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TELESCOPE

WST - the Wide-field Spectroscopic Telescope:
surveying the Universe in the 2040's and beyond

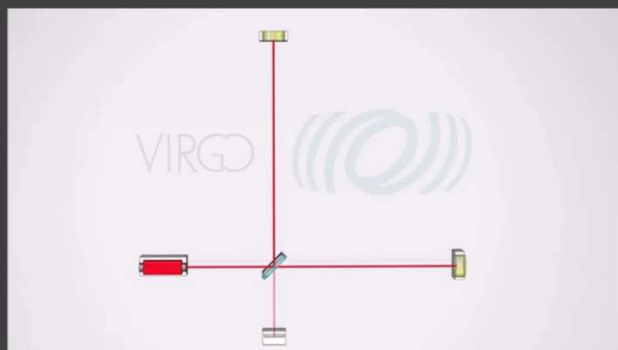
Einstein Telescope: the next generation European Gravitational Wave observatory

Michele Punturo
INFN, spokesperson ET collaboration



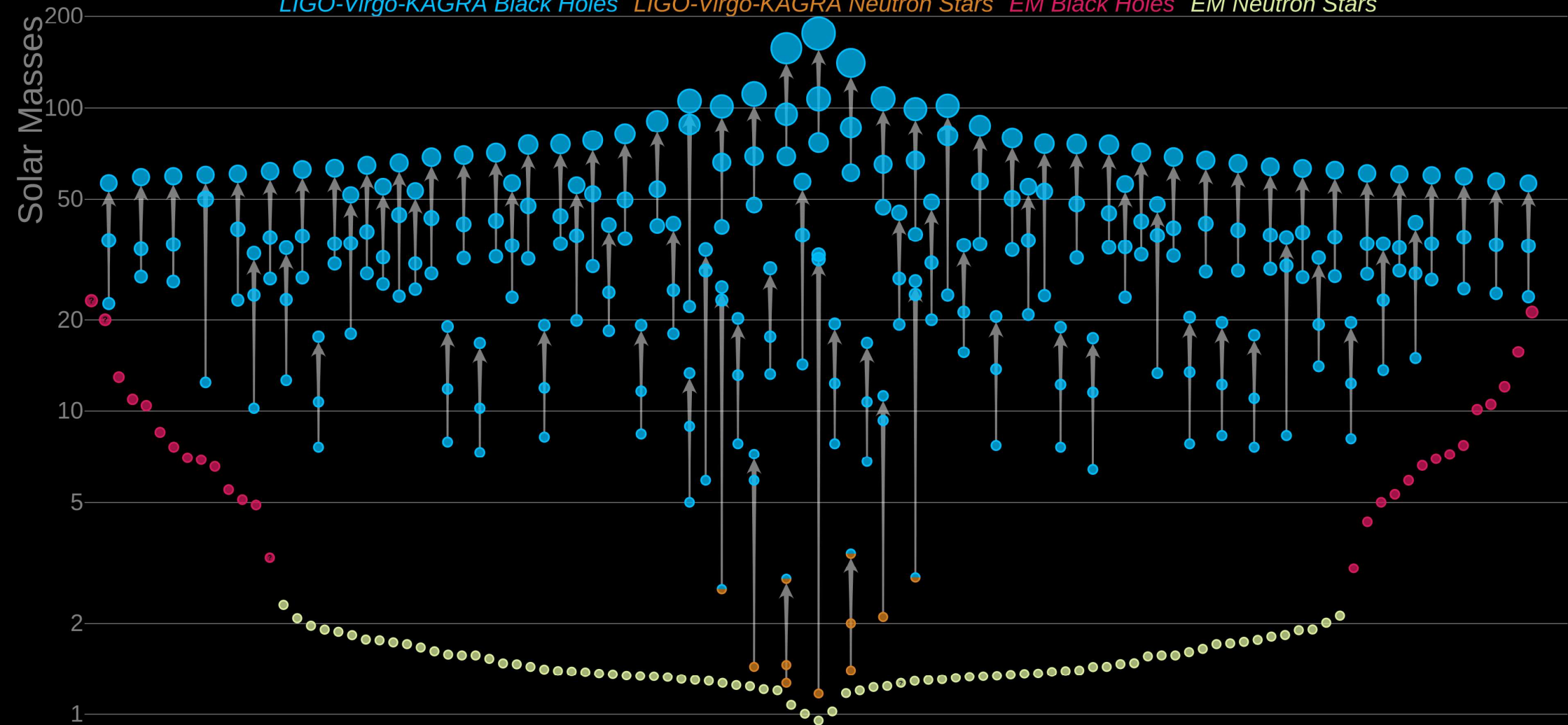


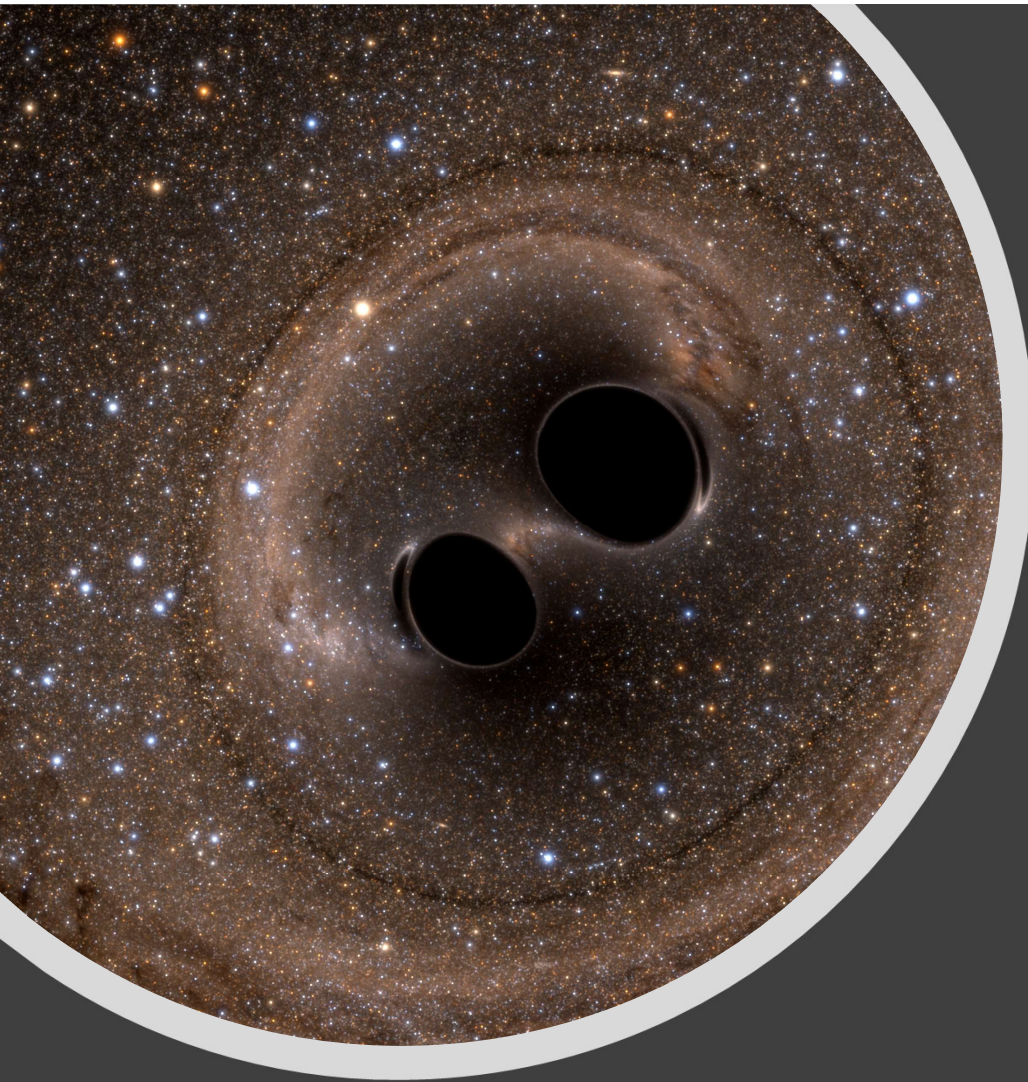
Current GW detectors



Masses in the Stellar Graveyard

LIGO-Virgo-KAGRA Black Holes *LIGO-Virgo-KAGRA Neutron Stars* *EM Black Holes* *EM Neutron Stars*



