A Low-Noise 1542nm Laser Stabilized to an Optical Cavity

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Background

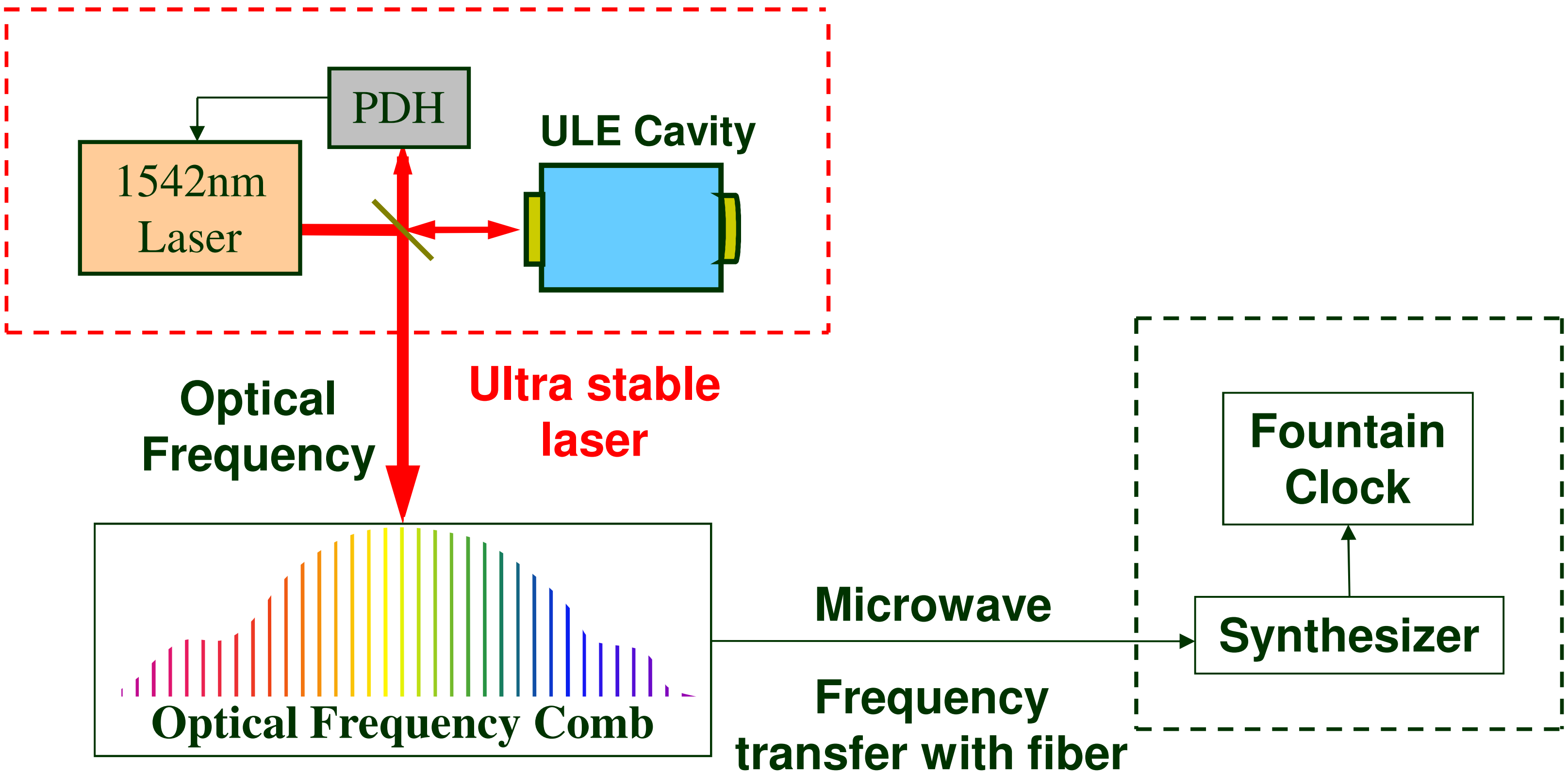
- Narrow linewidth laser are crucial in the research of the optical clocks, precision spectroscopy, measurement of fundamental physics constants and tests of fundamental physics
- Such lasers have potential to work as oscillator of fountain clock due to their high frequency stability in short term

Background

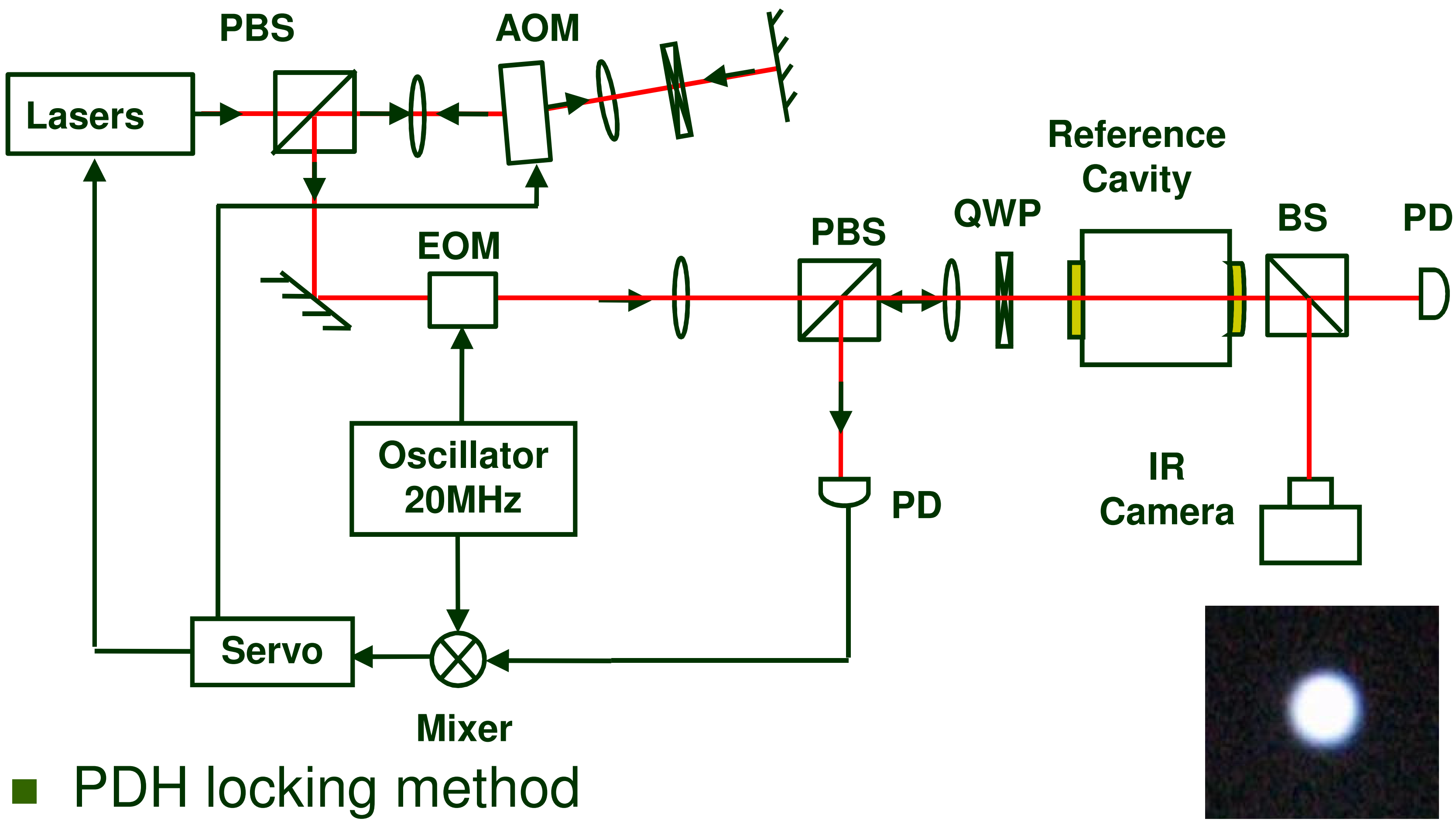
- Research work in our group in NIM is mainly focus on the Cs fountain clock.
- The short-term frequency stability of our fountain clock is merely 1E-13@1s,which is limited by the local oscillator (crystal)
- We need a new frequency source with frequency stability in the order of 1E-15@1s to replace the crystal oscillator
  - CSO (cryogenic sapphire oscillator)
  - Microwave source:
    Ultra stable laser
    optical frequency comb

