Laser frequency control at sub-Hz level

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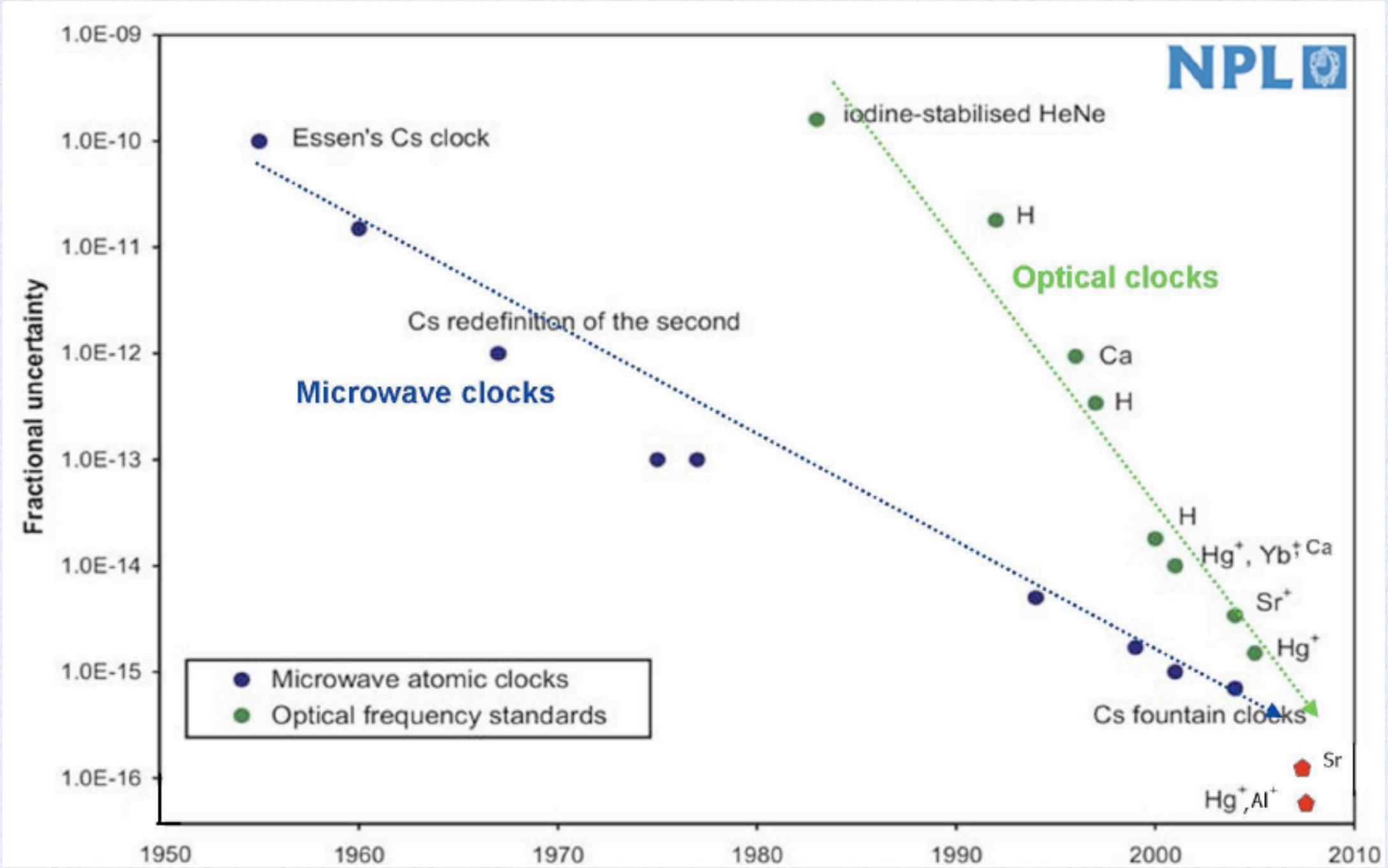
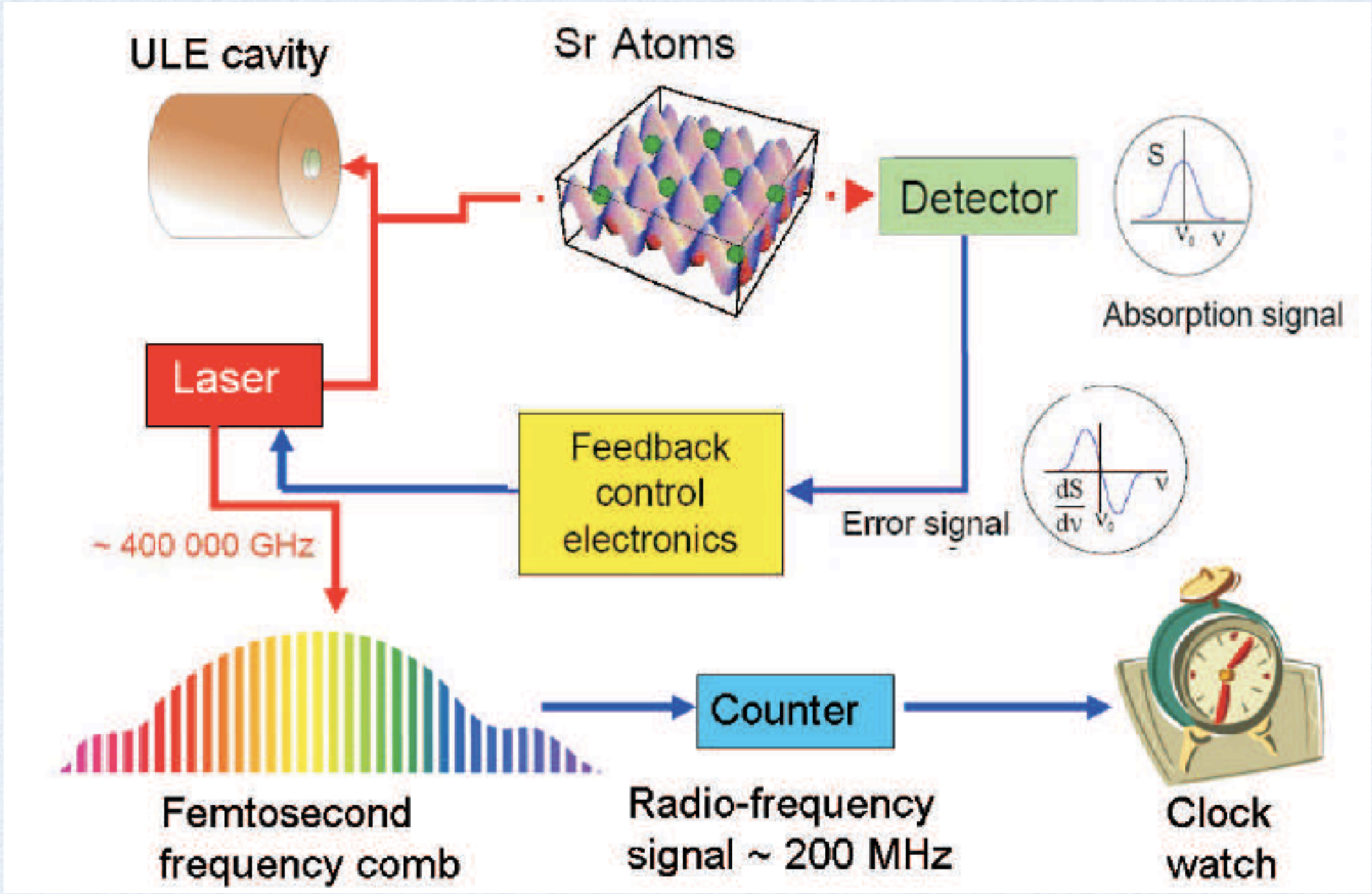
Outline

