Notes on ET and Future Prospects

M. Martinez

(ET steering committee)

ICREA IFAE EXCELENCIA SEVERO OCHOA BIST

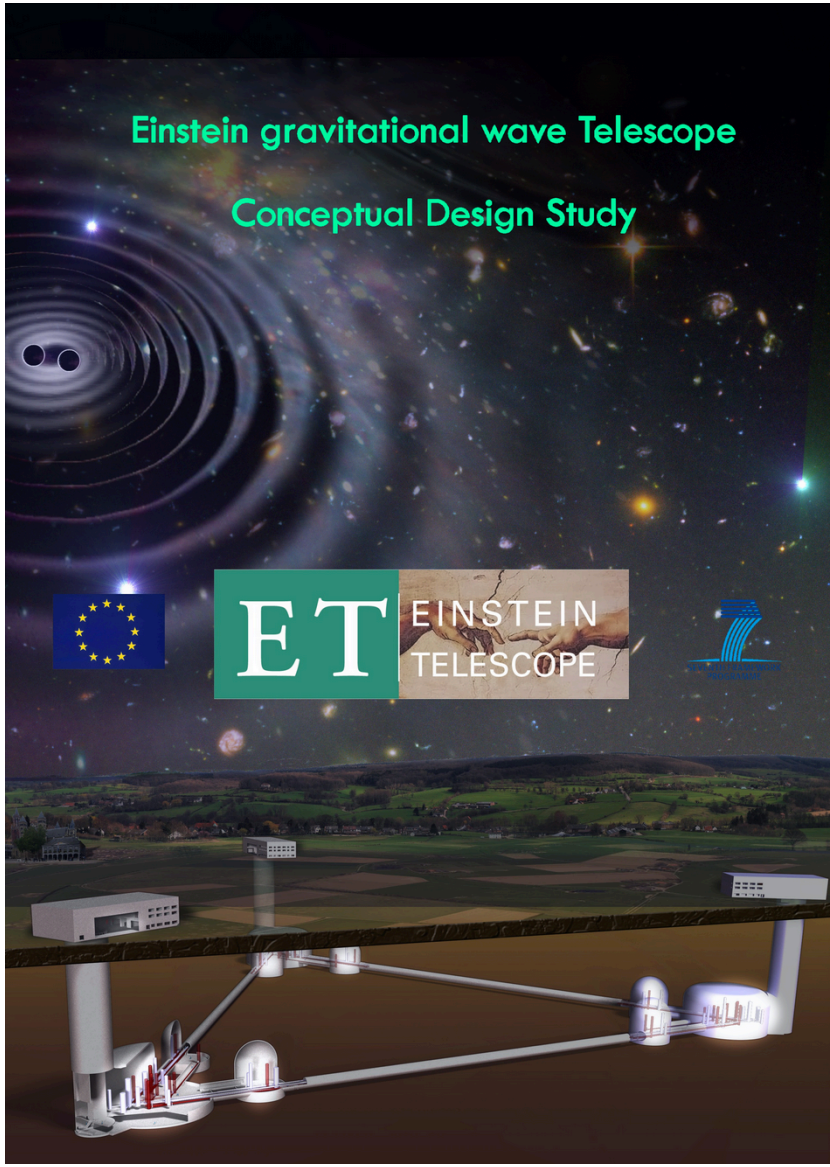
Virtual Iberian GW Meeting

20th October 2020

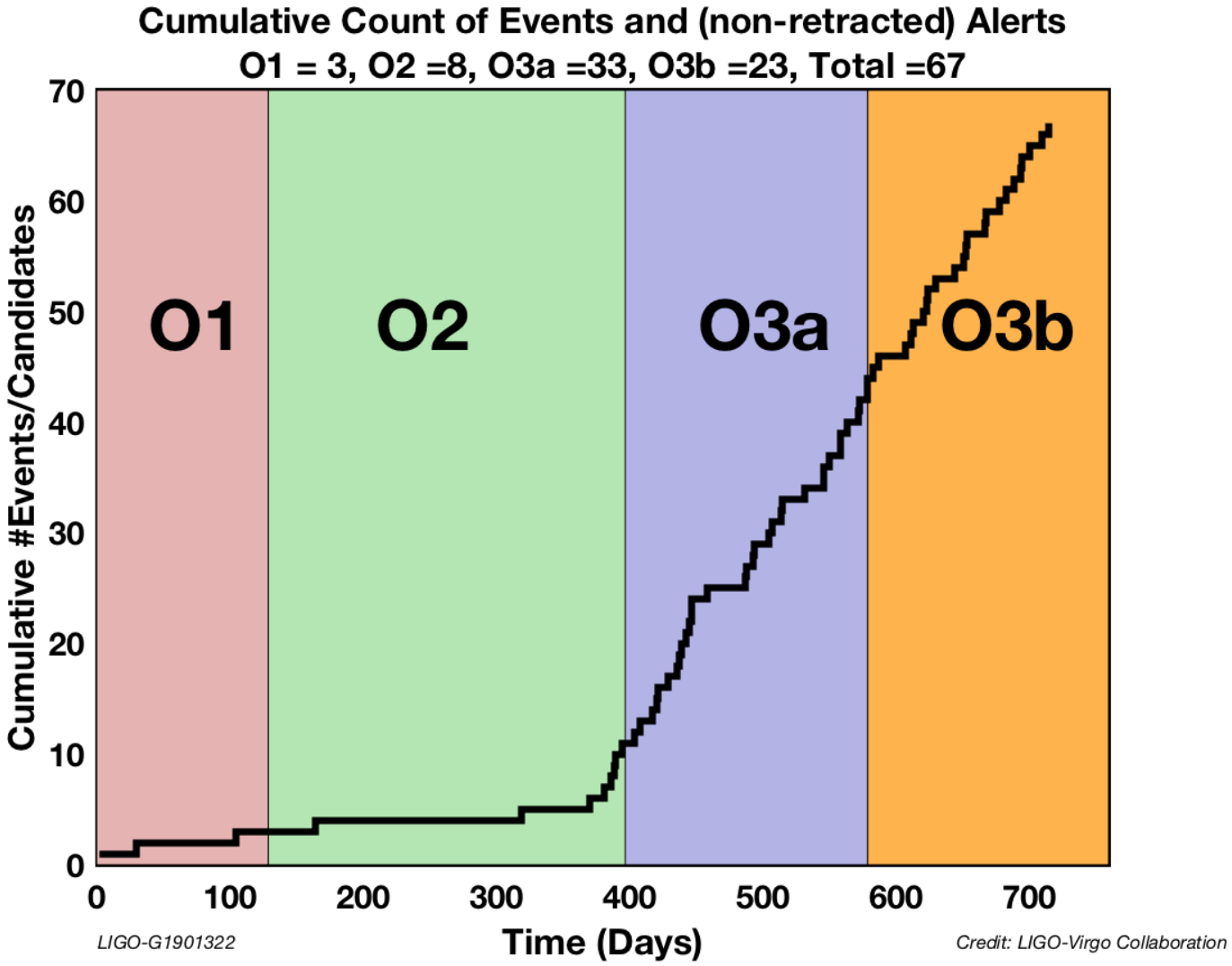
Outline

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

- Short Introduction
  - Timeline
  - Size of the project
  - Sensitivity & Physics potential
  - Technologies
  - Estimated cost
  - Location(s)
- Notes on ESFRI process
- Prospects



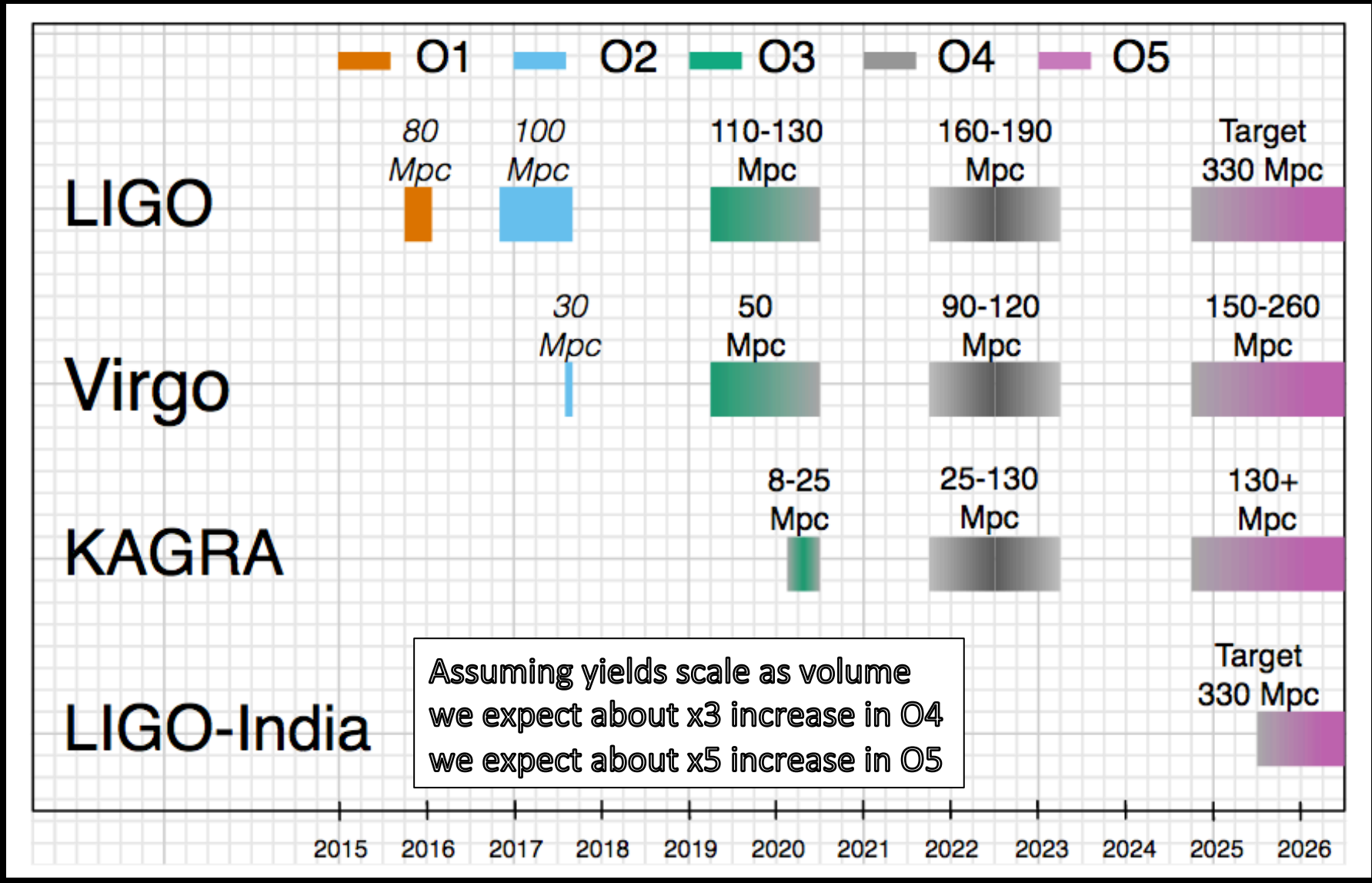
Interferometers



Observation Run	Network	Expected BNS Detections	Expected NSBH Detections	Expected BBH Detections
O3	HLV	1^{+12}_{-1}	0^{+19}_{-0}	17^{+22}_{-11}
O4	HLVK	10^{+52}_{-10}	1^{+91}_{-1}	79^{+89}_{-44}

