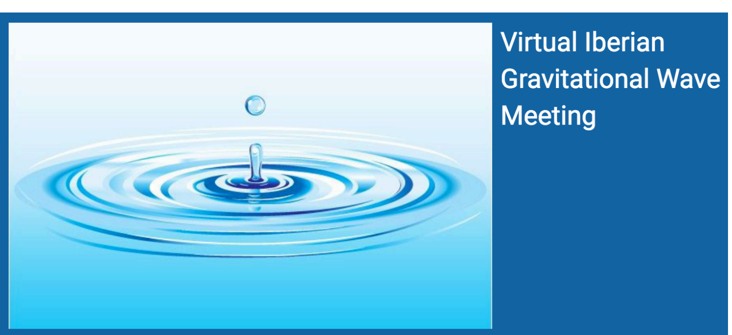
Overview of IFAE activities on GW Physics and Instrumentation in Virgo

Mario Martínez

On behalf of the IFAE-GW team



Virtual Iberian GW Meeting 2020

Outline

- IFAE @ Virgo
- Commissioning of Virgo
- Stray Light
- Optical Simulations
- Hardware Contributions

- Physics Program @ IFAE
- Multi-messenger initiatives
- Computing

- Involvement in ET
- Final notes

Personnel / Authors (Scientists)

NAME	Position	Activity	Authorship	Other Experiment
M. Cavalli-Sforza	Senior Scientist	Baffles	---	
O. Blanch	**Senior Scientist**	**Baffles**	**Y**	**CTA/Magic**
M. Martinez	**Senior Scientist**	**Team Leader**	**Y**	
Ll. Mir	**Senior Scientist**	**SLC coordinator**	**Y**	**ATLAS**
M. Kolstein	**Researcher**	**Simulation + Analysis Codes**	**Y**	**VIP**
C. Karathanasis	**PhD Student**	**Operations + Physics**	**Y**	**---**
A. Menendez	**PhD Student**	**Operations + Physics**	**Y**	**---**
A. Romero	**PhD Student**	**Operations + Physics**	**Y**	**---**
Albert Elias	Master Student		-----	---
Chantal Pitte	Master Student		-----	---

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A. Menendez	**PhD Student**	**Operations +**	**Y**	**---**
A. Romero				
Albert Elias				
Chantal Pitte	Master Student		-----	---

The team will hire at least an analysis-oriented LIGO/Virgo senior postdoc in 2021

Head Hunting process ongoing in Theory Division

Personnel (Engineers/Computing)*

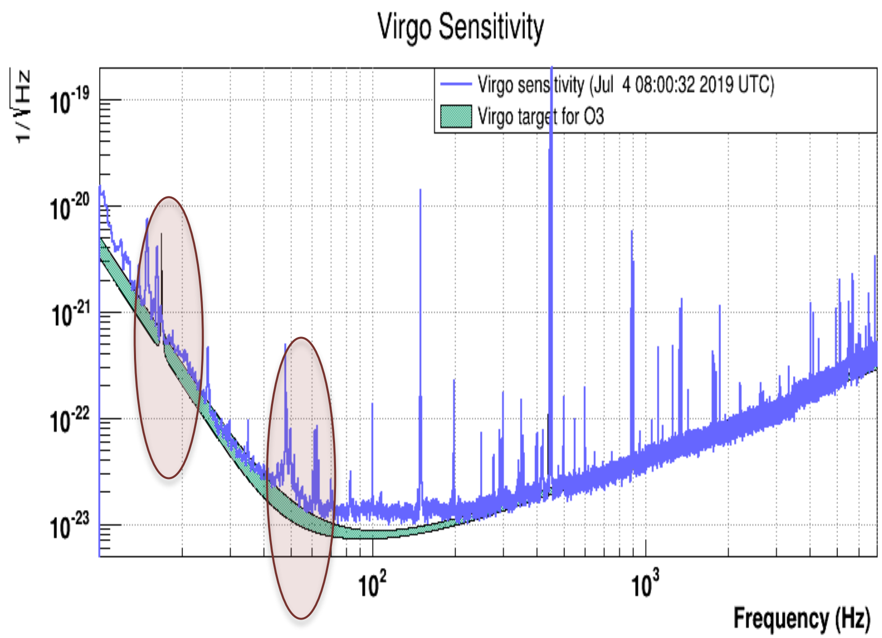
NAME	Position	Activity
Laia Cardiel	Staff Engineer	Electronics + Coordination
Pepe Illa / Joan Boix	Staff Engineers	Electronics
Otger Ballester/Cristobal Pio	Staff Engineer	DAQ/ Software Control
Julia Mundet /Rafael Garcia	Staff Engineers	Mechanics
G. Merino	Computing Scientists	PIC Director
Ch. Neissner	Computing Scientists	PIC-Virgo Liason/Astronomy
C. Acosta	Computing Scientists	Virgo Computing support

*** Not counting here technicians**

The group counts with the strong support from IFAE's technical division and PIC for computing infrastructure

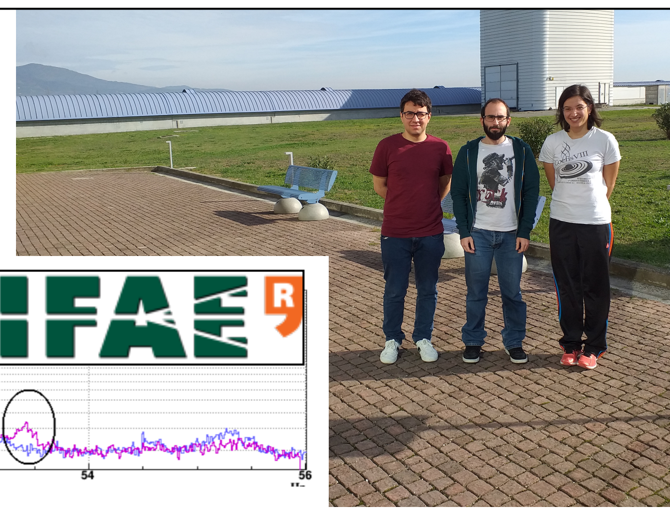
Operations and Commissioning

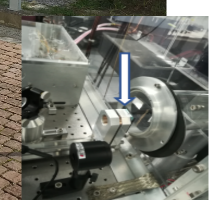
- IFAE took an energetic approach for the involvement in VIRGO operations in 2019



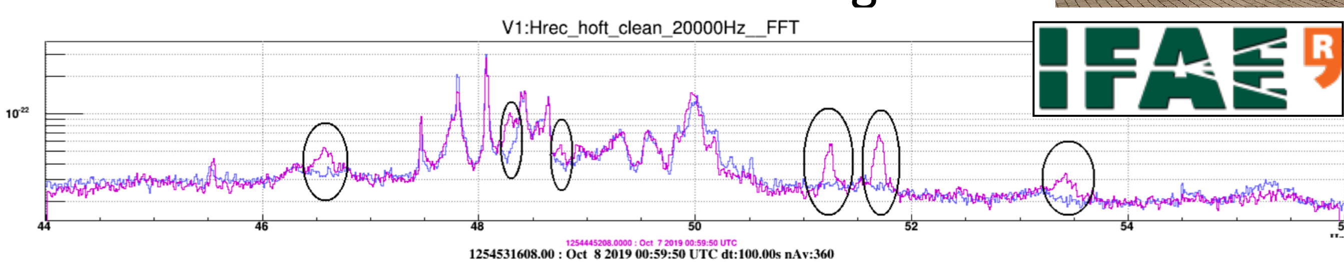
- 2 PhD students
 (Jan – May 2019 @ EGO)
  - Noise Hunting, B-field injections, Detector characterization, ROTA
  - Deep involvement in optical simulation tools

Results to be submitted to Galaxies Journal this month

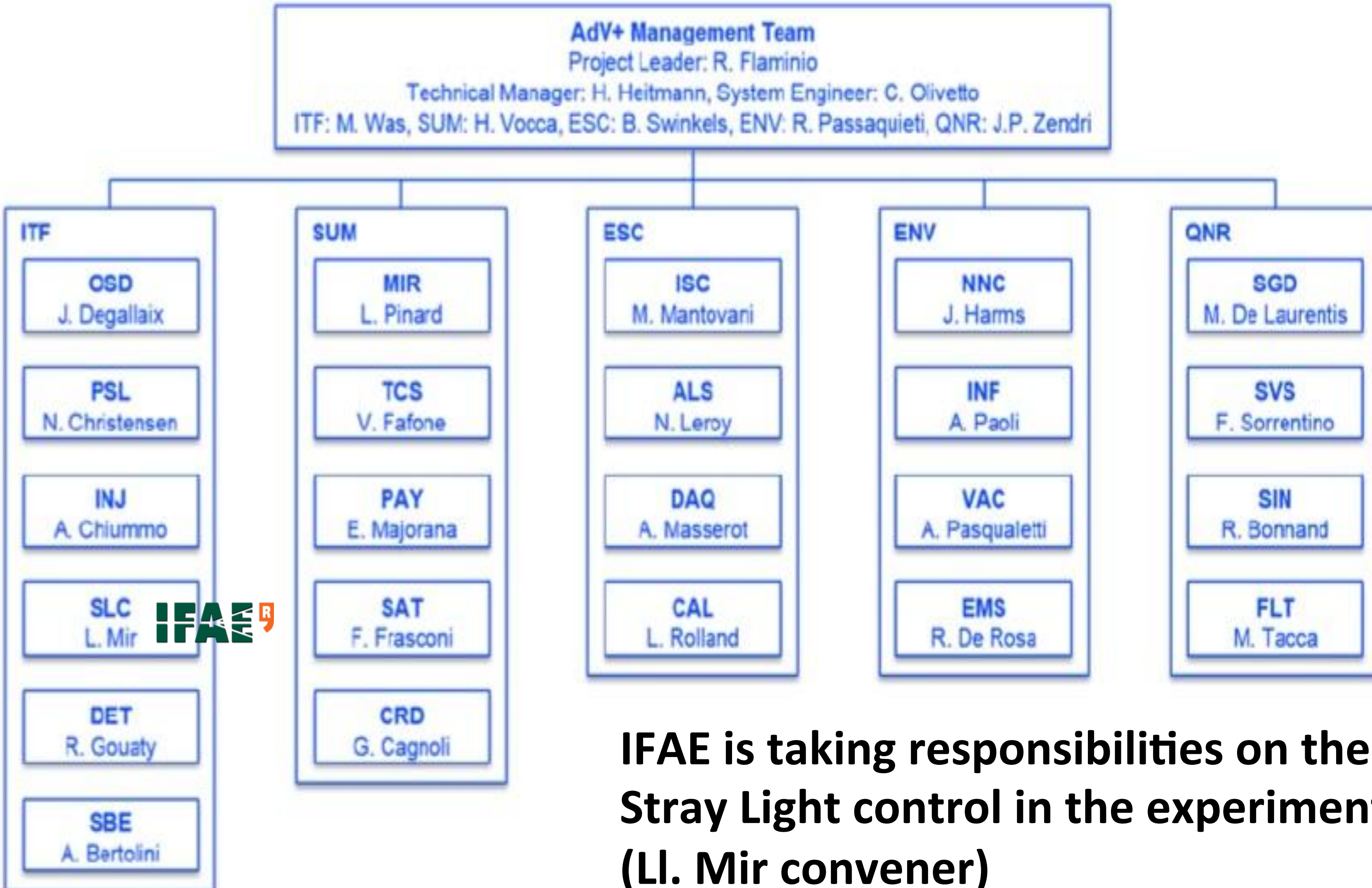




- 3 PhD students
 (October Break 2019 @ EGO)
  - Part of the ENV Noise hunting team

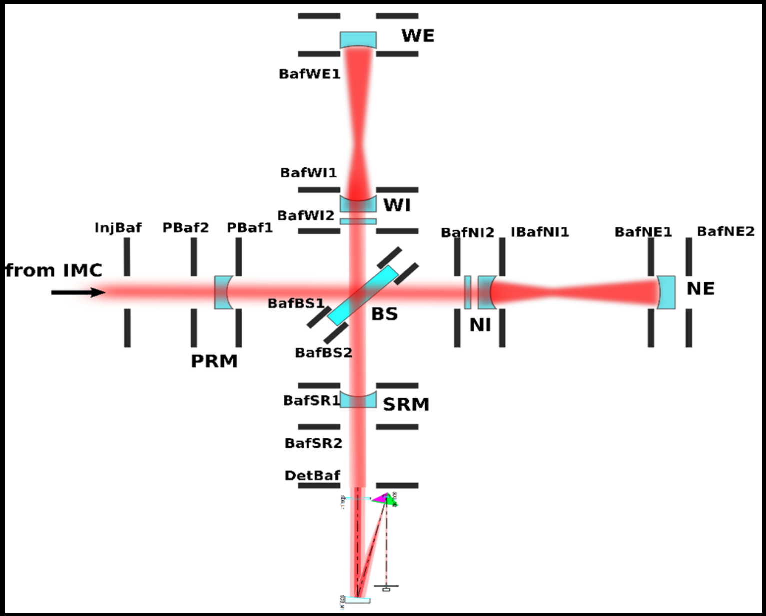


Virgo Management Chart

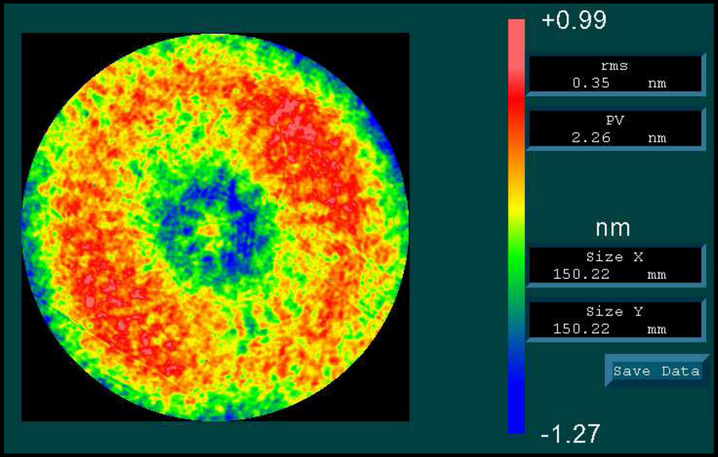


IFAE is taking responsibilities on the Stray Light control in the experiment (Ll. Mir convener)

Controlling Stray Light



polished with RMS < 0.1 nm

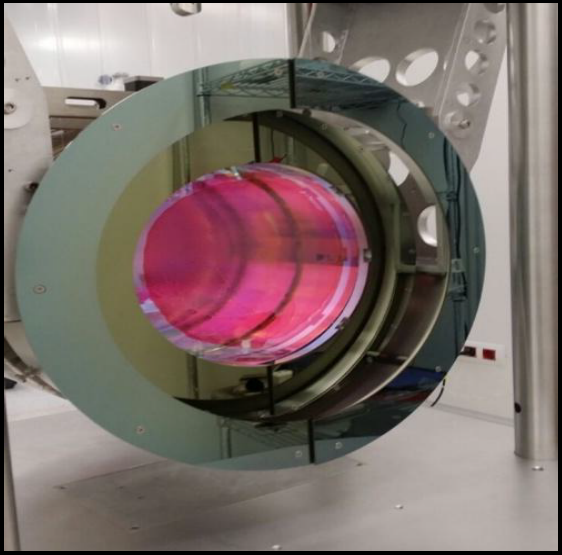


A large fraction of the light in the ITF (70%)
Is lost in the form of stray light mainly due to defects in the mirror surfaces + diffraction

