Program and abstracts

8 and 9 October 2019

Conference center
De Werelt Lunteren

43rd Meeting of the section *NNV Atomic Molecular and Optical Physics*

NWO

nederlandse
natuurkundige vereniging

43rd Meeting of the section

Atomic Molecular and Optical Physics (AMO)

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8 and 9 October 2019

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

Conference coordination:

Erna Gouwens (RU)

Tuesday 8 October 2019

10.00 **Arrival, registration**

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

chair: Robert Spreeuw

10.45 I 1 **Jun Ye** (JILA, National Institute of Standards and Technology and University of Colorado)
"Quantum matter and atomic clocks"

11.30 Short lectures: (Europa room)

O 1 **Felipe Bernal Arango** (Department of Quantum Nanoscience, Delft University of Technology)
"Cloaking NSOM probes"

O 2 **Matthijs Berghuis** (Eindhoven University of Technology)
"Strong light-matter coupling to enhance triplet exciton harvesting in tetracene crystal"

O 3 **Tom Bosma** (Zernike Institute for Advanced Materials, University of Groningen)
"Measuring spin-flip times of deep-level defects in SiC"

O 4 **Conor Bradley** (Qutech, Delft University of Technology)
"A 10-qubit solid-state spin register with quantum memory up to one minute"

12.30 **Lunch**

chair: Bas van de Meerakker

14.00 I 2 **Sandra Brünken** (FELIX Laboratory, Radboud University Nijmegen)
"Unravelling isomers of reactive ionic intermediates using FELIX"

14.45 Short lectures: (Europa room)

O 5 **Norman Ewald** (Institute of Physics, University of Amsterdam)
"Rydberg excitation of ultracold atoms interacting with trapped ions"

O 6 **Matthias Germann** (Laserlab, VU University, Amsterdam)
"Probing the proton-electron mass ratio through Doppler-free two-photon spectroscopy of HD^+"

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

15.45 Short lectures: (Europa room)

O 7 **Guoqiang Tang** (Institute for Molecules and Materials, Radboud University Nijmegen)
"Complete state-resolved dipolar bimolecular collissions"

O 8 **Amir Khodabakhsh** (Institute for Molecules and Materials, Radboud University)
"Time-resolved mid-infrared dual-comb spectroscopy: towards study of dynamic processes in plasma"

O 9 **Kenneth Lai** (Laserlab, VU University, Amsterdam)
"Testing quantum calculations with measurements on radioactive molecular hydrogen isotopologues"

O 10 **Pi Haase** (Van Swinderen Institute of Particle Physics and Gravity, University of Groningen)
"Magnetic hyperfine coupling constants with relativistic coupled cluster theory"

16.45 Poster presentations (odd numbers)

18.00 **Dinner (restaurant)**

19.15 Poster presentations (even numbers)

chair: **Femius Koenderink**

21.15 I 3 **Diederik Roest** (Theoretical High Energy Physiscs – Van Swinderen Institute for Part. Phys and Gravity, Groningen University)
" The Big Bang and the CMB: the latest news from the oldest light"

Wednesday 9 October

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

chair: **Steven Hoekstra**

08.45 I 4 **Julian Berengut** (UNSW, Sydney Australia)
"Searching for new physics in precision spectroscopy of atomic and ions"

09.30 Short talks (Europa room)

O 11 **Olga Lushchikova** (FELIX Laboratory, Radboud University Nijmegen)
"Spectroscopic characterization of copper clusters for catalytic CO_2 fixation"

O 12 **Reinier van der Meer** (Twente University)
"Optimizing spontaneous parametric down-conversion sources for boson sampling"

O 13 **Thomas Meijknecht** (van Swinderen Institute, Groningen University)
"Search for a permanent electron electric dipole moment (eEDM) using BaF molecules"

O 14 **Sylvianne Roscam Abbing** (ARCNL, Amsterdam)
"Divergence control of high-harmonic generation enables high brightness extreme-ultraviolet sources"

10.30 **Coffee/tea break**

chair: **Tim Taminiau**

11.00 I 5 **Claire Le Gall** (Cavendish Laboratory, University of Cambridge)
Collective ancilla memory for semiconductor quantum dots

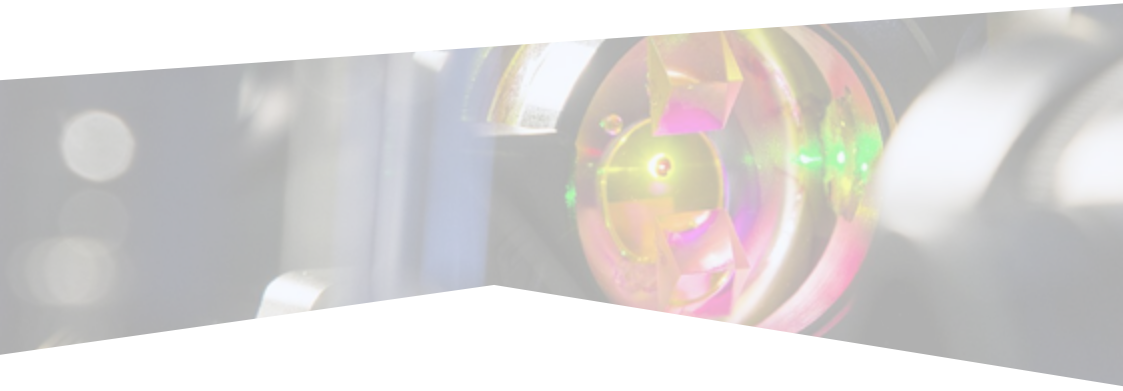
11.45 Short talks (Europa room)

O 15 **Charlaine Roth** (Laserlab, VU University, Amsterdam)
"High-precision Ramsey-comb spectroscopy in combination with high-harmonic generation"

O 16 **Maximilian Ruf** (Qutech, Technical University Delft)
A cavity-enhanced quantum network node in diamond"

O 17 **Najmeh Sadegh** (ARCNL, Amsterdam)
"Soft X-ray absorption spectroscopy of inorganic photoresists"

	O 18	**Thomas Secker** (Technical University Eindhoven) "Coupled-channels analysis of Feshbach resonances in a Mott insulator"
12.45	**Lunch**	
	chair:	**Herman Offerhaus**
13.55		Presentation winner poster award
	chair:	**Kjeld Eikema**
	O 19	**Martin Caldarola** (Technical University Delft) "Photothermal circular dichroism: a new technique to study chiral materials"
	O 20	**John Sheil** (ARCNL, Amsterdam) "Opacity of a laser-produced Sn plasma source of extreme ultraviolet light for nanolithography"
14.30	I 6	**Matteo Tacca** (NIKHEF, Amsterdam) How to measure a distance of one thousandth of the proton diameter? The detection of gravitational waves.
15.20	**Finish**	



Jun Ye

JILA, National Institute of Standards and Technology and University of Colorado

I 1

Quantum matter and atomic clocks

Relentless pursuit of spectroscopy resolution has been a key driving force for important scientific and technological breakthroughs, including the invention of laser and the creation of cold atomic matter. The most stable lasers now maintain optical phase coherence over tens of seconds. Meanwhile, precise quantum state engineering of individual atoms in both internal and external degrees of freedom has led to the unprecedented measurement performance for time and frequency. The use of many atoms not only enhances counting statistics, but also provides a powerful tool to protect against systematic uncertainties. At the core of the new three-dimensional optical lattice clock is a quantum gas of fermionic atoms spatially configured to guard against motional and collisional effects. This precise control of light-matter interactions is fostering new capabilities for probing fundamental and emerging phenomena.

Cloaking NSOM probes

O 1

Felipe Bernal Arango, Filippo Alpeggiani, Francesco Monticone, Andrea Alu, Thomas Krauss, Kobus Kuipers
Delft University of Technology

Measurement entails perturbation. This is a general truth both in classical and quantum physics. In the specific case of electrodynamics the act of measuring while perturbing the fields is clearly illustrated by the optical theorem, which tells us that one cannot have absorption without scattering. In the case of near-field scanning optical microscopy (NSOM), perturbation is especially evident when the electromagnetic modes of the nanophotonic structures under investigation are strongly confined and the mode volume is comparable to the effective size of the NSOM probe. The probe-structure interactions can be understood in terms of induced electric and magnetic dipole moments on the probe. Inspired by the concept of 'Cloaked sensors' we nanostructure the probe to balance the induced moments, so that the probe-structure interaction is minimized. At the same time, the cloaked probe still scatters light into its guided mode for near-field measurements. Our results show that by nano-structuring the probe one can control the interaction with the resonant mode of the sample, paving the way for non-perturbative near-field measurements.

Strong light-matter coupling to enhance triplet exciton harvesting in tetracene crystals

O 2

Matthijs Berghuis, Alexei Halpin, Quynh Le-Van, Mohammad Ramezani, Shaojun Wang, Shunsuke Murai, Jaime Gómez Rivas
Eindhoven University of Technology

Organic semiconductors are the basis of organic optoelectronic devices, such as organic LEDs and organic photovoltaics. To reach the best performance of these devices, we need to control and optimize the properties of the semiconductor, such as absorption and emission cross sections and the dynamics of excited states. A promising method to selectively control the exciton energy levels and their properties is by strong coupling to resonances in optical cavities. Strong coupling opens unique opportunities for modification of the optoelectronic properties and the dynamics of the system.

In this work, we fabricate arrays of silver nanoparticles that support collective plasmonic resonances. These resonances can couple strongly to singlet excitons in tetracene. We show that this coupling modifies the singlet energy level and, thereby, changes the absorption and emission spectra of tetracene. Most intriguingly, we observe a factor of four increase in the delayed fluorescence due to the enhanced harvesting of long-lived triplet excitons by strong light-matter coupling.

Measuring spin-flip times of deep-level defects in SiC

O 3

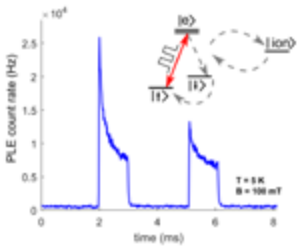
T. Bosma[1], D. van Hien[1], C. Gilardoni[1], P. Wolff[1], I. Ivanov[2], N. Son[2], and C. H. van der Wal[1]

[1] *Zernike Institute for Advanced Materials, University of Groningen*

[2] *Semiconductor Materials Research Division, Linköping University, Sweden*

Recent results of our group identified the molybdenum-impurity in SiC as a platform for quantum technology with spin-active emitters near telecom wavelengths [1]. Its bright optical transitions, together with long spin-dephasing times at 2 K, allow for efficient interfacing with neighboring quantum systems. However, the defect's T_1 spin lifetime has not yet been reported. We report measurements of this T_1 spin lifetime from pump-probe experiments, but find that the signals are influenced by dynamics via ionization levels with decay times similar to T_1. By adding extra optical control we can suppress the influence of the ionization dynamics, and we extract spin-flip times on the order of milliseconds at 2 K.

[1] T. Bosma *et al*., npj Quantum Inf. 4, 48 (2018)



A 10-qubit solid-state spin register with quantum memory up to one minute

O 4

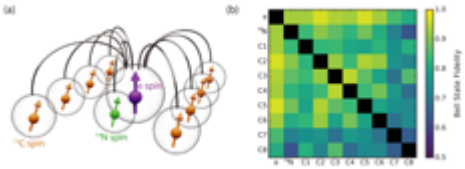
C.E. Bradley, J. Randall and T. H. Taminiau

QuTech, Delft University of Technology

Spins associated to defects in solids are promising qubits for quantum networks. Recent experiments have demonstrated high-fidelity operations and long-range entanglement. However, control has been limited to a few qubits, with entangled states of three spins demonstrated.

Here, we present novel control gates for an electron spin coupled to nuclear spins [1] and use these gates to realize a 10-qubit quantum register using an NV-centre in diamond (Figure 1a). We show that all qubits in the register can be pair-wise entangled (Figure 1b). Furthermore, we demonstrate 7-qubit entanglement, and coherence times up to 63(2) seconds. These are the largest quantum register and longest coherence times reported for solid-state spin qubits, opening the door to advanced quantum algorithms.

[1] C. E. Bradley *et al*., submitted. (arXiv:1905.02094)



Sandra Brünken

FELIX Laboratory, Institute for Molecules and Materials, Radboud University Nijmegen

I 2

Unravelling isomers of reactive ionic intermediates using FELIX

Hydrocarbon and nitrile ions play an important role in the chemistry of planetary atmospheres and the interstellar medium. Laboratory spectroscopic studies of these essential reaction intermediates give valuable insights on their geometrical and electronic structure, and provide accurate transition frequencies needed for their identification in space. Conventional absorption spectroscopy has in the past been successfully applied for spectroscopic studies of molecular ions, but is often hampered by low number densities and spectral congestion due to the multitude of species produced at high excitation energies during their formation process. These limitations can be overcome by performing experiments on mass-selected ions in cryogenic ion trap instruments.

Here I will present laboratory data on the gas phase spectra of several hydrocarbon and nitrile cations ranging in size from comparatively small systems (e.g., $C_3H_2^+$, CH_2CN^+) to PAH cations, made possible by recent developments of sensitive methods for action spectroscopy of cold, trapped ions. A focus will be on infrared experiments and methods to disentangle the isomeric composition of ionic samples, using the unique combination of a cryogenic ion trap instrument interfaced to the infrared free electron lasers at the FELIX Laboratory [1,2]. Progress towards rotational spectroscopic studies on some of these systems using a novel action spectroscopic scheme based on state-dependent attachment of He atoms to the cold molecular ions will be reported [3].

[1] Jusko *et al*., Faraday Discuss. (2019), in press, doi: 10.1039/c8fd00225h

[2] https://www.ru.nl/felix/

[3] Brünken *et al*., J. Mol. Spectrosc. 332 (2017) 67

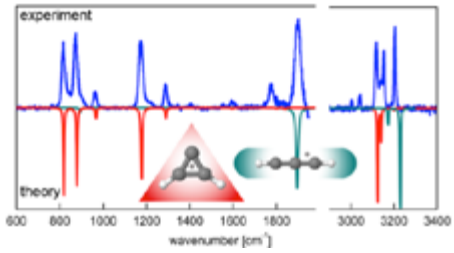


Figure 1: Vibrational spectra of two isomers of $C_3H_2^+$ recorded using Ne-tagging of cold ions in a cryogenic ion trap in combination with the intense and widely tunable IR-radiation of the FELIX lasers.

Rydberg excitation of ultracold atoms interacting with trapped ions

O 5

Norman V. Ewald, Thomas Feldker, Henrik Hirzler, Matteo Mazzanti, Henning A. Fürst, and Rene Gerritsma
University of Amsterdam

We report on the observation of interactions between ultracold Rydberg atoms and ions in a Paul trap [1]. Their observed inelastic collisions, manifested in charge transfer, exceed Langevin collisions for ground state atoms by almost three orders of magnitude in rate. The ion loss spectrum exhibits a tail on the red side of the Rydberg resonance which we attribute to the electric field of a single ion. Furthermore, we demonstrate Rydberg excitation on a dipole-forbidden transition with the aid of the electric field of a single trapped ion. The techniques may allow to create spin-spin interactions between atoms and ions [2] and to overcome recently observed heating due to ionic micromotion in atom-ion hybrids [3,4].

[1] N.V. Ewald, T. Feldker, H. Hirzler, H. Fürst, and R. Gerritsma, PRL **122**, 253401 (2019).
[2] T. Secker, R. Gerritsma, A.W. Glätzle, and A. Negretti, PRA **94**, 013420 (2016).
[3] T. Secker *et al*., PRL **118**, 263201 (2017).
[4] Z. Meir *et al*., PRL **117**, 243401 (2016).

