Simulations for MAGIS-100

HEP Meeting 28th April 2021

Leonie Hawkins, on behalf of the collaboration

Fermilab

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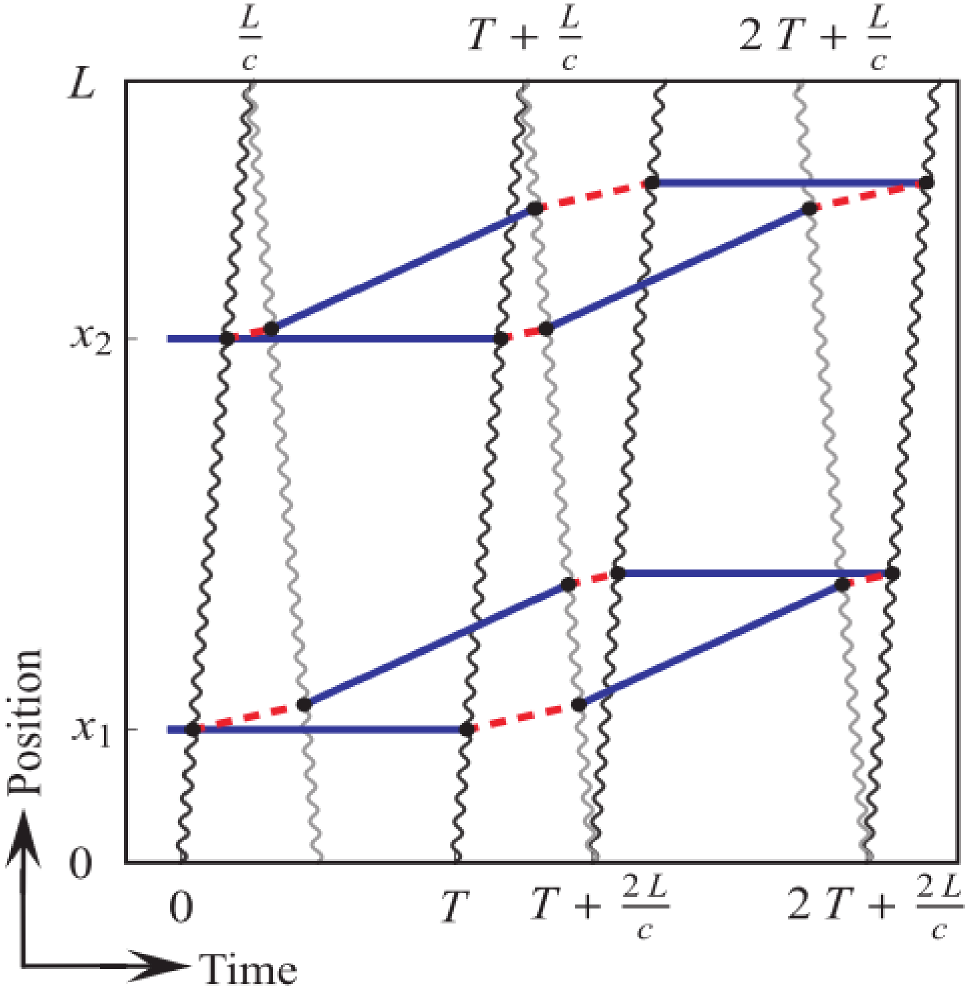
Light Pulse Atom Interferometry



- Superposition of atomic states to measure phase shift
- Search for new physics

More detail on light pulse atom interferometry: see Sam Hindley & Jack Ringwood's talks

