Gravitational Waves, and the Einstein Telescope

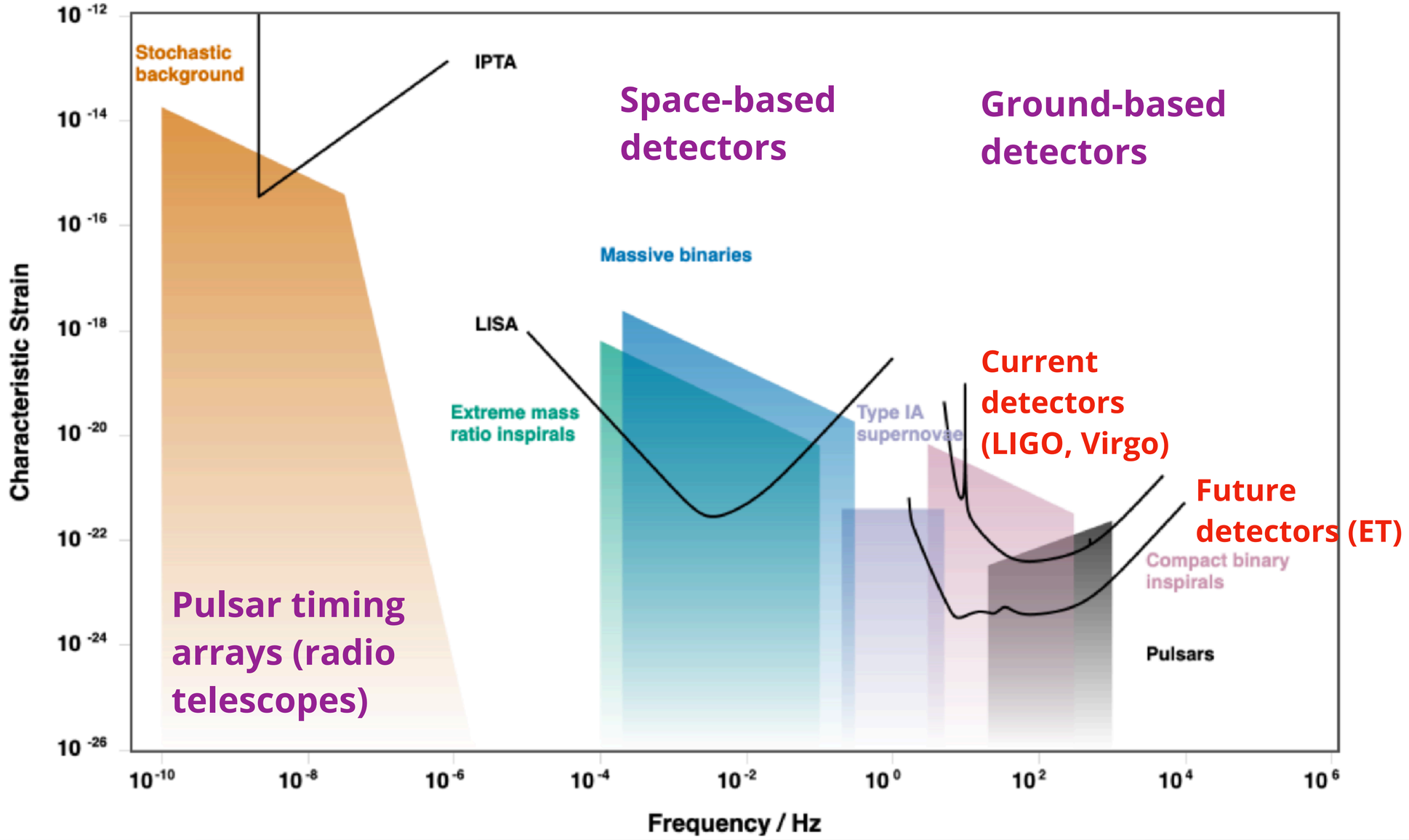
Andreas Freise

Nikhef Scientific diversity meeting (ESPP-NL), 13.01.2025

Gravitational Waves

- It took 100 years from Einstein's prediction to the first detection.
- Gravity is a weak force and spacetime "very stiff" → we need extreme astrophysical sources to generate measurable signals.
- Sources are time-varying mass quadrupoles, they generate propagating ripples in spacetime (GWs).
- The 10-year anniversary of the first detection is coming up this year!
- Gravitational waves opened up a whole new observable spectrum.
- With the Einstein Telescope we are preparing a new large research infrastructure for GW science in the next 60 years.

