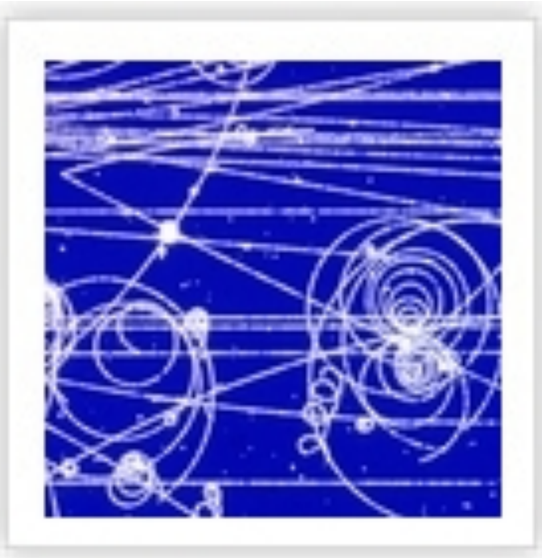
The Einstein Telescope Project

M. Martínez



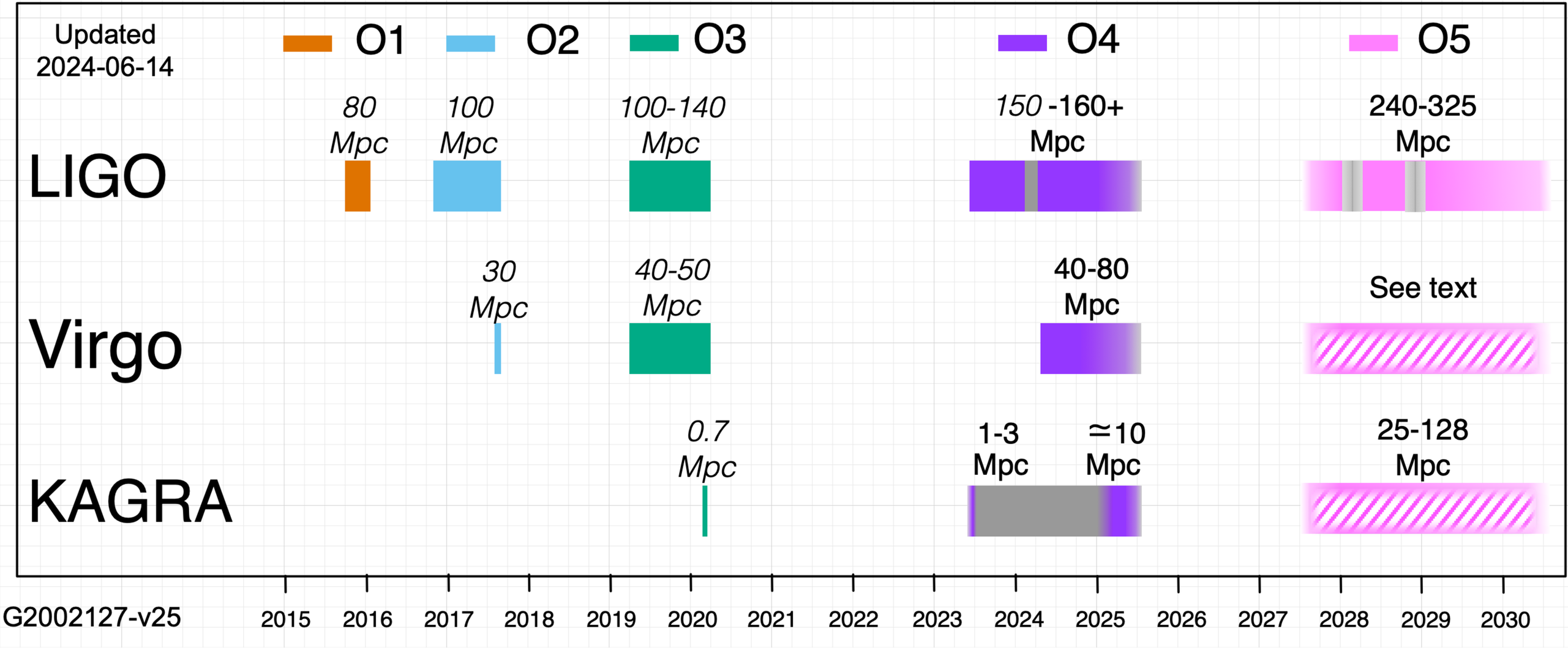
IMFP-2024, Benasque, September 2024

Outline

Einstein Telescope

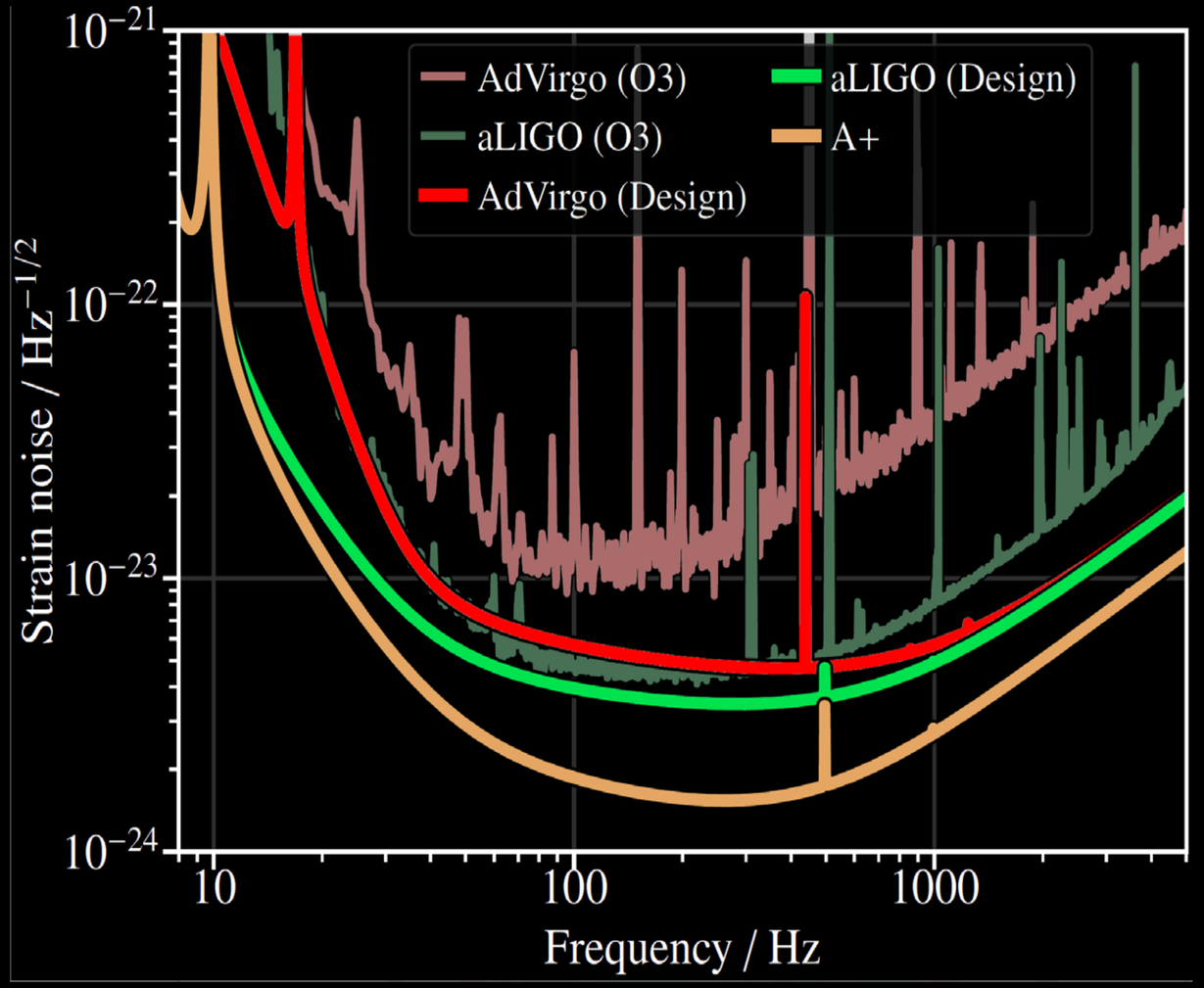
- Prospects for LVK by 2030
- ET Design & Discussions on Geometries
- ET Physics Prospects
- TimeLines, Locations and Cost
- Organisation and Political Support
- Preparatory Phase & work with CERN
- ET-Spain
- Final notes

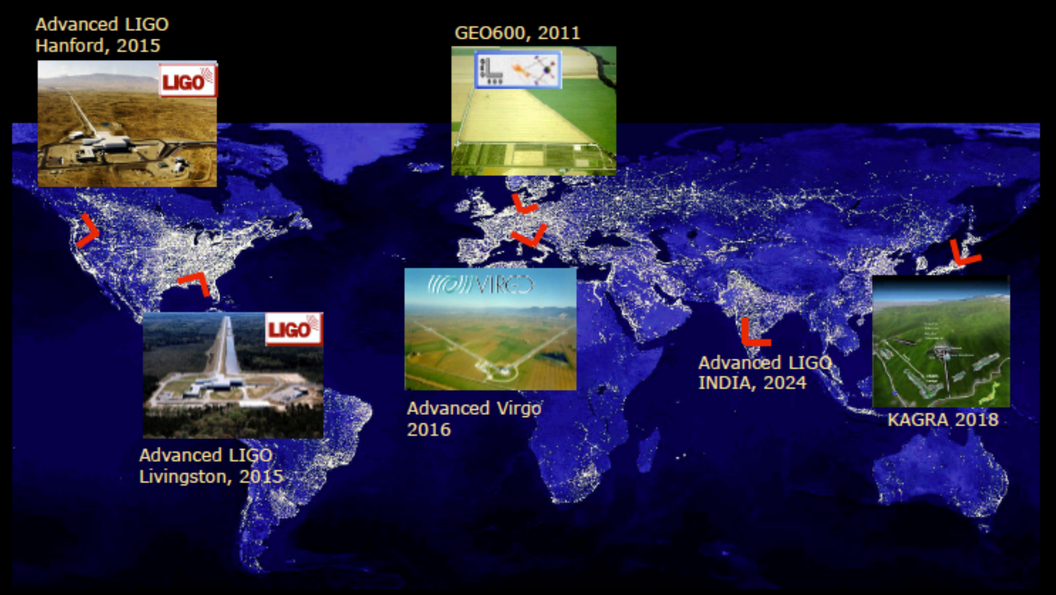
LVK Master Schedule



At present LVK program extends all the way to 2030

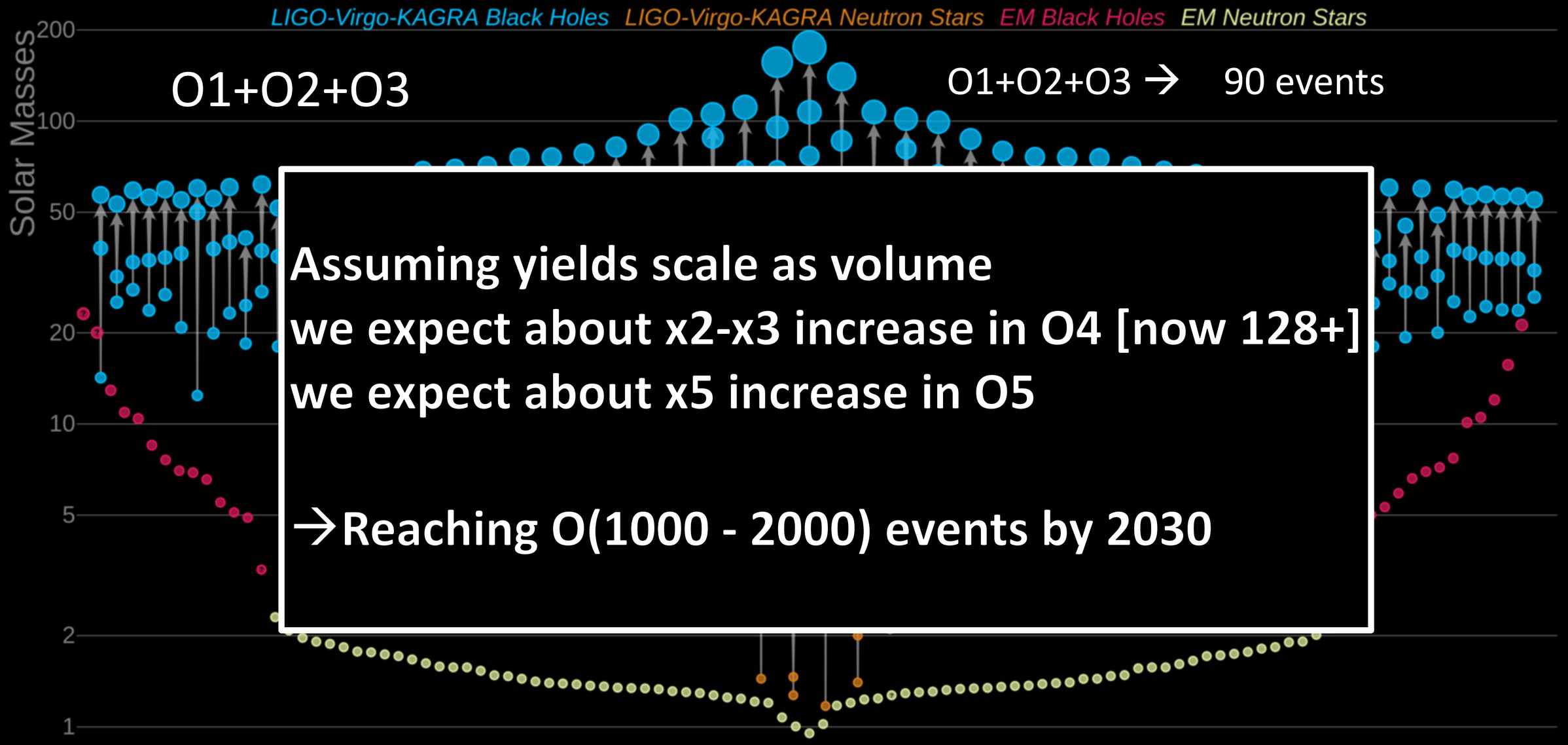
LVK sensitivity





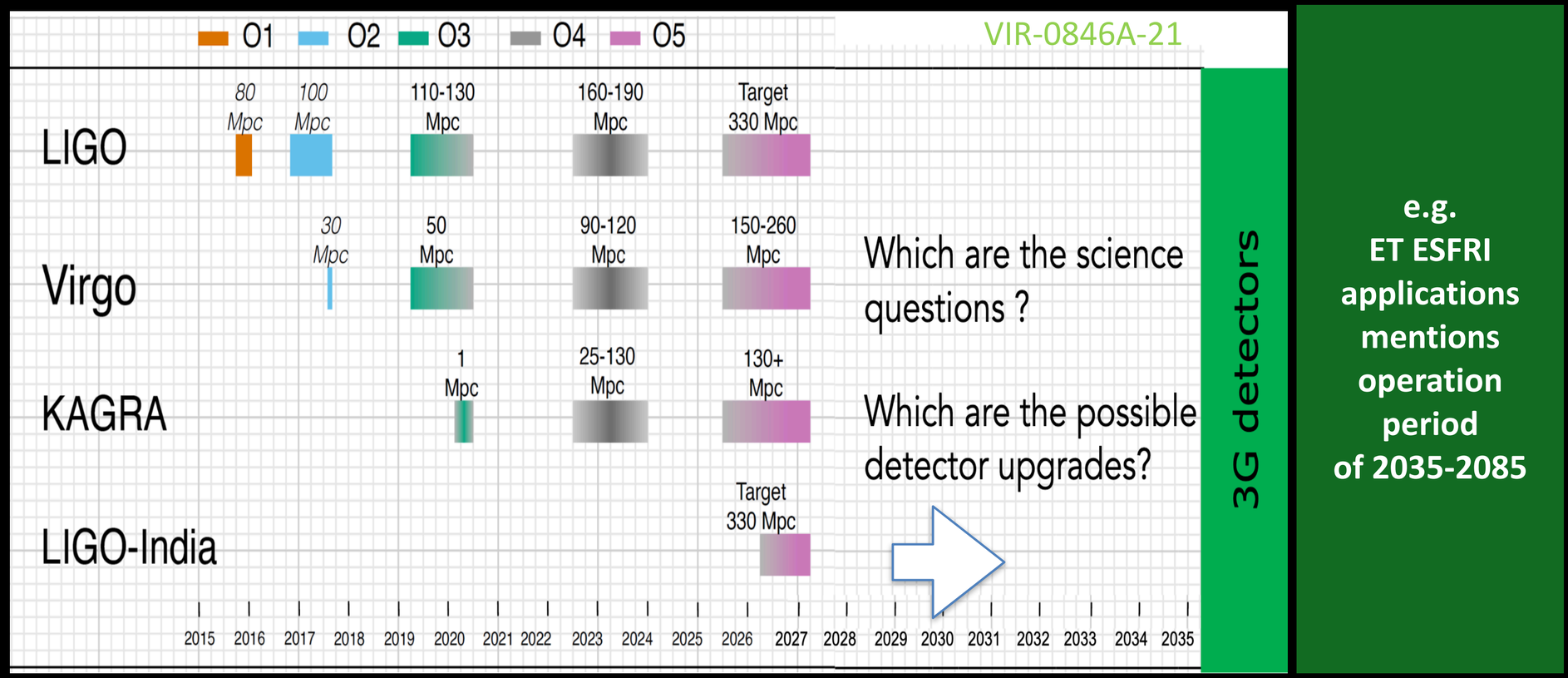
In the next 6 years the current Interferometers will reach their design sensitivity…

Masses in the Stellar Graveyard



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

What does the future hold?



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

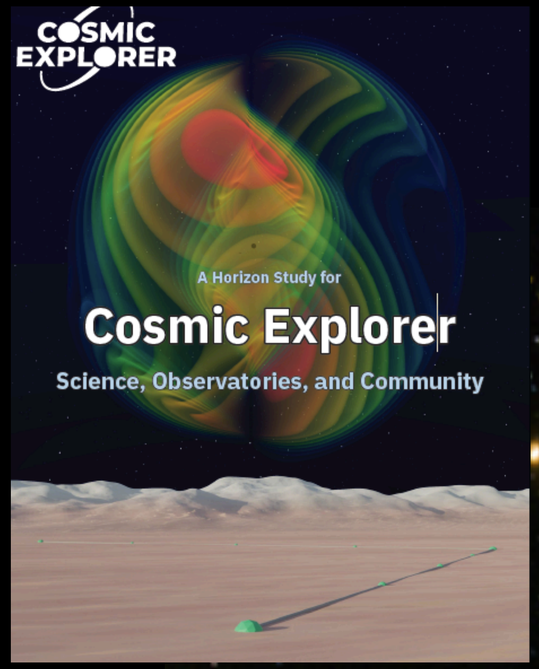
Post O5 (after mid 2028) planning just started