Probing the proton-electron mass ratio through Doppler-free two-photon spectroscopy of HD^+

O 6

M. Germann, S. Patra, K. S. E. Eikema, W. Ubachs and J. C. J Koelemeij
Vrije Universiteit Amsterdam

We have performed Doppler-free two-photon spectroscopy of cold, trapped HD^+ ions to measure a ro-vibrational transition frequency with a relative uncertainty of a few parts-per-trillion. Using highly precise *ab-initio* calculations [1], these measurements allow – for the first time – to determine the proton-electron mass ratio, μ, from molecular spectroscopy with a precision competitive with that of state-of-the-art Penning trap mass measurements [2, 3]. Hence, our method provides both a new value of μ and a cross check of existing methods. In addition, our results provide an indication of the values of the proton radius and Rydberg constant, and may even serve as a probe of physics beyond the Standard Model.

[1] V.I. Korobov, J.-Ph. Karr, L. Hilico, **Phys. Rev. Lett.** 118, 233001 (2017).
[2] F. Heiße *et al*. **Phys. Rev. Lett.** 119, 033001 (2017).
[3] S. Sturm *et al*. **Nature** 506, 467 (2014).

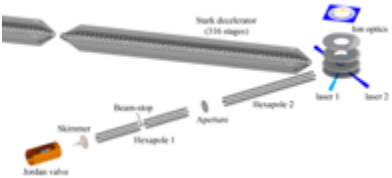
12

Complete state-resolved dipolar bimolecular collisions

O 7

Guoqiang Tang, Zhi Gao, Sebastiaan Y.T. van de Meerakker
Spectroscopy of Cold Molecules, Institute for Molecules and Materials, Radboud University Nijmegen

A detailed understanding of molecular interactions is crucial for the interpretation of microscopic dynamics. The crossed molecular beam technique proved to be a sophisticated approach to obtain detailed information of potential energy surfaces. Despite the success in studying collisions between atoms and molecules, complete quantum-state resolved bimolecular collisions are experimentally more challenging because of the low particle density in the colliding beams.
We combined a Stark decelerator and a hexapole in a crossed molecular beam configuration to produce two molecular beams of NO radicals and ND_3 molecules with an almost perfect quantum-state purity. State-resolved inelastic collisions between NO ($X^2\Pi_{1/2}, j=1/2, f$) and ND_3 ($j_k p=1_{1-}$) molecular beams are studied. From the measurement, we successfully observed the correlated energy transfer in rotationally NO-ND_3 inelastic collisions.



Time-resolved mid-infrared dual-comb spectroscopy: towards study of dynamic processes in plasma

O 8

Amir Khodabakhsh, Muhammad Ali Abbas, Qing Pan, Julien Mandon, and Frans J.M. Harren
Institute for Molecules and Materials, Radboud University, Nijmegen

Time-resolved dual-comb spectroscopy (TRDCS) is a powerful technique which simultaneously yields a broadband, high resolution, and time-resolved spectrum. For the first time, we developed a TRDCS system in the mid-infrared wavelength range – the so called “finger print” region –where most of the molecules have their fundamental ro-vibrational bands. We use our system to studying a CH_4 gas sample in an electrical discharge, performing time-resolved spectroscopy in millisecond and microsecond scales, while the discharge is modulated between dark and glow regimes. We monitor the production of C_2H_6, one of the discharge products, as well as the excitation of CH_4 molecules which allows us to simultaneously investigate the dynamics of both processes. We also observe the collisional relaxation process of the exited CH_4 molecules using different ro-vibrational exited states of CH_4. This new approach is a perfect tool to simultaneously monitor different aspects of the kinetics of fast chemical reactions, such as transient species, branching, free radicals, and molecular excited states.

Testing quantum calculations with measurements on radioactive molecular hydrogen isotopologues

O 9

K.-F. Lai[1], P. Czachorowski[2], M. Schloesser[3], M. Puchalski[4], J. Komasa[4], K. Pachucki[2], W. Ubachs[1], and E. J. Salumbides[1]

[1] Department of Physics and Astronomy, LaserLaB, Vrije Universiteit Amsterdam, De Boelelaan 1081, 1081 HV Amsterdam, The Netherlands

[2] Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland

[3] Tritium Laboratory Karlsruhe, Institute of Technical Physics, Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

[4] Faculty of Chemistry, Adam Mickiewicz University, Umultowska 89b, 61-614 Poznan, Poland

Molecular hydrogen, including its radioactive tritium-containing isotopologues, is a testing ground for quantum calculation in molecules. High resolution coherent anti-Stokes Raman scattering (CARS) measurements were performed on Q-branch fundamental vibrational splittings Q(J) ($v = 1 \leftarrow 0, \Delta J = 0$) of T_2, DT and HT. We present results Q(J) lines up to $J = 5$ with an uncertainty 0.0004 cm^{-1}. These measurements are compared to theoretical calculation, including relativistic and QED effect, with total uncertainty < 0.0004 cm^{-1}. The averaged difference between experimental results and calculations is less than 0.0002 cm^{-1}. High precision studies on these heavier species could help disentangling various mass-dependent terms in calculations.

Magnetic hyperfine coupling constants with relativistic coupled cluster theory

O 10

Pi A. B. Haase[1], Miroslav Iliaš[2], Ephraim Eliav[3], and Anastasia Borschevsky[1]

[1] Van Swinderen Institute of Particle Physics and Gravity, University of Groningen, Groningen, The Netherlands;

[2] Department of Chemistry, Faculty of Natural Sciences, Matej Bel University, Banska Bystrica, Slovakia;

[3] School of Chemistry, Tel Aviv University, Tel Aviv, Israel.

Accurate predictions of magnetic hyperfine coupling constants are crucial in different areas of atomic and molecular physics; from the determination of magnetic properties of exotic nuclei to the search for even better atomic or molecular clocks. In the field of precision experiments searching for new physics, the calculation of hyperfine coupling constants can serve as a benchmark of a given theoretical method by comparison with known experimental data.

We demonstrate the performances of two relativistic coupled cluster methods, which treat electron correlation and relativistic effects on highest level, for ground and excited states hyperfine coupling constants, using Cs, Ba and BaF as test systems. The results are in excellent agreement with experimental data and especially the excited state hyperfine coupling constants show a significant improvement compared to existing theoretical results.

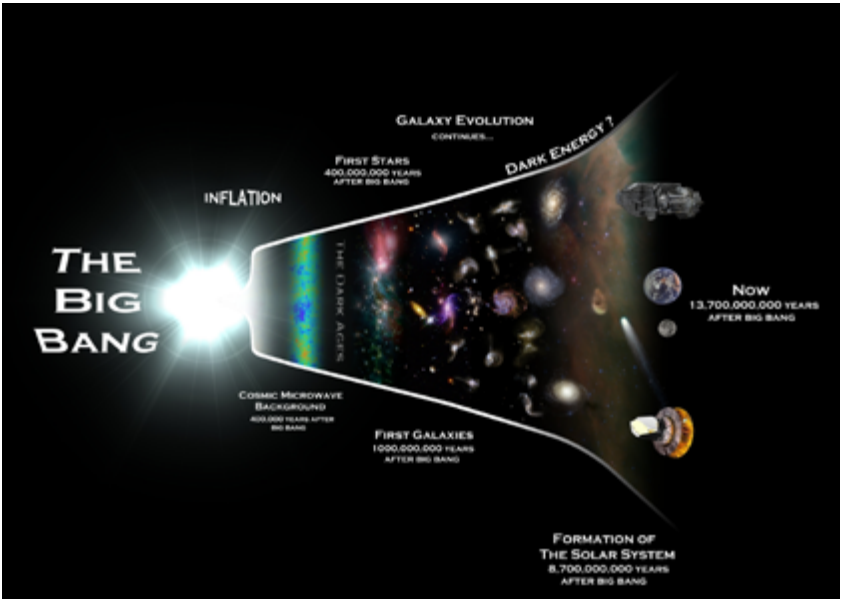
Diederik Roest

Van Swinderen Institute for
Particle Physics and Gravity
University of Groningen

13

The Big Bang and the CMB: the latest news from the oldest light

Recent years have seen remarkable progress in our understanding of the origin of the Universe. Detailed observations of the cosmic microwave background, the afterglow of the Big Bang, paint a surprisingly clear picture: both the entire Universe as well as the seeds for its large scale structures were created in its primordial phase. I will touch on the observational evidence and theoretical interpretation of this exciting development.



Julian Berengut

University of New South Wales
Sydney, Australia

I 4

Searching for new physics in precision spectroscopy of atoms and ions

The spectral properties of atoms and ions with more than a few electrons cannot be calculated with extremely high accuracy. Therefore, despite the extraordinary accuracy of precision spectroscopy, it is difficult to test the Standard Model in atomic systems by direct comparison of theory and experiment. On the other hand, differential measurements - for which the theory can be made sufficiently accurate - can provide strong tests of new physics.

Differential measurements in atomic systems include searches for parity-invariance and time-invariance violating amplitudes to probe the weak interaction [1]; changes in spectral energies over space and time to probe potential variations in fundamental constants [2] and violations of Lorentz invariance [3]; and precision isotope-shift measurements, which could uncover new force-carrying particles [4].

In this talk I will review recent developments in these searches. In particular, I will discuss emerging precision studies in highly charged ions, where the effects of new physics can be strongly enhanced [5].

[1] J. S. M. Ginges and V. V. Flambaum, Phys. Rep. 397, 63 (2004)

[2] T. Rosenband *et al*. Science 319, 1808 (2008)

[3] M. A. Hohensee *et al*. Phys. Rev. Lett. 111, 050401 (2013)

[4] J. C. Berengut *et al*. Phys. Rev. Lett. 120, 091801 (2018)

[5] M. G. Kozlov *et al*. Rev. Mod. Phys. 90, 045005 (2018)

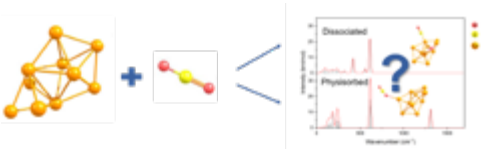
Spectroscopic characterization of copper clusters for catalytic CO_2 fixation

O 11

Olga V. Lushchikova
FELIX Laboratory, Radboud University Nijmegen

The catalytic recycling of CO_2 to liquid fuels, such as methanol, may help to control the atmospheric CO_2 content. Currently, methanol is produced industrially from syngas (CO_2-CO-H_2) under high temperature and pressure conditions over a Cu/ZnO catalyst. A broad range of studies suggest that the most active parts of the industrial catalyst are Cu nanoparticles.

To increase understanding of this reaction, we study the interaction of CO_2 and H_2 with copper clusters. For this, we elucidate the structure of Cu_n^+ (n=1-10) clusters, and subsequently investigate their interaction with some common feedstock molecules, such as CO_2, H_2 and methane. The methods we use are IR photodissociation spectroscopy and Density Functional Theory calculations.



Optimizing spontaneous parametric down-conversion sources for boson sampling

O 12

R. van der Meer[1], J.J. Renema[1], B. Brecht[2], C. Silberhorn[2], and P.W.H. Pinkse[1]
[1] *MESA+ Institute for Nanotechnology, Complex Photonic Systems (COPS), University of Twente*
[2] *University of Paderborn*

The next milestone in quantum information processing is to demonstrate an experiment at which a quantum device outperforms a classical computer. This can be achieved by sending single photons through a linear-optical network. However, this requires the generation of many spectrally pure (indistinguishable) single photons, which is a nontrivial task. Spectral impurity reduces the visibility of quantum interference of the photons, which can be mitigated by filtering at the cost of optical losses. Unfortunately, these losses are also detrimental to quantum interference.

We recently demonstrated how to analyze the role of imperfections in multiphoton interference experiments [1]. We now apply these results to the problem of constructing single photon sources. In this work we show that an optimum exists where we can outperform a classical computer, using off-the-shelf parametric down-conversion photon sources. These results show that demonstrating a quantum advantage using photonics is difficult, but possible.

[1] J.J. Renema *et al*,. arXiv: 1809.01953 (2018)

Search for a permanent electron electric dipole moment (eEDM) using BaF molecules

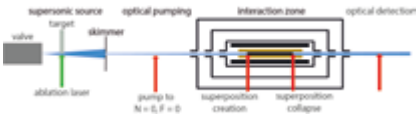
O 13

Thomas B. Meijknecht[1], the NL-eEDM collaboration[1,2]

[1] *Van Swinderen Institute, University of Groningen and Nikhef, National Institute for Subatomic Physics*

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

A permanent electron electric dipole moment (eEDM) is searched for using a BaF molecular beam. We performed spectroscopic measurements with a supersonic BaF beam. The lifetimes of the $A\Pi_{1/2}$ and $A\Pi_{3/2}$ states were measured. An eEDM search with a BaF beam puts stringent requirements on the fields in an interaction zone. The requirements are an electric field of O(10 kV/cm) and a magnetic field O(10 nT), both with small field gradients i.e. less than 1% inhomogeneity. We are currently building the interaction zone to work with the supersonic BaF beam. Ultimately the sensitivity will be improved using a substantially decelerated and laser-cooled BaF molecular beam.



Divergence control of high-harmonic generation enables high-brightness extreme-ultraviolet sources

O 14

Sylvianne Roscam Abbing, Filippo Campi, Faegheh Sajjadian, and Peter M. Kraus

Advanced Research Center for Nanolithography (ARCNL), Amsterdam, The Netherlands

High-harmonic generation (HHG) is a technique that enables broadband, ultrafast, and highly coherent extreme ultraviolet sources. However, the conversion efficiency of the process is low, but all applications of HHG require high-brightness sources. In addition, the HHG pulses have a double-Gaussian beam profile that gives rise to chromatic aberrations, which are rooted in the quantum-mechanical nature of the generation mechanism. By using both 800 nm and 400 nm femtosecond pulses for the generation process, we can manipulate the attosecond electron dynamics of the HHG process, which impacts the phase front of the generated pulses. We have shown by an extensive parameter study that the relative polarization, the ratio between and the phase of the two fields can be used to improve the beam profile by suppressing the tails of the spatial profile, while increasing the overall conversion efficiency. Our result pave the way towards high-brightness HHG sources with improved beam profiles.

Claire Le Gall

Cavendish Laboratory, University of Cambridge,
JJ Thomson Avenue, Cambridge,
United Kingdom

I 5

Collective ancilla memory for semiconductor quantum dots

Interfaces between single photons and single spins underpin the promise of flexible quantum architectures and unconditional security for communication. Their versatility arises from our ability to measure the spin information deterministically and use photons to generate entanglement between spins over large distances.

Using leading solid-state systems, semiconductor quantum dots (QDs) and Nitrogen Vacancies in diamond, important milestones have been reached [1]. In the case of QDs, their near-ideal optical properties have allowed to distribute entanglement at an unprecedented rate of 7.3 kHz. Thus far, fewer praises can be sung about their spin coherence. The electron couples to a mesoscopic ensemble of N~100,000 nuclei and gaining control over this many-body system to the point where nuclei are a resource is a frontier challenge in the field.

In this talk, I will present our latest efforts to control collective nuclear states [2, 3]. In our experiments, we operate the electron both as a control and a probe of the total nuclear spin polarisation, I_z. For a thermal nuclear ensemble, fluctuations of this polarisation ($\sim\sqrt{N}$) broaden the electron spin linewidth to ~100MHz (pink curve in Fig. 1D). Using an all-optical method to prepare the nuclei, we reduce the uncertainty on nuclear polarisation (purple curve in Fig. 1D) to well below the nuclear Zeeman energy (ω_z~20MHz), thus allowing to resolve the hyperfine levels of the electron-nuclear system (Fig. 1C) and access magnon modes, appearing as weakly allowed sideband transitions (Fig. 1E and F). The overarching goal is to use these collective nuclear modes for quantum storage [4], a decisive step towards a scalable distributed network.

