

# Gravitational Waves

LIGO, Virgo & Einstein Telescope



Mario Martínez, 18th May 2026  
(T-D Lee Institute visit @ IFAE)

# Group composition (2026)



Three PhD theses in 2023  
(Then industry + research positions)  
(A. Romero now staff in Annecy)

Not listing IFAE Technical Division / Computing staff

IFAE @ Virgo since 2018

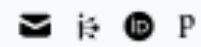
IFAE@ LIGO since 2024

IFAE @ ET since 2019

## STAFF RESEARCHERS



Matteo Cavalli-Sforza



Eugenio Coccia



Andrew Lundgren



Mario Martínez



Lluïsa Mir



## VISITOR RESEARCHERS



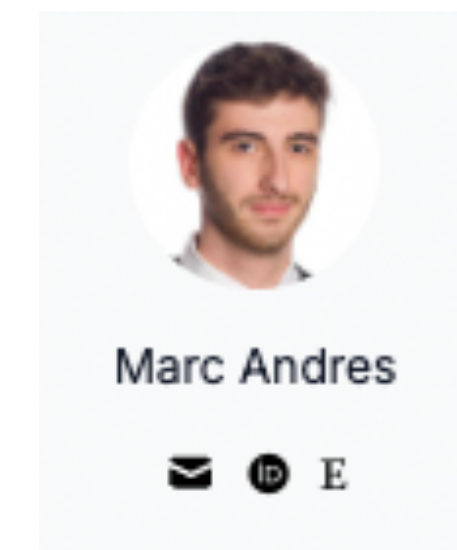
Michele Maggiore



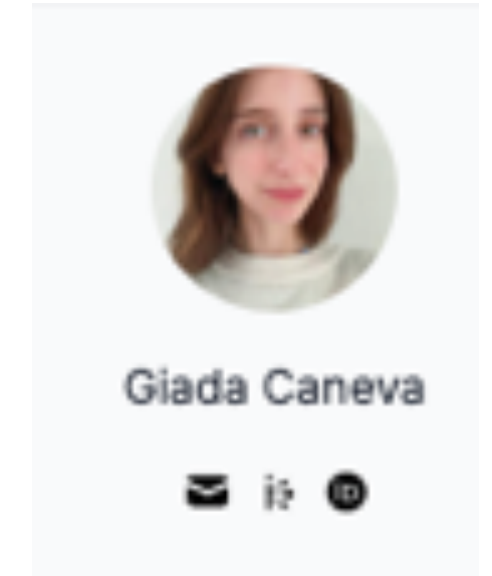
Prof. M. Maggiore (ET spokes person) visiting in 2024 & 2025 — and 2026



Part of IFAE's technical staff @ EGO in 2021



Marc Andres



Giada Caneva



Two PhD theses in 2025  
Now at MIT and Niels Bohr Inst.

## POSTDOC RESEARCHERS



Machiel Kolstein



Jam Sadiq



Avani Patel



Kanchan Soni

—> Two new postdocs coming (June - September)  
—> Headhunting for a junior leader (experimentalist)

## PHD STUDENTS



Catalina Mirtescu



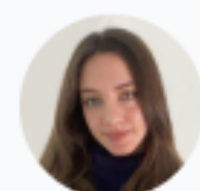
Dounia Nanadoumgar Lacroze



Sakshi Satish Madekar



Leonardo Toti



Elisabet Vallejo Pagès



Saqlain Afroz

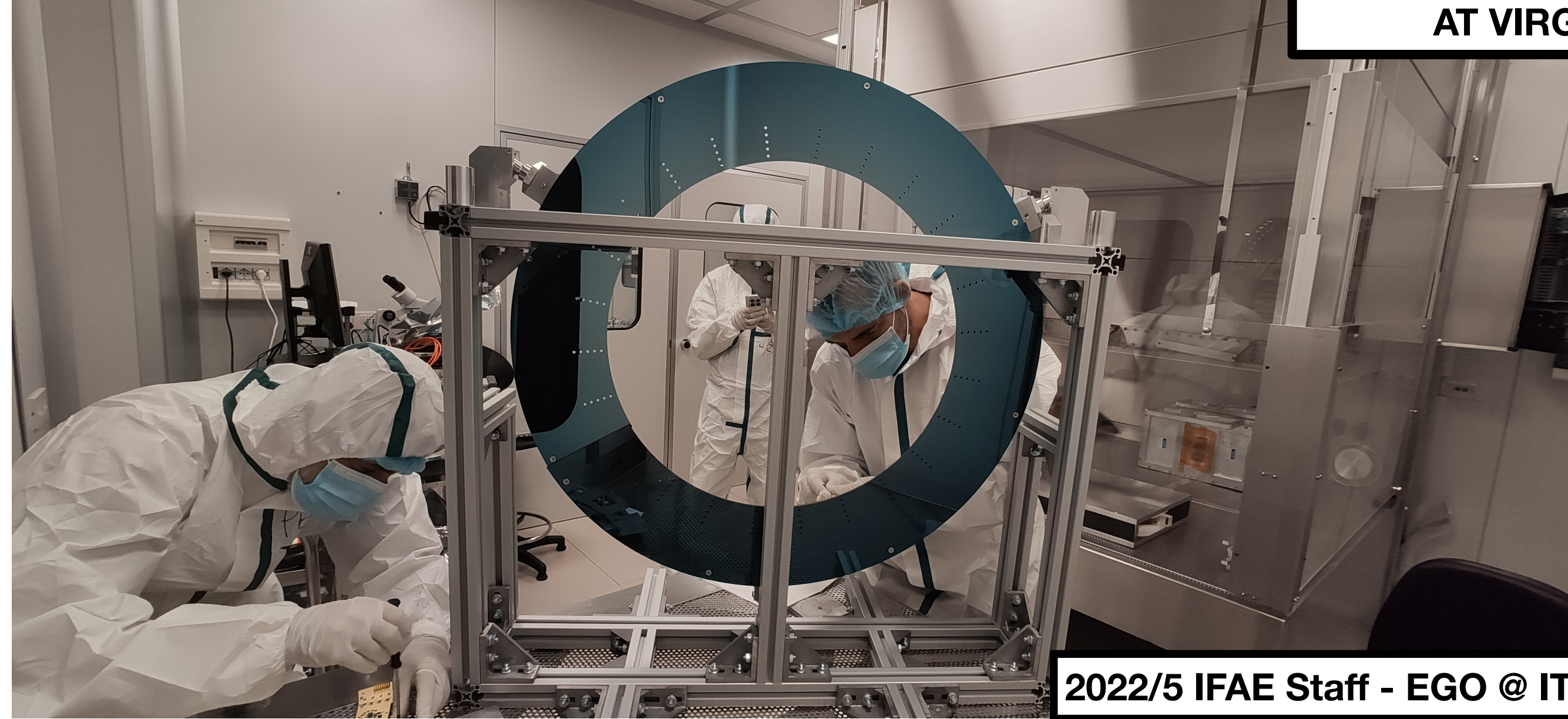
Five PhD students  
One new PhD students coming

# IFAE's R&D for LVK & ET

2026 TWO LARGE INSTRUMENTS AT VIRGO-EGO @ IT



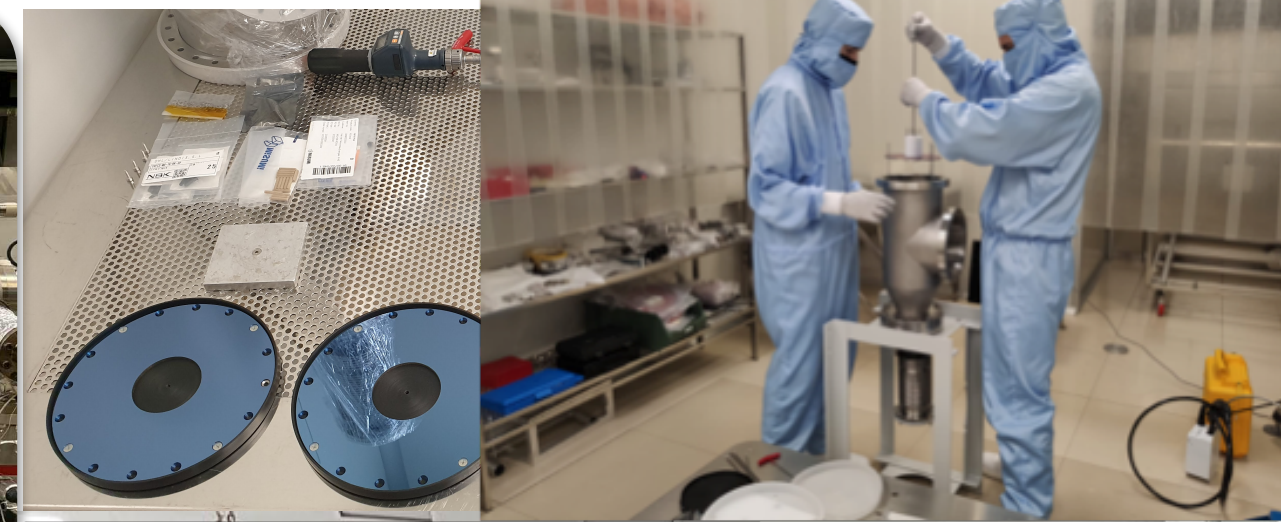
2021 FIRST INSTRUMENTED BAFFLE AT VIRGO-EGO @ IT



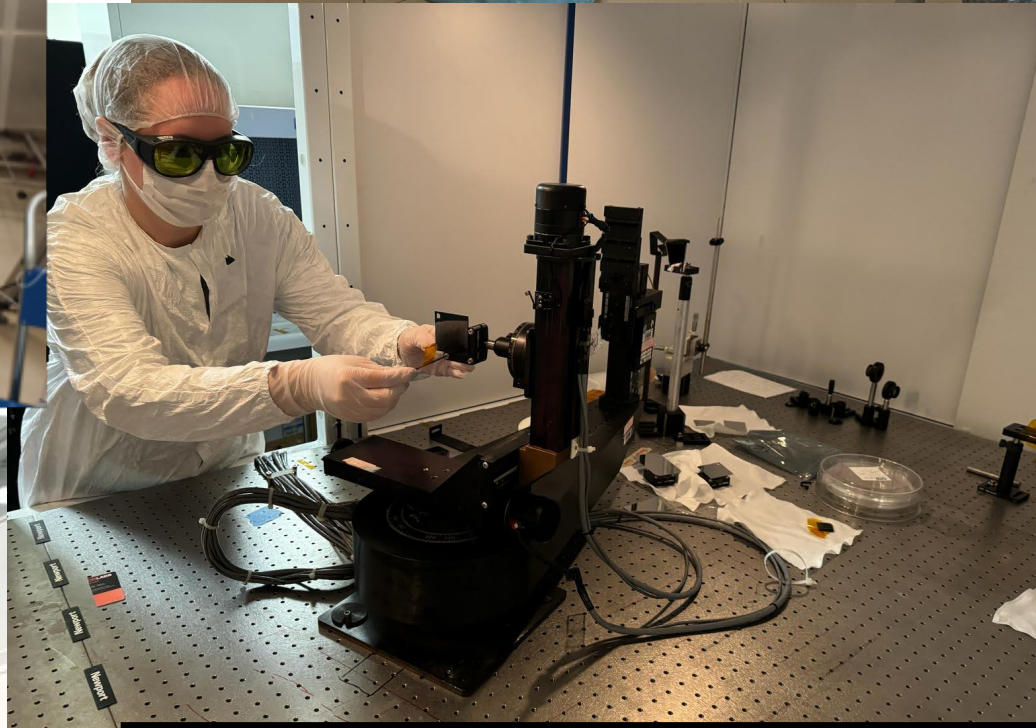
2022/5 IFAE Staff - EGO @ IT



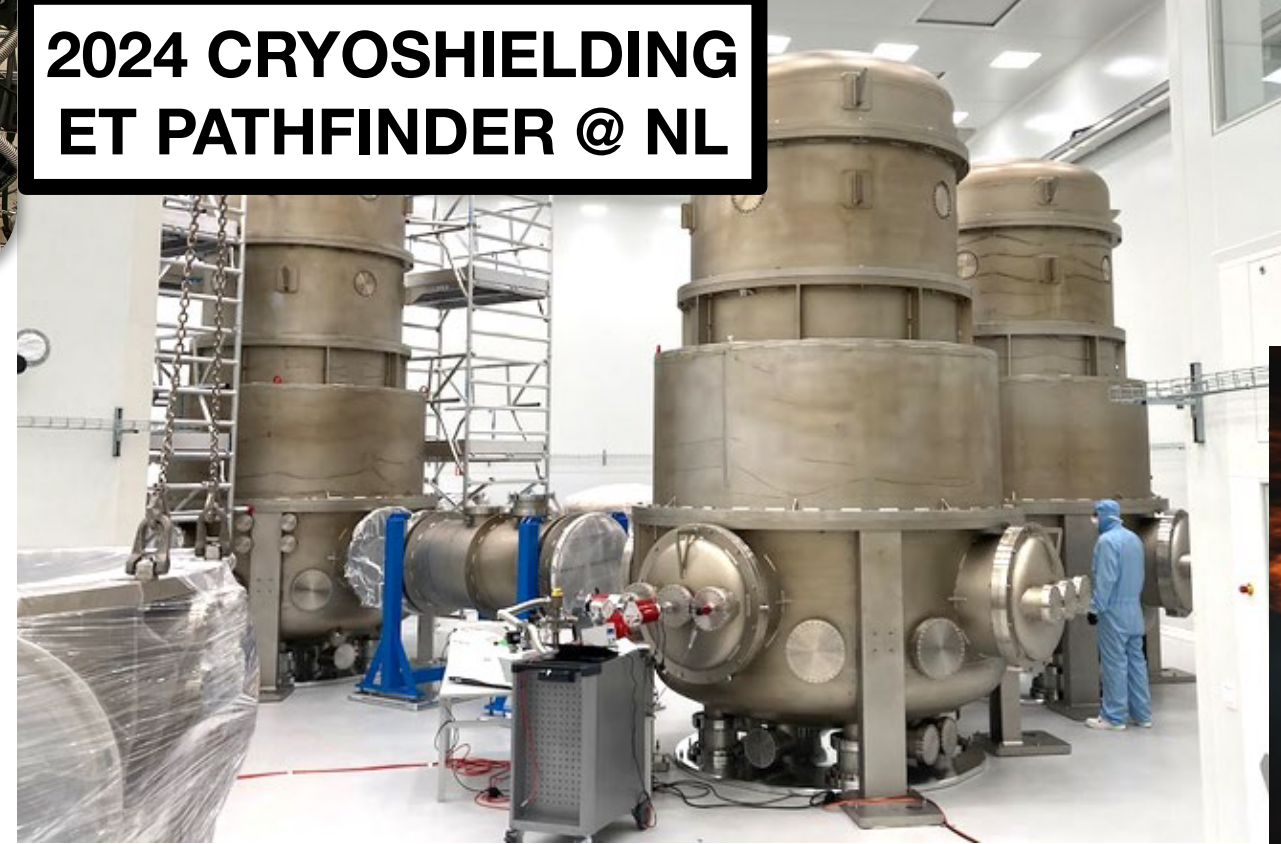
2024/6 DESIGN STUDIES AND BAFFLES FOR ET VACUUM PIPE @ CERN



2024 CRYOSHIELDING ET PATHFINDER @ NL



IFAE @ Caltech Optical Labs



September 30-October 2, 2025

Cosmic Explorer - Einstein Telescope Beamtube Workshop III

LIGO Hanford Observatory, Richland, Washington, USA

IFAE has made novel contributions to GW hardware since 2019 MoA with CERN for the Design of the ET Vacuum System  
Active participation in the flagship R&D platform @ Maastricht  
Close collaboration with USA in common ET/CE strategies  
Participating in a number of EU initiatives for EC fundings