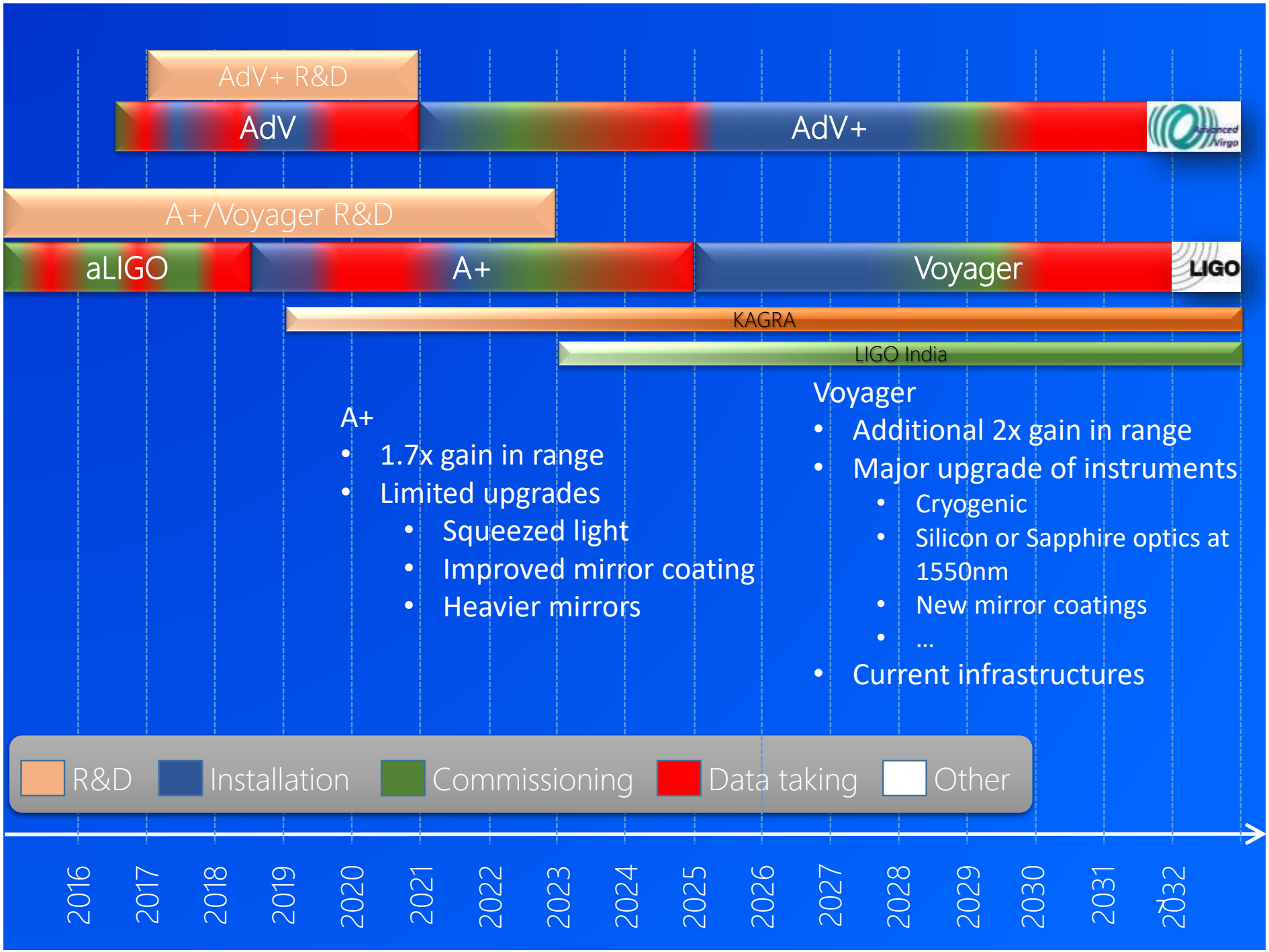
Observation Schedule

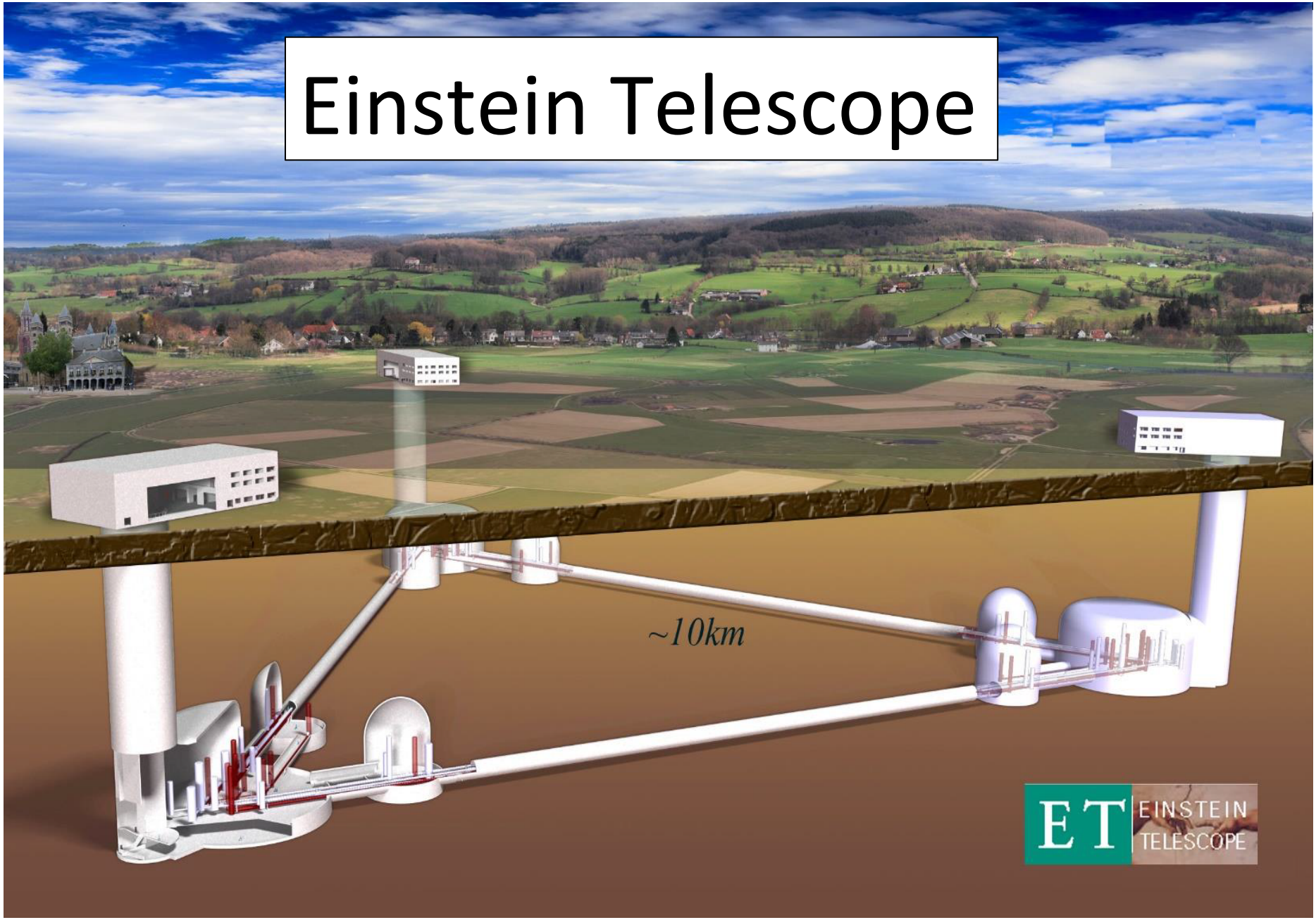
arXiv:1304.0670v10



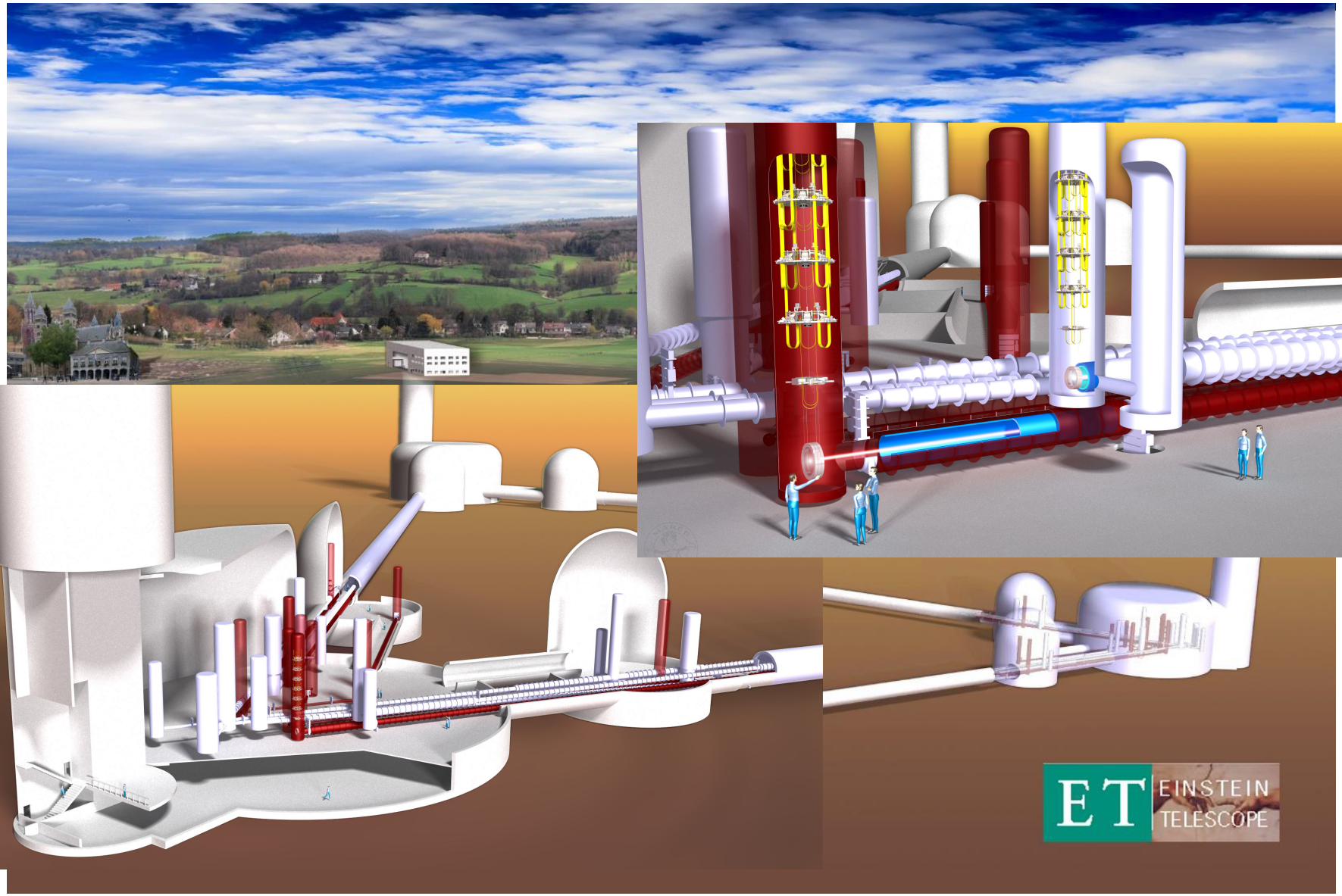
O3 (2019 – 2020) ended ; O4 expected by Spring 2022.

Observation periods 06 - O7 (TBC) will extend the program towards 2030s

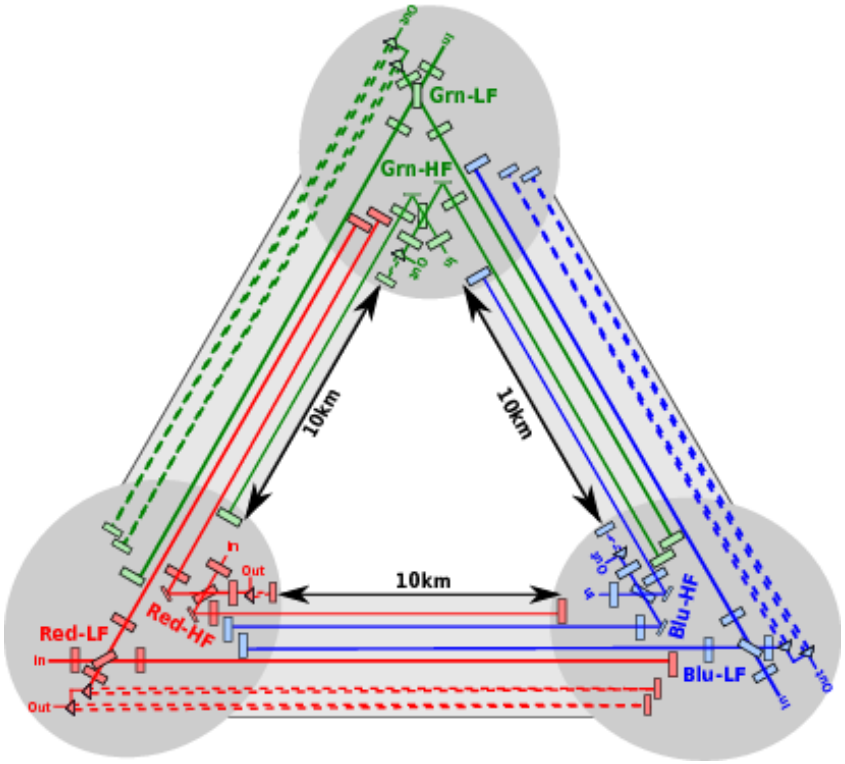

AdV+ R&D
AdV
AdV+
A+/Voyager R&D
aLIGO
A+
Voyager
KAGRA
LIGO India
A+
• 1.7x gain in range
• Limited upgrades
• Squeezed light
• Improved mirror coating
• Heavier mirrors
Voyager
• Additional 2x gain in range
• Major upgrade of instruments
• Cryogenic
• Silicon or Sapphire optics at 1550nm
• New mirror coatings
• …
• Current infrastructures
R&D
Installation
Commissioning
Data taking
Other
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032