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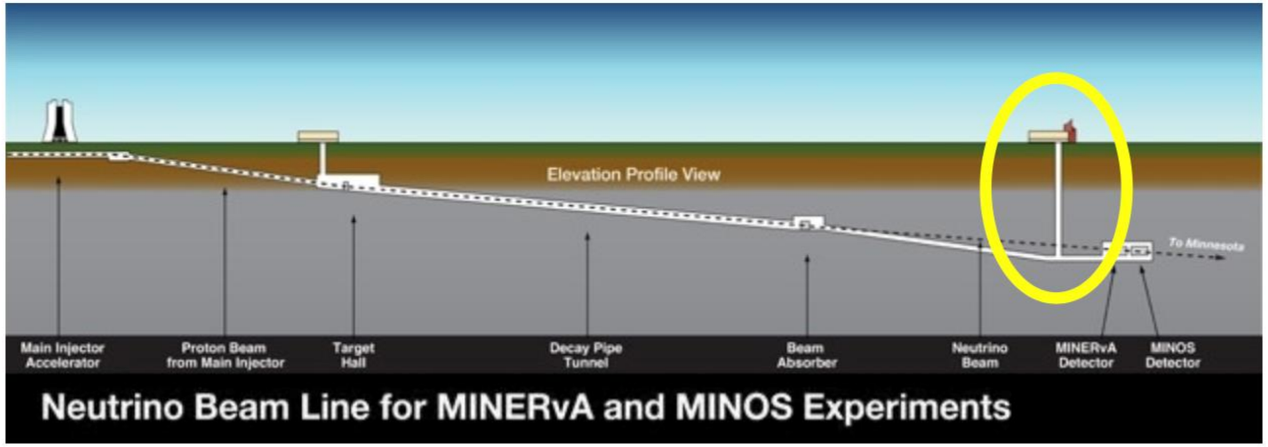
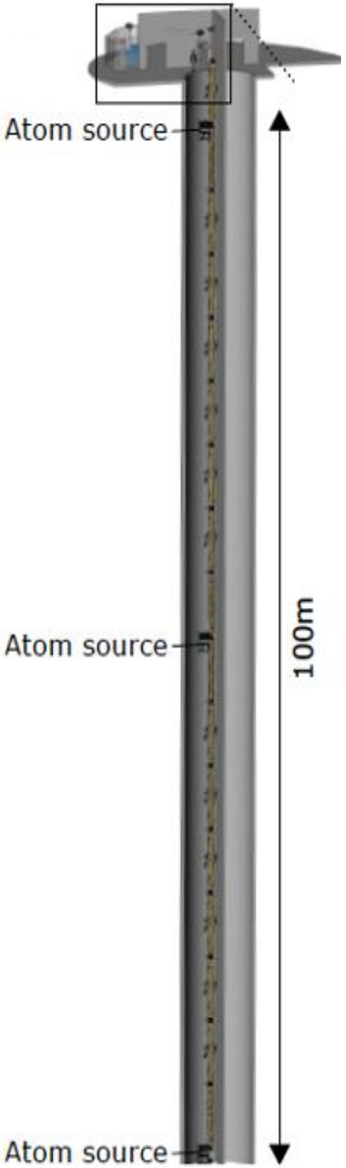
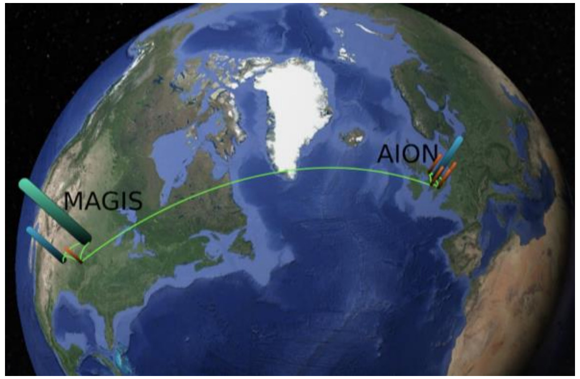
MAGIS-100 at Fermilab

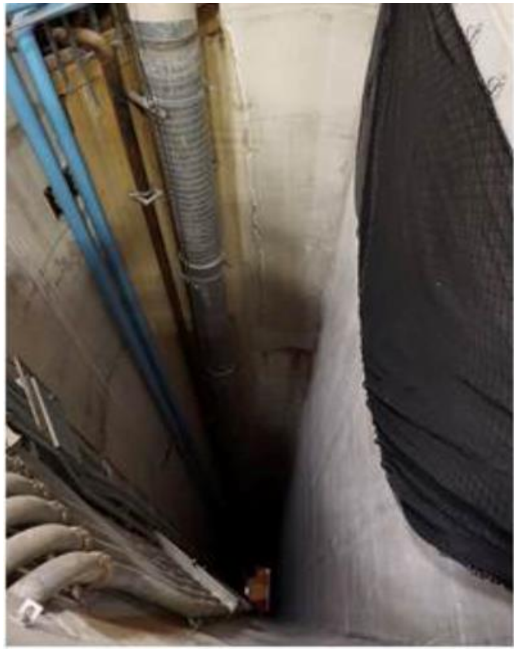
Interference of De Broglie waves to search for…

