Highlights 2015
A compilation of the best papers published within the last year
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We just concluded the International Year of Light (IYL) 2015. The European Physical Society played an important role, as illustrated by the EPS President in our previous Highlights collection. EPL has contributed by starting a series of IYL Perspective articles on light-based physics and technologies: they were published monthly, intercalated by Perspectives in the other areas of physics. These new articles met great success in terms of downloads and all their abstracts have been included in this Highlights of 2015 collection. In addition to the Perspectives, directly invited by me in my role as EiC, about 65 articles out of almost 800 published in EPL during 2015 have been selected by the Co-Editors and marked with the Editor’s Choice (EC) label. An appreciable fraction of the EC letters have been directly accepted by the Co-Editor without being externally refereed, and these have been published with the accepting Co-Editor’s name below the title. Besides being a distinction for the authors, direct acceptance is also a distinctive feature of EPL, which is made possible by the high scientific qualification of its Editorial Board. With an acceptance rate presently limited to 37% of the submitted manuscripts, the articles published in EPL have already passed through strict peer-review. Thus, the EC distinction, attributed to 8% of the published articles, represent only 3% of the submitted manuscripts. This booklet collects about three quarters of these EC articles, complemented by other letters of a similar high quality.

The aim of this collection is to show, within the limited space available, that EPL excellently covers all the disciplinary and multi-disciplinary sections of physics, as listed in the contents. The full series of papers can be found in the extended online version of our Highlights at epljournal.org/highlights-2015.

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Contents

Statistical & quantum mechanics, quantum information & complex networks 6

Nonlinear dynamics, fluid dynamics & mathematical methods 13

Elementary particles, fields & nuclear physics 17

Atomic & molecular physics 20

Electromagnetism, optics, acoustics, heat transfer & classical mechanics 21

Plasmas & fusion 24

Condensed matter: structural, mechanical & thermal properties 26

Condensed matter: electronic structure, electrical, magnetic & optical properties 30

Applied & interdisciplinary topics 41

Geophysics, astronomy & astrophysics 43

Conference sponsorship 48

Events calendar 2016 48

EPL’s publishing partners 49

Editorial Board 50

Front cover image: Topological defects in active turbulence Sumesh P. Thampi, Amin Doostmohammadi, Ramin Golestanian and Julia M. Yeomans 2015 EPL 112 28004.
Statistical & quantum mechanics, quantum information & complex networks

**Probing the Casimir force with optical tweezers**


2015 *EPL* 112 44001

We propose to use optical tweezers to probe the Casimir interaction between microspheres inside a liquid medium for geometric aspect ratios far beyond the validity of the widely employed proximity force approximation. This setup has the potential for revealing unprecedented features associated to the non-trivial role of the spherical curvatures. For a proof of concept, we measure femtonewton double layer forces between polystyrene microspheres at distances above 400 nm by employing very soft optical tweezers, with stiffness of the order of fractions of a fN/nm. As a future application, we propose to tune the Casimir interaction between a metallic and a polystyrene microsphere in saline solution from attraction to repulsion by varying the salt concentration. With those materials, the screened Casimir interaction may have a larger magnitude than the unscreened one. This line of investigation has the potential for bringing together different fields including classical and quantum optics, statistical physics and colloid science, while paving the way for novel quantitative applications of optical tweezers in cell and molecular biology.

**Interdisciplinary and physics challenges of network theory**

Ginestra Bianconi

2015 *EPL* 111 56001

Network theory has unveiled the underlying structure of complex systems such as the Internet or the biological networks in the cell. It has identified universal properties of complex networks, and the interplay between their structure and dynamics. After almost twenty years of the field, new challenges lie ahead. These challenges concern the multilayer structure of most of the networks, the formulation of a network geometry and topology, and the development of a quantum theory of networks. Making progress on these aspects of network theory can open new venues to address interdisciplinary and physics challenges including progress on brain dynamics, new insights into quantum technologies, and quantum gravity.
Boltzmann-Gibbs entropy is sufficient but not necessary for the likelihood factorization required by Einstein

Constantino Tsallis and Hans J. Haubold

2015 EPL 110 30005

In 1910 Einstein published a work on a crucial aspect of his understanding of the Boltzmann entropy. He essentially argued that the likelihood function of any system composed by two probabilistically independent subsystems ought to be factorizable into the likelihood functions of each of the subsystems. Consistently he was satisfied by the fact that the Boltzmann (additive) entropy fulfills this epistemologically fundamental requirement. We show here that entropies (e.g., the $q$-entropy on which nonextensive statistical mechanics is based) which generalize the BG one through violation of its well-known additivity can also fulfill the same requirement. This important fact sheds light on the very foundations of the connection between the micro- and macroscopic worlds, and consistently supports that the classical thermodynamical Legendre structure is more powerful than the role to it reserved by the Boltzmann-Gibbs statistical mechanics.

Height fluctuations in non-integrable classical dimers

Alessandro Giuliani, Vieri Mastropietro and Fabio Toninelli

2015 EPL 109 60004

We rigorously establish the asymptotic equivalence between the height function of interacting dimers on the square lattice and the massless Gaussian free field. Our theorem explains the microscopic origin of the sine-Gordon field theory description away from the free fermion point, which has previously been elusive. We use a novel technique, based on the combination of discrete holomorphicity with exact, constructive, renormalization group methods, which has the potential of being applicable to a variety of other non-integrable models at or close to criticality.

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Network topology with broken Onsager symmetry allows directional and highly efficient energy transfer

B. Sabass

2015 *EPL* **110** 20002

Time-reversal symmetry of most conservative forces constrains the properties of linear transport in physical systems. Here, we study the efficiency of energy transfer in dissipative oscillator networks where time-reversal symmetry is broken locally by Lorentz-force–like couplings. Despite their linearity, such networks can exhibit mono-directional transport and allow isolation of energy transfer in subsystems. New mechanisms and general rules for mono-directional transport are discussed. Combining network topology with Lorentz-force–like coupling, we show how efficiency at maximum power can surpass the common bound of 1/2 and may even approach unity.

Permutation min-entropy: An improved quantifier for unveiling subtle temporal correlations

Luciano Zunino, Felipe Olivares and Osvaldo A. Rosso

2015 *EPL* **109** 10005

The aim of this letter is to introduce the *permutation min-entropy* as an improved symbolic tool for identifying the existence of hidden temporal correlations in time series. On the one hand, analytical results obtained for the fractional Brownian motion stochastic model theoretically support this hypothesis. On the other hand, the analysis of several computer-generated and experimentally observed time series illustrate that the proposed symbolic quantifier is a versatile and practical tool for identifying the presence of subtle temporal structures in complex dynamical systems. Comparisons against the results obtained with other tools confirm its usefulness as an alternative and/or complementary measure of temporal correlations.
Synchronization in delayed multiplex networks
Aradhana Singh, Saptarshi Ghosh, Sarika Jalan and Jürgen Kurths
2015 EPL 111 30010

We study the impact of multiplexing on the global phase synchronizability of different layers in the delayed coupled multiplex networks. We find that at strong couplings, the multiplexing induces the global synchronization in sparse networks. The introduction of global synchrony depends on the connection density of the layers being multiplexed, which further depends on the underlying network architecture. Moreover, multiplexing may lead to a transition from a quasi-periodic or chaotic evolution to a periodic evolution. For the periodic case, the multiplexing may lead to a change in the period of the dynamical evolution. Additionally, delay in the couplings may bring upon synchrony to those multiplex networks which do not exhibit synchronization for the undelayed evolution. Using a simple example of two globally connected layers forming a multiplex network, we show how delay brings upon a possibility for the inter-layer global synchrony, that is not possible for the undelayed evolution.

Parametric description of the quantum measurement process
P. Liuzzo-Scorpo, A. Cuccoli and P. Verrucchi
2015 EPL 111 40008

We present a description of the measurement process based on the parametric representation with environmental coherent states. This representation is specifically tailored for studying quantum systems whose environment needs being considered through the quantum-to-classical crossover. Focusing upon projective measures, and exploiting the connection between large-$N$ quantum theories and the classical limit of related ones, we manage to push our description beyond the pre-measurement step. This allows us to show that the outcome production follows from a global-symmetry breaking, entailing the observed system’s state reduction, and that the statistical nature of the process is brought about, together with the Born’s rule, by the macroscopic character of the measuring apparatus.
Estimating the principal components of correlation matrices from all their empirical eigenvectors

Rémi Monasson and Dario Villamaina

2015 EPL 112 50001

We consider the problem of estimating the principal components of a population covariance matrix from a limited number of measurement data. Using a combination of random matrix and information-theoretic tools, we show that all the eigenmodes of the sample correlation matrices are informative, and not only the top ones. We show how this information can be exploited when prior information about the principal component, such as whether it is localized or not, is available by mapping the estimation problem onto the search for the ground state of a spin-glass-like effective Hamiltonian encoding the prior. Results are illustrated numerically on the spiked covariance model.

