Massimo Carpinelli
European Gravitational Observatory
Via E Amaldi,
56021 Cascina,
Italy

Pisa, 5th April 2025

Subject: Expression of Interest for UCLouvain to join Virgo Lab
Our Reference: 2025/IRMP/GW/VirgoLabEOI

Dear Massimo,
Copy to: Marco Pallavicini, Gianluca Gemme, others whom it concerns,

This letter serves as a formal expression of interest by the UCLouvain Gravitational Wave group (hereinafter referred to as simply "the UCLouvain group") to join the VirgoLab. 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

The UCLouvain group is a research group within the Institute for Research in Mathematics and Physics (IRMP) at Université Catholique de Louvain (UCLouvain). IRMP has several centres within it, and we are part of the Centre for Particle Physics, Cosmology and Phenomenology (CP3). The CP3 centre provides a stimulating environment for theoretical and experimental research in particle physics, astroparticle physics, GW physics, cosmology, and technology transfer. It contributes significantly to the following experiments: CMS and NA62 at CERN, IceCube, KM3NeT, Einstein Telescope, and Virgo.

Between 2020 and 2024 the instrumentation component of the UCLouvain group has focused mostly on Einstein Telescope research and development, with just one PhD student fully committed to Virgo. Recognising the challenges posed by the GW community in the next 5 years, in 2024 we were successful in securing considerable funding to increase the instrumental contributions of the group to Virgo, notably with a 2.3 M€ grant from the Walloon Region aimed to setup an extension of the laser & optics technological platform of the university. This extension will be dedicated to R&D for GW interferometers and should be functional as of September 2025. The grant also includes funding for some personnel. In this context, with the departure of permanent staff scientist Dr van Heijningen in 2023 and his recent replacement with Dr Goodwin-Jones in 2025, we are re-focusing the group to specialize on high power interferometry and optical mode control. This leverages our 5 years of experience in Phase Camera technology for Virgo, a project we have conducted in collaboration with Nikhef and Lyon (people involved at UCLouvain have been Ricardo Cabrita, prof. C. Lauzin and Dr J. van Heijningen), and is Dr Goodwin-Jones' specialty.

High power interferometry is highly relevant to the operation, commissioning, and potential upgrades of gravitational wave interferometers. We believe our contributions will help Virgo realize hundreds of kilowatts required in the arm cavities, which will be required for Virgo to collaborate meaningfully with LIGO in O5.

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.

Please turn over

LOUVAIN-LA-NEUVE | BRUXELLES | MONS | TOURNAI | CHARLEROI | NAMUR
Chemin du Cyclotron, 2 bte L7.01.01, 1348 Louvain-la-Neuve, Belgique
aaron.goodwinjones@uclouvain.be – www.uclouvain.be/irmp/

2. Scientific / Technological Case or Context of Opportunity

As described before, our groups primary interest is high power optical interferometry. Below we list our main previous contributions to running GW laser interferometers. Since, Dr Goodwin-Jones only joined in the Virgo collaboration February, his main previous contributions to LIGO are shown.

Example 1 – Phase camera and related commissioning. Our groups experimental activities meaningfully began in 2021, with the PhD thesis of Ricardo Cabrita, under the joint supervision of prof. C. Lauzin and Dr J. van Heijningen. In the first year of his PhD, Cabrita collaborated with Martin van Beuzekom (Nikhef) on the commissioning of the B1 and B4 phase cameras for the fourth observing run. Cabrita led several of the commissioning tasks such as:

- Measuring the sideband imbalance at different locking states;
- Troubleshooting phase camera signals;
- Measuring the modulation depth of the phase camera and updating the center of mass computation (reported in VIR-0234B-23).

He is also a valued member of the O4 optical characterisation group and has used the phase cameras as an independent verification of mode matching estimates, as reported in his GRAvitational-wave Science&technology Symposium (GRASS) conference paper[1]. He also contributed to the tuning of the thermal compensation system on the Power and Signal recycling mirrors (reported in VIR-0820A-22), within the OptChar and OSD groups. More recently he has been using phase camera data to update the simulation configurations in OSCAR, in co-ordination with Dr Degallaix (Lyon). After considering mode matching error signals from several phase camera locations, he has identified transmission phase cameras to be a promising diagnostic tool, as report [2]. Once we have verified the technique in simulation, we will make a formal proposal on its integration to the EGO council. In addition to the aforementioned contributions, Cabrita has spent 2 months at the EGO site.