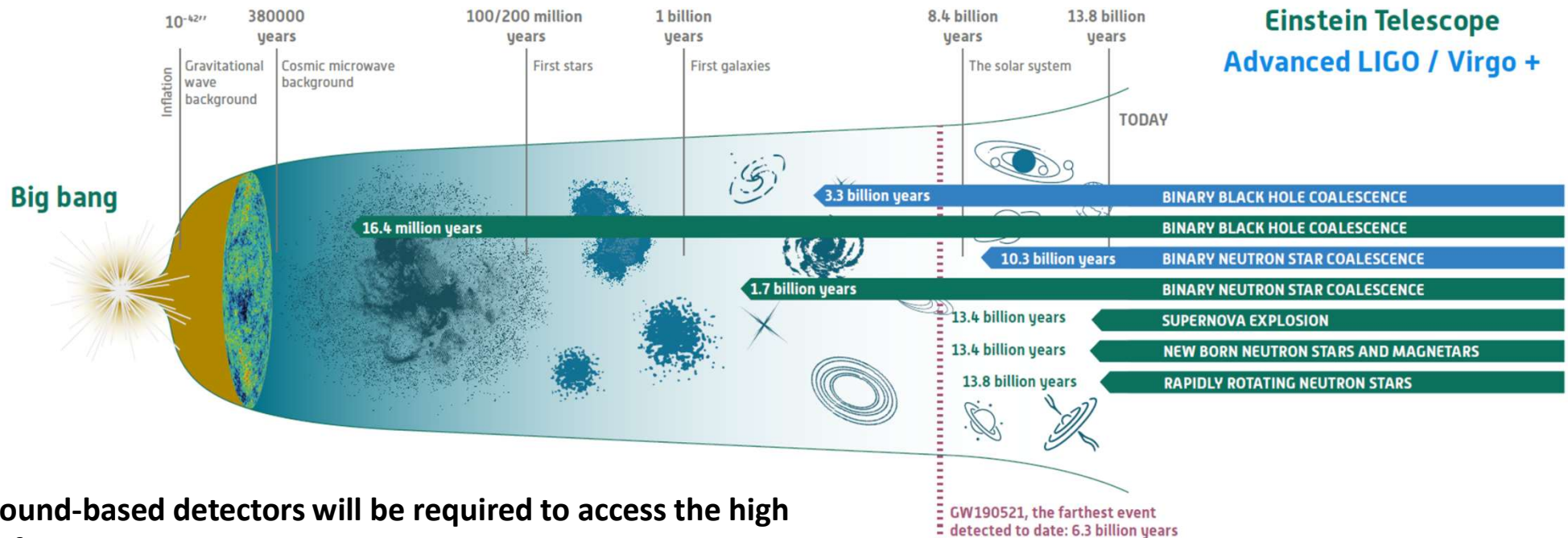


Monumental successes of the Advanced detectors

- First detection of GWs from a BBH system (GW150914)
 - Physics of BHs
- First detection of GWs from a BNS system (GW170817)
 - Birth of the multimessenger astronomy with GWs
 - Constraining EOS of NS
- Localisation capabilities of a GW source
- Measurement of the GW propagation speed
- Test of GR
- Alternative measurement of H_0
- GW polarisations
- Intermediate mass black hole (GW190521)

Exploring the deep Universe

- aLIGO and AdV achieved awesome results with a sensitivity poorer than the nominal one
- When they will reach or over-perform their nominal (updated) sensitivity, can we exploit all the potential of GW observations?
- 2nd generation GW detectors will explore the local Universe, even in their post-O5 configuration, initiating precision GW astronomy, but to have cosmological investigations a factor of 10 improvement in terms detection distance is needed



3G ground-based detectors will be required to access the high redshift Universe

Einstein Telescope (ET)

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$\geq 10\text{km}$

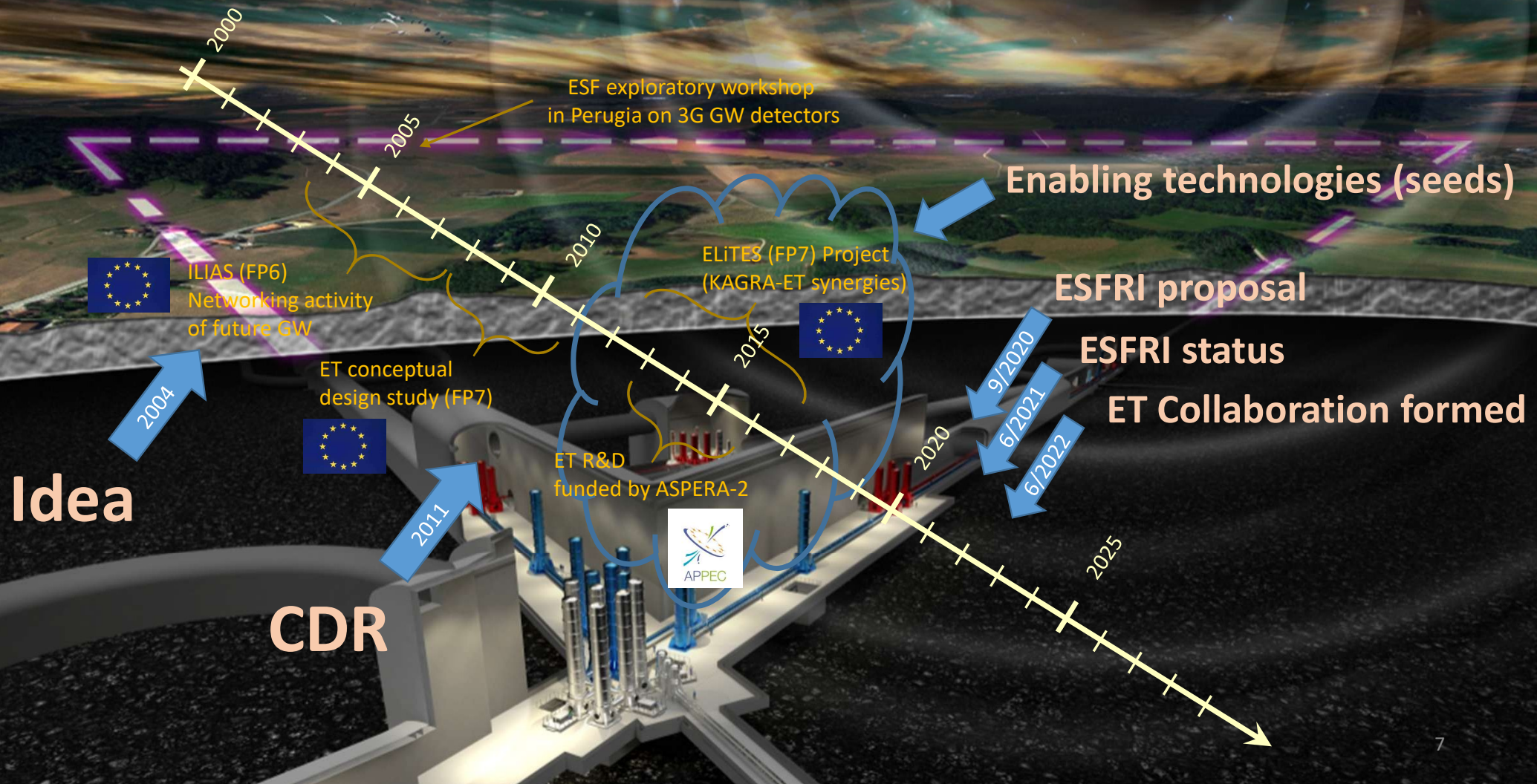
Corner halls
depth about
200m

ET pioneered (2004+) the idea of a 3rd generation GW observatory:

- A new infrastructure capable to host future upgrades for decades without limiting the observation capabilities
- A sensitivity at least 10 times better than the (nominal) advanced detectors on a large fraction of the (detection) frequency band
- **A dramatic improvement in sensitivity in the low frequency (few Hz – 10Hz) range**
- **High reliability** and improved observation capability
- **Polarisation disentanglement**

ET: a long path

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ET Observational Science in a nutshell



ASTROPHYSICS

- **Black hole properties**
 - origin (stellar vs. primordial)
 - evolution, demography
- **Neutron star properties**
 - interior structure (QCD at ultra-high densities, exotic states of 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
 - 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
- **Tests of General Relativity**
 - post-Newtonian expansion
 - strong field regime
- **Dark matter**
 - primordial BHs
 - axion clouds, 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

See Marica's talk

ET primary science target: low frequency

- One of the primary science targets of ET is to access the 1-10Hz frequency range
 - Intermediate mass black holes
 - Fill the gap between the stellar mass black holes (à la LIGO/Virgo) and the supermassive black holes (à la LISA)
 - Cosmology
 - high red-shift \rightarrow low frequency
 - Primordial BH and the Dark Matter quest
- Early warning in multimessenger astronomy with GW emitted by BNS