Multiscale complex network for analyzing experimental multivariate time series

Zhong-Ke Gao, Yu-Xuan Yang, Peng-Cheng Fang, Yong Zou, Cheng-Yi Xia and Meng Du

2015 EPL 109 30005

The multiscale phenomenon widely exists in nonlinear complex systems. One efficient way to characterize complex systems is to measure time series and then extract information from the measurements. We propose a reliable method for constructing a multiscale complex network from multivariate time series. In particular, for a given multivariate time series, we first perform a coarse-grained operation to define temporal scales and then reconstruct the multivariate phase-space for each scale to infer multiscale complex networks. In addition, we develop a novel clustering coefficient entropy to assess the derived multiscale complex networks, aiming to characterize the coupled dynamical characteristics underlying multivariate time series. We apply our proposed approach to the analysis of multivariate time series measured from gas-liquid two-phase flow experiments. The results yield novel insights into the inherent coupled flow behavior underlying a realistic multiphase flow system. Bridging multiscale analysis and complex network provides a fascinating methodology for probing multiscale complex behavior underlying complex systems.
Singular diffusion in a confined sandpile

R. S. Pires, A. A. Moreira, H. A. Carmona and J. S. Andrade Jr

2015 EPL 109 14007

We investigate the behavior of a two-state sandpile model subjected to a confining potential in one and two dimensions. From the microdynamical description of this simple model with its intrinsic exclusion mechanism, it is possible to derive a continuum nonlinear diffusion equation that displays singularities in both the diffusion and drift terms. The stationary-state solutions of this equation, which maximizes the Fermi-Dirac entropy, are in perfect agreement with the spatial profiles of time-averaged occupancy obtained from model numerical simulations in one as well as in two dimensions. Surprisingly, our results also show that, regardless of dimensionality, the presence of a confining potential can lead to the emergence of a power-law tail in the distribution of avalanche sizes.

The value of conflict in stable social networks

Pensri Pramukkul, Adam Svenkeson, Bruce J. West and Paolo Grigolini

2015 EPL 111 58003

A cooperative network model of sociological interest is examined to determine the sensitivity of the global dynamics to having a fraction of the members behaving uncooperatively, that is, being in conflict with the majority. We study a condition where in the absence of these uncooperative individuals, the contrarians, the control parameter exceeds a critical value and the network is frozen in a state of consensus. The network dynamics change with variations in the percentage of contrarians, resulting in a balance between the value of the control parameter and the percentage of those in conflict with the majority. We show that, as a finite-size effect, the transmission of information from a network B to a network A, with a small fraction of lookout members in A who adopt the behavior of B, becomes maximal when both networks are assigned the same critical percentage of contrarians.
Reentrant phase transitions and defensive alliances in social dilemmas with informed strategies

Attila Szolnoki and Matjaž Perc

2015 EPL 110 38003

Knowing the strategy of an opponent in a competitive environment conveys obvious evolutionary advantages. But this information is costly, and the benefit of being informed may not necessarily offset the additional cost. Here we introduce social dilemmas with informed strategies, and we show that this gives rise to two cyclically dominant triplets that form defensive alliances. The stability of these two alliances is determined by the rotation velocity of the strategies within each triplet. A weaker strategy in a faster rotating triplet can thus overcome an individually stronger competitor. Fascinating spatial patterns favor the dominance of a single defensive alliance, but enable also the stable coexistence of both defensive alliances in very narrow regions of the parameter space. A continuous reentrant phase transition reveals before unseen complexity behind the stability of strategic alliances in evolutionary social dilemmas.

Dynamic instability of cooperation due to diverse activity patterns in evolutionary social dilemmas

Cheng-Yi Xia, Sandro Meloni, Matjaž Perc and Yamir Moreno

2015 EPL 109 58002

Individuals might abstain from participating in an instance of an evolutionary game for various reasons, ranging from lack of interest to risk aversion. In order to understand the consequences of such diverse activity patterns on the evolution of cooperation, we study a weak prisoner’s dilemma where each player’s participation is probabilistic rather than certain. Players that do not participate get a null payoff and are unable to replicate. We show that inactivity introduces cascading failures of cooperation, which are particularly severe on scale-free networks with frequently inactive hubs. The drops in the fraction of cooperators are sudden, while the spatiotemporal reorganization of compact cooperative clusters, and thus the recovery, takes time. Nevertheless, if the activity of players is directly proportional to their degree, or if the interaction network is not strongly heterogeneous, the overall evolution of cooperation is not impaired. This is because inactivity negatively affects the potency of low-degree defectors, who are hence unable to utilize on their inherent evolutionary advantage. Between cascading failures, the fraction of cooperators is therefore higher than usual, which lastly balances out the asymmetric dynamic instabilities that emerge due to intermittent blackouts of cooperative hubs.
Nonlinear dynamics, fluid dynamics & mathematical methods

PERSPECTIVE

Lattice Boltzmann 2038

Sauro Succi

2015 EPL 109 50001

Based on the past twenty-five years of lattice Boltzmann research, we venture into a far-flung prediction for the next twenty-five, with past and future privileged over the present state of affairs.

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The many-body reciprocal theorem and swimmer hydrodynamics

Dario Papavassiliou and Gareth P. Alexander

2015 EPL 110 44001

We present a reinterpretation and extension of the reciprocal theorem for swimmers, extending its application from the motion of a single swimmer in an unbounded domain to the general setting, giving results for both swimmer interactions and general hydrodynamics. We illustrate the method for a squirmer near a planar surface, recovering standard literature results and extending them to a general squirming set, to motion in the presence of a ciliated surface, and expressions for the flow field throughout the domain. Finally, we present exact results for the hydrodynamics in two dimensions which shed light on the near-field behaviour.

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Chaotic explosions

Eduardo G. Altmann, Jefferson S. E. Portela and Tamás Tél

2015 EPL 109 30003

We investigate chaotic dynamical systems for which the intensity of trajectories might grow unlimited in time. We show that i) the intensity grows exponentially in time and is distributed spatially according to a fractal measure with an information dimension smaller than that of the phase space, ii) such exploding cases can be described by an operator formalism similar to the one applied to chaotic systems with absorption (decaying intensities), but iii) the invariant quantities characterizing explosion and absorption are typically not directly related to each other, e.g., the decay rate and fractal dimensions of absorbing maps typically differ from the ones computed in the corresponding inverse (exploding) maps. We illustrate our general results through numerical simulation in the cardioid billiard mimicking a lasing optical cavity, and through analytical calculations in the baker map.

Self-organization and self-avoiding limit cycles

D. Hexner and D. Levine

2015 EPL 109 30004

A simple periodically driven system displaying rich behavior is introduced and studied. The system self-organizes into a mosaic of static ordered regions with three possible patterns, which are threaded by one-dimensional paths on which a small number of mobile particles travel. These trajectories are self-avoiding and non-intersecting, and their relationship to self-avoiding random walks is explored. Near $\rho = 0.5$ the distribution of path lengths becomes power-law–like up to some cutoff length, suggesting a possible critical state.
Defect-induced phase transition in the asymmetric simple exclusion process

Johannes Schmidt, Vladislav Popkov and Andreas Schadschneider

2015 *EPL* **110** 20008

We reconsider the long-standing question of the critical defect hopping rate $r_c$ in the one-dimensional totally asymmetric exclusion process (TASEP) with a slow bond (defect). For $r < r_c$, a phase-separated state is observed due to queuing at the defect site, whereas for $r \geq r_c$ the defect site has only local effects on the stationary state of the homogeneous system. Mean-field theory predicts $r_c = 1$ (when hopping rates outside the defect bond are equal to 1) but numerical investigations seem to indicate $r_c \approx 0.80$ (2). Here we improve the numerics to show that $r_c > 0.99$ and give strong evidence that indeed $r_c = 1$ as predicted by mean-field theory, and anticipated by recent theoretical findings.

Stochastic efficiency for effusion as a thermal engine

K. Proesmans, B. Cleuren and C. Van den Broeck

2015 *EPL* **109** 20004

The stochastic efficiency of effusion as a thermal engine is investigated within the framework of stochastic thermodynamics. Explicit results are obtained for the probability distribution of the efficiency both at finite times and in the asymptotic regime of large deviations. The universal features, derived in Verley et al. (*Nat. Commun.*, **5** (2014) 4721), are reproduced. The effusion engine is a good candidate for both the numerical and experimental verification of these predictions.