- Ultralight dark matter (10^{-22} eV<m<eV)
- Future mid-band frequency gravitational waves test bed between aLIGO and LISA (30 mHz – 10 Hz)









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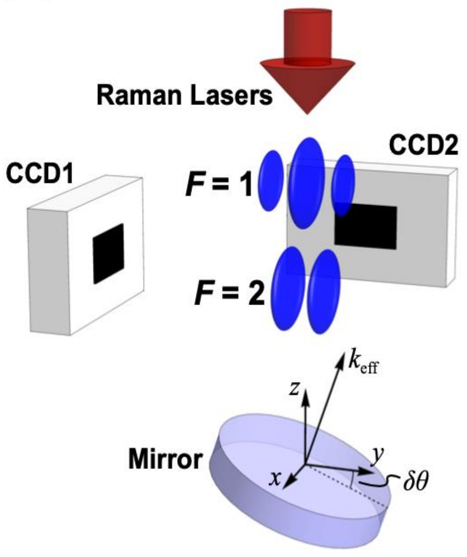
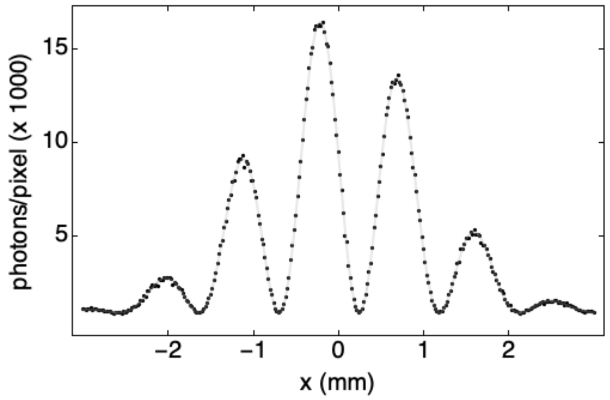
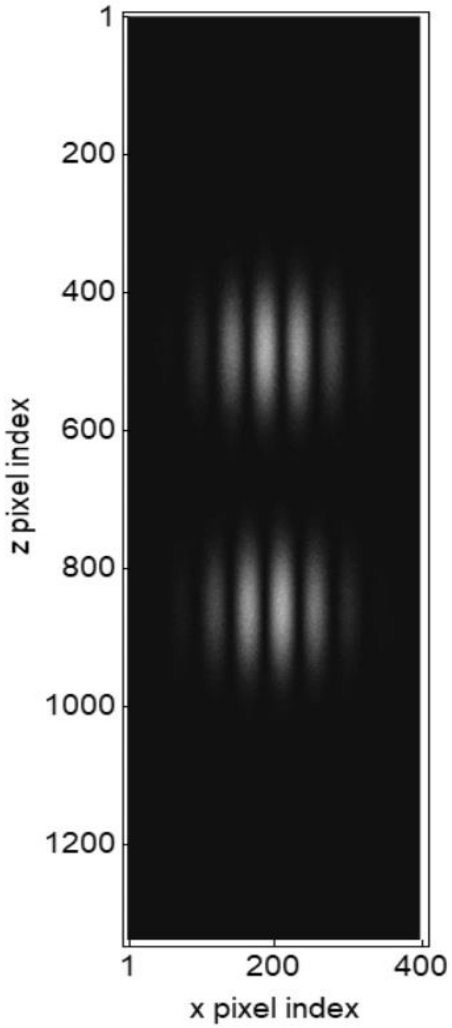
Simulation Work for MAGIS-100





- Detection system being delivered by UK collaborators
- Modelling wavefunction representing cloud & include systematics
  - Camera parameters, optics, noise, diffusion, cooling, LMT, etc.
- Compare precisions of fitting methods for phase
- Determine optimal operating parameters