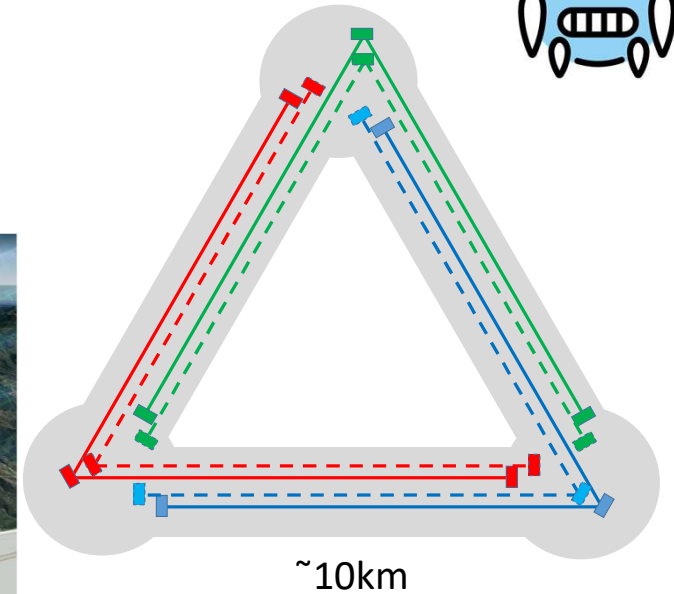
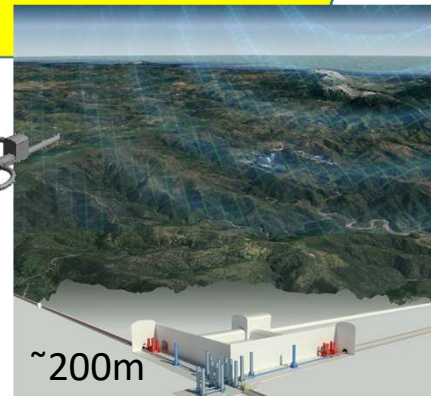
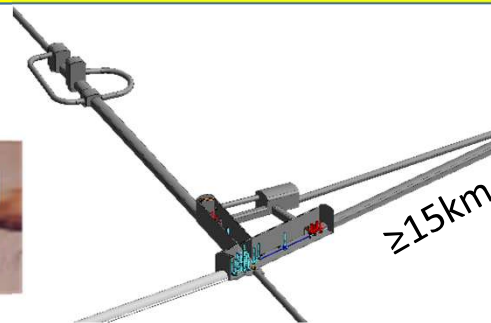
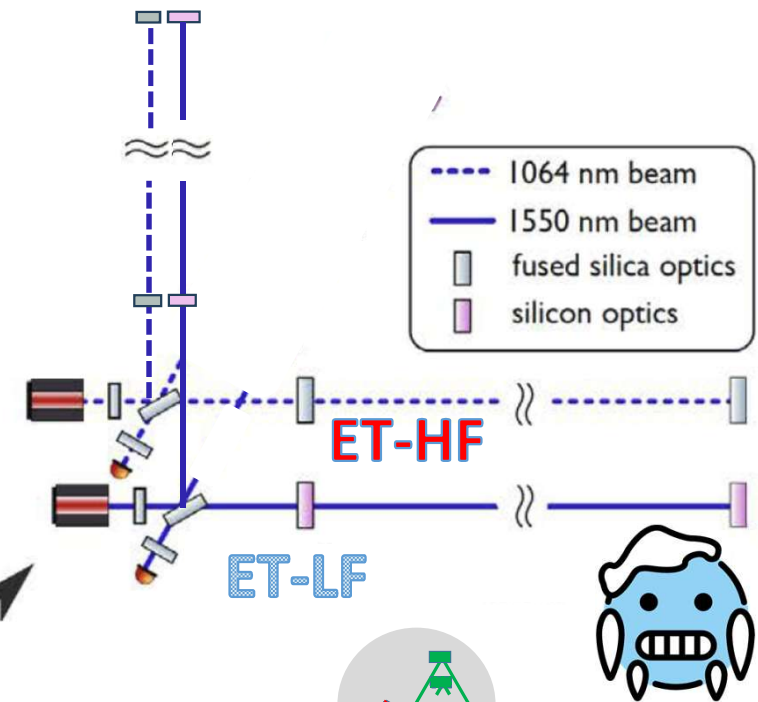
ET key elements

Requirements

- Wide frequency range
- Massive black holes (LF focus)
- Localisation capability
- (more) Uniform sky coverage
- Polarisation disentanglement
- High Reliability (high duty cycle)
- High SNR

Design Specifications

- Xylophone (multi-interferometer) Design
- Underground
- Cryogenic
- Triangular shape (2011)
- Multi-detector design
- Longer arms



Underground location

Pro

- Access to the low frequency:
 - 2-10Hz for ET
 - Reduction of the seismic and Newtonian Noise
 - Suppression of the atmospheric Newtonian Noise and of the wind impact
 - Reduction of the anthropogenic noise
 - Magnetic
 - Acoustic
 - Vibration
- Easier compatibility with the urbanization of the hosting region
 - Europe is generally a strongly urbanized continent
- Landscape impact

Cons

- Cost
- Challenging civil engineering
- Time needed to build it
- Limited possibility to upgrade the civil infrastructure in a medium-long term timeline
- More difficult operating environment in all the observatory phases (construction, integration, commissioning, maintenance and upgrade)

Michele Punturo

Image: St. Patrick's well, Orvieto, Italy,¹¹1537

ET geometry debate: Δ or (two) L

In the last two of years, the collaboration started the evaluation of the best configuration for ET, considering the alternative of two L configuration (as LIGO, Cosmic Explorer) to maximize the science return and reduce risks.

Since 2011 (CDS, triangle configuration) the situation drastically changed:

- ❑ First detections, GTWC-3 catalog \rightarrow BH population \rightarrow new evolution models;
- ❑ Science case developed;
- ❑ Know-how with advanced (L) detectors;
- ❑ International scenario (+ Cosmic Explorer in US);
- ❑ Two candidate sites strongly supported (and a potential third site...).



The collaboration is analyzing both configurations: **optimizing science return, differential risk assessment.**

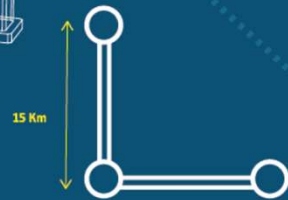
First results on the science return published in Marica Branchesi et al JCAP07(2023)068:

The 2L 15 km geometry shows an improved science return in a relevant number of science targets

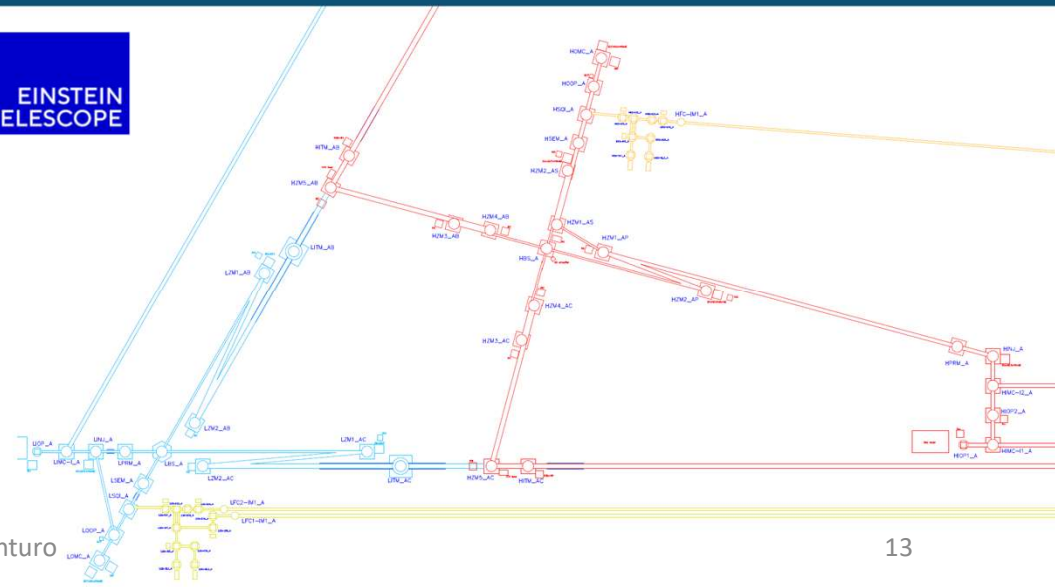
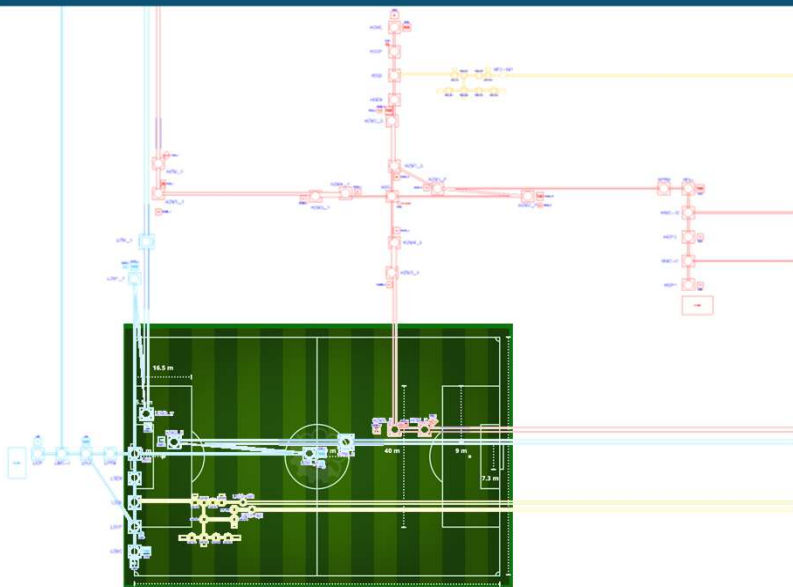
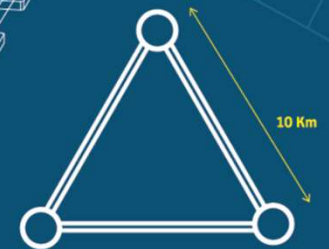
A preliminary differential risk analysis, provided by a specific committee, shown that for integration, commissioning, data taking and upgrade activities, the L geometry has a lower risk level