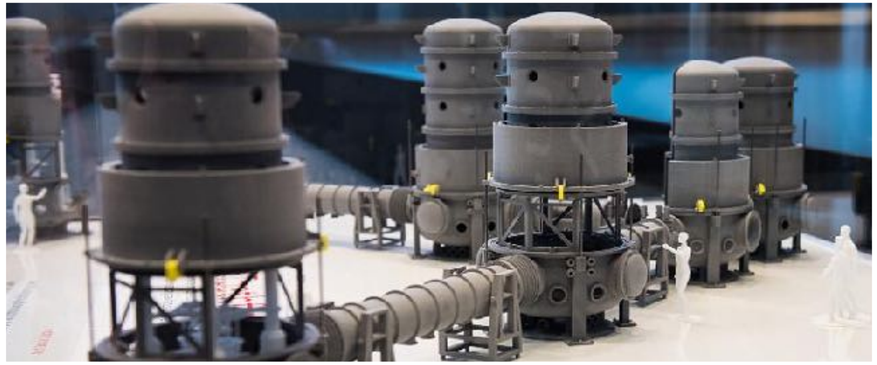
The GW spectrum



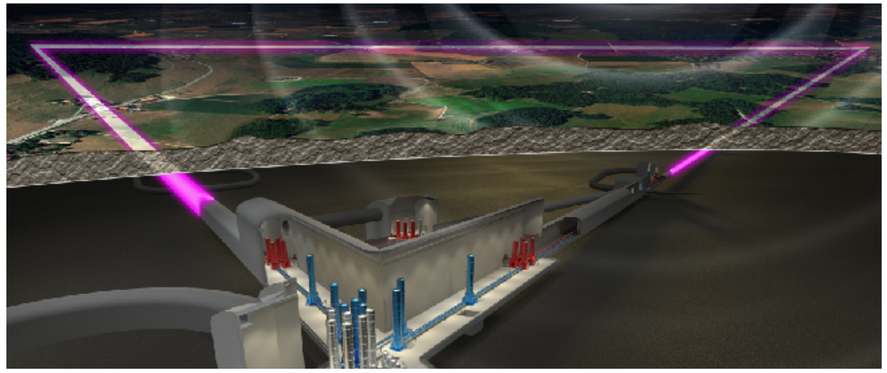
[http://gwplotter.com/]

GW programme at Nikhef: Ground-based detection

Virgo: large-scale detector in Italy, able to detect GWs, **currently taking scientific data, hardware upgrades are being prepared.**



ETpathfinder: 10m scale prototype interferometer, a testbed for future GW technologies, **currently under construction.**

