Hoja de Ruta 2021 ESFRI

El presente formulario deberá rellenarse por el representante de aquellas entidades nacionales o grupos de ellas que solicitan la participación de España en propuestas de nuevas infraestructuras de investigación a incluir en la Hoja de ruta ESFRI 2021, y deberá acompañarse por cartas de los representantes legales de las mismas indicando su respaldo a la misma.

El Formulario será utilizado para evaluar a nivel nacional el interés y la viabilidad de la propuesta y, servirá para tomar la decisión final de presentar oficialmente por parte del Ministerio de Ciencia Innovación y Universidades alguna propuesta nueva coordinada por España, o bien cartas de apoyo a alguna de las propuestas presentadas por otros Estados Miembro a la Nueva Hoja de Ruta de ESFRI 2021.

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

(La información solicitada podrá incluirse en inglés)

* Required

1. **Email address ***
   mmp@ifae.es

2. **Tratamiento de datos ***
   Mark only one oval.

   Los solicitantes autorizan al Ministerio de Ciencia, Innovación y Universidades 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. **(ACEPTADO)**

Datos de Contacto del coordinador nacional.

3. **Nombre y apellidos del solicitante en nombre de las entidades que apoyan la propuesta. ***

Mario Martínez Pérez

4. I**nstitución a la que pertenece ***

Instituto de Física de Altas Energías (IFAE)

5. **Correo electrónico ***
mmp@ifae.es

6. **Teléfono de contacto ***
+34 616395798

7. **Dirección postal: ***
IFAE/UAB CAMPUS BELLATERRA, 08193 BARCELONA

PARTE 1. INFORMACION GENERAL DE LA PROPUESTA DE INFRAESTRUCTURA EUROPEA

Descripción de la Propuesta.

8. **Acrónimo. ***

ET

9. **Título. ***

Einstein Telescope

10. **Página web, si existe.**

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

11. **Descripción breve de la infraestructura europea propuesta. ***

Einstein Telescope (ET) will be the European Third-Generation (3G) Gravitational Wave (GW) Observatory, designed to observe the whole Universe. ET will be a multi-detector, multi-interferometer observatory covering the whole spectrum observable from Earth with interferometric GW detectors. ET will put Europe at the forefront of the GW research being the first and most advanced 3G GW observatory. Thanks to the unprecedented sensitivity of ET, Europe will take the lead in the newborn multi-messenger astronomy by combining information delivered by ET with optical, IR, UV, gamma, cosmic ray and neutrino telescopes observations. ET, being a unique tool to investigate the spacetime fabric of the Universe, will impact on our knowledge of fundamental physics, and our understanding of the fundamental interactions governing the evolution of black-holes and neutron stars. The technologies needed for ET will affect industrial sectors, like lasers, sensors, optics, seismic isolation, and new materials.

The scientific background of ET is provided by the current network of GW detectors: Advanced Virgo in Europe and Advanced LIGO in the USA, recently joined by KAGRA in Japan, have brought the latest scientific revolution in astrophysics by detecting the GWs emitted by some of the most violent astronomical phenomena such as the coalescence of binary systems of black holes or neutron stars. This is a true revolution in physics, as it has opened a new era of observations of the universe through a new unstoppable messenger, GWs, capable of describing events that do not emit light and that complement the information collected by ordinary telescopes. Thanks to the beginning of the multi-messenger astronomy with GWs, several communities (cosmologists, astrophysicists, astroparticle physicists, nuclear and particle physicists) started to join their efforts. In 2025 we expect that LIGO-India will join the network, completing the Second-Generation (2G) GW detector landscape. ET constitutes the next step forward; it will be the Research Infrastructure (RI) pioneering the 3G GW observatories network. ET will observe the Universe well beyond the limits of current detectors, allowing us to observe, for example, coalescences of black holes back into the dark ages of the Universe.

Based on our experiences with the 2G GW observatories, this proposal is the result of a series of steps:

- The idea of a 3G GW observatory was conceived in the FP6 I3 activity ILIAS (2004-2008) and in an exploratory workshop funded by ESF in 2005;
- The conceptual design of ET was realized in an FP7 design study (2008-2011);
- Some of the enabling technologies of ET were developed in collaboration with the Japanese project KAGRA through an IRSES-FP7 project, ELiTES (2012-2017) and currently through the Interreg ET-pathfinder and E-TEST projects and the SarGrav facility;
- The detection of GWs by LIGO/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 (2023);
- Acquisition of legal status, creation of governance structure (2024);
- Completion of the technical design, land acquisition (2025);

- Beginning of the excavation works (2026);
- Start of operations (first half of the 2030s).

Within ApPEC, national funding organizations coordinate European astroparticle physics research. ET is one of ApPEC’s top priorities. ApPEC actively monitors and supports ET in general, and the realization of this ESFRI application in particular. An R&D proposal for 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 ET Collaboration and CERN have established a collaboration in areas of mutual interest and where CERN has an excellent track record. This concerns in particular civil engineering (underground tunnels), vacuum technology, cryogenics, control technology and project management. 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.

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 a 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.

12. **Características de la infraestructura propuesta ***

Mark only one oval.

Mejora o re-orientación de infraestructura existente

Nueva Infraestructura

13. Tipo. *

Deberá indicar si se trata de una infraestructura de sede única o distribuida.
Mark only one oval.

Infraestructura de sede única

Infraestructura distribuida

14. **Incluir detalles referentes a la localización de la(s) sede(s) de la infraestructura europea. Especialmente indicar aquellas que se localicen o pudieran localizarse en territorio nacional ***

The ET is a single site infrastructure. At the moment no decision has been taken on the definitive site location. The two potential host sites –Sardinia in Italy and the EUregio Meuse-Rhine (EMR) on the border between Belgium, Germany and The Netherlands– both secured significant (R&D) funding for ET, often on a national level. In Italy an underground facility at the Sos Enattos mine on Sardinia has been funded with national and regional funding as well as a dedicated cryogenic facility. For the EMR site two large EU Interreg projects have been approved with significant national, regional –and institutional– contributions. One for a laser-interferometry R&D laboratory (ET-pathfinder) and one for geology studies and a cold silicon mirror facility (E-TEST). Notably ET-pathfinder is envisaged to become the R&D laboratory for next-generation GW detection technology and as such welcomes new collaborators.

15. **En el caso de infraestructura distribuida indicar la localización de las entidades. que conforman el Nodo Nacional y cuál será su participación, indicando las instalaciones y equipamientos que formarán parte o prestarán servicio en la infraestructura europea. ***

Although the ET experiment itself will be placed at one location, the computing infrastructure needed for analysing the data will be distributed across several european countries. At this point no definite model of distributed computing exists yet, since the ET consortium is being formed.

16. **Ambito de aplicación en el que se enmarca la propuesta. (Indicar el área científica principal en la que se encuadraría la propuesta.) ***

Mark only one oval.

Energía

Medioambiente

Salud y alimentación Ciencias

Físicas e Ingeniería Ciencias

Sociales y Humanidades

e-infraestructuras

17. **Indicar en su caso otras áreas científicas relacionadas con la propuesta. Check all that apply.**

Energía

Medioambiente

Salud y alimentación Ciencias

Físicas e Ingeniería Ciencias

Sociales y Humanidades

e-infraestructuras

18. **Estado Miembro o miembro de EIROFORUM coordinador de la propuesta ***

Italy

The Netherlands

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

Below we present 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; Istituto Nazionale di AstroFisica; Istituto Nazionale di Geofisica e Vulcanologia; Università degli Studi di Sassari; Università degli Studi di Cagliari; European Gravitational Observatory
Netherlands: NWO-I / Nikhef; Maastricht University; University of Amsterdam; Vrije Universiteit Amsterdam; Utrecht University; Radboud University;University of Groningen
Germany: MPI for Gravitational Physics; RWTH Aachen University; University of Hamburg
United Kingdom: Science and Technology Facilities Council; University of Glasgow; University of Birmingham; University of Portsmouth; Cardiff University
France: Centre National de la Recherche Scientifique
Poland: University of Warsaw
Belgium: Université catholique de Louvain; Universiteit Antwerpen; Universiteit Gent; Katholieke Universiteit Leuven; Vrije Universiteit Brussel; Universiteit Hasselt; University of Liege; Université Libre de Bruxelles
Switzerland: Université de Genève

Participación a nivel nacional

20. **Indicar las instituciones españolas participantes, señalando su papel en la infraestructura europea que se propone. ***

A large number of institutions in Spain have expressed already interest in this ESFRI proposal. The list includes universities across Spain interested in gravitational wave physics; Spanish astronomy/astrophysics oriented centers involved in the multi messenger strategy for understanding the cosmos, and prominent research infrastructures in Spain motivated by the technological and computational challenges associated with the ET project. In the following, the expression of interest of the different institutions are collected:

The Universitat de les Illes Balears Group is one of the pioneering groups in Spain in the study of gravitational waves, playing an important role in the study of GW sources and the development of GW data analysis algorithms. The group is a member of LIGO and GEO, two major international projects dedicated to the detection of gravitational waves, leading several investigations within those collaborations. They are members of the LISA, consortium, the European space-borne gravitational wave detector, and are involved in the design study for ET, the third generation gravitational wave detector. They are interested in the science potential of ET observations of black holes and neutron stars, the development of new data analysis algorithms, waveform modelling, HP computing, fundamental physics studies and also in the commissioning and detector characterization.

