Analysis and recommendations from the French gravitational wave community on the Einstein Telescope

The Scientific Council of the GdR Ondes Gravitationnelles[1]

1. Introduction

Planned for the 2040 timeframe, the Einstein Telescope[2] (ET) project was endorsed by the ESFRI[3] in 2021, which led to the establishment of the international ET consortium (1,959 members from 284 laboratories in 33 countries) at the beginning of a preparatory phase spanning 2022–2026. ET will be an underground gravitational wave detector (a few hundred meters deep) and will consist of two types of interferometers: one operating at room temperature with high laser power optimized for high frequencies (based on technologies developed in LIGO and Virgo), and the other operating at cryogenic temperatures optimized for low frequencies. These choices maximize sensitivity at low frequencies, which is crucial for many scientific outcomes (early alerts for multi-messenger follow-up, massive and distant objects, waveform analysis of the inspiral phase, etc.), without compromising the sensitivity at high frequencies needed for other results (tests of general relativity, supernovae, neutron stars, etc.).

The GdR "Gravitational Waves," which includes 340 members and brings together French scientists in this field (ET, Virgo, LISA, PTA, theory, etc.), met in Paris on October 13, 2025, at the request of IN2P3, to discuss two questions considered very important for the future of the community: 1) What are the synergies and complementarities between ET and the French community? 2) What are the scientific and strategic issues related to the choice of geometry (triangle, L-shape) and the ET site? This letter summarizes the GdR discussions and highlights the points of convergence within the French community.

[1] https://gdrgw.in2p3.fr/.
[2] https://einsteintelescope.eu/.
[3] European Strategy Forum on Research Infrastructures : https://www.esfri.eu/.

2. Synergies and complementarities between ET and the French community (PTA, LISA, theory)

Synergies with theory

ET is part of the same scientific continuum as the current ground-based networks LIGO, Virgo, and KAGRA[4] (which detect gravitational waves in the ~10 to ~10^4 Hz frequency range), the LISA space mission[5] (~10^{-4} to ~10^{-1} Hz), radio observations of Pulsar Timing Arrays (PTA)[6] (~10^{-9} to ~10^{-7} Hz), and future CMB observations[7] (~10^{-16} Hz), all aiming to observe the Universe through gravitational waves. In particular, all these observations—except for those of the CMB—share a common need to develop sufficiently precise waveform models to fully exploit gravitational wave signals. The analytical and numerical efforts required to produce waveforms accurate enough for ET and other future detectors are thus inherently shared within the community. This theoretical expertise, which is crucial for the scientific success of ET, is particularly well-developed within the French community.

Synergies with data analysis

Furthermore, data analysis for ET will differ significantly from that currently conducted by the LIGO-Virgo-KAGRA (LVK) collaboration. In many respects, especially with the sensitivity expected in its final configuration, it will be closer to what is envisioned for LISA, involving long signals, a very large number of events, and strong correlations between sources and parameters. Numerical methods, particularly those for data analysis, are therefore inherently interconnected: advancements in one community can be readily applied to another. It will also be necessary to develop astrophysical and cosmological inference pipelines capable of processing populations on the order of millions of sources, imposing strong requirements in terms of scalability, global fitting, and high-performance computing. These methodological developments will be essential in each of the frequency bands (PTA, LISA, ET) considered separately. The French community, with its strong involvement in the LVK collaboration, is already making a decisive contribution to the development of the methods and infrastructures essential for future gravitational wave detectors, as evidenced, for example, by its leadership in developing the LISA Distributed Data Processing Centre at CNES.

