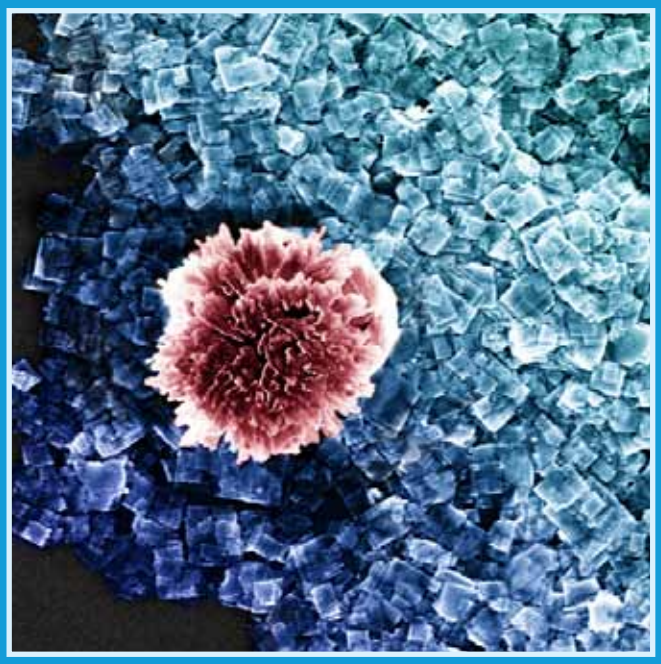
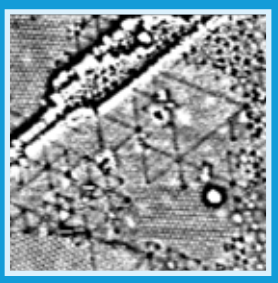
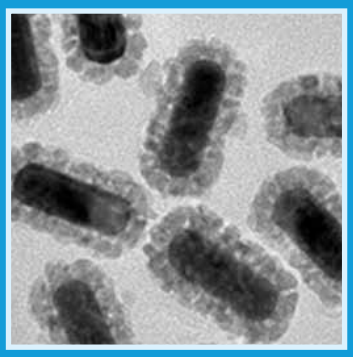
CENTER FOR NANOSCIENCE
ANNUAL REPORT 2015







CeNS
Center for NanoScience | LMU

CONTENTS

CENTER FOR NANOSCIENCE

ANNUAL REPORT 2015

WELCOME

CeNS - the grassroots movement exploring the nanoworld - is coming of age, showing that the nanosciences are not merely a transient hype but are here to stay. A likely reason for this is that at the nanoscale the different disciplines of physics, chemistry, biology, and the medical sciences begin to merge and can thus benefit from the cooperative development of new technologies and concepts as well as from an improving understanding. As this report shows, CeNS is strong and alive, and with the enthusiasm of its members, it will continue to provide a fertile ground for future collaborative endeavors and for new initiatives aiming at excellence.

Seven new members joined our self-assembling network in 2015, bringing it to a total of 106 members along with 268 associates. CeNS also welcomes its newly elected PhD student representatives Isabella Krämer, Ines Trübenbach, and Nicolas Coca Lopez.

"Channels and Bridges to the Nanoworld" – this title of our annual headline conference captured the atmosphere of its unique setting. This year, we again chose the island San Servolo with its breathtaking view of the lagoon of Venice, both as workshop venue and accommodation. In the spirit of CeNS and its focus on interdisciplinary education, the program committee welcomed many of the leading scientists in the diverse fields of the nanosciences.

International exchange is one of the focus points of CeNS and is implemented in a unique format within the Junior Nanotech Network (JNN). In the past year, Tim Liedl arranged the JNN with UC Santa Barbara acting as the partner institution. Within this "Self-Organized PhD Students Exchange Program" eleven participants from both Germany and the United States took part in a mix of lectures and hands-on experimental training developed by student counterparts of the hosting universities.

A key instrument of CeNS both to stimulate and to recognize top level research is its awards. The new CeNS Innovation Award was awarded together with several CeNS spin-off companies including attocube systems, ibidi, Nanion Technologies, and NanoTemper Technologies, in two categories recognizing an outstanding Master's and a PhD thesis in the fields of nanosciences and nanotechnology. The prizes were announced at the CeNS summer party in conjunction with "CeNS meets Industry", our annual event focused on exchange with industry. Eleven CeNS Publication Awards were given in three categories honoring remarkably successful cooperation projects within CeNS, outstanding research of an individual research group of CeNS, and research accomplishments specifically of young scientists. Finally, ten CeNS Travel Awards were given to PhD students that achieved important new results to support the presentation of their work at a scientific conference.

This report contains a compilation of the successful research activities and collaborative efforts within CeNS from the past year. We hope that you enjoy reading about CeNS' progress in 2015.

Finally, we thank the CeNS management team Susanne Hennig (managing director), Katharina Frank (program manager) and Claudia Leonhardt (team assistant) for their great enthusiasm, commitment and continuous support without which none of the above would have been possible. And last but not least, we congratulate Marilena Pinto (program manager, currently on leave) on her daughter.

Prof. Achim Hartschuh
Member of the Scientific Board of CeNS

NEW MEMBERS

PROF. CHASE BROEDERZ

LMU Munich

Professor Chase Broedersz studies the theoretical principles of living matter. The main research topics of the Broedersz group range from the organization of the bacterial chromosome to non-equilibrium dynamics in biological systems, and the mechanics and motility of cells. As an undergraduate Chase Broedersz studied physics at the VU Amsterdam. There, he also obtained a PhD in theoretical physics with Fred MacKintosh, specializing in soft living matter. In 2011 he moved to Princeton University as a Lewis-Sigler Theory Fellow, where he investigated chromosome organization and segregation in bacteria, and non-equilibrium dynamics in biological systems. Since the fall of 2015 he has been leading a group as a W2 professor in theoretical statistical and biological physics at LMU Munich.

DR. HANNA ENGELKE

LMU Munich

Dr. Hanna Engelke studied physics at Bayreuth University and Exeter University. She did her PhD with Joachim Rädler at LMU Munich, working on Fluorescence-Correlation-Spectroscopy and protein-membrane interactions. After graduating in 2010 she joined Jan Liphardt's lab at UC Berkeley where she received micro- and cell biology training, studying mechanical interactions of cells on collagen and nuclear import in cells as well as in *C. elegans*. She returned to LMU Munich in 2013, where she has estabilised her own group in the chemistry department. Hanna Engelke's research focuses on the mechanical interactions of cells and their environment. Her group uses optogenetics, exosomes and nanotechnology to manipulate behavior of cells and their environment to gain a better understanding of their interactions.

DR. BEATRIX FÖRSTER

LMU Munich

Dr. Beatrix Förster is group leader at the Gene Center of the LMU where she develops novel antibody drugs for the treatment of antibiotic resistant bacteria. After graduating from the University of Marburg in biomedical sciences she did her PhD at the MPI of Biochemistry with Axel Ullrich. She helped to found Suppremol, a biotech company that develops drugs for autoimmune diseases, and then moved to Stanford University to do research in the field of allergy and asthma. After returning to Germany she was head of a laboratory developing novel anti-cancer drugs at TRION Research GmbH. Prior to becoming a group leader at LMU she worked as a project manager for clinical and translational projects at the Helmholtz Zentrum München.

PD DR. JAN MINÁR

LMU Munich

Dr. Jan Minár carries out research on theoretical solid state physics. His research interests focus on the theoretical description of the electronic and magnetic structure of ordered and disordered solids, surfaces and nanostructures, based on density functional theory, as well as on various spectroscopical properties of

solid materials. After his studies in physical chemistry at the Technical University of Bratislava, he worked with Hubert Ebert and completed his PhD at LMU Munich in 2003. After a postdoctoral stay at the Forschungszentrum Jülich he moved back to LMU, where he started his habilitation in 2008. Since 2014 he has been a visiting professor at the West-Bohemian University in Pilsen. In 2015 he received a guest professorship in physics at the University of Cergy-Pontoise, Paris.

PROF. MATTHIAS PUNK

LMU Munich

Professor Matthias Punk studied physics in Innsbruck before moving to TU Munich to pursue a PhD in theoretical physics in the group of Wilhelm Zwerger, where he graduated in 2010 with a thesis on many-particle physics with ultracold quantum gases. He stayed at TU Munich for another year as a postdoc before moving to Harvard University in 2011, where he worked on strongly correlated electron systems in the group of Subir Sachdev. In 2013 he returned to Innsbruck and joined Peter Zoller's group at the Institute for Quantum Optics and Quantum Information. Since April 2015 Matthias Punk has been an assistant professor for theoretical solid state physics at LMU Munich, where he is continuing his work on correlated quantum systems, with an emphasis on cuprate superconductors and exotic states of matter in frustrated quantum magnets.

DR. ALEXANDER URBAN

LMU Munich

Dr. Alexander Urban studied physics at the University of Karlsruhe (TH) and at Heriot-Watt University in Edinburgh, Scotland. He obtained his PhD in 2010 from LMU Munich at the Chair for Photonics and Optoelectronics of Jochen Feldmann working on optothermal manipulation of phospholipid membranes and optical printing. In 2011 Alexander Urban joined the Laboratory for Nanophotonics (LANP) at Rice University, Houston, USA, as a postdoctoral researcher, working with Naomi Halas. In 2014 he returned to the Chair for Photonics and Optoelectronics at LMU Munich as a group leader. His current research interests are still plasmonics, but also novel, exciting light-emitting nanoparticles, such as carbon dots and organic/inorganic perovskite nanocrystals. His group uses optical spectroscopy to investigate the fundamental properties of nanocrystals, and learn how to exploit them for applications ranging from photodetectors and solar cells to LEDs and lasers.

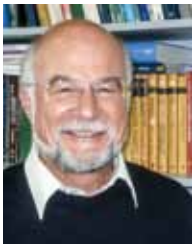
PROF. THOMAS WEITZ

LMU Munich

Prof. Thomas Weitz studied physics and electrical engineering at the University of Kaiserslautern and the University of Heidelberg. He performed his PhD work in the group of Klaus Kern at the Max Planck Institute for Solid State Research in Stuttgart and was awarded a PhD by the Ecole Polytechnique Fédérale de Lausanne in 2008. After a postdoctoral period in Klaus Kern's group, Thomas Weitz joined Amir Yacoby's research group at the Department of Physics at Harvard University as a postdoctoral candidate on a Feodor Lynen Research Fellowship in 2009. In 2010, he moved back to Stuttgart for a postdoc position in Klaus von Klitzing's lab. From 2011 to 2015, Thomas Weitz was a laboratory head at BASF SE Ludwigshafen, working on projects on organic electronics. In December 2015, he was appointed as a W2 professor at the Faculty of Physics (LMU).

MEMBERS' NEWS

AWARDS



Prof. Christoph Bräuchle (LMU) received the Walther-Nernst-Denkmünze from the Deutsche Bunsengesellschaft.

Prof. Dieter Braun (LMU) **and Judith Egger** won the art prize ""zwei:eins" for their work on the paradoxical search for the origins of life.

Prof. Hendrik Dietz (TUM) was awarded the Gottfried Wilhelm Leibniz Preis 2015 by the Deutsche Forschungsgemeinschaft.

Dr. Beatrix Förster (LMU) was nominated for the concept stage of the Science4Life Businessplanwettbewerb.

Dr. Ralf Jungmann (LMU & MPI for Biochemistry) received an ERC Starting Grant for his project "MolMap - From Tissues to Single Molecules: High Content in Situ Super-Resolution imaging with DNA-PAINT".

Dr. Michael Nash (LMU) received a Young Investigator Grant 2015 from the Human Frontier Science Program (HFSP).

Prof. Fritz Simmel (TUM) was awarded an ERC Advanced Grant for his project "AEDNA - Amorphous and Evolutionary DNA Nanotechnology".

Prof. Dirk Trauner (LMU) became a Morris S. Kharasch Visiting Professor at the University of Chicago and was awarded the Novartis Chemistry Lectureship 2014/2015.

Prof. Ernst Wagner (LMU) was promoted to Editor-in-Chief of The Journal of Gene Medicine (starting in 2016).

Prof. Joost Wintterlin (LMU) was awarded the "Preis für Gute Lehre" by the student representation of the Faculty of Chemistry and Pharmacy.

SPIN-OFF NEWS

CALLS & APPOINTMENTS

PD Dr. Markus Lackinger (Deutsches Museum) was appointed as an "Außerplanmäßiger" Professor at LMU Munich.

Dr. Michael Nash (LMU) accepted an offer as Tenure-Track Assistant Professor at the University of Basel, Department of Chemistry with joint affiliation at the ETH-Zürich Department of Biosystems Science and Engineering (located in Basel), associated with the Swiss National Research Center for Molecular Systems Engineering.

ATTOCUBE SYSTEMS

Attocube's FPS3010, an ultra-precise interferometric displacement measurement and analysis system, was rated 'BEST OF' product in 2015 by the Industry Award 'BEST OF'. The Industry Award honors products which stand out in terms of their economic, social, technological, and ecological values.

- www.attocube.com

ETHRIS

In March 2015 Ethris moved to a brand new building in Planegg. The facility offers 1500 m^2 lab and office space for more than 50 employees. The relocation allowed the labs and offices to be designed specifically according to the needs of Ethris' growing workforce in R&D and administration.

- www.ethris.com

GNA BIOSOLUTIONS

GNA Biosolutions, a manufacturer of ultrafast pathogen diagnostic instruments, received fresh capital of € 6 million in a series B financing round. The new investors are Robert Bosch Venture Capital (RBVC), SHS Gesellschaft für Beteiligungsmanagement GmbH, b-to-v Partners, and UnternehmerTUM-Fonds. GNA is using the funds from this financing round to bring its first product, the Pharos400 instrument, to market maturity.

- www.gna-bio.de

NANOTEMPER TECHNOLOGIES

In 2015, NanoTemper Technologies continued its rapid global expansion by opening four new subsidiaries in Boston, Cambridge, Bangalore and Krakow. The company currently employs more than 100 people at its headquarters in Munich and its seven subsidiaries.

- www.nanotemper.de

FROM FUNDAMENTAL RESEARCH TO APPLICATION: CENS INNOVATION AWARD 2015

On July 17, the CeNS Innovation Award was awarded at the Center for NanoScience for the first time. One PhD student and one master's student received the award for their innovative work in application-oriented nanoscience. The awardees were selected by a top-class jury, including Prof. Dr. Krubasik, president of the DPG, Prof. Khaled Karrai, scientific director of attocube systems, and members from LMU, TUM, and the University of Augsburg.

While most scientific prices emphasize findings and results in fundamental research only, the CeNS Innovation Award attaches importance to future applicability. The prize money is donated by four successful spin-offs of CeNS, all with their own company history directly connected to the idea of the award. The companies attocube systems AG, ibidi GmbH, Nanion Technologies GmbH and NanoTemper Technologies GmbH, together with CeNS, honored gifted and creative junior researchers, whose results are not only interesting for fundamental research but also promising for technological applications.

Aurora Manzi from the group of Professor Jochen Feldmann (LMU) received an award worth €3,000 in the "Master's thesis" category. In her thesis, Aurora Manzi explored, in cooperation with GE Global Research, the use of solar energy as an alternative to fossil fuels. The idea behind her master's thesis was to create a photocatalytic system able to recycle CO_2 and to transform it, from an undesired waste, into a valuable energy source, e.g. methane, by using solar energy to drive the uphill CO_2 reduction reaction. Aurora Manzi discovered a novel light-induced technique to convert under unrestrictive conditions a material prepared in an easy and well-defined way, such as cadmium sulfide nanorods, into copper sulfide nanorods, whose properties are suitable for in situ CO_2 reduction. Performing photocatalytic experiments, she demonstrated that the copper sulfide nanorods formed can be used as an efficient catalyst for CO_2 reduction to carbon monoxide and methane under broad visible light illumination. Aurora Manzi, who originally comes from Italy, is currently continuing her academic career as a PhD student in Professor Feldmann's group.

Prof. Tim Liedl (member of the CeNS board) and Prof. Khaled Karrai (scientific director attocube systems) presenting the CeNS Innovation Award to Aurora Manzi.

Prof. Khaled Karrai (scientific director attocube systems) presenting the CeNS Innovation Award in the category "PhD thesis" to Dr. Christof Mast.

In the "PhD thesis" category, the jury awarded the prize worth €6,000 to Dr. Christof Mast from the group of Professor Dieter Braun (LMU). In his PhD work Dr. Mast demonstrated how a reversible elongation process can be enhanced with the help of a thermal gradient. He also showed that a thermal trap is able to trigger a polymerase-driven, exponential replication of DNA via the cyclic fluid convection between the hot and cold boundaries of the reaction vessel. During the replication process, the product is concentrated in the center of the thermal trap and therefore protected against diffusion into the diluted reservoir. This new technique could be used for different applications. Firstly, in many applications, there is often just a little amount of solution available. The thermal trap could permit low-volume, fast, continuous and high S/N replication of DNA/RNA. Secondly, it could be used to set up the selective properties of an aptamer-creating machine. Aptamers are small ssDNA strands that are evolved to bind to a specific target. They are frequently used in biotechnological and therapeutic applications due to their specific chemical recognition ability.

