Contribution aux exercices de prospective nationale 2020-2030

Détecteurs et instrumentation associée

DEVELOPING A 3D OPTO-MECHANICAL SIMULATION FOR GRAVITATIONAL WAVE DETECTORS

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Informations générales

Titre : Developing a 3D opto-mechanical simulation for gravitational wave detectors

The terrestrial gravitational wave detectors as Virgo have been pursuing different upgrades since their initial design but scattered light is an old chestnut that always shows up to limit the sensitivity curve in some part. In order to better understand the sources of diffuse light and dump it efficiently in Virgo, developing a 3D opto-mechanical simulation will be very helpful. Such a design tool will be crucial for the Einstein Telescope, in order to tackle the scattered light issue in a systematic and deterministic way from the very beginning and meet the ambitious sensitivity goals. LISA will also have scattered light issues that can be studied with such a tool.

Préciser le domaine technologique

- Informatique
- Optique
- Mécanique

Préciser la motivation principale de recherche visée par la contribution :

- R&D Détection d'ondes gravitationnelles

1. Description des objectifs scientifiques et techniques

Despite dedicated upgrades of the gravitational wave detectors to reduce the sources of diffuse light and the coupling of the diffuse light with the interferometer, the detector improved sensitivity have always been partly limited by diffuse light. Two paths must be followed to reduce its impact in the next upgrades and in the Einstein Telescope detector. First, reduce the diffuse light at its source with better low-diffusion optics, efficient dumping of the secondary beams and of residual diffuse light, and by using absorbing material on the benches (mounts, optical breadboards, vacuum tank walls, ...). Second, reduce the coupling of the residual diffuse light with the interferometer by better controlling the optical resonances of the benches and optical mounts, and better controlling the relative positions of the benches and interferometer.

A large part of the Advanced Virgo upgrade was designed to reduce the scattered light: five optical benches have been suspended and put in vacuum, high quality of the optics polishing was required and the most critical secondary beams were identified and dumped. However, dumping the secondary beams has been difficult and further reduction of the diffuse light had to be dealt empirically after installation, during the commissioning, with the addition of beam dumps where we realized that they were needed.

Currently, the optical design of Virgo and of its optical benches is simulated using Optocad software. It is a 2D simulation of the propagation of a Gaussian beam through standard optical elements (mirrors and lenses). Based on the positions of the optical elements, a mechanical drawing of the mechanical parts to be installed on the benches (posts and mounts of mirrors, lenses and sensors) is then done to check the space constraints to ease the installation of the elements on the bench. But no integrated opto-mechanical simulation is performed, which limits the tracking of scattered light.

In Virgo, the main mirrors of the interferometer, viewports between different vacuum zones of the detector and optical elements on the benches have wedges or are tilted in order to separate the reflected secondary beams from the main beam. Wedges and tilts are either horizontal or vertical.

As a 2D simulation, Optocad cannot follow properly all these beams in 3D. In addition, since the mechanical parts around the mirrors and lenses are not simulated in Optocad, one cannot track the real beam path, clipping and diffusion, which limits the possibility to identify the risk of scattered light a priori.

A 3D opto-mechanical simulation would allow to better track the secondary beams in order to design proper mechanical parts and absorbing elements to dump the secondary beams and diffused light. Such a simulation will need to tackle the following:

- Gaussian beam propagation.
- realistic reflection and transmission coefficients for the optical elements to simulate the secondary beams.
- realistic geometry (wedge, tilt, orientation) of the optical elements.
- realistic diffusion profile for the optical elements.
- realistic geometry and material properties (absorption, reflection, diffusion) of the mechanical parts installed on the bench (bench surface, posts, mounts, ...). To achieve this goal, there must be a strong relation between mechanical CAO tools and this simulation tool for an overall integration.
- possibility to track a large number of secondary beams due to multiple reflections on the optical surfaces but also on the mechanical parts of the bench and its environment.

  Going further and simulate the coupling of the residual diffused light with the interferometer beam would require to also integrate information about resonance frequencies and quality factors of the most critical elements.
  Prospects for using Laguerre-Gauss beams in the interferometer are on-going. Their propagation could also be simulated.

2. Références