The Institute of Theoretical Physics (IFT-UAM/CSIC) participates very actively since 2015 in the International Consortium LISA (Laser Interferometer Space Antenna) of ESA, with several permanent and associate members (contratados Ramón y Cajal, etc) in the Cosmology and Fundamental Physics Working Groups of LISA. A member of KAGRA has joined IFT recently with an Atracción de Talento contract. The group has worked on GW Science since at least 2007, with the proposal of a new stochastic gravitational wave background from preheating after Inflation. The group's interest in ET is manifold, with developments in GW modeling as well as in Astrophysics, AstroParticle Physics, Cosmology and Fundamental Physics studies. As members of galaxy surveys like DES, PAU, DESI, Euclid and LSST, the group will be involved in multi-messenger aspects using optical and infrared telescopes.

The Institute for the Structure of Matter (IEM-CSIC) participates actively in LISA, with a permanent member playing a relevant role in the working groups for Fundamental Physics and for Cosmology. The Institute includes a Group of Gravitation and Cosmology, with implications in other gravitational wave interferometers. A staff researcher is in the process of joining the KAGRA collaboration, and there exist close contacts with the United Center for Gravitational Wave Astronomy in Hangzhou, leaders of the future Chinese missions TianQin and Taijin. The Group develops classical and quantum models of gravity and of dark matter with observational implications for the production and propagation of gravitational waves in the range of frequencies that ET will cover.

The Institute of Space Sciences (ICE, CSIC) is pioneer in Gravitational Wave Astronomy and through the Gravitational Astronomy-LISA group has participated in resonant detectors and in those based on laser and atomic interferometry, leading the Spanish contribution to the LISA Pathfinder mission of the European Space Agency (ESA), and currently leads the Spanish contribution to the LISA observatory (the ESA-L3 mission). The ICE has also experience in data analysis techniques for gravitational wave detection as well as in the theory, in particular in the modeling of gravitational wave sources and in studies of astrophysics, cosmology and fundamental physics using gravitational wave detections. For ET, ICE is interested in participating in instrumental and theoretical aspects of the project as well as in the associated data analysis.

The Applied Optics and Magnetism Group at the University of Cádiz is currently working in the design of low-frequency instrumentation for future space-based gravitational wave detectors, such as LISA. Specifically, it focuses on the study of novel electronic noise reduction techniques to improve the performance of advanced systems by means of a thorough understanding of noise processes. Within the multiple areas that a scientific infrastructure like ET would encompass, the Applied Optics and Magnetism Group is interested in the technology developments necessary for the implementation of the third-generation gravitational wave observatory in its low-frequency bandwidth.

The USC-IGFAE GW astronomy group formed in 2018 has experience in the LIGO-Virgo search for compact binary mergers (CBC) and characterization of astrophysical merger populations; members have contributed to analysis methods since the Initial detector era, and to the first ET Mock Data Challenge. Multi-messenger activity includes support for low-latency GW alerts and follow-up for ultra-high-energy neutrino counterparts in data from Pierre Auger Observatory. IGFAE's interests in ET include data analysis for CBC detection and astrophysical population studies; computing, with focus on CBC analysis; multi-messenger follow up including EM counterparts of neutron star binaries and UHE neutrino search with upgraded Auger detectors; also with a projected GW instrumentation lab at IGFAE, an interest in ET detector hardware construction is expected.

The Early Universe Cosmology (http://tp.lc.ehu.es/earlyuniverse/) group at the University of the Basque Country, UPV/EHU, is interested in the study of several different sources of primordial gravitational waves. In particular they are currently involved in the development of numerical simulations that will allow them to accurately compute the expected signals of GWs from the dynamics of cosmic strings and other topological defects, cosmological phase transitions as well as different processes that occur during inflation. One of the most interesting signals is the stochastic background generated by a network of cosmic strings. Its spectrum covers a large range of frequencies that overlap with the relevant frequency ranges of several different gravitational wave observatories. The observation of this stochastic background with ET will allow us to pinpoint the cosmological origin of this background. The discovery of any of these signals will open up a new window into our understanding of the physics of the early universe.

The Institute of Cosmos Sciences of the University of Barcelona (ICCUB) is active in several research lines related to GW and is a member of the Virgo collaboration. The gravity theory group investigates black holes in large dimensions and extensions of General Relativity. In observational cosmology they are engaged in cross-correlation studies of gravitational wave events and the general gravitational wave background, and electromagnetic counterparts in gamma-rays detectable with Magic and CTA. They are also active in studies of dynamical evolution of globular clusters as a channel to form black hole binaries. They are working on denoising techniques to detect more GW bursts without complex and computing-intensive templates. The ICCUB is contributing to Virgo Adv+ upgrades for the next observing run (O4, 2021) by developing new quadrant photo-detectors and e-out electronics operating in vacuum. The ICCUB is interested in Detector development for ET and can contribute in these areas. The ICCUB participates in computing and data analysis aspects of Virgo. They have contributed to the revision of the computing model, the migration of the software repository, and updates to software building and deployment tools. The ICCUB is thus interested in the definition of the computing and data handling strategy for ET, as well as on its data analysis.

The Universidad Politécnica de Madrid (UPM) has recently begun to participate in GW Science, with one permanent member joining the Cost Action - CA16104 " Gravitational Waves, Black Holes and Fundamental Physics" in 2017, and the International Consortium LISA as associate member of the Cosmology working group in 2018. UPM also was one of the 15 nodes participating in the Red Temática REDONGRA presented to the 2018 call. The Artificial Intelligence group at UPM has experience in applying Machine Learning and Deep Learning techniques to a variety of problems (security, smart cities, bioinformatics, heath, tourism), and is interested in providing support for the Data Analysis requirements that ET will bring. The UPM will thus contribute to its basic Science program with Cosmology and Fundamental Physics studies, and also to Data Analysis and Computing with state of the art techniques.

The institute for high energy physics in Barcelona (IFAE) is a member of the Virgo collaboration for the study of gravitational waves with the interferometer of the same name located in the EGO laboratory in Italy. IFAE has assumed central responsibilities in the experiment in terms of control of diffuse light in the interferometer, and actively participates in its commissioning and in the identification and reduction of background noise in the detector. In preparation for the upgrade of the experiment, IFAE is designing new deflectors, instrumented with photo-sensors around the main mirrors, for a better interferometer control. On the other hand, IFAE actively participates in the LIGO and Virgo data analysis, with special emphasis on those aspects related to fundamental physics and cosmology. As members of galaxy surveys like DES, PAU, DESI, Euclid and LSST, IFAE gets involved in multi-messenger aspects using optical and infrared telescopes. The ET will bring a big improvement in sensitivity and represents a formidable opportunity for the study of gravitational waves through terrestrial interferometry. IFAE would like to contribute both to the design and construction of the apparatus and the data analysis, based on experience and technology developed in Virgo. Via the PIC computing center, IFAE is already contributing significantly to the LIGO/Virgo computing challenge. It would be natural to expect computing to become a contribution to the ET project.

The group at the Astronomy and Astrophysics Department (DAA) of the Universitat de València (UV) is worldwide recognised by its expertise in relativistic astrophysics and has been working in the modelling of sources of GWs for over 20 years. Since 2016, the group (including members of the Mathematics Department) is in the Virgo Collaboration, contributing to the modelling of GWs through numerical simulations, the astrophysical interpretation of GW events and to Data Analysis. The group, together with additional members of the DAA and the Observatory of the UV (OAUV), participates in ongoing electromagnetic follow-up observations (GTC, NOEMA, ASAS-SN) of GW candidates. The group's main interests in ET are on Data Analysis, GW modelling, and Astrophysics and Multi-messenger aspects. The rapid-response robotic telescopes of the OAUV can also contribute to multi-messenger observations.

CIEMAT is interested in contributing to the computing infrastructure and services of the ET. CIEMAT, together with IFAE, operates the PIC data center, that contributes to the worldwide LHC computing infrastructure as a Tier-1 site. PIC also supports data storage, processing and analysis of astroparticle physics and cosmology experiments (MAGIC, CTA, PAU among others). CIEMAT supports PIC as one of the data centers for ET.

Barcelona Supercomputing Center-Centro Nacional de Supercomputación (BSC-CNS) is the national supercomputing centre in Spain. They specialise in high performance computing (HPC) and manage MareNostrum, one of the most powerful supercomputers in Europe, located in the Torre Girona chapel. BSC is at the service of the international scientific community and of any industry that requires HPC resources. Their multidisciplinary research team and their computational facilities –including MareNostrum– make BSC an international centre of excellence in e-Science. Since its establishment in 2005, BSC has developed an active role in fostering HPC in Spain and Europe as an essential tool for international competitiveness in science and engineering. The centre manages the Red Española de Supercomputación (RES), and is a hosting member of the Partnership for Advanced Computing in Europe (PRACE) initiative. They actively participate in the main European HPC initiatives, in close cooperation with other European supercomputing centres. With a total staff of more than 650 R&D experts and professionals, BSC has been successful in attracting talent, and their research focuses on four fields: Computer Sciences, Life Sciences, Earth Sciences and Computer Applications in Science and Engineering. Most of BSC's research lines are developed within the framework of European Union research funding programmes, and the centre also does basic and applied research in collaboration with leading companies such as IBM, Microsoft, Intel, Nvidia, Repsol and Iberdrola. The quality of their investigation has been recognized by the Spanish government with the Severo Ochoa Excellence Centre grant for cutting edge Spanish science. In the near future the BSC-CNS will host one of the largest European supercomputers, after being selected by the EuroHPC. This new MareNostrum 5 will be part of the first supercomputing roadmap promoted by the European Union and will have a peak performance of 200 petaflops (200 x 1015 floating-point operations per second). It is expected to come into operation on January 2021. BSC-CNS participates in several European initiatives and projects as contributor of HPC and HPDA technologies for Spain, in order to guarantee the access to the latest supercomputing technologies for the complete duration of the project. Current projects supported include: Gaia (ESA mission), European Genome-Phenome Archive (EGA) and Large Hadron Collider (LHC).