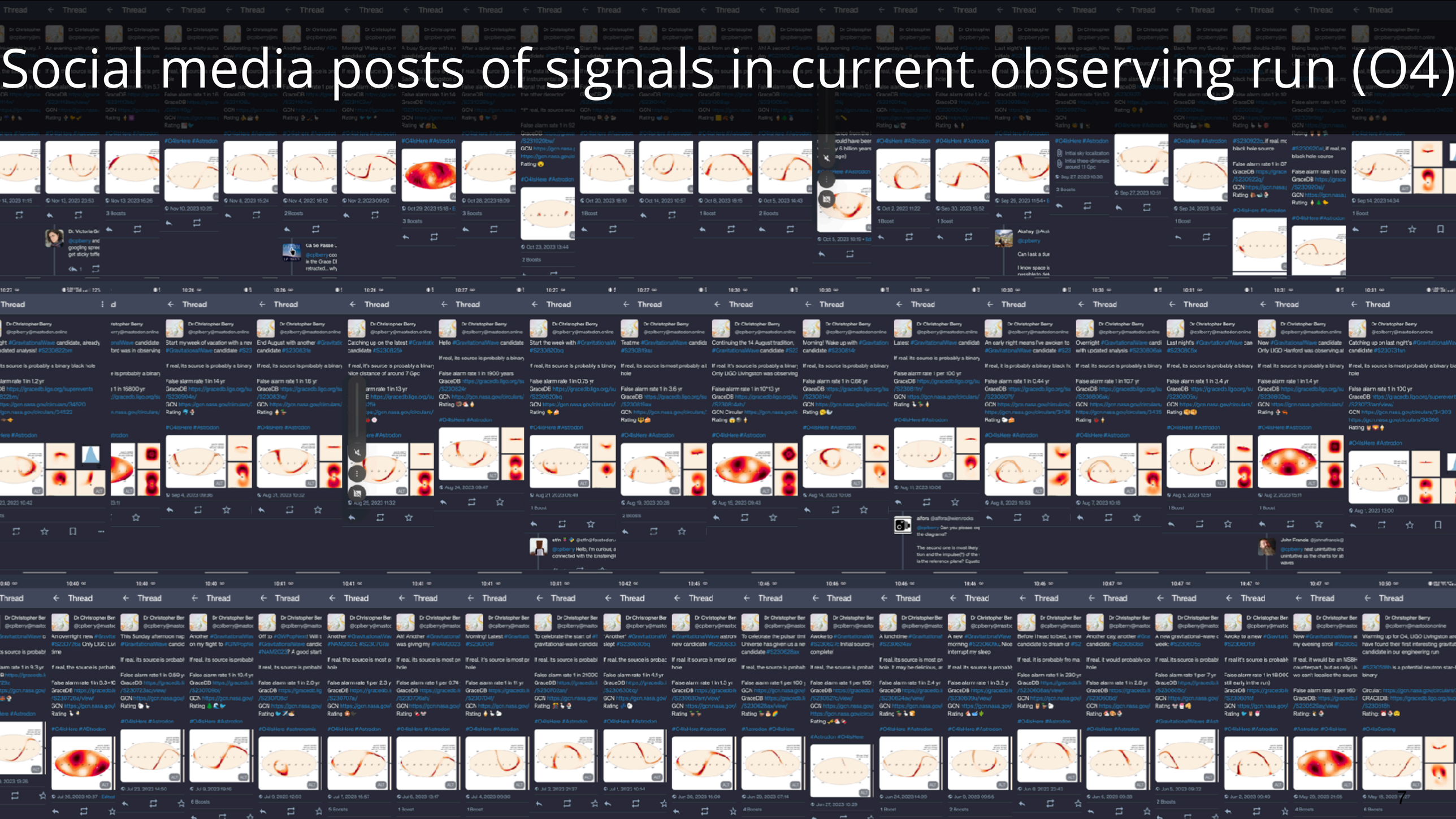


Einstein Telescope: plan for future observatory in Europe, **research and technology development, preparation for new large infrastructure.**

Current affairs at Virgo and LIGO

Global detector network (LVK)

Social media posts of signals in current observing run (O4)

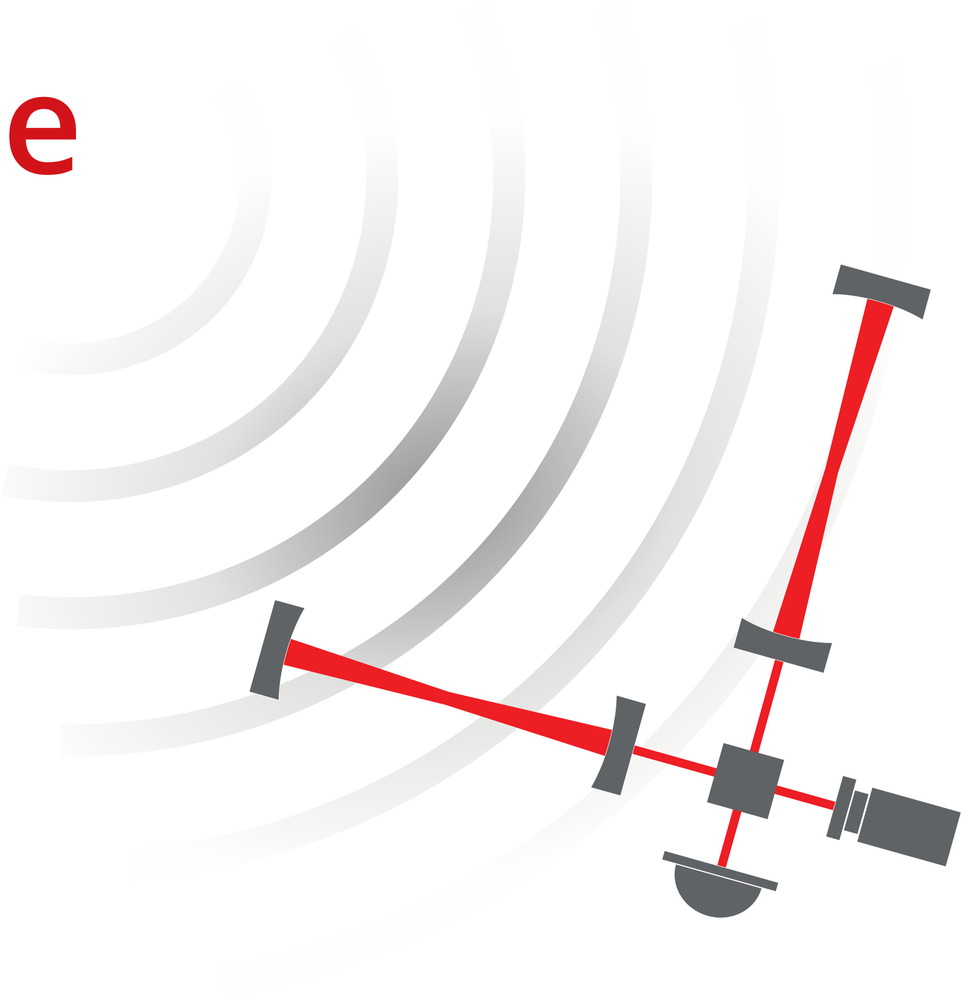


2024 VIRGO AWARDS

IGWN: one to rule them all!

- The LIGO, Virgo and Kagra collaborations are planning to **dissolve** and to form a **one joint collaboration**, currently called ‘International Gravitational Wave Network’ (IGWN).
- IGWN originally started with the idea to find away to obtain more computing resources for the joint data analysis.
- **During an IGWN committee meeting, here at Nikhef in January 2024, we suddenly decided for a much bolder change! This will have a strong impact on all projects!**
- A formation committee is now writing the charter, bylaws and policies and procedures. Plan is to transition this year.

