# Poster Abstracts

**66th Lindau Nobel Laureate Meeting**
**26 June – 1 July 2016**

EDUCATE. INSPIRE. CONNECT. LINDAU NOBEL LAUREATE MEETINGS WITH YOUNG SCIENTISTS · SINCE 1951

LINDAU
NOBEL LAUREATE
MEETINGS

| # | First Author | Title |
|---|---|---|
| **Atomic, Molecular, Optical and Fundamental Measurements** | | |
| 1 | Nicholas Ayres | Testing Time Reversal Symmetry with Ultracold Neutrons |
| 2 | Lisa Schmöger | Cold highly charged ions for novel optical clocks and the search for α variation |
| 3 | Sven C. Sidenstein | Coordinate-targeted fluorescence nanoscopy with multiple off-states |
| **Quantum Optics, Quantum Information and Photonics** | | |
| 4 | Julia Benedikter | Silicon Vacancy Centres in Microcavities – an Efficient Single Photon Source at Room Temperature |
| 5 | Rohit Chikkaraddy | Half-light Half-molecule at Room Temperature |
| 6 | Sébastien Hartmann | Ghost imaging with superluminescent diodes |
| 7 | Benjamin A. Stickler | Ro-translational cavity cooling of nanoscale needles and discs |
| 8 | Leo Yu | Quantum networking with quantum dot spins and telecom photons |
| **Astronomy, Astrophysics and Cosmology** | | |
| 9 | Patrick C. Breysse | High-redshift astrophysics using every photon |
| 10 | Joseph Callingham | Dying young and frustrated: Understanding the evolution of young radio galaxies |
| 11 | Kohei Kamada | Particle physics and cosmological magnetic fields |
| 12 | Christina Kreisch | Cosmological Signatures of Massive Self-Interacting Neutrinos |
| 13 | Matus Rybak | Revealing the Nature of Dark Matter and distant Galaxies with Strong Lensing |
| 14 | Suraphong Yuma | Discovery of [OII] Blobs: A New Systematic Approach to Understand Galaxy Evolution |

POSTER OVERVIEW

| # | First Author | Title |
|---|---|---|
| **Bio-Physics** | | |
| 15 | Matjaz Humar | Lasers inside live cells |
| 16 | Kirsten Schnorr | Tracing the Dynamics of Molecules in Real Time using Femtosecond XUV and X-Ray Laser Pulses |
| 17 | Thomas J. A. Wolf | Investigating DNA Base Photoprotection Mechanisms with Ultrafast NEXAFS Spectroscopy |
| **Solid-State, Materials Science and Condensed Matter Physics** | | |
| 18 | Naureen Akhtar | Smart Surfaces |
| 19 | Aftab M. Hussain | Silicon Nanotube Field Effect Transistors for Ultra Low-Power High-Performance Computing |
| 20 | S. Ichinokura | Atomically Thinned Two-dimensional superconductors |
| 21 | Martin Kaltenbrunner | Perovskite Solar Cells - Ready for Takeoff |
| 22 | B.Q. Lv | Experimental Discovery of Weyl semimetal TaAs |
| 23 | Johanna C. Palmstrom | Elastoresistance as a Probe of Electronic Nematicity in Fe-based Superconductors |
| 24 | Hiroshi Sugimoto | Silicon based novel functional nanomaterials |
| 25 | Hendrik Weimer | Dissipative quantum many-body dynamics |
| **High Energy Physics** | | |
| 26 | M. Diakaki | A new transparent XY-MicroMegas neutron beam profiler |
| 27 | Lena Funcke | Small Neutrino Masses from Gravitational θ-Term |
| 28 | Julian Garcia Pardinas | Measurement of the CP-violating weak phase $\phi_s$ in $B^0_s \rightarrow (K^+\pi^-)(K^-\pi^+)$ decays at LHCb |
| 29 | Pedro C. Malta | New limits on heavy ALPs: an analysis of SN 1987A, again |
| 30 | Sebastian Zell | On the substructure of the cosmological constant |

## Testing Time Reversal Symmetry with Ultracold Neutrons

*Nicholas Ayres*[1]

[1]Department of Physics and Astronomy, University of Sussex, Falmer, Brighton BN1 9QH, UK

The electric dipole moment of the neutron is one of our most sensitive experimental probes into the fundamental symmetries that underpin our understanding of the universe. A nonzero electric dipole moment of a fundamental particle would imply violation of time reversal symmetry, and therefore of charge-parity (CP) symmetry: the symmetry between matter and antimatter. CP symmetry is a known trouble spot in the standard model: not only does the standard model predict far too little CP violation to explain the observed dominance of matter over antimatter in the universe, it also fails to explain why the strong interaction does not violate CP.

At the Paul Scherrer Institute in Switzerland, an experiment is underway to search for this fundamental parameter. Ultracold neutrons are produced at a new source powered by one of the most intense proton beams in the world. Using a magnetic resonance technique developed by Nobel Laureate Norman Ramsey, their precession frequencies in magnetic and electric fields are measured to extraordinary precision. Observing a nonzero electric dipole moment would be a smoking gun for new physics beyond the standard model.





## Cold highly charged ions for novel optical clocks and the search for $\alpha$ variation

*Lisa Schmöger*[1,2], *O. O. Versolato*[1,2], *M. Schwarz*[1,2], *M. Kohnen*[2], *A. Windberger*[1], *B. Piest*[1], *S. Feuchtenbeiner*[1], *J. Pedregosa*[3], *T. Leopold*[2], *T. M. Baumann*[1], *M. Drewsen*[4], *T. Pfeifer*[1], *P. O. Schmidt*[2], *and J. R. Crespo López-Urrutia*[1]

[1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany
[2]Physikalisch-Technische-Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany
[3]Aix-Marseille Université, Ave Escadrille Normandie-Niémen, 13397 Marseille, France
[4]Aarhus University, Bygning 1520, 8000 Aarhus C, Denmark

Novel optical clocks based on forbidden transitions in sympathetically cooled highly charged ions (HCIs) can show improved operation in order to to set new limits on possible variations of the fine-structure constant $\alpha$ in space or time. A spatial variation across cosmological distances of this fundamental constant has been claimed based on astrophysical observations. This astrophysical finding directly maps onto a terrestrial time variation of $\alpha$ on the order of $10^{-19}$ per year. However, its magnitude is still too small for laboratory consistency checks in the scope of atomic physics. The currently best benchmarks are based on frequency comparisons between different optical clocks with a relative accuracy of a few $10^{-18}$ per year.

Forbidden optical transitions in HCIs offer multiple advantages for the development of novel optical clocks and the subsequent search for $\alpha$ variation. Compared with atoms or singly charged ions, in HCIs, the wavefunction of the optically E1-forbidden active electron is much reduced in size. This implies an extremely suppressed sensitivity to external field perturbations, such as those due to interrogation by lasers or blackbody radiation. Additionally, forbidden optical transitions found near level crossings in HCIs are extremely sensitive to possible drifts in $\alpha$ due to enhanced relativistic effects.

However, all known sources of HCIs produce them at high temperatures - typically in the MK regime - which severely limits the achievable spectral resolution of photonic studies. We have developed an experiment for retrapping, cooling and high-precision laser spectroscopy of HCIs [1]. It is based on continuously laser-cooled $Be^+$ Coulomb crystals in a linear cryogenic Paul trap [2] for stopping the motion of externally produced HCIs and sympathetically cooling them to the mK scale. This cooling induces the formation of stable mixed crystals – down to a single HCI cooled by a single $Be^+$ ion [3]. Adding HCIs to the quantum toolbox is one important goal within the scope of next-generation experiments. One aims at applying quantum logic schemes to HCIs and developing an HCI optical clock, the other one at direct VUV frequency comb spectroscopy of electronic transitions in HCIs.

[1] L. Schmöger et al., Rev. Sci. Instrum. **86**, 103111 (2015)
[2] M. Schwarz et al., Rev. Sci. Instrum. **83**, 083115 (2012)
[3] L. Schmöger et al., Science **347**, 1233 (2015)

## Coordinate-targeted fluorescence nanoscopy with multiple off-states

*Sven C. Sidenstein*[1,2], *Johann G. Danzl*[1,2], *Carola Gregor*[1], *Nicolai T. Urban*[1], *Peter Ilgen*[1], *Stefan Jakobs*[1], *and Stefan W. Hell*[1]

[1]Max Planck Institute for Biophysical Chemistry, Department of NanoBiophotonics, Am Faßberg 11, Göttingen, Germany
[2]Equal contributors.

