**Formulario de solicitud de apoyo institucional para los grupos del CSIC que presenten una candidatura a la**

**Hoja de Ruta ESFRI 2021**

El presente formulario deberá remitirse a la Comisión para la Coordinación y Racionalización de Infraestructuras Científicas y Técnicas Singulares (ICTS) y participación en Infraestructuras Europeas de Investigación (IEI) del CSIC (icts-esfri@csic.es) para su valoración. La información aportada será utilizada para evaluar el interés y la viabilidad de la propuesta, y servirá para tomar la decisión sobre al apoyo institucional del CSIC a la misma. El formulario deberá cumplimentarse por el representante de los grupos/grupo del CSIC que deseen presentar una candidatura a la Hoja de Ruta ESFRI-2021.

En caso de evaluación favorable, se remitirá al proponente una carta de apoyo firmada por el representante legal del CSIC, a fin de que pueda ser incorporada a la solicitud nacional que se presente ante el Ministerio de Ciencia, Innovación y Universidades.

\*\* No se descarta que en el proceso de evaluación se pueda contactar con los solicitantes para posibles aclaraciones adicionales.

*Nota: El formulario es una versión simplificada del diseñado por el Ministerio de Ciencia, Innovación y Universidades, atendiendo a la necesidad de evitar la duplicidad de esfuerzos.*

[*https://eshorizonte2020.es/index.php/ciencia-excelente/infraestructuras-de-investigacion/esfri/procedimiento-nacional-para-el-apoyo-a-nuevas-propuestas-a-la-hoja-de-ruta-2021-de-esfri*](https://eshorizonte2020.es/index.php/ciencia-excelente/infraestructuras-de-investigacion/esfri/procedimiento-nacional-para-el-apoyo-a-nuevas-propuestas-a-la-hoja-de-ruta-2021-de-esfri)

* ***Campos obligatorios***
	1. **Dirección de correo electrónico del proponente\***

Project Proposers: Michele Punturo (michele.punturo@pg.infn.it) and Harald Lück (harald.lueck@aei.mpg.de)

Spanish Representative at the ET Steering Committee: Mario Martínez Pérez (IFAE, UAB and ICREA): mmp@ifae.es

CSIC Coordinator: Carlos F. Sopuerta (ICE, CSIC and IEEC):  sopuerta@ice.csic.es

* 1. **Tratamiento de datos \***

☒Los solicitantes autorizan al CSIC al uso de la información proporcionada en el presente formulario para la evaluación de la propuesta en el marco del proceso nacional de actualización de la Hoja de ruta ESFRI 2021.

# **Datos de Contacto del coordinador.**

* 1. **Nombre y apellidos del coordinador nacional que representa a las entidades que apoyan la propuesta. \***

Mario Martínez Pérez (IFAE, UAB and ICREA)

* 1. **Nombre y apellidos del coordinador del CSIC. \***

*Sólo en el caso que no coincida con el coordinador nacional*

Carlos Fernández Sopuerta (ICE, CSIC and IEEC)

* 1. **ICU al que pertenece el coordinador del CSIC\***

Instituto de Ciencias del Espacio (Campus UAB, Carrer de Can Magrans s/n, 08193 Cerdanyola del Vallès, Barcelona)

* 1. **Correo electrónico del coordinador del CSIC \***

sopuerta@ice.csic.es

* 1. **Teléfono de contacto del coordinador del CSIC \***

Work Phone: 93 737 9788 (ext. 933021)

Mobile Phone: 644 00 46 36

* 1. **Nombres e ICUS de personal del CSIC que participa en la propuesta \***

Amaro-Seoane, Pau - Instituto de Ciencias del Espacio (ICE)

Elizalde Rius, Emili - Instituto de Ciencias del Espacio (ICE)

Fernández Sopuerta, Carlos - Instituto de Ciencias del Espacio (ICE)

Isern i Vilaboy, Jordi - Instituto de Ciencias del Espacio (ICE)

Mezcua Pallerola, Mar - Instituto de Ciencias del Espacio (ICE)

Nofrarias Serra, Miquel - Instituto de Ciencias del Espacio (ICE)

Rea, Nanda - Instituto de Ciencias del Espacio (ICE)

Tolos, Laura - Instituto de Ciencias del Espacio (ICE)

Mena Marugán, Guillermo - Instituto de Estructura de la Materia (IEM)

Barbero González, J. Fernando - Instituto de Estructura de la Materia (IEM)

Calcagni, Gianluca - Instituto de Estructura de la Materia (IEM)

García-Bellido Capdevila, Juan - Instituto de Física Teórica (IFT and UAM)
Nesseris, Savvas - Instituto de Física Teórica (IFT)
Kuroyanagi, Sachiko - Instituto de Física Teórica (IFT)
Rodríguez, María José - Instituto de Física Teórica (IFT)

García Figueroa, Daniel - Instituto de Física Corpuscular (IFIC)
Navarro Salas, José - Instituto de Física Corpuscular (IFIC and UV)
Fabbri, Alessandro Fabbri - Instituto de Física Corpuscular (IFIC and UV)
Olmo, Gonzalo - Instituto de Física Corpuscular (IFIC and UV)

Agudo Rodríguez, Iván - Instituto de Astronomía de Andalucía (IAA)
Barceló Serón, Carlos - Instituto de Astronomía de Andalucía (IAA)
Castro Tirado, Alberto Javier - Instituto de Astronomía de Andalucía (IAA)
Pérez Torres, Miguel - Instituto de Astronomía de Andalucía (IAA)

# **PARTE 1. INFORMACION GENERAL DE LA PROPUESTA DE INFRAESTRUCTURA EUROPEA**

**Descripción de la Propuesta**

* 1. **Acrónimo. \***

ET

* 1. **Título. \***

Einstein Telescope

* 1. **Página web, si existe.**

<http://www.et-gw.eu>

* 1. **Descripción breve de la infraestructura europea propuesta. \***

After the first generation of laser-interferometric gravitational-wave detectors (GEO600, TAMA, LIGO, Virgo) reached or approached their design sensitivities, demonstrating the effectiveness of the working principle, the second generation (LIGO, Virgo) started their operations in 2015 with the first direct detection of gravitational waves from a Binary Black Hole (BBH) coalescence. This revolutionary detection marked the beginning of Gravitational Wave Astronomy and was worth the Nobel Prize in Physics 2017. The two first science observation runs of the LIGO-Virgo Collaboration ended with 10 detections of BBHs and one of a Binary Neutron Star (BNS). The BNS system was followed up by numerous electromagnetic observations in a wide range of the spectrum, providing revolutionary science. Currently, LIGO and Virgo are in the third observation run with approximately 1-2 detections per week.

These considerations led the Gravitational Wave (GW) community to start investigating a new (third) generation (3G) of detectors. The Einstein Telescope (ET) will be an observatory of the third generation aiming to reach a sensitivity for GW signals emitted by astrophysical and cosmological sources about a factor of 10 better than the advanced detectors currently operating, and will cover an extended frequency range from 2 to$10^{4}$Hz. An observatory with such a level of sensitivity will open the era of routine GW Astronomy (many per day), becoming a main player in multiband GW Astronomy in particular and in Multimessenger Astronomy in general. It will also have an enormous potential for revolutionary discoveries in Fundamental Physics.

A 3G observatory is the only logical (and economic) step to overcome the ultimate limitations of the present 2G observatories. Worldwide, the proposed ET research infrastructure is the most advanced project. Compared to the present observatories, ET features 3-4 times longer cavities, much reduced thermal noise by using silicon mirrors cooled to below 20 K, superior low-frequency sensitivity by combining an underground seismically-quiet site with a state-of-the-art isolation and compensation scheme for residual seismically induced noise. ET will furthermore employ powerful lasers, cutting-edge sensors and modern control technology. The triangular layout housing multiple interferometers allows ET to operate as a stand-alone observatory with source polarization and localization capabilities even before the Cosmic Explorer in the USA joins the network. All combined, ET will surpass the best attainable ultimate sensitivity of present observatories by an order of magnitude (corresponding to a thousand-times-larger volume coverage) allowing to observe GW sources over the full history of the Universe. Depending on source characteristics, ET could track a GW signal from a NS merger for up to 24 hours allowing ample time to notify electromagnetic telescopes to study such events in detail. ET is expected to remain at the forefront of GW research for at least half a century.

