# Quantum science discussion

MAGIS Science and Simulation meeting

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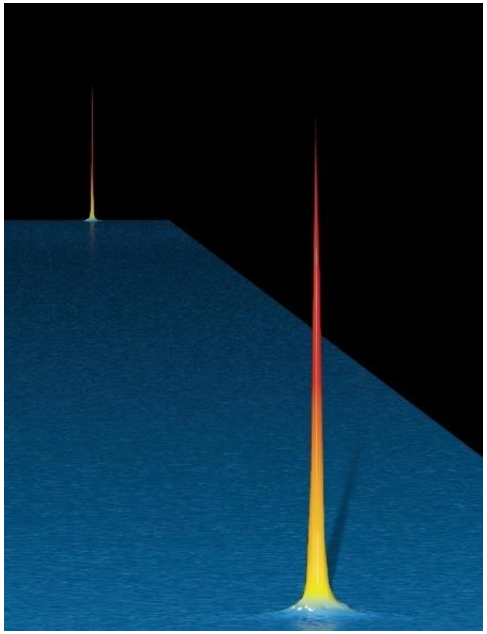
# MAGIS-100 quantum science

**Long duration interferometers (9 seconds)**

- Can we maintain coherence for long times?
- High acceleration sensitivity for DM + new forces (~$T^2$)
- Modifications of QM (e.g., spontaneous localization) cause anomalous decoherence

*Technical challenges:* Imperfect vacuum (atom loss), temperature of atom ensemble (cloud expands), rotation compensation (laser deflection)



*Large wavepacket separation*

**LMT for high spatial separation (>meters)**

- Large momentum transfer atom optics
- High acceleration sensitivity (~n)
- Macroscopic quantum superposition state

*Technical challenges:* Atom-light pulse efficiency (atom loss, contrast), pulse area limits (spontaneous emission), cloud vs beam size (contrast), multipath/multiloop effects (detection systematics), long T interferometer (see above), laser wavefront aberrations (contrast, systematics), AC Stark compensation (laser spectrum control)

# Quantum science results

- Results/goals can be harder to quantify than other science (DM/GW) where target sensitivity/bounds are quoted

- More binary: We observed interference at record long time, record wavepacket separation, long-baseline gradiometer, …

- Quantitative results are in meter, seconds, hk

- In some cases, makes sense to quote best performance for interferometer contrast, phase resolution, sensitivity, differential phase noise

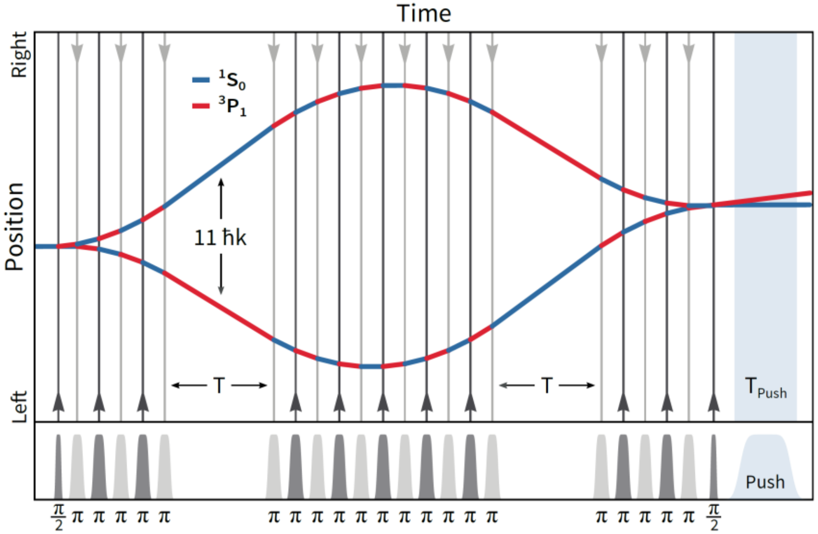
- Ultimately, quantum science performance directly translates to sensitivity to other science goals (another good metric)

- Nevertheless, at performance limit there is a tradeoff between record performance (meters/seconds/hk) and metrologically useful sensitivity. Practical compromise should be considered.

