ROOM-TEMPERATURE, SOLID-STATE QUANTUM SENSORS

Michael Trupke,
University of Vienna

OVERVIEW

Consortium

PHILIPS

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SAL SILICON AUSTRIA LABS

CTR CARINTHIAN TECH RESEARCH

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Project

QSense4Life

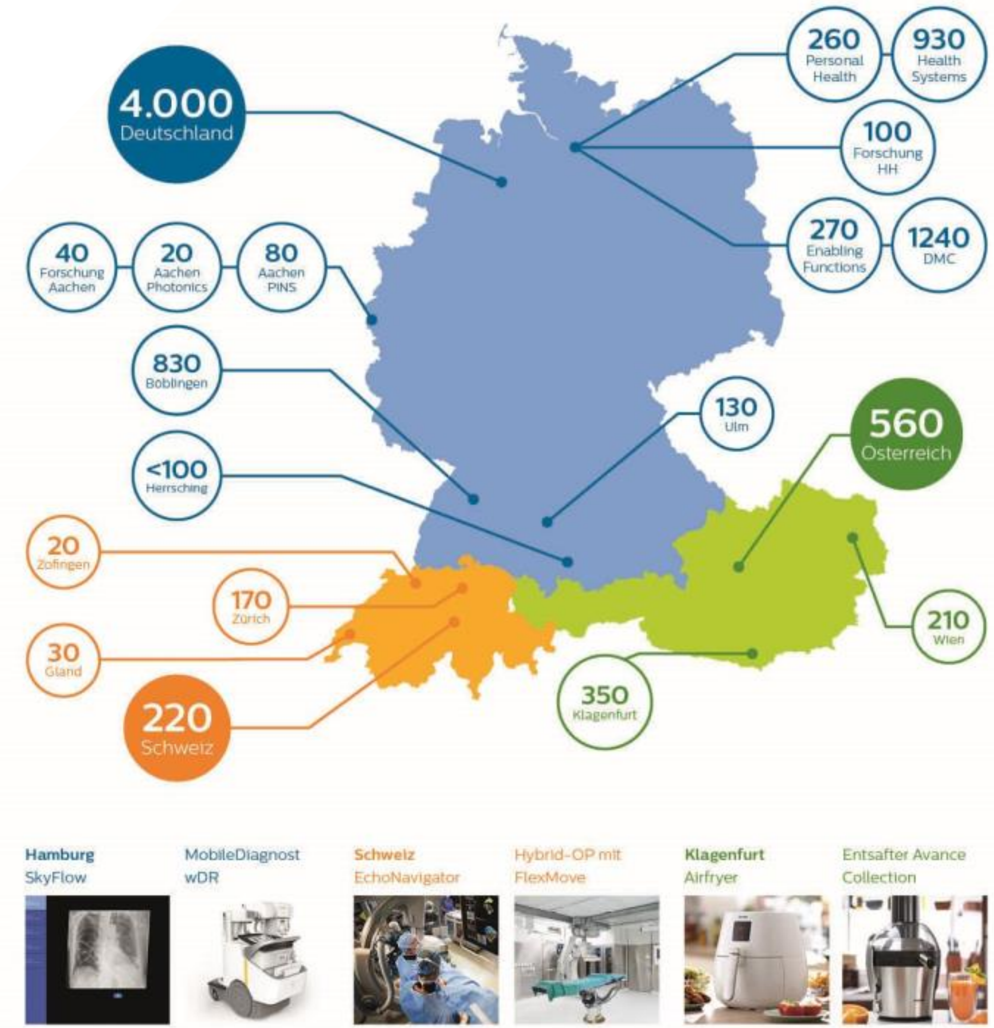
Aim

Desktop-scale system for fluid NMR/ESR analysis

Based on

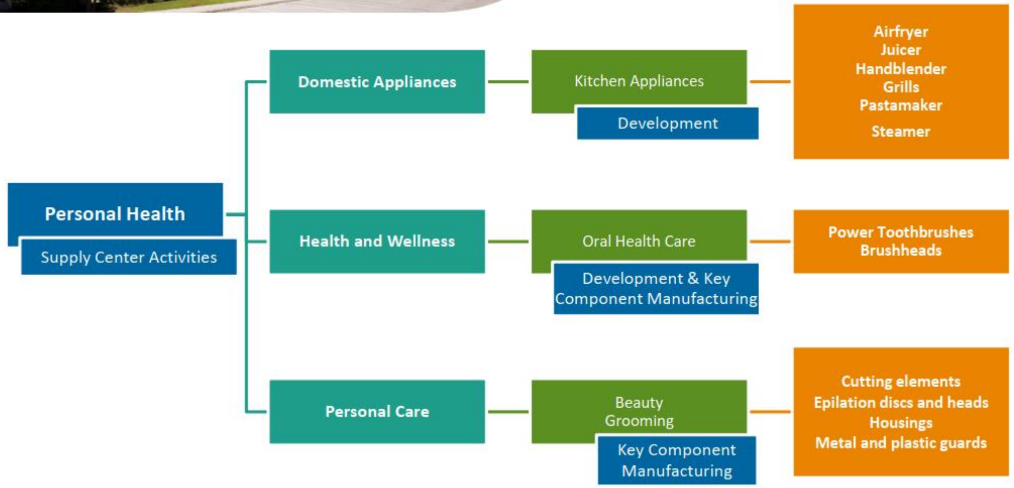
Quantum sensor qubits in diamond

PHILIPS HEALTHCARE - APPLICATIONS



Worldwide activities in healthcare

- Advanced Molecular Imaging
- Breathing and Respiratory care
- Clinical Informatics
- Computed Tomography Machines & Solutions
- Customer Service Solutions
- Diagnostic ECG
- EEG Neuroimaging
- Emergency Care and Resuscitation Solutions
- Enterprise telehealth portfolio
- Fluoroscopy
- Hospital Respiratory Care
- Image Guided Therapy Devices
- Interventional X-ray Systems and Solutions
- Medical parts & supplies
- Mother & Child Care
- MRI Systems & Solutions
- Pathology
- Patient Monitoring
- Radiation Oncology
- Radiography
- Refurbished Systems
- Sleep
- Ultrasound



INFINEON TECHNOLOGIES AUSTRIA – PRODUCTION

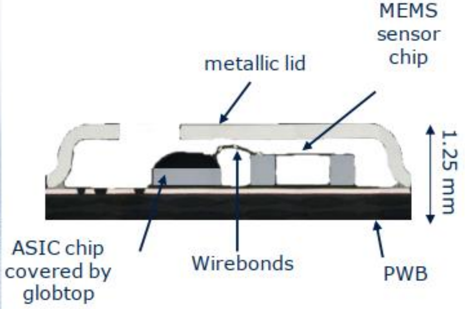
Product palette




Automotive	Industrial Power Control	Power Management & Multimarket	Digital Security Solutions
› 32-Bit-Mikrocontroller für Antriebsstrang, Sicherheit und Fahrerassistenzsysteme › 3D ToF-Sensoren › Diskrete Leistungshalbleiter › Druck- und Magnetfeldsensoren › IGBT-Module › Industrie-Mikrokontroller › Leistungs-ICs › Radar-Sensor-ICs (77 GHz) › Spannungsregler › Transceiver (CAN, LIN, Ethernet, FlexRay™)	› "Bare Die"-Geschäft › Diskrete IGBTs › IGBT-Module für niedrige, mittlere und hohe Leistungsklassen › IGBT-Modul-Lösungen inkl. IGBT-Stacks › Intelligente IGBT-Module mit integrierter Steuerung, Treiber und Schalter › Siliziumkarbit-MOSFETs und -Module › Treiber-ICs	› Ansteuer-ICs › Chips für Silizium-Mikrofone › Diskrete Niedervolt- und Hochvolt-Leistungshalbleiter › Chips für Drucksensoren › GPS-Signalverstärker › HF-Antennenschalter › HF-Leistungstransistoren › Kundenspezifische Chips (ASICs) › Niedervolt- und Hochvolt-Treiber-ICs › Radarsensor-ICs (24 GHz, 60 Ghz) › Schutzdioden gegen elektrostatische Entladung › Siliziumkarbid-Dioden	› Eingebettete Sicherheitscontroller › Kontaktbasierte Sicherheitscontroller › Kontaktlose Sicherheitscontroller › Sicherheitscontroller mit kontaktloser sowie kontaktbasierter Schnittstelle (Dual-Interface)

