# Gravitational wave research at UCLouvain

BelGW meeting | 27.10.2020

Data analysis

Computing

Theory

Instrumentation

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Andres Tanasijczuk

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Federico De Lillo, Antoine Depasse

# Anisotropic search in the SGWB and inspiraling PBHs

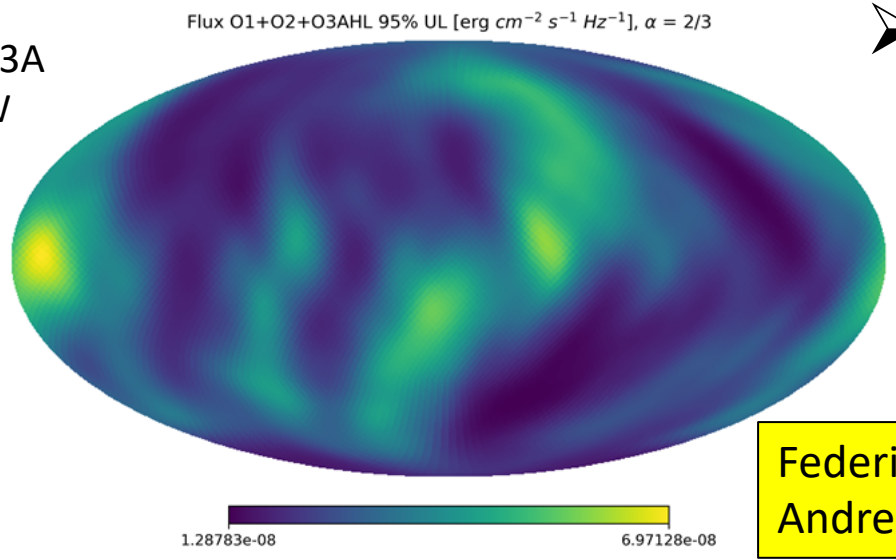
- Stochastic GW background (SGWB) from superposition of unresolved sources;
- Searches by correlating detector outputs;
  - Anisotropic: spherical harmonics (extended sources), **broadband radiometer** (point-like sources), narrowband radiometer (point-like, known sources);
  - Also search for specific signatures of cosmic strings models (see slide 5).

GW flux using O1,O2,O3A from LIGO only and GW energy flux model:

$$\mathcal{F}(f,\Theta) = \mathcal{F}_\alpha(\Theta)\left(\frac{f}{f_{\rm ref}}\right)^{\alpha-1}$$

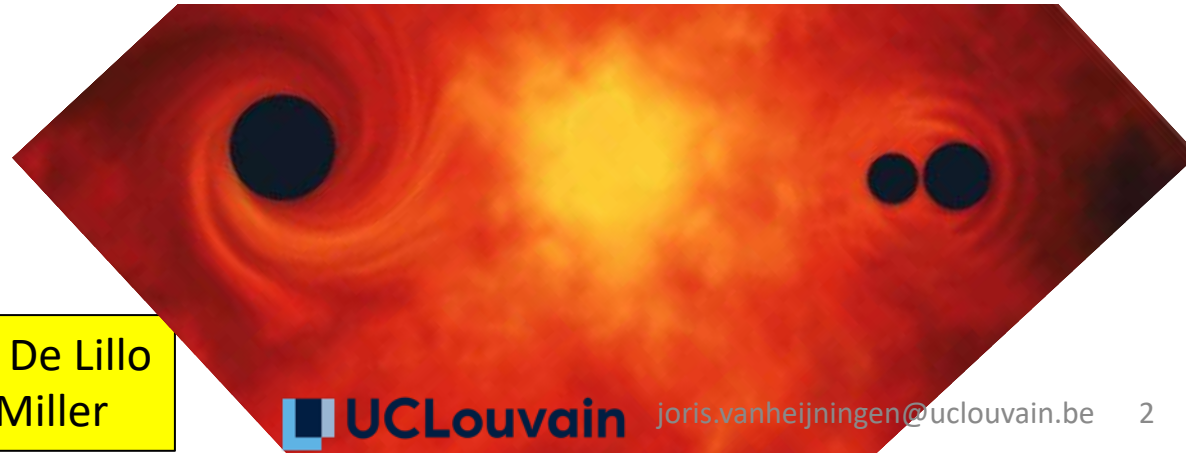
, with

$$\mathcal{F}_\alpha(\Theta) = \frac{c^3\pi}{4G} f_{\rm ref}^2 \mathcal{P}(\Theta)$$



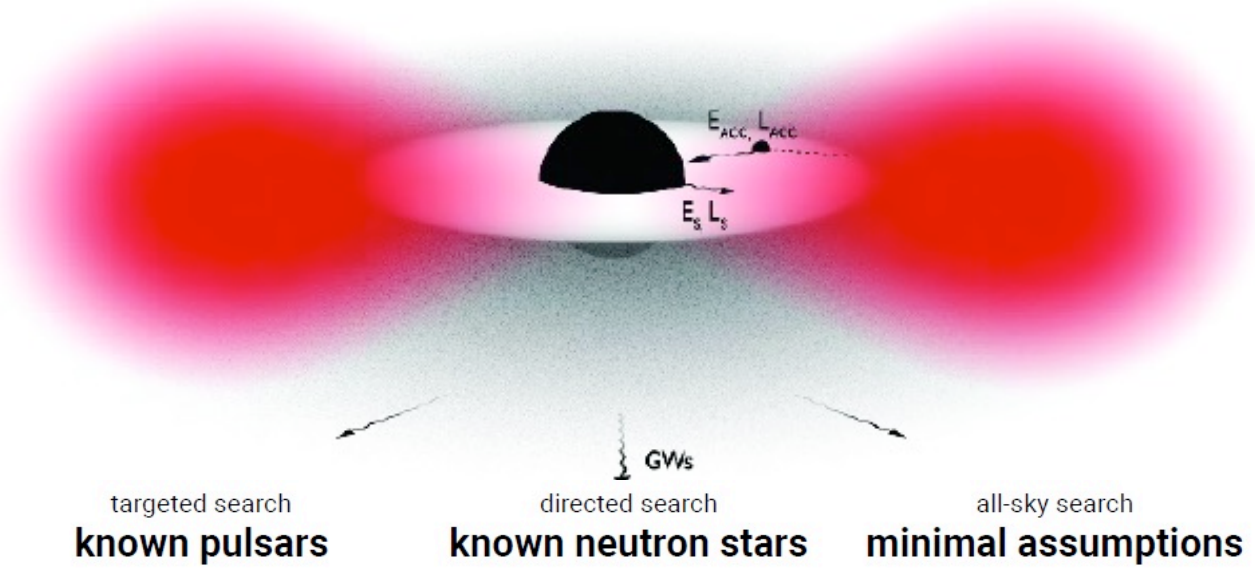

B.P. Abbott et al., Phys. Rev. Lett. **118**, 121102 (2017)

