ESFRI MoS

ESFRI Monitoring System

Strategy Report on Research Infrastructures

ROADMAP 2021

Proposal Report

Submitted on 2020-09-05

PROPOSAL SUBMISSION THROUGH ESFRI MOS+

PROPOSAL COORDINATOR:
Michele Punturo

RI NAME:

Einstein Telescope

PART A: GENERAL INFORMATION

PART B: SCIENTIFIC CASE

PART C: IMPLEMENTATION CASE

ESFRI MoS

ESFRI Monitoring System

ROADMAP **2021**

Part A: General Information

SECTION 1: GENERAL DATA

NAME

FULL NAME : Einstein Telescope

ACRONYM: ET

TYPE

Selection: SINGLE-SITED

CLASS

Selection: NEW RESEARCH INFRASTRUCTURE

TIMELINE

DESIGN: 2008 - 2017

The conceptual phase of the design with the first feasibility study has been performed in 2008-2011. From 2011 to 2017 the conceptual design has been updated considering the evolutions of current facilities.

PREPARATION: 2018 - 2027

Intense qualification of the two candidate sites already started. Main activities are site selection, legal structure of ET, ET technology development, site preparation.

IMPLEMENTATION (CONSTRUCTION): 2026 - 2035

Implementation will start with the excavation works call for tender opening.

OPERATION: 2035 - 2080

The scientific operation for users is expected to start in 2035. Operation costs will incur from 2033 onwards for commissioning.

TERMINATION: 2081 - 2085

In this phase, the underground infrastructure will be secured.

ESTIMATED COSTS

TOTAL INVESTMENT: 1912

DESIGN: 5

The design cost consists mainly of the conceptual design funded by the EC in FP7. Additional contributions from other European (ILIAS, ELiTES, GraWIToN, ASPERA) and national grants.

PREPARATION: 171

The preparation cost includes the preliminary, definitive, operative documentation needed to launch the call for tender for the realisation of the infrastructure. It also includes ET technology development costs.

IMPLEMENTATION (CONSTRUCTION): 1736

The implementation cost will depend upon the selected site. Here a conservative evaluation is presented.

TERMINATION: 40

The estimated termination cost is based on one year of running costs and on the cost for securing the underground infrastructure.

AVERAGE ANNUAL OPERATION COSTS: 37

This estimate of the ET operations cost includes –apart from the cost related to the running of the ET RI– also the expenses for maintenance, consumables, local administrative- & support staff, local computing facilities, etc. It does not include the costs for remote computing facilities.

HEADQUARTERS

INSTITUTION NAME: European Gravitational Observatory (EGO)

INSTITUTION ADDRESS: Via E. Amaldi 56021 Cascina (Pisa) Italy

WEBSITE

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

LOGO

File: et-new-logo.png

IMAGE

File: ET_pictoria-ESFRI-reduced.png

DESCRIPTION

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 fundamental physics knowledge, 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 materials.

BACKGROUND

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, which 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 veritable revolution, as it has opened a new era of observing the universe through a new unstoppable messenger, GWs, capable of describing events that do not emit light or that complement the information collected by telescopes. Thanks to the beginning of the multi-messenger astronomy with GWs, several communities (astronomers, astrophysicists, astroparticle physicists, nuclear and particle physicists) started to join their efforts. In 2025 we expect that LIGO-India will join, completing the Second-Generation (2G) GW detector landscape. ET constitutes the next step forward; it will be the RI pioneering the 3G GW observatories network. ET will observe the Universe, well beyond the limits of the current detectors, allowing us to observe, for example, coalescences of black holes back into the Dark Age of the Universe.

STEPS TO IMPLEMENTATION

Past steps:
+3G GW observatory idea conceived in the FP6 I3 activity ILIAS (2004-2008) and in an exploratory workshop funded by ESF (2005);
+ET CDR in FP7 design study (2008-2011);
+Part of the enabling technologies of ET developed in collaboration with the Japanese project KAGRA through an IRSES-FP7 project, ELiTES (2012-2017) and currently through the Interreg ETpathfinder and E-TEST projects and the SarGrav facility;
+The detection of GWs by LIGO/Virgo
The next preparatory steps toward the implementation of ET are well defined:
- formalising the ET collaboration (2021-2022)
-Selection of the hosting site and beginning of the land acquisition process (2024);
-Acquisition of legal status, creation of governance structure (2025);
-Fixing the operative TDR, site optimised (2026), finalising the land acquisition (2027);
- Main call for tender (2026)
-Beginning of the excavation works (2027);
-Start of operations (about 2035).

SCIENTIFIC DOMAIN

Selection: PHYSICAL SCIENCES & ENGINEERING

OTHER RELEVANT DOMAIN

☐ DIGIT

☐ ENERGY

☐ ENVIRONMENT

☐ HEALTH & FOOD

☐ PHYSICAL SCIENCES & ENGINEERING

☐ SOCIAL & CULTURAL INNOVATION

SECTION 2: POLITICAL SUPPORT

LEGAL STATUS

Selection: None

Comment:

RFOs and RPOs already started to meet to work on the possible ET governance

Upload the relevant updated legal entity statutes/agreement of your RI

No file uploaded

POLITICAL SUPPORT - LEAD COUNTRY / ENTITY

1	**COUNTRY/ENTITY TYPE:**	MS/AC Countries
	COUNTRY/ENTITY:	ITALY
	NATIONAL MINISTRY/COUNCIL OF THE ENTITY:	Ministro dell'Università e della Ricerca
	EOS/COUNCIL RESOLUTION:	PS_EoS_L_IT.pdf

POLITICAL SUPPORT - PROSPECTIVE MEMBER COUNTRY/ENTITY

1	**COUNTRY/ENTITY TYPE:**	MS/AC Countries
	COUNTRY/ENTITY:	SPAIN
	NATIONAL MINISTRY/COUNCIL OF THE ENTITY:	Ministerio de Ciencia e Innovacion
	EOS/COUNCIL RESOLUTION:	PS_EoS_PM_ES.pdf
2	**COUNTRY/ENTITY TYPE:**	MS/AC Countries
	COUNTRY/ENTITY:	THE NETHERLANDS
	NATIONAL MINISTRY/COUNCIL OF THE ENTITY:	Ministry of Education, Culture and Science
	EOS/COUNCIL RESOLUTION:	PS_EoS_PM_NL.pdf
3	**COUNTRY/ENTITY TYPE:**	MS/AC Countries
	COUNTRY/ENTITY:	BELGIUM
	NATIONAL MINISTRY/COUNCIL OF THE ENTITY:	Interministerial Conference for Science Policy
	EOS/COUNCIL RESOLUTION:	PS_EoS_PM_BE.pdf
4	**COUNTRY/ENTITY TYPE:**	MS/AC Countries
	COUNTRY/ENTITY:	POLAND
	NATIONAL MINISTRY/COUNCIL OF THE ENTITY:	Minister of Science and Higher Education
	EOS/COUNCIL RESOLUTION:	PS_EoS_PM_PL.pdf

POLITICAL SUPPORT - INCLUSION IN NATIONAL RESEARCH INFRASTRUCTURE ROADMAP(-S)

1	**NATIONAL ROADMAP COUNTRY:**	THE NETHERLANDS
	FUNDS EARMARKED OR ALLOCATED:	0
	RELEVANT POLITICAL	https://www.nwo.nl/binaries/content/documents/nwo-en/common/documentation/application/nwo/permanent-

	DOCUMENT:	commission/roadmap-large-scale-scientific-infrastructure/Roadmap+grote+onderzoeksfaciliteiten-en.pdf
	NATIONAL ROADMAP COUNTRY:	GREECE
2	**FUNDS EARMARKED OR ALLOCATED:**	0
	RELEVANT POLITICAL DOCUMENT:	http://nkfih.gov.hu/national-research-infrastructure-roadmap
	NATIONAL ROADMAP COUNTRY:	BELGIUM
3	**FUNDS EARMARKED OR ALLOCATED:**	0
	RELEVANT POLITICAL DOCUMENT:	https://www.ewi-vlaanderen.be/sites/default/files/bestanden/large_scale_research_infrastructure_in_flanders_-_flemish_participation_in_international_research_infrastructures_2020.pdf

FINANCIAL COMMITMENT - LEAD COUNTRY/ENTITY

1	**COUNTRY/ENTITY TYPE:**	MS/AC Countries
	COUNTRY/ENTITY	ITALY
	AUTHORITY NAME:	Ministero dell'Università e della Ricerca
	ADDRESS:	Via Trastevere 76/a Roma
	CONTACT PERSON:	Gianluigi Consoli
	E-MAIL:	gianluigi.consoli@miur.it
	PHONE:	+ 39 06 9772.7050
	EoC:	FC_EoC_L_IT.pdf

FINANCIAL COMMITMENT - PROSPECTIVE COUNTRY/ENTITY NAME

No Financial Commitment - Prospective Member entries

COVERAGE OF REAL AND ESTIMATED COSTS

	EURO (M€)	**PERCENTAGE (%)**	**COMMENT**
TOTAL INVESTMENT	47.8	2.8	
DESIGN	5	100	Conceptual design (funded by EC) and other design activities.
PREPARATION	42.8	25	Financial support already delivered or committed by some European countries mainly addressed to the qualification of the site candidates to host ET.
IMPLEMENTATION (CONSTRUCTION)	0	0	Although a sharing of the implementation cost is not fixed, there is a general agreement that the hosting country will sustain a major fraction of the RI implementation costs (excavation, services, ...)
TERMINATION	0	0	
AVERAGE ANNUAL OPERATION COSTS	0	0	The annual cost is expected to be 37M€, the subdivision between the partners will be defined in the legal agreement of the ET RI.