The Einstein Telescope



The science case for ET

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 (with 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

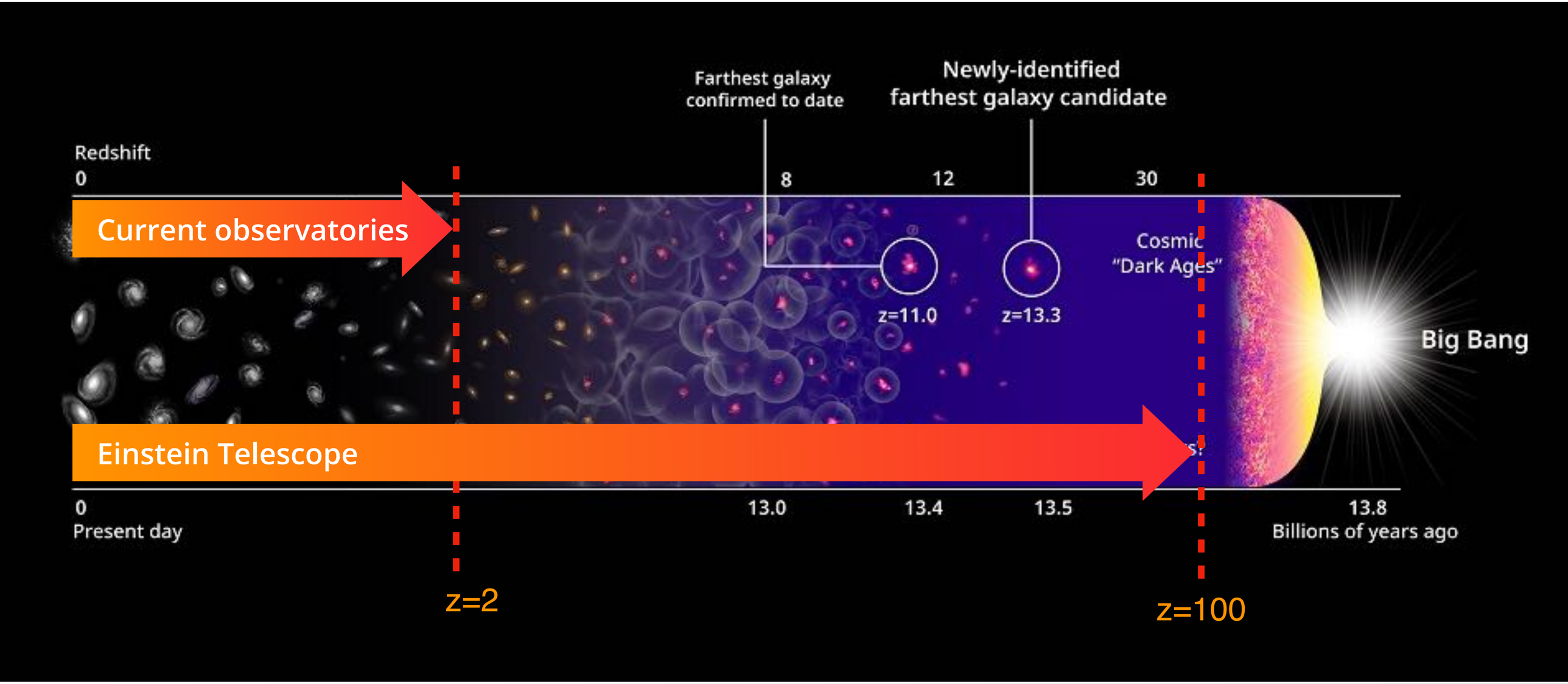
Tests of General Relativity
- post-Newtonian expansion
- strong field regime

Dark matter
- primordial BHs
- axion clouds, dark matter on compact objects

Dark energy and modifications of gravity
- dark energy equation of state
- modified GW propagation

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

A leap into the past



ET Organisation (ETO)

Nikhef is co-leading the new Einstein Telescope Organisation
ETO management team : 11 people
ETO total in-kind staff : 36 people, and growing!

