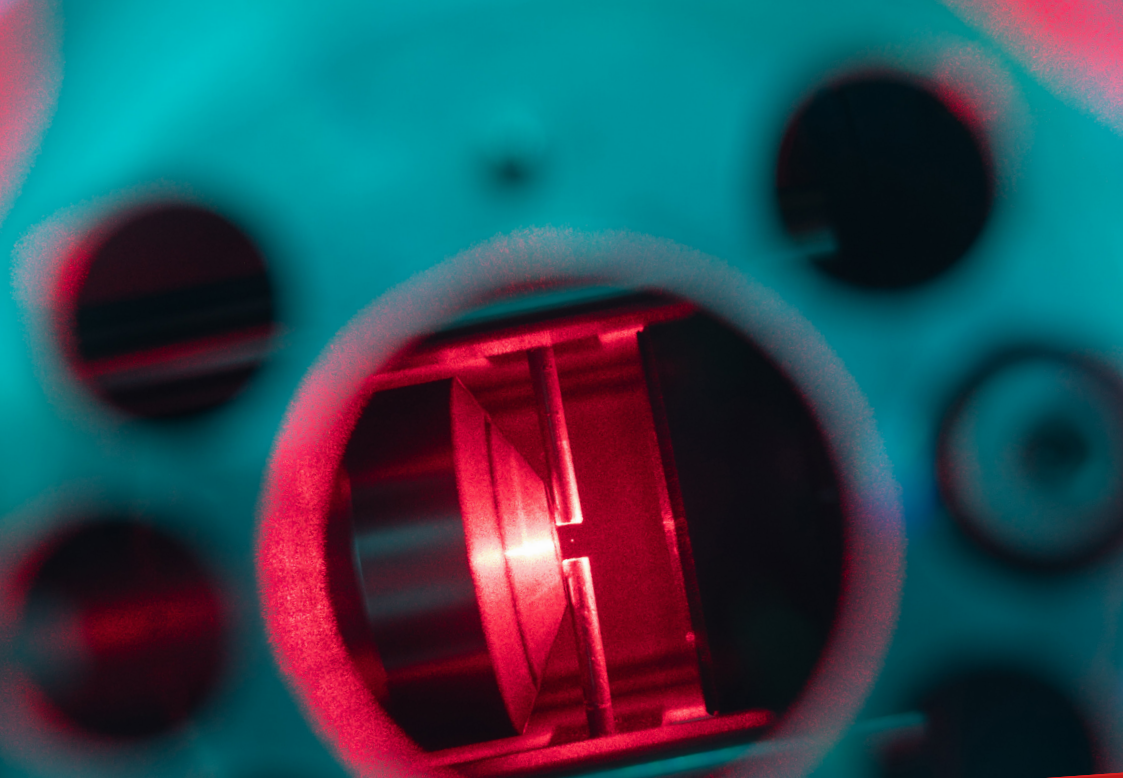


Program and abstracts

10 and 11 October 2023

Conference center
Hotel Zuiderduin Egmond aan Zee

46th Meeting of the NNV section Atomic Molecular and Optical Physics

NWO

nederlandse
natuurkundige vereniging

46th Meeting of the NNV section
Atomic Molecular and Optical Physics (AMO)

Program and abstracts

Conference center
Hotel Zuiderduin Egmond aan Zee

10 and 11 October 2023

Scientific Commitee:

• Lyuba Amitonova • Giel Berden • Anastasia Borschevsky • Klaasjan van Druten • Kjeld Eikema • Richard Hildner • Steven Hoekstra • Servaas Kokkelmans • Wolfgang Löffler • Herman Offerhaus (chair) • Jolijn Onvlee • Dries van Oosten • Sylvania Pereira • Said Rodriquez • Tim Taminiau

Program Committee:

• Kjeld Eikema • Steven Hoekstra

This meeting is organized under the auspices of the NNV-section Atomic, Molecular and Optical Physics, with financial of The Netherlands Foundation of Scientific Research Institutes.

Conference coordination:

Erna Gouwens (RU)

Tuesday 10 October 2023

10.00 **Arrival, registration**

10.40 **Opening by the chair of the section AMO Herman Offerhaus**

chair: Lyuba Amitonova

10.45 **I 01** **Francesca Calegari**
(Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany)
"Ultrafast chiroptical switching"

11.30 Short lectures: (Europa room)

O 01 Grite Abma (Institute for Molecules and Materials, Radboud University, Nijmegen)
"Isomer resolved spectroscopy using universal probes"

O 02 Vincent Barbé (LaserLaB, Vrije Universiteit Amsterdam)
"Laser excitation of the $1S - 2S$ transition in singly-ionized helium"

O 03 Madhav Mohan (Eindhoven University of Technology)
"Robust control and optimal Rydberg states for neutral atom two-qubit gates"

O 04 Komal Chaudhary (ARCNL, Amsterdam)
"Optically enhancing photoacoustic signals using ultra-thin semiconductor coatings on metal surfaces"

12.30 **Lunch**

chair: Giel Berden

14.00 **I 02** **Florian Meinert** (University of Stuttgart, Germany)
"Microscopy of molecular vibrations in ion-Rydberg-atom dimers"

14.45 Short lectures: (Europa room)

O 05 Matteo Fisicaro (Institute of Physics, Leiden University)
"Acoustic interference of surface and bulk waves in SAW cavities"

O 06 Lara van Tetering (HFML-FELIX Laboratory, Radboud University, Nijmegen)
"Structural characterization of mobility-selected ions"

15.15 **Coffee/tea break (attach posters)**

15.45 Short lectures: (Europa room)

O 07 **Premjith Thekkeppatt** (van der Waals Zeeman Institute, University of Amsterdam)
"Towards open-shell weakly bound RbSr fermionic molecules"

O 08 **Sara Marzban** (QuTech and Kavli Institute of Nanoscience, Delft University of Technology)
"Frequency tunable, cavity-enhanced single erbium quantum emitter in the telecom band"

O 09 **Kevin Murzyn** (ARCNL, Amsterdam)
"High-harmonic generation far below Abbe's diffraction limit"

O 10 **Marnix Vreugdenhil** (Nanophotonics, Utrecht University)
"Subsurface laser induced damage in silicon carbide"

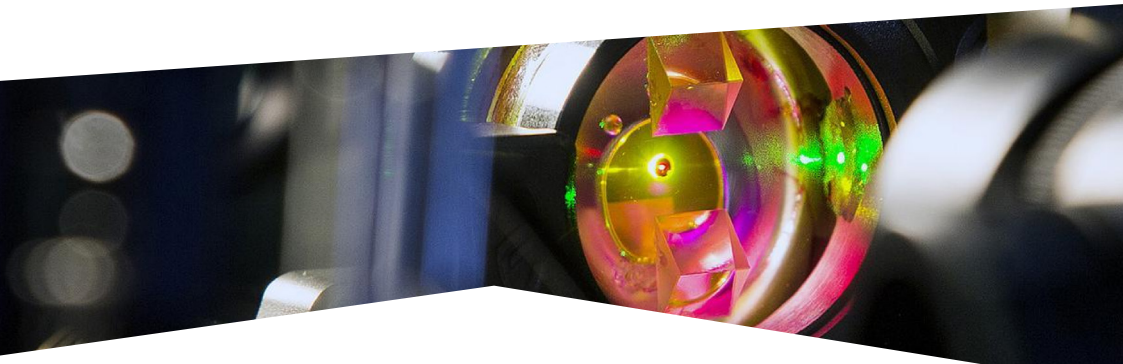
16.45 Poster presentations (odd numbers)

18.00 **Dinner (restaurant)**

19.15 Poster presentations (even numbers)

chair: **Kjeld Eikema**

21.15 I 03 **Wim Ubachs** (LaserLaB, Vrije Universiteit Amsterdam)
"Searches for new physics via precision measurements of hydrogen molecules"



Wednesday 11 October 2023

08.00 **Breakfast** (restaurant, please remove the luggage from your room)

chair: **Silvania Pereira**

08.45 I 04 **Femius Koenderink** (AMOLF, Amsterdam)
"Shrinking light to the scale of a molecule and keeping it there for hundreds of optical cycles"

09.30 Short talks

O 11 **Vashist Ramesh** (AMOLF, Amsterdam)
"Arcsine laws and weak ergodicity breaking in optical resonators"

O 12 **Thomas Kotte** (Optic Research Group, Delft University of Technology)
"Highly efficient transmission diffraction grating through the use of composite elementss"

O 13 **Rodrigo Gonzales Escudero** (LaserLaB, Vrije Universiteit Amsterdam)
"Ultrastable optical frequency distribution to multiple users and a virtual time scale based on a network of atomic clocks"

O 14 **Bart Schellenberg** (van Swinderen Institute, University of Groningen)
"Real-time classification of optically levitated nanoparticles"

10.30 **Coffee/tea break**

chair: **Steven Hoekstra**

11.00 I 05 **Steven Jones** (van Swinderen Institute, University of Groningen)
"Comparing hydrogen and antihydrogen"

11.45 Short talks (Europa room)

O 15 **Coen Sweers** (Eindhoven University of Technology)
"Ponderomotive bunching of a relativistic electron beam for a super radiant Thomson source"

O 16 **Francesco Verdelli** (DIFFER, Eindhoven)
"Surface lattice resonances for polaritonic chemistry"

O 17 **Robert de Keijzer** (Eindhoven University of Technology)

"Recapture probability for anti-trapped Rydberg states in optical tweezers"

O 18 **Laura Dreissen** (LaserLaB, Vrije Universiteit Amsterdam)
"Towards searches for new physics with entangled Ba^+ ions"

12.45 **Lunch**

chair: Herman Offerhaus

13.55 Presentation winner poster award

chair: Klaasjan van Druten

O 19 **Fenling Zhang** (ARCNL, Amsterdam)
"Compression of ultrafast mJ-level pulses via loose focusing in a gas cell"

O 20 **Janko Nauta** (Swansea University, Wales, United Kingdom)
"Gravitational and spectroscopic studies of antihydrogen in the ALPHA experiment"

14.30 I 06 **Lauriane Chomaz** (University of Heidelberg, Germany)
"Dipolar quantum phenomena in ultracold gases of magnetic atoms"

15.20 **End of program**

Francesca Calegari,[1,2,3]

1. Center for Free-Electron Laser Science, DESY, Germany
2. Institut für Experimentalphysik, University of Hamburg, Germany
3. The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Germany

I 01

Ultrafast chiropractical switching

Attosecond science is nowadays a well-established research field, which offers formidable tools for the realtime investigation of electronic processes. In this context, we have demonstrated that attosecond pulses can initiate charge migration in aromatic amino-acids [1] as well as in the DNA nucleobase adenine [2]. These pioneering investigations have been done in ionized molecules and there is still a long path towards attochemistry and the control of the reactivity of neutral molecules via electronic coherences.

Here, I will show our most recent work devoted to the investigation of charge migration in neutral molecules and its applications to manipulate the outcome of photochemical and photophysical processes. We exploited our new light source delivering few-femtosecond UV pulses [3] in order to photoexcite below the ionization threshold and trigger electronic dynamics in the chiral molecule methyl-lactate. We used time-resolved photoelectron circular dichroism (TR-PECD) to image charge migration and disclose - for the first time - its impact on the molecular chiral response. We show that charge migration enables an ultrafast chiroptical switching effect where the amplitude and direction of the photoelectron current generated by PECD can be controlled on a sub-10 fs timescale [4]. These results provide important perspectives to exploit charge-directed reactivity for controlling the chiral properties of matter at the electron time scale.

[1] F. Calegari *et al*., "Ultrafast electron dynamics in phenylalanine initiated by attosecond pulses," Science 346, 336-339 (2014).

[2] E. P. Månsson *et al*., "Real-time observation of a correlation-driven sub 3 fs charge migration in ionised adenine" (Nature) Commun. Chem. 4, 73 (2021)

[3] M. Galli, *et al*., "Generation of deep ultraviolet sub-2-fs pulses," Optics Letters 44, 1308-1311 (2019).

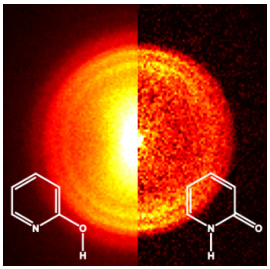
[4] V. Wanie *et al*., "Ultrafast chiroptical switching in UV-excited molecules," arXiv:2301.02002 (2022).

Isomer resolved spectroscopy using universal probes

O 01

G.L. Abma, Z.P. Krüger, M. Balster, A. van Roij, N. Janssen, D.A. Horke
Radboud University, Nijmegen

Even in the cold environment of a molecular beam, complex molecules exist as several isomers. While current experiments allow for isomer-resolved-spectroscopy using double-resonance schemes, experiments employing universal probes are blind to isomerism. We present an alternative approach that utilises electrostatic deflection to create isomer-pure molecular beams. We combine this with photoelectron imaging based on femtosecond multiphoton ionization. We demonstrate the first separation of the isomeric structures of 2-pyridone/2-hydroxypyridine (figure 1), and subsequent isomer-resolved photoelectron spectroscopy. Moreover, this approach can also be combined with chirality measurements based on photoelectron circular dichroism. This enables fully isomer-resolved chirality measurements, as we demonstrate for the rotational isomers of epichlorohydrin. Generally, the technique presented can be used to add isomer resolution to any molecular beam-based experiment where the probe lacks isomer sensitivity.



Laser excitation of the 1S – 2S transition in singly-ionized helium

O 02

V. Barbé[1], E.L. Gründeman[1], A. Martínez de Velasco, A.E. Díaz Calderon[1], L.S. Dreissen[1], R. Taieb[2], K.S.E. Eikema[1]
[1]LaserLaB, Vrije Universiteit Amsterdam
[2]Sorbonne Université, Paris, France

Our goal is to measure the $1S - 2S$ transition in He^+ to better than 1 kHz. This would enable improved tests of quantum electrodynamics and searches for physics beyond the standard model. We report on the first laser excitation of this transition, combining near-infrared light with extreme-ultraviolet radiation produced by high-harmonic generation. Within a single 150 fs pulse, a 46 nm photon ionizes ground-state helium, then the 1S-2S in He^+ is driven with one 32 nm and one 790 nm photon, and nine 790 nm photons ionize $He^+(2S)$ to He^{2+}. Our results are consistent with TDSE calculations, and pave the way for precision laser spectroscopy of He^+.

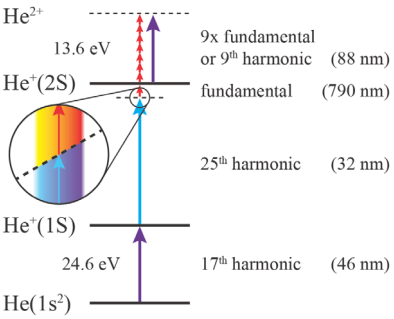
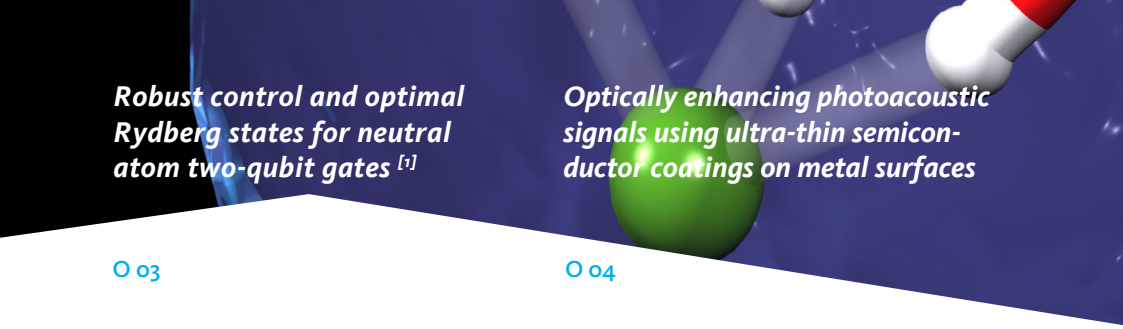


Figure 1: excitation and detection scheme.



Robust control and optimal Rydberg states for neutral atom two-qubit gates [1]

O 03

M. Mohan, R. de Keijzer, S. Kokkelmans
Eindhoven University of Technology, Eindhoven, The Netherlands

Neutral atoms trapped in optical tweezers provide a scalable platform towards realizing a quantum computer. Strong interactions obtained by exciting these atoms to electronic states with high principal quantum numbers n, termed *Rydberg states* – are leveraged to generate multi-qubit gates. Various factors – such as spontaneous emission from the Rydberg state and laser intensity noise – contribute to infidelity of such gates. We introduce two strategies to mitigate such losses for near-term quantum computers. Using quantum optimal control (QOC) theory, we optimize experimental control parameters to obtain high-fidelity, robust gates with a pulse time close to the fastest possible pulses [2]. By carrying out a comprehensive error budget, we introduce the concept of *optimal Rydberg states* – states that maximize the fidelity of the considered gates – and present a method to obtain these states.

[1] arXiv:2212.10159 Mohan, de Keijzer, Kokkelmans Accepted for publication in Physical Review Research
[2] Quantum 6, 712 (2022) Jandura, Pupillo

Optically enhancing photoacoustic signals using ultra-thin semiconductor coatings on metal surfaces

O 04

K. Chaudhary, T. van den Hooven, P. Planken
Advanced Research Center for Nanolithography (ARCNL), The Netherlands

We present a novel approach for enhancing the strength and detection of weak photoacoustic signals by coating a metal surface with ultra-thin, absorbing semiconductor layers. These nanolayers act like absorbing nano-etalons and possess a large real part of the complex refractive index, enabling increased reflection sensitivity of the layer to tiny changes in the optical thickness induced by strain waves. By coating metal surfaces with semiconductor layers of small thicknesses on the order of 5-10 nm, we achieve upto 15 times enhancement compared to the signal obtained from a bare metal. Additionally, an increased control over the absorption offered by choosing different thicknesses of the semiconductor coatings and by choosing suitable pump-probe wavelengths, provides greater flexibility for tailoring the absorption of light in the metal or the semiconductor. Our approach is simple, material-efficient, less sensitive to light incidence angle and require less power, making it even more practical for real-world applications.