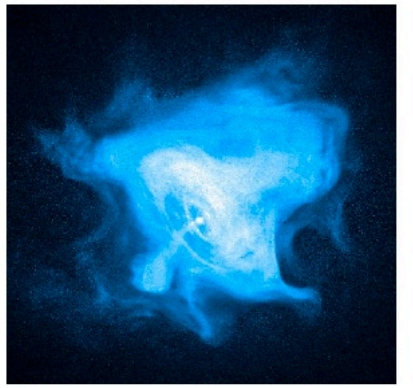
- Primordial black holes (PBHs) could form early in the universe in halos or binaries;
- While GW searches have focused on >0.1 $M_{sun}$ regime, theoretically PBHs could be extremely light;
- For PBHs of mass $[10^{-7}, 10^{-3}]M_{sun}$ , the inspiral would give rise to (transient) CWs. soon on adapt NS techniques;
- Search towards galactic center. Plan .

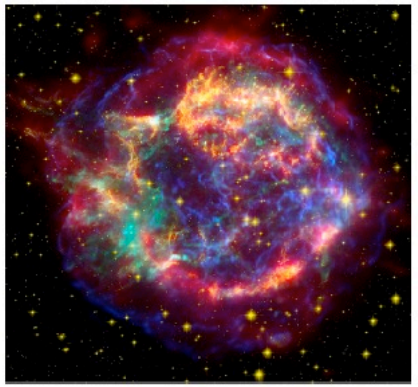


Federico De Lillo
Andrew Miller

# Continuous waves from boson clouds





¯_(ツ)_/¯

computational cost

search sensitivity

[NASA/CXC/SAO/F.Seward et al.][Courtesy NASA/JPL-Caltech]

- Dark matter can form clouds around black holes if its Compton wavelength is comparable to the size of the black hole
- Boson clouds can emit continuous gravitational waves as they annihilate after superradiance ($\Omega_b < \Omega_{BH}$)
- This system will emit quasi- continuous GW;
  - $\nu_{GW} \approx 2\ m_b$ ;
  - $m_b$ sensitivity around [$10^{-13}$ - $10^{-11}$] eV;
- Methods on vector boson clouds and search in advanced detector data for nearby galactic binaries is planned.

Antoine Depasse
Andrew Miller

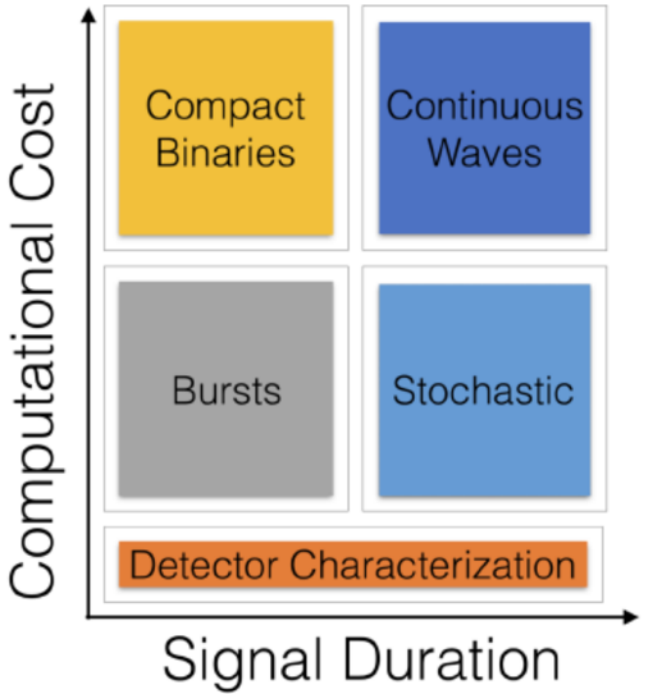
# Computing efforts for the LIGO Virgo collaboration

Virgo **online** computing at EGO;

- Data collection, calibration and monitoring (O($10^5$) auxiliary channels)
- DetChar and data validation
- Low-latency searches (for public alerts)

Virgo **offline** computing at several centers, including UCLouvain;

- Common distributed computing
- Contribute CPU for opportunistic use




Andres Tanasijczuk

https://github.com/AndresTanasijczuk/SlurmDagman

June 2020 CPU LIGO/Virgo CPU accounting (core hours)

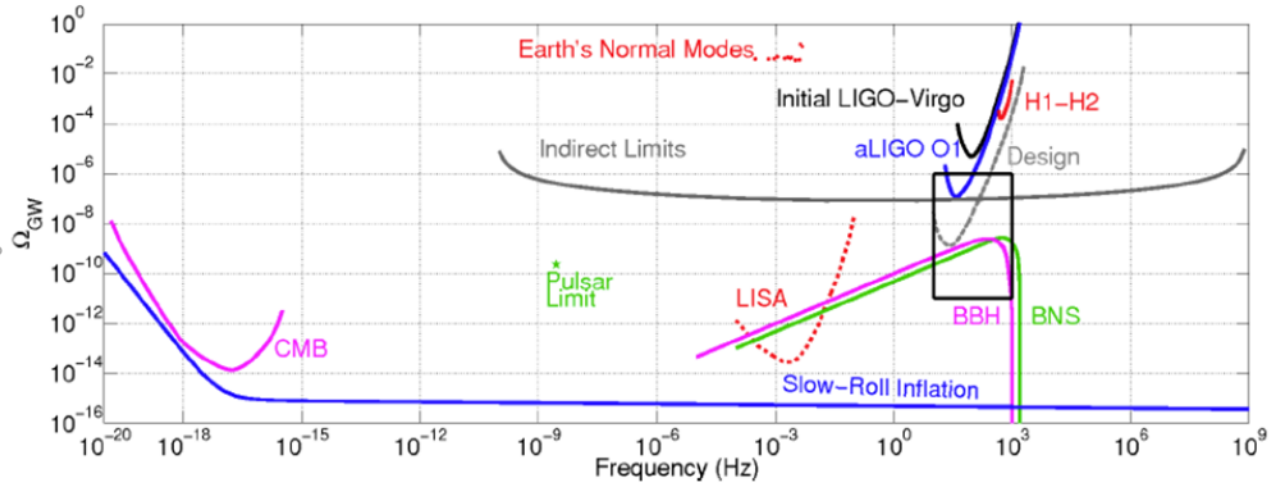
| | total |
|---|---|
| SURFsara | 381 K |
| Nebraska-CMS | 360 K |
| INFN-T1 | 349 K |
| PIC | 200 K |
| LIGO_US_LSU_SuperMIC | 179 K |
| UCSD CMS Tier2 | 171 K |
| MWT2 ATLAS UC | 128.7 K |
| Georgia Tech | 72.3 K |
| BelGrid-UCL | 54.2 K |
| IN2P3-CC | 33.5 K |
| SU ITS | 22.8 K |
| AGLT2 | 20.8 K |
| LIGO-WA-CE | 8.44 K |
| LIGO_US_LSU_QB2 | 7.81 K |
| LIGO-CIT-CE | 7.50 K |
| Nebraska-Omaha | 6.77 K |
| UWM - NEMO | 5.42 K |
| ND_CAML | 2.591 K |
| NIKHEF-ELPROD | 1.541 K |
| LIGO-LA-CE | 1.166 K |

