ULTRAHIGH FINESSE CAVITY-ENHANCED SPECTROSCOPY OF DEUTERIUM MOLECULE FOR QED TESTS

NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ
Faculty of Physics, Astronomy and Informatics

UNIVERSITÉ DE RENNES 1

M. Zaborowski, M. Słowinski, K. Stankiewicz, F. Thibault, A. Cygan, H. Jóźwiak, G. Kowzan, P. Masłowski, A. Nishiyama, N. Stolarczyk, S. Wójtewicz, R. Ciuryło, D. Lisak, P. Wcisło

21.06.2022

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Motivation of hydrogen molecule studies

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Motivation of hydrogen molecule studies

Most abundant molecule in the Universe

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Relatively easily calculable system!

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A tool for fundamental physics studies!

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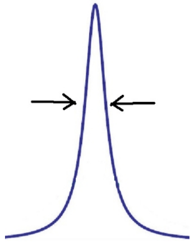
Rich spectrum of long living rovibrational levels (10^5 –10^6 s)



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Tests of relativistic and quantum electrodynamics corrections in molecular systems.

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Direct $\alpha^5 m$

$\alpha^6 m$ $\alpha^7 m$ using BO

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- **Searching for new physics**

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Fifth force (f.e. long-range hadron-hadron)

Extra dimensions

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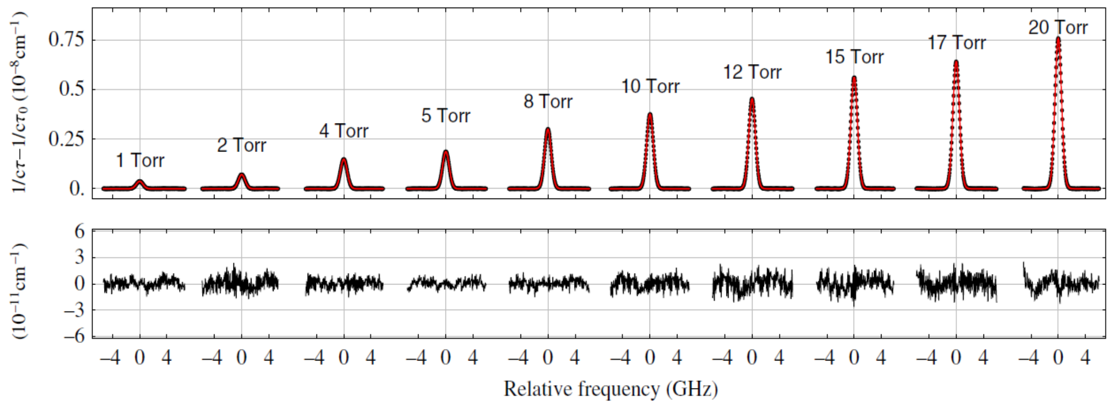
Components of the experiment

Ultraprecise measurement of the 2-0 S(2) line position in D_2



Best measurement in homonuclear hydrogen at the moment of publication!

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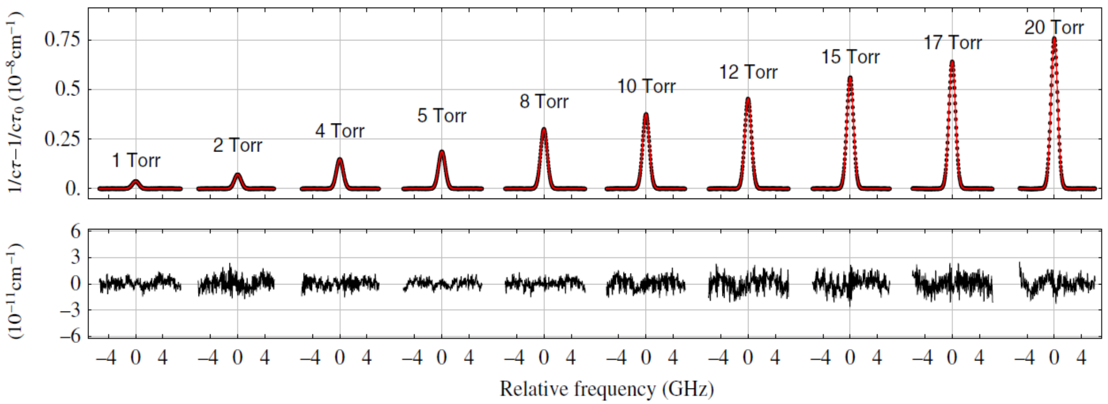

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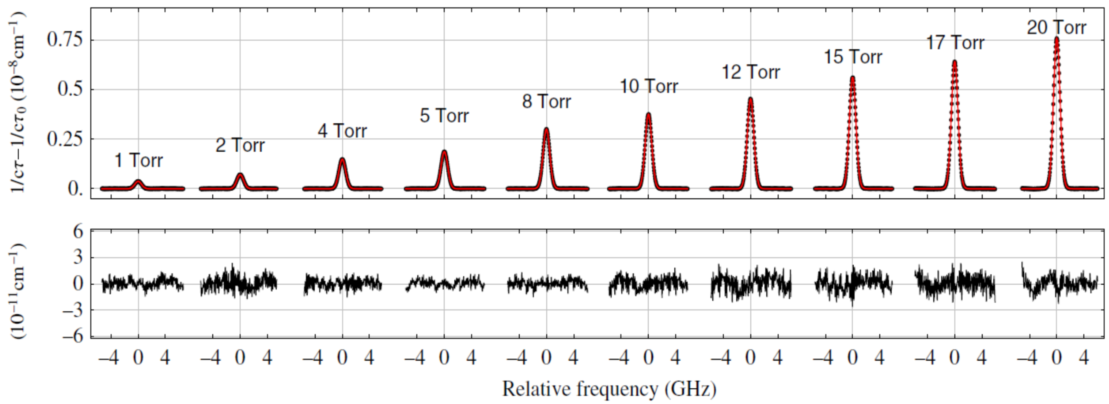

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Important elements:

- **Frequency stabilized cavity ringdown spectrometer (FS-CRDS)**

M. Zaborowski, M. Słowinski, K. Stankiewicz, F. Thibault, A. Cygan, H. Jóźwiak, G. Kowzan, P. Masłowski, A. Nishiyama, N. Stolarczyk, S. Wójtewicz, R. Ciuryło, D. Lisak, P. Wcisło

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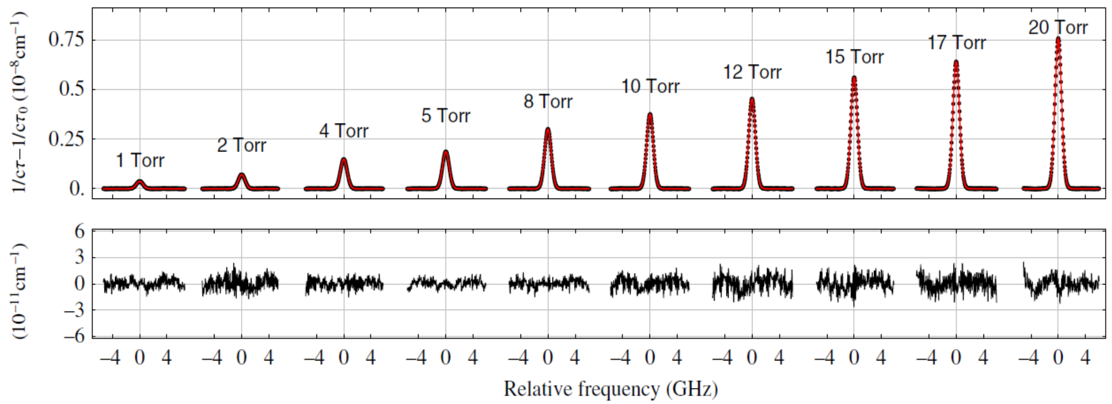

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Important elements:

- **Frequency stabilized cavity ringdown spectrometer (FS-CRDS)**
- **Ultrahigh finesse of 637 000**

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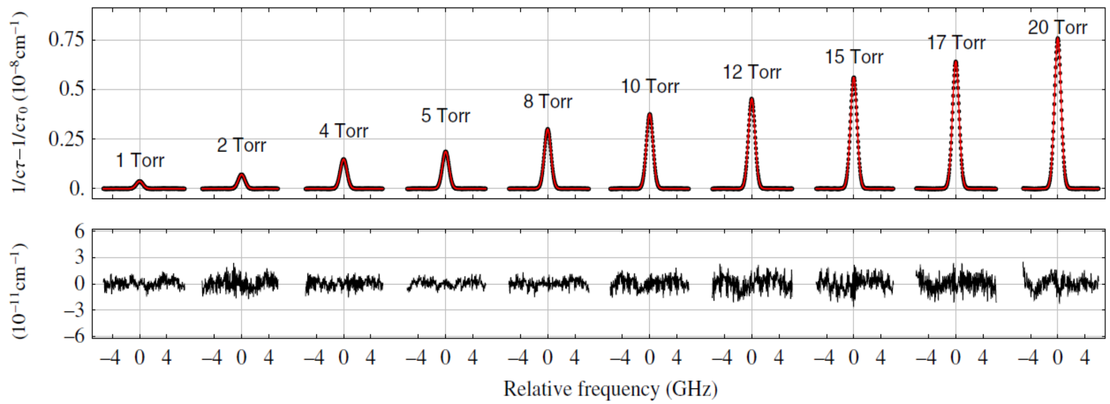