Synergies with other observations (electromagnetic observations, other gravitational wave observation bands, astroparticles)

ET will need to be integrated into a multi-band and multi-messenger observational landscape. Coordination with gamma-ray observatories (CTA, HESS, SVOM, THESEUS, COMCUBE), neutrino detectors (KM3NeT, DUNE), and other electromagnetic follow-up facilities (such as LSST and Euclid)—in which the French community has already made significant

[4] https://www.ligo.caltech.edu/ ; https://www.virgo-gw.eu/ ; https://gwcenter.icrr.u-tokyo.ac.jp/en/.
[5] https://www.lisamission.org/.
[6] https://ipta4gw.org/.
[7] https://cmb-s4.org/.

investments—will be crucial for fully exploiting transient sources, particularly compact binary systems. Improved localization requires the presence of a network, and the commissioning of Cosmic Explorer[8] (CE) would be a major asset. Effective coordination among the communities involved in ET, CE, and second-generation detectors is essential to optimize the scientific exploitation of a global network incorporating third-generation detectors. The synergy with gravitational wave detectors operating in other frequency bands is particularly strong for the study of stochastic backgrounds, which could produce signals detectable by ET, LISA, PTAs, and CMB experiments. Complementarity with LISA is further enhanced by the existence of multi-band sources, potentially observable first by LISA and then by ET. For these sources, it is important that ET be operational during or shortly after (within a few years at most) LISA's operation. Finally, it should be noted that some scientific objectives do not depend on the establishment of a global network of third-generation detectors, although they would be significantly strengthened by such a network. For example, a single third-generation detector would not only enable the detection and characterization of potential exceptional gravitational wave signals but also allow the study of the properties of black hole and neutron star populations at high redshift.

Synergies in technological development

KAGRA provides valuable experience in accessing low frequencies, cryogenics, and underground installation. High-frequency detectors like LIGO/Virgo serve as testbeds for the technologies required for ET, whether in high-power lasers, squeezing sources, or advanced detection schemes such as balanced homodyne detection (BHD). In this context, LIGO, Virgo, and KAGRA play a research and development role for ET. There is also synergy with Cosmic Explorer (CE) in designing the detectors, with joint instrumental meetings (XGCD meetings) and certain infrastructure aspects, particularly vacuum tubes, which are also linked to CERN. Collaboration between CE and ET to share expertise in studying, budgeting, and modeling noise sources will be particularly important. The establishment of the International Gravitational Wave Network (IGWN) in place of LVK foreshadows the creation of a global collaboration for third-generation detectors, within which these co-developments can be formalized.

3. Scientific and strategic stakes in choosing the geometry (triangular, L-shaped) and the site

The Einstein Telescope project envisions two competing technical configurations: one in a triangular design—a subterranean network with three 10-kilometer arms forming an equilateral triangle—and the other in a "2L" design—meaning two underground L-shaped detectors with 15-kilometer arms, located at two separate sites. Regarding the location, three European regions are currently under consideration: the Sos Enattos site in Sardinia (Italy), the Euregio Meuse-Rhine (a border region spanning Belgium, Germany, and the Netherlands), and the

[8] https://cosmicexplorer.org/.

Lusatia region in Saxony (Germany). These three candidates are undergoing geophysical, environmental, and infrastructure studies to determine the optimal option, based on factors such as subsurface stability, environmental impact, and the scientific and technical capabilities of the regions. The approximate geodesic distances between the three candidate sites are as follows:

Sites	**Distances**
Sos Enattos ↔ Euregio Meuse-Rhin	~ 1400 km
Sos Enattos ↔ Lusatia	~ 1500 km
Euregio Meuse-Rhin ↔ Lusatia	~ 600 km

Considerations regarding the geometry

In this comparison between the 2L configuration and the triangular configuration, we consider only the scientific and technical aspects[9], excluding elements related to budget, financial risks, or the environmental impact of the two options. These dimensions will also need to be taken into account before any final decision is made.

The triangular geometry offers specific advantages. For the stochastic background (SGWB) and parameter inference in general, it allows the construction of a particularly useful "null stream." However, this configuration features a more original design that diverges from current detectors, which implies increased technological risk; this risk would only be truly mitigated within a global network of detectors, whereas an isolated triangle would remain particularly vulnerable in this regard. In particular, certain environmental noises may exhibit strong correlations that could negatively affect the triangle's sensitivity[10].