Example 2 – Simulation contributions to LIGO 40m. Prior to his appointment at UCLouvain, Dr Goodwin-Jones was working at the Caltech 40m. His primary contribution was the development of a software package[3] that accurately modelled the length sensing and control loops, optical suspensions, auxiliary optics and local angular loops. This package was used for two projects: firstly, to aid the development of machine learning based controls[4] at the 40m and secondly, to aid prototype of the balanced homodyne update for the 40m. Both techniques are planned for implementation in LIGO and are being prototyped at the 40m.

Example 3 – Simulation contributions to LIGO Livingston. Dr Goodwin-Jones also aided the development of the LIGO finesse package. This package integrates the optical simulation software Finesse with Finite Element models of the test masses to capture thermal effects. Dr Goodwin-Jones specific contributions were to the optimisation of the mode matching between the OPO, Filter Cavities, OMC and SRC at LLO[e.g. 5,6], the modelling of the angular control loops[e.g. 7] during lock acquisition, including identifying a transverse mode sideband of the 9 MHz frequency sideband that was causing lock losses due to Gouy phase accumulation.

Example 4 – O4a Frequency dependant squeezing & mode matching. Dr Goodwin-Jones was also active in commissioning the audio diagnostic field at LLO[e.g. 8,9]. This audio diagnostic field was essential for the commissioning of frequency dependant squeezing. In addition, he is also a certified cleanroom operator and has experience with inverted pendulums, single wire suspensions and suspended optical benches.

Please turn over

---

[1] Ricardo Cabrita, 'Sensing mode mismatch with the phase cameras at Advanced Virgo', presented at the GRAvitational-wave Science&technology Symposium 2022 (GRASS2022), Padova (Italy), Jun. 2022. doi: 10.5281/zenodo.6758929.

[2] Cabrita, R., Goodwin-Jones, A., Heijningen, J.V., Demin, P., Beuzekom, M.V., Tacca, M., Bruno, G., Lauzin, C. (2025). Resonant enhanced detection of the higher-order modes of a locked cavity. arXiv preprint arXiv:2505.03525.

[3] Goodwin-Jones, Finese-40m, Software, available at https://finesse.docs.ligo.org/finesse-40m/

[4] Moc, K., Prakash, A., Goodwin-Jones, A., Adhikari, A., 'Reinforcement Learning for Lock Acquisition of the LIGO 40-Meter Interferometer', *in prep, 2025*.

[5] Goodwin-Jones, Kabagoz, Sanchez "Updated SQZ path length's" Update to Finesse-LIGO, https://git.ligo.org/finesse/finesse-ligo/-/merge_requests/46.

[6] Goodwin-Jones, Mullavey , Betzwieser , Cullen , Blair, Brown. "OPO -> XARM Mode Sensing Measurement using ADF", LIGO Electronic Logbook Number 61000, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=61000

[7] Brown, Kuns, Cao, Capote, Hall, Jadhav, Goodwin-Jones, Mansell, Blair, 'Proceedings of Hot stuff: Thermal issues in future detectors workshop'. LIGO Technical Document, T2500154. Available to IGWN consortium members

[8] Goodwin-Jones, Cullen, Mullavey , Laxen, Xu, Ganapathy. "ADF Field Debugging II & Coupled Cavity Mode Sensing", LIGO Electronic Logbook Number 60919, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=60919

[9] Goodwin-Jones, Jia. "OPO -> XARM Mode Sensing Measurement using ADF", LIGO Electronic Logbook Number 61666, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=61666

Chemin du Cyclotron, 2 bte L7.01.01, 1348 Louvain-la-Neuve, Belgique
Tél. +32 (0)10 47 31 52 – fax +32 (0)10 47 25 30 – aaron.goodwinjones@uclouvain.be – www.uclouvain.be/irmp

This combination of simulation, table top, prototype and detector experience will be very useful in developing new techniques to control the interferometer when operating at high optical powers. We offer this expertise via visits to the Virgo Site, development of models in our local lab and calls with commissioners.

Example 5 – Superattenuator & Control. PhD student Morgane Zeoli, under the joint supervision of Dr J. van Heijningen (UCLouvain) and prof Ch. Collette (ULiège) has been working since September 2022 on the development of low-frequency, vacuum-compatible, interferometric inertial sensors. While this work was mainly aimed to Einstein Telescope (cryogenic version of the sensor), its relevance for Virgo_nEXT has been recognized by the Virgo Collaboration too, which has included this activity in the SuperATtenuator (SAT) subsystem subgroup. The improved resolution of the sensors compared to commercial products allows for environmental monitoring of ultra-low vibration environments, such as the suspended benches. They can be used in the characterization of the detector seismic isolation chain performance and for improving seismically isolated testbenches.

