To: EGO Director - EGO Council Chair - Virgo Spokesperson

From:

Matteo Barsuglia, barsu@apc.in2p3.fr

Astroparticule et Cosmologie (APC, CNRS UMR7164)

10 rue A.Domon et L.duquet, 75013 Paris, France

Subject: Expression of Interest to join VirgoLab

Paris, 10/5/2025

Dear Colleagues,

This letter serves as an expression of interest by *Astroparticule et Cosmologie* (hereinafter referred to as “APC) to join the VirgoLab, as described in VIR-1025B-24. We understand that VirgoLab operates, commissions, and upgrades the Virgo interferometer, and we are willing to contribute to its mission and to the achievement of its goals.

The APC is a research institute located in Paris, devoted to particle astrophysics and cosmology. APC gathers about 220 persons and it is supported by CNRS, Université Paris Cité, CEA, Observatoire de Paris and CNES. APC hosts a group of the Virgo Collaboration since 2008. Our expertise and ongoing research activities are relevant to the operation, commissioning, and potential upgrades of gravitational wave interferometers.

Connected with VirgoLab's activities our experience the group has various and long-standing expertise, among them: optics/interferometry, quantum noise reduction through squeezing techniques, auxiliary benches, mode-matching telescopes, radio-frequency electronics, optical simulation and design, interferometer sensing and control, Newtonian noise estimation, pipeline developments for GW astrophysical searches, open data methods, multi-messenger searches.

Our possible involvement in VirgoLab would encompass the following areas:

- **Squeezing**
    - **Technical Development:** Contributing to the design, development, testing and commissioning of squeezing technologies, especially technologies related to frequency dependent squeezing.
- **Auxiliary benches (Detection and injection systems)**
    - **Technical Development:** Contributing to the design, development, testing and commissioning of mode-matching telescopes for injection and detection systems and related auxiliary benches.

We are also open to contributing to other areas based on the evolving needs of VirgoLab and the expertise within our group (i.e. simulation, controls, noise hunting and others).

The APC Virgo group today is composed by ~ 15 persons. The exact FTE and persons that could be allocated to VirgoLab activities would be computed following the exact definition of VirgoLab boundaries and responsibilities. APC also hosts also a clean room fully equipped where instrumentation can be tested and assembled, as well as mechanical and electronics workshops.

We are ready to discuss our potential participation further and provide any additional information that may be required.

Sincerely,

Matteo Barsuglia, on behalf of APC group

10/05/2025

Letter of Intent

To: EGO Director - EGO Council Chair - Virgo Spokesperson

Date: May 9th 2025

From: Laboratoire d'Acoustique de l'Université du Mans, UMR CNRS 6613, Avenue Olivier Messiaen 72085 Le Mans Cedex 9 France // Head of the lab : dirlaum@univ-lemans.fr Scientist in Charge : francois.gautier@univ-lemans.fr

Subject: Expression of Interest to join VirgoLab

Dear Sir/Madam,

This letter serves as a formal expression of interest by Laboratoire d'Acoustique de l'Université du Mans (hereinafter referred to as "LAUM", if applicable) to join the VirgoLab, as described in VIR-1025B-24. We understand that VirgoLab operates, commissions, and upgrades the Virgo interferometer, and we are willing to contribute to its mission and to the achievement of its goals.

1. Introduction

LAUM is a laboratory within Le Mans University and Centre National de la Recherche Scientifique specializing in fundamental and applied research in Acoustics and Vibration.

The laboratory has a staff of around 170: lecturers, researchers, engineers and technicians, PhD students, post-docs and associate researchers. The LAUM's activities are mainly focused on "audible" acoustics, but also include research into vibrations and ultrasound. Studies focus on wave propagation in fluids (at rest or in flow) and solids (porous, granular or composite materials, vibrating structures), as well as on coupling mechanisms.

Since 2023, a group of the laboratory (2 FTE) has been participating in Virgo's activities, through collaboration with the APC laboratory (AstroParticles and Cosmology, M. Barsuglia's team) and the Virgo team in charge of technical and environmental noise (I. Fiori's team).

We believe that our participation in VirgoLab would be mutually beneficial, allowing us to contribute our knowledge and resources to the advancement of gravitational wave science in Europe and beyond, while also providing our members with valuable experience and opportunities within a leading international collaboration.

This letter outlines our main areas of interest and potential contributions to VirgoLab.

2. Scientific / Technological Case or Context of Opportunity

Our group has a strong background in acoustics, which include modeling, characterization of acoustic, vibratory and vibroacoustic phenomena, and the design of solutions for their control. We list below 3 examples of subjects which can be linked to VirgoLab's activities

- **Analysis and modelling of technical noise due to acoustic and vibratory sources (Simulations-focused example)**
  Acoustic and vibratory noise in experimental rooms comes from a wide range of technical equipment such as pumps and air conditioning systems, which act as complex vibroacoustic sources. We have expertise in the analysis of airborne and structural sources, their coupling with their environment (floor, building walls, room air domain) and the development of appropriate vibroacoustic models, which provide keys to noise reduction. These models are based on modal approaches in the low-frequency range and on statistical energy analysis in the high-frequency range. These models can also be fed and verified using systematic correlations with monitored data, enabling transfer path analysis to be developed. The application of these acoustic or vibroacoustic models concerns 1/ the development of attenuation techniques and the design of optimized configurations, 2/ the estimation of Newtonian noise of vibroacoustic origin and also 3/ a contribution to the estimation of scattered light noise.

