Institut national de physique nucléaire
et de physique des particules

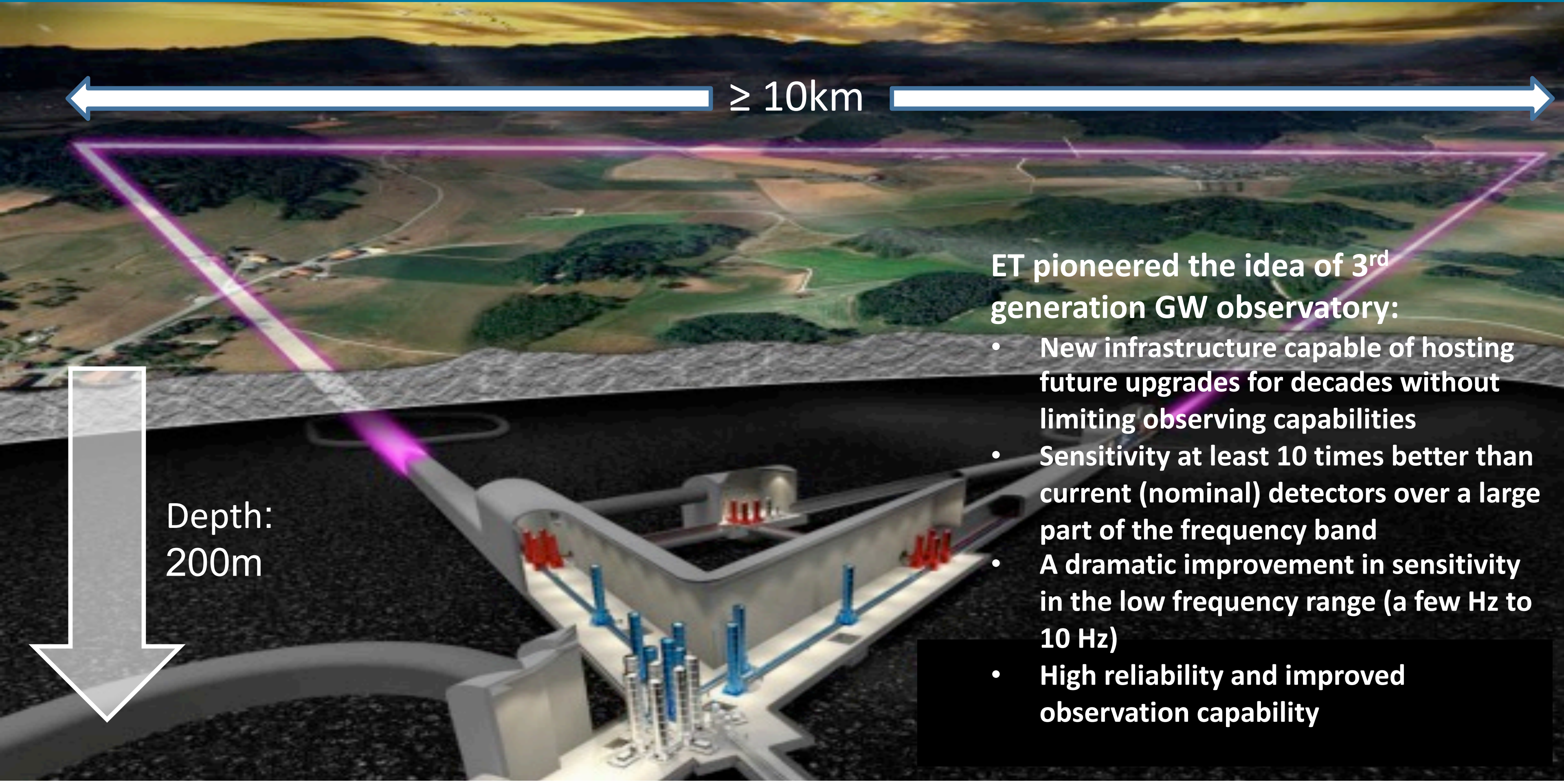
The Einstein Telescope Project

Conseil Scientifique de l'IN2P3

Paris, July 3rd, 2023

Patrice Verdier (IP2I Lyon – IN2P3) - patrice.verdier@in2p3.fr

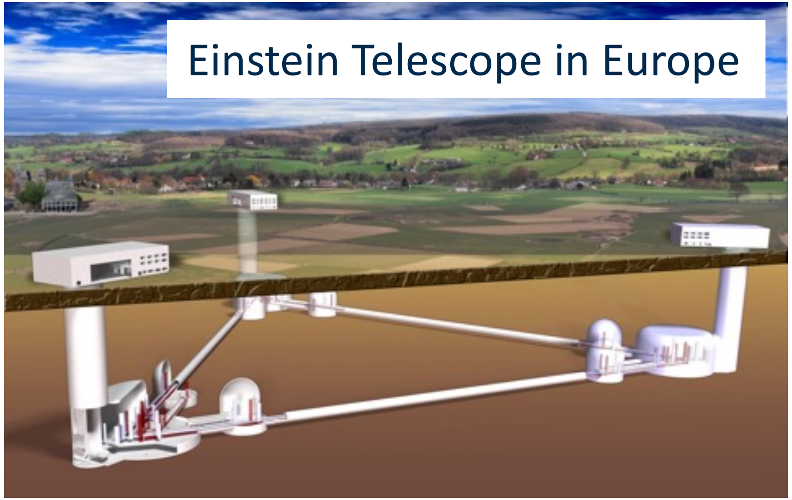
Einstein Telescope

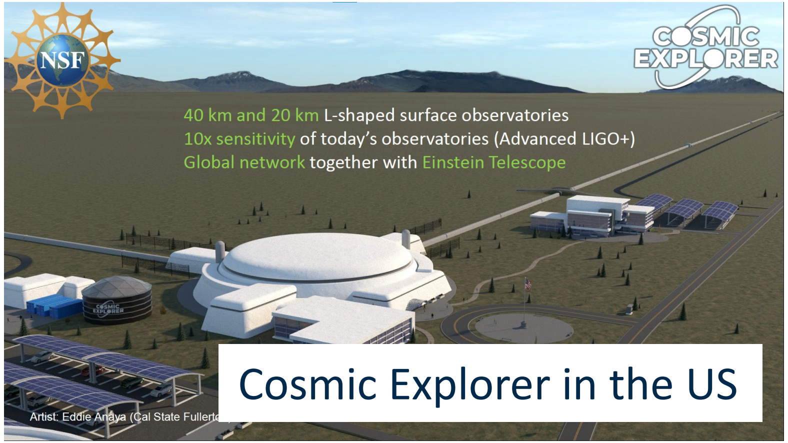


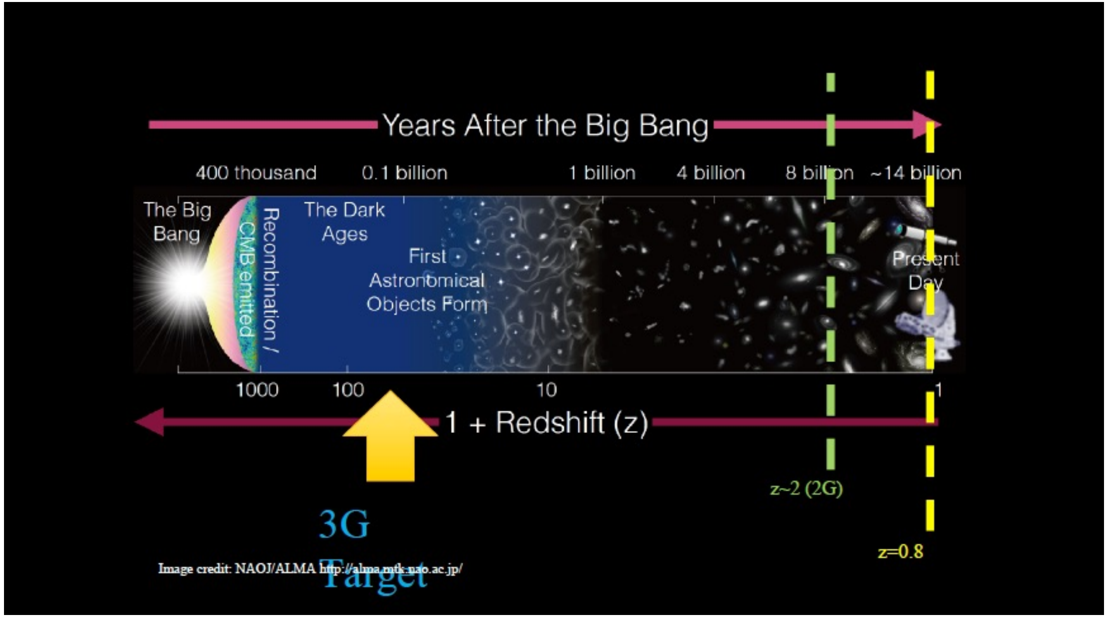
ET pioneered the idea of 3rd generation GW observatory:

- New infrastructure capable of hosting future upgrades for decades without limiting observing capabilities
- Sensitivity at least 10 times better than current (nominal) detectors over a large part of the frequency band
- A dramatic improvement in sensitivity in the low frequency range (a few Hz to 10 Hz)
- High reliability and improved observation capability

