GDR Ondes Gravitationnelles: workshop ”développement des détecteurs”

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Laboratoire APC, Bâtiment Condorcet, 10 rue Alice Domon et Léonie Duquet, 75013, Paris

Recueil des résumés

Contents

1

Mot d’accueil

2

Basics on Quantum Optical Noise and Squeezing (40’ + 20’ de questions)

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Basics on Quantum Noise and Squeezing

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Quantum noise arises from the basic principles of quantum theory. It is a limitation in all high-sensitivity measurements, when other sources of noise are mastered.
When the quantum noise level is attained, there still exist ways to reduce the impact of quantum noise on sensitivity by “squeezing”its effect on the observable of interest.
Gravitational wave detection has always been a deeply rooted motivation for developing ideas and techniques to attain the quantum noise level and go beyond it if possible.
Today, GW detection is an amazing application of squeezing with an eminent place among the many applications proposed along the years.
As for many quantum phenomena, there are different manners of discussing qualitatively the origin and effects of quantum noise and squeezing.
First, a laser beam is a flow of photons. Shot noise is due to the statistics of photon counting and it is the simplest way to understand quantum noise in intensity measurements.
Then, a deeper understanding requires to describe quantum fluctuations of the various field observables involved in a more general measurement.
In the talk, I give a simple presentation of this understanding and discuss the principles of its application to the domain of gravitational wave detection with optical interferometers.

3

Le bruit quantique dans Virgo/ET (40’ + 20’ de questions)

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4

Mesures sous la limite quantique standard en interférométrie atomique

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Je montrerai comment l’utilisation d’états atomiques non classiques permet d’améliorer la sensibilité de capteurs quantiques basés sur des méthodes d’interférométrie atomique au delà de la limite quantique, liée à la détection des populations dans les ports de sortie des interféromètres, et je dresserai un panorama des activités dans le domaine, qui a récemment connu un regain d’intérêt.

Contributions (15’ + 5’ de questions) / 5

Study of the optical losses as a function of beam position on the mirrors in a 285 m suspended Fabry-Perot cavity

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Optical losses introduce noise, impair noise reduction techniques, and degrade signal gain in gravitational wave detectors. The squeezed vacuum state of light is a well-established method for quantum noise reduction. An optical cavity, often called a filter cavity, is essential to impose a frequency-dependent phase rotation on the squeezed vacuum. In the Virgo gravitational wave detector, the filter cavity is 284.9 meters long with a finesse of about 10,000.

In this talk, we report on the characterization of optical losses within the Virgo filter cavity. By using cavity angle information, we reconstructed the beam position inside the cavity and conducted an in-situ optical loss mapping. Our findings indicate that optical losses depend significantly on the beam’s position on the input mirror, while losses are more uniform on the end mirror. The lowest measured losses are comparable to those expected from pre-installation mirror characterizations. The larger discrepancies observed for certain beam positions are likely due to contamination. Additionally, this methodology enabled the regulated identification of an optimal cavity axis position within half an hour, achieving some of the lowest round trip losses ever recorded. This work contributes to meeting the stringent loss requirements for the optical cavities of future gravitational wave detectors, such as the Einstein Telescope and Cosmic Explorer.

Contributions (15’ + 5’ de questions) / 6

Resonant behavior of linear three-mirror cavities

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The implementation of Fabry-Perot cavities in gravitational-wave detectors has been pivotal to improving their sensitivity, allowing the observation of an increasing number of cosmological events with higher signal-to-noise ratio. Notably, Fabry-Perot cavities play a key role in the frequency-dependent squeezing technique, which provides a reduction of quantum noise over the whole observation frequency spectrum. In this context, linear three-mirror cavities could be of interest because of the additional control that they can provide.

Contributions (15’ + 5’ de questions) / 7

Optical characterization of the Fabry-Perot arm cavities of Virgo and preparation of the numerical methods

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Optical characterization is crucial to models correctly the behavior of the interferometer and to optimise its working condition. In order to estimate some optical parameters of the Virgo arm Fabry-Perot cavities (such as g-factor, radius of curvature (RoC) of the test masses, finesse, mismatching with respect to the input beam) a free spectral range (FSR) measurement campaign is currently being carried out. Such scans of arm cavities allow to compare the optical parameters with the design values, and also act on the tuning of the RoC actuators to equalize the two arm parameters. This presentation will be focused on the last measurements done and the modal analysis used to perform the optical parameters estimation. Such analysis is crucial to prepare robust numerical methods for the optical characterization of post-O4 and Virgo_nEXT, in the context of the stable recycling cavities.

