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.
- sources to generate measurable signals.
- spacetime (GWs).
- The 10-year anniversary of the first detection is coming up this year!
- Gravitational waves opened up a whole new observable spectrum.
- GW science in the next 60 years.

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• Gravity is a weak force and spacetime "very stiff" \rightarrow we need extreme astrophysical

• Sources are time-varying mass quadrupoles, they generate propagating ripples in

• With the Einstein Telescope we are preparing a new large research infrastructure for





The GW spectrum





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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.



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Current affairs at Virgo and LIGO



Global detector network (LVK)

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VIRGO

GEO 600



LIGO

LIGO INDIA KAGRA

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2024 VIRGO AWARDS



IIOJJVIRGD



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.
- A formation committee is now writing the charter, bylaws and policies and procedures. Plan is to transition this year.

• 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!







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



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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

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A leap into the past

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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

- 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

Updated 2024-07-11	— 01	O 2	— O3	— O
LIGO	80 Mpc	100 Мрс	100-140 Мрс	<i>150</i> -16 Мрс
Virgo		30 Мрс	40-50 Мрс	50- M
G2002127-v26	2015 2016	2017 2018 2	019 2020 2021	2022 2023 2024 20

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

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Cosmic Explorer Timeline





https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf21107

Duration of Project phases

- Decommissioning/Divestment

Terminology from NSF infrastructure lifecycle, documented in the Research Infrastructure Guide (RIG)



LIGO Observatories, future upgrades

- LIGO-T2200287: "Current planning has O5 running through the end of 2028, so 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]

the first post-O5 upgrades should be designed to be available for installation at the start



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





- upgrade towards O5.

- funding.





Virgo detector

• At Nikhef we are preparing a number of hardware upgrades (funded by a NWO WI) for Virgo

• 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







The ET timeline, now outdated







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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

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LISA







Statements

- and cosmology."
- risk and cost of this project."



• "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

• "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









Summary

- 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!

• Gravitational wave detectors have successfully opened a new window to the universe,









Andreas Freise, 13.01.2025

... end.



