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et de physique des particules

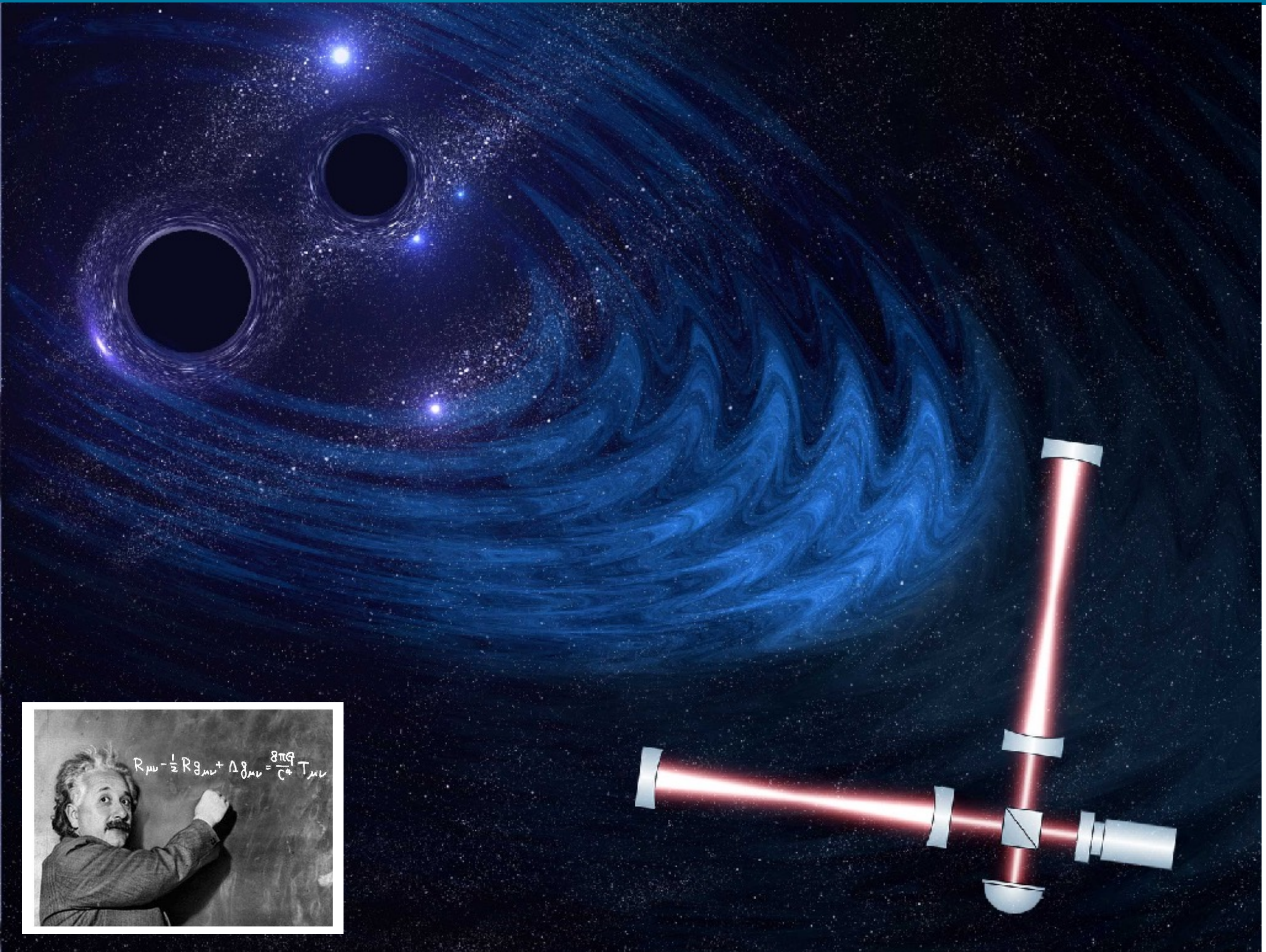
The Einstein Telescope Project

Journée thématiques
Ondes Gravitetionnelles à Lyon

Lyon, April 24th, 2023

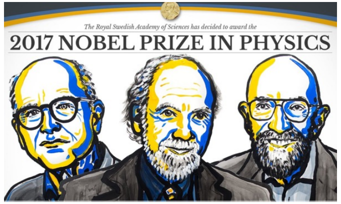
Patrice Verdier (IP2I Lyon – IN2P3) - patrice.verdier@in2p3.fr

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



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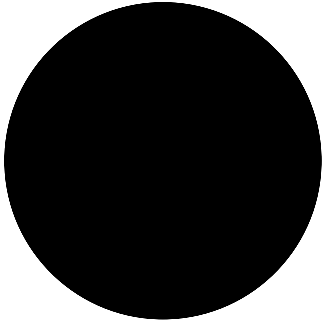
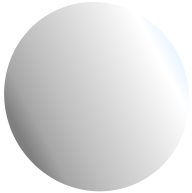
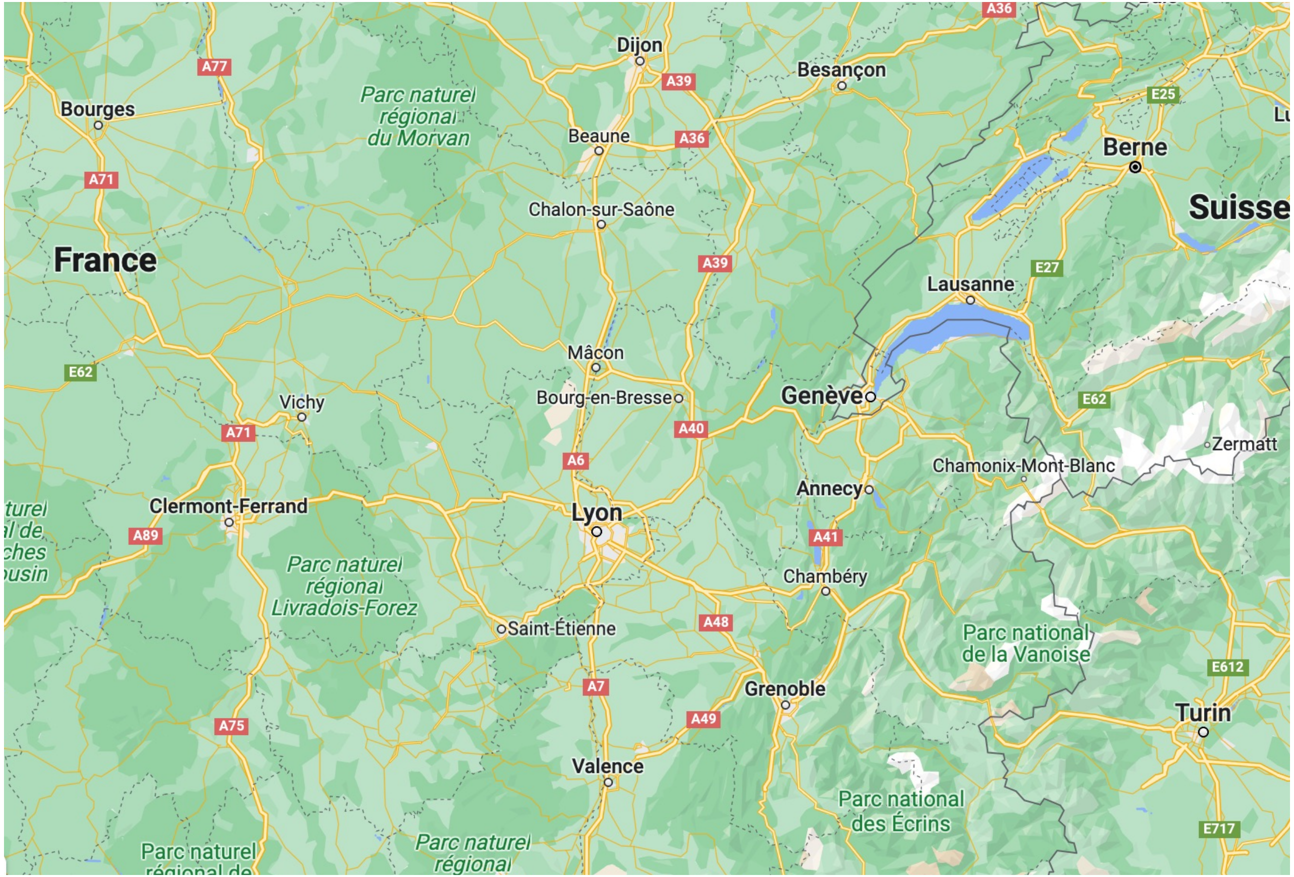
Black hole 15$M_\odot$