- Introduction to optical atomic clocks
- Lock to a high-finesse cavity
- Optical atomic frequency references
- Optical frequency combs
- Optical frequency links

Optical atomic clocks

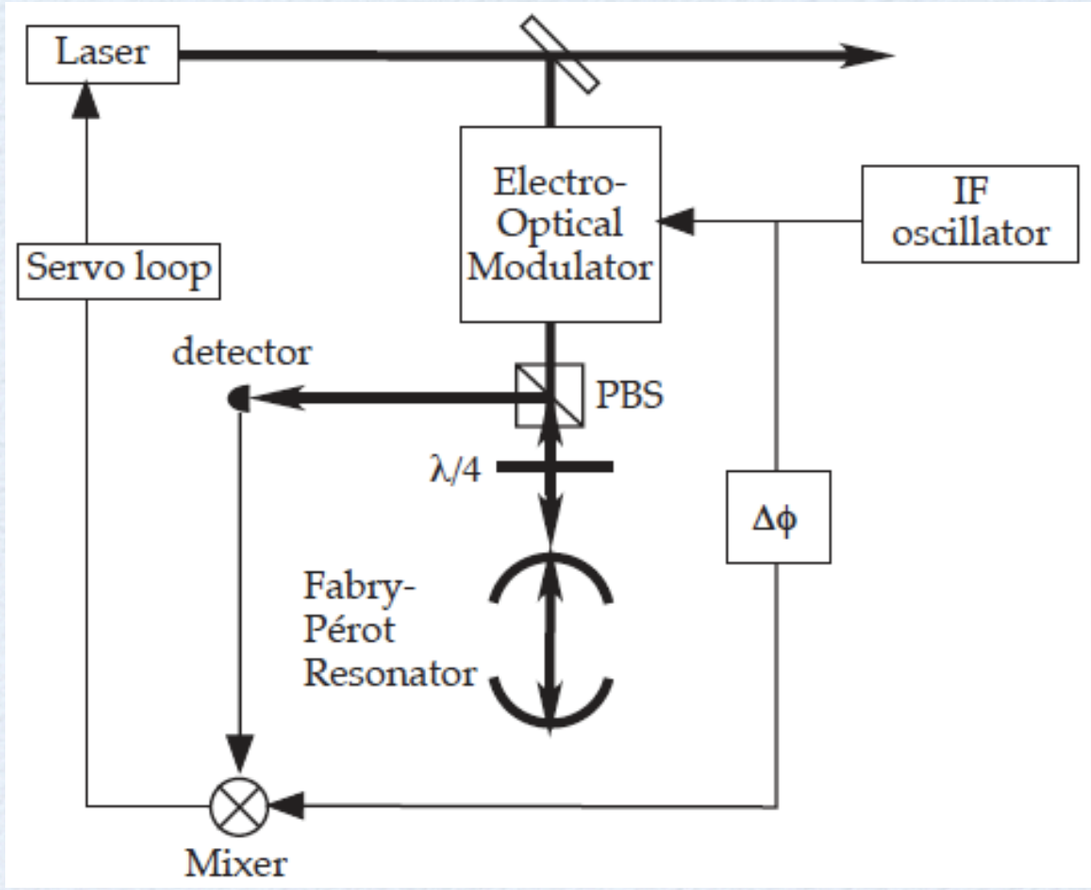


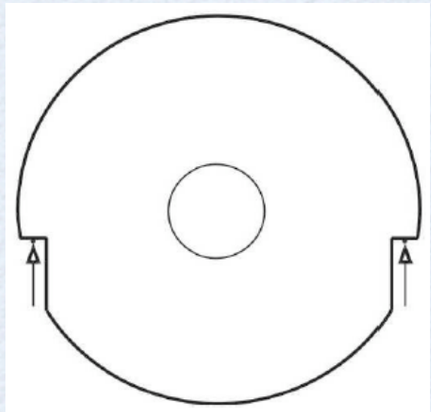
Optical atomic clocks

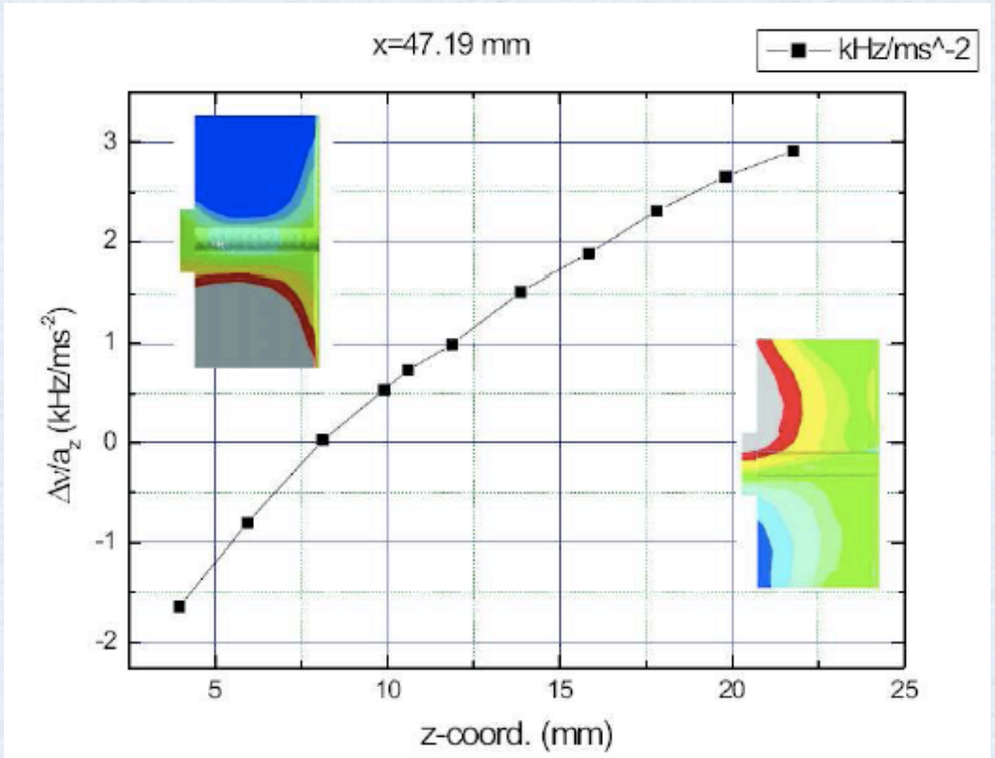


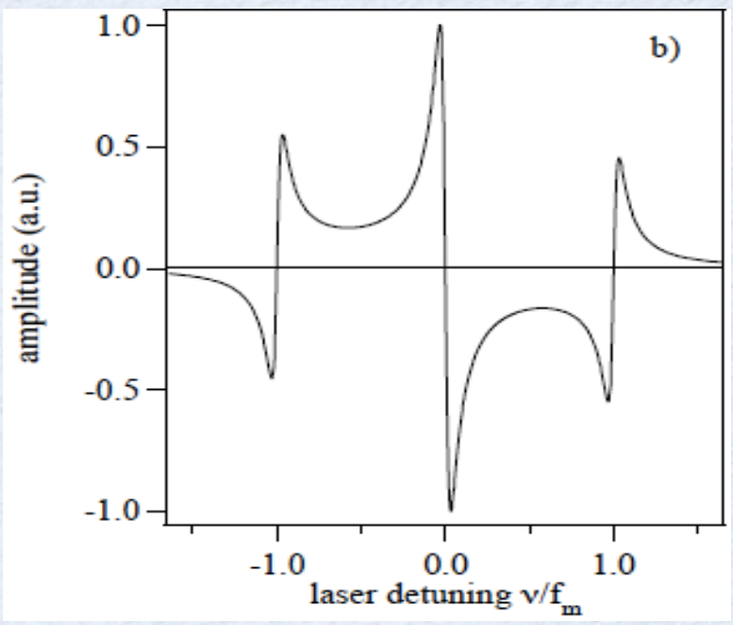
Lock to an high-finesse FP cavity

- PDH technique
- FP cavity with F=0.5 M
- ULE spacer
- Symmetrically suspended
- Temperature stabilized