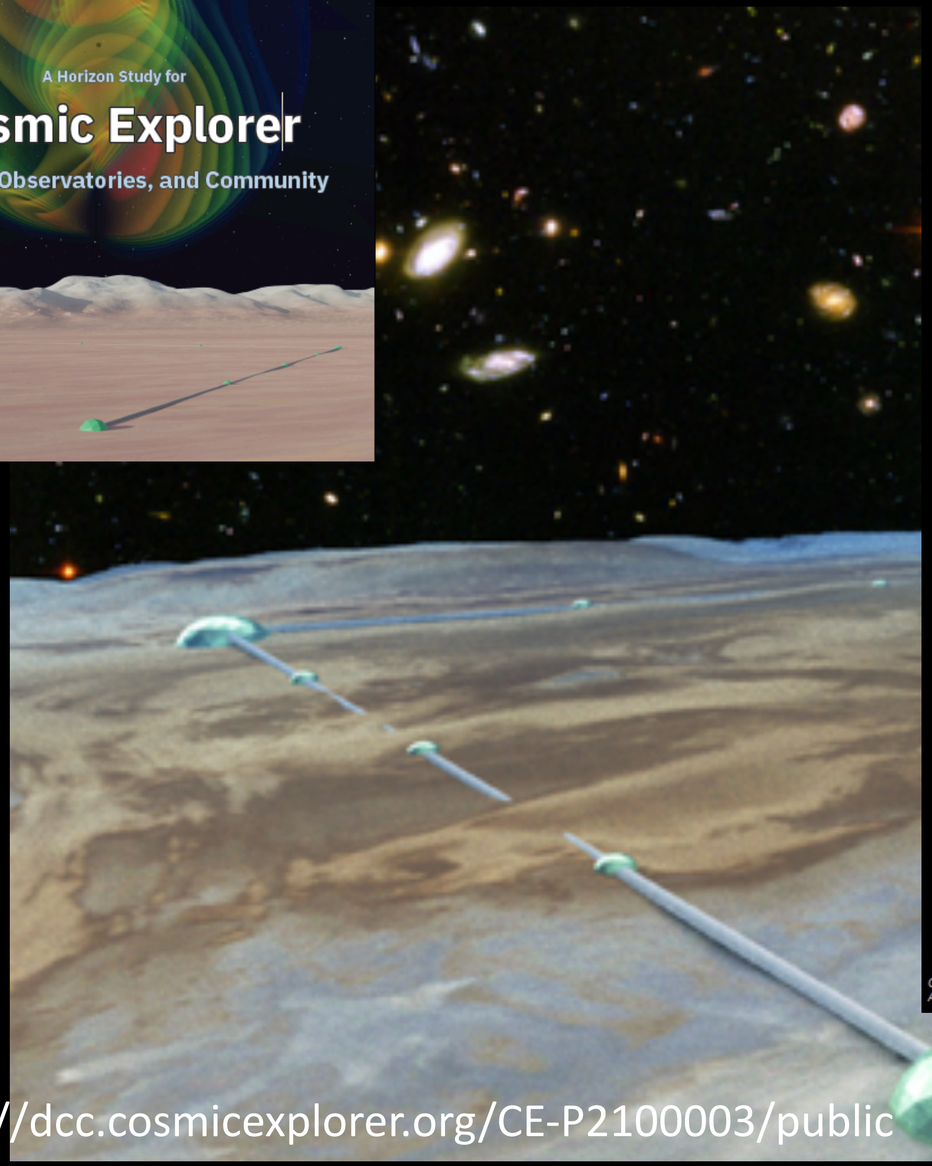
New facilities
ET, CE, NEMO
…

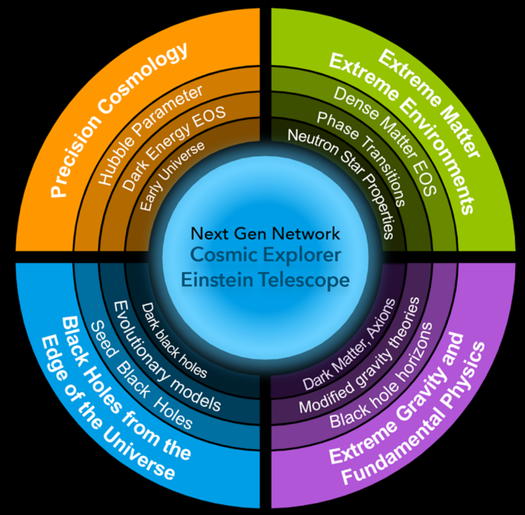
Old slide : now post-O5 is beyond 2029

Cosmic Explorer (USA)

https://cosmicexplorer.org/







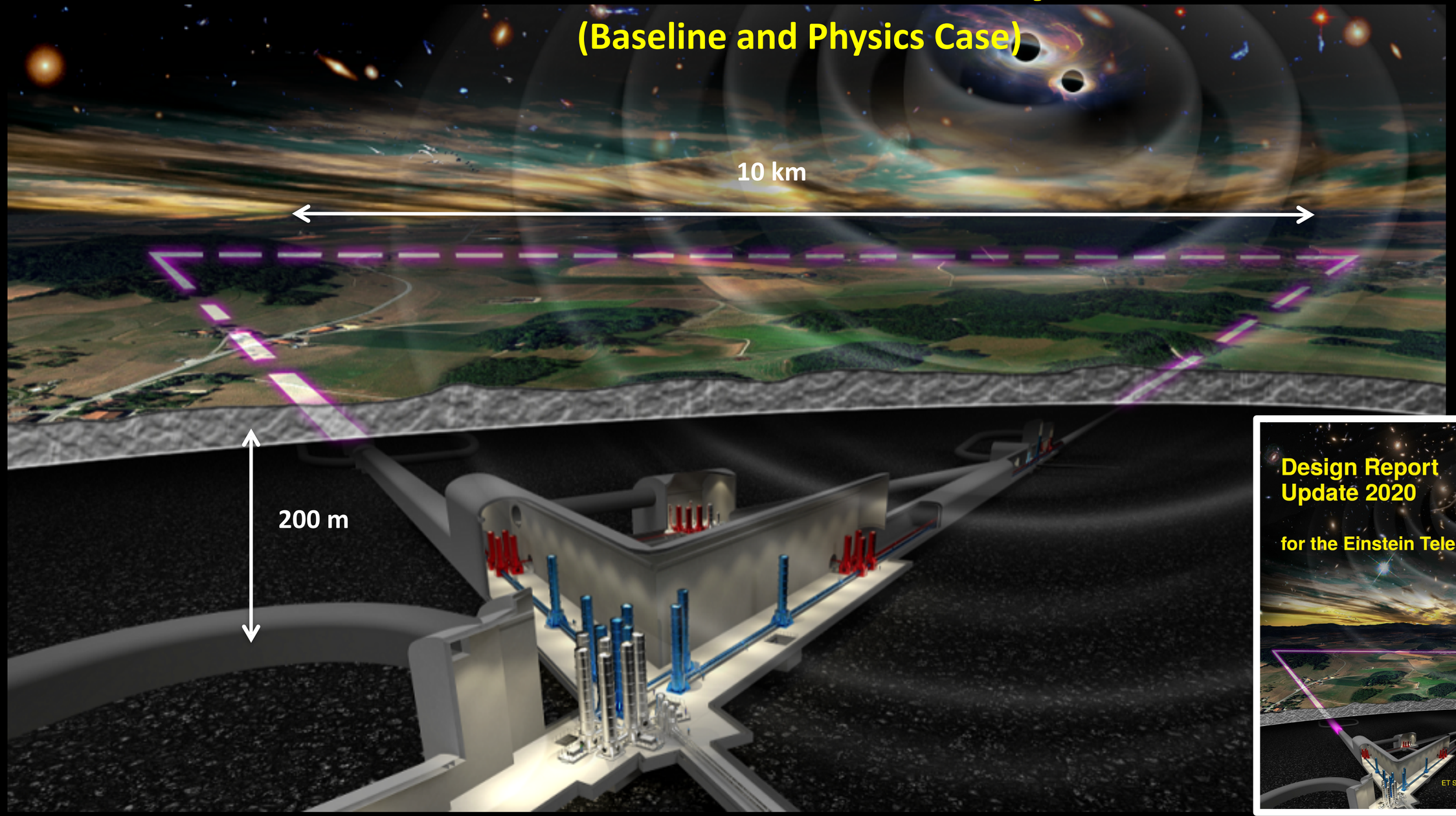
http://dcc.cosmicexplorer.org/CE-P2100003/public

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

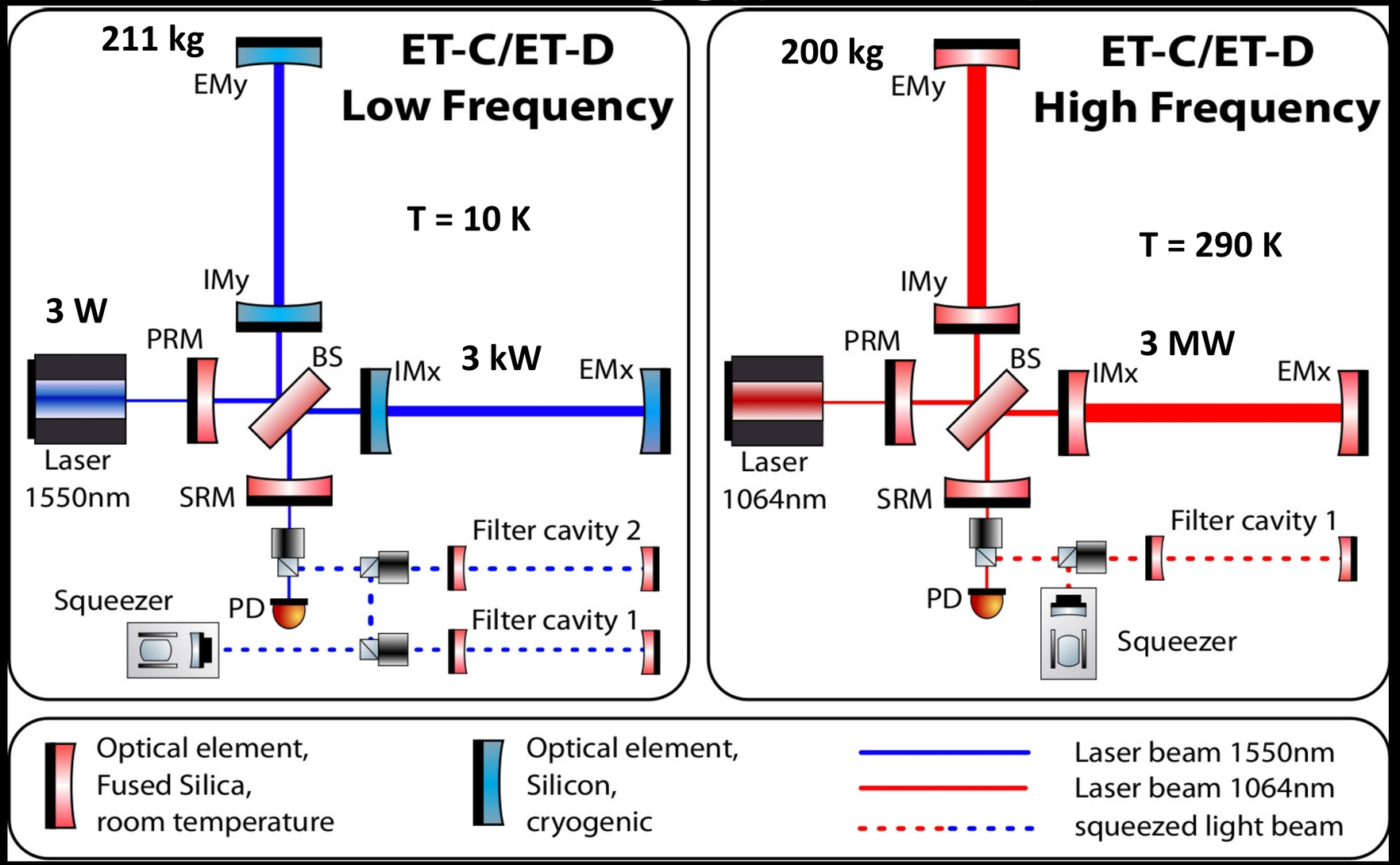
The Einstein Telescope

(Baseline and Physics Case)

First CDR in 2010 - 2011



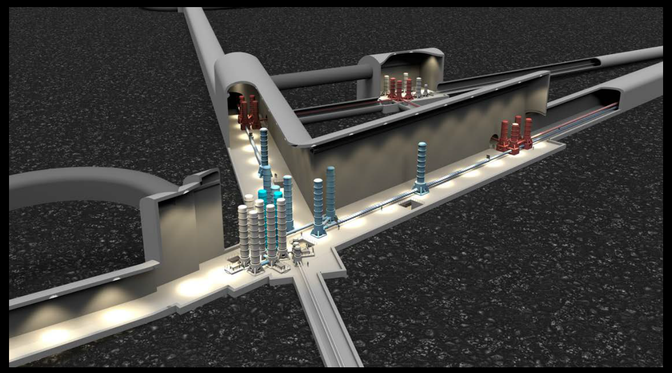
2nd Gen → ET

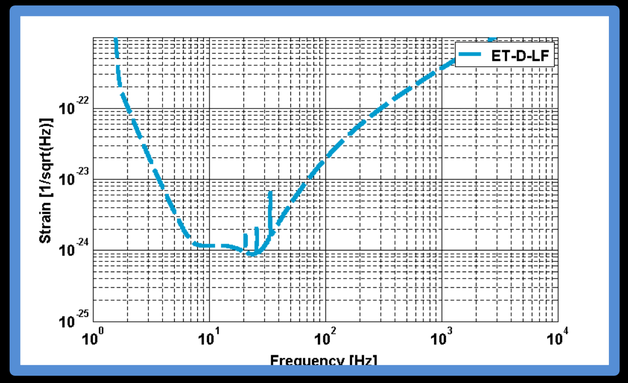


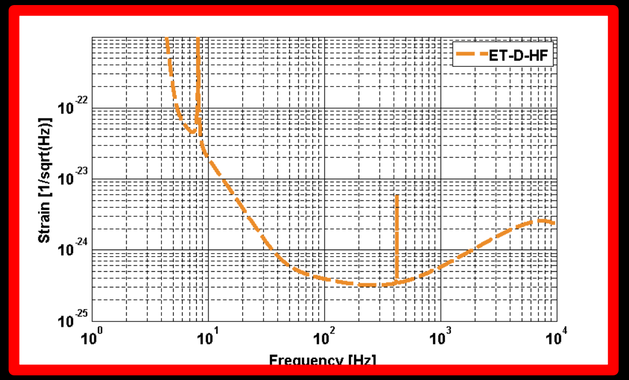
Underground
Cryogenic
Silicon mirrors
1550 nm (Si transparent)
New optical coatings
New suspensions / seismic controls

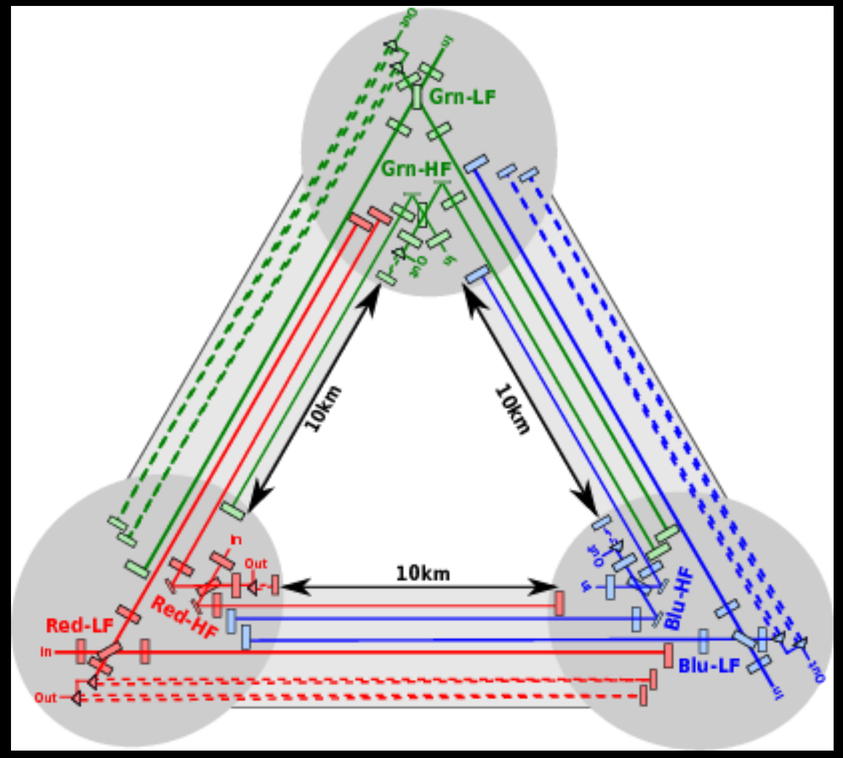
More powerful lasers
Larger fused silica mirrors
1064 nm (silica transparent)
New optical coatings
New thermal compensation systems

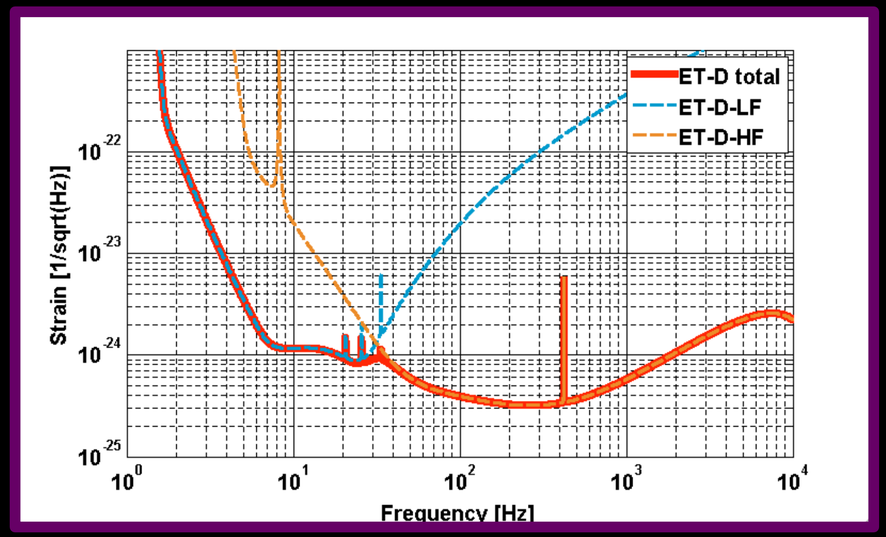
Einstein Telescope (6 in 1) Xylophone



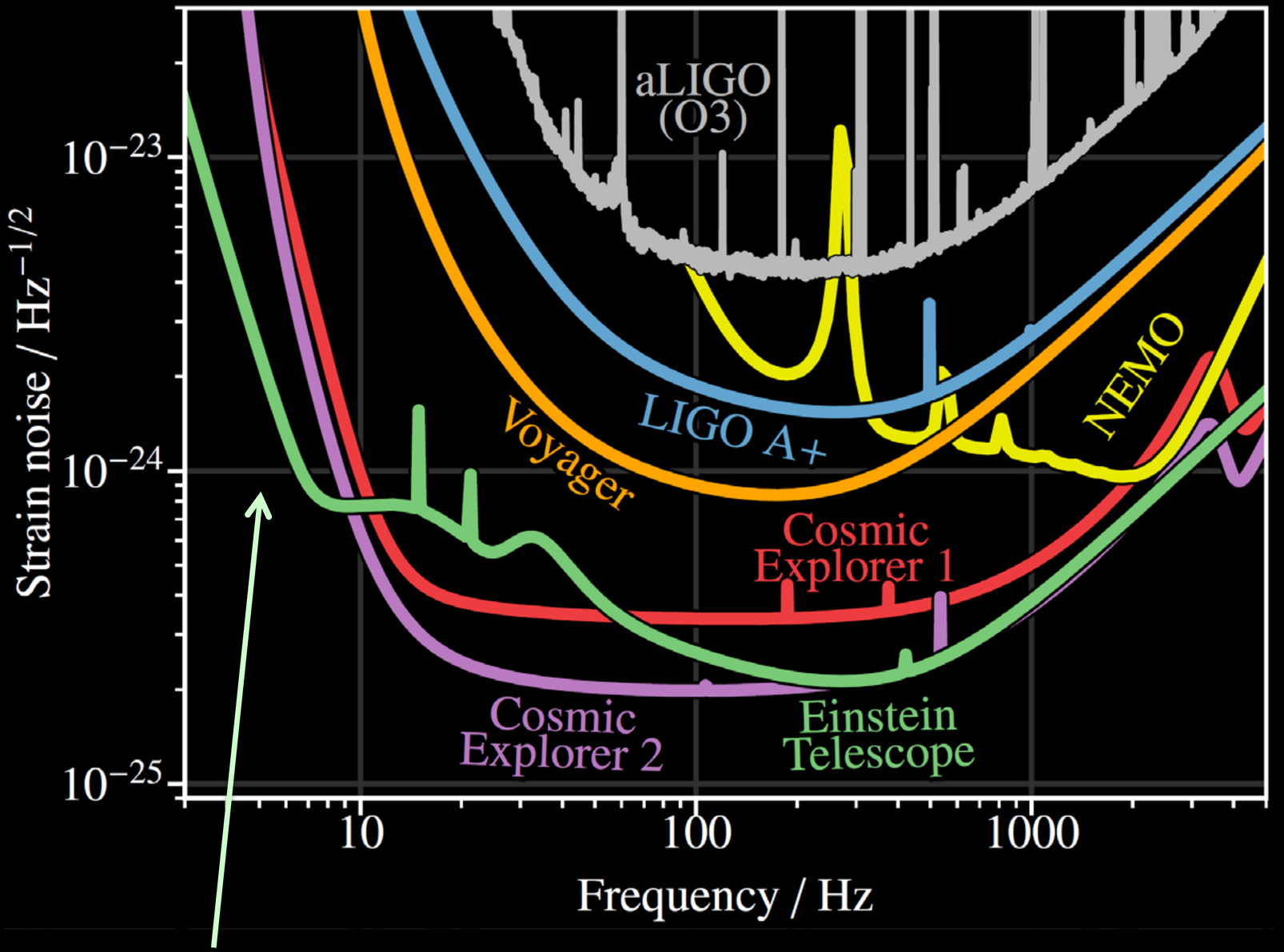








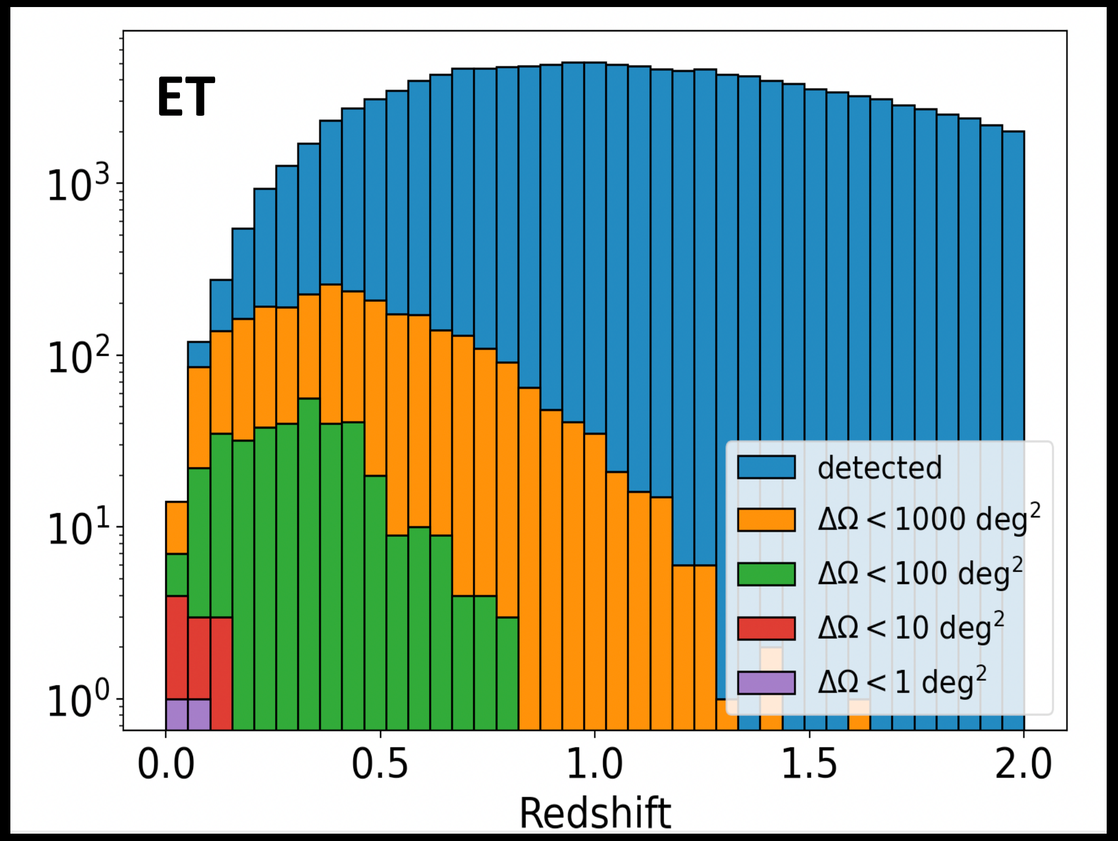
Each interferometer decoupled into 2 devices independent for the best sensitivity to low and high frequency

