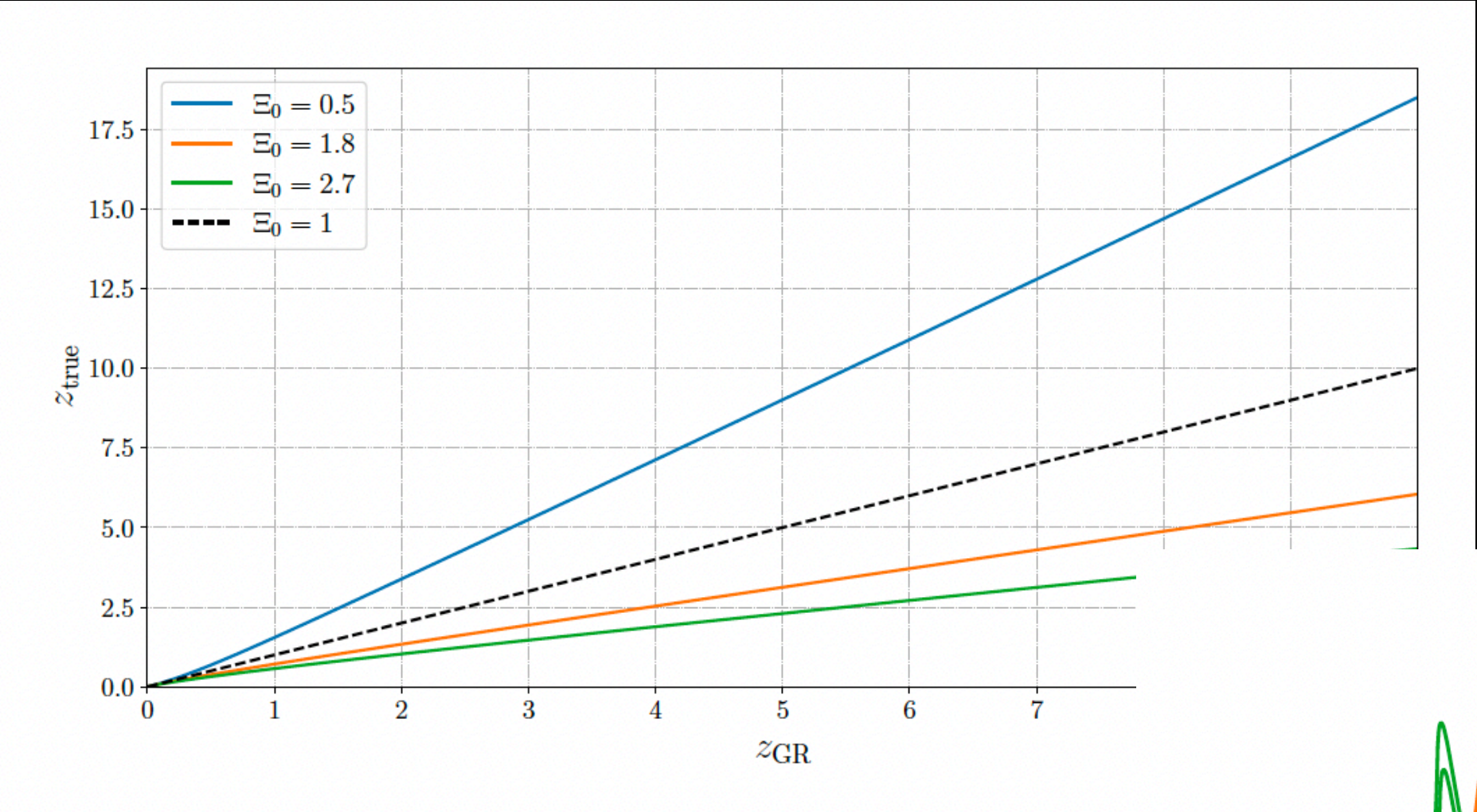
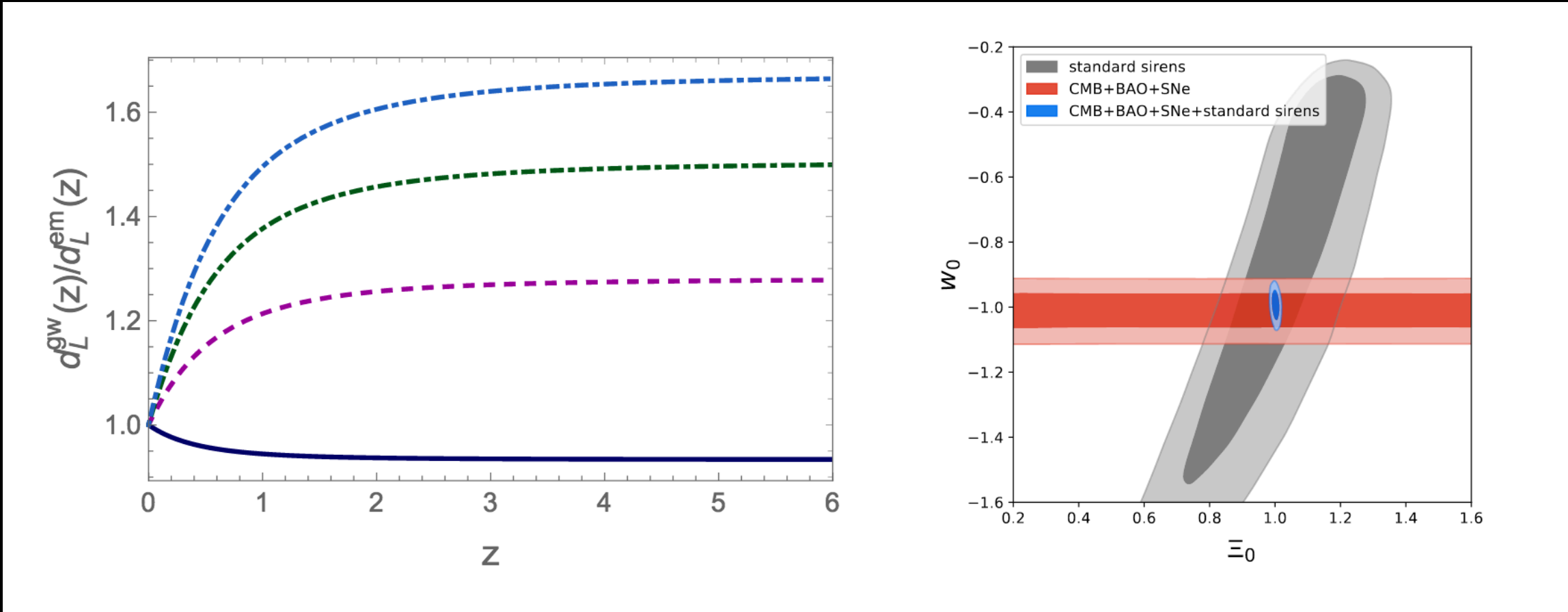


$$d_L(z) = \frac{1 + z}{H_0} \int_0^z \frac{dz'}{\sqrt{\Omega_M(1 + z')^3 + \frac{\rho_{\text{DE}}(z')}{\rho_0}}},$$

$$\frac{d_L^{\text{gw}}(z)}{d_L^{\text{em}}(z)} = \Xi_0 + \frac{1 - \Xi_0}{(1 + z)^n}$$

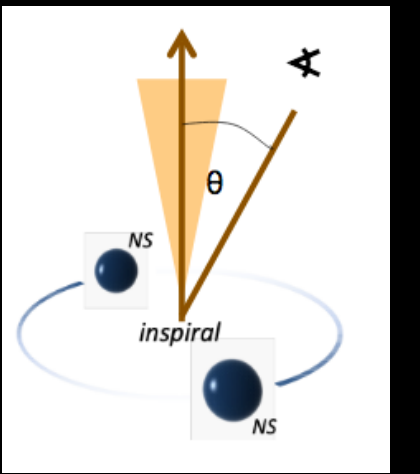
Finke, Foffa, Iacovelli, Maggiore, Mancarella 2021

Relationship between light distance and redshift contains information on high redshift cosmology