■ www.cens.de/research/cens-innovation-award

CENS PUBLICATION AWARDS 2015

On November 27, the winners of the 2015 CeNS Publication Awards were announced to the CeNS members during a celebratory event. This award recognized remarkably successful cooperation projects within CeNS as well as outstanding research by individual research groups from CeNS (see page 49 ff. for the winning publications).

"Best Interdisciplinary Publications":
Tim Liedl and Aleander Högele
Erwin Frey and Andreas Bausch
Dirk Trauner, Achim Hartschuh and Thomas Bein
Ernst Wagner and Christoph Bräuchle

"Scientific Breakthroughs":
Bettina Lotsch
Erwin Frey
Dieter Braun
Achim Wixforth and Hubert Krenner

"Best Junior Scientist Publications":
Diana Pippig
Michael Nash
Jessica Rodríguez-Fernández

■ www.cens.de/research/cens-publication-award

Dr. Habeeb Muhammed Madathumpady Abubaker and Dr. Jessica Rodríguez-Fernández (here with CeNS board members Prof. Achim Hartschuh and Prof. Claudia Veigel) were among the winners in the category "Best Junior Scientist Publication" with a publication in JACS.

EVENTS & ACTIVITIES

FOCUS WORKSHOPS

In 2015, CeNS supported three workshops co-organized by CeNS members. One highlight was the **6th Workshop on Nanotube Optics and Nanospectroscopy (WONTON) 2015**, which took place from June 1-4 at Kloster Banz in Upper Franconia. The workshop was jointly organized by Tobias Hertel (Julius-Maximilians University Würzburg) and CeNS members Achim Hartschuh and Alexander Högele (both LMU) and focused on the latest experimental and theoretical developments in the field of carbon nanotube spectroscopy and nanooptics. The meeting brought together young and experienced researchers to facilitate discussion of the most current research on these intriguing two-, one-, or zero-dimensional materials.

Two more workshops took place at the ICTP in Trieste. The **Workshop on Interacting Fermions: Precision Theory and Experiment** from July 6 - 10, co-organized by CeNS spokesman Ulrich Schollwöck, addressed recent theoretical and experimental developments in interacting/disordered fermionic and spin systems with special emphasis on results and techniques which have controlled accuracy.

The **Conference on Frontiers of Nanoscience** from August 24 - September 1, co-organized by Jan von Delft, brought together internationally renowned experts and researchers to address the most topical experimental and theoretical issues in the field of nanoelectronics.

■ www.cens.de/calendar/past-workshops-events

CENS WORKSHOP VENICE 2015

The title of the CeNS workshop 2015 "Channels and Bridges to the Nanoworld" spoke for itself: twenty-five talks over five days combined various aspects of nanoscience with the magical atmosphere of San Servolo and Venice. The program committee, Jochen Feldmann, Jan Lipfert, Christian Ochsenfeld, Friedrich Simmel, and Dirk Trauner, had invited renowned international scientists to give the graduate students and postdoctoral researchers of CeNS an overview of current research topics on nanometer-scale science. These included single molecule spectroscopy, cryo-EM techniques, biomolecular design, organic electronics, carbon nanostructures, and nanoparticles with different applications. In addition, CeNS Innovation Award winner Aurora Manzi presented her research.

The evenings were dedicated to exploring late summer Venice with its charming piazzas, restaurants, canals, and bridges.

■ www.cens.de/calendar/past-workshops-events/venice-2015

CENS MEETS INDUSTRY

The event "CeNS meets Industry" has a long tradition but is renewed annually by speakers from very different branches of industry. No matter where they work now, they all share a background in physics or chemistry, often as CeNS alumni. Dr. Eike Friedrich's talk shed light on the activities of OSRAM, one of the two leading light manufacturers in the world. Former CeNS member Dr. Stefan Thalhammer presented R&D work at HEIDENHAIN GmbH, a manufacturer of measurement and control technology. A classical consulting firm (McKinsey) was presented by two IDK alumni, Dr. Dorothea Schupp and Dr. Stephan Heucke. Henrik Klagges gave fascinating insights into starting his own company TNG Technology Consulting. The company today employs many physicists, including quite a few CeNS alumni. Last but not least, Dr. Daniel Aydin spoke about strategic development by identifying and developing corporate growth fields at BASF.
The CeNS summer party that followed deserved its name, and the Salinenhof at LMU was the perfect setting for a barbecue on a hot summer evening, where the guests were able to chat, relax, or simply enjoy the music by the CeNS band "UnCeNSiert".

■ www.cens.de/calendar/past-workshops-events/cens-meets-industry-2015/

ORIGIN OF LIFE MUNICH (OLIM)

To promote an interdisciplinary approach to the experimental study of the origin of life, scientists around CeNS have decided to form a new research network: the Origin of Life Initiative Munich (OLIM). OLIM was inaugurated on the occasion of a lecture by the renowned prebiotic chemist John Sutherland (MRC Laboratory of Molecular Biology, Cambridge) on July 3, 2015. The aim of the network is to discover experimentally verifiable facts that shed light on the question of how molecules could autonomously evolve into living systems. The network will be based at LMU, but will maintain close links with groups at the Technical University Munich and the Max Planck Institutes for Astronomy and Biochemistry. Modern Origin of Life research draws on insights from the fields of astronomy, geology, chemistry, physics, and - last but not least - biology.

■ www.biosystems.physik.lmu.de/olim/index.html

MÜNCHNER INDUSTRIEGESPRÄCHE

The Munich Industry Talks (Münchner Industriegespräche) of the German Physical Society (DPG) are an event series jointly organized by the Arbeitskreis Industrie und Wirtschaft (AIW) of the DPG, a platform for physicists and physics in industry and economy, and the Center for NanoScience.
The Industry Talks bring together physicists from industry and academia. The overall goal is to establish a regional forum for physicists to exchange experiences, covering topics on the interface between fundamental research and industrial applications. Physicists who are on the verge of finishing their PhD get insights into career options for physicists in industry; physicists from industry can learn about research and development activities in industry as well as in academia.
The talks in 2015 included two CeNS spin-offs, presented by Dr. Bernd Irmer, CEO of nanotools, and Dr. Federico Bürsgens, managing director of GNA biosolutions. A further highlight was the talk by Professor Joachim Rädler, who spoke about the success story of CeNS, emphasizing the successful knowledge transfer between academia and industry.

Dr. Valentin Kahl, ibidi GmbH

■ www.dpg-physik.de/dpg/gliederung/ak/aiw/industriegespraeche/muenchen

CENS ASSO-CIATES

JUNIOR NANOTECH NETWORK

PhD students from CeNS teamed up with their peers from UCSB for the 2015 round of the Junior Nanotech Network (JNN) "Nanostructures and biomaterials: macromolecular bridges between physics and biology". In May, eleven graduate students from Santa Barbara were the hosts for eleven CeNS students, and in September the German group hosted the UCSB students for a visit to Munich.

A central part of the first JNN session in Santa Barbara was dedicated to laboratory work. Over two weeks, the visiting students could choose between various modules that were organized and taught by the UCSB students. The tutorials focused on hands-on work so that the guest students could fabricate and measure their own samples and extend their technical skills. The two-day projects also provided plenty of time for detailed technical discussions as well as the interpretation of the results obtained. In addition to the hands-on modules, the students, the UCSB faculty, and invited speakers presented their research during a four-day symposium. Besides sharing a common interest in science, the students connected very well on a personal level from the first day and spent most of their free time together enjoying various activities – a wine tasting trip to the Santa Ynez valley, hiking in the beautiful Channel Islands National Park, and an exciting weekend trip to San Diego.

During the second part of the JNN, eleven UCSB students visited CeNS, doing lab rotations and

performing hands-on experiments in the labs on topics such as inelastic light scattering on 2D semiconductor materials, DNA origami scaffold preparation, or surface-mediated synthesis of 2D organic networks. Another highlight was the CeNS workshop "Channels and Bridges to the Nano-world" on the beautiful island of San Servolo (see page 12), where the JNN participants presented their projects in two poster sessions. After their return to Munich, the students continued with lab rotations at LMU, TUM, MPI for Biochemistry, Deutsches Museum, or the University of Augsburg. Excursions to the Center for Virtual Reality at the Leibniz Rechenzentrum, the Research Neutron Source in Garching, and the Physics Department at the University of Augsburg complemented the program. The Californian students also enjoyed barbecues with CeNS PhD students and PIs, the Oktoberfest's vivid atmosphere, a hiking weekend in the Alps, and a dinner in a typical Bavarian restaurant. Strong ties between German and Californian students were established not only by these activities but also by the unusual housing concept, since private accommodation for all guests was provided by the host students.

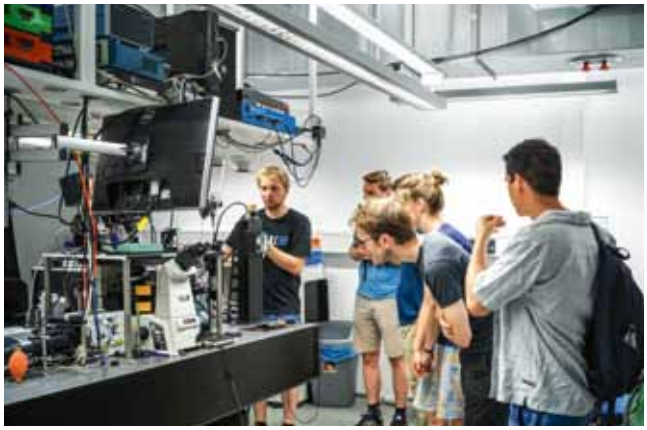
The 2015 JNN was a true scientific and social success for all participants and will certainly help to deepen existing collaborations and to establish new co-operations between CeNS Munich and UC Santa Barbara.

■ www.cens.de/international/exchange-programs/jnn/

CENS LAB TOURS

To foster interactions within CeNS, the successful CeNS lab tours were continued in 2015. The first tour in February was devoted to the LMU physics department. After a joint lunch prepared by the CeNS management, the students were guided through the labs by peer PhD students and learned about research and infrastructures in the labs of Prof. Feldmann, Prof. Gaub, Prof. Lipfert and Dr. Nickel. The second tour took place at the MPI for Biochemistry in July and raised a lot of interest. The labs involved were those of Petra Schwille, Ralf Jungmann, and Carsten Grashoff. The tour was followed by a student-organized barbecue on the MPI campus. Both lab tours were a perfect way to meet new people and to discuss new ideas within CeNS.

- www.cens.de/young-academics



KEY QUALIFICATION WORKSHOPS

Successful and effective publishing is crucial for success in science, so writing skills and the ability to produce scientific illustrations are important for all PhD students. This was reflected by two key qualification workshops organized by CeNS in 2015: "Optimizing writing strategies for getting published in English" and "Adobe Illustrator for scientific illustrations". Both workshops were very popular among the CeNS students.

- www.cens.de/calendar/past-workshops-events

SCIENCE ROCKS!

Since 2010, the CeNS associates have organized regular informal seminars where PhD students present their research topic in an unconventional way. The 2015 talks included "The best way to eat spaghetti or: An analogy to reptation of semiflexible polymers" and "Why one misfit spoils the whole cell party". Before and after the talks, the students have the chance to meet other PhD students, make new acquaintances from other groups, and discuss nanosciences. The event is an ongoing success, entirely managed by PhD students.

- www.cens.de/calendar/science-rocks

CENS STUDENT REPRESENTATIVES

For the third time, three CeNS student representatives were elected by the CeNS associates in an online election: Dian-Jang Lee (pharmacy department), Luisa Kneer, and Franziska Kriegel (both from the physics department). They initiated new formats like a company visit at Roche and continued student-related events such as the lab tours (see above), the Welcome Event for new students or the well-established "Science in a nutshell". We thank Franziska, Luisa and Dian-Jang for their commitment.

- www.cens.de/young-academics

From left to right: CeNS student representatives 2015 Dian-Jang Lee, Luisa Kneer, and Franziska Kriegel

CENS TRAVEL AWARDS

In 2015, ten CeNS PhD students won a CeNS Travel Award of up to €1,500 to present their research at international conferences and workshops:

Fatma Meltem Aygüler (AG Prof. Thomas Bein)
Talk at the E-MRS 2015 Fall Meeting, Warschau

Fabian Baumann (AG Prof. Hermann Gaub)
Poster at the Biophysical Society 60th Annual Meeting, Los Angeles

Alesja Ivanova (AG Prof. Thomas Bein)
Talk at 2015 MRS Spring Meeting, San Francisco

Dian-Jang Lee (AG Prof. Ernst Wagner)
Talk at the 2015 American Association of Pharmaceutical Scientists (AAPS) Annual Meeting, Orlando

Klara Malinowska (AG Prof. Hermann Gaub)
Talk at the Gordon Research Conference & Seminar on "Cellulosomes, Cellulases & Other Carbohydrate Modifying Enzymes", USA

Peter Röttgermann (AG Prof. Joachim Rädler)
Poster at the Biophysical Society 59th Annual Meeting, Baltimore

Eva-Maria Roller (AG Prof. Tim Liedl)
Poster at the "Metamaterials'2015 - Advanced Electromagnetic Materials in Microwaves & Optics" conference, Oxford

Katharina Schwinghammer (AG Prof. Bettina Lotsch)
Talk and Poster at the 1st International Solar Fuels Conference 2015, Uppsala

Tobias Verdorfer (AG Prof. Hermann Gaub)
Poster at the Biophysical Society 60th Annual Meeting, Los Angele

Fabian Wehnekamp (AG Prof. Don Lamb)
Poster and Poster Talk at the Biophysical Society 59th Annual Meeting, Baltimore

■ www.cens.de/research/cens-travel-award


SELECTED
RESEARCH
PROJECTS

SELECTED RESEARCH PROJECTS

1 **C. Bräuchle, D.C. Lamb:** It all happens in the neck – new insights into HIV-1 membrane scission

2 **C. Bräuchle, E. Wagner:** Quantification of receptor targeting under flow conditions

3 **E. Frey:** Quantifying protein diffusion and capture on filaments

4 **C. Grashoff, M. Rief:** Extracellular rigidity sensing by talin isoform-specific mechanical linkages

5 **M.A. Nash, D.A. Pippig and H.E. Gaub:** Strong and precise hands on single molecules

6 **A. Hartschuh:** Femtosecond laser pulse shaping microscopy on graphene

7 **D. Braun:** Continuous replication and selection towards increasing length by a heat flux across an open pore

8 **M. Lackinger, W.M. Heckl:** Post-synthetic decoupling of on-surface synthesized covalent nanostructures

9 **E. Frey:** Evolutionary games of condensates in coupled birth–death processes

10 **T. Liedl, A. Högele:** Self-assembly of fluorescent nanodiamonds on DNA origami

11 **P. Schwille:** Reconstitution of protein gradient oscillations in artificial membrane compartments

12 **J. Rodríguez-Fernández:** Hierarchical nanoparticle clusters: bringing together NIR plasmonic metals and NIR plasmonic semiconductors

13 **J. Lipfert:** Biological magnetometry: torque on superparamagnetic beads in magnetic fields

14 **E. Frey, J. Rädler:** Emergence and persistence of collective cell migration on small circular micropatterns

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19 **B.V. Lotsch, C. Ochsenfeld:** A tunable azine covalent organic framework platform for visible light-induced hydrogen generation

20 **J. Polleux:** Fabrication of plasmonic nanoparticle arrays for light-assisted chemical synthesis and cellular manipulation

21 **O. Lieleg:** Modulating mucin hydration and lubrication by deglycosilation and polyethylene glycol binding

22 **R. Metzler:** Enzymatic reactions and response times in bacterial gene regulation at low concentrations

23 **D.C. Lamb:** Early steps in the assembly of HIV

24 **D.C. Lamb:** The biophysics of Actin

25 **R. Metzler:** Search times of transcription factors for their binding site on DNA with real sequence

26 **T. Liedl, E. Frey:** Magnetic propulsion of microswimmers with DNA-based flagellar bundles

27 **T. Bein, B. Nickel:** A highly-ordered 3D covalent fullerene framework

28 **T. Bein, C. Bräuchle, E. Wagner:** Multifunctional polymer-capped mesoporous silica nanoparticles for pH-responsive targeted drug delivery

29 **T. Bein:** Room temperature synthesis of covalent–organic framework films through vapor-assisted conversion

30 **T. Bein:** Stabilization of the trigonal high-temperature phase of formamidinium lead iodide

1

IT ALL HAPPENS IN THE NECK – NEW INSIGHTS INTO HIV-1 MEMBRANE SCISSION

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The main structural protein Gag of HIV-1 traffics to the host cell membrane to form a virus shell around its RNA-genome. In late stages of virus assembly HIV-1 recruits in a consecutive manner the cellular endosomal sorting complex required for transport (ESCRT) machinery to drive membrane scission and virus release. The actual membrane constriction and fission mechanism however remained unclear and whether membrane fission was driven from inside the HIV-1 budding neck, by narrowing the membrane form the outside by large lattices surrounding the neck or from within the bud could not be fully answered. The group of Prof. D.C. Lamb and Prof. C. Bräuchle approached this important question in virology by super-resolution fluorescence microscopy of ESCRT components Tsg101, ALIX, CHMP4B and CHMP2A in virus infected cells to resolve the size and the structure of ESCRT complexes during HIV-1 budding below the diffraction limit. They deliberately employed antibody labelling of endogenous or HA-tagged ESCRT proteins to avoid any artefacts from overexpression of large fluorescent protein fusions, which are normally used in PALM imaging. All colocalizing ESCRT clusters exhibited closed, circular structures with an average size (full-width at half-maximum) between 45 and 60 nm or a diameter (determined using a Ripley's L-function analysis) of roughly 60 to 100 nm. The size distributions for colocalizing clusters were narrower than for non-colocalizing clusters, and significantly smaller than the HIV-1 bud at the membrane. In the case of ALIX, a cloud of individual molecules surrounding the central clusters was often observed, which we attribute to ALIX molecules incorporated into the nascent HIV-1 Gag shell. HIV-1 membrane scission is thus driven by ESCRT protein assemblies inside a confined structure, such as the bud neck, rather than by large lattices around the neck or in the bud lumen.