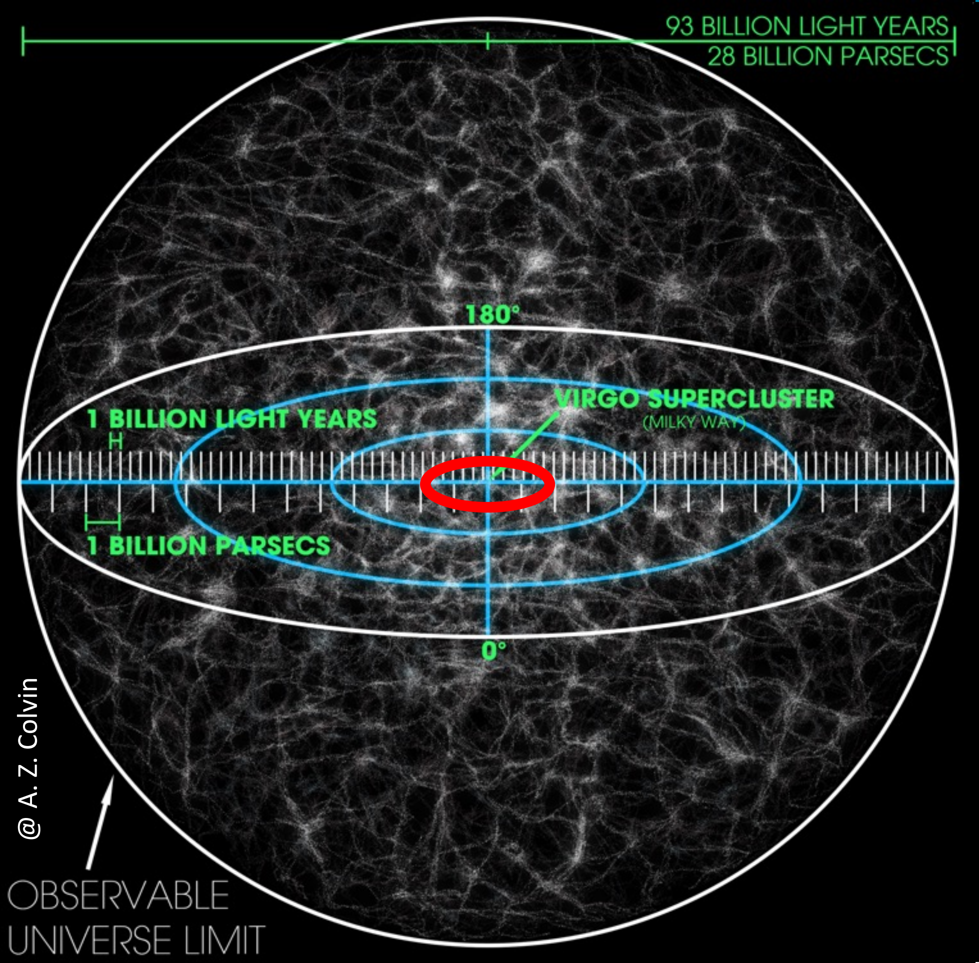
GW detection with 3rd gen. interferometers

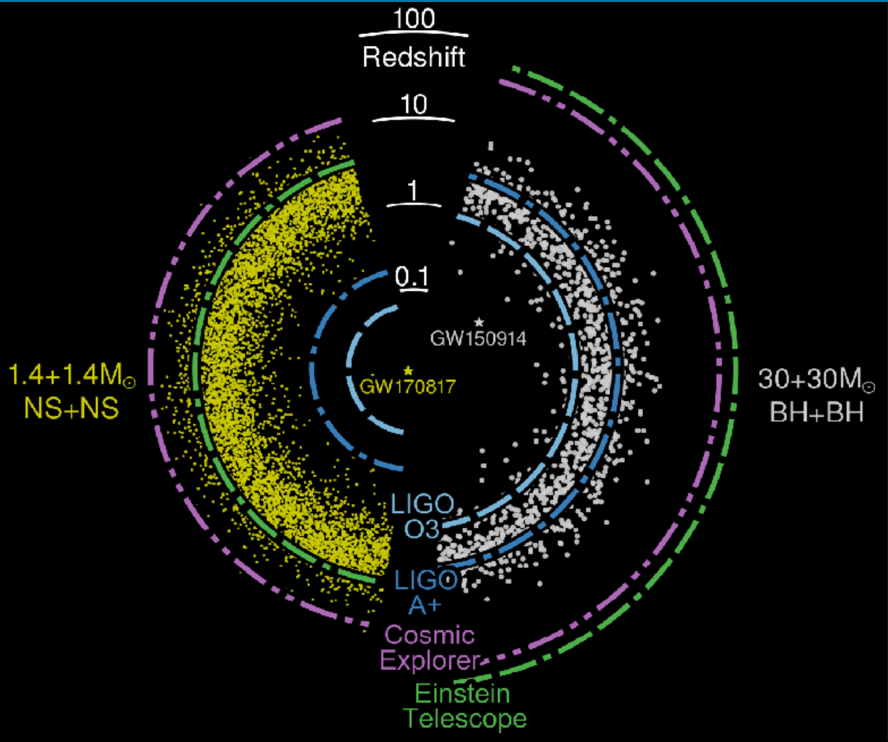






Introduction





Einstein Telescope aims to study most of the observable Universe

GW science programme

ASTROPHYSICS

Black hole properties
origin (stellar vs. primordial)
evolution, demography

Neutron star properties
interior structure, equation of state & properties of dense matter, demography

Multi-band and –messenger astronomy
joint GW/EM observations (GRB, kilonova,...)
multiband GW detection (LISA)
neutrinos

Detection of new astrophysical sources
core collapse supernovae
isolated neutron stars (Radio, X, g and GW, FRB, …)
stochastic background of astrophysical origin

FUNDAMENTAL PHYSICS AND COSMOLOGY

The nature of compact objects
near-horizon physics, tests of no-hair theorem
exotic compact objects, phase transition in dense matter

Tests of General Relativity
post-Newtonian expansion, strong field regime

Dark matter
primordial BHs
axions, dark matter accreting on compact objects

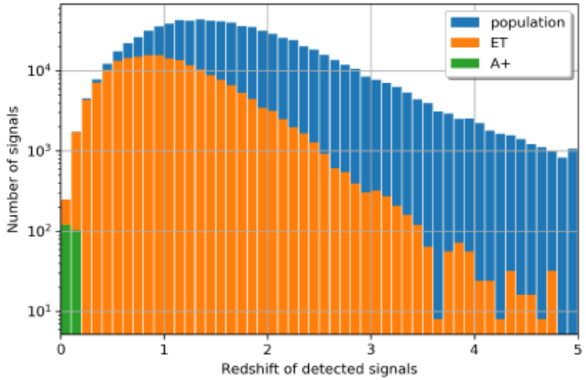
Dark energy and modifications of gravity on cosmological scales
dark energy equation of state,
modified GW propagation

Stochastic backgrounds of cosmological origin inflation, phase transitions, cosmic strings

The “unexpected” ?

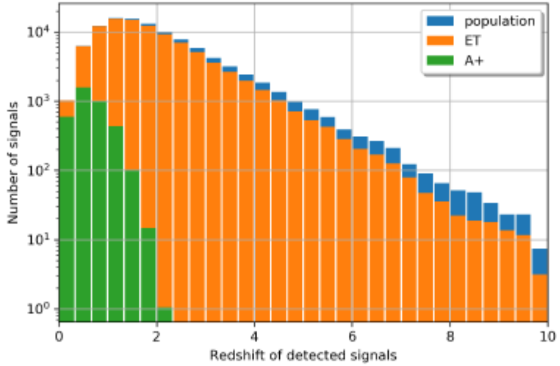
ET sensitivity

BINARY NEUTRON-STAR MERGERS

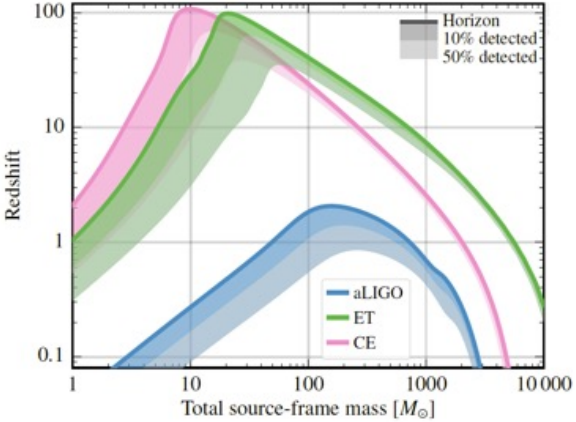


~1 detection every 30s

BINARY BLACK-HOLE MERGERS



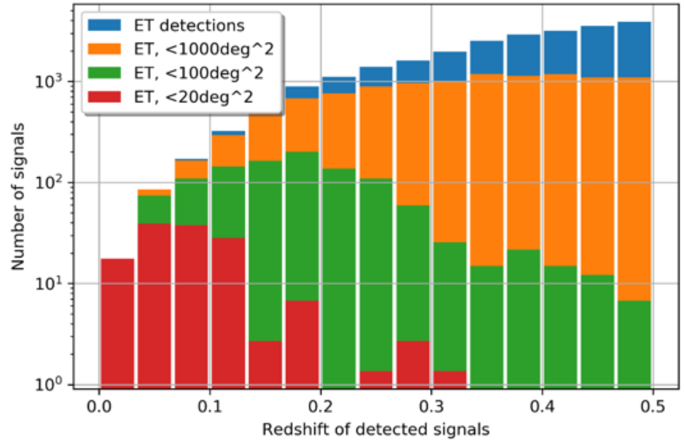
- 10^5-10^6 BBH detections per year
- 10^4-10^5 BNS detections per year among which ~10-100 with EM counterparts
- High SNR events
- Overlapping events



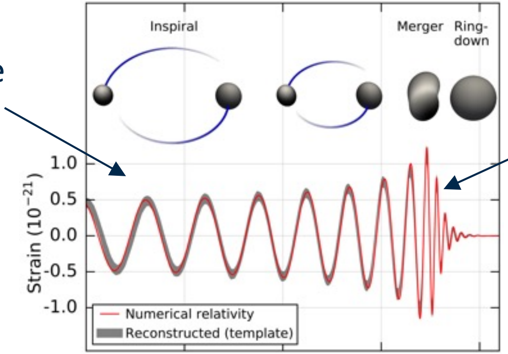
- ET 1st Mock Data challenge in progress
- 40 papers since 2022 summer on ET science

ET sensitivity

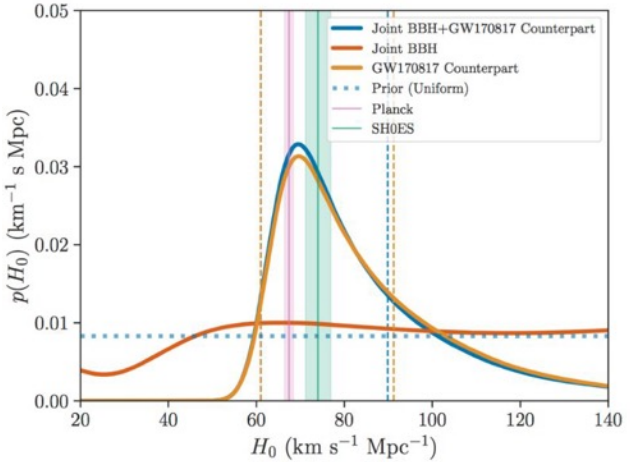
- **BNS detection with EM counterparts and localization precision < 20 deg²** : o(10-100) per year
- Overlap with many BBH signals
- Potentially, very long signals
- ET will be able to provide alerts few hours before the merger



