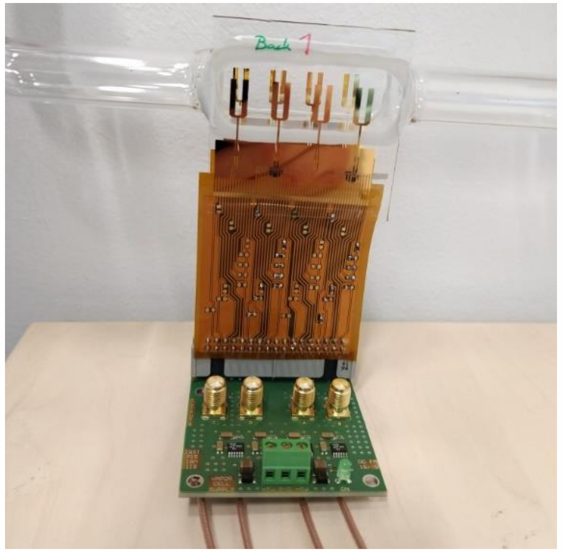
Towards an Optogalvanic Flux Sensor for Nitric Oxide Based on Rydberg Excitation



Patrick Kaspar, Fabian Munkes, Yannick Schellander, Joshua Fabian, Malte Kasten, Luana Rubino, Lea Ebel, Lars Baumgärtner, Denis Djekic, Patrick Schalberger, Holger Baur, Robert Löw, Tilman Pfau, Norbert Frühauf, Jens Anders, Edward Grant, and Harald Kübler

July 20th 2021

University of Stuttgart, 5th Institute of Physics

Motivation

- Targeted application: Breath gas analysis

- Why nitric oxide?
  - ➢ Signaling inflammatory diseases
  - ➢ Blood pressure regulation
  - ➢ Immune system

- Human and other specimen
  - ➢ [1]Humans exhale between 1-2000 ppb
  - ➢ Large gas volumes needed

https://www.gas-dortmund.de/index-gas.php?lan=1&spath=420 04.03.2019

https://biox.stanford.edu/highlight/toenail-trim-saves-lab-mice-common-life-threatening-skin-condition, 04.03.2019

[1]M. Jorissen et al., *Allergy* **56**, 1026 (2001)
American Journal of Respiratory and Critical Care Medicine **171**, 912 (2005).