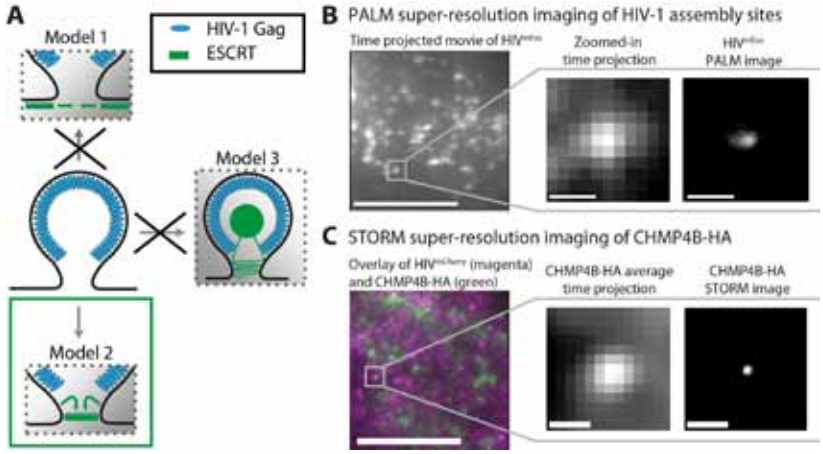

Figure 1. High-resolution imaging of ESCRT proteins at HIV-1 assembly sites to elucidate the membrane scission mechanism in HIV-1 budding. **A** Scheme of the main models for membrane scission driven by protein assemblies either surrounding the neck (model 1), forming within the neck (model 2) or inside the bud (model 3). **B** PALM super-resolution imaging of HIV-1 assembly sites. **C** STORM super-resolution imaging of CHMP4-HA protein assemblies colocalizing with individual HIV-1 assembly sites, both right panels show a time-projection of the whole movie, scale bar 2 µm, a zoom into one single assembly site and a reconstructed high-resolution image, scale bars 500 nm.

■ **J. Prescher, V. Baumgärtel, S. Ivanchenko, A.A. Torrano, C. Bräuchle, B. Müller, D.C. Lamb:** *Super-Resolution Imaging of ESCRT-proteins at HIV-1 Assembly Sites;* PLoS Pathogens, DOI 10.1371/journal.ppat.1004677 (2015)

2

QUANTIFICATION OF RECEPTOR TARGETING UNDER FLOW CONDITIONS

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Selective cellular binding of drug and gene delivery systems and their specific uptake are crucial for their efficiency. Experiments to assess their specific binding capacity *in vitro* are usually performed as cell culture assays under static conditions. In this work, a novel microfluidic technique was developed with which cellular binding of nanoparticles was quantified for the first time under flow conditions. This approach enables reduced sedimentation and diminished static interactions of the nanoparticles, highlighting the interactions of high affinity like receptor-ligand binding. Certain tumor cells have high copies of such specific receptors on their surface presenting a good target for tumor therapy. By coupling suitable targeting ligands on the surface of nanoparticles the binding to such receptors is mediated. Using the microfluidic setup, we tested the effect of two short peptides on the binding to target cells. One peptide addresses the tyrosine kinase c-Met/HGF receptor and the other the transferrin receptor (TfR). The c-Met binding peptide cMBP2 was found to enhance the binding to target cells specifically whereas the peptide B6 (TfR targeting) promoted cellular binding due to unspecific interactions such as electrostatic attraction. The authors showed that the method is a powerful tool to select adequate targeting ligands on nanoparticles and hence improve the development of delivery systems.

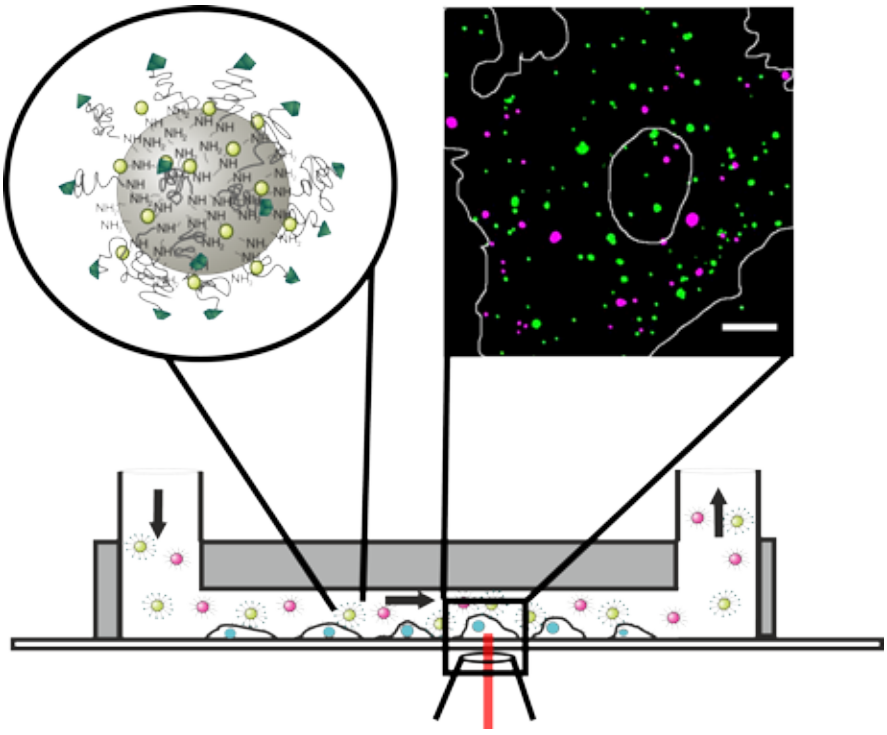

Figure 1. Schematic drawing of a receptor targeting experiment under flow conditions: Model nanoparticles with ligand (green) and differently labeled, internal control particles (magenta) are passed over a target cell monolayer. In case of successful targeting, nanoparticles with ligand bound in higher amounts to the cells than control nanoparticles.

■ **E. Broda, F. Mickler, U. Lächelt, S. Morys, E. Wagner, C. Bräuchle:** *Assessing potential peptide targeting ligands by quantification of cellular adhesion of model nanoparticles under flow conditions;* J Controlled Release 213, 79 (2015)*

* CeNS Publication Award 2015

3

QUANTIFYING PROTEIN DIFFUSION AND CAPTURE ON FILAMENTS

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The functional relevance of regulating proteins is often restricted to specific binding sites such as the ends of microtubules or actin-filaments. An efficient localization of proteins on these functional sites is of great importance. In this respect, recent experimental studies suggested that several key players involved in regulation of microtubules and actin-filaments utilize a one-dimensional diffusive motion on the filament to target the functional end. For microtubules, it has been suggested experimentally that diffusive motion along the filament strongly enhances the protein's end-binding efficiency as a prerequisite for catalytic regulatory functions [1]. Since this pioneering work many *in-vitro* experiments suggested that a broad class of plus-end binding proteins for microtubules undergoes diffusive motion along the filament before binding to the functional end (the "diffusion and capture mechanism"). However, since a thorough theoretical description is missing, a comprehensive understanding how diffusion on these filaments enhances tip-binding has remained elusive. In our manuscript we achieve such a theoretical description and provide a simple – yet fully quantitative – analysis of the process.

Our theory explains how and why end-association due to diffusion and capture is highly efficient as compared to direct tip-binding from solution alone. As a consequence, diffusion and capture substantially enhances the reaction velocity of enzymatic reactions, where proteins and filament ends are to each other as enzyme and substrate. We show that the ensuing reaction velocity can effectively be computed within an effective Michaelis-Menten framework. This approach considerably reduces the complexity of the mathematical problem. Further, the effective theory is completely quantitative in that it depends solely on experimentally accessible parameters.

For typical microtubule-associated proteins our theory predicts that the dissociation constant is reduced by several orders of magnitude with respect to the standard value in absence of diffusion along microtubules. Our theory allows us to rank the contribution of filament diffusion to end-binding quantitatively for many different microtubule- and actin-associated proteins. We predict that diffusion and capture significantly beats the diffusion limit for the rate of direct protein association for practically all proteins diffusing on microtubules and actin-filaments.

The generality and simplicity of our result makes it easily applicable in different fields of research where diffusion on one- dimensional substrates plays a role. This is not restricted to cytoskeletal filaments in cell biology but may well be applicable in genetics where diffusive motion of transcription factors along DNA is a well documented fact.

■ **E. Reithmann, L. Reese, E. Frey:** *Quantifying protein diffusion and capture on filaments;* Biophys. J. 108, 787-790 (2015)

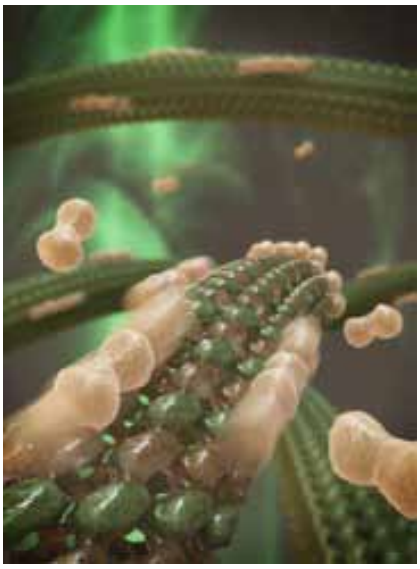

Image: Christoph Hohmann, NIM.

4

EXTRACELLULAR RIGIDITY SENSING BY TALIN ISOFORM-SPECIFIC MECHANICAL LINKAGES

Dr. Carsten Grashoff (Max Planck Institute for Biochemistry, Martinsried)
■ www.biochem.mpg.de/en/rg/grashoff
Prof. Matthias Rief (TU München, Physics Department)
■ bio.ph.tum.de/home/e22-prof-dr-rief/rief-home.html

The ability of cells to adhere and sense differences in tissue stiffness is crucial for organ development and function. The central mechanisms by which adherent cells detect extracellular matrix compliance, however, was unknown. Using two single-molecule-calibrated biosensors that allow the analysis of a previously inaccessible but physiologically highly relevant force regime in cells, we could demonstrate that the integrin activator talin establishes mechanical linkages following cell adhesion, which are indispensable for cells to probe tissue stiffness. Talin linkages are exposed to a range of piconewton forces and bear, on average, 7–10 pN during cell adhesion depending on their association with F-actin and vinculin. Disruption of talin's mechanical engagement does not impair integrin activation and initial cell adhesion but prevents focal adhesion reinforcement and thus extracellular rigidity sensing. Intriguingly, talin mechanics are isoform specific so that expression of either talin-1 or talin-2 modulates extracellular rigidity sensing.

■ **K.A. Austen, P. Ringer, A. Mehlich, A. Chrostek-Grashoff, C. Kluger, C. Klingner, B. Sabass, R. Zent, M. Rief, C. Grashoff:** *Extracellular rigidity sensing by talin isoform-specific mechanical linkages;* Nat Cell Biol 17, 1597-1606 (2015)

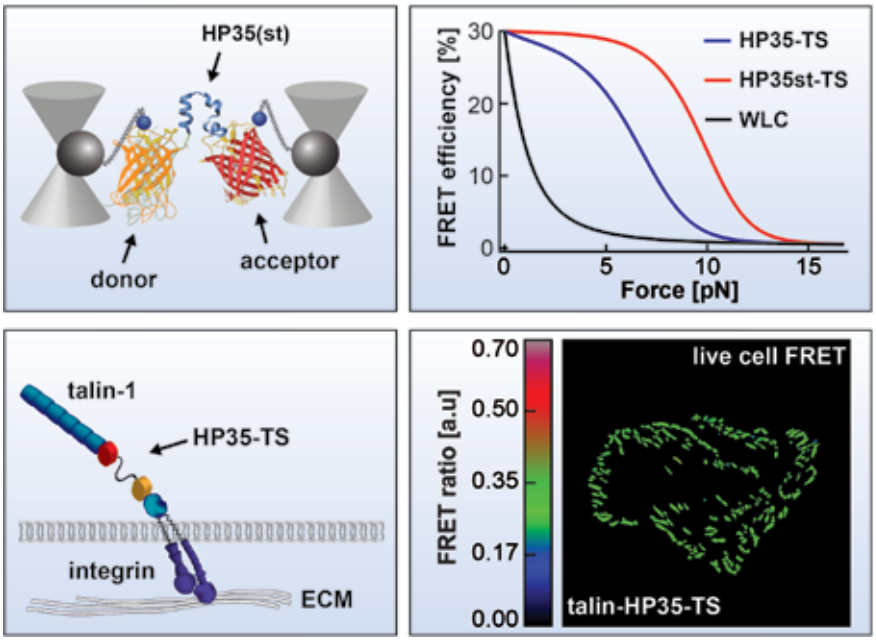

Figure 1. Upper left: Single-molecule force spectroscopy was used to calibrate novel FRET-based tension sensors comprising a donor and an acceptor fluorophore that are linked by the mechano-sensitive villin headpiece peptide (HP35). **Upper right:** The HP35-based tension sensor (HP35-TS) is most sensitive to mechanical forces of 6–8 pN. A stabilized version (HP35st-TS) responds to mechanical forces of 9–11 pN. **Lower left:** The HP35-TS was inserted into talin-1, which connects extracellular matrix (ECM) receptors called integrins with the intracellular actin cytoskeleton. **Lower right:** Expression of the talin-HP35 sensor in cells allows force measurements across talin-1. Such live cell FRET experiments revealed that talin-1 bears mechanical loads of about 7–10 pN and is essential for cells to feel ECM rigidity.

5

STRONG AND PRECISE HANDS ON SINGLE MOLECULES

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Single-molecule force spectroscopy with the atomic force microscope resolves the mechanical stability of molecular mechanics and receptor ligand interactions. Reliable molecular handles are required to precisely apply to and measure forces on individual biomolecules. The quantification of the stability of (1) monovalent Strep-Tactin with a peptide tag (Strep-Tag II) and (2) mechanostable Cohesin Dockerin (Coh:Doc) enables understanding molecular mechanics with high yield data acquisition and increased throughput in single-molecule experiments. These two handle complexes evolved as strong linkers to site-specifically apply forces to target protein domains. Furthermore, a new statistical treatment of rupture force distributions obtained with such handles allows resolving dual binding conformations of receptor-ligands (figure) that are not observable using bulk biochemical methods. Assessing the force propagation through such multidomain complexes by MD-simulations (3) further deepens the understanding of the mechanical function even at the level of individual atoms.

