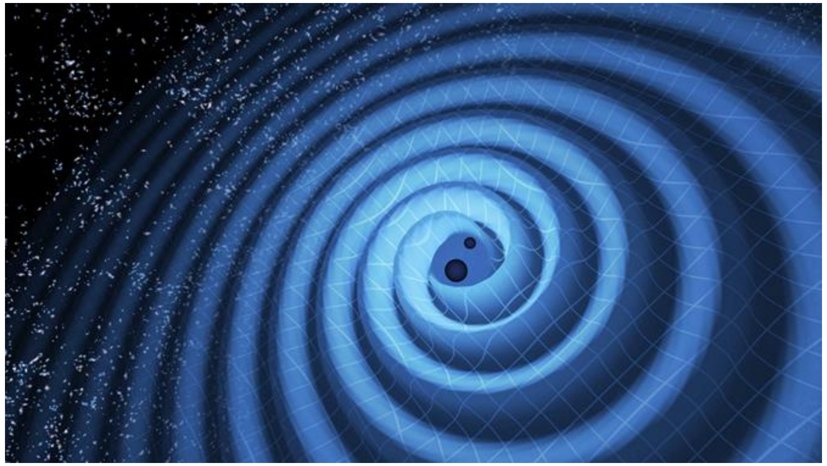
Banc suspendu sous vide et développements associés

R. Gouaty, on behalf of the LAPP gravitational waves group



LAPP instrumental activities in Virgo and towards ET

- **LAPP involved in design, construction, installation and commissioning of Virgo detector**

