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And finally, thank you for your support. I hope you will find this collection of interest and that you will consider NJP as the journal of choice for your next paper.

Eberhard Bodenschatz
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# CONTENTS

## Atomic and molecular physics

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics of integrated magneto-optical traps for atom chips</td>
<td>9</td>
</tr>
<tr>
<td>S Pollock, J P Cotter, A Laliotis, F Ramirez-Martinez and E A Hinds</td>
<td></td>
</tr>
<tr>
<td>Universal contact of strongly interacting fermions at finite temperatures</td>
<td>9</td>
</tr>
<tr>
<td>Hui Hu, Xia-Ji Liu and Peter D Drummond</td>
<td></td>
</tr>
<tr>
<td>Resonant Hawking radiation in Bose–Einstein condensates</td>
<td>9</td>
</tr>
<tr>
<td>I Zapata, M Albert, R Parentani and F Sol</td>
<td></td>
</tr>
<tr>
<td>Angle-resolved electron spectroscopy of the resonant Auger decay in xenon with meV energy resolution</td>
<td>10</td>
</tr>
<tr>
<td>Johan Söderström, Andreas Lindblad, Alexei N Grum-Grzhimailo, Oksana Travnikova, Christophe Nicolas, Svante Svensson and Catalin Miron</td>
<td></td>
</tr>
<tr>
<td>Low-energy electron point projection microscopy of suspended graphene, the ultimate ‘microscope slide’</td>
<td>10</td>
</tr>
<tr>
<td>J Y Mutus, L Livadaru, J T Robinson, R Urban, M H Salomons, M Cloutier and R A Wolkow</td>
<td></td>
</tr>
<tr>
<td>Regimes of classical transport of cold gases in a two-dimensional anisotropic disorder</td>
<td>10</td>
</tr>
<tr>
<td>L Pezzè, M Robert-de-Saint-Vincent, T Bourdel, J P Brantut, B Allard, T Plisson, A Aspect, P Bouyer and L Sanchez-Palencia</td>
<td></td>
</tr>
<tr>
<td>Normal modes of trapped ions in the presence of anharmonic trap potentials</td>
<td>11</td>
</tr>
<tr>
<td>J P Home, D Hanneke, J D Jost, D Leibfried and D J Wineland</td>
<td></td>
</tr>
</tbody>
</table>

## Optics and imaging

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposal for an optomechanical traveling wave phonon–photon translator</td>
<td>11</td>
</tr>
<tr>
<td>Amir H Safavi-Naeini and Oskar Painter</td>
<td></td>
</tr>
<tr>
<td>Evidence for subwavelength imaging with positive refraction</td>
<td>12</td>
</tr>
<tr>
<td>Yun Gui Ma, Sahar Saheldivan, C K Ong, Tomáš Tyc and Ulf Leonhardt</td>
<td></td>
</tr>
<tr>
<td>Nonlocal restoration of two-mode squeezing in the presence of strong optical loss</td>
<td>12</td>
</tr>
<tr>
<td>Russell Bloomer, Matthew Pysher and Olivier Pfister</td>
<td></td>
</tr>
<tr>
<td>Near-, mesoscopic and far-field regimes of a subwavelength Young’s double-slit</td>
<td>12</td>
</tr>
<tr>
<td>J Le Perchec, A Barbara and P Quémerais</td>
<td></td>
</tr>
<tr>
<td>Invisibility cloaking without superluminal propagation</td>
<td>13</td>
</tr>
<tr>
<td>Janos Perczel, Tomáš Tyc and Ulf Leonhardt</td>
<td></td>
</tr>
</tbody>
</table>

## Quantum optics and lasers

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapped ions in optical lattices for probing oscillator chain models</td>
<td>13</td>
</tr>
<tr>
<td>Thaned Pruttivarasin, Michael Ramm, Ishan Talukdar, Axel Kreuter and Hartmut Häffner</td>
<td></td>
</tr>
<tr>
<td>Laser interferometry with translucent and absorbing micromotors</td>
<td>13</td>
</tr>
<tr>
<td>D Friedrich, H Kaufer, T Westphal, K Yamamoto, A Sawadowsky, F Ya Khalili, S L Danilishin, S Goßler, K Danzmann and R Schnabel</td>
<td></td>
</tr>
<tr>
<td>Two-photon quantum walks in an elliptical direct-write waveguide array</td>
<td>14</td>
</tr>
</tbody>
</table>
New Journal of Physics: Highlights of 2011

**Condensed matter**

- **Monopole defects and magnetic Coulomb blockade**
  Sam Ladak, Dan Read, Tolek Tyliszczak, Will R Branford and Lesley F Cohen

- **Antimagnets: controlling magnetic fields with superconductor–metamaterial hybrids**
  Alvaro Sanchez, Carles Navau, Jordi Prat-Camps and Du-Xing Chen

- **Graphene, universality of the quantum Hall effect and redefinition of the SI system**
  T J B M Janssen, N E Fletcher, R Goebel, J M Williams, A Tzalenchuk, R Yakimova, S Kubatkin, S Lara-Avila and V I Fal'ko

- **Sensing external spins with nitrogen-vacancy diamond**
  Bernhard Grotz, Johannes Beck, Philipp Neumann, Boris Naydenov, Rolf Reuter, Friedemann Reinhard et al

- **Hot electrons in magnetic point contacts as a photon source**
  A M Kadigrobov, R I Shekhter, S I Kulinich, M Jonson, O P Balkashin, V V Fisun, Yu G Naidyuk, I K Yanson, S Andersson and V Korenivski

- **Two-dimensional quantum liquids from interacting non-Abelian anyons**
  Andreas W W Ludwig, Didier Poilblanc, Simon Trebst and Matthias Troyer

**Soft matter and biophysics**

- **Emergence of microstructural patterns in skin cancer: a phase separation analysis in a binary cell mixture**
  C Chatelain, T Balois, P Ciarletta, M Ben Amar

- **Quantal concept of T-cell activation: adhesion domains as immunological synapses**
  Erich Sackmann

- **Wet granular walkers and climbers**
  Z S Khan, A Steinberger, R Seemann and S Herminghaus

- **Measurement of the exchange rate of waters of hydration in elastin by 2D T2–T2 correlation nuclear magnetic resonance spectroscopy**
  Cheng Sun and Gregory S Boutis

- **Phase separation and near-critical fluctuations in two-component lipid membranes: Monte Carlo simulations on experimentally relevant scales**
  Jens Ehrig, Eugene P Petrov and Petra Schwille

**Plasma physics**

- **Spontaneous disordering of a two-dimensional (2D) plasma crystal**
  Sergey K Zhidanov, Markus H Thoma and Gregor E Morfill

- **Demonstration of the synchrotron-type spectrum of laser-produced Betatron radiation**
  S Fourmaux, S Corde, K T Phuoc, P M Leguy, S Payeur, P Lassonde, G Naidyuk, G Lebrun, C Fourment, V Malka et al
### Statistical physics and complex systems

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zipf's law unzipped</td>
<td>23</td>
</tr>
<tr>
<td>Seung Ki Baek, Sebastian Bernhardsson and Petter Minnhagen</td>
<td></td>
</tr>
<tr>
<td>Adaptive-network models of swarm dynamics</td>
<td>24</td>
</tr>
<tr>
<td>Cristián Huepe, Gerd Zschaler, Anne-Ly Do and Thilo Gross</td>
<td></td>
</tr>
<tr>
<td>Inferring network topology from complex dynamics</td>
<td>24</td>
</tr>
<tr>
<td>Srinivas Gorur, Shandilya and Marc Timme</td>
<td></td>
</tr>
<tr>
<td>The importance of interlinguistic similarity and stable bilingualism when two languages compete</td>
<td>24</td>
</tr>
<tr>
<td>J Mira, L F Seoane and J J Nieto</td>
<td></td>
</tr>
<tr>
<td>Geography versus topology in the European Ownership Network</td>
<td>25</td>
</tr>
<tr>
<td>Stefania Vitali and Stefano Battiston</td>
<td></td>
</tr>
<tr>
<td>Orientation statistics of small particles in turbulence</td>
<td>25</td>
</tr>
<tr>
<td>Alain Pumir and Michael Wilkinson</td>
<td></td>
</tr>
</tbody>
</table>

### Astrophysics, cosmology and gravitation

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holographic dual of collimated radiation</td>
<td>25</td>
</tr>
<tr>
<td>Veronika E Hubeny</td>
<td></td>
</tr>
<tr>
<td>Experimental evidence of analogue Hawking radiation from ultrashort laser pulse filaments</td>
<td>26</td>
</tr>
<tr>
<td>E Rubino, F Belgiovane, S L Cacciatori, M Clerici, V Gorini, G Örtenzi, L Rizzi, V G Sala, M Kulesik and D Faccio</td>
<td></td>
</tr>
<tr>
<td>Astrophysical jets: insights into long-term hydrodynamics</td>
<td>26</td>
</tr>
<tr>
<td>D Tordella, M Belan, S Massaglia, S De Ponte, A Mignone, E Bodenschatz and A Ferrari</td>
<td></td>
</tr>
</tbody>
</table>
New Journal of Physics: Highlights of 2011

