Title: Towards an optogalvanic flux sensor for nitric oxide based on Rydberg excitations

Speakers: Harald KÃ¼bler

Collection: Cold Atom Molecule Interactions (CATMIN)

Date: July 15, 2022 - 3:10 PM

URL: https://pirsa.org/22070019

Abstract: I will talk about the applicability of a new kind of gas sensor based on Rydberg excitations. From a gas mixture the molecule in question is excited to a Rydberg state. By succeeding collisions with all other gas components this molecule ionizes and the emerging electrons can be measured as a current.

I will show Doppler-free spectra for the A

Towards an Optogalvanic Sensor for Trace Gases

Patrick Kaspar, Fabian Munkes, Philipp Neufeld, Lea Ebel, Yannick Schellander, Robert Löw, Tilman Pfau, and Harald Kübler

University of Stuttgart, 5th Institute of Physics

IQST Integrated Quantum Science and Technology

macQsimal

DFG Deutsche Forschungsgemeinschaft

Optogalvanic Detection of CW Rydberg Excitations in Thermal Nitric Oxide

Patrick Kaspar, Fabian Munkes, Philipp Neufeld, Lea Ebel, Yannick Schellander, Robert Löw, Tilman Pfau, and Harald Kübler

University of Stuttgart, 5th Institute of Physics

IQST Integrated Quantum Science and Technology macQsimal DFG Deutsche Forschungsgemeinschaft

Motivation

- Targeted application: Breath gas analysis

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

Motivation

- Targeted application: Breath gas analysis

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

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

Motivation

- Targeted application: Breath gas analysis
- Why nitric oxide?
  - Signaling inflammatory diseases

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

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

Motivation

- Targeted application: Breath gas analysis

- Why nitric oxide?
  - Signaling inflammatory diseases
  - Blood pressure regulation

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

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

Motivation

- Targeted application: Breath gas analysis
- Why nitric oxide?
  - Signaling inflammatory diseases
  - Blood pressure regulation
  - Immune system
- Human and other specimen

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

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

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

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

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

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).

Motivation

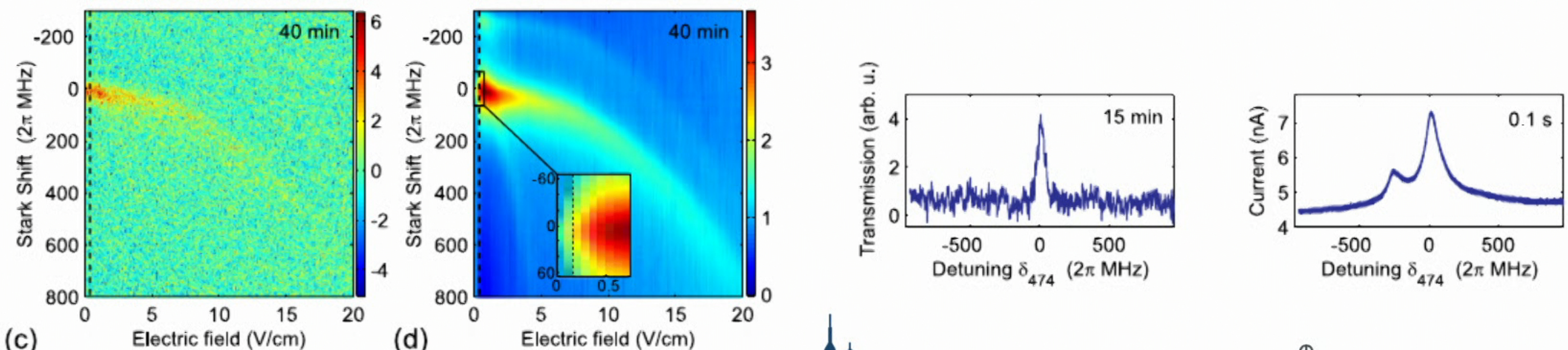
PRL **110,** 123002 (2013) PHYSICAL REVIEW LETTERS week ending 22 MARCH 2013

Electrical Readout for Coherent Phenomena Involving Rydberg Atoms in Thermal Vapor Cells

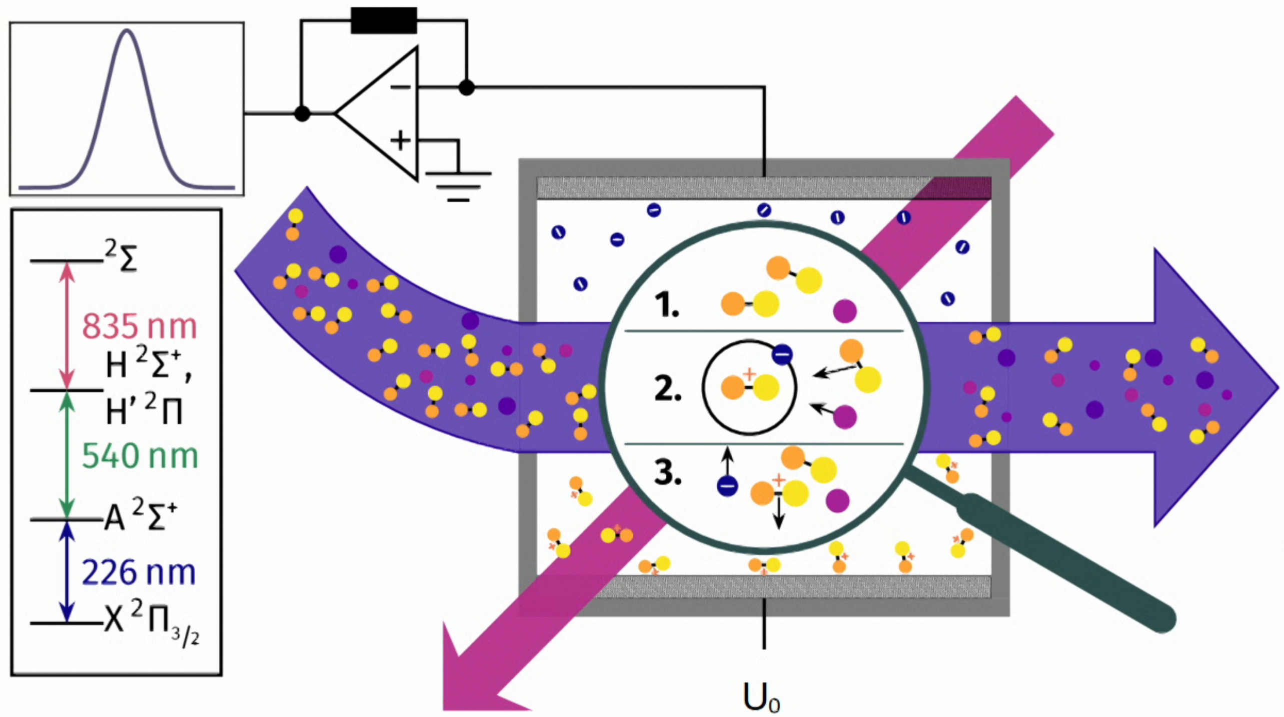
D. Barredo, H. Kübler, R. Daschner, R. Löw, and T. Pfau

5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany

(Received 28 September 2012; published 21 March 2013)



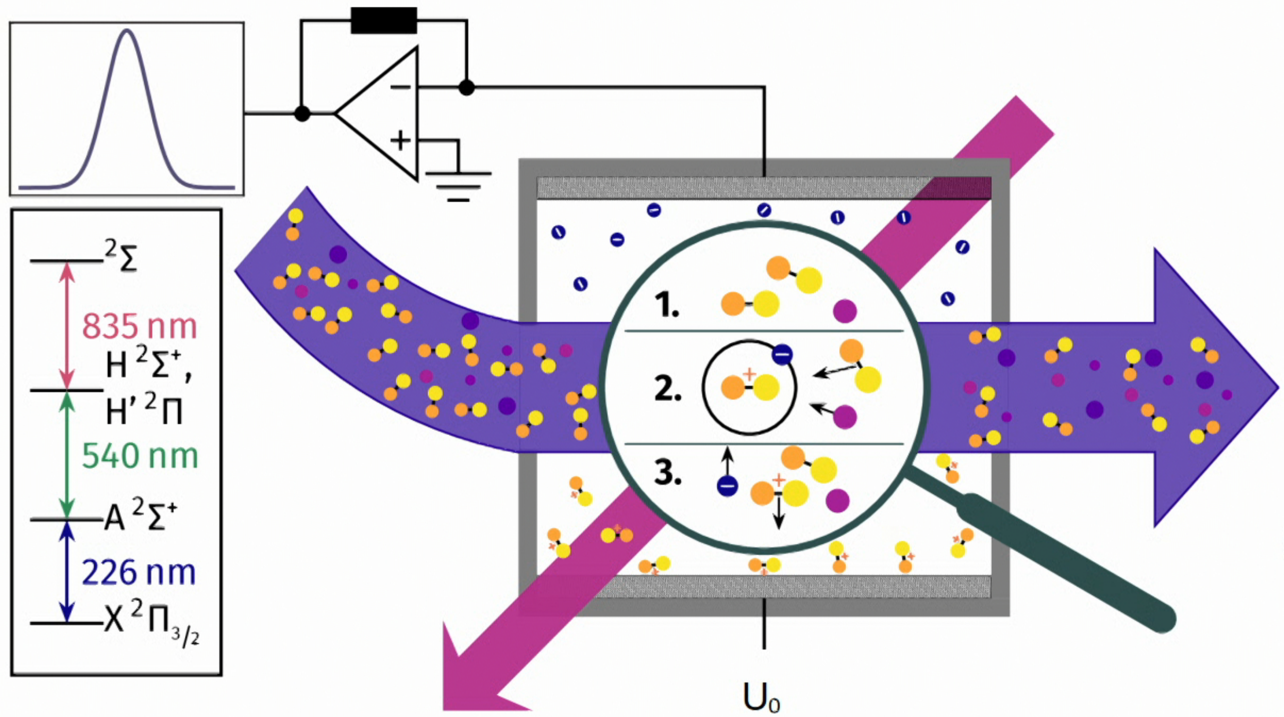
Sensing Principle



[1]J. Schmidt et. al. *Applied Physics Letter* **113**, 011113 (2018)

