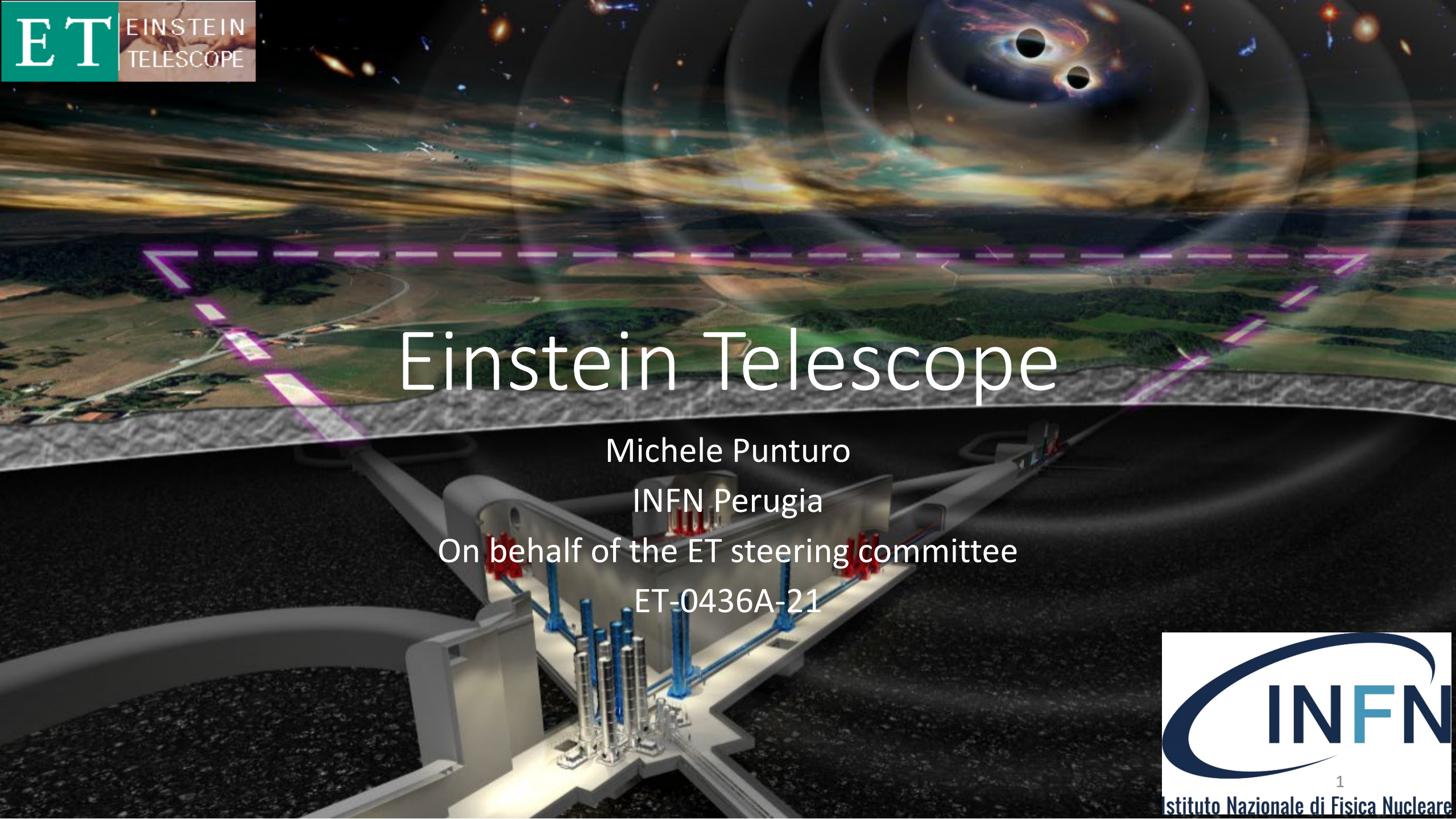


Einstein Telescope

Michele Punturo
INFN Perugia
On behalf of the ET steering committee

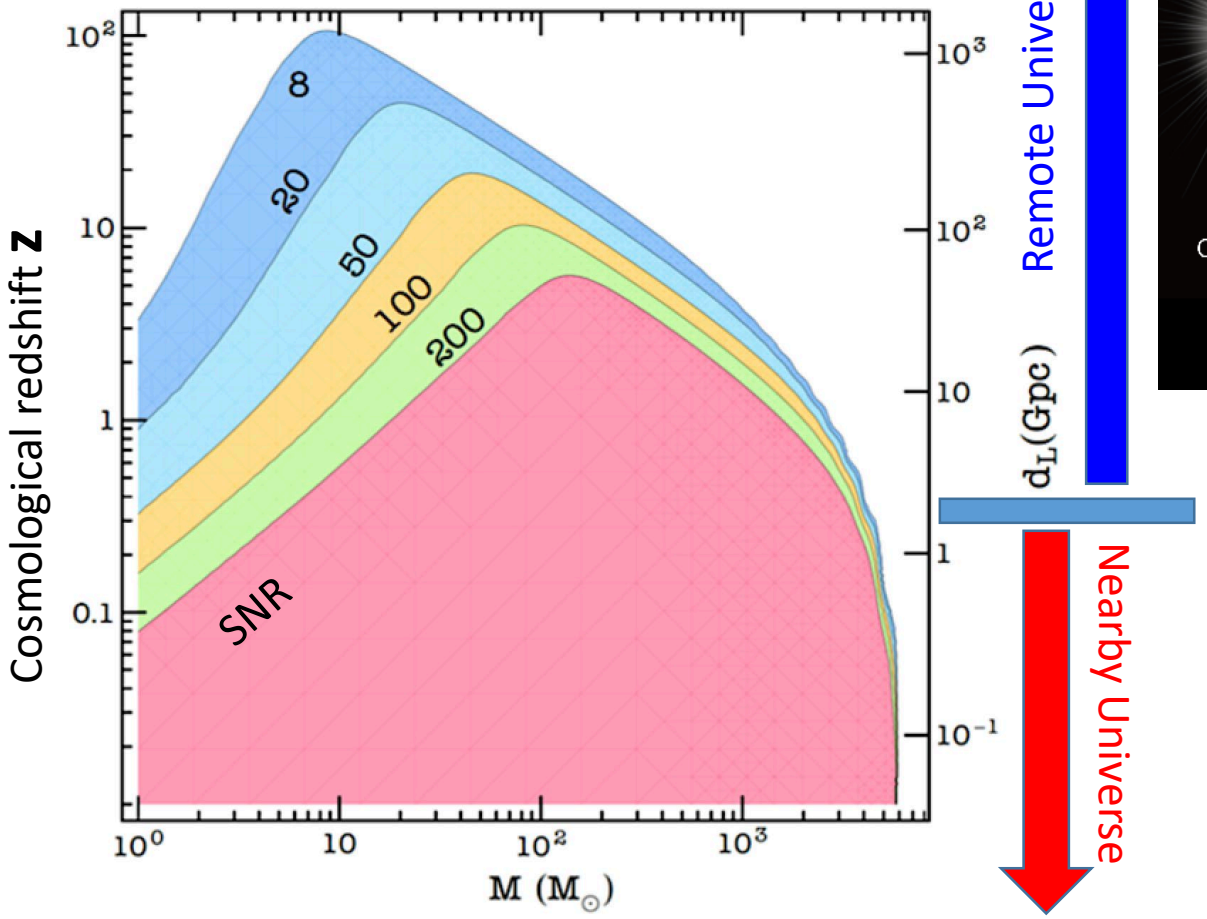
ET-0436A-21

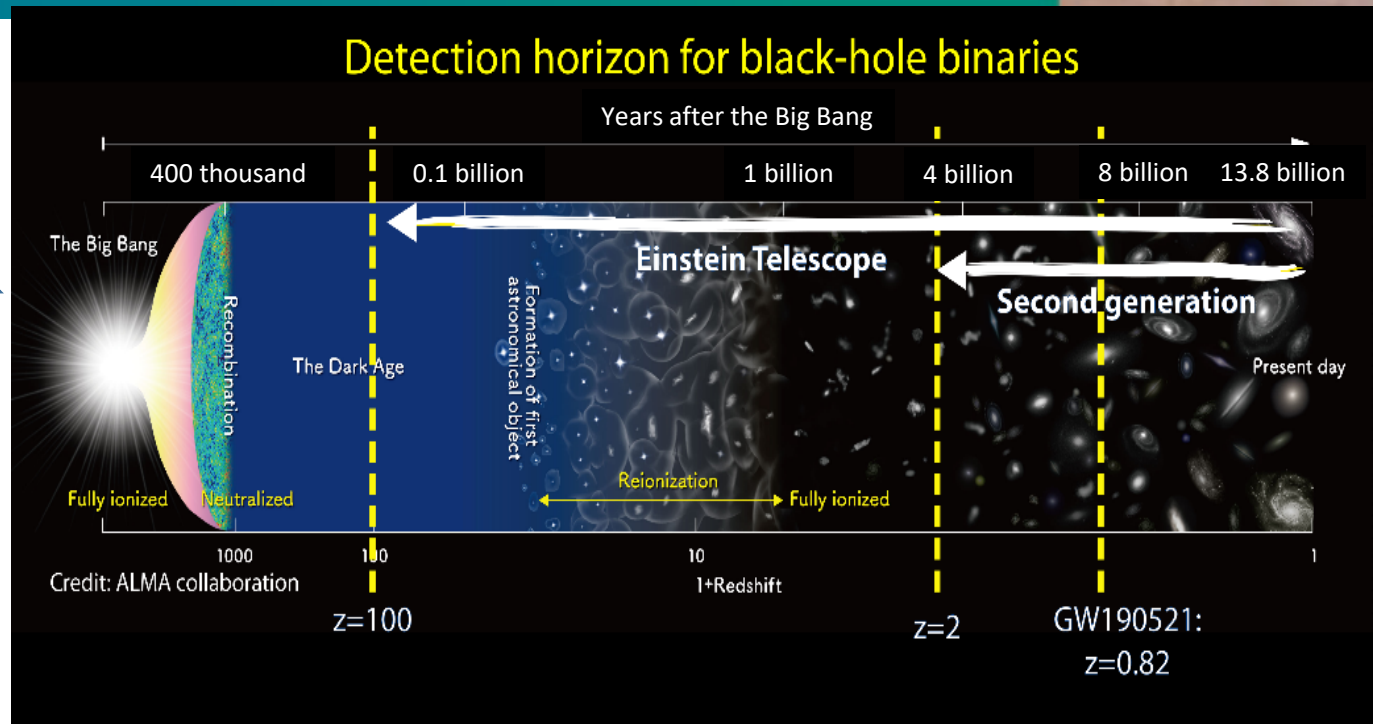
What is Einstein Telescope (ET)?

- ET is the project aiming to realise the European 3rd Generation Gravitational Wave observatory
- ET has been a pioneer idea that defined the concept of 3rd generation GW observatory:
  - A sensitivity at least 10 times better than the (nominal) advanced detectors on a large fraction of the (detection) frequency band
  - Wideband (possibly wider than the current detectors) accessing the frequency band below 10Hz
  - High reliability and improved observation capability
- ET has a long and important history that formed first the ET community and now the ET project