Dark stars and boosted dark matter annihilation rates
Cosmin Ilie, Katherine Freese and Douglas Spolyar

High-energy particle physics

Quark–gluon plasma at the RHIC and the LHC: perfect fluid too perfect?
James L Nagle, Ian G Bearden and William A Zajc

Study of neutrino interactions with the electronic detectors of the OPERA experiment
The OPERA Collaboration

Measurement of charm production in neutrino charged-current interactions
The CHORUS Collaboration

A search for new physics in dijet mass and angular distributions in $pp$ collisions at $\sqrt{s} = 7$TeV measured with the ATLAS detector
The ATLAS Collaboration

New insights into particle detection with superheated liquids
The PICASSO Collaboration

Nanophysics

Coupling and guided propagation along parallel chains of plasmonic nanoparticles
Andrea Alù, Pavel A Belov and Nader Engheta

Spin waves in zigzag graphene nanoribbons and the stability of edge ferromagnetism
F J Culchac, A Latgé and A T Costa

Resistance switching at the nanometre scale in amorphous carbon
Abu Sebastian, Andrew Pauza, Christophe Rossel, Robert M Shelby, Arantxa Fraile Rodriguez, Haralampos Pudis and Evangelos Eleftheriou

Quantum measurements between a single spin and a torsional nanomechanical resonator
B D'Urso, M V Gurudev Dutt, S Dhingra and N M Nusran

Ultrathin BaTiO$_3$ templates for multiferroic nanostructures
Xumin Chen, Seolun Yang, Ji-Hyun Kim, Hyung De Kim, Jee-Sung Kim, Geoffrey Rojas, Ralph Skomski, Haidong Lu et al

Quantum physics

Experimental amplification of an entangled photon: what if the detection loophole is ignored?
Enrico Pomarico, Bruno Sanguinetti, Pavel Sekatski, Hugo Zbinden and Nicolas Gisin

Quantum eavesdropping without interception: an attack exploiting the dead time of single-photon detectors
Henning Weier, Harald Krauss, Markus Raub, Martin Fürst, Sebastian Nauerth and Harald Weinfurter

Quantum process tomography with coherent states
Saleh Rahimi-Keshari, Artur Scherer, Ady Mann, A T Rezakhani, A I Lvovsky and Barry C Sanders

Experimental observation of time-delays associated with electric Matteucci–Pozzi phase shifts
Shawn A Hilbert, Adam Caprez and Herman Batelaan

Quantum reading capacity
Stefano Pirandola, Cosmo Lupu, Vittorio Giovannetti, Stefano Mancini and Samuel L Braunstein

List of editors

Editorial Board
Atomic and molecular physics

Characteristics of integrated magneto-optical traps for atom chips

S Pollock¹, J P Cotter¹, A Laliotis²,³, F Ramirez-Martinez²,³ and E A Hinds¹

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We investigate the operation of pyramidal magneto-optical traps (MOTs) microfabricated in silicon. Measurements of the loading and loss rates give insights into the role of the nearby surface in the MOT dynamics. Studies of the fluorescence versus laser frequency and intensity allow us to develop a simple theory of operation. The number of ⁸⁵Rb atoms trapped in the pyramid is approximately L⁶, where L ≤ 6 is the size of the pyramid opening in mm. This follows quite naturally from the relation between capture velocity and size and differs from the L²⁶ often used for describing larger MOTs. Our results represent substantial progress towards fully integrated atomic physics experiments and devices.

Universal contact of strongly interacting fermions at finite temperatures

FOCUS ON STRONGLY CORRELATED QUANTUM FLUIDS: FROM ULTRACOLD QUANTUM GASES TO QCD PLASMAS

Hui Hu, Xia-Ji Liu and Peter D Drummond

ARC Centre of Excellence for Quantum-Atom Optics, Centre for Atom Optics and Ultrafast Spectroscopy, Swinburne University of Technology, Melbourne 3122, Australia


The recently discovered universal thermodynamic behavior of dilute, strongly interacting Fermi gases also implies a universal structure in the many-body pair-correlation function at short distances, as quantified by the contact I. Here, we theoretically calculate the temperature dependence of this universal contact for a Fermi gas in free space and in a harmonic trap. At high temperatures above the Fermi degeneracy temperature, T ≳ T_f, we obtain a reliable non-perturbative quantum virial expansion up to third order. At low temperatures, we compare different approximate strong-coupling theories. These make different predictions, which need to be tested either by future experiments or by advanced quantum Monte Carlo simulations. We conjecture that in the universal unitarity limit, the contact or correlation decreases monotonically with increasing temperature, unless the temperature is significantly lower than the critical temperature, T ≲ T_c ≳ 0.2T_f. We also discuss briefly how to measure the universal contact in either homogeneous or harmonically trapped Fermi gases.

Resonant Hawking radiation in Bose–Einstein condensates

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We study double-barrier interfaces separating regions of asymptotically subsonic and supersonic flow of Bose-condensed atoms. These setups contain at least one black hole sonic horizon from which the analogue of Hawking radiation should be generated and emitted against the flow in the subsonic region. Multiple coherent scattering by the double-barrier structure strongly modulates the transmission probability of phonons, rendering it very sensitive to their frequency. As a result, resonant tunneling occurs with high probability within a few narrow frequency intervals. This gives rise to highly non-thermal spectra with sharp peaks. We find that these peaks are mostly associated with decaying resonances and only occasionally with dynamical instabilities. Even at achievable non-zero temperatures, the radiation peaks can be dominated by spontaneous emission, i.e. enhanced zero-point fluctuations, and not, as is often the case in analogue models, by stimulated emission.
Angle-resolved electron spectroscopy of the resonant Auger decay in xenon with meV energy resolution

Johan Söderström1,2, Andreas Lindblad1,3, Alexei N Grum-Grzhimailo4, Oksana Travnikova1, Christophe Nicolas1, Svante Svensson1,2 and Catalin Miron2

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2011 New J. Phys. 13 073014

The angle-resolved resonant Auger spectrum of Xe is investigated with a record high meV energy resolution in the kinetic energy region of 34.45–39.20 eV at hν=65.110 eV, corresponding to the resonant excitation of the Auger Xe∗ 4d5/2−16p state. New lines have been observed and assigned in the spectra. The results of previous measurements concerning energies, intensities and angular distribution asymmetry parameters have been refined, complemented and, for some of the lines, corrected.

Low-energy electron point projection microscopy of suspended graphene, the ultimate ‘microscope slide’

J Y Mutus1,2, L Livadaru1,2, J T Robinson2, R Urban1,2, M H Salomons1,2, M Cloutier1,2 and R A Wolkow1,2

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Point projection microscopy (PPM) is used to image suspended graphene by using low-energy electrons (100–205 eV). Because of the low energies used, the graphene is neither damaged nor contaminated by the electron beam for doses of the order of 10⁴ electrons per nm². The transparency of graphene is measured to be 74%, equivalent to electron transmission through a sheet twice as thick as the covalent radius of sp²-bonded carbon. Also observed is rippling in the structure of the suspended graphene, with a wavelength of approximately 26 nm. The interference of the electron beam due to diffraction off the edge of a graphene knife edge is observed and is used to calculate a virtual source size of 4.7±0.6 Å for the electron emitter. It is demonstrated that graphene can serve as both the anode and the substrate in PPM, thereby avoiding distortions due to strong field gradients around nanoscale objects. Graphene can be used to image objects suspended on the sheet using PPM and, in the future, electron holography.

Regimes of classical transport of cold gases in a two-dimensional anisotropic disorder

FOCUS ON QUANTUM SIMULATION

L Pezzé, M Robert-de-Saint-Vincent1, T Bourdel, J-P Brantut2, B Allard, T Plisson, A Aspect, P Bouyer and L Sanchez-Palencia

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We numerically study the dynamics of cold atoms in a two-dimensional disordered potential. We consider an anisotropic speckle potential and focus on the classical dynamics, which is relevant to some recent experiments. Firstly, we study the behavior of particles with a fixed energy and identify different transport regimes. At low energy, the particles are classically localized due to the absence of a percolating cluster. At high energy, the particles undergo normal diffusion, and we show that the diffusion coefficients scale algebraically with the particle energy, with an anisotropy factor that is significantly different from that of the disordered potential. At intermediate energy, we find a transient sub-diffusive regime, which is relevant to the time scale of typical experiments. Secondly, we study the behavior of a cold atomic gas with an arbitrary energy distribution, using the above results as the groundwork. We show that the density profile of the atomic cloud in the diffusion regime is strongly peaked and, in particular, that it is not Gaussian. Its behavior at large distances allows us to extract the energy-dependent diffusion coefficients from experimental density distributions. For a thermal cloud released into the disordered potential, we show that our numerical predictions are in agreement with experimental findings. Not only does this paper give insights into recent experimental results, but it may also help in the interpretation of future experiments searching for deviation from classical diffusion and traces of Anderson localization.
Normal modes of trapped ions in the presence of anharmonic trap potentials

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1 Current address: Institute of Quantum Electronics, ETH Zürich, Schafmattstrasse 16, 8093-Zürich, Switzerland.


