International Workshop on Rogue Waves

Innovation Building E100

University of Vermont, Burlington, USA

Workshop Schedule

Dec. 17, 2022

Time	Speaker	Talk Title	Format
9:00 - 9:30	Dudley	Recent advances understanding rogue waves and analogies in nonlinear fibre optics	online
9:30-10:00	Chow	Fermi-Pasta-Ulam-Tsingou Recurrence, Breathers, Cascading Mechanism and Rogue Waves	online
10:00-10:30	J.S. He	New localized solutions in the Davey-Stewartson equation	online
10:30-11:00	Coffee Break		
11:00-11:30	Ling	Elliptic-rogue waves in nonlinear soliton equations	online
11:30-12:00	Slunyaev	Coherent groups in stochastic sea waves	online

12:00-13:30 Lunch

Time	Speaker	Talk Title	Format
13:30-14:00	Ohta	Interaction of rogue waves	in-person
14:00-14:30	Buckingham	Universality of High-Order Rogue Waves	in-person
14:30-15:00	Genash	Complex interactions of breathers	online
15:00-15:30	Coffee Break		
15:30-16:00	Bilman	High-Order Rogue Waves and Solitons, and Solutions Interpolating Between Them. Part I: Universal Features	online
16:00-16:30	Miller	High-Order Rogue Waves and Solitons, and Solutions Interpolating Between Them. Part II: Distinctive Features	online
16:30-17:00	Kevrekidis	Some Case Examples of Existence, Stability and Dynamics of Rogue Wave Patterns	in-person
17:00-17:30	Akhmediev	Waves that appear from nowhere	online

19:00-21:00 Dinner

Dec. 18, 2022

Time	Speaker	Talk Title	Format
9:00 - 9:30	Chabchoub	Extreme Waves in Counter-Propagating Wave Fields	online
9:30-10:00	Clarkson	Special polynomials associated with Painleve equations	online
10:00-10:30	B. Yang	Universal rogue wave patterns associated with the Okamoto polynomial hierarchy	online
10:30-11:00	Coffee Break		
11:00-11:30	J.C. Chen	Rogue waves in the massive Thirring model	online
11:30-12:00	Baronio	Quadratic Rogue Waves Resonantly Radiating Without Higher Order Dispersions	online

12:00-13:30 Lunch

Time	Speaker	Talk Title	Format
13:30-14:00	Feng	Rogue waves and their patterns in the vector nonlinear Schrodinger equation	in-person
14:00-14:30	Cole	Transverse instability of Peregrine rogue waves	online
14:30-15:00	Pelinovsky	Periodic waves in the discrete MKDV equation: modulational instability and rogue waves	in-person
15:00-15:30	J. Yang	Partial-rogue waves that come from nowhere but leave with a trace	in-person

Book of Abstracts

Recent advances understanding rogue waves and analogies in nonlinear fibre optics

John M. Dudley

Institut FEMTO-ST, Université Bourgogne Franche-Comté CNRS UMR 6174, Besançon, France

In 2007, experiments studying noise in optical supercontinuum generation suggested that instabilities observed in nonlinear optical fibre propagation could be analogous to hydrodynamic rogue waves. This proposal was greeted with great interest in both the optics and hydrodynamics communities, but it soon became apparent that establishing such an analogy rigorously would require a great deal of additional work. After giving a general overview of the progress made over the last 15 years, we will describe recent developments, and in particular the use of tools from artificial intelligence such as neural networks and sparse regression to yield new insights into complex nonlinear rogue wave dynamics in optics. The talk will present both numerical and experimental results. This work has been carried out together with: M. Mabed, A. Ermolaev, C. Lapre (Université Bourgogne Franche-Comté FEMTO-ST); F. Meng (Jilin University ICB); A. Sheveleva, C. Finot (Université Bourgogne Franche-Comté); and G. Genty (Tampere University).

Fermi-Pasta-Ulam-Tsingou Recurrence, Breathers, Cascading Mechanism and Rogue Waves

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The Fermi-Pasta-Ulam-Tsingou recurrence (FPUT) broadly describes special tendency of a multi-mode nonlinear system to return to its initial states after complex stages of evolution. Realization in hydrodynamic wave channels occurred in the 1970s. In 2000s and 2010s, cycles of FPUT have been observed using optical waveguides. Both settings utilize the nonlinear Schrödinger equation as a model. A 'cascading mechanism' has been proposed recently to elucidate FPUT. The modulation instability of a small amplitude, fundamental frequency disturbance has been studied intensively. Higher order harmonics exponentially small initially will nevertheless grow at a larger rate. Eventually, all such modes attain roughly the same magnitude at one instant in time. A breather is formed. Subsequently, the breather decays. Modulation instability resumes at sufficiently small amplitude and the cycle is repeated, leading to FPUT. Here theoretical analysis is performed on many other 'integrable' systems, e.g., the Hirota equation, the coherently coupled nonlinear Schrödinger equations and the discrete Ablowitz-Ladik system. Applications to fluid mechanics and optics will be discussed. (Partial financial support has been provided by the Research Grants Council contract HKU17204722. This work is a joint effort with Dr. H. M. Yin of the University of Hong Kong.)