Working Principle

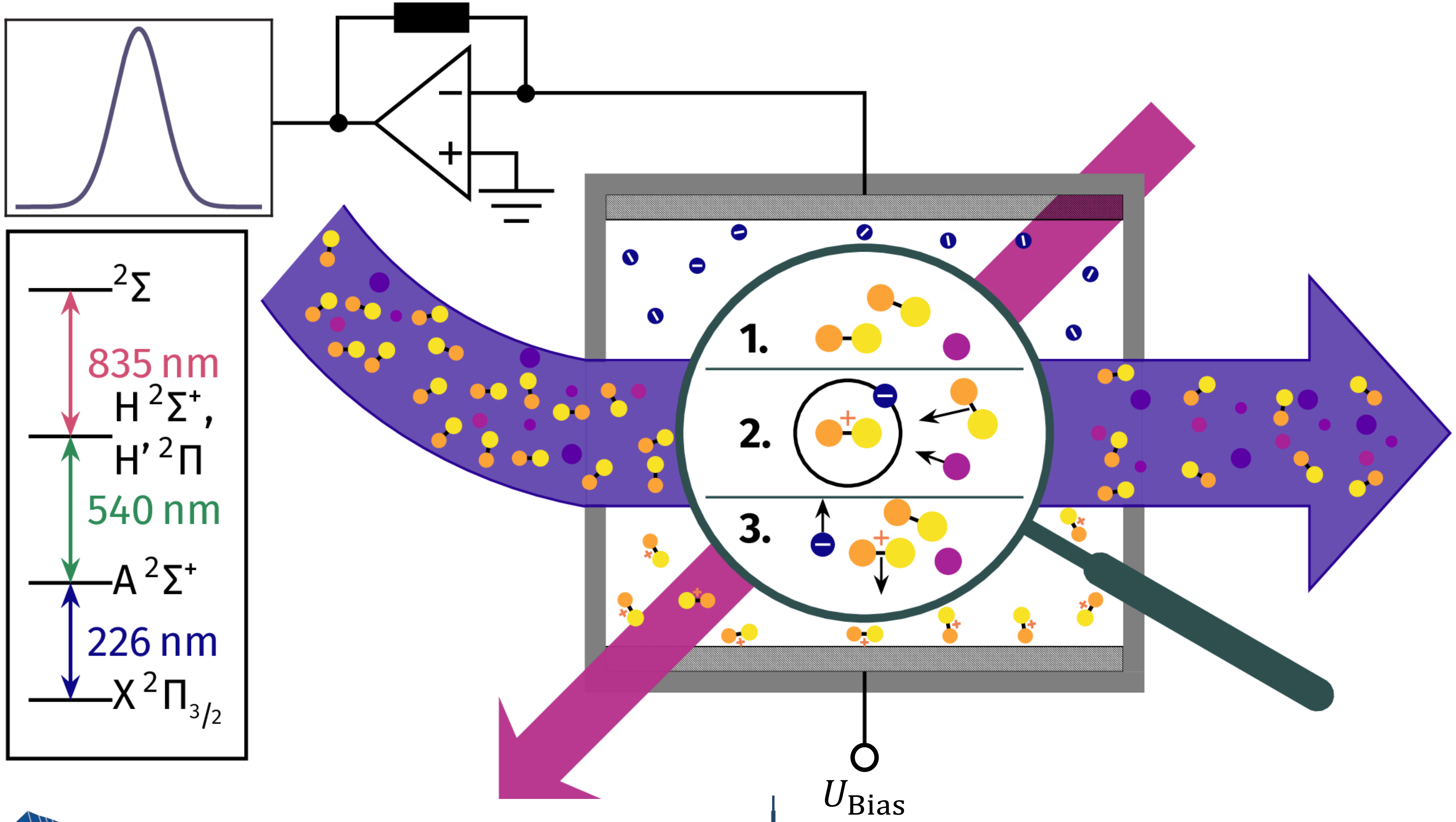
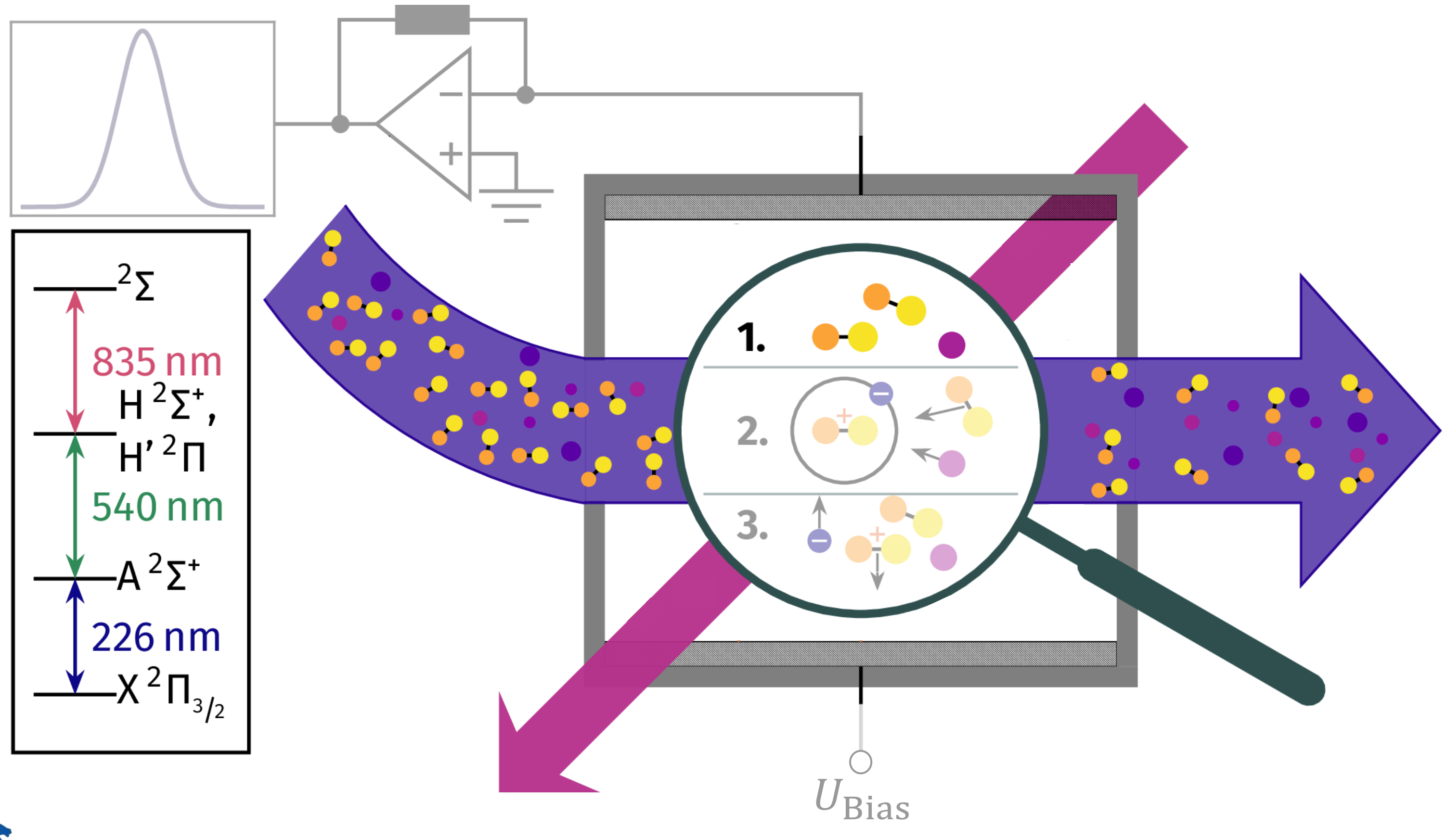
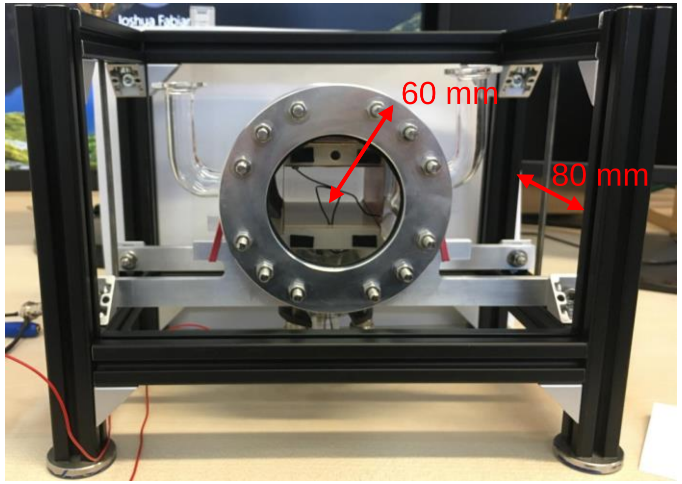
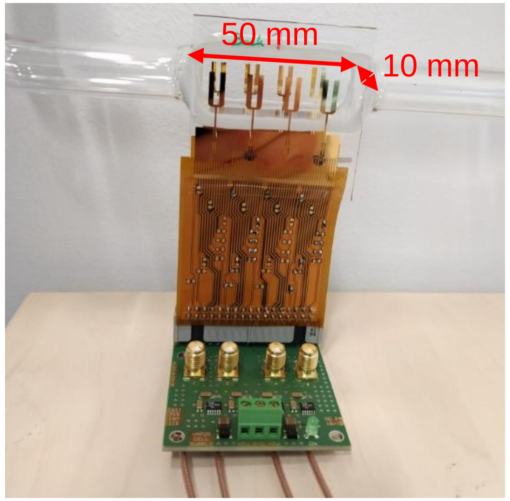


Figure: F. Munkes , Masterthesis, Continuous wave absorption spectroscopy on the $X^2\Pi_{1/2}$ to $A^2\Sigma^+$ transition of nitric oxide, University of Stuttgart 2020