■ **F. Baumann, M. S. Bauer, L. F. Milles, A. Alexandrovich, H.E. Gaub, D.A. Pippig:** *Monovalent Strep-Tactin for strong and site-specific tethering in nano spectroscopy;* Nature Nanotechnology, doi:10.1038/nnano.2015.231 (2015)*

■ **M.A. Jobst, L.F. Milles, C. Schoeler, W. Ott, D.B. Fried, E. A. Bayer, H.E. Gaub, M.A. Nash:** *Resolving dual binding conformations of cellulosome cohesin-dockerin complexes using single-molecule force spectroscopy*; eLife, DOI:10.7554/eLife.10319.001 (2015)

■ **C. Schoeler, R.C. Bernardi, K.H. Malinowska, E.Durner, W. Ott, E.A. Bayer, K. Schulten, M.A. Nash, H.E. Gaub:** *Mapping Mechanical Force Propagation through Biomolecular Complexes;* Nano Letters, doi:10.1021/acs.nanolett.5b02727 (2015)

* CeNS Publication Award 2015

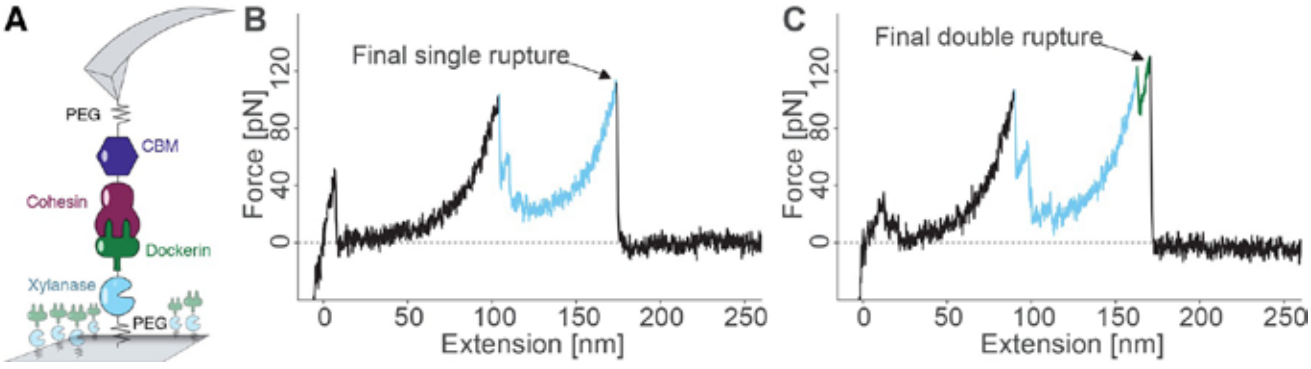

Figure 1: A typical experimental configuration and recordings of single-molecule unfolding and unbinding traces. (A) Schematic depiction showing the pulling geometry with CBM-Coh on the AFM Cantilever and Xyn-Doc on the glass substrate. Each fusion protein is site-specifically and covalently immobilized on a PEG-coated surface. **(B-C)** Each force vs. extension trace shows PEG linker stretching (black), Xylanase unfolding and subsequent stretching (blue), and Coh:Doc complex rupture. The Coh:Doc complex rupture occurred in two distinct event types: single (B) and double (C) ruptures. The 8-nm contour length increment separating the double peaks was assigned to Doc unfolding (C, green).

6

FEMTOSECOND LASER PULSE SHAPING MICROSCOPY ON GRAPHENE

Prof. Achim Hartschuh (LMU München, Chemistry Department)
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The linear dispersion of the massless Dirac Fermions in graphene is enabling an ever increasing number of optical and optoelectronic applications. It is also responsible for a particularly strong, nonlinear optical response. In collaboration with a group working on theoretical modeling we showed experimentally that this response consists of three different signal contributions: First, a contribution from near-degenerate four-wave mixing (ND-FWM). Second, a broad-band photoluminescence signal extending from the blue into the near-infrared range. And third, a contribution from the microscopic polarization induced by the laser. The latter is particularly difficult to distinguish because of the dominating ND-FWM signal. Using a newly developed ultrafast laser pulse shaping microscope we were able to isolate these different signal contributions [1].
Laser pulse shaping is based on the idea of controlling the spectral amplitude and phase profile of a broadband pulse through a device called spatial light modulator. With this the spectrally dispersed frequency components of the pulse can be manipulated individually providing flexible control over the pulse characteristics. In our experiment we focused laser pulses with a duration of 15 fs to a diffraction limited spot using a high numerical aperture objective. Because virtually all optical elements affect the spectral phase and with this the duration of the laser pulse, the spectral phase has to be determined in the focus of the microscope objective and compensated appropriately. We showed that graphene's four-wave mixing signal is ideally suited for this purpose [2]. First, we demonstrated that the ND-FWM signal of graphene is instantaneous. This means that graphene does not exert any spectral phase on the laser pulse, presumably as a consequence of its linear dispersion, and that the shortest pulse creates the highest ND-FWM signal. We then demonstrated the iterative compression of broadband pulses using a self-optimizing feedback scheme.

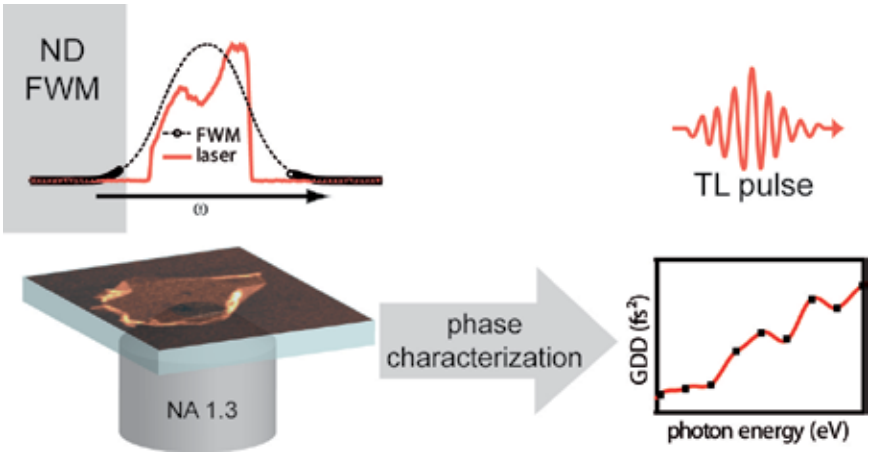

Figure 1. Focusing of short laser pulses on single layer graphene results in a strong nonlinear response that is dominated by near-degenerate four-wave mixing (ND-FWM). This signal can be used to characterize the spectral phase of a laser pulse, given in terms of the group delay dispersion (GDD). This is possible because graphene itself does not exert a spectral phase.

■ **[1] T. Winzer, R. Ciesielski, M. Handloser, A. Comin, A. Hartschuh, E. Malic:** *Microscopic view on the ultrafast photoluminescence from photo-excited graphene;* Nano Letters 15, 1141 (2015)

■ **[2] R. Ciesielski, A. Comin, M. Handloser, K. Donkers, G. Piredda, A. Lombardo, A. C. Ferrari, A. Hartschuh:** *Graphene Near-Degenerate Four-Wave Mixing for Phase Characterization of Broadband Pulses in Ultrafast Microscopy;* Nano Letters 15, 4968 (2015)

7

CONTINUOUS REPLICATION AND SELECTION TOWARDS INCREASING LENGTH BY A HEAT FLUX ACROSS AN OPEN PORE

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■ www.biosystems.physik.lmu.de

The Braun lab could achieve the positive length selection and autonomous replication in an open thermal trap, published in Nature Chemistry. They could could show that a thermal gradient is not only cycling molecules for PCR (which acts as a proxy also for prebiotic replication chemistries) and not only accumulating the molecules in the trap. What was interesting is that if this replication trap is fed from the outside by a continuous throughflow, an unexpected and very sharp selection pressure for the length is applied. Only larger molecules stay inside the trap and shorter ones go through it. So the replicating molecules are selected towards increasing length, an effect shown in experiment where 75 bases could outcompete the replication of 36 bases.
Thus, a reversal of the famous Spiegelman result from the 1960s could be achieved. Not the longer, not the faster replicating and shorter nucleic acids remain inside the pore space. So evolution - irrespective of the function and for each molecule individually - is pushed towards longer polymer lengths, a prerequisite for the evolution of complexity.

The setting also allows for the continuous feeding of the reaction. The replication experiments could be sustained for more than 6 hours, leading to a 150-fold replication of the molecules inside the trap, triggering a fest mutation dynamics if the PCR reaction chosen as replication chemistry would not be so error-prone. So a thermal gradient, focussed across a thin pore for a mere 2.5 millimeters is enough to host an evolution towards ever longer molecules. We think, this result is a very interesting starting point for a number of long term replication scenarios with a more realistic replication chemistry. Also, the continuous outflow in steady state allows to continously report the replicated sequences inside the trap. So if sequencing should be possible (we need some post-amplification to do that), we can observe autonomous, molecular evolution over long time scales.

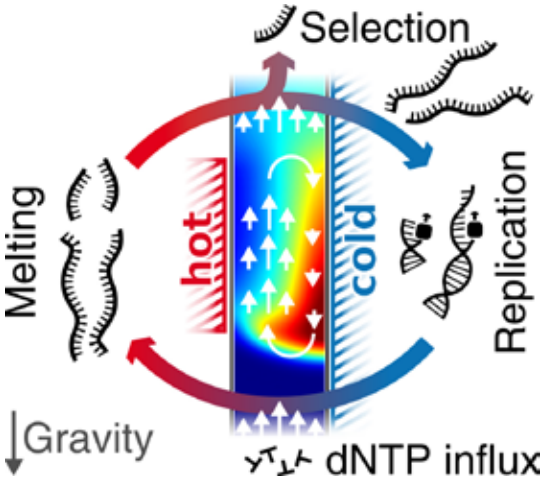

Figure 1: Flux of thermal energy across geological cracks near a heat source leads to replication and length selective accumulation of oligonucleotides especially in a feeding throughflow situation. As a result, longer DNA is better replicated as shorter DNA, overcoming the tyranny of the shortest, found by Spiegelman in the 1960s.

■ **M. Kreysing, L. Keil, S. Lanzmich, D. Braun:** *Heat flux across an open pore enables the continuous replication and selection of oligonucleotides towards increasing length;* Nature Chemistry, doi:10.1038/nchem.2155 (2015)*

* CeNS Publication Award 2015

8

POST-SYNTHETIC DECOUPLING OF ON-SURFACE SYNTHESIZED COVALENT NANOSTRUCTURES

PD Dr. Markus Lackinger, Prof. Wolfgang M. Heckl
(TU München, Department of Physics and TUM School of Education, and Deutsches Museum)
■ www.2d-materials.com

On-surface synthesis of covalent organic nanostructures often requires a chemical contribution of reactive metal surfaces to drive or initiate the coupling reactions. On the other hand, many and in particular electronic applications preclude metal surfaces as supports. Hence, strategies for electronic decoupling of the covalent networks from the synthetically indispensable metal surfaces after their synthesis are highly desired. The group of Markus Lackinger and Wolfgang Heckl demonstrates that the high affinity of iodine to metal surfaces can be exploited for intercalation of an iodine monolayer between covalent nanostructures and metal surfaces. Indications for the suitability of this approach were provided by studying the surface-chemistry of 1,3-diiodobenzene on Cu(111). Surprisingly, instead of a less-well defined distribution of higher oligomers, exclusively trimers with similar conformation, i.e. *m*-terphenyl, arranged in a regular pattern were observed. Most importantly, Scanning Tunneling Microscopy revealed adsorption of these trimers on top of a close packed iodine monolayer. Since activation of the coupling reaction is only possible directly in contact with the metal surface, it is concluded that the trimers were detached from the Cu(111) surface after their formation. Density functional theory simulations provide evidence for covalent bond formation between the formally diradicalic trimers and iodine atoms of the chemisorbed monolayer. This study lays the foundation for exploring deliberate exposition of on-surface synthesized covalent organic nanostructures that are adsorbed on strongly interacting metal surfaces to iodine vapor after their synthesis as possible strategy for detachment and decoupling.

■ **A. Rastgoo-Lahrood, J. Björk, W.M. Heckl, M. Lackinger:** *1,3-Diiodobenzene on Cu(111) - an exceptional case of on-surface Ullmann coupling;* Chem. Commun. 51 (68), 13301 (2015)

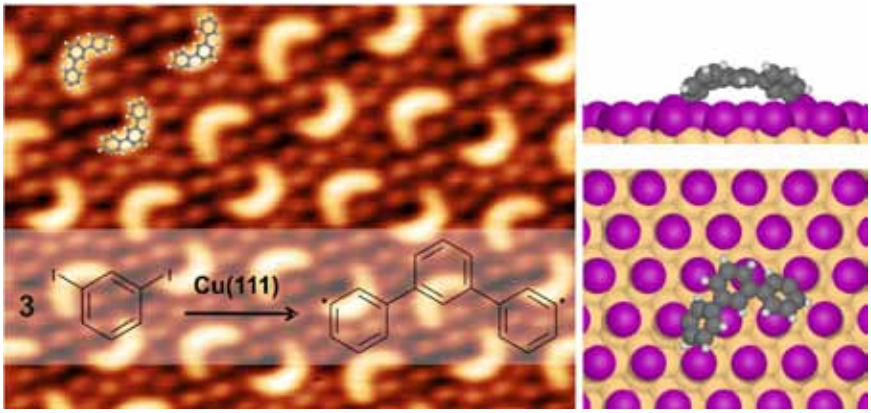

Figure 1. STM image of the outcome of Ullmann type coupling of 1,3-diiodobenzene on Cu(111). Surprisingly, the coupling was self-limiting to covalent trimers, i.e. *m*-terphenyl. The model shows a DFT-optimized structure that is in accord with the experimental observation. Accordingly, the trimers form covalent bonds to surface-bound iodine atoms.

9

EVOLUTIONARY GAMES OF CONDENSATES IN COUPLED BIRTH–DEATH PROCESSES

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Condensation is a collective behavior of particles observed in both classical and quantum physics. For example, when an equilibrated, dilute gas of bosonic particles is cooled to a temperature near absolute zero, the ground state becomes macroscopically occupied (Bose-Einstein condensation). Whether novel condensation phenomena occur far from equilibrium is a topic of vivid research.
In this work, a generic class of condensation phenomena was explained that occur in both classical and quantum systems. Interestingly, this condensation does not proceed into a single but into multiple states. It is expected that this phenomenon can be observed in driven-dissipative quantum systems of non-interacting bosons. The same kind of condensation also arises, most unexpectedly, as the selection of strategies in evolutionary zero-sum games. These games comprise, for example, the prominent rock-paper-scissors game and its lizard-spock extension.
On a mathematical level, the dynamics of both the condensation of bosons and the selection of strategies are described by a coupled birth-death process. Thus, by identifying the strategies that prevail in an evolutionary game, one identifies the quantum states that become condensates in a driven-dissipative bosonic system. The selection of the condensates is determined by a collective quantity: the vanishing of relative entropy production guides the formation of order. Although this process proceeds exponentially fast, the system never comes to rest. Instead, the occupation numbers of condensates may oscillate and the bosons may engage in complex games. The rules of these games can be tuned, for example to design a rock-paper-scissors game of condensates.
How such evolutionary games of condensates may be realized in an experiment with bosons poses an interesting question for future research.

Figure 1. Condensation of bosons in a driven-dissipative system corresponds to the selection of strategies in evolutionary game theory. The physical principles behind this condensation were explained by analyzing the dynamics of the underlying birth-death process. Image: Christoph Hohmann, NIM.

■ **J. Knebel, M. F. Weber, T. Krüger, E. Frey:** *Evolutionary games of condensates in coupled birth-death processes;* Nature Communications 6, 6977 (2015)*

* CeNS Publication Award 2015

10

SELF-ASSEMBLY OF FLUORESCENT NANODIAMONDS ON DNA ORIGAMI

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- www.softmatter.physik.uni-muenchen.de/liedl_group
- www.nano.physik.uni-muenchen.de/nanophotonics

Fluorescent nanodiamonds containing nitrogen-vacancy centers have attracted much attention as a new class of stable fluorescent markers and as promising candidates for spin-based quantum technologies. So far, however, ineffective surface functionalization of nanodiamonds has been a serious barrier to their handling and wider application. Within a collaborative effort we have developed a novel and reliable surface modification method by using a PEG-labeled biopolymer as stable coating molecule to assemble functionalized fluorescent nanodiamonds in predefined 1D, 2D and 3D geometries with the help of DNA origami. Optical studies confirmed that the fluorescence properties of the nitrogen-vacancy color centers in assembled nanodiamonds are preserved upon surface modification and DNA assembly. In principle, our work allows constructing highly ordered nanodiamond arrays or heterostructures to study spin-spin interactions as well as for in vivo optical imaging and labeling applications.

- **T. Zhang, A. Neumann, J. Lindlau, Y. Wu, G. Pramanik, B. Naydenov, F. Jelezko, F. Schüder, S. Huber, M. Huber, F. Stehr, A. Högele, T. Weil, T. Liedl:** *DNA-based self-assembly of fluorescent nanodiamonds;* J. Am. Chem. Soc. 137, 9776-9779 (2015)*

* CeNS Publication Award 2015

11

RECONSTITUTION OF PROTEIN GRADIENT OSCILLATIONS IN ARTIFICIAL MEMBRANE COMPARTMENTS

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- www.biochem.mpg.de/en/rd/schwille

The MinCDE protein machinery, wich orchestrates the positioning of the division ring in E.coli bacteria, shows a distinct oscillation of protein concentrations between the two cell poles, which are based on self-organization through reaction-diffusion. We have been able to reconstitute these self-organized oscillations of purified proteins in artificial cell-shaped compartments, as well as the faithful downstream positioning of protofilaments of the Z division ring. This could be the first step towards autonomous division of an artificial cell system, which we aim to establish in a bottom-up synthetic biology approach. Our research in the past year has been devoted to quantitatively analyzing the biophysical and biochemical design features of this very simple and archetypical kind of a biological oscillator, particularly highlighting the role of the membrane, acting as a heterogeneous catalyst and providing spatial cues in two and three dimensions.

