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Noise Analysis of a Two-Colour, Two-Photon, Rubidium Optical Clock

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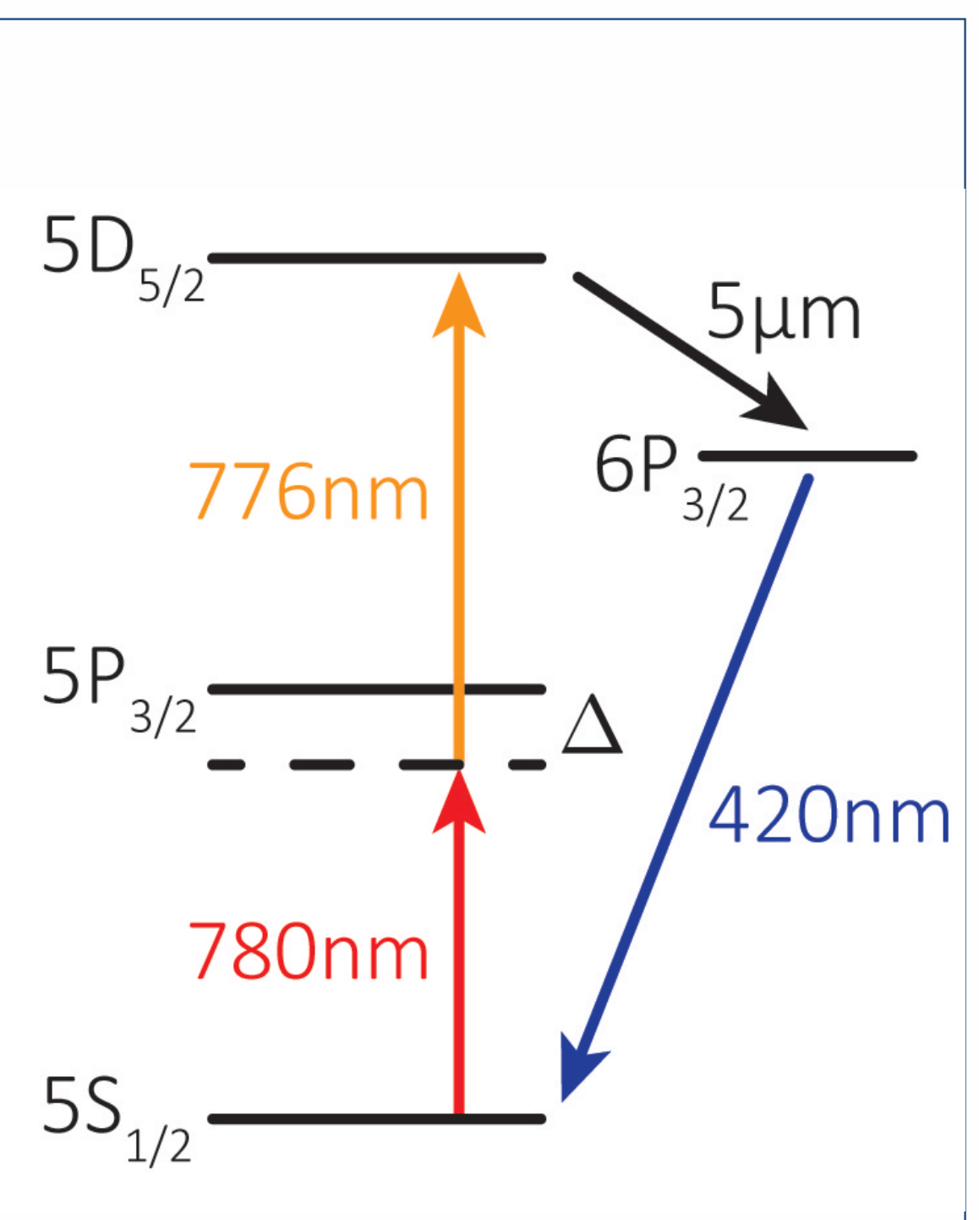
Introduction

