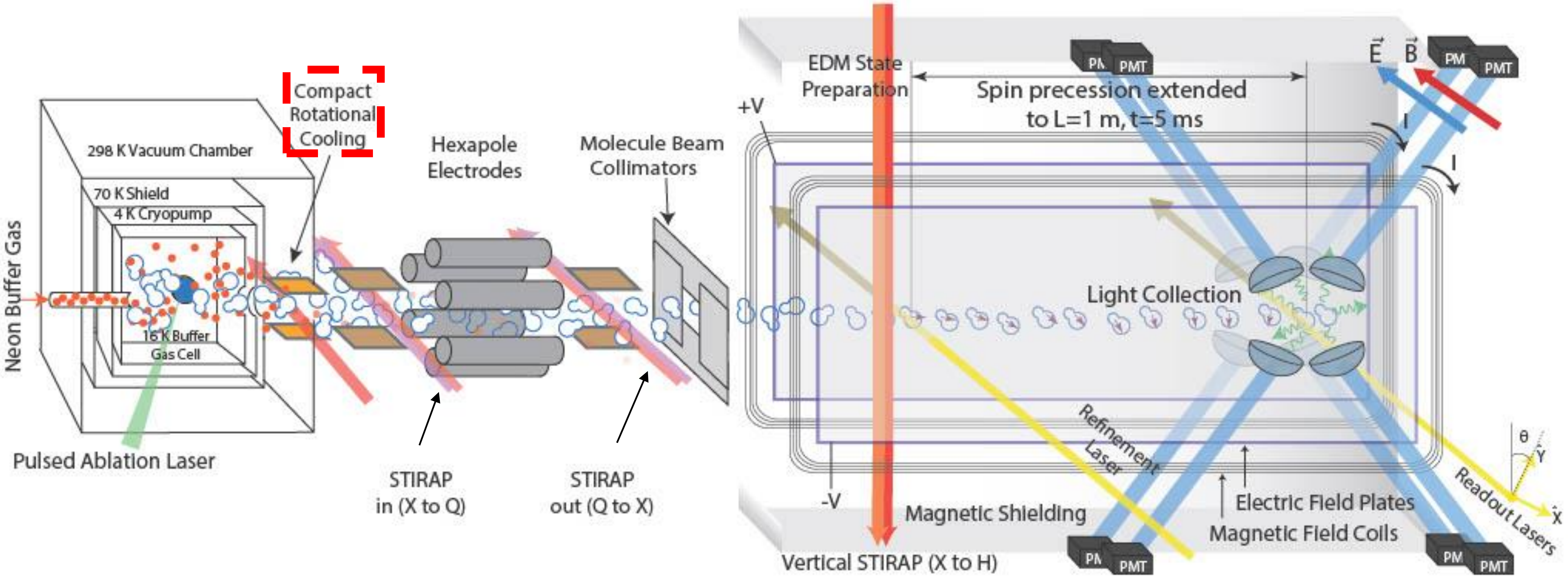
Optical Frequency Synthesis in ACME III

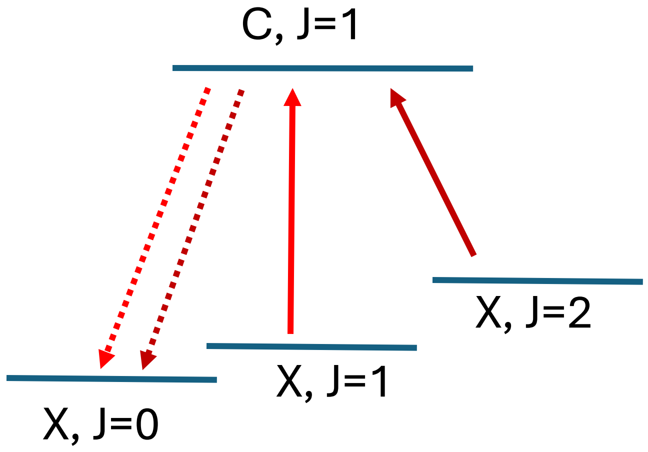
Collin Diver

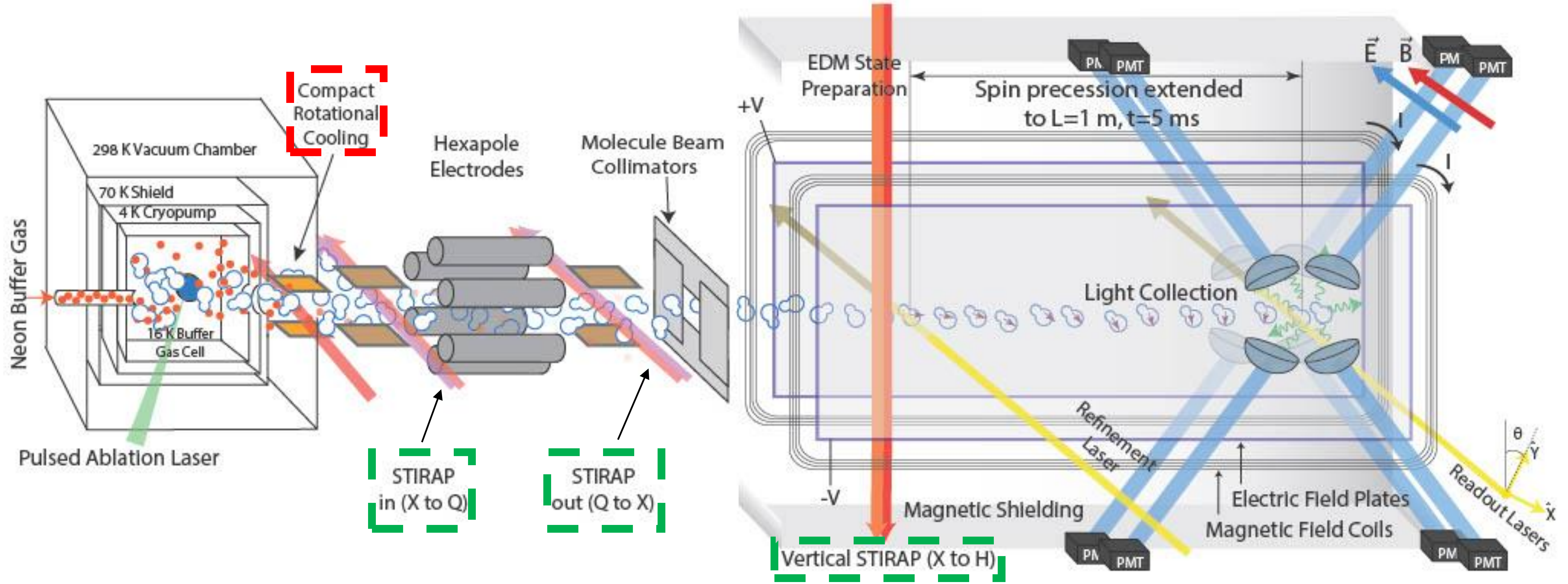
Gabrielse Group



Rotational cooling