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Effect of inertia on model flocks in a turbulent environment
Ashok Choudhary, Divya Venkataraman and Samriddhi Sankar Ray
2015 *EPL* 112 24005

We study flocking of self-propelled, interacting microorganisms with finite sizes and mass immersed in a turbulent flow. In the presence of the competing interactions of self-propulsion and the carrier turbulent flow, as is typical in nature, we show that including the effect of inertia is essential for the stability of flocks. We examine the problem from the point of view of global as well as local order and the statistics of the velocity of the microorganisms as a function of the inertia, the interaction radius, the level of self-propulsion as well as noise.

Run-and-tumble dynamics of self-propelled particles in confinement
Jens Elgeti and Gerhard Gompper
2015 *EPL* 109 58003

Run-and-tumble dynamics is a wide-spread mechanism of swimming bacteria. The accumulation of run-and-tumble microswimmers near impermeable surfaces is studied theoretically and numerically in the low-density limit in two and three spatial dimensions. Both uni-modal and exponential distributions of the run lengths are considered. Constant run lengths lead to peaks and depletions regions in the density distribution of particles near the surface, in contrast to exponentially distributed run lengths. Finally, we present a universal accumulation law for large channel widths, which applies not only to run-and-tumble swimmers, but also to many other kinds of self-propelled particles.

High-impact research
EPL had more than 568,800 article downloads in 2015.
Goals and challenges in experimental nuclear astrophysics

Michael Wiescher

2015 EPL 109 62001

This paper provides an overview of the present questions, goals, and challenges in the field of experimental nuclear astrophysics. A number of different stellar environments and the associated conditions for nuclear-reactions–driven nucleosynthesis events and patterns are discussed. Experimental goals are presented and specific activities and initiatives are summarized for each of these burning environments. New facilities are under development and will help to provide a sound experimental base for understanding the evolution of the elements in our Universe.

The production of hidden charm baryon $N^*(4261)$ from $\pi^- p \rightarrow \eta_c n$ reaction

Xiao-Yun Wang and Xu-Rong Chen

2015 EPL 109 41001

With an effective Lagrangian approach and the isobar model, we explore the discovery potential of the $N^*(4261)$ production via $\pi^- p$ scattering. Moreover, the background from the $\pi^- p \rightarrow \eta_c n$ reaction through s-channel and u-channel by exchanging a nucleon pole is also considered. It is found that the center-of-mass energy $W \approx 4.1 - 4.4$ GeV is the best energy window for searching the $N^*(4261)$ resonance, where the $N^*(4261)$ signal can be easily distinguished from background. The relevant calculations will be conductive to search for the $N^*(4261)$ resonance in further experiment and have a more comprehensive understanding of hidden charm baryons.

Elementary particles, fields & nuclear physics
Anomalous Fano resonance of massive Dirac particle through a time-dependent barrier

Cunxi Zhang, Jie Liu and Libin Fu

2015 *EPL* 110 61001

As is well known Fano resonance arises from the interference between a localized state and a continuum state. Using the standard Floquet theory and the scattering matrix method, we study theoretically the massive Dirac particle transmission over a quantum barrier with an oscillating field. It is found that the massive relativistic particles can generate not only normal Fano resonance in the transmission due to the interference between a localized state (bound state) and the continuum state, but also anomalous Fano resonance due to the interference between a delocalized state (extended state) and the continuum state. The dependence of line shapes on driving parameters for these two kinds of Fano resonances is quite different. For normal Fano resonance the asymmetry parameter is approximately proportional to a power law of the amplitude of the oscillating field, while for the anomalous Fano resonance the asymmetry parameters change slightly with different oscillation amplitudes. In practice, the anomalous Fano resonance can be identified by observing asymmetry parameters in experiment.

Intense vacuum ultraviolet and infrared scintillation of liquid Ar-Xe mixtures


2015 *EPL* 109 12001

Vacuum ultraviolet light emission from xenon-doped liquid argon is described in the context of liquid noble gas particle detectors. Xenon concentrations in liquid argon from 0.1 ppm to 1000 ppm were studied. The energy transfer from the second excimer continuum of argon (~ 127 nm) to the second excimer continuum of xenon (~ 174 nm) is observed by recording optical emission spectra. The transfer almost saturates at a xenon concentration of ~ 10 ppm for which, in addition, an intense emission in the infrared at a peak wavelength of 1.17 µm with 13000 ± 4000 photons per MeV deposited by electrons had been found. The corresponding value for the VUV emission at a peak wavelength of 174 nm (second excimer continuum of xenon) is determined to be 20000 ± 6000.
Results of transmission experiments of vacuum ultraviolet light through a 11.6 cm long cell filled with pure and xenon-doped liquid argon are described. Pure liquid argon shows no attenuation down to the experimental short-wavelength cut-off at 118 nm. Based on a conservative approach, a lower limit of 1.10 m for the attenuation length of its own scintillation light could be derived. Adding xenon to liquid argon at concentrations on the order of parts per million leads to strong xenon-related absorption features which are used for a tentative assignment of the recently found near-infrared emission observed in electron-beam excited liquid argon-xenon mixtures. Two of the three absorption features can be explained by perturbed xenon transitions and the third one by a trapped exciton (Wannier-Mott) impurity state. A calibration curve connecting the equivalent width of the absorption line at 140 nm with xenon concentration is provided.
Spatial phase-resolved optical emission spectroscopy for understanding plasma etching uniformity

V. Milosavljević and P. J. Cullen

2015 *EPL* **110** 43001

Plasma chemistry of an oxygen-argon discharge in an electron cyclotron resonance (ECR) plasma etcher with a SiO₂ wafer is observed. The study involves: Phase-resolved optical emission spectroscopy (PROES) of neutral atomic argon (Ar I) and oxygen (O I) spectral lines, spectroscopic ellipsometry of the wafer and a magnetic-field measurement of the ECR etcher’s electro-magnet. Spatial PROES results together with the ellipsometry and magnetic-field measurements are used to assess the plasma etching uniformity of the SiO₂ wafer. To evaluate the cross-dependences of the measured outputs for a wide range of process parameters, a design-of-experiment approach is taken. Spatial PROES of the oxygen atom shows a different spectral radiation pattern for the oxygen from the gas phase and those from the solid phase due to surface etching.
Electromagnetism, optics, acoustics, heat transfer & classical mechanics

**PERSPECTIVE**

Casimir torque between nanostructured plates

R. Guérout, C. Genet, A. Lambrecht and S. Reynaud

2015 *EPL* **111** 44001

We investigate in detail the Casimir torque induced by quantum vacuum fluctuations between two nanostructured plates. Our calculations are based on the scattering approach and take into account the coupling between different modes induced by the shape of the surface which are neglected in any sort of proximity approximation or effective medium approach. We then present an experimental setup aiming at measuring this torque.

**PERSPECTIVE**

Trapped quantum light

M. Brune and J. M. Raimond

2015 *EPL* **110** 20001

Matter-field interaction finds its simplest implementation in Cavity Quantum Electrodynamics (CQED). A single two-level atom is coupled to a few photons stored in a single mode of a high-quality resonator. In the strong-coupling regime, the coherent atom-field interaction overwelms dissipative processes. This situation illustrates the basic quantum postulates. It is also ideal for the exploration of the quantum-classical boundary and for the realization of quantum information protocols. We briefly describe the general frame of CQED. We illustrate its fundamental interest by discussing two recent experiments, performed with circular Rydberg atoms and superconducting millimeter-wave cavities.
**Light at the extremes: From femto- to atto-science for real-time studies of atomic and electronic motions**

Giulio Cerullo, Sandro De Silvestri and Mauro Nisoli

2015 *EPL* 112 24001

The progress in the generation of ultrashort pulses has continuously triggered the introduction of new spectroscopic and measurement techniques which offer the opportunity to investigate unexplored research areas with unprecedented time resolution. Few-optical cycle pulses tunable from near-infrared to visible-UV allow to shed light on ultrafast electronic relaxation processes and to achieve real-time detection of molecular vibrations and structural dynamics. High-energy few-optical cycle pulses allow the efficient production of high-order harmonics up to XUV spectral region, leading to the generation of attosecond pulses shedding light on electron wave packet dynamics in complex molecules.