- ET is now becoming also a (formal) scientific collaboration

ET Science in a nutshell

- ET is the pioneer project of the 3G GW observatory in Europe
- Few words on ET science hereafter





The combination of

- distances and masses explored
- number of detections
- detections with very high SNR

will provide a wealth of data expected to generate **revolutions in astrophysics, cosmology and fundamental physics**

ESFRI

ET Science in a nutshell

ET EINSTEIN TELESCOPE

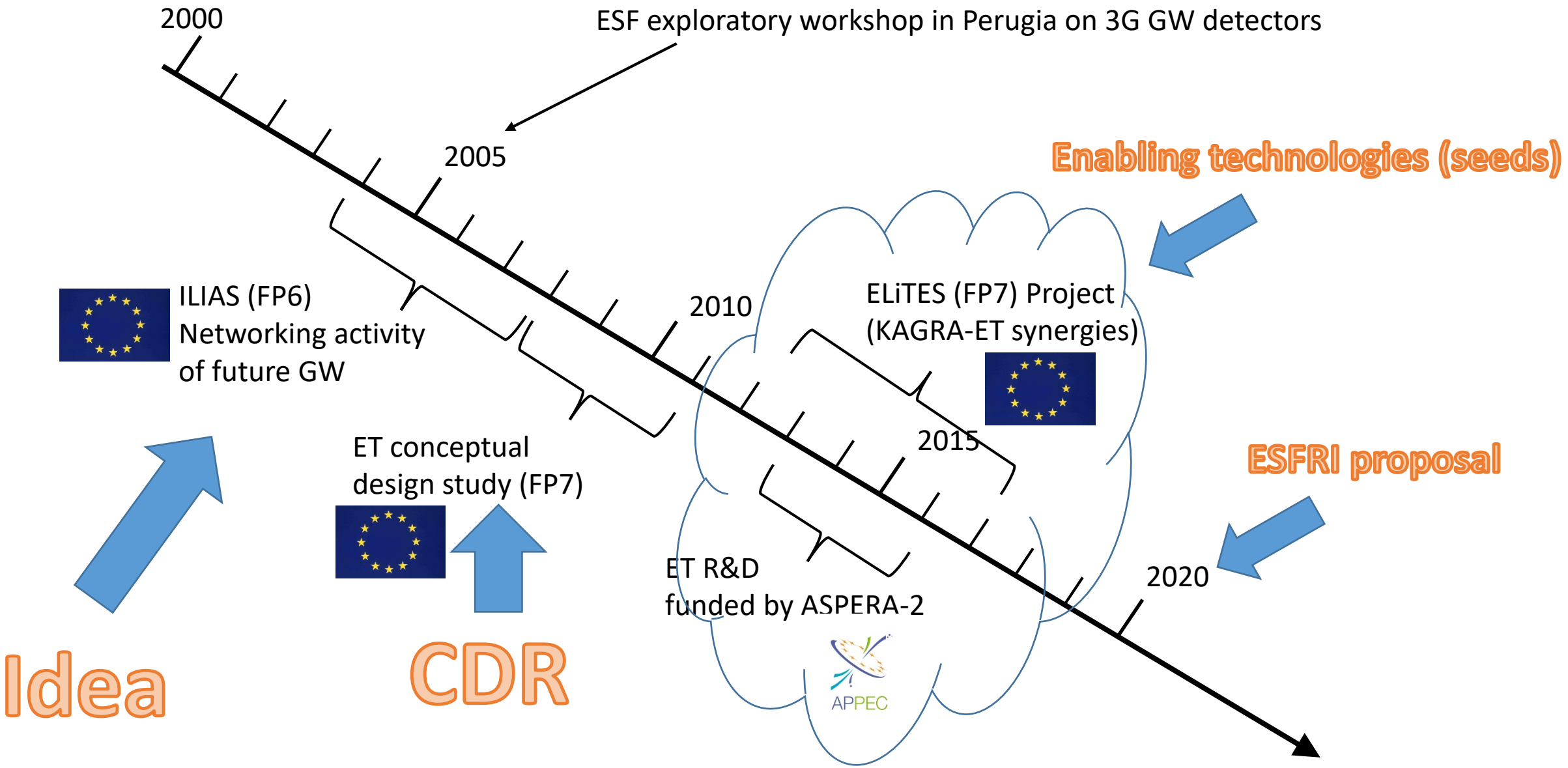
ASTROPHYSICS

- **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

ET long path


2000
ESF exploratory workshop in Perugia on 3G GW detectors
2005
Enabling technologies (seeds)
ILIAS (FP6)
Networking activity
of future GW
2010
ELiTES (FP7) Project
(KAGRA-ET synergies)
2015
ET conceptual
design study (FP7)
ESFRI proposal
ET R&D
funded by ASPERA-2
2020
APPEC
Idea
CDR