RedIRIS, the Spanish NREN ("National Research and Education Network"), is a research infrastructure that belongs to the Ministry for Science and Innovation (MINCI), which funds its activity and sets up the basic strategic guidelines. Since 2004, MINCI has entrusted the management of RedIRIS to Red.es, a state-owned organization, belonging to the Spanish Ministry for Economic Affairs and Digital Transformation. Red.es is the Government Agency in charge of promoting digital transformation in Spain, through several projects related to digital public services and digital economy. Red.es also manages the registry for domain names under ".es", as well as RedIRIS, (http://www.rediris.es). RedIRIS, the Spanish NREN, provides advanced connectivity services, as well as other ICT services (including security, AAI, collaborative tools and others) to over 500 affiliated and connected institutions, such as universities, technological centres, and research institutions. In order to provide its advanced connectivity services, RedIRIS manages an optic fibre backbone of 15.000 Km. This backbone is connected to regional and international research and education networks, thus creating an Intranet for e-science in which high-speed, end-to-end connections can be easily deployed and monitored. RedIRIS, together with other European NRENs, co-manages GÉANT, the Pan-European Research and Education Network, which connects them with other research networks as Internet 2 (USA), Red CLARA (Latin America), EUMEDCONNECT (Mediterranean), etc. RedIRIS services are mostly relevant for those research centers which are active in the field of e-science, which requires intensive use of several IT services, some of which (such as advanced connectivity, security and digital identity management) are provided by RedIRIS to its users. In order to improve the provision of these services, RedIRIS cooperates closely with other e-infrastructures, and it is also actively involved on the EOSC project (European Open Science Cloud).

The group at University of Salamanca is involved in several lines of research, namely gravitation, cosmology and relativistic astrophysics from both theoretical and computational sides. Related to gravitational waves (GW), the group has interest in using this and other complementary astroparticle messengers to put constraints to current poorly known or unexplored, exotic physics related to objects in the strong gravity regime. They have interest and a trajectory of previous experience in the study of neutron stars (NS). In particular the equation of state of matter (EoS) including both ordinary matter and the more exotic so-called dark matter that may modify the characteristics of the GW signal when emitted by such a hybrid object in coalescing binaries. In addition to the before mentioned, neutron star properties: ellipticities, tidal deformabilities or, more generally, emission of continuous waves from non-axisymmetry from residual crustal deformation, magnetic field energy or from superfluid components in the stellar interior can constitute different kinds of "mountains" that largely influence the strength and form of the signal. Having accurate description of the associated microphysics is a key problem in current model building and we have devoted much of our efforts into this.

The group of Relativistic Astrophysics of the Department of Applied Physics (DFA) of the University of Alicante (UA) is worldwide recognized by its expertise in the physics of neutron stars, in all their manifestations and astrophysical scenarios. They have a long scientific track of modeling neutron stars through numerical simulations, including their facet of sources of Gws, and the astrophysical interpretation of GW events. Recently, the group has incorporated a new member with expertise in black holes and extended theories of gravity with interests in predictive semiclassical models beyond general relativity, including GW signals from regular black holes and other exotic objects. The group's main present interests in ET would focus on the modeling of Neutron Stars as GW sources and their Multi-messenger aspects.

The work of the University of Murcia (UM) group is dedicated to the study of the dynamics of GW sources for terrestrial as well as space-borne detectors. The group's research follows two main strands: (i) Black hole perturbations, where the aim is to calculate the system's quasi-normal mode frequencies allowing for deviations from GR. Past work also includes the calculation of the gravitational waveform from EMRI systems. (ii) Single neutron stars, where the main aim is to explore unstable oscillation modes and stellar ellipticity (i.e. neutron star "mountains") as potential sources of GWs. The group's research profile falls within ET's GW modelling and model building and Astrophysics areas.

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.

21. **Incluir ficheros con las cartas de apoyo a la propuesta por parte de cada institución nacional implicada en la misma firmada por el representante legal de la misma.**

Files submitted:

We will include letters from (23 institutions):

CSIC, IEM, Bilbao, IFAE, USC, BSC, IFT, ALBA, UIB, ICE, UAM, USAL, Alicante, UPM, RedIris, Valencia, IFIC, Canfranc, Ciemat, Murcia, Cadiz, ICCUB, PIC

22. **¿Está involucrada alguna ICTS en la propuesta? ¿Cuál(es)? ***

ALBA
BSC-RES
RedIris
LSC-Canfranc

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 del mismo desde el diseño, pasando por la preparación, implementación/construcción, operación y desmantelamiento.

23. Diseño desde la fecha: January 1st 2008

24. Diseño hasta la fecha: December 1st 2026

25. Preparación desde la fecha: January 1st 2020

26. Preparación hasta la fecha: December 1st 2022

27. Implementación/construcción desde la fecha: December 1st 2026

28. Implementación/construcción hasta la fecha: December 1st 2035

29. Operación desde la fecha: January 1st 2033

30. Operación hasta la fecha: December 1st 2053

31. Desmantelamiento desde la fecha: 1st January 2054

32. Desmantelamiento hasta la fecha: 1st January 2058

Apoyo financiero a la Propuesta.

33. Inversión total: (seguir el siguiente formato: valor en euro de la inversión asegurada; % sobre el total del concepto; Comentarios) *

47,8 M€; 2,8%; Devoted to preparatory work, and corresponding to a total cost of 1900 M€

34. Diseño: (seguir el siguiente formato: valor en euro de la inversión asegurada; % sobre el total del concepto; Comentarios)

5M€; 100%; Conceptual design (funded by EC) and other design activities.

35. Preparación: (seguir el siguiente formato: valor en euro de la inversión asegurada; % sobre el total del concepto; Comentarios)

42,8 M€; 25%; Financial support already delivered or committed by some European countries mainly addressed to the qualification of the site candidates to host ET.

36. Implementación: (seguir el siguiente formato: valor en euro de la inversión asegurada; % sobre el total del concepto; Comentarios)

0M€, 0%; No implementation costs have been executed at this point.

37. Media anual de costes de operación. (seguir el siguiente formato: valor en euro de la inversión asegurada; % sobre el total del concepto; Comentarios) *

0M€, 0%; No operation costs have been executed at this point.

38. Terminación: (seguir el siguiente formato: valor en euro de la inversión asegurada; % sobre el total del concepto; Comentarios)

0M€, 0%; No termination costs have been executed at this point.

39. Estimación de la contribución nacional a la Construcción de la infraestructura europea que se propone (Indicar la estimación del valor de la contribución de España a la construcción.) *

The total cost of the infrastructure is about 1.900M€ (core cost). The cost of the infrastructure is dominated by the costs of the civil work, estimated of the order of 780M€ for the construction of 30kms of tunnels and experimental caverns, followed by the vacuum system with an estimated cost of about 565M€. The cost for the detectors (mirrors, lasers, suspension, feedback systems, etc) is estimated to be of the order of 220M€. Finally, about 145M€ are needed for general infrastructure, cryogenics, laboratories, clean rooms, etc. The Spanish Industry is well known worldwide by its competence in carrying out large civil construction projects and the Spanish research centers have collected an extended experience from their involvement in major projects, like for example the LHC at CERN. It is therefore expected that Spain, being part of the ET consortium, would have access to significant industrial returns to the investment.

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. As mentioned above, it is expected that some of the contributions could be in-kind and translate into significant contracts for Spanish industries. This estimation does not consider the fact that the host countries for the infrastructure are expected to contribute more to the total cost.

40. **Estimación de la contribución nacional a la Operación de la infraestructura europea que se propone (Indicar la estimación del valor de la contribución de España a la operación.) ***

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. It is difficult at this point to quantify the operation costs assigned to Spain but assuming a 2% contribution from Spain it would translate into about 0.74M€ per year. It is foreseen that such contribution could be done in-kind in terms, for example, of computing serviced to the experiment.

41. Indicar el plan previsto para la financiación nacional, mencionar la existencia de recursos y sus posibles orígenes (proveniente de las propias instituciones,, ayudas de gobiernos regionales, nacionales, etc). Describir las posibilidades de uso de fondos adicionales procedentes de los fondos estructurales europeos, fondos de inversión privados u otros. *

At present, the different Spanish 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, especially 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. Also at the European level, Spain is currently participating in several COST actions related to GW astronomy (GWVerse, PHAROS, G2Net, QG-MM) and it aims at continuing along these lines in the future.

Additionally to funding, Spanish groups in ET will apply for computer time at the Spanish Supercomputing Network (RES) and to PRACE at the European level. For multimessenger observations, groups will apply to astronomical observing time at the instruments of the Astronomical Infrastructure Network (RIA). At the international level we will apply for observing time at observatories and space missions operating with an open-access policy.

As pointed out it is difficult to estimate at this point the Spanish contribution as the ET consortium is being formed. Assuming a contribution at the level of 2%, Spain would invest about 40M€ in the period of ten years. Large part of the investment however would be in-kind, like for example in terms of HPC computing services given the huge demand of computing resources foreseen. In addition, Spain, as part of the ET consortium would be in very good position to obtain large contracts and industrial returns (maybe larger than the anticipated investment), in a scenario in which the costs of the experiment are largely dominated by the construction of large tunnels, experimental caverns and ultra-high vacuum infrastructures.