- **Some areas of technical expertise:**

  - **Optical benches and sensors**

  - **Output Mode Cleaner cavities**

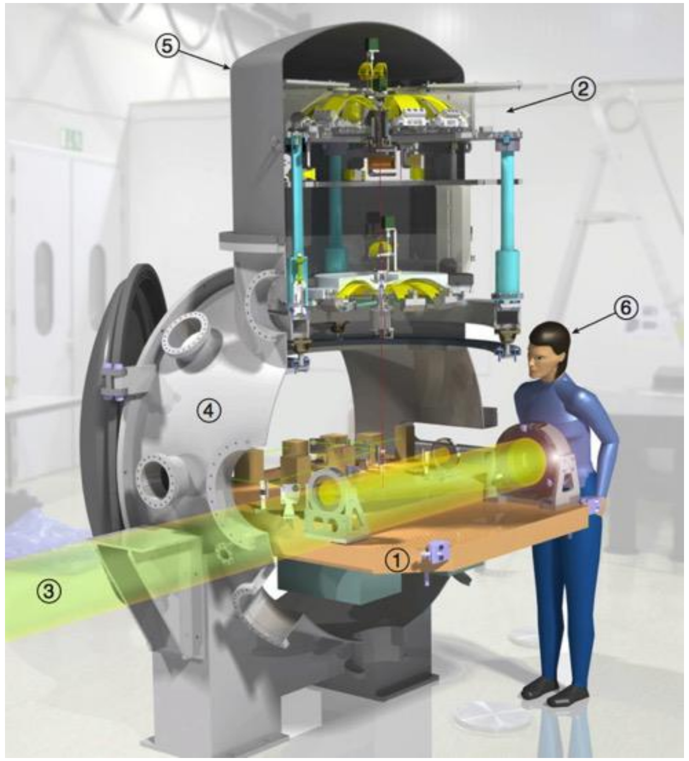
  - **Photon calibrators**

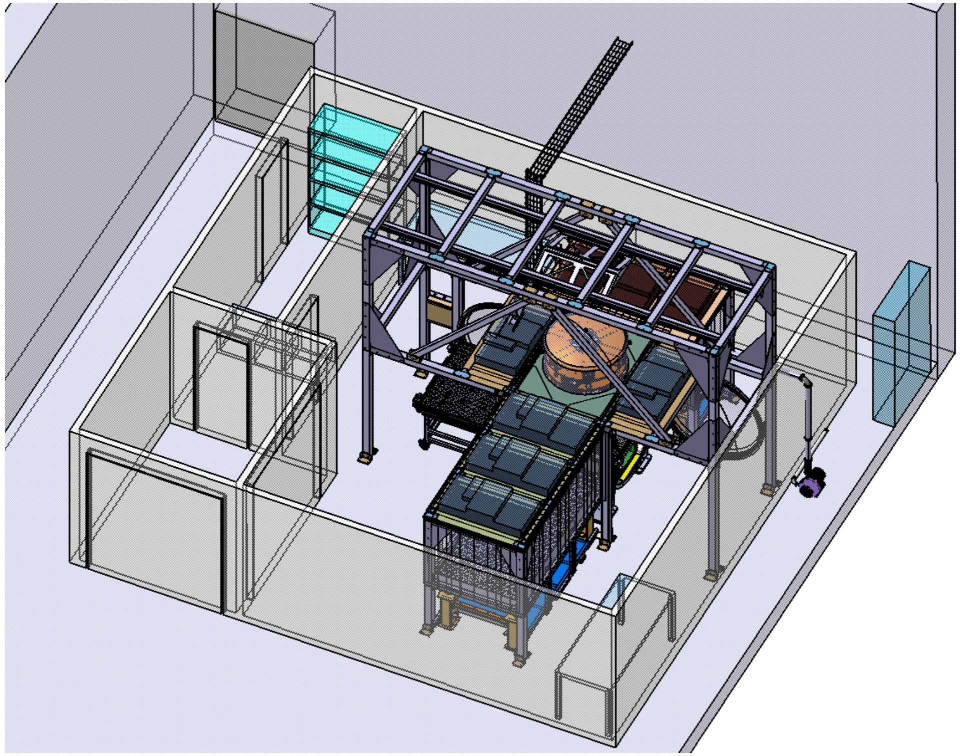
  - **Digital electronic and software for real time controls**

  - **Data Acquisition**

R&D platform: an optical bench suspended under vacuum

Install at LAPP an optical bench suspended under vacuum
for developments and tests in optics, mechanics and electronics of the next decade





- 7 benches installed at Virgo between 2015 and 2021, in operation.
- Optical bench including on-board electronics inside a air-tight container.

Need a new clean room at LAPP/Université Savoie Mont-Blanc to host the new system.

R&D platform: main objectives

- **Precise measurements of back-scattered light** (budget from ANR, March 2023→ March 2026)
- **Development and tests of new optical cavities for "Output Mode Cleaner"**
- **Design and test a Sagnac interferometer as a bench tilt sensing**

  → to improve suspension controls: reduction of tilt-translation couplings
- **Measurements of thermal noise from coatings of interferometer mirrors**

R&D in optics:
the focus of this talk

- **Tests and integration of new electronics**
  - move the digital processing out of the vacuum tank → less thermal dissipation
  - distribution of electrical power without contact → better seismic isolation
  - characterization of low noise photodiode preamplifiers in quiet environment

See talk from **F. Frappez, N. Letendre** given in session 5 **« électronique et computing »**

- **Tests and integration of new mechanical designs**
  - improve bench local controls in position
  - improve thermal dissipation from the bench to outside
  - improve the cleanliness

