Advancing Photonic Pressure Standards

Progress and Outlook of the MQB-Pascal Project

MQB-Pascal
Pascal QUANTUM
follow-up

www.mqb-pascal.ptb.de

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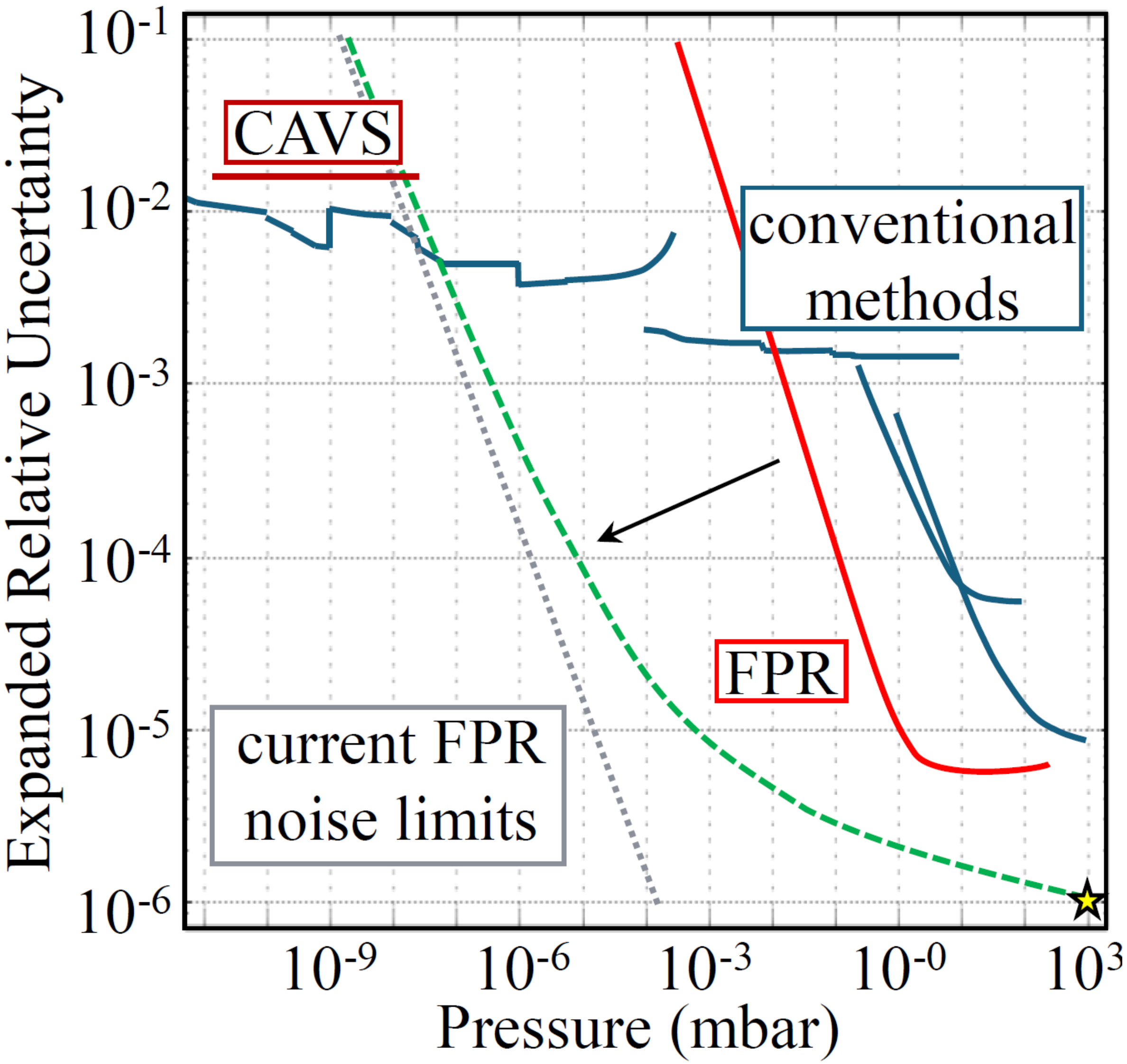
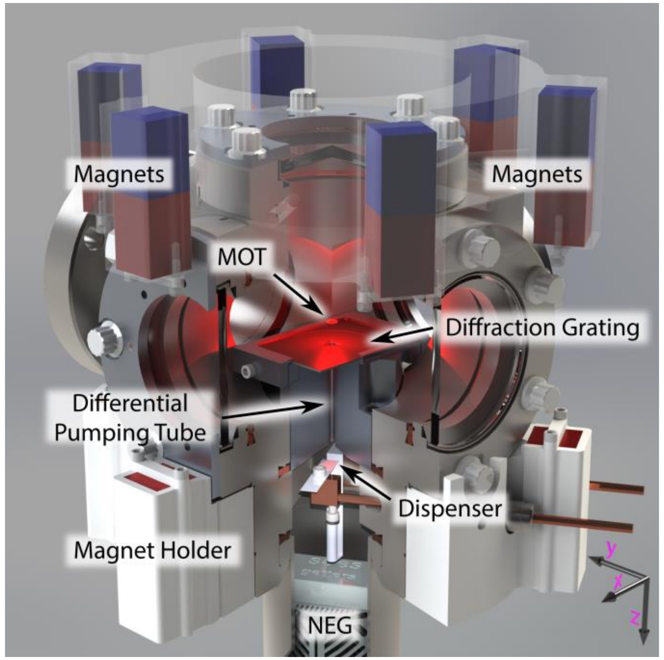
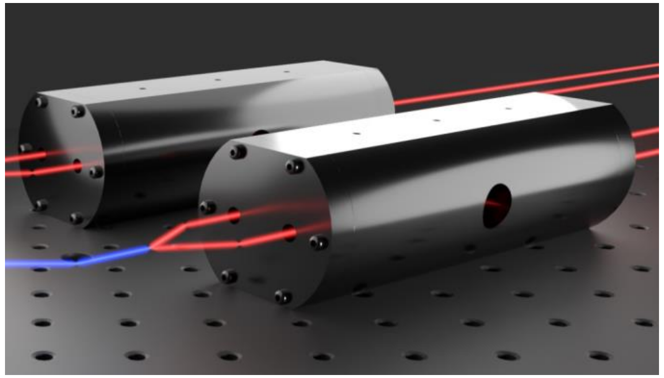
EUROPEAN PARTNERSHIP
Co-funded by the European Union
METROLOGY PARTNERSHIP
EURAMET