Identify early the inspiral …

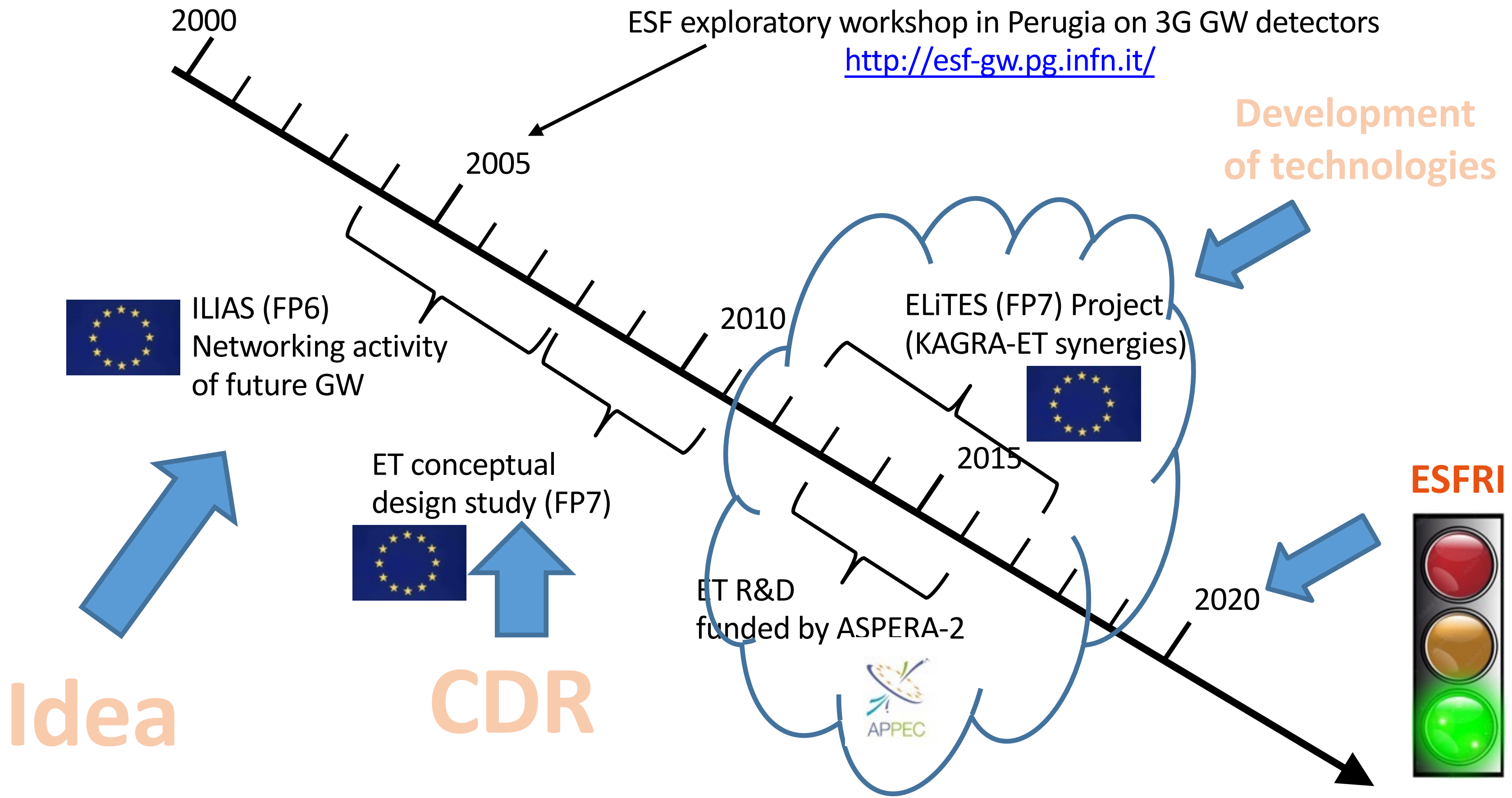


… and provide alert before the merger phase



- And with ~500 BNS-EM detection, we can reach Planck resolution on H_0 measurement

The genesis of the Einstein Telescope



The genesis of the Einstein Telescope

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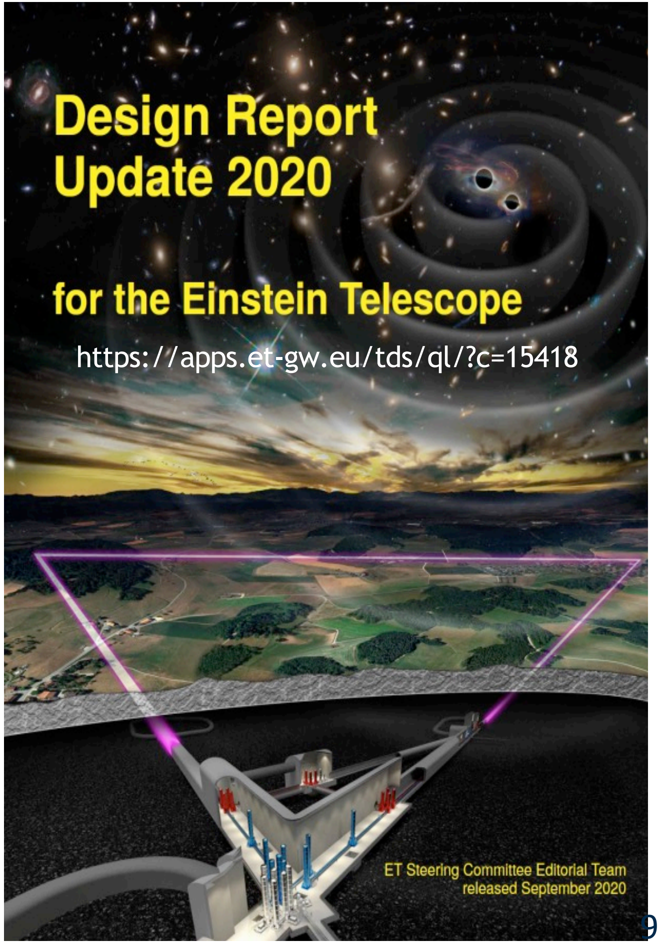
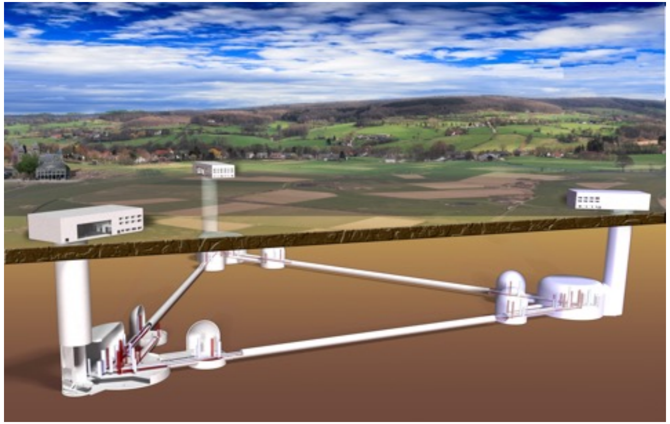
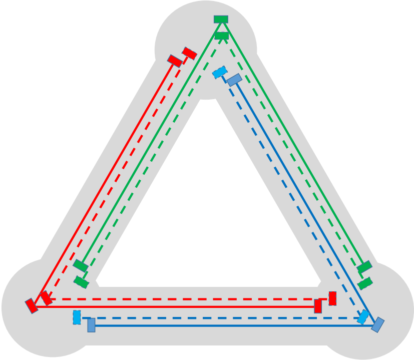
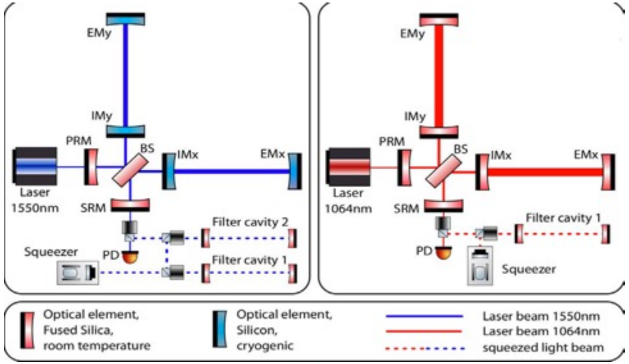
ESFRI



