ESFRI European Strategy Forum on Research Infrastructures

ET

EINSTEIN TELESCOPE

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RI Name	Einstein Telescope
RI Acronym	ET
SWG Chair Signature	José Luis Martinez
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SCIENTIFIC CASE	
SCIENTIFIC EXCELLENCE	☐LOW ☐MEDIUM ☐HIGH ☒VERY HIGH

The current astronomical observations utilise a wide spectrum of electromagnetic means from the radio waves to gamma rays. With the advancement of the multi-messenger approach, charged particles and neutrinos are also enriching the field. The first observation of the gravitational wave from a black hole merger opened a new possibility to use the gravitational force as a probe, which is very weak but couples universally with mass and energy, enabling a significant leap forward in astronomy, cosmology and astrophysics. It would also contribute to the investigation of the fundamental law of physics in particle and nuclear physics. The proposed Einstein Telescope (ET) is the first implementation of the so-called 3rd generation gravitational antenna, to realise these opportunities with an order of magnitude improvement in the detection sensitivity over the current gravitational wave antennas. The sensitivity improvement will not only drastically increase the number but also extend the kinds of detectable sources, which is essential for the wide scope of research.

The basic principle of detecting the gravitational wave with a laser interferometer has been successfully demonstrated by the current facilities worldwide. The ET must significantly scale up the size of the facility while maintaining and even improving the precision of the setup. Operating the sensors in a cryogenic environment is essential to reduce the detection noise and this method has been employed by the Japanese KAGRA experiment which is in its commissioning phase. Its effectiveness has still to be demonstrated. Most of the required technologies do exist and the ET project is driven by the group with a proven track record to develop instruments which had led to the successful detection of gravitational waves. However, there are still many significant efforts needed to push those technologies from the current state of the art to the level needed.

- An organisational structure is in place to follow and react upon the technological progress and results from the development work. **It is recommended to assess the expected physics performance of the ET for different failure scenarios where the detector could not achieve designed performances and to develop mitigation plans. In the event that the funding does not proceed as planned or the cost of the detector increases, it might become necessary to set a priority in physics programme and to descope the detector. The collaboration should be prepared for such processes.**

PAN-EUROPEAN RELEVANCE	☐LOW ☐MEDIUM ☐HIGH ☒VERY HIGH

The Einstein Telescope (ET) will significantly enhance the capacities of the current second-generation gravitational wave telescopes, i.e. Advanced VIRGO in Europe, Advanced LIGO in the USA and KAGRA in Japan, which will be joined by LIGO-India in 2025. It will enable to explore a wider space and provide a unique sensitivity at low frequencies. It will be at the forefront of third generation (3G) gravitational wave telescopes and should constitute a 3G network with Cosmic Explorer (USA) in the 2040s, working also in synergy with the LISA space interferometer that will bring the measurements at very low frequencies.

The detection and study of gravitational waves is typical of the scientific topics which require investing in research infrastructures in wide multi-national collaborations to cover the high capital investments and gather the required scientific and technological expertise, with a stepped improvement building on the experience progressively gained by the community. It is a powerful unifier of the European scientific community in astroparticle physics and beyond, from astronomy and cosmology to particle and nuclear physics. The ET Consortium already brings together a large number of scientists from many different laboratories across Europe. Open access data policy (after a proprietary period) will allow the wider community to access the data. In addition, numerous technological challenges will lead to a strong tie with industry and innovations likely to find other applications.

- Two possible sites have been identified, one in Sardinia in Italy and the other in the EUregio Meuse-Rhine on the border between Belgium, Germany and The Netherlands. A Memorandum of Understanding was signed with CERN for joint technological developments. The ET project is one of the selected programmes in astroparticle physics projects in the APPEC *European Astroparticle Physics Strategy 2017-2026,* which quotes "It also strongly supports Europe's next-generation ground-based interferometer, the Einstein telescope (ET) project, in developing the required technology and acquiring ESFRI status". EGO is a partner of the ESCAPE Cluster, and the gravitational wave community was involved in its predecessor, ASTERICS. The preliminary studies of the ET were supported by several EC-funded projects, which include the Interregional programme, a training network and also exchanges with Japan that has led to a long-term collaboration with KAGRA.