**Evolution of ultrasonic impulses in chains of spheres using resonant excitation**


2015 *EPL* 109 54002

It is demonstrated that broad-bandwidth ultrasonic signals containing frequency components in excess of 200 kHz can be created in spherical chains using harmonic excitation at 73 kHz. Multiple reflections created a periodic waveform containing both harmonics and sub-harmonics of the original forcing frequency, due to non-linear Hertzian contact. These discrete frequencies represented some of the many allowed non-linear normal modes of vibration of the whole chain. Excitation at a single fixed frequency could thus be used to produce wide-bandwidth impulses for different lengths of spherical chains. Experimental results were in good agreement with theoretical predictions.
Analysis of the topological charge of vortex beams using a hole wheel

Olivier Emile, Janine Emile, Bruno Viaris de Lesegno, Laurence Pruvost and Christian Brousseau

2015 EPL 111 34001

The measurement of the topological charge of a vortex beam is demonstrated using the diffraction pattern produced by hole wheel. The resulting mandala-like interference pattern depends on the number of holes relatively to the topological charge. The interference at the centre of the pattern—bright or dark—enables us to determine the topological charge in a procedure when hole wheels with different number of holes are applied. This method is direct and wavelength independent. It does not require any image analysis and could find applications in classical telecommunications or quantum optics using twisted light.

Ghost imaging using labyrinth-like phase modulation patterns for high-efficiency and high-security optical encryption

Wen Chen and Xudong Chen

2015 EPL 109 14001

Ghost imaging has attracted more and more current attention due to its marked physical characteristics, and many physical applications, such as sensing and optical security, have been explored. In this letter, we propose ghost imaging using labyrinth-like phase modulation patterns for optical encryption. Since only one phase-only mask should be pre-set and the labyrinth patterns occupy only few spaces, high-efficiency storage or transmission of system keys can be implemented. In addition, each labyrinth pattern (i.e., phase modulation pattern) possesses high randomness and flexibility, hence high security can be guaranteed for the proposed optical encryption.
Plasmas & fusion

PERSPECTIVE

Light for controlled fusion energy: A perspective on laser-driven inertial fusion

Stefano Atzeni

2015 EPL 109 45001

The status of laser-driven inertial confinement fusion research is briefly reviewed. The recent major achievement of fusion energy release exceeding the energy delivered by the laser to the fuel (Hurricane O. et al., Nature, 506 (2014) 343), and the efforts towards ignition demonstration using indirect-drive are discussed. Physics model reliability is addressed. The potentials of alternative schemes, in particular direct-drive shock ignition, are also illustrated.

Plasma density temporal evolution in a high-power microwave pulse compressor switch

L. Beilin, A. Shlapakovski, M. Donskoy, T. Queller and Ya. E. Krasik

2015 EPL 109 25001

Time-resolved optical-emission spectroscopy measurements are used to evaluate plasma density in an interference switch during the extraction of a nanosecond output pulse from a high-power microwave compressor. The compressor represents a resonant cavity connected to an H-plane waveguide tee with a shorted side arm filled with helium at a pressure of 2 x 10^5 Pa; the plasma discharge in the tee side arm is triggered by a Surelite laser. A nanosecond-scale dynamics of the plasma density is obtained by analyzing the shape of the helium spectral lines. The analysis of the experimental data evidences a correlation between the rise time of the plasma density and the peak power of the microwave output pulse. Numerical simulations of the microwave energy release from the cavity with the appearance of the plasma yield results in good agreement with the measured output pulse peak power and waveform.
Solid-hexatic-liquid transition in a two-dimensional system of charged dust particles

O. F. Petrov, M. M. Vasiliev, O. S. Vaulina, K. B. Stacenko, E. V. Vasilieva, E. A. Lisin, Y. Tun and V. E. Fortov

2015 EPL 111 45002

Two-stage melting is observed experimentally in a confined monolayer of dust particles in plasma. The pair correlation and bond-angular correlation functions, the number of topological defects, and the pair potentials are measured and analyzed. The bond-orientational correlation functions show a clear solid-to-hexatic-to-fluid transition, in perfect agreement with the Berezinskii-Kosterlitz-Thouless transition theory.

Spontaneous formation and spin of particle pairs in a single-layer complex plasma crystal


2015 EPL 112 45003

In an experiment with a single-layer plasma crystal, spontaneous pairing of particles was observed upon a sudden reduction of the discharge power. The pairs were oriented vertically with the upper particle above the crystal layer and the lower particle beneath it, the pair size was about 0.2 mm. The pairs were spinning around their vertical axis with the upper particle leading and the lower one following it; the rotation speed was 10–13 Hz. Spinning particle pairs disturbed the plasma crystal through interaction with their neighbors. Upon further reduction of the discharge power, the spinning pairs proliferated in the plasma crystal and eventually it melted. The experiment was performed with micron-size polymer particles suspended in the radio-frequency (rf) argon plasma at a pressure of 157 mtorr. We propose a theoretical model of a spinning particle pair based on the plasma wake effect. Spinning particle pairs can be used as a diagnostic tool for plasma wakes or as a generic model of a 2D system of vortices.
Cold atoms: A field enabled by light

L. Fallani and A. Kastberg

2015 EPL 110 53001

Besides being a source of energy, light can also cool gases of atoms down to the lowest temperatures ever measured, where atomic motion almost stops. The research field of cold atoms has emerged as a multidisciplinary one, highly relevant, e.g., for precision measurements, quantum gases, simulations of many-body physics, and atom optics. In this focus article, we present the field as seen in 2015, and emphasise the fundamental role in its development that has been played by mastering light.

Nano-supracrystallinity

Marie Paule Pileni

2015 EPL 109 58001

Here it is shown that the chemical and physical properties of a collection of nanocrystals either isolated or self-assembled in 3D superlattices called supracrystals markedly depend on the crystalline structure of the nanocrystal.

Using entanglement to discern phases in the disordered one-dimensional Bose-Hubbard model

Andrew M. Goldsborough and Rudolf A. Römer

2015 EPL 111 26004

We perform a matrix-product-state–based density matrix renormalisation group analysis of the phases for the disordered one-dimensional Bose-Hubbard model. For particle densities \(N/L = 1, 1/2\) and 2 we show that it is possible to obtain a full phase diagram using only the entanglement properties, which come for free when performing an update. We confirm the presence of Mott insulating, superfluid and Bose glass phases when \(N/L = 1\) and \(1/2\) (without the Mott insulator) as found in previous studies. For the \(N/L = 2\) system we find a double-lobed superfluid phase with possible re-entrance.
Pairing in a system of a few attractive fermions in a harmonic trap

Tomasz Sowiński, Mariusz Gajda and Kazimierz Rzażewski

2015 EPL 109 26005

We study a strongly attractive system of a few spin-(1/2) fermions confined in a one-dimensional harmonic trap, interacting via two-body contact potential. Performing exact diagonalization of the Hamiltonian we analyze the ground state and the thermal state of the system in terms of one- and two-particle reduced density matrices. We show how for strong attraction the correlated pairs emerge in the system. We find that the fraction of correlated pairs depends on temperature and we show that this dependence has universal properties analogous to the gap function known from the theory of superconductivity. In contrast to the standard approach based on the variational ansatz and/or perturbation theory, our predictions are exact and are valid also in a strong-attraction limit. Our findings contribute to the understanding of strongly correlated few-body systems and can be verified in current experiments on ultra-cold atoms.

Enhanced wavelength-dependent surface tension of liquid-vapour interfaces

F. Höfling and S. Dietrich

2015 EPL 109 46002

Due to the simultaneous presence of bulk-like and interfacial fluctuations the understanding of the structure of liquid-vapour interfaces poses a long-lasting and ongoing challenge for experiments, theory, and simulations. We provide a new analysis of this topic by combining high-quality simulation data for Lennard-Jones fluids with an unambiguous definition of the wave-number–dependent surface tension $\gamma(q)$ based on the two-point correlation function of the fluid. Upon raising the temperature, $\gamma(q)$ develops a maximum at short wavelengths. We compare these results with predictions from density functional theory. Our analysis has repercussions for the interpretation of grazing-incidence small-angle X-ray scattering (GISAXS) at liquid interfaces.
Impurity-induced island pinning during electromigration

M. Jongmanns, A. Latz and D. E. Wolf

2015 EPL 110 16001

We study the electromigration-induced drift of monolayer Ag islands on Ag(111) which contain one Cu atom. For this purpose a three-dimensional self-learning kinetic Monte Carlo model was extended, and a realistic many-body potential was used. The only free parameters of the model are the effective valences of the Ag and Cu atoms. Due to the impurity, the island drift is significantly reduced, especially for small islands. This is traced back to sequential pinning and depinning events, which are analyzed in detail. Surprisingly, this phenomenon is qualitatively independent of the impurity’s effective valence, as long as the impurity does not detach from the island edge. How strongly the drift velocity is reduced depends on the effective valence.

