Cosmic inflation, Quantum information and the pioneering role of John S Bell in Cosmology

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According to the theory of cosmic inflation, the large scale structures observed in our Universe (galaxies, clusters of galaxies, Cosmic Background Microwave - CMB - anisotropy …) are of quantum mechanical origin. They are nothing but vacuum fluctuations, stretched to cosmological scales by the cosmic expansion and amplified by gravitational instability. At the end of inflation, these perturbations are placed in a two-mode squeezed state with the strongest squeezing ever produced in Nature (much larger than anything that can be made in the laboratory on Earth). This article studies whether astrophysical observations could unambiguously reveal this quantum origin by borrowing ideas from quantum information theory. It is argued that some of the tools needed to carry out this task have been discussed long ago by J. Bell in a, so far, largely unrecognized contribution. A detailed study of his paper and of the criticisms that have been put forward against his work is presented. Although J. Bell could not have realized it when he wrote his letter since the quantum state of cosmological perturbations was not yet fully characterized at that time, it is also shown that Cosmology and cosmic inflation represent the most interesting frameworks to apply the concepts he investigated. This confirms that cosmic inflation is not only a successful paradigm to understand the early Universe. It is also the only situation in Physics where one crucially needs General Relativity and Quantum Mechanics to derive the predictions of a theory and, where, at the same time, we have high-accuracy data to test these predictions, making inflation a playground of utmost importance to discuss foundational issues in Quantum Mechanics.