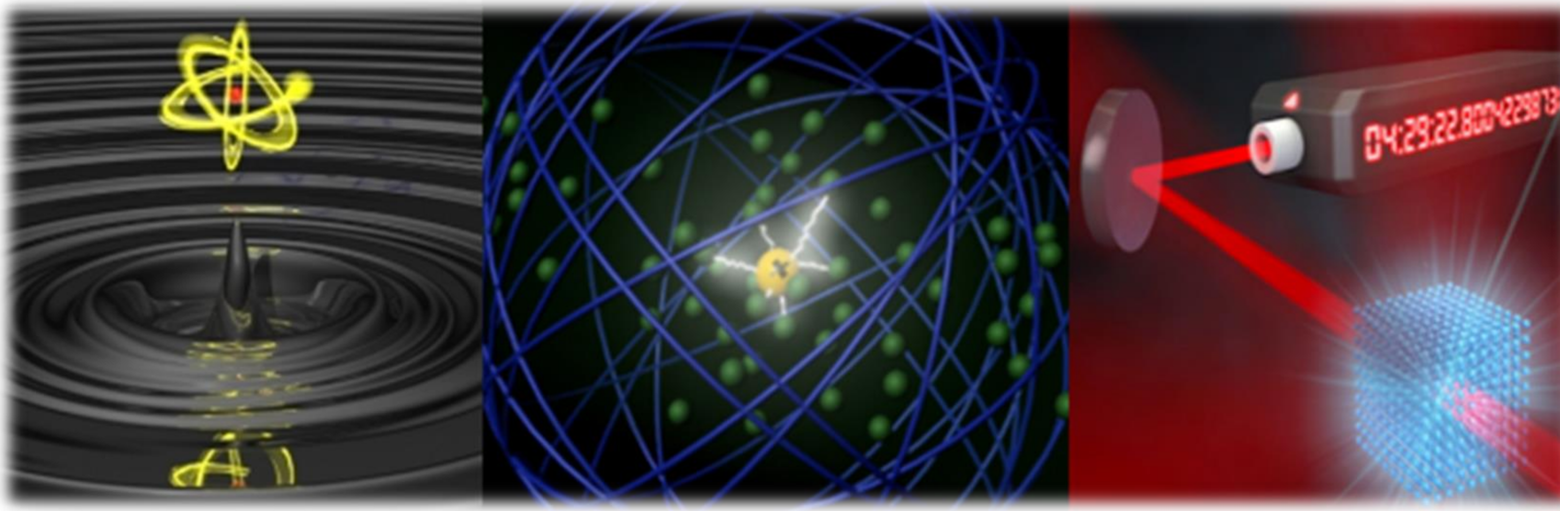
Extremes in atomic physics

(Superlative in der Atomphysik)



