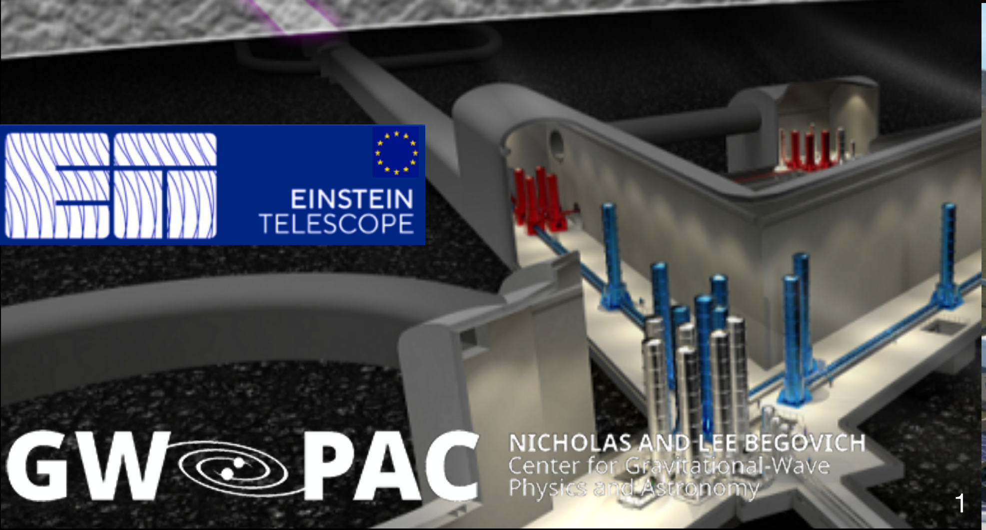
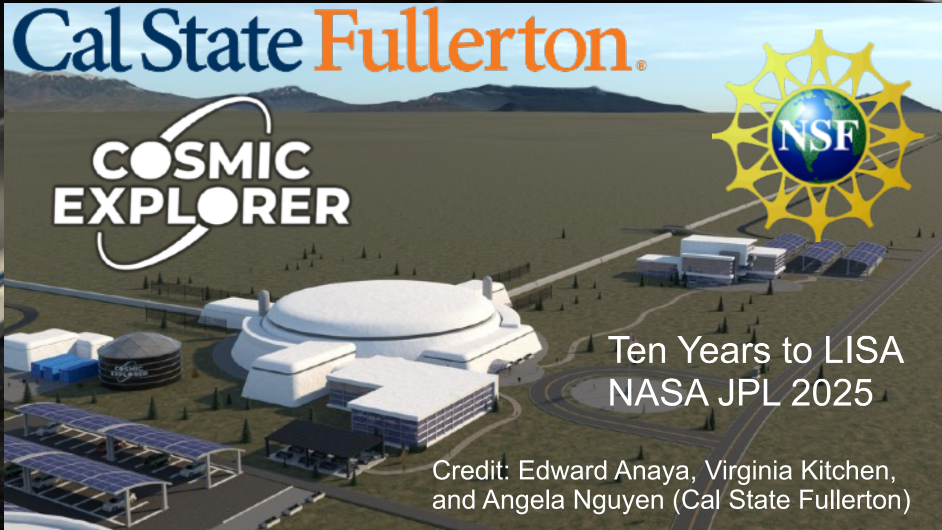
ET/CE-what we hope to build, and what we could optimistically do by 2040

Joshua Smith (on behalf of the CE Project)
The Nicholas and Lee Begovich Center
for Gravitational-Wave Physics and Astronomy
California State University Fullerton

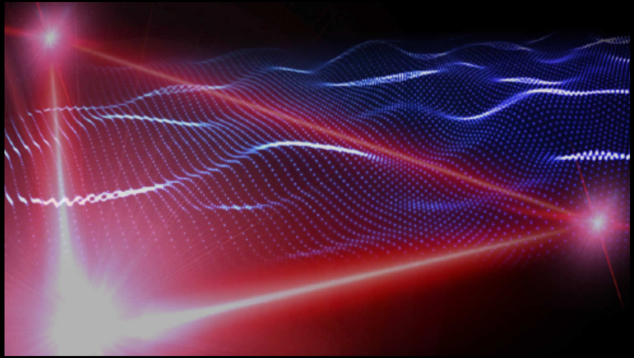


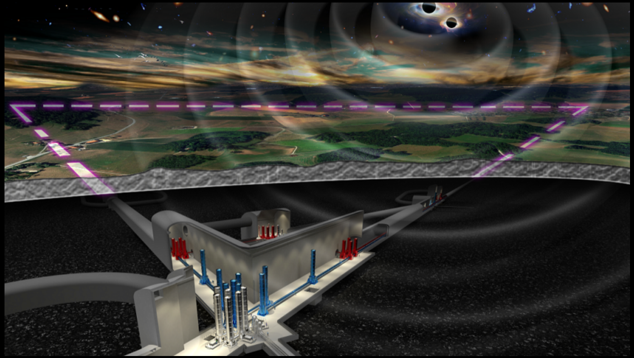


Ten Years to LISA
NASA JPL 2025

Credit: Edward Anaya, Virginia Kitchen, and Angela Nguyen (Cal State Fullerton)

Next-generation gravitational-wave observatories





LISA

- 2.5 million km triangular interferometer in space
- GW frequencies 0.1mHz—1Hz

Einstein Telescope (ET)