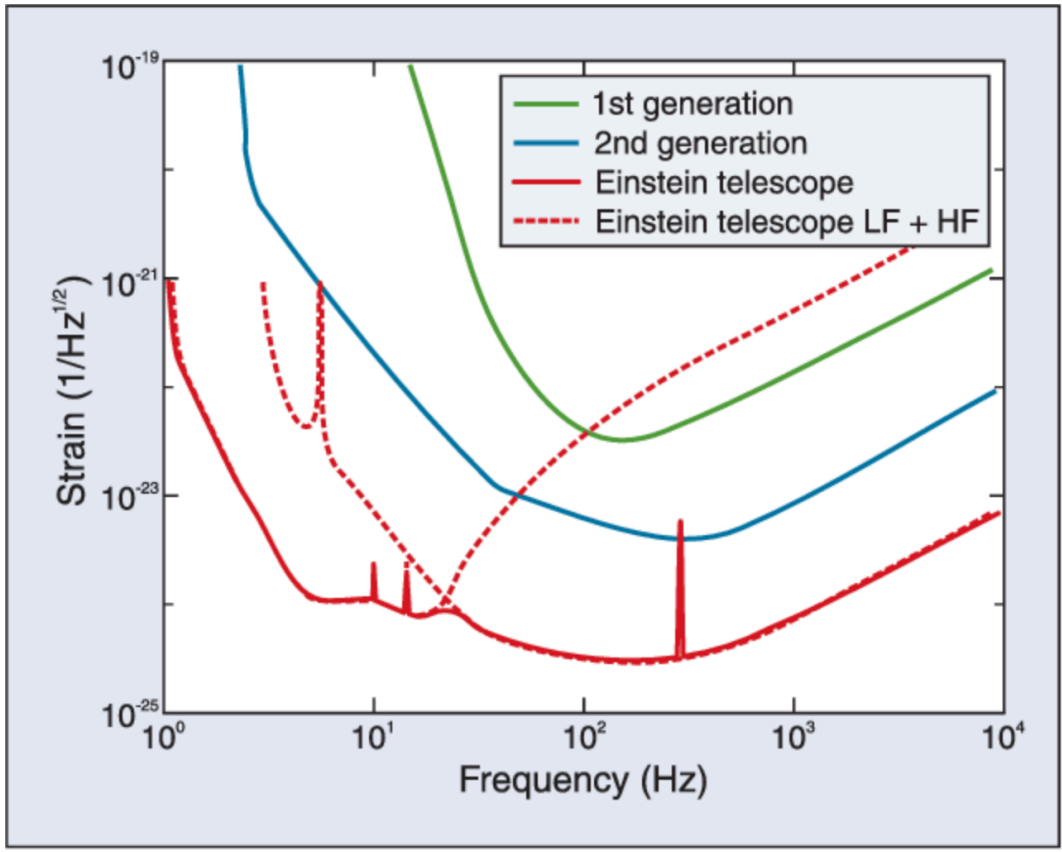

Einstein Telescope
~10km
ET
EINSTEIN
TELESCOPE

Size of Project

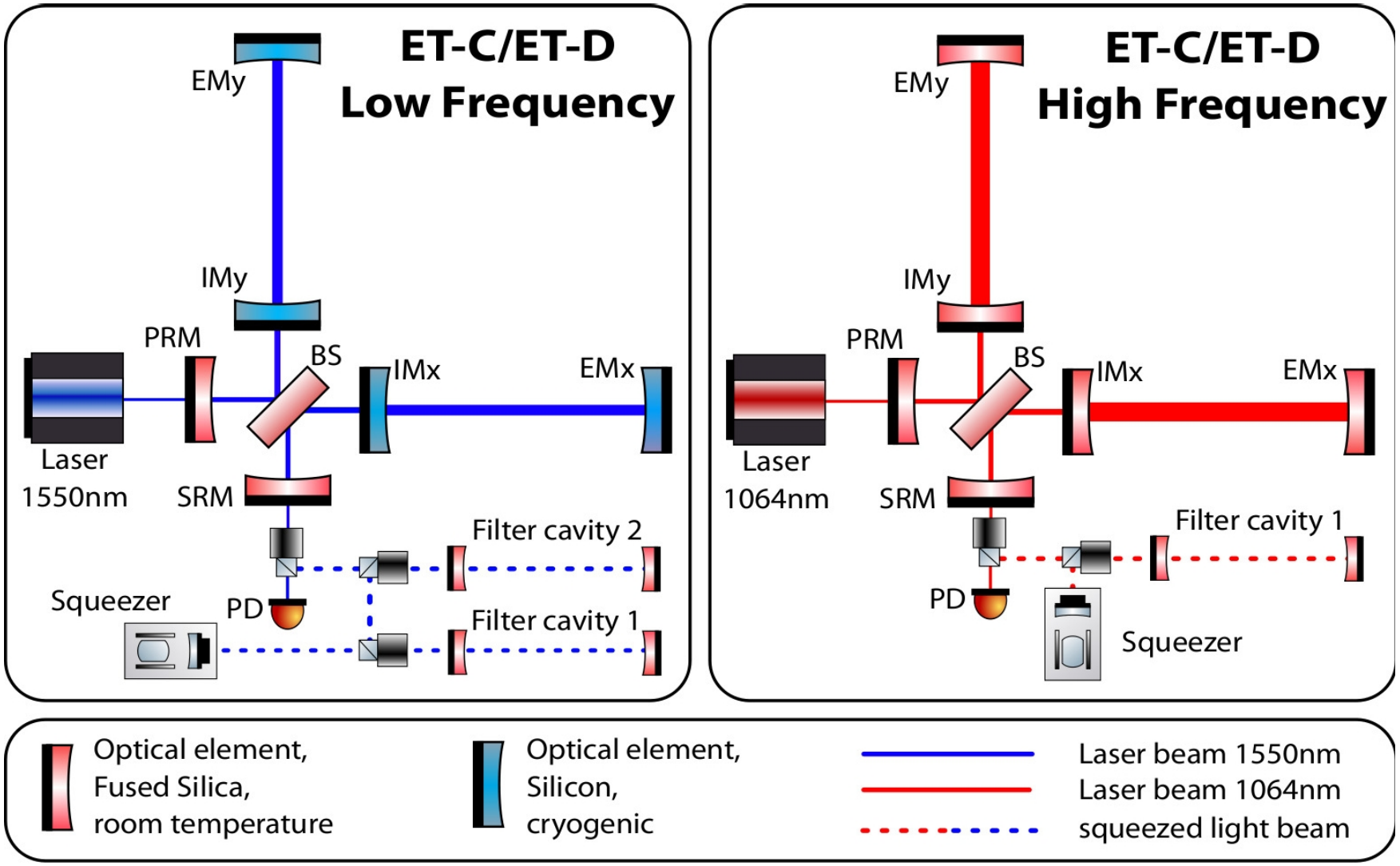


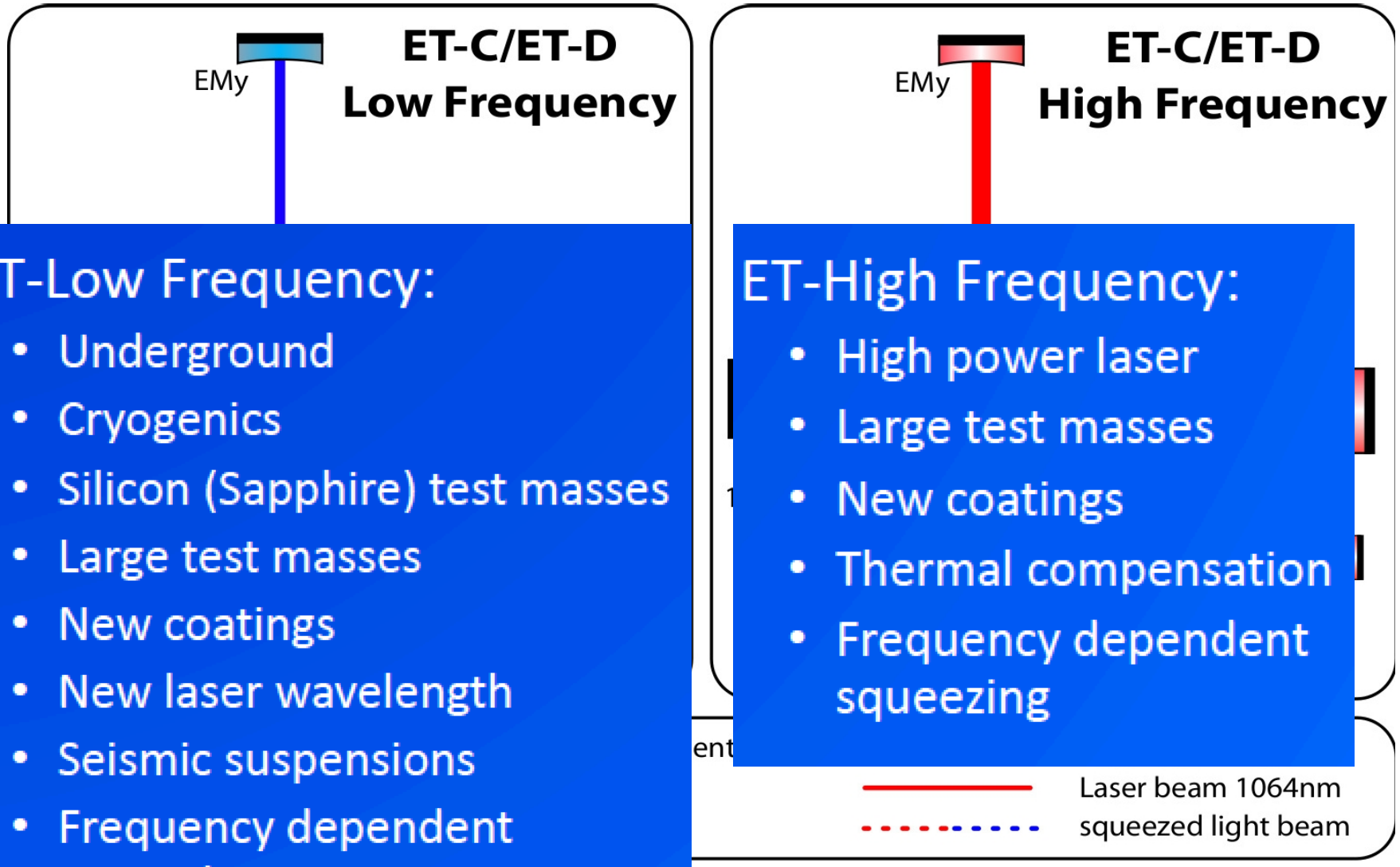
Einstein Telescope (6 in 1) Xylophone



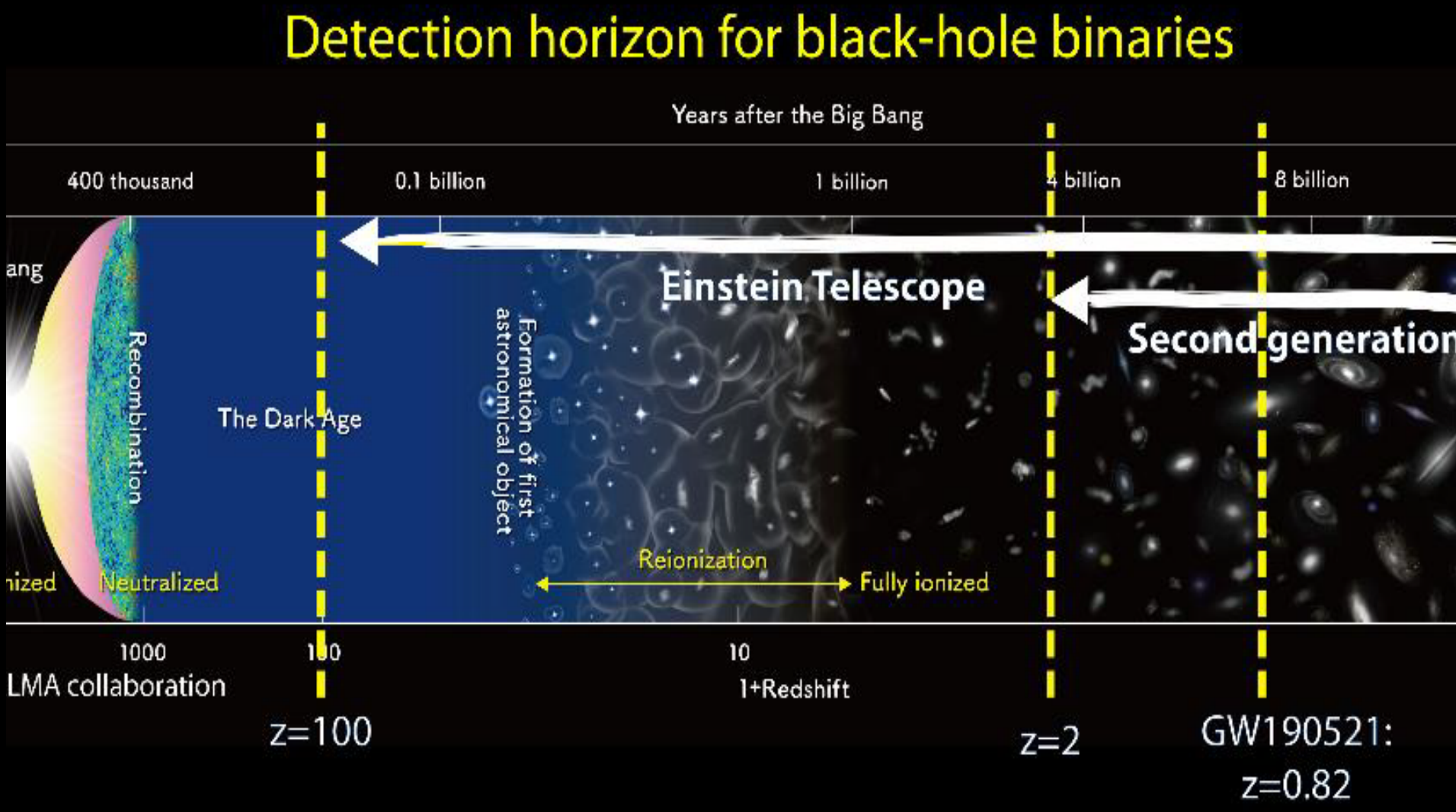


- Underground to bit seismic/newtonian noise
- Longer arms of 10km instead of 3 km in Virgo (4 km in LIGO)
- Triangle configuration of 3 ITFs for measuring polarization and for vetoing on glitches
- Each decoupled in 2 devices for low and high frequency best performance


ET-C/ET-D
Low Frequency
EMy
IMy
PRM
BS
IMx
EMx
Laser
1550nm
SRM
Filter cavity 2
Squeezer
PD
Filter cavity 1
ET-C/ET-D
High Frequency
EMy
IMy
PRM
BS
IMx
EMx
Laser
1064nm
SRM
Filter cavity 1
PD
Squeezer
Optical element,
Fused Silica,
room temperature
Optical element,
Silicon,
cryogenic
Laser beam 1550nm
Laser beam 1064nm
squeezed light beam

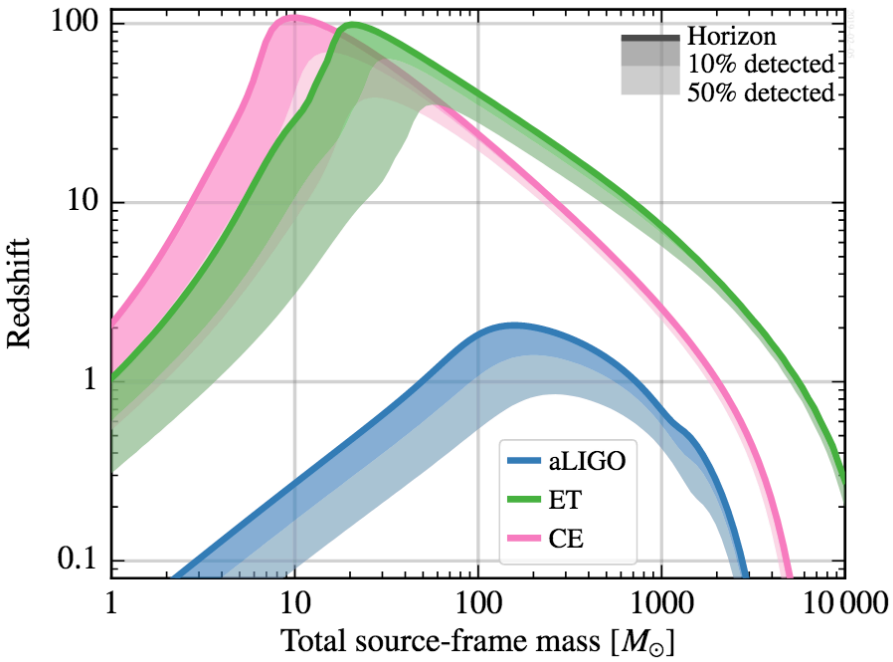

EMy
ET-C/ET-D
Low Frequency
EMy
ET-C/ET-D
High Frequency
ET-Low Frequency:
• Underground
• Cryogenics
• Silicon (Sapphire) test masses
• Large test masses
• New coatings
• New laser wavelength