PARTE 2. EXCELENCIA CIENTÍFICA:

Misión de la infraestructura.

42. 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: *

The shared vision of the ET community is that GWs open a new window into the cosmos, which could revolutionize humanity's understanding of the Universe in which we live. This translates into the infrastructure's ambitious **mission** to push the limits in our ability to detect GWs and learn more about the evolution of our Universe, down to its earliest form right after the Big Bang.

Impact on the main field
Building upon a rich history, extraordinary discoveries and a Nobel prize, the field has evolved spectacularly in the past 50 years. The first GW detections and observations of the past few years have already resulted in many remarkable results in **astrophysics** and **fundamental physics**. Extraordinary as they are, these results only mark the beginning of a new scientific era. Current Second-Generation (2G) GW detectors have intrinsic limitations that only allow us to get a first glimpse through this new window.

ET is the first of the Third-Generation (3G) of GW detectors, designed to bring the GW revolution to its full potential. With an order-of-magnitude better sensitivity and a wider accessible frequency band with respect to 2G detectors, ET will be able to explore much further into our universe. A dramatic increase in the number of high-quality detections is expected. It will allow us to look in much more (statistical) detail at black holes and neutron stars, and determine their properties (such as mass, spin, distance, tide) with unprecedented accuracy. ET will also be able to detect several other kinds of new signals from other sources such as stochastic backgrounds of GWs, and signals from isolated pulsars or supernovae. These new discoveries will have major **scientific impact**, as they allow us to address a huge number of key issues related to astrophysics, fundamental physics and cosmology.

As explained in the Science Case, ET will shine light on the cosmic history of stellar evolution, the origin (stellar versus primordial), evolution and demographics of black holes, and the interior structure of neutron stars, with potentially important implications for the fundamental theory of strong interactions at ultra-high densities. It will also allow to investigate dark matter candidates that cannot be tested by other means and will perform exquisite tests of the theory of General Relativity in its strong-gravity regime. It will have the potential to elucidate the nature of dark energy (the mysterious form of energy which is hypothesized to permeate all of space, tending to accelerate the expansion of the universe) and lead to modifications of General Relativity on cosmological scales, and to provide an image of the earliest moments after the Big Bang and of physics at correspondingly high-energy scales, through the detection of stochastic GW backgrounds of cosmological origin.
It should also be stressed that, besides a guaranteed extraordinary outcome in astrophysics, fundamental physics and cosmology, ET will be a discovery machine, that will penetrate deeply into uncharted territories, where surprises are bound to await us.

Impact on other fields
Beyond this field, the development of GW observatories has had, is having and promises to have (indirect) impact on other fields of scientific research, including the science of classical and quantum measurements and high-precision spacetime metrology at large, optics, quantum optics and laser systems, space science and technology, geology and geodesy, material science and technology, cryogenics and cryogenic electronics, computing and methods in theoretical physics. Much of this impact has to do with **technological innovations**: realising ET will require direct technological innovations in the fields of detector optics, seismic attenuation and computational techniques.
Given the scale of all these developments it is difficult to predict all the possible technological returns. Here, we mention just two examples where technology development in the field of GWs has led to applications and spin-offs in other fields. In the first case, innovation in technologies dealing with the tiniest vibrations found unexpected application in stem cell research, with nanovibrations triggering stem cell differentiation. The technique has potential applications for example in the growth of bone tissue [1]. A second spinoff is the exploitation of GW-detector technology for the ongoing development of an early earthquake warning system based on gravity strain meters. 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 well before the arrival of seismic waves, giving a faster advance warning of earthquakes [2]. Previous detector developments have witnessed similar unexpected spin-off of innovations.

[1] Robertson S.N. et al. 2018, Phil. Trans. R. Soc. A 376, 20170290. (doi:10.1098/rsta.2017.0290)
[2] Juhel K. et al. 2018, JGR Solid Earth, 123,12, 10.889 (doi:10.1029/2018JB016698)

43. Describa el beneficio que supondría dicha misión para España, en caso de participar en la misma *

In 2015 the first gravitational wave was detected and it opened the avenue to a new field of observatory astronomy. Since then, all over Europe and beyond, the R&D for the next generation of gravitational wave detectors picked up speed and substantial milestones have already been achieved. Based on a European design study, a 3rd generation telescope is under discussion in Europe. The Einstein Telescope will be a key infrastructure for astroparticle physics and cosmology for the next decades. It will provide about an order of magnitude sensitivity increase with respect to currently operating detectors and, furthermore, extend the observation band towards lower frequencies. This will increase the observable volume of the universe and, correspondingly, the event rate by a factor of more than one million. These formidable results will be achieved by combining all presently known scientific breakthroughs of measurement science in a single observatory. The Spanish groups are eager to play a major role developing the technological foundations of this large-scale infrastructure and exploit the facility. We want to push technologies beyond the current state-of-the-art in order to build the infrastructure. Many of those technologies will have applications beyond basic research. Given the tremendous benefits that the participation in ET can bring to the country, Spain cannot miss the opportunity to be part of the ET consortium from its initial formation.

The developments will be embedded in internationally coordinated research scheme. They will strengthen the Spanish leadership and visibility in the developments for gravitational wave detectors and science, established mainly through the outstanding contributions of UIB, UV, IFAE, UB, IGFAE, ICE and several other CSIC Institutes and will involve many others in the future. The scientific questions addressed through the ET project are fundamental to the field and most of them can only be addressed through such an infrastructure. It is desirable that Spain becomes a full member of this international effort from the beginning, otherwise its role in the major scientific breakthroughs and of the governing bodies of the ET consortium cannot be assured. The Spanish groups concerned have the vision and capability to be active players in all aspects of the preparations of ET.

The large number of participating institutes from physics, geology, laser technology, crystallography, mechanical engineering, and computer sciences demonstrates the high relevance and broad interest in the topic at the international level. The interdisciplinary approach will drive the developments and the cooperation of the partners on the national Spanish and international level as well as with the Spanish and European high-tech industry. The ET is of the highest priority in the European Strategy for Astroparticle Physics 2017-2026 of the Astroparticle Physics European Consortium (APPEC), supported by the world-wide community of GW scientists and the IUPAP Gravitational Waves International Committee (GWIC).

The Spanish community must join this effort now, or it will miss the connection and future data rights to do science, and the technological opportunities that will open up. We envision that several new Spanish partners will get involved in this new gravitational wave telescope if Spain supports the application. They will contribute with their experience from other large scale projects in particle physics, astronomy and astro-particle physics, as well as with theoretical studies and also the development of new computing concepts. Science and technological developments towards ET are one of the main objectives of the Spanish gravitational wave community and of astroparticle physics in general.

The international interest and the corresponding investments in gravitational wave technology are now immense. The proposed activity will enable Spanish universities and Spanish research centers to participate in, and contribute to, the development of technologies for third generation gravitational wave telescopes. The timescales foreseen for the realisation of ET demand that critical technology developments are initiated now in Spain in order to major contribute to the full technical design. In fact, to realize such third generation gravitational wave detector progress in non-classical light, advanced lasers emitting hundreds of Watt of continuous power, novel signal enhancing techniques, interferometry using diffractive optics, cryogenic cooling of critical optical components, vibration isolation techniques, monolithic suspensions for the optical components is required. These technological challenges of the instruments need also a parallel evolution of the analysis tools and of the knowledge of astronomical sources. Spanish groups are in a position to contribute to this integrated effort and be responsible of several subsystems only if they are getting involved now.

The Einstein Telescope will face a difficult challenge in computing that the Spanish groups can contribute to. The computing concept of ET will build on the experience from the second generation of gravitational wave telescopes. But the challenge for ET goes much beyond the current state-of-the-art. The data must be made accessible to the scientific community and to some extent later also to the interested public. The participation of ET in multi-messenger approaches - to which many other Spanish groups are interested- is an important scientific goal with direct impact on the computing. With ET we will discover a much larger variety of events, in a much larger parameter space with substantially increased resolution in these parameters. Very large catalogs for template fits will be required and Spanish groups are leading this effort. At the same time new data analysis/data mining approaches including deep learning methods for the identification of the events as well as for the parameter estimates will need to be developed.

We want to stress that there are many benefits to be gained by undertaking such an effort at the Spanish and European level. First and foremost is the benefit, or rather the necessity, of pulling together elements of various communities in instrument development, laser physics, quantum optics, relativity, astrophysics, and computational science in several countries in the EU, whose combined expertise is needed to solve important problems in one of the most exciting areas of science to emerge in this new century.

The scientific excellence of the institutions involved in this ET project, the quality of human resources, the sophistication and the dimension of scientific infrastructures, such as laboratories and instruments, the inter-sectorial component due to the foreseen presence of high-tech private companies paying a role in the construction of the experiment, offer a unique opportunity for young Spanish researchers who will be in the position to start their professional and scientific career under optimal conditions, and be able to spread the knowledge generated. These trained scientists will therefore be capable of mastering “big science” aspects, having high quality management know-how, derived also from private sector expertise.