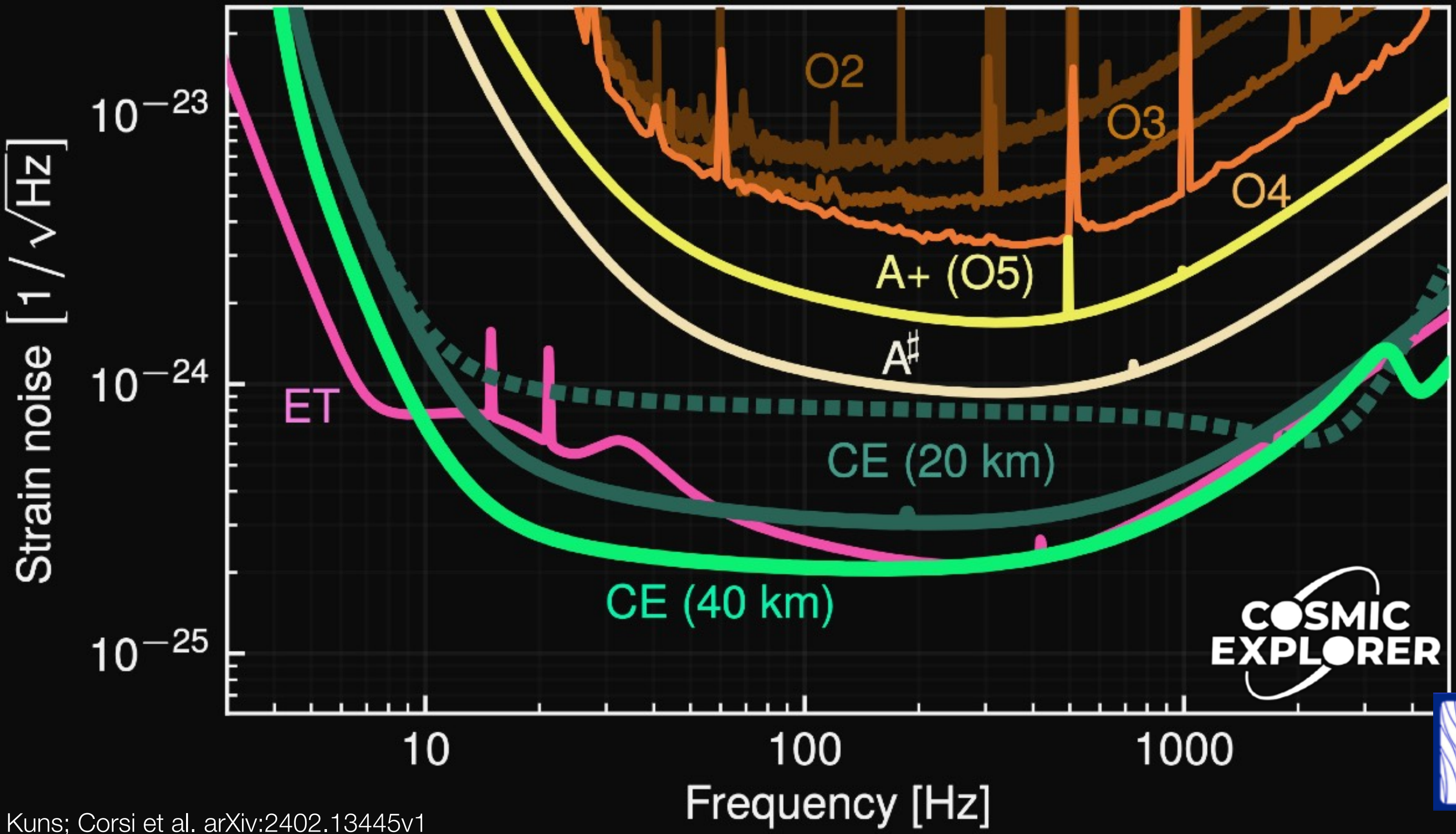
- 10 km underground triangle
- 6 interferometers in “xylophone” configuration:
  - Cryogenic low frequency
  - High power high frequency
- GW frequencies 7Hz—2kHz

Cosmic Explorer (CE)

- 20 km and 40 km L-shaped surface observatories
- scaled up LIGO technology & enhancements
- GW frequencies 10Hz—2kHz

Images courtesy Einstein Telescope, LISA, Cosmic Explorer

From LIGO-Virgo-KAGRA to the next generation



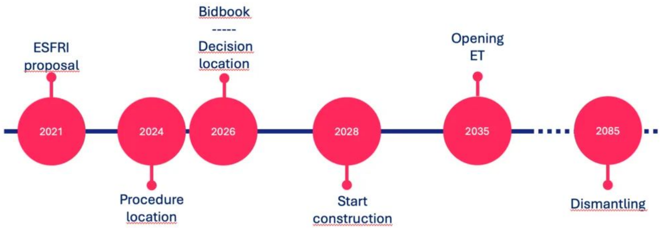
Kuns; Corsi et al. arXiv:2402.13445v1

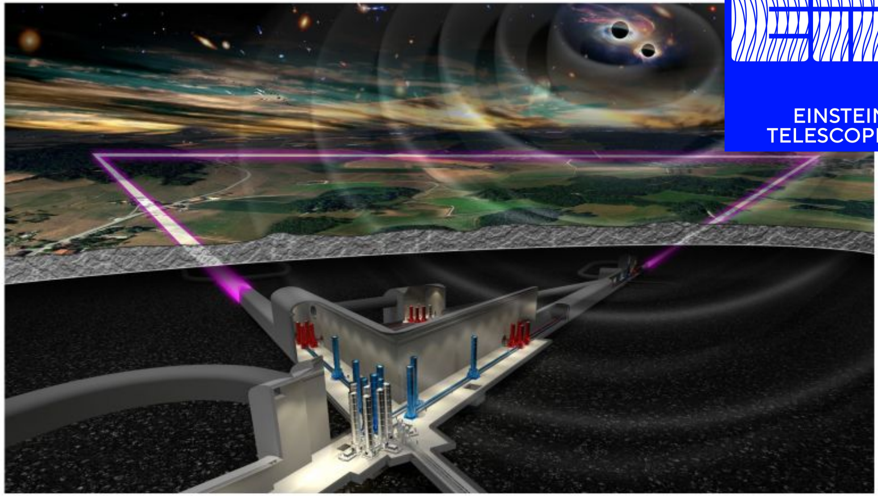
2023

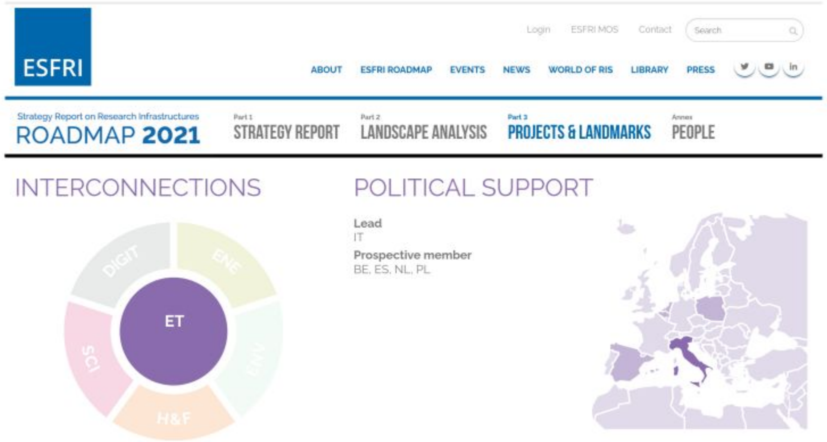
Next-generation (~2035)

ESFRI roadmap!

- Since 2021, on the European Strategy Forum on Research Infrastructures (ESFRI) roadmap.
- Presented by Italy with support from the Netherlands, Belgium, Spain, and Poland.
- ET now supported by 9+2 countries; in Board of Governmental Representatives (BGR): Italy, the Netherlands, Belgium, Spain, Poland, France, Croatia, Greece, UK + Germany, Austria as observers.
- ET Consortium led by INFN and Nikhef.