• Seismic suspensions
• Frequency dependent squeezing
ET-High Frequency:
• High power laser
• Large test masses
• New coatings
• Thermal compensation
• Frequency dependent squeezing
Laser beam 1064nm
squeezed light beam

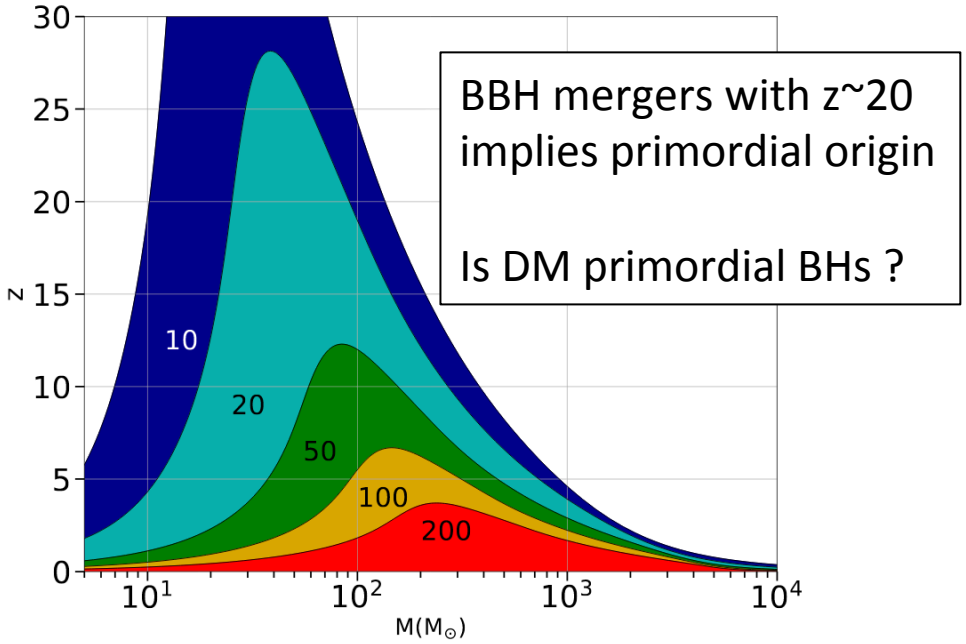
ET reach


Detection horizon for black-hole binaries
Years after the Big Bang
400 thousand
0.1 billion
1 billion
4 billion
8 billion
ang
Recombination
The Dark Age
Formation of first astronomical object
Einstein Telescope
Second generation
Reionization
nized
Neutralized
Fully ionized
1000
100
10
LMA collaboration
1+Redshift
z=100
z=2
GW190521:
z=0.82

ET Science Case

https://arxiv.org/pdf/1912.02622.pdf
https://arxiv.org/pdf/1903.09260.pdf



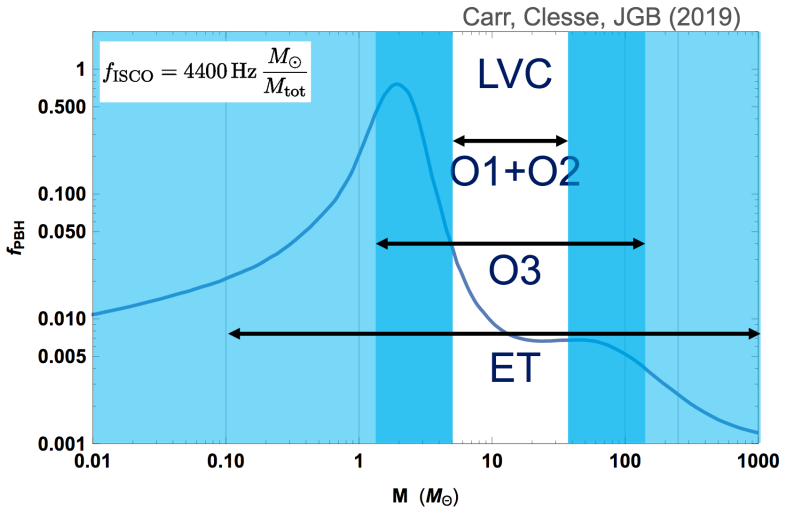


BBH mergers with z~20 implies primordial origin

Is DM primordial BHs ?

- BBH to z ≈ 20
  10^6 BBH/yr
  masses up to 10^3 $M_\odot$
- BNS to z ≈ 2
  10^5 BNS/yr
  (15-50/yr with counterpart)
- high SNR

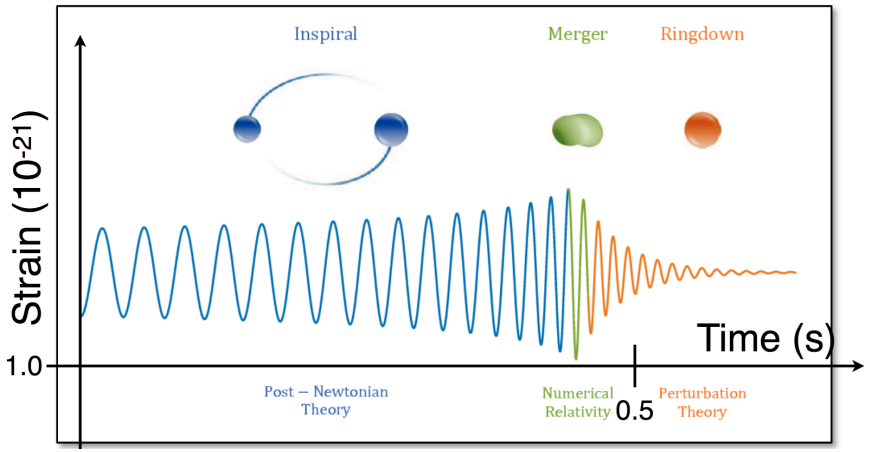
PBH mass spectrum

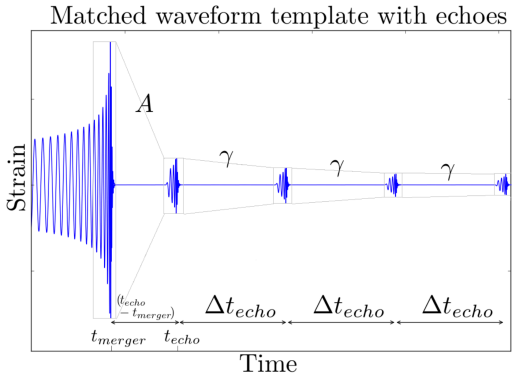


ET Science Case

(focused on fundamental physics)

