Cancellation of laser phase noise for high fidelity quantum gate

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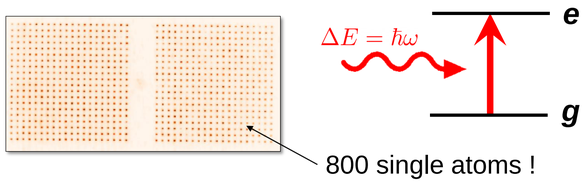
Goal 6 moonshot 大森 PM
大規模・高コヒーレンスな動的原子アレー型・誤り耐性量子コンピュータ

What is phase noise ?

Our research

We manipulate atoms trapped in an array of optical tweezers and try to develop quantum computation and simulation.

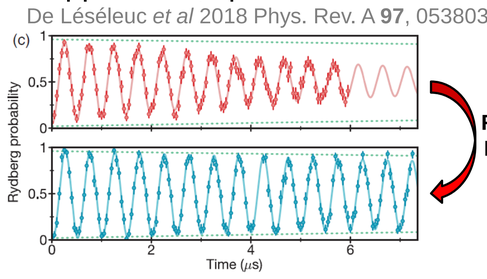
We manipulate atoms using lasers and perform quantum gates : building blocks of quantum computers.



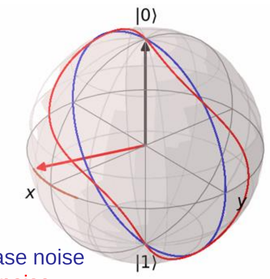
Phase noise decrease fidelity

To improve fidelity and meet the requirement for quantum error correction, 3 main sources of error have been identified : Doppler shift, spontaneous emission, **laser phase noise**.

De Léséleuc *et al* 2018 Phys. Rev. A **97**, 053803



Reduction of Phase noise

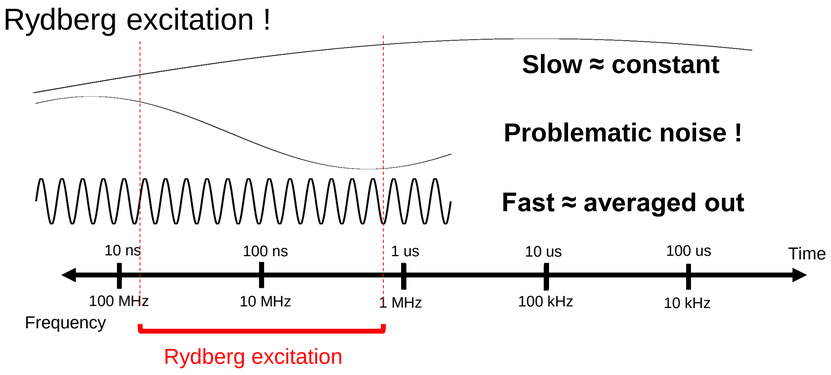


- No Phase noise
- Phase noise

Harry Levine *et al* 2018 Phys. Rev. Lett. **121**

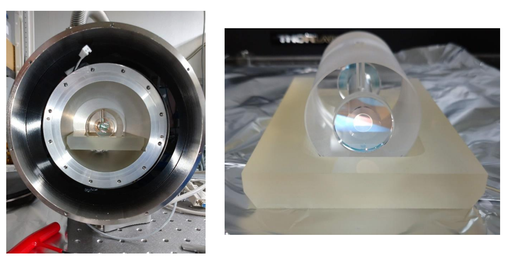
Fourier Frequency and time-scale

Phase noise that matters is in the time-scale of the Rydberg excitation !