Conceived as an underground laboratory with three large tunnels of 10 km each and the corresponding caverns, ET will require large civil engineering. This is an opportunity for Spain with worldwide leading industries capable of taking such enterprise. Vacuum technologies are also a key aspect in the project since ultra-high vacuum is required along the full 10 km arms. Technological centers in Spain, like ALBA, are in the position to contribute to the project and profit in collaboration with Spanish industries from the industrial returns the project will generate. The extreme sensitivity of the experiment imposes the need for new standards in suspension systems, cryogenics and fast feedback systems. The participation of Spain in the project will allow the research centers to acquire unique know-how. As it is already being the case in the upgrade of the 2G interferometers, new monitoring systems based on novel silicon technologies for infrared light detection are being investigated. This opens the opportunity for those Spanish centers familiar with the design and construction of precise silicon detectors for particle physics and astroparticle physics experiments to enlarge their capacities towards infrared detection in demanding vacuum restrictions. Finally, the computing challenge for the analysis of the ET data and the need for prompt public alerts to telescopes around the world is enormous and comparable to that of the LHC experiments at CERN. In particular, the use of HPC capacities will be crucial in which Spain is a top world player via the BSC infrastructure . Moreover, an intense R&D will be needed to cope with the analysis of the data online and a large investment will have to be made in deep learning approaches, particularly suitable for the analysis of the spectrograms. Therefore, the participation of Spain in ET will also promote the development of new e-infrastructures and expert software.

Relevancia paneuropea

44. Describa la "singularidad" de su infraestructura. Cómo se encuadra su 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. *

ET, just as its predecessors, responds to the desire from a broad scientific community to observe signals from across the cosmos to understand the very origins of our Universe. Despite their success, in terms of distances explored, the current reach of 2G observatories such as LIGO and Virgo is limited to a region that, on cosmological scales, is still our local neighborhood.

ET will allow GW science to move into the realm of cosmology by probing a thousand-times larger volume of deep space compared to what can ultimately be reached by the present 2G observatories, allowing us to study sources across the entire history of our Universe. ET's unique sensitivity at low 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. For this reason, ET is a top priority of the European astroparticle physics community organized by APPEC. For a broad and large research community (several thousands of researchers) –(astro)particle physicists, astronomers and cosmologists – ET will be the instrument of choice for many decades to come. In the 2040s, ET is expected to be complemented by the Cosmic Explorer in the USA to operate as a 3G 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 in the low frequency band around 1 mHz.

GW detection using laser interferometry dates back to the 1980s. After the 1G GW observatories LIGO, Virgo and GEO (which ran until 2011, established key technologies and forged a closely collaborating global community), we now have 2G GW observatories. These came online in 2015 when Advanced LIGO started its first science run to almost immediately record 'GW150914', the iconic and Nobel Prize winning first direct detection of a GW event traced back to a binary black-hole merger. Advanced Virgo started data taking in 2017 and soon after the first binary neutron-star merger was recorded ('GW170817'), attracting huge scientific and media attention. Today, the catalogue of detected GWs is approaching 100 events. In 2020, KAGRA in Japan will join the network to be followed by LIGO-India in around 2025. The 2G network of observatories will continue to take data for another decade. Extraordinary as they are, the results obtained by 2G detectors are a first step towards our exploration of the Universe with GWs. We have just opened a new window on the Universe, and ET will bring the GW astronomy revolution to a full realisation.

The current 2G infrastructures leave the following challenges unmet:

- *Detecting sources of GWs that lie beyond the brightest ('nearby') sources.* By being able to look at sources further away, we can learn about our Universe in its earlier state. ET will be able to reveal supernova explosions, very massive black hole mergers (hundreds or even thousands of solar masses black holes); very distant sources, ideally from the epoch before first stars formed.
- *Providing deep details about the objects generating the GW sources* to fuel research into general relativity, a quantum theory of gravity, black holes, neutron stars and primordial GWs.
- *Providing "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.* 2G observatories currently 'trigger' (electromagnetic) telescopes *after* the occurrence of a cataclysmic event, in time to record the final (fractions of) seconds of the characteristic 'chirp' when massive objects merge or explode. If these telescopes would have sufficient time to be pointed to the right patch of the sky, they could actually 'see' the cataclysmic event itself. Notably, to date the only GW event studied across the electromagnetic spectrum yielded an unprecedented flood of publications and a novel way to assess the Hubble constant capturing the expansion of our Universe.

The combination of distances and masses explored, sheer number of detections, and detections with very high signal-to-noise ratio will provide a wealth of data that have the potential of triggering revolutions in astrophysics, cosmology and fundamental physics (see arXiv:1912.02622 for an extended discussion of the scientific potential of ET).

45. Explique el valor añadido de crear una infraestructura de investigación de relevancia paneuropea como solución más apropiada para abordar las necesidades expuestas en lugar de un programa de investigación o cualquier otra iniciativa: *

The nature of astrophysics requires a RI to fuel research with high-quality data. At present, no existing research infrastructure or combination of research infrastructures can meet the challenges described above. With the extraordinary success (and capital investment) of the 2G GW detectors in achieving the extreme experimental performance needed to detect GWs (as an illustration: a displacement sensitivity one hundred thousand times smaller than a proton inside an atom is needed), taking the interferometry concept a step further into a 3G GW observatory is the only logical and economic step to overcome the ultimate limitations of the present 2G observatories.

The physics of ET is crucial for advances in a large variety of disciplines that try to answer the question of how the Universe is composed, how it evolves, and which principles govern its constituents. For instance, ET will provide new knowledge about the behavior and interactions of dark matter, knowledge that would be essential for progressing in particle physics beyond the standard model. Besides, it will boost the activity in multi-messenger astronomy and, by means of this collaborative enterprise, we will reach a deep understanding of the physics of neutron stars, which in turn will be the gate to important advances in relativistic astrophysics (describing the behavior of matter in intense electromagnetic fields) as well as in some aspects of chromodynamics (describing the behavior of matter in the internal regions of the star). In addition, the gravitational wave astronomy of ET will permit a much profound comprehension of black holes, of their gravitational field, and of the propagation of their radiation.

Exploiting the experience with the 2G technologies, ET is designed to improve on nearly all aspects: compared to the present observatories, ET will feature 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 will allow 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 will be able to track a GW signal from a neutron star merger for up to 24 hours allowing ample time to notify electromagnetic telescopes to study such events in detail. The project poses a challenge for engineering and innovation in many aspects, from the construction of the tunnels that will host the interferometer, to the cryogenics required for the vacuum installations, the laser optics involved for the operational demands, or the improvement of isolation techniques that will be necessary, to say some examples. Moreover, the interpretation of the observations will require the comparison with waveforms obtained with highly sophisticated numerical simulations, and the collected data will be handled and treated with procedures that fall into the category of big data processing. Worldwide, the proposed ET research infrastructure will be the most advanced in its kind, expected to remain at the forefront of GW research for at least half a century.

Besides its technological capabilities, we are confident ET will become a very effective RI in terms of serving a wide international community, following successful European examples such as Virgo. Boosted by the 2008-2011 EU Design Study, the ET community has already 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. In total, the global picture is that of a common endeavor for a community of scientists and engineers that clearly surpass the typical broadness in scope of a program of research, and that offers a collection of added values in science, in technology, and in innovation.

46. Incluir la relación con infraestructuras nacionales existentes, incluyendo expresamente si forman parte del mapa de ICTS vigente, aprobado el 7 de noviembre de 2018. *

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 multi-messenger 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. LSC is supporting this ESFRI application.

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), 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 research centers and ICTS, with dedicated resources for the LHC experiments, would play an important role in the processing and distribution of the ET datasets. Both RES and RedIRIS are supporting this ESFRI application.

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. ALBA forms already part of the list of institutions supporting the ET ESFRI application.

Impacto socioeconómico

47. Describa en qué manera su infraestructura contribuirá a abordar algunos de los grandes retos de la sociedad y contribuirá a los Objetivos de Desarrollo sostenible: *

ET is an RI dedicated to discoveries in the field of fundamental science, providing insights into the origins of our Universe and Earth. As such it does not directly address urgent societal challenges. However, it is well documented that fundamental research is the first step in an innovation pipeline towards wider impact.

Specifically, ET pushes technologies beyond the current state of the art in a variety of fields, contributing to new technologies that could have an impact on socially relevant themes. The European Commission has defined **Key Enabling Technologies** (KETs), which provide the basis for much-needed innovation across industrial sectors. Technology development for ET overlaps four of the six defined KETs, i.e.: photonics, advanced materials, nanotechnology, micro and advanced manufacturing technologies. Examples from the ET context include amongst others: ultra-stable lasers, low-loss thin films, high-power optical fibres, high-efficiency photo-detectors, new thin-film materials, innovative coating procedures, advanced real-time control systems, ultra-low noise electronics, innovative production techniques for optical components and the largest ultrahigh vacuum system ever built.

As illustration we mention two recent examples of impact enabled by fundamental research in the GW field:

- The *Find A Better Way* (FABW) project, worth 2.8 M£ total, is funding the first-in-man study (planned for 2020) of bone graft technology that has arisen directly from the STFC funding program in gravitational waves. The technology makes use of nanoscale vibrations to persuade adult stem cells to differentiate into bone building cells.
- Laser technology and a high-precision interferometric readout, developed in the context of GW research, has been used to upgrade the *Gravity Recovery and Climate Experiment Follow-On* (GRACE-FO) mission, aimed at providing a unique view of Earth's climate and achieving far-reaching benefits to society and the world's population.

48. Describa brevemente el impacto económico directo previsto de su infraestructura en el sitio y la región donde se ubicará la instalación (en caso que sea en territorio nacional), o en el nodo/ nodos nacionales en caso de infraestructura distribuida: *

The infrastructure will not be based on Spain but it is expected that the economical impact will be reflected as well in the member states of the ET Consortium as it is the case for other facilities outside Spain like for example CERN. In the following we offer a description of the benefits expected from the infrastructure as a whole.

The economic impact of ET stems from initial demand of goods and services necessary for the construction and operation of the infrastructure. Such initial demand induces further multiplicative effects along the supply chain, and also due to workers' induced expenditure.