Small fraction coupling to the ITF kills GW signals

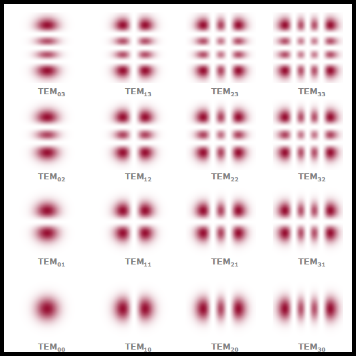
ITF is full of passive baffles (AR coated) to eliminate the diffused light across (99.5%)

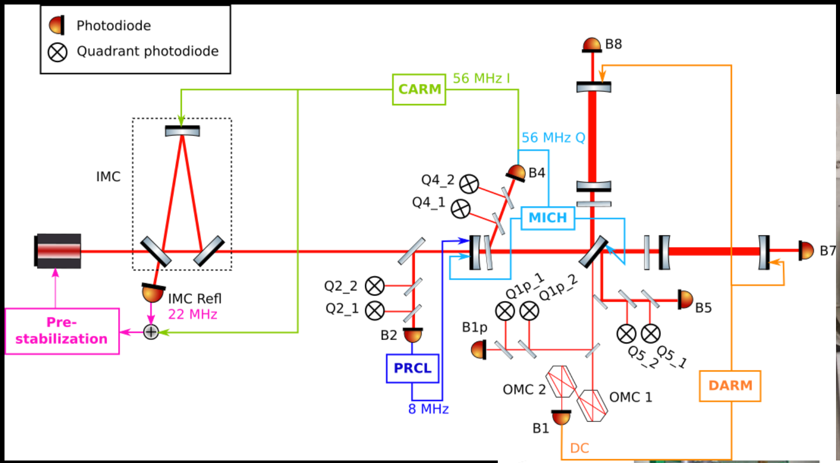
No real control/monitoring on where light goes

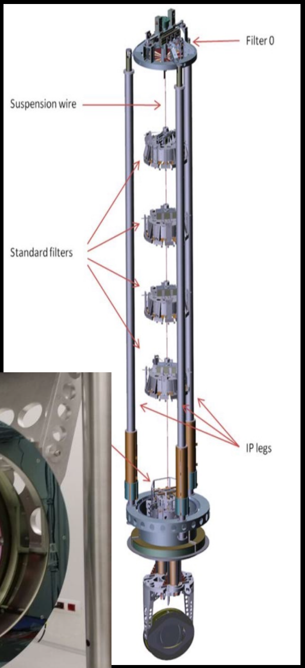


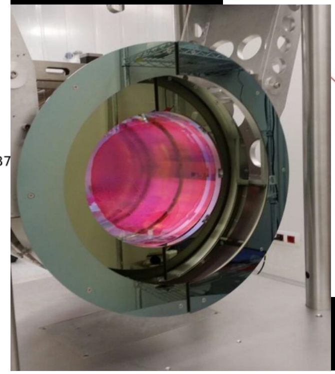
Monitoring light around mirrors will allow to

- Efficient alignment of ITF after shutdowns
- Dynamic mapping of mirror surfaces / defects
- Monitoring of developing laser high modes
- Correlate with ITF glitches



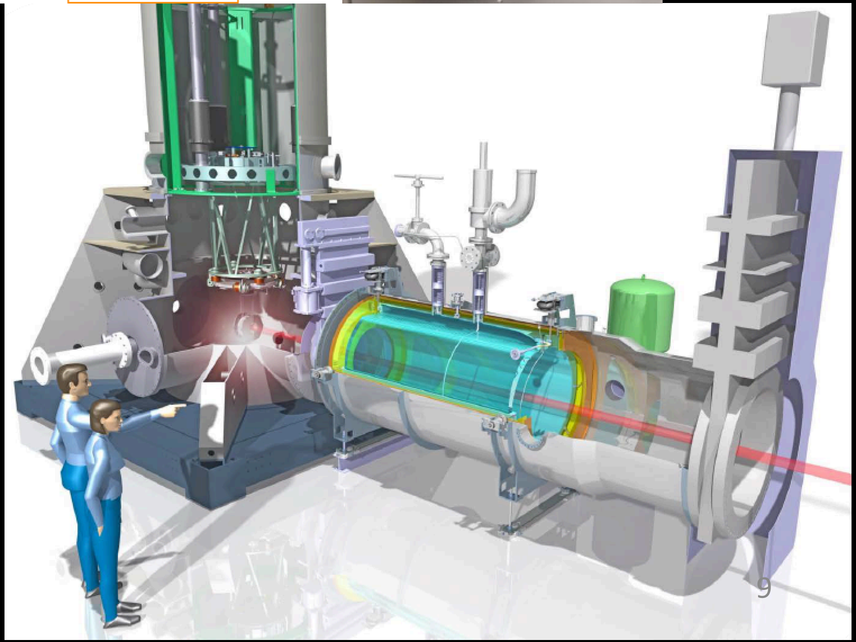




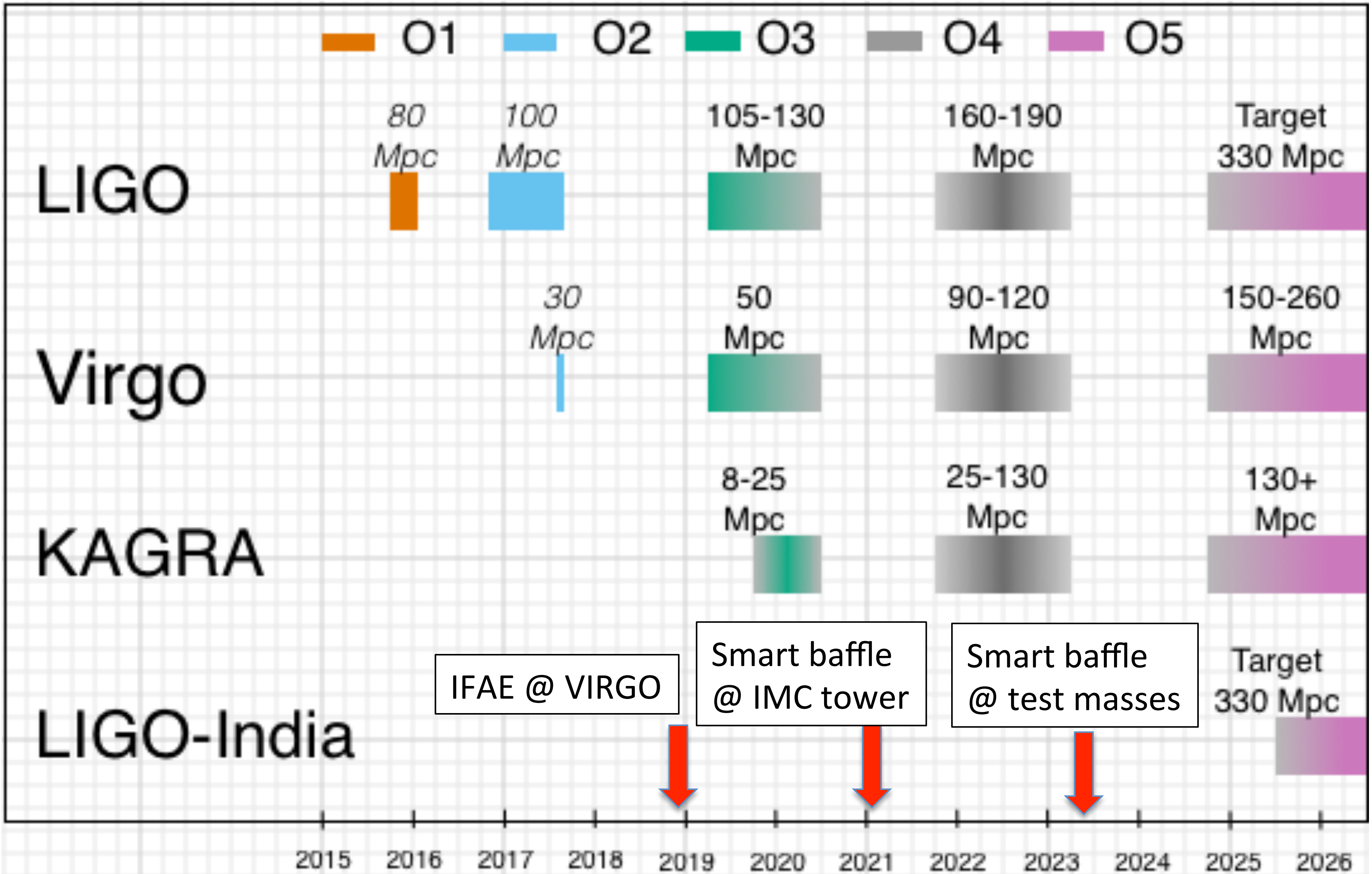


Nice but challenging:

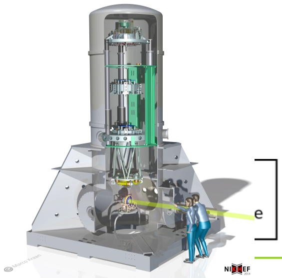
- Sensors on 1064 nm (IR)
- UHV (10^{-9} mbar)
- No active cooling possible
- Reflectivity less than 0.5%
- Total scattering under control
- Limited RO cabling → wireless RO
- Negligible induced EM noise near mirrors
- ……

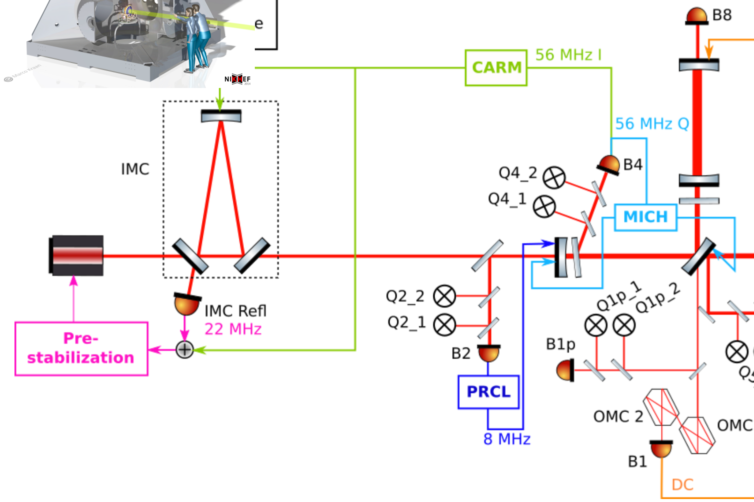


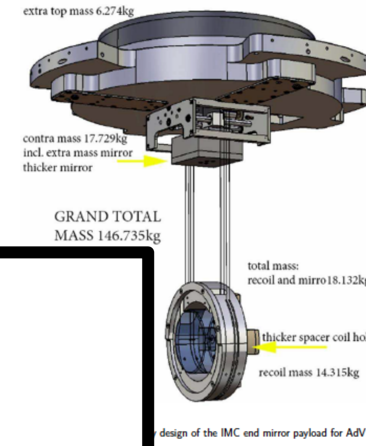
LVK Schedule



Baffle Prototype in IMC

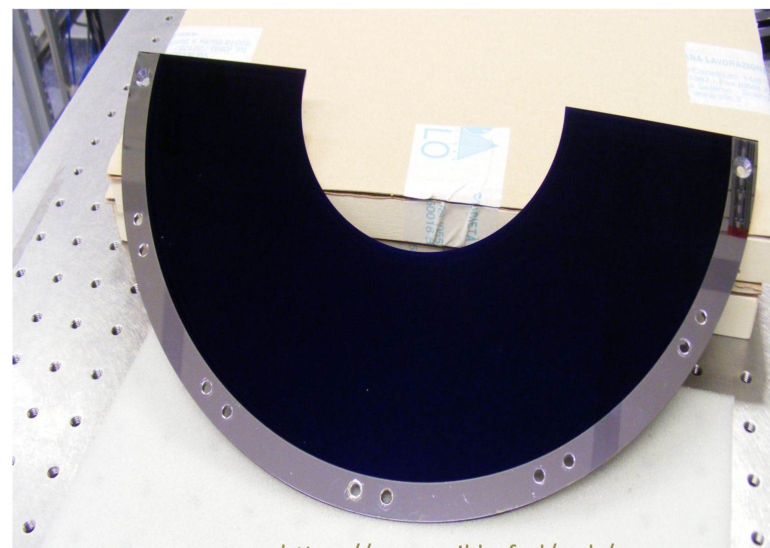






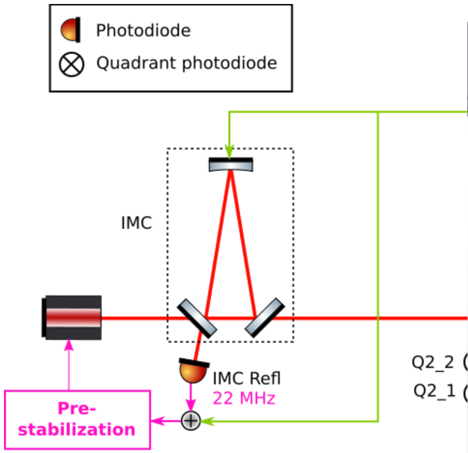
Plan to redesign the payload
for the Input Mode Cleaner mirror

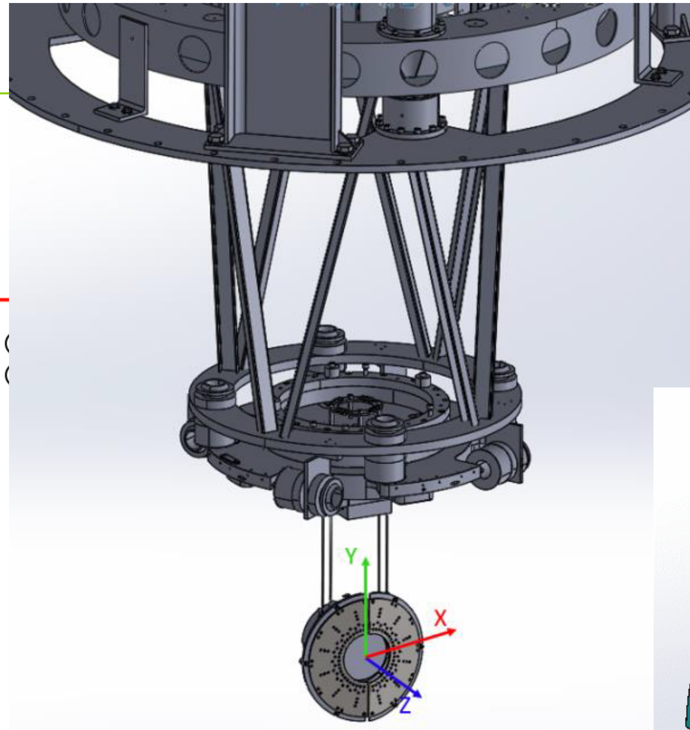
→ Opportunity to integrate
an instrumented baffle without
affecting the main interferometer

