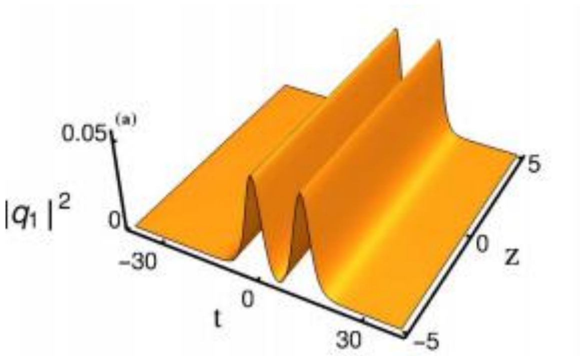
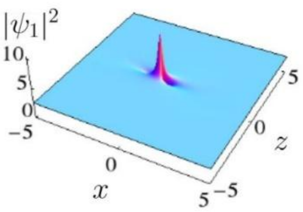
Major Research Areas

Soliton in Physical and Biological Systems



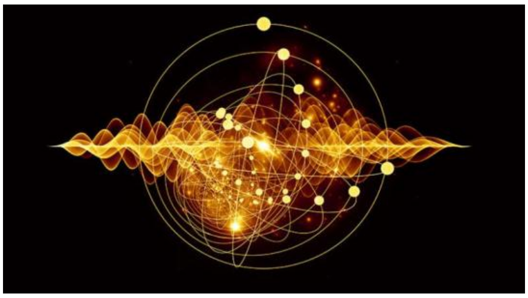
Soliton, an interesting localized coherent object found as a solution of certain class of nonlinear evolution equations of dispersive type. These solitons explain a variety of interesting physical phenomena including optical communication through nonlinear optical fibers, spin dynamics in ordered magnetic systems, switching dynamics in nanostructured ferromagnetic films, and multi-layered structures, electromagnetic wave propagation in ferromagnetic and dielectric media, molecular reorientation in liquid crystals, energy transfer in biologically important macromolecules such as protein and DNA. The above problems are being studied in depth theoretically both at the analytical and numerical levels in the case of bulk systems, in films at the nanoscale, chains and wires, and efforts are made to match the outcome with experiments. Also studies on the understanding of coherent structures in (2+1) and (3+1) dimensional nonlinear dispersive systems of physical interest, modeling, analysis and simulation of wave systems including ocean waves, tsunami and seismic waves, developing new applications of soliton propagation in nonlinear optical media and classical computation via shape changing soliton collisions and chaos and connection to quantum computation are being undertaken.

Rogue waves



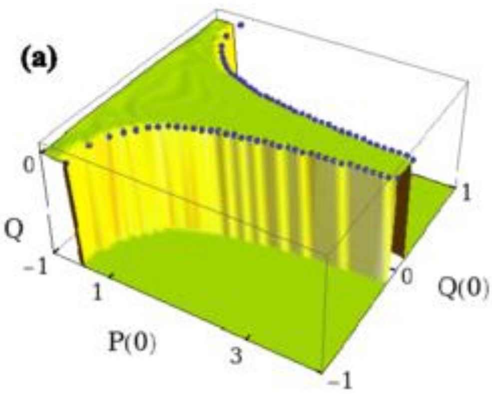
Rogue waves are large amplitude waves occasionally appearing in the ocean which are capable of having disastrous effects on oil tanks and cruise ships. A well known description of an rogue wave is that it appears from nowhere and disappears without a trace. Recently efforts have been made to explore the rogue wave excitation through “nonlinear process”. We are carrying our theoretical investigations on the formation of rogue waves and analyze their structures. We also investigate matter rogue wave solutions of the Gross-Pitaevski equation and study their dynamical evolutions. We investigate the integrability properties of a family of generalized two component nonlinear Schrödinger equation as well.