The ET consortium has performed an ex-ante impact analysis, evaluating the economic impact of total output (TO), value added (VA), and employment generated by the project. TO measures the increase of the volume of economic activity. VA measures the new value, i.e. the contribution to GDP, net of the duplication effects due to the value of intermediate goods and services. Our impact studies provide estimates of the effects of ET along the mentioned dimensions.

<u>Main outcomes</u>

The estimated TO multiplier is 3.6, meaning that €1 of initial expenditure generates a TO of €3.6. The estimated VA multiplier ranges between 1.4 and 1.55. Finally, the estimated employment multiplier ranges between 18 and 21 person-year (py) per M€, spread over the expected construction and operating phases. For both phases, the annual estimated economic impact is obtained by applying the multipliers to the estimated annual expenditure. Moreover, appropriately discounted, annual flows are summed up to provide a measure of the present value (PV) of the economic impacts.

<u>Construction phase</u>

The estimated budget for construction is 1.7 G€, about 50% of which relates to building activities (excavation and building of tunnels and facilities), and 50% to the installation of specific technological infrastructures including vacuum, cryogenics, suspensions and optics systems. The associated overall impacts in absolute values are:

- TO: 6.1 G€;
- VA: 2.4 to 2.6 G€;
- Employment: about 34,000 py over the construction period (about 1,500 py are construction site workers and the remaining 32,500 are jobs created along ET supply-chain).

It is worth mentioning that the scientific and technological activities at preparation stage, i.e. before construction, also generate a relevant economic impact (not included in the analysis).

Operating phase

At the operating phase, the annual estimated budget is 37 M€ and relates to labor (researchers, technologists, technicians, and administrative staff) goods and other services, including IT equipment, maintenance, machineries' materials, security, electricity, etc. Accordingly, the absolute values of the impact per year are:

- TO: 133 M€;
- VA: 52 to 57 M€;
- Employment: about 880 py (where 160 is the ET staff and 720 are jobs created along ET supply-chain).

Finally, a significant part of the economic effect, about 50%, is expected to impact the regional economy, while the remaining 50% is expected to impact outside the region (national, EU and international level). Industry will be able to exploit the opportunities of the technology cooperation with science by increasing or improving their existing expertise, being able to introduce new technologies in existing markets or in penetrating new markets.

The ET project will generate 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 envisioned laser innovation can be applied to the welding of special plastics, spectroscopic measurements in medical applications and treatment of gallstones (cholelithotripsy).

The scientific importance and international exposure of ET will attract 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 choose a career in STEM. Moreover, the ET project is in line with the socio-economic development strategies outlined by the two candidate host regions.

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.

49. **Indique brevemente el impacto esperado de su 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 España: ***

As an international effort, it is expected that the impact will be distributed evenly across the member states of the ET Consortium, as it is the case for other facilities outside Spain like for example CERN. In the following we offer a description of the benefits expected from the infrastructure as a whole.

In terms of goods and services, ET will provide mostly **data for fundamental scientific use** through an open-access scheme.

ET will facilitate **education and training** of scientists, engineers and technicians, in particular early-career researchers in the emerging field of GWs and astroparticle physics. Scientists permanently based at the RI will collaborate with many visitors and PhD students who will stay on the ET site for extended periods to carry out their research. The high-tech, frontier science and international nature of ET will translate into a unique training environment, teaching highly wanted skills set. In addition, through joint development projects with industry ET will train a group of highly sought after and versatile professionals for the physics-based industrial sector. Moreover, many physics PhD graduates pursue careers in neighboring non-science sectors, for instance in the financial sector.

In terms of **knowledge utilisation**, the GW community has a strong track record stimulating impact in a variety of fields including photonics, material sciences, low noise optomechanical systems, inertial sensors etc. as will be described in more detail in the following sections.

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

ET will push technologies beyond the current frontier. R&D facilities (such as ET-pathfinder and E-TEST R&D facilities) are already being set up to develop the required technological level, where possible in collaboration with industry. The active involvement of companies will generate patents, licences and spin-offs. Throughout the preparation, construction and operational phases, we anticipate the creation of public-private research infrastructures, larger collaborations and high-tech clusters, benefitting the European and regional innovation ecosystem for both industry and society. For example, in Sardinia, other RIs and projects (SRT, SarGrav, ARIA project, SPTF) led to the establishment of the Sardinia AeroSpace District (DASS), a cluster of 29 firms and public research institutions promoting social and technological innovation.

Earlier research in the GW field has already led to various commercial activities:

- A spin-off from the Gravitational Physics Group at Nikhef, Innoseis, developed a highly effective lightweight wireless seismic sensors, having huge potential for application in the oil & gas industry.
- Image-quality metrics and artefact detection algorithms were commercialised by medical technology company Optos. This research has led to a 25% increase in yield in one of the major device components, about 0.5 M$/year on this component alone.
- Expertise in fused silica monolithic suspensions was utilised in high-tech gravimeters for monitoring gravitational anomalies. The work has gained significant buy-in including financial support from industrial partners in the oil & gas industry, defence & security, environmental monitoring and space applications.

ET requires a long-term third-party supply of high-tech instrumentation and expertise in areas such as cryogenics, computation, optics, mechanics. As such it will attract or retain firms and talents (students and researchers) to the site area.

Part of the impact on innovation activities is driven by the technology/knowledge transfer that occurs when high-tech providers work and cooperate with the ET team. An ET procurement contract will trigger an intense collaboration process between suppliers and ET staff aimed at effectively designing, testing and manufacturing the required product or service. These efforts challenge firms to acquire new knowledge since they will have to find technical solutions to meet the stringent ET demands. This likely will involve custom-made solutions that will greatly enhance their skills and knowledge and, therefore, their market value. The suppliers benefit from learning-by-doing through the improvement of existing equipment and machineries, of production processes and also through the provision of new goods and services, which might be requested by other potential clients around the world. Similar industry-RI synergy has been achieved for the current 2G GW observatories. For ET, the process of scouting for technologies and business opportunities has started and is already effectuated with R&D projects in the preparation phase, boosting positive impact in later phases as well.

Innovation-oriented industries will be involved in the design and implementation phases (to develop new technologies and to construct parts), as well as in the operation phase (to enable further upgrades and to benefit from a high density of brain power). We will also invest in creating a test/demo/development site to facilitate not just R&D but also potential partner engagement, cross-sectoral collaboration, etc.

Estrategia de usuarios y política de acceso

50. **En lo posible de una estimación en cifras cuantitativas del tamaño de las comunidades científicas y tecnológicas nacionales 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 in Spain hosting groups participating in GW experiments: LIGO (UIB, IFGAE-USC), Virgo (UV, IFAE-UAB, ICCUB), LISA Pathfinder (ICE-CSIC), and LISA (ICE-CSIC, IEM-CSIC, IFT-UAM-CSIC, UIB, ICCUB, UCM, MOA-UCA, U. Granada, UPM, UPV/EHU, UPC). These groups cover the different aspects of GWs, including experiments, data analysis and theory. A number of the groups are participating already in developing technology for current experiments (ICE-CSIC, ICCUB, IFAE-UAB, MOA-UCA, UPC). Additionally, there are a number of institutions that have shown interest in the multi-messenger component of GWs using the observatories in the electromagnetic spectrum (IAA-CSIC, IAC, IFT-UAM-CSIC, CIEMAT, among other) and neutrino detectors (IFIC-UV-CSIC, IFGAE-USC).

Regarding the direct implication in ET, 22 Spanish institutions support this proposal, including groups with a total of about 100 researchers willing to contribute to the project. The list not only includes groups participating in current experiments but also groups willing to apply their expertise (technological, computational, …) to the new project. So far more than 780 researchers have signed the ET letter of intent, 55 of them from 19

Spanish institutions.

In addition to the institutions directly interested in ET, there is a GW community in Spain that has grown significantly over the last few years. This community 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.

In a wider sense several scientific communities will benefit from the results of ET. The Spanish astronomical community, organized as the Spanish Astronomical Society (SEA) with more than 800 members, has already shown a deep interest in the results from current gravitational wave observations. The ET project will serve as an astronomical observatory with direct service to this astronomical community. ET will also probe gravity in the strong field regime and their results will be of interest for the Spanish community of specialists in relativity, organized as the SEGRE with about 90 members. The observations of events involving neutron stars will serve as a nuclear physics laboratory and are thus of interest to the nuclear physics community.

51. **Describa la estrategia de acceso propuesta para su infraestructura y las posibilidades de desarrollar una comunidad de usuarios de tamaño razonable ***

ET will not be a RI allowing individual parties (“users”) to operate (“use”) the infrastructure for an allotted amount of time as many other RIs. As such, there is no user strategy in the traditional sense. Instead, ET will take data based on designs developed by a large community, which will be exploited by an even larger community to do groundbreaking research. In terms of user strategy and community, we therefore distinguish formal membership of the ET Collaboration and the use of ET data by the GW community beyond the Collaboration.

<u>ET Collaboration</u>
In conjunction with drafting the ET plans, a prospective ET community has already formed, providing the expertise necessary for the vast spectrum of work to come. Given the current size of GW collaborations (>1300 for the LIGO Scientific Collaboration, >500 for the Virgo Collaboration, >360 KAGRA, >1100 for the LISA Consortium), it can be expected that when ET is conducting observations that the membership of the ET Collaboration will be large, certainly exceeding 1000 people. The consortium will eventually consist of a wide range of professionals:

- Experimental physicists developing and improving on the detector science, commissioning the detectors, and maintaining proper operation;
- Physicists performing data analysis to best detect signals and conduct parameter estimation;
- Astrophysicists, cosmologists, and specialists in fundamental physics interpreting data analysis results;
- Engineers, technicians, computer scientists, geophysicists, and others contributing in other ways.