Background

Ultra stable cavity → Ultra stable laser → Optical frequency comb → Ultra stable microwave source



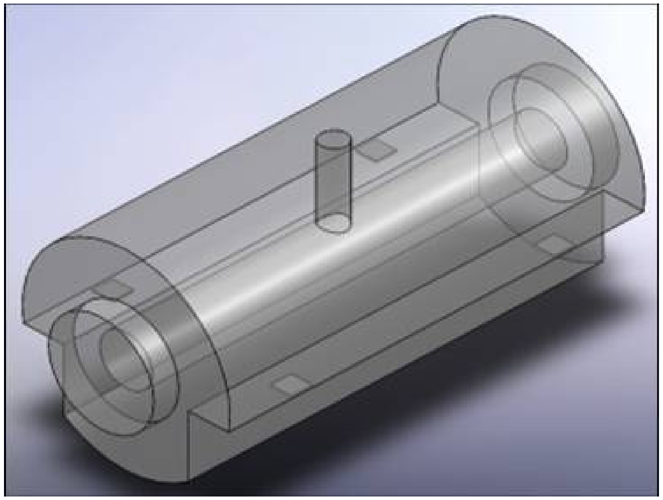
Principle

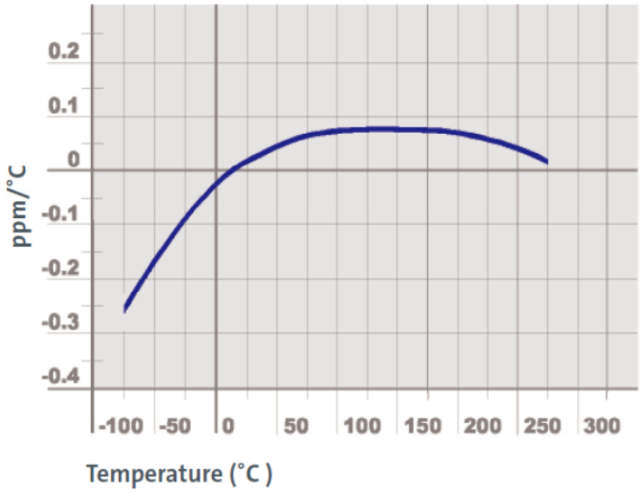


- PDH locking method
- Laser source: ECL laser, 1542.14nm, linewidth ~5kHz
- Incident power to the FP Cavity: 24 μW

Reference Cavity

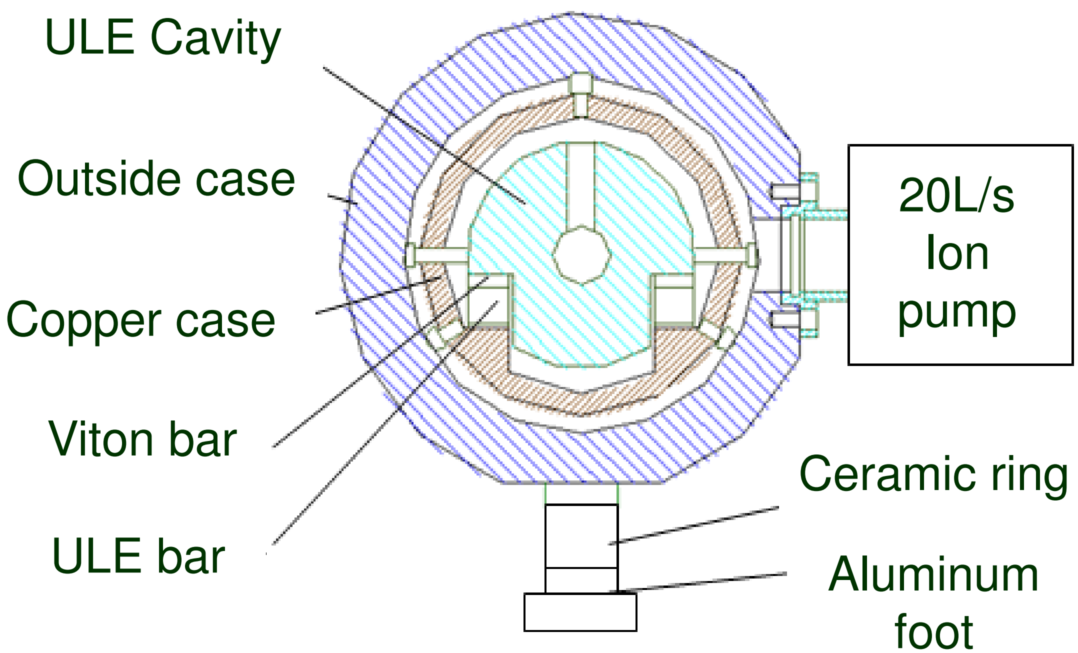
- Reference cavity: Notched cylindrical cavity
  L=10cm, D=5cm
- Mirrors: flat - concave cavity, concave mirror: R=50cm
  F=246,000
- Supporting points: optimized using finite element analysis software. Cavity length change under the gravity: ΔL = 3.43E-11 m
- Material: ULE glass, both cavity and mirror substrate, zero crossing temperature (ZCT) expected 25-33° C