SOCIO-ECONOMIC IMPACT	☐LOW ☐MEDIUM ☐HIGH ☒VERY HIGH

Being fundamental research, the goal of the Einstein Telescope (ET) project is not directly connected to applications benefitting immediately the society as such. On the other hand, the research subject of the ET fascinates the general public and generates their interest in science, which by itself is an important asset. Cultivating scientific thinking in the society is an important mission of basic research through stimulating the curiosity of the public. In parallel, being a large facility that requires very advanced scientific instrumentation, the ET project naturally benefits industries by stimulating their participation in the technological developments and through the knowledge transfer for the items developed by the institutes and laboratories participating in the project. This will result in the boost of industry capabilities and competitiveness. Many technologies developed for the ET are also beneficial for other fields of science in both fundamental and applied research. The ET will provide excellent educational

opportunities for not only scientists but also engineers and technicians.

The economic impact, as well as the impact on society and environment, depends on the site. Technological benefits could be for both directions: while the ET project would provide a wealth of technological knowhow, it could also take advantage of the achievement made by other fields. For instance, the substantial ongoing development effort in quantum and nano devices are extremely useful for the ET. An overall picture describing such a symbiotic relation in the technological effort would be useful to assess the socio-economic impact.

It is recommended to make sure that contributions by the industries are directly and visibly acknowledged, providing ET industry awards for example. It will be also useful to keep record of the impact made by the ET project in boosting the economy and improving society locally, in Europe and globally.

USER STRATEGY AND ACCESS POLICY	☐LOW ☐MEDIUM ☐HIGH ☒VERY HIGH

The Einstein Telescope (ET) will serve the global science community. The entire global gravitational wave community, currently 2500 - 3000 scientists, is targeted as the primary user community of the telescope. Beyond this core community, the facility will provide triggers for observations to the global astrophysicist community, with breakthroughs expected in several astrophysical fields, and the data will be of use for astroparticle physicists, cosmologists and experts in the general theory of relativity. More generally, contributions to particle and nuclear physics, and to a wider field of experimental physics on technological aspects, are expected. Open access to data is expected to increase the user community compared to the current one.

The user categories are on the one hand the members of the ET Collaboration, who are expected to be more than 1000 people with different profiles, and on the other hand the people outside of the collaboration using the data. About 700 people from 17 European countries and about 70 people from countries outside signed the Letter of Intent to participate in the ET Collaboration, where the members are expected to contribute to the construction of the ET and will benefit from the full data analysis services. The data provided publicly include the Open Public Alerts and the Einstein Telescope data after the proprietary period. Special projects to access data not made open for public, so called “sub-threshold data”, will be enabled through competitive calls or negotiated procedures. **No detail is given about the difference between the released data and sub-threshold data, and about how this specific access to data will be organised and granted. This should be better elaborated to ensure a fair process, and if for instance some tools or data are kept inside the collaboration this should be explained.**

A bibliometric analysis covering the period from 1999 to 2019 was performed to support the evaluation of the relevant communities, which is said to comprise more than 200 000 persons in each of the astrophysics and cosmology domains and nearly 300 000 in experimental physics, and to identify their affiliation. Even if some of the article authors (in particular doctoral students and post docs) may have left the field the potentially interested community is large, as well as the number of interested laboratories and institutions.

The Conceptual Design Report is signed by 217 scientists from 12 countries. They provided the user needs to be taken into account in the design. The services to be provided by the ET include Open Public

Alerts, an event database, event data which will be prepared and provided quickly and more processed and complete scientific data to be published later, and public analysis software. Access to data will be provided by an evolution of the current Gravitational Wave Open Science Center (GWOSC). The possibility to develop joint projects on data and technologies and to provide tutorials, topical meetings and schools are also among the services, as well as a secondment programme.