# LVK operations and commissioning

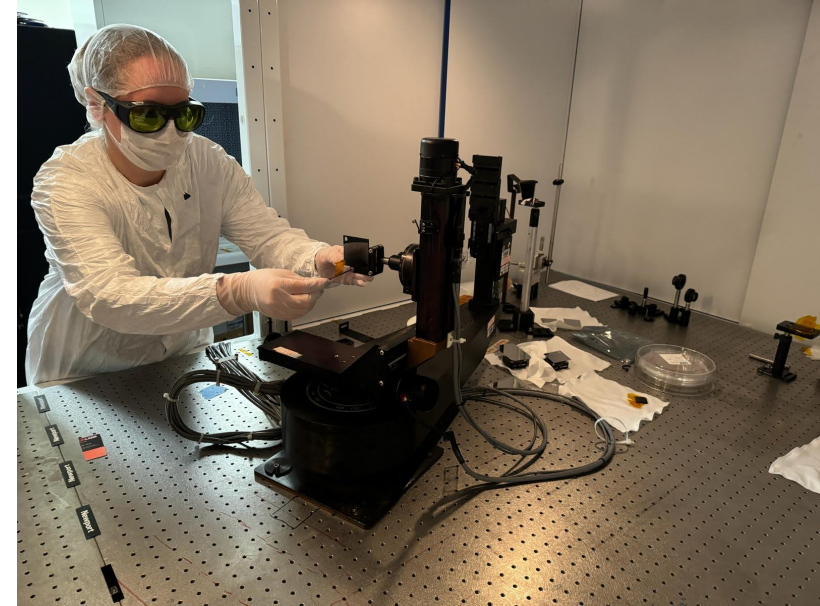
IFAE took an energetic approach for the involvement in VIRGO operations since 2019

2025 → 1 person @ EGO  
Work on Auxiliary Optics and interferometer alignment in collaboration with EGO Optics Department

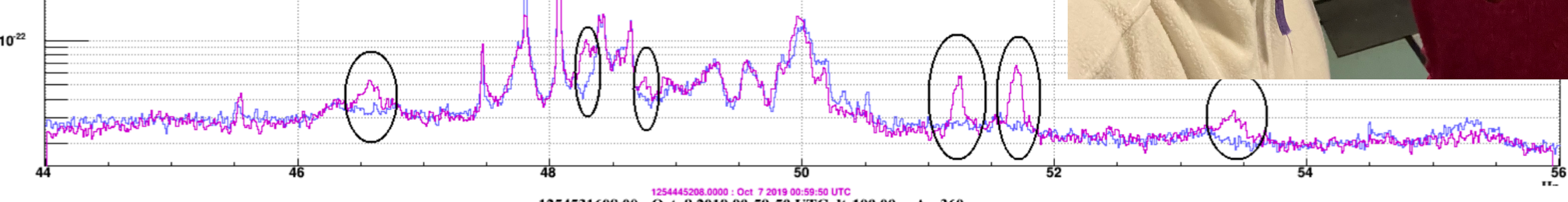
**2019 Results Published**  
*A Cirone et al 2019 Class. Quantum Grav. 36 225004*  
*I. Fiori et al., Galaxies 2020, 8(4), 82*

2021 + 2023 → 3+1 people @ EGO  
IMC baffle operations  
ITF commissioning & h(t) calibration  
Magnetic Injections

2024 → 2 +1 people @ EGO  
IMC baffle operations  
ITF commissioning & h(t) calibration  
Magnetic Injections



2019. → 3 people based @ EGO  
2020. ITF commissioning / Noise hunting



# Computing resources for VIRGO/LIGO at PIC

Joined the LIGO/VIRGO Grid in Summer 2019.

Effective site integration from day 1 thanks to common sw stack with other supported experiments: LHC, DUNE, CTA

CPU and GPU access through HTCondor. Transparent & efficient access to sw and data through CVMFS (recently moved to Pelican)

Overall contribution to IGWN Grid since Jan'24 (data from [GRACC](#))

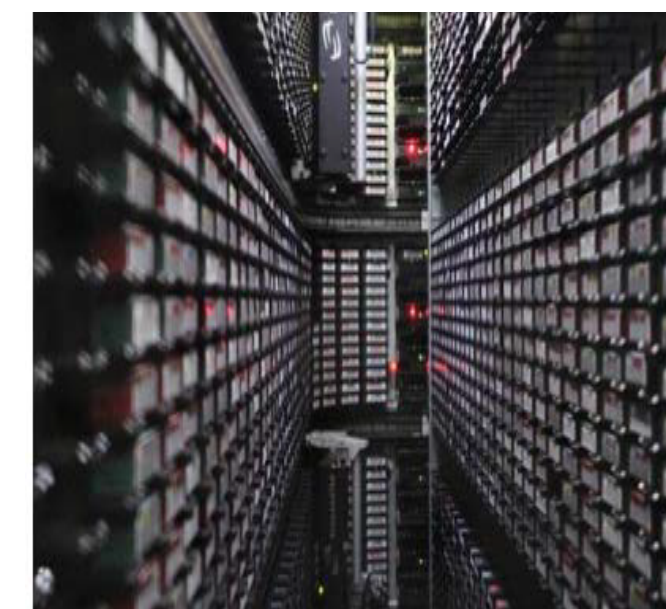
- **6% of the CPU**
- **14% of the GPU**

**Opportunistic resources only**

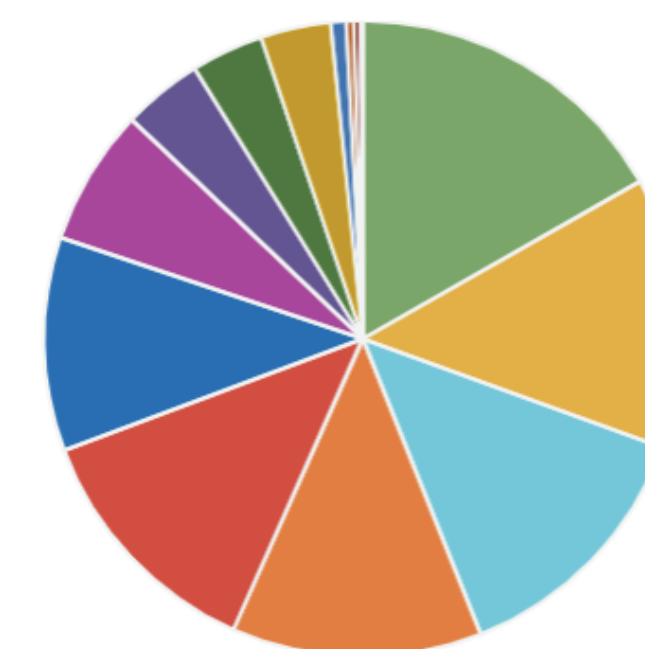
**PIC high-quality contributed to LIGO/Virgo Grid since 2019**

—> **Repeating efforts to translate this into recognised in-kind**

—> **Recently hired a Comp Scientists at PIC working for LVK support**

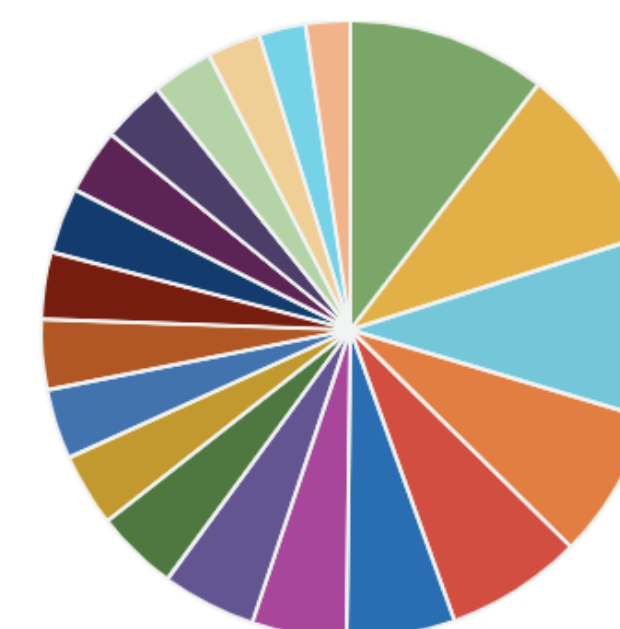


GPU Wall Hours by Facility ⚠



	total
ND_CAMLGPU	173 K
pic	142 K
SDSC-PRP-OSPool-Provisioner	138 K
SURFsara	131 K
ComputeCanada-Cedar	130 K
LIGO-CIT-CE	112 K
Georgia_Tech_PACE_CE_LIGO	71 K
LSU-SuperMIC-CE1	42 K

Core Hours by Facility ⚠



	total
Albert Einstein Institute	12 Mil
NIKHEF-ELPROD	12 Mil
CHTC	11 Mil
INFN-T1	9 Mil
SURFsara	9 Mil
PIC	7 Mil
ComputeCanada - Cedar	6 Mil
USdC	6 Mil

# IFAE Physics Analysis @ LVK & ET papers

- A rich physics program using LVK data including a number of short-author list Q1 paper [not listing here LVK papers with many authors]

- **Stochastic GWs**

- A. Romero et al., Phys. Rev. Lett. 126, 151301 (2021)
- A. Romero et al., Phys. Rev. Lett., vol. 128, 051301 (2022)

- **Test of GR & Cosmology using GWs**

- G. Caneva et al., Phys. Rev. Lett. 132, 251401 (2024)
- S. Mastrogiovanni et al., Annalen Phys. 536 (2024) 2, 2200180
- R. Gray et al., JCAP 12 (2023) 023.
- S. Mastrogiovanni et al., Phys.Rev.D 108 (2023) 4, 042002

- **Search for CBC events using AI**

- A. Menendez et al., CQG 41 135018 (2024)
- M. Andres-Carcasona et al., Mon. Not. Roy. Astron.Soc. 527 (2023) 2, 2887-2894
- A. Menéndez-Vázquez, et al., Phys. Rev. D 103, 062004 (2021).

- **Search for Dark Matter and PBHs**

- M. Andres-Carcasona et al., Phys.Rev.D 107 (2023) 8, 082003
- M. Andrés-Carcasona et al., Phys. Rev. D 110, 023040 (2024)
- G. Morras et al., Phys.Dark Univ. 42 (2023) 101285