Duplicate the effort

«L» geometry



Δ geometry



Michele Punturo

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 Enabling Technologies

- 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

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)	$5 \cdot 10^{-10} \text{ m}/f^2$	$5 \cdot 10^{-10} \text{ m}/f^2$
Gravity gradient subtraction	none	factor of a few

• ET-HF:

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

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INFN
Istituto Nazionale di Fisica Nucleare

Evolved laser technology

Evolved technology in optics

Highly innovative adaptive optics

High quality opto-electronics and new controls

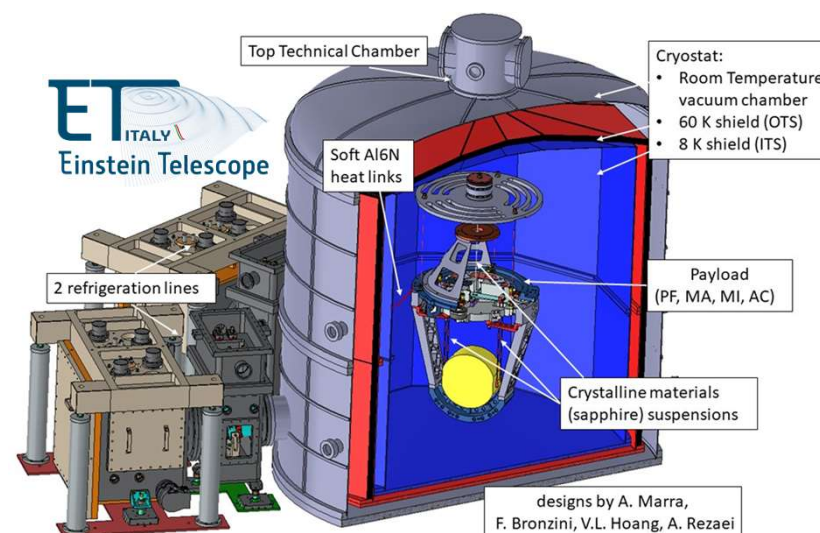
Challenges in Cryo-cooling

ET operative temperature $\sim 10\text{K}$

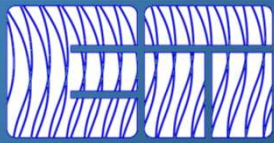
Key issues

- Acoustic and vibration noises
- Laser absorption and heat extraction
- Cleanliness and contamination
- Cooling time (large masses, commissioning time, ...)
- Infrastructures
- Technology (cryo-fluids or cryo-coolers)
- Materials
- Safety

Michele Punturo



Amaldi Research Center in Rome



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Low Frequency special focus

- Low noise site
- Underground infrastructure
- 17m tall seismic filtering suspensions
 - Large impact on cavern engineering and costs

R&D in active-passive filtering systems and seismic sensors

Credits: A. Freise

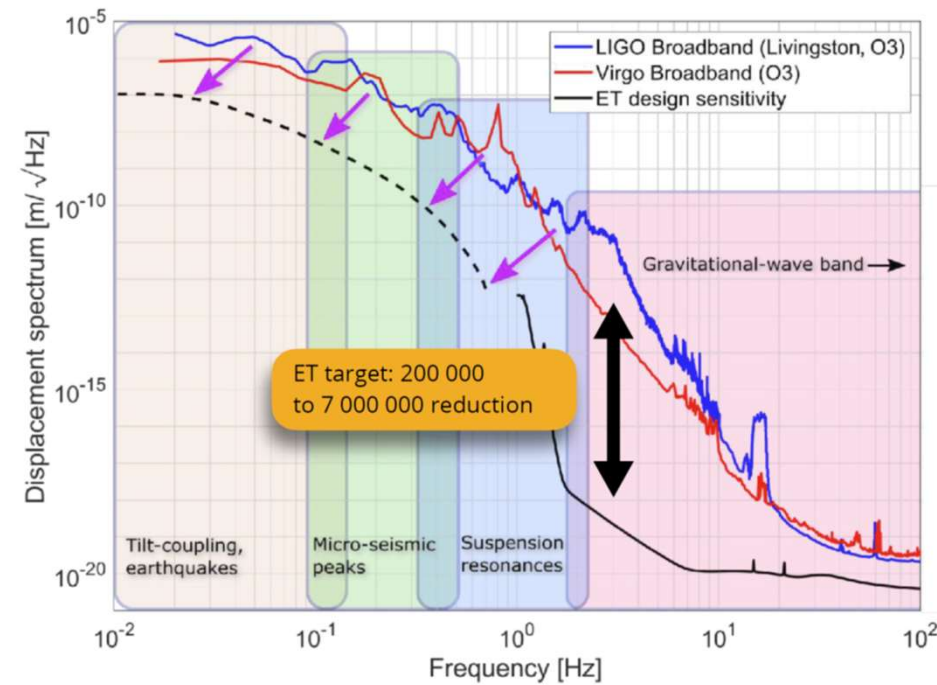
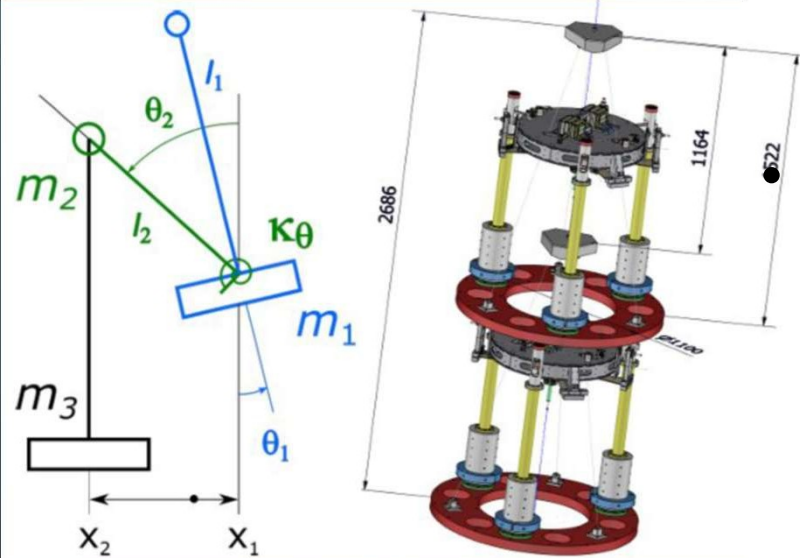


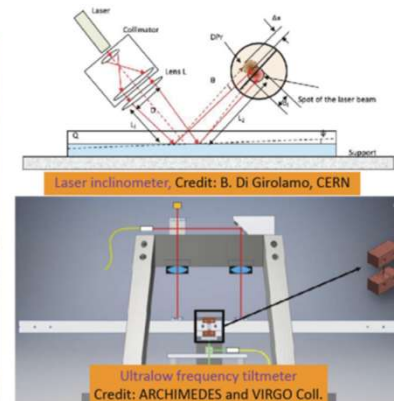
Image: Conor Mow-Lowry



6-D interferometric readout inertial sensor
Credit: Conor Mow-Lowry, VU Amsterdam



Low frequency seismometers
Credit: Christophe Collette, U. Liege



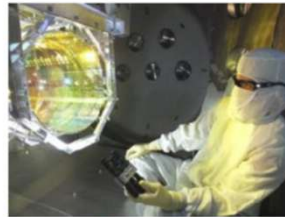
Laser inclinometer, Credit: B. Di Girolamo, CERN
Ultralow frequency tiltmeter
Credit: ARCHIMEDES and VIRGO Coll.