Florian Meinert

Physikalisches Institut, Universität Stuttgart, Germany

I 02

Microscopy of molecular vibrations in ion-Rydberg-atom dimers

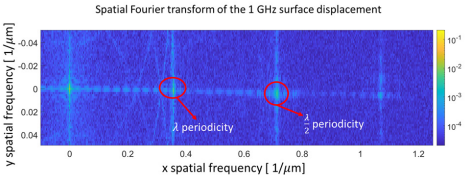
I will report on the direct imaging of molecular vibrations using ion microscopy of laser cooled atomic ensembles. Specifically, we have studied a novel type of a charged dimer composed of a Rubidium ion bound to a high-n Rydberg atom. The binding mechanism results from an ion-induced dipole in the Rydberg atom, which is position dependent and flips its orientation at the molecule's equilibrium bond length. Due to its small binding energy, the ion-Rydberg-atom dimer features a bond length on the micrometer scale and vibrates on timescales as long as hundreds of nanoseconds. We have constructed a novel pulsed ion microscope with high spatial and temporal resolution, which allows us to access these length and timescales and enabled the direct imaging of molecular alignment, orientation and vibration. In the second part of my talk, I will report on the status of another project, which aims to achieve control over very long lived circular Rydberg states of Strontium trapped in optical tweezers for quantum simulations.

Acoustic interference of surface and bulk waves in SAW cavities

O 05

M. Fisicaro, Y. Doedes, T. Steenbergen, W. Löffler
Leiden Institute of Physics, Leiden University

Surface acoustic wave (SAW) cavities consist of two mirrors confining SAWs, which in our case are excited at 1 GHz (λ=2.8 µm) by a transducer placed inside the cavity. Using an optical interferometer, we image the spatial surface displacement at 1 GHz. Next to the expected spatial periodicity of λ/2 corresponding to standing SAWs, we found a λ-periodicity signal which we attribute to interference of bulk acoustic waves (BAWs) and SAWs. Knowledge of the strength of this λ signal can be used to quantify the amount of BAWs, which is important because one of the main sources of loss is scattering of SAWs into bulk acoustic waves (BAWs) by the acoustic mirrors. We therefore propose monitoring the λ signal as a novel method to optimize SAW cavities.



Structural characterization of mobility-selected ions

O 06

L. van Tetering, K. Houthuijs, J. Schuurman, J. Martens, G. Berden, J. Oomens
Radboud University, Nijmegen

Mass spectrometry (MS) often faces challenges when it comes to assigning the complete molecular structure of detected compounds. To overcome this bottleneck, MS is frequently combined with infrared ion spectroscopy (IRIS) to characterize the structure of gas-phase ions. However, IRIS alone fails to capture isomer-selective infrared spectra in mixtures. With trapped ion mobility spectrometry (TIMS) such isomers can be separated based on their mobility, thereby extending the selectivity of MS and IRIS. This combination was realized on a prototype TIMS-enabled FT-ICR MS connected to the beamline of the free-electron laser FELIX.

First results focus on the characterization of saccharide isomers. Mobility data shows that the Cs^+ adduct of raffinose has a different mobility than maltotriose. Therefore, the mobility filter is applied to separate these isomers and distinguish the oligosaccharides using the far-IR range of FELIX. Additionally, maltotriose exhibits two mobility peaks for the Cs^+-adduct. By employing TIMS, a combined IR spectrum of the two conformations can be decomposed and definitively assign their structure using quantum-chemical calculations.

Towards open-shell weakly bound RbSr fermionic molecules

O 07

P. Thekkeppatt, D. Digvijay, S. Lepleux, N. Wach, J. He, N.J. van Druten, F. Schreck
Van der Waals-Zeeman Institute, University of Amsterdam

Ultracold dipolar molecules offer an ideal platform for quantum simulation, precision measurement and quantum chemistry. The ultracold polar molecules produced so far are closed-shell molecules. We aim to produce fermionic ultracold polar, open-shell RbSr molecules, in order to extend the range of possibilities offered by ultracold molecular physics.

Our novel approach utilises confinement induced resonances (CIR) in a strongly interacting ^{87}Rb-^{87}Sr bose-fermi mixture. Unlike alkali atoms, Feshbach resonances in alkali – alkaline-earth atoms are extremely narrow due to the non-magnetic ground state of alkaline earth atoms. We take advantage of CIR, which strongly couples an excited trapped state of a very weakly bound molecule to the atomic pair state. Moreover, this had the advantage of collisional stability of fermionic molecules in a 3D lattice, which will increase the lifetime of the weakly bound molecules. Thereafter we will perform STIRAP to transfer the atoms to a relatively deeply bound state that is ideal for ground-state transfer.

Frequency tunable, cavity-enhanced single erbium quantum emitter in the telecom band

O 08

Y. Yu[1], D. Oser[2], G. Da Prato[1], E. Urbinati[1], J. Avila[3,4] Y. Zhang[1], P. Remy[5], **S. Marzban**[2], S. Groblacher[1], W.Tittel[2,3,4]

[1] *Kavli Institute of Nanoscience, The Netherlands*
[2] *QuTech, TU Delft, The Netherlands*
[3] *Department of Applied Physics, University Genève, Switzerland*
[4] *Constructor University Bremen, Germany*
[5] *SIMH Consulting, Chêne-Bourg, Switzerland*

Single quantum emitters embedded in solid-state hosts are an ideal platform for realizing quantum information processors and quantum network nodes. In this work, linear Stark tuning of the emission frequency of a single Er ion embedded in a lithium niobate crystal and coupled evanescently to a silicon nano-photonic crystal cavity is demonstrated. By applying an electric field along the crystal c-axis, we achieve a Stark tuning greater than the ion's linewidth without changing the single-photon emission statistics of the ion. These results are a key step towards rare earth ion-based quantum networks.

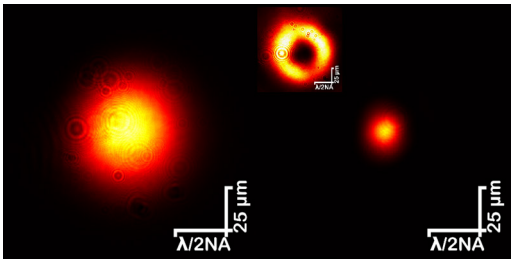
High-harmonic generation far below Abbe's diffraction limit

O 09

K. Murzyn,[1] M. van der Geest[1], L. Guery[1], Z. Nie[1], P.M. Kraus[1,2]
[1] *Advanced Research Center for Nanolithography (ARCNL), The Netherlands.*
[2] *Department of Physics and Astronomy, and LaserLaB, Vrije Universiteit Amsterdam, The Netherlands.*

Super-resolution microscopy is a powerful tool to resolve processes on the nm-scale. Label-free techniques are the preferred choice for imaging unstained biological samples and nanoscale semiconductor devices. Here a new microscopy technique is proposed based on generation of harmonics in solid materials from a diameter smaller than the Abbe limit. Using an approach like STED microscopy [1] this effect can be used to improve the resolution and to look into the nanoscale electronic properties of solids.

[1] S.W. Hell, J. Wichmann, Opt. lett., **1994**, 19, 780-782



Subsurface laser induced damage in silicon carbide

O 10

M. Vreugdenhil, T. Doeksen, A. van der Heiden, T. Oosterman, D. van Oosten
Utrecht University

Subsurface dicing is the process of laser cutting a material by generating a line of defects below the surface, along which the material easily breaks [1]. To effectively apply this process, it is important to know the subsurface Laser Induced Damage Threshold (LIDT) of the material. To this end, we investigated subsurface Laser Induced Damage (LID) for several materials. During these experiments we noticed that the subsurface LIDT of silicon carbide (SiC) displayed an unexpected dependence on pulse duration.
During this talk, I will present the results of both surface and subsurface LID experiments on SiC and BK-7 glass. During these experiments, we varied the pulse duration over a range between 200 fs and 24 ps. These materials show a very different dependence on pulse duration, despite having similar band gap energies. I will conclude by presenting a simple and qualitative model which we use to explain the pulse duration dependence of the LIDTs of both materials.

[1] J. van Borkulo *et al*., ECS Transactions 18.1 (2009).

Wim Ubachs

LaserLab Amsterdam - Vrije Universiteit Amsterdam

I 03

Searches for new physics via precision measurements on hydrogen molecules

Comparisons between highly accurate measurements of level spacings in the hydrogen molecule with advanced quantum electrodynamical calculations for this four-particle quantum system may be regarded as tests of the Standard Model of Physics, as well as searches for physics that goes beyond: possible variation of fundamental constants, the existence of 5^{th} forces, or of extra dimensions. The value of the dissociation energy has been a benchmark target and now perfect agreement has been found between experiment and theory for H_2, D_2 and HD isotopologues at the 10-digit level. A new direction is now pursued in the study of vibrational splittings in hydrogen; this may be the test ground with great potential for future improvements in accuracy.

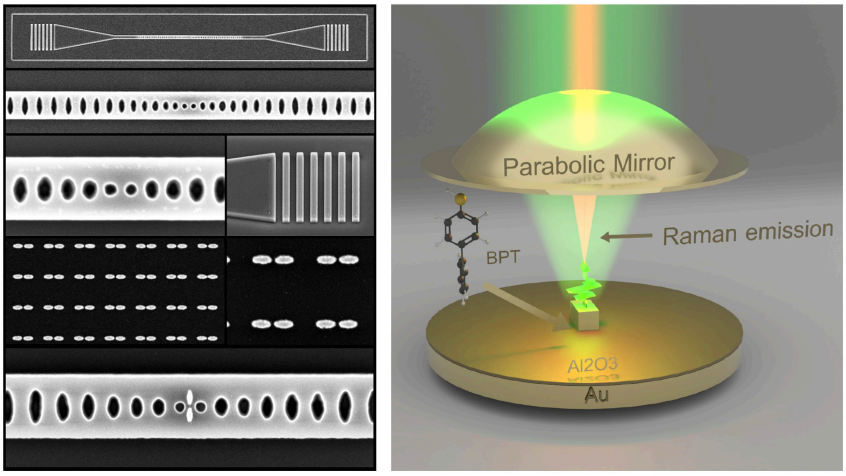
Femius Koenderink[1,2]

[1]Department of Physics of Information and Center for Nanophotonics, AMOLF
[2]Van der Waals-Zeeman Institute, University of Amsterdam

I 04

Shrinking light to the scale of a molecule and keeping it there for hundreds of optical cycles

Nanophotonics is the science of controlling light on length scales far smaller than the wavelength. Light-matter interaction benefits from confining light to as small a volume as possible, for as long as possible, for which a variety of dielectric and metallic resonator nanostructures have been proposed. However, the smaller the volume into which you shrink light, the faster light leaks away. Very recently the field of extreme nanophotonics emerged, using nanometric metal junction that resonate for about 20 optical cycles to shrink light to $\lambda^3/10^6$, which is less than the v We combine this approach of plasmonic antennas to photonic microcavities that can imbue plasmonics with high-Q, and thereby sharp, long-lived resonances. I will discuss the surprising physics of these hybrids, their realization, and applications to single-emitter fluorescence and surface-enhanced Raman scattering.



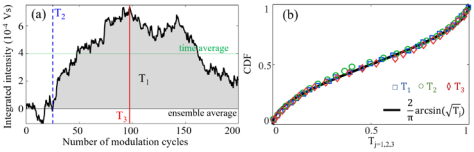
Two concepts for hybrid plasmonic-photonic resonators – lithographic (left [Isabelle Palstra]) and based on the nanocube-on-mirror geometry, in a Fabry-Perot microcavity (right [Ilan Shlesinger & Jente Vandersmissen]).

Can the electrical conductivity of semiconductors be enhanced by strong light-matter interactions?

O 11

V.G. Ramesh, K.J.H. Peters, S.R.K. Rodriguez
AMOLF, Amsterdam, The Netherlands

Consider a laser-driven resonator operated as a sensor. The goal is to detect perturbations to its resonance frequency by monitoring the time-integrated transmitted or reflected intensity. Our question is, given a time budget to estimate the mean time-integrated intensity, what yields a better estimate: one measurement of duration τ, or m independent and identically distributed measurements of duration τ/m? For an ergodic process, both approaches are equally accurate. However, we have recently shown that the time-integrated intensity emitted by a linear resonator breaks ergodicity "weakly" [1]. This result is a consequence of the existence of the arcsine laws (Fig. 1) for coherently-driven resonators. In this contribution we will elucidate the origin of these arcsine laws, and discuss their important implications for detection strategies involving coherently-driven resonators



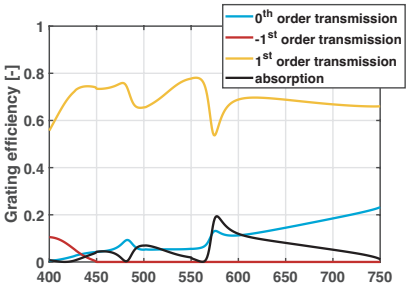
[1] V.G.Ramesh *et al.*, arXiv:2208.07432 (2023)

Highly efficient transmission diffraction grating through the use of composite elements

O 12

T.P.S. Kotte, H.P. Urbach, A.J.L. Adam
Delft University of Technology, The Netherlands

We present a novel method for creating transmission gratings that exhibit high efficiency across the entire visible spectrum. Our approach involves the use of elements made up of two materials, with one part composed of the substrate material (glass) and the other part made of a metal.
This design promotes scattering towards a specific direction, without relying on resonance phenomena. Consequently, the scattering behaviour is largely independent of the wavelength of incident light.
By combining many elements into a grating, we achieve a substantial increase in light scattered into the desired order. This results in the realization of a highly efficient transmission grating that covers the entire visible spectrum. The numerically calculated efficiency for such a grating made out of glass and silver is shown in the figure.



Ultrastable optical frequency distribution to multiple users and a virtual time scale based on a network of atomic clocks

O 13

R. González Escudero,[1] M.A. Weiss,[2] J.C.J. Koelemeij[1]
[1] *Vrije Universiteit Amsterdam*
[2] *Marc Weiss Consulting LLC, Aptos, CA, USA*

Time and frequency distribution through fiber-optic networks is considered an enabling technology for various emerging applications including quantum communication, quantum sensing and accurate terrestrial positioning systems [1]. Here, we report a branched optical network that exploits code-division multiple access methods inspired by mobile telecommunication systems to disseminate an ultrastable optical signal to multiple users with substantially reduced user-to-user cross talk. As such it represents a scalable method to disseminate ultrastable optical signals of quantum clocks to many users via optical networks. In a second activity, we have realized a virtual network time scale based on four simulated atomic clocks, connected and compared with picosecond precision via a White Rabbit fiber-optic Ethernet network. The virtual time scale outperforms each of the simulated clocks, offers resilience to link and clock failures, and paves the way for an improved network-based realization of coordinated universal time, UTC.

[1] J.C.J. Koelemeij *et al.,* Nature 611, 473-478 (2022)

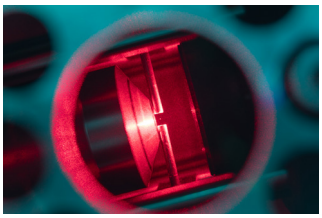
Real-time classification of optically levitated nanoparticles

O 14

B.J. Schellenberg, M. Morshed Behbahani, N. Balasubramanian, T.H. Fikkers, S. Hoekstra
Van Swinderen Institute, University of Groningen, The Netherlands and Nikhef, Amsterdam, The Netherlands

Nanospheres have evolved into an exciting platform for innovative measurement opportunities. When introducing nanoparticles into an optical trap, their mass and shape are not immediately apparent. Particles from mono-disperse solutions of spheres have been observed to carry some ellipticity [1], or they may aggregate to form composite structures [2]. We combined a number of methods to determine the properties of trapped nanoparticles, which have previously only been used separately. We demonstrate that the use of multiple classification techniques is in certain cases required to avoid ambiguous results, which is a key step towards realising precision measurements using levitated nanoparticles.

[1] Rademacher *et al*., Appl. Phys. Lett. 121, 221102 (2022)
[2] Ahn *et al*., Phys. Rev. Lett. 121, 033603 (2018)



Steven Jones

Van Swinderen Institute,
University of Groningen

I 05

Comparing Hydrogen and Antihydrogen

The Standard Model predicts that matter and antimatter are always created and destroyed in equal amounts, yet the universe we see today contains almost no antimatter. By making antimatter in the lab and comparing it to its matter counterpart, we can search for subtle differences that might explain this asymmetry, and reshape our understanding of physics. Antihydrogen is an exciting tool for testing matter-antimatter symmetries, and in the last decade, the field of antihydrogen physics has advanced from proof-of-principle measurements to precision spectroscopy.

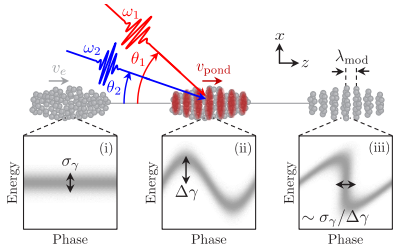
I will give an overview of the techniques used in the ALPHA experiment to produce, trap, and accumulate antihydrogen, and report on our latest spectroscopic and gravitational measurements. I will also introduce a novel source of (regular) hydrogen being developed at Groningen, based on threshold photodissociation of the BaH^+ molecular ion. This source is designed to be compatible with antihydrogen experiments, with the aim of making direct comparisons (i.e., with both species measured in the same trap, at the same time, and using the same lasers) between hydrogen and antihydrogen that are insensitive to systematic effects.

Ponderomotive Bunching of a Relativistic Electron Beam for a Superradiant Thomson Source

O 15

C.W. Sweers, B.H. Schaap,[1]
P.W. Smorenburg,[2] O.J. Luiten,[1]
[1] *Eindhoven University of Technology*
[2] *ASML Netherlands B.V.*

Imposing a density modulation, or microbunching, on an electron beam may improve the brightness of a Thomson source by orders of magnitude via superradiant emission. We analytically and numerically analyze a new method to create microbunching on a relativistic electron beam. Here, an electron beam interacts with a copropagating beat wave formed by two laser pulses. Via the ponderomotive force, the beat wave imposes an energy modulation onto the electron beam, which is transformed into a density modulation. We show that this method can create microbunching for relativistic electron beams. Additionally, effects of the electron beam emittance and energy spread on the quality of the microbunching is studied. Finally, we propose a superradiant extreme ultraviolet Thomson source based on ponderomotive bunching.



