MenloSystems

Complete, Ultra-Stable Laser System for Sr Optical Lattice Clocks

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EPIC Industrial Quantum Photonics Technology Summit

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Menlo Systems

PRECISION IN PHOTONICS. TOGETHER WE SHAPE LIGHT.

Optical Frequency Combs

Ultrastable Lasers

Terahertz Solutions

fs Fiber Lasers

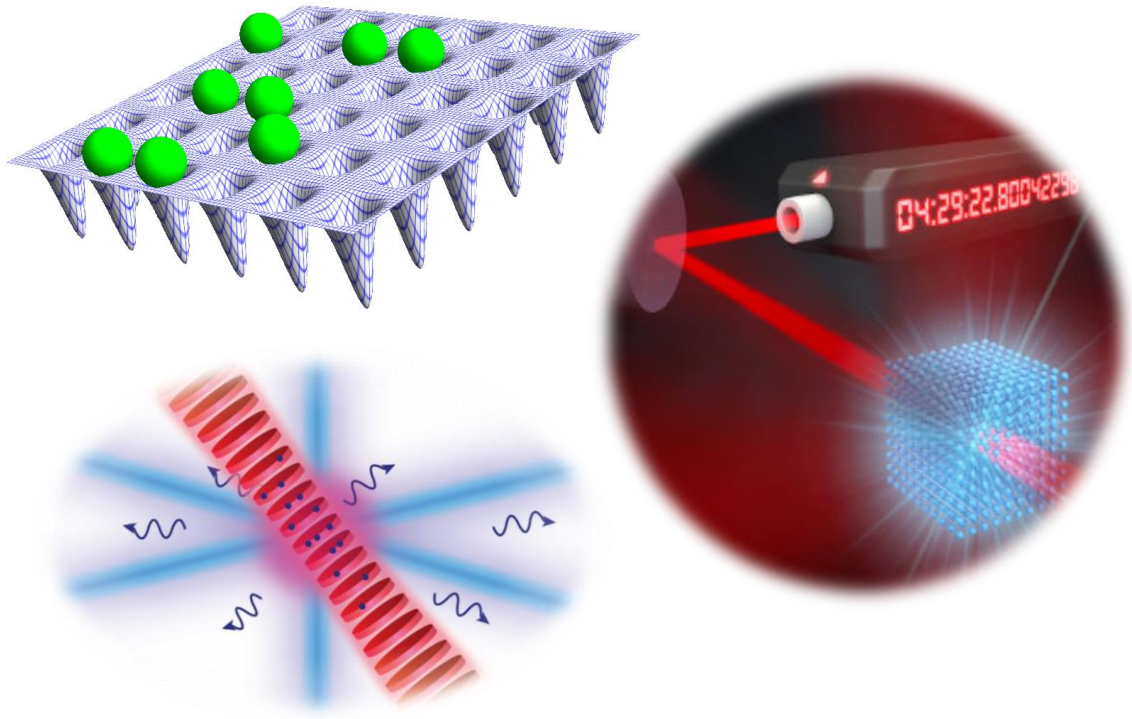
Quantum Laser Systems

Solutions for Space

Quantum Laser Systems

MOTIVATION

- Optical clocks require local oscillators with exceptional optical coherence
  - → Requires highly sophisticated, complex systems
- Better accuracy requires oscillation frequency of clock in optical region
  - → Requires suitable optical clockwork
- Demands on clocks to be more user-friendly, transportable



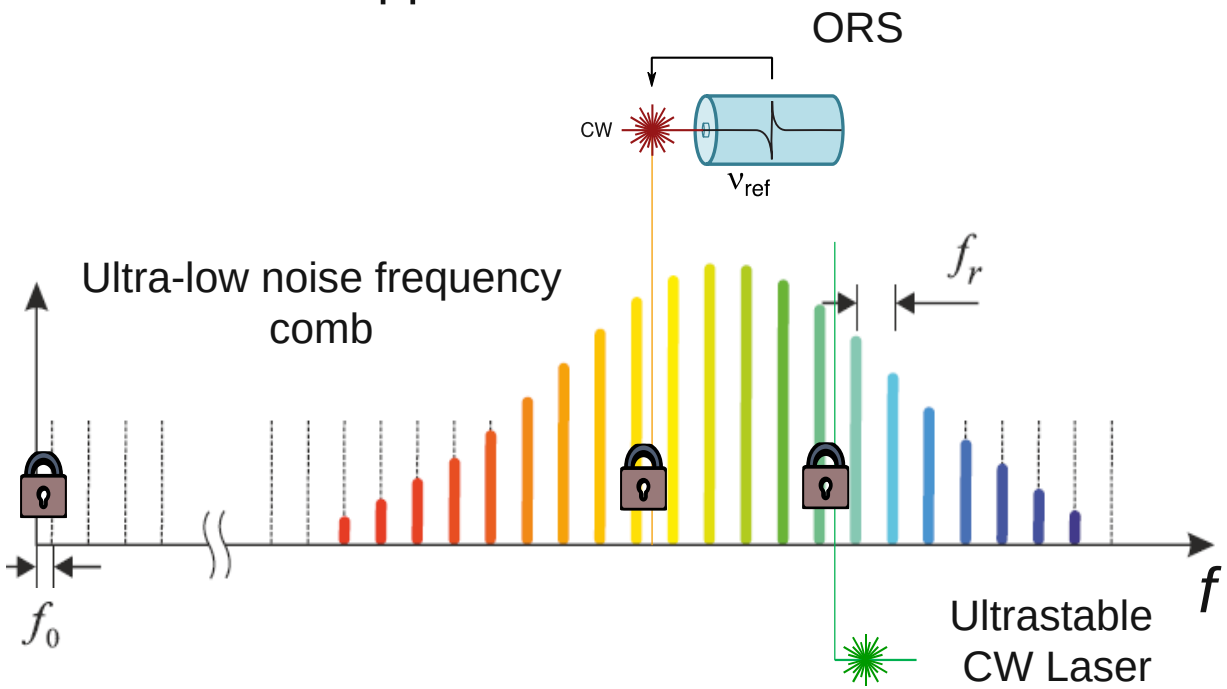
Oelker, E., *et al., Nat. Photonics* **13,** 714–719 (2019)

