Marie Curie ITN cQOM
Summary of the Scientific Achievements

Name of Fellow: Jie Li
Principal Investigator: David Vitali
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During the contract of my Marie Curie fellowship in the quantum optics group led by Prof. David Vitali at the University of Camerino, I have done four theoretical works, which I will briefly introduce in the following.

In the work J. Li et al, **New J. Phys. 17 (2015) 103037**, we investigate a general scheme for generating, either dynamically or in the steady state, continuous variable entanglement between two mechanical resonators with different frequencies. We employ an optomechanical system in which a single optical cavity mode driven by a suitably chosen two-tone field is coupled to the two resonators. Significantly large mechanical entanglement can be achieved, which is extremely robust with respect to temperature. As far as we know, this could be the best result, in terms of the degree of entanglement and its robustness against thermal noise, for achieving mechanical entanglement in optomechanical systems.

In the work S. Zippilli, J. Li, D. Vitali, **Phys. Rev. A 92, 032319 (2015)**, we use a similar technique mentioned above, i.e. a two-tone driving strategy, to generate steady-state entanglement in a chain of harmonic oscillators. To be specific, we show that a squeezed bath, simulated by quantum reservoir engineering with bichromatic drives that acts on the central element of a harmonic chain, can drive the whole system to a steady state featuring a series of nested entangled pairs of oscillators that, ideally, covers the whole chain regardless of its size. The scheme could be applied to many different physical systems.

In the work J. Li, et al, **arXiv:1508.00466** (now under review in PRL), we provide a simple procedure able to probe the hypothetical presence of the collapse noise with a levitated nanosphere in a Fabry-Perot cavity. Collapse models postulate the existence of intrinsic noise which modifies quantum mechanics and is responsible for the emergence of macroscopic classicality. Assessing the validity of these models is extremely challenging because, it is nontrivial to discriminate unambiguously their presence in experiments where other hardly controllable sources of noise compete to the overall decoherence. In our scheme, we show that the stationary state of the system is particularly sensitive, under specific experimental conditions, to the interplay between the trapping frequency, the cavity size, and the momentum diffusion induced by the collapse models, allowing to detect them even in the presence of standard environmental noises.

The last work by J. Li, A. Xuereb, N. Malossi, and D. Vitali is still on-going, which works on achieving very large optomechancial coupling in the membrane systems. We show that, due to the optical interference, extremely large optomechanical coupling of the membrane relative motion can be achieved when the two membranes are placed very close to a resonance of the inner cavity formed by the two membranes, and in the limit of highly reflective membranes. This work will be completed and submitted soon.

During the fellowship, I have also attended the following **workshops**:

1) The annual cQOM ITN workshop, held in Diavolezza, Switzerland, 1-5 Feb, 2015;
2) The workshop on "**Levitation in (quantum) physics**", held in Univ. of Vienna, 14-15 May, 2015.
3) The workshop on "**Non-interferometric Tests of the Quantum Superposition Principle**", held at International Centre for Theoretical Physics (ICTP), Trieste, Italy, 17-18 Sept, 2015. An invited talk was presented on testing collapse models using a levitated nanosphere system. The talk was based on the work, arXiv:1508.00466.

The **publications** and preprints I have achieved during the fellowship are listed as follows:

1) J. Li, I. Moaddel Haghighi, N. Malossi, S. Zippilli, and D. Vitali. *Generation and detection of large and robust entanglement between two different mechanical resonators in cavity optomechanics*. **New J. Phys. 17 (2015) 103037**.
   http://iopscience.iop.org/article/10.1088/1367-2630/17/10/103037/meta

2) S. Zippilli, J. Li, and D. Vitali. *Steady-state nested entanglement structures in harmonic chains with single-site squeezing manipulation*. **Phys. Rev. A 92, 032319 (2015)**.
   http://journals.aps.org/pra/abstract/10.1103/PhysRevA.92.032319

3) J. Li, S. Zippilli, J. Zhang, and D. Vitali, *Discriminating the effects of collapse models from environmental diffusion with levitated nanospheres*. **arXiv:1508.00466**. Under review in PRL.
   http://arxiv.org/abs/1508.00466

At last, I have also conducted a teaching activity. I gave a 60 hours course on "**University Physics**" (textbook by Philip R. Kesten and David L. Tauck, English version, edition 2014) to first- and second-year undergraduate students in a cooperative teaching programme between Univ. of Camerino and a Chinese university in Jilin, 9 March-15 April, 2015.