https://arxiv.org/pdf/1912.02622.pdf
https://arxiv.org/pdf/1903.09260.pdf

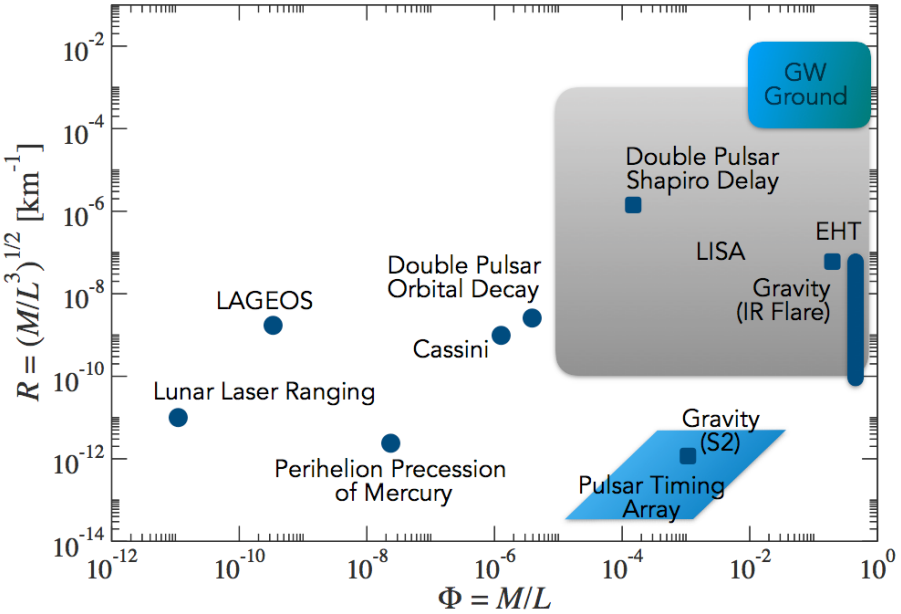


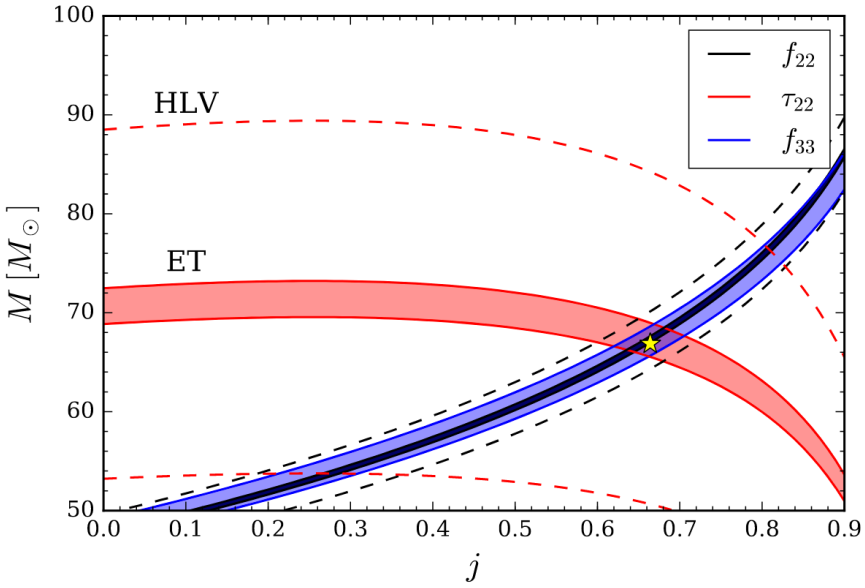


Study of rightdown opens the window for

- Tests of GR in strong regime
- Search for exotic objects
- Access Quantum Gravity effects

Modified inspiral from axion clouds ?





ET Science Case

https://arxiv.org/pdf/1912.02622.pdf
https://arxiv.org/pdf/1903.09260.pdf

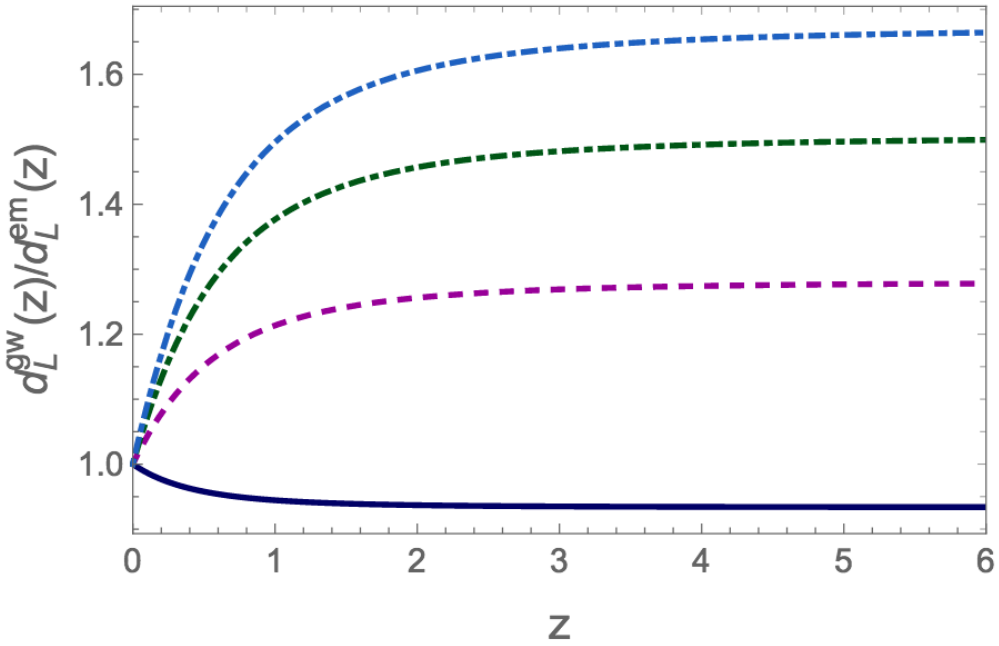
Is dark energy just a cosmological constant, or does the dark energy equation-of-state vary with redshift?

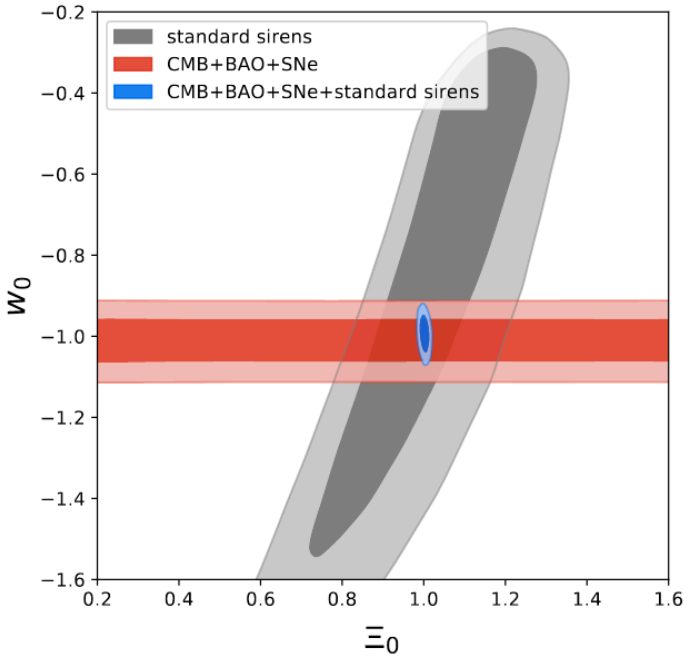
$$d_L(z) = \frac{1+z}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_M(1+z')^3 + \frac{\rho_{\rm DE}(z')}{\rho_0}}},$$

Relation between luminosity distance and z carries information about cosmology

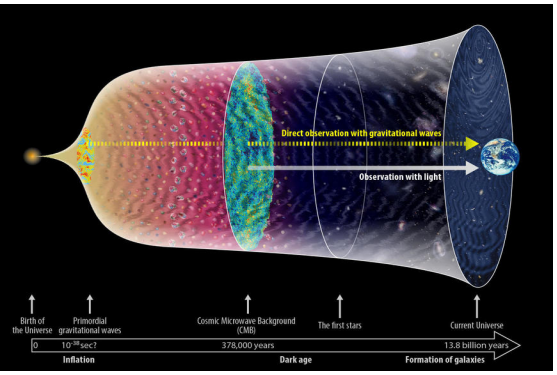
In models with modified GR:

$$\frac{d_L^{\rm gw}(z)}{d_L^{\rm em}(z)} = \Xi_0 + \frac{1-\Xi_0}{(1+z)^n}$$





After few years and collecting few hundreds of BNS events ET can make a stringent test

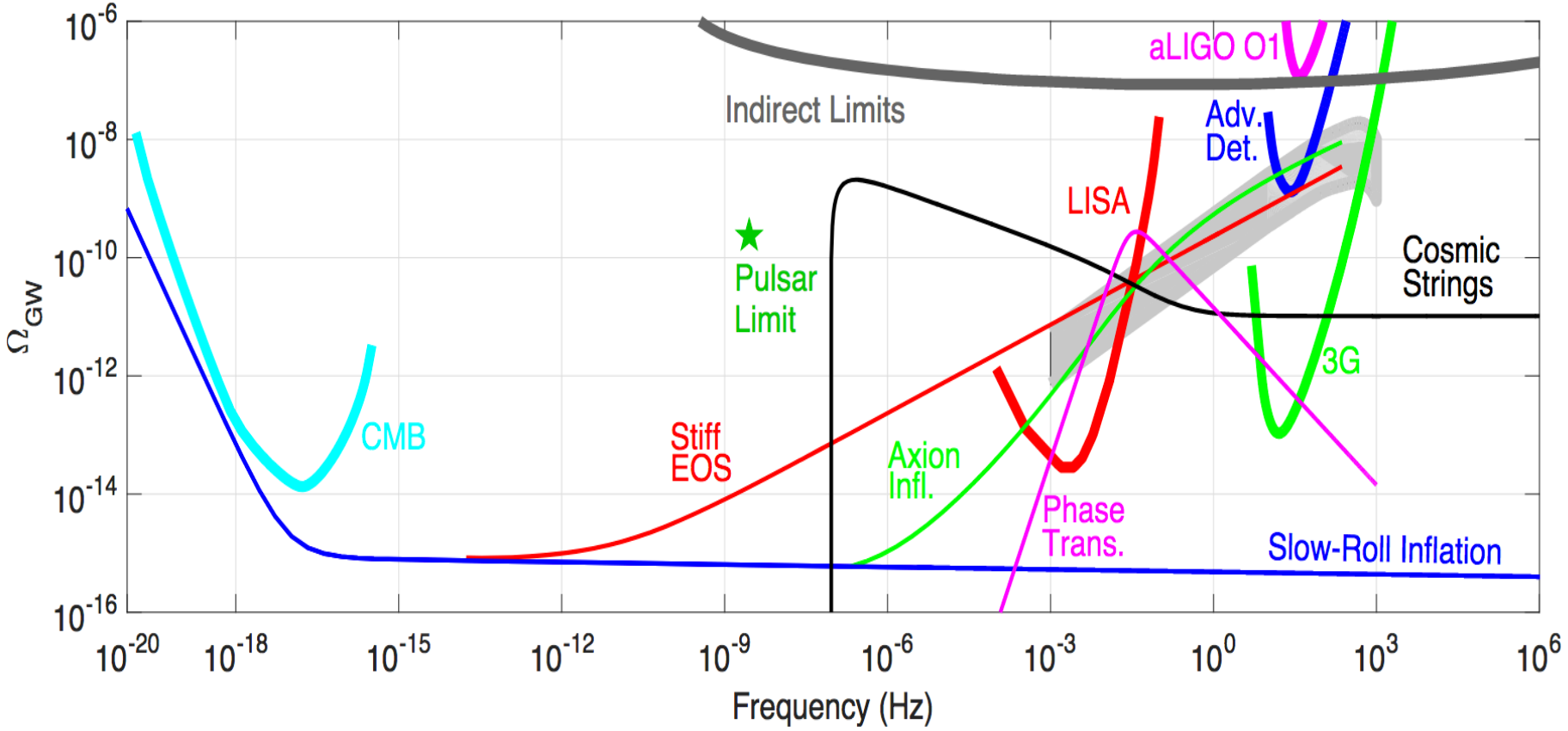


ET Science case

Cosmological stochastic background opens

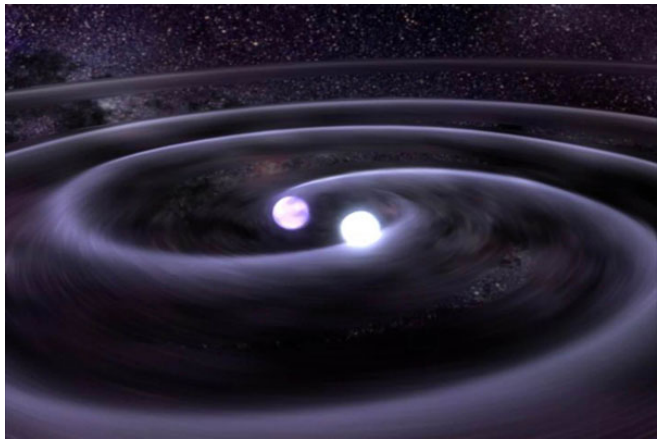
- **Early Universe Inflation**
- **Phase transitions**
- **Cosmic Strings**