We theoretically and experimentally examine the effects of anharmonic terms in the trapping potential for linear chains of trapped ions. We concentrate on two different effects that become significant at different levels of anharmonicity. The first is a modification of the oscillation frequencies and amplitudes of the ions’ normal modes of vibration for multi-ion crystals, resulting from each ion experiencing a different curvature in the potential. In the second effect, which occurs with increased anharmonicity or higher excitation amplitude, amplitude-dependent shifts of the normal-mode frequencies become important. We evaluate normal-mode frequency and amplitude shifts, and comment on the implications for quantum information processing and quantum state engineering. Since the ratio of the anharmonic to harmonic terms typically increases as the ion–electrode distance decreases, anharmonic effects will become more significant as ion trap sizes are reduced. To avoid unwanted problems, anharmonicities should therefore be taken into account at the design stage of trap development.
Evidence for subwavelength imaging with positive refraction

Yun Gul Ma¹, Sahar Sahebdivan², C K Ong³, Tomáš Tyc²,4 and Ulf Leonhardt²

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⁴ Faculty of Science, Kotlarska 2 and Faculty of Informatics, Botanicka 68a, Masaryk University, 61137 Brno, Czech Republic


The resolution of lenses is normally limited by the wave nature of light. Imaging with perfect resolution was believed to rely on negative refraction, but here we present experimental evidence for subwavelength imaging with positive refraction.

Near-, mesoscopic and far-field regimes of a subwavelength Young’s double-slit

J Le Perchec¹, A Barbaza²,³ and P Quémérais²,⁴

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⁴ Max-Planck-Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany


The coupling distance between two narrow resonating slits made in a thick metal screen strongly modulates the optical spectral features of their scattering resonances. We show that these non-trivial modulations result from dipolar-type interactions between the slits. The radiation damping, frequency shift and local light enhancement of these modes vary with the coupling distance, and we derive analytical expressions for these physical quantities. We also explain how transmission and antenna-like radiation pattern can be tuned with specific incidence angles.

Nonlocal restoration of two-mode squeezing in the presence of strong optical loss

Russell Bloomer, Matthew Pysher and Olivier Pfister

Department of Physics, University of Virginia, Charlottesville, VA 22903, USA


We present the experimental realization of a theoretical effect discovered by Olivares and Paris (2009 Phys. Rev. A 80 032329), in which a pair of entangled optical beams undergoing independent losses can see nonlocal correlations restored by the use of a nonlocal resource correlating the losses. Twin optical beams created in an entangled, Einstein–Podolsky–Rosen (EPR) state by an optical parametric oscillator above threshold were subjected to 50% loss from beamsplitters in their paths. The resulting severe degradation of the amplitude-quadrate correlations between the two beams was then suppressed when another, independent EPR state impinged upon the other input ports of the beamsplitters, effectively entangling the losses inflicted to the initial EPR state. The additional EPR beam pair was classically coherent with the primary one but had no quantum correlations with it. This result may find applications as a ‘quantum tap’ for entanglement.
Invisibility cloaking without superluminal propagation

Janos Perczel1, Tomáš Tyč2 and Ulf Leonhardt1

1 School of Physics and Astronomy, University of St Andrews, North Haugh, St Andrews KY16 9SS, UK
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Conventional cloaking based on Euclidean transformation optics requires that the speed of light should tend to infinity on the inner surface of the cloak. Non-Euclidean cloaking still needs media with superluminal propagation. Here we show by giving an example that this is no longer necessary.

A light trajectory is shown against the distribution of the \( \varepsilon_{\sigma} \) values. The light ray enters the device, completes a loop, bounces off the mirror twice and leaves the cloak with its original direction restored (A). Panel (B) gives a closer view of the vicinity of the inner branch of the cloak. Objects placed within the white region are invisible.

Quantum optics and lasers

Trapped ions in optical lattices for probing oscillator chain models

FOCUS ON QUANTUM SIMULATION

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We show that a chain of trapped ions embedded in microtraps generated by an optical lattice can be used to study oscillator models related to dry friction and energy transport. Numerical calculations with realistic experimental parameters demonstrate that both static and dynamic properties of the ion chain change significantly as the optical lattice power is varied. Finally, we lay out an experimental scheme to use the spin degree of freedom to probe the phase space structure and quantum critical behavior of the ion chain.

Laser interferometry with translucent and absorbing mechanical oscillators

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The sensitivity of laser interferometers can be pushed into regimes that enable the direct observation of the quantum behaviour of mechanical oscillators. In the past, membranes with subwavelength thickness (thin films) have been proposed to be high-mechanical-quality, low-thermal-noise oscillators. Thin films from a homogeneous material, however, generally show considerable light transmission accompanied by heating due to light absorption, which potentially limits quantum opto-mechanical experiments, in particular at low temperatures. In this paper, we experimentally analyse a Michelson–Sagnac interferometer including a translucent silicon nitride (SiN) membrane with subwavelength thickness. We found that such an interferometer provides an operational point that is optimally suited for quantum opto-mechanical experiments with translucent oscillators. In the case of a balanced beam splitter of the interferometer, the membrane can be placed at a node of the electro-magnetic field, which simultaneously provides lowest absorption and optimum laser noise rejection at the signal port. We compare the optical and mechanical models of our interferometer with experimental data and confirm that the SiN membrane can be coupled to a laser power of the order of 1 W at 1064 nm without significantly degrading the membrane’s quality factor of the order of 106, at room temperature.

(a) Multiple interference model used to calculate the complex reflection and transmission coefficients \((r, t)\) of a translucent material with thickness \(d\) and non-zero absorption \(\text{Im}(\varepsilon_{\sigma}) > 0\) surrounded by vacuum \(n_1 = 1\). (b) Membrane position in the Michelson–Sagnac ifo with respect to the counterpropagating light fields \(a_1\) and \(a_2\).
Two-photon quantum walks in an elliptical direct-write waveguide array

**FOCUS ON INTEGRATED QUANTUM OPTICS**

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Integrated optics provides an ideal testbed for the emulation of quantum systems via continuous-time quantum walks. Here, we study the evolution of two-photon states in an elliptic array of waveguides. We characterize the photonic chip via coherent light tomography and use the results to predict distinct differences between temporally indistinguishable and distinguishable two-photon inputs, which we then compare with experimental observations. This work highlights the feasibility of emulation of coherent quantum phenomena in three-dimensional waveguide structures.

![Schematic representation of the integrated waveguide circuit (drawing not-to-scale) and associated output.](image)

All-optical switching of photonic entanglement

**FOCUS ON INTEGRATED QUANTUM OPTICS**

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Future quantum optical networks will require the ability to route entangled photons at high speeds, with minimal loss and added in-band noise, and—most importantly—without disturbing the photons’ quantum state.

Here we present an all-optical switch that fulfills these requirements and characterize its performance at the single-photon level. It exhibits a 200 ps switching window, 120:1 contrast, 1.5 dB loss, and induces no measurable degradation in the switched photons’ entangled-state fidelity (<0.002). As a proof-of-principle demonstration of its capability, we use the switch to demultiplex a single quantum channel from a dual-channel, time-division-multiplexed entangled photon stream. Furthermore, because this type of switch couples the temporal and spatial degrees of freedom, it provides an important new tool with which to encode multiple-qubit quantum states on a single photon.

![Schematic drawing of the experimental setup.](image)

Attosecond control of electron–ion recollision in high harmonic generation

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We show that high harmonic generation driven by an intense near-infrared (IR) laser can be temporally controlled when an attosecond pulse train (APT) is used to ionize the generation medium, thereby replacing tunnel ionization as the first step in the well-known three-step model. New harmonics are formed when the ionization occurs at a well-defined time within the optical cycle of the IR field. The use of APT-created electron wave packets affords new avenues for the study and application of harmonic generation. In the present experiment, this makes it possible to study harmonic generation at IR intensities where tunnel ionization does not give a measurable signal.

![Schematic drawing of the experimental setup.](image)
Demonstration of integrated microscale optics in surface-electrode ion traps

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In ion trap quantum information processing, efficient fluorescence collection is critical for fast, high-fidelity qubit detection and ion–photon entanglement. The expected size of future many-ion processors requires scalable light collection systems. We report on the development and testing of a microfabricated surface-electrode ion trap with an integrated high-numerical aperture (NA) micromirror for fluorescence collection. When coupled to a low-NA lens, the optical system is inherently scalable to large arrays of mirrors in a single device. We demonstrate the stable trapping and transport of $^{40}$Ca$^+$ ions over a 0.63 NA micromirror and observe a factor of 1.9 enhancement of photon collection compared to the planar region of the trap.