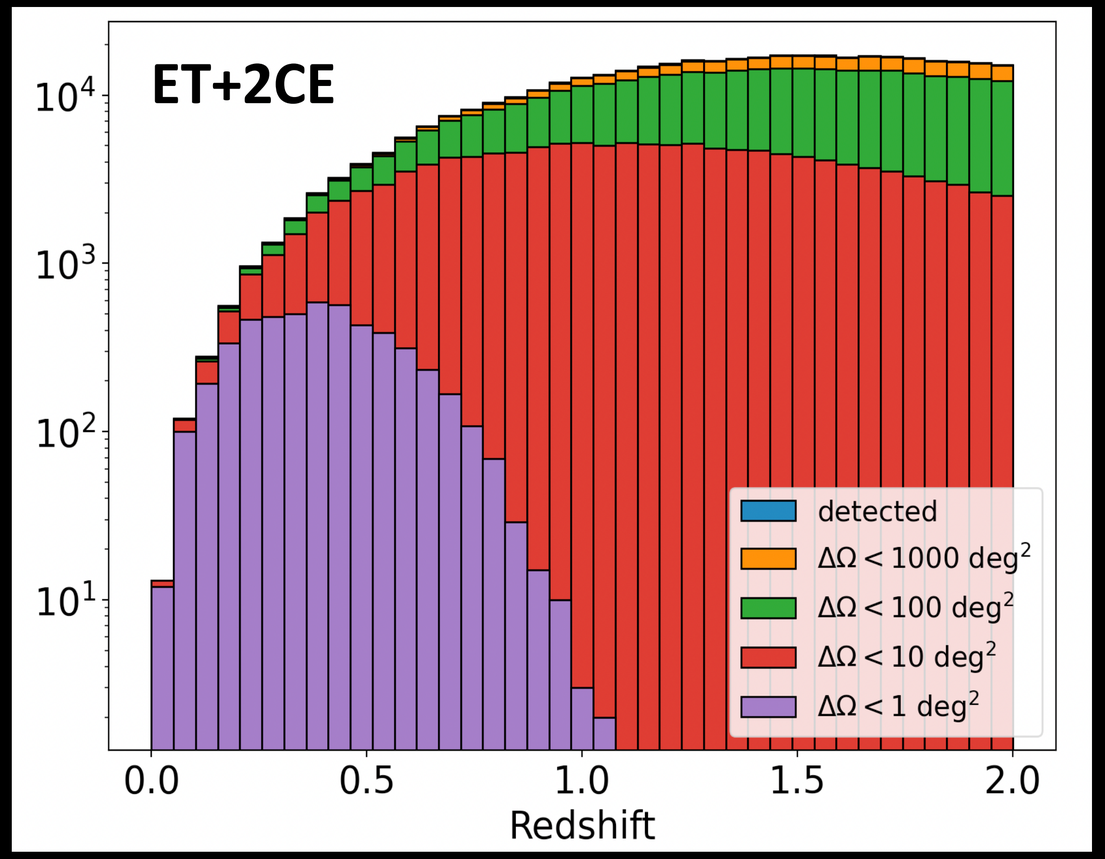


About one order of magnitude improvement w.r.t current detectors

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

Sky localization





ET only configuration would allow for O(100) events / year with a sky-localizations (90% CL) < 100 deg^2

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

ET Science

arXiv:1912.02622

ET Science Blue Book will be ready by September 2024 (this month)

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

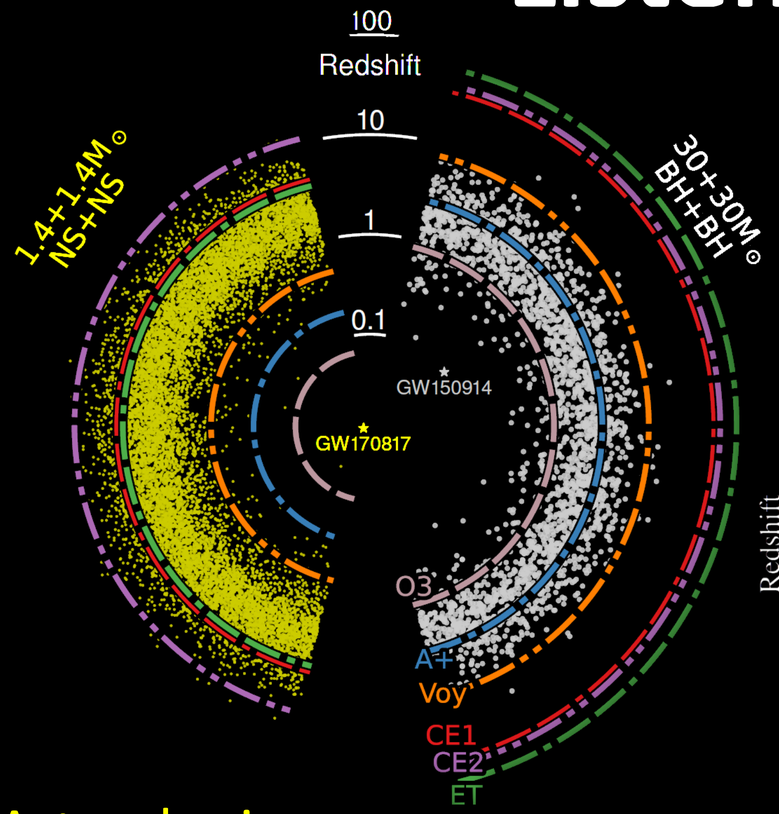
- **Stochastic backgrounds of cosmological origin and HEP**

– inflation, first-order phase transitions

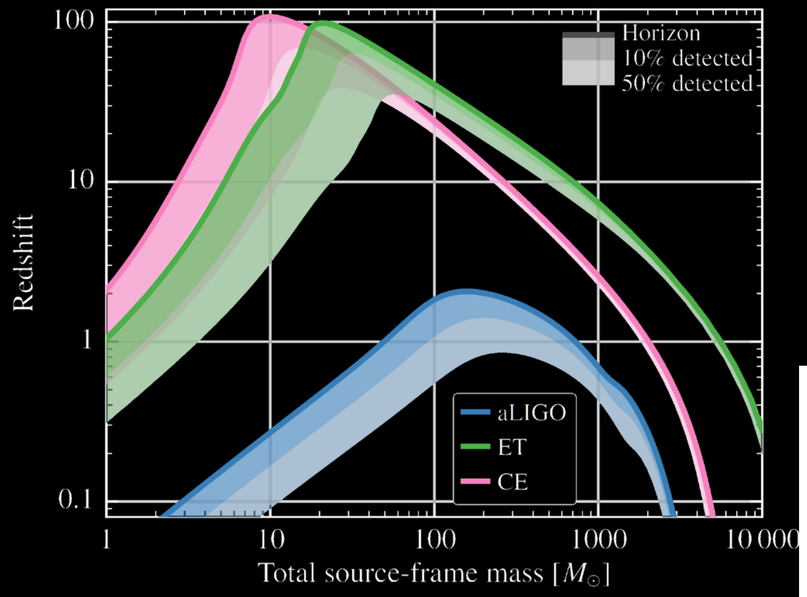
– cosmic strings, domain walls..

Listening the whole Universe

Iacovelli et al. 2022

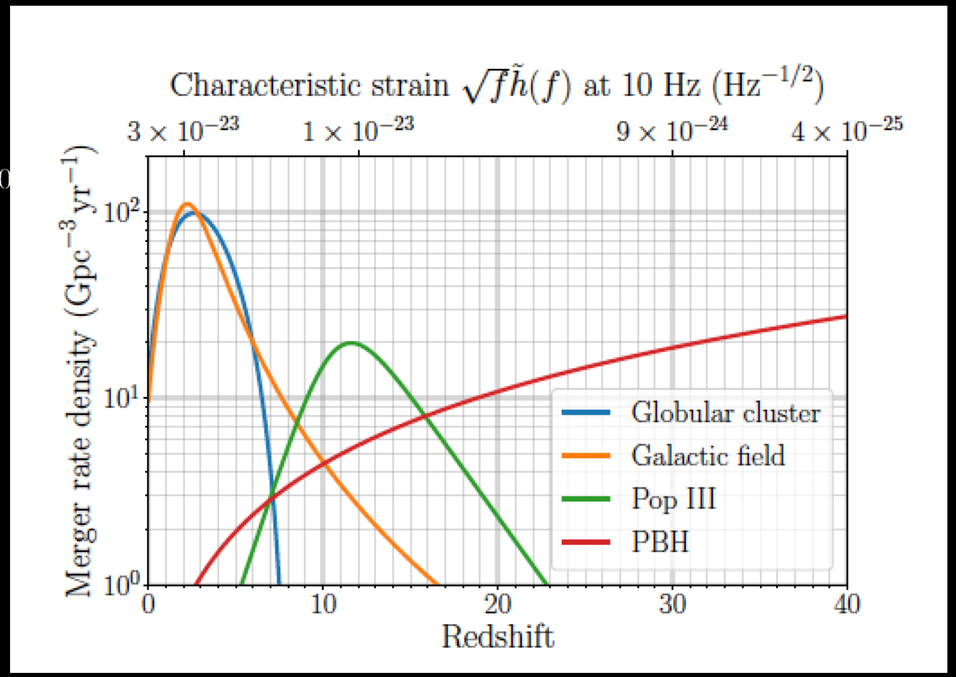


- 10^6 BH-BH / year up to z ~20 (230 Gpcs) and 10^3 M_{sun}
- 10^5 NS-NS / year up to z~2
- O(10^2 – 10^3) GW events with EM counterparts

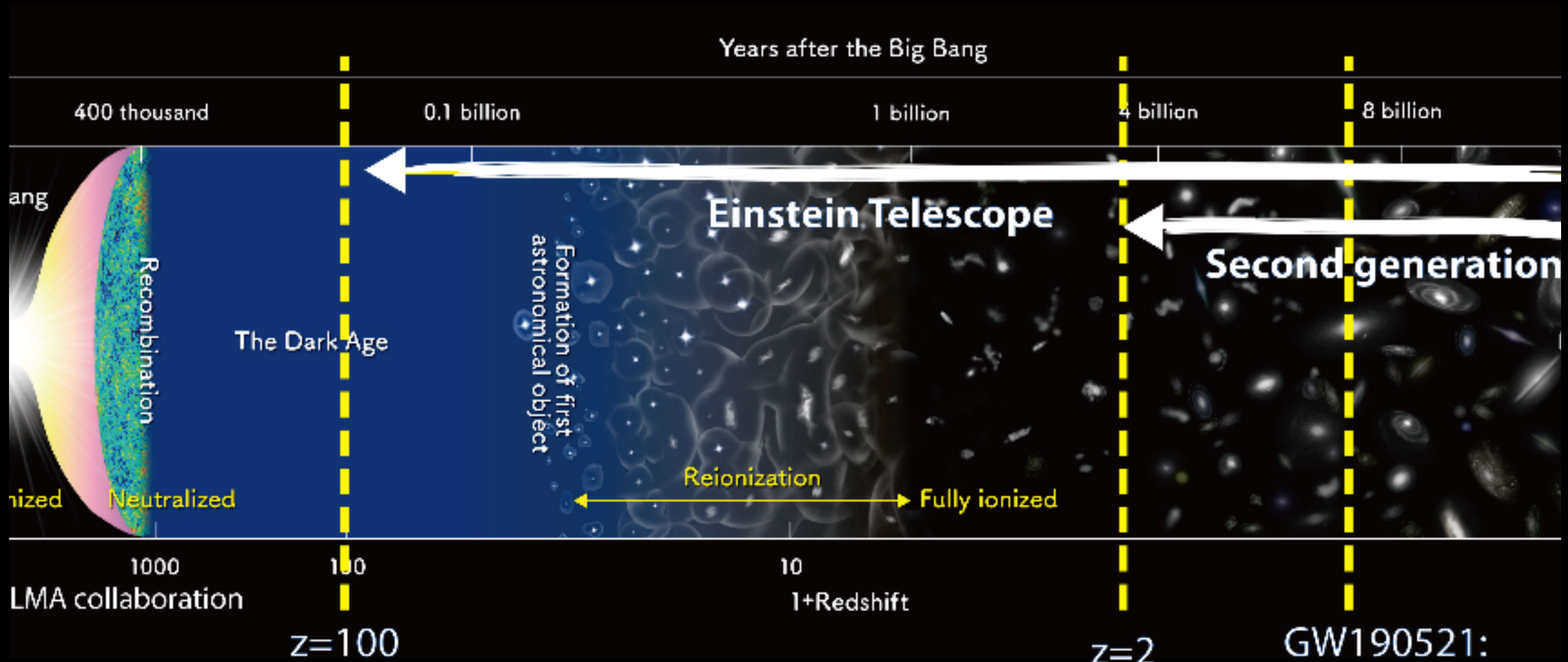


Astrophysics

- 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



Detection horizon for black-hole binaries

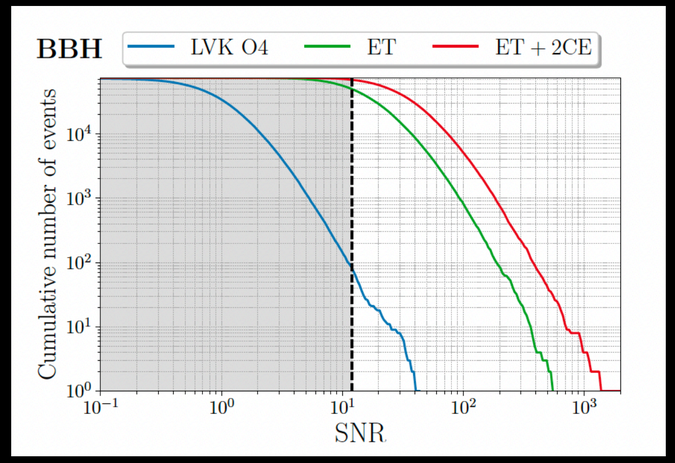


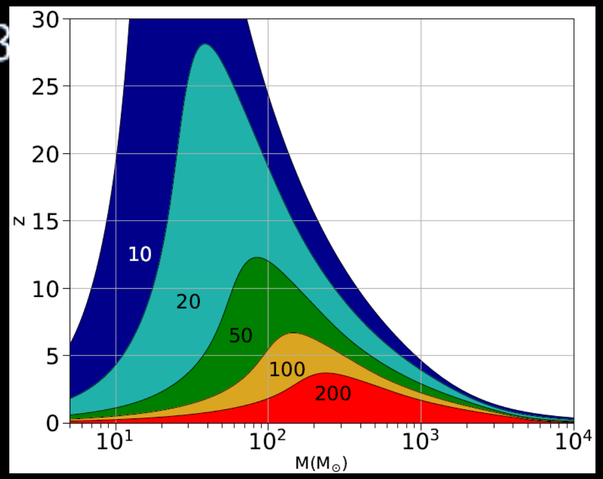
Huge rate of detections (about 1 per minute)
Extended redshift coverage up to the Dark Age

- Test for primordial BH origin
- Cosmology & Cosmography

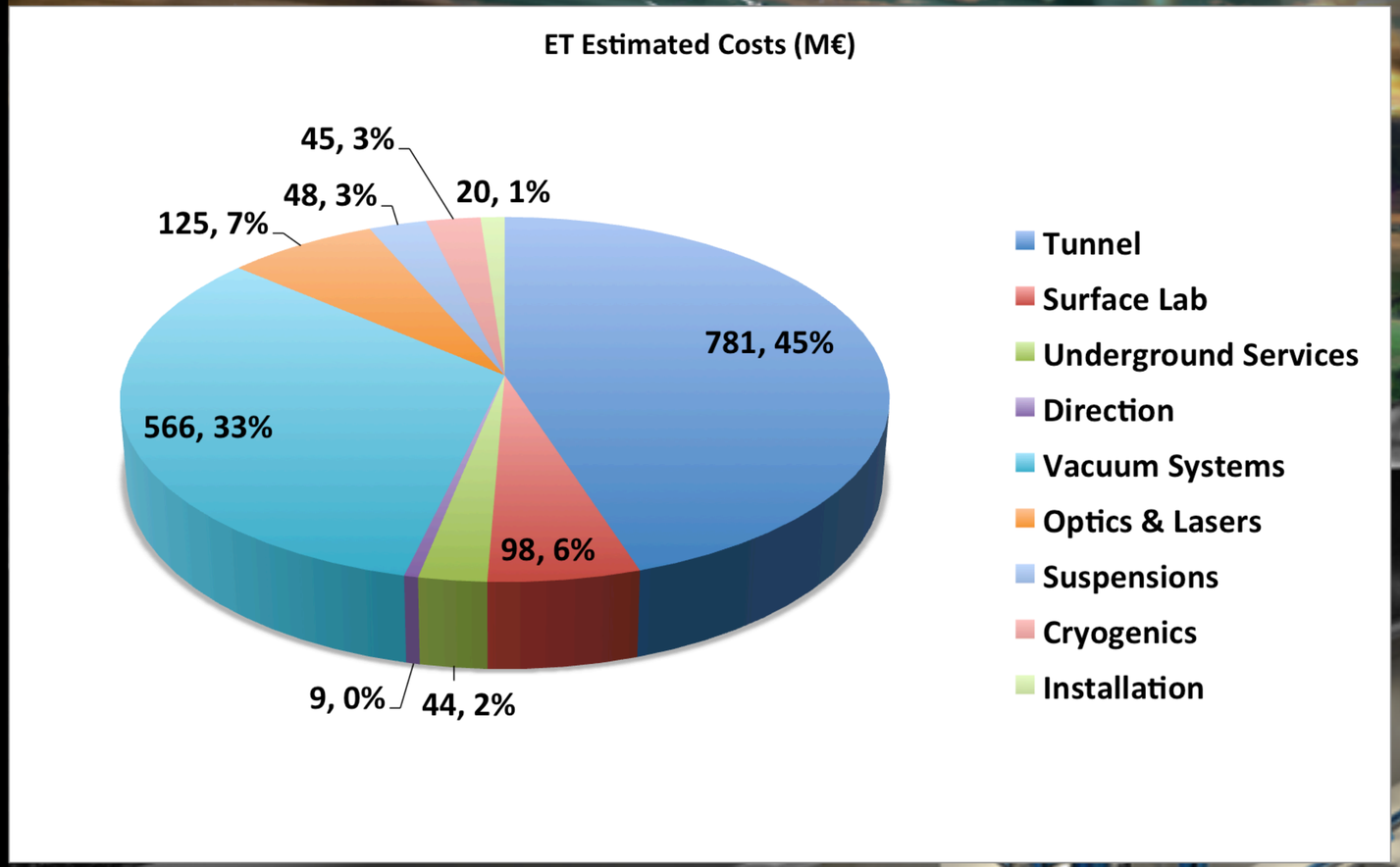
Many events with very large Signal-to-Noise ratios

- Precision tests of GR predictions and detailed BH studies





Estimated cost (EU accounting)



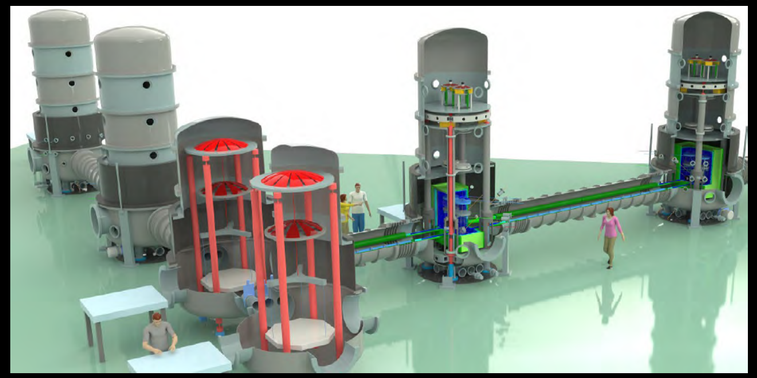
Preparatory phase (170M€)

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

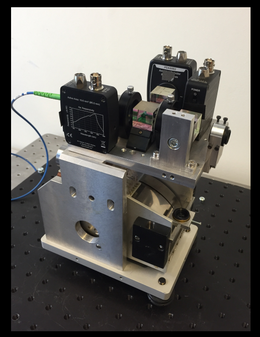
Construction : 1900 M€ (in 10 years)
M&O : 37M€ /year

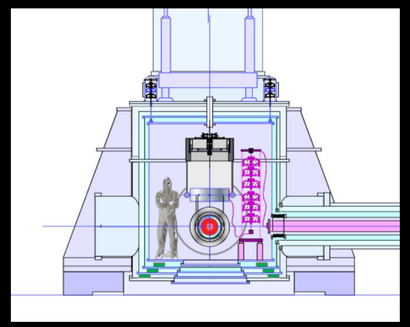
Host country is expected to contribute with > 50% of the total cost

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)



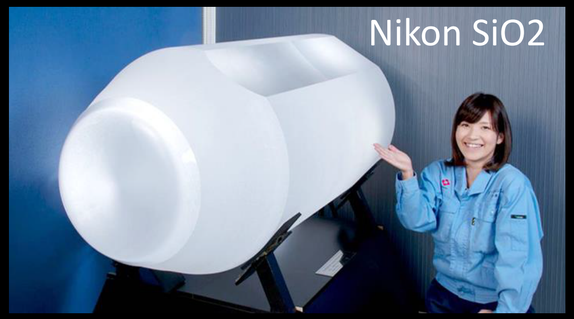


R&D in active mitigation
of seismic / Newtonian noise

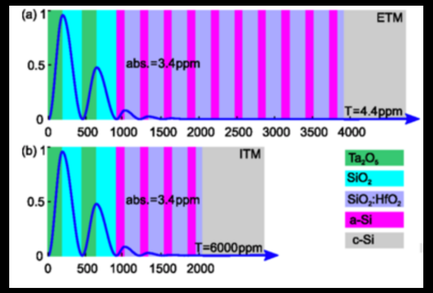
R&D on IR photo sensors

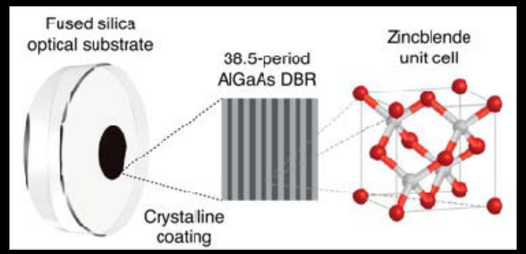
@ Rome and other R&D places
in cryogenic suspension

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)

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

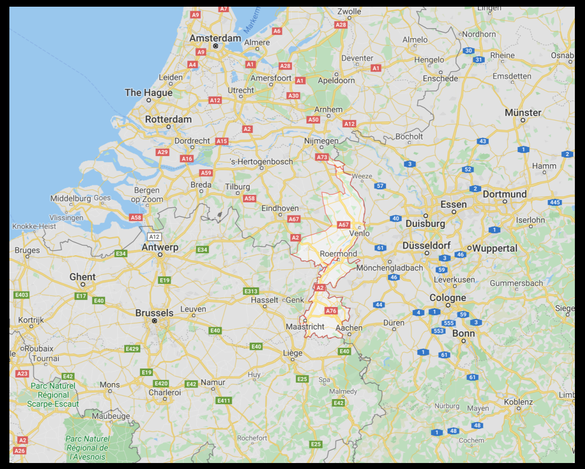
Glasgow
Amsterdam
Maastricht
Louvain
Hamburg
Hannover
Görlitz
Karlsruhe
Lyon
Padova
LNGS
Rom
Sos Enatos

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

Google Earth

Locations ?