Quantum Solvable systems and entanglement



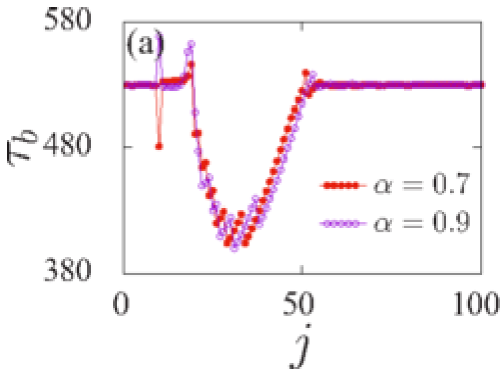
Solving position dependent mass systems is one of the interesting research areas in quantum mechanics. Quantizing such position dependent mass quantum systems is one of the challenging problems since the associate Hamiltonian is usually of non-standard type. We are quantizing certain non-standard Hamiltonians associated with Liénard type nonlinear oscillators. We use von-Roos symmetric ordering procedure to write down the appropriate quantum Hamiltonian. We solve the underlying Schrödinger equation and obtain eigenvalues and eigenfunctions of a class of nonlinear oscillators. We investigate the order ambiguity problem of a class of position dependent mass quantum systems. Further, we construct criteria to detect the entanglement in bipartite states using non-Hermitian operators and develop to identify the non-k-separability in Greenverger-Horne-Zeilinger, W and Dicke classes of multipartite states using elements of density matrices.

PT-Symmetric Systems



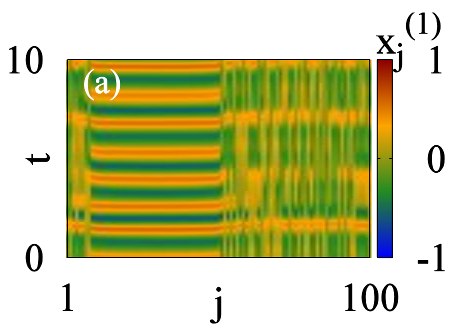
Considerable interest has been shown ininvestigating systems which do not show parity (P) and time-reversal (T) symmetries separately but which exhibit a combined PT symmetry. Studies have been made on the dynamics corresponding to their counterparts in mechanical and optical systems. We have unearthed the occurrence of spontaneous symmetry breaking phenomenon in such systems and studied their possible applications. Importantly, we have focused on the application of spontaneously symmetry broken states of optical PT symmetric systems over unidirectional light transport. We have investigated on the remedies to overcome these two possible demerits in applying usual PT symmetric systems for the latter application, namely, (i) in balancing loss and gain of the system (ii) in controlling the blow-up response of the system. Our studies and results also highlight the role of nonlinearities over PT symmetric systems.

Bifurcation Theory



Bifurcation is the change in dynamics of the system with respect to the change in the values of a control parameter. Study of dynamical systems with slowly varying control parameters has been continued to be an active topic of research due to the strong relevance with many natural phenomena. For instance, the weight of a rocket in flight slowly decreases due to the burning of fuel and improves the speed of the rocket, catalytic activities in chemical reactors slowly decline due to chemical erosion and decrease the reactor performance catastrophic transitions, regime shift, drought, extreme precipitation and flooding occur because of the bifurcation in the system which depends on the time-dependent parameter as well as the velocity of the parameter variation. To understand the emergence of above said natural phemomena, one has to understand the bifurcation scenario of the natural system, which required a deep knowledge about the parameter variation. Aprofound research has been made and is in progress to study many aspects associated with this phenomenon for natural and physical systems.