European Strategy Forum on Research Infrastructures

ESFRI Roadmap

ET EINSTEIN TELESCOPE

ESFRI Strategy Report on Research Infrastructures ROADMAP 2021

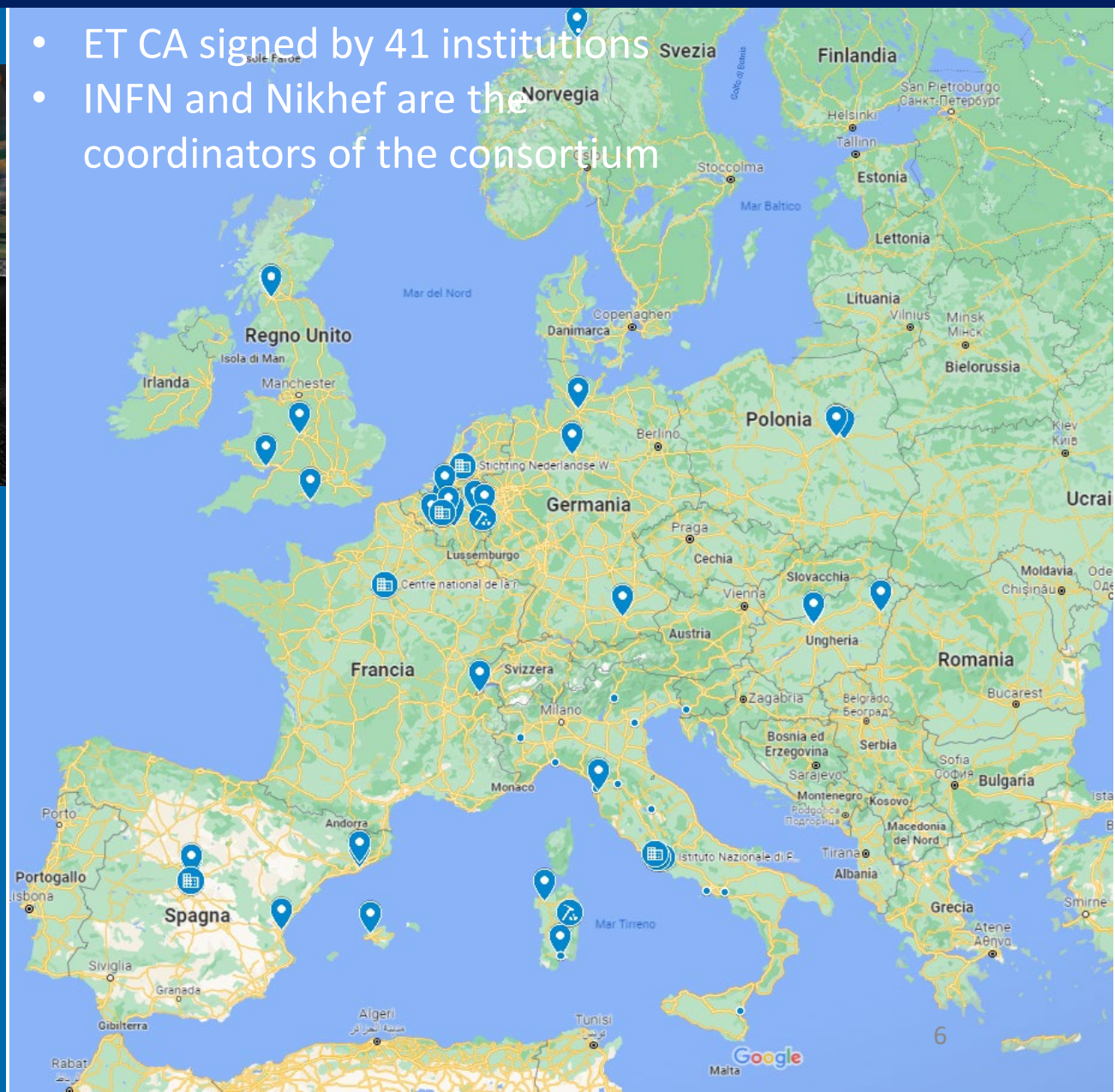
Proposal submitted by:

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

Now in the project and in the collaboration activities also agencies or institutions belonging to:

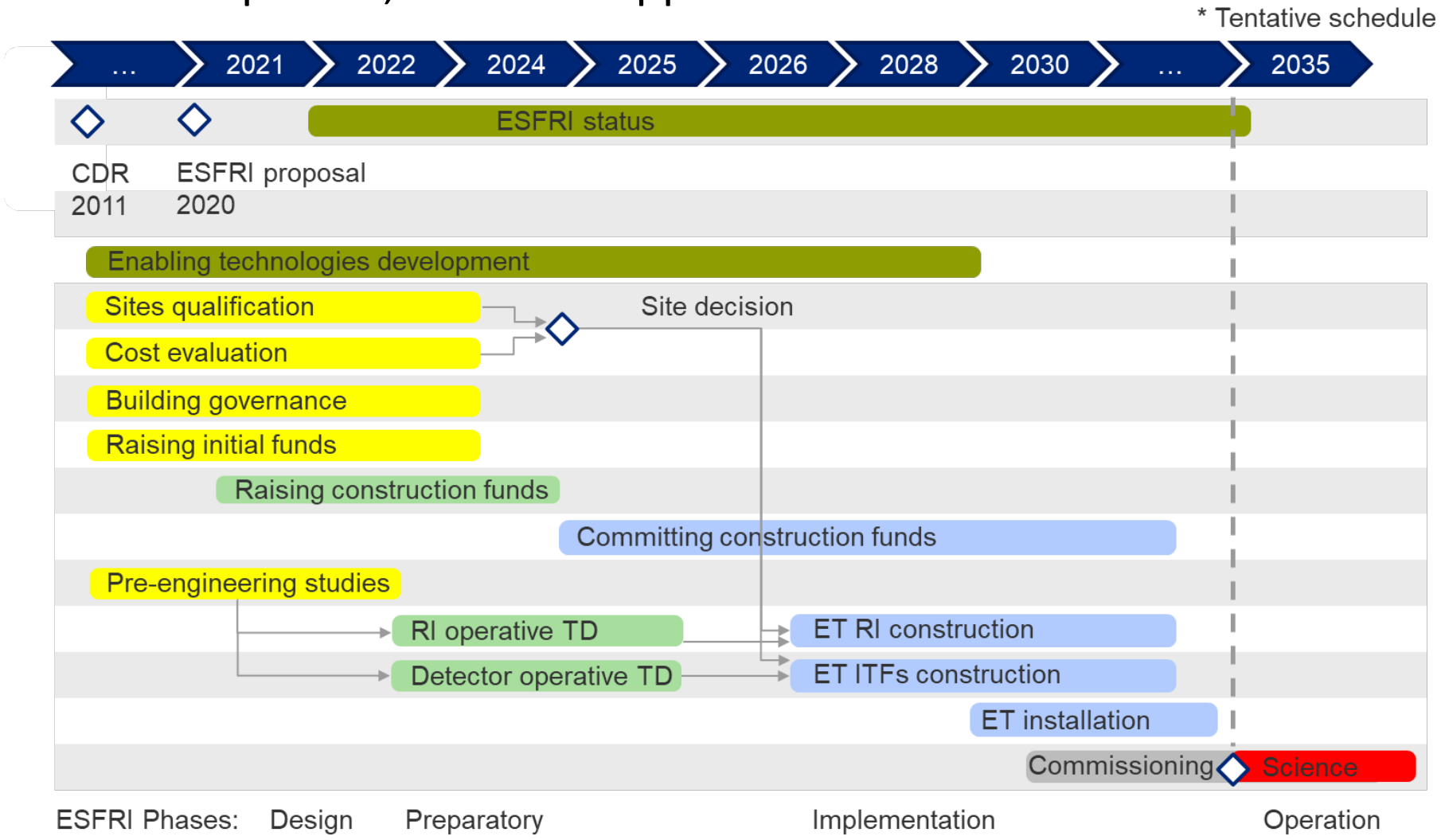
- **France**
- **Germany**
- **Hungary**
- **Switzerland**
- **UK**