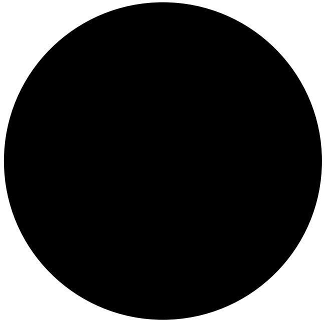
Neutron star 1.4 $M_\odot$



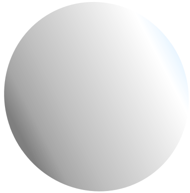


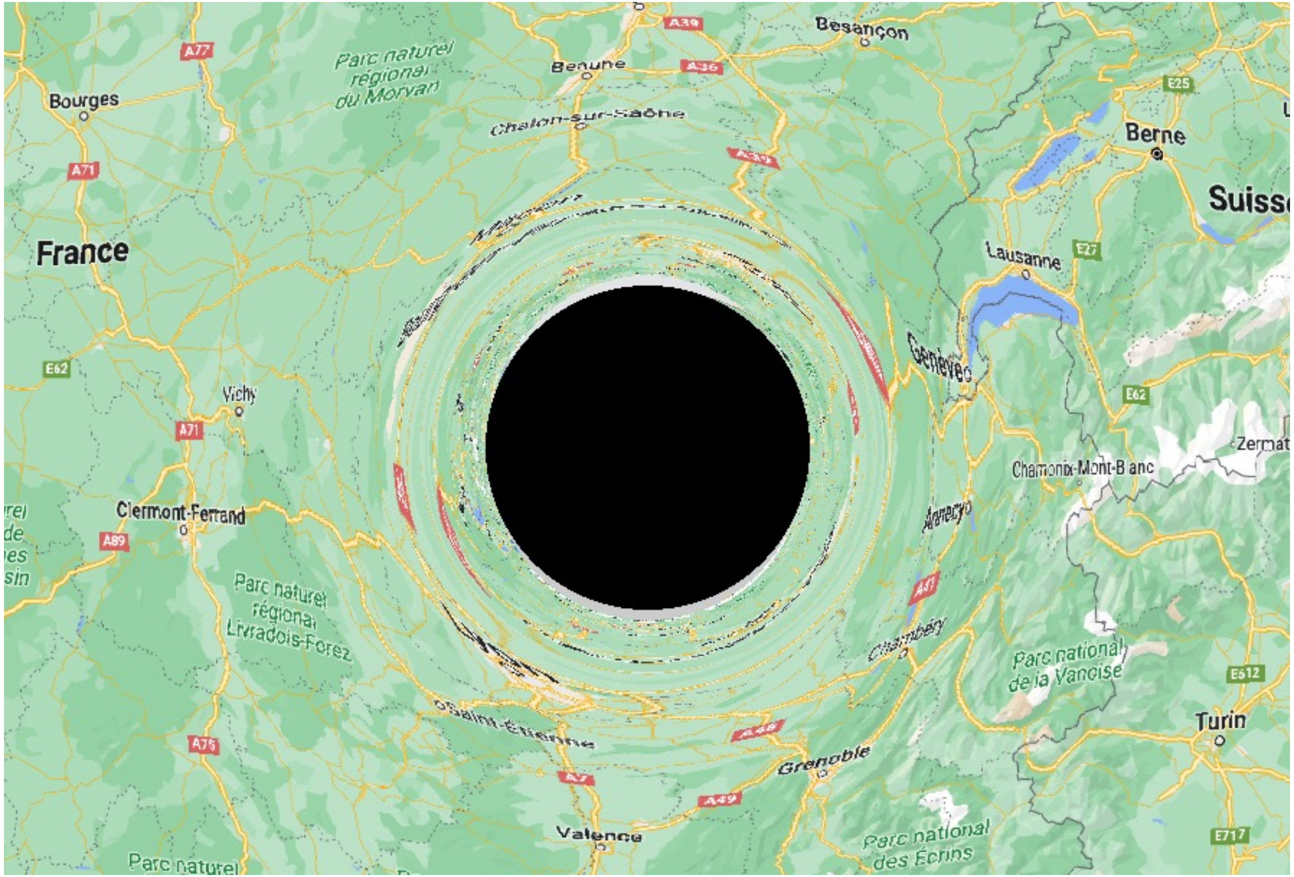
Introduction

Black hole 15$M_\odot$



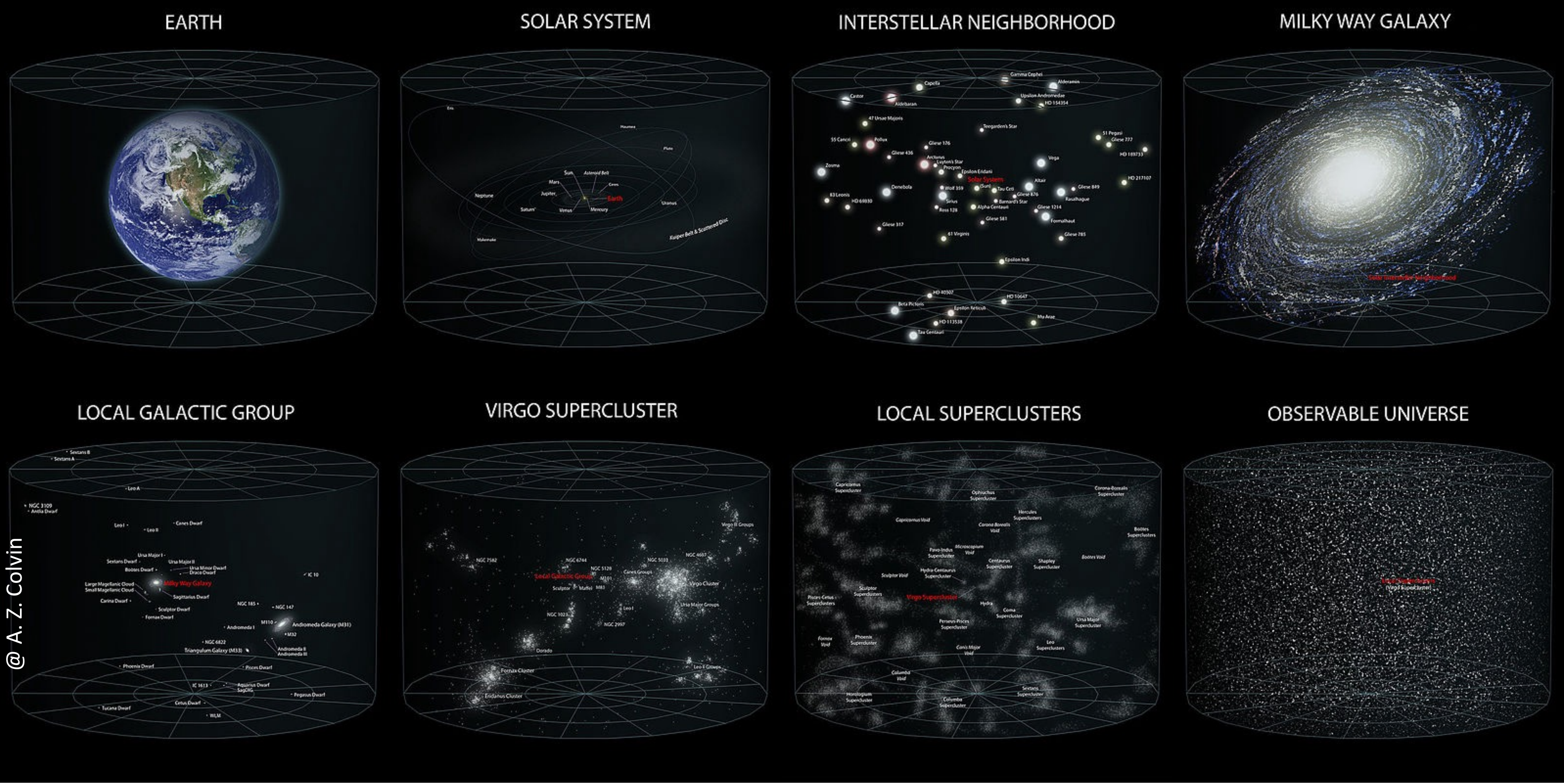
Neutron star 1.4 $M_\odot$





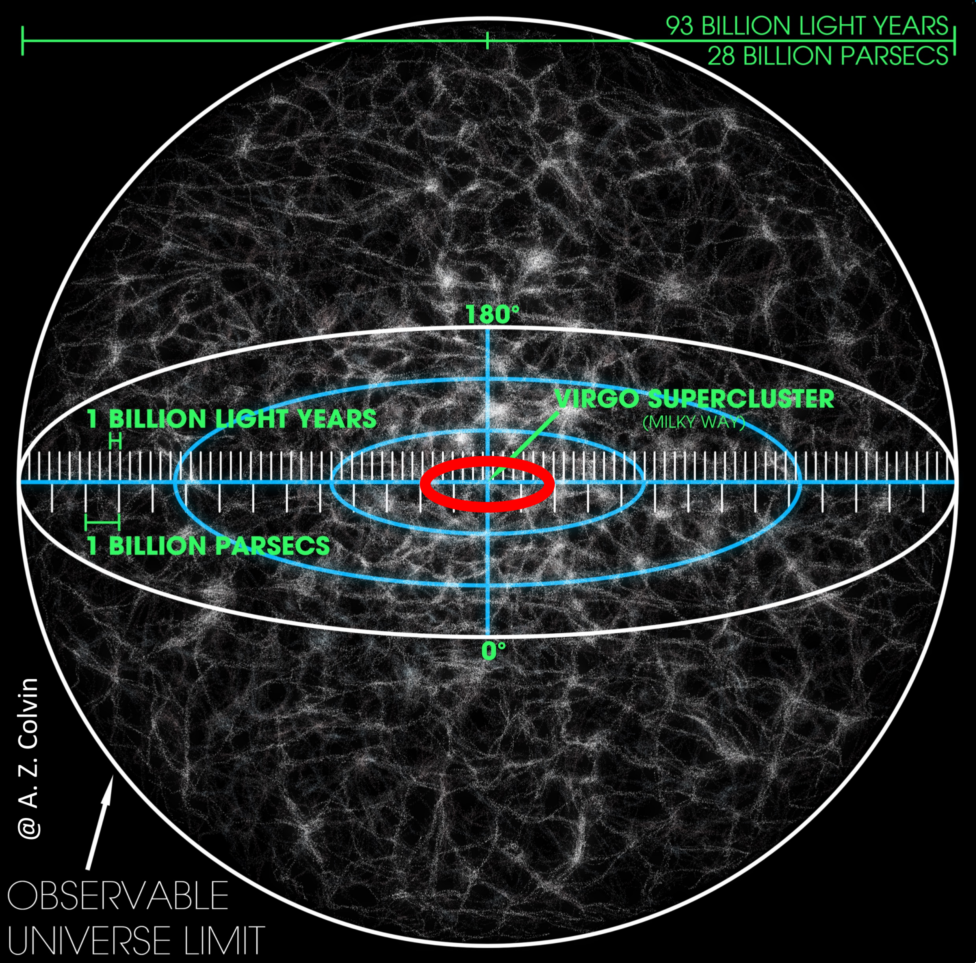
@ David Ball, University of Arizona: http://bhpire.arizona.edu/research/tools/black-hole-photo-filter/