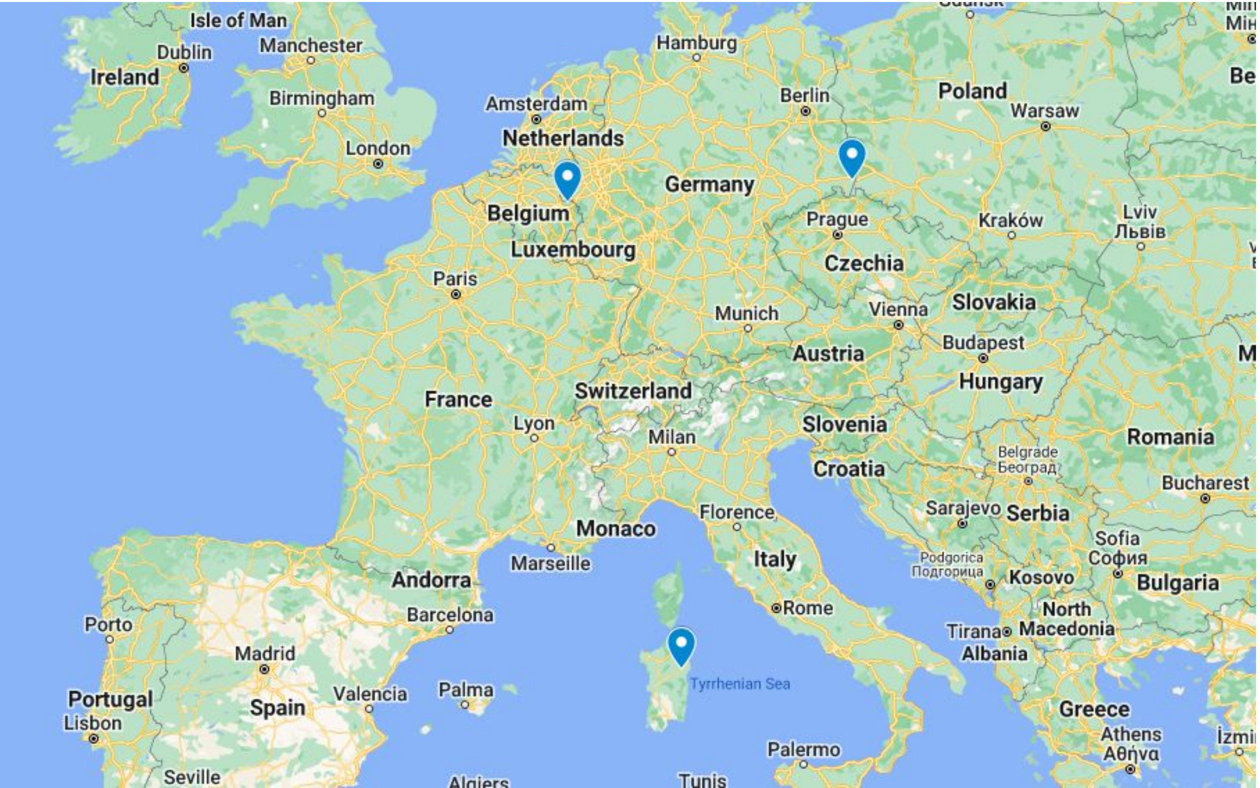




Slide Courtesy Einstein Telescope, Archisman Ghosh

Slide Courtesy Einstein Telescope, Archisman Ghosh

Where?



Two formal candidate sites:

- North of **Sardinia** (Sos Enattos, Lula area, Barbagia)
- **EMR** EURegio (border between Belgium, the Netherlands, and Germany)

Proposed third potential site:

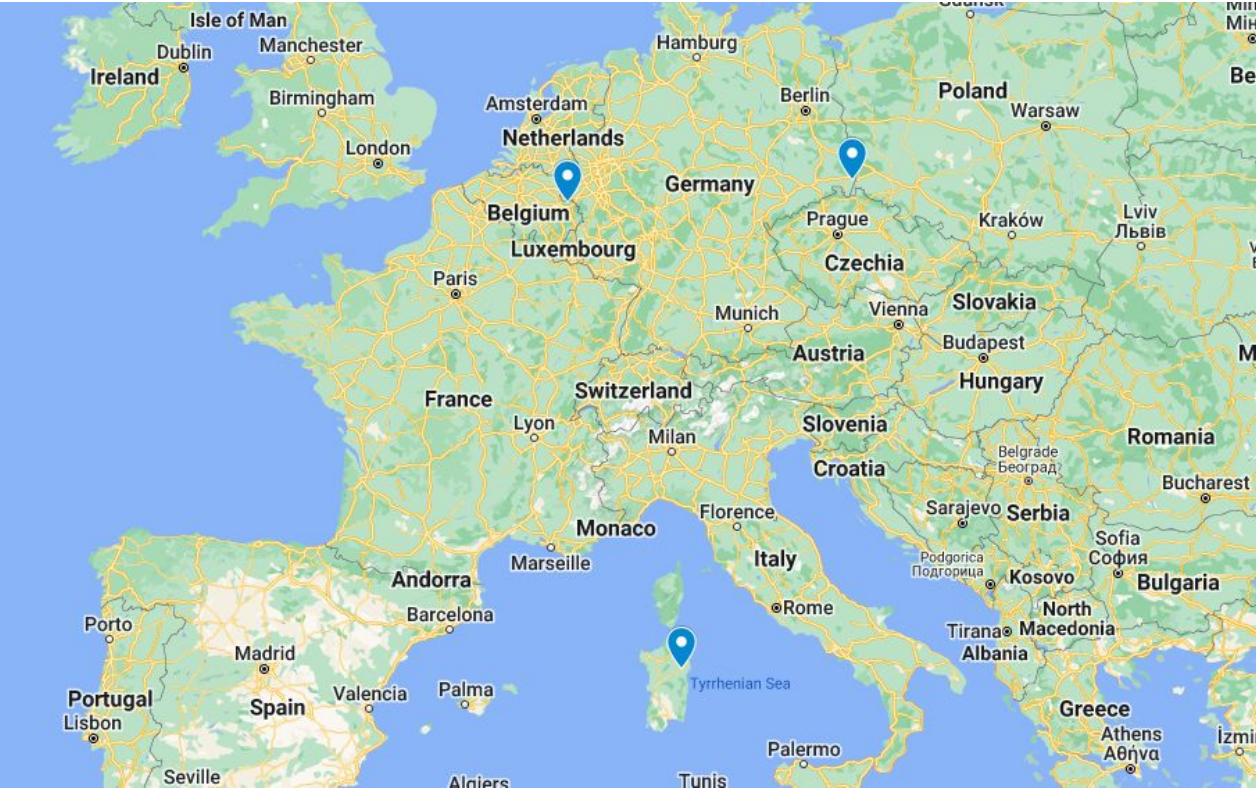
- Lausitz, **Saxony**, Germany

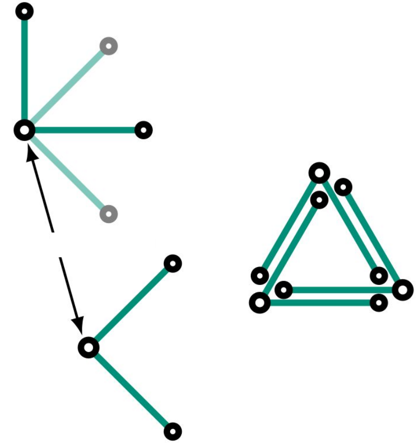
Site evaluation is a complex task dependent on:

