XXXV cycle Ph.D. course in Physics

First year report

Ph.D. student: Barbara Garaventa
Supervisor: Fiodor Sorrentino

RESEARCH ACTIVITY

My research activity focuses on the reduction of quantum noise which limits the sensitivity of gravitational wave (GW) detectors. My work develops both at the quantum optics laboratory in the Physics Department of Genoa and at the gravitational waves detector Virgo, located in Cascina (Pi).
Quantum optical tecniques, in particular the injection of squeezed states of light in the interferometer, are introduced to reduce quantum noise.
Quantum noise is due to vacuum fluctuations that entering from the dark port of the detector and it determines two complementary effects: shot noise, which depends on phase fluctuations of the optical field, dominates at high frequencies and decreases with laser power; radiation pressure noise (RPN), which depends on amplitude fluctuation of the optical field, dominates at low frequencies and increases with laser power. Currently, RPN doesn't limit the sensitivity of GW detector because the low frequency sensitivity is dominated by tecnical noises. In the future, we will be dominated at low frequency by RPN, so we will need phase squeezing on high frequency and amplitude squeezing on low frequency: so we will need to rotate the squeezing ellipse with the frequency. The simplest method to rotate the squeezing angle, which will be applied in the ongoing upgrades in Virgo and LIGO, is to use a filter cavity. Another tecnique is to inject, from the dark port of the interferometer, two EPR (Einstein-Podolsky-Rosen) entangled beams at different frequencies and to use interferometer both as a filter cavity and as a GW detector. In an experiment to prove this concept, we will use a non-degenerate OPO (Optical Parametric Oscillator), that is an optical resonator with a non linear crystal of KTP. Under optical pumping with a visible laser field, the OPO generates two IR fields (signal and idler) at different frequencies; signal and idler fields are entangled due to energy and momentum conservation in the nonlinear process: measuring quantum fluctuations on the idler produces conditional squeezing on the signal field.
During the first year of PhD I tested optical components in the Department of Genoa for the EPR experiment that will soon be installed in the EGO site (European Gravitational Observatory), in particular I have been involved in studying the performance and diffraction efficiency of an acousto-optical modulator (AOM). I am also collaborating in the development of the optical design for the EPR experiment. During the lockdown, I was able to align the optical cavities in the 1500W laboratory at Virgo, via remote connections. Optimizing the alignments is fundamental as the misalignments reduce the level of observable squeezing. Therefore a system is needed that automatically aligns them both for AdV$^+$ (the next upgrade of Advanced Virgo) experiments, but also for the EPR experiment. I therefore collaborated in developing a simple method through a c# program for an

automatic alignment of the optical cavities, starting from the information obtained from the manual alignment of optical cavities present in the EGO site, using Kinesis software.

COURSES ATTENDED

- **Biosensing** (O. Cavalleri, E. Angeli)

  Exam passed on June in form of a seminar on article analysis:

  “Dual-Functional Plasmonic Photothermal Biosensors for Highly Accurate Severe Acute Respiratory Syndrome Coronavirus 2 Detection”, G. Qiu, Z. Gai, Y. Tao, J. Schmitt, G. A. Kullak-Ublick, and J. Wang

- **Quantum Optics** (D. Ferraro)

  Exam passed on July in form of a seminar on article analysis:

  “Squeezed states of light”, D. F. Walls

- **Fondamenti di Quantomeccanica e Applicazioni** (P. Zanghì, P. Solinas)

  Exam passed on September in form of seminars on :

  article analysis “Quantum Nondemolition Measurements”, V. B. Braginsky, Y. I. Vorontsov, K. S. Thorne;

  and on quantum cryptography, in particular the BB84 protocol.

- **Criogenia Applicata** (R. Musenich)

  Exam scheduled shortly.

PAPERS / CONFERENCES

B Garaventa et al., “Frequency-dependent squeezing generation with EPR entanglement”, J. Phys.: Conf. Ser. 1548, 012013 (2020)

V. Sequino,B. Garaventa et al., “EPR experiment for a broadband quantum noise reduction in gravitational wave detectors”, GRASS

Commissioning Training Virgo (Follow-up session), working period June-July 2020, oral talk on July 24, 2020.