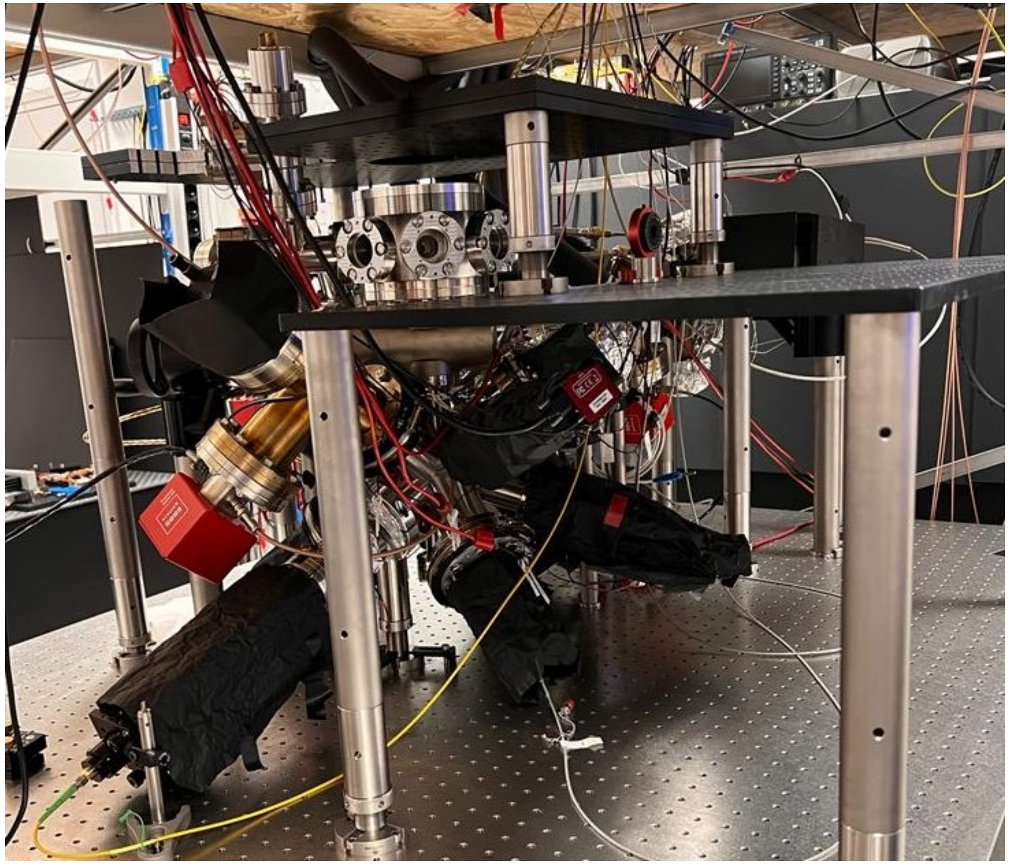
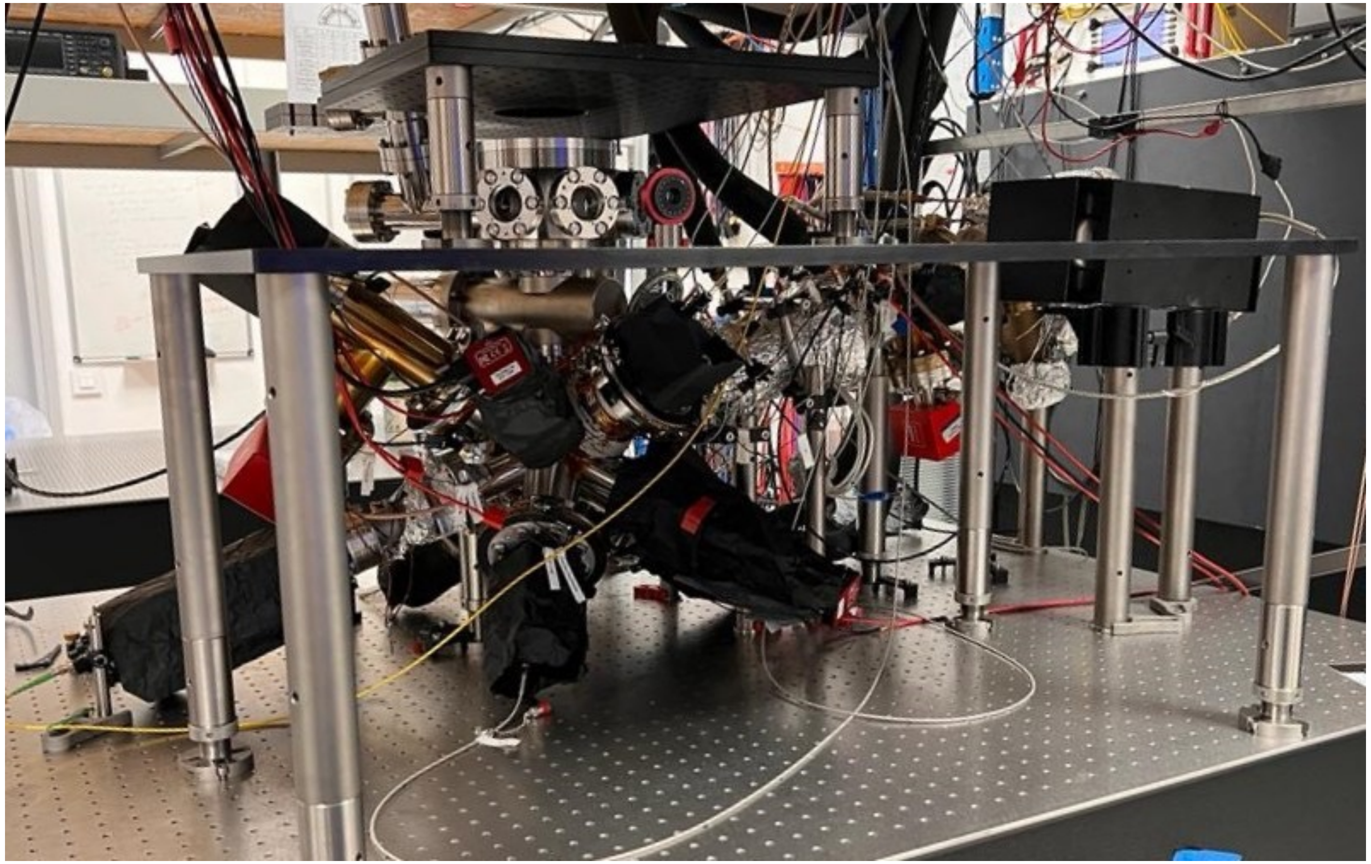
Progress on an Yb-based active optical atomic clock

Martina Matusko

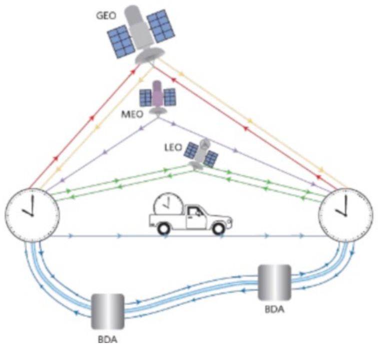




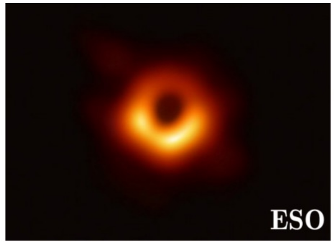
Introduction

M. Gross at al. Physics reports 93 (5), 301-396 (1982)

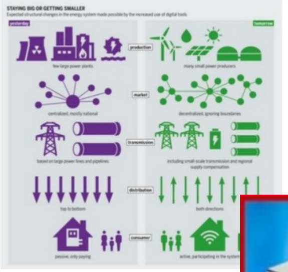
- GPS/GNNS



- VLBI



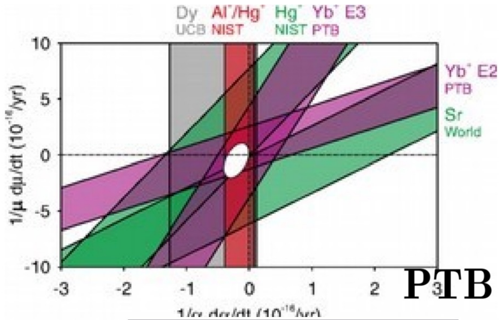
- Smart grids



- Telecommunications

- Variation of fundamental constants

Huntemann et al. *Phys. Rev. Lett.* **113**, 210802 (2014)



- Relativistic geodesy

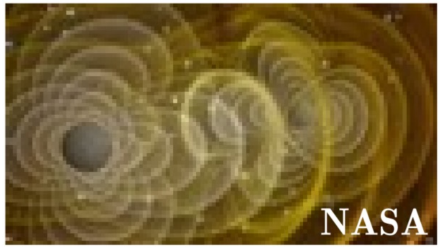
Lisdat et al. *Nat Commun* **7**, 12443 (2016)

- Dark matter detection

Derevianko et al. *Nature Phys* **10**, 933–936 (2014)