SECTION 4: RESEARCH INFRASTRUCTURE CONSORTIUM

COORDINATOR

	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	ITALY
	INSTITUTION NAME:	Istituto Nazionale di Fisica Nucleare
1	**INSTITUTION ADDRESS:**	Piazza dei Caprettari 70, Roma
	REPRESENTATIVE:	Antonio Zoccoli
	EMAIL:	presidenza@presid.infn.it
	TELEPHONE:	+39 06 6840031
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	THE NETHERLANDS
	INSTITUTION NAME:	Nikhef
2	**INSTITUTION ADDRESS:**	Science Park 105, 1098 XG Amsterdam, the Netherlands
	REPRESENTATIVE:	Stan Bentvelsen
	EMAIL:	s.bentvelsen@nikhef.nl
	TELEPHONE:	+31 205925001

PARTICIPANTS

	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	SPAIN
	INSTITUTION NAME:	Universitat de Barcelona
1	**INSTITUTION ADDRESS:**	C/ Martí i Franquès 1, Barcelona, 08028, Spain
	REPRESENTATIVE:	Domènec Espriu
	EMAIL:	vr.recerca@ub.edu
	TELEPHONE:	(+34) 934 035 512
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	ITALY
	INSTITUTION NAME:	Istituto Nazionale di Geofisica e Vulcanologia
2	**INSTITUTION ADDRESS:**	Via di Vigna Murata, 605 - 00143 Rome - Italy
	REPRESENTATIVE:	Carlo Doglioni
	EMAIL:	presidente@ingv.it
	TELEPHONE:	(+39) 6 51860460
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	SPAIN
	INSTITUTION NAME:	Institut de Ciències de l'Espai
3	**INSTITUTION ADDRESS:**	Campus UAB, Carrer de Can Magrans s/n, 08193 Barcelona, Spain
	REPRESENTATIVE:	Diego F.Torres
	EMAIL:	dtorres@ice.csic.es
	TELEPHONE:	(+34) 937379788
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	SPAIN
	INSTITUTION NAME:	Institut de Física d'Altes Energies
4	**INSTITUTION ADDRESS:**	IFAE/UAB Campus Bellaterra, Barcelona 08193, Spain
	REPRESENTATIVE:	Ramon Miquel
	EMAIL:	rmiquel@ifae.es
	TELEPHONE:	(+34) 93 170 2726
	COUNTRY/ENTITY TYPE:	Third Countries
	COUNTRY/ENTITY:	United Kingdom

INSTITUTION NAME: University of Portsmouth
5 **INSTITUTION ADDRESS:** University House, Winston Churchill Avenue, Portsmouth PO1 2UP, UK
REPRESENTATIVE: Andy Lundgreen
EMAIL: Bob.Nichol@port.ac.uk
TELEPHONE: (+44) 23 9284 3117

COUNTRY/ENTITY TYPE: MS/AC Countries
COUNTRY/ENTITY: GERMANY
INSTITUTION NAME: Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.
6 **INSTITUTION ADDRESS:** Hofgartenstrasse 8, 80539 München, Germany
REPRESENTATIVE: Alessandra Buonanno
EMAIL: alessandra.buonanno@aei.mpg.de
TELEPHONE: (+49) 331 567-7220

COUNTRY/ENTITY TYPE: MS/AC Countries
COUNTRY/ENTITY: GERMANY
INSTITUTION NAME: Leibniz Universität Hannover
7 **INSTITUTION ADDRESS:** Welfengarten 1, D-30167 Hannover, Germany
REPRESENTATIVE: Volker Epping
EMAIL: praesident@uni-hannover.de
TELEPHONE: (+49) 511 762 2201

COUNTRY/ENTITY TYPE: MS/AC Countries
COUNTRY/ENTITY: THE NETHERLANDS
INSTITUTION NAME: Maastricht University
8 **INSTITUTION ADDRESS:** "Minderbroedersberg 4-6, 6211 LK Maastricht, The Netherlands"
REPRESENTATIVE: Martin Paul
EMAIL: m.paul@maastrichtuniversity.nl
TELEPHONE: (+31) 43 38 82746

COUNTRY/ENTITY TYPE: Third Countries
COUNTRY/ENTITY: United Kingdom
INSTITUTION NAME: University of Birmingham
9 **INSTITUTION ADDRESS:** Edgbaston, Birmingham B15 2TT, United Kingdom
REPRESENTATIVE: Amelia Petch
EMAIL: a.petch@bham.ac.uk
TELEPHONE: (+44) 121 4158516

COUNTRY/ENTITY TYPE: Third Countries
COUNTRY/ENTITY: United Kingdom
INSTITUTION NAME: University of Glasgow
10 **INSTITUTION ADDRESS:** University Avenue, Glasgow G12 8QQ, United Kingdom
REPRESENTATIVE: Diane Foster
EMAIL: Diane.Foster@glasgow.ac.uk
TELEPHONE: (+44) 1413304167

COUNTRY/ENTITY TYPE: MS/AC Countries
COUNTRY/ENTITY: GERMANY
INSTITUTION NAME: RWTH Aachen University
11 **INSTITUTION ADDRESS:** Templergraben 55, 52062 Aachen, Germany
REPRESENTATIVE: Ulrich Rüdiger
EMAIL: rektor@rwth-aachen.de
TELEPHONE: (+49) 241 80 94000

COUNTRY/ENTITY TYPE: MS/AC Countries
COUNTRY/ENTITY: SPAIN
INSTITUTION NAME: Universitat de València
12 **INSTITUTION ADDRESS:** Avenida Blasco Ibáñez, 13, 46010 Valencia
REPRESENTATIVE: Carlos Hermenegildo

	EMAIL:	vicerec.investigacio@uv.es
	TELEPHONE:	(+34) 9638 64109
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	GERMANY
	INSTITUTION NAME:	University of Hamburg
13	**INSTITUTION ADDRESS:**	Universität Hamburg, Mittelweg 177, 20148 Hamburg, Germany
	REPRESENTATIVE:	Heinrich Graener
	EMAIL:	katrin.seelhorst@uni-hamburg.de
	TELEPHONE:	(+49) 40 42838-9596
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	SPAIN
	INSTITUTION NAME:	Universitat de les Illes Balears
14	**INSTITUTION ADDRESS:**	Cra. Valldemossa km.7.5. E-07122 Palma de Mallorca
	REPRESENTATIVE:	Enrique García Riaza
	EMAIL:	alicia.sintes@uib.es
	TELEPHONE:	(+34) 971 172010
	COUNTRY/ENTITY TYPE:	Third Countries
	COUNTRY/ENTITY:	United Kingdom
	INSTITUTION NAME:	Cardiff University
15	**INSTITUTION ADDRESS:**	30-36 Newport Road, Cardiff CF24 0DE, UK
	REPRESENTATIVE:	Elid Morris
	EMAIL:	morrise12@cardiff.ac.uk
	TELEPHONE:	(+44) 29 2087 4396
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	ITALY
	INSTITUTION NAME:	Università degli Studi di Cagliari
16	**INSTITUTION ADDRESS:**	Via Università 40, 09124 Cagliari - Italy
	REPRESENTATIVE:	Maria Del Zompo
	EMAIL:	rettore@unica.it
	TELEPHONE:	(+39) 70 659670
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	SPAIN
	INSTITUTION NAME:	Instituto de Estructura de la Materia, Agencia Estatal Consejo Superior de Investigaciones Científicas
17	**INSTITUTION ADDRESS:**	C/ Serrano, 113 bis, 119, 121 y 123. Madrid 28006, Spain
	REPRESENTATIVE:	Mena Marugan Guillermo Antonio
	EMAIL:	mena@iem.cfmac.csic.es
	TELEPHONE:	(+34) 91 561 6800
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	ITALY
	INSTITUTION NAME:	Istituto Nazionale di AstroFisica
18	**INSTITUTION ADDRESS:**	Viale del Parco Mellini, 84 - 00136 Rome - Italy
	REPRESENTATIVE:	Nicolò D'Amico
	EMAIL:	nicolo.damico@inaf.it
	TELEPHONE:	(+39) 6 35533 351
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	SWITZERLAND
	INSTITUTION NAME:	Université de Geneve
19	**INSTITUTION ADDRESS:**	Rue du Général-Dufour 24, 1204 Genève, Switzerland
	REPRESENTATIVE:	Brigitte Gaillot
	EMAIL:	Brigitte.Galliot@unige.ch
	TELEPHONE:	(+41) 22 379 7196
	COUNTRY/ENTITY TYPE:	Third Countries

	COUNTRY/ENTITY:	United Kingdom
	INSTITUTION NAME:	University of Strathclyde
20	**INSTITUTION ADDRESS:**	50 George St, Glasgow, G1 1QE, UK
	REPRESENTATIVE:	Alison McFarlane
	EMAIL:	alison.mcfarlane@strath.ac.uk
	TELEPHONE:	(+44) 141 548 2522
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	BELGIUM
	INSTITUTION NAME:	Vrije Universiteit Brussel
21	**INSTITUTION ADDRESS:**	Pleinlaan 2, 1050 Brussel, Belgium
	REPRESENTATIVE:	Caroline Pauwels
	EMAIL:	Caroline.Pauwels@vub.ac.be
	TELEPHONE:	(+32) 2 629 20 10
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	POLAND
	INSTITUTION NAME:	University of Warsaw
22	**INSTITUTION ADDRESS:**	Krakowskie Predmiescie 26/28, Warsaw, Poland
	REPRESENTATIVE:	Maciej Duszczyk
	EMAIL:	prorektornauka@adm.uw.edu.pl
	TELEPHONE:	(+48) 22 552 0350
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	POLAND
	INSTITUTION NAME:	Copernicus Astronomical Center
23	**INSTITUTION ADDRESS:**	Bartycka 18, Warsaw, Poland
	REPRESENTATIVE:	Piotr Zycki
	EMAIL:	ptz@camk.edu.pl
	TELEPHONE:	(+48) 22 841 0041
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	POLAND
	INSTITUTION NAME:	National Centre for Nuclear Research
24	**INSTITUTION ADDRESS:**	ul. Andrzeja Sołtana 7, 05-400 Otwock, Poland
	REPRESENTATIVE:	Ewa Rondio
	EMAIL:	ewa.rondio@ncbj.gov.pl
	TELEPHONE:	(+48) 22 273 1585
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	BELGIUM
	INSTITUTION NAME:	Fonds Wetenschappelijk Onderzoek - Vlaanderen
25	**INSTITUTION ADDRESS:**	Egmontstraat 5, 1000 Brussel, Belgium
	REPRESENTATIVE:	Hans Willems
	EMAIL:	hans.willems@fwo.be
	TELEPHONE:	(+32) 2 550 15 26
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	SPAIN
	INSTITUTION NAME:	Instituto de Física Teórica UAM-CSIC
26	**INSTITUTION ADDRESS:**	C/ Nicolás Cabrera 13-15, Campus de Cantoblanco, 28049 Madrid, Spain
	REPRESENTATIVE:	Luis Ibáñez
	EMAIL:	luis.ibannez@uam.es
	TELEPHONE:	(+34) 912 999 809
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	ITALY
	INSTITUTION NAME:	Università degli Studi di Sassari
27	**INSTITUTION ADDRESS:**	Piazza Università 21, Sassari (SS), Italy