[1] W. B. Gao *et al*. Nature Photonics 9, 373-373 (2015)

[2] D. A. Gangloff *et al*. Science 364, 62-66 (2019)

[3] J. H. Bodey *et al*. arXiv:1906.00427 (2019)

[4] E. V. Denning *et al*. arXiv:1904.11180 (2019)

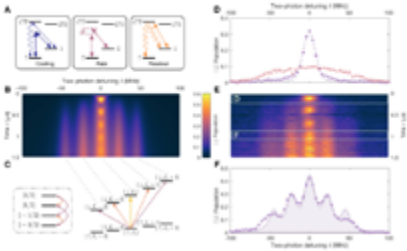


Figure 1: Spectrally resolved nuclear magnons.

High-precision Ramsey-comb spectroscopy in combination with high-harmonic generation

O 15

C. Roth L.S. Dreissen, E.L. Gründeman, J.J. Krauth, M.F.M. Collombon, and K.S.E. Eikema
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We combine for the first time Ramsey-comb spectroscopy (RCS), based on pairs of frequency-comb pulses, and high-harmonic generation (HHG). This coherent process enables upconversion of high-intensity (near-) infrared laser pulses to the vacuum and extreme ultraviolet (VUV and XUV). However, plasma creation in the HHG medium induces a time-dependent phase shift, which is detrimental for the RCS method. We investigate such phase shifts by measuring the atomic phase evolution with RCS of the $5p^6 \rightarrow 5p^5 8d$ transition in xenon at 110 nm (seventh harmonic). While phase effects can be significant for short timescales (< 16 ns), they become negligible for longer inter-pulse delays. It enabled us to perform spectroscopy with the highest relative accuracy (2.3×10^{-10}) achieved so far with HHG, mainly limited by the short transit time of the xenon atoms through the refocused VUV beam. The results show great promise for measuring accurately the 1S-2S transition frequency in He^+ to improve tests of quantum electrodynamics theory.

A cavity-enhanced quantum network node in diamond

O 16

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[1] *QuTech and Kavli Institute of Nanoscience, Delft University of Technology*
[2] *QuTech and Netherlands Organization for Applied Scientific Research (TNO)*

Future quantum networks rely on entanglement shared between their nodes; one promising node candidate are nitrogen-vacancy (NV) centers in diamond. We have recently achieved success rates of generating entanglement between nodes of 40 Hz [1]; these rates are limited by the emission probability of a spin-selective NV photon in the zero-phonon line, as well as the photon collection efficiency [1]. Embedding a NV center between two micron-spaced highly reflective mirrors can address both challenges, benefitting from large Purcell enhancement. Here, we present results of cavity experiments using novel devices [2] that combine optically coherent NV centers with micrometer-thin diamond membranes.

[1] P. Humphreys *et al*., Nature 558, 268-273, 2018
[2] M. Ruf et al., Nano Letters 19, 3987-3992, 2019

Soft X-ray absorption spectroscopy of inorganic photoresists

O 17

N. Sadegh, L.F. Campi, J. Haitjema, M. van der Geest, P. Kraus, and A.M. Brouwer, S. Castellanos Ortega
ARCNL - Advanced Research Center for Nanolithography, Science Park 106, 1098 XG Amsterdam,

Metal-oxo clusters such as tin-oxo cage compounds are synthesized in our group as promising new extreme- ultraviolet (EUV) resists, while little is known regarding the EUV driven chemistry. Broadband soft-x ray photons with energies of 25-45 eV generated from a high harmonic set-up were used for X-ray absorption spectroscopy (XAS) of these inorganic materials.

The resultant XAS spectra show an overall increase in the sample's transmission with exposure doses up to ~1500 mJ/cm^2. Complimentary, RGA (Residual Gas Analyzer) measurements, performed in IMEC, showed that only hydrocarbon compounds are released with no indication for the outgassing of tin-containing materials. In the XAS spectra, two peaks around 27 and 40 eV were observed with a corresponding blue and red shift trend over exposure, which could be ascribed tentatively to a decrease and increase in the negative charge density of tin and oxygen atoms, respectively, as a result of a previously proposed condensation reaction.

Coupled-channels analysis of Feshbach resonances in a Mott insulator

O 18

Thomas Secker and Servaas Kokkelmans
Eindhoven University of Technology, The Netherlands

Ultracold atomic gas experiments have proven to be a versatile ground for studying quantum mechanics, quantum many-body physics, quantum simulation and computation. A precise model for two-body collisions in those systems is essential. Coupled-channels models can accurately describe the two-atom system at ultracold temperatures by detailed interaction potentials that are finetuned by just a few parameters, determined from experiment. We extend such a coupled-channels model [1] to include the situation in a Mott insulator phase of ultracold bosonic atoms, where two atoms are confined to one lattice site. Of particular importance is the specific conversion between the on-site interaction energy, which remains finite in the lattice when the scattering length is diverging. Recently spectroscopic techniques allowed for a precise experimental determination of the on-site interaction energy in a system of ^{7}Li [2], we analyze this data with our model to improve the precision of current lithium interaction potentials.

[1] N. Gross et al., Comptes Rendus Physique 12, 4 (2011).
[2] J. Amato-Grill *et al.*, Phys. Rev. A 99, 033612 (2019).

Photothermal Circular Dichroism: a new technique to study chiral materials

O 19

P. Spaeth[1], S. Adhikari[1], L. Le[1], T. Bauer[2], **M. Caldarola[2]**, L. Kuipers[2] and M. Orrit[1]
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[2] *Technical University Delft*

Chirality, the absence of mirror-symmetry in an object, is a fundamental property of many materials. Here, we present a new optical technique that combines photothermal microscopy with polarization-tailored light beams to obtain an enantioselective optical signal. Our technique is sensitive to the differential absorption of right and left circularly polarized light: $\Delta\sigma = \sigma_{-L} - \sigma_{-R}$, which is nonzero for chiral absorbing objects. Figure 1 shows a proof-of-principle set of measurements with individual chiral nanostructures of different handedness that evidences the enantioselective capabilities of the technique.

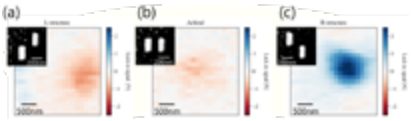

Figure 1: Photothermal circular dichroism images of plasmonic nanostructures. Optical image of a left-handed (a), achiral (b), and right-handed (c) gold nanorod dimer. Insets: SEM images of the respective structures.

Opacity of a laser-produced Sn plasma source of extreme ultraviolet light for nanolithography

O 20

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[2] *Vrije Universiteit Amsterdam*
[3] *University of Groningen*
[4] *Los Alamos National Laboratory, USA*

Highly charged tin ions are employed in next-generation nanolithography as sources of narrow-band extreme ultraviolet light at a wavelength of 13.5 nm. These ions are bred in laser-produced plasmas (LPPs) formed by irradiating tin microdroplets with high-intensity lasers. The interpretation of experimental spectra recorded from such LPPs necessitates an understanding of the opacities of such plasmas. In this work, we present tin-plasma opacities calculated using the Los Alamos opacity code ATOMIC at conditions relevant to the production of 13.5 nm photons. The calculations, performed under the assumption of local thermodynamic equilibrium, reveal surprising contributions from highly-excited states to the total opacity. The topic of atomic structure completeness and its influence on the calculated opacity will be discussed. Finally, we compare our theoretical calculations with experimental spectra recorded at ARCNL. The single-temperature, single-density approach adopted in the calculations is found to excellently reproduce the experimental spectra.

Matteo Tacca

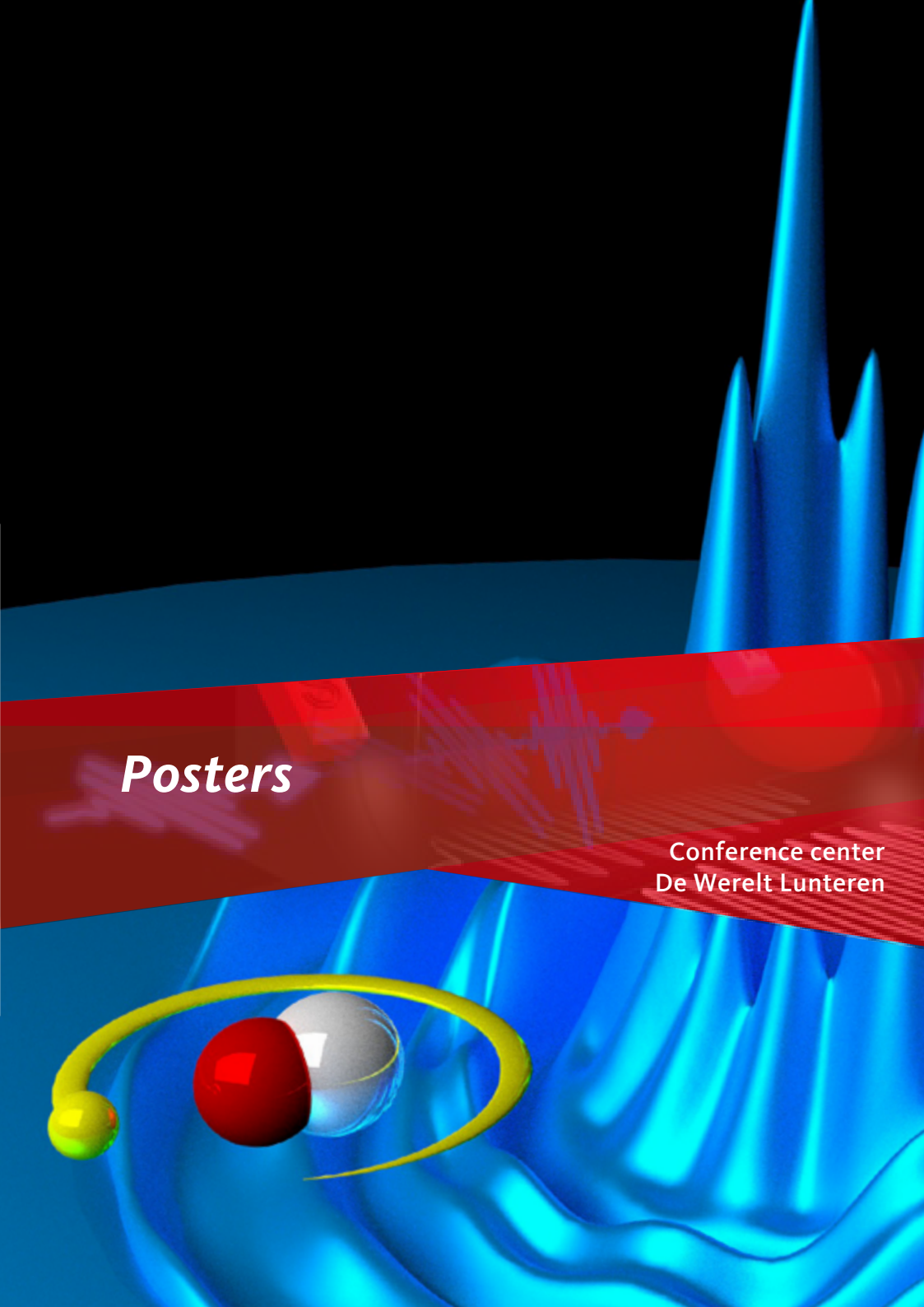
Detector R-and-D Nikhef, Amsterdam

16

How to measure a distance of one thousandth of the proton diameter? The detection of gravitational waves.

The detection of gravitational waves (GW) is one of the main challenges of contemporary physics. The existence of gravitational radiation is one of the most important predictions of the General Theory of Relativity: every accelerating massive body loses energy by emitting a traveling distortion of the space-time metric. Despite this great generality, the gravitational interaction weakness imposes stringent requirements on the bodies that can emit non-negligible amounts of energy by gravitational waves: they are emitted by violent astrophysical phenomena such as coalescences of neutron stars or black holes. The first direct observation of a gravitational wave emitted by the coalescence of two black holes was done in 2015, while the first detection of a gravitational wave emitted by the merging of two neutron stars was made in 2017. These observations allowed important tests of General Relativity and opened a totally new window onto the Universe, providing a new tool for astrophysics and cosmology.

In order to detect Gravitational Waves, the design and the implementation of very sensitive, complex and technologically advanced instruments, able to detect the infinitesimal time varying strains in space-time, are needed. Among the various proposed experimental methods, long baseline optical interferometry was the first able to directly detect gravitational waves: Virgo in Europe and LIGO in USA are two large-scale, Earth-based Fabry-Pérot Michelson interferometers operating for the last years. In this presentation the instrumental challenges of a gravitational-wave interferometer will be discussed, focusing mainly on the optical ones.



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Conference center
De Werelt Lunteren

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P 2 **Sonakshi Arora** (Kavli Insititute of Nanoscience, Delft University of Technology, Delft, The Netherlands)
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P10 **F.M.J. Cozijn** (LaserLaB, Vrije Universiteit Amsterdam)
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P58 **Peter van der Slot** (Laser Physics and Nonlinear Optics, University of Twente)
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"Supercontinuum generation in media with sign-alternated dispersion"

Mid infrared dual-comb spectroscopy using a passive optical reference

P 1

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Life Science Trace Gas Facility, Molecular and Laser Physics, Institute of Molecules and Materials,Radboud University, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands
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The mid-infrared spectral region is of special interest for gas spectroscopy, as many molecules have strong fundamental ro-vibrational transitions (for example, CH, NH, OH stretching modes) in this wavelength region. Here, we present a dual-comb spectrometer using a passive optical reference work-ing in the 2.5-4.3 μm spectral region. Mid Infrared source is based on singly resonant OPO, pumped by two near-infrared frequency combs with a slightly different repetition rates, locked to stable RF sources. Broadband molecular spectra of the analyte are recorded by detecting the heterodyne signal between the two mid-infrared beams. A passive optical reference cell is used to correct the spectral instabilities of the mid infrared optical frequency combs. This configuration allows the recording of single- and multispecies molecular spectra in the wavelength region between 2.5-4.3 μm, with a spec-tral resolution of 0.2 cm^{-1} (6 GHz), with absolute frequency calibration.

Visualization of edge states in topologically non-trivial photonic crystals

P 2

Sonakshi Arora[1] and Nikhil Parrapurath[2], Thomas Bauer[1], René Barczyk[2], Filippo Alpeggiani[1], Ewold Verhagen[2], Kobus Kuipers[1]
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Topologically-protected edge states exist at the interface between two materials with different band topologies. With phase- and polarization-resolved optical near-field microscopy we investigate the properties of the edge states at a topological photonic interface between two photonic crystals and directly visualize their propagation. We analyse higher-order Bloch harmonics that compose the fields of the edge state, and retrieve its dispersion and decay length. Further analysis reveals signatures of underlying photonic spin-orbit coupling, manifested by spatially-varying spin densities. This opens the route for localized polarization-selective excitations. In our work, we explore the small amount of spin-spin scattering that distinguishes photonic topological edge states from their electronic counterparts. The photonic edge states offer promising applications for routing and manipulating light at the nanoscale.

