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Gravitational waves and primordial black holes from chirality imbalanced QCD first-order phase transition with P and CP violation

The chirality imbalance in QCD is spontaneously induced by a repulsive axial-vector interaction from the instanton anti-instanton pairing at high temperature above the chiral phase transition, and vanishes at low temperature. The chiral chemical potential μ5 is in the same magnitude as estimated from the sphaleron transition. Phase transition of the chirality imbalance is always a first-order one in the early universe with P and CP violation. The spectra of gravitational waves and the formation of the primordial black holes from this first-order phase transition will be discussed and the effect of a strong magnetic field will also be analyzed. The gravitational waves produced by chirality imbalance can be detected by LISA, Taiji and DECIGO, with the peak energy density locating in the range of 10^−11 to 10^−9 and the peak frequencies lying in the range of 10^−5 Hz to 10^−2 Hz. The spectrum with larger axial vector coupling strength and stronger magnetic field has higher peak energy density and lower peak frequency. According to this trend, the gravitational waves spectra might also be able to be detected by SKA, IPTA and EPTA. The Phase transition inverse duration β/H* calculated from the bounce solution is in the order of 10^4 which is much higher than typical value 10–100 from electroweak phase transitions. Based on the mechanism of postponement of the false vacuum decay, it is found that the formation of the primordial black hole is not favored because the phase transition completes in an extreme short time due to the large value of β/H* and thus the false vacuum energy density decays sharply.

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