	REPRESENTATIVE:	Massimo Carpinelli
	EMAIL:	mcarpinelli@uniss.it
	TELEPHONE:	(+39) 79229588
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	SPAIN
	INSTITUTION NAME:	Agencia Estatal Consejo Superior de Investigaciones Científicas
28	**INSTITUTION ADDRESS:**	Serrano 117, 28006 Madrid, Spain
	REPRESENTATIVE:	Elena Domínguez Cañas
	EMAIL:	elena.dominguez@uah.es
	TELEPHONE:	(+34) 609 777 507
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	POLAND
	INSTITUTION NAME:	Institute of Mathematics
29	**INSTITUTION ADDRESS:**	Sniadeckich 8, 00-656 Warsaw, Poland
	REPRESENTATIVE:	Lukasz Stettner
	EMAIL:	l.stettner@impan.pl
	TELEPHONE:	(+48) 22 5228100
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	BELGIUM
	INSTITUTION NAME:	Fonds de la Rechercheur Scientifique - FNRS
30	**INSTITUTION ADDRESS:**	5, Rue d'Egmont, B-1000 Bruxelles, Belgium
	REPRESENTATIVE:	Veronique Halloin
	EMAIL:	veronique.halloin@frs-fnrs.be
	TELEPHONE:	(+32) 2 504 92 04
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	BELGIUM
	INSTITUTION NAME:	Université de Namur
31	**INSTITUTION ADDRESS:**	Rue de Bruxelles 61, B-5000 Namur, Belgium
	REPRESENTATIVE:	Naji Habra
	EMAIL:	naji.habra@unamur.be
	TELEPHONE:	(+32) 81 72 49 95
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	BELGIUM
	INSTITUTION NAME:	Université de Mons
32	**INSTITUTION ADDRESS:**	Place du Parc, 20, 7000 Mons, Belgium
	REPRESENTATIVE:	Philippe Dubois
	EMAIL:	rectorat@umons.ac.be
	TELEPHONE:	(+32) 65 373001
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	ITALY
	INSTITUTION NAME:	European Gravitational Observatory
33	**INSTITUTION ADDRESS:**	Via E. Amaldi, 5, 56021 Cascina (Pisa), Italy
	REPRESENTATIVE:	Stavros Katsanevas
	EMAIL:	stavros.katsanevas@ego-gw.it
	TELEPHONE:	(+39) 50752325
	COUNTRY/ENTITY TYPE:	MS/AC Countries
	COUNTRY/ENTITY:	BELGIUM
	INSTITUTION NAME:	Universiteit Antwerpen
34	**INSTITUTION ADDRESS:**	Prinsstraat 13, 2000 Antwerpen, Belgium
	REPRESENTATIVE:	Ronny Blust
	EMAIL:	ronny.blust@uantwerpen.be
	TELEPHONE:	(+32) 3 265 30 05

COUNTRY/ENTITY TYPE: MS/AC Countries
COUNTRY/ENTITY: NORWAY
INSTITUTION NAME: Norwegian University of Science and Technology
35 **INSTITUTION ADDRESS:** Hovedbygningen, Gløshaugen, Høgskoleringen 1 7034 Trondheim NORWAY
REPRESENTATIVE: Anne Borg
EMAIL: anne.borg@ntnu.no
TELEPHONE: (+47) 73593413

COUNTRY/ENTITY TYPE: MS/AC Countries
COUNTRY/ENTITY: HUNGARY
INSTITUTION NAME: WIGNER Research centre for physics
36 **INSTITUTION ADDRESS:** 29-33 Konkoloy-Thege Street, Budapest, 1121 Hungary
REPRESENTATIVE: Péter Jozsef Lévai
EMAIL: levai.peter@wigner.hu
TELEPHONE: (+36) 30 6312359

COUNTRY/ENTITY TYPE: MS/AC Countries
COUNTRY/ENTITY: HUNGARY
INSTITUTION NAME: Institute for Nuclear Research - ATOMKI
37 **INSTITUTION ADDRESS:** 18/c Berm tér, Debrecen, 4026 Hungary
REPRESENTATIVE: Zsolt Dombradi
EMAIL: director@atomki.hu
TELEPHONE: (+36) 52 509260

COUNTRY/ENTITY TYPE: MS/AC Countries
COUNTRY/ENTITY: HUNGARY
INSTITUTION NAME: Research Centre for Astronomy and Earth Sciences - CSFK
38 **INSTITUTION ADDRESS:** 15-17 Konkoloy-Thege Street, Budapest, 1121 Hungary
REPRESENTATIVE: Laszlo Kiss
EMAIL: kiss.laszlo@csfk.mta.hu
TELEPHONE: (+36) 30 4911682

COUNTRY/ENTITY TYPE: MS/AC Countries
COUNTRY/ENTITY: BELGIUM
INSTITUTION NAME: Université catholique de Louvain
39 **INSTITUTION ADDRESS:** Place de l'Université 1; B-1348; Belgium
REPRESENTATIVE: Vincent Blondel
EMAIL: recteur@uclouvain.be
TELEPHONE: (+32) 10 47 88 05

Upload the corresponding inter-institutional and multi-lateral agreement, e.g. a Memorandum of Understanding (MoU): (upload with limit 10 MB)

File: LoI-ET-Total.pdf

ESFRI MoS

ESFRI Monitoring System

ROADMAP 2021

Part B: Scientific Case

SECTION 1: SCIENTIFIC EXCELLENCE

1.1 Identify the scientific field (-s) and - if applicable - the inter- or multidisciplinary scope of your RI

The core scientific field is gravitational wave (GW) physics, meant as the exploration of the Universe up to cosmological distances using GWs as messenger. The field has a rich multidisciplinary impact, with implications ranging from astrophysics to cosmology, nuclear and fundamental physics, geophysics and geology, photonics and laser technologies, metrology, optics, quantum technologies, system controls, material science.

1.2 Outline the scientific vision and mission, its short and long term impact on the main research field (-s) and its potential impact on other fields - if any - as well as on innovation

Vision and mission:
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 100 years. The first GW detections and observations of the last 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 peer 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 test 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, beside 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, cryogenic instrumentation and detectorscryogenics 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, (doi:10.1098/rsta.2017.0290)
[2] Juhel K. et al. 2018, (doi:10.1029/2018JB016698)

1.3 Describe if and how your RI corresponds to a long term science programme by a well-established science community and if and how your RI addresses a (inter- or multidisciplinary) scientific frontier opening novel possibilities in (several) research (fields)

Joint strategy
The international GW scientific community has shaped its future through close collaboration: it has coordinated scientific data acquisition and publications between the LIGO and Virgo (and now KAGRA in Japan) collaboration, jointly planned machine upgrades, exchanged technologies, and shared computing resources worldwide. All this is coordinated through multilateral agreements and the Gravitational Wave International Committee (GWIC). GWIC’s roadmap 2010-2040 outlines the future of GW detection and science, with ET the pioneer 3G GW observatory. The crucial role of ET for the future of GW research was confirmed by GWIC’ s 3G detection subcommittee. Finally, the G7 GSO included ET and the global network of GW detectors in its list of Global Research Infrastructures Case Studies, as a result of a coordinated effort of the GW community. ET research will allow the full convergence of the European GW community into a pan-European project.
Frontier science
ET is designed to cross today’s scientific frontiers by providing unprecedented GW detection capabilities. This will open new possibilities in many research fields (see 1.2): astrophysics, by observing almost the whole Universe; fundamental physics, by investigating the deepest nature of gravity and spacetime and signals from early Universe; nuclear physics, by probing the state of matter in the neutron-star core. Along the way, it will cross technology frontiers in optics, precision mechanics, material science, control and analysis methods, and quantum technology. This multidisciplinary richness is highlighted by the variety of institutions supporting ET. Notably, the first detection of GWs and other messengers from a neutron-star-binary coalescence resulted in a publication with 3674 authors involving 60 scientific collaborations. Emerging from ET preparations, joint efforts are already ongoing across Europe in areas such as geology, sensors, mirror and laser technology, vibration attenuation, cryogenics

1.4 Outline the cutting edge science and the used technology

Science
Scientifically, ET stands on the shoulder of giants, starting with Einstein’s 1916 prediction of GWs. Via the construction of the first- and second-generation GW observatories, the scientific developments culminated in the 2015 observation of GWs and 2017 Nobel prize. ET is the next step in this journey, combining a proven scientific basis with the next steps in cutting-edge technology.

Technology
Based on well proven and experimentally tested concepts, ET will exploit cutting-edge

technologies and drive them to their physical limits. It combines the well-proven technologies from the advanced LIGO and Virgo detectors (ultra-sensitive optical interferometry, complex seismic isolation systems with a combination of passive isolation based on chains of pendulums and active isolation, and squeezing) with beyond-state-of-the-art systems planned for the advanced detectors (cryogenic mirrors and frequency dependent squeezing), in an infrastructure designed to accommodate several technology upgrades over many decades.
To reach its objectives, ET is designed to outperform the 2G GW observatories through its size (to increase the signal produced by the GW) and underground configuration (to reduce the impact of seismic noise and gravity gradient noise induced by seismic waves and motion of air masses).
ET will implement frontier technologies: (a) large high-purity coated silicon test masses and suspension systems cooled to below 20 K using innovative, efficient and low-noise cryogenic techniques, (b) high-power, ultra-stable lasers to enable the high-precision readout of differential test-mass motion, (c) quantum technologies to overcome the standard quantum limit of detector sensitivity, (d) advanced environmental monitoring systems using extensive sensor arrays for data-quality control and environmental-noise cancellation, (e) leading-edge vacuum engineering for the overall infrastructure hosting the largest ultra-high vacuum system on Earth.

1.5 Identify the scientific leadership that was recruited to lead the preparation of your RI and elaborate how you will recruit and consolidate the scientific leadership and overall competences for the implementation and operation of the proposed RI

Leading experts from the scientific and technical teams of Virgo/LIGO and GEO 600 participate in ET with proven competences needed to realise the RI. Civil infrastructure experts are now collaborating with ET, forming with the scientists the Instrument Science Board (ISB). In the coming years the ET Collaboration will transform into a consortium under strong management. Further experts will be recruited as ET evolves. The GW community has a strong track record of attracting excellent researchers.

1.6 Describe how the scientific concept of your RI was tested and found feasible and summarise the main findings concerning the scientific case from the design (and feasibilty) study report and the feedback from the relevant scientific community (-ies)

Concept
The ET design is based on well proven and experimentally tested concepts; specifically, long-baseline, high-power laser interferometry, which was essential to the recent breakthrough GW observations. Laser interferometry is the only known technology compatible with the sensitivity target of ET, and has proven its outstanding reliability by enabling the high duty cycle of current detectors.

Track record
Crucial for a successful implementation of innovative technologies in each of the current GW detectors LIGO, Virgo, GEO 600, and KAGRA was the coordinated effort of various laboratories and prototype facilities, which made it possible to develop, test and characterise the technologies beforehand. The swift commissioning progress in all existing detectors is a clear demonstration of the success of this scheme, which will be adopted for ET.