- Geophysics and environment
- Finances and organization
- Services, infrastructures

Slide Courtesy Einstein Telescope,
Archisman Ghosh

Geometry





***J*ournal of Cosmology and Astroparticle Physics**
An IOP and SISSA journal

Science with the Einstein Telescope: a comparison of different designs

Marica Branchesi,[1,2,*] Michele Maggiore,[3,4,*] David Alonso,[5]
Charles Badger,[6] Biswajit Banerjee,[1,2] Freija Beirnaert,[7]
Enis Belgacem,[3,4] Swetha Bhagwat,[8,9] Guillaume Boileau,[10,11]

General Relativity and Quantum Cosmology

[Submitted on 15 Mar 2025]

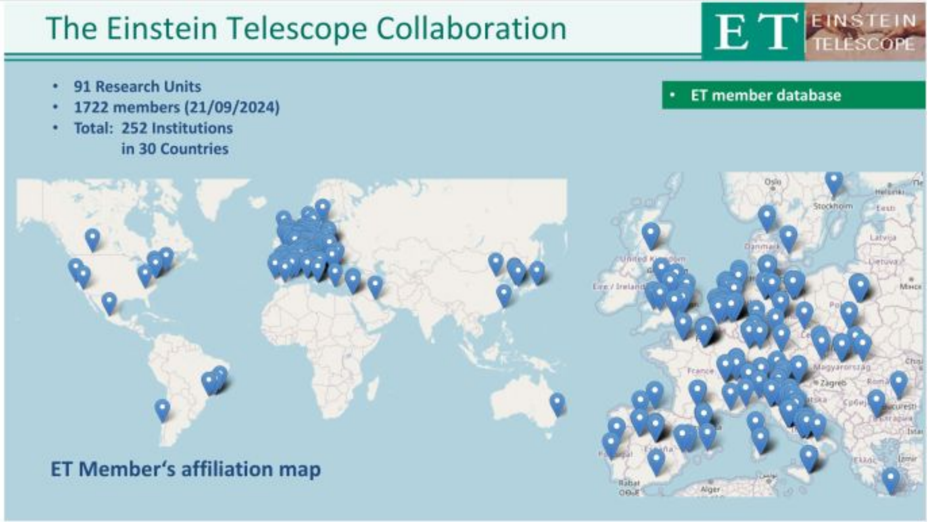
The Science of the Einstein Telescope

Adrian Abac, Raul Abramo, Simone Albanesi, Angelica Albertini, Alessandro Agapito, Michalis Agathos, Conrado Albertus, Nils Andersson, Tomás Andrade, Igor Andreoni, Federico Angeloni, Marco Antonelli, John Antoniadis, Fabio Antonini, Manuel Arca Sedda, M. Celeste Artale, Stefano Ascenzi, Pierre Auclair, Matteo Bachetti, Charles Badger, Biswajit Banerjee, David Barba-González, Dániel Barta, Nicola Bartolo, Andreas Bauswein, Andrea Begnoni, Freija Beirnaert, Michał Bejger, Enis Belgacem, Nicola Bellomo, Laura Bernard, Maria Grazia Bernardini, Sebastiano Bernuzzi, Christopher P. L. Berry, Emanuele Berti, Gianfranco Bertone, Dario Bettoni, Miguel Bezares, Swetha Bhagwat, Sofia Bisero, Marie Anne Bizouard, Jose J. Blanco-Pillado, Simone Blasi, Alice Bonino, Alice Borghese, Nicola Borghi, Ssohrab Borhanian, Elisa Bortolas, Maria Teresa Botticella, Marica Branchesi, Matteo Breschi, Richard Brito, Enzo Brocato, Floor S. Broekgaarden, Tomasz Bulik, Alessandra Buonanno, Fiorella Burgio, Adam Burrows, Gianluca Calcagni, Sofia Canevarolo, Enrico Cappellaro, Giulia Capurri, Carmelita Carbone, Roberto Casadio, Ramiro Cayuso, Pablo Cerdá-Durán, Prasanta Char, Sylvain Chaty, Tommaso Chiarusi, Martyna Chruslinska, Francesco Cireddu, Philippa Cole, Alberto Colombo, Monica Colpi, Geoffrey Compère, Carlo Contaldi, Maxence Corman, Francesco Crescimbeni, Sergio Cristallo, Elena Cuoco, Giulia Cusin, Tito Dal Canton, Gergely Dálya, Paolo D'Avanzo, Nazanin Davari, Valerio De Luca, Viola De Renzis, Massimo Della Valle, Walter Del Pozzo, Federico De Santi, Alessio Ludovico De Santis, Tim Dietrich, Ema Dimastrogiovanni, Guillem Domenech, Daniela Doneva, Marco Drago, Ulyana Dupletsa, Hannah Duval, Irina Dvorkin, Nancy Elias-Rosa et al. (385 additional authors not shown)

Einstein Telescope (ET) is the European project for a gravitational-wave (GW) observatory of third-generation. In this paper we present a comprehensive discussion of its science objectives, providing state-of-the-art predictions for the capabilities of ET in both geometries currently under consideration, a single-site triangular configuration or two L-shaped detectors. We discuss the impact that ET will have on domains as broad and diverse as fundamental physics, cosmology, early Universe, astrophysics of compact objects, physics of matter in extreme conditions, and dynamics of stellar collapse. We discuss how the study of extreme astrophysical events will be enhanced by multi-messenger observations. We highlight the ET synergies with ground-based and space-borne GW observatories, including multi-band investigations of the same sources, improved parameter estimation, and complementary information on astrophysical or