Quantum technologies

COMPLETE LASER SYSTEM FOR QUANTUM TECH

FC1500-Quantum

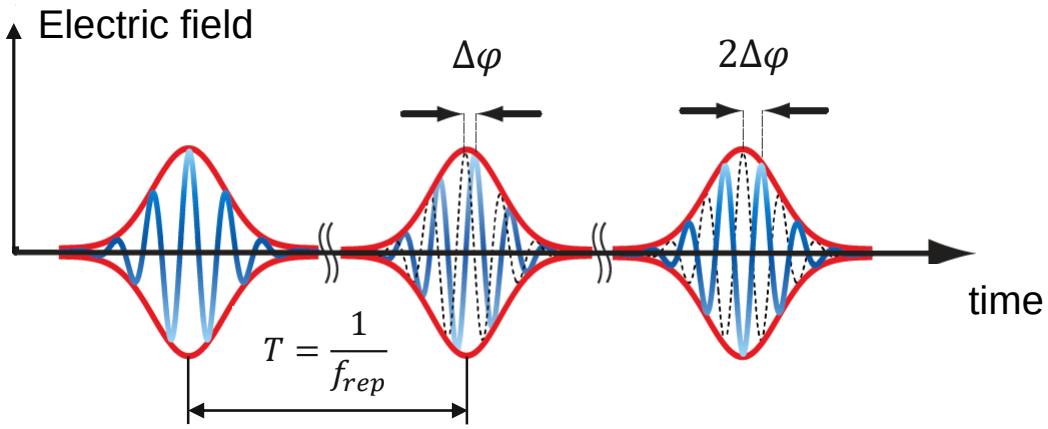
- Multi-branch ultra-low-noise frequency comb
- Optical reference system (ORS)
- Range of CW lasers suitable for application



System basics

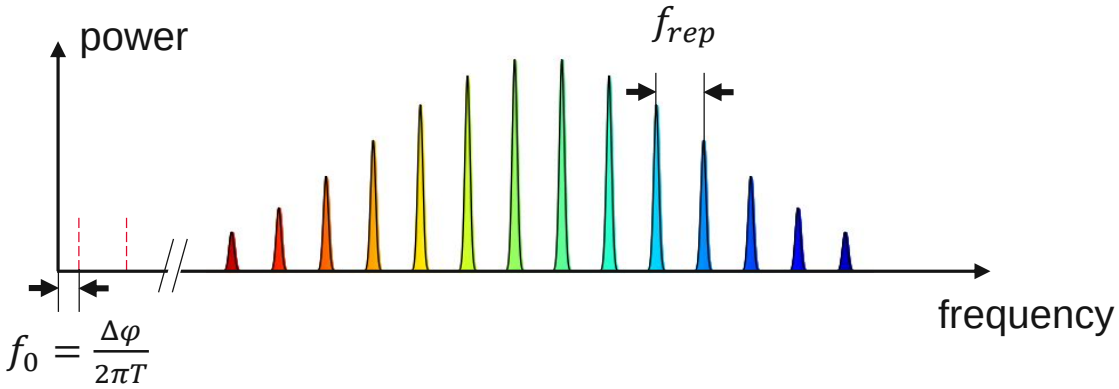
FREQUENCY COMB

TIME DOMAIN – femtosecond pulse train



Fourier transform

FREQUENCY DOMAIN – frequency comb



An optical frequency comb is a pulsed laser with stabilized repetition rate and carrier-envelope-offset frequency

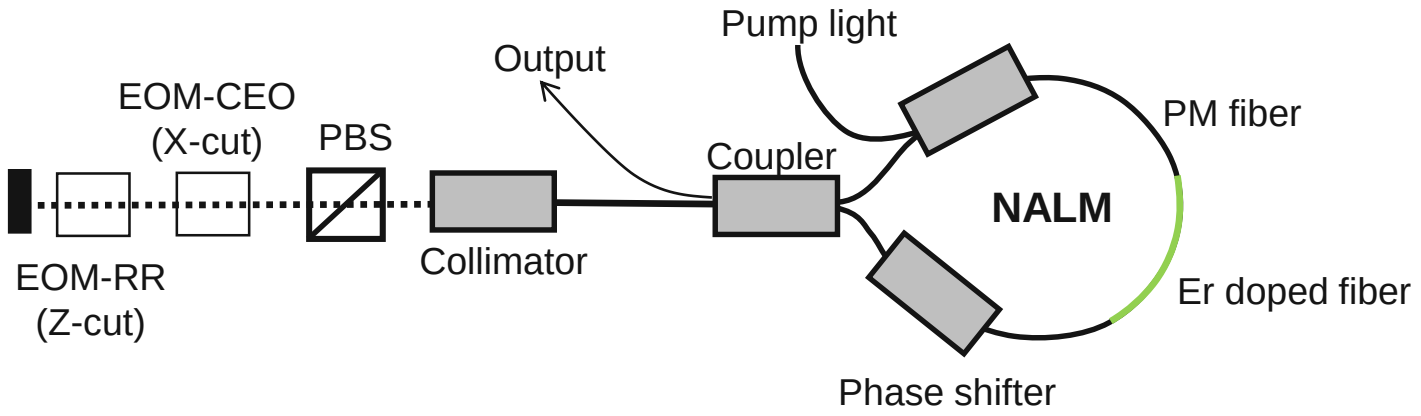
$$f_n = n \cdot f_{rep} + f_0 \qquad n \in \mathbb{N}_0$$

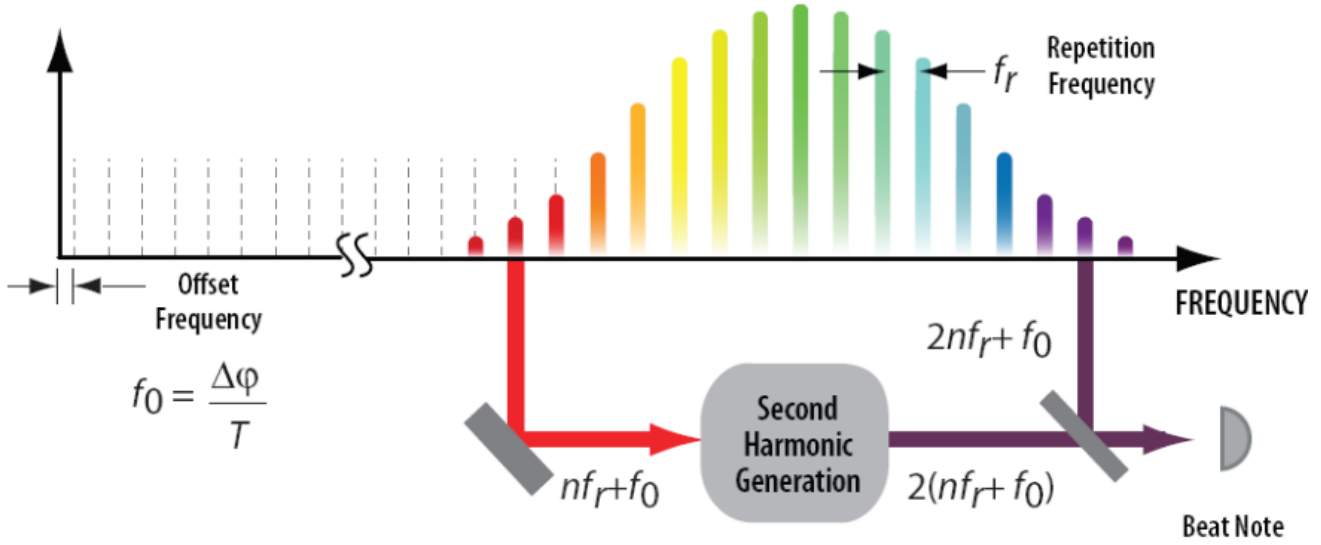
e.g. 429 THz (698 nm) **250 MHz** **35 MHz**