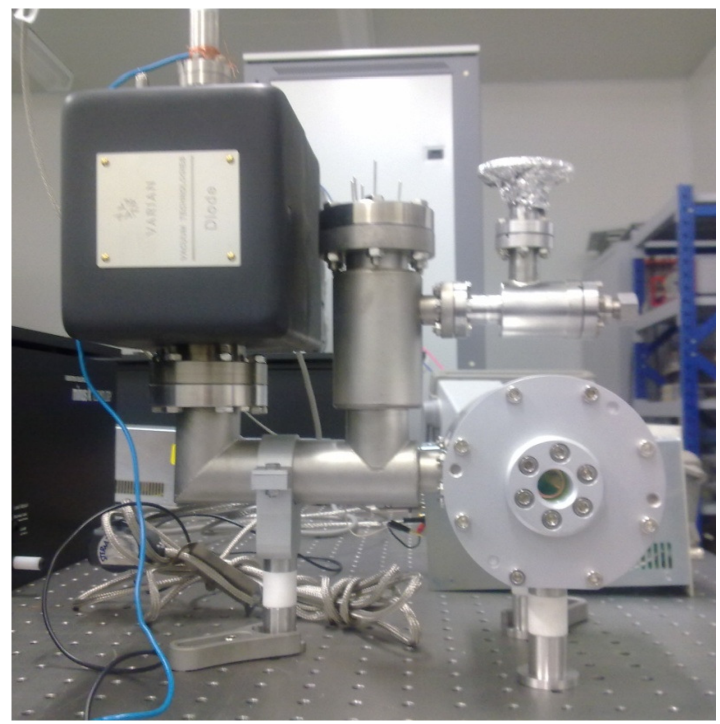




Vacuum Chamber

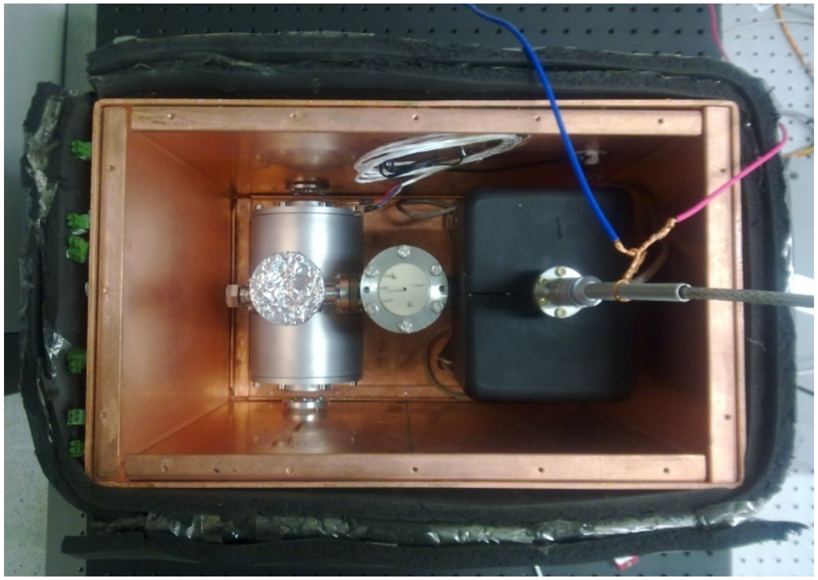
- 20 L/s Ion pump
- Pressure < 1×10^{-6}Pa





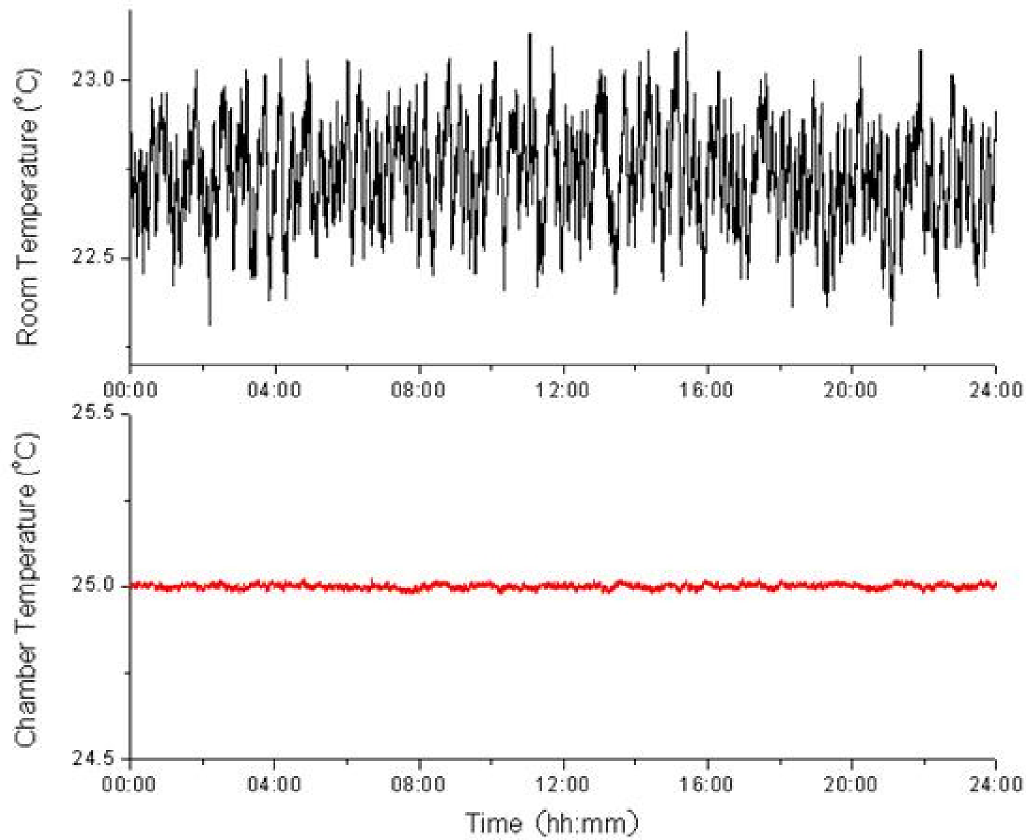
Temperature Control System

- The whole vacuum system are shielded by a copper case.
- The copper case is wound by copper coil for heating, keep the temperature stable and uniform distributed
- Temperature controlled @ ~25° C