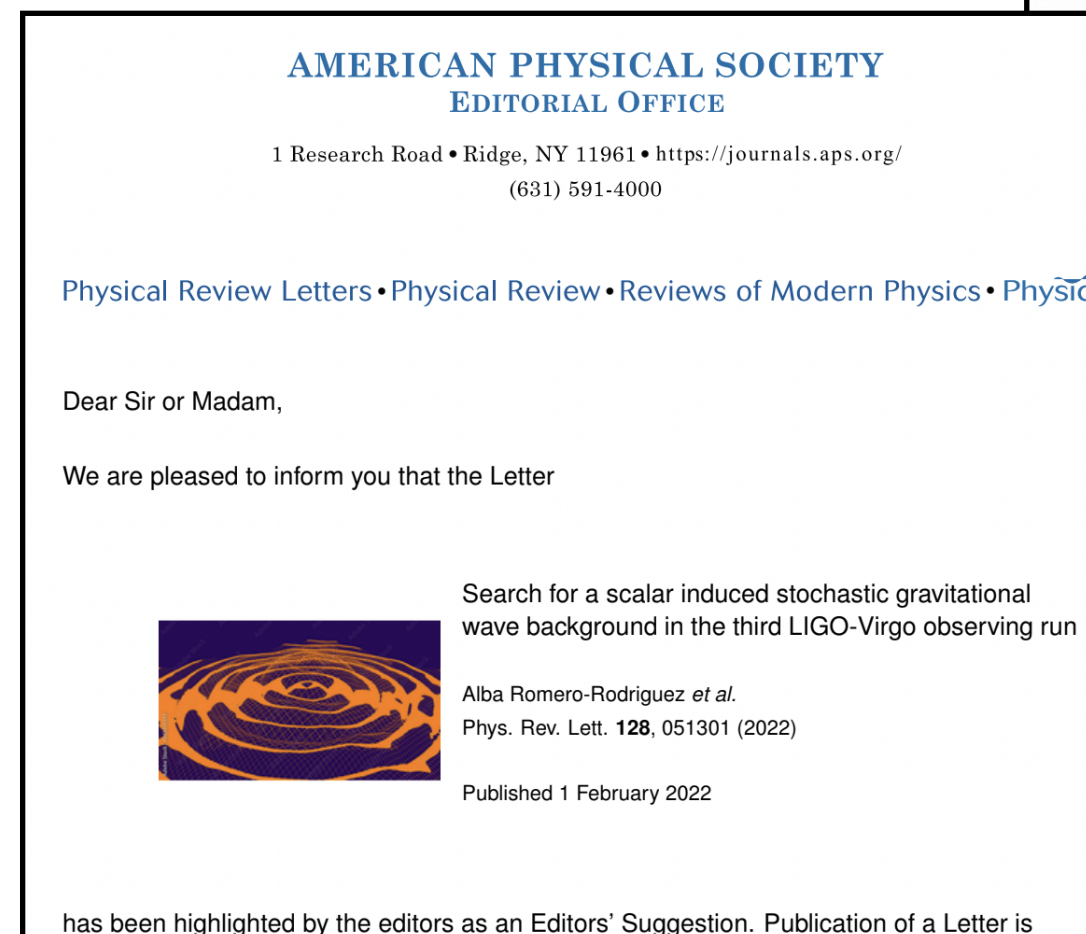
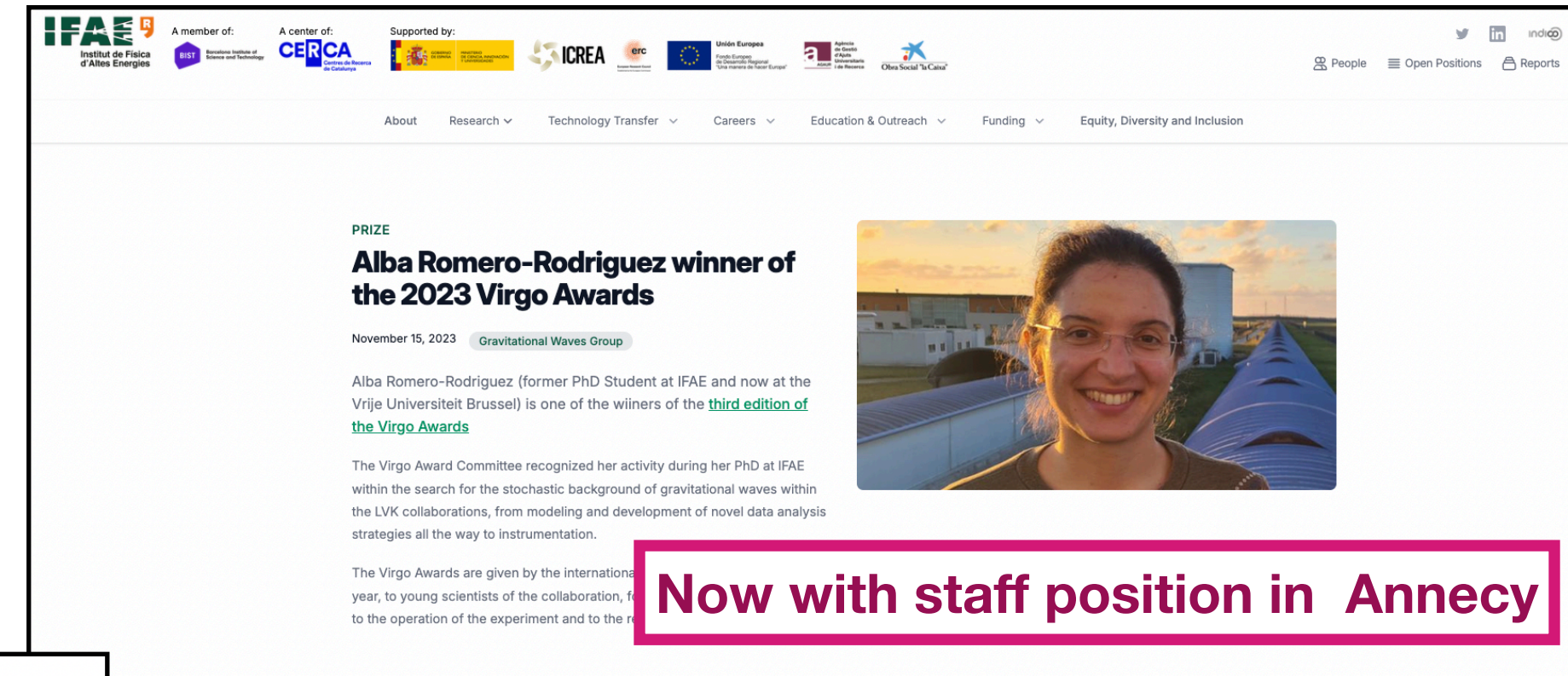
- **Also a number for. Hardware and Simulations for both Virgo and ET**

- M. Andres-Carcasona et al., Phys.Rev.D 107 (2023) 6, 062001
- M. Andres-Carcasona et al., Phys.Rev.D 108 (2023) 10, 102001
- A. Macquet et al., Class.Quant.Grav. 40 (2023) 7, 077001
- O. Ballester et al., CQG 39 (2022) 115011
- A. Romero-Rodríguez et al, 2021, Class. Quantum Grav. 38 045002
- A. Romero-Rodríguez et al., Galaxies 10, 86 (2022)

IFAE members also playing important roles in some of the O3 and O4 LVK analyses

- Main contacts in Stochastic GWs in O3
- Main contacts in pyRing (ringdown analysis) & beyond GR analyses
- Main contacts in a number of Continuous GW searches
- Main contacts in Cosmology (measure of H0) O3 analysis + H2 weights for O4

