Sahand Mahmoodian

Curriculum Vitae

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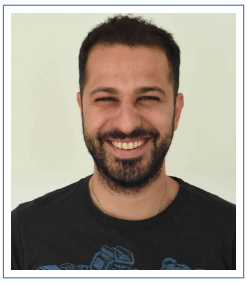

Summary and Career Goals

I'm a theoretical physicist working in the fields of quantum optics and photonics in systems where light–matter interaction can be tailored. My research in this area focuses on engineering light–matter interaction to generate new and useful quantum states of light. I'm interested in using these new quantum states to develop useful quantum technologies.

I am currently leading a research group at the University of Sydney composed of one postdoc, three PhD students, one honours student and two research associates. My research is currently funded by my ARC Future Fellowship and my PhD students also receive funding from the Sydney Quantum Academy.

My career goal is to perform outstanding research and teaching in an environment that fosters excellent physics research and education. In the next few years, I see myself leading a medium-sized research effort in quantum optics theory and its applications in quantum technologies. I also foresee significant collaboration with experimental groups. I am an enthusiastic teacher and see teaching as a central role of an academic. I am excited to incorporate new research-level concepts into coursework and I have a vision to develop coursework that teaches students multiple approaches to solve problems in physics (both novel numerical and analytic approaches) and understand applications in technology.

Employment

2021-present **ARC Future Fellow**, *School of Physics, The University of Sydney, NSW, Australia.*
Future Fellowship title: Emergent many-body phenomena in engineered quantum optical systems. Start date 1st of June, 2021.

2017-2021 **Postdoctoral Researcher**, *Institute for Theoretical Physics, and The Institute for Gravitational Physics (Albert Einstein Institute), Hannover, Germany.*
Principal Investigator: Prof. Klemens Hammerer
Area of Study: Generating few- and many-body states of light in one-dimensional systems.

2013-2016 **Postdoctoral Researcher**, *Niels Bohr Institute, University of Copenhagen, Denmark.*
Principal Investigators: Profs. Anders Sørensen and Peter Lodahl
Area of Study: Theoretical and numerical investigation of light–matter interaction in photonic nanostructures. Quantum nanophotonic systems for quantum information processing.
Funding: Danish Council for Independent Research (FNU) Individual Postdoctoral Grant

Education

2008-2013 **Ph.D. in physics**, *The University of Sydney*.
Date of Award: 14 June 2013
Thesis Title: Perturbative Methods for Localised States in Photonic Crystals.
Advisors: Prof. C. Martijn de Sterke and Prof. Ross C. McPhedran
Area of Study: Developed and applied semi-analytic methods for examining photonic crystal waveguide and cavity modes.
External Stay: University of Toronto with Prof. John Sipe

2004-2007 **Bachelor of Science (Advanced) Honours I**, *The University of Sydney*.
First class honours with majors in physics and mathematics

Publications

I have published 30 journal papers and preprints which have received over 5000 citations (Google Scholar). I currently have four papers with more than 500 citations, two of which have more than 1000 citations. For a complete list of published work, see my Google Scholar profile or my ORCID profile. My best publications include:

[1] S. Mahmoodian, G. Calajó, D. Chang, K. Hammerer, and A. Sørensen. Dynamics of Many-Body Photon Bound States in Chiral Waveguide QED. *Phys. Rev. X* **10**, 031011, 2020.
We showed that waveguide systems with coupled two-level systems constitute a platform with a photon-number-sensitive nonlinear interaction response. We described the dynamics using a simple class of many-body photon states called photon bound states (class of Bethe Ansatz eigenstates). The many-body photon-bound states behave as emergent quasiparticles that have their own distinct dispersion behaviour. We also established a previously unseen link between photon bound states (purely quantum mechanical objects) and classical soliton propagation in waveguide QED. We showed that the system can also produce photons with a large amount of entanglement. I did all the analytic calculations. The idea was proposed by A.S.S., K.H. and myself.

[2] N. Tomm*, S. Mahmoodian*, N.O. Antoniadis, R. Schott, S.R. Valentin, A.D. Wieck, A.Ludwig, A. Javadi, R.J. Warburton. Direct observation of photon bound states using a single artificial atom. *Nat. Phys.*, 2023. ** denotes equal contribution*
*First direct experimental observation of photon bound states by observing the difference in delay of one and two photons. I proposed this experiment to the group in Basel and I adapted the theory in **[1]** to their platform. I worked with our press team to prepare a press release and this work received significant coverage with articles appearing in Newsweek, Canberra Times COSMOS and elsewhere.*

[3] S. Mahmoodian. Chiral light-matter interaction beyond the rotating-wave approximation. *Phys. Rev. Lett.* **123**, 133603, 2019.
I presented a new many-body light-matter interaction model in the ultrastrong coupling limit. The ground states are novel two-mode squeezed states that are entangled with the atom. I showed that the solutions to the model can be expressed using an angular momentum ansatz.