- Our **WLCG Tier2** now accepts LVC jobs and plans to extend with ~500 Virgo worker nodes in ~June 2021;
- Cluster uses **SLURM** batch system, application on git;
- Start deployment of **StashCache** server.

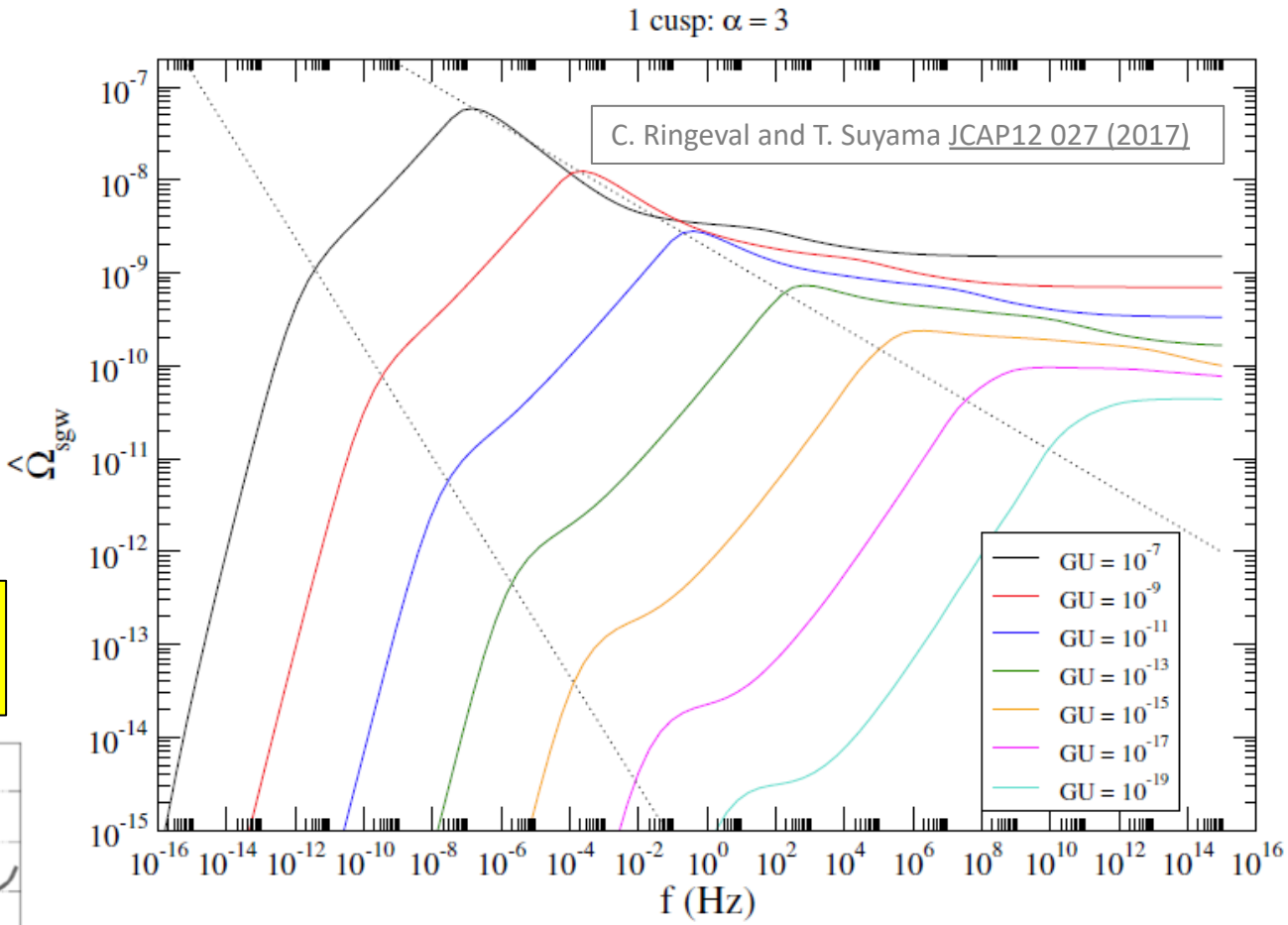
# Stochastic GW Background from Cosmic Strings

- Topological defects that could have formed in the early Universe;
- Predictions on average GW energy density in the universe from cosmic strings.

Christophe Ringeval
Disrael da Cunha



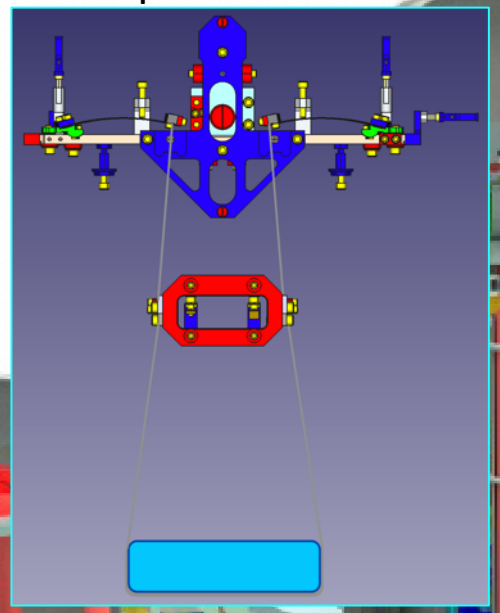

B.P. Abbott et al., Phys. Rev. Lett. **118**, 121101 (2017)




| Model | LIGO | EPTA | LIGO + EPTA |
|---|---|---|---|
| 2C | $GU \leq 1.1 \times 10^{-10}$ | $GU \leq 3.4 \times 10^{-11}$ | $GU \leq 1.0 \times 10^{-11}$ |
| LNK | – | $GU \leq 6.8 \times 10^{-11}$ | $GU \leq 7.2 \times 10^{-11}$ |
| HNK | $GU \leq 8.8 \times 10^{-14}$ | $GU \leq 6.4 \times 10^{-12}$ | $GU \leq 6.7 \times 10^{-14}$ |
| MIX | $GU \leq 1.4 \times 10^{-8}$ | $GU \leq 1.1 \times 10^{-11}$ | $GU \leq 5.9 \times 10^{-12}$ |