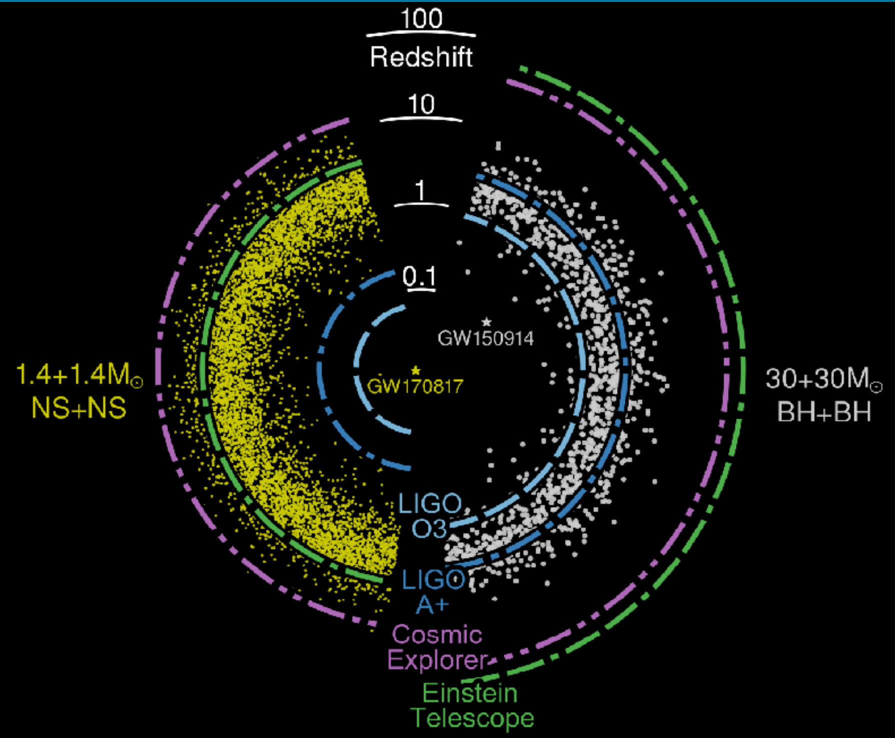
Introduction



@ A. Z. Colvin

Introduction





Einstein Telescope aims to study most of the observable Universe

GW spectrum

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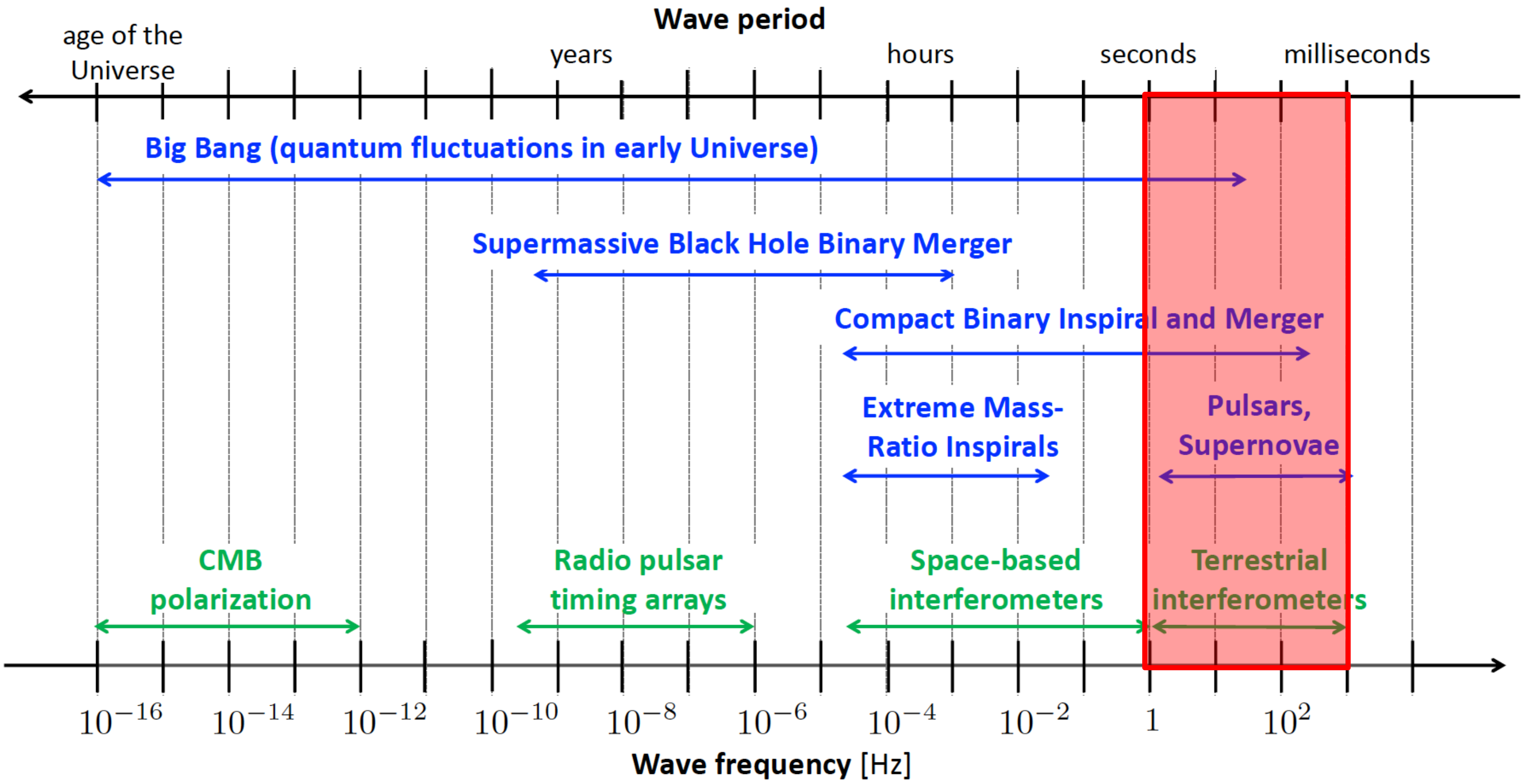
Physical phenomenon, Search techniques



The LIGO-Virgo-KAGRA (LVK) network

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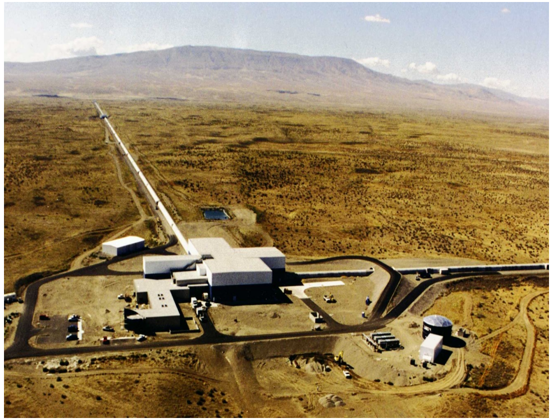
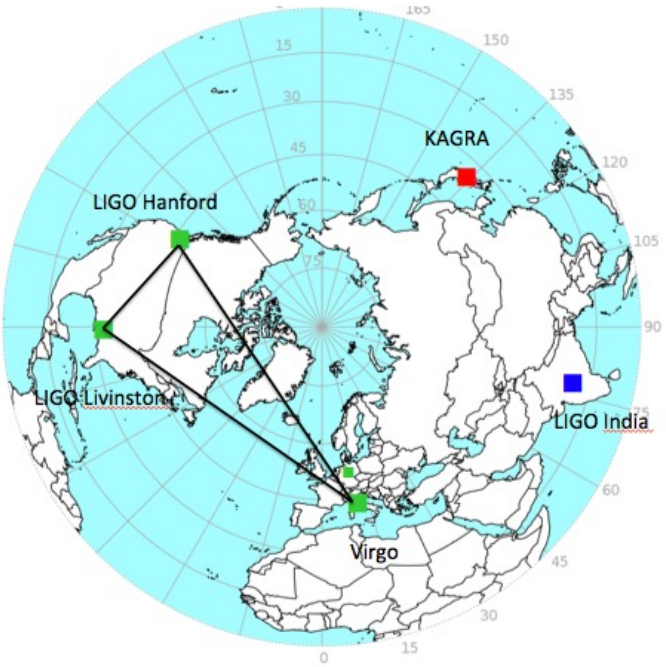
LIGO Hanford