Surface lattice resonances for polaritonic chemistry

O 16

F. Verdelli,[1] J.M. Scheers,[2]
M.S. Abdelkhalik,[2] A. Baldi,[3]
J. Gómez Rivas[2]
[1] *DIFFER, Eindhoven*
[2] *Eindhoven University of Technology*
[3] *Vrije Universiteit Amsterdam*

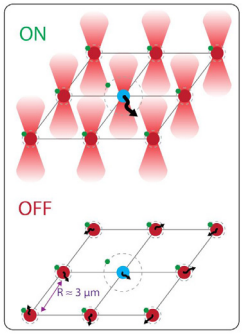
It has been shown recently that reaction rates can be influenced under strong coupling of molecular vibrations with Fabry-Perot modes in optical cavities. This observation and subsequent works have opened a new field of research, known as polaritonic chemistry. We investigate here the effects of vibrational strong coupling (VSC) with extended optical modes in nanoparticle arrays on selected chemical reactions. Periodic arrays of nanoparticles with subwavelength period sustain sharp optical modes known as surface lattice resonances (SLRs). These modes are the result of the enhanced radiative coupling of the nanoparticles in the array, mediated by in-plane diffraction orders. The reactions under study are the solvolysis of p-nitrophenyl acetate (PNPA) and saponification of ethyl acetate. By monitoring the time-dependent absorbance and transmission of the products, we retrieve the reaction rates. While the saponification reaction does not show any enhancement/suppression of its kinetics under VSC, the solvolysis of PNPA is affected by the coupling with the cavity. Our findings introduce a novel platform for polaritonic chemistry.

Recapture probability for anti-trapped Rydberg states in optical tweezers

O 17

R.J.P.T. de Keijzer,
S.J.J.M.F. Kokkelmans, O.T.C. Tse,
Eindhoven University of Technology

In a neutral atom quantum computer, the qubits are individual neutral atoms trapped in optical tweezers. Excitations to Rydberg states form the basis for the entanglement procedure that is at the basis of multi-qubit quantum gates. However, these Rydberg atoms are often anti-trapped, leading to decoherence and atom loss. In this work, we give a quantum mechanical description of the anti-trapping loss rates and determine the recapture probability after Rydberg excitation, distinguishing between having the laser traps turned on and off. We find there is ample time (≈ 30 μs, in a Strontium-88 system) needed for the wave functions to expand out of the trap. Therefore, even with traps on, ≈ 100% recapture probabilities can be expected for times in which significant entanglement operations between atoms can be performed.



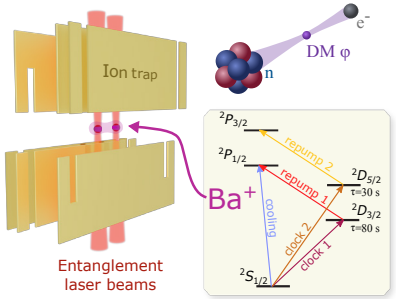
Towards searches for new physics with entangled Ba^+ ions

O 18

L.S. Dreissen
LaserLaB, Vrije Universiteit Amsterdam

The exquisite degree of quantum control over both electronic and motional states in trapped ions have made them powerful tools for searches for physics beyond the Standard Model. Recently, a data driven search for a dark matter boson with accurate isotope shift measurements in ytterbium yielded puzzling observations [1]. Here I present the prospect to further explore this route via entangled Ba^+ isotopes in a decoherence-free state. The lifetime of the first two electronically excited states (>10 s) enable especially long coherence times and upscaling of the ion number. Most systematic shifts are common mode and Ba^+ does not suffer from large nuclear deformation that may hamper the search. At an expected accuracy of <10mHz, yet unexplored parameter range can be probed.

[1] J. Hur et al., Phys. Rev. Lett. 128, 163201 (2022)

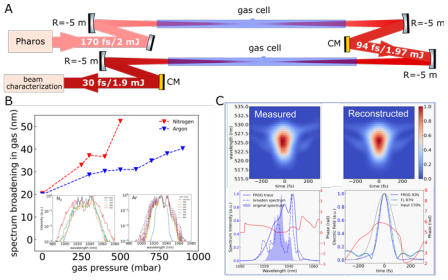


Compression of ultrafast mJ-level pulses via loose focusing in a gas cell

O 19

F. Zhang,[1,2] A. Pelekanidis,[1,2] M. Du1,[2] K. Eikema,[1,2] S.Witte,[1,2]
[1] *ARCNL, Amsterdam*
[2] *Laserlab, Vrije Universiteit Amsterdam*

Developing ultrafast lasers with both high average power and pulse energy remains a great technological challenge. Ytterbium-doped gain media enable high average power scaling, but are limited to ~200 fs pulse duration. Inspired by the CASCADE concept[1], we explore the ability to compress high-energy pulses by loose focusing in a noble gas to induce nonlinear spectrum broadening, while limiting unwanted nonlinear effects such as self-focusing. Using double-pass CASCADE, we demonstrate post-compression of 2 mJ 170 fs Yb: YAG laser pulses to ~30 fs with 90% overall efficiency, with excellent spatial properties and stability. Chirped-mirror compression between passes further improves the efficiency of the spectral broadening.



[1] Tsai M S, *et al*., Sci. Adv. 8(31): eabo1945, (2022)

Gravitational and spectroscopic studies of antihydrogen in the ALPHA experiment

O 20

J. Nauta, on behalf of the ALPHA collaboration
Swansea University, Swansea, Wales, UK

The ALPHA collaboration at CERN investigates the properties of antihydrogen with the aim of testing fundamental physics. Antihydrogen, formed by combining positron and antiproton plasmas in a Penning trap, is magnetically trapped, and stored in a cryogenic vacuum for many hours. Recent developments have led to accumulation of thousands of antiatoms, and production of cold samples by direct laser cooling [1].

The 1S-2S transition in hydrogen has been determined with a fractional uncertainty of 4.2×10^{-15}, while in antihydrogen we have reached a precision of 2×10^{-12}. With the aim of reaching hydrogen-like precision, we have implemented an active hydrogen maser and a Cs fountain as local realisation of the SI second. This will enable us to perform fractional frequency measurements at the level of 10^{-15} or better.

The behaviour of pure antimatter in free fall has previously not been observed. A recently built new vertical trapping apparatus, ALPHA-g, allows measurements of the acceleration of antihydrogen in Earth's gravitational field.

[1] Baker C. J. *et al*., 2021 Nature 592, 35.

Lauriane Chomaz

Quantum Fluids,
University of Heidelberg, Germany

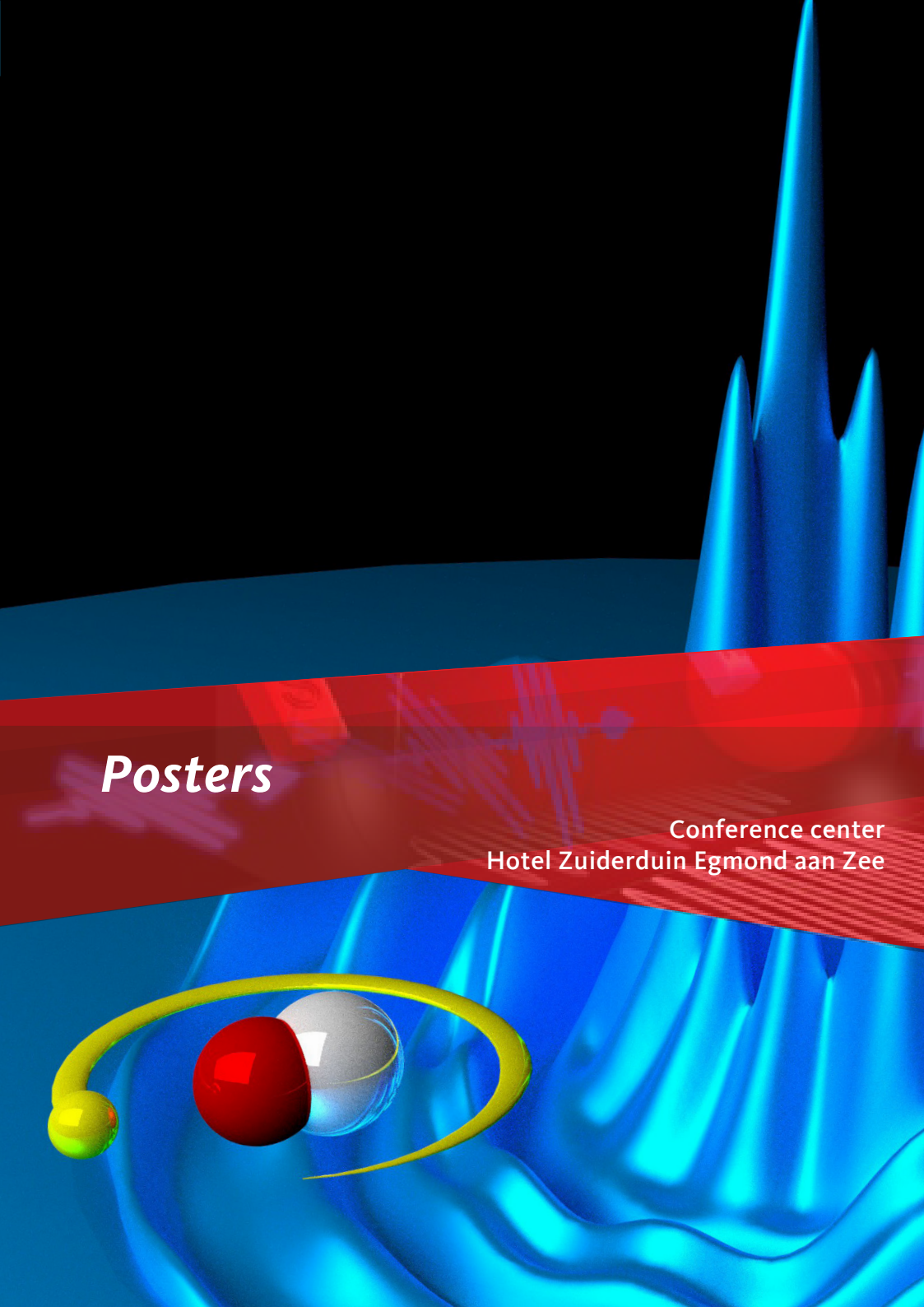
I 05

Exotic many-body states in dipolar quantum Bose gases of magnetic atoms

Ultracold quantum gases provide a pristine platform to study few-body and many-body quantum phenomena with an exquisite degree of control. The achievement of quantum degeneracy in gases of atoms with large magnetic dipole moments in their electronic ground states has opened up new avenues of research in which long-range anisotropic dipole-dipole interactions play a crucial role. In the case of Bose gases, these interactions compete with the conventional short-range contact interactions, and thanks to so-called Feshbach resonances, this competition can be tuned by changing the strength of the contact forces.

In the case of the most magnetic atoms (erbium and dysprosium), fine control of this interaction competition and of the gas geometry has led to the discovery of novel many-body quantum states. These states include elementary excitations such as the roton modes and equilibrium states such as liquid-like droplets, droplet crystals and supersolids, a paradoxical phase of matter that simultaneously exhibits solid and superfluid orders.

A unique mechanism, based on the effect of quantum fluctuations themselves, underlies the stabilisation of these new phases. In my talk, I will review the experimental research progress made in the field of magnetic dipolar gases over the last few years, highlight key results obtained in my former working group in Innsbruck, and finally discuss the future research directions that I am developing in my new research group in Heidelberg, focusing on quantum gases of magnetic atoms in lower dimensional spaces, in and out of equilibrium.



Posters

Conference center
Hotel Zuiderduin Egmond aan Zee

Poster Program 2023

P 1 **Roya Ahemeh** (LaserLaB, Vrije Universiteit Amsterdam)
"Solving a 9σ discrepancy between hyperfine theory and experiment in trapped HD^+ ions"

P2 **Erik Baalbergen** (Huygens-Kamerlingh Onnes Laboratorium, Leiden University)
"Laser synchronized relaxation oscillation in superconducting nanowire single photon detectors"

P3 **Rick Beltman** (Zernike Institute for Advanced Materials, University of Groningen)
"Towards waveguide-enhanced EIT for divacancy color centers in silicon carbide"

P4 **Rick van den Berg** (Eindhoven University of Technology)
"Smart*Light: A high brilliance ICS X-ray Source"

P5 **Matthijs Berghuis** (Eindhoven University of Technology)
"Room temperature exciton-polariton condensation emerging from bound states in the continuum"

P6 **Falco Bijloo** (AMOLF, Center for Nanophotonics, Amsterdam)
"Nonlinear metasurfaces for asymmetry and displacement metrology"

P7 **Klaas Bijlsma** (Zernike Institute for Advanced Materials, University of Groningen)
"Single and double electron capture in low-energy collisions of Sn^{3+} ions with molecular hydrogen"

P8 **Necj Blaznik** (Debye Institute for Nanomaterials Science, Utrecht University)
"Imaging spin-1 trapped quantum gasses using spin-dependent off-axis holography"

P9 **Simona Borelli** (Eindhoven University of Technology)
"Direct observation of Sub-Poissonian Statistics of Free Electrons with Sub-picosecond Resolution"

P10 **Ana Caballo** (Spectroscopy of Cold Molecules, IMM, Radboud University)
"Towards an ultrafast view of Dissociative Electron Attachment"

P11 **Francesco Corazza** (Advanced Research Center for Nanolithography, ARCNL, Amsterdam)
"Integrated XUV Ultrafast Spectroscopy and Scatterometry of Nanostructures"

P12 **Malaquias Correa Anguita** (University of Twente)
"Experimental simulation of loop quantum gravity on a photonic chip"

P13 **Antariksha Das** (QuTech and Kavli Institute of Nanoscience, Delft University of Technology)
"Silicon vacancies in 4H-SiC for quantum networks and quantum sensing"

P14 **Olga Duda** (HFML-FELIX Laboratory, IMM, Radboud University)
"Towards driving and controlling isomerisation using far-IR pulses"

P15 **Pieter van Essen** (Advanced Research Center for Nanolithography, ARCNL, Amsterdam)
"Revealing the microscopic electron dynamics responsible for the suppression of high-harmonic generation in semiconductors"

P16 **Dion Engels** (Advanced Research Center for Nanolithography, ARCNL, Amsterdam)
"High-Resolution Spectroscopic Imaging of Atoms and Nanoparticles in Thin Film Vaporization"

Poster Program 2023

P17 **Ties Fikkers** (Van Swinderen Institute, University of Groningen)
"A polyatomic molecular cryogenic buffer gas beam for tabletop precision experiments"

P18 **Nelson de Gaay Fortman** (University of Amsterdam)
"Spontaneous symmetry breaking in plasmon lattice lasers"

P19 **András Gácsbaranyi** (Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam)
"A continuously operating compound optical clock"

P20 **Claudia Galantini** (Eindhoven University of Technology)
"Sensing interactions in atomic quantum systems"

P21 **Louis Gallagher** (University of Amsterdam)
"Quantum gates with trapped ions and optical tweezers"

P22 **Genevieve Geehan** (Van Swinderen Institute, University of Groningen)
"High Accuracy Calculations of Properties of Heavy Atoms and Molecules"

P23 **Leo Guery** (Advanced Research Center for Nanolithography, ARCNL, Amsterdam)
"Spectrally-resolved broadband XUV Fourier transform holography"

P24 **Junyu He** (Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam)
"Towards a continuous atom laser"

P25 **Rik van Herk** (Eindhoven University of Technology)
"Quantum computing with neutral strontium atoms"

P26 **Yanik Herrmann** (QuTech and Kavli Institute of Nanoscience, Delft University of Technology)
"Coupling Tin-Vacancy Centers in Diamond to Open Fiber-based Microcavities"

P27 **Joost van Hofslot** (Van Swinderen Institute, University of Groningen)
"Laser cooling a slow molecular beam of BaF"

P28 **Stefan van den Hoven** (Adaptive Quantum Optics, University of Twente)
"Single photons in an interferometer: Forbidden outcomes"

P29 **Julius Huijts** (Eindhoven University of Technology)
"Sub-picosecond ultracold electron bunches"

P30 **Maksym Illienko** (Advanced Research Center for Nanolithography, ARCNL, Amsterdam)
"Surface nanostructuring to optimize generation and detection of light-induced acoustics"

P31 **Deon Janse van Rensburg** (Eindhoven University of Technology)
"Tweezer arrays of rubidium atoms for hybrid quantum computing"

P32 **Kirsten Kanneworff** (Institute of Physics, Leiden University)
"Long time-delay quantum interference of single photons produced by a quantum dot - cavity system"

P33 **Giel Keijsers** (AMOLF, Center for Nanophotonics, Amsterdam)
"Irreversibility and broken detailed balance in a perovskite cavity"

P34 **Stach Kuijpers** (Spectroscopy of Cold Molecules, IMM, Radboud University)
"ND_3-ND_3 scattering in near-merged beams"

Poster Program 2023

P35 **Mingpeng Liang** (Eindhoven University of Technology)
"Refractive index biosensing using quasi bound states in the continuum"

P36 **Roy van der Linden** (Advanced Research Center for Nanolithography, ARCNL, Amsterdam)
"Efficient extreme-ultraviolet high-order wave mixing from laser-dressed silica"

P37 **Zihao Lu** (University of Cambridge, United Kingdom – AMOLF, Amsterdam)
"On the microscopic theory of natural optical activity in a disordered medium of light scatterers"

P38 **Marijn Man** (Theoretical and Computational Chemistry, IMM, Radboud University)
"Using Li_2 + Na collisions to test models of ultracold collisions"

P39 **Andrés Martínez de Velasco** (LaserLaB, Vrije Universiteit Amsterdam)
"Towards precision 1S-2S spectroscopy of trapped He+"

P40 **Charlie Mattschas** (MESA+ Institute for Nanotechnology, Adaptive Quantum Optics (AQO), University of Twente)
"Stabilizing optical microcavities in 3D"

P41 **Wander van der Meer** (LaserLaB, Vrije Universiteit Amsterdam)
"Performing high precision spectroscopy on ultracold ammonia molecules in an electrostatic trap"