Product example:

Silicon MEMS microphone



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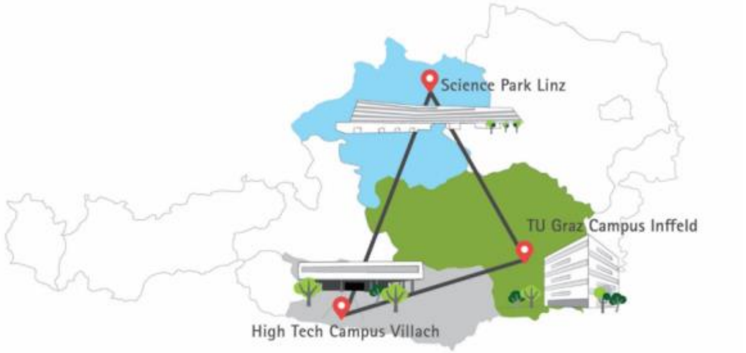
CTR → SILICON AUSTRIA LABS – COORDINATION AND SYSTEMS INTEGRATION

SAL SILICON AUSTRIA LABS

CTR CARINTHIAN TECH RESEARCH

The Austrian Research Center for Electronic Based Systems



Financing & Company type

140 Mio. Euro public funding until 2023

140 Mio. Euro investment by industry partners

Public-Private-Partnership

GmbH (Ltd.) organized under private law

Graz – HQ
Systems Integration

Villach
Sensor Systems
Power Electronics

Linz
RF-Systems

Shareholders

50.1 % Republic of Austria

10 % Styrian Business Promotion Agency SFG

10 % State of Carinthia

4.95 % Upper Austrian Research GmbH UAR

24.95 % Industrial Association FEEI

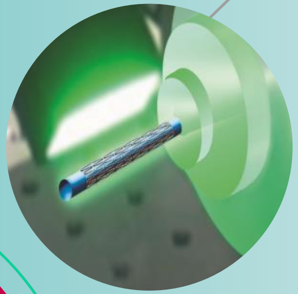
Bundesministerium Verkehr, Innovation und Technologie | Das Land Steiermark | LAND KÄRNTEN | LAND OBERÖSTERREICH | FEEI

R & D AT SILICON AUSTRIA LABS (EX CTR)

Microsystem-Technology

- MEMS / MOEMS
- Simulation/Design/Integration
- MEMS Prozess-Technologies
- Test & Characterisation

Photonic Sensor Systems



- Raman
- UV-VIS-NIR-MIR
- Imaging
- Laser Systems
- THz

Bringing Technologies into Application

Packaging & Heterointegration

- Functional packaging
- Advanced packaging
- Micro-Mechatronic Modules
- Rapid Prototyping

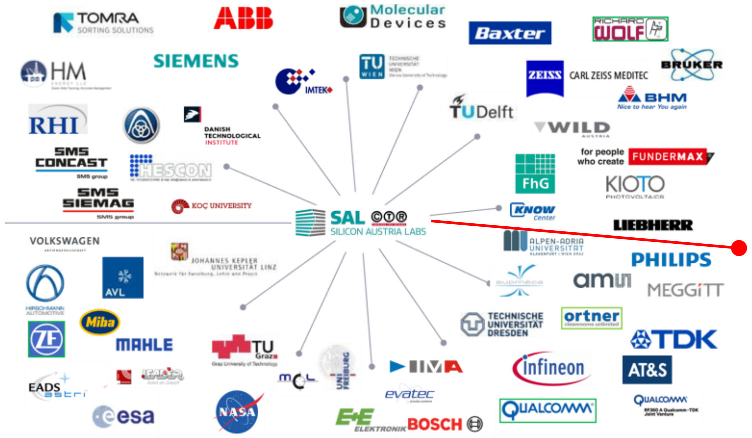
Smart Systems

- Systems for quality and process control
- SAW-based sensors
- Photovoltaics
- Sensores for e-mobility

Modelling & Design | Simulation | Experimental R&D | Prototyping | Characterisation | Testing

NETWORK OF RESEARCH AND INDUSTRY

Founded	1997
Employees	60 (+14 PhD students) excl. Master students
Turnover 2018	~7 Mio.€
Shareholder	Silicon Austria LABS GmbH 50,1% Republic of Austria 10% State of Carinthia 10% Styrian Business Promotion Agency SFG 4,95% Upper Austria Research GmbH UAR 24,95% Industrial Association FEEI
Network	Forschung Austria, EPoSS, ECSEL Austria, IVAM, AG Sensorik, AG Innovation IV, me2c Cluster TU Wien, JKU Linz, AAU Klagenfurt, TU Graz, TU Dresden, Uni Freiburg, TU Clausthal, EPFL, TU Delft, CNRS, KOC University



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ASSIC
Austrian Smart Systems Integration Research Center

UNIVIE – QUANTUM MICRO-DEVICES

Optical Microcavities

nature > light: science & applications > letters > article

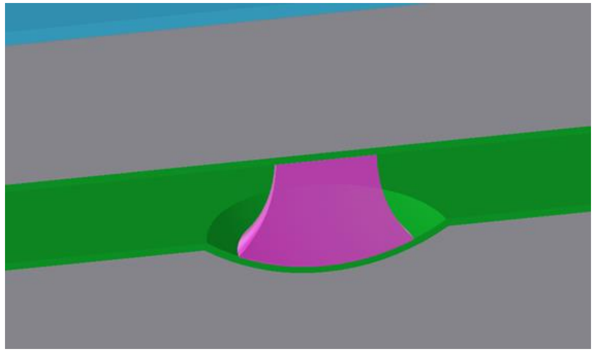
Light Science & Applications

Letter | OPEN | Published: 10 April 2019

Silicon microcavity arrays with open access and a finesse of half a million

Georg Wachter, Stefan Kuhn, Stefan Minniberger, Cameron Salter, Peter Asenbaum, James Millen, Michael Schneider, Johannes Schalko, Ulrich Schmid, André Felgner, Dorothee Hüser, Markus Arndt & Michael Trupke

Light: Science & Applications 8, Article number: 37 (2019) | Download Citation



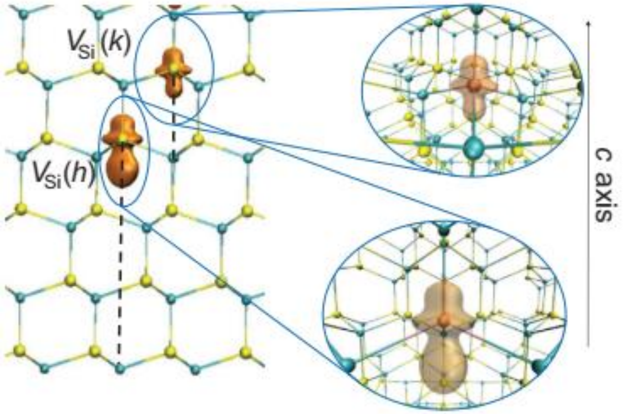
Qubits in Silicon Carbide

PHYSICAL REVIEW APPLIED (2019)