GW team very visible in numerous int. conferences and workshops across the years

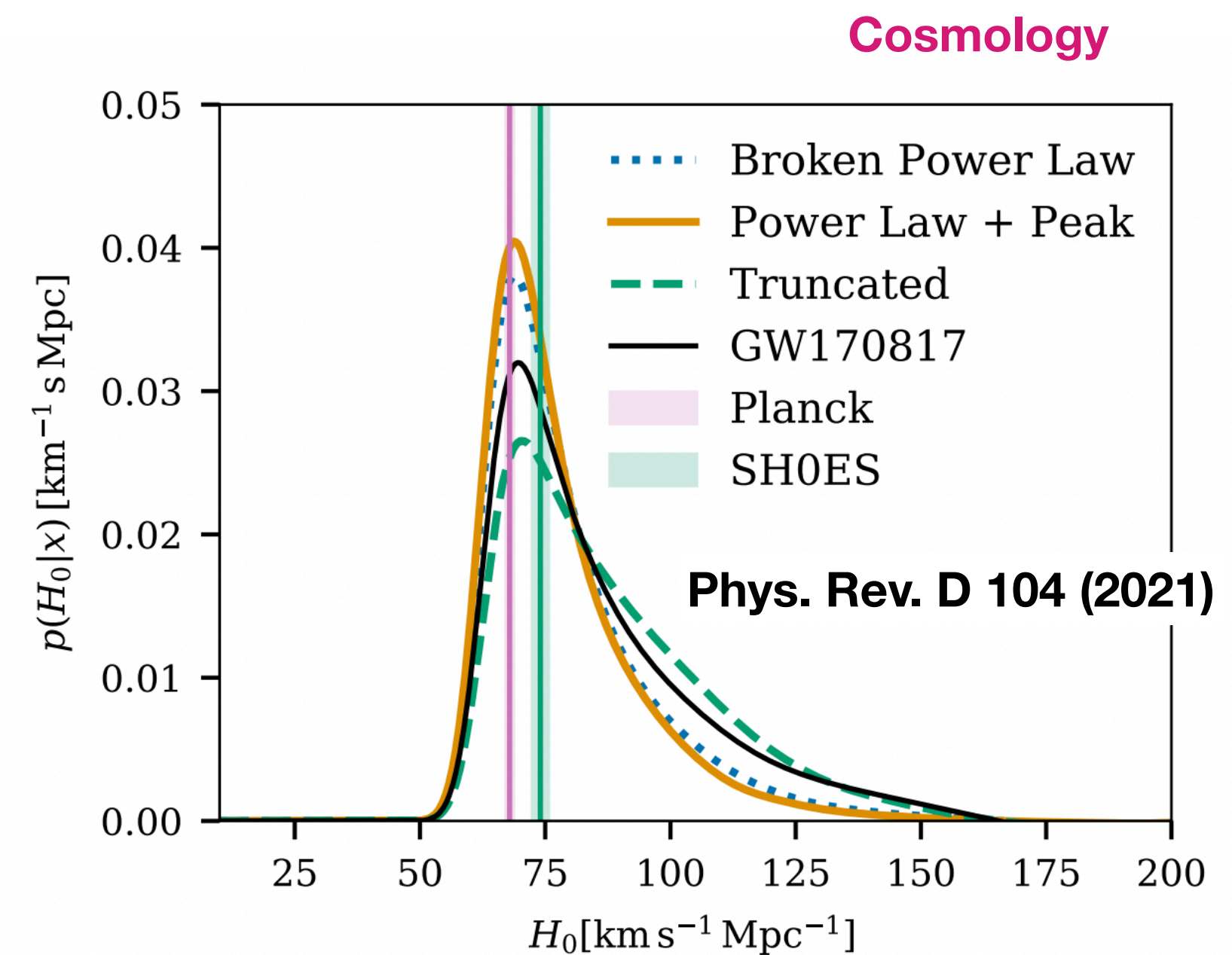
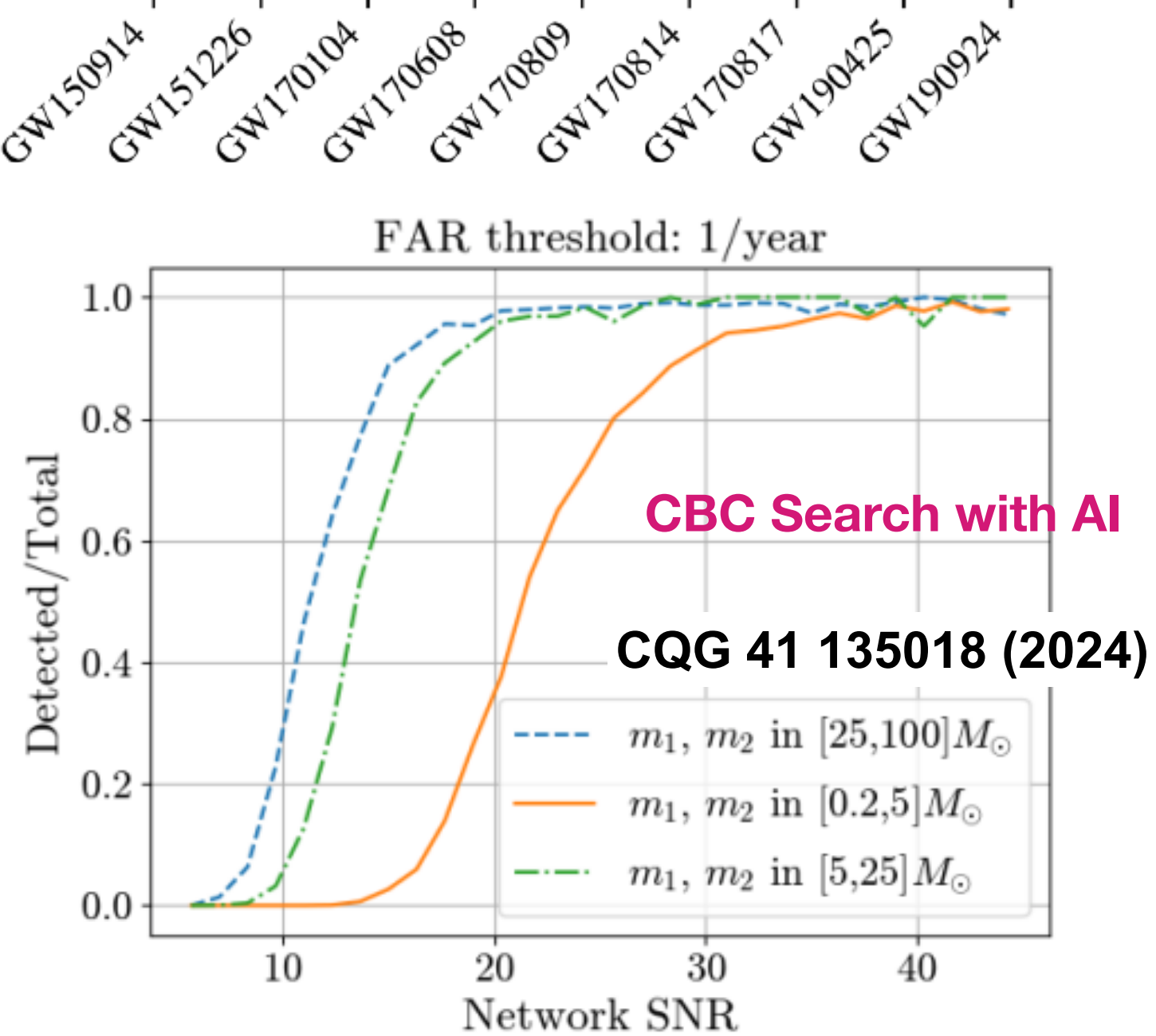
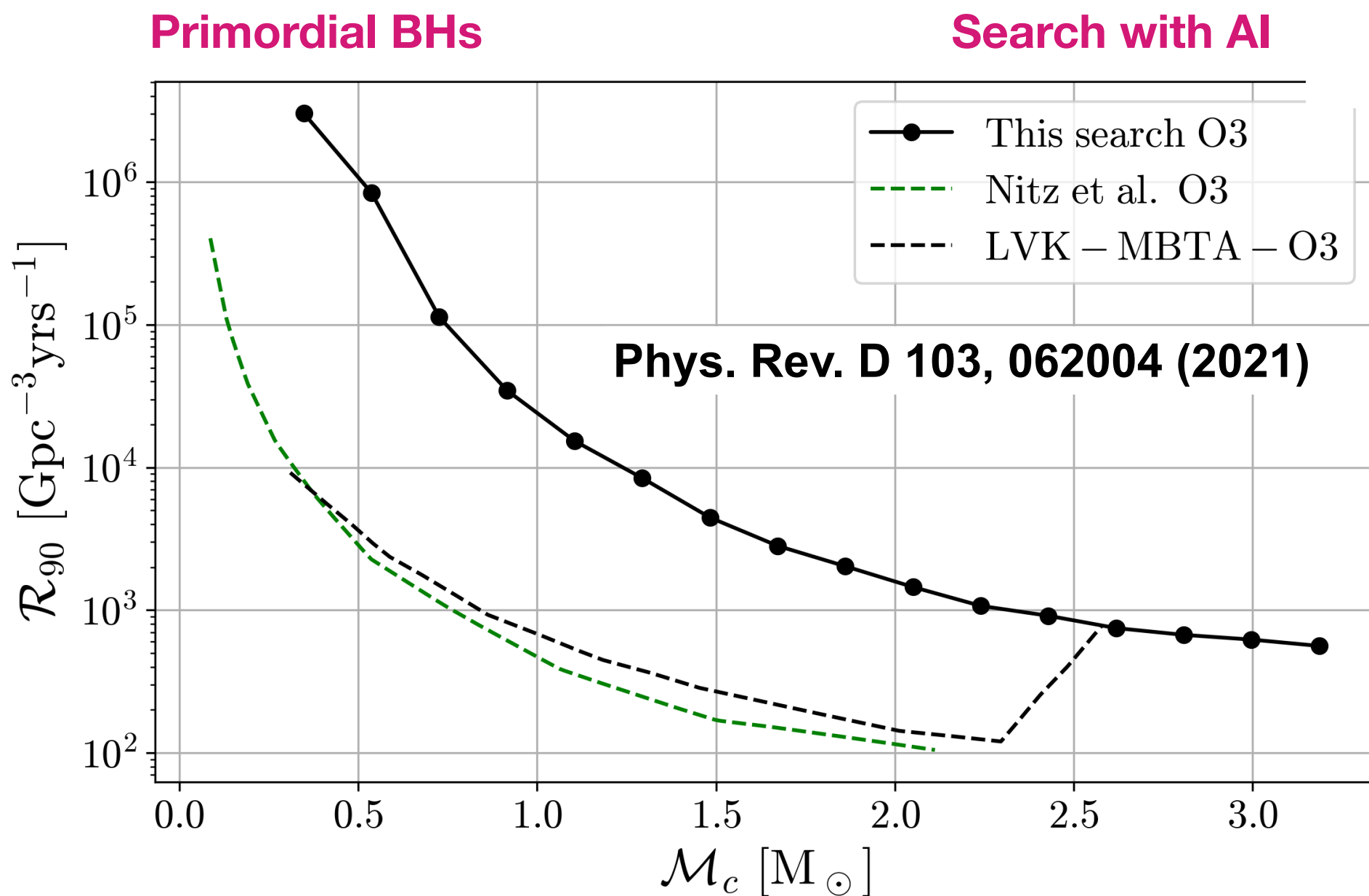
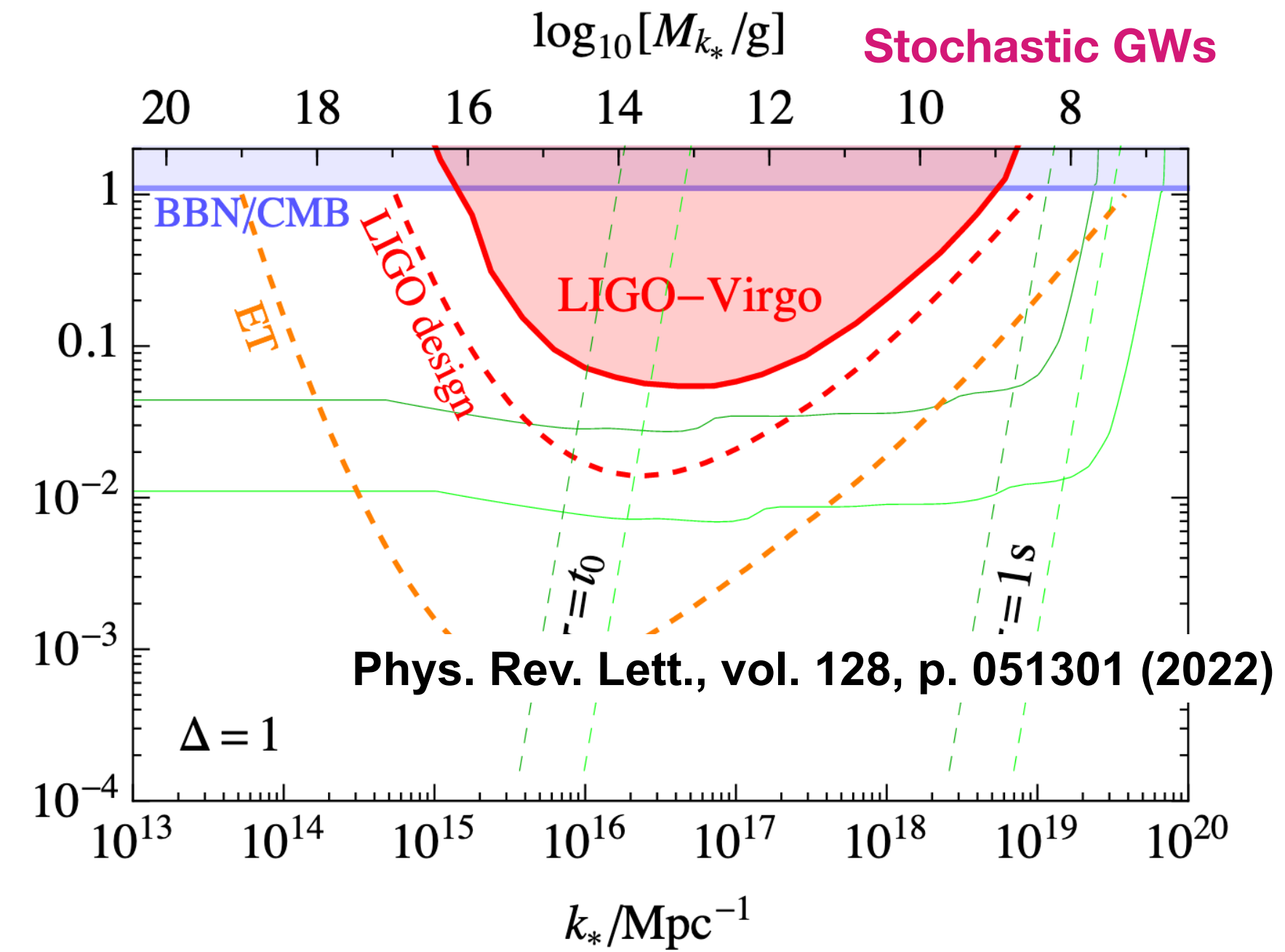
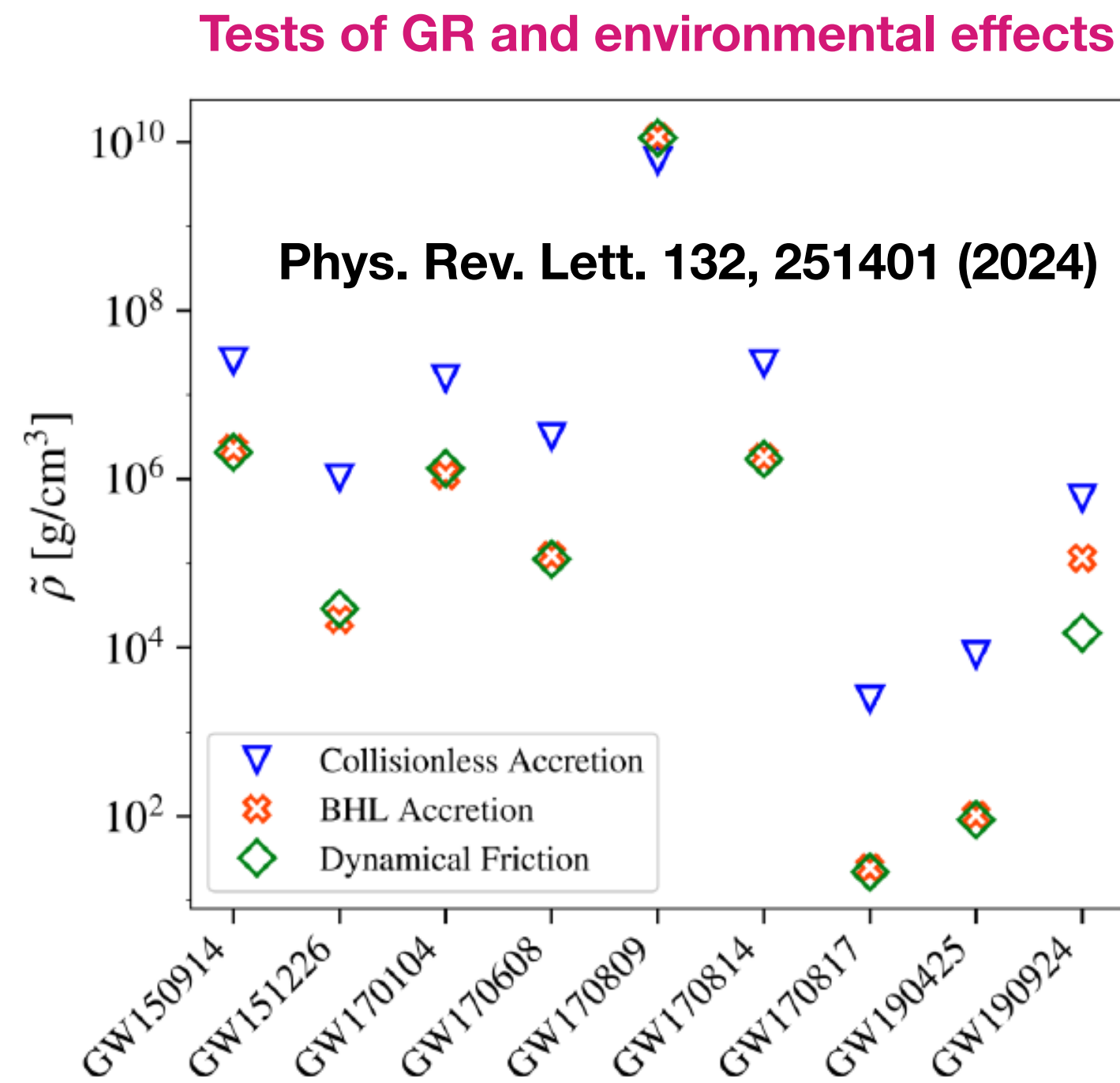
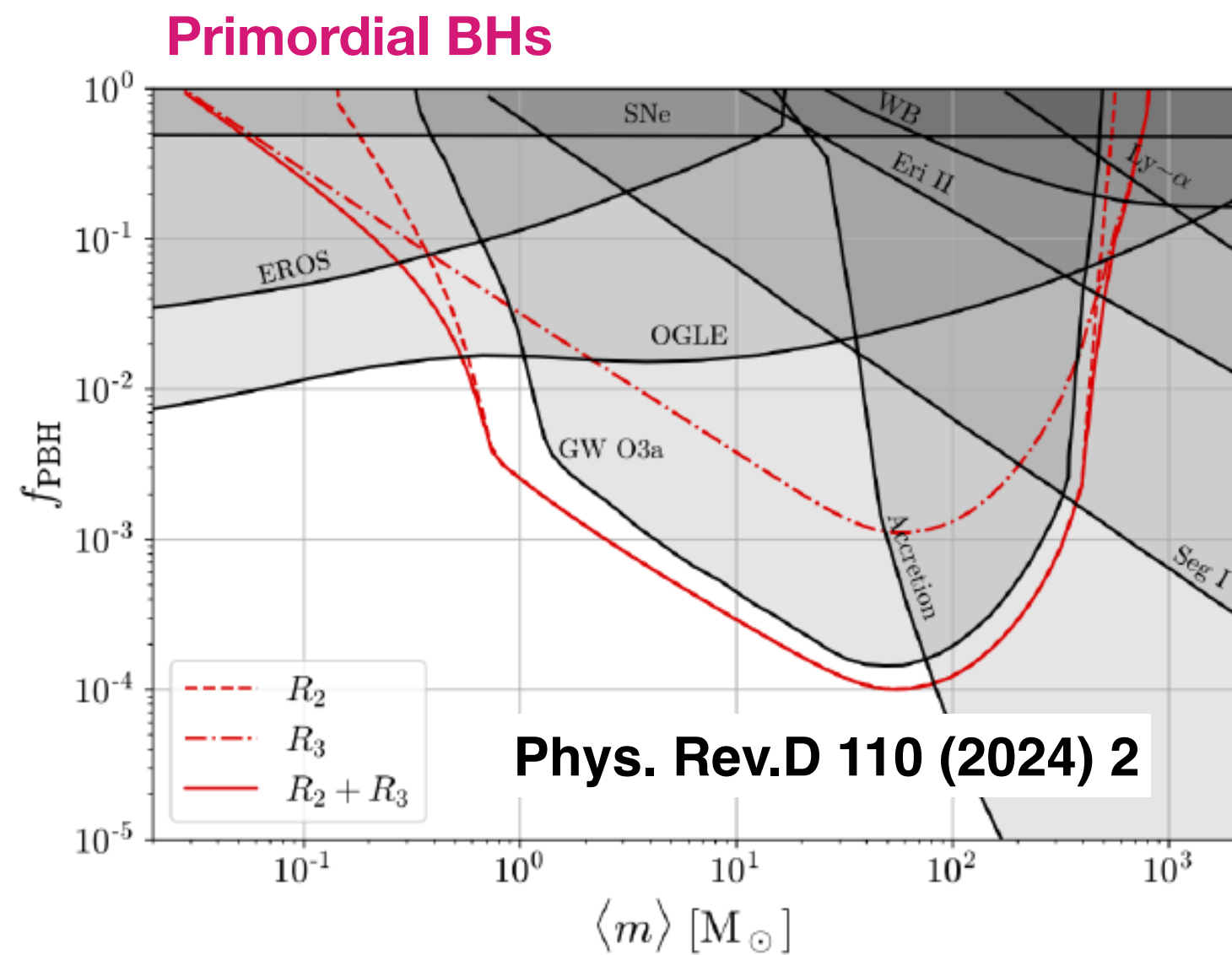