Feasibility assessments
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.

Living design: https://apps.et-gw.eu/tds/?content=3 & r=16984

1.7 Upload the design (and feasibility) study final report, if available: (upload with limit 10 MB; in case the document is longer than 30 pages, please also provide an executive summary of maximum 4 pages)

File: ET_DU_short_03Sept2020.pdf

2.1 Position in the RI landscape and describe if and how your RI addresses a gap in the current RI landscape in Europe (and beyond) and thus responds to unaddressed needs of user communities, i.e. describe the `uniqueness` of the RI. If not, describe which value your RI adds to the existing European research capacity in one or more fields of research and innovation

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 & Virgo is limited to a region that, on cosmological scales, is still our local neighborhood, leaving much of the curiosity of scientists unquenched.

ET will allow 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 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, see 4.1) – (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 improve the sky localization. The envisaged start of ET's operational phase in 2035 is also very well matched to ESA's LISA space mission which aims to study GWs at very low frequencies.

2.2 Indicate current infrastructures or services that are operational and accessible for the relevant science communities, if any, and explain why they are not adequate

Current infrastructures
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.

Open challenges
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 (the Dark Ages).
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).

2.3 Explain why your RI is the most appropriate solution to address this need and what the added value is of performing the research activities within a RI instead of a research programme

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 is needed that is one hundred thousand times smaller than a proton inside an atom), 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.

Exploiting our 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.

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 2035.

2.4 Describe how your RI contributes to the enhancement and realisation of the European Research Area[1]

European collaboration
GW physics is an extremely collaborative discipline, as attested by the 3674 authors on the groundbreaking paper on GWs and other cosmic messengers. RIs such as the current 2G GW observatories play pivotal roles in these international collaborations. ET is designed to

provide not only an immense body of data but also automated triggers and preliminary information for immediate follow-up observations by other types of observatories, strengthening collaborative multi-messenger science in Europe. Realising ET, as is already evident from the preparatory phase, will bring European researchers closer together and strengthen coordination within the ERA. The resulting links foster knowledge exchange on a scale often surpassing the ERA.

Scientific and engineering excellence
ET is firmly positioned to become the world's most sensitive GW observatory in the next decade. Not surprisingly, this prospect attracts top scientists, engineers and technicians to Europe as is evident not only from the numerous new tenure-track and faculty positions at long-standing European GW research groups but also by the emergence of entirely new GW research groups at a number of universities. Exhilarating science of Nobel Prize quality and a large pool of excellent scientists is an ideal mix to attract the most talented (science) students. Similarly, cataclysmic events like black-hole and neutron-star mergers, ET's mindboggling technologies and impressive underground location easily catch the interest of the general public and notably young people deciding whether or not to pursue a career in science. All combined, GW research in general and ET in particular will strongly boost scientific and technical excellence and power of the ERA.

Open science
ET is also well aligned to meet the open science ambition of the ERA. Early on, the (world-wide) GW community already adopted open access policies. As of 2019, GW science, including real-time GW detection alerts, is publicly available (https://www.gw-openscience.org/interactive/).

Innovation power
Beyond science, ET will be a hub for innovation in various domains. The development of novel seismic sensors already led to a successful start-up company. In areas like mirror technology, lasers, vibration-free cooling, modern control technology and various sensors and actuators often joint efforts with industrial partners have already started. In Maastricht, the laser-interferometer R & D laboratory ETpathfinder has been partially funded by an EU Interreg program and also in Rome and Liège major R & D facilities for notably cryogenically operated optics (silicon) optics have been funded. Collectively these efforts will enhance economic competitiveness and growth in the ERA. Finally, a large fraction of the actual capital investment needed for the construction of ET will be distributed, in accord with EU tendering rules, and find its way to European industry.

2.5 Describe how your RI will contribute to aligning national investments in your field (-s) at the European level

Capital investment for GW observatories exceeds what can realistically be expected from a single European country. The Virgo observatory was initiated in the 1990s as a joint Italian-French endeavor. Subsequently, The Netherlands, Poland, Hungary, Spain, Germany and Belgium joined. Similarly, LIGO in the USA would have been less successful without important European contributions from notably Germany and the UK. Since a decade, Virgo and LIGO collaborate as a worldwide consortium. Almost all European groups see ET as their next GW focus. ET will build upon the successes of Virgo and LIGO, continuing joint R & D programs and sharing of construction (large capital investment), commissioning and exploitation (long-term commitment) responsibilities according to what each participating country can or is willing to contribute. A special role is reserved for (and expected from) the host(s) towards the required capital investment and exploitation costs. Discussions within the ET Collaboration have started with the aim to start construction around 2025; acquiring the ESFRI status is expected to accelerate the financial negotiations.
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 (ETpathfinder) and one for geology studies and a cold silicon mirror facility (E-TEST). Notably ETpathfinder is envisaged to become the R & D laboratory for next-generation GW detection technology and as such welcomes new collaborators.

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 –on a different note– project management. GW science is included prominently in the briefing book of the European Strategy for Particle Physics.

Within APPEC, national funding organizations coordinate European astroparticle physics research. ET is one of APPEC's top priorities and APPEC actively monitors and supports ET in general and the realization of this ESFRI application in particular.

2.6 Describe how your RI will effectively (re-) orient resources from the relevant science communities and stimulate `joint programming`, e.g. contributing complementary instrumentation, activating partnerships, training of young researchers in the relevant field (-s) of science

The immense scale and complexity of a GW observatory like ET means that building it involves a myriad of subsystem R & D programs being carried out by collaborations of all sizes and shapes. ET's frontier-crossing technologies are unthinkable without custom-made partnerships and the involvement of hundreds of young researchers all across Europe becoming a new generation of high-tech experts. Once operational, this joint programming will continue, with upgrades and, most importantly, a wide range of collaborative GW research programs enabled by ET. Experiences with 2G GW observatories confirm this picture of consortium building around the RI.

Technology development for ET has already led to new collaborations with experts in fields like geology/hydrology, civil engineering, vacuum, cryogenics, lasers and controls. Notably the site characterization is performed in close collaboration between ET groups and geology /hydrology experts at both candidate sites, supported by jointly acquired funding. Similarly, civil engineering studies are ongoing for both sites in a coordinated way. Vacuum workshops were recently held at Livingston (USA) and at CERN. Collaborations with cryogenic experts have started at various locations. An MoU between ET and CERN on joint technological developments has recently been signed, attracting new technical competences to ET. On a global scale, instrumentation for next-generation GW observatories is addressed in the annual Gravitational-Wave Advanced Detector Workshop, typically week-long meetings which also serve as platforms for the training of young scientists.

On the scientific side, with the first GWs observed, the field enjoys an ever-increasing interest from notably the larger astroparticle physics, astronomy and cosmology communities. These collaborations are expected to continue to evolve following new observations from the present 2G observatories, and take flight due to the prospect of the revolutionary 3G GW detection capabilities.

2.7 Describe the (potential) linkages between your RI and existing (European) platforms, networks and other (ESFRI) RI, e.g. European Technology Platforms (ETP), Joint Programming Initiatives (JPI), ERA-nets, Public-Private Partnerships (PPP) and projects under FP7 or Horizon 2020

The field of GWs in general and ET in particular are firmly rooted in various EU programs and platforms:

ET is a pillar of the science vision of the European platform for astroparticle physics (APPEC). APPEC itself –and thereby the field of GWs– profited from the EU ERA-NET funded ASPERA networking activity, e.g. several so-called 'APPEC Technical Forum' events were (and still are) organised on joint GW-industry technology issues.

GWs are also connected –together with e.g. KM3NeT and CTA (both with ESFRI status), IceCube, etc.– to the recently concluded H2020 project ASTERICS focused on multi-messenger astrophysics. The European Gravitational Observatory, the ET headquarter, is included in the ASTERICS sequel H2020 project European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures (ESCAPE).

ET benefited from an EU FP7 funded Design Study, which allowed the consortium to publish an elaborate Conceptual Design Report in 2011 and also forge a close collaboration between the entire European GW community, i.e. joining the groups focused on Virgo and those focused on LIGO. The FP7 ELiTES project funded the exchange of researchers between Europe and Japan focused on cryogenic technologies for ET and LCGT (now KAGRA) GW observatories. Even though it formally only covered the years 2012-2016, KAGRA has become a long-term collaborator. KAGRA participated in the last LIGO-Virgo Observation Run and various European groups continued collaboration with our Japanese colleagues, also on aspects beyond cryogenics.

The GraWIToN Initial Training Network, funded for the 2014-2018 period by European Commission under FP7-Marie Curie Actions, supported the training of 14 young researchers (PhD students) in the field of GWs.

ET is a key subject of the recently approved AHEAD2020 project, an I3 activity recently funded in H2020 (March 2020), focused on multi-messenger astronomy.

ET related activities are also supported by regional EU funding schemes. In the EUregios Flanders-Netherlands and Meuse-Rhine, two Interreg projects were subsidized: ETpathfinder and E-TEST.

Several GW researchers benefited from personal ERC grants.

2.8 Describe how your RI will leverage European competitiveness in research and innovation, e.g. uniqueness of technical offer, advancement of technical standards, innovation in research process, effective impact on the innovation of research products and setting reference standards in data management

Operation
Once operational, ET will be the most advanced instrument of its kind, offering unprecedented GW detection capabilities as outlined earlier. This will strengthen European competitiveness.

Construction
The realisation of ET presents a multitude of technical challenges. Many of which will be addressed in collaboration with industry. Most require first-in-kind innovations which are likely to find applications elsewhere as well. Typical areas requiring major development are listed below.

Photonics is obviously the main technology for ET. ET will set a standard in specifications and characteristics of optical components like silicon optics, fibred opto-electronics, low noise lasers.
Metrology is another sector where ET will generate innovation. Stringent requirements of optical components will require the development of metrology at atomic level, using interferometric techniques, applied at large components like the main ET mirrors.
ET will impact on surface science and technologies, crucial in many industrial processes; the requirements of the ET mirrors in terms of polishing, coating and geometry will need the development of new technologies in this sector, where already 2G detectors demonstrated their innovation potential. The new large silicon mirrors will set a new standard in terms of optical and mechanical dissipation for silicon optics.
Once completed, ET will host the largest vacuum volume on Earth. To do so economically will require an innovative procurement of the many tens of kilometers of large diameter vacuum pipes commensurate with an installation procedure guaranteeing the ultra-high vacuum specifications. Joint workshops involving ET scientists, colleagues working on the American

Cosmic Explorer project, scientists working in the world's largest HEP laboratories like CERN, and high-tech industries in Europe and the USA have already started.

