2023 Helmholtz – OCPC – Programme

for the involvement of postdocs in bilateral collaboration projects

PART A

Title of the project:

Nanomechanical resonators for high-frequency gravitational wave detection

Helmholtz Centre, division:

DESY-FH

Project leader:

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Description of the project (max. 1 page)**:**

Fueled by recent achievements of km-scale gravitational-wave observatories, efforts towards the development of "down to lab-scale" detectors are currently gaining momentum [1]. By virtue of their smaller dimensions, these detectors target gravitational-waves above the established observation window (i.e., 10 to 10^4 Hz) at "ultra-high-frequencies" (i.e., 10^4 to 10^{19} Hz). The sources proposed for generating potentially observable signals in this frequency range are of cosmological origin or require new physics beyond the Standard Model.

The levitated sensor detector [2,3] is one of this new kind of detectors. In our research we investigate a similar setup comprising a dielectric membrane incorporated inside an optical cavity close to the input mirror. The watt-scale optical field inside the cavity results in a pronounced radiation pressure force acting on the membrane, which “traps” the membrane at an antinode of the optical field. A passing gravitational wave displaces membrane and end mirror with respect to the input mirror, thereby moving the membrane from its equilibrium position in the optical trap. This results in a restoring force exerted on the membrane, which causes the membrane to oscillate. This interaction is resonantly enhanced when the frequency of the GW matches the resonance frequency (~ 100 kHz) of the trapped membrane. The membrane's motion is read out via phase modulation of an additional probe field.

A major limiting noise source in the levitated sensor detector is the thermal noise acting on the membrane as a consequence of intrinsic losses and impinging residual gas particles. A first goal of this project is to identify an optimal membrane design for the application described above. Based on an understanding of the mechanisms limiting the membranes mechanical Q factor, state of the art methods (e.g., strain engineering, phononic crystal design, topology optimization, machine learning) [4] shall be applied in this process. In addition to mechanical characteristics also optical properties of the membrane (e.g., reflectivity, absorption, scattering) shall be considered. A second goal of the project is to design a prototype setup of a membrane-based levitated sensor detector, with a focus on optics, vacuum, and cryogenics.

[1] Aggarwal, Nancy, et al. "Challenges and opportunities of gravitational-wave searches at MHz to GHz frequencies." *Living reviews in relativity* 24.1 (2021): 1-74
[2] Arvanitaki, Asimina, and Andrew A. Geraci. "Detecting high-frequency gravitational waves with optically levitated sensors." *Physical review letters* 110.7 (2013): 071105
[3] Aggarwal, Nancy, et al. "Searching for new physics with a levitated-sensor-based gravitational-wave detector." *Physical review letters* 128.11 (2022): 111101
[4] Sementilli, Leo, Erick Romero, and Warwick P. Bowen. "Nanomechanical dissipation and strain engineering." *Advanced Functional Materials* (2021): 210524

Description of existing or sought Chinese collaboration partner institute (max. half page)**:**

All Chinese institutes that are interested in this project.

Required qualification of the postdoc:

- PhD in a related subject area or relevant industrial experience
- Experience/Knowledge
    - Optical instrumentation
    - Nanomechanical resonators
    - Numerical simulations, FEM (e.g., COMSOL, Ansys)
    - Data analysis in Python, Matlab or similar
    - Proven ability to publish in international journals
- Additional skills
    - Proven ability to demonstrate creativity, innovation and team-working within work
    - Proven ability to work without close supervision
- Language requirement
    - Ability to communicate in English