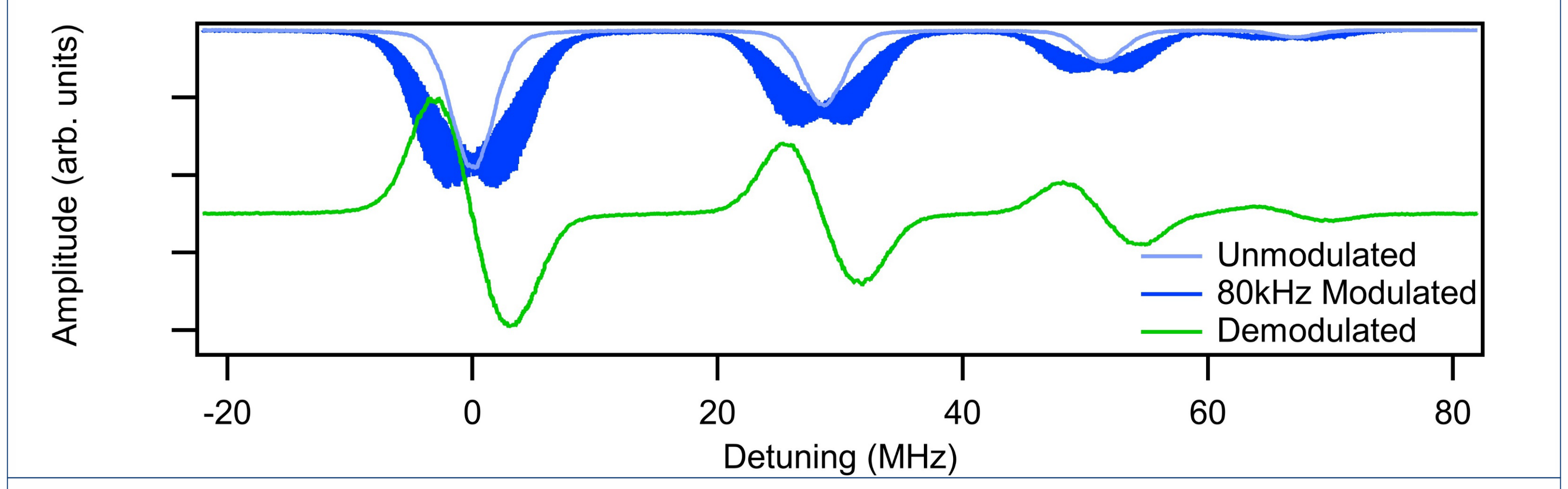
- Atomic frequency standards (AFS) are currently for a variety of purposes, including providing prec timing devices for global navigation satellite syste (GNSS)
- An AFS uses the frequency of an atomic transitio provide a timing reference
- The frequency stability (σ(τ)) of an ideal atomic c is related to the signal-to-noise (SNR) of the measured transition, the transition frequency (ω) and the transition linewidth (Γ):

$$\sigma(\tau) \propto \frac{\Gamma}{\omega} \frac{1}{SNR\sqrt{\tau}}$$



Two-colour, two-photon transition in ^{87}Rb (Δ=detuning from $5P_{3/2}$)