Precise measurements of back scattered light: main motivations

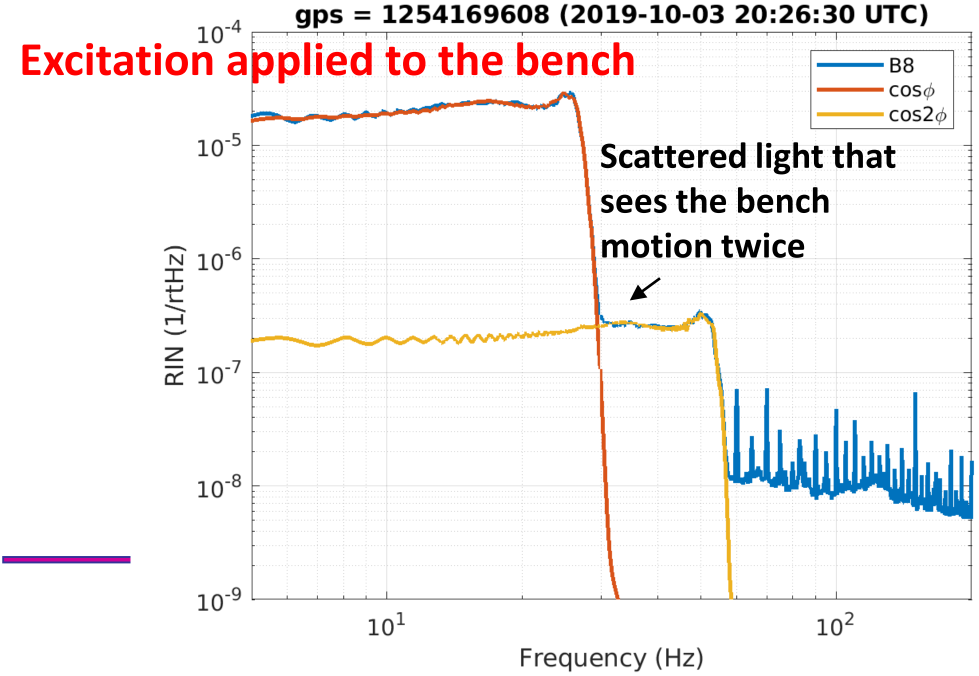
- Sensitivity of gravitational wave detectors limited by scattered light noise (despite lots of efforts already made to mitigate it)
  - Biggest impact at low frequency (few Hertz – few tens of Hertz) → will be come even more critical for ET
  - At higher frequencies, around mechanical resonances of bench parts

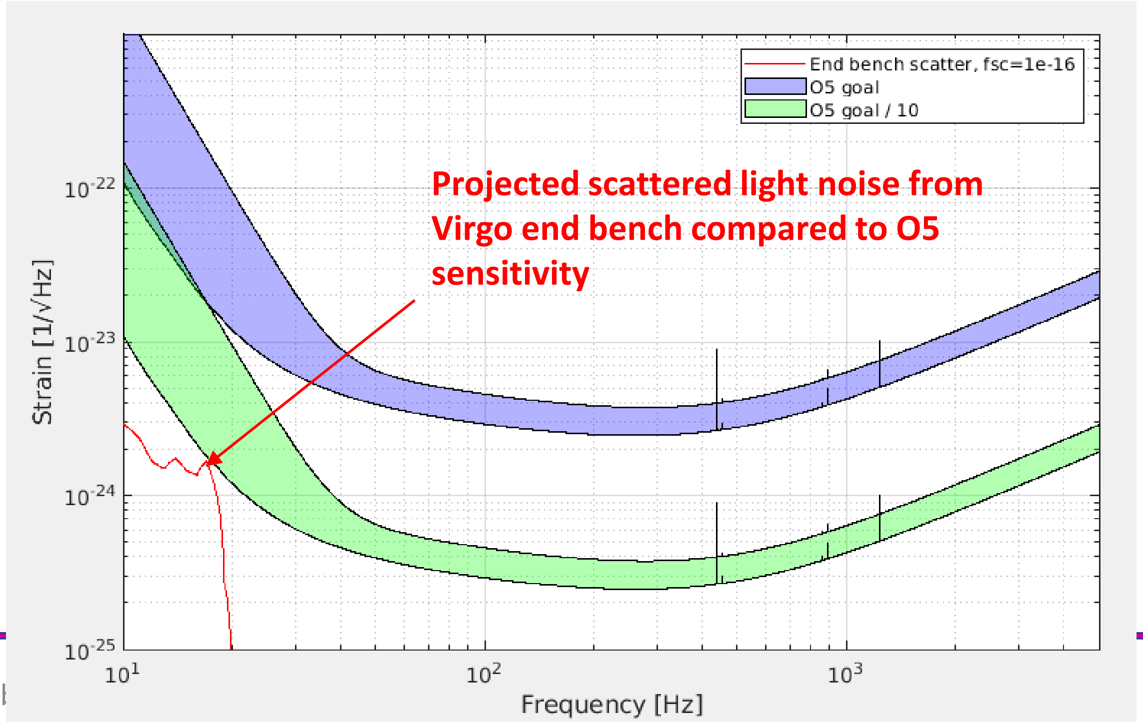
  → **Need precise measurements of scattered light to characterize components installed on the GW detectors**