Chimera States

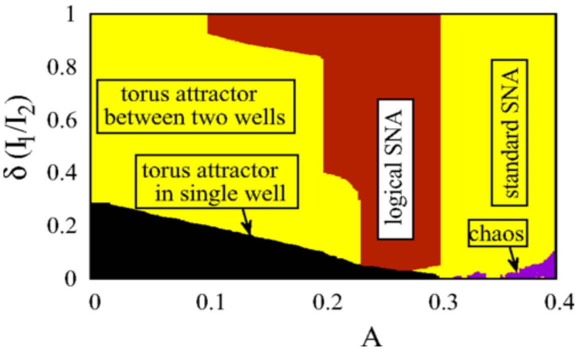


Chimera state represents an intriguing phenomenon in a dynamical network of coupled elements, which spontaneously separates into two coexisting domains with dramatically different behavior. They occur, surprisingly, in networks of identical units and symmetric coupling schemes. Such a remarkable phenomenon was initially found in nonlocally coupled identical oscillators. It has been subsequently studied in globally as well as locally coupled oscillator networks, planar oscillators, heterogeneous networks, oscillators with more than one population, two-dimensional map lattices, and experimentally in chemical oscillators, an optical system, electrochemical, and coupled mechanical oscillators. Owing to the strong resemblance of chimera states with real world applications, investigation around the chimera states is even more important due to the strong relevance of such states with many natural phenomena including unihemispheric sleep of certain mammals and birds where one brain hemisphere appears to be inactive while the other remains active, ventricular fibrillation (one of the primary causes of sudden cardiac death in humans), blackouts of power grid networks, social systems (organization of coupled populations), neural systems (firing patterns of neurons, coordinated and uncoordinated brain activity, etc.), and so on. Substantial amount of research has been made and is in progress to explore chimera states and various other coupled dynamical states in networks of physical and biological oscillators.

<u>Neuronal Dynamics</u>

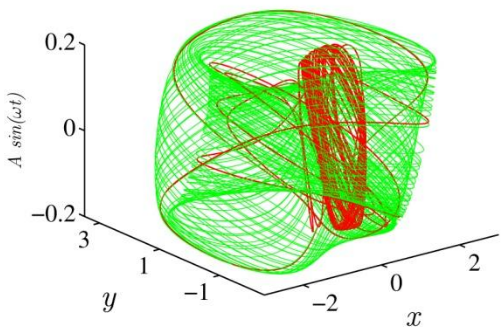
Neuronal dynamics is one of the contemporary research areas and developing branch in the field of nonlinear dynamics. Profound research in this field helps us to understand some basic mechanisms of brain such as language learning, attention, memory, decision making and many other cognitive functions.Neurons are cells specialized for the integration and propagation of electrical events. It is through such electrical activity that neurons communicate with each other as well as with muscles and other end organs. Therefore, an understanding of basic electrophysiology is fundamental to appreciating the function and dysfunctions of neurons, neural systems, and the brain. Further,understanding brain is possible by considering each neuron as an individual oscillator which bursts voltage periodically. To explain this mechanism several models have been proposed in the literature. To name a few we cite Hodgkin-Huxley model, FitzHugh-Nagumo model, Hindmarsh-Rose model, Integrate and fire model. All these models serve to be paradigmatic. A typical human brain consists of several million neurons, hence its functions can be understood only by studying the collective behaviour of networks of neurons.We have been systematically exploring collective dynamical states in such one, two and three dimensional networks of neuronal oscillators. Further our research focusses in exploring the dynamical aspects of single as well as collective neurons both computationally and experimentally by electronics implementation.

Chaotic Computing



Strange nonchaotic attractors (SNAs) are attractors whichpossess fractal geometry but exhibit no sensitive dependenceon initial conditions.Experimental observations of SNAs have been reported in a quasiperiodicallydriven magnetoelastic ribbon system, in electronic circuits, in a plasma system, in an electrochemical cell, and in a system near the torus-doubling critical point.Physically, SNAs are relevant to situations such as localization of quantum particles in spatially quasiperiodic potentialsystems.Quasiperiodically driven nonlinear systems exhibit strange nonchaotic attractors (SNAs) to deterministic input signals.If one uses two square waves in an aperiodic manner as input to a quasiperiodically driven double-well Duffing oscillator system, the response of the system can produce logical output controlled by such a forcing.The interplay of nonlinearity and quasiperiodic forcing yields logical behavior, and the emergent outcome of such a system is a logic gate. This proves that SNA is an efficient tool for logical computations. Our research is mainly focused on investigating the logical behaviour of SNA of several nonlinear systems and effect of noise in logical computations.

