

IFAE-GWs

Mario Martínez



On behalf of the IFAE-GW team

ET



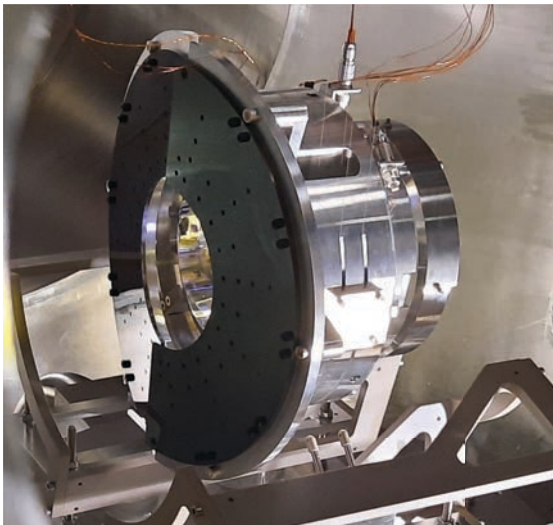
EINSTEIN
TELESCOPE

ET-Spain Meeting
8th Oct. 2021

Overview of Activities

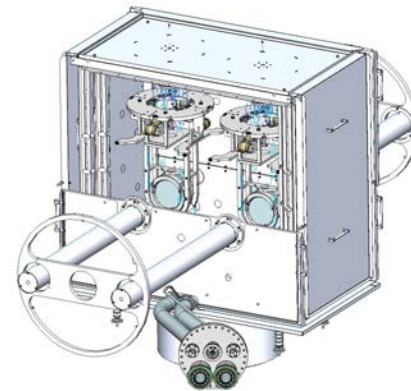
On Virgo 2nd Generation Experiment

- Instrumentation for AdV+
- Coordinating SLC WG
- Stray light simulations and determination of induced noise affecting sensitivity
- Commissioning activities @ Virgo
- Physics analysis @ LVK
- LVK Computing using PIC



On ET 3rd Generation experiment

- ETpathfinder cryogenics
- Development of instrumented baffles
- Coordinating ISB WG on Stray Light
 - Simulations of ITF layouts
- Involved on OSB Cosmology WG
- Involved in Computing via PIC
- Signed light MoU for ET construction



- Steering Committee Representative
- Coordinating EU-INFRADEV ESFRI call

Personnel / Authors (Scientists)

NAME	Position	Activity
O. Blanch	Senior Scientist	Instrumentation
M. Martinez	Senior Scientist	Team Leader
Ll. Mir	Senior Scientist	SLC coordinator
M. Kolstein	Researcher	Simulation + Analysis Codes
C. Karathanasis	PhD Student	Operations + Physics
A. Menendez	PhD Student	Operations + Physics
A. Romero	PhD Student	Operations + Physics
M. Andres	PhD Student	Simulations + Physics
J. Caneva	PhD Student	Operations + Physics
A. Macquet	Postdoc	Simulations + Physics
O. Piccinni (UNESCO-L'Oreal Fellow)	PostDoc (→ Feb 2022)	Operations + Physics

+ Master students (4 students/year)

+ strong support from IFAE's Technical and Computing Divisions

+ strong synergy with IFAE's TH Division (see Oriol Slides)

Operations and Commissioning

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

2019 Results Published

A Cirone *et al* 2019 *Class. Quantum Grav.* 36 225004

I. Fiori *et al.*, *Galaxies* 2020, 8(4), 82

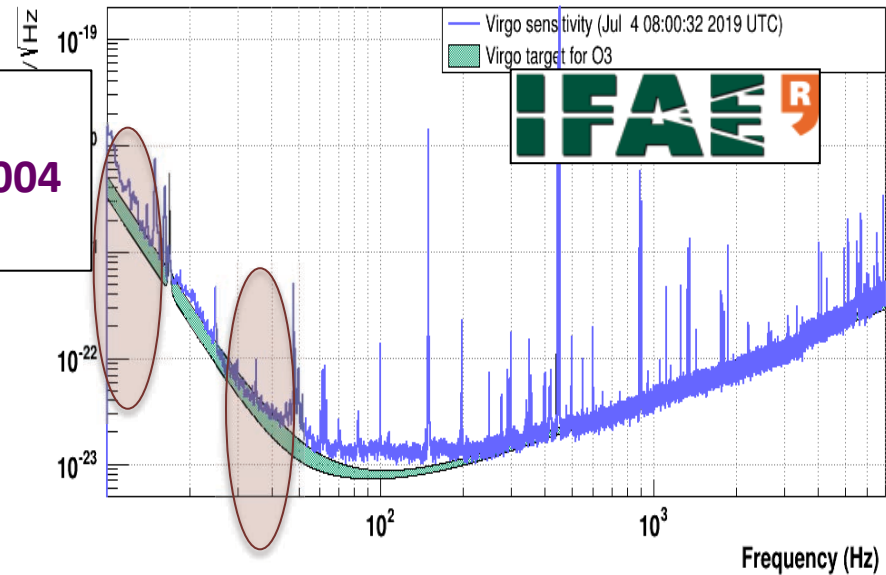
2021 (now) 3 people based @ EGO

→ IMC operations

→ ITF commissioning

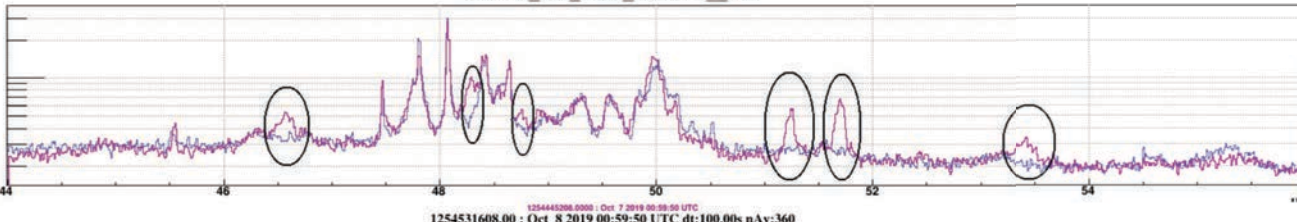
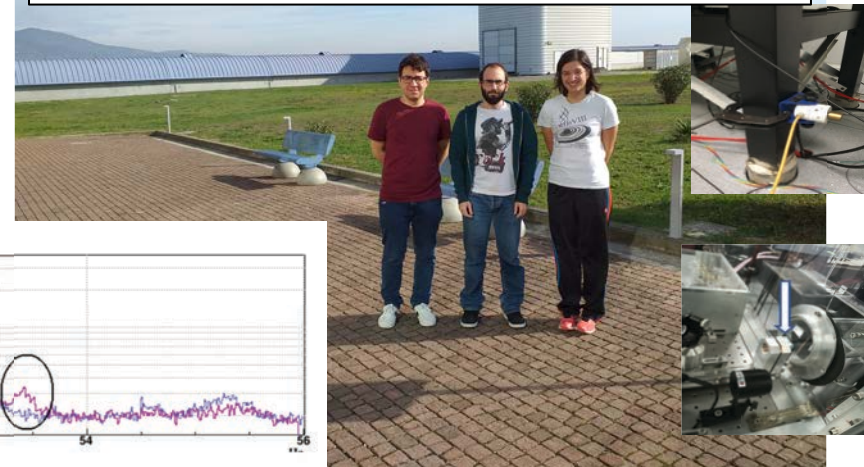