Boosted by the 2008-2011 EU Design Study, the ET community has evolved into a group of close to 1000 researchers from all European countries involved in GW research. ET has an annual 2-day symposium, many sub-activities in different settings and frequent ET-steering group meetings, all working towards a common goal: the realization of the anticipated ET schedule aimed at a start of data taking in 2034.

Two sites are still in the running to host ET: Sardinia in Italy and the Meuse-Rhine Euroregion on the Belgian-Dutch-German border with a decision expected around 2023. Both sites already profit from EU structural and/or EU Interreg project subsidies targeted at a better understanding of the local geology and specific testbeds for new technologies required to make ET a success. Throughout, collaboration with (local) industries as well as with other fields (geology, material sciences, cryogenics, optics, controls and machine learning, etc.) is actively pursued.

* 1. **Características de la infraestructura propuesta. \***

***Marque sólo una opción.***

☐Mejora o re-orientación de infraestructura existente

☒Nueva Infraestructura

* 1. **Tipo. \***

***Marque sólo una opción.***

☒Infraestructura de sede única

☐Infraestructura distribuida

* 1. **En el caso de infraestructura distribuida indicar la localización de las entidades que conforman el Nodo Nacional y cuál será su participación. Describir las localizaciones, instalaciones y equipamiento del CSIC que formarán parte de la infraestructura. \***

The infrastructure will have a unique location to be decided, but the computing for Data Analysis will be distributed. The ICTS that relevant here are the infrastructures of the "Red Española de Supercomputación" (Spanish High-performance Computing Network) in which the CSIC participates.

Given the important role that the Einstein Telescope will play in Multimessenger Astronomy, any ICTS in the area of Astronomy and Astrophysics has the potential to play an important role in the follow-up of electromagnetic counterparts to gravitational wave detections that the Einstein Telescope will make. In particular the [Calar Alto Astronomical Observatory (CAHA](http://www.ciencia.gob.es/portal/site/MICINN/menuitem.8ce192e94ba842bea3bc811001432ea0/?vgnextoid=a8b62fb6feb0b410VgnVCM1000001d04140aRCRD)).

In the development of instrumentation, the National Center of Accelerators (CNA), a combined center of the University of Sevilla and CSIC, can contribute to technological developments for ET. Similarly, the National Center for MicroElectronics (CNM) in Barcelona has the potential to contribute to the development of optical sensors for the control of the interferometers.

* 1. **Ámbito de aplicación en el que se enmarca la propuesta. (Indicar el área científica principal en la que se encuadraría la propuesta.) \***

*Marque sólo una opción***.**

☐Energía

☐Medioambiente

☐Salud y alimentación

☒Ciencias Físicas e Ingeniería

☐Ciencias Sociales y Humanidades e-infraestructuras

* 1. **Indicar en su caso otras áreas científicas relacionadas con la propuesta.**

***Marcar las necesarias.***

☐Energía

☒Medioambiente

☐Salud y alimentación

☒Ciencias Físicas e Ingeniería

☐Ciencias Sociales y Humanidades e-infraestructuras

* 1. **Estado Miembro o miembro de EIROFORUM coordinador de la propuesta \***

Italy and The Netherlands

* 1. **Indicar otros países y sus instituciones participantes en la propuesta. (utilizar una línea por país de acuerdo al siguiente formato: país; institución; coordinador) \***

# The table below presents the list of non-Spanish institutions that expressed interest in signing the ET MoU at the time of preparing this document. It is expected that more institutions will be added before the deadline for ESFRI document submission in May 2020.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Italy | Istituto Nazionale di Fisica Nucleare | INFN | Via Enrico Fermi , 40 - 00044 Frascati (Rome) Italy | Michele Punturo |
| Italy | Istituto Nazionale di AstroFisica | INAF | Viale del Parco Mellini, 84 - 00136 Rome - Italy | Enzo Brocato |
| Italy | Istituto Nazionale di Geofisica e Vulcanologia | INGV | Via di Vigna Murata, 605 - 00143 Rome - Italy | Gilberto Saccorotti |
| Italy | Università degli Studi di Sassari | UniSS |  | Massimo Carpinelli |
| Italy | Università degli Studi di Cagliari | UniCa | Via Università 40, 09124 Cagliari - Italy | Giuseppe Mazzarella |
| Italy | European Gravitational Observatory | EGO | Via E. Amaldi Cascina Pisa | Stavros Katsanevas |
| Netherlands | NWO-I / Nikhef | NWO-I | Amsterdam, NL | Frank Linde |
| Netherlands | Maastricht University | UM | Maastricht, NL | Stefan Hild |
| Netherlands | University of Amsterdam | UvA | Amsterdam, NL | Frank Linde |
| Netherlands | Vrije Universiteit Amsterdam | VU | Amsterdam, NL | Frank Linde |
| Netherlands | Utrecht University | UU | Utrecht, NL | Frank Linde |
| Netherlands | Radboud University | RU | Nijmegen, NL | Frank Linde |
| Netherlands | University of Groningen | RUG | Groningen, NL | Frank Linde |
| Germany | MPI for Gravitational Physics | AEI | Hannover, DE | Harald Lück |
| Germany | RWTH Aachen University | RWTH | Aachen, DE | Achim Stahl |
| Germany | University of Hamburg | UHH | Hamburg, DE | Roman Schnabel |
| United Kingdom | Science and Technology Facilities Council | STFC | Polaris Way, Swindon SN2 1SZ, UK | Sheila Rowan |
| United Kingdom | University of Glasgow | UoG | University Avenue, Glasgow G12 8QQ, UK | Sheila Rowan |
| United Kingdom | University of Birmingham | UoB | Edgbaston, Birmingham B15 2TT, UK | Andreas Freise |
| United Kingdom | University of Portsmouth | UoP | Portsmouth, UK | Ian Harry |
| United Kingdom | Cardiff University | CU | 30-36 Newport Road, Cardiff CF24 0DE, UK | Steve Fairhurst |
| France | Centre National de la Recherche Scientifique | CNRS | 3, Rue Michel-Ange, 75016, Paris, France | Matteo Barsuglia |
| Poland | University of Warsaw | UW | Krakowskie Predmiescie 26/28, Warsaw, Poland | Tomasz Bulik |
| Belgium | Université catholique de Louvain | UCLouvain | Place de l'Université 1; B-1348; Belgium | Giacomo Bruno |
| Belgium | Universiteit Antwerpen | UAntwerpen | Prinsstraat 13, 2000 Antwerpen, Belgium | Nick van Remortel |
| Belgium | Universiteit Gent | UGent | Sint-Pietersnieuwstraat 25, 9000 Gent, Belgium | Dirk Ryckbosch |
| Belgium | Katholieke Universiteit Leuven | KULeuven | Oude Markt 13, 3000 Leuven, Belgium | Thomas Hertog |
| Belgium | Vrije Universiteit Brussel | VUB | Pleinlaan 2, 1050 Brussel, Belgium | Alexandre Sevrin |
| Belgium | Universiteit Hasselt | UHasselt | Martelarenlaan 42, 3500 Hasselt, België | Milos Nesladek |
| Belgium | University of Liege | ULiege | Place du 20-Août, 7, B-4000 Liège (Belgique) | Frederic Nguyen |
| Belgium | Université Libre de Bruxelles | ULB | Avenue Franklin D. Roosevelt 50B-1050 Bruxelles | Christophe Collette |
| Switzerland | Universite' de Geneve | UniGe |  | Michele Maggiore |

# **Participación a nivel CSIC**

* 1. **Detallar el papel del grupo/ de los grupos del CSIC en la infraestructura europea que se propone y, en su caso, en el nodo nacional propuesto\***

Gravitational Astronomy - LISA Group - Institute of Space Sciences (ICE) - The group has a long expertise in thermal and magnetic environments for gravitational-wave detection, and also in computer software and hardware (in particular flight hardware like the one provided for the ESA LISA Pathfinder mission, the technology demonstrator for the future LISA space-based GW observatory, the ESA-L3 mission). The group has also expertise in Data Analysis (in particular for the European Space Agency LISA Pathfinder mission) for gravitational-wave detection. There are also several efforts in the development of science for Gravitational Wave Astronomy in the areas of Astrophysics, Source modeling, and Fundamental Physics, for both ground-based and space-based detectors.