Direct observation of size scaling and elastic interaction between nano-scale defects in collision cascades


2015 EPL 110 36001

Using in situ transmission electron microscopy, we have directly observed nano-scale defects formed in ultra-high-purity tungsten by low-dose high-energy self-ion irradiation at 30 K. At cryogenic temperature lattice defects have reduced mobility, so these microscope observations offer a window on the initial, primary damage caused by individual collision cascade events. Electron microscope images provide direct evidence for a power-law size distribution of nano-scale defects formed in high-energy cascades, with an upper size limit independent of the incident ion energy, as predicted by Sand et al. (EPL, 103 (2013) 46003). Furthermore, the analysis of pair distribution functions of defects observed in the micrographs shows significant intra-cascade spatial correlations consistent with strong elastic interaction between the defects.
Capillary stretching of fibers

C. Duprat and S. Protiere

2015 EPL 111 56006

We study the interaction of a finite volume of liquid with two parallel thin flexible fibers. A tension along the fibers is imposed and may be varied. We report two morphologies, i.e. two types of wet adhesion: a weak capillary adhesion, where a liquid drop bridges the fibers, and a strong elastocapillary adhesion where the liquid is spread between two collapsed fibers. We show that geometry, capillarity and stretching are the key parameters at play. We describe the collapse and detachment of the fibers as a function of two nondimensional parameters, arising from the geometry of the system and a balance between capillary and stretching energies. In addition, we show that the morphology, thus the capillary adhesion, can be controlled by changing the tension within the fibers.

Refraction index of shock compressed water in the megabar pressure range


2015 EPL 112 36001

We compressed water to megabar pressures by laser driven shock waves and evidenced transparent, opaque and reflecting phases as pressure increases. The refraction index of water in the first two states was measured using a VISAR system. At high compression a sharp increase of the real and imaginary part of the refraction index is observed. Experiments were performed at the LULI and RAL laboratories.
Condensed matter: electronic structure, electrical, magnetic & optical properties

**PERSPECTIVE**

The intrinsic heterogeneity of superconductivity in the cuprates

A. Shengelaya and K. A. Müller

2015 *EPL* **109** 27001

In the hole-doped, high-temperature superconducting cuprates, an intrinsic heterogeneity is found, from the early observations to recent data. Below optimum doping, the heterogeneity consists of dynamic metallic and, at low temperatures, superconducting regions in the form of clusters or stripes, which develop and decay as a function of time and location in the antiferromagnetic lattice. This behaviour is underlined by the interesting linear relation between the oxygen isotope shifts of the magnetic penetration depth and the critical temperature with a slope that is a factor 2 larger than expected for the homogeneous distribution of superfluid density. Allusion is also made to the Bose-Einstein condensation reported in structurally heterogeneous, polycrystalline polymer platelets as well as especially to the heterogeneous distribution of visible and dark matter in the Universe, which point to a change of paradigm in modern physics.

**PERSPECTIVE**

State-of-the-art techniques for calculating spectral functions in models for correlated materials

K. Hallberg, D. J. García, Pablo S. Cornaglia, Jorge I. Facio and Y. Núñez-Fernández

2015 *EPL* **112** 17001

The dynamical mean-field theory (DMFT) has become a standard technique for the study of strongly correlated models and materials overcoming some of the limitations of density functional approaches based on local approximations. An important step in this method involves the calculation of response functions of a multiorbital impurity problem which is related to the original model. Recently there has been considerable progress in the development of techniques based on the density matrix renormalization group (DMRG) and related matrix product states (MPS) implying a substantial improvement to previous methods. In this paper we review some of the standard algorithms and compare them to the newly developed techniques, showing examples for the particular case of the half-filled two-band Hubbard model.
Perspective on terahertz spectroscopy of graphene

Ivan Ivanov, Mischa Bonn, Zoltán Mics and Dmitry Turchinovich

2015 *EPL* 111 67001

Graphene has been an intensely studied material, owing to its unique band structure and concomitant outstanding electronic properties. In the past decades, ultrafast terahertz (THz) spectroscopy has developed into a powerful tool to characterize ultrafast charge carrier dynamics in a wide range of materials and material structures. In this Perspective we review recent experimental work exploring the ultrafast electron dynamics in graphene in the THz spectral range, and present a simple thermodynamic picture describing the THz linear, nonlinear, and photo-induced conductivity of this remarkable material.

Superconductivity above the lowest Earth temperature in pressurized sulfur hydride

Antonio Bianconi and Thomas Jarlborg

2015 *EPL* 112 37001

A recent experiment has shown a macroscopic quantum coherent condensate at 203 K, about 19 degrees above the coldest temperature recorded on the Earth surface, 184 K (−89.2 °C, −128.6 °F) in pressurized sulfur hydride. This discovery is relevant not only in material science and condensed matter but also in other fields ranging from quantum computing to quantum physics of living matter. It has given the start to a gold rush looking for other macroscopic quantum coherent condensates in hydrides at the temperature range of living matter $200 < T_c < 400$ K. We present here a review of the experimental results and the theoretical works and we discuss the Fermiology of $H_3S$ focusing on Lifshitz transitions as a function of pressure. We discuss the possible role of the *shape resonance* near a *neck disrupting* Lifshitz transition, in the Bianconi-Perali-Valletta (BPV) theory, for rising the critical temperature in a multigap superconductor, as the Feshbach resonance rises the critical temperature in Fermionic ultracold gases.
**PERSPECTIVE**

**Optics and photonics at nanoscale: Principles and perspectives**

Zhi-Yuan Li

2015 *EPL* **110** 14001

Nanophotonics is a multidisciplinary frontier of science that merges nanoscience and nanotechnology with conventional optics and photonics. We focus on two principal issues of nanophotonics: manipulation of optical field and light-matter interaction via various optical nanostructures. These two issues are behind all the efforts to explore, design, and build nanophotonic devices to accomplish the fundamental cause of large-scale optical integration for information processing, interconnection, and computing. We discuss various mechanisms of light-matter interaction enhancement to realize bright fluorescence, Raman, and nonlinear optical radiation, and explore methodologies and various devices for highly sensitive optical sensing and detecting, ultrahigh spatial resolution imaging, and high-efficiency energy conversion between light and electricity, heat, and other forms. All these concepts, insights, methodologies, and technologies in nanophotonics will set a solid platform to explore and achieve better future information and energy technologies that use light as powerful information and energy carriers and as prominent media to probe and manipulate the intrinsic properties of matters via light-matter interaction.

**Metamorphosis of the transistor into a laser**

M. Feng and N. Holonyak jr.

2015 *EPL* **109** 18001

Based on the invention and operation of the transistor, the alloy diode laser, the quantum-well diode laser and the high-speed heterojunction bipolar transistor (HBT), we have invented and realized now a transistor laser (TL). The transistor laser is a three-terminal technology providing coupling and the coherent light emission in the transistor. The quantum-well (QW) heterojunction bipolar transistor laser, inherently a fast switching device, operates by transporting a small minority base charge density $\sim 10^{16} \text{ cm}^{-3}$ over a nanoscale base thickness (<900 A) in picoseconds. The TL, owing to its fast recombination speed, its unique three-terminal configuration, and complementary nature of its optical and electrical collector output signals, enables resonance-free base current and collector voltage modulation. It is a compact source of electro-optical applications such as nonlinear signal mixing, frequency multiplication, negative feedback, and optoelectronics logic gates.
**EPL: Highlights**

**Blue-to-green single photons from InGaN/GaN dot-in-a-nanowire ordered arrays**

E. Chernysheva, Ž. Gačević, N. García-Lepetit, H. P. van der Meulen, M. Müller, F. Bertram, P. Veit, A. Torres-Pardo, J. M. González Calbet, J. Christen, E. Calleja, J. M. Calleja and S. Lazic

2015 *EPL* **111** 24001

Single-photon emitters (SPEs) are at the basis of many applications for quantum information management. Semiconductor-based SPEs are best suited for practical implementations because of high design flexibility, scalability and integration potential in practical devices. Single-photon emission from ordered arrays of InGaN nano-disks embedded in GaN nanowires is reported. Intense and narrow optical emission lines from quantum dot-like recombination centers are observed in the blue-green spectral range. Characterization by electron microscopy, cathodoluminescence and micro-photoluminescence indicate that single photons are emitted from regions of high In concentration in the nano-disks due to alloy composition fluctuations. Single-photon emission is determined by photon correlation measurements showing deep anti-bunching minima in the second-order correlation function. The present results are a promising step towards the realization of on-site/on-demand single-photon sources in the blue-green spectral range operating in the GHz frequency range at high temperatures.