Virgo Sensitivity



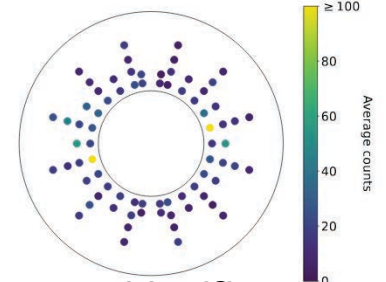
2019 → 3 people based @ EGO

→ ITF commissioning /Noise hunting



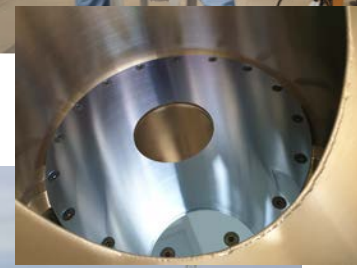
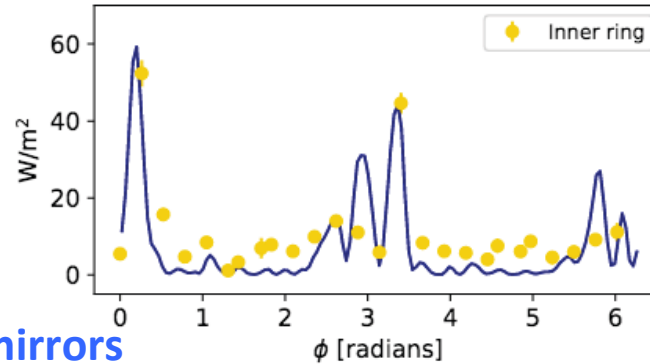
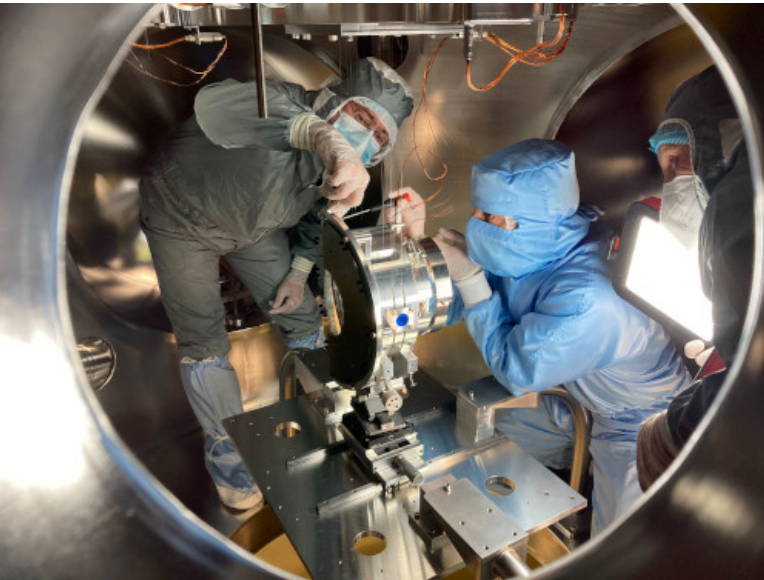
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1254531608.00 | Oct 8 2019 00:59:50 UTC dt:100.00s nAv:360

Instrumented baffle @ Virgo

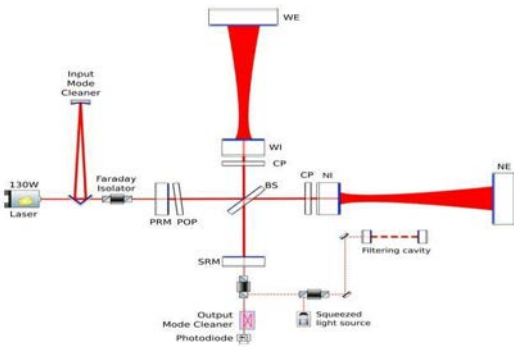


Installed in April 2021 @ EGO

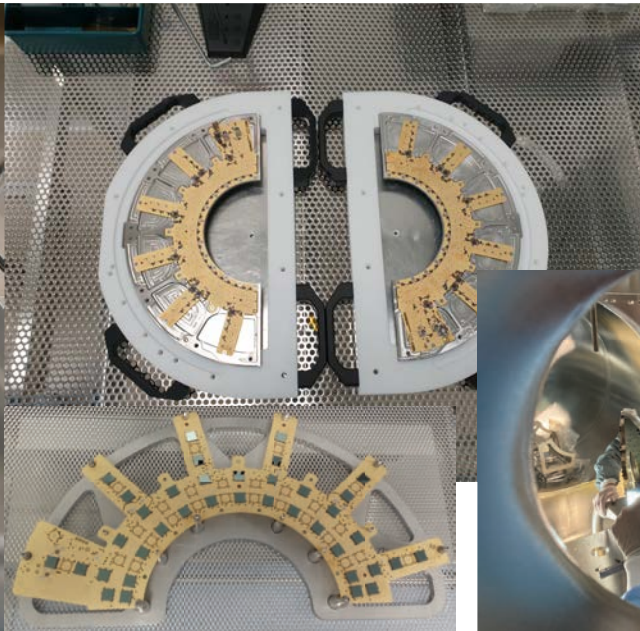
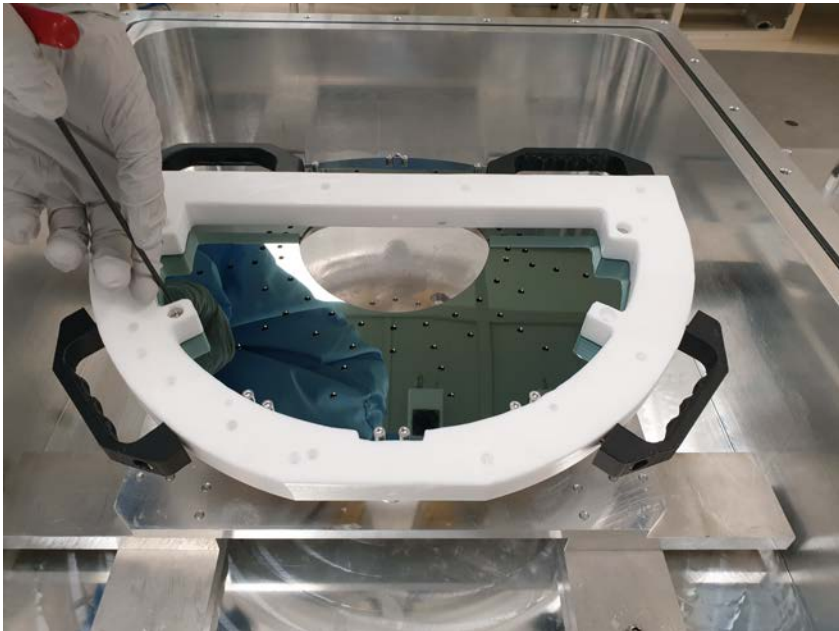
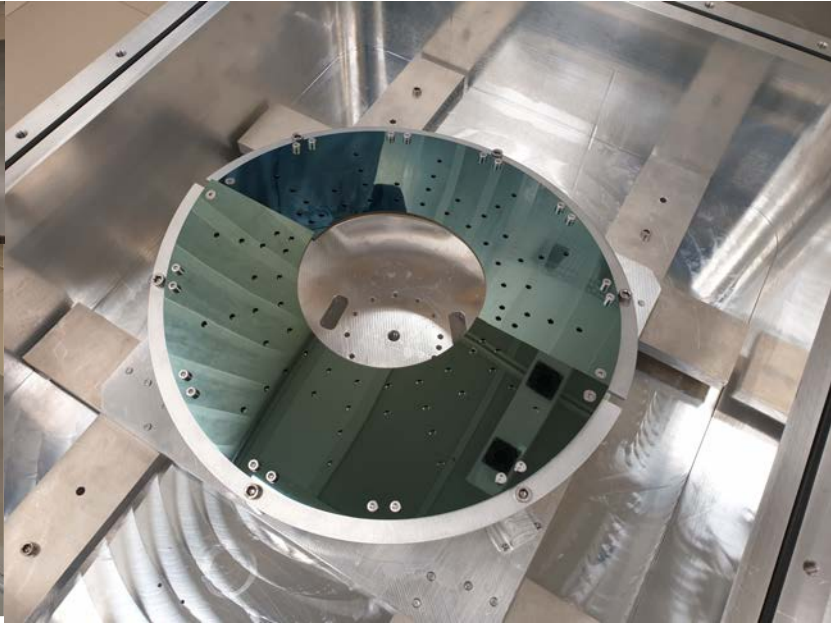
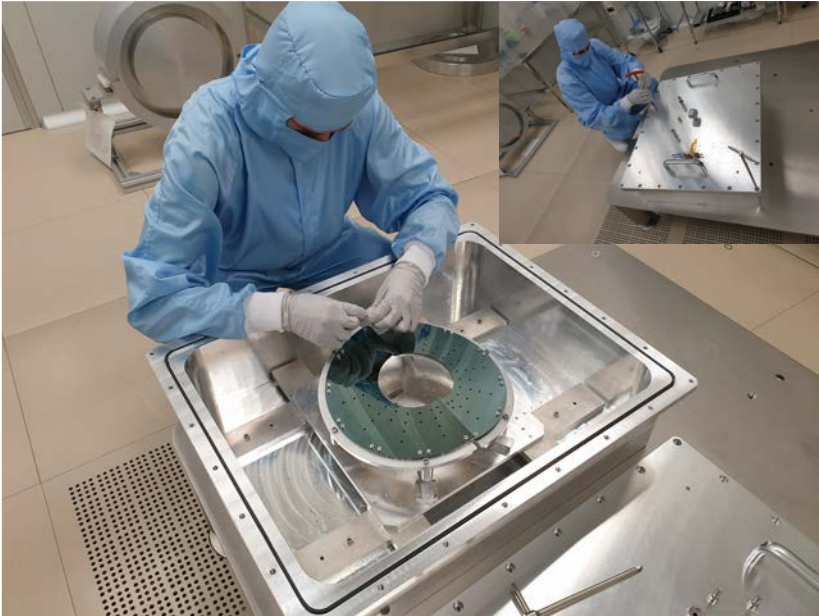
The installation of the first instrumented baffle in Virgo has demonstrated that the active monitoring of the stray light at the core optics of interferometers is feasible.