System basics

ULTRA-LOW NOISE FREQUENCY COMB

- Er-fiber fs laser (1560 nm) modelocked with NALM
  - → Figure 9® technology
- $\Delta\lambda$ = 40 nm, τ_p < 100 fs
- f_{rep} typically 250 MHz
- CEO and rep rate measured and stabilized with actuators



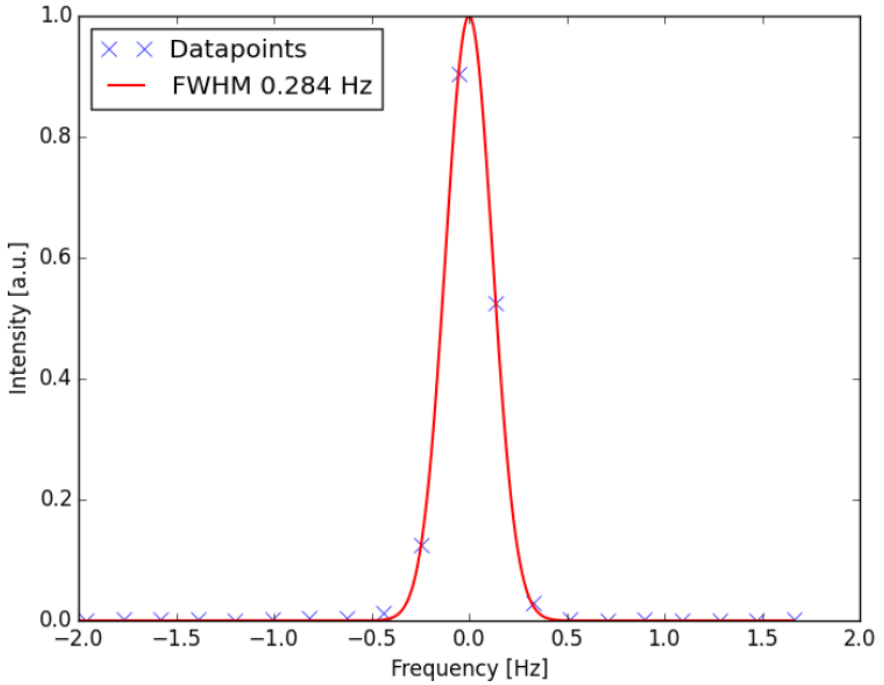


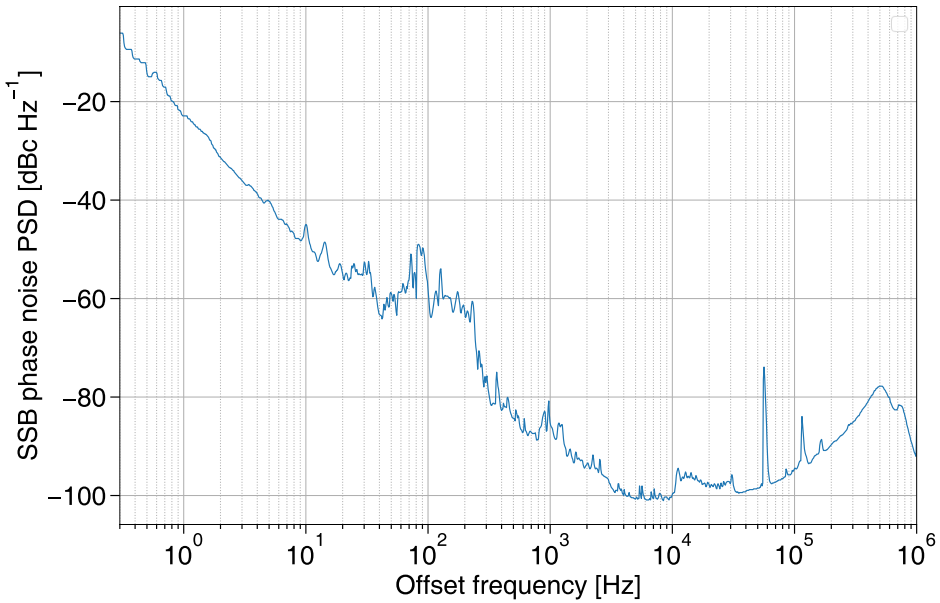
Hänsel, W. *et al.*, **U.S. Patent 13/778,672**;
Lezius, M. *et al.*, ***Optica* 3, 1381 (2016)**

FC1500-Quantum

OPTICAL REFERENCE SYSTEM (ORS)

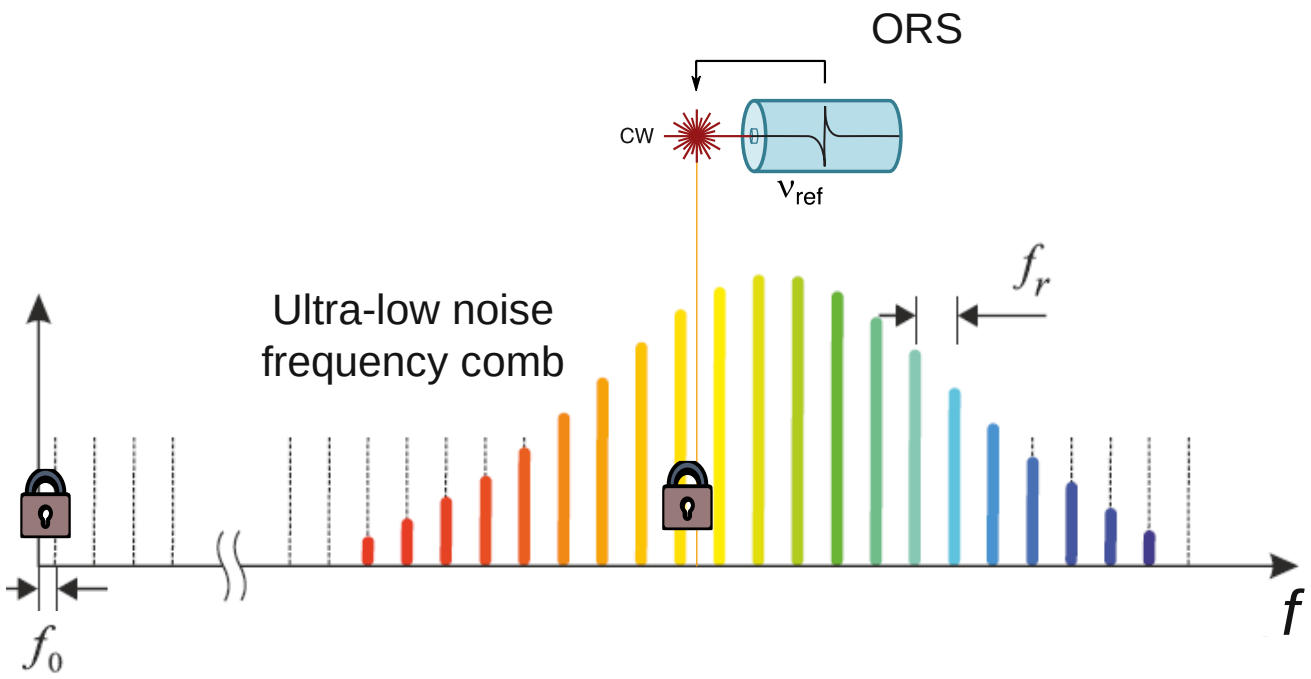
- 12 cm Fabry-Pérot reference cavity (ULE glass)
- Crystalline mirror coatings on fused silica substrates
- PDH locked laser at 1542.14 nm (194.4 THz)
- MDEV < 7×10^{-16}
- Linewidth < 1 Hz