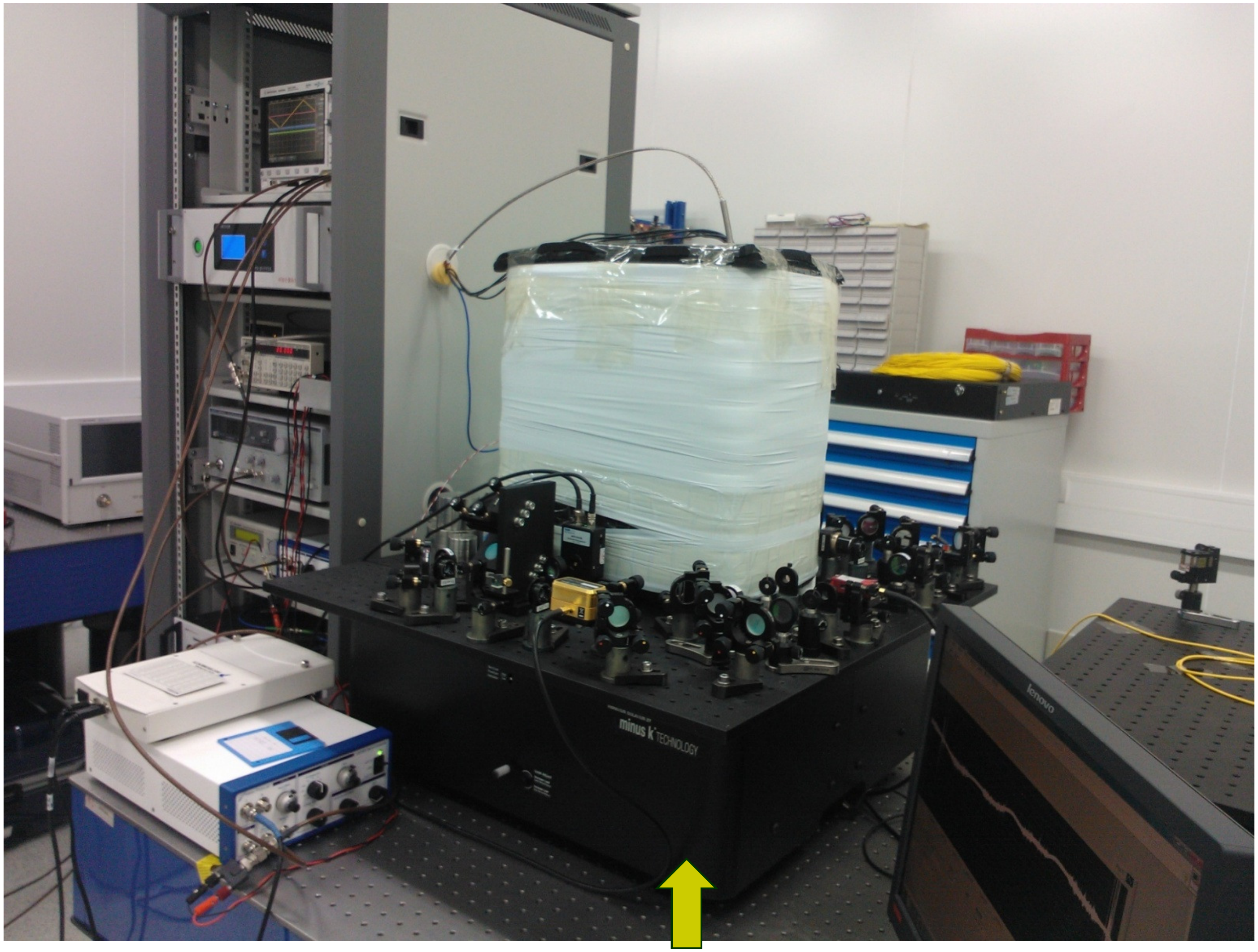


Temperature Control System

- In 24 hours:
  - room temperature fluctuation <1° C
  - temperature fluctuation outside the vacuum: <20mK



