Synchronization In Non Dissipative Optical Lattices

D. Hennequin, P. Verkerk
Laboratoire PhLAM, Bat. P5 - Université Lille1, FRANCE
daniel.hennequin@univ-lille1.fr

Optical lattices are one of the most efficient tools to manipulate cold atoms, by tuning or adjusting parameters such as the mesh and height of the sites (atom confinement, atomic density), or the lattice geometry. They became a toy model in many fields. When they strongly interact, cold atoms in optical lattices offer deep similarities with condensed matter systems. They allowed to observe the superfluid-Mott insulator quantum phase transition, the Tonks-Girardeau regime, and more generally the superfluidity properties, including the instabilities.

On the other hand, interesting behaviors are also found in noninteracting systems. In particular, cold atoms in optical lattices made possible the observation of the transition between Gaussian and power-law tail distributions, in particular the Tsallis distributions. They also allowed the observation of Anderson localization. They also appear to be an ideal model system to study the dynamics in the classical and quantum limits. In non dissipative optical lattices, both the classical and the quantum situations are experimentally accessible, and it is even possible to change quasi continuously from a regime to the other. Moreover, the extreme flexibility of the optical lattices makes it possible to imagine a practically infinite number of configurations by varying the complexity of the lattice and the degree of coupling between the atoms and the lattice. Many results have been obtained during these last years in the field of quantum chaos, mostly using very simple potentials, mainly 1D. For example, chaos is obtained only with a periodic (or quasi-periodic) temporal forcing of the amplitude or frequency of the lattice, and only the temporal dynamics of the individual atoms is studied.

Recently, it appeared necessary to introduce more complex potentials, in particular 2D potentials. Although the dynamics of particles in 2D potential has been extensively studied in the past, it was mainly in model potentials. Experimental optical lattices approach these models at best on a limited domain, at the bottom of the wells. But in most cases, the potential is more complex, and leads to a more complex and richer dynamics. Understanding accurately the classical dynamics of atoms in real potentials is important, in particular because it has significant consequences in the corresponding quantum systems.

The most common approach for the study of complex dynamics in conservative systems is statistical, e.g. evaluating the percentage of the chaotic area in the phase space. However, a more deterministic approach is possible, as in dissipative systems. In a recent study, the dynamics of atoms in different 2D conservative optical lattices were studied and different types of chaotic dynamics were observed, leading to different macroscopic behaviors. It was shown in particular that the lifetime of atoms in the lattices depend drastically on their dynamics.

In a lattice resulting from the interference of 2 orthogonal pairs of counter-propagating stationary waves. The mesh is a square, and the two directions in space are strongly coupled. Therefore the dynamics is expected to be fully chaotic when anharmonicity is high enough, i.e. for high enough energy of the atoms. This fully chaotic regime is effectively observed, except when the lattice is red detuned as compared to the atomic transition. In this case, chaos disappeared almost completely, and the dynamics remains essentially quasiperiodic, although the nonlinearities are the same.

We try to understand here the mechanisms inhibiting appearance of chaos. We show that at the bottom of the wells, the resonance frequencies in both directions are degenerate, but when the atom energy increases, this degeneracy should obviously disappear because of the anharmonicity of the potential. However, we show that the motions in both directions remain locked to the same frequency on a large domain, following a synchronization mechanism close to the frequency locking process of dissipative systems. Because of the conservation of energy, it is not a strict frequency locking, but the quasiperiodic regime appears to be mainly a frequency locked periodic regime with small sidebands. Even when the edges of the wells are approached, chaos appears very marginally, in a regime where the frequencies remain locked. This synchronization, not as strict as that of a dissipative system, is nevertheless a mechanism powerful enough to explain that chaos cannot appear in such conditions.