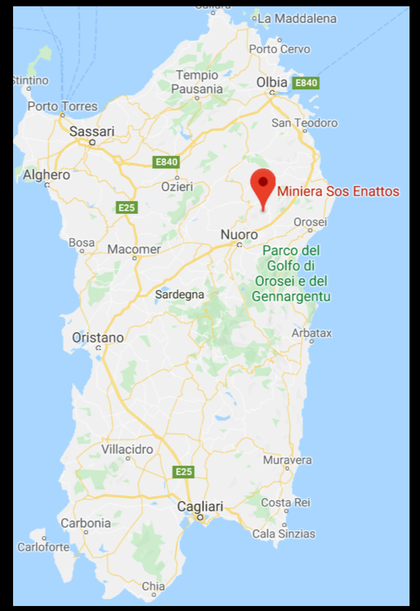
O(50 M€) investment
Lab in construction



30 M€ investment
ETparthfinder

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

O(50 M€) investment
Lab in construction

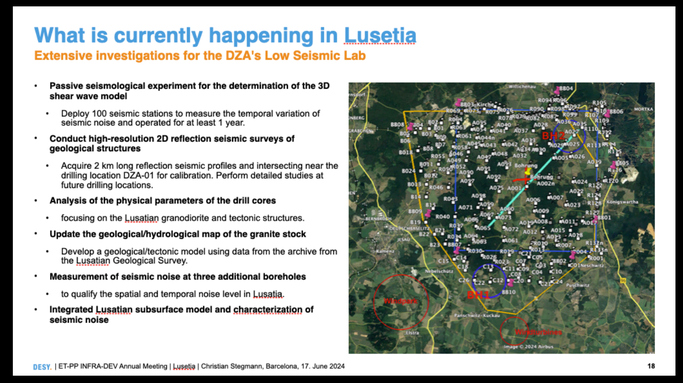


@ Limburg area (border NL-B-D)
→ Promoted by Nikhef

@ 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
→Recent positive political signs (TBC) for ET@DE

@ Sardinia
→ Promoted by INFN



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**

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 servirranno 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.

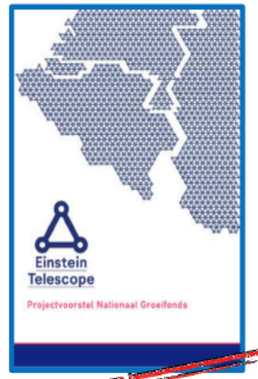
Germany asking for local support O(10M€) to carry our a comprehensive study and maybe push for a candidature

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

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 2021 the Netherlands Ministry 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

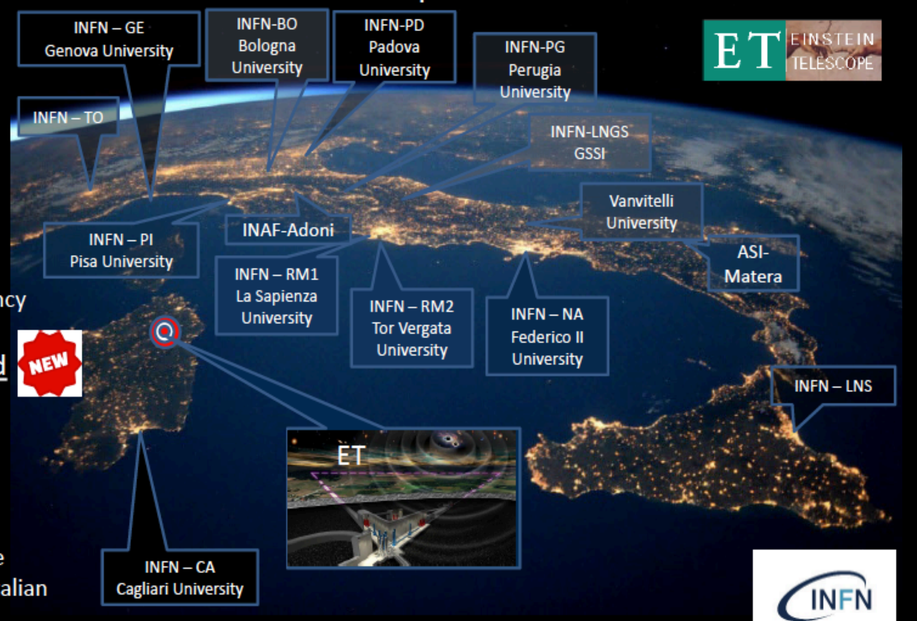
Next Generation EU Investment focused on ET enabling technology and Sardinian site candidature support

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



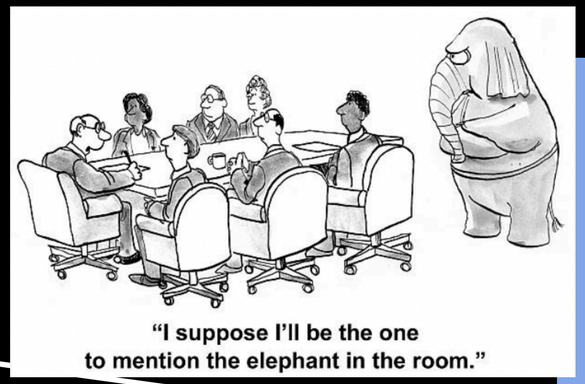
Ongoing layout discussion

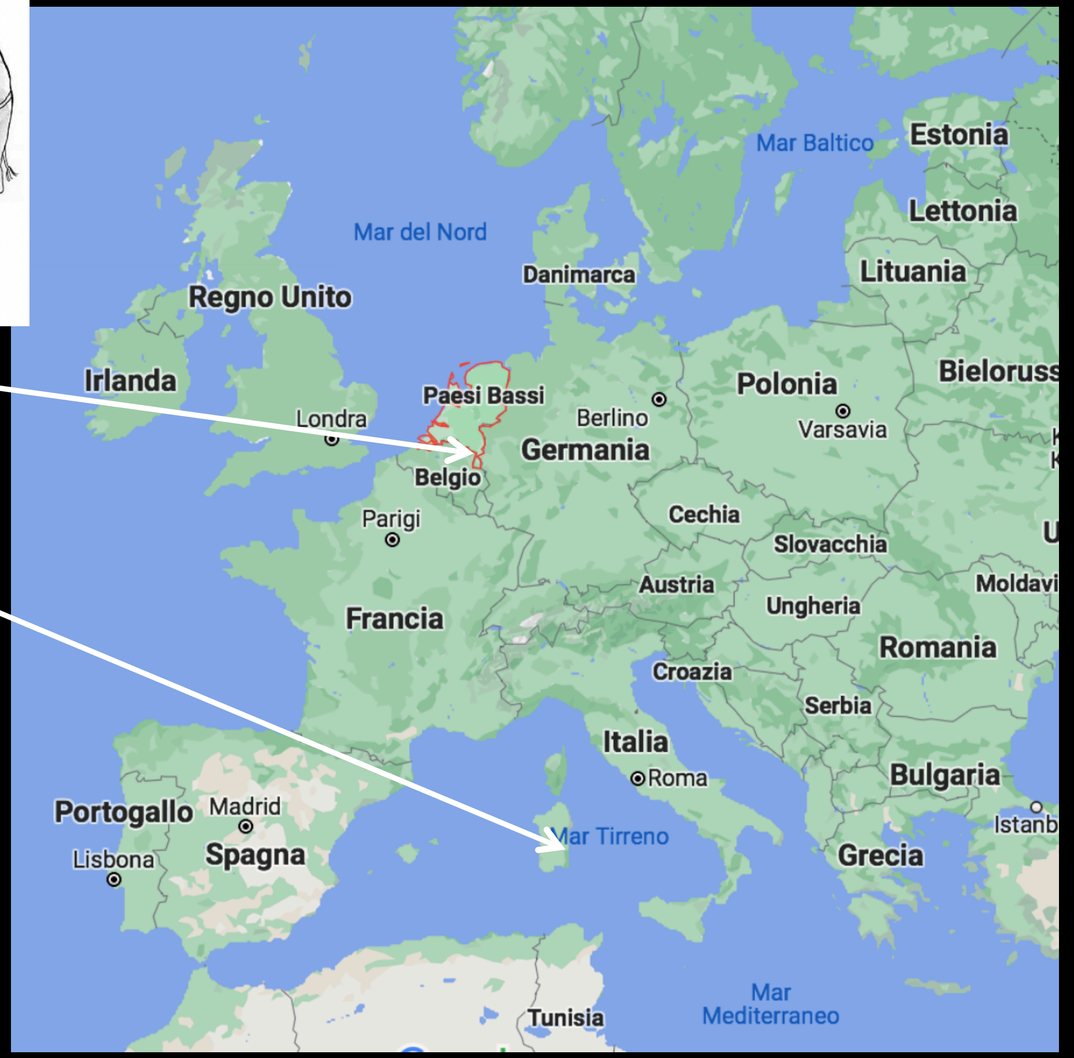
Branchesi, Maggiore et al. 2023

Two scenarios
- D of 10 km
- D of 15 km

Two scenarios
- 2L of 15 km
- 2L of 20 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

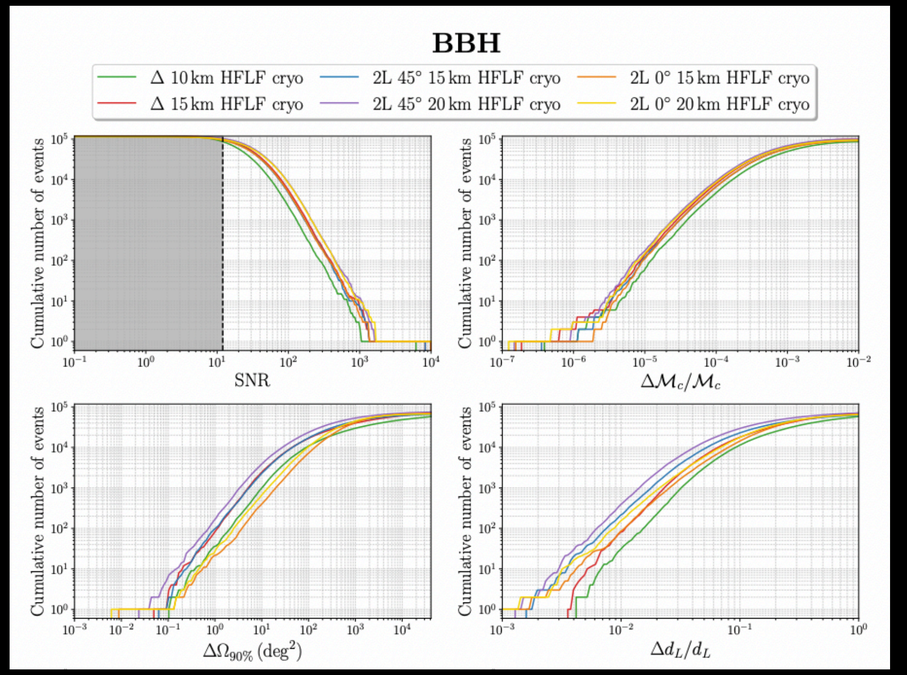
—> ETO received the mandate to present full cost of risk analysis

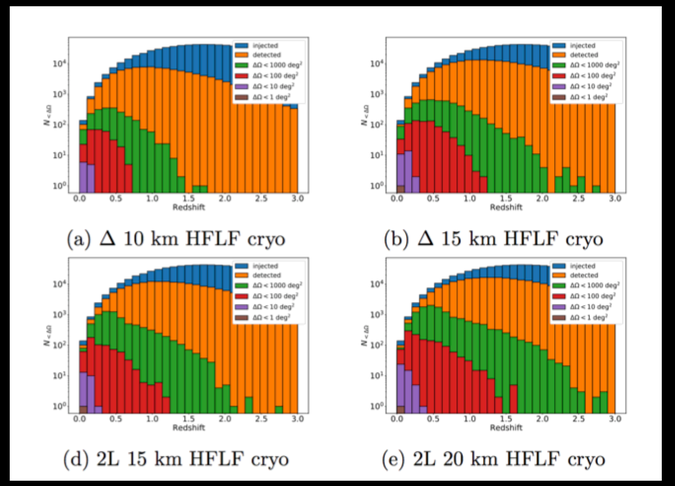
—> Will compare underground 10 km ET triangle vs underground 2L 15km

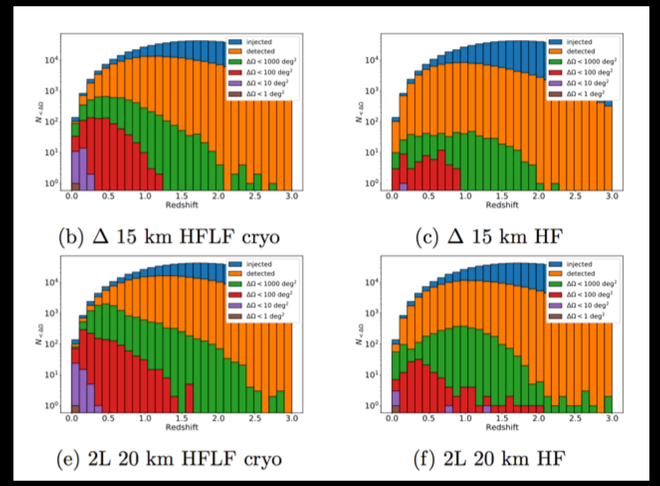
Comparative studies
(only physics potential)

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 Δ10km
- Only LF makes BNS pre-meger alerts possible —> impact on multi messenger
- Concerns about possible correlations in the Δ compromising stochastic searchers



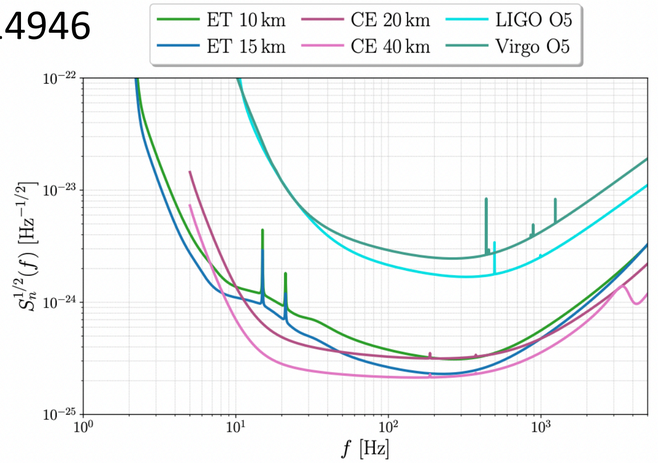


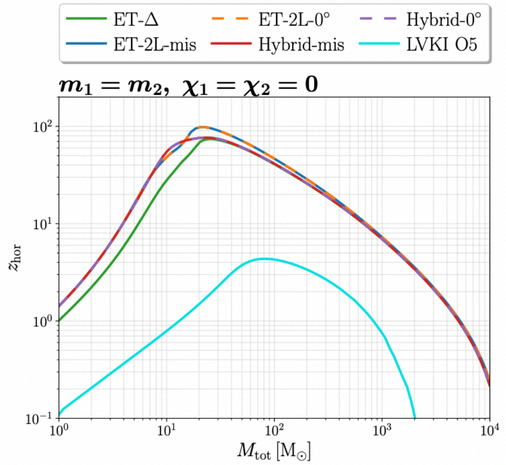


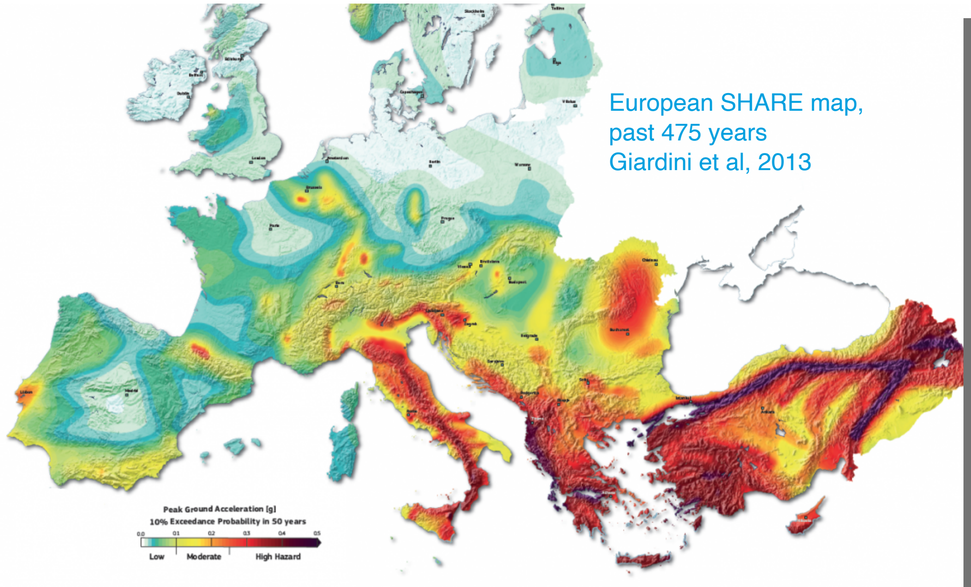
On surface + Underground ?

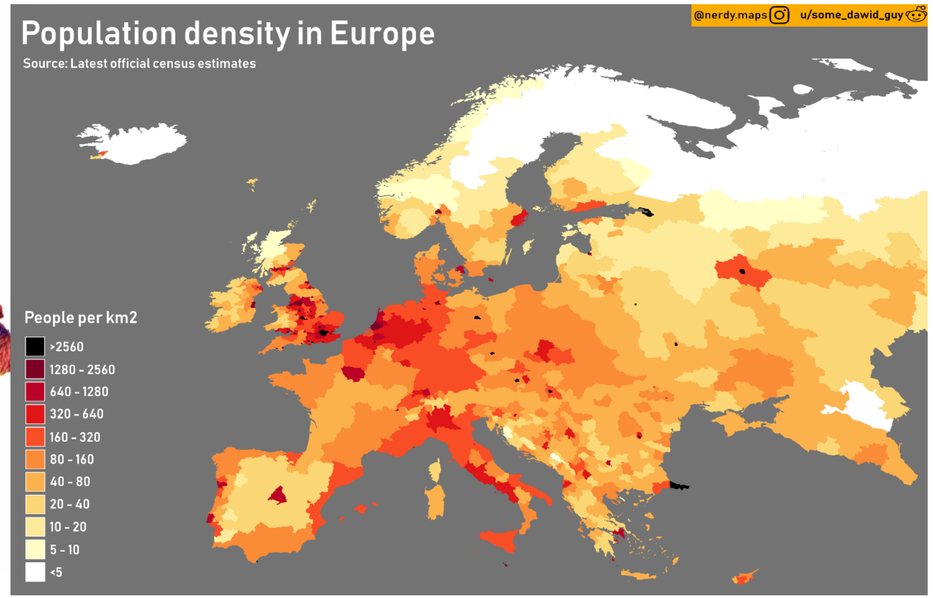
https://arxiv.org/pdf/2408.14946

- 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 2Okm) 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 two years of very serious work —
—> geological studies
—> costs, legal frameworks..