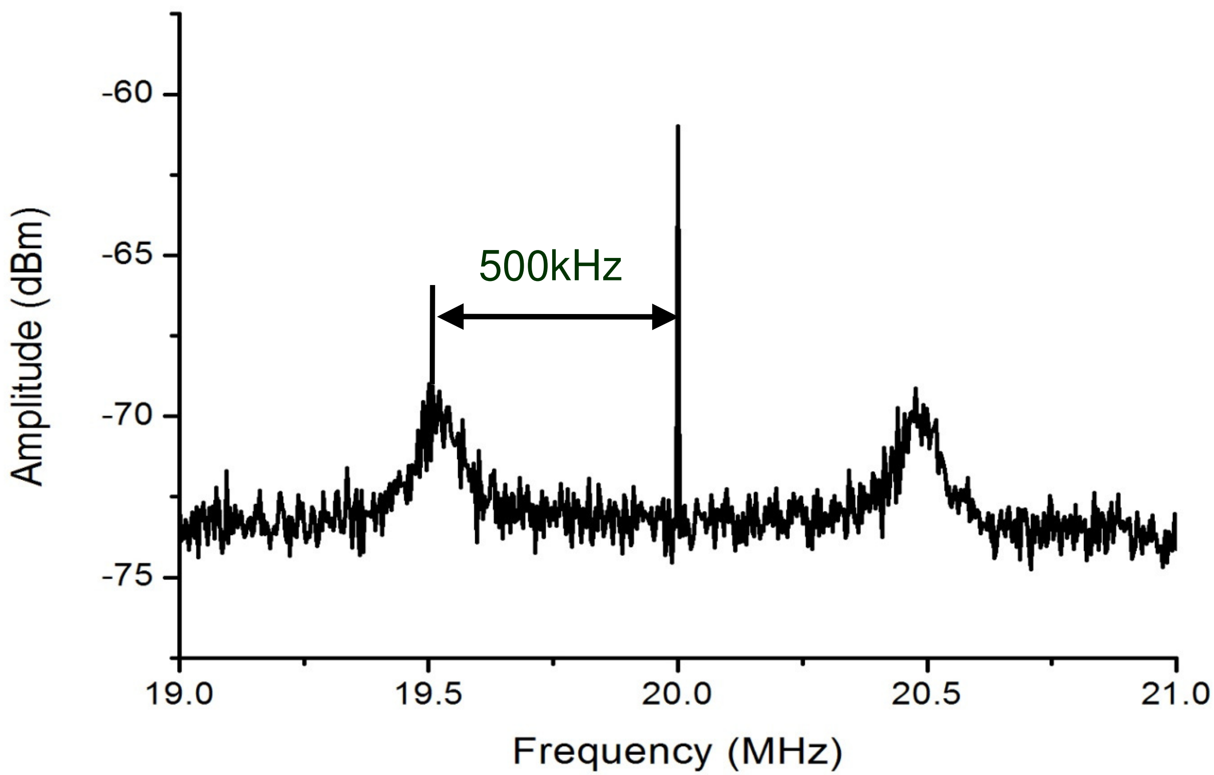
Laser System



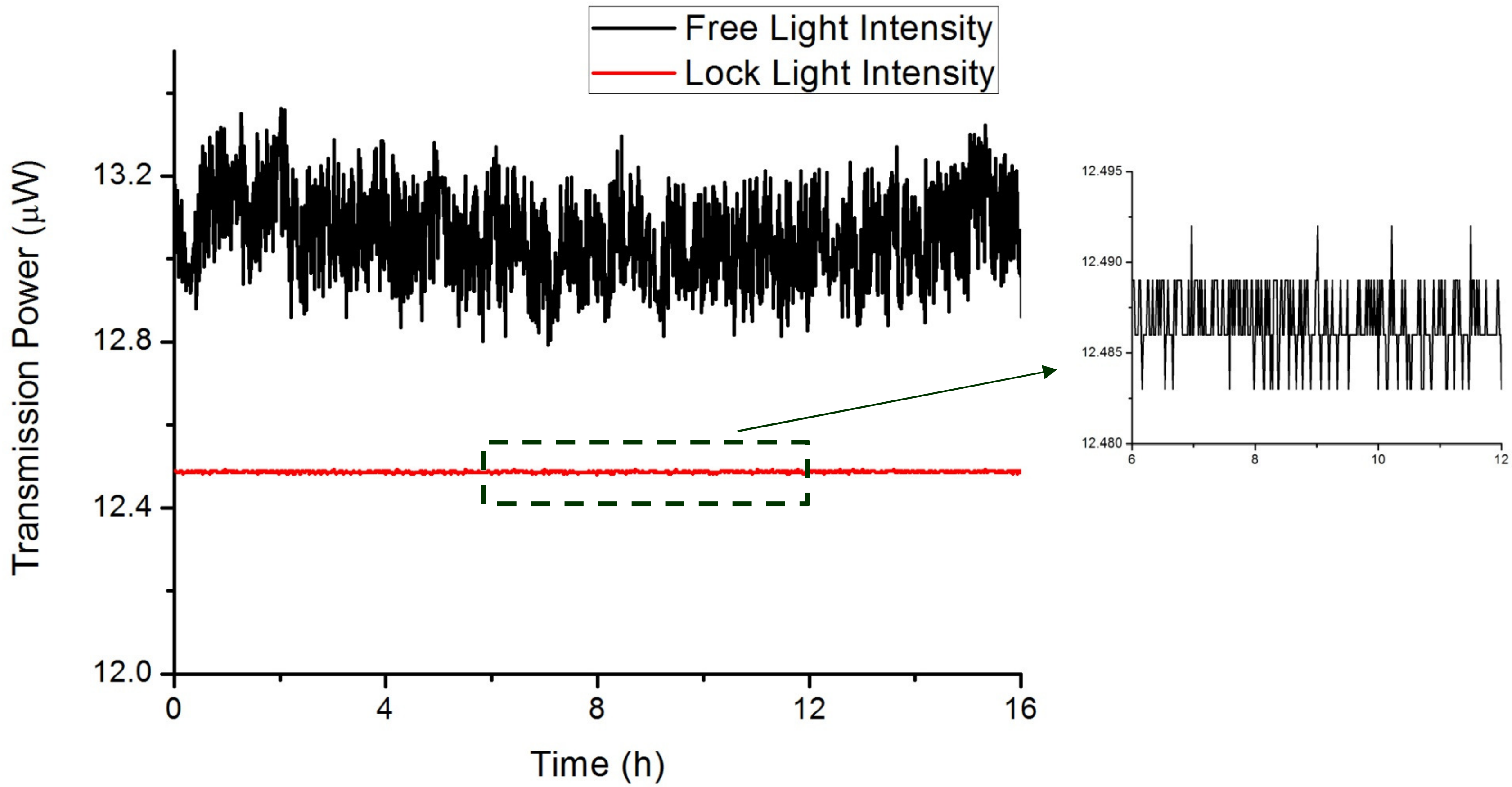
A Minus-K passive vibration isolation platform is employed

System locking

- Signal reflected from the FP Cavity
- Servo bandwidth: ~500kHz   Limited by the AOM
- Continuously locking: > 1 month