LIGO Livingston



KAGRA

Virgo

Einstein Telescope

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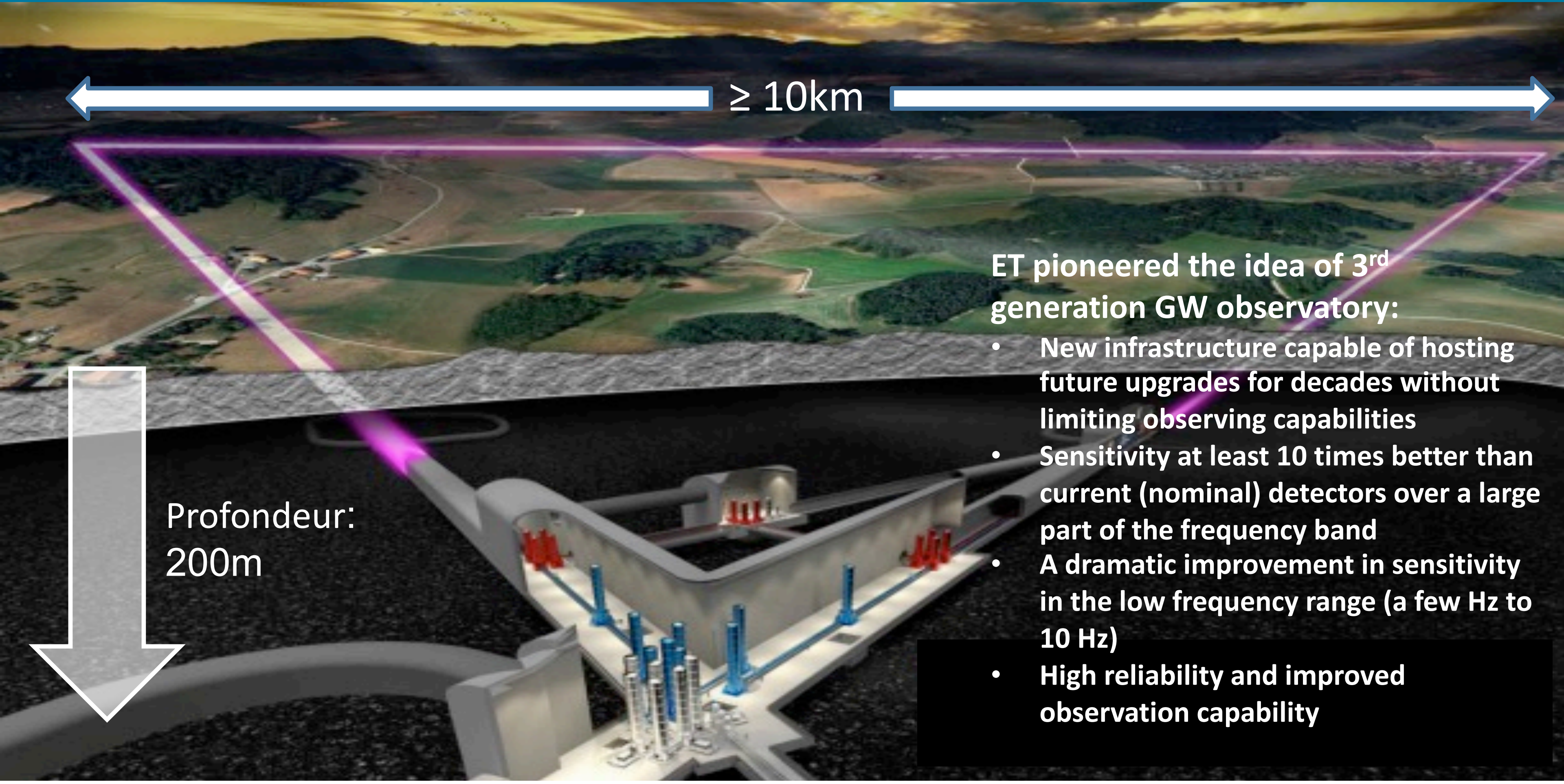


ET pioneered the idea of 3rd generation GW observatory:

- **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 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

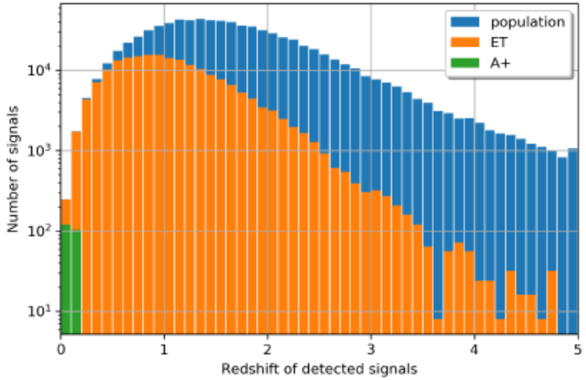
Dark energy and modifications of gravity on cosmological scales
dark energy equation of state,
modified GW propagation

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

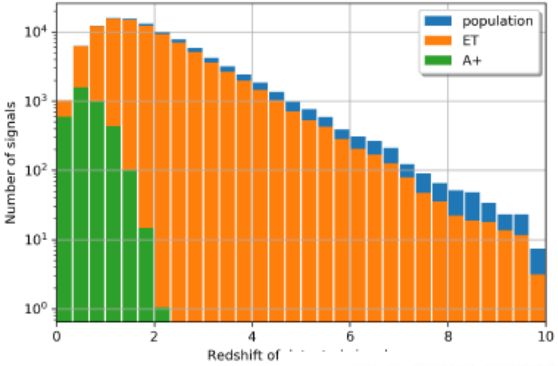
The “unexpected” ?

ET sensitivity

BINARY NEUTRON-STAR MERGERS

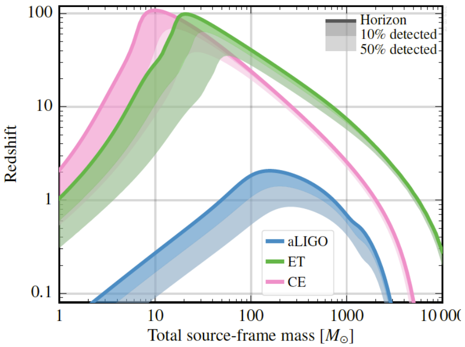


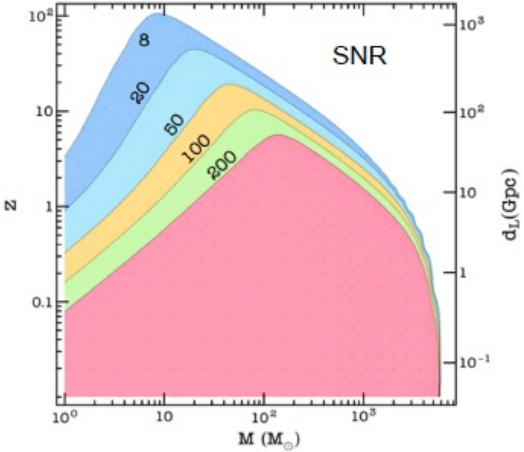
BINARY BLACK-HOLE MERGERS



- 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

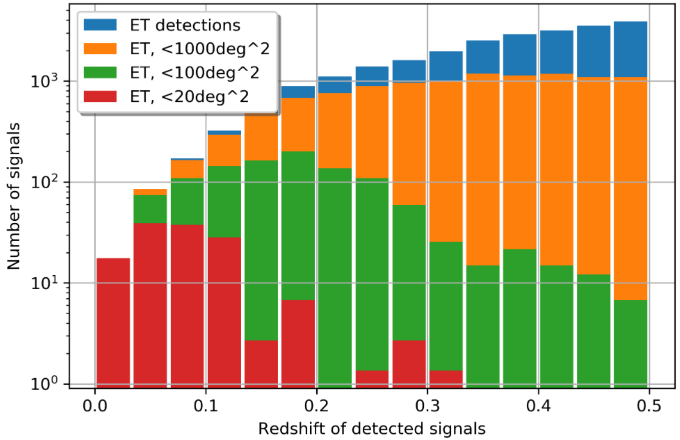
~1 detection every 30s



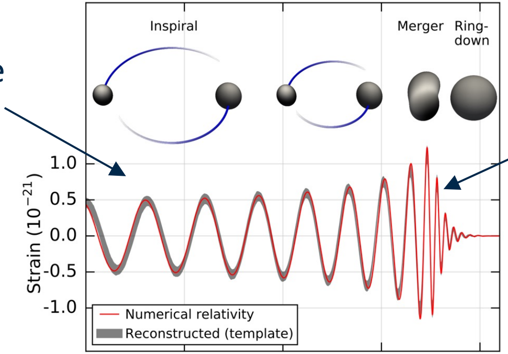


ET sensitivity

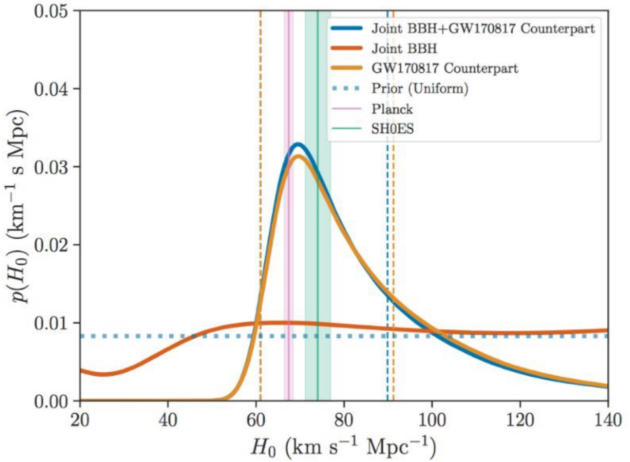
- **BNS detection with EM counterparts and localization precision < 20 deg²** : o(10-100) per year
- Overlap with many BBH signals
- Potentially, very long signals
- ET will be able to provide alerts few hours before the merger