Einstein Telescope Framework

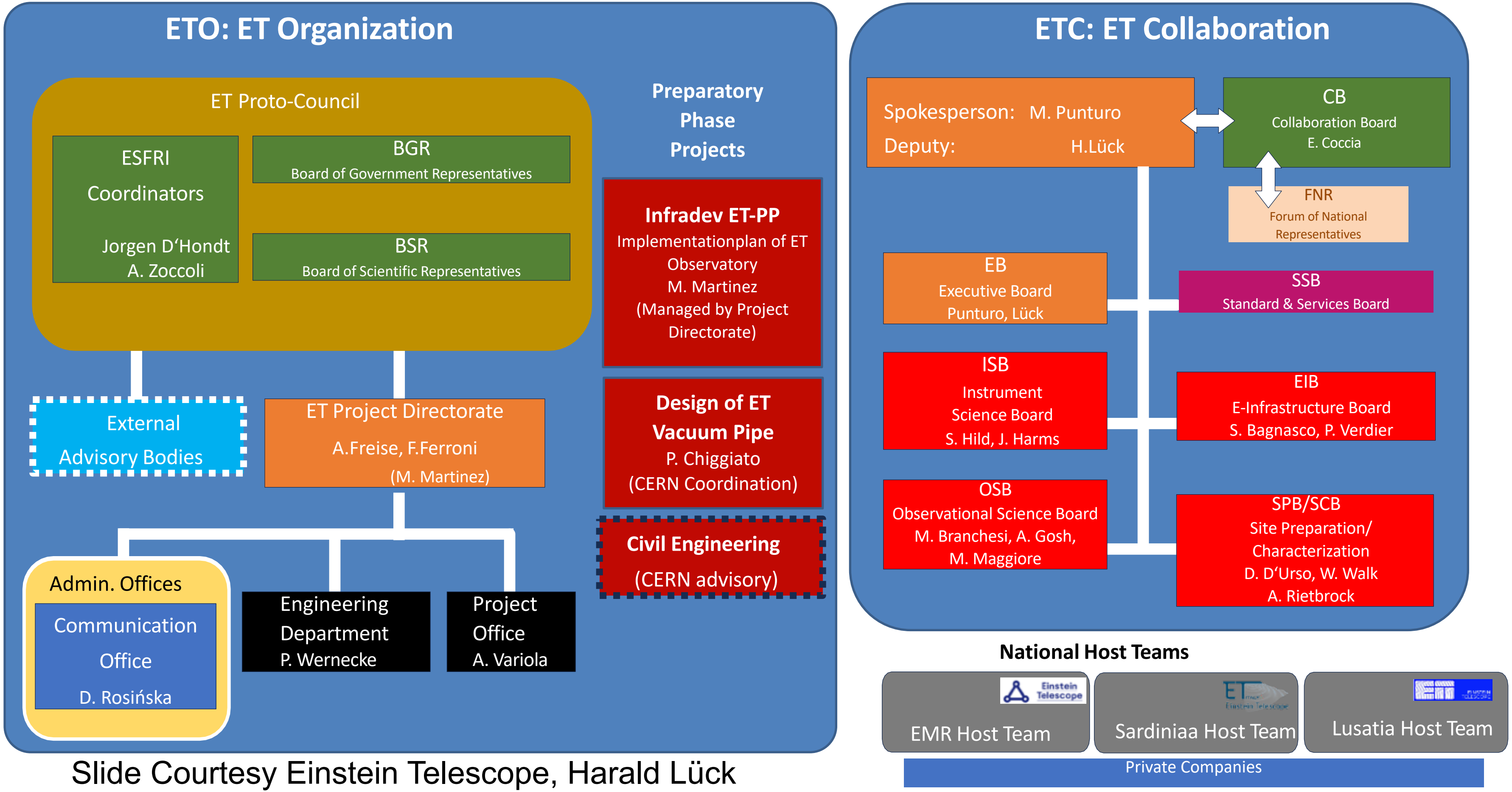
- The ET framework is composed by 3 pillars:
  - **ET Collaboration** formally structured and operative
  - **ET Organization** set up by the funding agencies, with the direct supervision of the involved national governments in Europe
  - **National host teams**, preparing the candidature of the ET sites



Current Pivotal Activities

- **Updating the ET science case**, considering the two possible configurations under evaluation: Δ or 2L
  - Blue Book expected within 02/2025 → **public now!**
- **Defining the key elements of the ET detector**
  - Currently defining the Product Breakdown Structure (PBS)
    - Relational DB of all the ET elements
  - The WBS is the next step
  - Preparing a preliminary TDR (first version expected in 07/2025)
  - ET optical layouts in the Δ and L geometry
- **Evaluating the risks in the ET project**
  - Differential risk evaluation Δ vs 2L (ETC)
  - Detailed risk evaluation (ETO)
- **Realizing a European network of R&D infrastructures**
  - Overall investment >60M€
  - Developing the ET enabling technologies
- **Developing the design of the ET governance, civil and technical infrastructures, evaluating their costs**
  - Both the geometries under evaluation
- **Preparing the bidbook for the candidature of the sites,**
  - National host teams characterizing the sites, ETC validating the results
  - Large contracts (O(20M€) per site) with private company consortia