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- **Frequency stabilized cavity ringdown spectrometer (FS-CRDS)**
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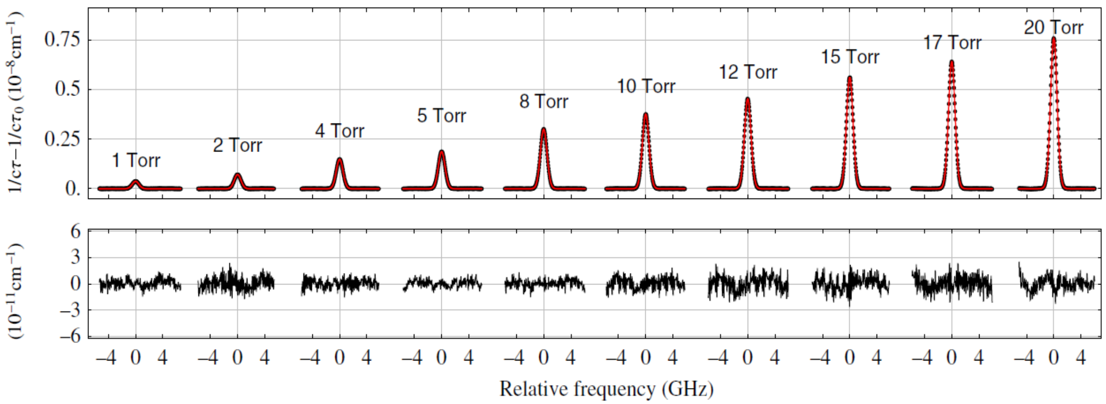

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- **Very sophisticated line-shape speed-dependent billiard-ball profile (SDBBP)**

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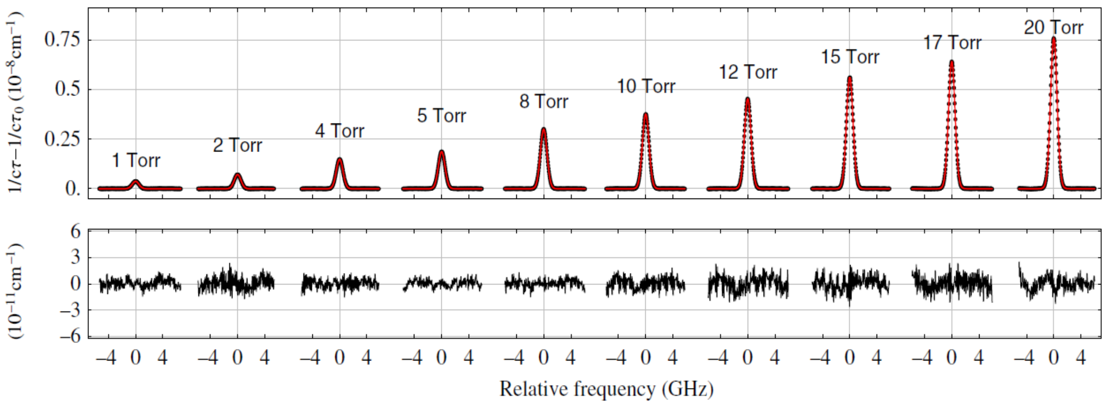

Absolute accuracy - 161 kHz

Relative accuracy ~ 10^{-9}

$$\nu_{S(2)\ 2\text{-}0} = 187{,}104{,}300.40(17)\ \text{MHz}$$

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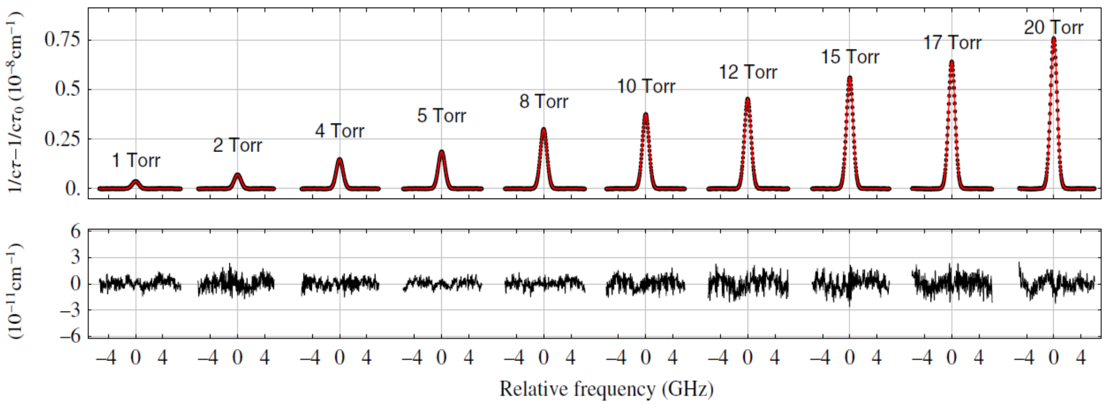

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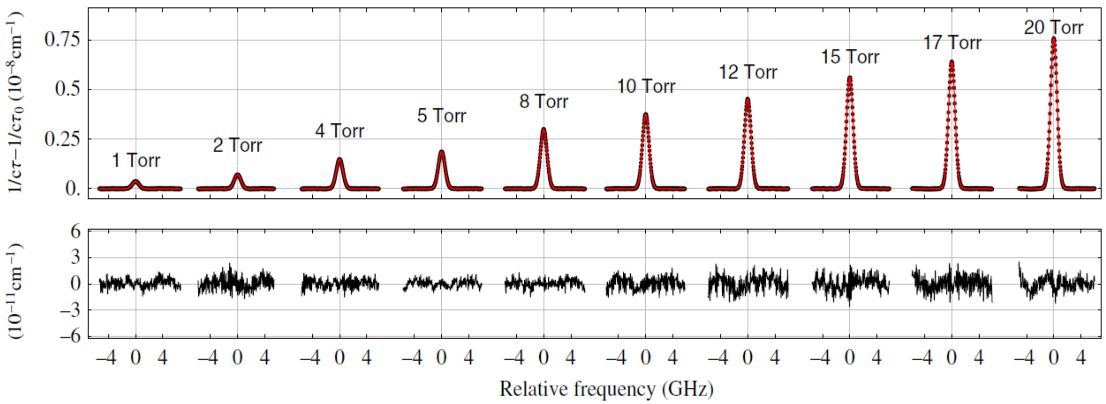

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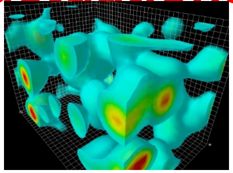
We see the effect of vacuum fluctuations!