FC1500-Quantum

COMB REFERENCED TO ORS



- ORS acts as reference for short-term stability of system as a whole
- ULN comb is optically referenced to ORS
  - → transfers stability, accuracy, and linewidth to all comb lines
- 1560 nm emission from comb amplified and spectrally shifted
  - → Stabilized comb line for all necessary wavelengths
  - → Spectral purity preserved over entire spectrum, from UV to IR

“ Spectral purity transfer ”

Complete, Ultra-Stable Laser System for Sr Optical Lattice Clocks

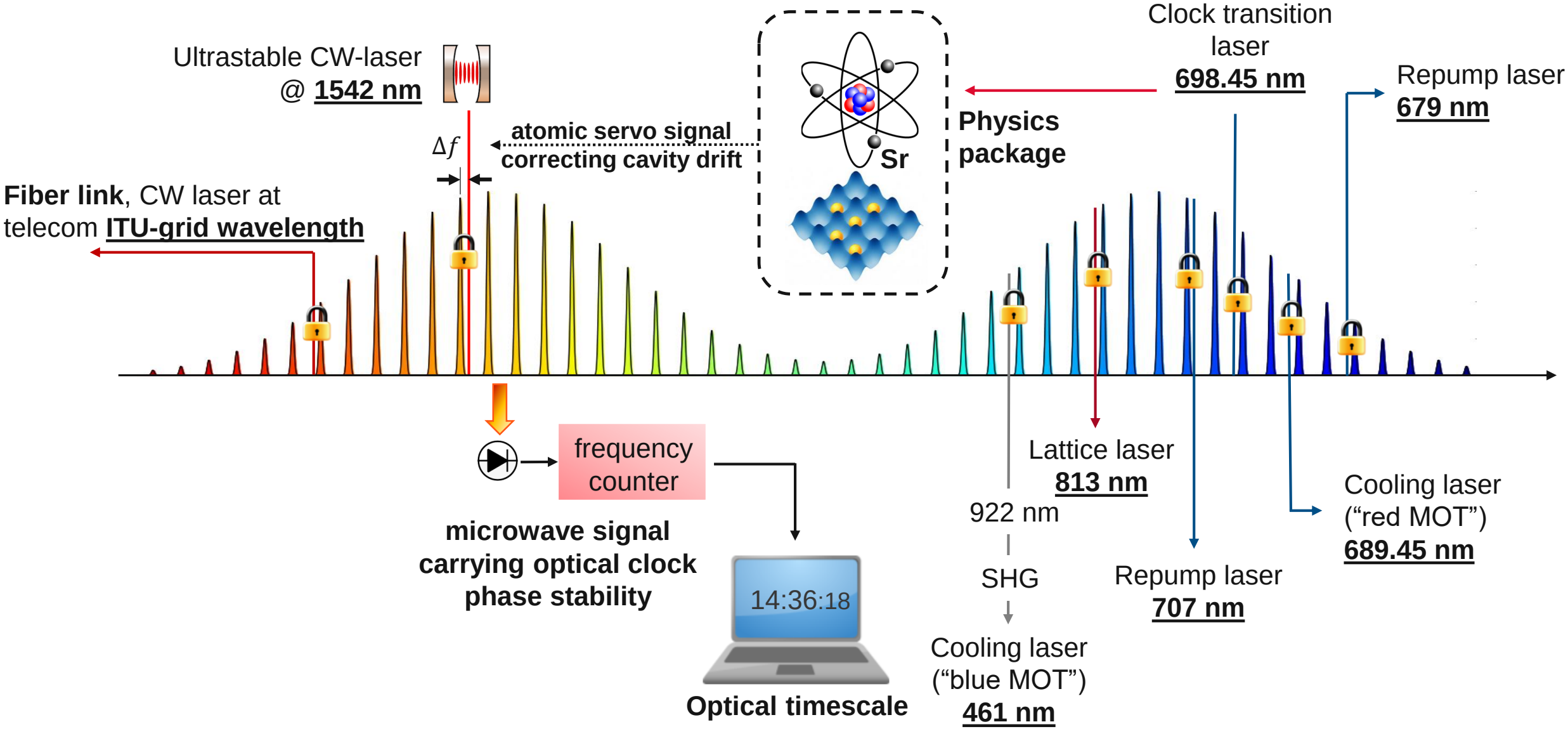
FC1500-QUANTUM

Control and driving electronics for optical frequency comb and CW lasers

Multi-branch, ultrastable optical frequency comb and phase-locked CW lasers

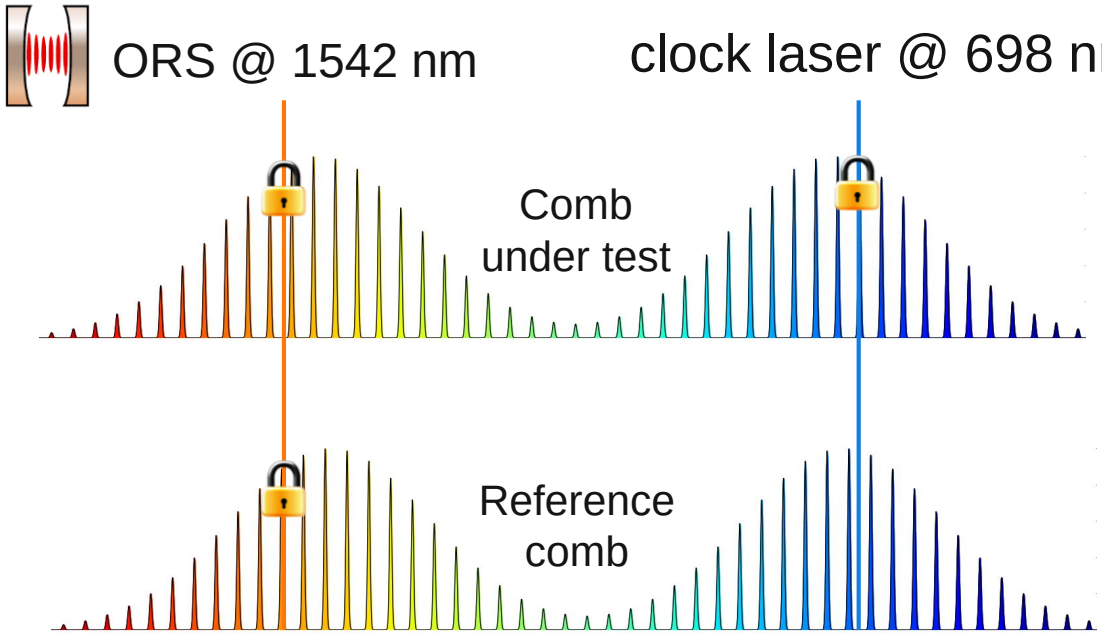
Ultrastable CW-laser, Crystalline coating mirrors