Now building the big baffles in main mirrors
→ Great effort in front of us for next two years



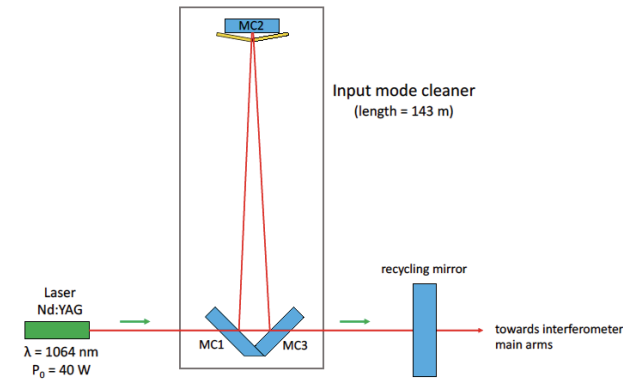
Installation @ IMC end mirror (April 2021)



Simulations

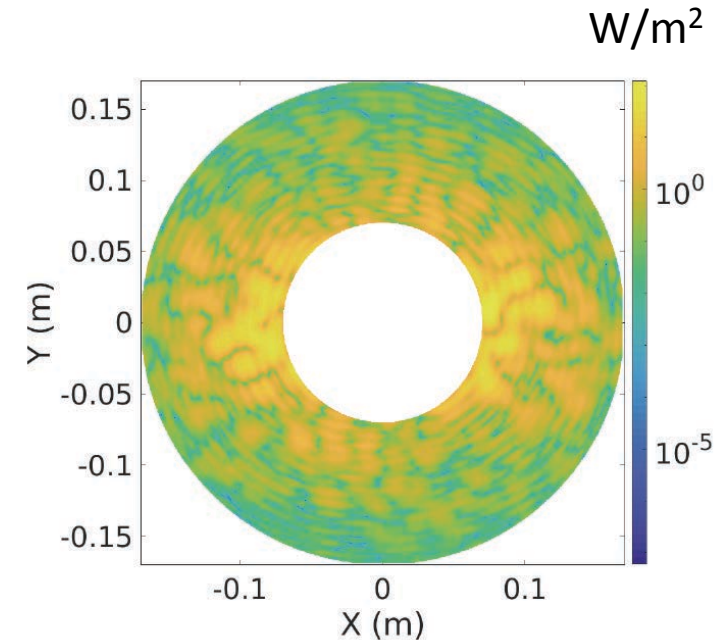
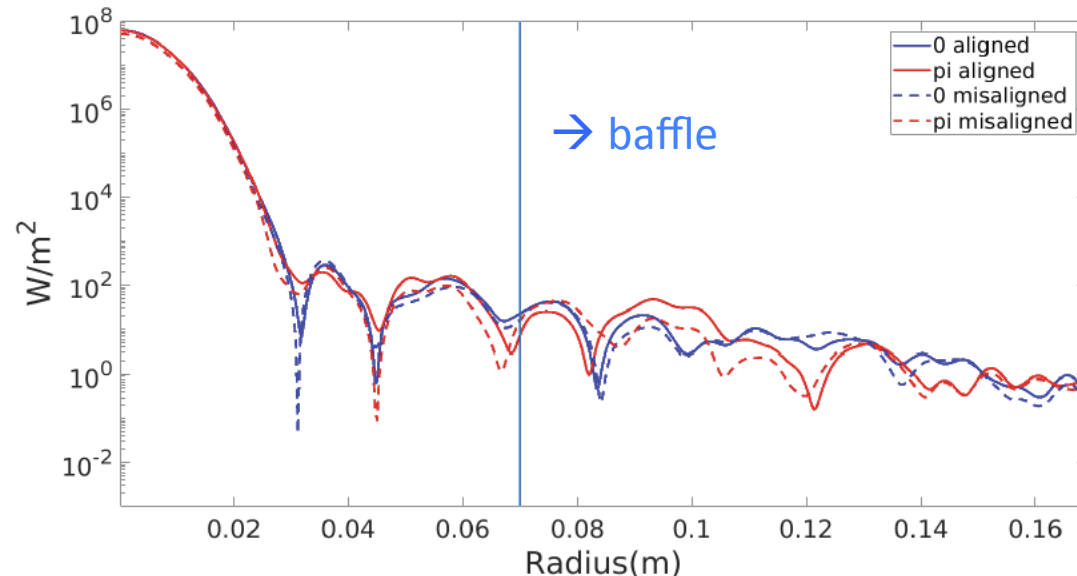
Simulations were used to optimize the sensor layout and determine the level of light power to be exposed to