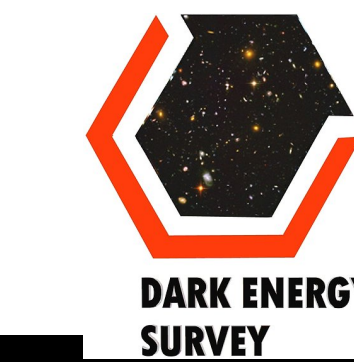
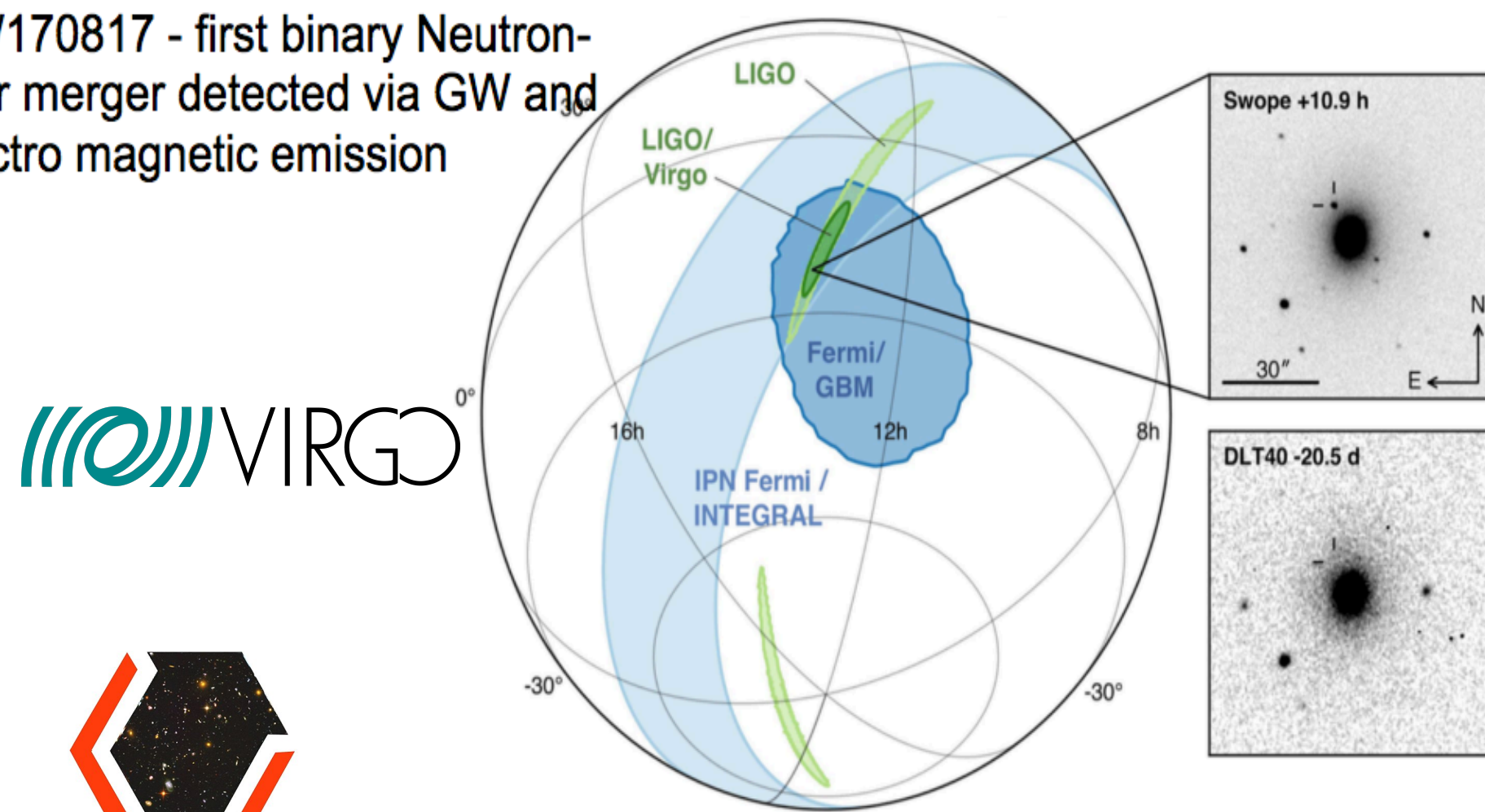


After a few years and collecting a few hundred BNS events ET can do a rigorous test using the BNS narrow mass distribution vs z

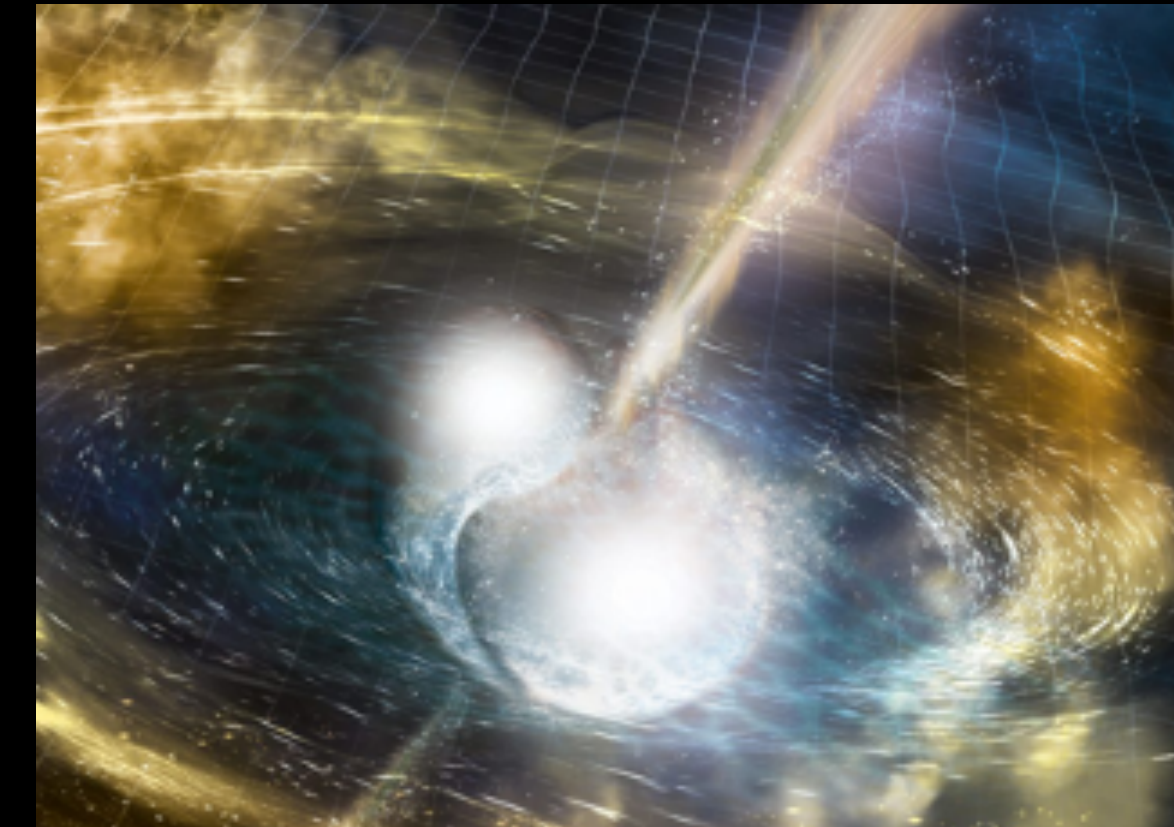
Hubble Constant



GW170817 - first binary Neutron-Star merger detected via GW and electro magnetic emission



DARK ENERGY SURVEY
70 observatories - Astrophys.J. 848 (2017) no.2, L12



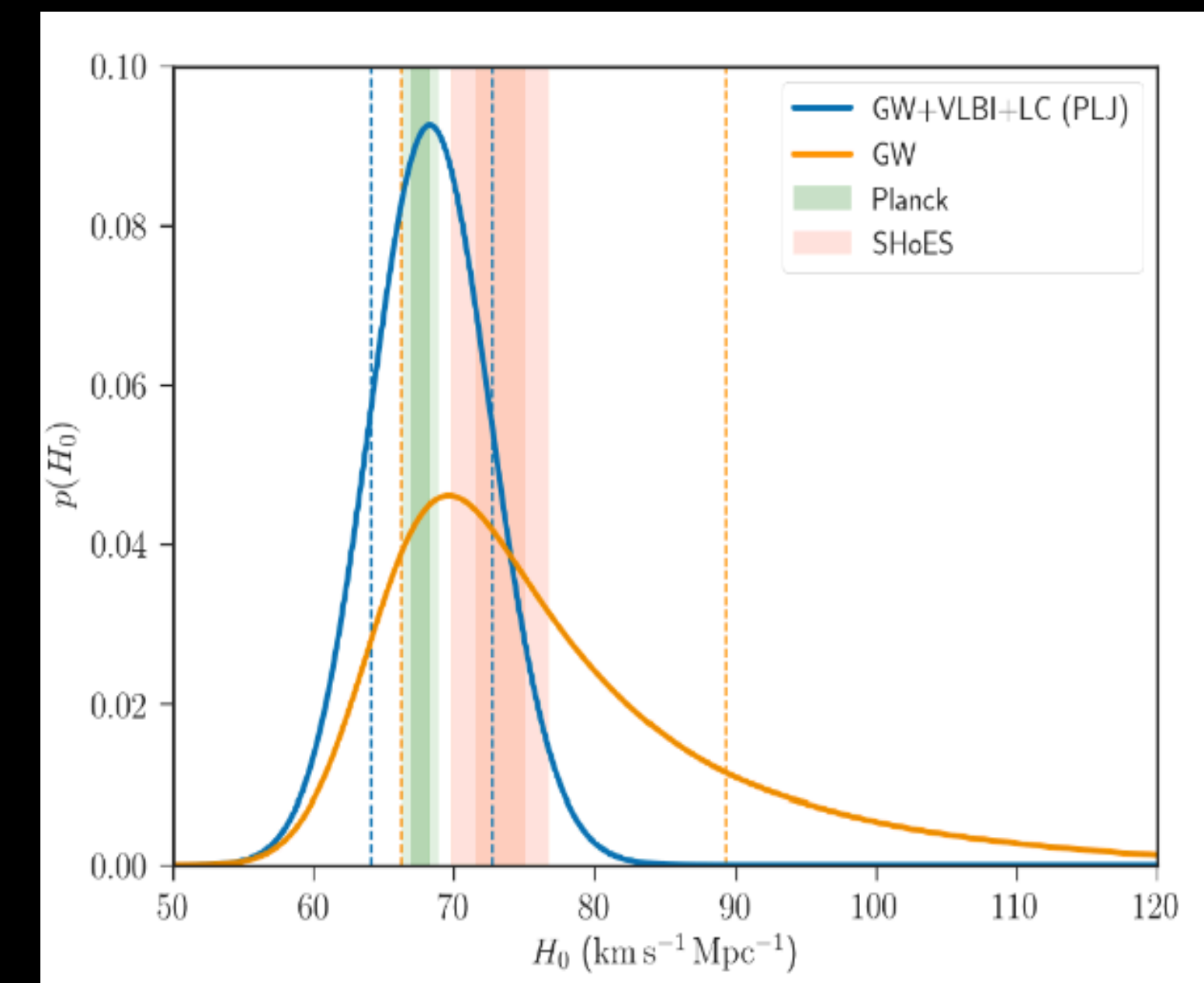
Few events of BNS will allow for few % precision in the determination of H_0