- ET CA signed by 41 institutions
- INFN and Nikhef are the coordinators of the consortium

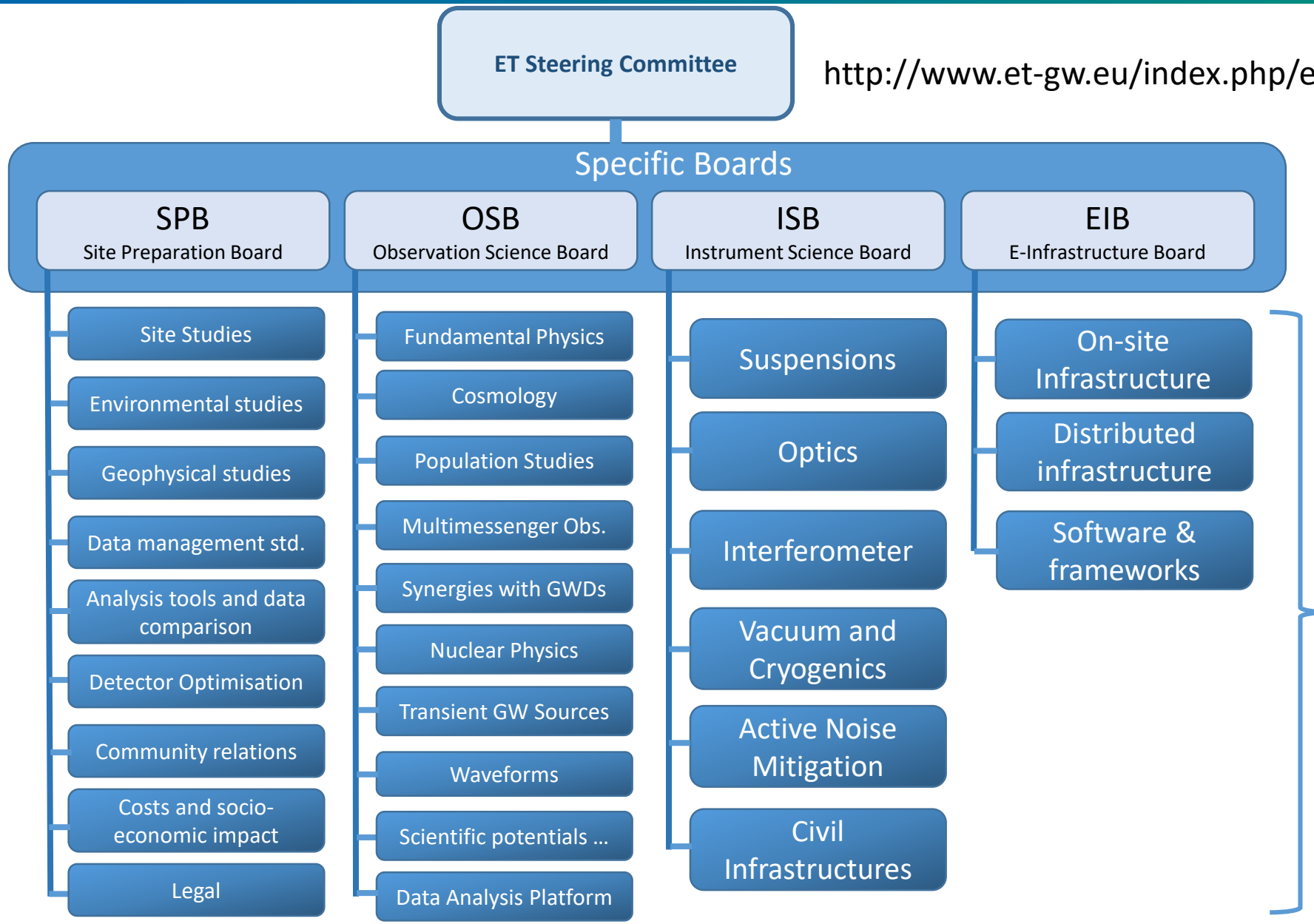


ET timeline

- ET timeline presented to ESFRI
  - As expected, the ESFRI approval boosted the activities at all the levels:
    - Scientists
    - Agencies
    - Governments