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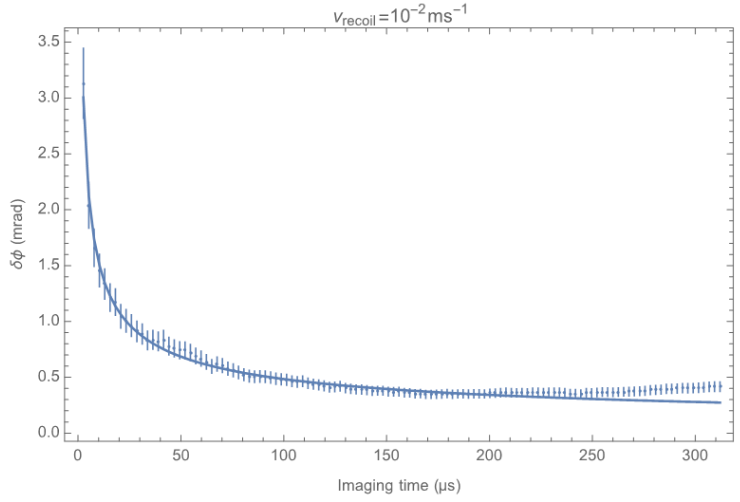
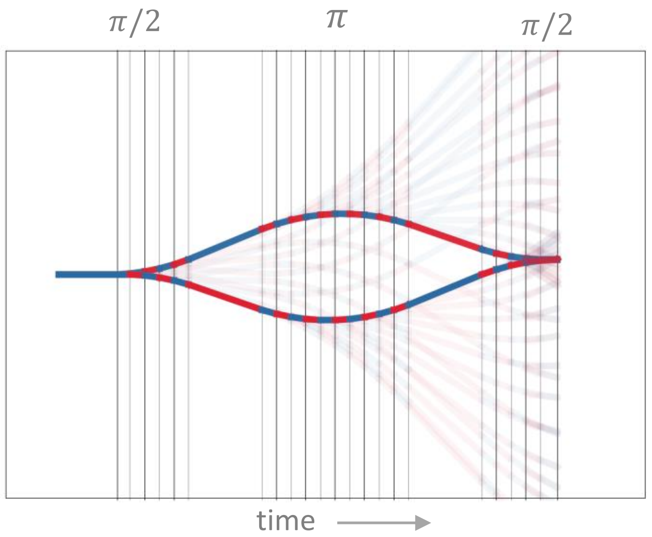
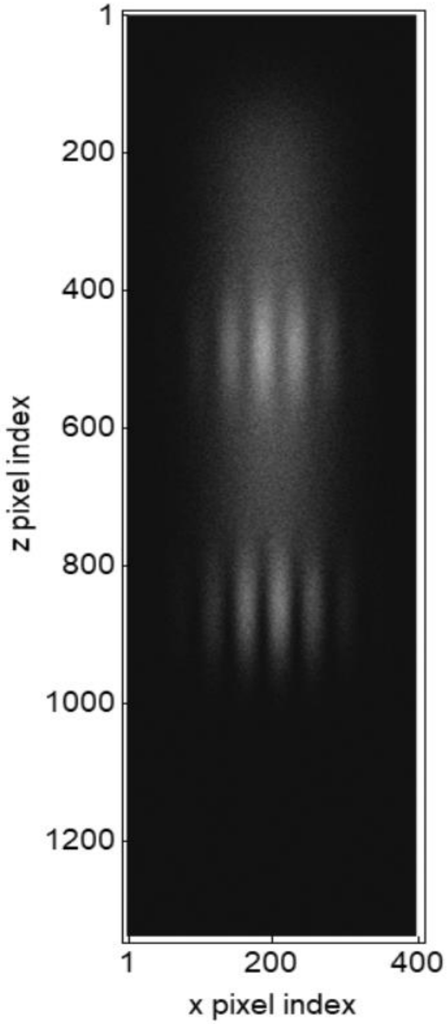
Examples of Case Study Systematics





- Cloud diffusion
  - Determining the optimal imaging duration
  - 150 microseconds
- Camera parameters
  - Readout noise, Q.E., pixel sizes
- Large momentum transfer
  - Effects of pulse inefficiencies on signal extraction