Sensing Principle

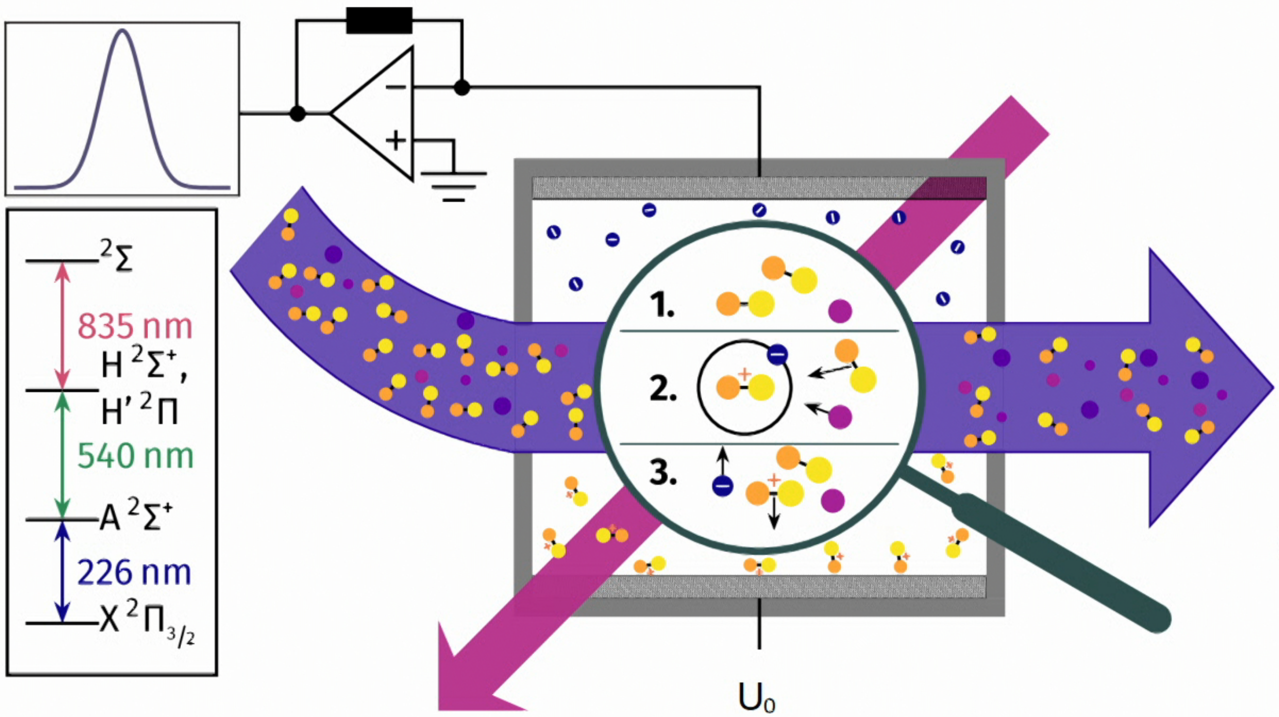
- Gas sensor[1] developement requires:



[1]J. Schmidt et. al. *Applied Physics Letter* **113**, 011113 (2018)

Sensing Principle

- Gas sensor[1] developement requires:
  - Precise knowledge about involved states including State substructure

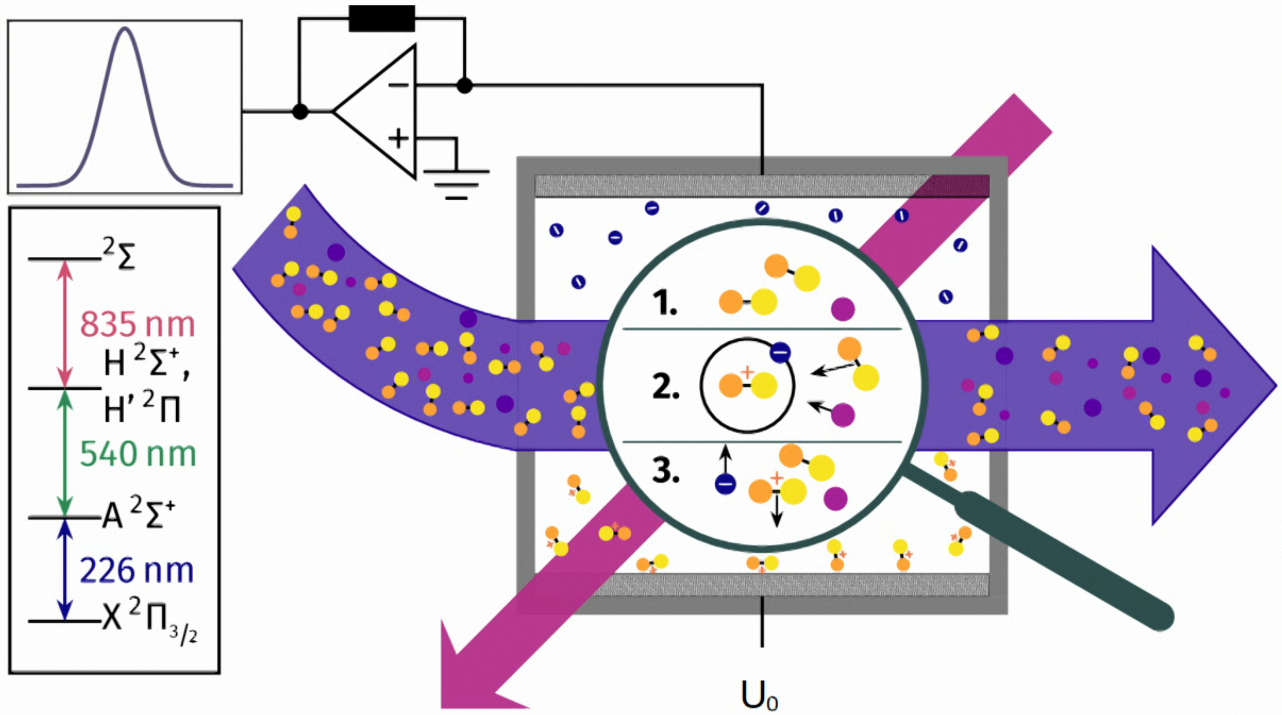


[1]J. Schmidt et. al. *Applied Physics Letter* **113**, 011113 (2018)

Sensing Principle

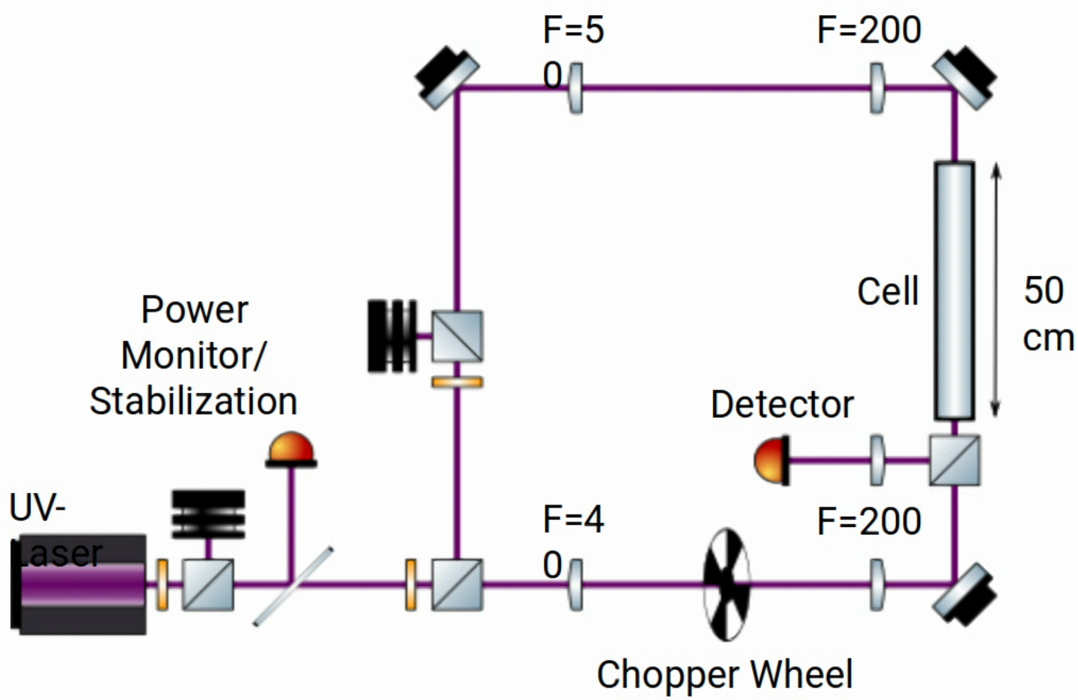
- Gas sensor[1] developement requires:
  - Precise knowledge about involved states including State substructure

- Opimization of excitation path



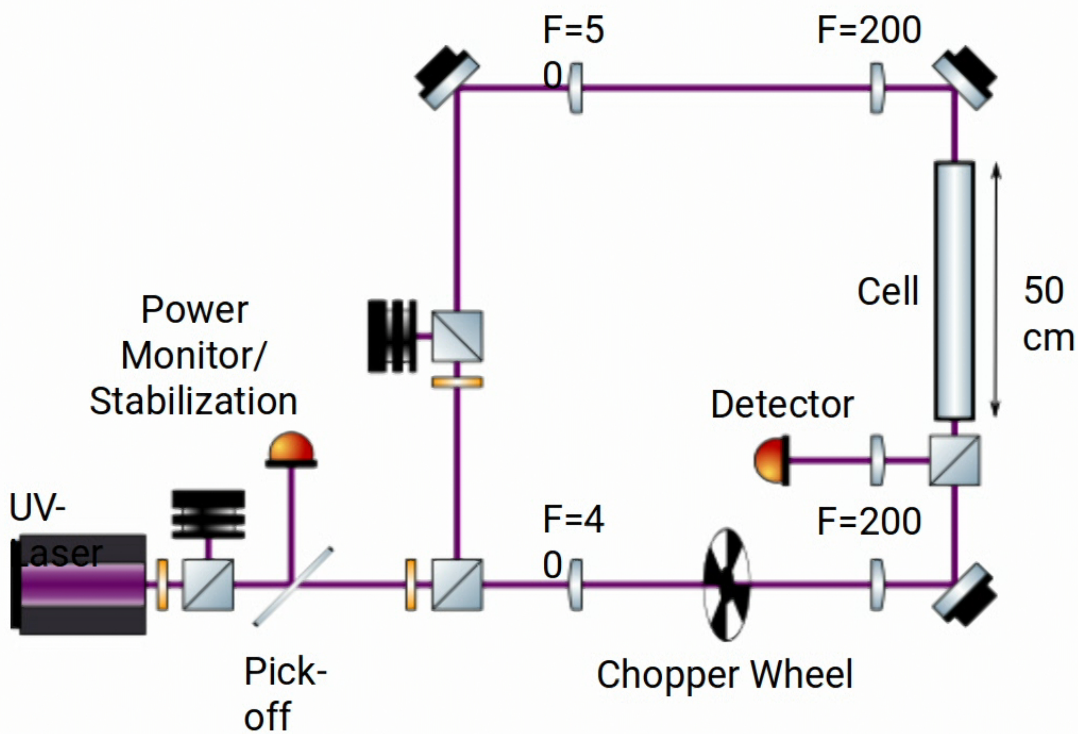
[1] J. Schmidt et. al. *Applied Physics Letter* **113**, 011113 (2018)