Vizualized Roadmap: Pressure Ranges + Uncertainties





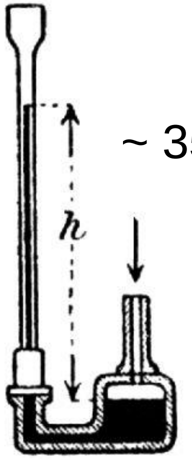
CAVS



FPR

Benefits of Density-based Approaches

F/*A*-methods



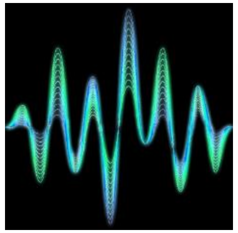
~ 350 years

~ 50 years

$$p = \frac{F}{A}$$

(conventional)
force per area

kg m s



Frequency: $\delta(\nu) < 10^{-17}$

New SI: $u(k) = 0$

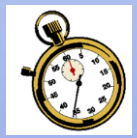
Improved theory
$u(n_{He}-1) < 10^{-6}$

Especially useful for vacuum

$$p = \rho kT$$

approximation for and ideal gas

methods based
on gas density



K m s

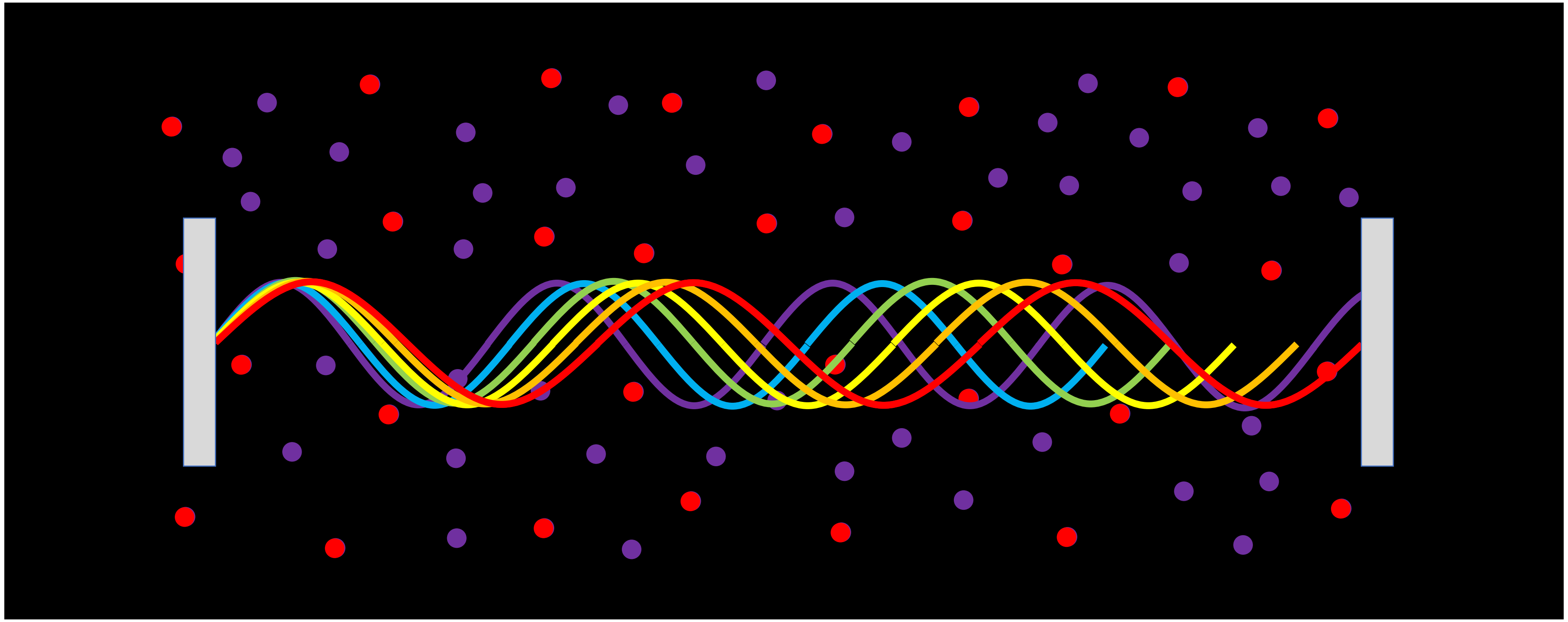
The quantum-based realisations via the gas density already provide lower uncertainties for parts of the targeted pressure interval with a lot of potential for improvement, while the *F*/*A*-methods have not undergone any major changes for decades.

Example: FP-Refractometry for Pressure Assessments

$$\lambda_n = c_n / f$$

$$\frac{\Delta f}{f} \propto (n-1)$$

$$\rho \approx \frac{2\varepsilon_0}{\alpha}(n-1)$$



‘*MQB-Pascal*’ – Overview (including 18SIB04)

Increased Team (12 ➡ 19)

NMIs & DIs — Univ. (exp.) — Univ. (theo.) — Industry

MQB-Pascal

2023 - 2026

follow-up

Start of MQB-Pascal

M25/36

Project Goals

Obj. 1) Primary realisation and calibration services with QB-techniques at several NMIs/DIs

Obj. 2) Further development and dissemination of QB-based transfer standards.

Obj. 3) Improved uncertainties of relevant gas parameters for nitrogen

Obj. 4) Verification by comparison

Obj. 5) Drive forward the take-up into the complete measurement supply chain

Ongoing challenges

Long-term goals:
QB-techniques established in all areas from NMIs to end users

Pre-project Status

pV-work issue solved: Thermodynamic effects are negligible

Suitability of various spacer materials evaluated

Improved gas parameters for He and Ar

Different methods (RAY, UINT, etc.)

Transportable system (ring comparison)

Short term performance (0.04 ppm deviations)

GAMOR method:
- Elimination of the influence of drifts
- Better gas purity

2019 - 2022

Predecessor 18SIB04

‘*MQB-Pascal*’ Objectives

Obj. 1) Primary realisation and calibration services with QB-techniques at **several NMIs/DIs**

Obj. 2) Further development and dissemination **of QB-based transfer standards.**