Formal membership of the ET Collaboration allows stakeholders to actively participate in the design and realisation of the detectors, contribute to decisions regarding ET strategies, and benefit from data analysis services.

<u>Beyond the collaboration</u>
For the “user” strategy directed outside of the ET Collaboration the most important aspect will be the transfer of ET data to the greater astrophysical and astroparticle communities. Automated triggers and preliminary information will rapidly be communicated to allow for immediate multi-messenger

follow-up observations and results from a deeper analysis of the data will be released later. The ET strategy will be based on an evolution of the current LIGO-Virgo user strategy. ET will produce Open Public Alerts (OPAs) that will be distributed through the consolidated NASA GCN system. The worldwide astronomers and astroparticle physics communities can freely access these alerts. OPAs will be produced by ET alone or in collaboration with the upgraded 2G+ GW detectors and eventually other 3G detectors like Cosmic Explorer. No MOU will be necessary to access the OPAs, but we envisage MOUs for special studies on sub-threshold events.

ET data will be openly released shortly after the acquisition. This delay time will decrease according to the increased confidence in the data quality and calibration. It is expected to have an initial delay time of about 18-24 months which will eventually decrease to delays of a few months.

The OPAs for GW events have already demonstrated to be effective. As an example, during the O3 LIGO-Virgo observational period, 44% of the alerts published on the NASA GCN system are GW candidate follow-up events. The astronomy community around the world is highly motivated to observe and understand the physical systems that are producing GWs. This interest from the astronomy community will undoubtedly increase with ET’s superior sensitivity, having more events observed, and especially extending back farther into the history of the Universe.

To increase the community benefiting from ET, the Collaboration will make a major effort in making data understandable and usable by non-specialists, providing documentation of what the data comprises, and making publicly available analysis tools or easy to use corrected data sets.

52. Describa la política de acceso de su infraestructura en cuanto al modo de acceso, las condiciones de acceso, y las medidas de apoyo que facilitan el acceso: *

According to the definition used in the Integration Activities actions funded within the European Framework Programmes, the access mode to the Einstein Telescope RI will be almost exclusively “virtual”. External scientific communities will have free access to two “services”: **ET Open Public Alerts** and, after a proprietary phase, to **ET data**.

Data
Storage, access, usage and preservation are intertwined aspects of data management, and ET will implement all of these aspects, compliant with international standards, building upon experiences in current GW observatories.

Open Public Alerts
Presently there is a public alert system for GW events so that electromagnetic and astroparticle observers around the world can attempt rapid follow-up and afterglow detections. ET is designed to provide many more and earlier OPAs. Therefore, ET will implement a low-latency analysis system, based on specific software, specific computing power and a team of scientists capable to provide fast supervision to the automatic alert system. This system will be the evolution of the current OPA system managed by the LIGO and Virgo experiments.

Special projects

It will be possible to select special projects for accessing sub-threshold data for specific development or scientific targets. These special projects will be selected either on competitive calls or on negotiated procedures organised by the ET Collaboration.

53. Describa la forma en que se ha involucrado a la comunidad de usuarios en la elaboración de su 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 and 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 9^{th} 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). 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 the Science case for ET was published, 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 itsobjectives. 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.

54. 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 GW communities have worked for more than 15 years to develop and refine data access and analysis pipelines to promote the best possible data use. ET will build upon these tried and tested procedures. A Data Management Plan (DMP) will be developed aimed at primary raw data, secondary processed data (for data analysis), and tertiary derived data (such as published analysis results).

Policies will include:

Data transfer
Policies and tools will be developed for reliable raw data transfer to off-site computing facilities, with the required latencies, 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.

Data access
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 jointly developing tools and strategies to distribute it on the computing infrastructure as soon as it is produced. This way we will guarantee easy and efficient access to data, software and computing resources, extracting further scientific value. Support for accessing the data will be offered in a way similar as implemented for the current GW network (software, tutorials, instructions, workshops). Data access will be optimized to maximize synergy with other (ESFRI) RIs.

Interoperability with other observatories
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
Open Access and long-term preservation will be managed by implementing an Open Archival Information System (OAIS)-compliant archive, based on the ISO 13721 standard.

Long-term data preservation
After a pre-defined 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. The OAIS model calls for definition of a “Designated User Community”; 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 exploit the data.

Scientific publications

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

55. 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 amount of computing needed to extract the scientific results, both in low-latency search and parameter estimation, cannot be naively extrapolated from current activities; this would predict an increase by at least three orders of magnitude. Similarly to what is currently happening with High-Luminosity LHC at CERN, intense R&D and Mock Data Challenges are planned in the preparation phase to reduce requirements within the bounds of what can be provided in the 10-years' timescale, taking into account realistic technological 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 several PB.
Most 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 centers, 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 computing resources, most GW workloads are 'embarrassingly parallel' and we will plan for many possible evolutions, depending upon the roles of e.g. Deep Learning (calling for special clusters for algorithm training), Big Data techniques for low-latency searches on streaming data, high parallelism on HPC clusters (e.g. for Numerical Relativity), or even quantum or neuromorphic computing. In general, flexible cloud access to heterogeneous resources provided by a shared e-Infrastructure will be required.

At the national level, the computing infrastructure needed for ET is already in place for large experiments like those at the LHC or GAIA. Close contacts have been already established with both: the national HPC network (RES) led by the BSC center and the RedIris infrastructure, expressing their explicit interest in the ET project. Other research centers interested in ET, like for example PIC, have also significant computing capacities and accumulated know-how on large projects.

56. 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 many players, and e-infrastructures form the supporting frame for such networks. The three current 2G GW observatories are, at the time of writing, building the International Gravitational-Wave Observatory Network (IGWN), 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, electromagnetic, cosmic rays and neutrino observatories for **multi-messenger astronomy**; the shared e-infrastructures will form the backbone of this 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 jointly developed GWOSC. Building on 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; here, again, 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.

57. En el caso de que se precise de una infraestructura electrónica específica, describa la interfaz con las redes de comunicación existentes a nivel nacional: No need (RedIris/RES)

Most of the computing needed for ET data processing will take place off-site, including most of the low-latency searches. On the decade timescale, it is generally foreseen that a large distributed scientific computing and data storage infrastructure, stemming from the current EOSC-related EU projects, will be available to cater to the needs of large, computing-hungry collaborations, with the High-Luminosity LHC experiments leading the way, and others, such as the Square Kilometer Array, following suit. The collaboration will therefore need to join such efforts early on (also given the fact that Mock Data Challenges will be performed well in advance of the actual observation), to pursue commonalities with the larger physics computing community and to use such infrastructures as its main e-needs provider, for example using a common AAI system or exploiting common Open Data platforms.

The efficient usage of a large scale, heterogeneous distributed e-infrastructure, with the need to exploit accelerators or low-level parallelism, will also require the building of a core computing group with the relevant expertise. In addition, it will be crucial to ensure coordination with other 2G+ and 3G GW projects and astronomy infrastructures to build and manage an alert generation and management infrastructure to provide triggers for multi-messenger astronomy.

In the national perspective, there will be no need for new e-infrastructure. The computing capacity and know-how accumulated in centers like for example the RES-BSC and RedIris in Spain would be sufficient to play an important role in the ET computing challenge as a whole.

PARTE 3. IMPLEMENTACIÓN:

Trabajo preparatorio y planificación

58. 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. *

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 3G GW science. A further step was taken with the ET Conceptual Design Report 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. This study concluded 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.
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 cryogenic 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. Notably, cryogenic test masses will be further

investigated within the context of two recently approved Interreg projects: ETpathfinder and E-TEST, while a low noise cryogenic facility is under development at SarGrav.
One of the consequences of extending the observation band to lower frequencies 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. Depending on the quality of the location, innovative technologies may have to be used to further reduce the environmental impact on the detector. These technologies are currently being developed for the upgrade of the Virgo detector and include the reduction of terrestrial gravity gradient noise and the implementation of a quiet infrastructure to prevent the detector environment from being impaired by e.g. ventilation and pumping.
Following the ET design study, a Mock Data Challenge was conducted. It explored the unique capabilities offered by ET, and aimed at the analysis of signals from compact-binary coalescences in a signal-rich environment (ET is expected to detect up to a few million signals annually). It was found that existing data-analysis algorithms can be adopted for ET to detect and analyse these signals, but new algorithms are needed to fully exploit the scientific potential of ET.
The emergence of the new field of multi-messenger (including GW) astrophysics revealed the need to develop low-latency GW data analyses and an 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 provide alerts. The computing resources, software and infrastructures needed to rapidly acquire, analyse and interpret a larger volume of multi-messenger data than today will be based on the invaluable experience acquired by the GW community currently involved in the multi-messenger effort with current GW detectors.

The full report of the feasibility studies can be found at:

https://1drv.ms/b/s!AmoHzai09yjjgcYnwfnXac_S98KIeQ?e=WyhHyQ

59. 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. 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: *

As we have mentioned previously, the ET project has already participated in several programmes of the European Commission. 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.

Besides 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 devoted to complete the design and to carry out a full characterization of the proposed sites in Italy and The Netherlands.

60. 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. *

The feasibility of detecting GWs with long-baseline laser interferometers has been proven by the current detectors that achieved the first detection in 2015 and are now regularly releasing new signal events. Several new technologies that have been identified for ET, such as frequency-dependent squeezing and large mirrors, are part of approved upgrade plans for Advanced LIGO and Advanced Virgo (2019-2024+).