Observation with GWs and EM optics

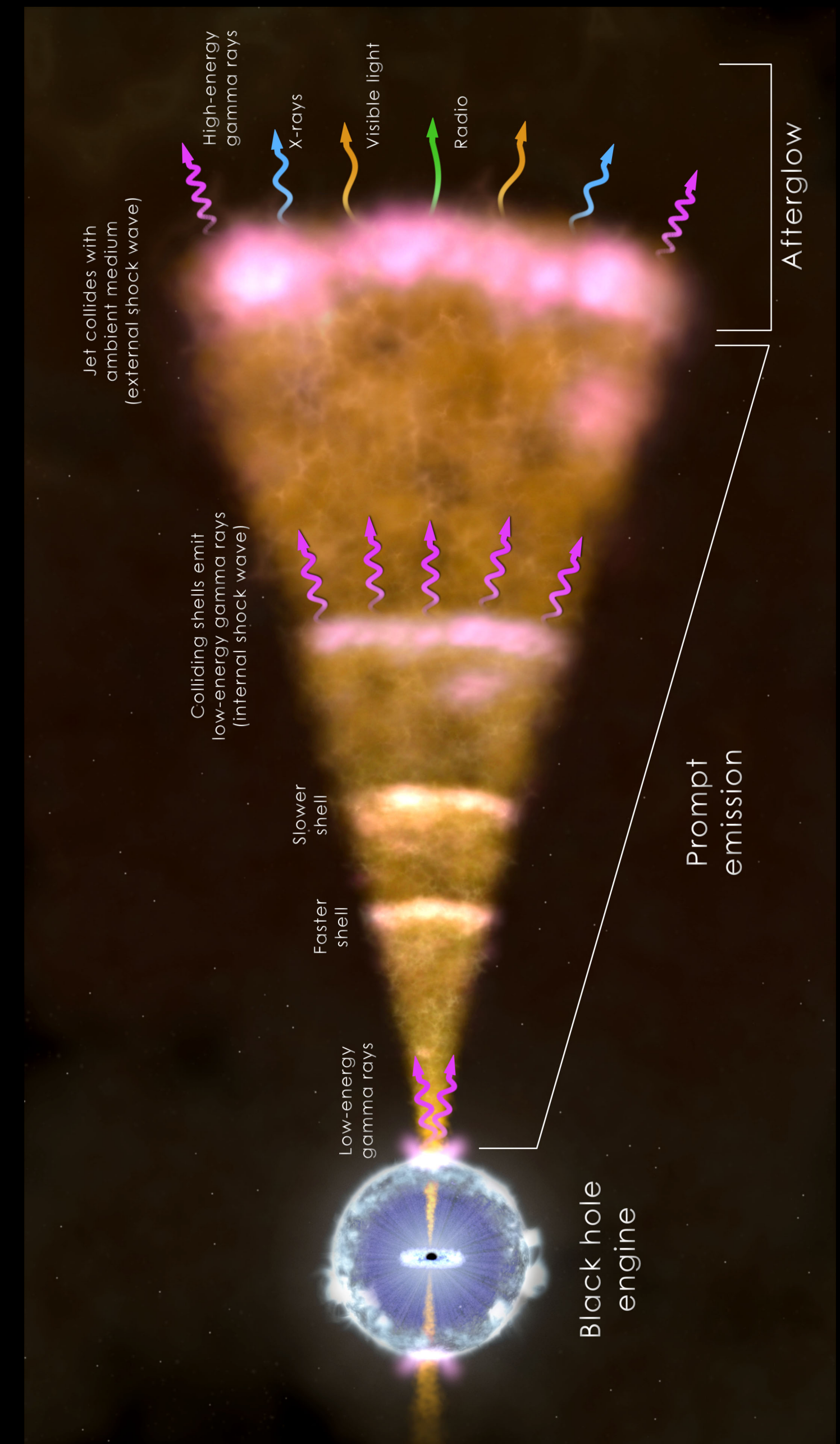
$$v_H = H_0 d \quad (\text{GW} + \text{EM})$$

Direct measurement of Hubble parameter H_0

$$H_0 = 69 \pm 5 \text{ km s}^{-1} \text{ Mpc}^{-1}$$



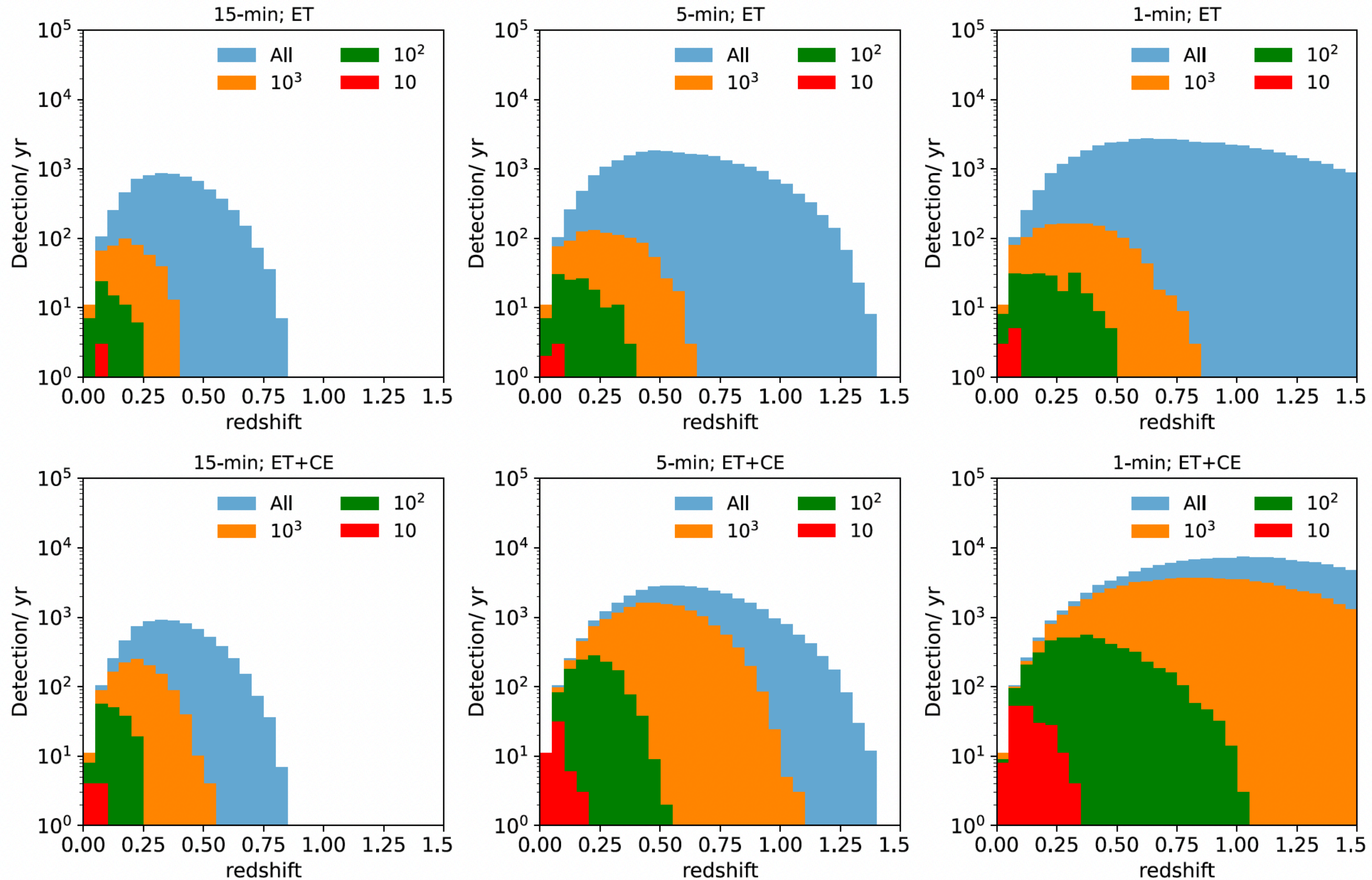
Multi-messenger



ET will operate in synergy with a number of large infrastructures

To understand early emission O(few seconds after mergers) GRBs
Prompt on-axis EM detections are necessary —> early warnings