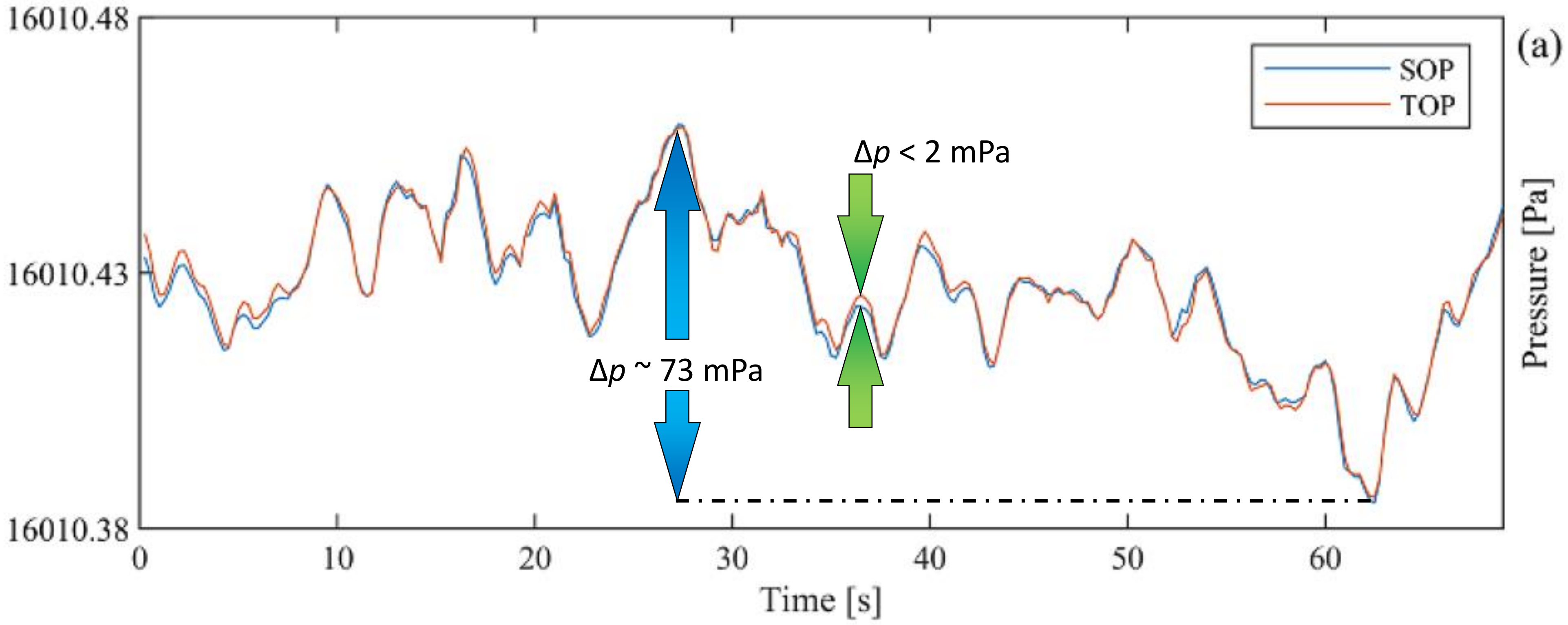
Obj. 3) Improved uncertainties of relevant gas parameters **for nitrogen**