New localized solutions in the Davey-Stewartson equation

Jingsong He

Institute for Advanced Study

Shenzhen University, P. R. China

It is well-known that there are two kinds of Davey-Stewartson (DS) equation, i.e, DSI and DSII, for different physical settings. In this talk, we will provide genuine two-dimensional rogue wave solution expressed by a rational form for the DSII. For the DSI, we shall present that the higher-order lump solutions undergo a large scattering angle after a head-on collision, localized rogue wave and line rogue wave on a solitonic background. Moreover, we will also show two kinds of doubly localized two-dimensional rogue wave, i.e., the line segment and lump-type rogue wave, for the Davey-Stewartson I equation in the background of dark solitons or a constant. The first two results are constructed by Darboux transformation, but the third is given by the Hirtoa method. The main contents of the talk have been published in three papers joint with several co-authors: Physical Review Research 2(2020) 033376 (2020); Physical Review E 105 (2022) 014218 (2022), and Journal of Nonlinear Science3 1 (2021) 67.

Elliptic-rogue waves in nonlinear soliton equations

Liming Ling

South China University of Technology, China

Abstract:

In this talk, we would like to introduce the general elliptic-rogue waves for the NLS, mKdV and sine-Gordon equation with the aid of Darboux-Backlund transformation and theta functions. It is very interesting that the fundamental elliptic-rogue waves can be represented by a rational form in terms of the theta and Zeta functions. Furthermore, the baseband modulational analysis for elliptic waves is performed to interpret the physical meaning of these elliptic-rogue waves. (This work is joint with my Ph.D. student Xuan Sun)

Coherent groups in stochastic sea waves

Alexey Slunyaev

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National Research University Higher School of Economics, Nizhny Novgorod, Russia
V.I. Il'ichev Pacific Oceanological Institute, FEB RAS, Vladivostok, Russia

Nonlinear coherent wave groups in deep water and their manifestation in irregular sea surface waves are discussed. The emergence of coherent structures leads to large values of the dynamic kurtosis, longer extreme events, large deviation from the dispersion relation. These wave structures may be described in terms of envelope solitons of the nonlinear Schrodinger equation even when the groups contain just a few wave cycles of very steep waves. This relation provides clues for constructive description of the complicated nonlinear wave dynamics. In particular, soliton-type wave group content can be revealed using the proposed Windowed Inverse Scattering Technique. According to the direct numerical simulation of hydrodynamic equations, the specific effects start to appear at relatively small values of the Benjamin–Feir index. The hydrodynamic envelope solitons can persist for dozens of wave periods and longer, and greatly increase the probability of rogue wave occurrence. Most of extreme waves occur on top of the coherent groups.

The research is supported by the RSF grant No 22-17-00153.

Some recent references

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Interaction of rogue waves

Y. Ohta

Kobe University, Japan

Since the rogue waves are localized in time and often in space also, it is naturally expected that they do not interact each other unless they are closely located in space-time. We study the interaction between rogue waves in close distance by taking simple examples of superposition of rogue wave solutions.

Universality of High-Order Rogue Waves

Robert Buckingham

University of Cincinnati, USA

We will discuss a series of recent results indicating that high-order rogue-wave behavior is universally described for a variety of different equations and initial conditions by a family of functions connected to the Painleve-III hierarchy and first encountered by Suleimanov in 2017. This is joint work with Deniz Bilman, Bob Jenkins, and Peter Miller.

