Practical quantum optical sensing for Fossil Energy

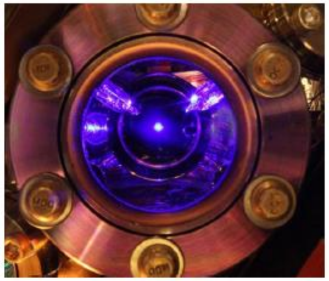
Ben Lawrie

Quantum Sensing Team
Quantum Information Science Group
Oak Ridge National Laboratory

Quantum sensors…

Described by quantum mechanics, but largely compatible with classical electrodynamics. Useful for sensing up to standard quantum limit

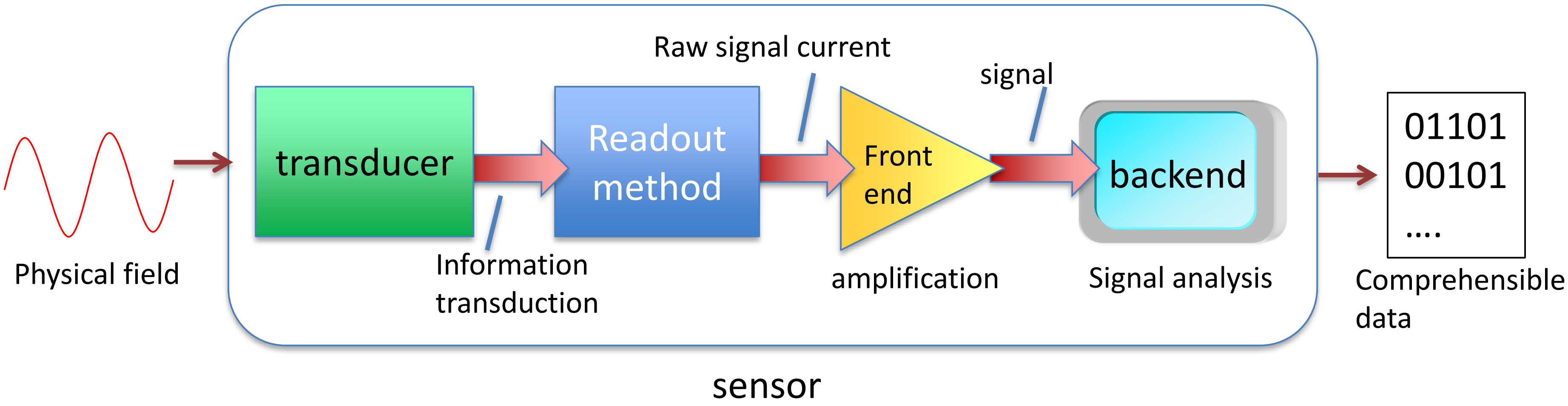
Atomic clocks and interferometers, single spin qubits, etc, relying on coherent dynamics of quantum states



Quantum enhancements enabled by squeezing or entanglement

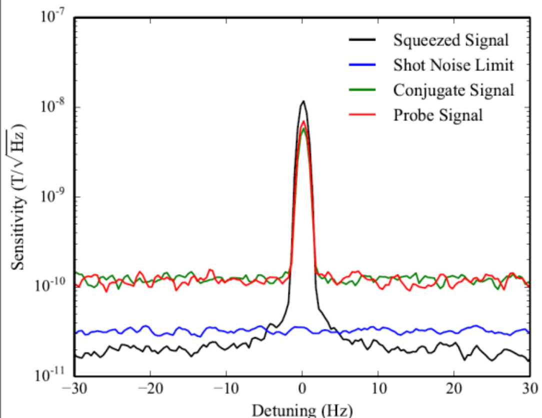
Sensors in General

- Sensors can be defined as devices that detect physical quantities by transducing them to (potentially macroscopic) understandable signals
- One way to construct a sensor:

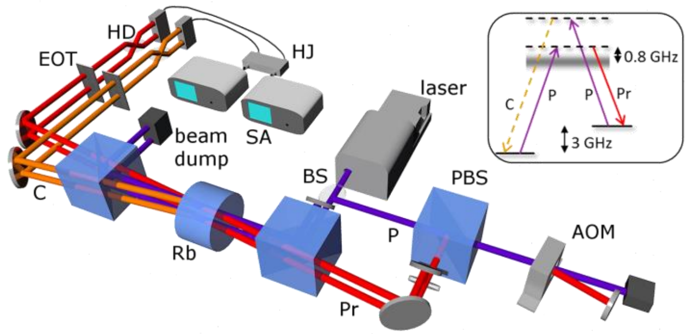


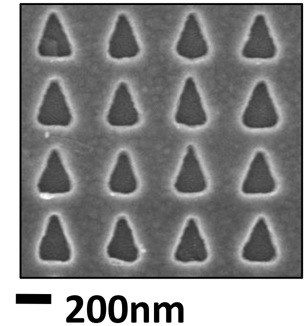
- Noise occurs in each component

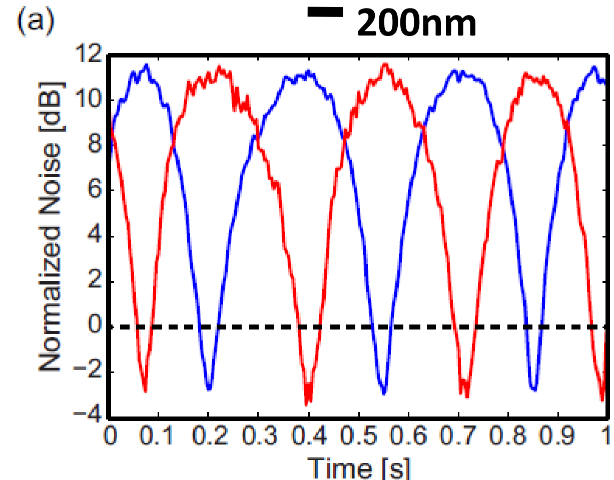
Quantum Sensing with Squeezed Light



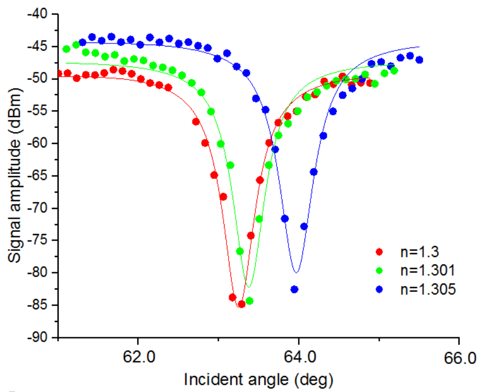
Optics Letters, 39, 6533 (2014)