P42 **Daniel Ochoa** (LaserLaB, Vrije Universiteit Amsterdam)
"Towards an H_2^+ Molecular Ion Clock"

P43 **Clara Robalo Pereira** (Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam) "Quantum simulation with trapped ions and optical tweezers"

P44 **Antonius Pelekanidis** (Advanced Research Center for Nanolithography, ARCNL, Amsterdam)
"Multi-wavelength ptychography with extreme ultraviolet vortex beams"

P45 **Kevin Peters** (AMOLF, Center for Nanophotonics, Amsterdam)
"Memory-Induced Self-Oscillations in Nonlinear Resonators"

P46 **Mio Poortvliet** (Institute of Physics, Leiden University)
"Systematic study of the photon quality from a quantum dot cavity single photon source by Rabi tuning"

P47 **Jasper Postema** (Eindhoven University of Technology)
"Scalable Quantum Error Correction on a Neutral Atom Platform"

P48 **Margriet van Riggelen** (QuTech and Kavli Institute of Nanoscience, Delft University of Technology)
"Characterization of quantum gates on nitrogen-vacancy center in diamond using randomized benchmarking"

P49 **Daan de Ruiter** (MESA+ Institute for Nanotechnology, University of Twente)
"Time-domain Physical Unclonable Functions"

Poster Program 2023

P50 **Violetta Sharoglozova** (MESA+ Institute for Nanotechnology, Adaptive Quantum Optics (AQO), University of Twente)
"Particle Velocity Measurement in Classically Forbidden Regions"

P51 **Robert Smit** (Institute of Physics, Leiden University)
"Towards a resonant excitation of the 'forbidden' triplet state of a single molecule"

P52 **Chris Sparling** (Spectroscopy of Cold Molecules, IMM, Radboud University)
"Revealing the importance of molecular axis alignment and symmetry-breaking in photoelectron elliptical dichroism"

P53 **Kim Steenbakkers** (HFML-FELIX Laboratory, IMM, Radboud University)
"Leak-out spectroscopy as alternative method to rare-gas tagging for the Renner-Teller perturbed $HCCH^+$ and $DCCD^+$ ions"

P54 **Petr Steindl** (Institute of Physics, Leiden University)
"Cross-polarization-extinction enhancement and spin-orbit coupling of light for quantum-dot cavity quantum electrodynamics spectroscopy"

P55 **Kees Steinebach** (LaserLaB, Vrije Universiteit Amsterdam)
"Alpha and helion particle nuclear charge determination from precision measurements in quantum degenerate helium"

P56 **Hannah Strauch** (Physical Institute, University of Göttingen, Germany)
"Measurement and analysis strategies for EUV pump-probe spectroscopic imaging"

P57 **Pierre Sustar** (Spectroscopy of Cold Molecules, IMM, Radboud University)
"Electric field control of ND_3-H_2 collisions"

P58 **Alexandra Tsoukala** (Spectroscopy of Cold Molecules, IMM, Radboud University)
"Towards controlled reactive collisions between S atoms and D_2 molecules"

P59 **Matthijs Velsink** (Advanced Research Center for Nanolithography, ARCNL, Amsterdam)
"Subsurface imaging of opaque layers using ultrafast photoacoustics"

P60 **Etienne Walraven** (Theoretical and Computational Chemistry, IMM, Radboud University)
"How to become the chosen one: Deterministic tweezer loading of ultracold molecules"

P61 **Siwen Wang** (Spectroscopy of Cold Molecules, IMM, Radboud University)
"Using laser based thermal desorption source to study UV photoionization of biomolecules"

P62 **Sven Weerdenburg** (Optics Research Group, Delft University of Technology)
"Reflective Lensless Microscopy with a Table-Top High Harmonic Generation Coherent EUV Source"

P63 **Erik Woering** (Zernike Institute for Advanced Materials, University of Groningen)
"Revealing structure-function properties of the organic polyelectrolyte ProDOT via single-molecule spectroscopy"

Poster Program 2023

P64 **Tom Wolterink** (Institute for Physics, University of Rostock, Germany)
"Order-invariant two-photon quantum correlations in PT-symmetric interferometers"

P65 **Xingpeng Xu** (Zernike Institute for Advanced Materials, University of Groningen)
"Ultrafast coherent control of single molecules via two-photon excitation at room temperature"

P66 **Sheng Zhou** (Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam)
"Towards continuous superradiant lasing on the clock transition of strontium"

P67 **Rutger Zijlstra** (HFML-FELIX Laboratory, IMM, Radboud University)
"Towards gas-phase supported cluster catalysis"

P68 **Jerry Kamer** (Institute of Physics, Leiden University)
"Dissociative Ionization of Benzonitrile"

P69 **Lucas van Sloten** (Van Swinderen Institute, University of Groningen)
"Stark deceleration of molecules for precision measurements"

Solving a 9σ discrepancy between hyperfine theory and experiment in trapped HD^+ ions

P 1

R. Ahemeh, D. Kliukin,T. Klijn Velderman, K.S.E. Eikema, J.C.J. Koelemeij
Vrije Universiteit Amsterdam

Previously we have carried out Doppler-free laser vibrational spectroscopy of trapped, laser-cooled HD^+ molecular ions with a relative uncertainty of a few parts-per-trillion (ppt) [1]. Combined with accurate theoretical predictions and other recent precision measurements, our HD^+ data can potentially improve the literature value of the electron's relative atomic mass from 29 ppt to 18 ppt [2]. Surprisingly, the Doppler-free spectroscopy also revealed a large (8.5 kHz, or 9σ) deviation between the observed and theoretically predicted hyperfine structure.
In order to resolve the discrepancy, we are currently performing electron spin resonance spectroscopy of various hyperfine transitions in HD^+ to measure the hyperfine structure with a target uncertainty of 0.1 kHz.
The results should allow establishing whether the discrepancy stems from proton-electron, deuteron-electron, or spin-rotation interactions, and/or from an extraordinarily large yet overlooked systematic effect in the previous experiments.

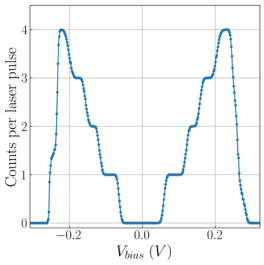
[1] Patra *et al*.., Science 369, 1238-1241 (2020)
[2] Karr and Koelemeij, *Mol. Phys*. (2023)
DOI: 10.1080/00268976.2023.2216081

Laser synchronized relaxation oscillation in superconducting nanowire single photon detectors

P 2

F.B. Baalbergen,[1] I.E. Zadeh,[2] M.J.A. de Dood,[1]
[1] *Huygens-Kamerlingh Onnes Laboratorium, Leiden University*
[2] *Department of Imaging Physics (ImPhys), Eindhoven University of Technology*

Photon number resolving detectors are an important resource for, among others, optical quantum computing. We explore superconducting nanowire single photon detectors (SNSPDs). In order to extend the use of existing detectors to photon number resolving detectors, the heat transfer from the electronics of the current-carrying nanowire to the substrate and vice-versa must be well understood.
We experimentally show nano detectors of various sizes that exhibit saturation of detection events to the laser repetition rate. Relaxation oscillations occur outside the superconducting phase of the nanowire. Coupling of the electronics of the nanowire to the thermal bath of the substrate allows for synchronization of these relaxation oscillations to integer multiples of the laser pulse repetition rate.



Towards waveguide-enhanced EIT for divacancy color centers in silicon carbide

P 3

R. Beltman,[1] J. Hendriks,[1] J. Ul-Hassan,[2] N.T. Son,[2] O. Trojak,[3] A. Politi,[3] C.H. van der Wal[1]
[1] Zernike Institute for Advanced Materials, University of Groningen
[2] Linköping University, Sweden
[3] University of Southampton, UK

Divacancy centers in SiC possess promising properties for applications in quantum information technology, such as long coherence times and emission close to telecom wavelengths. These defect centers can be coherently controlled all-optically by using electromagnetically induced transparency (EIT). However, inhomogeneous broadening of the ensemble of defects can prevent one from reaching full transparency [1]. Here, we explore the option to increase the transparency by using monolithic SiC waveguides, which reduces additional inhomogeneous broadening due to strain at the interface with the core and cladding layers when compared to non-SiC cladding. We use heavily doped cladding layers to confine light in the core and to create p-i-n junctions for future additional electric control. We show that this method allows for creating single-mode waveguides, where confinement of light over long distances can aid in reaching full transparency in EIT.

[1] O.V. Zwier, *et al*., Journal of Applied Physics 131.9 (2022).

Smart*Light: A high brilliance ICS X-ray Source

P 4

R.G.W. van den Berg, D.F.J. Nijhof, I.J.M van Elk, C. Sweers, P.H.A Mutsaers, O.J. Luiten
Eindhoven University of Technology

At Eindhoven University of Technology, a lab-based tabletop Inverse Compton Scattering (ICS) source is being commissioned. This compact and affordable X-ray source will bridge the gap between conventional lab X-ray sources and synchrotrons. In the ICS process photons are bounced off a relativistic electron bunch, converting them into X-ray photons through the relativistic Doppler effect.

The electron bunches for the ICS process are created by a combination of a 100 kV DC photo electron gun and a bunching cavity. These electrons are subsequently injected into an X-band accelerator.
The high gradient X-band accelerator is adapted from an original design for the Compact Linear Collider (CLIC).
The accelerated electron bunches are focused and collide with a focused 12 mJ/pulse 800 nm laser beam thereby producing X-ray photons with energies between 10 and 40 keV.
An overview of the design and results of the commissioning will be given.

Room temperature exciton-polariton condensation emerging from bound states in the continuum

P 5

Matthijs Berghuis,[1] J.L Pura,[2] G.W. Castellanos,[1] S. Murai,[3] D.R. Abujetas,[4] E. van Heijst,[1] M. Ramezani,[1] J.A. Sanchez-Gil,[2] J. Gómez Rivas,[1]

[1] *Eindhoven University of Technology,*

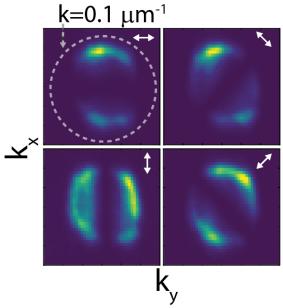
[2] *IEM-CSIC, Madrid, Spain*

[3] *Kyoto University, Japan*

[4] *Fribourg University, Switserland*

We demonstrate polariton condensation from a bound state in the continuum (BIC) in a silicon metasurface. BICs are optical modes with infinitely long lifetimes in lossless surfaces due to the cancellation of the radiation to the far field. We show that our system supports a BIC where the radiation leakage at normal incidence is suppressed due to the quadrupolar character of the mode, which results in a vanishing of the overlap integral of the mode and the radiation continuum.

The theoretical infinite lifetime of the BIC results in a low condensation threshold and vortex emission with no intensity in the normal direction (see Figure).



Nonlinear metasurfaces for asymmetry and displacement metrology

P 6

F. Bijloo,[1,2] P.M. Kraus,[2] A. den Boef,[2,3] A.F. Koenderink[1]

[1] *AMOLF, Center for Nanophotonics, Amsterdam*

[2] *ARCNL, Amsterdam*

[3] *ASML, Veldhoven*

The field of nanophotonics has created a diverse range of tools for controlling the optical properties of resonant scattering structures that depend strongly on intricate details at the nanoscale [1]. The abundant and customizable mode structure, resulting from strong multiple scattering and near-field effects, provides flexible means to manipulate and govern nonlinear light processes, including efficient frequency conversion and nonlinear wavefront shaping [2]. To facilitate nonlinear processes, it is crucial to have greatly enhanced electric fields, achievable through sharp resonances in nonlinear metasurfaces [3]. In this study, we investigate the remarkable sensitivity of nonlinear scattering processes to geometric alterations in nanostructured surfaces.

[1] Evlyukhin, A. B., Reinhardt, C., & Chichkov, B. N. (2011). *Physical Review B, 84*(23), 235429.

[2] Koshelev, K., Kruk, S., Melik-Gaykazyan, E., Choi, J. H., Bogdanov, A., Park, H. G., & Kivshar, Y. (2020). *Science, 367*(6475), 288-292.

[3] Koshelev, K., Lepeshov, S., Liu, M., Bogdanov, A., & Kivshar, Y. (2018). *Physical review letters, 121*(19), 193903.

Single and double electron capture in low-energy collisions of Sn^{3+} ions with molecular hydrogen

P 7

K. Bijlsma,[1,2] I. Rabadán,[3] L. Assink,[1,2] E. de Wit,[1] A. Kleinsmit,[1]
[1] *University of Groningen*
[2] *ARCNL, Amsterdam*
[3] *Universidad Autónoma de Madrid, Spain*

We report experimental single and double electron capture cross sections for Sn^{3+} ions impacting on H_2 (and D_2) molecules in the wide energy range of 0.4 – 153 eV/u. A crossed-beam type experiment with a decelerated Sn^{3+} ion beam and an H_2 gas jet is performed. Charge-state resolved Sn ion numbers are measured with a retarding field analyzer. We find the single capture cross section to be relatively energy-independent over the energy range 1 - 100 eV/u and to decrease for both lower and higher energies. The double capture cross section shows a remarkable increase by an order of magnitude upon decreasing energy from roughly 60 to 20 eV/u. We compare our experimental results to semiclassical calculations and discuss the possible origins of the observed behavior. In addition we will discuss the relevance of our data to state-of-the-art EUV nanolithography machines.

Imaging spin-1 trapped quantum gasses using spin-dependent off-axis holography

P 8

N. Blaznik, O.J. Phillips, M. Duran Gutierrez, P. van der Straten,
Debye Institute for Nanomaterials Science and Center for Extreme Matter and Emergent Phenomena, Utrecht University

We present a novel spin-sensitive imaging method for trapped quantum gases by incorporating digital off-axis holography with polarization-contrast imaging. The method relies on different phase delays for orthogonal polarization components of the probe light due to the anisotropic polarizability of spin-polarized atoms. Due to its inherent heterodyne gain, it allows for probe doses two orders of magnitude lower than phase contrast imaging, while recording both phase delay and intensity from a single image [1]. By introducing a second reference beam, we can reconstruct the spin distribution of the trapped atomic cloud and study *in-situ* spin dynamics with a temporal resolution of less than 1 ms. This allows for observation and investigation of spin textures and the formation of topological defects within spinor quantum gasses, which opens a new window of opportunities for potential applications in spintronics.

[1] J. Smits *et al.*, 2020 Opt. Lett. 45, 981-984

Direct observation of Sub-Poissonian Statistics of Free Electrons with Sub-picosecond Resolution

P 9

S. Borrelli, T.C.H. de Raadt, K.A.H. van Leeuwen, O.J. Luiten
Eindhoven University of Technology, Eindhoven, The Netherlands

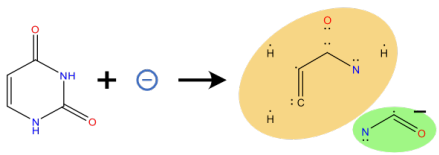
Measuring the fermion statistics of free electrons has long posed a significant scientific challenge due to the limited temporal resolution of available detectors. Fermion statistics is experimentally observed as electron anti-bunching, which corresponds to a lower coincidence rate on the detector compared to the classical Poisson distribution. Additionally, anti-bunching can also occur due to Coulomb scattering between electrons. Directly measuring electron anti-bunching requires precise determination of particle arrival times within extremely short time windows.
We propose here a novel method for accurately determining the arrival time statistics of electrons in a continuous beam with a sub-ps resolution. We present measurements covering time windows ranging from 100 ns to a few-100 fs at beam currents of 6 nA and 46.2 nA, enabled by the proposed technique,We demonstrate a Poissonian-like behavior at nanoseconds time scale. Furthermore, for the first time, we have observed pronounced sub-Poissonian statistics within time windows ranging from a few picoseconds to a few-hundred femtoseconds.

Towards an ultrafast view of Dissociative Electron Attachment

P 10

A. Caballo, Y. Dauletyarov, D.A. Horke,
Radboud University, Nijmegen

One of the crucial interactions between low-energy electrons (0-20 eV) and neutral molecules is Dissociative Electron Attachment, where an electron is captured by a molecule leading to fragmentation. Despite its key implications (from DNA damage to astrochemistry) much remains to be understood. Here we present a novel experimental approach currently under construction in our lab to study this with ultrafast time resolution. In this approach a short (sub-nanosecond) electron pulse is generated by photoemission from a nanotip, driven by a 150 kHz femtosecond laser. The electron pulse interacts with (bio)molecules of interest, produced via laser-based thermal desorption. Anionic and neutral products will be detected in a time-of-flight spectrometer. This approach will allow us to detect all species produced in a typical DEA event, and to study the fragmentation dynamics in the future.



Integrated XUV Ultrafast Spectroscopy and Scatterometry of Nanostructures

P 11

F. Corazza,[1] L. Guery,[1] Z. Nie,[1] P. Kraus,[1,2]
[1] Advanced Research Center for Nanolithography, Amsterdam,
[2] Department of Physics and Astronomy, and LaserLaB, Vrije Universiteit, Amsterdam, The Netherlands

In this abstract, we propose a novel approach based on high harmonic generation (HHG) for accessing structural and material-related characteristics of nanostructures. In the XUV domain, it is possible to exploit a reflection configuration to harvest and analyse the light scattered by a nanostructured sample for extracting information about the dimensions and shapes. Pump-probe techniques enable to observe material-specific carrier dynamics down to the attosecond time scale.
The proposed system consists of an XUV scatterometer designed for analysing the 0^{th} diffraction order signal from the sample, whose spectrum can be fit to numerical models for retrieving structural characteristics. The employment of HHG together with the use of few-cycle pulses enables to access electrons and holes dynamics also in layered samples [1], providing insightful information about the charge transport across complex nanostructures.