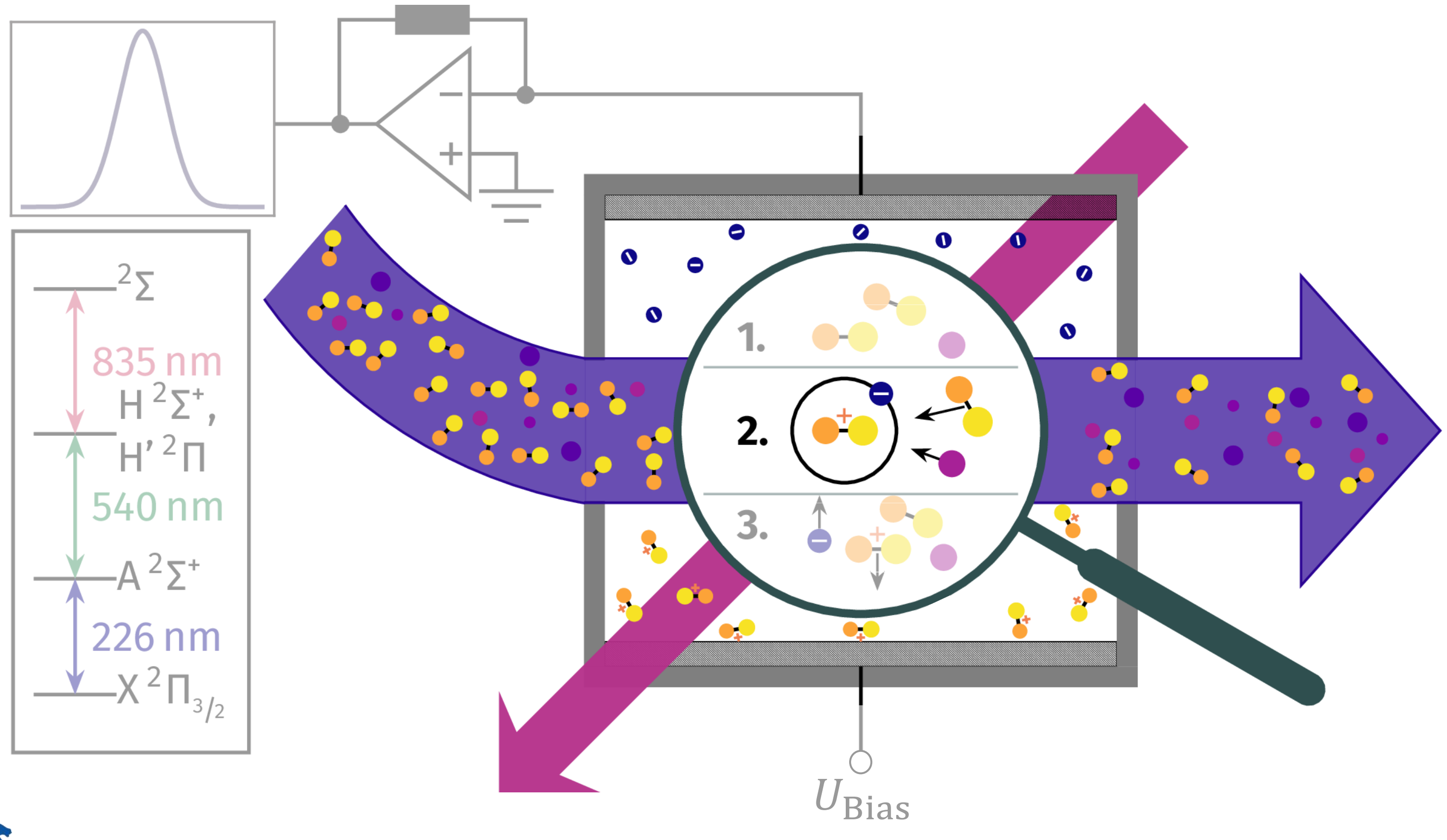
Step One: Excitation







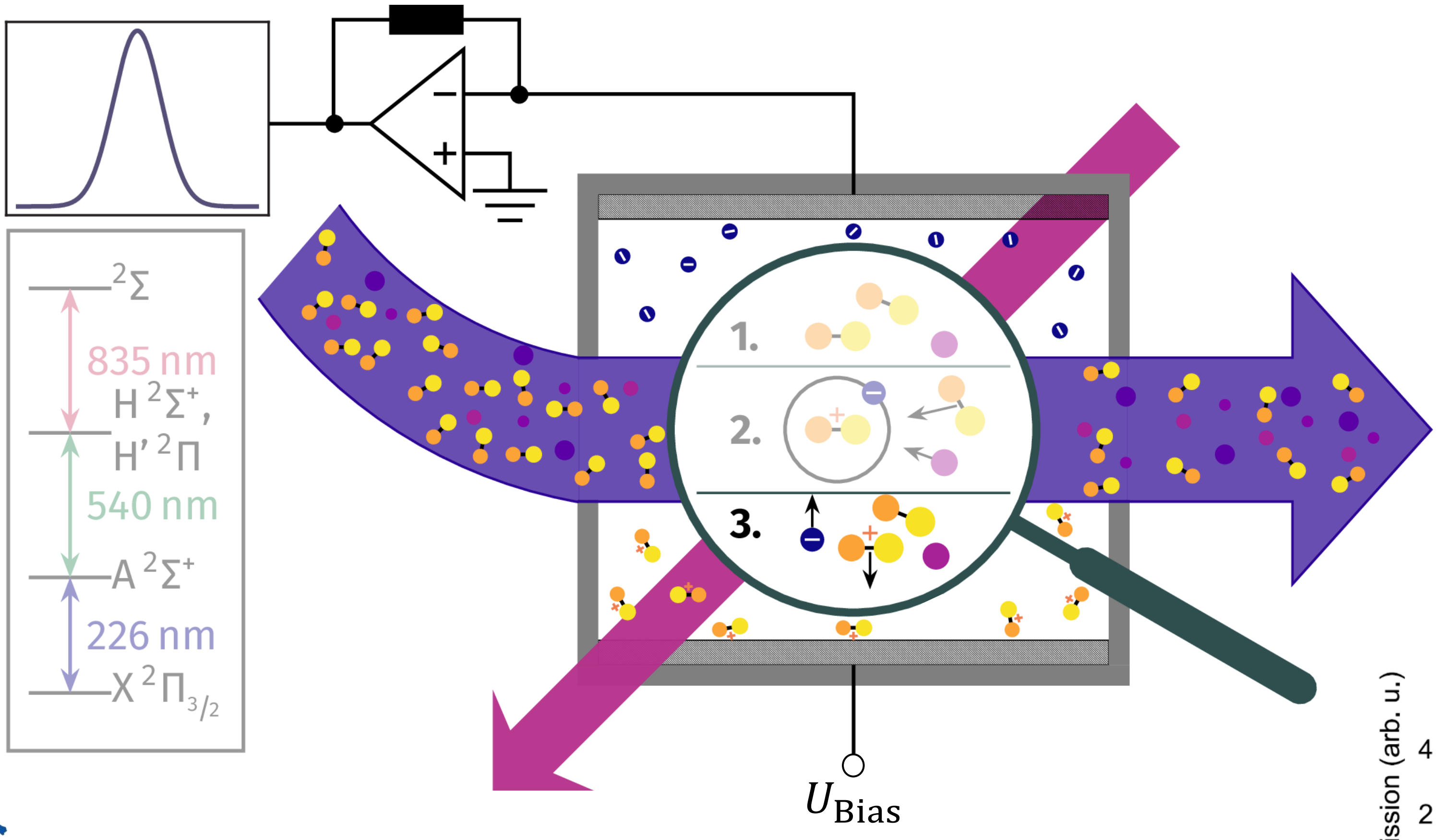
Step Two: Collision



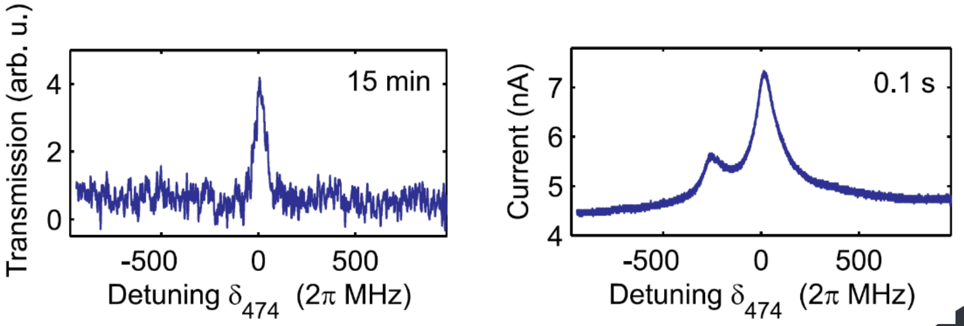
- Ionization energy[1]: 9.25 eV
- Rydberg states: 9.24 eV
- Additional charges due to:
  - Photoeffect
  - Ionization of different species
  - Results in an ionization background

[1]A. Bernard, *On the 3d Rydberg states of the NO molecule*, Molecular Physics 73:1, 221-234 (1991)