**Magnetoelastic relaxations in EuTiO₃**


2015 *EPL* **109** 57004

The multiferroic properties of EuTiO₃ are greatly enhanced when a sample is strained, signifying that coupling between strain and structural, magnetic or ferroelectric order parameters is extremely important. Here resonant ultrasound spectroscopy has been used to investigate strain coupling effects, as well as possible additional phase transitions, through their influence on elastic and anelastic relaxations that occur as a function of temperature between 2 and 300 K and with applied magnetic field up to 14 T. Antiferromagnetic ordering is accompanied by acoustic loss and softening, and a weak magnetoelastic effect is also associated with the change in magnetization direction below ~2.8 K. Changes in loss due to the influence of magnetic field suggest the existence of magnetic defects which couple with strain and may play a role in pinning of ferroelastic twin walls.
Quantification of absorption contributions in microstructured silicon fabricated by femtosecond laser pulses

Yan Peng, XiangQian Chen, YunYan Zhou, Kun Luo, Jian Xu, Ron Henderson, JianMing Dai and YiMing Zhu

2015 EPL 110 68005

Microstructured silicon material, fabricated by femtosecond laser pulses, has a lot of crucial applications in silicon-based photovoltaics, photo-detectors, and super-hydrophobic devices etc., due mainly to the high absorption in both visible and infrared regions. However, the mechanisms attributed to its high-absorption characteristics have never been accurately quantified, which limits further the exploitation of this kind of material. Here, we experimentally quantify different absorption contributions in microstructured silicon fabricated by femtosecond laser pulses, which can be attributed to dopant impurities in the silicon substrate, doping impurities induced during the laser fabrication process, absorption enhancement from the light-trapping structure, and surface disordered material formed also during the laser fabrication process. From these analyses, we determine that with the assist of a light-trapping structure, dopant impurities in the silicon substrate contribute much more to the infrared absorption than those of the doping sulfur impurities induced during the fabrication process. Furthermore, the infrared absorption of material can be annealing-insensitive. These results have important implications for the design and fabrication of high-efficiency optoelectronic devices.

Theory of diffusive $\Psi_0$ Josephson junctions in the presence of spin-orbit coupling

F. S. Bergeret and I. V. Tokatly

2015 EPL 110 57005

We present a full microscopic theory to describe the Josephson current through an extended superconductor-normal metal-superconductor (SNS) diffusive junction with an intrinsic spin-orbit coupling (SOC) in the presence of a spin-splitting field $\mathbf{h}$. We demonstrate that the ground state of the junction corresponds to a finite intrinsic phase difference $0<\Psi_0<2\pi$ between the superconductor electrodes provided that both $\mathbf{h}$ and the SOC-induced $SU(2)$ Lorentz force are finite. The nontrivial $\Psi_0$ is closely related to the appearance of an equilibrium spin current in the normal metal with the spin projection parallel to the exchange field direction. In the particular case of a Rashba SOC we present analytic and numerical results for $\Psi_0$ as a function of the strengths of the spin fields, the length of the junction, the temperature and the properties of SN interfaces.
First-principles simulation of electron mean-free-path spectra and thermoelectric properties in silicon

Bo Qiu, Zhiting Tian, Ajit Vallabhaneni, Bolin Liao, Jonathan M. Mendoza, Oscar D. Restrepo, Xiulin Ruan and Gang Chen

2015 EPL 109 57006

The mean free paths (MFPs) of energy carriers are of critical importance to the nano-engineering of better thermoelectric materials. Despite significant progress in the first-principles–based understanding of the spectral distribution of phonon MFPs in recent years, the spectral distribution of electron MFPs remains unclear. In this work, we compute the energy-dependent electron scatterings and MFPs in silicon from first principles. The electrical conductivity accumulation with respect to electron MFPs is compared to that of the phonon thermal conductivity accumulation to illustrate the quantitative impact of nanostructuring on electron and phonon transport. By combining all electron and phonon transport properties from first principles, we predict the thermoelectric properties of the bulk and nanostructured silicon, and find that silicon with 20 nm nanograins can result in a higher than five times enhancement in their thermoelectric figure of merit as the grain boundaries scatter phonons more significantly than that of electrons due to their disparate MFP distributions.

Exactly solvable 2D topological Kondo lattice model

Igor N. Karnaukhov and Igor O. Slieptsov

2015 EPL 109 57005

A spin-1/2 Kitaev sublattice interacting with a subsystem of spinless fermions is studied on a honeycomb lattice when the fermion band is half-filled. The model Hamiltonian describes a topological Kondo lattice with the Kitaev interaction, it is solved exactly by reduction to free Majorana fermions in a static Z₂ gauge field. A yet unsolved problem of a hybridization of fermions and local moments in the Kondo lattice at low temperatures is solved in the framework of the proposed model. The Kondo hybridization gap is opened and the system is fixed in insulator and spin insulator states, due to the spin-fermion nature of the gap. We will show that the hybridization between local moments and itinerant fermions should be understood as hybridization between corresponding Majorana fermions of the spin and charge sectors. The RKKI interaction between local moments is not realized in the model, a system demonstrates a “quasi-Kondo” scenario of behavior with realization chiral gapless edge states in topological nontrivial phases. The ground-state phase diagram of the interacting subsystems calculated in the parameter space is rich.
Correlation of crystal quality and extreme magnetoresistance of WTe$_2$

Mazhar N. Ali, Leslie Schoop, Jun Xiong, Steven Flynn, Quinn Gibson, Max Hirschberger, N. P. Ong and R. J. Cava

2015 *EPL* 110 67002

High-quality single crystals of WTe$_2$ were grown using a Te flux followed by a cleaning step involving self-vapor transport. The method is reproducible and yields consistently higher-quality single crystals than are typically obtained via halide-assisted vapor transport methods. Magnetoresistance (MR) values at 9 tesla and 2 kelvin as high as 1.75 million $\%$, nearly an order of magnitude higher than previously reported for this material, were obtained on crystals with residual resistivity ratio (RRR) of approximately 1250. The MR follows a near $B^2$ law ($B = 1.95(1)$) and, assuming a semiclassical model, the average carrier mobility for the highest-quality crystal was found to be 167,000 cm$^2$/Vs at 2 K. A correlation of RRR, MR ratio and average carrier mobility $\mu_{\text{avg}}$ is found with the cooling rate during the flux growth.

Multidomain switching in the ferroelectric nanodots

Pierre-William Martelli, Séraphin M. Mefire and Igor A. Luk’yanchuk

2015 *EPL* 111 50001

Controlling the polarization switching in the ferroelectric nanocrystals, nanowires and nanodots has an inherent specificity related to the emergence of depolarization field that is associated with the spontaneous polarization. This field splits the finite-size ferroelectric sample into polarization domains. Here, based on 3D numerical simulations, we study the formation of 180° polarization domains in a nanoplatelet, made of uniaxial ferroelectric material, and show that in addition to the polarized monodomain state, the multidomain structures, notably of stripe and cylindrical shapes, can arise and compete during the switching process. The multibit switching protocol between these configurations may be realized by temperature and field variations.
**Novel electronic and phonon-related properties of the newly discovered silicide superconductor Li$_2$IrSi$_3$**

Hong-Yan Lu, Ni-Na Wang, Lei Geng, San Chen, Yang Yang, Wen-Jian Lu, Wan-Sheng Wang and Jian Sun

2015 *EPL* **110** 17003

By means of first-principles calculations, we investigate the electronic structure, lattice dynamics, and electron-phonon coupling of the newly discovered silicide superconductor Li$_2$IrSi$_3$. The band structure shows obvious three-dimensional character, and the number of hole pockets around the center of the Brillouin zone depends on whether spin-orbit coupling is taken into consideration. For the phonon-related properties, a phononic-crystal–like behavior with a frequency gap in the range $400 \, \text{cm}^{-1} < \Omega < 411 \, \text{cm}^{-1}$ is discovered, which makes Li$_2$IrSi$_3$ a good candidate for controlling the propagation of phonons. The electron-phonon coupling constant $\lambda$ equals 0.52, and the estimated superconducting transition temperature $T_c \approx 4.1 \, \text{K}$ is close to its experimental value, suggesting that Li$_2$IrSi$_3$ is a weak-coupling phonon-mediated superconductor.