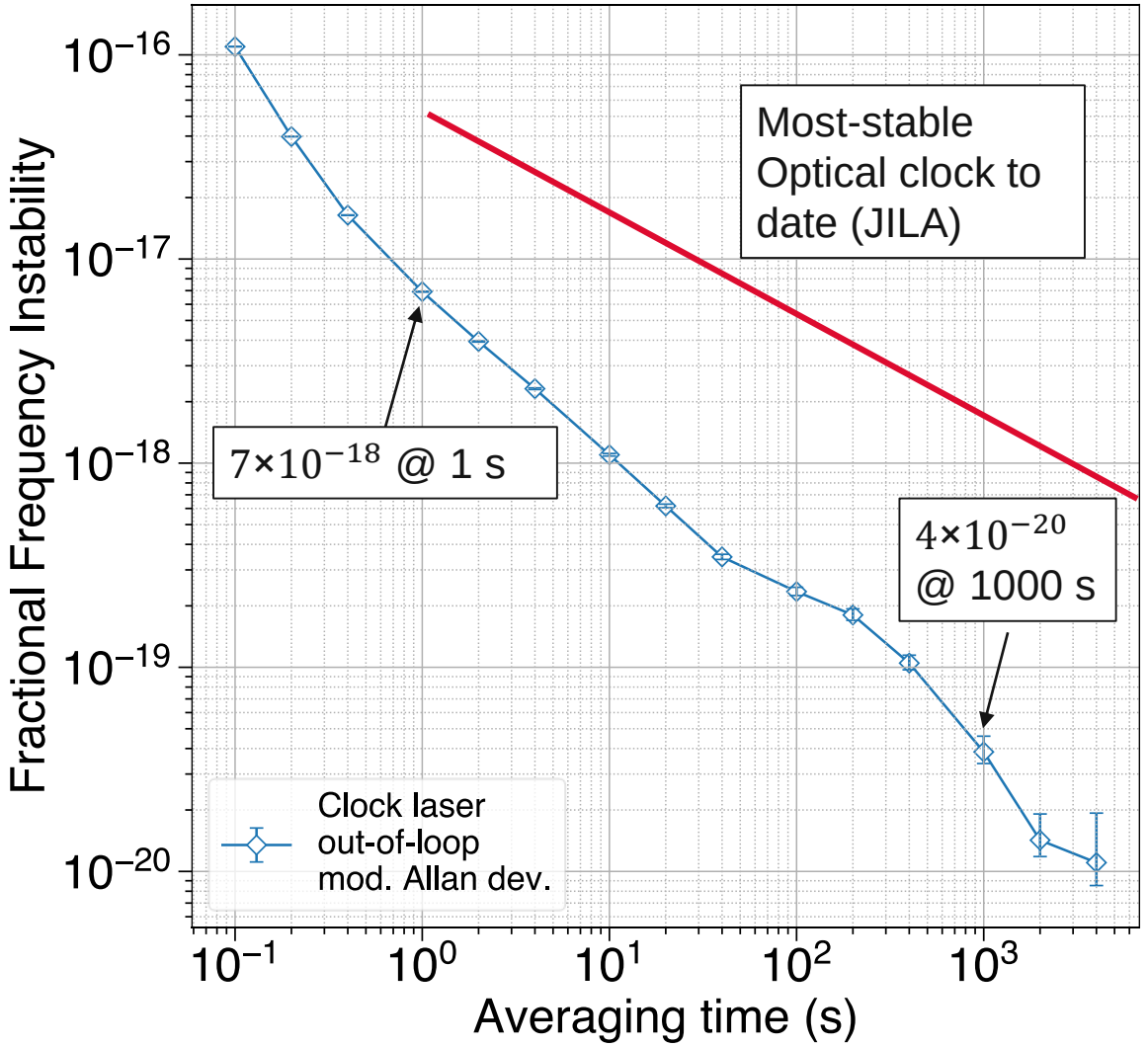
Sr optical lattice clock laser system



Complete, Ultra-Stable Laser System for Sr Optical Lattice Clocks

FRACTIONAL FREQUENCY STABILITY

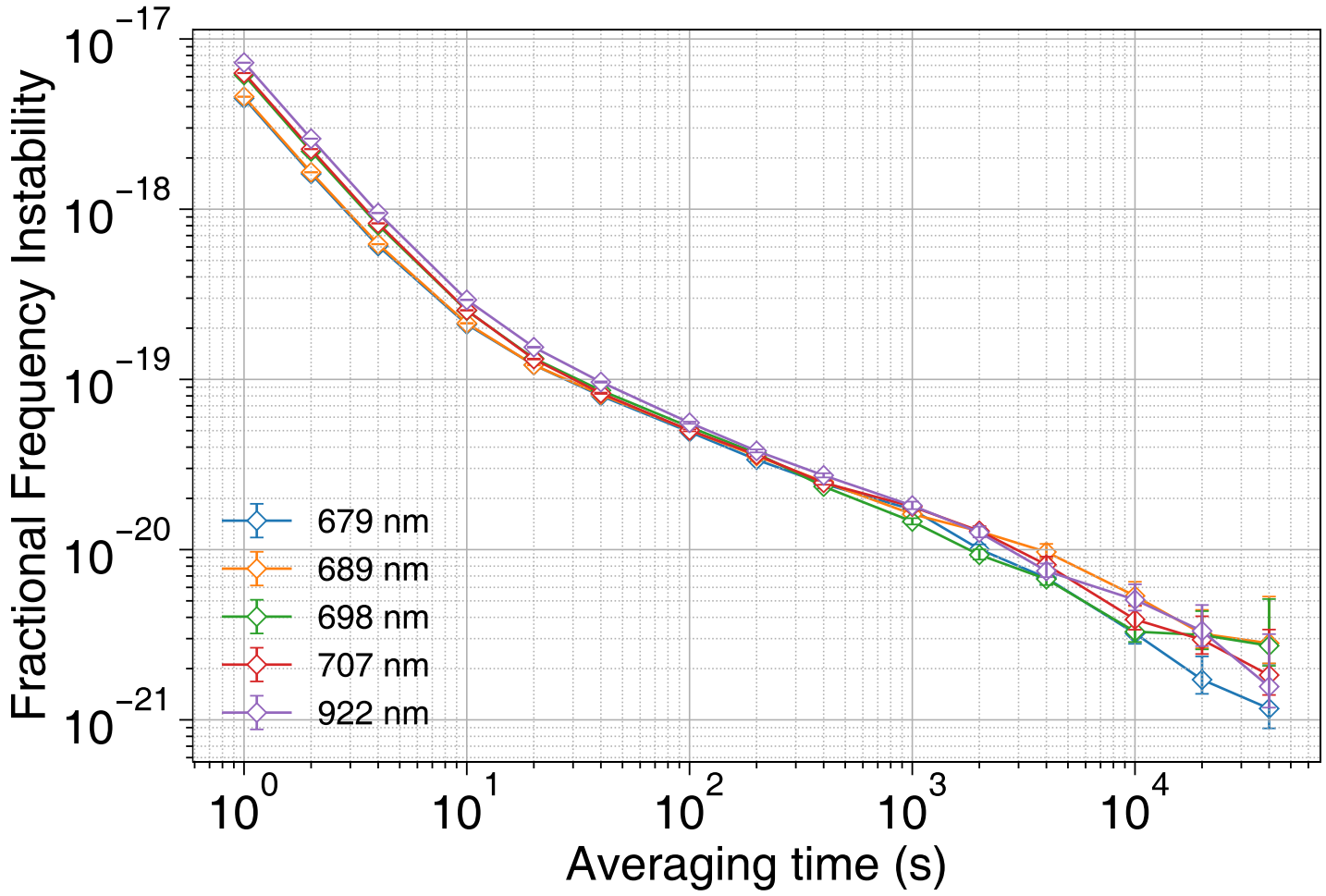




Residual comb instability approx. 1 order of magnitude lower than the most stable Sr lattice clock reported to date

