Correlation-enhanced interaction of a Bose-Einstein condensate with parametric magnon pairs and virtual magnons

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Nonlinear wave interactions are responsible for the various aspects of the behavior of different systems in nature, including processes in the Earth's ocean and atmosphere, dynamics of stars, and even the evolution of the Universe. In the field of magnetism, the use of nonlinear phenomena often opens tempting prospects for applications of magnonics and spintronics in neuromorphic computing, microwave data processing, and nanoscale wave logic circuits. Spin waves (and their quanta–magnons) in magnetically ordered materials are highly nonlinear compared to, for example, phonons or photons in solids. One of the most suitable systems for studying magnons is single-crystalline ferrimagnetic yttrium iron garnet (YIG, $Y_3Fe_5O_{12}$) and in particular, films made out of it. The strong nonlinearity, combined with the high quality factor of magnons in YIG, facilitates the observation of various types of nonlinear interaction processes [1–3]. For example, the phenomenon of Bose-Einstein condensation of magnons at the bottom of their frequency spectrum, observed in YIG films [4,5], has provided significant assistance in these studies. In our experiments, this condensation was achieved by the parametric pumping of magnons with microwave radiation.

In the currently presented experimental and theoretical study, we reveal several nonlinear processes that involve not only "real" quasiparticles (the eigenmodes of the medium), but produce as a final result virtual quasiparticles (out-of-spectrum waves) caused by various types of nonlinear interactions. The most nontrivial and intriguing process involves a pair of parametrically excited magnons and a partially coherent Bose-Einstein condensate (BEC). This process is enhanced by full phase correlations in parametric magnon pairs with opposite wavevectors.

[1] O. V. Prokopenko et al., *Recent Trends in Microwave Magnetism and Superconductivity*, Ukr. J. Phys. **64**, 888 (2019).
[2] A. V. Chumak et al., *Roadmap on Spin-Wave Computing*, IEEE Trans. Magn. **58**, 0800172 (2022).
[3] A. J. E. Kreil et al., *Tunable Space-Time Crystal in Room-Temperature Magnetodielectrics*, Phys. Rev. B **100**, 020406 (2019).
[4] S. O. Demokritov et al., *Bose–Einstein Condensation of Quasi-Equilibrium Magnons at Room Temperature under Pumping*, Nature **443**, 430 (2006).
[5] A. A. Serga et al., *Bose–Einstein Condensation in an Ultra-Hot Gas of Pumped Magnons*, Nat. Commun. **5**, 3452 (2014).