**Topological hierarchy insulators and topological fractal insulators**

Jing He, Ying Liang and Su-peng Kou

2015 *EPL* **112** 17010

Topological insulators are new states of quantum matter with metallic edge/surface states. In this paper, we point out that there exists a new type of particle-hole symmetry-protected topological insulator—the topological hierarchy insulator (THI), a composite topological state of a (parent) topological insulator and its defect-induced topological mid-gap states. A particular type of THI is the topological fractal insulator, which is a THI with self-similar topological structure. In the end, we also discuss the possible experimental realizations of THIs.
Effect of surface functionalization on the electronic transport properties of Ti$_3$C$_2$ MXene

G. R. Berdiyorov

2015 EPL 111 67002

The effects of surface functionalization on the electronic transport properties of the MXene compound Ti$_3$C$_2$ are studied using density-functional theory in combination with the nonequilibrium Green’s function formalism. Fluorinated, oxidized and hydroxylated surfaces are considered and the obtained results are compared with the ones for the pristine MXene. It is found that the surface termination has a considerable impact on the electronic transport in MXene. For example, the fluorinated sample shows the largest transmission, whereas surface oxidation results in a considerable reduction of the electronic transmission. The current in the former sample can be up to 4 times larger for a given bias voltage as compared to the case of bare MXene. The increased transmission originates from the extended electronic states and smaller variations of the electrostatic potential profile. Our findings can be useful in designing MXene-based anode materials for energy storage applications, where enhanced electronic transport will be an asset.

Emergent BCS regime of the two-dimensional fermionic Hubbard model: Ground-state phase diagram

Youjin Deng, Evgeny Kozik, Nikolay V. Prokof’ev and Boris V. Svistunov

2015 EPL 110 57001

For over half a century, the Hubbard model has played a paradigmatic role in attempts to understand quantum phenomena exhibited by correlated electrons in solids. Despite a substantial effort and the apparent simplicity of the model, its behavior in many important regimes has remained unknown. Here we study superfluidity in the two-dimensional Hubbard model with controlled error bars up to the coupling strength $U = 4$ and filling factor $n = 0.7$. We show, by means of unbiased diagrammatic Monte Carlo simulations, that in this regime the superfluid transition is governed by Fermi liquid physics with an emergent weak BCS-type coupling driving the instability. The corresponding ground-state phase diagram in the $(n, U)$ plane describes the competition between the superfluid states of $p$- and $d$-wave symmetry. We also report dimensionless coupling constants in this effective BCS regime.
Quantum oscillations and upper critical magnetic field of the iron-based superconductor FeSe

Alain Audouard, Fabienne Duc, Loïc Drigo, Pierre Toulemonde, Sandra Karlsson, Pierre Strobel and André Sulpice

2015 EPL 109 27003

Shubnikov-de Haas (SdH) oscillations and upper critical magnetic field ($H_{c2}$) of the iron-based superconductor FeSe ($T_c = 8.6$ K) have been studied by tunnel diode oscillator-based measurements in magnetic fields of up to 55 T and temperatures down to 1.6 K. Several Fourier components enter the SdH oscillations spectrum with frequencies definitely smaller than predicted by band structure calculations indicating band renormalization and reconstruction of the Fermi surface at low temperature, in line with previous ARPES data. The Werthamer-Helfand-Hohenberg model accounts for the temperature dependence of ($H_{c2}$) for magnetic field applied both parallel ($\mathbf{H} \parallel ab$) and perpendicular ($\mathbf{H} \parallel c$) to the iron conducting plane, suggesting that one band mainly controls the superconducting properties in magnetic fields despite the multiband nature of the Fermi surface. Whereas Pauli pair breaking is negligible for $\mathbf{H} \parallel c$, a Pauli paramagnetic contribution is evidenced for $\mathbf{H} \parallel ab$ with Maki parameter $\alpha = 2.1$, corresponding to Pauli field $H_p = 36.5$ T.

Majorana fermion exchange in strictly one-dimensional structures

Ching-Kai Chiu, M. M. Vazifeh and M. Franz

2015 EPL 110 10001

It is generally thought that the adiabatic exchange of two identical particles is impossible in one spatial dimension. Here we describe a simple protocol that permits the adiabatic exchange of two Majorana fermions in a one-dimensional topological superconductor wire. The exchange relies on the concept of “Majorana shuttle” whereby a $\pi$ domain wall in the superconducting order parameter which hosts a pair of ancillary majoranas delivers one zero mode across the wire while the other one tunnels in the opposite direction. The method requires some tuning of parameters and does not, therefore, enjoy full topological protection. The resulting exchange statistics, however, remain non-Abelian for a wide range of parameters that characterize the exchange.
A generalized perspective on non-perturbative linked-cluster expansions

K. Coester, S. Clever, F. Herbst, S. Capponi and K. P. Schmidt

2015 EPL 110 20006

We identify a fundamental challenge for any non-perturbative approach based on finite clusters resulting from the reduced symmetry on graphs, most importantly the breaking of translational symmetry, when targeting the properties of excited states. This can be traced back to the appearance of intruder states in the low-energy spectrum, which represent a major obstacle in quasi-degenerate perturbation theory. Here a generalized notion of cluster additivity is introduced, which is used to formulate an optimized scheme of graph-based continuous unitary transformations allowing to solve and to physically understand this major issue. Most remarkably, our improved scheme demands to go beyond the paradigm of using the exact eigenvectors on graphs.
Using light to probe neuronal function

Vincent R. Daria and Hans-A. Bachor

2015 *EPL* **111** 38001

In the last few years a multi-disciplinary approach has been launched to investigate the brain using new techniques, which are capable of probing neuronal function across the entire length scales of the brain. Here, we discuss optical tools and spatial light patterning techniques to investigate brain function from the perspective of individual neurons and neuronal circuits. We discuss both biochemical and genetic tools to stimulate neurons, as well as techniques to record neuronal activity. We discuss optical projection and imaging tricks that can be dynamically customized to a particular neuron morphology and neuronal circuit layout facilitating a systematic study of their input/output transfer functions. These optical techniques will play a major role towards understanding the operation of a brain.

Activity-driven fluctuations in living cells

É. Fodor, M. Guo, N. S. Gov, P. Visco, D. A. Weitz and F. van Wijland

2015 *EPL* **110** 48005

We propose a model for the dynamics of a probe embedded in a living cell, where both thermal fluctuations and nonequilibrium activity coexist. The model is based on a confining harmonic potential describing the elastic cytoskeletal matrix, which undergoes random active hops as a result of the nonequilibrium rearrangements within the cell. We describe the probe’s statistics and we bring forth quantities affected by the nonequilibrium activity. We find an excellent agreement between the predictions of our model and experimental results for tracers inside living cells. Finally, we exploit our model to arrive at quantitative predictions for the parameters characterizing nonequilibrium activity, such as the typical time scale of the activity and the amplitude of the active fluctuations.
Assessing node risk and vulnerability in epidemics on networks

T. Rogers

2015 *EPL* **109** 28005

Which nodes are most vulnerable to an epidemic spreading through a network, and which carry the highest risk of causing a major outbreak if they are the source of the infection? Here we show how these questions can be answered to good approximation using the cavity method. Several curious properties of node vulnerability and risk are explored: some nodes are more vulnerable than others to weaker infections, yet less vulnerable to stronger ones; a node is always more likely to be caught in an outbreak than it is to start one, except when the disease has a deterministic lifetime; the rank order of node risk depends on the details of the distribution of infectious periods.

Dynamics of an asymmetric bilayer lipid membrane in a viscous solvent

R. J. Bingham, S. W. Smye and P. D. Olmsted

2015 *EPL* **111** 18004

Bilayer lipid membranes (BLMs) are an essential component of many biological systems, forming a functional barrier between the cell and the surrounding environment. When the membrane relaxes from a structural perturbation, the dynamics of the relaxation depends on the bilayer structure. We present a model of a BLM in a viscous solvent, including an explicit description of a “thick” membrane, where the fluctuations in the thickness of a monolayer leaflet are coupled to changes in the lipid density within that monolayer. We find dispersion relations describing three intuitive forms of bilayer motion, including a mode describing motion of the intermonolayer surface not noted previously in the literature. Two intrinsic length scales emerge that help characterise the dynamics; the well-known Saffman-Delbrück length and another, $l_r$, resulting from the intermonolayer friction. The framework also allows for asymmetry in the BLM parameters between the monolayer leaflets, which is found to couple dynamic modes of bilayer motion.
Perspective on the Cosmic Microwave Background

J. Dunkley

2015 *EPL* **111** 49001

I give a view of Cosmic Microwave Background research, briefly describing its evolution and summarizing recent observations that include the *Planck* satellite and ground-based experiments. I describe some of the cosmological properties that the community has been able to extract from its rich information, and look to future goals for upcoming observations.