- Only ~10% of molecules start in J=0
- Optically pump from J=1, 2 into J=0





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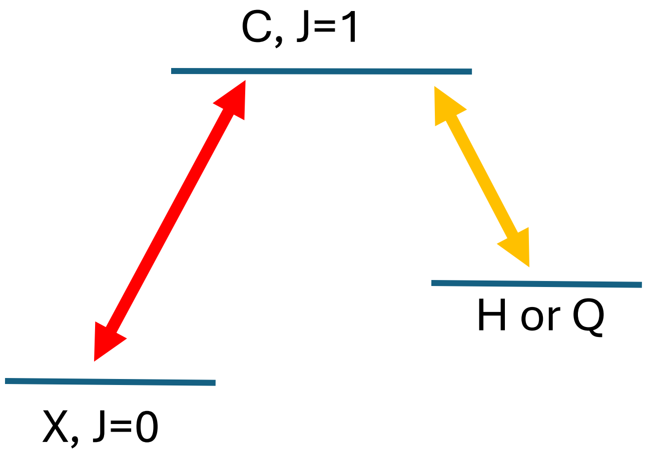
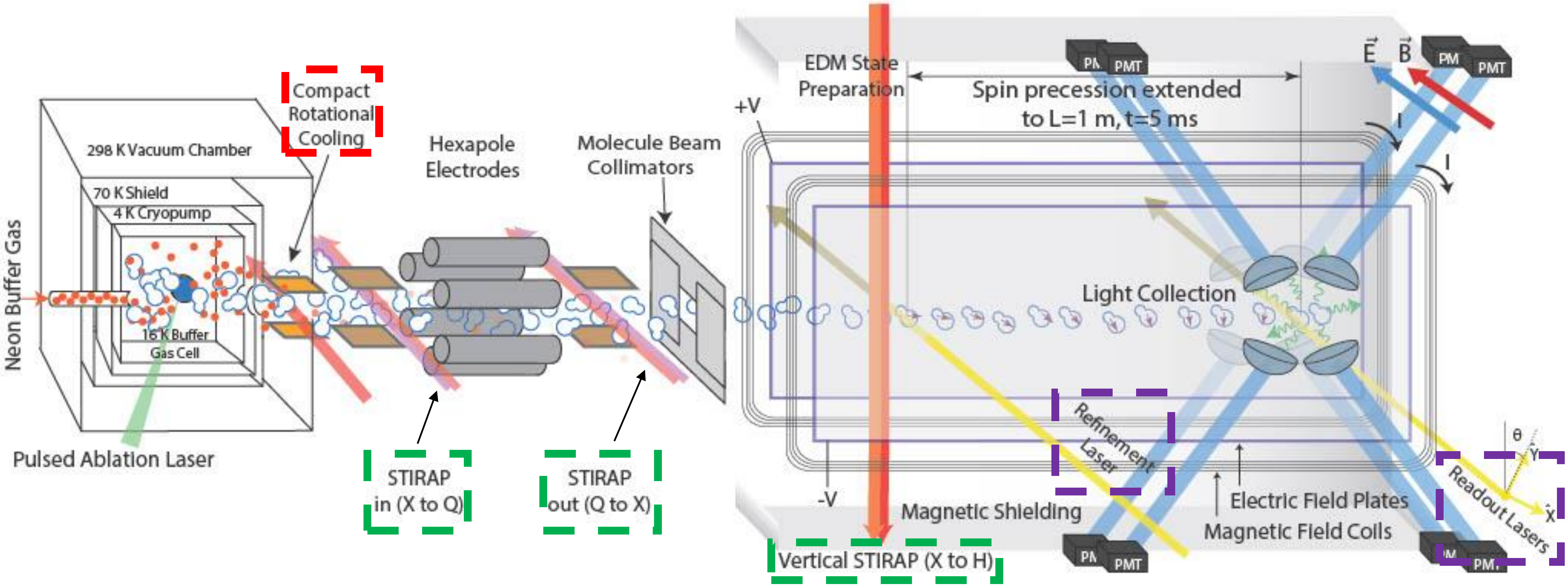
STIRAP