Optical Properties of Vanadium in 4*H* Silicon Carbide for Quantum Technology

L. Spindlberger,[1] A. Csóré,[2] G. Thiering,[2] S. Putz,[3,*] R. Karhu,[4] J. Ul Hassan,[4] N.T. Son,[4] T. Fromherz,[1] A. Gali,[2,5] and M. Trupke[3,†]

(accepted)

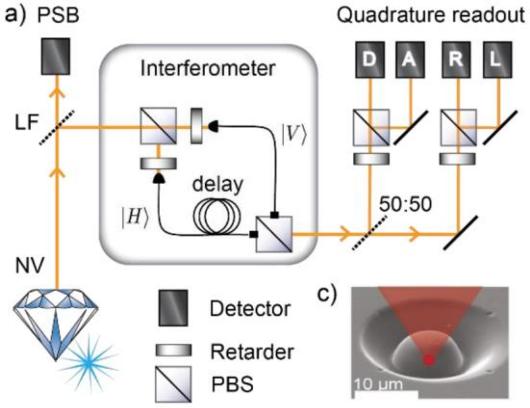


Spin-Photon Entanglement

Scalable spin-photon entanglement by time-to-polarization conversion

Rui Vasconcelos[1,*], Sarah Reisenbauer[1,2,*], Cameron Salter[1,*], Georg Wachter[1,2], Daniel Wirtitsch[1,2], Jörg Schmiedmayer[2], Philip Walther[1], and Michael Trupke[1,2,*]

arXiv:1812.10338

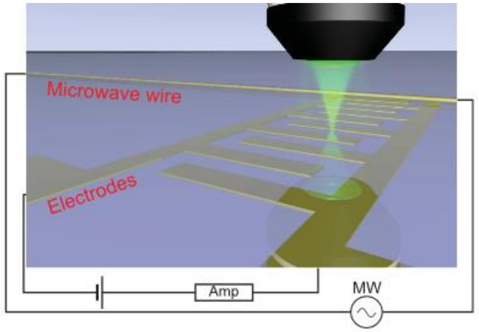


Electrical Qubit readout

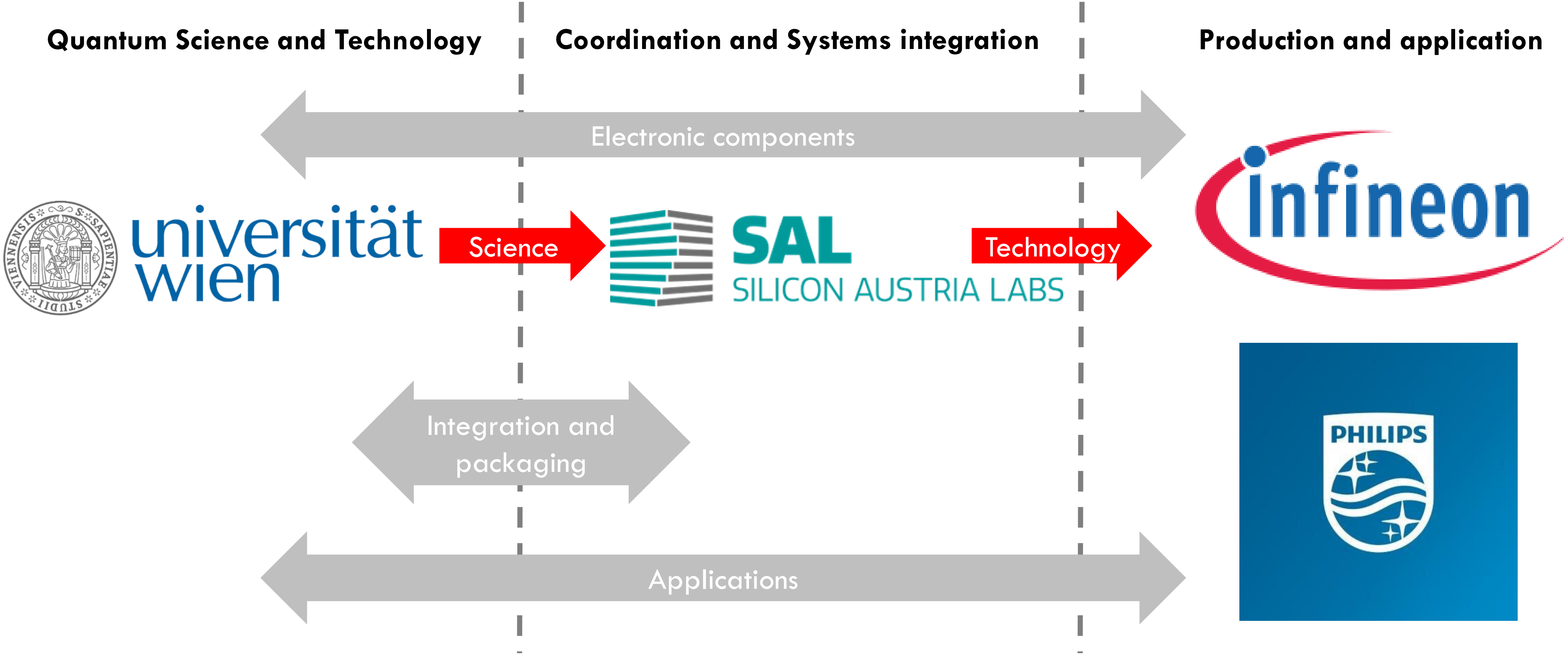
Photoelectrical imaging and coherent spin-state readout of single nitrogen-vacancy centers in diamond

Petr Siyushev, Milos Nesladek, Emilie Bourgeois, Michal Gulka, Jaroslav Hruby, Takashi Yamamoto, Michael Trupke, Tokuyuki Teraji, Junichi Isoya, Fedor Jelezko

Science 15 Feb 2019:
Vol. 363, Issue 6428, pp. 728-731
DOI: 10.1126/science.aav2789



PROJECT FLOW



WHAT IS A QUANTUM SENSOR?

A sensor which makes use of

I. A quantum object

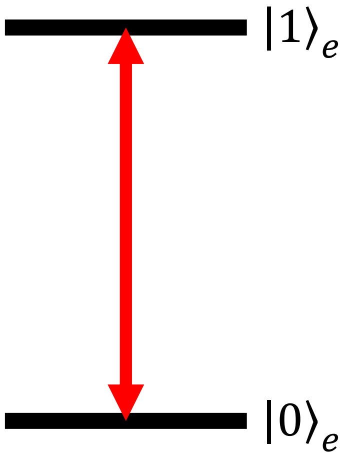
(can be nanoscale)