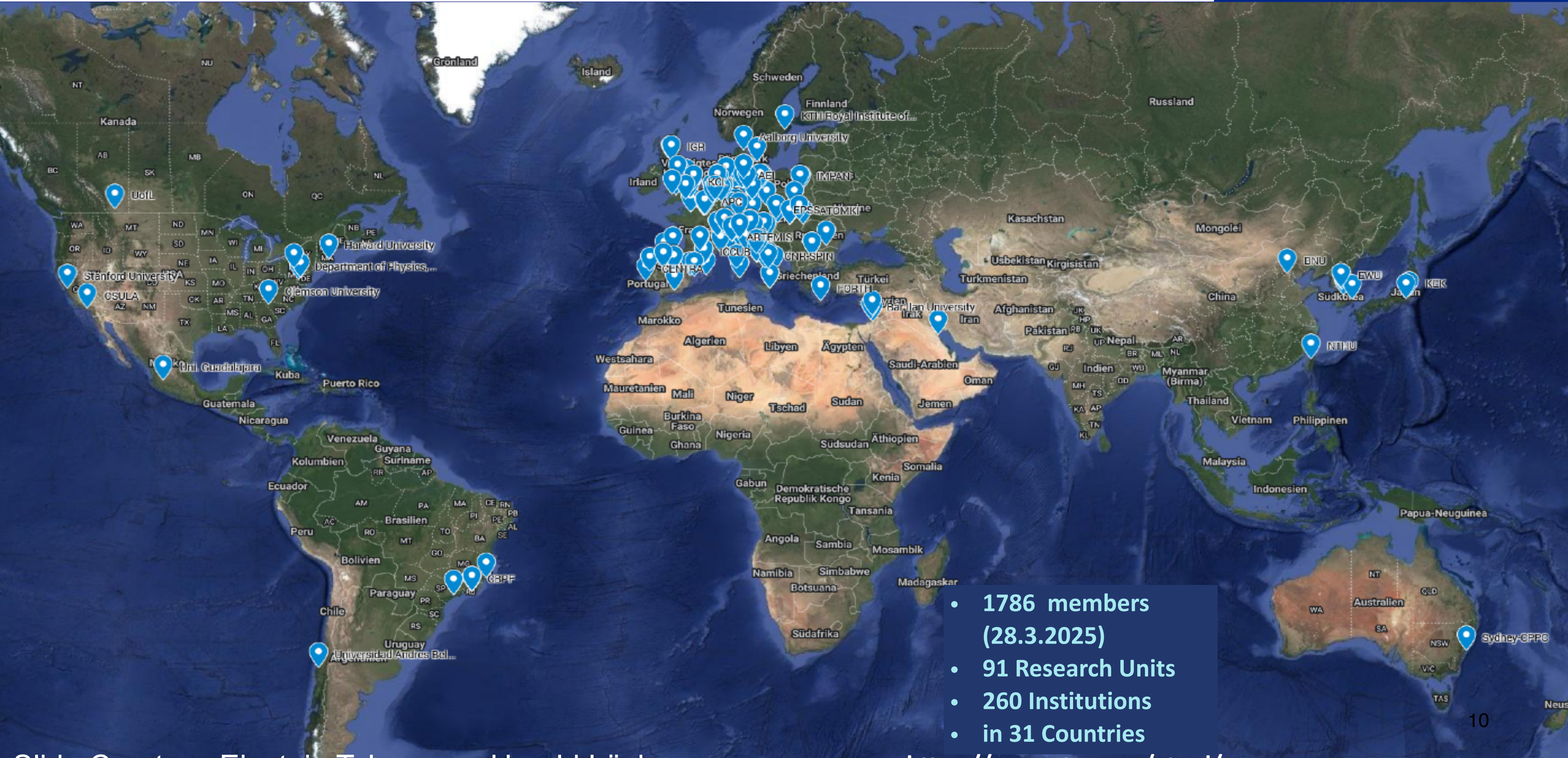
Slide from: Michele Punturo



Slide Courtesy Einstein Telescope, Harald Lück

ET Collaboration Member‘s Affiliation Map

EINSTEIN TELESCOPE



- 1786 members (28.3.2025)
- 91 Research Units
- 260 Institutions
- in 31 Countries

https://apps.et-gw.eu/etmd/

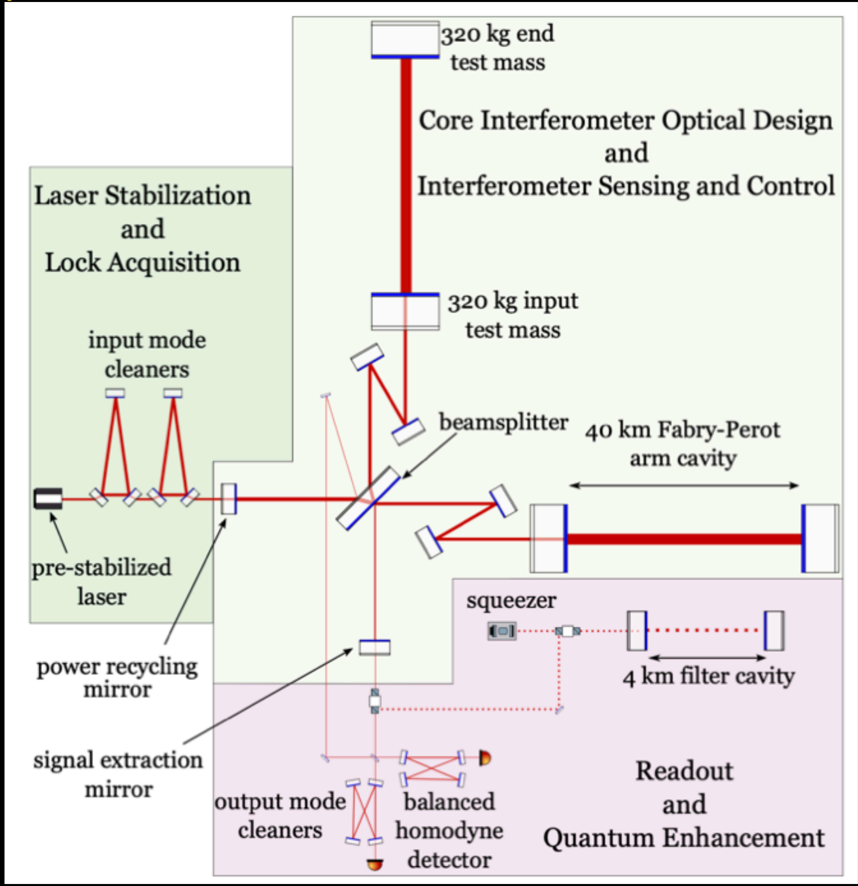
Slide Courtesy Einstein Telescope, Harald Lück

Next-Generation Gravitational-Wave (ngGW) Subcommittee of MPS Advisory Committee (MPSAC)

- Established by NSF, Chaired by Vicky Kalogera (Northwestern)
- Charge: "...recommended list of GW detection network configurations that will deliver a detector with sensitivity an order of magnitude greater than the LIGO A+ design...."
- Cosmic Explorer submission: Evans, Corsi, +: arXiv.2306.13745
- MPSAC "Kalogera Report" approved by NSF, public March 2024
- Outcome: **Cosmic Explorer recommended US next-gen Observatory**
    - If ET: one 40km Cosmic Explorer observatory
    - Else: one 40km and one 20km Cosmic Explorer

https://nsf-gov-resources.nsf.gov/files/mpsac-nggw-subcommittee-repor-2024-03-23-r.pdf?VersionId=uhdtblJUPYsavIl5EUuSNQJcFdRr92q_