IFAE papers as PRL and PRD editors suggestions



# Highlights of (recent) Results

With IFAE scientists at the front

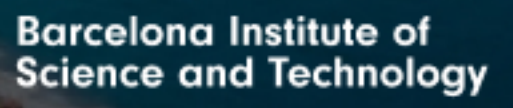
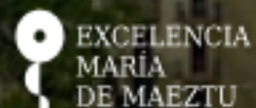
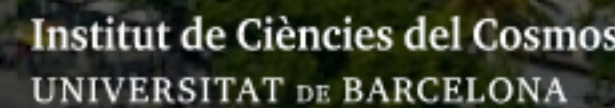
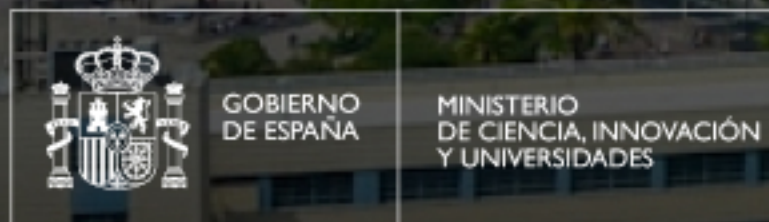




# LIGO-VIRGO-KAGRA COLLABORATION MEETING

Barcelona, September  
23rd – 27th, 2024

[lvkmeeting2024.ifae.es](http://lvkmeeting2024.ifae.es)



# The Einstein Telescope

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

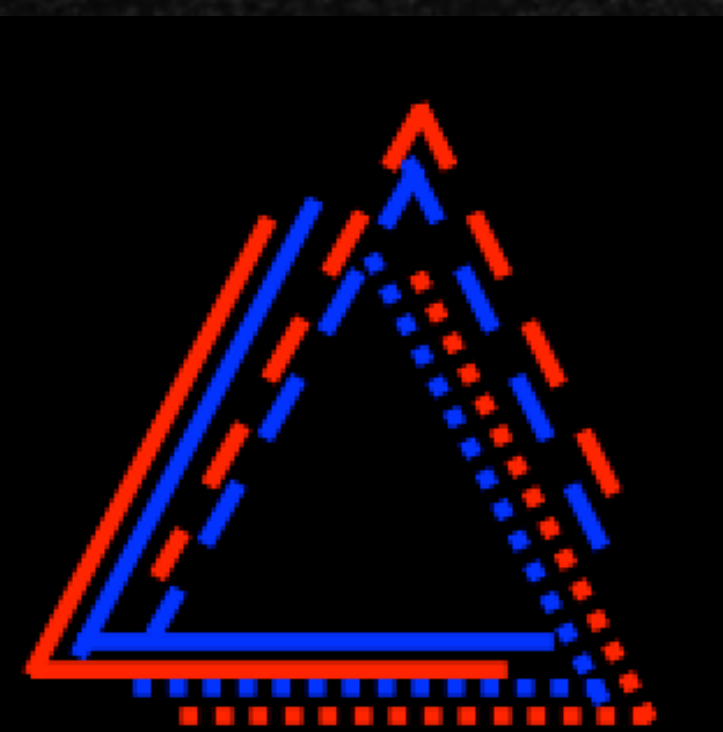
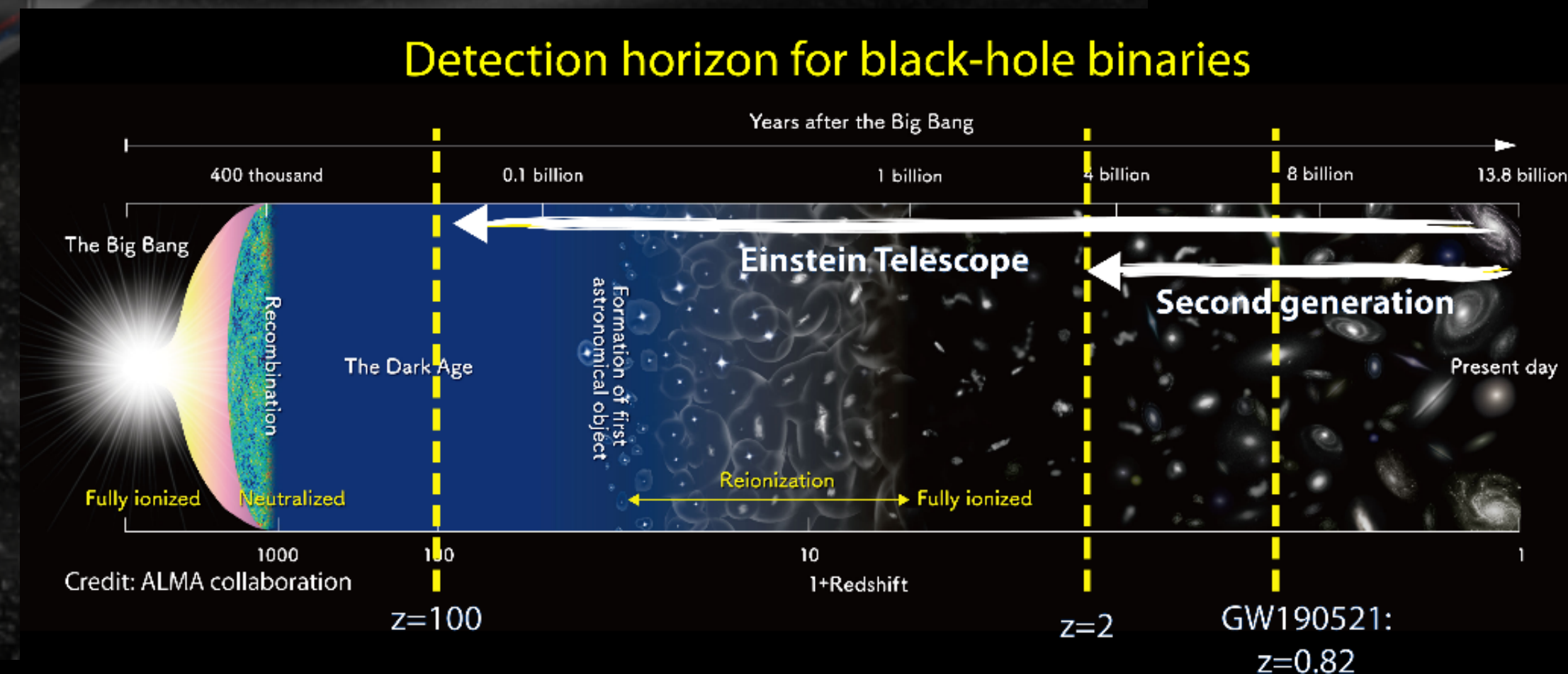
Gravitational Waves detector  
based on laser interferometry  
with 10 - 15 km arms underground

Mapping the whole universe

10 km

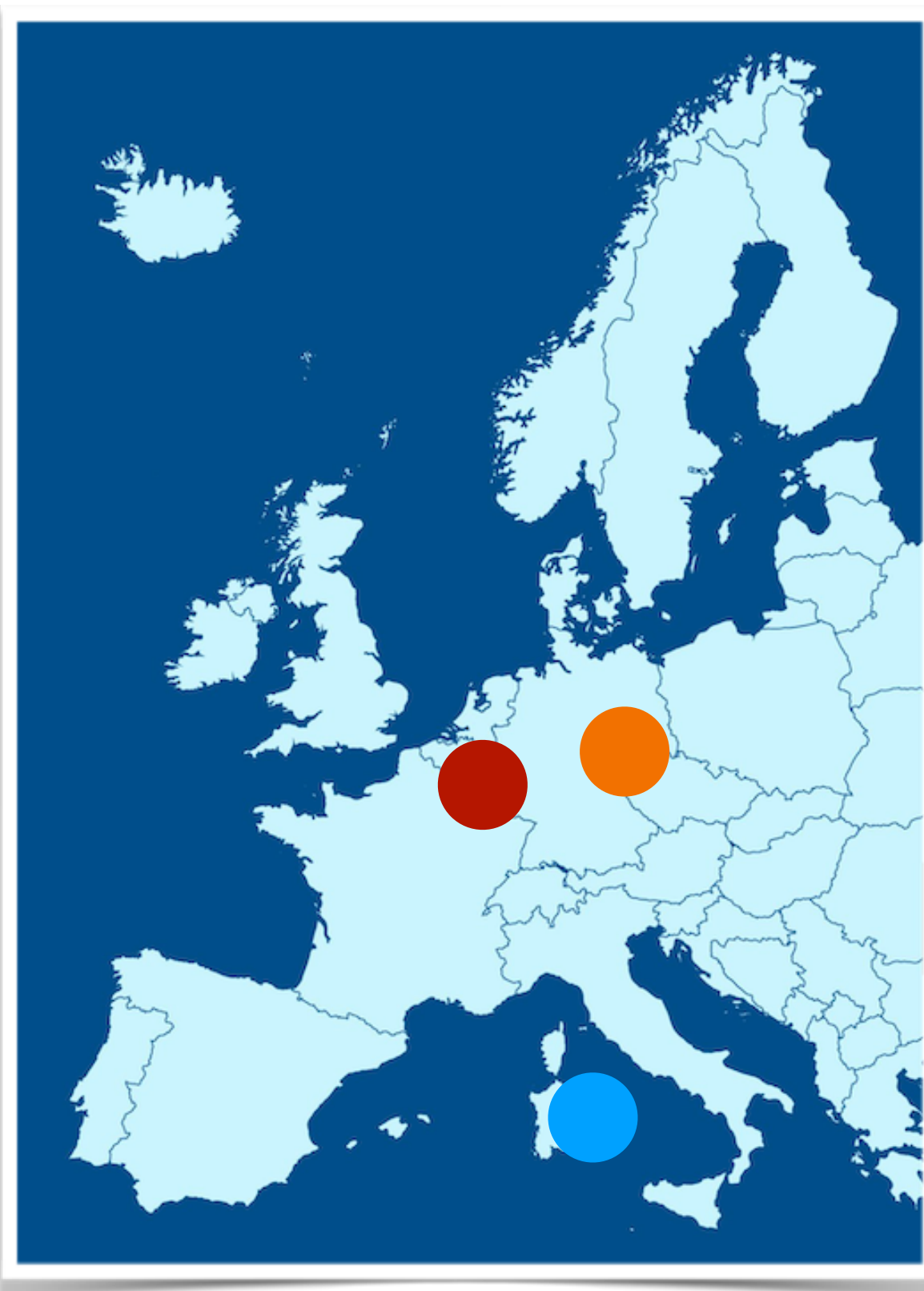
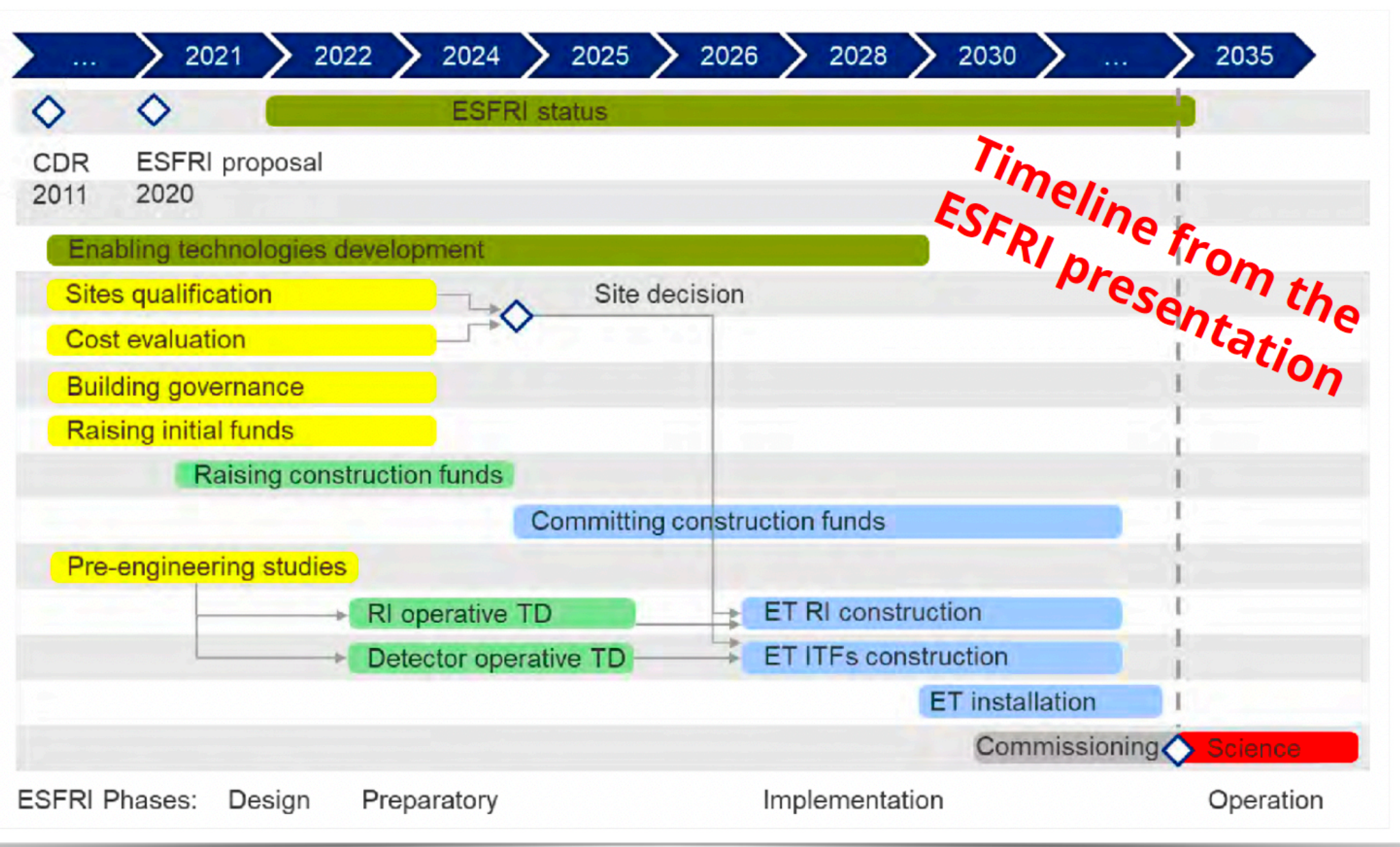
- Large UHV volumes
- Cryogenics
- Lasers and precise optics
- High precision mechanics
- Low noise controls
- High quality opto-electronics
- Innovative adaptive optics
- Innovative IR detection