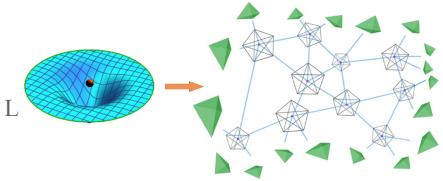
[1] S. Cushing; *et al.*, Science advances 6.14 (2020): eaay6650

Experimental simulation of loop quantum gravity on a photonic chip

P 12

M. Correa Anguita,[1]
R. van der Meer,[1] Z. Huang,[2]
D.Qu,[3] P. Hooijschuur,[1] H. Liu,[4]
M. Han,[3,4], J.J. Renema,[1] L. Cohen,[5]
[1] University of Twente, The Netherlands
[2] University of Shanghai for Science and Technology, China
[3] Atlantic University, USA
[4] Friedrich-Alexander Universität Erlangen-Nürnberg, Germany
[5] University of Colorado Boulder, USA

One leading solution to the unification of general relativity and quantum theory is Loop Quantum Gravity (LQG). Simulating LQG may be important for providing predictions which can then be tested experimentally. However, such complex quantum simulations cannot run efficiently on classical computers, and quantum computers or simulators are needed. Here, we experimentally demonstrate quantum simulations of transition amplitudes of LQG on an integrated photonic processor. We simulate a basic transition of LQG and show that the derived transition amplitude falls within 4% error with respect to the theoretical prediction, despite experimental imperfections.



Silicon vacancies in 4H-SiC for quantum networks and quantum sensing

P 13

S.J.H. Loenen, G.M. Timmer, T.W. de Jong, **A. Das**, T.H. Taminiau
QuTech and Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands

Point defects in 4H-SiC have great potential for scalable quantum applications, Among these, the negatively charged silicon vacancy center (SiV^-) standing out due to its impressive attributes such as the long spin coherence time (T_2 = 0.8 ms [1]) and the potential for achieving lifetime-limited optical linewidths in nanostructures [2]. Our work focuses on fabricating nanophotonic structures in 4H-SiC and precisely implanting defects within these structures. By utilizing nanopillars, waveguides, and photonic crystal cavities (PCCs), we enhance the optical properties of the V_2 center, advancing control over V_2 defects and its surrounding spin bath.. Furthermore, we are working towards efficient fiber coupling to the waveguides and PCCs so that we can use the V_2 center as a qubit for versatile quantum technologies.

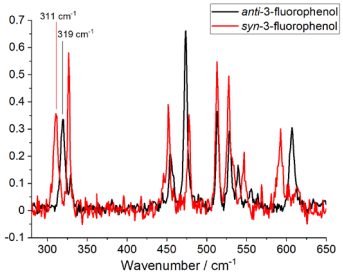
[1] Nagy, R . *et al.,* Nature Communications . 10.1 (2019).
[2] Babin, C , *et al.,* Nature Materials . 21, 67 – 73 (2022).

Towards driving and controlling isomerisation using far-IR pulses

P 14

Olga Duda,[1,2] J. Bakker,[1] D. Horke,[2]
[1] *Radboud University, Institute for Molecules and Materials, FELIX Laboratory, Nijmegen*
[2] *Radboud University, Institute for Molecules and Materials, Nijmegen*

Isomerisation reactions are a vital part of many chemical reactions. *Meta*-substituted phenols are a simple example of rotational isomers and hence a good model system for studying IR-driven isomerisation. 3-fluorophenol exhibits –OH vibrational bands in the 250-350 cm^{-1} region, with isomer-specific frequencies (as shown below). Further spectral differences between the two isomers can also be resolved. We are now focusing on probing the response and population transfer of 3-fluorophenol following IR excitation of selected isomer-specific bands via IR-UV double resonance spectroscopy. We will present results of this proof-of-principle experiment aimed at observing direct population transfer between the *syn*- and *anti*- isomers, as well as understanding the vibrational energy redistribution in substituted phenols.



Revealing the microscopic electron dynamics responsible for the suppression of high-harmonic generation in semiconductors

P 15

P.J. van Essen,[1] K. Muryn,[1] B. de Keijzer,[1] P.M. Kraus,[1,2]
[1] *Advanced Research Center for Nanolithography, Amsterdam, The Netherlands*
[2] *Department of Physics and Astronomy, and LaserLaB, Vrije Universiteit, Amsterdam, The Netherlands*

Optical modulation of high-harmonics generation (HHG) in solids enables the detection of material properties such as the band structure, and exciting new applications such as super-resolution imaging in semiconductors. Various recent studies [1,2] have shown optical modulation of HHG in solids, in particular suppression of HHG is observed. Thus far, the microscopic electron dynamic processes responsible for the suppression of HHG are poorly understood. Here, we use pump-probe solid-HHG spectroscopy to access the electron dynamics in semiconductors. Interpretive theoretical context is provided by using simulations based on semiconductor-Bloch equations. We study ZnO as probative material, offering a steppingstone to the general understanding of suppression of HHG in semiconductors.

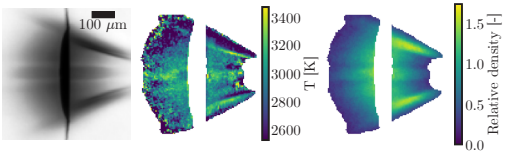
[1] Y. Wang, *et al*., Phys. Rev. B 107, L161301 (2023)
[2] S. Xu *et al*., Opt. Express 30(26) 47733-47743 (2022)

High-Resolution Spectroscopic Imaging of Atoms and Nanoparticles in Thin Film Vaporization

P 16

D.J. Engels,[1] R.A. Meijer,[1] H.K. Schubert,[1] W. Ubachs,[1,2] O.O Versolato[1,2]
[1] *Advanced Research Center for Nanolithography, Amsterdam*
[2] *Vrije Universiteit Amsterdam*

We investigate tin vapor created from a thin film after irradiation by a laser pulse; a case inspired by EUV generation for state-of-the-art nanolithography.
We investigate such a tin vapor using high-resolution spectroscopic imaging. This results in a spatially resolved spectrum for each pixel with a 10 µm and 10 cm^{-1} resolution respectively.
Each spectrum contains many atomic resonances of neutral tin and a broadband contribution from nanoparticles. We use the resonances to reveal a homogeneous temperature profile throughout the vapor of around 3000 K. We also obtain spatially resolved atomic densities and combine this with the temperature map to create an electron density map.



A polyatomic molecular cryogenic buffer gas beam for tabletop precision experiments

P 17

T.H. Fikkers,[1] M.C. Mooij,[2,3] J.W.F van Hofslot,[1,2] R. Bause,[1,2] H.L. Bethlem,[1,3] A. Boeschoten,[1,2] A. Borschevsky,[1,2] S. Hoekstra,[1,2] S. Jones,[1,2] K. Jungmann,[1,2] V. Marschall,[1,2] T.B. Meijknecht,[1,2] L. van Sloten,[1,2] R.G.E. Timmermans,[1,2] A. Touwen,[1,2] W. Ubachs,[3] J. de Vries,[2,4] L. Willmann,[1,2] Y.A. Chamorro Mena,[1] L.F. Pašteka[1]

[1] *Van Swinderen Institute, Rijksuniversiteit Groningen*

[2] *National Institute for Subatomic Physics, Nikhef*

[3] *Department of Physics and Astronomy, Vrije Universiteit Amsterdam*

[4] *Institute of Physics, University of Amsterdam*

Polyatomic molecules have become important candidates for testing parity and time violating physics beyond the standard model. Polyatomic molecules allow for an improved eEDM measurement. Unlike diatomic molecules, polyatomic molecules can combine favorable characteristics like parity doublets in the ground state and heavy nuclei without in principle a loss of laser-coolability. It is the aim of this project to combine theory with experiment for a range of polyatomic molecules in order to find optimal candidates for future eEDM searches. This poster focuses on the development of a versatile cryogenic buffer gas source capable of producing a range of polyatomic molecules in an intense and slow beam.

Spontaneous symmetry breaking in plasmon lattice lasers

P 18

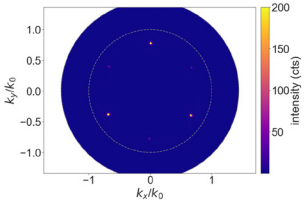
N. de Gaay Fortman,[1,2] R. Kolkowski,[2,3] D. Pal,[2] S.R.K. Rodriguez,[2] P. Schall,[1] A.F. Koenderink,[2,1]

[1] *Universiteit van Amsterdam*

[2] *AMOLF, Amsterdam*

[3] *Aalto University, Finland*

Spontaneous symmetry breaking is the fascinating phenomenon where a system spontaneously evolves to a lower-symmetric state. In photonics, different platforms exist to study this effect, which mainly focus on symmetry breaking in intensity. We report for the first time spontaneous symmetry breaking in a new platform: the plasmonic distributed feedback laser. When lasing from the K-points, this system provides distinct signals in the Fourier and real space, which we simultaneously capture for a single laser shot. With different analysis techniques we retrieve not only the relative intensity between the degenerate K and K' modes (Fourier space), but also their relative phases (real space). Both the relative intensity and relative phase are picked randomly for every pulse. This platform provides the ability to create a spatial landscape of relative phase, which will open important studies into spontaneous symmetry breaking over space and into the emergence of spatial coherence in degenerate lattice lasers.



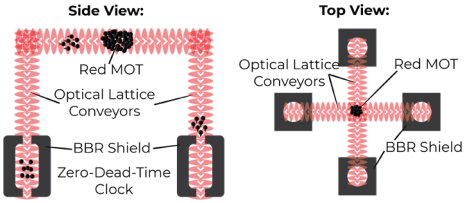
A continuously operating compound optical clock

P 19

A. K. Gacsbaranyi, S. Wolzak, A. Sitaram, S. Sakar, P. Bouyer, F. Schreck
Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam

The stability of conventional passive optical lattice clocks is limited by its pulsed operation - Dick-effect. During the preparation of the atomic sample Ramsey spectroscopy is inactive, therefore the phase of the local oscillator cannot be tracked, making the Allan deviation scale as $1/\sqrt{\tau}$, with τ the measurement time [1]. By interleaving two clocks, one operating during the dead-time of the other, a near $1/\tau$-dependence can be achieved [2].

We present developments on an optical clock. Strontium atoms from a continuously replenished red magneto-optical trap are transported via optical lattice conveyors to one of four interrogation chambers. Those can be instructed to operate on individual Ramsey times or in a two zero-dead-time configuration, presumably enabling a precision of 10^{-18} in 100s.



Sensing interactions in atomic quantum systems

P 20

C. Galantini,[1, 2, 3] L. Verwaal,[1, 2, 3] E. Ichir,[1] R.S. Lous[1, 2, 3]
[1] *Technische Universiteit Eindhoven*
[2] *Center for quantum materials and technology, Eindhoven*
[3] *Eindhoven Hendrik Casimir Institute*

Hybrid ion-atom systems combine the well-controllable platforms of trapped ions and ultracold quantum gases and link them together by the intermediate-range ion-atom interaction. These quantum systems offer opportunities for buffer gas cooling, quantum simulation of many-body systems, as well as state-to-state quantum chemistry [1]. To fully benefit from the combination, it is essential to understand, characterize, and control the interactions between the atoms and ions. Therefore, at TU/e, a new experimental setup is being built combining a trapped ion – Yb^+ - with dipolar atoms - Dy. The progress on the design will be illustrated, and an overview of what we plan to do is presented.
natural resonances.

[1] R. S. Lous and R. Gerritsma, Ultracold ion-atom experiments: cooling, chemistry, and quantum effects, AAMOP 71, 65 (2022).

Quantum gates with trapped ions and optical tweezers

P 21

L.P.H Gallagher, Z. Ackerman, M. Mazzanti, C. Robalo Pereira, N. Diepeveen, R.X. Schüssler, A. Safavi Naini, R.J. Spreeuw, R. Gerritsma.
Universiteit van Amsterdam

Optical tweezers offer new opportunities to manipulate trapped ions for quantum information processing. Two techniques to implement quantum logic gates have been theoretically developed in our group. These are based on qubit state-dependent potentials delivered by optical tweezers in combination with either electric fields [1], or strong polarization gradients in the tweezer waist [2,3]. The gates may offer key benefits such as infrastructural simplification – the light only has to be supplied from one direction - and enhanced long-ranged interactions between the ion qubits.

We present the ongoing development to realize these gates experimentally. Specifically, the design and construction of a microfabricated ion trap and UHV setup, and the optimization of a programmable UV tweezer array. Photon scattering in the tweezer can be suppressed using Laguerre-Gaussian tweezer modes generated by our spatial light modulator.

[1] M. Mazzanti *et al*., PRL 127, 260502 (2021).
[2] R.J.C. Spreeuw PRL 125, 233201 (2020).
[3] M. Mazzanti *et al*., arXiv:2301.04668 (2023).

High Accuracy Calculations of Properties of Heavy Atoms and Molecules

P 22

G.P. Geehan
University of Groningen

Probing the properties of heavy atoms and molecules to ever greater accuracy provides ample opportunity for advancements in our understandings nuclear structure and to further extend the limits of atomic structure calculations [1-2]. In heavy atoms and molecules the role of relativistic and correlation effects are of great importance and their study adds to our understanding of these effects [3]. Numerical methods such as Fock space couple cluster, configuration interaction (CI) and CI combined with many-body perturbation theory are at the forefront of high accuracy atomic calculations. In this work calculations of properties of heavy atoms and molecules are carried out using highly accurate and relativistic numerical methods.

[1] Blaum *et al*., Phys. Scr. 2013, 014017 (2013)
[2] Porsev *et al*., Phys. Rev. Lett. 127, 253001 (2021)
[3] Dzuba *et al*., Phys. Rev. A. 90, 012504 (2014)

Spectrally-resolved broadband XUV Fourier transform holography

P 23

L. Guery,[1] X. Schaad,[1] N. Kuzkova,[1,2] P.M. Kraus,[1,2]
[1] *Advanced Research Center for Nanolithography, Amsterdam, The Netherlands*
[2] *Department of Physics and Astronomy, and LaserLaB, Vrije Universiteit, Amsterdam, The Netherlands*

Fourier transform holography (FTH) in the extreme-ultraviolet (XUV) spectral region has great potential for table-top lensless 3D-imaging at the nanoscale. The broadband FTH approach, employing time-domain measurements of the interference signal of two ultrashort coherent XUV pulse replicas generated by the high-harmonic generation (HHG) process, allows spectrally-resolved diffraction patterns to be recorded. In this work, far-field diffraction patterns in a silica thin film sample were recorded at precisely controlled time delays between two broadband XUV pulses, allowing the spectral information for each pixel to be recovered. Monochromatized diffraction patterns for multiple HHG harmonics can then be obtained. This method opens future possibilities for lensless imaging using broadband HHG sources and should allow for time-resolved measurement in a pump-probe scheme to be combined with this technique.

Towards a continuous atom laser

P 24

J. He,[1] N. Grenier[2], R. González Escudero,[1] C.C. Chen,[1] J. Minář,[3,4] S. Bennetts,[1] B. Pasquiou,[5] F. Schreck[1,4]
[1] *Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam*
[2] *École normale supérieure Paris-Saclay, France*
[3] *Institute for Theoretical Physics, University of Amsterdam*
[4] *QuSoft, The Netherlands*
[5] *Laboratoire de Physique des Lasers, Université Sorbonne Paris Nord, France*

A continuous atom laser would be a promising source for quantum sensing, providing a high-flux, low-divergence beam while avoiding measurement dead time [1]. We plan to outcouple such a beam from a Bose-Einstein condensate that we can continuously sustain [2]. Our approach sends a Sr beam from an oven through a sequence of spatially separated laser cooling stages till the atoms accumulate in a protected area where they condense. Our next steps will be to enhance the purity of the BEC and to outcouple a continuous atom laser beam using a three-photon transfer to an untrapped state [3].

[1] *Phys. Rep.* **529**, 265 (2013).
[2] *Nature* **606**, 683 (2022).
[3] *Phys. Rev. A* **93**, 053417 (2016).

Quantum computing with neutral strontium atoms

P 25

R. van Herk,[1,2,3,] Z. Guo,[1,2,3]
D. Janse van Rensburg,[1,2,3]
M. Venderbosch,[1,2,3] I. Knottnerus,[1,2,3,4]
A. Urech,[4,5] Y.C Tseng,[4] R. Spreeuw,[4,5]
F. Schreck,[4,5] R. Lous,[1,2,3] E. Vredenbregt,[1,2,3]
S. Kokkelmans[1,2,3]
[1] *Eindhoven University of Technology*
[2] *Eindhoven Hendrik Casimir Institute*
[3] *Center for Quantum Materials and Technology, Eindhoven*
[4] *University of Amsterdam*
[5] *QuSoft Amsterdam*

In our project we aim to build a quantum co-processor as part of a hybrid quantum computer. This will be experimentally realized by trapping strontium-88 atoms in a 2D array of optical tweezers, generated by a spatial light modulator. As qubit states we plan to use the ground 1S0, and clock state 3P0 of the Sr atom. Transitions between these states will be driven by a 698 nm laser and a strong magnetic field. Global excitations to Rydberg states with a 317 nm laser will be used to generate entanglement between the qubits.

On this poster, we will report on the progress we have made so far on building the experimental setup and loading atoms in a blue and red magneto-optical trap. We also report on our future plans on algorithms and online accessibility.

Coupling Tin-Vacancy Centers in Diamond to Open Fiber-based Microcavities

P 26

Y. Herrmann,[1,2] J. Fischer,[1,2]
J. Brevoord,[1,2] C. Sauerzapf,[1,2,3]
L. Wienhoven,[1,2] L. Feije,[1,2]
M. Pasini,[1,2] R. Hanson[1,2]
[1] *QuTech, Delft University of Technology, The Netherlands*
[2] *Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands*
[3] *3rd Institute of Physics, IQST, and Research Center SCoPE, University of Stuttgart, Germany*

Quantum networks [1] are promising for applications such as secure communication and distributed quantum computing. Diamond color center qubits like the nitrogen-vacancy center and the group IV-vacancy centers are excellent node candidates, but they have limited collectable coherent photon emission.
Integration into a tunable, open microcavity can boost collection via the Purcell effect [2]. We report on our most recent results on coupling single tin-vacancy centers to the cavity and the Purcell-enhanced emission. Such a system may speed up entanglement rates in present day networks by at least a factor of 100, a critical step towards large scale diamond-based quantum networks.