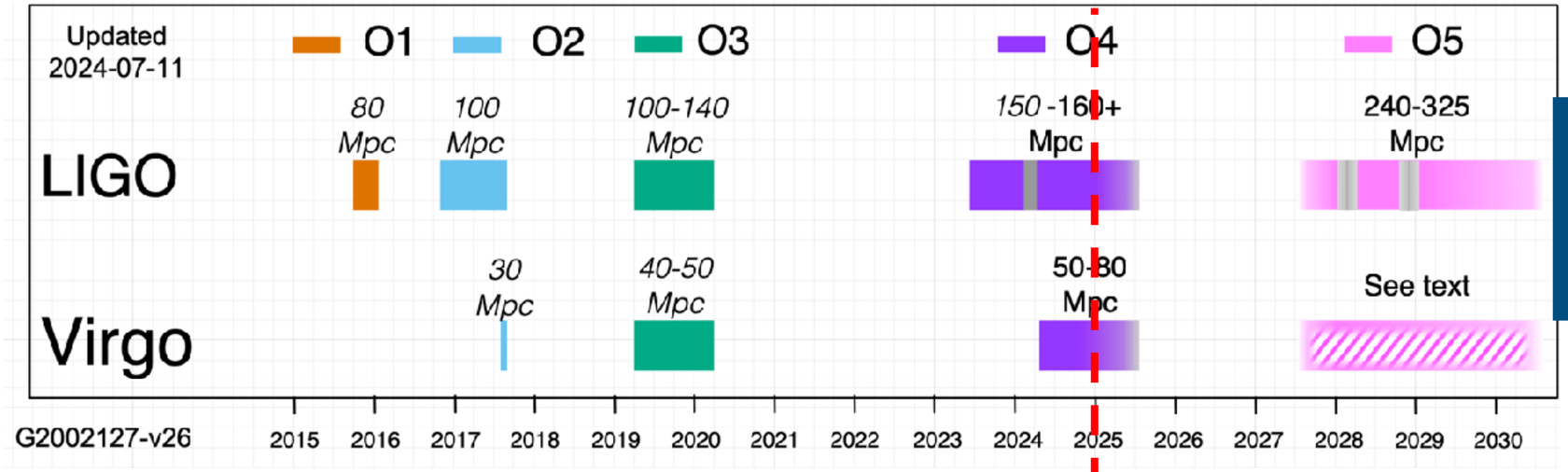
Einstein Telescope at CERN

not science

- We already make good use of CERN's technical support (vacuum, civil engineering). We strongly believe this partnership is not only useful for ET but also CERN and Nikhef. (Instead of e.g. us partnering with ESO).
- We want CERN technical teams to continue to provide support for the ET project. But we would like CERN to be allowed to use some of its own funds for their technical support.
- ET must not become a competitor to any accelerator related project!
- We do not expect CERN to build or run ET. But the technical and operational expertise from CERN would speed up the development of the infrastructure, and reduce the risk and cost of this project.

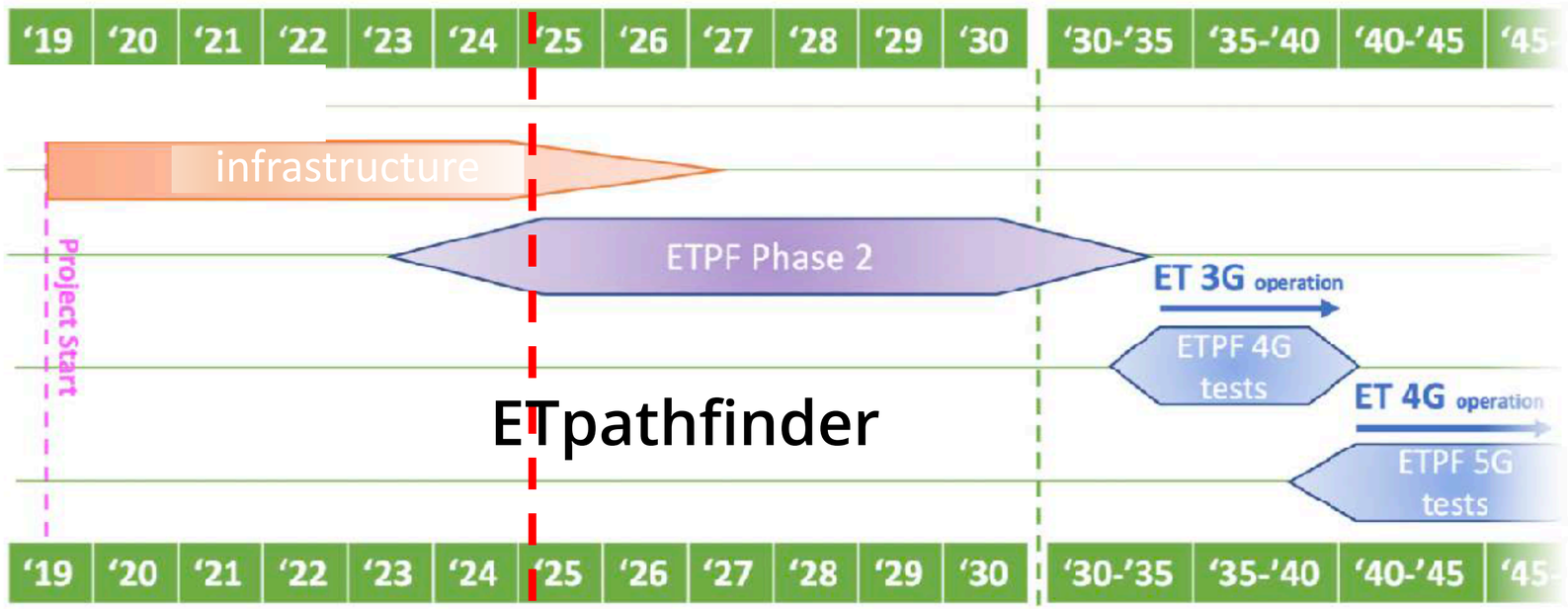
Project timelines

Long term schedule



Upgrades and observations until CE and ET operate (>2035)