Step Three: Detection

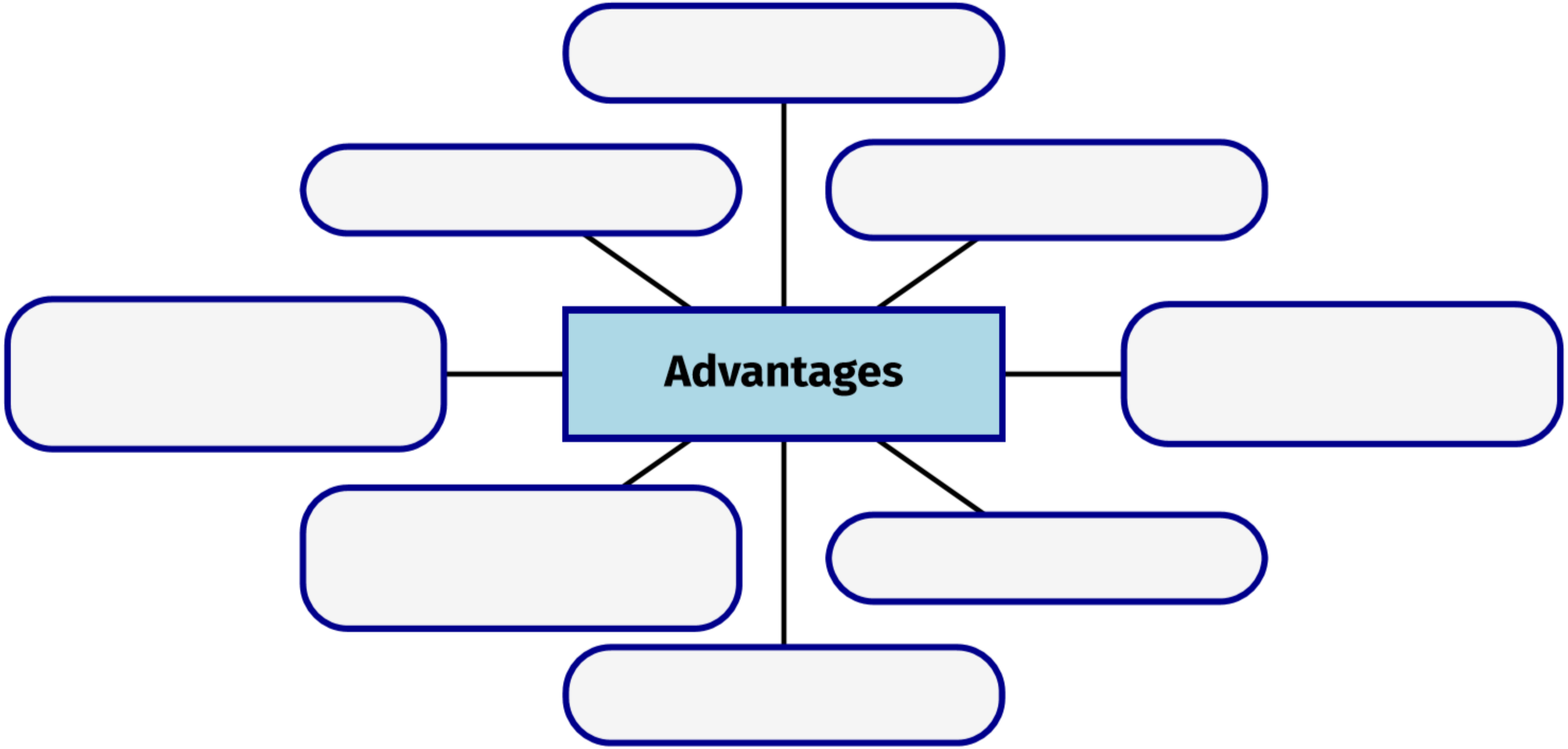


- Bias Voltage: 0-10 V
- Conversion: current to voltage via a trans-impedance amplifier
- Removal of ionization background possible
- Comparison to optical detection[1]:
  - Better signal to noise ratio
  - Higher bandwidth



[1]D. Barredo et al., *Phys. Rev. Lett* **110**, 123002 (2013)