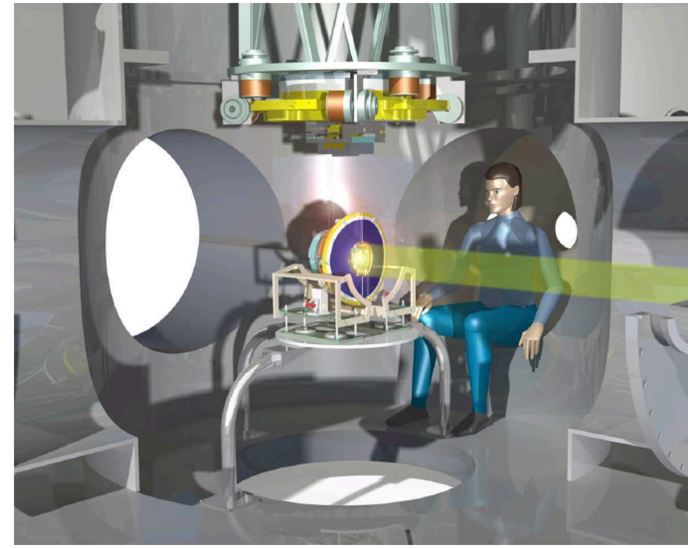


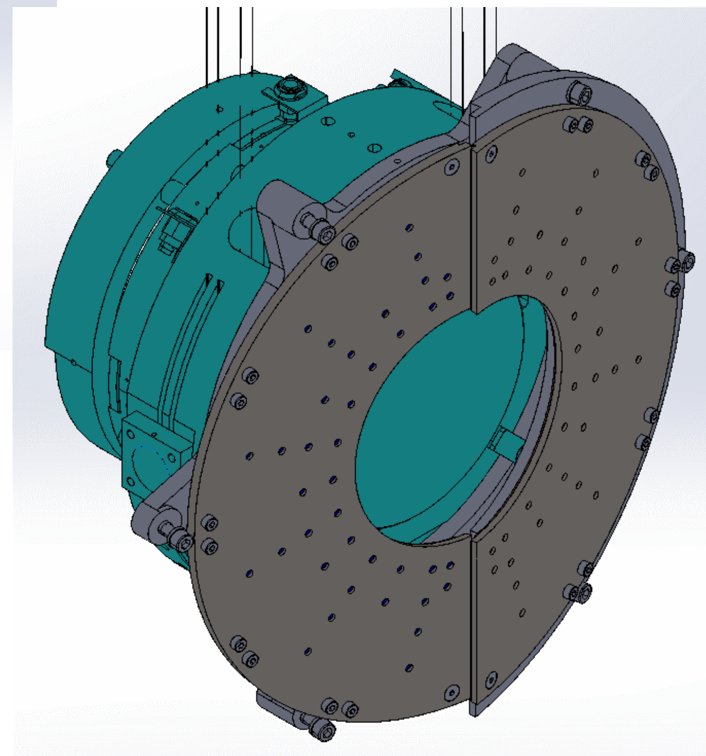
https://www.nikhef.nl/pub/departments/mt/projects/virgo/inputmode/

Conceptual Design







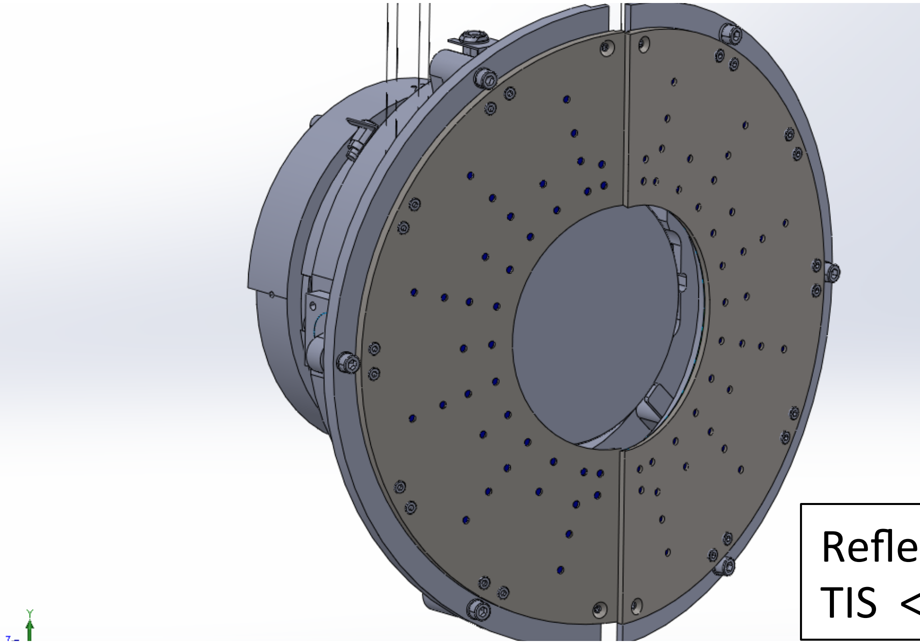


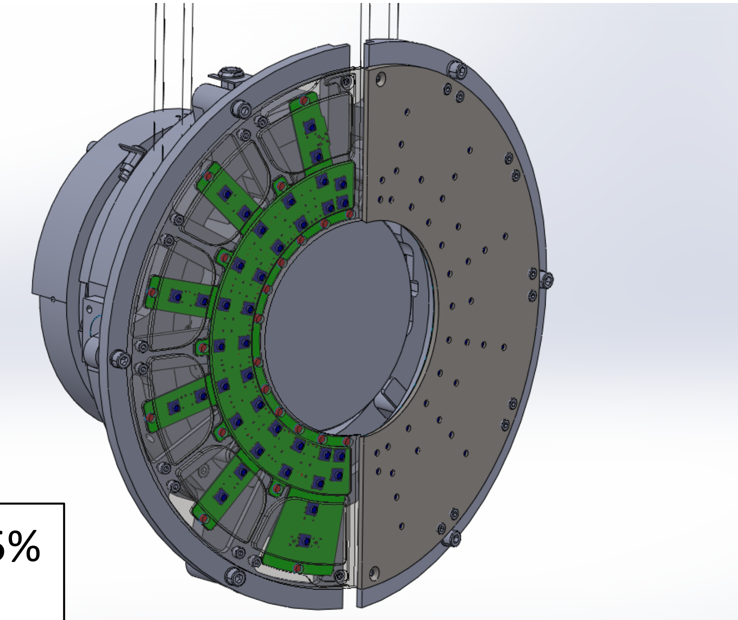
Instrumented baffles with
photo-sensors surrounding mirror

Preserve weight/shape of current (non-instrumented) baffle as much as possible

Preserve Optical Properties (TIS, reflectivity)

Conceptual Design (cont.)





Reflectivity 0.5%
TIS < 500 ppm

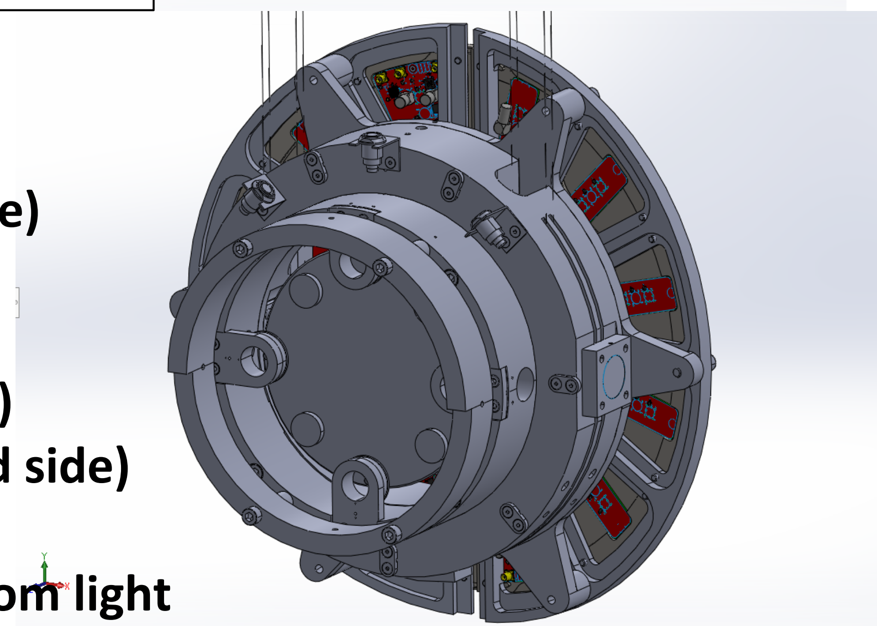


Photo-sensors located behind plate

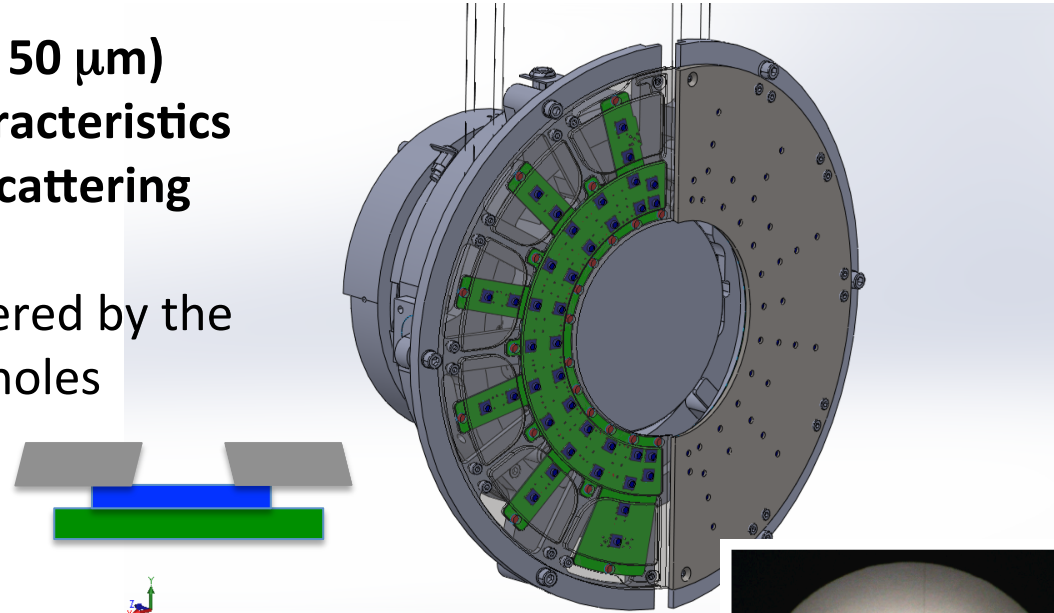
- Number of sensors 76 (38 in each 1/2 baffle)
- Sensors mounted in large PCBs
- Sensors active area 0.49 cm2
- Light reaches sensors through conical (12^{o}) holes of 4 mm of diameter (in the polished side)

→ Avoid scattering in edges and hide PCB from light

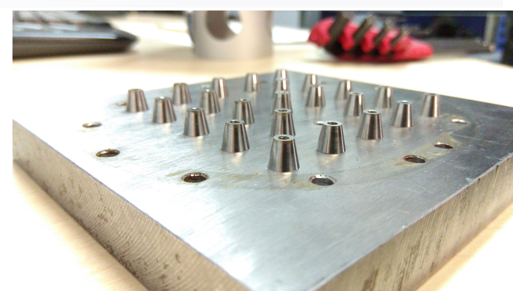
Notes on precise mechanics

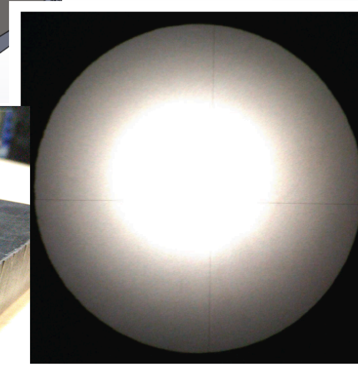
Sharp edges with very small RoC (< 50 μm) are needed to preserve optical characteristics of the baffle itself → low induced scattering

Photo-sensors and PCBs will be covered by the stainless-steel with conical-shaped holes centered around sensor surface.

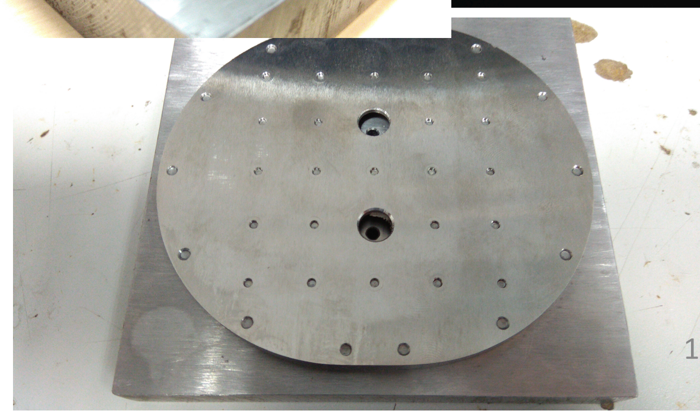


→ Full R&D performed to achieve the level of precision required in RoC in the baffle edges → Drilling + lapping using inserts



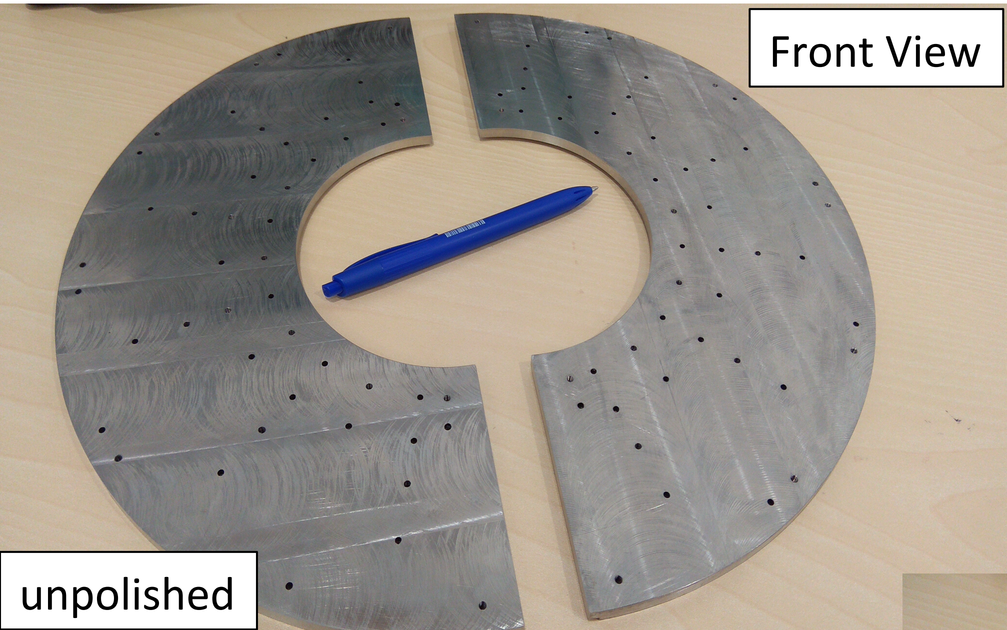


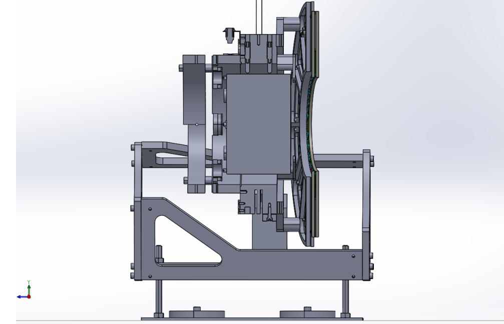
→ EDM wire cutting and electro-erosion techniques available in house @ IFAE for such precise work **(5 – 10 μm precision achieved)**