Cosmology – LISA Group – Instituto de Física Teórica (IFT) – Experts in Early and Late Universe: Inflation, CMB, Large Scale Structure, Dark Energy and Dark Matter. Members of ESA Missions Euclid and LISA. Coordinators of Primordial Black Holes Work Package in LISA Cosmology WG. Experts in Data Analysis and Science (construction of PBH waveforms, estimation of stochastic backgrounds, determination of cosmological parameters, interpretation in terms of fundamental physics with Multimessenger GW Astronomy) for both space and ground-based telescopes.

Gravitation and Cosmology Group - Instituto de Estructura de la Materia (IEM) - Members of the group develop theoretical models of classical or quantum gravity and dark energy models that modify the production and/or propagation of gravitational waves within the range of observable frequencies in the Einstein Telescope. In a first pre-experimental phase, a study o the physical observables and predictions of these models will be made, using numerical simulations that integrate our scenarios into the instrument pipelines. In a second phase, the models will be verified with the real data. The numerical simulation activities will be carried out in collaboration with other institutes.

Theory group - Instituto de Física Corpuscular (IFIC) - The Group has some research lines in gravitational physics, black holes and cosmology, and more specifically, in topics at the interface of gravity and quantum physics. Gravitational waves are fundamental tools to test the strong field regime of Einstein's theory of general relativity and to confront any potential modification, or effective quantum corrections, of the pure classical Einstein field equations. Gravitational waves also represent a new window into the early Universe, allowing us to probe beyond the Standard Model physics through high energy phenomena like the reheating of the universe after inflation, first order phase transitions during the thermal era, and the possible formation and evolution of cosmic strings.Therefore, the group is very interested in participating and supporting the ET project from the theoretical side, and to enhance the group already established scientific collaboration with the astrophysics and Virgo group at the University of Valencia within the wider perspective of the ET project.

Stellar Physics, Extragalactic Astronomy, and Radioastronomy and Galactic Structure Departments – Instituto de Astrofísica de Andalucía (IAA) - There is already a lot expertise in the multiwavelength follow-up of gravitational wave alerts reported by LIGO-Virgo, making use of ground-based facilities such as the BOOTES Network of Robotic Telescopes and larger-diameter telescopes at OSN, CAHA, and La Palma (10.4m GTC) by means of target-of-opportunity programs at PI level. Also, in the radio and mm follow-up of gravitational wave alerts reported by LIGO-Virgo, making use of ground-based facilities such as NOEMA (at PI level) and at the European VLBI Network (at co-I level). They also participate at the PI level at the European VLBI Network (EVN) programmes aimed at probing the scenarios of Tidal Disruption Events (TDEs) in Supermassive Black Holes, and at the co-PI level at the EVN and e-MERLIN programmes aimed at following up gravitational wave alerts reported by LIGO-Virgo, as well as testing Blazar as potential sources of neutrinos. There is also expertise on theoretical analysis of probes of the nature of black hole candidates; also on analysis of potential observational signatures of quantum gravitational effects.

**Planificación del ciclo de vida de la infraestructura.**

*Describir brevemente cuál es la planificación del Proyecto, incluyendo los plazos del mismo para las distintas fases: diseño, preparación, implementación/construcción, operación y desmantelamiento.*

The Einstein Telescope project has already been through a Conceptual Design Study funded by the FP7 programme, Project ET - *Einstein gravitational-wave Telescope* (FP7 - INFRASTRUCTURES-2007-1. SP4 CAPACITIES. Grant Agreement 211743), of the European Commission, **from** May, 2008 **to** July, 2011. We refer to this as the Phase 0 of the Einstein Telescope. The outcome of this study was the document *Einstein gravitational wave Telescope conceptual design study* (Ref.: ET-0106C-10), authored by the ET Science Team (including some of the CSIC members listed in point 8 of this document) and presented on May 20th, 2011. It can be found in the following link: <http://www.et-gw.eu/index.php/etdsdocument> .

Another EU project for ET studies was ELiTES (*ET-LCGT Telescopes: Exchange of Scientists*. FP7-PEOPLE-IRSES Grant Agreement 295153), which run **from** March, 2012 **to** February, 2016. Finally, there has been a recent EU project, GraWIToN - *Gravitational Wave Initial Training Network* (FP7-PEOPLE-2013-ITN Grant Agreement 606176), also devoted to ET science and developments.

An R&D proposal ET was approved by ApPEC in 2012 and run **from** May, 2013 **to** April, 2016. Moreover, a Governing Council was instituted and a scientific collaboration was organized through the ET Science Team. Furthermore, ET was included on various roadmaps. In particular, ET featured prominently on the agenda of the recent CERN town meeting leading to an update of the European Particle Physics Strategy.

The top-level schedule to move forward in the ET project is:

* 1. **Technical Design Phase: From** 2008 **– to** 2026

This takes into account studies that have already been started towards the final specification of the instrument elements. This also includes a precise cost definition.

* 1. **Site Preparation Phase: From** 2020  **– to** 2022

This includes analysis of different sites and the site selection process as well as preparatory works to install the detector. It involves technical/political activity as well as the establishment of requirements for the site characteristics through an intense experimental activity. The conceptual phase of the design with the first feasibility study has been performed in 2008-2011. From 2017 to 2021 the design is specialised on the two candidate sites to host the research infrastructure. Development activities are expected to continue beyond the formal end of this phase.

* 1. **Implementation/Construction Phase: From** 2026 **- to** 2035

Implementation starts with the beginning of the excavation works. This includes also the manufacture of the different components of the detector instrument as well as their installation in the detector state and the engineer tests. The beginning of the detector installation is estimated around 2030.

* 1. **Operations Phase: From** 2033 **– to** 2050 (extension of operations foreseen)

The end date of scientific operations is tentative. It is expected that the infrastructure will last for several decades, with different phases of technological improvements that will increase the detector sensitivity. The scientific operation is expected to start in 2035, but operation costs will occur from 2033. Upon completion of the operations program it is planned a period of about three years for termination of the experiment and for securing the underground infrastructure.

# **Apoyo financiero a la Propuesta.**

* 1. **Estimación de la contribución de España y del CSIC a la construcción de la infraestructura europea que se propone \***

The total cost of the infrastructure is about 1.9 Billion Euro (core cost). It is difficult to estimate at this point the Spanish contribution as the ET consortium is being formed. As a preliminary estimate one can take as an example the case of the ATLAS or CMS LHC experiments at CERN for which Spain participated at the level of 2% in the initial construction phase. This would lead to a total core contribution of about 40 Million Euros integrated in a period of about 10 years. It is expected that some of the contributions could be in-kind. This estimation does not consider that fact that the host countries for the infrastructure are expected to contribute more to the total cost.

* 1. **Estimación de la contribución de España y del CSIC a la fase de Operación de la infraestructura europea que se propone \***

The annual operation cost is approximately 37 Million Euro. In order to compute the Spanish contribution one should consider a model of fair share of operation costs according to the number of researchers from different countries. Assuming a 2% contribution from Spain it would translate into about 0.74M€ per year.