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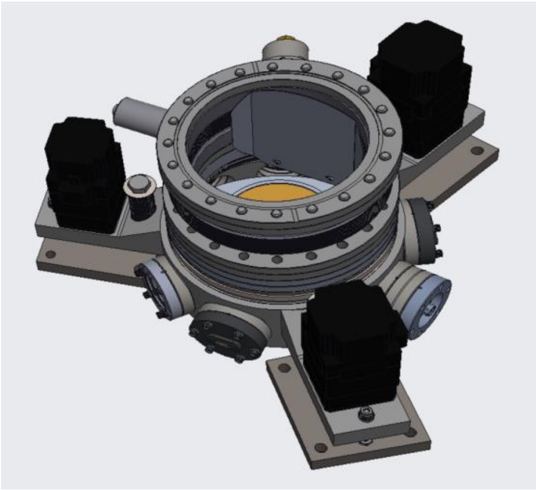
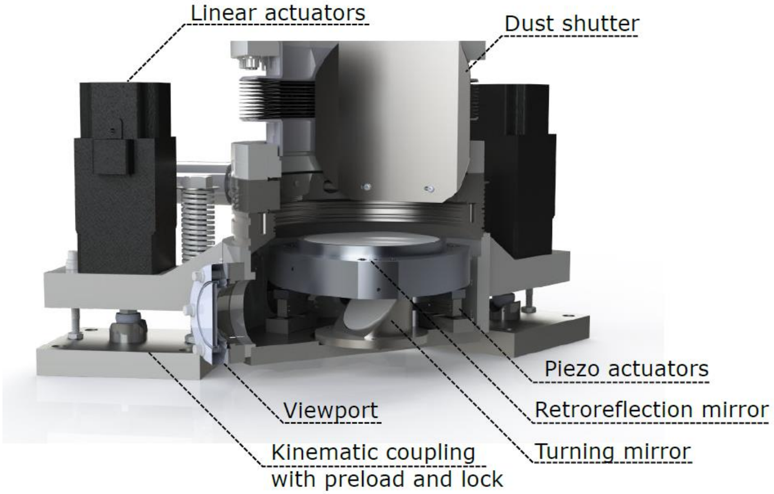
Ongoing and Future Work

- Build upon simulations to develop full model
- Data analysis ready for data taking
  - Mock data challenge
- Fabricating hardware at Liverpool: in vacuum optics



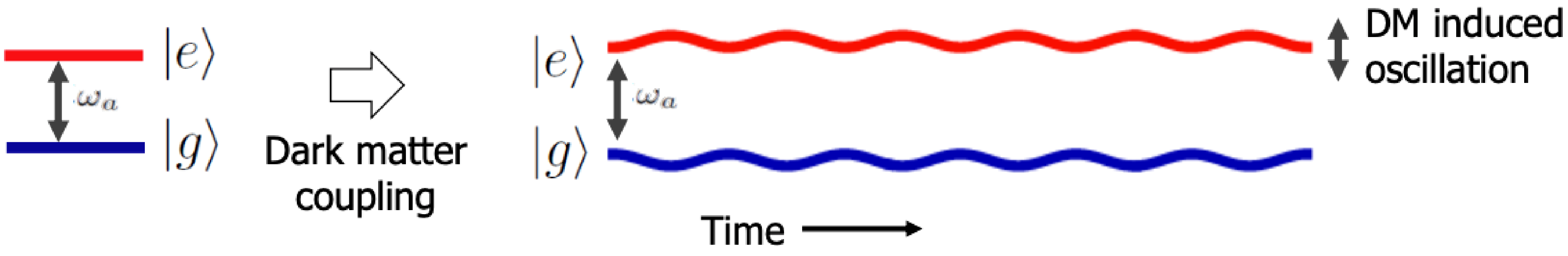


Questions?

Backup Slides

Dark Matter Detection with Atom Interferometry

- Affects fundamental constants (m_e and α), altering atomic energy level separation



$$\Delta\phi \sim \omega_A\left({}^{2L}/_{c}\right)$$

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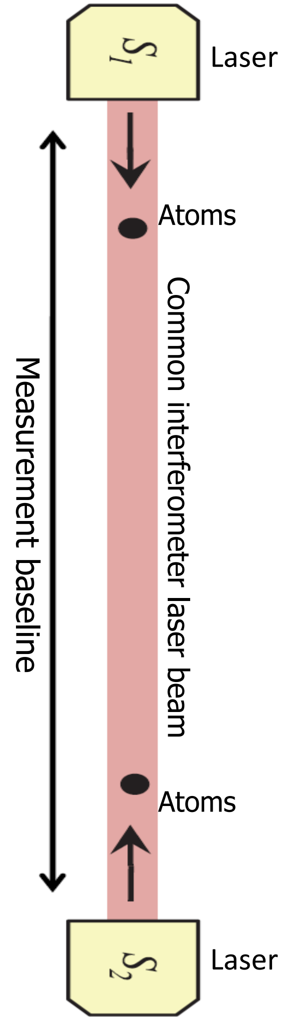
Gravitational Wave Detection