Dr. Tim Langen

5. Physikalisches Institut (Prof. Tilman Pfau)

17. Januar 2018

Universität Stuttgart
5. Physikalisches Institut

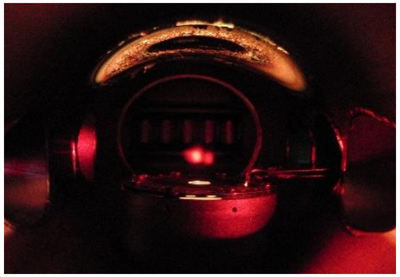
The proton radius puzzle

The most precise scales

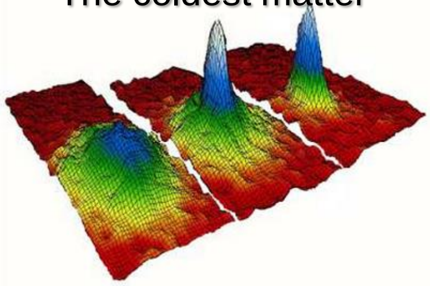
The smallest light portions

The most precise measurement of zero

Laser cooling and trapping

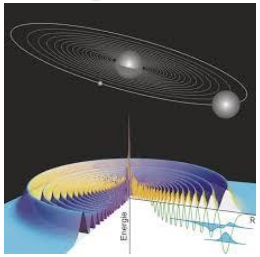


The coldest matter

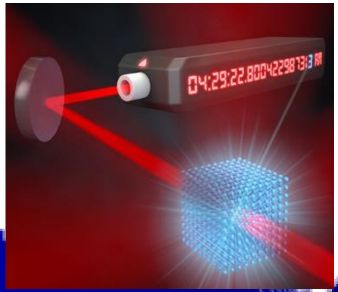


The most dilute liquid

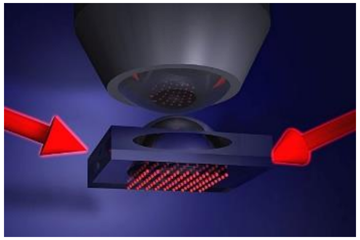
The largest atoms



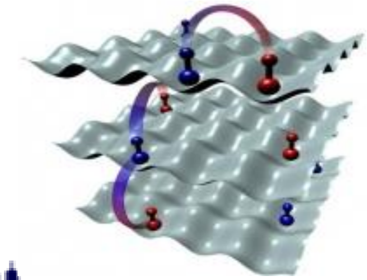
The most precise clock



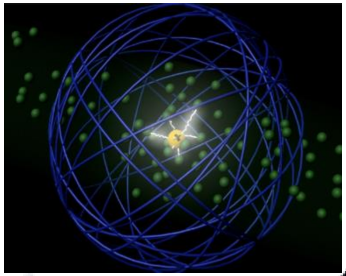
Building materials, one atom at a time



The coldest molecules



The coldest ions



Extremes in atomic physics

Precision spectroscopy

The proton radius puzzle

The most precise scales

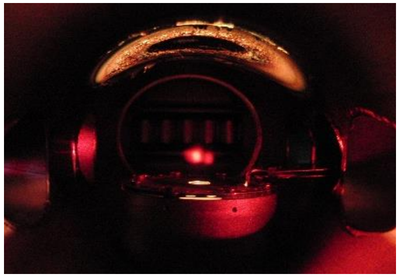
(Moderately) Hot gases of atoms and molecules