Far-field superresolution fluorescence microscopy discerns fluorophores residing closer than the diffraction barrier by briefly transferring them in different signalling (on) and non-signalling (off) states. In coordinate-targeted superresolution variants, such as stimulated emission depletion (STED) microscopy, this state difference is created by the intensity minima and maxima of an optical pattern, causing all fluorophores to assume the off-state, except at the minima. While strong spatial confinement of the on-state enables high resolution, it also subjects the fluorophores to excess intensities and state cycles at the maxima. Here, we address these issues by driving the fluorophores into a second off-state that is inert to the excess light. By using reversibly switchable fluorescent proteins as labels, our approach is demonstrated to reduce bleaching and enhance resolution in live-cell STED microscopy. Using two and more transitions to off-states is a general strategy for augmenting the power of coordinate-targeted super-resolution microscopy. Reference: Danzl, Sidenstein et al. Nature Photonics 10, 122–128 (2016)

## Silicon Vacancy Centres in Microcavities - an Efficient Single Photon Source at Room Temperature

*Julia Benedikter*[1,2], *Elke Neu*[3], *Christoph Becher*[3], *Theodor W. Hänsch*[1,2], *and David Hunger*[1,2]

[1]Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany
[2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany
[3]Universität des Saarlandes, Campus E2 6, 66041 Saarbrücken, Germany

Single photon sources are an integral part of various quantum information applications. Solid state emitters offer on-demand single photon emission without the need for very involved set-ups. The emission properties, especially the very narrow single phonon line, and stability of the silicon vacancy (SiV) centre in diamond make it a promising candidate for a single photon source at room temperature. Especially for quantum cryptography or for shot-noise-unlimited spectroscopy, high efficiency is desirable. We use fibre-based microcavities [1, 2] to Purcell-enhance and efficiently collect the emission of single SiV centres in nanodiamonds. We operate in the bad emitter regime, where a cavity with a mode volume of a few cubic wavelengths can achieve high effective Purcell factors up to about 20.

We report on measurements on narrow-line bright single SiV centres in free space and in an ultra-small mode volume cavity and compare rates and time constants. We thereby demonstrate a narrow band, clean, and bright single photon source at room temperature

[1] Hunger et al., NJP 12, 065038 (2010)

[2] Hunger et al., AIP Advances 2, 012119 (2012)

## Half-light Half-molecule at Room Temperature

Rohit Chikkaraddy[1] and Jeremy J Baumberg[1]

[1]NanoPhotonics Centre, Cavendish Laboratory, University of Cambridge, Cambridge, CB3 0HE, UK

Complete mixing of energy states of molecules and light provides profound effects in quantum optics and quantum chemistry. Achieving these mixed states with visible light at the single-molecule level is severely hindered by the conflict between the molecular homogeneous linewidth and the low quality factor of the necessary ultra-small photonic cavities. Recently, cavities based on plasmon-polaritons have gained major attention for boosting the light-matter interaction at room temperature. However, to date it has not been possible to achieve strong coupling with single-quantum emitters (molecules or semiconductor quantum dots) due to the difficulty in constructing a reliable ultra-small plasmonic cavity which incorporates quantum emitters at the right position and orientation.

Here, I will present innovative plasmonic nanocavity which confines light to single-molecule and achieve *strong* mixing of light and molecule. Nanocavity is fabricated via reliable self-assembly of nanoparticle-on-mirror with controlled molecular dipole orientation [1]. By scaling the cavity volume below 100 nmˆ3 and using host-guest chemistry to align 1-10 protectively-isolated dye molecules, we reach the strong-coupling regime at room temperature and in ambient conditions. Dispersion curves from >50 plasmonic nanocavities display characteristic anticrossings, with Rabi frequencies of 300 meV for 10 molecules which drops to 90 meV for single molecules, matching quantitative models. Strong coupling of single molecules can lead to modification of photochemistry, opening up the exploration of complex natural processes such as photosynthesis and new pathways towards manipulation of chemical bonds. We also find that, in this case specific vibrations become coupled to the mixed light-matter states.

References:

[1] R. Chikkaraddy, et al., Accepted (2016) *Nature*.



## Ghost imaging with superluminescent diodes

Sébastien Hartmann[1] and Wolfgang Elsäßer[1]

[1]Institute of Applied Physics, Technische Universität Darmstadt, 64289 Darmstadt, Germany

Ghost imaging (GI) exploits the intensity correlations of light to reconstruct an object. A "ghost image" is obtained by correlating the total transmitted or reflected intensity of an illuminated object with the intensity of a highly correlated reference beam which itself doesn't interact with the object. Intriguingly, the image is formed by the non-interacting reference photons.

Having emerged two decades ago, GI studies have moved from predominant fundamental research to more application orientated developments still striving for a breakthrough application. The actual hot topics in the field of classical GI are the development of simplified computational schemes related to single-pixel cameras [1] and the search for new applications such as imaging of temporal objects by time-domain GI [2] as well as imaging in turbulent environments [3].

We choose a different approach to contribute to the applicability of GI, namely by simplifying the light source concept. One key issue is in our view the lack of feasible and easy-to-operate light sources. Initially demonstrated with entangled photon pairs [4], a first step towards practicality was laid with a thermal light GI experiment utilizing more feasible classical light sources. However, all state-of-the-art GI light sources rely either on complex, rather bulky combinations of coherent light with spatially randomizing optical elements or on incoherent lamps with monochromating optics suffering strong losses of efficiency and directionality.

Here, we propose a GI scheme based on the combination of a broad-area superluminescent diode (BA-SLD) and an interferometric non-linear detection technique [5]. The intensity correlations of this spectrally broadband opto-electronic emitter can thus be measured at sub-femtosecond timescale [6]. A detailed coherence analysis of the BA-SLD light will be given quantifying the coherence time, the photon statistics as well as the number of spatial modes in order to evaluate its suitability as a classical GI light source. We will finally show a proof-of-principle imaging experiment of a double slit mask. From a fundamental point-of-view, this work demonstrates the GI phenomenon for the first time with intrinsically fully incoherent light. Technologically, the most compact light source is introduced to the field holding interesting features such as directionality, high output power as well as tailorable coherence properties. By analyzing the differences with established GI schemes, we will discuss the potential for long range GI sensing applications as well as the introduction of even simpler light sources such as LEDs in future work.

[1] Y. Zhang et al., J. Opt. 18, 035203 (2016).
[2] P. Ryczkowski et al., Nat. Photon. 10, 167 (2016).
[3] M. Bina et al., Phys. Rev. Lett. 110, 083901 (2013).
[4] T.B. Pittman et al., Phys. Rev. A 52, R3429(R) (1995).
[5] S. Hartmann, A. Molitor, and W. Elsäßer, Opt. Lett. 40 (24), 5770 (2015).
[6] F. Boitier, A. Godard, E. Rosencher, and C. Fabre, Nat. Phys. 5, 267 (2009).

# Ro-translational cavity cooling of nanoscale needles and discs

*Benjamin A. Stickler*[1]

[1]Faculty of Physics, University of Duisburg-Essen, Lotharstr. 1, 47048 Duisburg, Germany

Laser cooling the ro-translational degrees of freedom of large molecules or nanoparticles is a challenging problem with far-reaching implications: It may help to address fundamental questions such as the thermalization of a single particle or the validity of the quantum superposition principle at high mass scales [1]. In addition, the control of levitated nanoparticles enables the design of ultra-sensitive force sensors [2]. Motivated by experiments [3] demonstrating optical manipulation of thin silicon nanorods, I investigate the interaction between dielectric needles or discs and the laser field of a high finesse cavity. It is shown that such anisotropic nanoparticles can be efficiently captured from free flight, at velocities much higher than those required to trap dielectric spheres, and that ro-translational cavity cooling is possible. I derive the quantum master equation for the coupled particle-cavity dynamics, including Rayleigh scattering, and demonstrate that efficient cooling into the deep quantum regime is achievable. Applications of these systems for high mass quantum interference experiments, ro-translational cavity optomechanics and single particle thermodynamics are discussed.

[1] M. Arndt and K. Hornberger, Nature Physics 10, 271 (2014).
[2] D. C. Moore, A. D. Rider, and G. Gratta, Phys. Rev. Lett. 113, 251801 (2014).
[3] S. Kuhn, P. Asenbaum, A. Kosloff, M. Sclafani, B.A. Stickler, S. Nimmrichter, K. Hornberger, O. Cheshnovsky, F. Patolsky, and M. Arndt, Nano Lett. 15, 5604 (2015).





# Quantum networking with quantum dot spins and telecom photons

*Leo Yu*[1], *Chandra M. Natarajan*[1,2,3], *Tomoyuki Horikiri*[1,2], *Carsten Langrock*[1], *Jason S. Pelc*[1], *Michael G. Tanner*[3], *Eisuke Abe*[2], *Sebastian Maier*[4], *Christian Schneider*[4], *Sven Höfling*[4], *Martin Kamp*[4], *Robert H. Hadfield*[3], *Martin M. Fejer*[1], *and Yoshihisa Yamamoto*[1,2]

[1]E. L. Ginzton Laboratory, Stanford University, Stanford, California, USA
[2]National Institute of Informatics, Hitotsubashi 2-1-2, Chiyoda-ku, Tokyo 101-8403, Japan
[3]School of Engineering, University of Glasgow, Glasgow G12 8QQ, Scotland, UK
[4]Technische Physik, Physikalisches Institut, Universität Würzburg, Würzburg, Germany

Quantum physics can empower current network infrastructures with fundamentally new functionalities such as quantum key distribution and distributed quantum computation, motivating the research for a quantum internet. Promising underlying qubits of this internet include electron spins in III-V semiconductor quantum dots (QDs), because they feature scalability, the fastest spin manipulation and photon emission among the matter qubits. However, in a quantum internet that comprises multifarious nodes and spans long distances, practical quantum communication is limited by photon attenuation, which-path information leakage, decoherence, and distinguishability.