Example 6 – Computing. We are not sure whether computing is considered to be part of the scope of VirgoLab, but we believe that it is a crucial part of the experiment. We therefore take the liberty of including this item among the list of examples of our past contributions. Since 2021 the UCLouvain CP3 computing center, which currently features 4500 compute cores and 2.5 PB of storage, is available to LVK for job submission over the GRID. In addition, we have been operating an Open Science Data Federation (OSDF) origin server (previously called "StashCache Origin") on our computing centre to host and serve Virgo data to GW analysis codes submitted over the GRID. The service has been operational for almost three years now hosting Virgo detector environmental data and user-derived physics data from O3 and O4 . Dr A. Tanasijczuk, and Dr P. Demin, who are permanent staff members of our group, maintain the facility. Their contribution is critical, but only requires a relatively low level of commitment in Virgo. A. Tanasijczuk is currently chair of the ET "Software Frameworks and Data Challenge Support" division and may increase his level of commitment to Virgo when his mandate comes to an end.

Example 7 – Data Quality. In collaboration with other members of the lensing group, prof Janquart has automated fast data quality tools to go from trigger to parameter estimation without human innervation, bespoke for lensing studies. We are keen to expand this area of the group and support data quality estimates.

3. Description of the Proposed Contribution

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

Technical Development: In the new extension of the UCLouvain laser & optics technological platform mentioned above, we plan to build a 10m long, high-power, suspended, power recycled, optical cavity with the same optical g-factor as the Virgo arms. We will use Virgo style control systems and Virgo style phase cameras. The facility has two aims:

- To test new optical mode matching techniques, utilize existing Virgo hardware (such as the phase cameras, CCHRoC, Ring Heaters and CO2 lasers),
- Test parametric instability mitigation techniques with the Virgo phase camera

We recognise that "interferometer time" at Virgo is valuable and financially expensive. When the interferometer is not down for upgrades, it is desirable to keep it in "observation mode". Our new facility allows to train personnel on the Virgo DAQ and high-power optical control, before they go to Virgo, so they can be as productive as possible and commissioning breaks can be as short as possible. Our new facility draws inspiration from the collaboration between LIGO lab and OzGrav's new TCS center in Adelaide and the High Optical Power Facility in Perth. Our new facility complements existing prototypes in Europe and fills a gap between European prototypes such as: the Hannover prototypes (GEO600 & the 10m) which use LIGO style hardware and Einstein Telescope Pathfinder – which runs at low power, in cryogenic conditions. This will involve close collaboration with the *"Sensing and Actuation"* and *"Controls and Simulation"* technical teams, with the goal of facilitating the '*Detector Commissioning*' VirgoLab project.

Instrumentation Support: We will contribute to the monitoring and optimisation of the phase cameras, in collaboration with NIKHEF and the *"Sensing and Actuation"* technical teams. This would involve being available during commissioning and observing runs to diagnose remotely, or travel to EGO and fix the phase cameras. We already have an identical phase camera at UCLouvain to help us diagnose issues (see above project). The falls within the "*Detector Operations and Maintenance" and "Detector Commissioning"* projects.

Detector characterization: As detailed before, we have extensive experience in optical simulations. We are willing to actively maintain the O5 Finesse models, ensuring that they match real Virgo data. This will likely involve large parameter searches on our computing cluster to tune Finesse parameters and obtain close agreement between the simulated and real detector outputs. This work draws inspiration from Goodwin-Jones' contributions to simulation in

LOUVAIN-LA-NEUVE | BRUXELLES | MONS | TOURNAI | CHARLEROI | NAMUR
Chemin du Cyclotron, 2 bte L7.01.01, 1348 Louvain-la-Neuve, Belgique
Tél. +32 (0)10 47 31 52 – fax +32 (0)10 47 25 30 – aaron.goodwinjones@uclouvain.be – www.uclouvain.be/irmp

O4 simulations for LIGO. We will motivate this simulation development by proposing new optical mode matching techniques, using existing Virgo hardware to facilitate rapid commissioning in O5. This work will be carried out in conjunction with the *"Controls and Simulation"* technical team and is in the *"Detector Commissioning"* project.