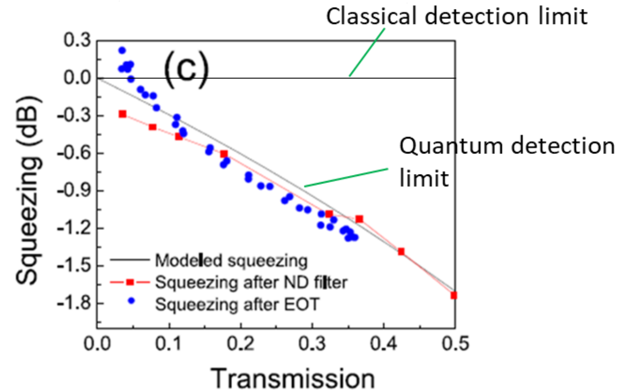




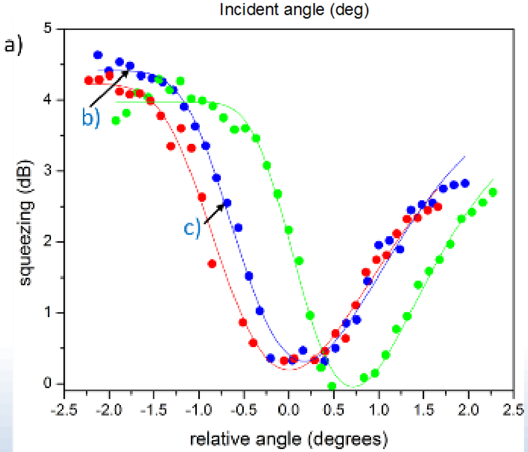


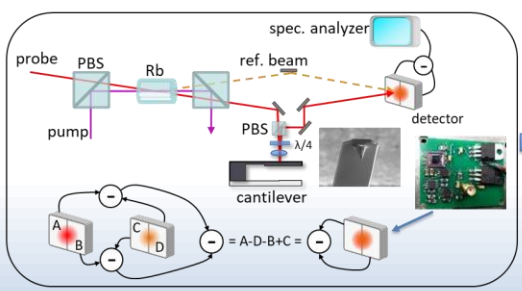
Optica 3, 985-988 (2016).

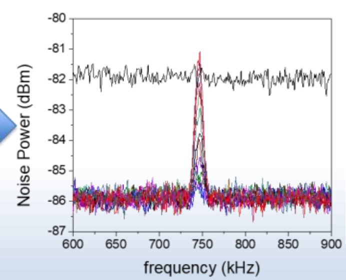


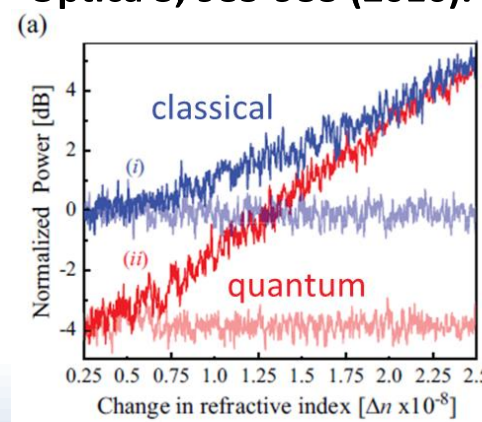


Phys. Rev. Lett. 110, 156802 (2013)









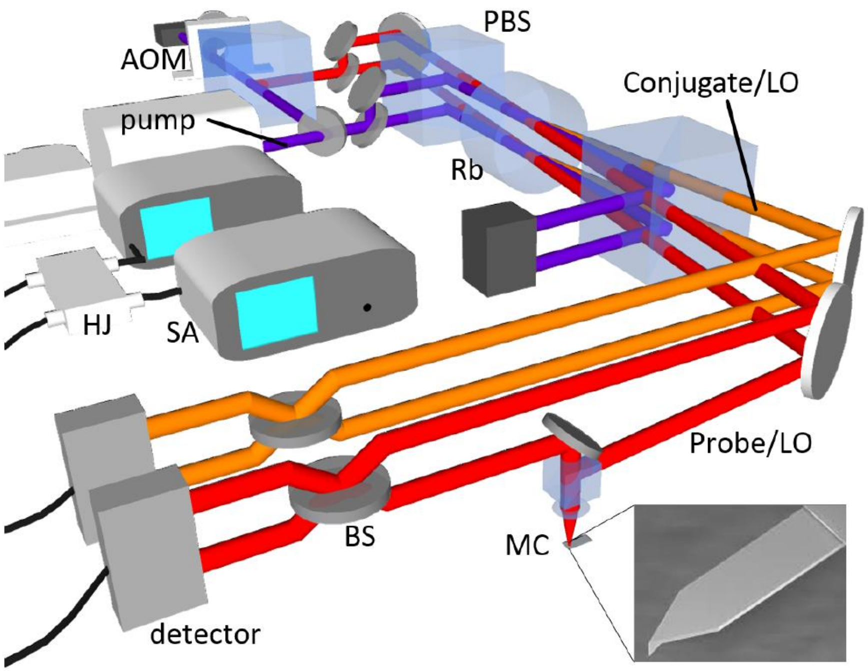
Optica 5, 628-633 (2018).

Phys. Rev. A 92, 053812 (2015).

ACS Photonics, 3, 8 (2016).