Ultra-fast laser induced gas flow visualization using digital holography

P 3

Dashdeleg Baasanjav[1], Javier Hernandez-Rueda[1,2], Allard P. Mosk[1], and Dries van Oosten[1]
[1] *Debye Institute for Nanomaterials Science, Utrecht University*
[2] *Kavli Institute of Nanoscience, Delft University*

We study femtosecond laser-induced flows of air at a water/air interface, at micrometer length scales, by recording the transient reflectivity of shock waves. We simultaneously induce two flow fronts using two adjacent laser pump spots with a spatial light modulator. When two fronts meet, a stationary shock wave is produced, the length of which is a measure of the local flow velocity. By changing the distance between the pump spots, we map out the flow velocity around them. We find gas front velocities near the speed of sound of air for two laser excitation energies. This versatile method of using the spatial light modulator opens up the possibility of using arbitrary illumination patterns that could lead to more complex effects.

Kerr frequency comb generation in silicon nitride micro-ring resonators

P 4

Y. Klaver, **H.M.J. Bastiaens,** K.-J. Boller
Laser Physics and Nonlinear Optics group, University of Twente

Frequency comb generation in waveguide micro-ring resonators on a chip enables to realize compact, portable, and robust coherent sources with a large bandwidth span, finding use in various applications including precision spectroscopy, frequency metrology, and optical clocks. Essential properties for the resonator are a high quality factor and small mode volume to yield a low threshold, a dispersion engineered cross section to fulfill phase matching conditions, and appropriate optical laser excitation.

We demonstrate Kerr comb generation in micro-ring resonators fabricated from stoichiometric silicon nitride (Si3N4) with various ring diameters and coupling parameters [1]. We report on the dependence of the threshold and the generated comb spectrum on the quality factor of the resonator and pump power, respectively.

[1] C.G.H. Roeloffzen *et al., "Low-loss Si_3N_4 TriPleX optical waveguides: technology and applications overview"*, IEEE J. Sel.Top. Quant. Electron. **24,** 4400321 (2018).

Exploring the polarization dependence of supercontinuum generation in silicon-nitride waveguides

P 5

R.A.M. van Zon, **H.M.J. Bastiaens,**
N.M. Lüpken, C. Fallnich, and K.-J. Boller
Laser Physics and Nonlinear Optics group,
MESA+ Institute for Nanotechnology,
University of Twente

The broad coherent spectra obtained by supercontinuum generation (SCG) are of significant importance for applications in, e.g., spectroscopy and precision metrology. Of particular interest is SCG using integrated optical waveguides fabricated from stoichiometric silicon nitride (Si_3N_4), which has provided the broadest supercontinuum on a chip [1]. Although SCG in silicon-nitride waveguides is extensively studied, it is limited to input beams polarized to excite either the fundamental (quasi) TE- or TM-mode of these waveguides.
Here, we explore the dependence of SCG in silicon-nitride waveguides on varying polarization directions of the pump and varying birefringence of the waveguide cross-section, both experimentally and numerically. Applying pump light polarized to excite the TE and TM modes simultaneously, we find that the generated SC spectrum becomes much broader than the spectra from the separately excited TE- and TM-modes.

[1] J. P. Epping *et al.*, *"On-chip visible-to-infrared supercontinuum generation with more than 495 THz spectral bandwidth"*, Opt. Express **23**, 19596 (2015).

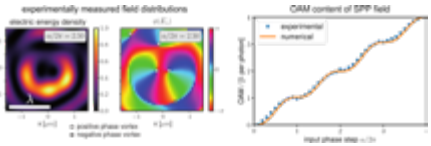
Fractional orbital angular momentum in 2D light fields

P 6

Thomas Bauer and Kobus Kuipers
TU Delft

Mapping intriguing quantum-mechanical concepts to physically straightforwardly accessible optical systems has led to a number of promising new research fields such as topological photonics. One recent example of such a map is the analogy between the Aharonov-Bohm effect and the vortex topology of light fields containing fractional orbital angular momentum (OAM).

Here, we experimentally study the creation and annihilation of optical vortices with integer topological charge existing in surface plasmon polariton waves while adiabatically increasing the fractional OAM content of the underlying field. By measuring the individual components of the complex spatial field distribution with sub-wavelength resolution, we are able to follow the step-wise increase of the total topological index of the field at half-integer OAM, analogous to the increase of the vortex strength of the magnetic flux line in the Aharonov-Bohm effect.



Towards metastable helium atom interferometry

P 7

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Oleksiy Onischenko, Wim Vassen, Kjeld S.E. Eikema, and Hendrick L. Bethlem
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We plan to measure the recoil velocity of a helium-4 atom in the triplet metastable state (He*) when it absorbs a photon. An atom interferometry scheme will be used for sensitive velocity measurements, leading to an h/M measurement for helium. Combined with the well-known values of the proton-to-electron mass ratio, the Rydberg constant and the helium mass, the fine-structure constant (α) can be obtained.

Alternatively, α can be obtained from electron g-factor data combined with QED theory. These measurements are performed in different domains of physics, thus providing a consistency test of physics.

We have produced a He* BEC in a hybrid magnetic/optical trap and loaded ultracold samples into a crossed optical dipole trap (ODT). We plan to transfer the sample to a shallow horizontal optical lattice and to accelerate this lattice, which will induce Bloch oscillations. These are an important tool in the interferometry scheme. We show the expected behaviour of atoms in the lattice and prospects for He*-interferometry.

Spectral investigation of Sn laser-produced plasmas in the extreme ultraviolet range

P 8

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[2] *Vrije Universiteit Amsterdam, The Netherlands*
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Tin (Sn) laser-produced plasmas (LPPs) are of great technological interest, being used as sources of extreme ultraviolet light in next-generation nanolithographic applications. This is because of the emission of Sn in a 2% bandwidth around 13.5 nm which is suitable for such applications. Due to the complex electronic configurations of the relevant ions $Sn5^+$…$Sn14^+$, arising from their open 4d and 4p subshells, spectroscopic investigation of these plasmas can be quite challenging. In this work, we describe Sn LPP spectra through a comparison with charge-state resolved Sn ion spectra recorded in an Electron Beam Ion Trap (EBIT), focusing in the 14 – 21 nm region. Finally, we apply Collisional Radiative Modeling and the relativistic Flexible Atomic Code, to aid with the interpretation of experimental EBIT spectra.

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Evolution of the unitary Bose gas for broad- to narrow Feshbach resonances

P 9

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Eindhoven University of Technology

The recent experimental investigation of ultracold Bose-gases in the strongly interacting regime has provided us with interesting insights regarding the dynamical evolution of the gas and the build-up of few-body correlations in a many-body environment. In these experiments, the gas is quenched to unitarity by altering an applied magnetic field to the resonant value of a Feshbach resonance [1-3].

Building on previous research regarding the formation of pairs in quenched unitary Bose gases [4], we investigate the effect of the resonance width on the evolution of embedded two-body interactions, finding that the dynamics of broader resonances evolve more rapidly than the dynamics of narrower resonances at early times. We contribute this difference to a decrease in quantum depletion that Bose-enhances open-channel interactions. Instead, we see that an increasing amount of closed-channel molecules is formed for narrow resonances, whose importance is quantified in terms of the Z-parameter[4]. The magnitude of this parameter is found to be an increasing function of both resonance width and time.

Cryogenic cavity-enhanced spectroscopy to resolve hyperfine spectrum in HD

P 10

F.M.J. Cozijn, M.L. Diouf, E.J. Salumbides, and W. Ubachs
LaserLaB, Vrije Universiteit Amsterdam

Ro-vibrational transitions in hydrogen are an excellent benchmark value to test fundamental theories to extreme accuracies. For example, our recently observed Doppler-free transitions within the first overtone band of HD can contribute to the proton radius puzzle when determined with kHz accuracy. However, the observed Doppler-free R(1) transition is composed of 21 overlapping hyperfine components. This severely complicates the extraction of an accurate transition frequency, which is currently limited to 50 kHz accuracy. A new experimental setup, which is currently in construction, is aimed to resolve this difficulty. Here we will benefit from a cryogenic high-finesse cavity within the frequency-comb referenced NICE-OHMS (Noise-Immune Cavity-Enhanced Optical Heterodyne Molecular Spectroscopy) experiment. The NICE-OHMS detection scheme is significantly upgraded by benefiting from parallel demodulation using a high-speed digital lock-in amplifier. These upgrades are expected to give over a 100-fold increase in signal size, which will allow us to resolve sub-structure within the hyperfine spectrum, potentially isolate an individual hyperfine component and allows detection of the simpler R(0) transition

Lamb dips and Lamb peaks in the saturation spectrum of HD

P 11

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[1] Department of Physics and Astronomy, LaserLaB, Vrije Universiteit
[2] Laboratoire de Physique des Lasers, Université Paris 13

Molecular hydrogen has evolved into a benchmark quantum test system for fundamental physics. Recent independent sub-Doppler determinations of the weak dipole R(1) transition in the (2,0) overtone band of HD at λ~1.38 μm yield a discrepancy of 900 kHz or 9σ in combined uncertainty. We present measurements using Noise-Immune Cavity-Enhanced
Optical Heterodyne Molecular Spectroscopy (NICE-OHMS), where the laser is locked to a Cs absolute frequency standard via an optical frequency comb. The obtained saturation spectrum is found to exhibit a composite and pressure-dependent line shape, involving a Lamb-dip and a Lamb-peak. We propose an explanation of this behavior based on the effects of crossover saturation resonances in the hyperfine structure, which is made quantitative with a density matrix calculation. This leads to resolution of the outstanding discrepancy between the two previous determinations, which enables the comparison of the measured R(1) transition frequency with the most accurate calculations.

Broadband multi-species trace gas detection by upconverting mid-infrared supercontinuum light into the near-infrared

P 12

Khalil Eslami Jahromi, Qing Pan, Amir Khodabakhsh, and Frans J.M. Harren
Trace Gas Research Group, Department of ` Molecular and Laser Physics, Radboud University, Nijmegen, The Netherlands

The advancement in compact, stable, and broadband mid-infrared (MIR) supercontinuum sources (SC) makes it possible to generate a beam containing a wide spectral range with high power and directionality for absorption spectroscopy. Although gas molecules exhibit strong absorption features in MIR region, the low sensitivity of MIR detector arrays operating at room temperature is a challenge. However, by upconverting MIR SC light into near-infrared (NIR), leveraging the benefits of sensitive and cost-effective CCD detectors are feasible.
Here, we present the performance and development of a multi-species trace gas sensor by upconverting MIR SC light into NIR and utilization of a grating-based spectrometer in combination with a CCD camera. High speed sensing (~20 ms), sub-ppmv sensitivity (for ethane), wide spectral coverage (>1.3 μm), 4.5 cm^{-1} resolution, linear response to different gas concentrations and satisfactory results for globally calculating the concentrations of mixture gases are the prominent features for such a sensor.

Towards a steady-state superradiant active optical clock

P 13

Francesca Famà, Shayne Bennetts, Kei Sawada, Rodrigo González-Escudero, Chun-Chia Chen, Benjamin Pasquiou, and Florian Schreck, *et al.**

**The iqClock consortium www.iqclock.eu*

Institute of Physics, University of Amsterdam

Superradiant lasers have been proposed as a next generation optical atomic clock [1]. Recently, a pulsed superradiant laser was demonstrated using the ^{87}Sr clock transition [2], but a clock with millihertz stability requires steady-state operation.
Building on our earlier work [3,4] we have now demonstrated sources ideal for pumping a steady-state superradiant laser. Our steady-state beam guided horizontally by a dipole laser has a radial temperature of ~1μK and a flux >3x107 ^{88}Sr/s. We have also demonstrated operation of this architecture on the ^{87}Sr isotope, that is of particular interest for clocks. We will describe the next generation machine that we are constructing based on these techniques, which aims to produce a steady-state superradiant laser for time standards.

[1] Meiser *et al.*, PRL **102**, 163601 (2009).

[2] Norcia *et al.*, Sci Adv **2**, 10, e1601231 (2016).

[3] Bennetts *et al.*, PRL **119**, 223202 (2017).

[4] Chen *et al.*, arXiv:1810.07157 (2018).

State transfer in optomechanics via STIRAP

P 14

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[1] *Universiteit Leiden*

[2] *UCSB*

We adopt a well-established technique of state transfer STImulated Raman Adiabatic Passage from Atomic Physics to Optomechanics. The state is transferred between mechanical modes (0.2 MHz and 1.3 MHz) of a highly stressed SiN membrane via optomechanical interaction. The membrane is placed in the middle of a high finesse cavity and the system is in the sideband resolved regime. The membrane is patterned with a phononic crystal which increases the quality factor of the mechanical modes localized in the defect of the phononic crystal 2 orders of magnitude, allowing state transfer with efficiencies of 90%. The experimental results are in perfect agreement with the theory.

A high average-power table-top high-harmonic generation source for spectroscopy in the water window

P 15

F. Campi, and P. M. Kraus
**Advanced Research Center for Nanolithography (ARCNL), Amsterdam, The Netherlands*

High-harmonic generation has enabled the investigation of electronic processes on their intrinsic timescales, owing to the attosecond temporal structure of the generated pulses. In order to attain a comprehensive picture of the dynamics ensuing excitation in a pump-probe experiment, element sensitivity of the probe pulse is beneficial. In the past decade, a few groups have succeeded in generating supercontinua spanning the water-window up to the oxygen K-edge (540 eV), but the wide-spread application as spectroscopic source has been hindered by the low available fluxes. A mid-IR high-power laser system (>100 W) will be installed in our group. Consequently, we expect to be able to generate soft X-ray pulses up to 600 eV, and at unprecedented average-power levels. Here, we present the design of our beamline along with proposed experiments. Particular technical challenges are sustaining several bars of gas pressure while minimizing reabsorption, and filtering out the high-power driving laser pulses from the generated soft x-rays.

An approach towards hybrid integrated diode lasers for the visible spectra range

P 16

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[1] University of Twente, the Netherlands
[2] University Muenster, Germany

Integrating diode laser sources in the visible range into photonic circuits, for controlling wavelength tuning or for reducing the spectral linewidth, can enable, e.g., chip-sized multicolor light engines for life-science applications [1] or drive multiple narrow-linewidth transitions in portable optical clocks [2]. Current approaches with grating feedback and bulk or fiber optical beam combining lead to devices of appreciable size, restricted spectral control and suffer from mechanical perturbations. Hybrid integrated lasers, formed by a diode laser amplifier and a low-loss waveguide feedback circuit [3] can avoid these disadvantages, but have only been realized at telecom wavelengths. We present our approach for realizing a first hybrid integrated diode-SiN laser in the visible, to generate light around 690 nm via optical feedback from an integrated micro-ring Vernier filter.

[1] A. T. Mashayekh *et al*., Proc. SPIE 10922, 109221U-1 (2019)
[2] S. G. Porsev, Phys. Rev. A 78, 032508 (2008)
[3] R. M. Oldenbeuving *et al*., Las. Phys. Lett. 10, 015804 (2013)

Measuring deep UV and extreme UV induced luminescence in metal-oxo based photoresists

P 17

Maarten van der Geest[1], Najmeh Sadegh[1], Sonia Castellanos[1], and Peter Kraus[1]

[1] *Advanced Research Center for Nanolithography (ARCNL), Amsterdam, The Netherlands*

The next generation of integrated circuits will require new photoresists for 13.5 nm extreme ultraviolet (XUV) radiation, such as titanium-oxo clusters and metal-oxo resists in general. The photochemistry of these resists under XUV radiation is poorly understood. We studied the visible/UV fluorescence following deep-UV excitation and observed only slight red-shifts and decay-time differences between the luminescence of a titanium-oxo cluster containing bisthienylcarboxylate (TiBTC, figure 1) ligands and free bisthienylcarboxylic acid, indicating no significant quenching contribution from the titanium-oxo cluster. We use high-harmonic generation to generate ultrashort pulses of XUV radiation around the titanium $M_{2,3}$-edge (43 eV) and will investigate the luminescence quenching following XUV excitation.