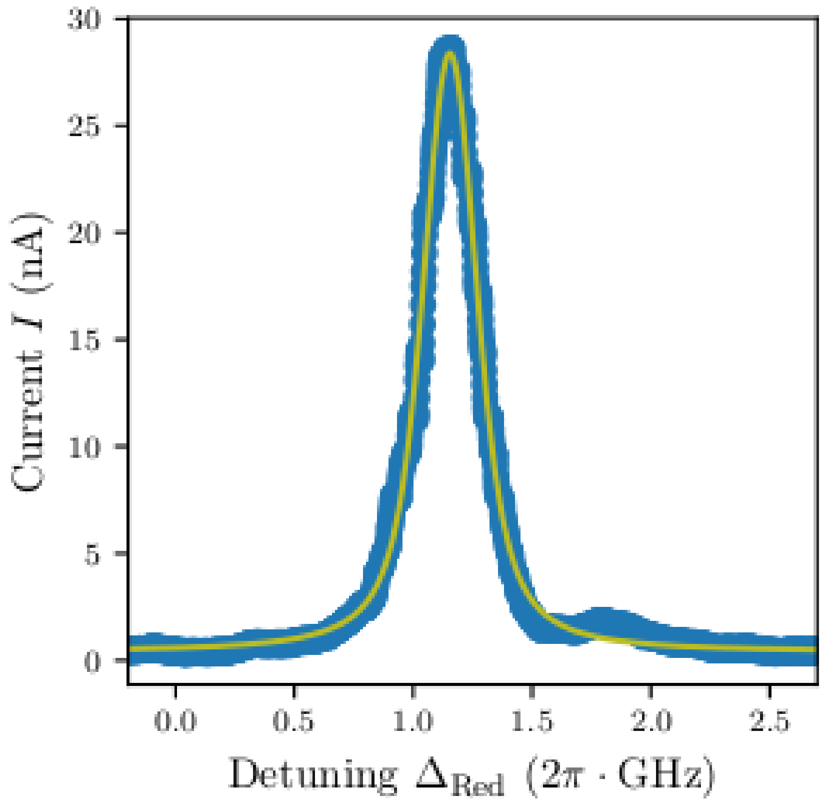
Advantages of the Sensor Principle

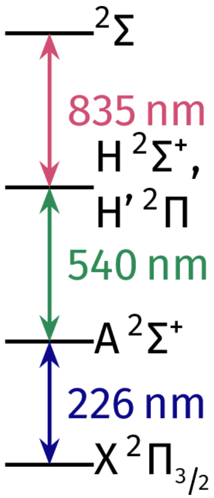


[1]J. Schmidt et al., Appl. Phys. Lett. 113, 011113 (2018)

Rydberg Excitation and Current Conversion

- Large current: 30 nA at 0.5 mbar
- Estimated quantum efficiency 10^{-4} at 1 kHz bandwidth
- Measured with a rack based commercial amplifier
- Compared to proof of concept experiment[1]:
  - 10 × increase for sensitivity
  - 100 × increase in temporal resolution

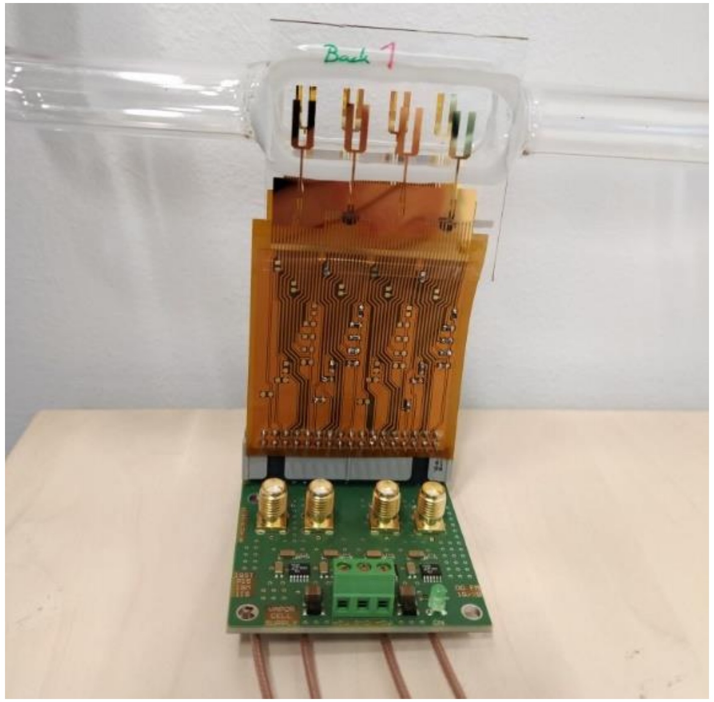


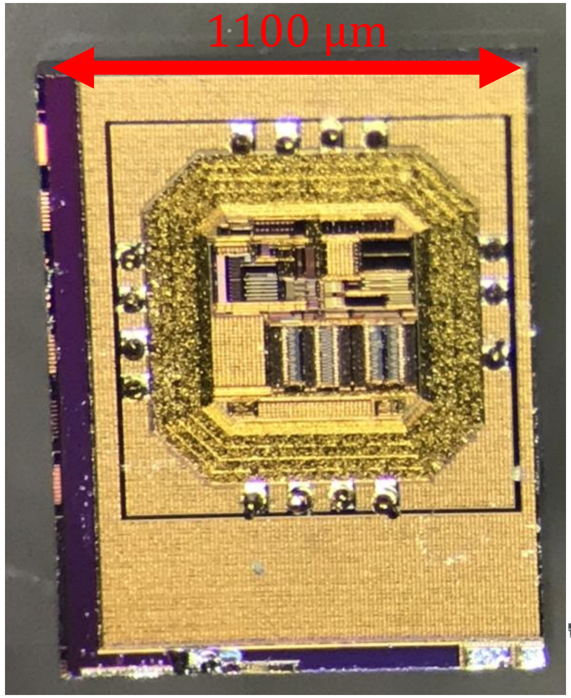


[1]J. Schmidt et al., Appl. Phys. Lett. 113, 011113 (2018)