Here we overcome these limitations using four operations that are broadly identifiable as quantum networking: frequency downconversion, quantum erasure, time-bin encoding, and mediated two-photon interference. First, we frequency downconvert 910-nm single photons from a QD to the lowest-loss 1.5-$\mu$m telecom band [1], reducing the photon attenuation by 3 dB/km. Our downconversion technique is nearly background-free and thus improves single-photon statistics and coherence. Second, we use sub-10 picosecond, broadband pulses as a quantum eraser of which-path information in photon energies, thereby demonstrating the entanglement between a QD spin qubit and a photon polarization qubit [2]. The ultrafast downconversion further leads to record-high fidelity (over 90%) of entangled spin-photon pairs in the solid-state [3]. Third, circumventing fiber birefringence, we encode the photon polarization qubit of the QD in a time-bin basis, allowing its correlation with the QD spin qubit to persist across a 2-km fiber channel [4]. Fourth, through two quantum downconverters, we mediate two-photon interference between disparate photons from a QD and from an independent source, achieving a mean photon-wavepacket overlap of greater than 0.89 in spite of photons' original wavelength mismatch (900 and 911 nm) [4]. These central quantum-networking operations will enable practical communication between solid-state spin qubits across long distances.

[1] J. S. Pelc, L. Yu et al., Opt. Express **20**, 27510 (2012).
[2] K. De Greve, L. Yu et al., Nature **491**, 421 (2012).
[3] K. De Greve, P. L. McMahon, L. Yu et al., Nat. Commun. **4**, 2228 (2013).
[4] L. Yu et al., Nat. Commun. **6**, 8955 (2015).

## High-redshift astrophysics using every photon

*Patrick C. Breysse*[1], *Ely D. Kovetz*[1], *Mubdi Rahman*[1], *and Marc Kamionkowski*[1]

[1]Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218 USA

Large-scale galaxy surveys have greatly expanded our knowledge of the distant universe in recent years. However, at very high redshifts, the utility of such surveys is limited, as only the brightest galaxies are accessible even in the deepest surveys. Recently, intensity mapping has arisen as a promising technique for observing the large population of fainter sources undetectable by traditional means. An intensity mapping survey measures how the intensity of a chosen spectral line varies on scales much larger than any individual source. Measurements can be easily made at different redshifts by observing at slightly different frequencies. Such an observation thus makes use of all of the photons in a given line from the entire source population, allowing statistical constraints to be placed on the properties of even the faintest galaxies.

A significant experimental effort is underway to perform these measurements in a wide variety of lines [1,2,3]. We highlight some of the immense astrophysical potential of these measurements using the example of a CO intensity mapping survey targeting redshifts between 2 and 3, similar to the proposed COMA experiment [1]. We demonstrate how the one-point statistics of a CO intensity map can be used to measure the luminosity function of the source population, which can in turn be used to place powerful constraints on the cosmic star formation history. We then show how cross-correlating CO with other lines, such as the $^{13}$CO isotopologue, can place even stronger constraints on the molecular gas dynamics within a high-redshift galaxy.

[1] Li, T. Y. et al., ApJ, **817**, 169 (2016)

[2] Dore, O. et al., arXiv:1412.4872 (2014)

[3] Crites, A. T. et al. Proceedings of the SPIE, **9153**, 91531W (2014)

## Dying young and frustrated: Understanding the evolution of young radio galaxies

*Joseph Callingham*[1]

[1]The University of Sydney, CSIRO Astronomy and Space Science, and CAASTRO

Radio astronomers have identified a group of compact radio sources which have been hypothesised to represent an early stage of radio galaxy evolution. However, such an interpretation is contentious as it is possible that these sources are not young but are confined to a small spatial scales due to a high density medium. One of the main reasons there has not been resolution between these two competing hypotheses is because the absorption mechanism responsible for the turnover in their radio spectra is still ambiguous since the spectra of these sources below the turnover has not been well enough sampled to date. It is vital to understand the formation and evolution of radio galaxies as such sources influence the re-ionisation of the early Universe and the temperature anisotropies seen in the cosmic microwave background radiation.

The Murchison Widefield Array (MWA), a Square Kilometre Array (SKA) precursor, has conducted an all-sky survey at low radio frequencies (72 to 231 MHz). This survey provides an unparalleled number of compact sources with broad spectral coverage below the spectral turnover. In this poster I will outline the survey, present results of spectral modelling of these sources and discuss the impact such a frequency domain has on our understanding of radio galaxy evolution. In particular, I will highlight the challenges that processing such a large data set entailed and the statistical tools we had to develop to conquer the huge data flow, something other science fields will soon have to address with the growth of data science.

## Particle physics and cosmological magnetic fields

*Kohei Kamada*[1]

[1]School of Earth and Space Exploration, Arizona State University, 650 E. Tyler Mall, Tempe, AZ-85287, USA

Recently, it is suggested that there are large-scale magnetic fields in the cosmic voids, or in the intergalactic spaces, from the non-detection of the (secondary) GeV gamma-rays from blazars. Since we do not know any mechanisms to develop such magnetic fields after galaxy formation, they are likely generated in the very early Universe, perhaps before the Big Bang Nucleosynthesis, if ever. If they carry helicity, there can have more interesting features. From the chiral anomaly in the Standard Model of Particle Physics, they will be the source of the chiral asymmetry of the fermions in the hot plasma in the early Universe. If they originated from the helical hypermagnetic fields generated by a mechanism before the electroweak phase transition, the chiral anomaly induces the baryon asymmetry or the matter-anti matter asymmetry before that due to the left-right asymmetric structure of the Standard Model. Here I explain the possible relations between the cosmological magnetic fields and baryon asymmetry of the Universe, investigating the evolution of magnetic fields from the early Universe to the present based on the observation. In particular, there is a possiblity that the present matter anti-matter asymmetry of the Universe without introducing any baryon number violating new physics beyond the Standard Model can be explained. This presentation is based on the work Ref. [1].

[1] Tomohiro Fujita and Kohei Kamada, Phys.Rev. D93 (2016) no.8, 083520





## Cosmological Signatures of Massive Self-Interacting Neutrinos

*Christina Kreisch*[1], *Francis-Yan Cyr-Racine*[2], *Olivier Doré*[3], *and Kris Sigurdson*[4]

[1]Max Planck Institute for Astrophysics
[2]Department of Physics, Harvard University
[3]NASA Jet propulsion Laboratory, California Institute of Technology
[4]Department of Physics and Astronomy, University of British Columbia

Probing physics behind the neutrino's mass can reveal exciting knowledge about potential new interactions in the relatively unexplored neutrino sector. In the standard cosmological model, neutrinos decoupled from the primordial plasma when the universe had a temperature of $\sim 1.5$ MeV. However, the presence of new interactions in the neutrino sector, such as those responsible for neutrino mass, can significantly delay the onset of neutrino free-streaming. These effects are measurable with observables like the Cosmic Microwave Background (CMB) and matter clustering. Previous work by [1] investigated interacting massless neutrinos and found that CMB and baryon acoustic oscillation data could not rule out an interacting neutrino cosmology. Because there were features suggesting novel neutrino effects, more work is warranted to make a statistically significant statement. Intriguingly, interacting neutrinos can alleviate the tension between direct $H_0$ measurements and the value of $H_0$ inferred from the CMB. Changing neutrino physics also affects the way dark matter (DM) clusters even without direct neutrino-DM interactions, a surprising observation.

For the first time we study the cosmological physics of self-interacting neutrinos while self-consistently taking into account neutrino mass. We find the neutrino mass and self-interaction have a compounded damping effect on the matter power spectrum for small scales and alter the CMB temperature power spectrum phase and amplitude. We present new parameter constraints from recent CMB data sets and galaxy surveys on the interaction strength, neutrino mass, number of neutrino species, and cosmological parameters. Future measurements by neutrino and astrophysical observatories, such as IceCube and LSST, will provide stringent tests of neutrino interactions and the cosmological problems they propose to solve.

[1] F.-Y. Cyr-Racine and K. Sigurdson, Limits on Neutrino-Neutrino Scattering in the Early Universe, Phys. Rev. D90 (2014).

## Revealing the Nature of Dark Matter and distant Galaxies with Strong Lensing

*Matus Rybak*[1], *Simona Vegetti*[1], *and John P. McKean*[2,3]

[1]Max Planck Institute for Astrophysics, Garching, Germany
[2]Kapteyn Institute, Groningen, the Netherlands
[3]ASTRON, Dwingeloo, the Netherlands

While the Cold Dark Matter model has been very successful in explaining a wide range of phenomena, it faces serious challenges on (sub-)galactic scales; namely, cosmological simulations predict a large number of dark matter subhalos - clumps within a dark matter halo of a galaxy; which is at least an order of magnitude larger than that inferred from observations. In particular, in a Warm Dark Matter scenario, less massive subhalos ($10^7$ solar masses) are wiped out, while larger structures are left unperturbed, providing a good fit to observations.