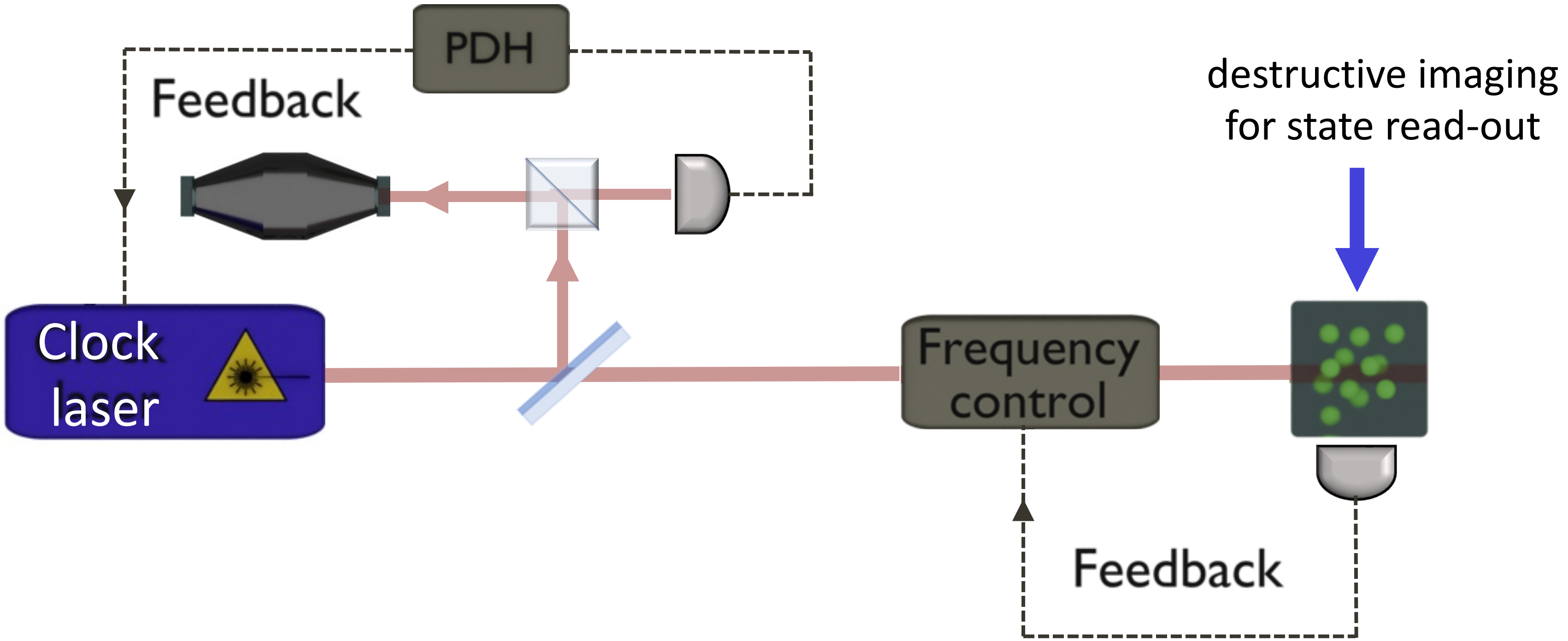
- Gravitational wave detection

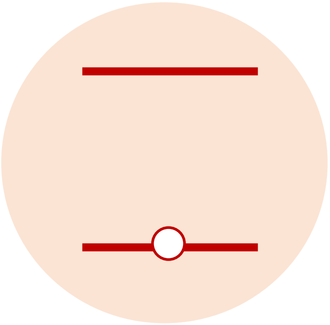
McGrew et al. *Nature* **564**, 87–90 (2018)