Light and the distribution of time

D. Calonico, M. Inguscio and F. Levi

2015 *EPL* **110** 40001

Light allows to time travel: light from the Universe offers the possibility to look back to its ancestral epochs, at the very first moments. Nowadays light is also a carrier that allows time to travel, bringing atomic clocks references with the most advanced precision. The frontier of timekeeping and time transfer using light paves the way to unprecedented applications in science and metrology. Light is fundamental in the present effort to redefine the unit of time, to improve our knowledge of fundamental physics laws, geodesy, radioastronomy. Light could be also a new mean to investigate dark matter in the known Universe and possibly to detect gravitational waves.
Measurements of Newton’s gravitational constant and the length of day

J. D. Anderson, G. Schubert, V. Trimble and M. R. Feldman

2015 EPL 110 10002

About a dozen measurements of Newton’s gravitational constant, G, since 1962 have yielded values that differ by far more than their reported random plus systematic errors. We find that these values for G are oscillatory in nature, with a period of \( P = 5.899 \pm 0.062 \) yr, an amplitude of \( (1.619 \pm 0.103) \times 10^{-14} \) m\(^3\)kg\(^{-1}\)s\(^{-2}\), and mean-value crossings in 1994 and 1997. However, we do not suggest that G is actually varying by this much, this quickly, but instead that something in the measurement process varies. Of other recently reported results, to the best of our knowledge, the only measurement with the same period and phase is the Length of Day (LOD—defined as a frequency measurement such that a positive increase in LOD values means slower Earth rotation rates and therefore longer days). The aforementioned period is also about half of a solar activity cycle, but the correlation is far less convincing. The 5.9 year periodic signal in LOD has previously been interpreted as due to fluid core motions and inner-core coupling. We report the G/LOD correlation, whose statistical significance is 0.99764 assuming no difference in phase, without claiming to have any satisfactory explanation for it. Least unlikely, perhaps, are currents in the Earth’s fluid core that change both its moment of inertia (affecting LOD) and the circumstances in which the Earth-based experiments measure G. In this case, there might be correlations with terrestrial-magnetic-field measurements.

A note on initial state entanglement in inflationary cosmology

Sugumi Kanno

2015 EPL 111 60007

We give a new interpretation of the effect of initial state entanglement on the spectrum of vacuum fluctuations. We consider an initially entangled state between two free massive scalar fields in de Sitter space. We construct the initial state by making use of a Bogoliubov transformation between the Bunch-Davies vacuum and a four-mode squeezed state, and then derive the exact power spectrum for one of the scalar fields. We demonstrate that an oscillatory spectrum hardly appears for the initially entangled state unless an \textit{ad hoc} absolute value of the Bogoliubov coefficients is chosen.
Absence of an effective Horizon for black holes in Gravity's Rainbow

Ahmed Farag Ali, Mir Faizal and Barun Majumder

2015 *EPL* **109** 20001

We argue that the divergence in time for an asymptotic observer occurs because of specifying the position of the Horizon beyond the Planck scale. In fact, a similar divergence in time will also occur for an in-going observer in Gravity’s Rainbow, if we again specify the position of the Horizon beyond the Planck scale. On the other hand, if we accept the occurrence of a minimum measurable length scale associated with a universal invariant maximum energy scale in Gravity’s Rainbow, then the time taken by both the in-going and asymptotic observers will be finite.

Multi-disformal invariance of non-linear primordial perturbations

Yuki Watanabe, Atsushi Naruko and Misao Sasaki

2015 *EPL* **111** 39002

We study disformal transformations of the metric in the cosmological context. We first consider the disformal transformation generated by a scalar field $\phi$ and show that the curvature and tensor perturbations on the uniform $\phi$ slicing, on which the scalar field is homogeneous, are non-linearly invariant under the disformal transformation. Then we discuss the transformation properties of the evolution equations for the curvature and tensor perturbations at full non-linear order in the context of spatial gradient expansion as well as at linear order. In particular, we show that the transformation can be described in two different ways: one that clearly shows the physical invariance and the other that shows an apparent change of the causal structure. Finally we consider a new type of disformal transformation in which a multi-component scalar field comes into play, which we call a “multi-disformal transformation”. We show that the curvature and tensor perturbations are invariant at linear order, and also at non-linear order, provided that the system has reached the adiabatic limit.
Information theory approach to the Landers aftershock sequence

Abigail Jiménez

2015 *EPL* **111** 19001

The study of seismicity is becoming increasingly important with recent disasters such as the Gorkha event in Nepal in 2015. Our models mostly depend on the information given by a seismic catalog, such as rates of events and magnitudes. It has also been shown that seismicity presents long-range correlations. Here, we think about how they should be introduced in our models. We divide the region into cells and represent their activity as a time series. We then calculate how much information one cell has about the others in a future time. We find that the higher information content is in each cell with itself. By representing the region as a complex network, we can see that the information between distant cells passes thorough hubs that correspond to the main events. So we conclude that long-range interactions should be introduced as the interaction with the mainshocks, not with other cells except, perhaps, in the nearest neighbourhood.

Anomalous diffusion of volcanic earthquakes

Sumiyoshi Abe and Norikazu Suzuki

2015 *EPL* **110** 59001

Volcanic seismicity at Mt. Etna is studied. It is found that the associated stochastic process exhibits a subdiffusive phenomenon. The jump probability distribution well obeys an exponential law, whereas the waiting-time distribution follows a power law in a wide range. Although these results would seem to suggest that the phenomenon could be described by a temporally fractional kinetic theory based on the viewpoint of continuous-time random walks, the exponent of the power-law waiting-time distribution actually lies outside of the range allowed in the theory. In addition, there exists the aging phenomenon in the event-time averaged mean squared displacement, in contrast to the picture of the fractional Brownian motion. Comments are also made on possible relevances of random walks on fractals as well as nonlinear kinetics. Thus, problems of volcanic seismicity are highly challenging for science of complex systems.
Interplay of waves and eddies in rotating stratified turbulence and the link with kinetic-potential energy partition

Raffaele Marino, Duane Rosenberg, Corentin Herbert and Annick Pouquet

2015 EPL 112 49001

The interplay between waves and eddies in stably stratified rotating flows is investigated by means of world-class direct numerical simulations using up to $3072^3$ grid points. Strikingly, we find that the shift from vortex- to wave-dominated dynamics occurs at a wave number $k_R$ which does not depend on the Reynolds number, suggesting that the partition of energy between wave and vortical modes is not sensitive to the development of turbulence at the smaller scales. We also show that $k_R$ is comparable to the wave number at which exchanges between kinetic and potential modes stabilize at close to equipartition, emphasizing the role of potential energy, as conjectured in the atmosphere and the oceans. Moreover, $k_R$ varies as the inverse of the Froude number as explained by the scaling prediction proposed, consistently with recent observations and modeling of the Mesosphere–Lower Thermosphere and of the ocean.

Shear viscosity in magnetized neutron star crust

D D Ofengeim and D G Yakovlev

2015 EPL 112 59001

The electron shear viscosity due to Coulomb scattering of degenerate electrons by atomic nuclei throughout a magnetized neutron star crust is calculated. The theory is based on the shear viscosity coefficient calculated neglecting magnetic fields but taking into account gaseous, liquid and solid states of atomic nuclei, multiphonon scattering processes, and finite sizes of the nuclei although neglecting the effects of electron band structure. The effects of strong magnetic fields are included in the relaxation time approximation with the effective electron relaxation time taken from the field-free theory. The viscosity in a magnetized matter is described by five shear viscosity coefficients. They are calculated and their dependence on the magnetic field and other parameters of dense matter is analyzed. Possible applications and open problems are outlined.
Conference sponsorship

In 2015, EPL identified a select number of events to receive sponsorship funding. Several conferences were awarded sums to assist with registration, travel and/or accommodation fees to allow young researchers to attend. At most of these events awards were given for best poster and/or oral presentation. Recipients received a cash award, certificate and an invitation to submit their poster or next article to EPL. Sponsorship or support was available at the following conferences, schools and workshops.

- International Year of Light, Paris
- PHOTOPTICS 2015, Berlin
- DPG Biophysics symposium, Berlin
- Middle European Cooperation in Statistical Physics (MECO 40), Hungary
- Annual European Rheology Conference (AERC), Nantes
- Nuclear Astrophysics, York
- EPS Young Minds Prize, Barcelona
- Quantum Fluid Clusters, Toulouse
- Graphene Week, Manchester
- Vibrations at Surfaces, San Sebastian
- Ferroelectric Liquid Crystals, Prague
- Soft Matter Self-Assembly, Varenna
- Complex Photonics, Varenna
- META’15, New York
- Annual Austrian/Swiss Physical Society Meeting, Vienna
- Diamond Users Meeting, Didcot
- European Nuclear Physics Conference (EUNPC15), Groningen
- Iberian Rheology Meeting (IBEREO), Coimbra
- GraphITA, Bologna
- International Liquid Crystal Elastomer Conference (ILCEC15), Erice

Events calendar 2016

The EPL team regularly attends conferences around the world to meet the research community and promote the journal. If you would like EPL to attend or support your event, please contact the Executive Editor at info@epljournal.org. A list of conferences, which may change frequently as new events arise, is kept up to date at epljournal.org/events.
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