Contributions (15' + 5' de questions) / 8

Preliminary Noise Budget for the Laser Interferometer Lunar Antenna

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The sensitivity of today's gravitational wave detectors is limited by a multitude of noise sources, defining an exploitable frequency band around 10 Hz to 10 kHz. Although these instruments are isolated by several orders of magnitude from the Earth's seismic activity thanks to advanced isolation systems, seismic noise prevents any detection below a few Hz. During the Apollo missions, seismometers were deployed on the lunar surface. The analysis of these data showed that the Moon is extremely quiet, with an upper limit on the seismic background noise around 1000 times quieter than on Earth around 0.2 Hz. For this reason, the Moon is considered a unique environment for gravitational astronomy. Additionally, gravitational waves are known to excite free oscillations of rigid bodies. We will present a preliminary noise budget for the Laser Interferometer Lunar Antenna (LILA) project, which aims to build and operate a gravitational detector on the edge of a lunar crater, combining two methods of detection: a suspended test-masses interferometer as performed on Earth and a laser strainmeter to monitor excited normal modes of the Moon.

Contributions (15' + 5' de questions) / 9

Optimisation de la sensibilité d'un dispositif de caractérisation des modes mécaniques d'un miroir via un interféromètre de Michel-

son dans le cadre du monitoring du phénomène d'instabilités paramétriques

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Le phénomène d'instabilités paramétriques constitue une des limitations à l'augmentation de la puissance intra-cavité sur chaque bras de l'interféromètre du détecteur VIRGO. Pour implémenter une solution active d'atténuation de ce phénomène, il est nécessaire d'être capable de monitorer son évolution en temps réel, par exemple, en caractérisant l'évolution des modes mécaniques résonnants impliqués. Nous présentons ici un dispositif de caractérisation des modes mécaniques d'un miroir situé dans le bras de test d'un interféromètre de Michelson. La sensibilité de mesure de déplacement démontrée expérimentalement de 4.5×10^{-16} m/√Hz pour des fréquences supérieures à 35 kHz est compatible avec la caractérisation de modes mécaniques excités thermiquement d'un miroir de facteur de qualité de 5×10^{5}. L'utilisation d'un interféromètre de Michelson au lieu d'une cavité permet d'implémenter ce dispositif sur le détecteur VIRGO.

Contributions (15' + 5' de questions) / 10

Testing the interferometric detection system of LISA

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La contribution française au Consortium LISA, spécifiquement sur l'aspect instrumental, se concentre sur le développement des moyens de tests au sol pour LISA. Plus précisément, l'une des tâches de la communauté française est de tester et de valider les performances du système de détection interférométrique (IDS), composé de modèles représentatifs vol du banc optique LISA (UKATC), du système laser (NASA) et des phasemètres (AEI).

La configuration de test IDS est actuellement en cours de développement afin de vérifier que la stabilité picométrique est atteinte dans l'IDS (EM et QM) et de caractériser le coefficient de couplage tilt-to-length des interféromètres du banc optique.

La configuration de test est composée de plusieurs sous-ensembles comprenant l'IDS, le Beams Simulator et le Test Mass Simulator. Le laboratoire APC est chargé du développement du banc optique Beams Simulator qui est destiné à simuler et à stimuler l'interface avec le banc optique sur le satellite distant et l'OB adjacent sur le vaisseau spatial local.

Pour cette contribution, je présenterai le principe de fonctionnement du BSIM et de la configuration de test IDS globale, je donnerai une mise à jour sur le développement du projet et un aperçu des activités de prototypage. Je détaillerai ensuite comment le coefficient Rx TTL du banc optique LISA sera caractérisé au cours de cette campagne de tests.

Contributions (15' + 5' de questions) / 11

Modelling Newtonian Noise from acoustic origin in the terminal buildings at the Virgo's site

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Among the noises affecting gravitational wave detectors, Newtonian Noise results from variations in the gravity field induced by fluctuations of the mass distribution in the vicinity of sensitive optical elements, in particular test masses. This paper focuses on the modeling of Newtonian Noise of acoustic origin, i.e. resulting from the presence of an infrasound acoustic field in experimental rooms.

The study shows that acoustic noise in the NEB and WEB terminal buildings of the Virgo detector is mainly generated by the air-conditioning system. The acoustic field in these buildings, simulated by a finite element code, exhibits modal behavior in the frequency range studied [0-30Hz], which is validated by direct measurement using an antenna of infrasound microphones.

The resulting Newtonian Noise is estimated and compared with the sensitivity level of Advanced Virgo. The possibilities of limiting this noise by controlling the acoustic level are explored, in particular by estimating the effect of adding acoustic absorbing material, the effect of reducing the fan rotation speed, and the effect of modifying the position of the air injection and suction points.

Contributions (15' + 5' de questions) / 12

Virgo: stable cavities and auxilary optics

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During the commissioning for the O4 observation run, the currently implemented marginally stable recycling cavities in Virgo have created difficulties with locking and alignment, as well as degrading the performances of the interferometer. Thus, for the next observation run, Virgo is planning to implement stable recycling cavities, and will pause the implementation of larger test masses for the time being. Theses changes impact the auxiliary optics that APC is in charge of. In this talk, I will present the work that has been done on end-bench mode-matching telescopes for the larger test masses, as well as the current work on the mode-matching telescopes for the injection and detection benches.