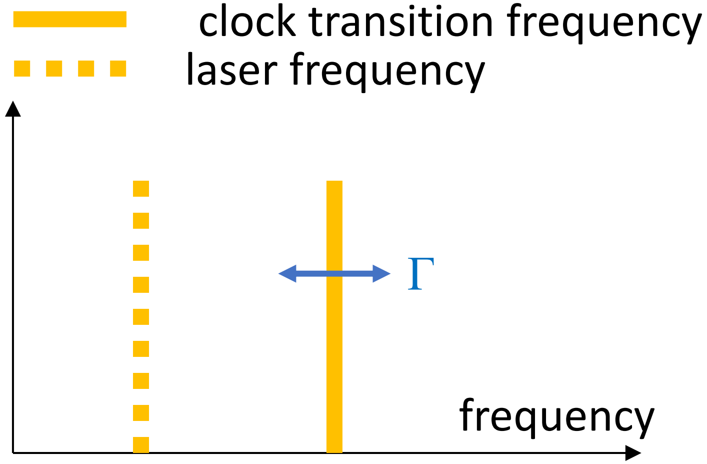


Applied physics ⟷ Fundamental physics

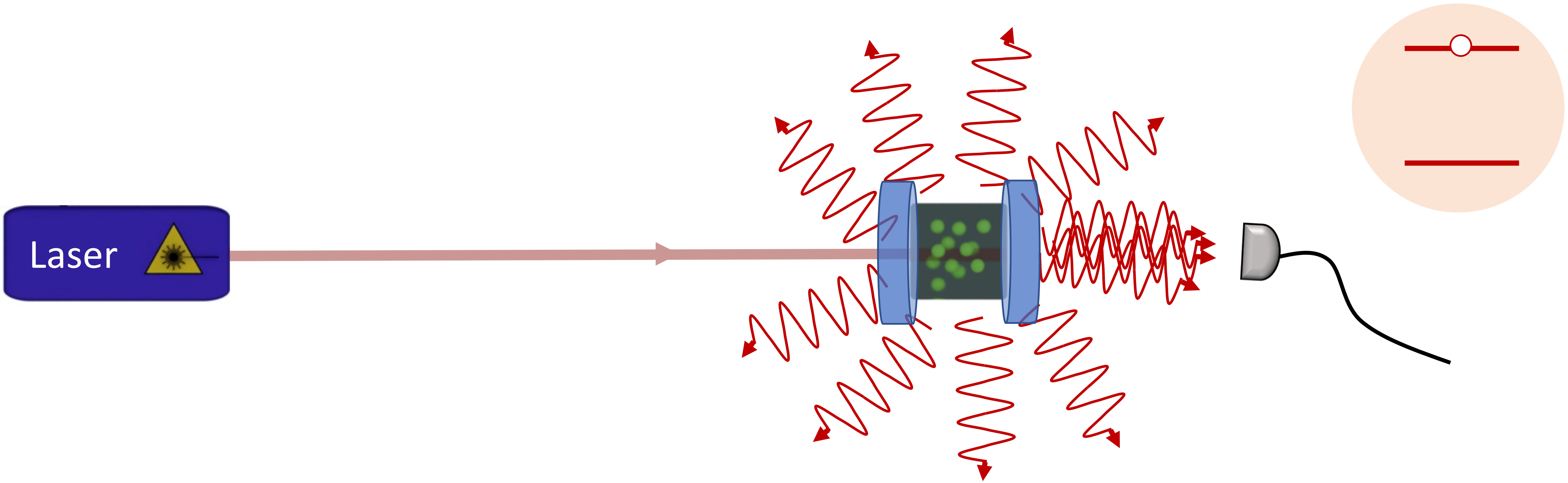
Passive atomic clocks





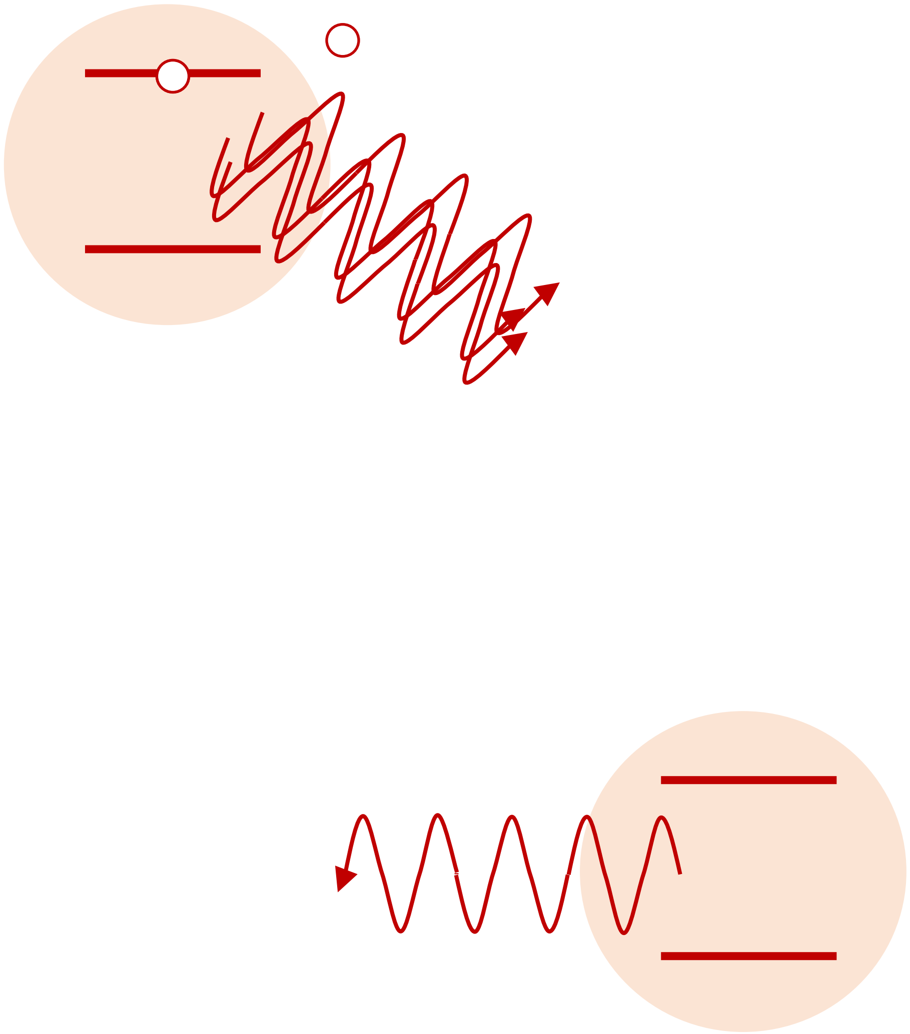


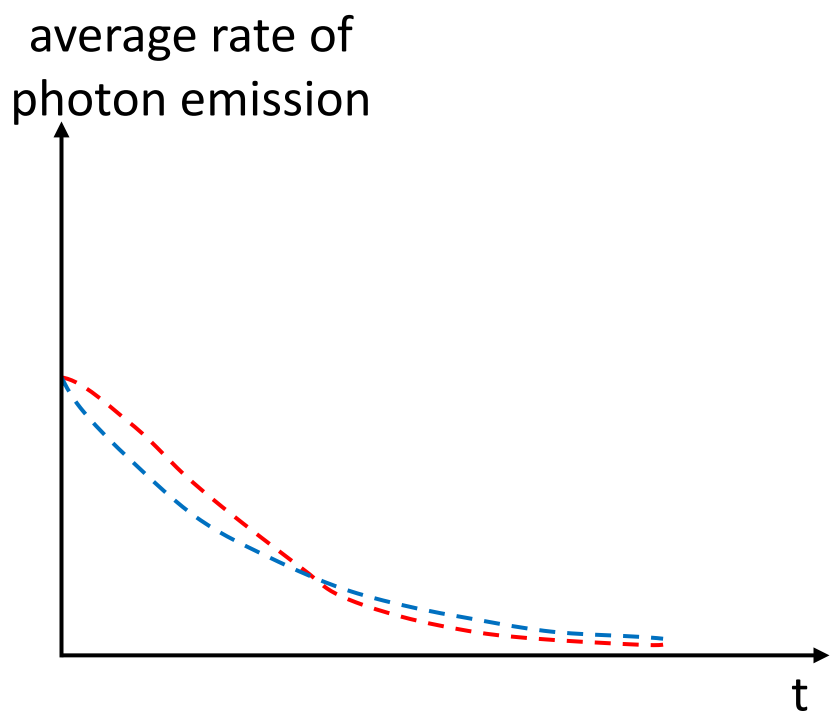
Idea for an active (optical) atomic clocks



