Discovered at Last! Stochastic Gravitational Waves Background – Implications of 15 Years of NANOGrav Data –

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What kind of observations will allow us to capture the moment of the birth of the Universe? The quantum effects of the inflaton field that induced inflation in the early Universe created density fluctuations of approximately $\mathcal{O}(10^{-5})$ on the large scale of the Universe. Galaxies were created when matter gravitationally collapsed in regions of high density. Here, matter refers to both baryons, and dark matter, which is five times more abundant than baryons.

At the end of June in 2023, it was reported that the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) had observed stochastic gravitational wave (GW) background (SGWB) [1] that have existed since the early Universe.

After 15 years of observing the correlation of radio signals periodically emitted by multiple pulsars, NANOGrav has observed a signal specific to the SGWBs in the nanohertz band. If SGWBs are present, they are observed because they modify the periodicity of the precise pulsar radio waves.

SGWBs are also known to be produced by mergers of supermassive black holes at the centers of galaxies, but this signal has a different spectral shape. If the small-scale density fluctuations produced by inflation are large, the second-order nonlinear effect of the density fluctuations can produce large SGWBs (called the induced gravitational waves). We have proposed that these induced GWs match the signal exactly [2]. Furthermore, such a large density fluctuation is expected to collapse into a primordial black hole that is lighter than the Sun. Its abundance amounts to about 2 % of the total of dark matter. The Einstein Telescope (ET) and Cosmic Explorer (CE) can in the future discover GWs emitted by the coalescence of binary primordial black holes. Such future gravitational wave experiments are expected to verify the quantum nature of the inflaton field and discover the primordial black holes.

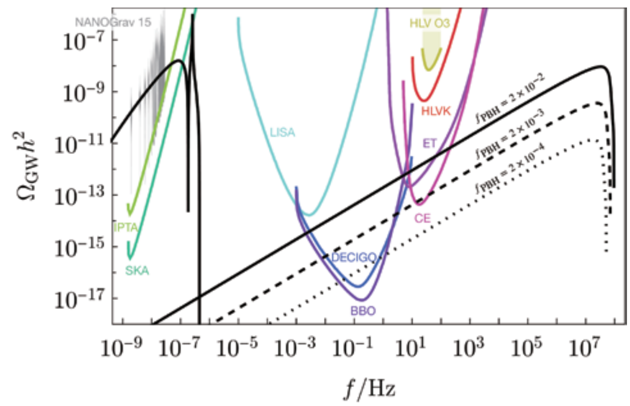

Figure 1: NANOGrav data of background gravity waves in the 10^{-9} Hertz band over a 15-year period (shaded in gray). The data are explained by the induced gravity waves (black curves) created by density fluctuations of the early Universe origin, and will be tested in detail in future observations IPTA and SKA. The gravitational wave signal (black diagonal line) produced by the coalescence of the binary primordial black holes (PBHs) corresponds to 2 % of dark matter, which will be tested by future gravitational wave observations such as DECIGO, BBO, ET, CE, etc. For other detailed explanation, please refer to the original paper [2].

References

[1] Agazie, G., et al.: 2023, *ApJ*, **951**, L8.
[2] Inomata, K., Kohri, K., Terada, T.: 2024, *Phys. Rev. D*, **109**, 063506.