New Optics

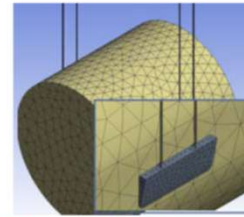
Credits: A.Freise

Absorption of "best 45 cm" MCZ Si: 1.5 μ m

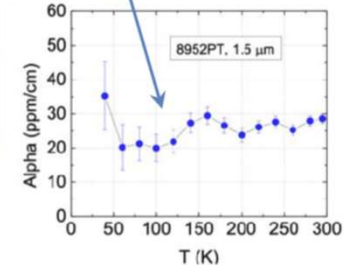
Stanford/Glasgow/Berkeley/Caltech 2019



Advanced LIGO – 40 kg / ET 200 kg



Nikon SiO₂



• Substrates Challenge:

- Substrate (ET-HF silica / ET-LF silicon) of 200 kg-scale, diam \geq 45cm, with required purity and optical homogeneity/abs.
- Silicon Challenge:
 - Czochralski (CZ) method produced test masses could have the required size, but show absorption excesses due to the (crucible) contaminants
 - Float Zone (FZ) produced samples show the required purity, but of reduced size (20cm wrt \geq 45cm required)
 - Magnetic Czochralski (mCZ) could be the possible solution?

• Coating Challenge:

- major challenge over recent years:
 - Amorphous dielectric coating solutions often either satisfy thermal noise requirement (3.2 times better than the current coatings) **or** optical performance requirement (less than 0.5ppm) – not both
 - AlGaAs Crystalline coatings could satisfy ET-LF requirements, but currently limited to 200mm diameter.

Other relevant challenges

- Auxiliary optics, adaptive optics and thermal compensation of optical aberrations
- Precision mechanics, alignment and positioning
- **Vacuum** (*the largest volume under UHV in the World*):
 - More than 120km of vacuum pipes
 - ~1 m diameter, total volume $9.4 \times 10^4 \text{ m}^3$
 - 5×10^{-11} mbar for H_2 , 5×10^{-12} mbar for N_2 , 10^{-11} for H_2O and less than 10^{-14} mbar for Hydrocarbons
 - Lifetime 50 years
 - Cost
 - Joint development with CERN involving ET and CE
- Low noise controls
- Computing
 - Computation intensive, not data intensive
- **Governance & Organisation**


Vacuum
pipe →
CERN

Vacuum
towers →
EGO

<https://cerncourier.com/a/cern-shares-beampipe-know-how-for-gravitational-wave-observatories>

BEAMPIPES FOR GRAVITATIONAL WAVE TELESCOPES 2023

Beampipe know-how for GW observatories

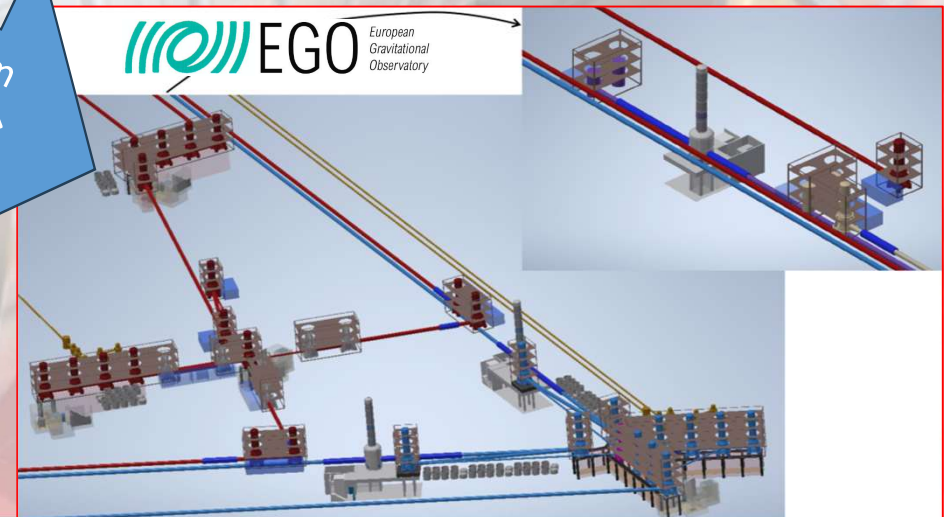


The direct detection of gravitational waves (GWs) in 2015 opened a new window into the universe, allowing researchers to explore the merging data from the currently four gravitational wave detectors (GWTs) in operation: LIGO in the US, Virgo in Italy, KAGRA in Japan and GEO600 in Germany. Operations are ongoing to build a fifth detector, the Einstein Telescope (ET), based on Michelson interferometry with Fabry–Perot cavities, which reveals the expansion and contraction of space at the level of ten-thousandths of the size of an atomic nucleus, i.e. 10^{-18} m. Despite the extremely low strain that needs to be detected, an average of one GW is measured per week of measurement by studying and

Beam me up
The participants of the March workshop that was dedicated to vacuum technologies for beam-pipes of

solutions were adopted, then the vacuum pipe system would amount to half the estimated cost of the CE and almost one-third of the ET, with underground civil engineering the dominant amount. Reducing the cost of vacuum systems requires the development of different

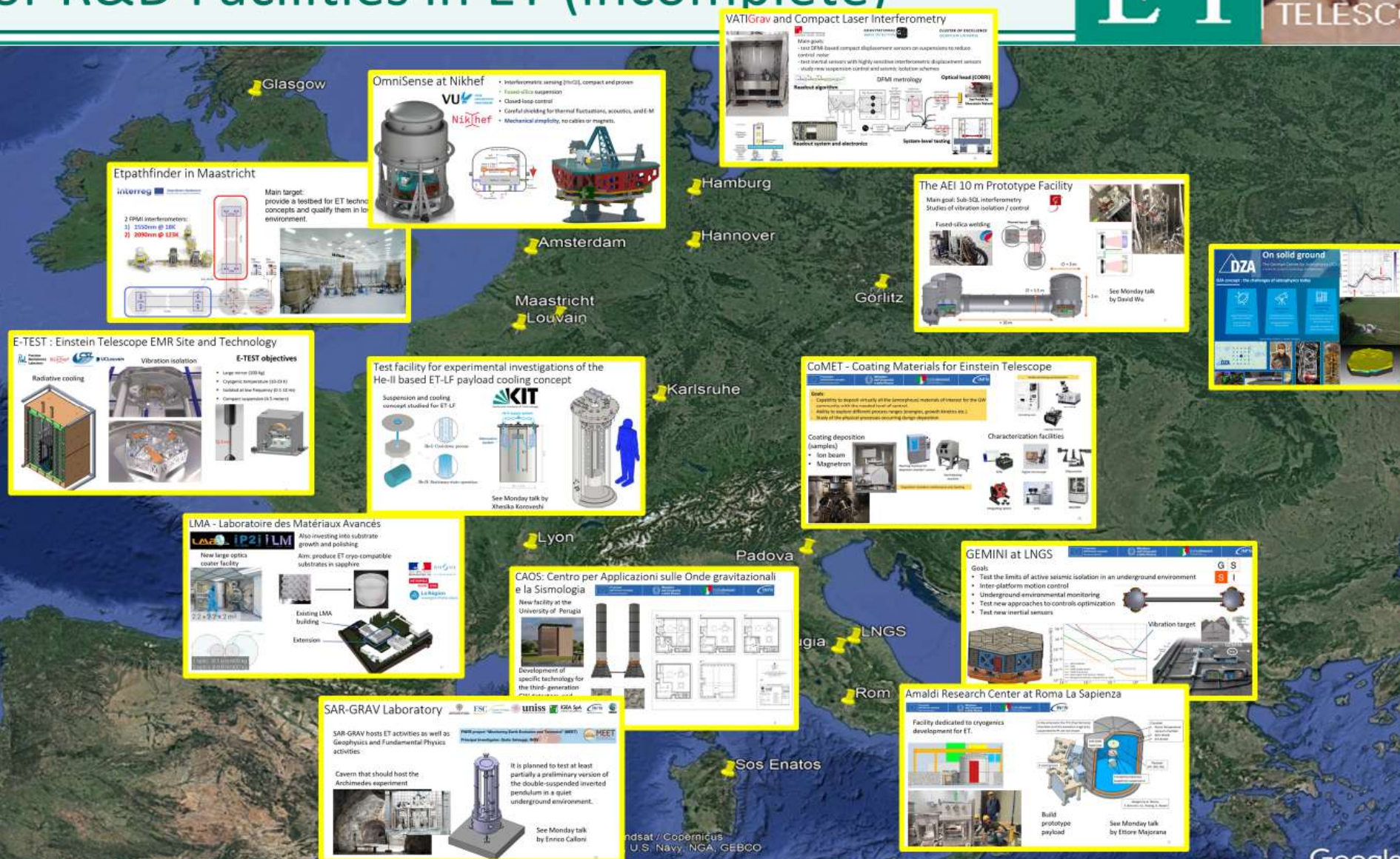
vacuum systems provided a starting point for the presentations of ongoing developments. To conduct an effective cost analysis and reduction, the entire process must be taken into account – including raw-material production and treatment, manufacturing, surface treatment, logic