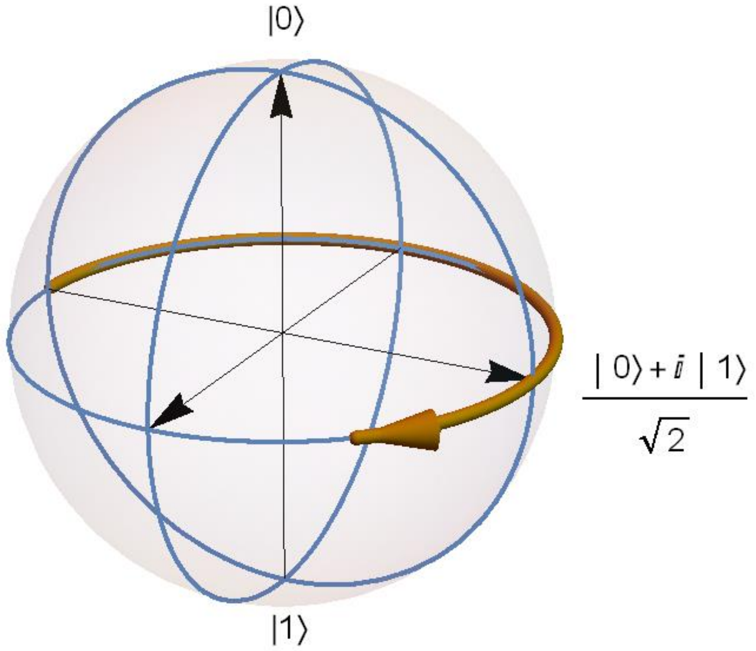
II. Quantum interference

(high sensitivity)

III. Quantum entanglement

($\propto N$ vs. $\propto \sqrt{N}$)





$$\psi = |0\rangle_e + e^{i\phi}|1\rangle_e$$

NITROGEN VACANCY

Defect in diamond lattice: substitutional nitrogen with adjacent vacancy

Spin-free environment

→Long spin coherence time > 2ms

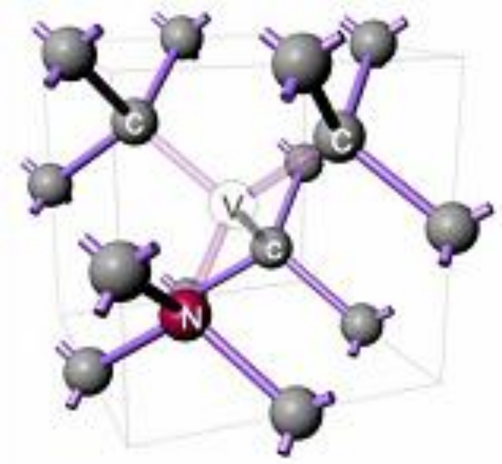
Optical initialisation and readout

Sensitive to magnetic and electric fields, temperature, strain…

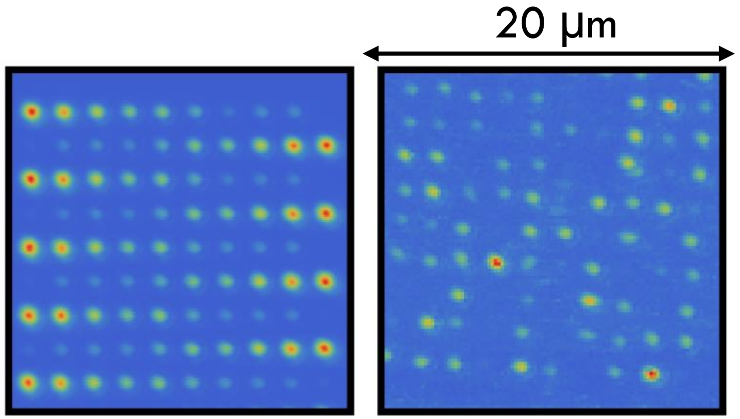
Nanoscale

non-toxic

Can be implanted



Meijer et al., *Appl. Phys. A* **83** *2*, 321-327 (2006)



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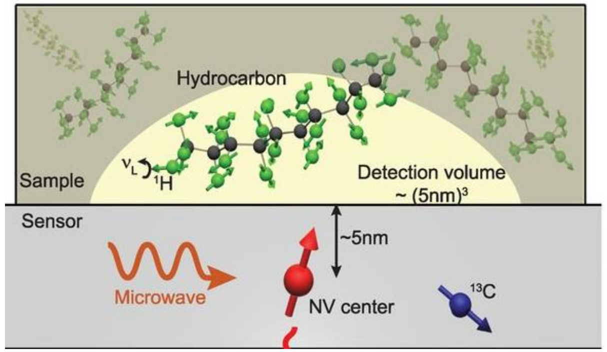
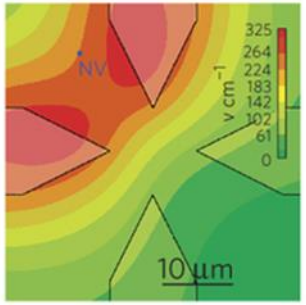
Review: Doherty, M. W., Manson, N. B., Delaney, P., Jelezko, F., Wrachtrup, J., & Hollenberg, L. C. „The nitrogen-vacancy colour centre in diamond“. *Physics Reports* **528**(1), 1-45 (2013).

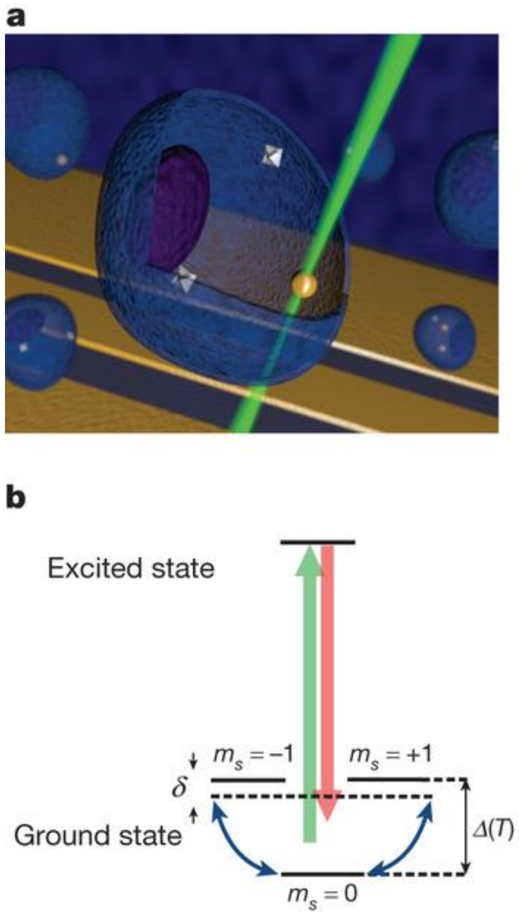
NV SENSING APPLICATIONS



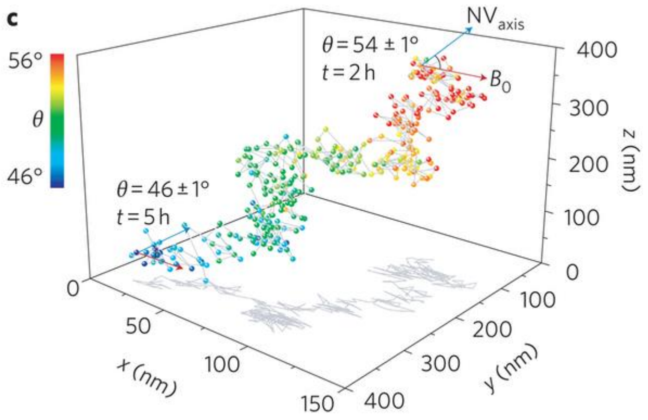
Nano-NMR (Wrachtrup, Jelezko, Walsworth groups)



