Analogue cosmological particle creation in a quantum fluid of light

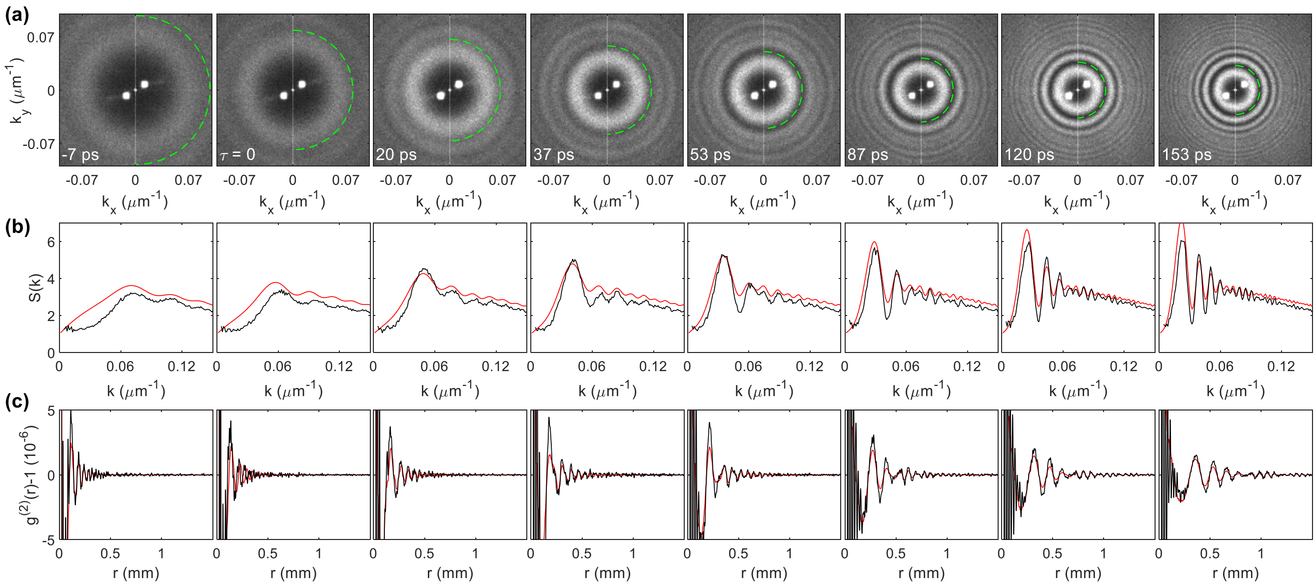
Jeff Steinhauer[1,2], Murad Abuzarli[1], Tangui Aladjidi[1], Tom Bienaimé[1], Clara Piekarski[1], Wei Liu[1], Elisabeth Giacobino[1], Alberto Bramati[1], and Quentin Glorieux[1]

[1]*Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-PSL Research University, Collège de France, Paris 75005, France*

[2]*Department of Physics, Technion—Israel Institute of Technology, Technion City, Haifa 32000, Israel*

The rapid expansion of the early universe after the big bang resulted in the spontaneous production of cosmological particles out of vacuum. This idea dates back to Schrödinger who studied particle production in the expanding universe. This mechanism is at the origin of the anisotropies in the cosmic microwave background, according to the cosmology inflationary model. Since 1990, several successive space missions have improved the resolution of the CMB power spectrum measurements, revealing the presence of characteristic peaks well described by acoustic oscillations in the quantum fluid of photons and baryons in the early universe. It suggests that cosmic inflation is the correct theory.

Analogue systems are essential to explore this theory since it allows measuring over time, which is impossible for the real CMB. As the acoustic peaks are independent of the microscopic description of the medium, the study of cosmological particle creation in an analogue universe formed in a quantum fluid is possible.



Analogue cosmological particle creation in a quantum fluid of light. **(a)** The structure factor $S(k_x, k_y, k_z, = 0, \tau)$ at various times after the second quench. The dashed green curve indicates the first minimum of the red curves in (b). The symmetric white points near the center of all panels are due to spurious fringes in the imaging system. **(b)** Radial profiles of (a). The black lines are the experimental data, and the red curves are the prediction for analogue cosmological particle creation. **(c)** Density-density correlations. The experimental (black) and theoretical (red) curves are obtained from (b) by the spherical Fourier transform of Eq. 6.

In this work, we report analogue cosmological particle creation in the laboratory using a quenched 3-dimensional quantum fluid of light. Our quantum fluid is a near-resonant laser pulse traversing a warm atomic vapor cell. Within the vapor cell, the two-body repulsive interactions between photons are mediated by the atoms, due to Kerr nonlinearity induced by the atomic resonance. In this geometry, the interactions are suddenly quenched to zero when the laser beam exits the vapor celland this configuration mimics an expanding universe, since a rapid reduction of the interactions causes a sudden red shift of the excitation energy.

We find acoustic peaks in the density power spectrum in close analogy with the angular power spectrum of the cosmic microwave background. The process is shown to be spontaneous, since it is seeded only by shot noise quantum fluctuations. Furthermore, we observed density oscillations in the time domain, and find that the long-wavelength particles provide a window to early times before the quench.
We discuss the possible implications of this principle for the cosmic microwave background. This work introduces a new quantum fluid based on light propagating in a hot atomic vapor, as cold as an atomic Bose-Einstein condensate.