Optica 2(5) 393-399 (2015)

Truncated nonlinear interferometry

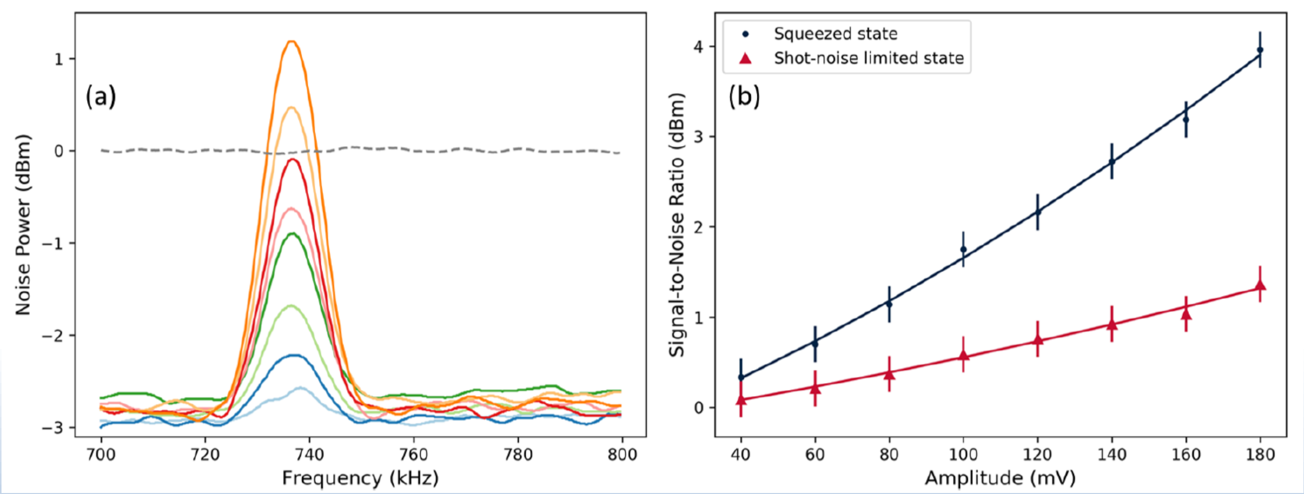


Backaction noise is limited by power incident on cantilever

Shot noise is limited by combined laser power on detectors

Signal can be transduced onto probe or probe's local oscillator

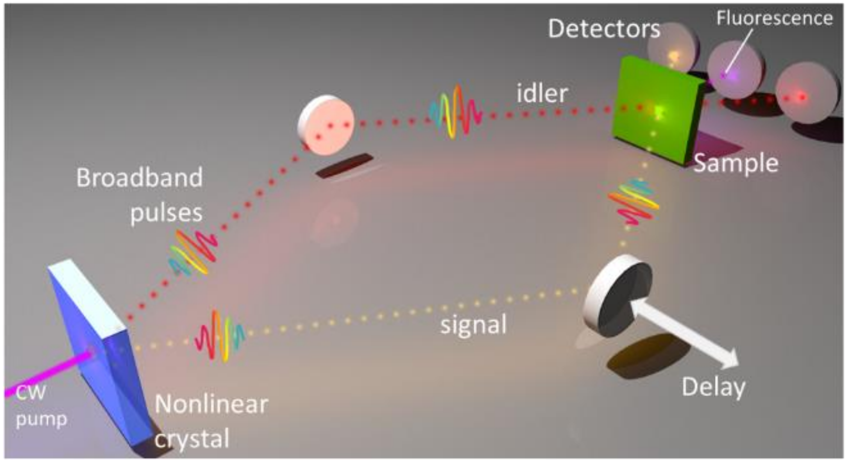
$$\Delta^2\phi_{tSU(1,1)} = \frac{2\eta + (1-2\eta)\text{sech}^2(r) - 2\eta\tanh(r)\sin(\phi)}{2\eta|\alpha|^2\sin^2(\phi)}$$