- **K. Zieske, P. Schwille:** *Reconstituting geometry-modulated protein patterns in membrane compartments;* Methods Cell Biol 128, 149-163 (2015)

12

HIERARCHICAL NANOPARTICLE CLUSTERS: BRINGING TOGETHER NIR PLASMONIC METALS AND NIR PLASMONIC SEMICONDUCTORS

Dr. Jessica Rodríguez-Fernández (LMU München, Physics Department)

■ www.phog.physik.lmu.de/people/project-leaders/rodriguez_jessica/index.html

Doped semiconductor nanoparticles (NPs), alike anisotropic noble metal NPs, are characterized by strong plasmon resonances in the near-infrared (NIR). While the plasmon modes of metal NPs are essentially 'locked' after synthesis, in semiconductor NPs doping serves as an additional knob for plasmon tuning 'post-synthesis' while keeping NPs' size and shape unchanged. The investigation of optical effects stemming from the interaction of NIR plasmonic metal and semiconductor NPs is of high interest, but it has remained elusive due to the challenge of bringing together both NP types in a controlled fashion.

In this work, M. A. Habeeb Muhammed, Markus Döblinger, and Jessica Rodríguez-Fernández have devised novel and well-defined core-shell nanoparticle clusters comprised of both material types, and that are characterized by a unique NIR optical response. Such clusters consist of plasmonic gold nanorod cores (Au NRs) encapsulated by a shell of self-assembled $Cu_{2-x}Se$ NPs that can be made plasmonic (x>0) or non-plasmonic (x=0) on demand depending on the vacancy-doping level of the semiconductor. The clusters were obtained by self-limiting self-assembly of CdSe NPs on surface-modified Au NRs, followed by Cd^{2+}/Cu^{+} cation exchange on the supraparticle shell to yield $Cu^{2}Se$. Experimental and optical modeling results proved the unique and reversibly tunable optical response of these clusters. In the absence of vacancy-doping, their NIR plasmonic response was shown to be all-metallic in character. In contrast, for low and high vacancy-doping levels, it was demonstrated that the clusters' NIR plasmon resonances have, respectively, either a mixed metallic-semiconductor or an all-semiconductor character. These unique, hierarchical, colloidal assemblies may serve as model systems to investigate the crosstalk between plasmonic metals and plasmonic semiconductors at the nanoscale.

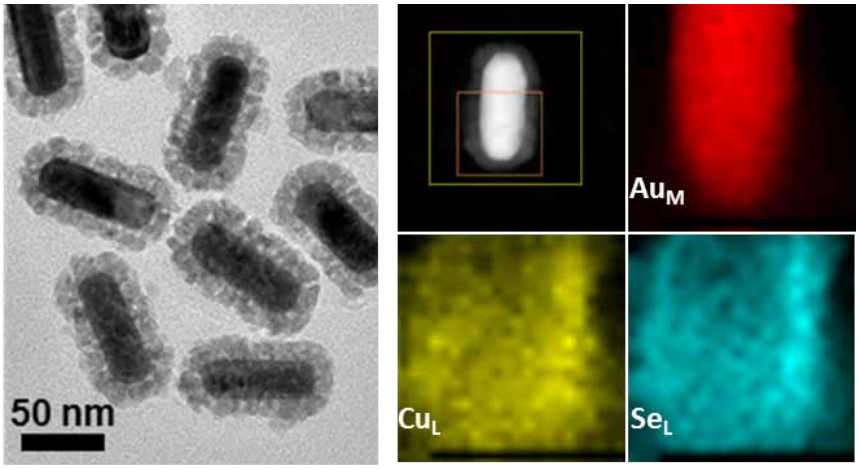

Figure 1. Representative transmission electron microscopy micrograph (left) and elemental mapping (right) of the Au NR@$Cu_{2-x}Se$ clusters.

■ **M.A.Habeeb Muhammed, M. Döblinger, J. Rodriguez-Fernández:** *Switching Plasmons: Gold Nanorod–Copper Chalcogenide Core-Shell Nanoparticle Clusters with Selectable Metal/Semiconductor NIR Plasmon Resonances;* J. Am. Chem. Soc. 137 (36), 11666 (2015)*

* CeNS Publication Award 2015

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BIOLOGICAL MAGNETOMETRY: TORQUE ON SUPERPARAMAGNETIC BEADS IN MAGNETIC FIELDS

Prof. Jan Lipfert (LMU München, Physics Department)
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In biophysics, usually tools from physics are used to study biology, e.g. by applying physical models to biological systems or measurement techniques from the physical sciences to biological questions. Scientists from the CeNS and the TU Delft have now taken the opposite route: they have used tools from biology to study a physical problem.
They were interested in the magnetic properties of small (~ 1 µm) superparamagnetic beads that are used routinely in biotechnological and diagnostic applications; in addition, they are at the heart of single-molecule measurements in magnetic tweezers. In magnetic tweezers, a molecule of interest, such as double-stranded DNA, is tethered between a glass slide and a small magnetic bead. By applying external magnetic fields, it is possible to apply both forces and torques to the beads and thus the tethered molecules. While the overall magnetization of the beads and the resulting forces were well understood, there was controversy about the nature of the anisotropy that enables the beads to be rotated.

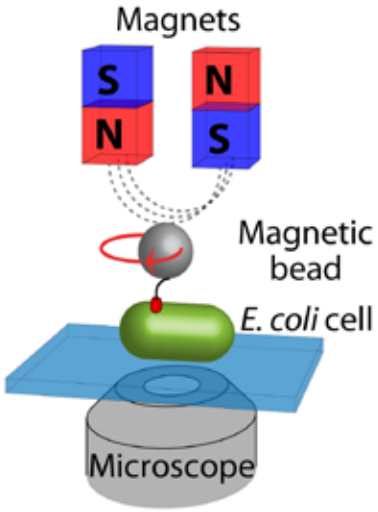

Figure 1. Schematic of a single *E. coli* cell (green) attached to a glass surface. A micrometer-sized magnetic bead (grey) is attached to the bacterial flagellar motor (red), which rotates the bead (indicated by the red arrow). Magnets on top of the observation volume are used to apply an external magnetic field and can stall the motor. The bead's position is tracked by imaging it in a microscope (shown below).

To probe the magnetic anisotropy, the authors carried out two types of experiments. First, they attached cells of the bacterium *E. coli* to the glass surface and attached the superparamagnetic beads to the flagellar motors of the cells (Figure 1). The flagellar motor is a powerful rotational molecular motor that allows *E. coli* cells to swim. In this experiment, the flagellar motors provided a convenient way to apply an approximately constant torque and to rotate the micrometer sized particles. By studying how externally applied magnetic fields slow down and eventually stall the motor, the authors could quantitatively test and rule out some of the previously proposed models. In a second experiment, the beads were attached to the surface via double-stranded DNA molecules, such that thermal fluctuations lead to rotational fluctuations. The rotational fluctuations were measured as a function of the field to further test the magnetic models.
Together, the two measurements ruled out models that proposed that the beads behave in part as permanent (ferro-)magnets and support models that feature an anisotropy in the induced magnetization. The results provide a quantitative understanding of the torques in magnetic tweezers that will help to further optimize magnetic tweezers measurements. In addition, they suggest that even small beads and relatively modest fields that are easily generated in the laboratory can generate torques large enough to stall even powerful molecular motors.

■ **M.M. van Oene, L.E. Dickinson, F. Pedaci, M. Köber, D. Dulin, J.W.J. Kerssemakers, J. Lipfert, N.H. Dekker:** *Biological Magnetometry: Torque on Superparamagnetic Beads in Magnetic Fields;* Phys. Rev. Lett. 114, 218301-6 (2015)

14

EMERGENCE AND PERSISTENCE OF COLLECTIVE CELL MIGRATION ON SMALL CIRCULAR MICROPATTERNS

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- www.theorie.physik.uni-muenchen.de/lsfrey
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In many instances in biology cells migrate collectively in a coordinated and directed manner. Examples are morphogenesis, tissue repair and angiogenesis. The resulting migration patterns within the cell sheets can often be described as two-dimensional active fluids exhibiting characteristic long-ranged correlations. From the perspective of physics of living matter it is of interest, how local rules of cell-cell interactions lead to collective behavior with emergent novel properties at large scales. In a collaborative project between experimental biophysics and theoretical modeling we systematically studied collective rotation within a cellular model system consisting of a small number of cells on circular adhesion patterns. Cells confined to circular micro-patterns were found to undergo spontaneous phases of collective rotation. These rotational states were analyzed using cell tracking and analysis of the resulting time courses. It was found that the persistence of the rotational states increased with the number of cells in the confining system but exhibited a pronounced discontinuity from four to five cells. This discontinuity was accompanied by a geometric rearrangement of cells within a system to a configuration featuring a central cell. Theoretical simulations employing an extended version of the cellular Potts model reproduced the emergence of vortex states as well as the dependence of their stability on cell number. The key ingredient in the model was the integration of intracellular polarization (seen as light to dark blue color in the schematic illustration) and intercellular coupling via mechanotransduction. Hence, experiment and theory show that the coupling of internal polarization of neighboring cells and the interplay between geometric confinement and spatial arrangement of cells result in distinct migratory states in finite size ensembles. The approach raises hopes that advanced Potts models in interplay with migration experiments on suitably designed micro-patterns will allow for scrutinizing local interaction rules guiding collective migration in more complex situations.

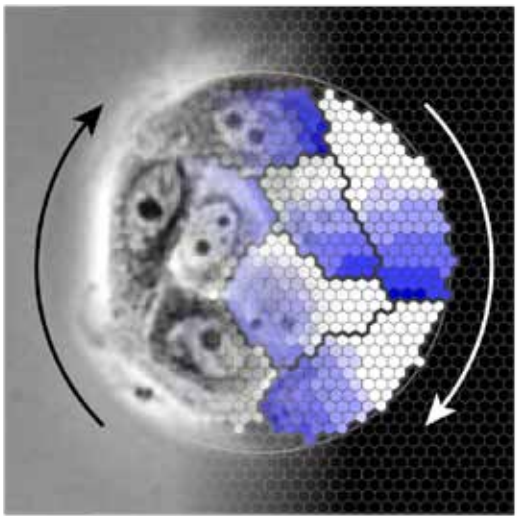

Figure 1. Illustration of collective rotation of cells within circular micropatterns in experiment (left) and cellular Potts model (right).

■ **F.J. Segerer, F. Thüroff, A. Piera Alberola, E. Frey, and J.O. Rädler:** *Emergence and Persistence of Collective Cell Migration on Small Circular Micropatterns;* Physical Review Letters 114 (22), 228102 (2015)

15

SWEET BIOPHYSICS: THE GLYCOCALYX AND ITS ROLE IN MEMBRANE PROTEIN DYNAMICS AND BACTERIAL ADHESION

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The membrane of nearly every eukaryotic cell is covered with a thick layer of various sugar structures, called "glycocalyx". This term sums up all types of extracellular glycosylation, ranging from sugar "trees" in the size of some nanometres attached to membrane proteins up to huge sugar polymers with various modifications in the size of hundreds of nanometres. Despite it was discovered about half a century ago that the extracellular side of a cell is heavily glycosylated, the modification remains enigmatic.

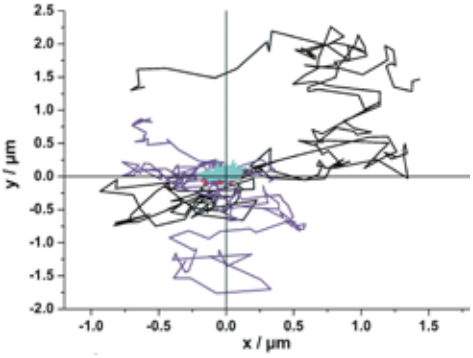

Figure 1. Shown are trajectories of single fluorescent streptavidin molecules on the cell membrane. These streptavidins are capable to induce artificial networks of membrane proteins with different strengths. For low interconnections, the spatial mobility is high (black and purple). In contrast, for stronger interconnection, the network becomes so rigid that the membrane proteins are almost completely immobile (red and cyan).

In several investigations, some exciting functions of the glycocalyx could be unravelled and as well be employed as a platform to actively modify central parameters of the cell.
First, metabolic labelling was used to analyse how different glycosylation patterns of membrane proteins affect their spatiotemporal mobility within the membrane. It was observed that certain sugar modifications significantly reduce spatiotemporal dynamics of the underlying membrane proteins by enabling them to engage into a supramolecular network via interconnecting proteins (galectins).
Inspired by this, a method employing the streptavidin-biotin system to artificially interconnect membrane proteins not dependent on their glycosylation type was developed. Using this approach, the spatiotemporal dynamics of the membrane proteins can be tuned from normal mobility down to completely "frozen" conditions in a precise and robust way. With this, central properties of the cell like mobility and endocytosis can easily be controlled.
In a third project, the focus lied on the important process of bacterial adhesion. Here, the membrane protein glycosylation was used as a platform to cover the membrane with photoswitchable mannose, the ligand for adhesive organelles of *E. coli*. It was proven that the conformation of the photoswitch critically affects the potency of *E. coli* to adhere to the cells: With the mannose pointing towards the bacteria, adhesion was normal, however, when the mannose was orientated away from the cell and buried inside the glycocalyx, the adhesion was significantly impaired.
Taken together, the results of these projects highlight the importance of the glycocalyx for various processes and their potential to function as platform to actively modify cellular processes. New aspects will hopefully be unravelled soon to gain more knowledge about this fascinating part of the cell.

■ **Möckl L., Lindhorst T.K., Bräuchle C.: Artificial Formation and Tuning of Glycoprotein Networks on Live Cell Membranes:** *A Single-Molecule Tracking Study;* ChemPhysChem 17(6), 829 (2016)
Inside cover picture for ChemPhysChem

L. Möckl, A. Müller, C. Bräuchle, T.K. Lindhorst: *Switching first contact: photocontrol of E. coli adhesion to human cells;* Chem. Comm. 52, 1254 (2016)

L. Möckl, A. Horst, K. Kolbe, T. Lindhorst, C. Bräuchle: *Microdomain Formation Controls Spatiotemporal Dynamics of Cell Surface Glycoproteins*; ChemBioChem 16(14), 2023 (2015)
Inside cover picture for ChemBioChem September 2015, 14(16)

16

ULTRAFAST HELICITY CONTROL OF SURFACE CURRENTS IN TOPOLOGICAL INSULATORS AT ROOM TEMPERATURE

Prof. Alexander W. Holleitner (TU München, Walter Schottky Institut and Physics Department)
■ www.nanoptronics.de

In recent years, a class of solid-state materials, called three-dimensional topological insulators, has emerged. In the bulk, a topological insulator behaves like an ordinary insulator with a band gap. At the surface, conducting gapless states exist showing remarkable properties such as helical Dirac dispersion and suppression of backscattering of spin-polarized charge carriers. The characterization and control of the surface states via transport experiments is often hindered by residual bulk contributions. Prof. Holleitner and his team demonstrated that surface currents in Bi_2Se_3 and further bismuth chalcogenides can be controlled by circularly polarized light on a picosecond timescale with a fidelity near unity even at room temperature. They reveal the temporal separation of such ultrafast helicity-dependent surface currents from photo-induced thermoelectric and drift currents in the bulk. The results uncover the functionality of ultrafast optoelectronic devices based on surface currents in topological insulators.

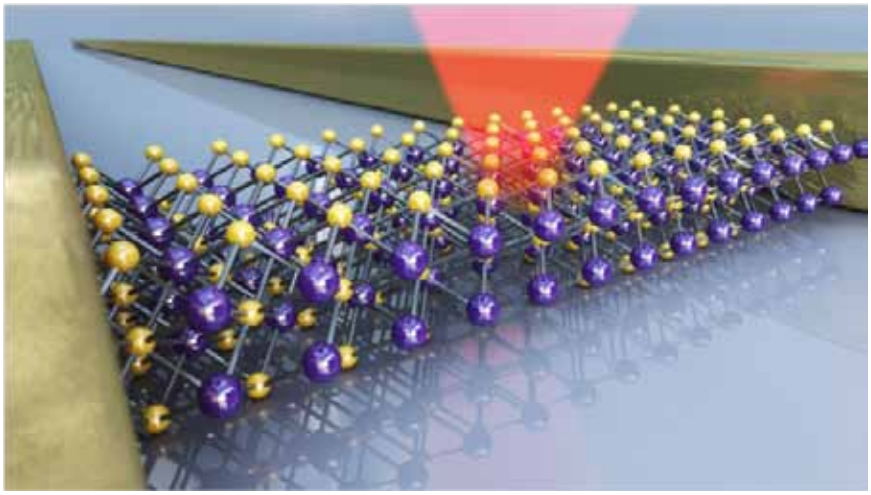

Figure 1. Artistic representation of a 3D topological insulator, such as Bi_2Se_3, which is contacted by metal striplines. The latter allow the Holleitner group to read-out the picosecond current dynamics of the surface states of the topological insulator by on an on-chip pump-probe spectroscopy. Image: Christoph Hohmann, NIM.