Underground infrastructure



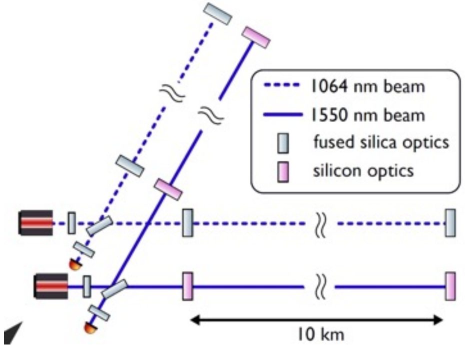




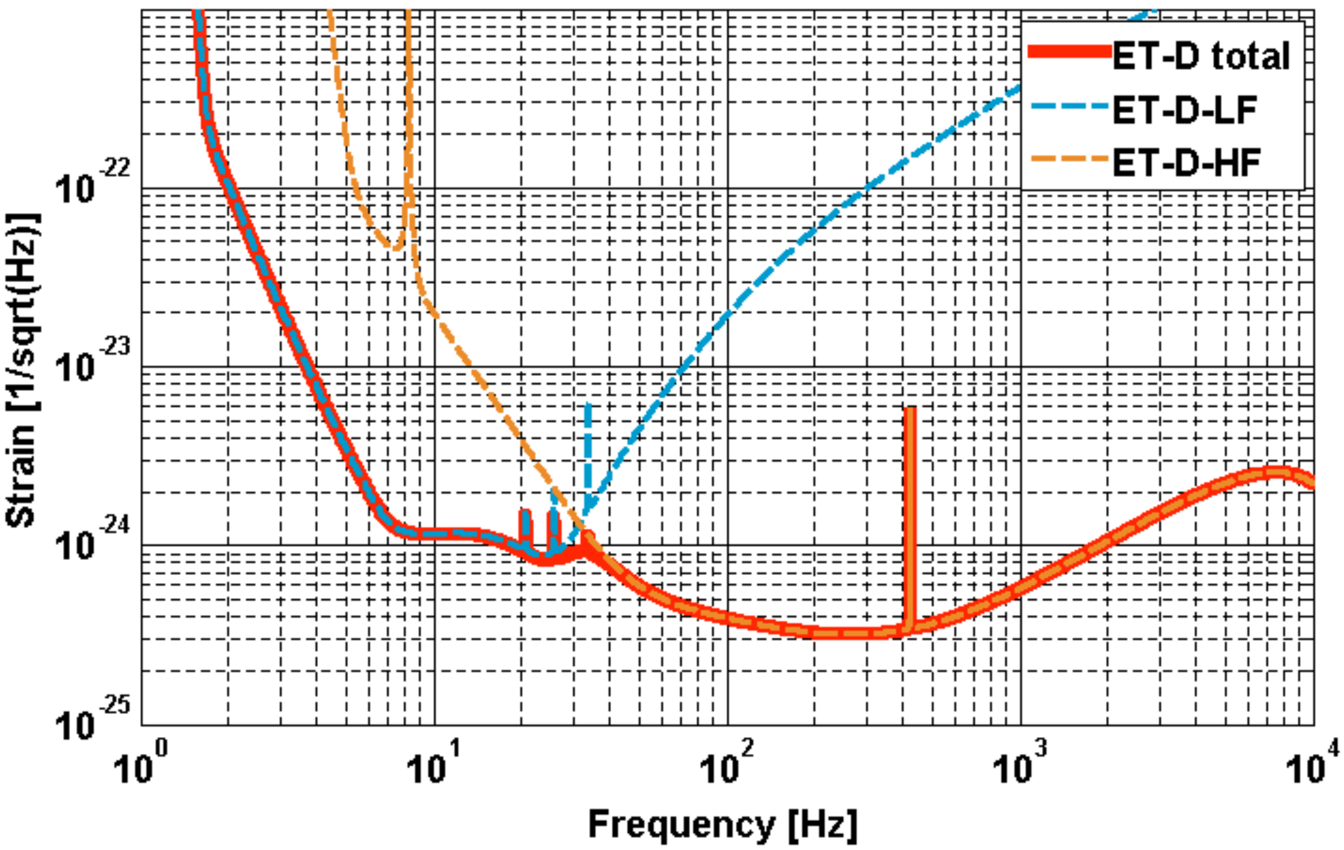
Parameter	ET-HF	ET-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10-20 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	45 cm/ 57 cm
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase (rad)	tuned (0.0)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

Xylophone: 2 sensitive interferometers at different frequencies

Triangle configuration to have 3 detectors in the same infrastructure



ET Sensitivity



ET technologies

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

Challenging engineering

New technology in cryo-cooling

New technology in optics

New laser technology

High precision mechanics and low noise controls

High quality opto-electronics and new controls

ET-LF:

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

ET-HF:

- High power laser
- Large test masses
- New coatings
- Thermal compensation
- Frequency dependent squeezing

Evolved laser technology

Evolved technology in optics

Highly innovative adaptive optics

High quality opto-electronics and new controls

Technologies and challenges for ET

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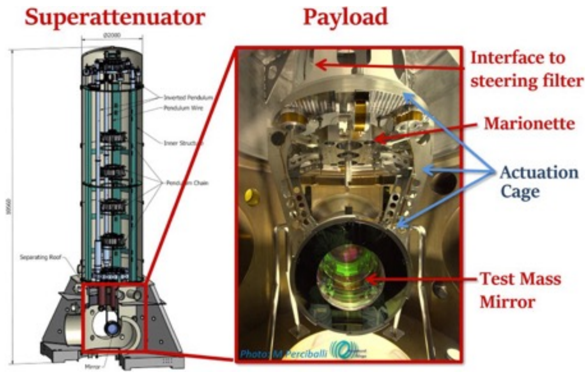
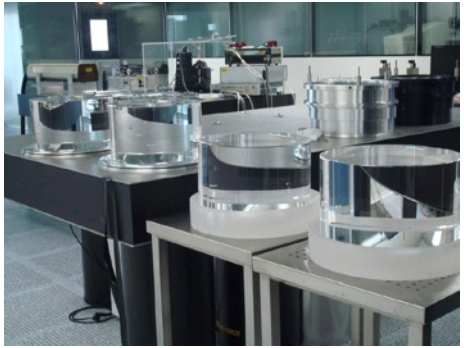
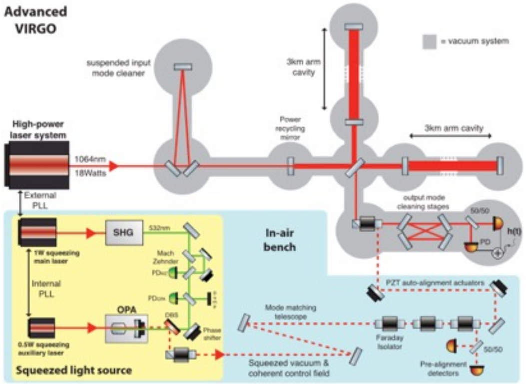
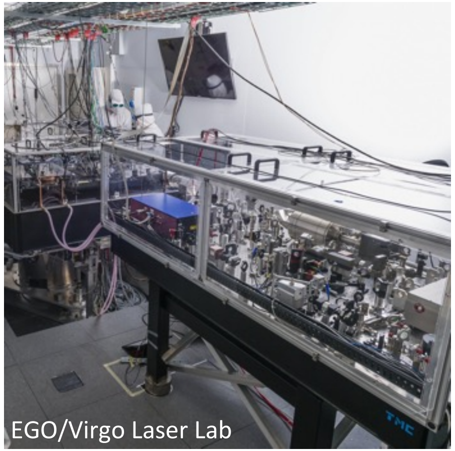
- Extrapolation of current or planned technologies for Virgo and LIGO
  - Squeezing (quantum states of light)
  - High power lasers
  - Bigger mirrors
  - New thin films for mirrors
  - Thermal compensation techniques
  - Seismic suspension systems
- Technologies not tested in Virgo and LIGO (prototypes and/or R&D in progress)
  - Cryogenics (=> KAGRA)
  - New cryogenic materials
  - New laser wavelengths








EGO/Virgo Laser Lab

⇒ Implementation of R&D programs

Vacuum pipe system

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Vacuum systems planned for 3G detectors are likely to be the largest UHV systems built

- The beam tube is its most important component (~1/2 of the cost of the system)
- 120 km of UHV tubes of 1 m diameter, total volume ~10^5 m3
- Vacuum requirements: factor > 5 stricter than Virgo:
- 10^{-10} mbar for H2, 10^{-11} mbar for N2, < 10^{-14} mbar for hydrocarbons
- Lifespan: 50 years - Preliminary estimated cost ~560 M€

Joint development with CERN involving Einstein Telescope and Cosmic Explorer (US Project)

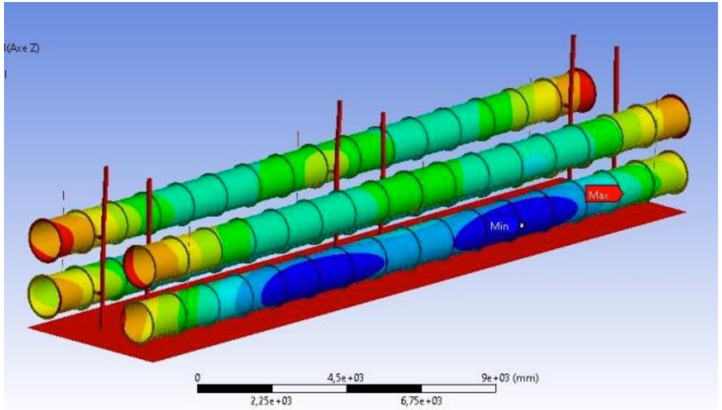
WP1: Design and engineering of the vacuum chamber [CNRS coordination]

Four designs are being considered:

- Baseline: Virgo-like solution adapted to ET tunnel
- Corrugated wall: 1.3-mm thick wall with regular corrugations
- Double wall chamber with thermal insulator between the two walls
- Pipeline

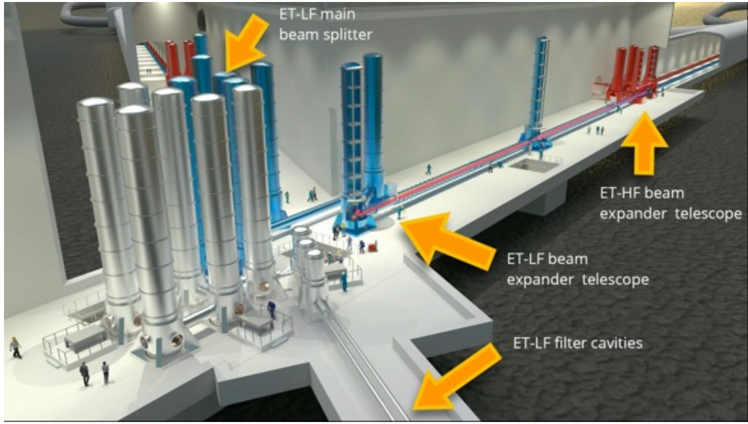
For the first two, we have a detailed:

- thermal-structural analysis;
- vibration modal analysis;
- design of different support systems (rigid and suspended);
- positioning in the tunnel.

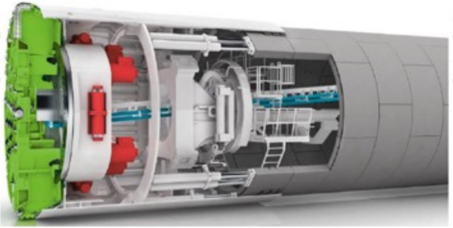


Infrastructure

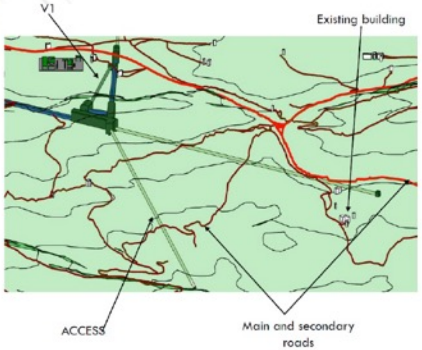
- stratégie pour la construction des tunnels et cavernes
- gestion infrastructure souterraine
- intégration dans l'environnement local



Taille, forme des cavernes ?