Collective effects in atomic radiation

Two close atoms d « λ

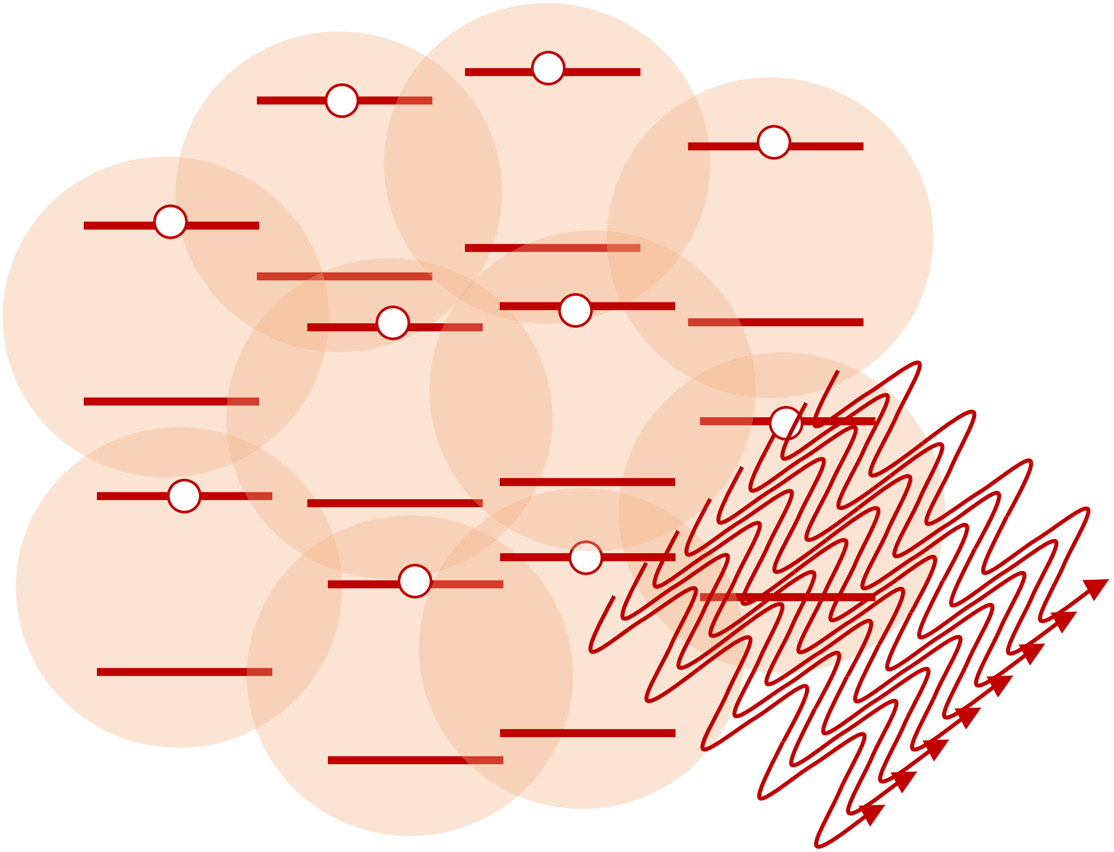


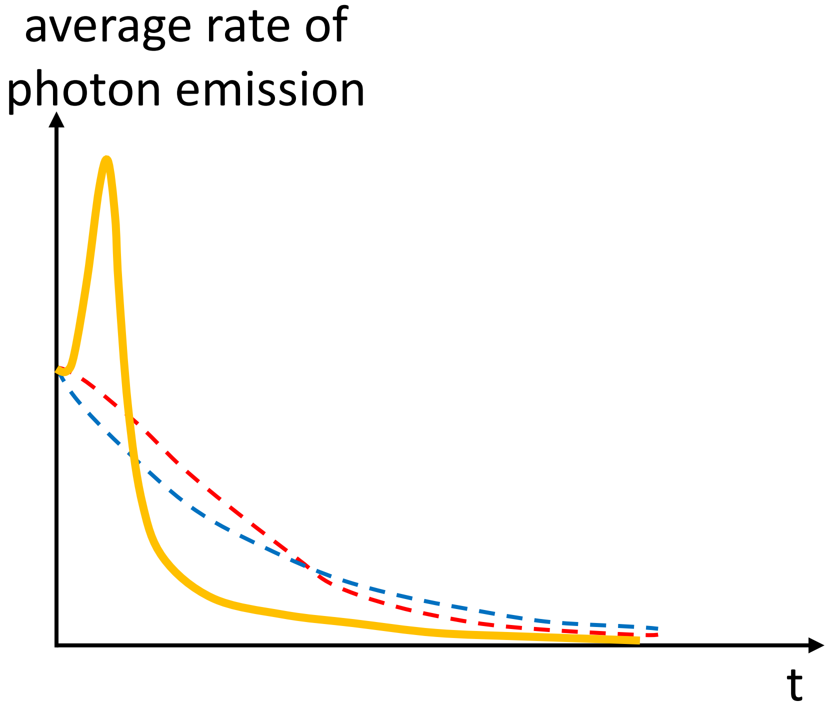


M. Gross at al. Physics reports 93 (5), 301-396 (1982)

Collective effects in atomic radiation

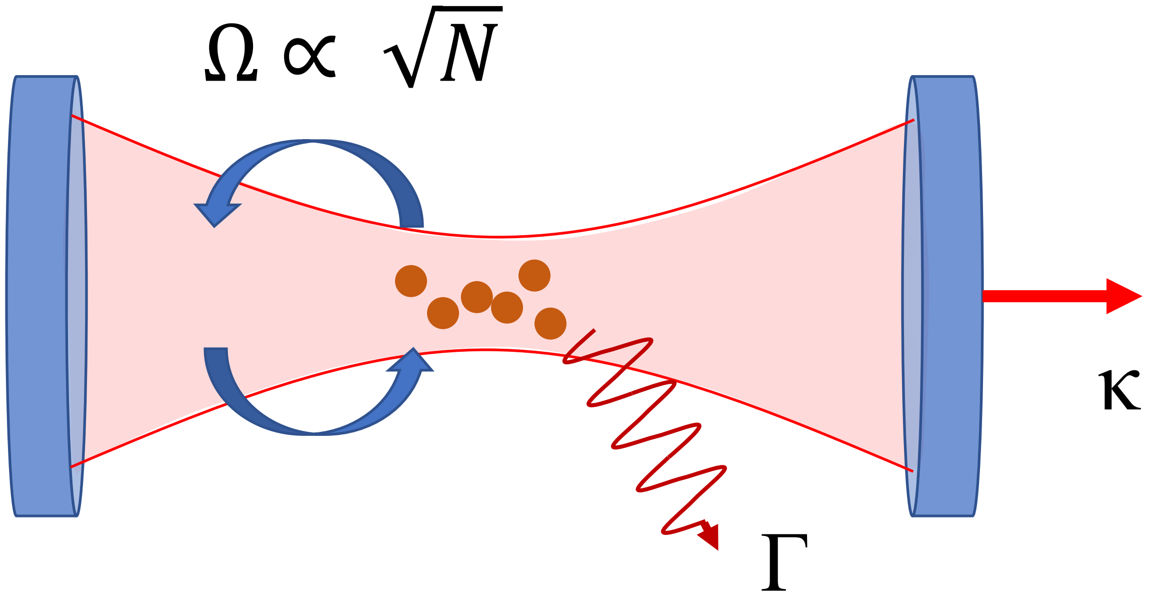
N close atoms d « λ





M. Gross at al. Physics reports 93 (5), 301-396 (1982)

Cavity superradiance



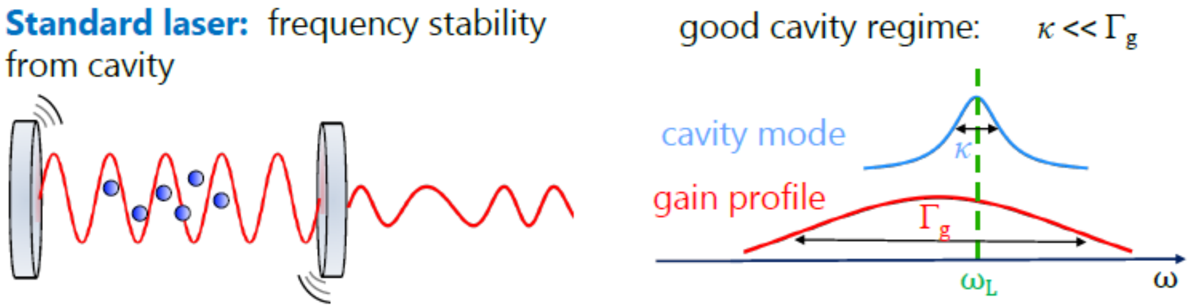
Collective strong-coupling regime

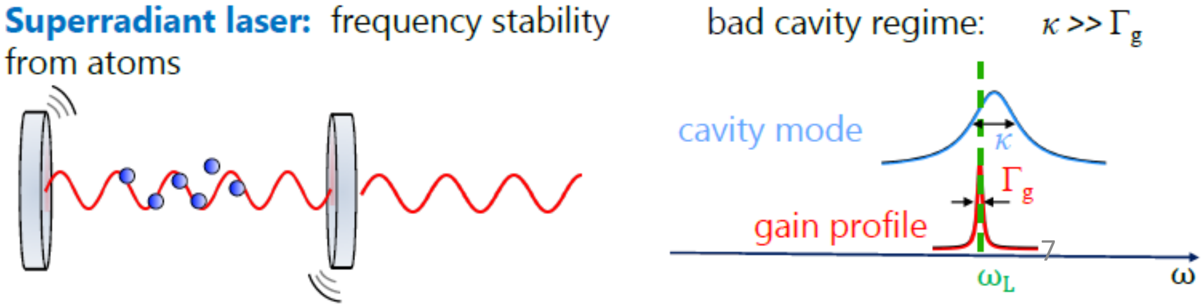
$$\Omega^2 \gg \kappa\Gamma$$

→ superradiance

Bad–cavity regime

$$\kappa \gg \Gamma$$





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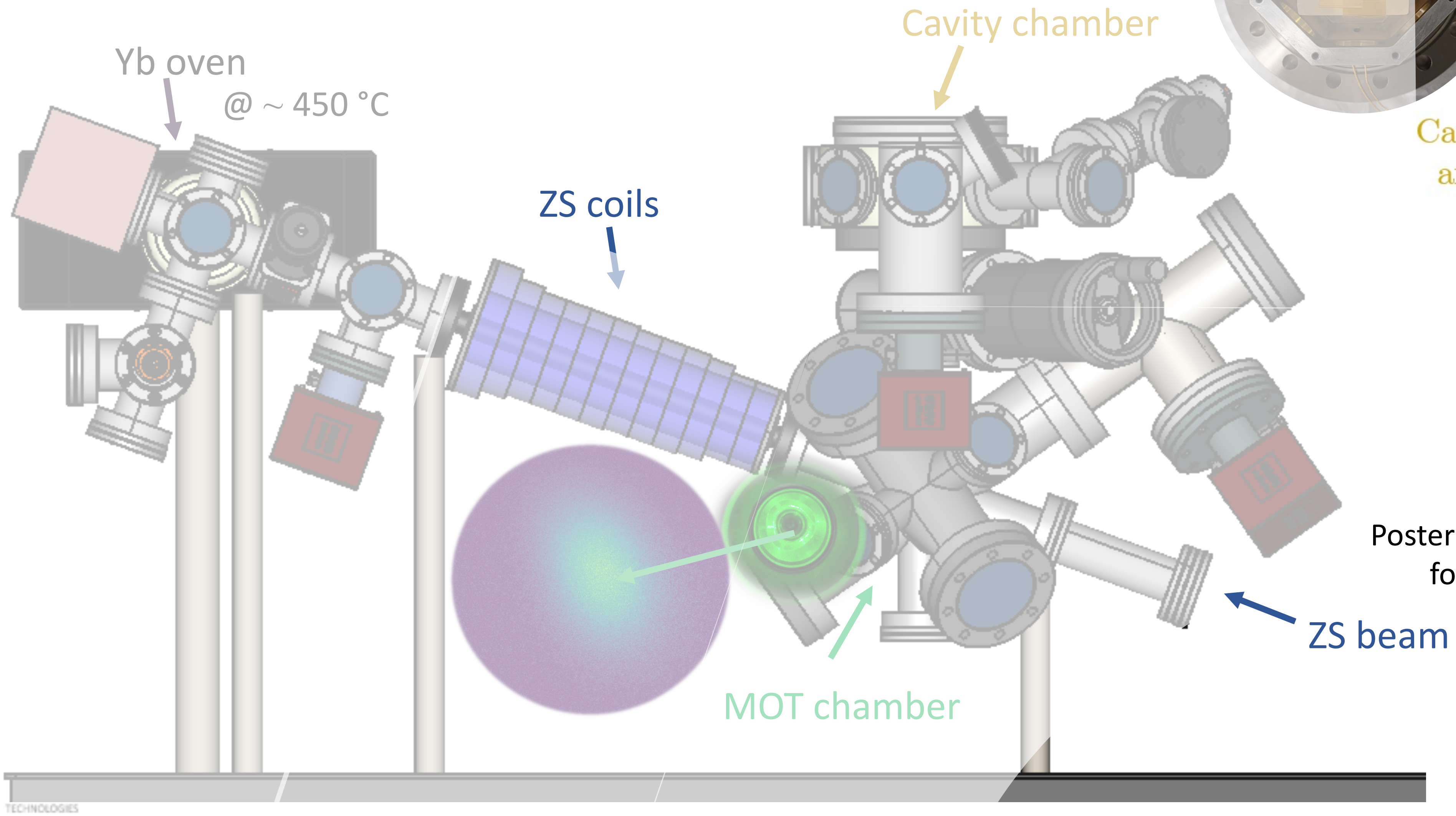
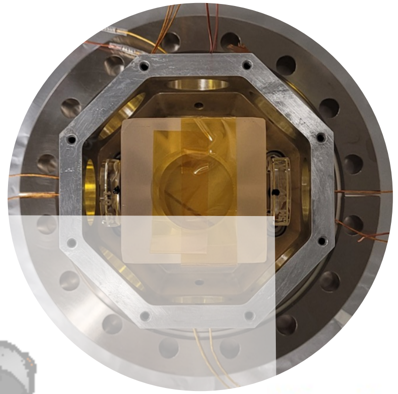
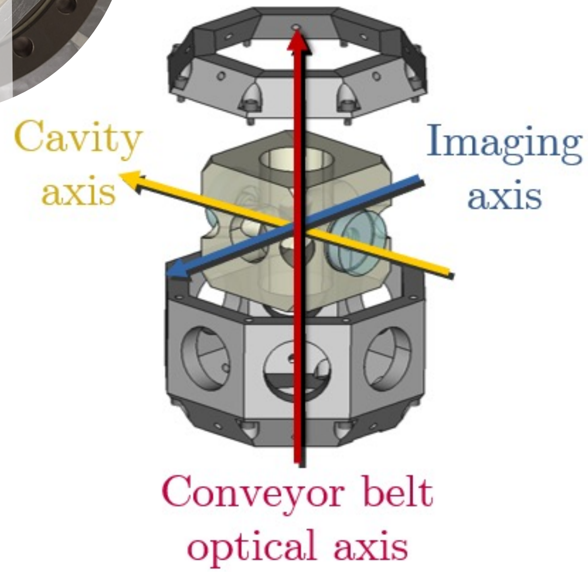
E. Bohr (2023). Exploring superradiance for enhanced sensors
[PhD Thesis, Niels Bohr Institute]