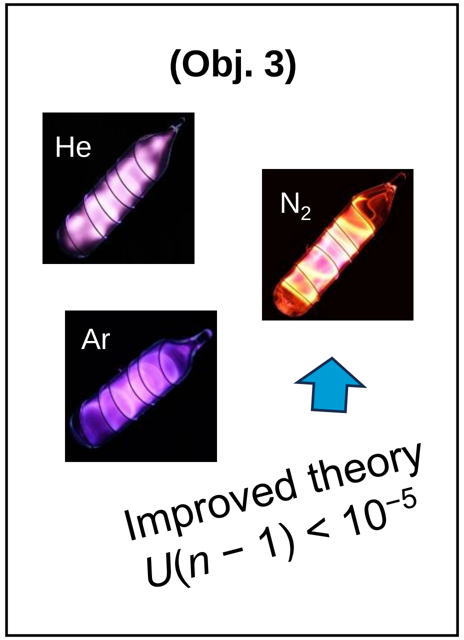
Obj. 4) Verification by comparison

Obj. 5) Drive forward the take-up into the complete measurement supply chain

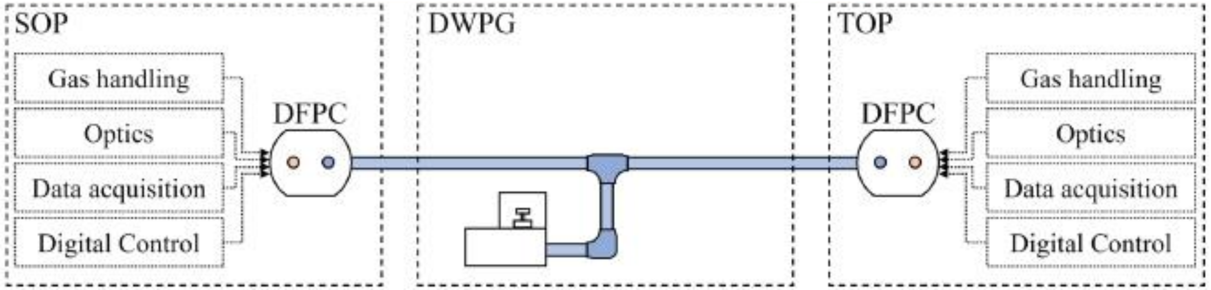
Objectives

Performance: FPRs compared to a DWPG





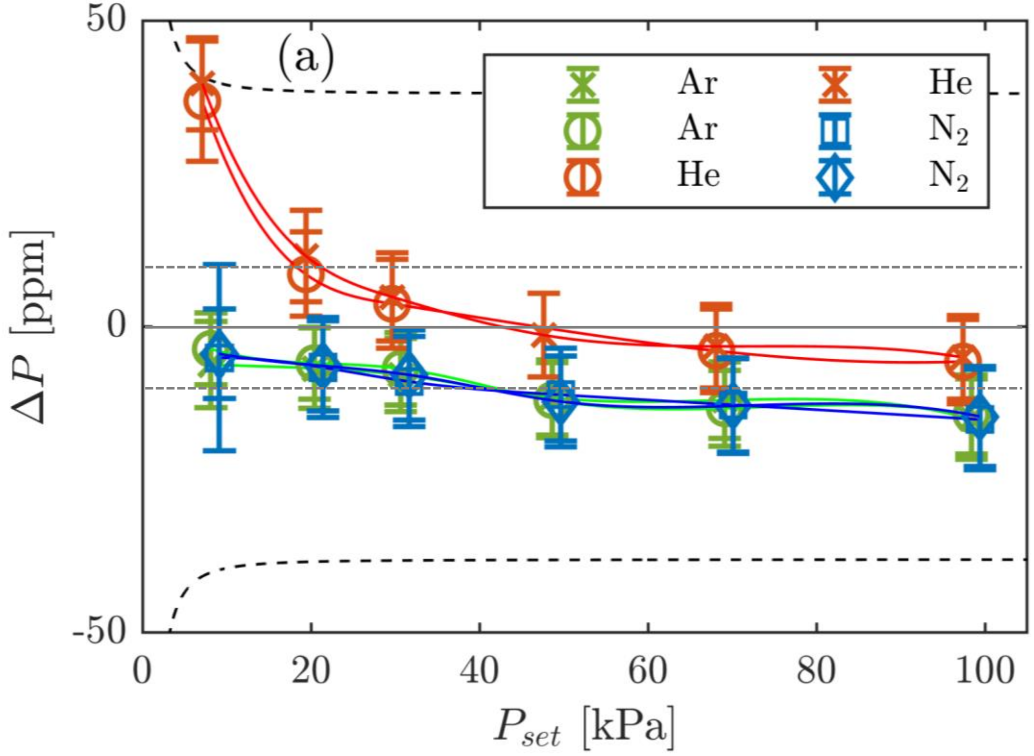
Forssén, C., Silander, I., Zakrisson, J., Axner, O., & Zelan, M. (2021). The short-term performances of two independent gas modulated refractometers for pressure assessments. *Sensors*, *21*(18), 6272.