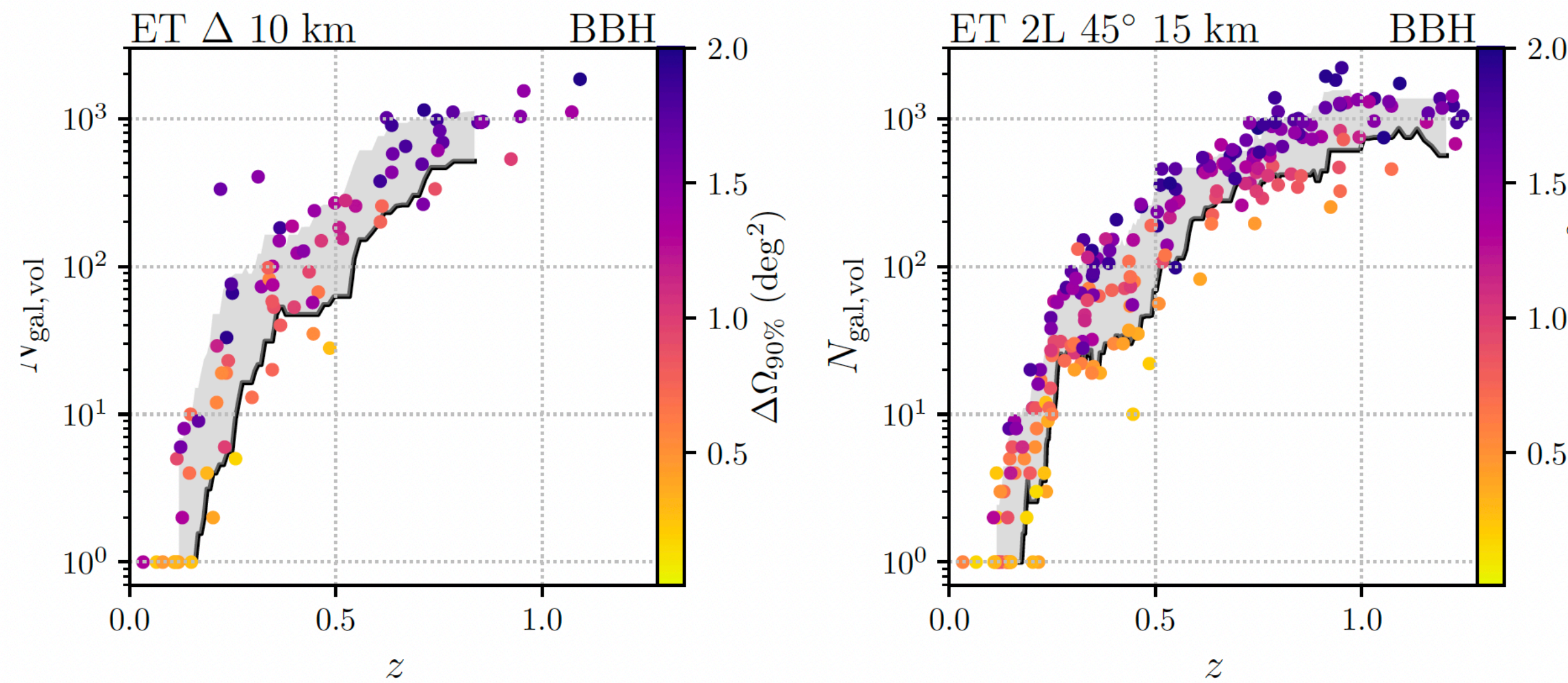
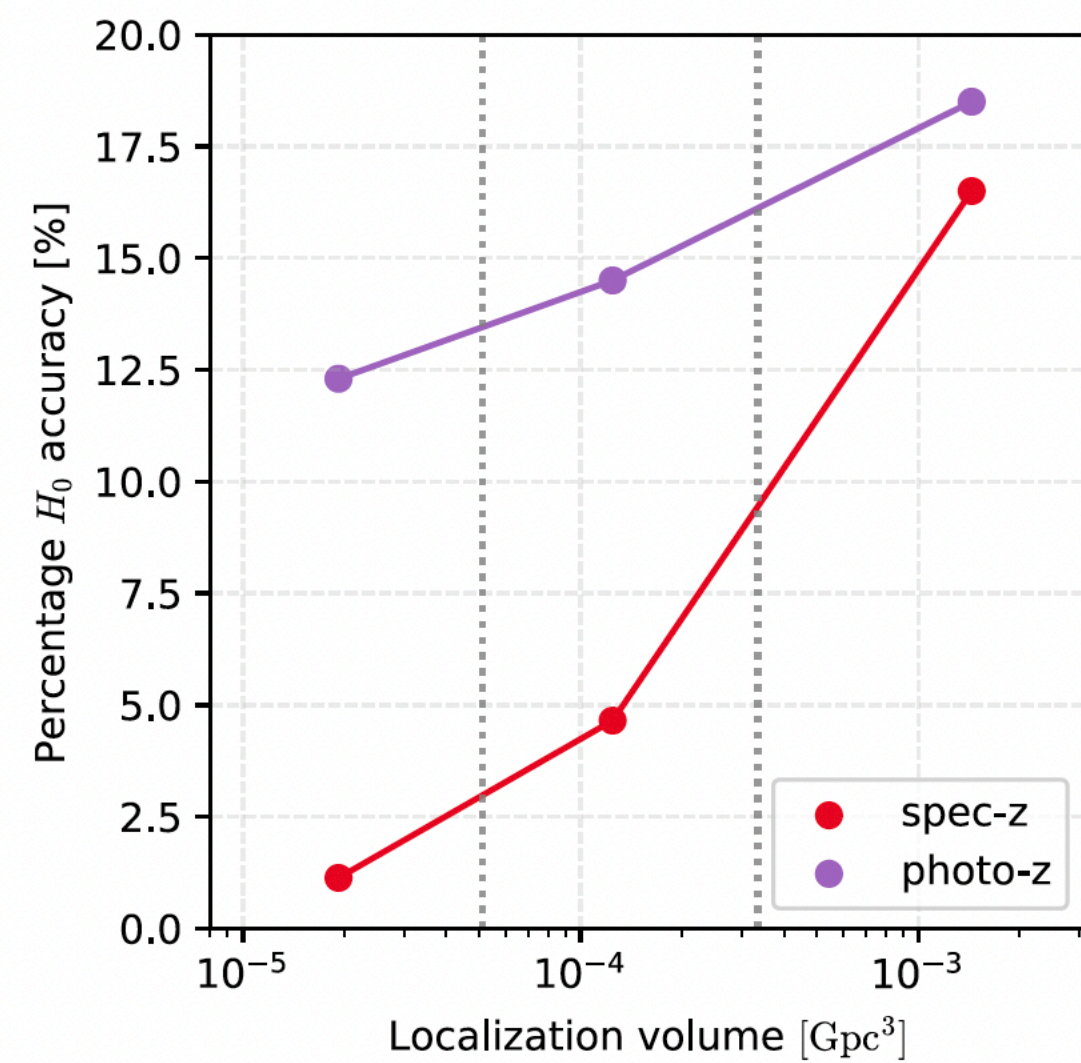
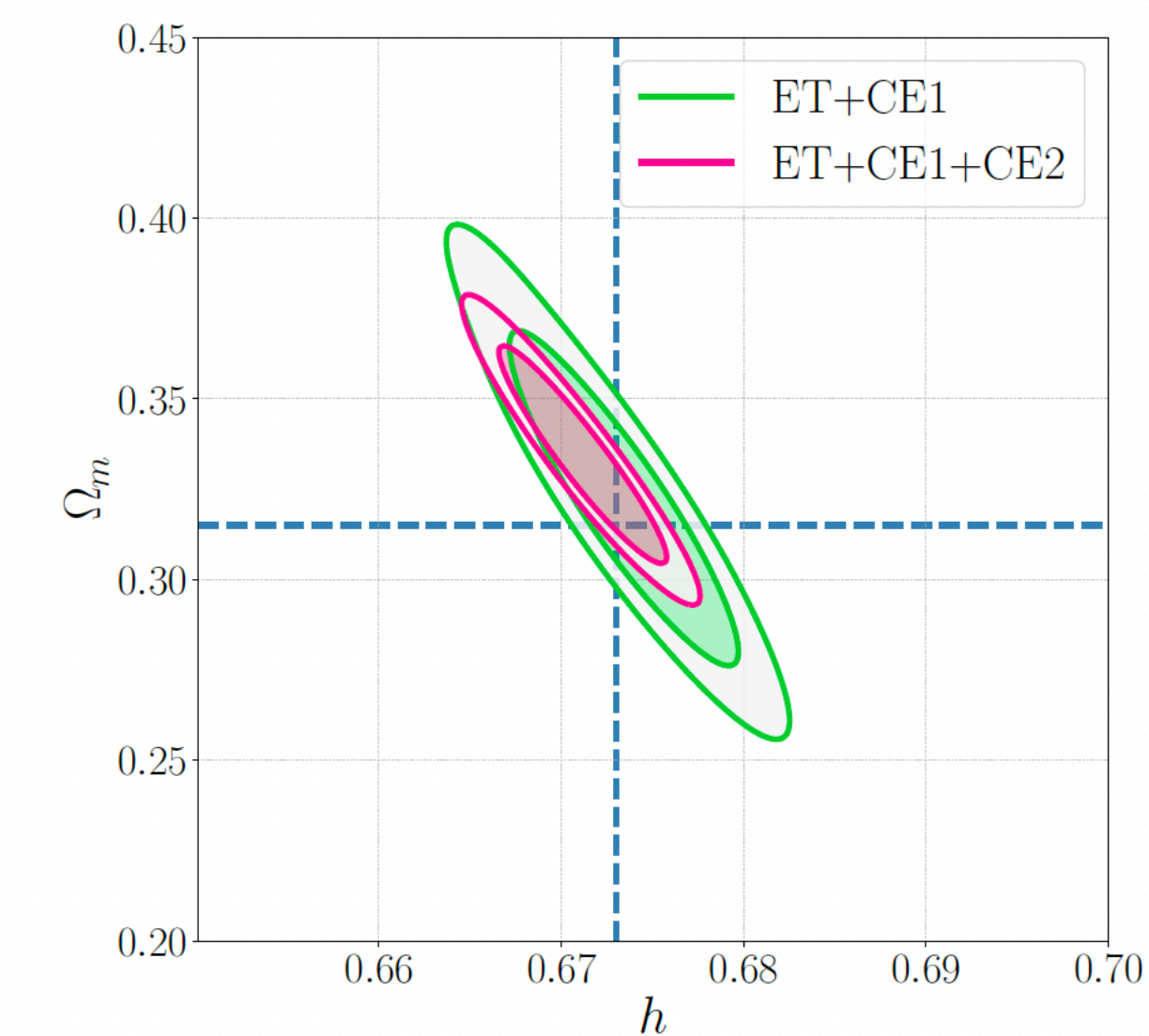
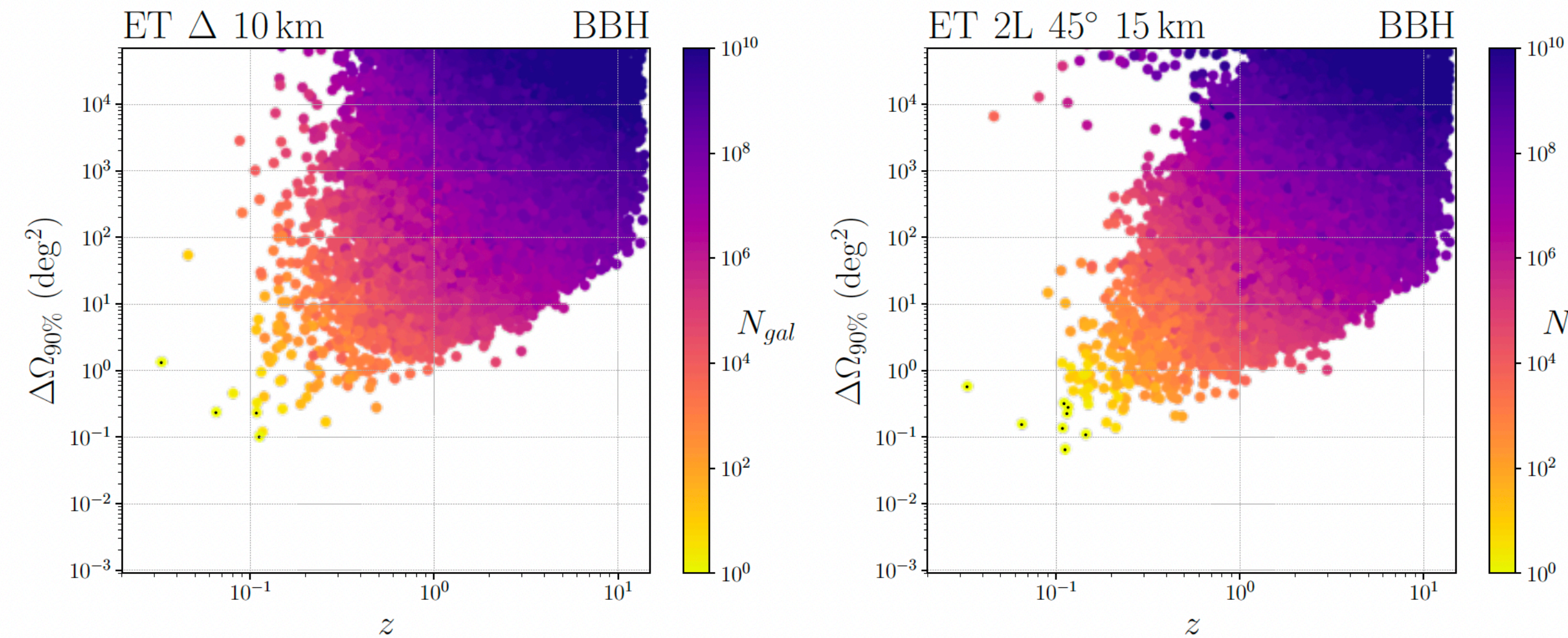
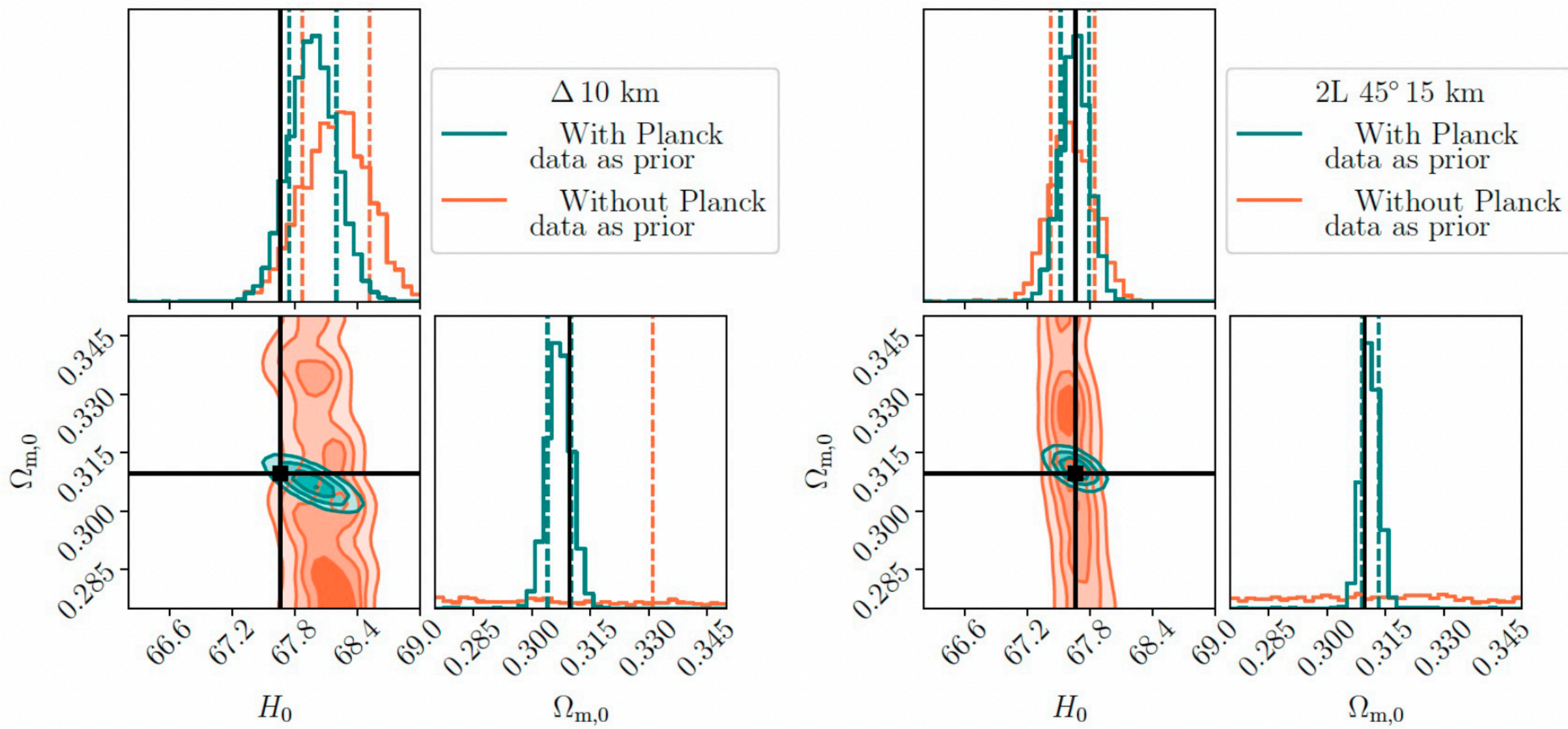
Sky localization