Identify early the inspiral …

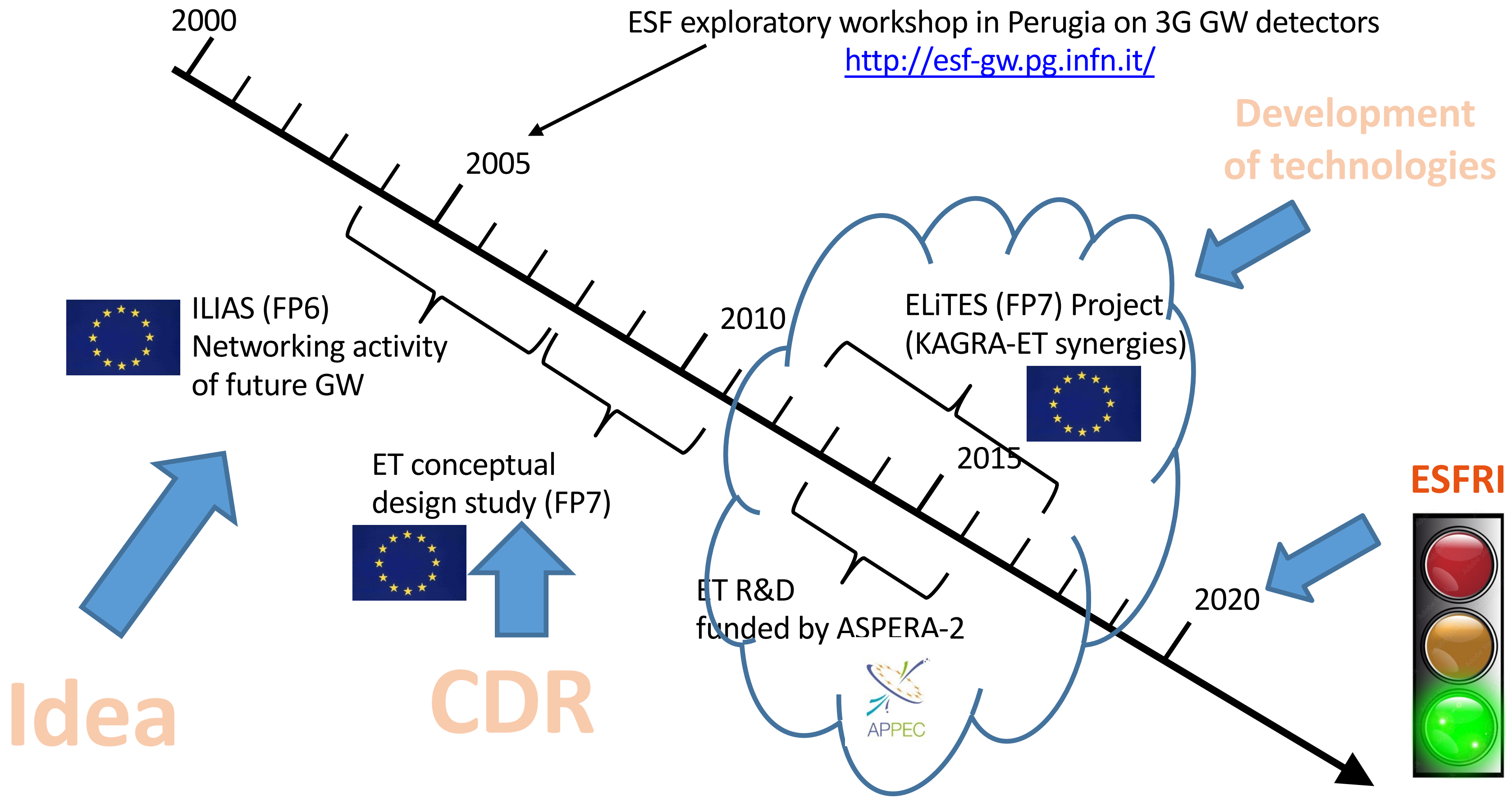


… and provide alert before the merger phase



- 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

ESFRI

Underground infrastructure

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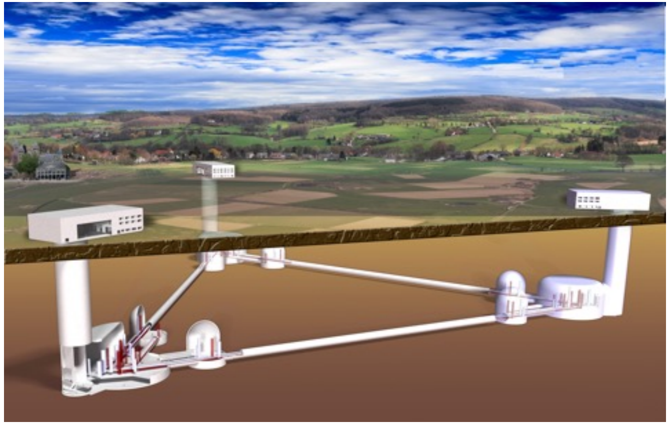
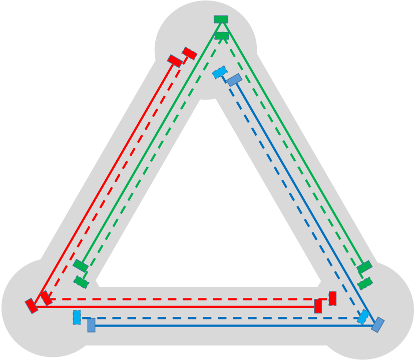
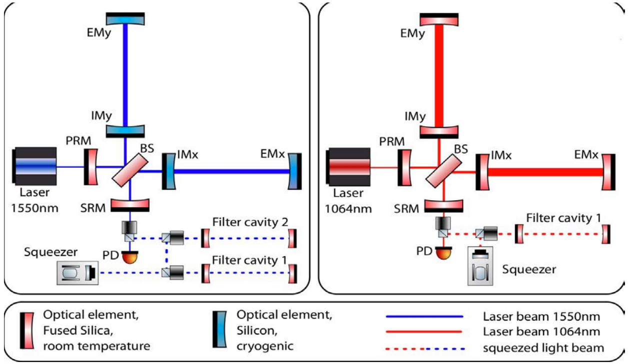


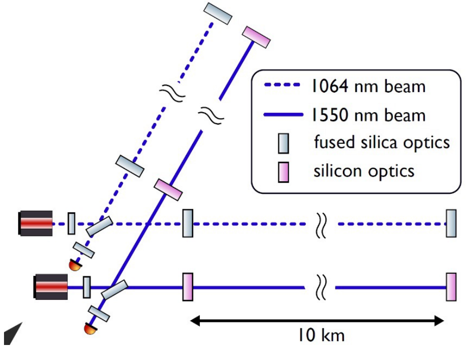




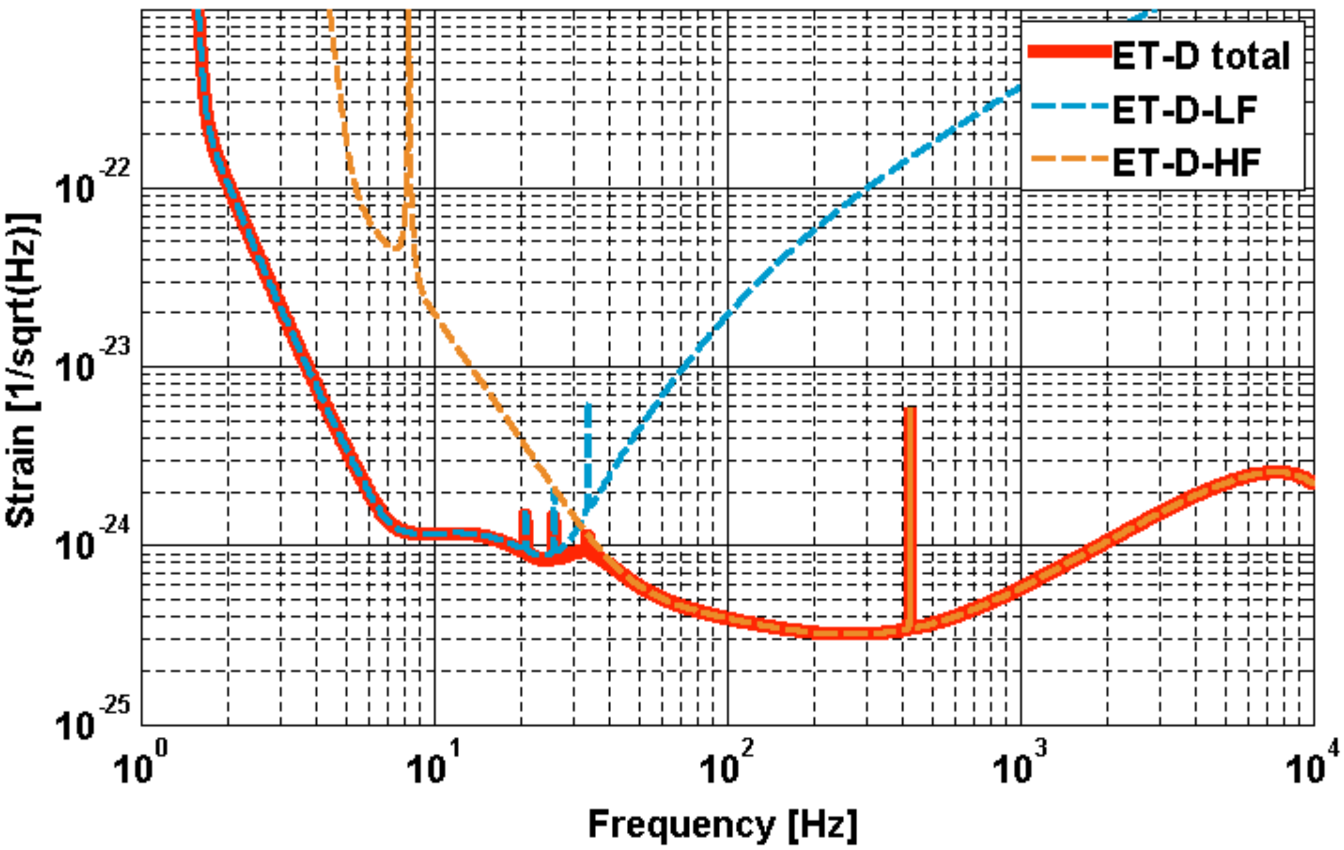
Parameter	ET-HF	ET-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10-20 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	45 cm/ 57 cm
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase (rad)	tuned (0.0)	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)	$5 \cdot 10^{-10}$ m$/f^2$	$5 \cdot 10^{-10}$ 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