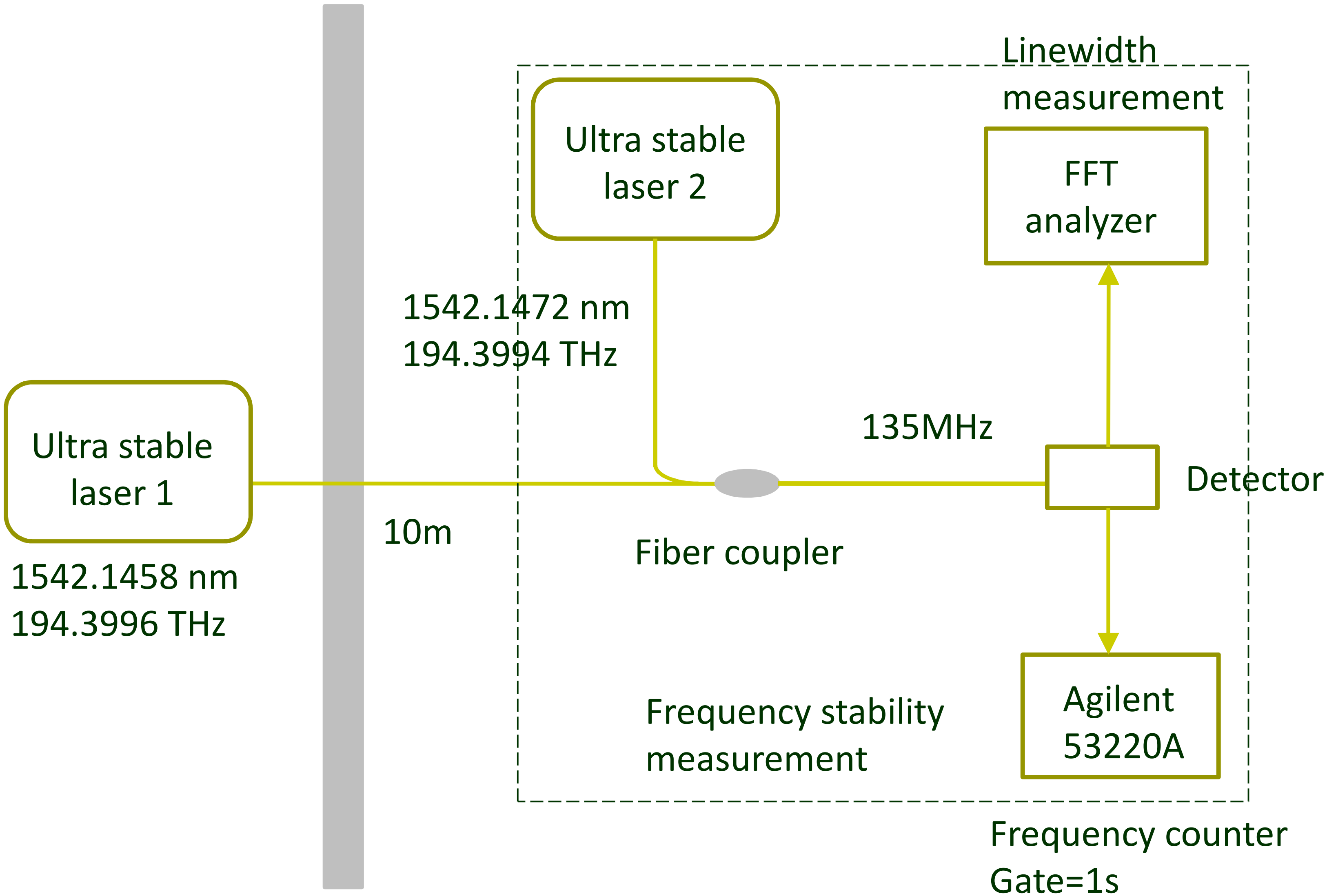
Laser Power Stabilization



- Intensity fluctuation:
  - Intensity free running: 2.18%
  - Intensity locked: 0.36%