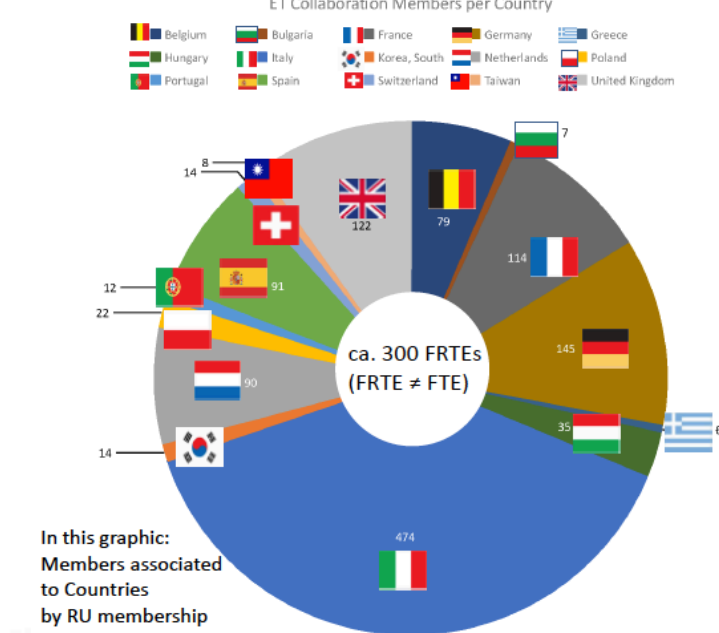
ET + CE would allow for O(1000) events / year with sky-localizations (90% CL) < 10 deg²

