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EDITORIAL

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Editorial

Hydrodynamics of low-dimensional quantum systems

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1. Introduction

One of the most important questions of modern science is that of emergent behaviours in complex systems. This asks the following: if we know well the fundamental laws of physics, can we still predict the relevant behaviours of physical systems of interest? These typically contain a large amount of basic objects, such as particles or quantum spins. When those interact with one another, new behaviours emerge at large scales, according to laws which may be difficult to predict, but which are universal, independent from most microscopic details. This occurs in a diversity of systems, from electrons in a metal and spins in quantum magnets, to molecules in a gas and even flocks of birds. For instance, there is no point in attempting to describe the trajectories of every molecule in the air that surrounds us, yet one must understand the principles that explain why the motion of one person's vocal cords affects that of another person's eardrum the way it does, and at the speed of sound. *What are the emergent laws of dynamics at macroscopic scales of space and time? How to pass from the microscopic to the macroscopic?* While the forms of evolution equations is well understood, to extract information of physical relevance remains a lasting challenge.

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One successful approach consists in developing effective macroscopic equations. The simple example of sound propagation in air illustrates one of the most successful such frameworks: that of hydrodynamics. The science is old, starting in the 17th–19th centuries with Euler and Navier–Stokes equations, applicable to everyday fluids and gases. But modern research has shown that hydrodynamic ideas, beyond these 'conventional' equations, have much wider applicability.

One of the setups where non-conventional hydrodynamic theories have been most successful recently is that of low-dimensional quantum systems. The study of these systems from a hydrodynamics viewpoint has inspired developments in many directions. Indeed, the constraint of low dimensionality not only may drastically affect the large-scale dynamics, but also, offers new techniques—including those of integrability and of field theory—in order to get a much deeper understanding than what has been possible until now in higher-dimensional systems. The papers published in this special issue provide a broad overview of the current research on hydrodynamics of low-dimensional quantum systems, showing how active this research area is, and indication some of the most important directions of further research.

The papers study and bring new insight in this area. First, in quantum systems, an important question is about the emergence of phenomena that are of a purely quantum nature. The powerful techniques and theories available in low dimensions, often related to or based on hydrodynamics, allow us to the study these phenomena much more deeply. In this special issue, contributions investigated the dynamics of entanglement [3, 10, 24, 26], of operator spreading [20, 21] and of quantum coherences [14], the dynamical effects of quantum measurements [30] as well as how hydrodynamics gives us information on quantum wave functions [29]. In these fundamental endeavours, free fermions often, but not always, are a good initial setup. Second, in quantum many-body interacting systems, integrability plays a crucial role, and it turns out that the thermodynamics and hydrodynamics of integrability applies to a wide variety of systems. I fact, it is often useful to go back to the classical realm, in order to disentangle classical form quantum effects. In this special issue, contributions developed the hydrodynamic theory of integrable systems either quite generally [9, 13], or by focussing on gases of particles [6, 24], quantum spin systems [27], quantum and classical field theories [2, 16, 19], and even cellular automata [15, 17, 18, 21, 23] and ensembles of classical solitons of integrable partial differential equations [5, 28]. Third, of particular interest in one-dimensional quantum systems is their often very peculiar or anomalous transport properties. In this special issues transport effects and techniques are uncovered in free fermion models [8, 14], Tomanaga–Luttinger liquids [11], and fluid dynamics within a chiral background [1]. Finally, studying fundamental aspects of statistical mechanics, stochastic processes and hydrodynamics give much insight into low-dimensional many-body systems, and contributions in this special issue study phase transitions [22, 25], entropy dynamics [7], large-scale fluctuations [4, 17] and the emergence of the hydrodynamic equations [12].

Data availability statement

No new data were created or analysed in this study.