→ Q&A on conical shapes crucial

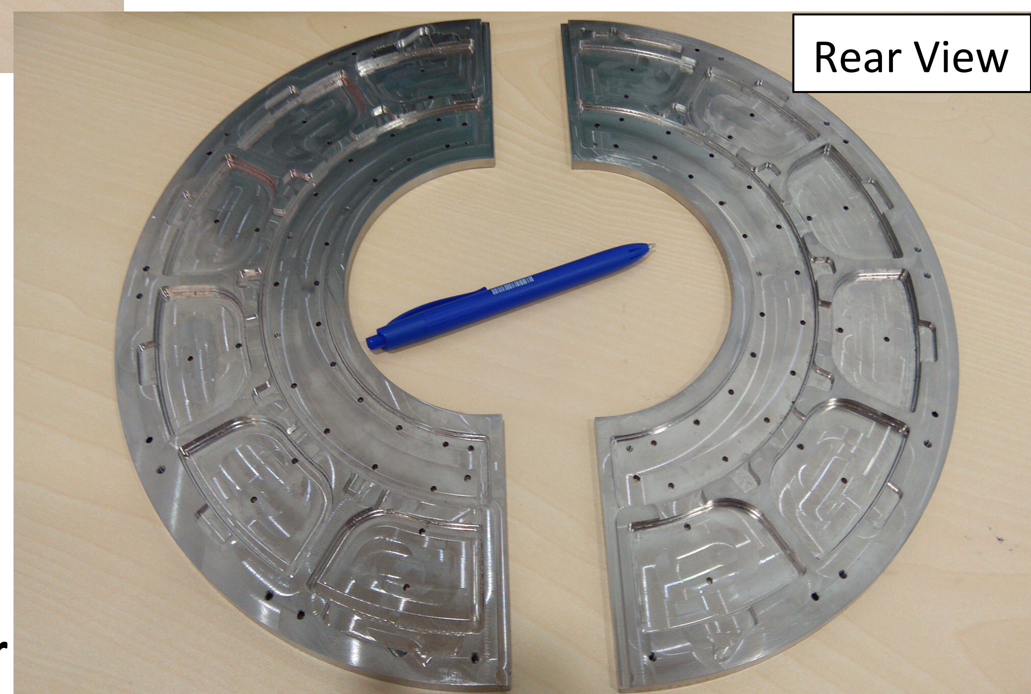
Baffle Production





Used initially AISI 304L stainless steel (same material as current baffle)

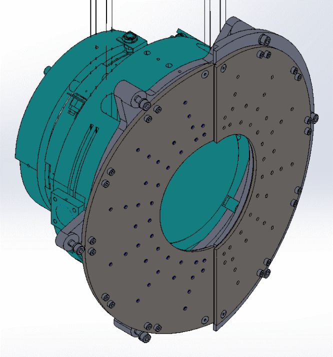
Final μ_r-characterization took take place (including thermal quenching) before mirror-polish and AR treatments

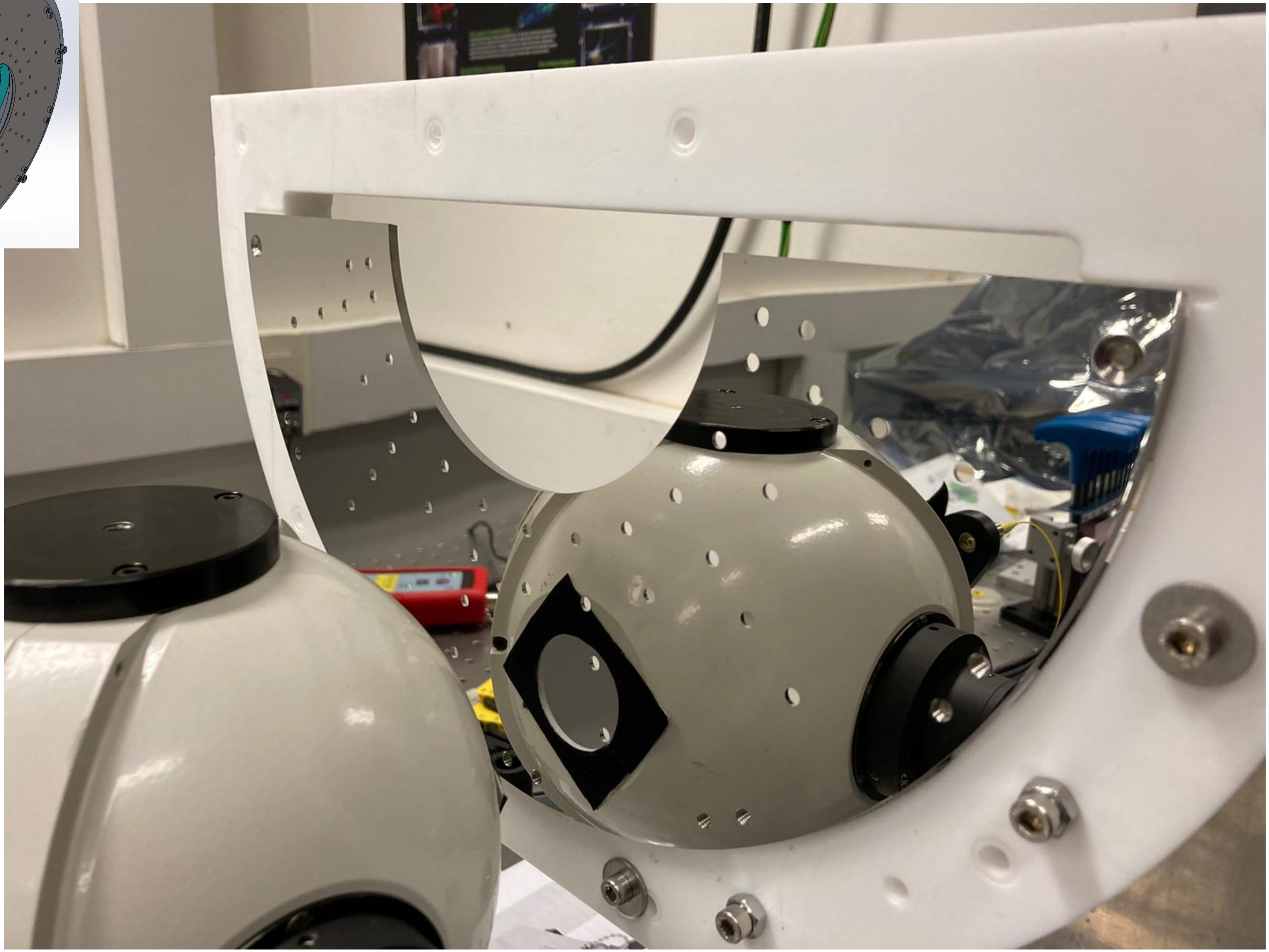


A second baffle produced now based on AISI 316LN stainless steel (certified $\mu_r \leq 1.005$)

→ Permeability monitored during the whole production process

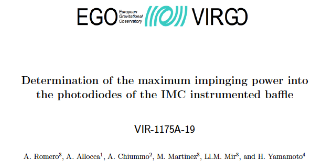
→ Guarantee no magnetic interactions with 1T dipoles in the rear of the mirror

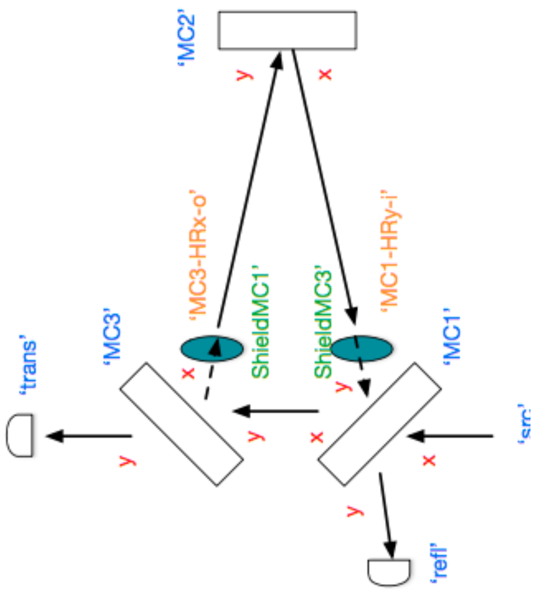




AISI 304L stainless steel polished ½ baffle being tested for TIS

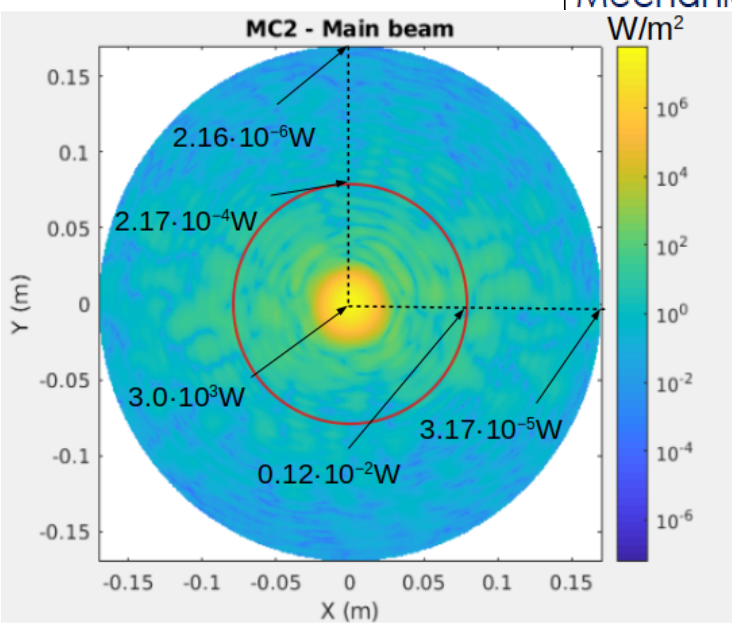
Simulations





For a 40 W Laser power deposited (in W) in the baffle

Scenario	IMC cavity	Baffle	Photodiode (0.49 cm^2)
Steady state, aligned cavity	1.4×10^4	0.20	0.003
Steady state, misaligned cavity	1.2×10^4	0.17	0.003
Completely misaligned beam	-	-	0.062
Mechanical drift	391	-	126 (for 10 ms)



Considering different scenarios of alignment of the cavity leading to moderate dose
→ Photo sensors would survive with large margins

A fast mechanical drift of the cavity in resonance would expose the sensors to 126 W for 10 ms (this is considered very conservative)

Laser induced damage threshold test on sensors reaching up to 50W/cm2 indicated no problem

arXiv:2008.13740

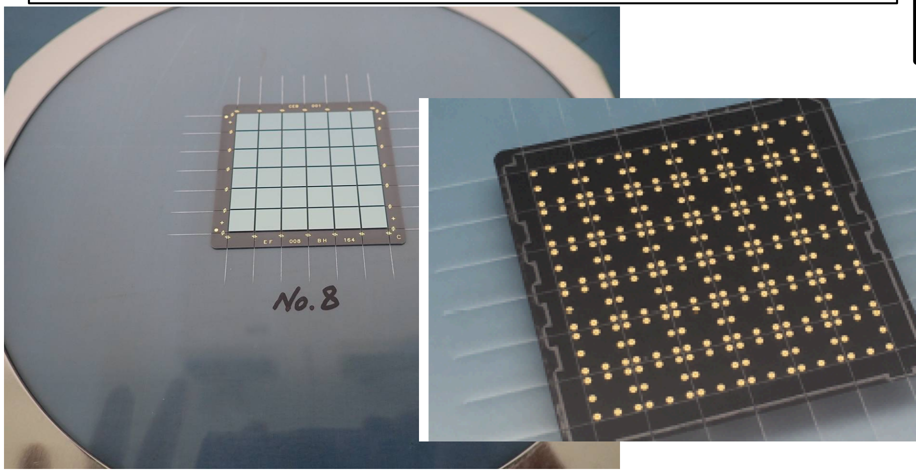
(for publication in CQG Journal)

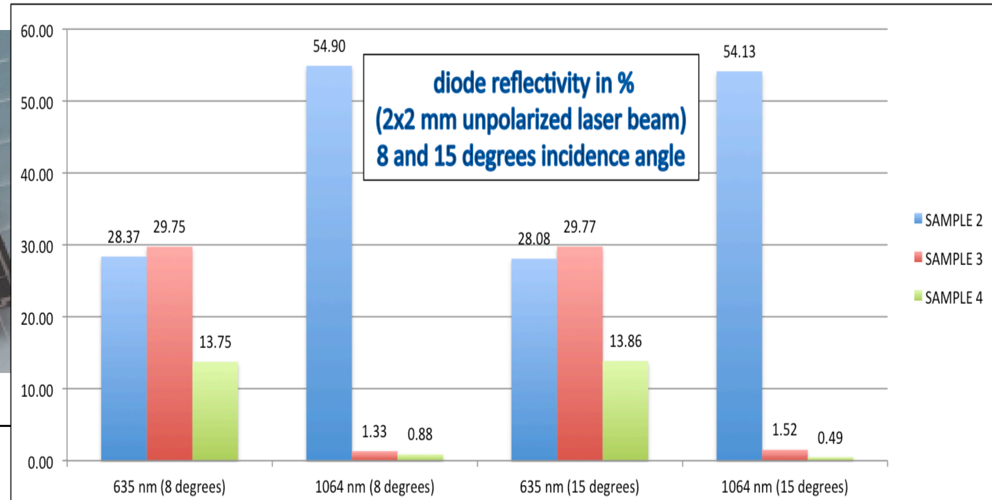
Photo Sensors

No Si-based IR photo sensor in the market is prepared for UHV compatibility

→ R&D line in collaboration with Hamamatsu put in place 1.5 years ago

Dimensions	7.37 x 7.37 mm^2
Sensitive area	6.97 x 6.97 mm^2
Operation temperature	-40 to 100 °C
Power dissipation	50 mW
Optical coating	Anti-reflective (1.8%)
Photosensitivity	600 mA/W