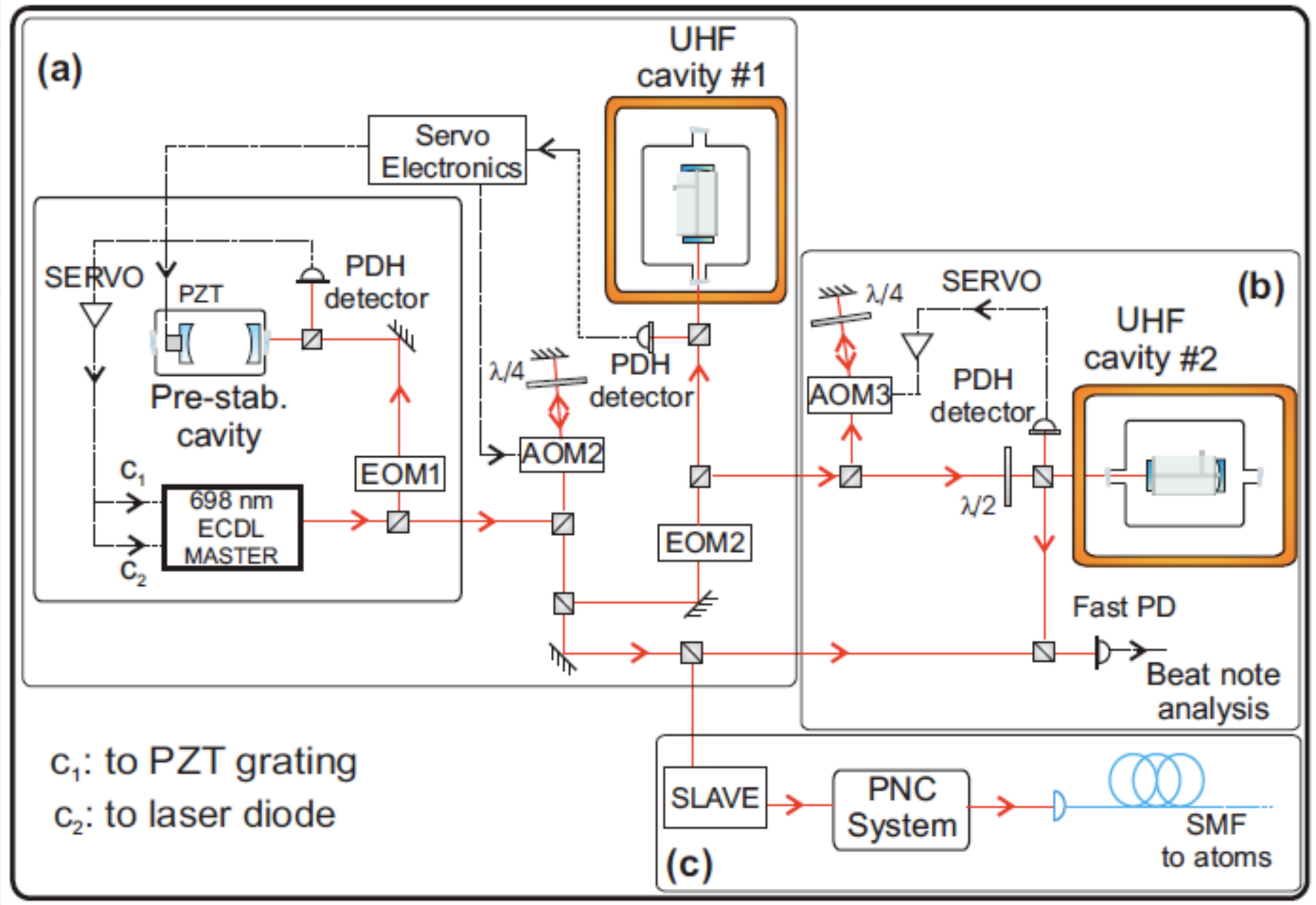




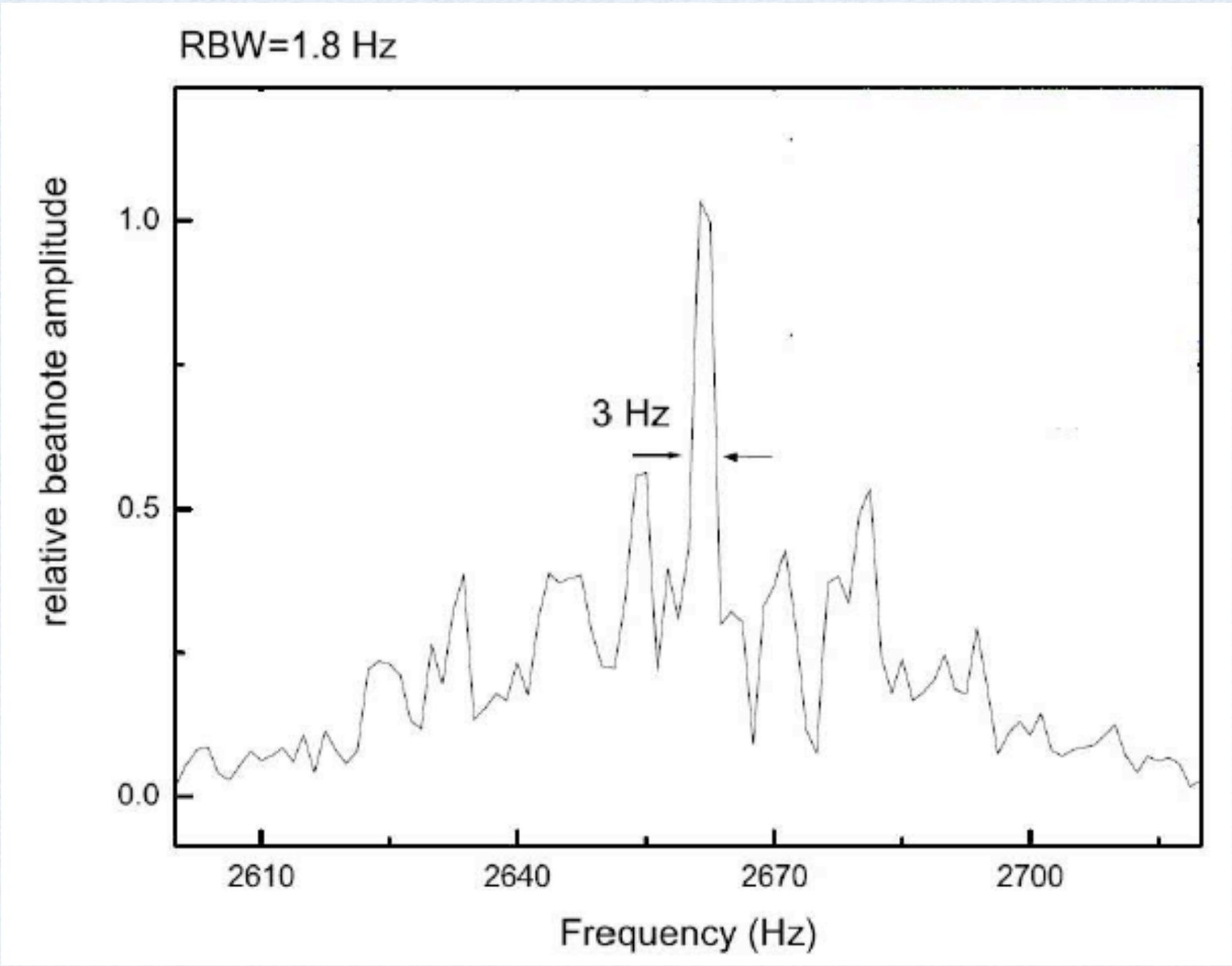