200 m



# The Einstein Telescope

*What. when. where. how much –*



Three sites formally expressed interest in hosting the infrastructure

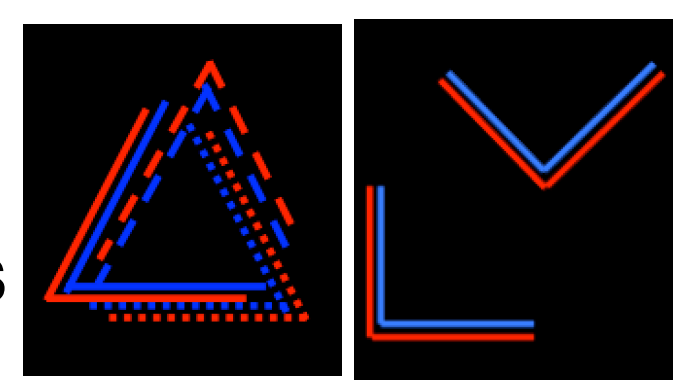
@ **Limburg area**  
(border NL-B-D)  
-> Promoted by **Nikhef**  
[About 900M€ secured]

@ **Sardinia**  
-> Promoted by **INFN**  
[About 1300M€ secured]

@ **Lusatia/Saxony**  
-> Promoted by **DESY**

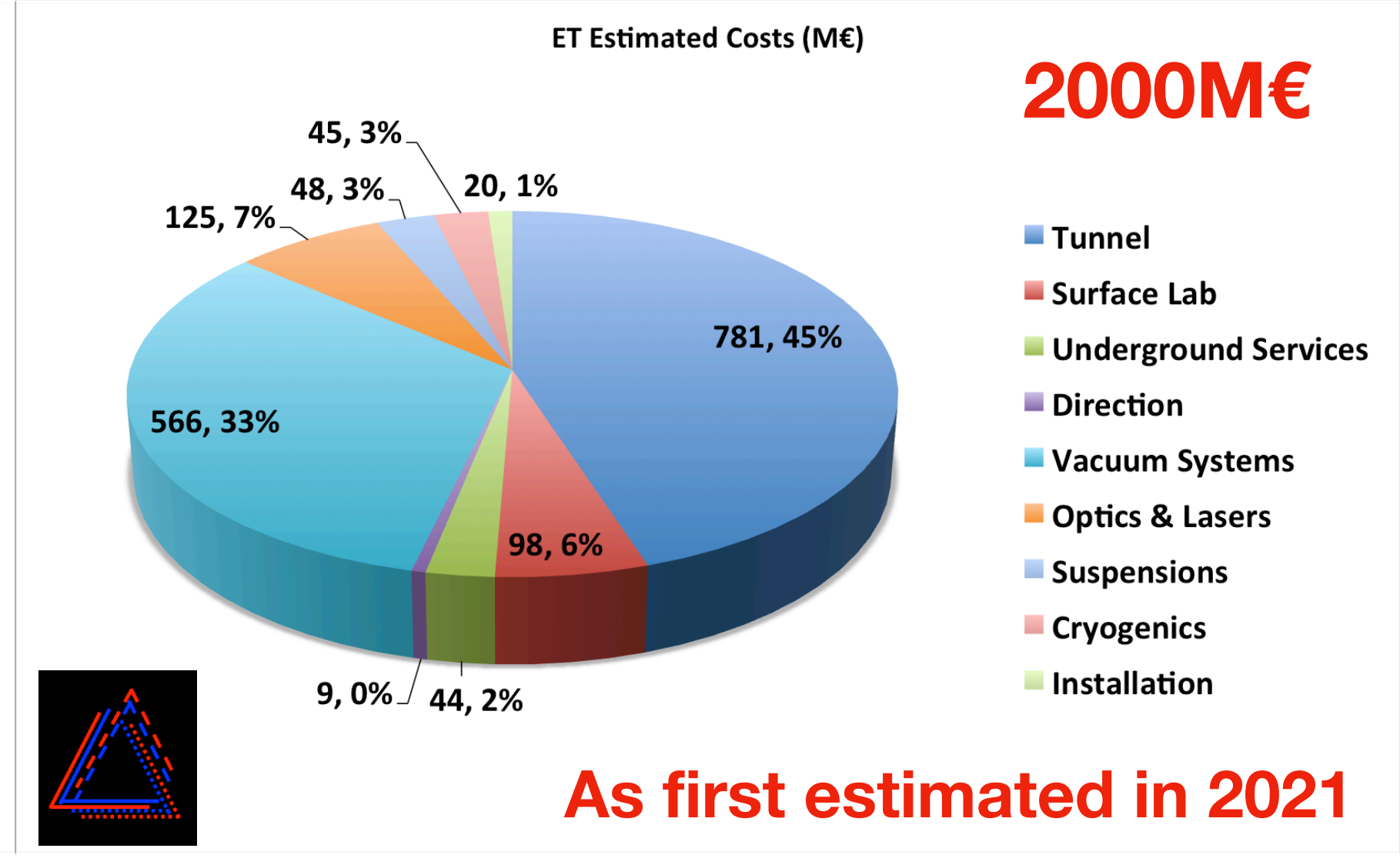
The three sites carrying out a full program of site characterization, noise evaluation, geology, costing, socio-economic impacts, sustainability, etc..

ET is evaluating the possibility of building a distributed 2 L 15km arm configuration instead of a single triangular 10km arm – work ongoing to compare options



**Current timeline**

- Site characterisation work finished by end of 2026 – tenders
- Site(s) decisions expected by end 2027



# Einstein Telescope as ESFRI



Funding & tender opportunities  
Single Electronic Data Interchange Area (SEDIA)

SEARCH FUNDING & TENDERS HOW TO PARTICIPATE PROJECTS & RESULTS WORK AS AN EXPERT

Preparatory phase of new ESFRI research infrastructure projects

TOPIC ID: HORIZON-INFRA-2021-DEV-02-01

Grant

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## Goals for ET Preparatory Phase

- Governance
- Financial architecture/plan/framework
- Industrial Returns and KTT
- ET legal entity
- Final ET design and cost evaluation
- Site or sites selection
- Construction funding
- User services
- Computing model
- Sustainability

**3.45M€**

single-stage

30 September 2021

Type of M

HORIZON  
Based [H

Deadline

20 Janua

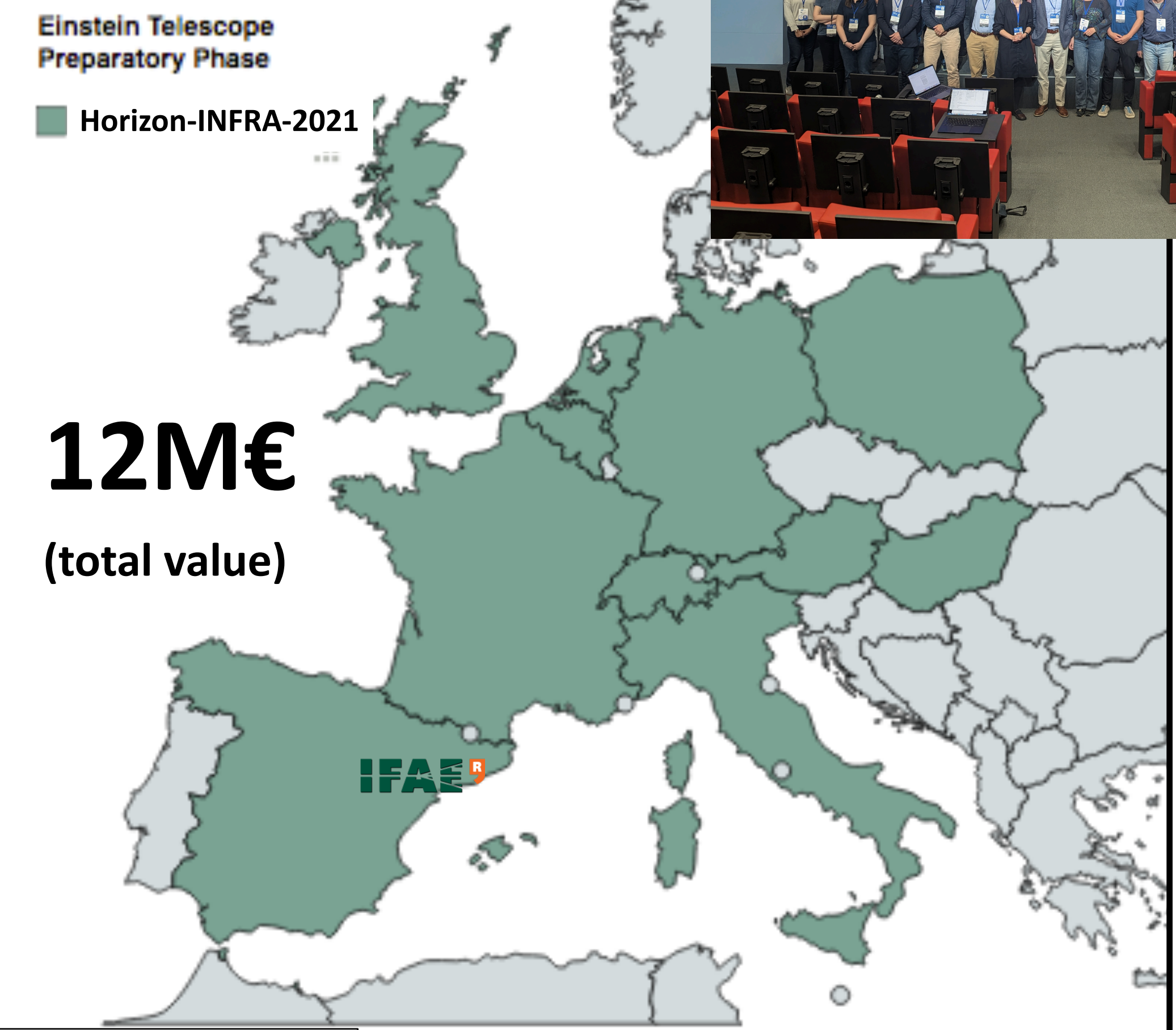


**ET-PP**  
Preparatory Phase for the Einstein Telescope  
Gravitational Wave Observatory  
Einstein Telescope will be the European Third-Generation Gravitational Wave Observatory, designed to observe the Universe by covering the