FEMTO-ST superradiant active optical atomic clock

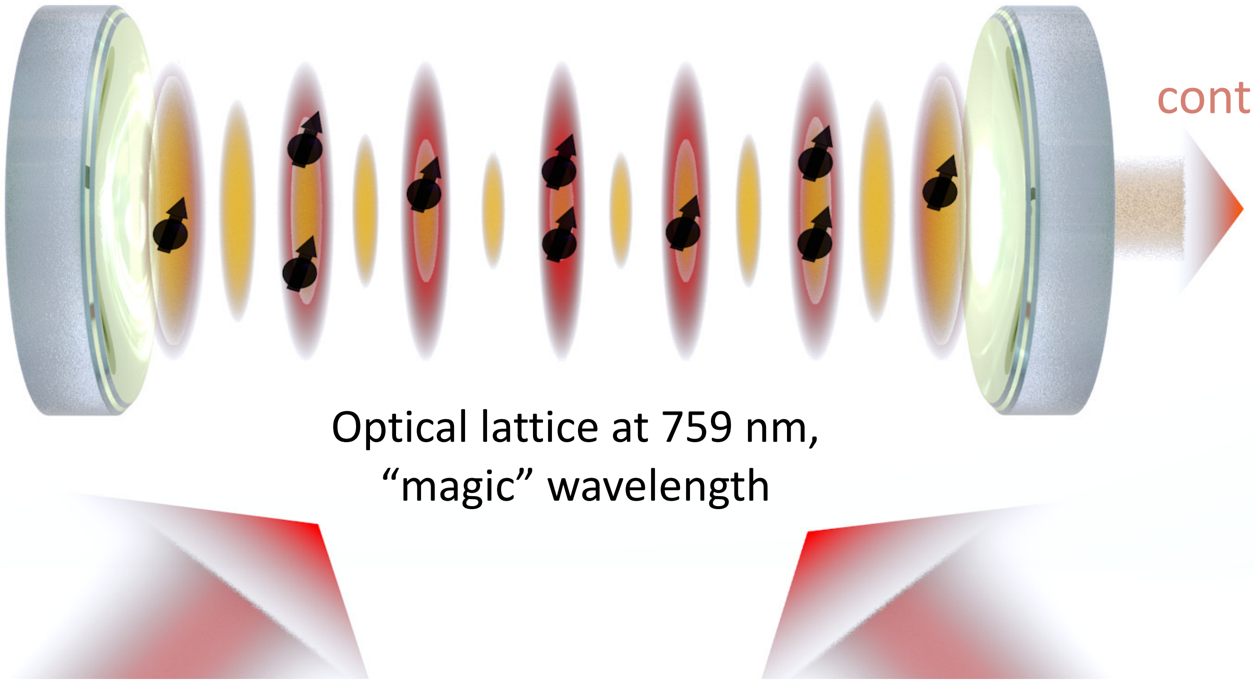




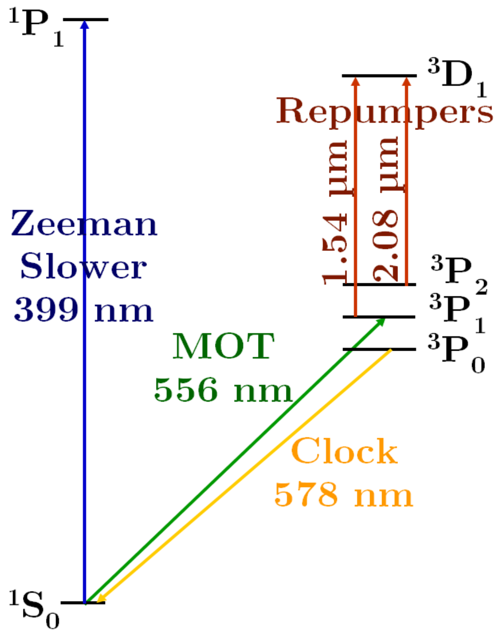


Poster: M. Hauden, Fabry-Perot cavity for ytterbium-based superradiant laser

FEMTO-ST superradiant active optical atomic clock



pulsed lasing
vs.
continuous lasing



- Γ ($^1S_0 \rightarrow {}^1P_1$): 29 MHz
- Γ ($^1S_0 \rightarrow {}^3P_1$): 182 kHz
- Γ ($^1S_0 \rightarrow {}^3P_0$): 7 mHz
- K (cavity): 500 kHz

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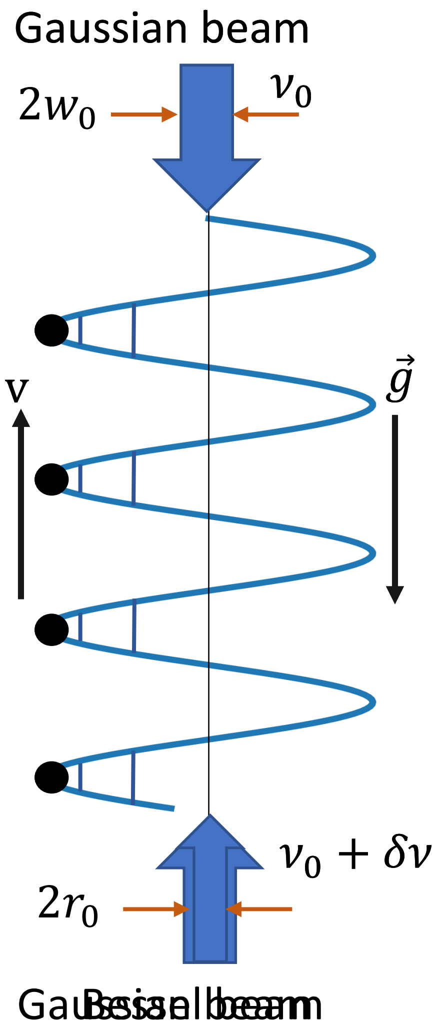
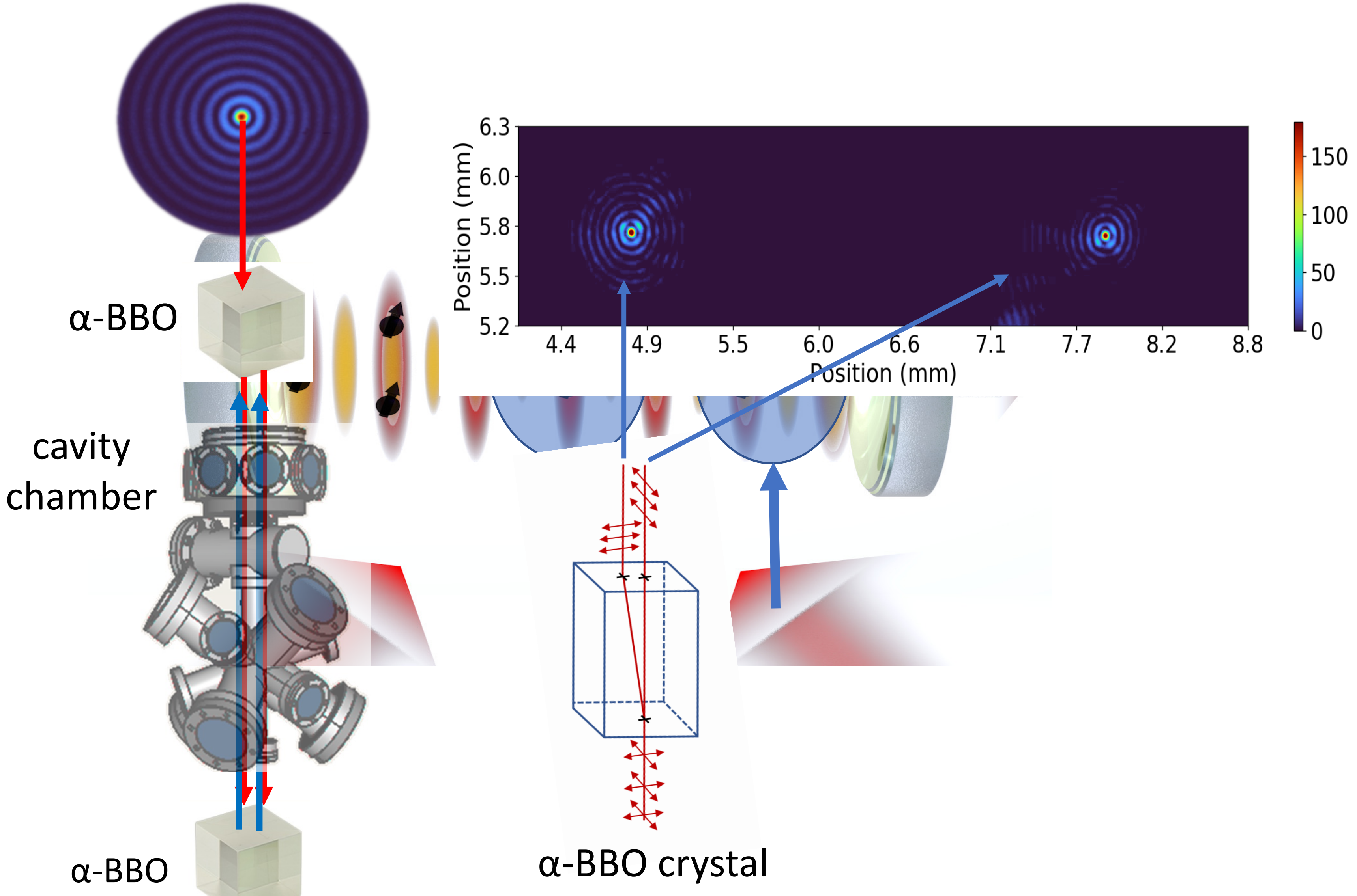
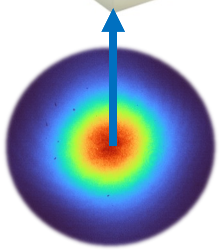
Optical transport







- Centers of both Gaussian and both Bessel beams overlap within < 10 µm
- α-BBO polarization-sensitive crystals on both sides of the optical conveyor belt

