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Parametric instabilities predictions for Advanced Virgo

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Now that gravitational waves from compact binary coalescences have been successfully detected by the global LIGO-Virgo network, a key challenge is to improve the detector sensitivity in order to detect more transient sources —weaker or located further away. The detectors' sensitivity can be enhanced by increasing the laser power travelling within the arm cavities, for it reduces the effect of the laser quantum phase noise, which is the fundamental noise that dominates the sensitivity in the high-frequency range (above a few hundreds of Hz). However, a nonlinear optomechanical phenomenon that has long been studied, and which is called parametric instabilities (PI), may limit the amount of energy stored in the Fabry-Perot resonator, and thus the laser power.

PI comes from the coupling of three modes: a mirror mechanical mode (MM) that sets the mirror surface in motion, the fundamental optical mode of an optical cavity (TEM00), and a higher order optical mode (HOM). Photons scattering from the TEM00 to a HOM can generate an optical beat note if the difference in frequencies of the two optical modes is equal to the MM resonance frequency. This beat note, in turn, can either damp or increase the mechanical motion via radiation pressure. The latter effect could lead to an excitation, that is, first exponentially growing, and then reaches a plateau after some time. The signal associated with this mirror excitation would be aliasing in the detection band, thus saturating the electronics.

In 2015, during the Observing Run 1 (O1), LIGO observed PIs when a mirror mechanical mode at 15 kHz became unstable, for an intracavity power of 50 kW. That is why we study the effects of PIs for the Virgo configuration with various parameters in order to scan PIs around theoretical and computed values so that we could take hypothetical errors into account. We, as well, compare results using perfect spherical maps and measured mirror maps. Alongside with which we study the effects of optical losses that can counterintuitively increase the parametric gain. Finally, we show that the O3 nominal intracavity power of 272 kW, could bring from zero to a few tens of unstable modes, depending on the radii of curvatures of the mirrors, if all the mechanical modes quality factors are assumed to be equal to 10^7.

Summary

Primary author: JACQMIN, Thibaut (Laboratoire Kastler Brossel/Sorbonne University)

Co-authors: Mr COHEN, David (LAL Orsay, IN2P3); PUPPO, Paola (ROMA1); Dr BOGAERT, Gilles (Artemis, CNRS); ALLOCCA, Annalisa (PI)

Presenter: JACQMIN, Thibaut (Laboratoire Kastler Brossel/Sorbonne University)

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