# Benchtop suspensions for ETpathfinder

all 3” optics expect
for the beamsplitters

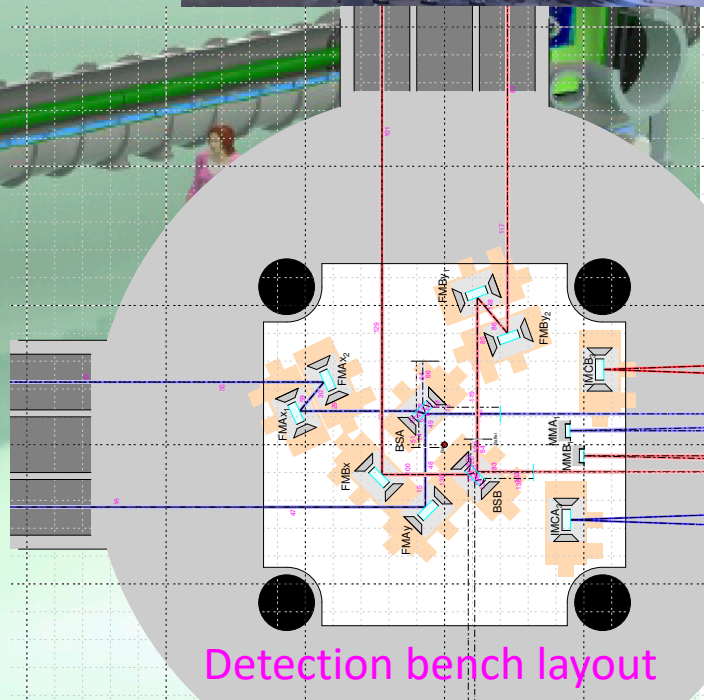


alterations underway

Maastricht University
Nikhef


Detection bench

Injection bench

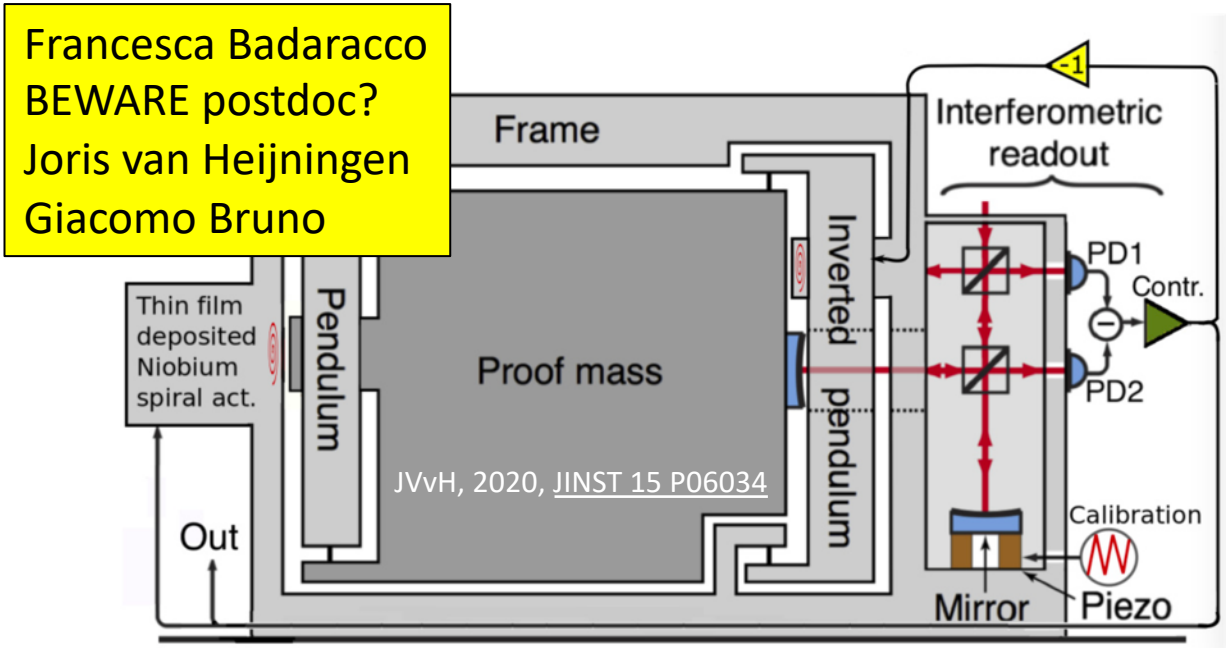



Nicolas Szilasi
Joris van Heijningen
Giacomo Bruno

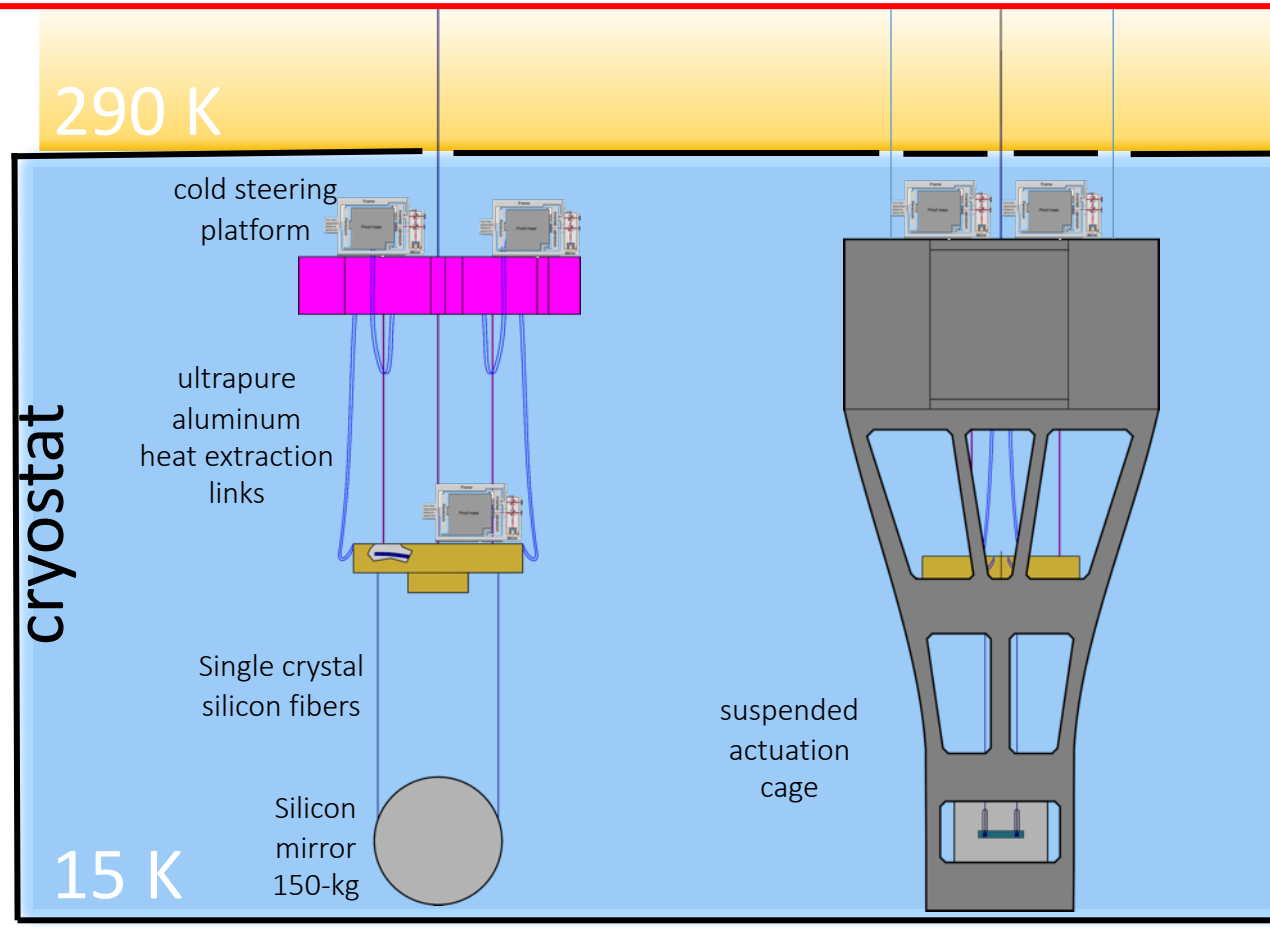
# Cryogenic inertial sensors and control for E-TEST

- Mechanics made out of Niobium (Nb), superconducting at T<9.2 K;
- Actuator of Nb wire, later deposited;
- We expect fm/√Hz sensitivity from 2 Hz onwards, interesting for ET;
- In collaboration with LIÈGE université and RWTH AACHEN UNIVERSITY;

Francesca Badaracco
BEWARE postdoc?
Joris van Heijningen
Giacomo Bruno