[1] M. Ruf *et al.*, J. Appl. Phys. 130, 070901 (2021)
[2] E. Janitz *et al.*, Optica 7, 1232-1252 (2020)

Laser cooling a slow molecular beam of BaF

P 27

J.W.F. van Hofslot,[1,2]
R. Bause,[1,2], H.L. Bethlem,[1,3]
A. Boeschoten,[1,2] A. Borschevsky,[1,2]
T.H. Fikkers,[1,2] S. Hoekstra,[1,2] S. Jones,[1,2]
K. Jungmann,[1,2] V. Marshall,[1,2]
T.B. Meijknecht,[1,2] M.C. Mooij,[2,3]
L. van Sloten,[1,2] R.G.E. Timmermans,[1,2]
A. Touwen,[1,2] W. Ubachs,[3] J. de Vries,[2,4]
L. Willmann,[1,2] (NL-*e*EDM collaboration)
[1] Van Swinderen Institute for Particle Physics and Gravity, University of Groningen
[2] National Institute for Subatomic Physics, Nikhef, Amsterdam
[3] Department of Physics and Astronomy, LaserLab, Vrije Universiteit Amsterdam
[4] Institute of Physics, IHEF, University of Amsterdam

An improved bound on the electron Electric Dipole Moment (*e*EDM) as a measure for CP-violation will put strong constraints on extensions of the Standard Model.
The NL-*e*EDM collaboration will use an intense, cold and slow molecular beam of heavy polar ^{138}BaF molecules to conduct a precision measurement of the *e*EDM. To make better use of the full beam flux for the *e*EDM measurement, the divergence of the molecular beam will be reduced using two-dimensional laser cooling. This poster discusses our recent activities towards implementing and demonstrating laser cooling to create a bright, collimated beam of BaF.

Single photons in an interferometer: Forbidden outcomes

P 28

S. van den Hoven
Adaptive Quantum Optics, University of Twente, The Netherlands

The well-known Hong-Ou-Mandel (HOM) effect is the first demonstration of perfect destructive interference of quantum amplitudes in a linear optical system with single photon Fock-states at input. A natural question to ask is whether we are able to predict similar behavior for systems of a general size, that is, predicting forbidden transitions for a given input state and a given linear optical system. Previous studies have found that certain symmetries between the input and output configuration in combination with a symmetric interferometer will always result into so called suppressions. But recently, a few examples have been found of suppressions which do not obey the suppression laws constructed in previous studies. In this work, we parametrize a general three-mode interferometer and we use a numerical optimization algorithm in order to find all three-mode interferometers that demonstrate forbidden transitions. These results help us to gain a better understanding of the fundamental reason behind suppressions. In addition, we compare the quality of the different interferometers for applications in quantum tomography.

Sub-picosecond ultracold electron bunches

P 29

J.V. Huijts, T.C.H. de Raadt, D.F.J. Nijhof, P.H.A. Mutsaers, O.J. Luiten
Eindhoven University of Technology

The Ultra Cold Electron Source (UCES) is based on near-threshold, femtosecond photoionization of a laser-cooled rubidium gas in a magneto-optical trap. The UCES accelerates bunches containing ~1000 electrons in a DC field up to energies of ~10 keV with a normalized emittance of ~1 nm·rad.

Recently, bunch lengths as short as 735±7 fs have been measured in the self-compression point by means of ponderomotive scattering of the electrons by a 25 fs, 800 nm laser pulse. The observed temporal structure of the electron bunch depends on the wavelength of the ionization laser, in agreement with detailed simulations of the atomic photoionization process. Showing that the bunch length limit imposed by the atomic photoionization process has been reached.

Surface nanostructuring to optimize generation and detection of light-induced acoustics

P 30

M. Illienko,[1] M. C. Velsink,[1] P. Sudera,[1] S. Witte,[1,2]
[1] Advanced Research Center for Nanolithography, Amsterdam,
[2] Dept. of Physics and Astronomy, Vrije Universiteit Amsterdam

Photoacoustic time-resolved pump-probe spectroscopy enables imaging and detection through optically opaque materials [1,2]. A significant challenge of this technique is a very low reflectivity change for probe light due to low strain amplitudes in photo-induced acoustic pulses and, as well as weak strain-optic coupling in many materials. We study the possibility to enhance strain generation and detection by nanostructuring the surface of the sample. Controlled diffraction of acoustic pulse might be used to direct acoustic waves and potentially look at interference effects, leading to signal enhancement.

[1] O. Matsuda, M. C. Larciprete, R. Li Voti, and O. B. Wright, "Fundamentals of picosecond laser ultrasonics," Ultrasonics **56**, 3 (2015)

[2] A. Antoncecchi, H. Zhang, S. Edward, V. Verrina, P. C. M. Planken, and S. Witte, "High-resolution microscopy through optically opaque media using ultrafast photoacoustics," Opt. Express, OE **28**, 33937 (2020).

Tweezer arrays of rubidium atoms for hybrid quantum computing

P 31

D. Janse van Rensburg,[1,2,3] Z. Guo,[1,2,3] R. van Herk,[1,2,3] M. Venderbosch,[1,2,3] I. Knottnerus,[1,2,3,4] A. Urech,[4,5] S. Lin,[1] Y.C. Tseng,[4], R. Spreeuw,[4,5] F. Schreck,[4,5] R. Lous,[1,2,3] E. Vredenbregt,[1,2,3] S. Kokkelmans,[1,2,3]

[1] *Eindhoven University of Technology*

[2] *Eindhoven Hendrik Casimir Institute*

[3] *Center for Quantum Materials and Technology, Eindhoven*

[4] *University of Amsterdam*

[5] *QuSoft, Amsterdam*

Our project has the goal of building a quantum co-processor consisting of neutral atoms in tweezer arrays. In this collaborative project between a team at the Eindhoven University of Technology (TU/e) and a team at the University of Amsterdam (UvA) there are three experimental setups: a demonstrator system using rubidium atoms at TU/e, the existing 1st generation strontium-based system at UvA and the 2nd generation strontium-based system at TU/e which is being constructed.

In this poster we present the status of our rubidium-based system. In particular we present our progress towards creating defect-free arrays of single 85Rb atoms, characterizations of the trapping potentials and our plans to implement single qubit rotations on the hyperfine ground states of the atoms.

Long time-delay quantum interference of single photons produced by a quantum dot - cavity system

P 32

K.N. Kanneworff, P. Steindl, M. Poortvliet, D. Bouwmeester, W. Löffler

Leiden Institute of Physics

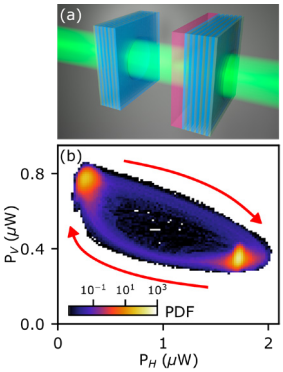
The quantum interference of two photons incident on a beam splitter tests for equality of the photons – the so-called SWAP test – is a key operation for many quantum network protocols from remote-entanglement generation to quantum position verification. For demonstration of such advanced protocols, it is often useful to temporally de-multiplex a single-photon source to obtain two single photons in two spatially separate modes. Low loss demultiplexing is challenging, and often only relatively slow switches have sufficient efficiencies. Here we use a quantum dot cavity-QED single-photon source and use long fiber delays to study the quantum interference of photons produced up to around 1μs apart, which is several thousand times the lifetime of around 300 ps. At such time delays, quantum dot spectral diffusion and other decoherence effects can have a strong influence, but we are able to demonstrate above 70% Hong-Ou-Mandel quantum interference visibility.

Irreversibility and broken detailed balance in a perovskite cavity

P 33

G. Keijsers,[1] B. Verdonschot,[1] K.J.H. Peters,[1] Z. Geng,[1] K. Malmir,[2] J.M. Smith,[2] S.R.K. Rodriguez,[1]
[1] *AMOLF, Amsterdam, The Netherlands*
[2] *University of Oxford, UK*

Imagine that you measure the output of an experiment, but the labels on the time axis are missing. How easily can you tell in which direction time flows? Or, how (ir) reversible are the system's dynamics? Here, we address this question in the context of a nonlinear optical resonator. Our system, a perovskite-filled Fabry-Pérot cavity, exhibits strong optical nonlinearity, multistability and polarization switching. Using concepts from stochastic thermodynamics, we quantify the degree of irreversibility in the switching dynamics, and relate the extent of this irreversibility to the type and strength of interactions present in our perovskite-filled cavity.



a) Cavity illustration. b) Probability density of polarization-resolved transmitted power through cavity exhibiting noise-induced switching. Direction-dependent transition trajectories (see arrows) evidence irreversible switching.

ND_3-ND_3 scattering in near-merged beams

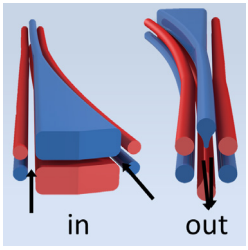
P 34

S. Herbers, **S. Kuijpers,** Y. Caris, A. Sharafeldeen,T. Karman, S.Y.T. van de Meerakker
Radboud University, Nijmegen, The Netherlands

Recently scattering between two dipolar molecules, NO+ND_3, has been studied at collision energies down to 0.1 cm^{-1} [1]. This was achieved by employing the merged-beam technique, guiding ND_3 through a curved hexapole. The small dipole moment of NO (0.16 D) ensured its trajectories remained unaffected.

Next, we would like to investigate collisions between two large dipoles such as ND_3+ND_3 (1.5 D). As such, a new way of merging the two molecular beams is required. This can be achieved using a Merged Electrostatic Guide (MEG) [2].

Here we present a newly designed MEG (see below), together with the first measurements of inelastic scattering cross sections between two strongly dipolar molecules, ND_3+ND_3.



[1] Tang, *et al*., Science 379, 1031 (2023)
[2] Gordon, Osterwalder, *Phys. Rev. Applied* 7, 044022 (2017)

Refractive index biosensing using quasi bound states in the continuum

P 35

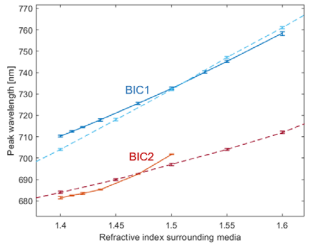
M. Liang,[1] T.V. Loon,[1] T. Delplace,[2] S. Mahajan,[1] S. Murai,[3] B. Maes,[2] P. Zijlstra,[1] J. Gómez Rivas[1]

[1] *Einhoven University of Technology*

[2] *Université de Mons, Belgium*

[3] *Kyoto University, Japan*

Refractive index biosensors have attracted increasing interest in recent years since they are indispensable tools for the early diagnosis of diseases. However, detecting low-concentration and complex biomolecules with low cost, high sensitivity, and high efficiency is still challenging. Quasi-bound states in the continuum (quasi-BICs) formed in dielectric metasurfaces (metasurfaces with very low losses) show promising perspectives in nanophotonic biosensing because of their high-quality factor resonances and significant near-field enhancements. Here, multiple quasi-BICs based of silicon nanoparticles have been realized in the visible range. The sensitivity has been checked with solutions of different refractive indexes. The results further confirm the promising potential application of quasi-BICs for biosensing.



Efficient extreme-ultraviolet high-order wave mixing from laser-dressed silica

P 36

R. van der Linden,[1] S.D.C. Roscam Abbing,[1] F. Campi,[1] B. de Keijzer,[1] C. Morice,[2] Z.Y. Zhang,[1] M.L.S. van der Geest,[1] N. Kuzkova,[1,2] P.M. Kraus,[1,3]

[1] *ARCNL, Amsterdam, The Netherlands*

[2] *Institute for Theoretical Physics Amsterdam and Delta Institute for Theoretical Physics, Universiteit van Amsterdam*

[3] *Department of Physics and Astronomy, and LaserLaB, Vrije Universiteit Amsterdam*

The emission of high-order harmonics from solids [1] under intense laser-pulse irradiation reaches well into the extreme ultraviolet (XUV) [2] and is revolutionizing our understanding of strong-field solid-light interactions. Nonetheless, solid high harmonic generation (HHG) suffers from low conversion efficiencies (CE) compared to gases, hindering wide-spread application. Here, non-collinear two-color wave mixing reveal perturbative intensity scalings accompanied by a CE enhancement of one order of magnitude. Supporting quantum theory reveals that the experiments follow a generation mechanism where interband and intraband nonlinear dynamics are boosted by Floquet-Bloch dressed states. Our approach proves to be a promising step towards all-solid coherent XUV sources essential for loss-tolerant QPV protocols.

[1] Ghimire, S. *et al.,* Nat. Phys. 7, 138–141 (2011)

[2] Luu, T. *et al*., Nature 521, 498–502 (2015)

On the microscopic theory of natural optical activity in a disordered medium of light scatterers

P 37

Z. Lu,[1,2] T. G. Parton,[1] B. Frka-Petesic,[1] K. Vynck,[3] S. Vignolini,[1]
[1] *University of Cambridge, UK*
[2] *AMOLF, Amsterdam, The Netherlands*
[3] *Université Claude Bernard Lyon 1, France*

Natural optical activity can be produced by disordered complexes of light scatters in the multiple scattering regime. This is due to the broken mirror symmetry of such structures, as they cannot be superimposed to their own mirror images [1]. Here we discuss the microscopic origin of optical activity in disordered systems composed of N ($N \geq 3$) spherical silver nanoparticles (AgNPs) with a diameter of 30 nm. Our numerical calculation shows that light scattering modifies the polarizability tensor of each individual AgNP, turning them into optically active particles which allows for local cross-coupling between electric and magnetic fields. The total output of optical activity thus reflects the statistical distribution of chiral states of particles regarding their geometric neighbors. We hope this new insight can advance the finding of highly optically active metamaterials in optical frequencies.

[1] Pinheiro, F. A., *et al.*, Phys. Rev. B 95.22 (2017): 220201.

Using Li_2 + Na collisions to test models of ultracold collisions

P 38

M.P. Man, T. Karman, G.C. Groenenboom
Radboud University, Nijmegen, The Netherlands

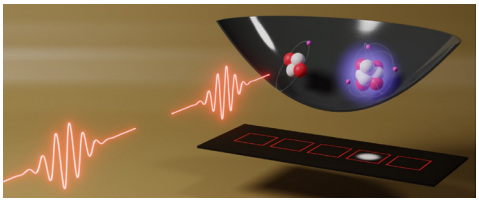
Ultracold molecular gases have many promising applications including precision measurements of fundamental constants and quantum simulation of many-body systems. However, these gases suffer from severe collisional losses. We could potentially prevent these losses by understanding their origin. An important observable is the sticking time of the collision complex. However, some recent measurements find longer sticking times than theoretically predicted. There are many possible explanations for this discrepancy: electric fields, hyperfine structure, or as yet unknown loss mechanisms. In experiments we cannot look at these factors separately, but using quantum scattering calculations we can. In this work we test the theory by Mayle et al. [PRA 87, 012709 (2013)] using Li_2+ Na quantum scattering calculations. We then study two extensions of this theory: lossy collisions and collisions in electric fields.

Towards precision 1S-2S spectroscopy of trapped He^+

P 39

A. Martínez de Velasco,[1]
E.L. Gründeman,[1] A.E. Díaz Calderón,[1]
L.S. Dreissen,[1] R. Taieb,[2] V.P.J Barbé,[1]
K.S.E Eikema,[1]
[1] *LaserLaB, Vrije Universiteit Amsterdam*
[2] *Sorbonne Université, Paris, France*

A precision measurement of the 1S-2S transition in He^+ could provide exciting new tests of the Standard Model, but the required extreme ultraviolet light is challenging. We developed Ramsey-comb spectroscopy (RCS, see PRL 123, 143001 (2019)) with high-harmonic generation to excite the transition with a combination of 790 nm and 32 nm light. RCS is based on recording multiple Ramsey fringes using two amplified and upconverted pulses from a frequency comb. Recently we excited the 1S-2S He^+ transition with a single pulse in an atomic beam (see our other contribution). Here we describe plans to extend this to full two-pulse RCS at 1 kHz accuracy (10^{-13}) with a single He^+ ion, co-trapped with Be^+ for cooling and readout.



Stabilizing optical microcavities in 3D

P 40

C.U. Mattschas, V. Sharoglazova,
M. Puplauskis, C. Toebes, J. Klaers
MESA+ Institute for Nanotechnology,
Adaptive Quantum Optics (AQO),
University of Twente, The Netherlands

Optical (micro-)cavities are the workhorse for studying light-matter interactions with important applications in lasing, sensing, and quantum simulations, to name a few. Open resonators in particular offer great versatility due to their tunability but pose challenges in terms of control. This concerns, on the one hand, the control of their length, and on the other hand, the relative orientation (tilt) of the mirror planes to each other. The latter becomes particularly important when working with optically unstable resonators, such as plane-parallel resonators.
There are numerous strategies to enhance stability using passive techniques, such as material selection, mechanical damping, or thermal compensation. But especially for tuneable microcavities often an active stabilization method with feedback control systems must be employed. Here, we present a novel method for tilt measurement and stabilization using inverse solving of the Schrödinger equation arising in the paraxial description of the cavity modes. Our method enables the highly precise determination of absolute tilt angles, making it suitable for microcavity applications that require the highest level of cavity parallelism.

Performing high precision spectroscopy on ultracold ammonia molecules in an electrostatic trap

P 41

W. van der Meer,[1] H.L. Bethlem[1,2]
[1] *LaserLaB, Vrije Universiteit Amsterdam*
[2] *VSI, University of Groningen,*
The Netherlands

In our setup, ammonia molecules ($^{14}NH_3$) are released vertically, decelerated by a conventional Stark decelerator to 90 m/s and brought to a standstill in a traveling wave decelerator, which holds the molecules near the top. Here, the molecules are cooled down to below 120 microkelvins and subsequently interrogated by microwave or infrared radiation. To avoid Stark shifts by the trapping fields, the trap is turned off and on quickly. In this way we can investigate molecules in a field-free environment with interrogation times of up to 3 milliseconds.

We present vibrational spectroscopy on the $v1^{+v3}$ overtone band around 1,5 microns with a precision of 10 kHz, which is a factor of 500 more precise than previous measurements. Using microwave radiation, we show that we can selectively pump away molecules in unwanted hyperfine states. We will discuss future experiments in a molecular fountain [1] to achieve even higher accuracies.