ET collaboration current organisation

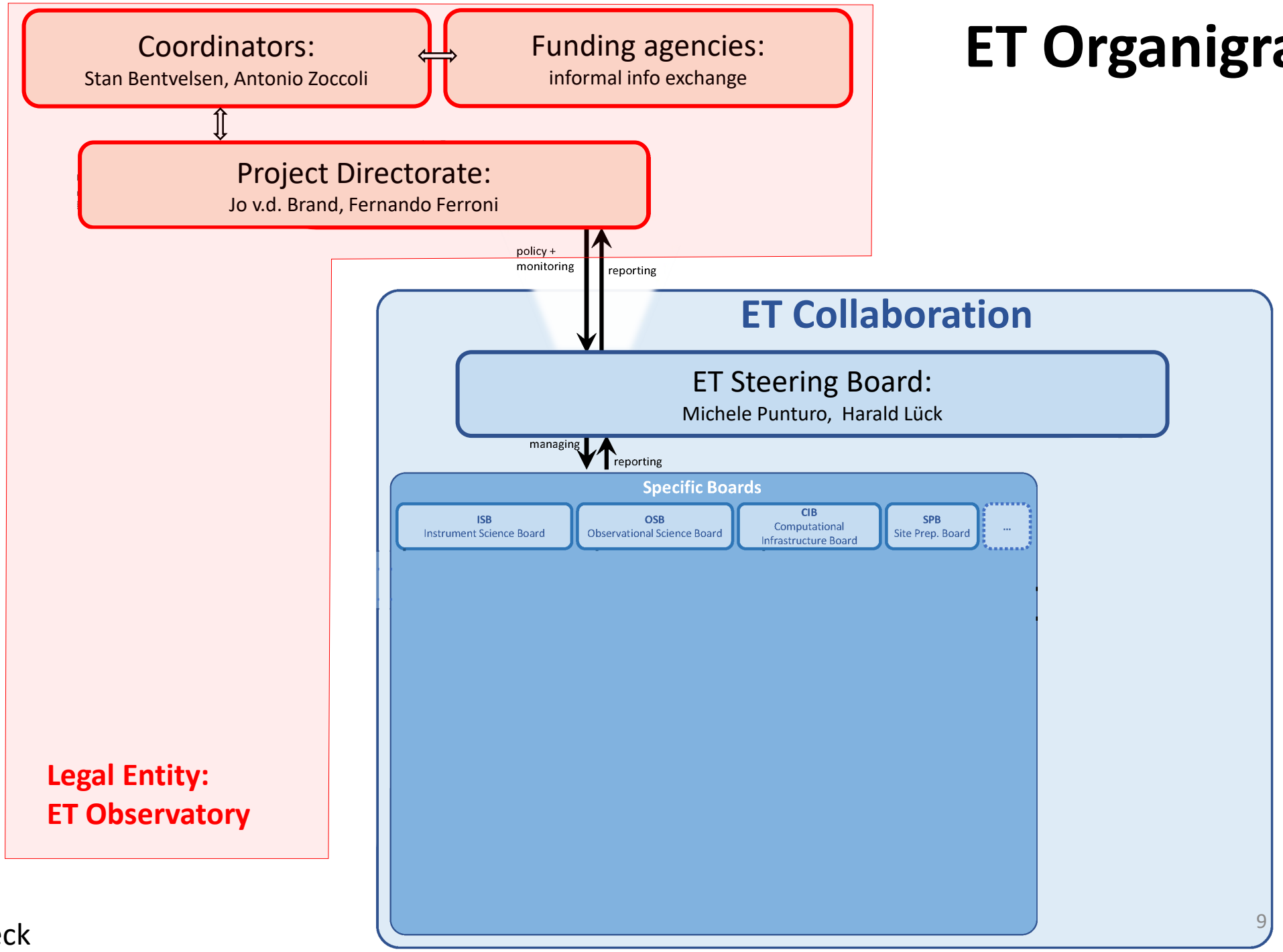


http://www.et-gw.eu/index.php/et-steering-committee

The proto-collaboration is currently the most organised component of the ET project

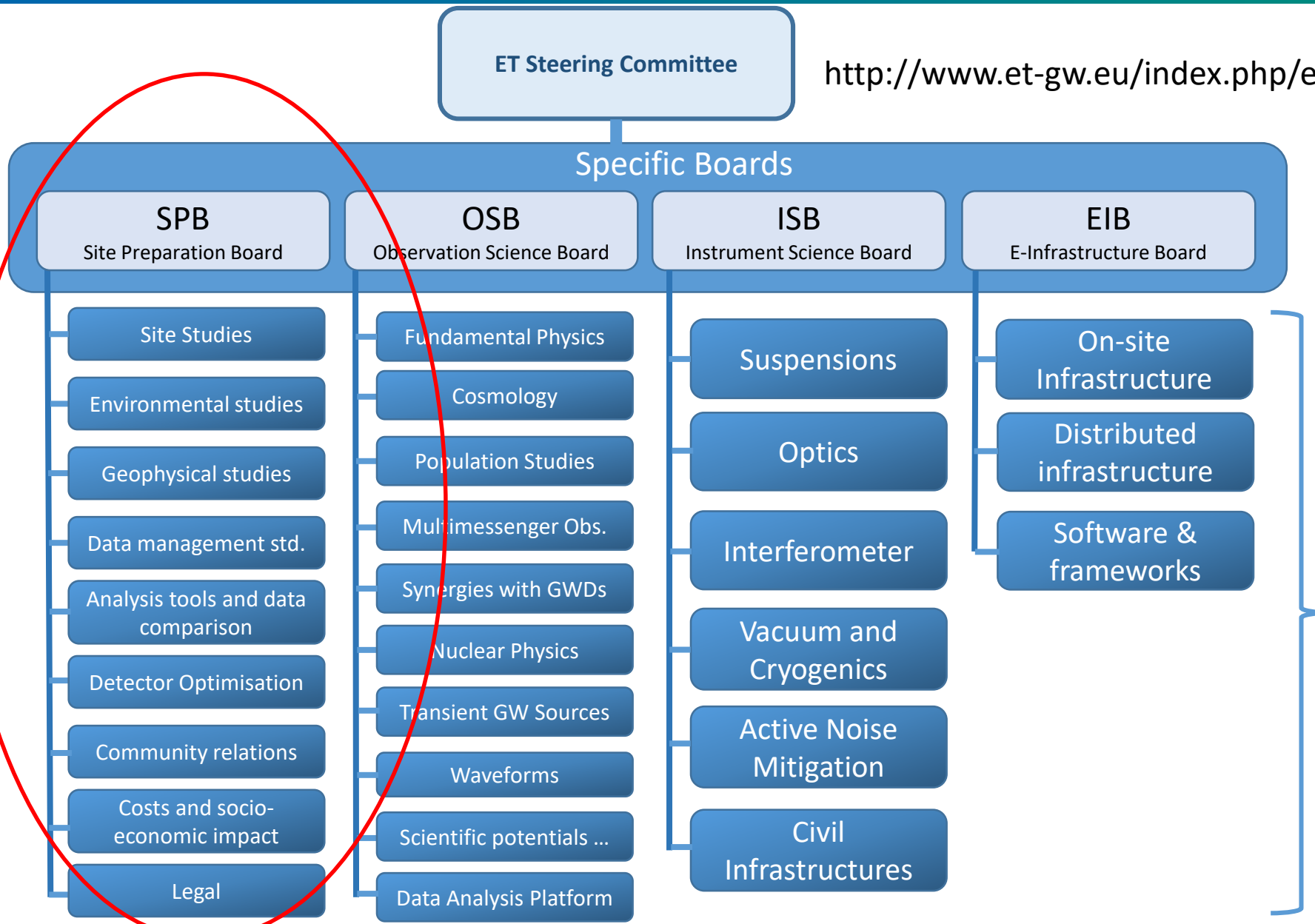
Divisions

ET Organigram



Slide animation: H.Lueck

ET collaboration current organisation



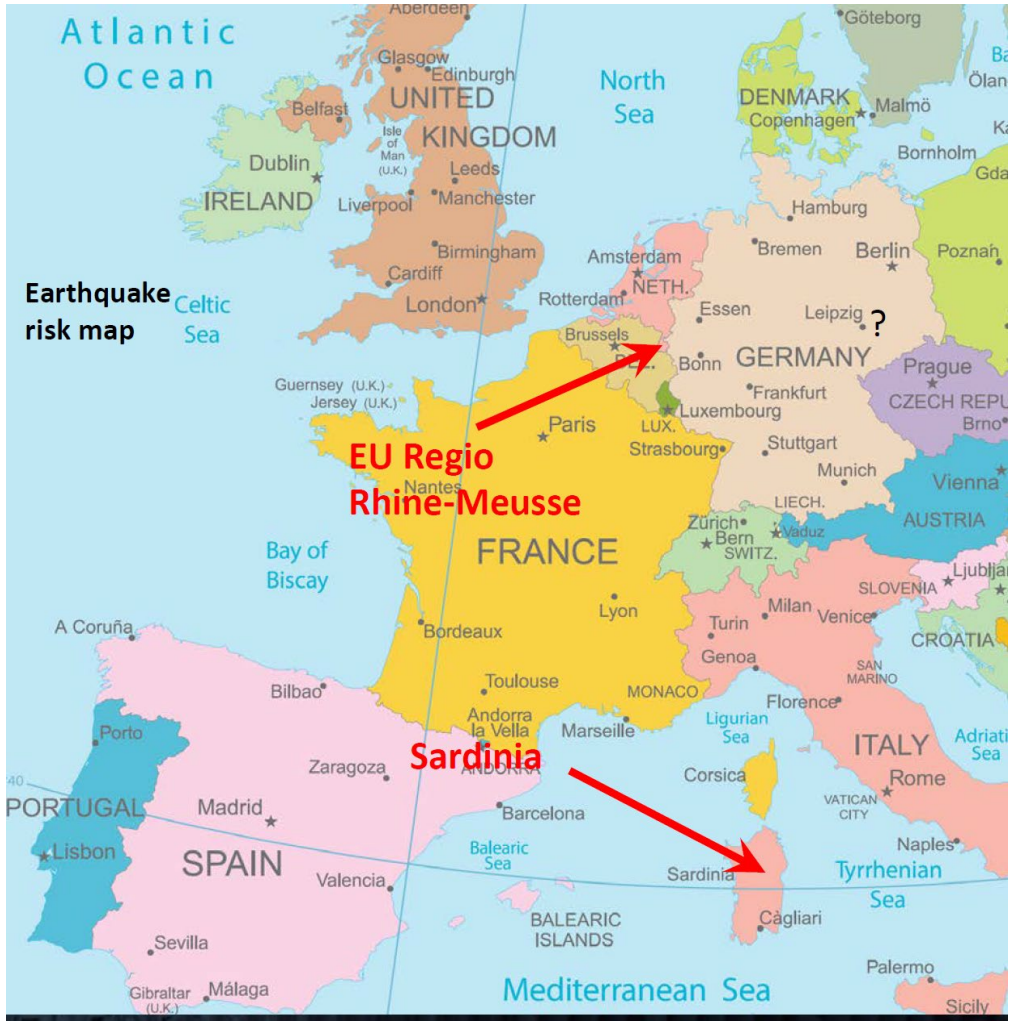
http://www.et-gw.eu/index.php/et-steering-committee