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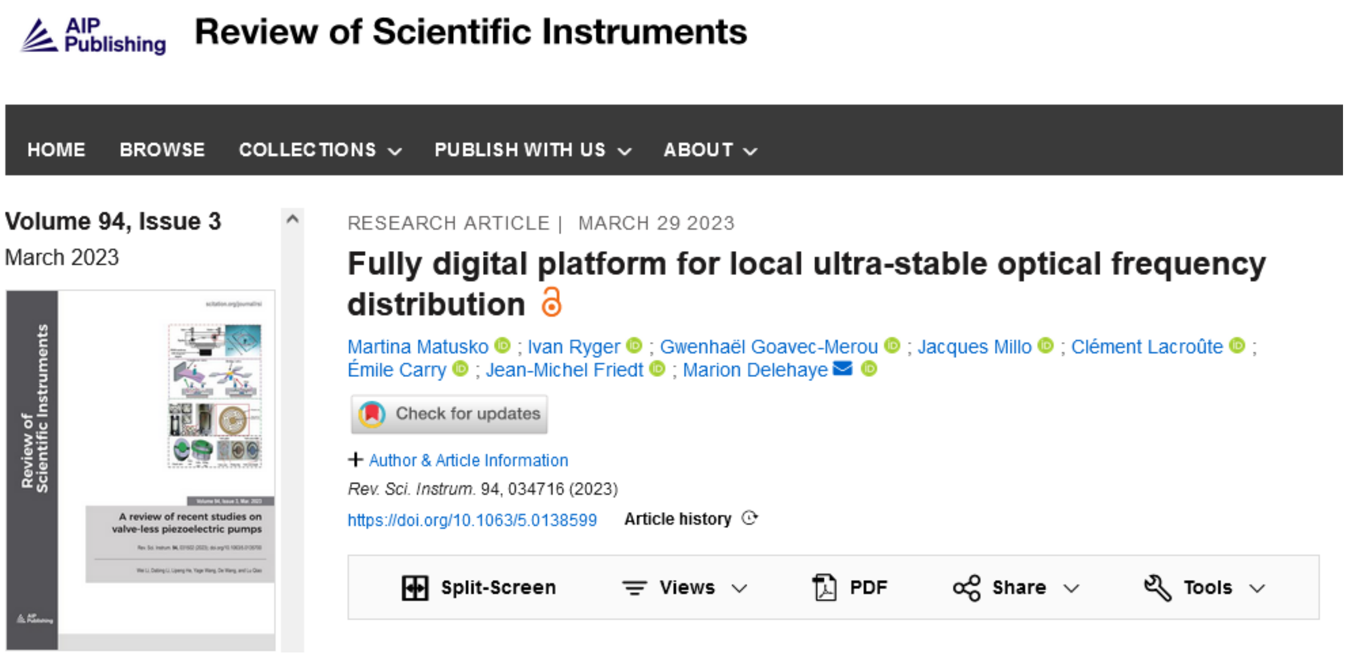
Local ultra-stable frequency dissemination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RESEARCH ARTICLE | MARCH 29 2023

Fully digital platform for local ultra-stable optical frequency distribution

Martina Matusko; Ivan Ryger; Gwenhaël Goavec-Merou; Jacques Millo; Clément Lacroûte; Émile Carry; Jean-Michel Friedt; Marion Delehaye

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Rev. Sci. Instrum. 94, 034716 (2023)

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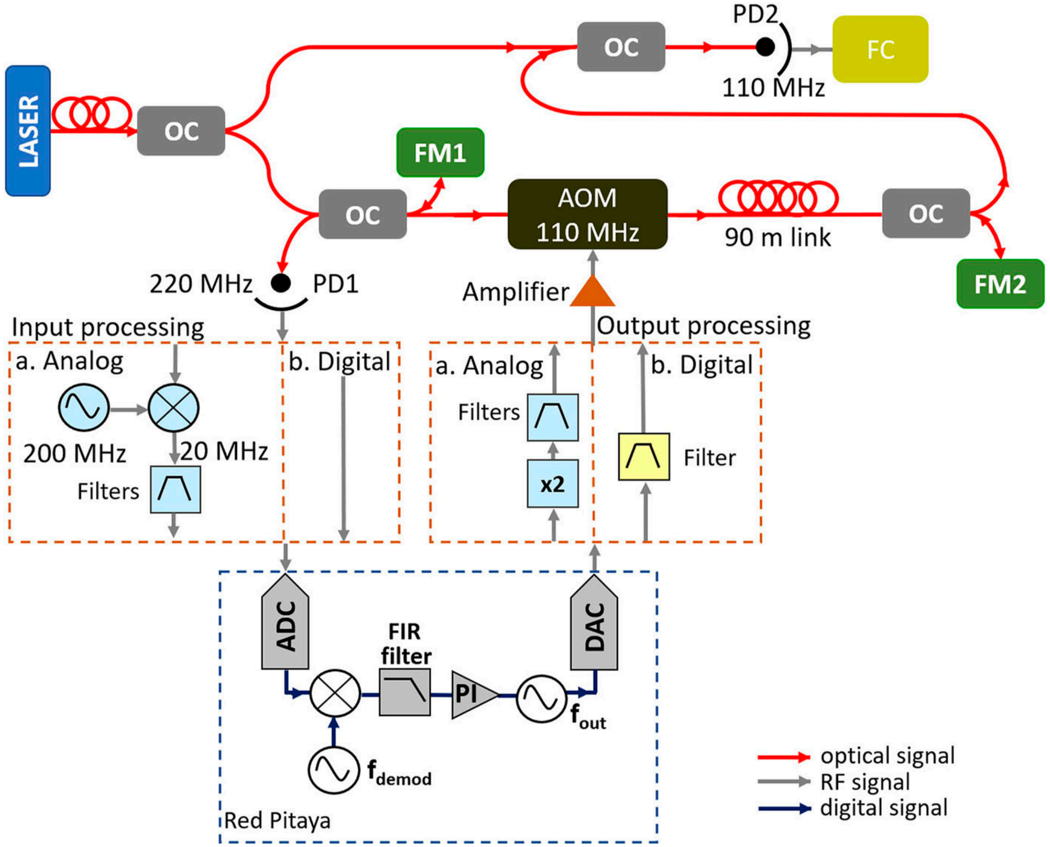
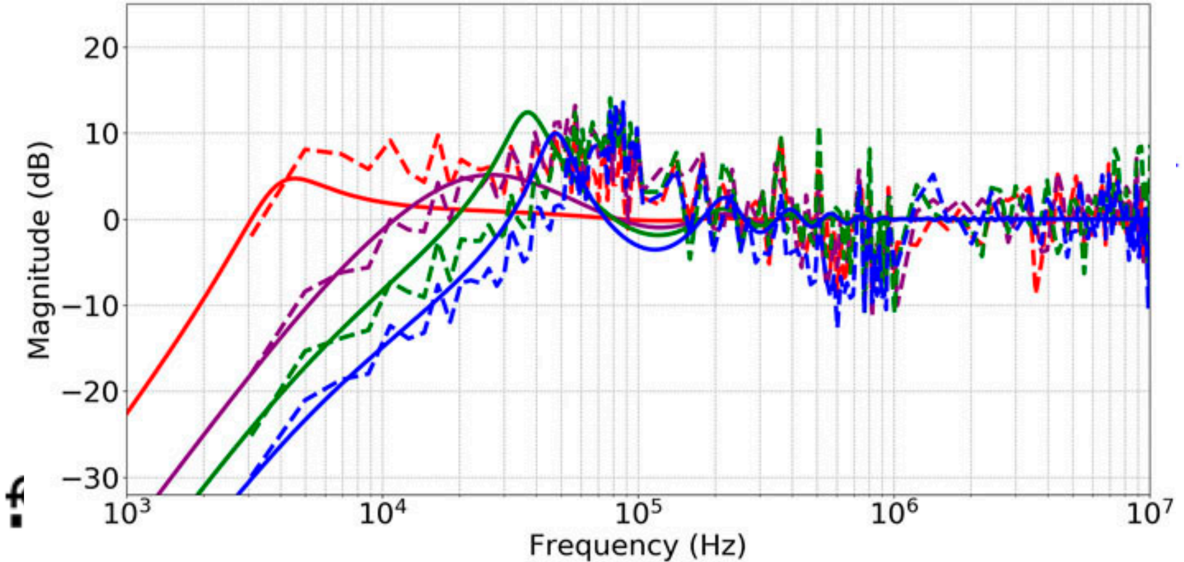




➢ frequency instability averaging down to 6×10^{-19} for 2000 s integration time

Conclusion

- ✓ Doppler-free spectroscopy for the green laser frequency stabilization
- ✓ Realizing cold atom ensemble
- ✓ Designing the two-site loading for the optical transport
- ✓ Fully digital setup for local ultra-stable frequency distribution with a novel characterization method
- ✓ Tunable length Fabry-Perot cavity assembly

Next steps

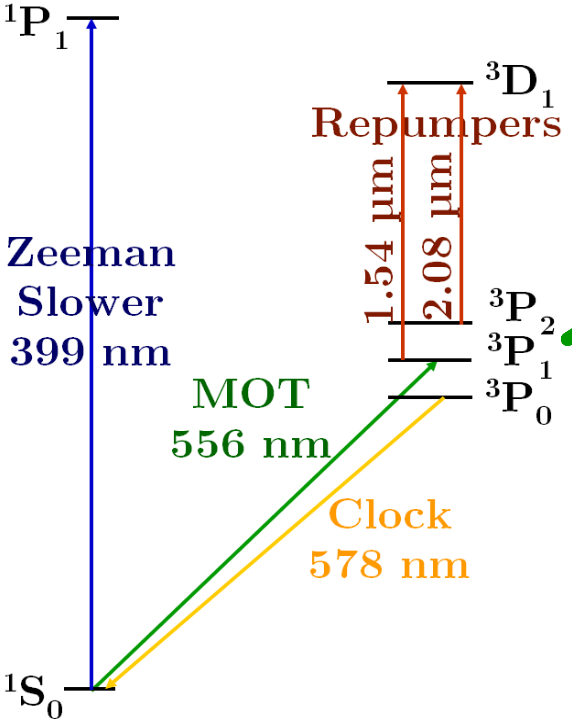
- ➢ Performing **optical transport** designed for two-site loading for continuous atom reloading
- ➢ Coupling atoms to the cavity
- ➢ Obtaining **superradiant pulses** at the cavity output
- ➢ Repumping scheme for extended pulse duration
- ➢ **Continuous superradiant signal** at the cavity output

