# Magnetic waveform sensing with ultracold atoms

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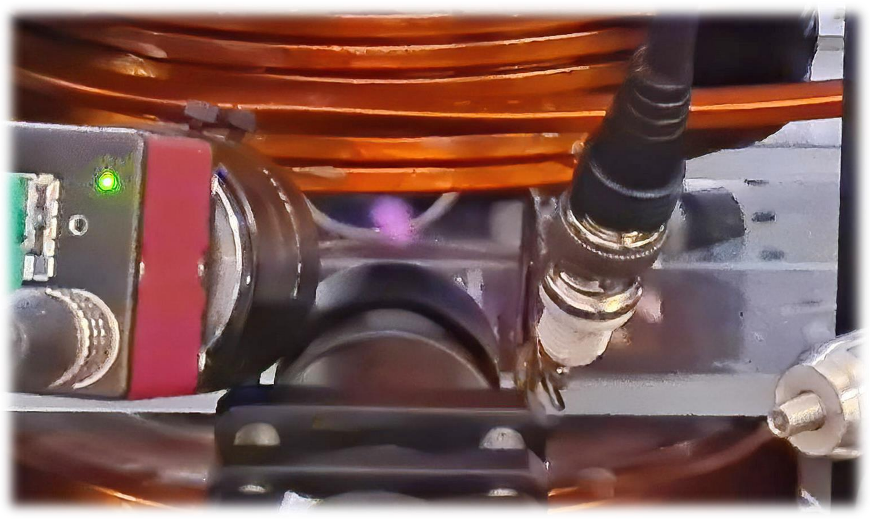
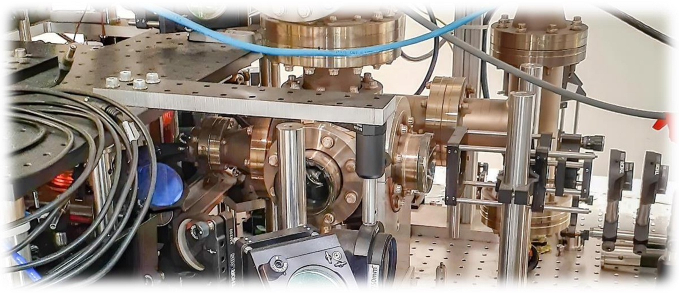
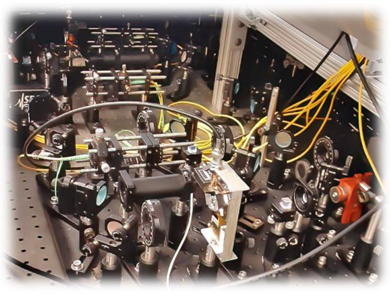
## As precise and cold as you can get



