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Sound waves from primordial black hole formations

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We present a numerical investigation of primordial black hole (PBH) formation from super-horizon curvature perturbations and the subsequent generation and propagation of sound waves, which can serve as a new source of stochastic gravitational wave backgrounds (SGWBs) presented in a companion letter. Using the Misner-Sharp formalism with an excision technique, our simulations extend to significantly later times than previous work and indicate that the near-critical perturbations produce a distinct compression wave featuring both overdense and underdense shells, while significantly supercritical perturbations yield only an underdense shell. We also show that a softer equation of state suppresses the formation of compression waves. Furthermore, the comoving thickness of sound shells remains nearly constant during propagation and scales with the Hubble radius at horizon re-entry, thereby serving as a key link between the gravitational-wave peak frequency and PBH mass in the companion letter. These results offer new insights into the dynamics of PBH formation and suggest potential observational signatures of PBHs in the gravitational wave (GW) spectrum from associated sound waves.

Primary author(s) : NING, Zhuan (HIAS and ITP-CAS); ZENG, Xiang-Xi (ITP, CAS); YUWEN, Zi-Yan; WANG, Shao-Jiang (Institute of Theoretical Physics, Chinese Academy of Sciences); DENG, Heling; CAI, Rong-Gen

Presenter(s) : NING, Zhuan (HIAS and ITP-CAS)

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