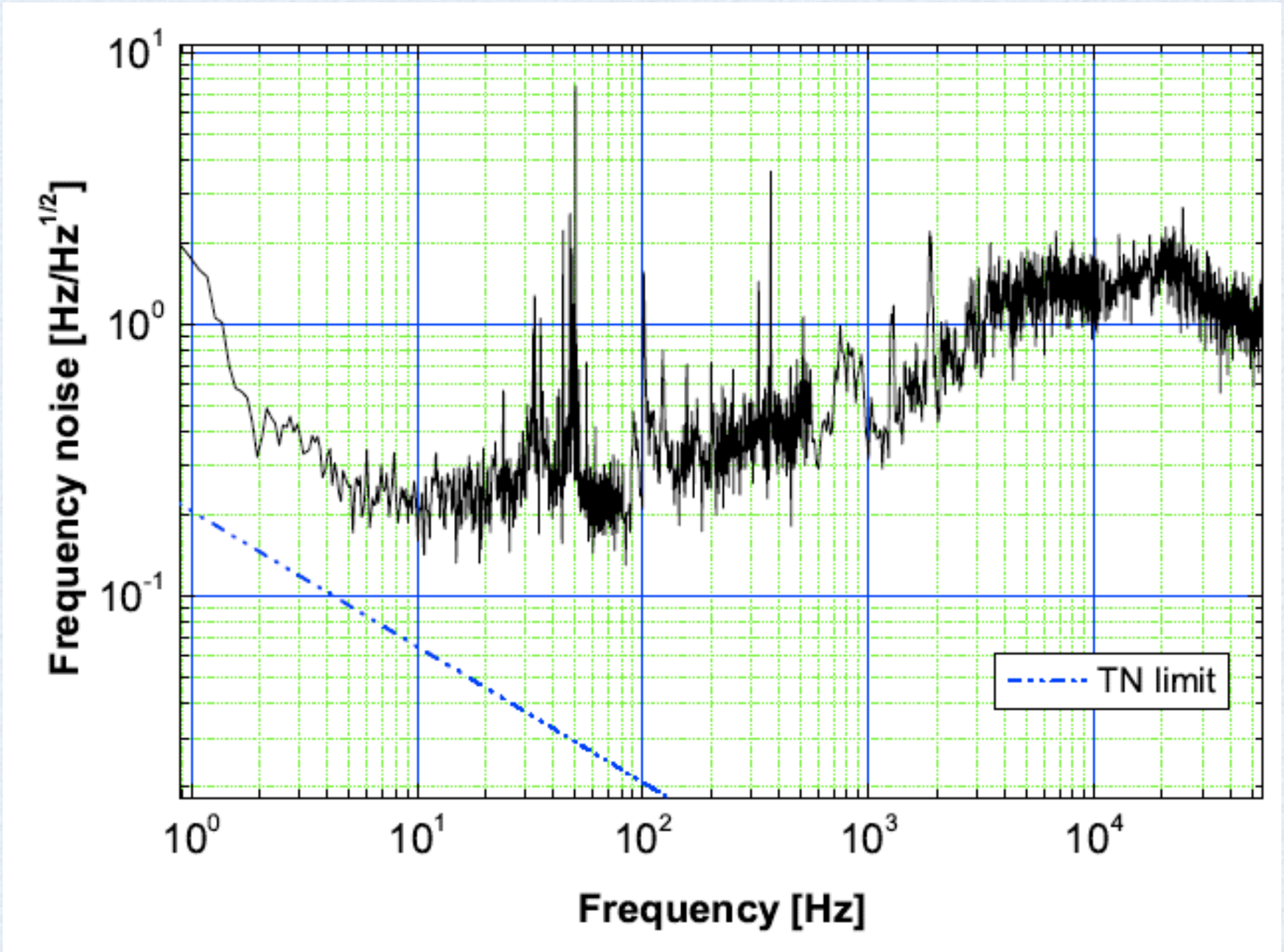
Test with two identical ultrastable lasers