Experimental Setup



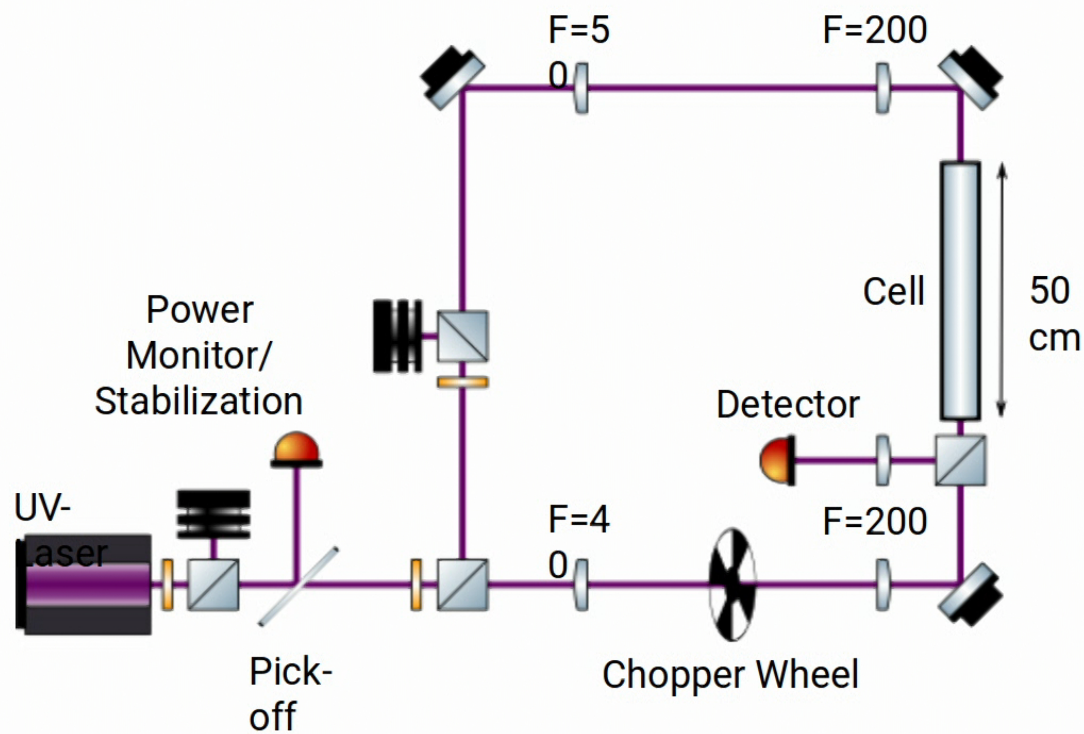
Experimental Setup

- Doppler-free saturation spectroscopy
  - Pump: 4 mW, Probe 0.4 mW
  - Pressure: 0.023 mbar



Experimental Setup

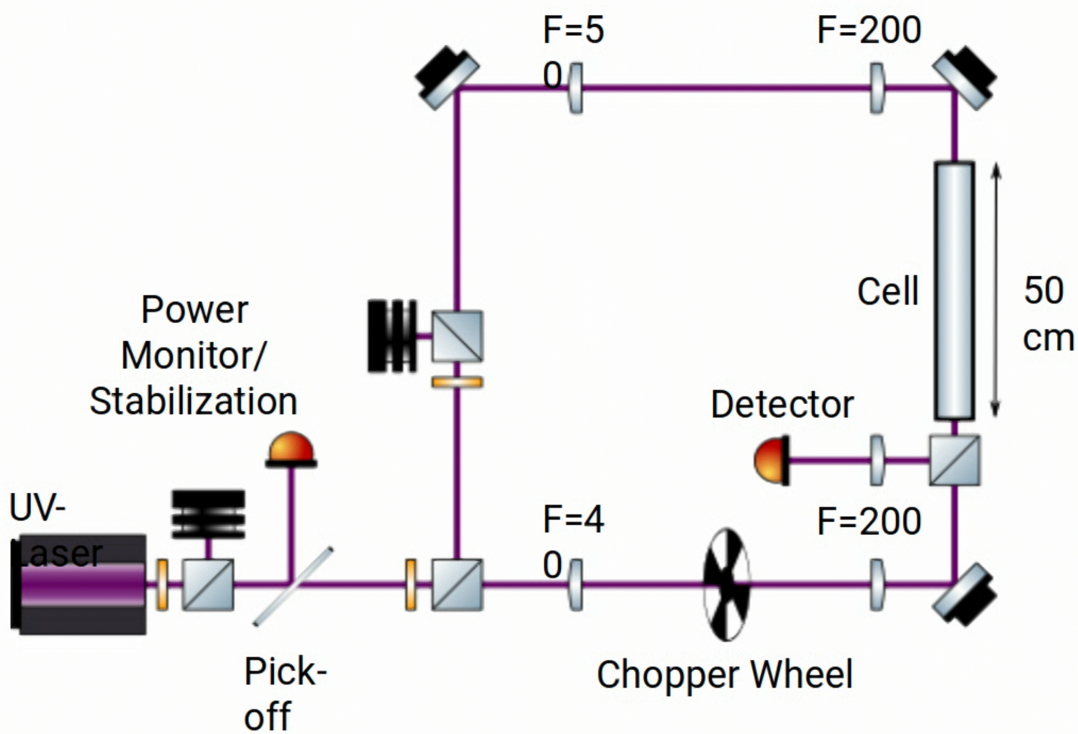
- Doppler-free saturation spectroscopy
  - Pump: 4 mW, Probe 0.4 mW
  - Pressure: 0.023 mbar
- Actively stabilized laser power



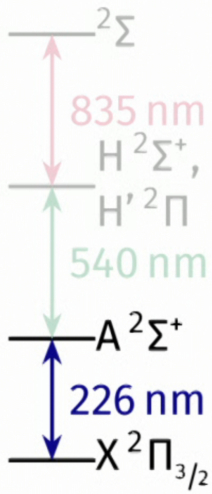
Experimental Setup

- Doppler-free saturation spectroscopy
  - Pump: 4 mW, Probe 0.4 mW
  - Pressure: 0.023 mbar

- Actively stabilized laser power
- Detection via lock-in amplifier

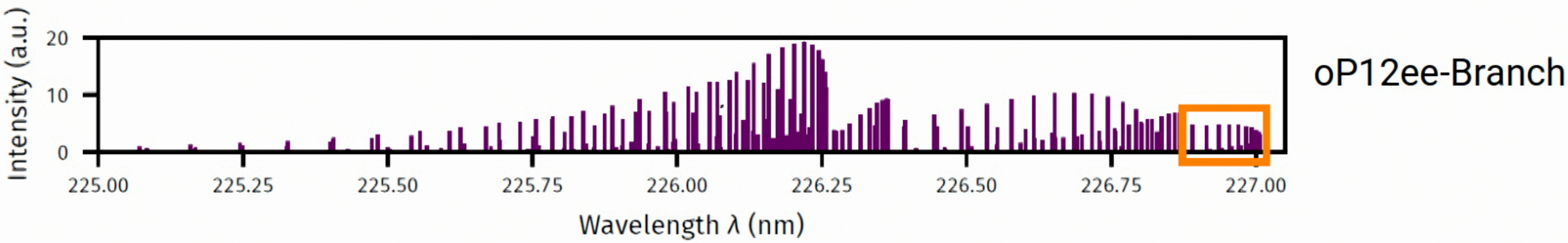


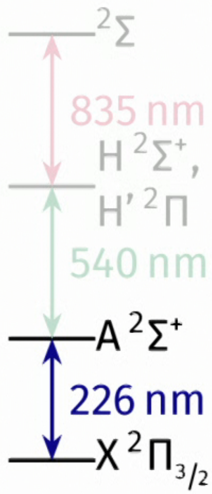
High resolution spectroscopy of the NO groundstate transition