■ **C. Kastl, C. Karnetzky, H. Karl, A.W. Holleitner:** *Ultrafast helicity control of surface currents in topological insulators with near-unity fidelity;* Nature Communications 6, 6617 (2015)

■ **C. Kastl, P. Seifert, X. He, K. Wu, Y. Li, A.W. Holleitner:** *Chemical Potential Fluctuations in Topological Insulator BiSbTe Films Visualized by Photocurrent Spectroscopy;* 2D Materials 2, 024012 (2015)

17

IN SITU STM OF CATALYTIC REACTIONS

Prof. Joost Wintterlin (LMU München, Chemistry Department)
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The chemical reactions in heterogeneous catalysis usually consist of long and complicated sequences of bond breaking and bond making on the surface of the catalyst. In most cases we do not have a full picture of these sequences, a major gap in our understanding of these industrially most important chemical reactions. In this project the Fischer-Tropsch synthesis was investigated by scanning tunneling microscopy (STM). In the Fischer-Tropsch synthesis, carbon monoxide (CO) reacts with hydrogen (H_2) to give linear hydrocarbons (C_nH_{2n+2}) and water (H_2O) on an iron or cobalt catalyst, a reaction that could become a major source of liquid fuels in the future. The sequence of reaction steps is certainly complex, but it is generally assumed that the dissociation of CO is critical. In chemical terms the dissociation of CO is the rate-limiting step. However, it is heavily disputed how CO, the molecule with one of the strongest known chemical bonds, can dissociate on the catalyst, in particular on a close-packed cobalt surface.

The figure shows an STM image of a close-packed cobalt surface under a CO atmosphere. One can see that the terraces between the atomic steps (the diagonal lines in the image) display a hexagonal pattern. It is formed by the molecularly adsorbed CO molecules, i.e., with their C-O bonds still intact. However, one can additionally see triangles of various sizes on the terraces. In this project it was shown that these triangles are created by adsorbed carbon atoms, as shown in the model. The C atoms occupy sites along the sides of the triangles. That the surface was partially covered by carbon atoms was proof that the CO molecules actually dissociate on this surface. (The oxygen atoms were reacted off by CO to give CO_2.) The data thus provide direct insight into the processes on the surface of a catalyst with atomic resolution. It should be mentioned that the conditions, in this case the CO pressure was 0.22 mbar, the temperature 220 °C, are extreme for an STM experiment - STM is usually performed under vacuum and at or below room temperature - but the dissociation was only seen under these conditions. A specially designed STM setup has been used for these experiments.

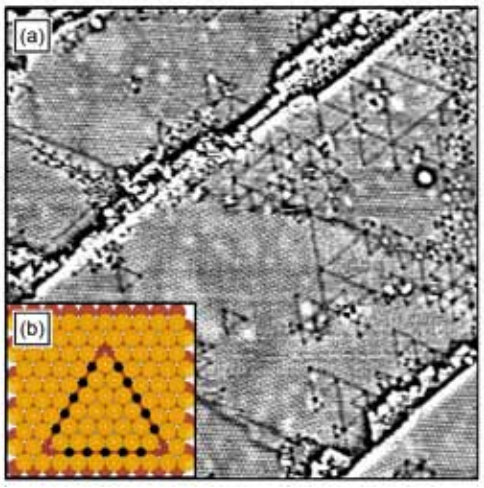

Figure 1. (a) STM image of a CO-covered Co(0001) surface, taken in 0.22 mbar of CO and at a temperature of 220 °C. **(b)** Model of the carbon-induced triangles; the cobalt atoms of the first two surface layers are shown in yellow and red, the carbon atoms in black.

■ **M. Ehrensperger, J. Wintterlin:** *In situ scanning tunneling microscopy of the poisoning of a Co(0001) Fischer-Tropsch model catalyst by sulfur;* J. Catal. 329, 49 (2015)

■ **B. Böller, M. Ehrensperger, J. Wintterlin:** *In situ scanning tunneling microscopy of the dissociation of CO on Co(0001),* ACS Catal. 5, 6802 (2015)

18

GRAPHENE LIQUID CELL FOR IR NANOSPECTROSCOPY OF NATIVE BIOSYSTEMS

Dr. Fritz Keilmann (LMU München, Physics Department)
■ www.softmatter.physik.uni-muenchen.de

Scattering scanning near-field infrared microscopy (s-SNOM) is a powerful spectroscopic tool for local chemical recognition. It is an AFM extended by an infrared illumination-and-back-scattering channel. Biological tissues, viruses, and proteins could up to now be investigated only in the form of dry samples, owing to strong water absorption in the infrared.

A new approach implements the required aqueous environment to map native biosystems at typically 20 nm spatial resolution. It employs monolayer graphene as a floating lid ontop the aqueous suspension to be studied. The graphene cover keeps wet samples stable because it presents an impermeable barrier to any liquid or gas, and thus prevents evaporation and tip wetting. On the other hand, graphene is transparent to infrared (as to any other light from visible to THz), and thus enables chemical nano-imaging and -spectroscopy by confined fields under the tip of an s-SNOM.

The experimental demonstration involved ca. 10 nm thick water pockets with some TM viruses trapped between two graphene monolayer sheets, on Si substrate. Because van der Waals forces squeeze the suspension the TMVs buckle the upper graphene layer which makes them detectable by AFM topography. The TMVs' identity is verified by their amide I and II infrared absorption bands, at ca. 1520 and 1660 cm^{-1}, respectively. The presence of water is demonstrated by its absorption at 1610 cm^{-1}.

The achievement of a liquid cell for s-SNOM, suited for 20 nm nanoimaging and -spectroscopy anywhere in the visible-to-THz spectral regions, should boost applications in biochemistry and biology. A 20-30 nm spacer grid could define a liquid sample space thin enough to be fully sampled by the tip's near field, and thick enough to visualize and track, for example, the assembly and interaction of protein complexes. A single graphene monolayer could cover freshly freeze-fractured or microtomed tissues such as from bone, to stabilize their native state for nanospectral imaging.

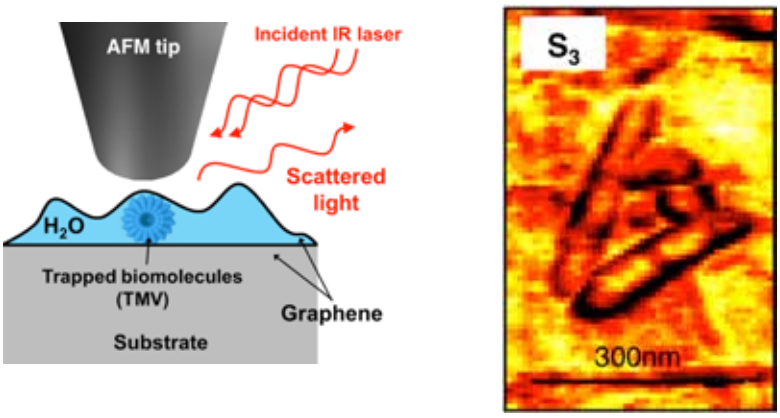

Figure 1. "Wet" s-SNOM setup with an infrared-compatible graphene liquid cell (left). An impermeable graphene monolayer stabilizes a 10 nm thick aqueous suspension of viruses, and allows probing the topography with an AFM tip. Simultaneously, an infrared absorption image is obtained by observing back-scattering, here of two TM viruses in near-field amplitude contrast (right).

■ **O. Khatib, J.D. Wood, A.S. Mcleod, M.D. Goldflam, M. Wagner, G.L. Damhorst, J.C. Koepke, G.P. Doidge, A. Rangarajan, R. Bashir, E. Pop, J.W. Lyding, M.H. Thiemens, F. Keilmann, D.N. Basov:** *Graphene-based platform for infrared near-field nanospectroscopy of water and biological materials in an aqueous environment;* ACS Nano 9, 7968 (2015)

19

A TUNABLE AZINE COVALENT ORGANIC FRAMEWORK PLATFORM FOR VISIBLE LIGHT-INDUCED HYDROGEN GENERATION

Prof. Bettina V. Lotsch
(LMU München, Chemistry Department and MPI for Solid State Research, Stuttgart)
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Prof. Christian Ochsenfeld (LMU München, Chemistry Department)
■ www.cup.uni-muenchen.de/pc/ochsenfeld

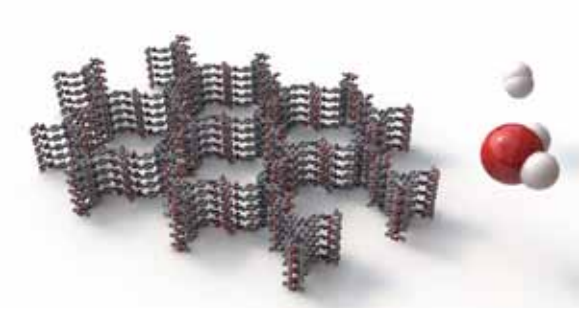

Figure 1. Covalent organic frameworks are highly porous, crystalline organic frameworks which owing to their molecular tunability show potential as a new generation of polymeric photocatalysts for water splitting. Image: Christoph Hohmann (NIM).

Photocatalytic water splitting holds promise as a green route for the capture and storage of solar energy into chemical fuels such as hydrogen. This process requires the design of efficient semiconductor photocatalysts that fulfill the prerequisites for the photocatalytic process - light harvesting, charge transport and charge collection for subsequent chemical transformations at the surface of the photocatalyst. Covalent organic frameworks (COFs) are a new class of porous polymers that are highly crystalline and carry the potential to work as such photocatalysts. We show that the COFs based on a triphenylarene platform can readily be tuned for the photocatalytic water reduction as a direct consequence of molecular engineering of the organic precursors. Using insights from density functional theory (DFT) calculations, a series of triphenylarylaldehydes was prepared that differs in the level of planarity as a function of increasing nitrogen content in the central aryl ring from 0 to 3 (N_0-, N_1-, N_2-, and N_3-COF). The resulting frameworks show promising optoelectronic properties required for photocatalytic hydrogen evolution in addition to high surface areas and crystallinity. The investigation of these COFs as a new generation of polymeric photocatalysts was gauged by determining the visible-light induced hydrogen evolution using triethanolamine as sacrificial electron donor and platinum nanoparticles as cocatalyst.

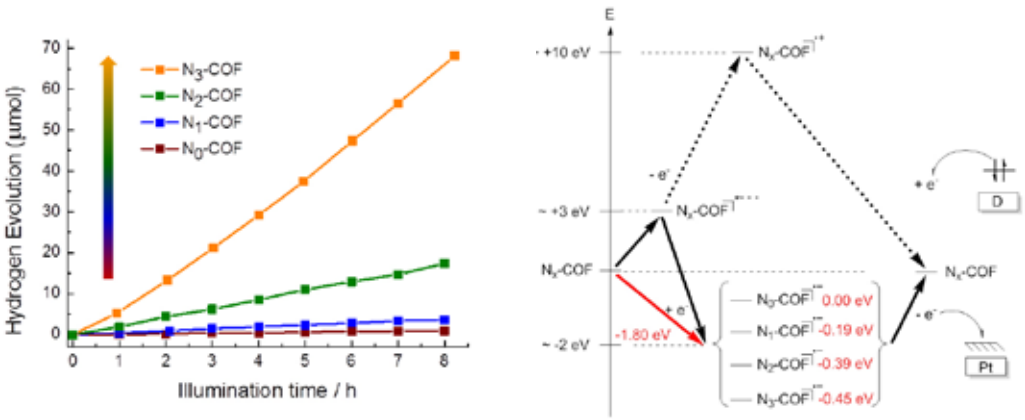

Figure 2. (a) Hydrogen production monitored over 8 h using N_x-COFs as photocatalysts. **(b)** Radical anion pathway calculated at the PBE0–D3/Def2–SVP level to explain the observed trend in photocatalysis.

Progressively enhanced hydrogen evolution with increasing nitrogen content in the COFs was observed as the average amount of hydrogen produced by N_0-, N_1-, N_2-, and N_3-COF was 23, 90, 438, and 1703 µmol h^{-1} g^{-1}, respectively, thus increasing by a factor of about 4

with each nitrogen introduced into the aryl ring. Computational studies performed at the PBE0-D3/def2-SVP level indicate that the increase in stabilization of the radical anions with increasing nitrogen content in the COFs directs the observed trend. Upon photocatalysis, the COFs were found to retain their structural integrity as determined by infrared and solid state NMR spectroscopy.

While synthetic challenges need to be overcome and better understanding of the charge carrier dynamics is required, these results highlight the potential of organic photocatalysis where molecular engineering of the precursors can lead to the development of efficient photocatalysts.

■ **V.S. Vyas, F. Haase, L. Stegbauer, G. Savasci, F. Podjaski, C. Ochsenfeld, B.V. Lotsch:** *A tunable azine covalent organic framework platform for visible light-induced hydrogen generation;* Nature Communications 6, doi 10.1038/ncomms9508 (2015)

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FABRICATION OF PLASMONIC NANOPARTICLE ARRAYS FOR LIGHT-ASSISTED CHEMICAL SYNTHESIS AND CELLULAR MANIPULATION

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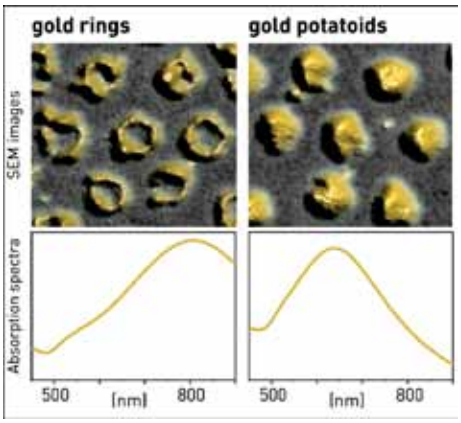
■ www.biochem.mpg.de/employees/23961/286870

Shaping and positioning noble metal nanostructures are essential processes that still require laborious and sophisticated techniques to fabricate functional plasmonic interfaces. The present study reports a simple photochemical approach compatible with micellar nanolithography and photolithography that enables the growth, arrangement and shaping of gold nanoparticles with tuneable plasmonic resonances on glass substrates. Ultraviolet illumination of surfaces coated with gold-loaded micelles leads to the formation of gold nanoparticles with micro/nanometric spatial resolution without requiring any photosensitizers or photoresists. Depending on the extra-micellar chemical environment and the illumination wavelength, block copolymer micelles act as reactive and light-responsive templates, which enable to grow gold deformed nanoparticles (potatoids) and nanorings. Optical characterization reveals that arrays of individual potatoids and rings feature a localized plasmon resonance around 600 and 800 nm, respectively, enhanced photothermal properties and high temperature sustainability, making them ideal platforms for future developments in nanochemistry and biomolecular manipulation controlled by near-infrared-induced heat.



■ **F. Kundrat, G. Baffou, J. Polleux:** *Shaping and Patterning Gold Nanoparticles via Micelle Templated Photochemistry;* Nanoscale (7), 15814 (2015)

21

MODULATING MUCIN HYDRATION AND LUBRICATION BY DEGLYCOSILATION AND POLYETHYLENE GLYCOL BINDING

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■ www.imetum.tum.de/forschung/biologische-hydrogele

A key property of mucin glycoproteins is their exceptional capacity to hydrate and lubricate surfaces. In vivo, mucins assemble into mucus hydrogels that cover the epithelium and protect it from dehydration and shear stress. A better understanding of the origin of these properties could lead to new treatment strategies for patients with poor mucus coverage, defective mucus production, or glycosylation as caused by Sjögren syndrome, dry eye, or in the case of certain bacterial infections. In this work, mucin coatings were used to show that mucin-associated glycans are essential for the formation of such hydrated and lubricating layers. Native mucins were compared with deglycosylated mucins by analyzing their hydration and it was shown that their lubricative potential in the boundary and mixed lubrication regime is linked to the hydration. The removal of glycans from the mucin resulted in a 3.5-fold decrease in hydration and an increase in friction by two orders of magnitude. This loss of function was successfully countered by grafting polyethylene glycol (PEG) molecules to defective mucins through lectin-glycan interactions. This lectin-PEG conjugation restored hydration and improves lubrication of the partially deglycosylated mucin coatings. The results presented here motivate that local complementation of defective mucus layers could prove to be a useful new treatment strategy for diseases where mucin glycosilation is compromised.