(a) Diagram of the experimental apparatus. The ion trap is mounted on a CPGA carrier placed in an ultra-high vacuum chamber with laser access across the surface of the device. Scattered fluorescent photons from a trapped $^{40}$Ca$^+$ ion collected by a relay optic are detected by a charge-coupled device (CCD) camera and a PMT. (b) Trap layout showing the integrated micromirror, rf rails and the dc control electrodes. The micromirror improves collection efficiency by locally increasing the collection solid angle.

Monopole defects and magnetic Coulomb blockade

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Magnetic monopoles, predicted by Dirac, entered a new paradigm with the discovery of emergent monopoles within dipole lattices known as bulk and artificial spin ices. The observation of monopoles in certain artificial systems, and their absence from other similar structures, is a significant puzzle. Connected artificial spin-ice structures attract much attention in terms of the possibility to read states electrically, and offer the possibility of monopole defect control via well-understood domain wall processes. Nevertheless, full comprehension of the underlying processes is lacking. Here, we establish one of the overriding components. We demonstrate using high-resolution scanning transmission x-ray microscopy (STXM) the cooperative process associated with two transverse domain walls that creates the monopole defect in NiFe. The feature size of the array is large compared to the exchange length in the ferromagnet, and the two transverse domain walls give a rich internal structure to the monopole defect vertex. The magnetic Coulomb repulsion between two domain walls carrying the same sign of magnetic charge stabilizes the monopole defects at fields greater than the depinning field for a single wall at that vertex. These observations allow us to form an overview of monopole defect control possibilities from extrinsic pinning as in Co arrays (the extreme extrinsic limit being isolated bar structures) to intrinsic pinning captured here.

A high-resolution STXM image of a monopole defect $-3q$ state in $-6.0\text{mT}$ field.

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VIDEO ABSTRACTS

Toward quantum superposition of living organisms Oriol Romero-Isart, Mathieu L Juan, Romain Quidant and J Ignacio Cirac 2010 New J. Phys. 12 033015


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Antimagnets: controlling magnetic fields with superconductor–metamaterial hybrids

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Magnetism is very important in various areas of science and technology, ranging from magnetic recording through energy generation to trapping cold atoms. Physicists have managed to master magnetism—to create and manipulate magnetic fields—almost at will. Surprisingly, there is at least one property that has been elusive until now: how to ‘switch off’ the magnetic interaction of a magnetic material with existing magnetic fields without modifying them. Here we introduce the antimagnet, a design that conceals the magnetic response of a given volume from its exterior, without altering the external magnetic fields, in some respects analogous to recent theoretical proposals for cloaking electromagnetic waves with metamaterials. However, unlike these devices, which require extreme material properties, our device is feasible and needs only two kinds of available materials: superconductors and isotropic magnetic materials. Antimagnets may have applications in magnetic-based medical techniques such as magnetic resonance imaging or in reducing the magnetic signature of vessels or planes.

Graphene, universality of the quantum Hall effect and redefinition of the SI system

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The Système Internationale d’unités (SI) is about to undergo its biggest change in half a century by redefining the units for mass and current in terms of the fundamental constants $h$ and $e$, respectively. This change crucially relies on the exactness of the relationships that link these constants to measurable quantities. Here we report the first direct comparison of the integer quantum Hall effect (QHE) in epitaxial graphene with that in GaAs/AlGaAs heterostructures. We find no difference in the quantized resistance value within the relative standard uncertainty of our measurement of $8.6\times10^{-11}$, this being the most stringent test of the universality of the QHE in terms of material independence.
Hot electrons in magnetic point contacts as a photon source

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We propose to use a point contact between a ferromagnetic and a normal metal in the presence of a magnetic field for creating a large inverted spin population of hot electrons in the contact core. The key point of the proposal is that when these hot electrons relax by flipping their spin, microwave photons are emitted, with a frequency tunable by the applied magnetic field. While point contacts are an established technology, their use as a photon source is a new and potentially very useful application. We show that this photon emission process can be detected by means of transport spectroscopy and demonstrate stimulated emission of radiation in the 10–100 GHz range for a model point contact system using a minority-spin ferromagnetic injector. These results can potentially lead to new types of lasers based on spin injection in metals.

Illustration of a spin-flip transition emitting a microwave photon, taking place in an inverted population spin-split electron system. The spin-polarization inversion is achieved by spin injection from a ferromagnet (F) into a normal metal (N) of small dimensions, across a potential barrier (I). The spin splitting, and therefore the photon emission frequency, is tuned by the external magnetic field. Stimulated emission is achieved by resonantly irradiating the spin injection region. A laser action can be achieved by adding suitable light resonators (not shown).

Two-dimensional quantum liquids from interacting non-Abelian anyons

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A set of localized, non-Abelian anyons—such as vortices in a $\rho_+^1i\rho_-$ superconductor or quasiholes in certain quantum Hall states—gives rise to a macroscopic degeneracy. Such a degeneracy is split in the presence of interactions between the anyons. Here, we show that in two spatial dimensions this splitting selects a unique collective state as ground state of the interacting many-body system. This collective state can be a novel gapped quantum liquid nucleated inside the original parent liquid (of which the anyons are excitations). This physics is of relevance for any quantum Hall plateau realizing a non-Abelian quantum Hall state when moving off the center of the plateau.

The collective state of a set of interacting, localized, non-Abelian anyons is a gapped quantum liquid, which is nucleated within the original parent liquid. The two liquids are separated by a neutral, chiral edge state.
Emergence of microstructural patterns in skin cancer: a phase separation analysis in a binary cell mixture

FOCUS ON THE PHYSICS OF CANCER

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Clinical diagnosis of skin cancers is based on several morphological criteria, among which is the presence of microstructures (e.g. dots, nests) sparsely distributed within the tumour lesion. In this study, we demonstrate that these patterns might be originated by a phase separation process. In absence of cellular proliferation, in fact, a binary mixture model, which is used to represent the mechanical behaviour of skin cancers, contains a cell–cell adhesion parameter that leads to a governing equation of the Cahn–Hilliard type. Taking into account a reaction-diffusion coupling between nutrient consumption and cellular proliferation, we show, both with analytical and numerical investigations, that two-phase models may undergo a spinodal decomposition even when considering mass exchanges between the phases. The cell–nutrient interaction defines a typical diffusive length in the problem, which is found to control the saturation of a growing separated domain, thus stabilizing the microstructural pattern. The distribution and the evolution of such emerging cluster morphologies, as predicted by our model, are successfully compared to the clinical observation of microstructural patterns in tumour lesions.

Spinodal decomposition in a two-phase mixture model giving labyrinth clusters of cancerous (green) and healthy (blue) cells. Cell–cell adhesion and nutrient consumption originate this microstructural patterning, which is compared to clinical observations in skin tumor lesions.

Adhesion micro-domains (ADs) formed during encounters of lymphocytes with antigen-presenting cells (APC) mediate the genetic expression of quanta of cytokines interleukin-2 (IL-2). The IL-2-induced activation of IL-2 receptors promotes the stepwise progression of the T-cells through the cell cycle, hence their name, immunological synapses. The ADs form short-lived reaction centres controlling the recruitment of activators of the biochemical pathway (the kinases Lck and ZAP) while preventing the access of inhibitors (phosphatase CD45) through steric repulsion forces. CD45 acts as the generator of adhesion domains and, through its role as a spacer protein, also as the promoter of the reaction. In a second phase of T-cell–APC encounters, long-lived global reaction spaces (called supramolecular activation complexes (SMAC)) form by talin-mediated binding of the T-cell integrin (LFA-1) to the counter-receptor ICAM-1, resulting in the formation of ring-like tight adhesion zones (peripheral SMAC). The ADs move to the centre of the intercellular adhesion zone forming the central SMAC, which serve in the recycling of the AD. We propose that cell stimulation is triggered by integrating the effect evoked by the short-lived adhesion domains. Similar global reaction platforms are formed by killer cells to destruct APC. We present a testable mechanical model showing that global reaction spaces (SMAC or dome-like contacts between cytotoxic cells and APC) form by self-organization through delayed activation of the integrin-binding affinity and stabilization of the adhesion zones by F-actin recruitment.

The mechanical stability and the polarization of the adhering T-cells are mediated by microtubule–actin cross-talk.

Summary of continuous interaction and kiss-and-run experiments.
Mechanisms of locomotion in microscopic systems are of great interest not only for technological applications but also for the sake of understanding, and potentially harnessing, processes far from thermal equilibrium. Downscaling is a particular challenge and has led to a number of interesting concepts, including thermal ratchet systems and asymmetric swimmers. Here we present a granular ratchet system employing a particularly robust mechanism that can be implemented in various settings. The system consists of wetted spheres of different sizes that adhere to each other, and are subject to a symmetric oscillating, zero average external force field. An inherent asymmetry in the mutual force network leads to force rectification and hence to locomotion. We present a simple model that accounts for the observed behaviour, underscores its robustness and suggests a potential scalability of the concept.