Cosmic Explorer design basics

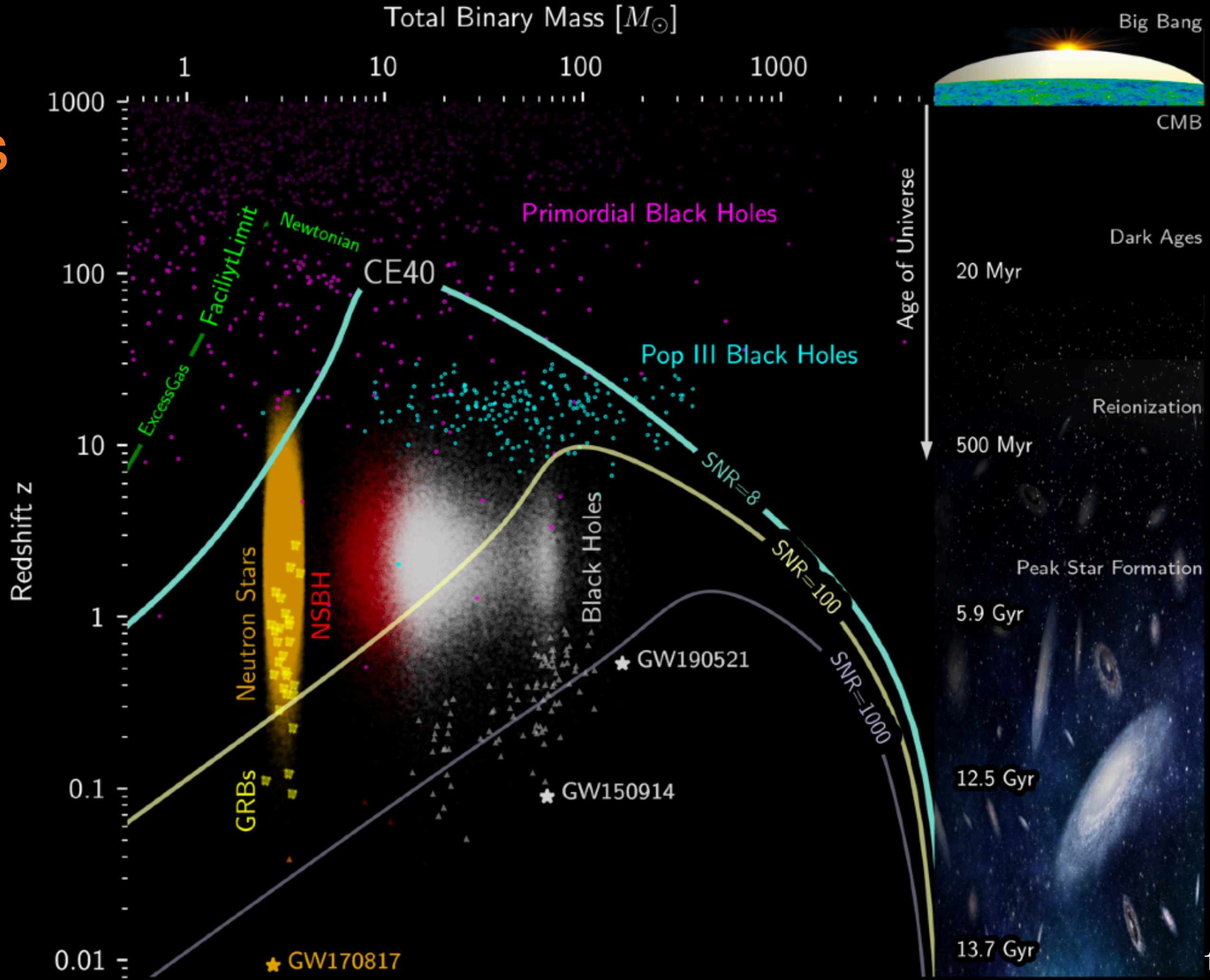


Frequency-dependent squeezing-enhanced dual-recycled Fabry-Perot Michelson interferometers (like LIGO A+)

Quantity	A+ (O5)	A# (O6)	CE
Arm length (km)	4	4	**40**
Wavelength (nm)	1064	1064	**1064**
Mirror mass (kg)	40	**100**	**320**
Mirror diameter (cm)	34	**46**	**70**
Arm power (MW)	0.8	**1.5**	**1.5**
Squeezing (dB)	6	**10**	**10**

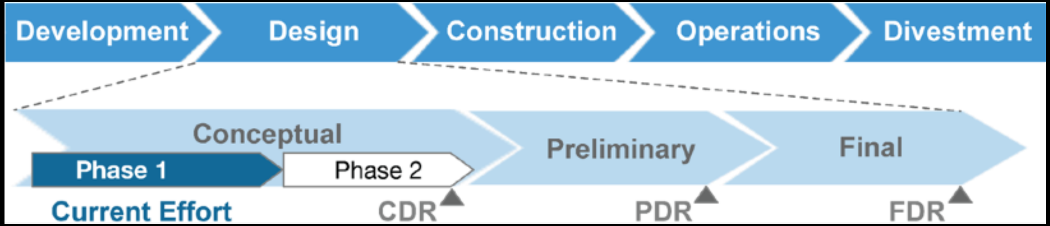
↑ Historical layout, for better, see later slides, talks, ask our session chair Paul Fulda, U Florida

Cosmic Explorer's view into the universe



CE White Paper
for NSF MSCAC ngGW,
arXiv:2109.09882

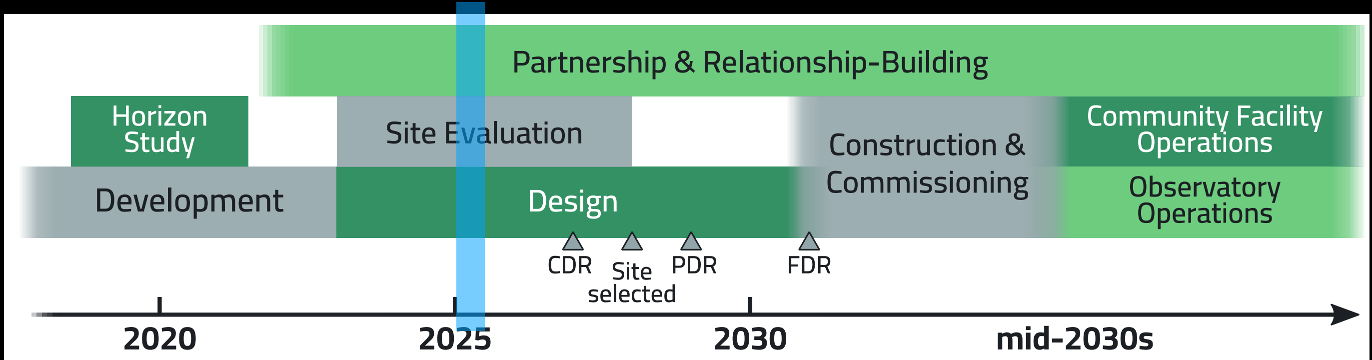
Cosmic Explorer Timeline



Infrastructure Lifecycle from NSF's [Research Infrastructure Guide]

Project phases

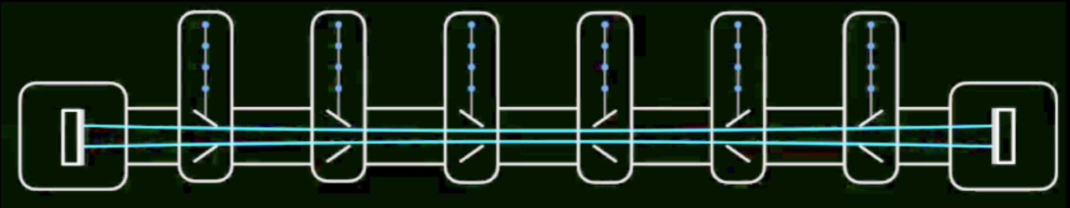
- Conceptual Design (3+years)
- Preliminary Design (2-3 years)
- Final Design (2 years)
- Construction (5 years)
- Operations (25 - 50 years)
- Decommissioning/Divestment