- Light scattered at small angles is the dominant contribution in kilometer long optical cavities, but it is hard to measure
- Evidences for light undergoing multiple scattering:

  → ultimately the most challenging, as it can bypass the seismic isolation

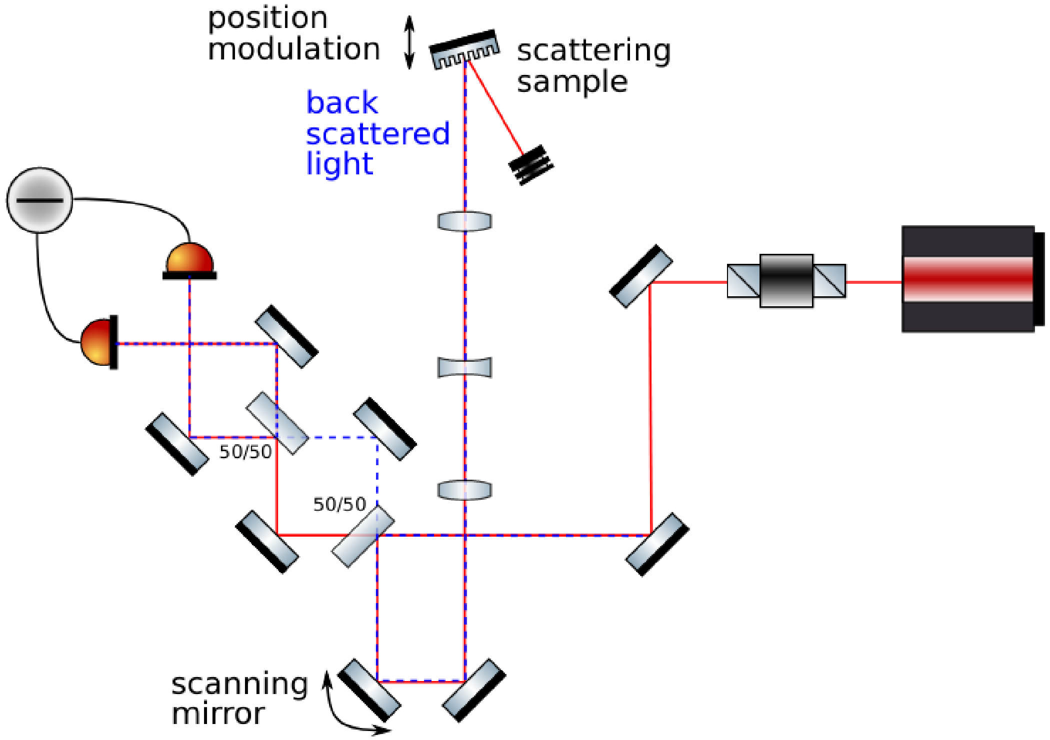
  → coupling mechanism needs to be better studied