Data and analysis tools will be made available publicly after the proprietary period. It is not specified whether some of them will be kept for internal usage inside the Collaboration. **If some data and/or tools are kept inside the Collaboration, clarification is needed on which ones, and the criteria on which the decision to open or not is taken should be spelled out.**

A summary of the expected liaison and collaboration with the current ESFRI projects and landmarks is desired.

E-NEEDS	☐LOW ☐MEDIUM ☒HIGH ☐VERY HIGH

Basic elements of the data management plan are given in the proposal, based mainly on prior work and practices of the GW community. The proposal demonstrates awareness of the core issues such as data transfer, data access, integration, preservation, sharing and usability. The community in the field is already using a common solution for data representation and access. There is ongoing work to align and integrate this with other international developments, including EOSC. Sufficient interoperability provisions are in place. OAIS compliance caters mostly for preservation and access needs, whereas other standards would be applicable for the data description and interoperability needs. **Developments in ongoing projects such as ESCAPE regarding interoperability need to be assessed for adoption and reuse.**

The proposal mentions that “ET is expected to detect a few million signals annually” and that “new algorithms are needed to fully exploit the scientific potential of ET” without further elaborating the types of analysis where these algorithms will implement and their computational resource requirements, especially whether real-time analysis needs are present. Certain computational tasks are characterized as “embarrassingly parallel” which is quite fortunate as it will allow for the exploitation of massively parallel computational infrastructures. **Other tasks, however, may impose different requirements that need to be catered for by specific architectures.**

Overall, the proposal demonstrates that the consortium possesses a good understanding of the relevant computing requirement in order to establish an appropriate infrastructure. Regarding the network infrastructure required for the off-site processing, the provided documentation regarding the network capacity requirements during the operation is adequate. Their assumption that the advancement in networking technology will supersede the anticipated needs of the infrastructure is realistic.

The targeted user community is fairly large. The consortium’s plans to enlarge the potential user community by enriching data in order to make them more accessible to non-specialists and by implementing analysis tools usable by non-experts in GWs are commendable and likely to have broader synergistic effects with other disciplines

OVERALL ASSESSMENT OF SCIENTIFIC CASE	☐LOW ☐MEDIUM ☐HIGH ☒VERY HIGH

The scientific case of the Einstein Telescope (ET) project, a third generation of the gravitational wave antennas, is excellent. With an order of magnitude increased sensitivity of the detector in detecting the gravitational wave compared to the current devices, it will open a new chapter in our understanding of the Universe providing unique data for astroparticle physics, astronomy and cosmology, as well as particle and nuclear physics. Combination with the other probes, the so-called multi messenger approach, will further enhance the progress of the field through this synergetic approach. The ET will encourage this by providing alert signals for their observation and by an open data policy to allow the wide scientific community to access the data.

In order to achieve its scientific goal, the ET collaboration needs to conduct intensive research and development (R&D) activities in a wide range of technologies in collaboration with industries. In addition to the economic impact through the construction of the required large infrastructure, collaborative R&D with industry will provide a long-term benefit providing them competitive edges in the high technology sector. Technology developed will also be useful for a wider range of experimental physics opening some innovative ways to perform measurements.

Although the proposal and attached documents describe the project well, the description remains sometimes qualitative, which was partly mitigated by the presentation during the hearing. **A continuous process of risk analysis for the progress in the critical technological developments is recommended.** The number of alerts issued by the ET is expected to be significantly larger than that by the current gravitational wave antennas. In order to ensure the follow-up measurements by the other facilities, in particular by the optical telescopes, some changes in their operation model might be required since they would need to interrupt the running observation programme. **Therefore, a management level consultation among the facilities is recommended, in addition to already well-established interactions among scientists**.