The smallest light portions

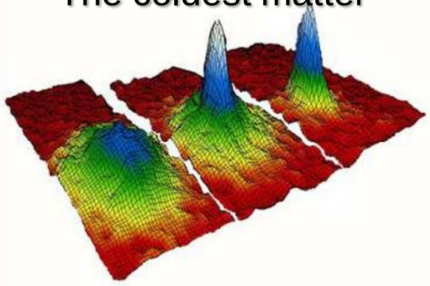
The most precise measurement of zero

Ultracold gases and their applications

Laser cooling and trapping

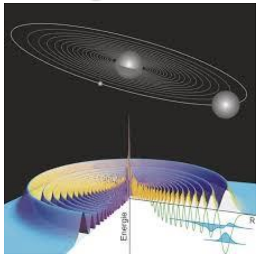


The coldest matter

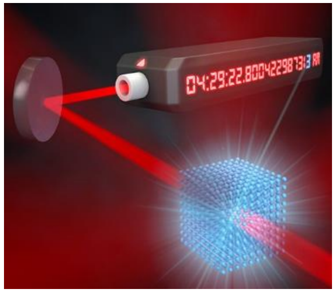


The most dilute liquid

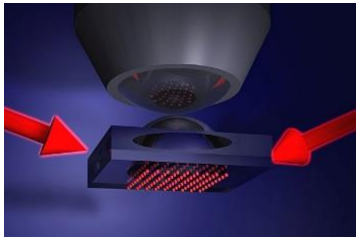
The largest atoms



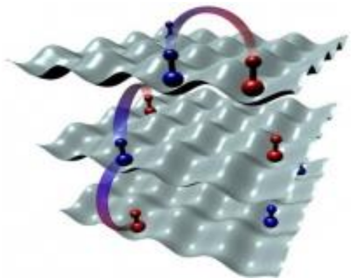
The most precise clock



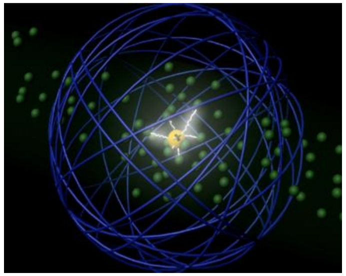
Building materials, one atom at a time



The coldest molecules



The coldest ions



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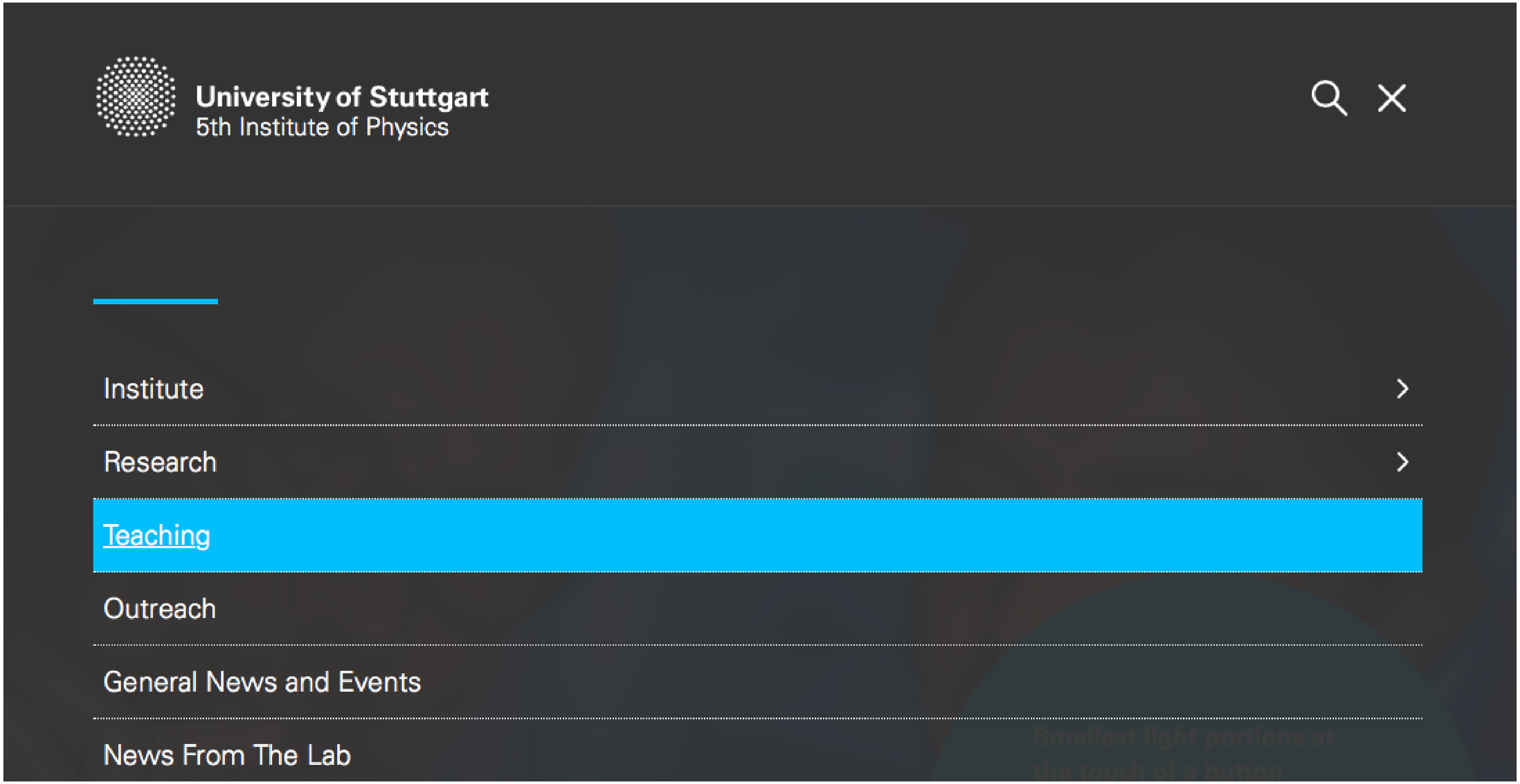

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University of Stuttgart › Faculty 08 ›

University of Stuttgart
5th Institute of Physics

DE / EN

Teaching

5th Institute of Physics

Teaching

Lectures and seminars offered by our institute
[Photo: Universität Stuttgart]

Current Course Offering (Winter Semester 2018/2019)

Seminar Summary:

Modern atomic, molecular and atomic physics provides us with unprecedented insights into the structure of our world. The goal of this seminar is to explore **recent exciting developments in this field**. While the focus will be on **experiments**, we will also discuss extensively the **theoretical background** of these experiments.

Starting with **ultra-high precision spectroscopy of the well-known hydrogen atom**, we will learn how **table-top experiments** can yield more **precise insights into the structure of the universe** than the largest particle accelerators, how **gases can be fully controlled atom by atom** and how some of the **most exotic states of matter** can be created and manipulated.

Contact:

Dr. Tim Langen

PWR 57, room 4.159

t.langen@
physik.uni-stuttgart.de

Seminar Schedule:

Note the new time!