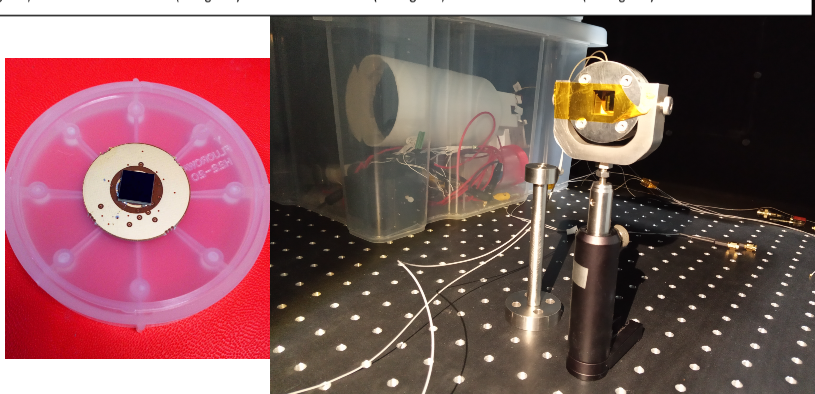


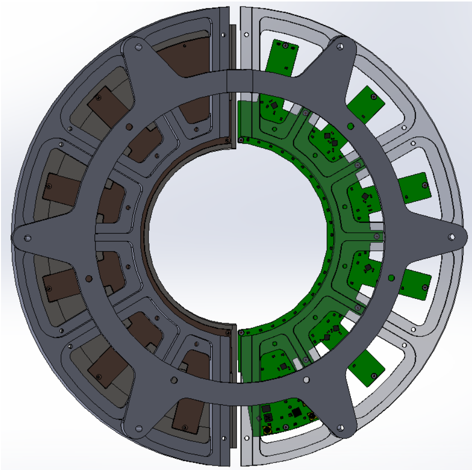


We received O(100) v3 set of sensors (1.8% reflectivity achieved) to build first baffle

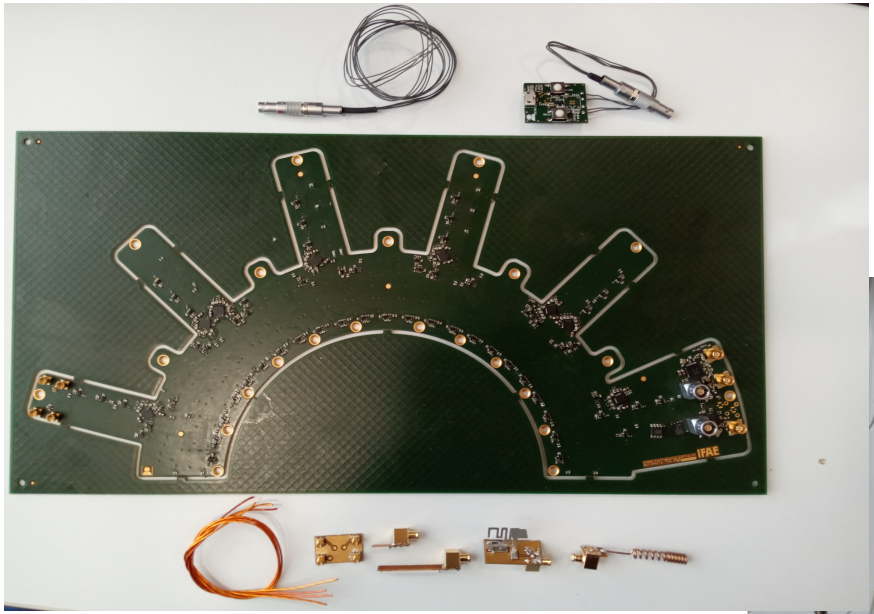
v4 production ongoing reaching 1% reflectivity

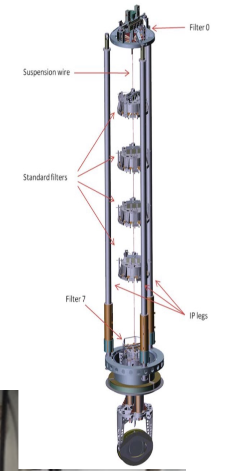
→ Optical performance tested in collaboration with IO-CSIC (Madrid)

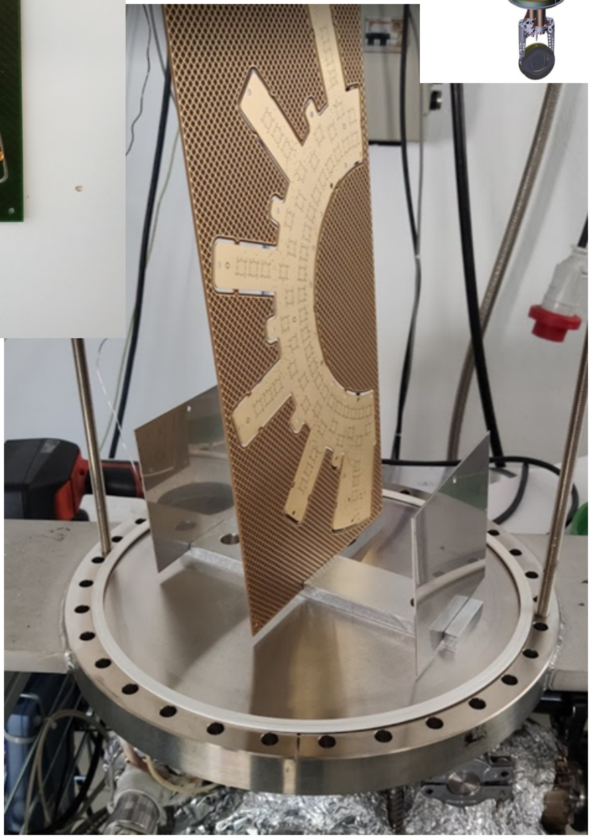




Electronics





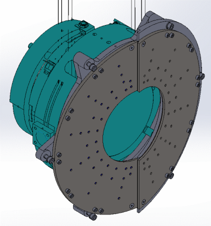


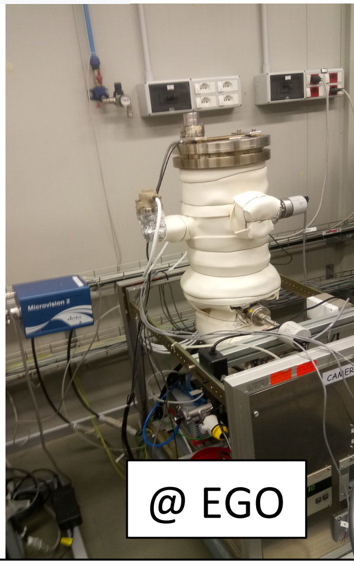
PCBs

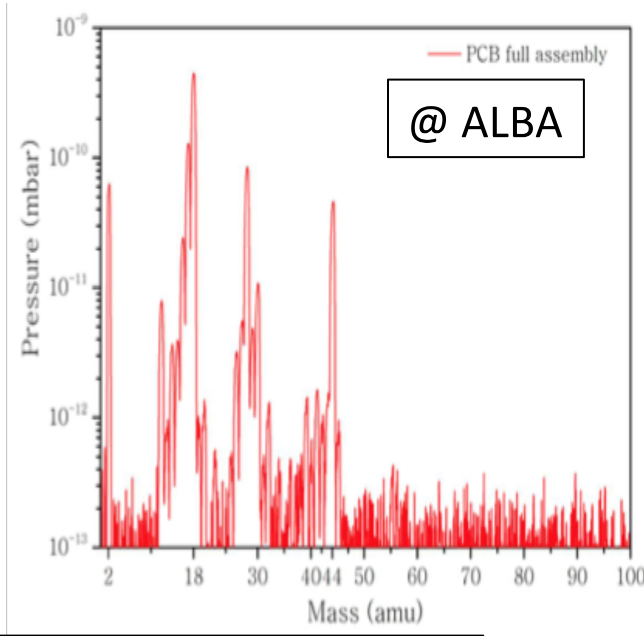
- **Made of polyamide with a gold cover**
- Custom shape to keep weight to minimum
- One PCB per half-baffle, connected with two coaxial connectors
- Reduced number of components in each PCB
- Single polarization level 3.3 VDC and total consumption < 2 W

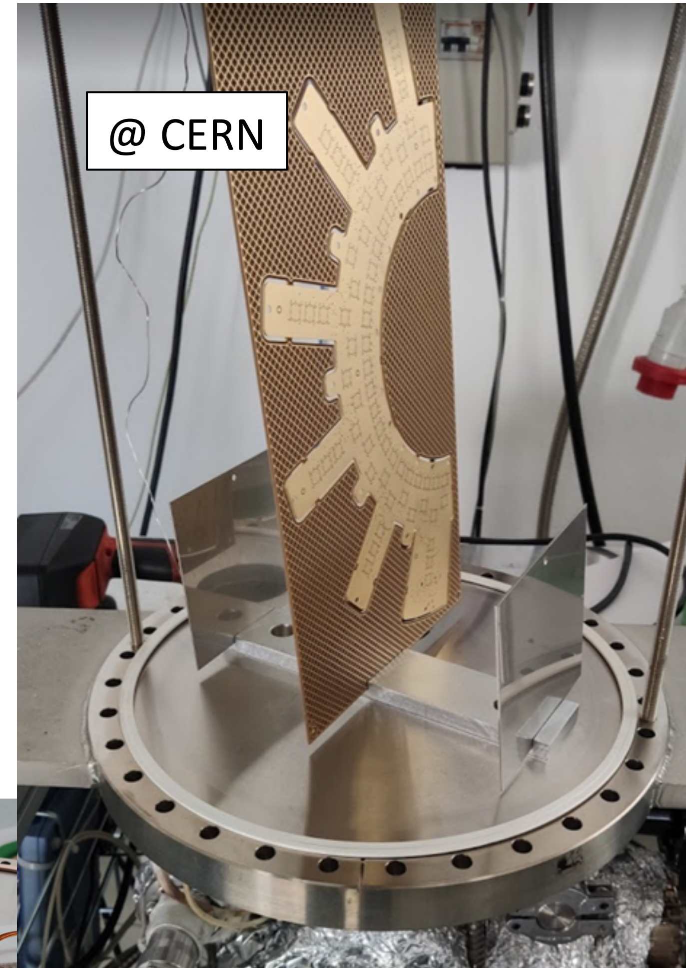
Electronics very well advanced /almost concluded
→ Including both wired and wireless RO options

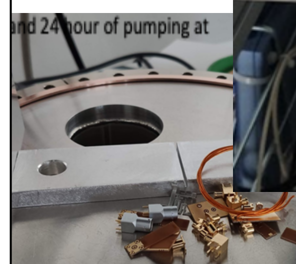
Vacuum Tests

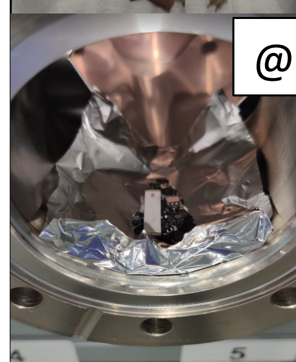


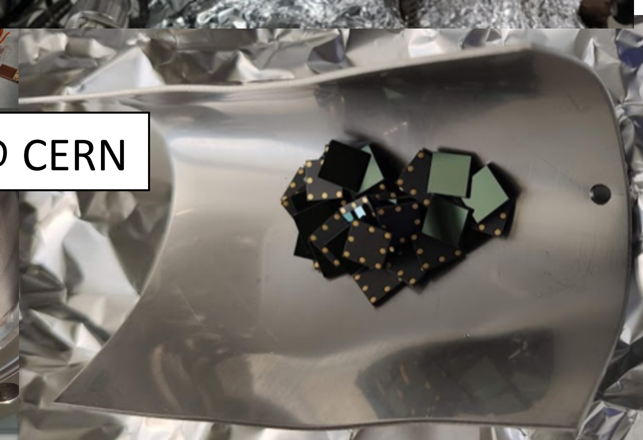












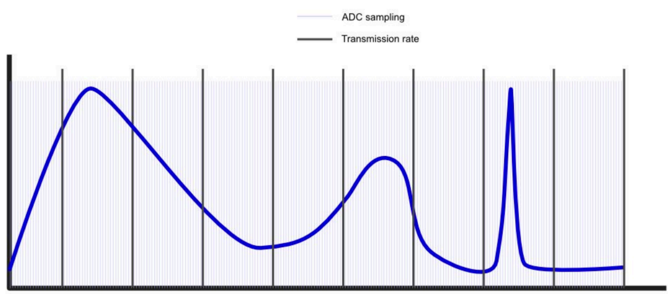
First test at ALBA and EGO satisfactory

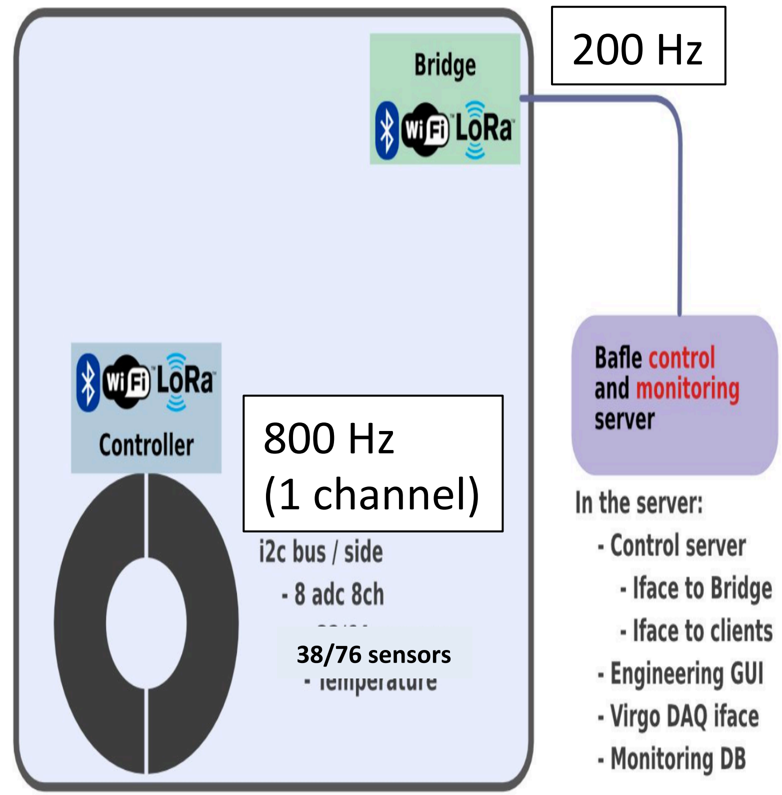
Intense collaboration with CERN Vacuum Department led to a stringent certification

Outgassing after 100C@24h -48h bakeout: in the range $10^{-7} – 10^{-9}$ mbar l/s

Tests with fully powered electronics will follow

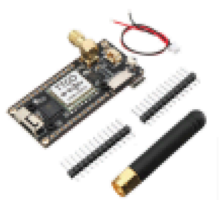
Readout & DAQ





Controller

- esp32 based
- Reads ADCs as fast as it can (~100Hz-200Hz)
- Preprocess data to send aggregated value
- Sends data to server (through bridge)