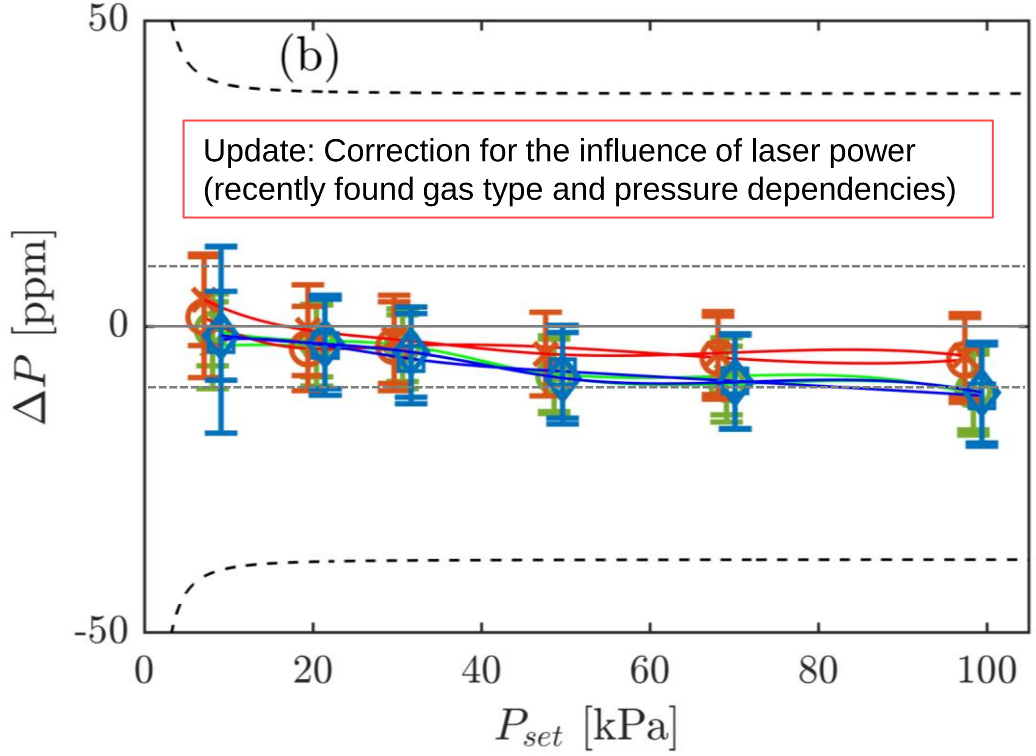
FPR measurements using helium, argon, and nitrogen

The FP-Refractometer was compared to DWPG (Fluke 2465A). Considering all known uncertainty contributions, the expanded uncertainty e.g. for argon-based pressure measurements is given by

$$U(P_{argon}) = [(0.98\ \text{mPa})^2 + (5.8 \times 10^{-6}\ P)^2 + (26 \times 10^{-12}\ P^2\ )^2\ ]^{1/2}\ .$$



Isak Silander, Johan Zakrisson, Ove Axner, and Martin Zelan, **Realization of the pascal based on argon using a Fabry–Perot refractometer**, Optics Letters 49 (12), 2024, pp. 3296-3299

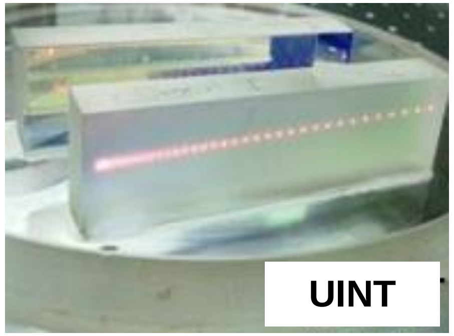


Johan Zakrisson, Isak Silander, Andre Kussicke, Tom Rubin, Martin Zelan, and Ove Axner, **Effect of absorption of laser light in mirrors on Fabry-Perot based refractometry**, Optics Express, 32, 2024, pp. 24656-24678

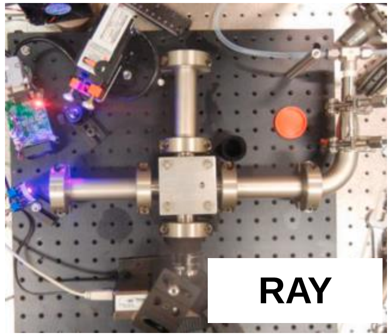
Diversity and Redundancy of Quantum-based Systems

Primary FPRs (Obj. 1)

Multitude of Quantum-based Technologies optimised for different Key-Applications (Obj. 2)