- Thursday, 07.02.19 12.45pm — Organizational Meeting and assignment of talks
- Thurday, 11.04.19 3.45pm — First talk

Location:

- Pfaffenwaldring 57, room 3.123

1.) The proton radius puzzle

Supervisor: Tim Langen

About:

- Hydrogen atom levels, their fine structure and corrections
- Relating spectroscopy to the proton radius
- Spectroscopy of muonic hydrogen
- What is going on?

Literature:

- *R. Pohl et al.,*
  The size of the proton
  Nature 466, 213–216 (2010)

- *A. Beyer et al.,*
  The Rydberg constant and proton size from atomic hydrogen
  Science 358, 79–85 (2017)

- *J.J. Krauth et al.,*
  The proton radius puzzle
  https://arxiv.org/abs/1706.00696

- *D. Castelvecchi*
  Proton-size puzzle deepens
  https://www.nature.com/news/proton-size-puzzle-deepens-1.22760

Source: Nature Publishing group / Paul Scherrer Institute

2.) The most precise scales

Supervisor: Harald Kübler

About:

- Penning ion traps
- Proton mass measurement
- Electron mass measurement

Source: Blaum group, Heidelberg

Literature:

- *F. Heiße et al.,*
  High-Precision Measurement of the Proton's Atomic Mass,
  Phys. Rev. Lett. 119, 033001 (2017)

- *S. Sturm et al.,*
  High-precision measurement of the atomic mass of the electron
  Nature 506, 467 (2014)

- *M. Schirber,*
  Proton loses weight
  https://physics.aps.org/synopsis-for/10.1103/PhysRevLett.119.033001

- *Hans Dehmelt,*
  Nobel Lecture
  https://www.nobelprize.org/uploads/2018/06/dehmelt-lecture.pdf

- *L.S. Brown, G. Gabrielse,*
  Geonium theory: Physics of a single electron or ion in a Penning trap
  Reviews of Modern Physics 58, 233 (1986)

3.) The smallest light portions

Supervisor: Mark Zentile

About:

- Technological aspects of AMO physics
- Rydberg atoms
- Hot atomic vapors
- Single photon sources

Literature:

- *Ripka, F., Kübler, H., Löw, R., Pfau, T.:*
  A room-temperature single-photon source based on strongly interacting Rydberg atoms.
  Science 362, 446-449 (2018).

- *MacRae, A., Brannan, T., Achal, R., & Lvovsky, A. I.:*
  Tomography of a High-Purity Narrowband Photon from a Transient Atomic Collective Excitation.
  Phys. Rev. Lett., 109, 033601 (2012).

- *Dudin, Y. O., & Kuzmich, A.*
  Strongly Interacting Rydberg Excitations of a Cold Atomic Gas.
  Science, 336, 887 (2012)

- *Shu, C. et. al.,*
  Subnatural-linewidth biphotons from a Doppler-broadened hot atomic vapour cell.
  Nat. Commun., 7, 12783 (2016).

4.) The most precise measurement of zero

Supervisor: Tim Langen

About:

- Standard model of particle physics
- Time-reversal symmetry breaking and
  the permanent electric dipole moment of the electron
- Basics of molecular level structure
- Cold molecules and their advantages

Literature:

- *J. J. Hudson, D. M. Kara, I. J. Smallman, B.E. Sauer, M. R. Tarbutt and E. A. Hinds,*
  Improved measurement of the shape of the electron
  Nature 473, 493 (2011)
- *Order of Magnitude Smaller Limit on the Electric Dipole Moment of the Electron.*
  The ACME Collaboration
  Science 343, 269-272 (2014)
- *W. B. Cairncross et al.,*
  A precision measurement of the electron's electric dipole moment
  using trapped molecular ions
  Phys. Rev. Lett. 119, 153001 (2017)
- *The ACME Collaboration,*
  Improved limit on the electric dipole moment of the electron
  Nature 562, 355-360 (2018)
- *D. DeMille, J.M. Doyle, A.O. Sushkov,*
  Probing the frontiers of particle physics with tabletop-scale experiments
  Science 357, 990-994 (2017)