We performed also studies on miss-aligned cavities



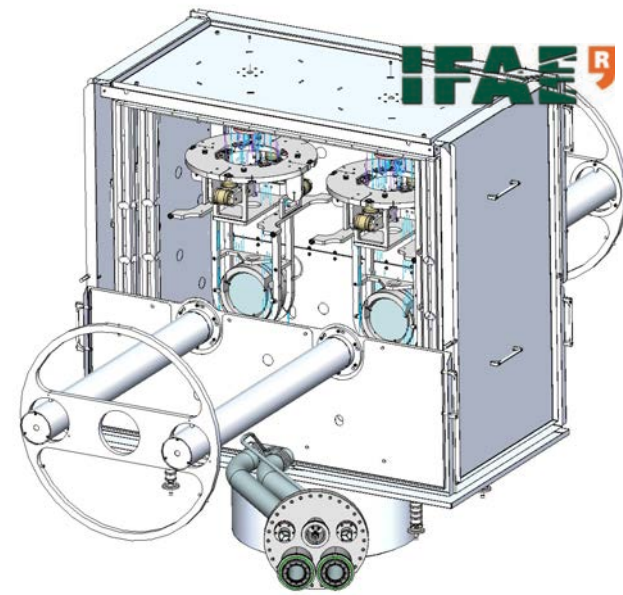
In close collaboration with Caltech and EGO/Pisa Scientists

Scenarios	Mirror + baffle	Baffle	Photodiode
Resonance	1.35×10^4 W	0.20 W	3.2×10^{-3} W
Misaligned (10 μ rad)	1.19×10^4 W	0.17 W	3.0×10^{-3} W
Extremely misaligned	-	-	2.1×10^{-2} W
Mechanical drift	390 W	-	130 (for 10 ms)



Plans for extended stays at Caltech (paid by LIGO) affected by Covid-19

ETpathfinder

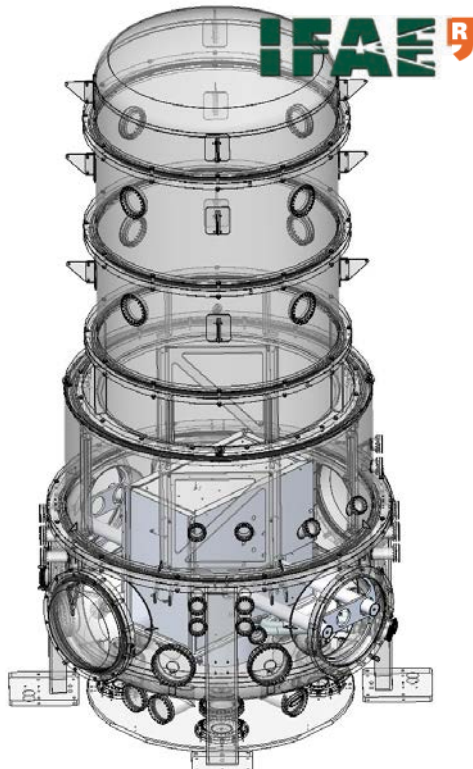


A collaboration has been established with Etpathfinder

→ IFAE redesigned the cryo-shielding and will coordinate the production of a prototype in local industry [paid by Nikhef]

→ Exploring the monitoring of the mirror surface at 10 Kelvin (instrumented baffle with sensors for $\lambda = 1550 / 2090 \text{ nm}$)

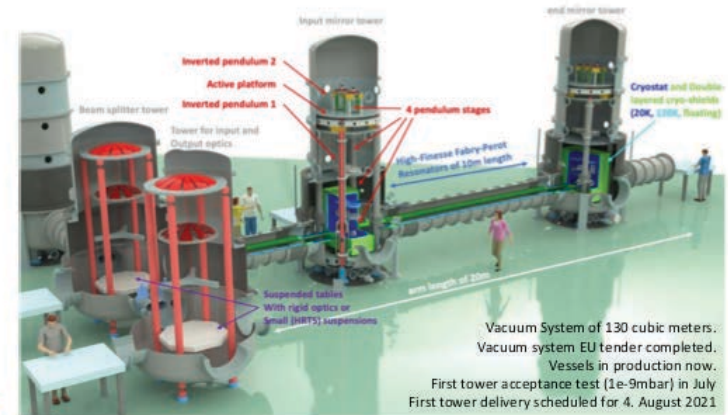
→ R&D on materials for coated baffles to reduce scattered light



ETpathfinder

- New facility for testing 3G technology in a low-noise, full-interferometer setup.
- Key aspects: **Silicon mirrors** (3 to 100+kg), **cryogenics** (cryogenic liquids and sorption coolers, water/ice management), **"new" wavelengths** (1550 and 2090nm), new coatings ...
- Start with 2 FPMI, one 120K and one 15K.
- **16 official partners from NL/B/G/FR** + a few more involved, but not yet official partners (like AEI, KIT, Bham, Cardiff, **Barcelona** etc.).
- **Initial capital funding of 14.5 Meuro (no personpower).**
- Detailed **Design Report** available at apps.et-gw.eu/tds/?content=3&r=17177
- **Open for everyone interested to join.**
- www.etpathfinder.eu