Phase separation and near-critical fluctuations in two-component lipid membranes: Monte Carlo simulations on experimentally relevant scales

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By means of lattice-based Monte Carlo simulations, we address the properties of two-component lipid membranes on the experimentally relevant spatial scales of the order of a micrometer and time intervals of the order of 1 s, using DMPC/DSPC lipid mixtures as a model system. Our large-scale simulations allowed us to obtain important results not reported previously in simulation studies of lipid membranes. We find that, for a certain range of lipid compositions, the phase transition from the fluid phase to the fluid–gel phase coexistence proceeds via near-critical fluctuations, whereas for other lipid compositions this phase transition has a quasi-abrupt character. In the presence of near-critical fluctuations, transient subdiffusion of lipid molecules is observed. These features of the system are stable with respect to perturbations in lipid interaction parameters used in our simulations. The line tension characterizing lipid domains in the fluid–gel coexistence region is found to be in the pN range. On approaching the critical point, the line tension, the inverse correlation length of fluid–gel spatial fluctuations and the corresponding inverse order parameter susceptibility of the membrane vanish. All these results are in agreement with recent experimental findings for model lipid membranes. Our analysis of the domain coarsening dynamics after an abrupt quench of the membrane to the fluid–gel coexistence region reveals that lateral diffusion of lipids plays an important role in the fluid–gel phase separation process.

Measurement of the exchange rate of waters of hydration in elastin by 2D $T_2$–$T_2$ correlation nuclear magnetic resonance spectroscopy

FOCUS ON THE PHYSICS OF MAGNETIC RESONANCE ON POROUS MEDIA

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We report on a direct measurement of the exchange rate of waters of hydration in bovine nuchal ligament elastin and aortic elastin at temperatures near, below and at the physiological temperature are reported here. Using an inverse Laplace transform (ILT) algorithm, we are able to identify four components in the relaxation times. While three of the components are in good agreement with previous measurements that used multi-exponential fitting, the ILT algorithm distinguishes a fourth component having relaxation times close to that of free water and is identified as water between fibers. With the aid of scanning electron microscopy, a model is proposed that allows for the application of a two-site exchange analysis between any two components for the determination of exchange rates between reservoirs.

The results of the measurements support a model (described by Urry and Parker 2002 J. Muscle Res. Cell Motil. 23 543–59) wherein the net entropy of waters of hydration should increase with increasing temperature in the inverse temperature transition.
**Plasma physics**

**Spontaneous disordering of a two-dimensional (2D) plasma crystal**

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Spontaneous disordering plays an important role in the physics of highly ordered complex plasmas. In this paper, an analytical theory is proposed for the process of ‘cold amorphization’, which has been observed. This consists of splitting a plasma crystal into sub-domains, followed by disordering. The results of recent simulations and experiments showing such spontaneous disordering have been reviewed and interpreted in this paper. Complex plasmas can serve as a powerful tool providing fundamental insight into this process generically.

Cluster of 721 particles, interacting via Yukawa-type forces, confined inside the parabolic well.

**Demonstration of the synchrotron-type spectrum of laser-produced Betatron radiation**

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Betatron x-ray radiation in laser–plasma accelerators is produced when electrons are accelerated and wiggled in the laser-wakefield cavity. This femtosecond source, producing intense x-ray beams in the multi-kiloelectronvolt (keV) range, has been observed at different interaction regimes using a high-power laser from 10 to 100 TW. However, none of the spectral measurements carried out were at sufficient resolution, bandwidth and signal-to-noise ratio to precisely determine the shape of spectra with a single laser shot in order to avoid shot-to-shot fluctuations. In this paper, the Betatron radiation produced using a 80 TW laser is characterized by using a single photon counting method. We measure in a single shot spectra from 8 to 21 keV with a resolution better than 350 eV. The results obtained are in excellent agreement with theoretical predictions and demonstrate the synchrotron-type nature of this radiation mechanism. The critical energy is found to be $E_c = 5.6 \pm 1$ keV for our experimental conditions. In addition, the features of the source at this energy range open up novel opportunities for applications in time-resolved x-ray science.

Three typical raw electron spectra. Horizontal axis, electron energy; vertical axis, exit angle; color scale, number of counts. The latter gives an indication of the beam charge.

**Chirped pulse Raman amplification in plasma**

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Raman amplification in plasma has been proposed to be a promising method of amplifying short radiation pulses. Here, we investigate chirped pulse Raman amplification (CPRA) where the pump pulse is chirped and leads to spatiotemporal distributed gain, which exhibits superradiant scaling in the linear regime, usually associated with the nonlinear pump depletion and Compton amplification regimes. CPRA has the potential to serve as a high-efficiency high-fidelity amplifier/compressor stage.

Higher gain measurement.  
(B) Initial seed output. (C) Amplified seed output. In (B) and (C), the circles represent the capillary output.
Redshift of few-cycle infrared pulses in the filamentation regime

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By focusing infrared (IR) pulses of low energy (~0.4 mJ) into an argon cell at a pressure of a few bars, a supercontinuum is generated with a long-wavelength tail that can exceed 1500 nm for initial pulse durations of ~5 fs in the single-filamentation regime. Numerical calculations simulating collisionless mechanisms. The dimensionless parameters calculated with the results suggest that it is possible to scale the observation to the supernova remnants using transformation and similarity criteria.

Surface science and thin films

Quantum reflection of ultracold atoms from thin films, graphene and semiconductor heterostructures

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We show that thin dielectric films can be used to enhance the performance of passive atomic mirrors by enabling quantum reflection probabilities of over 90% for atoms incident at velocities of ~1 mm s⁻¹, achieved in recent experiments. This enhancement is brought about by weakening the Casimir–Polder attraction between the atom and the surface, which induces the quantum reflection. We show that suspended graphene membranes also produce higher quantum reflection probabilities than bulk matter. Temporal changes in the electrical resistance of such membranes, produced as atoms stick to the surface, can be used to monitor the reflection process, non-invasively and in real time. The resistance change allows the reflection probability to be determined purely from electrical measurements without needing to image the reflected atom cloud optically. Finally, we show how perfect atom mirrors may be manufactured from semiconductor heterostructures, which employ an embedded two-dimensional electron gas to tailor the atom–surface interaction and so enhance the reflection by classical means.

Collisionless shockwaves formed by counter-streaming laser-produced plasmas

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The interaction between two counter-streaming laser-produced plasmas is investigated using the high-power Shenguang II laser facility. The shockwaves observed in our experiment are believed to be excited by collisionless mechanisms. The dimensionless parameters calculated
Microstructure and atomic configuration of the (001)-oriented surface of epitaxial Ni–Mn–Ga thin films

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The (001)-oriented surface of epitaxial off-stoichiometric Ni–Mn–Ga ferromagnetic shape memory alloys was studied in both austenitic and martensitic phases. Scanning tunneling microscopy (STM) imaging of the austenitic surface reveals a well-ordered and reconstruction-free surface exhibiting predominantly Mn–Ga termination. We found that only one of the two atomic species (Ga or Mn) is visible in STM, which is attributed to a pronounced geometric corrugation of the surface layer. After a transformation of the sample from the initial austenitic phase to the martensitic phase upon a high-temperature annealing step, a thorough investigation of the martensitic surface was conducted. On a larger scale, pronounced corrugation lines arise from the macroscopically twinned surface. A second corrugation feature is found on a distinctly smaller scale and is shown to originate from the modulated nature of the martensitic film structure. The irregularly spaced corrugation lines support the model of adaptive martensites.

Spin valve effect in single-atom contacts

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During the exothermic adsorption of molecules at solid surfaces, dissipation of the released energy occurs via the excitation of electronic and phononic degrees of freedom. For metallic substrates, the role of the non-adiabatic electronic excitation channel has been controversially discussed, as the absence of a band gap could favour an easy coupling to a manifold of electron–hole pairs of arbitrarily low energies. We analyse this situation for the highly exothermic showcase system of molecular oxygen dissociating at Pd(100), using time-dependent perturbation theory applied to first-principles electronic-structure calculations. For a range of different trajectories of impinging O2 molecules, we compute largely varying electron–hole pair spectra, which underlines the necessity to consider the high-dimensionality of the surface dynamical process when assessing the total energy loss into this dissipation channel. Despite the high Pd density of states at the Fermi level, the concomitant non-adiabatic energy losses nevertheless never exceed about 5% of the available chemisorption energy. While this supports an electronically adiabatic description of the predominant heat dissipation into the phononic system, we critically discuss the non-adiabatic excitations in the context of the O2 spin transition during the dissociation process.
Effect of oxygen plasma etching on graphene studied using Raman spectroscopy and electronic transport measurements

FOCUS ON CHEMICALLY MODIFIED GRAPHENE

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In this paper, we report a study of graphene and graphene field effect devices after their exposure to a series of short pulses of oxygen plasma. Our data from Raman spectroscopy, back-gated field-effect and magnetotransport measurements are presented. The intensity ratio between Raman ‘D’ and ‘G’ peaks, $I_D/I_G$ (commonly used to characterize disorder in graphene), is observed to initially increase almost linearly with the number ($N_e$) of plasma-etching pulses, but later decreases at higher $N_e$ values. We also discuss the implications of our data for extracting graphene crystalline domain sizes from $I_D/I_G$. At the highest $N_e$ value measured, the ‘2D’ peak is found to be nearly suppressed while the ‘D’ peak is still prominent. Electronic transport measurements in plasma-etched graphene show an up-shifting of the Dirac point, indicating hole doping. We also characterize mobility, quantum Hall states, weak localization and various scattering lengths in a moderately etched sample. Our findings are valuable for understanding the effects of plasma etching on graphene and the physics of disordered graphene through artificially generated defects.