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

ET-LF:

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

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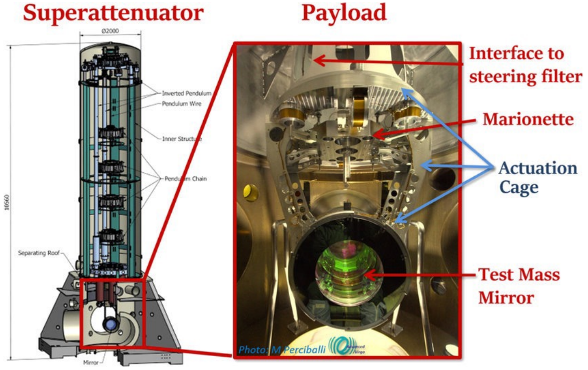
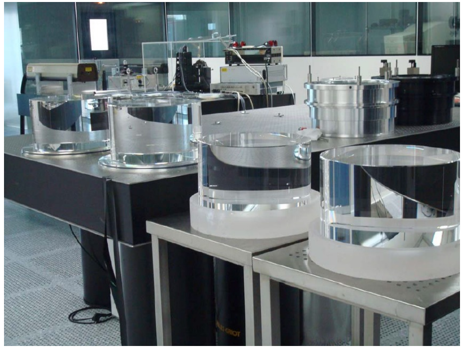
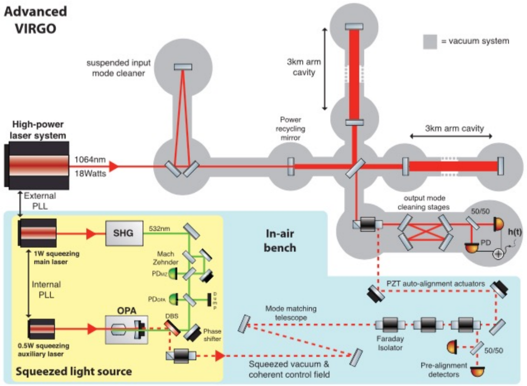
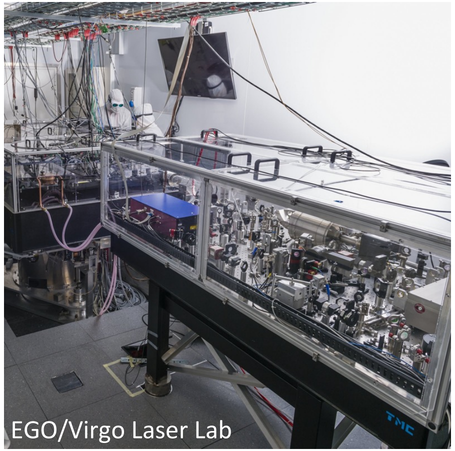
- Extrapolation of current or planned technologies for Virgo and LIGO
  - Squeezing (quantum states of light)
  - High power lasers
  - Bigger mirrors
  - New thin films for mirrors
  - Thermal compensation techniques
  - Seismic suspension systems
- Technologies not tested in Virgo and LIGO (prototypes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

⇒ Implementation of R&D programs








EGO/Virgo Laser Lab

Vacuum pipe system

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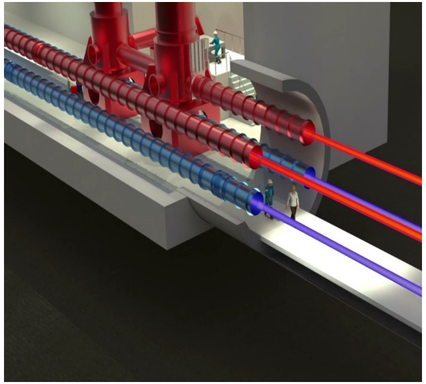
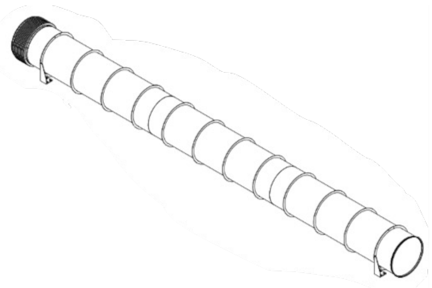
Vacuum systems planned for 3G detectors are likely to be the largest UHV systems built

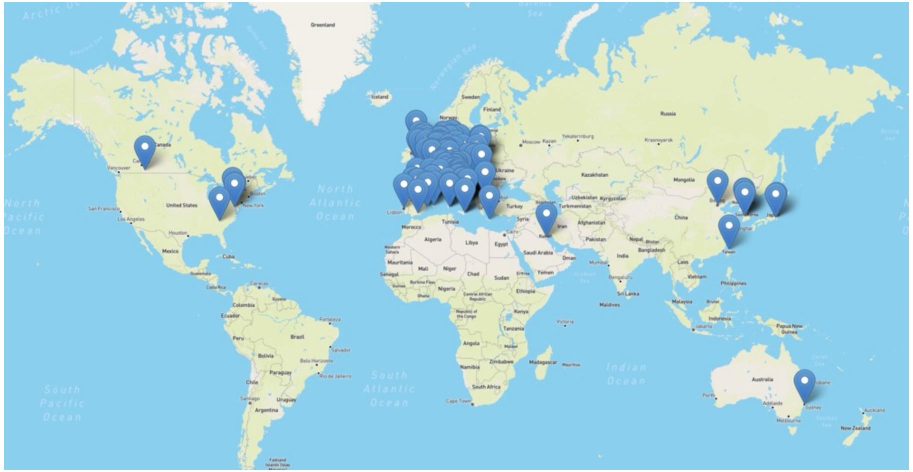
- The beam tube is its most important component (~1/2 of the cost of the system)
- 120 km of UHV tubes of 1 m diameter, total volume ~10^5 m3
- Vacuum requirements: factor > 5 stricter than Virgo:
- 10^{-10} mbar for H2
- 10^{-11} mbar for N2
- < 10^{-14} mbar for hydrocarbons
- Lifespan: 50 years
-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

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





ET Collaboration



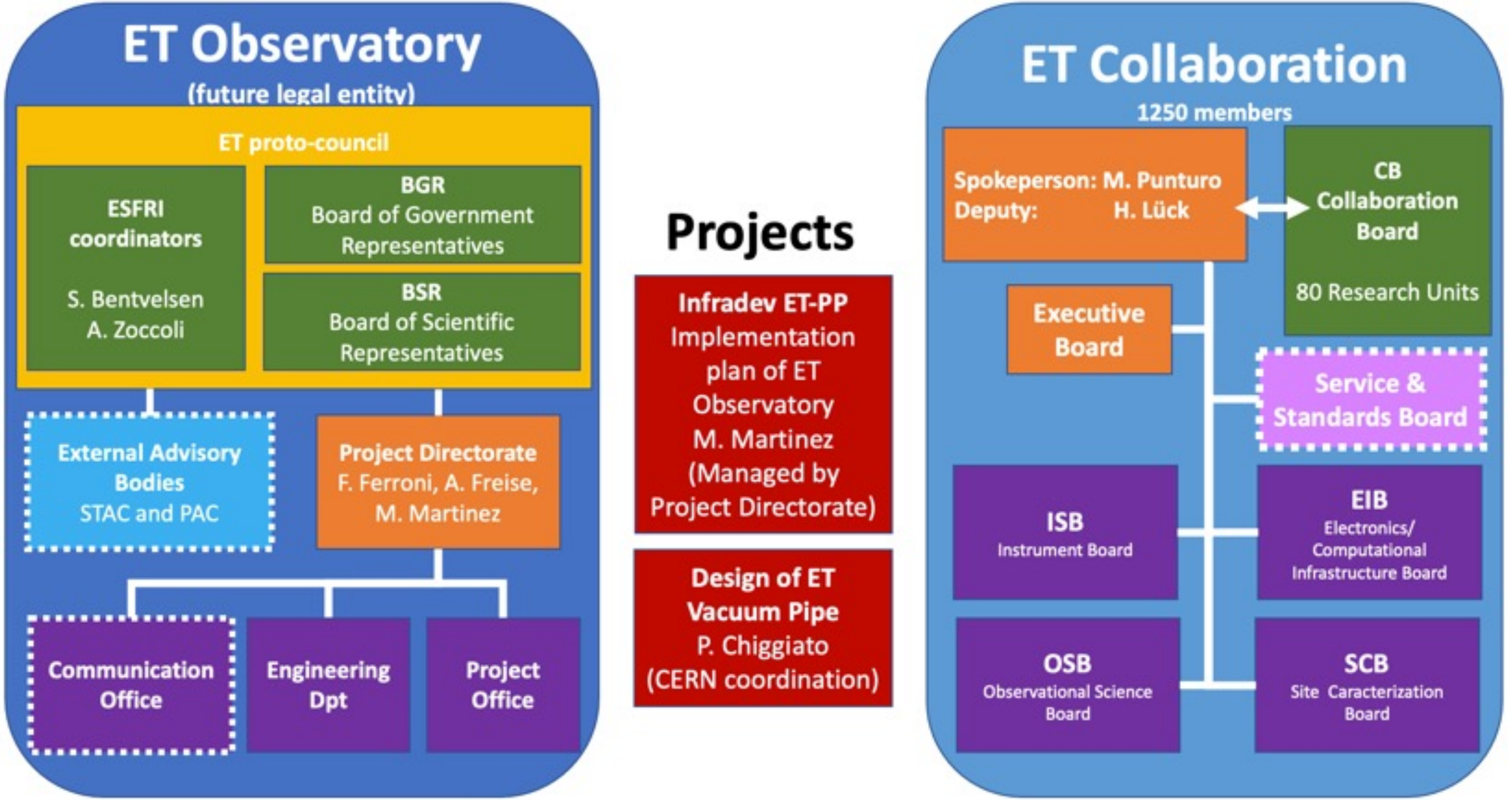
1370 collaborators from 202 institutes in 23 countries worldwide