Extreme Events



Studies on extreme events received notable attention in the past few decades owing to their catastrophic impact on nature and society. These events are occurring in an unexpected way, which causes disastrous consequences. The understanding and predicting of extreme events would have a considerable impact on society such as droughts, floodings, financial crisis, seasonal changes and climate forecasting to agriculture. We have studied the emergence of extreme and superextreme events in different dynamical systems.Besides, we paid notable attention to its dynamical origins, generating mechanism and different transitions. From the application point of view, we explore some possible prediction techniques of extreme events using early warning signal measurements.

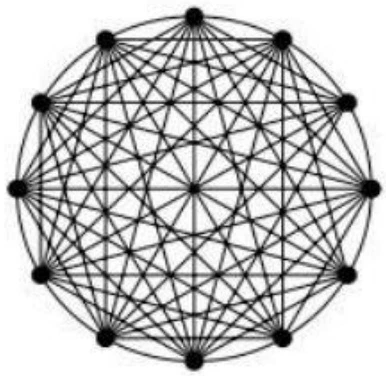
Quantum Cosmology

Cosmological models are considered due to the highly nonlinear nature of their evolution equations. In particular, we focus on quantum cosmology field models. We investigate these models from the symmetry analysis perspectives. Recently quantum cosmology for the non-minimally coupled scalar field cosmological model in Friedmann-Lemaître-Robertson-Walker (FLRW) geometry has been studied from the symmetry analysis point of view. The corresponding Wheeler-DeWitt (WD) equation is constructed on the two dimensional Lorentzian Manifold. The corresponding nature of solution of WD equation has been analyzed.

Symmetry Breaking

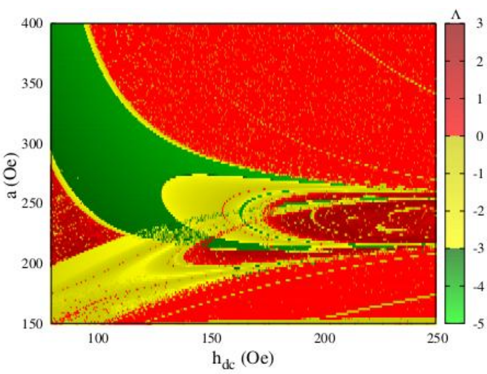
Symmetries are the most fundamental properties of the nature and are responsible for many physicalphenomena. Several natural systems including physical, chemical and biological systems can bemathematically modeled using ordinary and partial differential equations. Interesting phenomena canbe observed even when the symmetries present in the systems are broken either spontaneously orexplicitly. This type of symmetry breaking in the dynamical systems leads to rich variety of collectivedynamical states. In our recent research we have manifested the role of symmetry breaking in theformation of complex patterns in coupled systems and networks where these studies find applications inoptical systems. Importantly, we have shown that the occurrence of spontaneous symmetry breaking invarious optical and mechanical PT - symmetric systems and studied their applications. We have studied the nature of collective dynamical states in long range interacting system of globally coupled Stuart-Landau limit cycle oscillators with repulsive coupling and symmetry breaking coupling and identified a swing of synchronized states. We have also studied the existence of amplitude mediated imperfect chimera states in nonlocally coupled limit cycle oscillator networks. We have further identified quenched oscillations in conjugate coupling induced symmetry breaking oscillator system.