Complex interactions of breathers

Andrey Gelash

Laboratoire Interdisciplinaire Carnot de Bourgogne (ICB)

CNRS-Université Bourgogne Franche-Comté, Dijon, France

We present our recent theoretical advancements in the description of complex multiple nonlinear interactions of coherent solitary wave structures on unstable background - breathers. We also show experimental data obtained by our colleagues in a nearly conservative optical fiber system. As a theoretical model, we use the focusing one-dimensional nonlinear Schrödinger equation. First, we discuss the theoretical description and experimental observation of the nonlinear mutual interactions between a pair of copropagative breathers - breather molecules [1]. As a general case, we show that the resulting bound state of breathers exhibits moleculelike behavior with quasiperiodic oscillatory dynamics. At the same time, for specific commensurate conditions, the molecule oscillations become precisely periodic. Then we derive general analytical expressions describing the space-phase shifts that breathers acquire after collisions with each other [2]. Based on these expressions, we propose a general approach to manage multiple interactions of breathers [3]. The breather management approach allows adjusting the initial positions and phases of more than two moving breathers to observe various desired wave states at controllable moments of wave evolution. As proof-of-principle, we consider a couple of separated pairs of breathers initially synchronized in small-amplitude patterns. We obtain an explicit expression for the separation interval between the pairs so that the interactions of the breathers from the neighboring patterns lead to the formation of an extreme amplitude (rogue) wave or recurrence to the initial small-amplitude state. Experiments carried out on a light wave platform with a nearly conservative optical fiber system accurately reproduce the predicted dynamics and prove the viability of our nonlinear wave theory.

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High-Order Rogue Waves and Solitons, and Solutions Interpolating Between Them

Part I: Universal Features

Deniz Bilman

University of Cincinnati, USA

Abstract:

It is known from our recent work that both fundamental rogue wave solutions (with Peter D. Miller and Liming Ling) and multi-pole soliton solutions (with R. Buckingham) of the nonlinear Schrödinger (NLS) equation exhibit the same asymptotic behavior in the limit of large order in a shrinking region near the peak amplitude point, despite the quite different boundary conditions these solutions satisfy at infinity.

In this work, we place solitons and rogue wave solutions in a single continuum family of solutions of the NLS equation parametrized by a nonnegative real parameter M, whose different quantizations give rogue waves and solitons, in which case M becomes correlated with the order of these special solutions. We show that the above-mentioned similar asymptotic behavior in fact extends to a large region of the space-time, expanding in size as M→+infinity at a rate proportional to M. Within this region, the large-M asymptotic behavior of solutions is rather insensitive to any particular choice of specific unbounded and increasing sequence of values of M. This is joint work with Peter D. Miller.

High-Order Rogue Waves and Solitons, and Solutions Interpolating Between Them

Part II: Distinctive Features

Peter Miller

University of Michigan, USA

Abstract:

We show how rogue waves and solitons of arbitrary orders can be placed within a common analytical framework in which the "order" becomes a continuous parameter, allowing one to tune continuously between types of solutions satisfying different boundary conditions. In this scheme, solitons and rogue waves of increasing integer orders alternate as the continuous order parameter increases. For example, the Peregrine solution can be viewed as a soliton of order three-halves. As described in the previous talk by Deniz Bilman, in a bounded region of the space-time of size proportional to the order, these solutions all appear to be the same when the order is large. However, in the unbounded complementary region one sees qualitatively different asymptotic behavior along different sequences. In this talk we focus on the behavior in this exterior region. The asymptotic behavior is most interesting for solutions that are neither rogue waves nor solitons. This is joint work with Deniz Bilman.

Some Case Examples of Existence, Stability and Dynamics of Rogue Wave Patterns

Panos Kevrekidis,

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Abstract.

In the present work, we revisit a central paradigm of the analysis of rogue waves in nonlinear Schrodinger (NLS) equation systems, namely the Peregrine soliton. We examine how relevant patterns can be numerically extended to non-integrable variants of the NLS model, such as the general power-law nonlinearity, the third-order dispersion model, or a nonlocal variant of the NLS. We discuss how to think of the Peregrine solution as a self-similar waveform in space-time. We also examine generalizations of such waveforms in higher-dimensional models such as ones of the Davey-Stewartson type in 2+1 dimensions. Subsequently, we turn our attention to stability of periodic states such as the Kuznetsov-Ma soliton and consider information that these provide us in the limit (of infinite period) about the Peregrine solution stability in both continuum and discrete NLS-type models. A number of applications of the Peregrine states and their appearance are considered in continuum (e.g., Bose-Einstein multi-component condensates) and discrete (e.g., granular crystal) settings. Finally, time permitting, an entirely distinct mechanism of potential rogue structure formation in dissipative lattice nonlinear dynamical systems will also be proposed.

Waves that appear from nowhere

N. Akhmediev
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Abstract:

Waves that appear from nowhere are waves that we do not expect. Due to the unexpected nature of these events, they are dangerous for people who experience them. Mathematically, this feature can be represented by the solutions of evolution equations that are localised both in time and in space. In addition, the amplitude of these waves are commonly higher than the amplitude of regular waves around. The latter feature increases the danger carried by these waves. There is a large variety of rogue waves in nature. Even if we restrict ourselves with oceanic waves, we have to take into account several types of them. Firstly, these are surface waves on the interface between water and air. Secondly, these are internal waves in the stratified media such as the ocean water with salinity that vary along the vertical direction. Shallow water waves are another type of waves that appear in coastal areas. Each type has to be described by its own evolution equation. Rogue wave solutions of these equations vary. Examples will be presented in this talk.