- Raman process to transfer population between states with near unity efficiency





Rotational cooling

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STIRAP

- Raman process to transfer population between states with near unity efficiency

State preparation and readout

- Prepare initial spin state
- Readout precession phase

Laser Requirements

Linewidth = width of laser in frequency space
Stability = fluctuation of average frequency in ~1s time intervals

Rotational Cooling

- Doppler-broadened linewidth of >10 of MHz
  - Need frequency stability much better than 10 MHz

STIRAP

- Coherence and detuning between two lasers critical
- Two photon lineshape of ~1 MHz
  - Need narrow linewidth and stable frequency

State Preparation and Readout

- Typical transition linewidth of ~1 MHz
  - Need frequency stability much better than 1 MHz

1. Frequency stability
2. Frequency repeatability
3. Narrow linewidth

Absolute frequency reference

Antenna on roof of Mudd Hall

L1/L2 GPS signals

5 V Bias

GPS-steered rubidium clock

- GPS stabilization provides absolute frequency accuracy 1×10^{-13} in one day
- Rubidium clock provides short term (1 s) fractional stability 6×10^{-13}

Absolute frequency reference

Antenna on roof
of Mudd Hall

L1/L2 GPS
signals

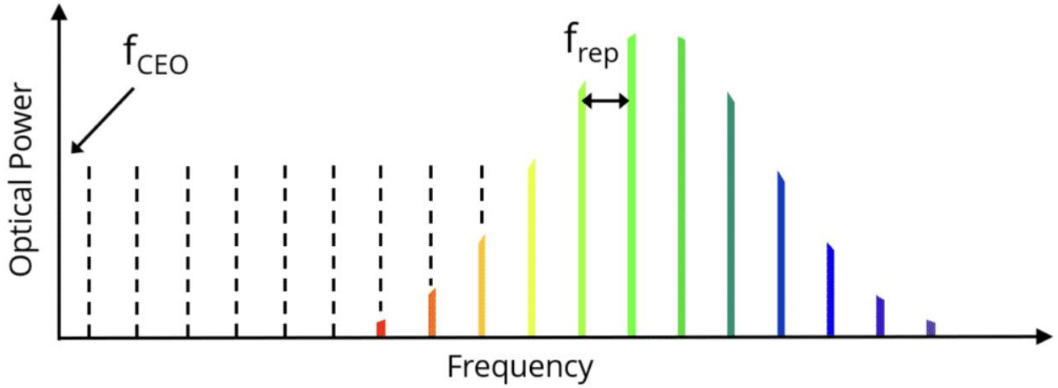
5 V Bias

GPS-steered rubidium clock

Stable 10 MHz
output

- GPS stabilization provides absolute frequency accuracy 1×10^{-13} in one day
  - ~40 Hz in optical domain
- Rubidium clock provides short term (1 s) fractional stability 6×10^{-13}
  - ~200 Hz in optical domain

FC1500-ULN
frequency comb



Absolute frequency reference

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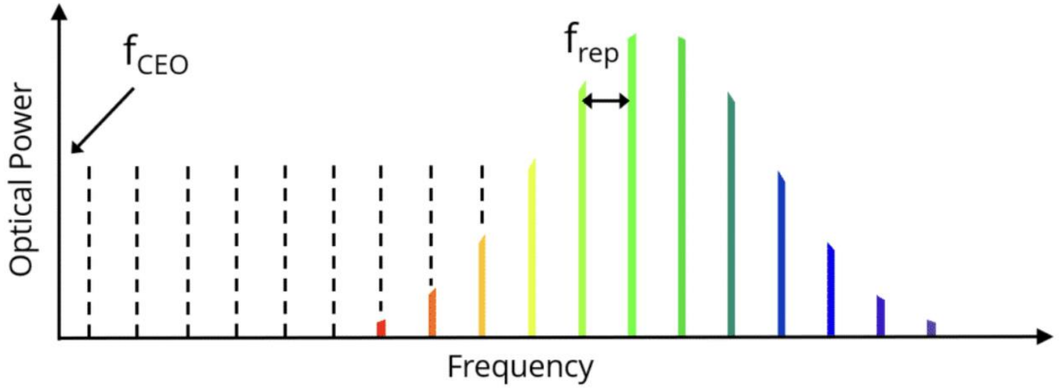
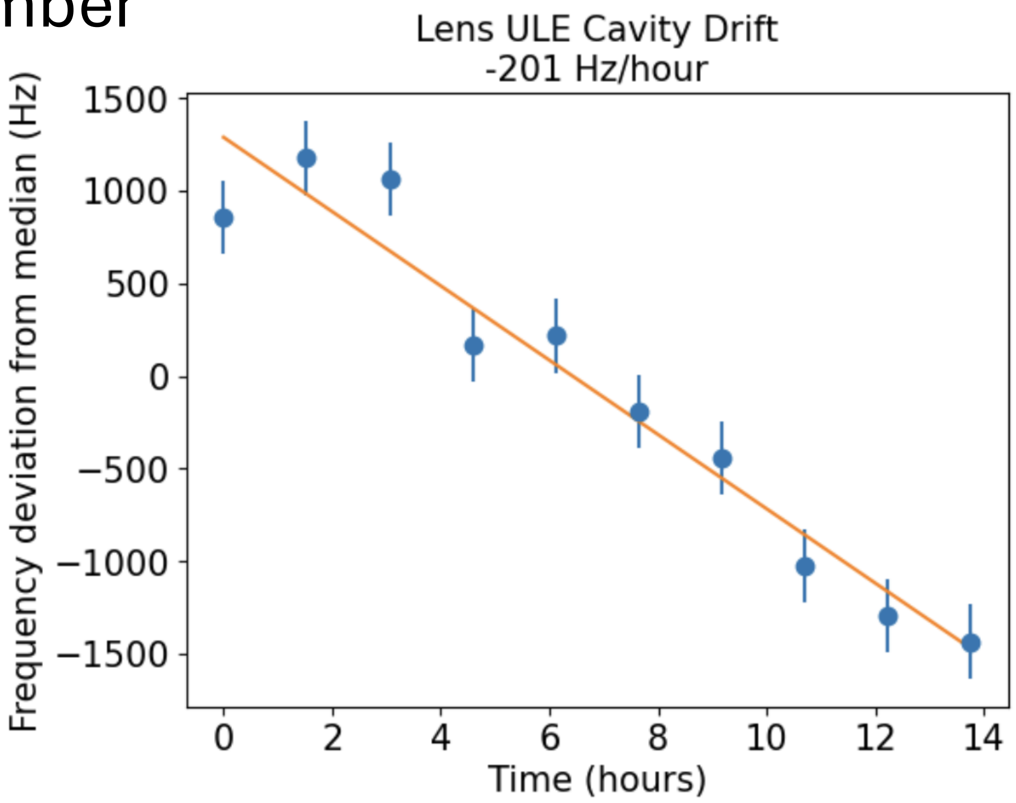