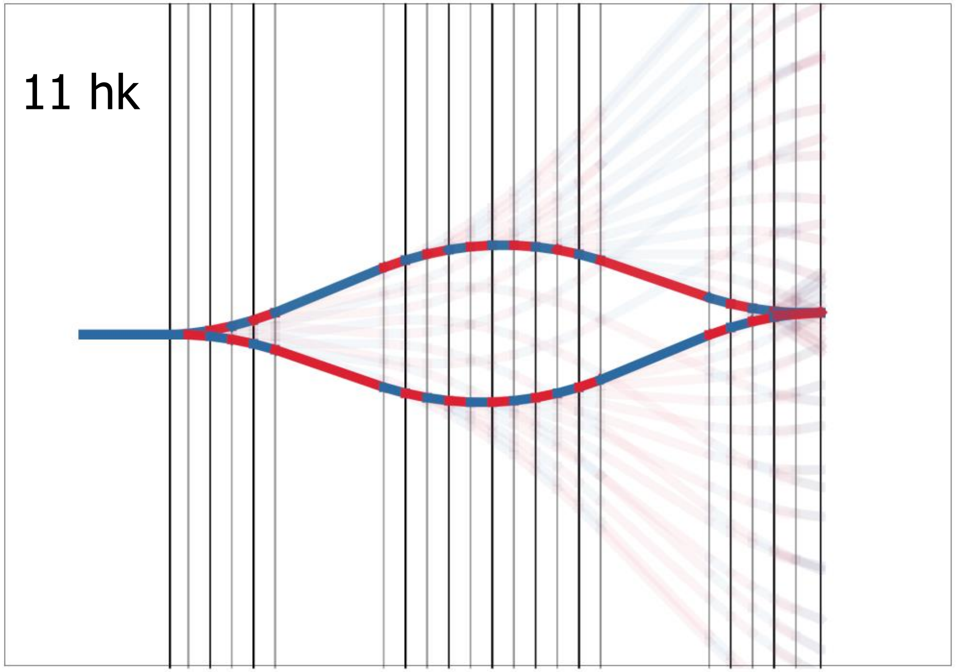
# LMT multipath effects

*Ideal LMT interferometer atom trajectories*

(here, 689 nm transition)



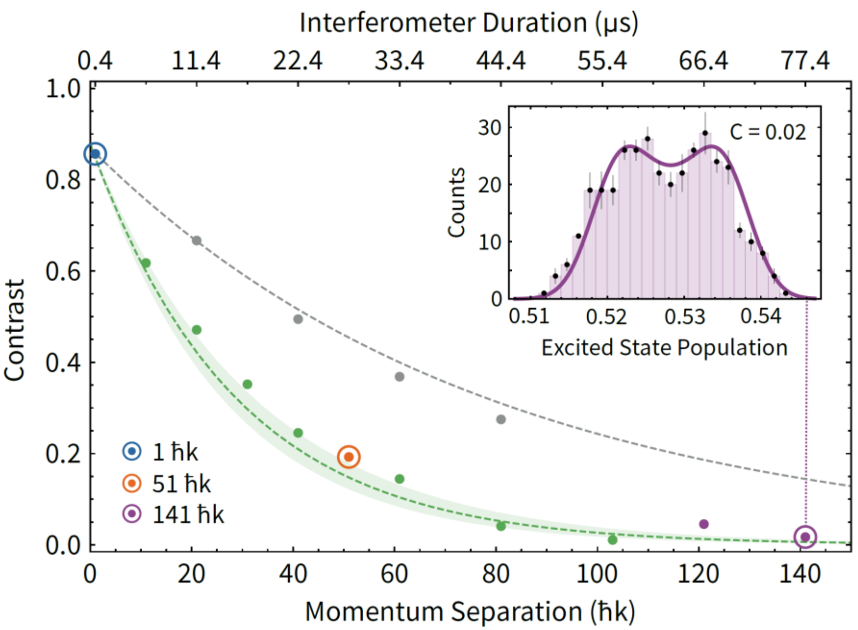

*Simulation of multipath effects including imperfect pulse efficiency*




- Detection and analysis more complicated due to additional ports
- Sum over extra paths (multipath + multiloop) causes systematic phase shifts
- Can be mitigated with TOF and shelving + blow away