Extreme Waves in Counter-Propagating Wave Fields

Amin Chabchoub

Kyoto University, Japan, and University of Sydney, Australia

It is well-known that nonlinear wave focusing originating from the universal modulation instability (MI) is responsible for the formation of strong wave localizations on the water surface and in nonlinear wave guides, such as optical Kerr media and plasma. Such extreme wave dynamics can be described by exact breather solutions of the nonlinear Schrödinger equation (NLSE). That said, it has been suggested that the MI weakens when the wave field becomes either broadband or directional. In this talk, the role of nonlinearity in the formation of extreme events in counter-propagating wave systems will be highlighted. Experiments on breathers in standing and quasi-standing wave states will be discussed. All collected collinear wave measurements are in excellent agreement with the hydrodynamic coupled NLSE and suggest that MI can undisturbedly prevail during the interplay of several wave systems and emphasize the potential role of unsteady NLSE solutions in rogue wave formation beyond the formal narrow-band and uni-directional limits.

Special polynomials associated with Painleve equations

Peter Clarkson

University of Kent, UK

Abstract:

Rogue wave patterns have been associated with special polynomials that arise in the description of rational solutions to Painleve equations. These special polynomials are often written as wronskians of orthogonal polynomials. In this talk I'll discuss several of the special polynomials associated with Painleve equations.

Universal rogue wave patterns associated with the Okamoto polynomial hierarchy

Bo Yang
School of Mathematics and Statistics
Ningbo University, China

Abstract:

We show that new types of rogue wave patterns exist in integrable systems, and these rogue patterns are described by the root structures of the Okamoto polynomial hierarchy. These rogue patterns arise when the tau functions of rogue wave solutions are determinants of Schur polynomials with index jumps of three, and the internal free parameters in these rogue waves get large. We demonstrate these new rogue patterns in the Manakov system and the three-wave resonant interaction system. For each system, we derive asymptotic predictions of its rogue patterns under large internal parameters through the Okamoto polynomial hierarchy, and also verify such predictions by comparing them to the true solutions. This is joint work with Prof. Jianke Yang.

Rogue waves in the massive Thirring model

Junchao Chen

Lishui University, China

Abstract:

In this talk, I will talk about general rogue wave solutions in the massive Thirring (MT) model. These rational solutions are derived by using the KP hierarchy reduction method and presented explicitly in terms of determinants whose matrix elements are elementary Schur polynomials. In the reduction process, three reduction conditions including one index- and two dimension-ones are proved to be consistent by only one constraint relation on parameters of tau-functions of the KP-Toda hierarchy. It is found that the rogue wave solutions in the MT model depend on two background parameters, which influence their orientation and duration. Differing from many other coupled integrable systems, the MT model only admits the rogue waves of bright-type, and the higher-order rogue waves represent the superposition of fundamental ones in which the non-reducible parameters determine the arrangement patterns of fundamental rogue waves. Particularly, the super rogue wave at each order can be achieved simply by setting all internal parameters to be zero, resulting in the amplitude of the sole huge peak of order N being 2N + 1 times the background. Finally, rogue wave patterns are discussed when one of the internal parameters is large. Similar to other integrable equations, the patterns are shown to be associated with the root structures of the Yablonskii-Vorob'ev polynomial hierarchy through a linear transformation. This work is joint with Bo Yang and Bao-Feng Feng.

Quadratic Rogue Waves Resonantly Radiating Without Higher Order Dispersions

F. Baronio,

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Temporal solitons are known to spontaneously emit resonant (or Cherenkov) radiation (RR) when they become phase-matched to linear dispersive waves. As first recognized for silica fibers, phase-matching can be realized close to the zero of the group velocity dispersion (GVD) due to the contribution from higher-order dispersions (HODs) [1-3]. The RR emission has attracted great applicative interest in photonic crystal fibers as tunable source of coherent emission (see [4] for a review), up to the deep-UV region [5], and as a spectral broadening mechanism in supercontinuum generation [6]. RR phenomena emerge also in other settings involving four-wave mixing processes [7], wave-breaking [8], or manifest themselves as multiple peaks assisted by spatially periodic variations [9]. All the mentioned schemes rely on operating close to one or more points of zero GVD where the role of HOD becomes essential.