Bridge used in the PoC

Bridge

- esp32 based
- Implements communication between controller and server

Server

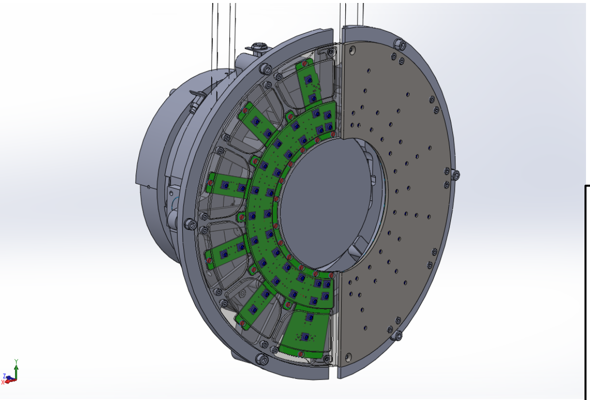
Baffle control and monitoring server

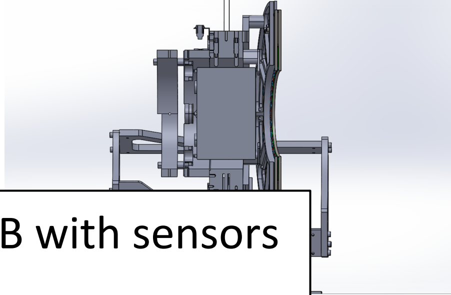
- Implements interface from clients (engineering GUI) to controller
- Provides data to Virgo frame distribution (fd)

We are considering a sampling rate of up to 800 Hz and a readout rate of 200 Hz

→ Faster readout will be considered for baffles in main arms in the future

Integration



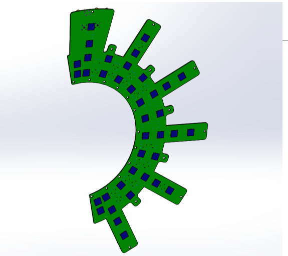


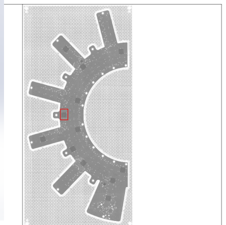
All components in house for assembly on PCB with sensors

Verification of integration (mechanics + electronics) and accessibility of connectors made with mockups

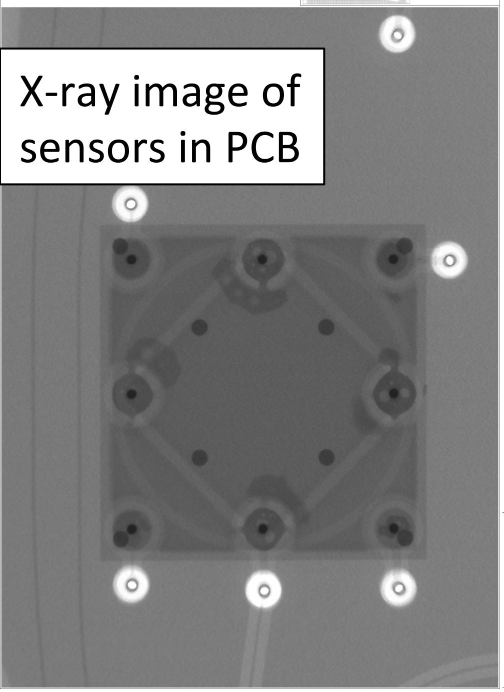
Integration included also careful balance of weight and center of gravity of the baffle as a whole

Test of integration in new IMC payload @ EGO scheduled for end of this month



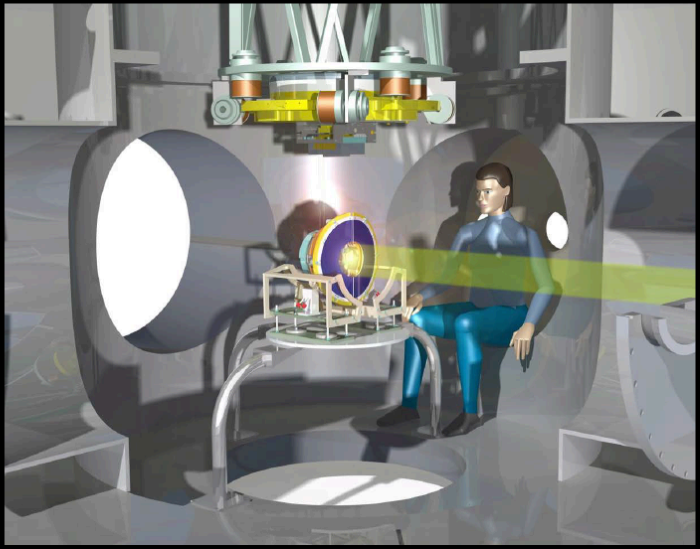


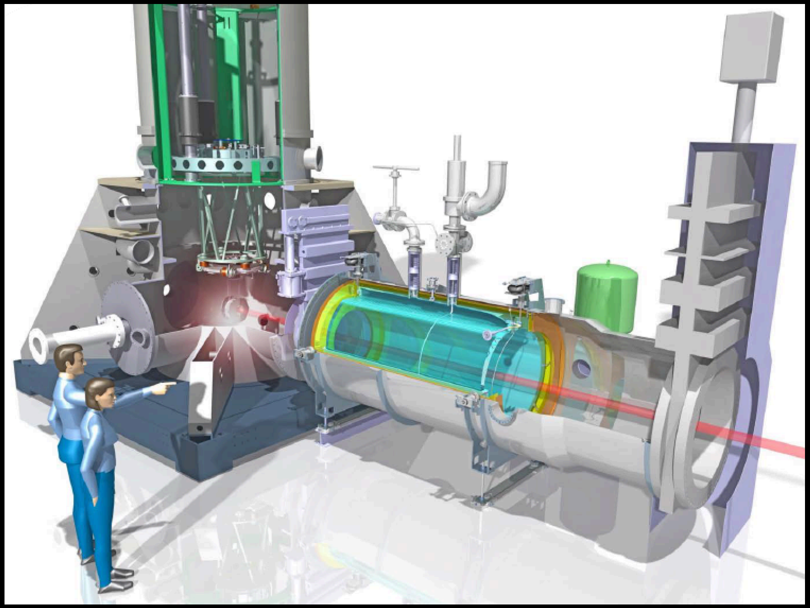
X-ray image of sensors in PCB



Exec. Summary on Baffles

- Developing instrumented baffles for Advanced Virgo+ arms leading to a better understanding and online control of the main scattered light contributions.
- A special R&D line on photo-sensors now in place as well as challenging/ new ideas in terms of geometry and readout to preserve baffle optical performance and payload attenuation
- A demonstrator is planned to be installed in the IMC end mirror by end 2020 / early 2021 followed by large baffles for main mirrors in long arms in 2023/2024.



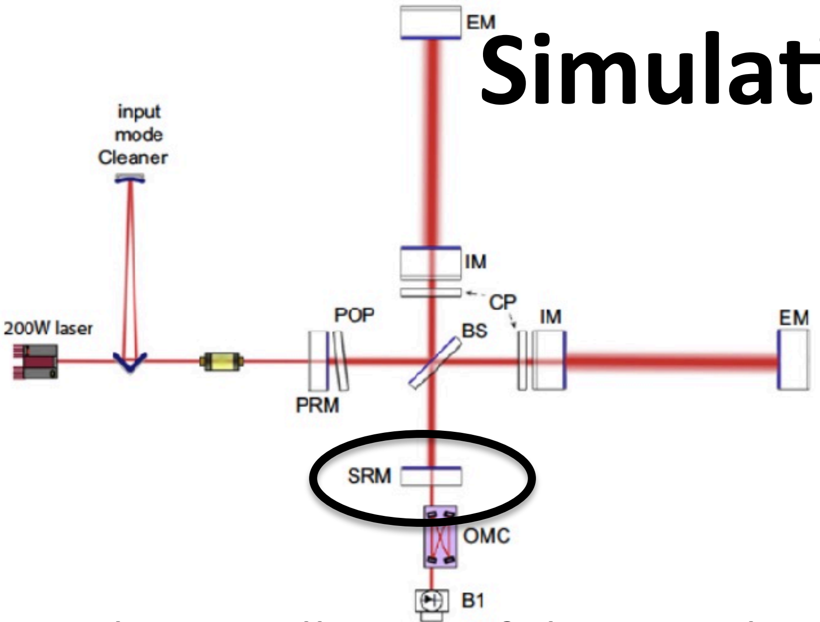


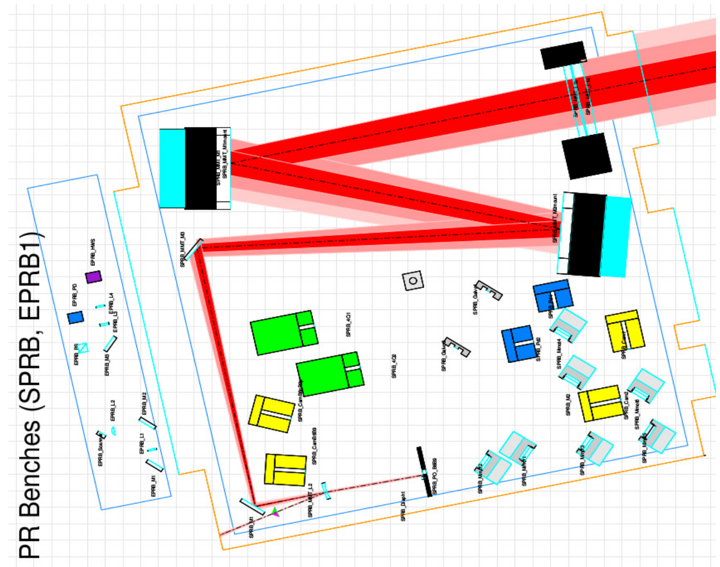
Other contributions related to Stray Light Control

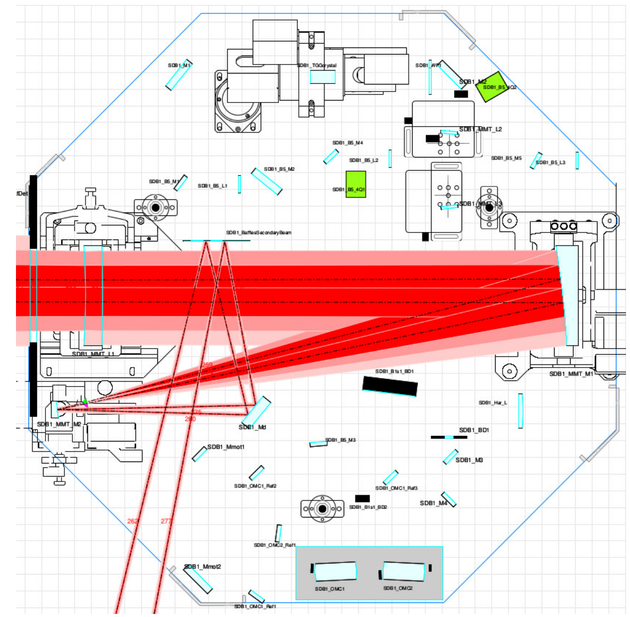
Signal Recycling Parking Position

Baffles for new Frequency Dependent Squeezing System

Simulation of Light Propagation

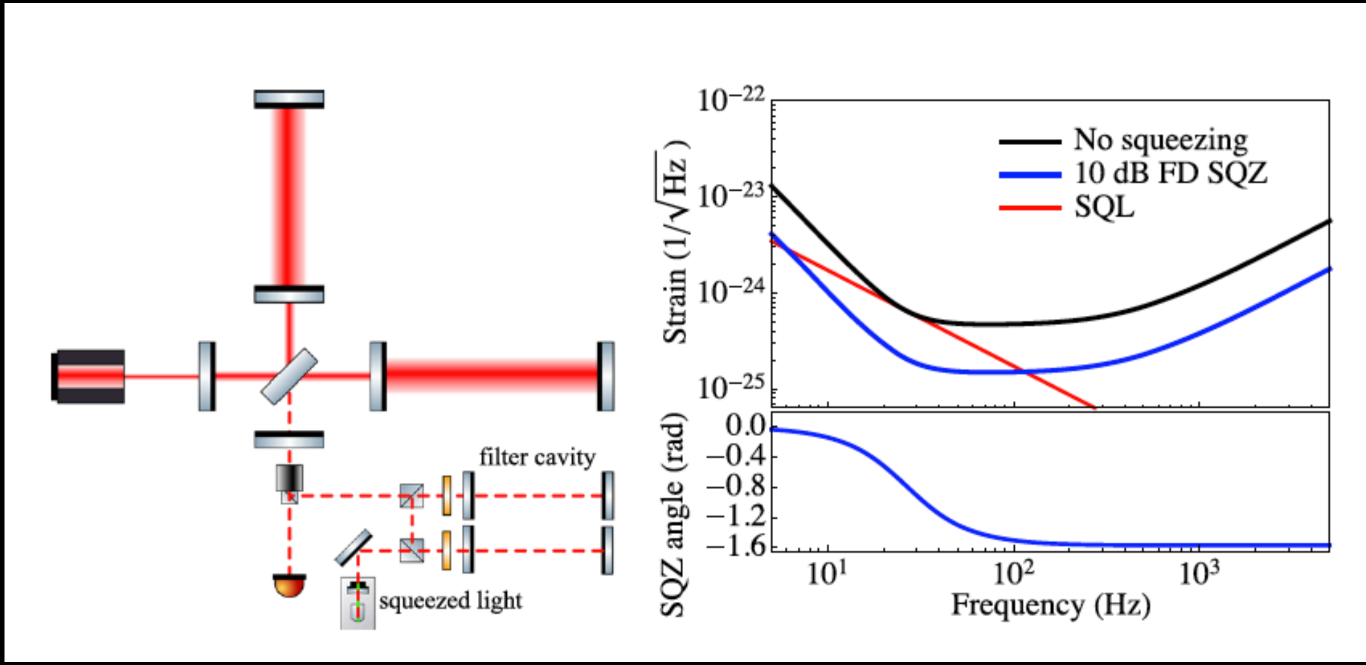




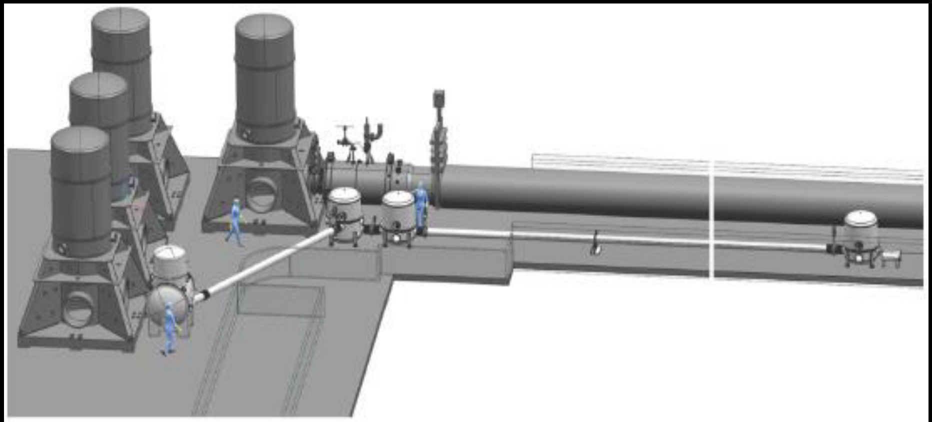


- The installation of the Signal Recycling (SR) Mirror translate into a factor x 2 improvement in sensitivity (@ 10^2 Hz)
- **Contribution on the 2D and 3D simulations of light propagation in ITF and signal recycling setup to determine the parking position for the SR mirror**
- In close collaboration with SR team (EGO)
- Work essentially concluded and an internal note in preparation