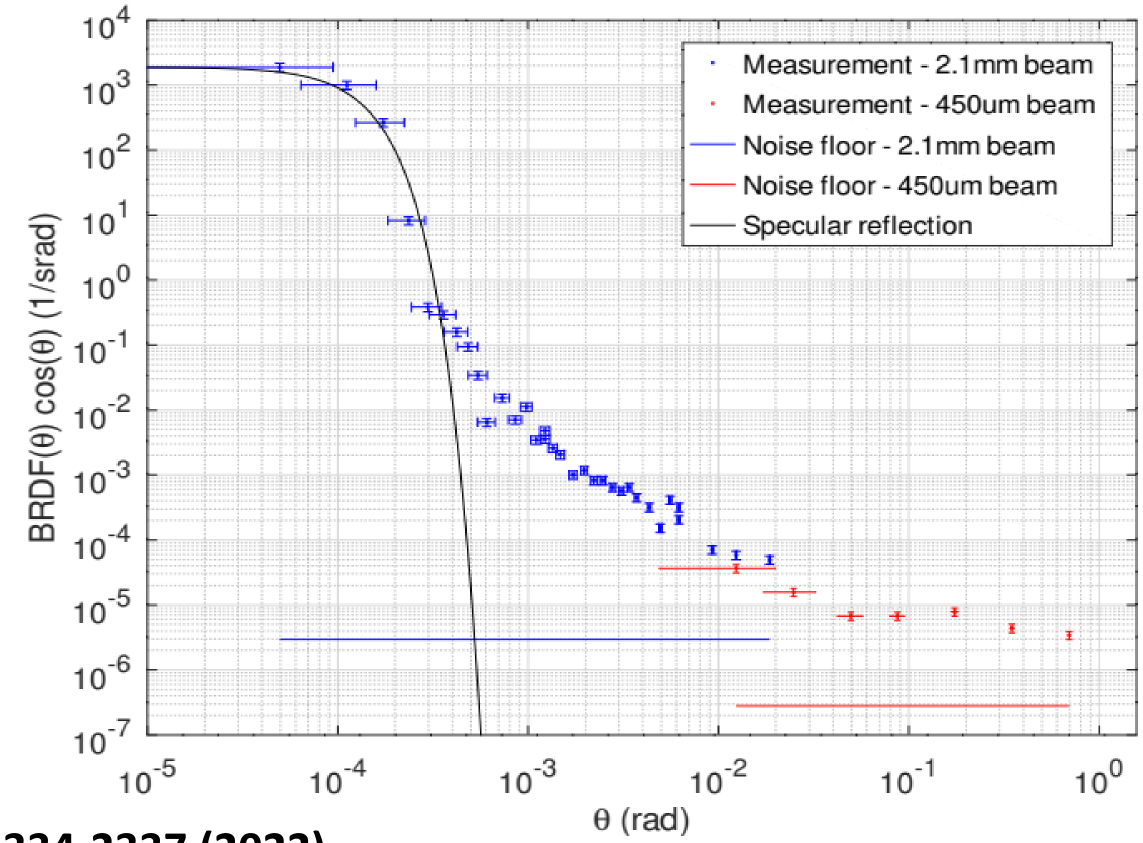




Precise measurements of back scattered light with back scatter meter

- Back scatter meter prototype already developed and tested on a non-isolated bench
  → achieved a sensitivity to recoupled back scattered light f_{sc}~10^{-14}





M. Was, E. Polini, Opt. Lett. 47(9), 2334-2337 (2022)

Precise measurements of back scattered light: next steps and perspectives

- Perform a systematic characterization of the components installed on the GW detector benches

- Improve back-scatter meter sensitivity, by placing the setup on an in-vacuum suspended bench:
  - More accurate control of the position modulation
  - Reduce beam jitter due to uncontrolled angular motions
  - Suppress pertubation due to air turbulences

  → Aims at a factor ~100 of improvement in sensitivity: 10^{-16} in fraction of scattered light
  → Measure of scattering at small angle (with large beams), with angular resolution of ~15 µrad, for Virgo like mirrors
  → Study of multiple scattering (simulations + measurements)

- Postdoc (ANR budget) to be hired for 2 years from fall 2024-fall 2025

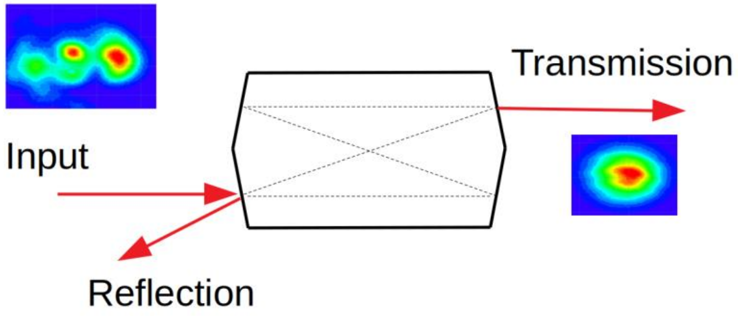
Development of new Output Mode Cleaner cavities: motivations