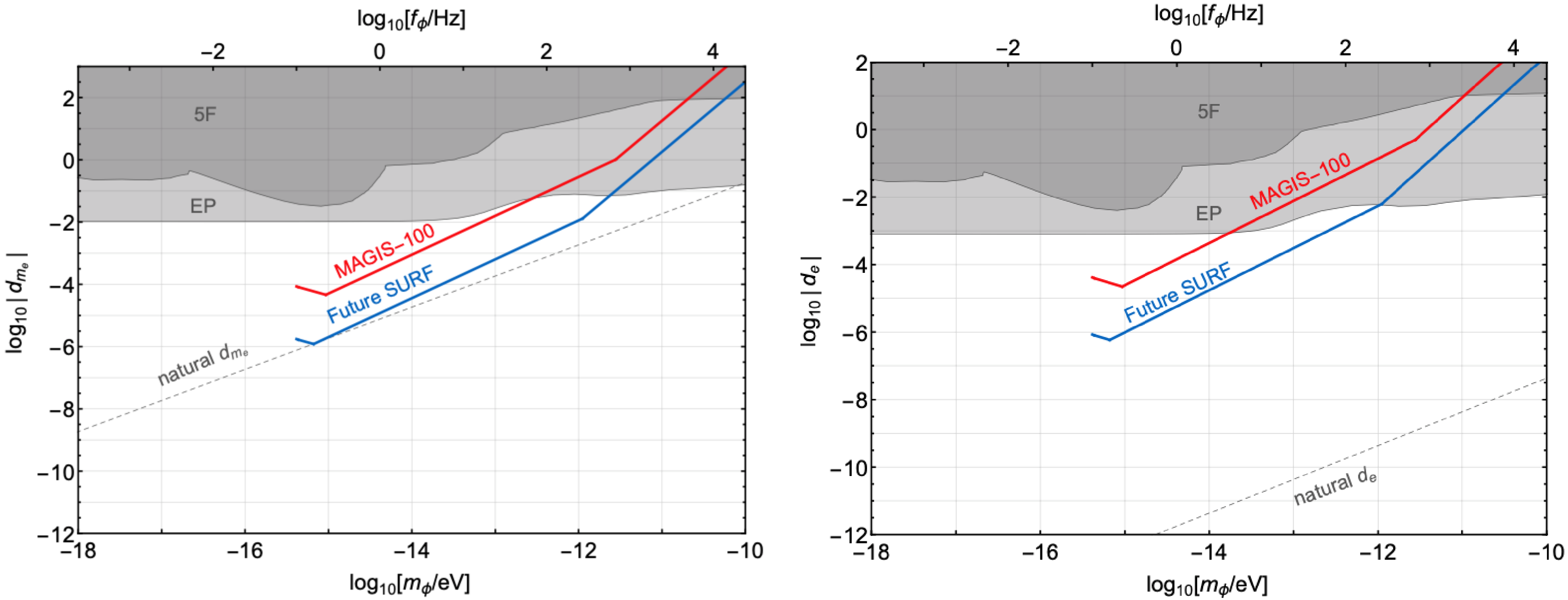
- Mid-band frequency gravitational waves (30 mHz – 10 Hz), between LIGO and LISA

$$\Delta\phi \sim \omega_A(2L/c)$$

- 2L/c term represents laser propagation time
- Atoms as inertial reference points & clocks
- GW cause strain in light travel time – phase shift



Sensitivity via Coupling to m_e and α



- Improve sensitivity to DM particles with mass < 10^{-15} eV or frequency < 0.1 Hz by 2 orders of magnitude