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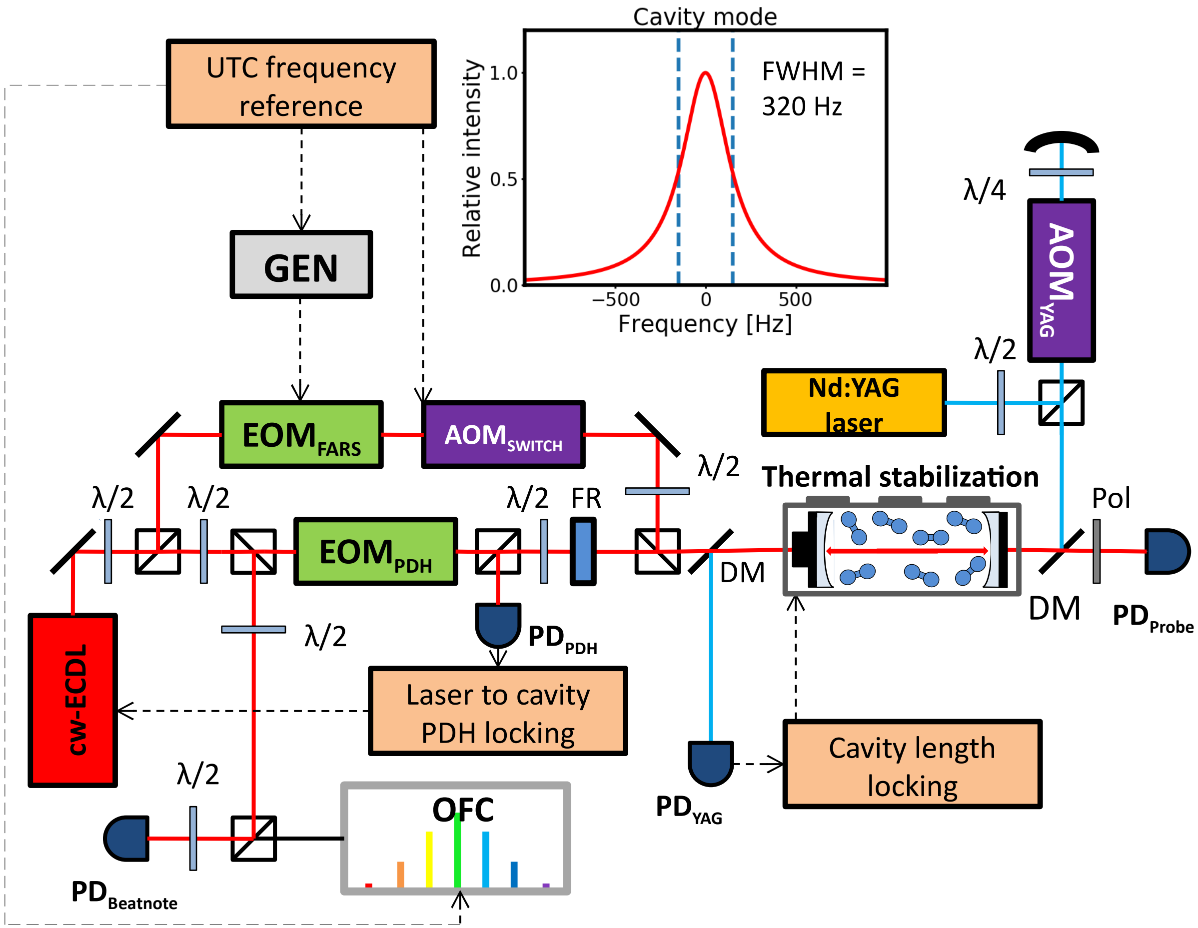

- **Ultrahigh finesse cavity**

Cavity stabilization - YAG

Laser stabilization - PDH

Freq. Measurement - OFC

Frequency-agile rapid scanning spectroscopy (FARS) technique

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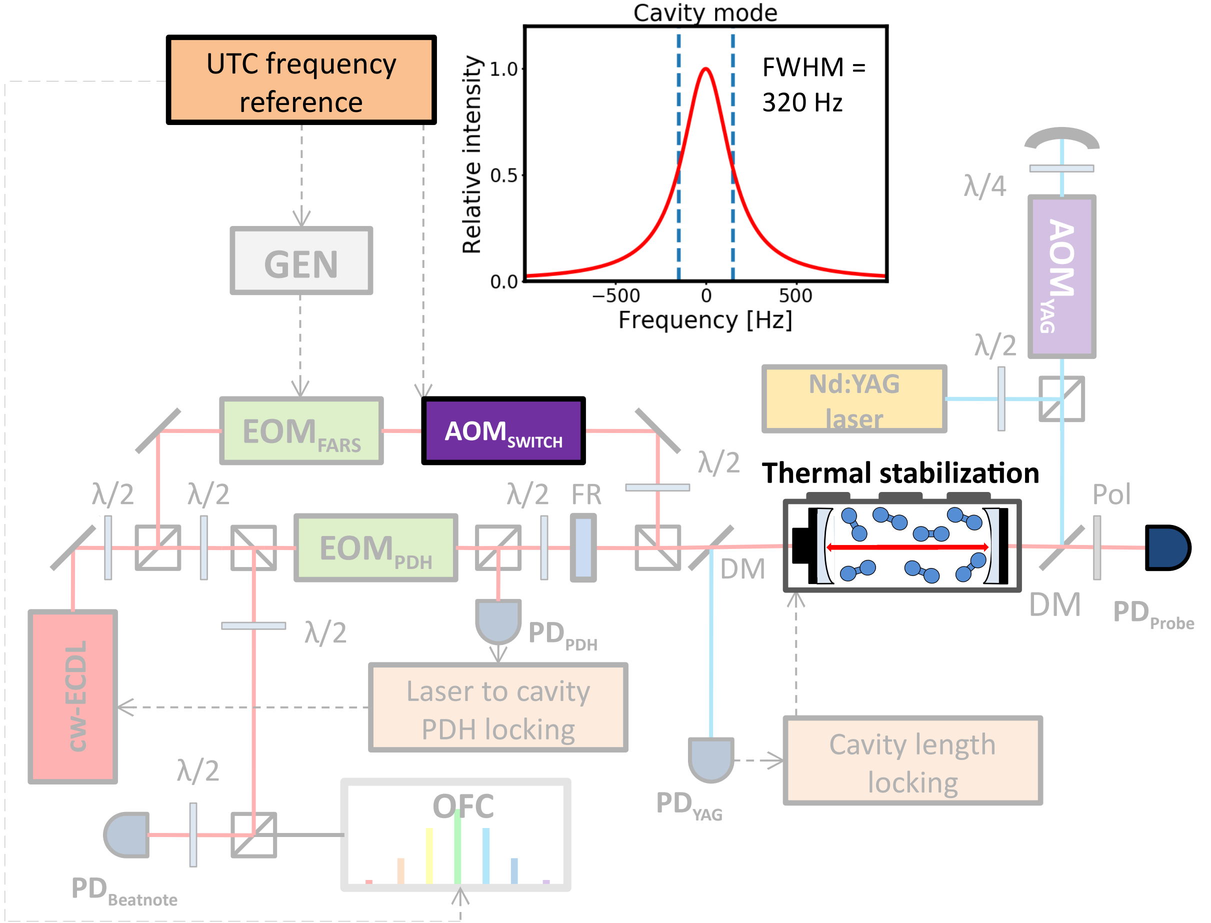

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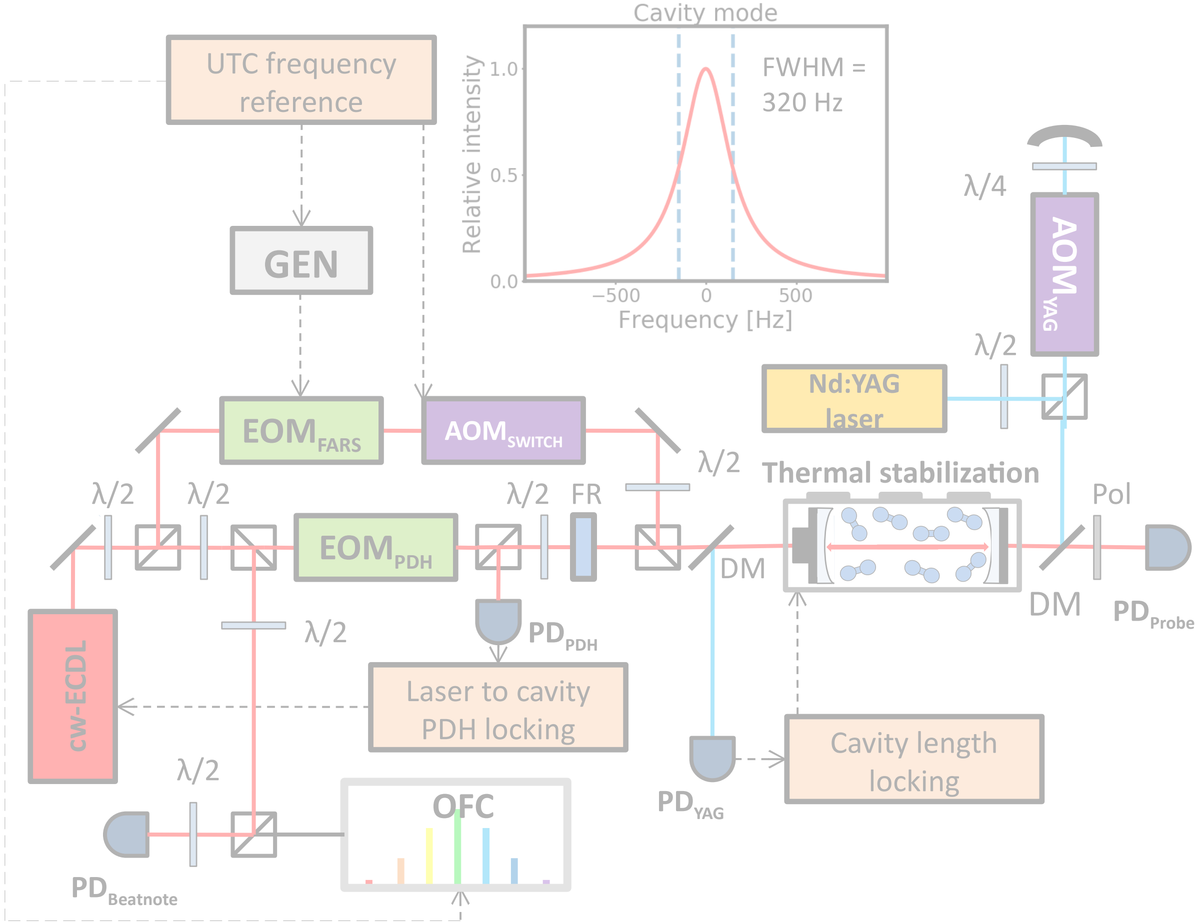