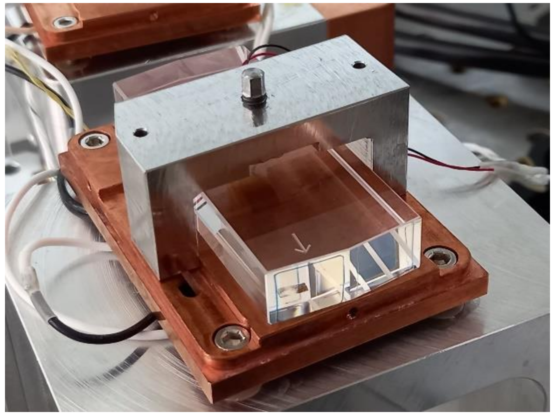
- Output Mode Cleaner cavity: filtering out high order modes and side bands at the interferometer output port
  → key component to reduce the contrast defect and reach targetted sensitivity

- Virgo Output Mode Cleaner is a bow-tie cavity made of a **monolithic substrate of fused silica**:

- Cavity optical length controlled with Peltier cells and small PZT actuator

- This type of cavity has been operated successfully in Virgo for more than 20 years





- **Now reaching limits of this technology:**
  - **2% of internal optical losses** > about half of the losses are due to **Rayleigh scattering inside the substrate**.
    → optical losses must be reduced for future detector upgrades (squeezing efficiency)

  - OMC length noise limited by **thermo refractive noise**:
    - about a factor 100 below O4 sensitivity with OMC lock precision of 10^{-13} m.
    - Noise coupling proportional to F^2, and √(dark fringe power) → may become critical for future sensitvity upgrades

Development of new Output Mode Cleaner cavities: proposed R&D

- **Develop and test an open OMC cavity**: beam propagating in vacuum inside the cavity
- Main requirements:
  - Bring the cavity optical losses below 1%
  - Ensure low cavity length noise: ≤ 10^{-16} m/√Hz
  - Preserve ability to adjust the cavity length (using piezoelectric ceramics bonded to the fused silica mirrors)

- Two mechanical construction schemes to be explored:
  - « tombstone » design: rectangular pieces of glass bonded to a glass breadboard, similar to LIGO/GEO design
  - drilled through glass spacer, with circular optics bonded to it, as is commonly used for optical reference cavities

- Open cavity will need to be tested on suspended bench in vacuum:
  - Avoid air turbulences for the beam resonating inside the cavity
  - Good seismic isolation required to qualify the mechanical design:
    - Measure mechanical resonances associated to the bonding
    - Measure length noise of the PZT actuator (larger bandwidth than current one)

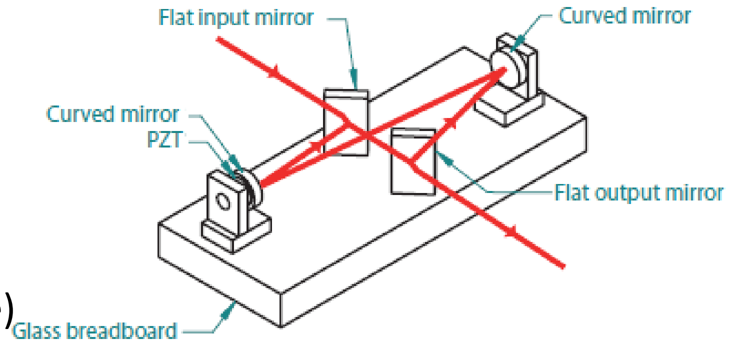
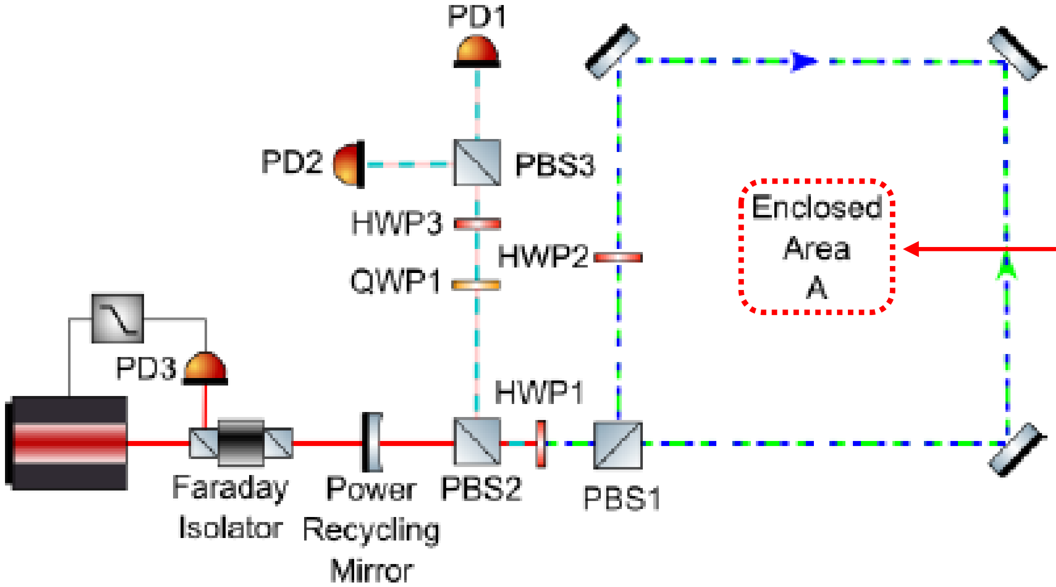