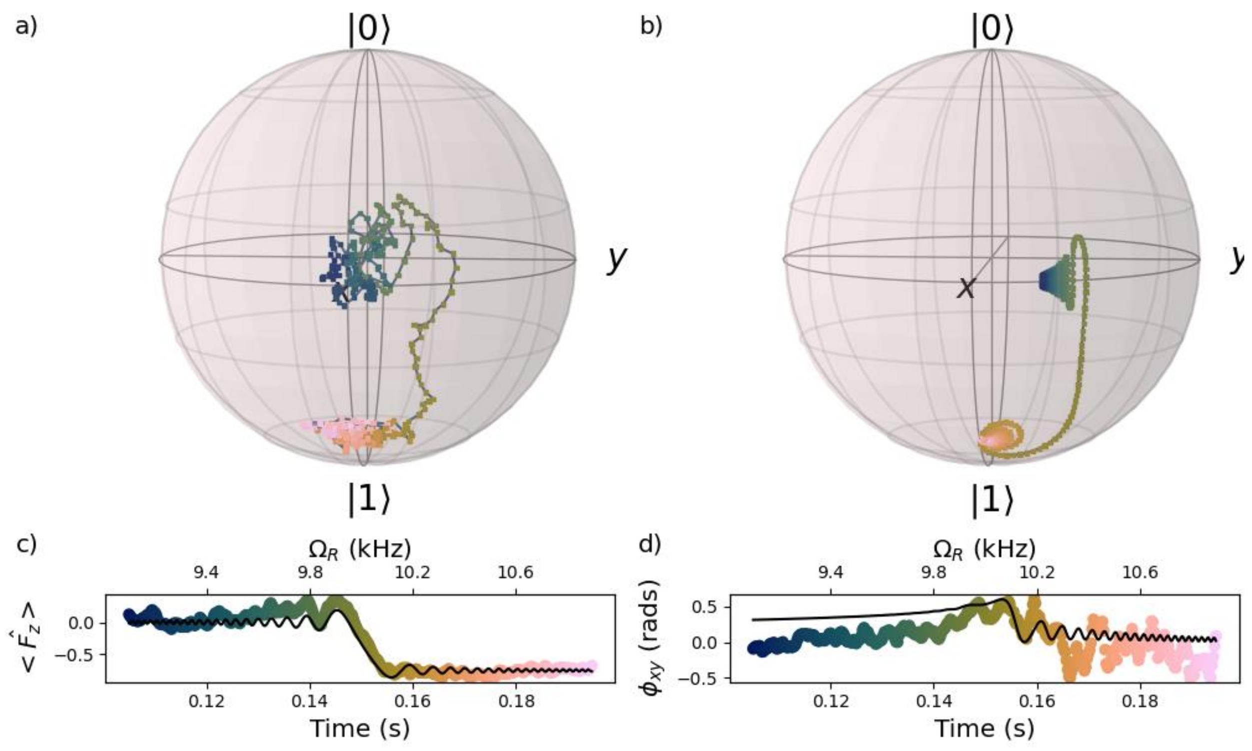
- In the spinor BEC lab, we use laser cooling to produce ultracold rubidium atoms
- Even the smallest signals can make a big difference to the energy levels of quantum systems
- If you measure the energy levels, you've measured the signal – "quantum sensing"!

- Quantum sensing is a booming area in quantum technology
- Headed by Dr. Lincoln Turner, our lab uses trapped cold atoms to make precise measurements of small magnetic signals


## A spectrum-analyser of spirals

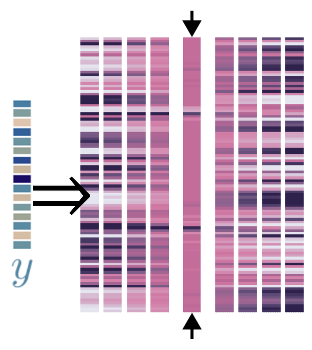
- Atoms can be tuned to certain frequencies using radio wave "dressing"
- If we sweep this dressing from low to high, then we can detect the amplitude and frequency of a sinusoidal signal
- (a) The dynamics of the atoms follow a pretty spiral

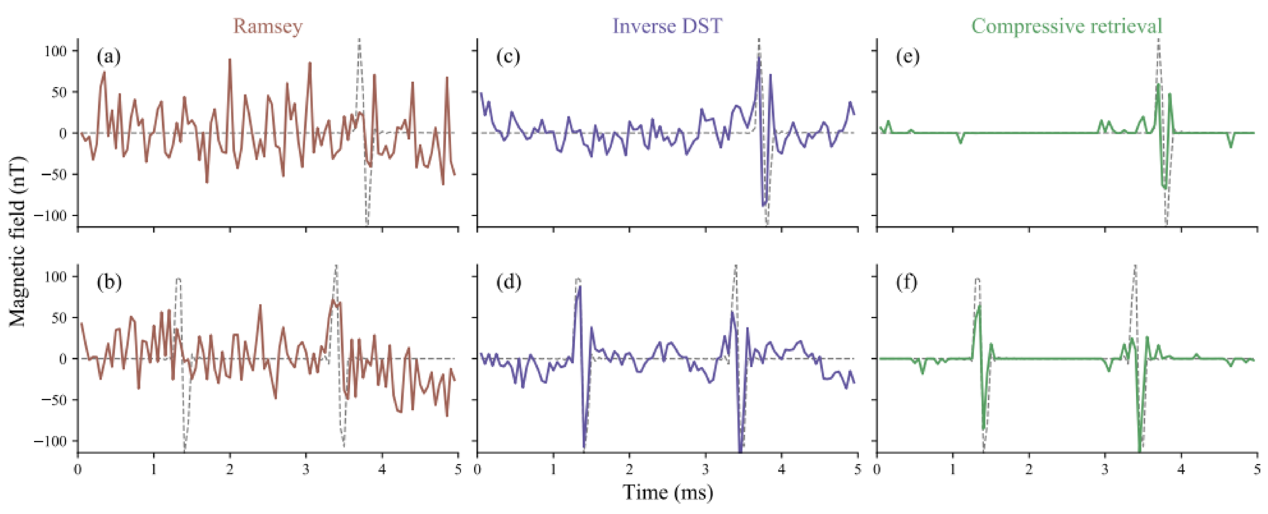



- (b) By fitting these dynamics to parameters in a differential equation, we have recover the amplitude and frequency of the original magnetic signal