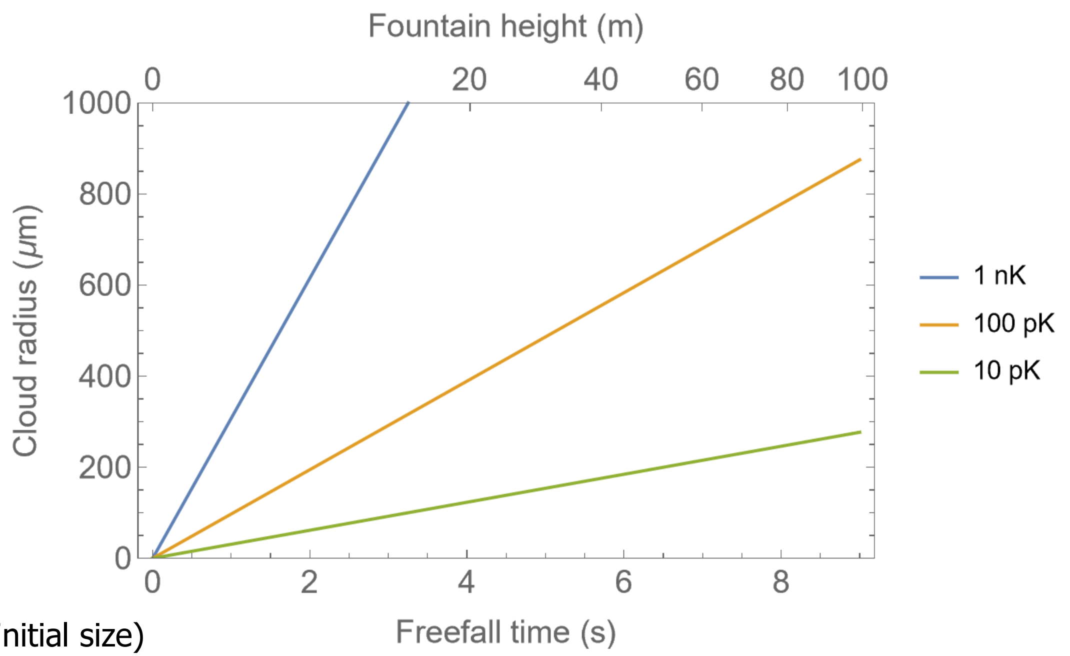
# How low in atom number should we go?

- Best LMT result depends on minimum SNR
- With better detection, we can push to higher LMT and still observer interference
- But fewer and fewer atoms will survive (low contrast)
- Practical compromise: suggest we aim for 1% atom number threshold




- Detection note: record LMT can be observed with either phase shear detection or binned detection.
- Binning requires scanning the phase on repeated shots, vs single shot readout with phase shear.
- Binning allows favorable tradeoff between light collection and resolution.

# Long duration interferometry

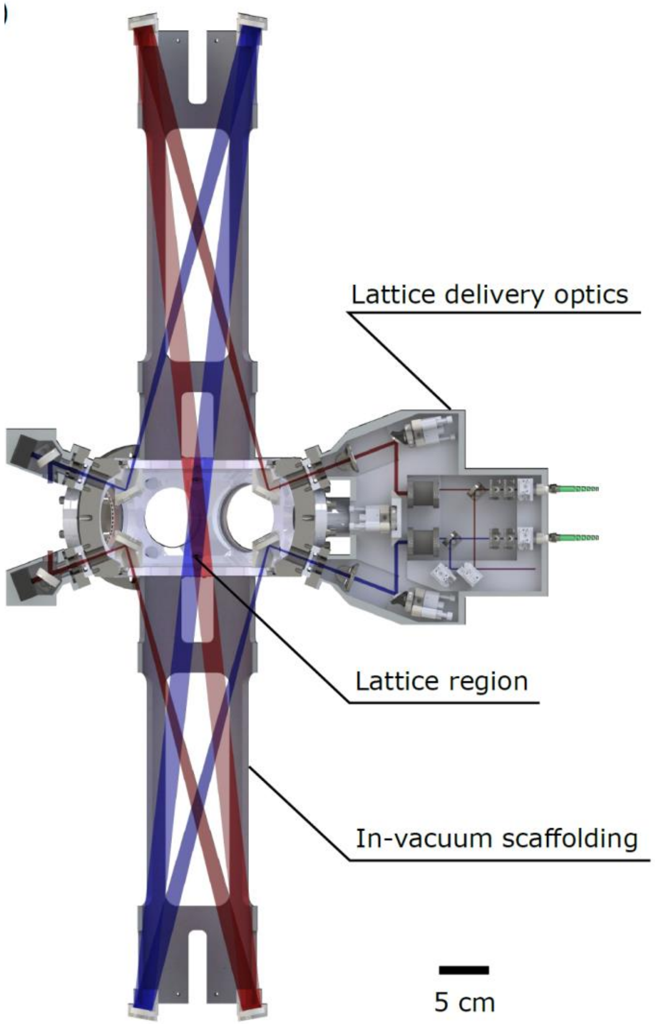



(here zero initial size)