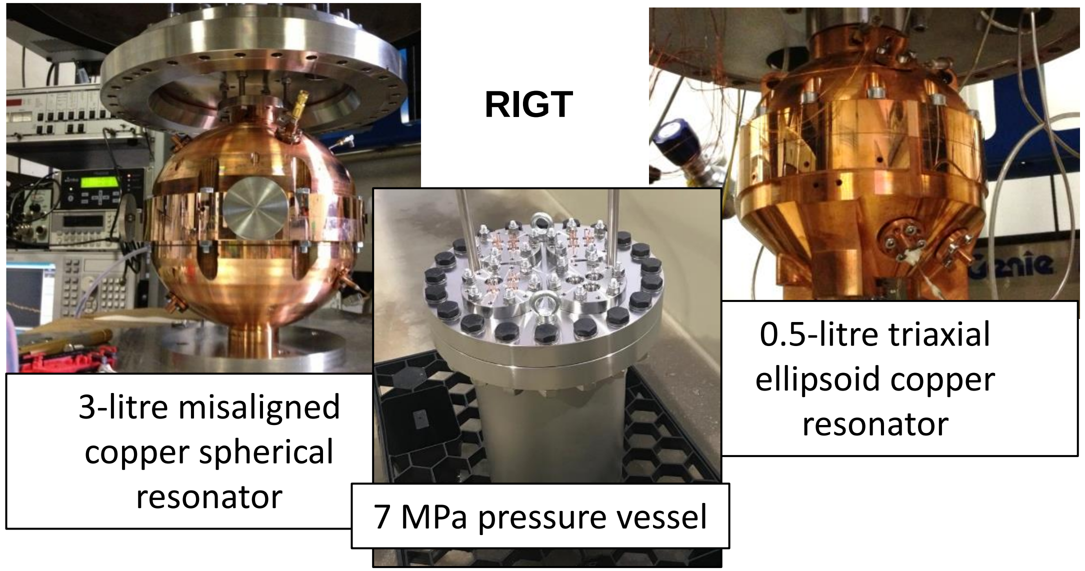


1. **RAY**: Rayleigh scattering
2. **UINT**: unbalanced homodyne interferometer
3. **DCGT**: dielectric constant gas thermometry
4. **RIGT**: refractive index gas thermometry
5. **RIGT***: utilising a superconductive microwave cavity

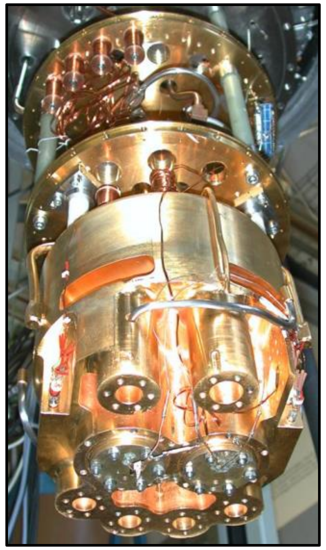


RIGT*

RIGT



DCGT



Two ring-type Comparisons under Preparation

RISE

LNE
LABORATOIRE NATIONAL DE MÉTROLOGIE ET D'ESSAIS

le cnam

CEM
CENTRO ESPAÑOL DE METROLOGÍA

UMEÅ UNIVERSITET

PTB

CZECH METROLOGY INSTITUTE

INRiM
ISTITUTO NAZIONALE DI RICERCA METROLOGICA

TÜBİTAK UME

Logos are shown only for the participants taking part in the ring-type comparisons

Comparing to world's most precise DWPGs (from the *Boltzmann* Project)

$\boldsymbol{U(P) = 1 \times 10^{-6} \quad (k=2)}$

Publications, Presentations & Workshops

- Stakeholder committee (number increasing, currently 25 member)
- 23 presentations at conferences (mainly talks, some poster)
- 6 peer-revied publications (3 of them jointly)
- 6 key standarisation bodies informed on their regular meetings
- Use of communication channels: websites, newsletter, social media
- Workshops (e.g., MQB-Pascal Workshop with hands-on experience)