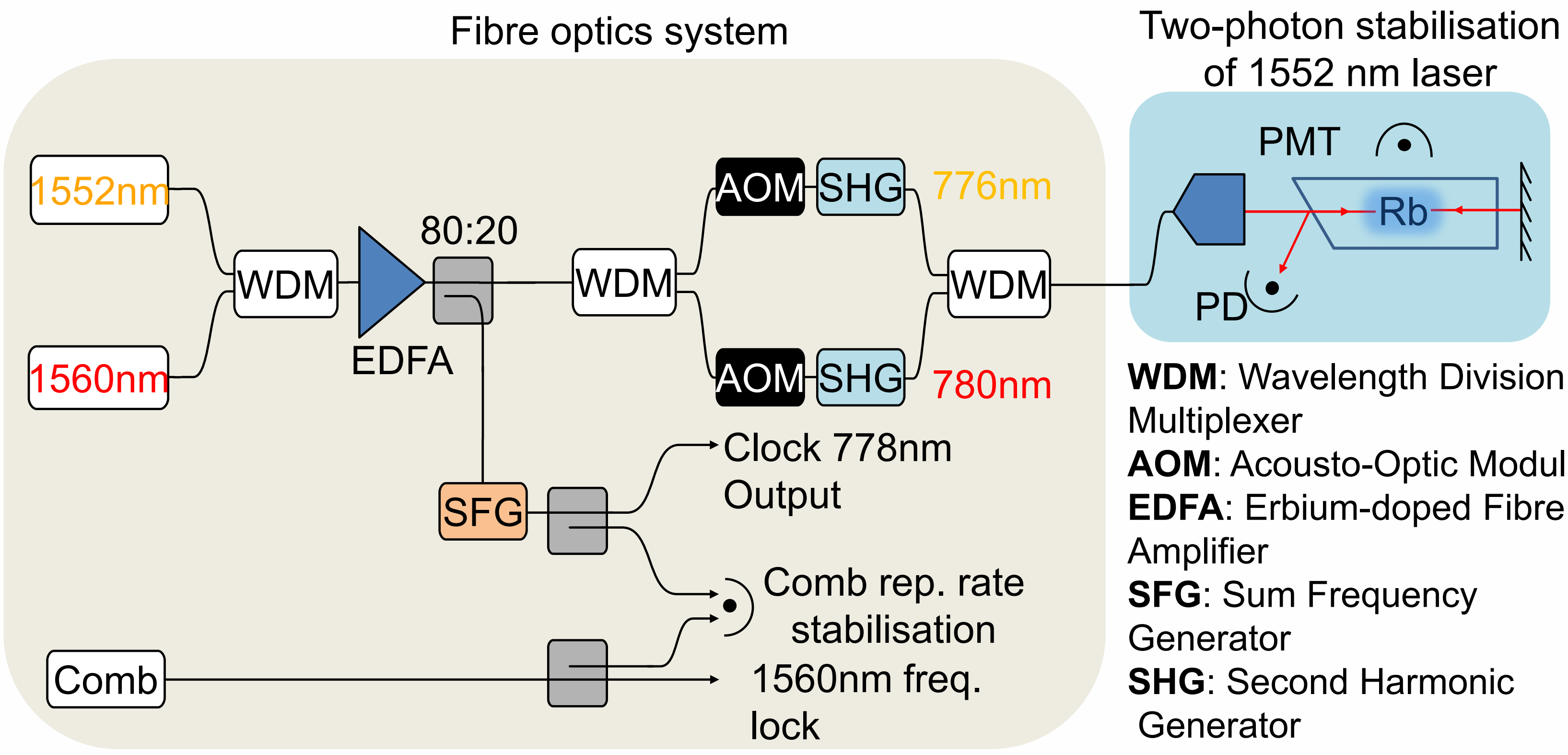
^{87}Rb Hyperfine Fluorescence Spectra ($5S_{1/2} \rightarrow 5D_{5/2}$)



Aims

- This work builds upon prior work [2] developing an optical clock using a dichroic, two-photon excitation scheme of the $5S_{1/2}$ to $5D_{5/2}$ transition in rubidium-87 (right)
- Develop low size weight and power (SWaP) optical clock compatible current small satellite technology
- Achieve short term stability of 10^{-13} at 1 second and 10^{-14} at 1000 seconds
- Provide a thorough characterisation of the noise sources of the clock

