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Monte Carlo simulation of the thermal radiation heat load to the cryogenic mirror and vacuum system of the Einstein Telescope

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A third-generation underground gravitational wave (GW) observatory, known as the Einstein Telescope (ET), will be developed by European countries together. It is designed as an equilateral triangle with 10 km long arms 200 to 300 meters underneath the ground and with detectors being located in each corner. Any two adjacent arms comprise two independent interferometers, and one interferometer will detect low-frequency gravitational wave signals (ET-LF), while the other will be optimized for operation at higher frequencies.

The most distinguishing and important feature of ET is that the frequency band of ET-LF will be expanded to lower frequencies compared to the current advanced gravitational wave detectors (Virgo, LIGO). In order to reduce seismic noise, thermal noise and other systematic noise, the beamline pipes require ultra-high or high vacuum conditions. In addition, the mirrors of ET-LF will be cooled to cryogenic temperatures below 20 K. Obviously, at this temperature the mirror will adsorb gases as a frost layer, degrading its optical properties. It is a challenging task to develop the vacuum pumping systems, based on cryopumps, to fulfil the requirements regarding pressure and frost mitigation aspects.

Basically, there are three different Monte Carlo based simulation approaches to simulate the thermal heat loads, i.e., the view factor method, the radiation exchange factor method and the direct ray trace method, and each has its own pros and cons. In this paper, the radiation exchange factor method is used, which results in a model framework where the temperatures of the components are external parameters that can be modified systematically. For this purpose a Test Particle Monte Carlo model has been established with the KIT in-house code ProVac3D, to allow for a systematic analysis of the thermal radiation heat load to the cryogenic and vacuum systems of the ET-LF. Several virtual surfaces are implemented in the simulation model to divide the physically very huge vacuum system into several domains in order to check particle conservation. Finally, a 55 x 55 matrix of radiation exchange factors with high precision is obtained and the heat loads to every surface are calculated. It was found that the resulting heat load is in an acceptable range.

Additionally, the heat load to the mirror has been systematically investigated by changing the temperature of the thermal baffles inside the cryopumps which are exchanging thermal radiation with the mirror, and the mirror emissivity. With these results an appropriate and justified design of a cryogenic vacuum pumping system of ET-LF can be developed in detail, a first concept of which will be proposed.

Submitters Country

Germany

Author: LUO, Xueli (Karlsruhe Institute of Technology)

Co-authors: Mr HANKE, Stefan (Karlsruhe Institute of Technology); Dr DAY, Christian (Karlsruhe Institute of Technology)

Presenter: LUO, Xueli (Karlsruhe Institute of Technology)

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