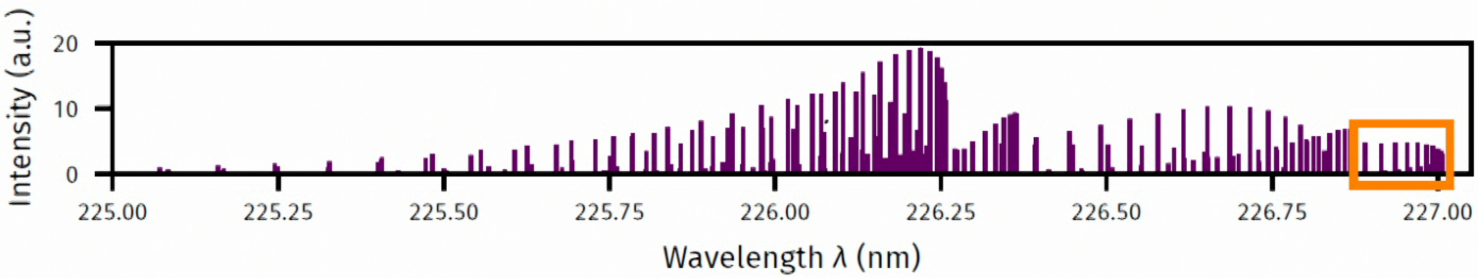
7

High resolution spectroscopy of the NO groundstate transition

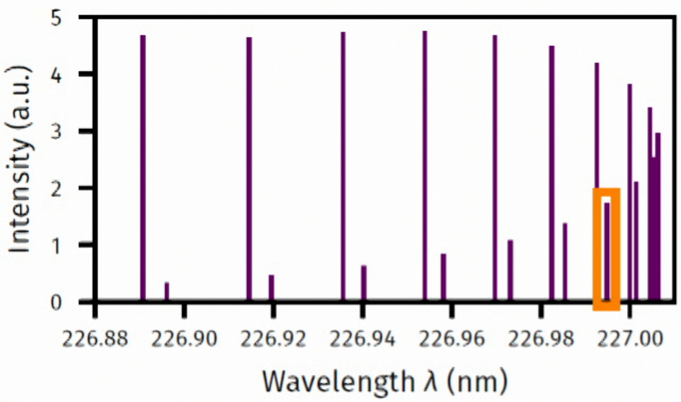


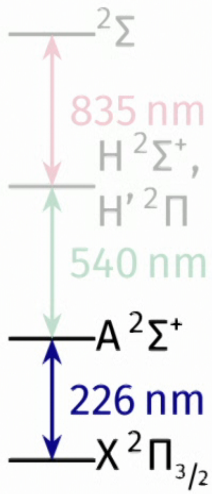


High resolution spectroscopy of the NO groundstate transition

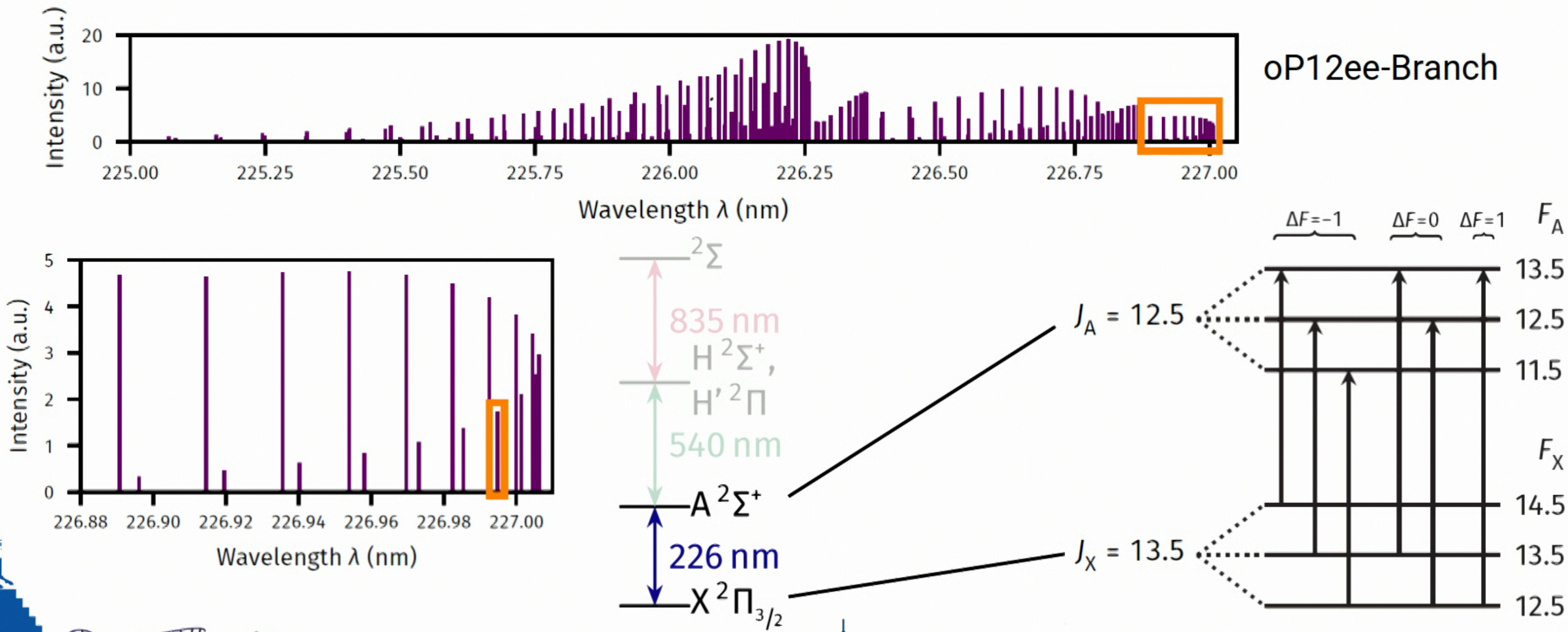


oP12ee-Branch



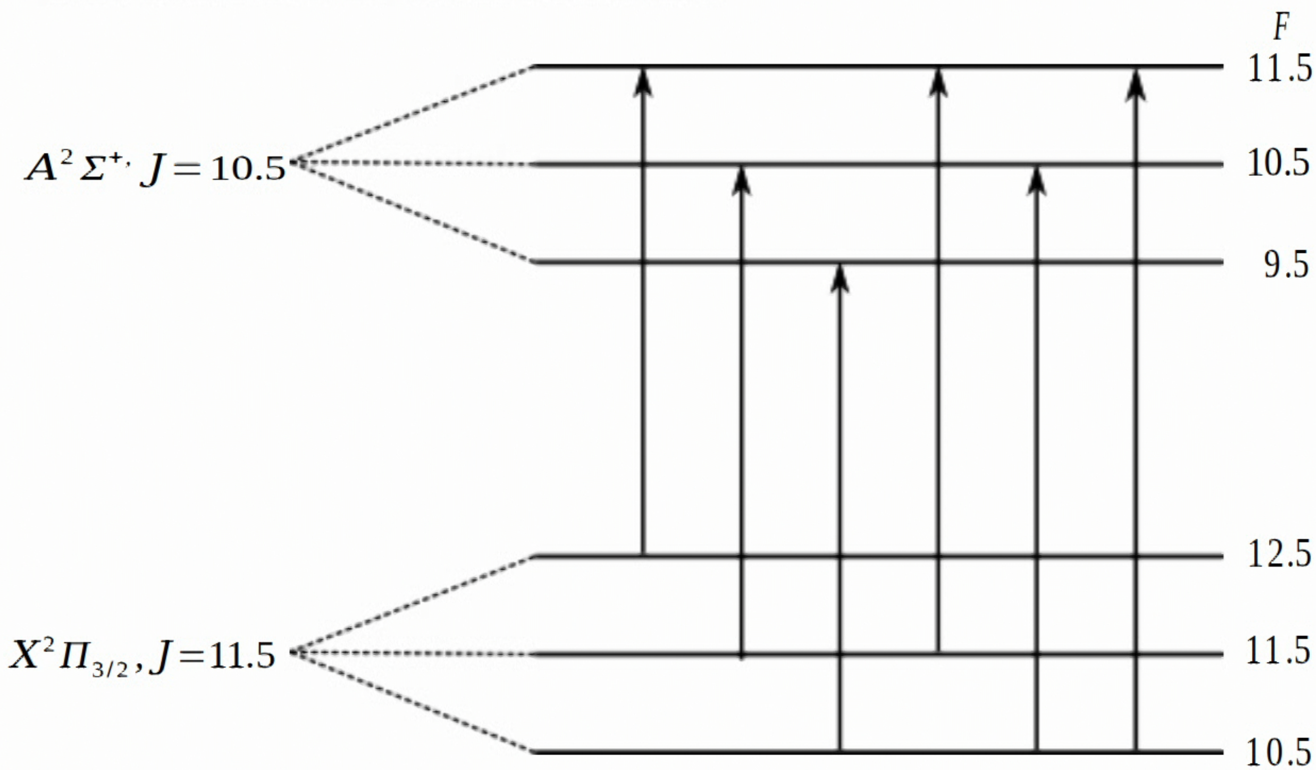


High resolution spectroscopy of the NO groundstate transition



Theoretical Treatment

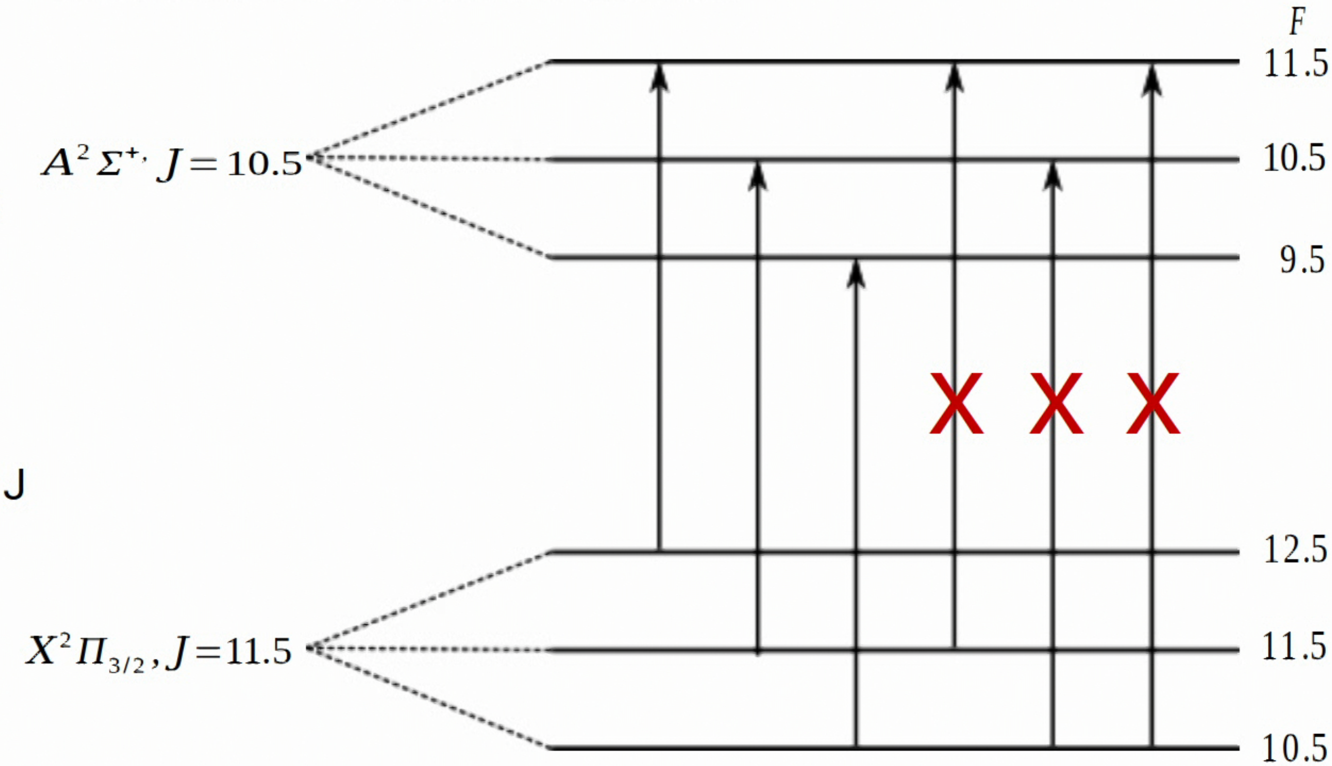
- Calculation with pGopher[1]
  - Includes fine & hyperfine structure
  - Calculation of full spectrum



[1] Colin M. Western, *Journal of Quantitative Spectroscopy and Radiative Transfer*, **186** 221-242 (2017)