To distinguish between these two scenarios, it is necessary to constrain the mass function of dark subhalos for a statistically significant sample of galaxies. Strong gravitational lensing is ideally suited for this task - a substructure in the halo of the lensing galaxy will introduce a perturbation to the Einstein arcs, allowing us to detect it; furthermore, this technique can be applied to a large sample of strongly lensed galaxies.

Although a significant progress has been made with data from the Hubble Telescope and Earth-based observatories, probing the subhalo mass function down to $10^6$ solar masses requires a superb sensitivity and resolution on milliarcsecond scales. Currently, data of this quality can be provided only by the long baseline interferometry; as a bonus, these observations provide a view into high-redshift galaxies with an unprecedented resolution, allowing us to study processes in galaxies more than 10 billion years ago.

However, the nature of interferometric data - which are not a simple picture of the sky, but its badly-sampled Fourier transform - and the data volume (typically $10^7 - 10^8$ datapoints) present a major challenge for any such analysis. I will present our work on developing a technique for processing strong lensing data from interferometers and the results of practical applications, namely:

- first high-resolution imaging of a strongly lensed galaxy SDP.81 located at redshift 3 (some 11 billion years ago) carried out with Atacama Large Millimeter /Submillimeter Array, revealing the properties of dust, gas, and physical conditions in a high-redshift starburst galaxy

- an on-going effort to detect $10^6$-solar-masses dark subhalos using the Global VLBI data.





## Discovery of [OII] Blobs: A New Systematic Approach to Understand Galaxy Evolution

*Suraphong Yuma*[1], *Masami Ouchi*[2], *Alyssa B. Drake*[3], *and Chris Simpson*[4]

[1]Department of Physics, Faculty of Science, Mahidol University, Thailand
[2]Institute for Cosmic Ray Research, The University of Tokyo, Japan
[3]CRAL, Observatorie de Lyon, Université Lyon, France
[4]Astrophysics Research Institute, Liverpool John Moores University, UK

In the present-day universe, galaxies can be divided into two main categories: young blue disk galaxies which are actively forming new stars, and old red elliptical galaxies that are passively evolving and forming no new stars any further. It is known that some of star-forming disk galaxies should evolve into passively-evolving ellipticals in the past. However, the process responsible for this physical transformation is still incomplete. Due to its relatively short timescale the galaxy in the middle of this transforming phase has not been observed yet. With wide and large-area imaging data from the Subaru telescope, we have discovered 12 galaxies at $z \sim 1.2$ (about 8.5 billion years ago) showing a largely extended ($> 30$ kpc or $\sim 100$ light years) [OII] nebula, which we call [OII] blobs (OIIBs). This is the first systematic search for galaxies with large-scale outflow by using only images taken by the telescopes. Some of these galaxies are experiencing the final phase of star formation with their gas heated and expelled out by active galactic nuclei (AGN) or supernova feedback, and quenching star formation whose process is a key to produce passively-evolving ellipticals. The number density of OIIBs with AGN is $5 \times 10^{-6}$ Mpc$^{-3}$ comparable with that of AGN driving outflow at the similar redshift. Meanwhile, the number density of all OIIBs including no AGN hosting galaxies is $6 \times 10^{-5}$ Mpc$^{-3}$, indicating that 3% of star-forming galaxies at $z \sim 1$ are quenching star formation through outflows involving spatially extended [OII] emission. Currently, we are extending the search to cover more than 9 billion years of the universe, which is roughly 70% of the age of the universe. We will be able to figure out the transformation process of galaxies at each epoch of the universe and ultimately understand how galaxies become what we see today.

## Lasers inside live cells

*Matjaz Humar*[1]

[1]Wellman Center for Photomedicine, Harvard Medical School, Massachusetts General Hospital, 65 Landsdowne St. UP-5, Cambridge, Massachusetts 02139, USA
[1]Condensed Matter Department, J. Stefan Institute, Jamova 39, SI-1000 Ljubljana, Slovenia

We have for the first time demonstrated a laser completely embedded within a single live cell. This achievement was featured on the cover of September issue of Nature Photonics [1], as well it triggered a huge scientific and media interest. The lasers were made out of solid polystyrene beads ten times smaller than the diameter of a human hair. We fed these laser beads to live cells in culture, which eat the lasers within a few hours. The lasers can act as very sensitive sensors, enabling us to better understand cellular processes. For example, we measured the change in the refractive index which is directly related to the concentration of chemical constituents within the cells. Further, lasers were used for cell tagging. Each laser within a cell emits light with a slightly different fingerprint that can be easily detected and used as a barcode to tag the cell. With careful laser design, up to a trillion cells (1,000,000,000,000) could be uniquely tagged. This would enable to uniquely tag every single cell in the human body, providing the ability the study cell migration including cancer metastasis. Further, by using a micro pipette, we injected a tiny drop of oil containing fluorescent dye into a cell. By analysing the light emitted by a droplet laser, we can measure that deformation and calculate the tiny forces acting within a cell. Finally, we realized that fat cells already contain lipid droplets that can work as natural lasers. That means each of us already has millions of lasers inside our fat tissue that are just waiting to be activated to produce laser light. The lasers inside cells could be used for unprecedented human-machine interfaces enabling accurate diagnosis, better understanding of human body and future applications till now only imaginable in science-fiction.

[1] Matjaž Humar, Seok Hyun Yun, Intracellular Microlasers, Nature Photonics 9, 572–576 (2015).





## Tracing the Dynamics of Molecules in Real Time using Femtosecond XUV and X-Ray Laser Pulses

*Kirsten Schnorr*[1,2], *Sven Augustin*[1], *Georg Schmid*[1], *Hannes Lindenblatt*[1], *Severin Meister*[1], *Claus Dieter Schröter*[1], *Robert Moshammer*[1], *Thomas Pfeifer*[1], *Andrew Attar*[2], *Aditi Bhattacherjee*[2], *and Stephen Leone*[2]

[1]Max-Planck-Institut für Kernphysik, Heidelberg
[2]University of California, Berkeley

Fundamental energy-transfer mechanisms within and among molecules drive a plethora of quintessential phenomena in nature, such as DNA repair and photosynthesis. Understanding and controlling these processes are important research fields shared by physics, chemistry, and biology. One particular aspect in the huge field of energy-transfer processes will be presented here: the relaxation dynamics of innershell-ionized molecules, in particular Interatomic/Intermolecular Coulombic Decay (ICD). ICD is a decay mechanism on the femtosecond (fs) time-scale that is ubiquitous in weakly bound systems. An excited atom or molecule relaxes by transferring its excitation energy to a neighbour, which is consequently ionized. The in-turn emitted low-energetic ICD electrons are known to damage chemical bonds efficiently by dissociative electron attachment, which may for instance lead to DNA damage in radiation therapy. Moreover, these genotoxic electrons may be employed as a tool to destroy malignant tissue by implanting certain absorber molecules where ICD is triggered spatially confined.

The general conditions under which ICD takes place, i.e., typical distances and decay times, are little known. However, these are obviously the prerequisites for understanding and controlling the process. On this poster, I am going to present the first time-resolved experiment on ICD employing an XUV-pump–XUV-probe scheme on neon dimers. By tracing those ion pairs that are only created if ICD took place by the time the probe pulse had arrived as a function of the pump-probe delay an ICD lifetime of 150,fs had been determined.

However, this method assumes that ICD follows an exponential decay, which corresponds to averaging the decay widths over all measured times. In order to resolve the non-exponential behaviour of ICD, another experiment was performed on Ne dimers employing an XUV-pump–THz-probe scheme.

Additionally, time-resolved experiments on the relaxation dynamics of dissociating methyl- and allyliodide molecules will be presented. The molecules are dissociated by a preceding UV pump pulse and the transition from a bound molecule to the isolated methyl- and allyl radical is probed by a delayed X-ray probe pulse.

Free-Electron Lasers and High Harmonic Generation sources are essential to these experiments as they provide the necessary fs temporal resolution in combination with a high degree of spatial localization due to state-selective ionization through XUV radiation and X-rays.

## Investigating DNA Base Photoprotection Mechanisms with Ultrafast NEXAFS Spectroscopy

*Thomas J. A. Wolf*[1], *Markus Gühr*[2], *and LCLS Thymine Collaboration*[3]

[1]Stanford PULSE Institute, SLAC National Accelerator Laboratory, Menlo Park, USA
[2]Stanford PULSE Institute, SLAC National Accelerator Laboratory, Menlo Park, USA
[2]Institut für Physik und Astronomie, Universität Potsdam, Potsdam-Golm, Germany

The Nucleobases, the building blocks of DNA, have huge absorption cross-sections for ultraviolet light, which is potentially dangerous to the molecular structure. Despite this, photoinduced DNA damage is a comparably rare event. It is well known that single nucleobases are protecting themselves against photodamage by depopulating the photoexcited state on a timescale of femtoseconds and picoseconds. The details of the underlying processes of this photoprotection mechanism involve Non-Born-Oppenheimer dynamics and are subject to ongoing experimental and theoretical studies.