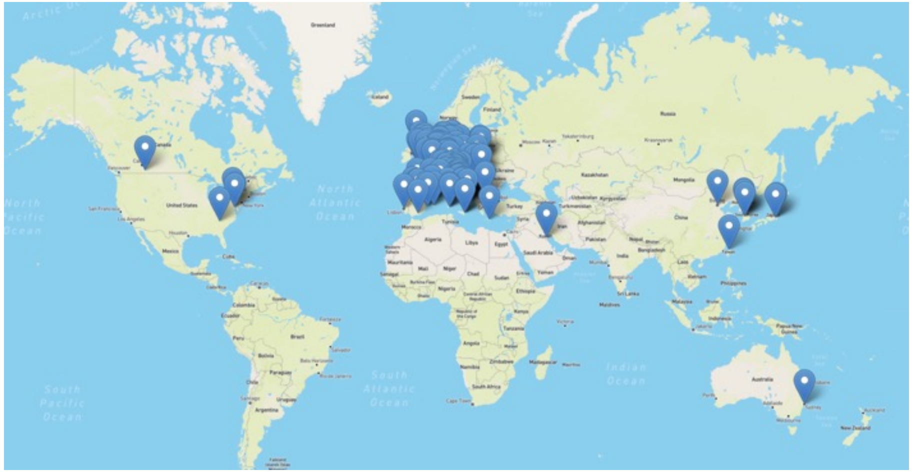
Méthode d'excavation ?



Installations existantes ?

+ Studies for the characterization of candidate sites in progress: drilling, ambient noise (seismic, wind turbine, magnetic ...)

ET Collaboration



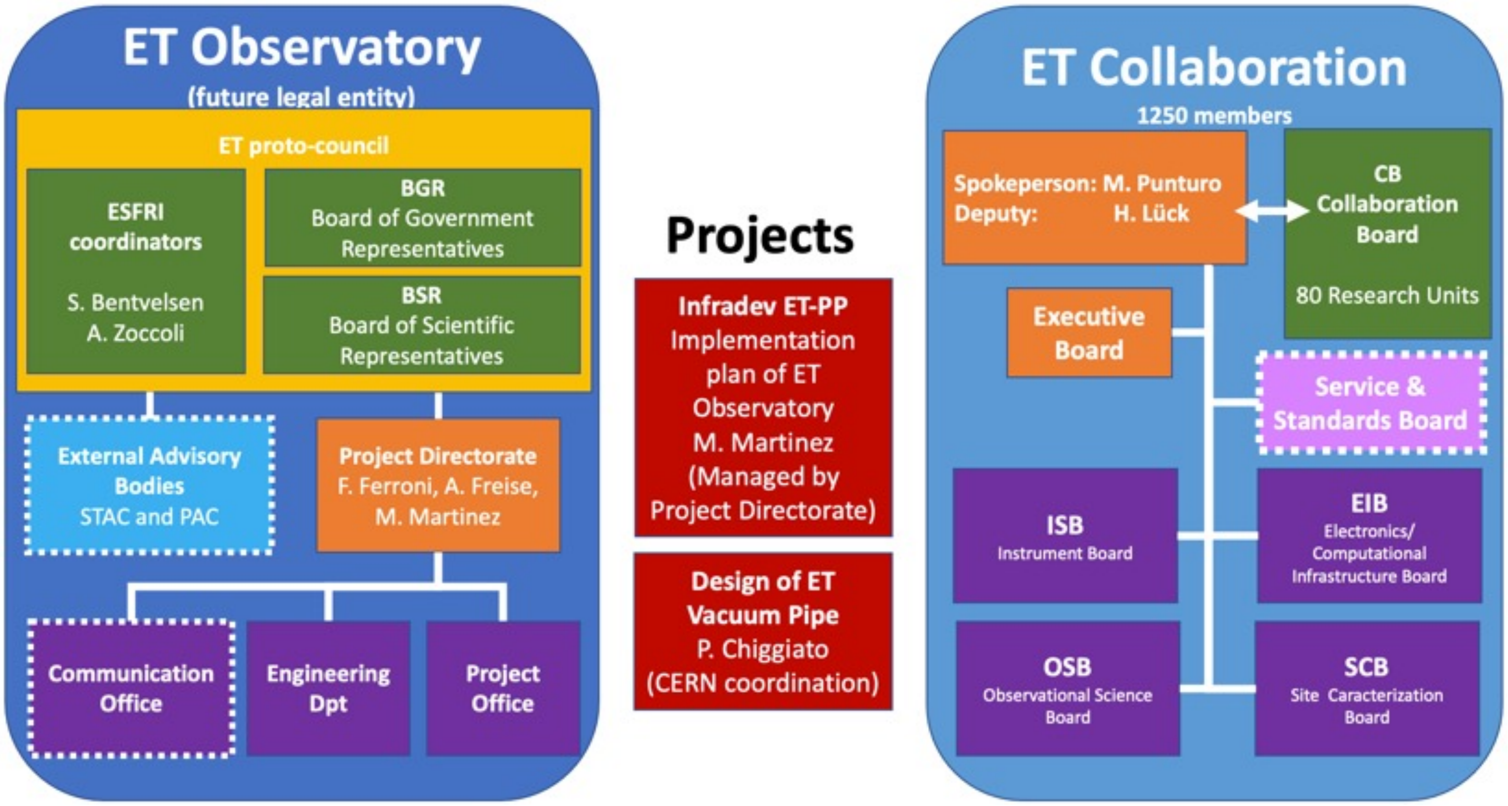
1370 collaborators from 202 institutes in 23 countries worldwide

Birth of the ET Collaboration
in June 2022 in Budapest

ET Infrastructure and ET Collaboration

The EU supports the creation of the ET infrastructure (ETO) through the financing of an Infradev project:

Einstein Telescope Preparatory Phase (ET-PP)



Since the summer of 2022, the ET structures are being put in place

ET-PP

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HORIZON-INFRA-2021-DEV-02 : « Developing and consolidating the European research infrastructures landscape, maintaining global leadership » - and therefore, accompanying EU to the assembly of newly registered IR ESFRI

Einstein Tescope Preparatory Phase (ET-PP): 4 years project (2022-2026)

Coordination: Mario Martinez (Espagne, IFAE) **Countries of participating institutes & laboratories:**

Germany, Austira, Belgium, Spain, France, Hungary, Italy, Netherlands, Poland, UK, Switzerland

EU Budget: 3,45 M€ **Total Budget :** 13,9 M€ i.e. in-kind of 10,45 M€ (salairies of permanent staff involved)

ET-PP will provide a detailed implementation plan for the ET infrastructure:

- the expansion of the ET consortium
- the legal framework, governance regimes and financial regulations to build and operate
- detailed technical design and costing of the ET observatory
- preparing the site selection
- costs of the site's infrastructure, socio-economic and environmental impacts
- technology transfer, procurement and industry involvement programs in engineering design and construction
- the required link with the scientific communities concerned regarding the detailed definition of the scientific programme
- User services and data access mode

ET-PP

WP1 Coordination and Management
WP2 Organization, Governance and Legal Aspects
WP3 Financial Architecture
WP4 Site Selection
WP5 Project Office ← IN2P3 Co-coordination
WP6 Technical Design
WP7 Transfer of Technology
WP8 Computing and Data Access
WP9 Sustainable Development Strategy
WP10 Education, Outreach and Citizen Engagement

WP1: Spanish responsibility in close connection with INFN and Nikhef

WP2-3-4: essentially INFN & Nikhef

WP6 & WP8: Responsibilities for collaboration scientific AND that is being set up => essentially in-kind

Essential IN2P3 contributions to ET-PP in order to prepare ETO

Schedule

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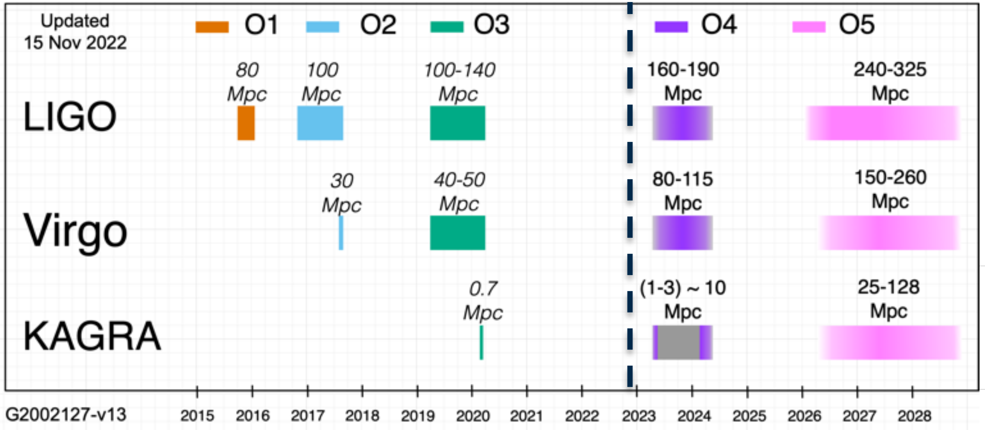
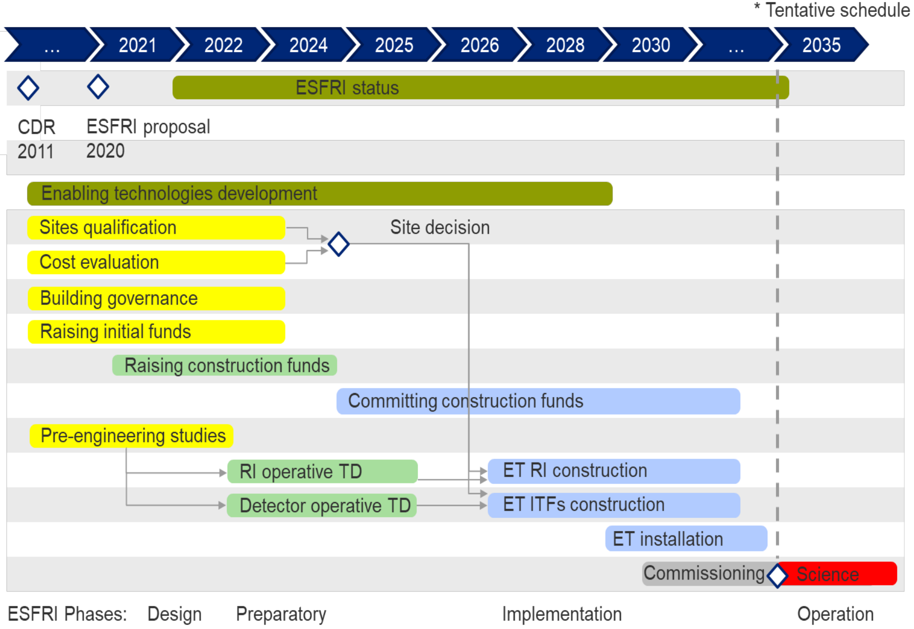