White Paper for NSF MSCAC ngGW
https://arxiv.org/abs/2306.13745

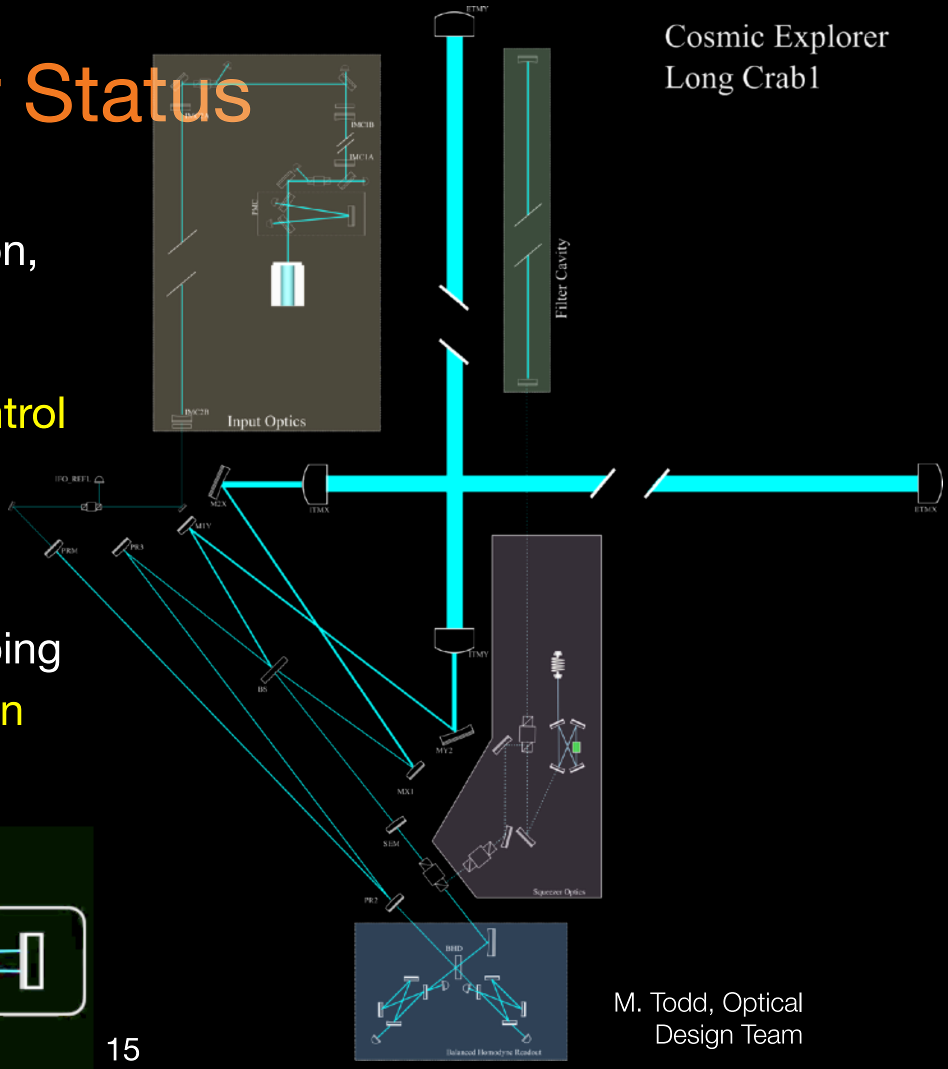
Cosmic Explorer Status

- Site evaluation: completed national identification, visiting regions, developing relationships
- Optical design converging on “Long Crab” with “Reverse aLIGO” as backup and wavefront control
- Stray light mitigation: baffle strategy solidifying
- Gravity gradient noise mitigation, data system architecture efforts starting
- Science Traceability Matrix (ala NASA) developing
- Observatory civil costing requests in preparation
- CE Beamtube Experiment started



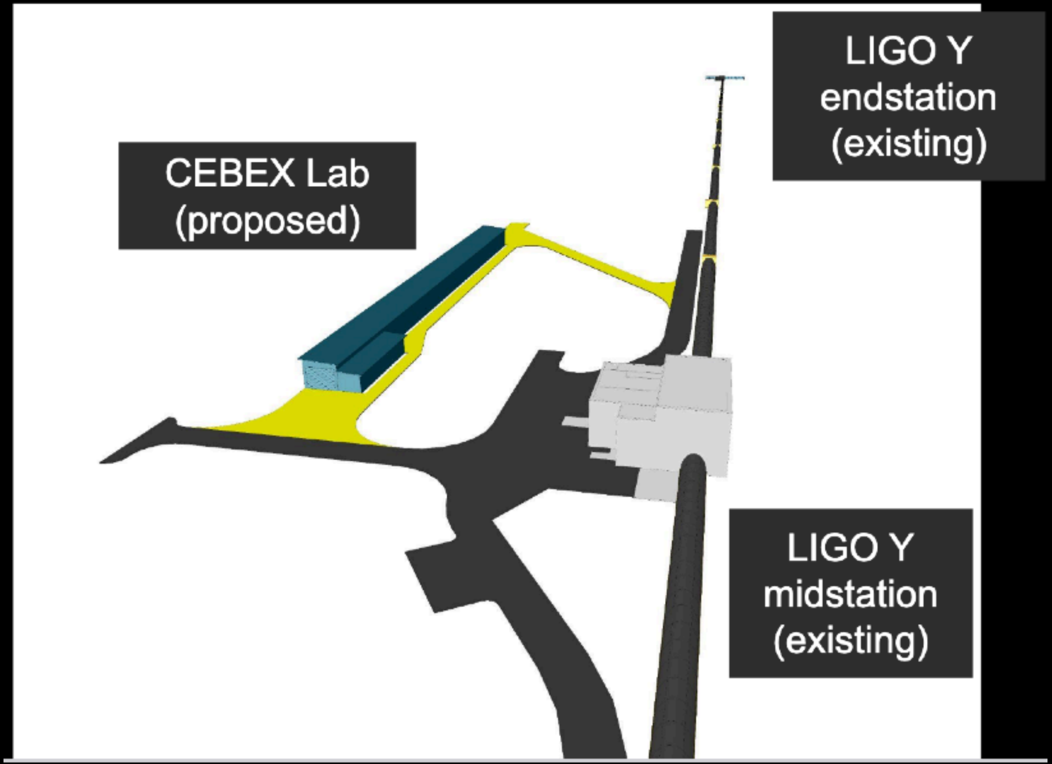
Suspended Baffle Configuration

A. Kontos, Stray Light Team



M. Todd, Optical Design Team

CEBEX Underway at LIGO Hanford



At LIGO Hanford, 120m-long sector test of Cosmic Explorer beam tube vacuum technology, with full instrumentation

Credit: Mike Zucker

https://dcc.cosmicexplorer.org/CE-G2400094

Physics > Instrumentation and Detectors

[Submitted on 1 Oct 2024]

Criteria for identifying and evaluating locations that could potentially host the Cosmic Explorer observatories

Kathryne J. Daniel, Joshua R. Smith, Stefan Ballmer, Warren Bristol, Jennifer C. Driggers, Anamaria Effler, Matthew Evans, Joseph Hoover, Kevin Kuns, Michael Landry, Geoffrey Lovelace, Chris Lukinbeal, Vuk Mandic, Kiet Pham, Jocelyn Read, Joshua B. Russell, Francois Schiettekatte, Robert M. S. Schofield, Christopher A. Scholz, David H. Shoemaker, Piper Sledge, Amber Strunk

Cosmic Explorer (CE) is a next-generation ground-based gravitational-wave observatory that is being designed in the 2020s and is envisioned to begin operations in the 2030s together with the Einstein Telescope in Europe. The CE concept currently consists of two widely separated L-shaped

Thank you, Questions?