The nucleobase thymine exhibits a spectroscopically bright $\pi\pi^*$ state, which is characterized by a single electron excitation from an occupied to an unoccupied molecular orbital, both with $\pi$ symmetry. Two possible ultrafast depopulation pathways have been proposed. They lead either directly back to the ground state through a conical intersection or via a second low-lying, spectroscopically dark $n\pi^*$ state, which is characterized by a single electron excitation from a lone pair orbital at one of the oxygens in thymine to the $\pi^*$ orbital. Quantum chemical simulations point to a relaxation to the $n\pi^*$ state. They also propose trapping of the population for at least some hundred femtoseconds in a local minimum of the $\pi\pi^*$ state before the $n\pi^*$ state is accessed. Unambiguous experimental confirmation of the $n\pi^*$ state's role and the timescale of its population can only be done with an experimental method, which can descern between the excited states based on their electronic characters.

In a recent experiment at the LINAC coherent light source (LCLS), we could show that time-resolved near-edge absorption fine structure (NEXAFS) spectroscopy in the gas phase exhibits this sensitivity to the excited state character. In NEXAFS spectroscopy, the 1s electrons of a specific element are resonantly excited to unoccupied molecular orbitals. Since 1s electrons are strongly localized around a specific nucleus, the cross-section of those resonances are highly sensitive to the localization of the empty valence orbital at this nucleus. The ground state NEXAFS spectrum of thymine at the oxygen edge exhibits a sharp resonance due to an excitation of oxygen 1s electrons to the $\pi^*$ orbital. If the molecule is preexcited by UV light, either the formerly occupied n or the $\pi$ orbital is now half filled and can contribute a new NEXAFS transition, dependent on which excited state is populated. Since the n orbital is considerably stronger localized at the oxygens than the $\pi$ orbital, we expected a strong NEXAFS signature, if the $n\pi^*$ state was populated during the dynamics, which was indeed the case. We clearly observed population of the $n\pi^*$ state to be 100 fs delayed with respect to the excitation. This finding not only experimentally pins down the mechanistic step of internal conversion to the $n\pi^*$ state, it also excludes the proposed trapping of the wavepacket in the $\pi\pi^*$ state for hundreds of fs.

## Smart Surfaces

*Naureen Akhtar*[1], *Vårin R. A. Holm*[1], *Peter J. Thomas*[2], *Benny Svardal*[2], *Simen H. Askeland*[1], *and Bodil Holst*[1]

[1]Department of Physics and Technology, University of Bergen, Bergen, Norway
[2]Christian Michelsen Research AS, Bergen, Norway

Owing to its excellent mechanical and thermal properties as well as optical performance, sapphire is extensively used as window in optical sensors for harsh conditions, for example underwater surveillance in the oil industry. However, under these conditions the sapphire surfaces are continuously exposed to oil and other fouling mixtures, which can lead to contamination of the window surface. Hence, making the surface underwater oleophobic would be highly desirable. We found out that a sapphire surface can change from oleophilic to superoleophobic depending on the crystal miscut, polishing method and initial cleanliness state when submerged in water. Moreover, giving the surface the hydrophilic character improves the underwater oleophobic character. This could be understood in the context of underwater superoleophobic surfaces found in nature that exhibit higher propensity for trapping water. Inspired by the underwater superoleophobic self-cleaning surfaces found in nature such as fish scales, sapphire surfaces could be further developed for maintenance free solutions for permanent underwater installation of optical instrumentation.

## Silicon Nanotube Field Effect Transistors for Ultra Low-Power High-Performance Computing

Aftab M. Hussain[1], Hossain M. Fahad[1], Amir N. Hanna[1], and Muhammad M. Hussain[1]

[1]Integrated Nanotechnology Lab (INL) and Integrated Disruptive Electronic Applications (IDEA) Lab, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia.

Information for anyone, anywhere, anytime is our goal. Thus, to empower the world population with ultra-mobile, energy efficient and high performance computing ability, we have developed a silicon nanotube field effect transistor (NTFET) which for the first time, contrary to the basic rule of modern semiconductor physics, shows high performance computing ability with ultra-low power consumption in an area efficient manner. Hence, it can extend the battery life of Internet of Things (IoT) devices without compromising their multi-tasking capability. The silicon NTFET has a unique core shell gate architecture that helps in achieving full volume inversion by giving a surge in minority carrier concentration in the vicinity of the channel, resulting in high performance computation. Gating from all possible sides allows to achieve ultra-low power computation. The unique nanotube architecture enables rapid roll-off at the source and drain junctions resulting in velocity saturation-induced higher drive current with efficient real estate consumption. The nanotube architecture compares favorably to the nanowire field effect transistors (FET) wherein extensive research has shown that although it has ultra-low off-state leakage current and a single device uses a very small area, its drive current generation per device is extremely low [1]. The NTFET architecture provides ~10× more power compared to a single nanowire FET of the same thickness [1, 2]. The nanowire FETs can be arrayed to increase the overall current output. However, this leads to higher chip area consumption and degradation of switching characteristics due to contact parasitics.

The core shell gate stacks in the nanotube architecture also provide superior control over short channel effects compared to the classical planar metal oxide semiconductor FET (MOSFET) and gate-all-around nanowire FET (GAA-NWFET). The conceptualized device offers an ideal blend of quantum ballistic transport of charge carriers and high-density integration capability for ULSI applications. We propose two experimental processes to fabricate these devices – the "bottom-up" approach wherein the silicon nanotube is epitaxially grown and in-situ doping is used for junction formation; and the "top-down" approach wherein the silicon surface is doped using implantation and then micro-machined to obtain the nanotube architecture [2, 3]. Our atomistic simulation study attests the superiority of the hetero-structure nanotube tunnel FET over a nanowire tunnel FET in case of tunnel transistors as well as for junctionless ones [4-6].

[1] H. M. Fahad, M. M. Hussain, Scientific Reports **2**, 475, (2012). [2] H. M. Fahad, A. M. Hussain, G. A. T. Sevilla, S. K. Banerjee, M. M. Hussain, Proc. SPIE **9083**, 90830K, (2014). [3] H. M. Fahad, C. E. Smith, J. P. Rojas, M. M. Hussain, Nano Letters **11**, 4393–4399, (2011). [4] H. M. Fahad, M. M. Hussain, IEEE Transactions on Electron Devices **60**, 1034-1039, (2013). [5] A. N. Hanna, M. M. Hussain, Journal of Applied Physics **117**, 014310, (2015). [6] A. N. Hanna, H. M. Fahad, M. M. Hussain, Scientific Reports **5**, 9843, (2015).





## Atomically Thinned Two-dimensional Superconductors

S. Ichinokura[1], A. Takayama[1], K. Sugawara[2], T. Takahashi[2,3], A.V. Matetskiy[4], L.V. Bondarenko[4], D.V. Gruznev[4], A.V. Zotov[4], A.A. Saranin[4], and S. Hasegawa[1]

[1]Department of Physics, University of Tokyo, Tokyo 113-0033, Japan
[2]WPI Research Center, AIMR, Tohoku University, Sendai 980-8577, Japan
[3]Department of Physics, Tohoku University, Sendai 980-8578, Japan
[4]Institute of Automation and Control Processes FEB RAS,690041 Vladivostok, Russia

Atomically thinned superconductors(ATSCs), where only one or a few atomic layers at the surface or interface becomes superconducting, have attracted considerable attentions owing to their strong two-dimensionality and expectation of functional superconductivities with high critical temperature or magnetic field. There are two different types of ATSCs: (i)thickness-reduced layered superconductors such as metal-doped graphite or transition-metal dichalcogenides and (ii)self-assembled single-layer materials on semiconductor substrates. In this study, we present first observations of superconductivity in Ca-intercalated bilayer graphene(Ca-BLG) and one-atom-layer Tl-Pb compound on Si surface(TlPb/Si). Since these materials are extremely unstable in air, we prepared the samples in ultrahigh vacuum(UHV) and measured resistivity *in situ*.

Graphene is a single atomic sheet of carbon with various novel electric properties such as the massless electrons, the high carrier mobility. One property conspicuous by its absence until recently, however, is superconductivity. Many intensive efforts have been made to fabricate superconducting graphene by doping metals like in bulk graphite. We show that the zero-resistance state occurs in Ca-BLG at 2 K, which directly proves the superconductivity in macroscopic scale[1]. Ca-BLG has been studied as the most promising candidate for superconducting graphene both experimentaly and theoreticaly, while it had not been accomplished because of difficulties in synthesizing high-quality samples and their high reactivity in air. We overcame this difficulty by sample growth and *in situ* measurement in UHV, resulting in first demonstration of superconductivity in bilayer graphene.

Superconductivity in absence of spatial inversion symmetry(SIS) is basically controlled by a Rashba effect(RE) which splits the Fermi surface and removes the spin degeneracy. The presence of RE is expected to be responsible for various uncommon features of the superconducting state and magnetoelectric effect. Recently, ATSCs on semiconductor substrate have been regarded as novel platforms for the study of broken SIS. In particular, the heavy-elements-adsorbed surfaces have large RE of the order of 100 meV. However, most of the large Rashba systems are insulator, so that superconductivity has never observed. Here, we report on the discovery of TlPb/Si that displays both RE and superconductivity at sizable energies[2]. The magnitude of the spin splitting due to RE is 250 meV. We also perform *in situ* resistivity measurements in UHV, which showed the superconductivity transition at 2.3 K.