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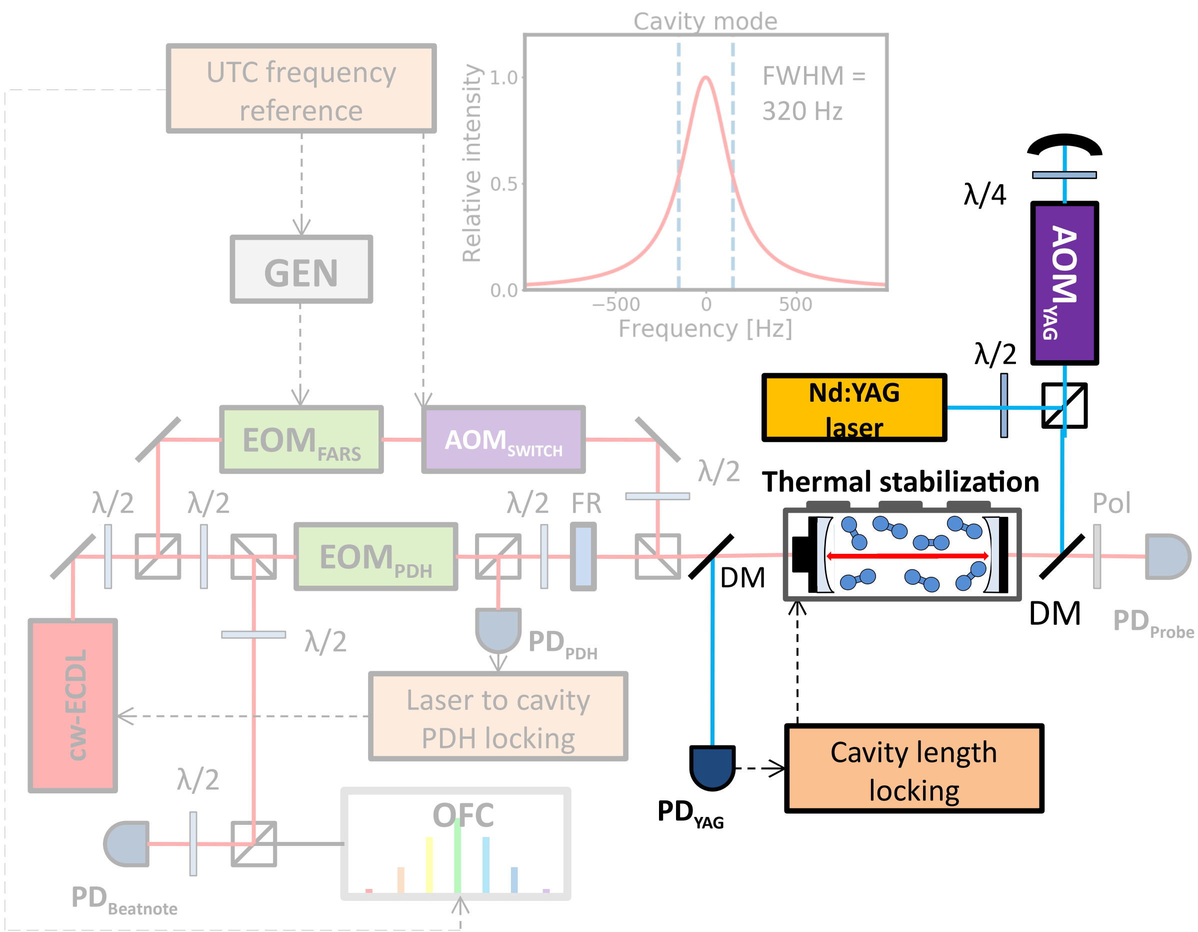

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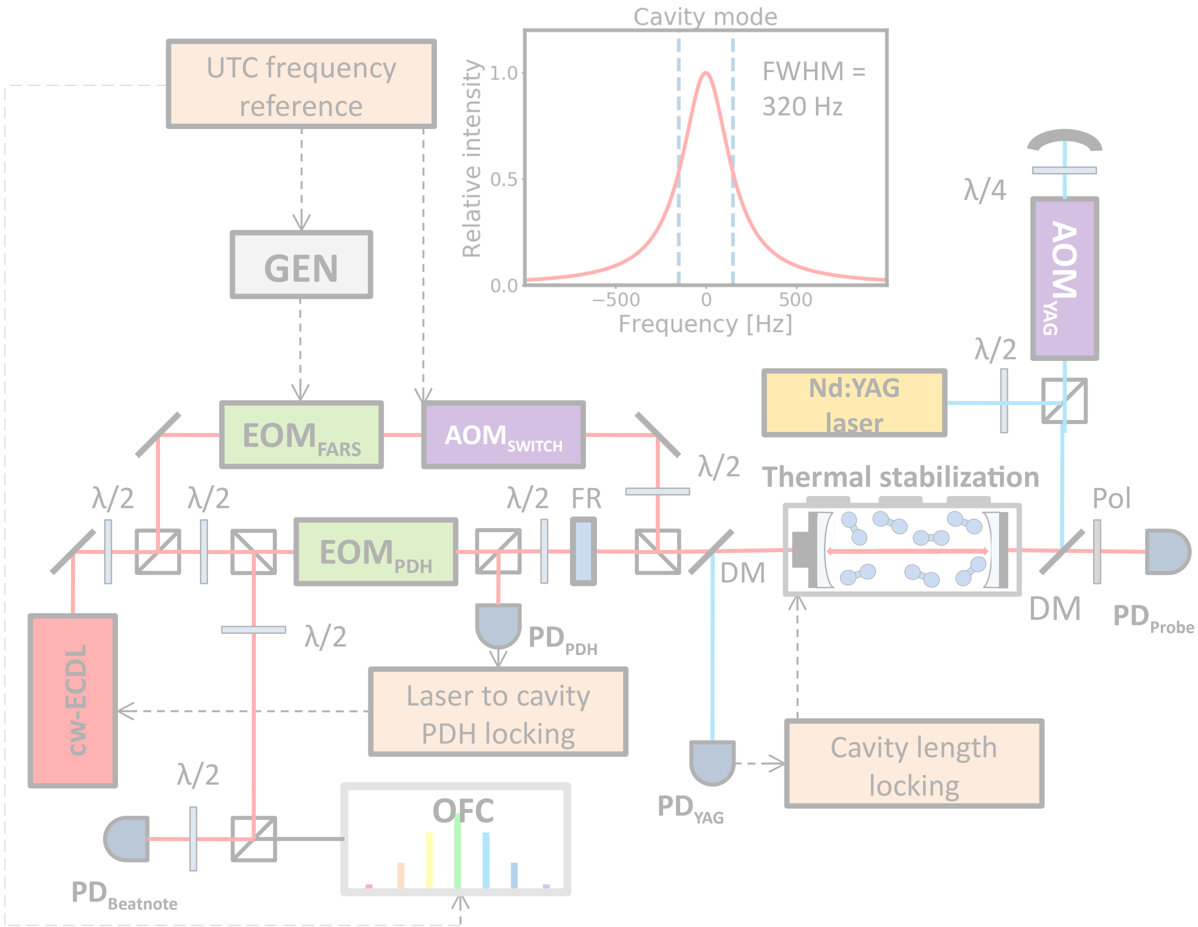