Baffles for FD Squeezing System



About a 300 m cavity
Same requirements on vacuum suspension, mirrors, etc..
as the central interferometer



IFAE will contribute with the construction of up to 16 double-sided new baffles inside the pipes for stray light control

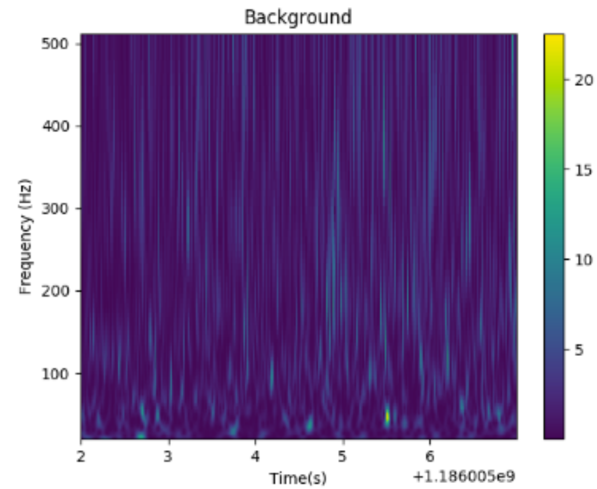
Physics Program

Biased towards Fundamental Physics and Cosmology
Centered around Compact Binaries Coalescence (CBC)

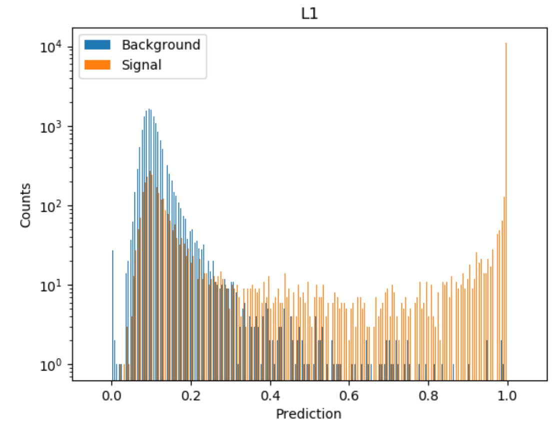
→ Primordial Black holes as DM candidates
→ Determination of H_0 using NS-NS and BH-BH binaries
→ Stochastic GW signals as window to the early universe

On CNNs and CBC

- Within the CBC LVC group (several talks given)
- Within COST action CA17137
  (in collaboration with E. Cuoco et al.,)

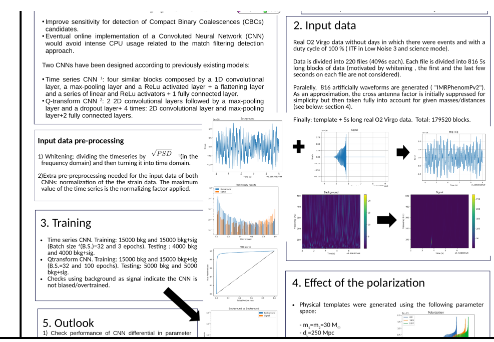


- We built CNNs trained to detect BH-BH in a given range of masses and distances separately for different ITFs and pairs of ITFs (6 independent CNNs)



  – Masses in 0.1 – 2 Msun or 25 - 100 Msun
  – Distances in range 1- 50 Mpcs or 100 - 1000 Mpcs
  – Flat in other (orientation/direction) variables

- Tested over O2 public catalogue successfully
- Followed by a fine scan over full O2 data

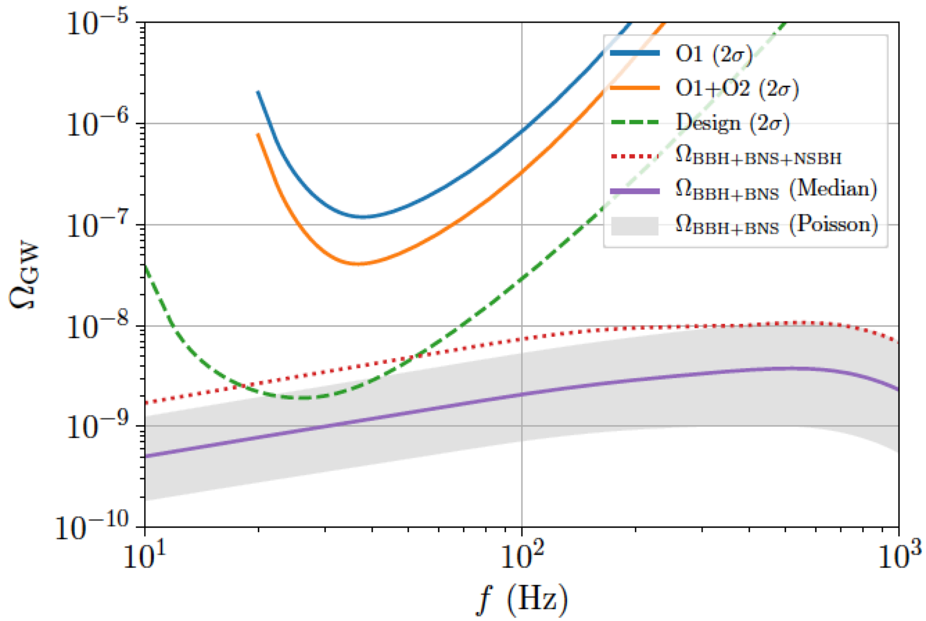


→ **Publication being finalized**

Applying it to O3 data now (results soon)

Poster contribution to Amaldi Conference

Search for Stochastic Signals



arXiv:1908.11174v1 [astro-ph.IM] 29 Aug 2019

Investigation of magnetic noise in Advanced Virgo

A Cirone[1,2], I Fiori[3], F Paoletti[4], M M Perez[5], A R Rodríguez[5], B L Swinkels[6], A M Vazquez[5], G Gemme[1], A Chincarini[1]

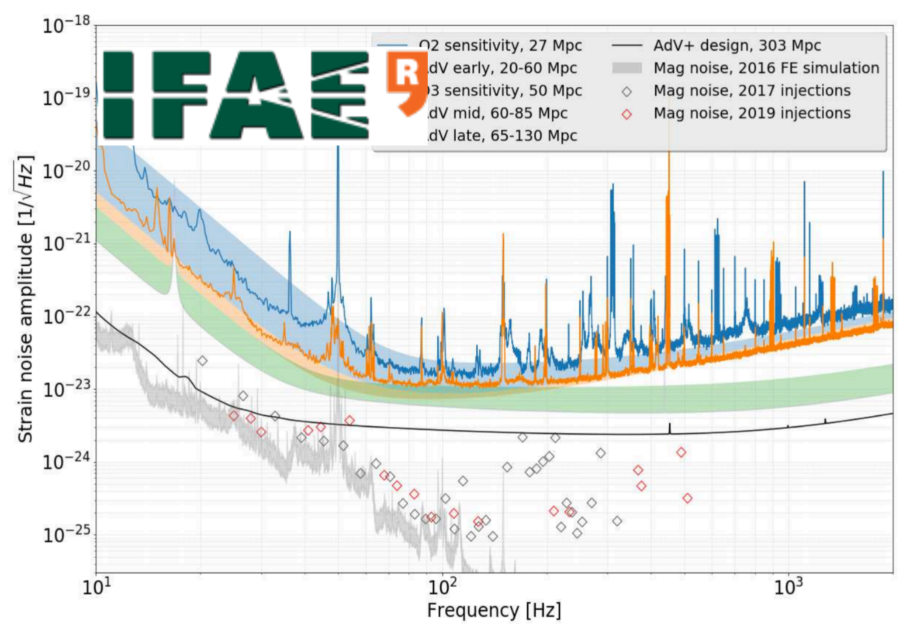
[1] INFN, Sezione di Genova, I-16146 Genova, Italy
[2] Dipartimento di Fisica, Università degli Studi di Genova, I-16146 Genova, Italy
[3] European Gravitational Observatory (EGO), I-56021 Cascina, Pisa, Italy
[4] INFN, Sezione di Pisa, I-56127 Pisa, Italy
[5] IFAE, Barcelona Institute of Science and Technology, Barcelona, and ICREA; Spain
[6] Nikhef, Science Park 105, 1098 XG Amsterdam, The Netherlands

E-mail: alessio.cirone@ge.infn.it

Abstract. The Advanced Virgo (AdV) sensitivity might be influenced by the effects of environmental noise, in particular magnetic noise (MN). In order to show the impact on the gravitational-wave strain signal h(t) and on the AdV sensitivity, we must understand the coupling between the environmental magnetic activity and the strain. The relationship between the environmental noise - measured by a physical environment monitor (PEM) - and h(t) is investigated using injection studies, where

A. Cirone et al.,
***Class. Quant. Grav.* 36, no.22, 225004**

Keywords: Magnetic noise, Gravitational waves, Advanced Virgo, strain sensitivity,



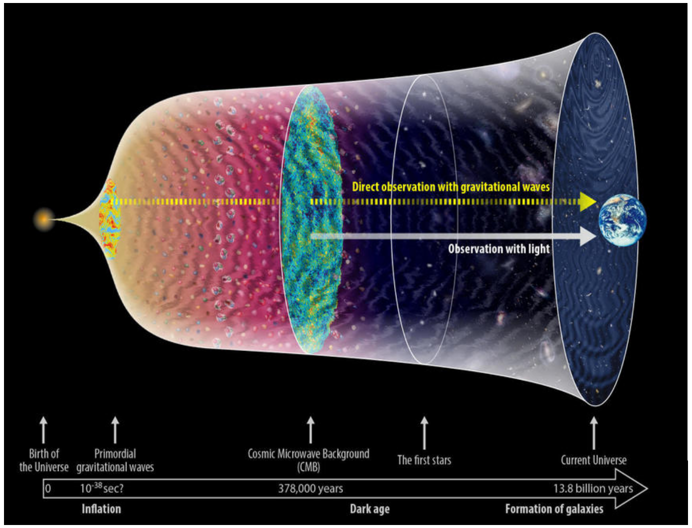
According to present projections a stochastic GW signal from BBH might be in the reach

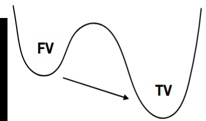
Signal is tiny → not detectable in single ITF
Requires to exploit the correlations between ITFs with noise assumed to be totally uncorrelated

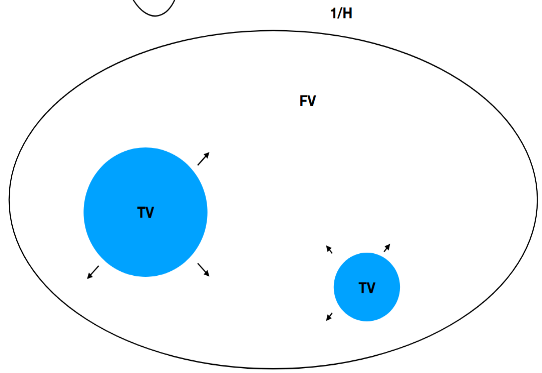
Earth B-Field (Schumann resonances) introduces dangerous long-distance correlations

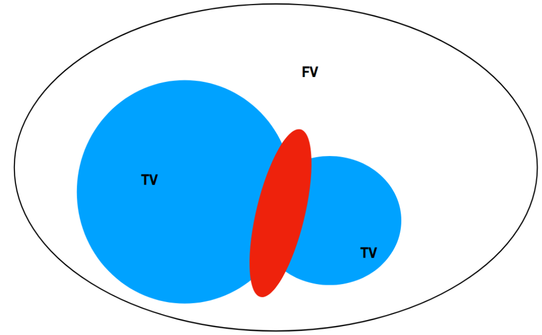
→ Magnetic injection tests at LIGO/Virgo

Towards O3 results









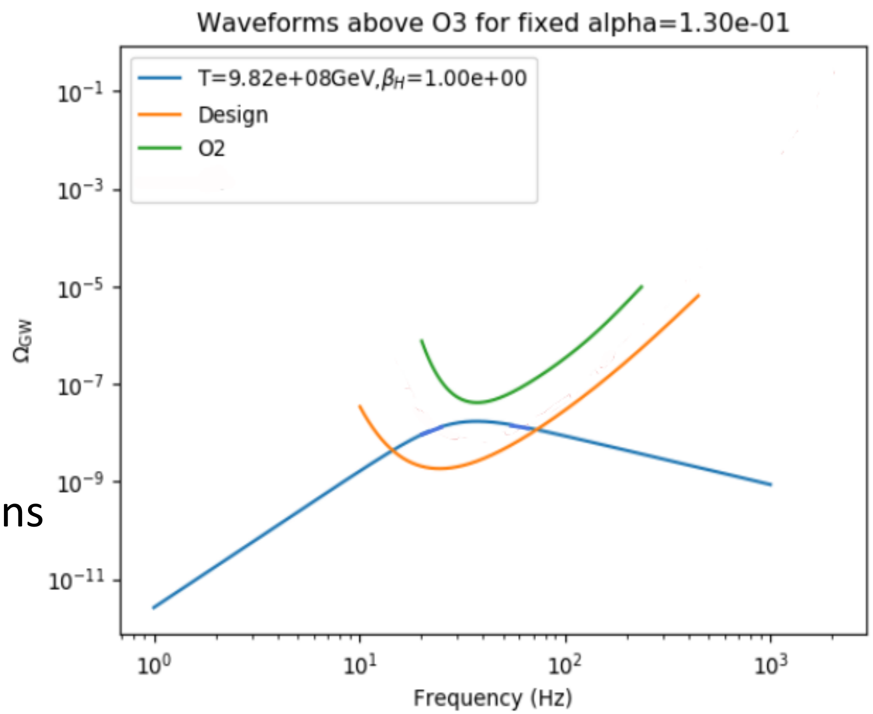
quantum or thermal nucleation of bubbles

Bubble collisions leading to GWs

IFAE is playing a central role in the LVC analysis on Stochastic GW signals

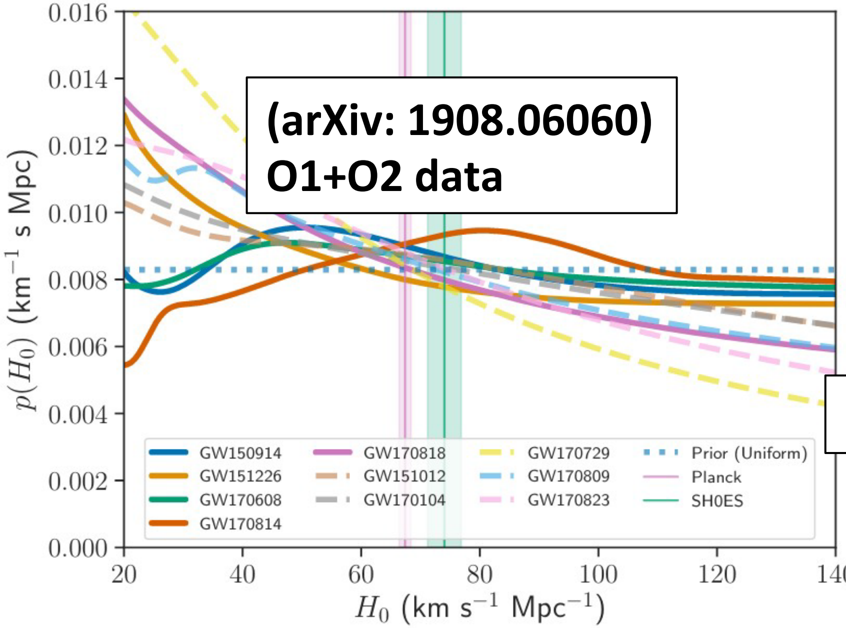
Involved in the generic search using O3 data