[1] S. Ichinokura, *et al.* ACS Nano **10,** 2761–2765 (2016).
[2] A. V. Matetskiy, S. Ichinokura, *et al.* Phys. Rev. Lett. **115,** 147003 (2015).

## Perovskite Solar Cells - Ready for Takeoff

Martin Kaltenbrunner[1]

[1]Department of Soft Matter Physics, Johannes Kepler University Linz, Altenbergerstr. 69, 4040 Linz, Austria.

Flexibility, compliance and weight will turn out to be key metrics for future electronic appliances and their power supplies. Imperceptible electronic wraps integrate nanometer thin film active components on sub-2-micrometer polymer foils and create devices unmatched in mechanical flexibility, stretchability and weight. Emerging applications like solar powered aviation or wearable electronics require photovoltaic technologies that are highly efficient, light-weight, low-cost, and stable during operation. Organolead halide perovskites constitute a highly promising class of materials, but suffer limited stability under ambient conditions without heavy and costly encapsulation.

Here we introduce methods, materials and design strategies for ultrathin (3 micrometer), highly flexible perovskite solar cells with stabilized 12% efficiency and a record power-per-weight as high as 23 W/g. To facilitate air stable operation, we introduce a chromium oxide-chromium interlayer that effectively protects the metal top contacts from reactions with the perovskite. We show prolonged stable operation in the maximum power point in ambient air of non-encapsulated planar perovskite solar cells with gold, and low-cost copper and aluminium electrodes. The use of a transparent polymer electrode treated with dimethylsulphoxide (DMSO) as bottom layer allows the deposition - from solution at low temperature - of pinhole-free perovskite films at high yield on arbitrary substrates, including thin plastic foils. These ultra-lightweight solar cells are successfully used to power aviation models. Potential future applications include unmanned aerial vehicles - from airplanes to quad-copters and weather balloons - for environmental and industrial monitoring, rescue and emergency response, and tactical security applications. In a hybrid architecture laminated atop pre-strained elastomers, such solar cells are highly stretchable and conformable. We introduce surface structuring as a light-trapping microstructure for improved efficiency. Prolonged operational lifetime and stability towards water ingress by superhydrophobic coatings will be discussed.

Funding from the FWF Wittgenstein award and the ERC advanced investigators grant “Soft Map” is acknowledged.

References:

M. Kaltenbrunner et al., Nature Communications 3, 770 (2012)
M. Kaltenbrunner et al., Nature 499, 458 (2013)
M. Kaltenbrunner et al., Nature Materials 14, 1032-1039 (2015)

## Experimental Discovery of Weyl semimetal TaAs

*B.Q. Lv[1,2], N. Xu[2], S. Muff[2], Z. D. Song[1], S. M. Nie[1], J. Z. Ma[1], B. B. Fu[1,2], P. Richard[1,3], G. F. Chen[1,3], X. Dai[1,3], Z. Fang[1,3], J. Mesot[2], J. H. Dil[2], M. Shi[2], H. M. Weng[1,3], T. Qian[1], and H.Ding[1,3]*

[1]Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
[2]Paul Scherrer Institute, Swiss Light Source, CH-5232 Villigen PSI, Switzerland
[3]Collaborative Innovation Center of Quantum Matter, Beijing, China

Weyl semimetals are a class of materials that can be regarded as three-dimensional analogs of graphene breaking time reversal or inversion symmetry. Electrons in a Weyl semimetal behave as Weyl fermions, which have many exotic properties, such as chiral anomaly and “magnetic monopoles” in the crystal momentum space. The surface state of a Weyl semimetal displays pairs of entangled Fermi arcs at two opposite surfaces connecting projections of two Weyl nodes with opposite chirality. However, the existence of Weyl semimetals has not yet been proved experimentally until 2015 [1,2]. Here we report the experimental realization of the Weyl semimetal phase in TaAs by observing spin polarized Fermi arcs and the longsought-after Weyl nodes with ARPES and SARPES [1,3,4]. The projected locations at the nodes on the (001) surface match well to the Fermi arcs, providing undisputable experimental evidence for the existence of Weyl fermionic quasiparticles in TaAs. Our first-principles calculations, matching remarkably well with the experimental results, further confirm that TaAs is a Weyl semimetal[1,3-5].

[1] B. Q. Lv, H. M. Weng, et al. Phys. Rev. X 5, 031013 (2015).
[2] S.-Y. Xu, et al. Science 349, 613 (2015).
[3] B. Q. Lv, N.Xu, H. M. Weng, et al. Nat. Phys. 11, 724 (2015).
[4] B. Q. Lv, S. Muff, T. Qian, Z. D. Song et al. Phys. Rev. Lett. 115, 217601 (2015).
[5] H. M. Weng et al. Phys. Rev. X 5, 011029 (2015).

## Elastoresistance as a Probe of Electronic Nematicity in Fe-based Superconductors

*Johanna C. Palmstrom*[1,2,3], *Hsueh-Hui Kuo*[1,2,4], *Jiun-Haw Chu*[1,2,3], *Steven A. Kivelson*[1,2,5], *and Ian R. Fisher*[1,2,4]

[1]Stanford Institute for Materials and Energy Sciences, SLAC National Accelerator Laboratory, CA, USA
[2]Geballe Laboratory for Advanced Materials, Stanford University, USA
[3]Department of Applied Physics, Stanford University, USA
[4]Department of Materials Science and Engineering, Stanford University, USA
[5]Department of Physics, Stanford University, USA

Iron-based superconductors are the newest family of unconventional, high critical temperature superconductors. These superconductors are considered unconventional because the superconducting gap function is not spherically symmetric, reflecting a pairing interaction between quasiparticles that is most-likely not driven simply by lattice vibrations. The first step in understanding these materials, and the nature of the pairing interaction, is to characterize the normal state from which the superconductor is formed, including the nature of any broken symmetry states that might affect the superconducting state. Recent evidence demonstrates the presence of a novel type of "electronic nematic" order, referring to spontaneously broken rotational symmetry driven by electron correlation effects, in iron-based superconductors. In this poster I will present a novel experimental technique, based on differential elastoresistance measurements, that directly reveals the nematic susceptibility of these materials. In particular, I will show that the nematic susceptibility diverges for compositions close to optimal doping (i.e. the composition that leads to the maximum critical temperature values) for several different families of iron-based superconductors. Courtesy of the fluctuation-dissipation theorem, the nematic susceptibility reveals the presence of nematic fluctuations. Our observations therefore raise the question of whether nematic fluctuations might play an important role in the superconducting pairing interaction in this broad family of materials [1].

[1] H.H. Kuo, J.-H. Chu, J. C. Palmstrom, S. A. Kivelson, I. R. Fisher, arXiv:1503.00402, to appear in Science.





## Silicon based novel functional nanomaterials

*Hiroshi Sugimoto*[1] *and Minoru Fujii*[1]

[1]Department of Electrical and Electronic Engineering, Graduate School of Engineering, Kobe University, Rokkodai, Nada, Kobe 657-8501, Japan

Silicon is one of the most important elements in electronics industry. In recent years, the great advancements have been made in the society of electronics and the size of each component is being decreased to nanometer scale. In the nanoscale silicon materials, the physical and chemical properties are modified drastically due to the quantum size effects. For example, in 1990, visible light emission from nanocrystalline silicon was reported despite their indirect nature of the bandgap. After discovery of the light emission, many research groups not only in electronics and photonics but also in biomedical fields, have studied the silicon nanocrystals and explore their applications.

Despite the numerous reports on silicon nanocrystals in solid matrices, the development of "colloidal" silicon nanocrystals had been challenging compared to II-VI and IV-VI compound semiconductor nanocrystals. Colloidal dispersion of silicon nanocrystals is particularly important for a variety of applications such as printable electronics and biophotonics. It is only recently that the quality of colloidal silicon nanocrystals has been improved in terms of crystallinity, size distribution, high stability in solution and high emission quantum yield.

In this work, we present a new type of silicon nanocrystal based functional materials targeting for applications in optoelectronics and biology. We first develop n- and p-type impurity doped silicon nanocrystals and investigate the electronic and structural properties in detail. We demonstrate that the doped silicon nanocrystals are colloidally stable and exhibit bright light emission in near-infrared range. We also produce biocompatible silicon based hybrid materials with metals and polymers to enhance their performance in photonic applications.

## Dissipative quantum many-body dynamics

*Hendrik Weimer*[1]

[1]Institute for Theoretical Physics, Leibniz University Hannover, Appelstr. 2, 30167 Hannover, Germany

In most experiments investigating coherent quantum dynamics, dissipation is an undesirable process. However, there have been several recent theoretical proposals for turning controlled dissipation into a useful resource, e.g., for the realization of interesting many-body quantum states, with applications in quantum simulation, quantum metrology, and quantum communication [1, 2, 3]. The main idea is to engineer the interaction with the environment such that the combination of coherent and dissipative dynamics drives the system in question to a stationary state identical to the quantum state of interest.