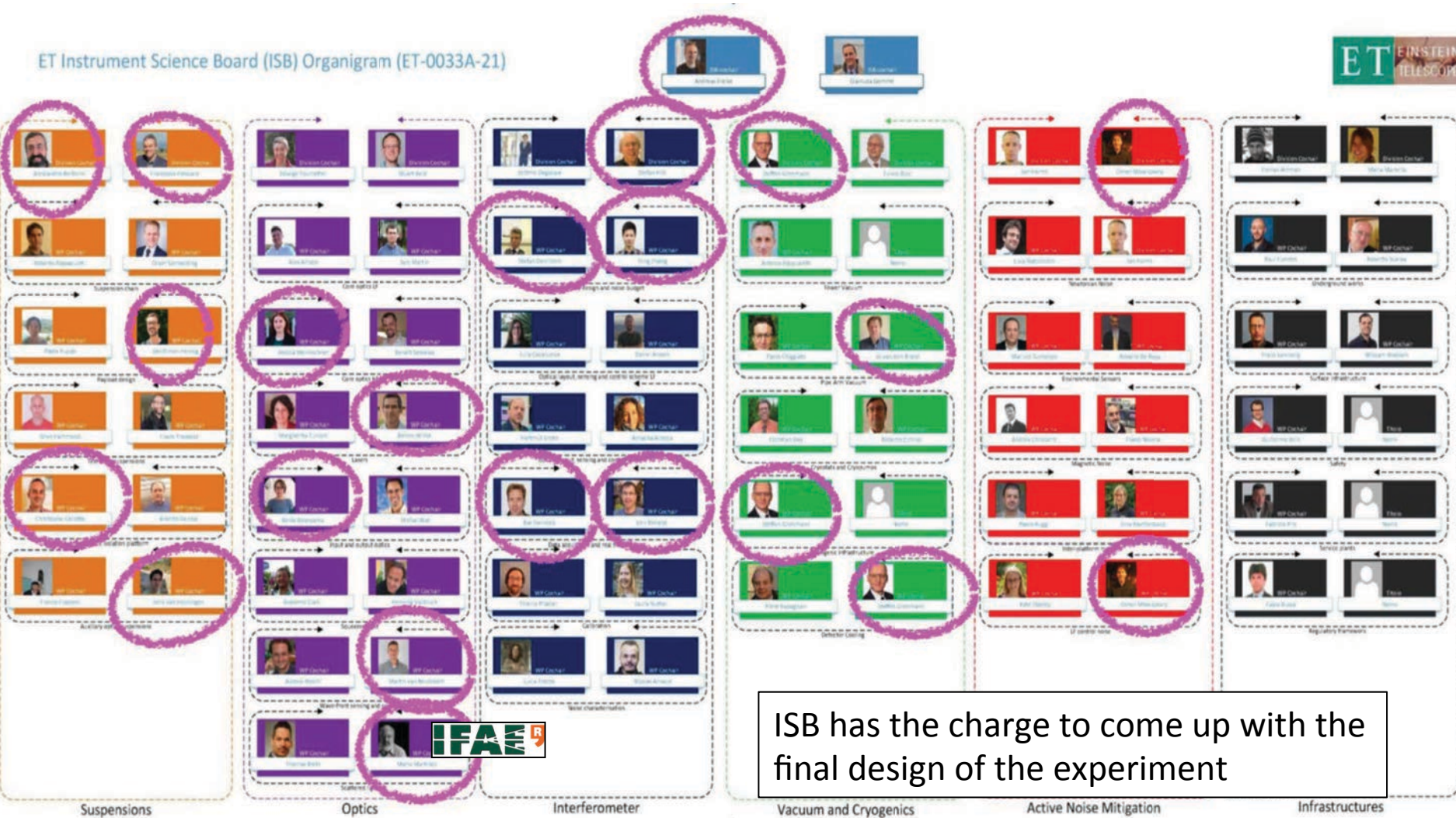
Nikhef SAC, 2021-05-26



Slide from last Nikhef SAC Meeting

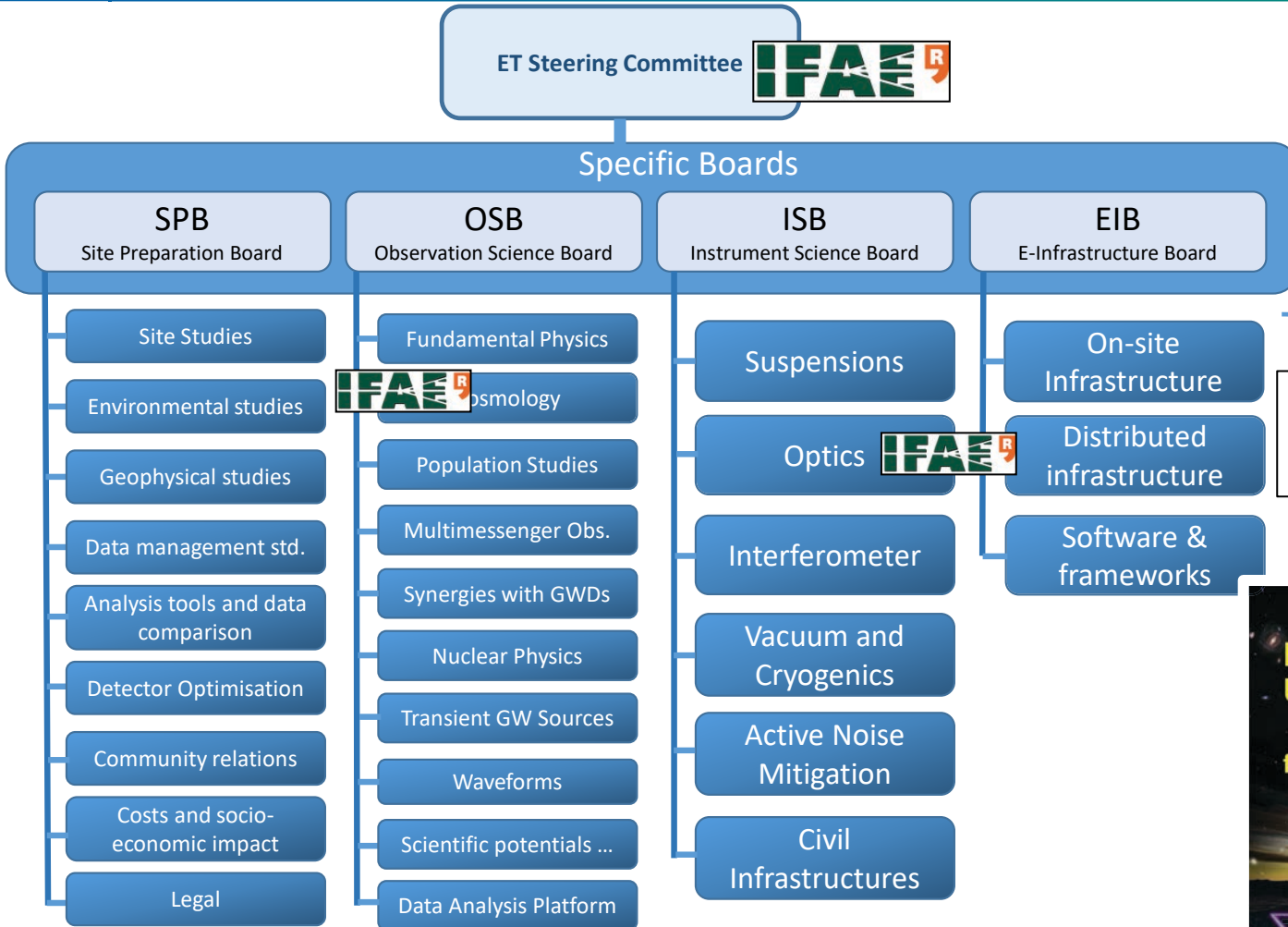
ETpathfinder in ET Instrument Science Board

ET Instrument Science Board (ISB) Organigram (ET-0033A-21)

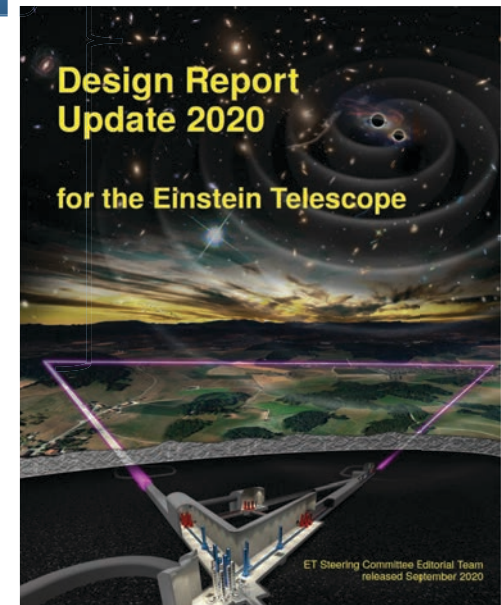


ISB has the charge to come up with the final design of the experiment

As one can expect there is a large overlap between ETpathfinder partners and ET ISB