## Einstein Telescope Preparatory Phase

Horizon-INFRA-2021

**12M€**  
(total value)

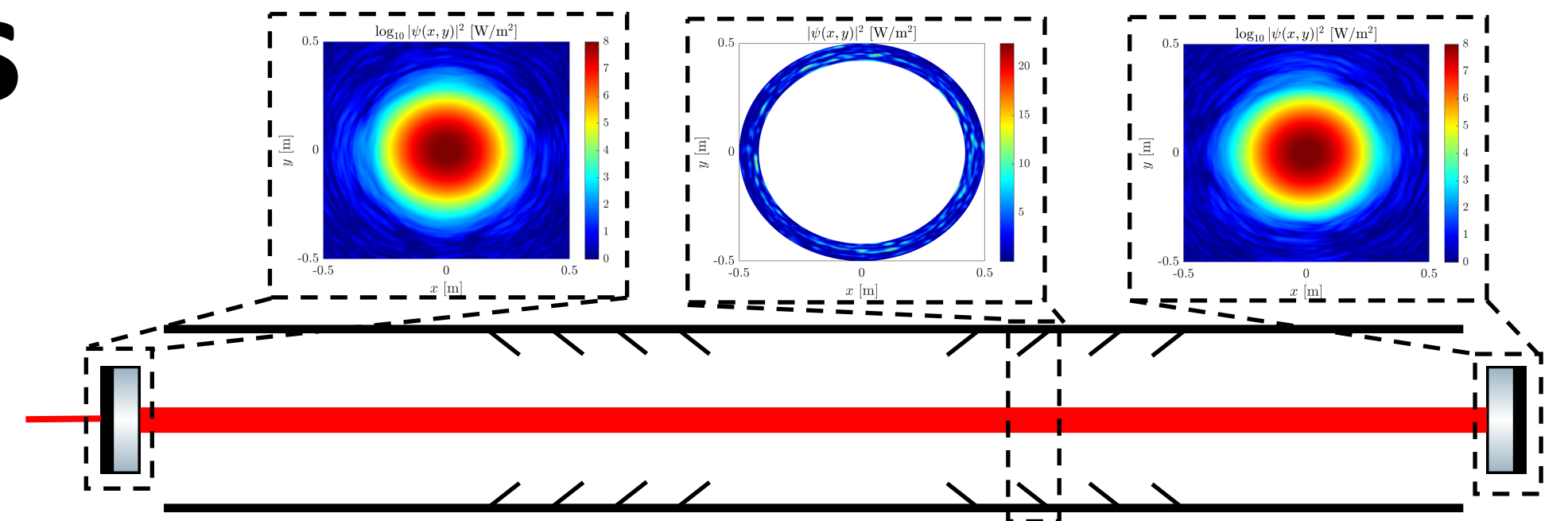
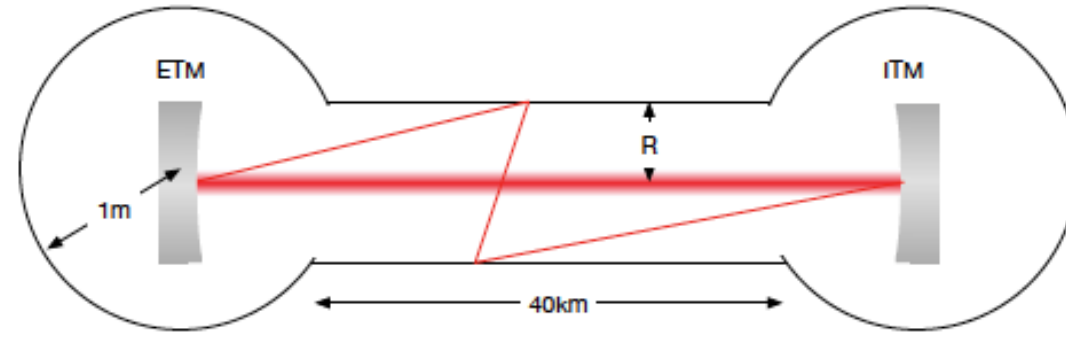
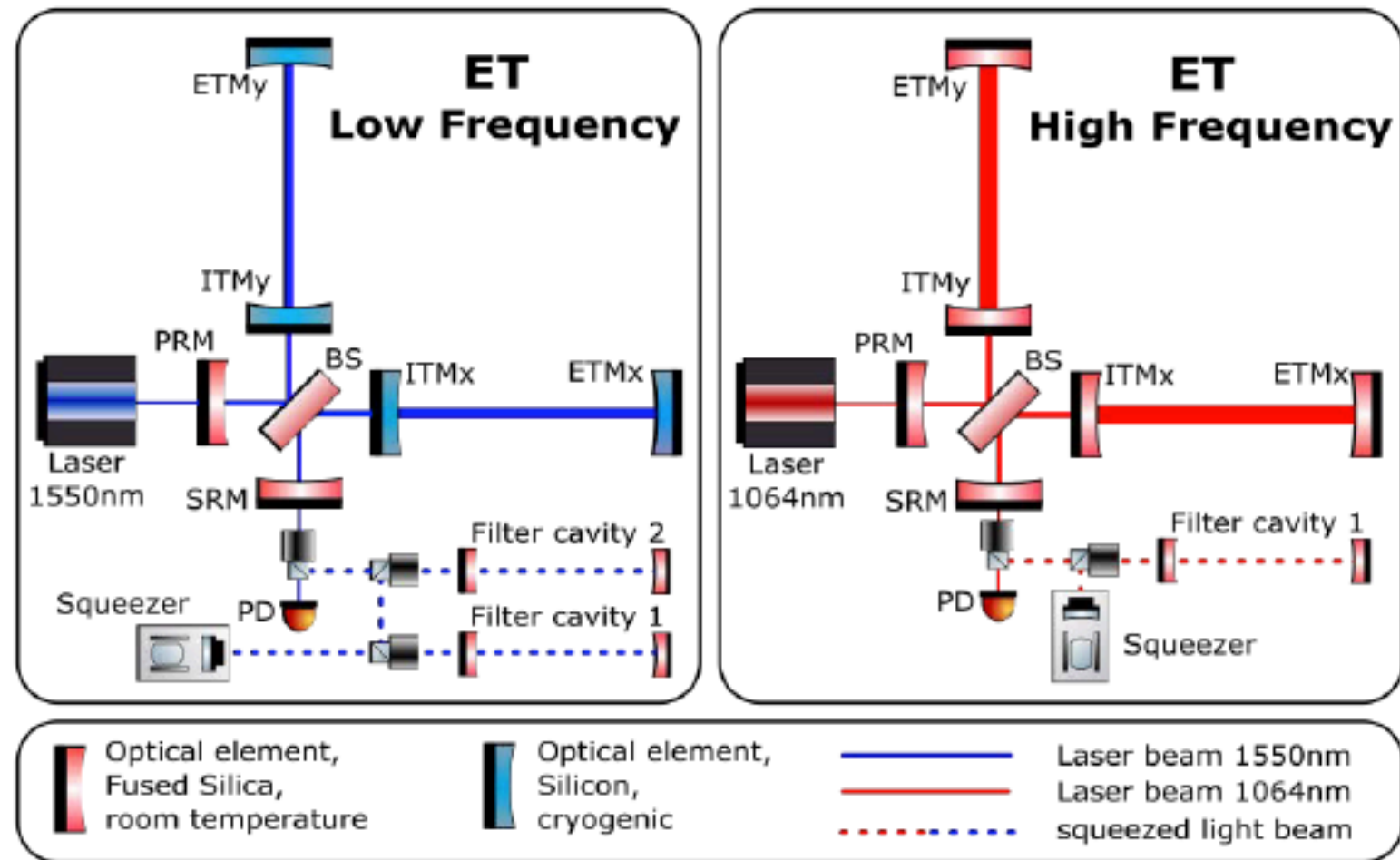


**Einstein Telescope Preparatory Phase (ET-PP) in 2022 – 2026**

**HORIZON-INFRA-DEV EU Project coordinated by IFAE**

→ <https://etpp.ifae.es> → 6 months more

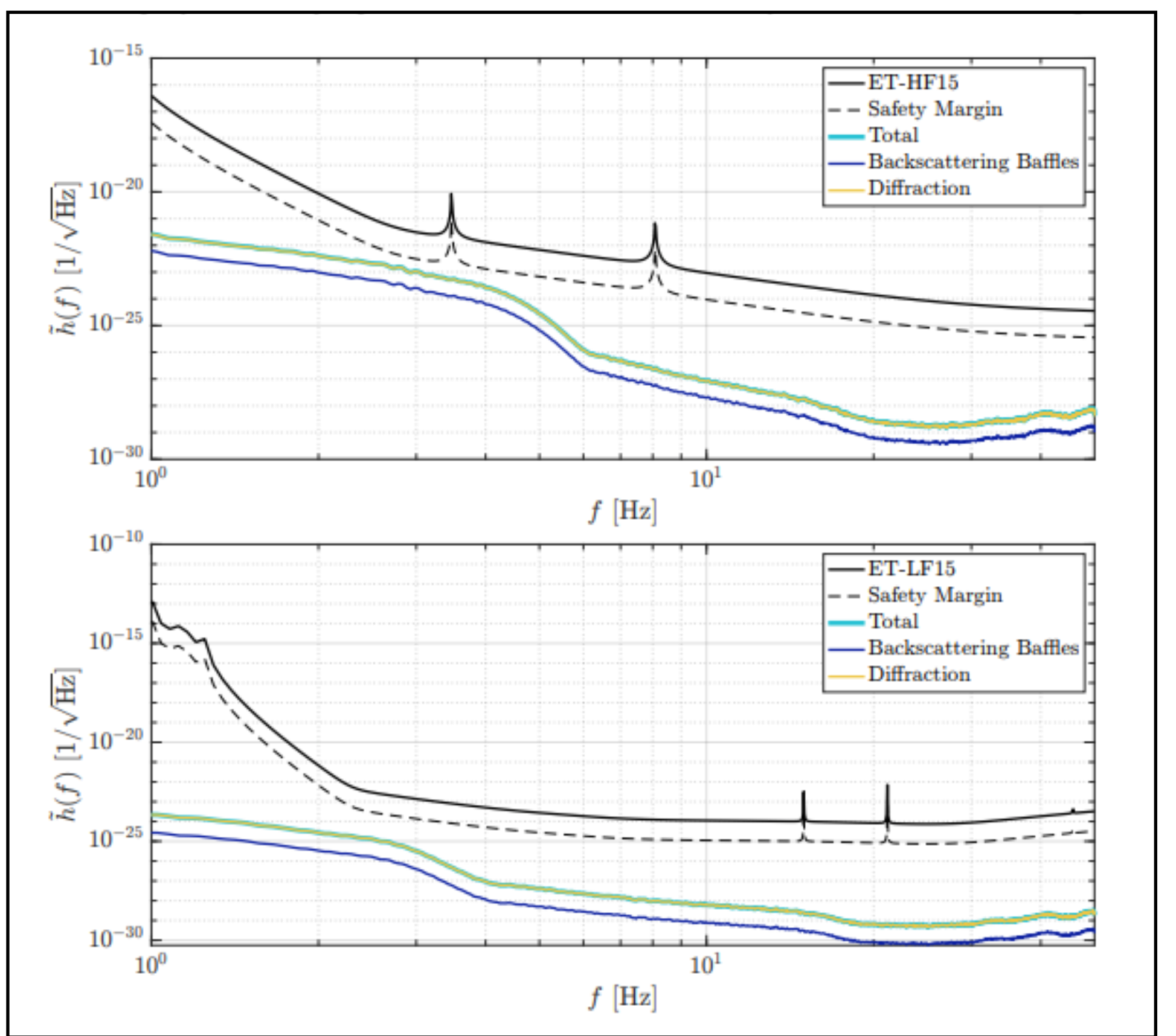
This is an intense activity with large international visibility  
— 4th annual meeting in BCN last week



IFO	$\lambda$	mode	mirror $\varnothing$	$R_C$	$w_0$	$z_0$	$w$	$g$ -factor
ET-HF	1064 nm	TEM <sub>00</sub>	62 cm	5070 m	1.42 cm	5000 m	12.0 cm	0.95
ET-LF	1550 nm	TEM <sub>00</sub>	45 cm	5580 m	2.9 cm	5000 m	9.0 cm	0.63

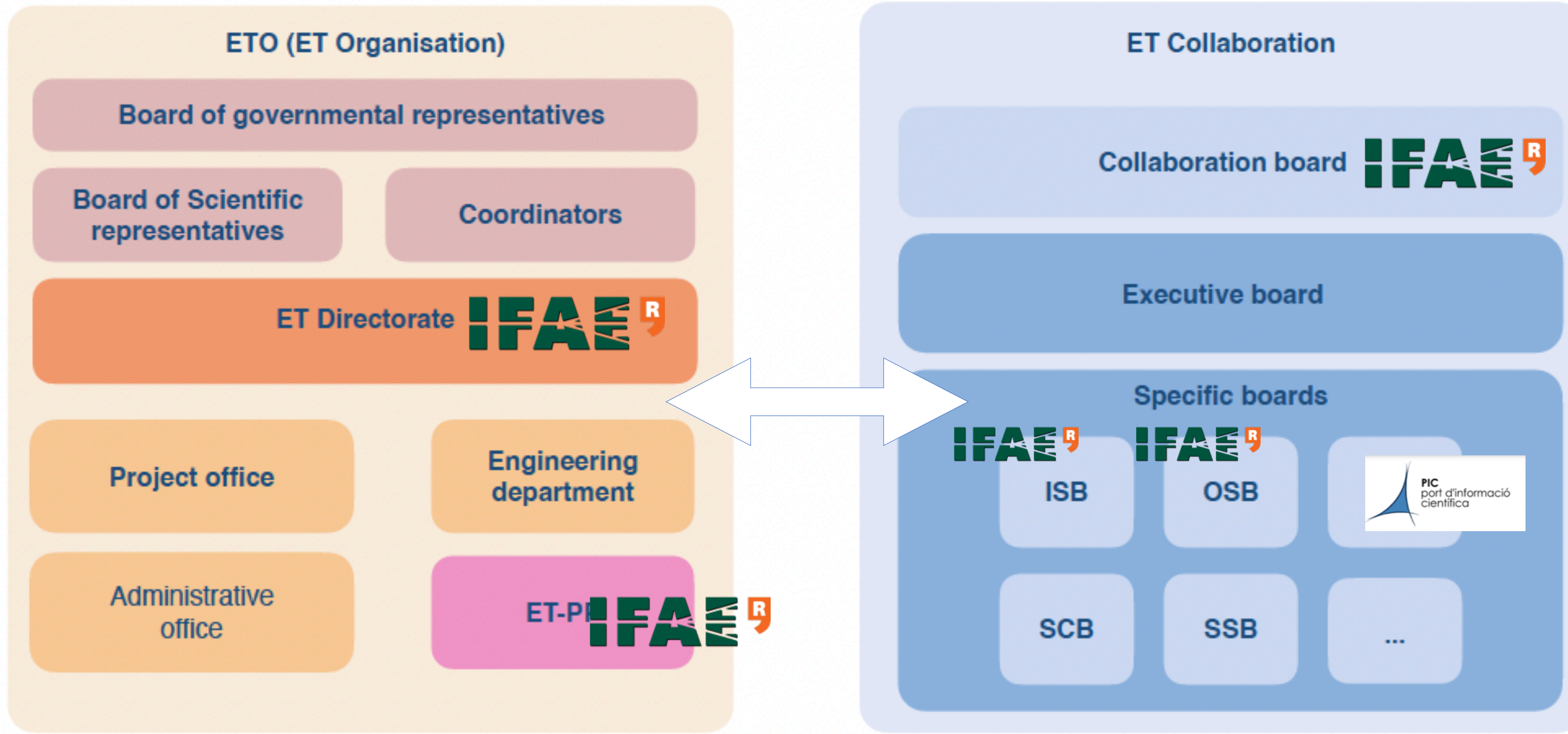
## Detailed simulations of the light propagation in the optical cavities

- > Crucial input to determine tune diameter [huge impact on cost]
- > Determines the mitigation strategy for reducing stray light noise
- > Determines the baffle requirements (dimensions and optical specs)
- > Determines the distribution of baffles in the 10km and 15km arms
- > Possible thanks to close relation with Caltech - LIGO since 2020
- > Running common ET/Cosmic Explorer meetings on Stray Light Control