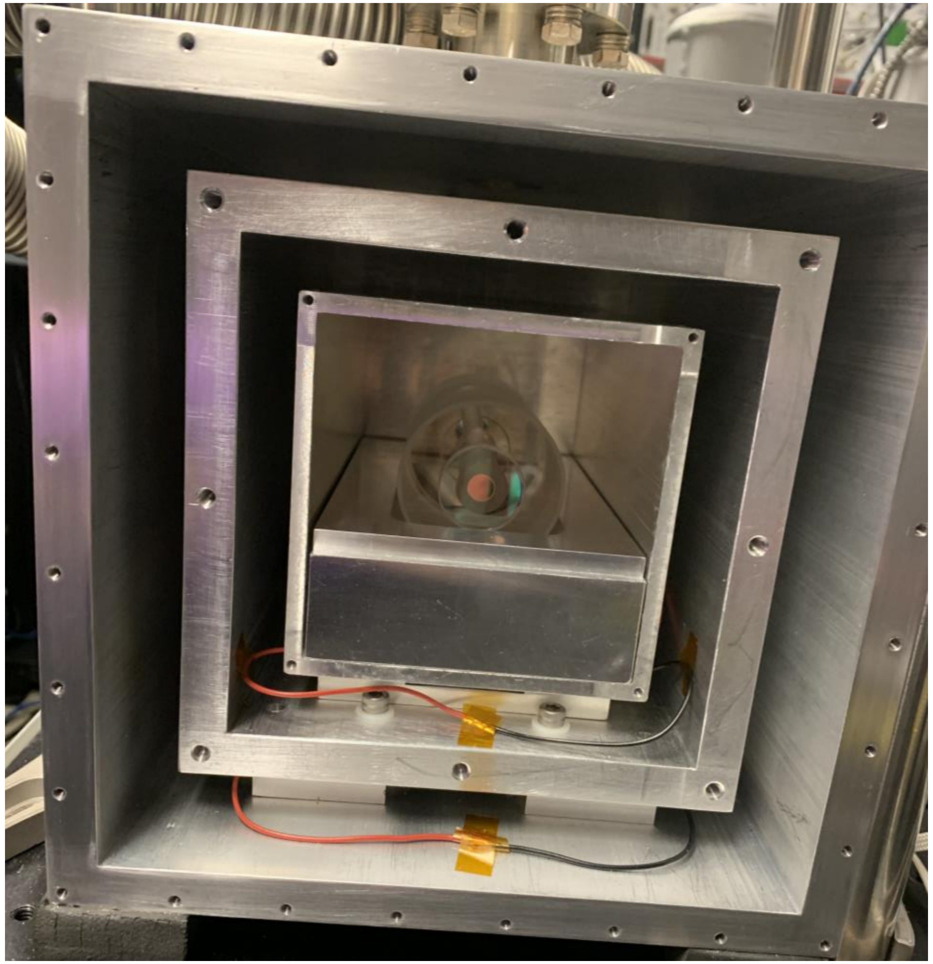
- GPS stabilization provides absolute frequency accuracy 1×10^{-13} in one day
  - ~40 Hz in optical domain
- Rubidium clock provides short term (1 s) fractional stability 6×10^{-13}
  - ~200 Hz in optical domain