Active control platform(s), maybe with inverted pendulum stage

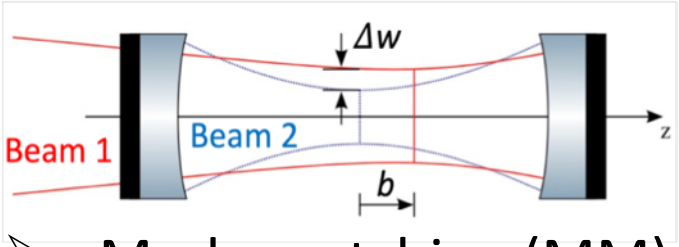



- The 290 K (active) and cold 15 K suspension designed, fabricated in Liège (LIÈGE université & CSL);
- We will contribute modern control techniques.


A. Bertolini et al.,2006, NIM A, 556, pp 616-623

M.B. Gray et al., 1999, Opt.Quant.Electron., 31, pp 571-582

# Mode mismatch mitigation for Advanced Virgo




- Mode matching (MM) sidebands;

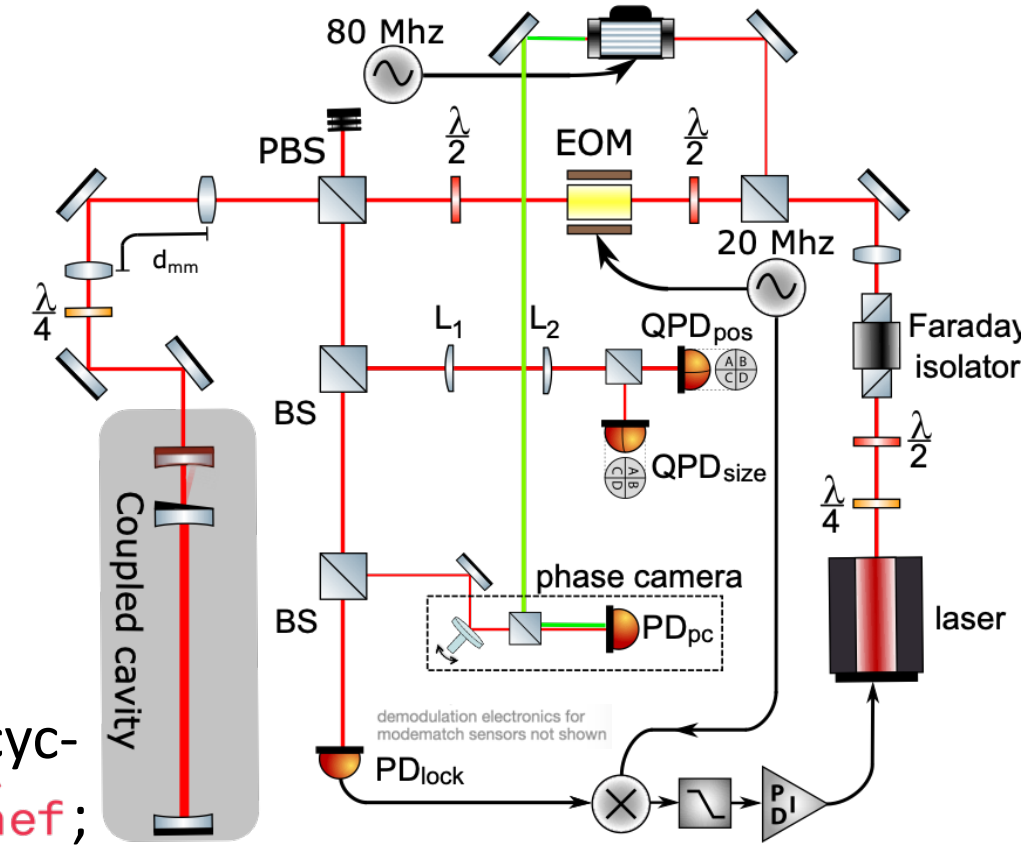



PhD student?
Joris van Heijningen

**Newly installed**

- Contibute to signal recycling control with Nikhef;

- Setup at UCLouvain to test MM techniques at 1550nm;
- Start with simple cavity and then proceeding to coupled cavity.