To safeguard against unwanted vibrations, a novel cooling technology, sorption cooling, will be applied at an unprecedented scale and special high-thermal conductivity fibers need to be developed stimulating innovations and joint developments with high-tech industry.

ET's vibration attenuation system will combine successful concepts developed already for the 2G GW observatories Virgo and LIGO with novel approaches in collaboration with industry.

Stable ET operation and high duty cycle will require advanced controls that could also be applicable in e.g. the chip manufacturing industry. Joint initiatives have already started to address these issues.

ET data analysis with event pile-up in the same time window demands innovative analysis algorithms to extract (weak) signals in the noisy data streams. To profit optimally from the multi-messenger astronomy potential, these algorithms must be able to flag interesting events in real time to allow other –e lectromagnetic, neutrino and cosmic-ray– observatories to also study the event.

2.9 By testing your RI against the ESFRI pan-European ex ante indicators, identify which indicators your RI meets and describe how

ET delivered a Conceptual Design Report in 2011. A Technical Design Report accompanies this ESFRI application. ET will be a single-sited research infrastructure and the site selection process (Sardinia or EUregio Meuse-Rhine) is outlined in this application as well and expected for 2024.

The membership indicator is high. The ET consortium assembles the entire European GW community behind this unique project. This community has a long history of international collaboration in RIs. A MoU has been agreed upon and a light governance scheme, now implemented, will be transformed in the coming 4 years into a strong centralized ET management. Whereas significant R & D funding has already been secured in a number of countries and via various schemes (EU, national and institutional), the raising of the required capital investment for the actual ET construction has only just begun.

The user strategy indicator is high. The technological opportunities and the discovery potential of ET are tremendous and appeal to a large community (research as well as industrial). Presently the ET members come from 17 European countries. Most scientists are from the pioneering countries Germany, France, Italy and the UK while in many other countries the interest in GW science is rapidly gaining momentum. Access, data-management and publication policies will build upon the successful policies pioneered and now established by the LIGO and Virgo consortia which basically achieved seamless cooperation between GW observatories worldwide with real-time public alerts of any GW detection.

The excellence indicator is high. Europe's top GW researchers are committed to ET. Following the first GW detections, many institutes are expanding or initiating GW research groups, i.e. GW research is growing rapidly. GWs are at the heart of the broader multi-messenger astronomy field of research and as such intimately connected with other large-scale research infrastructures such as IceCube, Auger, KM3NeT, CTA and many electromagnetic telescopes (ground-based and space-born). ET is already included in several sectorial roadmaps for large-scale research infrastructures and it will be included in many national ones.

The knowledge-transfer indicator is high. ET continues the sharing of R & D and construction responsibilities across the participating institutes as done successfully now for decades for its predecessors Virgo and LIGO. Through various workshops knowledge is disseminated not only on a European scale (e.g. the annual ET symposium) but even on a global scale (e.g. the annual GWADW). Training of young scientists (PhD students and postdocs) is well established in the field and benefits from existing schools and focused R & D laboratories such as e.g. ETpathfinder. Since industry will be involved in the procurement of the ET research infrastructure, the ET consortium is vigorously pursuing industrial collaboration on all aspects: civil engineering, vacuum system, cryogenics, optics and controls.

3.1 Describe the expected direct economic impact of your RI, e.g. the economic impact from direct spending in the site and region hosting the facility or the headquarters and the nodes of a distributed RI

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. We have 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.
Main outcomes
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.
Construction phase
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.

3.2 Describe the expected mid and long term socio-economic benefits of your RI, e.g. in terms of replacing/re-orientating costly infrastructures that are already in place and support to public policy

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 such as 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.

3.3 Estimate the impact on the innovation activity in the production of goods and services that will result from your RI, e.g. in terms of well-trained people, knowledge transfer, access programmes and services provided

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, as detailed in section 4, ET will provide virtual access, open access to data and open public alerts with low latency to the stakeholder communities in astronomy.

3.4 Describe the potential and role your RI can play in technological and social innovation

ET will push technologies beyond the current frontier. R & D facilities (such as ETpathfinder 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.

3.5 Describe how your RI will attract innovation-oriented resources from business, industries and public services, e.g. as users or suppliers

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.

3.6 Describe how your RI will contribute to tackling (grand) societal challenges

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 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.

3.7 If available, upload a socio-economic *ex-ante* impact study: (upload with limit 10 MB; in case the document is longer than 30 pages, please also provide an executive summary of maximum 4 pages)

File: 4page Socio-econmic caseof ET.pdf **File:** ET_socio_economic_all_w_title.pdf

SECTION 4: USER STRATEGY & ACCESS POLICY

4.1 Upload a table describing quantitatively (in estimated absolute figures as well as %) the targeted user community in terms of

1. scientific field (-s)
2. origin (i.e. local/regional, lead country, prospective member countries, participants, other European countries, other non-European third countries) and
3. sort (i.e. academia, business & industries, public services, other)

File: Targeted User communities 4.1 _2020-09-03.pdf

4.2 Elaborate how your RI has verified the above-described expected user community and user needs, e.g. through a survey

User community
The targeted user communities described in the above document (4.1) have been evaluated on the basis of the current usage of 2G GW detectors. The size estimate of the GW community is based on the numbers of the current collaborations (LIGO, GEO, KAGRA, Virgo) and of the future collaborations (LISA, ET, Cosmic Explorer). The size of the astronomy community is based on the current electromagnetic follow-up activities; the attraction toward the other above-mentioned communities is evaluated based on current preliminary experiences.

An indication of the size of the expected user community is the number of collaborators listed in the paper describing the observation of GWs and other messengers from the binary neutron star inspiral, GW170817. The paper had 3529 authors from more than 950 research institutions, despite restrictions in the collaboration reach on the basis of Memoranda of Understanding (MOUs). These numbers will be even larger with public event announcements, as will be done when ET is in observation mode. As further indications, the ET Letter of Intent (http://www.et-gw.eu/index.php/letter-of-intent) has been signed 759 times, and the ET design study publication was cited 547 times, a very large number for a physics article.

User needs
User needs have been included in the ET design, which resulted from a bottom-up community approach. The ET Conceptual Design Report was authored by 217 scientists from 12 countries.

4.3 Describe the user strategy agreed within your consortium and the possibilities to develop a reasonably sized user community considering costs and services based on your identification of demands and needs

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.

ET Collaboration
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, > 700 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.

Beyond the collaboration
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 decrease to delays of a few months eventually. The ET data management will be compliant with the FAIR constraints thanks also to the long practice on this subject given by Virgo and LIGO data sharing.
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. It is evident that 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 invest 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.

4.4 Describe how you have involved the above-described (potential) user community in the development of your RI proposal, e.g. in the definition of the scientific case and of the technical design specifications, in analysing costs versus benefits, in planning and funding (parts of) the RI

In total, the community that has contributed to the design study and preparatory R & D, and that signed the ET Letter of Intent, consists of about 700 scientists from 17 European countries and 70 scientists from outside Europe. Involvement in the design process was through the following collaborative projects:

The idea for 3G GW detectors was explored in the FP6-I3 initiative ILIAS (2004-2008, GA 506222);
An Exploratory Workshop funded by the European Science Foundation (2005) was the

starting point for the successful conceptual design study “Einstein Telescope” (2008-2011, GA 211743);
The underground and cryogenic enabling technologies were further developed in FP7-IRSES ELiTES (2012-2017, GA 295153), an exchange of scientists between ET and the Japanese KAGRA collaboration.

4.5 Provide a quantitative description of the services (including access modes and funding) which will be provided by your RI based on the user demands and needs: (upload with limit 10 MB; maximum 30 pages)

File: ET Services 4.5.pdf

4.6 Describe the envisaged (common) access policy of your RI in terms of access units, the access mode (-s), the conditions for access, the processes and interactions involved in the access and the support measures facilitating the access

According to the definition used in the Integration Activities actions funded within the European Framework Programmes, the access mode to the Einstein Telescope (ET) 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. Further details are described in section B5.1.

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.

SECTION 5: E- NEEDS

5.1 Outline the Data Management Plan (DMP) and data access policy of the RI. If applicable, describe how data would become accessible to the public

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 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 (see B5.3).

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 (see 4.6) by jointly developing tools and strategies to distribute it on the computing infrastructure as soon as it is produced (see 5.3). 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 realised 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 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 ISO13721 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.

5.2 Describe and quantify what e-infastructure services - e.g. resources for storage, computing, networking, tools for data management, security, access, remote analysis, etc. - your RI will need

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 (see B4.5). 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 (see B5.4) 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

5.3 Describe how the e-infrastructure services needed by your RI will be implemented, specifying the potential need of external e-infrastructure resources and the relations to external e-infrastructures

As mentioned in B5.2, 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. As can be seen by the required services, listed under B5.2, the data storage processing needs of such collaborations are not structurally different from the ones of ET. 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, as noted in B5.2), 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. A software strategy will be developed and implemented to provide the physics analysis groups with high-quality foundation libraries, efficient software, data and workload management tools.

Finally, we will 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. This is already a common effort among 2G detectors in the International Gravitational Wave observatories Network (IGWN) community.

5.4 Describe the compliance with the FAIR principles and how the RI will contribute to the development of the European and global e-infrastructure landscape at all levels (institutional, regional, national, international) - including e.g. the e-infastructure commons and the 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.

5.5 In case of a specific (non-horizontal) e-infrastructure, describe the interface with existing communication networks and technical design of your RI

As mentioned above, ET will implement its offline computing, and likely most of its low-latency searches, on shared external e-infrastructures.
While current 2G GW interferometers use on-site computing (and thus specific dedicated e-infrastructures) for all low-latency searches, they are investigating how to use external resources to do so, and reliable services deployment technologies already allow for that. Thus, unless special needs will be discovered (for example, the need for sizable AI clusters to manage some aspect of detector control such as glitch detection), we do not foresee very large on-site computing needs.

Logically the on-site infrastructure will need to be interfaced to the high-performance network needed to transfer data, to the distributed computing infrastructure and to the alert-generating network described in B5.3. Such a network of intercommunicating services and centres is well within today’s technology capabilities, so should be straightforward by 2030.