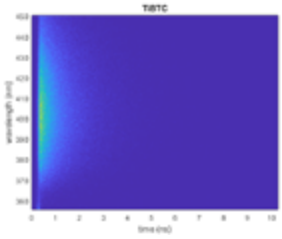


Figure 1 Deep UV induced luminescence decay (double exponential fit, 0.47&1.0 ns) of TiBTC.

Optical spectroscopy of transition metal defects in silicon carbide

P 18

C. M. Gilardoni[1], T. Bosma[1], F. Hendriks[1], B. Magnusson[2,3], A. Ellison[3], A. Gällström[2,4], I. G. Ivanov[2], N. T. Son[2], R. W. A. Havenith[1,5], and C. H. van der Wal[1]

[1] *University of Groningen*

[2] *Linköping University*

[3] *Norstel AB*

[4] *Saab Dynamics AB*

[5] *Ghent University*

Color centers in wide-bandgap semiconductors are attractive systems for quantum technologies. However, the optical transition frequencies of several suitable centers identified so far hinder their integration in communication technology. Several transition-metal impurities in silicon carbide emit at near telecom wavelengths, but their characterization is incomplete. We investigate the electronic structure of defects containing Mo in SiC. Both ground and optically excited states in this defect are composed of two Kramer's doublets each, arising from doubly degenerate orbital states split by SOC, reminiscent of the electronic structure of negatively charged Si vacancies in diamond.

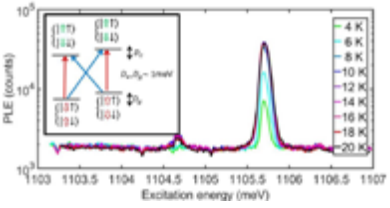


Figure 1 . Zero Phonon Lines corresponding to the two vertical optical transitions as a function of temperature; inset shows the proposed electronic structure of Mo defect in SiC.

Singularities of 2D random light waves

P 19

Thijs van Gogh, Thomas Bauer
and Kobus Kuipers
Kavli Institute of Nanoscience Delft,
Delft University of Technology

Singularities are points of a field where one of the parameters describing the field becomes undetermined. As exotic as they may sound, they are ubiquitous in nature. Well known examples include black holes and the bright stripes of light on the bottom of a pool. In electric and magnetic fields they arise as points where the phase becomes undefined (zero intensity), or where the direction of the polarization ellipse becomes undetermined (perfectly linear or circular polarization). Combining the electric and magnetic fields then also allows for the computation of the Poynting vector, which exhibits singularities where it vanishes. With our near-field optical microscope, we study these singularities of light with a sub-wavelength resolution in a random wave field on a chip by injecting a 2D chaotic photonic crystal cavity with laser light. Being able to switch between CW and pulsed lasers allows for investigation of both the frequency and time domain. We explore the differences between truly 2D random fields and 2D slices of a 3D field.

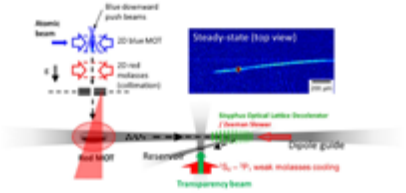
Almost degenerate steady-state strontium

P 20

R. González Escudero, C.-C. Chen, S. Bennetts,
B. Pasquiou, and F. Schreck
Van der Waals - Zeeman Institute,
Institute of Physics, University of Amsterdam

We demonstrate a steady-state strontium sample with a phase-space density approaching degeneracy. This represents a critical step towards a steady-state atom laser. Our machine achieves this by flowing atoms through spatially consecutive laser cooling stages. After precooling on a MHz-wide transition, we capture atoms in a steady-state narrow-line MOT [1]. A beam of atoms is then coupled into a dipole guide and transported to a dark region, where they accumulate and are further laser cooled. Here they reach almost degeneracy: a phase-space density of 1. We are now exploring further improvements [2] in a bid to reach steady-state quantum degeneracy.

[1] Bennetts *et al*., PRL **119**, 223202 (2017).
[2] Chen *et al*., arXiv:1810.07157 (2018).



Tests of fundamental physics using Ramsey-Comb spectroscopy on H^2

P 21

E.L. Gründeman, L.S. Dreissen, C. Roth, M.F.M. Collombon, J.J. Krauth, and K.S.E. Eikema
LaserLaB Amsterdam, Department of Physics and Astronomy, Vrije Universiteit Amsterdam

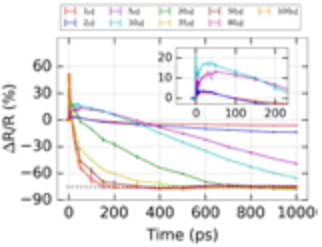
The dissociation energy (D_0) of H_2 is a benchmark value to test molecular quantum theory. A measurement of D_0 with an accuracy of 10 kHz could even be used to probe the proton radius to the level of 1%. In 2018 we achieved a 73 kHz-accuracy on the X-EF(0,0) Q1 transition in H_2 at 202 nm using Ramsey-comb spectroscopy. This, in combination with additional transitions measured in the group of Prof. Merkt (ETH Zürich), has led to an accuracy of 340 kHz for D_0 of ortho-H_2.
We now aim to further improve the accuracy on the Q1 transition to a level of 10 kHz by modifications in the experimental setup such as using an ultra-low noise frequency comb and by improving the collimation and density of the atomic beam. Finally we plan to measure the corresponding transition in para-H_2, which has no hyperfine structure (nuclear spin is zero) and therefore provides a very clean testing ground for theory.

Femtosecond time resolved pump-probe measurements on percolating gold in the ablation regime

P 22

Guido de Haan and Paul Planken
ARCNL, Amsterdam

We present results on femtosecond pump-probe measurements on thin nano-structured percolating layers of Au in the ablation regime. A strong pump pulse (~10^{13} W/cm^2) excites the Au layer and a delayed probe pulse measures the pump-induced changes in transmission and reflection, on a single shot basis. During the first few picoseconds the response is dominated by electron heating and cooling. Saturation of the accompanying reflection change for increasing pump power is most likely the result of saturation of changes in the electron occupancy in the conduction band at high powers. The strong reflection and transmission changes observed on a timescale of hundreds of picoseconds, together with SEM images of the aftermath, suggest that “phase-explosion” is the mechanism for violent removal of material.



Diatomic molecules as probes for nuclear anapole moment effect

P 23

Yongliang Hao,[1] Miroslav Ilias,[2] and Anastasia Borschevsky[1]
[1] *University of Groningen, Nijenborgh 4, 9747AG Groningen, The Netherlands;*
[2] *Matej Bel University, SK-97400 Banska Bystrica, Slovakia.*

The nuclear anapole moment can be used to test low-energy quantum chromodynamics and parity nonconservation in nuclei. Diatomic molecules possess rich and varied spectra and nearly degenerate energy levels, which provide strong enhancements for nuclear anapole moment effects, making it possible to search for new physics beyond the standard model in a small experiment. In order to extract the magnitude of nuclear anapole moment from measurements, a P-odd interaction coefficient W_A, which depend on molecular structure, needs to be calculated with high accuracy. In this presentation, the measurement principle is briefly introduced and the W_A coefficients calculated within different methods for some diatomic molecules of interest are presented and discussed.

Nonlinear optical response of WS_2

P 24

Javier Hernandez-Rueda, Marc Noordam, Irina Komen and Kobus Kuipers
Kavli Institute of NanoScience, TU Delft

Today, atomically thin 2D layered materials are at the focus of the optics and photonics community due to their unique optical properties. Particularly spectacular is their high nonlinear optical response upon intense light illumination, which has huge potential for applications based on these van der Waals hetero-structures. In this work, we study the nonlinear optical response of WS_2 flakes using spectrally-resolved multi-photon microscopy. We illuminate the sample using laser pulses at 775 nm and 1200 nm that are temporally and spatially overlapped. As a result, the emission spectrum illustrates peaks that correspond to second-harmonic generation, sum-frequency generation, third-harmonic generation and four-wave mixing. We find that the second- and third-order susceptibilities are remarkably large compared to those observed in other nonlinear media, especially around the exciton frequency. Moreover, we observe that the second-order processes drastically increase as the WS_2 layer thickness decreases, whereas the third-order processes illustrate the opposite tendency. Finally, we attribute this behaviour to a) the interplay of the electronic properties and multiple reflections and b) the symmetry of the system that favours or hinders the phase matching.

Opto-Spintronics in 2D van der Waals heterostructures

P 25

Jan Hidding[1], Jorge Quereda[1], Bart J. van Wees[1], Caspar H. van der Wal[1] and Marcos H. D. Guimaraes[1]
[1]Zernike Institute for Advanced Materials, University of Groningen

Spintronics aims at the transport and manipulation of electron spin, instead of electron charge. To obtain control of the spin, the unique properties of 2D van der Waals materials have been exploited and combined in heterostructure devices.
The transition-metal dichalcogenide (TMD) $MoSe_2$ in its monolayer form has a direct bandgap and spin-orbit splitting with opposite sign for opposite valleys.[1] This results in a coupling between the valley and spin degree-of-freedom, allowing to selectively create spin and valley polarization by absorption of circularly polarized light.[2] Furthermore, TMDs are able to imprint their large spin-orbit coupling in graphene allowing for new charge-to-spin conversion effects (Rashba-Edelstein effect) to appear.[3,4]
Here, we study the spectral and electrical response of the helicity-dependent photocurrents in phototransitors based on hBN/$MoSe_2$ and hBN/$MoSe_2$/graphene heterostructures. Our experiments give insights on the optical spin injection and spin-to-charge conversion in TMD and TMD/graphene heterostructures, opening up exciting possibilities for state-of-the-art two-dimensional spintronic applications.

Buffer gas cooling of a trapped ion to the quantum regime

P 26

H. Hirzler[1], T. Feldker[1], H. Fürst[1], N.V. Ewald[1], M.Mazzanti[1], D. Wiater[2], M.Tomza and R. Gerritsma[1]
[1] Van der Waals-Zeeman Instituut, Institute of Physics, Universiteit van Amsterdam
[2] Faculty of Physics, University of Warsaw, Poland

Both, trapped ions and ultracold atoms are excellents systems for studying many-body physics, precision spectroscopy and quantum information. This has raised the question whether the two systems can be advantageously combined. So far, the attainable collision energies are well below the regime where quantum effects become relevant. This is due to the radio-frequency electric field of the Paul trap which is required to confine the ion [1]. In our experiment we use ^{6}Li buffer gas to cool a single Yb+ ion down to ~42 μK corresponding to ~4 motional quanta in the harmonic potential of the Paul trap [2]. The meausured atom-ion collision energies reach the s-wave regime, which allows the search of quantum effects, such as atom-ion Feshbach resonances. Our results open the possibility to study quantum many-body phyiscs [3] and quantum chemistry in ultracold atom-ion mixtures [4].

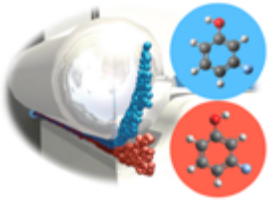
[1] M. Cetina *et al,* PRL 109, 253201 (2012)
[2] T. Feldker *et al,* Manuscript in preparation (2019)
[3] U Bissbort *et al,* PRL 111, 080501 (2013)
[4] M. Tomza *et al,* arxiv:1708.07832 (2017)

Towards structural-isomer-resolved ultrafast photochemistry

P 27

Daniel Horke
Institute for Molecules and Materials, Radboud University Nijmegen

The use of molecular control techniques based on electrostatic fields allows the spatial separation of species based on their dipole-moment to mass ratio. This includes, for example, the separation of different folding states of small peptides in the gas-phase, or the production of molecular beams containing only a single cluster stoichiometry. This enables the study of conformational or tautomeric effects with methods that are not inherently sensitive to these, for example, because they lack the necessary spectral resolution. We are setting up a femtosecond time-resolved photoelectron imaging experiment to study the ultrafast electronic dynamics following photoexcitation. This will allow us for the first time to elucidate how small structural changes, such as conformational variations, affect the photochemistry and ultrafast dynamics. In particular we will focus on tautomeric effects and interconversion in the nucleobases.



Electronic structure changes of gas-phase PAH cations as induced by successive atomic H attachment

P 28

Yining Huo*, Ronnie Hoekstra, and Thomas Schlathölter
Zernike Institute for Advanced Materials, University of Groningen

Successive attachment of hydrogen atoms to a PAH cations leads in geometrical transition from the planar aromatic molecules to puckered aliphatic system and the reduction of gap between HOMO-LUMO[1,2]. The DFT is adopted to illustrate the change of electronic structure for small PAH radical cations in different hydrogen states as Fig.1 indicates. The record partial ion yields for various photoionization channels as a function of photon energy and position of hydrogen attachment will be shown by combining the X-ray spectroscopy and mass spectrometry.

[1] S. Cazaux, L.Boschman, N. Rougeau, G. Reitsma, R. Hoekstra, D. Teillet Billy, S. Morisset, M. Spaans, T.Schlathölter.(2016) Scientific Reports 6.19835.
[2] S. Cazaux, Y. Arribard, D. Egorov, J. Palotás, R.Hoekstra, G. Berden and J. Oomens, and T. Schlathölter.(2019)Astrophysical Journal,875(1).

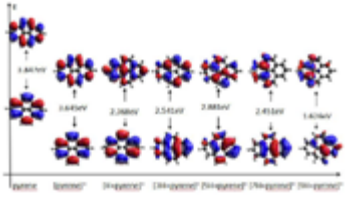


Figure.1 The HOMO-LUMO gap of the pyrene cation

Improved determination of the dissociation energy and ortho-para splitting of H_2

P 29

J. Hussels, C.-F. Cheng, H.L. Bethlem, K.S.E. Eikema, E.J. Salumbides, and W. Ubachs
VU Amsterdam; M. Beyer, N.J. Hölsch, F. Merkt, ETH Zurich; C. Jungen, UCL London.

Recent QED calculations of the dissociation energy (D_0) of H_2 approach accuracies similar to simple atoms, making it an excellent benchmark quantity in quantum chemistry. Precision measurements of the GK-X transition, combined with other precise measurements, provide an order-of-magnitude improved value for D_0. This transition is performed through Doppler-free two-photon spectroscopy using 179-nm radiation, generated by frequency up-conversion using a BBO and a special KBBF crystal. The fundamental pulses are the output of a chirp-compensated Ti:Sa oscillator-amplifier system seeded by a narrowband Ti:Sa laser at 716 nm, locked to a Cs-clock standard via a frequency comb. This enables sub-MHz accuracies, giving an improvement to the 10^{-9} accuracy level for D_0 of ortho- and para-H_2. Invoking a transition between the ortho- and para-H_2^+ ions, this gives a direct determination of the ortho-para splitting in H_2. Comparing these accurate results with improved calculations provides a test of QED and the Standard Model of Physics.

Time-resolved temperature measurement of plasmonic hot electrons using single-particle sub-picosecond anti-Stokes luminescence

P 30

Thomas Jollans[*]**,** Martín Caldarola†, and Michel Orrit[*]
** Huygens–Kamerlingh Onnes Laboratorium, Universiteit Leiden*
† Kavli Institute of Nanoscience, Technische Universiteit Delft

Upon excitation with a laser pulse, localized surface plasmon polaritons in a gold nanoparticle first thermalize into a hot electron bath, which then, in turn, thermalizes with the lattice through electron-phonon interactions, within a few picoseconds. We present first results of time-resolved measurements of the temperature during this process: The current temperature of the electrons is deduced from the Anti-Stokes luminescence of the nanoparticle [1]. The temporal information is elucidated by using a pump-probe configuration, in which luminescence spectra are acquired for different delays between two pulses. We show an apparently athermal instantaneous distribution of electron energies.