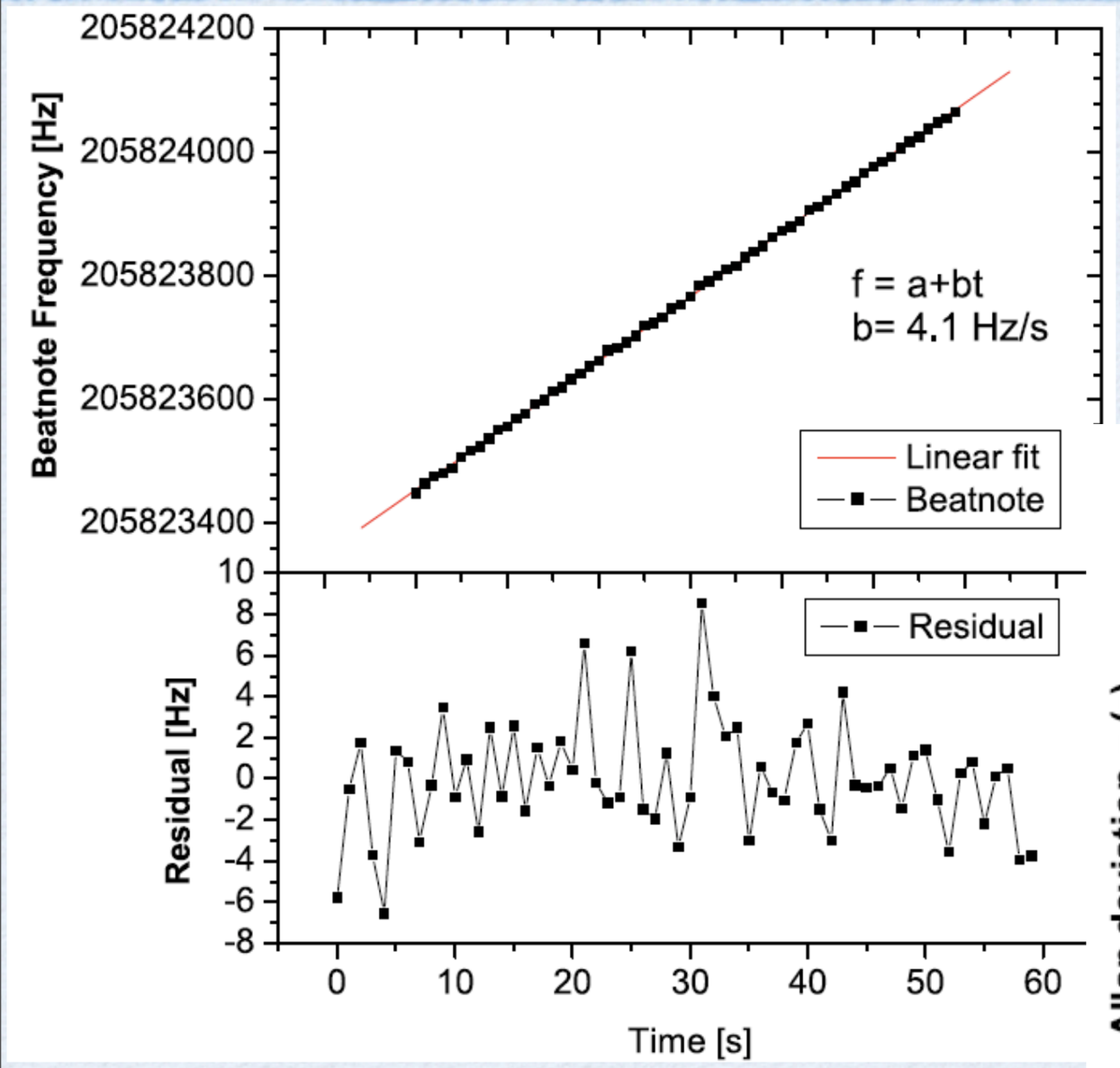
Beat note of two identical lasers

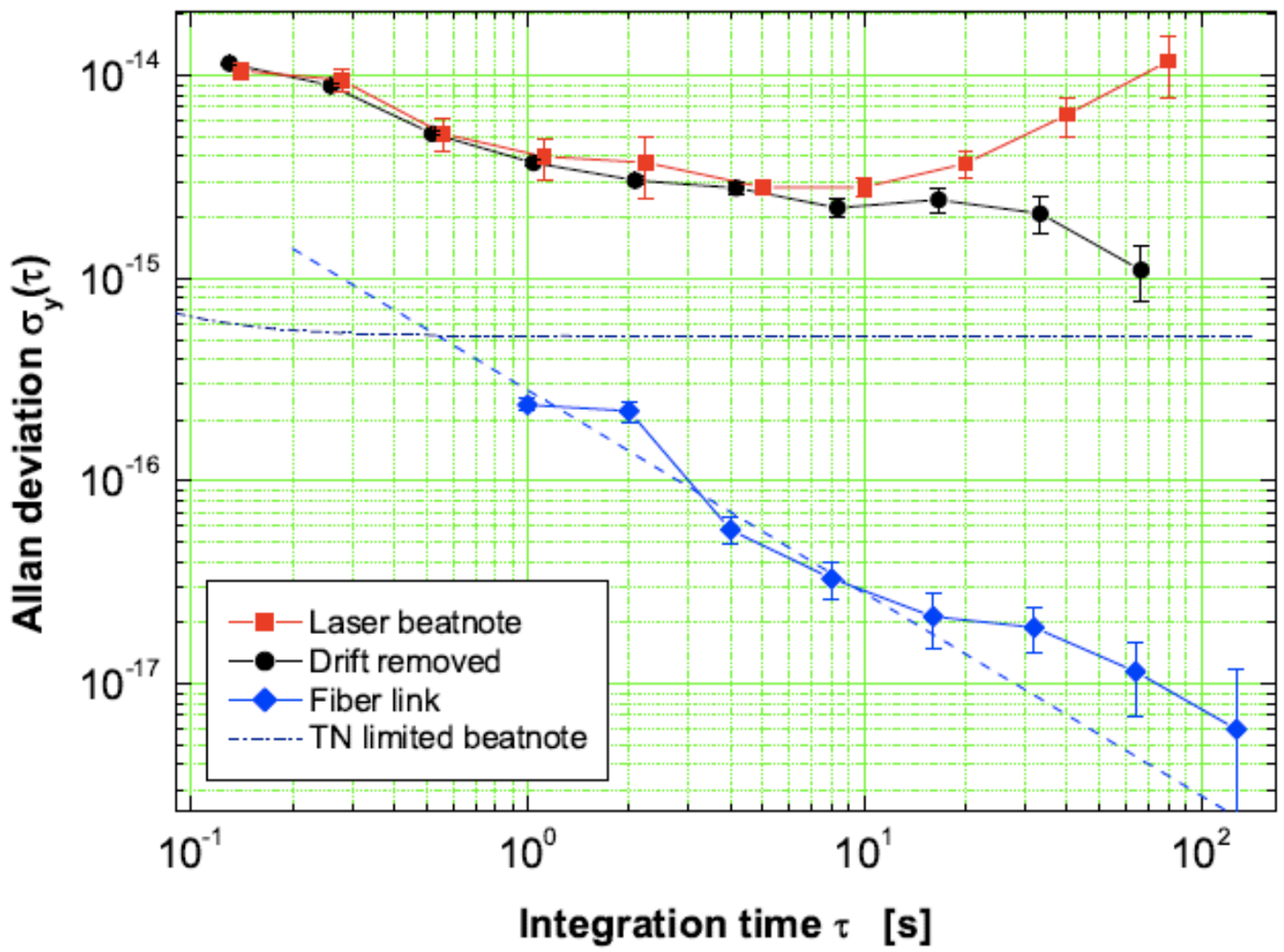


Frequency noise spectrum



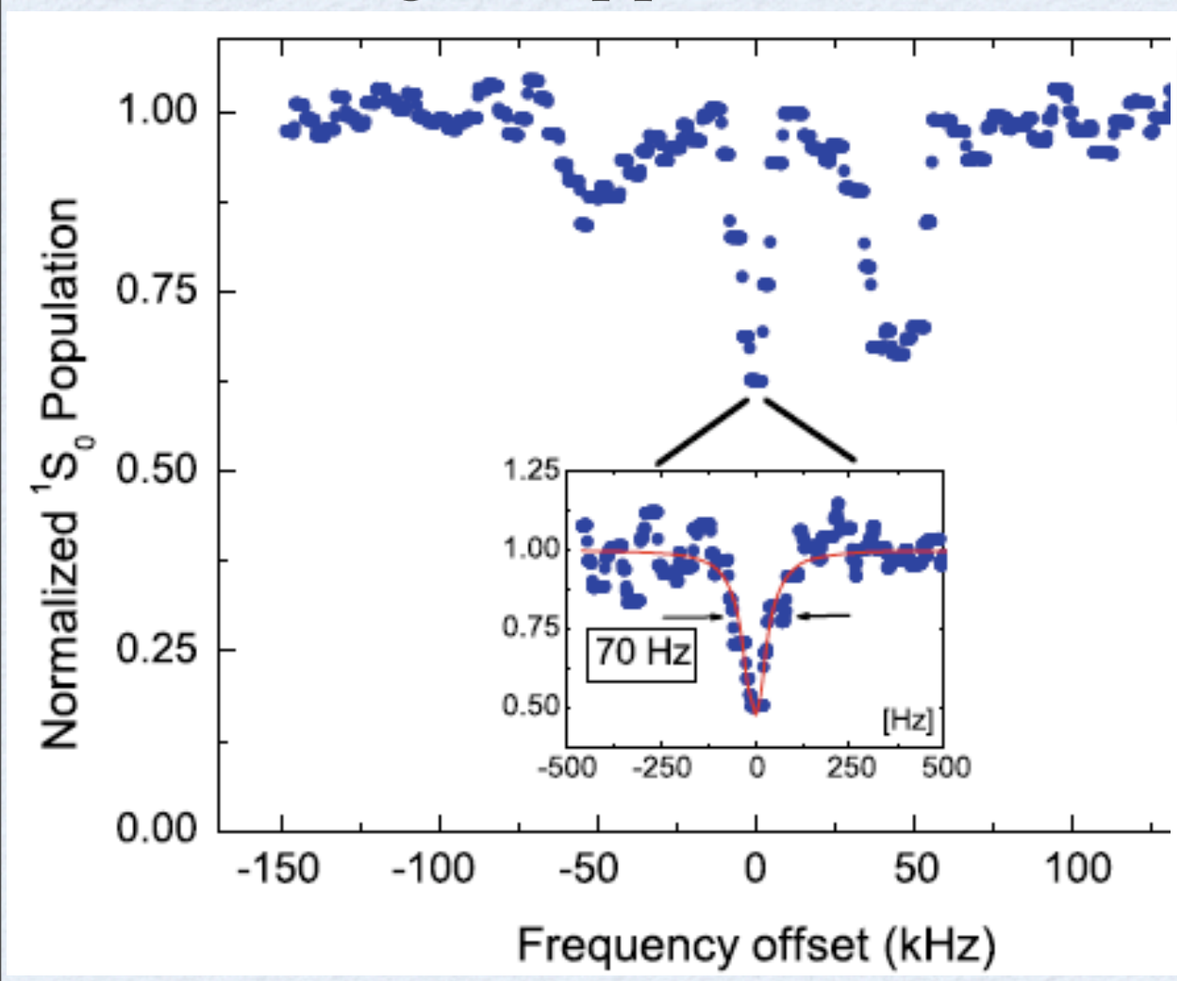
Allan variance and drift

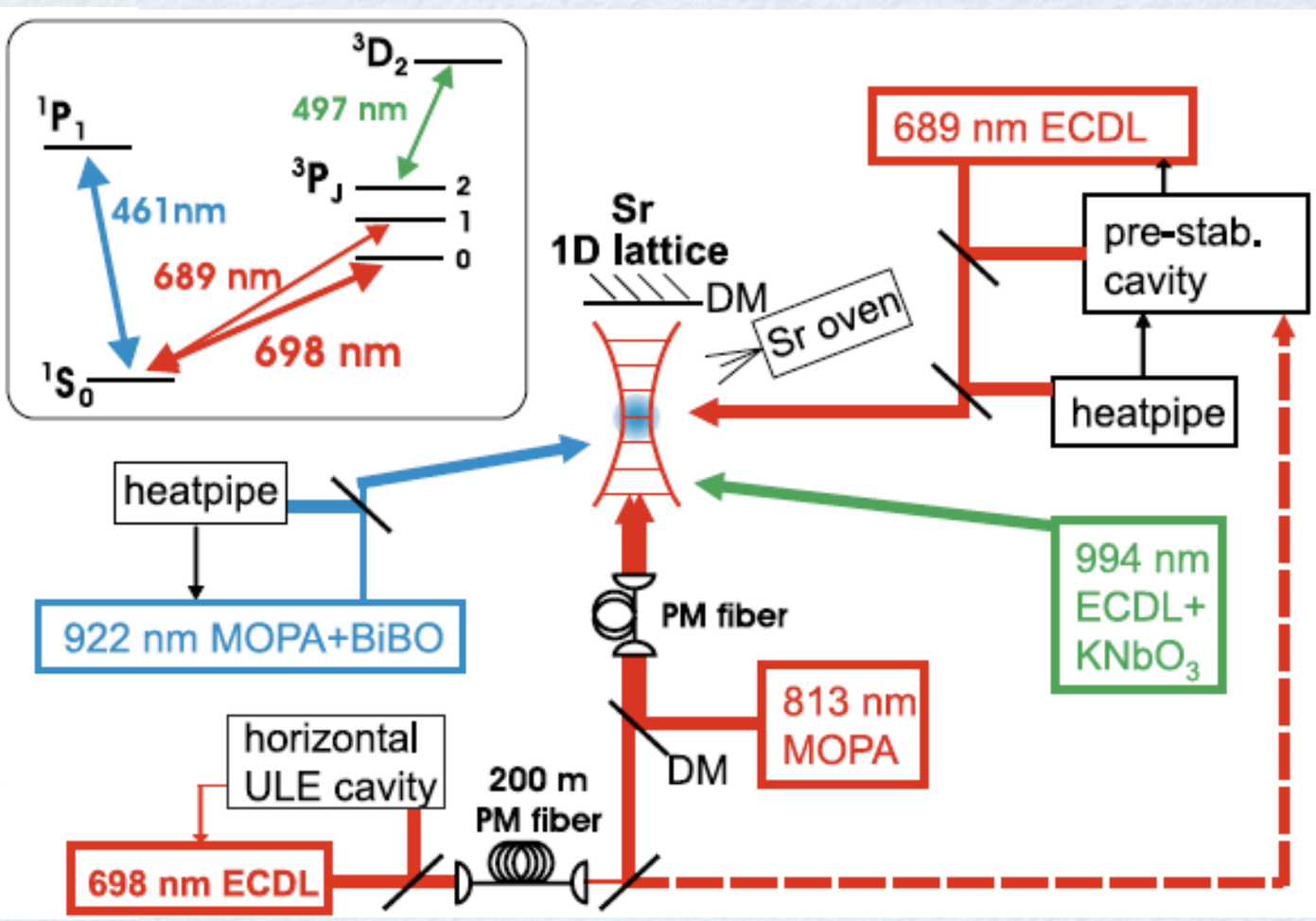




Optical atomic frequency references

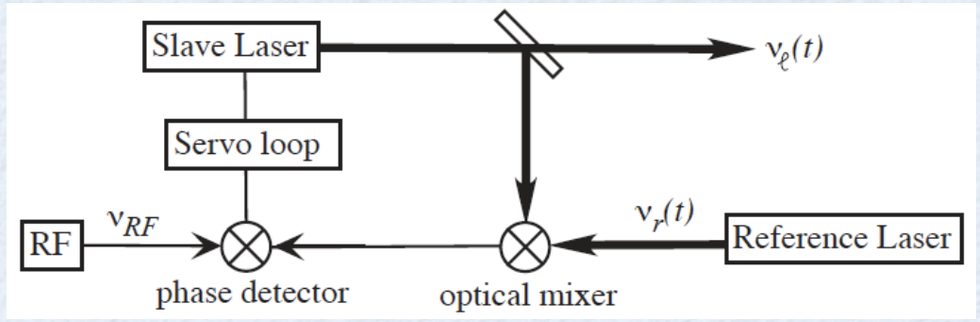
- Strongly forbidden optical transitions
- Laser cooling
- Lamb-Dicke confinement to suppress Doppler & recoil
  - neutral atoms in optical lattice
  - single trapped ion