Complete, Ultra-Stable Laser System for Sr Optical Lattice Clocks

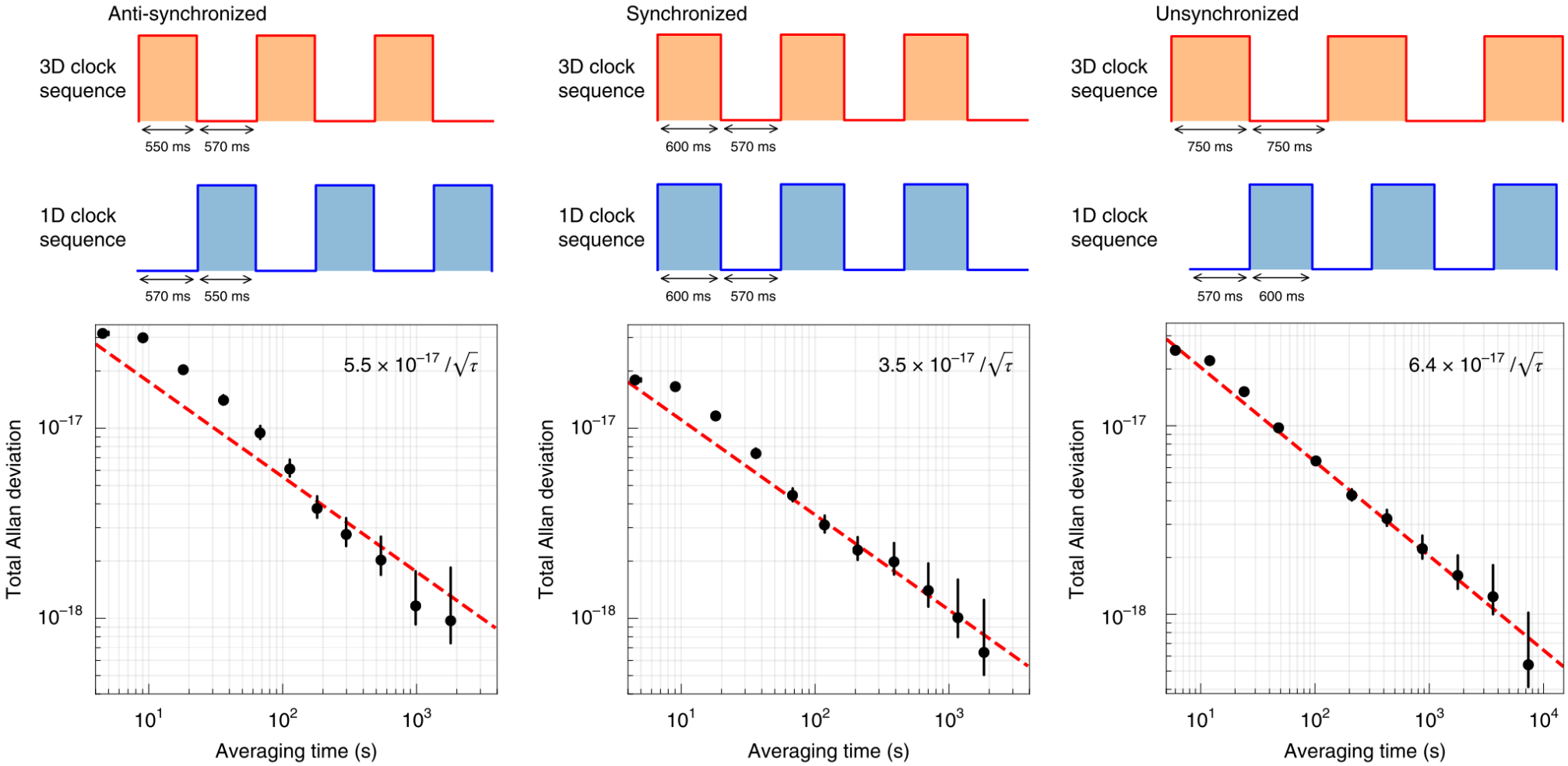
PHASE-LOCK STABILITY OF COMB-DISCIPLINED CW LASERS



2-day measurement. No cycle-slips, i.e., no loss of phase coherence.
Data taken with a Lambda counter, modified Allan deviation,
gate time 1 s, prefiltering 1 MHz band-pass.