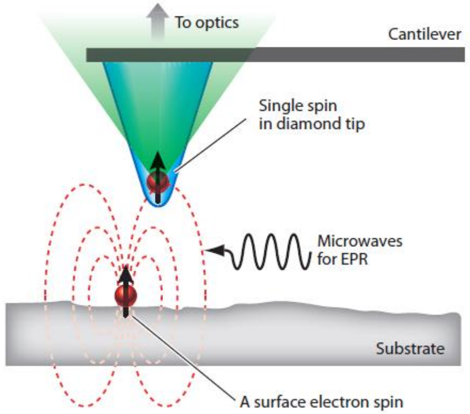
E-field sensing (Wracthrup, Doherty groups)



In vivo Thermometry (Lukin, Wrachtrup groups)



In-vivo magnetometry (Wrachtrup, Prawer, Hollenberg groups)



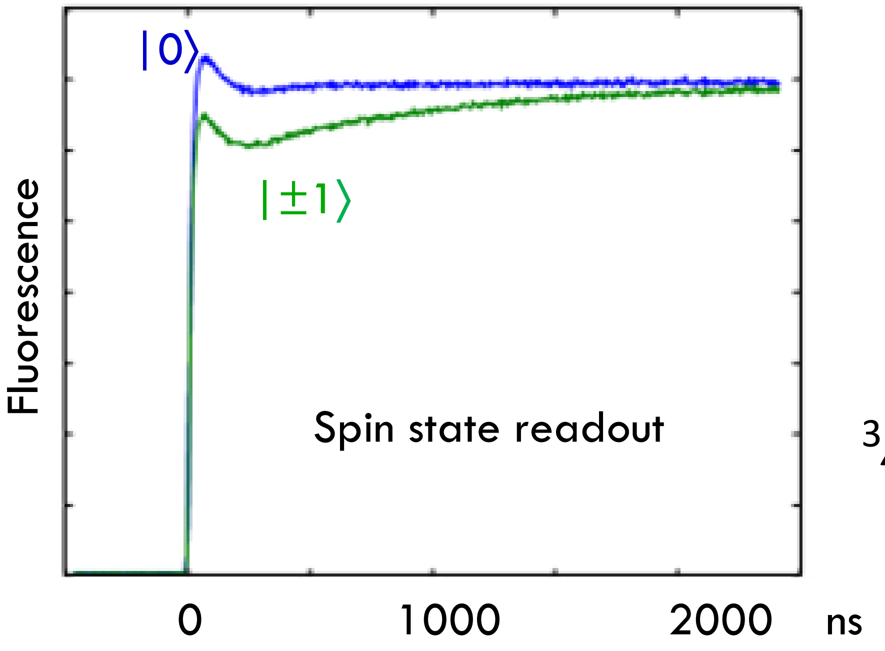
Scanning nano-sensor (Degen, Maletinsky, Lukin groups)

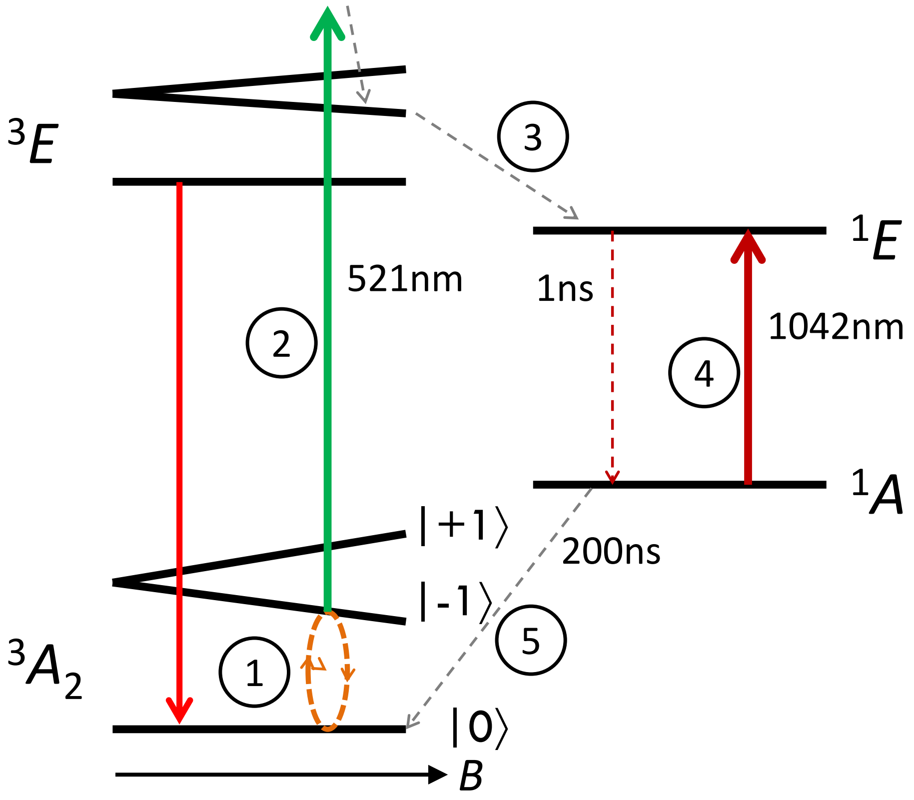
NV SPIN CONTROL AND READOUT – ROOM TEMP.

(Room temperature)