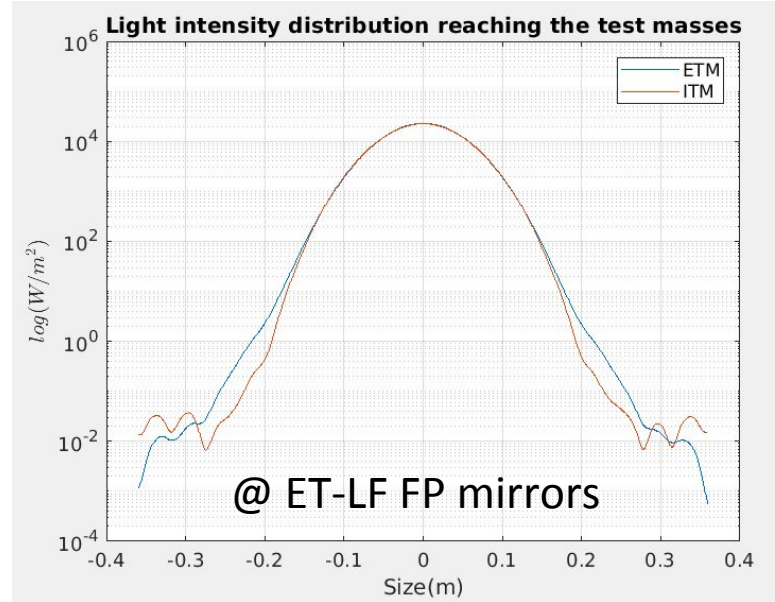
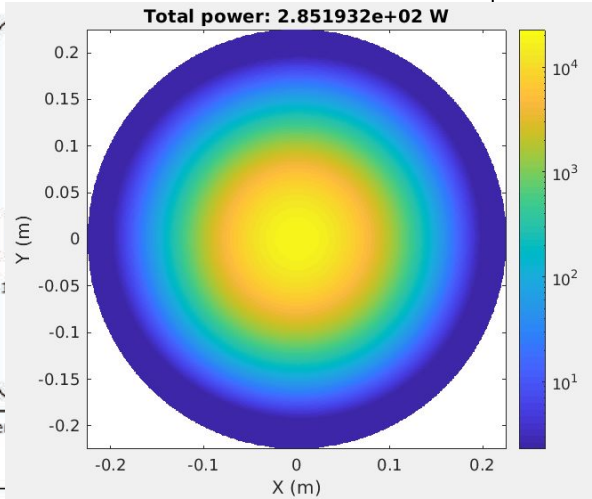
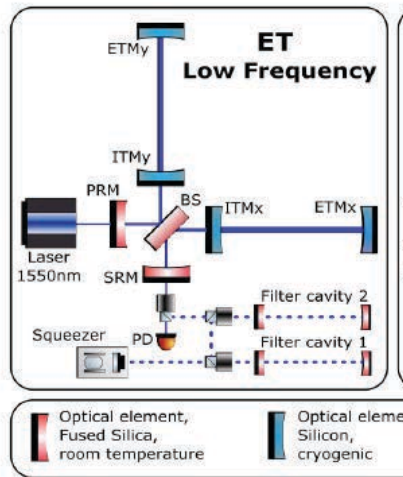


Contributions to the CDR revision in 2020



IFAE is very present in the ET organization chart

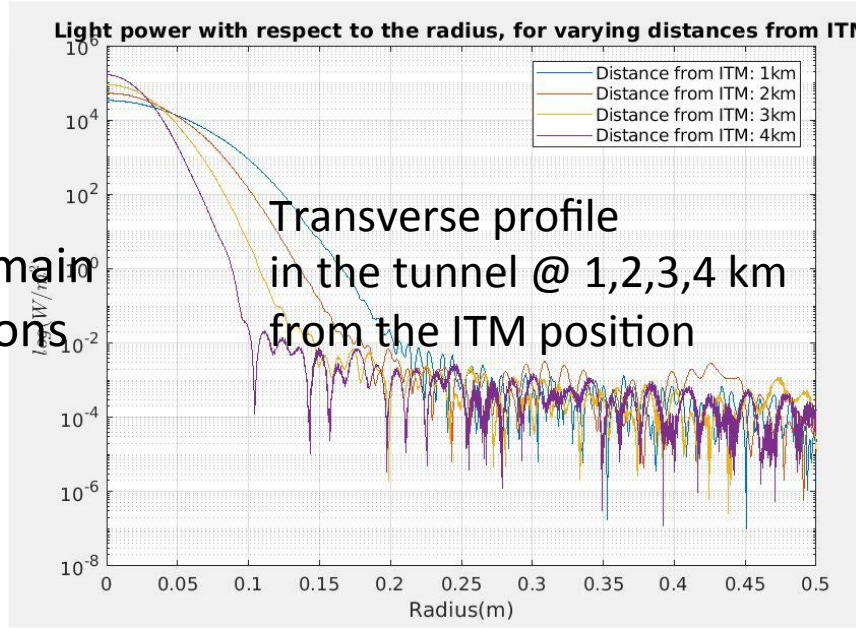
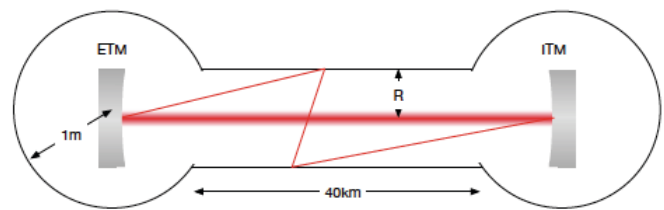
- ET Steering Committee
- Co-coordinating the Stray Light WG
- Good invited to the OSB-Cosmology WG

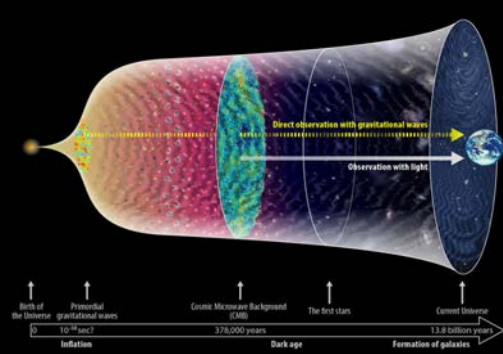


IFO	λ	mode	mirror \varnothing	R_C	w_0	z_0	w	g -factor
ET-HF	1064 nm	TEM ₀₀	62 cm	5070 m	1.42 cm	5000 m	12.0 cm	0.95
ET-LF	1550 nm	TEM ₀₀	45 cm	5580 m	2.9 cm	5000 m	9.0 cm	0.63

Running optical simulations to determine the best strategy for stray light mitigation in ET

The coupling of the light with the baffles in the main arms dictates the apertures and tunnel dimensions
 → Big impact in the design and project costs