BUT linewidth is broad ~200 kHz

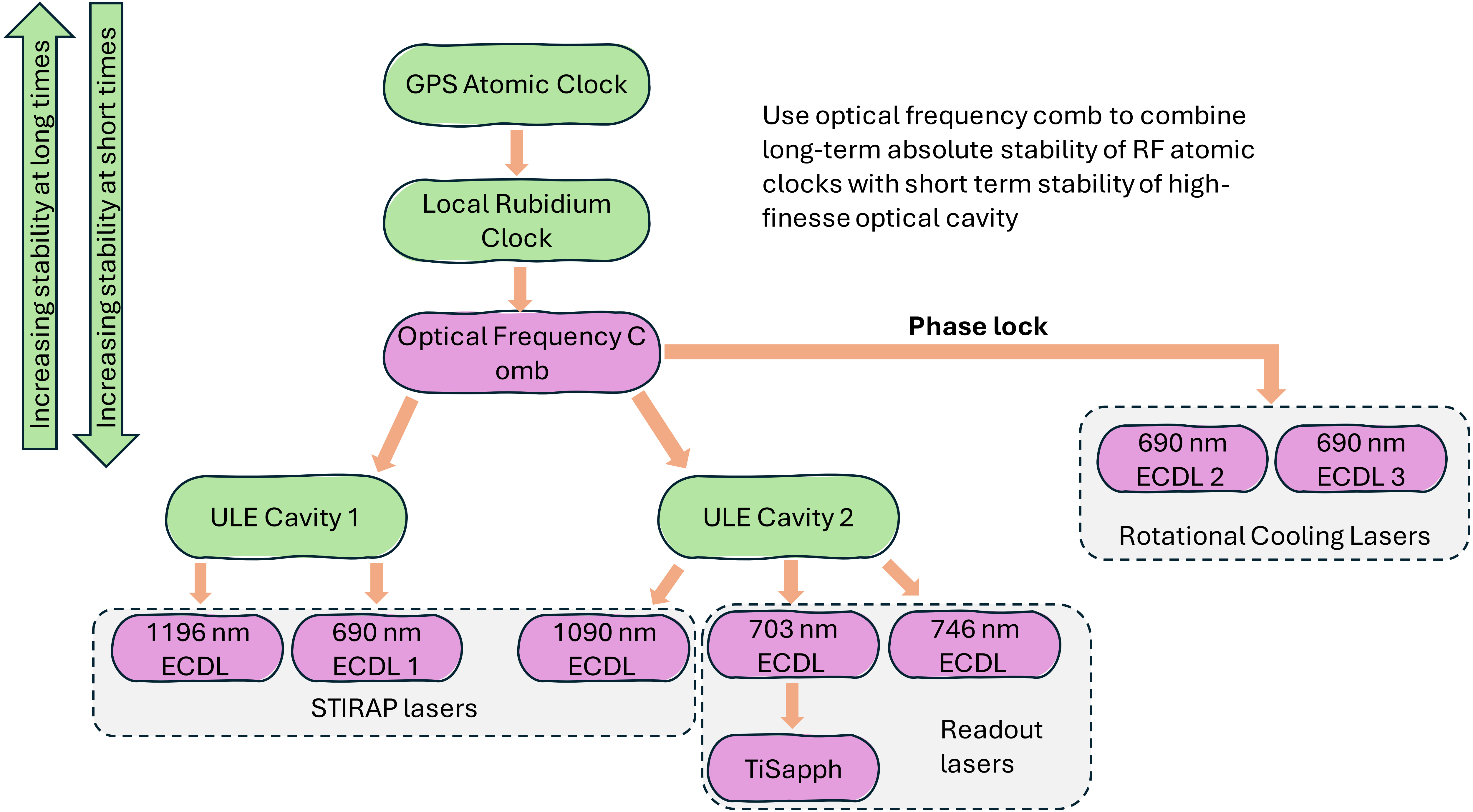
Pound-Drever-Hall Lock

- Lock laser to high-finesse optical cavity
  - Resonance linewidth of ~30 kHz
- Mirrors mounted to ultra low expansion (ULE) spacer
- Enclosed in temperature controlled vacuum chamber



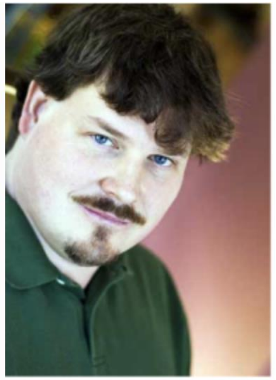


Use optical frequency comb to combine long-term absolute stability of RF atomic clocks with short term stability of high-finesse optical cavity