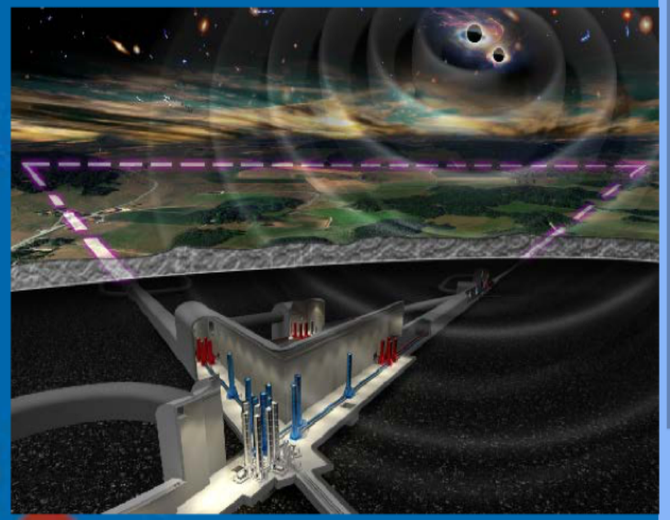
European Strategy Forum on Research Infrastructures

ET on the ESFRI roadmap

ET EINSTEIN TELESCOPE

ESFRI ROADMAP 2021

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



Project submitted by:

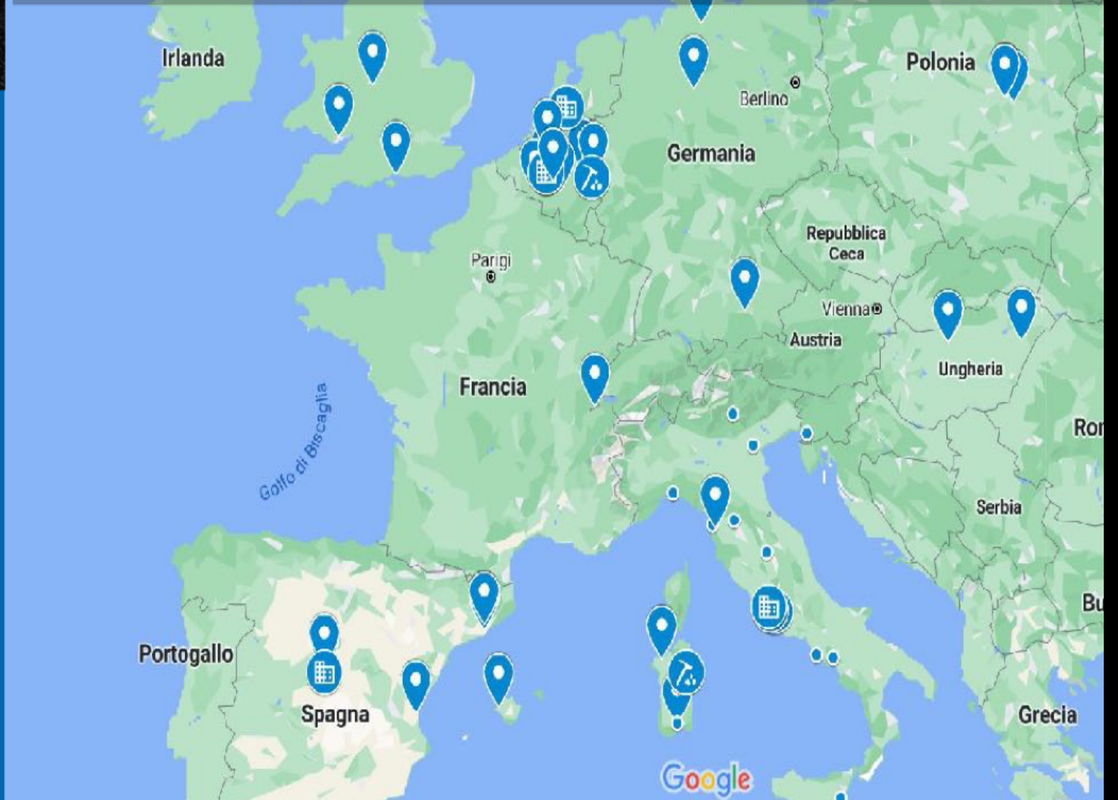
- **Italy** (Lead Country)
- Netherlands
- Belgium
- Spain
- Poland

30/06/2021:

ET is on the ESFRI roadmap!

ET Consortium

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



Einstein Telescope as ESFRI

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

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

Preparatory phase of new ESFRI research infrastructure projects

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

Grant

General

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Deadline model
single-stage

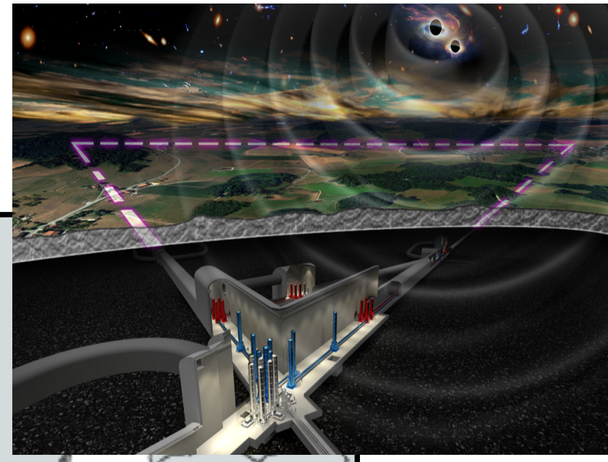
Planned opening date
30 September 2021

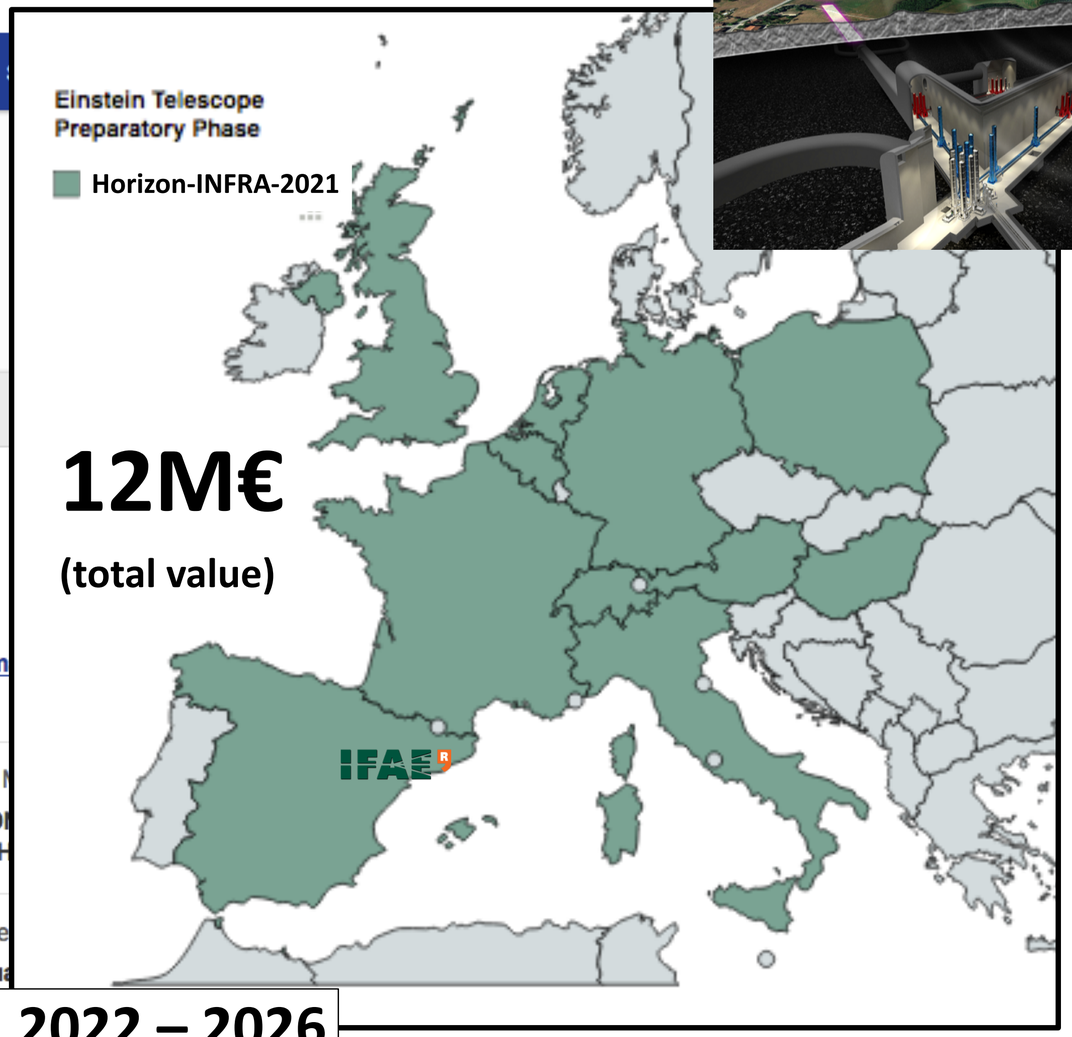
Deadline
20 Janua

Goals for ET Preparatory Phase

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

3.45M€





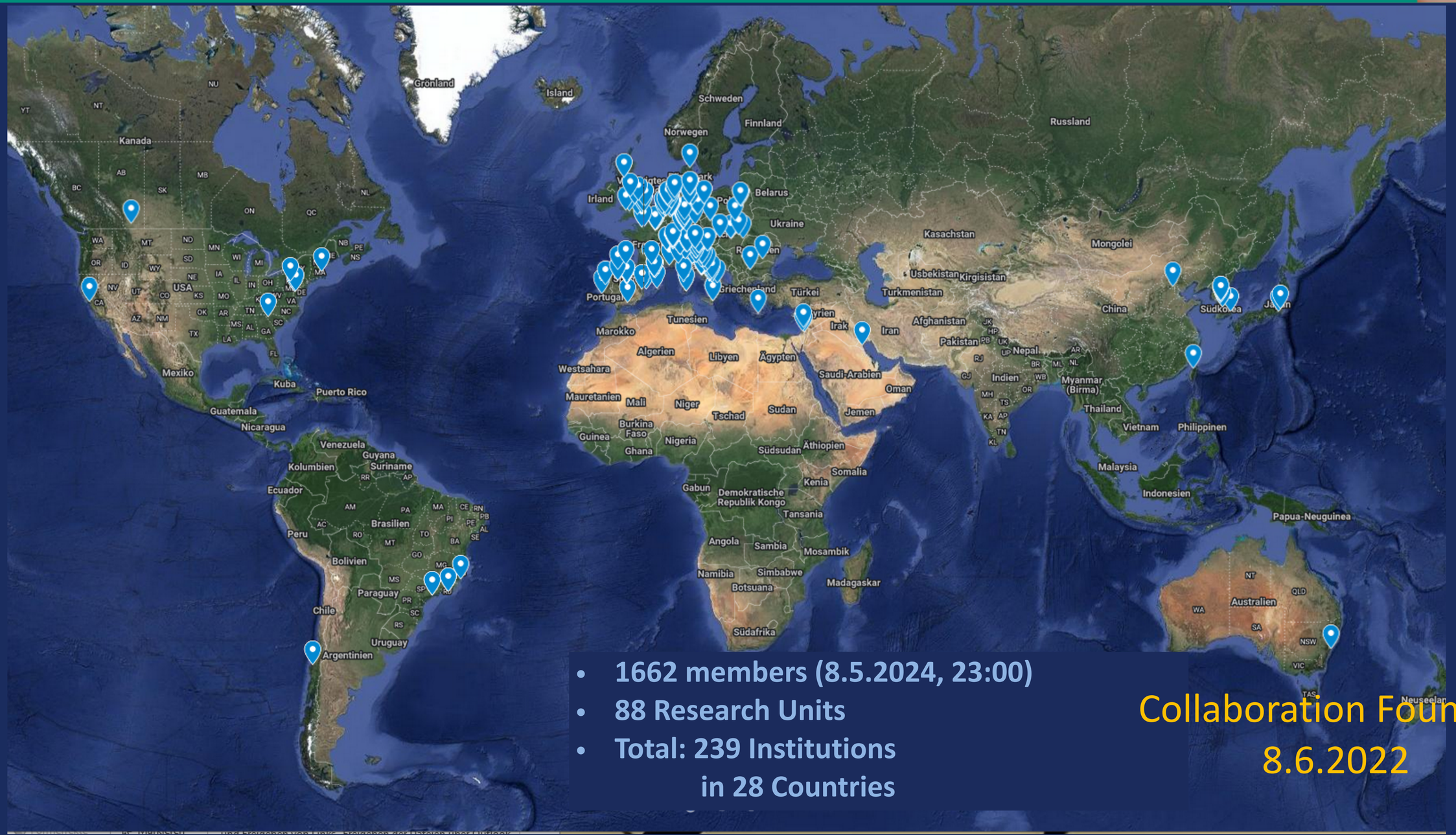
12M€

(total value)

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

→ https://etpp.ifae.es —> Two years more to go

ET Member‘s Affiliation Map



- 1662 members (8.5.2024, 23:00)
- 88 Research Units
- Total: 239 Institutions in 28 Countries

Collaboration Founding 8.6.2022

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

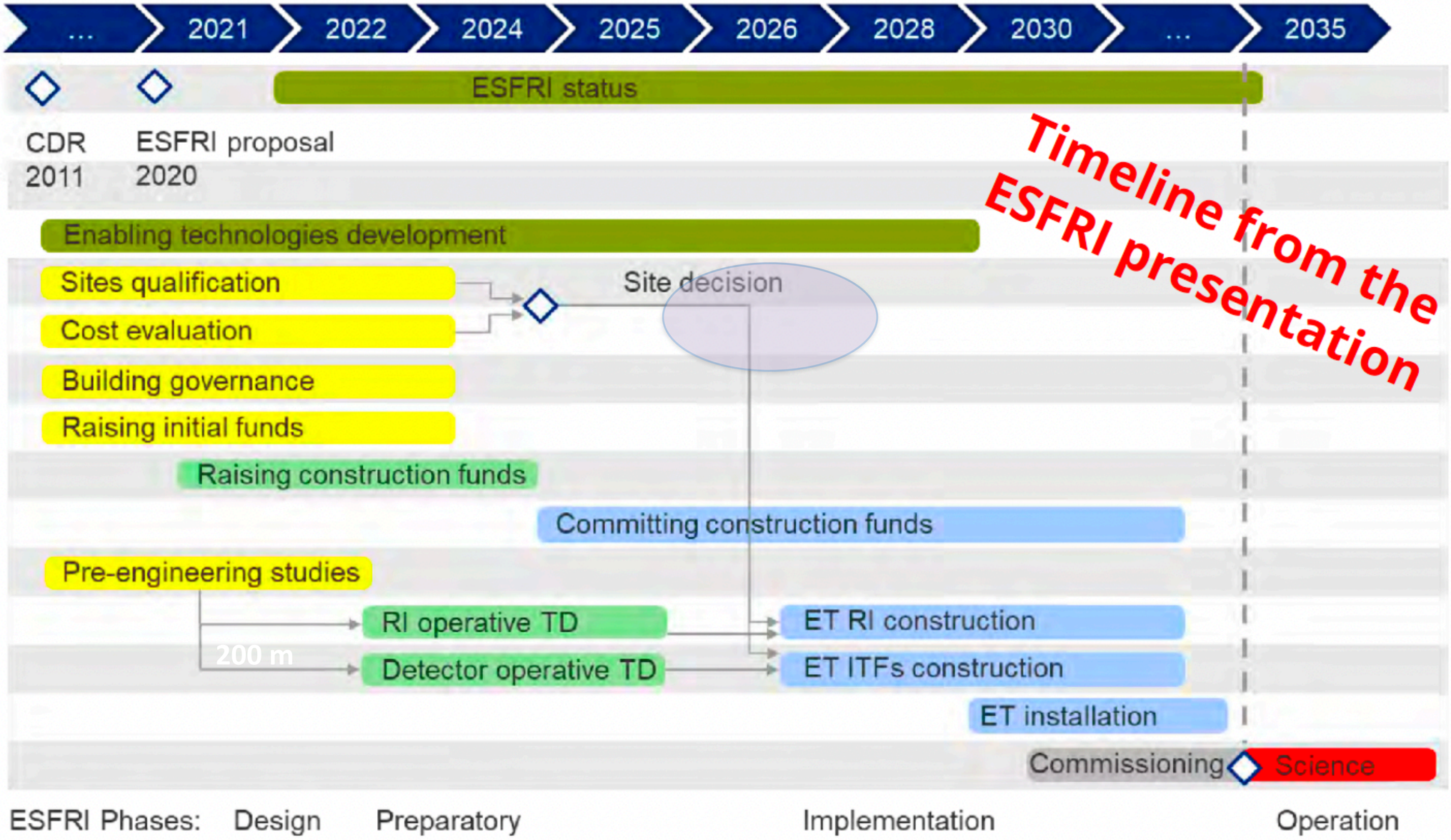
ET Collaboration

- 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 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 —> to be ready by early 2025

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

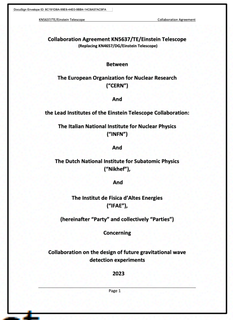
EMR Site investigations

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

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.

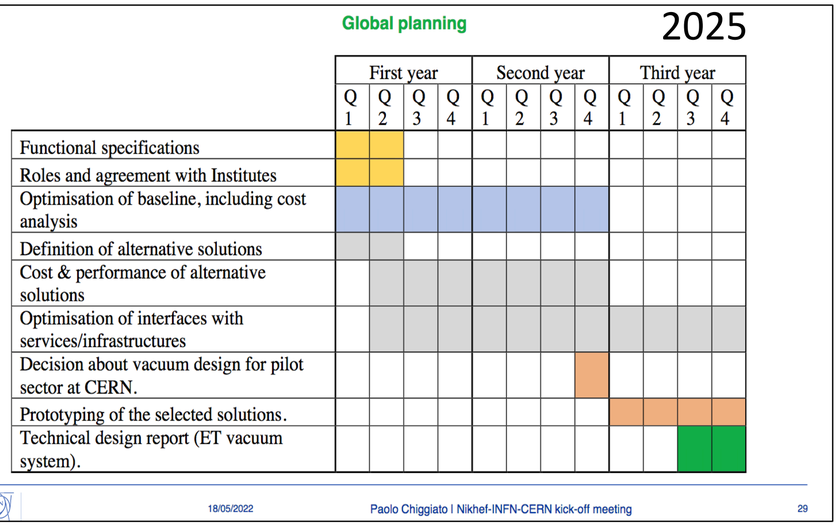
- **Document management**: project management requires specific tools, we are investigating the use of the CERN tool EDMS. CERN is providing support for a pilot study which has now started.

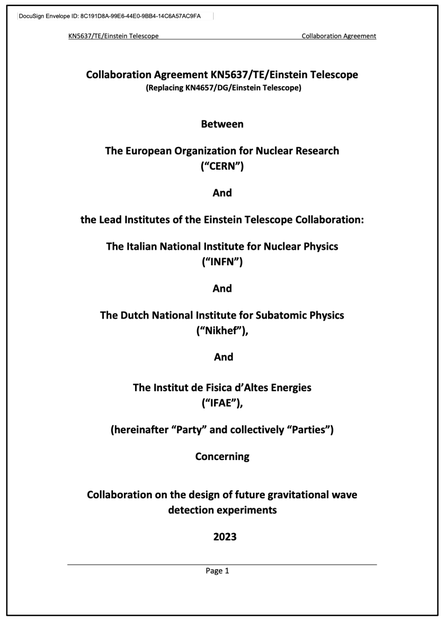
- **Engineering support**: technical designs at CERN are usually done by a large interdisciplinary team, including for example the safety group. We have organised several discussions with the relevant teams and are now formulating a plan for dedicated support for the design of the technical infrastructure.

ET & CE vacuum pipe design

MoU signed with CERN

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

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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"),

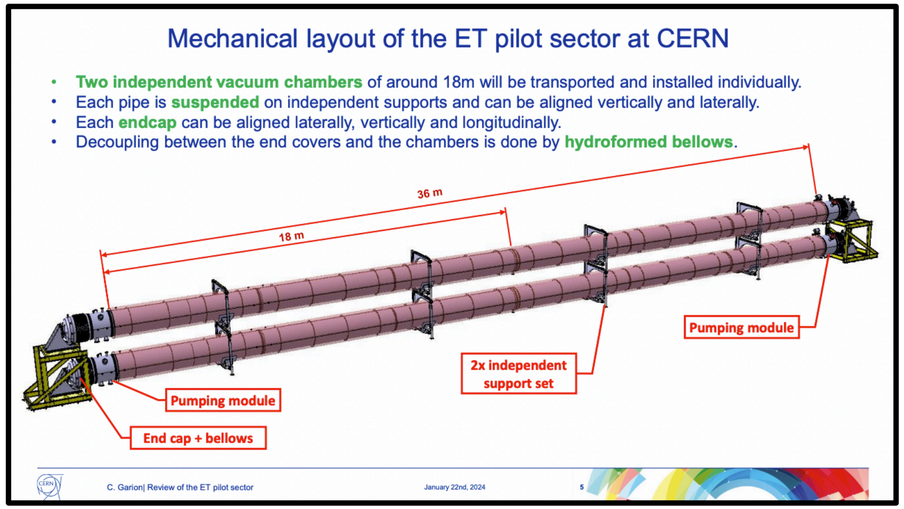
(hereinafter "Party" and collectively "Parties")

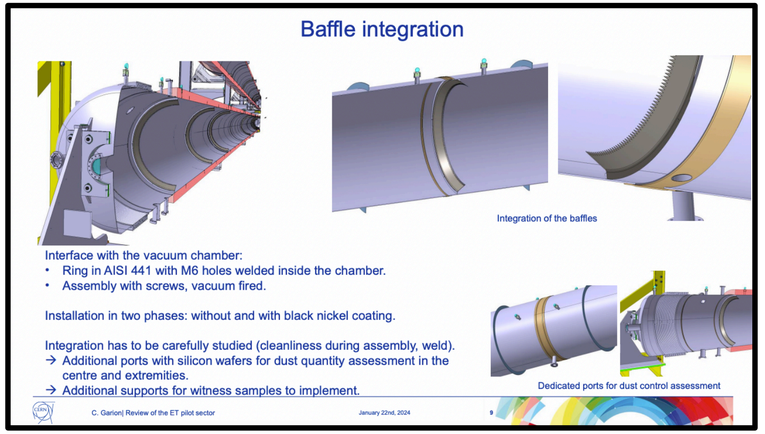
Concerning

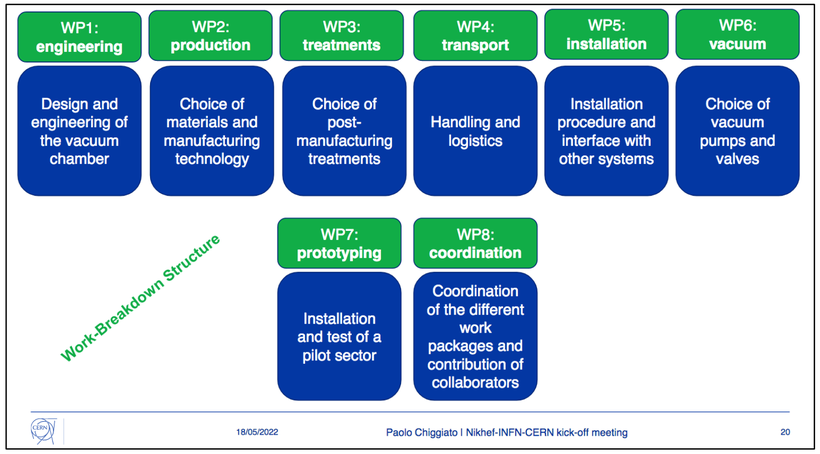
Collaboration on the design of future gravitational wave detection experiments

2023

Page 1







Led by CERN :