The proto-collaboration is currently the most organised component of the ET project

Divisions

ET site(s)

- Currently there are two sites, in Europe, candidate to host ET:
  - The Sardinia site, close to 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, ~~but still too preliminary to be a candidate~~



SPB: ET sites under characterisation

Euregio Meuse-Rhine

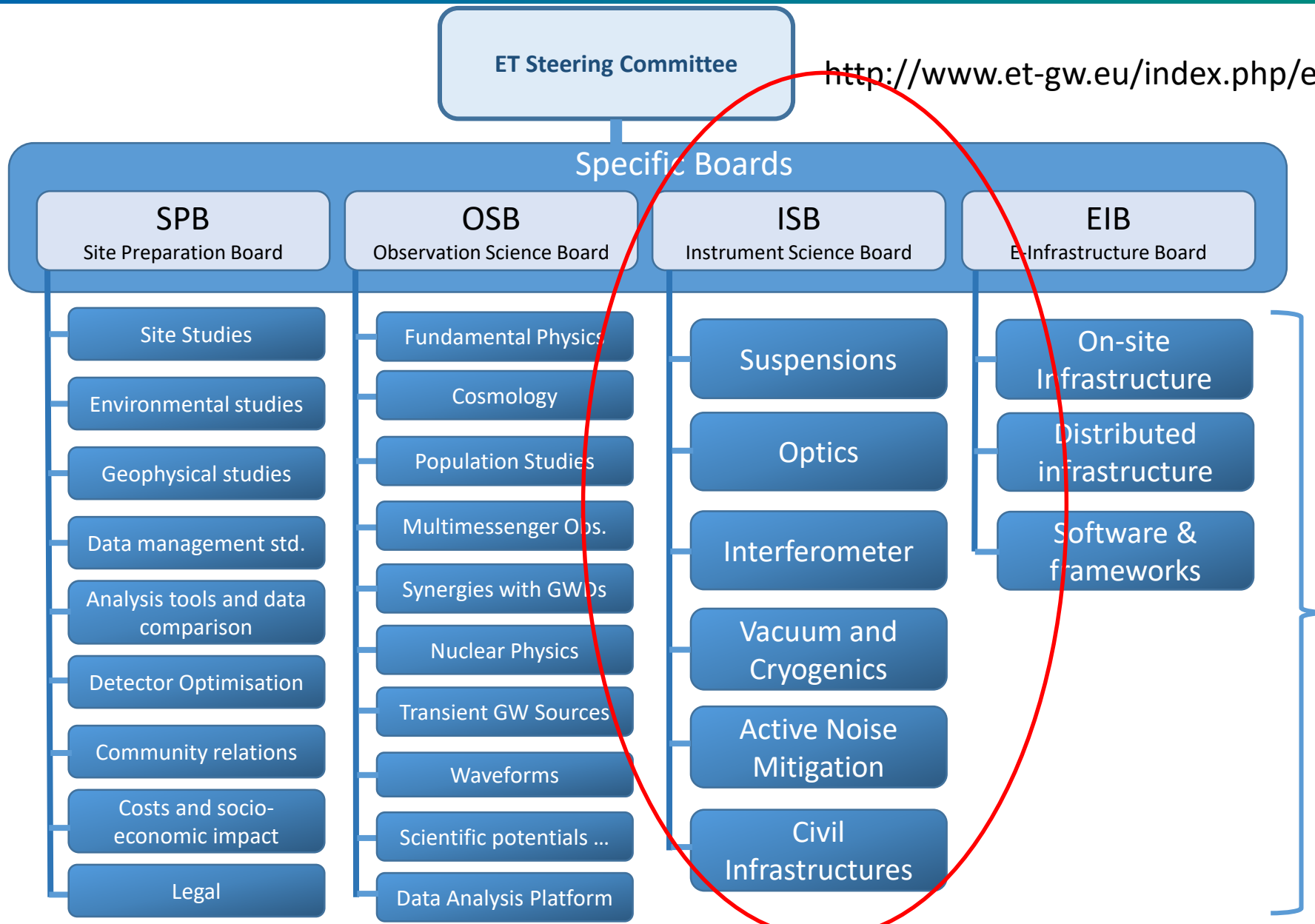
- A 250-m deep borehole has been excavated and equipped
  - Seismic data under acquisition and analysis
- 3-5 other boreholes expected
- Extensive active and passive site characterisation with sensor arrays in 2021
- Good seismic noise attenuation given by the particular geological structure
- Characterisation funded through Interreg grants

Sardinia

- Long standing characterisation of the mine in one of the corners continuing
  - Seismic, magnetic and acoustic noise characterisation ongoing at different depth in the mine
- Underground laboratory under construction (SarGrav)
- Two ~290m boreholes have been excavated, equipped and data taking is ongoing
- Intense & international surface investigations programme in Summer/Fall 2021
- Characterisation funded on regional and national funds

Link with the APOGEIA initiative (Stavros Katsanevas)?

ET collaboration current organisation



http://www.et-gw.eu/index.php/et-steering-committee

The proto-collaboration is currently the most organised component of the ET project

Divisions

Q1: Enabling Technologies

Challenging engineering

New technology in cryo-cooling

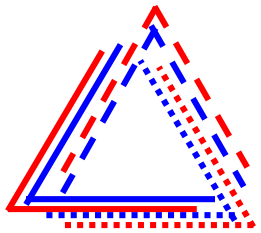
New technology in optics

New laser technology

High precision mechanics and low noise controls

High quality opto-electronics and new controls

- 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

- **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

Advanced detectors and their development programmes are a crucial de-risking factor for ET-HF

Challenging engineering Large Underground Infrastructures

Technical challenges on:

Self-induced acoustic, seismic and e.m. noises

Temperature and Humidity stabilisation

Safety

New challenges in optics (and material science)

- ET-LF requires new materials for the large mirrors in order to operate at cryogenic temperature:
  - Silicon (Sapphire) mirrors:
    - Challenges on size and geometry, polishing, thermo-mechanical properties (thermal noise), optical properties (absorption), handling, suspending
  - New High reflectivity coatings:
    - Challenges on material selection, doping, deposition procedures, impurities and defects, thermo-mechanical and optical properties, ageing
  - New lasers:
    - Current GW detectors uses 1064nm λ, ET-LF will use 1550nm (or ~2μm) λ lasers
  - New opto-electronics:
    - Faraday isolators, electro-optical modulators, fibres, photo-sensing

New challenges in Mechanics and Cryogenics

- ET Seismic Filtering will require to push forward 2nd generation technology:
  - Active and passive seismic filtering to have high efficiency, more compact suspension chains
- ET Cryogenics:
  - Challenges on the capability of cooling few hundreds kg test masses
    - without disturbing the interferometer
    - Reducing the cooling time
    - Avoiding the contamination of the mirrors
  - Challenges in the realisation of the payloads compatible both with the cryogenic and operation requirements (geometry, materials, ….)