ET refined science case

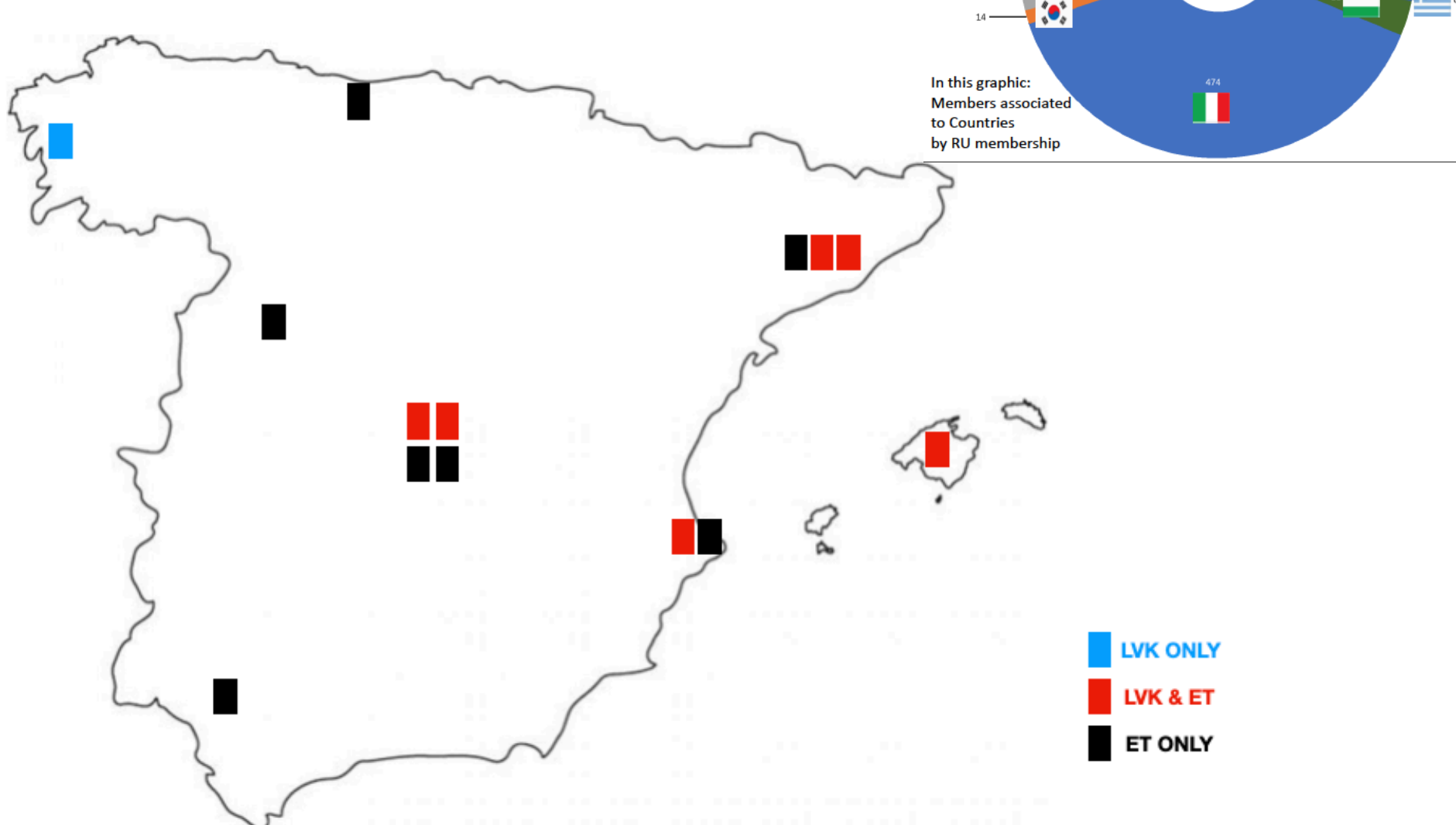
Cosmology with EM counterparts & Dark Sirens



Map of Spanish involvement in LVK/ET



Group	LVK	ET	Hardware	Computing	Note
CIEMAT	Virgo	Y	Y	YY	Still qualifying in Virgo
ICE	LISA	Y	YY-LISA	N	Not allocated FTEs for HD
IFAE	Virgo	Y	YY	YY	
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 majority has no hardware capacities
- Most of them are Theory and GW analysis oriented
- As today there is no consolidated large enough experimental community in GW is Spain.
- We are actively exploring synergies with other research centers in Spain to improve the situation

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

Italy-Spain Global Agreement (2nd July 2024)

- **Scientific cooperation agreement between Italy and Spain**
 - Spain politically supports Italian ET candidature in Sardinia
 - Spain will explore entering as full member in EGO's Council (Virgo)
 - (Limited) Funding originally included in the PGE 2005 draft for ET activities
 - Italy contributes to IFMIF-DONES in Granada **I am working hard these days to rescue the funds..**
- **Seed for possible bilateral programs...**



ET R&D (INFN-IFAE discussions)

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

INFN-IFAE Collaboration

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

 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

A

Aniello Grado

E

Elisabetta Cesarini

F

Francesco Fidecaro

G

Giacomo Ciani

L

Livia Conti

S

Stefano Bagnasco

+1

9:00 AM → 1:20 PM

Common Activities: Italian R&D Activites and Infrastructures

9:00 AM

Welcome

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

🕒 10m

9:10 AM

Introduction

Intro.pptx

🕒 10m

9:20 AM

3G Vacuum Systems and Cryogenics 

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

ET_Vacuum_Grado....

🕒 20m

9:40 AM

ET Infrastructure Consortium

Speaker: Michele Punturo (Istituto Nazionale di Fisica Nucleare)

ETIC-Italia-Spagna....