Advanced Virgo (AdV)

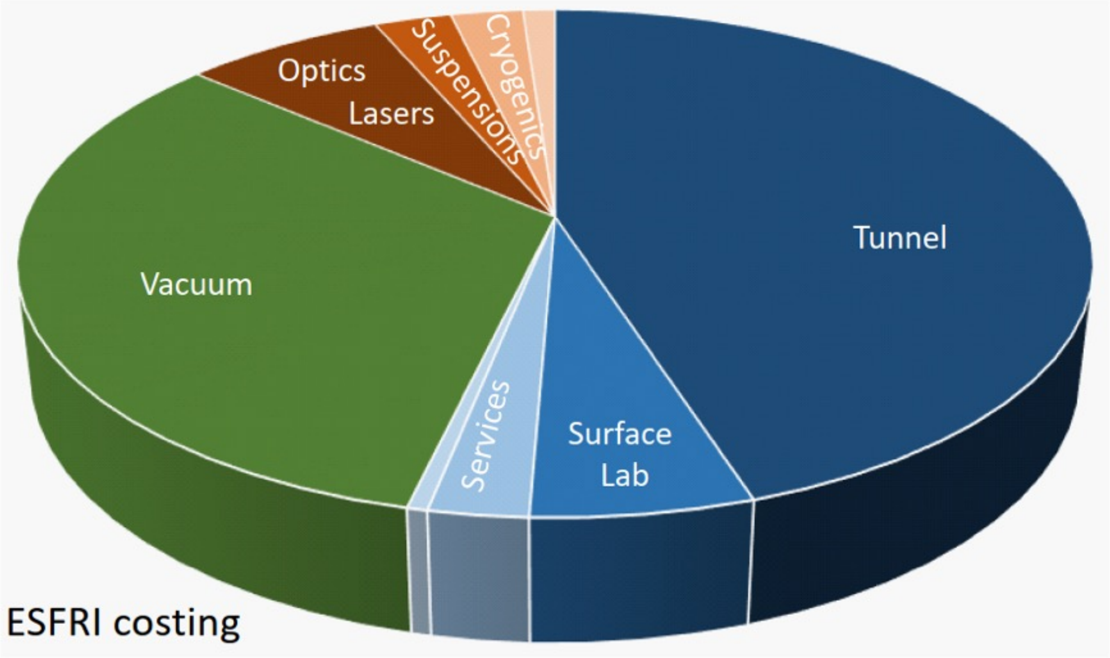
AdV+ phase 1

AdV+ phase 2



Virgo and LIGO are currently studying post-O5 upgrades, Virgo_nEXT and A#

Construction costs



2021

Tunnel	781 M€
Surface Lab	98 M€
Underground Services	44 M€
Direction	9 M€
	932 M€
Vacuum Systems	566 M€
	566 M€
Optics & Lasers	125 M€
Suspensions	48 M€
Cryogenics	45 M€
Installation	20 M€
	238 M€

Site candidates in Europe

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There are currently two candidate sites in Europe to host ET:

- The Sardinia site, near the Sos Enattos mine
- The EU Regio Rhine-Meusse site, close to the NL-B-D border
- A third option in Saxony (Germany) is under discussion

Sites are studied through

- seismic noise measurements at surface, borehole and mine (Sardinia)
- Magnetic and ambient noise measurements
- Geophysical and geotechnical characterizations
- …

Significant funds are required to develop a site application

Site candidates in Europe

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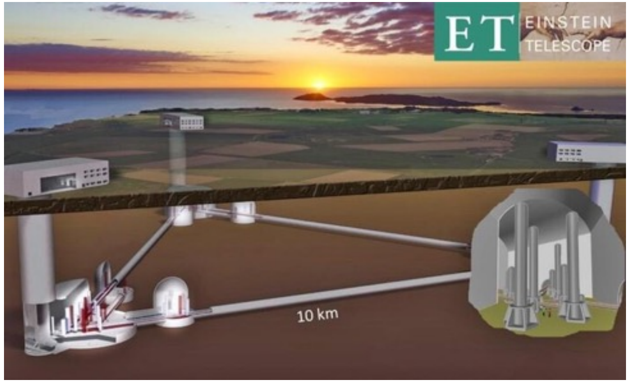
cnrs

Sardinia – Italy



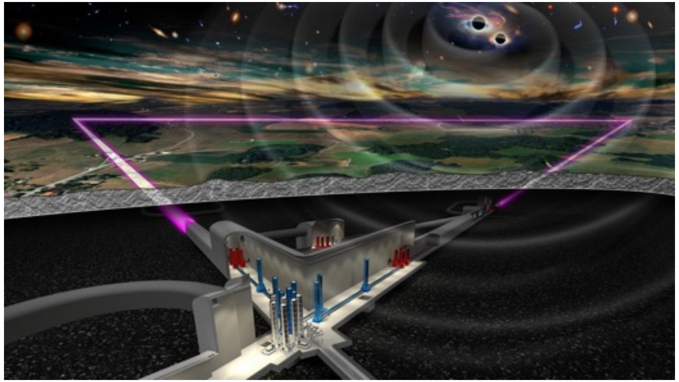
€50 million for R&D and preparatory work

ETIC in Italy

Einstein Telescope Infrastructure Consortium

"Multi-100 M€" financing to support ET's site in Sardinia

Euregio Meuse-Rhin Netherland



€42 million for R&D and preparatory work

ET-Pathfinder in Maastricht

"Multi-100 M€" financing if the ET site is in Euregio Meuse-Rhine

Saxe – Germany

New DZA laboratory (2022)

170 M€/year over 10 years

3 pillars: astrophysics, data science, technology

ET pathfinder in Maastricht

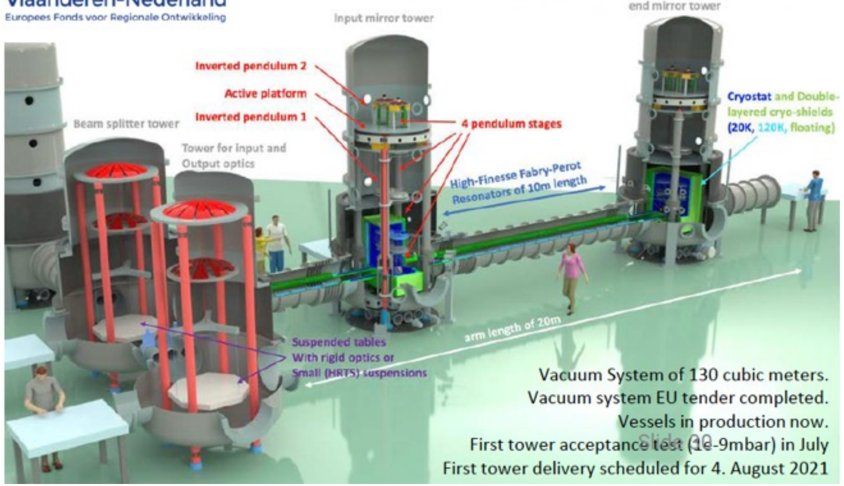
ET-PATHFINDER

- New facility for testing ET-LF technology in a low-noise, full-interferometer setup
- Key aspects: Silicon mirrors (3 to 100+kg), cryogenics cryogenic liquids and sorption coolers, water/ice management), "new" wavelengths (1550 and 2090nm), coatings etc
- Start with 2 FPMI, one initially at 120K and one 15K (2022+)
- >20 partners from NL/B/G/FR/SP/UK
- Initial capital funding of 14.5 MEuro
- Detailed Design Report available at apps.et-gw.eu/tds/?content=3&r=17177
- **Open for everyone interested to join**
- For more information please see:

  www.etpathfinder.eu

CREDIT: S. Hild

Interreg
Vlaanderen-Nederland
Europees Fonds voor Regionale Ontwikkeling



ETIC project in Italy

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cnrs

One of the axes of the ETIC project is the development of a cryo lab in Rome

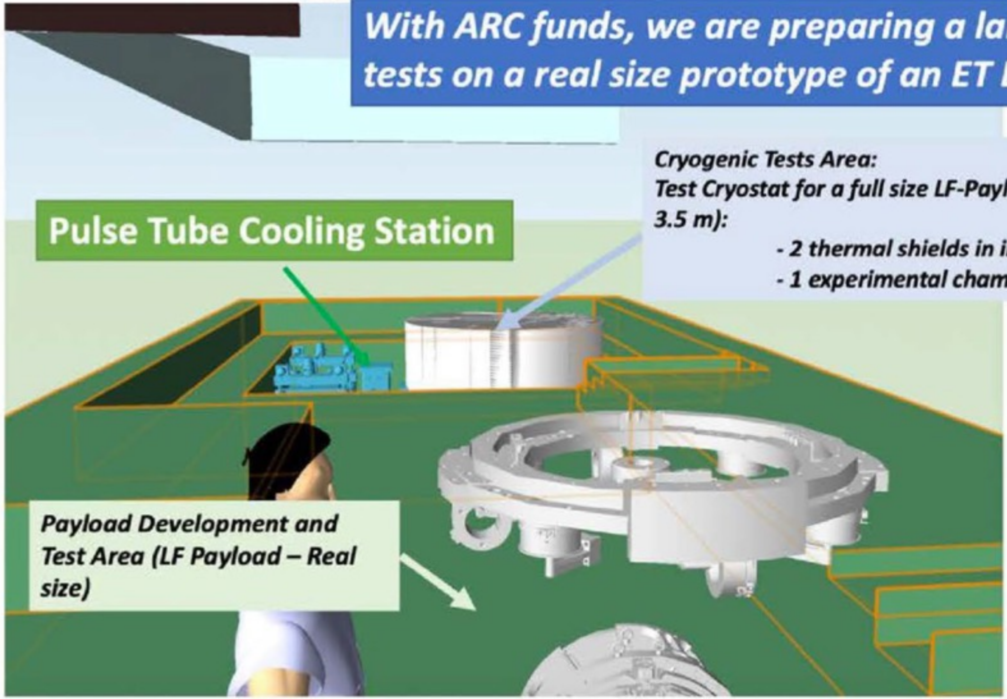
MINISTERO DELL'ISTRUZIONE, DELL'UNIVERSITÀ E DELLA RICERCA

INFN ROMA Istituto Nazionale di Fisica Nucleare

3G Gravitational-Wave Lab

AMALDI RESEARCH CENTER

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



The Rome1 ET Group:

From Virgo:

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

From CUORE:

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

From EGO:

Paolo Ruggi (EGO Researcher)

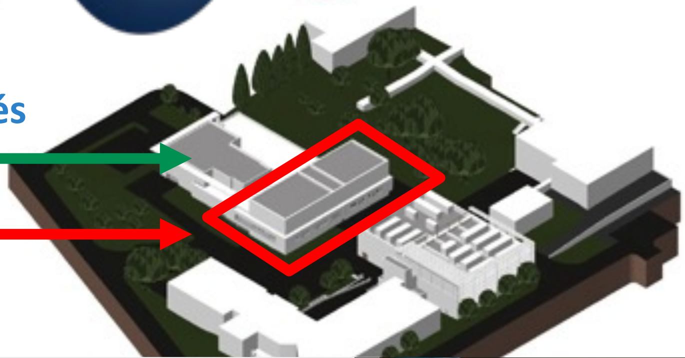
Extension of the LMA in Lyon

iP2i LES 2 INFINIS LYON

Laboratoire des Matériaux Avancés

Current

Extension



Contrat de Plan Etat-Région 2021-2027

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE
La Région Auvergne-Rhône-Alpes
RHÔNE LE DÉPARTEMENT
MÉTROPOLE GRAND LYON

An investment for:

- the extension of the LMA building
- the construction of a new coater allowing the deposition of thin films on very large substrates: Ø 1.6 m, 600 kg
- associated optical and metrology tools

LMA is a research infrastructure unique in the world

Developing technologies for future experiments (e.g. Einstein Telescope)

E-Infrastructure

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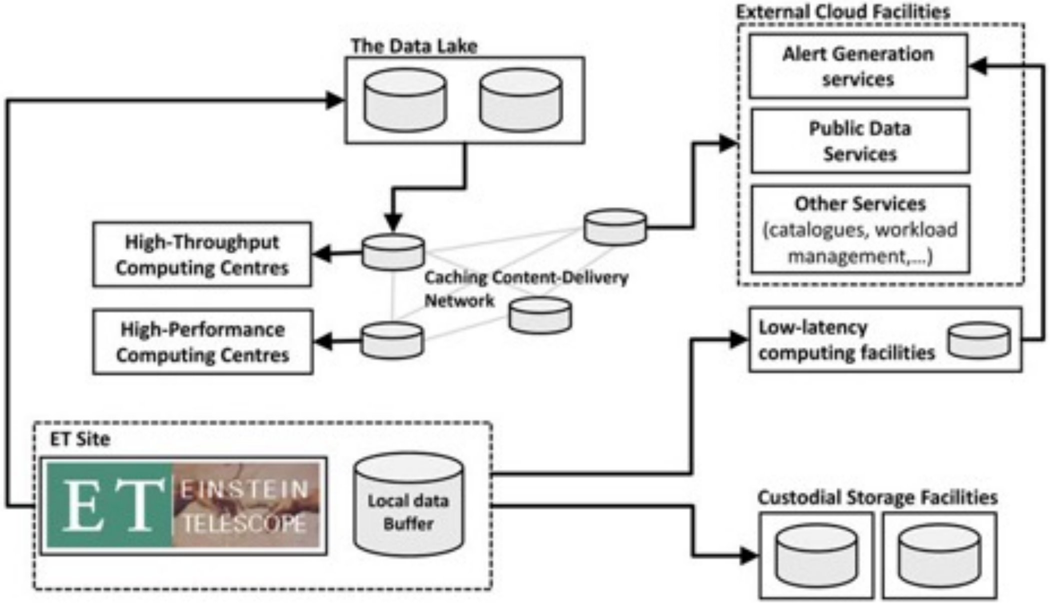
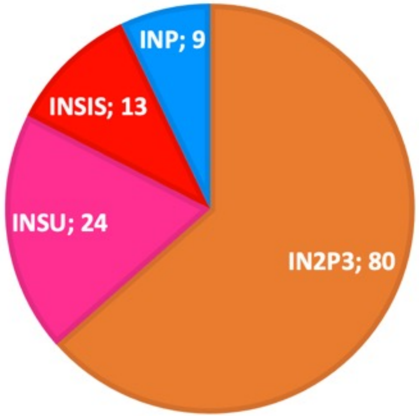
ET will use a **distributed computing infrastructure** in Europe, based largely on existing infrastructures such as CC-IN2P3 in France (ET = ~10% of an LHC exp. at CERN).

Increasing use of **high-performance parallel computing** (HPC) vs HTC computing.

Use of tools and services developed in the framework of the **European Open Science Cloud** and European projects such as ESCAPE for **multi-messenger physics**



ET France



126 French collaborators Officially joined the ET Collaboration

Einstein Telescope France

Research Unit (RU)	Laboratories
Artemis	ARTEMIS
Astroparticule et Cosmologie (APC)	APC
	IAS
	SUBATECH
IF-ILM	IF
	ILM
	MSME
IJCLab	IJCLab
	LKB Paris
IP2I - LMA	IP2I Lyon - IN2P3
	LMA - IN2P3
IPHC-L2IT	IPHC
	L2IT
LAPP	LAPP
Paris - Caen	Observatoire de Paris (GEPI, LUTH, SYRTE)
	GANIL / LPC Caen
	IAP

+ CC-IN2P3

Mailing list ET-France:

ET-FRANCE-L@IN2P3.FR

Meetings:

Création d'un espace « Einstein Telescope » sur

https://indico.in2p3.fr/category/1165/

Site web ET-France:

Hébergé au CC-IN2P3 https://et-france.in2p3.fr

ET-France and Industries

Einstein Telescope France

by Patrice Verdier on janvier 31, 2023

Organisé **le 23 mars 2023 à l'APC (Paris)** par le CNRS et le service du Ministère de l'Enseignement Supérieur et de la Recherche en charge de la liaison avec les industriels sur les Infrastructures de Recherche, ce premier séminaire a pour objectif de réunir scientifiques du monde académique et industriels en France. Pour préparer la contribution française à ce projet Européen, nous invitons les partenaires industriels qui aimeraient s'informer Einstein Telescope et éventuellement se joindre à nous dans ce défi.

Informations et inscriptions sur:

https://indico.in2p3.fr/event/28704/

First meeting organized with MESR to present ET to the French industries interested by this project

About 30 companies were present and have shown interest to works with us, either through dedicated/joint R&D program, either as manufacturer of components

Follow-up in progress with “IN2P3 Valorisation” responsible (S. Beurthey)

SWOT Analysis

Strengths	Weaknesses
CNRS contribution to ET is based on a strong experience and expertise that its scientists and laboratories acquired during 30 years on Virgo and in the LVK collaboration. EGO, the CNRS-INFN-Nikhef European laboratory for gravitational waves physics is a major asset and the R&D base to prepare 3rd generation interferometer technologies.	A national source of budget supporting R&D programs for ET technologies has to be identified in France. Italy, Netherlands, and Germany each obtained multi-year budget of the order of €50 millions.
Opportunities	**Threats**
Increasing the sensitivity at low frequencies is generating a vibrant R&D program, especially on cryogeny, optics, sapphire substrate, mirror coatings, lasers. ET can only be successful with strong industrial partnerships in which French industry could play an essential role.	The attractiveness of GW physics is generating a strong competition among the European community with ambitious new comers (and new countries) in this field of research, both on the aspects of technology development and of physics analysis.

Conclusion

Institut national de physique nucléaire et de physique des particules

Einstein Telescope is a very ambitious project for the late 2030s which requires:

- A large, structured and organized scientific collaboration
- A new Research Infrastructure / legal entity with operational and efficient services
- An intensive R&D program to develop new technologies
- Strong partnerships between academic research and industries

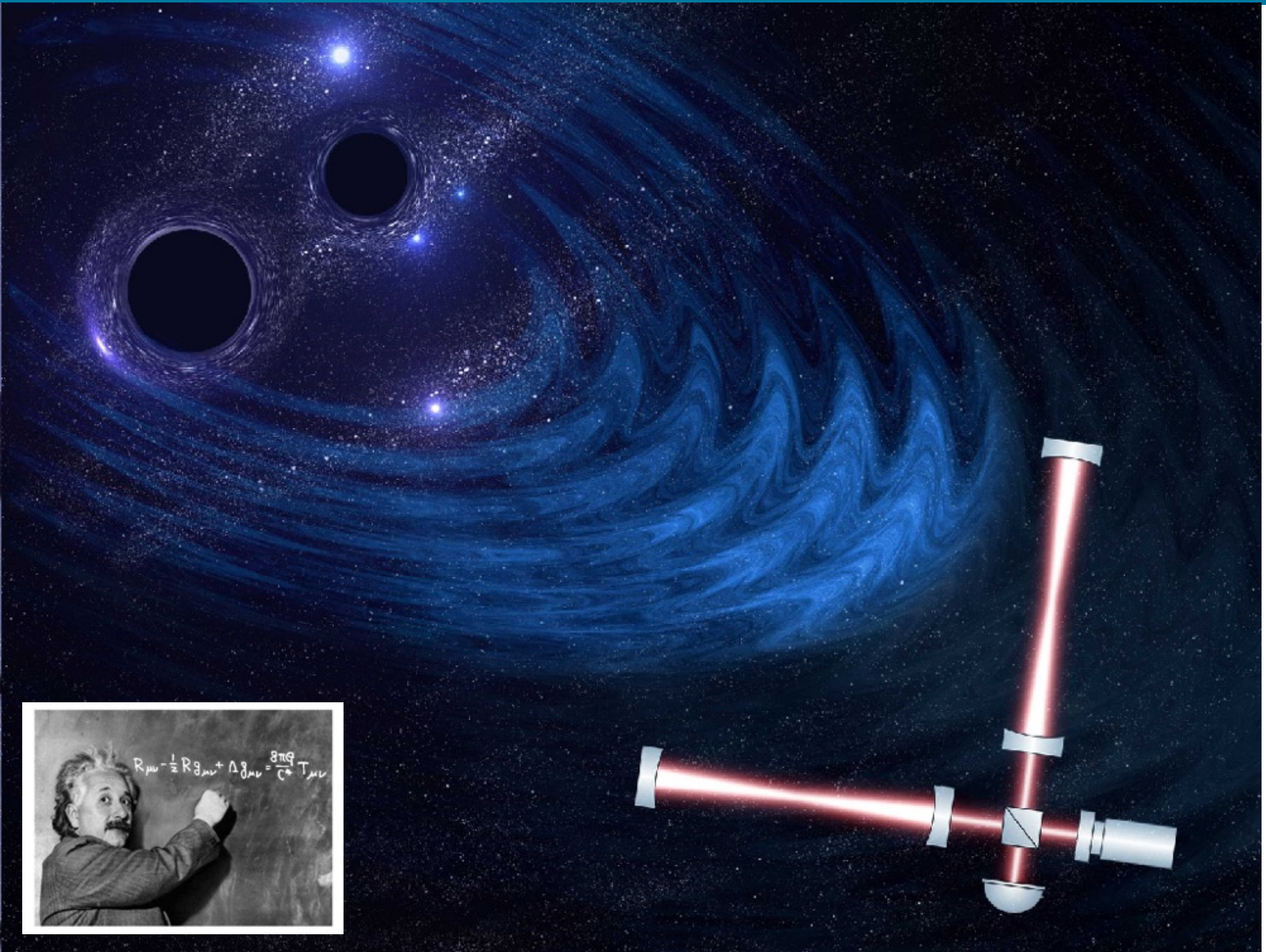
Preparing 3G experiments for ground-based GW detection has been identified as a priority in the Strategic Plan for French Nuclear, Particle and Astroparticle physics in the 2030 Horizon