* 1. **Indicar el plan previsto para la financiación del CSIC, mencionar la existencia de recursos y sus posibles orígenes. Describir las posibilidades de uso de fondos adicionales procedentes de los fondos estructurales europeos, fondos de inversión privados u otros. \***

At present, the CSIC groups have funded projects, mainly from the "Plan Nacional del Ministerio de Ciencia e Innovación", to do research in areas that involve Gravitational Wave Astronomy. In the future, we will apply for funding (both from National and Local funding agencies) for the ET developments, both for the instrument and for the required science developments. Some of the institutes involved have been awarded the Severo Ochoa and/or the Maria de Maeztu Excellence Center awards, which can be also of great help in the developments towards ET, specially from the point of view of incorporating PhD students and postdoctoral researchers to the project.

It has to be noted that the ET project is going to be a European project, and as such we plan, together with other European research institutions, to apply for funding of the European Commission, for both the technology and the science part.

# **PARTE 2. EXCELENCIA CIENTÍFICA**

**Misión de la infraestructura.**

* 1. **Describa la misión de la infraestructura europea propuesta, el impacto científico esperado a corto y largo plazo en las áreas científicas principales a las que prestará servicio y su impacto potencial en otras áreas si los hubiera, así como, las posibilidades de desarrollo tecnológico: \***

ET will be a laser-interferometer GW detector of third generation, improving by a factor of 10 the design sensitivity of the current second-generation detectors (LIGO and Virgo, which will be joined soon by KAGRA), increasing in this way by a factor of 1000 the sky volume reach will make it possible to continuously observe the distant, dark, dense and extreme Universe. This will have a tremendous impact in the already revolutionary science that is being done with GW detectors, with a strong impact in Astrophysics, Cosmology, and Fundamental Physics. It will also have a strong impact in Geophysics as well as in many technological areas associated with the instrumentation necessary for this type of detector.

The astronomical sources of GWs are systems where gravity is extremely strong, and often characterized by relativistic bulk motion of massive objects. The emitted radiation carries information about the nature of the space-time geometry, and is thus an invaluable tool to understand the behaviour of matter and geometry in extreme conditions of density, temperature, magnetic field and relativistic motion.

Black holes (BHs) and neutron stars (NSs) are among the most prominent sources of GWs for Earth bound detectors. ET will uncover the whole population of coalescing stellar and intermediate mass BHs in the Universe, allowing to study subtle relativistic effects and to identify possible deviations from General Relativity in the strong gravity regime. The detection of GWs emitted by several coalescing, and possibly also isolated, NSs will finally provide the determination of NSs equation of state, and other crucial information on their properties and demography. ET will also allow one to distinguish astrophysical from primordial black holes in the critical mass range. Also, the existence of exotic compact objects will be testable. ET will increase the chance to observe the onset of the explosion of a massive star and thus provides precious information about the explosion mechanism that gives birth to NSs or stellar-mass BHs. Thanks to the combined approach of Multimessenger Astronomy, the NSs merger and post-merger dynamics will be unveiled and its impact on element nucleosynthesis clarified. Stochastic GW backgrounds, due to the superposition of the GWs emitted by several uncorrelated sources, are another key target of ET. The detection of a background of cosmological origin, in particular, would allow to probe very early epochs in the evolution of the Universe.

This translates into the following powerful Science Case for the Einstein Telescope:

* Fundamental physics:
	+ The nature of gravity (tests of General Relativity and alternative theories)
	+ The nature of compact objects (no hair conjecture, GW echos, etc.)
	+ Black holes and the nature of dark matter (primordial black holes, etc.)
* Astrophysics of compact objects
	+ Neutron star properties (equation of state, demography, etc.)
	+ Black hole properties (mass range including the existence of intermediate-mass
	black holes, origin, evolution, demography, etc.)
	+ Core collapse supernovae
	+ Multi-messenger astronomy (stellar nucleosynthesis, physics of jets, cosmic rays
	 accelerations, neutrinos)
* Cosmology and cosmography
	+ Stochastic backgrounds of GWs of cosmological origin (inflation, phase transitions, cosmic
	strings, primordial black holes, etc.).
	+ Measurements of Cosmological parameters (Hubble constant, Dark Energy density, Dark Matter)
	+ Stochastic backgrounds of GWs of astrophysical or particle origin (unresolved populations, etc.)

To reach a displacement sensitivity of ~ $10^{-20 }$m (1/100000 of the proton size) it has been necessary to push most of the detector components to the edge of the technological development. This applies for example to the impressive combination of optics characteristics like size, surface figure, coating uniformity, low absorption. The same holds for the seismic isolation system to attenuate the ground vibration which required a long development period to reach the astonishing seismic attenuation level of twelve orders of magnitudes above few Hz. Given the scale of all these developments it is difficult to foresee all the possible technological returns. However, we can cite two examples where the knowledge and technology acquired in the field of GWs has led to applications and spin-offs in other fields. In the first, stem cell differentiation has been controlled by the application of nanoscale vibrations to the cells. This has potential applications in the growth of bone tissue.

The gravitational waves detector technology can be exploited for the ongoing development of an early earthquake warning system based on gravity strainmeters. The perturbation of the Earth's gravity due to an earthquake, which propagates at the speed of light, can be detected by a proper device before the seismic waves giving a faster advance warning of earthquakes.

* 1. **Describa el beneficio que supondría dicha misión para el CSIC, en caso de participar en la misma \***

The main benefits for the participation of CSIC in the ET project are:

* Participation in the fast-growing field of Gravitational Wave Astronomy: To take part in ET means to participate in the recently inaugurated area of Gravitational Wave Astronomy and the associated Multimessenger Astronomy, which have already produced revolutionary discoveries and won many international distinctions including the Nobel Prize in Physics 2017. When ET becomes a reality, it will dominate Gravitational Wave Astronomy in the high-frequency band and it will be one of the main players in Multimessenger Astronomy. Members of CSIC (IFT) participated in the first Multimessenger Kilonova discovery and their experience will be greatly enhanced by the ET sensitivity.
* Involvement in pushing Frontier Technologies: To take part in ET means to participate in cutting-edge technological developments in different areas (nanotechnology, photonics, advanced material science, data handling, and engineering and fabrication technologies) associated with extreme precision metrology: Ultramodern lasers with high power; suspension technology; vacuum systems; mirror coatings; cryogenic optics, quantum technologies for optical metrology; etc.

* Participation in a challenge to High-Performance Computing: The analysis of the data that ET will produce will present a huge challenge for computation, due to the amount of sources that are expected to be detected and the high precision we will have in the physical parameter estimation of them. It is clear that the most advanced techniques and technologies in computation should be developed and adapted to ET science. CSIC is participating in several high-performance computing infrastructures, which can benefit from the ET project, and at the same time, these infrastructures can enhance the role of CSIC researchers in ET.
* Strengthen CSIC leadership in Frontier Science: ET will be the main gravitational-wave infrastructure in Europe (and possibly in the world together with the planned Cosmic Explorer gravitational wave detector in the US) in the high-frequency band of the GW spectrum. It will be of a magnitude similar to the LHC experiment at CERN which has dominated particle physics in the last decades, with scientists all over the planet participating. In this sense, it is clear that CSIC needs to participate in a world-class scientific infrastructure such as ET in order to be at the forefront of the research in this important field with a huge impact in areas as important as Astrophysics, Cosmology, and Fundamental Physics.