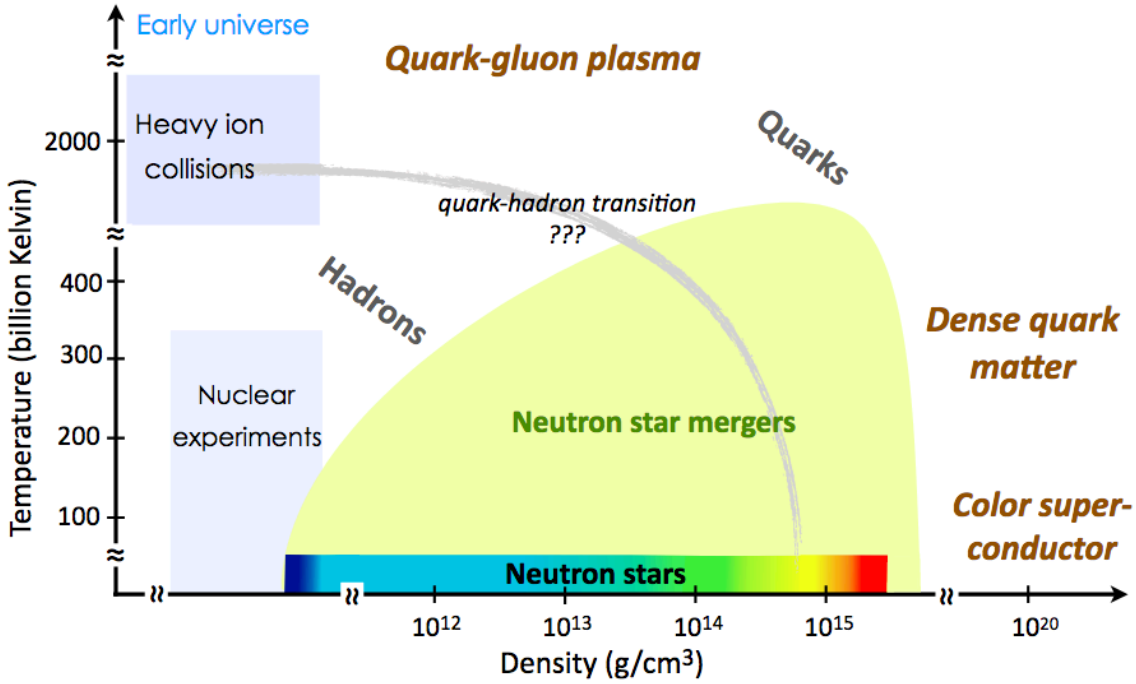
→ Truly HEP essence….

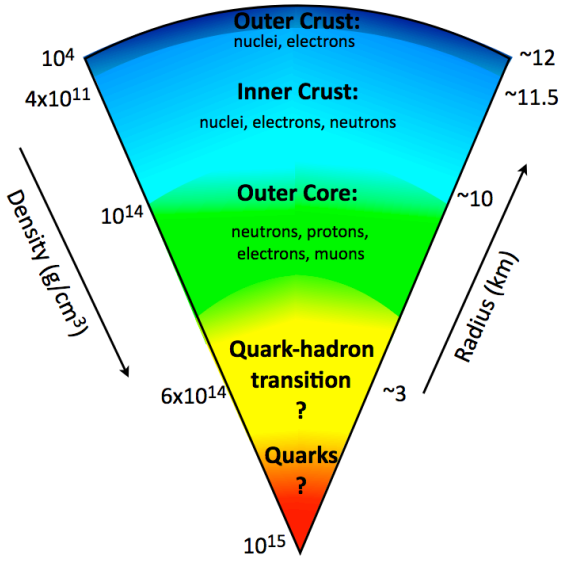


LIGO/Virgo might see the foreground coming from binary mergers soon…

Neutron stars

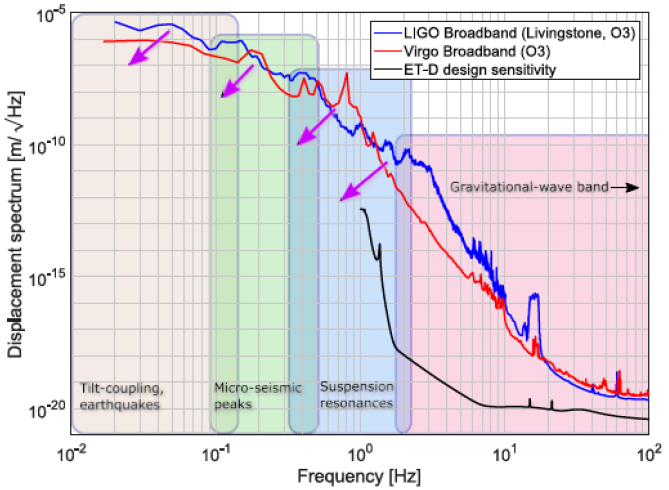






One could in principle access to the EoS of NS leading to studies of QCD in very dense / hot conditions

Updated CDR



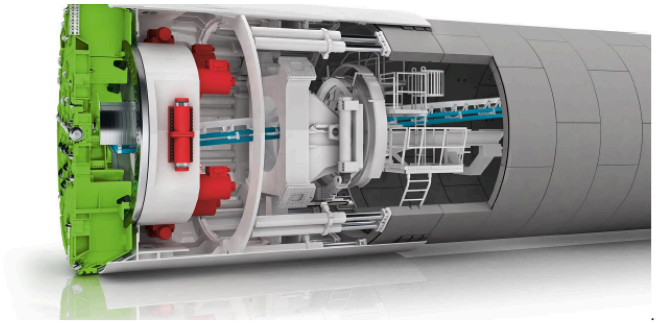
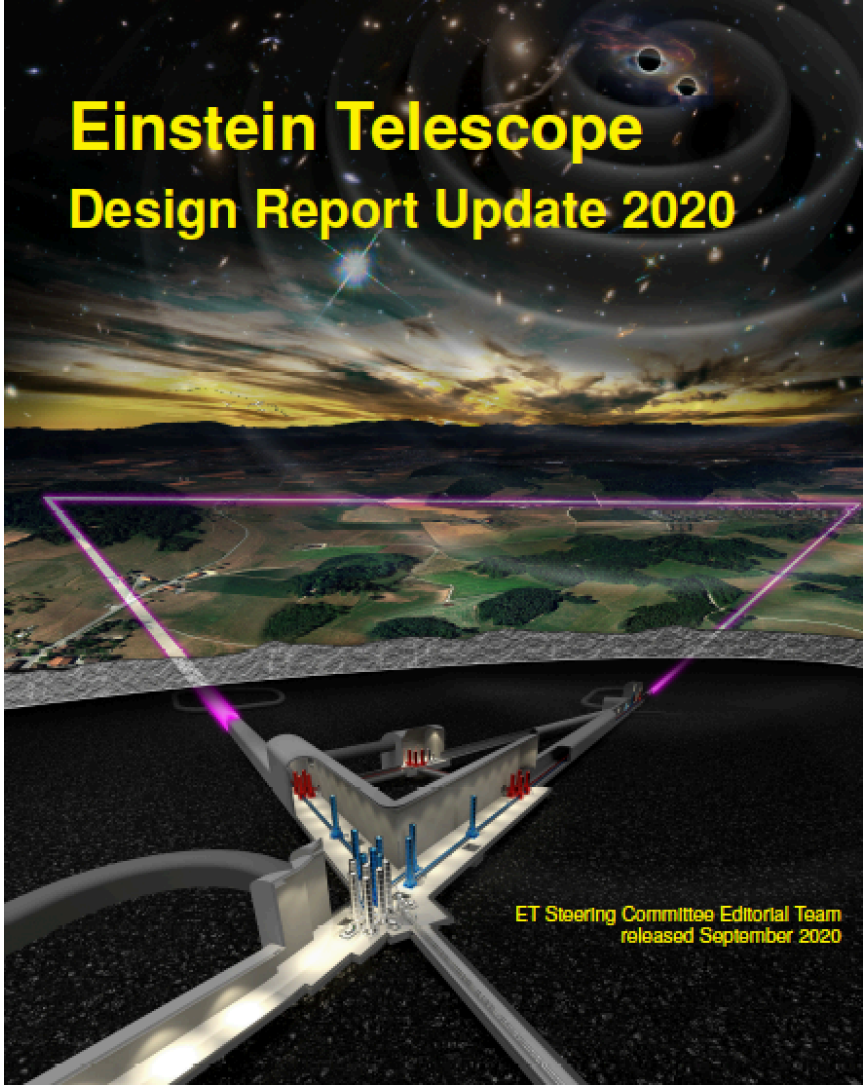


Figure 7.20: Single-shielded tunnel boring machine.
Source: *https://www.herrenknecht.com/en/products/productdetail/single-shield-tbm/, 12.08.2020*



CDR was completed in 2011 (still considered “” design but it is getting old…)
For the ESFRI estimate of costs some update in the infrastructure design was made (contacts with companies) and there was a revision of the full document by ET-SC

Next 5 years will be driven by R&D and the preparation of Technical Design Report

Estimated Cost

At the moment it is assumed ~1900 M€

Concept development and design phase (~5M€)

→ already covered

Preparation phase (~170M€)

→ Includes also decision of site

→ Technology development

→ 25% covered by some countries

Implementation phase (~1730M€)

→ 780M€ for civil work

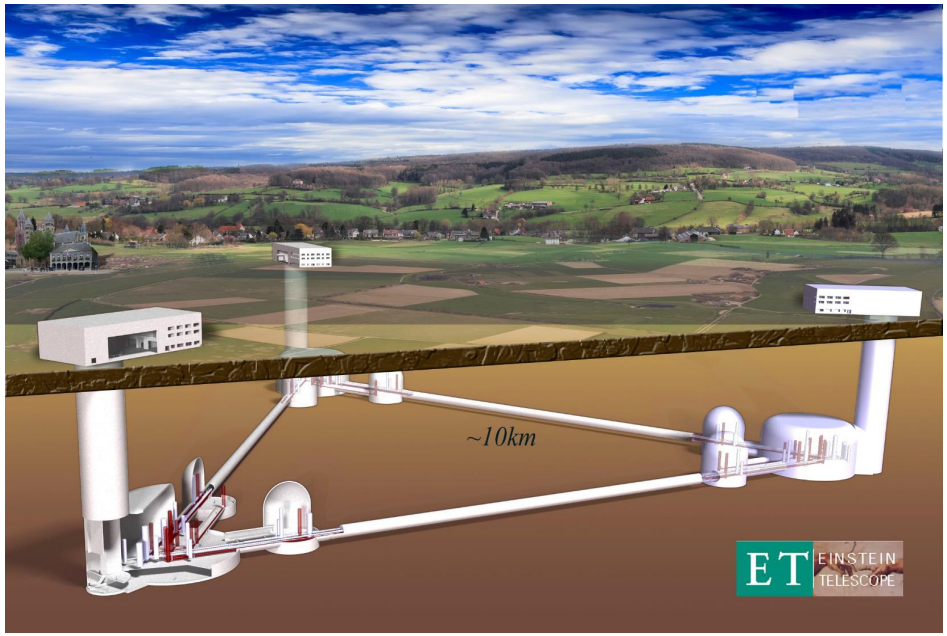
→ 565M€ for vacuum system

→ 220M€ experiment

→ 144M€ for infrastructure and services

Operational phase (~37M€/year)