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

—> Prototypes 40 m long + UHV tests

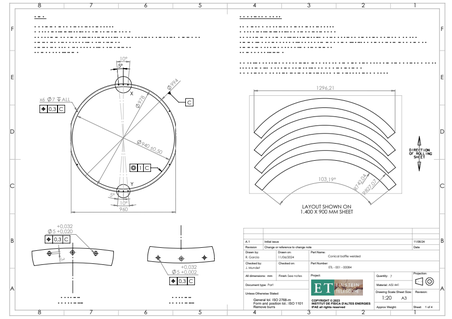
—> TDR by 2025 as main deliverable

—> [exploring extending action to 2027]

—> IFAE running stray light simulations

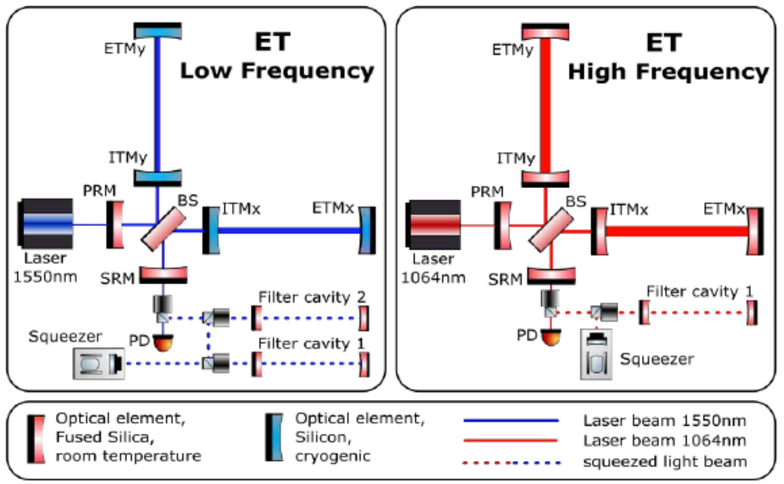
—> IFAE in-kind contribution - O(14) baffles (w/wo special optical coatings)

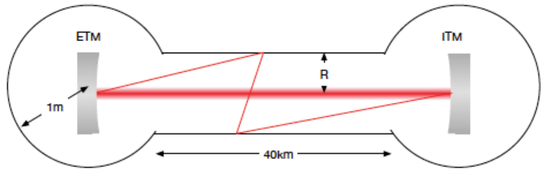
—> Synergy with LIGO and Cosmic Explorer

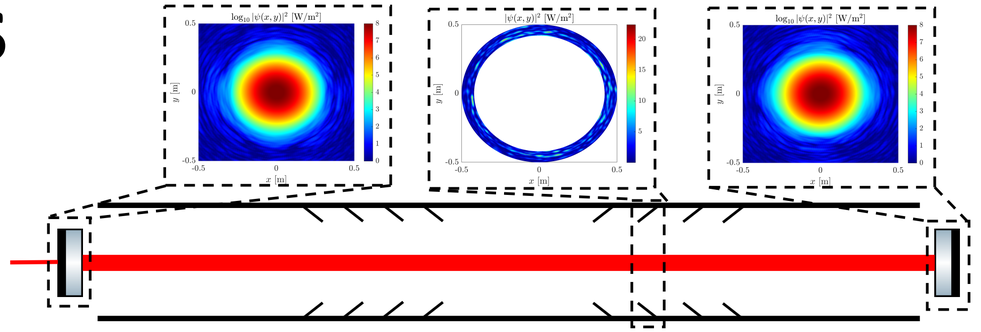


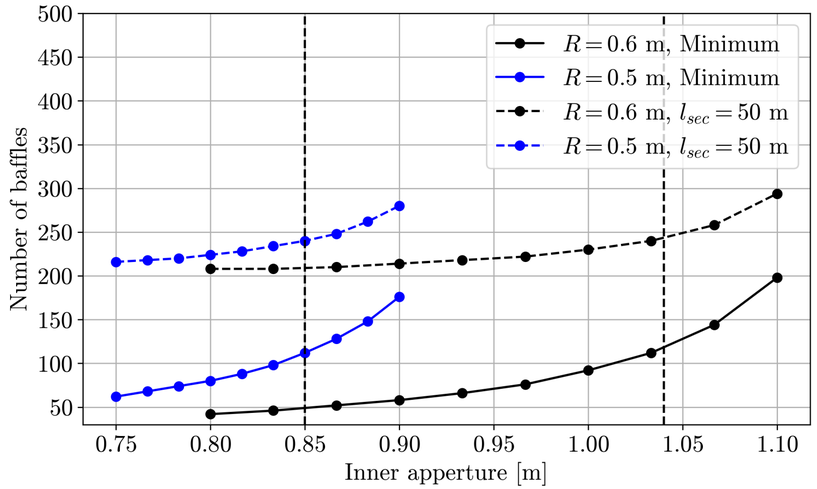
Launching baffle production now

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

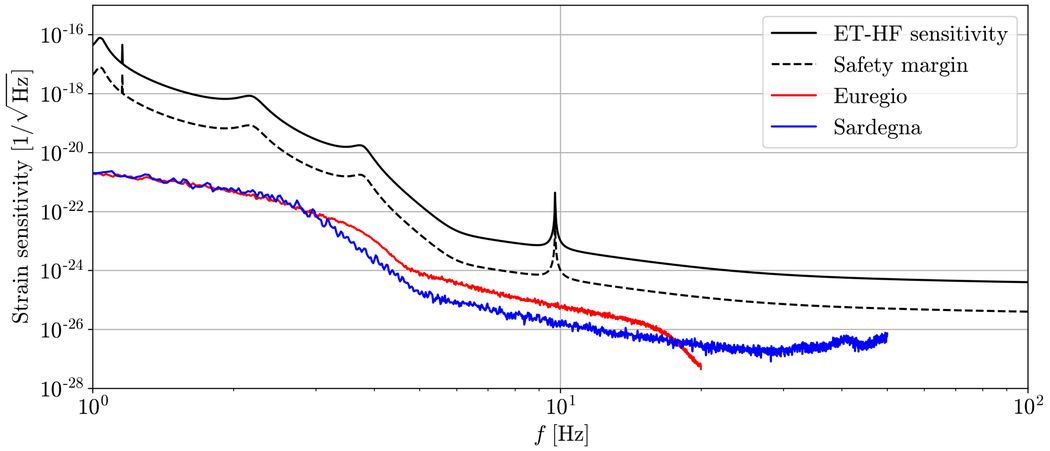
—> Determines the baffle requirements (dimensions and optical specs)

—> Determines the distribution of baffles in the 10km arm

—> 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)

ETO Engineering & CERN

Civil Engineering activity for ET in Phase 1 – MOU CERN

	Workpackages	Date
WP1	Cost Estimation Classification	Q3 2024
WP2	Shared tool for modelling	Q2 2025
WP3	Design of the underground civil infrastructure (ED)	Q4 2024
WP4	Coordination of local team activity	Q4 2026
WP5	Preliminary CE TDR	Q6 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,

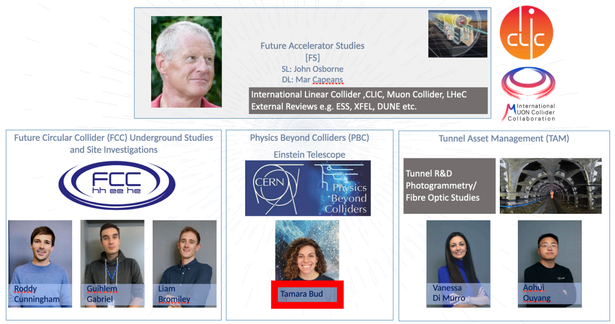
AND: THE DUTCH NATIONAL INSTITUTE FOR SUBATOMIC PHYSICS ("Nikhef"), established in Amsterdam, The Netherlands,

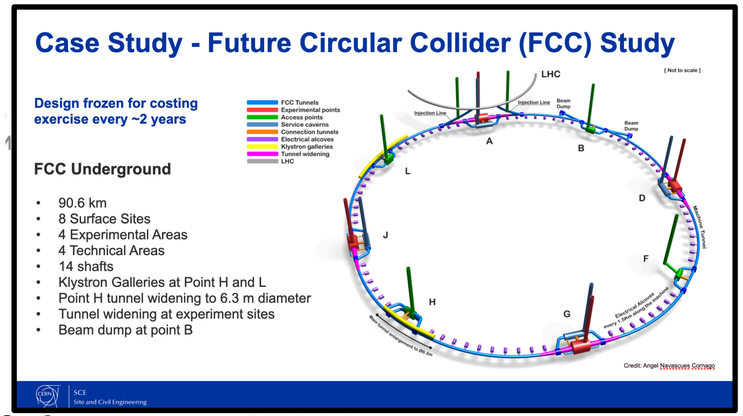
AND: THE INSTITUT DE FISICA D'ALTES ENERGIES ("IFAE"), established in Barcelona, Spain,

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

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

SCE-SAM-Future Studies Section





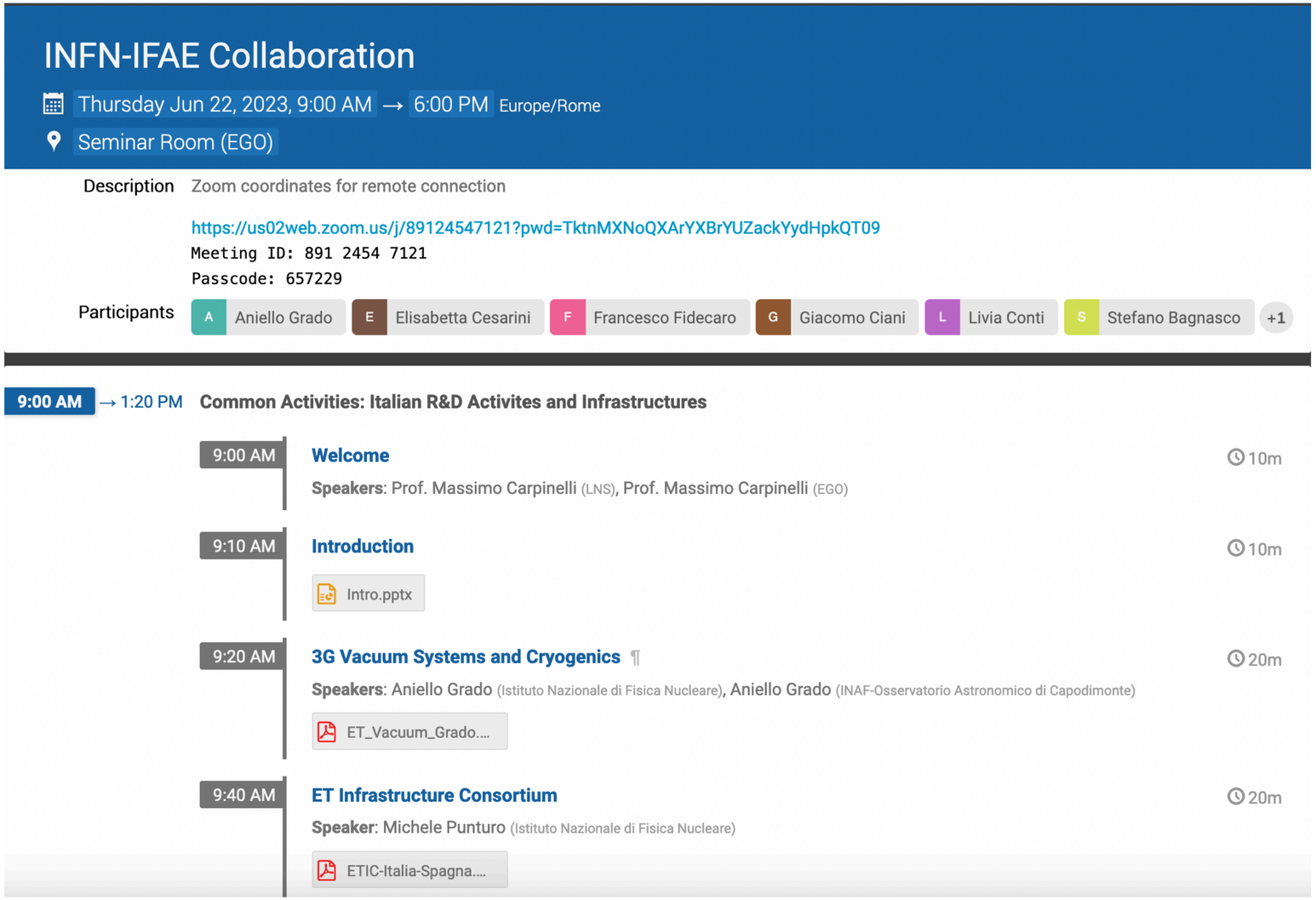
ET will count with the supervision of the same CERN team behind the recent FCC studies —> will guarantee the quality

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 being included in the PGE 2005 draft for ET - CERN activities
  - Italy contributes to IFMIF-DONES in Granada
- **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 Europe/Rome

Seminar Room (EGO)

Description Zoom coordinates for remote connection

https://us02web.zoom.us/j/89124547121?pwd=TktnMXNoQXArYXBrYUZackYydHpkQT09
Meeting ID: 891 2454 7121
Passcode: 657229

Participants 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

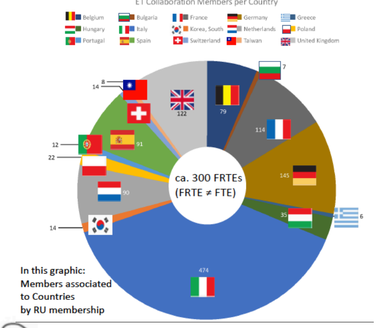
- ET optical layout
- Wavefront Sensing and Control
  - Phase cameras
  - Hartmann Wavefront Sensors
  - Optical Simulations
  - Quadrant photodiodes
  - ……..
- Actuators on Optics
  - Ring Heaters
  - Deformable Mirros
  - ……
- Quantum Noise Reduction
  - QNR simulations
  - Integrated squeezed vacuum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

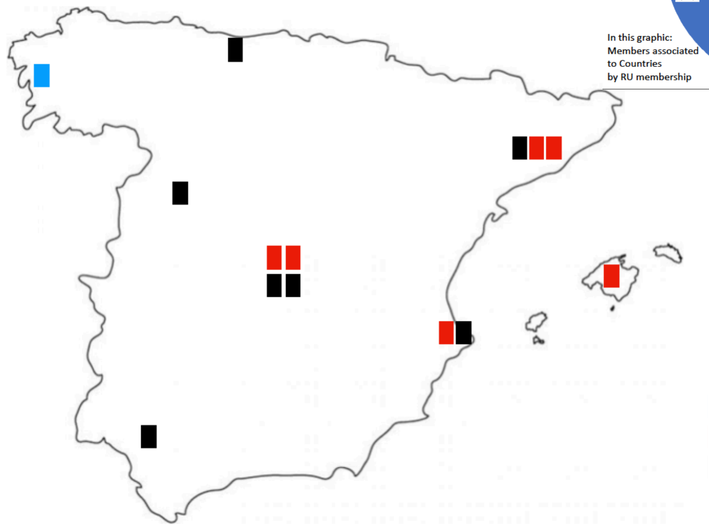
Sweet but always difficult and slow processe

It is time for the Spanish Institutions to move

Map of Spanish involvement in LVK/ET

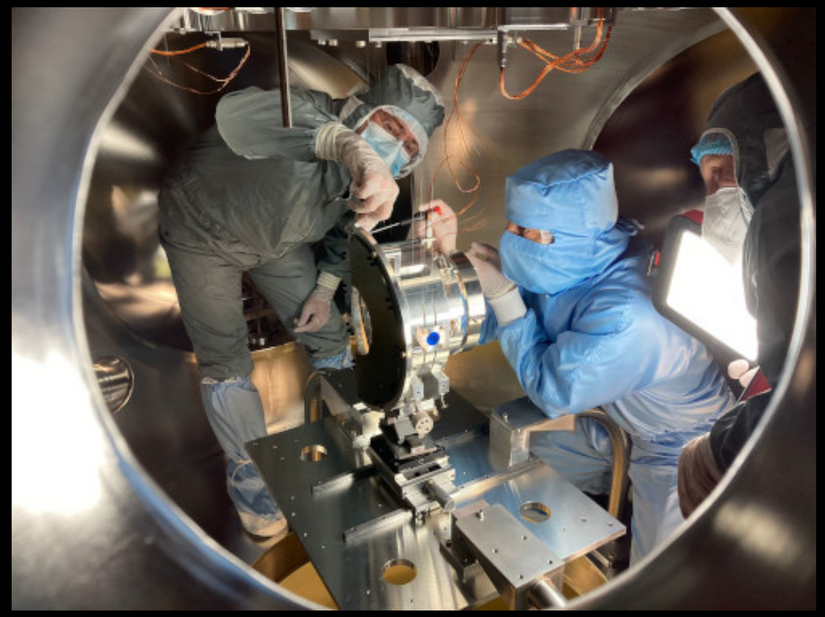
Group	LVK	ET	Hardware	Computing	Note
CIEMAT	Virgo	Y	Y	YY	Still qualifying in Virgo
ICE	LISA	Y	YY-LISA	N	Not allocated FTEs for HD
IFAE	Virgo	Y	YY	YY	
IFIC		Y			TH
UIB	LIGO	Y		Y	TH/Analysis
USC	LIGO	N			TH/Analysis
USAL		Y			TH
IFT	Virgo	Y			TH/Analysis
UCM		Y			TH
UCAN		Y			TH
ICCUB	Virgo	Y		Y	TH/Analysis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

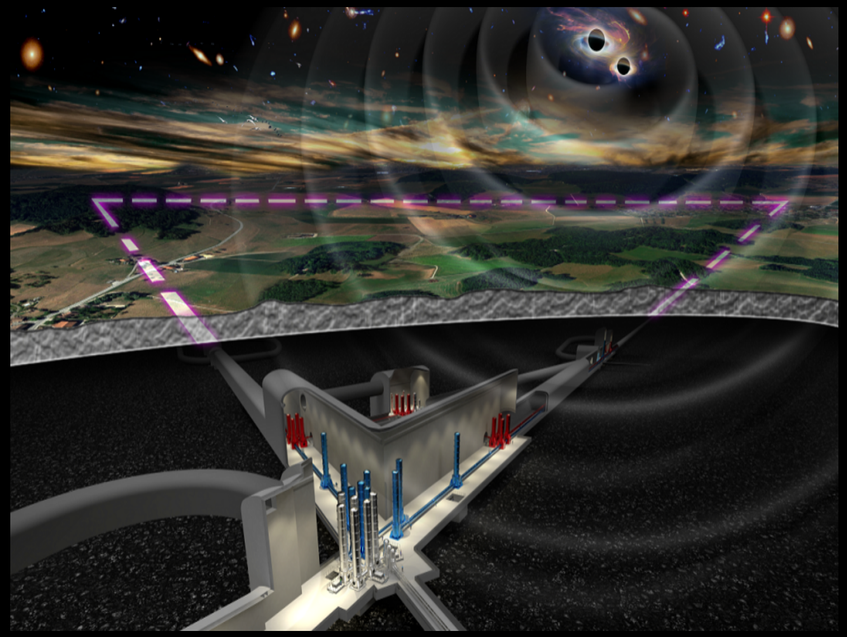




It is the time for HEP groups interested to build their hardware capacities participating in ET R&D programs

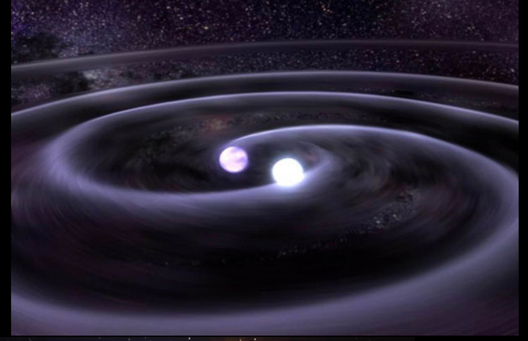
- There are many groups interested in ET, some of them from HEP, some of them detector builders
- A majority has no hardware capacities
- Most of them are Theory and GW analysis oriented
- As today there is no consolidated large enough experimental community in GW is Spain.
- We are actively exploring synergies with other research centers in Spain to improve the situation

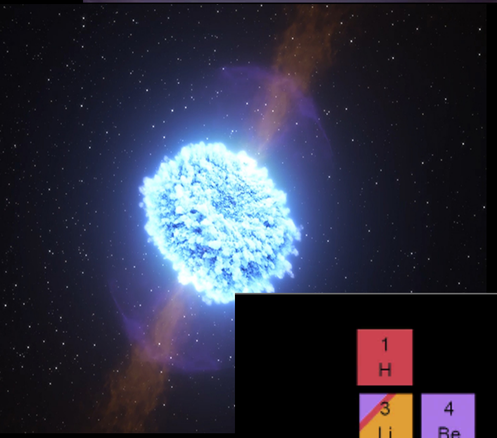




Final notes

- 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..





