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Concept Study of a Storage Ring Gravitational Wave Observatory for Earth-Based Multiband Detection and Terrestrial Gravity Noise Mitigation

This contribution addresses a first feasibility study for the measurement of millihertz Gravitational waves (mHz GWs) with a storage ring-based detector design that might aid in noise mitigation for Einstein Telescope (ET) by providing a terrestrial gravity noise (TGN) signal and could potentially enable multiband GW observations from Earth.

We propose an experiment based on the measurement of the time-of-flight signal of an ion chain circulating in a storage ring (circular particle accelerators where ion beams are stored for long periods, emitting synchrotron radiation). Compared to a particle traveling in such a storage ring with unaltered velocity, a GW induces a de- or acceleration, which leads to the built-up of an additional time-delay that particles require to complete a full revolution of the ring. Consequently, a GW signature should be observable as a variation of the relative ticking of such a storage ring clock compared to e.g. a reference atomic clock, which would not exhibit the same variation in its ticking. Due to the long storage duration of the circulating ions, the GW signal encoded in their arrival time is especially sensitive to slowly varying mHz GWs. One of the dominant noise sources inherent to the measurement principle, is the shot noise of the emitted synchrotron radiation of the ions. We derive the synchrotron radiation noise amplitude imprinted in arrival time signals of a circulating heavy ion chain using analytical computations and particle tracking simulations.

A storage ring-based gravitational wave observatory (SRGO) based on such an operational principle is expected to exhibit an optimum design sensitivity in the range of 10^{-4} Hz up to 10^{-2} Hz, which would open up the possibility for multiband GW observations on Earth. However, as all ground-based detectors, SRGOs face the same challenge of the strong terrestrial gravity noise (TGN) in the sub-Hertz band. This will be a limiting factor for the ability of the next-generation low-frequency GW detectors to detect in this band.

While it is still an open question if a sufficiently high sensitivity for the detection of GWs can be reached by improving the experiment design of SRGOs, it should feasible to capture a TGN signal in the range of millihertz up to Hertz frequencies with with a less accurate apparatus. Therefore, in the future, SRGOs might serve as a TGN sensor, which would help ET and other GW detectors to mitigate TGN and be able to detect lower frequency GWs from Earth.

Primary authors: Prof. GRÜNER, Florian (University of Hamburg, Institute of Experimental Physics); Prof. LISKE, Jochen (Hamburg Observatory); Dr SCHMIRANDER, Thorben (University of Hamburg, Institute of Experimental Physics)

Presenter: Dr SCHMIRANDER, Thorben (University of Hamburg, Institute of Experimental Physics)

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