ACME Collaboration

J. Doyle

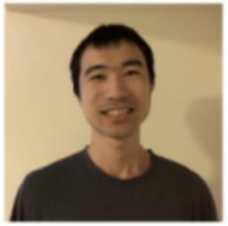


D. DeMille

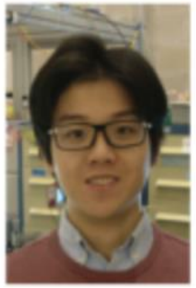
G. Gabrielse

X. Fan

X. Wu



P. Hu



Z. Han

S. Liu

M. Watts

C. Diver

N. Sasao

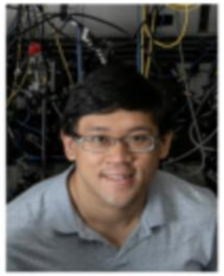
S. Uetake

T. Masuda

K. Yoshimura

A. Hiramoto

C. Meisenhelder



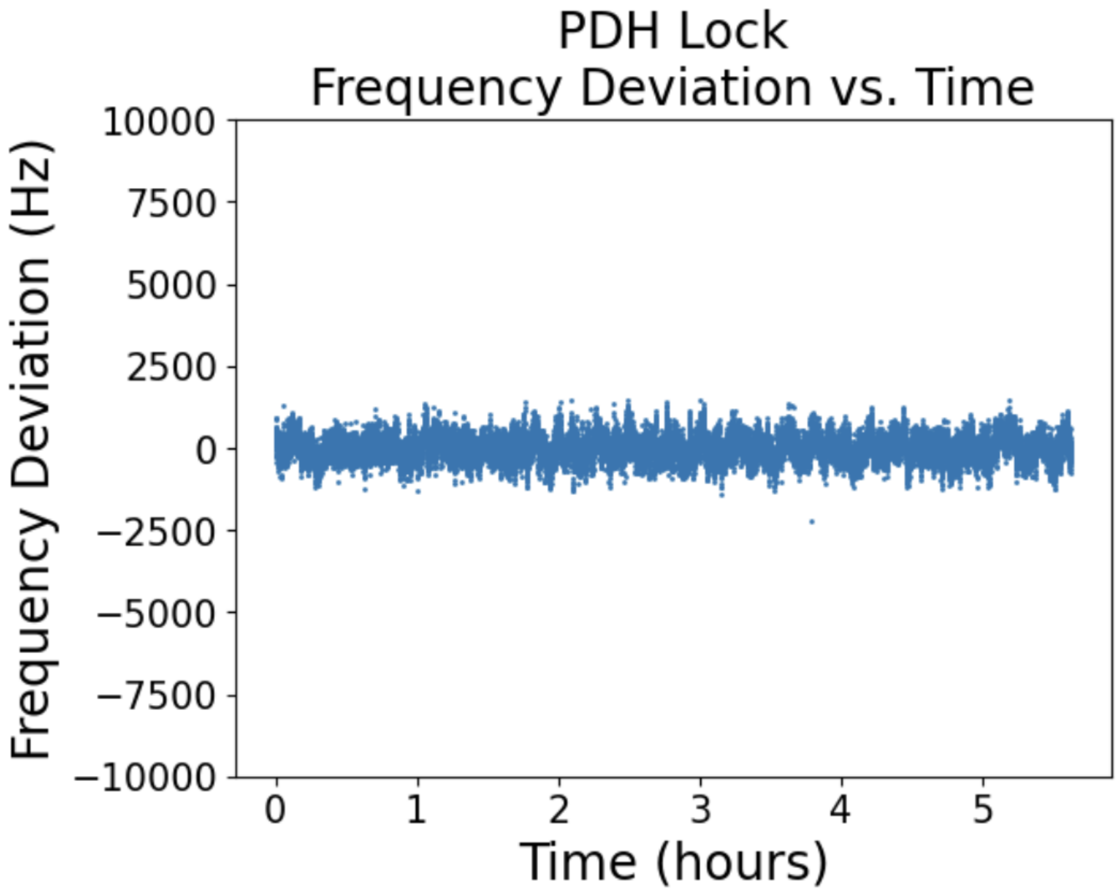
M. Watts

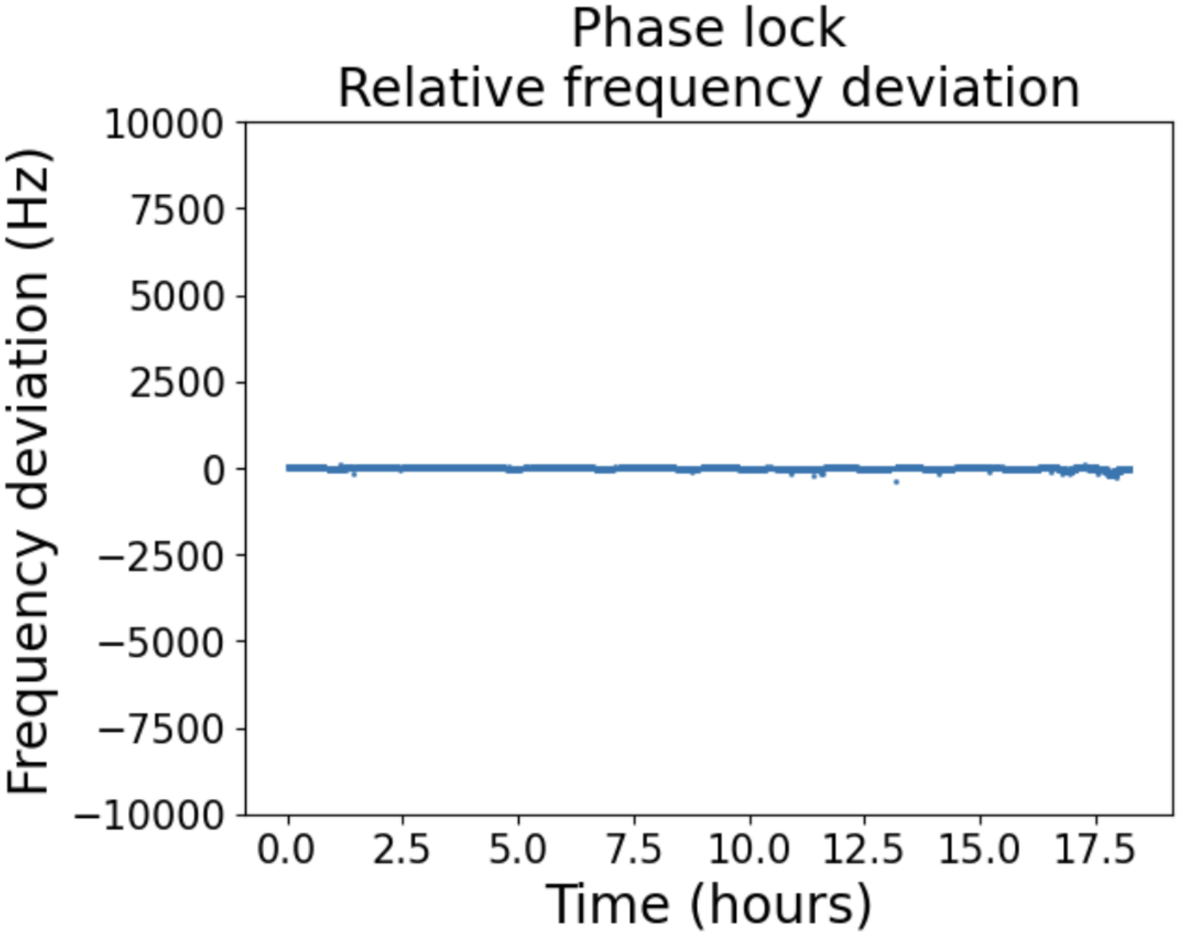
N. Hutzler

C. Panda

Extra slides

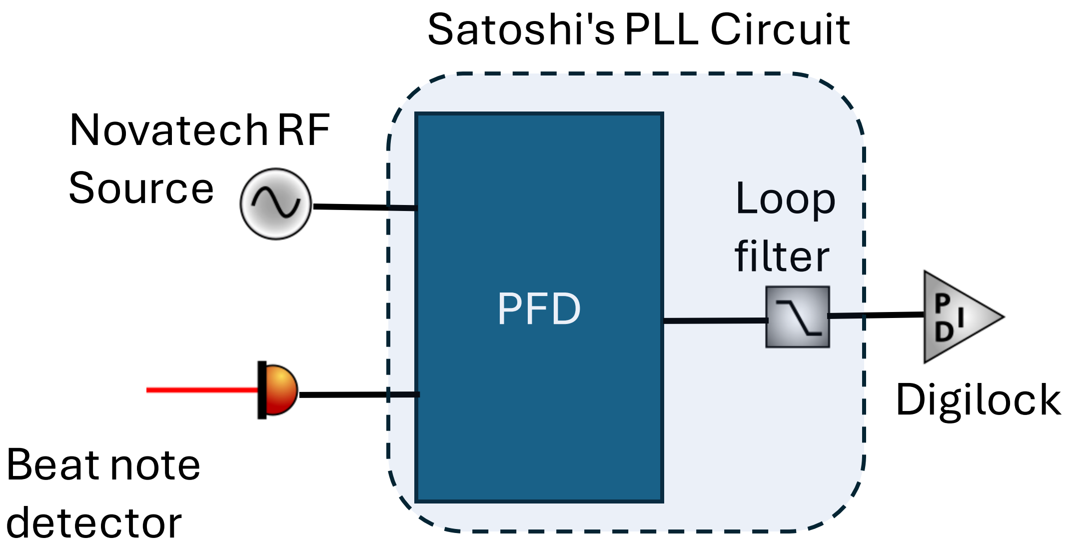
Performance

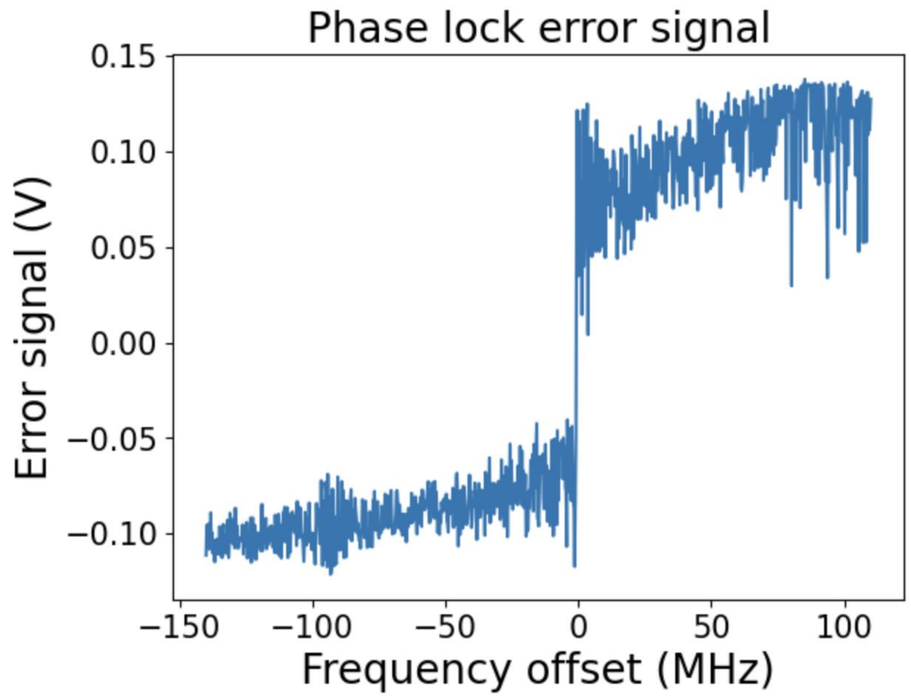




Phase lock

- Lock the phase between two lasers + some offset frequency
- Large capture range and sharp frequency discriminator