Laser-induced initialisation

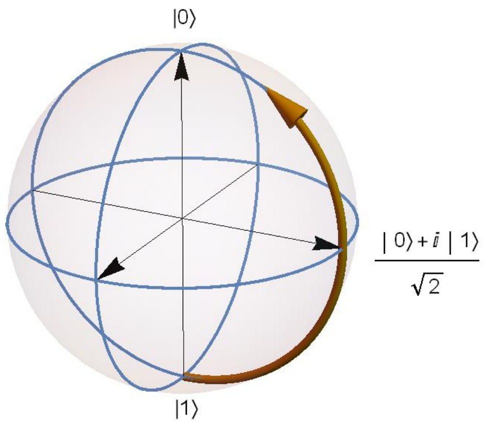
Spin-dependent fluorescence

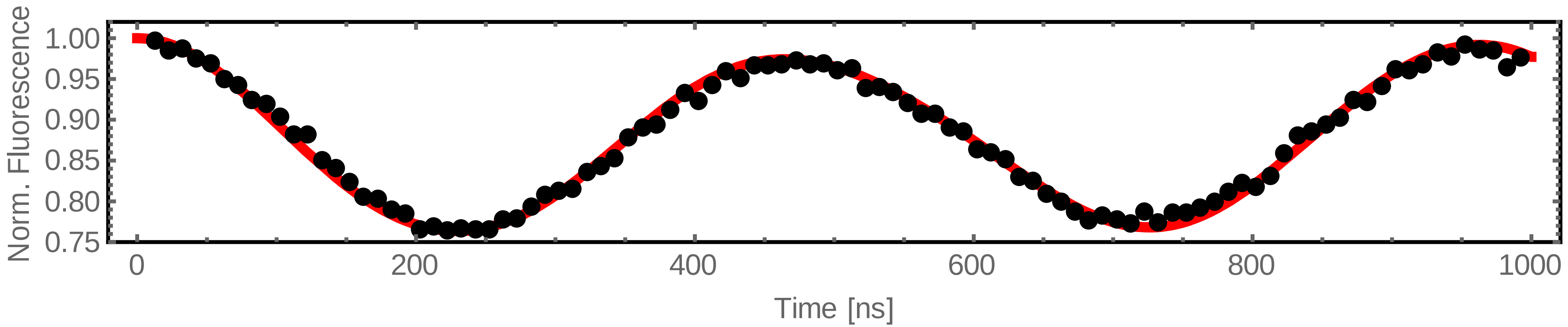




SPIN ROTATION OF THE ELECTRONIC QUBIT

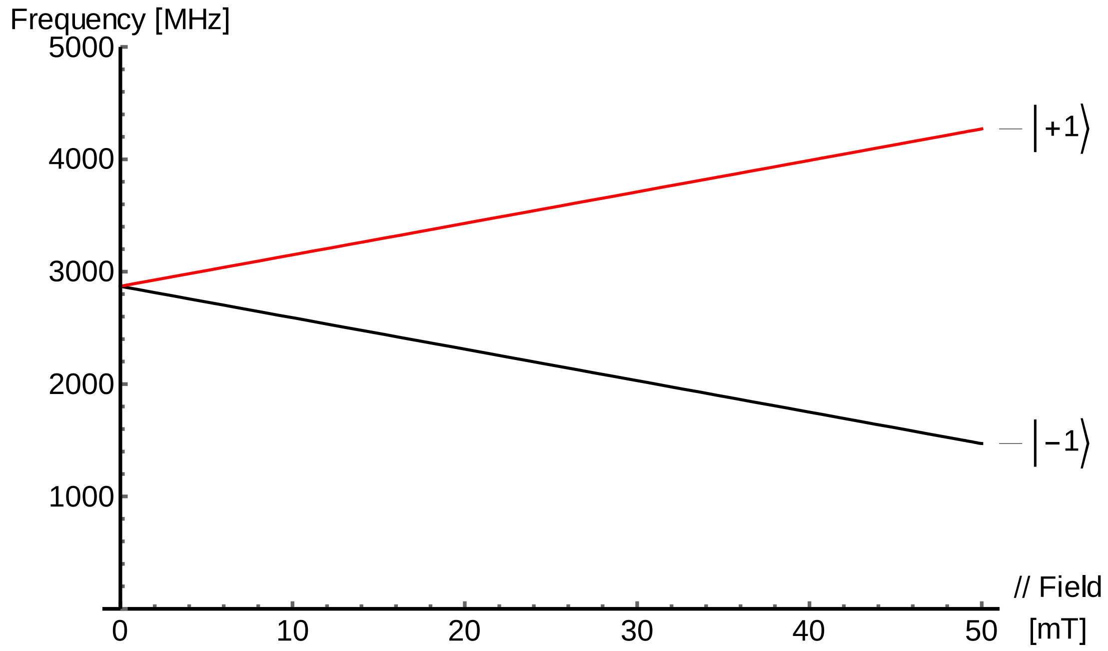
The electron resides in a magnetically quiescent environment for long coherence lifetime (>2ms), enabling high-fidelity quantum state transfer and high-resolution spectroscopy





SENSING WITH NV CENTRES

$$H= \begin{pmatrix} 0 & g\mu_B\beta_\perp & g\mu_B\beta_\perp^* \\ g\mu_B\beta_\perp^* & D_g + d_\parallel E_z + g\mu_B B_z & d_\perp(E_x + iE_y) \\ g\mu_B\beta_\perp & d_\perp(E_x - iE_y) & D_g + d_\parallel E_z - g\mu_B B_z \end{pmatrix}$$

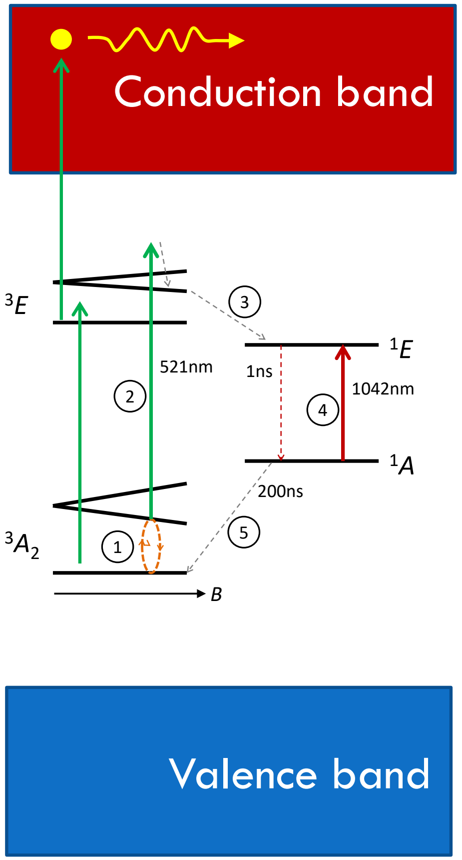


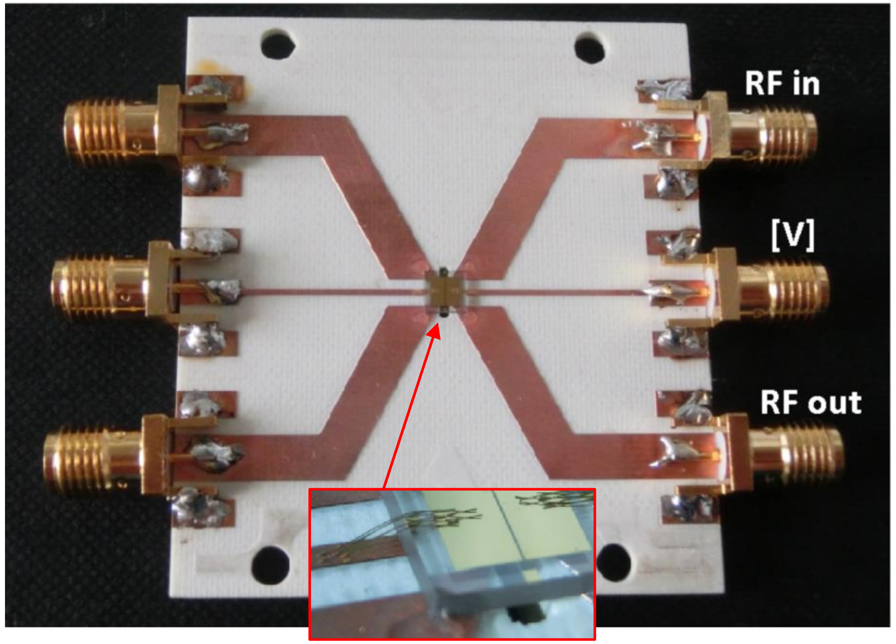
The spin-dependent fluorescence and the Zeeman shift due to magnetic field parallel to the NV axis enable:

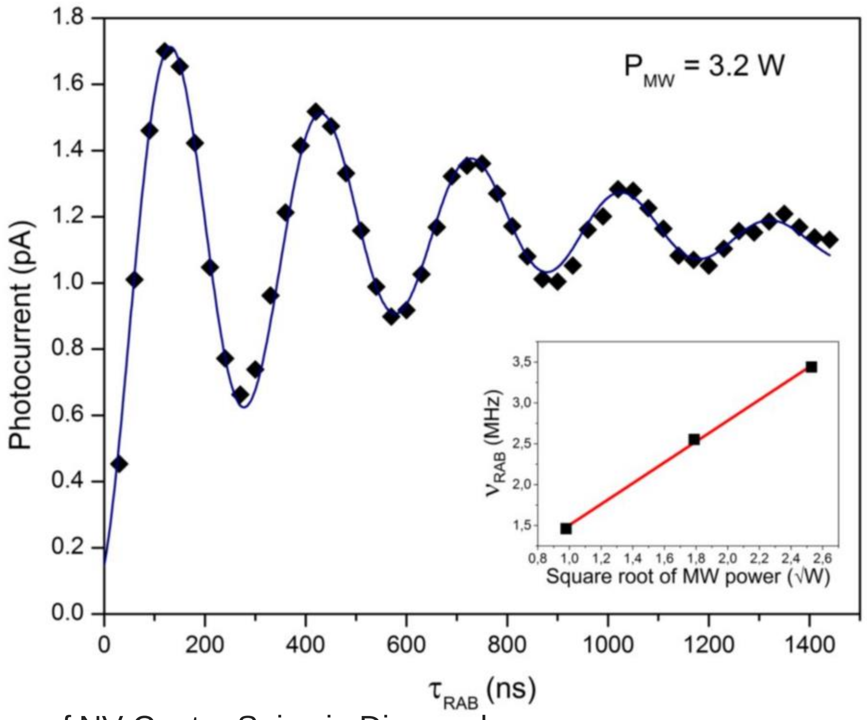
- Sensitive measurements of **DC fields** (~nanotesla sensitivity for a single NV)
- **Vector magnetometry** using multiple NV centres (along four crystalline axes)
- Detection of **oscillating fields** originating from e.g. external nuclear spins