It happens

Also in the plan for O4+O5

Physics Program

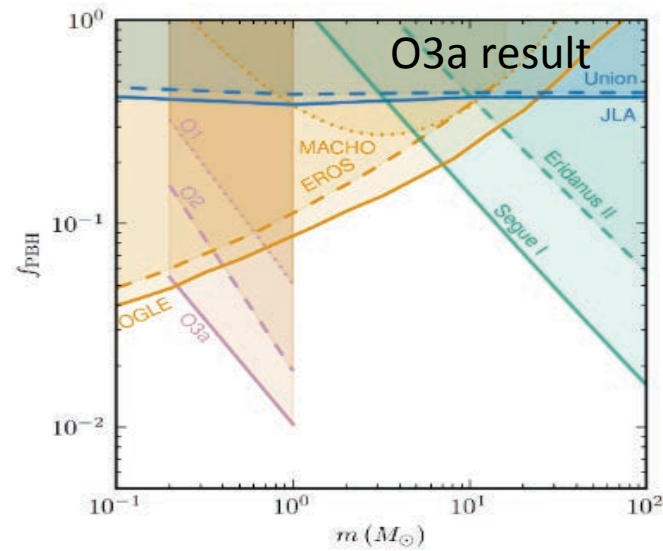
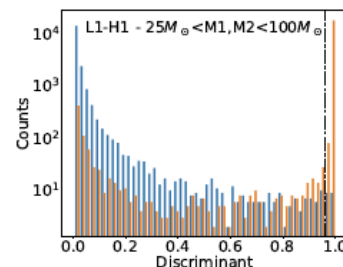
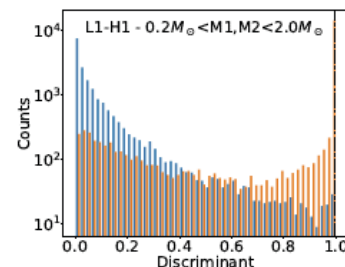
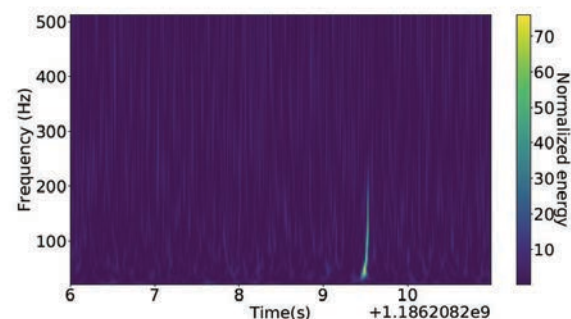
Biased towards Fundamental Physics and Cosmology

- Use Deep Learning Techniques in the search for signals
- Subsolar events and primordial Black holes as DM candidates
- Determination of H_0 using binaries and Cosmology/tests of GR
- Stochastic GW signals as window to the early universe
- Search for light boson clouds and BHs leading to GW signals
- Test of GR using IMR consistency and ringdown waveforms
- BH Spectroscopy and Thermodynamics

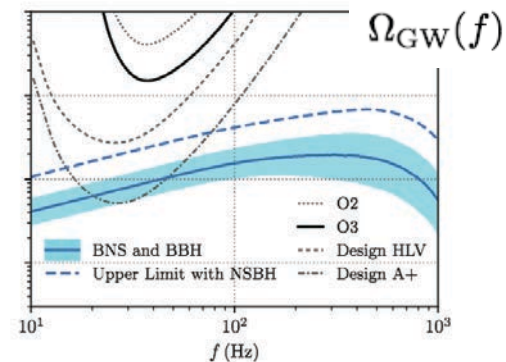
Searches for CBC and pBHs

A. Menéndez-Vázquez, et al., Phys. Rev. D 103, 062004

- **Use of Deep Learning to search for CBCs**
 - Implementing a CNN using 2-D spectrograms
 - **Published in Phys. Rev. D using O2**
 - Ongoing O3 work and extension to asymmetric binaries
 - **Second publication expected in the fall**
 - **Plan to implement a pipeline online in Virgo**
- **Traditional LVK search for sub-solar mass candidates using matched filtering**
 - A. Menéndez at the very core of the O3a analysis implementing new pipelines into the search
 - **Submitted to Phys. Rev. Lett. [arXiv:2109.12197]**
- **Part of the LVK core team of pBH fans** and close collaborations with theorists @ LVK running weekly meetings on pBH analyses
- **Plan to be also part of O3b + O4/O5 analyses**



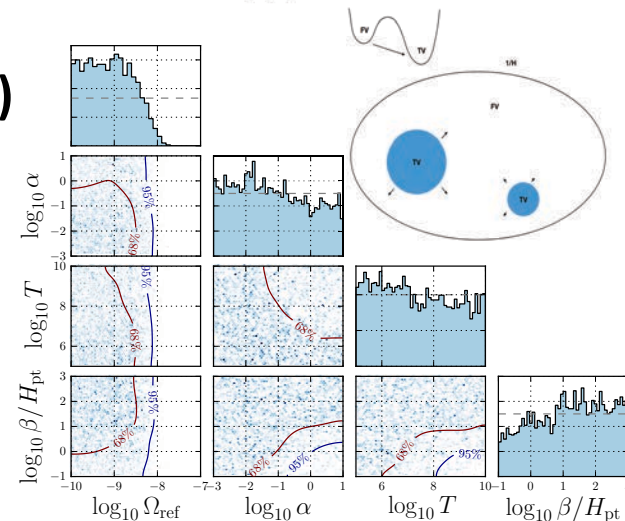
Search for Stochastic GWs



- **Deep involvement in the O3 analysis**
 - A. Romero at the very core team producing the LVK results [[arXiv:2101.12130](https://arxiv.org/abs/2101.12130), accepted by PRD]

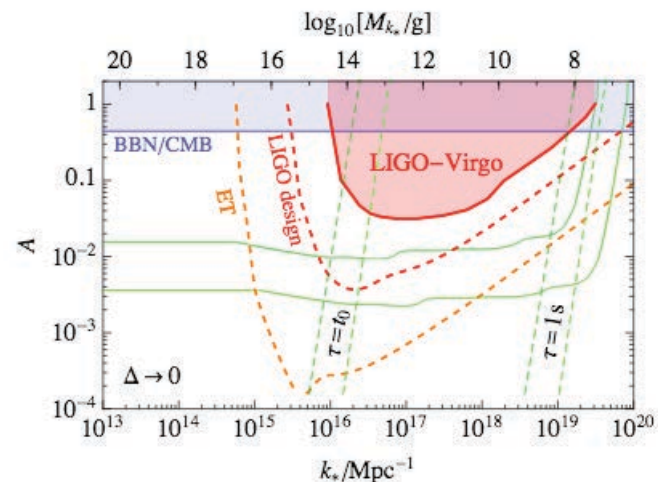
- **Reinterpretation in terms of strong first-order phase transitions into GWS (Temp – $10^7 - 10^9$ GeV)**
 - Motivated by IFAE-TH work by O. Pujolas et al.,
 - Incorporated in LVK O3 plan as short authorlist PRL driven by IFAE (as first authors)

A. Romero et al., Phys. Rev. Lett. 126, 151301 (2021)



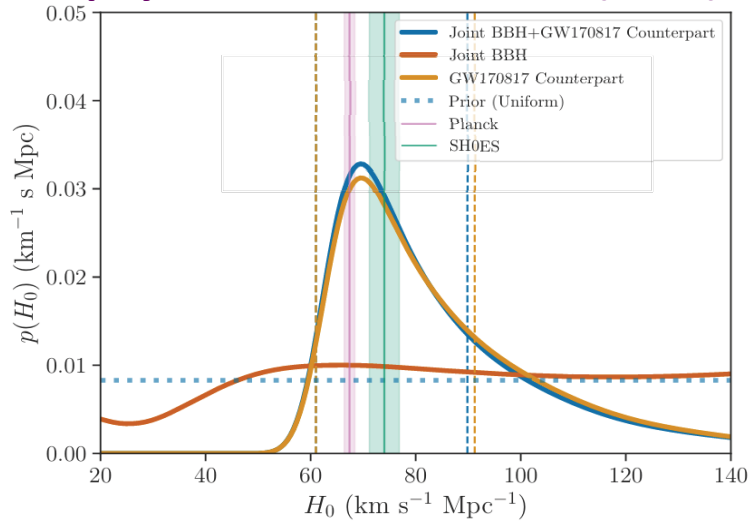
- **Reinterpretation in terms of pBH driven GWs signals from curvature fluctuations in close collaboration with IFAE-TH division**
 - <https://arxiv.org/pdf/2107.11660.pdf> (in PRL)

- **Participation in O4 version of the LVK analysis**
 - Liason with Detector Characterization
 - Development of analysis software
 - Interpretations (cosmic strings, phase transitions, pBH..)