Additionally, in the coming months we propose to initiate a working group dedicated to commissioning modelling, in collaboration with key member labs and EGO personnel. The format would follow the very successful "LIGO Commissioning Modelling" working group, which is led by commissioners and has been critical in enabling LHO and LLO to reach 350 kW of arm power.

We are a growing group and are very open to responding to the evolving needs of VirgoLab. 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. We will gladly welcome the exchange of personnel between Cascina and Louvain.

4. Costs, Calendar and Resources

Initially, our contribution would primarily involve the effort of our existing personnel working with a high fraction of their time on Virgo Instrumentation: Dr Goodwin-Jones, permanent research scientist with no teaching duties, Mr Cabrita, who will remain after the end of his PhD another 2 years with us as a postdoctoral researcher, prof. C. Lauzin, who is an expert in precision laser systems and Virgo member at a subthreshold SVAC, and prof. G. Bruno. In addition, we have appointed a postdoc and a PhD, who will both join us in September. Our computing activities are supported by Dr Demin and Dr Tanasijczuk, permanent IT staff members. All these personnel are current Virgo collaboration members and we propose including them in Virgo Lab. Depending on the SVAC threshold on individuals that will eventually be set to be part of VirgoLab, C. Lauzin, A. Tanasijczuk and P. Demin may stay out of the Louvain group list because their anticipated involvement in VirgoLab is not expected to be higher than 30%. It should however be noted that, as far as computing is concerned, the services currently provided by the UCLouvain computing center (computing power and operation of the OSDF origin server) do not require more commitment than what currently provided by A. Tanasijczuk and P. Demin.

We further collaborate with the current PI of our Vigo group, Prof Janquart. Initially, we propose not to include him in Virgo Lab, but, as the UCLouvain lab grows we would like to take on some data quality tasks, which he could lead. Finally, we are supported by a fully staffed mechanical and electrical workshop, who support our activities and would be available for VirgoLab contributions.

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 draw your attention to the fact that this letter is being drafted from the EGO site, where Dr Goodwin-Jones is supporting commissioning with 3 weeks of dedicated time. Our intent is to generalize such stays to all personnel involved in VirgoLab activities.

We anticipate the need for:

- Financial support for travel funding to and from the EGO site, to increase our on-site presence.
- Technical support from LAPP for the Virgo style data acquisition system.
- Linux credentials for remote access to the Virgo control room and relevant computing channels.
- As our group grows, it is foreseeable that we will request part funding for a PhD, to help justify time they spend doing commissioning activities at the Cascina site.
- As our lab becomes more prominent, some funding to help hosting external VirgoLab researchers, may be needed for cases where their home institutions cannot cover the costs.

We are aware that financial resources are allocated by EGO Council, national funding agencies, or research organizations. We will continue exploring funding opportunities through our institution, national agencies and on the European level, to support our involvement in VirgoLab.

We understand that Member Labs oversee maintaining and operating the equipment they provide. We envisage our contribution to be mostly in techniques and commissioning time at EGO. However, should the need occur, we are prepared to discuss the provision of equipment as part of a Memorandum of Agreement (MoA). Specifically, if motivated scientifically, we may propose changing or adding additional phase cameras locations. In this instance, we would gladly provide them, or, collaborate with Nikhef on their provision (as appropriate).

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

Please turn over

LOUVAIN-LA-NEUVE | BRUXELLES | MONS | TOURNAI | CHARLEROI | NAMUR
Chemin du Cyclotron, 2 bte L7.01.01, 1348 Louvain-la-Neuve, Belgique
Tél. +32 (0)10 47 31 52 – fax +32 (0)10 47 25 30 – aaron.goodwinjones@uclouvain.be – www.uclouvain.be/irmp

5. Stakeholders and Requirements

Our primary stakeholders are UCLouvain and the FNRS funding agency. The latter has recently become an official EGO council member.

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,

Aaron Goodwin-Jones

Dr Aaron Goodwin-Jones, Research Scientist
On behalf of Prof Giacomo Bruno, Prof. Clement Lauzin, Prof Justin Janquart, Dr Andres Tanasijczuk, Dr Pavel Demin and the rest of the UCLouvain GW group.

Chemin du Cyclotron, 2 bte L7.01.01, 1348 Louvain-la-Neuve, Belgique
Tél. +32 (0)10 47 31 52 – fax +32 (0)10 47 25 30 – aaron.goodwinjones@uclouvain.be – www.uclouvain.be/irmp