[1] A. Carattino, M. Caldarola, and M. Orrit, Nano Lett. **18**, 874 (2018).

Controlled tunnel couplings in a network of photon Bose-Einstein condensates

P 31

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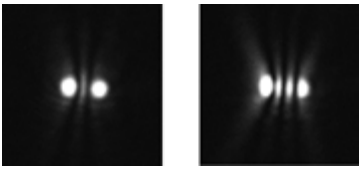
Coherent network computers have the potential to solve computationally hard problems in a significantly shorter computation time than standard computers. This is achieved by encoding computational problems in a network of coupled spins. A problem's solution can be obtained by finding the network's ground state energy. The encoding requires coupling that can be either ferromagnetic or antiferromagnetic. We demonstrate both types of coupling in a network of photon Bose-Einstein condensates in a microcavity. The microcavity consists of a plane mirror and a nanostructured mirror. Laser written nanostructures confine the photon condensates. The coupling type is determined by the distance between the condensates. The results show that photon condensate networks fulfill the requirements for coherent network computation and are therefore a promising platform for its implementation.



Time dependence of plasmonic near-fields studied by interferometric autocorrelation

P 32

Radoslaw Kolkowski, Annemarie Berkhout, Sylvianne Roscam Abbing, A. Femius Koenderink
Center for Nanophotonics, AMOLF, Amsterdam

Second-Harmonic Generation (SHG) in plasmonic nanostructures has been a target of extensive research over the past 15 years, focusing on many different aspects of this phenomenon, such as plasmonic enhancement, multipolar content, polarization effects, and time-resolved response. Here, we present our studies on plasmonic nanoantennas using interferometric autocorrelation (IAC), where two chirped femtosecond pulses with tunable mutual delay excite SHG in the sample. Compared to the reference measurement on a nonlinear crystal (Fig.1 left), SHG from gold nanoparticles shows reduced chirp signatures in their IAC trace (Fig.1 right). This effect enables to extract the temporal response function of nanoscale resonators.

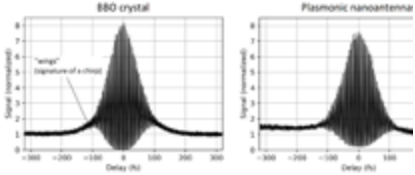


Figure 1. IAC trace of BBO crystal (left) and gold nanoantennas (right).

Exciton-polaritons in monolayer WS_2

P 33

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2D transition metal dichalcogenides (TMDCs) are semiconductors in which the electron-hole pairs in its valleys, having high binding energies, form stable excitons. Similar to plasmon-polaritons in graphene, these 2D TMDC excitons couple to light to form exciton-polariton modes. In monolayers of subnanometer thickness, these modes will be extremely confined and exhibit a strongly enhanced light-matter interaction. Additionally, a valley pseudospin can be attributed to the excitons, which opens the question on the chiral interactions of the exciton-polaritons. Recently, we theoretically demonstrated that a non-radiative polaritonic mode consists only if the dielectric functions above and below a monolayer of WS_2 are balanced [1], whereas an experimental situation implies a substrate. This can be compensated by covering the WS_2 with hexagonal boron nitride (hBN), where the combination of hBN and air will result in an effective dielectric function being balanced with respect to the substrate.

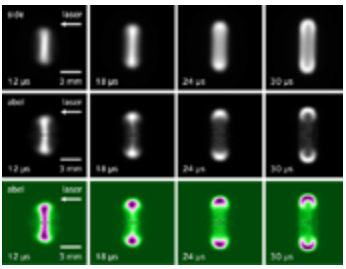
[1] Alpeggiani *et al*, Phys.Rev.B 97, 205436 (2018)

Flow induced shaping of laser plasmas in atmospheric-pressure helium

P 34

V. Kooij[1], F.M.A. Smitsr[1], and D. Bouwmeester[1]
[1] Quantum optics and quantum information, Leiden University, The Netherlands.

A plasma is formed by a focused high power infrared laser pulse in atmospheric-pressure helium and evolves to a toroidal shape. The plasma is observed with a CCD camera. The axial symmetry of the plasma allows to perform Abel inversion on the line integrated intensity data of the side view. The Abel inverted side view data provides detailed 2D images of the luminosity in the poloidal plane of the torus. By illuminating the centre of the torus with a second laser pulse at a series of delays and observing its intensity, the central pressure is probed as a function of time. Both techniques are combined to determine the flow that shapes the plasma.



Line integrated intensity
Linear grey scale

Abel inverted luminosity
Linear grey scale

Abel inverted luminosity
False color scale

Measurement of the 1S-2S transition of trapped He^+ via XUV Ramsey-Comb spectroscopy

P 35

J.J. Krauth, L.S. Dreissen, C. Roth, E.L. Gründeman, M.F.M. Collombon, and K.S.E. Eikema
LaserLaB Amsterdam, Department of Physics and Astronomy, Vrije Universiteit Amsterdam

High-precision laser spectroscopy of atomic hydrogen has led to an impressive relative accuracy in tests of bound-state quantum electrodynamics (QED) of about 10^{-12}. At this level of accuracy many systematics have to be studied very carefully and only independent measurements provide the ultimate cross-check. This has been proven recently by measurements in muonic hydrogen, eventually leading to a significant shift in the CODATA values of the proton charge radius and the Rydberg constant.

We aim to contribute to testing fundamental physics by measuring the 1S-2S transition in He+ for the first time. Combined with measurements in muonic helium this can probe the value of the Rydberg constant or test higher-order QED terms scaling with large powers of Z. We apply the Ramsey-comb method which we extend to the XUV using high-harmonic generation in order to excite a single, trapped He-ion. This poster gives insight into our experimental method, setup and current progress.

Towards frequency stabilization of a chip-based, ultra-narrow linewidth InP-Si_3N_4 hybrid laser

P 36

Rob Lammerink, Albert van Rees, Peter van der Slot, and Klaus-Jochen Boller
Laser Physics and Nonlinear Optics, University of Twente

Recently, hybrid integration of an InP semiconductor optical amplifier with a low-loss Si_3N_4 feedback circuit has enabled an ultra-narrow intrinsic linewidth of below 300 Hz [1]. Such high intrinsic frequency stability is of benefit for short-time measurements, such as for coherent optical data transmission. The intrinsic stability is a central advantage also for achieving long-term stability, via stabilizing the laser to an absolute frequency reference, specifically here, to ro-vibrational transitions of acetylene (C_2H_2) in the 1.55 μm telecom wavelength range.
We present the noise characteristics of the laser and discuss a stabilization scheme for a hybrid laser that is frequency-controlled with two integrated microring resonators and a phase-tuning section. We show that the laser possesses a sufficiently large mode-hop-free tuning range to efficiently stabilize the laser. Preliminary experimental data on performance of the stabilization will be presented.

[1] Y. Fan *et al*., "290 Hz Intrinsic Linewidth from an Integrated Optical Chip-based Widely Tunable InP-Si_3N_4 Hybrid Laser," in Conference on Lasers and Electro-Optics (2017)

New insights into irradiation damage of ultra-small G-rich oligoes

P 37

Wen Li[1], Xin Wang[1], Wesse[l] Douma[1], Ronnie Hoekstra[1], Marwa Abdelmouleh[2], Michal Ryszka[2], Jimmy Rangama[2], Violaine Vizcaino[2], Jean-Christophe Poully[2], and Thomas Schlathölter[1]

[1] *Zernike Institute for Advanced Materials, University of Groningen*

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Human telomere consists of TTAGGG repeats which were predicted to trap excitation energy due to their ability to form secondary structure G-quadruplex. We focused on studying 6 base G-rich single strand DNA, for example TGGGGT. ESI-MS had been applied to detect strand breakage and base lose for its high resolution and sensitivity. Soft X-ray induced fragmentations in G-quadruplex and G-rich monomers were very different. Meanwhile, high energy particle induced obvious different fragmentations to soft X-ray. Molecule dynamic simulation and Native PAGE also be used to analysis energy deposition, bond cleavage and conformation and structure change.

A rubidium focused ion beam instrument

P 38

Sheng Xu, Yang Li, Peter Mutsaers and Edgar Vredenbregt

Eindhoven University of Technology

Focused Ion Beams are important tools for the semiconductor industry. Essential applications are editing circuits and repairing masks in the development phase, and failure analysis during wafer processing. As a result of the reduction of feature sizes in semiconductor circuits, FIBs also face higher demands in terms of resolution and reduced damage. Here a FIB instrument that can overcome these limitations is presented. The essential innovation is the use of a new type of ion source based on photo-ionization of a laser-intensified and extremely cold atomic rubidium beam. The performance of the source was characterized by studying deliverable current, brightness and energy spread. The source was then mounted on a commercial FIB system and first ion microscopy and milling experiments were performed. Susequently, the properties of the new instrument will be optimized with the eventual aim of creating a practically useful prototype instrument. In addition, the interaction of rubidium ions with typical materials will be studied to investigate the essential suitability of a Rb^+ FIB for real-world applications.

State-to-state calculation of ultracold three-body collision in a magnetic field

P 39

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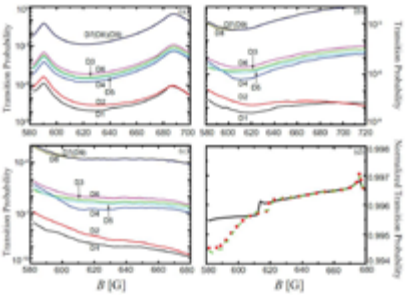
We present a multichannel numerical model to investigate the magnetically tuned alkali-metal three-body collision with hyperfine state-to-state resolution. Our model, with all realistic coupled hyperfine spin channels being included, can be simplified by using the separable approximation. The validity of the separable approximation is analyzed by the two-body coupled-channel scattering length, dimer energy and off-shell t-matrix. Then three-body results are given by using lithium and potassium atoms as examples. We find universal behavior of the normalized transition probabilities from different initial channels to deep atom-dimer channel for ultracold atom-dimer collisions[1].

[1] Jing-Lun Li and Shu-Lin Cong, Phys. Rev. A **99**, 022708 (2019).



Theoretical contribution to the search of CP-violation in molecules

P 40

Malika Denis[1], Pi A. B. Haase[1], Rob G. E. Timmermans[1], Ephraim Eliav[2], Nicolas R. Hutzler[3], and Anastasia Borschevsky[1]
[1] *Van Swinderen Institute, University of Groningen, Groningen*
[2] *School of Chemistry, Tel Aviv University, Tel Aviv.*
[3] *California Institute of Technology, Pasadena.*

New Charge and Parity violations absent in the Standard Model are assumed to be responsible for the large surplus of matter over antimatter in the universe. They could be observed through a set of interactions violating both parity and time-reversal symmetries (P, T odd), such as the electron Electric Dipole Moment, the nuclear Magnetic Quadrupole Moment...

Progress in the quest for CP violation via precision measurement is expected with the implementation of the laser cooling of molecules. Besides, triatomic molecules isoelectronic to the laser coolable diatomic molecules already employed are expected to exhibit the same assets as well as an advantageous vibrational structure, further improving the experimental precision.

We calculate the P, T odd molecular enhancement factors essential for the interpretation of the measurement in a set of promising systems for the search of beyond-the-Standard-Model CP violation.

Rotational State-dependent attachment of rare gas atoms to molecular ions

P 41

Aravindh Nivas Marimuthu, Britta Redlich and Sandra Brünken
FELIX Laboratory, Institute for Molecules and Materials, Radboud University Nijmegen

The spectroscopy of gas-phase molecular ions is a challenging task. Conventional absorption spectroscopy usually fails because the ions of interest cannot be produced in sufficient amounts and spectral contamination during formation. Therefore several "action spectroscopy" methods have been developed to overcome these limitations. Methods like infrared-predissociation via rare-gas tagging (IR-PD) or multiphoton dissociation spectroscopy (IRMPD) are routinely applied since many years for vibrational spectroscopy of molecular ions. Only in recent years several action spectroscopic methods have been developed to record rotational spectra, mostly via double resonance schemes, e.g. using laser-induced reactions.
Here we report on progress to establish another such method for pure rotational spectroscopy at a cryogenic ion trap instrument at the FELIX Laboratory using narrow-bandwidth THz radiation sources. This method utilizes a change in the rate of termolecular attachment of He atoms to molecular ions depending on their internal rotational excitation. Preparatory studies to apply this method to the molecular ions $C_3H_3^+$, $C_3H_2^+$, and CH_2CN^+ will be presented.

Traveling-wave stark deceleration of SrF and BaF molecules

P 42

Hidde Makaske, Parul Aggarwal and Steven Hoekstra, for the NL-eEDM collaboration
Van Swinderen Institute for Particle Physics and Gravity (VSI), University of Groningen, and Nikhef, Amsterdam

Probing the value of the electron electric dipole moment (eEDM) opens a window on physics beyond the Standard Model. In our experiment we make use of pulsed beam of BaF molecules, which originate from a cryogenic source at a typical velocity of 150 m/s. In order to improve our sensitivity to the eEDM we use a 4.5m long traveling wave Stark decelerator. This decelerator will lower the forward velocity of the molecules to 30 m/s.

The decelerator was already constructed for other experiments but has been upgraded such that it has a higher efficiency in slowing down the BaF molecules, through better alignment and enabling it to run at higher voltages.

Trapped ions in optical microtraps

P 43

M. Mazzanti[1], T. Feldker[1], H. Hirzler[1], N. Ewald[1] and R. Gerritsma[1]
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E-mail: m.mazzanti@uva.nl

Trapped ions are one of the most reliable platforms for quantum simulations; however, scalability of these systems is still troublesome. Here we present a way to tackle these scalability issues by moving to 2-dimensional ion crystals [1-6] (instead of the conventional 1-dimensional chain). Self-assembled 2D ion crystal have triangular symmetry and therefore are a natural system in which to study the quantum simulation of spin-frustration in triangular, hexagonal or kagome lattices. In order to engineer the spin-spin interaction between ions we will use novel optical microtraps [see e.g. [7]] that will allow us to manipulate the phonon spectrum of the 2D ion crystal [6,8]. In future, combining addressed ion operations with phono-mode engineering it should be feasible to equip the quantum simulator with a complete set of operations, leading to a 2-dimensional ion crystal quantum computer.

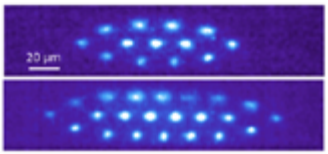

Figure: Two-dimensional ion crystals in one of our Paul traps.

Elastic scattering of three ultracold bosons

P 44

Paul Mestrom, Victor Colussi, Thomas Secker, and Servaas Kokkelmans
Eindhoven University of Technology, Eindhoven, The Netherlands

We study three-body elastic scattering of identical bosons at zero energy interacting via a pairwise finite-range potential. Using the Alt-Grassberger-Sandhas equations, we determine the behavior of the corresponding scattering amplitude that is closely connected to the three-body coupling constant that enters the many-body description of ultracold Bose gases. Our calculations cover the regime from strongly repulsive potentials towards attractive potentials supporting multiple two-body bound states, and are consistent with the few existing predictions for the three-body elastic scattering amplitude. In particular, we present the first numerical confirmation of the universal predictions for this scattering amplitude that are made in the strongly-interacting regime for a local nonzero-range potential, where the behavior of the three-body elastic scattering amplitude is log-periodic due to the Efimov effect. We also show how finite-range effects give rise to both universal and nonuniversal behavior in the weakly-interacting regime. We analyze resonances in the scattering amplitude that arise from weakly-bound three-body states.