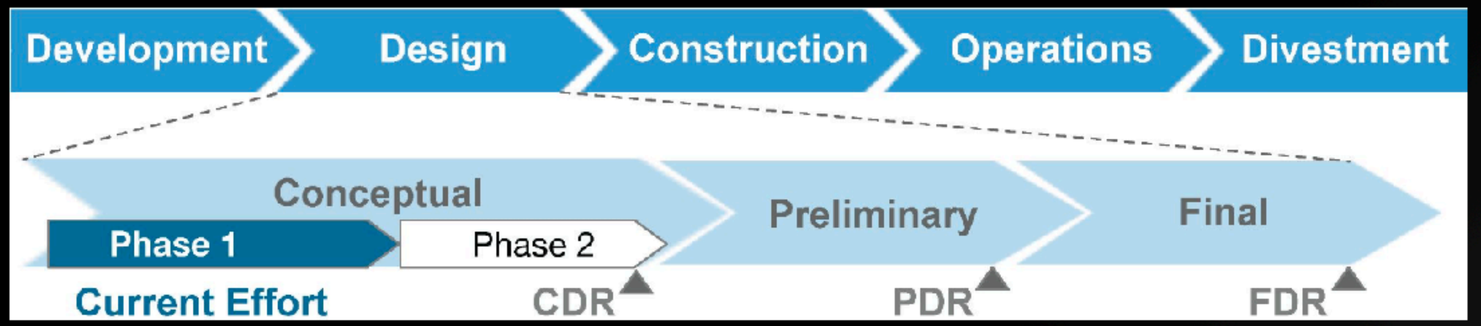
https://observing.docs.ligo.org/plan/

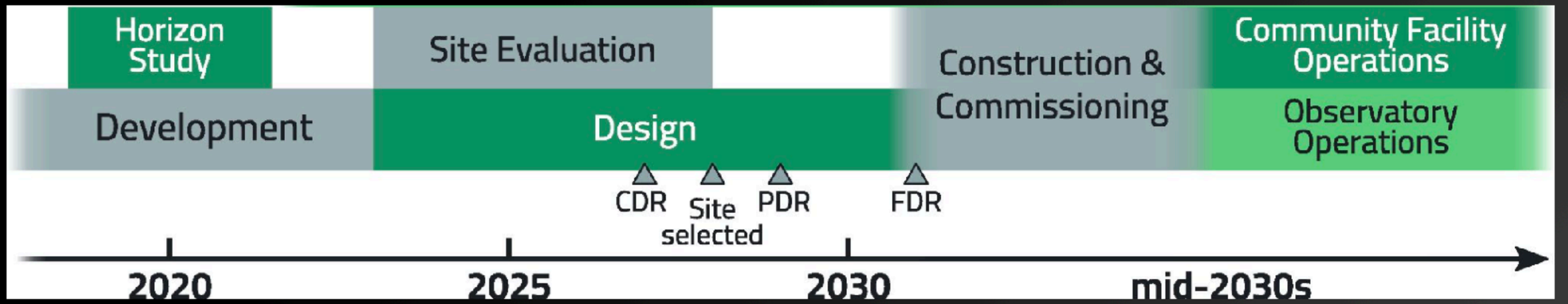


[Paul Kuijer]

Cosmic Explorer Timeline

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





[Matt Evans]

Terminology from NSF infrastructure lifecycle, documented in the Research Infrastructure Guide (RIG)
https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf21107

LIGO Observatories, future upgrades

- LIGO-T2200287: “Current planning has O5 running through the end of 2028, so the first post-O5 upgrades should be designed to be available for installation at the start of 2029, with operation continuing through the mid-2030s.”
- LIGO India will add a third detector to LIGO.
- Next upgrade plan “LIGO A♯”

  [LIGO-T2200287 / LIGO-T2200287]
- All upgrades to be discussed in global scope.
- “Dovetailing with Next Generation Facilities” [LIGO-P2300166]