# **Relevancia paneuropea.**

* 1. **Describa la "singularidad" de la infraestructura propuesta. Cómo se encuadra la infraestructura en el panorama europeo de infraestructuras de investigación, indicando si cubre un vacío existente y si existen necesidades de las comunidades de usuarios que no hayan sido abordadas en la actualidad por otras infraestructuras ya existentes. \***

The proposed infrastructure is unique. Einstein Telescope (ET), building upon a 2008-2011 EU Design Study, is world-wide the most advanced ground-based next-generation GW research infrastructure. ET will probe a thousand-times-larger volume of deep space compared to what can ultimately be reached by the present 2nd generation observatories such as LIGO & Virgo – allowing to study sources across the entire history of our Universe. ET is a top priority of the European Astroparticle Physics community organized by APPEC. ET’s unique sensitivity at low (2-20 Hz) frequencies will allow early ‘triggers’ to a multitude of world-wide observatories studying complementary messengers such as electromagnetic radiation, neutrinos and cosmic-rays collectively referred to as multi-messenger astronomy.

To reach these objectives, ET will implement frontier technologies: (a) large high-purity coated silicon test masses and suspension systems cooled to below 20K using innovative, efficient and low-noise cryogenic techniques, (b) high-power, ultra-stable lasers to enable the high-precision readout of differential test-mass motion, (c) quantum technologies to overcome the standard quantum limit of detector sensitivity, (d) advanced environmental monitoring systems using extensive sensor arrays for data-quality control and environmental-noise cancellation, (e) leading-edge vacuum engineering for the overall infrastructure hosting the largest ultra-high vacuum system on Earth.

For a broad and large research community –(astro)particle physicists, astronomers and cosmologists– ET will be the instrument of choice for many decades to come. In the 2040’s ET is expected to be complemented by the Cosmic Explorer in the USA to operate as a network which will further boost discovery potential and notably the sky localization. The envisaged start of ET’s operational phase in 2034 is also very well matched to ESA’s LISA space mission which aims to study GWs at very low frequencies.

The ET research infrastructure will allow the full convergence of the European GW community into a pan-European project. ET opens new possibilities in many research fields: astrophysics, by observing almost the whole Universe through the GW emission of binary black holes; Fundamental physics, by investigating the deepest nature of gravity and space-time; Nuclear physics, by probing the state of matter in the neutron-star core. This will be possible through extensive technological developments in lasers, optics, precision mechanics, material science, control and analysis methods, and quantum technology. This inter- and multidisciplinary richness is witnessed by the variety of the institutions that are supporting this proposal and by the heterogeneity of their institutional interests.

Operating a mind-boggling complex research infrastructure such as ET a few hundred meters underground poses not only many challenges but also raises opportunities. At many institutes all across Europe and at various levels joint efforts –often involving industry– vibrant activities are ongoing in areas covering geology, sensor-, mirror- and laser- technology, vibration attenuation, vibration-free cryogenics, etc. Some have already resulted in start-up companies.

A memorandum of agreement has been recently established among CERN, INFN (Italy) and Nikhef (The Netherlands) to collaborate in technological developments related to the ET proposal. This document is extendable to other countries and funding bodies. This demonstrates the evident synergies between CERN and many aspects of the ET project like, for example, civil engineering underground, site characterization, cryogenics, beam monitoring and control systems, micro-electronics, Si-based detector R&D, computing, or project management, for which CERN has an excellent record.

As it is already the case for LIGO-Virgo-KAGRA network for GW detection, the prompt public alerts of GW detections from ET will be input to multiple electromagnetic observatories as well as other types of detectors like neutrino or cosmic-ray observatories. As it already happened with the first binary Neutron Star detected by the LIGO-Virgo collaboration, the combination of multimessenger detections leads to revolutionary discoveries where the GW signal is a key part.

* 1. **Relación con infraestructuras nacionales existentes, incluyendo expresamente si forman parte del mapa de ICTS vigente, aprobado el 7 de noviembre de 2018. \***

In point 15 we already mentioned some ICTS connected with CSIC that can contribute as well as benefit from the ET project. We can extend this to other ICTS.

First of all, all the ICTS in the area of Astronomy and Astrophysics are relevant here since, as we have already discussed, ET will also be part of a global effort in Multimessenger Astronomy and it has already been shown with the first detection of coalescence of a Binary Neutron Star, that electromagnetic observatories operating in very different parts of the electromagnetic spectrum can have a strong impact. The Canfranc Underground Laboratory (LSC) can also have an impact in terms of the ET infrastructure, as they have already participated in seismic studies related to the project, as well as in aspects related to cryogenics and deep underground infrastructures as a whole.

The other area where we find ICTS of relevance for the ET project is Information and Communications Technology, where the two existing ones, the Spanish Network of High-Performance Computing (RES) and the [Spanish Academic and Research Network (RedIRIS)](http://www.ciencia.gob.es/portal/site/MICINN/menuitem.8ce192e94ba842bea3bc811001432ea0/?vgnextoid=f32303be3321b410VgnVCM1000001d04140aRCRD), which offer a great computing power and better and more secure communications to the scientific community, can have an impact for ET and the Spanish community participating in the project. The computing challenge of the ET project is comparable to that of the current LHC phase at CERN. Given the success and the accumulated experience in the operations of the WLCG Grid for the LHC experiments, it is expected that CSIC centers and ICTS, with dedicated resources for the LHC experiments, would play an important role in the processing and distribution of the ET datasets.

From the areas of materials, cryogenics, ultra-high vacuum technologies, and beam monitoring, there are three ICTS that are worth mentioning here. Two of them are the National Accelerator Center (CNA) and the ALBA Synchrotron, and they are important taking into account the close connection between the ET infrastructure and the infrastructure that accelerators usually have and they close collaboration with CERN. The third one is the Network of Clean Rooms for Micro- and Nano-manufacture (Red de Salas Blancas de Micro y Nanofabricación, MICRONANOFABS), which can provide their resources for the possible Spanish participation in the ET instrument, in those aspects related to detector development for laser control and monitoring of the interferometer performance.

# **Impacto socioeconómico**

* 1. **Describa en qué manera la infraestructura que se propone contribuirá a abordar algunos de los grandes retos de la sociedad y a los Objetivos de Desarrollo sostenible: \***

The ET project will generate high long-term socio-economic benefits due to its high technological and innovative content, the scientific relevance of the research activities conducted at the research infrastructure, and the related international exposure.

The demand of goods and services with high technological content, required by ET, both during construction and operations, will push the boundaries of technology and technical knowledge thus affecting the high-tech sectors of many countries. Spin-offs are likely to arise in key enabling technologies photonics, advanced materials, nanotechnology, micro-electronics, and advanced manufacturing technologies. These are priorities of the EU industrial policy and will fuel economic growth and job creation in a wide range of advanced products, processes and services including low-carbon energy solutions; more energy and resource-efficient manufacturing; and new medical products. For instance, the extension of the laser wavelength can be applied to the welding of special plastics, spectroscopic measurements in medical applications and cholelithotripsy.

The scientific importance and international exposure of ET will facilitate the attraction of high skilled human capital that will enhance the regional socio-economic performances in the long term. In both cases the ET project will play a key role in building an education network between regional schools and universities and encouraging students to follow a STEM education. Moreover, the ET project is perfectly in line with the socio-economic development strategies outlined by the two potential host regions.

Finally, the overlap between the technologies needed to upgrade current detectors and the ET technologies facilitate a smooth and relatively low risk implementation of the ET project. Medium/large facilities (laboratories and R&D centres) will be realized to develop ET technologies and the costs of these research infrastructures are taken into account.

* 1. **Indique brevemente el impacto esperado de la infraestructura en la actividad de innovación, en la producción de bienes y servicios, por ejemplo, en términos de capacitación de personal, transferencia de conocimiento, programas de acceso y servicios prestados para el CSIC \***

The ET Infrastructure will facilitate education and training of scientists and engineers, in particular early career researchers in the emerging field of gravitational waves and astroparticle physics. ET will provide a unique research environment in which scientists permanently based at the ET infrastructure will collaborate with many visitors and PhD students who will stay on the ET site for extended periods to carry out their research. In addition to core research qualifications and skills, training will include media relations, creativity, business skills, public outreach and presentation skills. This will help in particular the early career researchers to take on entrepreneurial, knowledge exchange and public engagement activities supported by local development managers. In addition, through development projects with industry and engagement within the wider gravitational wave and related communities we will create a group of highly sought after and versatile researchers with unique skill sets, which can support on local and international level the physics-based industrial sector. Moreover, many physics PhD researchers contribute to neighbouring sectors, for instance take up jobs in the financial sector or information and communication technologies.