Complete, Ultra-Stable Laser System for Sr Optical Lattice Clocks

SR CLOCK IN JUN YE'S LABS

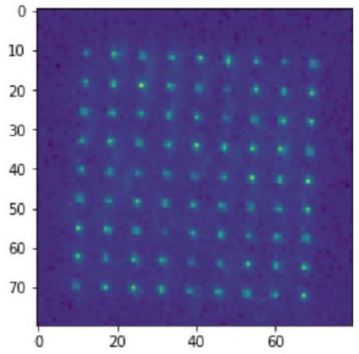


Oelker, E., Hutson, R.B., Kennedy, C.J. *et al.* "Demonstration of 4.8×10^{-17} stability at 1 s for two independent optical clocks." *Nat. Photonics* **13**, 714–719 (2019). https://doi.org/10.1038/s41566-019-0493-4

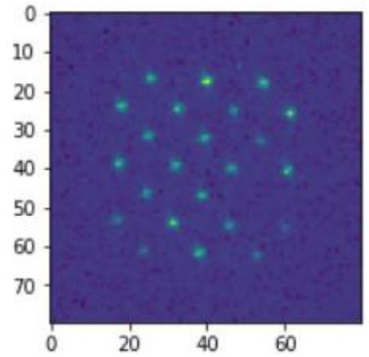
Quantum Laser System

EMERGING APPLICATIONS

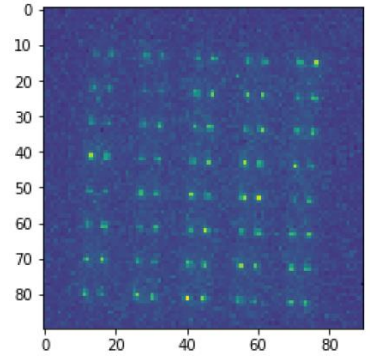
- Quantum computing: optical qubits with Rydberg states in tweezer-trapped neutral Sr atoms, e.g. Atom Computing



‘square grid’



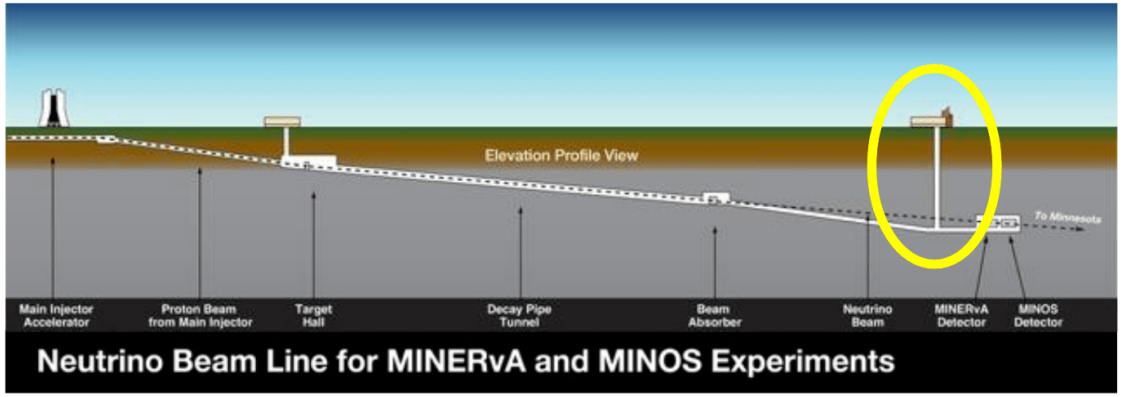
‘checkerboard’

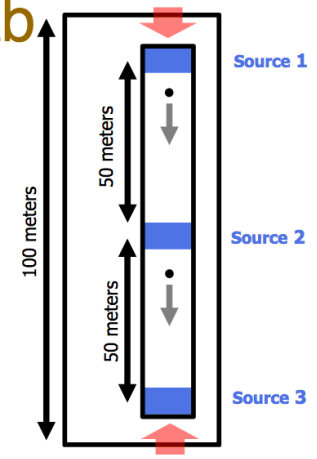


‘pairwise’

- Comb-disciplined lasers for atom interferometry, e.g. MAGIS-100 detector at Fermilab

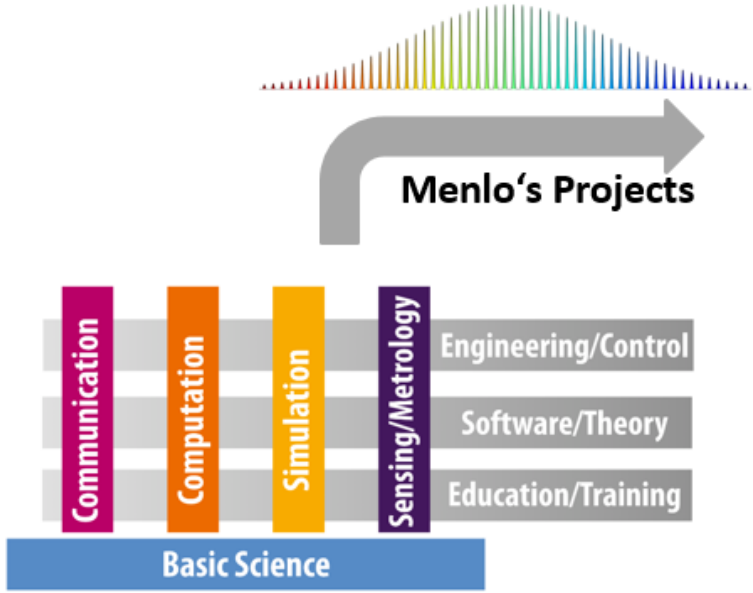
MAGIS-100 detector at Fermilab





Quantum Laser System

RUNNING PROJECTS



Europe's Quantum Flagship

quanten technologien

DARPA

Bundesministerium für Bildung und Forschung

QUANTUM FLAGSHIP

Quantum Communication

FaResQ fiber-based resonators for quantum technologies

Quantum Computation

CaLas compact, highly stable laser system for quantum information processing with calcium ions

Quantum Simulation

Qombs

Qombs quantum simulation and entanglement engineering in quantum cascade laser frequency combs

Quantum Sensing / Metrology

opticlock

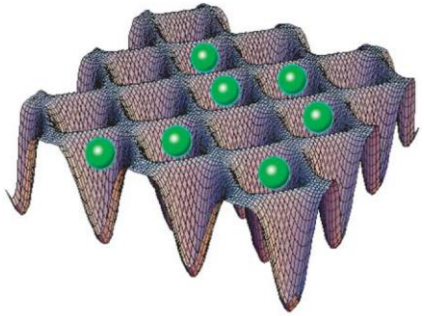
opticlock optical ion clock for users
PµreComb pure microwave radiation extraction from frequency combs
KECOMO Kerr comb microwave oscillator
QUASENS quantum sensor with strontium beams
SOLIS-1G strontium lattice clock in space