.

[1] C. Cheng *et al.,* Phys. Rev. Lett. **117**, 253201 (2016).

Towards an H_2^+ Molecular Ion Clock

P 42

A.D. Ochoa Franco, M. Beyer
Vrije Universiteit Amsterdam,
The Netherlands

This project aims to build a novel molecular clock based on weakly bounds states of the molecular hydrogen ion, exhibiting high sensitivity to peculiar effects predicted by quantum electrodynamics theory, and even to possible manifestations of physics beyond the Standard Model [1].

We are following a new approach to selectively generate molecular ions in single quantum states by exciting Rydberg states of the neutral molecule and subsequently field ionizing them [2]. This is especially important for homonuclear molecules where the vanishing dipole moment prohibits the use of unselective ion production via electron impact.

To have an accurate theoretical determination of the electric-dipole transition frequencies for comparison with experimental measurements, the AC Stark shift is calculated under the influence of blackbody radiation by computing the dynamic polarizabilities using sum over states. It is found that the energy shifts are on the order of Hz and the largest contribution comes from the continuum.

[1] A. Carington, Science 274, 1327 (1996).
[2] M. Beyer and F. Merkt, **Phys. Rev. X** 8, 031085 (2018).

Quantum simulation with trapped ions and optical tweezers

P 43

C. R. Pereira,[1] M. Mazzanti,[1]
Nella Diepeveen,[1] R. X. Schüssler,[1]
L. Bond,[2,3] R. Gerritsma,[1,2]
A. Safavi-Naini,[2,3]
[1] *Van der Waals–Zeeman Institute, Institute of Physics, University of Amsterdam*
[2] *QuSoft, Amsterdam, The Netherlands*
[3] *Institute for Theoretical Physics, University of Amsterdam, The Netherlands*

Trapped ion crystals offer a natural platform for quantum simulation as they present long coherence times, fully connected interactions and triangular lattice crystalline structure[1]. We generate an effective spin Hamiltonian in a 2D ion crystal by applying state-dependent Raman transitions on the ions, whose interaction is mediated by the crystal's phonon modes, and we further manipulate the phonon spectrum by applying optical tweezers. We thus achieve greater control over the spin interactions, broadening the range of accessible Hamiltonians[2].
In addition, we describe a theoretical framework for a fast phase gate combining optical tweezers, which couple spin and motion, and electric field pulses, which perform the gate operation and minimise time spent on secular motion.

[1] J.D. Espinoza *et al*., Phys. Rev. A 104, 013302
[2] M. Mazzanti *et al*., Naini Phys. Rev. Lett. 127, 260502

Multi-wavelength ptychography with extreme ultraviolet vortex beams

P 44

A. Pelekanidis,[1,2] F. Zhang,[1] M. Du,[1]
M. Gouder,[1] K.S.E. Eikema,[1,2] S. Witte,[1,2]
[1] *ARCNL, Amsterdam*
[2] *Laserlab, Vrije Universiteit Amsterdam, The Netherlands*

Light beams carrying orbital angular momentum (OAM), also known as vortex beams, have attracted interest for many technological applications [1]. One area of applications is lensless imaging [2,3]. In this work we experimentally demonstrate the high-quality ptychographic (lensless) imaging with a polychromatic extreme ultraviolet (XUV) vortex beam as illumination source. In particular, the XUV vortex beam is generated via high harmonic generation (HHG) driven by a NIR driving vortex beam with OAM equal to l_1=1. The resulting beam consists of multiple harmonics, which, according to the principle of OAM conservation, have OAM equal to l_q=ql_1, with q the respective harmonic order. The simultaneous reconstruction of both object and illumination wavefronts allows us to perform spectrally resolved vortex beam reconstruction and characterize the OAM beam properties, while imaging complex dispersive samples with diffraction-limited resolution.

[1] Shen *et al*., Light: Science & Applications, (2019), 8:90.
[2] Loetgering *et al*., Sci. Adv. (2020); 6:eaax8836.
[3] Wang *et al*., arXiv:2301.05563.

Memory-Induced Self-Oscillations in Nonlinear Resonators

P 45

K.J.H. Peters,[1] B. Braeckeveldt,[2] B. Verdonschot,[1], B. Maes,[2] S.R.K. Rodriguez[1]
[1] *AMOLF, Amsterdam*
[2] *University of Mons, Belgium*

In general, physical systems do not respond instantaneously to stimuli. It's well-known that systems with non-instantaneous linear response can host intriguing dynamics when driving, dissipation, and nonlinearity compete. However, much less is known about the dynamics of systems with non-instantaneous nonlinearity. Here, we will discuss how a non-instantaneous nonlinearity can lead to fascinating emergent behavior, including self-oscillations and period-doubling. We consider an optical microcavity with thermo-optical nonlinearity. The equations of motions describing this system contain a non-instantaneous nonlinearity with a characteristic memory time. We first demonstrate numerically self-oscillating behavior in a single microcavity. However, we find that the parameter range for which this behavior occurs is very limited. Interestingly, this constraint is lifted in systems of even just two coupled cavities. There, self-oscillations can be observed even when the memory time of the nonlinearity is many orders of magnitude larger than the dissipation time. Indeed, we have recently observed self-oscillations in coupled optical microcavities where the memory time is several orders of magnitude larger than the dissipation time.

Systematic study of the photon quality from a quantum dot cavity single photon source by Rabi tuning

P 46

M.T.L. Poortvliet, P. Steindl, I. Kuijf, H. Visser, A.C.J. van Amersfoort, D. Bouwmeester, W. Löffler
Leiden University, The Netherlands

In contrast to standard methods of picosecond pulse generation, full flexible digital control of the pulse properties can be achieved by carving GHz rate picosecond pulses from continuous wave narrow-linewidth laser light.
We use a commercial electro-optic modulator with a custom-made 35 GHz bandwidth electronic pulser to produce down to ~30 ps long optical pulses, and show that by careful calibration a pulse contrast beyond 1000 can be achieved. Flexible triggering of the pulses enables a systematic study of the effect of the pulse length on the resulting exciton Rabi oscillations in a III-V quantum dot - cavity system.
The photon quality of the emitted resonance fluorescence can be investigated as well, both the single-photon purity and indistinguishability by second-order photon correlations measurements.

Scalable Quantum Error Correction on a Neutral Atom Platform

P 47

J.J. Postema,[1] S.J.J.M.F. Kokkelmans,[1,2]
[1] *Eindhoven University of Technology, The Netherlands*
[2] *Eindhoven Hendrik Casimir Institute, The Netherlands*

Fault tolerant quantum computers require error rates well below physically achievable error rates. Thus, quantum error correction is a crucial ingredient for achieving impeccable fidelities to run large scale algorithms such as Shor's or Grover's. By encoding a single logical qubit within an ensemble of many physical qubits, protection against errors is enhanced, granted the density of errors is low enough. Different topological error correction codes such as the surface code provide a scalable tool towards error corrected quantum computing. Recently, experiment has proven that quantum error correction works in practice, for a superconducting device [1]. In Eindhoven, a neutral atom quantum computer is under construction. With specific application to this device, we investigate the performance of quantum error correction for this device, extracting error budgets and identifying platform-specific issues and solutions towards scalable error correction and its classical simulation.

[1] Suppressing quantum errors by scaling a surface code logical qubit. *Nature*, 2023, 614.7949: 676-681.

Characterization of quantum gates on nitrogen-vacancy center in diamond using randomized benchmarking

P 48

M. van Riggelen, H.P. Bartling, J. Yun, K.N. Schymik, T.H. Taminiau
QuTech and Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands

The nitrogen-vacancy (NV) center in diamond is a promising platform for quantum technologies. Using it in systems of ever increasing complexity will require thorough characterization and optimization. Here, we characterize the quantum gates on the electron spin and nitrogen nuclear spin of an NV center in isotopically purified diamond using randomized benchmarking (RB). RB gives a metric for the average gate fidelity by quantifying how well a quantum state 'survives' sequences of random gates. We found average gate fidelities >99.9% for the electron gates and >99.99% for the nitrogen gates.
For a certain type of electron gate we find that the results of RB disagree with those obtained using gate set tomography, another characterization method.
We believe this to be an indication of Non-Markovian noise, possibly due to drift in our external magnetic field.
The combination of RB and GST proves to be powerful to characterize gates and can be extended to carbon spins.

Time-domain Physical Unclonable Functions

P 49

D.J. de Ruiter, D.P. Stellinga, L. van der Hoeven, M.C. Velsink, P.W.H. Pinkse
MESA+ Institute for Nanotechnology, University of Twente

One can replace one-way functions (also known as hash functions) commonly found in cryptography with physical processes, known as physical unclonable functions (PUFs). Optical PUFs have been devised based on the complex response of scattering media to the spatial wavefront. However, such PUFs are intrinsically unpractical for use over larger distances. In this project, we design PUFs with a time-domain scattering response (tPUF), whose readout can be performed over a single spatial mode, in our case an optical fiber. These tPUFs are networks of micror-ing resonators, whose transfer function is highly complex and vary strongly from realization to realization as a result of manufacturing imperfections. These devices are developed for pulses with a very low number of average photons per pulse which negates any attempts at read-ing out the pulse shape in transit, thereby eliminating eavesdropping. These PUFs can then be used for a variety of applica-tions in asymmetric cryptography, such as proof of identity and secure messaging.

Particle Velocity Measurement in Classically Forbidden Regions

P 50

V. Sharoglazova, M. Puplauskis, C.U. Mattschas, C. Toebes, J. Klaers
MESA+ Institute for Nanotechnology, Adaptive Quantum Optics (AQO), University of Twente

For nearly a century, researchers have been fascinated by the intriguing features of quantum tunneling. In a previous study [1], we proposed a novel approach to explore evanescent phenomena at a step potential by examining particle motion within a system of coupled waveguides. In this system, the population transfer between the waveguides acts as a clock, enabling the determination of particle velocities. We implemented this approach for photons in a microcavity. By utilizing a novel nano-structuring method [2], we can guide these photons in an arbitrary potential landscape, specifically within a coupled waveguiding structure. By superimposing the coupled waveguides with a reflective step, we are able to measure the particle velocities in the classically forbidden region. We will present our latest results, shedding further light on the intriguing phenomenon of quantum tunneling.

[1] Klaers, J., Sharoglazova, V., & Toebes, C. (2023). Physical Review A, 107(5), 052201.
[2]Vretenar, M., Puplauskis, M., Klaers, J.. Adv. Optical Mater. 2023, 2202820.

Towards a resonant excitation of the 'forbidden' triplet state of a single molecule

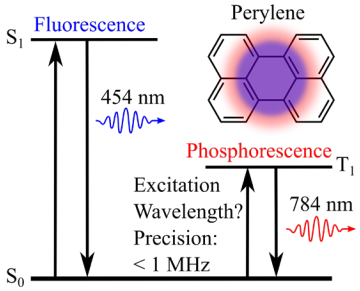
P 51

R. Smit,[1] Z. Ristanovic,[2] B. Kozankiewicz,[2] M. Orrit[1]

[1] *University of Leiden, The Netherlands*

[2] *IFPAN Warsaw, Poland*

In single-molecule spectroscopy, only a limited number of types of guest molecules, immobilized in a host matrix, present a lifetime-limited transition between the first two (spin-less) singlet states at low temperature. Potentially, the electron spins of these guest molecules can be manipulated on-demand by a transition to the 'forbidden' triplet state and allows access to nuclear spins for quantum memory or to switch fluorescence on/off: single-molecule optical switch. However, what wavelength would you need to excite this triplet? In this work, we successfully detected phosphorescence from guest molecules that exhibit stable lifetime-l imited resonances in the singlet transition. With a tunable laser we will try to find a sub-MHz transition to the triplet, around the wavelength that we found in the phosphorescence spectrum.



Revealing the importance of molecular axis alignment and symmetry-breaking in photoelectron elliptical dichroism

P 52

C. Sparling,[1,2] A. Ruget,[2] L. Ireland,[2] N. Kotsina,[2] O. Ghafur,[2] J. Leach,[2] D. Townsend[2,3]

[1] *Radboud University, Nijmegen, The Netherlands*

[2] *IPAQS, Heriot-Watt University, Edinburgh, UK*

[3] *ICS, Heriot-Watt University, Edinburgh,UK*

Photoelectron angular distributions (PADs) produced from the photoionization of chiral molecules using elliptically polarized light exhibit a forward/backward asymmetry with respect to the ionizing laser propagation direction. By recording these distributions using velocity-map imaging (VMI), the resulting photoelectron elliptical dichroism (PEELD) has been shown to be a sensitive tool for studying gas phase chiral molecules. The use of elliptically polarizations, however, produces PADs which do not exhibit any cylindrical symmetry. This leads to significant challenges when using conventional data acquisition and image processing strategies. Using novel VMI analysis methods based around Hankel transform tomography and machine learning, however, we have quantified – for the first time – significant symmetry-breaking contributions to PEELD signals. Developing a full understanding of the role these terms play in the photoionization of chiral molecules is clearly important if the potential of PEELD for future clinical applications is to be fully realized.

Leak-out spectroscopy as alternative method to rare-gas tagging for the Renner-Teller perturbed $HCCH^+$ and $DCCD^+$ ions

P 53

K. Steenbakkers,[1] T. van Boxtel,[1] B. Redlich,[1] G.C. Groenenboom,[1] P.C. Schmid,[2] O. Asvany,[2] S. Schlemmer,[2] S. Brünken[1]
[1] *Radboud University, Nijmegen The Netherlands*
[2] *Universität zu Köln, Germany*

Infrared predissociation action spectroscopy is a well-established technique to record vibrational spectra of reactive molecular ions. However, for Renner-Teller (RT) affected species the attachment of the messenger atom may have a significant impact on its spectral features. In order to investigate this effect, we have recorded the vibrational spectra of Ne- and Ar-tagged $HCCH^+$, where Ne-attachment led to a distortion and Ar-attachment to a complete quenching of the RT splitting. The newly developed leak-out spectroscopy (LOS) [1] provides a universal tag-free method. Here we apply it to the $HCCH^+$ cation and demonstrate that the LOS vibrational spectrum is equivalent to its previously recorded spectrum using laser-induced reaction [2]. Furthermore, we applied LOS to measure the first vibrational spectrum of the $DCCD^+$ cis bending.

[1] P. C. Schmid *et al*., J. Phys. Chem. A. 126(43), 8111-8117 (2022)
[2] S. Schlemmer. *et al*., Phys. Chem. Chem. Phys., 7(7), 1592-1600 (2005).

Cross-polarization-extinction enhancement and spin-orbit coupling of light for quantum-dot cavity quantum electrodynamics spectroscopy

P 54

P. Steindl, W. Löffler
Leiden Institute of Physics, The Netherlands

Resonant laser spectroscopy is essential for the characterization, operation, and manipulation of single-quantum systems such as semiconductor quantum dots. The separation of the weak resonance fluorescence from the excitation laser is key for high-quality single- and entangled-photon sources [1]. This is often achieved by cross-polarization laser extinction, which is limited by the quality of the optical elements. Recently, it was discovered that Fresnel-reflection birefringence in combination with single-mode filtering counteracting spin-orbit-coupling effects enables a three-order-of-magnitude improvement of polarization extinction [2]. Here, we further investigate this method and demonstrate it for cross-polarization-extinction enhancement in cryogenic confocal microscopy of a resonantly excited semiconductor quantum dot in a birefringent optical microcavity and observe a 10× improvement of the single-photon contrast [3].

[1] Snijders *et al*., Phys. Rev. Applied 9, 031002 (2018)
[2] Benelajla *et al*., Phys. Rev. X 11, 021007 (2021)
[3] Steindl *et al*., Phys. Rev. Applied 19, 064082 (2023)

Alpha and helion particle nuclear charge determination from precision measurements in quantum degenerate helium

P 55

K. Steinebach, Y. van der Werf, R. Jannin, H.L Bethlem, K.S.E Eikema
LaserLaB, Vrije Universiteit Amsterdam The Netherlands

Precision measurements on calculable systems are commonly used for tests of quantum electrodynamics (QED) calculations and are sensitive probes for the discovery of new physics. In our experiment we perform high precision spectroscopy on the doubly forbidden $2^3S_1 - 2^1S_0$ transition at 1557nm in both ^{3}He and ^{4}He trapped in a magic wavelength optical dipole trap.

We will give an update on our efforts to improve our ^{4}He measurement and we will present our recent measurement in a degenerate Fermi gas of 3He and the resulting ^{3}He - ^{4}He isotope shift. This measurement enables us to determine the squared charge radius difference between the alpha and helion particle with unprecedented accuracy. Compared to a recent determination of the absolute charge radii from spectroscopy of muonic He^+ ions, we find a remarkable 3.6 sigma disagreement. Our measurement serves as a check of the consistency of QED theory in helium atoms and of nuclear polarization effects in muonic helium.

Measurement and analysis strategies for EUV pump-probe spectroscopic imaging

P 56

H. Strauch,[1] B. van Wingerden,[1] D. Steil,[1] T. Hohage,[2] S. Mathias,[1] G.S.M. Jansen[1]
[1]I. Physical Institute, University of Göttingen, Germany
[2]Institute of Numerical and Applied Mathematics, University of Göttingen, Germany

Extreme ultraviolet (EUV) spectroscopy provides an element-resolved view of electronic, structural and magnetic dynamics. Similarly, coherent EUV light sources such as high-harmonic generation enable imaging with nanometer-scale resolution. However, the combination of spectral, spatial and temporal information remains challenging. We present the design for a table-top EUV pump-probe spectromicroscopy setup based on Fourier-transform spectroscopy and Fourier-transform holography. By imaging two phase-locked EUV pulses to separate reference and probe positions on the sample plane, both spectral and spatial information are encoded in the far-field diffraction pattern. Although full spectral information can be acquired conventionally by long reference-probe delay scans, the interferometric approach presents an opportunity to lower the sampling requirements: a single algorithm might reconstruct the full spectrally-resolved image from a much smaller data set. In this context, we will discuss opportunities to adapt both measurement and analysis to facilitate an efficient recording of multidimensional pump-probe spectroscopy data.