ESFRI MoS

ESFRI Monitoring System

ROADMAP 2021

Part C: Implementation Case

6.1 Complementing the identification of the lead country/entity, prospective member countries/entities, coordinator and participants from PART A, describe the envisaged final stakeholder community of your RI and elaborate on your strategies and plans on how your RI will obtain their commitment, including your plans to get listed in additional national RI roadmaps or similar strategical documents, National/Regional Research and Innovation Strategies for Smart Specialisation (RIS3) and Operational Programme (-s) from the European Structural and Investment Funds (ESIF)

Final community
The first stakeholder community for the ET will be the global GW community; the current group of scientists and institutes that have contributed to the design study and preparatory R & D, and that signed our Letter of Intent, consists of about 700 scientists from 17 European countries and 70 scientists from outside Europe. The global GW community targeted by ET is currently counting about 2500-3000 scientists and we expect a dramatic growth when ET will be operative. The neighboring communities described in 4.1 (> 100k users) are also targeted and involved. We will actively stimulate collaboration with additional countries to gain their scientific, financial and political support, with particular attention to the possibility to use structural or recovery funds. This will be achieved via our active participation in existing international consortia built around 2G facilities, via active scientific participation and outreach in the global area of fundamental and applied physics research and by engaging international review bodies to continuously monitor the scientific excellence of our RI and our user group. Although ET will become part of the global GW network consisting of several GW detectors spread around the world, the search for further commitment will concentrate on European candidates first.
We will strive for support of the local population and the important socio-economic and political actors near the site of the RI via active networking, popular outreach programs and interaction with local and national media. Specifically, with two candidate host sites, we are currently targeting regional strategies and opportunities to include ET:
+In the Netherlands, we will appeal to the opportunities laid down in the Research and Innovation Strategy for Smart Specialisation in the South Netherlands (RIS3-Zuid), which seems suitable for both the ET preparatory R & D facilities and ET itself.
+In Italy, we will work with the involved agencies (such as INFN and INAF) and with the Italian Ministry for Research to have ET included in the next revision of the National Plan for Research Infrastructures (PNIR). This action will increase and further normalize the involvement of the major national stakeholders. Another important step will be to have some of the enabling technologies of ET highlighted in the smart specialisations (S3) of the Regione Sardegna; currently, aerospace is one of the 6 specialisation areas identified in Sardinia and many of the referred technologies and facilities are related to ET (new materials, testing facilities, monitoring systems, the Sardinian Radio Telescope). This action will increase the engagement of the regional stakeholders.

7.1 Describe what type and level of assessment - including successful design and feasibility study (-ies) - your RI already has undergone

The key assessments for ET are based on the Conceptual Design Report (CDR) developed in 2008-2011 in FP7, a cornerstone document that triggered hundreds of scientific articles on the scientific and technical potential of ET, contributing to a “peer-assessment” of ET’s feasibility and relevance. Recently a sub-committee of the Gravitational Wave International Committee (GWIC) devoted to strategies, scientific potential and technology requirements for 3G GW detectors, assessed the technological, scientific, management, governance feasibility aspects of ET and other 3G detectors. Studies in collaboration with external engineering companies have been completed to preliminary assess feasibility and costs of the underground infrastructure. ET has been selected for national infrastructure roadmaps in the Netherlands, Hungary and the UK, is candidate for the Italian roadmap (under preparation), and entered the regional roadmap for international research infrastructure in Flanders.

7.2 Elaborate on the prior work that led to this proposal, e.g. the RI is based on an international networking activity like Integrated Infrastructure Initiatives (I3) or other programmes with external international evaluation

Ground-based GW detectors operate as a joint global network and have established an intense networking activity, governed by the Gravitational Wave International Committee (GWIC). ET has evolved directly from this work:
+ The idea for 3G GW detectors was explored in the FP6-I3 initiative ILIAS (2004-2008, GA 506222);
+ An Exploratory Workshop funded by the European Science Foundation (2005) was the starting point for the successful conceptual design study “Einstein Telescope” (2008-2011, GA 211743);
+ The underground and cryogenic enabling technologies were further developed in FP7-IRSES ELiTES (2012-2017, GA 295153), an exchange of scientists between ET and the Japanese KAGRA collaboration;
+ Essential R & D towards ET was supported by the FP7 ERANET ASPERA-2 (2013-2016);
+ We have trained the ET generation of scientists in FP7-ITN GRAWiTON (2014-2018);
+ The recently started H2020 I3 Initiative AHEAD2020 (GA 871158) further develops the multi-messenger astronomy scenario with ET.

7.3 Describe how the implementation of your RI was tested and found feasible and summarise the main findings concerning the implementation from the design (or feasabilty) study report (-s)

Detector technology
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 (see B1.7). Following the publication of the design report, further feasibility studies funded by European and national research programs (see C7.2) 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. These outcomes were used for the cost estimates of civil engineering reported in section C11.

7.4 Concerning the Technical Design Report (TDR), describe if all the relevant technologies are available or if and how much Research and Development (R&D) is needed in order to assess the full technical feasibility and draw a cost-book

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, ETpathfinder, 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 2035. A draft cost book is provided in C11.2.

7.5 Describe whether the industrial capacity for the implementation (construction) and operation is already in place (EU or international market) or whether it needs to be developed in relation to your RI, e.g. spin off companies, joint-ventures

Construction
A very large fraction of the industrial capability needed to realise the ET infrastructure and observatory is already available. Through the Virgo and GEO600 interferometers, the European industrial and research system developed the know-how and capabilities to implement ET. For example:
+ The large Virgo civil and technical infrastructure was realised by an Italian company;
+ The GEO600 and Virgo detectors components were provided mainly by European industries and research labs;
+ High-power lasers were produced in Germany (MPG, LZH), seismic suspensions conceived in Italy (INFN, Galli & Morelli) and the UK (Glasgow University) and seismic sensors in the Netherlands (Nikhef, Innoseis). Many of these components were adopted by GW infrastructures in the US and Japan;
+ International companies provide key components like optical metrology (Zygo);
+ The ET e-infrastructures are within the reach of current industrial capability, comparable to the large infrastructures for HEP already hosted in Europe;
+ Silica optics for ET high-frequency (HF) interferometers can be sourced in Germany (Heraeus), and their optical coatings are uniquely realised by a French laboratory (LMA-CNRS).

The low-frequency interferometers require silicon optics, for which currently available substrates and coatings are not yet compliant with ET requirements, and a new R & D activity with industry partners is the central theme of the recently funded ETpathfinder and E-TEST projects.

Useful for the cryogeny in ET will be one of the most sensitive cryogenic tiltmeters ever realized, under development at the underground low seismic noise SarGrav laboratory in Sardinia.

Operation
Industrial support services for the operation of ET (maintenance, upgrades) are in place or will be in place as a result of the construction phase.

7.6 Elaborate on the business case of your RI effectively linking the described scientific case, funding commitments, user strategy, access policy and Cost-Benefit Analysis (CBA) demonstrating the long term sustainability of the operations of your RI and explain whether and how this business case has already been reviewed

The realisation of a detailed business plan is one of the target of the preparatory phase and it will be necessary for achieving long-term sustainability of the RI. Hereafter we draft the key elements.
Value creation: ET will create a monumental scientific value thanks to its scientific potential above described. The multidisciplinary aspects of the ET targets are a key element of its long-term sustainability. In fact ET is promising new achievements in several sectors of astrophysics, nuclear and fundamental physics, cosmology covering a large and rich portfolio of targets. Furthermore, ET will create a great technological value in several sectors, like optics, laser technology and photonics, quantum technologies, material science, geophysics, computing science and system controls. This variety of targets will allow the scientific and technological sustainability for decades.
Financial plan: it has to be defined in the preparatory phase, but its sustainability is related both to the excellent scientific impact and to the clear socio-economic impact of the RI. The great scientific impact attracts the interest of a large community of scientists and then of the RFOs and RPOs. The human resources needs will be largely covered with the contribution of scientists and engineers belonging to these institutions. The clear socio-economic impact is attracting the financial resources of the national and (relevantly) local authorities that have access to national and regional funds (structural funds, Recovery funds, ….) . ET is planning to access to these funds as relevant component of its financial plan. Long term sustainability is also related to the relatively cheap cost of the maintenance of the RI, due to the specific characteristics of a GW observatory (with respect to other large RI).
Stakeholders engagement: ET is a crucial enterprise of the global GW community, fully committed to the realisation of this RI. But its multidisciplinary nature engages also stakeholders belonging to neighbouring communities (astronomers, cosmologists, geophysicists, particle physicists, …). National and regional authorities are obviously involved as political stakeholders.
Risk management: Risk management in ET is strongly moderated by the experience cumulated with the Virgo and LIGO RIs, but a risk plan needs still to be produced.
Data Management: The volume of data produced in ET will be important, but quite moderate with respect to other RIs that will exist in the same period. This will allow long term sustainability in a framework of solutions developed by the “market”. The compliance of the Data Management Plan with the FAIR constraints will allow long term sustainability thanks to the data sharing, preservation and management directives
Communication and outreach: visibility of the RI will be guarantee by an intense outreaching activity. The present experience with LIGO and Virgo will allow to define a successful strategy.
Monitoring: the monitoring of the ET performance will be continuous and transparent. It will be based on well established procedures adopted in existing international RI like CERN, EGO, ….

7.7 Describe your strategy for site selection and for siting. If your RI is single-site, explain how the site was or will be chosen. If your RI is distributed, explain how you have (will) select the headquarters and (national) nodes

ET will be single-sited. After preliminary assessment of various underground sites in Europe as part of the ET CDR, two candidate sites were proposed for the Einstein Telescope: one in the Euregio Meuse-Rhine and one in Sardinia. These two sites are currently under detailed investigation by means of geotechnical surveys, characterization of environmental noise and disturbances, and considering infrastructural and socio-economic criteria. Reports of the site assessment and socio-economic impact will be submitted to the community and to funding partners at the beginning of 2024. These reports will include cost estimates depending on site conditions, and outline the impact of site conditions on instrument design and science potential. The ET community will produce a site comparison evaluation. These reports and the evaluation will be used as input for the final site decision by a group of national governments in 2024 (see also C8.1).

7.8 Elaborate on the (prior) context of the site (-s) of your RI, e.g. a ‘ green-field’, part of a broader plan of site development (including synergetic initiatives, installation in the premises of pre-existing facilities of similar or different scope) and the ‘ value’ transferred to your new RI in terms of infrastructure, services and human resources

No existing underground site provides the space to host the ET detector. GW detectors need to be realised in quiet, isolated contexts; for this reason the approach for both the ET site candidates is to start from an almost “green-field” condition, without parallel development of nearby noisy infrastructures. The presence of a dismissed mine, but still accessible in full safety, in the site in Sardinia is allowing a wide characterisation of the site including the realisation of an underground laboratory (SarGrav) used both to characterise the site for ET, to prepare preliminary infrastructures and to perform precision experiments in gravitation. In the Euregio Meuse-Rhine, deep boreholes are present for characterisation activities. A substantial transfer of technology and human resources will occur from the current GW detectors (Virgo and GEO600) to ET as soon as the ET RI will be realised.

8.1 Describe the detailed planning for your RI as approved within the consortium complementing the timeline provided in PART A by specifying all phases, Work Breakdown Structure (WBS), deliverables and milestones, including investments decisions and possible updates and decommissioning

Design Phase
ET has concluded the conceptual design phase in an FP7-funded design study and more recent grants.