We will undertake a dedicated R&D program to advance selected technologies in parallel with the realisation of the RI. A new prototype interferometer, ET-pathfinder, is currently under construction and will be fully dedicated to test and validate new technologies for ET. This R&D facility will be fully operational by 2024 and will systematically test larger-sized mono-crystalline silicon mirrors in combination with various new coatings under cryogenic conditions to establish a base technology by the operational start of ET in 2033.

<u>Detector technology</u>
The design of ET is based on decades of experience in the design, commissioning and operation of GW interferometric detectors. In particular, most of the technologies that will be implemented in ET are incremental developments of technologies successfully implemented in current detectors: seismic isolation of large test masses, silica-fibers suspensions and low-noise dielectric coatings to reduce thermal noise, use of squeezed light to reduce quantum noise, stable high-power lasers, active control of thermal aberrations, gravity gradient noise cancellation, are or will be soon routinely implemented in detectors. Furthermore, some of the innovative and distinctive features of ET (underground operation, cryogenics) are currently being tested in the Japanese interferometer KAGRA, which, from this point of view, represents a crucial link between the second (advanced LIGO, Advanced Virgo) and Third-Generation GW detectors such as ET.

To achieve the projected sensitivity of ET it will be necessary to advance the state-of-the-art of the relevant technologies to their physical limits. The ET Conceptual Design Report describes in detail the technology and research requirements to achieve the ET sensitivity goal. Following the publication of the design report, further feasibility studies funded by European and national research programs studied several crucial aspects of the detector and did not identify insurmountable problems.

Underground infrastructure
Environmental disturbances to the operation of the observatory are a key aspect for the feasibility due to the targeted low-frequency sensitivity of ET. An extensive study of underground sites in Europe was carried out as part of the ET Design Study culminating in the ET Conceptual Design Report published in 2011. It was found that underground seismicity at most of these sites was compatible with the low-frequency science goals of ET considering the requirements of a seismic isolation system as well as direct gravitational coupling between the environment and the detector.

A feasibility study of the underground infrastructure and two independent excavation cost evaluations have been performed by a multidisciplinary team composed of GW experts (physicists and engineers who realised the current GW infrastructures), geologists and by external engineering firms that are world leaders in the design of underground infrastructures like tunnels and subways.

61. Explique brevemente el modelo de negocio de la infraestructura, y su aplicación al caso español expresando el interés de España de participar en la misma: *

The infrastructure is devoted to basic science and a business model will probably not apply completely. As an international project it is expected that the members of the ET consortium will benefit from the industrial returns originated according to their relative weight of their contributions. In the following some considerations are offered.

ET will be a RI fueling a wide range of fundamental research areas across the globe. Primary access is not via individual users, but through open data releases to the large international astronomy and physics communities. This community is already in place and contributed to the ET genesis. As such, the business case and Cost-Benefit Analysis must not only determine the (direct) economic benefits, but also the desirability of this investment in terms of cultural and technological advancement of the entire social community. We specifically emphasise two parameters with respect to the business case and costs-benefits evaluation of ET:

● The first one is related to its expected lifetime: ET is an observatory that will stand for many decades, allowing consecutive upgrades of the hosted detectors. This allows the amortization of the implementation costs of the research infrastructure on a timescale of 50 years. The ET sustainability is guaranteed by the operational model of GW detectors. GW facilities are at the frontier of current technology and increase their sensitivities by pushing technologies to their physical limits. This is typically coordinated via dedicated upgrade programs.

● The second parameter is related to the wide cultural spectrum of the ET science case. The science of ET is multi-disciplinary with a wide impact on astrophysics and astronomy, nuclear physics, general relativity, and fundamental physics. As a consequence, ET involves a large variety of communities interested in accessing ET data. We underline that the ET results will be crucial to exploit the potential of the newly born multi-messenger astronomy and for this reason the policy of the ET data access will be optimized to maximize the synergy with other research infrastructures, some of them being in the ESFRI roadmap (KM3NET, SKA, CTA, ELT, …). Data sharing is already implemented by 2G facilities, which are part of the cluster of ESFRI projects ESCAPE, and we foresee to implement the same strategies for ET.

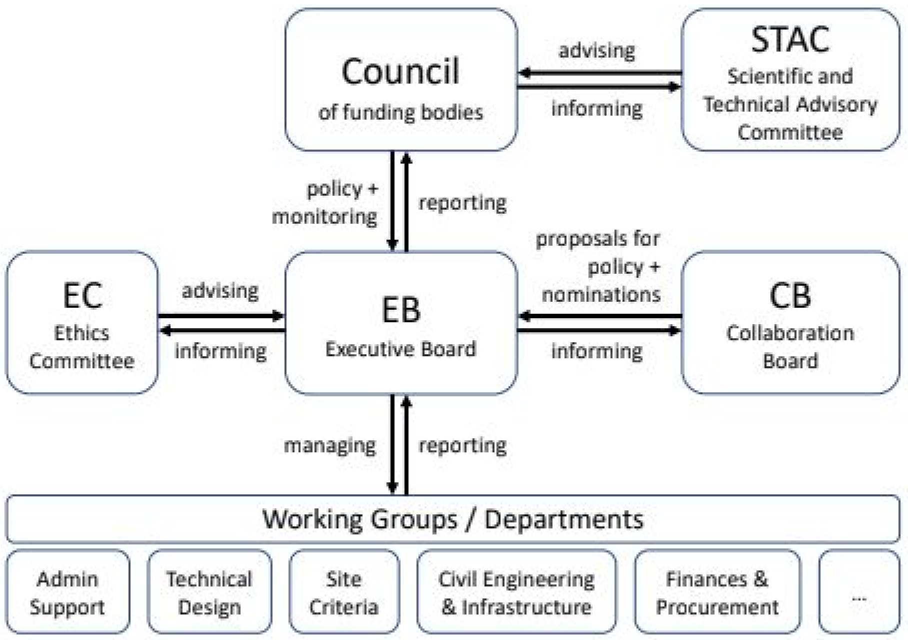
GW facilities exploit modern ultra-high vacuum solutions, the most silent cryogenic refrigerators, high sensitivity sensors, high power and ultra-stable lasers, advanced quantum optics, and super-mirrors optics. These advancements typically have relevant impact at industrial level by generating spin-offs on the various technological domains. In addition, these extreme technological solutions, propagated by teams of local experts connected to the site, are acting as technology drivers for the connected industries.

ET and the future network of 3G observatories have been presented to the GSO (Group of Senior Officials), a G7 body, and indicated as a study case for that international committee. Thus, the draft costs and benefits evaluations have been preliminarily reviewed and they will be further reviewed both at international and national level.

Gobernanza y gestión.

62. **Esbozar primeras ideas sobre la estructura legal si las hubiera.** *

Until its final legal structure is implemented (see below), an **interim governance structure** has been laid down in a MoU. In this temporary structure, the research ministries of the countries leading and officially supporting the ESFRI Application will set up an Interim Council in 2020. This Interim Council will approve and support a project management structure under an Executive Board [EB] - responsible for day-to-day management of the ET project – with for instance Working Groups for Technical Design, Civil Engineering and Infrastructure, Preparation Site Selection, Finances, etc., and a number of advisory bodies, like a Collaboration Board [CB], a Scientific and Technical Advisory Committee [STAC] and an independent Ethics Committee. For hierarchical and reporting lines, see Figure below. Skills descriptions will be based on best practices at RIs such as Virgo and GEO600. In parallel, the ministries will establish a Working Group to draft statutes towards ET’s final legal structure.



Since the start of the operational phase is foreseen at the earliest in 2033, and the site/hosting arrangement is yet to be decided, it is too early to decide upon the final organizational structure. It is evident that proven schemes such as EGO/Virgo for the exploitation of the gravitational wave observatory and CERN/LHC experiments for the exploitation of the LHC complex will be taken as inspiring examples to shape the ET organizational structure upon. The final structure will be in place before the tendering of the first contracts and start of the actual ET construction (implementation phase, anticipated to cover the 2026-2035 period).

As one of the options available to us, we will consider that the ET consortium will use as legal structure a European Research Infrastructure Consortium (ERIC). In this case, conform the ERIC Guidelines, an ERIC Council will be established and appoint an ET Director who will have the responsibility for the day-to-day management and who will report to the ERIC Council. During the implementation phase, the Director will be assisted by the heads of the following departments: Civil Engineering & General Infrastructure, Safety, Communications, Human Resources, Administration & Finance, Information Technology, and Research. Research consists of a number of sub-departments like Vacuum & Mechanics, Cryogenics, Interferometry, Controls and Physics.

The ERIC Guidelines also recommend various Advisory Committees –noteworthy examples are the Scientific & Technical Advisory Committee, Finance & Administrative Committee, In-Kind Review Committee, Ethics Committee and Facilities Committee– which each report directly to the ERIC council. The ERIC Statutes will define their tasks and their composition. Other legal structures will most likely have a similar structure.

Legal structure

The ET consortium will consider to use as legal structure an ERIC conform ERIC Guidelines. Until the ERIC is in place, the consortium will be governed by an Interim Council set up by the research ministries leading and officially supporting this ESFRI Application.

The final legal structure must be in place before the start of the actual ET construction and the tendering of the first contracts (foreseen in 2026). The ministries will also establish a Working Group with the task of drafting ERIC statutes in line with the ERIC Guidelines.

Transition

The transition from Interim Council to the final structure will be as follows. A new Council will be formed, replacing the Interim Council and leading the transition of restructuring through the whole organization. Consequently, the parts of the Interim project organization will continue its activities some time under the responsibility of the new Council.