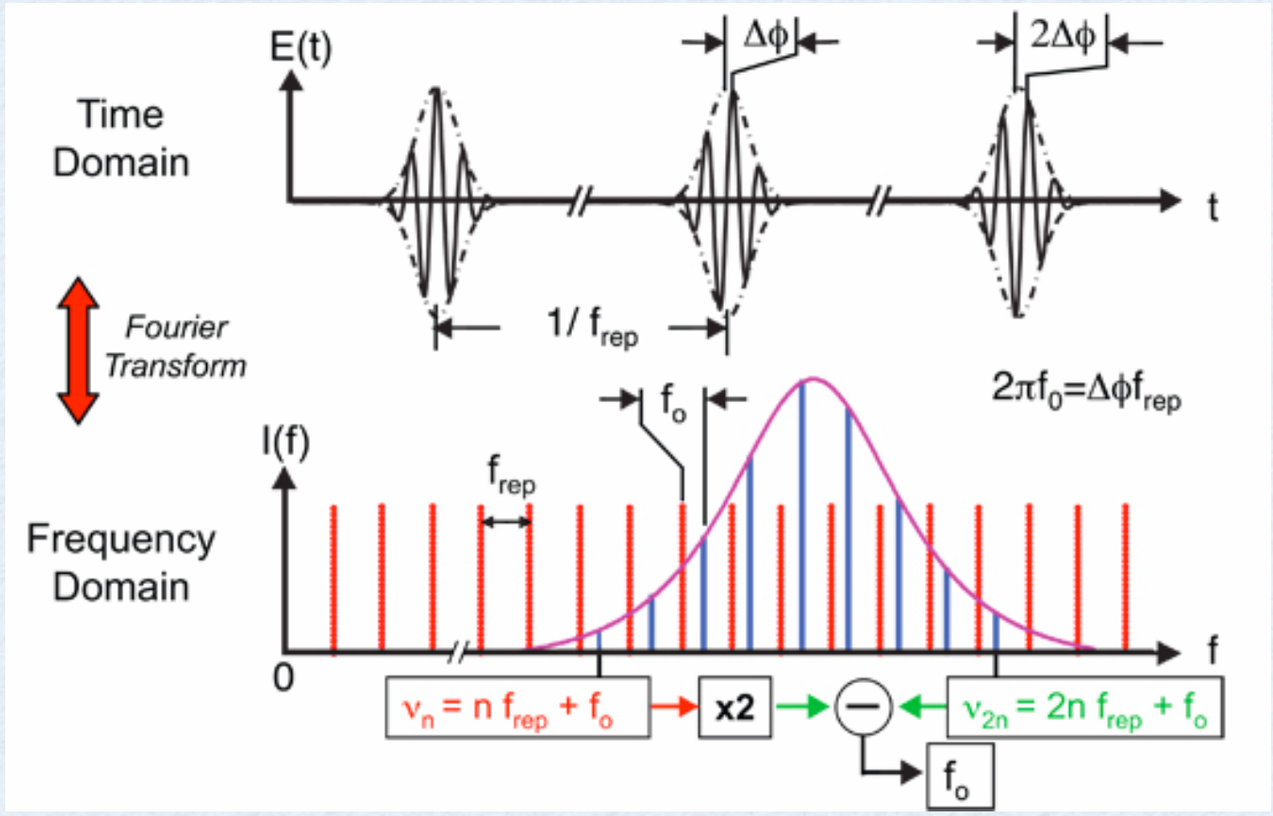


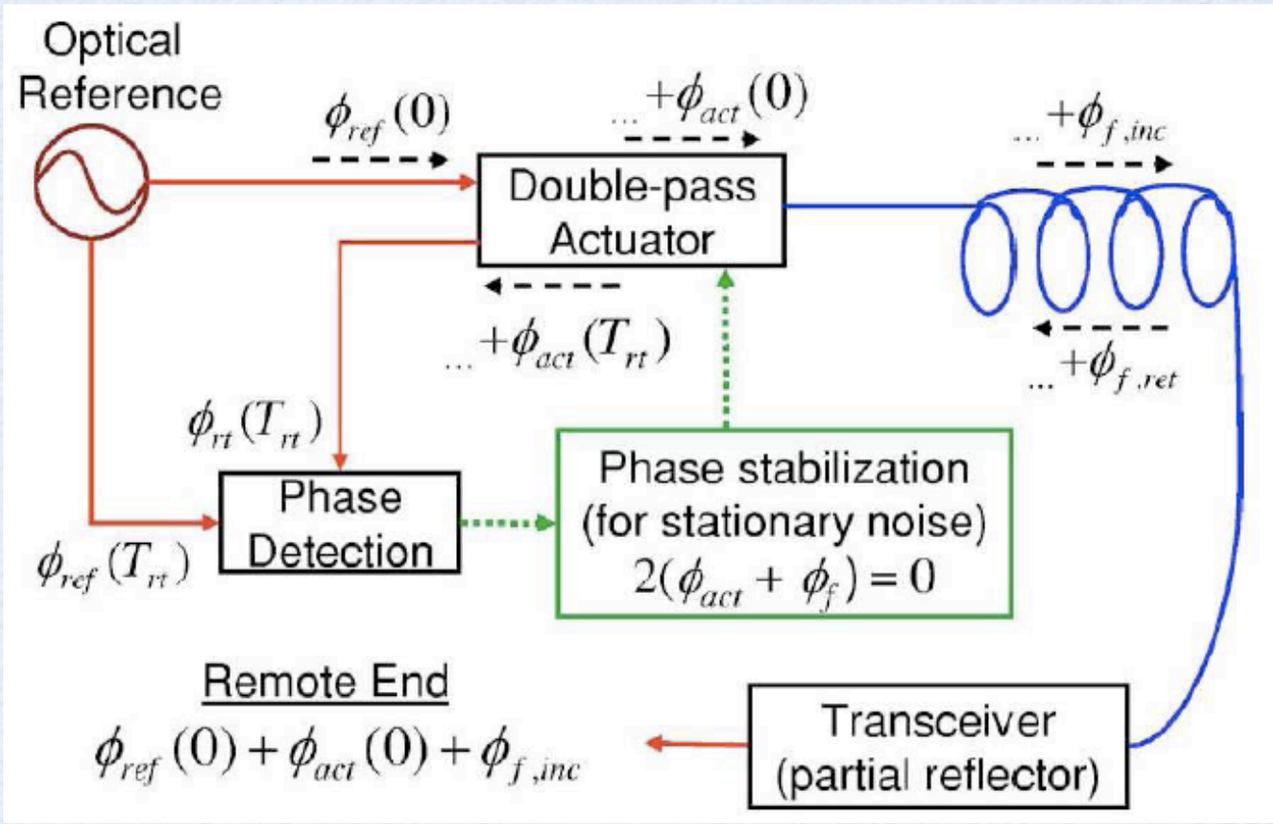


Optical frequency transfer

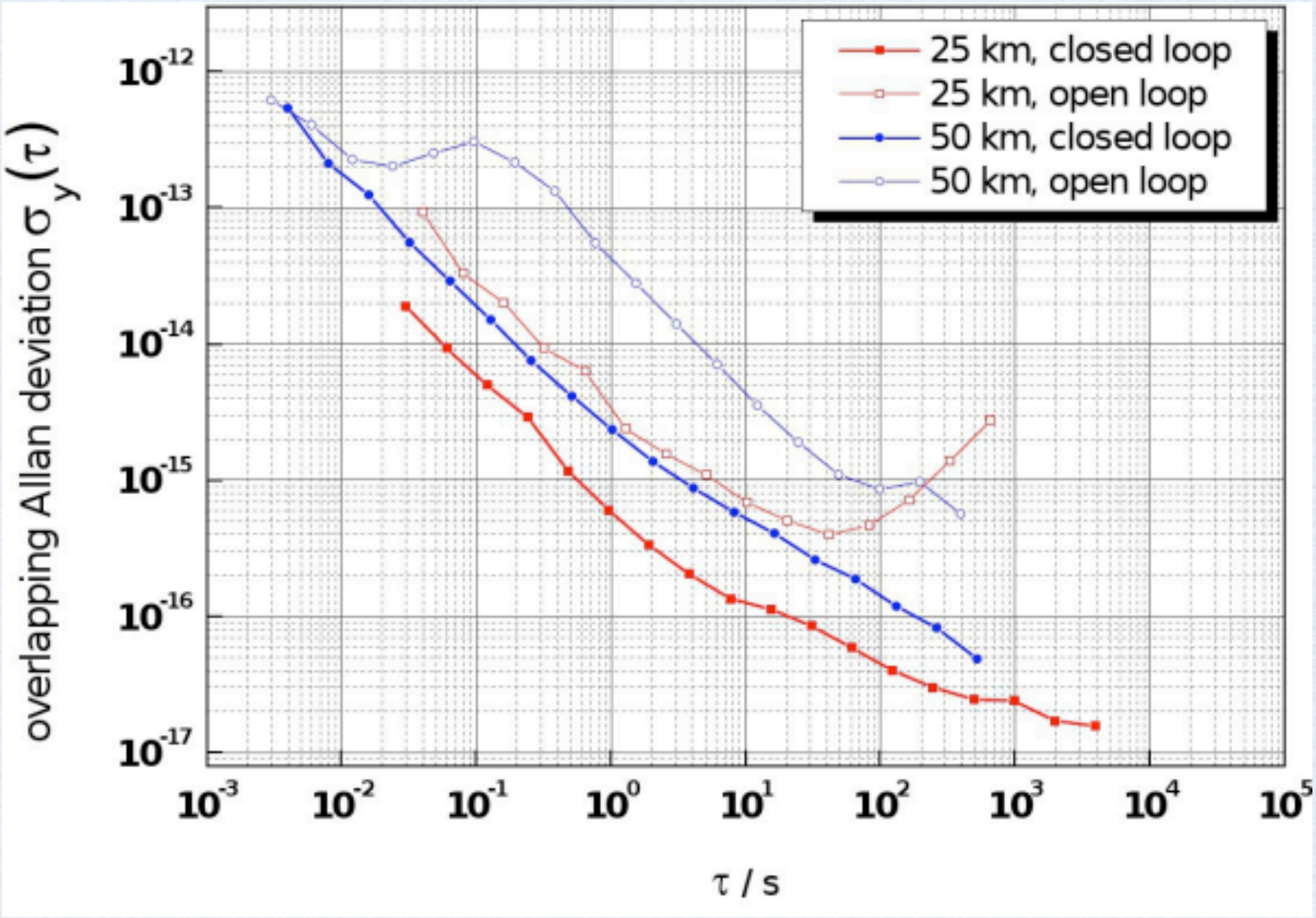
- Frequency reference can be provided by an ultrastable laser via PLL
- If reference laser has distant wavelength, use an OFC
- If reference laser is distant in space, use a two-way optical link