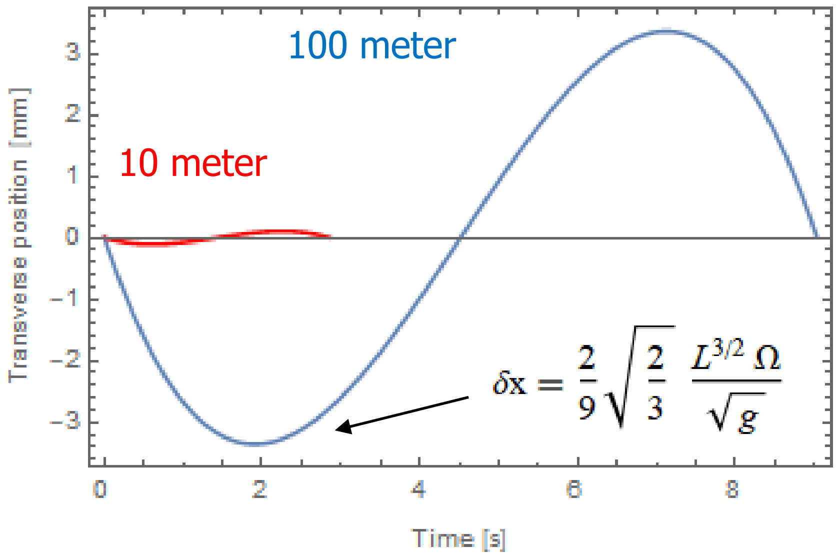
- Constraints, in decreasing order: vacuum ID, magnetic bias uniformity, camera FOV, interferometer laser size, high efficiency LMT region (uniform intensity)
- Cloud expansion set by atom source temperature
- State-of-the-art matter wave lenses can reach < 50 pK 3D temperature
- Tradeoff between initial size/temperature demands high phase space density (evaporatively cooled source)
- Better cooling comes at the expense of atom number and repetition rate

# Long T Coriolis deflection

*689 nm lattice for vertical atom launching before interferometry*

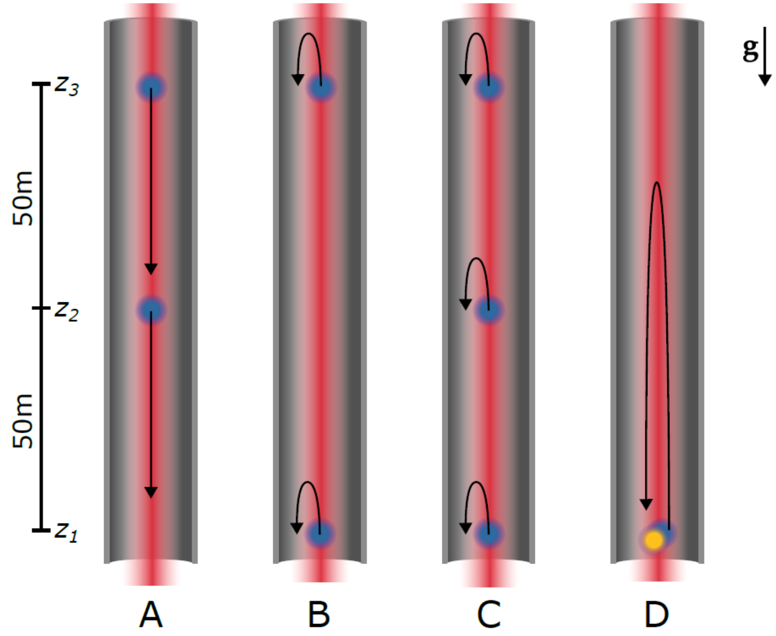



Minimum Coriolis displacement launch




- Large Coriolis deflection affects interferometer laser overlap (transfer efficiency) and detection
- Coriolis pre-compensation possible; launch at angle to minimize deflection, end in center
- Dynamic launch angle fine tuning with PZT delivery mirrors
- Impact on diagnostic camera usage

# Quantum science program




**Suggested order:**

1. 100 meter gradiometer, T ~ 100 ms – 1 s (B)
2. Long T single interferometer 50 meter drop (~A)
3. 50 meter drop gradiometer (A)
4. LMT with 50 meter drop for large wavepacket separation interferometer/gradiometer (A)
5. Max height launch (100 meters?) (D)

# Detection considerations

- Compromise between light collection and resolution.
- "Integration detection" system should aim for better light collection
- Still useful to have some resolution
  - LMT 'debris atoms' could be bad during integration detection if they all get binned. Some spatial resolution is still useful.
  - For extreme LMT, it helps improve contrast to analyze an ROI near the center of the cloud (where lasers are more uniform).
- Field of view is important for long T (cloud expansion, deflection)
- For very low density/low atom number, hardware binning may make sense to reduce read noise, at the expense of resolution
- In vacuum lenses provide option for high solid angle, but very limited resolution at full aperture (limited by depth of field)