Theoretical Treatment

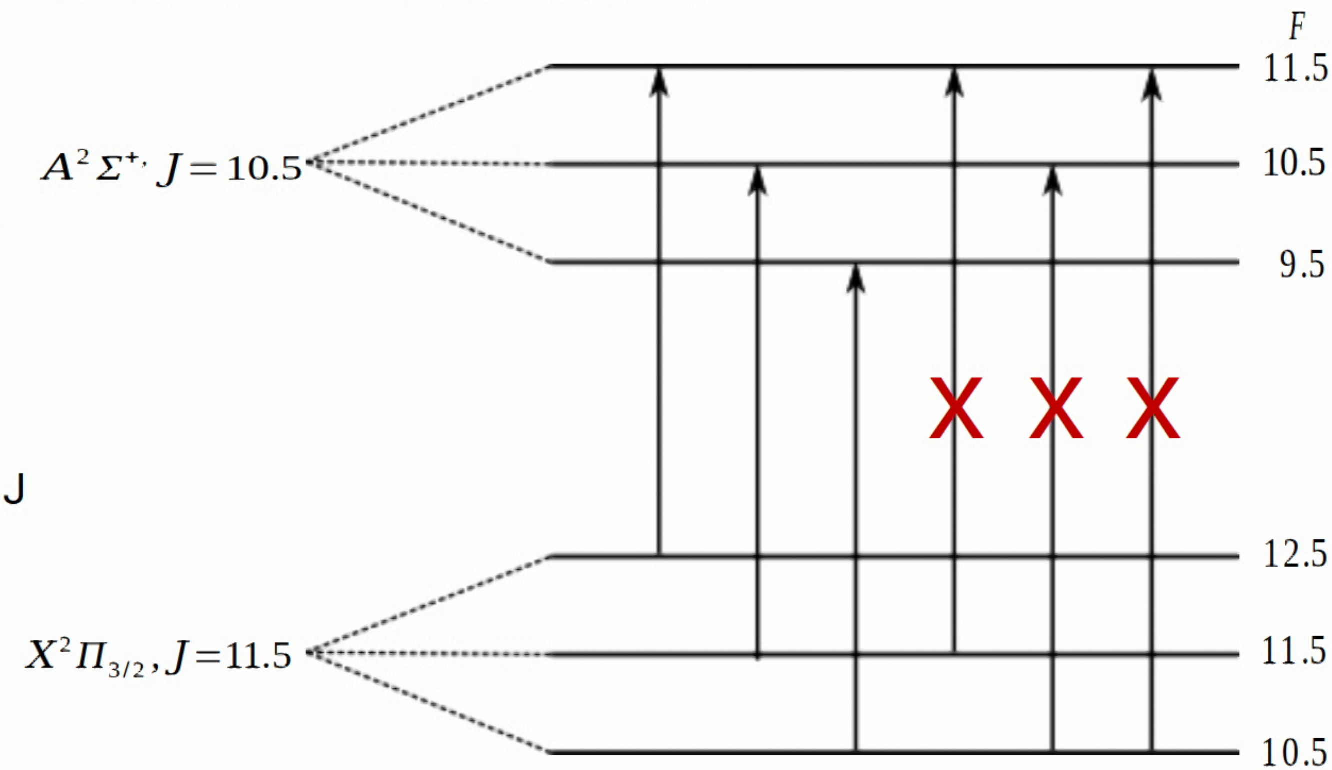
- Calculation with pGopher[1]
  - Includes fine & hyperfine structure
  - Calculation of full spectrum
- Six hyperfine transitions per J
  - Three transitions very weak



[1] Colin M. Western, *Journal of Quantitative Spectroscopy and Radiative Transfer*, **186** 221-242 (2017)

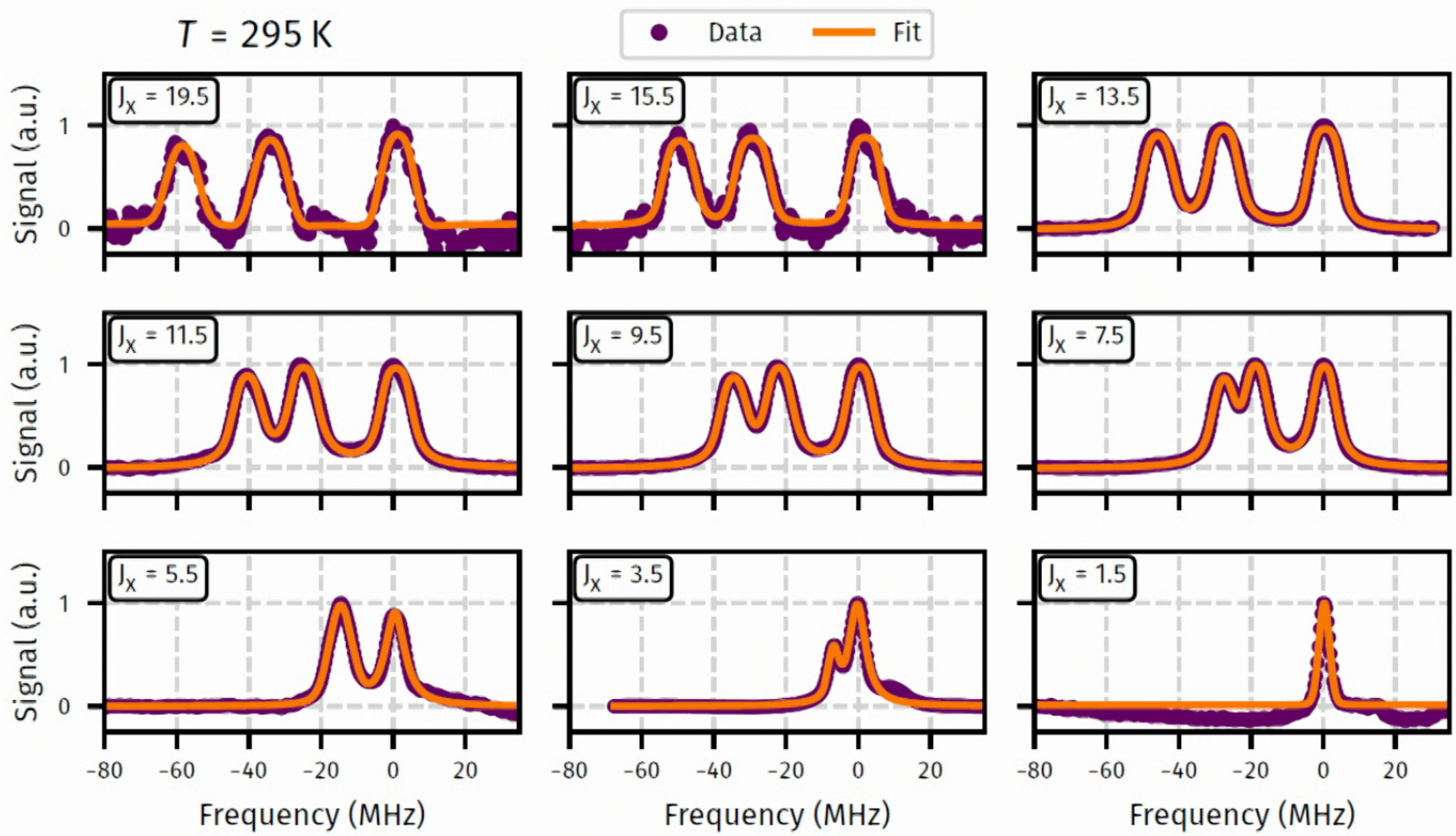
Theoretical Treatment

- Calculation with pGopher[1]
  - Includes fine & hyperfine structure
  - Calculation of full spectrum
- Six hyperfine transitions per J
  - Three transitions very weak
  - Retrieve splitting of remaining lines

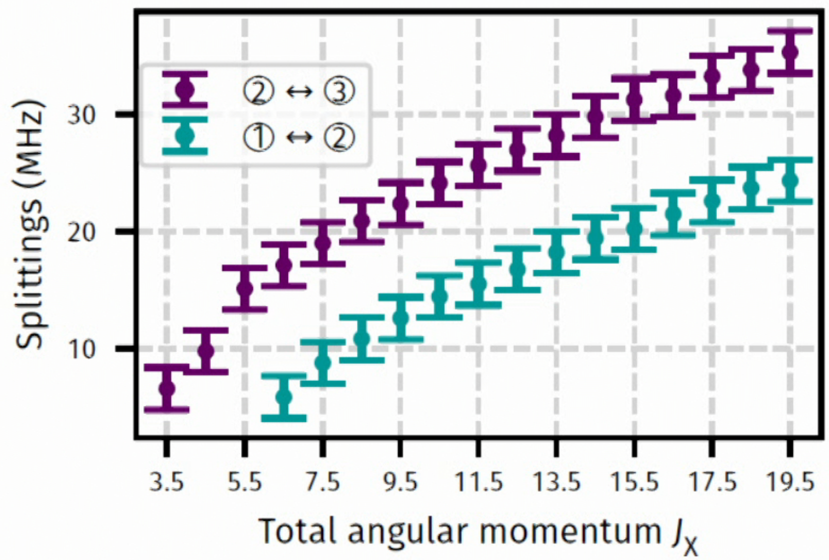


[1] Colin M. Western, *Journal of Quantitative Spectroscopy and Radiative Transfer*, **186** 221-242 (2017)

Hyperfine splittings for different J-Values



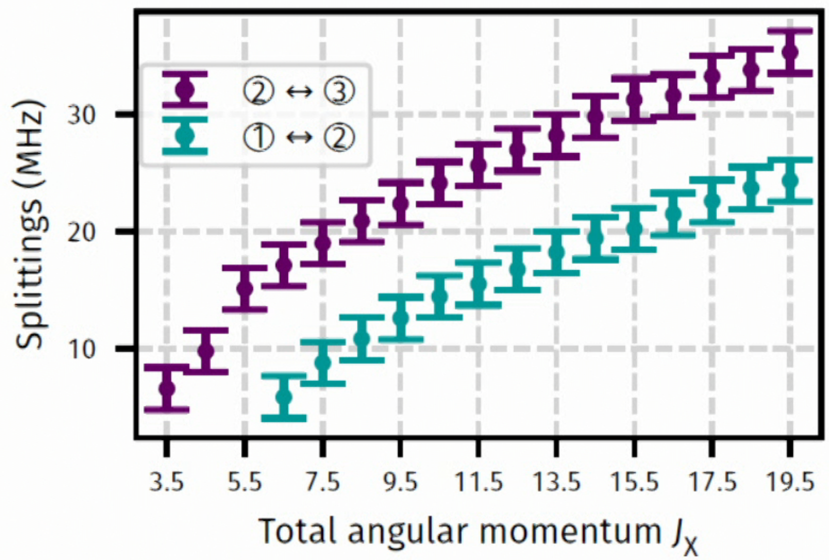
Analysis – Determination of molecular constants



[1]Colin M. Western, Journal of Quantitative Spectroscopy & Radiative Transfer 186 (2017) 221-242

Analysis – Determination of molecular constants

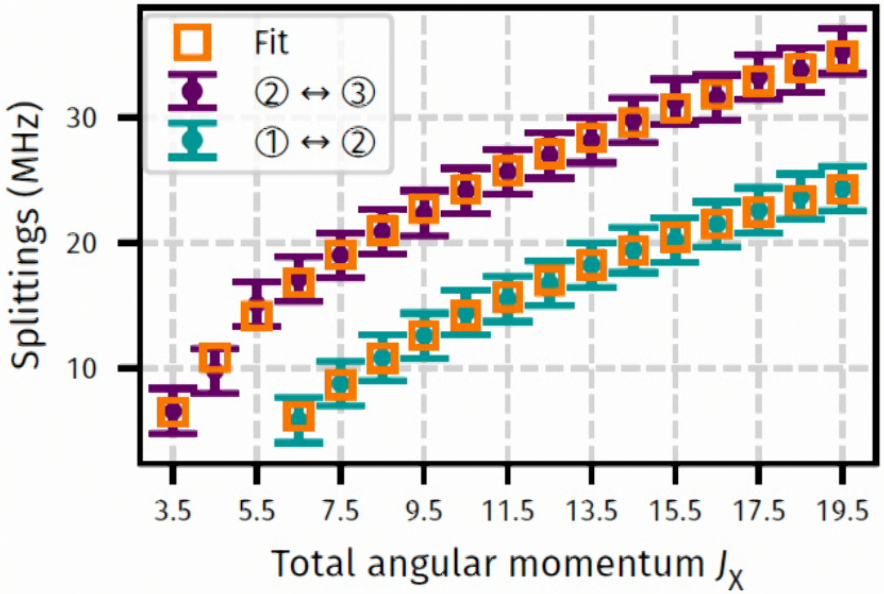
- Theoretical description via empirical constants
- Well known for the ground state