Optical link frequency transfer



430 km optical fiber link

Fiber link from LENS – UNIFI (Firenze) to INRIM (Torino) - 430 km

Torino:
2 Cs fountains
(one cryogenic),
3 Hydrogen masers,
1 Yb lattice clock
(under development)

Firenze:
2 Sr lattice clocks
(one transportable)

430 km link : two EDFAs, two 1.5 μm laser

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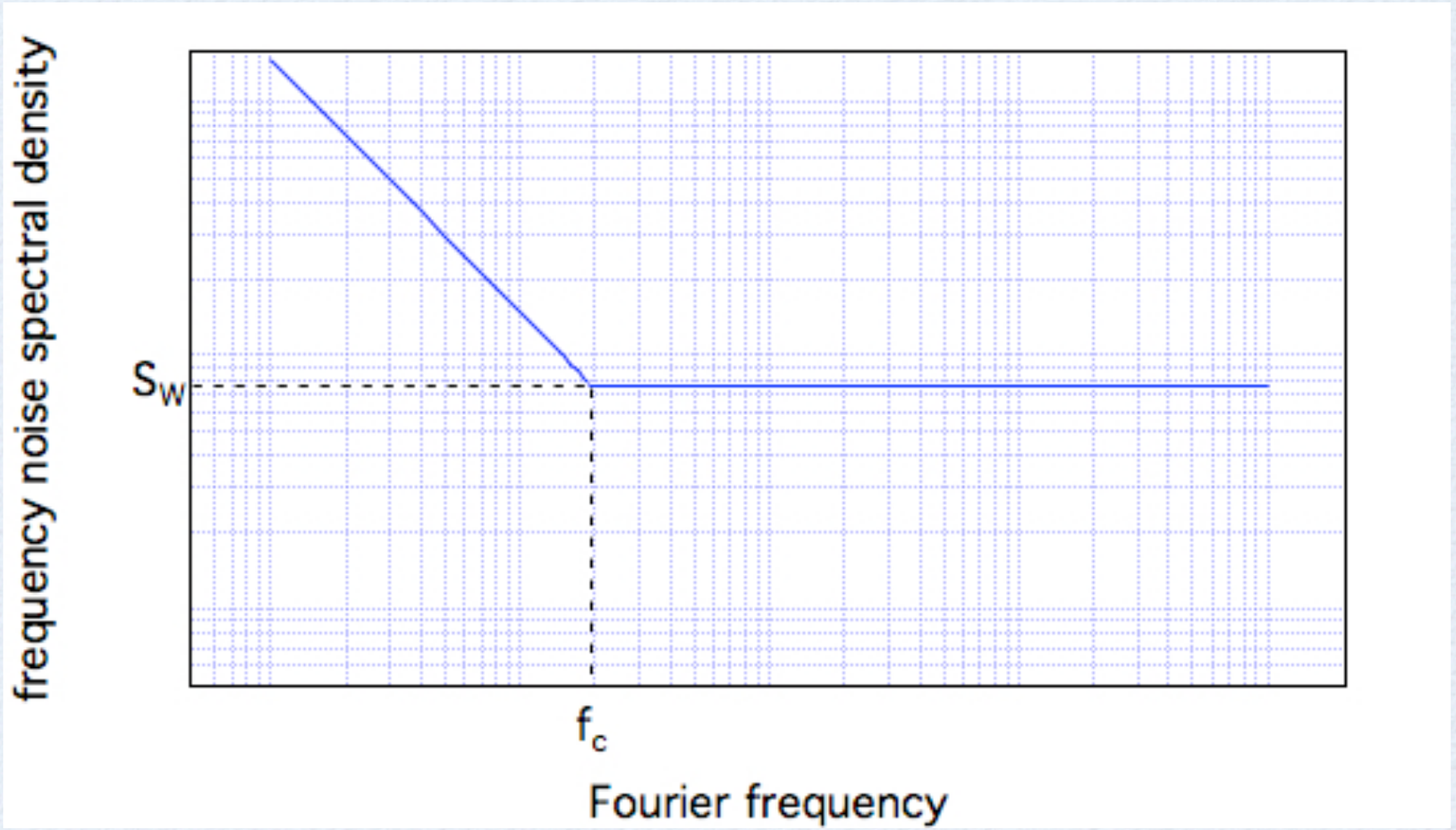
Control bandwidth requirements



- If $f_c \ll S_W$, white noise dominates and the laser line has Lorentzian shape with linewidth $\Delta\nu = S_W$
- If $S_W \ll f_c$, flicker noise dominates and the laser line has Gaussian shape with linewidth $\Delta\nu \sim \sqrt{f_c S_W}$
- For line narrowing, the control bandwidth must be larger than S_W and f_c

Conclusions

- Sub-Hz linewitdth can be achieved with tight electronic control of laser frequency, provided
  - a stable frequency reference with sufficient SNR
  - sufficient control bandwidth

- Current systems are approaching thermal noise of reference FP cavity (i.e. below $10^{-15}/\sqrt{\text{Hz}}$)
- Optical atomic clocks based on ultracold atoms in optical lattices or trapped ions can reach frequency instabilities in the 10^{-17} range
- Accurate frequencies can be distributed via two-ways optical links + fs optical frequency combs

Our team

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Nicola Poli	Researcher, Università di Firenze
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Denis Sutyrin	PhD student, Università di Pisa
Luigi Cacciapuoti	Long term guest, ESA-Noordwijk
Marella de Angelis	Long term guest, CNR
Marco Prevedelli	Long term guest, Università di Bologna

Previous members and visitors

Andrea Alberti, PhD student
Andrea Bertoldi, Post-doc
Sergei Chepurov, Institute of Laser Physics, Novosibirsk, visitor
Robert Drullinger, NIST, Long term guest
Marco Fattori, PhD student
Gabriele Ferrari, Researcher, INFM/CNR
Vladyslav Ivanov, Post-doc
Marion Jacquey, Post-doc
Giacomo Lamporesi, PhD student
Chris Oates, NIST, visitor
Torsten Petelski, PhD student
Juergen Stuhler, Post-doc

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- ✓ Ente Cassa di Risparmio di Firenze (CRF)
- ✓ European Space Agency (ESA)
- ✓ Agenzia Spaziale Italiana (ASI)
- ✓ Istituto Nazionale per la Fisica della Materia (INFM)
- ✓ Istituto Nazionale Geofisica e Vulcanologia (INGV)

http://coldatoms.lens.unifi.it/