There are important synergies between Einstein Telescope, existing 2G detectors (LIGO-Virgo-KAGRA) and future detectors (Cosmic Explorer)

- Expertise acquired on EGO-Virgo and in LVK is crucial:
  - For the reduction of risks in a >B€ project
  - To consolidate GW teams in France with talented young scientists and engineers
- French participation to ET is at this stage well controlled regarding the challenges of 2G detectors for the next ~15 years

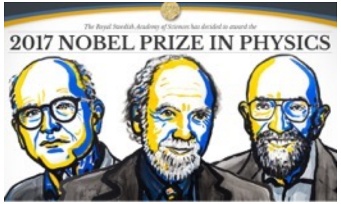
RESERVE

Introduction



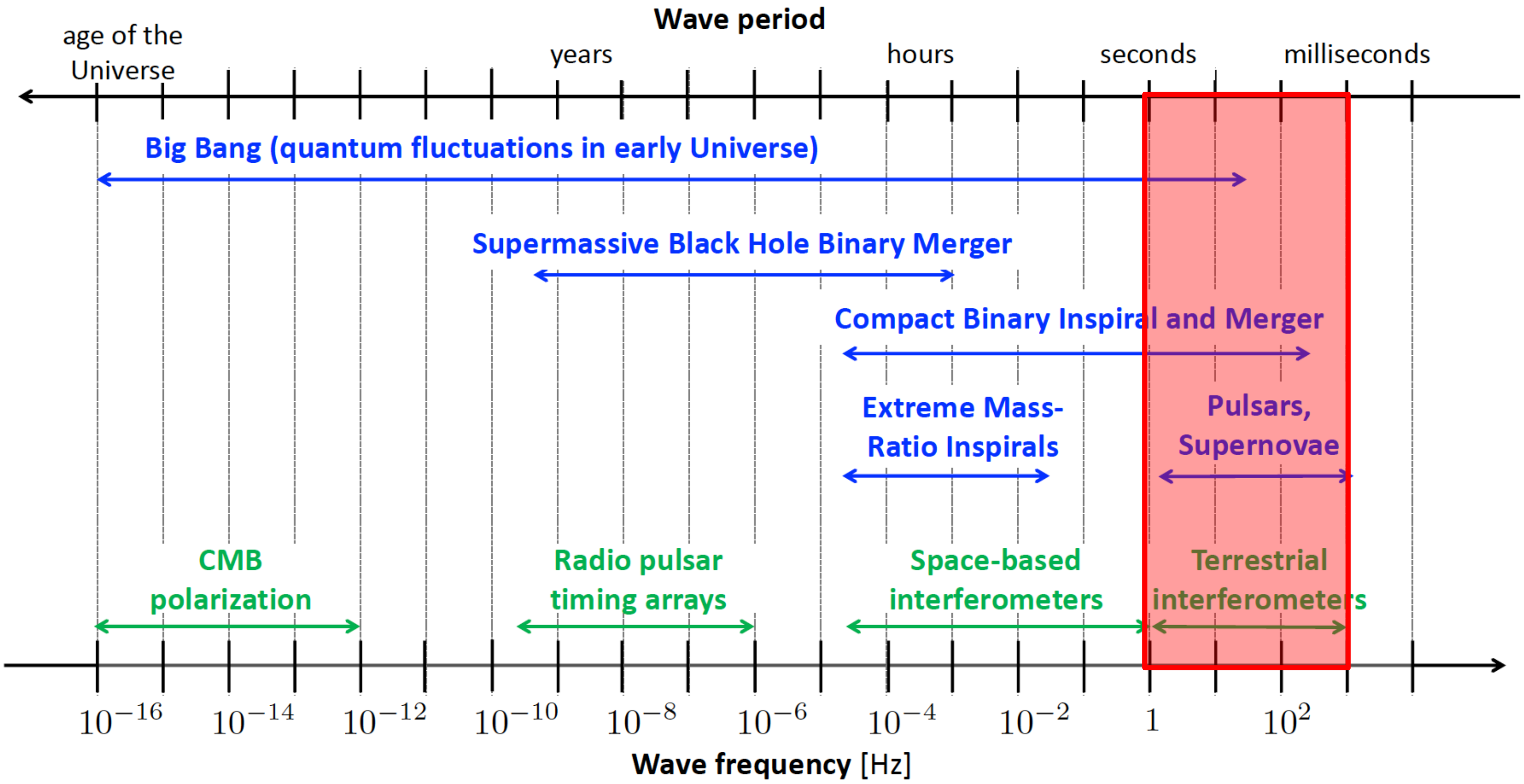
100 years after their prediction as part of Einstein's theory of general relativity, the discovery of gravitational waves opens a new way to explore and study the Universe!

Nobel Prize in Physics 2017

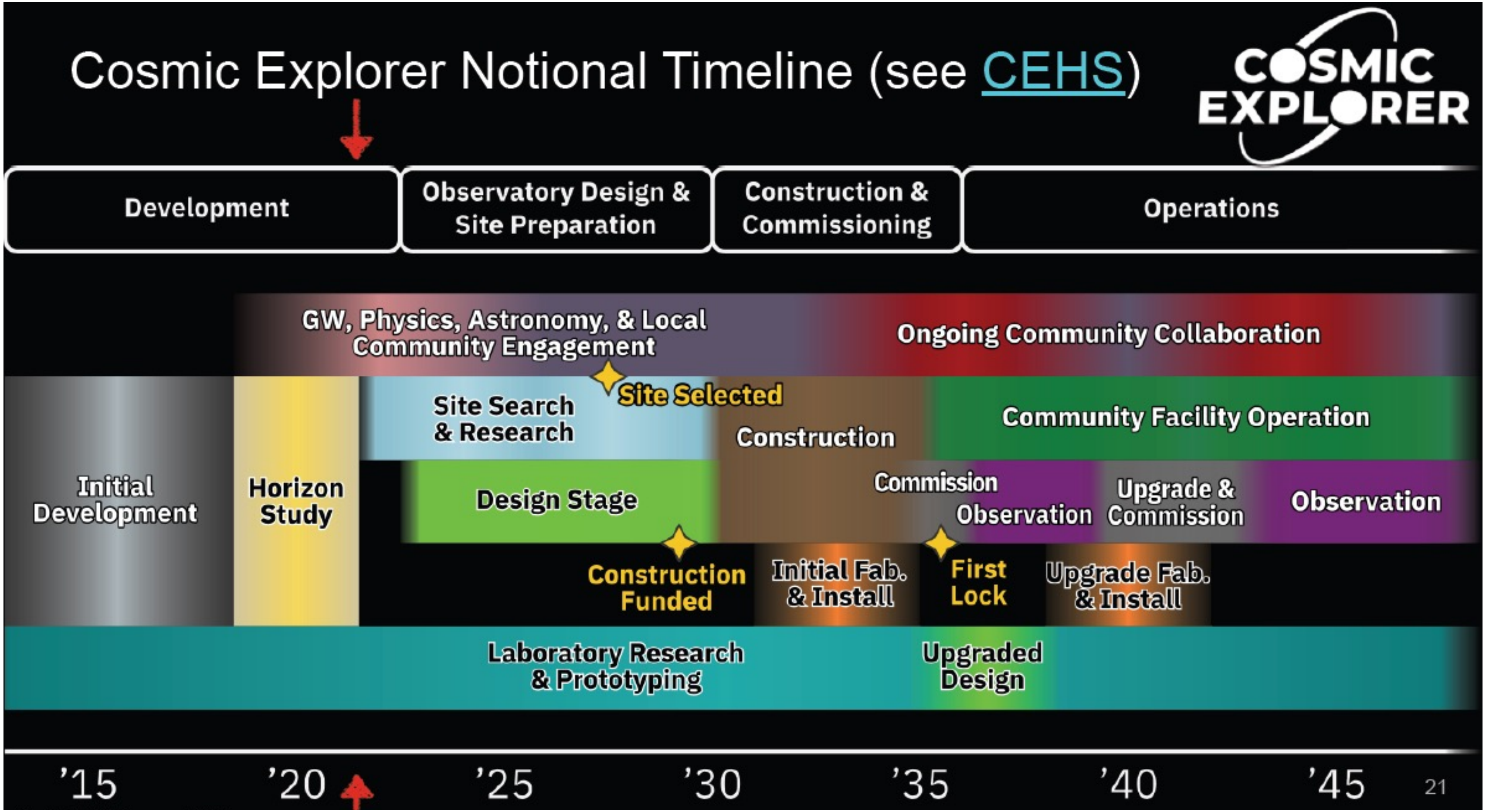


GW spectrum

Physical phenomenon, Search techniques



CE Timeline


Cosmic Explorer Notional Timeline (see CEHS)
COSMIC EXPLORER
Development
Observatory Design & Site Preparation
Construction & Commissioning
Operations
GW, Physics, Astronomy, & Local Community Engagement
Ongoing Community Collaboration
Initial Development
Horizon Study
Site Search & Research
Site Selected
Construction
Community Facility Operation
Design Stage
Commission
Observation
Upgrade & Commission
Observation
Construction Funded
Initial Fab. & Install
First Lock
Upgrade Fab. & Install
Laboratory Research & Prototyping
Upgraded Design
'15
'20
'25
'30
'35
'40
'45
21