Figure 2. CAD view of the GEO 600 OMC. All parts are made of fused silica except for the PZT. The glass breadboard is 400 mm × 160 mm and 38 mm thick.

M. Prijatelj et al., 2012 Class. Quantum Grav. 29 055009

Sagnac interferometer as an angular sensor: principle and motivations

- Principle of the experiment: measure the relative phase shift between the two counter-propagating beams



$$\Delta\varphi = \frac{8\pi}{\lambda c}\vec{\omega}\cdot\vec{A}$$

Angular velocity of the bench

- Proposal : explore the use of a Sagnac interferometer as a sensor of the angular motion of the in-vacuum suspended bench

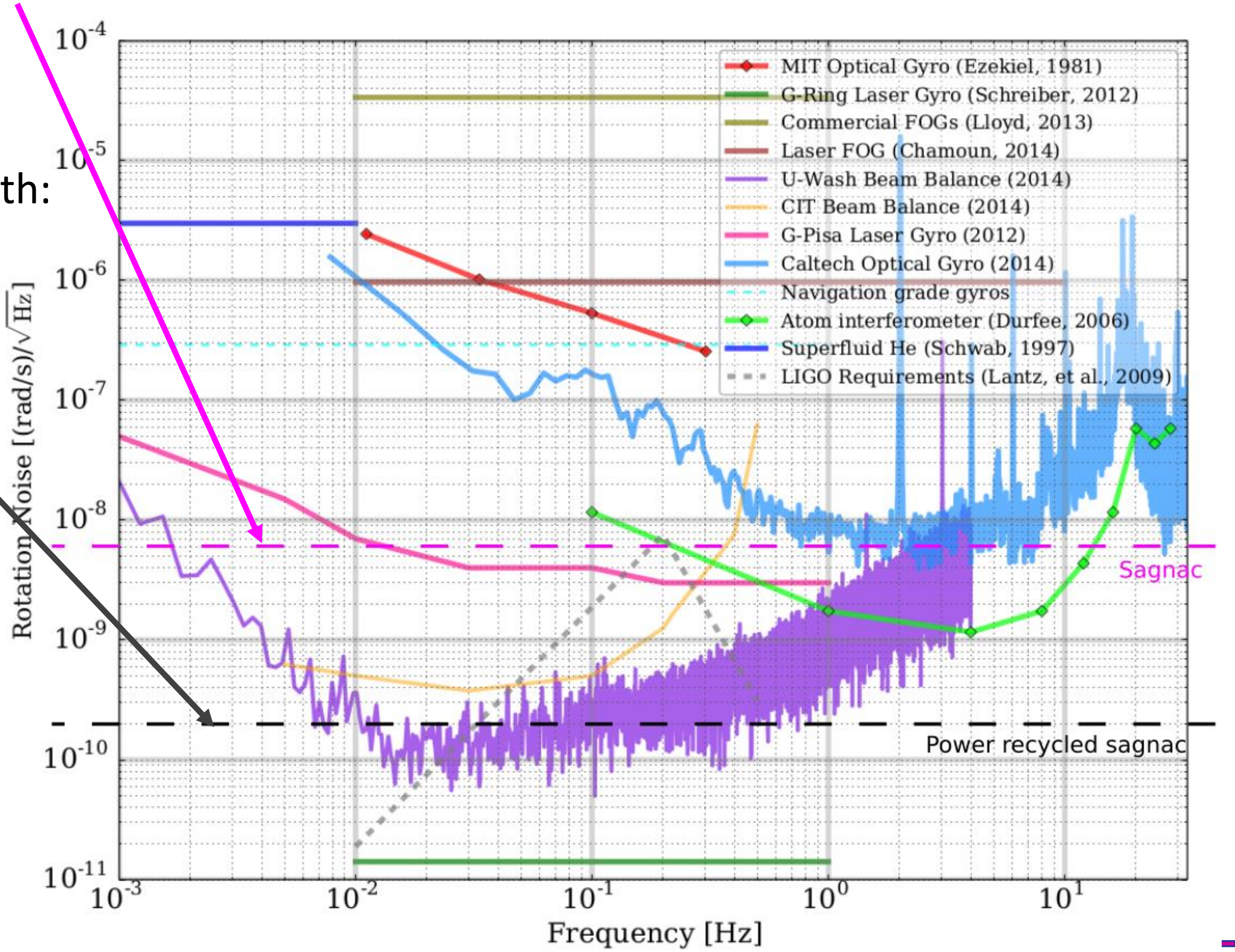
- Main motivations:
  - Use it either as a sensor fully installed on the bench or as a reference to characterize other sensors
  - Improve angular control of the bench / reduce cross coupling between angular and translation motions
    → reduce the coupling of scattered light with GW detectors, in particular at low frequencies (few Hertz) where it is challenging