Custom Trans-Impedance Amplifier

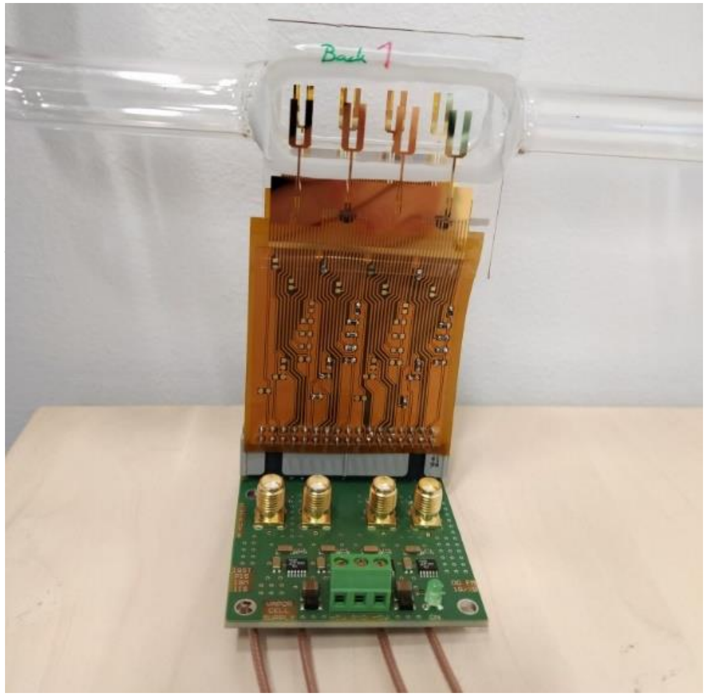
- Individually configurable via flex PCB
- Max. config. noise floor: $0.6\ \frac{\mathrm{fA}}{\sqrt{\mathrm{Hz}}}$
- Max. trans-impedance: $150\ \mathrm{G\Omega}$
- Theoretical detection limit: $\approx 3\ \mathrm{ppb}$
- No optimized charge conversion yet
- No modulation technology employed so far

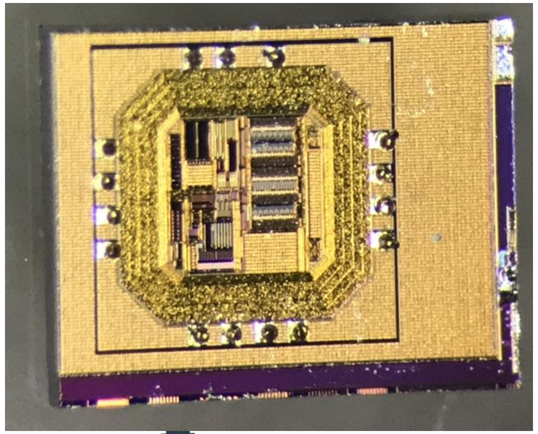




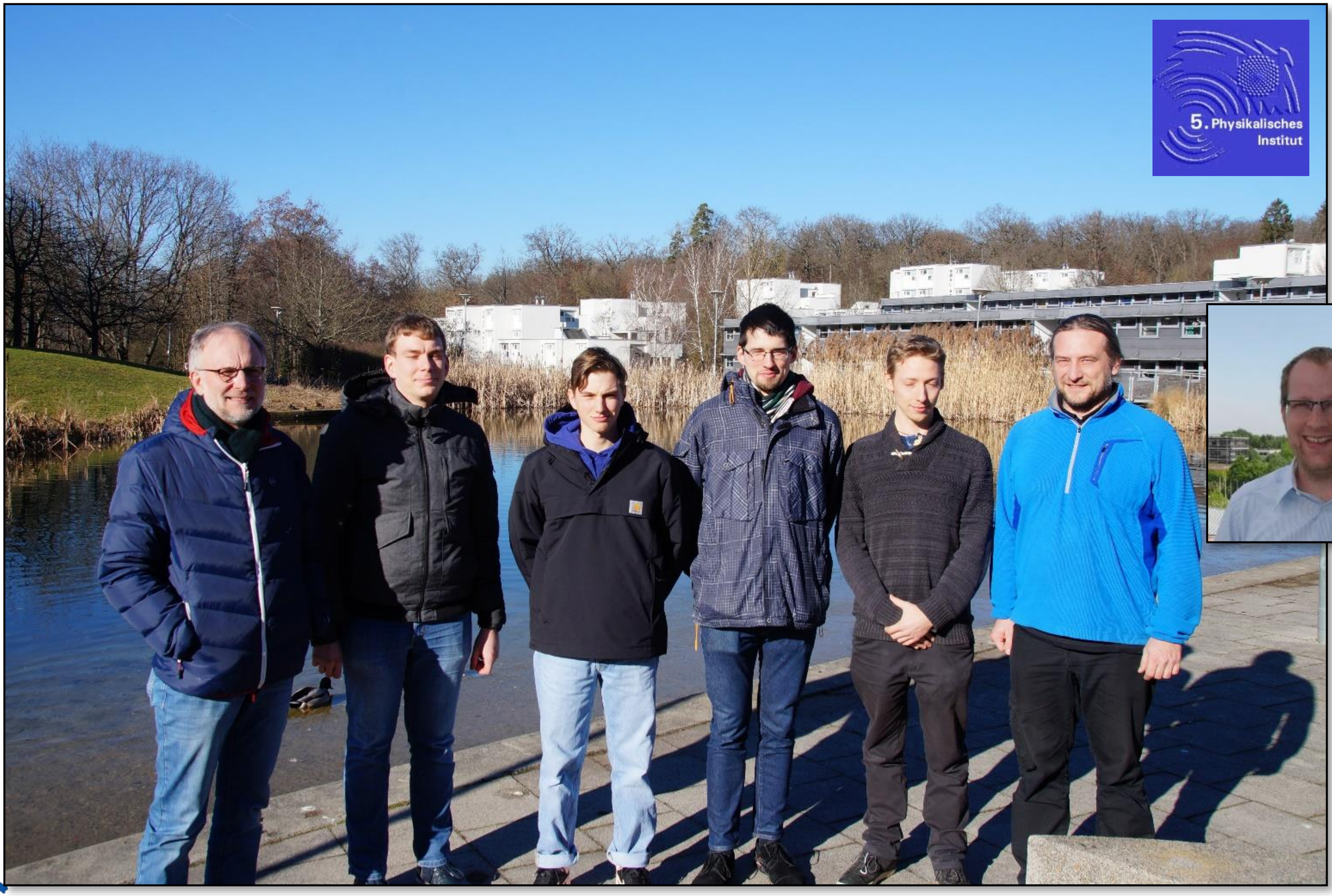
Summary and Outlook

- Cw laser excitation converted into currents up to $30\ \mathrm{nA}$ at $0.5\ \mathrm{mbar}$
- Estimated quantum efficiency of 10^{-4}
- Improvements: Sensitivity $\times\ 10$, temporal resolution $\times\ 100$
- Replace rack based amplifier by custom made onboard amplifier
- Optimization of the charge conversion
- Measurements with gas mixtures of NO and N_2