K. Agatsuma et al., Opt. Express 27, 18533-18548 (2019)

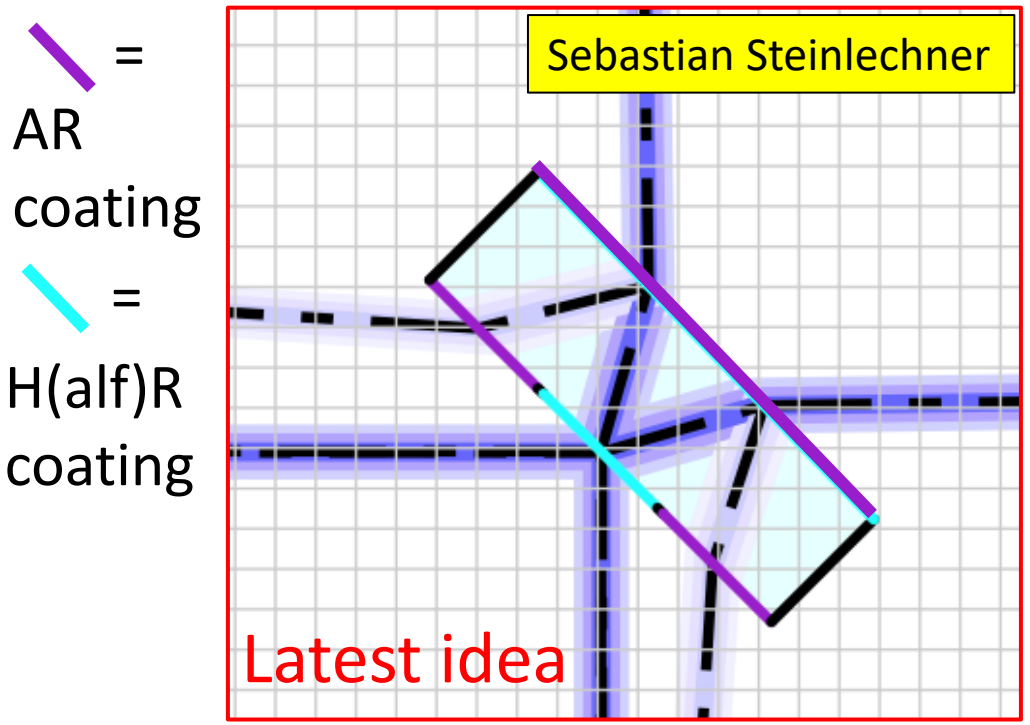
# Summary of gravitational wave efforts at UCLouvain

- We contibute to the LIGO/Virgo collaboration and third generation detector prototypes in data analysis, computing, theory and instrumentation;

- Anisotropic search in SGWB, **continuous waves** from primordial black holes, boson clouds and **dark photon search (see Andrew's talk)**;
- We host large(r) clusters for the LVC to process their calculations on and will soon host h(t) with which submitted jobs can work;
- Work on stochastic GW background predicts GW energy density by in the Universe from cosmic strings;
- Ramping up an instrumentation effort for Advanced Virgo+ (mode mismatch), ETPathfinder (benchtop suspensions) and E-TEST (cryogenic suspension control and inertial sensing).


# Bonus slides

# What about the beam splitters?



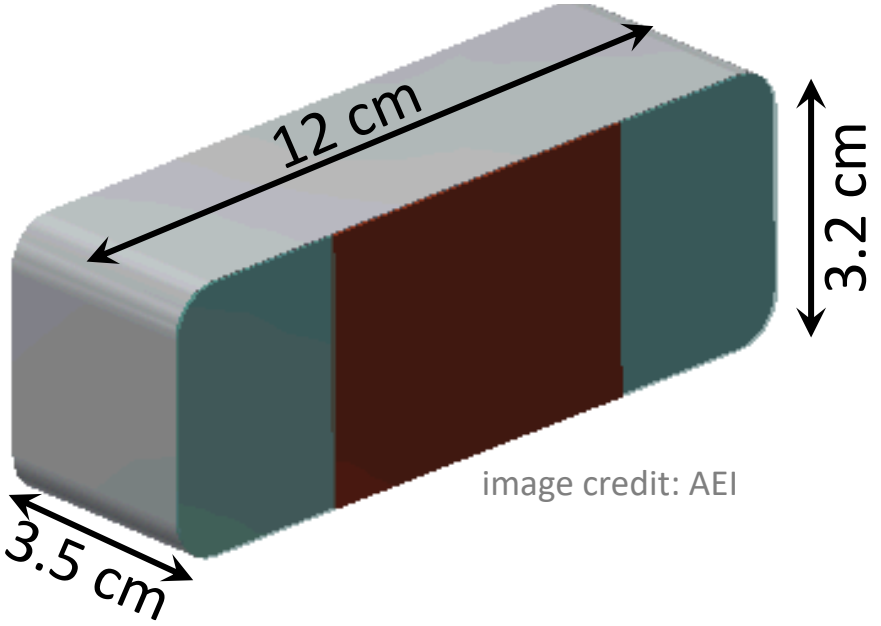




image credit: AEI

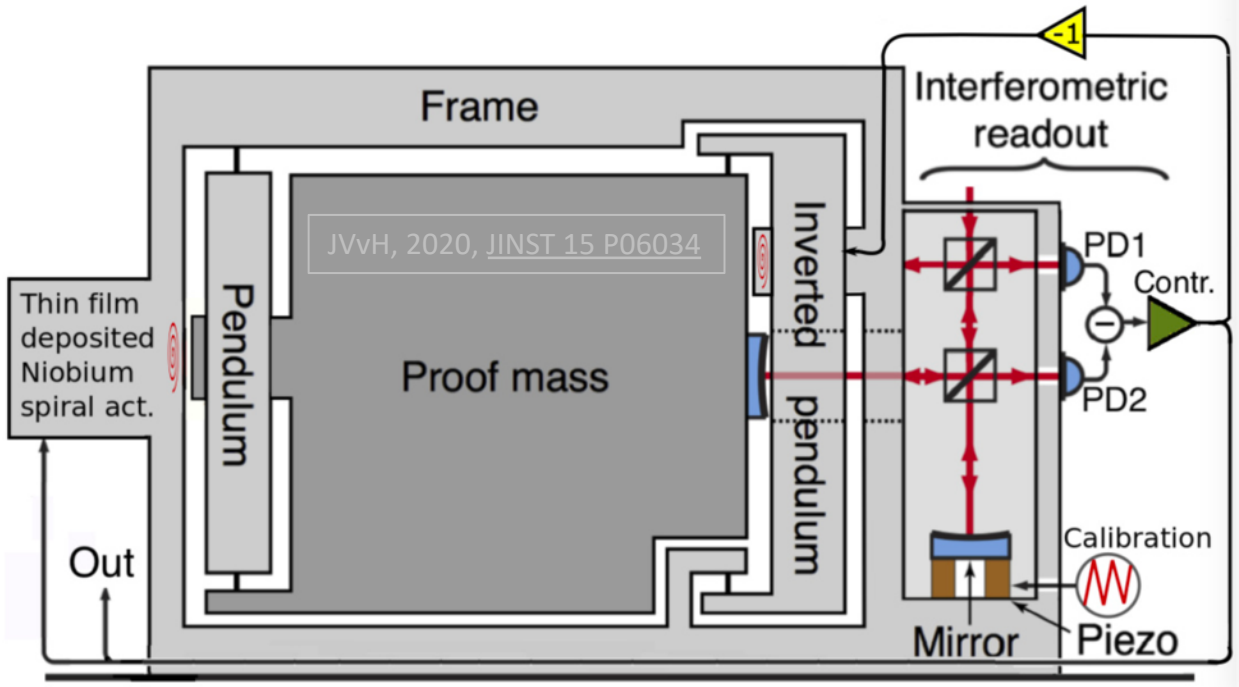
- Secondary beams out of the beam splitter have to be dumped properly;
- A round optic of sufficient diameter to extinguish these beams (5”) would be too large and too heavy for the suspensions;
- The latest plan is rectangular fused silica beam splitters weighing 300g.