■ **T. Crouzier, K. Boettcher, A.R. Geonnotti, N.L. Kavanaugh, J.B. Hirsch, K. Ribbeck, O. Lieleg:** *Modulating Mucin Hydration and Lubrication by Deglycosilation and Polyethylene Glycol Binding;* Advanced Materials Interfaces 2(18), 1500308 (2015)

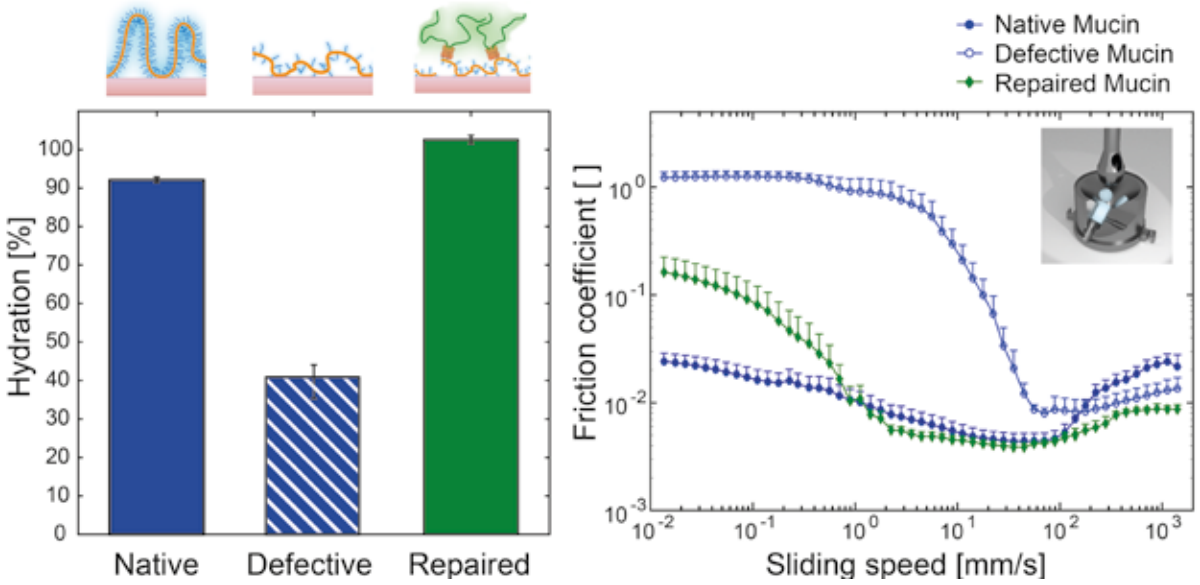

Figure 1. The hydration of partially deglycosylated mucins can be restored by grafting PEG chains to the mucin backbone through lectin-glycan interactions. As a consequence, the defective mucins recover their lubricating potential and reduce the friction coefficient, e.g. in a steel/PDMS tribology pairing, by up to two orders of magnitude. This is achieved by a mechanism called hydration-lubrication.

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ENZYMATIC REACTIONS AND RESPONSE TIMES IN BACTERIAL GENE REGULATION AT LOW CONCENTRATIONS

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■ www.agnld.uni-potsdam.de/~metz/index.html

Many chemical reactions in biological cells occur at very low concentrations of constituent molecules. Thus, due to the partitioning of the cell volume many enzymatic reactions run off at very low concentrations of enzymes or substrates. Concurrently, transcriptional gene regulation is often controlled by poorly expressed transcription factors such as the *E. coli* lac repressor with few tens of copies. The binding process of a transcription factor to DNA can in fact be mapped onto the Michaelis-Menten problem (Fig. 1). In these situations the basic assumption for modelling such reactions based on mean concentrations necessarily breaks down.
In this work we study the effects of inherent concentration fluctuations of substrate molecules on the seminal Michaelis-Menten scheme of biochemical reactions. We present a universal correction to the Michaelis-Menten equation for the reaction rates. The relevance and validity of this correction for enzymatic reactions and intracellular gene regulation is demonstrated. Our analytical theory and simulation results confirm that the proposed variance corrected Michaelis-Menten equation predicts the rate of reactions with remarkable accuracy even in the presence of large non-equilibrium concentration fluctuations. The major advantage of our approach is that it involves only the mean and variance of the substrate molecule concentration. Our theory is therefore accessible to experiments and not specific to the exact source of the concentration fluctuations.

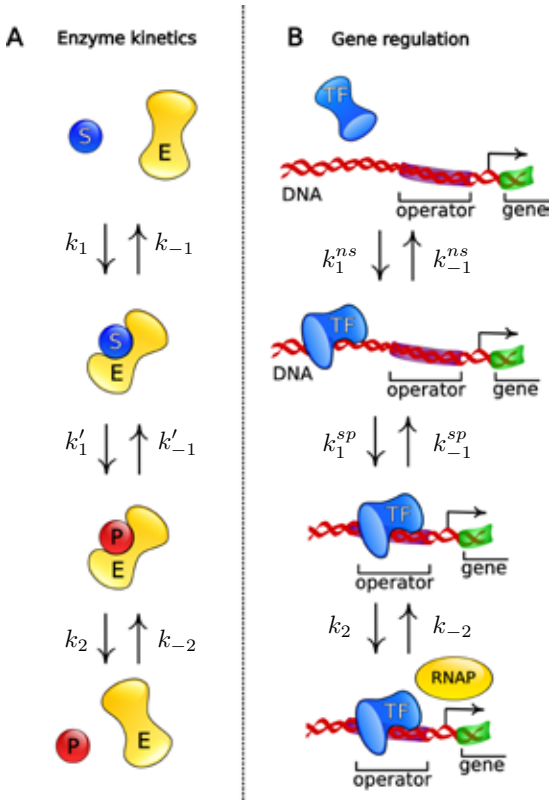

Figure 1. Mapping of the binding process of a transcription factor protein to DNA (Right column) and the steps of an enzymatic reaction (Left column).

■ **O. Pulkkinen, R. Metzler:** *Variance-corrected Michaelis-Menten equation predicts transient rates of single-enzyme reactions and response times in bacterial gene regulation;* Scientific Reports 5, 17820 (2015)

23

EARLY STEPS IN THE ASSEMBLY OF HIV

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Assembly of HIV has been extensively studied at the plasma membrane, but very little is known about the preassembly of the structural protein gag into oligomers in the cytosol. It is speculated that small oligomers of Gag exist, but they had not been experimentally shown. To investigate the behavior of cytosolic gag, the group of Professor Lamb applied a myriad of correlation spectroscopy methods to HIV-expressing cells, which are sensitive to motion on different timescales. This work was a tour-de-force investigation. Using Raster Image Correlation Spectroscopy (RICS), they could show that two subpopulations of gag exist in the cytosol. The faster diffusing species of the two populations is monomeric, but moves more slowly than expected for a gag monomer. By measuring a number of gag mutants, they could show that the decrease is mobility is due to transient interactions of gag with RNA. With Time Image Correlation Spectroscopy (TICS), they showed that the second, slow moving population is formed of small gag oligomers. Using the number and brightness (N&B) method, the group of Lamb could further estimate the size of these oligomers (between 3-5 gag molecules) and could show that the oligomerization depends on the concentration of gag in the cell. Mutations to the nucleotide capsid (NC) domain or to the capsid dimerization domain changed the propensity of gag to oligomerize in the cytosol. Hence, for the first time, the formation of small gag oligomers in the cytosol could be confirmed. These oligomers are believed to form a nucleus for assembly of HIV particles at the plasma membrane.

■ **J. Hendrix, V. Baumgärtel, W. Schrimpf, S. Ivanchenko, M.A. Digman, E. Gratton, H.G. Krausslich, B. Müller, D.C. Lamb:** *Live-cell observation of cytosolic HIV-1 assembly onset reveals RNA-interacting Gag oligomers;* J Cell Biol 210, 629 (2015)

■ **J. Prescher, V. Baumgärtel, S. Ivanchenko, A.A. Torrano, C. Bräuchle, B. Müller, D.C. Lamb:** *Super-Resolution Imaging of ES-CRT-Proteins at HIV-1 Assembly Sites*; PLoS Pathog 11, e1004677 (2015)

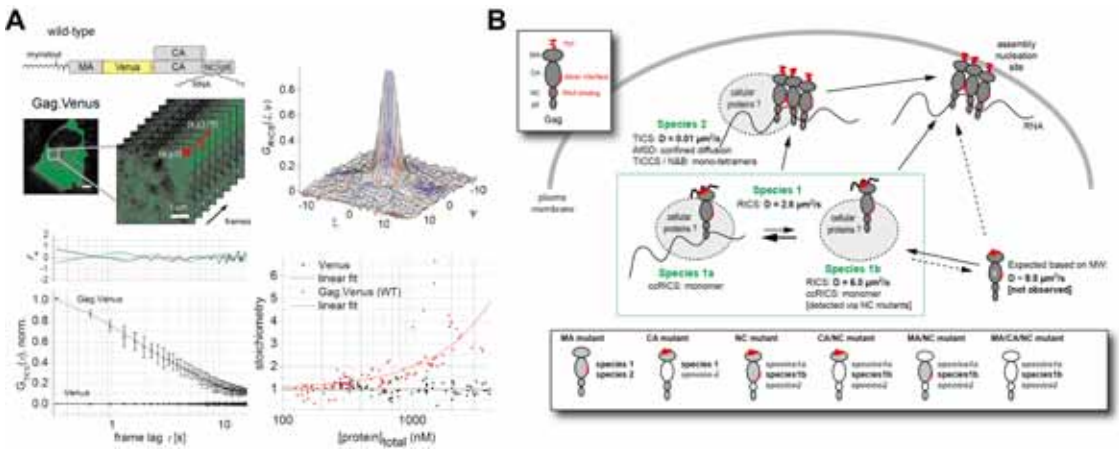

Figure 1. Dynamics of cytosolic Gag in the early assembly of HIV. (A) Representative Raster Image Correlation Spectroscopy (top), Temporal Image Correlation Spectroscopy (middle) and Number and Brightness (bottom) analyses of cytosolic Gag in living HeLa cells. **(B)** A model of cytosolic Gag dynamics summarizing the results of the paper. Gag interacts dynamically with RNA (Green box: Species 1a and Species 1b), giving rise to a normally diffusive, yet slow Gag species (Species 1), as well as to a confined diffusive, very slow Gag oligomer (Species 2). Breaking interactions through the NC-domain leads to faster diffusion, but Gag still interacts with other cytosolic components (Species 1b and illustrated by a grey ellipse).

24

THE BIOPHYSICS OF ACTIN

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Actin filaments are involved in a multitude of processes within the cell including cell migration, cytokinesis, endocytosis, and mechanosensation. Using a minimal reconstituted system, the group of Lamb investigated the affect of regulatory proteins on the growth of single growing actin filaments in vitro. They discovered that all associated proteins tested altered the growth and shrinkage at the filament ends. What was unexpected was that all actin side-binding proteins altered the kinetics in a long-range fashion, which was observed up to several microns from the site where the protein was attached. The side-binding proteins effected the elongation kinetics, mechanical properties, fragmentability and filament asymmetry. The group developed a mathematical model to describe their accurate TIRF microscopy data and thereby estimate a 'characteristic length' over which the side-binding protein alters filament properties. The results not only ended with the notion that actin filament growth kinetics are unique (which was asserted in a recent publication, but also provided clues as to how filament elongation, fragmentation, structure and asymmetry can be locally regulated in the cell. Another major aspect of this work that the group of Lamb could establish the plausibility of treadmilling (the process by which a filament grows on one end and shrinks on the other simultaneously) as a mechanism driving actin turnover during cell migration, an issue that has been strongly debated in recent years.

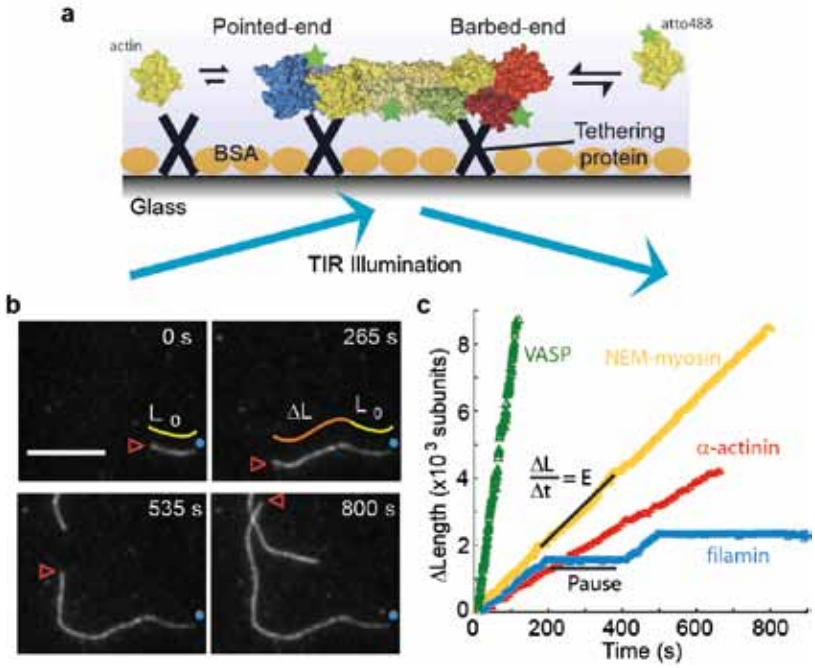

Figure 1. Investigation of actin dynamics using TIRFM. (A) A schematic of total internal reflection illumination and single actin filament imaging of filaments tethered to a glass surface. Filaments grow from the addition of subunits at either the barbed- or the pointed-end. **(B)** Selected frames from a movie showing the growth of a single actin filament that is tethered to the surface via α-actinin. The barbed-end is marked by a red arrowhead and the pointed-end by a blue dot. The elapsed time interval is given in seconds. Scale bar: 5 μm. L0 and ΔL are the initial filament length and the change in length, respectively. **(C)** The dynamics of actin elongation at the barbed end, ΔL, as a function of time for single filaments grown on surfaces with different tethering proteins at a concentration of 1 μM actin in solution.

■ **A.H. Crevenna, M. Arciniega, A. Dupont, N. Mizuno, K. Kowalska, O.F. Lange, R. Wedlich-Soldner, D.C. Lamb:** *Side-binding proteins modulate actin filament dynamics;* eLife 4, e04599 (2015)

25

SEARCH TIMES OF TRANSCRIPTION FACTORS FOR THEIR BINDING SITE ON DNA WITH REAL SEQUENCE

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Recent experiments demonstrate that gene regulatory proteins, so called transcription factors (TFs), indeed use the Berg-von Hippel facilitated diffusion mechanism to locate their target sequences on DNA in living bacteria cells: TFs alternate between sliding motion along DNA and relocation events through the cytoplasm. From simulations and theoretical analysis we study the TF sliding motion for a large section of the DNA sequence of a common E.coli strain, based on the two state TF model with a fast sliding search state and a recognition state enabling target detection, in the presence of competing binding molecules, so called blockers. For the probability to detect the target before TF dissociation from the DNA, the TF search times self consistently depend heavily on whether or not an auxiliary operator (an accessible sequence similar to the main binding operator at the start of the gene) is present in the genome section. Importantly, within our model the extent to which the interconversion rates between search and recognition states depend on the underlying nucleotide sequence is varied. A moderate dependence is shown to maximise the capability to distinguish between the main operator and similar sequences. Moreover, these auxiliary operators serve as starting points for DNA looping with the main operator, yielding a spectrum of target detection times spanning a large range in magnitude. Auxiliary operators are shown to act as funnels facilitating target detection by TFs. One of the main consequences of this analysis is that individual search times may vary by two orders of magnitude, in accordance with experiments. As shown in the figure, for relevantly long sequences the results for different parameters converge and due to the presence of the mirror operator O3 show a large spread.

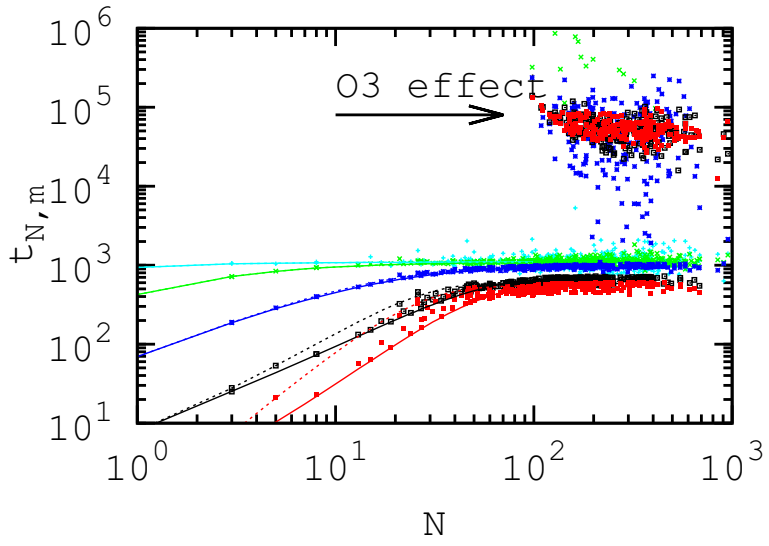

Figure 1. Typical target binding site detection times of the TF for different model parameters.

■ **M. Bauer, E. S. Rasmussen, M. A. Lomholt, R. Metzler:** *Real sequence effects on the search dynamics of transcription factors on DNA;* Scientific Reports 5, 10072 (2015)

26

MAGNETIC PROPULSION OF MICROSWIMMERS WITH DNA-BASED FLAGELLAR BUNDLES

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Many microorganisms use appendages, so-called flagella, to swim or propel through viscous environments. By imitating these microstructures, artificial microswimmers with promising applications in fields ranging from biomedical health care (e.g. drug delivery) to non-equilibrium physics (e.g. swarming) can be constructed. DNA-based self-assembly presents a promising new route for this endeavour as it offers the advantage of a systematic design, large scale production and straightforward functionalization. By attaching the DNA-filaments to biocompatible magnetic microparticles, hybrid structures were created that, when rotated in an external magnetic field, propel by means of a flagellar bundle similar to self-propelling bacteria. A quantitative model reveals a superior swimming speed of our constructs compared to swimmers with a single appendage due to a length-dependent bending stiffness of the DNA bundles.