At the same time, dissipative quantum many-body systems are extremely challenging to analyze, as most theoretical tools developed for equilibrium systems cannot be applied. I will present the initial steps towards a deeper understanding of these systems by introducing a variational principle for the non-equilibrium steady states of the quantum master equation describing the dynamics [4]. In particular, I will apply this approach to study phase transitions in dissipative extensions of the Ising model and show their importance to ongoing experiments on ultracold Rydberg atoms [5]. Finally, I will present first results on the extension of the variational principle to the full relaxation dynamics of dissipative quantum many-body systems [6].

## References

[1] S. Diehl, A. Micheli, A. Kantian, B. Kraus, H. P. Büchler, and P. Zoller, Nature Phys. **4**, 878 (2008).

[2] F. Verstraete, M. M. Wolf, and J. Ignacio Cirac, Nature Phys. **5**, 633 (2009).

[3] H. Weimer, M. Müller, I. Lesanovsky, P. Zoller, and H. P. Büchler, Nature Phys. **6**, 382 (2010).

[4] H. Weimer, Phys. Rev. Lett. **114**, 040402 (2015).

[5] H. Weimer, Phys. Rev. A **91**, 063401 (2015).

[6] V. R. Overbeck and H. Weimer, Phys. Rev. A **93**, 012106 (2016).





## A new transparent XY-MicroMegas neutron beam profiler

*M. Diakaki*[1], *E. Berthoumieux*[1], *T. Papaevangelou*[1], *F. Gunsing*[1,2], *E. Dupont*[1], *M. Kebbiri*[1], *P. Sizun*[1], *E. Monmarthe*[1], *D. Desforge*[1], *L. Tassan-Got*[3], *L. Audouin*[3], *E. Ferrer-Ribas*[1], *J. Heyse*[4], *P. Schillebeeckx*[4], *and the n_TOF collaboration*[5]

[1]Commissariat à l' Energie Atomique (CEA/IRFU), Saclay, France
[2]European Organization for Nuclear Research (CERN), Geneva, Switzerland
[3]IPN, Orsay/ Universite Paris-Sud, Orsay, France
[4]JRC-IRMM Geel, Belgium
[5]cern.ch/ntof

A MicroMegas detector based on microbulk technology [1] with a real two-dimensional readout structure based on strips was developed for the first time, obtained by segmenting both the mesh and the anode. This results in a very low-mass device with good energy resolution capabilities. Such a detector is practically “transparent” to neutrons, being ideal for in-beam neutron measurements. It will be used as a quasi-online neutron beam monitor and profiler at neutron Time-Of-Flight facilities, as the n_TOF facility (CERN, Geneva), GELINA (IRMM, Geel) and NFS (GANIL, Caen).
After a gradual improvement of the design of the microbulk by testing a series of prototypes, the first real detector was made. The amplification area of 60x60 $mm^2$ is separated in mesh and perpendicular anode strips. The width of the strips is 1 mm. The detector data acquisition system is based on the AGET - reduced CoBo technology [2]. Appropriate front-end cards have been developed for the protection of the AGET chips, the voltage distribution and the readout of the strips. The whole setup showed good energy resolution and the potential for good spatial resolution and was installed at the n_TOF facility at CERN [3]. The results were very promising and will be shown.
The development of such a low mass and high radiopurity imaging detector offers new possibilities for several challenging measurements, such as neutron induced charged particle reactions and angular distributions of emitted particles, axion searches, the neutrinoless double beta decay etc, and its applicability to such searches is being explored.

References
[1] S. Andriamonje et al. (the n_TOF collaboration), J. Korean Phys. Soc. 59, 1597 (2011).
[2] GET, General electronics for TPC, ANR proposal / GET-QA-000-0005, AGET Data Sheet.
[3] C. Rubbia et al., A High Resolution Spallation driven Facility at the CERN-PS to measure Neutron Cross Sections in the Interval from 1 eV to 250 MeV, CERN/LHC/98-002-EET (1998).

# Small Neutrino Masses from Gravitational $\theta$-Term

*Gia Dvali*[1,2,3] *and* *Lena Funcke*[1,2]

[1]Arnold Sommerfeld Center, Ludwig-Maximilians-Universität, Theresienstr. 37, 80333 München, Germany
[2]Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany
[3]Center for Cosmology and Particle Physics, Department of Physics, New York University, 4 Washington Place, New York, NY 10003, USA

The observed small neutrino masses are one of the greatest mysteries in current particle physics. Many possible origins have been proposed so far, such as the see-saw mechanism, radiative corrections, or large extra dimensions. All these models, however, require new interactions beyond the Standard Model or additional spatial dimensions.

In our work [1], we present how a neutrino condensate and small neutrino masses emerge from only one single wide-spread assumption: that gravity contains a topological $\theta$-term, analogous to the famous $\theta$-term of QCD. Such a gravitational $\theta$-term may arise since wormholes or virtual micro black holes carry global charges away from our universe. Building on the fact that a gravitational $\theta$-term leads to the emergence of a bound neutrino state analogous to the $\eta'$ meson of QCD, we compute the consequent formation of a neutrino vacuum condensate. Without making any additional assumptions, we show that this condensate effectively generates small neutrino masses.

Our neutrino mass generation model implies numerous phenomenological consequences. The cosmological neutrino mass bound vanishes since we predict the neutrinos to be massless until the phase transition in the late universe, $T \sim$ meV. Coherent radiation of new light particles in the neutrino sector can be detected in prospective precision experiments. The deviations from an equal flavor rate due to enhanced neutrino decays in extraterrestrial neutrino fluxes can be observed in future IceCube data. The current cosmological neutrino background only consists of the lightest neutrinos, which, due to enhanced neutrino-neutrino interactions, either bind up, form a superfluid, or completely annihilate into massless bosons. The strongly coupled relic neutrinos could provide a contribution to cold dark matter in the late universe, together with the new proposed particles and topological defects, which may have formed during neutrino condensation. The enhanced interactions may also solve the puzzle of the reactor antineutrino anomaly and could be a source of relic neutrino clustering in our galaxy, which possibly makes the overdense cosmic neutrino background detectable in the KATRIN experiment. The prospective measurement of the polarization intensities of gravitational waves can falsify our neutrino mass generation model.

[1] Gia Dvali and Lena Funcke, arXiv:1602.03191 [hep-ph]





# Measurement of the CP-violating weak phase $\phi_s$ in $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$ decays at LHCb

*Julian Garcia Pardinas*[1] *and Matthew William Kenzie*[2]

[1]Universidade de Santiago de Compostela, Spain
[2]CERN, the European Organisation for Nuclear Research, Switzerland

The huge abundance asymmetry between matter and antimatter observed in the Universe remains as a mistery within the framework of the Cosmological and Particle Physics Standard Models. Only the weak interaction (of the four fundamental ones) is known to mediate processes where the Charge-Parity (CP) symmetry is violated, this meaning different production rates for particles and antiparticles. However, the size of this effect is very small, and the discovery of new particles involved in CP-violating processes would be needed to provide an explanation for the fenomenon.

The LHCb (Large Hadron Collider beauty) experiment is designed to study CP violation in the decays of hadrons containing $b$ (beauty) quarks, produced in proton-proton collisions in the LHC at CERN. New heavy particles may enter such processes via "quantum loops", modifying the properties of the transition. Thus, the discovery of new particles can be inferred through the accurate measurement of CP-violating observables (constructed from the distributions of the decay products) and the identification of anomalies with respect to the expectations from the Standard Model of Particles.

The decay $B_s^0 \to K^{*0}(\to K^+\pi^-)\bar{K}^{*0}(\to K^-\pi^+)$ is a golden channel in LHCb for the study of CP violation. The observable to be measured in this case is the weak phase $\phi_s$, arising in the interference between the amplitudes of $B_s^0$ mesons decaying directly into $K^{*0}\bar{K}^{*0}$ and those decaying after $B_s^0 - \bar{B}_s^0$ oscillation. It is possible to generalise this framework to include other $K\pi$ components in the decay chain, increasing the available statistics and thus the accuracy of the measurement. In this occasion, the first analysis aimed at measuring $\phi_s$ in $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$ decays is presented, with the $K\pi$ pairs either arranged in a scalar non-resonant configuration or originating from a $K^{*0}$, a $K_0^*(1430)^0$ or a $K_2^*(1430)^0$ resonance.

## New limits on heavy ALPs: an analysis of SN 1987A, again

*Joerg Jaeckel*[1], *Pedro C. Malta*[2], *and Javier Redondo*[3]

[1]Institute for Theoretical Physics, U. Heidelberg (Germany)
[2]Brazilian Centre for Research in Physics, CBPF (Brazil) and Institute for Theoretical Physics, U. Heidelberg (Germany)
[3]University of Zaragoza (Spain) and Max Planck Institute for Physics (Germany)

Axion-like particles (ALPs) are generic hypothetical pseudo-scalar fields that are predicted in many beyond the Standard Model scenarios [1]. They are coupled to two photons via

$$\mathcal{L}_{a\gamma\gamma} = \frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu} + \frac{1}{2} m_a^2 a^2,$$

where $a$ represnts the ALP, while $F_{\mu\nu}$ denotes the usual electromagnetic field-strength tensor. Contrary to the usual QCD axion [2], for ALPs $g_{a\gamma\gamma}$ and $m_a$ may be treated independently. Our aim here is to study massive ALPs with masses ranging from keV to a few tens MeV in the context of supernovae, specifically SN 1987A.