In the hearing, the collaboration expressed the following opinion: ***The operation of the current gravitational antennas should continue till the ET starts taking data, given their scientific potential. Once the ET becomes fully operational, they will be no longer competitive and there is no compelling reason to continue operation.*** **This view is fully supported by the committee.** It should be noted that the proposal states instead that "ET will not replace existing infrastructures as it will have unprecedented GW detection capabilities. Existing 2G GW infrastructures are expected to remain operational in upgraded form (2G+) and coordinate with ET to form a powerful GW network". **The committee thinks that a network should be formed rather with the other 3G gravitational antennas under development when they would become operational.**

IMPLEMENTATION	
STAKEHOLDER COMMITMENT	☐LOW ☐MEDIUM ☒HIGH ☐VERY

	HIGH

There appears to be a wide global interest from the various stakeholders, both users and providers in developing this RI and five countries have provided letters of political support with the lead (IT) having committed financial support. A strategy on how to identify and secure funds has been laid out however there is no documented strategy to secure the necessary financial commitments from other partners. That being said, ET has also been included onto three national roadmaps (NL, BE, GR) and, as stated by one reviewer: "*…there is clear and strong interest to build ET, there is a number of research organisations and researchers involved all over the Europe and outside*."

Given the estimated construction costs (ca. €1.73 Billion) it was considered that it will be crucial that in coming years (max 2-3 years) there should be significally more countries involved with political support, later followed by financial commitments from national governments/funding authorities.

Furthermore, it has yet to be decided where the single-sited RI will be located, which is of considerable concern at the outset. It was indicated however that this will be done by 2024 with the decision on hosting being mostly a national government issue.

Efforts are continuing to secure national commitments.

Recommendations:

- **The ESFRI recommends that a strong emphasis is placed on enlarging the circle of countries supporting ET both politically and financially.**

PREPARATORY WORK & PLANNING	☐LOW ☐MEDIUM ☒HIGH ☐VERY HIGH

The conceptual design was funded by the EC in FP7 with additional contributions from other European (ILIAS, ELiTES, GraWIToN, ASPERA) and national grants. The proposers have clearly laid out the previous and next steps towards implementation.

Regarding the business case there is a difference of opinion between the reviewers. While a business case with the specific elements required has been provided it is suggested that not enough detail has been forthcoming to satisfy all reviewers – a general overview about the key elements of the business case has been provided yet whether and how this will be reviewed is a little unclear.

The reviewers are confident that technological/constructions issues can be tackled. And while the site selection has yet to be agreed, and this is a concern, the two proposed sites have been investigated in terms of geophysics, characterisation of environmental noise and disturbances, and infrastructural and socio-economic aspects.

Furthermore, a description of the chain from design phase to upgrades and finally a decommissioning phase has been described in the proposal. While it is not very detailed it provides an adequate overview about the ET life-cycle.

Recommendations:

- **The ESFRI considers it imperative that the timeline for site selection is met. Regarding the process for site selection, the ESFRI strongly recommends that an appropriate mediation plan**

is also put in place and that updates are provided to the ESFRI on this process up until site selection.

- **The ESFRI recommend that a mitigation plan is put in place if site selection cannot be completed by 2024.**

GOVERNANCE, MANAGEMENT AND HUMAN RESOURCES POLICY	☐LOW ☐MEDIUM ☒HIGH ☐VERY HIGH

The proposers indicate that since the operational phase is foreseen to commence at the earliest in 2035 and that the site/hosting arrangement is yet to be decided, it is too early to decide upon the final organisational structure. It was argued that this approach is not satisfactory as it does not sufficiently address the relevant MKRs and so the applicants endeavoured to address this during the hearing.

It is also worth noting that some examples could be followed by way of recommendation, such as the GW Observatory. Furthermore, as one reviewer stated, addressing such issues now would be well justified considering the complexity of planning of the ET infrastructure, the dedicated interim governance structure as well as operative management team with responsibilities and reporting lines.

An organisational structure was presented and generally laid out but much hinges on the site decision as this will impact final governance structures and approvals as required investments come to light.

While appropriate KPIs have been listed there is a lack of detail and as one reviewer points out "*some are very superficial*" and that "*they should be differentiated on the different phases, and measure the advances on the scientific, technological aspects and construction"*.