The QNOSEs



Institute for Smart Sensors

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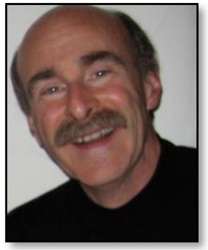
Institute of Large Area Microelectronics

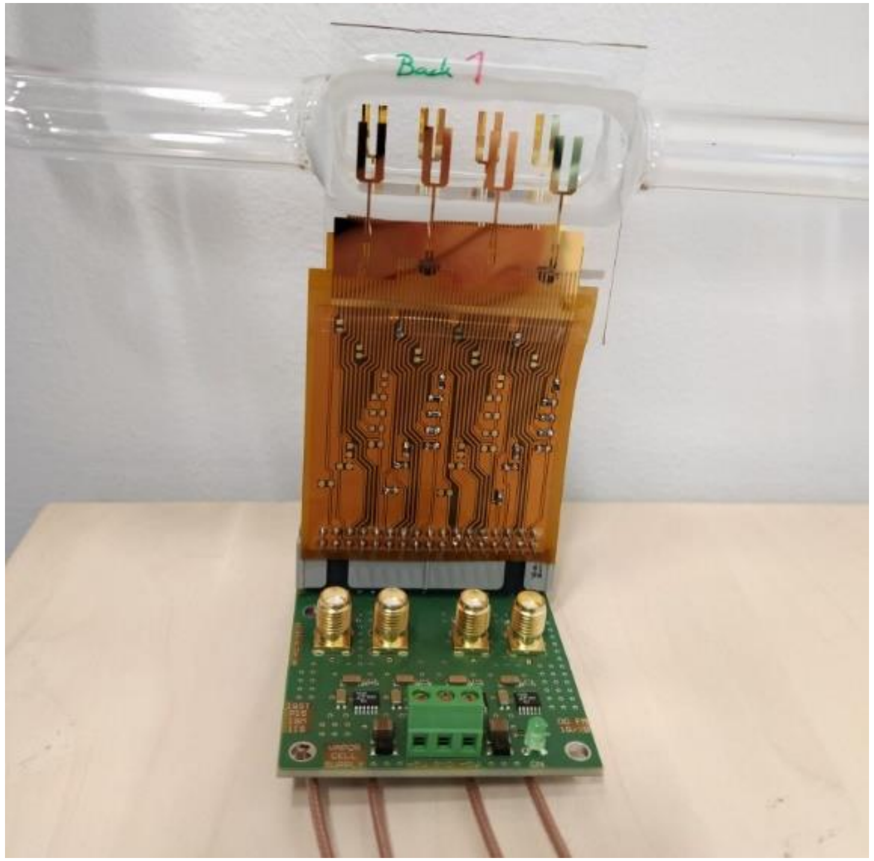


The University of British Columbia
Department of Chemistry

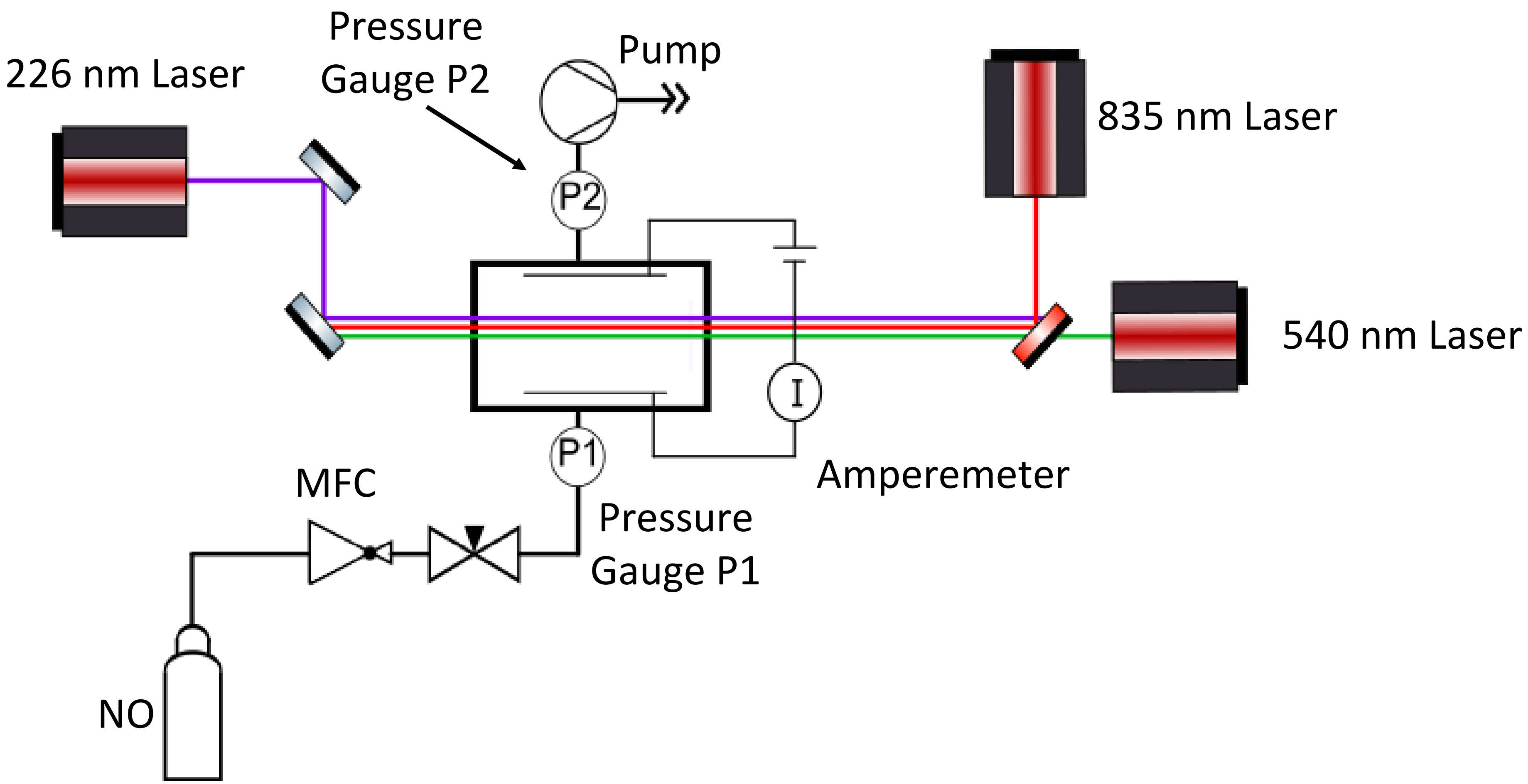
Not shown: Joshua Fabian, Malte Kasten, Luana Rubino, Lea Ebel, Denis Djekic, Holger Baur