ALPs may be produced in the core-collapse as a star becomes a supernova (SN) and be emitted in all directions during the explosion [3]. Given that they are massive, their life-time is finite and they eventually decay in two photons – usually in the gamma-ray spectrum – after covering a certain distance. The latter, due to their boosted parent ALP, have small, but not negligible, decay angles. This fact implies that ALP-originated photons would also be able to reach Earth from directions other than the one of line-of-sight. The gamma-ray signal would then arrive with considerable delay, possibly as large as $\Delta t \sim 10^7$ s, as well as from non-trivial directions, thus forming a halo in the sky around the SN.

We discuss the time and angular distributions of the ALP-originated gamma-ray signal in the concrete case of SN 1987A. At the time of the SN event, which was accompanied by a 10 s neutrino burst, measurements recorded no excess of radiation, thus imposing an upper limit on the number of photons arriving at the detector [4]. We use this limit to constrain the ALP parameter space by calculating the photon flux as a function of $g_{a\gamma\gamma}$ and $m_a$ and demanding it to be smaller than the observed one.

Given that the gamma-ray signal from SN 1987A may be extended until today, we also obtain bounds based on more modern instruments, such as Fermi-LAT. Looking into the future we also estimate the possible improvements if the red supergiant Betelgeuse goes supernova.

[1] G.G. Raffelt, L. Stodolsky, Phys. Rev. D 37, 1237 (1988).

[2] R.D. Peccei, H.R. Quinn, Phys. Rev. Lett. 38, 1440-1443 (1977).

[3] A. Payez, C. Evoli, T. Fischer, M. Giannotti, A. Mirizzi, A. Ringwald, JCAP 1502, 006 (2015).

[4] E. Chupp, T. Verstrand, C. Reppin, Phys. Rev. Lett. 62, 505 (1989).





## On the substructure of the cosmological constant

*Sebastian Zell*[1]

[1]Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 Munich, Germany
[1]Arnold Sommerfeld Center, Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 Munich, Germany

We investigate how a classical metric can be understood as expectation value of an appropriate quantum state. In this approach, only the Minkowski metric is fundamental. Any other solution is due to the mean field effect of a graviton bound state [1].

In [2], we apply this idea to de Sitter spacetime and study if we can equip the cosmological constant $\Lambda$ with a substructure. For small times, we are able to define the notion of a bound-state graviton, as opposed to an asymptotically free one. Using $N = M_p^2/\Lambda$ bound-state gravitons per Hubble volume (where $M_p$ is the Planck mass), we construct a quantum state with the classical metric as expectation value. The rest energy of the bound state gravitons matches the classical energy associated with the cosmological constant.

In this fully-quantum picture, we calculate redshift as the stimulated emission of a graviton. An external particle loses energy because it deposits gravitons in the bound state. Similarly, particle production in a de Sitter background no longer happens in vacuum, but arises as a scattering process. It is caused by the decay of bound-state gravitons.

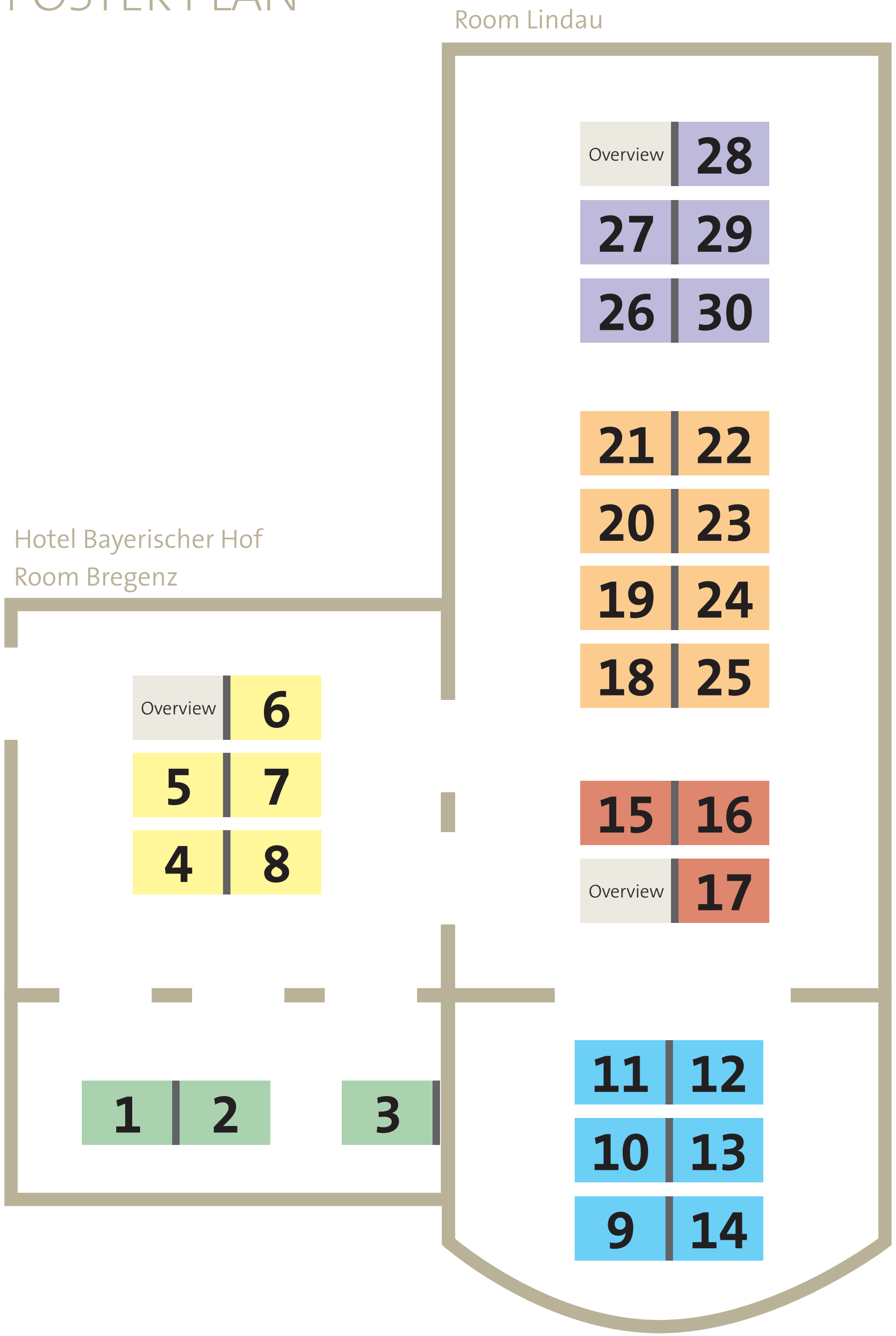
In contrast to the semi-classical treatment, a crucial novelty of this approach is that it naturally predicts the back-reaction of these processes on the metric. Since the number of gravitons changes during scattering, the bound state starts to evolve. This leads to quantum corrections of the corresponding rates. More importantly, we conclude as in [1] that the classical metric ceases to be valid after a finite time.

This point of view fundamentally changes the question about the naturalness of the cosmological constant. Its smallness is required to ensure that the description by a classical metric does not break down on any observable time scale.

[1] G. Dvali and C. Gomez, J. Cosmol. Astropart. Phys. **1401**, 023, (2014)

[2] G. Dvali, C. Gomez and S. Zell, in preparation

# POSTER PLAN




# INFORMATION

**Poster Session**
The poster session will take place on Tuesday, 28 June 2016, from 17.00 - 18.30 hrs in rooms „Lindau“ and „Bregenz“ at Hotel Bayerischer Hof. Poster presenters are requested to be present at their poster walls during the full duration of the poster session.

**Poster Awards**
This brochure includes a voting sheet. Please put your voting sheet in one of the boxes or return it to the Young Scientists Desk by Wednesday, 29 June 2016, at the latest. The winners will be announced during the boat trip on Friday, 1 July 2016.

**Poster Setup**

- All poster walls have a useable area of 120 cm width and 150 cm height.
- Posters may be set up between 13.00 and 15.00 hrs on Tuesday, 28 June 2016.
- Posters have to be provided by the authors; no on-site printing is available. Tape and fixing pins are available in the poster area.
- Posters have to be placed on designated walls – please refer to the poster number published in this brochure.
- Posters have to be removed by the presenters immediately after the poster session. Posters not removed will not be stored.

Council for the Lindau Nobel Laureate Meetings
Foundation Lindau Nobel Laureate Meetings

Alfred-Nobel-Platz 1
88131 Lindau
Germany

www.lindau-nobel.org