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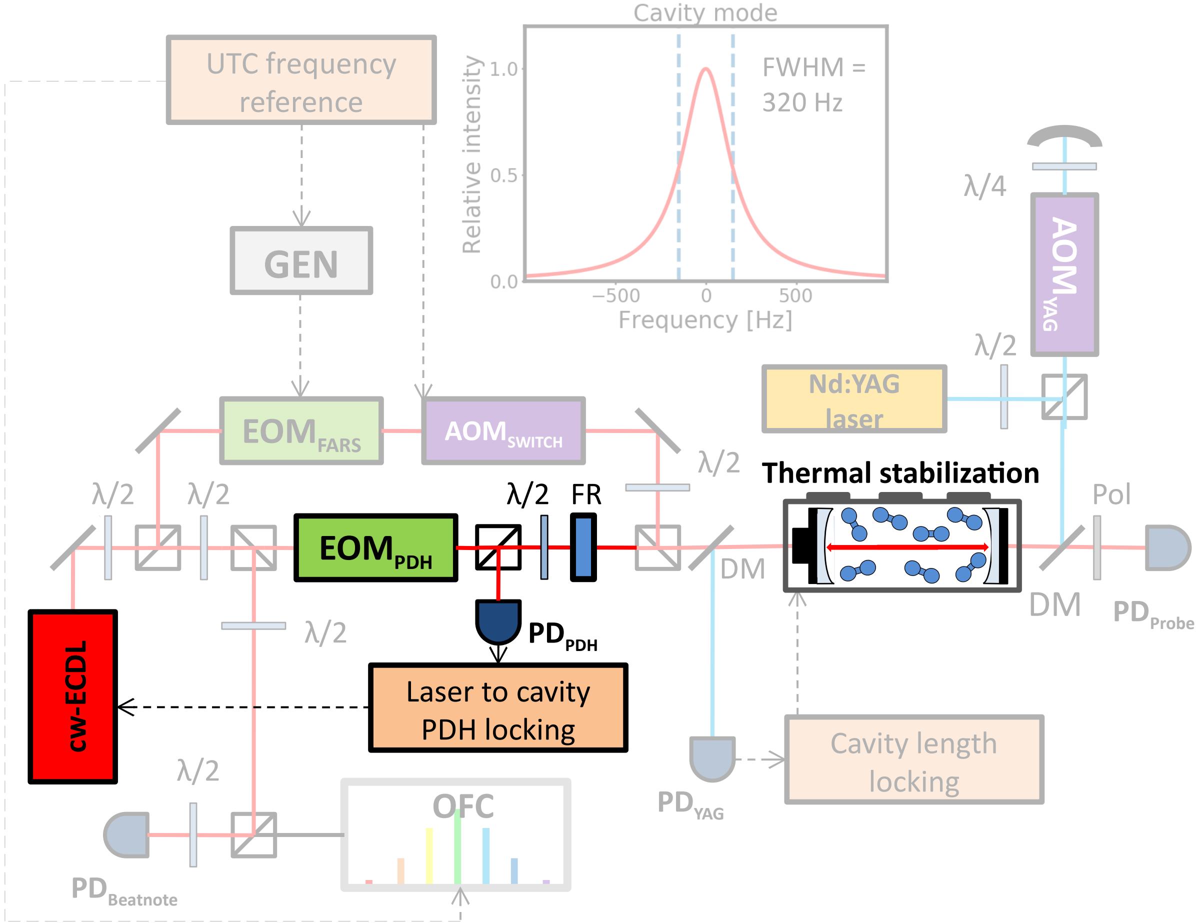

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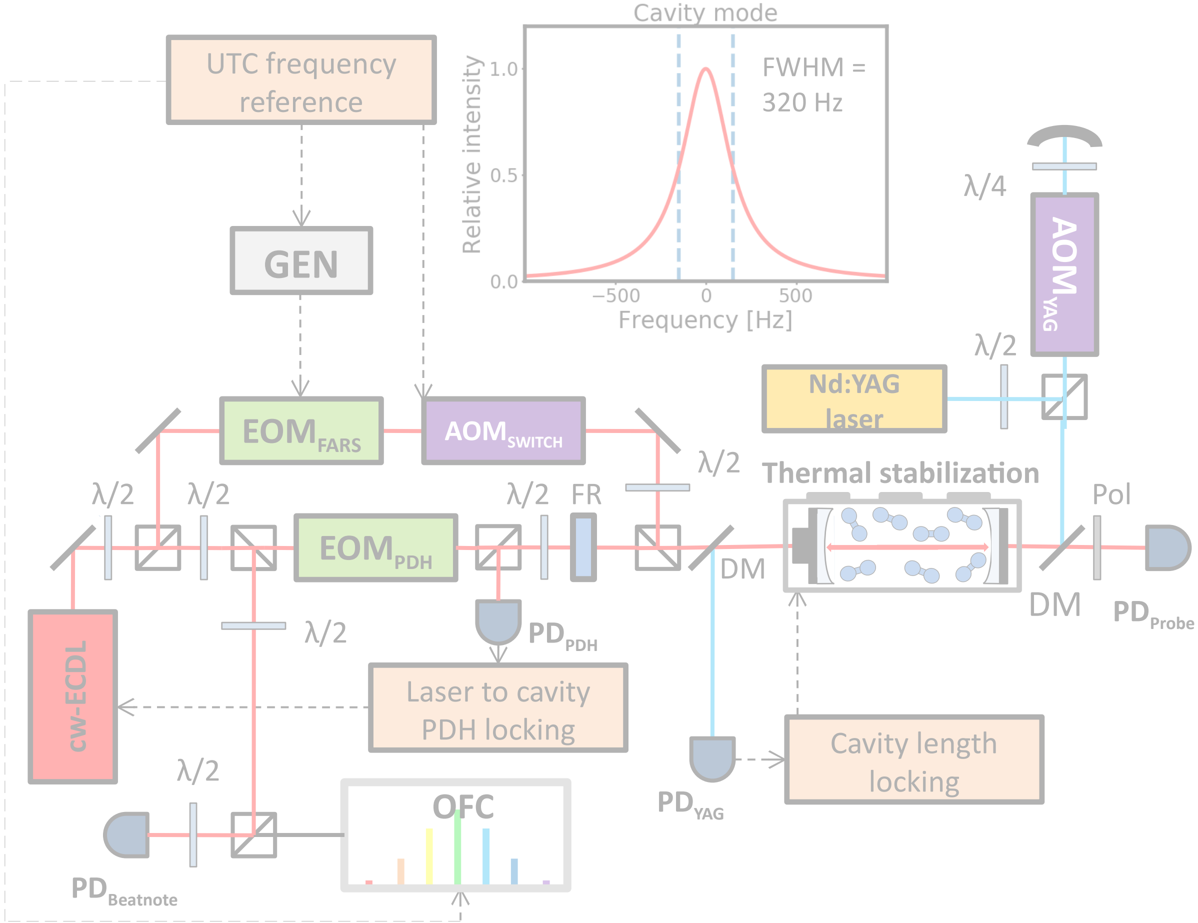

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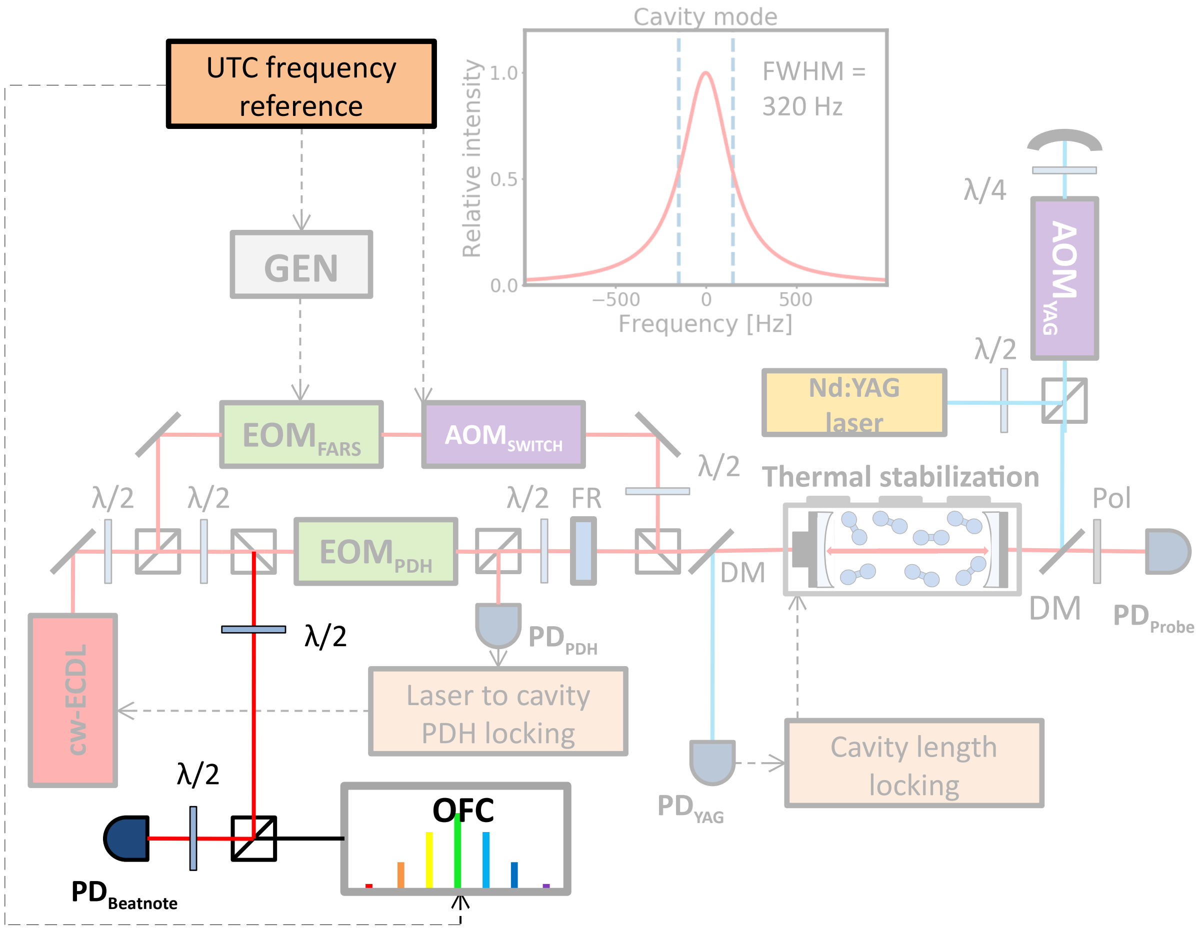