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References

[1] Abanov A G and Wiegmann P B 2022 Anomalies in fluid dynamics: flows in a chiral background via variational principle *J. Phys. A: Math. Theor.* **55** 414001
[2] Abeya A, Biondini G and Prinari B 2022 Manakov system with parity symmetry on nonzero background and associated boundary value problems *J. Phys. A: Math. Theor.* **55** 254001
[3] Alba V and Carollo F 2022 Hydrodynamics of quantum entropies in Ising chains with linear dissipation *J. Phys. A: Math. Theor.* **55** 074002
[4] Bernard D 2021 Can the macroscopic fluctuation theory be quantized? *J. Phys. A: Math. Theor.* **54** 433001
[5] Bonnemain T, Doyon B and El G 2022 Generalized hydrodynamics of the KdV soliton gas *J. Phys. A: Math. Theor.* **55** 374004
[6] Bulchandani V B, Kulkarni M, Moore J E and Cao X 2021 Quasiparticle kinetic theory for calogero models *J. Phys. A: Math. Theor.* **54** 474001
[7] Chakraborti S, Dhar A, Goldstein S, Kundu A and Lebowitz J L 2022 Entropy growth during free expansion of an ideal gas *J. Phys. A: Math. Theor.* **55** 394002
[8] Dean D S, Doussal P L, Majumdar S N, Schehr G and Smith N R 2021 Kernels for non interacting fermions via a green's function approach with applications to step potentials *J. Phys. A: Math. Theor.* **54** 084001
[9] Durnin J, Luca A D, Nardis J D and Doyon B 2021 Diffusive hydrodynamics of inhomogenous Hamiltonians *J. Phys. A: Math. Theor.* **54** 494001
[10] Eisler V 2021 Entanglement spreading after local and extended excitations in a free-fermion chain *J. Phys. A: Math. Theor.* **54** 424002
[11] Gluza M, Moosavi P and Sotiriadis S 2022 Breaking of Huygens–Fresnel principle in inhomogeneous Tomonaga–Luttinger liquids *J. Phys. A: Math. Theor.* **55** 054002
[12] Hannani A and Huveneers F 2022 Derivation of Euler equations from quantum and classical microscopic dynamics *J. Phys. A: Math. Theor.* **55** 424005
[13] Ilievski E 2023 Popcorn drude weights from quantum symmetry *J. Phys. A: Math. Theor.* **55** 504005
[14] Jin T, Gautié T, Krajenbrink A, Ruggiero P and Yoshimura T 2021 Interplay between transport and quantum coherences in free fermionic systems *J. Phys. A: Math. Theor.* **54** 404001
[15] Klobas K and Prosen T 2022 On two reversible cellular automata with two particle species *J. Phys. A: Math. Theor.* **55** 094003
[16] Koch R, Caux J-S and Bastianello A 2022 Generalized hydrodynamics of the attractive non-linear Schrödinger equation *J. Phys. A: Math. Theor.* **55** 134001
[17] Kuniba A, Misguich G and Pasquier V 2022 Current correlations, drude weights and large deviations in a box–ball system *J. Phys. A: Math. Theor.* **55** 244006
[18] Lopez-Piqueres J, Gopalakrishnan S and Vasseur R 2022 Integrability breaking in the rule 54 cellular automaton *J. Phys. A: Math. Theor.* **55** 234005
[19] Mazzoni M, Pomponio O, Castro-Alvaredo O A and Ravanini F 2021 The staircase model: massless flows and hydrodynamics *J. Phys. A: Math. Theor.* **54** 404005
[20] McCulloch E and von Keyserlingk C W 2022 Operator spreading in the memory matrix formalism *J. Phys. A: Math. Theor.* **55** 274007
[21] Medenjak M 2022 Operator spreading in quantum hardcore gases *J. Phys. A: Math. Theor.* **55** 404002
[22] Pallister J S, Gangardt D M and Abanov A G 2022 Limit shape phase transitions: a merger of arctic circles *J. Phys. A: Math. Theor.* **55** 304001
[23] Pozsgay B 2021 A Yang–Baxter integrable cellular automaton with a four site update rule *J. Phys. A: Math. Theor.* **54** 384001
[24] Ruggiero P, Calabrese P, Doyon B and Dubail J 2021 Quantum generalized hydrodynamics of the Tonks–Girardeau gas: density fluctuations and entanglement entropy *J. Phys. A: Math. Theor.* **55** 024003
[25] Schütz G M and Karevski D 2022 Dynamical phase transitions in annihilating random walks with pair deposition *J. Phys. A: Math. Theor.* **55** 394005
[26] Scopa S, Krajenbrink A, Calabrese P and Dubail J 2021 Exact entanglement growth of a one-dimensional hard-core quantum gas during a free expansion *J. Phys. A: Math. Theor.* **54** 404002
[27] Stéphan J-M 2022 Exact time evolution formulae in the XXZ spin chain with domain wall initial state *J. Phys. A: Math. Theor.* **55** 204003

[28] Tovbis A and Wang F 2022 Recent developments in spectral theory of the focusing nls soliton and breather gases: the thermodynamic limit of average densities, fluxes and certain meromorphic differentials; periodic gases *J. Phys. A: Math. Theor.* **55** 424006
[29] Yeh H-C, Gangardt D M and Kamenev A 2022 Emptiness formation in polytropic quantum liquids *J. Phys. A: Math. Theor.* **55** 064002
[30] Zadnik L, Bocini S, Bidzhiev K and Fagotti M 2022 Measurement catastrophe and ballistic spread of charge density with vanishing current *J. Phys. A: Math. Theor.* **55** 474001