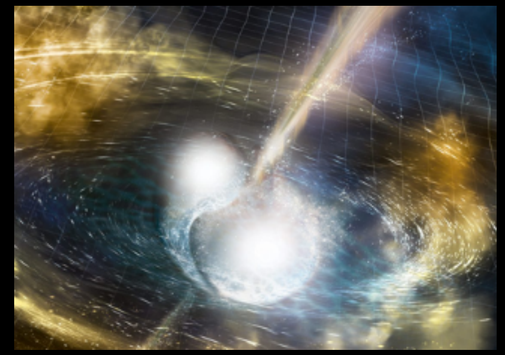
Kilonova

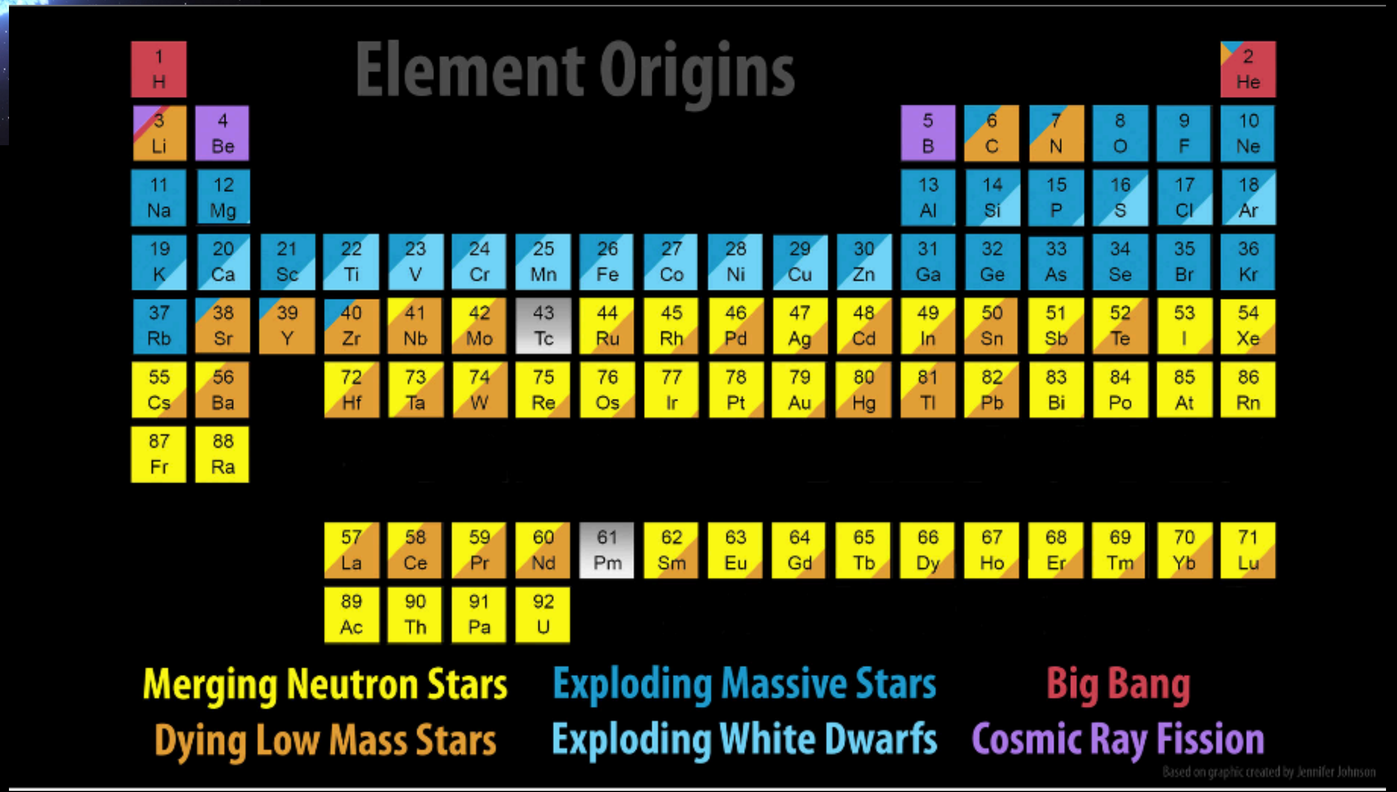
Open the door for studying EoS of neutron stars

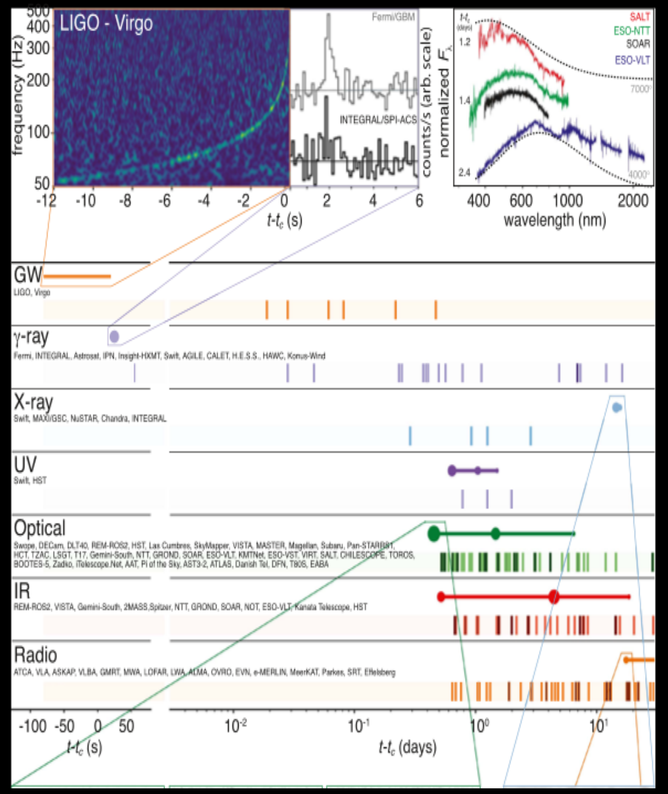
→ data already disfavor some models

Shows the production mechanism of heavy elements

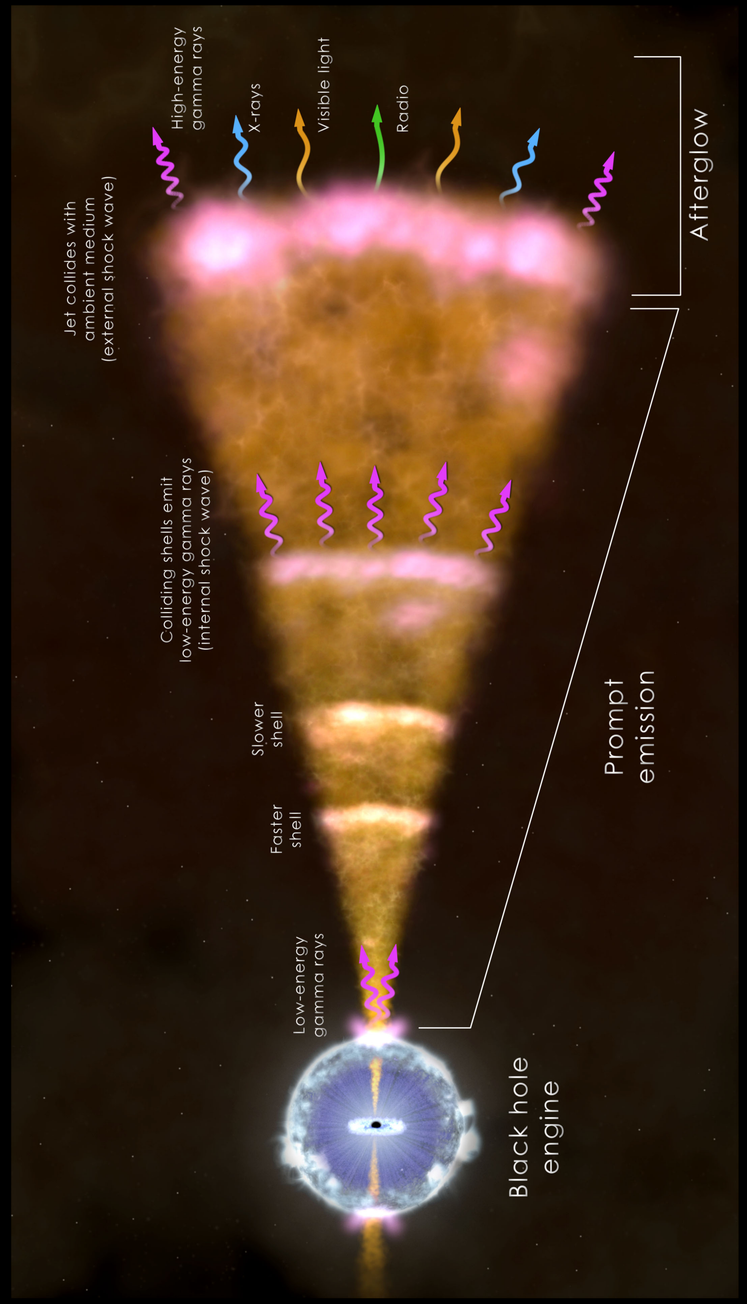
Initiates an era of multi-messenger approach







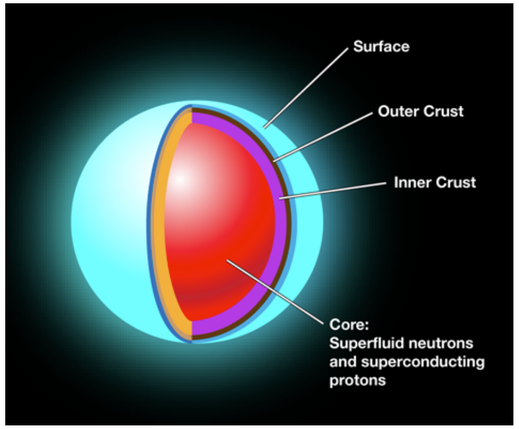
Multi-messenger

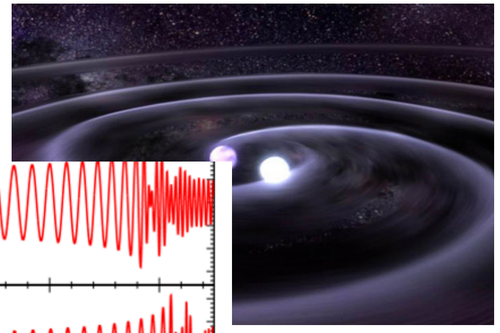


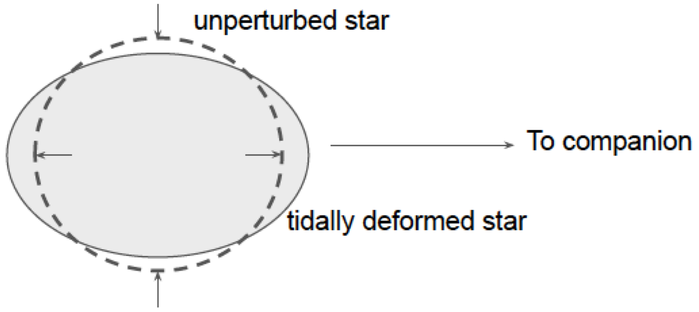
ET will operate in synergy with a number of large infrastructures

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

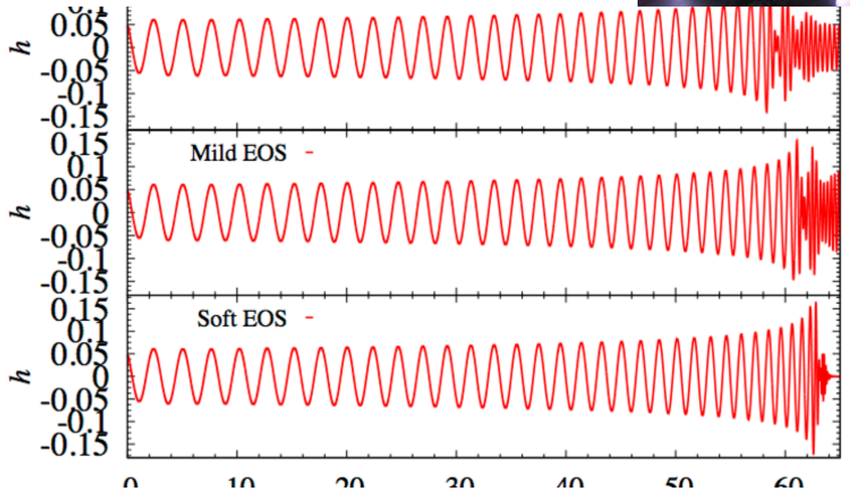
Neutron stars



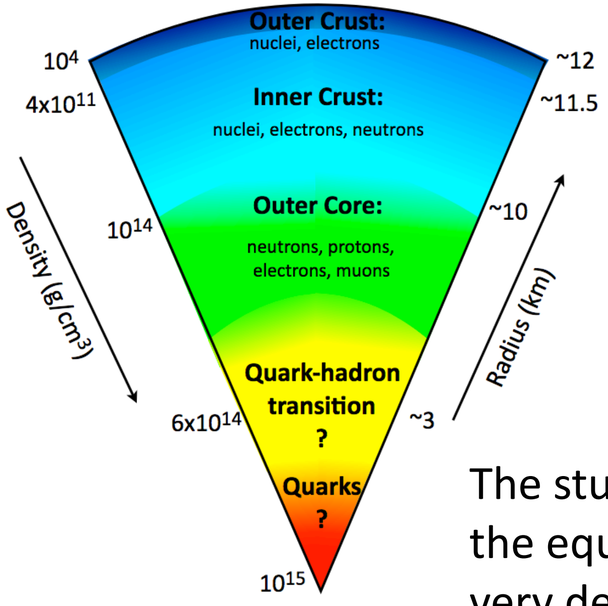


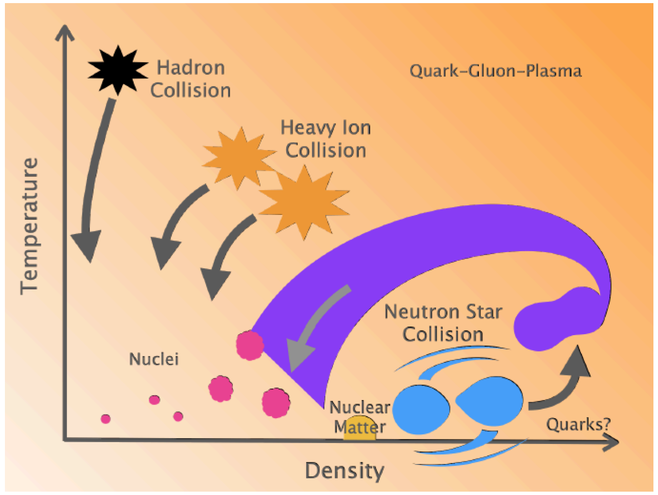


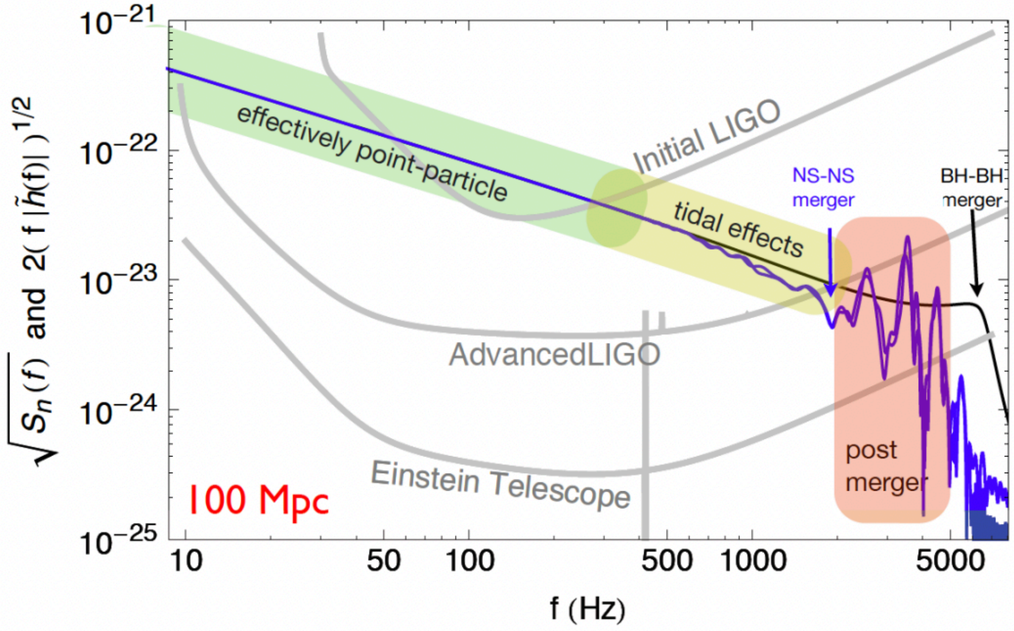
perturbed star changes quadrupole moment of the system
→ tends to radiate more energy as GWs
→ orbit evolves faster



1-2 solar masses is an object with a diameter of 20KM (1/70000 the size of the sun)

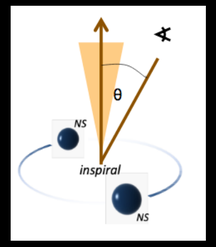


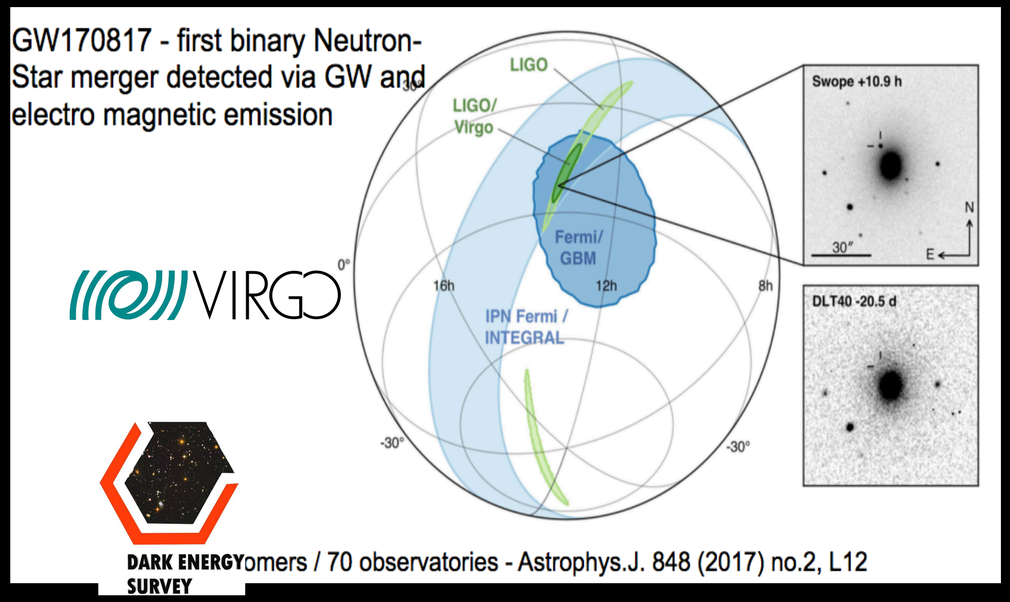


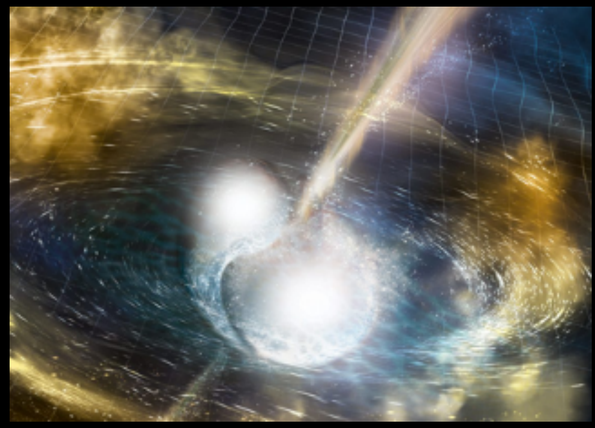


The study of neutron star mergers allows to study the equation of state of the star involving QCD in very dense and high regimes temperatures.

Hubble Constant







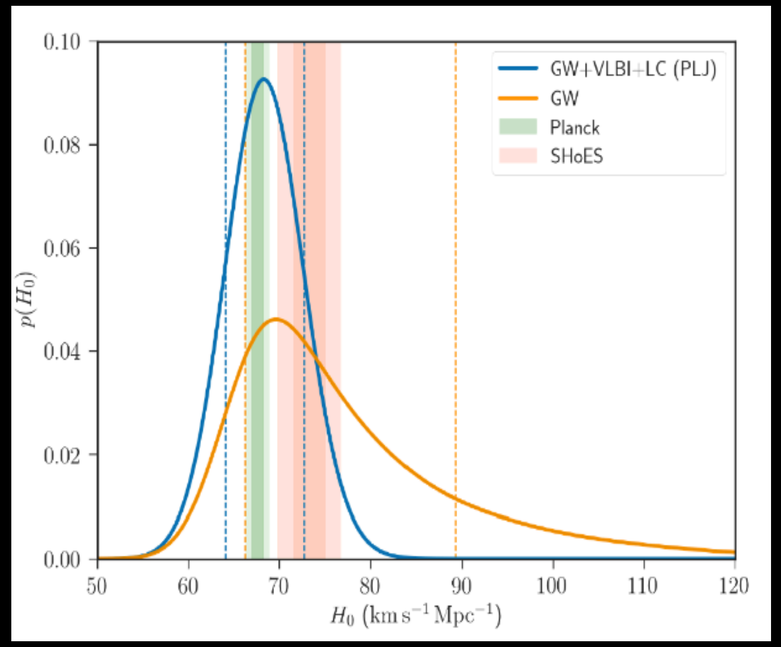
Few events of BNS will allow for few % precision in the determination of H_0

Observation with GWs and EM optics

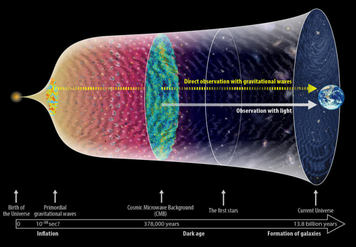
$$v_H = H_0\, d \quad \text{(GW + EM)}$$

Direct measurement of Hubble parameter H_0

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



Cosmology



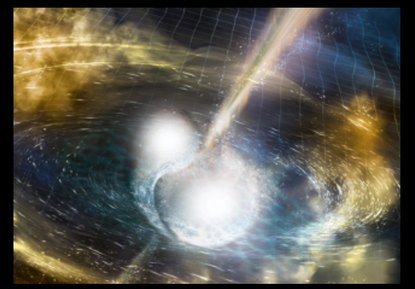
$$m_{\rm det} = (1+z)m$$

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

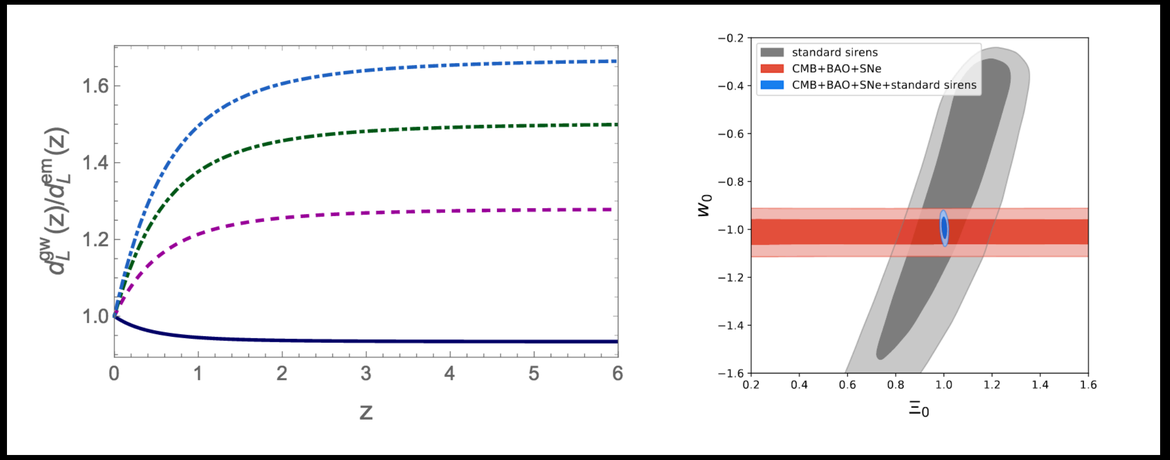
Relationship between light distance and redshift contains information on high redshift cosmology