In terms of knowledge transfer, the gravitational wave community has a strong track record stimulating impact in a variety of fields including photonics, material sciences, low noise optomechanical systems, inertial sensors, etc.

Access programmes in the traditional sense (of e.g. synchrotrons and beam sources) are not applicable to the ET infrastructure. However, we will provide virtual access, access to data and open public alerts with low latency to the stakeholder communities in astronomy.

In the case of CSIC, the participation in a challenging project, as the ET project certainly is, will be a driver for the improvement of the scientific and technological resources that the CSIC institutes have. It will certainly improve the quality of these services as well as increasing the variety of them. The specific services that will benefit from this participation have a direct connection to the benefits of the ET project that we have mentioned in different parts of this document.

* 1. **Indique, en su caso, la relación con el Plan de Actuación del CSIC, plataformas tecnológicas y/o temas estratégicos. \***

ET clearly touches several strategic areas that will appear in the "Plan de Actuación del CSIC" currently in preparation. At the same time, ET will also be a crucial element to face several of the challenges (Desafios) that currently CSIC is formulating. Moreover, the scientific and technological magnitude of the ET project allows it to have intersection with several of the Technological Platforms that CSIC has recently presented.

Finally, it is worth mentioning that the Strategic Plan of several of the CSIC groups includes Gravitational Wave Astronomy as a main activity. Not only recently, but also since many years ago.

# **Estrategia de usuarios y política de acceso**

* 1. **En lo posible de una estimación en cifras cuantitativas del tamaño de las comunidades científicas y tecnológicas del CSIC potenciales usuarias de la infraestructura. \***

The main scientific users of the infrastructure are the gravitational wave community and part of the astronomical community interested in multi-messenger astronomy with GWs. Currently there are 14 institutions (3 of them CSIC) in Spain hosting groups participating in GW experiments: LIGO (UIB, IFGAE-USC), Virgo (UV, IFAE-UAB, ICCUB) and LISA (ICE-CSIC, IEM-CSIC, IFT-UAM-CSIC, ICCUB, UCM, MOA-UCA, U. Granada, UPM, UPV/EHU, UPC, UIB).

These groups cover the different aspects of GWs, including experiments, data analysis and theory. Additionally, there are a number of institutions that have shown interest in the multi-messenger component of ET, using the observatories in the electromagnetic spectrum (IAA-CSIC, IAC, IFT-UAM-CSIC, CIEMAT, among other) and neutrino detectors (IFIC-UV-CSIC, IFGAE-USC). This community has grown significantly over the last few years and is structured as the Spanish GW Network (REDONGRA) funded by the Ministry (FPA2011-15393-E, PI. C. Bona and FPA2015-69815-REDT, PI. C. Sopuerta) and a series of yearly Iberian GW meetings on-going since 2011. A number of the groups are participating already in developing technology for current experiments (ICE-CSIC, ICCUB, IFAE-UAB, MOA-UCA, UPC) and will probably be interested in participating in ET as well. In all aspects of current GW experiments the CSIC is well represented with 6 ICUs with direct participation. So far more than 750 researchers have signed the ET letter of intent, 40 of them from 14 Spanish institutions.

* 1. **Describa la forma en que se ha involucrado a la comunidad de usuarios en la elaboración de la propuesta, por ejemplo, en la definición del caso científico y de las especificaciones técnicas del diseño de la misma, en el análisis de coste/beneficio, en la planificación y la financiación de la infraestructura: \***

The initial planning phase (2008-2011) was supported as Design Study by the European Commission (FP7 Grant Agreement 211743) and finalized with the elaboration of the Conceptual Design Document signed by researchers from 55 European institutions, including (ICE-CSIC, UIB). The ET community in Europe created after the Design Study is currently in the process of becoming the ET collaboration with the intent of submitting a proposal for an ESFRI. This process was initiated in the 9th ET symposium (2018) by making an open call to the European GW community to sign a letter of intent for the ET collaboration.

The ET project is organized in 5 Working Groups with participation of researchers and institutions all over Europe (including researchers in Spanish institutions, and several researches in CSIC institutes). Since 2008 there have been 10 ET symposiums devoted to setting up the science case and addressing the technological challenges of the experiment. In addition, numerous technical meetings have been taken place devoted to specific topics of the WGs. Spain has contributed to some of the WG (e.g. Alicia Sintes at the WG2 coordinated the long term seismic studies at the Canfranc Laboratory). In 2019 it was published the Science case for the Einstein telescope, with the participation of Prof. Juan García-Bellido (out of 18 authors), a document in preparation for the ESFRI submission, on behalf of the ET steering committee.

At the EU level, the roadmap for the European ASPERA network for Astroparticle Physics (2008) included "gravitational waves" as one of their objectives. In particular, the 3rd generation GW detector ET was included in the Magnificent Seven list. The European Astroparticle Physics Strategy 2017-2026 (APPEC) highlights GWs among its strategic activities and strongly supports the ET project. The CERN Physics Briefing book (2019) for the European Strategy for particle physics mentions the *multiple synergies between Particle and Astroparticle Physics at the level of infrastructure, detectors, interaction models and physics goals.*

At the international level, ET has been promoted and supported by the Gravitational Wave International Committee (GWIC). Since 1997 GWIC has served to facilitate international collaboration and cooperation in the construction, operation and use of the major GW detection facilities worldwide, including LIGO, Virgo and LISA. In 2010 they published the GWIC roadmap “The future of gravitational wave astronomy” identifying ET as high priority. In 2019 the GWIC-3G subcommittee published the 3G Science Case for third generation detectors including ET as the European GW detector in the future international 3G network.

# **Necesidades electrónicas.**

* 1. **Describa brevemente el Plan de gestión de datos y la normativa de acceso a los datos de la infraestructura. Describa cómo los datos serían accesibles al público: \***

The ET Collaboration will develop a Data Management (DM) Plan based on the research and outreach goals of the facility.

DM Policies will include:

- Transfer of raw and processed data to the relevant computing infrastructures, with the required latencies;

- Easy and efficient data access for the designated user community;

- Interoperability with other operative GW and EM observatories;

- Open access to data;

- Long-term data preservation.

The detailed policies and tools will be developed for the different types of data: primary raw data, secondary processed data (h(t) or “strain” and associated data quality vectors) used for data analysis, and tertiary derived data such as published analysis results.

Policies and tools will be developed for reliable raw data transfer to off-site facilities, in more than one copy, for custodial storage; the actual tools and strategies will depend on the details of the infrastructure available at the time of data taking. Exploitation of processed data, and a subset of raw data, deemed useful for analysis, possibly including relevant data from ancillary sensors, will be granted to the relevant communities by developing tools and strategies to distribute it on the computing infrastructure as soon as they are produced. This way we will guarantee efficient access to data, software and computing resources.

A software repository with facilities for continuous integration will ensure uninterrupted availability and reliable usability of the tools. A central Data Catalogue will allow discovery of available data and a common and ubiquitous Authentication and Authorization Infrastructure (AAI) will grant access to computing resources.

Open Access and Long Term preservation will be managed by implementing an OAIS-compliant archive, based on the ISO 13721 standard (Open Archival Information System).