## Asking the right questions

- Measuring sparse, pulsed signals in the time domain is inefficient
- Most of the time there is no signal to measure, so there is almost no point in doing so
- Better to measure in frequency domain where information is spread out
- In fact we can reconstruct a full signal from an incomplete set of measurements – "compressive sensing"!

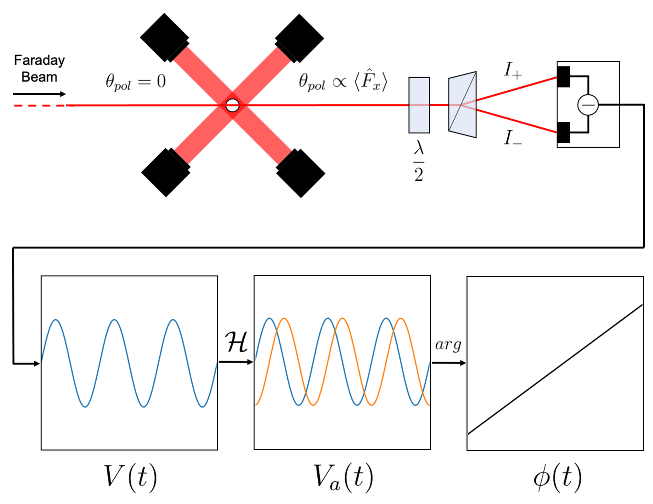




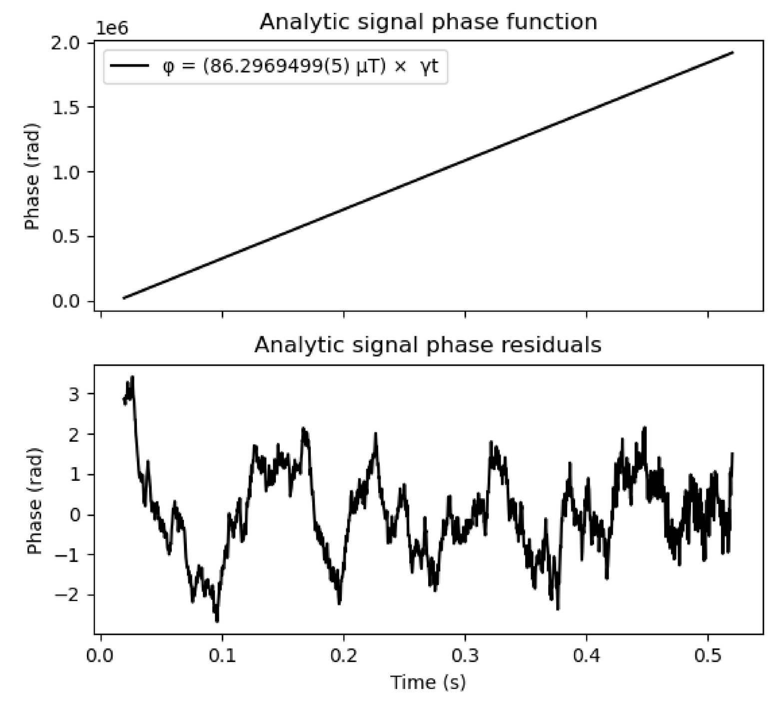

- (above) The true signal is the sparsest that fits measured data
- (left) Best results when only 60% of measurements are used

