PhD thesis proposal: Automatic alignment control for the Phase II of the Advanced Virgo gravitational-wave detector.

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Context:

Ground-based detectors have been directly detecting gravitational waves since 2015, thanks to a network of gravitational waves observatories, presently formed by four kilometric-scale detectors scattered around the world. The European Gravitational Observatory (EGO) hosts the Virgo detector, located in the countryside of Pisa (Italy). EGO is a french-italian-deutch Consortium which purpose is, among others, ensuring the functioning of the Virgo antenna, its maintenance, operation and upgrades; carrying out research in the field of gravitation of common interest for the members of the Virgo Collaboration; promoting contacts among scientists and engineers; the dissemination of information and providing advanced training for young researchers.

The first three observing runs of the Advanced version of these detectors have revolutionized astrophysics. Not only have they detected hundreds of Binary Compact Objects, which led to the ground-breaking multi-messenger detection of a Binary Neutron Star combining gravitational waves with electromagnetic observations, but also shed new insights about stellar evolution, cosmology or compact objects, among others.

All the detectors are based on the Michelson interferometer principle, improved in order to reach the needed sensitivity to detect gravitational waves. The main modification being the addition of 4 optical cavities, two of them kilometric, that need to be suspended. The two shortest ones are called the recycling cavities and are used for increasing the effective power inside the interferometer and to improve the signal to noise ratio in the most interesting frequency range.

The control of the shortest cavities has been a major challenge when trying to reach the best sensitivity of the detector due to their marginally-stable nature. For this reason, after the fourth Observing Run which is set to end in early 2025, the Advanced Virgo detector will be upgraded. The main change concerns the replacement of the marginally-stable recycling cavities by stable ones. This will require developing and implementing a completely new angular control scheme for them.

Target:

The first part of the PhD will be devoted to familiarizing with the angular control strategies that will be implemented during the commissioning of Advanced Virgo phase II and the corresponding simulation tools. In particular, focusing on their robustness against the detector (potential) optical defects. Understanding which optical parameters are critical in advance and foreseeing mitigation strategies will save a lot of commissioning time in the installation phase.

Near the end of the first year, the stable recycling cavities will be installed on the Advanced Virgo detector; the candidate will have a key role in the commissioning of the control of the cavities and the tuning of the working point of the detector, with particular focus on the angular part. These points are crucial for reaching the best sensitivity of the detector and for ensuring high duty cycle in view of the next data taking.

<u>International</u> working environment:

The PhD candidate work will be splitted between IJCLab in Orsay and EGO in Italy, the site hosting the Advanced Virgo gravitational wave detector, an improved Michelson interferometer with 3-km arm lengths. IJCLab hosts the CALVA platform which is designed to study the control of a suspended cavity for Advanced Virgo with a 50m-long Fabry-Perot cavity. By design, the tools used on the CALVA platform are the same as for Virgo, which facilitates sharing technology between the systems and testing control techniques.

The complementarity of the two sites makes the proposal very attractive. The Virgo site is the place where the studies with actual optics and optical cavities that are part of the full interferometer

will be carried out. This is interesting as the student will work on the real detector.However, working on site involves difficulties, in particular the very rigid time schedule which imposes periods of time during which experiments cannot be carried, and also the fact that the optical design is fixed. On the other hand, the CALVA site is not tied to this strict time schedule and the facility is always available and allows to test alternative solutions and original ideas, that could be then implemented in the detector.

Candidate:

The PhD candidate must hold a master degree in physics at the starting date of PhD contract. Applications follow the rules of the Marie Curie program. Candidates must have spent a maximum of 12 months in France during the 36 months preceding their recruitment. Taking this condition into account, all applications will be considered without discrimination (gender, nationality, religion, etc.).

Supervisors:

50% Vincent Loriette, IJCLab, EDOM, HDR in 2003: The subject of my PhD (1992-1995) was to design and make the optical metrology tools required to test the passive optical components of Virgo and other GW detector. I'm a CNRS researcher since 1995 and have worked full time for Virgo until now, except for a few years were I was involved half-time in the Calva experiment. Since 2023 I work full time on Calva. I am (co-)author of 352 publications on GW detection, optical metrology, optical microscopy, adaptive optics, and my h-factor is 87.Until now, I fully supervised five theses and number of postdocs in various fields of experimental optics : optical metrology for the Virgo GW detector, super-resolution optical microscopy for health institutes, adaptive optics for biomedical imaging, time gated microscopy for cancer diagnosis, and 3D imaging for functional neurology. All of my PhD students have obtained permanent positions in laboratories in France, Israel and the US, or in private companies in France and the US.

50% Julia Casanueva, EGO, Italy: I have made my PhD in the control of the Advanced Virgo detector from 2014-2017 at Université Paris-Sud. My work focused on the simulation and implementation of the global longitudinal, angular and frequency controls, as part of the Interferometer Sensing and Control working group (for which I become chair in March 2023). Since then I have worked on this topic while on-site at EGO, Italy, where I have a permanent contract. I actively participate to the design of the upgrades and the commissioning of the Advanced Virgo detector in view of the Observing runs O1, O2, O3 and O4. I have also contributed to other working groups such as the Auxiliary Laser System, that provides an auxiliary laser source that helps in the control of the interferometer. Finally, I am chair of the Working group "Optical Design Sensing and Control" of the Low Frequency detector of Einstein Telescope, which is the European project that will push the detection band even further than the present generation of terrestrial detectors. Between 2019 and 2022 I have been the supervisor on-site for a master thesis and then PhD thesis.

Complementarity of the supervisors:

Vincent Loriette is experienced in a wide range of instrumental optics disciplines and is participating to the Virgo detector building and improvements since 1992. In the early stages of development he conceived and built the optical metrology tools that are used so far to characterize the properties of all passive optical components of all current GW detectors. Afterwards he acquired skills in designing and making various optical systems like optical microscopes or adaptive optics loops. He may thus bring alternative solutions to particular problems based on its wide knowledge and expertise in experimental optics. Julia Casanueva is fully in charge of the on-site implementation of the Interferometer Sensing and Control system in Virgo. She is a young researcher but has worked in the field of optics for Virgo since her PhD and fully masters its ecosystem (optics, design, computing,…). Associating a young dynamic supervisor which is fully involved in the task of designing and commissioning of cavities for Virgo, with a senior director which has been involved in Virgo for more than 30 years and has a wide spectrum of expertise in experimental optics and optical design seems to be a reassuring complementary duo. Moreover, Vincent Loriette and Julia Casanueva have already worked together on the CALVA experimental facility in the past years.