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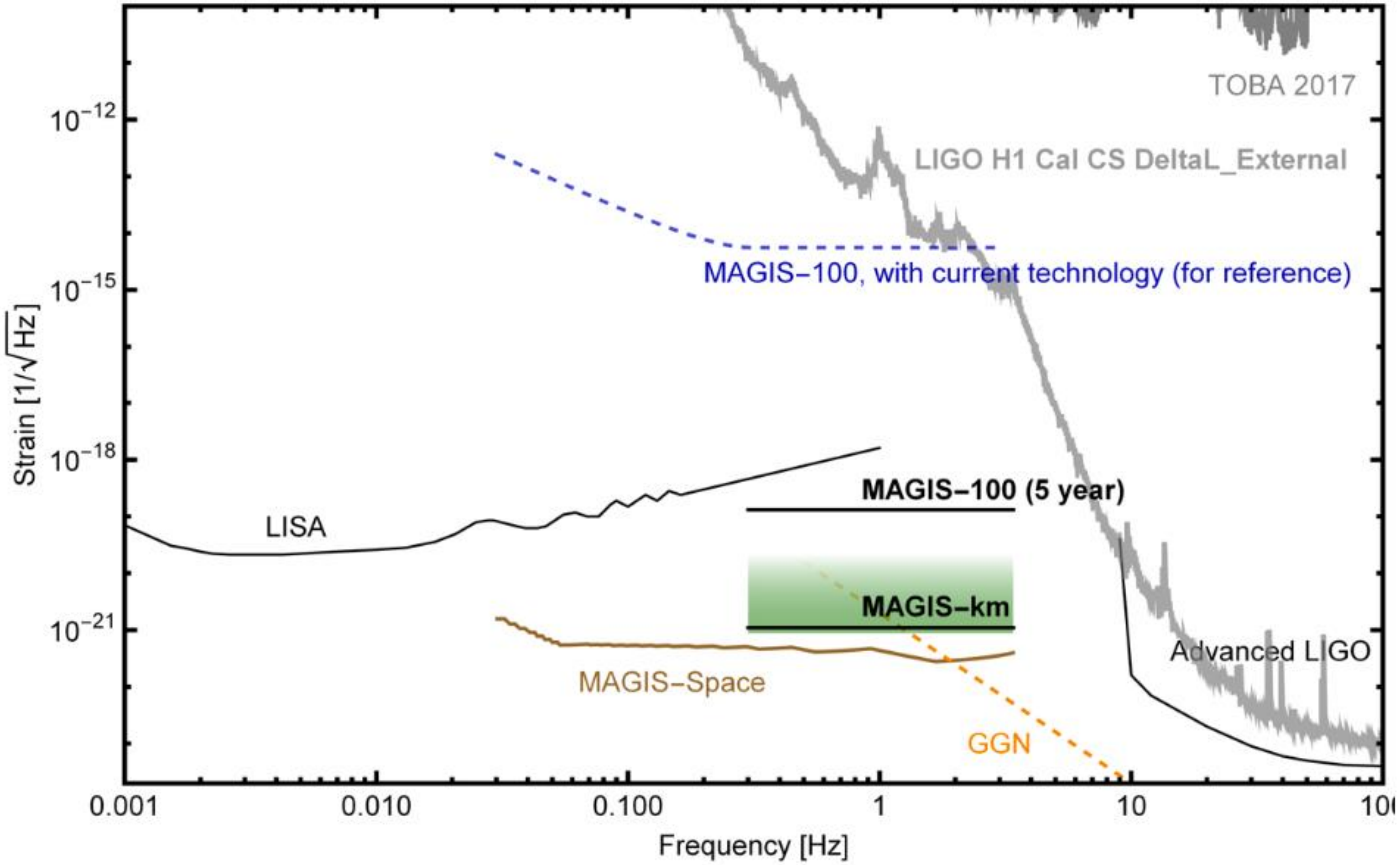
Sensitivity to Gravitational Waves