Sagnac interferometer as an angular sensor: proposed R&D

- Build a first prototype (with homodyne detection) to achieve a shot noise limited optical phase sensitivity of 5×10^{-10} rad/√Hz with 100 mW of input laser power, 1m² of enclosed area

- Then improve further the sensitivity at 1.5×10^{-11} rad/√Hz with:
    - Power recycling cavity of finesse ~300
    - 1 W of input power

- Suspended bench in vacuum is necessary:
    - To remove acoustic motion of the optics and air turbulence
    - To validate and calibrate the setup
    - To test the setup with the proposed use case in GW



Korth, W. Z. et al, Passive, free-space heterodyne laser gyroscope, 2016 Class. Quantum Grav. 33035004

Measurements of thermal noise from coatings of interferometer mirrors

- See **R. Flaminio's talk** given in session 1 **« miroirs et coatings »**

- LAPP participating to ANR project « **MICRONG**» (Collaboration LAPP, LMA, CEA-LETI, III-V Lab, RIBER)
  Main Goal: develop AlGaAs coatings of very high optical quality on 200 mm diameter mirrors

- Use in-vacuum suspended bench to measure new mirror coating thermal noise in the future

Some information on budget

Estimation of costs

- clean room **195-265 k€**

on-going preparation of hiring a company for project management, to better define the clean room design and estimate more precisely the budget

- scientific equipment: **570-620 k€** - recently re-evaluated by **+50 k€** due to vacuum chamber cost update after market consultation (PUMA)

    including optomechanics for scattered light measurement, as 1st experiment

Current resources: 425 k€ (mainly for equipment)

- 140 k€ (Labex Enigmass: vacuum tank ~~and bench mechanics~~)
- 225 k€ (ANR: suspension and optomechanics)
- 60 k€ (LAPP: bench mechanics, 1st step of clean room project management)

Missing budget : 340 to 460 k€

- 180-250 kEuros for infrastructure (clean room) > asking to IN2P3
- 160-210 kEuros for scientific equipment > plan to ask to EGO