[1]Colin M. Western, Journal of Quantitative Spectroscopy & Radiative Transfer 186 (2017) 221-242

Analysis – Determination of molecular constants

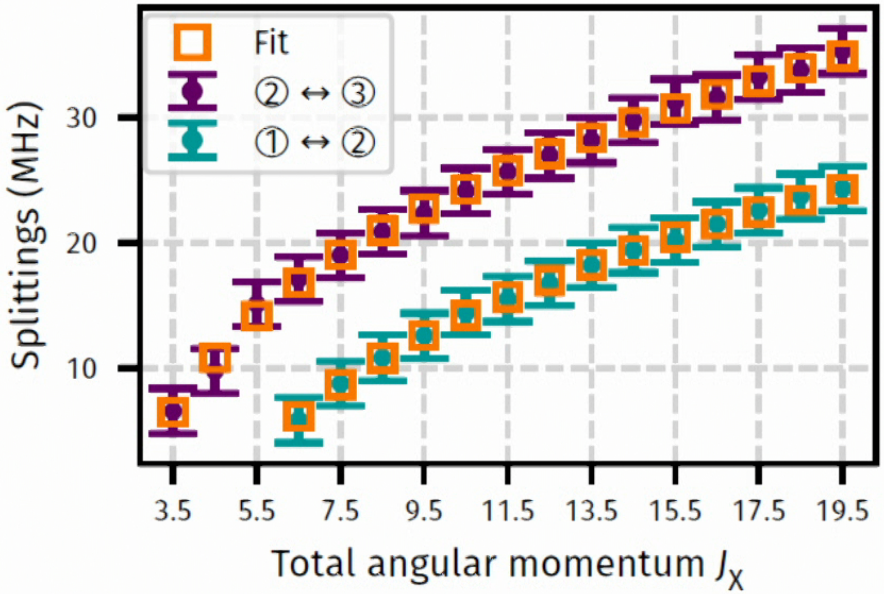
- Theoretical description via empirical constants
- Well known for the ground state



[1]Colin M. Western, Journal of Quantitative Spectroscopy & Radiative Transfer 186 (2017) 221-242

Analysis – Determination of molecular constants

- Theoretical description via empirical constants
- Well known for the ground state
- Lowest three datapoints left out



[1]Colin M. Western, Journal of Quantitative Spectroscopy & Radiative Transfer 186 (2017) 221-242

Further resolution increase

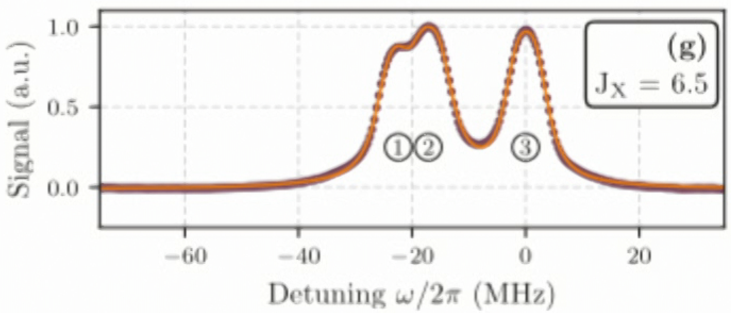
- Very good agreement between our and previous measurement

Constant	This work	Ref. [35]
c	5.29(53)	5.59(64)
b	41.06(9)	41.66(51)
eQq_0	−7.31(12)	−7.31(23)
b_F	42.82(26)	43.52(30)

Reference [35]:
M.Brouard et. Al., J. of Mol. Spec. 282 (2012) 42-49

Further resolution increase

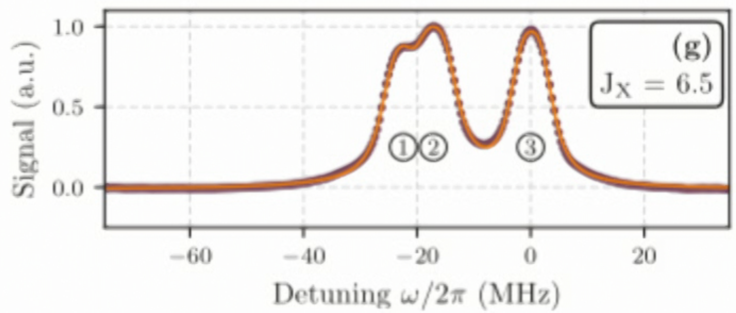
- Very good agreement between our and previous measurement



Reference [35]:
M.Brouard et. Al., J. of Mol. Spec. 282 (2012) 42-49

Further resolution increase

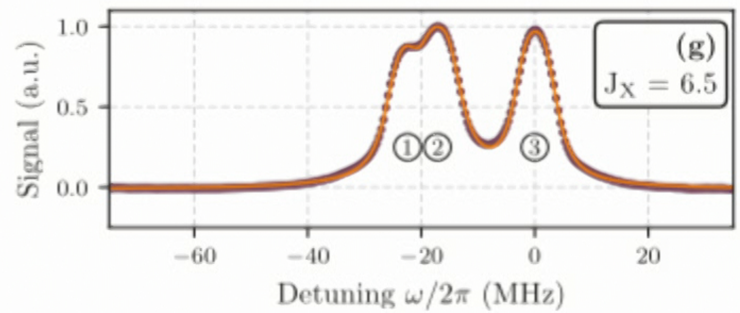
- Very good agreement between our and previous measurement
- Higher resolution possible at lower pressure

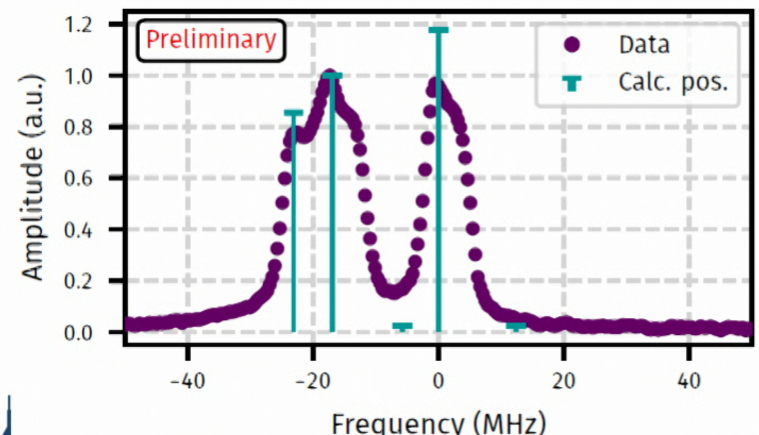


Reference [35]:
M.Brouard et. Al., J. of Mol. Spec. 282 (2012) 42-49

Further resolution increase

- Very good agreement between our and previous measurement
- Higher resolution possible at lower pressure

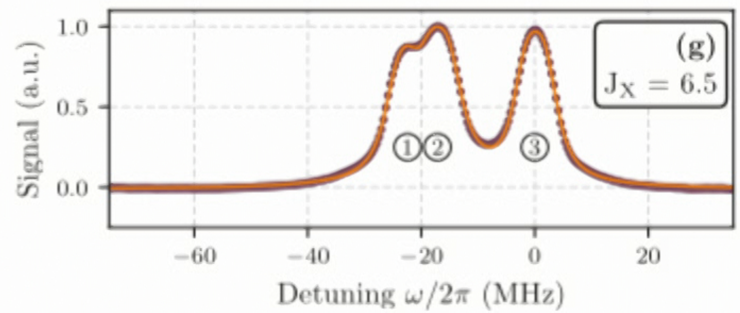


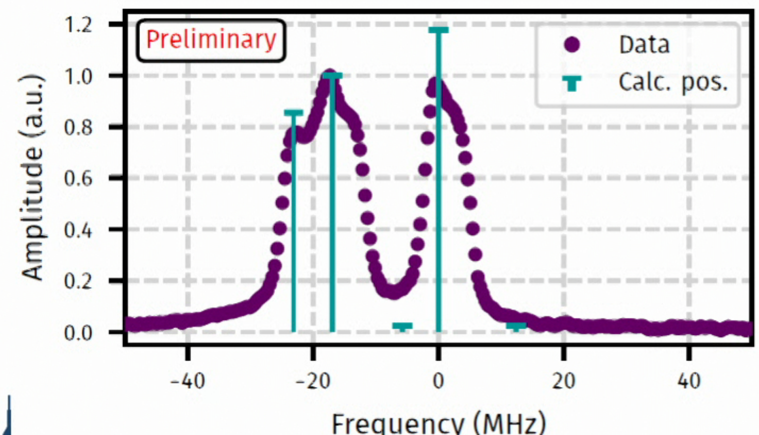


Reference [35]:
M.Brouard et. Al., J. of Mol. Spec. 282 (2012) 42-49

Further resolution increase

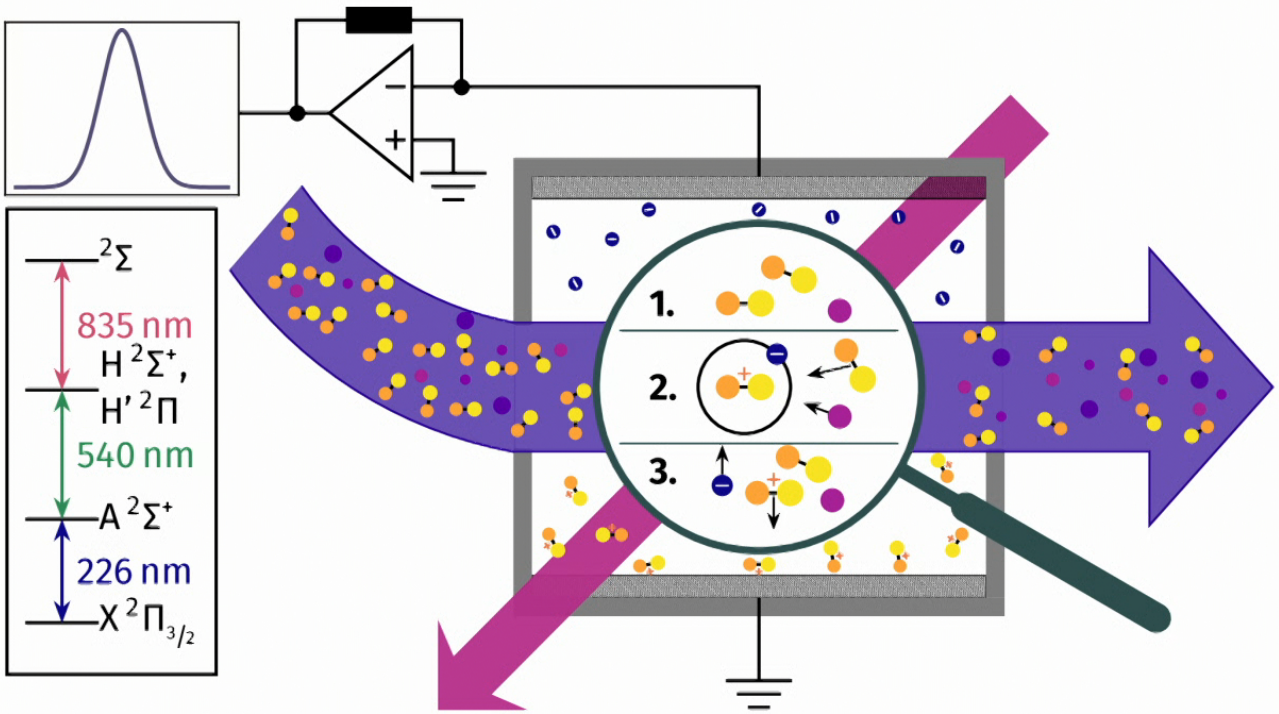
- Very good agreement between our and previous measurement
- Higher resolution possible at lower pressure
- Measure saturation intensity
  - Important for optimization of the sensor
  - Analysis of broadening mechanisms