Collective Motion in Coupled Nonlinear Systems



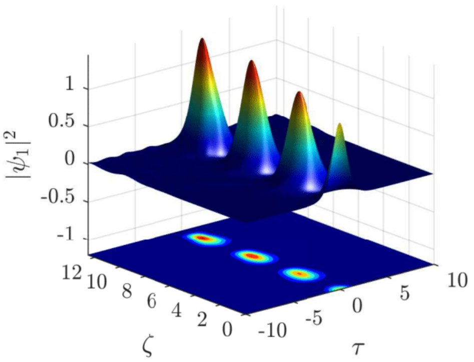
Generally, dynamical systems are rarely isolated, which can be well understood through coupled oscillators. When the oscillators are coupled, they have the capability to exhibit a unique and wide variety of phenomena namely dynamical synchronization, enhancing stochastic, vibrational and coherent resonance, inducing system size resonance, chimera state, amplitude death, signal amplification, signal transmission, quenching of oscillators and so on. Nevertheless, all these structures are dependent upon the nature of coupling and local dynamics of individual systems. In addition to these, a rich variety of other collective behaviors such as clusters with phase-flip transition, conventional chimera, solitary state and complete synchronized state which have been identified using different coupling architectures. Also, the symmetry breaking in such systems leads to an increased disorderliness in the dynamical behavior of oscillatory states and consequently results in a rich variety of dynamical states. Depending on the strength of the nonisochronicity parameter, we find various dynamical states such as amplitude chimera, amplitude cluster, frequency chimera, and frequency cluster states. In addition have also finddisparate transition routes to recently observed chimera death states in the presence of symmetry breaking even with global coupling.

Magnetization reversal and Spin-Torque Nano Oscillators (STNOs)



In spin-valve nanostructure the reversal and oscillation of magnetization of the free layer due to spin-transfer torque has immense applications such as Magnetic Random Access Memory(MRAM) and submicrowave generation respectively. The mismatch created between the direction of the spin of charge carriers polarized by the pinned layer and magnetic moments in free layer exerts a torque on the magnetization of the free layer, called spin transfer torque. We found that exploiting spin-polarized current to switch the magnetization of the ferromagnetic layer in spin-valve is more advantageous than using magnetic field. We demonstrated further that the short pulse of spin-polarized current can be employed for switching. We have numerically studied the existence of periodic, multiply periodic and chaotic behaviors in spin-valve systems due to the periodic applied magnetic field in the presence of constant spin current and external magnetic field. The synchronization of multiple STNOs is important in order to create more power in microwave generation. We have studied the possibilities of in-phase and anti-phase synchronized oscillation induced by common periodic applied magnetic field, in addition to the dc spin current and magnetic field, in physically uncoupled STNOs. Also we have found the synchronized oscillation in serially connected/coupled STNOs due to the applied ac magnetic field through macromagnetic simulation. We identify the regions of synchronization in parameter space where the coupled STNOs can produce more power and also that the common oscillating magnetic field is advantageous than oscillating spin current for serially connected STNOs. Recently, we study the synchronization behavior, locking characteristics and removal of multi-stability in serially and parallelly coupled STNOs by ac/dc magnetic field and spin current. We further extend our studies by introducing the time-delay.

Nonlinear optics



Nonlinear optics is the study of how intense light interacts with matter in Kerr like (nonlinear) medium. The optical response of a material usually scales linearly with the amplitude of the electric field. Nevertheless, at high input powers, the refractive index of the material can change more rapidly leading to many nonlinear effects including self-phase modulation, higher order harmonic generation and solitons. In particular, after the discovery of optical solitons, the optical communication system can lead to high bit-rate transport employing the optical solitons as the potential candidates. To this end, all-optical integrated devices including switching and memory devices using solitons are at the maximum exploration. As a vital contribution, we theoretically demonstrate soliton steering in nonlinear coupled dimers exploiting parity-time symmetry in a form of equal gain and loss. We show that if the length of the PT-symmetric system is set to 2π, contrary to the conventional one that operates satisfactorily well only at the half-beat coupling length, the PT dimer remarkably yields an ideal soliton switch exhibiting almost 99.99% energy efficiency with an ultralow critical power, which in turn can make powerful integrated components even with the inclusion of material absorption.