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Probing Exotic Scalar Fields by Utilizing the GPS System

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Some beyond-standard-model theories, such as the Axi-Higgs model (Leo WH Fung, 2021), suggest the existence of exotic light scalar fields that couple to matter. During high-energy astrophysical events such as binary neutron star (BNS) mergers, these scalar fields may be emitted as radiation. Our project proposes a novel method to detect such radiations, namely, using the Global Positioning System (GPS). GPS satellites have atomic clocks onboard to correct for relativistic effects, so they form a quantum sensor array around the globe, which is a potential facility available for astronomical observations. The interactions between the emitted light scalar field and the atomic clocks can generate effective changes in fundamental constants, such as the electron mass and the fine-structure constant, imprinting measurable signals in atomic clocks. Therefore, we may be able to detect the signal of light scalar radiation by utilizing satellite data. This method has a few advantages. First of all, the facility it utilizes already exists, meaning that there is no need to build expensive new apparatus. Secondly, our previous calculations (Conner Dailey, 2020) show that other forms of signal, such as the gravitational wave signal, are shielded from the atomic clocks on the GPS, thanks to their low sampling rates. Moreover, since about 20 years'worth of GPS data is available in the database, we can trace back in time to search for low-mass scalar field bursts, by correlating to LIGO data or short gamma-ray bursts.

In our previous paper (Conner Dailey, 2020), we discussed the possibility of utilizing the GPS to detect a monochromic signal of light scalar fields. In an actual BNS event, rather than a monochromic signal, we would expect an emission waveform closely related to the inspiral of the BNS, which is then modified by propagation effects. By considering the quadrupole radiation, we derive an expression of the waveform, and hence an expression for the spectral density (up to a multiplicative constant, which depends on the strength of the coupling). Also, by utilizing sample satellite data, we analyzed the background noise in the satellite data. From that, we can calculate the signal-to-noise ratio as a function of frequency. This would tell us which part of the signal is visible to the detectors, and how strong the coupling should be to let the signal be visible. Another interesting question is how well the timing information from the GPS network can be used to localize the event in the sky.

References

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Leo WH Fung, L. L.-C.-H., et al. (2021). Axi-Higgs Cosmology. https://arxiv.org/abs/2102.11257.

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