[1] P.M.A. Mestrom, V.E. Colussi, T. Secker, and S.J.J.M.F. Kokkelmans, arXiv:1905.07205v1 [physics.atom-ph] (2019).

A buffer-gas cooled molecular source of BaF in the search for an eEDM

P 45

Maarten C. Mooij[1], Wim Ubachs[1], Hendrick L. Bethlem[1] and the NL-eEDM collaboration: Parul Aggarwal[2], Alexander Boeschoten[2], Anastasia Borschevsky[2], Malika Denis[2], Kevin Esajas[2], Pi A.B. Haase[2], Yongliang Hao[2], Steven Hoekstra[2], Klaus Jungmann[2], Virginia R. Marshall[2], Thomas B. Meijknecht[2], Rob G.E. Timmermans[2], Anno Touwen[2], Lorenz Willmann[2], and Yanning Yin[2]

[1] *LaserLaB, Department of Physics and Astronomy, Vrije Universiteit Amsterdam, The Netherlands*

[2] *Van Swinderen Institute, University of Groningen, Groningen, The Netherlands*

We are constructing a setup to measure the electric dipole moment of the electron in a Stark decelerated, laser cooled beam of BaF molecules. In Amsterdam we are in charge of building a cryogenic beam source for an intense beam (target: 5×10^{10} BaF molecules per pulse) at low velocities (180 m/s). We will give a status-update of the buffer gas beam source that is currently being built at the VU and the femtosecond laser system that we use for detecting both the BaF molecules and the Ne buffer beam.

Optically levitated nanoparticles

P 46

M. Morshed Behbahani[1], L. van Sloten[1], L. Blaauw[1], K. Jungmann[1], G. Palasantzas[2], L. Willmann[1], and S. Hoekstra[1]

[1] *Van Swinderen Institute,*

[2] *Zernike Institute for Advanced Materials University of Groningen*

Optically levitated nano- and microparticles systems provide a wide variety of precision sensing applications. In our group we optically trap individual silica nanospheres with a diameter of 143 nm and interferometrically detect the particle's oscillation frequency in all three spatial dimensions. This research is part of an NWA Startimpuls project, which explores the use of trapped nanoparticles as vibration and force sensors. Since the particle's oscillation frequency is dependent on the intensity gradient of the trapping laser and on the properties of the particle, trapping of various types of nanospheres under various conditions allows us to benchmark the light-particle interaction theory. To optimize force and vibration sensing, feedback cooling of the particle's center-of-mass motion under high-vacuum conditions is required. We report on our progress towards this goal.

Cluster formation in quenched unitary Bose Gases

P 47

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In the last few years, research groups started to explore the unitary Bose gas, which is experimentally extremely challenging. A sudden quench of atomic interactions makes it possible to observe this strongly-interacting system and the dynamics at unitarity, where the interactions are as strong as allowed by quantum mechanics. Unlike the Fermi counterpart, this regime for bosons is dominated by losses, due to the absence of Pauli repulsion. As a result, when the state at unitarity is probed again in the weakly-interacting regime, the number of remaining unbound atoms is primarily reduced by losses and formation of molecules. In Ref. [1], we have modelled quench experiments by solving equations of motion for first and second-order correlations (or clusters), explicitly including losses and found agreement for shorter times with experimental data of Ref. [2]. The deviation for longer times is attributed to the absence of higher-order correlations and/or equilibrating effects. In particular, the importance of higher orders has been anticipated in Ref. [3] and their inclusion is currently under investigation.

[1] S. Musolino, V.E. Colussi, and S.J.J.M.F. Kokkelmans, arXiv:1904.00908v1 (2019).

[2] C. Eigen, J.A.P. Glidden, R. Lopes, N. Navon, Z. Hadzibabic, and R. P. Smith, Phys, Rev. Lett, 119, 250404 (2017).

[3] V. E. Colussi, S. Musolino, and S.J.J.M.F. Kokkelmans, Phys. Rev. A 98, 051601(R) (2018).

Enhancement of second- and third-order nonlinear processes on metal nanostructures and 2D materials

P 48

Marc Noordam, Javier Hernandez-Rueda, Lars Talsma and Kobus Kuipers
Department of Quantum Nanoscience, TU Delft

Nonlinear processes on a surface are interesting for nanoscale sensing applications and frequency conversion. However, the processes are very weak even while using intense pulsed lasers, thus making practical applications hard to realize. Luckily, there are several ways to enhance these nonlinear processes, using nanostructured surfaces or 2D layered materials. In this work we study the enhancement of second- and third- harmonic generation, sum-frequency generation and four-wave mixing using two femtosecond laser pulses with different frequencies. This enhancement is explored on a nanostructured gold surface and/or a WS2 flake consisting of a different number of layers. For the nanostructures on gold we find enhancement factors of more than three orders of magnitude depending on their geometric parameters. For isolated WS2 flakes, despite being only a few atomic layers thick, we observe various nonlinear optical effects with a higher efficiency than a semi-infinite gold surface.

The IR spectrum of protonated buckminsterfullerene, $C_{60}H^+$

P 49

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We present what is to our knowledge the first experimental IR spectrum of gaseous protonated C_{60}. The spectrum covers the 500 – 1800 cm^{-1} range and was recorded using IR multiple-photon dissociation (IRMPD) spectroscopy employing the FELIX free electron laser and a quadrupole ion trap mass spectrometer with an atmospheric pressure chemical ionization (APCI) source. Our experimental approach allows us to record the spectrum of $C_{60}H^+$ free from any contamination of the isobaric $^{13}C^{12}C_{59}^+$ ion, which is abundant in the mass spectrum.

The significant symmetry lowering of $C_{60}H^+$ as compared to C_{60} yields a rich vibrational spectrum. We analyze this spectrum on the basis of density functional theory (DFT) computed spectra using different methods and basis sets.
We believe that this spectrum is of substantial astrophysical interest, especially in light of the recent detections of C_{60} and C_{60}+ in circumstellar environments, and Harold Kroto's hypothesis that fullerenes are most abundant in their protonated form.

An unbiased view on perovskite quantum dot intermittency by changepoint analysis

P 50

Isabelle Palstra, Ilse Maillette de Buy-Wenniger, Biplab Patra, Erik Garnett, and Femius Koenderink
Center for Nanophotonics, AMOLF, Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam

Many quantum dots show fluorescence intermittency or blinking, i.e., abrupt changes in brightness. A common method to analyze intermittency is by grouping measured time-stamped single-photon detection events into equal-length time bins, and analyzing bin-to-bin variations. However, such grouping of data averages out features and even causes systematic artefacts in e.g. distributions of emitter lifetimes and on/off times. An alternative approach to analyzing intermittency data is with changepoint analysis (CPA). This method uses Bayesian statistics for unbiased detection of jumps without introducing any artificial timescales in the analysis, making it free from artefacts [1,2]. We will present a side-by-side comparison of CPA and traditional binning analysis on numerically generated intermittency data (Monte Carlo simulation of quantum dots) and show that CPA avoids significant errors in on/off times distributions, and the estimation of the number of states between which a dot switches. We use CPA to analyze measured intermittency behavior of CsPbSe3 perovskite quantum dots. These emitters exhibit a host of "grey" states, very different from the on/off behavior of CdSe dots.

EUV spectroscopy on highly charged tin ions in an electron beam ion trap

P 51

J. Scheers[1,2], A. Ryabtsev[3], C. Shah[4], H. Bekker[4], F. Torretti[1,2], J. Sheil[1], J. Berengut[5], W. Ubachs[1,2], R. Hoekstra[1,6], J. R. C. Lopez-Urrutia[4], and O. O. Versolato[1]

[1] *ARCNL*

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[3] *I nstitute of Spectroscopy Moscow*

[4] *Max Planck Institute Heidelberg*

[5] *UNSW Sydney*

[6] *University of Groningen*

Extreme ultraviolet (EUV) light emission from a laser-produced tin plasma is used in state-of-the-art nanolithography. The EUV emission stems from electronic transitions in primarily Sn^{8+} to Sn^{14+} that have complex open 4d-subshells. We present spectroscopy on highly charged tin ions trapped in an Electron Beam Ion Trap (EBIT) located at the Max Planck Institute for Nuclear Physics in Heidelberg. A matrix inversion technique is introduced to obtain charge-state-resolved EBIT spectra. Using the Cowan code, resonant $4p^5$-$4p^44d$ transitions are assigned in Sn^{15+}. Although this ionic state has received little attention in literature, it exhibits strong emission features within the industrially relevant 2% bandwidth around 13.5nm. Collisional-radiative modelling is performed using the Flexible Atomic Code in order to describe anomalous line intensities observed in the EBIT spectra.

High-resolution imaging of controlled molecular collisions using a Zeeman decelerated beam

P 52

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Spectroscopy of Cold Molecules, Radboud University Nijmegen

Molecular scattering experiments are a valuable tool in understanding molecular interactions on the most fundamental level. For these experiments, Stark or Zeeman decelerators can be used to prepare beams of neutral molecules with an electric or magnetic dipole moment, respectively.

In this work a multistage Zeeman decelerator is employed that features a novel design optimized for scattering experiments. It can be used to produce packets of paramagnetic atoms or molecules with a selected mean velocity and a narrow velocity spread, resulting in a well-defined collision energy and energy resolution.

We present the first crossed-beam scattering experiment using a Zeeman decelerated molecular beam. The narrow velocity spreads of our Zeeman decelerated beam (NO molecules) results in high-resolution scattering images, thereby fully resolving quantum diffraction oscillations in the angular distribution for NO-Ne collisions, and product-pair correlations in the radial distribution for NO-O_2 collisions.

Timescale of interactions in a Bose-Einstein condensate of photons

P 53

Marcel Scholten[1], S. Greveling[1], C. Beulenkamp[1,2] and D. van Oosten[1]

[1] *Debye Institute for NanoMaterials Science, Utrecht University*

[2] *Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck*

Bose-Einstein condensation, a thermodynamic phenomenon characterised by a macroscopic occupation of the ground state, is mostly known for atoms. However, it can also be achieved with other bosonic (quasi-)particles, such as exciton-polaritons, magnons and photons. Preliminary experiments indicate that Bose-Einstein condensates of photons are weakly interactive. To gain insight into the mechanism behind these interactions, we investigate their timescale by varying the timescale on which we pump. We scan the duration of the pump pulse from 100 ns to 2500 ns and replace the single pump pulse with a double pulse, varying the time between the pulses over a range from several nanoseconds to several microseconds. In each case, we study the size of the condensate wavefunction as a function of the number of condensate phorons. On this poster we will report on the experimental results and the implications for the interaction mechanism.

High accuracy prediction of the hyperfine coupling constants and the field shifts of tin

P 54

M.L. Reitsma and A.Borschevsky G.J.H. Brussaard[2], O.J. Luiten[1]

Van Swinderen Institute, University of Groningen

The magnetic dipole and electric quadrupole coupling constants for several electronic states of neutral tin were calculated using the relativistic Fock Space Coupled Cluster (FSCC) method[1] in combination with the finite field approach[2]. Field shifts for several transitions were also determined by calculating the transition energy while varying the nuclear charge radius. The effects of different basis sets and model spaces on the results were investigated and used to determine the uncertainty on the final values.

The predicted parameters will be used for extraction of the nuclear properties (magnetic dipole and electric quadrupole moments, and nuclear charge radii) of various tin isotopes from measurements carried out at ISOLDE.

[1] U. Kaldor and E. Eliav, Adv. Quantum Chem. 31, 313 (1998)

[2] H.J. Monkhorst, Int. J. Quantum Chem., 12: 421-432 (1977)

Applying the interaction picture to model Kerr frequency comb generation

P 55

Bas Schuttrups[1,2], Peter van der Slot[1], Bernard Geurts[2], Klaus-Jochen Boller[1]

[1] *Laser Physics and nonlinear Optics,*

[2] *Multiscale Modeling and Simulation, University of Twente*

The Lugiato-Lefever equation (LLE) is often used to model Kerr frequency comb generation and various mathematical techniques have been used to solve this equation. Typically, these techniques use a split-step method that is often supplemented with additional optimization steps. An alternative and promising method is the '4th-order Runge-Kutta method in the Interaction Picture' (RK4IP) [1], which has been successfully used to model supercontinuum generation and various phenomena in Bose-Einstein condensates.
The algorithm is memory efficient and provides fourth-order global accuracy.
We use the RK4IP algorithm as an efficient and robust solver for the LLE. We discuss the implementation and present first modelling results of Kerr frequency comb generation in silicon nitride rings.

[1] B. M. Caradoc-Davies, "Vortex dynamics in Bose–Einstein condensates," Ph.D. dissertation, Univ. Otago, Dunedin, New Zealand, 2000

Small diameter Velocity Map Imaging lens for crossed molecular beam experiments

P 56

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The traditional Eppink-Parker design for Velocity Map Imaging (VMI) works well for single molecular beam experiments such as photodissociation, but for crossed molecular beam experiments such as inelastic or reactive scattering a large diameter (~70 mm) of the traditional lens reduces the molecular beam intensity at the beam crossing point. To make a VMI lens with a much smaller diameter (~ 20 mm), several mini versions of VMI electrodes were constructed using different types of material and tested by imaging O+ fragments from photodissociation of O_2 at 225 nm. First results were encouraging and helped to determine specific points that require further improvements.

Hybrid InP-Si_3N_4 dual-frequency laser for generating high-purity microwave signals

P 57

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The generation of spectrally pure microwave and millimeter wave signals via optical heterodyning is of interest for various applications, e.g., for wireless communication. In particular, semiconductor lasers enable highly integrated and complex microwave photonic devices. However, semiconductor lasers suffer from large intrinsic optical linewidths, typically a few hundreds of kHz [1], due to the short photon lifetime in the cavity and consequently high phase-noise. To address this problem, we propose and demonstrate dual wavelength generation with narrow intrinsic linewidth enabled by a single InP amplifier butt coupled to a long and low loss Si_3N_4 feedback circuit consisting of two tunable, frequency-selective feedback mirrors. We are able to generate narrow beat notes at various microwave frequencies, for instance around 11 GHz. When fitting a Voigt profile, we obtain narrow Gaussian and Lorentzian linewidths as low as 290 kHz and 6 kHz, respectively.

[1] Photon. Res. **2**, B70-B79 (2014)

Towards x-ray free-electron laser oscillators

P 58

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Free-electron lasers generating x-ray wavelengths typically operate in the self-amplified spontaneous emission (SASE) regime. Self-seeding by filtering an SASE pulse and subsequently amplifying the filtered optical pulse can be used to improve the coherence properties of the light produced. To obtain fully coherent optical pulses would require an oscillator configuration. At these wavelengths, single-crystal diamond can be used as a highly reflecting Bragg reflector. Here we consider 6 Bragg reflectors and 2 compound refractive lenses to create a stable ring resonator. To avoid excessive heating of the mirrors, we consider a so-called RAFEL configuration where a large fraction of the light is extracted from the resonator. Wavelength tuning is obtained by rotating the mirrors to change the Bragg condition. Assuming LCLS-II like parameters, we show lasing at 3.05 keV photon energy with substantial output power and high degree of coherence.