ELECTRICAL SPIN DETECTION

Convert spin to charge: spin-selective ionization. Does not require optical signal collection or expensive photon counters. Enhanced signal by more than ×1000.

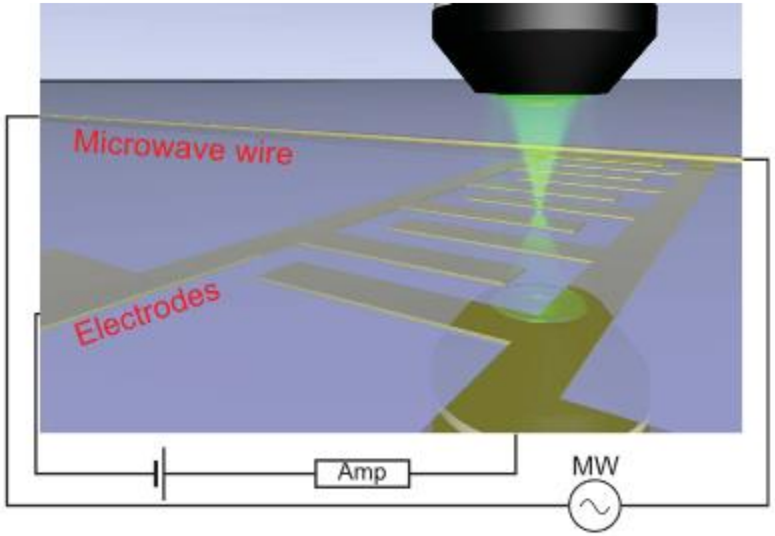


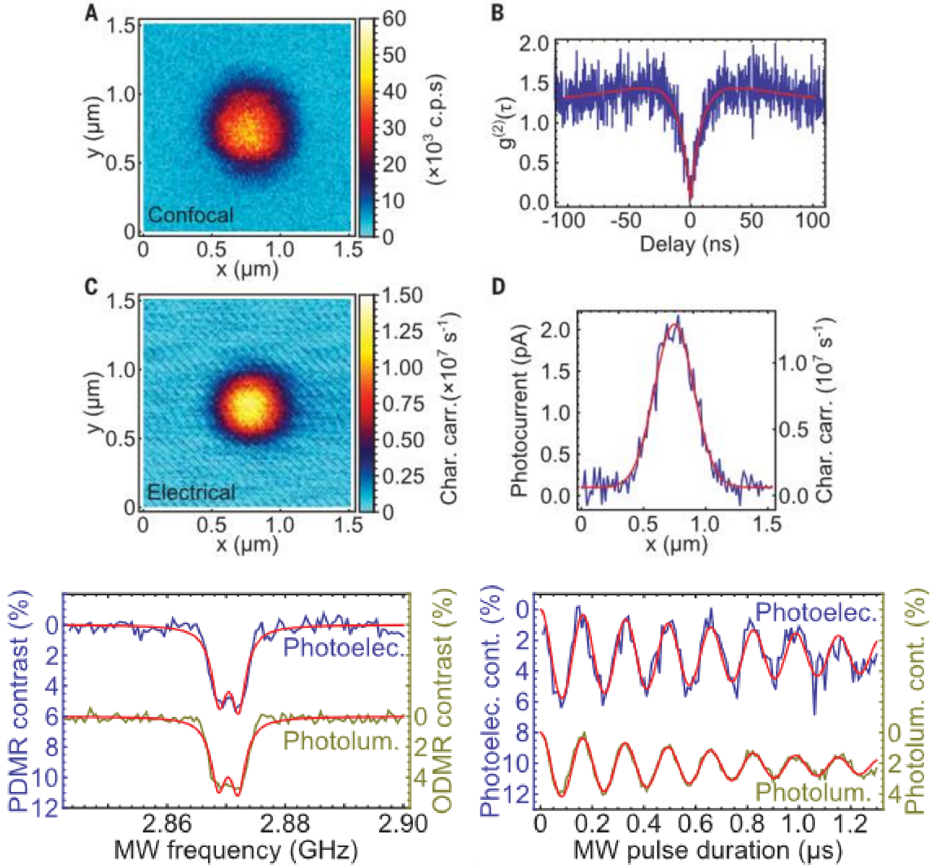




Gulka M, et al.. Pulsed Photoelectric Coherent Manipulation and Detection of NV Center Spins in Diamond. ***Physical Review Applied***. 2017 Apr 28;7(4):044032.
Bourgeois, E. et al., 2017. Enhanced photoelectric detection of NV magnetic resonances in diamond under dual-beam excitation. ***Physical Review B***, *95*(4), p.041402.