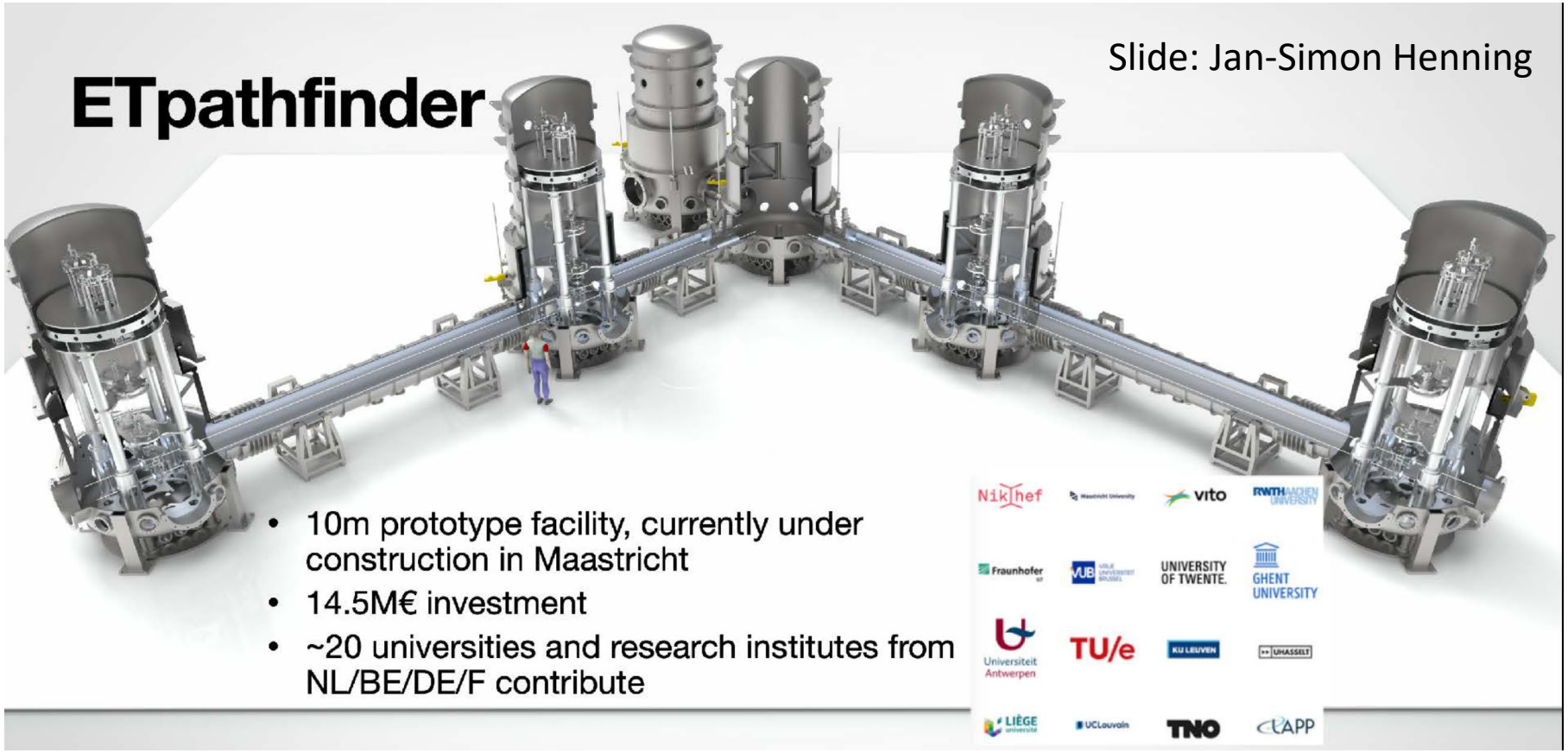
New challenges in sensing and actuation

- Current detectors are dominated (at low frequency) by “technical” noises
- ET has science targets in this low-frequency regime
- The low frequency (but not only the LF) is the realm of the noises generated in the sensing-feedback-actuation control loop chain
- ET needs to develop
  - Low noise sensing devices
  - New control methods (Machine Learning?)
  - Low noise actuation tools
  - Thermal compensation systems
  - Adaptive optics

A network of new R&D infrastructures

- The technological evolution requested by ET is stimulating the growth of a series of new facilities and infrastructures where ET R&D is performed:
  - ET pathfinder

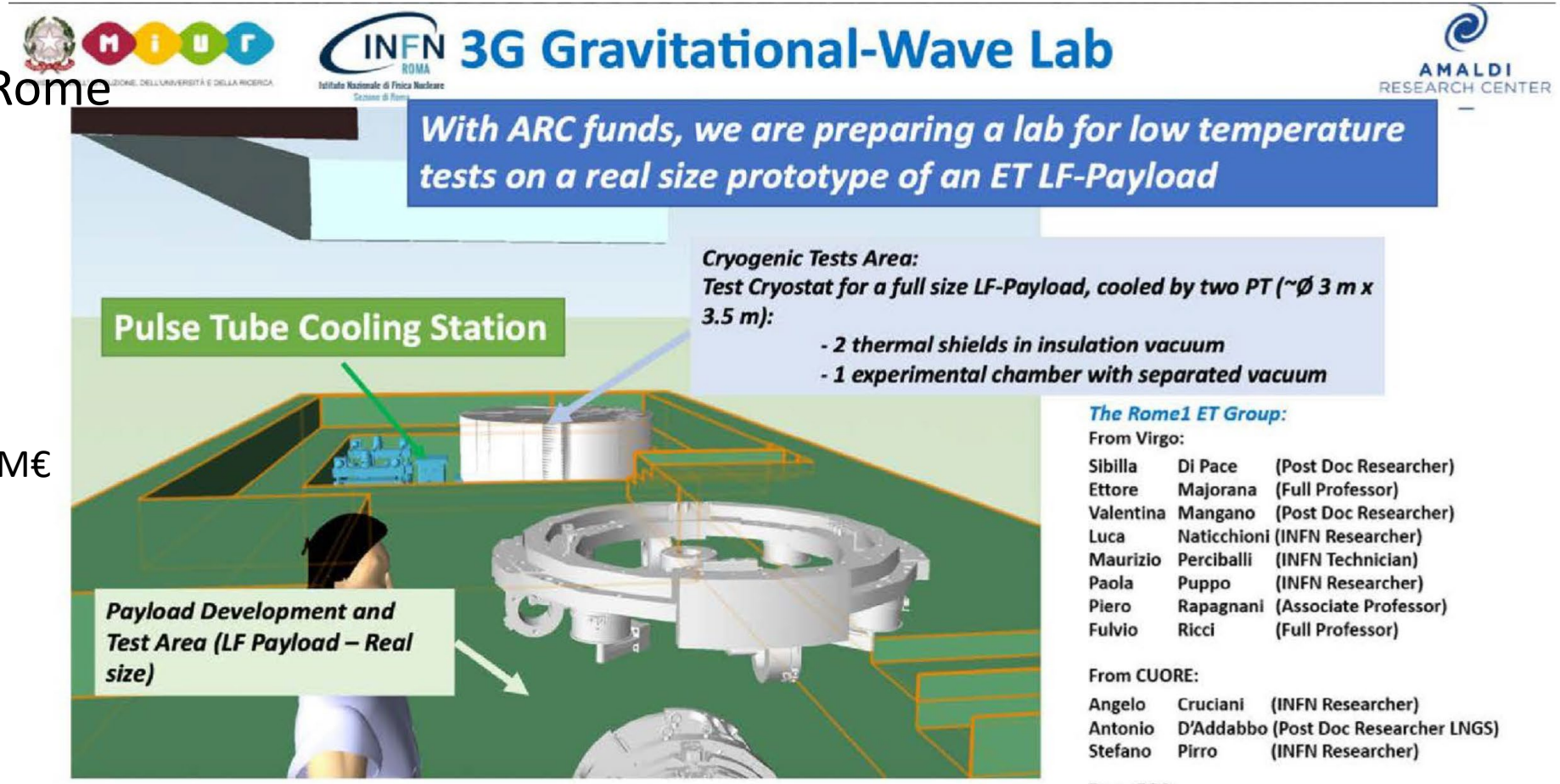
Inauguration 8 November 2021



A network of new R&D infrastructures

- The technological evolution requested by ET is stimulating the grown of a series of new facilities and infrastructures where ET R&D is performed:
  - ET pathfinder
  - Amaldi Centre, Rome