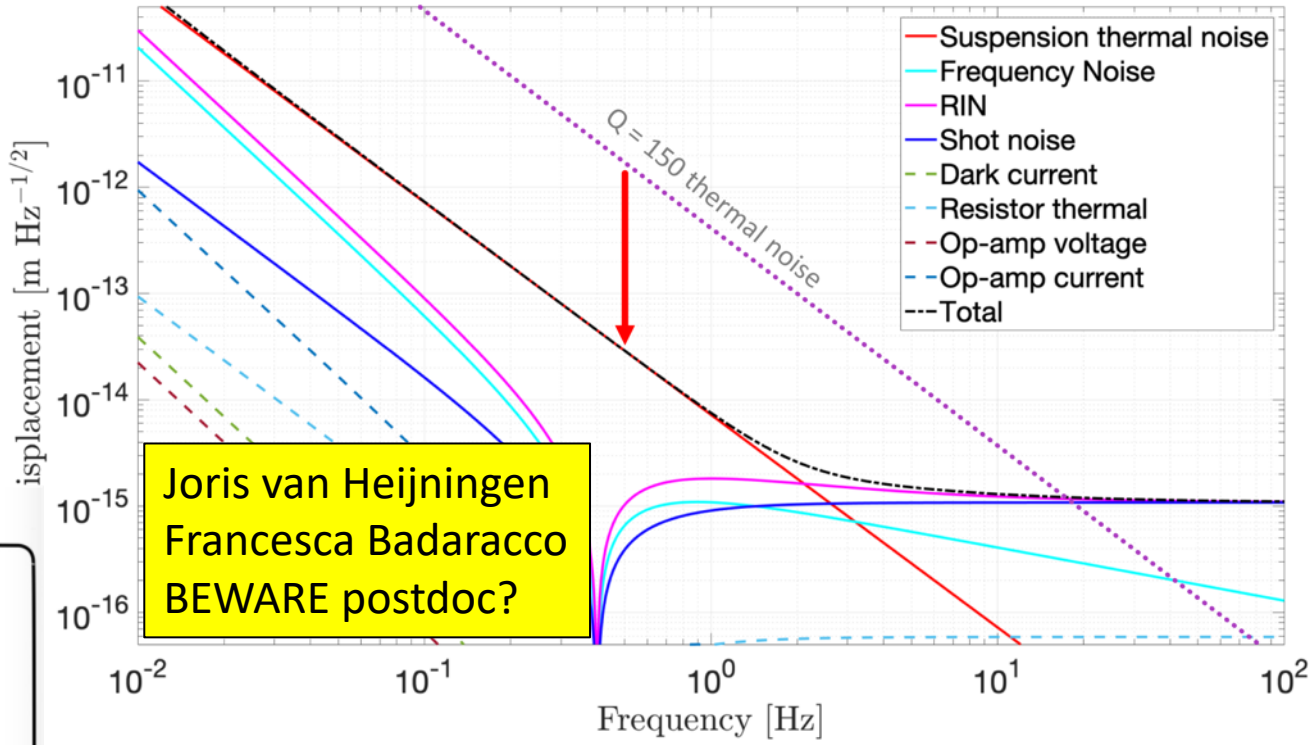
# Cryogenic superconducting inertial sensor for E-TEST

- Room temperature version was limited by coil-magnet actuator resulting in Q = 150;

JVvH et al., 2018, IEEE SAS Seoul, pp. 1-5

- Mechanics made out of Niobium (Nb), which is superconducting at T<9.2 K;
- Actuator of Nb wire, later deposited.




Joris van Heijningen
Francesca Badaracco
BEWARE postdoc?