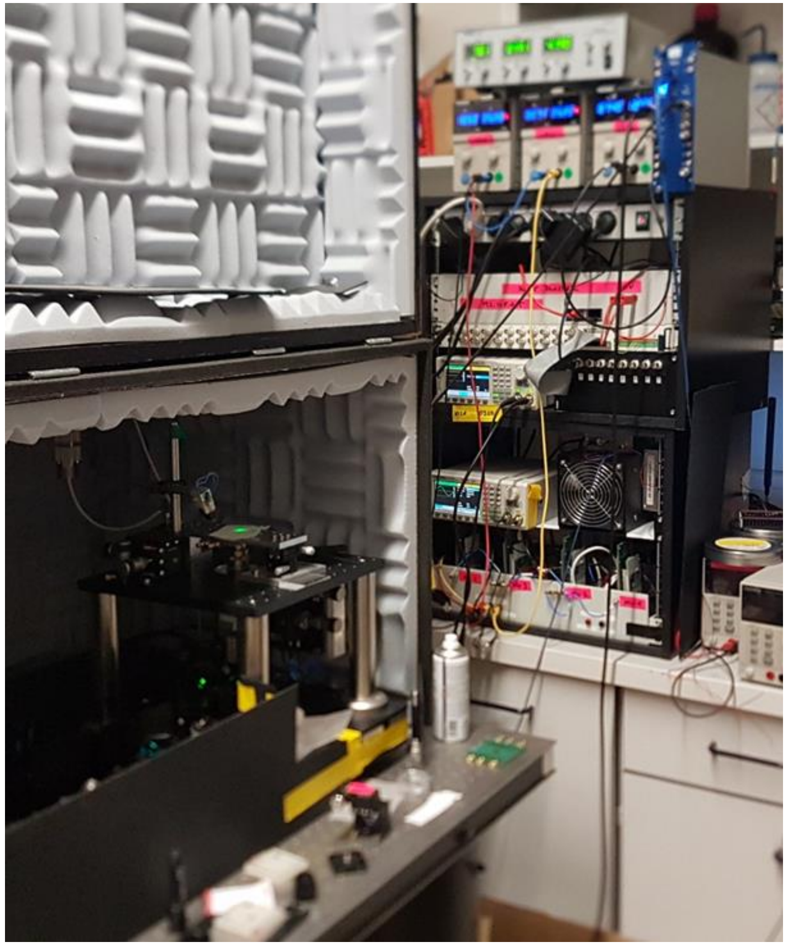
SINGLE QUBIT ELECTRICAL READOUT





P. Siyushev et al., *Science* **363**, 728-731 (2019)

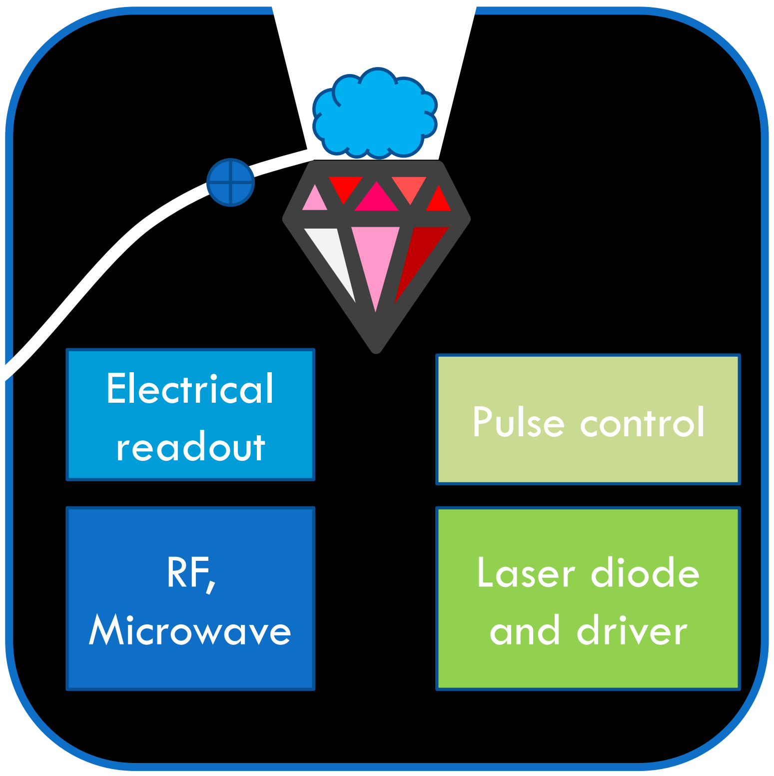
AIM: COMPACT SENSOR FOR LIQUID ANALYTES

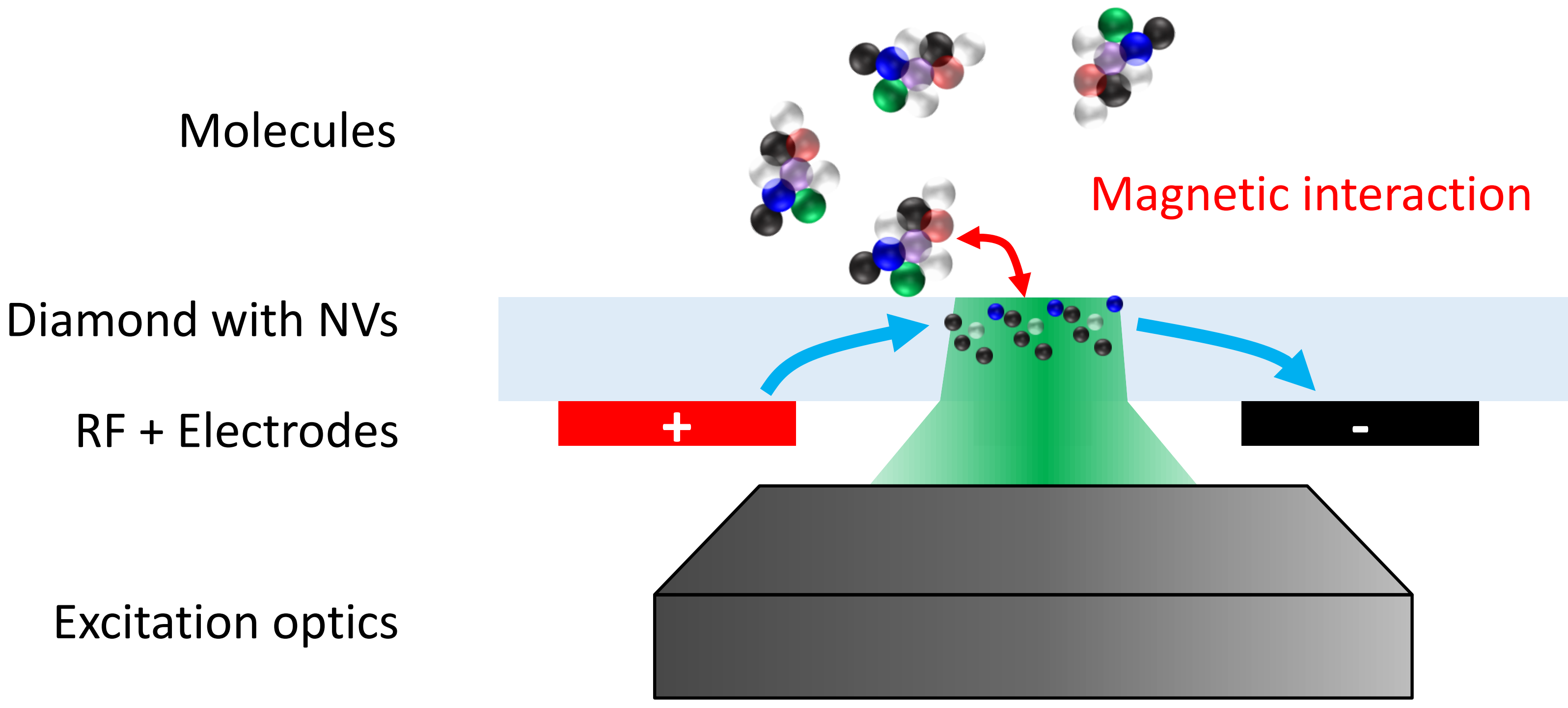


Desktop package enabling use of nano-ESR/NMR for:
health services, nutrition analysis,
citizen science, and more.

Requires robust design, detailed understanding of molecular spin interactions, and extremely sensitive readout electronics.

PROJECT: DEVICE OVERVIEW





EXAMPLE OF INTEGRATION: SPIN-DEPENDENT PHOTOCURRENT AMPLIFIER

Presently used:

General-purpose lock-in amplifier

Next step:

Tailor-made multi-stage using commercial IC

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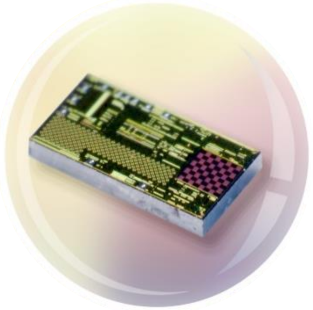
Final device:

Specialized IC



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M.T.

G. Wachter

S. Reisenbauer

S. Putz

S. Minniberger

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C. Hirschl

G. Auböck

K. Harms

J. Pribosek

T. Moldaschl

R. Leitner

F. Starmans

R. Waldner

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F. Michl

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FFG Forschung wirkt.

FWF Der Wissenschaftsfonds.

QUANTERA

HORIZON 2020

European Commission

WWTF

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