Source: Science magazine

5.) Laser cooling and trapping

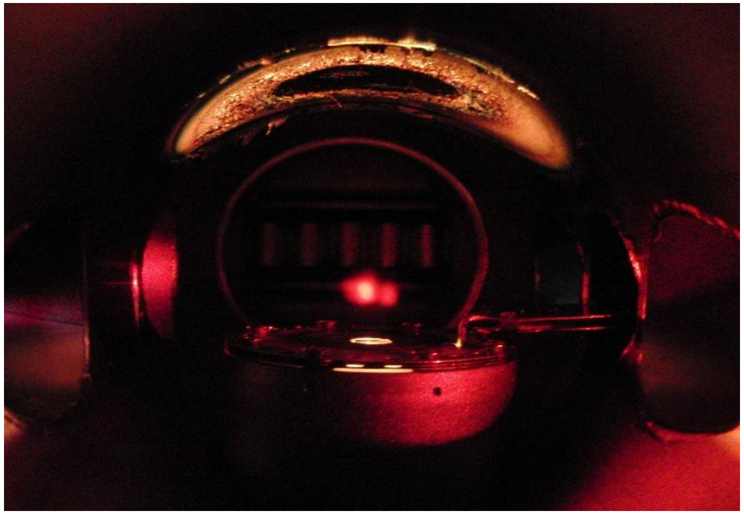
Supervisor: Tim Langen

About:

- Basics of laser cooling: Doppler cooling, sub-Doppler cooling, optical molasses
- Magneto-optical trapping
- Example: Laser cooling of molecules

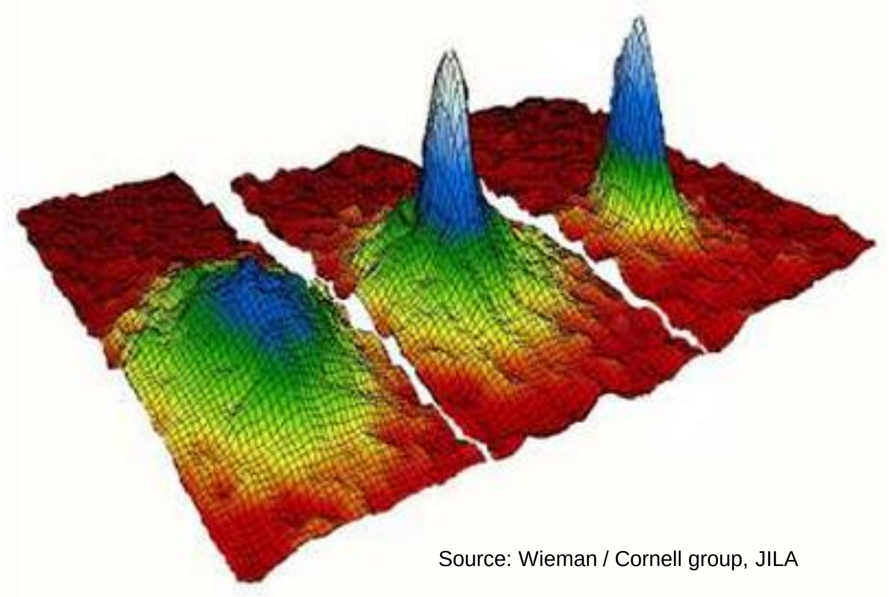
Literature:

- *H. Metcalf, P. van der Straten*
  Laser cooling and Trapping
- *C. Foot*
  Atomic Physics
- *W.D. Phillips*
  Nobel Lecture: Laser cooling and trapping of neutral atoms
  Rev. Mod. Phys. 70, 721 (1998)
- *Shuman, E. S., Barry, J. F. & DeMille, D.,*
  Laser cooling of a diatomic molecule
  Nature 467, 820–823 (2010).
- *D. DeMille*
  Direct Laser Cooling & Trapping of Diatomic Molecules
  https://www.youtube.com/watch?v=hIkh-Rt-Zxk



6.) The coldest matter

Supervisor: Robert Löw



About:

- Evaporative cooling
- Bose-Einstein condensation of dilute gases
- Gross-Pitaevskii equation
- Ultracold Fermi gases
- Contact interaction and Feshbach resonances

Literature:

- *L. Pitaevskii, S. Stringari,*
  Bose-Einstein Condensation and Superfluidity
- *C. J. Pethick and H. Smith*
  Bose-Einstein Condesation in Dilute Gases
- *W. Ketterle, D.S. Durfee, D.M. Stamper-Kurn*
  Making, probing, and understanding Bose-Einstein condensates
  arXiv:cond-mat/9904034
- *M. H. Anderson, J. R. Ensher, M. R. Matthews, C. E. Wieman, E. A. Cornell*
  Observation of Bose-Einstein Condensation in a Dilute Atomic Vapor
  Science 269, 198 (1995)
- *B. DeMarco, D. S. Jin*
  Onset of Fermi Degeneracy in a Trapped Atomic Gas
  Science 285, 1703 (1999)

7.) The most dilute liquid

Supervisor: Tim Langen

About:

- Dipolar interactions
- Extended Gross-Pitaevskii equation
- Dilute quantum liquids
- Self-bound dipolar droplets

Literature:

- *T. Lahaye, C. Menotti, L. Santos, M. Lewenstein, and T. Pfau*
  The physics of dipolar bosonic quantum gases
  *Rep. Prog. Phys. **72**, 126401 (2009)*

- *H. Kadau, M. Schmitt, M. Wenzel, C. Wink, T. Maier, I. Ferrier-Barbut, T. Pfau:*
  Observing the Rosensweig instability of a quantum ferrofluid
  *Nature **530**, 194 (2016)*

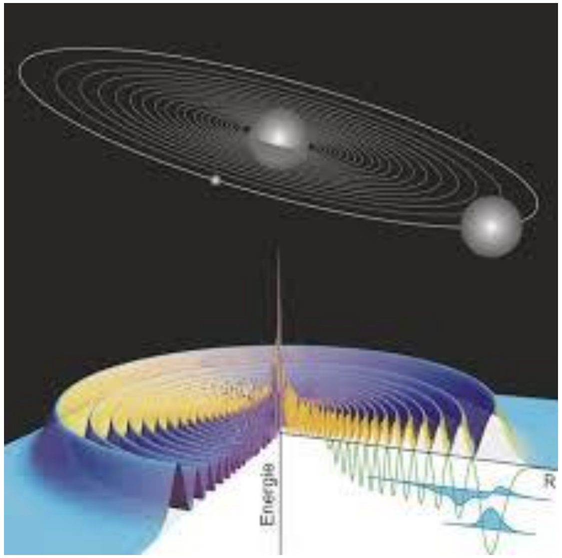
- *L. Chomaz, S. Baier, D. Petter, M. J. Mark, F. Wächtler, L. Santos, F. Ferlaino,*
  Quantum-fluctuation-driven crossover from a dilute Bose-Einstein condensate to a macro-droplet in a dipolar quantum fluid,
  *Phys. Rev. X **6**, 041039 (2016)*

- *M. Schmitt, M. Wenzel, B. Böttcher, I. Ferrier-Barbut, T. Pfau:*
  Self-bound droplets of a dilute magnetic quantum liquid
  *Nature **539**, 259 (2016)*

- *C. R. Cabrera, L. Tanzi, J. Sanz, B. Naylor, P. Thomas, P. Cheiney, and L. Tarruell*
  Quantum liquid droplets in a mixture of Bose-Einstein condensates
  *Science **359**, 301-304 (2018)*

8.) The largest atoms

Supervisor: Florian Meinert



About:

- Properties of Rydberg atoms
- Rydberg atoms in dense atomic gases and BECs
- Long-range two-body interactions between Rydberg atoms
- Rydberg blockade and „superatoms“
- Dense ensembles: Formation of Rydberg molecules

Literature:

- *R. Löw, H. Weimer, J. Nipper, J. B. Balewski, B. Butcher, H. P. Büchler, T. Pfau,*
  An experimental and theoretical guide to strongly interacting Rydberg gases,
  J. Phys. B: At. Mol. Opt. Phys. ***45****, 113001 (2012).*

- *A. Gaetan, et al.,*
  Observation of collective excitation of two individual atoms in the Rydberg blockaded regime,
  Nat. Phys. ***5****, 115-118 (2009).*

- *L. Béguin, A. Vernier, R. Chicireanu, T. Lahaye, A. Browaeys,*
  Direct measurement of the van der Waals Interaction between Two Rydberg Atoms,
  Phys. Rev. Lett. ***110****, 263201 (2013).*

- *P. Schauß, M. Cheneau, M. Endres, T. Fukuhara, S. Hild, A. Omran, T. Pohl, C. Gross, S. Kuhr, I. Bloch,*
  Observation of spatially ordered structures in a two-dimensional Rydberg gas,
  Nature ***491****, 87-91 (2012).*