IFAE recognised now as the reference inside ET for these aspects

# IFAE @ LVK&ET Organization



2024/5 IGWN Sessions

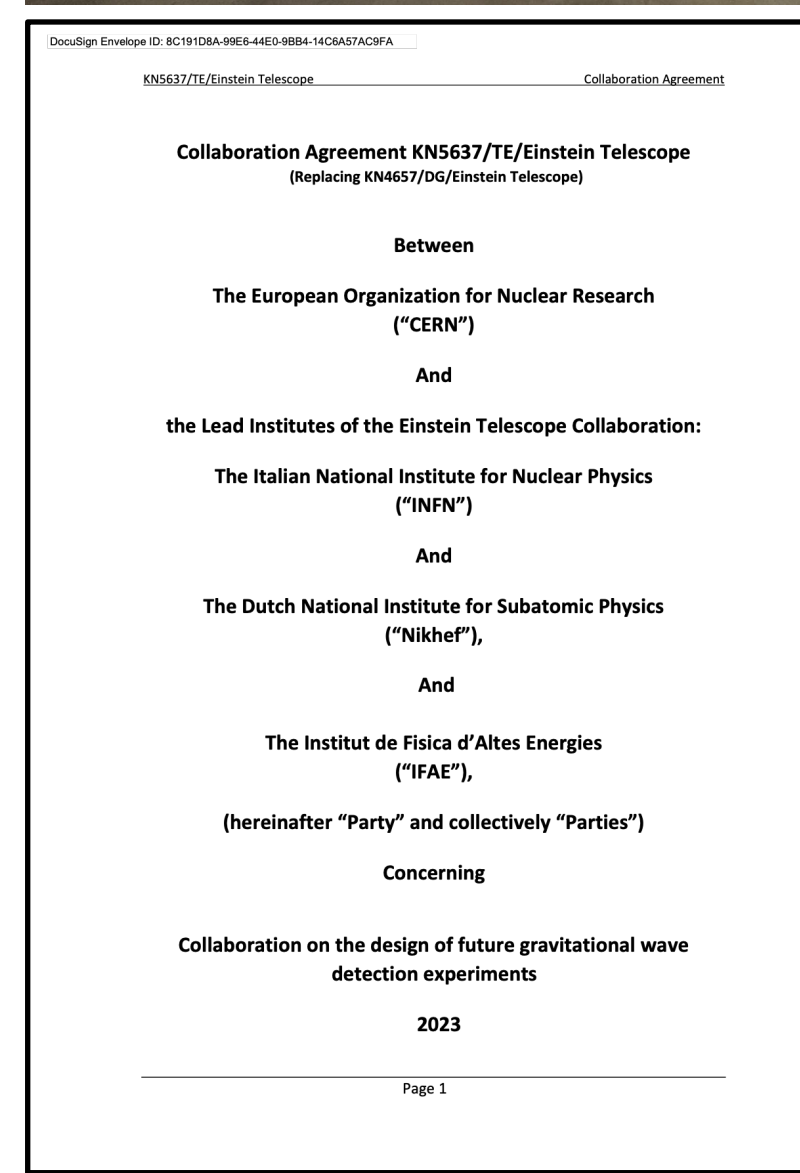


IFAE is central in LKV & ET Governance

- Part of ETO Directorate and Coordinator of ET-PP EU project
- Chair of the ET Collaboration board (until end 2025)
- Convener of Virgo - SLC WG ; Programme Committee
- Co-convener of ET-SLC WG (until 2021 — fall 2025)
- Co-chair of the IGWN design committee

IFAE is member of the ETO funders group & ET-COMPASS

IFAE — CERN MoUs on Vacuum and Civil Engineering work



ET Vacuum Workshop @CERN

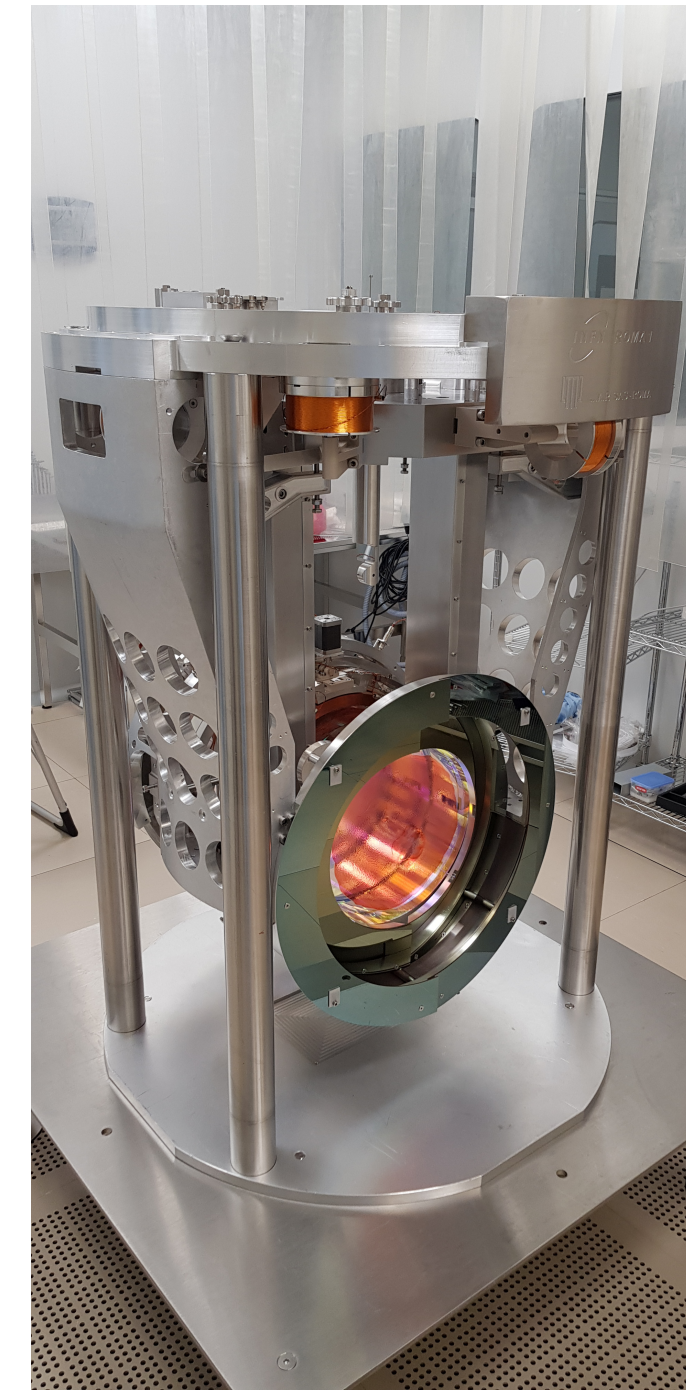
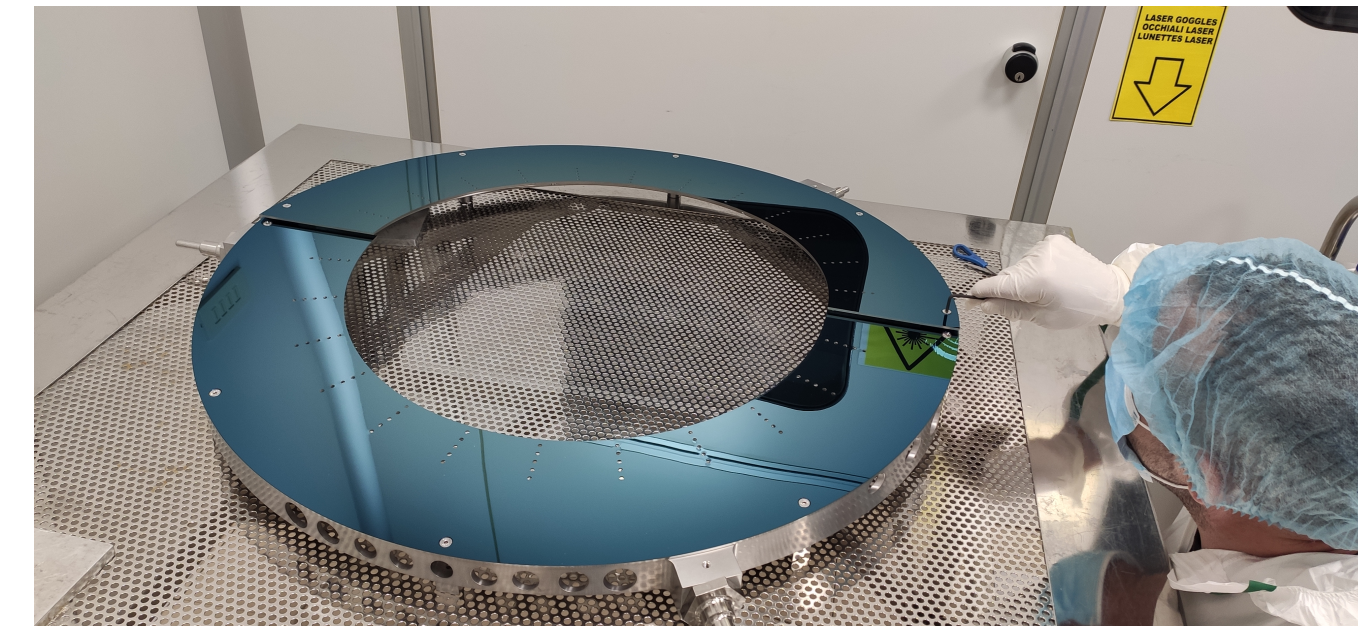
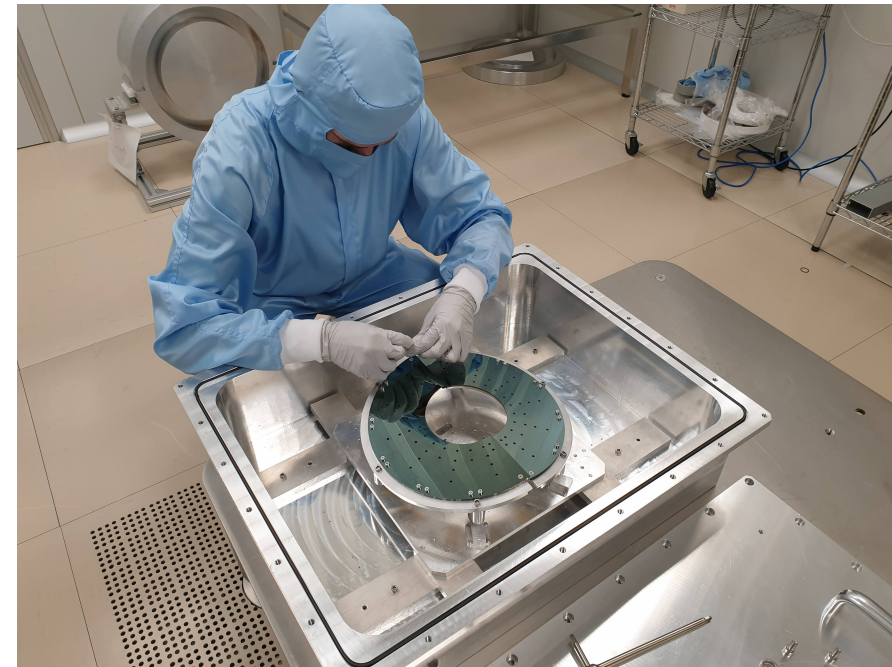


# Some key ideas for 2026-27

New competences in advanced optics  
 — initiating close collaboration with the  
 UPC Applied Optics Engineering Dept.

- Use the imminent Virgo upgrade as a unique opportunity and as an advanced R&D platform to increase the experimental community working on Gravitational Waves and the capacities of the Spanish industry in preparation for ET  
 — this is relevant for ET-HF & ET-LF

- Stray light control — already happening
- Payloads for the main mirrors
- Control systems for the mirrors



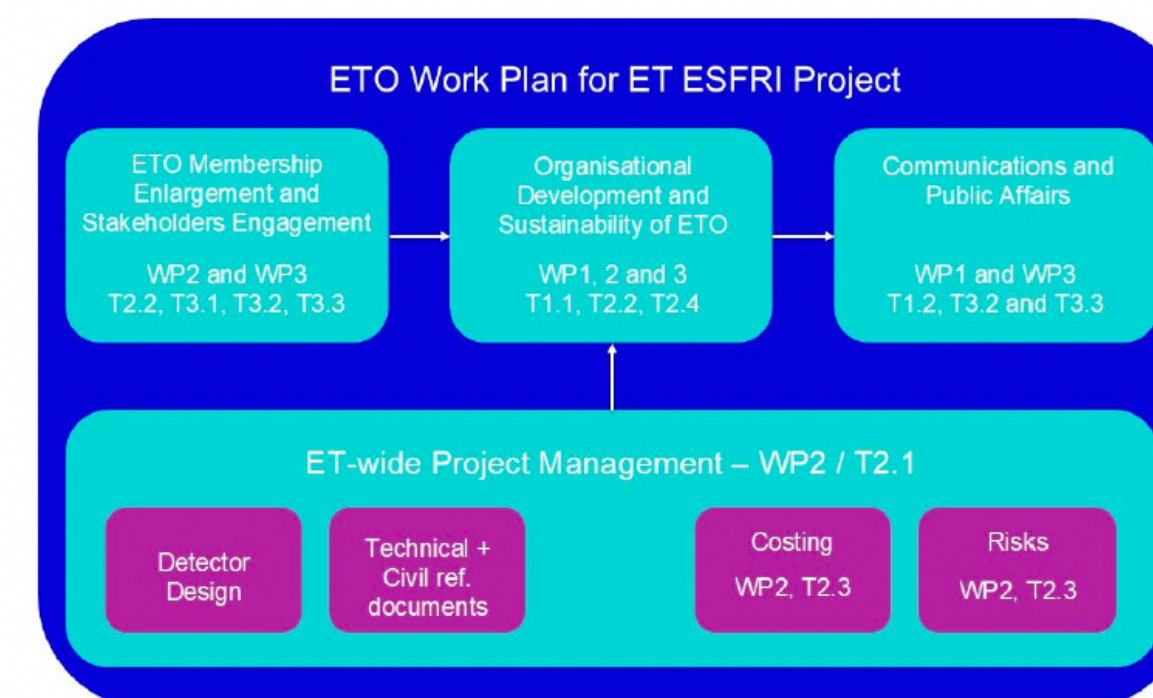
- Get involved in the flagship ET R&D platform for development the new cryogenic technology for ET-LF.  
 — also opens possible involvement in the ET cryotrap

- Cryogenics — already happening
- Stray light control in cryogenic temperatures @ 1550 nm
- Participation in EU INFRA-DEV and INFRA-TECH calls for R&D



- Maintain IFAE a central player in the ET Governance

- ET-PP Coordination
- ET-COMPASS activities on ET cost and risk evaluation



# Let's work together



We are excited to explore potential synergies in the GW field with you