Preparation Phase
The first crucial milestone, expected in 2024, will be the ET site selection. It will be based on various aspects: site customisation of the design of the infrastructures, cost evaluation and financing schemes, site qualification and comparison, local funding support. The ET community plans to deliver for this phase two site qualification reports, two specialised underground and surface infrastructure projects, two cost evaluations and two funding scheme reports. For a project of this magnitude it is evident that the selection of the final site will be decided by the involved national governments or an ET (interim) Council with representatives of the governments. The ET community will suggest a site selection procedure, e.g. on the basis of bid books and including an evaluation by a group of independent international experts without conflict of interest.
As soon as the site is selected, the preparatory phase can be carried out in full extent: the final sharpening of the technical specifications of the infrastructure will be completed, including the underground RI design (a crucial asset of ET), surface RI design (technical and civil infrastructures located on the surface, (close to the corners of the underground facility), the detector specifications and costs evaluations. We will start from the preliminary design of the selected site to evolve towards the definitive design and the operative design, needed to launch the excavation of the underground infrastructure.
Throughout the preparation phase we will assess global GW science priorities and optimize the ET detector topology accordingly. The initial detector design will be updated based on the RI design and progress of ongoing R & D into ET enabling technologies.
In this phase the governance scheme will be final and the new RI project will acquire its legal status. Land acquisition will take place. We will work on permission requests and tender procedures. Very important are the communication management and user policies.
Milestones: Site decision (Q3 2024); investment decision(Q1 2025); land acquisition (Q1 2027).
Deliverables: Site selection documents (Q1 2024); RI-TDR (Q1 2026), detector-TDR (Q2 2026), governance scheme and legal status (Q1 2025).

Implementation Phase
The implementation phase will start with the excavation works call for tender opening. These works presumably will span about six years. Civil works on the surface will proceed in parallel. The procurement of the detector components will probably start in 2026 and the installation in 2032, in parallel with the last phases of the RI construction. As ET will be composed by multiple detectors and interferometers, the pre-commissioning and commissioning phase for ET can already partly start in parallel with the installation phase.
Milestones: Start of excavation and construction (2027), handover of underground facilities (2033), start of installation (2032), start commissioning (2035).

Operational phase
We expect to start ET operations in the middle of the 2030s. ET operations will last for decades – alternating periods of data taking with upgrades similar to the way 2G GW detectors are operated now– thanks to the large margin of improvement of ET’s sensitivity allowed by the characteristics of the RI.
Milestones: Full operation (2035), first detection (2037).
Deliverables: Wide range of detections/measurements, data/science outcomes, spin-offs, visitors, awareness, etc.

Updates
ET is designed as a platform for ongoing upgrades in the detector technology. This will be a continuous activity initiated even before ET is fully operational.

Decommissioning phase
Since ET's operation phase will be long, it is difficult to make predictions about the decommissioning phase. ET will develop a surface-based research center that probably will survive the operational phase of the underground infrastructure. Reuse of the underground infrastructure will be an opportunity for the activities such as a research center. In any case the underground tunnels and caverns will be relatively easily secured, because ET will be free from radioactive and chemical contaminants.

8.2 If available, upload a visual illustration of your planning

File: ET-roadmap-Timeline20200902.pdf

8.3 Define the main objectives and tasks of your preparation phase and the aspects of readiness-to-implement within its 2-3 years reach

Site selection
The main objective for the early preparation phase is selecting the ET site and focusing the design on this particular site. The ET community currently considers two candidate sites to host the RI. ET site selection will be based on a mixture of technical, political and financial parameters (see 7.7 and 8.1). To achieve this target, two parallel tasks are defined, the first is qualifying the seismic, geological and environmental characteristics of the sites, the second is building a financial scheme for each site. Site selection triggers a number of technical objectives, such as the completion of the RI technical design, which are partially influenced by the characteristics of the selected site.
Legal entity
A legal entity and governance structure will be established in time for the land acquisition and construction phases.
R & D
Some of the enabling technologies will also be developed in the early phase.

8.4 Explain how your RI will reach the firm decisions for implementation by the involved stakeholders and the financial commitment by a critical mass consortium within the permanence time on the ESFRI Roadmap, i.e. maximally ten years

The existing GW detectors in Europe have been realised in a binational framework; currently the Advanced Virgo collaboration is composed by scientists belonging to institutions of eight European countries. ET joins the institutions and funding agencies engaged in these previous experiences and attracts new ones. A clear milestone in the decision for implementation is the selection of the site (2024); this will define the country/countries more exposed to RI construction and the ones more engaged in the detector construction. The possibility to access regional structural funds or recovery funds will facilitate the financial commitment of the hosting country/countries. The next milestone towards defining the overall distribution of the implementation duties is the formation of the legal entity implementing ET (2025); this step, well within the ESFRI ten years' time limit will mark the beginning of the implementation phase of the underground research infrastructure.

9.1 Describe the project organisation for the preparation and for the implementation of your RI as approved within your consortium with clearly defined skills, responsibilities and reporting line

Until a final legal structure is implemented (see 9.3/9.4), an interim governance structure is necessary. For such a 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 9.2. 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.

9.2 Upload an organisation chart of the project organisation for the preparation

File: ET-Governance_CB-v2.0.pdf

9.3 Outline the governance for operation with clearly defined responsibilities and reporting lines, including all bodies, senior managers, Supervisory and other Advisory Boards such as a Ethical Board - if appropriate

Since the start of the operational phase is foreseen at the earliest in 2035, 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 –n oteworthy 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.

9.4 Elaborate on the chosen or preferred legal structure, how you intend to implement it with particular attention to the transition from the project organisation to the (final) governance

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 [see 9.1].
The final legal structure must be in place before the start of the actual ET construction and the tendering of the first contracts (in 2026). The ministries will also establish a Working Group with the task of drafting ERIC statutes in line with the Guidelines.
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. In the transition phase we will manage all the formal aspects for personnel and properties.

9.5 Describe the managerial skills and competences – including scientific - needed for the preparation, implementation (construction), operation and termination of your RI and how you will recruit them

The organization structures discussed in C9.1/9.3 will determine the positions that will need to be filled to establish and operate ET. As ET has been conceived by the international GW community that is already involved in multiple 2G GW and complementary observatories, it can rely on long-term experience, best practices, and experienced staff to determine the knowledge, skills and abilities needed for each position. Recruitment will target said international community via transparent procedures. A complex recruiting plan will be realised, considering the initial phase, where the ET legal status is still not defined and the final phase, when ET will have a legal status definition. In the first phase, we will profit of the personnel already recruited in the 2G facilities.

9.6 Identify all measurable and credible Key Performance Indicators (KPI) for both the scientific case as well as the implementation case in all phases

Scientific case
+ Design/Preparation/Construction phases: number of publications about ET science potential, number of researchers publishing on the ET science potential, number of researchers in the ET consortium, citations of the publications about ET science potential.
+ Operation phase: numbers of publications using ET data, number of researchers using ET data, citations of the publications using ET data, number of researchers in ET consortium, ET sensitivity with respect to the anticipated design sensitivity, duty cycle, number and SNR of GW sources with respect to anticipated ones.
+ Termination phase: numbers of publications using ET data, number of researchers using ET data, citations of publications using ET data, number of researchers in ET consortium
Implementation case
+ Design/Preparation phases: number of persons working in this phase, budget available, documentations available, number of internal reviewers and FTE used to review the design documents, number of external reviewers and FTE used to review of the design document, environmental impact.
+ Implementation phase: number of persons working in this phase, budget available, budget contingency, time contingency, number of internal reviewers and FTE used to review the implementation documents, number of external reviewers and FTE used to review the implementation documents, environmental impact.
+ Operation phase: number of persons working in this phase, budget available, sensitivity of the instrument with respect to the anticipated design sensitivity, duty cycle of the instrument, environmental impact.
+ Termination phase: number of persons working in this phase, budget available, budget contingency, time contingency, environmental impact.

9.7 Describe your plans for the independent scientific monitoring and evaluation of your RI when in operation

The ET Council (whether ERIC or otherwise) will set up an independent Scientific and Technical Advisory Committee. This Committee shall at least annually evaluate the scientific, technical and strategic performance of ET in its various phases and formulate recommendations on progress and future technical, scientific, and strategic goals and opportunities. The evaluation committee will use proven evaluation procedures such as used by national funding agencies or EIRO facilities like CERN. An independent Ethics Committee will monitor and advise the ET Council on ethical issues and values as described in a Code of Conduct and Ethical Behavior.

10.1 Describe how your RI will help European scientific communities' mobility and internationalisation, i.e. link your access policy - particularly the excellence-driven access mode - to your (scientific) human resources policy

The ET access policy will comply with the European Charter for Access to Research Infrastructures. Its implementation descends from the successful and well-established access model adopted for the present worldwide GW detectors network (see 4.6). Excellence-driven access mode (to data or to the instrument) could be facilitated by competitive calls. To guarantee a high quality, the applications are reviewed by a selection committee of internal and external scientific and technology experts. The appointment of experts is the task of the ET Director. A transparent and documented procedure must provide an equal level playing field for nominations resulting in a diverse committee with in particular about 50% women. Secretarial and administrative support of the reviewing committee will be provided by the ET project office.
The access model enhances internationalisation automatically, since wide access and participation is guaranteed by its open and inclusive nature which does not limit applications to the ET Collaboration and in particular allows and encourages groups and individuals from countries with less budget for GW research to participate.
Education in ET science, training in the use of ET tools and project management, and dedicated ET fellowships will attract excellent people and further enhance competences and thus mobility of individual scientists and engineers, in particular the early-career scientists among them. Scientific and technology training and education will be organised by experienced researchers and engineers in the collaboration, e.g. during topical workshops. On-site training in calibration, commissioning and detector characterisation will further enhance skills. External companies will be hired for training in cultural and personal development. Also for training in science communication, outreach skills and awareness of unconscious bias, external companies will be hired.

10.2 Describe the approved staffing plan for the preparation - and if able for the implementation (construction) - of your RI, i.e. the skills and competences needed and how they will be recruited

Embedded within the ET organizational structure (see section C9), a project management structure will be established that resembles that of other large RIs in (astro)particle physics. A technical project manager (TPM) will be appointed, who will form a team with the scientific leader of the ET Collaboration. The TPM must have proven competencies in leading large technical projects in a scientific environment, such as large infrastructures for astroparticle physics (e.g. LIGO/Virgo), particle physics (e.g. CERN) or space research (e.g. ESA). The TPM will have executive power and head a project office consisting of a project engineer, a civil engineer, a manufacturing engineer, a cost and schedule officer, a safety and QA/QC manager, a communication and outreach officer and administrative and secretarial staff. These competences will be sought in the collaboration and if necessary externally hired. The TPM and the staff in the project office will be recruited using transparent and documented procedures to ensure a diverse team. In particular, the goal is to staff the project office with 50% women. For continuity the TPM will be appointed for the full duration of the preparation and construction phase. The scientific leader will be elected by the collaboration for one or two terms of several years.