The superradiant team

Marion Delehaye | Sebastian Ponciano Ojeda | Martin Hauden | Martina Matusko | Jana El Badawi

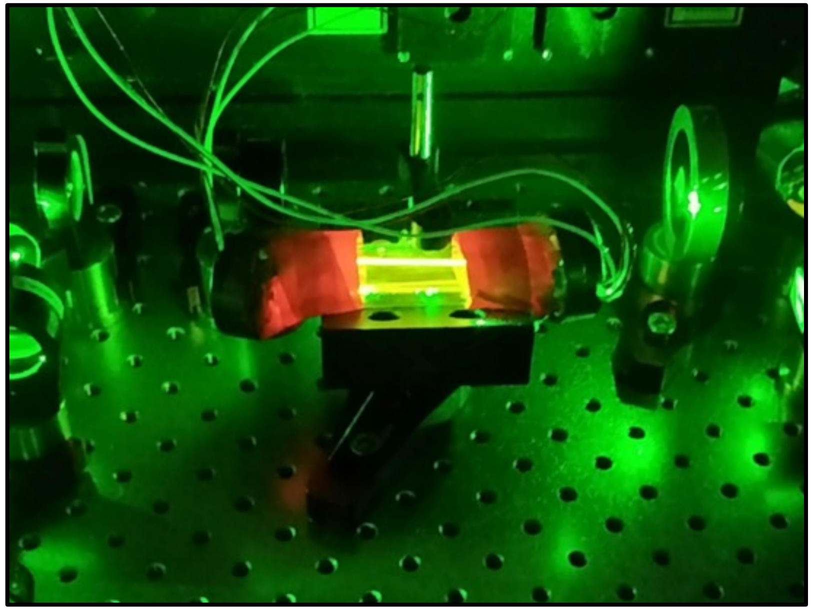
Thank you for your attention!

Iodine spectroscopy



Magneto-optical trap transition: 181 kHz wide
Laser stabilization required

Molecular reference: iodine sub-Doppler spectroscopy
Dareau, Alexandre. PhD. Paris, Ecole normale supérieure, 2015.



Referencing of iodine transition frequency at 556 nm

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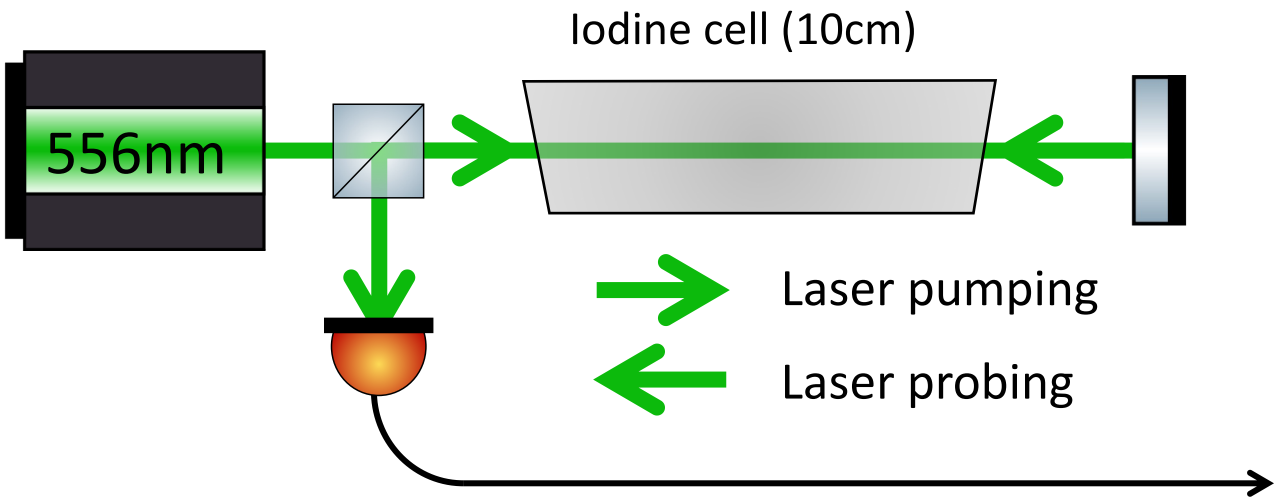
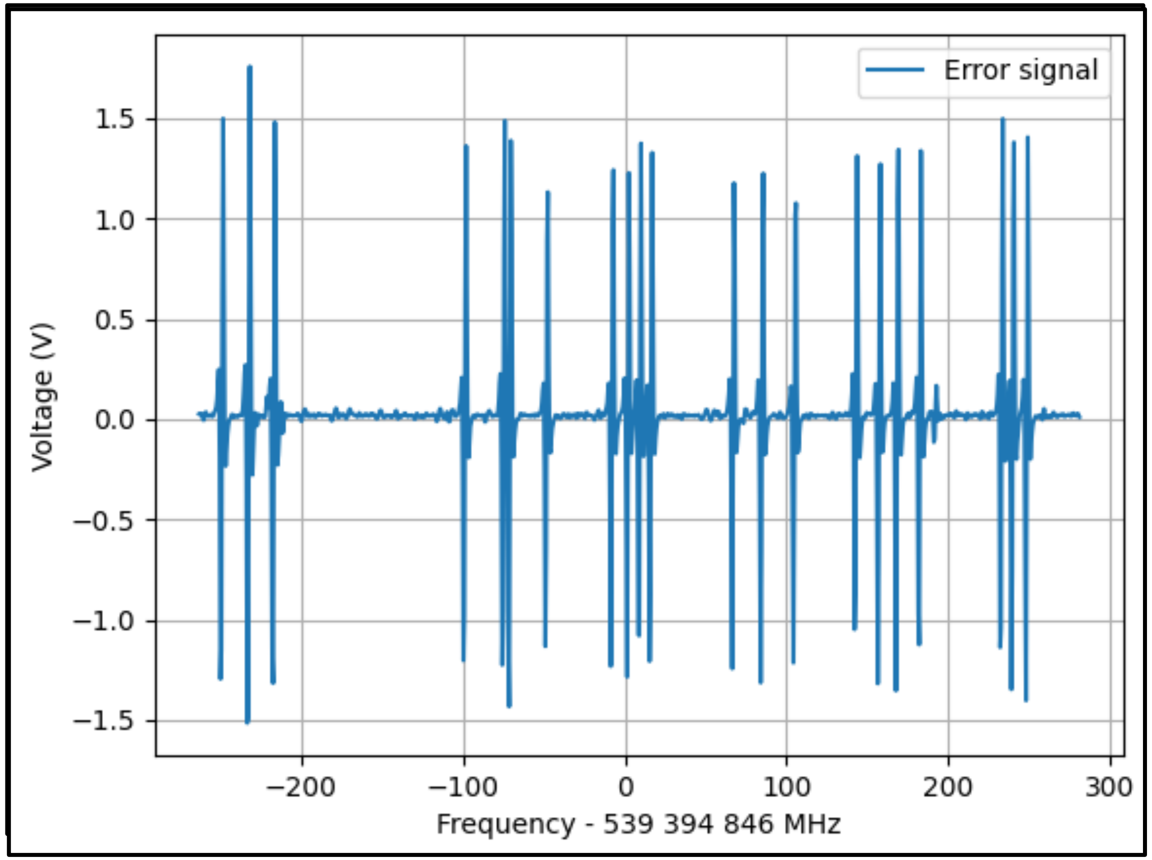
Iodine spectroscopy

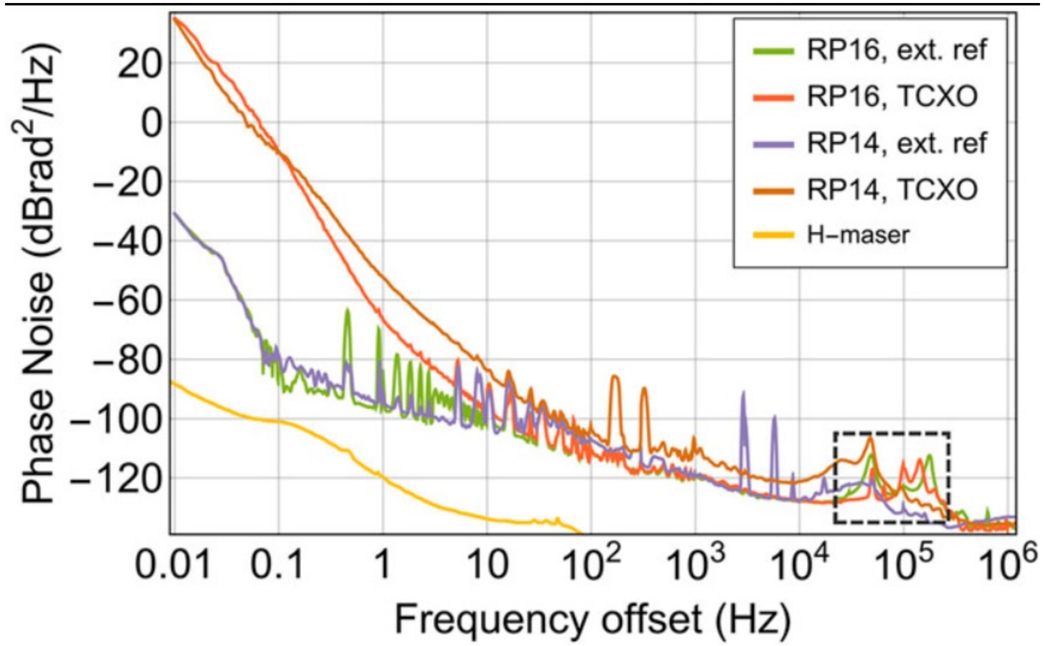
Sub Doppler saturated spectroscopy setup