Conductivity as a function of back-gate voltage measured in single-layer graphene sample ‘3’ before and after two oxygen plasma pulses. The inset panel is an optical image of sample ‘3’.

Zipf’s law unzipped

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Why does Zipf’s law give a good description of data from seemingly completely unrelated phenomena? Here it is argued that the reason is that they can all be described as outcomes of a ubiquitous random group division: the elements can be citizens of a country and the groups family names, or the elements can be all the words making up a novel and the groups the unique words, or the elements could be inhabitants and the groups the cities in a country and so on. A random group formation (RGF) is presented from which a Bayesian estimate is obtained based on minimal information: it provides the best prediction for the number of groups with $k$ elements, given the total number of elements, groups and the number of elements in the largest group. For each specification of these three values, the RGF predicts a unique group distribution $N(k) \propto \exp(-bk)/k^\gamma$, where the power-law index $\gamma$ is a unique function of the same three values. The universality of the result is made possible by the fact that no system-specific assumptions are made about the mechanism responsible for the group division. The direct relation between $\gamma$ and the total number of elements, groups and the number of elements in the largest group is calculated. The predictive power of the RGF model is demonstrated by direct comparison with data from a variety of systems. It is shown that $\gamma$ usually takes values in the interval $1 \leq \gamma \leq 2$ and that the value for a given phenomenon depends in a systematic way on the total size of the dataset. The results are put in the context of earlier discussions on Zipf’s and Gibrat’s laws, $N(k) \propto k^{-2}$ and the connection between growth models and RGF is elucidated.

Probability distributions, $P(k)$, of words in the novel Ulysses by James Joyce. The full and dashed curves give the predictions for the normal and random-group distributions, respectively.

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Adaptive-network models of swarm dynamics

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We propose a simple adaptive-network model describing recent swarming experiments. Exploiting an analogy with human decision making, we capture the dynamics of the model using a low-dimensional system of equations permitting analytical investigation. We find that the model reproduces several characteristic features of swarms, including spontaneous symmetry breaking, noise- and density-driven order–disorder transitions that can be of first or second order, and intermittency. Reproducing these experimental observations using a non-spatial model suggests that spatial geometry may have less of an impact on collective motion than previously thought.

Inferring network topology from complex dynamics

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Inferring the network topology from dynamical observations is a fundamental problem pervading research on complex systems. Here, we present a simple, direct method for inferring the structural connection topology of a network, given an observation of one collective dynamical trajectory. The general theoretical framework is applicable to arbitrary network dynamical systems described by ordinary differential equations. No interference (external driving) is required and the type of dynamics is hardly restricted in any way. In particular, the observed dynamics may be arbitrarily complex; stationary, invariant or transient; synchronous or asynchronous and chaotic or periodic. Presupposing a knowledge of the functional form of the dynamical units and of the coupling functions between them, we present an analytical solution to the inverse problem of finding the network topology from observing a time series of state variables only. Robust reconstruction is achieved in any sufficiently long generic observation of the system. We extend our method to simultaneously reconstructing both the entire network topology and all parameters appearing linear in the system’s equations of motion. Reconstruction of network topology and system parameters is viable even in the presence of external noise that distorts the original dynamics substantially. The method provides a conceptually new step towards reconstructing a variety of real-world networks, including gene and protein interaction networks and neuronal circuits.

The importance of interlinguistic similarity and stable bilingualism when two languages compete

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One approach for analyzing the dynamics of two languages in competition is to fit historical data for the number of speakers of each with a mathematical model in which the parameters are interpreted as the similarity between those languages and their relative status. Within this approach, on the basis of a detailed analysis and extensive calculations, we show the outcomes that can emerge for given values of these parameters. In contrast to previous results, it is possible that in the long term both languages may coexist and survive. This happens only where there is a stable bilingual group, and this is possible only if the competing languages are sufficiently similar, in which case its occurrence is favored by both similarity and status symmetry.
Geography versus topology in the European Ownership Network

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In this paper, we investigate the network of ownership relationships among European firms and its embedding in the geographical space. We carry out a detailed analysis of geographical distances between pairs of nodes, connected by edges or by shortest paths of varying length. In particular, we study the relation between geographical distance and network distance in comparison with a random spatial network model. While the distribution of geographical distance can be fairly well reproduced, important deviations appear in the network distance and in the size of the largest strongly connected component. Our results show that geographical factors allow us to capture several features of the network, while the deviations quantify the effect of additional economic factors at work in shaping the topology. The analysis is relevant to other types of geographically embedded networks and sheds light on the link formation process in the presence of spatial constraints.

Orientation statistics of small particles in turbulence

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The statistics of the alignment of axisymmetric microscopic particles in fully developed turbulent flow is studied numerically and theoretically. Direct numerical simulations (DNS) of turbulent flows demonstrate that rod-like particles are more strongly aligned with the vorticity vector than with the principal strain axis. To elucidate this property, we compare the evolution obtained in a turbulent flow with a simpler model, where the velocity gradient of the flow is replaced by a fluctuating random matrix, whose temporal correlations reproduce the properties observed in DNS. In contrast with the DNS results, this model exhibits a strong alignment of the rods with the direction of the fastest stretching of the symmetric part of the random matrix. We argue that the correlation between the rod axis and the vorticity vector arises from similarities between the equations of motion governing these quantities.

Astrophysics, cosmology and gravitation

Holographic dual of collimated radiation

FOCUS ON STRONGLY CORRELATED QUANTUM FLUIDS: FROM ULTRACOLD QUANTUM GASES TO QCD PLASMAS

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We propose a new and simple method of estimating the radiation due to an accelerated quark in a strongly coupled medium, within the framework of the anti-de Sitter (AdS)/conformal field theory (CFT) correspondence. In particular, we offer a heuristic explanation of the collimated nature of synchrotron radiation produced by a circling quark, which was recently studied by Athanasiou et al (2010 Phys. Rev. D 81 26001). The gravitational dual of such a quark is a coiling string in AdS, whose backreaction on the spacetime geometry remains tightly confined, as if ‘beamed’ towards the boundary. While this appears to contradict conventional expectations from the scale/radius duality, we resolve the issue by observing that the backreaction of a relativistic string is reproduced by a superposition of gravitational shock waves. We further demonstrate that this proposal allows us to reduce the problem of computing the boundary stress tensor to merely calculating geodesics in AdS, as opposed to solving linearized Einstein’s equations.
Experimental evidence of analogue Hawking radiation from ultrashort laser pulse filaments

FOCUS ON CLASSICAL AND QUANTUM ANALOGUES FOR GRAVITATIONAL PHENOMENA AND RELATED EFFECTS

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Curved space–times and, in particular, event horizons of astrophysical black holes are expected to excite the quantum vacuum and give rise to an emission of quanta known as Hawking radiation. Remarkably, many physical systems may be considered analogous to black holes and as such hold promise for the detection of Hawking radiation. In particular, recent progress in the field of transformation optics, i.e. the description of optical systems in terms of curved space–time geometries, has led to a detailed description of methods for generating, via superluminal dielectrics, a blocking horizon for photons. Our measurements highlight the emission of photons from a moving refractive index perturbation induced by a laser pulse that is in quantitative agreement with the Hawking model. This opens an intriguing and readily accessible observation window into quantum field theory in curved space–time geometries.

Astrophysical jets: insights into long-term hydrodynamics

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Astrophysical jets are ubiquitous throughout the universe. They can be observed to emerge from protostellar objects, stellar x-ray binaries and supermassive black holes located at the center of active galaxies, and they are believed to originate from a central object that is surrounded by a magnetized accretion disc. With the motivations to understand whether hypersonic Newtonian jets produce any similarity to the morphologies observed in jets from young stellar objects (YSOs) and whether numerical codes, based on Godunov-type schemes, capture the basic physics of shocked flows, we have conceived a laboratory experiment and performed three-dimensional (3D) numerical simulations that reproduce the mid-to-long-term evolution of hypersonic jets. Here we show that these jets propagate, maintaining their collimation over long distances, in units of the jet initial radius. The jets studied are quasi-isentropic, are both lighter and heavier than the ambient and meet the two main scaling parameter requirements for proto-stellar jets: the ejection Mach number and the ambient/jet density ratio.

Video abstracts can add value and visibility to our work since it is a quick and entertaining (with a lot of room for creativity) way to get an idea of the motivation and content of the paper.

