Rotating and Spiralling Optomechanical Cavity Solitons

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Optomechanical forces in a cloud of cold atoms under the action of a coherent beam of light lead to self-structuring in single mirror feedback configurations [1] and optical cavities (see left panel in Fig. 1) [2]. Orbital angular momentum (OAM) in the input laser beam can induce rotational dynamics and atomic transport in the transverse light-atom structures [3,4]. Here we consider an optical cavity containing a thermal cloud of two-level atoms at constant low temperature T where the atomic motion is overdamped by means of optical molasses beams. In this regime, the medium dynamics is described by a Smoluchowski equation describing the dipole force and spatial diffusion for an atomic density distribution $n(\boldsymbol{r},t)$ where t is the time and $\boldsymbol{r}$ is in the plane perpendicular to the direction of propagation. This equation is coupled to that of an electric field $\mathcal{E}(\boldsymbol{r},t)$ propagating inside a ring cavity under the action of the external pump $\mathcal{E}_0(\boldsymbol{r})$ (left panel in Fig. 1).

We identify parameter regions where the regular transverse patterns of hexagonal shape in both the light intensity and the atomic density are bi-stable with homogeneous states. Here optomechanical cavity solitons corresponding to peaks in both the light intensity and the atomic density are stable solutions of the coupled system [2]. When the input laser beam contains OAM, we observe that the optomechanical cavity solitons rotate in the azimuthal direction (central panel in Fig. 1) and even spiral down towards the centre of the optical beam if the pump contains a radial phase with a convex profile (right panel in Fig. 1). We can then demonstrate controlled atomic transport in localised wave-packets corresponding to the rotating and spiralling solitons.

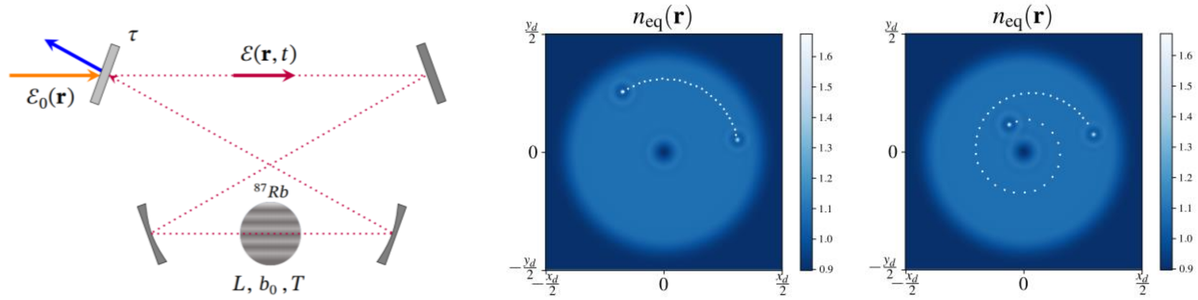

Fig. 1 Left panel: ring cavity configuration of a cloud of cold atoms under the action of an external laser beam blue detuned to the atomic resonance. Central panel: a cavity soliton in atomic density rotating around the beam centre in the presence of a pump carrying OAM. Right panel: same as the central panel but showing spiral motion of the cavity soliton in the presence of a convex profile in the radial phase of the pump.

The spiral motion of the cavity solitons towards the beam centre can be used to induce cavity soliton interactions leading to possible bound-states, merging and annihilations [5]. Optomechanical cavity solitons in a new phase of the system characterised by honeycombs in the light intensity and hexagonal peaks in the atomic density [6] are also investigated. Note that transitions from hexagonal to honeycomb intensity patterns do not rely on the vicinity of plane-wave optical bi-stability but are related to the transport character of the cold atom nonlinearity. Our multiple configurations of atomic transport of localised density wave-packets allow the operator to design and control new methods for the study of the interaction of cold atoms trapped in optical cavities.

References

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This is an accepted author mansuscript of the following confernece contribution: Baio, G., Robb, G. R. M., Ackemann, T., Yao, A. M., & Oppo, G-L. (2021). Rotating and spiralling optomechanical cavity solitons. In 2021 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC) [9542508] IEEE. https://doi.org/10.1109/CLEO/Europe-EQEC52157.2021.9542508