Directly measuring the bosonic enhancement of the refractive index in ultra-cold Bose gases

P 59

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The atom-light interaction in dilute (ultra-) cold atom clouds is often described by taking into account only the single atom polarizability. The (complex-valued) refractive index of such a dilute sample is derived by the product of the density and the polarizability of a single-atom. However, for ultra-cold atom samples and cold samples at high densities collective effects have a significant influence on the value of the refractive index [1, 2]. This effect has only been measured indirectly so far [3]. Here, we apply a holographic imaging technique to measure both the real and imaginary part of the refractive index simultaneously, allowing direct measurement of deviations from the single-atom model.

[1] O. Morice, Y. Castin, and J. Dalibard, **Phys. Rev. A** 51, *3896* (1995) (Frans artikel)
[2] M. Naraschewski and R. J. Glauber, **Phys. Rev. A** 59, *4595* (1999) (Glauber)
[3] P.C. Bons, R. de Haas, D. de Jong, A. Groot, and P. van der Straten, **Phys. Rev. Lett.** 116, *173602* (2016)

Quantum dot based source of photonic cluster states

P 60

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Multi-photon entangled states, in particular, loss-resilient graph and cluster states are interesting for use from universal quantum computing to metrology. Lately, it was discovered that even all-optical repeaters might be possible with those. Despite these promises, deterministic production of many-photon cluster states is still an open problem.The workhorse of quantum optics, SPDC, is an intrinsic probabilistic process, so it is very hard to scale beyond the current record of 12-photon entanglement. A deterministic source of multi-photon entangled states would shift a large part of challenges in photon-based quantum information processing into the resource, i.e., the cluster state. We investigate a potential deterministic source of photonic cluster states based on InAs QDs in micropillar cavity working as an efficient single photon source. In principle, using charged-exciton transition such system can directly produce linear cluster states. Here we present experimental results based on a "normal" continuous and pulsed single photon source and linear optical manipulation. We show experimental results, compare to theoretical predictions, and explore limitations regarding achievable rates, stability and interference contrast.

Search for the electron EDM with polyatomic molecules

P 61

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The search for the electron electric dipole moment (eEDM) is an important probe for physics beyond the standard model. The NL-eEDM experiment uses the laser-coolable diatomic molecule barium monofluoride (BaF) to perform this search. It was pointed out in [1] that polyatomic molecules isoelectronic to these laser-coolable diatomic molecules such as BaF, could also be used in the search for the eEDM. These molecules are potentially laser-coolable and their more complicated vibrational structure allows for full polarization and internal co-magnetometry which increases the experimental precision.

In this work we investigate if the triatomic molecule barium monohydroxide (BaOH) can be used in an eEDM experiment, focusing on the production of this molecule in a cryogenic source and on the traveling-wave Stark deceleration.

[1] I. Kozyryev and N. R. Hutzler., *Phys. Rev. Lett.* 119, 13 (2017)

State-to-state controlled collisions approaching the Wigner regime

P 62

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At low energies in molecular scattering, interactions are dominated by the wavelike nature of matter. In this regime, collisions are governed by only a few interfering quantum scattering states, so-called partial waves. At even lower energies, only one type of partial wave dominates the scattering process and cross-sections behave according to Wigner's threshold laws [1]. We investigate the scattering behaviour of the NO-He system in a crossed-molecular beam collision experiment. Reaching collision energies down to 0.3 K, we elucidate partial wave resonances and approach the onset of the Wigner regime. We furthermore develop a new interaction potential at the CCSDT(Q) level. Results show remarkable agreement between experimentally and theoretically obtained resonance behaviour. Our approach allows molecular interactions to be probed at sub-Kelvin temperatures via direct cooling methods and will allow us to connect the fields of physical chemistry and ultracold physics.

[1] E. P. Wigner, Phys. Rev. **73**, 1002 (1948)

Roadmap to Rb-Sr dipolar rovibronic ground-state molecules

P 63

P. Thekkeppatt, L. Reichsöllner, V. Barbé, S. Charpignon, B. Pasquiou, N.J. van Druten, F. Schreck

Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam

Ultracold dipolar molecules offer an ideal platform for investigations in the fields of quantum simulation, precision measurements and quantum chemistry. Thus far, the ultracold polar molecules that have been produced are closed-shell molecules, which limits their range of application. Our goal is to produce RbSr ultracold polar, open-shell molecules, in order to extend the range of possibilities offered by ultracold molecular physics. We present an efficient quantum-engineering approach to the production of RbSr molecules. The first step is the creation of Rb-Sr atom pairs in the ground-state of an optical lattice, starting from quantum-degenerate clouds of ^{87}Rb and ^{84}Sr. The following step is the magneto-association of these atom pairs into weakly-bound molecules, using a magnetic Feshbach resonance that we identified and that should allow efficient molecular association. With this aim, we designed a highly stable power supply for high magnetic fields, in order to achieve efficient adiabatic transfers from the atom pair state to the weakly-bound molecular state. We describe the laser system that we intend to use for the final step of the molecule production, which is the coherent state-transfer to the rovibronic ground-state using STImulated Raman Adiabatic Passage (STIRAP).

A programmable Rydberg quantum simulator

P 64

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In recent years optical tweezers have emerged as a versatile platform for the simulation of quantum systems. In tweezer experiments, atoms are trapped in tightly focused off resonant dipole traps after a pre-cooling stage. Light assisted collisions can then lead to either a single, or no, atom remaining. With the addition of a microscope objective to our strontium quantum gas machine, we have been able to create optical tweezers and observe the first signs of single atoms, which are the initial building block for a programmable quantum simulator. With the addition of a phase-only spatial light modulator and acousto-optic deflector to our setup, we will be able to program the positions of the individual dipole traps as well as sort the remaining atoms into the desired traps. To complete the toolbox of our quantum simulator, Rydberg excitations can be used to engineer state-dependent interactions atoms in neighboring tweezers. This poster will present our progress towards building this programmable Rydberg quantum simulator.

Temporal wavefront shaping for security applications

P 65

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Recently, we applied wavefront shaping techniques to implement quantum-secure readout of a physical unclonable key for authentication [1]. Unfortunately, spatial wavefront shaping is unsuitable for long distance use. We therefore propose to use wavefront shaping in the time domain. We show temporal focusing of a pulse through a complex medium. Furthermore, we investigate a secure communication method based on physical unclonable functions in the time domain. We will report on the progress.

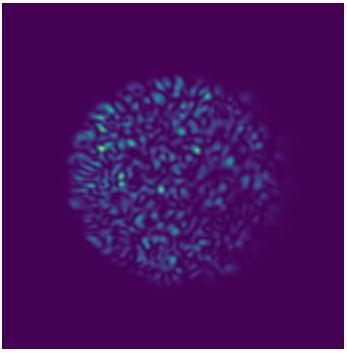


Figure 1: Image of the speckled output from a Ø 105 µm multimode fiber. If the input is an ultrashort pulse, time-domain wavefront shaping can temporally refocus the output in one speckle.

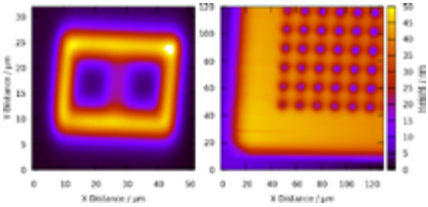
[1] S.A. Goorden *et al*., *Quantum-secure authentication of a physical unclonable key*, Optica 1, 421-424 (2014)

Controlling the transverse flow of light in a high-finesse optical microresonator

P 66

Mario Vretenar, and Jan Klaers
MESA+ Institute for Nanotechnology Complex Photonic Systems (COPS), University of Twente

Controlling the flow of light is a fundamental requirement for photon Bose-Einstein condensate (pBEC) coherent network computers. Such computers should be capable of finding the ground state of spin glass systems significantly faster than conventional computers. This is a well known computationally hard problem to which many other useful computational problems may be mapped. We have implemented a direct laser writing method for the nanostructuring of mirrors, which allow us to control the transverse flow of light in high finesse optical microresonators and thus create pBEC networks with individually adjustable couplings. This permanent nanostructuring method may also be complemented by a reversible method using a thermopolymer for fine tuning and fast reprogramming of the network. We present some of the created structures.



Soft X-ray photofragmentation of gas phase oligonucleotides

P 67

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In many cancer treatments, the antimetabolite drug 5-fluorouracil (5-FU) is used as a chemotherapeutic agent. In combination with radiotherapy, FU acts as a radiosensitizer which enhances the efficacy of ionizing radiation on tumor cells.

Here we explore the potential of FU incorporated in gas-phase protonated oligonucleotides for the investigation of X-ray induced charge and energy migration in these systems.

In a first series of experiments, conducted at the 3rd generation synchrotron BESSY II (Berlin), we have studied the ionization and fragmentation of $[FUAG+H]^+$ stored in a radio frequency ion trap for different photon energies. The fragmentation pattern exhibits a clear dependence on the photoionization site.

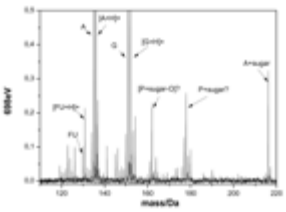

Figure 1: Photofragmentation spectrum of $[FUAG+H]^+$ for the photon energy 698eV.

The reaction mechanism of CO_2 hydrogenation over metal clusters

P 68

Frank J. Wensink, Olga V. Lushchikova, Sandra D. Wiersma, and Joost M. Bakker
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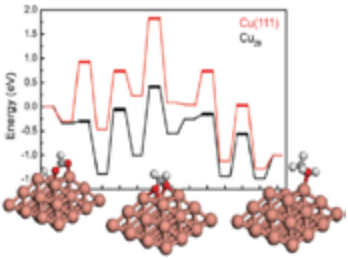
We aim at reducing atmospheric CO_2 levels by recycling it into a fuel, contributing to a circular economy. Current catalysts are able to produce methanol from CO_2 and H_2, but the efficiency of this process is low. Therefore we plan on using clusters, which are nanometer sized metal particles, to mimic the active site in catalysis. Chemical reactions occur in the ion trap, and the reaction mechanism is determined by structure determination of intermediate reaction species. Combination of the intense IR laser FELICE and ICR mass spectrometry allow for this characterization. Modification of the potential energy surface will eventually lead to a more efficient catalyst.

Waugh, *Catal. Today* **15**, 51 (1992)
Yang *et al*., *PCCP* **12**, 9909 (2010)



Probing nuclear size effects with quantum degenerate helium

P 69

Y. van der Werf, R. Jannin, W. Vassen, and K.S.E. Eikema
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High-precision spectroscopy on calculable quantum systems provides stringent tests of atomic structure calculations and possibilities to determine fundamental constants. Spectroscopy of normal atomic and muonic hydrogen can be used to determine the proton size, but it has led to conflicting results. We investigate helium, where the isotope shift between ^{3}He and ^{4}He can be used to extract the alpha and helion particle size difference.

Therefore, we are improving our previous measurement of the isotope shift on the narrow (8 Hz) doubly-forbidden 2 $^3S_1 \rightarrow 2\ ^1S_0$ transition at 1557 nm. We produce a quantum degenerate gas of metastable 2 $^3S_1$ helium, which we trap in a magic-wavelength optical dipole trap at 320 nm, and excite with a highly stabilized spectroscopy laser.

For bosonic ^{4}He we recently determined the transition with 200 Hz accuracy [1]. We are now working to reach a similar precision for fermionic ^{3}He, exhibiting very different quantum-statistical behaviour, to provide the best differential nuclear size measurement to date.

[1] Nat. Phys.14, *1132-1137* (2018)

Characterization of a cryogenic molecular beam source for a sensitive electron-EDM measurement

P 70

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Measurement of an electron-EDM plays a promising role in search for physics beyond Standard Model. We aim to improve the current sensitivity of eEDM measurements using a buffer-gas cooled molecular beam of BaF. A cryogenic source producing intense, cold and slow molecular beams has been constructed in our lab. By virtue of absorption and laser-induced fluorescence signal, we are able to characterize the beam. Currently we produce SrF molecules, but soon we will switch to BaF. Loading this beam into a travelling-wave Stark decelerator will yield much slower (~30 m/s) molecular beams. We will report on recent progress towards this goal.

[1] NL-eEDM is a joint research program of the VSI, the VU Laserlab and Nikhef.

Supercontinuum generation in media with sign-alternated dispersion

P 71

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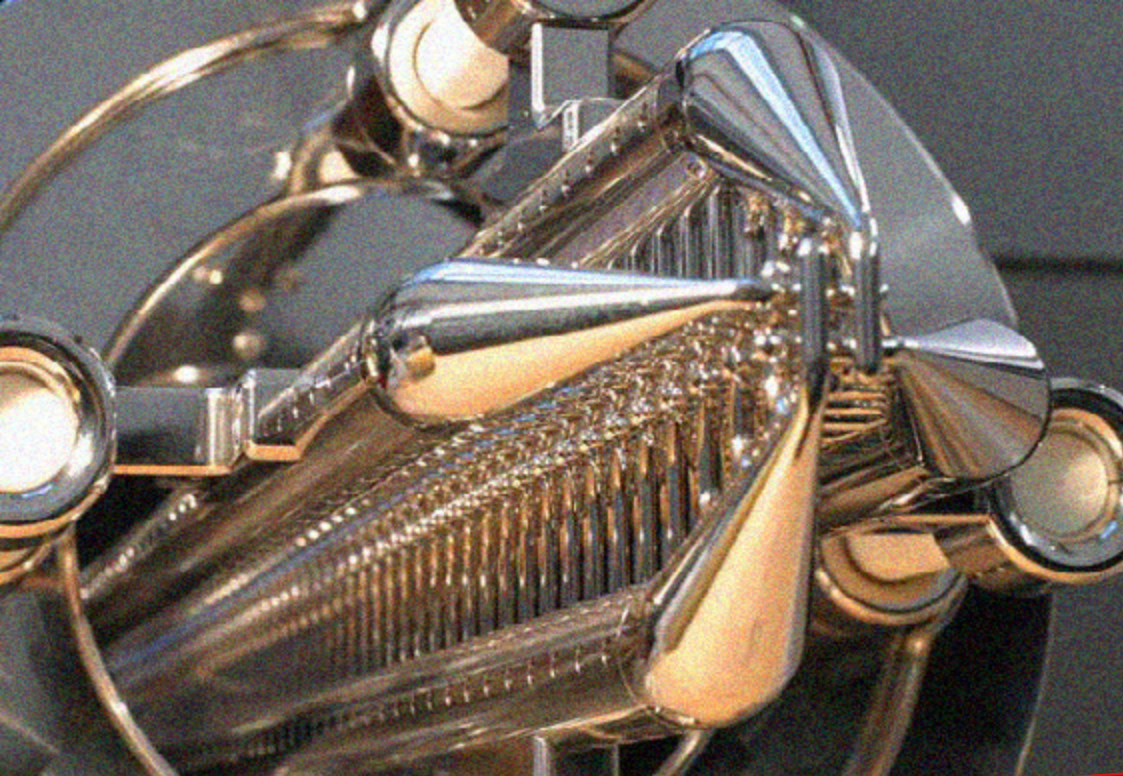
When an ultrafast optical pulse with high intensity is propagating through transparent material a supercontinuum can be coherently generated by self-phase modulation, which is essential to many photonic applications. However, the presence of dispersion causes stagnation of spectral broadening past a certain propagation length, requiring an increased input peak power for further broadening. Overcoming such spectral stagnation will be key to achieve practical integrated supercontinuum devices. We present a concept to drive supercontinuum generation with significantly lower input power. We demonstrate the effect experimentally in dispersion alternating fiber and numerically in integrated photonic waveguides.



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