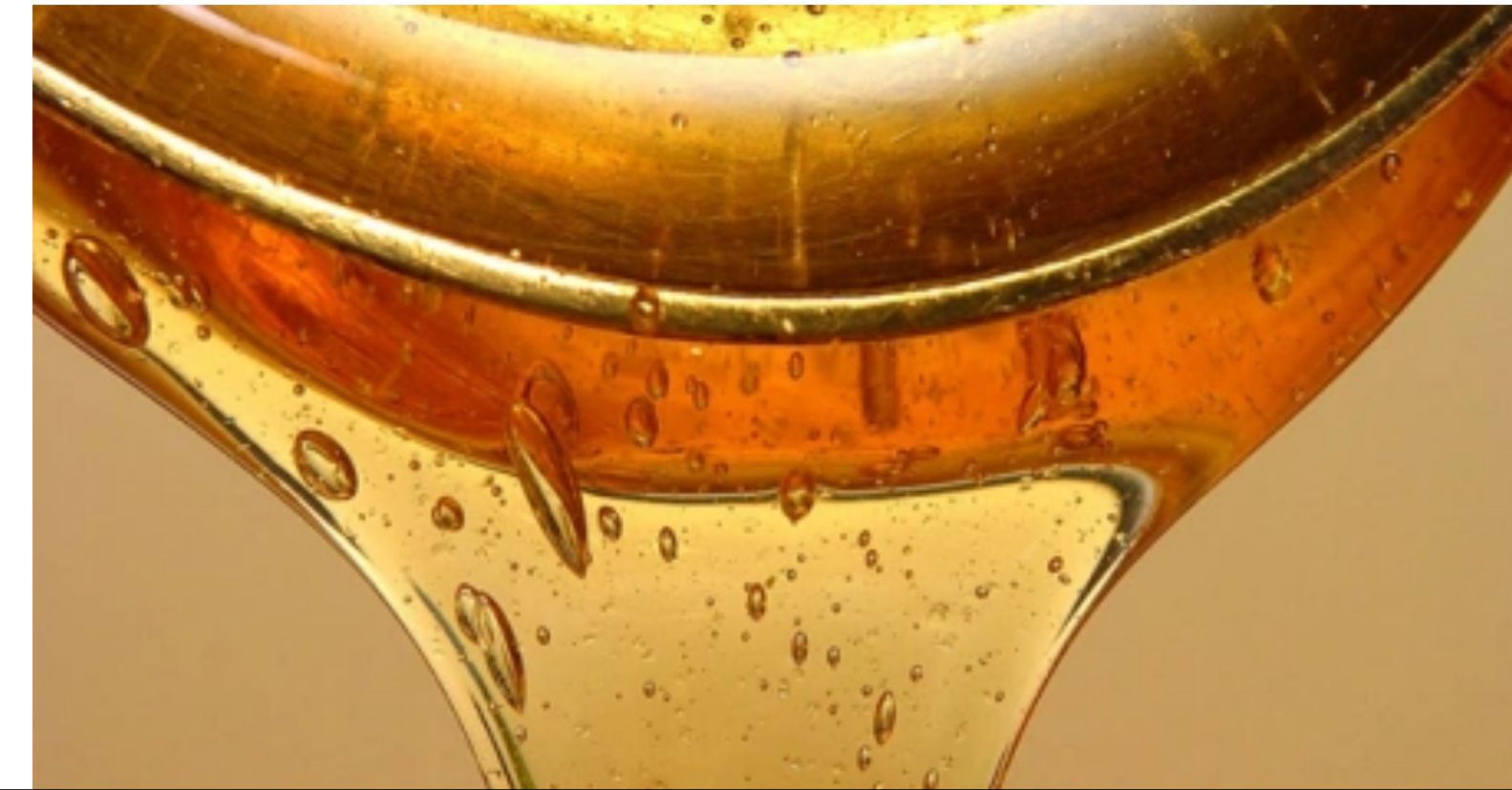
🕒 20m

Ongoing discussions with INFN to figure out possible synergies for R&D
—> Unique opportunity to enlarge the lines of competence in the Spanish Institutions

Possible areas of R&D

- 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

- ET optical layout
- Wavefront Sensing and Control
 - Phase cameras
 - Hartmann Wavefront Sensors
 - Optical Simulations
 - Quadrant photodiodes
 -
- Actuators on Optics
 - Ring Heaters
 - Deformable Mirrors
 -
- Quantum Noise Reduction
 - QNR simulations
 - Integrated squeezed vacuum source
 -