The competences of task leaders will be those of experts in the assigned task such as for detector subsystems, site activities, data acquisition, data processing and data analysis and simulations of detector response. They will be sought in the collaboration via transparent procedures with the goal of 50% women and 20% early-career scientists and engineers at the second management level.

For the preparation of an application for legal status such as ERIC, legal experts will be hired from specialised companies. A dedicated person in the collaboration will coordinate the process and provide the link between the companies, the ET Council and the ministries.

10.3 Outline the human resources policy for the operation of your RI, i.e. skills and competences needed, hiring, equal opportunities, secondments, education and training of staff and users

For the operation of ET, a large staff of scientists, engineers and technicians will be hired at the site. Several technical departments will be present (such as civil infrastructure, vacuum and cryogenics, optics, electronics, safety). A site manager, typically an experienced ET scientist, will coordinate the on-site operation and people seconded to the site of the ET detector for long-term support of the daily operation of the ET detector will join the project office.

The ET Learning and Development policy comprises a strategic program of training and educational activities. It comprises (on-site) training of safely operating the detector by internal experts, workshops organised by experienced ET scientists for education in ET science and technology and the use of ET tools and training by externally hired experts on competences such as cultural development skills, and communication. Early-career scientists will be offered additional training of skills like project management and personal development skills, also provided by hired external experts.

A Code of Conduct and Ethical Behavior for the Collaboration defines its values and the rules at the workplace. Monitoring compliance with the Code is the mandate of an external Ethics Committee that reports to the ET Council.

A policy plan for Equality, Diversity and Inclusion (EDI) defines measures and performance indicators for staffing the project office and appointing persons in leadership positions. In particular for leadership positions the goal is 50% women and 20% early-career scientists. The ET Collaboration will cooperate with other large research organisations to improve diversity and in particular gender equality at scientific conferences.

11.1 Complementing the estimated costs as provided under PART A, describe the top-level breakdown of cost elements with overall order of magnitude estimates for all phases, including – in case of a distributed RI - for Central Hub, National Nodes and main upgrades. Please indicate the confidence levels of your estimates for each element. Please indicate if they are based on suppliers' quotations

The investment cost of the ET project, split over the different project phases, is summarised in PART A; a preliminary, but more detailed cost description is uploaded in C11.2. Hereafter a top-level breakdown (VAT excluded) is described for each phase of the project. Cost estimate accuracy is 10% with the exception of the civil engineering costs, which we assign a 15% margin.

Concept development and design phase [5 M€]
The conceptual design phase is completed.

Preparation phase (PP) [171 M€]
The preparation phase is composed of many activities of different nature. We already started a preliminary PP addressed both to the selection of the best site and to the development of the technologies. National investments are used to qualify the two candidate sites through seismic, environmental and magnetic noise measurements both on surface and underground; borehole excavations and available mine adaptations are ongoing. The investments in these activities are already partially committed and amount to about 16 M€. Technology development is the most expensive fraction of the preparatory phase, amounting to about 95 M€ over ten years. Completion of the project documentation needed for the implementation phase (legally defined in civil engineering projects as "preliminary project", "definitive" and "operative project") by specialised external companies is estimated at 38 M€. Land acquisition, setting up the governance and the ET legal entity and other management activities constitute the remainder (22 M€) of the indicated budget.

Implementation phase (IP) [1736 M€]
In the Implementation phase, both the infrastructure and detectors will be realised. The main cost for the ET infrastructure will be excavation of the tunnels and caverns. We estimate the excavation cost, described in the preliminary cost book, based on the evaluations of two major companies interrogated on similar designs. The infrastructure is completed by technological facilities (ventilation, services, etc.), surface buildings and roads. The excavated land treatment, civil works direction and contingency (normal for tunneling) is included. The overall evaluation of the infrastructure cost is 932 M€. The second leg of the implementation phase is the realisation of the detectors; the main cost in the realisation of the detectors is the vacuum system (566 M€); then we have cryogenics, suspensions, lasers, optics and integration costs (238 M€). The overall estimate, for this second leg, is 804 M€.

Operational phase [37 M€/year]
For the operational cost estimate we studied, scaled and adapted the cost components of the largest astroparticle physics underground laboratory in Europe (the INFN Gran Sasso Laboratory) and of the largest European GW detector, Virgo. It covers costs for electric power, maintenance, safety, administration and personnel. Offline computing costs are excluded.

Decommissioning phase [40 M€]
The decommissioning cost is difficult to evaluate in detail, since the ET infrastructure can remain in operation for about 50 years. A rough evaluation is made considering the need to dismantle the main components of the detectors and the facilities, and the need to guarantee the safety of the closed site. Additional considerations on the cost evaluation are in the cost book, in C11.2.

11.2 Please upload your cost models and cost-book analysis, if available

File: ET Cost Book-20200902.pdf

11.3 Describe the essence of your investment plan – in terms of current level of financial commitments, the (conditional) intentions to (co-) fund the implementation (construction) costs and access, site-premium and kind of formal investment commitments (in cash and/or in-kind), the plans to fund operating costs - and to what (sub-) set of stakeholders you have presented your investment plan

According to the current ET costs evaluation, a large fraction of the cost is due to the excavation cost and to the RI's realisation and notably its vacuum system. It is obvious that the commitment scheme cannot be independent of where ET is hosted. The common design of the infrastructure, supported by a fraction of the committed budget, must be differentiated for the two candidate sites to host ET where geology and orography are different. The current commitment of the participating countries and institutions is then mainly focused on the technical design and on the preparation phase, where important actions to qualify and select the site, to build a common governance and to form the ET legal entity are needed.

For the construction phase, the ET community expects that the excavation costs will be mainly supported by the hosting country or countries. The site implementation and detectors construction will probably be supported by a mixture of in cash and in kind contributions of the supporting countries and institutions; the proportions between in kind and in cash will be strongly affected by the legal status decided for the ET governance.

Operation costs will be covered in cash by the participating countries, according to a scheme still to be defined, but presumably similar to the ones used for international governmental organisations. In kind contributions will still be used in the operation phase, for major upgrades of the hosted detectors.

11.4 Indicate whether you intend to use other sources of fundings like for example loans of the European Investment Bank (EIB) - or equivalent national credit systems - and use the Access to risk finance under Horizon 2020

For the implementation phase we expect to access to international funding instruments. Depending upon the selected site to host the ET infrastructure, it will be also considered to access the support of the European Investment Bank and its services (like the assistance service Jaspers). In particular, if the site in Sardinia (Italy) will be selected ET could have access to the European Regional Development Fund, to the Cohesion fund and to Recovery funds for the construction of the infrastructure. Interreg funds are and will be used to support developments related to ET.

SECTION 12: RISKS

12.1 Describe the scientific developments or competing projects elsewhere that could affect the research outputs expected from your RI

ET, with its triangular configuration corresponding to three nested interferometers, is designed to have an extraordinary science output even when operated as a single GW detector. Further enhancement of its capabilities exploits synergies with other detectors that could be operating at the same time. The planned US 3G GW detector “Cosmic Explorer” is both an opportunity to strengthen the scientific potential of ET, and a potential competitor for the role of leading 3G GW infrastructure in the world.

ET and the space interferometer LISA target very different sources, because of the different frequency ranges covered. Still, some black-hole binaries could be observed first by LISA and when they merge, 5-10 years later, by ET. Such multi-band GW observations would provide remarkable information.

Flagship initiatives such as the ESFRI-listed CTA and KM3NeT projects and the ESA-led THESEUS project also have the potential of strongly enriching the scientific output of ET.

12.2 Identify the risks (scientific, technological, political, financial, etc.) that your RI could face in the different phases and describe your mitigation strategies to tackle them

Preparation phase
In preparatory phase the first risks come from the underestimation of the RI requirements that are crucial to allow the ET detectors to achieve their design sensitivity; namely: a) seismic and gravity gradient noise; b) acoustic and other vibrational technical noises. Here, the mitigation strategy consists in: a) detailed qualification of the candidate sites through an intense site characterization activity; definition of stringent site selection criteria; definition of the zone-of-respect requirements; development and certification of noise suppression methods; deeper excavation; and b) implementation of strict design specifications addressed to suppress technical noise.
Still in the preparation phase, delays may arise in the land acquisition phase.
Furthermore, delays in the development of some ‘enabling technologies’ can pose a risk to the project. To mitigate this risk, these advances over the state of the art are being explored in the KAGRA detector (namely, related to underground construction and cryogenic operation) and a new interferometer for ET-related R & D, ETpathfinder, which is currently under construction and will be fully dedicated to test and validate new technologies for ET not accessible at KAGRA. Finally, the support of ET activities through the existing multilateral organisation EGO/Virgo will decrease the overall risk.
Also, difficulties in the constitution of a suitable ‘political’ organization for the management of the RI could lead to severe delays in the project.

Implementation phase
In the Implementation phase, any problems in the underground infrastructure construction, both technical and financial, for example due to a discontinuous availability of funds, would lead to serious delays in the construction of the RI. To mitigate this risk, we plan to optimise the excavation procedure to allow parallel implementation of the technology and services of the excavated tunnels and caverns. Furthermore, even without a full detector suite, ET will generate groundbreaking science.

Operational phase
Difficulties might arise in managing a complex infrastructure. To oversee the smooth operation of the RI, an international committee will be appointed , to study all the past history of management of the current detectors and producing a good-practices handbook and to oversee the regular operation of the RI.

12.3 From the risks identified in 12.2., describe more specifically the main risks that could delay, increase costs of or make the realisation of your RI impossible (maximum 1000 characters with spacing)

The construction of the underground site, of the civil facilities and of the vacuum systems will dominate the total project construction costs and duration; any major problem, both technical and financial, for example due to a discontinuous availability of funds, would lead to serious delays in the construction of the research infrastructure.

Moreover, the ET project represents a challenge exceeding the capabilities of a single national funding agency. For this reason, it will require a supranational organization, with the aim of coordinating the action of many different actors, operating at different levels (political, financial, technical and scientific). This complex organization, which will have to represent the interests of the international scientific community, of national agencies and local stakeholders, will be essential for the success of the project.

12.4 If available, upload a technical options analysis (upload with limit 10 MB, maximum 30 pages)

No file uploaded