This geometry also imposes significant infrastructure constraints, such as the size of cryostats complicating the realization of the vertices, the management of five to six vacuum tubes per tunnel, or the need for periscopes that could reach heights of up to four meters. Conversely, the 2L configuration allows for longer low-frequency squeezing filter cavities, which relaxes certain constraints on coatings and/or control.

However, the 2L configuration is not without its challenges. It presents increased risks at low frequencies related to mirror size: the longer the arms, the larger the mirrors must be, and it is currently unknown whether sufficiently large mirrors can be built for 15 km arms, whereas 10 km arms seem feasible. An intermediate option could involve 10 km arms for the low-frequency

[9] A. Abac *et al*. [ET Collaboration], The Science of the Einstein Telescope, (2025) [arXiv:2503.12263]; M. Branchesi *et al*., Science with the Einstein Telescope: a comparison of different designs, JCAP 07 (2023), 068 [doi:10.1088/1475-7516/2023/07/068] [arXiv:2303.15923].
[10] K. Janssens *et al*., Correlated 0.01-40 Hz seismic and Newtonian noise and its impact on future gravitational-wave detectors, Phys. Rev. D 109 (2024) no.10, 102002 [doi:10.1103/PhysRevD.109.102002] [arXiv:2402.17320]; K. Janssens *et al*., Impact of correlated seismic and correlated Newtonian noise on the Einstein Telescope, Phys. Rev. D 106 (2022) no.4, 042008 [doi:10.1103/PhysRevD.106.042008] [arXiv:2206.06809].

detector and 15 km arms for the high-frequency detector. Mirror size is a research and development topic on par with the expected tenfold gains in laser power, squeezing, and other key improvements. The expansion of the LMA (Laboratoire des Matériaux Avancés in Lyon) and the new thin-film deposition machine, whose construction has just begun, are specifically aimed at addressing these challenges for both CE and ET.

Studies also emphasize that, regardless of the specific geometry chosen, the presence of a high-performance low-frequency instrument is crucial for many major scientific cases (particularly multi-messenger follow-up of neutron star binaries, intermediate-mass black hole binaries, certain long-duration signals, and components of the stochastic background), so maintaining this low-frequency capability is a structuring element of the design. Consequently, it will be essential to focus particular attention on developing the technologies needed to achieve the targeted low-frequency sensitivity in the coming years.

The French community nevertheless emphasizes the idea that the arms should be as long as possible, that a 2L geometry is more favorable for multi-messenger science due to better localization, and that such a configuration is better suited to managing technological risks.

Considerations regarding the site

The site selection must consider both geometric constraints and scientific objectives. If a site allows for the construction of a 20 km L-shaped interferometer, it would naturally be preferable. In a 2L configuration, it is desirable to maximize the distance between the two sites to optimize sky localization, as network studies show that angular localization performance is dominated by the baseline length between detectors. In a triangular configuration, priority should be given to selecting a site with the least seismic noise, as a seismically quiet environment allows the instrument's frequency to be lowered and directly influences access to several major scientific objectives.

4. Conclusions

In conclusion, the French community wishes to emphasize that ET should be operational during, or immediately after, LISA and in coordination with CE to maximize the scientific return of the detector. Furthermore, the L-shaped geometry appears to be the least risky from a technological and operational standpoint while enabling optimal scientific return due to its longer arms. The presence of a low-frequency instrument is crucial and must not be overlooked. In the 2L configuration, it is important to maximize the distance between the two sites to optimize the localization of sources in the sky. Finally, a site that allows for the construction of a 20 km L-shaped interferometer should be prioritized.

In general, in keeping with the tradition of international cooperation that has structured the ground-based gravitational wave detector community (LVK and soon IGWN) for many years, it seems crucial that any irreversible decision regarding the site or geometry of ET be made in agreement with the CE project and the NSF (National Science Foundation). This will allow for a coordinated examination of the options to optimize costs, scientific complementarity, and the overall environmental impact of the future network of third-generation gravitational wave detectors.