Electric field control of ND_3-H_2 collisions

P 57

P. Sustar, S. Kuijpers,
S.Y.T. van de Meerakker
Radboud University, Institute for Molecules and Materials, Nijmegen

We are studying inelastic molecular collisions between ammonia and hydrogen by using the Stark decelerator technique which provides a full velocity and quantum state control of the ammonia molecular beam. By coupling a Velocity Map Imaging technique with a 1+1' REMPI scheme employing VUV radiation we were able to obtain images, which directly reflect the scattering probability of these collisions in a cold regime (1K). Here, the collision dynamics are dominated by quantum mechanical effects, such as tunnelling and interference. This quantum behaviour can be directly seen as sharp increases in the Integral Cross Section. As a next step, we want to manipulate these collisions with strong electric fields, while maintaining our ability to image the molecules. The large electric dipole moment of ammonia makes it of great interest for electric field-controlled collisions.
In this poster, I will present the latest ICS measurements.

Towards controlled reactive collisions between S atoms and D_2 molecules

P 58

A. Tsoukala, X.-D. Wang, S. Pieters, B. Vonk, S.Y.T. van de Meerakker, J. Onvlee
Radboud University, Nijmegen

Controlling chemical reactions is one of the greatest challenges in the field of molecular reaction dynamics. In our lab we combine a Zeeman decelerator with Velocity Map Imaging (VMI) in a crossed molecular beam setup. The decelerator allows for full velocity and quantum state control of paramagnetic atoms or molecules prior to collisions, while VMI together with near-threshold ionization can probe the reaction products with high precision. This combination of techniques enables scattering experiments with extraordinary resolution, revealing intimate details of molecular collisions that are washed out otherwise.
Using this powerful combination of techniques for inelastic scattering experiments, we have been able to observe quantum phenomena such as diffraction oscillations and scattering resonances. Now, for the first time we study reactive collisions between excited sulfur atoms (S) and deuterium (D_2) molecules and we detect the SD reaction product with full quantum-state resolution. In this contribution, I will describe our experimental approach and present our latest findings for this prototypical insertion reaction.

Subsurface imaging of opaque layers using ultrafast photoacoustics

P 59

M.C. Velsink,[1] M. Illienko,[1] S. Witte[1,2]
[1] *Advanced Research Center for Nanolithography (ARCNL), Amsterdam*
[2] *Dept. of Physics and Astronomy, Vrije Universiteit Amsterdam*

Ultrafast photoacoustics can be used to "look through" opaque thin layers, by both exciting an acoustic pulse and detecting its echo optically at the top surface [1]. For a single layer, the arrival time of the sharp echo gives a precise measure of the local thickness. Multiple echoes will appear for more complicated layer stacks, allowing for subsurface structure analysis. Here, we demonstrate a spot scanning pump-probe method based on modulated asynchronous optical sampling, which enables fast spatially resolved photoacoustic imaging. We investigate the depth and transverse resolution of the method, showing that thickness variations can be resolved down to nanometer levels. Furthermore, we analyze the role of the probe wavelength in signal strength for different metal layers.

[1] A. Antoncecchi et al., High-resolution microscopy through optically opaque media using ultrafast photoacoustics, *Opt. Express* **28**, 33937-33947 (2020)

How to become the chosen one: Deterministic tweezer loading of ultracold molecules

P 60

E.F. Walraven,[1] A.M.R. Tarbutt,[2] T. Karman[1]
[1]*Institute for Molecules and Materials, Radboud University, Nijmegen*
[2]*Centre for Cold Matter, Imperial College London, UK*

Molecules at microkelvin temperatures may become versatile building blocks for, among other things, quantum simulation and quantum computing. These quantum devices can be built using an array of optical tweezers, where each tweezer must contain a single molecule. The question then arises how to go from having a gas of cold molecules to deterministically loading single molecules into these tweezers. This poster will show how to perform efficient loading of such a setup by investigation of molecular collisions in this ultracold regime using quantum scattering calculations.

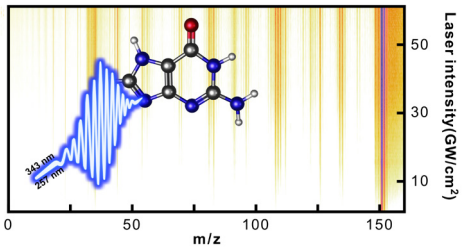
Using laser based thermal desorption source to study UV photoionization of biomolecules

P 61

S. Wang, Y. Dauletyarov, D.A. Horke
[1] *Radboud University, Nijmegen, The Netherlands*

A major obstacle to the gas-phase study of larger (bio)molecular systems is the vaporisation step, that is, the introduction of intact sample molecules into the gas-phase. A promising approach is the use of laser based thermal desorption (LBTD) source.

I will introduce our LBTD source combing with high-repetition rate femtosecond lasers, so it allows detailed investigations of power dependencies and fragmentation onsets that provide a 'fingerprint' of a particular molecular system. At the same time, by changing the time delay between two ionization lasers, the time-resolved photofragmentation dynamics can be studied.



Reflective Lensless Microscopy with a Table-Top High Harmonic Generation Coherent EUV Source

P 62

S. Weerdenburg,[1] Y. Shao,[1,2] R. Horsten,[1] W. Coene,[1,3]
[1] *Optics Research Group, Delft University of Technology, The Netherlands*
[2] *Debye Institute, Utrecht University, The Netherlands*
[3] *ASML Research, The Netherlands*

Lensless microscopy, also known as diffractive microscopy, has gained significance in the semiconductor industry due to the demand for short-wavelength or actinic metrology and imaging systems. Recent progress in high-harmonic sources for Extreme Ultraviolet (EUV) and Soft X-Rays (SXR) radiation, as well as advancements in computing power, have contributed to its revival. A beamline has been designed and constructed at TU Delft, which is configured for grazing incidence lensless microscopy for EUV and SXR using a high-brightness High Harmonic Generation (HHG) source that can operate at a wide range of wavelengths. The reconstructed images have been obtained by probing a single-layer patterned sample with a narrow bandwidth coherent beam at 18 nanometers at an angle of incidence of 20 degrees relative to the surface, resulting in a set of conical far-field diffraction patterns. To reconstruct the images with anamorphic resolution due to an elongated probe, Tilted Plane Correction (TPC) and an iterative reconstruction engine based on Automatic Differentiation Ptychography (ADP), a TensorFlow framework, have been employed. Further improvements in probe size are expected to enhance the resolution of the reconstructed images.

Revealing structure-function properties of the organic polyelectrolyte ProDOT via single-molecule spectroscopy

P 63

E.F. Woering,[1] O. Livadiotis,[1] M.A. Duma,[1] J. Kardula,[2] R.C. Chiechi,[2] R. Hildner[1]
[1] Zernike Institute for Advanced Materials, Groningen University, The Netherlands
[2] Stratingh Institute for Chemistry, Groningen University, The Netherlands

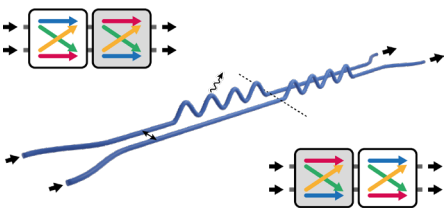
Organic conjugated polymers represent a promising class of high-performance materials, which could find uses in bioelectronics or organic solar cells. Their backbone is often assumed to determine the electronic and optical properties. However, the interplay of the backbone and side groups on these properties remain largely unexplored by ensemble measurements due to their conformational flexibility. Here, we perform temperature-dependent single-molecule photoluminescence spectroscopy on a conjugated polyelectrolyte bearing polar functional groups (ProDOT-TetEster), and explore the influence of the polarity and bulkiness of the surrounding environment. We were able to show that (i) The polarity of the surrounding matrix has no effect on the average transition energy, which we attribute to side-chain "scaffolding"; (ii) Librational motion of phenyl rings of the matrix causes substantial spectral diffusion; (iii) A correlation between the intra-chain delocalisation and electron-phonon coupling to low-energy vibrations (of the polyelectrolyte and/or matrix) exists.

Order-invariant two-photon quantum correlations in PT-symmetric interferometers

P 64

T.A.W. Wolterink, M. Heinrich, S. Scheel, A. Szameit
Institute for Physics, University of Rostock, Germany

Multiphoton correlations in linear photonic quantum networks are governed by matrix permanents. Yet, surprisingly few systematic properties of these crucial algebraic objects are known. As such, predicting the overall multiphoton behavior of a network from its individual building blocks typically defies intuition. In this work we identify sequences of concatenated two-mode linear optical transformations whose two-photon behavior is invariant under reversal of the order. We experimentally verify this systematic behavior in parity-time-symmetric complex interferometer arrangements of varying composition. Our results underline new ways in which quantum correlations may be preserved in counterintuitive ways even in small-scale non-Hermitian networks.



Ultrafast coherent control of single molecules via two-photon excitation at room temperature

P 65

X. Xu,[1] U. Scherf,[2] R. Hildner,[1]
[1] *Zernike Institute for Advanced Materials, Groningen University, The Netherlands*
[2] *Wuppertal University, Germany*

Quantum coherent control has been a powerful technique to understand and manipulate ultrafast photoinduced processes for more than twenty years[1]. In a coherent control experiment, one can exploit quantum interference between competing pathways of multiphoton transitions toward the desired outcome by tailoring the spectral phase and/or amplitude of the electromagnetic field of the exciting laser[2].
Here, we demonstrate that the two-photon transition of single conjugated molecules embedded in a solid matrix can be controlled by sequences of shaped femtosecond pulses at room temperature. Varying the spectral phase of the pulses, we observe phase-dependent photoluminescence signals corresponding to the two-photon excitation probability. Notably, cancellation of the transition probability by so-called “dark pulses”[3] is observed in some molecules, which shows the ability to exert (full) coherent control of single molecules in condensed phase at room temperature.

[1] Zewail *et al*., Acc. Chem. Res. 13(10), 360-368 (1980).
[2] Wilma *et al*., J Am Chem Soc. 140(45), 15329-15335 (2018).
[3] Meshulach *et al*., Nature. 396, 236-242 (1998).

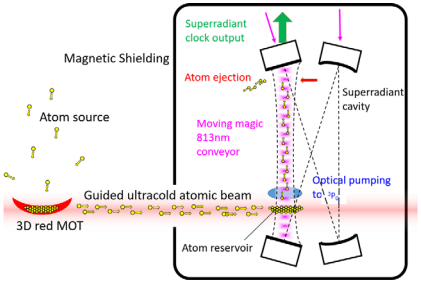
Towards continuous superradiant lasing on the clock transition of strontium

P 66

S. Zhou, F. Famà, C.B. Silva, B. Heizenreder, S. Bilicki, A. Sitaram, S. Sarkar, S. Bennetts, F. Schreck
Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam The Netherlands

Continuous superradiant optical clocks could directly produce light with mHz stability [1]. This approach decouples clock performance from limitations in ultrastable resonators, simplifying transportable clocks and reducing required averaging times. Pulsed superradiance was demonstrated on the $1S_0$-$^3P_0$ 'mHz' ^{87}Sr transition [2], however, continuous operation is needed for clocks.
We will describe our continuous superradiant laser apparatus using the strontium mHz clock transition. Our approach loads continuous cold atoms [3] into a moving lattice within a bow-tie cavity allowing high atom numbers with long lifetime.

[1] Meiser *et al*., PRL 102, 163601 (2009).
[2] Norcia *et al*., Phys. Rev. X, 8, 021036 (2018).
[3] Chen *et al*., Nature 606, 683-687 (2022).

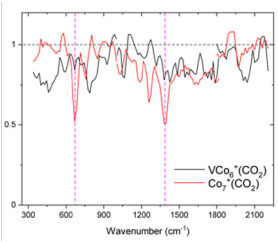


Towards gas-phase supported cluster catalysis

P 67

R.T. Zijlstra, W.D. Pradeep, J.M. Bakker
Radboud University, Nijmegen, The Netherlands

Ever increasing energy demands require more efficient catalytic processes in the chemical industry. However, since these catalytic processes are often poorly understood, it is difficult to predict a catalyst's performance for a given process. In order to get a better understanding of this, we use gas-phase clusters to model the active sites of a catalyst using a dual target dual laser ablation source. By doping a cluster with a second material we are also able to investigate the effect of foreign elements on the catalytic performance. The produced clusters are reacted with molecules of interest and the reaction products are investigated using a combination of mass spectrometry and infrared multiphoton dissociation using the FELICE infrared free electron laser. We demonstrate how vanadium doping alters the reactivity of cobalt clusters towards CO_2.

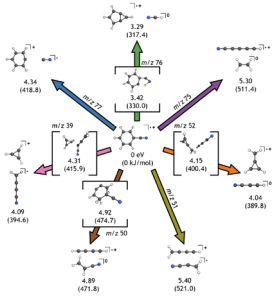


Dissociative Ionization of Benzonitrile

P68

J. Kamer,[1] D. Schleier,[1,2] M.J.E. Donker,[1] P. Hemberger,[3] A. Bodi,[3] J. Bouwman,[4]
[1] *Leiden University, The Netherlands*
[2] *Universität Duisburg-Essen, Germany*
[3] *Swiss Light Source, Switzerland*
[4] *CU Boulder, USA*

Benzonitrile has been detected in multiple astronomical objects through rotational spectroscopy [1]. In the interstellar medium (ISM), it is subject to the strong interstellar radiation field that may lead to (dissociative) ionization. We used i2PEPICO spectroscopy at the VUV beamline of the Swiss Light Source to study the photoelectron spectroscopy and dissociative photoionization of benzonitrile. Using Density Functional Theory calculations we identified pathways for all prominent observed fragmentation products. Moreover, we extract accurate dissociation energies by fitting the experimental data with a statistical model. The observed products give insights into the aromatic chemistry in the ISM and may guide observations of new interstellar molecules.



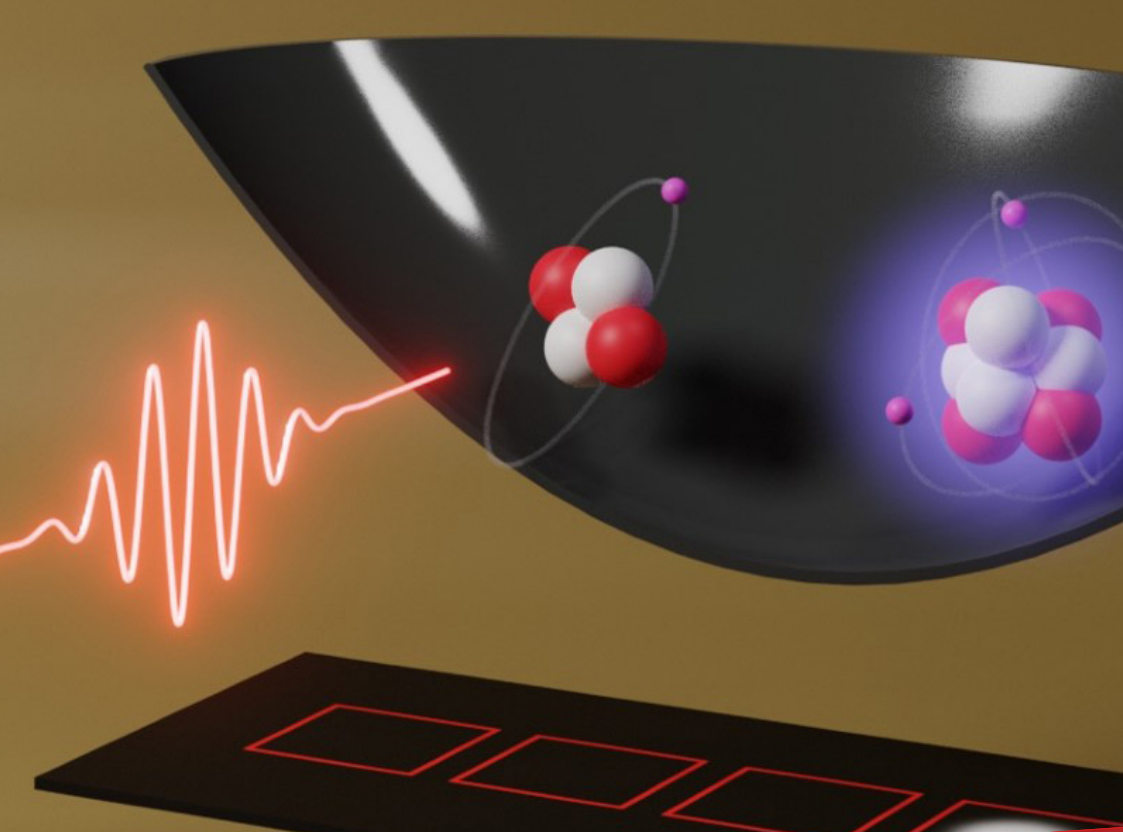
[1] Andrew M. Burkhardt, *et al*., Nat. Astron. 5, 181–187 (2021).

Stark deceleration of molecules for precision measurements

P 69

L. van Sloten, L. Huisman, S. Hoekstra, and the NL-eEDM collaboration
Van Swinderen Institute, University of Groningen and Nikhef, The Netherlands

Precise measurements on molecules represent a highly sensitive approach to detect physics beyond the Standard Model. In the NL-eEDM collaboration, barium monofluoride (BaF) molecules are used to probe the electron electric dipole moment (eEDM) with high precision. The molecules need to be measured for as long as feasible to improve statistical sensitivity. This is accomplished by utilizing a traveling-wave Stark decelerator that reduces the longitudinal velocity of a beam of BaF molecules. Here we present the development of the high-voltage electronics required for the operation of the decelerator. The high-voltage waveforms are produced by means of home-made transformers. These need to have sufficient power output to overcome the capacitive load of the decelerator and to reach the desired voltage amplitude. Furthermore, a large enough bandwidth is required such that they can operate within the desired velocity range of the molecules. Precise control of the high-voltage waveforms is crucial for effective deceleration and the minimization of molecular losses. However, the complex equivalent circuitry of the decelerator makes this a challenging endeavor.



This meeting is organized under the auspices of the NNV-Section Atomic, Molecular and Optical Physics, with the financial support of the Netherlands Organisation for Scientific Research.

This program is compiled by Kjeld Eikema and Steven Hoekstra

Design

Sophie van Kempen, bno www.visueleidentiteit.com