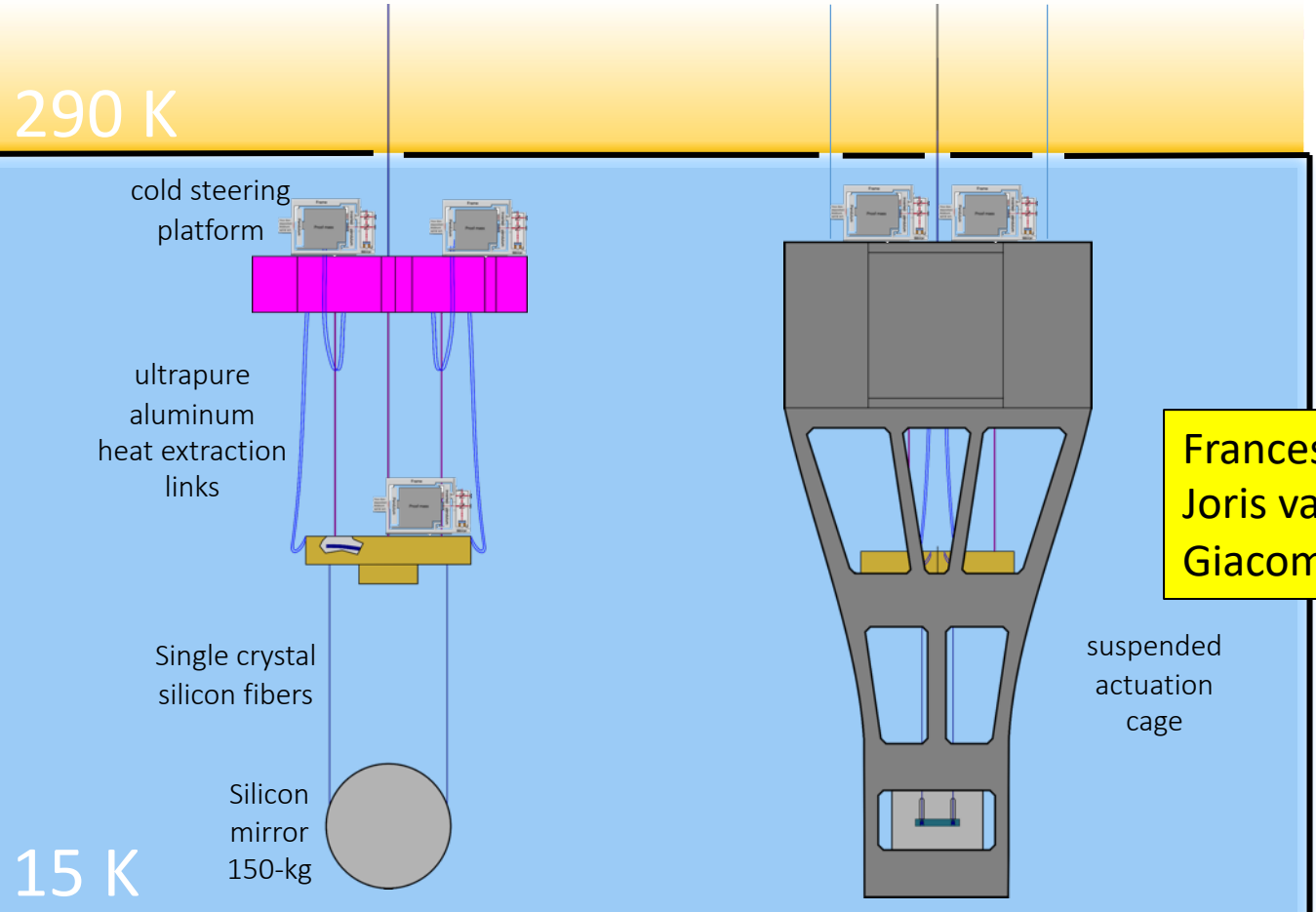
- This will result in Q = $10^4$ and reduce the thermal noise by a factor 50;
- Inertial sensor development in collaboration with LIÈGE université and Physics Institute III | RWTH AACHEN UNIVERSITY ;
- Ultimately to be deployed in E-TEST.

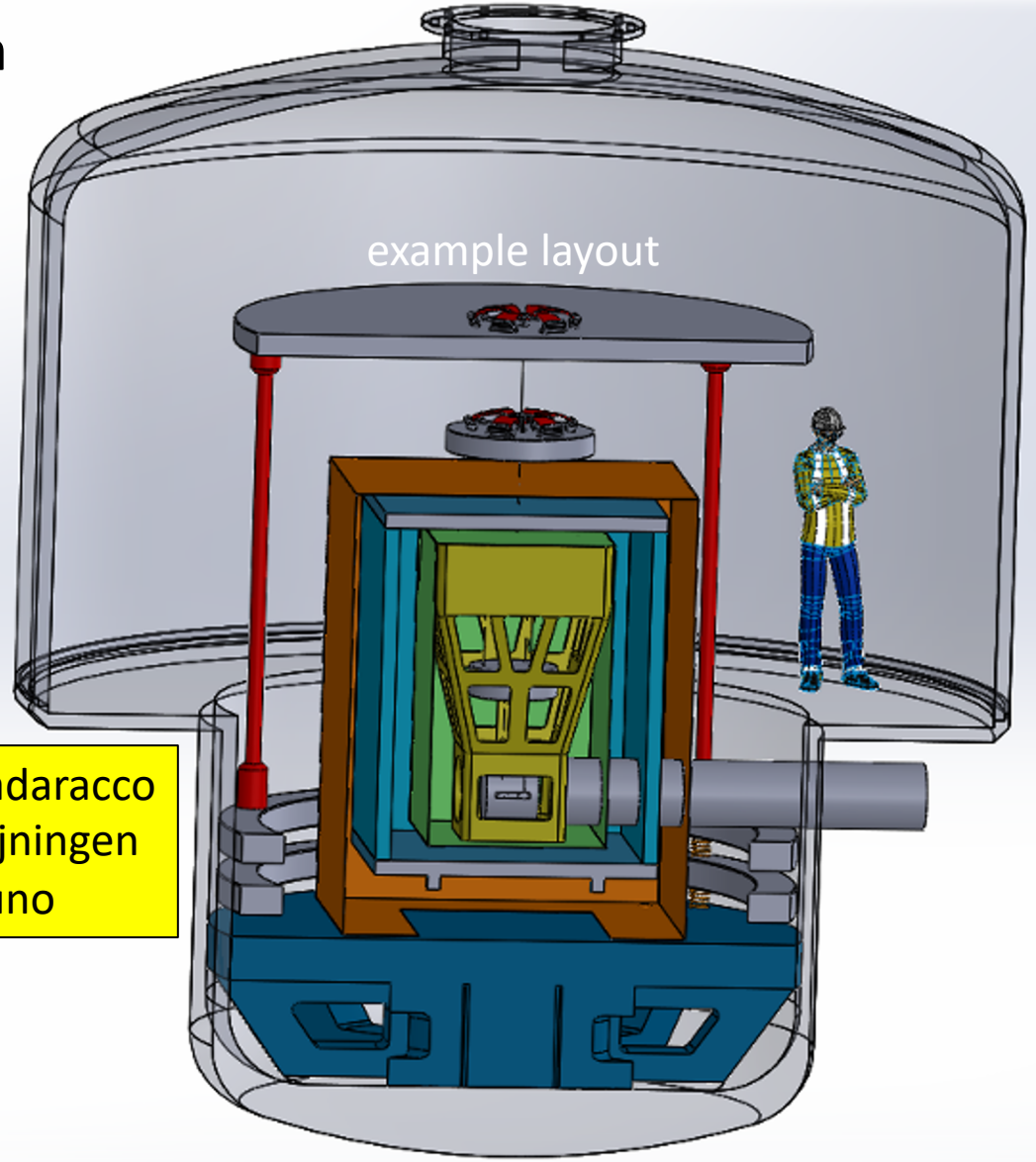
A. Bertolini et al.,2006, NIM A, 556, pp 616-623

M.B. Gray et al., 1999, Opt.Quant.Electron., 31, pp 571-582

# Cryogenic suspension of an ET sized optic (½ E-TEST)

- The room temperature (active) and cold suspension designed and fabricated in Liège (LIÈGE université & CSL);
- We will contribute to the control strategy with modern control techniques.




Francesca Badaracco
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