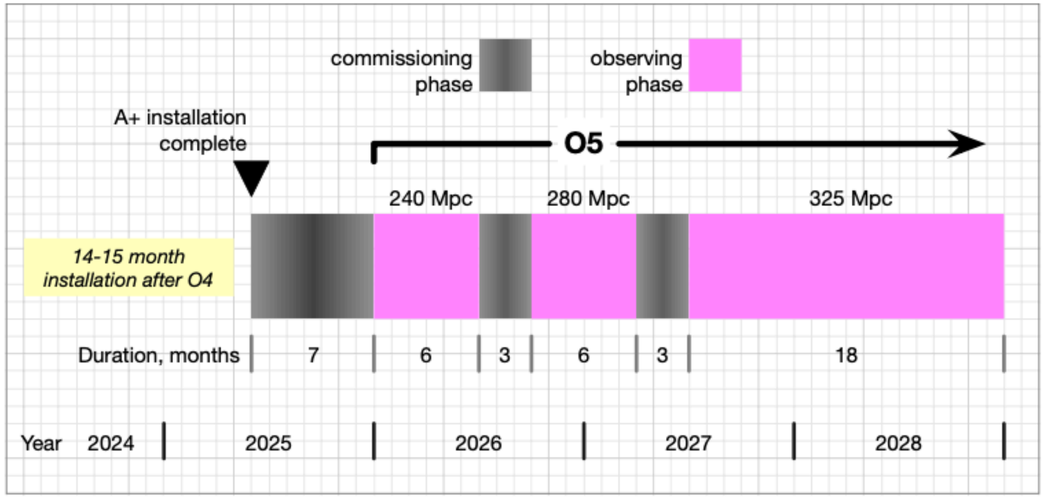


Figure 3: Proposed O5 timeline, with O5 ending at the end of 2028.

Virgo detector

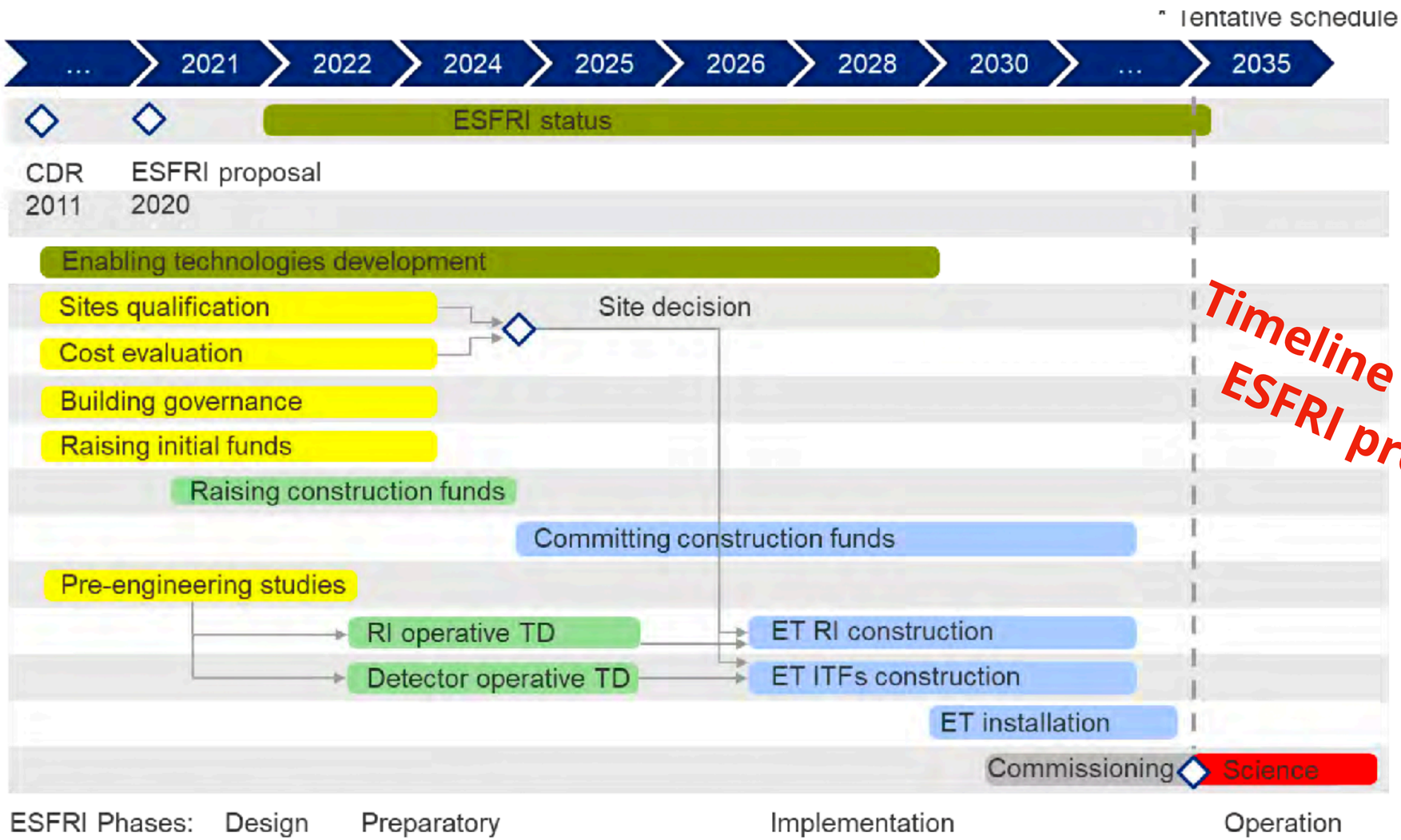
- At Nikhef we are preparing a number of hardware upgrades (funded by a NWO WI) for Virgo upgrade towards O5.