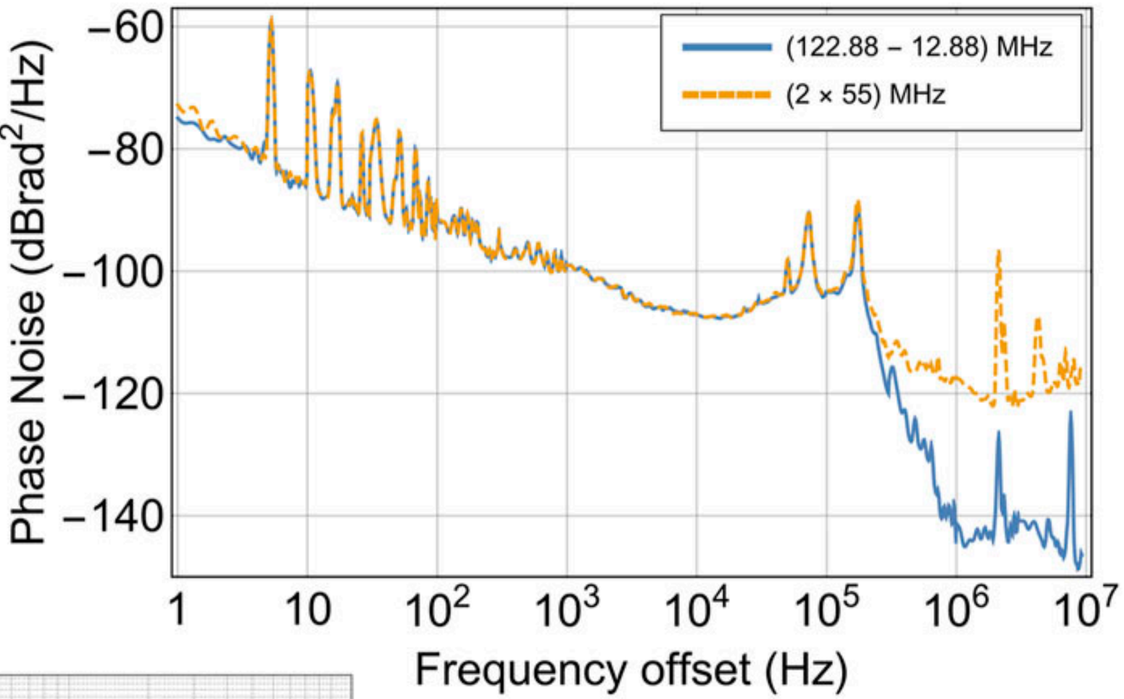


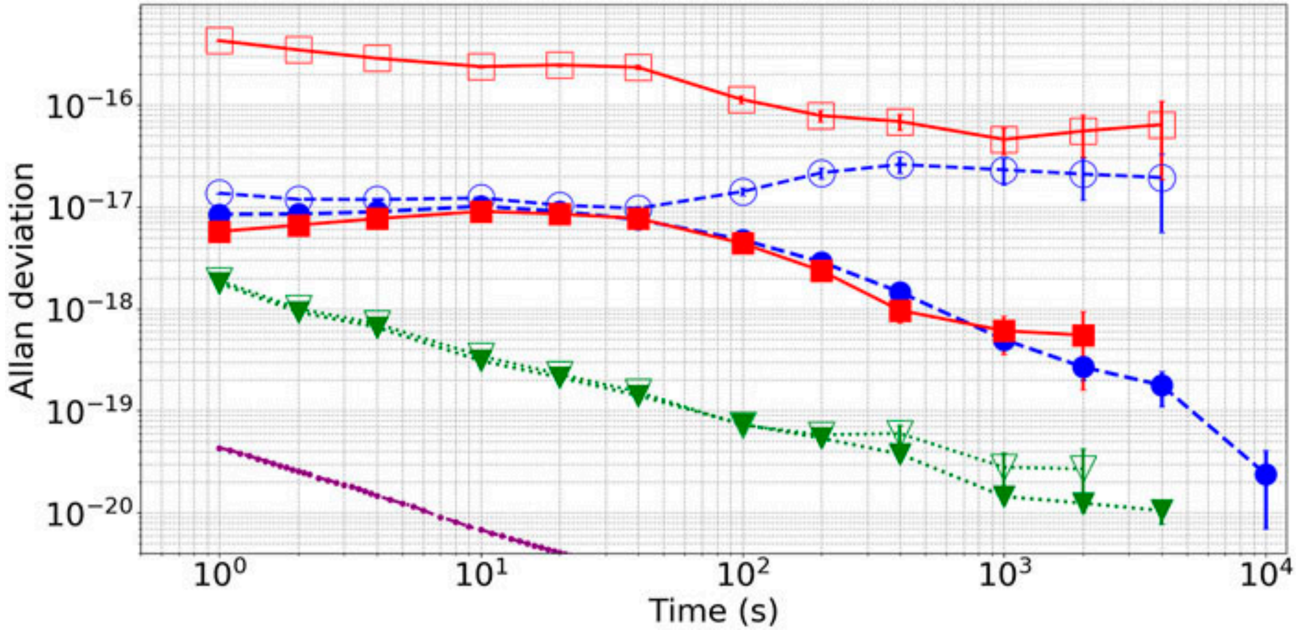


Contra-propagating beams lead to atom velocity selection → sharp absorption signal

Local ultra-stable frequency dissemination







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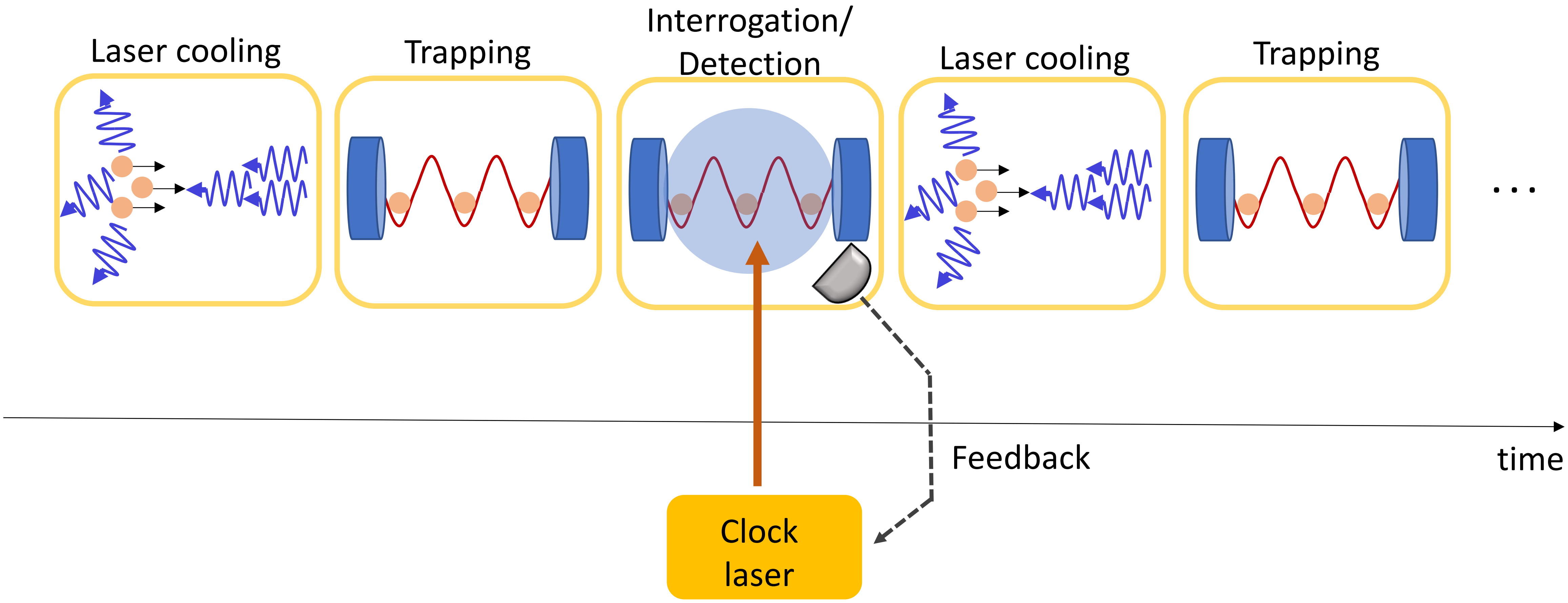
Passive atomic clock cycle scheme



Passive atomic clocks