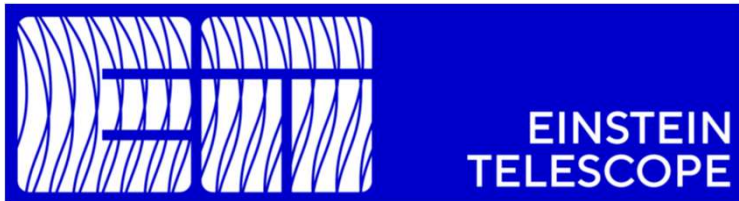


Major R&D Facilities in ET (incomplete)

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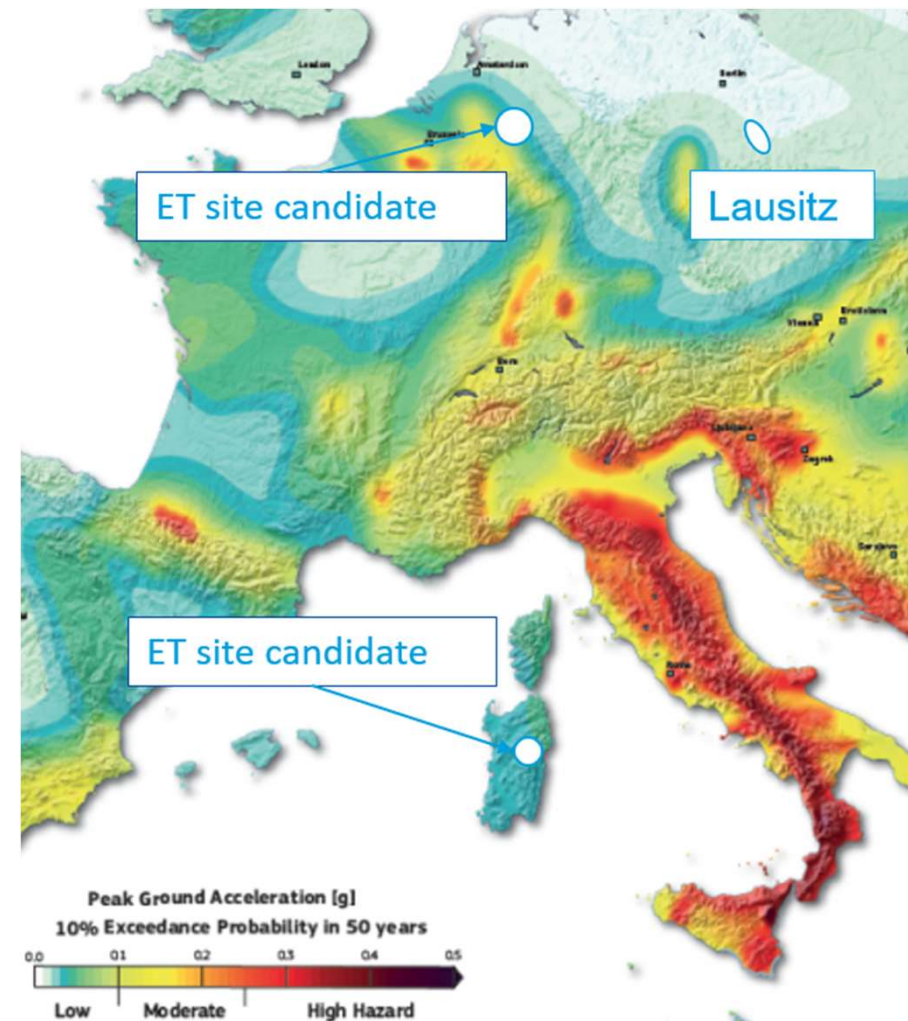
From the XIII ET symposium, an incomplete selection of the presented large facilities



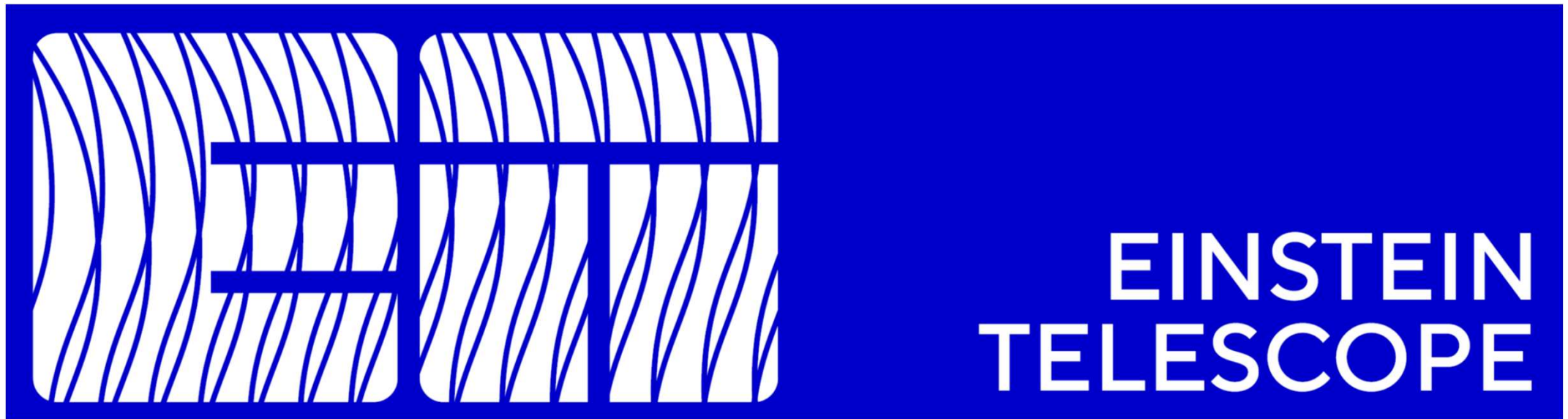


- Two sites formally candidate to host ET:
 - EMR EUregio, border region between Nederland, Belgium and Germany
 - Sardinia (Lula area, Barbagia)
- A third potential site, located in Saxony (Lausitz), is now proposed
- Overall site evaluation is a complex task depending on:
 - Geophysical and environmental quality
 - Financial and organization aspects
 - Services, infrastructures

ET candidate sites



ET framework



The ET framework



ETO: ET Organization

ET Proto-Council

ESFRI
Coordinators

J. D'Hondt
A. Zoccoli

BGR

Board of Government Representatives

BSR

Board of Scientific Representatives

External
Advisory Bodies

ET Project Directorate
A.Freise, F.Ferroni
M. Martinez

Admin. Offices
Communic.
Off.

Eng. Dept

Project Off.

ET Collaboration



Spokesperson: M. Punturo
Deputy: H.Lück

CB
Collaboration Board
Chair E. Coccia

BGR Composition:
Members: Italy, The Netherlands, Belgium, Spain,
Poland, France, Croatia, Greece, UK
Observers: Germany, Austria