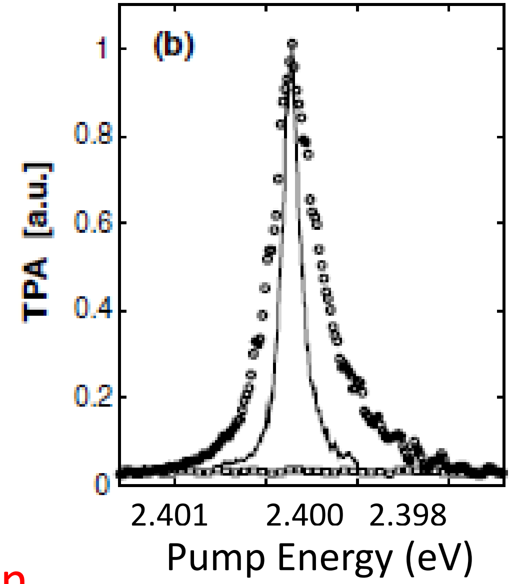
Quantum Spectroscopies

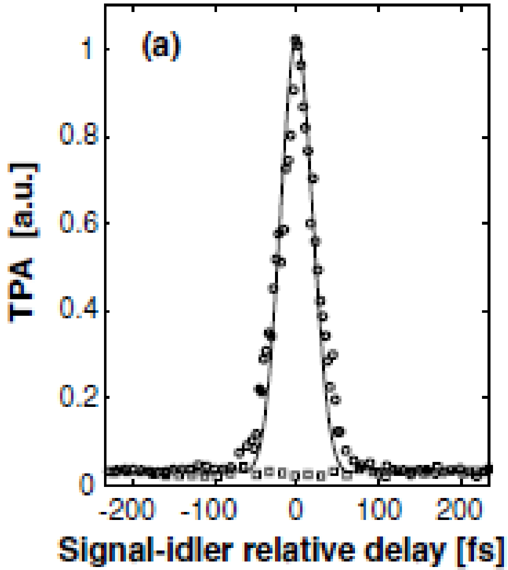
$\Delta\omega_s + \Delta\omega_i$ is limited only by the pump linewidth (~0.5 neV!), and $\Delta(t_s - t_i)$ by the temporal overlap between signal and idler photons (<50 fs).

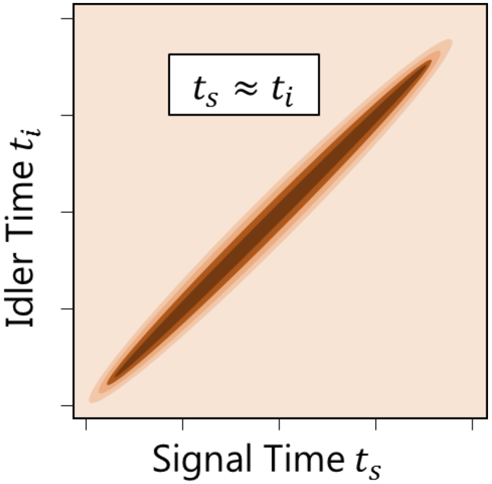
This yields 10^8 improved resolution beyond the Fourier limit.

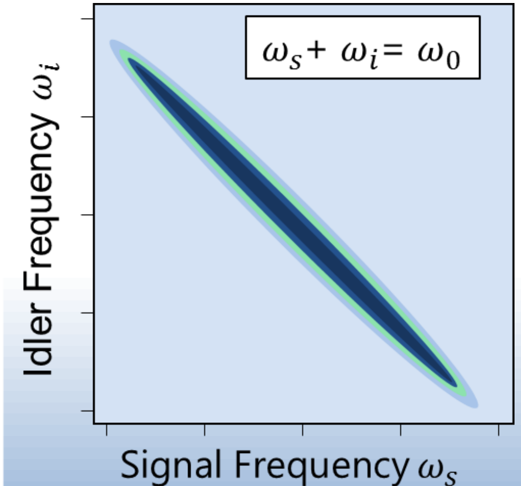


10^5 improvement demonstrated in clean atomic systems









Dayan et al., *Phys Rev Lett*, **93**, 023005 (2004)

Path beyond the current state of the art?

- Improved common mode rejection to reach standard quantum limit
- Path toward low loss distributed quantum sensing?
- Transduction of signals onto local oscillators with squeezed state injection outside of fiber platform?
- Development of nonlinear fiber sensors for FE applications?