Laser Locking Methods

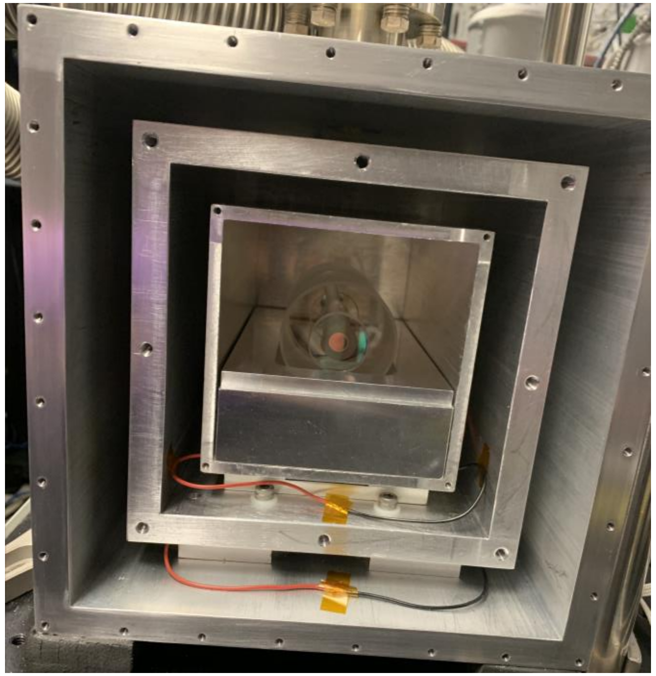
Phase lock to frequency comb

- Frequency comb is locked to GPS-steered rubidium clock
- Robust against mechanical perturbation
- Long-term frequency is fixed by absolute frequency reference
- Simpler than PDH lock

- Phase detection circuit provided by Satoshi Uetake

PDH Lock to ultra-low expansion high-finesse cavity

- Narrow linewidth
- Long-term drifts are corrected by comparison to frequency comb



Outline

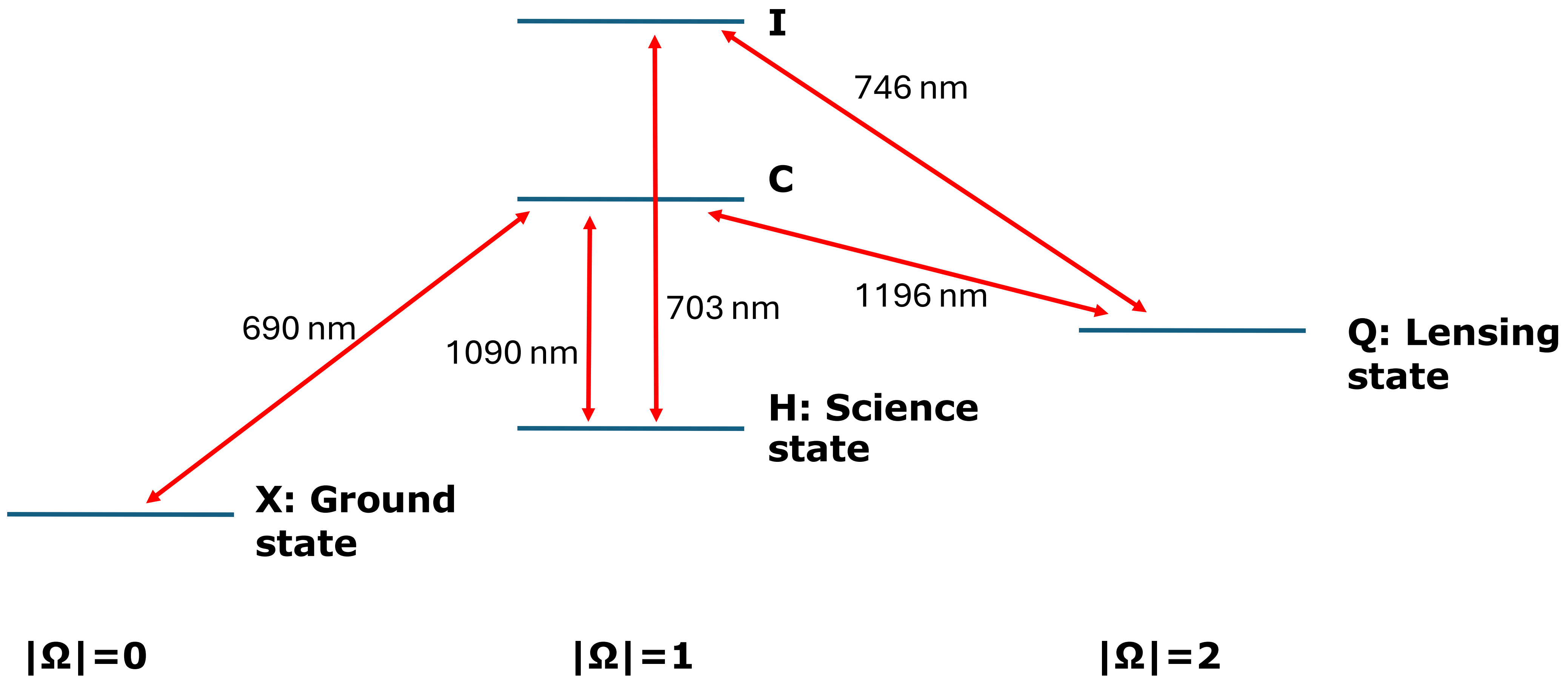
- ACME laser functions
- Laser control architecture

ACME Electron EDM

- Electron EDM gives energy shift proportional to electric field

$$U_{d_e} = -d_e E_{eff}$$

Thorium Monoxide Level Structure



ACME Electron EDM

- Electron EDM gives energy shift proportional to electric field

$$U_{d_e} = -d_e E_{eff}$$

- Highly polar molecule ThO provide both confinement and very large electric fields of ~80 GV/cm