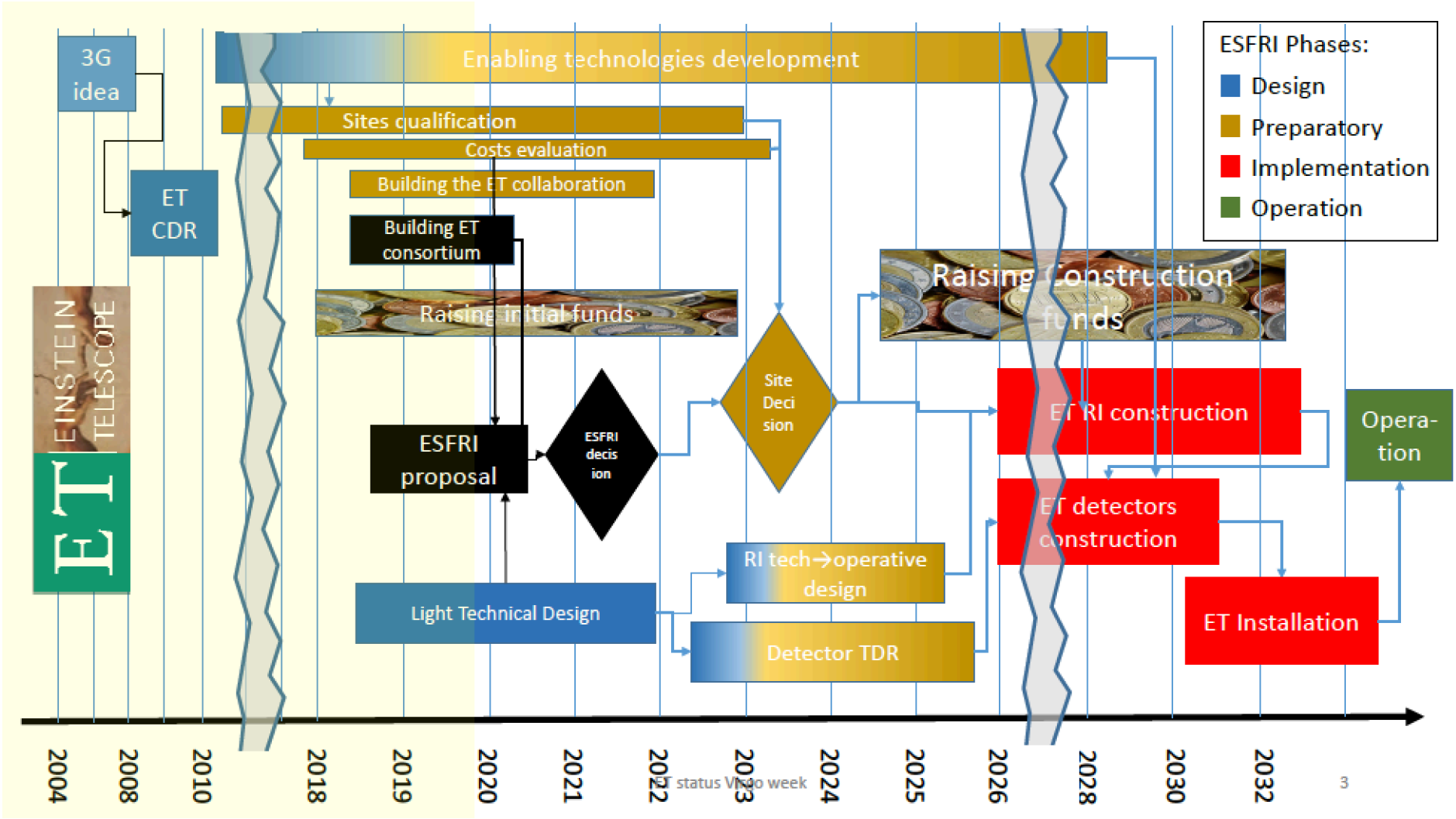
Decommissioning phase (~40M€)



As it is common in this kind of projects about 40% of the costs is civil work

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

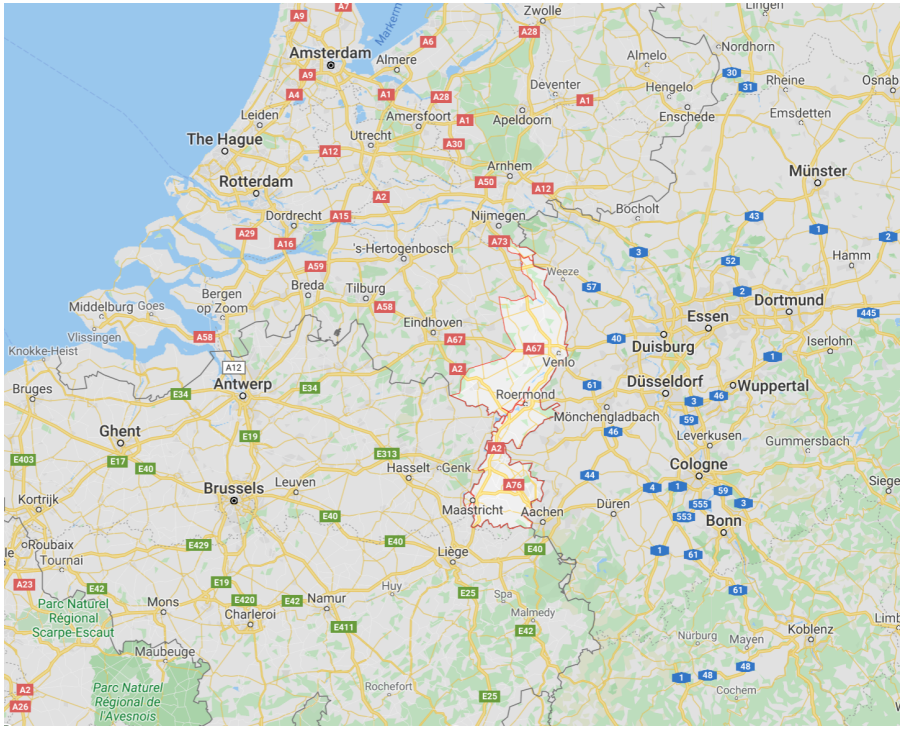
Timeline for ET



Operations by 2035

Locations

Two “competing” sites

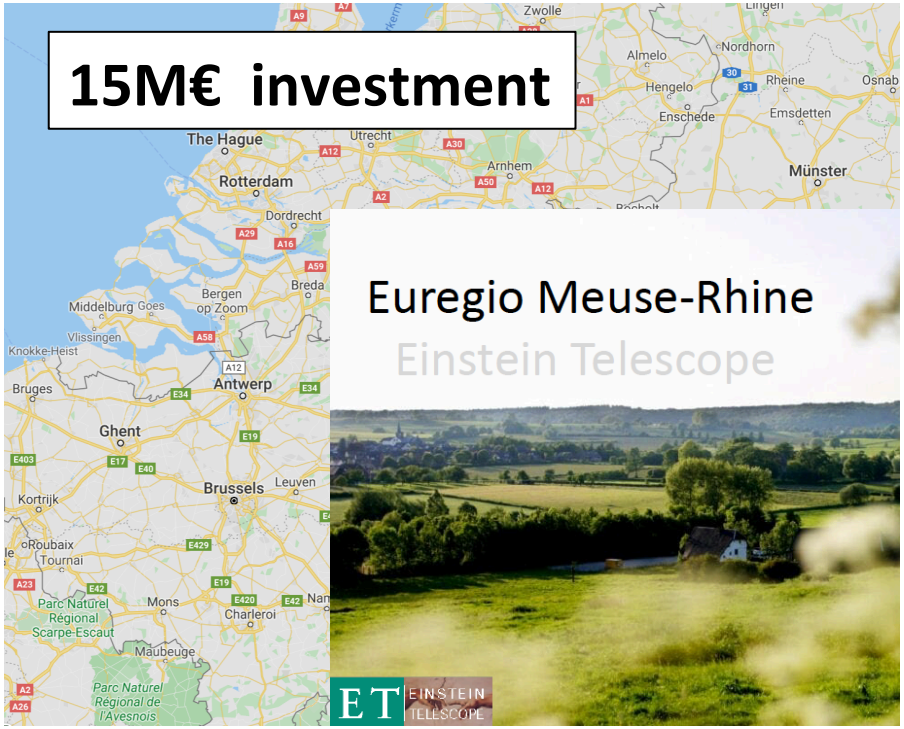


@ Limburg area (in the NL-B-D border)
→ Sponsored by Nikhef

@ Sardinia
→ Sponsored by INFN

Locations

Two “competing” sites



@ Limburg area (in the NL-B-D border)
→ Sponsored by Nikhef

@ Sardinia
→ Sponsored by INFN

Locations

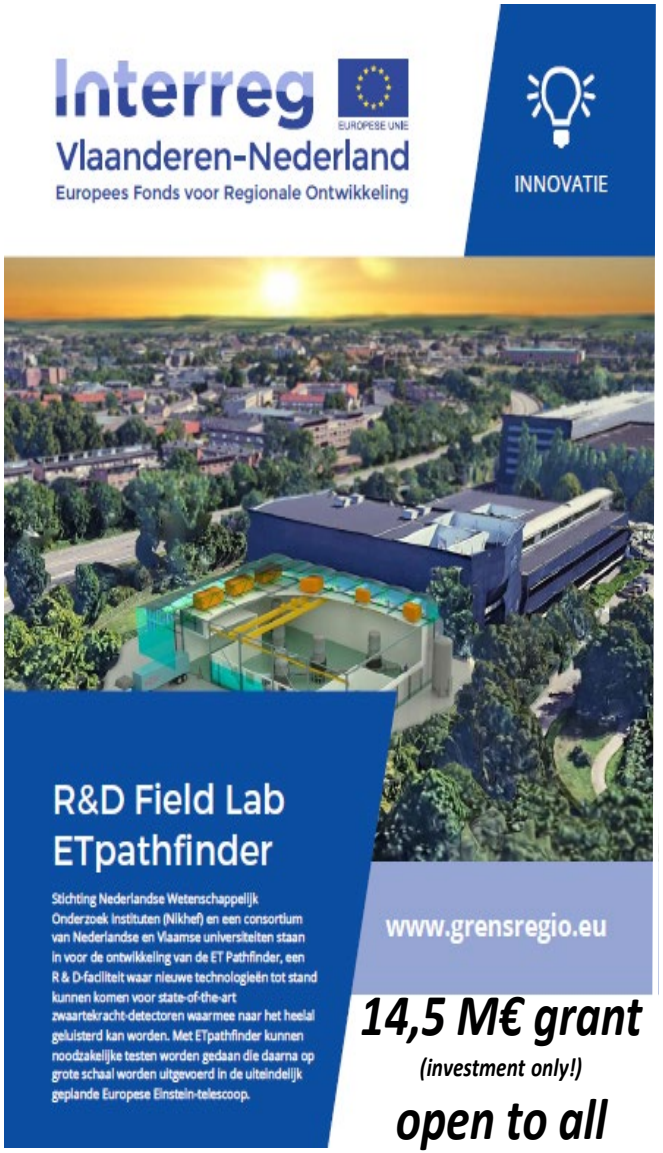
Two “competing” sites

The scenario of two Ls is being put slowly on the table
(will not be discussed openly until ESFRI process is done)

@ Limburg area (in the NL-B-D border)
→ Sponsored by Nikhef

@ Sardinia
→ Sponsored by INFN

New technologies: *ETpathfinder R&D lab*



14,5 M€ grant

(investment only!)

open to all

1st phase: 2019-2022 (funded)

envisaged for many more decades

see: https://www.etpathfinder.eu/

Focus:

- *cryogenic silicon mirrors*
- *controls*

Projectleader:

S. Hild, Maastricht University

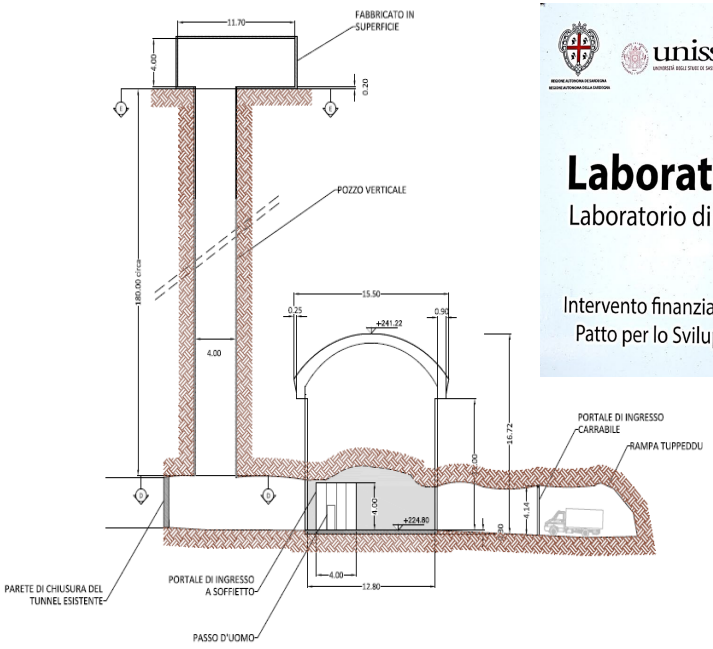
Sar-Grav Laboratory in Sos Enattos

Funded by Regione Sardegna (4M€)