- **A.M. Maier, C. Weig, P. Oswald, E. Frey, P. Fischer, T. Liedl:** *Magnetic Propulsion of Microswimmers with DNA-Based Flagellar Bundles;* Nano Letters, 16 (2), 906-910 (2016)

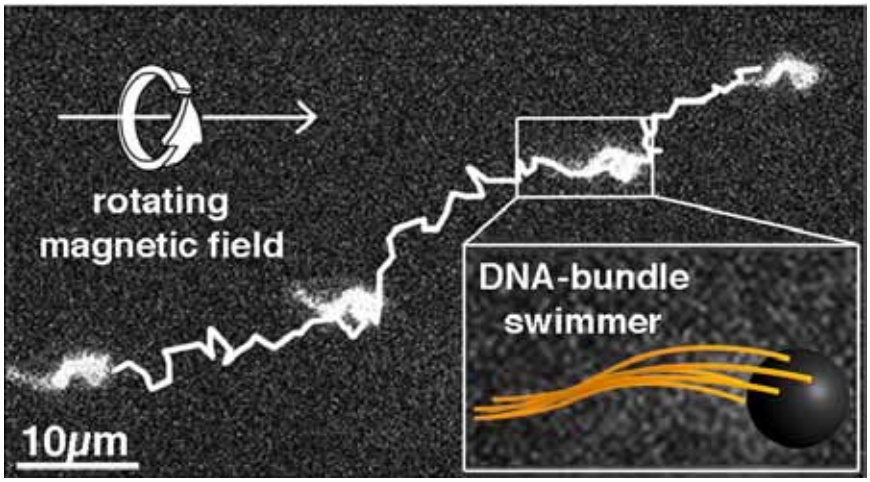

Figure 1. Snap shots of a movie showing a magnetic particle that is decorated with DNA-filaments and driven by an external, rotating magnetic field.

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A HIGHLY-ORDERED 3D COVALENT FULLERENE FRAMEWORK

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PD Dr. Bert Nickel (LMU München, Physics Department)
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Organic periodic networks are of interest for numerous applications, including organic electronics. The groups of Thomas Bein and Bert Nickel describe the first example of a highly-ordered 3D covalent fullerene framework based on hexakis-functionalized fullerene building blocks. The structure of the building blocks was designed to induce a high periodicity and porosity by an evaporation induced self-assembly strategy of the fullerene precursor templated by a liquid-crystalline block-copolymer. Nitrogen sorption analysis of the fullerene framework after template removal reveals a sharp maximum of the pore size distribution at 7.5 nm, confirming its highly ordered, uniform, almost single crystalline quality. Additionally, the electronic properties were studied by field effect mobility and impedance measurements. The researchers show the feasibility of the fullerene core serving as a new structural motif for building blocks in self-assembly processes with liquid-crystalline block-copolymers. A periodic porous covalent framework constructed completely from fullerene building blocks has never been demonstrated before. The authors suggest that this newly developed type of covalent fullerene frameworks will provide access to a wide range of hybrid materials with chemically tailored pore walls and encapsulated guests with tuneable chemical and physical properties.

■ **N.K. Minar, K. Hou, C. Westermeier, M. Döblinger, J. Schuster, F.C. Hanusch, B. Nickel, G.A. Ozin, T. Bein:** *A Highly-Ordered 3D Covalent Fullerene Framework;* Angewandte Chemie International Edition 54, 7577 (2015)

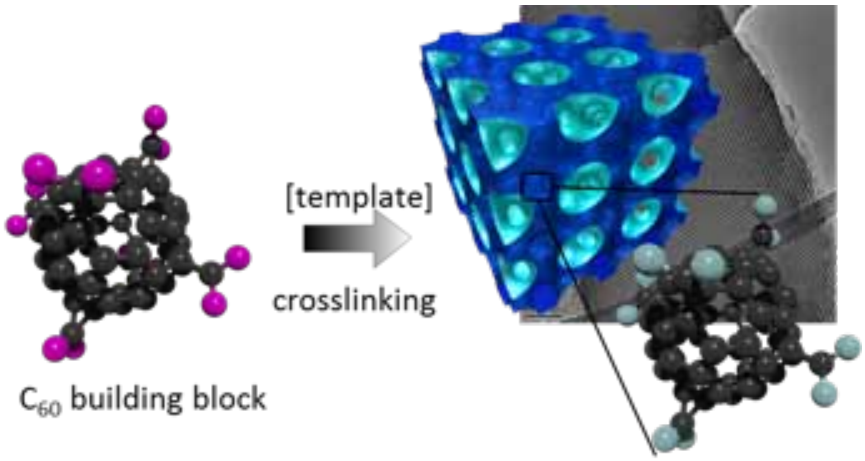

Figure 1. Each fullerene in the highly ordered framework is separated from the next by six functional groups and the mesoporosity is controlled by template-directed, evaporation induced self-assembly with a block copolymer. The TEM image in the background shows the periodic porous fullerene framework.

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MULTIFUNCTIONAL POLYMER-CAPPED MESOPOROUS SILICA NANOPARTICLES FOR PH-RESPONSIVE TARGETED DRUG DELIVERY

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A central challenge of drug delivery research is the targeted transport of drugs to diseased tissue and the subsequent controlled release of the drugs in that region. Mesoporous silica nanoparticles allow for efficient transport and release of drugs. In the past, the group of Thomas Bein has developed multifunctional mesoporous silica nanoparticles, creating a toolbox of functionalisation techniques to allow for the attachment of ligands that control targeting and release. A collaboration of the CeNS groups of Thomas Bein, Christoph Bräuchle and Ernst Wagner now resulted in the design of polymer-capped nanoparticles that are tightly closed under physiological pH, but open up in response to the acidic milieu that is created by cells after particle uptake. With this system they could show successful release of drugs within cancer cells. Furthermore, they could attach ligands to the particles that allow for targeting of tumor cells. First mouse experiments showed the great potential of these drug carriers.

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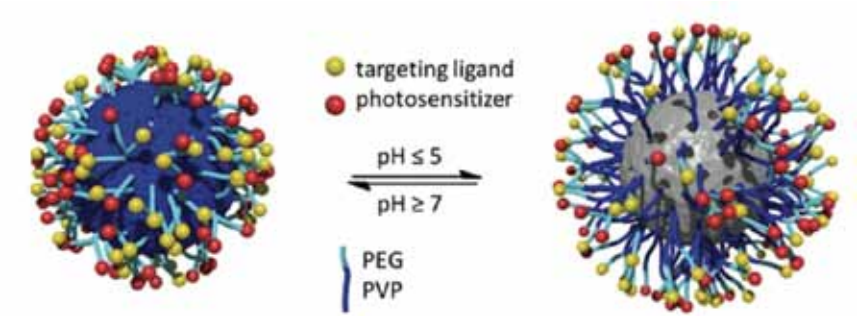

Figure 1. Concept of the pH-responsive delivery system. The pores can be reversibly opened and closed through changes in the water solubility of the polymer.

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ROOM TEMPERATURE SYNTHESIS OF COVALENT–ORGANIC FRAMEWORK FILMS THROUGH VAPOR-ASSISTED CONVERSION

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Covalent organic frameworks are of great interest for the construction of atomically precise nanostructures with well-defined pore systems and a vast space of possible functionalities and interfaces that can be defined through specifically designed molecular building blocks. Thin films of these nanosystems are of particular interest for specific functionalities such as chemical sensors or optoelectronics. Here the groups of Thomas Bein and Paul Knochel report the facile synthesis of several two-dimensional covalent organic frameworks (2D-COFs) as films by vapor-assisted conversion at room temperature. High-quality films of benzodithiophene-containing BDT-COF and COF-5 with tunable thickness were synthesized under different conditions on various substrates. BDT-COF films of several micrometer thickness exhibit mesoporosity as well as textural porosity, whereas thinner BDT-COF films materialize as a cohesive dense layer. In addition, the formation of COF-5 films with different solvent mixture compositions serving as vapor source was studied. Room temperature vapor-assisted conversion is an excellent method to form COF films of fragile precursors and on sensitive substrates.

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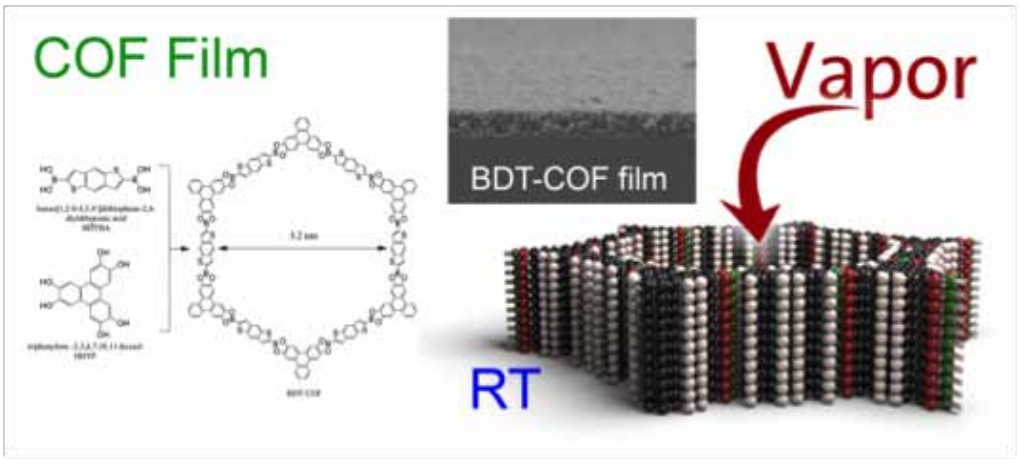

Figure 1. Schematic representation of (left) BDT-COF structure and film, (right) the room temperature vapor-assistant conversion process.

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STABILIZATION OF THE TRIGONAL HIGH-TEMPERATURE PHASE OF FORMAMIDINIUM LEAD IODIDE

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Solar cells based on inorganic-organic hybrid perovskites are now approaching the efficiencies demonstrated for polycrystalline silicon. So far, the material with the potentially highest efficiency is formamidinium lead iodide ($FAPbI_3$), which has been recently shown to exceed 18% power conversion efficiencies when the material is mixed with a small amount of $MAPbBr_3$. In this project, we focus on the origin of the high performance and stability of $FAPbI_3$ that incorporates small amounts of methylammonium (MA), via in-depth X-ray scattering and photophysical measurements. Our results show that the inclusion of MA in the lattice completely stabilizes the desired trigonal (*P*3*m*1) black phase in a temperature range which spans from room temperature up to 250 °C. Additionally, we do not observe any accompanying lattice shrinkage, nor any change in the band gap of the semiconductor, and therefore have isolated the effect of the methylammonium cation in the lattice. We find that the stabilized $FAPbI_3$ exhibits a drastic extension of the lifetime of the photoexcited species, which results in a two-fold increase of the power conversion efficiency.

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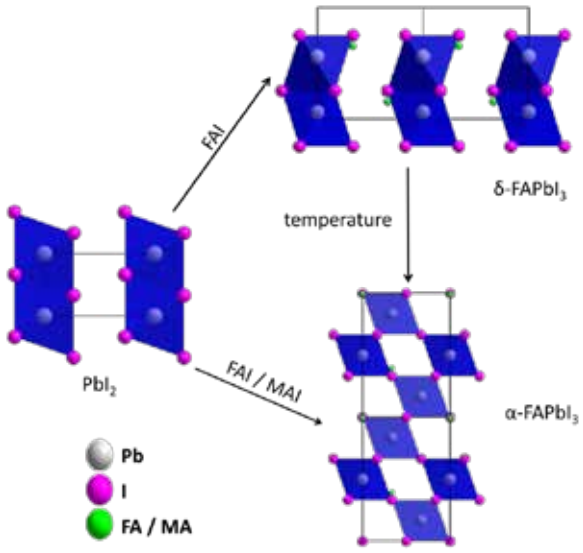

Figure 1. By incorporating a second organic cation (MA) into the lattice of a hybrid perovskite solar cell it was possible to fully suppress the crystal phase change at operating temperatures and to achieve a two-fold increase of the resulting solar cell efficiency.

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THESES

MASTER'S THESES

Constantin Ammar: Origin of the exponential decay of viability during carbon starvation of *E. coli* (LMU, J. Rädler / TUM, U. Gerland)

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Dominic Berchtold: Microscopic fluorescence imaging of pH gradients and electrophoresis at an inorganic self-assembled membrane in a microfluidic non-equilibrium (LMU, D. Braun)

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Chia-Hong Chung: Perovskite Crystal Growth (LMU, T. Bein)

Annette Ding: Development of a tissue-on-a-chip setup to investigate the diffusion of molecules across a cell/biopolymer interface (TUM, O. Lieleg)

Alexandra Fink: Occupancy and Stochastic Transitions of Cells on Multi-Well Micropatterns (LMU, J. Rädler)

Veit Giegold: Studies on the Electronic and Vibrational Coherence in Individual Defect-doped (5,4)-Carbon Nanotubes using Femtosecond Pulse Shaping (LMU, A. Hartschuh)

Nadja Giesbrecht: Solution processed Wide Band Gap Perovskites for Optoelectronic Applications (LMU, T. Bein)

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Katja Zieske: Molecular Self-Organization and Pattern Formation during Bacterial Cell Division – A cell-free Reconstitution Approach (LMU, P. Schwille)

HABILITATION

Christoph Küper: Zur osmoprotektiven Rolle des Transkriptionsfaktors NFAT5 und der Cyclooxygenase-2 in der Niere (LMU, C. Veigel)

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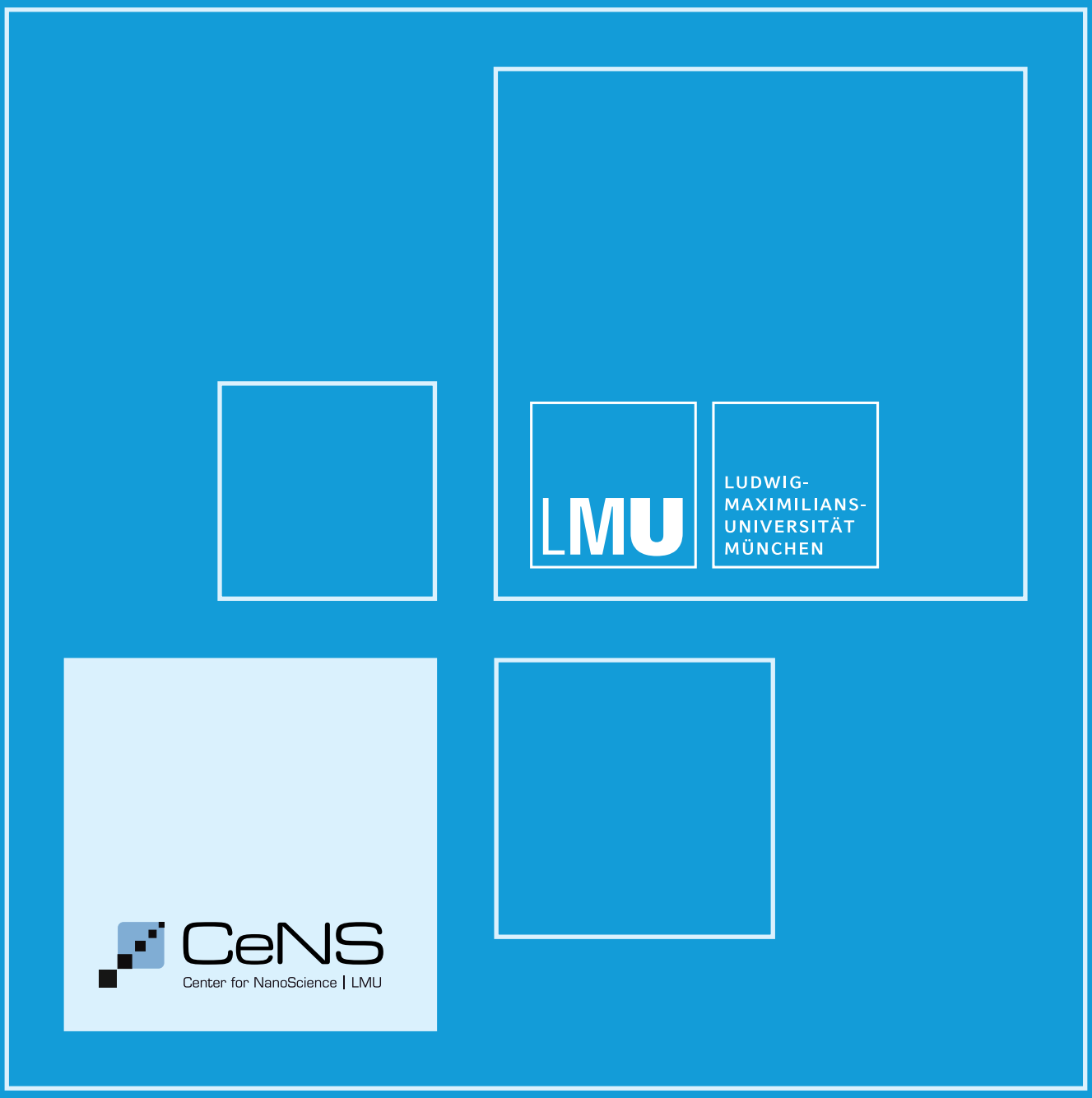
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