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Dark stars and boosted dark matter annihilation rates

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Dark stars (DSs) may constitute the first phase of stellar evolution, powered by dark matter (DM) annihilation. We investigate here the properties of DSs, assuming that the DM particle has the properties required for explaining the excess positron and electron signals in the cosmic rays detected by the PAMELA and FERMI satellites. Any possible DM interpretation of these signals will require exotic DM candidates, with annihilation cross-sections a few orders of magnitude higher than the canonical value required for correct thermal relic abundance for weakly interacting DM candidates; additionally, in most models, the annihilation must be preferentially to leptons. Secondly, we study the dependence of DS properties on the concentration parameter of the initial DM density profile of the halos where the first stars are formed. We restrict our study to the DM in the star due to simple (versus extended) adiabatic contraction and minimal (versus extended) capture; this simple study is sufficient to illustrate dependence on the cross-section and concentration parameter. Our basic results are that the final stellar properties, once the star enters the main sequence, are always roughly the same, regardless of the value of the boosted annihilation or concentration parameter in the range between $c=2$ and $c=5$: stellar mass $\sim 1000 M_\odot$, luminosity $\sim 10^7 L_\odot$ and lifetime $\sim 10^6$ years (for the minimal DM models considered here; additional DM would lead to more massive DSs). However, the lifetime, final mass and final luminosity of the DSs show some dependence on the boost factor and concentration parameter, as discussed in this paper.

High-energy particle physics

Quark–gluon plasma at the RHIC and the LHC: perfect fluid too perfect?

FOCUS ON STRONGLY CORRELATED QUANTUM FLUIDS: FROM ULTRACOLD QUANTUM GASES TO QCD PLASMAS

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Relativistic heavy-ion collisions have reached energies that enable the creation of a novel state of matter termed the quark–gluon plasma. Many observables point to a picture of the medium as rapidly equilibrating and expanding as a nearly inviscid fluid. In this paper, we explore the evolution of experimental flow observables as a function of collision energy and attempt to reconcile the observed similarities across a broad energy regime in terms of the initial conditions and viscous hydrodynamics. If the initial spatial anisotropies for all collision energies from 39 GeV to 2.76 TeV are very similar, we find that viscous hydrodynamics might be consistent with the level of agreement for $v_2$ of unidentified hadrons as a function of $p_T$. However, we predict a strong collision energy dependence for the proton $v_2(p_T)$. The results presented in this paper highlight the need for more systematic studies and for a re-evaluation of previously reported sensitivities to the early time dynamics and properties of the medium.
Study of neutrino interactions with the electronic detectors of the OPERA experiment

The OPERA Collaboration
CERN CH-1211, Genève 23, Switzerland and the Laboratori Nazionali del Gran Sasso, I-67010 Assergi (L’Aquila), Italy


The OPERA experiment is based on a hybrid technology combining electronic detectors (EDs) and nuclear emulsions. OPERA collected muon–neutrino interactions during the 2008 and 2009 physics runs of the CNGS neutrino beam, produced at CERN with an energy range of about 5–35 GeV. A total of $5.3 \times 10^{19}$ protons on target equivalent luminosity have been analysed with the OPERA EDs: scintillator strips target trackers and magnetic muon spectrometers equipped with resistive plate gas chambers and drift tubes, allowing a detailed reconstruction of muon–neutrino interactions. Charged current (CC) and neutral current (NC) interactions are identified, using the measurements in the EDs, and the NC/CC ratio is computed. The momentum distribution and the charge of the muon tracks produced in CC interactions are analysed. Calorimetric measurements of the visible energy are performed for both the CC and NC samples. For CC events, the Bjorken-\(y\) distribution and the hadronic shower profile are computed. The results are compared with a detailed Monte Carlo simulation of the response of EDs.

View of the OPERA detector; the neutrino beam enters from the left. The upper horizontal lines indicate the two identical super-modules (SM1 and SM2). The target area is made of walls filled with lead/emulsion bricks interleaved with 31 planes of plastic scintillators (TT) per SM. The VETO detector and a magnet with its inserted RPC planes are indicated by arrows, as well as some PT and XPC planes. The brick manipulator system (BMS) is also visible.

Measurement of charm production in neutrino charged-current interactions

The CHORUS Collaboration
CERN CH-1211, Genève 23, Switzerland


The nuclear emulsion target of the CHORUS detector was exposed to the wide-band neutrino beam of the CERN SPS of 27 GeV average neutrino energy from 1994 to 1997. In total, about 100 000 charged-current (CC) neutrino interactions with at least one identified muon were located in the emulsion target and fully reconstructed, using newly developed automated scanning systems. Charmed particles were searched for by a program recognizing particle decays. The observation of the decay in nuclear emulsion makes it possible to select a sample with very low background and minimal kinematical bias. In all, 2013 CC interactions with a charmed hadron candidate in the final state were selected and confirmed through visual inspection. The charm production rate induced by neutrinos relative to the CC cross-section is measured to be $\sigma(\nu_N \to \mu^- pX)/\sigma(CC) = (5.75 \pm 0.32(\text{stat})\pm0.30(\text{syst}))\%$. The charm production cross-section as a function of neutrino energy is also obtained. The results are in good agreement with previous measurements. The charm–quark hadronization produces the following charmed hadrons relative to charm quark branching ratios (in %): $f_{D^+}=43.7\pm4.5$, $f_{D_s^+}=19.2\pm4.2$, $f_{\Lambda_c^+}=25.3\pm4.2$ and $f_{\Xi_c^+}=11.8\pm4.7$.

A search for new physics in dijet mass and angular distributions in pp collisions at $\sqrt{s} = 7\text{TeV}$ measured with the ATLAS detector

The ATLAS Collaboration
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A search for new interactions and resonances produced in LHC proton–proton (pp) collisions at a centre-of-mass energy $\sqrt{s} = 7\text{TeV}$ was performed with the ATLAS detector. Using a dataset with an integrated luminosity of 36 $pb^{-1}$, dijet mass and angular distributions were measured up to dijet masses of $\sim 3.5\text{TeV}$ and were found to be in good agreement with Standard Model predictions. This analysis sets limits at 95% CL on various models for new physics: an excited quark is excluded for mass between 0.60 and 2.64 TeV, an axigluon hypothesis is excluded for axigluon masses between 0.60 and 2.10 TeV and quantum black holes are excluded in models with six extra space–time dimensions for quantum gravity scales between 0.75 and 3.67 TeV. Production cross section limits as a function of dijet mass are set using a simplified Gaussian signal model to facilitate comparisons with other hypotheses. Analysis of the dijet angular distribution using a novel technique simultaneously employing the dijet mass excludes quark contact interactions with a compositeness scale $\Lambda$ below 9.5 TeV.
New insights into particle detection with superheated liquids

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We report new results obtained from calibrations of superheated liquid droplet detectors used in dark matter searches with different radiation sources (n, α, γ). In particular, detectors were spiked with α-emitters located inside and outside the droplets. It is shown that the responses have different temperature thresholds, depending on whether α-particles or recoil nuclei create the signals. The measured temperature threshold for recoiling 210Pb nuclei from 214Po α-decays was found to be in agreement with test beam measurements using mono-energetic neutrons. A comparison of the threshold data with theoretical predictions shows deviations, especially at high temperatures. It is shown that signals produced simultaneously by recoil nuclei and α-particles have more acoustic energy than signals produced by one or the other separately. A model is presented that describes how the observed intensities of particle-induced acoustic signals can be related to the dynamics of bubble growth in superheated liquids. A growth scenario that is limited by the inertia of the surrounding liquid shows a trend that is supported by the data. An improved understanding of the bubble dynamics is an important first step in obtaining better discrimination between particle types interacting in detectors of this kind.

Stopping power in keV μm⁻¹ for α-particles (continuous), fluorine nuclei (dotted) and carbon nuclei (dash-dotted) in C4F10 calculated with SRIM. In the energy range below 500 keV fluorine always has the higher dE/dx.

Nanophysics

Coupling and guided propagation along parallel chains of plasmonic nanoparticles

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We derive a dynamic closed-form dispersion relation for the analysis of the entire spectrum of guided wave propagation along coupled parallel linear arrays of plasmonic nanoparticles, operating as optical ‘two-line’ waveguides. Compared to linear arrays of nanoparticles, our results suggest that these waveguides may support more confined beams with comparable or even longer propagation lengths, operating analogously to transmission-line segments at lower frequencies. Our formulation fully takes into account the entire dynamic interaction among the infinite number of nanoparticles composing the parallel arrays, considering also the realistic presence of losses and the frequency dispersion of the involved plasmonic materials, providing physical insights into the guidance properties that characterize this geometry.