Phase noise measurement

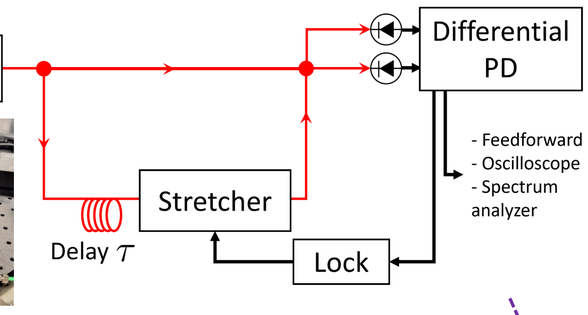
ULE Fabry-Perot cavity's error signal



$$s_{\mathrm{FP}}(f) = \frac{K}{1 + 4if/f_c}.$$

× Bulky system
× Complex and hard to set up
× Mainly good at low frequencies

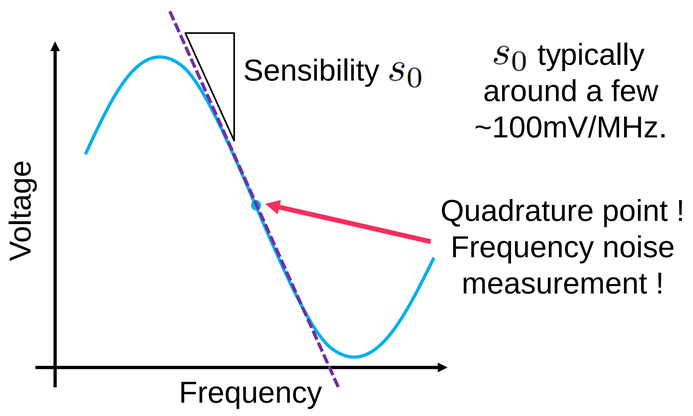
Fiber Mach-Zehnder Interferometer (MZI)



✓ Easy and quick to set up
✓ Small and compact
✓ Scalable
✓ Resilient system : doesn't require a lot of maintenance

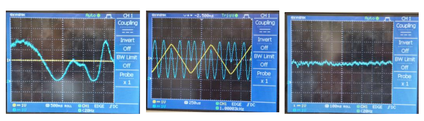
At the quadrature of the fringe, the MZI measure the phase noise !

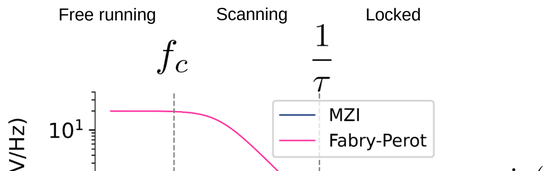
$$I(t) = E_0^2 \cos[\phi(t) - \phi(t-\tau)]$$
$$\simeq E_0^2[\phi(t) - \phi(t-\tau)]$$



s_0 typically around a few ~100mV/MHz.

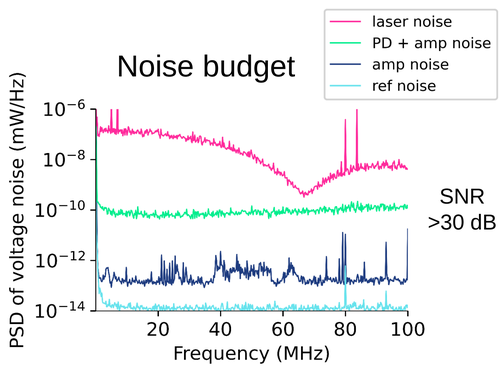
Quadrature point ! Frequency noise measurement !





$$s_{\mathrm{MZI}}(f) = s_0 \frac{\sin(\pi f\tau)}{\pi f\tau} e^{-i\pi f\tau}$$

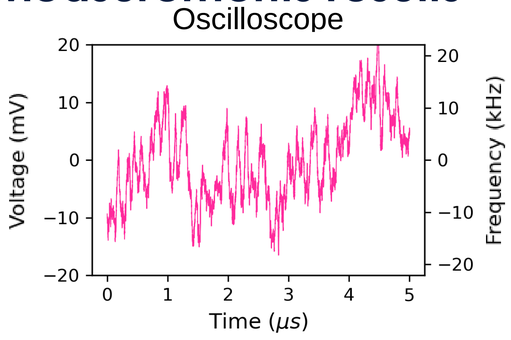
Noise budget



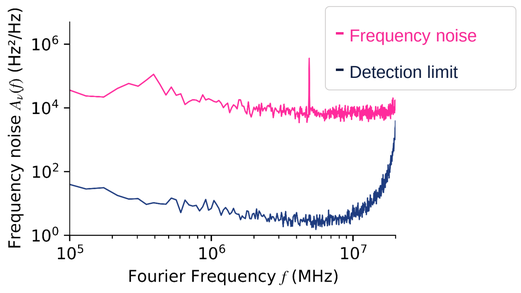
SNR >30 dB

Measurements results

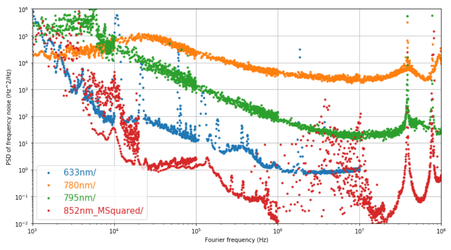
Oscilloscope



Spectrum Analyzer



- Diode Laser
- ECDL
- He-Ne
- Ti-Saph



linewidth — Important information !