A clear HR policy has been drawn up with good education and training plans. The recruitment plans appear satisfactory and its noted that recruitment will target an international community via transparent procedures using the best practices, and experienced staff to evaluate the knowledge, skills and abilities needed for each position.

FINANCES	☐LOW ☒MEDIUM ☐HIGH ☐VERY HIGH

Some financial commitments have been provided. A high level cost breakdown has been presented with the different costs for the different project phases and with the major costs inside each phase. While a scheme still has to be devised it would appear that operational costs will be covered in cash by the participating countries.

The funding opportunities to help cover costs have not been well identified however, which is a problem and so needs to be addressed and site selection would appear to ultimately impact this.

Several innovations are expected and, as was indicated by the applicants, industrial partners are willing to invest. A business case will be presented to Member States.

A preliminary cost book has also been presented and estimated costs and time schedules have been outlined for the principal cost elements in all phases. Possible models for membership contributions however should also be included.

Recommendations:

- **Much effort is still necessary to meet the required financial costs. The ESFRI recommend that extra effort is afforded to meet these targets and that regular progress updates are provided to the ESFRI.**

RISKS	☐LOW ☐MEDIUM ☒HIGH ☐VERY HIGH

Due to the size and complexity of ET a number of technical as well as financial and governance risks exist. The major risks have been clearly identified in all phases along with the associated mitigation strategies.

FINDINGS ASSESSMENT OF IMPLEMENTATION	☐LOW ☐MEDIUM ☒HIGH ☐VERY HIGH

There is strong interest from a large research community to build a very ambitious telescope. However, the proposal still needs to satisfy some key requirements for a project on the ESFRI roadmap. These have been presented in this report.

Considering that it will be a new single-sited research infrastructure with next generation technologies, it is clear that the planning and construction (including the planning of in-kind contributions) is complex and long-term. While much effort has been carried out the work that is required over the coming years in securing funding and ultimately the location cannot be underestimated. The timelines indicated for the preparatory phase are very ambitious.

OVERALL CONCLUSIONS & RECOMMENDATIONS	
OVERALL FINDINGS	☐LOW ☐MEDIUM ☒HIGH ☐VERY HIGH

The joint recommendation from PSE and IG to EB is to include the project Einstein Telescope in the coming ESFRI RoadMap for 2021.

However, we would like to point out some issues for the future follow up or monitoring of this project:

1) A continuous process of risk analysis for the progress in the critical technological developments is recommended. This should include the following elements: It is recommended to assess the expected physics performance of the ET for different failure scenarios where the detector could not achieve designed performances and to develop mitigation plans. In the event that the funding does not proceed as planned or the cost of the detector increases, it might become necessary to set a priority in physics programme and to descope the detector. The collaboration should be prepared for such processes.

2) No detail is given about the difference between the released data and sub-threshold data, and about how this specific access to data will be organised and granted. This should be better elaborated to ensure a fair process, and if for instance some tools or data are kept inside the collaboration this should be explained.
3) The number of alerts issued by the ET is expected to be significantly larger than that by the current gravitational wave antennas. In order to ensure the follow-up measurements by the other facilities, in particular by the optical telescopes, some changes in their operation model might be required since they would need to interrupt the running observation programme. Therefore, a management level consultation among the facilities is recommended, in addition to already well-established interactions among scientists.
4) The committee concurs the following view expressed by the ET proponents during the hearing: The operation of the current gravitational antennas should continue till the ET starts taking data, given their scientific potential. Once the ET becomes fully operational, they will be no longer competitive and there is no compelling reason to continue operation. The committee thinks that a network should be formed with the other 3G gravitational antennas under development when they would become operational.

Einstein Telescope is a very ambitious project, which has a keen interest from a growing research community. It will be a single-sited infrastructure that aims to establish a European Third-Generation Gravitational Wave Observatory and has a broad global GW scientific community behind it. However, some key requirements necessary for a project on the ESFRI roadmap are lacking. The focal point being the lack of clarity.