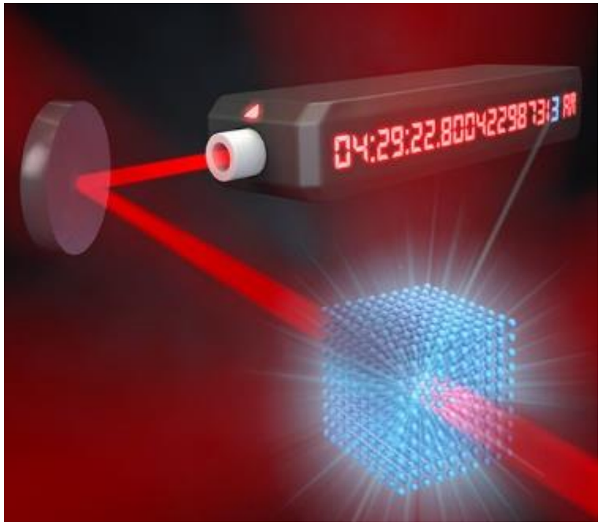
- *V. Bendkowsky, B. Butscher, J. Nipper, J. S. Shaffer, R. Löw, T. Pfau,*
  Observation of ultralong-range Rydberg molecules,
  Nature ***458****, 1005-1008 (2009).*

9.) The most precise clock

Supervisor: Tilman Pfau

About:

- Ramsey interferometry
- Optical clocks
- Ultrastable resonators and lasers
- A Fermi degenerate optical lattice clock
- Many-body interactions in optical clocks



Source: Ye group, JILA

Literature:

- *S. L. Campbell et al.,*
  A Fermi-degenerate three-dimensional optical lattice clock
  Science 358, 90 - 94 (2017).

- *T. L. Nicholson et al.*
  Systematic evaluation of an atomic clock at 2 x 10-18 total uncertainty
  Nature Communications 6, 6896/1-8 (2015).

- *A. D. Ludlow, M.M. Boyd, J. Ye , E. Peik , and P. O. Schmidt,*
  Optical atomic clocks
  Reviews of Modern Physics 87, 637 - 701 (2015).

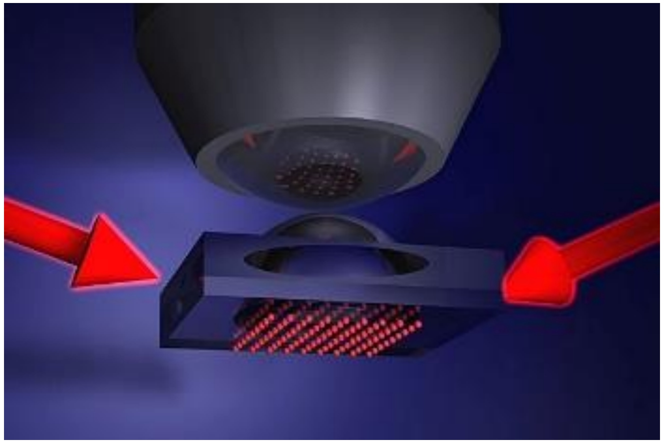
- *X. Zhang and J. Ye,*
  Precision measurement and frequency metrology with ultracold atoms
  National Science Review 3, 189 - 200 (2016).

10.) Building materials, one atom at a time

Supervisor: Tim Langen

About:

- Bosonic quantum gases on a lattice: Bose-Hubbard model
- Superfluid-to-Mott-insulator quantum phase transition
- Single-site resolved observation of an atomic Bose-Hubbard system
- Optical tweezer arrays



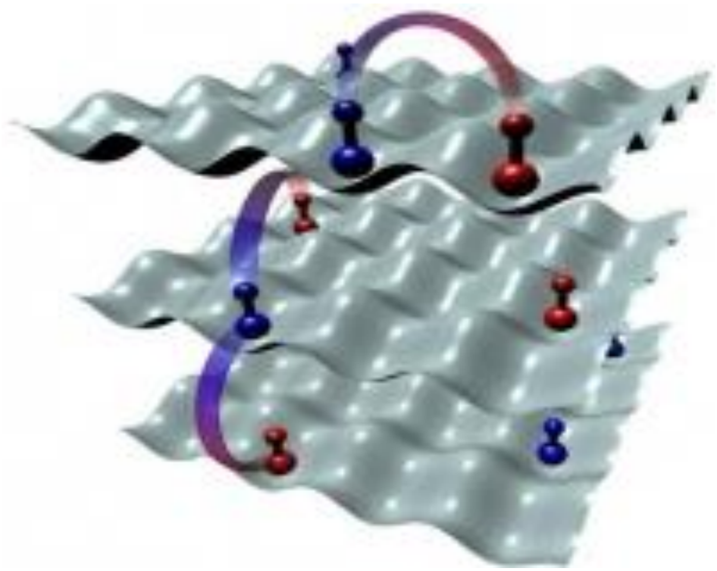
Source: Greiner group, Harvard

Literature:

- *I. Bloch, J. Dalibard, W. Zwerger,*
  Many-body physics with ultracold gases,
  Rev. Mod. Phys. ***80****, 885 (2008).*
- *M. Greiner, O. Mandel, T. Esslinger, T. W. Hänsch, I. Bloch*
  Quantum phase transition from a superfluid to a Mott insulator in a gas of ultracold atoms,
  Nature ***415****, 39-44 (2002).*
- *W.S. Bakr, A. Peng, M. E. Tai, R. Ma, J. Simon, J. I. Gillen, S. Fölling, L. Pollet, M. Greiner,*
  Probing the Superfluid-to-Mott Insulator Transition at the Single-Atom Level,
  Science ***329****, 547-550 (2010).*
- *M. Endres et al.,*
  Atom-by-atom assembly of defect-free one-dimensional cold atom arrays
  Science ***354****, 1024 (2016).*
- *D. Barredo et al.,*
  Synthetic three-dimensional atomic structures assembled atom by atom
  Nature ***561****, 79 (2018).*

11.) The coldest molecules

Supervisor: Mingyang Guo



Source: Ye group, JILA

About:

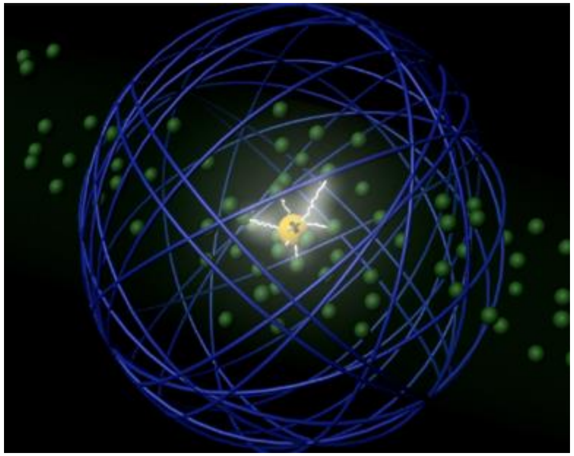
- Feshbach association, STIRAP and molecular BECs
- Molecules in optical lattices
- Single molecules in optical tweezers
- Dipolar physics and cold chemistry with bialkali molecules

Literature:

- *K.-K. Ni et al.,*
  A High Phase-Space-Density Gas of Polar Molecules,
  Science 322, 231 - 235 (2008)
- *M. H. G. de Miranda et al.,*
  Controlling the quantum stereodynamics of ultracold bimolecular reactions,
  Nature Physics 7,502-507 (2011)
- *B. Yan et al., Observation of dipolar spin-exchange interactions with lattice-confined polar molecules,*
  Nature 501, 521 - 525 (2013).
- *M. Guo et al., Creation of an ultracold gas of ground-state 23Na87Rb molecules*
  Physical Review Letters 116, 205303(2016)
- *S. Moses, J. Covey , T. Miecnikowski, D. Jin, and J. Ye,*
  New frontiers for quantum gases of polar molecules
  Nature Physics 13, 13 - 20 (2017)
- *L. R. Liu, J. D. Hood, Y. Yu, J. T. Zhang, N. R. Hutzler, T. Rosenband, K.-K. Ni*
  Building one molecule from a reservoir of two atoms.
  Science 360, 900 (2018)

11.) The coldest ions

Supervisor: Florian Meinert



About:

- Conventional ion traps and micromotion
- Rydberg atoms in dense atomic gases and BECs
- Ionization of Rydberg atoms
- Ion-atom interactions

Literature:

- *Kleinbach, K.S., Engel, F., Dieterle, T., Löw, R., Pfau, T., Meinert, F.*
  Ionic Impurity in a Bose-Einstein Condensate at Submicrokelvin Temperatures
  Phys. Rev. Lett. 120, 193401 (2018).

- *Engel, F., Dieterle, T., Schmid, T., Tomschitz, C., Veit, C., Zuber, N., Löw, R., Pfau, T., Meinert, F.*
  Observation of Rydberg Blockade Induced by a Single Ion.
  Phys. Rev. Lett. 121, 193401 (2018).

- *M. Tomza, K. Jachymski, R. Gerritsma, A. Negretti, T. Calarco, Z. Idziaszek, P. S. Julienne*
  Cold hybrid ion-atom systems
  arXiv:1708.07832 (2018)

- *J. B. Balewski, A. T. Krupp, A. Gaj, D. Peter, H. P. Büchler, R. Löw, S. Hofferberth & T. Pfau*
  Coupling a single electron to a Bose–Einstein condensate
  Nature 502, 664–667 (2013)