After a predefined grace period, validated processed data will be released under an appropriate open licence, most likely in the context of some wider Open Science initiative such as the heirs of current Virtual Observatory projects like ESCAPE. This is already routinely done in the 2G observatories network through the GWOSC (https://www.gw-openscience.org/). The OAIS model calls for definition of a “Designated User Community”, who will be using the archive; the information to be preserved should be “independently understandable” to this community. Usability will thus be ensured by releasing the software needed to access it with an Open Source licence. All data and metadata formats, along with all required software, will be thoroughly documented, applying FAIR principles and enabling researchers from outside the collaboration, science practitioners and students to profitably exploit the data.

Final scientific results, and relevant supplementary data where needed, will be published whenever possible in Open Access journals, archived and indexed in trusted repositories.

* 1. **Indicar a nivel nacional qué tipo de servicios de infraestructuras electrónicas necesitará su infraestructura, por ejemplo, recursos para almacenamiento, computación, redes, herramientas para la gestión de datos, seguridad, acceso, análisis remoto, etc., y en su caso si se ha establecido contactos con los proveedores de dichos servicios: \***

The actual amount of computing needed to extract the science results, both in low-latency search and parameter estimation, cannot be naively extrapolated from current activities; to do so would predict an increase by at least three orders of magnitude. Similarly to what is currently happening with HL-LHC, intense R&D activities and Mock Data Challenges are planned in the preparation phase to reduce such requirements within the bounds of what can be provided in the 10-years timescale, taking into account realistic computing technology developments.

The on-site computing infrastructure will be limited to detector control and environmental monitoring, data acquisition, buffering and transfer, with a local cache of the order of some PB.

Most data processing (including much of the low-latency searches) will take place off-site, on common e-infrastructures and some baseline services:

* Custodial storage services with data duplicated on several sites for long-term archival;
* Data Management services cataloguing the data, allowing for data recovery, and managing data transfers reliably;
* Data Access services distributing the data, adopting a “Data Lake” and Content Delivery Network model;
* Network services (provided by NRENs and Géant), such as links between data centres, access to the GPN and possibly to an environment like LHC-ONE;
* A common AAI infrastructure based on trusted IdPs and an ET authorization service, federated with other GW initiatives.

As for the computing resources, most GW workloads are embarrassingly parallel but we will need to plan for many possible evolutions, depending upon the roles e.g. of Deep Learning calling for special clusters for algorithm training, Big Data techniques for low-latency searches on streaming data, lower-level parallelism on HPC clusters, or even, given the timescale, Quantum or Neuromorphic Computing. In general, flexible cloud access to heterogeneous resources provided by a shared e-Infrastructure will be required.

From the national point of view, the existing network of super-computation (RES) has been playing a significant role in providing significant CPU resources for the intense computation of theoretical models, instrumental to extract the signal of gravitational waves from the LIGO and Virgo data. The huge events rates expected at ET and the need for a prompt identification of candidates to facilitate the electromagnetic follow-ups will impose even stronger requirements in the computing model, in terms of the size of the banks of theoretical models employed to analyse the data, data transfer rates, and the online selection of events. As already pointed out, the computing needs will become comparable to those at the LHC. It is therefore expected that a distributed computing model will be put in place, for which CSIC centers, with extended living experience on the subject, will be in a privileged position to play a significant role.

* 1. **Describir brevemente cómo la infraestructura cumplirá con los principios FAIR y la forma en que la infraestructura contribuirá al desarrollo de la infraestructura electrónica europea, por ejemplo, su relación con el European Open Science Cloud (EOSC): \***

GW research is necessarily a network effort by several players, and e-Infrastructures form the supporting frame for such networks. The three current 2G interferometers are, at the time of writing, building the IGWN actually starting from a coordination and integration effort at the e-Infrastructure level, aiming at a common distributed computing and alert generating infrastructure.

In the same way, as described throughout this proposal, ET will be part of a global network of GW, EM, cosmic rays and neutrino observatories for multi-messenger astronomy, and again the shared e-Infrastructures will form the backbone of such network, possibly with the alert service being an original contributed service.

The GW community already has a success story of publicly releasing data through the GWOSC (<https://www.gw-openscience.org/>), another communal effort: papers have been published by teams outside the LVC collaborations. Building on top of that experience, and moving towards the common EOSC platforms that will be available at the time of ET data taking, ET will be able to vastly contribute to the European Open Data landscape.

The relative simplicity of the structure of science-rich GW data, and their final storage on OAIS-compliant repositories, will greatly ease the compliance to FAIR principles; again, here the long timescale helps. We expect that, throughout the ET design and implementation phases, the GW community will continue its collaboration to bring EOSC services to full maturity, so that they will be the natural platform for ET data storage, cataloguing, processing and sharing. The integration of GW e-Infrastructure and unique open-access data into the EOSC, together with data from other observatories and possibly with high quality data from e.g. magnetometers or seismometers, will provide the EU and the global research community an invaluable asset for Open Science.

# **PARTE 3. IMPLEMENTACIÓN:**

**Trabajo preparatorio y planificación**

* 1. **Para determinar el estado de madurez de la propuesta, describa brevemente el procedimiento seguido para la definición del concepto científico de su Infraestructura y las principales conclusiones de su estudio de viabilidad. \***

ET ESFRI proposal is the natural evolution of a series of steps: conceiving the idea of a 3G GW observatory, in the FP6 integration activity (ILIAS, 2004-2008) in FP6 and in an Exploratory workshop funded by the European Science Foundation in 2005. The conceptual design of ET has been realised in a design study FP7 grant (2008-2011). Some of the enabling technologies of ET have been developed in collaboration with the Japanese project KAGRA through an IRSES-FP7 project, ELiTES (2012-2017). Finally, the detection of GW by LIGO and Virgo, gave the final green light for the new phase of the ET project. The next steps toward the implementation of ET are well defined: selection of the hosting site among the two candidates (2023) through full qualification of the sites, definition and creation of the governance of ET (2024), completion of the RI technical design (2025), land acquisition (2025), completion of the observatory technical design (2025), beginning of the excavation works (2026).

* 1. **Indicar si se trata de un proyecto previamente financiado por algún programa de la Unión Europea, programa nacional o programa regional, y en su caso, incluir el valor de la financiación recibida en particular por las instituciones nacionales, detallando la recibida por el CSIC. Especialmente, mencionar el trabajo previo que condujo a esta propuesta, p. ej., la participación en las Acciones Integradas de Infraestructura u otros programas con programas externos con evaluación internacional, detallando igualmente la participación CSIC. \***

As we have mentioned previously, The Einstein Telescope project has already participated in several programmes of the European Commission. It can be said that it actually was started with the Conceptual Design Study funded by the FP7 programme (FP7 - INFRASTRUCTURES-2007-1. SP4 CAPACITIES. Grant Agreement 211743), which run **from** May, 2008 **to** July, 2011. Another EU project for ET studies was ELiTES (*ET-LCGT Telescopes: Exchange of Scientists*. FP7-PEOPLE-IRSES Grant Agreement 295153), which run **from** March, 2012 **to** February, 2016. There has been a recent EU project, GraWIToN - *Gravitational Wave Initial Training Network* (FP7-PEOPLE-2013-ITN Grant Agreement 606176), also devoted to ET science and developments. Finally, there are currently ongoing COST actions where the science of ET is central to the actions main topic: (i) The action *Gravitational waves, black holes and fundamental physics* (GWverse; Grant Agreement COST CA16104), running **from** April 2017 **to** April 2021. (ii) The action *Quantum gravity phenomenology in the multi-messenger approach* (QG-MM; Grant Agreement COST CA18108), running **from** March 2019 **to** March 2023. (iii). The action *The multi-messenger physics and astrophysics of neutron stars* (PHAROS; Grant Agreement COST CA16214, running **from** November 2017 **to** November 2021. (iv) The action *A network for Gravitational Waves, Geophysics and Machine Learning* (G2NET; Grant Agreement COST CA17137), running **from** October 2018 **to** October 2022. Moreover, the ET community has plans to submit/participate in more applications for EU funding.