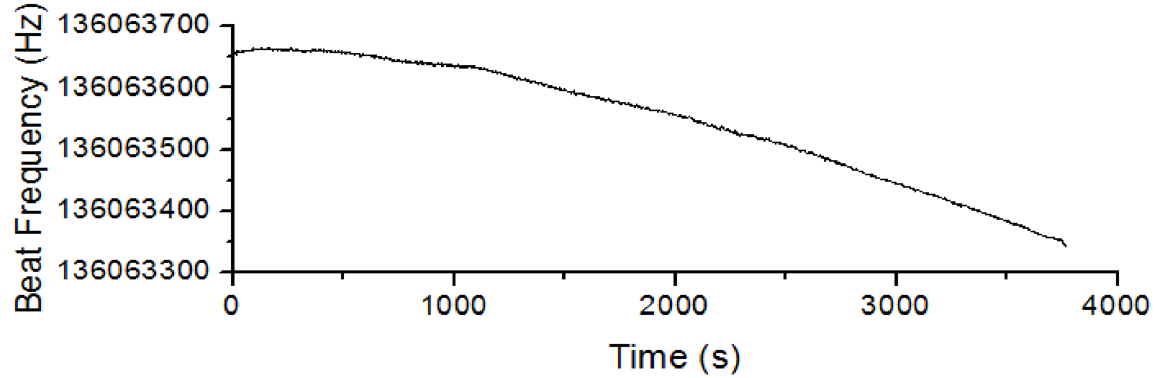
Improved 1 order

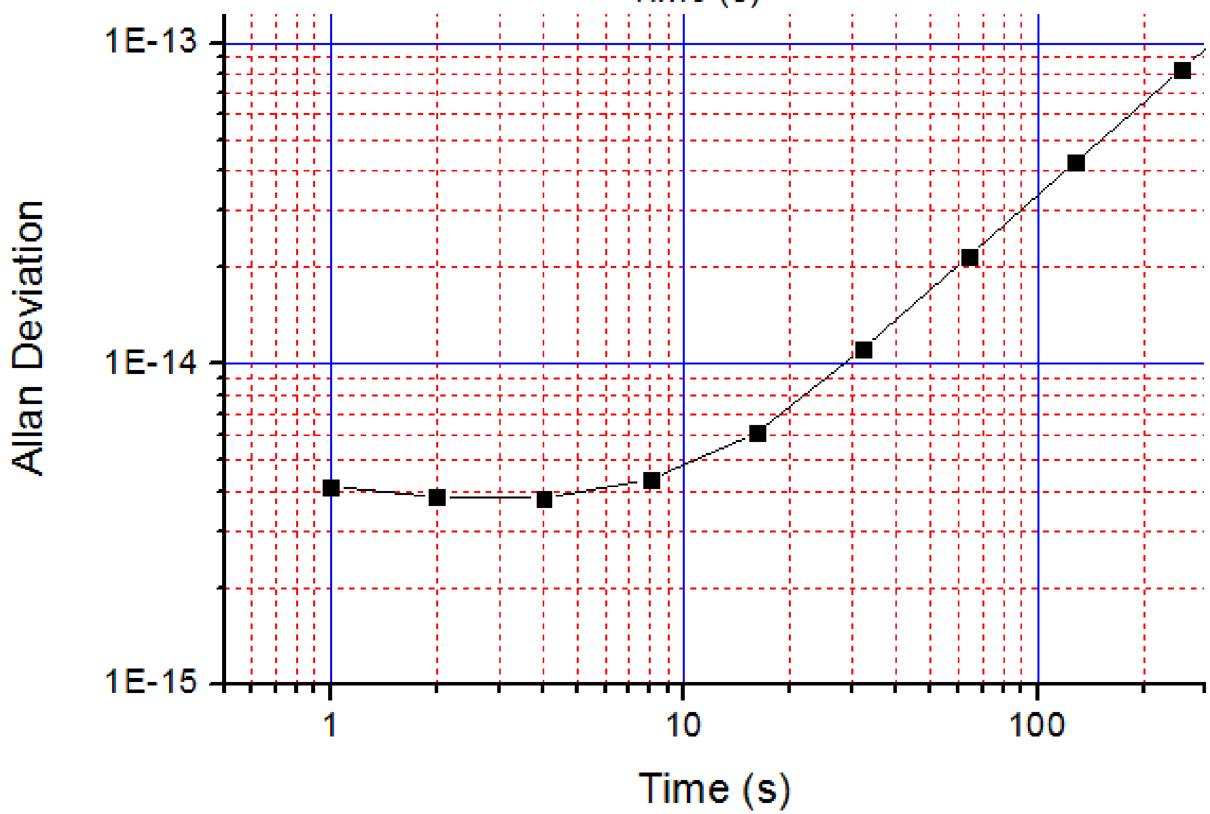
Beat Frequency Measurement



Frequency Stability

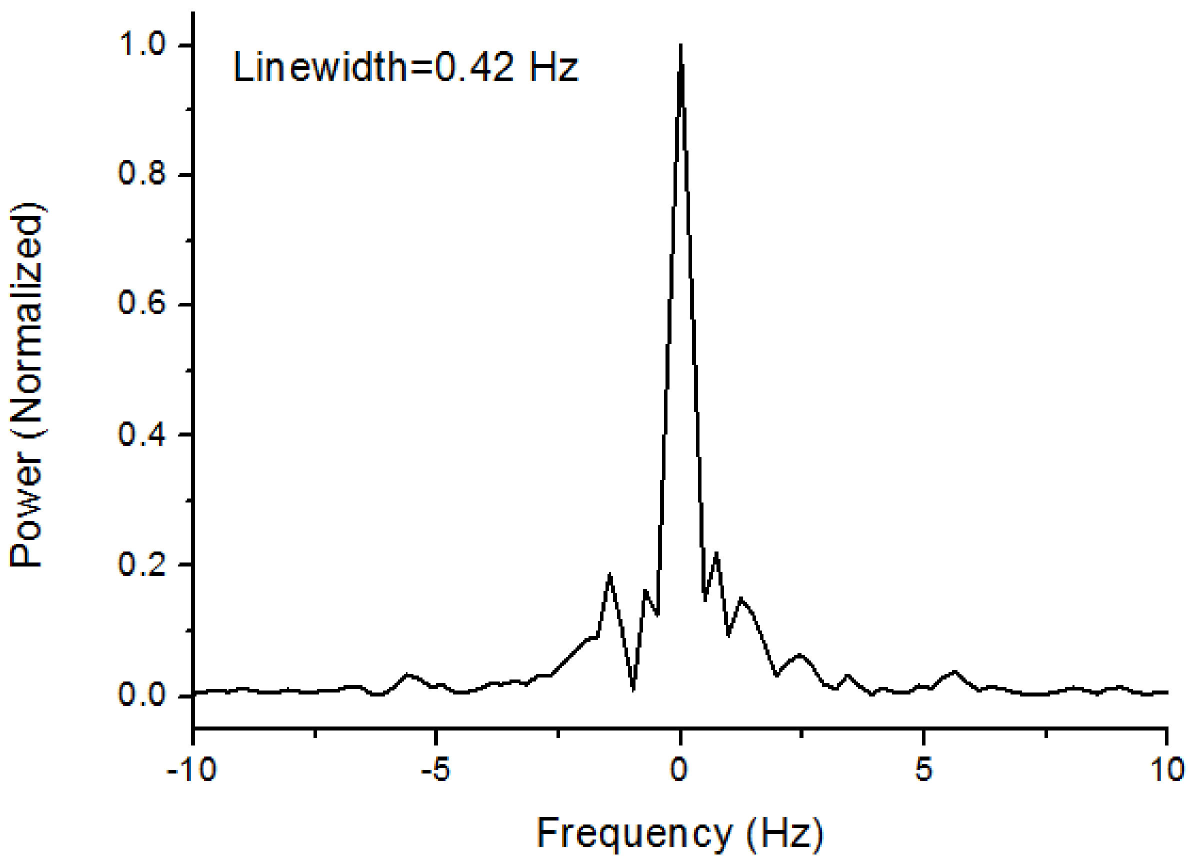
- Gate=1s, Beat frequency stability: ~4E-15 @1s
- Laser frequency stability: ~3E-15@1s
- Frequency stability increase @ >10s
- Beat frequency shift due to the temperature change
- Improve the frequency stability >10s by stabilize the temperature @ ZCT of the FP cavity