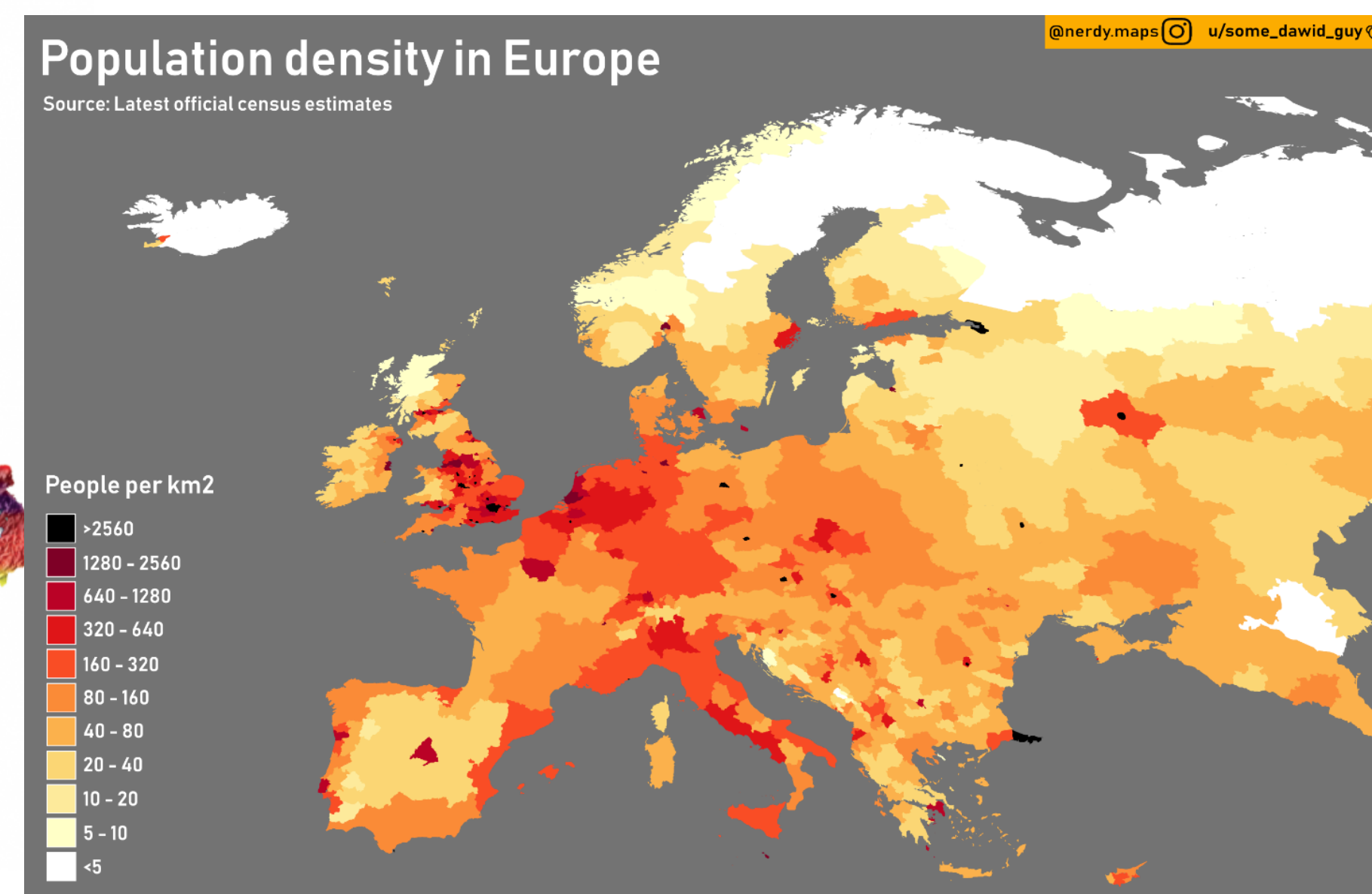
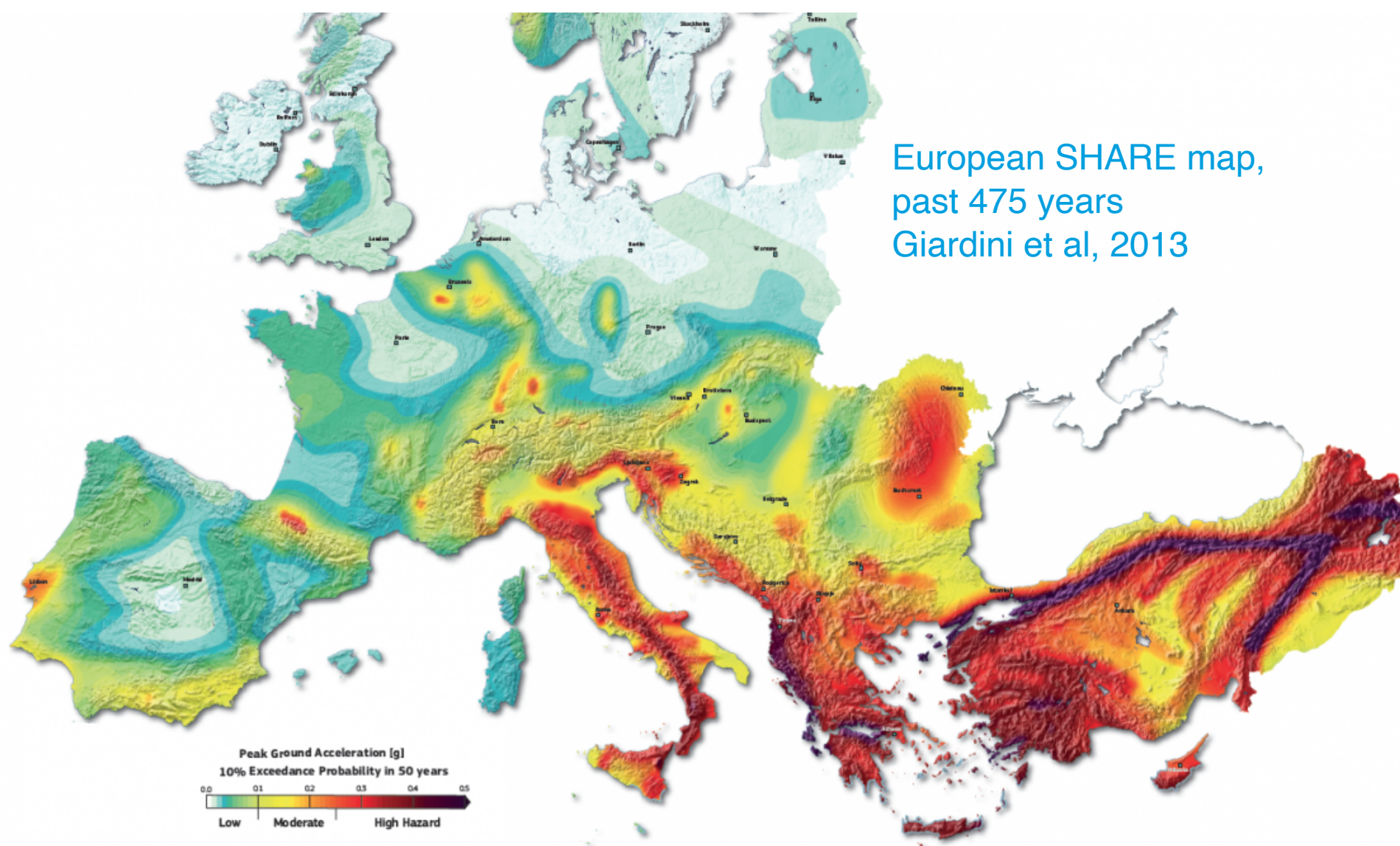
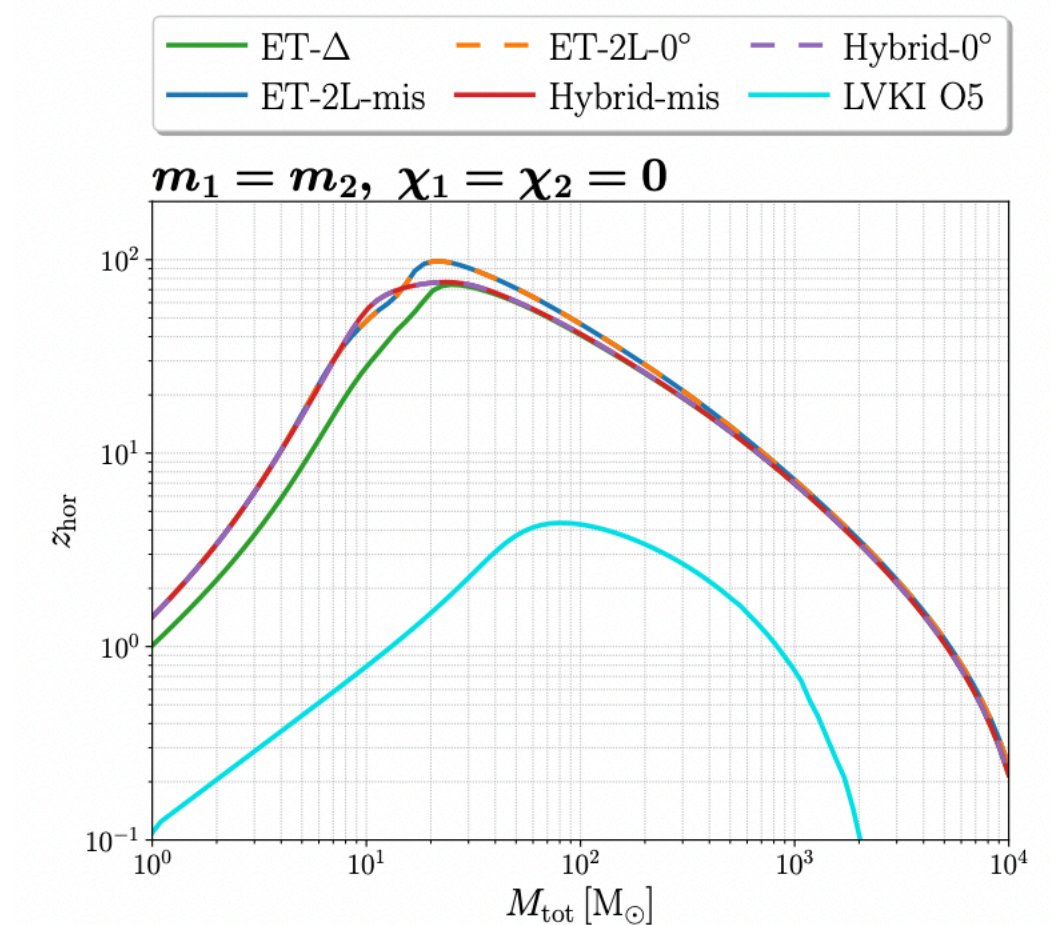
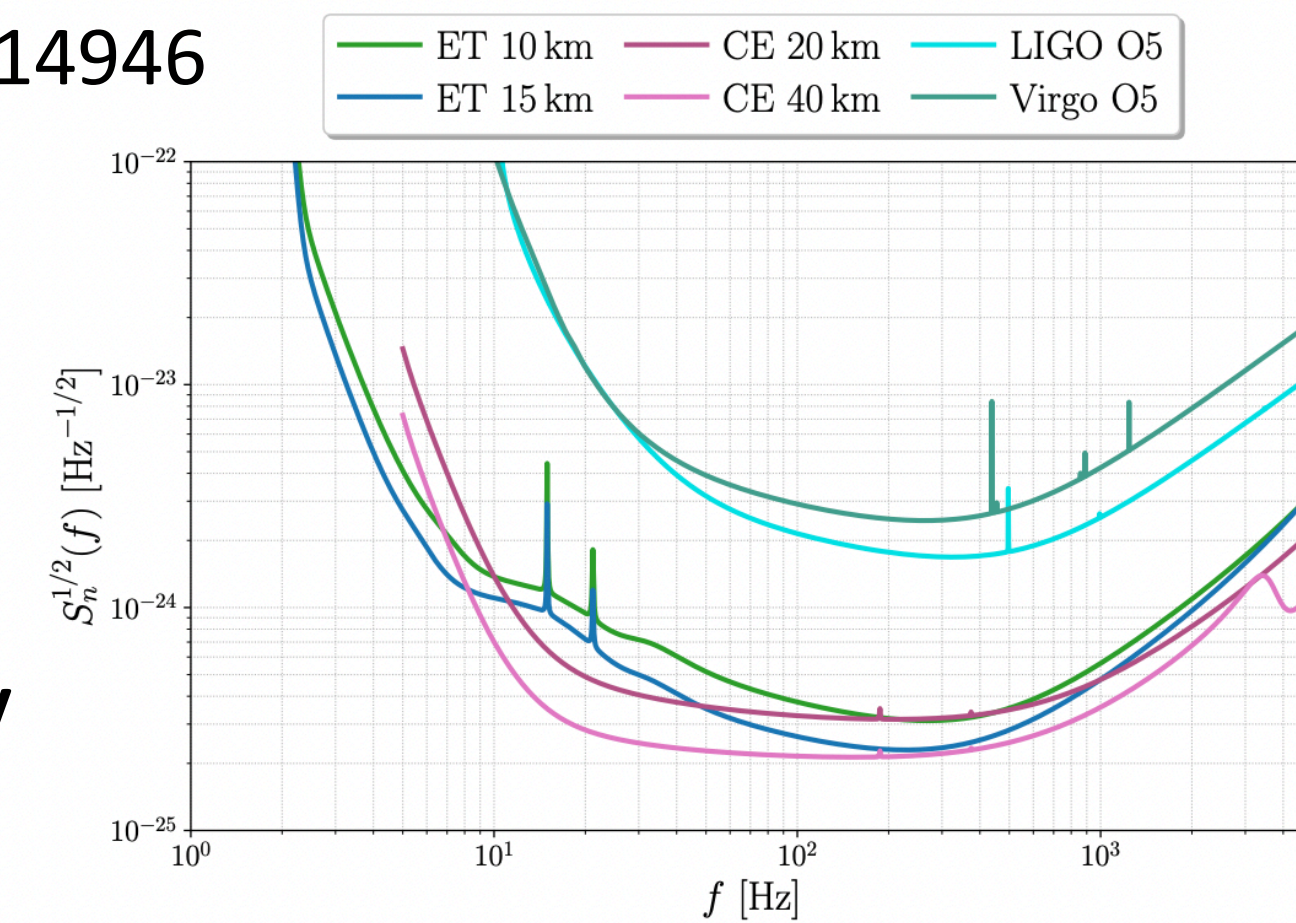


Sweet but always difficult and slow processes

It is time for the Spanish Institutions to move

On surface + Underground ? <https://arxiv.org/pdf/2408.14946>

- 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 20km) L-shaped one... you need to find a flat stable and empty place.
- Simulations for 2L hybrid (surface + underground) rather competitive



A surface solution would make Spain a unique place in Europe

A feasibility study would need O(10M€) and a few years of very serious work —

—> geological studies

—> costs, legal frameworks..

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)”
- Spanish Ministry decided to have a strategic alliance with Italy
 - Relevant for ET —> might translate into funding for ET-Spain
- ET-Spain needs to grow and get experimental community more involved.
 - There is a window of opportunity for us in case ET goes also on surface..