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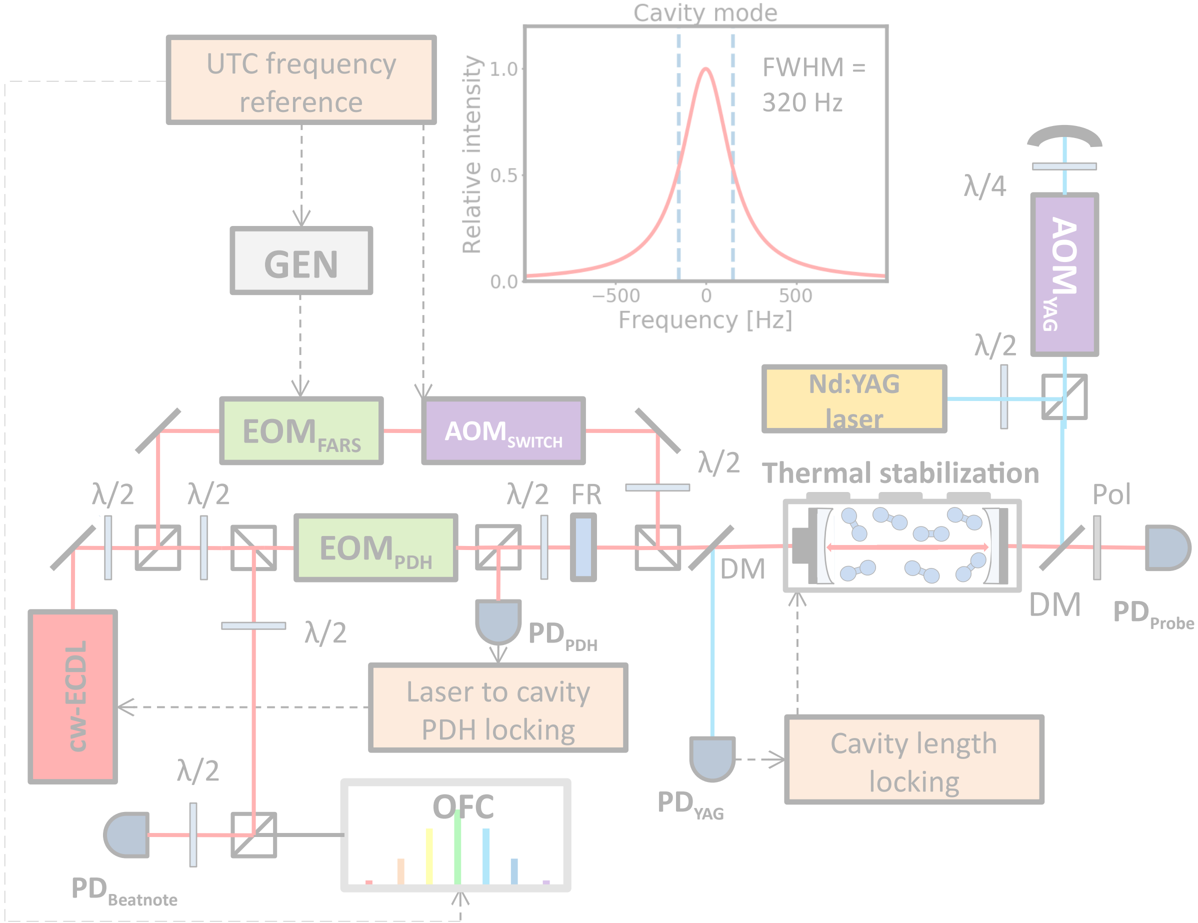

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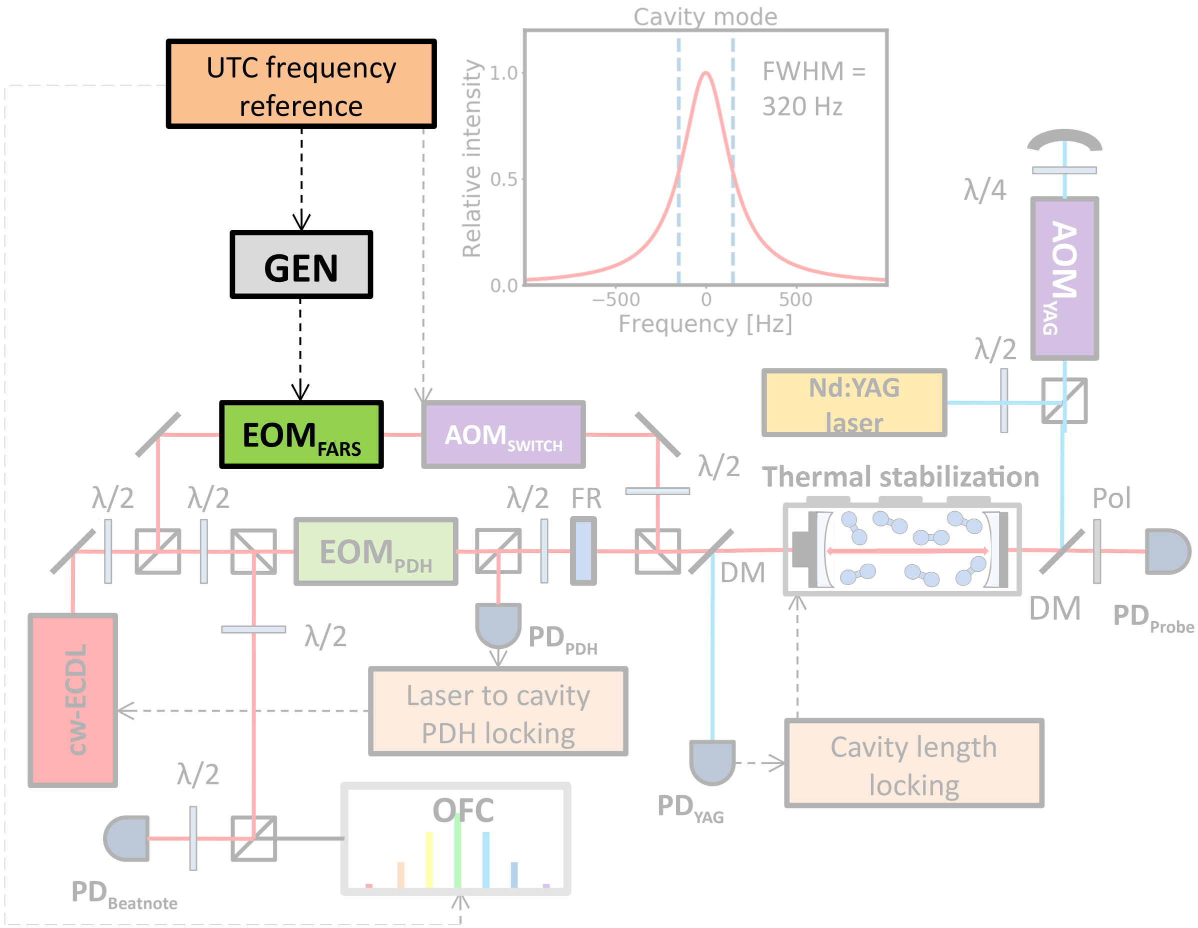

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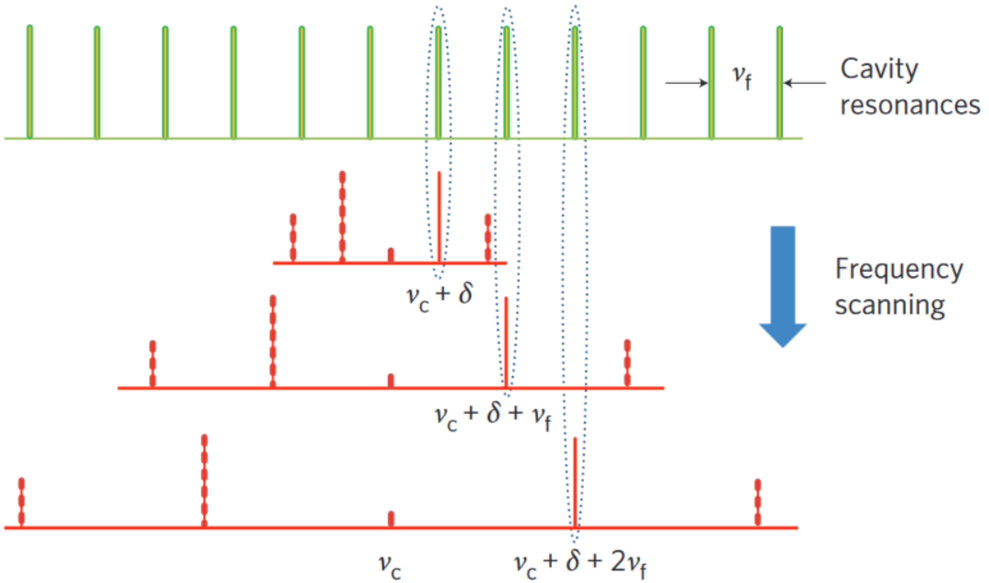
FARS technique



G.-W. Truong et al. Nat. Photonics 7, 532–534 (2013)

In FARS technique an electo-optic modulator is used to rapidly tune the frequency of the laser (sideband) over successive modes of the optical cavity.