[**4**] S. Mahmoodian, M. Čepulkovskis, S. Das, P. Lodahl, K. Hammerer, and A.S. Sørensen. Strongly Correlated Photon Transport in Waveguide Quantum Electrodynamics with Weakly Coupled Emitters. *Phys. Rev. Lett.* **121**, 143601, 2018.
This work showed that optically deep ensembles of two-level atoms coupled to waveguides can induce strongly correlated photon transport. This was an unexpected result and has opened the door to observing strongly correlated photon transport in nanofiber platforms with trapped atoms. We were able to obtain analytic expressions and universal scaling relations for the transmitted power and correlation functions. A.S.S. and I conceived this project. I did the calculations.

[**5**] I. Söllner, S. Mahmoodian, S. Lindskov Hansen, L. Midolo, A. Javadi, G. Kiršanskė T. Pregnolato, H. El-Ella, E.H. Lee, J.D. Song, S. Stobbe, and P. Lodahl. Deterministic photon–emitter coupling in chiral photonic circuits. *Nat. Nanotechnol.* **10**, 775–778, 2015.
In this manuscript we demonstrated chiral light-matter interaction and non-reciprocal emission of light into a photonic waveguide. It was one of a number of seminal papers that demonstrated chiral light–matter interaction. I played a critical role in conceiving the experiment, designing the sample, doing the theory, and helping process the data. This work attracted a lot of attention and was picked up by Danish and international media. For example see: report in DR.dk

[**6**] S. Mahmoodian, P. Lodahl, and A.S. Sørensen. Quantum networks with chiral-light–matter interaction in waveguides. *Phys. Rev. Lett.*, **117**, 240501, 2016.
We proposed and analyzed a scheme for realizing a quantum network composed of simple two-qubit nodes each in the form of an on-chip optical Mach-Zehnder Interferometer. Chiral-light–matter interaction allows the simple nodes to perform both loss-tolerant local two-qubit gates and generate internode entanglement. I did the theory and calculations. The idea was proposed by A.S.S. and myself.

[**7**] Peter Lodahl, Sahand Mahmoodian, Søren Stobbe, Arno Rauschenbeutel, Philipp Schneeweiss, Jürgen Volz, Hannes Pichler, Peter Zoller. Chiral quantum optics, *Nature* **541**, 473, 2017.
Our group was invited by Nature to write a review on chiral light-matter interaction. This review was written with other world leaders in this field and has become an authoritative piece of work. It has not only led to enormous interest within the field but has seen chiral light-matter interaction become valued by other areas in quantum optics. This has been cited more than 1000 times

[**8**] P. Lodahl, S. Mahmoodian, and S. Stobbe. Interfacing single photons and single quantum dots with photonic nanostructures, *Reviews of Modern Physics* **87**, 347, 2015.
This 54 page review article is a tour de force published in the world's foremost physics review journal. The work reviewed the entire literature associated with quantum dots and photonic nanostructures and set the stage for future work. It helped expand the emerging field of quantum optics with engineered light–matter interaction. It has now been cited more than 1300 times.

[**9**] Adarsh S Prasad, Jakob Hinney, Sahand Mahmoodian, Klemens Hammerer, Samuel Rind, Philipp Schneeweiss, Anders Sørensen, Jürgen Volz, and Arno Rauschenbeutel. Correlating photons using the collective nonlinear response of atoms weakly coupled to an optical mode, *Nature Photonics* **14**, 719, 2020.
*This work showed, for the first time, that weakly coupled atomic ensembles can be used to generate anitbunched or bunched states of light. We showed that the photon correlations of the light can be tuned by changing the optical depth of the atomic ensemble. This work is related to patent **[P4]**. I did the theory calculations that supported the experiments.*

Patents

My research has led to significant innovation. I am listed as a co-inventor on four patents for on-chip quantum photonics and single photon sources. Some of these patents have been licensed by my colleagues' startup Sparrow Quantum and are being developed further.

[**P1**] Sahand Mahmoodian, Immo Söllner, Søren Stobbe and Peter Lodahl, *Efficient spin-photon interface using glide-plane symmetric waveguide.* US10261250B2, EP3154899A1. Priority date 16-06-2014.

[**P2**] Sahand Mahmoodian, Immo Söllner, Søren Stobbe, and Peter Lodahl, *Optical Devices having an Efficient Light-Matter Interface for Quantum Simulation.* US20170160474A1. Priority date 14-07-2014.