Simulation results: comparison of the magnetic field distribution at frequency f = 585 THz (snapshot in time) for: (a) parallel chains, antisymmetric mode, (b) symmetric mode, (c) isolated chain. The figure shows how the anti-symmetric mode may be able to confine light without compromising on sensitivity to losses.
Spin waves in zigzag graphene nanoribbons and the stability of edge ferromagnetism

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We studied the low-energy spin excitations of zigzag graphene nanoribbons of varying width. We found their energy dispersion at small wave vectors to be dominated by antiferromagnetic correlations between the ribbon’s edges, in accordance with previous calculations. We point out that spin wave lifetimes are very long owing to the semi-conducting nature of electrically neutral nanoribbons. However, the application of very modest gate voltages causes a discontinuous transition to a regime of finite spin wave lifetimes. On further increasing doping, the ferromagnetic alignments along the edge become unstable against transverse spin fluctuations. This makes the experimental detection of ferromagnetism in this class of systems very delicate and poses a difficult challenge to the possible use of these nanoribbons as the basis for spintronic devices.

Quantum measurements between a single spin and a torsional nanomechanical resonator

FOCUS ON DIAMOND-BASED PHOTONICS AND SPINTRONICS

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While the motions of macroscopic objects must ultimately be governed by quantum mechanics, the distinctive features of quantum mechanics can be hidden or washed out by thermal excitations and coupling to the environment. We propose a system consisting of a graphene nanomechanical oscillator (NMO) coupled with a single spin through a uniform external magnetic field, which could become the building block for a wide range of quantum nanomechanical devices. The choice of graphene as the NMO material is critical for minimizing the moment of inertia of the oscillator. The spin originates from a nitrogen-vacancy (NV) center in a diamond nanocrystal that is positioned on the NMO. This coupling results in quantum non-demolition (QND) measurements of the oscillator and spin states, enabling a bridge between the quantum and classical worlds for a simple readout of the NV center spin and observation of the discrete states of the NMO.

Resistance switching at the nanometre scale in amorphous carbon

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The electrical transport and resistance switching mechanism in amorphous carbon (a-C) is investigated at the nanoscale. The electrical conduction in a-C thin films is shown to be captured well by a Poole–Frenkel transport model that involves nonisolated traps. Moreover, at high electric fields a field-induced threshold switching phenomenon is observed. The following resistance change is attributed to Joule heating and subsequent localized thermal annealing. We demonstrate that the mechanism is mostly due to clustering of the existing sp2 sites within the sp3 matrix. The electrical conduction behaviour, field-induced switching and Joule-heating-induced rearrangement of atomic order resulting in a resistance change are all reminiscent of conventional phase-change memory materials. This suggests the potential of a-C as a similar nonvolatile memory candidate material.
Ultrathin BaTiO$_3$ templates for multiferroic nanostructures

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The structural, electronic and dielectric properties of high-quality ultrathin BaTiO$_3$ films were investigated. The films, which were grown by ozone-assisted molecular beam epitaxy on Nb-doped SrTiO$_3$(001) substrates and have thicknesses as low as 8 unit cells (u.c.) (3.2 nm), are unreconstructed and atomically smooth with large crystalline terraces. A strain-driven transition to three-dimensional (3D) island formation is observed for films of 13 u.c. thickness (5.2 nm). The high structural quality of the surfaces, together with dielectric properties similar to bulk BaTiO$_3$ and dominantly TiO$_2$ surface termination, makes these films suitable templates for the synthesis of high-quality metal-oxide multiferroic heterostructures for the fundamental study and exploitation of magneto-electric effects, such as a recently proposed interface effect in Fe/BaTiO$_3$ heterostructures based on Fe–Ti interface bonds.

Quantum physics

Experimental amplification of an entangled photon: what if the detection loophole is ignored?

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The experimental verification of quantum features, such as entanglement, at large scales is extremely challenging because of environment-induced decoherence. Indeed, measurement techniques for demonstrating the quantumness of multiparticle systems in the presence of losses are difficult to define, and if they are not sufficiently accurate they can provide wrong conclusions. We present a Bell test where one photon of an entangled pair is amplified and then detected by threshold detectors, whose signals undergo postselection. The amplification is performed by a classical machine, which produces a fully separable micro–macro state. However, by adopting such a technique one can surprisingly observe a violation of the Clauser–Horne–Shimony–Holt inequality. This is due to the fact that ignoring the detection loophole opened by the postselection and the system losses can lead to misinterpretations, such as claiming micro–macro entanglement in a setup where evidently it is not present. By using threshold detectors and postselection, one can only infer the entanglement of the initial pair of photons, and so micro–micro entanglement, as is further confirmed by the violation of a nonseparability criterion for bipartite systems. How to detect photonic micro–macro entanglement in the presence of losses with the currently available technology remains an open question.
Quantum eavesdropping without interception: an attack exploiting the dead time of single-photon detectors

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The security of quantum key distribution (QKD) can easily be obscured if the eavesdropper can utilize technical imperfections in the actual implementation. Here, we describe and experimentally demonstrate a very simple but highly effective attack that does not need to intercept the quantum channel at all. Only by exploiting the dead time effect of single-photon detectors is the eavesdropper able to gain (asymptotically) full information about the generated keys without being detected by state-of-the-art QKD protocols. In our experiment, the eavesdropper inferred up to 98.8% of the key correctly, without increasing the bit error rate between Alice and Bob significantly. However, we find an even simpler and more effective countermeasure to inhibit this and similar attacks.

Quantum process tomography with coherent states

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We have developed an enhanced technique for characterizing quantum optical processes based on probing unknown quantum processes only with coherent states. Our method substantially improves the original proposal (Lobino et al 2008 Science 322 563), which uses a filtered Glauber–Sudarshan decomposition to determine the effect of the process on an arbitrary state. We introduce a new relation between the action of a general quantum process on coherent state inputs and its action on an arbitrary quantum state. This relation eliminates the need to invoke the Glauber–Sudarshan representation for states; hence, it dramatically simplifies the task of process identification and removes a potential source of error. The new relation also enables straightforward extensions of the method to multimode and non-trace-preserving processes. We illustrate our formalism with several examples, in which we derive analytic representations of several fundamental quantum optical processes in the Fock basis. In particular, we introduce photon-number cutoff as a reasonable physical resource limitation and address resource versus accuracy trade-off in practical applications. We show that the accuracy of process estimation scales inversely with the square root of photon-number cutoff.
Experimental observation of time-delays associated with electric Matteucci–Pozzi phase shifts

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In 1985, Matteucci and Pozzi (1985 Phys. Rev. Lett. 54 2469) demonstrated the presence of a quantum mechanical phase shift for electrons passing a pair of oppositely charged biprism wires. For this experimental arrangement no forces deflect the electrons. Consequently, the result was reported as a non-local type-2 Aharonov–Bohm effect. Boyer (2002 Found. Phys. 32 41–50; 1987 Nuovo Cimento B 100 685–701) showed theoretically that the Matteucci–Pozzi effect could be associated with a time delay caused by a classical force. We present experimental data that confirm the presence of a time delay. This result is in contrast to the situation for the original magnetic Aharonov–Bohm effect. On similar theoretical grounds, Boyer has also associated classical forces and time delays with the magnetic Aharonov–Bohm effect. Recently, we reported the absence of such observable time delays. The contrast with our current work illustrates the subtle nature of Aharonov–Bohm effects.

Quantum reading capacity

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The readout of a classical memory can be modelled as a problem of quantum channel discrimination, where a decoder retrieves information by distinguishing the different quantum channels encoded in each cell of the memory (Pirandola 2011 Phys. Rev. Lett. 106 090504). In the case of optical memories, such as CDs and DVDs, this discrimination involves lossy bosonic channels and can be remarkably boosted by the use of nonclassical light (quantum reading). Here we generalize these concepts by extending the model of memory from single-cell to multi-cell encoding. In general, information is stored in a block of cells by using a channel-codeword, i.e. a sequence of channels chosen according to a classical code. Correspondingly, the readout of data is realized by a process of ‘parallel’ channel discrimination, where the entire block of cells is probed simultaneously and decoded via an optimal collective measurement. In the limit of a large block we define the quantum reading capacity of the memory, quantifying the maximum number of readable bits per cell. This notion of capacity is nontrivial when we suitably constrain the physical resources of the decoder. For optical memories (encoding bosonic channels), such a constraint is energetic and corresponds to fixing the mean total number of photons per cell. In this case, we are able to prove a separation between the quantum reading capacity and the maximum information rate achievable by classical transmitters, i.e. arbitrary classical mixtures of coherent states. In fact, we can easily construct nonclassical transmitters that are able to outperform any classical transmitter, thus showing that the advantages of quantum reading persist in the optimal multi-cell scenario.

Information gain $G$ versus reflectivities, $\kappa_0$ and $\kappa_1$, for $n = 5$ (left panel) and $n = 1$ (right panel). Here $G$ provides the number of bits per cell which are gained by the single-copy EPR transmitter $\left| \xi \right\rangle \left\langle \xi \right|$ over all the classical transmitters in the readout of an optical memory with marginal cell $\Phi = (\kappa_0, \kappa_1)$. Note that the highest values of $G$ occur for $\kappa_0$ or $\kappa_1$ close to 1 (high reflectivities).
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