- A 200m^2 **surface Laboratory** with annexed control room;
- 120m^2 **underground Laboratory** under construction

Focus:

Low seismic noise experiments (e.g. Archimedes O(600k€)) Cryogenic Payloads, low frequency and Cryogenic sensors development

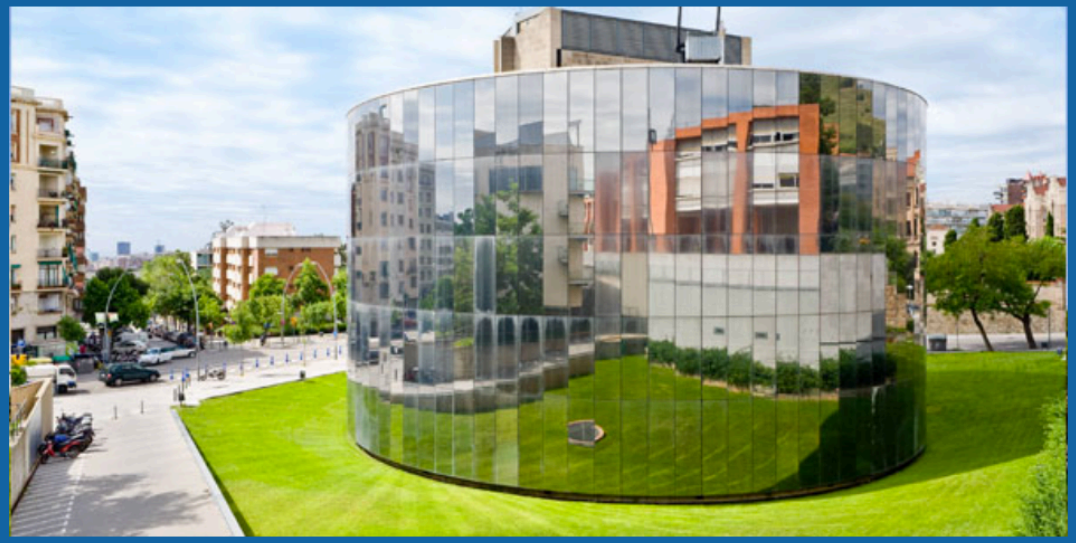


SWOT analysis ET project

	Helpful	Harmful
Internal	**Strengths:** • Monumental Science Potential (ET & 3G science books) • Uniqueness of the project in Europe (pan-European) • Minimal ESFRI requirements accomplished • A large fraction of the technologies are either available or pioneered by AdV+: synergies • Planning better defined after ET-SC intense work • Initial preparatory phase funding assured in (few) countries thanks to the 2 sites candidature	**Weaknesses:** • Human resources currently limited by the intense AdV+/aLIGO activities: conflicts under discussion • Technical design report still to be produced: cost estimation still to be consolidated • Lack of civil engineering support/competences • Two sites still candidate: competition & de-focusing • Official involvement of other EU governments still pending
External	**Opportunities:** • Echoes of the GW discoveries • Lifetime of AdV+/aLIGO and realisation timeline of ET matches • It is possible to deliver science without "holes" • Timeline matches with LISA • 3G plans also in US • Strong interest of the neighbouring scientific communities (Astronomers, Nuclear physicists, ..) • Potential interest of the HEPP community (and CERN) to exploit synergies	**Threats:** • Delays (including COVID) could reduce timeliness • Selection of the site could reduce the interest of some of the governments • 3G plans also in US

I would add:

1/ A 2B€ project is a lot of money for the size the of the GW community
→ Community needs to grow
2/ The GW community is not used to manage such a big project



Spanish Meeting on ET ESFRI proposal preparation

3 February 2020
Nexus Building at UPC Campus Nord, Barcelona
Europe/Madrid timezone

Ove
Rele
ET L
INS
INS
Tim
Reg
Reg
Part
VID
Meeting venue

Dedicated meeting in Spain this winter to collect explicit interest on ET In preparation for ET ESFRI submission

Document submitted to the Ministry on late February

→ Included the formal support of 23 institutions (4 ICTS)
→ Interaction with Ministry representatives → proposal is strong

→ Spain finally provided formal political support for ET ESFRI candidature

ET ESFRI submission

(9th September 2020)

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

Presentada la propuesta para incluir el Einstein Telescope en la hoja de ruta ESFRI

- El Einstein telescope es un ambicioso proyecto de observatorio terrestre de ondas gravitacionales de tercera generación.
- 40 instituciones europeas firman la propuesta, 8 de ellas españolas.
- La propuesta recoge el interés de hasta 23 instituciones españolas.

Madrid / Barcelona, 10 de Septiembre de 2020

El consorcio del Einstein Telescope ha presentado la propuesta para incluir el proyecto para un futuro observatorio de ondas gravitacionales en la actualización de 2021 de la hoja de ruta del Foro Estratégico Europeo para Infraestructuras de Investigación (ESFRI), el programa que describe las principales infraestructuras de investigación futuras en Europa.

El Einstein Telescope (ET) es el proyecto más ambicioso para un futuro observatorio terrestre de ondas gravitacionales. Su diseño conceptual ha sido apoyado por una subvención de la Comisión Europea. Ahora un consorcio de países europeos y de instituciones de investigación y universidades en Europa ha presentado oficialmente la propuesta para la realización de dicha infraestructura con el apoyo político de cinco países europeos: Bélgica, Polonia, España y Holanda, liderados por Italia. El consorcio ET reúne a unas 40 instituciones de investigación y universidades de varios países europeos, incluidos también Francia, Alemania, Hungría, Noruega, Suiza y Reino Unido. El Observatorio Gravitacional Europeo (EGO) en Italia constituye su sede de transición.

El Einstein Telescope ha despertado un gran interés en la comunidad científica española implicada en ondas gravitacionales, que incluye a todos los centros que actualmente participan en programas terrestres (LIGO / Virgo / KAGRA) y espaciales (LISA), así como una fuerte comunidad. Investigadores españoles han contribuido de forma significativa al desarrollo del programa de física de ET, así como a la preparación del informe de diseño técnico de ET.

Además, motivados por el desarrollo de nuevas tecnologías y los potenciales retornos significativos para la industria española, también se brindó un apoyo explícito por parte de instituciones de investigación, incluidas algunas "Infraestructuras Científicas y Técnicas Singulares" (ICTS). En total, hasta 23 instituciones españolas apoyaron la iniciativa ESFRI, lo que resultó en el apoyo político formal de España a la candidatura del ET.

Politically supported by 5 countries
(Italy, Netherlands, Belgium, Poland, Spain)

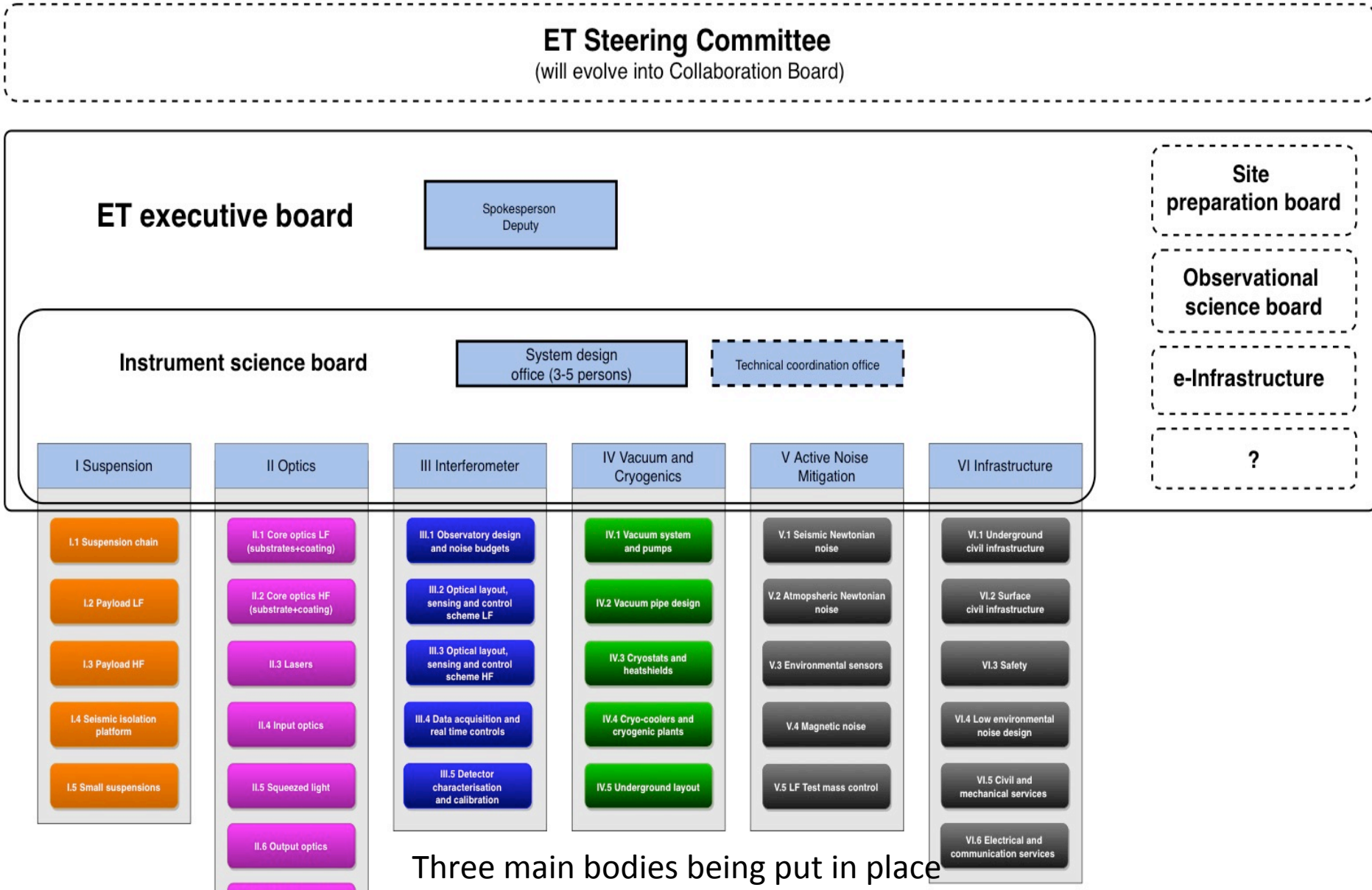
Preparatory meeting on 17th September with ESFRI representatives from supporting countries

- ESFRI will review the proposal in two panels (Scientific and Implementation)

- Suggested ET-SC to define an informal external Review Panel to prepare a priory Q&A
→ Ongoing

ET consortium includes 40 institutions
(8 from Spain) from 11 countries including also France, Germany, Hungary, Norway, Switzerland, UK

ET-SC has focused now on ET Organization



Three main bodies being put in place

- **Instrumented Science Board**
- **Observational Science Board**
- **Site Preparation Board (charge now being defined)**

ET Steering Committee

I. SUSPENSION
1. Suspension chain
2. Payload LF
3. Payload HF
4. Seismic Isolation Platforms

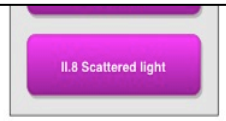
II. OPTICS
1. Core Optics LF
2. Core Optics HF
3. Lasers
4. Input Optics
5. Output Optics
6. Squeezed Light
7. Wavefront sensing and control
8. Scattered Light

III. INTERFEROMETER
1. Design and Noise Budget
2. Optical Layout
3. DAQ
4. Detector Characterization
5. Calibration

IV. VACUUM/CRYOGENICS
1. Vaccum system
2. Vaccum pile design
3. Cryostats and heatshields
4. Cryo-coolers and cryogenic plants
5. Underground layout

V. ACTIVE NOISE MITIGATION
1. Seismic Newtonian noise
2. Atmospheric newtonian noise
3. Environmental sensors
4. Magnetic noise
5. Test mass control

V. INFRASTRUCTURE
1. Underground civil infrastructures
2. Surface civil infrastructures
3. Safety
4. Low environmental noise design
5. Civil and mechanical services
6. Electrical and communication services



Consider if you want to play a role in the definition of the TDR

ET symposium coming

(30th November – 3rd December)

11th Einstein Telescope Symposium

30 November 2020 to 3 December 2020
Annecy
Europe/Paris timezone

https://indico.in2p3.fr/event/20576/timetable/?view=standard

Science, Infrastructure and Organization will be discussed
Effort to attract other communities supporting also ET