Observational
Science Board

Site Preparation/
Characterization

National Host Teams

EMR 
Host Team

Private companies

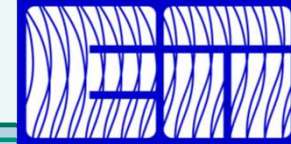
Sardinia TETI 
Host Team

Private companies

Saxony
Host Team

Private companies

The Einstein Telescope Collaboration



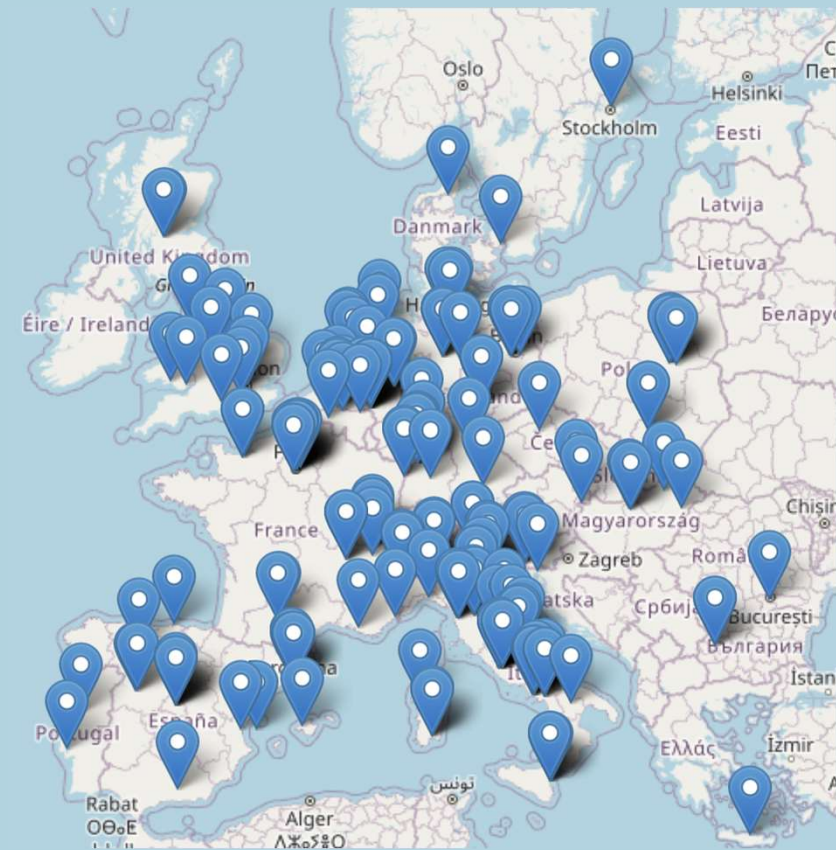
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- 92 Research Units
- 1780 members (08/03/2025)
- Total: 260 Institutions
in 31 Countries

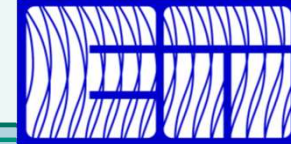
- ET member database



ET Member's affiliation map



The Einstein Telescope Collaboration

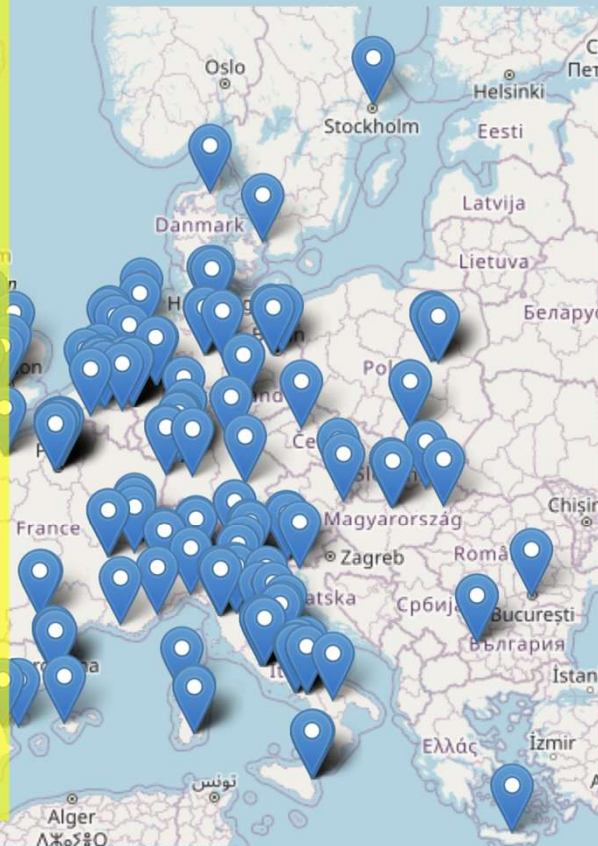
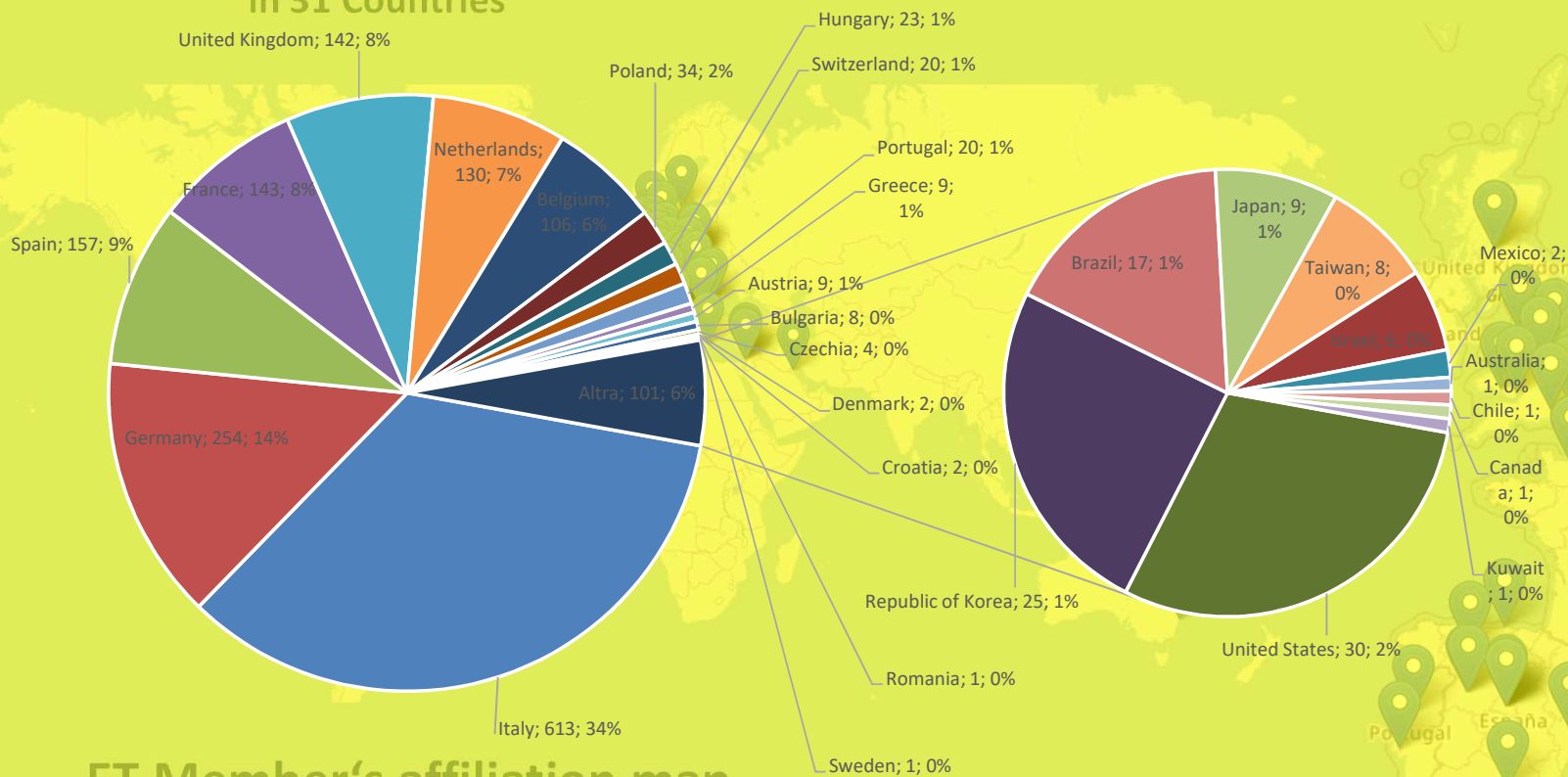