Apart from this, the participating countries in ET have obtained national and local funding for performing preliminary studies for ET and also to start developing technology beyond the current second generation of ground-based gravitational wave detectors. Also, at the Spanish level, there have been several funded projects (from the *Agencia Estatal de Investigación* and other funding agencies) that have produced scientific results of relevance for the ET project. In particular the projects related with LIGO, Virgo, and LISA.

In total, the ET project has received already a targeted financial support of 47,8M Euros (about 2.5% of the total anticipated core cost) by some European countries. It has been dedicated to complete the design and to carry out a full characterization of the proposed sites in Italy and The Netherlands.

* 1. **Con el fin de tener una idea de la viabilidad técnica de la propuesta, describa brevemente si todas las tecnologías relevantes para la construcción de la infraestructura están disponibles o si se necesita investigación y desarrollo, y en qué medida. \***

In terms of feasibility of the proposal, Gravitational Wave detection has recently reached its breakthrough with the first observations of coalescing pairs of black holes and neutron stars. Essential for this success was the development of long-baseline, high-power laser interferometry, which also forms the basis of ET design. Crucial for a successful implementation of innovative technologies in each of the current GW detectors LIGO, Virgo, GEO600, and KAGRA was the coordinated effort of various laboratories and prototype facilities, which made it possible to develop, test and characterize the technologies beforehand. The swift commissioning progress in all existing detectors is a clear demonstration of the success of this scheme, which will be adopted for ET.

Laser interferometry is the only technology compatible with the sensitivity target of ET, and in addition has proven its outstanding reliability enabling a high duty cycle of current detectors. The feasibility of key technologies for ET was assessed by a sequence of EU funded projects starting in 2004 with the FP6-I3 JRA ILIAS-STREGA, which ended in 2008. This activity was a first investigation of potential solutions to reduce thermal noise with new materials and cryogenics to enable third-generation GW science. A further step was taken with the ET Conceptual Design Study funded by the EU within FP7 from 2008 to 2011, which resulted in a comprehensive and detailed investigation of infrastructure and technology requirements for ET, and of its science case. It was concluded in this study that most of the technologies of ET are advanced developments of technologies used in current detectors. This concerns the vacuum system, seismic isolation, high-power lasers, squeezed-light technology for quantum-noise reduction, electronics and detector control. However, a defining feature of the ET design is the extension of the GW observation band of current detectors towards lower frequencies, which requires R&D of new key technologies, especially with respect to the mitigation of thermal and environmental noise. In this regard, EU-funded projects following the design study led to crucial insight and experience. The project ET R&D (2013 - 2016) within the FP7 ERA-NET ASPERA-2 framework targeted the initial investigation and development of new enabling technologies, which included the high-power lasers, cryogenics, new materials for test masses, and environmental-noise mitigation. An exchange of experts between the KAGRA and ET communities for the development of cryogenics technology was funded through the FP7-IRSES ELiTES project (2012-2017). KAGRA is the first GW detector to implement cryogenics, and therefore is an important collaborator for the development and testing of ET technologies.

A defining feature of ET is the extension of the GW observation band towards lower frequencies with respect to current detectors to enable new contributions to its science case. One of the consequences is that environmental disturbances and therefore the quality of the detector site play an important role. Strong mitigation of the environmental noise is achieved by constructing ET underground. Again, invaluable experience of operating an interferometer underground was gained with KAGRA, the only GW detector so far to be located underground. Innovative technologies might have to be employed to further mitigate the impact of the environment on the detector depending on site quality. These technologies are currently being developed for upgrades of the Virgo detector, which includes the realization of quiet infrastructure to avoid that the detector environment is spoiled, e.g., by ventilation and pumps, and also the mitigation of terrestrial gravity noise.

A Mock Data Challenge was performed following the ET design study. It explored the unique capabilities offered by ET, and it targeted the issue of analyzing signals from compact-binary coalescences in a signal-rich environment (up to a few million such signals can be expected per year in principle detectable with ET). It was found that existing data-analysis algorithms can be adopted in ET to detect and analyze these signals, but new algorithms are needed to fully exploit ET’s science potential.

The new multi-messenger astrophysics including GW observations showed the high importance to develop low-latency GW data analyses and infrastructure for rapid and responsive communications with the astronomical community. To fully exploit the scientific potential of each GW source, ET will be part of the globally coordinated multi-messenger ground- and space-based resources and will send alerts. The computing resources, software and infrastructures to rapidly obtain, analyze and interpret a higher volume of multi-messenger data will be based on the invaluable experience acquired by the GW community currently operating the multi-messenger effort with GW detectors.

* 1. **Otra información que considere relevante\***

In summary, the Einstein gravitational-wave Telescope (ET) will be a ground-breaking Earth-based detector of third generation, which will improve by a factor of 10 the design sensitivity of the current second generation of gravitational detectors (LIGO and Virgo) that made the 2015 breakthrough with the first ever direct detection of gravitational waves, showing beyond doubt the last prediction of Einstein's General Relativity and providing revolutionary discoveries in astrophysics regarding Black Holes and Neutron Stars. As a consequence, the 2017 Physics Nobel Prize was awarded to the founders/leaders of the LIGO detector and collaboration. Nowadays, the second-generation of ground-based detectors are making detections at a rate of 1-2 per week. ET will be making several detections per day with much better sensitivity, which will open the door to revolutionary discoveries not only in Astrophysics, but also in Cosmology and Fundamental Physics. In particular to the details of the expansion history of the Universe (and in consequence to dark energy and dark matter research), to the detailed structure of Black Holes and Neutron Stars (and in consequence to check whether the *no-hair* conjecture is true and to understand the equation of state of neutron stars and the behaviour of matter at densities not accessible to Earth-based experiments), and even to test General Relativity and alternative theories of gravity (giving as a key towards quantum gravity and beyond Einstein Physics).

From the point of view of Technology, like already happened with the second generation detectors, ET will be based in cutting-edge technologies that has the potential to drive advances in several areas of engineering. More specifically, the main frontier technologies that ET will be pushing are: (i) Large high-purity coated silicon test masses and suspension systems cooled to below 20K using innovative, efficient and low-noise cryogenic techniques. (ii) High-power, ultra-stable lasers to enable the high-precision readout of differential test-mass motion. (iii) Quantum technologies to overcome the standard quantum limit of detector sensitivity. (iv) Advanced environmental monitoring systems using extensive sensor arrays for data-quality control and environmental-noise cancellation (in particular gravity-gradient noise). (v) Leading-edge vacuum engineering for the overall infrastructure hosting the largest ultra-high vacuum system on Earth.

All of this makes ET a revolutionary project that has the potential to change under understanding of the Universe as well as many key technologies with impact in the socio-economical situation of the European Union. In this sense, the support of CSIC to this project as well as its involvement in it will be crucial for the success of ET and for the excellence research mission of CSIC.

Finally, as it is already the case for the LIGO-Virgo-KAGRA consortium, the ET community will actively evaluate possible fruitful sharing of knowledge between GW science and research activities connected to climate change studies, the development of sustainable technologies, as well as protection and safety aspects related to early alerts and the monitoring of climate evolution. Considering that GW detectors are fully embedded in the Earth's environment and are unique in this aspect, potential synergies should exist. Studying, monitoring, modelling, and mitigating sources of environmental noise (which span geophysics, Earth tremors, soil density fluctuations, weather, sea activity, atmosphere density perturbations, geomagnetism, cosmic rays, etc.) is part of GW detector design and operation as well as selection studies of new detector sites. One can share interest in the data samples, the methodologies, new sensors (smart seismic and acoustic arrays are being developed for Newtonian noise determination). The design of new smart, low noise and sustainable large infrastructures, as well as the analysis of big data samples with analysis techniques, such as pattern recognition, leading to distributed alerts and earthquake early warnings are in the list of possible returns to society.