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

Calendrier Virgo (2G)

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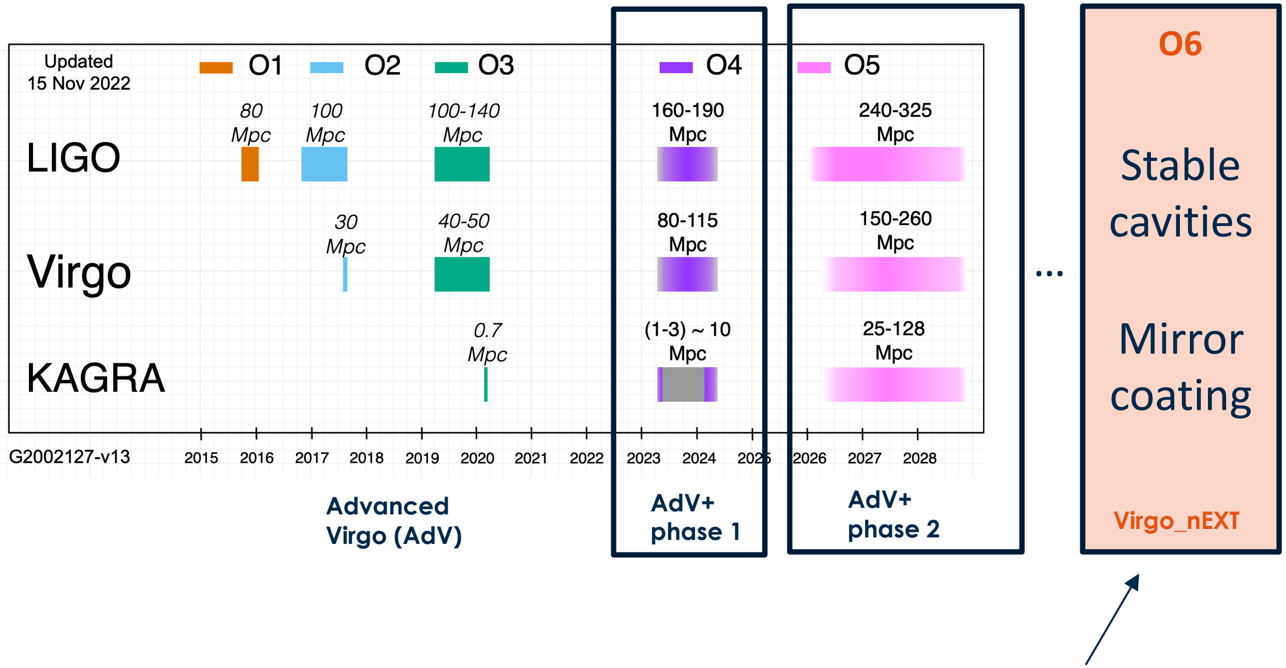

Virgo and LIGO are currently studying post-O5 upgrades, Virgo_nEXT (not yet approved) and A#

KAGRA is also planning major upgrades

Calendrier ET (3G)

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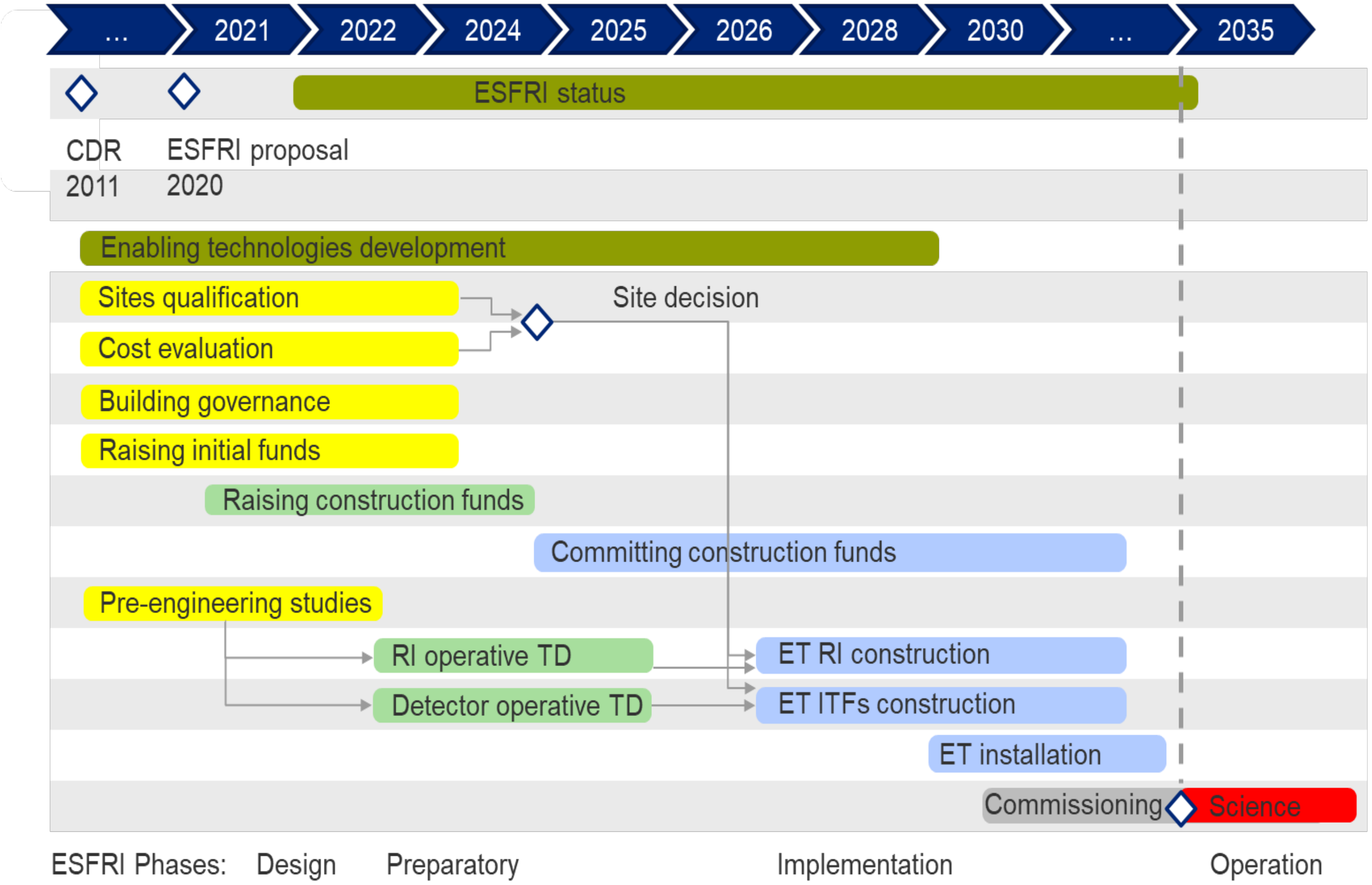
* Tentative schedule



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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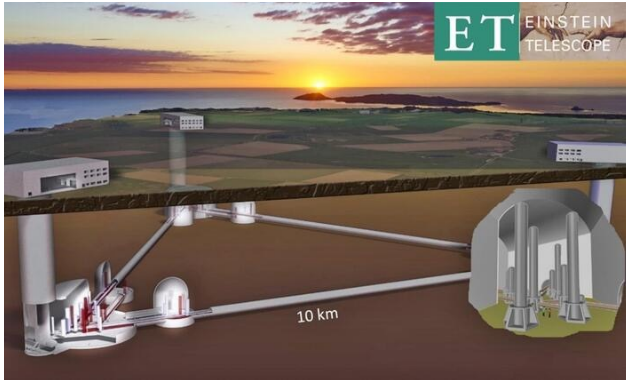
Sardinia – Italy



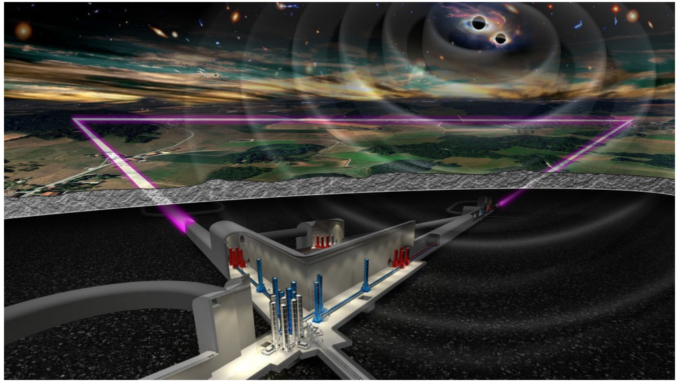
€50 million for R&D and preparatory work

