# Graphene induced exotic time crystalline phases of hybrid nano-mechanical resonator modes

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Discrete Time Crystal (DTC) is a stable dynamic phase of a many-body system, when system oscillates at a frequency which is not same as frequency of the Hamiltonian of the system. We report observation of Classical Discrete Time Crystal (c-DTC) in naturally occurring mechanical modes of a graphene-silicon nitride hybrid nano electro-mechanical system (NEMS). We observe collective transition of the system from non-crystalline structure to different crystalline phases: subharmonic, anharmonic or a novel biharmonic phase. We model this system using two coupled nonlinear oscillators. This coarse-grained minimal model provides understanding of the nature of these phases and more importantly phase transitions. These observations and results provide initial steps towards spectral categorization of naturally occurring DTC phases, thereby developing a dictionary (between interacting modes and spectral signatures), akin to what has been achieved in solid state crystallography. Furthermore, such categorized DTC phase can also be used as unique spectral identities for a broad range of applications in information technology or as sensors for small seed perturbations.

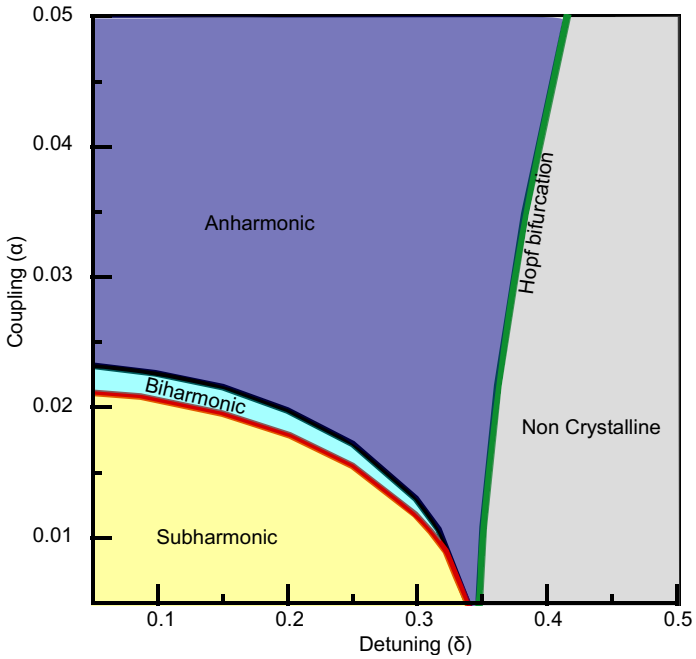


Figure 1: Different time-crystalline phases in parameter space.

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