Here we show that a completely different mechanism can take place, where the RR is emitted, in a quadratic medium, *without any contribution from HOD*. Specifically, we predict that two-color Peregrine solitons (PS) and Akhmediev breathers (AB) with leading-order component at fundamental frequency (FF) sustained by Kerr-like nonlinearity due to cascading may radiate thanks to the fact that the weaker component at optical second-harmonic (SH) becomes resonant with linear dispersive waves [10] (see f.i. Fig. 1). This resonance is driven by GVD at SH, without requiring any contribution from HOD. According to such mechanism, the primary RR frequencies occur around the SH, which also lead, through further non-degenerate mixing processes, to radiated linear waves around the FF.

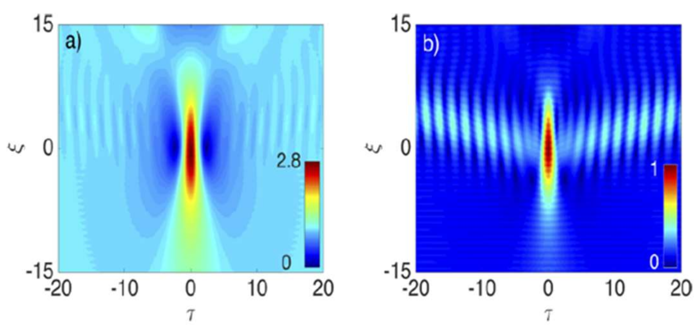

Fig.1. *Numerical spatiotemporal dynamics of the FF (a) and SH (b) components of a typical radiating PS.*

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Rogue waves and their patterns in the vector nonlinear Schrodinger equation

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ABSTRACT

In this talk, we are concerned with the general rogue waves and their patterns in an integrable M-component nonlinear Schr¨odinger (NLS) equation. As an extension of an interesting work by Yang *et al.* for the scalar NLS equation and the Manakov system [1, 2], we construct the degenerate rogue wave solution of the vector NLS equation which is expressed by τ functions that are determinants of K ×K block matrices (K = 1, 2, ・ ・ ・ ,M) with an index jump of M + 1. We then focus on the patterns for the case M = 3. The patterns of the rogue waves for M = 3 and K = 1 are thoroughly investigated. This is a joint work with Dr. Chengfa Wu and his students at Shenzhen University, China.

References

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Transverse instability of Peregrine rogue waves

Justin Cole
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Rogue waves, or "freak waves", are large amplitude waves that suddenly appear and then disappear. Originally the subject of folklore, these types of waves have now been observed in numerous physical systems such as water waves and fiber optics. A common rogue wave model is the one space, one time (1+1) nonlinear Schrodinger (NLS) equation and the Peregrine soliton solution which has a peak amplitude three times that of the background. However, in deep open water a more complete description is that of the 2+1 hyperbolic NLS equation with two significant transverse dimensions. It will be shown that the Peregrine soliton is transversely unstable to both long and short wavelength perturbations. Moreover, the instability spectrum coincides with that of the background plane wave.

Periodic waves in the discrete MKDV equation: modulational instability and rogue waves

Dmitry Pelinovsky

McMaster University, Canada

Abstract:

We derive the traveling periodic waves of the discrete modified Korteweg-de Vries equation by using a nonlinearization method associated with a single eigenvalue. Modulational stability of the traveling periodic waves is studied from the squared eigenfunction relation and the Lax spectrum. We use numerical approximations to show that, similar to the continuous counterpart, the family of dnoidal solutions is modulationally stable and the family of cnoidal solutions is modulationally unstable. Consequently, algebraic solitons propagate on the dnoidal wave background and rogue waves (spatially and temporally localized events) are dynamically generated on the cnoidal wave background.

Partial-rogue waves that come from nowhere but leave with a trace

Jianke Yang

University of Vermont, USA

Abstract:

Partial-rogue waves, i.e., waves that "come from nowhere but leave with a trace", are analytically predicted and numerically confirmed in the Sasa-Satsuma equation. We show that, among a class of rational solutions in this equation that can be expressed through determinants of 3-reduced Schur polynomials, partial-rogue waves would arise if these rational solutions are of certain orders, where the associated generalized Okamoto polynomials have real but not imaginary roots, or imaginary but not real roots. We further show that, at large negative time, these partial-rogue waves approach the constant-amplitude background, but at large positive time, they split into several fundamental rational solitons, whose numbers are determined by the number of real or imaginary roots in the underlying generalized Okamoto polynomial. Our asymptotic predictions are compared to true solutions, and excellent agreement is observed. This is joint work with Dr. Bo Yang and will appear in Phys. Lett. A.