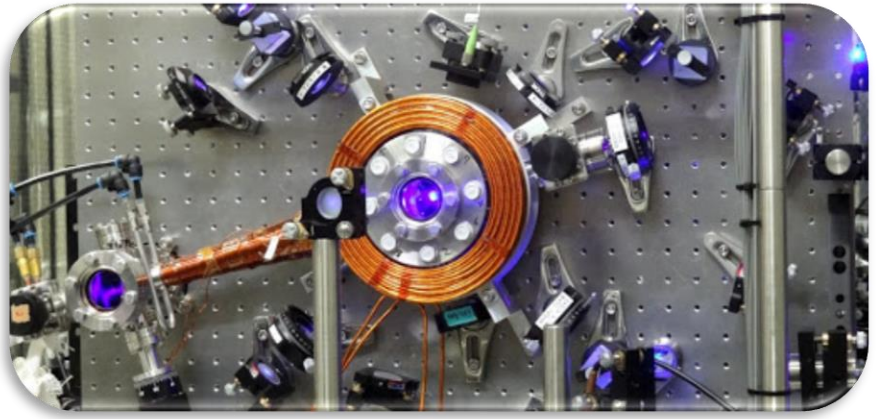
... and more to come!

Complete, Ultra-Stable Laser System for Sr Optical Lattice Clocks

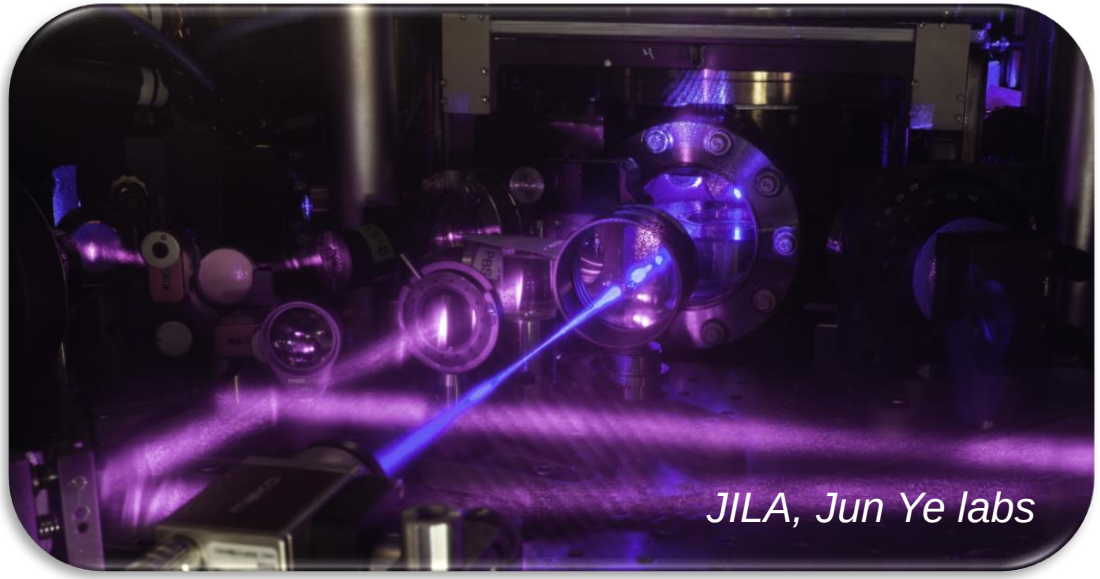
SUMMARY

- Full laser system referenced to ULN frequency comb
- Supports short-term stability down to 10^{-18}, 10^{-20} long-term
- Ready for integration into physics package
  - → Sr optical lattice clock
  - → Additional applications in quantum computing, quantum sensing, quantum communications…





RIKEN, Katori Labs



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Thank you for your attention!

Dr. Gabrielle Thomas

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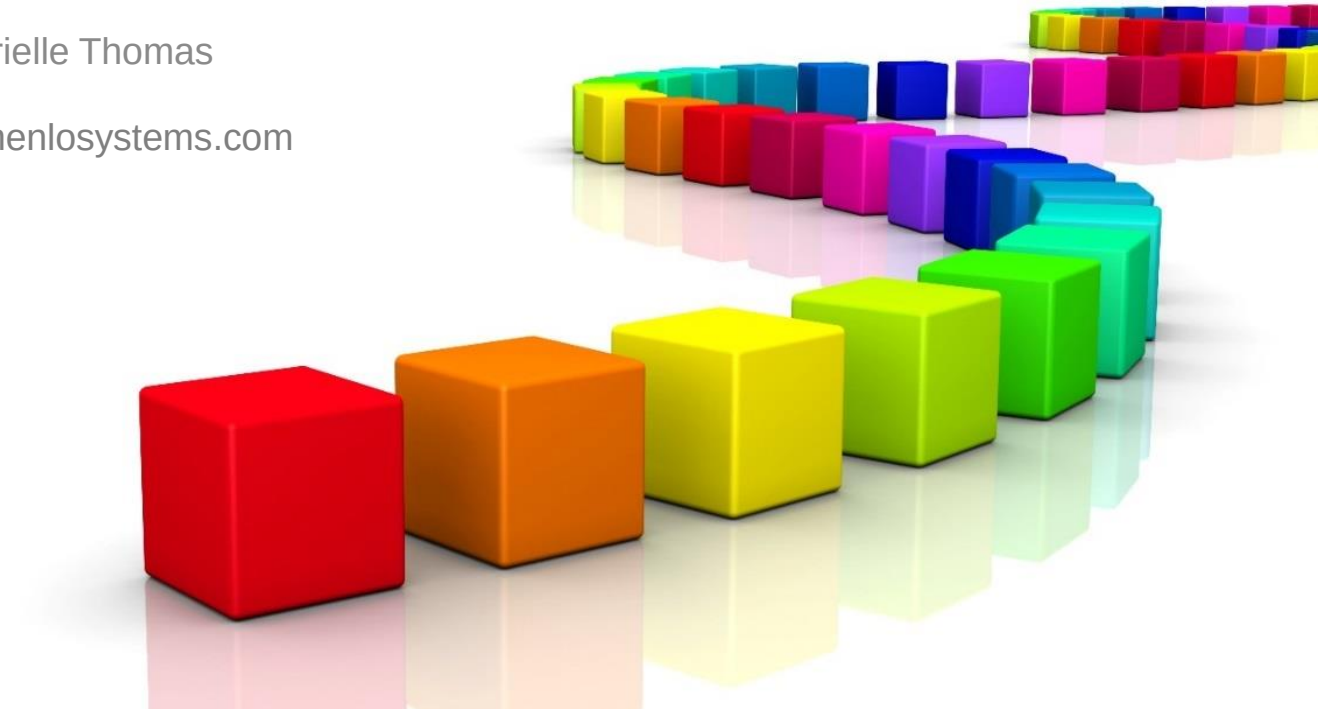

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