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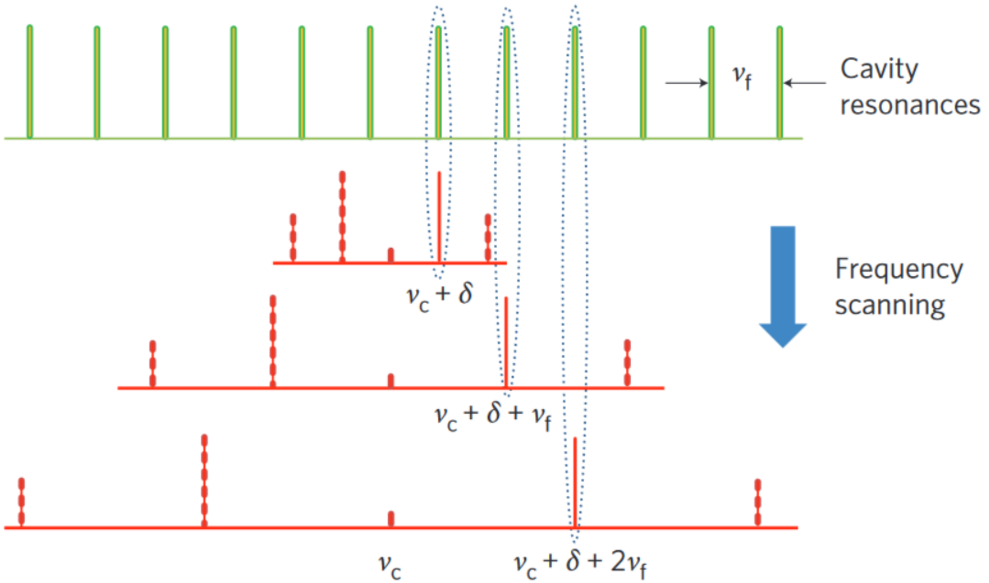
FARS technique

G.-W. Truong et al. Nat. Photonics 7, 532–534 (2013)



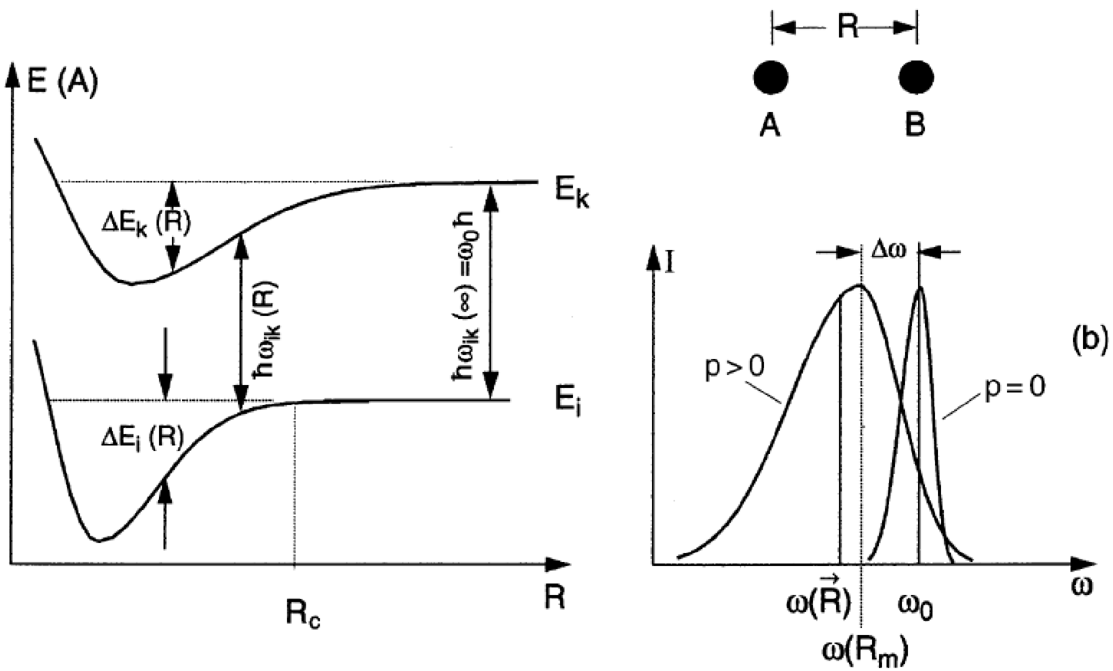
In FARS technique an electo-optic modulator is used to rapidly tune the frequency of the laser (sideband) over successive modes of the optical cavity.

Reduces the time related to laser tuning and relocking

Reduces the common experimental noise of the spectrum background

Line-shape model

Collisional effects ⟷ Perturbation of molecular resonances



Wolfgang Demtröder, Laser Spectroscopy, 2008

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Line-shape model

H_2	HD	D_2

Very pronounced and untypical collisional effects

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Very pronounced and untypical collisional effects

Importance of beyond Voigt effects

P. Wcisło et al. J. Chem. Phys. 141, 074301 (2014)
P. Wcisło et al. Phys. Rev. A 91, 052505 (2015)
M. Słowiński et al. *Phys. Rev. A* 101, 052705 (2020)
M. Słowiński et al. *JQSRT* 277, 107951 (2022)

More about it on my other talk - Accurate experimental validation of ab initio quantum scattering calculations using the spectra of He-perturbed H_2.

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Datasets of beyond Voigt line-shape parameters

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Model used in this work:

6 line shape parameters: pressure broadening and shift, their speed-dependence and Dicke parameter

+

Billiard ball collision model

+

Line-shape coefficients and the Doppler broadening fixed in experimental spectra according to ab initio calculations

M. Zaborowski, M. Słowinski, K. Stankiewicz, F. Thibault, A. Cygan, H. Jóźwiak, G. Kowzan, P. Masłowski, A. Nishiyama, N. Stolarczyk, S. Wójtewicz, R. Ciuryło, D. Lisak, P. Wcisło

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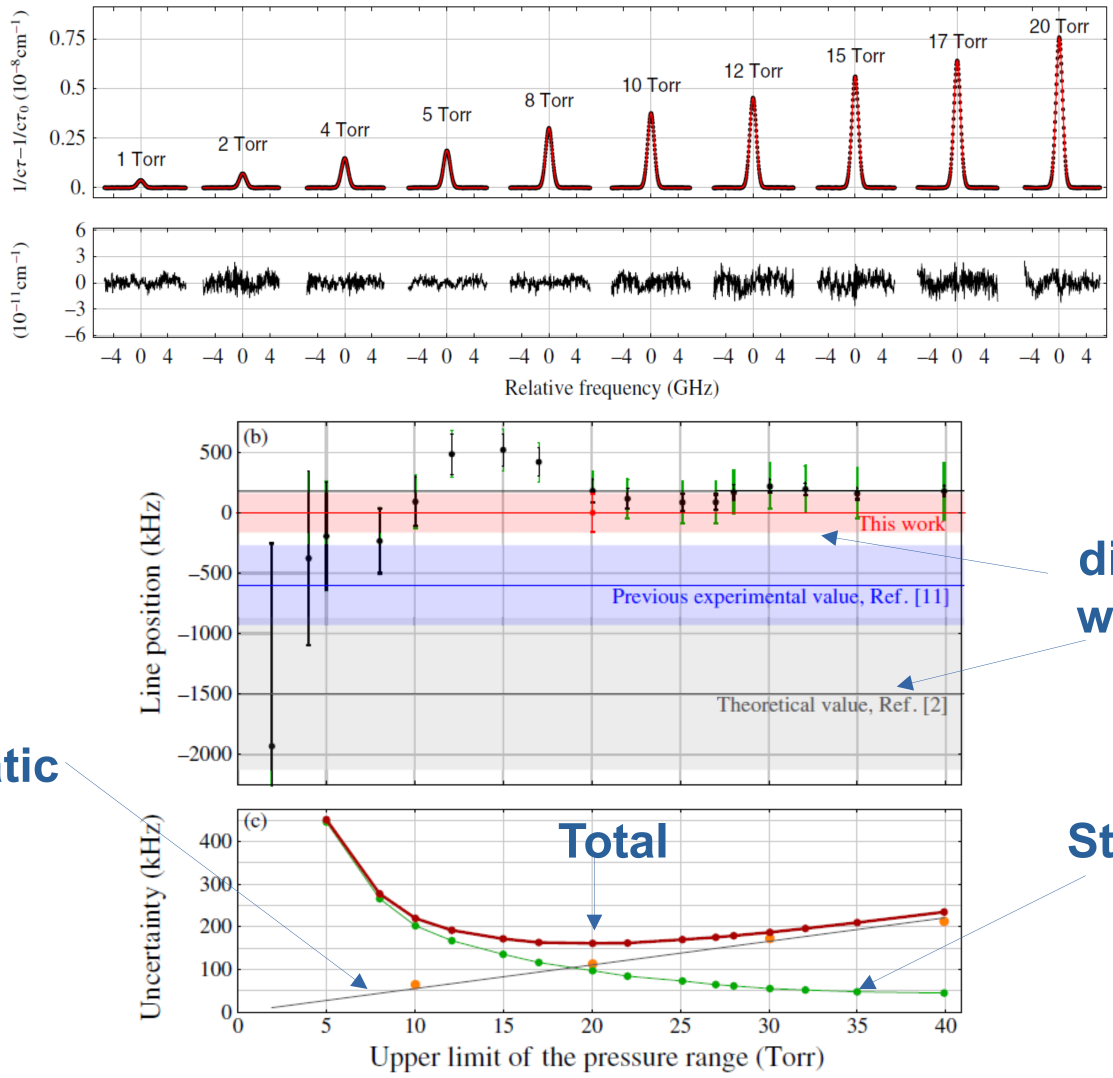
Measurement



