PEOPLE – MARIE CURIE ACTIONS:	Marie Curie Career Integration Grants (CIG)
FP7 Call for Proposals:	FP7-PEOPLE-2013-CIG
Grant Agreement No.	PCIG13-GA-2013-618353
Acronym:	SUPTANGO
Project website:	https://research.chalmers.se/project/6064

Dr. **Jonas Bylander**, Assoc. Prof.
Chalmers University of Technology, Dept. Microtechnology and Nanoscience, Gothenburg, Sweden
jonas.bylander@chalmers.se +46 31 772 5132

Final report – Publishable summary

Objectives, and description of the work carried out

The original objective of this project was to experimentally demonstrate steady-state entanglement between superconducting qubits by means of controlling their interaction with their environment using novel microwave manipulation techniques. Due to developments in the field before this project had even started, I had to redirect my work and instead follow the contingency plan, which had different particular activities and goals within the same general field, namely

- *to develop microwave nonlinear superconducting resonators and nonclassical states of microwave radiation, and*
- *aim to apply these systems to quantum information science.*

In particular, our systems may be used for continuous-variable quantum computing with nonclassical states of microwave radiation, currently a booming field.

With the alternative plan put into action, this project was quite successful, as described in the results and impact section below and as shown by the list of publications. The work was mainly experimental and involved, to a large extent, the supervision of junior scientist.

Main results and potential impact

These results have potential applications in quantum information technology with superconducting quantum circuits. Paper 2 presents a novel and scalable method for ultra-sensitive detection of the state of a quantum bit of information; paper 1 demonstrates amplification of microwaves at the ultimate limit of sensitivity, and in paper 6 we employ the same type of system to study parametric oscillations; papers 3–5 explore a novel regime of nonlinear dynamics in superconducting microwave oscillators; and paper 7 demonstrates a source of quantum entangled photons. Papers 2–7 represent steps toward continuous-variable quantum information processing with nonclassical states of microwave radiation.

Career progression and impact of the Marie Curie CIG

The Marie Curie CIG has been very helpful at the outset of my career as an independent researcher and faculty member at Chalmers. It has defrayed part of my salary costs and also helped attract additional funding.

I passed the Swedish “docent” habilitation in 2015 and am holding a permanent faculty position as an associate professor since 2017. I am currently main advisor of two PhD students, and I co-manage the laboratory which consists of 15 people and is growing.

Publications from this project

1. M. Simoen, C. W. S. Chang, P. Krantz, J. Bylander, W. Wustmann, V. S. Shumeiko, P. Delsing, and C. M. Wilson. "Characterization of a multimode coplanar waveguide parametric amplifier." ***Journal of Applied Physics*** vol. 118, 154501 (2015).
2. P. Krantz, A. Bengtsson, M. Simoen, S. Gustavsson, V. Shumeiko, W. D. Oliver, C. M. Wilson, P. Delsing, and J. Bylander. "Single-shot read-out of a superconducting qubit using a Josephson parametric oscillator." ***Nature Communications*** vol. 7, 11417 (2016).
3. I.-M. Svensson, A. Bengtsson, P. Krantz, J. Bylander, V. Shumeiko, and P. Delsing. "Period-tripling subharmonic oscillations in a driven superconducting resonator." ***Physical Review B*** vol. 96, 174503 (2017).
4. I.-M. Svensson, A. Bengtsson, J. Bylander, V. Shumeiko, and P. Delsing. "Period multiplication in a parametrically driven superconducting resonator." ***Applied Physics Letters*** vol. 113, 022602 (2018).
5. I.-M. Svensson, M. Pierre, M. Simoen, W. Wustmann, P. Krantz, A. Bengtsson, G. Johansson, J. Bylander, V. Shumeiko, and P. Delsing. "Microwave photon generation in a doubly tunable superconducting resonator." ***Journal of Physics: Conference Series*** vol. 969, 012146 (2018).
6. A. Bengtsson, P. Krantz, M. Simoen, I.-M. Svensson, B. H. Schneider, V. Shumeiko, P. Delsing, and J. Bylander. "Nondegenerate parametric oscillations in a tunable superconducting resonator." ***Physical Review B*** vol. 97 144502 (2018).
7. B. H. Schneider, A. Bengtsson, I.-M. Svensson, T. Aref, G. Johansson, J. Bylander, and P. Delsing. "Observation of broadband entanglement in microwave radiation from the dynamical Casimir effect." Preprint arXiv:1802:05529 (2018).

Selected other dissemination and outreach measures during the project

- Main supervisor of 2 PhD students, 2 postdocs; co-advisor of 8 PhD students, 3 postdocs; supervisor and examiner of 4 MSc students; supervisor of 1 BSc project (3 students)
- Teacher of two master's-level courses: Quantum Optics and Quantum Informatics and Modeling and Fabrication of Micro- and Nanodevices
- Gave invited talks at two international conferences
- Organized one international conference (LT28) and edited its Proceedings; organized two local scientific events; gave one public seminar invited by the Swedish Royal Academy of Engineering Sciences
- Member of the Faculty Senate of Chalmers University of Technology
- Active peer reviewer

Additional major grants secured as PI or co-PI during this project

- Knut and Alice Wallenberg Foundation, Project Grant 2015–2019, "Quantum states of photons and relativistic physics on a chip," 5 M€. (One out of 5 PIs)
- Knut and Alice Wallenberg Foundation, Jubilee Donation 2018–2027, "Wallenberg Center for Quantum Technology," 60 M€ plus 20 M€ co-financing from participating universities. (One of five PIs in this multi-university research center with further participation by national industry. The contribution to the local environment at Chalmers is ca. 30 M€.
- EU H2020-FETFLAG – Flagship on Quantum Technologies, Quantum Computing pillar, 2018–2021, Funding ID 820363, "OpenSuperQ – An Open Superconducting Quantum Computer," a consortium with 10 partners (10 M€). I am PI for Chalmers: 2.3 M€.