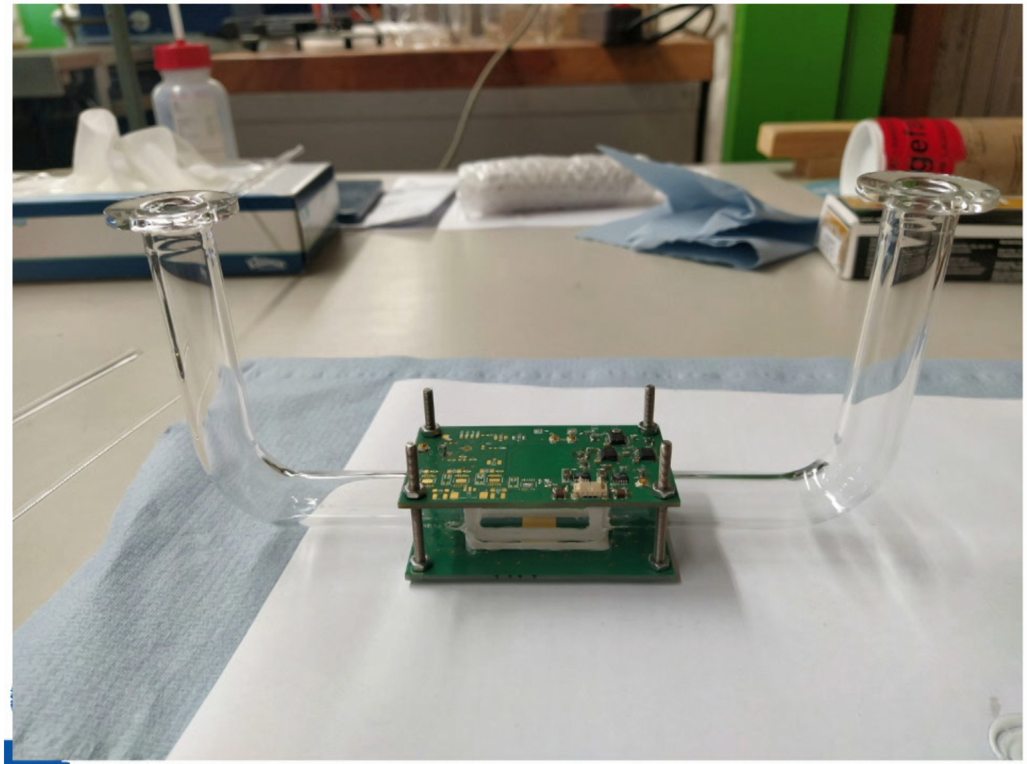


Reference [35]:
M.Brouard et. Al., J. of Mol. Spec. 282 (2012) 42-49

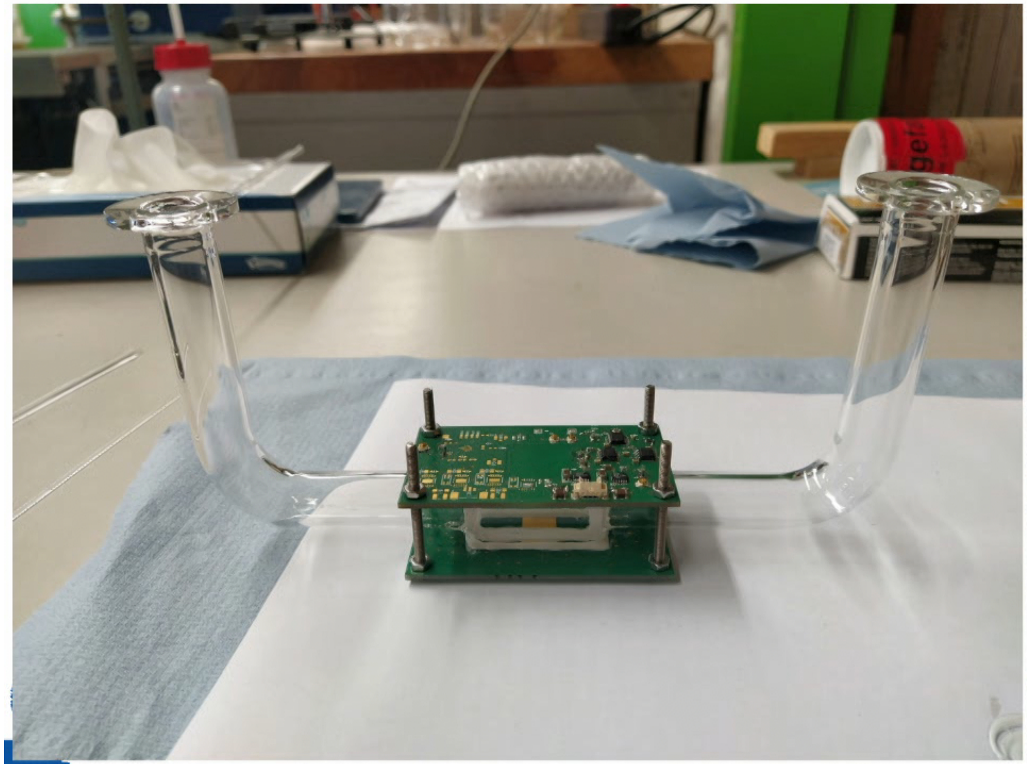
Investigation of the current signal

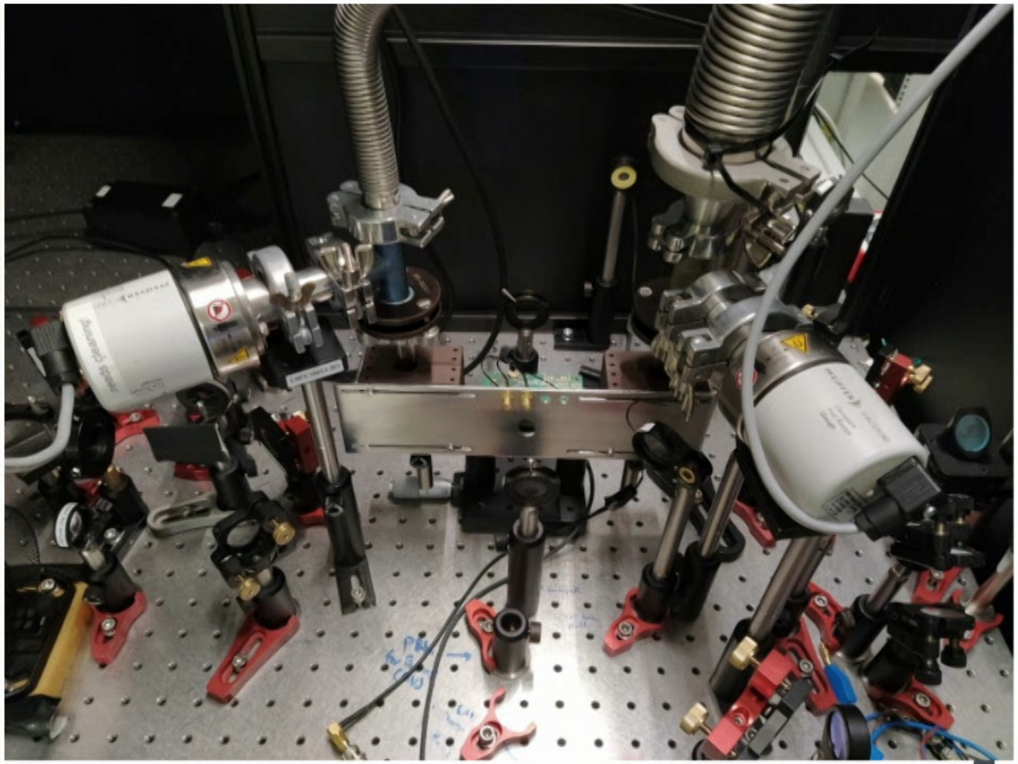


Cell with onboard amplifier

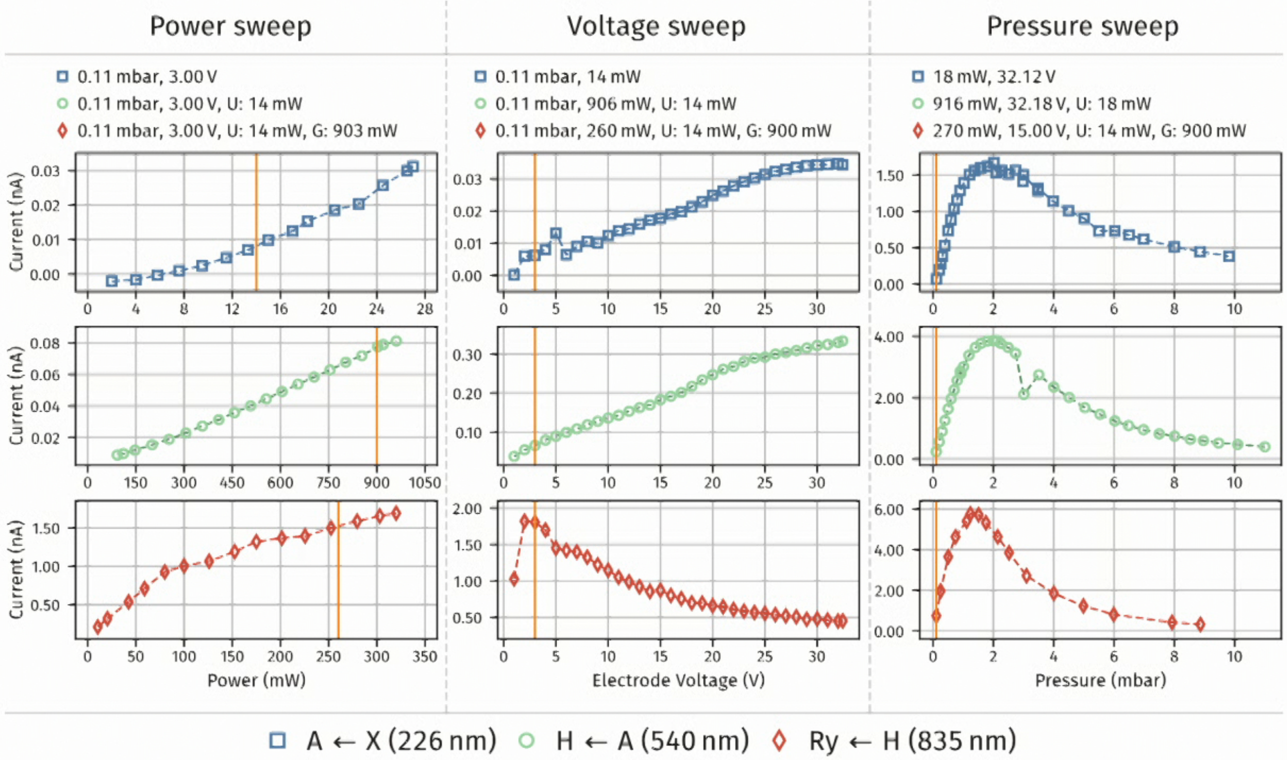


Cell with onboard amplifier

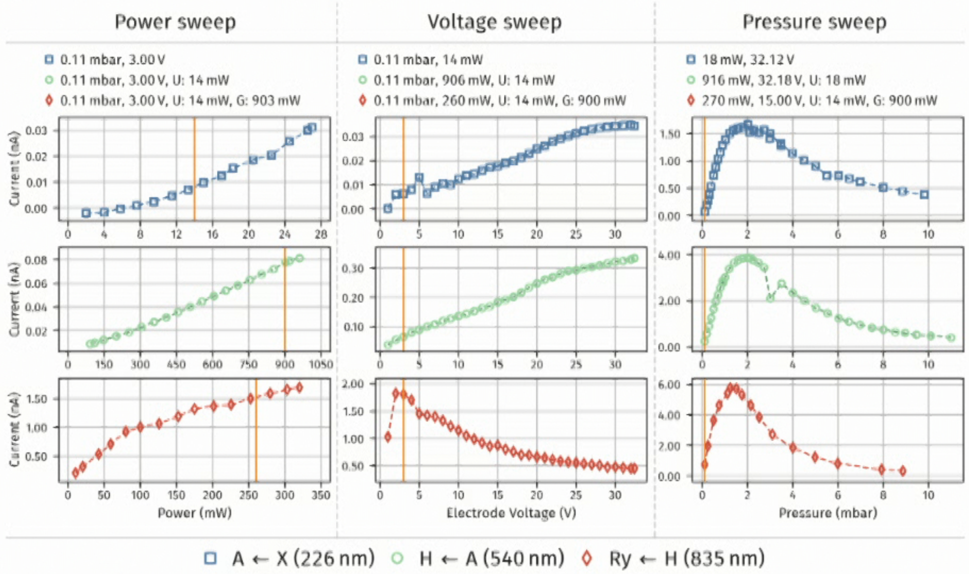




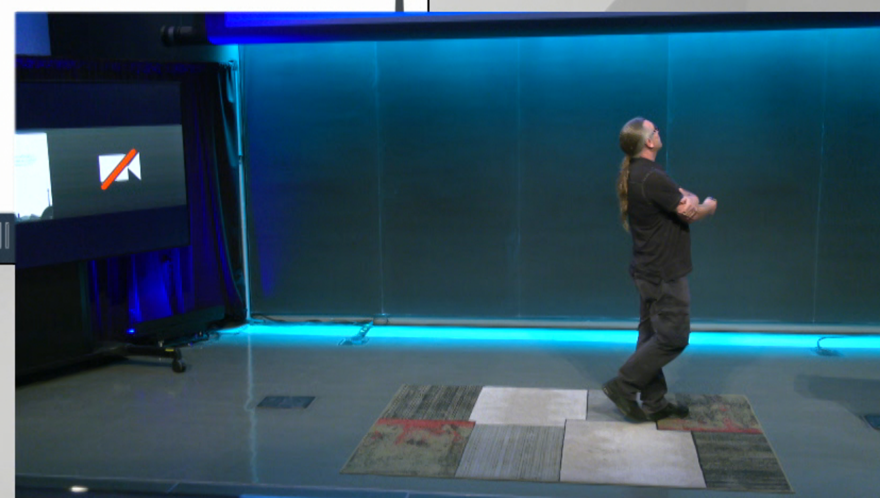
Investigation of the current signal



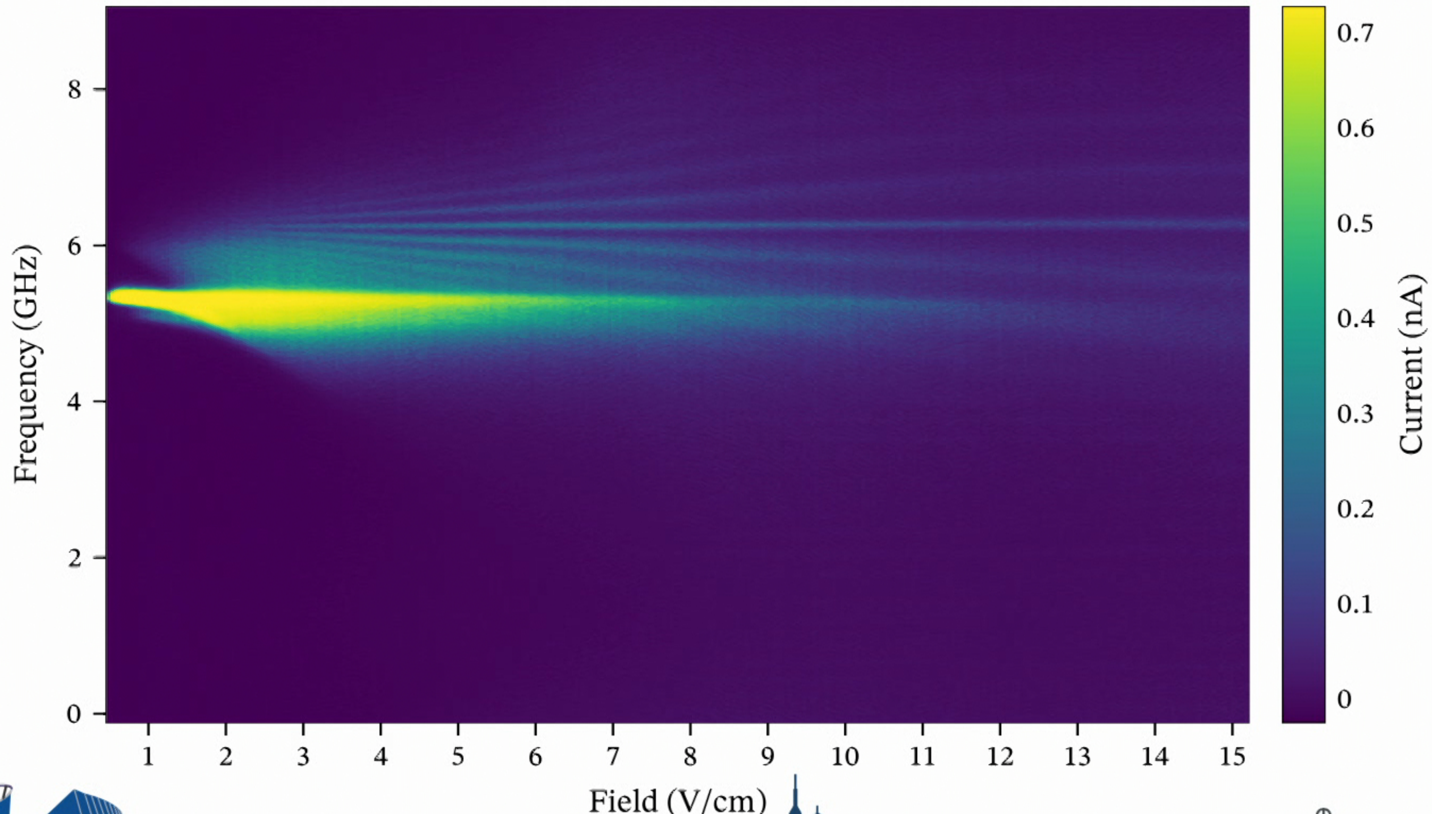
Investigation of the current signal



- Quantum efficiency estimated at marked parameters to 10^{-5}



First CW Stark Map



Outlook

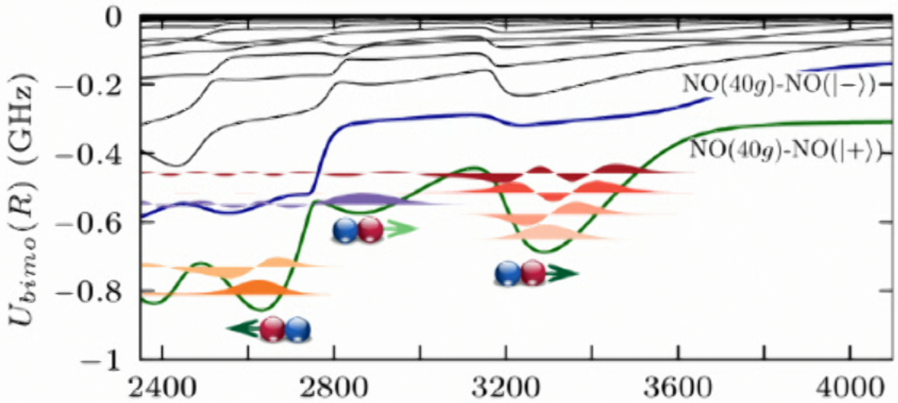
- Rydberg Stark-Effect measurements: Analysis of Rydberg states and assignment
- Test measurements NO in N2 and first human breath samples

Outlook

- Rydberg Stark-Effect measurements: Analysis of Rydberg states and assignment
- Test measurements NO in N2 and first human breath samples
- Optimization of detection efficiency and Signal to noise ration
  - Modulation of red or green laser
  - Lock-in amplifier

Outlook

- Rydberg Stark-Effect measurements: Analysis of Rydberg states and assignment
- Test measurements NO in N2 and first human breath samples
- Optimization of detection efficiency and Signal to noise ration
  - Modulation of red or green laser
  - Lock-in amplifier



The QNOSEs

- Bachelor students
  - Pascal Pruy
  - Andre Bisquerra
  - Michael Iljewicz
  - Joshua Fabian
  - Malte Kasten
  - Luana Rubino

- Collaborators
  - Ed Grant (UBC Vancouver)
  - Stephen Hogan (UCL)