The spectra for all the pressures were fitted simultaneously

2.3 σ discrepancy with theory

Systematic part

Total

Statistical part

M. Zaborowski, M. Słowinski, K. Stankiewicz, F. Thibault, A. Cygan, H. Jóźwiak, G. Kowzan, P. Masłowski, A. Nishiyama, N. Stolarczyk, S. Wójtewicz, R. Ciuryło, D. Lisak, P. Wcisło

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Uncertaintity

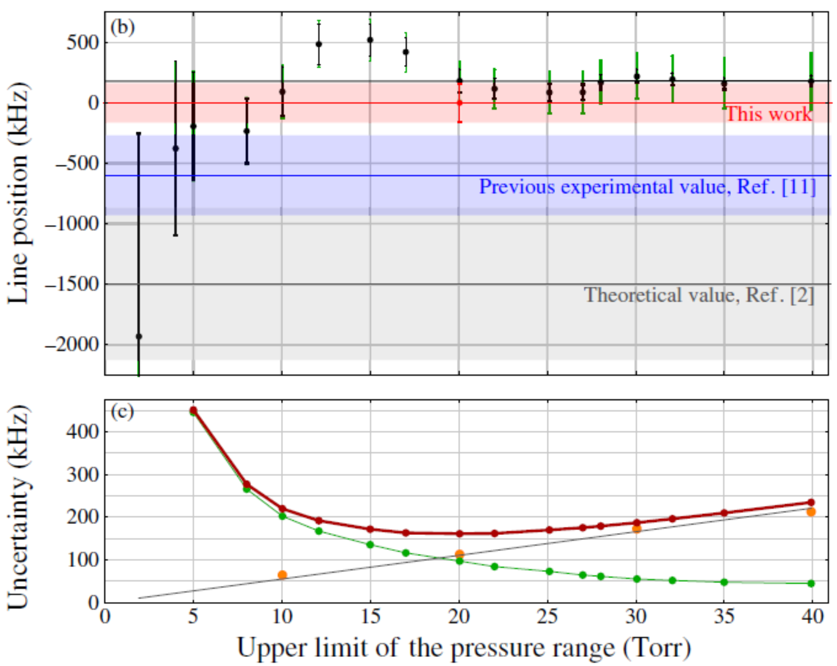

Table 1. Standard Uncertainty Budget to Experimental Determination of the Frequency of the S(2) 2–0 Transition in D_2[a]

Uncertainty Contribution	$u(\nu_0)$ (kHz) 1 to 20 Torr	$u(\nu_0)$ (kHz) 1 to 40 Torr
1. Line shape profile	111	222
2. Statistics, 1σ	96	40
3. Instrumental systematic shift [18]	47	47
4. Etalons	46	21
5. Temperature instability	5	5
6. Relativistic asymmetry [27]	3	3
7. Laser source stability	< 1	< 1
8. Pressure gauge nonlinearity	1	1
Standard combined uncertainty	**161**	**231**

[a]Middle and right column show uncertainties estimated for the fitted datasets of 1–20 Torr and 1–40 Torr, respectively.

Absolute accuracy - 161 kHz

Relative accuracy ~ 10^{-9}

$$\nu_{S(2)\ 2\text{-}0} = 187{,}104{,}300.40(17)\ \text{MHz}$$

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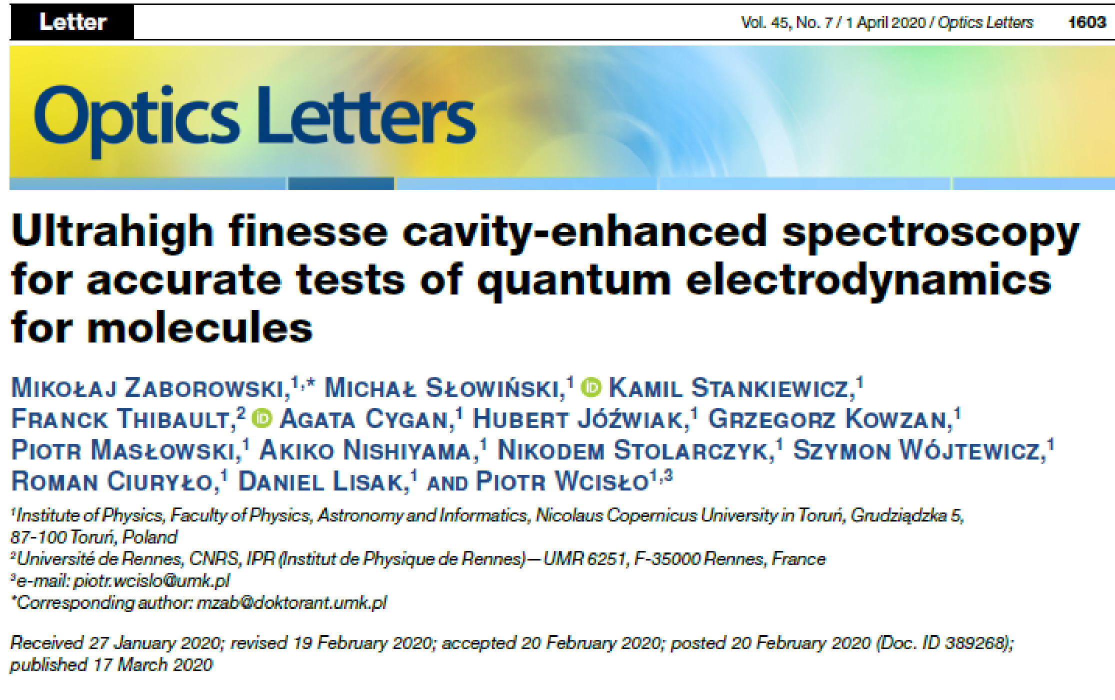
Summary

- **We performed the best measurement of the 2-0 S(2) line position in D_2**


Letter Vol. 45, No. 7 / 1 April 2020 / *Optics Letters* 1603

Optics Letters

Ultrahigh finesse cavity-enhanced spectroscopy for accurate tests of quantum electrodynamics for molecules

MIKOŁAJ ZABOROWSKI,[1,*] MICHAŁ SŁOWIŃSKI,[1] KAMIL STANKIEWICZ,[1] FRANCK THIBAULT,[2] AGATA CYGAN,[1] HUBERT JÓŹWIAK,[1] GRZEGORZ KOWZAN,[1] PIOTR MASŁOWSKI,[1] AKIKO NISHIYAMA,[1] NIKODEM STOLARCZYK,[1] SZYMON WÓJTEWICZ,[1] ROMAN CIURYŁO,[1] DANIEL LISAK,[1] AND PIOTR WCISŁO[1,3]

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[2]*Université de Rennes, CNRS, IPR (Institut de Physique de Rennes)—UMR 6251, F-35000 Rennes, France*
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Received 27 January 2020; revised 19 February 2020; accepted 20 February 2020; posted 20 February 2020 (Doc. ID 389268); published 17 March 2020

Absolute accuracy - 161 kHz **Relative accuracy ~ 10^{-9}**

$$\nu_{S(2)\ 2\text{-}0} = 187{,}104{,}300.40(17)\ \text{MHz}$$

Summary

- We performed the best measurement of the 2-0 S(2) line position in D_2
- At the moment of publication it was the best measurement in homonuclear hydrogen molecule

Letter
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Thank you for your attention!

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