Funding: macQsimal

Optogalvanic Spectroscopy – Supplemental Slides

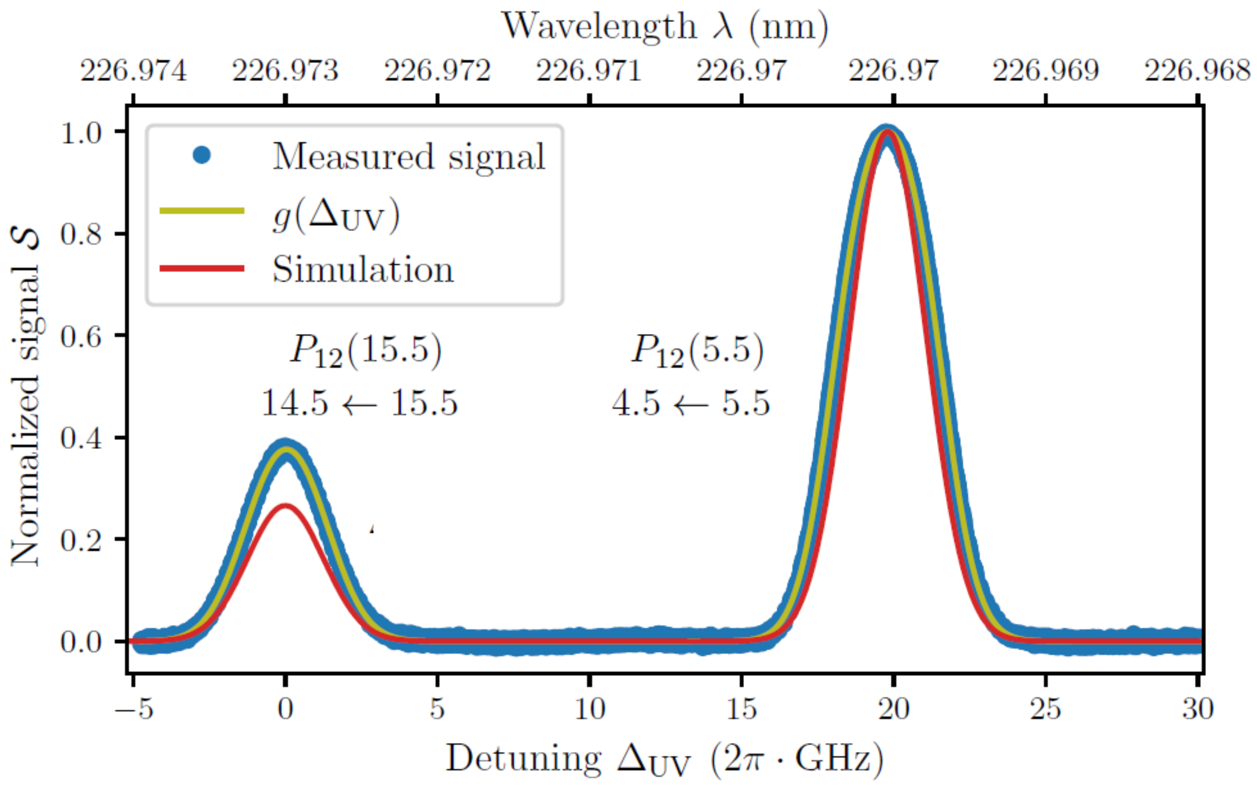


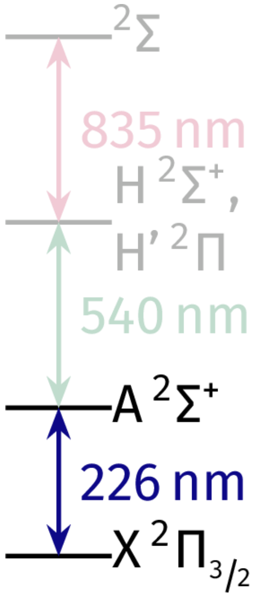
Optical Setup



Groundstate Transition $A^2\Sigma^+ \leftarrow X^2\Pi_{3/2}$

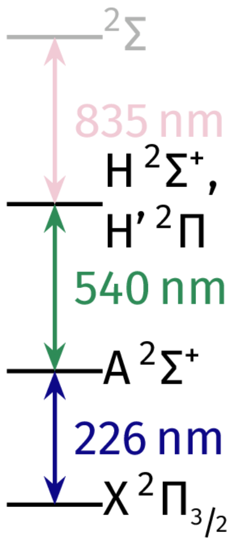
- Two spin-orbit components: $X^2\Pi_{1/2}$ and $X^2\Pi_{3/2}$
- Excitation via: $P_{12}(J_X = 5.5)$
- Verification via adjacent peak
- Simulation with pgopher[1]
  - $\Delta_{\mathrm{Sim}} \approx 2\pi \cdot 19.80$ GHz
  - $\Delta_{\mathrm{Meas}} \approx 2\pi \cdot 19.76$ GHz





[1]C. M. Western "Pgopher: A program for simulating totational, vibrational and electronic spectra," *J. Quant. Spectrosc. Radiat. Transf.* **186**, 221-242 (2017)

Intermediate Transition $\mathbf{H}^2\boldsymbol{\Sigma}^+ \leftarrow \boldsymbol{A}^2\boldsymbol{\Sigma}^+$



- Adjacent states: $H'^2\Pi$ and $H^2\Sigma$
- Excitation via: $\mathrm{R}_{11}(J_A = 4.5, N_A = 4)$
- Dipole forbidden transition $s \rightarrow d$
- Optically not resolvable