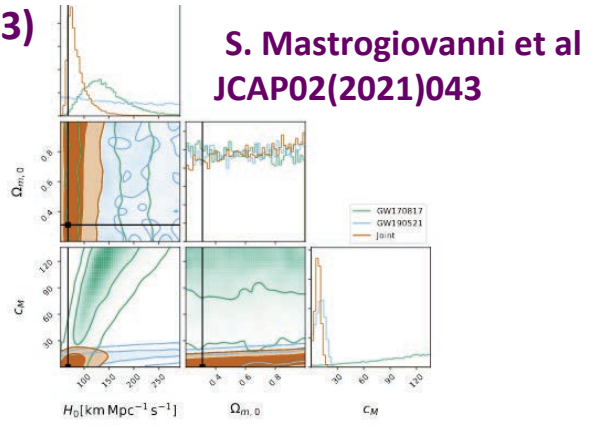
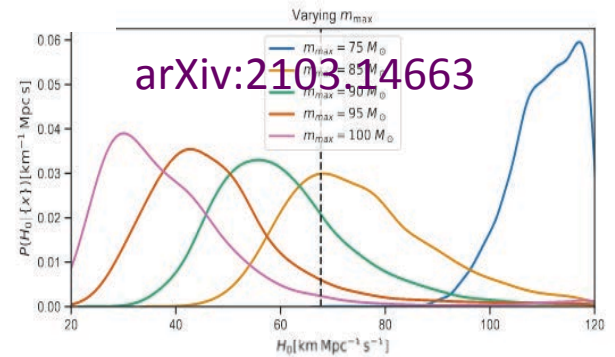
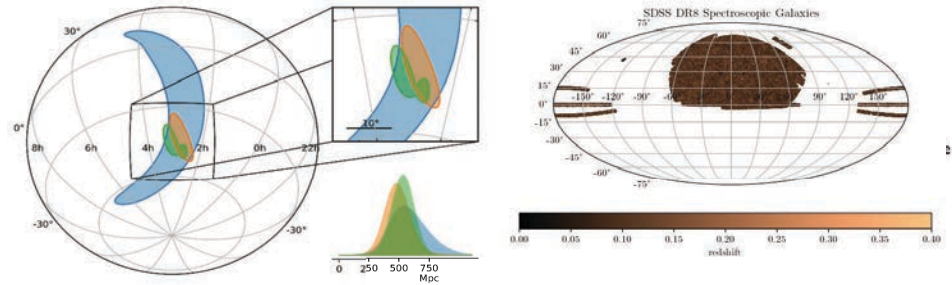
H0 determination and Cosmology

Astrophys J 909 Number 2 218 (2021)



Comoving distance $D_C(z) = \frac{c}{H_0} \int_0^z dz' \frac{H_0}{H(z')}$ Hubble constant (current expansion rate)
 Hubble parameter (expansion rate)

$$\frac{H^2(z)}{H_0^2} = \Omega_r (1+z)^4 + \Omega_m (1+z)^3 + \Omega_\Lambda + \Omega_k (1+z)^2$$



S. Mastrogiovanni et al
 JCAP02(2021)043

Within LVC Cosmology WG (for both O2 and O3)
 (C. Karathanasis author of O2 paper and editor of O3 paper)

- Contributing to the development of a refined PE to improve the determination of the sky position and distance

(Monthly Notices of the Royal Astronomical Society, Volume 499, Issue 3)

- Improve the use of galaxy catalogues in H0 determination
- Explore modified Cosmology models using single events with GWs + EM signals (GW170817 and GW190521)



PIC
port d'informació
científica

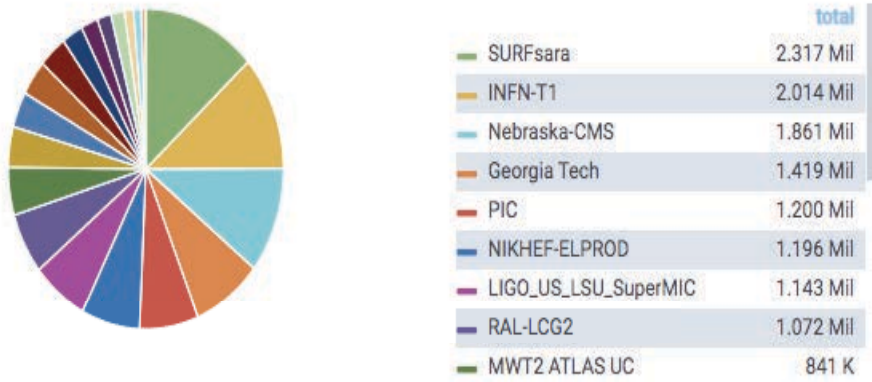
Computing



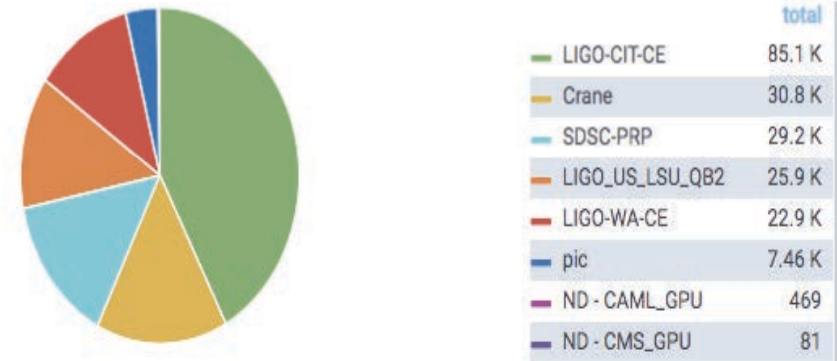
PIC is the LHC Tier 1 Spanish Center

Integrated in the GW LVK computing grid

Core Hours by Facility



GPU Wall Hours by Facility



Providing 7% of total LVC CPU last year
Providing 4% of total LVC GPU last year

At the moment they are opportunistic resources

Initial discussion with Virgo to define potential in-kind contributions via computing services in the future

Plan to contribute to ET efforts as well

IFAE Theory Division in **ET**

Oriol Pujolàs

IFAE TH members

seniors:

Diego Blas – co-chair of **LISA** Dark Matter WG



Oriol Pujolàs – in **ET** OSB Div2-cosmology



IFAE TH members

also:

Eduard Massó

Alex Pomarol

Mariano Quirós

postdocs:

L delle Rose

R Ferreira

E Sfakianakis

V Vaskonen

R Vicente

B von Harling

G Zahariade

IFAE TH expertise

- **Stochastic GW backgrounds** from the early universe:
 - Cosmological phase transitions
 - Topological defect networks
 - PBH binaries
 - GWs induced by scalar perturbations
 - GWs as probes of QCD axion models
 - Axions and ALPs
- **Dark matter**
 - Ultra-light bosons
 - Dark Matter environmental effects
- Participation in other projects (LISA)
- Proposal of new GW detector concepts

Quirós

Pomarol

Pujolàs

Massó

Blas

IFAE TH contribution

In the **connection with High Energy Physics**

(T up to $\sim 10^9$ GeV !)

- **Relic SGWBs** generated in the early universe
- Identify well motivated & detectable new physics models
- Spectrum characterization
- **Dark Matter signals**: axions, ALPs, light bosons, PBHs
- Synergies with other observatories