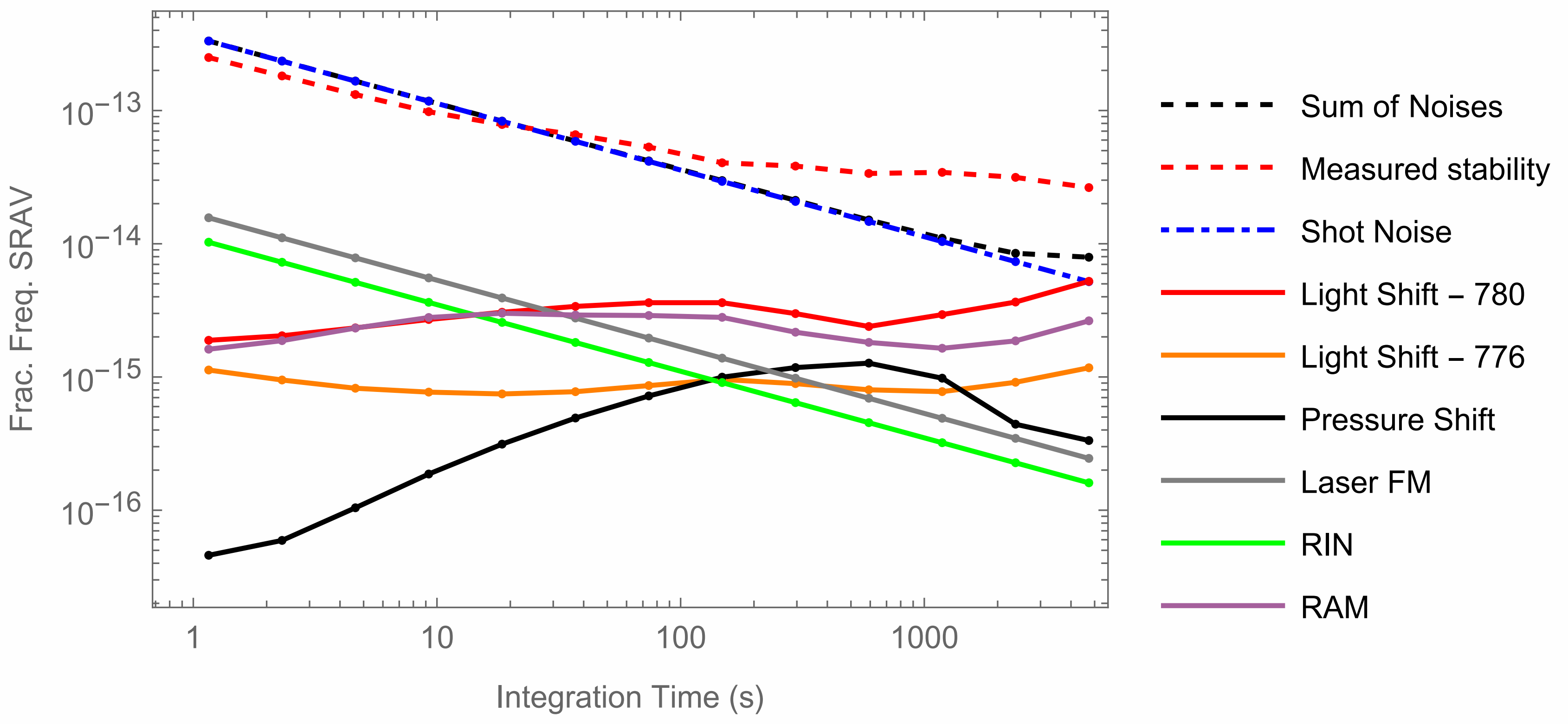
Clock Architecture



WDM: Wavelength Division Multiplexer
AOM: Acousto-Optic Modulator
EDFA: Erbium-doped Fibre Amplifier
SFG: Sum Frequency Generator
SHG: Second Harmonic Generator
PD: Photodetector
PMT: Photo-Multiplier Tube

Optical fibre layout of the two-colour two-photon clock. The stable clock output is used to stabilise the repetition rate of the optical frequency comb. An output of the optical frequency comb is used in a phase lock loop to stabilise the frequency of the 1560 nm laser. The two-photon transition is used to stabilise the frequency of the 1552 nm laser.

Noise Analysis



Any change in the energy of the $5S_{1/2}$, $5P_{3/2}$, or $5D_{5/2}$ levels of Rb^{87} will cause a change in the frequency of our clock output.

Light shifts are fluctuations in energy levels of an atom due to the intensity of laser light being used to excite the transition. Light shifts were measured by holding the power of one laser constant and varying the other. The resulting change in clock frequency was measured.

Pressure shifts are fluctuations in energy levels of an atom due to changes in pressure of rubidium vapour. Pressure shifts were measured by varying the temperature and measuring the clock frequency.

Shot noise is determined by the random arrive of photons at the measurement device (PMTs). This provides a limit to how stable our clock can be.

Discussion

- We see good agreement with our summed noise sources and stability between τ = 1 and τ = 100 s. Deviations past 100 s may be due to an unmeasured noise source, or fluctuations in contribution to noise within a factor of 2
- Temperature shifts are in close agreement with [2]
- Further measurement of the effect of stray magnetic fields (Zeeman shifts) are to be taken
- Additionally, a prototype has been developed with size, weight, and power of 25 L, 10 kg and 100 W. With this prototype we are able to achieve similar optical powers at the cell. We are confident we can replicate this stability in the updated prototype

References

[1] T. P. Yunck, C. H. Liu, and R. Ware, *A History of GPS Sounding*, Terr. Atmos. Ocean. Sci. **11**, 1 (2000).

[2] K. W. Martin, G. Phelps, N. D. Lemke, M. S. Bigelow, B. Stuhl, M. Wojcik, M. Holt, I. Coddington, M. W. Bishop, and J. H. Burke, Compact Optical Atomic Clock Based on a Two-Photon Transition in Rubidium, Phys. Rev. Appl. 9, 1 (2018).

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