## A continuous quantum measurement?

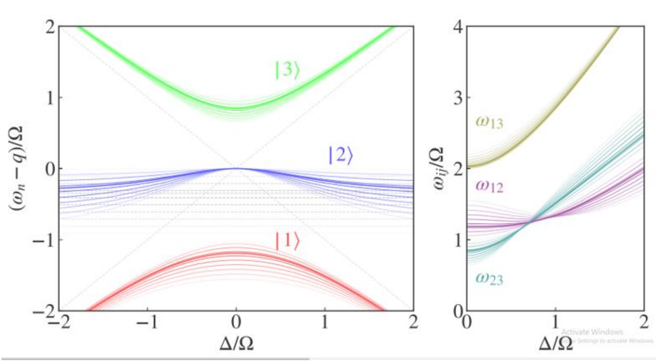
- A quantum superposition collapses when you measure it, right?
- (left) Instead, we can gently measure the spin of our atoms with a weakly coupled laser beam




- This prevents a full collapse and keeps the atoms mostly intact
- A continuous measurement allows the monitoring of atoms (and signal) over a long period of time
- (right) … which allows us to take extremely precise measurements!

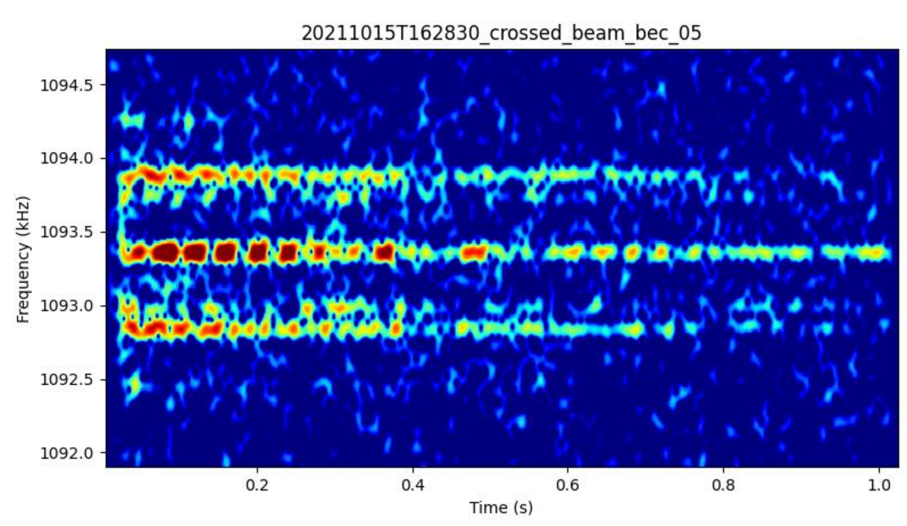



## Magical measurements



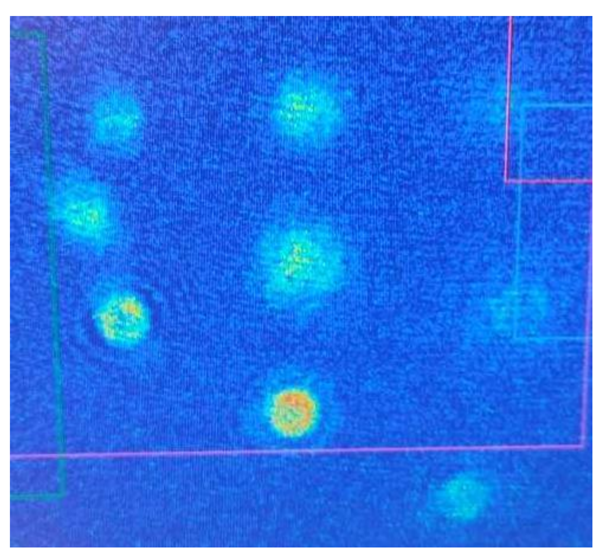
- Noise and interference are a huge problem when taking such precise measurements
- We "dress" the atoms in radio waves for quadratic suppression of unwanted signals
- Add microwaves for quartic suppression – "magic ratio"!

- (above) Energy difference of ω12 has little change even when error Ω/Δ is added to signal
- (right) Faraday Spectrogram showing measurement of small sinusoidal magnetic signal. Beating between the middle and outside indicates atomic transitions driven by signal




## More traps, more power, more stability

- We are working towards taking multiple measurements in a single shot
- We plan to use an array of traps, which can each record one projective measurement
- (right) Stern-Gerlach projective measurement of an array of 3 trapped atom clouds that were in a superposition



- (left) A new high precision coil driver which to prevent slow magnetic drift

- "Anti-noise" feedforward removes electrical interference just like noise-cancelling headphones
- (right) New GPU-based simulator allows use to test new sensing ideas faster