Grant: About 11M€



Slide P.Rapagnani

A network of new R&D infrastructures

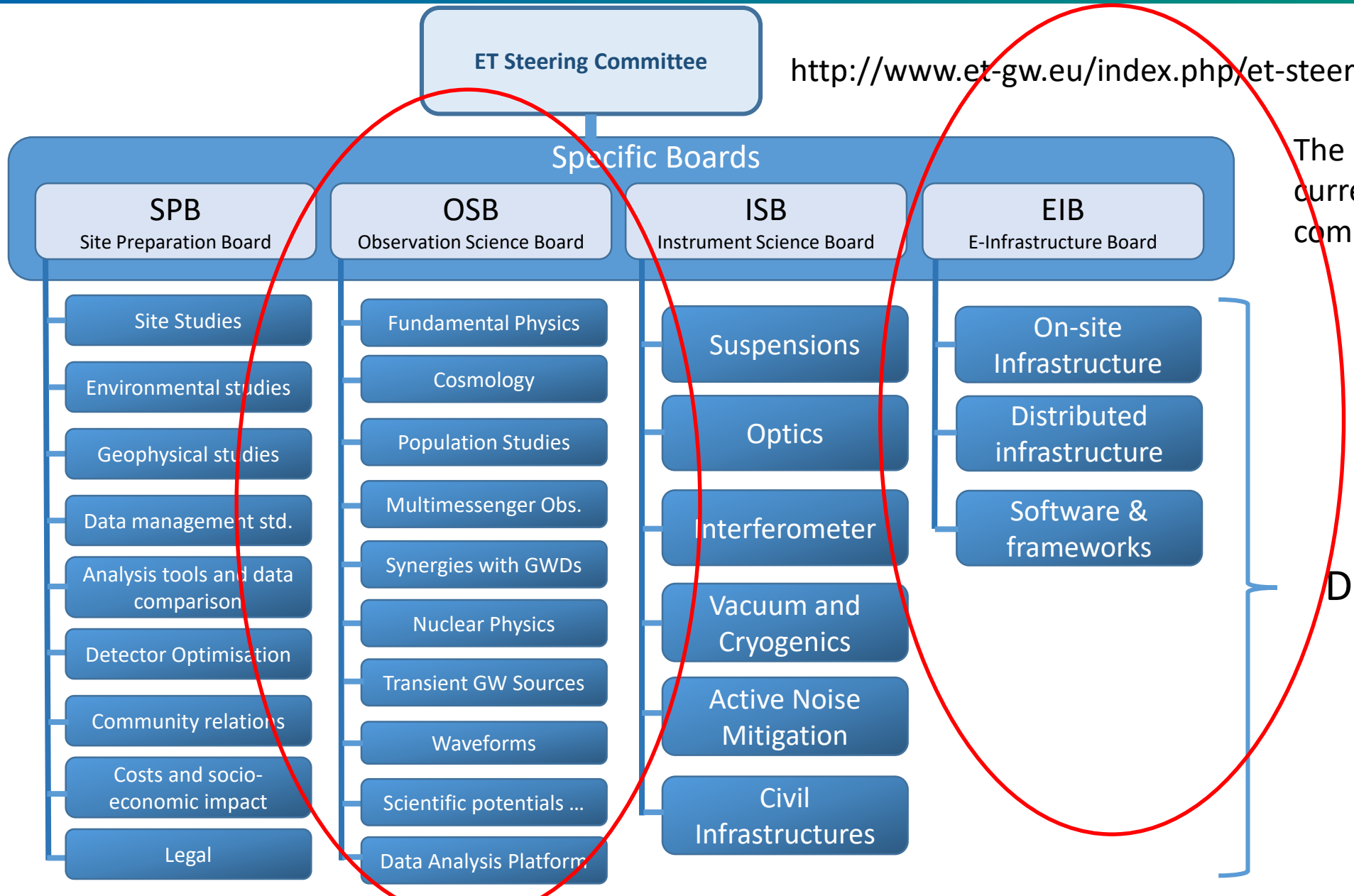
- The technological evolution requested by ET is stimulating the grown of a series of new facilities and infrastructures where ET R&D is performed:
  - ET pathfinder
  - Amaldi Centre, Rome
  - Sar-Grav lab in Sardinia
  - Other sites under preparation

The SarGrav Laboratory

Founded with 3.5 M€ by the Regione Autonoma della Sardegna (RAS) to host low seismic noise underground experiments (low seismic noise experiments, cryogenic payloads, low frequency and cryogenic sensor development)

- ~ 900 m^2 surface Laboratory
- 3 Underground stations equipped for measurements at different depths
- ~ 50 m^2 underground area available
- planned a 250 m^2 underground Lab
- First experiment: Archimedes (founded by INFN)

ET collaboration current organisation



http://www.et-gw.eu/index.php/et-steering-committee

The proto-collaboration is currently the most organised component of the ET project

Divisions

DAQ, Data stream conditioning, Computing

- GW data is a continuous stream output where the signal is embedded in the noise
  - Challenges: Data Acquisition technologies, data filtering and conditioning
- Low latency analysis and GW alerts
  - Crucial technologies for the Multi-Messenger-Astronomy
    - Efficient computing
      - GPUs, HPC and parallel algorithms
    - Machine Learning and Artificial Intelligence
    - Data Distribution
- Data preservation
  - Technologies and methods
  - Virtual Observatory

Summarizing

1) Photo-sensing, optics, electronics, opto-electronics, quantum technologies

2) Monitoring, sensing and actuation:

- Monitoring and/or sensing
- Control and actuation
- Adaptive systems and compensation

- ET
- CTA
- SKA
- KM3NeT
- ….

3) Surface and material technologies, coatings

4) Efficient computing and algorithms:

- ML and AI
- High efficiency and low carbon solutions (GPUs, FPGA, ..)
- Low latency alerts
- Data distribution
- Data preservation

ET EINSTEIN TELESCOPE

Proposed approach

- The richness of the Astro-particle research, under the APPEC hat, is given by the diversity and heterogeneity of technologies to capture the “sidereus nuncii”
- The proposal should match this peculiarity of our research field with the EU requests:
  - To have a part of the proposal aiming to build a common technological platform between the different ESFRI projects
    - Keywords: integration, synergies
  - To devote a fraction of the proposal to develop project specific technologies
    - Keywords: specialisation, cross-fertilisation
  - Balancing to be defined

Proposed roadmap

- 27/10 – 03/11 multilateral discussions
- ~4/11 first meeting of the XXXX proposal
  - Agreement on the topics and first definition of the WPs
  - Definition of the involved ESFRI RI
  - Definition of the core beneficiaries
- ~16/11 Second meeting of the XXXX proposal
  - Definition of the management team
  - Definition of the WPs list
  - Draft definition of the writing team
- Contacts:
  - Michele Punturo michele.punturo@pg.infn.it
  - Harald Lück harald.lueck@aei.mpg.de
  - Andreas Freise a.freise@nikef.nl
  - Gianluca Gemme gianluca.gemme@ge.infn.it