Remark : The linewidth of the laser is not the only relevant quantity to measure

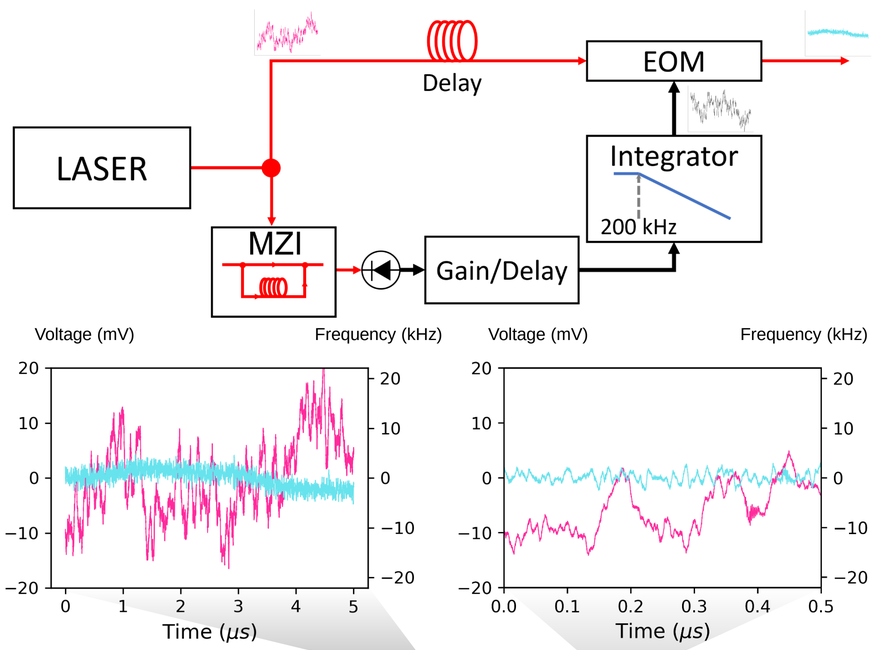
Diode laser have too much phase noise.
Ti-Sa have very low noise.

→ Can we find a solution for diode lasers ?

Phase noise cancellation

Feedforward for high frequencies !

Feedback is limited by the time the information takes to go to the correction point.
Reaching 1 MHz is already a challenge…
Feedforward doesn't suffer this limitation !

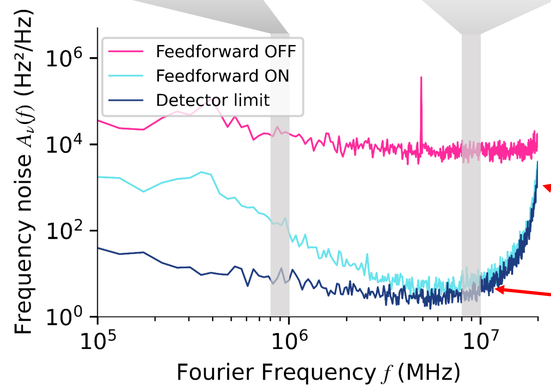


✓ Easy to assemble
✓ Compact and scalable
✓ Good even at high frequencies (> 1 MHz)

✓ 10 mW output
✓ Noise reduction as far as 10 Hz²/Hz

From 1 MHz up to 20 MHz cancellation

Noise cancellation up to 30 dB



Reaching measurement limit

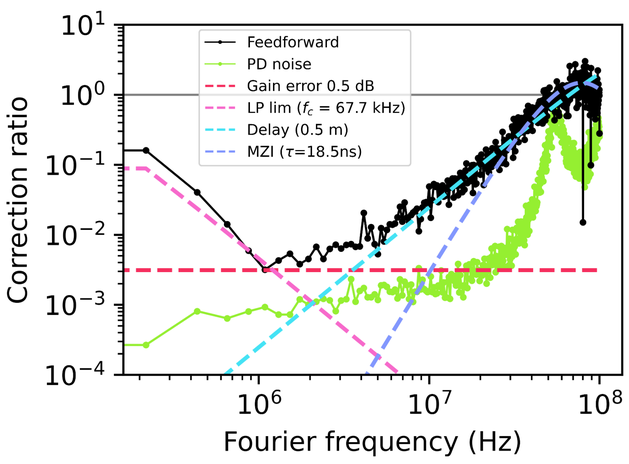
Bandwidth & Noise limit

Noise limit

$$C(f) = \pm G \frac{if/f_c}{1 + if/f_c} \frac{\sin(\pi f\tau)}{\pi f\tau} e^{i2\pi f\tau_d}$$

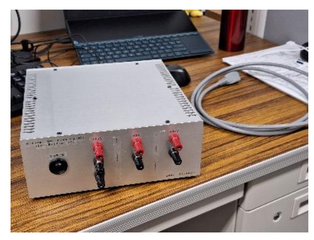
Gain — LP filter — MZI — Delay

& Instrument noise



Coming soon

Packaging of the phase noise cancellation system



New system for 960 nm doubled to 480 nm

Adapt the system to 960 nm light and use second harmonic generation to obtain noise cancelled 480 nm light used with 780 nm in Rydberg excitation.