- **Development of acoustic treatments to minimize sound levels in the sensitive areas at low frequency (Technology-focused example)**
  The noise level in a cleanroom results from internal sources (mainly air-conditioning vents) and also from sources external to the room (external environmental noise), whose contributions are significant since the acoustic insulation of the wall is generally poor at low frequencies, particularly if the wall is a lightweight partition. The development and implementation of elastic and acoustic metamaterials in this context is a way of insulating the sensitive room without using heavy partitions. We have expertise in the design of acoustic metamaterials, consisting of panels or layers with periodic architectures including locally resonant or non-resonant inclusions, which improve sound absorption (for the treatment of internal sources) and sound insulation (for the treatment of external sources). Designing effective barriers for low and ultra-low frequency sound insulation or absorption is a real challenge in acoustics. We think that the application of a strategy based on the use of metamaterials can bring real progress in the development of an ultra-quiet cleanroom by pushing back the performance limits of existing solutions.

- **Parametric instabilities analysis (Fundamental Physics/Instrumentation-focused example)**
  The laboratory has expertise in modeling the self-sustained acoustic oscillations involved in the operation of many sound sources, particularly musical instruments. These self-sustained oscillations are instabilities resulting from a non-linear interaction between two quantities involved in a highly resonant phenomenon. This mechanism is at the origin of friction-induced squealing, valve instability and flutter instability. In the Virgo detector context, parametric instabilities result from an opto-mechanical coupling in which the radiation pressure applied to the mirror couples a vibratory mode with a transverse mode of the optical beam. The transposition of know-how on acoustic dynamic systems to the case of parametric instabilities is possible and is favored by the fact that parametric instabilities could possibly be studied experimentally using an acoustic analog, since the higher-order modes of the optical beam and an ultrasonic beam have the same structure.

3. Description of the Proposed Contribution

Our proposed involvement in VirgoLab would encompass the following potential contributions:

- **Technical development: design of acoustic treatments**
  The development of acoustic treatments contributing to reduction of acoustic and vibratory origin within the Detector Commissioning project in collaboration with the Infrastructure team (I. Fiori's team), which who we are already collaborating. Practically, this could involve development of 1/ soundproofing solutions for equipment and racks in the CEB, NEB and WEB, 2/ acoustic treatments for level reduction in the CEB (decrease of the reverberation) and in the INJ and DET labs, based on conventional solutions or on metamaterial solutions.

- **Noise Detector characterization: estimation of Newtonian noise from acoustic and vibroacoustic origin in the experimental halls**
  Acoustic field in the experimental halls is mainly generated by the HVAC system whose inlets and outlets are acting as acoustic monopoles exciting the room modes. A precise estimation of the pressure field in the experimental halls can be derived from a modal model, from which the fluctuations in the gravity field, i.e the Newtonian Noise (NN) can be derived and its contribution to the noise budget can be estimated (collaboration with APC, M. Barsuglia). This approach can be extended to take into account more complex sources (walls vibration, equipment vibrations) and can be used to define HVAC recommendations (in particular, optimal inlet/outlet locations).

- **Modelling of the mechanical damping of the coatings / Analysis of the parametric instabilities**
  Parametric instability gain depends on multiple parameters: quality factors of the mechanical and optical modes, optical power of the beam, extent of the contact zone, frequency coincidence between modes. We are interested in studying the instability threshold, and in particular the mechanical damping of the mirror, for which the coating plays an essential role. This damping is particularly low to limit thermal noise. It results from the substrate, the individual layers and also the interfaces between these layers. The exact effect of these interface zones is not well understood and can be studied using a numerical model including the effect of the interfaces acting as transition zones with gradients of specific effective properties. Collaboration with LMA (M. Granta) and ARTEMIS (W. Chaibi) is underway on this subject.

We are also open to contributing to other areas based on the evolving needs of VirgoLab and the expertise within our group. We are keen to engage with the existing VirgoLab Technical Teams and Projects to identify areas where our skills and resources can be most effectively utilized.

4. Costs, Calendar and Resources

Initially, our contribution would primarily involve the effort of our existing personnel, i.e 2 FTE consisting in 1(PhD) + 0.4 (PhD) +0.2 (Pr.) + 4*0.1 (Pr.).

We understand that the successful accomplishment of VirgoLab tasks, particularly the timely installation and commissioning of the O5 upgrade, will demand strong and continual presence at EGO site. Our group commits to support that effort as much as reasonably possible.

We anticipate the need for a mission of several weeks for a phD student each year (including travel to EGO, access to environment measurements).

We understand that Member Labs are in charge of maintaining and operating the equipment they provide..

We are aware that financial resources are allocated by EGO Council, national funding agencies, or research organizations. We will explore potential funding opportunities through our institution and national agencies to support our involvement in VirgoLab.

We are prepared to work towards the establishment of a MoA with EGO should our application be successful.

5. Stakeholders and Requirements

Our primary stakeholders are Le Mans University and Centre National de la Recherche Scientifique.

We understand that as a contributing group, our main requirements would be to have effective communication channels within VirgoLab, opportunities for our members to actively participate in relevant projects and technical teams, and recognition for our contributions to the scientific and technical advancements of Virgo.

We are committed to adhering to the policies and procedures of VirgoLab, including those related to resource allocation and publications.

We are ready to discuss our potential participation further and provide any additional information that may be required. We look forward to the possibility of joining the VirgoLab and contributing to its continued success.

Sincerely,

Francois Gautier, Professor,
Scientific in charge
May 9th 2025

Olivier DAZEL, Professor
Head of LAUM
May 9th 2025