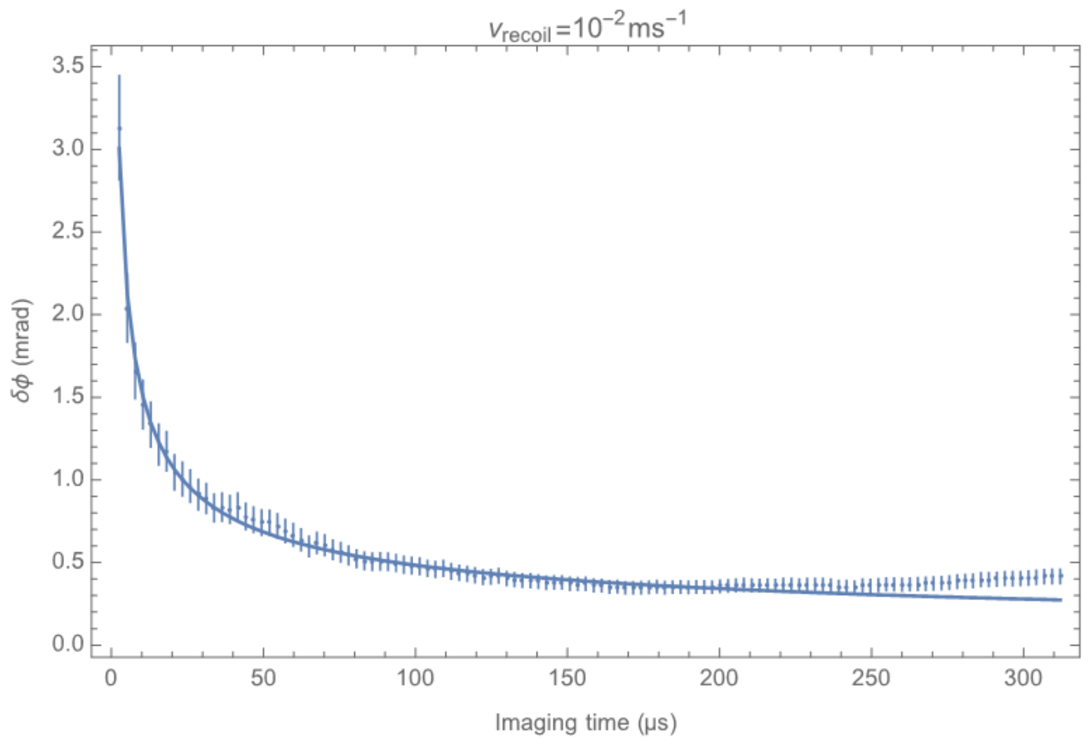


Cloud Diffusion

- **Aim:** Putting limits on imaging time due to atom cloud diffusion
- Scattered photons: velocity kicks

$$v_{rec} = \frac{\hbar \mathbf{k}}{m} = 10^{-2}\,\mathrm{m\,s^{-1}}$$

- Repeated cycles over full imaging time causes smearing



Camera Options Study: Camera List






Camera	Type	Pixels	Pixel Size (µm)	R.O. Noise (e^-/pixel)	Q.E.
Princeton Instruments ProEM-HS	CCD	1024x1024	10	<1	95%
PTGrey Grasshopper3 USB-3	CCD	1384x1032	6.45	7.02	77%
Backfly USB-3 23S6M-C	sCMOS	1920x1200	5.86	6.97	41%
Hamamatsu ORCA-Flash4.0 LT+	sCMOS	2048x2048	6.5	1.5	65%
Ximea MD028MU-SY	CCD	1940x1460	4.54	8.8	70%
CS2100M-USB - Quantalux	sCMOS	1920x1080	5.04	<1.5	45%

Camera Options Study: Results

Camera	$\Delta\phi$ Mean (rad)	$\Delta\phi$ Error (rad)
Princeton Instruments ProEM-HS	-6.99×10^{-5}	$1.25\times10^{-2} \pm 0.14$
PTGrey Grasshopper3 USB-3	-3.64×10^{-4}	$1.65\times10^{-2} \pm 0.14$
Backfly USB-3 23S6M-C	-1.55×10^{-5}	$2.76\times10^{-2} \pm 0.14$
Hamamatsu ORCA-Flash4.0 LT+	-2.8×10^{-4}	$1.58\times10^{-2} \pm 0.14$
Ximea MD028MU-SY	-8.29×10^{-4}	$2.81\times10^{-2} \pm 0.14$
CS2100M-USB - Quantalux	-1.26×10^{-4}	$2.84\times10^{-2} \pm 0.14$

- Not accounting for new physics: $\Delta\phi$ values inputted as 0 in this simulation
- Other factors:
  - Refined analysis tools
  - Cost

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