@ XXIV IMEKO World Congress

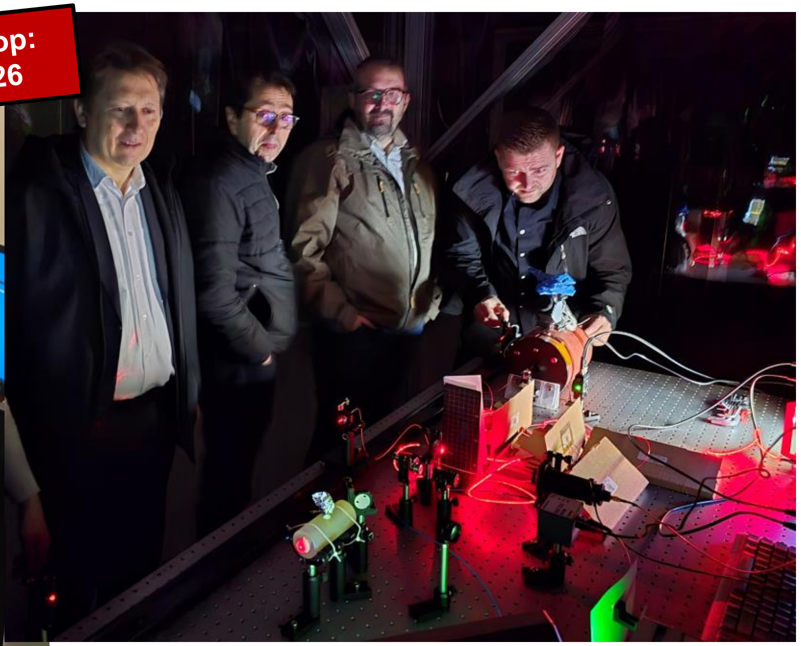
MQB Pascal Quantum follow-up

INFOTherm

PriSpecTemp

(Obj. 5)

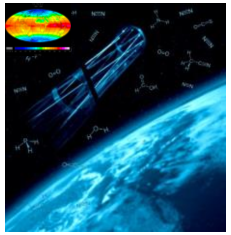
Next Workshop: Summer 2026



Impact

Industry:

- Accurate and fast measurements
- Potentially calibration-free
- Minimised dimensions
- Lower costs



Environment & health:

- Improved accuracy in assessments for climate models (remote sensing)
- Follow WHO recommendation to reduce or eliminate the use of mercury

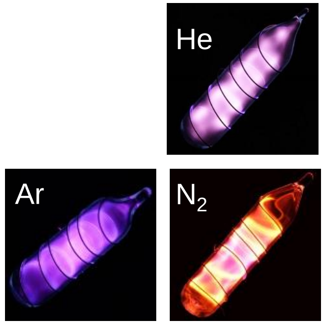
Metrology:

- Primary methods based on density assessment
- Lower uncertainties
- Automated and faster calibrations

Science:

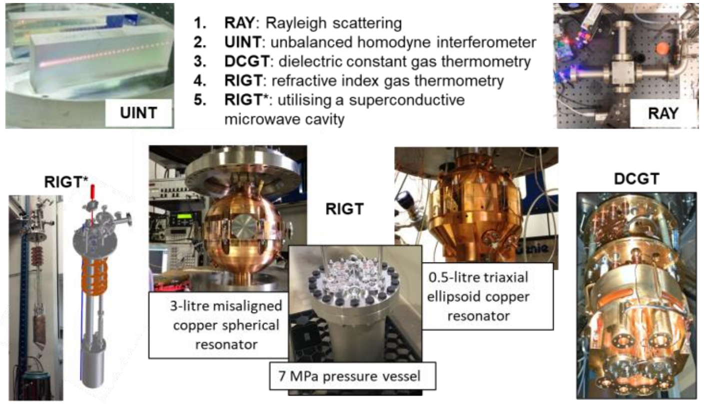
$$\frac{n^2-1}{n^2+2}=\frac{1}{3\varepsilon_0}\alpha\rho$$

- Improvement of ab-initio calculations of gas parameters
- Validation of fundamental theoretical models

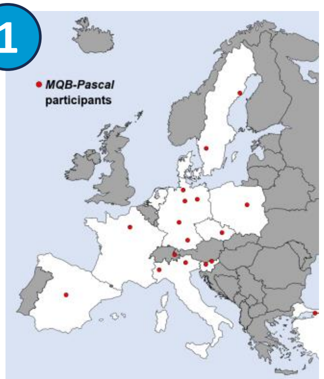


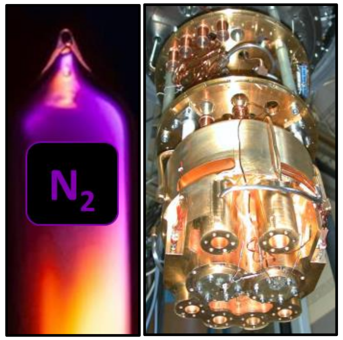
Summary

2 Validated performance (diversity and redundancy)



1 Infrastructure (cutting-edge primary FPRs in at least 3 countries)





3 complete set of relevant gas parameters for nitrogen, including uncertainties

FPR-based ***T***

Success?!

Breath gas analysis

PriSpecTemp
Remote sensing follow-up

Industrial quantum-based pascal

initiate Industrial uptake 5

$$p = \frac{F}{A}$$

4 transferring the world's highest accuracy as good as possible to gas parameters

$$p = \rho k T$$