- At the same time the international project and organisation are undergoing major changes.

- A re-orgnanisation of the Virgo and EGO as organisations is underway (Jorgen D'Hondt and Rosemarie Aben are members of the 'Implementation Committee'). The idea is to create a 'VirgoLab', inspired by LIGO Lab, but in a distributed form :"VirgoLab consists of cross-institutional VirgoLab Projects and VirgoLab Technical Teams with personnel from EGO and the External Labs."

- Upgrade plans and decisions for the project: A key decision for Virgo's participation in the O5 run is whether to install stable recycling cavities ("Plan A") or proceed with other upgrades and join O5 with reduced sensitivity ("Plan B"). The decision will be made in the first half of 2025, considering factors like technical readiness, LIGO-Virgo-KAGRA (LVK) plans, run planning, and available funding.

The ET timeline, now outdated



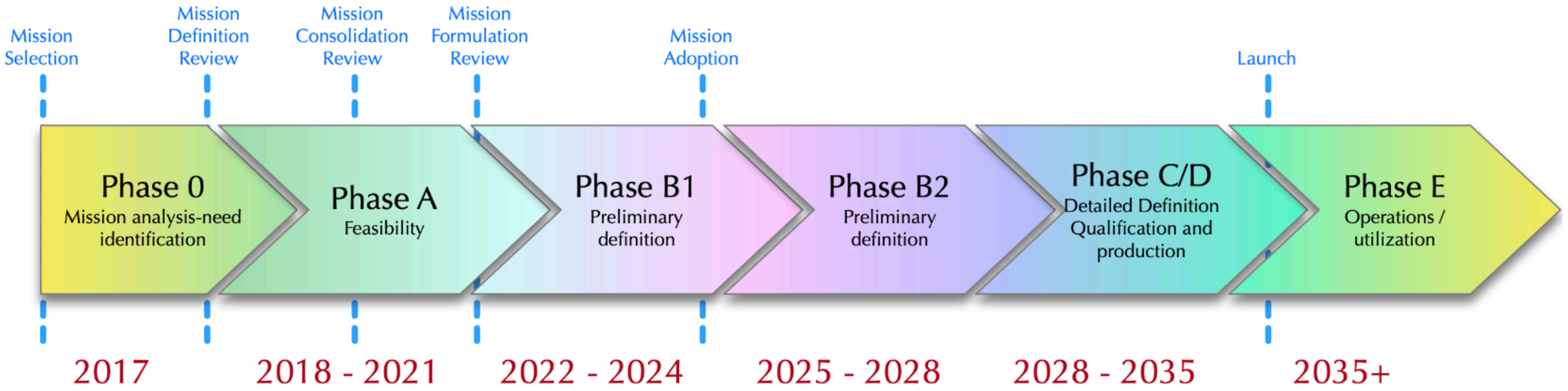
Timeline from the 2020 ESFRI presentation

ETO Milestones

We have identified critical milestones, many which are out of our (ETO) control, but are essential for advancing along the defined roadmap (timings are estimated):

1) Approval of ETO's new organisational and legal definition, Q1 2025
2) ETO resources available, Q1 – Q4 2025 (money – in-kind personnel)
3) Project Baseline definition and release 1.0.
   (limited to detector and preliminary civil engineering), Q4 2025
4) Project structure finalised, Q3 2025
5) New ESFRI roadmap release, 2026
6) Initial site preparation work completed 2025-2026
7) Technical work with CERN completed 2027
8) The bid process definition, TBD
9) Site selection process, TBD

LISA


Mission Selection
Mission Definition Review
Mission Consolidation Review
Mission Formulation Review
Mission Adoption
Launch
Phase 0
Mission analysis-need identification
Phase A
Feasibility
Phase B1
Preliminary definition
Phase B2
Preliminary definition
Phase C/D
Detailed Definition
Qualification and production
Phase E
Operations / utilization
2017
2018 - 2021
2022 - 2024
2025 - 2028
2028 - 2035
2035+

Statements

- “Gravitational wave are a powerful new messenger from cosmic objects that are otherwise hard to observe. Earth-based detectors with a sensitivity such as the Einstein Telescope are required to fully realise the potential of gravitational-wave science, providing unique experimental data for fundamental physics, astrophysics and cosmology.”

- "The Einstein Telescope will provide Europe with a flagship science project. This facility will operation for at least 50 years. The technical and operational expertise from CERN would speed up the development of the infrastructure, and reduce the risk and cost of this project."

Summary

- Gravitational wave detectors have successfully opened a new window to the universe, providing unique new data.
- Fully exploiting this new area of science cannot be done in the current 30-years old infrastructures.
- New research infrastructures such as the Einstein Telescope (ET) are being prepared now.
- The ET project strongly benefits from CERN. Nikhef and CERN can benefit from ET. The ET leadership has a strong CERN background.
- We plan for ET to be visible during the CERN strategy update, and aim at a small change in the status quo. Our exact strategy is still to be decided. Input is very welcome!

… end.