ETIC in Italy

Einstein Telescope Infrastructure Consortium

"Multi-100 M€" financing if ET's site is 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

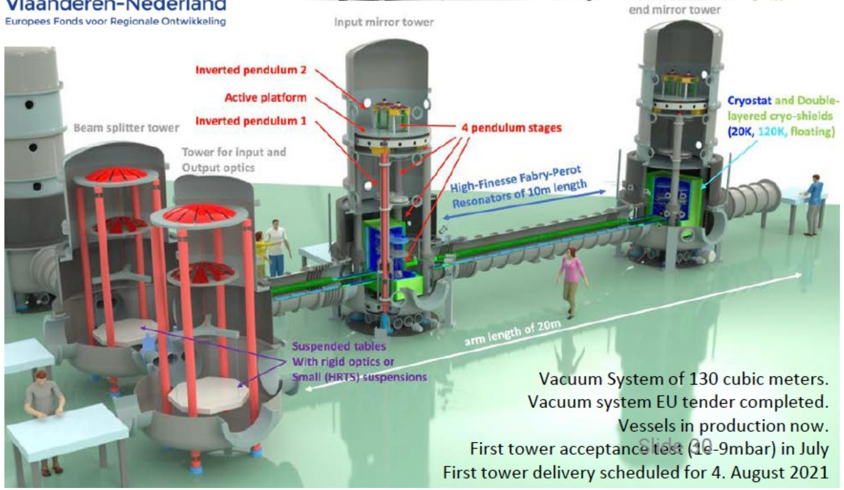
ET-PATHFINDER

- 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

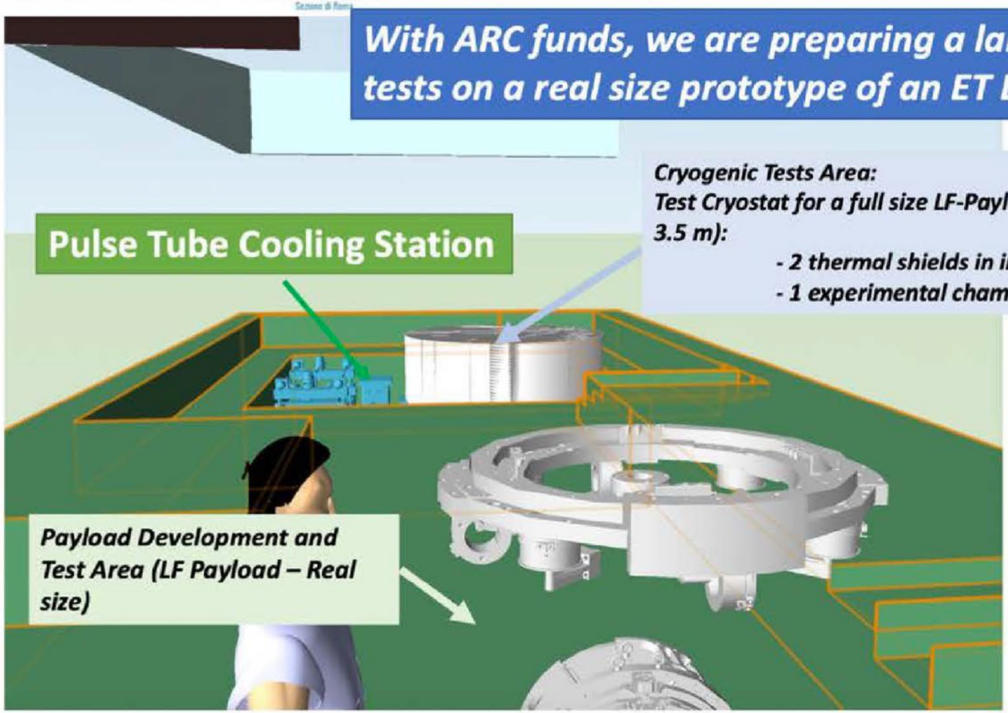
One of the axes of the ETIC project is the development of a cryo lab in Rome

MINISTERO DELL'ISTRUZIONE, DELL'UNIVERSITÀ E DELLA RICERCA

INFN ROMA Istituto Nazionale di Fisica Nucleare

3G Gravitational-Wave Lab

AMALDI RESEARCH CENTER



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:

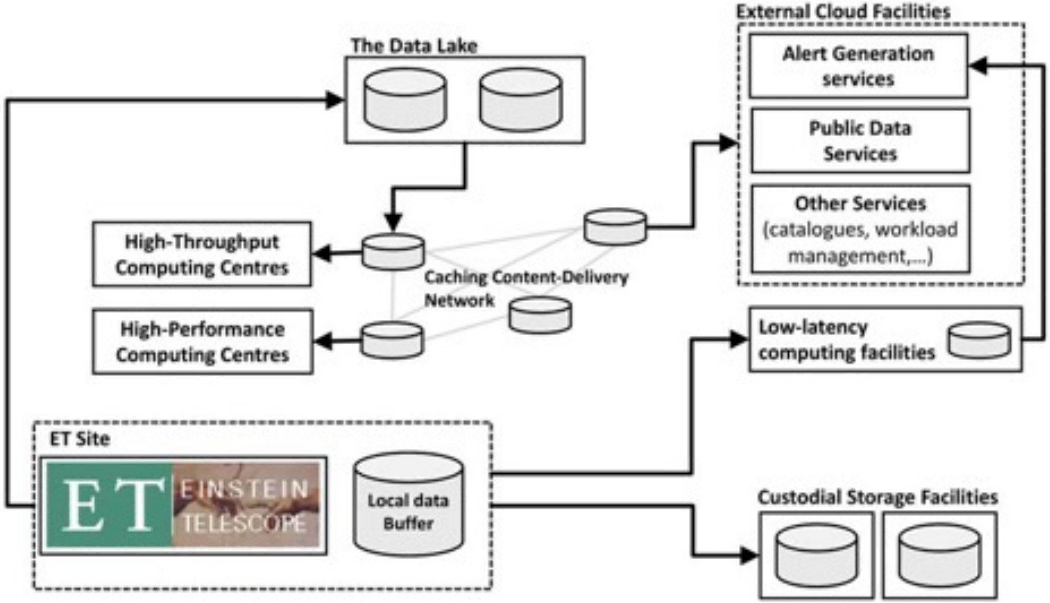
Angelo	Cruciani	(INFN Researcher)
Antonio	D'Addabbo	(Post Doc Researcher LNGS)
Stefano	Pirro	(INFN Researcher)

From EGO:

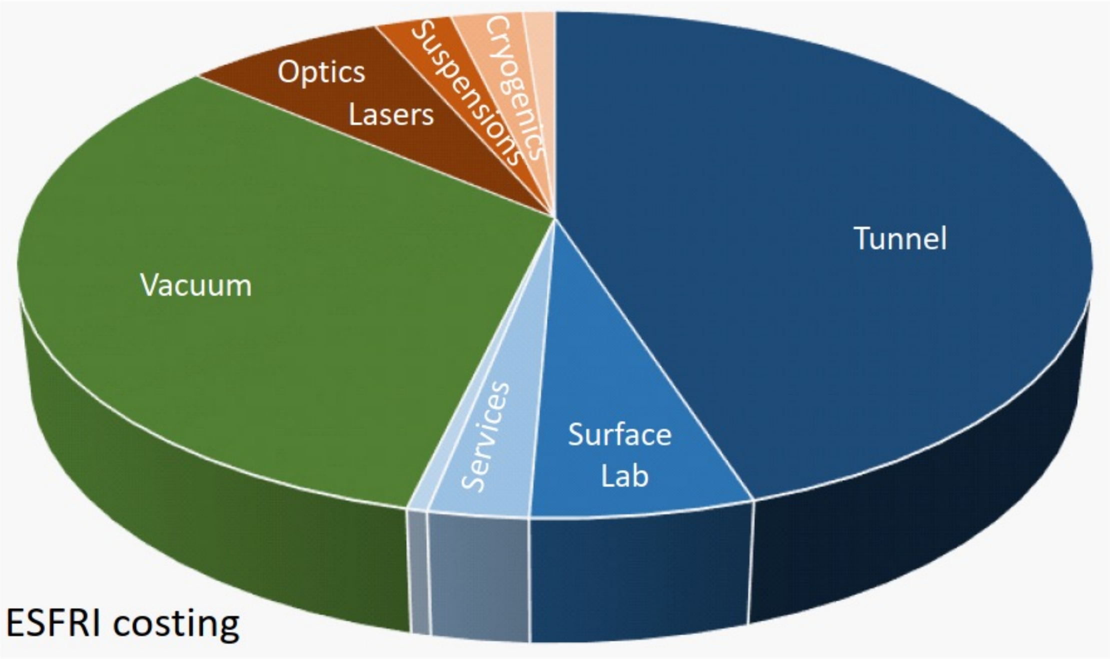
Paolo Ruggi (EGO Researcher)

High Performance Computing and Data

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**



Construction costs



	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€

2021

Conclusion

Einstein Telescope is a very ambitious project which requires:

- An intensive R&D program to develop new technologies
- A large, structured and organized scientific collaboration
- Strong partnerships between academic research and industries

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