[**P3**] Søren Stobbe, Sahand Mahmoodian, David Garcia and Peter Lodahl, *A slow-light generating optical device and a method of producing slow light with low losses.* US20180217331A1. Priority date 20-04-2015.

[**P4**] Philipp Schneeweiss, Jürgen Volz, Arno Rauschenbeutel, Sahand Mahmoodian, and Anders S. Sørensen, *Device for generating single photons* European patent: PCT/EP2019/075386. Date of receipt 20-09-2019

Prizes, Awards, and Grants

Falling Walls Foundation Physical Science Breakthrough of the Year Finalist (2023)

School of Physics Foundation Grand Challenge seed funding prize (Quantum many-body techniques for machine learning) 2022 and 2023 ($100k)

Australian Research Council (ARC) Future Fellowship 2020 (June 2021-present)

Danish Council for Independent Research (FNU) Individual Postdoctoral Grant (2013-2015)

First place - Best Poster Award - CEWQO Brussels (2014)

Third place - Best student presentation - PECS-X Santa Fe (2012)

First place - Best student research poster - CUDOS workshop (2010)

First place - Student competition (MC Udos) - CUDOS workshop (2010)

Australian Postgraduate Award Scholarship (2008-2011)

Third place - Student competition (Single Photon Sauce) - CUDOS workshop (2012)

School of Physics Science Foundation Scholarship No. III (2007)

Teaching

2021-present **Lecturer**, *The University of Sydney*.

Semester 1 (2023-2024): Second-year undergraduate Optics (Advanced) module, 13 lectures, teaching approximately 60 students. I modernised a course that had remained the same for decades thus effectively preparing a completely new optics course. I wrote approximately 80 pages of text-book-like detailed lecture notes from scratch. Employed new teaching methods such as "flipped" lectures, used demonstrations, presented numerical approaches. Prepared completely new problem sets, quizzes, tutorials, exams and assignment.

Semester 2 (2023): Solid-state-device Physics for Electrical Engineers. 12 lectures. I took over this course from a colleague. I taught this from the textbook *Semiconductor Physics and Devices* by Donald Neaman.

2017-2021 **Assistant Lecturer**, *Leibniz University, Hannover.*
I prepared lecture material and gave lectures in quantum optics and advanced quantum mechanics. I led computational physics modules in Introductory Quantum Mechanics (Python) and Analytical Mechanics (Mathematica). This involved coming up with and implementing new computational exercise problems.

2013-2016 **Assistant Lecturer**, *Niels Bohr Institute, University of Copenhagen.*
I prepared coursework for quantum nanophotonics with Prof. Lodahl. This included developing a module on computational electromagnetism. I was also responsible for the problem sets.

Postdoc and Student Supervision

2021-present **Current project supervision**, *The University of Sydney.*
I employ one postdoctoral researcher. I am the lead supervisor of three PhD students and one BSc Hons student.
I have supervised one MSc student to completion and one BSc Hons project (1 year project) to completion.

2017-2021 **Project supervision**, *Leibniz University, Hannover.*
I cosupervised one PhD. student working on many-body quantum optics.

2013-2016 **Project supervision**, *Niels Bohr Institute, University of Copenhagen.*
Cosupervised two MSc projects.

Professional Services

Referee.
I appreciate a robust peer-review process, and as such I try to excel as a referee. I regularly review manuscripts for *Physical Review Letters* and *Physical Review A*. Additionally, I have reviewed manuscripts for *Reviews of Modern Physics*, *Physical Review X*, *Nature Communications*, *Optica*, *Optics Letters*, and *Optics Express*.

Languages, Interests and Hobbies

English (native), Farsi (fluent), Danish (intermediate), Russian (beginner)

Resistance training (kettle bells, snatch and clean and jerk lifts, body-weight-based), Manual photography (Rolleiflex Automat), and cooking pasta.

References

Andrew Doherty, Professor, School of Physics, The University of Sydney.
email: andrew.doherty@sydney.edu.au phone: +61 2 9351 7645
I currently collaborate with Andrew at The University of Sydney.

Klemens Hammerer, Professor, Leibniz University, Hannover, Germany.
email: klemens.hammerer@itp.uni-hannover.de phone: +49 511 762 17072
I worked as a postdoc with Klemens at the Institute for Theoretical Physics, Leibniz University, Hannover.

Anders Sørensen, Professor, the Niels Bohr Institute, Copenhagen, Denmark.
email: anders.sorensen@nbi.ku.dk phone: +45 3532 5240
I worked as a postdoc with Anders at the Niels Bohr Institute.

Peter Lodahl, Professor, The Niels Bohr Institute, Copenhagen, Denmark.
email: lodahl@nbi.ku.dk phone: +45 3532 5306
I worked as a postdoc with Peter at The Niels Bohr Institute.