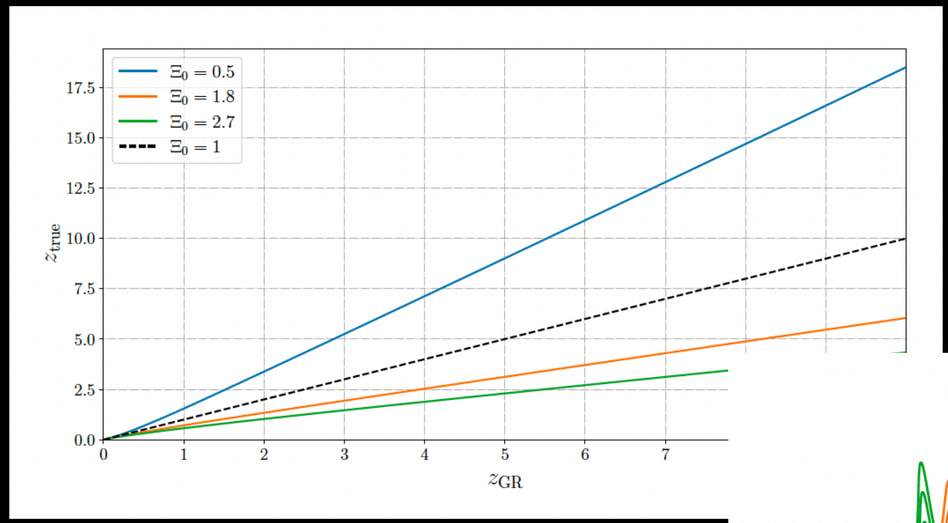
in models beyond GR

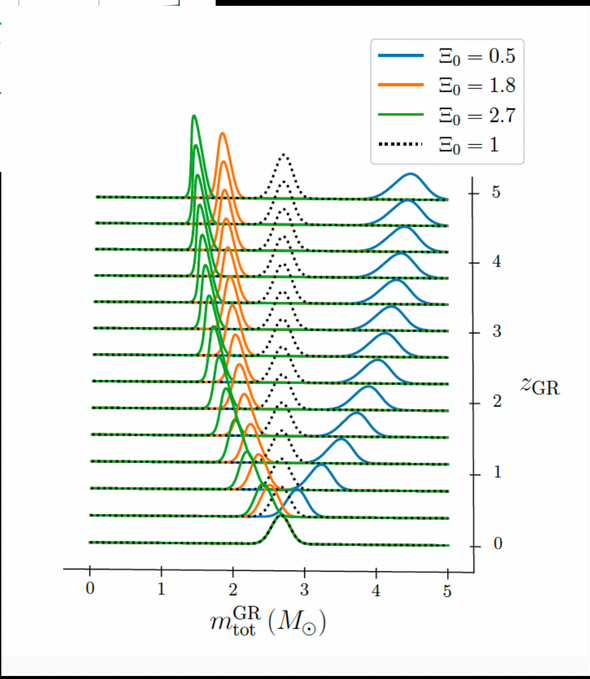
$$\frac{d_L^{\rm gw}(z)}{d_L^{\rm em}(z)} = \Xi_0 + \frac{1-\Xi_0}{(1+z)^n}$$



Finke, Foffa, Iacovelli, Maggiore, Mancarella 2021

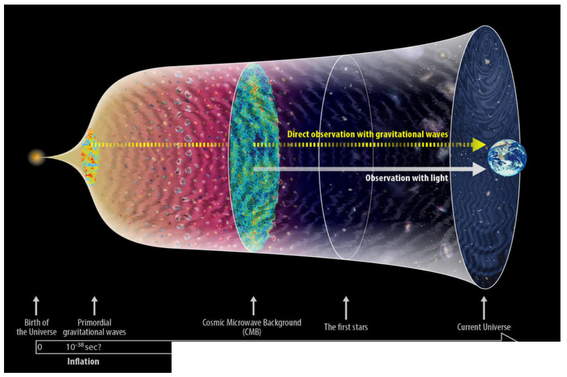






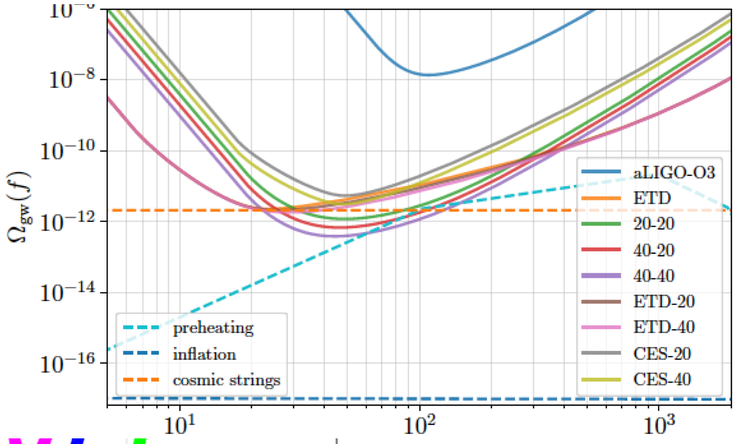
After a few years and collecting a few hundred BNS events ET can do a rigorous test using the BNS narrow mass distribution vs z

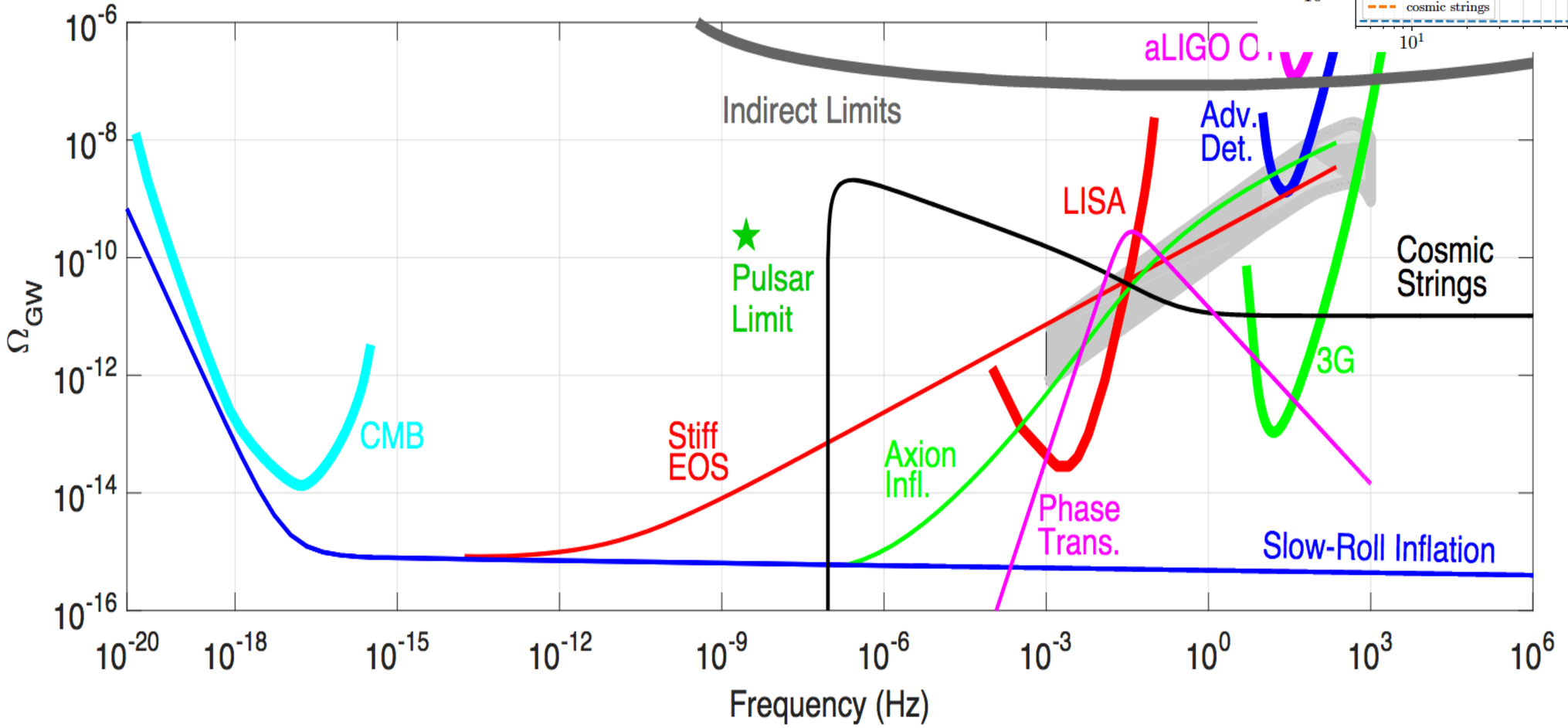
Cosmology



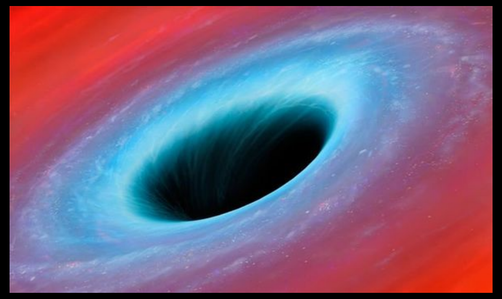
Stochastic signals are a single gate to:

- **Inflation in the early universe**
- **Cosmological phase transitions**
- **Presence of topological defects, cosmic strings**



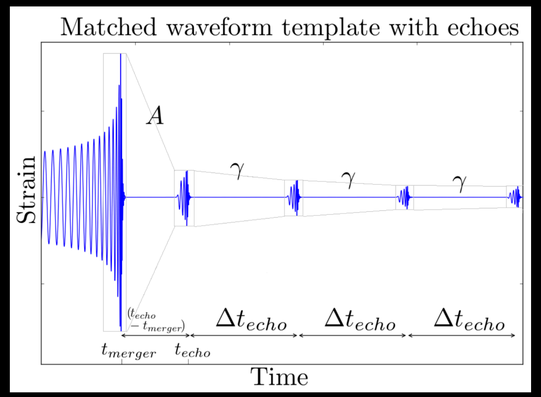


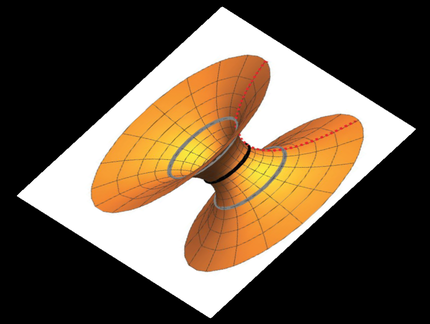
ET and CE provide a window at high frequency → high temperatures

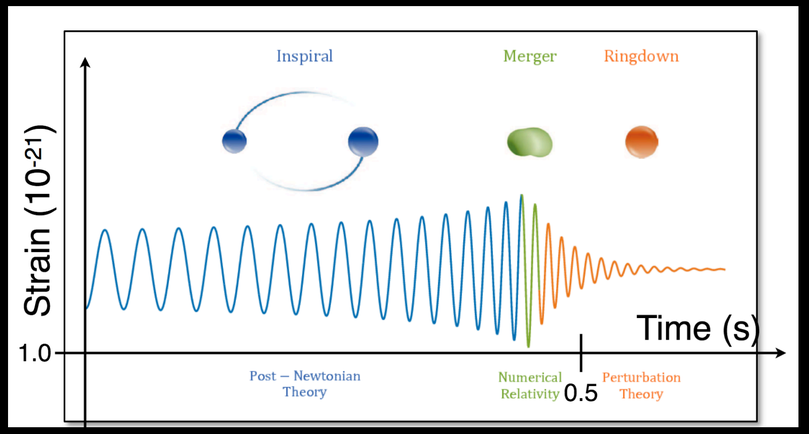


General Relativity Tests (I)

M. Maggiore et al., JCAP, 1912.02622



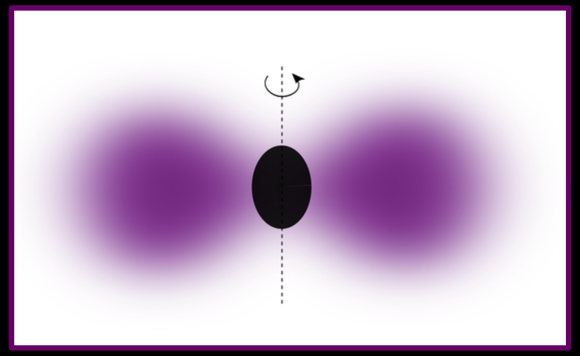




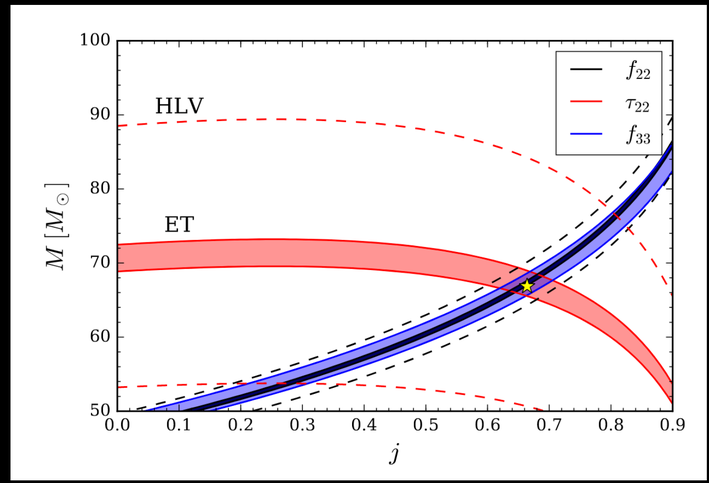
Accurate test of GR predictions
in the inspiral phase

Study of the “ringdown” phase allows for

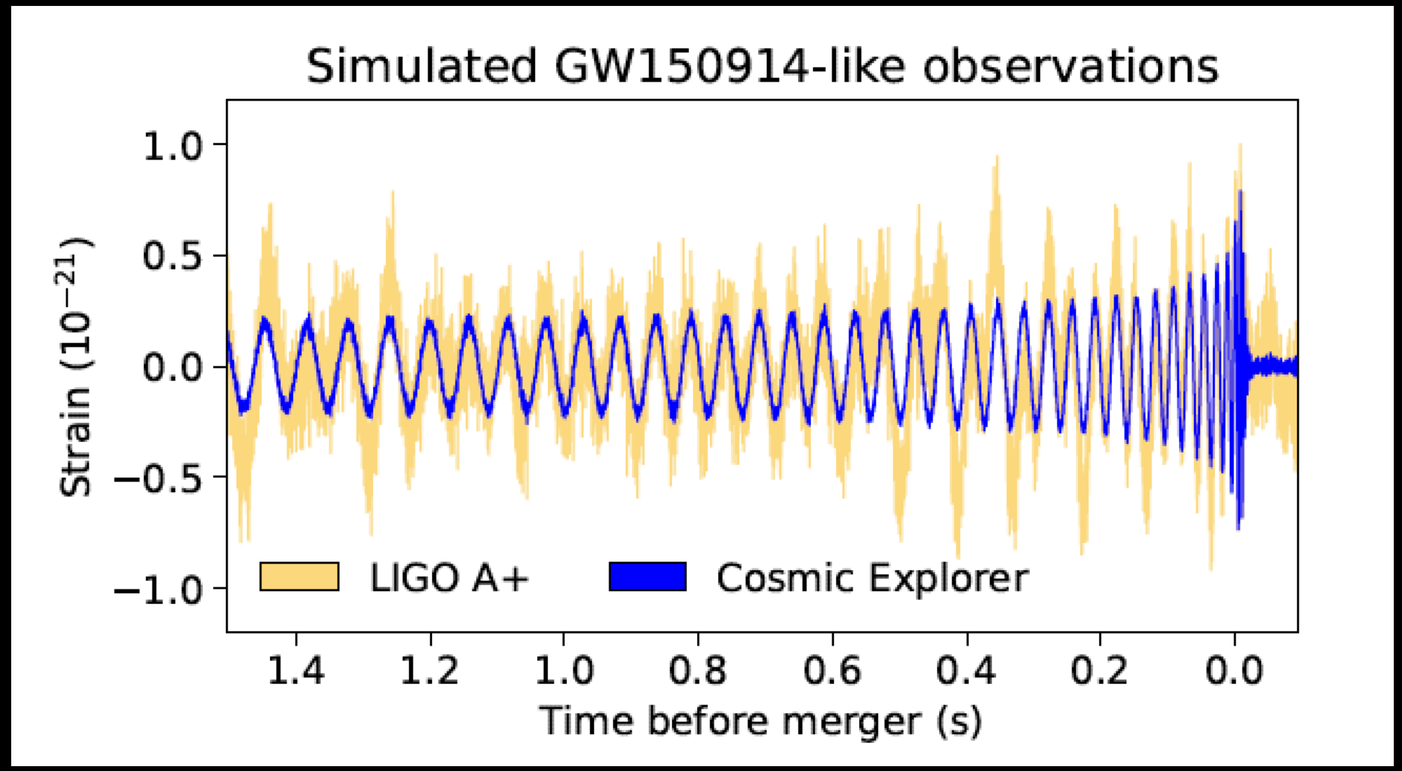
- GR test near the BH horizon
- "no-hair" theorem test
- Search for exotic objects
- Access to quantum theoretical effects on the event horizon.



Presence of axion clouds (dark matter)?
Monochromatic gravitational wave signals



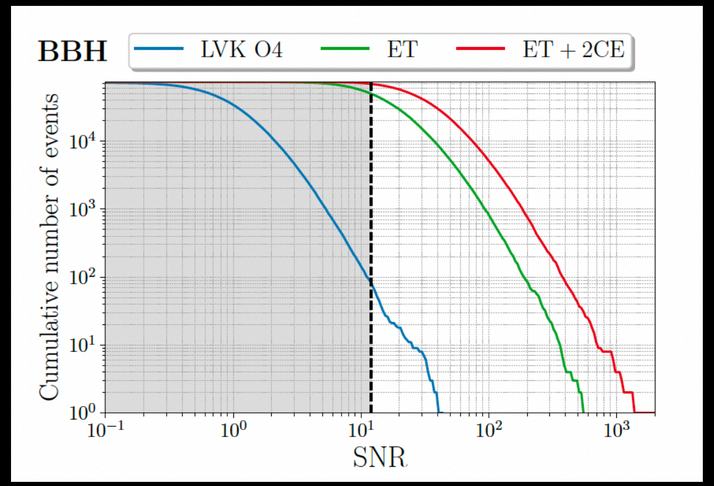
General Relativity Tests

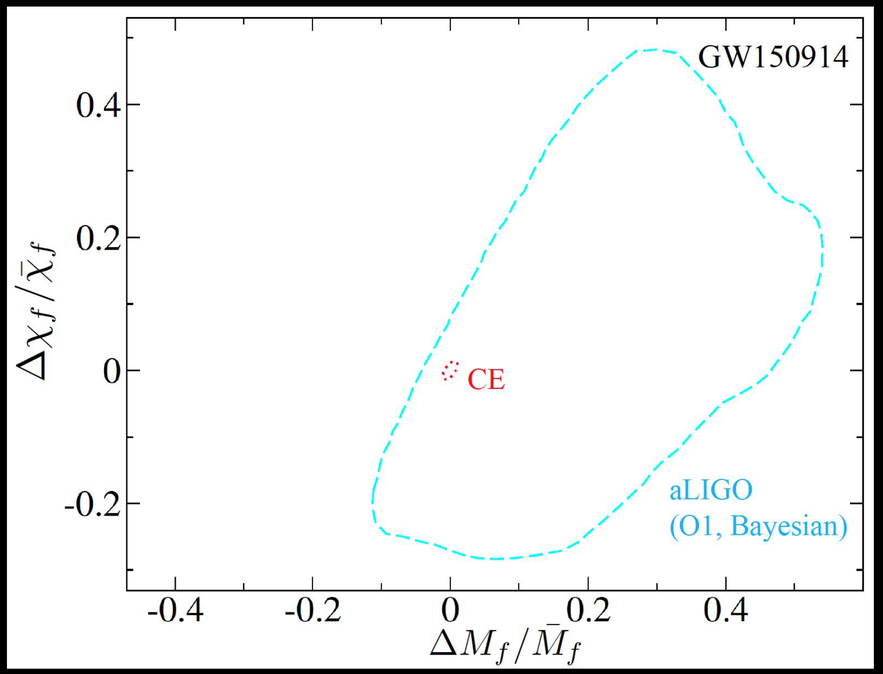


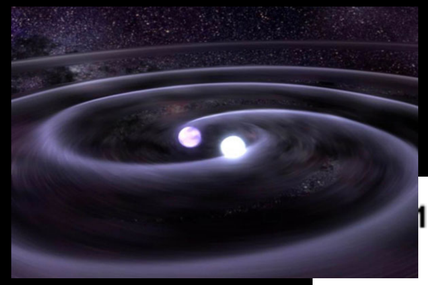
$$\frac{\Delta M_{\rm f}}{\bar{M}_{\rm f}} = 2\frac{M_{\rm f}^{\rm insp} - M_{\rm f}^{\rm postinsp}}{M_{\rm f}^{\rm insp} + M_{\rm f}^{\rm postinsp}},$$

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

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







Complementarity

LISA and ET become complementary now
that the same signal can be followed
by LISA and ET in different Hz ranges

LISA pre-warns ET