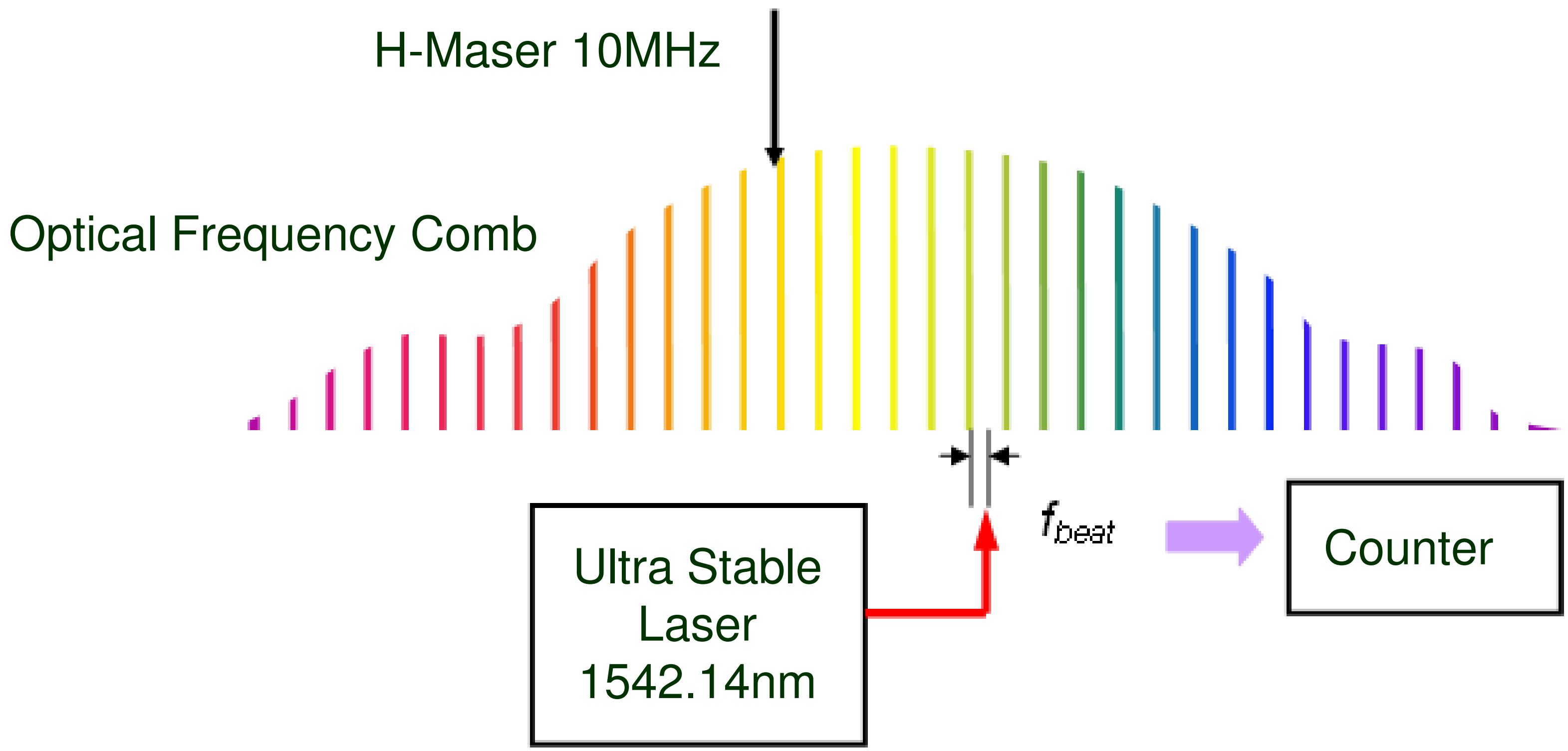
Linewidth

- Span: 97.5Hz, Resolution: 244mHz
- Beat linewidth: 0.42Hz, laser linewidth <0.3Hz



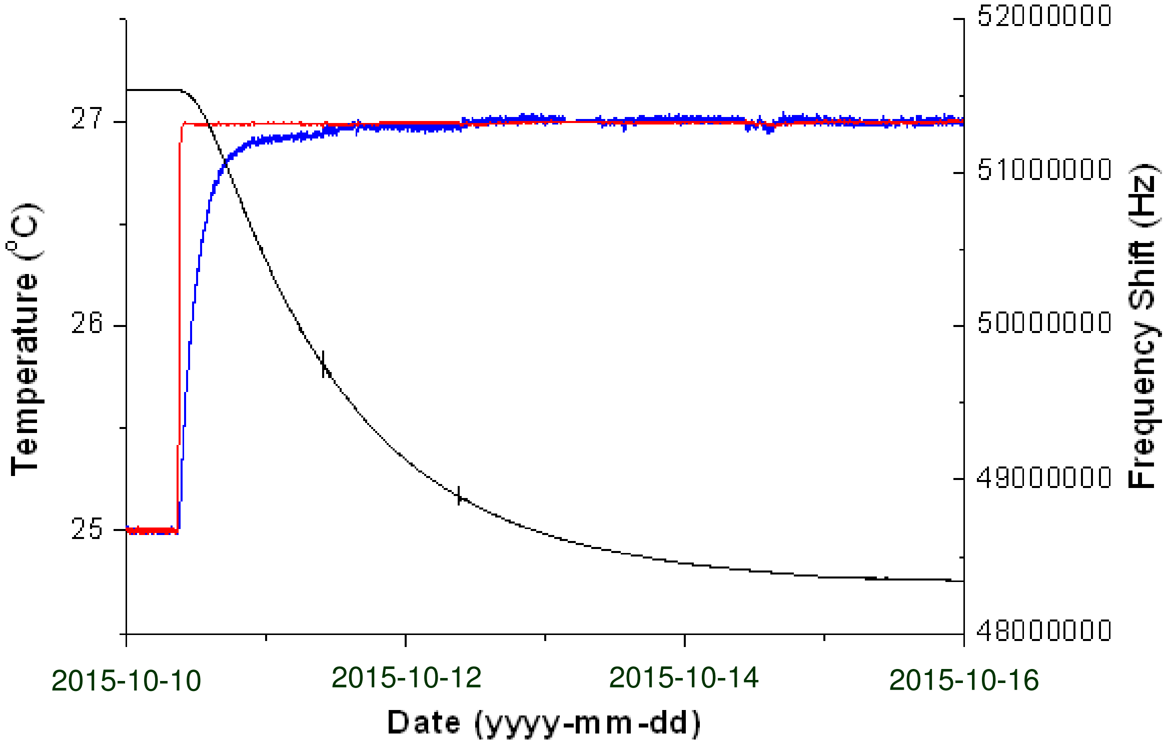
Searching for the ZCT

- locking a optical frequency comb to a H-maser
- Searching the ZCT by measuring the beat of the ultra stable laser and the adjacent comb tooth around the laser frequency.



Searching for the ZCT

Increase the temperature of the temperature control system and measure the beat frequency



Red: temperature of the copper case

Blue: temperature outside of the vacuum chamber

Black: Beat frequency

Temperature transfer time constant (1 -> 1/e): 29h 35min

The work has not finished yet until yesterday

Further Improvement

- Searching for the ZCT and stabilize the temperature at ZCT
- Add a fiber noise cancellation system or move two laser closer
- Control the temperature of the EOM and suppress the RAM

Summary & Prospect

- The 1542nm laser with the frequency stability of 3×10^{-15} @1s is achieved.
- The linewidth of the laser is measured <0.3Hz
- For further improvement, we will seek and stabilize temperature of the optical cavity at the ZCT to improve the frequency stability over 10s.
- In further works, we aim to develop such a microwave source with frequency stability in the order of 10^{-15} using the optical frequency comb and apply it as the local oscillator for Cs fountain clock to improve its short-term stability.

Thanks!