Preparing interpretations with emphasis on GWs from strong first-order phase transitions in the early universe (Temp – 10^7 – 10^9 GeV)



See talk by O. Pujolas tomorrow

H0 determination and Cosmology

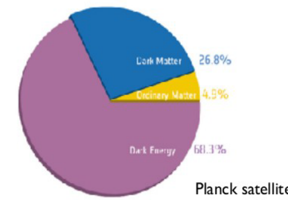


Comoving distance $D_C(z) = \frac{c}{H_0}\int_0^z dz' \frac{H_0}{H(z')}$ Hubble constant (current expansion rate) Hubble parameter (expansion rate)

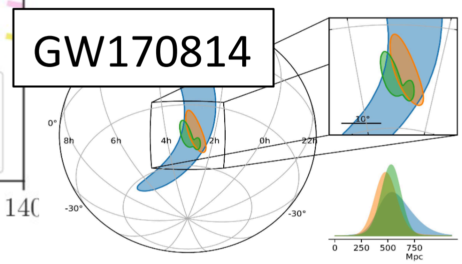
$$\frac{H^2(z)}{H_0^2} = \boxed{\Omega_r}(1+z)^4 + \boxed{\Omega_m}(1+z)^3 + \boxed{\Omega_\Lambda} + \boxed{\Omega_k}(1+z)^2$$

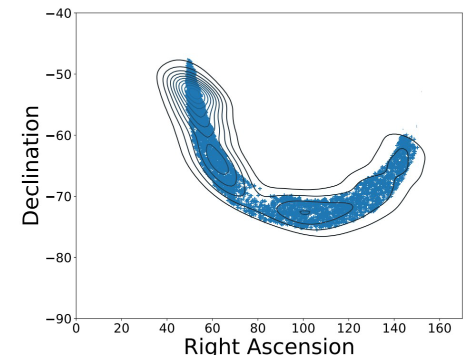
Radiation **Dark Energy**

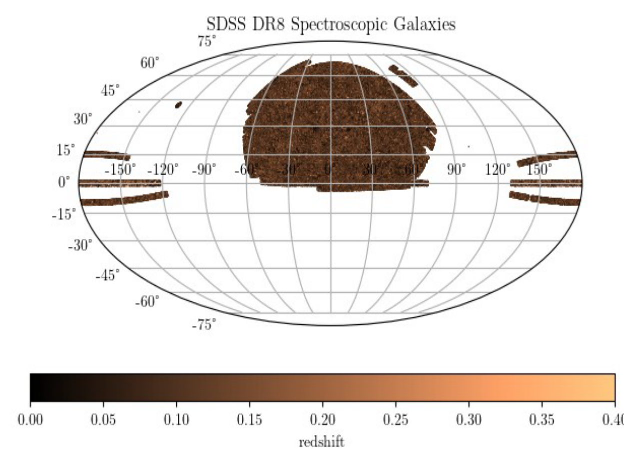
Matter (baryonic or dark) **Curvature**



Planck satellite







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 (BBH injection tests in normal galaxies and AGNs)
- Improve the use of galaxy catalogues in H0 determination (for example use of galactic magnitudes)
- Explore extracting other Cosmological parameters in addition to H0

Other multi-messenger Initiatives

Kick-off Meeting COST Action CA18108: QG-MM (Quantum Gravity phenomenology in the Multi-Messenger approach)

2 Oct 2019, 09:00 → 4 Oct 2019, 18:00 Europe/Madrid

Aula Magna (Casa de Convalescència)

https://indico.ifae.es/event/536/overview

cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Organized by IFAE @ Downtown Barcelona

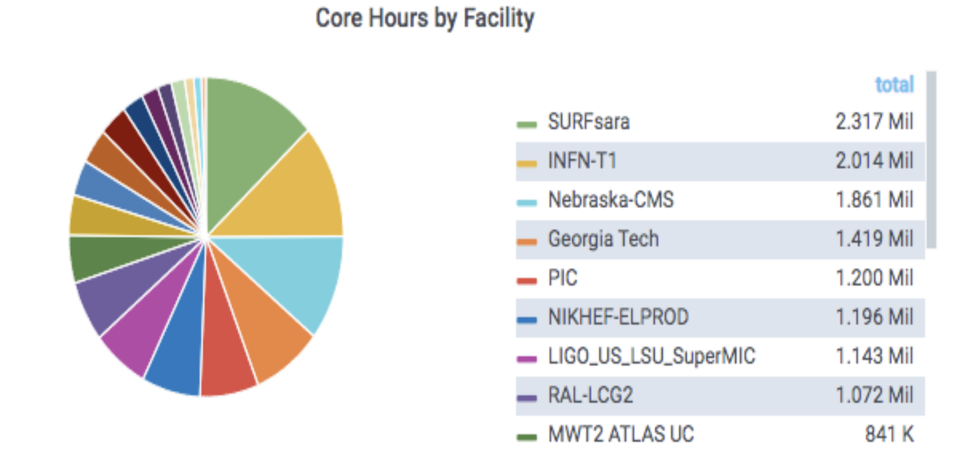
Collaborative effort of IFAE-CTA / IFAE-GWs/IFAE-TH groups

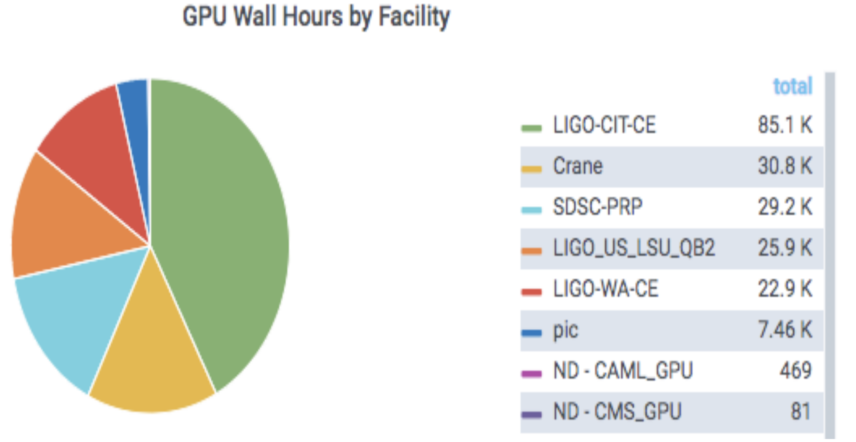
Computing

PIC
port d'informació
científica

One of 12 Tier-1 LHC data processing centers, only one in Spain

~20 PB on disk, ~20 PB on tape





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

Future enlargement subject to funding

Virgo CM @ IFAE (April 2020)*

Virgo Week, April 27-30, 2020

27-30 April 2020
Europe/Madrid timezone

- Overview
- Timetable
- Registration Instructions
- Registration
- Participant List

Welcome to the Virgo Week in Barcelona!

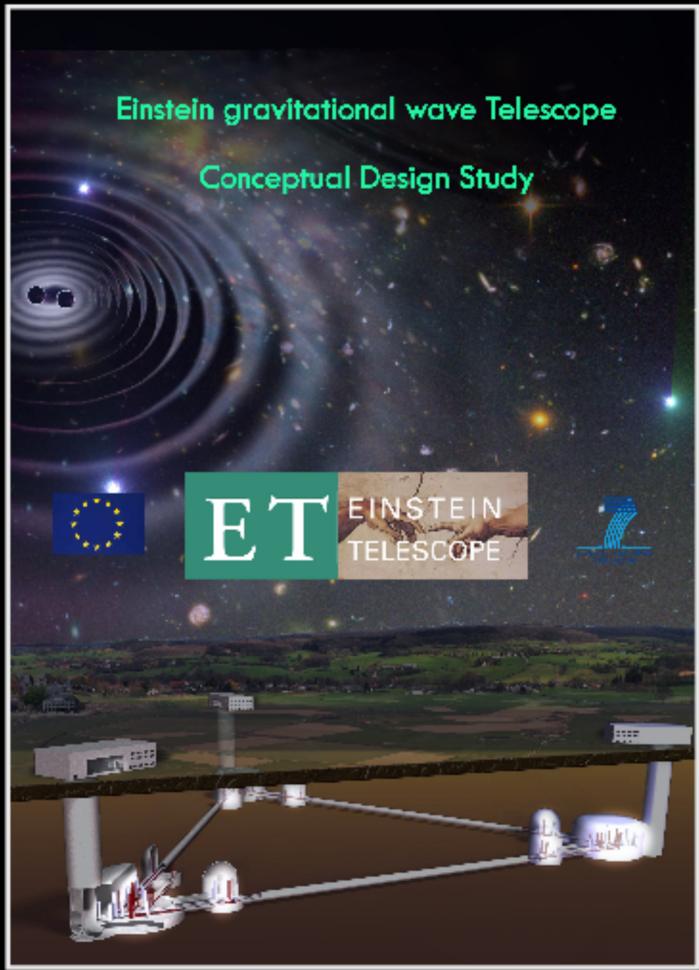
The Virgo Collaboration week will be held from 27th to 29th April 2020 in Barcelona, hosted by the the Institut de Física d'Altes Energies (IFAE). The venue is the Hotel Campus Barcelona, located on the UAB campus in Bellaterra, 25 km north of the Barcelona city centre. The meeting will begin at 9 am on Monday and finish on Wednesday at 5:30 PM.

* Originally planned for October 2019, postponed due to 1 month commissioning campaign

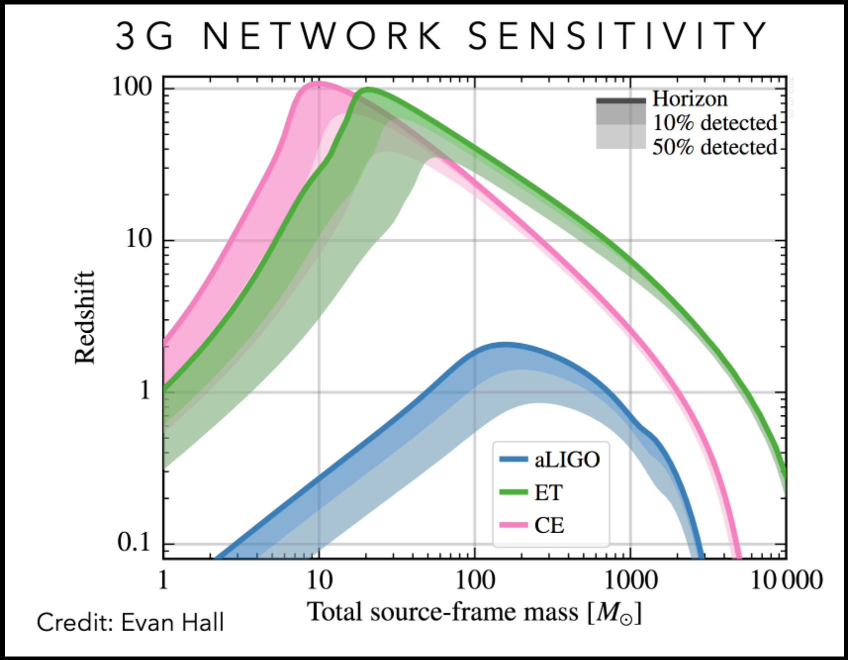
Future Interferometers
(3G ground based)

Getting already involved in the 3G discussions

→ M. Martinez part of the ET Steering committee
  → Preparing ESFRI proposal for EU
  → Leading discussions with Spanish Funding Agency

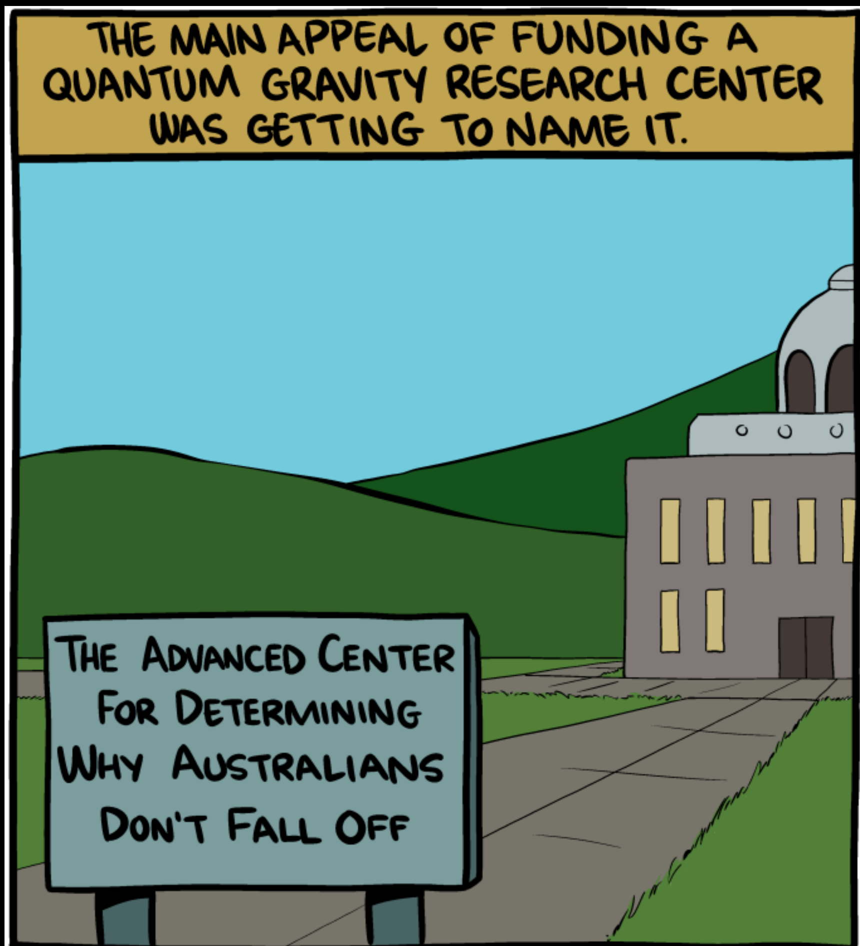


Einstein Telescope (EU) : 10km, underground
Cosmic Explorer (USA): 40km interferometer
Projects for next decades



To reach redshift up to z = 10 - 100

Final notes



The GWs field is/will be one of the leading lines of research in Fundamental Physics and Cosmology in the next decades

New window to the early universe and inflation, DM searches, etc…

Applying HEP culture @ IFAE

→ Deep involvement in operations and commissioning campaigns

→ New instrumentation for a very delicate environment

→ Contribute to main physics topics using O3 data and beyond

→ Exploring 3G projects for next decades