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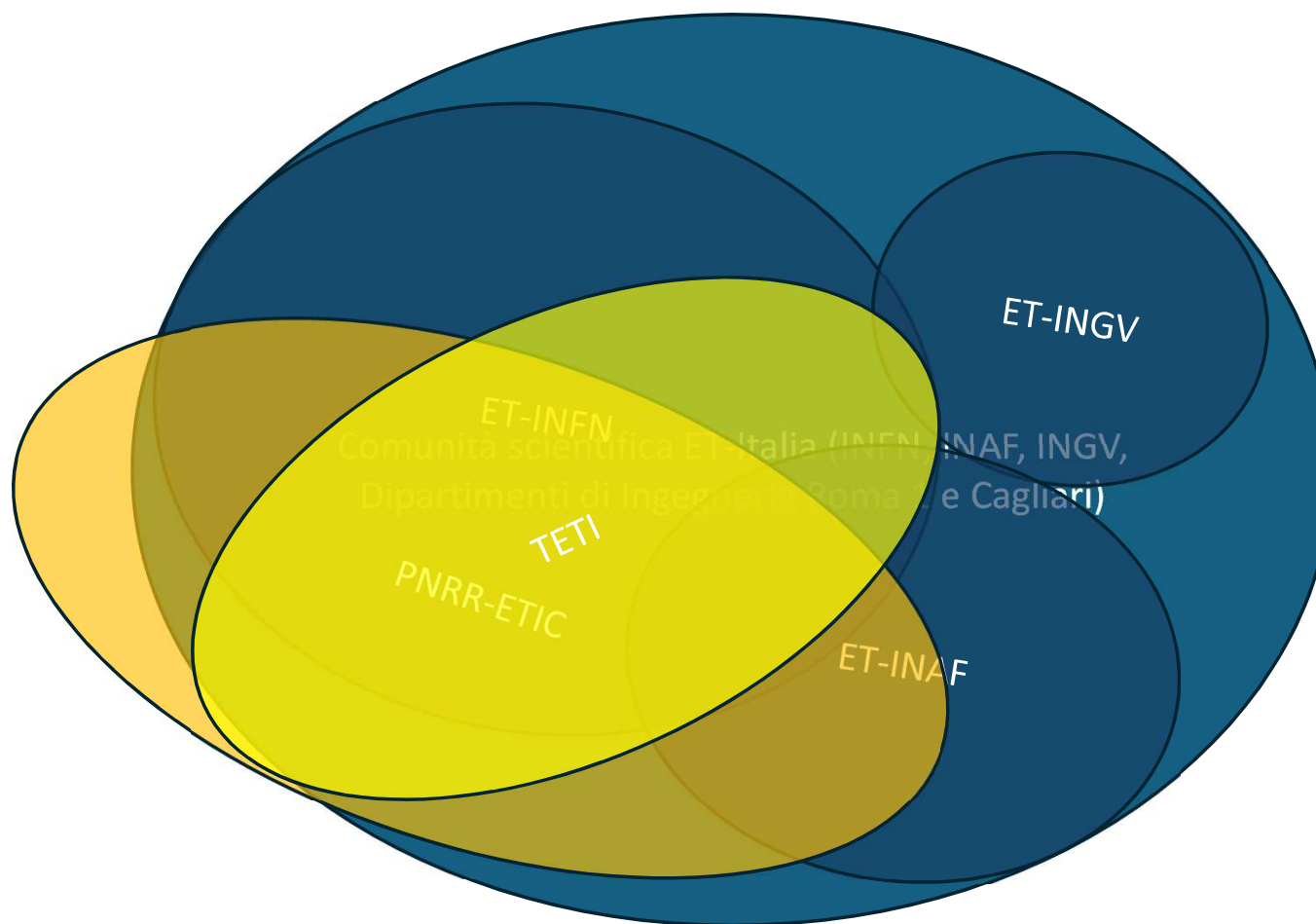
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ET Members



Il framework italiano di ET





Finanziato
dall'Unione europea
NextGenerationEU



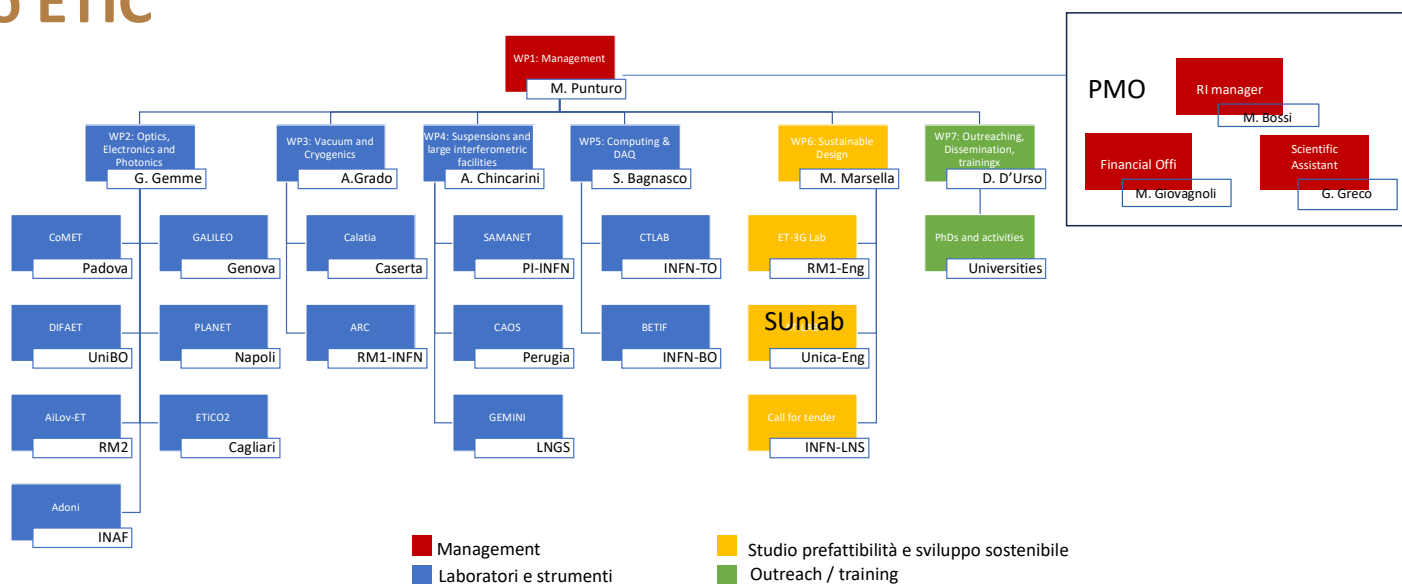
Ministero
dell'Università
e della Ricerca



Italiadomani
PIANO NAZIONALE
DI RIPRESA E RESILIENZA



Il Progetto ETIC



2 principali ambiti di attuazione:

1. Lo studio di pre-fattibilità sul sito nell'area di Sos Enattos
2. Il rafforzamento della rete di laboratori che concorrono allo sviluppo scientifico e tecnologico necessario a ET

- 148 attività
- 27 unità operative: 3 enti di ricerca, 11 università
- 36 mesi (01.01.2023 – 31.12.2025)
- 50M€ ~

Italian Candidature activities

Public Presentation of the new RAS-INFN-INAF-INGV lab, Thursday 20/03/2023, Lula (Nu)



**EINSTEIN TELESCOPE
E ENABLING TECHNOLOGIES (KET):
SFIDE INNOVATIVE, OPPORTUNITÀ
E PROSPETTIVE FUTURE**

**19 MARZO 2025 / ORE 10:30
CAMERA DI COMMERCIO
DI NUORO
VIA MICHELE PAPANDREA 8, NUORO**

PROGRAMMA

10:30	Welcome coffee e registrazione
11:00	Saluti istituzionali Alessandra Todde , Presidente della Regione Autonoma della Sardegna Giuseppe Meloni , Vicepresidente della Regione Autonoma della Sardegna Alessandro Cardini , Direttore Sezione INFN di Cagliari
11:45	Sessione tecnica Giovanni Bisoffi , INFN, Coordinatore del Team for Einstein Telescope in Italy: <i>La candidatura italiana di Einstein Telescope in Sardegna, stato attuale e prospettive</i> Michele Ponturo , INFN, Responsabile Internazionale del Progetto Einstein Telescope e Responsabile Scientifico del Progetto PNRR Einstein Telescope Infrastructure Consortium (ETIC): <i>Einstein Telescope - Temi e tecnologie rilevanti per il Progetto</i> Gaetano Schillaci , INFN, Responsabile per l'esecuzione dello studio di fattibilità dell'infrastruttura di ET — progetto ETIC: <i>Lo studio di fattibilità: stato e prospettive</i>
13:00	Mara Mangia , Sardegna Ricerche: <i>Presentazione dell'avviso, Manifestazione di interesse per lo sviluppo di soluzioni tecnologiche innovative nell'ambito delle Key Enabling Technologies rilevanti per il progetto Einstein Telescope</i>
13:15	Light lunch di networking
14:30	Approfondimento sugli ambiti tecnologici a cura di INFN
16:00	Sessione Q&A e chiusura dei lavori

EVENTO DEL PERCORSO
**VERSO UN FUTURO
SOSTENIBILE** INNOVAZIONE NEI SETTORI
CHIAVE DELLA SARDEGNA

COESIONE ITALIA 2021-27 SARDEGNA

Cofinanziato dall'Unione europea




ET-SunLab

Sardinia Underground Laboratory for Einstein Telescope

Timeline & Conclusions

- ET timeline is under review, but grosso modo:
 - ET science case (Blue Book) will be published in the next days
 - ET detector preliminary TDR should be delivered in July 2025
 - The Italian host team should be able to conclude its evaluation of ET in Sardinia within the 2025
 - The Dutch host team should follow in 2026
 - Hence, I (personally) hope that the ET framework will be able to define geometry, site(s) and roughly evaluate the cost of the civil infrastructures within the 2026
 - In the same time window, the path toward the future ET legal entity could be defined
- Funding
 - Large funding $O(\leq 10^9\text{€})$ promised by the Italian and the Dutch Governments
 - $O(\leq 10^8\text{€})$ investment aggregated in the two sites for the candidature and the development of the enabling technologies
- Conclusions:
 - ET is a challenging adventure; we are working to make it real